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PEOPLE
MARIE CURIE ACTIONS

Marie Curie Initial Training Networks (ITN)
Call: FP7-PEOPLE-ITN-2008

PART B

"Path2SKA"

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B.1 LIST OF PARTICIPANTS

	Industrial Involvement Level			**Legal Entity**	**Department**	**Person-in-charge**
	1	**2**	**3**			
Network Participants						
UOXF.DB				The Chancellors, Masters and Scholars of the University of Oxford	Physics (Astrophysics)	Steve Rawlings
ASTRON				Netherlands Institute for Radio Astronomy (ASTRON)	ASTRON Science Department	Raffaella Morganti
UCAM				The Chancellors, Masters and Scholars of the University of Cambridge	Physics, University of Cambridge, Cavendish Laboratory	Paul Alexander
Deimos Engenharia	✓			DEIMOS Engenharia SA	Ground Segment	Nuno Catarino
INAF				Istituto Nazionale Di Astrofisica	INAF- Rome Observatory	Roberto Scaramella
JIVE				Joint Institute for V.L.B.I. in Europe (J.I.V.E.)	JIVE	Hubrecht Jan van Langevelde
CENTRA- IST				Instituto Superior Tecnico	Centra - Instituto Superior Tecnico	Mario Santos
UMAN				The University of Manchester	School of Physics & Astronomy/Jodrell Bank Centre for Astrophysics	Michael Kramer
MPG				Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V.	MPI für Radioastronomie (MPIfR)	Rainer Beck
OBSPARIS				Observatoire De Paris	GEPI, LERMA	Wim van Driel
NOVA				Universiteit Utrecht on behalf of Nederlandse Onderzoekschool voor Astronomie	NOVA	Huub Rottgering
QINETIQ	✓			QinetiQ Limited	Applied Technologies	Christopher Pickering
ClearSpeed	✓			ClearSpeed Technology plc	ClearSpeed Technology plc	Russell David

Associatedd Partners						
Square Kilometre Array Project Development Office (SPDO)					http://www.skatelescope.org/	Richard Schilizzi
Aristotle University of Thessaloniki					http://www.auth.gr/home/index_en.html	John-Hugh Seiradakis
Allen Telescope Array (ATA)					http://www.seti.org/ata/	Geoff Bower
National Research Centre Canada (NRC.CNRC)					http://www.nrc-cnrc.gc.ca/	Sean Dougherty
Chronos Technology		✓			http://www.chronos.co.uk/index.php	Charles Curry
Geomerics		✓			http://www.geomerics.com/	Mike Hobson
Giant Metrewave Radio Telescope (GMRT)					http://www.gmrt.ncra.tifr.res.in/	D J Saikia
IBM		✓			IBM Research Division , NY	Bruce Elmegreen
MonetDB		✓			http://monetdb.cwi.nl/	Martin Kersten
MeerKAT					http://www.ska.ac.za/	Justin Jonas
University College Cork					http://www.ucc.ie/en/	Denise Gabuzda
US Technology Demonstration Program (US TDP)					http://skatdp.astro.cornell.edu/	Lyn Baker
University of Bath					http://www.bath.ac.uk/	Cathryn Mitchell
University of Malta					http://www.um.edu.mt/	Kristian Zarb Adami
Science & Technology		✓			http://www.stcorp.nl/	Erik Zoutman
Stockholm University					http://www.su.se/	Garrelt Mellema
Western Australia: International Radio Astronomy Research Centre					http://www.uwa.edu.au/	Peter Quinn
University of Orleans					http://www.univ-orleans.fr/	Rodolphe Weber

B.2 PROJECT OVERVIEW AND OBJECTIVES

This proposal is about **people** but recognises how an **iconic project** can stimulate the organization and delivery of their training. The people in question are early-stage European scientific researchers who have the potential to become future leaders in the European Research Area. The project in question is the next-generation radio telescope the Square Kilometre Array (SKA). The SKA is one of just two future astrophysical facilities on the European Roadmap for Research Infrastructures (ESFRI). It is a global project with strong and effective European leadership. It promises a genuinely transformational science return. Its design and exploitation presents technological challenges demanding symbiotic partnerships between academia and industry**.** The "Path to SKA", or Path2SKA, proposal combines training-through-research with training in research and complementary skills. It will train scientists and technologists able to move easily between the academic and industrial sectors and between countries. Its focus is the path to the iconic SKA.

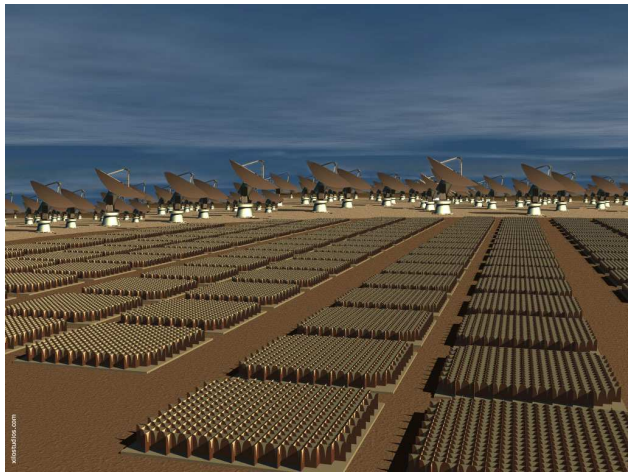
Path2SKA is structured to ensure that European scientific researchers in academia and industry are trained as part of one team. Their research, although often technological and 'blue skies' in nature, will be closely connected to front-line scientific problems via the use and development of SKA pathfinders in Australia, India, Southern Africa and the USA, as well as in Europe. They will be closely connected to the design of the SKA itself via the Path2SKA SKA simulations programme, and interfaces with the FP7-funded proposal PrepSKA[1]. The global reach of Path2SKA helps it meet the obligation of promoting transnational employability. Path2SKA also aims to promote the inter-sectoral employability of its recruited researchers. Solving the scientific and technological challenges on the path to the SKA is certain to bring diverse benefits to the European private sector, and Path2SKA has attracted industrial partners ranging from small-and-medium-sized enterprises (SMEs) to multi-nationals. Path2SKA fellows can expect to make significant research contributions in SKA simulation, soft- and firm-ware, data processing and data analysis. Some will go on to form the core of the global research community needed to use and develop the SKA itself, but many will pursue careers in other areas, widening the impact of Path2SKA on society.

Although directed at supporting the European Research Area, Path2SKA must connect seamlessly with a global community working towards the SKA. It must be inclusive of all the stakeholders. This, and the desire for strong academic-industrial partnership, means that Path2SKA must have a large number of full and associated partners. The full academic partners are accustomed to working in large pan-European consortia through EC-supported programmes like RadioNET, PrepSKA and SKADS. Although academic-industrial partnerships are not yet common in astrophysics, Path2SKA provides a perfect platform for transforming this situation, with a goal that industrial partners will attract the skilled people needed for them to play an active role in SKA design and construction.

The full academic partners are organized via the European SKA Consortium (ESKAC) of which the Path2SKA coordinator is a vice-Chair. To help address the diverse technological challenges, Path2SKA includes three full and five associated industrial partners. Other associated partners include the Europe-based international SKA Project Development Office (SPDO), most of the key SKA pathfinder programmes, and some smaller European Universities with specific expertise. The commitment of the academic partners to Path2SKA is demonstrated by the fact that most ask for just 24 months EC funding per PhD project, the remaining costs (typically a further 12 to 36 months, plus, in some countries, University fees and other costs) to be born by the host institutions. The commitment of the industrial partners is demonstrated by their significant unfunded contributions in terms of expertise and participation in the training programme.

[1] The twinning of a Marie Curie training programme with an R&D programme was, in FP6, pioneered for SKA with MCCT-SKADS and SKADS. As in that pairing, Path2SKA and PrepSKA are entirely complementary programmes.

B.3 S&T QUALITY



The main theme of this proposal is to train the next generation of scientists and engineers who will design, develop and use the next-generation radio telescope, the Square Kilometre Array (SKA). This facility will be supported by an IT infrastructure designed to handle data rates comparable to the current internet traffic of the Earth. It acts as a superb vehicle for building up a skilled, pan-European research base as it demands a supra-disciplinary approach that must embrace emerging areas like e-Research; it also requires a close academic-industrial partnership. The scale of the SKA means it can only be constructed as a global project, and the ITN proposal Path2SKA will ensure that European researchers are ideally placed to maintain leadership of its Science and Technology (S&T).

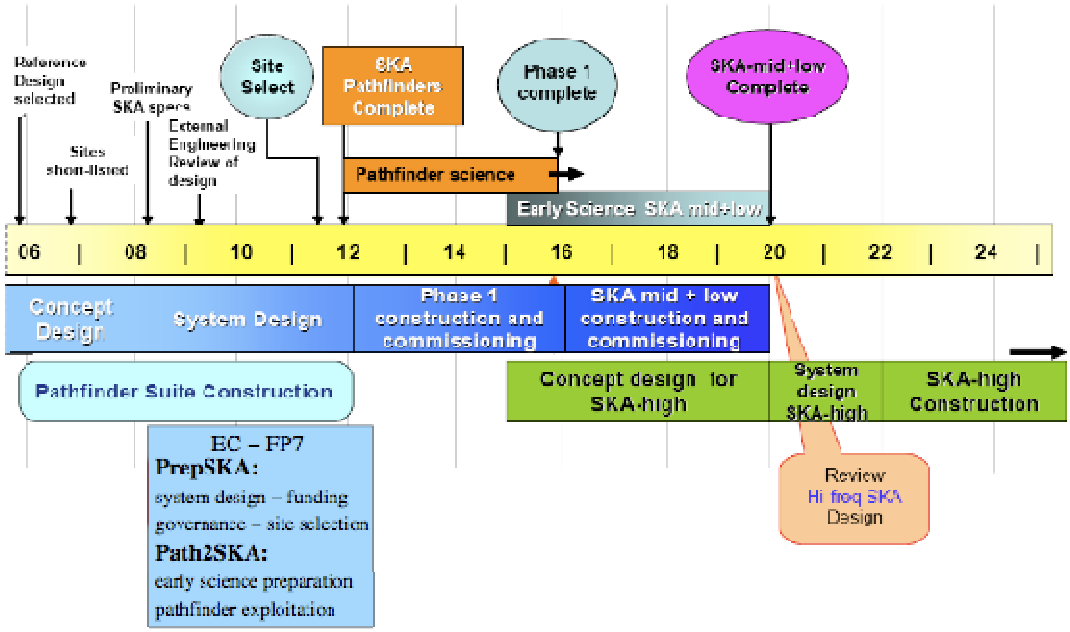
The four main **S&T Objectives** of the research programme are to train Path2SKA fellows to:

1. Use innovative techniques to exploit SKA pathfinders to generate a broad range of world-leading science from conventional astronomy to emerging areas like astro-particle physics.
2. Lead science simulation and associated software work influencing SKA design, building the future research community needed for continued European leadership in this iconic project.
3. Participate in the invention and development of novel technologies that are needed to optimize the design of the SKA, and which are likely to find wider applications in society.
4. Embrace and implement 21st-century solutions to data processing, management and analysis.

Path2SKA will foster close working relationships between academia and industry based around a set of research projects, mainly leading to a PhD and often explicitly inter-sectoral, alongside training in groundbreaking science, cutting-edge technology and core skills. It unites the European groups of renowned excellence in radio astronomy with industrial partners, forming a collaborative framework that aims to firmly establish European leadership in SKA-related training. A linked proposal PrepSKA has already been funded through the FP7 Capacities Programme, covering the complementary areas of SKA design, location, governance, component procurement and funding.

B.3.1. State of the art of the SKA project and S&T Objectives of Path2SKA

The SKA project comprises a massive, international and multidisciplinary effort to advance fundamental physics through radio astronomy, in which the European Community holds a leading role. It will require the coordinated efforts of scientists specialising in the entire spectrum of topics in astrophysics, experts in fundamental mathematics and statistics, and engineers of a large range of specialisation. The ultimate aim of the project will be to construct the most powerful radio telescope in the world: over 50-times more sensitive than existing radio telescopes and with the capacity to conduct surveys of the sky up to a million-times faster. The telescope will consist of an array of antennas with total collecting area of around one million square kilometres, spread across a desert landscape (in either Australia or Southern Africa) and covering a frequency range of ~70 MHz to ~10 GHz (in Phase-I, by ~2015, and -II, by ~2020); we will not in this proposal consider the 10-25 GHz capabilities of Phase-III, planned for beyond 2020.



A wide-bandwidth optical fibre network will connect the antennas to a central data-processing facility, forming effectively the largest IT infrastructure on Earth. The SKA science impact will be widely felt in astro-particle physics, cosmology, fundamental physics, galactic and extragalactic astronomy, solar system science and astrobiology. Since its conception, the SKA effort has grown to comprise 19 countries and 55 institutes, including roughly 200 scientists and engineers. European leadership in the SKA has been evident from the start, and the SKA Programme Development Office (SPDO), established in the Netherlands, has recently moved to the UK. In the FP7-funded PrepSKA proposal, the SPDO manages the largest `SKA Design' work-package PrepSKA-WP2.

The SKA Key Science Projects (KSPs) address fundamental questions in physics, typically far beyond the remit of conventional astronomy. Four of the five KSPs require just SKA Phases-I&II.

1st. **Probing the Dark Ages at redshift *z*>6.** As the first stars and galaxies formed, their ionising UV radiation produced a fundamental change in the surrounding intergalactic medium, from a nearly completely neutral state to the nearly completely ionised Universe in which we live today. The most direct probe of this era, the Epoch of Re-ionisation (EoR), and of the first large-scale structure formation, will be obtained by imaging neutral Hydrogen (HI) and tracking the phase transition from neutral to ionised gas. Moreover, the SKA will provide an un-obscured view of the first galaxies and super-massive black holes.

2nd. **Galaxy Evolution and Cosmology.** Hydrogen is the main baryonic component of the Universe. With a sensitivity to H I allowing detection in galaxies out to redshifts z > 2, the SKA will both follow the assembly of galaxies and use their H I emission as a tracer for cosmology. A key unknown addressed by 21st Century astronomy is how galaxies formed; the SKA will delineate how they converted gas to stars over a large fraction of cosmic time, and how their environment affects their properties. Simultaneously, Baryon Acoustic Oscillations (BAOs), remnants of early density fluctuations in the Universe, serve as a tracer of the accelerating expansion of the Universe. The SKA will assemble a huge sample of galaxies, measure BAOs and other features as a function of redshift, and hence constrain the equation-of-state of dark energy and the absolute mass scale of neutrinos.

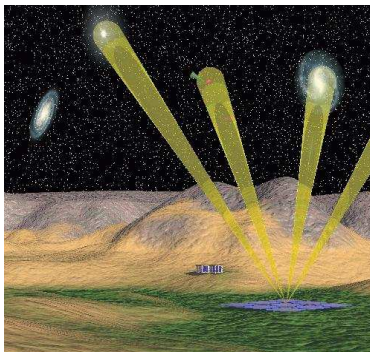
3rd. **The Origin and Evolution of Cosmic Magnetism.** Magnetic fields likely play an important role in star and galaxy formation. Unlike gravity, which has always been present, magnetic fields may have been generated essentially *ab initio* in galaxies and clusters of galaxies. By measuring the Faraday rotation towards large numbers of radio sources, the SKA will track the evolution of magnetic fields in galaxies and clusters over a large fraction of cosmic time, addressing the question of whether magnetic fields are primordial.

4th. Strong Field Tests of Gravity Using Pulsars and Black Holes. With magnetic field strengths as large as 10^{14} Gauss, rotation rates approaching 1000 Hz, central densities exceeding 10^{14} g cm^{-3}, and normalized gravitational strengths of order 0.4, neutron stars represent one of the most extreme laboratories in the Universe. Their utility as fundamental laboratories has already been demonstrated through results from observations of a number of objects, resulting in two Nobel Prizes. The SKA will find many new milli-second pulsars and engage in high-precision timing of them in order to construct a Pulsar Timing Array for the detection of nanoHertz gravitational waves, and to probe the space-time environment around black holes via both ultra-relativistic binaries (e.g., pulsar-black hole binaries) and pulsars orbiting the central super-massive black hole in the centre of the Milky Way.

The 5th KSP, **The Cradle of Life,** must largely await Phase-3 (>2020) SKA, although its most exciting aspect, searches for transmissions from another civilisation in the Universe, will be undertaken earlier, and at sensitivities sufficient to detect "leakage TV" in the nearest planets. In general, the SKA has "Exploration of the Unknown" as an underlying philosophy. Wherever possible, the SKA design is being developed to allow maximum flexibility in the evolution of its capabilities, probing virgin parameter space, especially in the time domain. This philosophy is essential as many of the outstanding questions when the SKA is in full operation are not known yet.

Significant scientific advances in these KSPs can be made with the SKA pathfinders described in Sec B.3.3, but there is currently no coherent European effort to coordinate such an effort. By drawing together the different scientific and technological skills of the full Path2SKA partners, and by collaborating on a project-by-project basis with key associated partners (e.g. SKA pathfinders), **Path2SKA creates the innovative research environment needed to address S&T Objective-1.**

Furthermore, in FP6, SKADS funded a comprehensive trans-European programme of science simulations that are generating predictive tools for the SKA[1] - the basis for the upcoming SPDO-led Reference Science Mission (RSM). As PrepSKA excludes any science simulation work, the SPDO supports placing research projects of Path2SKA fellows (WP3 of Sec B.5.2) at the heart of the RSM, allowing Europe to maintain leadership in SKA science built up through SKADS. Thus, **Path2SKA creates the innovative research environment needed to address S&T Objective-2.**



SKA technology will rely on five major systems: sensors, signal transport, signal processing, computing and software. Significant innovative research is needed to deliver the design and implementation of the systems needed to meet the science specifications of the instrument, powering on-going international efforts in the SKA pathfinders and (largely) technical, rather than scientific, demonstrators such as the SKADS-built EMBRACE and 2-PAD. The goals of the innovative work have been directed towards expanding fields of view FoV, increasing instantaneous bandwidth or tuning range, and maintaining the standards of low system noise set by previous generations of telescopes. Several concepts are under development around the world for new designs of wide-band, single-pixel feeds. Phased-array feeds (PAFs) at the focus of a dish may be a cost-effective way to increase the FoV - up to several tens of square degrees - and hence transform the survey speed of a single dish. Aperture arrays (AAs) provide ultimate flexibility by directly sampling the incident electric field without moving parts: they can form many widely separated beams on the sky, which can be `re-pointed' almost instantaneously.

[1] The SKADS Simulated Skies can be downloaded from http://s-cubed.physics.ox.ac.uk

PrepSKA-WP2 addresses the technological challenges of the SKA but has no identified dedicated effort by PhD students or industry as (i) there are obvious risks of putting inexperienced researchers on the critical path of an R&D project and (ii) the incorporation of industrial partners into PrepSKA awaits the resolution of IPR issues. However, in areas of soft- and firm-ware, data processing and data analysis (c.f. PREPSKA-WP2-P8&9), there are already identifiable generic SKA-related research projects suitable for inexperienced researchers participating in joint academic-industrial research programmes. In this way, and in partnership again with the SPDO, **Path2SKA creates the innovative research environment needed to address S&T Objective-3.**

Given the luxury of being able to pursue research off the PrepSKA critical path, it becomes possible to investigate the most original, 'blue skies' approaches to the SKA technological challenges, particularly in the e-Research and high-performance computing arenas, both via PhD projects and research projects based in the full industrial partners. In this way, **Path2SKA creates the innovative research environment needed to address S&T Objective-4.**

B.3.2 Role of Associated Partners

Path2SKA offers training in a broad range of specific scientific and technological topics that are crucial over the upcoming period of SKA development. We list the titles of the proposed projects in Secs B.3.3-7, indicating the full partners (FP) and associated partners (AP) involved in each project. Four types of associated partners are involved in Path2SKA

- Partners who operate SKA pathfinders to be used by Path2SKA projects (Sec B.3.3)
- Industrial partners with technical expertise and a developing interest in SKA
- Academic partners with complementary skills or data and an interest in SKA
- Partners that link this proposal to the international SKA efforts, most notably the SPDO

The projects are grouped into thematic categories to stress the multidisciplinary nature of Path2SKA; a description of the relevant **research methodology** introduces each category. We emphasise the innovative research methods and technologies underpinning Path2SKA.

B.3.3 State of the art of SKA pathfinders and related Path2SKA research projects

The SKA pathfinders available to Path2SKA fellows feature a range of innovative technologies:

- ASKAP (Australian SKA Pathfinder) is connected to Path2SKA through associated partner Western Australia. It is a mid-frequency (0.7-1.8 GHz) pathfinder of ~30-40 medium (12m) dishes with Focal Plane Array (FPA) feeds, operational 2011-2012.
- ATA (The Allen Telescope Array) is an associated partner to Path2SKA. It is a mid- to high-frequency (0.5-11.2 GHz) array of small (6m) dishes with single-pixel wide-band feeds. It is operational now with 42 dishes, with plans to enlarge the array by a factor ~10.
- APERTIF (APERture Tile In Focus) is full partner ASTRON's mid-frequency (0.9-1.7 GHz) FPA pathfinder on the Westerbork Synthesis Radio Telescope (WSRT). It forms 25 beams in a continuous FoV. A first astronomical image with a prototype FPA on one WSRT dish has been obtained, with full operation by end 2010.
- e-EVN (electronic European VLBI Network) is full partner JIVE's pathfinder for long-baseline fibre-connected dish interferometry. It started science observations in 2006 through the EC-funded EXPReS project, with increasing capabilities up to 2009.
- EMBRACE (Electronic Multi-Beam Radio Astronomy ConcEpt) is ASTRON's ~GHz regime 1-polarisation analogy/digital AA demonstrator built using SKADS funding in FP6.
- eMERLIN (electronic MERLIN) is Manchester's pathfinder for medium-baseline, fibre-connected dish interferometry; test-mode observations in 2009 and full operation early 2010.
- EPTA (European Pulsar Timing Array) is a collaboration between the five largest radio telescopes in Europe: Effelsberg; WSRT; Nancay; Lovell; and the Sardinia Radio

Telescope. These facilities will combine their observations of a set of millisecond pulsars, with the primary aim of detecting a stochastic Gravitational Wave Background.

- GMRT (Giant Metre-wave Radio Telescope GMRT) is an associated partner to Path2SKA. It is mid-frequency (0.08-1.5 GHz) array of 30 large (45m) dishes in India.
- LOFAR (Low Frequency Array) is ASTRON's low-frequency (10-80, 120-240 MHz) AA pathfinder, forming at least 8 separated beams. About 40 LOFAR stations are funded in The Netherlands with stations in Germany, France, Sweden and the UK (potentially Poland etc).
- MeerKAT (Karoo Array Telescope) is an associated partner to Path2SKA. It will be a mid-frequency (0.5-2.5 GHz) pathfinder of 80 medium (12m) dishes in Southern Africa.
- 2-PAD (2-polarisation All-Digital) is the UK (Cambridge, Manchester and Oxford) ~GHz regime 2-polarisation all-digital AA demonstrator built using FP6 SKADS funding.

In Path2SKA we have devised a coherent programme of research projects exploiting the key attributes of these pathfinders, combining their capabilities when scientifically advantageous. The range of science topics to be addressed is wide, from studies of the Sun to the Epoch of Re-ionisation (EoR), but with a general emphasis on new research approaches linked to SKA KSPs; we expect strong links to develop between PhD students within a given KSP. The fellows will belong to the privileged group of researchers with first access to these world-class instruments. They will develop new observing strategies and techniques, and obtain and analyse astronomical data using powerful computers with the explicit aim of publishing high-quality results. These projects are:

- Surveys for Extreme Scattering Events and follow-up studies of SZ clusters with the ATA (FP: Oxford AP: ATA); both probe different aspects of dark matter in the Universe
- Transient radio sources with the e-EVN (FP: JIVE, ASTRON, Manchester AP: MeerKAT); may detect new classes of object such as neutron star-neutron star mergers; KSPIV
- Determining the history of accretion onto super-massive black holes using e-EVN, eMERLIN, GMRT, WSRT and LOFAR (FP: INAF-Bologna, ASTRON, Cambridge, NOVA-Leiden, Manchester, Oxford); KSPII
- Removing intense foregrounds from LOFAR data, potentially allowing the first detection of an HI signal from the EoR (FP: ASTRON, NOVA-Groningen AP: Stockholm); KSPI
- Image reconstruction of EMBRACE, 2-PAD and LOFAR data on the Sun with the goal of understanding its 22-year magnetic activity cycle. (FP: CENTRA-IST, ASTRON, Cambridge, Oxford, Manchester IP: Deimos Engenharia)
- Rotation Measure Synthesis, probing the cosmic origin of magnetic fields using eMerlin and LOFAR (FP: Cambridge, MPIfR AP: Canadian NRC, Cork); KSPIII
- Timing of multiple pulsars using novel multi-beaming techniques with LOFAR (FP: Manchester, ASTRON, NOVA-Amsterdam, Oxford AP: Orleans, Thessaloniki); KSPIV
- High-precision pulsar timing with the EPTA (FP: INAF-Cagliari, Manchester, ASTRON, MPIfR, Paris), potentially making the first detection of gravitational waves; KSPIV
- Using pulsars to make the most detailed map to date of the Galactic B-field (FP: MPIfR, Manchester, Oxford AP: Thessaloniki); KSPIII
- Finding new pulsars with LOFAR and APERTIF (FP: NOVA-Amsterdam, Manchester IP: MonetDB), potentially allowing new constraints on General Relativity: KSPIV
- Understanding how star-forming galaxies and embedded radio-loud and radio-quiet AGN affect the early evolution of proto-clusters of galaxies. (FP: NOVA, ASTRON); KSPII
- Holistic view of the HI Universe through a targeted and blind survey. (FP: Paris, ASTRON AP: MeerKAT); benchmark surveys for the SKA; KSPII
- High-resolution low-frequency study of radio sources with LOFAR long baselines (FP: MPIfR, Cambridge, Manchester, Oxford AP: Cork); a fresh look at particle acceleration

B.3.4 SKA simulation and related Path2SKA research projects

These projects are based on SKA science and data simulations led internationally by European groups through SKADS funding in FP6. Path2SKA will go forward seamlessly from the SKADS tasks DS2-T1 (sky simulations) and DS2-T2 (data simulations). Given access to the tools[1] developed by DS2-T1, sky simulations can now be pursued as PhD projects. Given the combined astrophysics and High-Performance Computing (HPC) skills needed to take forward DS2-T2, this is the one area of Path2SKA that demands new algorithms developed by Experienced Researchers (ERs) who will be either PhD-trained astrophysicists seeking to develop skills in HPC, or vice versa. All projects will be pursued alongside the SPDO as part of their Science Reference Mission.

- Simulation of the gas accretion and dynamics in groups and clusters of galaxies (FP: Manchester, NOVA-Groningen, Oxford); KSPII
- Simulations of the HI signal from the EoR. (FP: Lisbon CENTRA-IST, ASTRON); KSPI
- End-to-end simulations of an SKA equipped with FPAs (FP: NOVA-Groningen, ASTRON AP: Canadian NRC)
- Imaging software for very extended interferometers (ER at FP: MPIfR, ASTRON, Cambridge, Manchester, Oxford)
- Detecting and characterising line and continuum detections in huge datasets (ER at FP: ASTRON AP: MeerKAT, Western Australia)
- Flexible and highly parallelized next-generation self-calibration algorithms (ER at FP: Oxford, ASTRON AP: MeerKAT, Western Australia, US TDP)

B.3.5 Calibration challenges and related Path2SKA research projects

The calibration of SKA-related interferometers is a complex problem that requires the development of novel calibration schemes in three separate areas: (i) schemes for amplitude and phase correction for mechanical, electrical and electronic variations in the signal path; (ii) schemes that use non-astronomical data to aid in the calibration of ionospheric (and tropospheric) signal corruptions; and (iii) next-generation self-calibration schemes exploiting the astronomical data itself (see Sec. B.3.4). All calibration schemes must operate in the presence of varying degrees of Radio Frequency Interference (RFI), and optimum RFI mitigation strategies need to be developed. In all these areas the PATH2SKA programme intends to benefit from expertise in industry that has not previously been closely integrated with radio astronomy. The research will be closely tied to applications for real-world astronomical facilities for which there are a mixture of generic and specific (e.g. to different technologies like FPAs, AAs and single-pixel feeds) problems that must be addressed. In the case where developments are needed for the SKA itself, the work will be closely tied to SKA simulation work (Sec B.3.4) and PREPSKA-WP2-P9-T5.

Two full and two associated industrial partners will play a major role in this thematic area: Chronos Technology, Deimos Engenharia, QinetiQ and S&T. These companies bring complementary skills in the use of GPS data for calibration, calibration systems for satellite radio interferometers, calibration of large-element-number synthetic aperture radar systems and model-based control. The two full industrial partners will each hire and train an Industrial Early-stage Researcher (IESR).

- In Deimos Engenharia**,** the goal of the IESR will be to facilitate knowledge transfer in calibration techniques for small precisely-calibrated interferometers. (FP: Deimos Engenharia, IST-Centra, ASTRON, Cambridge, Manchester, Oxford).
- In QinetiQ, the goal of the ESR will be to facilitate knowledge transfer in broad-band beam-forming and calibration of large arrays. (FP: QinetiQ, Cambridge, Manchester, Oxford)

[1] The SKADS Simulated Skies can be downloaded from http://s-cubed.physics.ox.ac.uk

These researchers will interact with PhD students in ASTRON, Cambridge and Oxford.

- Calibration for FPAs (FP: ASTRON IP: S & T)
- Calibration and RFI mitigation for AAs (FP: Oxford IP: QinetiQ AP: Malta)
- Ionospheric calibration using GPS receivers (FP: Oxford AP: Bath IP: Chronos Technology)
- Advanced pattern matching for removing RFI (FP: Cambridge AP: GMRT, MeerKAT)

B.3.6 Data processing challenges and related Path2SKA research projects

The data processing and imaging requirements of the SKA pathfinders, as well as the SKA itself, are such that both new algorithm development and High-Performance Computing (HPC) are a necessity. HPC solutions must be found, and algorithms and code must be optimised and professionally documented. In all these areas the PATH2SKA programme intends to benefit from expertise in industry that has not previously been central to radio astronomy. The Visiting Scientist Bruce Elmegreen (IBM) will play a key role in achieving this goal. In the case where developments are needed for the SKA itself, the work will be closely tied to PREPSKA-WP2-P9.

One full and two associated industrial partners will contribute: ClearSpeed, Geomerics & IBM. The full industrial partner ClearSpeed will hire and train an Initial Early-stage Researcher (IESR).

- In ClearSpeed**,** the goal of the IESR will be to facilitate knowledge transfer in the architectural development of powerful processors (FP: ClearSpeed, Oxford).

The Path2SKA PhD programmes in this area are

- New methods for efficient data processing with APERTIF and LOFAR (FP: ASTRON AP: IBM through Visiting Scientist Bruce Elmegreen)
- High-Performance Computing for radio astronomical processing techniques (FP: Oxford. ClearSpeed, AP: Malta)
- Wavelet basis functions for wide-field imaging (FP: Cambridge IP: Geomerics)

B.3.7 Database and data analysis challenges and related Path2SKA research projects

With the extreme data-rates being produced by SKA pathfinders, and ultimately the SKA, data-storage and retrieval becomes an increasing challenge. Path2SKA will benefit from the participation of dedicated e-Research groups (e.g. the OeRC in Oxford) and industrial partners. In databases, the associated partner MonetDB will play a major role through the Visiting Scientist Martin Kersten. Innovative data analysis work will benefit from the Visiting Scientist Devinder Sivia. Where developments are needed for the SKA itself, the work will be closely tied to PREPSKA-WP2-P9-T4. The Path2SKA PhD programmes in this area are

- Next-generation database tools for analysis of simulated SKA skies (FP: Paris, Cambridge, Manchester, MPIfR, Oxford IP: MonetDB)
- Combining SKA and other future datasets for next-generation cosmological experiments (FP: INAF-Rome, Oxford plus Visiting Scientist Devinder Sivia)

B.3.8 Integration into the overall research training collaboration

The thematic categories and specific projects demonstrate the breadth of Path2SKA across multiple disciplines in a team combining academic organisations and the private sector. Key issues are

- Contribution from a number of partners to each project
- Good representation of the SKA Key Science Projects
- Close ties to SKA pathfinder and SKA technical developments
- Mobility of the hired Path2SKA fellows between the full and associated partners
- Substantial overlap and inter-dependence to encourage parallel advances in all fields
- Fundamental involvement from the industrial partners (explicit in ~50% of the projects)

B.4 TRAINING

B.4.1 Motivation and overview of the proposed training programme

The six main **Training Objectives** of Path2SKA are:

- **Training-through-research** based on the set of specific projects outlined in Sec B.3
- Induction into a large, diverse and global **research community** focused on a common goal
- Exploiting **inter-sectoral** and **transnational mobilit**y via **secondments** and shorter visits
- **Local training** in core research skills within both academic and industrial environments
- **Network-wide training**, in generic or specialized S&T and **complementary skills**
- Training in the development of concise and accurate oral and written **communication** skills

The management and quality control of Path2SKA are described in Sec. B.5.2. The common goal of the research projects and associated training activities is to prepare researchers to use and develop the SKA and its pathfinders exploiting, wherever possible, academic-industrial partnership. The SKA is easily the most ambitious radio telescope ever envisioned and it will produce breakthrough science. The depth and breadth of the skills needed by Path2SKA fellows requires a training programme of huge scope, beyond the capabilities of one or a few EC countries. The demands of Path2SKA in multi-disciplinary training will generate a highly skilled cadre of fellows.

Less than half of the Path2SKA fellows are likely to go on to long-term career linked to the science or technology of the SKA, so Path2SKA must be designed to address the wider needs of the European Research Area. Path2SKA will provide training in generic research and complementary skills. In this regard, the mix of Universities, research facilities and industries in the network is crucial, as is the programme of **secondments** and networking explicit in the research projects.

Most early-stage researchers move between sectors within the first few years of their research careers, most commonly PhD students leaving a University and joining the private sector just after obtaining their PhD, or after a few additional years of academic work. Path2SKA will attempt to `break the mould' of such rather dated training methods by promoting, as far as possible, equality of training opportunities for the Early-Stage Researchers (ESRs) registered for PhDs, the Experienced Researchers (ERs) and the Industrial ESRs (IESRs). Although their eventual careers will be diverse, we anticipate that all fellows will draw on skills gained during their Path2SKA training to maximize their career potential, as well as benefiting from the emphasis in their early research training on mobility between sectors and between countries. Training will initially be focused locally, but network-wide training will always be available, and gain in emphasis as Path2SKA progresses.

Training-through-research is organized via the projects outlined in Sec B.3, and detailed in Sec B.5. These are arranged into thematic areas, but designed such that Path2SKA fellows are part of a coherent research team in which they will benefit from interacting with other fellows both inside and outside their theme. To some extent these interactions will develop naturally via email etc, but Path2SKA will set-up structures aimed at developing Path2SKA as a vibrant **research community**. These structures are described in **"other networking activities"** below.

Local training will exploit established and proven structures which will bring the additional benefit of connecting Path2SKA fellows to much larger groups of researchers inside their home institutes. Although local customs, academic curriculae and requirements vary throughout Europe, the following gives a fair description of the schedule of local training at a Path2SKA academic partner.

Each fellow will be assigned a primary and secondary research supervisor (for a PhD), or mentors (for ERs) who will be responsible for one-to-one research training and pastoral care. Recalling that

recruited researchers will typically have a first degree in computer science, engineering, mathematics or physics, they will attend courses setting out the basics of astrophysics, astro-particle physics and cosmology, covering theory and practice, including technical elements. They will develop research skills through courses on IT, software packages, coding and high-performance computing, typically based on practical assignments. They will take courses on oral and written communication. They will be expected to attend weekly astrophysics colloquia given by internationally-recognized experts, and encouraged to interact with the speaker in a social setting afterwards. They will attend other seminars, journal clubs and national and European meetings as directed by their research supervisors. The graduate course will mix taught material with student-led discussion groups. The material will be interdisciplinary including computational and numerical methods, engineering and statistics. Students can take advantage of courses arranged by a University, e.g. in languages and other transferrable skills. They will be encouraged to attend courses outside the University, e.g. on third-party software packages like IDL. Fellows will be asked to write reports at the end of their 1st and 2nd years describing their research plans and achievements. Local staff members who are not either of the fellow's supervisors, or mentors, will assess this material alongside each Fellow's personal career development plan, reporting back Path2SKA management. Progression from a probationary research student to a PhD is contingent on satisfactory progress. Fellows will be encouraged to visit schools. Path2SKA ERs will benefit from interacting with all other (up to 50 or so) local postdocs covering a wide range of research areas, and can participate in, and help organize, regular postdoc-organised `journal clubs'.

Many of the academic partners operate radio telescopes, often literally "in their backyard" and many are building SKA-preparatory instruments there. This allows additional training activities:

- "Early science" experiments to bring fellows together in a structured and challenging environment where they will combine their skills in a joint pathfinder experiment
- Scientific interaction with visiting international observers, besides SKA pathfinders (Sec B.3.3): Cambridge hosts AMI; Manchester will soon host an ALMA Regional Centre; MPIfR hosts Effelsberg; Paris hosts Nancay; INAF hosts the Sardinia Radio Telescope

Training in complementary skills will take place in three main ways. First, the industrial partners will provide professional courses in technology transfer, intellectual property issues, project management and entrepreneurship. Second, the academic partners will provide courses on IT skills, presentation skills, languages, ethics and communication. Third, the organization of all network-wide events, be they face-to-face meetings or videoconferences, will include elements dedicated to complementary skills. Given the added value of the network-wide training opportunities of this large ITN, these elements of Path2SKA will be compulsory for all fellows.

Path2SKA is designed to ensure "on-the-job" training in organizational and leadership skills. The ESRs and ERs will either be working towards a PhD, or be working on projects with well-defined goals. Although guided by supervisors and mentors, the detailed planning required to achieve their goals in a timely manner is ultimately the responsibility of the ESRs and the ERs. Path2SKA will support initial training in core skills such as proposal writing, task co-ordination and the use of IT and presentational aids. It will also provide a support structure in which the more experienced fellows can advise and guide the less experienced ones. In both sectors there will be opportunities for fellows to lead small-project teams or undergraduate-training projects in a University.

To train the Path2SKA fellows in complementary skills, courses will be offered by QinetiQ, which is an FTSE-250 company with over 8000 scientists, specializing in the transfer of high technology to market. QinetiQ will organize joint training in technology transfer, IP and project management and offer these courses to other network members via their QinetiQ Learning and Development Group. These could be held in the new QinetiQ Conference Centres either at the Malvern or

Farnborough sites. Other courses in complementary skills will last 4 days, with 20-25 participants (including ITN members). Hard and electronic copies of all presentations will be made available to the participants. These courses would form part of the Career Exploratory aspects of the training. The courses are aimed at increasing the awareness of fellows, alerting them to applications of their research in industry and educating them in the possibilities of commercial exploitation of results.

Early-stage researchers visiting ClearSpeed will benefit from an open and dynamic environment. Formal training is provided in the basic essentials of working life including health and safety. Technical training is provided by a combination of external courses, internal seminars and "on the job" training. Employees are encouraged to contribute to the seminar programme by presenting on their areas of expertise or interest. There are mentoring programmes and formal training courses for specialist areas such as software development tools. ClearSpeed supports and encourages short-term **secondments** to the company, introducing University-based fellows to the practical aspects of applying research in a commercial environment, the experiences of growing a business, and entrepreneurship in general. ClearSpeed provides on-line support, forums and user group meetings (typically two each year) where users of its products are encouraged to share their experiences. ClearSpeed would encourage this as a training forum and communication route for all projects within Path2SKA that are using, or interested in using, its products as part of the research.

At Path2SKA events, Deimos Engenharia will give an introductory course (4-6 hours) on mid-sized software management tools and techniques. This would be a practice-oriented course, mainly using `real world' examples. The course will include software design tools and procedures, coding and documentation standards, validation and testing, as well as time and human resources management. There is regular in-house training in areas like software development, programming languages, project management, quality standards, etc. The length of these courses will go up to several days, typically given as half-day sessions. These courses will be open to the Path2SKA consortium.

B.4.2 Structure

The network-wide training events will feature one large training event each year organized in Path2SKA. All four will be open annual events of 5 days duration. Three Visiting Scientists (Sec. B.4.3) will assist in their organization. Subjects of network-wide interest that will be covered in the yearly events include: data analysis, databases and the Web, high-performance computing, numerical algorithms, future trends in computer technology, proposal writing, current topics in radio astronomy, and working towards constructing and using the SKA (science and technology). The following mix of the possible practical formulae for the organization of these events has been chosen, in order to optimize their impact on the training programme. The team of three Visiting Scientists (Sec B.4.3), who will play leading roles in these events, provides an excellent match to the multidisciplinary approach of the networking activities. The wide scope of subjects to be covered warrants their presence at each of them plus a further three (different) external experts.

- Event 1 "Path to SKA: Basic Steps", to provide training in some of the more fundamental themes through a series of courses: 25 Path2SKA participants, 3 outside experts, 3 Visiting Scientists. Venue: one used regularly for astronomy meetings, in Sesimbra, 40 km from Lisbon
- Event 2 "Path to SKA: First Steps towards Using the SKA", with both lectures and related practical assignments, focusing more on the data analysis, computing and algorithms aspects of the SKA: 20 participants, 3 external experts, 3 Visiting Scientists. Venue: University of Malta
- Event 3 "Path to SKA: Further Steps towards Using the SKA", with both lectures and related practical assignments, focusing more on the radio astronomical aspects of the SKA: 20 participants, 3 external experts, 3 Visiting Scientists. Venue: at INAF, Rome Observatory site

- A final showcase international network Conference, Event 4 "Path to SKA: the Final Step", to let the fellows show their achievements of the past 4 years in Path2SKA to the international community: 25 participants, 3 external experts, 3 Visiting Scientists. Venue: Paris Observatory

We propose that sufficient time will be allocated at each of these large meetings for constructive and structured interactions between Path2SKA fellows only, without the presence of their supervisors and other senior staff, to encourage them to interact with their peers and to seek out knowledge on their own. The projects that will be undertaken in Path2SKA cover a wide range of topics and disciplines and the students have a great opportunity to learn from each other. As well as allowing cross-fertilization it also helps to build confidence and experience in scientific discussions.

In addition there will be four **training courses,** each of 3 days duration, with 20 Path2SKA participants and 3 outside experts. We have elected to site these more specialized meetings close to the geographical centre of the network.

- Course 1 "Science and Instrumentation for Wide-field imaging and Calibration" (ASTRON). Focus on PAFs and AAs, both on technical aspects and science, and have some practical assignment on the related data calibration (MeqTree and Peeling software etc.).
- Course 2 "e-VLBI/SKA training course" (JIVE). Training for potential e-EVN users, e.g. how to prepare e-EVN observing proposals and how to interpret the data analysis pipeline results, and potential of SKA. This could be organized parallel to the EVN2010 Symposium.
- Course 3 "Path2SKA deep and wide field surveys and the e-EVN: connecting pipelines" (JIVE). SKA pathfinders have an ability to demonstrate top-quality science in VLBI mode using e-VLBI technologies - in particular for semi-automated observations of transient radio sources triggered by external facilities (e.g. SKA pathfinders, Sec B3.3). The observations will be based on methodology developed under the FP6 EXPReS project. Participants will get hands-on experience in conducting real-time observations and pipeline data processing. The events will be organized in two formats: as two stand-alone 1-2 day seminars at JIVE, and as one-day extensions to other appropriate events, e.g. a regular EVN Symposium (scheduled for 2010-11) and an annual NOVA School hosted at ASTRON and JIVE.
- Course 4 "Radio observations and the ionosphere" (at the Lorentz Centre in Leiden). The turbulent ionosphere has a dramatic impact on low-frequency radio data and a number of correction techniques are currently being investigated. Topics will include: (i) physics of the ionosphere; (ii) statistical methods describing the ionosphere; (iii) impact of the ionosphere on data quality; (iv) mathematical methods to remove the ionosphere; (v) training in software systems that are capable of dealing with aspects of the ionospheric perturbances.

Other networking activities will be organized throughout the Path2SKA structure

- Video conferencing: the advances that have been made in free and easy to use Video conferencing software mean that it can now also be used as an effective training tool. Path2SKA will set up a series of one-hour-long bi-weekly training video conference sessions which will be on a diverse range of topics from proposal writing through to the latest developments by the SKA engineering team. Fellows will be involved in choosing some of the topics so that they can define which areas of their knowledge are able to benefit from these sessions. This will allow all of the fellows to interact with the appropriate expert on each of the topics. As well as an important learning tool, this networking ensures regular contact amongst the Path2SKA team.
- Electronic web-based networking: this indispensable tool for the smooth operation of a multi-partner network will be used to its full extent, including the active use of WiKi pages to share information and documents. The SKADS WiKi provides an excellent model to follow and develop. Furthermore, the Path2SKA administrator will, under the scientific guidance of the ERs and IESRs, link together and properly document various web-based guides to software and data analysis in radio astronomy, etc; training will also be provided in web-page creation skills.

- Visits and secondments between Path2SKA participants will be actively pursued, given the complementary nature of the PhD projects and the skills that can be acquired in this manner. The minimum level of this programme is defined by the demands of the joint projects, but we anticipate a much larger networking programme will develop naturally as research links develop.
- Seminars: all participants have regular seminar series, and most regularly organize special conferences or meetings where ESRs and ERs can show the results of their projects.
- Summer-student programmes: some partner institutes (e.g. ASTRON) already have programmes that provide 10-weeks-long, hands-on research experience in radio astronomy. A number of additional positions focused on Path2SKA-related research will be organized.
- Attendance at international conferences to disseminate the results of Path2SKA: there will be numerous suitable national, regional (e.g. EAS), and international meetings (e.g. IAU and others) – a number of specifically SKA-related events are expected to be organized during 2009-2012
- Exchange of "best practice" and knowledge transfer with other ITN and astronomy projects: e.g., large projects in ground-based optical (E-ELT/ESO) and space-borne radio/IR astronomy (Herschel/Atlas project), and the MCCT-SKADS and RadioNET FP7 activities

Collaboration with networking activities of related EC programmes will ensure that over the duration of Path2SKA, major networking activities will be developed within the framework of two other EC-financed programmes whose subjects are likely to be of interest to the Path2SKA fellows, and vice-versa: (the last few events of) FP6 MCCT-SKADS and FP7 RadioNet. Path2SKA fellows will be able to register for all these events, providing they fulfill the criteria of eligibility. The various networking activities proposed by RadioNet, are complementary to those of the Path2SKA activities since they focus on teaching the *métier* of current radio astronomy, whereas Path2SKA looks to the future in skills such as data analysis, databases, computing, and numerical algorithms.

B.4.3 Role and contribution of participants from within and outside the network

Three Visiting Scientists (VS) will assist in the organization of the large events, each on the basis of a one-month-per-event contract basis. Their individual and combined expertise complements the multidisciplinary nature of Path2SKA. Furthermore, three different external experts funded by Path2SKA will be invited to each of the events, to cover the wide scope of subjects covered.

Dr. **Bruce Elmegreen** works in the Physical Sciences Department of the Research Division of IBM. His interests in astrophysics include star formation, interstellar matter, and galactic structure. He joined IBM from a faculty position at Columbia, and introduced the IBM Research Division to hardware accelerators for multi-particle simulations of molecular dynamics, fluid motions, electromagnetic interactions, and stellar systems. This led to IBM's design and manufacture of the MDGRAPE-2 accelerator. Dr. Elmegreen has written nearly 200 articles on star formation and related topics and given over 100 invited research talks. He has served on numerous review panels for NASA and NSF and was Chair of the Publications Board of the American Astronomy Society. In 2001, he received the Dannie Heineman Prize of the American Physical Society in Astrophysics.

Prof. **Martin Kersten** has devoted most of his career to the development of database systems. The latest incarnation is the open-source system MonetDB, which demonstrates viability of the column-storage approach as a sufficient base for both an efficient SQL and XQuery database solution. The system is developed by the Database Architectures and Information Access group of CWI, which he established in 1985, and which hosts a strong group of experimental scientists. He founded MonetDB as a spin-off SME. established in 2008 by Centrum Wiskunde & Informatica (Centre for Mathematics & Computer Science) in Amsterdam, The Netherlands. The mission of MonetDB is to manage, maintain, and disseminate its database technology developed into the open-source market.

Dr. **Devinder Sivia** did his Ph.D at the Cavendish Laboratory in Cambridge. He worked at the Los Alamos National Laboratory in the USA and the ISIS facility at the Rutherford Appleton Laboratory in the UK before his recent move to St Catherine's College, Oxford. He has published three related books in the Oxford Chemistry Primers series, and regularly gives a graduate lecture course on Bayesian data analysis at the Ecole Centrale in Paris, and in Oxford. He also ran the annual Neutron Training Course during his last 4 years at RAL. His main expertise is applying Bayesian methods to scientific data analysis. The generic nature of the methodology has brought him into contact with people from a wide variety of backgrounds: theorists and experimentalists, astronomers, condensed matter physicists, chemists and geographers. This broad appeal is reflected in the range of journal articles that cite his tutorial book on the Bayesian approach to data analysis.

B.4.4 Justification of Size of Training Section and Balance of ESRs and ERs

The SKA is a single global project uniting essentially all radio astronomy groups worldwide, with a single SKA Project Development Office. It is also a genuinely transformational science instrument with a science case and technological demands that cross traditional discipline boundaries. Path2SKA has to be a large network both to ensure representation of all the main SKA stakeholders and to cover the key science and technology areas. The academic partners in Path2SKA are used to organising large joint research efforts through RadioNET and SKADS. The industrial partners have embraced the possibilities of joining this pan-European structure as it gives them a direct way to `plug into' the SKA on European and global scales. The role of the **Supervisory Board** and industry in the definition of the skills requirements is discussed in Sec B.5.2

Of the 31 Path2SKA fellows, 28 will be ESRs, with 25 undertaking PhDs. The three ERs are needed to address a specific area: `high-performance software for radio astronomy'. Their deliverables will provide benefit to all Path2SKA fellows, and the ERs will benefit from Path2SKA training as their expertise will not initially be fully developed in both astrophysics and software.

	Early-stage and experienced researchers to be financed by the grant agreement			
Network Team	Early-stage researchers (ESR) (person-months) (A)	Experienced researchers (ER) (person-months) (B)	Visiting Scientists (VS) (person-months) (C)	Total (A+B+C)
1	96	24	4	124
2	96	24	4	124
3	72			72
4	48			48
5	72			72
6	36			36
7	48			48
8	48			48
9	48	24		72
10	72		4	76
11	48			48
12	24			24
13	24			24

B.5 IMPLEMENTATION

We describe in Sec B.5.1 the capacities of the ten academic and three full (Level-1) industrial partners to Path2SKA. The associated partners are detailed in Sec B.1, noting the five Level-2 industrial partners, letters from which are attached. We describe in Sec B.5.2 the work-packages (WPs), task distribution, milestones, deliverables and schedule. The management work-package explains the organization of decision-making, communication, monitoring, result dissemination, intellectual property and recruitment. The other work packages highlight research synergies. All of the 25 Path2SKA PhD projects involve more than one partner, and 10 are based explicitly on inter-sectoral research. The three Path2SKA ERs will be based in the academic sector, and the three IESRs will be based in industry, but their work plans ensure significant research interaction.

B.5.1. Capacities of Host Institutions

The Path2SKA full partners are either Universities, research institutes with established links[1] to Universities or companies. All the larger academic partners are key players in the international SKA project, have modern research infrastructures (e.g. supercomputing facilities), and have exceptionally strong track records in training PhD students. Their typical yearly intake of PhDs is 15, so Path2SKA will constitute ~20% of their intake, providing no capacity or recruitment problems. The smaller groups (JIVE and IST-CENTRA) have made a strategic decision to place ~50% of their PhD intake into Path2SKA, and the larger groups will help them recruit strong fellows. The industrial full partners have established effective procedures for training researchers and have, or through Path2SKA will develop, strong links with students undertaking PhD projects.

The **University of Oxford** (http://www.ox.ac.uk) and its Astrophysics (http://www-astro.physics.ox.ac.uk/) sub-Department has the fastest-growing radio astronomy group in Europe. It works closely with the Oxford e-Research Centre (OeRC; http://www.oerc.ox.ac.uk/) that will play a major role in the training of Path2SKA early-stage researchers in advanced ICT. **PATH2SKA group:** S. Rawlings (Observational Cosmology, 20%); A. Trefethen (Numerical Methods, 5%); M. Jones (experimental radio cosmology, 10%); S. Salvini (HPC, 15%); A. Karastergiou (pulsars and exotic objects, 10%); A. Taylor (radio interferometry, CMB, 10%); I. Hook (Cosmology, 10%). **Publications:** Carilli C. & Rawlings S, 2004: `Science with the Square Kilometre Array', Elsevier; Martinez-Sansigre, Rawlings et al., 2005: `The obscuration by dust of most of the growth of supermassive black holes'. Nature, 436, 666; Jones M., et al., 2005: `H_0 from an orientation-unbiased sample of Sunyaev-Zel'dovich and X-ray clusters'. MNRAS, 357, 518)

ASTRON (http://www.astron.nl/index.php) is the Netherlands Institute for Radio Astronomy. It provides front-line observing facilities (WSRT and LOFAR) and has a world-leading technology development programme. **PATH2SKA group:** R. Morganti (AGN, HI, 20%); G.de Bruyn (EoR, ISM, 10%); T. Oosterloo (HI, ISM 10%); M. Garrett (Distant Galaxies, 5%); J. van Leeuwen (pulsars, FPGA development 10%); M. de Vos (systems modeling, 10%); R. Nijboer (aperture synthesis calibration, 10%); J. Romein (performance computing, 10%); J. Nordam (astronomical simulations, 20%). **Publications:** de Bruyn, A. G., Brentjens, M. A., 2005: Faraday rotation measure synthesis. A&A 441, 1217; Verheijen, M. A. W., Oosterloo, T. A., et al., 2008: APERTIF, a focal plane array for the WSRT in "The Evolution of Galaxies through the Neutral Hydrogen Window" (arXiv:0806.0234); Romein, J. W., Broekema, P.C, et al., 2006: AstronomicalReal-Time Streaming Signal Processing on a BlueGene/L Supercomputer in ACM Symposium on Parallel Algorithms and Architectures (SPAA'06), Cambridge, MA, pp. 59-66

The **University of Cambridge** (http://www.cam.ac.uk/) hosts the world-famous Astrophysics Group at the Cavendish Laboratory (http://www.mrao.cam.ac.uk). The group operates the Mullard Radio Astronomy Observatory where the "Arcminute Microkelvin Imager" has just been commissioned. **PATH2SKA Group:** P. Alexander (Galaxy evolution, 10%); D. Green (Supernova remnants, 10%); J. Riley (AGN, 15%); M. Hobson (early universe cosmology, 5%); A.

[1] e.g., PhD students working at ASTRON or JIVE will be embedded in the graduate school for astronomy, NOVA

Faulkner (pulsars, radio telescope design, 5%); K. Grainge (cosmology, 5%); A. Scaife (imaging algorithms, 10%). **Publications:** Garn T., Green D.A., Hales S.E.G., Riley J.M., Alexander, P., 2007: Deep 610-MHz Giant Metrewave Radio Telescope observations of the Spitzer extragalactic First Look Survey field - I. Observations, data analysis and source catalogue. MNRAS 376, 1251; Feroz F., Hobson M.P., 2008: Multimodal nested sampling: an efficient and robust alternative to Markov Chain Monte Carlo methods for astronomical data analyses. MNRAS, 384, 449, 2008; McEwen J.D., Scaife A.M.M., 2008. Simulating full-sky interferometric observation. astro-ph/0803.2165v1

Deimos Engenharia (http://www.deimos.pt/) is a Level-1 industrial partner to Path2SKA. It is a private Portuguese Aerospace Engineering company, delivering advanced design solutions and turnkey space software systems since 2002. The company's business is mainly focussed in space systems design and operational software systems development and validation. The Path2SKA activity will take place in the Ground Segment division alongside the team developing the SMOS Level 1 Prototype Processor (http://www.smos.com.pt/). **PATH2SKA Group:** N. Catarino (image reconstruction, 15%); J. Barbosa (calibration algorithms 10%); A. Gutierrez (SMOS project management, 10%). **Publications:** A Gutierrez, J Barbosa, N Almeida, N Catarino, J Freitas, M Ventura & J Reis, 2007: SMOS L1 processor prototype: From digital counts to brightness temperatures. Proceedings of the Geoscience and Remote Sensing Symposium, 2007 (IGARSS 2007), pp. 3626-3630; SMOS L1PP Team, 2008: SMOS L1 Processor L0 to L1a Data Processing Model, online at http://smos.com.pt/project_docs.html; SMOS L1PP Team, 2008: SMOS L1 Processor L1a to L1b Data Processing Model, online at http://smos.com.pt/project_docs.html

The “Istituto Nazionale di Astrofisica” (INAF; http://www.inaf.it/) coordinates all astrophysical research in Italy. INAF expertise in radio astronomy is strong and runs several radio telescopes, including the new SRT (Sardinia Radio Telescope). **PATH2SKA Group**: N. D’Amico (pulsars, 10%); L. Feretti (radio sources, 10%); A. Possenti (pulsars 20%); I. Prandoni (cosmology, 20%). **Publications**: Prandoni, I.; Parma, P.; Wieringa, M. H.; de Ruiter, H. R.; Gregorini, L.; Mignano, A.; Vettolani, G.; Ekers, R. D., 2006, A&A 457, 517, "The ATESP 5 GHz radio survey. I. Source counts and spectral index properties of the faint radio population"; Burgay, M.; D'Amico, N.; Possenti, A.; Manchester, R. N.; et al., "An increased estimate of the merger rate of double neutron stars from observations of a highly relativistic system", 2003, Nature, 426, 531; Lyne, A. G.; Burgay, M.; Kramer, M.; Possenti, A. et al, "A Double-Pulsar System: A Rare Laboratory for Relativistic Gravity and Plasma Physics", 2004, Science, 503, 1153

The Joint Institute for VLBI in Europe (**JIVE; http://www.jive.nl/**) is the pan-European entity which operates the EVN and, via the FP6 EXPReS project, is developing real-time VLBI, culminating in the e-EVN. **PATH2SKA Group:** H. J. van Langevelde (galactic astronomy, masers, 10%); Leonid Gurvits (AGN, 10%); Z. Paragi (microquasars, supernovae, 20%). **Publications:** Frey, S., Gurvits, L.I., Paragi, Z., Gabányi, K.E. (2008): High-resolution double morphology of the most distant known radio quasar at z = 6.12, Astron. Astrophys. 484, L39; Paragi, Z., Kouveliotou, C., Garrett, M.A., Ramirez-Ruiz, E., van Langevelde, H.J., Szomoru, A., Argo, M. (2007): e-VLBIdetection of SN2007gr, ATel #1215; Vlemmings, W.H.T., van Langevelde, H.J. (2007): Improved VLBI astrometry of OH maser stars, Astron. Astrophys. 472, 547

The Instituto Superior Tecnico (IST; http://www.ist.utl.pt/), is the largest and most reputed school of Science and Engineering in Portugal. IST is a member of CLUSTER, the prestigious network of leading European Universities of Technology. Via its participation in SKADS, the Multidisciplinary Centre for Astrophysics (**IST-CENTRA** - http://centra.ist.utl.pt) is leading the build-up of SKA activity in Portugal, including development of a site for AA demonstrators. IST-CENTRA's Path2SKA group has recently bought a server with 32 processors and 64GB of RAM for simulations related to SKA. **PATH2SKA Group:** M. Santos (EoR, 30%); I. Lopes (solar physics, stellar evolution, 15%); P. Castro (CMB, 10%); A. Mourão (cosmology with supernovae, 5%). **Publications:** Santos, M. G., Amblard, A., Pritchard, J., Trac, H., Cen, R. and Cooray, A., 2008: Cosmic Reionization and the 21cm signal: simulations and analytical models. ApJ, **689**, 1;

Passos, D., Lopes, I., 2008: Phase Space Analysis - The Equilibrium of the Solar Magnetic Cycle. Solar Physics, **250**, 2, 403; Santos, M. G., Cooray, A. and Knox, L., 2005: Multifrequency Analysis of 21 Centimeter Fluctuations from the Era of Reionization. ApJ, **625**, 575-587.

The University of **Manchester** (http://www.manchester.ac.uk/) was created in 2004 combing Manchester and UMIST. The Jodrell Bank Centre for Astrophysics runs Jodrell Bank Observatory and the 76-m Lovell Telescope. It hosts the SPDO. **PATH2SKA Group:** M. Kramer (pulsars, gravity tests, 10%); B. Stappers (pulsars, radio instrumentation, 10%); R. Battye (cosmology, 10%); S. Kay (clusters, 10%); S. Mao (gravitational lensing, 10%). **Publications:** M. Kramer, D. C. Backer, J. M. Cordes, T. J. W. Lazio, B. W. Stappers, S. Johnston, 2004: Strong-field tests of gravity using pulsars and black holes, New Astronomy Review, **48**, 993; J. van Leeuwen, B. W. Stappers, 2008. *40 YEARS OF PULSARS:* Millisecond Pulsars, Magnetars and More, AIP Conference Proceedings, **983**, 598 (2008); A. R. Duffy, R. Battye, R. Davies, A. Moss, P. N. Wilkinson, 2008. Galaxy redshift surveys selected by neutral hydrogen using the Five-hundred metre Aperture Spherical Telescope, MNRAS, **383**, 150

The **Max Planck Institute for Radio Astronomy** (MPIfR; http://www.mpifr-bonn.mpg.de/english) is the leading radio astronomical institute in Germany. It operates the 100-m telescope at Effelsberg and the first international LOFAR station. **PATH2SKA Group:** R. Beck (magnetism, 10%); A. P. Lobanov (jets, 10%); J. A. Zensus (AGN, 5%); J. Anderson (interferometry, 20%); E. Ros (AGN, 5%). **Publications:** A.P. Lobanov: Imaging Across the Spectrum: Synergies Between SKA and Other Future Telescopes, in Exploring the Cosmic Frontier: Astrophysical Instruments for the 21st Century, ISBN 978-3-540-39755-7, Springer, (2007), p. 39; X. H. Sun, W. Reich, A. Waelkens, T. A. Enßlin: Radio observational constraints on Galactic 3D-emission models, Astronomy & Astrophysics, **477**, 573 (2008); R. Stepanov, T. G. Arshakian, R. Beck, P. Frick, M. Krause: Magnetic field structures of galaxies derived from analysis of Faraday rotation measures, and perspectives for the SKA, Astronomy & Astrophysics, **480**, 45

The **Observatoire de Paris** (http://www.obspm.fr/) is the research centre leading French involvement in the SKA. It operates the Nançay telescope. Contributing to Path2SKA are the GEPI (Galaxies, Stars, Physics, and Instrumentation) Department and LERMA (Laboratory for Studies of Radiation and Matter in Astrophysics. **PATH2SKA Group:** W. van Driel (HI, 20%); M. Lehnert (galaxies, 10%); F. Viallefond (interferometry, 10%); F. Levrier (simulations, 20%). **Publications:** O'Neil, K., Bothun, G., van Driel, W. & Monnier Ragaigne, D.: 2004, A new HI catalog of Low Surface Brightness Galaxies out to z=0.1 – tripling the number of massive LSB galaxies known, A&A, **428**, 823; Wilman et al., 2008: "A semi-empirical simulation of the extragalactic radio-continuum for next-generation radio telescopes", MNRAS, **388**, 1335; Levrier, Falgarone, & Viallefond, 2006: "Fourier phase analysis in radio-interferometry". A&A, **456**, 2

NOVA (http://www.astro.rug.nl/~NOVAeduc/) is a federation of the astronomical institutes of the Universities of Amsterdam, Groningen, Leiden, Nijmegen & Utrecht, recognised by the Royal Netherlands Academy of Arts and Sciences in 1992. All graduate astronomy education in the Netherlands is within NOVA. **PATH2SKA Group:** T. van der Hulst (galaxy evolution, 15%); H. Rottgering (distant AGN and galaxies, 15%); G. Miley (distant AGN, 15%); I. Snellen (compact radio sources, 10%); P. Barthel (AGN and starburst galaxies, 10%); M. Verheijen (HI and galaxy kinematics, 15%). **Publications:** van der Horst, J., Rol, E., Wijers, R. A. M. J., Strom, R., Kaper, L., Kouveliotou, 2005: The radio afterglow of GRB 030329 at centimetre wavelengths: evidence for a structured jet or non-relativistic expansion. ApJ, 624, 1160; Zaroubi, S., Thomas, R.M., Sugiyama, N., Silk, J., 2007: Heating of the intergalactic medium by primordial miniquasars, MNRAS, 375, 1269; Venemans, B.P., Rottgering et al, 2007: Protoclusters associatedd with z ~ 2 radio galaxies. I. Characteristics of high-redshift protoclusters. A&A 461, 82

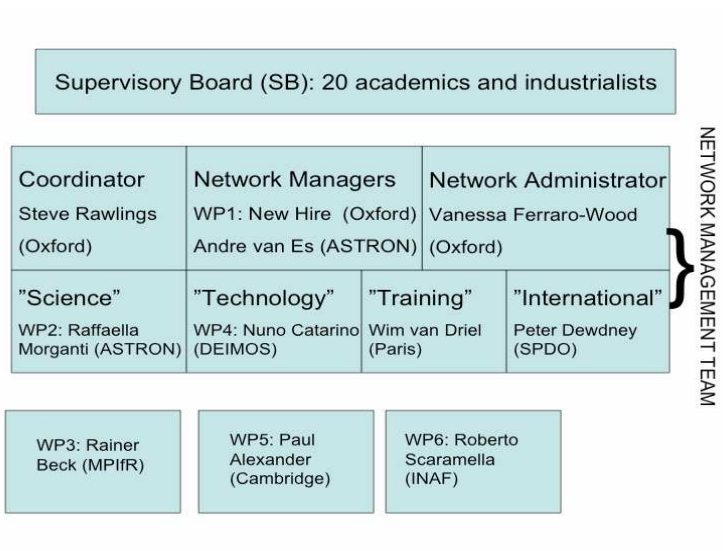
QinetiQ (http://www.qinetiq.com/) is a Level-1 industrial partner to Path2SKA. It is a leading international defence and security technology company. It develops innovative technology-based solutions and products and provides technology-rich support services. The Signal Processing group in Malvern, UK, comprises a team of 20 scientists and engineers, covering a wide range of

capabilities in signal and information processing. Areas of expertise include adaptive filtering and broad-band beam-forming. There are currently five PhD students co-supervised by senior staff in the group, and three further students received PhD degrees within the last year. **PATH2SKA Group:** M. Macleod (digital signal processing and RF sensing, 5%); N. Salmon (microwave and mmwave hardwarde beam-formers, 5%). **Publications:** M. Hayes, S.K. Kassim, J.A.Chambers, M.D. Macleod, "Exploitation of Quasi-Orthogonal Space Time Block Codes in Virtual Antenna Arrays: Part I – Theoretical Capacity and Throughput Gains", VTC 2008, Singapore; W. Addison, M.D. Macleod, "Online Bayesian Direction of Arrival Estimation with Drifting Sensor Locations", EUSIPCO 2008, Lausanne; N.A Salmon, J. Beale, J. Parkinson, S. Hayward, P. Hall, R. Macpherson, R. Lewis, A, Harvey, 'Digital beam-forming for passive millimetre wave security imaging', 2nd European Conference on Antennas and Propagation, November, 2007, Edinburgh.

ClearSpeed Technology (LSE:CSD; http://www.clearspeed.com/) is a Level-1 industrial partner to Path2SKA. It is a fabless semiconductor company that delivers advanced parallel-processing solutions for applications ranging from commerce to science to security. ClearSpeed's products include chips, accelerator boards, rack modules, software and support. Its head office and core design team are located in Bristol UK. ClearSpeed has a successful track record of working with and providing solutions to academia, ranging from training year-in-industry students to the supply of HPC accelerators to the Tokyo Institute of Technology**. PATH2SKA Group:** P. Winser (HPC, 10%); K. Cameron (software and processor design, 10%); D. Stuttard (parallel processing systems, 5%); R. McConnell (parallel processing systems 5%); R. David (semiconductors, 2%).

B.5.2 WP1. Management Strategy and Work Plan

The Path2SKA Project Office will be in Oxford comprising a to-be-hired 50%-time network manager (NM), and a 50%-time network administrator Vanessa Ferraro-Wood. Additional management, at the 25% level, will be provided by Andre van Es at ASTRON: he is the SKADS Project Manager, and will ensure continuity between the two programmes. The NM will chair a Network Management Team (NMT). It will meet regularly (at least bi-monthly, by telecon) to monitor progress. The NMT will make low-level (or non-strategic) decisions.



The **Supervisory Board** (SB) will provide top-level oversight, meeting in person once per year at the time of Path2SKA events (Sec B.4), and by telecon halfway between these events. It will consist of one representative per full partner, one per associated industrial partner, and one each from the SPDO, MeerKAT and Western Australia. This ensures equal representation of academia and industry. The SB will define the **skills requirements** for fellows and the **recruitment strategy**: calls for applications, Recruitment will follow the principles set out in the European Charter for Researchers and in the Code of Conduct for the Recruitment of Researchers.

Continuous **communication** between Path2SKA partners will be ensured by cross-membership of the SB and the NMT, open web-based minutes of the NMT, and a web-based tool for transmitting emerging concerns to management. The SB will monitor the effectiveness of Path2SKA and advise on high-level changes. At the inaugural SB, the deputy Path2SKA

coordinator Raffaella Morganti will lead discussions on how to put procedures in place ensuring that the likely gender imbalance on the SB, and to a lesser extent on the NMT, does not translate into gender discrimination, and how to ameliorate this imbalance over the course of Path2SKA.

The approach to **Intellectual Property** Rights (IPR) will, as far as possible, follow those normally used in EC-funded research. Background IPR will be identified at the project outset, and regularly updated as the result of work running parallel to Path2SKA. Foreground IP generated by Path2SKA partners will be shared among the generating partners on fair and reasonable terms. The use of this IP outside Path2SKA would only be granted on fair and reasonable terms. Path2SKA will ensure that its fellows follow current best practice by briefing them following recruitment, and directing them towards courses on IPR organized by industrial partner QinetiQ (Sec B.4).

The **financial management strategy** of Path2SKA will be in the control of the NMT, overseen by the SB. There is much project management expertise throughout Path2SKA. Steve Rawlings has been Head of Oxford Astrophysics since Oct 2005, is a vice-Chair of ESKAC, and was a former chair of the International SKA Science Working Group; he managed the Oxford node of the FP5 SISCO RTN. Raffaella Morganti is Head of Astronomy at ASTRON and coordinates their node of the Marie Curie EST ESTRELA. Most of the academic partners are active in SKADS, MCCT-SKADS, PrepSKA & RadioNet, and many were active in ANGLES and ESTRELA.

Path2SKA management will follow a simple **Implementation Plan** from T0=Oct 2009

- T0. Recruitment completed. Goal: fair selection of qualified individuals.
- T0-T0+12. Basic training. Emphasis on local training, network-wide training via video-conferencing and compulsory complementary skills courses, and first research visits to partners. Goals: (i) trained in basic research and complementary skills; (ii) inducted into Path2SKA community; (iii) oral and written presentation of project plan and initial results.
- T0+12-T0+24. First research outputs. Emphasis on completion of significant original research and increase in networking. Goals: (i) ERs and IESRs complete training and deliver outputs (e.g. software) and reports; (ii) ESRs present first results at a network or other international event, and publish first papers or reports.
- T0+24-T0+36. Development of research skills. Emphasis on secondment to partners to develop core PhD research material. Goals: (i) publications and reports based on synthesis of complex ideas and material; (ii) visibility of research outputs in the global SKA project.
- T0+36-T0+48. Completion of PhD thesis. Goal: high-quality research output and good career prospects either within or outside the SKA project.

Path2SKA will pay particular attention to **Network Quality Monitoring**

- Recruitment: well-defined recruitment strategy to ensure fairness of selection.
- WP leaders will ensure tri-monthly monitoring of fellows using information from fellows, supervisors and mentors via web-based tools (c.f. European Charter for Researchers).
- **Dissemination of results** to follow the timetable of the **Implementation Plan**
- NMT to use the effectiveness of the **dissemination of results** (e.g. publications and presentations) to measure network success using metrics alongside other more flexible tools.
- Path2SKA will set specific targets for research outputs and skill developments to be monitored both during the network duration and after its completion.
- The fellows will be expected to self-organize to provide regular reports on their strategic concerns regarding the aims and delivery of the training network.

WP2. Science Exploitation of SKA Pathfinders

PhD2.1, Oct 2009 to Sep 2012, supervised by Aris Karastergiou and Angela Taylor at **Oxford** (funding: 2yrEC+1yrMatch). Uses ATA-42 and GMRT data for Extreme Scattering Event (ESE) searches and point-source surveys for SZ follow-up. Milestones: (i) an optimum ESE search strategy; and (ii) proof of concept of SZ programme. Deliverable: PhD project on ESEs and SZ.

PhD2.2 will, from Oct 2009 to Sep 2013, be supervised by Zsolt Paragi and Huib van Langevelde at **JIVE** (funding: 3yrEC+1yrMatch). Will develop new observational e-EVN rapid response for

transient radio sources. Milestones: (i) defined observing strategy; (ii) proof of concept of dynamic VLBI observations. Deliverables: PhD on semi-automated follow-up of discovered transients.
PhD2.3 will, from Oct 2009 to Sep 2012, be supervised by Isabella Prandoni and Luigina Feretti at **INAF-Bologna** (funding: 2yrEC+2yrMatch). Will combine data from e-EVN, eMERLIN, GMRT, and LOFAR with near-IR data to study the cosmic evolution of AGNs. Milestones: production of deep, wide-field images from long-baseline arrays. Deliverables: PhD on `the microJy population'.
PhD2.4 will, from Oct 2009 to Sep 2013, be supervised by Ger de Bruyn at **ASTRON,** registered at **NOVA-Groningen** (funding: 2yrEC+2yrMatch). Will analyse 60-230 MHz LOFAR data to identify and remove discrete sources and their side-lobes, crucial for the success of the EoR experiment. Milestone: optimum use of the LOFAR pipeline to remove point sources. Deliverable: PhD on model for the foregrounds that will be included in the LOFAR EoR simulation pipeline.
PhD2.5 will, from Oct 2010 to Sep 2012, be supervised by Ilidio Lopes at **CENTRA-IST** with **Deimos Engenharia** (funding: 3yrEC). Will work on image reconstruction for EMBRACE/2-PAD/LOFAR data, addressing the origin of the 22-year magnetic cycle of the Sun. Milestone: algorithms and processing model. Deliverable: PhD on the solar cycle dynamo mechanism.
PhD2.6 will, from Oct 2009 to Sep 2012, be supervised by Dave Green and Julia Riley at **Cambridge** (funding 2yrEC+1yrMatch)**.** Use eMERLIN and LOFAR to investigate magnetic fields via Faraday rotation and depolarization and determine the role they play in structure formation in the early Universe. Milestone: new techniques for the reduction of high-resolution polarization data. Deliverable: PhD on polarization structure at high resolution of radio sources.
PhD2.7 will, from Oct 2009 to Sep 2012, be supervised by Ben Stappers and Michael Kramer at **Manchester** (funding 2yrEC+1yrMatch)**.** Will use the multi-beaming capabilities of LOFAR to carry out novel timing observations of pulsars to complement GLAST and LIGO. Milestones: (i) establish multi-telescope timing programme; and (ii) first dynamic spectra for ionospheric weather studies; and (iii) LOFAR implementation. Deliverable: PhD on timing pulsars with LOFAR.
PhD2.8 will, from Oct 2010 to Sep2013, be supervised by Andrea Possenti and N. D'Amico at **INAF-Cagliari** (funding 2yrEC+1yrMatch**).** Will undertake high-precision pulsar timing with the EPTA. Milestones: (i) selection of sources to be regularly observed, (ii) database of pulsar profiles; and (iii) optimal strategy for scheduling. Deliverable: PhD on search for gravitational waves.
PhD2.9 will, from Oct 2010 to Sep 2012, be supervised by Rainer Beck at **MPIfR** (funding 2yrEC+1yrMatch**).** Will constrain the Galactic B-field based on Rotation Measure (RM) values from the current and new populations of pulsars discovered by ASKAP, LOFAR and MeerKAT. Milestone: database of RMs from pulsars. Deliverable: PhD on models of the Galactic B-field.
PhD2.10 will, from Oct 2009 to Sep 2013, be supervised by Joeri van Leeuwen at **ASTRON** and registered at **NOVA-Amsterdam** (funding 2yrEC+2yrMatch**).** Will use LOFAR and APERTIF to determine the local neutron-star population and characterise the fast-transient sky. Milestones: (i) **MonetDB**-based detection pipeline; (ii) port and scale-up for APERTIF processing. Deliverable: PhD on real-time pulsar-survey, fast-transient database and processing pipeline.
PhD2.11 will, from Oct 2009 to Sep 2013, be supervised by Huub Rottgering at **NOVA-Leiden** (funding 2yrEC+2yrMatch**)**. Will combine LOFAR and Herschel surveys to study the dependence of star-formation and AGN activity on redshift. Milestones: (i) production of the deepest low-frequency radio maps ever made, and (ii) a significant improvement of the radio-IR photometric redshift techniques. Deliverable: PhD on the space density of distant proto-clusters.
PhD2.12 will, from Oct 2010 to Sep2013, be supervised by Wim van Driel at **Paris** (funding 3yrEC**)**. Will use large HI surveys (blind, Arecibo; targeted Nancay/MeerKAT) to address the local baryon budget, gas properties as a function of galaxy and stellar mass, and structural parameters. Milestone: reduction of data to an on-line database. Deliverable: PhD on HI populations.
PhD2.13 will, from Oct 2009 to Sep 2013, be supervised by James Anderson, Andrei Lobanov, and Manuel Perucho at **MPIfR** (funding 2yrEC+2yrMatch**)**. Will use LOFAR long baselines to study the small-scale polarized structures of radio sources. Milestone: study of the low-energy electron

evolution process in large radio galaxies. Deliverable: PhD on spectral index and Faraday rotation maps of radio galaxies as observed by LOFAR, and simulations of electron migration and ageing.

WP3. SKA Simulation

PhD3.1 will, from Oct 2009 to Sep 2012, be supervised by Richard Battye, Scott Kay and Shude Mao at **Manchester** (funding 2yrEC+1yrMatch**)**. Will use numerical hydrodynamics simulations to study gas accretion and dynamics in groups of galaxies. Milestones: (i) identification of halos for re-simulation; (ii) study of gas accretion in field and group galaxies; (iii) investigation of tidal stripping. Deliverable: PhD on study of an SKA experiment to reconstruct galaxy potentials.

PhD3.2 will, from Oct 2009 to Sep 2011, be supervised by Mario Santos at **CENTRA-IST** (funding 3yrEC**).** Will work on simulations of the HI signal from the EoR, taking into account fluctuations in the spin temperature. Milestones: (i) end-to-end simulation of the HI signal plus foregrounds; (ii) determination of optimal estimators for the EoR signal, and best foreground cleaning techniques. Deliverable: PhD on large semi-numerical simulation of the HI signal

PhD3.3 will, from Oct 2009 to Sep2013, be supervised by Thijs van der Hulst in **NOVA-Groningen** (funding 2yrEC+2yrMatch**)**. Will develop end-to-end simulation of an SKA equipped with FPAs and how source parameters can be made robust against calibration errors. Milestones: instrumental effects relevant for calibration implemented in software; description of relevant source parameters implemented in software. Deliverables: PhD on HI simulation; software tools.

ER3.1 will be employed at **MPIfR** from Oct 2009 to Sep 2011, mentored by James Anderson. The researcher will advance the techniques of wide-field long-baseline radio astronomy and to develop and commission software, primarily using MeqTrees. Milestone: development and publication of a study of multi-beam observational techniques for improving ionospheric and instrumental calibration of aperture arrays. Deliverables: (i) report on the fringe-finding algorithms in MeqTrees and comparisons with existing software packages; (ii) software to incorporate VLBI delay; (iii) software to identify sub-regions of interest in low-frequency wide-field data.

ER3.2 will be employed at **ASTRON** for 24 months from Oct 2009 to Sep 2011, mentored by Raffaella Morganti and Tom Oosterloo. The location in ASTRON will ensure easy access to data from an FPA (APERTIF) and AAs (LOFAR and EMBRACE). The research will focus on how to detect sources and how to optimally parameterise these detections (both continuum and spectral line). Milestones: (i) published source parameterisation and extraction techniques; (ii) implementation. Deliverable: software tools with links to work on databases in WP6.

ER3.3 will be employed at **Oxford** for 24 months from Oct 2009 to Sep 2011, mentored by Stef Salvini and Anne Trefethen in the OeRC. Will build on MeqTrees and other software to support Path2SKA PhDs by developing next-generation self-calibration software tools**.** Their Oxford base ensures access to state-of-the-art SKA simulations to test these algorithms. Milestones: (i) design of code generator with a future-proofed plan for implementation; (ii) implementation on one or more hardware platform. Deliverable: `next-generation MeqTrees' with links to calibration in WP4.

WP4. Calibration Challenges

IESR4.1 will be employed Oct 2010 to Sep 2012 by **Deimos Engenharia,** mentored by Jose Barbosa. Will transfer knowledge on calibration techniques, reconstruction methods for interferometers, and generic knowledge on software development. Milestones: (i) implemented code and analysis by comparison with third-party tools; (ii) validation of calibration algorithms. Deliverables: "Scientific Validation Report" and a "Software Performance Report".

IESR4.2 will be employed Oct 2010 to Sep 2012 by **QinetiQ**, mentored by Malcolm Macleod. Will transfer knowledge on techniques for broadband beam-forming and for calibration of large arrays. Milestone: design ideas for future hardware and software implementation. Deliverables: reports on recommended algorithms, their estimated performance, and ideas for their efficient implementation.

PhD4.1 will, from Oct 2009 to Sep 2013, be supervised by Ronald Nijboer and Tom Osterloo at **ASTRON** (funding 2yrEC+2yrMatch**)**. Will work on accurate calibration of FPA systems. Milestones: (i) LOFAR-based calibration techniques used to study APERTIF front-ends and

modeled using MeqTrees; (ii) model-based control tool verified through deep images using the **APERTIF** front-ends. Deliverable: PhD Thesis and improved software tools

PhD4.2 will, from Oct 2009 to Sep 2013, be supervised by Mike Jones at **Oxford** (funding 2yrEC+2yrMatch**).** Will design and implement various algorithms for calibration and RFI mitigation in astronomical AA systems. Milestones: (i) benchmarking of new algorithms based on PCA/ICA for nulling of man-made RFI; (ii) benchmarking of new algorithms for nulling man-made interference. Deliverable: PhD thesis and implementation of a suitable RFI-rejection algorithm

PhD4.3 will, from Oct 2009 to Sep 2013, be supervised by Steve Rawlings at **Oxford** (funding 2yrEC+2yrMatch**)**. Will develop calibration for long LOFAR baselines using data from GPS receivers. Milestone: commissioning of GPS system at Chilbolton. Deliverables: (i) PhD on ionospheric correction at Chilbolton; and (ii) improved ionospheric and astronomical datasets.

PhD4.4 will, from Oct 2009 to Sep 2013, be supervised by Paul Alexander and Keith Grainge at **Cambridge** (funding 2yrEC+2yrMatch**).** Will implement, in a portable way, a new pattern-matching-based approach to RFI detection and mitigation in large datasets. Milestones: (i) demonstration and publication of novel algorithms on fake data; and (ii) application of algorithms to Pathfinder data. Deliverable: PhD thesis and portable algorithm for RFI excision.

WP5. Data Processing and Imaging Challenges

IESR5.3 will, from Oct 2010 to Sep 2012, be employed by ClearSpeed, mentored by Simon McIntosh-Smith. Will identify requirements for the SKA processing and power constraints and commonalities with applications like emerging wireless standards. Milestone: architectural improvements for cost-and-power-efficient processing. Deliverable: report on SKA processing.

PhD5.1 will, from Oct 2009 to Sep 2013, be supervised by John Romein and Marco de Vos at **ASTRON** (funding 2yrEC+2yrMatch**)**. Will establish requirements for the various functional steps, in terms of processing power, memory and data transport patterns and benchmark them for various technologies. Milestones: technology benchmark verified with evaluation code. Deliverable: optimization report for two selected technology platforms with recommendations for SKA.

PhD5.2 will, from Oct 2009 to Sep 2013, be supervised by Stef Salvini and Anne Trefethen at **Oxford** (funding 2yrEC+2yrMatch**)**. Will translate radio-astronomical processing techniques to multi-core systems. Milestones: (i) single-core versions of MaxEnt methods on small images; (ii) algorithms extended to clusters and ClearSpeed technology, tested on larger images. Deliverables: (i) multi-core MaxEnt methods; and (ii) multi-core methods for Bayesian object detection.

PhD5.3 will, from Oct 2009 to Sep 2013, be supervised by Paul Alexander and Mike Hobson at **Cambridge** (funding 2yrEC+2yrMatch**)**. Will develop wide-field imaging using wavelet basis functions with properties intermediate between the Fourier basis now used and the natural spherical-harmonic basis. Milestones: (i) publication of new wide-field imaging algorithms; and (ii) implementation using GMRT data. Deliverable: portable algorithm for wide-field imaging.

WP6. Database and Data Analysis Challenges

PhD6.1 will, from Oct 2009 to Sep2102, be supervised by Francois Viallefond and Francois Levrier at **Paris** (funding 3yrEC**)**. Will develop next-generation database tools for simulated SKA datasets to ensure optimum interoperability of sky and technical simulations. Milestones: (i) proof of efficiency of the **MonetDB** system; (ii) adaptation to a new database system; (iii) definition of meta-data based on a Science Data Model. Deliverables: PhD on upgraded SKA database.

PhD6.2 will, from Oct 2009 to Sep 2013, be supervised by Isobel Hook and Roberto Scaramella at **INAF-Rome** (funding 2yrEC+2yrMatch**).** Will use SKA sky simulations together with simulations for other future facilities to develop Bayesian methods of joint cosmological analysis. Milestones: (i) assessment of techniques for SKA data analysis; (ii) forecasts for SKA. Deliverables: PhD on combining SKA forecasts with those from other future experiments.

B.6 IMPACT

B.6.1 Improvement of the career prospects of the fellows

Through processes like ASTRONET (http://www.astronet-eu.org/) in Europe and the Decadal Review in the USA, the international astrophysical community is setting the strategy towards the future. There is a consensus on the big questions of astrophysics, cosmology and astro-particle physics to be addressed and the instrumentation needed for them. The SKA is a key element in this strategy and European leadership in this project is internationally recognised (Sec B.4), and explains the prominence of the SKA in the ESFRI road map. The SKA pathfinders are both excellent science instruments in their own right, and provide unique opportunities for training and building up experience. The Path2SKA programme incorporates almost all of the key SKA pathfinders (Sec B.3) - in Australia, India, Southern Africa and the USA as well as Europe - and thus ensures that the European ESRs become an integral part of the global SKA effort.

The immediate benefits of the involvement of the fellows in the program will be through the in-depth knowledge and hands-on experience they will acquire with this new generation of science instruments. This will directly improve their career prospects for positions at the growing number of universities and institutes that have the science utilization of the pathfinders in their strategy, as well as with the large community that is preparing for a role in the deployment, commissioning and scientific exploitation of the SKA. There is already direct evidence of genuine growth in job opportunities in this area within the academic sector: for example, the UK Higher Education Funding Council has recently funded six new permanent academic positions in physics departments in the south-east of England on the basis of the LOFAR-UK project. As industry ramps up its technical role in SKA, and Path2SKA is an important part of this process, one can anticipate a similar growth of job opportunities in the private sector. The fellows in Path2SKA will be embedded in the international SKA project, and trained in the benefits of academic-industrial partnerships in a global context, thus enhancing their capacity to progress their careers.

The longer-term benefits for the fellows will follow naturally from this boosting of their career. Experience with e.g. WSRT (NL), MERLIN (UK) and the VLA (US) clearly shows that an early involvement in break-through science instruments, in particular in the early-science stages has a lasting positive impact on the career of both astrophysical and technical scientists. Many of the young scientists and engineers that participated in instruments at PhD and postdoctoral level then are key international players within astrophysics and other areas of research now.

The fellows will also benefit from the multi-disciplinary scope of the proposed programme, and the supra-disciplinary nature of the SKA project itself. Since the programme focuses on state-of-the-art instrumentation, there are unique training and coaching opportunities. The programme is organized so as to maximize interaction and synergy between scientific exploitation of pathfinders and technical academic-industrial collaborations. To stimulate this interaction, the programme includes joint Early-Science Experiments (Sec B.4), where input from a variety of disciplines and projects have to be combined, e.g. simulations, calibration, data processing and management. Industrial experience comes in through joint academic-industry projects and Visiting Scientists.

The programme has been designed such that the fellows will have a large degree of mobility between the participating members in each thematic area. This will allow them to get acquainted with several partner institutions, from which their short- and long-term career perspective will directly benefit. The inter-dependence of the projects encourages parallel advances in all fields, positioning the fellows better for their future scientific career.

The immediate benefits for the partners are foremost in the building up of a sizeable group of well-trained researchers becoming available for early science with the pathfinders and for the simulation and technical work needed to design the SKA. This will boost the scientific and technical output of the participating institutions from a very early stage. Regardless of whether the researchers stay within the participating institutions or whether they start new user communities in other places, this is a large benefit to the success of the pathfinders. There is also the immediate benefit of a group of researchers that have been trained and experienced in the collaboration between science institutes and industrial parties. The skills built up will be of great value for the realization of the SKA, which will lead to a higher impact for the partners in the deployment and commissioning. The industrial partners accrue the potential for future commercial benefits by getting hands-on experience in inventing and developing technologies that may prove crucial to the SKA.

In the longer term, the proposed training programme will have a significant contribution to building up a new generation of experienced radio-astronomical researchers that will play a strong role in the implementation of the science strategy, thus improving the impact of the pathfinders and the SKA. The academic partners have invested in the science case and technical development of the SKA. They expect the main scientific return on these investments in the exploitation phase of the SKA. With its strong and coherent programme, Path2SKA will have a significant leverage in the exploitation phase, as some of the PhD students move on to postdoctoral and tenured academic positions. Many fellows will also pursue careers in the private sector. Path2SKA will have played an important part in building up a European reservoir of technical expertise that can bring benefits to wider areas of society. Having spent their early career working on an iconic physics project, there is obviously huge potential to forge long-term positive links between academia and industry.

One of the immediate benefits for European research is in the boosting of the early-science output from the European pathfinders (LOFAR, e-MERLIN, e-EVN). The availability of committed and well-trained researchers, in particular PhD students, is of vital importance to the science impact, as has demonstrated with many large science facilities in physics. Since scientific career opportunities are readily available through the pathfinders, the European research potential will be directly strengthened through the proposed programme. Also, the European influence in the SKA will be much strengthened by the programme. Another benefit is the sharing of technical expertise between the academic and industrial partners. It is certainly to be hoped that many of the industrial partners participating in Path2SKA will be able to quickly take an active part in the design and construction of the SKA, and attract the best researchers and technologists into their companies.

The longer term benefits for European research follows naturally since the scientific impact of the pathfinders and the SKA will last for many decades. Strengthening the European position in an early stage will have a sustainable impact on the scientific return for Europe. Through the participating industrial partners, the strategic position of European industry will be strengthened in the long term. Innovative European ICT companies, especially SMEs, have not yet been deeply involved in SKA development. The scope of the Path2SKA training programme is very well suited to open up this involvement. Path2SKA is expected to set the collaboration models for such companies, with will yield a strategic advantage of European SMEs in the SKA construction phase.

One of the main pillars of the European Research Area, and of the 2008 Work Plan, is to increase the impact of European scientific and technological cooperation by countering the fragmentation of knowledge. The proposed programme will lead to a knowledge transfer between researchers on a European scale, but also over a broad range of scientific and technical areas of expertise. Sharing of knowledge across geographical borders and research domains is stimulated. Since collaborations target the SKA era, this impact will be both immediate and on the longer term.

The future SKA European knowledge base has a firm scientific and technological basis of a high-tech nature. Both the radio astronomical research and the technology are highly advanced. Europe adopted the phased array antenna concept as its key technology. The FP6 SKA Design Study (SKADS) demonstrated the potential of this concept, which is now firmly embedded in the SKA specification. These technologies have a very large technological and economical (spin-off) potential. The European-wide impact aimed for in this project, creating a large European knowledge base in these technologies and having industry as one of the target groups (for specific events) will thus help increase the European technological and industrial competitiveness.

B.6.2. Longer-term collaborations

Path2SKA extends the existing European SKA community with several new collaborations. Through Path2SKA, the new partner country Portugal becomes firmly embedded both at the academic and industrial level. The proposed programme brings a new dimension to the collaboration through the coherent programme for training of a new generation of experts in radio astronomy and instrumentation. Provisions have been taken to make this collaboration sustainable, in particular through the yearly networking events (Sec B.4). This concept is applied at a national level (e.g. in the Dutch research school NOVA), and through Path2SKA can be introduced at a European scale. The partners are committed to continuing these network events, presumably through the European SKA Consortium (ESKAC). Furthermore, the Early-Science Experiments (Sec B.4) should be extended to other SKA pathfinders. The involvement of a broad international group of students and trainers is vital. Therefore, the collaboration of such experiments will definitely be continued into the SKA roll-out and exploitation. The concept has been exercised on a smaller scale e.g. in joint observations of Jupiter with the Nancay Array and LOFAR test-stations. These experiments have proven to be very useful in building up longer lasting collaborations.

The SME partners in the proposed programme are new to the SKA project, although two of them have been involved in the development of LOFAR. A key driver for the private partners to participate is to establish longer-term relationships with the academic institutes involved in the SKA. Such collaborations between private high-tech ICT companies and the academic institutions are of vital importance for the SKA. Collaborations between radio astronomical institutes and private technology partners have been highly successful at a national level. The proposed programme carries this to a European level, thus significantly increasing the expected impact. These same general issues apply to the participation of larger companies like Level-1 industrial partner QinetiQ and Level-2 industrial partner IBM. Both the smaller and larger companies see the mutual advantages of collaborating together in Path2SKA, and it seems likely that industry-industry partnerships created by Path2SKA will carry forward into other future opportunities.

With a focus on training, there will be a natural flow of information between industry and academia that is often stifled in a formal contractual collaboration. This will lay the groundwork for longer-lasting partnership, certainly at a bilateral level, but the intention is that the private partners will form the core of a European Industrial SKA Forum. Long-term sustainability of academia-industry cooperation is promoted by the thematic categories and specific projects proposed (Sec B.5) since:

- Each project includes a number of partners ensuring a dense collaboration network develops
- There is a good representation of the SKA key science programmes ensuring long-term sustainability as these will be continued during the construction and exploitation of the SKA.
- There are close ties to SKA technical developments in all work-packages, ensuring a long-term working collaborations are established at the level of fellows and institutes, that will last well into the development and construction phase of the SKA

Path2SKA formalizes new and existing collaborations at the level of scientific partnerships, targeted at joint exploitation of pathfinders and at building up experience in simulations, calibration, processing and data handling. These activities and research lines go far beyond the timeline of the Path2SKA. Therefore the collaborations will be lasting right into the SKA era.

B.6.3. Relevance of training events and Visiting Scientists

The benefits of opening up training events (Sec B.4) to external participants are

- It facilitates knowledge exchange between Path2SKA fellows and the broadest possible community interested in the science and technology on the pathway to the SKA
- It enhances, through networking, the career prospects of the Path2SKA fellows
- By providing external reference points, it reinforces mutual recognition of the benefits of Path2SKA training amongst the partners
- It maximises the global visibility and impact of Path2SKA on the European Research Area

The three Visiting Scientists (VSs) bring expert knowledge from three different areas of technology. This is complementary to the scientific expertise of the senior investigators at the partner institutions and thus increases the effectiveness of the training. The VSs will raise the knowledge and expertise of the Path2SKA researchers and thus increase the breadth and quality of their short- and long-term research. By associating each visiting scientist both to a specific work package and to the programme-wide networking events, the relevance and impact of their role is maximized.

Visiting Scientist Dr. Bruce Elmegreen, from Associated Partner IBM, brings expert knowledge from a global computing company to the work-package dealing with data processing (WP5). From his industrial background, Dr. Elmegreen will provide training and coaching on state-of-the-art computing technologies and trends to that work-package. At the overall programme level, he will provide insights and conceptual training to the full group of fellows at the Networking Events.

Visiting Scientist Prof. Martin Kersten, from Associated Partner MonetDB, brings expert knowledge and tooling from a high-tech database SME to the work-package dealing with databases and data analysis (WP6). The large data-streams generated by SKA pathfinders and the SKA itself requires new and innovative approaches towards databases and data retrieval. Through the involvement of Prof. Kersten the fellows can get access to such a system with expert training on optimization and specialization. At the overall programme level, Prof. Kersten will share knowledge on advanced architectures that will be beneficial to many other projects as well.

Visiting Scientist Dr. Devinder Sivia, from St Catherine's College Oxford, brings expert knowledge on Bayesian data analysis to the work-package dealing with databases and data analysis (WP6). Bayesian methods have only recently become feasible for application in the data-intense areas of astrophysics. Dr. Sivia will allow the students to quickly ramp up on this new approach, which has a large potential in the field. He will also bring in relevant experience and knowledge from his broad network in a variety of scientific disciplines (theorists and experimentalists, astronomers and condensed matter physicists, chemists and geographers). By sharing this at the networking events, he will allow the fellows to connect to a wider field and build up multi-disciplinary experience.

In addition to their specific research expertise, the three VSs bring a long experience in training and coaching on scientific method and working in large research projects. This will be a relevant and valuable addition to the group of trainers and supervisors at the partners. Through the Visiting Scientists the collaboration with industrial partners is further fostered. This is very relevant to the long-term goals of the proposed programme and to the expected impact as described above.

B.7 ETHICAL ISSUES

This proposal does not contain any ethical issues.

ETHICAL ISSUES TABLE

	YES	PAGE
Informed Consent		
• Does the proposal involve children?	NO	
• Does the proposal involve patients or persons not able to give consent?	NO	
• Does the proposal involve adult healthy volunteers?	NO	
• Does the proposal involve Human Genetic Material?	NO	
• Does the proposal involve Human biological samples?	NO	
• Does the proposal involve Human data collection?	NO	
Research on Human embryo/foetus		
• Does the proposal involve Human Embryos?	NO	
• Does the proposal involve Human Foetal Tissue / Cells?	NO	
• Does the proposal involve Human Embryonic Stem Cells?	NO	
Privacy		
• Does the proposal involve processing of genetic information or personal data (e.g. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)	NO	
• Does the proposal involve tracking the location or observation of people?	NO	
Research on Animals		
• Does the proposal involve research on animals?	NO	
• Are those animals transgenic small laboratory animals?	NO	
• Are those animals transgenic farm animals?	NO	
• Are those animals cloned farm animals?	NO	
• Are those animals non-human primates?	NO	
Research Involving Developing Countries		
• Use of local resources (genetic, animal, plant etc)	**NO**	
• Impact on a local community	**NO**	
Dual Use and potential for terrorist abuse		
• Research having direct military application	NO	
• Research having the potential for terrorist abuse	NO	
I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	YES	

ENDPAGE

PEOPLE
MARIE CURIE ACTIONS

Marie Curie Initial Training Networks (ITN)
Call: **FP7-PEOPLE-ITN-2008**

PART B

"Path2SKA"

SKA Program Development Office
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UK

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www.skatelescope.org

Manchester, 27 August 2008

To whom it may concern

I am writing in my capacity as the Director of the SKA Program Development Office (SPDO) to express my full support for the Path2SKA proposal being submitted by Prof Steve Rawlings. Path2SKA complements the global technical activities for the SKA coordinated by the SPDO as part of FP7 PrepSKA, and is designed to integrate seamlessly with those activities.

PrepSKA is pulling together R&D knowledge from around the world to generate a detailed design for Phase 1 of the SKA. In separate strands of work coordinated by Funding Agencies in Europe, it will also address many of the governance and legal issues surrounding the establishment of a formal SKA construction project. Between now and 2011, I estimate that ~€150M is being spent on R&D alone for the SKA. There is an increasing level of coordination and cooperation around the world as we build a comprehensive, inter-linked set of development activities that will eventually form the basis of the organisation that will construct, operate and exploit the SKA. Path2 SKA is an important element of that set of activities.

The Path2SKA proposal addresses aspects of the international program that could not be included in the currently funded work on the SKA – in particular training of young researchers (ERs) and science simulations. The SKA will be the major radio astronomy facility in the world and is projected to have a lifetime of 50 years. Growing the community of users for the SKA is an essential component of the global strategy for the SKA, and Path2SKA will ensure a leading role for European researchers in exploiting the investment in the SKA. The three themes proposed in PrepSKA of science exploitation, science simulation, and software, calibration, and data processing will provide the Early-Stage and Experienced Researchers with hands-on experience that will be excellent preparation for productive research careers using the SKA or in the industry sector.

I have reviewed the Path2 SKA proposal and am impressed with its focus and its connection to the global efforts. I therefore support, in the strongest possible terms, the funding of this work, and am prepared to serve on the Supervisory Board.

Richard Schilizzi

Prof. Richard T. Schilizzi
Director, SKA Program Development Office

UNIVERSITY OF CALIFORNIA, BERKELEY

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO SANTA BARBARA • SANTA CRUZ

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ASTRONOMY DEPARTMENT
21 August 2008

Dear Steve Rawlings,

I am pleased to represent the Allen Telescope Array (ATA) in its participation in the **Pathway to the SKA** program as an Associate Partner. International collaboration is a critical aspect of the SKA program. We look forward to the opportunity to work with you and your colleagues.

The ATA is one of the first SKA pathfinders to be operational and, therefore, represents an important opportunity to study the new science, new techniques, and new operational model of the SKA era. The ATA is a 42-element centimeter wavelength interferometer with a flexible digital signal path. Key science projects of the ATA are focused on surveys of radio transients, extragalactic hydrogen, pulsars, and the search for extraterrestrial intelligence.

We have identified two research projects as suitable points of collaboration between Pathway to the SKA and the ATA. These are in the areas of extreme scattering events and point source identification for studying the Sunyaev-Zeldovich effect. Graduate students in the program will be able to make extended visits to the ATA, learning observing techniques and developing science programs.

Regards,

Geoffrey Bower
Professor of Astronomy

National Research Council Canada | Conseil national de recherches Canada

Herzberg Institute of Astrophysics | Institut Herzberg d'astrophysique

Dominion Radio Astrophysical Observatory | Observatoire fédéral de radioastrophysique

NRC · CNRC

21 August 2008

To whom it may concern,

The Dominion Radio Astrophysical Observatory of the National Research Council of Canada's Herzberg Institute for Astrophysics is an Associate Partner in the EC Path2SKA proposal.

The NRC-DRAO is an active partner in science and technology research and development directly aimed at the SKA. In conjunction with the university community in Canada, we are developing technologies in a number of areas that include:

- low-cost, high-performance parabolic dishes made from composite materials allowing construction of lightweight, rigid reflectors that permit novel, optimized dish designs, especially at higher observing frequencies.
- phased focal-plane array (FPA) feeds that enable a large instantaneous field-of-view, essential to attain many of the science goals of the SKA.
- astronomical performance low-noise amplifiers that operate at room temperature and aim to attain the SKA receiver sensitivity goals at very low cost.
- novel beam-forming technology for FPAs using innovative space-time filtering techniques
- simulations of the astronomical response of FPAs on parabolic dishes as a design optimization tool
- leading edge large, high-density digital system architectures and sub-system designs for the correlator, essential to combine the data from very large number of receptors in the SKA
- calibration and science post-processing algorithms for deep wide-field imaging with focal-plane arrays.
- simulations of pulsar science surveys with SKA pathfinders and the SKA

The wide range of SKA-related research and development in Canada, led by some of the leading scientists and engineers in these fields today, are readily matched to the many projects proposed in the Path2SKA proposal. Hence ,there are large number of opportunities for student participation in SKA research and development in Canada.

I look forward to the opportunity to help graduate students supported through the Path2SKA programme to identify projects and co-supervisors at institutes across Canada.

Yours faithfully,

Sean Dougherty
Director, Dominion Radio Astrophysical Observatory.

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20th August 2008

Dear Professor Rawlings

Path2SKA

Chronos Technology Ltd is a UK based company with internationally leading expertise in timing and synchronisation.

It has recently become apparent that GPS and associated technology within the interests of Chronos Technology can assist in precise timing, synchronisation and calibration for next-generation radio telescopes. To date, the company's expertise is mainly in telecommunications applications. However, recent collaborations with the University of Bath have lead to broadening interests in the area of Space Weather. Space Weather is a key issue for calibration and GPS technology is of primary importance here. The University of Bath will contribute expertise in the use of GPS to investigate the ionosphere and in providing background information in GPS signal processing.

Chronos is interested to be involved in the Path2SKA project through collaborations with Oxford University. The involvement will include participation in the Industrial Advisory Board, Project Supervisory Board, PhD supervision and providing industrial work experience. Chronos can also offer training in timing and synchronisation for telecommunications networks. As founder, owner and Managing Director of Chronos Technology, I will take personal involvement in this project and welcome the opportunity to develop closer academic and industrial links within the UK and across Europe through Path2SKA.

Yours sincerely

Charles Curry

Charles Curry
Managing Director

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29 August 2008

Paul Alexander
Cavendish Laboratory
J J Thomson Avenue
Cambridge
CB3 0HE, UK

Dear Paul,

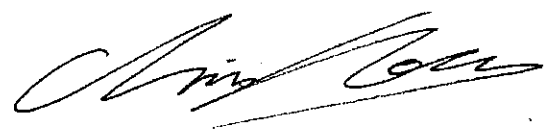
Subject: Path2SKA

Further to our conversations I am very pleased that you have considered Geomerics as an Associate Partner for the SKA project, and we are delighted to join. I understand that the expectation is that we will take students or post-docs on short-term internships at Geomerics, where we will focus on training the latest hardware-acceleration techniques for general data-processing algorithms. Such techniques are now essential in gaining maximum performance from modern multi-core processors, and the skills are highly transferrable.

I also understand that I will be expected to sit on the Supervisory Board for the project, which will not be a problem. I hope that I am able to add some value to the Board.

I look forward to working together with you on this exciting project.

Yours sincerely,



Chris Doran

NCRA • TIFR

National Centre for Radio Astrophysics

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D.J.Saikia
Dean, NF

NCRA:TIFR:2008
August 27, 2008

Prof. Steve Rawlings
Head – Department of Astrophysics
University of Oxford
Wellington Square
Oxford
OX1 2JD
United Kingdom

Dear Steve,

I am pleased to say that the NCRA Faculty discussed our participation in the EC FP7 PATH2SKA program and recommended that we participate in this program. I understand from our discussions that our commitment will be our willingness to host a European Ph.D. student for an extended visit upto a year and the cost will be borne by the EC Program. It will be our pleasure to do this and we look forward to such a visit.

In continuation of our discussions, I am also pleased to serve on the supervisory board of this program.

With regards and best wishes,

Yours sincerely

D. J. Saikia

D.J.Saikia
Dean, NF

Dr. Thomas N. Theis
Director, Physical Sciences

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e-mail: ttheis@us.ibm.com

IBM Research Division
Thomas J. Watson Research Center
1101 Kitchawan Road
Yorktown Heights, NY 10598
Fax: 914 945-1484

August 25, 2008

Professor Steve Rawlings, Head of Astrophysics
Department of Physics
University of Oxford
Denys Wilkinson Building
Keble Road, Oxford
Oxon, OX1 3RH

Dear Professor Rawlings,

IBM Research is committed to support the research and training activities of the Path2SKA proposal. IBM will encourage IBM Researcher and distinguished astrophysicist, Dr. Bruce Elmegreen, to be a member of the Supervisory Board. Through Dr. Elmegreen, IBM has already developed many links with ASTRON and the SKA pathfinders. We have been collaborating with ASTRON on LOFAR since 2004 in support of their correlator on BlueGene computers. We have also collaborated to develop low-noise amplifier and beam-former chips with SiGe technology for the ASTRON SKA pathfinder. We are collaborating with the University of Manchester and Oxford University on digital signal processing for the 2PAD project. Dr. Elmegreen periodically visits ASTRON and has been discussing related technology with SKA-related astronomers at various places around the world for the last 5 years. He has also established excellent working relationships between astronomers and the IBM technical staff in Europe.

The Marie Curie Initial Training Network is an important opportunity for IBM to help educate young people in fields related to technology and computer science. IBM Research expects to play an active role in this education process by providing direct counsel during personal visits and through email communications, and by assisting with training workshops. Dr. Elmegreen is familiar with both the astronomical aspects of this project, having a PhD in Astrophysics himself, as well as the technical parts. He will recruit European IBM technical staff for the training workshops.

IBM Research has a long history of working with Universities on joint research projects, and has hired numerous young PhD's from these programs over the years. In the field of radio astronomy, IBM has awarded the Space Astrophysics Laboratory at Uppsala University two Shared University Research Grants to help them develop streaming data software for their LOFAR Outrigger in Sweden program. We hired one of their PhD students to work with our computer scientists in New York last fall. IBM Research also partially supports a PhD student at the University of Manchester working with the 2PAD SKA prototype project.

We look forward to many exciting possibilities for training young people as part of the Path2SKA program, and we look forward to participating in the joint research in this very interesting project.

Sincerely,

Thomas N. Theis
Director, Physical Sciences

MONETDB

August 26, 2008

Prof. Steve Rawlings,
Head of Astrophysics,
Denys Wilkinson Building
Keble Road
Oxford, OX1 3RH
United Kingdom

Dear Prof. Rawlings:

With this letter I want to confirm that MonetDB BV is willing to participate in the Path2SKA project proposal as an industrial level-2 partner. The mission of MonetDB is to maintain, to enhance, and to disseminate the leading edge open-source database system MonetDB originally developed at the Center for Mathematics & Computer Science, the Netherlands. This mission is implemented through near to market activities and secondment of the key developers to projects/clients for targeted R & D activities. We see it as an excellent opportunity to further improve our offerings to the market. In particular, the needs of the scientific community for long term and innovative database management.

MonetDB will organize and deliver hands-on workshops for the project partners at reasonable fees, and participate in feedback and consultancy meetings on the database requirements. Furthermore, its director/ chief scientist and his seniors contribute to the success of Path2SKA through a negotiated scheme of visiting researcher actions at any of the partners' institutes, such that take up of technology is simplified and impact maximized.

I accept the invitation to become a member of the supervisory board of Path2SKA.

I am looking forward to a successful application and follow up implementation of the project.

Sincerely,

Prof.dr. Martin L. Kersten
Director

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Prof S Rawlings
Oxford Astrophysics
Oxford University
OX1 3RH
UK

25 August 2008

MeerKAT Project and Path2SKA

Dear Steve

This letter serves to confirm that the MeerKAT project, representing the National Research Foundation (NRF), wishes to be an Associate Partner in the proposed Path2SKA FP7 ITN. The goals listed in the proposal are well aligned with the priorities of our own MeerKAT project plan, and in particular with the postgraduate student training programme we have set up here in South Africa.

All of the work programmes specified in the proposal are relevant to the MeerKAT, particularly because of its role as an SKA "pathfinder". We are willing and keen to assist with student supervision, and exchange of technical and scientific information as and when required by the programmes. We also hope that South African students might participate by registering at European universities. In addition, I am willing to serve on the Path2SKA Supervisory Board.

Yours sincerely

J I Jonas

Prof Justin Jonas
Associate Director: MeerKAT Science & Engineering
Chair: Department of Physics & Electronics, Rhodes University

s[&]t
dependable solutions

S&T Corperation
PoBox 608, 2600 AP Delft
Telephone +31 15 2629889

To:
Steve Rawlings
Department of Physics
University of Oxford
Keble Road
Oxford, OX1 3RH

date: 8-26-2007

Subject: Letter of Support for the Path2SKA programme

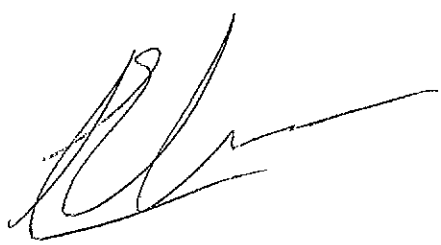
Ref: OXF-LET-8001

Herewith we confirm that our company supports the Path2SKA programme. We feel that great research synergies can be achieved and we foresee possibilities for joint academic/industrial opportunities. The mentioned programme will serve as an excellent training opportunity for the PhD student working with us. Furthermore we welcome the possibility to strengthen the relation with the other programme partners and extend the already exsisting partnership with ASTRON as established during the LOFAR project.

Ofcourse we are happy to participate actively in the supervisory board.

The subject of the research proposed here is to study the use of model-based control for streaming calibration. The reseach will have three phases. In the first phase, the LOFAR based calibration techniques will be used to study the behavior of the prototype APERTIF front-ends. Since the ultimate performance indicator is the dynamic range in final synthesised maps, the APERTIF front-ends will be correlated with the remaining WSRT dishes (for selected number of beams). The system will be modelled in the (off-line) MeqTree toolkit to compare against real-data. It is expected that a statistical study of the residual errors in the correlated data will reveal patterns that can be brought in the models of the FPA feed (in particular for the temporal component).In the second phase, the models thus developed will be introduced in the model-based control tool and applied for APERTIF observations. The performance of the calibration will be verified through deep images using the APERTIF front-ends, comparing against WSRT MFFE. In the third phase of the research, it will be studied how the analysis of residual calibration errors can further enhance the full calibration chain. The effect of short-term gain/phase fluctuations in the FPA elements on the dynamic range in the final maps will be quantified.

Ir. A. E. Zoutman (Managing director)



THE UNIVERSITY OF WESTERN AUSTRALIA
FACULTY OF Life and Physical Sciences

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Premier's Fellow
School of Physics
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35 Stirling Highway, Crawley WA 6009
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Prof. Steve Rawlings,
Oxford Astrophysics,
Department of Physics
Denys Wilkinson Building,
Keble Road, Oxford, OX1 3RH, UK

21 August, 2008

Dear Prof. Rawlings,

The astronomy and astrophysics community in Western Australia in currently going through a period of rapid growth and development. Through funds provided by the WA State Government, the University of Western Australia and the Curtin University of Technology, my colleagues Prof. Staveley-Smith, Prof. Steve Tingay, Prof. Peter Hall and I have begun a program of hiring and development in order to make WA into an important national and international centre to support the development of the SKA project. Together with Prof. Brian Boyle, director of the ATNF, I represent Australia on the International SKA Science and Engineering Committee and we are both working within the Australian SKA Coordination Committee to ensure the proposed Australian SKA site and funded ASKAP project provide international opportunities for collaboration and research.

In February this year, the Premier of Western Australia announced a grant of $20m AUD to establish a new International Radio Astronomy Research Centre in WA. The Centre will involve collaborations with local, national and international institutions as well as industry. The Centre will focus its resources on doing front-line research through international collaborations; working with CSIRO on the ASKAP program and contributing to the international effort to develop the SKA. It is expected that the final arrangements for the establishment of the Centre will be concluded by October 2008 and it will commence operations by May 2009.

Following discussions with my colleagues at UWA, Curtin University, CSIRO and other Australian universities that will be involved in the Centre, I would like to express our collective support as a community of Australian radio astronomy and astrophysics researchers, for the FP7 Path2SKA proposal that you are leading. It is our desire, through involvement with the Path2SKA proposal, to encourage, support and facilitate training and research opportunities for international PhD students. The new Centre will provide a logical focal point for Australian involvement in Path2SKA. Through the Centre, we will be initiating a major PhD and staff hiring program in 2009, adding to existing opportunities from UWA and Curtin University. The Centre funded programs related to SKA and ASKAP development, in coordination with CSIRO, SPDO and PrepSKA, will provide a significant number of new opportunities for first rate PhD programs. We look forward to finding excellent students from Europe to take up these new opportunities and for Australian student involvement in European programs. I am also willing to take part in the management processes for the Path2SKA program as required.

Best regards,

Prof. Peter Quinn,
Premier's Fellow, University of Western Australia