Proposal

1: Scientific and/or technical quality

1.1 Concept and Objectives of RadioNet FP7

The radio astronomy window is uniquely broad, spanning 5 decades of frequency and wavelength. A huge variety of different phenomena can be studied through metre, centimetre, millimetre and sub-millimetre observations. These range from the imprint of the last scattering surface on measurements of the cosmic microwave background emission, to the complex astro-chemistry observed in comets in our backyard. A wide variety of radio telescopes and observing techniques are required in order to cover the entire radio spectrum. The technology used to address this huge range of wavelength, is as diverse, as it is advanced. Radio astronomy stands on the brink of a new golden era – in particular, several large facilities are either coming on-line, are under construction or in an advanced preparatory phase e.g. APEX, LOFAR, Yebes-40m, SRT, ALMA and SKA (FP7 PrepSKA). In addition, many of the existing radio telescopes in Europe and elsewhere, have undergone, or are in the process of undergoing, significant facility upgrades. Examples include SCUBA-2 for the JCMT, the IRAM telescopes, e-MERLIN, EVLA and the Effelsberg 100-m telescope. In Australia and South Africa, the respective SKA pathfinders – ASKAP and MeerKAT - have each been funded to the tune of about 75 million Euro. All these instruments are set to transform radio astronomy in its broadest context, and the community is expected to grow significantly over the course of the next 4 years, embracing the full extent of the wider global astronomical community. Around the world, there can hardly have ever been a better time for graduate students to embark on a career in radio astronomy!

This proposal seeks to build on the highly successful FP6 Integrated Infrastructure Initiative also called RadioNet. RadioNet FP6 has transformed radio astronomy in Europe. It is now natural for most, if not all, radio astronomers to think in terms of European collaboration as the way to proceed; this situation did not exist across the broad subject five years ago. The transnational access programme has formed the core of RadioNet activities, and has ensured a level of support and transparency that has been necessary in order to fully exploit the open skies policy that has been at the core of the operations philosophy of most radio astronomical facilities for decades. Similarly, the networking activities have had a transformational effect on the way science is conducted in Europe; they have provided a natural forum for developing European collaboration, for the sharing of ideas and results and for the establishment of future research activities. This international cooperation also extends to R&D for the sophisticated technologies required by modern astronomical techniques. The digital explosion of recent years has driven a revolution in such technologies and it is rare to find a group that is expert in all aspects of the skills required to build the full range of modern equipment required. For example, many of our telescopes are now connected with fibre optics and have been equipped with highly capable, first-generation, digital backends, and developments funded in past EC programmes are leading to the production of large camera and focal-plane arrays for Europe’s single-dish telescopes, increasing their efficiency by large factors. All of these advances will result in a tsunami of data, as astronomers take advantage of the new capabilities presented to them by the engineers. Beginning this year, instruments such as e-MERLIN, ALMA and LOFAR will start to routinely generate 0.5-100 TBytes per day, *every* day. To handle such prodigious quantities of data, European radio astronomers are working on new software and modern parallel computing techniques, again in a collaborative manner to take advantage of the different skills that exist around Europe.

The general objective of RadioNet, as an Integrating Activity, is to optimise the use and development of European radio astronomy infrastructure. A primary goal will be to ensure that European researchers have access to the radio astronomical facilities they need to undertake the science they wish to pursue. Another major goal is to ensure that key technical developments in Radio Astronomy are supported on a European-wide basis, pooling the broad range of skills, resources and expertise that exists within the RadioNet family. This will provide a critical mass that will ensure that progress is not made slowly in isolation but quickly and efficiently, via a broad-based, yet well-focused, scientific and engineering collaboration.

Many of the activities (in particular the Joint Research Activities) are inter-dependent. As a collective body, RadioNet can provide the coordination and overview that is essential to ensure that these are properly matched, and that the end user, the astronomer, plays a major part in shaping the final overall product. The telescope facilities that we have recognised as being of paramount interest to the astronomical community in terms of trans-national access, are also those that will benefit most directly from the JRA projects proposed here. At the same time, building on the highly positive experience of RadioNet FP6, sufficient Management & Networking mechanisms are in place to provide the level of coherent feedback and response that is absolutely vital in ensuring that the project delivers a fully integrated and flourishing Radio Astronomy development programme.

RadioNet FP7 thus looks forward to a significantly enhanced level of European collaboration and cooperation in the future.

The principal and specific objectives of RadioNet, supported by the defined milestones, are:

- To provide an integrated radio astronomy network which will ensure that European scientists have access to world-class facilities;

- To provide an integrated research and development programme which will support and enhance European radio astronomy facilities;

- To develop a programme of networking activities which will ensure close European collaboration in engineering and science, sharing their knowledge and expertise, expanding the use community,

- To foster the development of the next generation of astronomers in the use of the current state-of-the-art and future radio astronomy facilities;

- To foster the development of the next generation of engineers who will lead the design and construction of the instruments of the future;

- To prepare for the next generation of world-class radio astronomy facilities through a wide discussion of their scientific motivation, through integrated research and development initiatives, and through the planning of the future structure of European radio astronomy;

- To promote public knowledge of radio astronomy and public understanding of the science that they fund through the development of a network of visitor centres.

These objectives will serve to strengthen the European astronomical community; to enhance the scientific output of its members, both in quality and quantity; and to ensure that it is well placed to take full advantage of the new generation of facilities under construction or being planned.

1.2 Progress beyond the state-of-the-art:

The state-of-the-art in radio astronomy facilities and technology has advanced tremendously over recent years, especially since the start of the FP6 RadioNet I3. These past few years have seen the widespread introduction of fibre networks and digital transmission of data for distributed arrays (e.g. e-EVN, e-MERLIN, LOFAR), and the development of multi-pixel cameras and focal-plane arrays (PHAROS in FP6 RadioNet) for single dishes, some of which are just about to be deployed for testing and astronomical use. There has been a transformation in the bandwidth, low noise capabilities and overall performance of mm/submm hardware, much of which was made possible by the AMSTAR JRA in FP6 RadioNet. The techniques of data handling and the implementation of new algorithms for interferometry have also advanced significantly; one of the most impressive developments has been the introduction of ParselTongue by ALBUS in FP6 RadioNet, which provides a new and valuable framework for the efficient development and testing of algorithms and data pipelines, and which is in use in many observatories around the world.

These new capabilities enhance the already impressive capabilities of Europe's facilities, but they are only a taster for what will come in the next few years.

1.2.1 Networking activities

The provision of research infrastructures (RIs) by themselves does not guarantee that excellent science will be achieved, although their existence is clearly a pre-requisite. Networking activities provide the lubrication necessary to enable an Integrating Activity such as RadioNet to achieve its desired impact. There is an over-arching requirement to provide opportunities for interaction on scientific and engineering fronts; to enable the discussion of future research directions; to ensure that the next generation of scientists and engineers are exposed to, and become familiar with, the capabilities of the RIs; to protect the radio frequency environment in which the RIs operate and to ensure that the results which are generated are made available to the general public in a comprehensible and coherent form.

To this end, we are proposing a series of networking activities (NAs) that will significantly enhance the services provided by the RIs. The NAs are specifically designed to be strongly linked to each other and to the TNA facilities and JRAs, to ensure that the Integrating Activity is indeed integrated and coherent. Specifically:

- WP2 (Science Working Group) will organize a series of workshops focusing on the science goals of the facilities, but having a wide coverage of different techniques (e.g. radio, IR, optical, X-ray etc.). WP2 will also have strong connections with WP5 (Training for Radio Astronomers), WP6 (Network of Visitor Centres) and WP7 (Spectrum Management). It will also provide input to the work of the various JRAs, guiding the specification and capabilities of the instrumentation R&D.

- WP3 (Engineering Forum) will focus on enhancing the communication, training and scientific interactions amongst engineers. It will have strong links with all RadioNet facilities and JRAs, ensuring information exchange on a wide variety of subjects. As for WP2, it will also ensure that links exist with WP5 and WP7, both essential activities for engineers as well as scientists.

- WP4 (Future facilities); several major facilities (LOFAR, ALMA, e-MERLIN) will be commissioned during the period of FP7 RadioNet or, in the case of SKA, will be proposed for construction. It is essential to have a NA that prepares the radio and broader astronomical community for the emergence of these facilities, to continue to assess their impact on existing facilities and to discuss, in a European context, how such facilities might be managed. WP4 will therefore require strong links to the existing RIs and to WP2.

- WP5 (Training) is an essential NA whose work will underpin much of the activities undertaken by the TNA facilities, by WP2, WP3 and WP6. It will also educate astronomers in the latest techniques and instrumentation.

- WP6 (Visitor Centres) will ensure that there is a coherent programme to inform the public of the results arising from their investment, through the taxes they pay, in the funding of the broad range of facilities to which European astronomers have access. WP6 will provide the mechanism to ensure integration of such the outreach activities of the major facilities and to use the multiplicative factor that such collaboration produces to increase the quality of the material produced. It will be closely linked with WP2, WP3, TNAs and JRAs.

- WP7 (Spectrum Management): radio facilities operate in an increasingly commercialised RFI environment and this NA will continue the excellent work done in WP6 to provide a European voice within the regulatory bodies to protect the radio astronomy bands. It will, of necessity, work closely with the RIs, WP3 and WP4.

1.2.2 Transnational Access activities – coherence and quality

Observations at cm, mm and sub-mm wavelengths offer a powerful and unique view of the cosmos: they probe dust-enshrouded regions where stars form in our own and other galaxies; they probe the distribution of dark matter via the detection of neutral hydrogen in nearby galaxies; they are able to detect relativistic plasma created in extreme environments around black holes, neutron stars and supernovae, they offer the simplest way to measure large-scale magnetic fields; and they provide the highest angular resolution and most precise astrometric measurements in all of astronomy.

These capabilities require a range of facilities from individual radio telescopes to global networks of antennas. European astronomers have access to the world's best facilities providing all these capabilities, many of them based within Europe, often with a proud tradition of 'operating an open-skies' approach, in which access is offered to the entire international community, solely on the basis of scientific merit and technical feasibility. These facilities are diverse, and even the most experienced astronomers require assistance with planning, executing, analysing and interpreting their observations. The Trans-National Access Programme presented here provides access to these facilities for all European astronomers and in particular, provides the facilities with the resources to offer the highest level of professional support for both new and experienced users.

The facilities include world-leading instruments offering unique capability over an unprecedented range of wavelengths – from the largely uncharted territory of the decametric emission to be observed by LOFAR, to the sub-mm emission measured by the JCMT, IRAM and now APEX. These facilities are all hosted by research organisations, universities or national observatories, in which world-class research is being carried out. TNA-supported astronomers receive support at each stage of the observing process, have the opportunity to interact with scientists and engineers at these institutes, and very often develop long-term collaborations with staff at working at the facilities.

The subsequent tables provide detailed descriptions of each instrument but the portfolio of facilities can be summarised as follows. Large single dish telescopes at Effelsberg and Sardinia (under construction) provide high sensitivity at centimetre wavelengths with low angular resolution. Their signals can be analysed at high time resolution for pulsar observations and high spectral resolution to detect a wide range of molecules. Higher frequencies require high, dry sites and more specialised telescopes (JCMT , APEX, Plateau du Bure and Pico Veleta) but provide a unique capability to observe thermal emission from cool dust associated with star-formation on all scales and at all distances from the nearest stars to the most distant galaxies. Compact arrays of antennas (WSRT and LOFAR) are especially good for imaging neutral hydrogen and carrying out wide area surveys. Larger arrays (e-MERLIN and the European VLBI Network) are used to study individual objects with sub-arcsecond to milli-arcsecond resolution.

Continued technical development and substantial investments over the past few years have maintained the global competitiveness of all these facilities: the SRT (Sardinia) will be a new 64-m telescope with continuous frequency coverage; LOFAR is an ambitious aperture array instrument capable of very wide fields of view at low frequencies; APEX is capable of THz observations; Effelsberg has doubled its sensitivity at high frequencies; e-MERLIN is increasing its sensitivity by more than an order of magnitude and the EVN is being transformed into a real-time VLBI network

European radio astronomers have a proud history of collaboration, built upon the platform of the EVN. The high level of support it offers owes much to EC Framework Programme funding. The TNA programme fosters this collaborative spirit amongst a much wider range of radio and sub-mm facilities, and also opens these facilities up to a wider range of European astrophysicists.

1.2.3. JRA programme

Various exciting technical opportunities exist to boost the scientific capacity of the RadioNet facilities in the next decade. Many of these facilities already define the state-of-the-art in radio astronomy by being completely new facilities or by introducing advanced new instrumentation on existing telescopes. Examples of these are a number of new multi-pixel arrays on the millimetre telescopes, new large dishes in Sardinia (Italy) and Yebes (Spain), the development of e-MERLIN and e-VLBI, and the construction of LOFAR. The same technological advances are also enabling the development of new radio-telescope concepts, currently under construction, such as ALMA, several SKA pathfinders and eventually the SKA.

The JRA activities in this proposal build on the successful activities within FP6 RadioNet. They form a coherent programme aimed at providing innovative developments to support the scientific programmes on the RadioNet telescopes and keep the facilities state-of-the-art.

A common element to all the JRAs is that they directly address the effectiveness with which the existing radio-telescopes can be deployed in the next decade. For example, the deployment of multi-pixel detectors will revolutionise single-dish astronomy by enhancing the large scale imaging speed by many orders of magnitude. Moreover, this has the potential to keep European (mm and cm) interferometer arrays competitive even when globally funded new arrays with very many elements are being built in the Southern hemisphere (ALMA and SKA pathfinders).

The development of multi-pixel arrays is a theme common to two of the JRAs: AMSTAR+ (WP9) for mm/submm telescopes and APRICOT (WP10) for cm/mm telescopes. Although the goals of the two JRAs are similar, i.e. to provide major enhancements to the field-of-view and, thereby survey, capabilities of single-dish telescopes, the techniques and technologies involved are very different in the two wavelength regimes.

The volume of data which will be produced by multi-pixel cameras on single-dishes will be similar to that generated by the new generation of interferometers. They will require flexible, powerful, digital backends which can be used for a variety of different applications. The JRA UniBoard (WP11) will develop a generic digital processing board that will enhance the signal processing capabilities of the existing telescopes for spectroscopy, pulsar searches and high-resolution interferometry. Finally, the software JRA ALBiUS (WP8) will underpin much of the other R&D work. It will bridge the gap between existing and new data processing tools and bring new, much desired, algorithms to the RadioNet facilities. At the same time it will provide the tools to the community to seamlessly start using various new international facilities. The fact that NRAO (USA) is a partner in this project demonstrates the global approach that has been taken for this important issue.

The innovation and synergy between RadioNet facilities and new global facilities (e.g. ALMA and SKA) is vital for the health of the European radio-astronomy. First, there is the technological argument. The proposed programme offers the possibility to make use of innovative techniques close at home, at the existing infrastructures, offering the obvious advantage of immediate and direct access to the equipment and test results. Moreover, the AMSTAR+ and APRICOT projects have a strategic role in securing the supply of Monolithic Microwave Integrated Circuits (MMICs) in Europe. Even more important is the vital role that the RadioNet facilities must play in the scientific upbringing of the next generation of radio-astronomers. Clearly, without state-of-the art facilities in the next decade, European astronomers will not be ready to successfully compete for observing time or play a leading role in the deployment of the large global telescope projects, especially the SKA.

1.3 S/T methodology and associated work plan

1.3.i) Work plan

RadioNet FP7 involves 25 partners contributing effort to 20 different work packages (7 NAs, 4 JRAs and 9 TNAs). The full work package list is reproduced in Table 1.3a. Technically there is very little direct dependency between one work package and another. This is a deliberate decision on the part of the RadioNet consortium – it serves to minimise the possible growth of inter-related risks, and makes the project management simple and transparent. Each WP runs in an entirely independent way – a failure in one WP has no immediate consequence for another.

At the same time, the work programme is very much an integrated endeavour. At the core of our proposal sits the Transnational access programme and the astronomical user community. Each TNA largely runs independently but there is significant overlap in the kind of science each facility addresses. For example, an observing programme observing blank fields with SCUBA-2 (WP13), is very likely to be complemented with a deep e-MERLIN map (WP14) of the same field. For the astronomer, a common proposal tool, known as "NorthStar" (originally funded via RadioNet FP6), provides the same entry interface to both instruments. In addition, the same astronomer can seek support to present his/her work at meetings and workshops sponsored by the Science Working Group (WP2). He or she, can also expand their knowledge in terms of observing techniques or data analysis tools, by attending schools and training workshops run by WP5 (Training for Radio Astronomers). The opportunity to attend a school on mm-interferometry will introduce him or her to the opportunities of studying the SCUBA-2 sample with the IRAM PdB interferometer, permitting the gas mass to be determined via molecular emission from highly redshifted CO. In the meantime, WP5 (Engineering Forum), WP7 (Spectrum management) and WP8 (User Software) are active in ensuring that this astronomer receives the best possible quality data and is able to exploit it to its full potential. The fruits of this grand effort can be used by WP6 (Visitors Centre) to enthral and enthuse the larger general public, and young school children and college undergraduates in particular. With funding secured, and with expertise readily available, the Joint Research Activities (WPs 9, 10 & 11) are pushing the state-of-the-art in astronomical instrumentation forward, in order to meet the challenge of our astronomer's next proposal and new demands for better and more data, extending over ever larger fields of view.

The previous paragraph may paint an idealised picture of the way RadioNet FP7 can serve one individual astronomer. Nevertheless, there are elements described therein, that clearly demonstrate the natural integration that characterises our programme. At the base of this overall strategy, lies an experienced project management. In the following sections we present a more detailed description of our planned activities within RadioNet FP7.

1.3.ii) Work package timing

1.3.iii) Detailed work package description

We present the timing and a detailed work description of the various RadioNet FP7 work packages (WPs) via the following figures and tables:

- Gantt chart presenting the timing of the different WPs and their components
- Work package list (Table 1.3a);
- Deliverables list (Tables 1.3b1 and 1.3b2);
- List of milestones (Table 1.3c);
- Description of each work package (Table 1.3d WPs 1-20)
- Summary effort table (Table 1.3e)