REPORT OF THE VISITING COMMITTEE FOR INAF

ISTITUTO DI RADIOASTRONOMIA (IRA)
OSSERVATORIO ASTRONOMICO DI CAGLIARI (OAC)

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EXECUTIVE SUMMARY

Both institutes are performing outstandingly, within the contraints of the structures in which they operate. IRA differs from INAF's other institutes in that it is the sole Italian facilitating organisation for Italian metre and centimetre-wave radio astronomy, a unique band for studying several fundamental constituents of the Universe. The role of IRA is therefore comparable to that of ESO for Italian optical, infrared and millimetre astronomy and ASI for Italian space astronomy.

Our main conclusion is that as a normal research institute within an underfinanced INAF, the IRA cannot remain competitive on the long term with organisations that facilitate radio astronomy in other countries. The lack of autonomy, coupled with the decrease of funding and failure to hire new scientific staff since 2001 make it impossible to set priorities and plan for the future. The crisis in staffing is exacerbated by (i) an archaic centralised national hiring system that takes no account of the need for succession planning to provide continuity in expertise, (ii) poor salaries and (iii) difficulty in obtaining promotion for engineers as well as for scientists. We therefore regard the decision to move IRA from a structure within the National Research Council (CNR) to a structure within INAF as flawed.

We urge INAF to develop IRA as a semi-autonomous structure, recognising it as the facilitating institute for Italian radio astronomy. ASTRON in the Netherlands, the Australian National Telescope Facility (ATNF) in Australia and the National Radio Astronomy Observatory (NRAO) in the U.S. are all appropriate models for such a structure. ***It is essential that the new entity be provided with a stable long-term budget for operation, research and development.*** Continuing the status quo will have the consequence that Italian radio astronomy will become increasingly uncompetitive internationally. However, in an autonomous structure that is properly supported, IRA can continue to prosper and excel as a leading organisation in European and world-wide radio astronomy.

Provided such an autonomous structure with a stable integral budget is established, IRA should be invited to take the lead in developing a prioritized long-term strategic plan for Italian radio astronomy. There should be strong involvement by the external radio astronomical community in preparing such a plan.

We make several remarks and recommendations pertaining to the Italian radio astronomical facilities.

* IRA plays a prominent national and international role in VLBI. There are several excellent reasons why support of this activity should continue.

* We are surprised that as yet no organisational structure is in place for managing the Sardinia Radio Telescope, after it has been commissioned in 2009 and we are very concerned that there is also no plan for SRT operation after this time. ***INAF must quickly resolve the uncertainty in the long-term organizational structure of the SRT and ensure that an operational plan for managing the SRT is developed within the next few months.*** We discuss aspects of such an organisational structure in Section 4.2. The system adopted should be clearly defined and

streamlined to maximise efficiency of operation and minimise interfaces between participating organisations. We are not competent to judge the need to take account of possible regional sensitivities in the SRT organisation.

Regarding receiver development for the SRT, we recommend that the highest priority should be constructing single-beam receivers for VLBI and pulsar timing. Development of additional multibeam systems at frequencies > 20 GHz should await an evaluation of the high-frequency performance of the telescope and its site.

* The Medicina and Noto telescopes are important elements in the EVN. We therefore recommend that the operation of the Noto Telescope as a VLBI element be supported. In view of the budget problems and the need to support the operation of the SRT, we also suggest that single-dish operation of this telescope should be continued only if external funds can be found**.**

* IRA is presently involved in several scientific and technological activities in preparation for SKA, including participation in LOFAR, an array that is now expanding to European dimensions. There is also the participation in scientific exploitation of the Atacama Large Millimeter/sub-mm Array (ALMA) via the ALMA Regional Centre (ARC) being established in IRA Bologna for all Italy. It is crucial for the long-term future of radio astronomy in Italy that these activities be supported properly and strengthened.

We were impressed by the high quality of the scientific and technical staffs of both institutes. In spite of the staffing and budget problems, ***the productivity of both IRA and the OAC has been very high.*** Members of the IRA and OAC scientific staff are international leaders in several important branches of astrophysics and have been invited to give many reviews. The engineering staffs at both institutes are innovative and enthusiastic and are participating in several cutting-edge technological developments. We note that whereas there is a severe lack of junior staff researchers at Bologna, there is a lack of senior staff scientists at Cagliari.

Finally, we remark that public outreach is extremely important in exploiting the unique aspects of astronomy for educational, social and cultural goals. Outreach is also an important tool that can strengthen national advocacy for astronomy and the visibility of INAF. Both institutes are doing an excellent job in outreach activities with extremely limited resources. We hope that INAF will be able to strengthen outreach activities at both institutes.

1. INTRODUCTION

1.1. Procedures. The Visiting Committee met at the Bologna Headquarters of the Istituto di Radioastronomia (IRA) from the afternoon of 26 to 29 November 2007. The first three days were devoted to an evaluation of IRA. The Osservatorio Astronomico di Cagliari (OAC) was reviewed on the fourth.

During the visit we attended 23 presentations and conducted confidential personal and group interviews with members of the staff. These interviews involved scientific and engineering staff at all levels of both organizations stationed at Bologna, Firenze, Noto and Cagliari. On the afternoon of 28 November we visited the Medicina facilities of IRA and viewed the technical laboratories and visitor centre.

Organization of the visits was a substantial amount of work for many IRA and OAC staff. We are grateful to the Directors and to all those involved for this preparation and thank the IRA staff for their outstanding hospitality. Although about 20 members of the scientific and technical staff were flown from the OAC to Bologna for our visit, this cannot replace the usefulness of a personal visit to the institute. Similarly, our impressions of the IRA departments at Noto and Firenze are based on interactions with the relevant staff and miss first-hand knowledge afforded by site visits.

1.2 Structure of Report. Although the research of IRA and the OAC are both predominantly in the field of radio astronomy, the two institutes differ considerably in scope (see Section 3) and size. Most of our report will deal with the much larger IRA. After discussing the facilitating role of IRA (Section 3), this report will deal first with facilities (Section 4). Particular attention is given to the Sardinia Radio Telescope, whose construction involves work by both institutes (Section 4.2). We then address the staffing situation (Section 5), and the structures and budgets, (Section 6). In our view, the problems in these areas have resulted in a crisis that is severely damaging to IRA and to radio astronomy in Italy. We discuss the scientific and technological aspects of the institutes in Sections 7 and 8. Education and public outreach are covered in Section 9.

The report concentrates on the specific problems facing Italian radio astronomy and IRA. Other INAF visiting committees will undoubtedly address problems that are generic to INAF research institutes, such as the shortage of research funding for postdocs and PhD students and their poor salaries.

Our main conclusion is that, given the structure in which they must operate, both institutes are performing excellently. However, in its present form, as a normal research institute within an underfinanced INAF, IRA cannot remain competitive with organisations that facilitate radio astronomy in other countries unless conditions are improved.

We urge INAF to develop IRA as an autonomous or semi-autonomous structure either within or outside INAF, recognising it as the facilitating institute for Italian radio astronomy. ASTRON in the Netherlands, the ATNF in Australia and the NRAO in the U.S. are all appropriate models for such a structure. It is essential that the new entity be provided ***with a stable long-term budget***

for operations, technical research and development. Continuing the status quo will have the consequence that Italian radio astronomy will become increasingly uncompetitive internationally and may well undergo a terminal decline. However, in an autonomous structure that is properly supported, IRA can continue to prosper and excel as a leading organisation in European and world-wide radio astronomy.

2. UNIQUENESS OF RADIO ASTRONOMY

Because of IRA's role as a provider of radio astronomical infrastructure, we shall first stress the uniqueness of radio astronomy as a technique in astrophysics. Optical and infrared astronomy are mainly concerned with thermal emission processes. At millimetre and sub-millimetre wavelengths radio astronomy contains unique diagnostic tools for studying thermal emission from molecular gas and dust.

Centimetre and meter-wave radio astronomy, however, provides ***information about several processes that probe fundamental constituents of the Universe that cannot be observed by optical or millimetre telescopes***. Examples are synchrotron emission and neutral hydrogen. Synchrotron-emitting relativistic plasma is now known to be ubiquitous in galaxies, stars and clusters and provides unique diagnostics for studying the properties and evolution of magnetic fields. The 21 cm neutral hydrogen line also provides crucial information about evolution from the epoch of reionisation to the present time. Likewise, pulsars are cosmic laboratories through which astronomy can be used to test basic physics. We note that radio astronomy has produced more Nobel prizes in physics than any other branch of astronomy.

The importance of radio astronomy extends beyond the confines of astrophysics**.** Radio astronomy developed from electrical engineering roots and later led and exploited developments in signal processing and information sciences. Since its inception radio astronomy has frequently driven cutting edge technological developments. For example, the need to observe the faintest radio sources stimulated construction of the most sensitive radio receivers. Radio spectroscopy and interferometry led to the development of new digital signal processing approaches and pushed the limits of image processing science. Very long baseline interferometry (VLBI) has driven the development of the most accurate clocks and video recorders. Radio astronomy technology and know-how has fed back into practical applications ranging from geodesy[1] and time keeping to earth remote sensing and weather satellite technology.

3. SPECIAL ASPECTS OF IRA – A FACILITATING INSTITUTE

The IRA and the OAC are the sole INAF institutes involved mainly in radio astronomical research and IRA is the institute that has driven the development of radio astronomy in Italy since its inception. Furthermore, IRA is the only INAF institute with ***distributed sites***, operating radio telescopes at Medicina and Noto and technological laboratories at Medicina, Noto and Firenze. Furthermore IRA together with the OAC and the Arcetri Observatory is constructing the Sardinia Radio Telescope (SRT), a new large facility near Cagliari.

[1] Geodesy is an important activity of IRA. See Section 7.5.

IRA is ***different from most of INAF's other institutes*** in that it performs a facilitating function for Italian centimetre-wave and metre-wave radio astronomy, comparable to that of ESO for optical infrared and millimetre astronomy and ASI for space astronomy. Although some other INAF activities, such as participation in the Large Binocular Telescope and the Galileo Telescope, also have facilitating aspects, ***IRA is the sole facilitator of centimetre and meter-wave astronomy in Italy.*** The tasks of IRA include operating Italian radio telescopes, conceiving, developing and participating in new national and international radio facilities and representing Italy in international radio astronomical consortia such as the EU network, "Radionet" and the European VLBI Network (EVN). In addition, the establishment of the Alma Regional Centre at Bologna will give IRA a role (together with ESO) in facilitating Italian millimetre and sub-millimetre astronomy.

Presently one of IRA's most important facilitating functions is to provide infrastructure in Italy for very long baseline interferometry (VLBI). VLBI is a unique and powerful technique because it provides the highest resolution imaging of the Universe available at any waveband, with spatially resolved information on scales down to sub-milliarcseconds.

In most countries successful institutes that have a facilitating role in radio astronomy are separated structurally from optical astronomical development. There are good reasons for this. Such a facilitating institute must have (i) a degree of long term stability, (ii) flexibility to optimise tradeoffs between operation, technical research, development strategic planning, (iii) streamlined interfaces with government and (iv) a fast decision making process, conducive to developing joint ventures with industry and international partners.

Examples of institutes with facilitating tasks similar to IRA are ASTRON in the Netherlands, the Australia Telescope National Facility (ATNF) in Australia and the National Radio Astronomy Observatory (NRAO) in the USA. ***We note that these are all independent and (semi)autonomous organisations*** within larger managing structures (NWO, CSIRO and AUI/NSF respectively).

4. FACILITIES

4.1 EVN Participation. IRA plays a prominent national and international role in VLBI, mainly in the context of the European VLBI Network (EVN). The EVN, the most sensitive VLBI network in the world, is an array of mainly European radio telescopes co-founded by IRA in 1980. The Italian telescopes at Medicina, Noto and Sardinia (from 2009) are an important part of the EVN and IRA astronomers and engineers have played a crucial role in its development and exploitation.

There are several reasons why IRA participation in VLBI should be supported.

(i) The EVN is making fundamental contributions to a broad range of galactic and extragalactic astrophysical research. Topics being addressed by the EVN include tracing the earliest stages of star formation by studying the evolution of galactic masers, monitoring the evolution of supernovae in nearby starburst galaxies, the physics of relativistic jet outflows in radio galaxies

and quasars, probing the local interstellar medium in distant galactic nuclei through HI absorption and probing dark matter through studies of gravitationally lensed radio sources.

(ii) Sensitivity limitations have until recently restricted the application of VLBI to relatively bright radio sources, but several developments are presently underway such as the replacement of tape recorders by fibre links that will increase the sensitivity of VLBI by more than an order of magnitude. This will broaden the astrophysical applications of VLBI enormously, allowing the study of a range of astrophysical objects and phenomena that were previously inaccessible with VLBI.

(iii) Technical developments for VLBI and the EVN are an important stepping stone in realising the Square Kilometre Array, the planned global next-generation radio telescope.

(iv) The Italian radio telescopes are an important contribution to the projected baseline coverage of the EVN. Their addition to the network substantially improves the dynamic range of the resultant EVN maps.

(v) Italian/ IRA radio astronomers are at the forefront of many international VLBI-driven research programmes.

4.2. The Sardinia Radio Telescope (SRT) Despite a regrettable delay in its funding and the withdrawal and re-entry of ASI into the project, the 64-meter diameter SRT is nearing completion in Sardinia. With its actively controlled surface, the SRT has the potential of operating at frequencies of up to 100 GHz. The most important applications for the SRT include VLBI participation at frequencies of ≥10 MHz and pulsar timing. These are both research fields in which Italian radio astronomers excel. The competitiveness of the SRT in other areas depends on (i) its actual performance at high-frequencies, (ii) the speed of completion and instrumentation on competing high-frequency telescopes, such as the 100m-diameter Green Bank Telescope and the 50m-diameter Large Millimetre Telescope in Mexico which is located at a height of 4600m.

We were impressed by the progress that is being made in the construction of the SRT. However, we were surprised to hear that the telescope is being developed without a proper project manager. Commissioning of the SRT is planned for early 2009, but we learned that this may be subject to a delay of several months.

The main risks to the project are the accuracy of the telescope surface that can be achieved and possible delays in developing some of the required software. Special attention should be paid to ***software development***, an item that is frequently underestimated and often determines the critical path for radio telescope projects. The Committee notes that a considerable part of the several years delay before the Green Bank Telescope was fully operational was due to software problems.

For the SRT it is planned to make use of existing software packages for the off-line data reduction. We regard this as a good decision. However it is essential to ensure that the conversion routines for transforming data from the digital backends and autocorrelators to

formats compatible with the available software packages are completed and tested in a timely fashion

We are concerned that as yet no ***organisational structure*** is in place for managing the SRT after it has been commissioned. Such an operational plan is needed urgently. The plan should include detailed operational and development requirements, together with necessary manpower and budgets.

The absence of such a management plan is related to the uncertainty in how the telescope will be managed after it has been commissioned. This appears to be a highly sensitive matter amongst the parties concerned. The most logical organizational structure is that the SRT be managed by IRA. There are several reasons for this. First, VLBI was the major scientific driver for the SRT and will be one of the most important applications for it. Combining the management of all Italian radio telescopes would be more efficient and would avoid duplication of tasks. Other reasons for adopting such a management structure are the role of IRA in developing testing and integrating instrumentation for the SRT at Medicina and Firenze, the fact that the SRT was conceived by IRA and the position of IRA in European VLBI. Similar situations work well elsewhere. Examples are the Green Bank Telescope, operated by NRAO with headquarters in Charlottesville, the Australian Telescope at Narrabri, operated by the ATNF, with headquarters in Sydney and the ESO telescopes in Chile.

However, there are additional aspects of the SRT that may need to be taken into account when deciding the optimum management structure. We were informed about the regional importance of the telescope to Sardinia, the possibility that additional regional funding might be provided by the Sardinian authorities and the need to satisfy regional cultural sensitivities in the management model that is adopted. As outsiders we cannot judge the general importance of the regional dimension and this is not our task. However, given the budgetary situation for radio astronomy as a whole, it would seem important to maximise any regional contributions to the operations funding. Also, it is desirable that scientists and engineers involved with the SRT will be located close to an academic environment that can motivate them, while keeping an adequate technical staff at the SRT site to insure operations and maintenance of the radio telescope.

We reiterate that the uncertainty in the long-term organizational structure for the management of the SRT should be resolved immediately and that an operational plan for the SRT must be developed within the next few months. The management structure adopted should be clearly defined and streamlined to optimise the operation of the SRT, with a minimum of interfaces between participating organisations.

This choice of first-generation ***receivers for the SRT*** appears reasonable. In particular the plans for science that can be done with the 7-beam receiver system are interesting and competitive. For the second-generation receivers, we recommend that:

(i) Priority of receiver development for the SRT should be placed on fully equipping the SRT with single-beam receivers for VLBI and pulsar timing.

(ii) Development of additional multibeam systems at frequencies > 20 GHz should await an evaluation of the high-frequency performance of the telescope and its site.

(iii) A collaboration with external groups should be considered for providing some additional sophisticated receivers, such as high-frequency multibeam receivers...

(iv) User input should be solicited from interested users throughout Italy on additional large projects for the SRT that require receiver development. However, before sanctioning additional receiver or other development for such projects, their international competitiveness should be carefully reviewed. A direct competition with organizations with larger telescopes should be undertaken only if the science, the performance limits of the SRT and the weather conditions can ensure an advantage for the SRT. Because of the large lead-times in constructing receivers, it is advisable to start such a process with a user meeting during 2008.

4.3 The Medicina and Noto Radio Telescopes The Medicina and Noto telescopes provide very ***important coverage in projected baseline for the EVN***, thereby enhancing the dynamic range of its images. The continued use of both telescopes for VLBI should be supported. The Noto telescope, together with the SRT, it is one of the six telescopes in the EVN that operate at frequencies of 20 GHz and higher and there is a possibility of upgrading the Medicina Telescope for operation at up to 45 GHz. In addition to its role in VLBI, the Medicina Telescope is an important test bed for developing instrumentation for all three Italian radio telescopes, including the SRT. We regard the use of Medicina and Noto in single dish mode as less important than their use as VLBI elements.

In view of the budget problems and the need to support the operation of the SRT, we suggest that an attempt be made to secure additional external funding to support the operation of the Noto telescope, in as far as it continues to be operated as a single dish. Possible funding sources could be the EU trans-national access programme or ASI[2]. Operating the NOTO telescope with reduced IRA manpower, e.g. as a joint venture with the University of Catania and/or the Catania Astrophysical Observatory is another option that could be investigated. Closer interaction of the IRA scientists with those at the Catania University and Observatory would have an additional advantage. It would help counteract the relative scientific isolation of the IRA group at Noto.

4.4 The Northern Cross, LOFAR and SKA. IRA astronomers and engineers are involved in several developments in preparation for the Square Kilometre Array (SKA). SKA is planned as the next-generation global radio facility that will define radio astronomy for several decades, starting in about 2015. SKA has as its goal providing two orders of magnitude increase in sensitivity over existing facilities at metre to centimetre wavelengths. To achieve this goal will require a telescope with one square kilometre of collecting area - one hundred times more collecting area than the Very Large Array (VLA). IRA is playing an important role in the development and planning of SKA. IRA is presently involved in several activities in preparation for SKA. It is important that these activities be properly supported to maximize the influence and presence of Italy in SKA.

[2] We note that ASI presently supports the Matera radio telescope and gives partial support to the SRT. It might be worth exploring with ASI the possibility of including the Matera and Noto telescopes in a combined geodesic and astronomical network operated by IRA, with partial funding by ASI.

Several pathfinder facilities are being developed on the road to the technology and astronomy of SKA. One of the most important of these is the Low Frequency Array (LOFAR) presently being constructed in the Netherlands, with extensions in Germany and the United Kingdom. This is a facility designed to explore the Universe at frequencies of ~ 30 MHz to ~ 240 MHz with unprecedented depth using phased arrays. Becoming involved with LOFAR is an excellent way for IRA to exploit their existing scientific and technical expertise, on the way to securing a more substantial role in SKA. The science of LOFAR surveys dovetails well with the scientific interests of IRA staff in clusters and surveys. With support from Bologna University, IRA has equipped part of the east-west arm of the Northern Cross as a first step in becoming involved with LOFAR. ***We applaud this initiative.*** The resultant low-frequency interferometer with the LOFAR core in the Netherlands will be an interesting test and development facility that will also do a limited amount of science.

LOFAR is presently evolving from a purely Dutch array to a European facility, with baselines of several hundred kilometres. LOFAR stations are already funded in several countries outside the Netherlands. Obtaining a more significant role in LOFAR (e.g. placing standard LOFAR stations at the Italian radio telescope sites, or completely equipping the Northern Cross for operation at LOFAR frequencies) would require 0.5 – 3 M€ of additional funding. However, this would (i) build on Italian involvement in the EVN, (ii) amount to only a small increment in the total cost of Italian radio astronomy infrastructure and (iii) be an excellent stepping stone to a larger degree of involvement in SKA.

The development of technology for SKA in Europe is being supported by the EU. IRA is involved in several cutting-edge technological developments in this area, including development of optical links, phased arrays and new techniques to excise radio frequency interference (RFI).

Long-baseline interferometry, involvement with LOFAR and the development of the necessary forefront technology are all logical stepping stones on the road to SKA. These developments should be supported and strengthened, if at all possible.

4.5 The ALMA Regional Centre. The Atacama Large Millimetre Array (ALMA) is the largest ground based project in astronomy. The facility is planned to be finished in 2012, with a start of 'early science' in 2010. ALMA will be used to investigate the 'cool universe', focusing on broadband emission from dust and spectral lines from atoms and molecules. It will provide high resolution images of protostars, star-forming regions, dust enshrouded galaxies, as well as objects in our solar system. ALMA will study molecules and dust in galaxies and quasars at high redshift and should provide cosmologically important information on galaxy evolution. ALMA images will complement high angular resolution centimetre measurements, as well as optical and infrared results. The angular resolution of ALMA will exceed that of the Hubble Space Telescope.

The ALMA Regional Centre (ARC) node at IRA in Bologna was proposed in an "Expression of Interest" sent to ESO in March 2005. The Bologna ARC will carry out essential tasks for Italian ALMA users that are not funded by ESO in the core ALMA program. The mission of the ARC

node will include observer support, development of specific software for Italian users and stimulating the use of ALMA in Italy.

The Bologna ARC node is foreseen as being staffed by 3 permanent scientists, an ARC Manager, a system manager and an administrative assistant, together with 4 post doctoral fellows. At present, office space, the ARC Manager and 2 postdoctoral fellows are envisaged. In the "early science" phase of ALMA it is essential that non-specialist users are given extensive help to produce science based on observations with ALMA.

We regard the creation of the Italian ARC node at Bologna as an excellent initiative and an important step in optimising Italian participation in ALMA. The proposed staffing levels are a minimum for carrying out the tasks of such a regional centre, provided they are supported with stable funding. As with other facilitating positions with IRA, it is essential that the temporary postdoc positions are provided with long-term funding so that internationally competitive three-year contracts can be offered. We also regard it as important to bring the ARC node at Bologna to full strength before the "early science" with ALMA begins.

Given the multiwavelength research activities of most of the IRA staff, we expect interest in ALMA within IRA and Italy as a whole to grow as the time to submit proposals approaches. The appointment of young permanent staff with interests in this area would be an obvious way of stimulating additional interest.

5. THE STAFF CRISIS

We regard the staffing situation at IRA as causing a threat to the future of the institute and of Italian radio astronomy in general. To summarise the problems:

* There has only been one appointment to the scientific staff of IRA since 2001.

* The age distribution of scientific staff is extremely skewed towards older researchers, with about 8 of the 24 scientists on the verge of retirement.

* There appears to be virtually no prospect for promotion between career levels, either for the scientific or technical staff. Furthermore, we learned that no scientist under 45 has reached the level of Associate Professor. This is in contrast to the situation in comparable organisations abroad. In the case of the technical staff, the poor career prospects are exacerbated by the low salaries in comparison with industry.

* The centralised system for recruitment via an examination and national allocation of positions is peculiar to Italy. It is clearly unsuitable for a facilitating institute such as IRA that is charged with the operation and development of astronomical infrastructure. In such an organisation it is essential to be able to plan ahead and match the scientific and technological expertise of the staff to the necessary tasks.

* There is a chronic lack of administrative staff at IRA. Even the Director of IRA does not have a secretary. Again, this is an inefficient use of resources and the wrong way to run a facilitating institute.

* The funds available to support postdocs and PhD students are insufficient. Although we understand that this is a general problem for INAF institutes, the lack of young researchers appears much more pronounced for the IRA than for the OAC. The poor salaries, short-term contracts and general lack of research funding makes it unattractive for foreign postdocs and PhD students to take up positions in Italy.

The scientific staffing problems appear less acute at the OAC than at IRA. In contrast to the institute at Bologna several junior appointments were made at Cagliari during the last few years. This appears partly due to the injection of regional funding into the OAC. We note that whereas there is a lack of senior radio galaxy researchers at the OAC, there is a lack of junior radio galaxy researchers at IRA Bologna.

Despite the problems mentioned above, we were impressed by the high quality of the scientific and technical staffs of both IRA and the OAC. An excellent feature of the IRA staff demographics that deserves commendation is the presence of women in senior positions. IRA has had two women directors during the last decade.

6. BUDGETS, FLEXIBILITY AND STRUCTURE

We note that the normal budget of the IRA has decreased substantially since it was incorporated into INAF. In a situation where less than 15% of the budget is flexible, it would appear impossible for INAF to support a facilitating institute such as IRA. We therefore regard the decision to move IRA from a structure within the Research Council to a structure within INAF as unfortunate.

In our view, the mission of IRA in operating and developing radio astronomical infrastructure requires:

(i) A stable integral budget for salaries, operations maintenance of facility infrastructures, technical research and development and new initiatives (e.g. LOFAR and SKA), comparable with similar institutes abroad.

(ii) Autonomy in controlling the integral institute budget.

(iii) Authority to participate in international ventures, independent of central control by INAF.

We commend IRA for supplementing the normal budget of the institute with additional sources of project funding, e.g. from the EU and industry. As an autonomous structure IRA would be in a stronger position to seek external funding from industry.

Provided IRA can be reorganised as an autonomous or semi-autonomous structure with a stable integral budgets, we suggest that this institute be invited to take the lead in developing a

prioritized long-term strategic plan for Italian radio astronomy, with participation of the external radio astronomical community. The plan should integrate scientific and technological drivers and take into account involvement by Italy in the SKA and its pathfinders. Special attention should be given to succession planning, in order to ensure preservation and development of the necessary technological and scientific expertise. However, the development of such a plan would only be useful after organizational changes have been affected, but not with the present unstable budgets and lack of flexibility in staffing.

In a broader context, we suggest that INAF should consider instituting an independent visiting committee to review administration matters within the INAF organisations as a whole. Such a review could consider the efficiency of administrative procedures and the balance of administrative resources between the institutes and the central INAF organisation. It would be wise to include a few scientists and some experts experienced in administrative procedures in non-Italian research institutes on such a committee.

7. SCIENCE OF IRA AND OAC

7.1 General Remarks. Despite the staff crisis and budget uncertainty ***the productivity of both institutes has been high, with staff playing an international leadership role in several fields and large numbers of invited reviews.*** We shall address some of these activities in more detail.

7.2. Surveys, radio galaxies and clusters of galaxies Extragalactic radio sources are important as laboratories for studying high-energy processes and as probes of massive galaxies and clusters and their evolution. Since their seminal surveys with the Northern Cross in the nineteen sixties, scientists from the Bologna group have been major players in studying all aspects of extragalactic radio sources and their evolution. IRA scientists have built on their expertise at radio wavelengths to carry out multiwavelength studies of radio sources using front-line facilities throughout the electromagnetic spectrum, including space facilities such as HST, Spitzer, Chandra and XMM. This science is of high quality and has had considerable impact on the field. Bologna-led surveys have played an important role in the cosmological interpretation of radio source counts and multivariate luminosity functions. Studies of radio sources in clusters have provided fundamental observations of radio halos and cluster magnetic fields and their relation to the hot X-ray gas. Important Bologna results on the nature of radio sources include topics as diverse as the forming of relativistic jets on sub-parsec scales with VLBI, through the fuelling of their nuclei with the HST to studies of ageing of synchrotron-emitting electrons in the oldest giant megaparsec-scale radio sources within and outside clusters.

There is also a small but excellent radio galaxy group at OAC, composed of junior staff researchers. Most members of this group were trained at Bologna and there is considerable collaboration between the OAC and Bologna groups. An additional interest of the OAC radio galaxy group is in the study of H_2O megamasers, a field where in which have made fundamental contributions.

Again, we note that whereas there is a lack of senior radio galaxy researchers at the OAC, there is a lack of junior radio galaxy researchers at the IRA Bologna.

7.3 Pulsars (OAC). The Cagliari group has an excellent track record in pulsar research. The group has contributed important hardware and software to the Parkes Survey, which in recent years doubled the total number of known pulsars, and it discovered the first double pulsar. Pulsars are interesting in their own right, but perhaps even more so, on account of their applications as accurate clocks. Thus the double pulsar, discovered by the Cagliari group, provides extremely accurate tests of general relativity. Other binary pulsars provide accurate neutron stars masses, and through these constrain the equation of state - i.e. quantum mechanics - at supranuclear densities. Through the dispersion of the pulse arrival times, the hot interstellar medium can be studied at otherwise inaccessible scales. With the Sardinia Radio Telescope Cagliari pulsar researchers can be expected to continue its successful collaborations with other pulsar groups, (e.g. Jodrell Bank and Sydney) in pursuit of these studies. Observations with the Pulsar Timing Array can potentially discover gravitational waves from the Big Bang. The dual-frequency receiver is eminently suited for this and other pulsar work, in allowing accurate correction for time-dependent dispersion. However, the delay in completion of the SRT means that pulsar survey work (e.g. pulsars in globular clusters) faces stiff competition from the superior GBT.

7.4 Interstellar medium, star formation (IRA) and astrochemistry (OAC) Research on star formation and the dense interstellar medium is carried out by IRA both at Bologna and Firenze. The larger group at Firenze – that focuses more on nearby galaxies – takes good advantage of its close interaction with colleagues at the Arcetri Observatory, hampered only by an apparently limited access to university students and a lack of own funding for postdocs. The small group at Bologna has fruitful collaborations with Italian and international colleagues. Although observations with the Medicina 32m telescope form an important part of the research, the focus appears to be shifting towards millimetre and submillimetre interferometric observations.

The astrochemistry group at OAC has a broad approach, covering laboratory spectroscopy, computational chemistry, chemical modelling and observations, with a focus on planetary environment and complex molecules. It would seem natural that in the future, their observational work should focus on the SRT and ALMA. ALMA images will provide astrochemists with more accurate estimates of abundances and allow the locations of individual species within galaxies to be pinpointed for the first time, The extension of astrochemical studies to extragalactic astronomy will be a growth area during the ALMA era and would be a logical future activity for this group.

7.5 Geodesy (IRA) The geodesy group within IRA is a very active one. It participates regularly in geodetic VLBI observations. Members of the group have measured the relative motion across Italy of four crustal plates, combining GPS measurements with VLBI using the Medicina, Noto and Matera telescopes. With VLBI the group monitors the wider European and Mediterranean crustal deformation; monitor the tropospheric water vapour, and serves as part of the international geodesic network. This latter application requires accurate local ties, with everything this implies, e.g. accurate knowledge of telescope deformation under gravity. Finally, it participates in geodetic research at Antarctica. The international connections of the group, e.g. in the Intenational VLBI Service are excellent.

To maintain the excellence of geodesy at IRA in the future, several actions are required.

(i) A more stable group size should be established. With two graduate students finishing, the group will be halved.

(ii) Geodesy should be recognised as an integral and individual part of INAF in the statutes of the INAF/IRA, so that the geodesy group can enter into agreements with other geodetic research groups nationally and internationally.

(iii) Integration of the Matera Telescope into the IRA network with the Medicina, Noto and Sardinia telescopes would greatly enhance the geodetic research (Section 4.3).

We suggest that the feasibility and desirability of these three actions, and the integration of the IRA geodesy in other Italian geophysical research, are investigated and discussed in the long-term planning for the future of IRA and of Italian Radio Astronomy (Section 6).

8. TECHNOLOGY DEVELOPMENT

We were impressed by the technological developments that we saw during our visit to Medicina and the technological projects that we heard are being pursued at Firenze and Sardinia. The quality of the technological staff is high and we commend their enthusiasm.

The major ***front-end developments*** are devoted to the Sardinia Radio Telescope (SRT). At present, there is a dual frequency 0.4 GHz and 1.4 GHz system, a 5.7 to 7.7 GHz single beam system for Very Long Baseline Interferometry (VLBI), and a 20 GHz seven beam system for single dish mapping. The seven beam system is being installed on the Medicina radio telescope. Judging by the receivers we saw at Medicina, all of these Front Ends should be internationally competitive. The use of relatively inexpensive cooled high mobility transistor (HEMT) amplifier front ends should be possible up to 100 GHz, the limit of the SRT. We discussed the receivers for the SRT at length in Section 3.2. The technological accomplishments of the IRA receiver development groups are excellent. Their collaborations and participation in international instrumentation projects (e.g. Herschel and BLAST) have obtained high recognition and visibility.

The ***back end developments*** at the IRA are also very impressive. The prototype of the VLBI formatter is an important contribution to maintaining the operation of the European VLBI network at a high level. This project is now completed and digital base-band converters are being made in Noto following an endorsement by the EVN.

The next projects will be the development of continuum back ends and spectrometers for the SRT. The continuum backend development will start with a 2 GHz wide component with the aim to cover 28 GHz, the bandwidth to be expected from HEMTs at the higher frequencies possible with the SRT. We expect that these spectrometers will be competitive internationally, provided that the relevant software is made available in a timely fashion.

9. EDUCATION AND OUTREACH

9.1 Interaction with Universities. Our impression is that both IRA and the OAC are well integrated into their respective neighbouring universities. IRA staff members give courses at Bologna University and have close collaborations with university staff. Most IRA Ph.D students are recruited from the nearby universities. We applaud the action of Bologna University in providing funding for the LOFAR test facility at Medicina.

Although IRA staff members at Firenze appear to be integrated well into the Arcetri Observatory they appear to have limited access to Ph.D students. Cultivation of a closer relationship between IRA and Firenze University could help address this problem.

9.2 Public Outreach. Public outreach is an essential part of any publicly funded scientific endeavour. Outreach is also an important tool that can strengthen national advocacy for astronomy and the visibility of INAF. The presence of internationally front-line radio observatories at Medicina and Sardinia provides a unique opportunity for INAF to profile itself by means of visible outreach activities.

* The staff of IRA is conducting valiant efforts at outreach at Medicina. The Visitor Centre is impressive. We commend IRA for obtaining limited funding to run these from a local bank.

* We were also presented with a presentation of the outreach activities of the OAC. These activities appear to be outstanding and making excellent use of the fact that a large radio telescope is under construction in Sardinia.

We hope that INAF can find the resources to strengthen outreach activities at both institutes.