Science with the Multipurpose Interferometer Array [MIA]

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Resumen / El Instituto Argentino de Radioastronomía está construyendo el prototipo de un arreglo interferométrico de antenas denominado Multipurpose Interferometric Array (MIA), que estará compuesto por elementos de unos 5 m de diámetro de disco y receptores digitales de 1.4 GHz con un ancho de banda final de 1000 MHz. En su configuración media -pero escalable-, MIA incluirá 16 de estos elementos, para alcanzar una resolución angular del arcosegundo. Los objetivos científicos que motivan el desarrollo de MIA se presentan en esta contribución; los mismos abarcan desde estudios de temporización de púlsares, fuentes transitorias, ráfagas rápidas de radio, hasta estudios de líneas y continuo asociados al universo temprano y fuentes no térmicas en general.

Abstract / The Instituto Argentino de Radioastronomía is building the prototype of an interferometric antenna array, called the Multipurpose Interferometric Array (MIA), which will be composed of elements of about 5-m disk diameter and 1.4 GHz digital receivers with a final bandwidth of 1000 MHz. In its medium – but expandable – configuration, MIA will include 16 of such elements, to achieve an angular resolution of an arcsecond. The scientific objectives motivating the development of MIA are presented in this paper, ranging from timing studies of pulsars, transient sources, fast radio bursts, to line and continuum studies related to the early universe and non-thermal sources in general, among others.

Keywords / instrumentation: high angular resolution — pulsars: general — early universe

1. Introduction

At the end of 2023, the future of radio astronomy in Argentina looks promising. There are two deep space stations with a diameter of 35 m, built and operated by the European Space Agency (DS3 in Malargüe, Mendoza, since 2012) and the Chinese Launch and Tracking Central (CLTC-CONAE-NEUQUÉN in Bajada del Agrio, Neuquén, since 2018). Backends have been specially built at IAR for them, to take advantage of the percentage of observing time open to the community, to perform radio science experiments. The China-Argentina Radio Telescope (CART) is expected to be fully assembled in 2024: a 45-m dish that will operate from a few to about 50 GHz. The Large Latin American Millimeter Array (LLAMA) radiometer, with a 12-m dish in the region of La Puna, at almost 5000 m a.s.l., is also expecting to be erected during 2024 and will cover the (50 – 950)-GHz range. The two 30-m radio telescopes at IAR, which were completely refurbished in 2018, are continuously recording data for pulsar and magnetar timing projects. They are single-dish instruments that reach a maximum angular resolution, in the lowest frequency bands (L, S), of several arcminutes.

At low frequencies, radio instruments with medium to high angular resolution are essential to study a plethora of phenomena that occur in sources of very different types, from star forming regions to black holes and cosmology. However, observations at low frequencies can be severely affected by radio frequency interference (RFI). RFI is highly problematic, and its importance has been steadily increasing. This is demonstrated by satellite missions such as the Fast On-Orbit Recording of Transient Events*, which provided the image shown in Fig. 1, taken from Haggerty (2010); see also Light (2020).

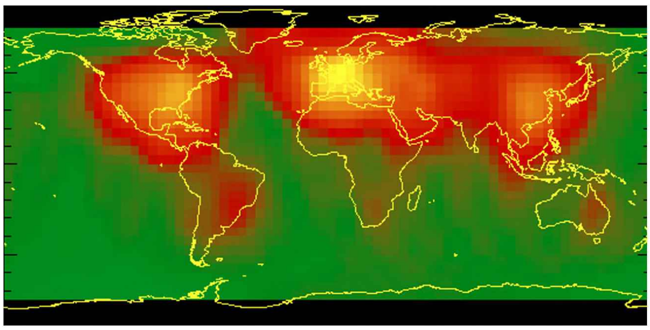

Fig. 1. Background radiation at 131 MHz, as a measure of radio frequency interference (taken from Haggerty, 2010, their Fig. 9). Scale: 0 to 0.016 $\mathrm{mv\,m^{-1}}$. Data were collected from the FORTE spacecraft; Creative Commons Attribution License.

Argentina has large areas of sparsely populated land and, according to Fig. 2, offers one of the most important niches for the location of an instrument operating

**FORTE* spacecraft was designed and built by Los Alamos and Sandia National Labs (P.I. A. R. Jacobson), and operates up to 300 MHz.

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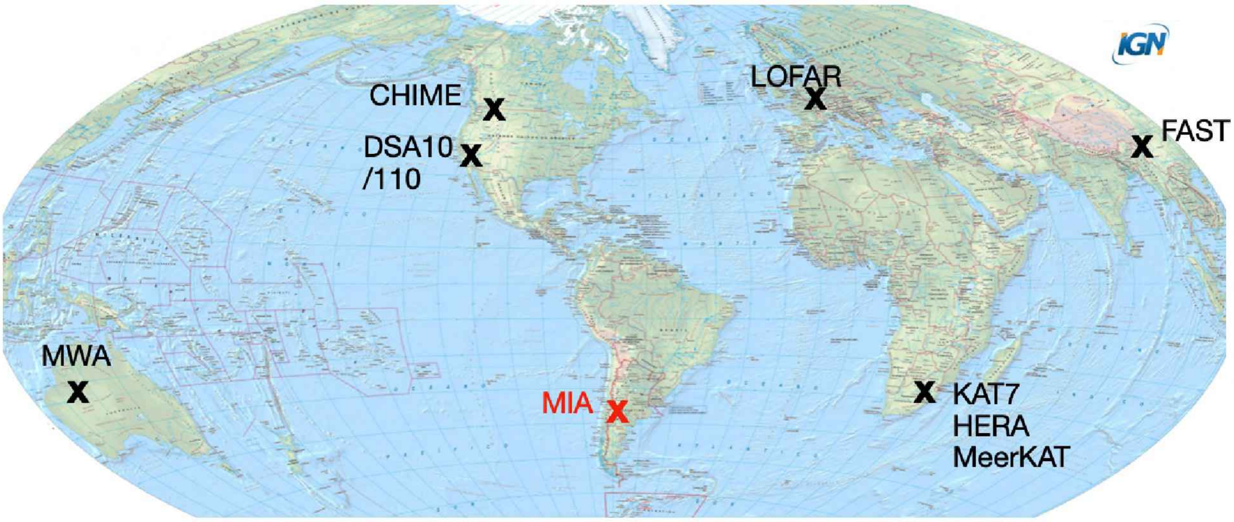

Fig. 2. Geolocalization of instruments with (some) similar characteristics to MIA. CHIME: Canadian Hydrogen Intensity Mapping Experiment; DSA10/110: Deep Synoptic Array 10/110; LOFAR: Low Frequency Array; KAT7: Karoo Array Telescope; HERA: Hydrogen Epoch of Reionization Array; MeerKAT: 'more of' KAT; FAST: Five-hundred meter aperture spherical radio telescope; MWA: Murchinson Widefield Array. Planisphere provided by the Instituto Geográfico Nacional, Ministerio de Defensa, Argentina; `www.ign.gob.ar/images/MapasWeb/PLANISFERIO/PLANISFERIO-2016.jpg`.

with high sensitivity and angular resolution at low frequencies.

2. Technical specifications of MIA

The Multipurpose Interferometer Array is a radio interferometer project consisting of modular ensembles of elements formed by 5-m radio antennas. The receivers will operate between 100 and 2000 MHz with an instantaneous bandwidth of 250 MHz, expandable to 1000 MHz. The development is planned in three steps: (i) the first antenna will be a technology demonstrator (TD) to be completed in early 2024; (ii) a 3-element pathfinder located at the IAR (MIA-P); (iii) a 16-element instrument, MIA-16, with a maximum baseline of 55 km, sensitivity equivalent to a 36-m diameter dish, field of view of 4 degrees, angular resolution down to 1 arcsecond, to be deployed at an interference-free site in western Argentina. This instrument will be upgradeable to MIA-32/64. The astronomical exploration of the universe in the low frequency bands is very challenging because man-made radio noise, which constitutes the bulk of RFI, is a major problem. Therefore, instruments must be placed in very remote locations.

Table 1 lists the basic properties of MIA. A full description can be found in Gancio et al. (2024).

Figure 3 shows the prototype antenna to be replicated, Antenna 0, which is under construction. Given Argentina's geographic longitude range, it will be able to track an event during intervals of the day when it is invisible to other instruments.

Table 1. Main parameters of MIA.

Parameter	Value
Number of antennas Pathfinder / MIA-16	3 / 16
Mounting	azimuthal
Dish diameter	5 m
Minimum baseline	50 m
Maximum baseline	5 km
Maximum angular resolution at L-band	1.5″
Temperature of receivers	50 K
Final bandwidth	1000 MHz

Fig. 3. MIA antenna/element design; Antenna 0. Details of their design are available in Gancio et al. (2024).

3. Science with MIA

The four key areas where MIA can make significant scientific contributions are presented in what follows.

3.1. Transient sources

Because of its ability to process signals in a high-resolution (timing) system analysis mode, MIA will be able to:

- Detect and measure pulses in magnetars;
- Detect the radio counterparts of Gamma Ray Bursts, produced by high-energy events (e.g., hypernovae, radio flares, mergers of compact binary systems);
- Observe giant flares from magnetars;
- Detect Fast Radio Bursts, investigate their origin, monitor repeaters, launch and follow up alerts from similar instruments at other Earth distances (Fig. 4);
- Discover pulsars, study known pulsars, analyze glitches and starquakes, compile data to search for variations in their periods, and contribute to the NANOGrav project and other Pulsar Timing Arrays for gravitational wave detection.

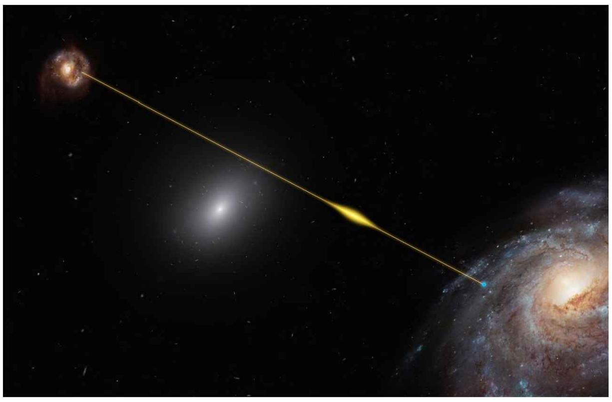

Fig. 4. Artist's impression of the fast radio burst (FRB) 181112, ESO public images, eso.org. Credit: ESO/M. Kornmesser.

3.2. Non-thermal sources

The 2-GHz coverage will make it possible to:

- Search for, observe and study possible radio counterparts of unidentified/unassociated gamma-ray sources, both from recent catalogs and from the thousands of sources expected to be detected by new instruments such as the Cherenkov Telescope Array;
- Study active galactic nuclei and their variability, participate in multi-frequency studies, respond rapidly to alerts of changing intensity phenomena (e.g., the radio galaxy Cygnus A as imaged by Perley et al., 1984, in their Fig. 1)**;
- Perform time-resolved radio-spectral studies of compact binary systems such as X-ray binaries;
- Study the morphology and spectral distribution of supernova remnants;
- Map extended non-thermal continuum sources;
- Search for Pevatron counterparts.

**see also https://www.nrao.edu/archives/items/show/33385

3.3. Neutral hydrogen

MIA will cover the range of the 21-cm line, for close sources and up to high redshifts; this will allow:

- Study the HI at cosmological distances, contributing to efforts to characterize the epoch of reionization;
- Study nearby or extended galaxies (e.g., Fig. 5);
- Conduct investigations of the interstellar medium at high angular resolution.

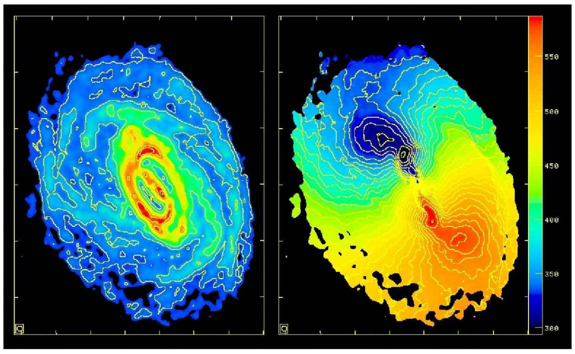

Fig. 5. HI distribution (*left panel*) and velocity field (*right panel*) of the radio galaxy Circinus. ATCA HI image by B. Koribalski (ATNF, CSIRO), K. Jones, M. Elmouttie (University of Queensland) and R. Haynes (ATNF, CSIRO), www.narrabri.atnf.csiro.au/public/images/circ/; see also Koribalski et al. (2018).

3.4. Astrophysical plasmas

The expected high range, spectral resolutions and sensitivity, together with the nearly 2-GHz coverage, will make it possible to:

- Contribute to the characterization of the physics and kinematics of HI regions (e.g., Figure 6);
- Study the variability of OH masers in star-forming regions and in evolved massive stars;
- Study of star-forming regions in general;
- Study the emission from Jupiter and the Sun.

4. MIA prospects

Building an instrument like MIA is a great challenge for the IAR and for Argentina. It will be the first radio interferometer completely designed, tested and integrated in the country. Its technology is cutting-edge and has only recently been mastered by IAR engineers, thanks to the upgrades of the two main radio telescopes in use at the Institute and the ongoing collaboration with several international partners. In particular, work on the new ultra-high-bandwidth digital cards for the Next Generation Event Horizon Telescope and collaboration with

Fig. 6. Lagoon nebula, VLT Survey Telescope. Credit: ESO/VPHAS+ team.

the CASPER developers have allowed our experts to gain insight into new technologies.

The biggest challenge, however, is obtaining the necessary funding for such a project. In the first stages of the design and construction of the first engineering model, we made use of an institutional grant (Proyecto de investigación de Unidad Ejecutora or PUE) from CONICET, and funds from our technology transfer and services activities. We are now applying for new grants from international agencies to complete the Pathfinder.

For the final instrument, MIA-16/32/64, we will need an international partner. We know that this type of instrument is an excellent opportunity for several of our frequent international associates. In the next few years, the final design of MIA will give way to the construction of the actual instrument, ushering in a new era of IAR and radio astronomy from South America.

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