RADIO ASTRONOMY HIGHLIGHTS IN 2016

Major advances in radio surveys, which are playing an increasingly important role in radio astronomy, have characterized the year 2016. They represent a powerful tool to detect large number of objects over a wide range of redshifts and obtain information on the intensity, polarization and distribution properties of radio sources across the sky. These studies are generally focused on synergies allowed by multi-frequency and multi-resolution observations, and therefore provide innovative knowledge, which paves the way to SKA science.
In addition, several results have been obtained in science, in particular from ALMA, and significant improvements in instrumentation and techniques have been reached. An essential list includes:

1-RADIO SURVEYS

- **ALMA** survey of Hubble Ultra Deep Field: a blind three-dimensional search of cold gas and dust in the early Universe revealed a previously unknown abundance of star-forming gas.

- **GLEAM**: Galactic and Extragalactic All-sky MWA survey has been completed. The extragalactic catalogue, in the first year of observations, covers 24,831 square degrees, and contains 307,455 radio sources above 50 mJy, in the frequency range 72--231MHz, and a resolution of ≈ 2'.

- **The GMRT** 150 MHz all-sky radio survey was published in the TGSS ADR1. This is a survey of the full sky north of -53deg, at 25" resolution. The survey has identified about 1/2 million radio sources.

- **LoTSS**: LOFAR Two-meter Sky Survey is a deep 120-168 MHz imaging survey. Preliminary images have been released, providing 44,000 sources at resolution of 25arcsec, typical noise levels of less than 0.5 mJy/beam, on an area of about 350 square degrees. The final survey will observe 3170 pointings for 8 hrs each, producing ~5arcsec resolution images with a sensitivity of ~0.1mJy/beam.

- **VLASS**: the Sky Survey for the enhanced VLA in the 2-4 GHz band, has started observations. This Pilot Survey has been defined to cover ~2400 square degrees, and 200 hours has been allocated.

2-SCIENCE

- **Fast Radio Bursts**: Important developments have been reached to help solving the mystery of fast radio bursts. For the first time, the fast bright radio burst FRB 121102 has been identified as a repeating event, demonstrating that its source survives the energetic events that cause the bursts. Owing to interferometric observations with classical radio telescopes and VLBI, the source of radio bursts has been finally pinpointed as a distant dwarf galaxy.

- **Black holes and AGN**: The detection of gravitational waves demonstrated the existence of binary black holes and suggested that these are more abundant than some previous

estimates. Studies of the innermost black holes and AGN regions, with both classical interferometers and the VLBI networks, have provided new information on processes governing the black hole feed and interactions, and the jet formation. Image the base of the jet at the core of the galaxy Cygnus A at very high resolution (GMVA) and of M87 at 10 Schwarzschild resolution showed new details on the jet base properties. Moreover, from the orbital motion of cold molecular gas detected with ALMA, high precision measurements of black hole masses have been obtained.

- **Gas in stars and galaxies**: A three-dimensional map has been created from ALMA data, showing the star-forming gas as it evolves over cosmic time, from the present to about two billion years after the Big Bang. Galaxies that are rich in carbon monoxide (CO), a tracer molecule that identifies regions rich in molecular gas and primed for star formation, have been detected in the HUDF. These galaxies represent a substantial contribution to the star-formation history of the universe. ALMA studies also revealed that low mass stars could harbor big reservoir of CO. This has important implications on planet formation.

- **Distant Universe**: The detection of most distant Oxygen at z = 7.2, i.e. only 700 million years after the Big Bang, has been reported. This has important implications to understand how galaxies were formed and what caused the cosmic reionization.

- **HI**: We had the highest z detection (z=0.376) of HI emission in the early data of the CHILES deep HI VLA project on the Cosmos Field

- **Asteroids**: The number of discovered near-Earth asteroids (NEAs) has reached 15,000 in 2016, with an average of 30 new discoveries each week. This milestone marks a 50 percent increase in the number of known NEAs since 2013, when discoveries reached 10,000 in August of that year. The results are both scientifically valuable providing information on asteroid characteristics, and important in helping to constrain impact probabilities.

3 - INSTRUMENTATION

- **ALMA Band 5**: First light has been detected from the new receivers installed at the ALMA antennas in Band 5, i.e. covering wavelengths from 1.4 to 1.8 millimeters, a range previously untapped by ALMA. This upgrade allows astronomers to detect faint signals of water in the nearby Universe.

- **ALMA-mmVLBI**: The call for 1-mm Very Long Baseline Interferometry (VLBI) proposals to use phased ALMA at Band 6 in Cycle 4, have been released in collaboration with the Event Horizon Telescope Consortium (EHTC). The EHTC comprises the Submillimeter Array, the James Clerk Maxwell Telescope, the Submillimeter Telescope, the Atacama Pathfinder Experiment, the South Pole Telescope, the Large Millimeter Telescope Alfonso Serrano, the IRAM 30m telescope, and an antenna from the Northern Extended Millimeter Array.

- **ALMA polarimetry**: unprecedented capability for polarimetry in millimeter/submillimeter wavebands has been probed by observation of 3C 286. Data reveal details not seen before and clearly show that the magnetic field is stronger and more ordered towards the inner region of the jet that emerges from the quasar. ALMA

polarization studies will have many applications in many fields (e.g. giant molecular clouds in nearby galaxies, radio galaxies, circum-nuclear disks of AGN).

- **FAST**: First light was detected from the world's largest single-aperture radio telescope, Five-hundred-meter Aperture Spherical radio Telescope, with a structure of 4450 reflector panels. The radio telescope has now started test operations.

- **HERA**: The Hydrogen Epoch of Reionization Array is a staged experiment to measure 21 cm emission from the primordial intergalactic medium (IGM) throughout cosmic reionization ($z=6-12$), and to explore earlier epochs of our Cosmic Dawn ($z\sim30$). The full HERA instrument will be a 350-element interferometer in South Africa consisting of 14-m parabolic dishes observing from 50 to 250 MHz. Currently, 19 dishes have been deployed on site and the next 18 are under construction.

- **LWA**: The Long Wavelength Array is a multipurpose radio telescope operating in the frequency range 10 –88 MHz, with stations at the VLA site, at Sedilla and Owens Valley, which has observed with individual stations and is preparing for interferometric observations.

- **MeerKAT**: First light radio image of MeerKAT array in South Africa has revealed the existence of many distant radio galaxies and detected about 1,300 galaxies in a region of sky where only 70 had been previously observed. In this way, MeerKAT has shown the potential of observing much deeper into space than ever before.

- **PAF:** Pilot continuum survey is ongoing in many places with Wide-field broad-band radio imaging with phased array feeds (PAF), to demonstrate the viability and potential of using PAFs to rapidly and accurately survey the sky at radio wavelengths. ASKAP is indeed in commissioning and early science phase with surveys expected to start in 2018. Similarly, the hardware of Apertif on the WSRT (PAFs on 12 telescope, forming 37 beams on the sky increasing the FoV 30 fold and survey speed 20 fold) is operational and commissioning has started.

- **Space VLBI**: the VLBI satellite RadioAstron continued to obtain high-resolution images at tens microarcsec resolution of AGN, as BL Lac and 3C273, and H2O Masers.

4 - TECHNIQUES

- **Gravitation Waves**: After the first detection of gravitational waves (GW) from merging black holes with tens of solar masses, radio telescopes all over the world are collaborating with LIGO/VIRGO in an effort to promptly react to any alert, and evaluate strategies to plan adequate observations. Moreover, Radio Pulsar Timing Arrays over the world continue to make progress toward detecting nHz GWs, complementing the work by LIGO and Virgo.

- **Big Data**: Development of high-level architectures that reduce power consumption for cross-correlation of data from large interferometer arrays by one to two orders of magnitude, algorithms (machine learning) for real-time detection and classification of fast transient signals in high volume data streams, tools for data archiving, mining, and distribution and visualization.

- **RFI** : Management of radio-frequency interferences (RFI), both internally and externally generated, to deal in particular with low frequency data. The RFI environment of modern radio telescopes has been characterized and machine-learning techniques have been explored for the interference mitigation.