12 New Technologies for Radio Astronomy

K. Y. Lo and Alan H. Bridle

CONTENTS

INTRODUCTION

In this 400th year since the invention of the optical telescope, and in celebration of the *New Vision 400* conference held in Beijing in 2008,* we discuss how new radio astronomical techniques have led to important discoveries in astronomy. We then describe how further technical developments are leading to new facilities such as the Atacama Large Millimeter/submillimeter Array (ALMA), the largest ground-based astronomical facility now under construction, and to the next-generation radio astronomy facilities, collectively named the Square Kilometre Array (SKA), or the SKA Program.

The advent of new technologies in radio astronomy, ironically, has little to do with the invention of the optical telescope 400 years ago. Developed from techniques of radio broadcasting and communication, and especially propelled by the rapid advancement of radar techniques during World War II, radio astronomy opened up the first electromagnetic window into the Universe beyond the visible wavelengths and transformed a view of the Universe that had previously been based entirely on optical studies of stars and nebulae. The most fundamental discoveries made by radio astronomers involve phenomena not observable in visible light, and four Nobel Prizes in Physics have been awarded for discoveries enabled by radio astronomy techniques.

DISCOVERIES ENABLED BY RADIO ASTRONOMY TECHNIQUES

The advent of new techniques leading to new discoveries in the Universe is a pervading theme in astronomy. The transformation of our understanding of the Universe due to radio astronomy is rather

* See: http://nv400.uchicago.edu/.

profound. Table 12.1 gives a list of major new astronomical phenomena discovered as a result of new radio astronomy techniques, as well as the resulting new understanding of the Universe.

Radio astronomy from the ground covers a very wide wavelength range: $\lambda \sim 30$ m to ~300 μm, corresponding to a frequency range of ν ~10 MHz to ~1 THz. In radio astronomy, the techniques of reception and detection of the electromagnetic wave are different from those at optical wavelengths. Whereas geometric optics governs the design of optical telescopes, electromagnetic wave theory governs the design of radio telescopes, taking account of the wavelength explicitly because it is no longer negligible compared with the dimensions of the telescope. The detection of radio waves is based on heterodyne detection (or coherent detection) of the electric field $\boldsymbol{E}$, whereas the detection of visible light is via incoherent detection of E^2, the intensity of the electric field—i.e., photon counting. Heterodyne detection of the radio wave involves the use of a nonlinear detector that produces a beat signal between the radio signal and a local oscillator (reference) signal. In a domestic radio receiver, the beat signal is the sound waves we hear. Because the wavelength of radio waves is some millions of times greater than that of light, the diffraction limit of a single-dish radio telescope, λ/D, is typically in the range of degrees to arcminutes, whereas the angular resolution of ground-based optical telescopes without adaptive optics is limited by atmospheric fluctuations to about 0.5 arcsec.

By the 1920s, radio communication techniques were developed to the extent that there were commercial radio broadcasting, a worldwide network of commercial and government radiotelegraphic stations, and extensive use of radiotelegraphy by ships for both commercial purposes and passenger messages. In 1932, Karl Jansky at Bell Laboratories was assigned to investigate the sources of radio

TABLE 12.1

New Astronomical Phenomena Discovered via Radio Astronomy Techniques

Discovery	Impact	Year	Ref.
Milky Way radio noise	Cosmic radio emission exists	1933	1
Solar radio noise	Radio emissions of normal star	1945	2
21 cm line of atomic hydrogen	Interstellar medium important component of galaxies	1951	3
Double nature of radio galaxies	Need for large-scale energy transport from AGNs	1953	4
Cosmic microwave background (CMB)	Remnant heat of Big Bang	1965	5
Pulsars	Neutron stars exist	1968	6
Polyatomic interstellar molecules	Astrochemistry, precursors of life in space	1968	7
Molecular clouds	Birthplaces of stars and planets	1971	8
Superluminal motion in AGNs	Relativistic potential wells in Galactic nuclei	1971	9
Galactic center source Sgr A*	Subparsec-scale structure at center of Milky Way	1974	10
Flat H I rotation curve of M31	Dark matter halos of galaxies	1975	11
Binary pulsar	Gravitational radiation	1975	12
Anisotropy of CMB	Origins of cosmological structure	1989	13
Pulsar companions	Exoplanets	1992	14

References: (1) Jansky (1933); (2) Southworth (1945); Appleton (1945); (3) Ewen and Purcell (1951); (4) Jennison and Das Gupta (1953); (5) Penzias and Wilson (1965); (6) Hewish et al. (1968); (7) Cheung et al. (1968); (8) Buhl (1971); (9) Cohen et al. (1971); (10) Balick and Brown (1974); (11) Roberts and Whitehurst (1975); (12) Hulse and Taylor (1975); (13) Smoot et al. (1992); (14) Wolszczan and Frail (1992).