31. FAR-INFRARED AND SUB-MILLIMETER ASTRONOMY IN ANTARCTICA

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ABSTRACT

The wavelength range from 5 to 500 μm is one of the most technologically difficult for astronomers. For this reason, and also because of poor atmospheric transmission, the region has until recently been underexploited relative to, say, the radio and optical regions. To avoid the poor transmission and high emissivity of the atmosphere, astronomers have frequently resorted to balloons, stratospheric aircraft or even satellites to carry out the observations. The high altitude, extremely low temperatures and low humidity of the Antarctic plateau combine to make it potentially the best site on earth for far-infrared and sub-mm astronomy. Indeed, at some wavelengths, it is the only place on earth from which ground-based astronomy is possible. This research note reviews the current status of Antarctic astronomy in the far-infrared and sub-mm, and suggests potential areas for Australian involvement.

31.1 SCIENCE IN THE FAR-IR AND SUB-MM

31.1.1 Continuum Studies

The main atmospheric windows in this region are 30, 60, 150, 350 and 1300 μm, almost all of which are good enough for observations from Antarctica. By making broad-band observations at these wavelengths many important issues can be addressed. These include:

(a) Determination of dust masses in galaxies and star formation regions and estimation of A_v
(b) Polarimetry studies of dense clouds to determine magnetic field direction
(c) Determination of the far-infrared wavelength dependence of interstellar extinction
(d) Studies of primordial starlight reprocessed by galactic dust
(e) Cosmic background radiation studies
(f) Mass loss from highly evolved AGB stars

31.1.2 Spectral Line Studies

Astrophysically important spectral lines at these wavelengths, which lie in regions where the atmosphere is transparent, arise from:

(a) Atomic and ionic fine structure (e.g. [CI], [CII])
(b) Metal hydrides (e.g. MgH, SH^+, HCl)
(c) Carbon monoxide (J = 1–0, 2–1, 3–2, 4–3, 7–6 .... higher level isotope lines)
(d) Molecular hydrogen
(e) HD
(f) Complex molecules (in the sub-mm)
(g) High density tracers (CS, HCO^+ and HCN)

By making use of these lines to provide density, temperature and dynamical information through their strengths, widths and velocities, important advances can thus be expected in studies of:

(a) Cooling of primordial collapsing clouds
(b) Cooling of early galaxies
(c) Star formation
(d) Structure and composition of the interstellar medium
(e) Planetary formation

In addition, important measurements of stratospheric ozone and other components of earth's atmosphere can be carried out.

31.2 FAR-IR AND SUB-MM TECHNOLOGY

It is in this wavelength region that the techniques of optical astronomy and those of radioastronomy meet. Depending on the application and on the current state of technology, either direct (optical) detection or heterodyne (radio) detection may give the best performance. Figure 1 (Harris 1990) shows diagrammatically the different techniques in use. This is an area of research currently undergoing a revolution in overseas laboratories. The performance of both direct and heterodyne systems has improved by over an order of magnitude in recent years and the way is clear for further major advances.

In Australia, there has so far been only a relatively small effort in developing far-IR and sub-mm instrumentation (or Terahertz Technology, as it is sometime known). An important side benefit of an active Australian Antarctic astronomy program would be the stimulation of THz research both in industry and academia. This could greatly improve Australia's capabilities in an important and rapidly developing area.

31.3 WHY ANTARCTICA?

The best infrared observatories in the world are on high, dry mountain top sites, where the low water vapour content improves the atmospheric transparency and the low temperature reduces the infrared thermal background radiation from both atmosphere and telescope. On the Antarctic plateau these gains are multiplied still further. In addition, in the mid-IR to mm regime, the very low water vapour density over the Antarctic plateau considerably improves the atmospheric transparency even opening some new 'windows' which are opaque at other observing sites.

On Mauna Kea, Hawaii, the best ground based site now in use, the atmospheric water vapour content is as low as 1 mm of precipitable (ppt) H_20 only about once a week on average. Even then, the atmospheric transmission in the 350 μm window is only about 30% and highly variable making calibration impossible. Measurements at the South Pole indicate an average of 0.2 to 0.5 mm of ppt H_20, with the best values below 0.1 mm (Bally 1989). At a site above 4000 m elevation, on the highest part of the Antarctic plateau, we expect this to fall as low as 0.05 mm of ppt H_20. We can therefore expect to make observations in the 350 μm window nearly all the time (Townes and Melnick 1990).

In addition to conditions peculiar to the IR and sub-mm, an Antarctic plateau site offers other advantages over a mid-latitude site:

1. The possibility of continuous monitoring of sources for long periods, as a source will never set. Observations will be possible in both the Antarctic day and night for all but the short end of the IR and optical spectrum.

2. Certain sources, such as the Magellanic Clouds, are poorly placed in the sky during southern winter at mid-latitude sites but will be high in the sky from Antarctica.

3. Significant cost advantages compared to space-based missions, which provide the only alternative for many possible observations, as well as relative ease of serviceability and maintenance.

The prestige of strong Australian participation in a genuinely international scientific research facility sited in the region claimed as Australian Antarctic Territory should make Antarctic astronomy attractive politically. Looking to the next century, an international Antarctic base will be an ideal precursor to an international space or moon-based observatory, politically, scientifically and logistically.

31.4 INTERNATIONAL PLANS IN IR AND SUB-MM

A number of countries have demonstrated interest in Antarctic astronomy, including Argentina, Germany, France, India, Italy, Japan, Russia, the UK and the USA, as well as Australia. Several of these have undertaken exploratory experiments. The most developed plans come from the Center for Astrophysical Research in Antarctica (CARA) in the USA, which has been funded and has initial plans for three telescopes at the South Pole.

1. The Antarctic Submillimeter Telescope and Remote Observatory (ASTRO); a 1.7 m diameter sub-mm telescope scheduled for permanent installation in late 1993.

2. The Cosmic Background Radiation Anisotropy (COBRA) project; a microwave radiation detector to survey for anisotropies in the cosmic microwave background on angular scales from 15 arcmin to 20°.

3. The South Pole Infrared Explorer (SPIREX); a 60 cm transportable telescope with a near infrared array camera and spectrometer, designed to exploit the minimum of zodiacal emission in the 2.27 – 2.45 μm window.

Beyond these, there are proto-designs for a major observatory, with a 3 m class optical-IR telescope, a 10 m sub-mm dish, a 30 m mm dish, an 8 m class optical telescope and an interferometric array of sub-mm and optical telescopes.

ASTRO is by far the most developed project to date (Stark 1989). ASTRO has a 1.7 m diameter carbon-fibre dish with a surface accuracy of 8 μm rms. All optics are off-axis, leading to high beam efficiency and low sidelobe levels. Beam-switching can be performed without changing the illumination of the primary mirror, thus minimising signal offsets. The principle targets for study will be [CI] at 609 μm and the J = 4→3 transition of CO at 650 μm.

It is clear that the best way for Australia to commence an Antarctic astronomy program is via international collaborations. At present the most likely partners are the USA (through CARA), France and the British Antarctic Survey. Links with the former Soviet Union, who operate a station at Vostok, have been established and Russian astronomers are keen to collaborate. Vostok, at 3500 m altitude, has the best climate of all the existing stations and the Russians have developed overland transport techniques that would be invaluable in establishing any high altitude observatory.

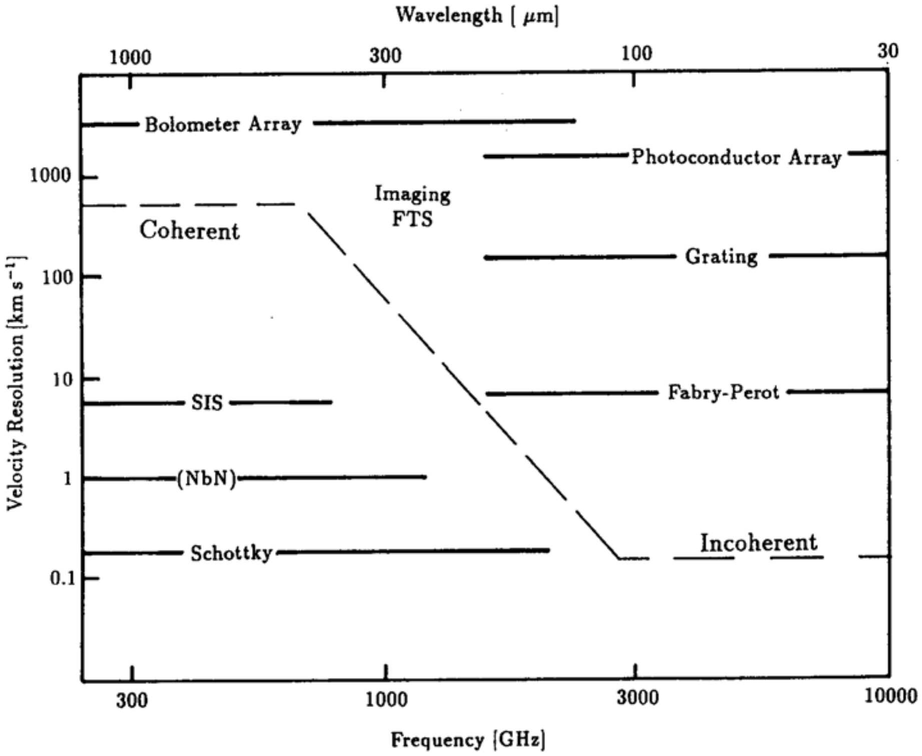

Figure 1. Representative overview of appropriate detection techniques as a function of frequency and velocity resolution. The heterodyne receivers are not ranked by resolution, but by total frequency coverage. 'SIS' refers to common Pb and Nb junctions; NbN refers to the developing niobium nitride technology.

31.5 CONCLUSION

It is also clear that simply 'buying into' a share of a facility operated by one of these nations would bring only minimal benefit to Australia. We therefore seek to establish ourselves as an active and technologically equal partner by developing instrumentation for site testing and other research now urgently required. The operation of such a program, particularly if receiving logistical support through the Australian Antarctic Division, would considerably enhance Australia's scientific prestige.

The CARA group are well funded and some of their members have been actively pursuing Antarctic astronomy for several years. If we are not to be left completely behind in what, we believe, is one of the most important current developments in astronomy, we must move quickly along an optimum development path. We should:

1. Establish strong international links, especially with CARA, France and the Vostok operation. (This has already begun, with assistance from DITAC.)

2. Begin collaborative site-testing and survey observations from the Antarctic plateau. This would be done with the logistical support of our international partners and perhaps also with the assistance of the Antarctic Division. The science generated here will not be spectacular, but it is an essential step.

3. Join in the development of a major international observatory to be built on the Australian Antarctic Territory. Given the important advances likely to be made in the far-IR and sub-mm, such an observatory may well include a large sub-mm dish or an array of medium-size telescopes.

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