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SUB-MM SCIENCE WITH THE HEINRICH HERTZ TELESCOPE

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Abstract. A short account of the present state of the Heinrich Hertz Telescope is given. A summary of measurements carried out at wavelengths of 0.6 mm and 0.35 mm is presented.

1. Introduction

In the sub-mm range, radio astronomers have imaged only a small number of regions in the necessary detail, which requires accurate pointing, calibration, high resolution and signal-to-noise ratios. Many high quality images with single telescopes are needed to understand the overall physical conditions before high resolution imaging of these sources with ALMA can be undertaken.

2. The Heinrich Hertz Telescope

The Heinrich Hertz Telescope (HHT) is a 10-m diameter sub-mm telescope located on Mt. Graham at an elevation of 3.2 km. The HHT is operated by the Sub-millimeter Telescope Observatory (SMTO) on behalf of Steward Observatory and the Max-Planck-Institut für Radioastronomie (see, e. g., Baars et al. 1999). The surface of the HHT has been adjusted on the basis of results from a series of Holography measurements, using a receiver and software lent by NRAO. The dynamic range of the receiver was considerably improved. During the latest Holography experiment, in Sept. 1998, the last 5 days were used to determine the RMS error from the scatter in the data, without adjusting the surface. The scatter was 12 μm; this was taken as the RMS of the surface. The best independent check of the Holography data are measurements of efficiencies from data taken for the planets and Moon. In Fig. 1 we show the main beam efficiencies in the lower curve. The behavior does not follow the simple Ruze relation (see, e. g. Rohlfs & Wilson 1999). Where given, the errors are the

RMS scatter about the measured value. All data were taken with heterodyne receivers. The efficiency at 0.35 mm is somewhat below the value expected on the basis of the surface accuracy. This may be caused by assumptions about planet temperatures, the receiver optics, or errors in the corrections for atmospheric absorption. The efficiency at 0.87 mm is anomalously small; this must be due to losses in the 0.87 mm receiver itself, which has complex optics.

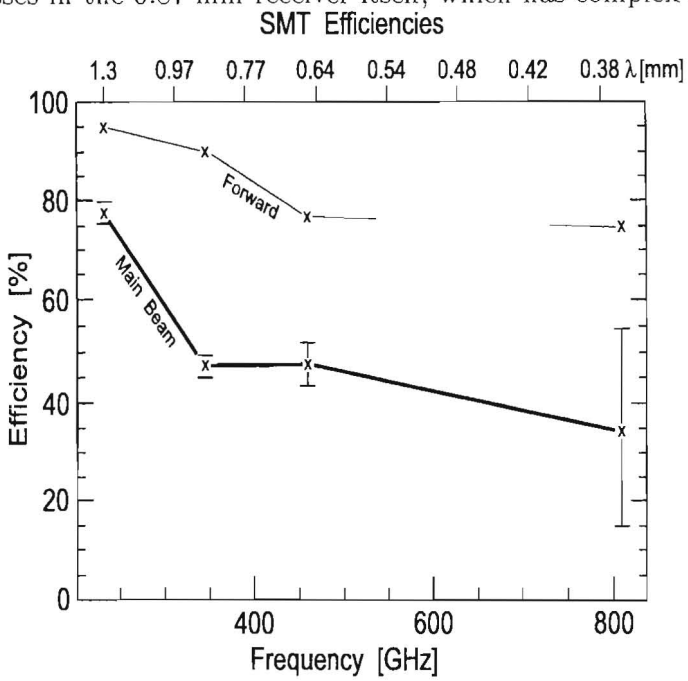

Fig. 1. The forward (thin) and main beam efficiencies (thick) of the HHT as a function of frequency (below). The main beam efficiencies are based on Saturn and Mars data. The forward efficiencies are based on Moon data. The error bars represent the RMS scatter about the mean values.

The ultimate limit to the effective use of single telescopes is pointing (see, e.g., Rohlfs & Wilson 1999). We have used one 24-hour period every month to take data for the pointing model. By May 1998, we succeeded in reaching a pointing RMS error of 2.5″. In order to reach a 1″ RMS error, we have started measurements with an optical telescope mounted behind the subreflector. This allows us to survey many hundreds of stars in a few hours, in contrast to the ~50 sources which we could use for radio pointing. Gradually, we plan to shift to a combination of radio and optical measurements.

3. Receivers

The facility heterodyne receivers are mounted in the left-hand Nasmyth focus cabin. These are (1) a 1.3 mm SIS mixer single- channel single-pixel facility system from Steward Observatory, (2) a 0.87 mm two-channel single-pixel facility receiver from MPIfR, and (3) a 0.6 mm single-channel single-pixel SIS mixer re-

ceiver from Steward Observatory. The facility spectrometers consist of Acoustic Optical Spectrometers (AOS) from MPIfR and filter banks from the U. of Texas. There are two AOS's with total bandwidths of 1 GHz (1 MHz resolution) and a single AOS with a 250 MHz total bandwidth (385 kHz resolution). The filter banks have bandwidths of 128 MHz (1 MHz resolution), 62.5 MHz (250 kHz resolution), and 8 MHz (62.5 kHz resolution). In the right-hand focus, there is a single-channel 4-color Bolometer for broadband continuum measurements and the superconducting Hot Electron Bolometer (HEB) heterodyne receiver from the Harvard-Smithsonian Center for Astrophysics (Kawamura et al. 1999a). In 1998, this receiver operated between 0.5 mm and 0.35 mm. The tests which were made in March 1998 resulted in the first successful astronomical measurements with this type of receiver. To date, this is the only superconducting HEB system which has been used to obtain astronomical data. The facility receivers are in hybrid dewars, while the HEB is in a wet dewar. In the 1998/99 season, the HEB was optimized for 0.35 mm operation, and use of the HEB has allowed the imaging of a number of sources in the CO J=7-6 line, and the $^3P_2$-$^3P_1$ line of CI. At 0.35 mm the HHT has an angular resolution of 13″, comparable to interferometers operating at 3 mm.

4. Weather

Weather is an important factor in sub-millimeter astronomy. Following standard practice, we use an uncooled mixer receiver system, centered on the 1.3 mm window (225 GHz), to monitor the optical depth, $\tau(225)$, of the atmosphere every half hour. As far as statistics are concerned, El Niño had a negative influence on observing in the southwest U.S. in early 1998, while Hawaii profited. After El Niño, from April 1998 to April 1999, the HHT weather statistics, where available, are very comparable to the CSO weather statistics for Mauna Kea. Starting in January 1999, a **priority observing scheme** was introduced: Whenever $\tau(225)$ reached a value of 0.06 or less, the normal observing program (at 1.3 mm or 0.87 mm) was replaced by a priority proposal, which could be carried out only in the best weather. When $\tau(225)$ increases to >0.075 the normal observing program is restarted. If the HEB has been cooled, changes between normal and priority programs require <20 minutes. So far, the priority observing system has functioned well and will be continued. The observational results obtained in 1999 demonstrate the effectiveness of the HHT for sub-mm observations.

5. Science done with the HHT

In the following, we list a few of the projects carried out with the HHT. If observers are not noted, these are among the authors of this paper. A number of warm galactic clouds were mapped in the $J = 7 - 6$ line of CO with this receiver. Since the $J = 7$ level is 156 Kelvins above the ground state, these CO data provide unique high resolution information about warm molecular clouds. Typical is the image of the outflow source IRAS 20126+4104 (Kawamura et al. 1999b)

The most well known galactic outflow source is in the Orion KL region. The map of this region in the $J = 7 - 6$ line of CO was made using the 'On-the-Fly'

mapping technique. There are three prominent features in this map: The CO outflow, the weaker outflow Orion S, and the Orion Bar, at the interface of the HII region. A similar map, with slightly lower angular resolution, but with much higher sensitivity, was made in the $J = 4 - 3$ line of CO.

In addition to Orion, maps in the $J = 7 - 6$ line of CO have been made of other regions of active star formation, such as Cepheus B, S 106 and ON 1. The most extensive map is that of the Cepheus B region, which contains a compact H II region and a small NIR cluster. The Cepheus B image is near an O-B association and the HII region S 155. The ON 1 region contains a number of interstellar masers. ON-1 is a warm molecular cloud mapped by Bieging (Steward Observatory), Churchwell (Wisconsin) & Pankonin (NSF). There is a nearby ultra compact HII region; this is an indication that the evolution of ON-1 is more advanced than that of Cepheus B.

Two fine structure lines of neutral carbon, C I, can also be observed in the submm wavelength region. The $^3P_1$–$^3P_0$ and $^3P_2$-$^3P_1$ lines of C I have been imaged in W3 east and west. W3 is a galactic molecular cloud/HII region complex. The eastern part of W3 contains compact HII regions, ultra-compact HII regions, outflow sources and masers, whereas the western part contains cooler clouds with compact sub-mm continuum sources, but no outflow sources or masers. Thus, this source has both early and later phases of star formation.

In addition to molecular clouds, there have been a number of studies of the molecular circumstellar envelopes (CSE's) of late type stars. Bieging and Gensheimer have detected the $J = 7-6$ line of CO in 10 CSE's. When combined with data for lower J transitions of CO, one can estimate the local H_2 density.

Fairly large images of the galaxies Messier 82, IC 342 and Maffei 2 have been made by Henkel et al. (1999) in the $J = 7 - 6$ and/or $J = 4 - 3$ lines of CO. These results confirm the presence of $J = 4 - 3$ CO line emission outside the nuclei of these galaxies. The presence of warm gas in the center of M82 has been known for some time. However, the extent of warm gas has not been determined previously. A quantitative analysis of the M82 CO data shows that the best agreement requires Photon Dominated Regions (PDR).

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