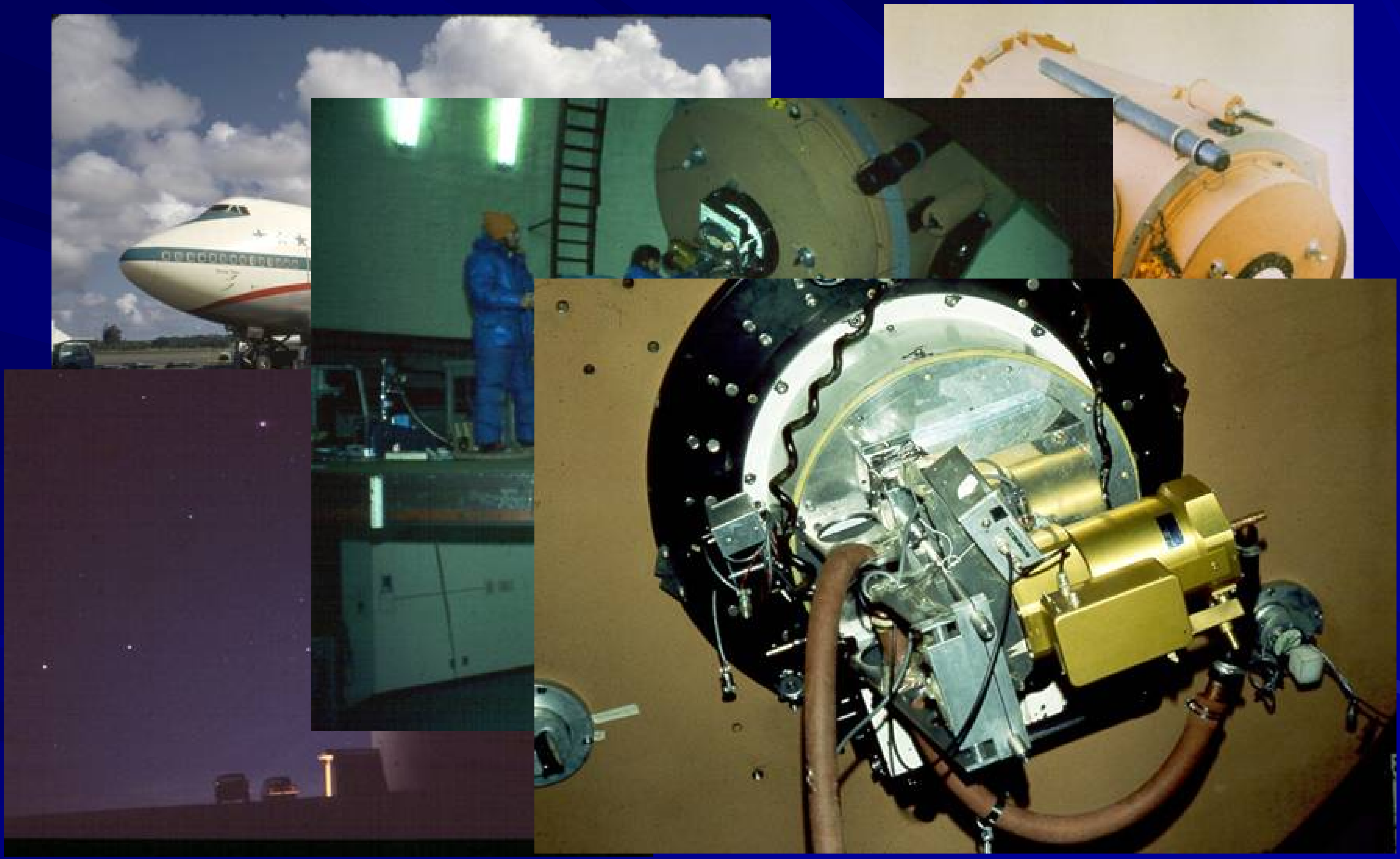
# Continuum

# Submillimetre Astronomy from UKIRT

Ian Robson

UK ATC

# Submillimetre means high - how high can we get ? let's go to Hawaii ! (1975, 76)




ELEVATION – 11,000 FT.
DANGER:
SUDDEN STORMS, HIGH WINDS, FOG.
RAIN, HAIL, SNOW, FREEZING
TEMPERATURE, ALTITUDE SICKNESS


SAVE WATER !!
DO NOT FLUSH
TOILET
SOFT-WEVE

Astron. Astrophys. 59, 209—213 (1977)

ASTRONOMY AND ASTROPHYSICS

# Submillimetre Lunar Emission

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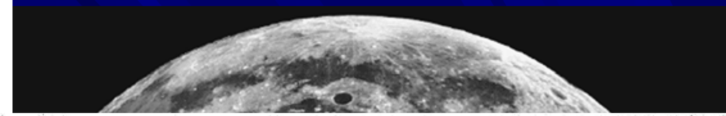
Received October 4, 1976; revised February 23, 1977

**Summary.** We present a map of lunar thermal emission obtained through the 350 μm atmospheric window. A brief description of the photometer and data collection is given. Previous observational work concerning lunar roughness is discussed. Several empirical expressions are fitted to measurements made from the contour map, the expressions providing the best fit involving a term dependent on the earth's zenith angle at the point under observation. A theoretical map is also compared with the observational data and found to disagree markedly due to the absence of any roughness considerations.

**Key words:** submillimetre astronomy — thermal mapping

where $z$ is the zenith angle of the source and $\alpha$ the atmospheric transmission coefficient which, for the spectral region in question, is dependent on the water vapour content of the atmosphere. In the analysis and construction of this map it is assumed that the percentage change in $e^{-\alpha \sec z}$ during the time of observation is negligible. Measurements of dew-point carried out at the telescope site indicate that it is unlikely that $\alpha$ was greater than 1.0 and therefore, if $\alpha$ is assumed constant, the limits on percentage transmission change due to changes in $z$ are 12% total and 4% for the four central scans relevant to selenographic equator measurements.

At the time of observation no absolute calibration of flux against lunar temperature was possible and so the





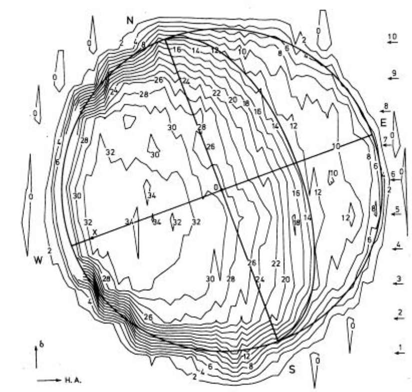



**Fig. 1.** Observed contour map. Data were obtained between 1240 and 1400 G.M.T. on 2nd March, 1975. The individual scans are marked by numbered arrows. The lunar disc was 75% illuminated (age 19.4 days), the sub-solar point and disc centre being marked by $x$ and $o$ respectively. The lines EOW and NOS represent the equator and meridian through the disc centre. The separation in longitude between the subsolar and subearth points is 60°. In this orientation, Mare Crisium would be in the upper right hand quadrant. The contour numbers refer to the following brightness temperatures:

| Number | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
|---|---|---|---|---|---|---|---|
| $T_B$(K) | 94 | 113 | 132 | 151 | 170 | 189 | 208 |
| Number | 22 | 24 | 26 | 28 | 30 | 32 | 34 |
| $T_B$(K) | 227 | 246 | 265 | 284 | 302 | 321 | 340 |

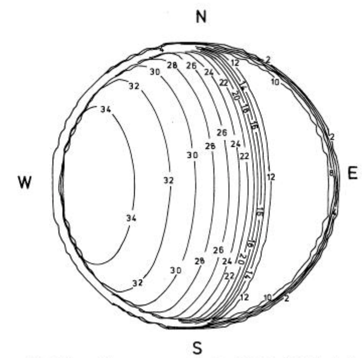



**Fig. 2.** Theoretical contour map, taken from M. J. Pugh (Ph.D. thesis, 1975). It is that of a smooth homogeneous sphere lunar model convolved with a beam comparable in width to that used for the observational map. The contour numbers represent $T_B$(K)/10

any point on the lunar surface, where the sun's zenith angle is $\psi$, is given by

$$I \alpha \cos \psi$$

except for areas near the edge of insolation (see, for example, Wesselink, 1948).

For wavelengths where we are essentially measuring surface temperature we would, therefore, expect:

$$T \propto \cos^{1/4} \psi \qquad (2)$$

but it is known that surface roughness affects the above proportionality and, in general:

$$T \propto \cos^{n} \psi \qquad (3)$$

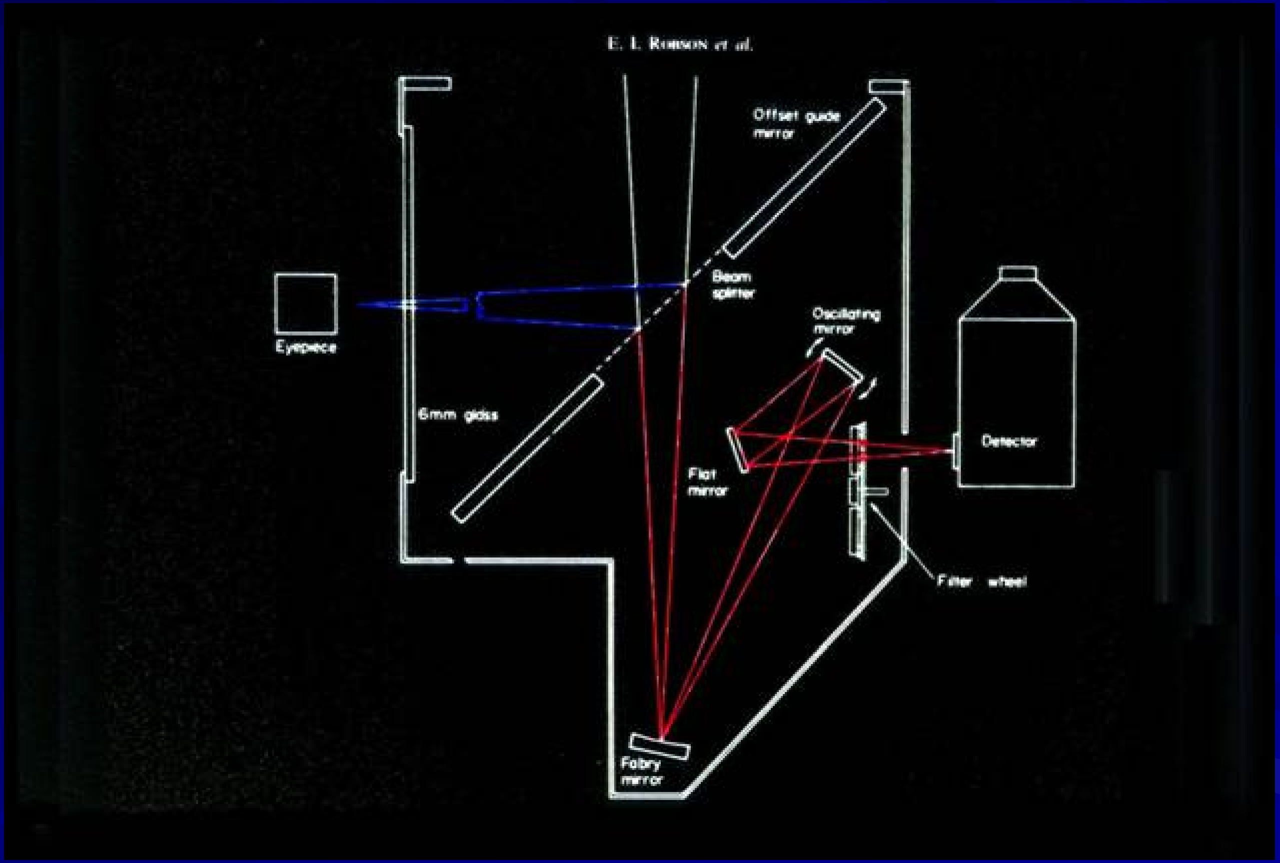
where $n$ is dependent on wavelength. Extensive work has been done on directional characteristics of lunar thermal emission in the wavelength region 10–12 μm. Montgomery et al. (1966) measured $n$ at various phase angles and showed that at full moon it was 1/6 (in agreement with Pettit and Nicholson, 1930) but increased to the Lambertian prediction of 1/4 at larger phase angles (Fig. 3).

At longer wavelengths, the characteristic depth of emission becomes important and a phase lag $\varepsilon$, with respect to optical phase, is introduced so that along the selenographic equator:

$$T \propto \cos^{n}(\psi - \varepsilon)$$

$\varepsilon$ being positive east of the sub-solar point. The 3.3 mm maps of Gary et al. (1965), taken at phases of 43°, 76° and 100° after full moon, show $n$ to be approximately 1/4 with $\varepsilon$ taken to be 22°, this value having been deduced from the maps. Measurements of phase lag at wavelengths of 8 mm (Salomonovich, 1962) and 1 mm (Low and Davidson, 1965) yield 30° and 6° respectively. Without measurements of the brightness temperature of the sub-earth point for phases close to full moon, $\varepsilon$ cannot be separated from roughness contributions to the

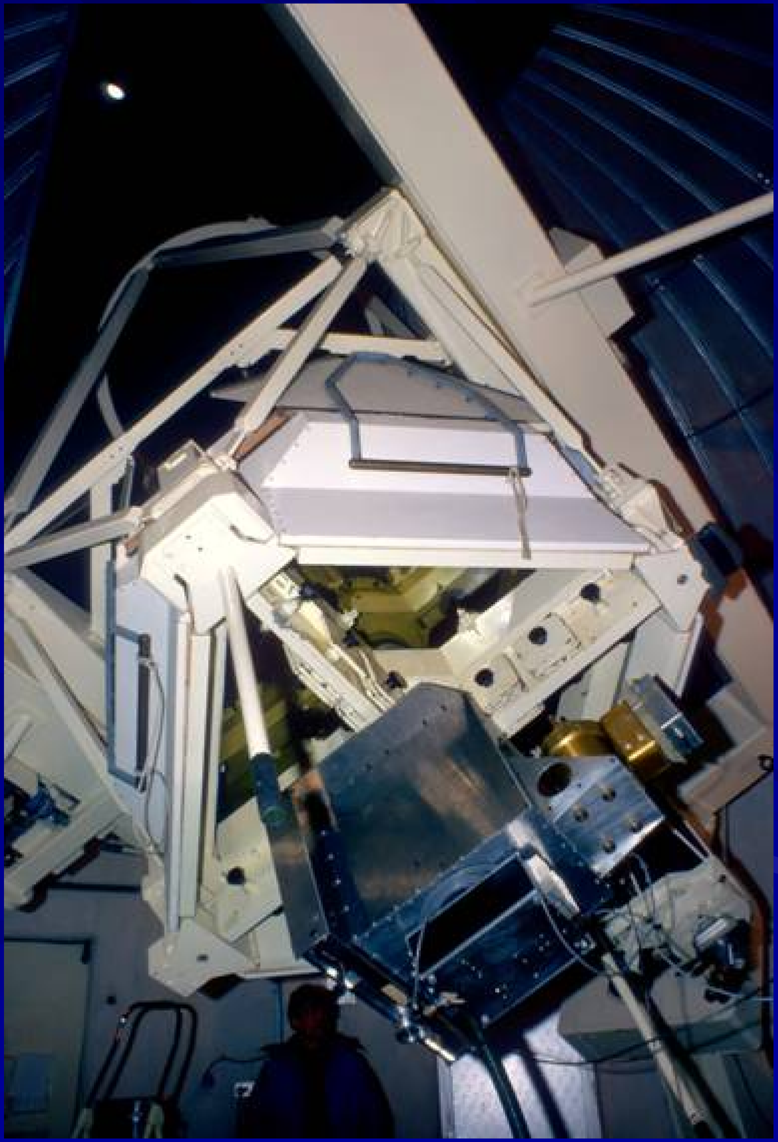
# We need a submillimetre photometer!




Lots of lessons learned about optics, control of stray light, filtering, chopping

# Testing on the Flux Collector at Tenerife: 1978

Is it breathing?

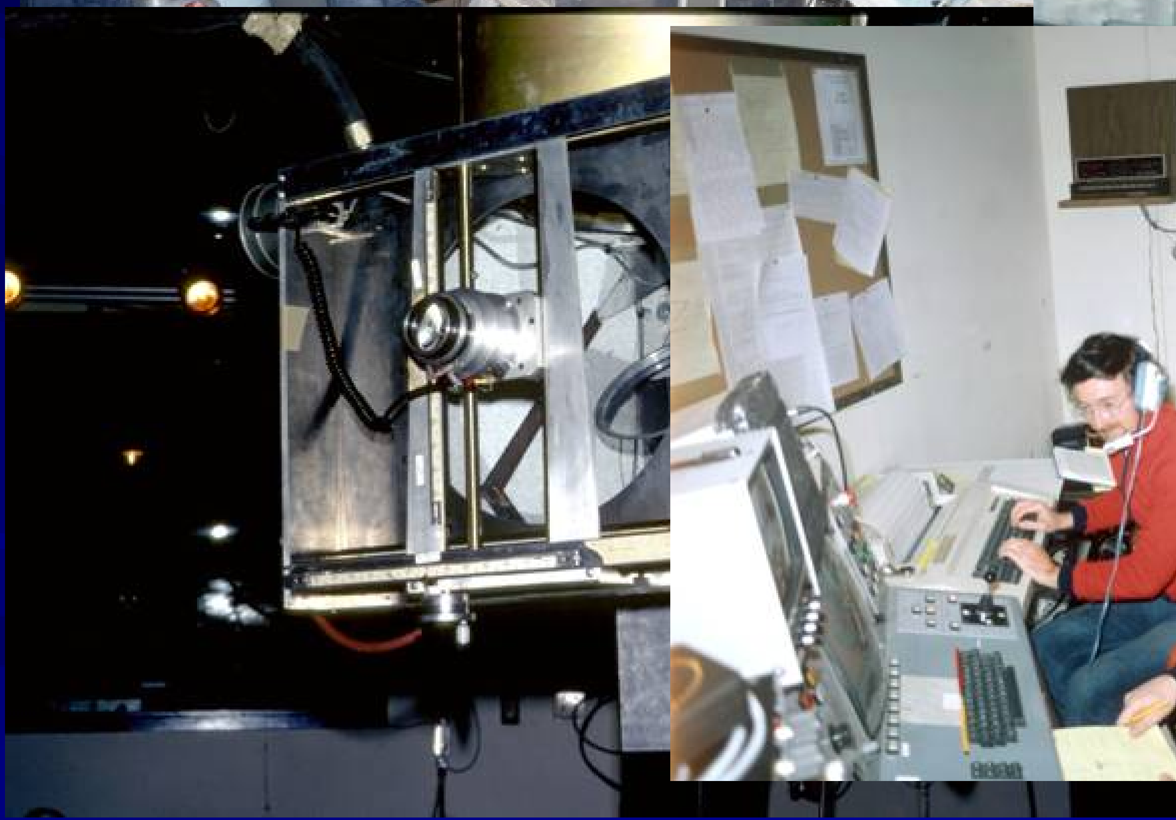


# The UKIRT Era: 1978-88

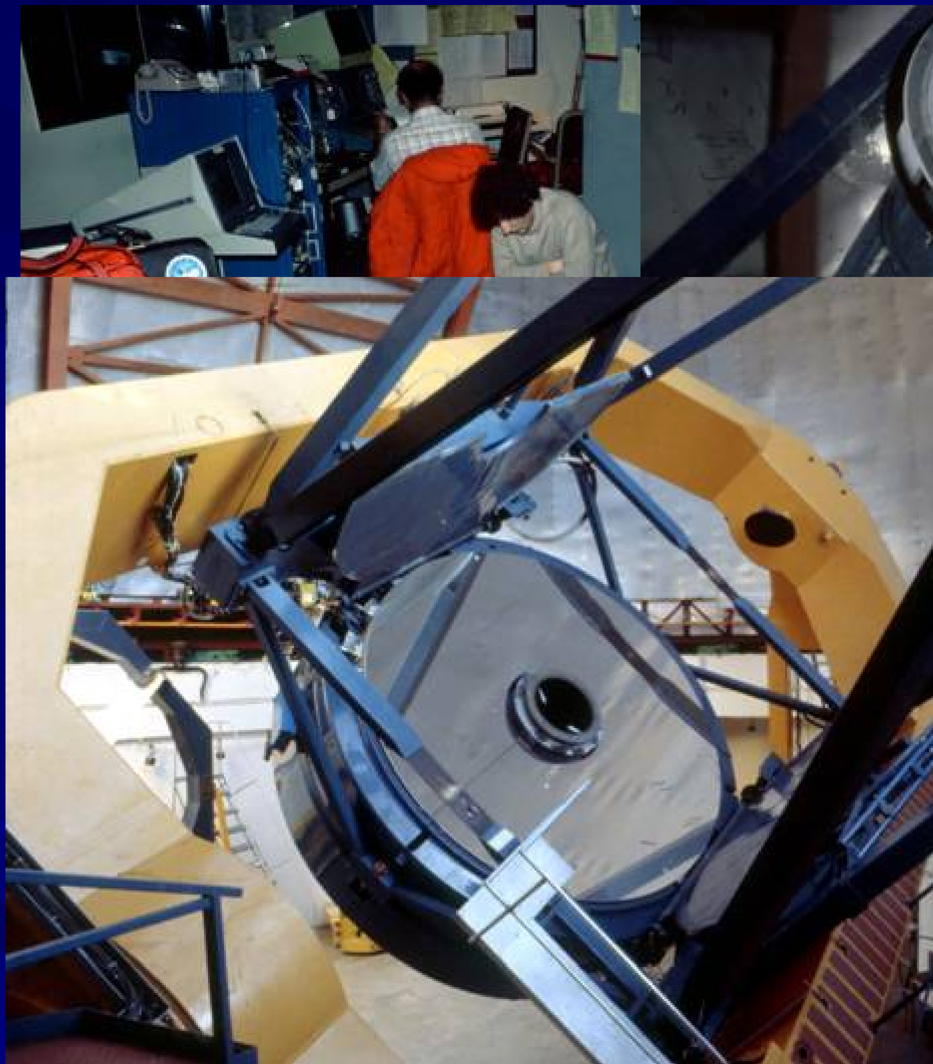
Original idea was a folded prime for the submillimetre

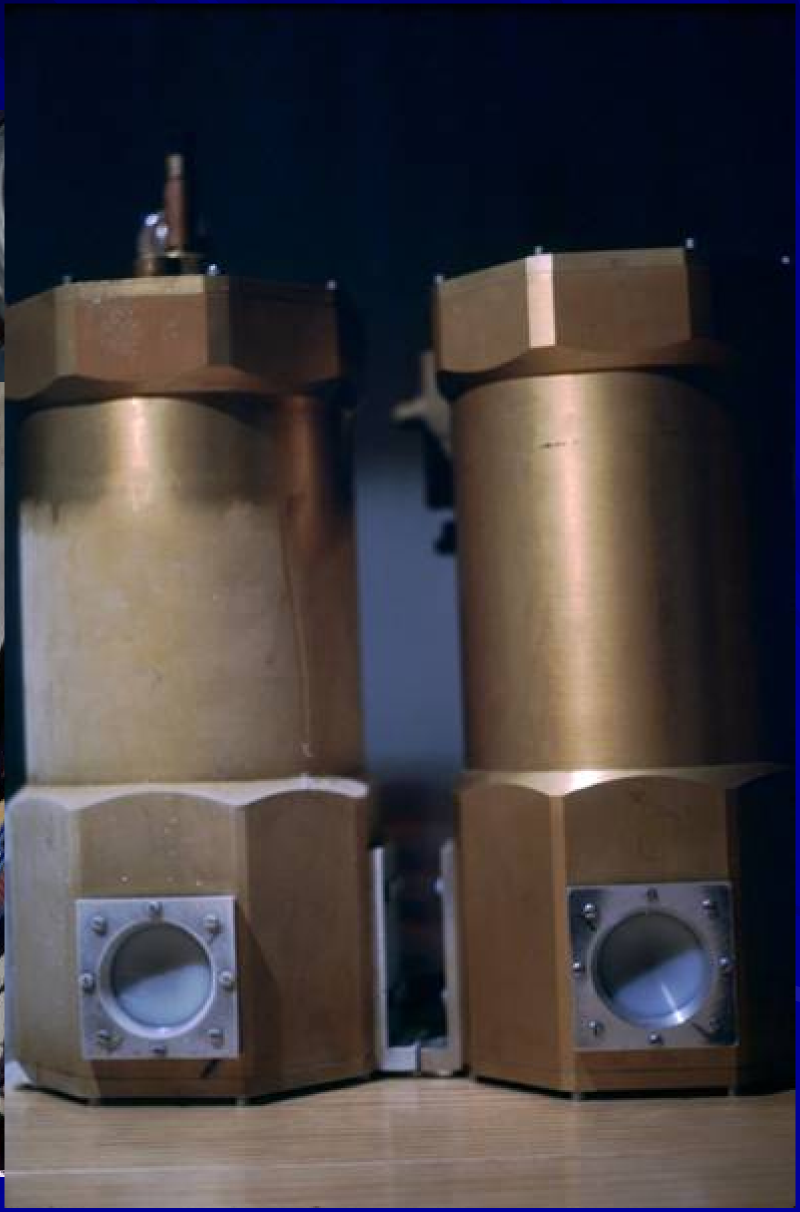
One of my first contributions was to cancel this – to the delight of the project





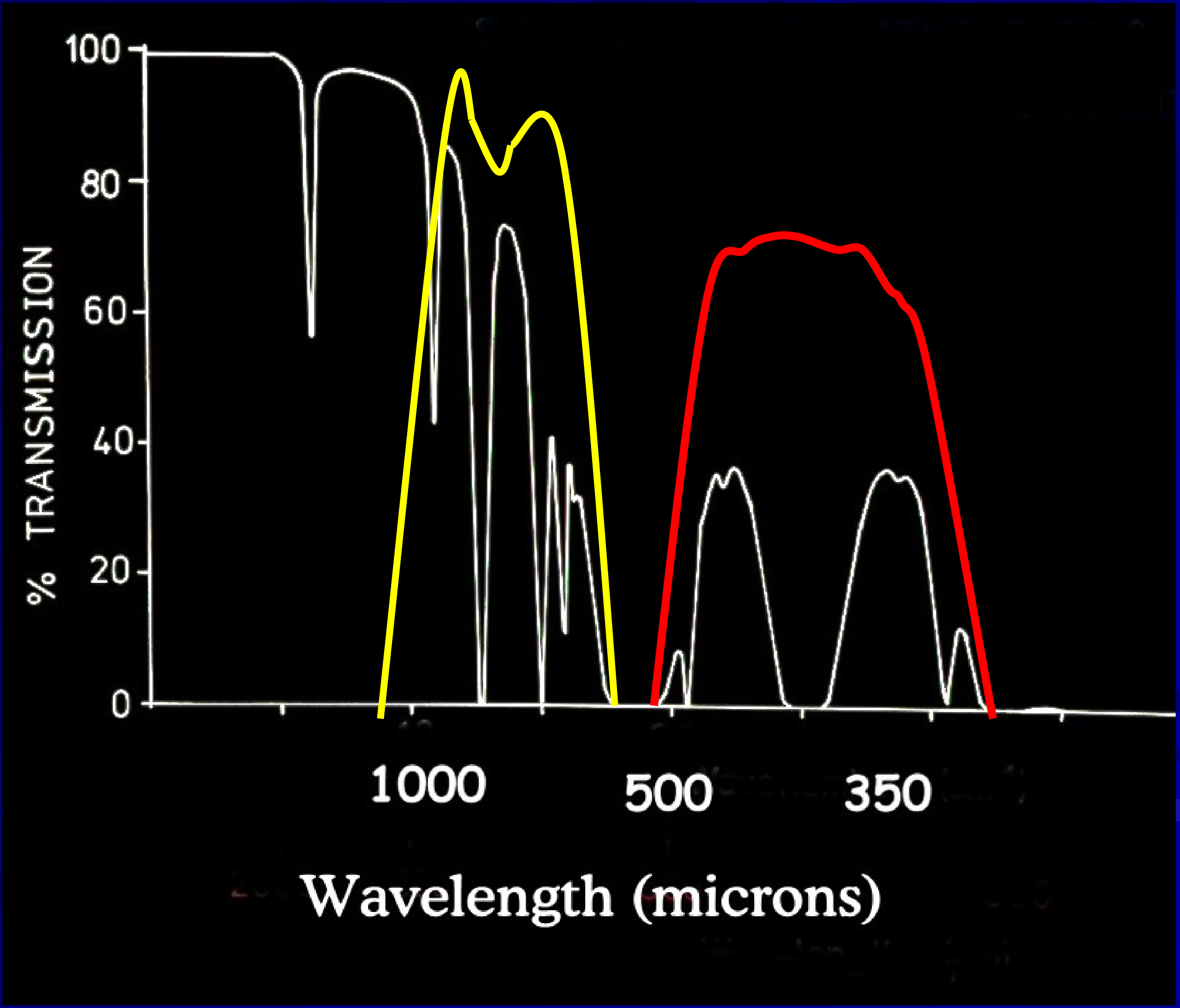

# Everything wasn’t rosy!





# Progress was slow

- Poor telescope tracking in south
- Poor data analysis software – do it yourself
- Poor overall sensitivity
- Only calibration source was Mars
- Progress was limited to the brightest submillimetre objects, usually at 800 microns and understanding the ‘observing system’ (filters, atmospheric attenuation)


100
80
60
40
20
0
% TRANSMISSION
1000
500
350
Wavelength (microns)

ICARUS 48, 127–139 (1981)

# The Submillimeter Spectra of the Planets: Narrow-Band Photometry

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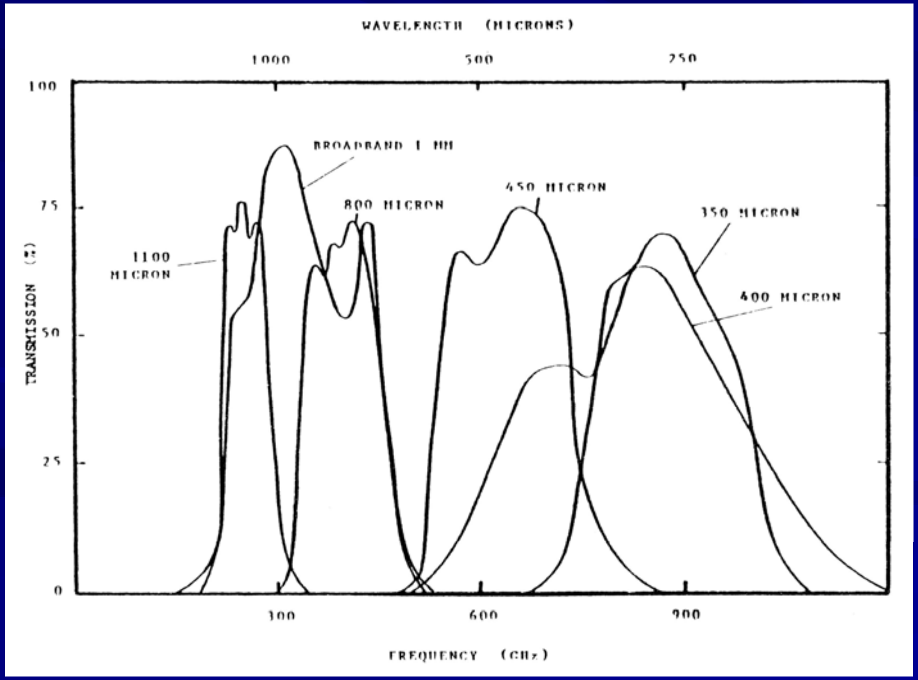
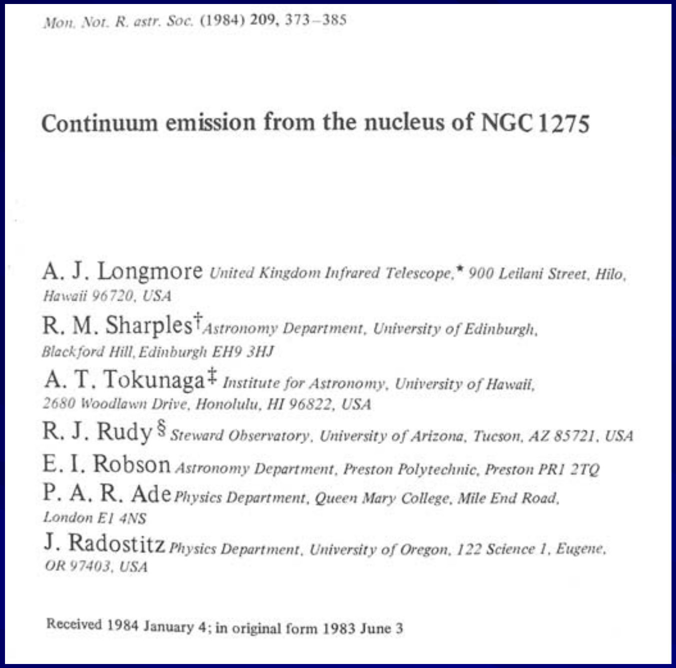
Received April 1, 1981; revised July 30, 1981

Multicolor submillimeter observations of Jupiter, Saturn, Mars, and Uranus are reported. Narrow-band filters are used to define three passbands between 300 and 1600 $\mu$m to give accurate spectrophotometric data. A method for determining the atmospheric opacity from a single set of multicolor observations of a known source is shown to be consistent with secant plot data taken during very stable observing conditions. Such extinction data show that in the submillimeter region significant fluctuations in opacity occur over periods as short as 1 hr. At the time of observation the rings of Saturn were nearly edge-on and thus the disc brightness is determined without contribution from the ring emission. Comparisons with data obtained at earlier epochs give an estimate of the ring brightness as a function of wavelength. The disc emission spectra for Saturn, Jupiter, and Uranus are compared with various atmospheric models and other observations.

# Steady Improvements – 1980-81

- Detector sensitivity – improved by using $He^3$ at 0.35K rather than pumped $He^4$ at 1.2K
- Filter improvements – separate out the 450 and 350 micron windows





*Mon. Not. R. astr. Soc.* (1984) **209**, 373–385

# Continuum emission from the nucleus of NGC 1275

A. J. Longmore *United Kingdom Infrared Telescope,* 900 Leilani Street, Hilo, Hawaii 96720, USA*

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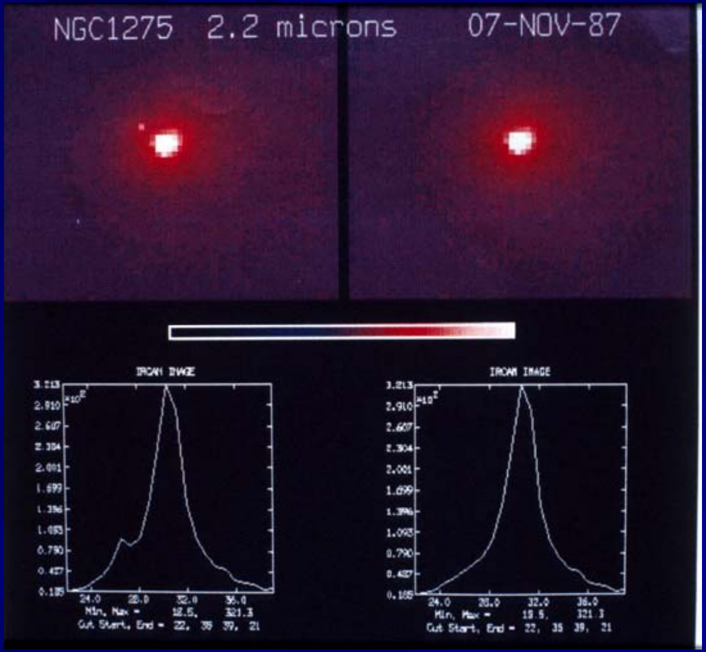
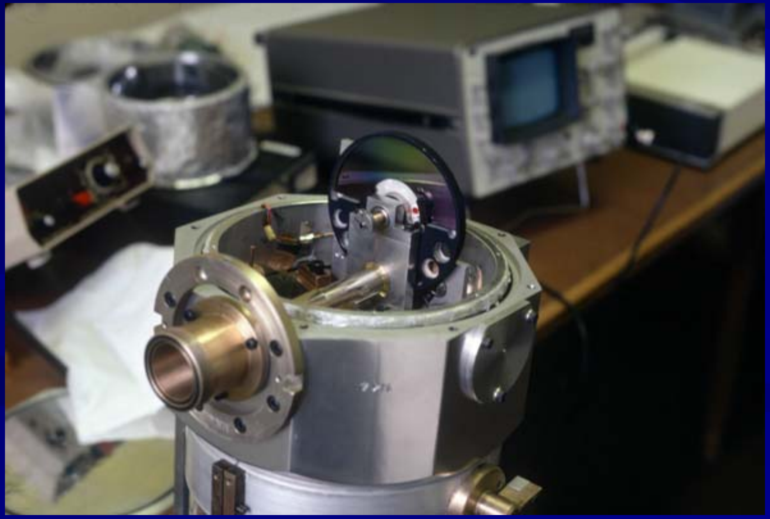
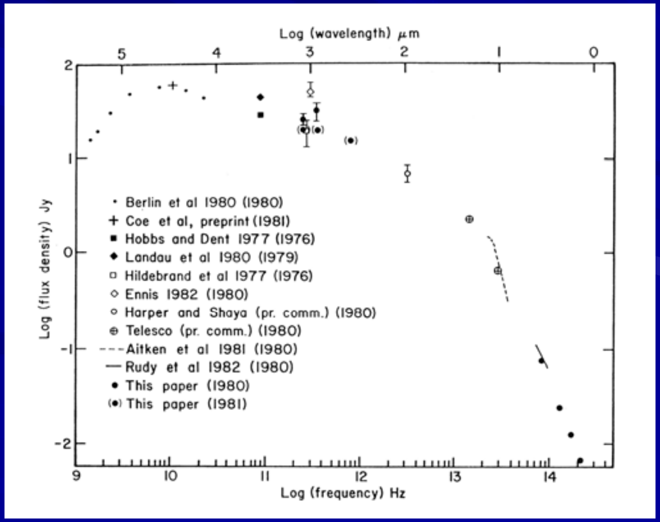
Received 1984 January 4; in original form 1983 June 3





*Mon. Not. R. astr. Soc.* (1984) **211**, 543–547

# The submillimetre and millimetre spectrum of NGC 5128

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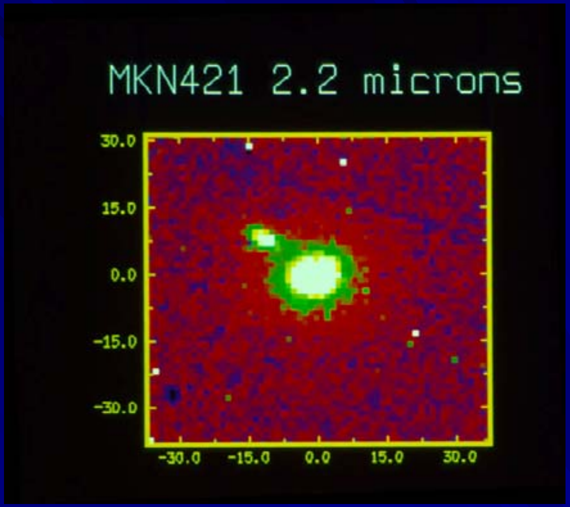
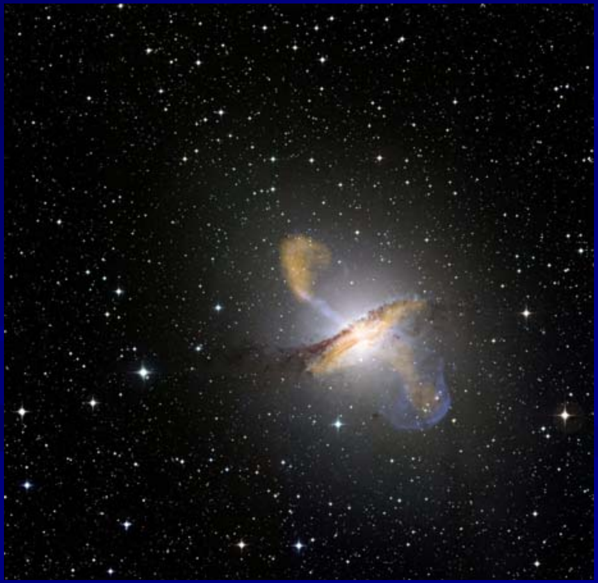


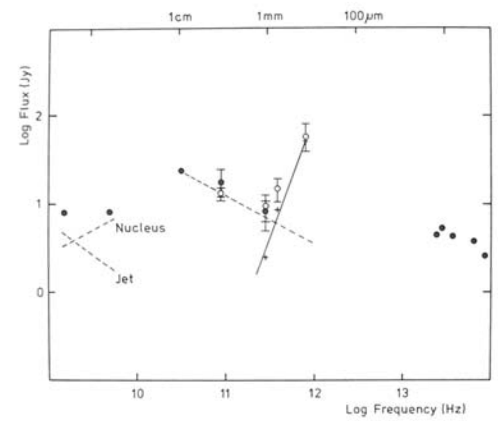
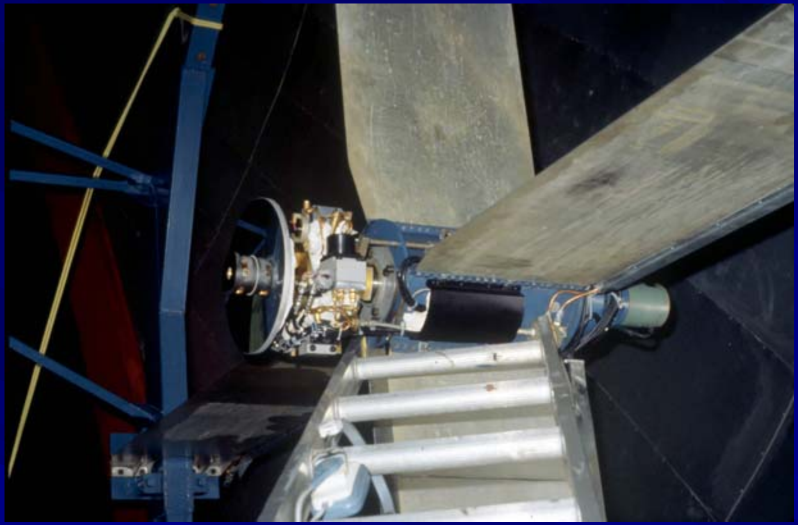


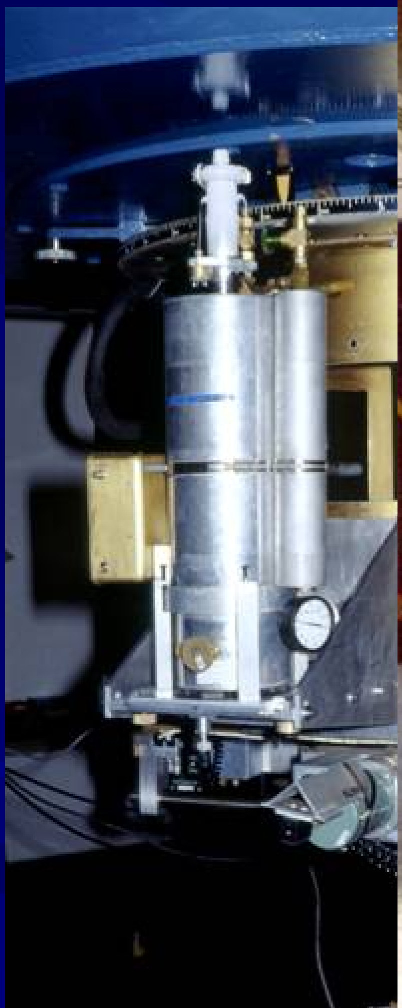

**Figure 1.** The spectrum of NGC 5128. The open circles represent the present work and other data are from the following sources: $\lambda<100\,\mu m$ from Grasdalen & Joyce (1976), $\lambda=1100\,\mu m$ from Hildebrand *et al.* (1977), $\lambda=3.3$ and 9.5 mm from Kellermann (1974), $\lambda=6$ and 20 cm from Schreier *et al.* (1981). The dotted lines between $10^9$ and $10^{10}$ Hz indicate the spectrum decomposed into nuclear and jet components. Between $10^{10}$ and $10^{12}$ Hz the dotted line indicates the assumed nuclear spectrum while the crosses and solid line represent the deduced thermal component.

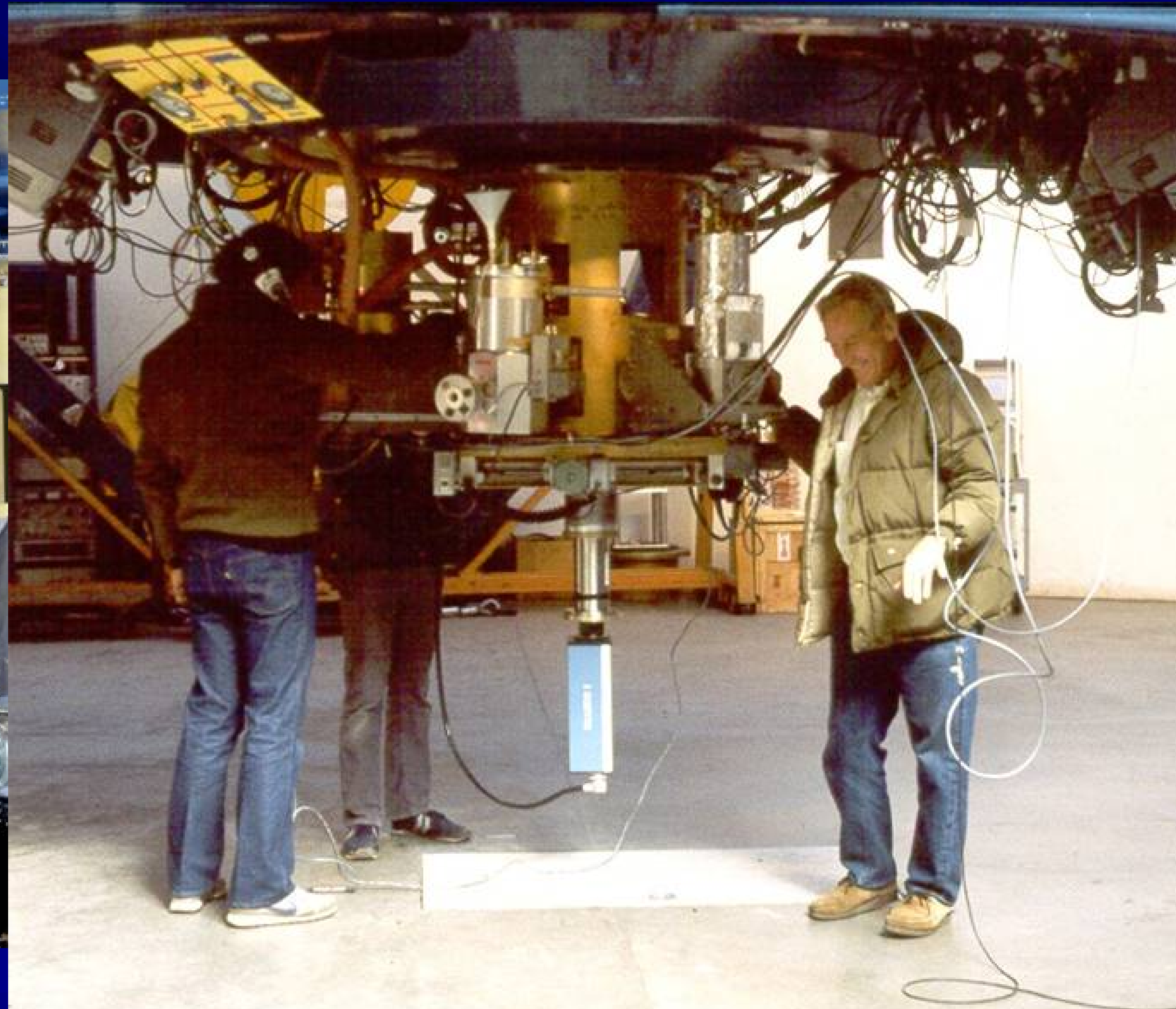
# The breakthrough – *f*/35 operations: 1981- 85



- The enormous advantages of a chopping secondary
- Stable baselines – huge improvement in detectivity
- A telescope with a guiding TV and adequate pointing and tracking
- Feed the detector direct at Cass – just like the IR

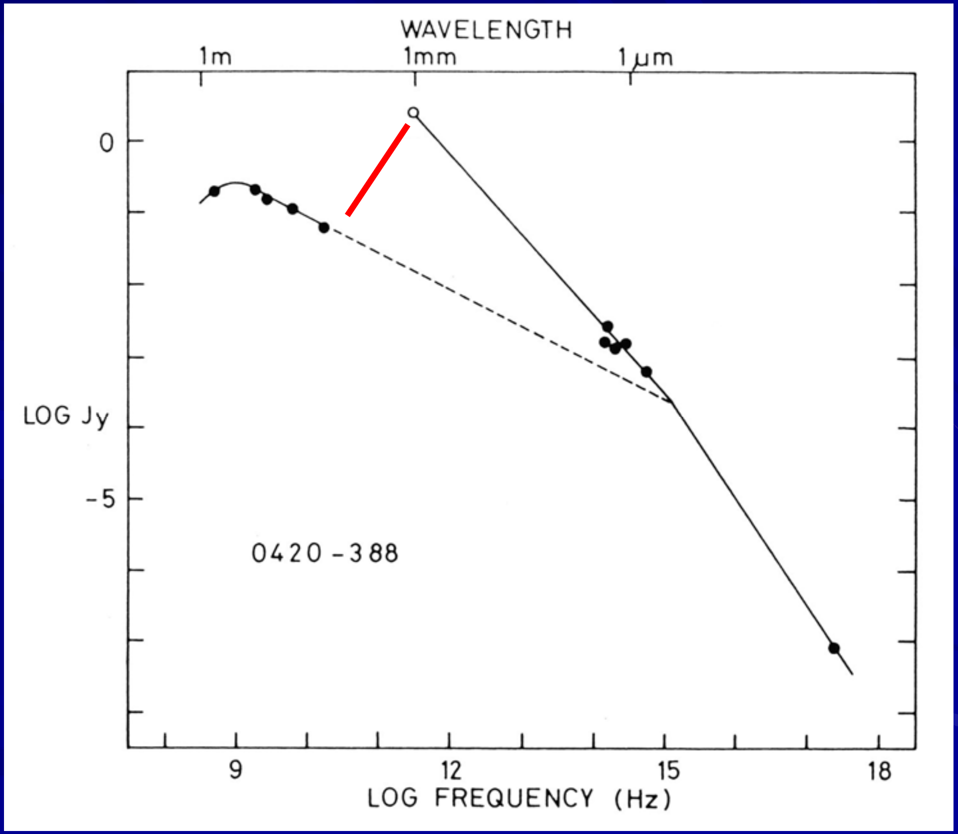
# And – the Oregon 'Photometer'





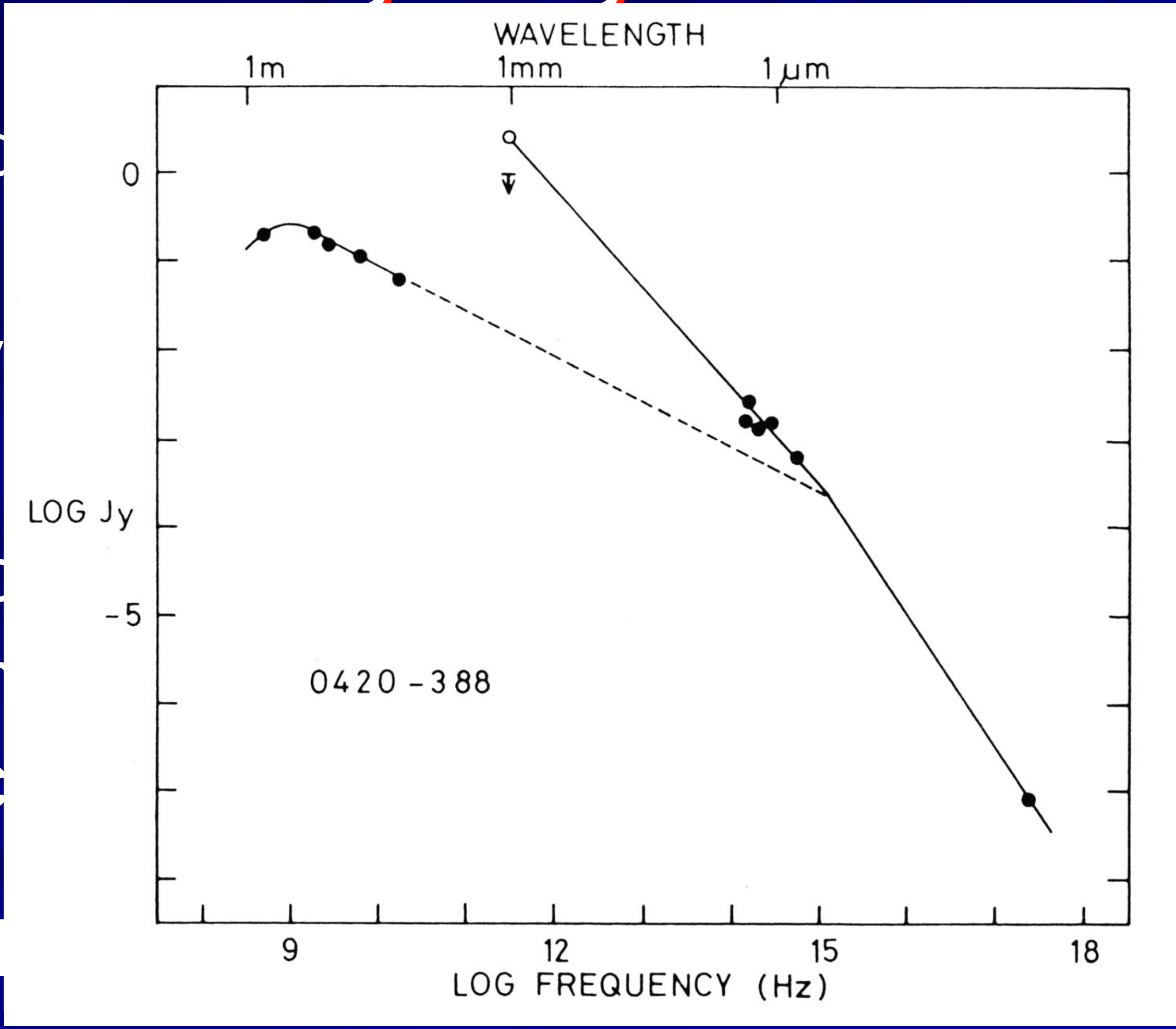
# The quasar mystery

- Reported detection of a number of optically selected quasars at 1mm – around 1 Jy
- A new physical mechanism ???



# The quasar mystery

- Reported
  selected
- New phy
- We selec
- Interestin
- No detec
  selected ss
  and woul ade



THE ASTROPHYSICAL JOURNAL, 273:58–63, 1983 October 1


MILLIMETER AND SUBMILLIMETER OBSERVATIONS OF 3C 273

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E. I. ROBSON[2]
Division of Physics and Astronomy, Preston Polytechnic
M. G. SMITH[2]

We report the first d
together with contempo
show that the continuur
to the infrared with a c
There is no evidence
with optically thin synch
*Subject headings:* infrar

Reprinted from Nature, Vol. 303, No. 5913, pp. 154–156, 15 September 1983


## A flare in the millimetre to IR spectrum of 3C273

E. I. Robson*, W. K. Gear†, P. E. Clegg†, P. A. R. Ade†, M. G. Smith‡, M. J. Griffin†, I. G. Nolt§, J. V. Radostitz§ & R. J. Howard||

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Boulevard, Tucson, Arizona 85705, USA

**Over the past two years some of us (I**
**M.G.S., and I.G.N.) have been mon**
**submillimetre spectrum of 3C273 (r**
**elsewhere a quiescent millimetre-to-**
**index α = −0.7 ($S_\nu \propto \nu^\alpha$) connecting**
**mid-IR. Our discovery of a concurre**
**millimetre spectrum of 3C273 impl**
**this range of frequency originates i**
**source. The flare was seen to propa**
**whilst decaying at shorter waveleng**
**flare is suggestive of an event withi**
**source. Millimetre wavelength vari**
**reported[3,4] but with very little temp**
**Rieke and Lebofsky[14] have reviewe**
**bility.**

The near IR ($J, H, K, L$) data were obtained with the co
user UKIRT photometer UKT6, with either 8 or 12 arc
tures and chopper throws of 15 or 30 arc s at 12.5 Hz. C
tion was made with respect to the standard stars of Elias
their respective $J, H, K, L$ flux densities were taken to

| | $J$ | $H$ | $K$ | |
|---|---|---|---|---|
| HD77281 | 2.19, | 1.48, | 0.96, | 0.4 |
| HD106965 | 1.71, | 1.14, | 0.74, | 0.3 |
| BD+32954 | 7.01, | 9.85, | 7.42, | 3.8 |

THE ASTROPHYSICAL JOURNAL, 280:102–106, 1984 May 1


MILLIMETER-WAVE OBSERVATIONS OF FI

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*Received 1983 May 27; accepted 1983 October 21*

ABSTRACT

We present measurements at wavelengths between 0.4 and 2.0 mm of a sample of 26 compact, flat spectrum radio sources. These observations extend the known radio spectra of this class of sources to higher frequencies and show that most of these sources are still flat at short millimeter wavelengths. The spectral shapes are consistent with an inhomogeneous synchrotron model (with some degree of relativistic beaming); however, the lack of concurrent multifrequency data prevents us from making more definite conclusions at this stage.

*Subject headings:* radiation mechanisms — radio sources: galaxies

letters to nature

*Nature* **323**, 134 - 136 (11 September 1986); doi:10.1038/323134a0

## A new infrared spectral component of the quasar 3C273

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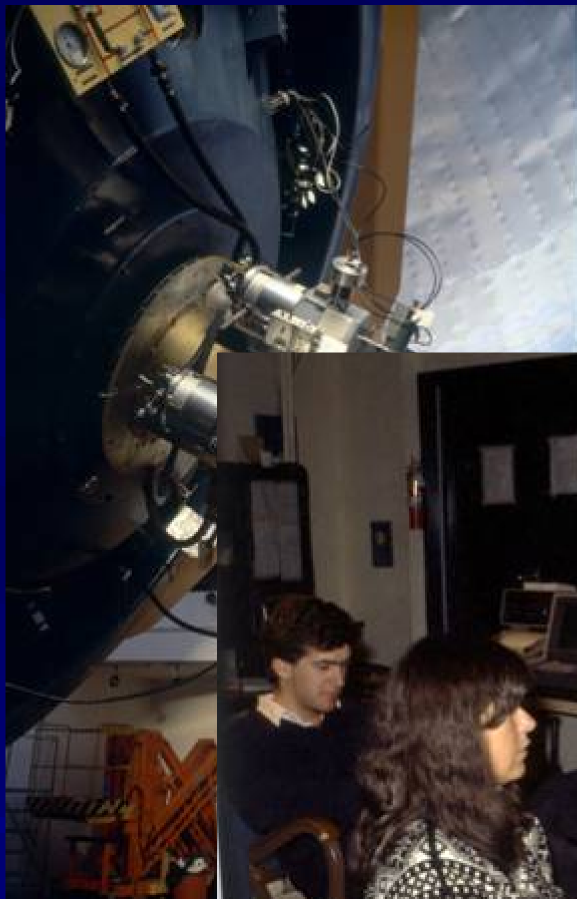
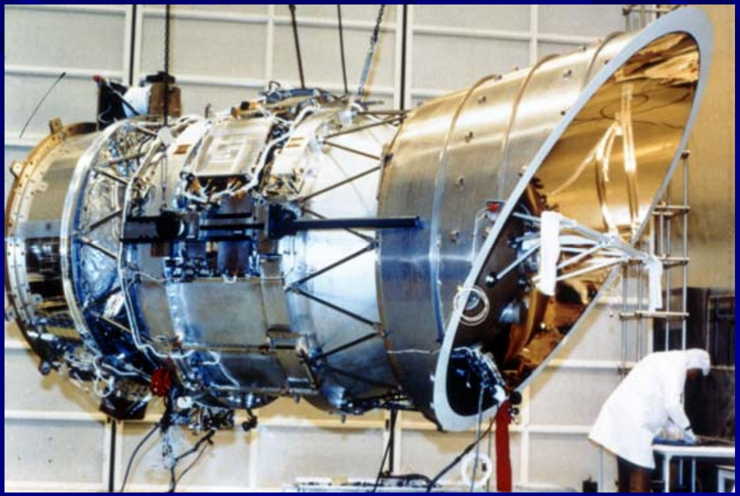
||Geneva Observatory, CH 1290 Sauverny, Geneva, Switzerland
¶Affiliated to the Space Science Department of ESA

**Following the dramatic infrared to millimetre-wavelength flare in the quasar 3C273 during 1983[1], we have continued to monito overall continuum emission. Recent measurements show that th µm to 3-mm emission has decayed to a level well below any seen previously[2,3], while the 1–4-µm emission has remained relativel constant. This behaviour has revealed the presence of an appare non-variable component which dominates the near-infrared emission in 3C273 and includes the small 'bump' at ~3.5 µm in t power-law continuum previously noted by Neugebauer *et al.* [3]. T origin of this component is probably not thermal re-radiation b dust grains but may be due to free–free emission from very den broad-line clouds[4].**

# Steady Development and new faces

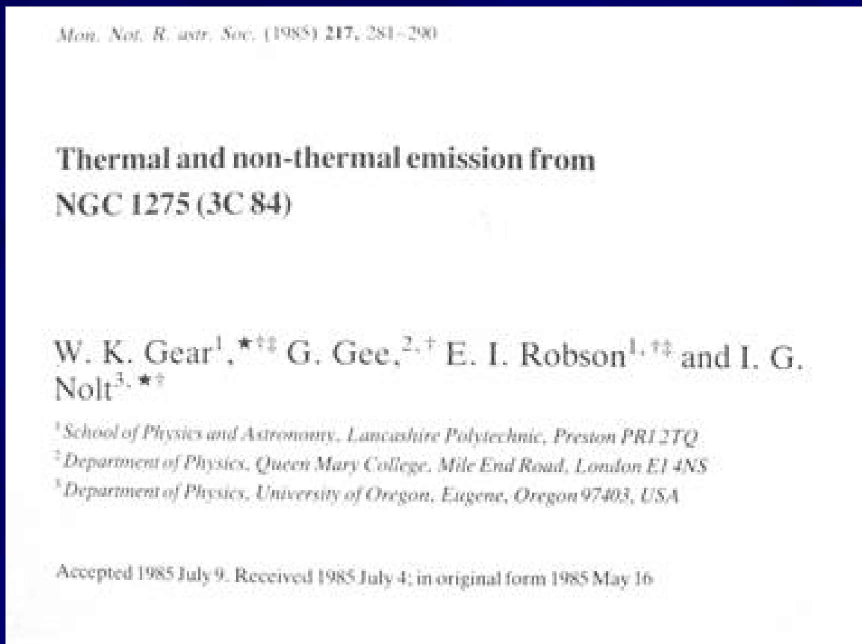


# The time of IRAS



- Awarded many months of morning twilight time to undertake IRAS follow-up in the submm
- Programme soon terminated – used normal observing slots instead
- Good success

# The dusty Universe – was there thermal emission from radio-loud AGNs ?


Mon. Not. R. astr. Soc. (1985) 217, 281–290

Thermal and non-thermal emission from NGC 1275 (3C 84)

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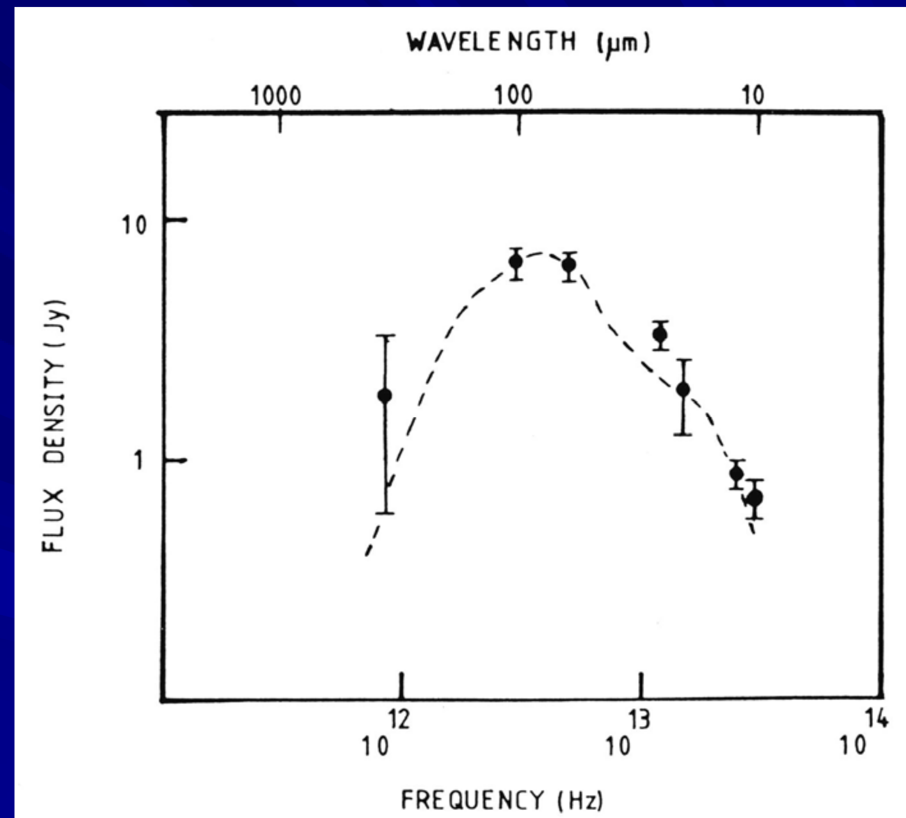
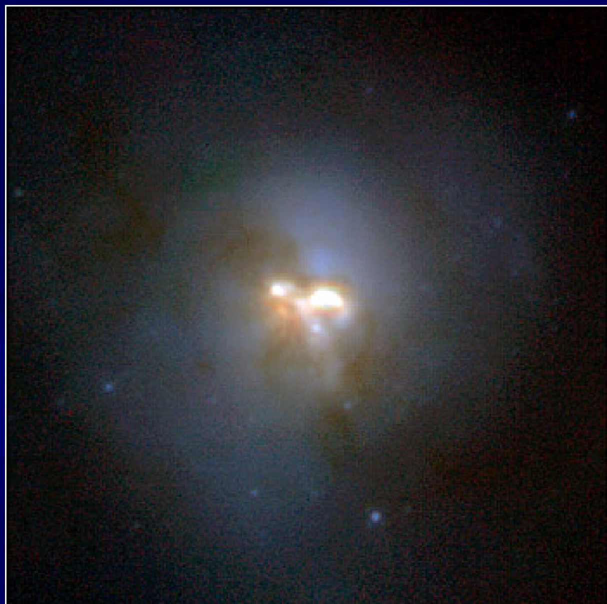
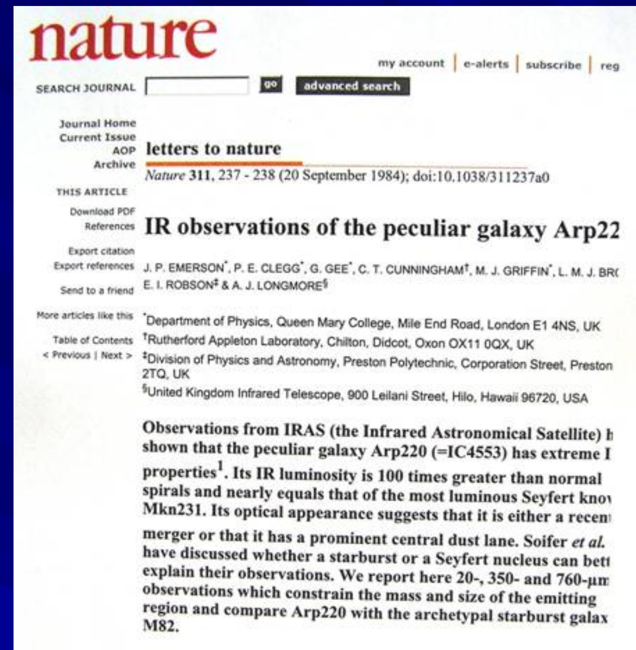



- Thermal emission similar to NGC1068
- L ~7×$10^{10}$ $L_o$ and M ~ $10^9$ $M_o$
- Problem of galaxy depletion in $10^8$ y
- Lack of OB stars suggests star formation driven by cooling flow from the Perseus cluster

- Subtraction of the variable synchrotron component

# Super-Starburst galaxies - ULIRGs





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letters to nature

*Nature* 311, 237 - 238 (20 September 1984); doi:10.1038/311237a0

## IR observations of the peculiar galaxy Arp22

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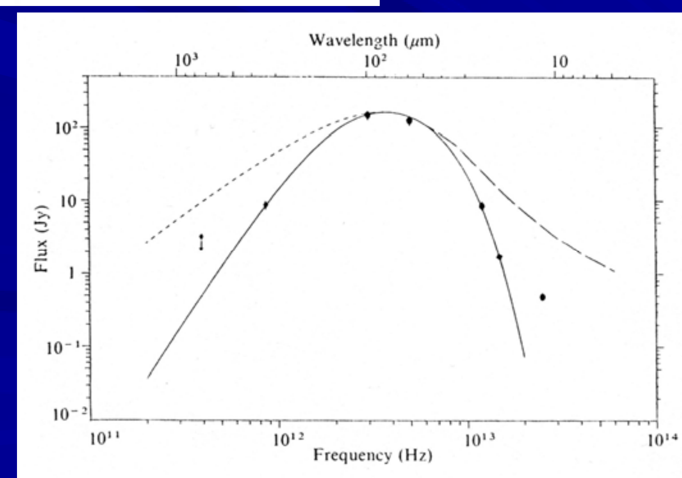
§United Kingdom Infrared Telescope, 900 Leilani Street, Hilo, Hawaii 96720, USA

**Observations from IRAS (the Infrared Astronomical Satellite) h shown that the peculiar galaxy Arp220 (=IC4553) has extreme I properties[1]. Its IR luminosity is 100 times greater than normal spirals and nearly equals that of the most luminous Seyfert kno Mkn231. Its optical appearance suggests that it is either a recen merger or that it has a prominent central dust lane. Soifer *et al.* have discussed whether a starburst or a Seyfert nucleus can bett explain their observations. We report here 20-, 350- and 760-µm observations which constrain the mass and size of the emitting region and compare Arp220 with the archetypal starburst galax M82.**



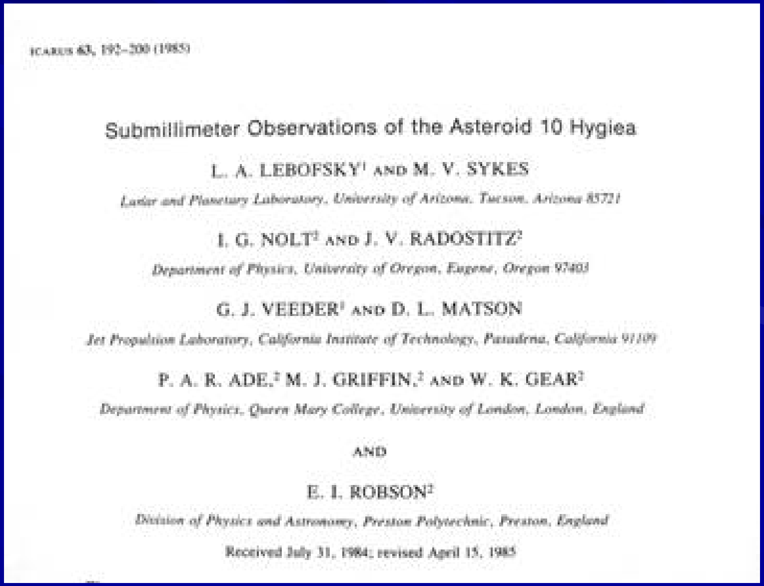

- IRAS discovery
- 20, 350, 760 micron observations in May 1984
- Cuts across the source at 20 microns indicates all emission within the 4-arcsec beam – and consistent with IRAS 25 micron flux
- $T_D$ = 61K; L ~ $10^{12}$ $L_o$ (~100×M82)

# Multiwavelength Observations

- UKIRT was essentially unique covering the near-IR (JHK); mid-IR (LMNQ) and submillimetre on one facility (and ignoring Visphot)
- This made it extremely powerful for undertaking multi-wavelength observations, closely-spaced in time
- But, the IRTF had a better mid-IR photometer – lots of effort spent on UKIRT mid-IR photometers.

# So, collaborate with IRTF

- Undertake submm and near-IR observations with UKIRT and the mid-IR with the IRTF.
- Needed some helpful scheduling
- Interesting results


ICARUS 63, 192–200 (1985)

Submillimeter Observations of the Asteroid 10 Hygiea

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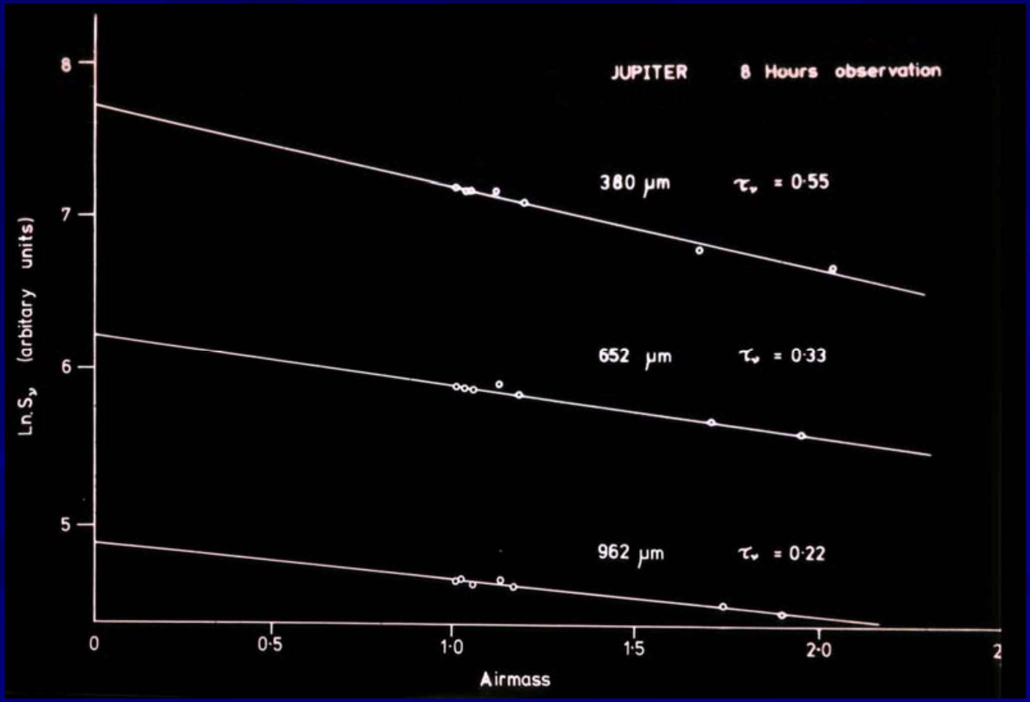
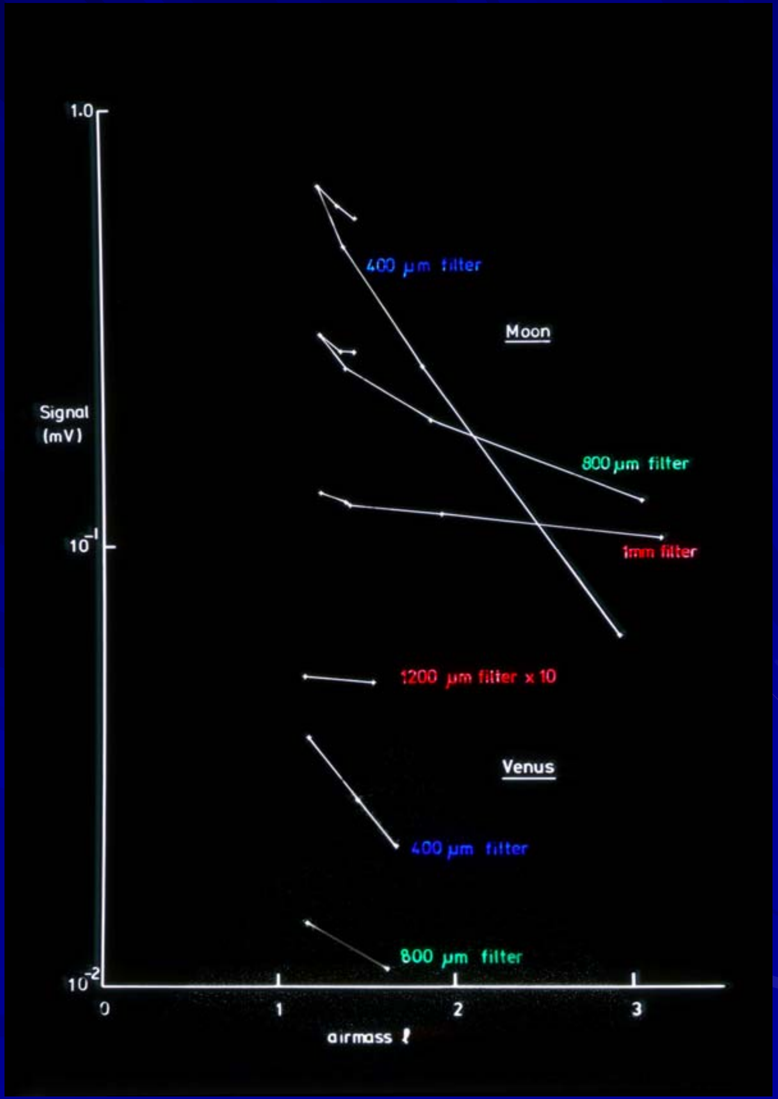
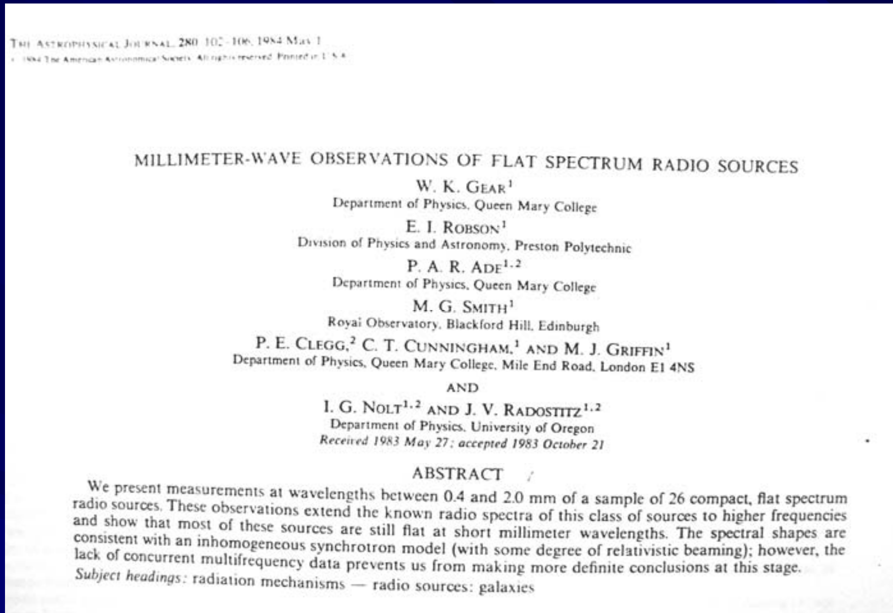
Received July 31, 1984; revised April 15, 1985

Continued improvements in filters isolating the transmission windows and in improvements to the NEFD

Extensive experiments with two- and three-position chopping To understand most optimum observing technique





The Astrophysical Journal, 280: 102–106, 1984 May 1


MILLIMETER-WAVE OBSERVATIONS OF FLAT SPECTRUM RADIO SOURCES

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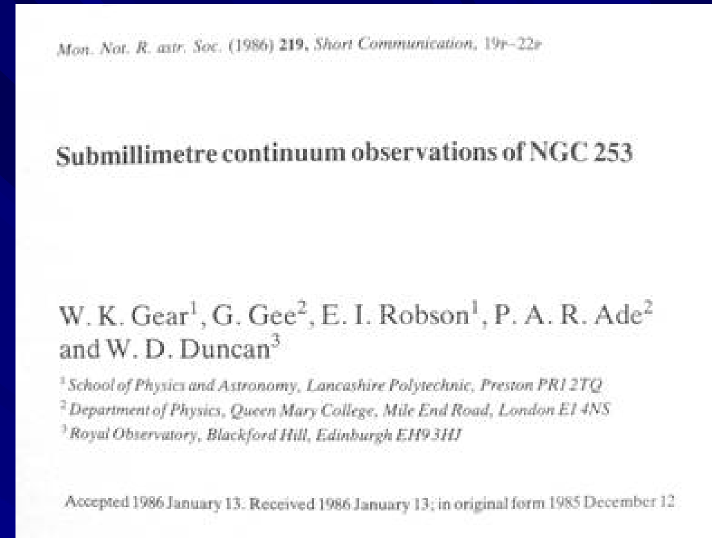
ABSTRACT

We present measurements at wavelengths between 0.4 and 2.0 mm of a sample of 26 compact, flat spectrum radio sources. These observations extend the known radio spectra of this class of sources to higher frequencies and show that most of these sources are still flat at short millimeter wavelengths. The spectral shapes are consistent with an inhomogeneous synchrotron model (with some degree of relativistic beaming); however, the lack of concurrent multifrequency data prevents us from making more definite conclusions at this stage.
*Subject headings:* radiation mechanisms — radio sources: galaxies



*Mon. Not. R. astr. Soc.* (1986) **219**, *Short Communication*, 19P–22P

**Submillimetre continuum observations of NGC 253**

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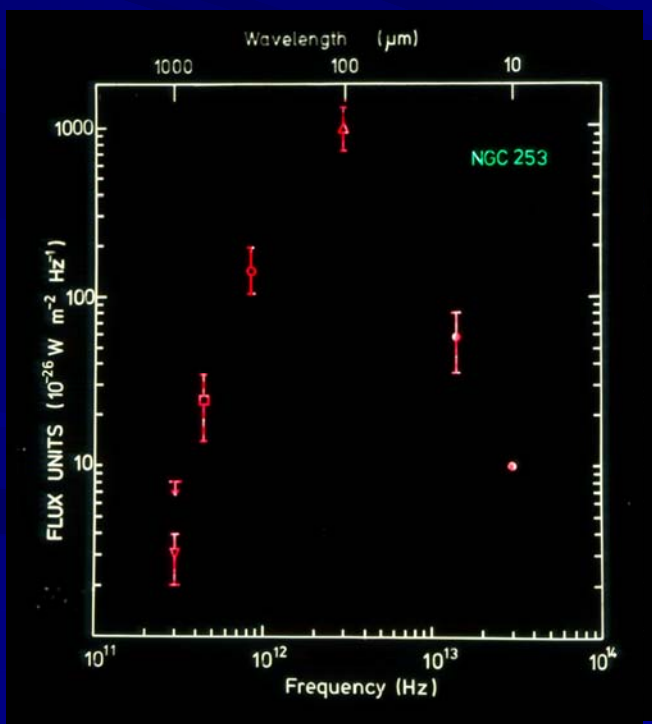
Accepted 1986 January 13. Received 1986 January 13; in original form 1985 December 12




- Afternoon-twilight with 2mm ppwv
- ‘Mapped’ at 350 μm – extended
- Data suggest the ISM is an ensemble of massive molecular clouds – unlike the preferred model for M82 of large number of very small clumps

THE ASTROPHYSICAL JOURNAL, 340:150–161, 1989 May 1


# MULTIFREQUENCY OBSERVATIONS OF BLAZARS. IV. THE VARIABILITY OF THE RADIO TO ULTRAVIOLET CONTINUUM

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## ABSTRACT

We present the results of analysis of the variability properties of the high-frequency radio (centimeter) to ultraviolet continua of a sample of nine blazars. Three sources, 0851+202 (OJ 287), 1641+399 (3C 345) and 2223−052 (3C 446), have sufficiently complete spectral and temporal coverage to enable detailed comparisons to be made between the light curves obtained at the various wavebands. The infrared and optical variations of these sources are well correlated. In OJ 287 there is also a significant correlation between the centimeter variations and those at higher frequencies. In 3C 446, however, the centimeter variations appear to be uncorrelated with those at higher frequencies. A strong correlation is observed between the near-infrared flux levels and the near-infrared spectral slopes of the BL Lac objects, in the sense that the spectra are *steeper* when the sources are *fainter*. A similar correlation is observed to hold in optically violent variable (OVV) quasars during large-amplitude flare events; in general, however, the spectra of the OVV quasars exhibit no significant correlation between flux level and spectral slope. We deduce that an additional nonvariable 1–5 μm component may be present in the near-infrared spectra of OVV quasars. We also note that the supposed BL Lac object, 1308+328, shows properties intermediate between the two classes and clearly merits further study.

*Subject headings:* BL Lacertae objects — quasars — radiation mechanisms — radio sources: variable

*Received 1987 October 26; accepted 1988 October 3*

ICARUS 65, 244–256 (1986)

## Submillimeter and Millimeter Observations of Jupiter

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*Mon. Not. R. astr. Soc.* (1986) **219**, 835–840

## Submillimetre observations of a disc around the embedded source GL 490

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*Mon. Not. R. astr. Soc.* (1990) **244**, 458–464

## Dust around H II regions – II. W49A

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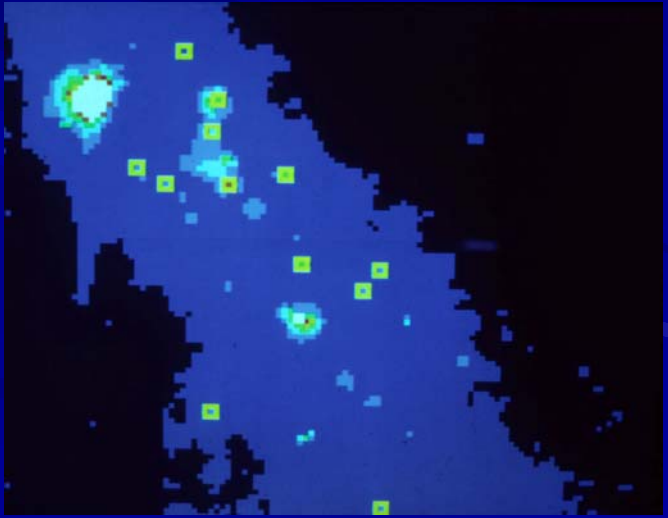
Accepted 1989 December 12. Received 1989 November 7

**SUMMARY**

Submillimetre continuum maps, and *IRAS* calibrated raw data maps, on which a new 'destriping' technique has been used, are presented of W49A, showing extensive emission from cool dust in the region. The dust emission is fitted by a greybody function with a temperature of 50 K and submillimetre spectral index $\beta = 1.8 \pm 0.2$, consistent with previous work. The cloud is shown to be optically thin at wavelengths longer than 150 $\mu$m, so the submillimetre fluxes can be used to estimate the total dust mass, which is found to be 2400 $M_{\odot}$. The 'filling factor' implies that the dust cloud is highly fragmented on small scales, possibly indicating continuing star-forming activity. The total far-infrared luminosity of the cloud is found to be $2.7 \times 10^7\ L_{\odot}$, making W49A one of the most luminous star-forming regions in the Galaxy. The morphology of the cloud is diagnosed as consisting of an association of H II regions surrounded by a dust cloud composed of grains at two characteristic temperatures.




WARNING
HAZARDOUS ROAD
DRIVE WTIH CARE

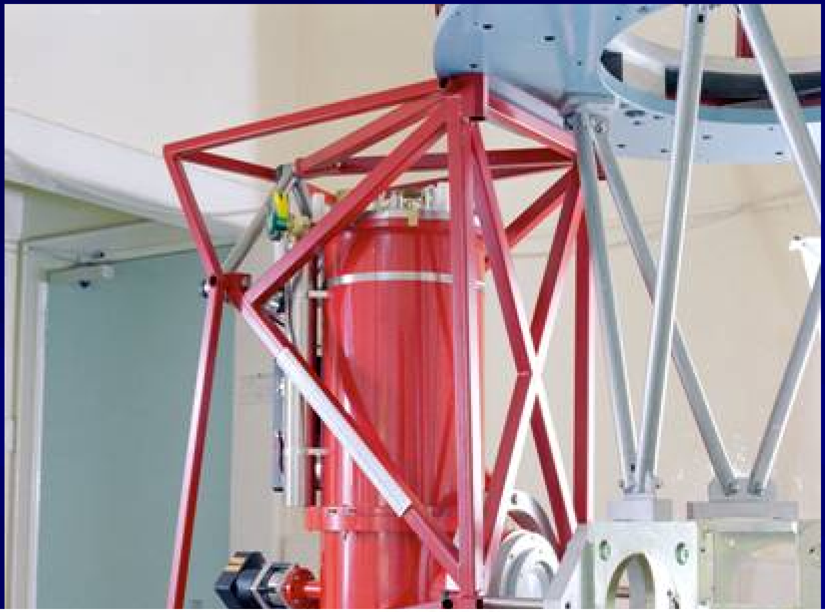

HFT 880

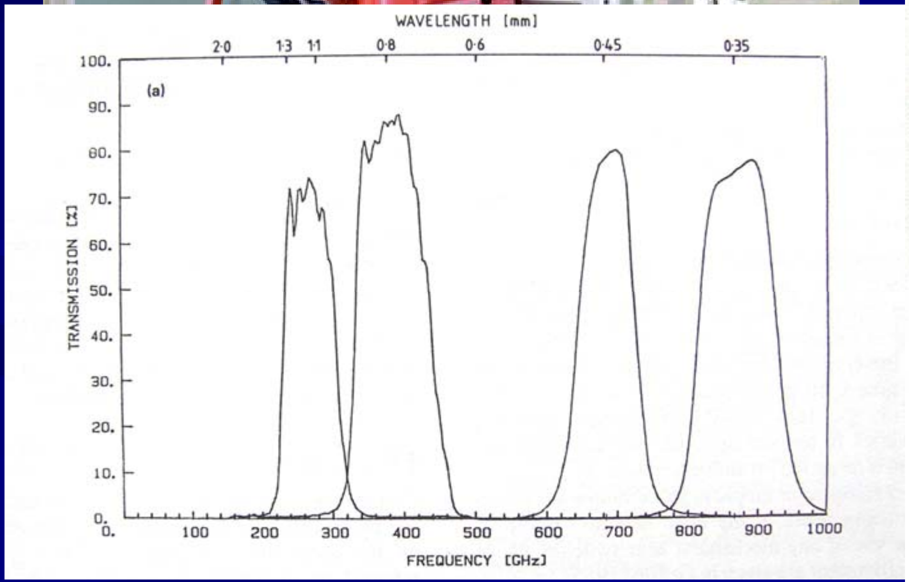
# Remote observing and eavesdropping

- Dedicated line from the ROE
- Dedicated remote observing room
- Lots of lessons learned for the future:
  - Voice communication vital
  - Reliability of comms vital
  - Remote observing is a sociological experiment as well as a scientific experiment
- Extensive pre-planning essential
- Software tools vital


VAX/VMS Phone Facility
19-MAY-1987
UKIRT::UKREMOTE
Over
Lorna Doone in Hawaii, eh?
Over
Are we going to 1921 now?
over
UKIRT::ADAMUSER
Wish we could offer you one of our excellent Lorna Doone biscuits that we are
muncghing here...
over
Why not, I'm from Devon too.
Over
Yes, we are setting up on it now. We will follow your plan to do these two
sources while building up some air mass with Uranus. I have not had a chance
to estimate water vapour. So far we have not got much shortwards o
VT220

# UKT14 on UKIRT: Jan 1986-Feb 1988





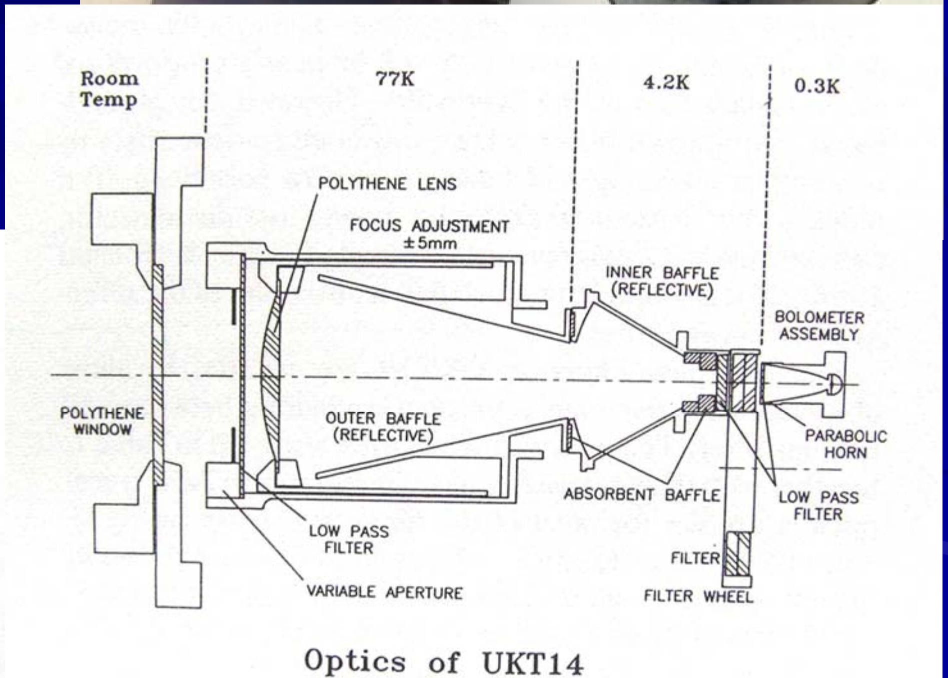




**Figure 2.** Optical arrangement of UKT14.

Mon. Not. R. astr. Soc. (1988) **231**, *Short Communication*, 55P–62P

**Millimetre and submillimetre observations of the emission from dust in compact H II regions**

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Accepted 1988 January 19. Received 1988 January 14

*Mon. Not. R. astr. Soc.* (1989) **241**, 119–133

# Infrared and submillimetre observations of the $\rho$ Ophiuchi dark cloud

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Accepted 1989 April 14. Received 1989 April 14; in original form 1988 December 15

**Summary.** A survey of part of the $\rho$ Ophiuchi dark cloud region at wavelengths from 2 to 1100 $\mu$m is presented. The *IRAS* source 16235 − 2416 is identified with a previously discovered 80-$\mu$m source. A new method of background subtraction for *IRAS* raw data is outlined. A new submillimetre source, SM1, is reported, which is a cool condensation of dust. The continuum fluxes of SM1 are fitted with a greybody spectrum with dust grain temperature 15 ± 5 K. The mass and density of SM1 are such that it is a candidate protostellar object.

The grain emissivity coefficient $\beta$ is found to be 2.2 ± 0.3 at submillimetre wavelengths, a value usually taken to be indicative of the presence of grain mantles. A new, intermediate-resolution spectrum around 2–4 $\mu$m shows the distinctive absorption feature at 3.07 $\mu$m attributed to water-ice, confirming the presence of solid $H_2O$ on dust grains. The visual extinction ($A_V$ = 12) is lower than that usually associated with grain mantling in the $\rho$ Oph dark cloud complex.



**Table 1.** Measured flux densities (in Jy) at each waveband for various apertures. (I) 7 × 5 arcmin² centred on 16235 − 2416 (not colour corrected). (II) 63-arcsec-diameter circular aperture centred on SM1. (III) 3-arcmin-square aperture centred on SM1 (*IRAS* data not colour-corrected).

| λ/μm | I (±30%) | II | III |
|---|---|---|---|
| 12 | 294 | - | 116.6 ± 30% |
| 25 | 502 | - | 197 ± 30% |
| 60 | 4632 | - | 1951 ± 30% |
| 100 | 10,580 | - | 4062 ± 30% |
| 350 | - | 421 ± 8% | 2360 ± 10% |
| 450 | - | 236 ± 10% | - |
| 800 | - | 38 ± 8% | 167 ± 10% |
| 1100 | - | 12.4 ± 11% | 66.7 ± 10% |




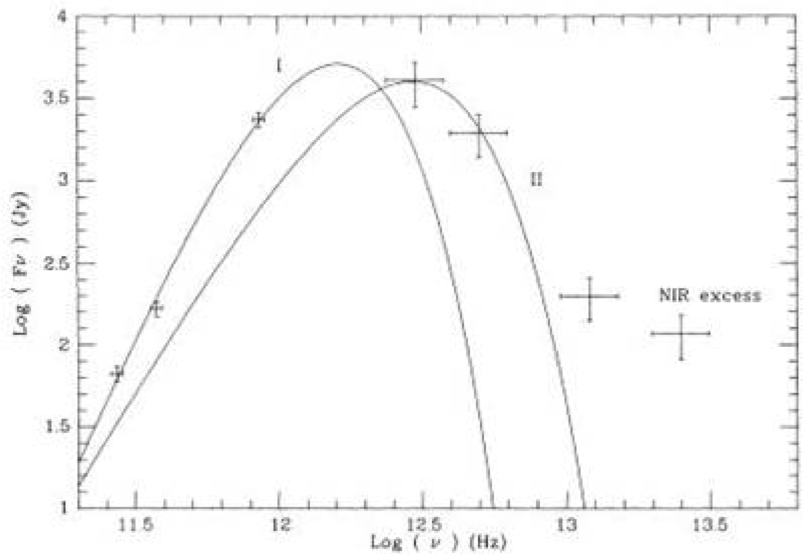


**Figure 4.** Log(flux) versus log(frequency) for a 3-arcmin square-aperture, centred on SM1, using both *IRAS* and UKIRT data. Two greybody curves have been fitted to the data, (I) $T$ = 15 K, $\beta$ = 2.2 (II) $T$ = 36 K, $\beta$ = 1, corresponding to SM1 and IRS1, respectively. It is not possible simply to add these two curves to obtain the total detected flux, due to the different source extends and the different beam sizes of the detectors. The NIR excess is clearly visible at 12 and 25 $\mu$m.

Almost the very last submm observation from UKIRT

The JCMT is on the way!

*Mon. Not. R. astr. Soc.* (1990) **243,** 126–132

**A millimetre/submillimetre common user photometer for the James Clerk Maxwell Telescope**

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Accepted 1989 August 30. Received 1989 August 25; in original form 1989 March 22

**SUMMARY**

We describe a multi-wavelength common user millimetre/submillimetre receiver which is now in operation on the James Clerk Maxwell Telescope (JCMT)* on Mauna Kea, Hawaii. It is a single channel photometer employing a composite germanium bolometric detector cooled by helium-3 to 0.35 K. The receiver has a set of bandpass filters allowing observations to be made in all of the atmospheric transmission windows between 350 $\mu$m and 2 mm.

## A new era – 1988 - 97

# Sensitivity improvements

| NEFDs | 800μm | 400μm |
|---|---|---|
| UKIRT, He4 (1978) | 200 Jy | 500 Jy |
| UKIRT He3 (1983) | 10 Jy | 25 Jy |
| UKIRT-UKT14 (1987) | 6 Jy | 15 Jy |
| JCMT- UKT14 (1989) | 500 mJy | 4 Jy |
| SCUBA (1997) | 80 mJy<br>*37 pixels*<br>*850/750μm* | 450 mJy<br>*91 pixels*<br>*450/350μm* |