Mid Infrared Astronomy at UKIRT

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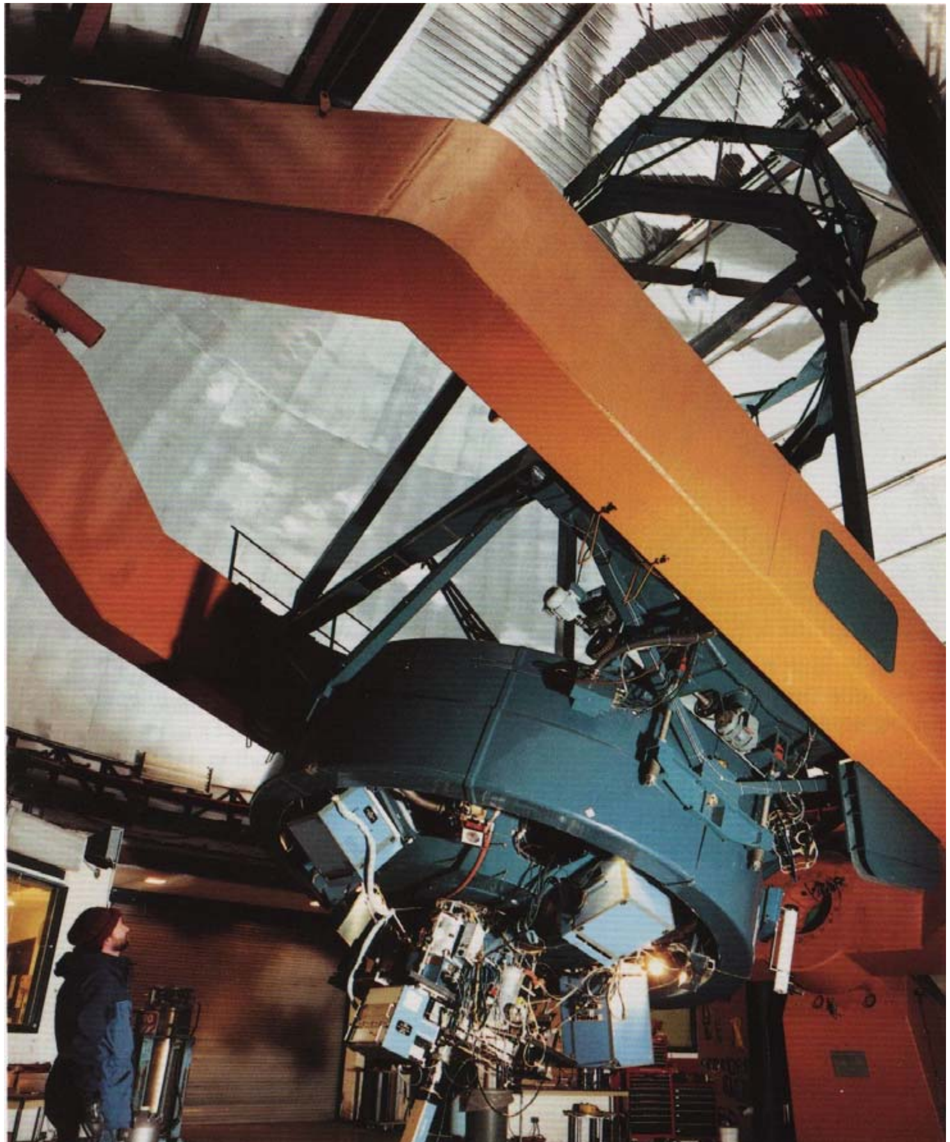
Oxford University

In the beginning.....



- There was a big telescope dedicated to the IR and built for minimal cost
- On the best site
- With a 3.8-m diameter mirror
- A choice of f/9 or f/36 focal ratios
- A guide camera that could detect ~mag 12 (on a good night)
- Telescope optics that were not very well collimated
- Great ambition and huge potential
- A fantastic sense of adventure and camaraderie

In the beginning…..

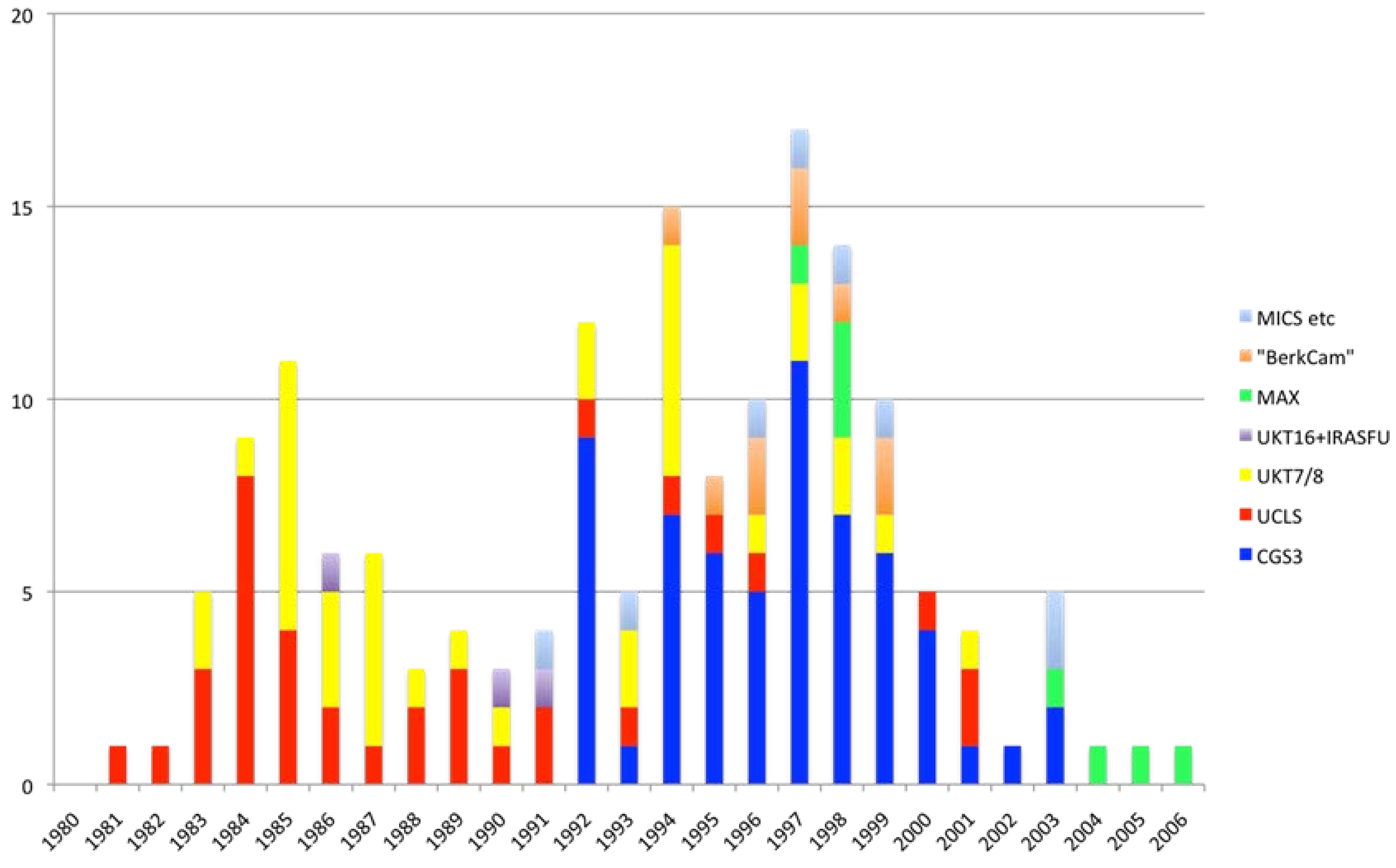
UK INFRARED TELESCOPE	*Nights*
M.J.Selby, with R.Wade, ICST: *Infrared speckle interferometry*	11
T.J.Lee, UKIRT; with E.E.Becklin, University of Hawaii; and C.J.Lonsdale, University of Edinburgh: *High resolution survey of the Orion Nebula at four infrared wavelengths*	6
T.J.Lee, UKIRT; with D.A.Allen, AAO: *Commissioning of common user spectrophotometers*	20
J.H.Hough, with J.Bailey, Hatfield Polytechnic Observatory; R.F.Jameson, University of Leicester; and D.J.Axon, University of Sussex: (a) *Near infrared and visible polarimetry of BL Lac type objects*. (b) *Near infrared and visible polarimetry of cataclysmic variables*	6
P.W.J.L.Brand, with C.D.Impey, University of Edinburgh; P.M.Williams and R.D.Wolstencroft, ROE: *Infrared photometry and polarimetry of BL Lac objects*	6
P.M.Williams, ROE; with T.J.Lee and D.H.Beattie, UKIRT: *Infrared spectrometry of quasars and Seyfert galaxies*	7
M.J.Barlow, UCL; with M.Cohen, University of California: *Mass loss rates from 2–10 μm photometry of O-stars*	5
D.H.Martin, with G.J.White, N.J.Cronin, QMC; and R.E.Hills, MRAO: *Commissioning and observations with UKIRT submillimetre heterodyne receiver system*	13
R.D.Wolstencroft, ROE; with H.M.Dyck, University of Hawaii; T.J.Lee, UKIRT; and C.J.Lonsdale, University of Edinburgh: *Infrared polarimetry of molecular clouds and H II regions*	6

QJRAS : SRC telescope allocations, Q3 1979

UKIRT's Mid-IR Instruments

- Bolometers: UKT7, UKT8, UKT16 + IRASFU
  (1980 and 1984 to 1994)
- Spectrometers: UCLS, (1980-92)
  CGS3, 1990-2000)
- Cameras : BerkCam, MIRAC, MAX, MICS
  MIRACLE (1990s)
- Imaging polarimeters : GSFC (1989), NIMPOL
- Michelle (2001-2002 and Jan-Mar 2004)

Mid-IR Publications



The Bolometers 1980-1994

Single channel instruments: aperture photometry

Many projects combined near-IR and/or sub-mm observations to characterise objects

Two peaks in publications:

Mid 1980s :

- Samples of galaxies often combined data from UKIRT and IRTF.
- Investigation of thermal and non-thermal contributions to the mid-IR emission from classes of AGN
- Solar System Objects
- IRAS detections : PPN etc

Mid 1990s Long term monitoring of variable objects e.g.

- Blazars and Quasars
- Wolf –Rayet Stars and Dust production

Retired in 1994 : Photometry then provided by summing the CGS3 detectors

Galaxy Continua

e.g. Ward et al 1987

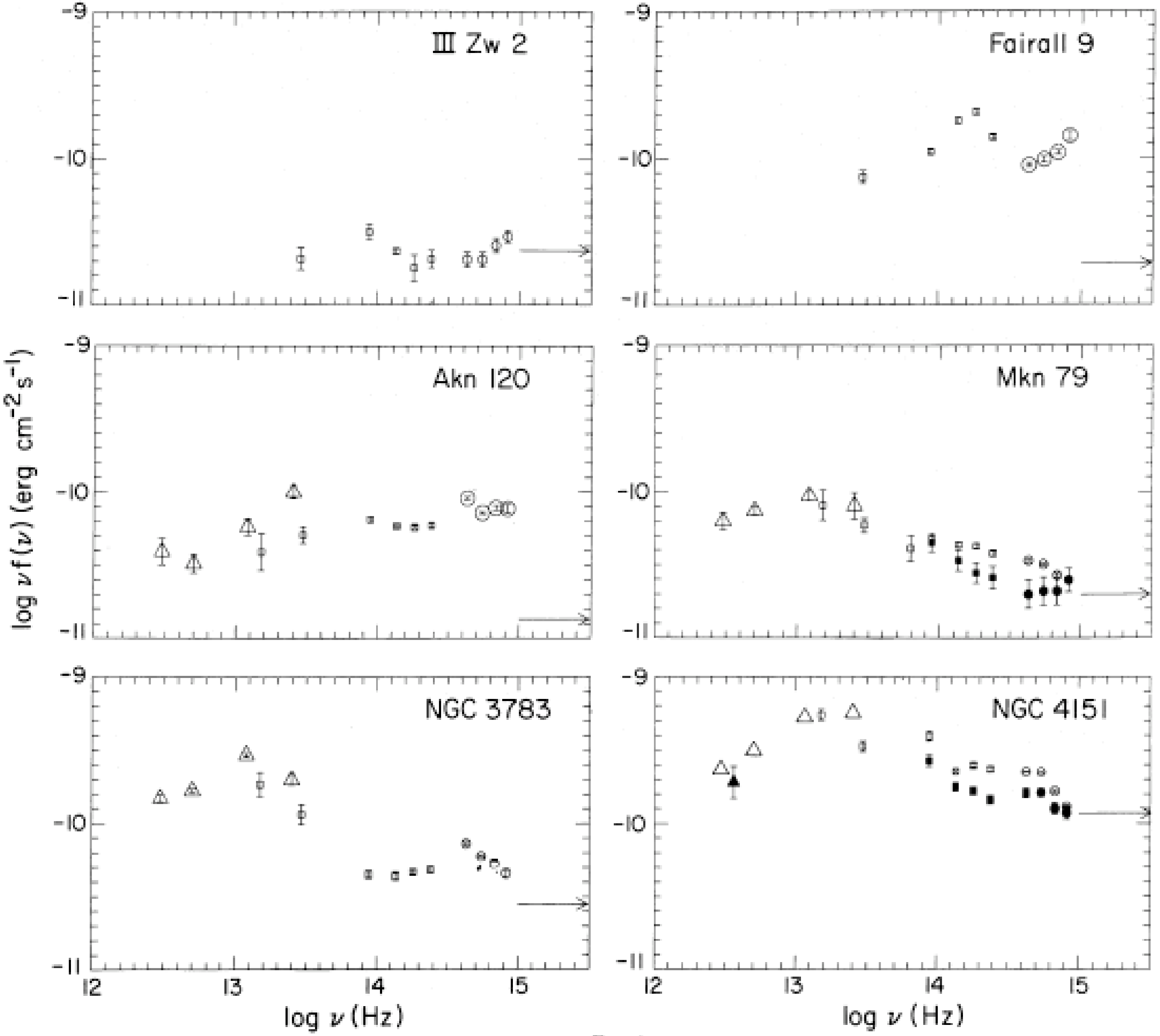


FIG. 1a

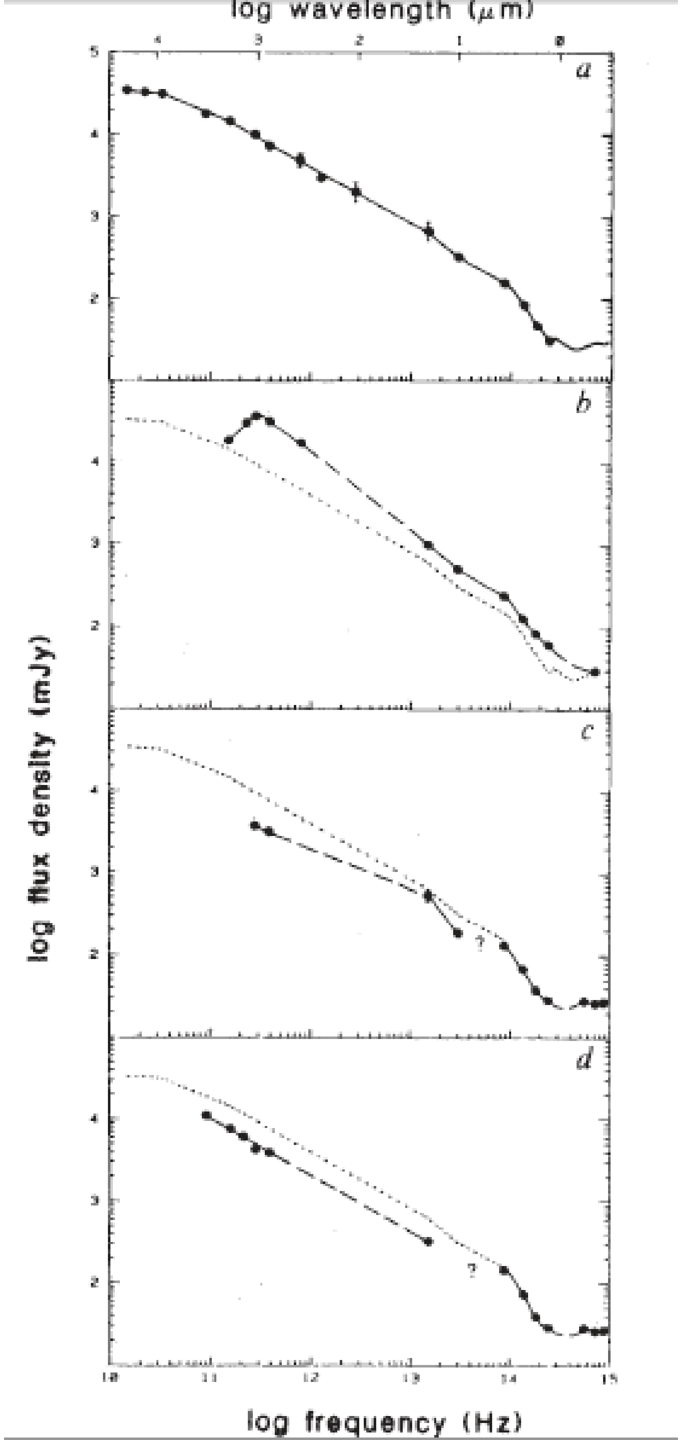
FIG. 1.—Energy distributions for the Seyfert 1 galaxies in our sample arranged by class: (*a*) class A, bare AGNs; (*b*) class B, reddened AGN; (*c*) class C galaxy-dominated AGN; and (*d*) unclassifiable AGNs (too little data). Where optical data were taken through apertures larger than 10", large symbols have bee used to highlight the increased likelihood of stellar contamination. *Circles*, optical *UBVR* photometry; *squares*, ground-based infrared *JHKLMNQ* photometr *filled circles and squares*, starlight-subtracted data. *Open triangles*, *IRAS* 12, 25, 60, and 100 μm photometry; *filled triangles*, smaller aperture KAO measurement Upper limits are 3 σ. For reference, we indicate at the right of each plot the value of νf(ν) measured at log ν = 18.08 (6 keV) to give an indication of the power bei radiated in the X-ray band.

Monitoring of Blazars

(sub)mm andIR monitoring of flares

e.g. Robson et al (1986)

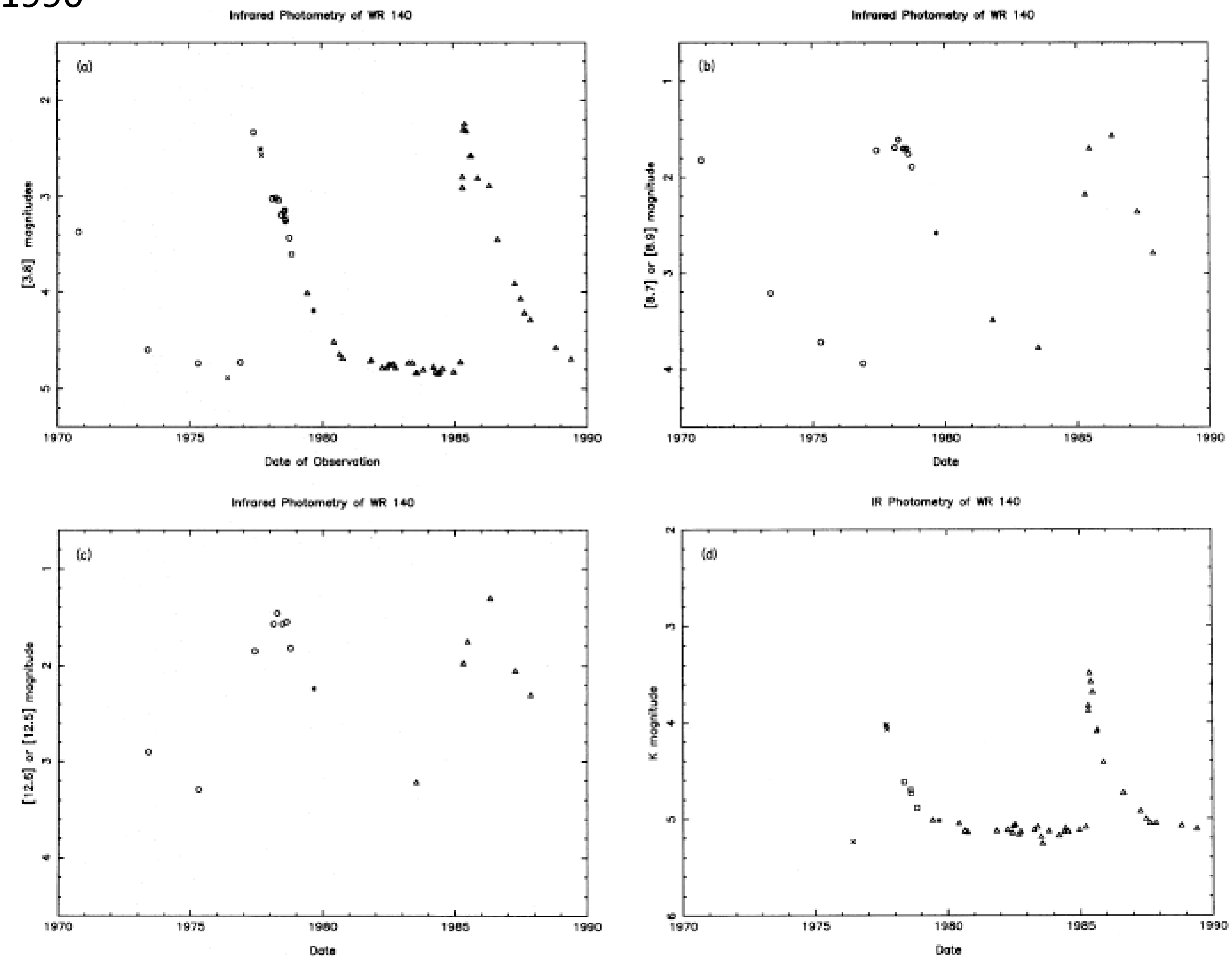
Evolution of 3C273 from 1983 to 1986



Dust production in W-R stars

Williams et al 1990

The Wolf–Rayet system HD 193793 – I 665



UCL Spectrometer (1980-1991)

30 Si:As Rockwell detectors

Individually mounted and connected to a bias resistor and FET

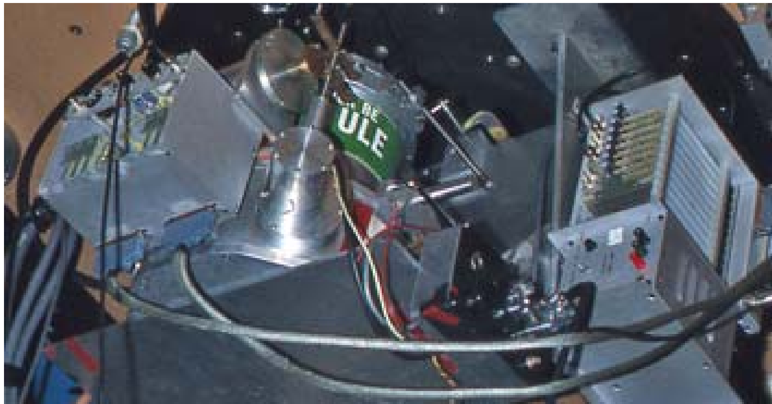
Warm pre-amps mounted on the cryostat

30 up/down counters synchronised to the chop movement to provide the signal.

Shipped and reassembled for each observing run.

UKIRT (and Palomar) gave the best sensitivity and so most extragalactic work was done there.

Characterization of emission from many classes of objects at UKIRT, IRTF and/or the AAT



Galaxy Spectra

Mid-IR spectrum is an excellent discriminator of dominant nuclear energy source.

Generic' HII region galaxy spectrum, modulated by different silicate extinction depths

AGN : Seyfert 2s have deeper Silicate absorption than S1

UIR emission bands :

- carriers destroyed by hard AGN photons

Low metallicity/high excitation nuclei

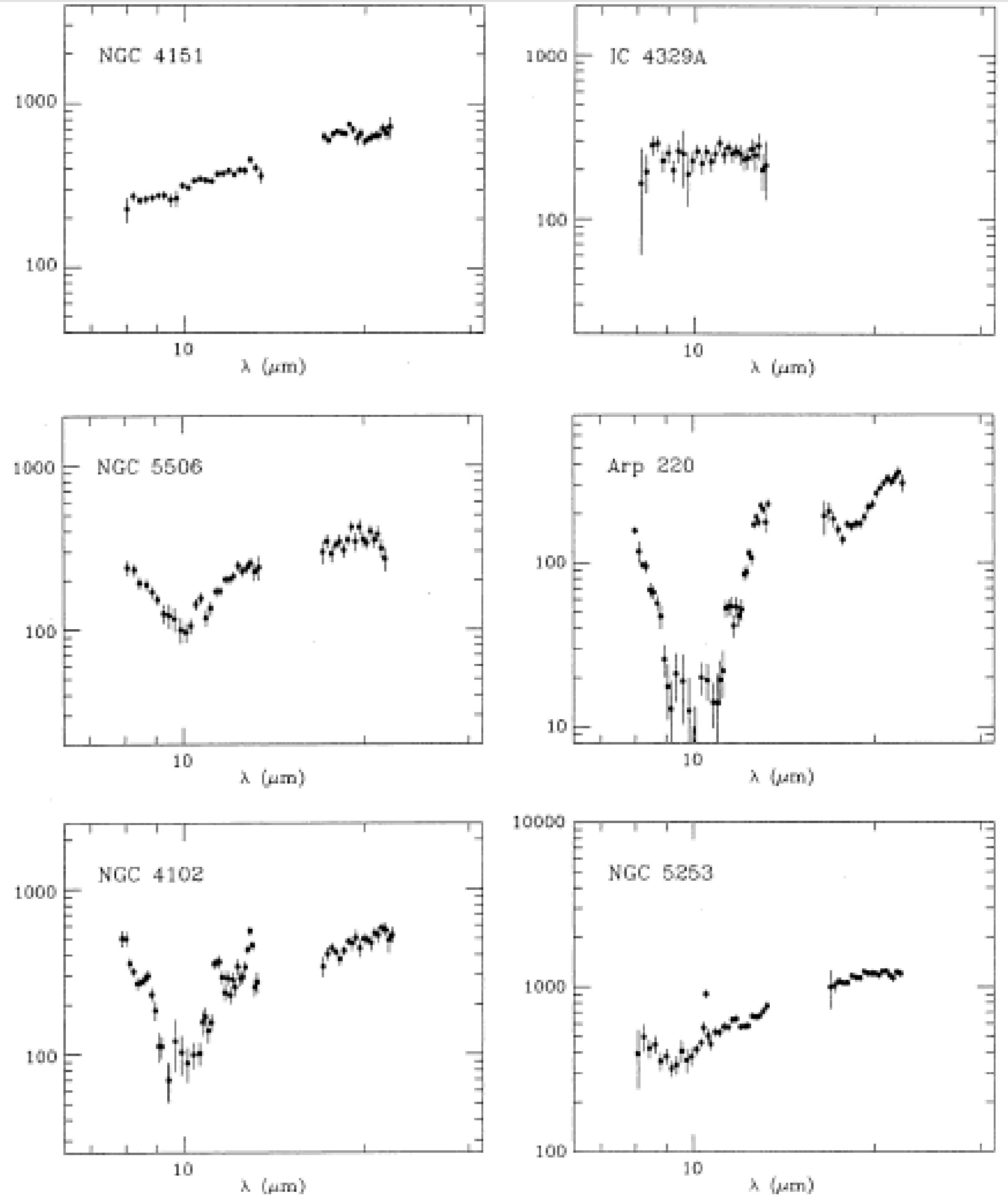
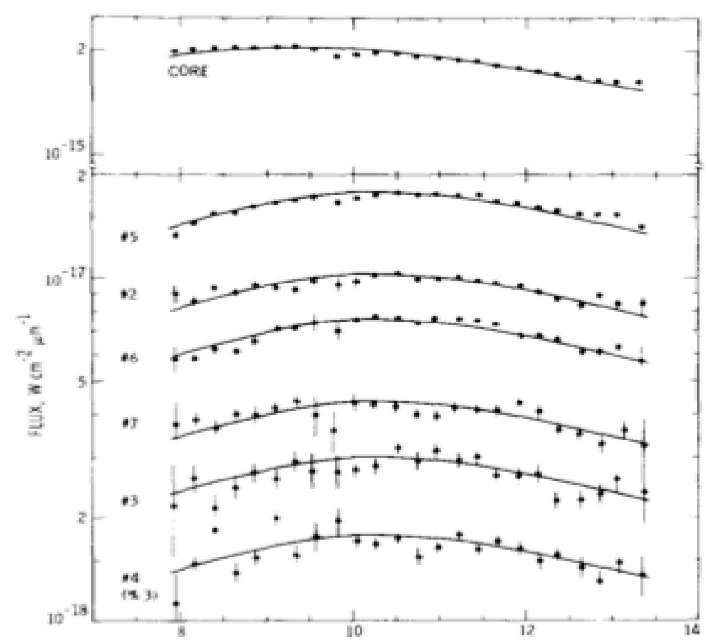


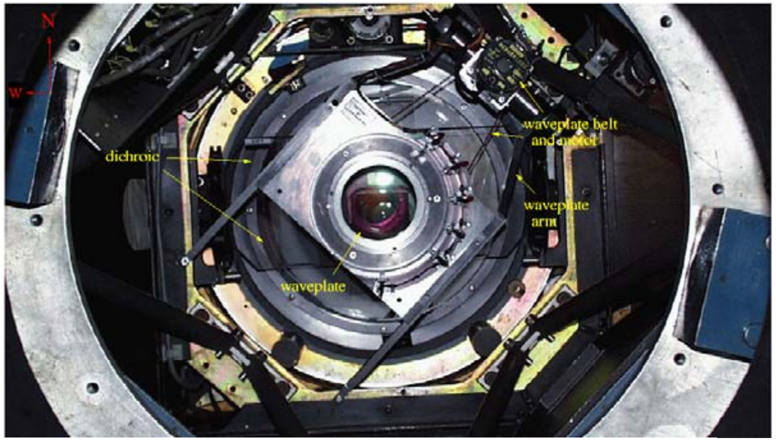
Fig. 1. 8-13 and 17-22 μm energy spectra (in units of 10^{-19} Wem^{-2}) of six galaxy nuclei showing the diversity of spectral shapes in this region. NGC 4102 has a spectrum dominated by the UIR features together with [NeII] emission, whilst NGC 5253 is a much higher excitation HII region galaxy with a strong [SIV] line. NGC 5506 and Arp 220 have obvious silicate absorption bands, the former also shows a [SIV] emission line whilst the latter has weak UIR emission bands. NGC 4151 is a Seyfert galaxy with evidence of a dust emission peak near 20 μm whilst IC 4329A has a featureless spectrum that could have thermal and/or non-thermal contributions in the mid-infrared. (Data from refs 5,7,13,24,36).

Comet IRAS Araki Alcock

- Closest approach to earth 4.7 10^6km in May 1983 while we were observing.
- Even from MK it was a spectacular fuzzy object as it whizzed cross the sky, moving by >30 degrees in the night.
- Autoguided on the nucleus as it tracked 10 degrees across the sky using the quadrant stuck on the monitor.
- Spectra at several positions showed silicate emission in the coma but featureless blackbody emission on the core.
- Spatial scans and brightness temperature arguments indicated a nucleus size of 5km



Mid-IR polarimetry



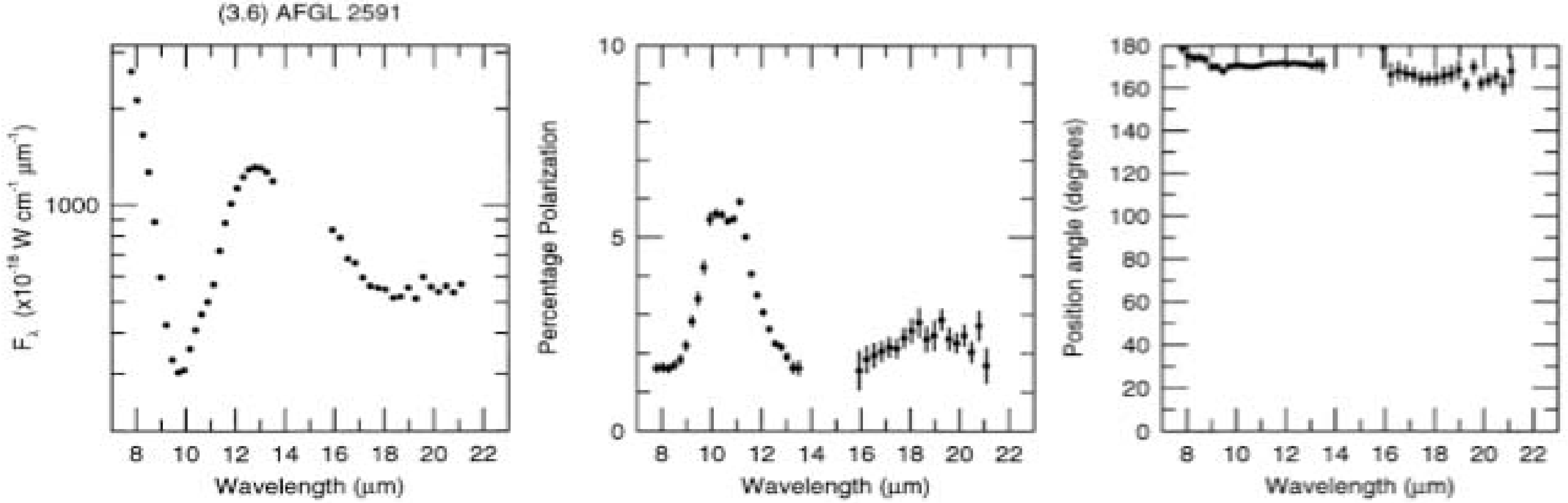
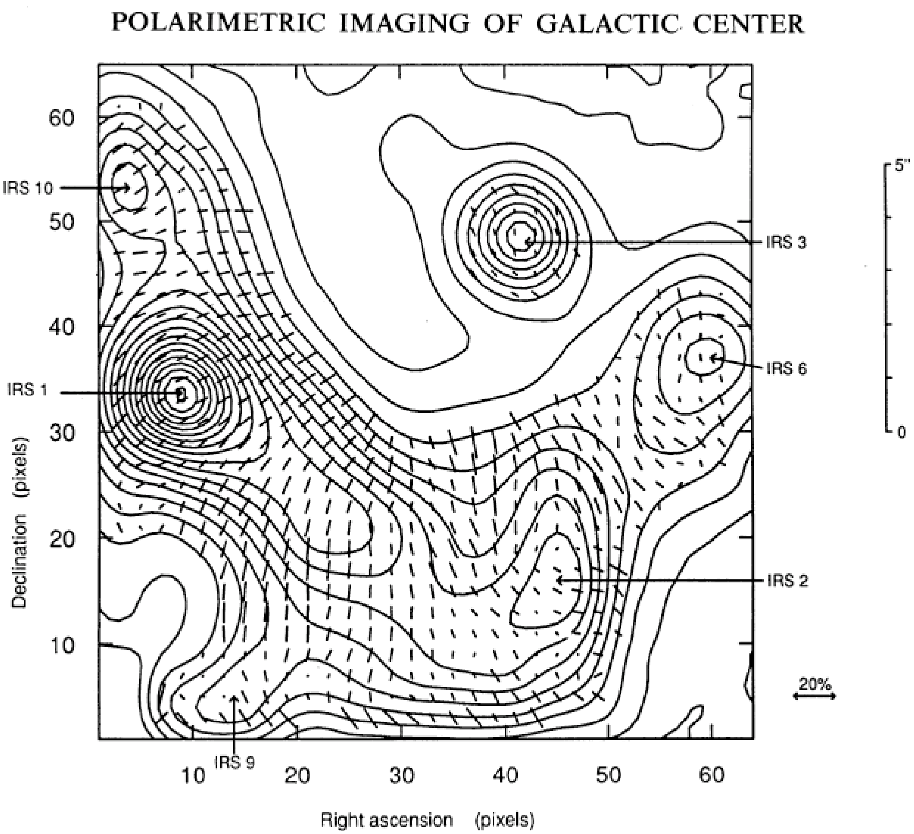
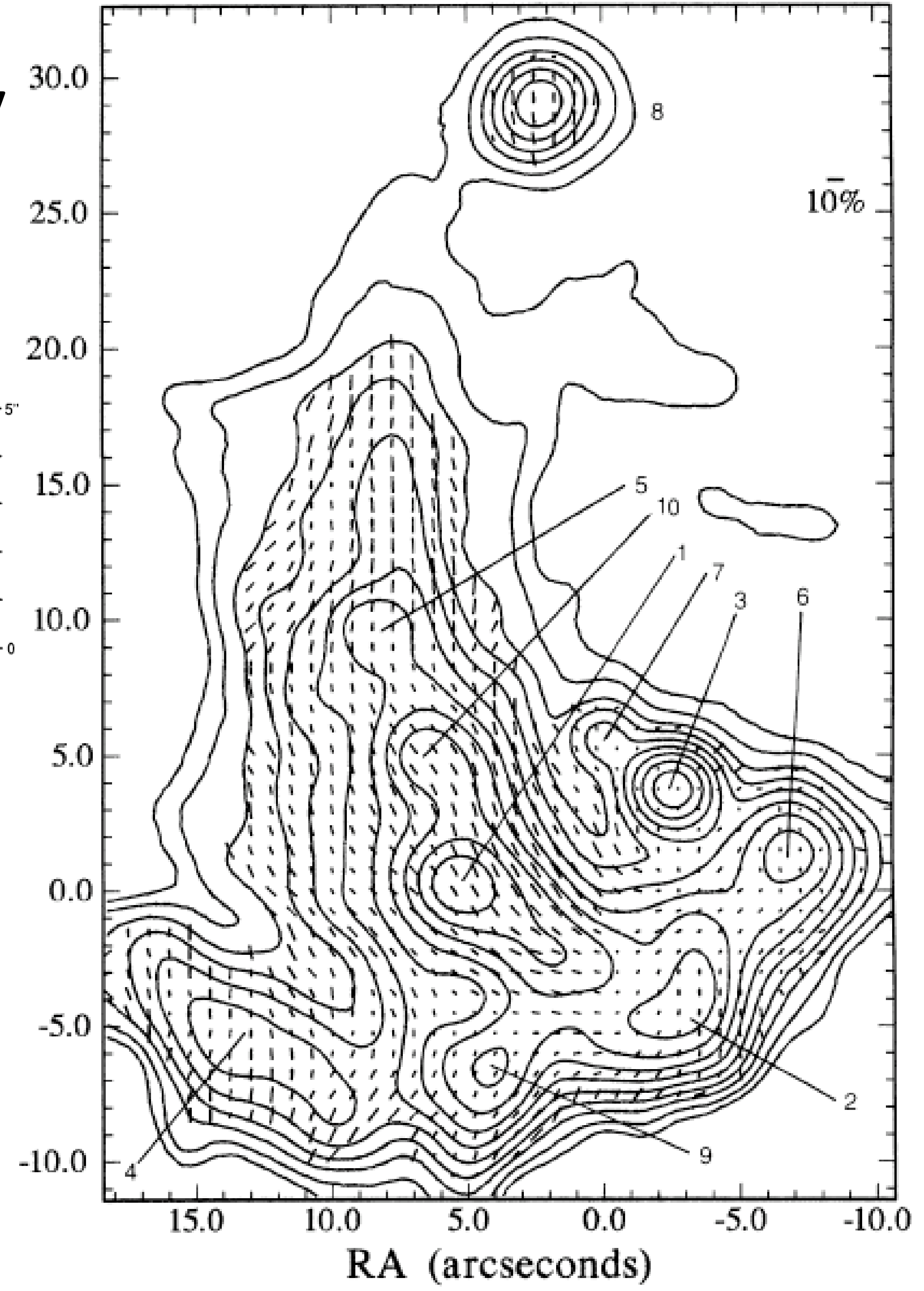


Figure 3 — *continued*

- UCLS, GSFCam, NIMPOL , Michelle
- Using a KRS5 grid and CdS and CdSe waveplates rotated by a custom stepper motor installed above the dichroic initially and later using IRPOL
- Apart from early work by Capps & Dyck, this is accounts for almost all mid-IR polarimetry available to date.

Imaging Polarimetry





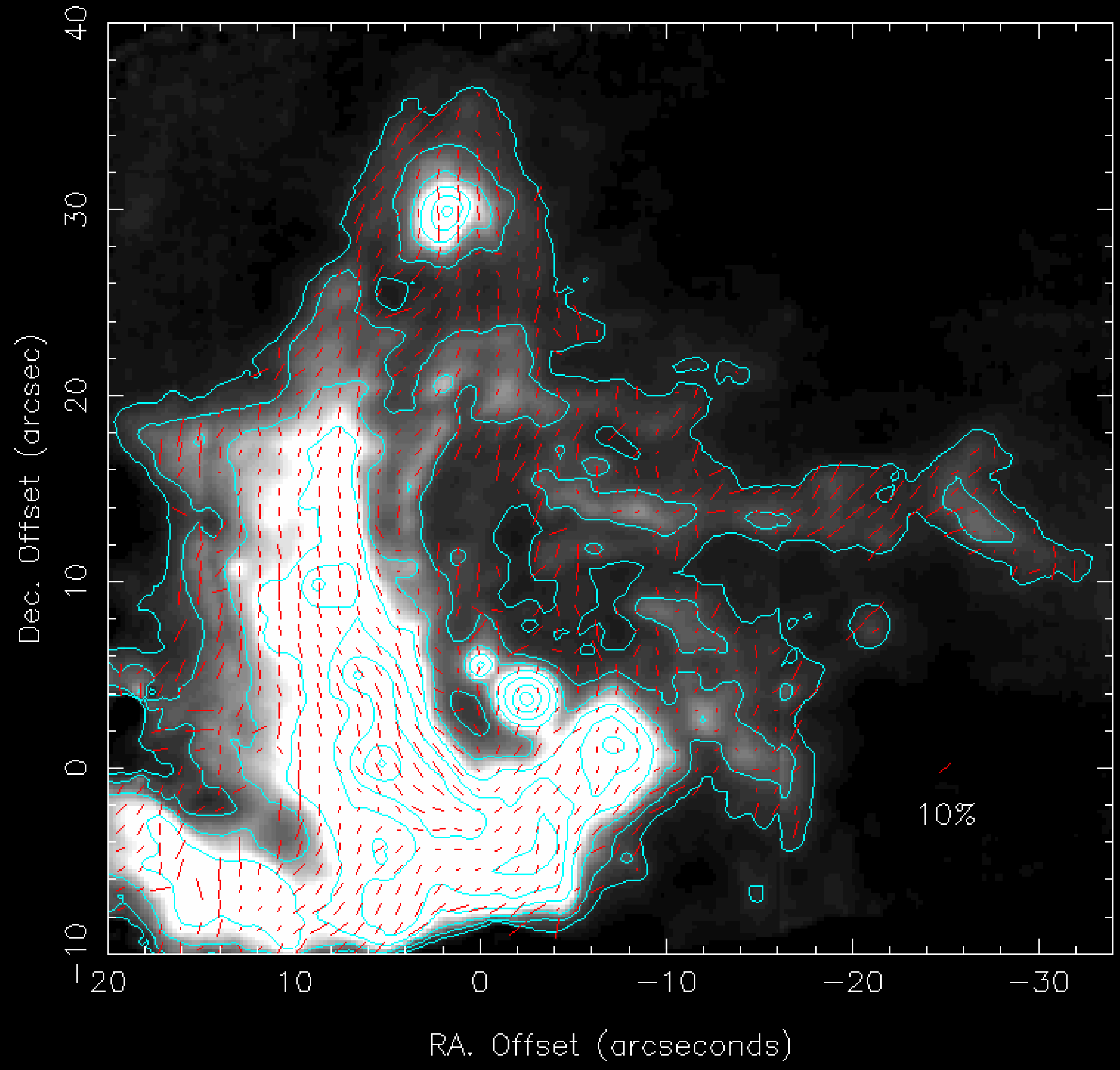
Goddard camera (1989),

NIMPOL (1995),

Michelle (2004)

Michelle (UKIRT)

Glasse et al (2003)



CGS3 1990-1998

- Built at UCL
- 32 Si:As detectors
- Produced ~60 papers from 1992-2006
- Mostly Galactic objects
- Stellar, ProtoStellar and PPN
- Mid-Infrared calibration

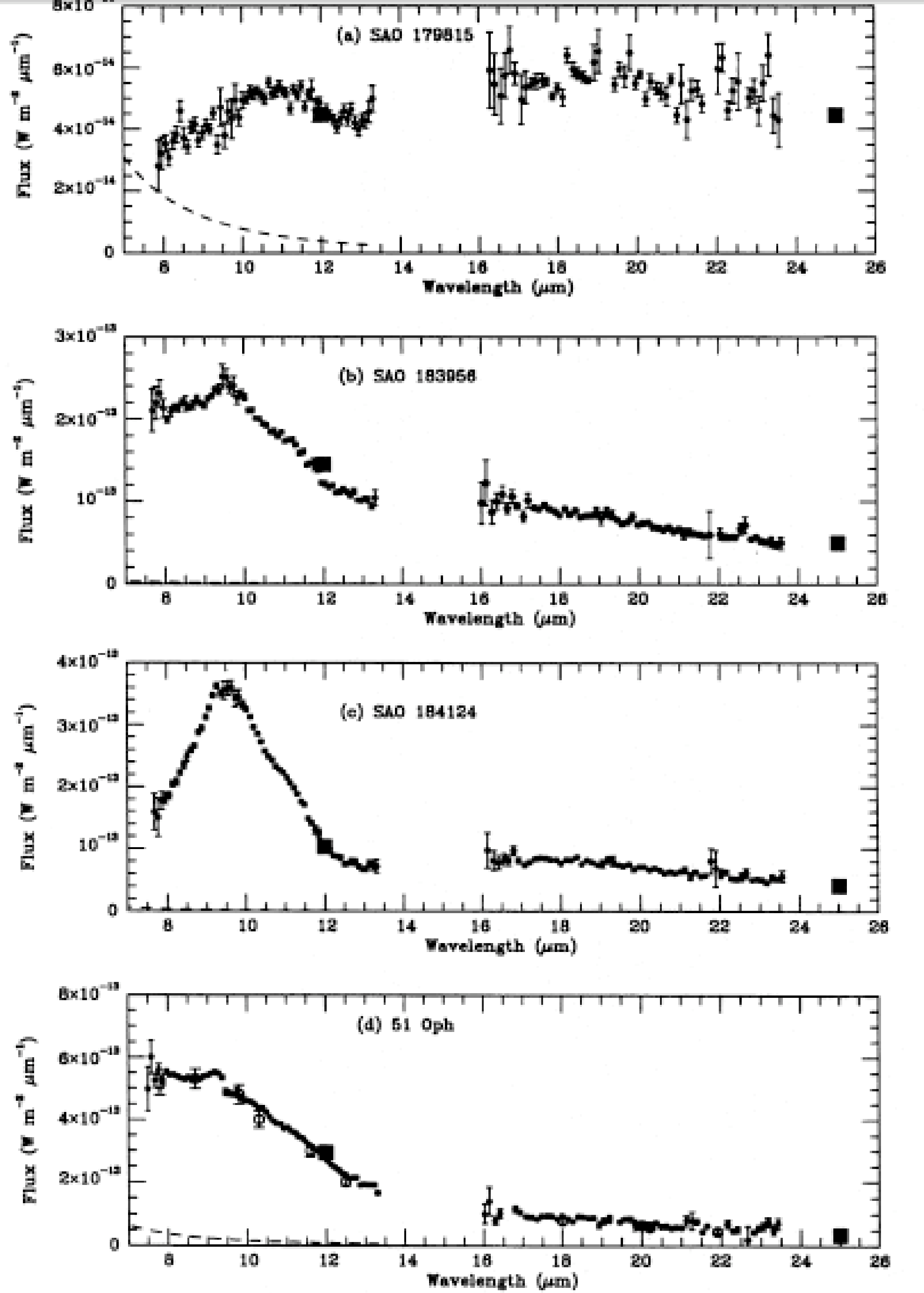


Figure 1. CGS3 10- and 20-μm spectra of Vega-like stars. Points with error bars: observed spectrum; filled squares: *IRAS* data; d model atmosphere (see text).

Sylvester et al 1996

Justtanont (1996) Spectroscopy of post-AGB objects with unusual spectral features

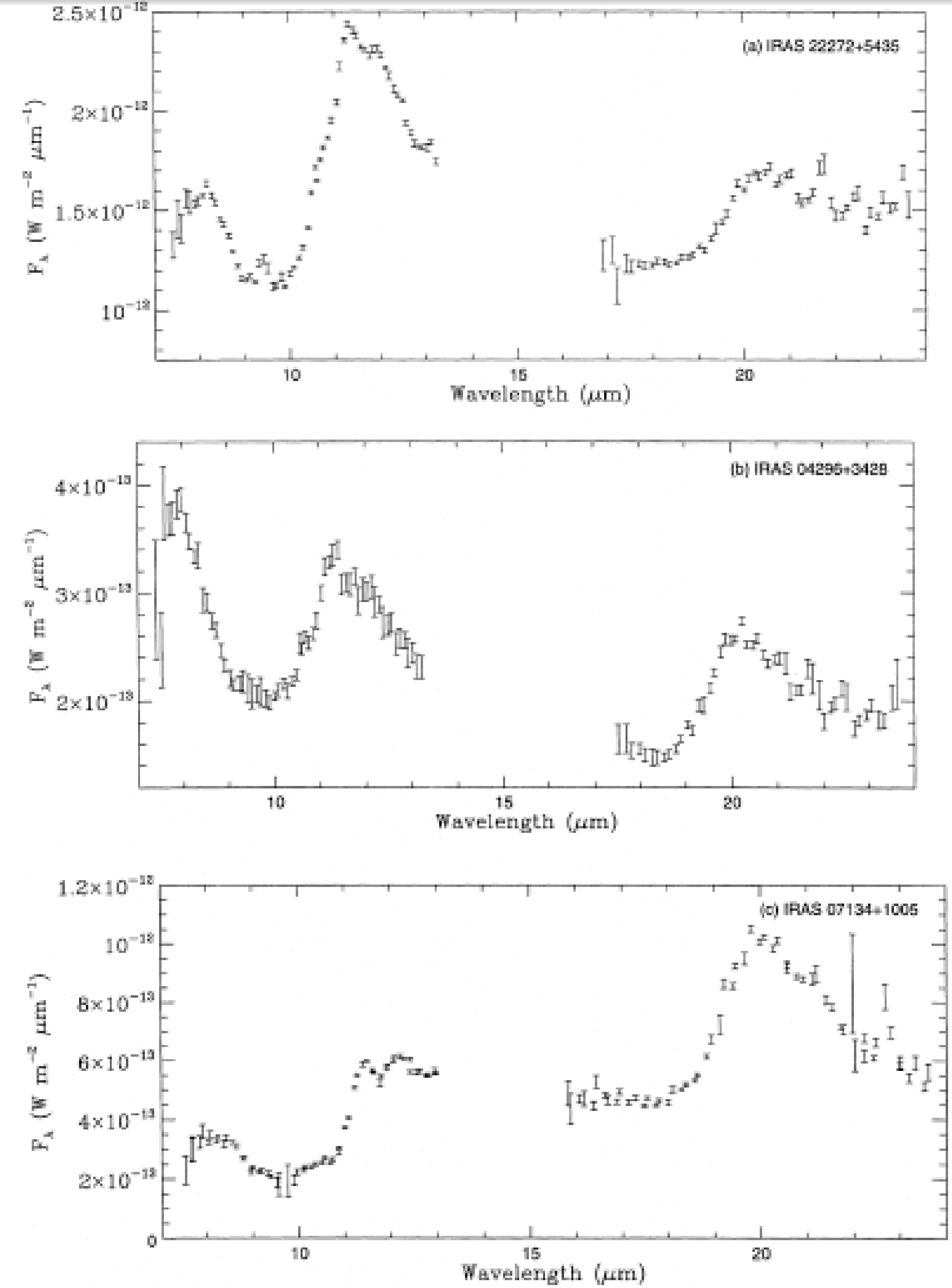
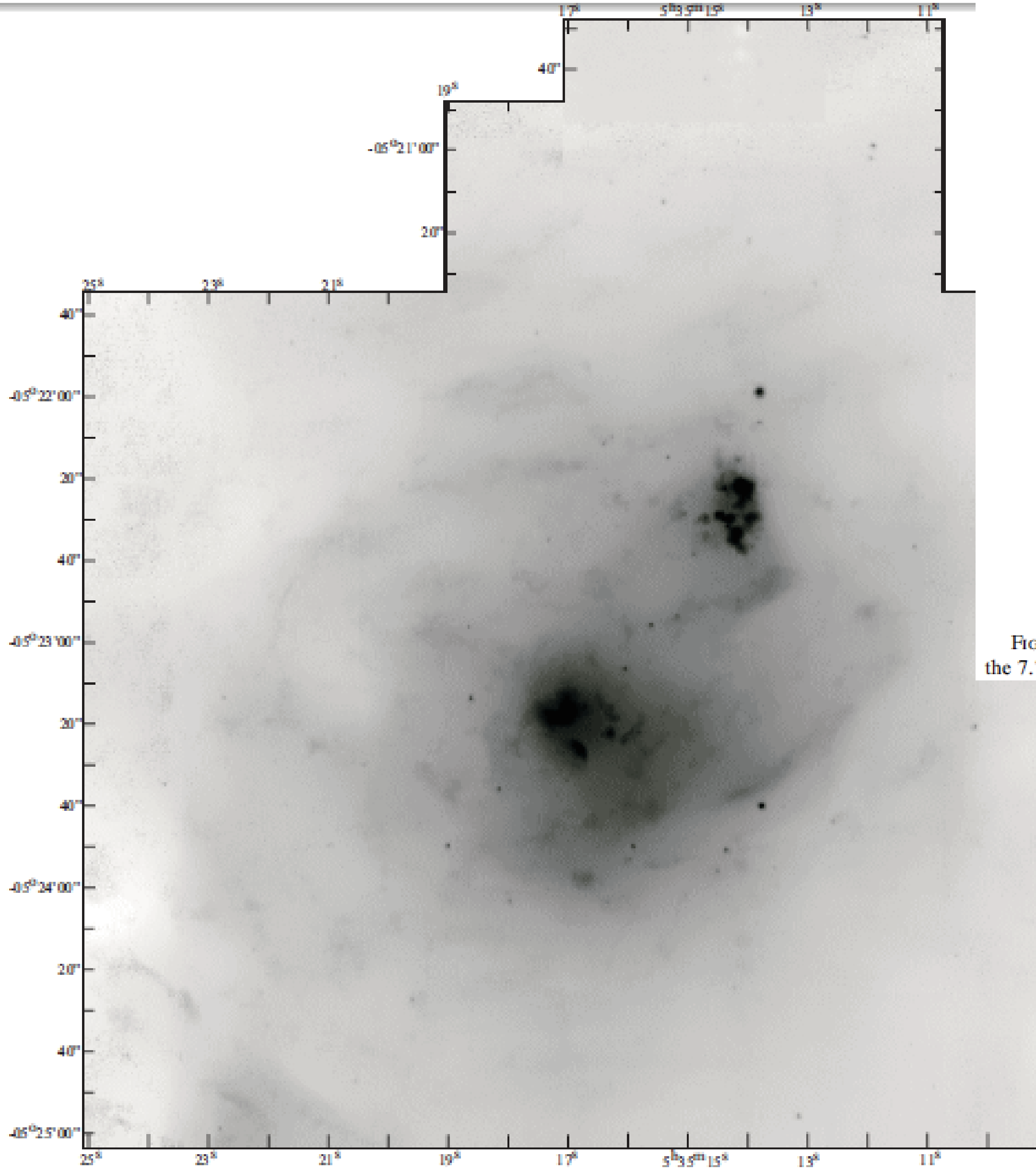


Fig. 2a–h. The 10 and 20 μm spectra of the post-AGB and related objects. The sources are again ordered as a function of decreasing spectral type for the post-AGB objects (**a**–**f**). **a** IRAS 22272+5435; **b** IRAS 04296+3429; **c** IRAS 07134+1005; **d** SAO 163075; **e** GL 2688; **f** GL 618; **g** GL 3068; **h** IRAS 21282+5050 Note that the 10 and 20-μm spectra illustrated in **a** and **b** for IRAS 22272+5435 and 04296+3429, respectively, were obtained using CGS3, whereas UCLS 10-μm spectra of these objects are shown in Figs. 1a and b

10μm Cameras

- GSFC (Gezari) :Imaging Polarimetry 58x62
- MIRACLE 58 x 62 Cameron et al 1993
- Berkley Camera Keto et al (1992) 10 x 64
- MAX Robberto & Herbst (1998) 128 x 128
- MIRAC 128 x 128 Rockwell
- MICS Imager/Spectrometer (Miyata et al 1999)
- MIRAS 128 x 128



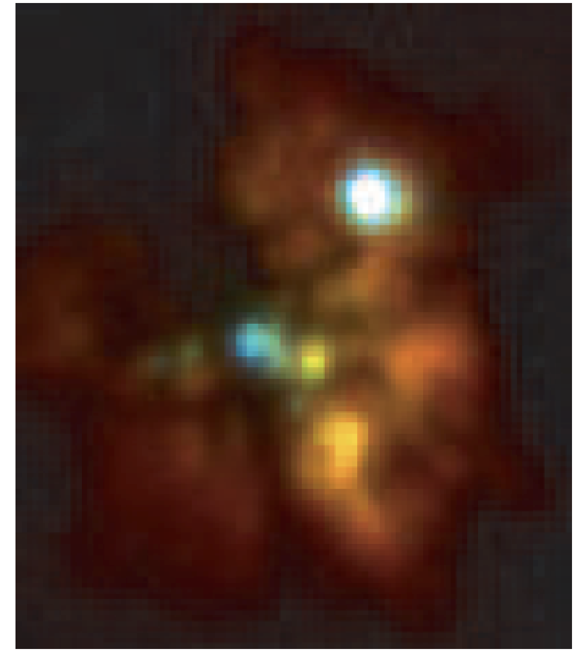


Fig. 9.—Color composite image of the BN/KL region obtained combini the 7.7 μm (*blue*), 12.4 μm (*green*), and 19.9 μm (*red*) images.

Fig. 2.—Final 10 μm mosaic of the Orion Nebula. The two saturated sources at the center of the field are (1) to the southeast, the Ney-Allen Nebula, in correspondence with the Trapezium stars, and (2) to the northwest, the BN/KL complex.

Robberto et al (Max)

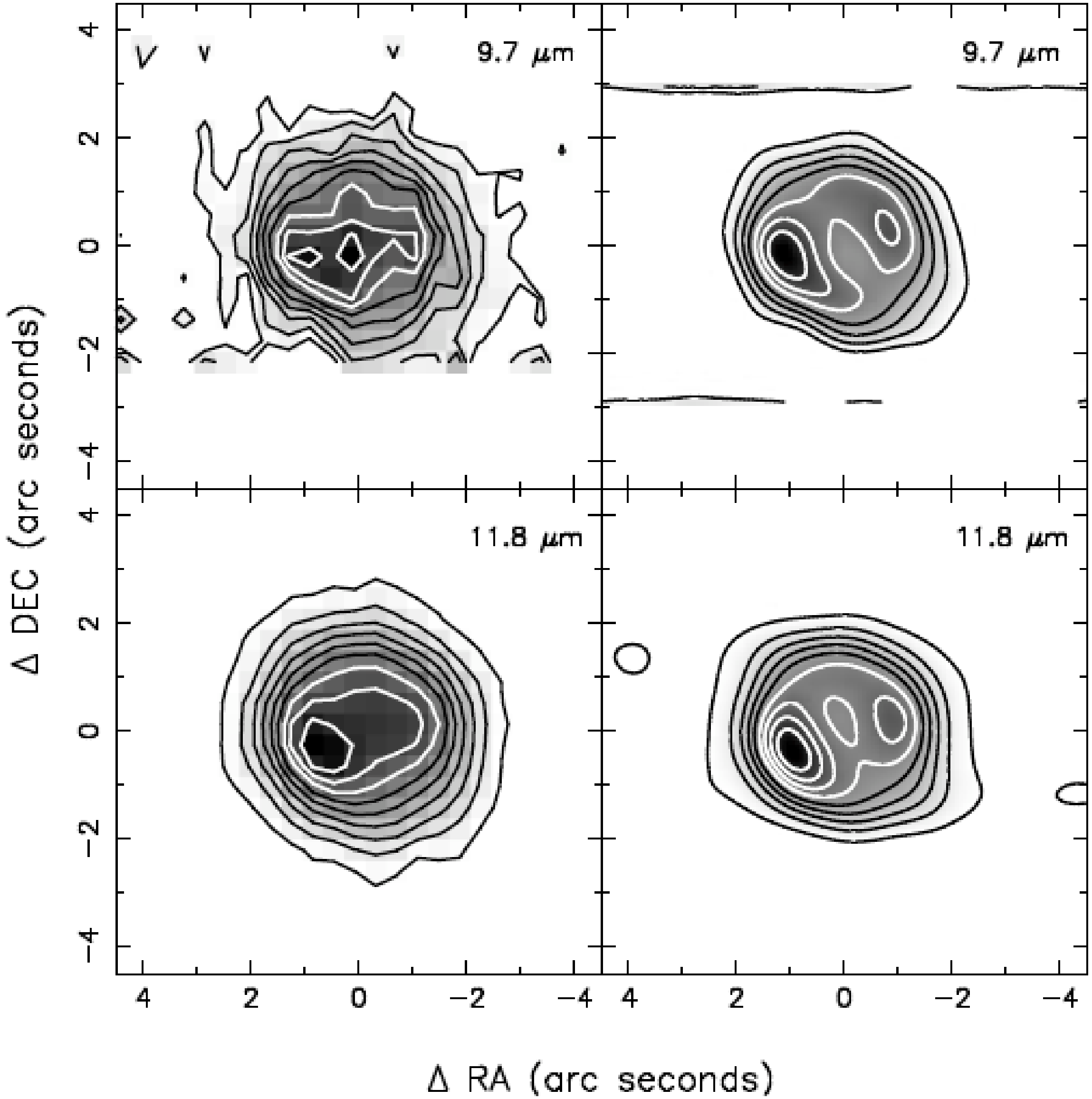


FIG. 3.—Images of IRAS 07134 + 1005 (*left*) and deconvolved images (*right*) at 9.7 and 11.8 μm. The central F5 Ia star can be seen peaking in the center of the toroid's two limb-brightened peaks at 9.7 μm; at 11.8 μm, the dust emission overpowers the star. The central star was subtracted from the 9.7 μm image before deconvolution. The spacings of the contour levels in all four images are 10% of the peak. The lowest contour levels are also 10% of the peak value for all images except the deconcolved 9.7 μm image (*top right panel*), which has the lowest contour level that is 30% of the peak. Peak values for figures, in the order left to right, top to bottom, are 0.68, 1.0, 2.4, and 4.3 Jy arcsec^{-2}.

Meixner et al 1997 (Berkeley Camera)

Impact of Mid-IR results

Established the nature of mid-IR emission from different classes of galaxy

Demonstrated the remarkable differences in spectral characteristics of AGN and HII region nuclei

Helped clarify the properties of the UIR bands – leading to the identification as C-rich particles that exist in the regions surrounding HII regions

Measured the thermal properties of asteroids and comets

Elucidated the properties of Vega excess disks and PPN

Identified the polarimetric signatures of amorphous and crystalline silicate grains and the ability to trace magnetic fields at arcsec resolution

~10% of the published output (> 150 papers over 20 years).

The combination of mid-IR with near-infrared and sub-mm instruments offered real advantages . Long term programmes and UKIRT Service were critical to many projects