40th Anniversary of the First Far Infrared Fine-Structure Line Observations:

Recollections of the First Ten Years

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With photographs from the collection of George E. Gull
Cornell Univerrsity

Heidelberg, June 8, 2015

A Puzzling Observation that proved to be wrong

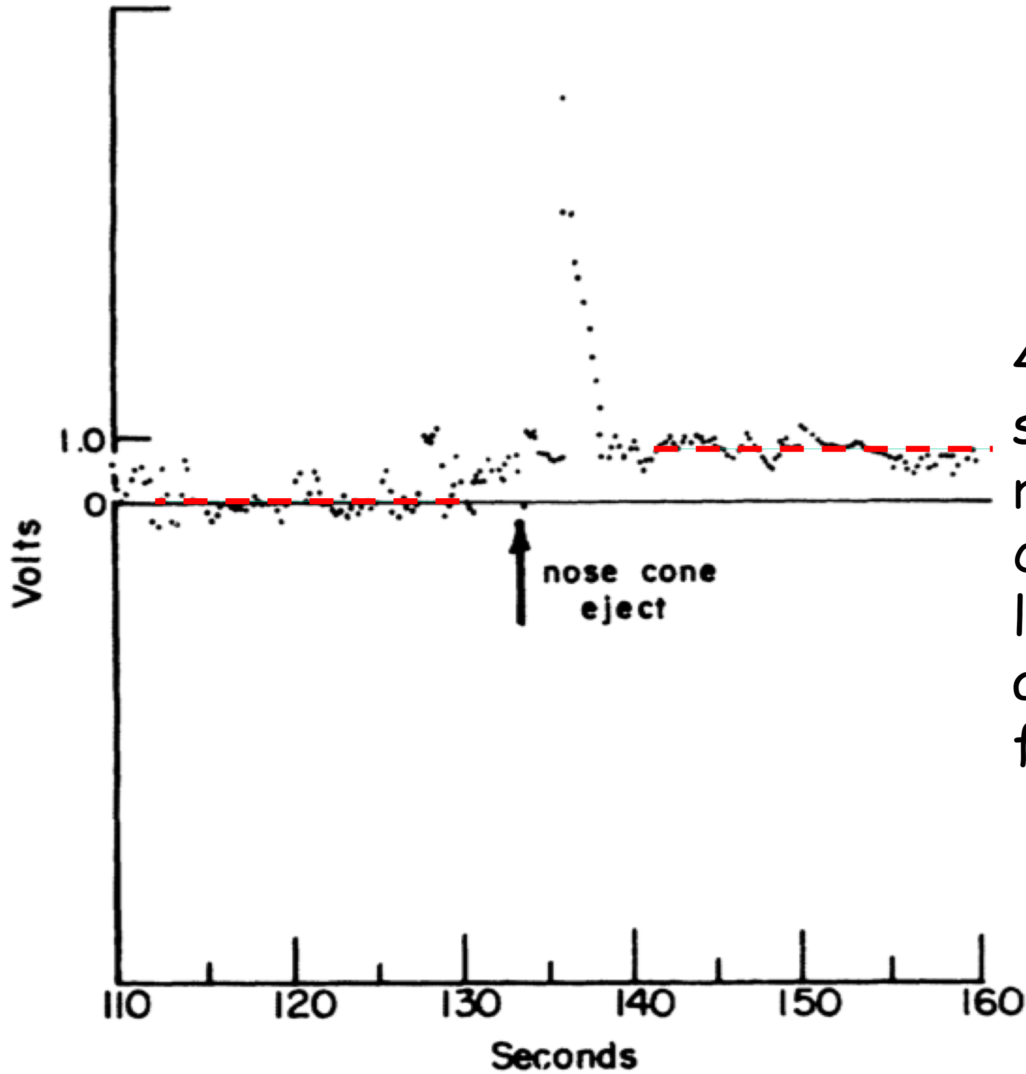


FIG. 1. Data points obtained just prior to and after ejection of the telescope cover and nose cone. The big signal just after ejection is produced by the warm nose cone. However, this signal goes away as the telescope's viewing direction is moved.

400 – 1300 μm mean signal strength before and after rocket nose cone and cryogenic cover ejection from a launched liquid helium cooled telescope at an altitude of 130 km on a flight on February 29, 1968.

Kandiah Shivanandan, James R. Houck & Martin Harwit
Physical Review letters 21, 1460- 1462, 1968

Vahé Petrosian's 1970 Predicted Fine-Structure Line Emission from M42: At the time, none of these lines had yet been observed.

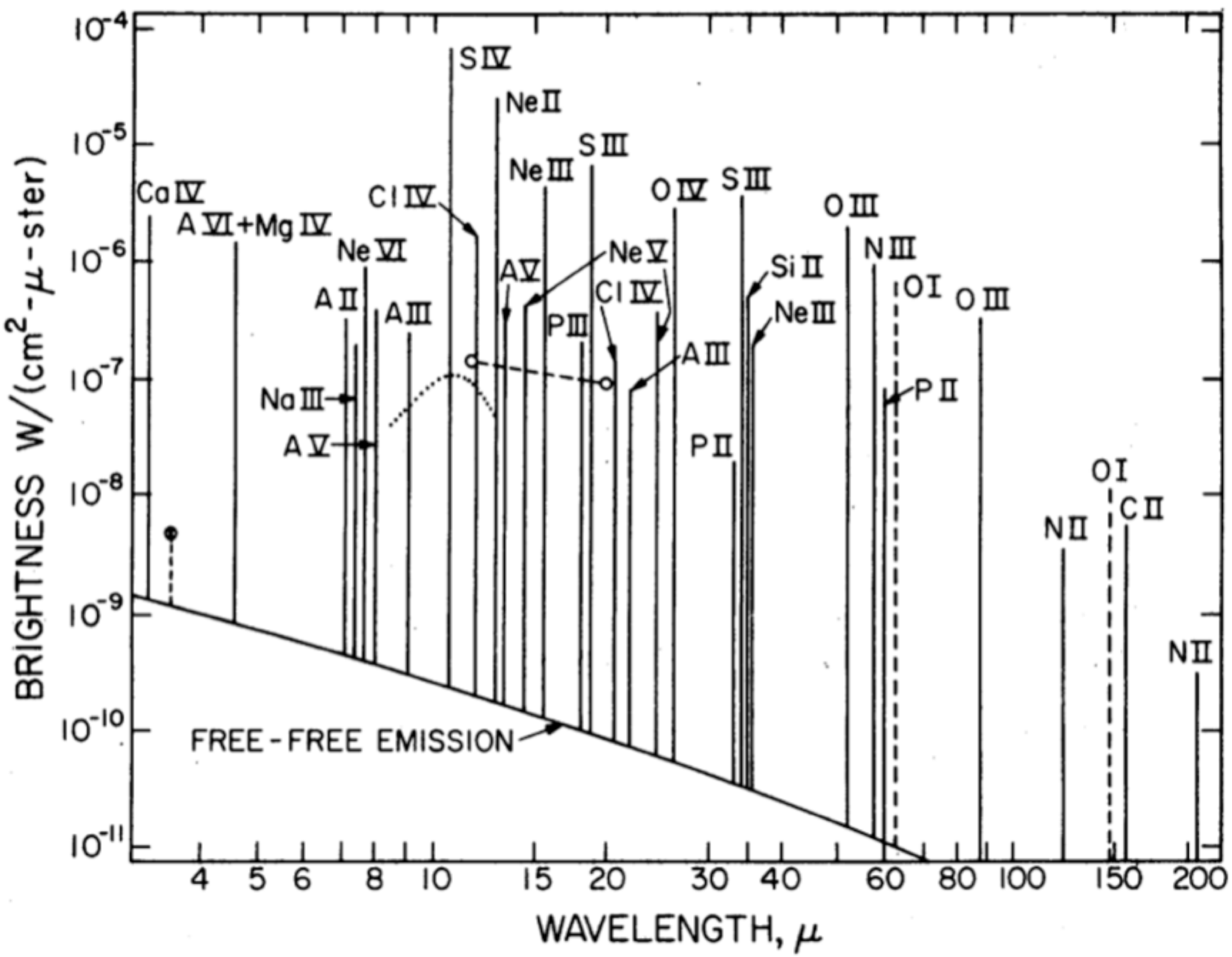


FIG. 3.—Fine-structure line intensities for the Orion Nebula averaged over 4′ of arc region. Free-free emission intensity obtained from extrapolation of the radio data with $T_e = 7000°$ K. Circled cross, from Ney and Allen (1969), refers to the whole nebula (4′ of arc). Open circles, from same authors, refer to 26″ of arc region around the Trapezium. *Dotted lines*, observations of Stein and Gillett (1969) for 15″ of arc region around the Trapezium.

V. Petrosian, ApJ 159, 833, 1970

The NASA Lear Jet at NASA's Ames Research Center
south of San Francisco

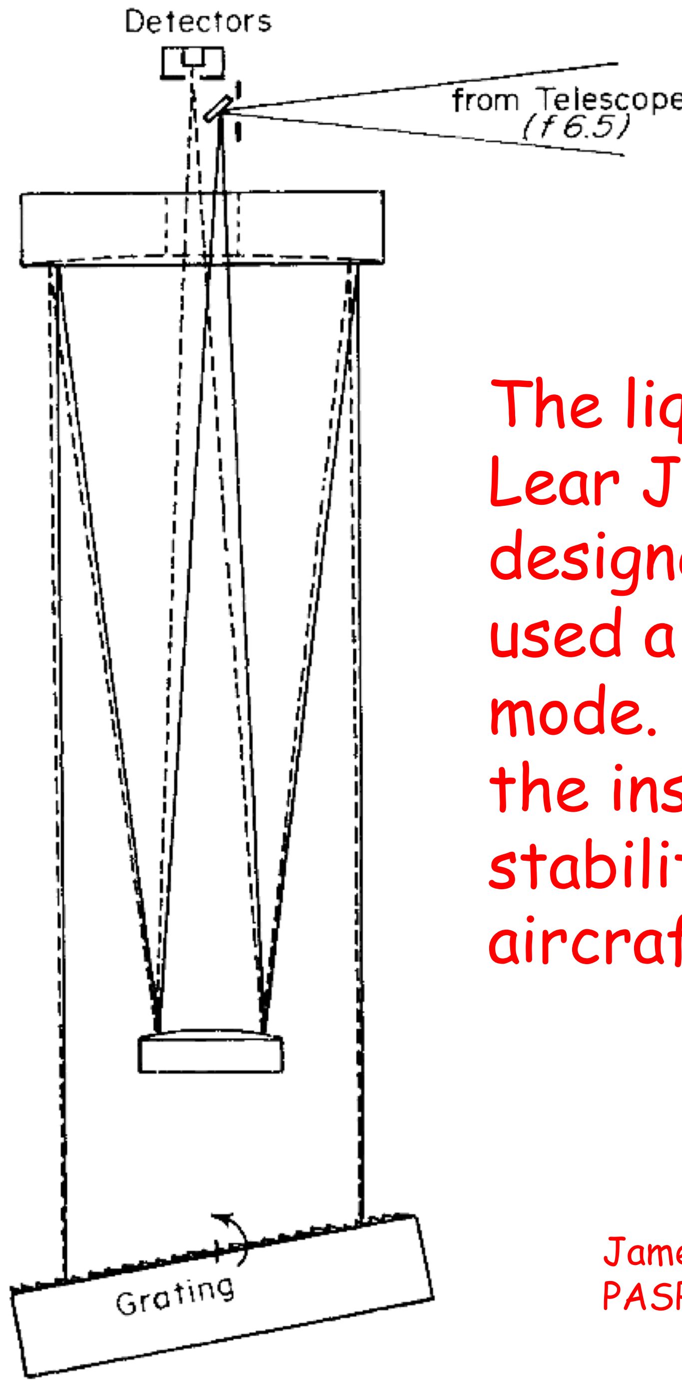


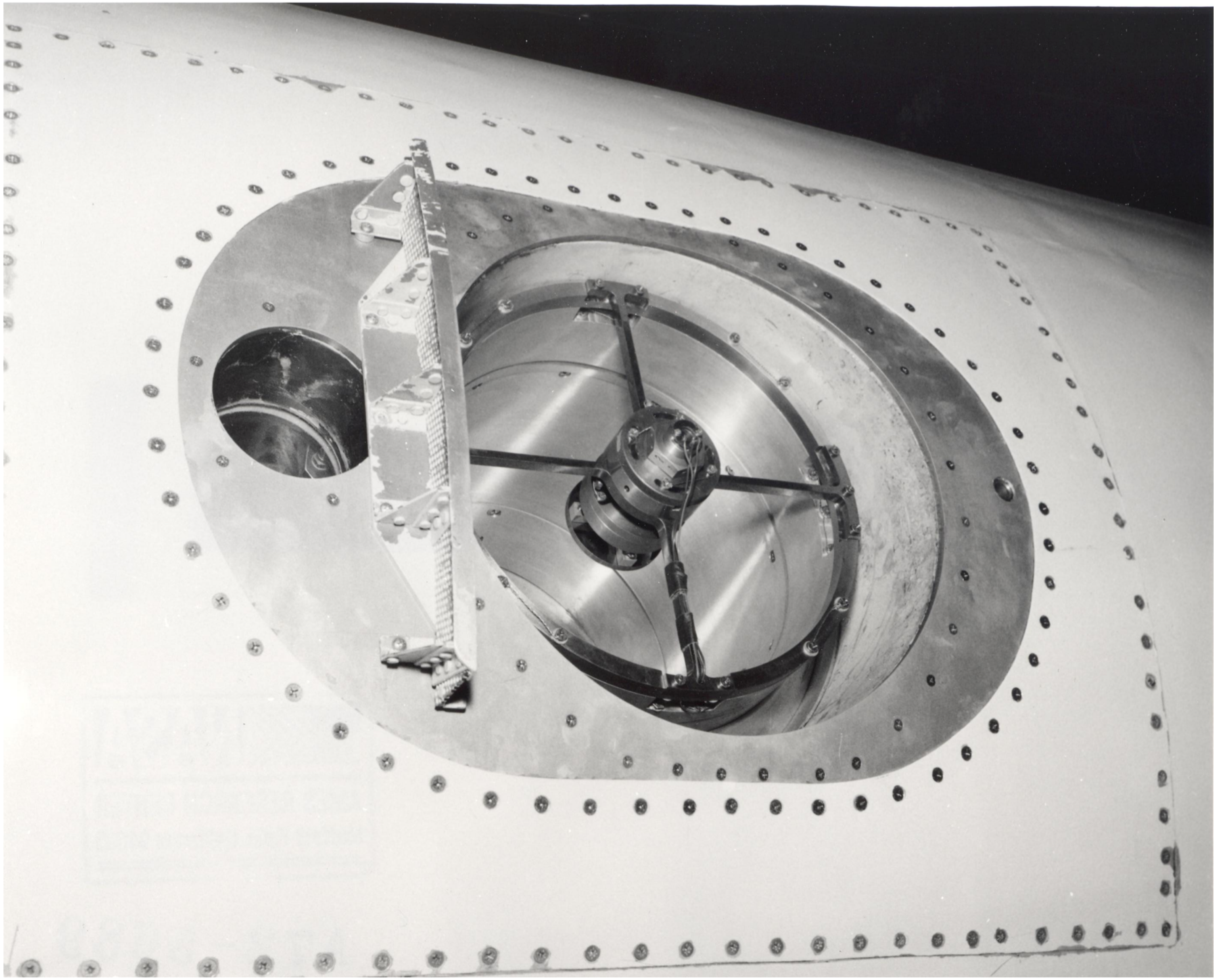
FIG. 1—Schematic drawing of the spectrometer.

The liquid-helium-cooled Lear Jet spectrometer designed by Jim Houck used a grating in Littrow mode. The simplicity of the instrument lent stability in the noisy aircraft environment.

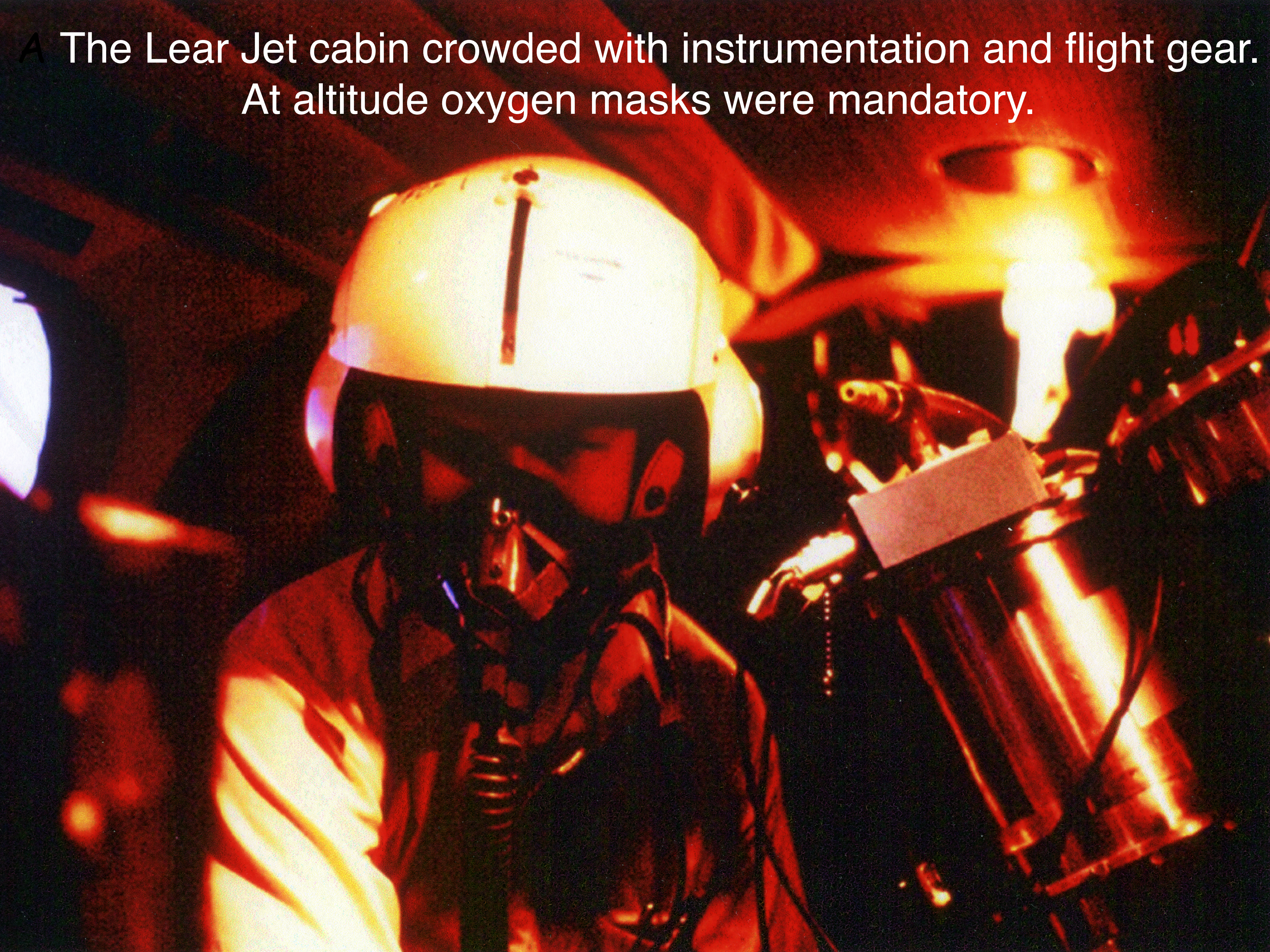
James R. Huck & Dennis B. Ward, PASP, 91 140-142, 1979.

Dennis Ward checking the Lear Jet telescope's eyepiece before a flight

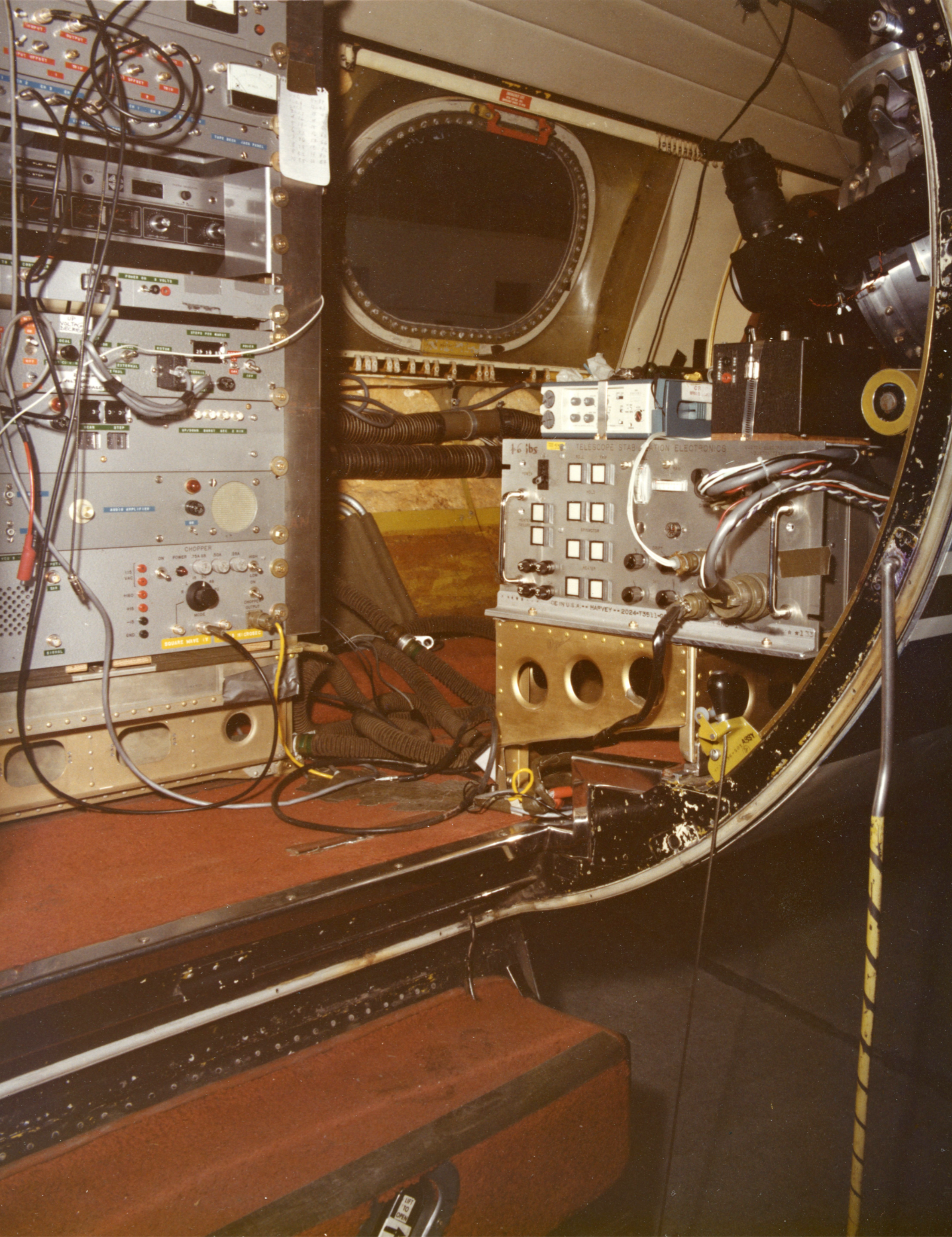
GEORGE GULL ALIGNING THE CRYO-OPTICS IN THE TINY LEAR JET CABIN



Opening in the side of the NASA Lear Jet through which the 30-cm (12-inch) telescope and its guide optics viewed the sky.



The Lear Jet cabin crowded with instrumentation and flight gear. At altitude oxygen masks were mandatory.



Left: View of the Lear Jet cabin through its open door and the steps, below, leading into its cabin. With the door closed one observer sat on the steps facing the data console

Right: Gary Melnick sitting on these steps, checks the incoming data flow.

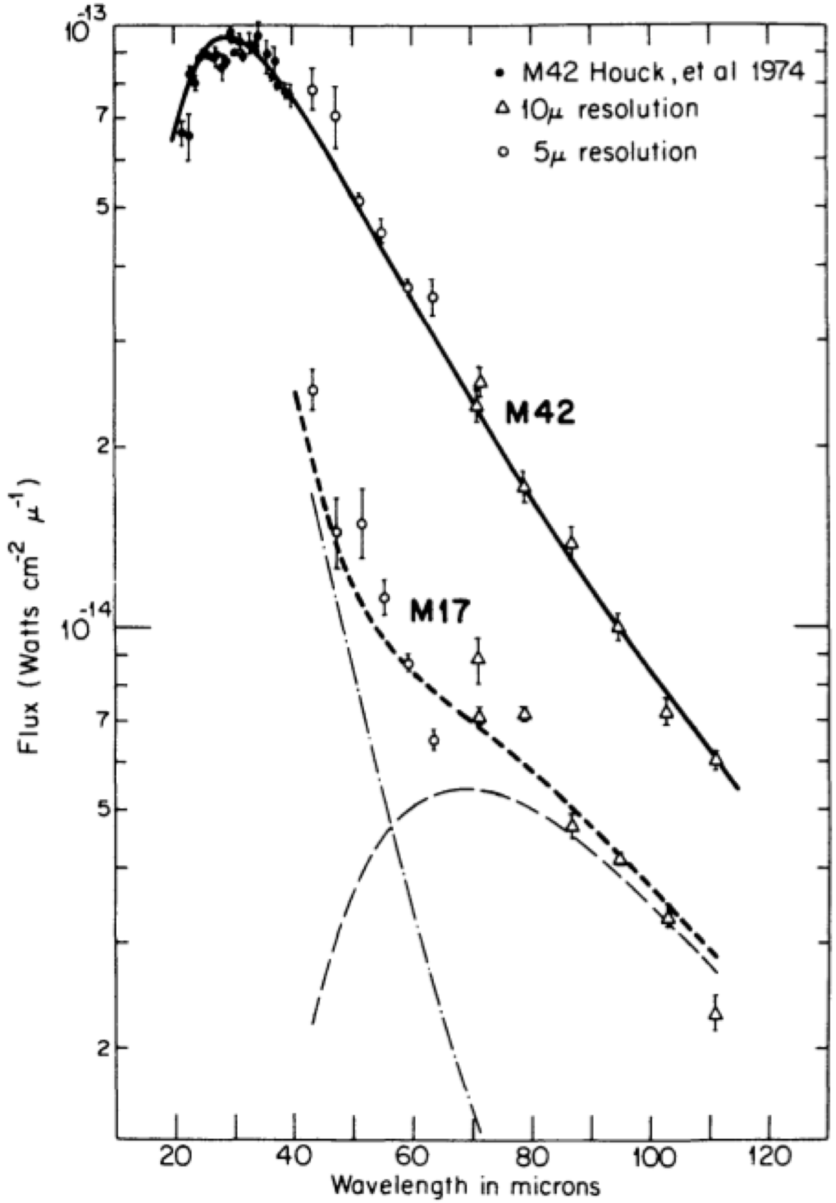


FIG. 1.—Spectra of M17 and M42, including M42 data from Houck *et al*. 1974. A 100 K blackbody (————) is diluted to fit the M42 data; the M17 data are fitted with a sum (— — — —) of diluted 30 K (—— ——) and 150 K (—— • —— •) blackbody functions with λ^{-2} emissivity dependence on wavelength.

An early coarse FIR M42 spectrum obtained with NASA's Lear Jet

Dennis B. Ward, Brian Dennison, George E Gull, and Martin Harwit, ApJ L75-77, 1976

Lear Jet Observations of [OIII] 88 µm Emission: Initial Discovery and Further Findings

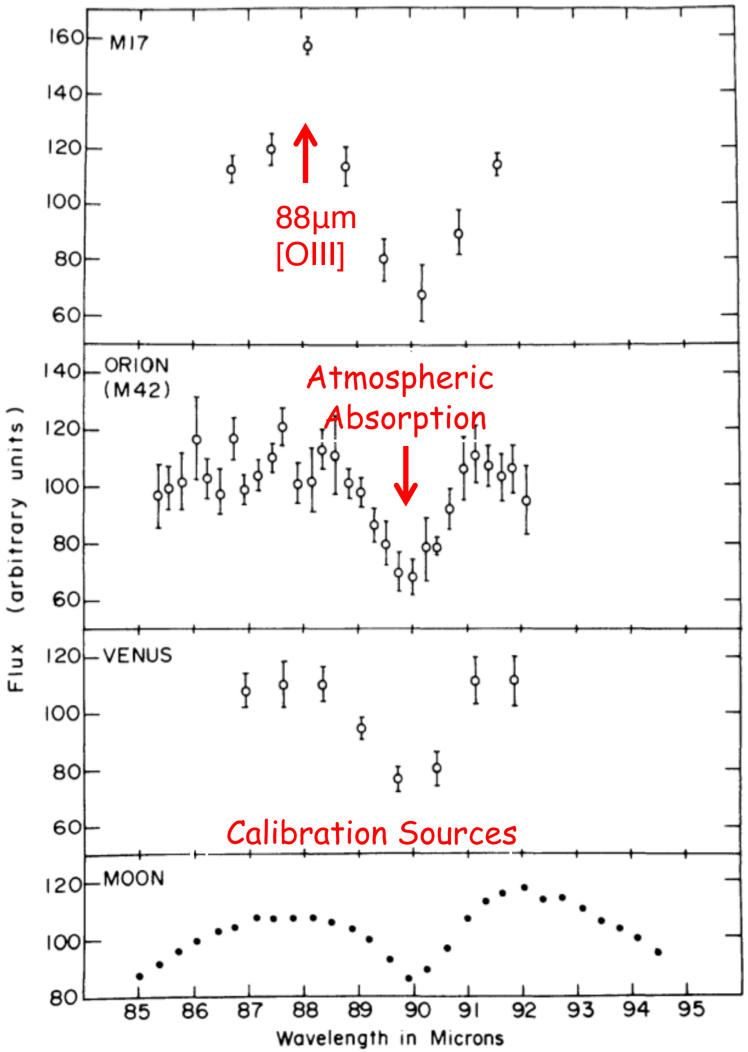
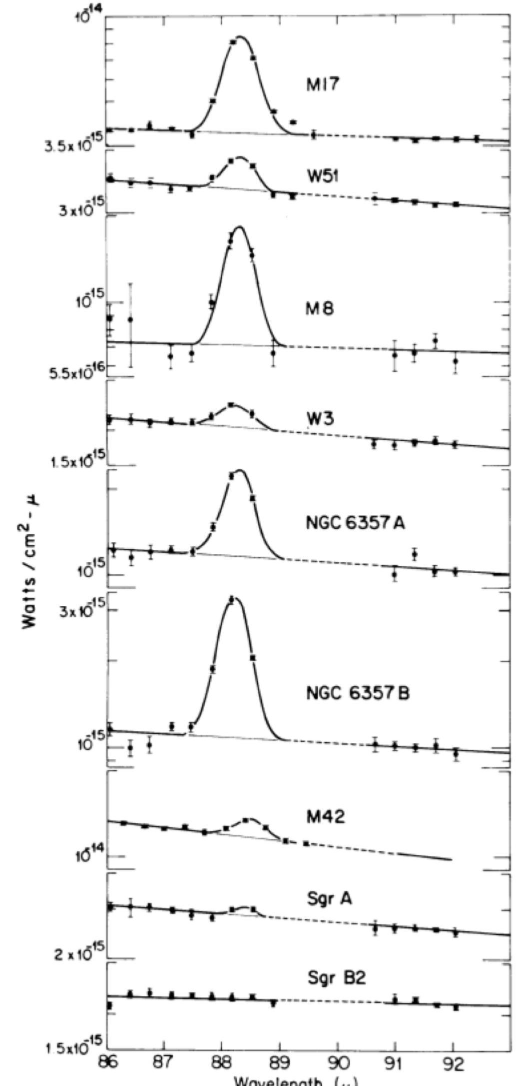


FIG. 1.—Raw spectra of M17, M42, Venus, and the Moon. The spectra have been normalized to the same scale, and overall slopes have been removed by division with appropriate blackbody functions.

Discovery of the 88 µm line April 1975

Dennis B. Ward, Brian Dennison, George E. Gull & Martin Harwit, ApJ 202, L31-32, 1975



The 88 µm line observed in December 1976 and June 1977 at twice the earlier spectral resolution. The M17/M42 line strength ratio is clearer here.

Frank W. Dain, George E. Gull, Gary Melnick Martin Harwit & Dennis B. Ward, ApJ 221 L17-21, 1978

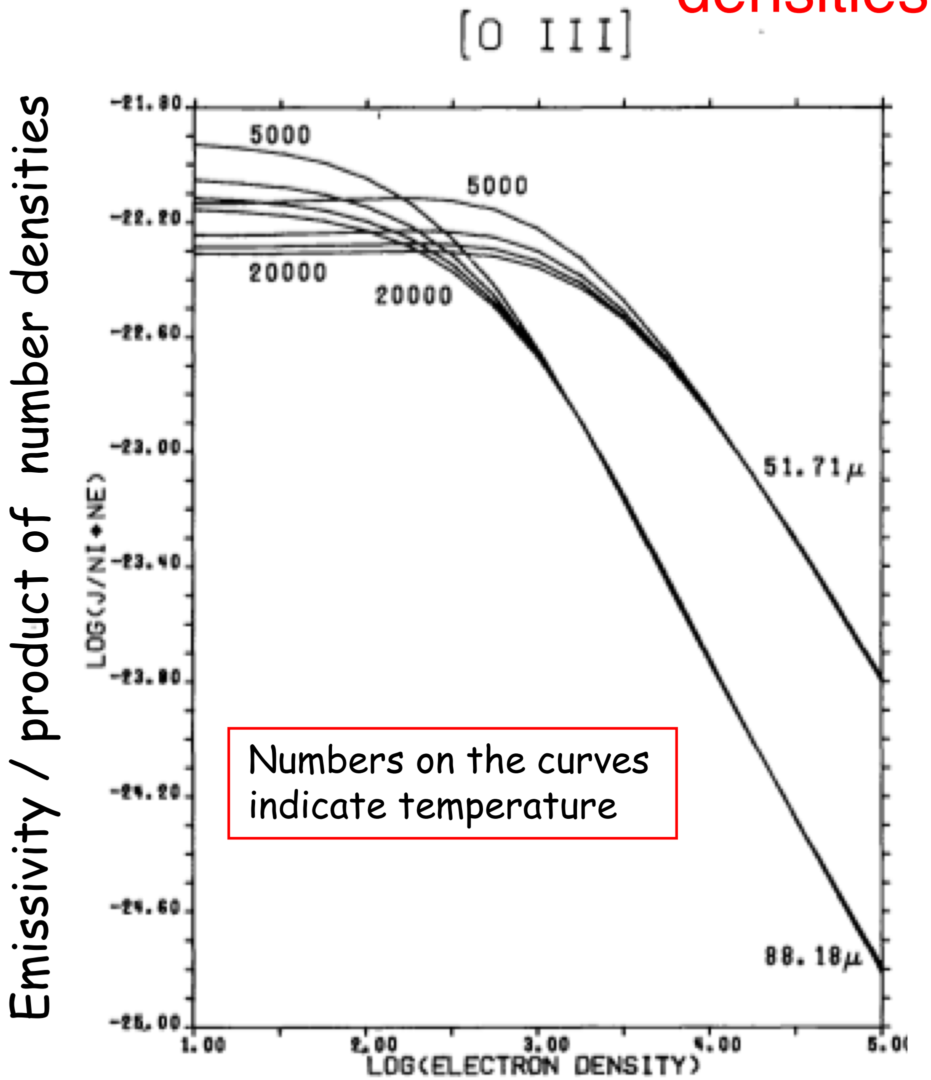
Janet Simpson in 1975 with with colleagues from the NASA Ames Research Center's (NARC) Airborne Astronomy Support Group.

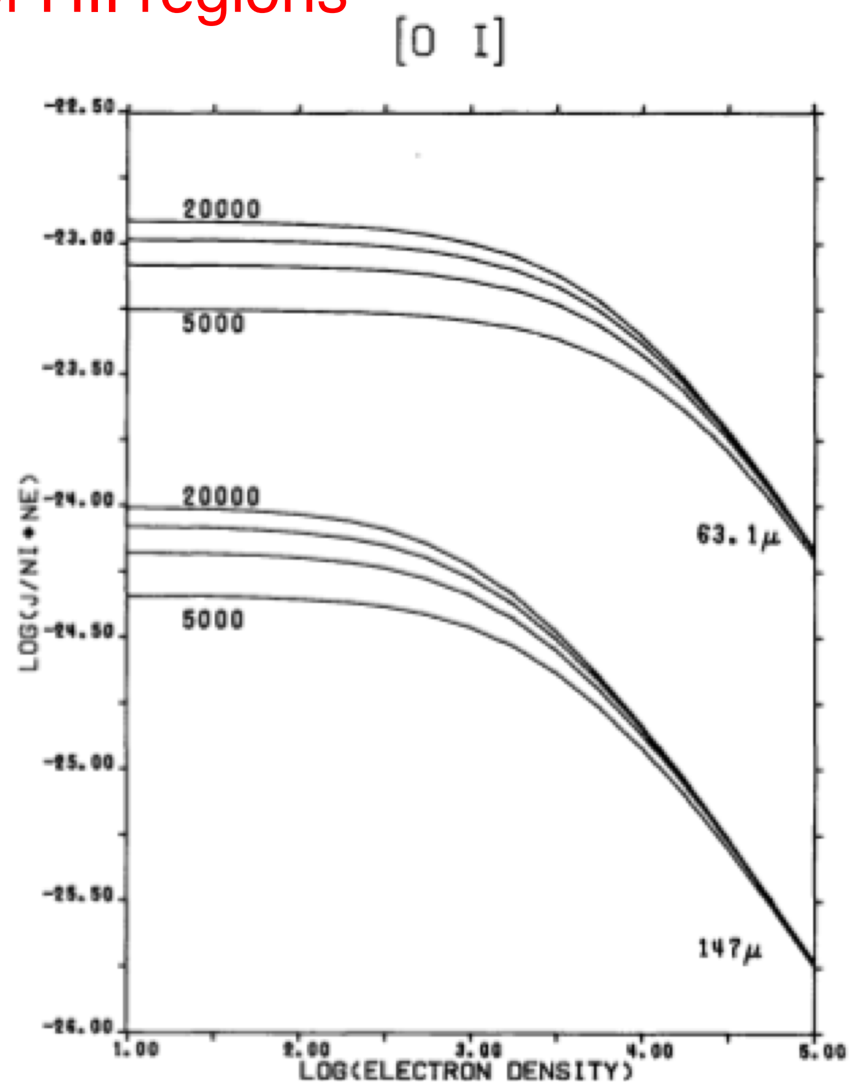
Her paper that year was the first theoretical study predicting far-infrared fine-structure line strengths as well as guidelines for their interpretation.

Astronomers Ed Erickson and Larry Caroff, both sporting moustaches at the time, respectively are on her left and right. Fred Witteborn, one of the early planners of the Spitzer mission, is in the rear on the extreme left.

NASA/ARC photo

In an article published in 1975, Janet Simpson provided the foundations on which fine-structure line strengths could be readily interpreted in terms of temperatures and densities of HII regions





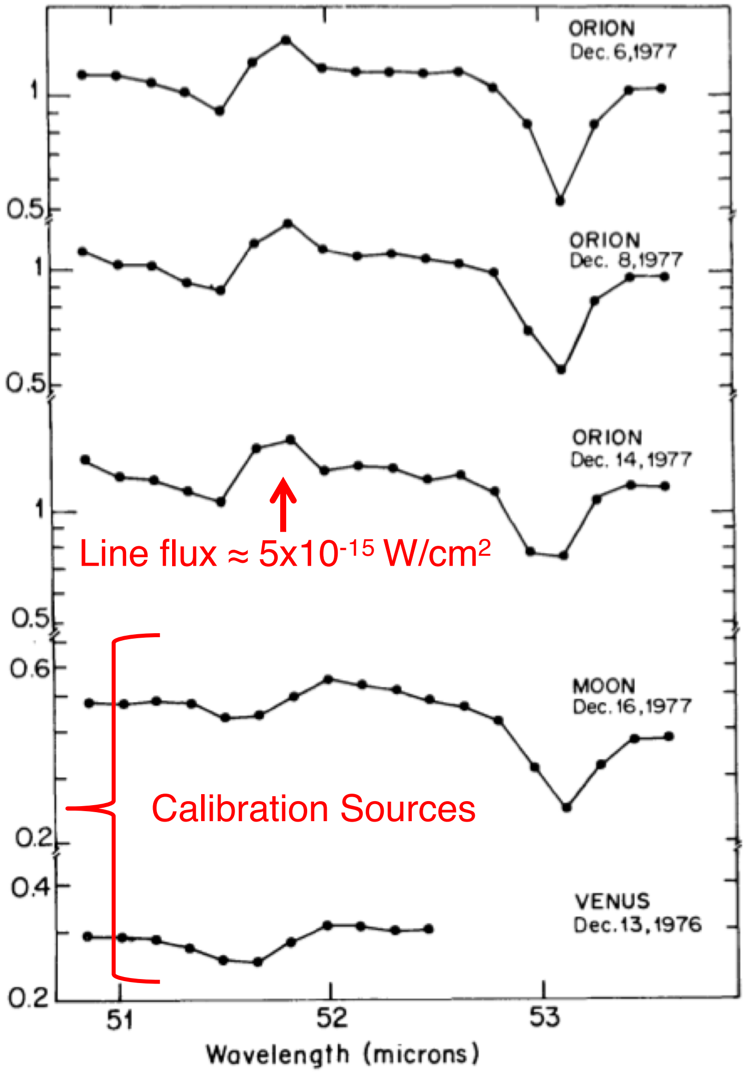
Janet P. Simpson, A&A 39, 43-60, 1975

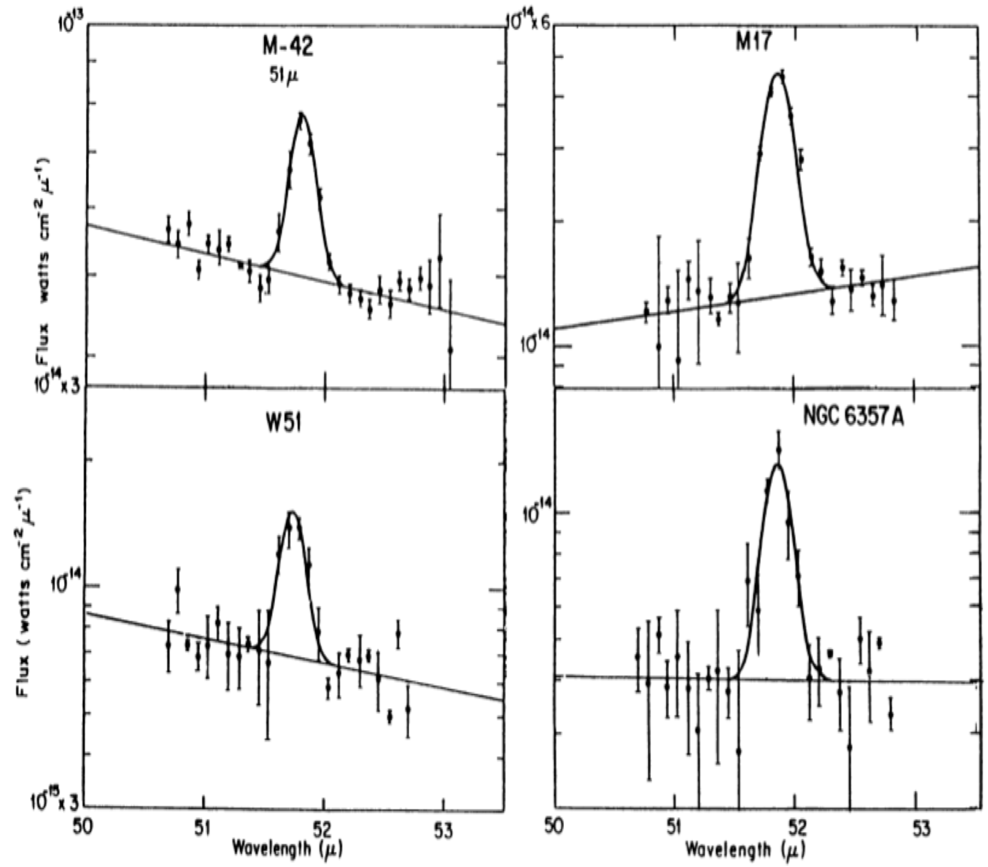
Left to right:

Alan Moorwood,
Jean Paul Baluteau,
John Beckman,
Ezio Bussoletti, and
Michel Anderegg
shown before a flight on the Kuiper Airborne Observatory. Baluteau's far infrared Fourier Transform Spectrometer mounted on the telescope is seen behind them.

November/December 1975

[OIII] 51.8 μm Detections from the Lear Jet





Observations obtained with the Lear Jet 30-cm telescope at 13.7 km altitude and spectral resolution 150

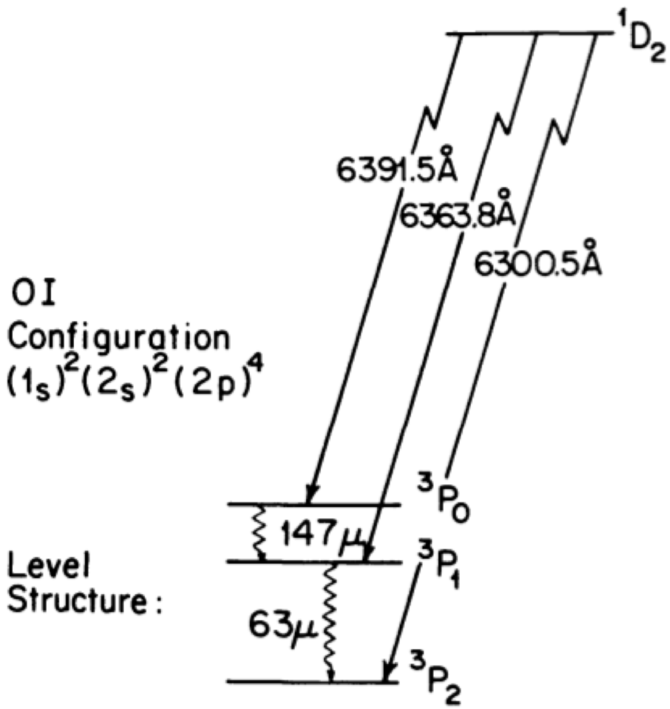
First Detection of the line December 1977

Gary Melnick, George E. Gull, Martin Harwit & Dennis B. Ward, Ap. J. 222 L137-140, 1978

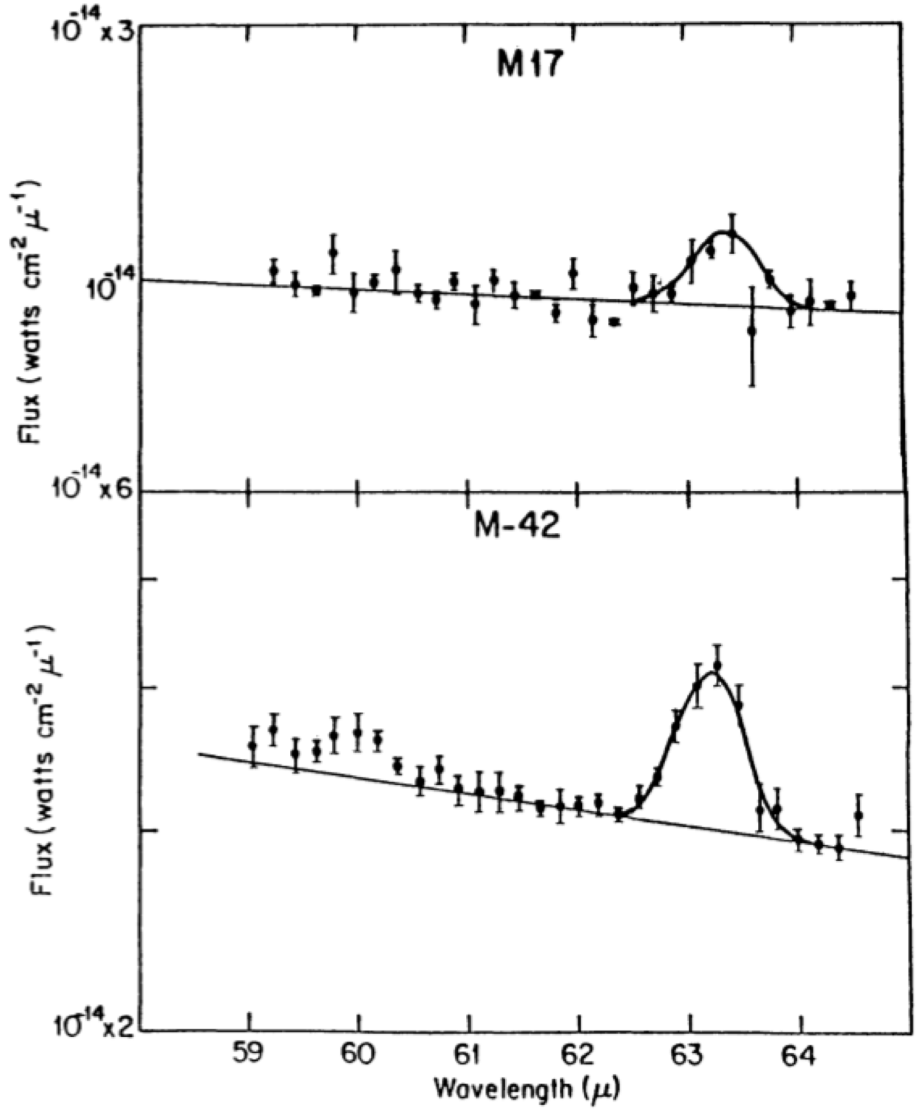
Four Months Later, April 1978

Gary Melnick, George E. Gull & Martin Harwit, ApJ 227, L 35-38, 1979

First Detections of the 63.2 μm Line

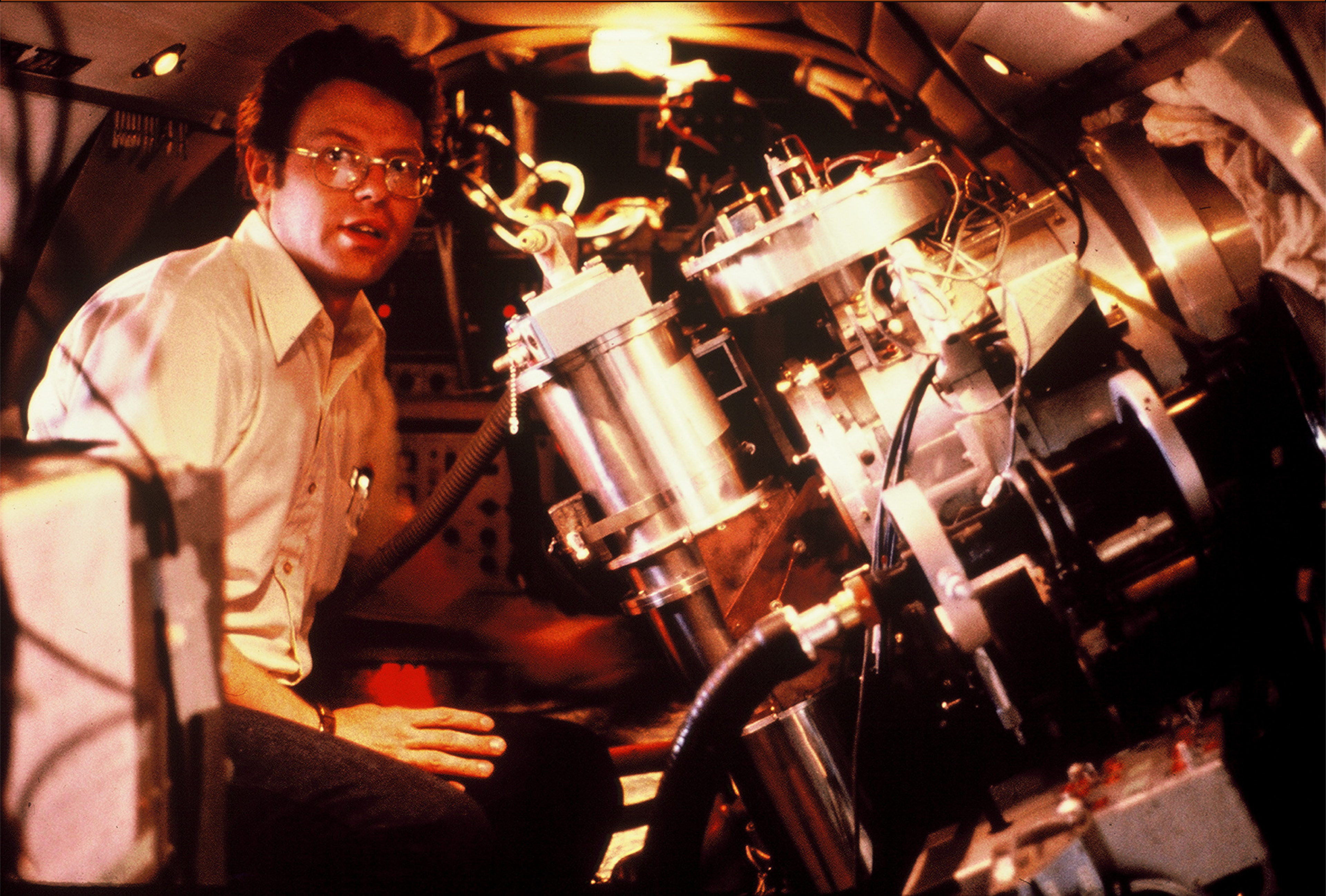


The 63.2 μm emission obtained from the Lear Jet with spectral resolution R = 150. The emission from Orion was considerably more luminous than we had expected, but could be explained in terms of models of expanding HII regions being developed by Jesse K. Hill and David Hollenbach. The level diagram included in our paper is reproduce here to show the uncertainties still encountered, in precise FIR fine-structure line positions. In submitting this paper we were unaware that laboratory data of P. B. Davies et al., J. Chem. Phys. 68, 1135, 1978 had shown the $^3P_0$-$^3P_1$ wavelength to be 145.525μm..



Gary Melnick, George E. Gull & Martin Harwit ApJ 227, L29-33, 1979

Ray W. Russell checking the instruments prior to flight



November 27, 1979 Lear Jet Detection of the C^+ line in M42 and NGC 2024 between 157 and 158μm

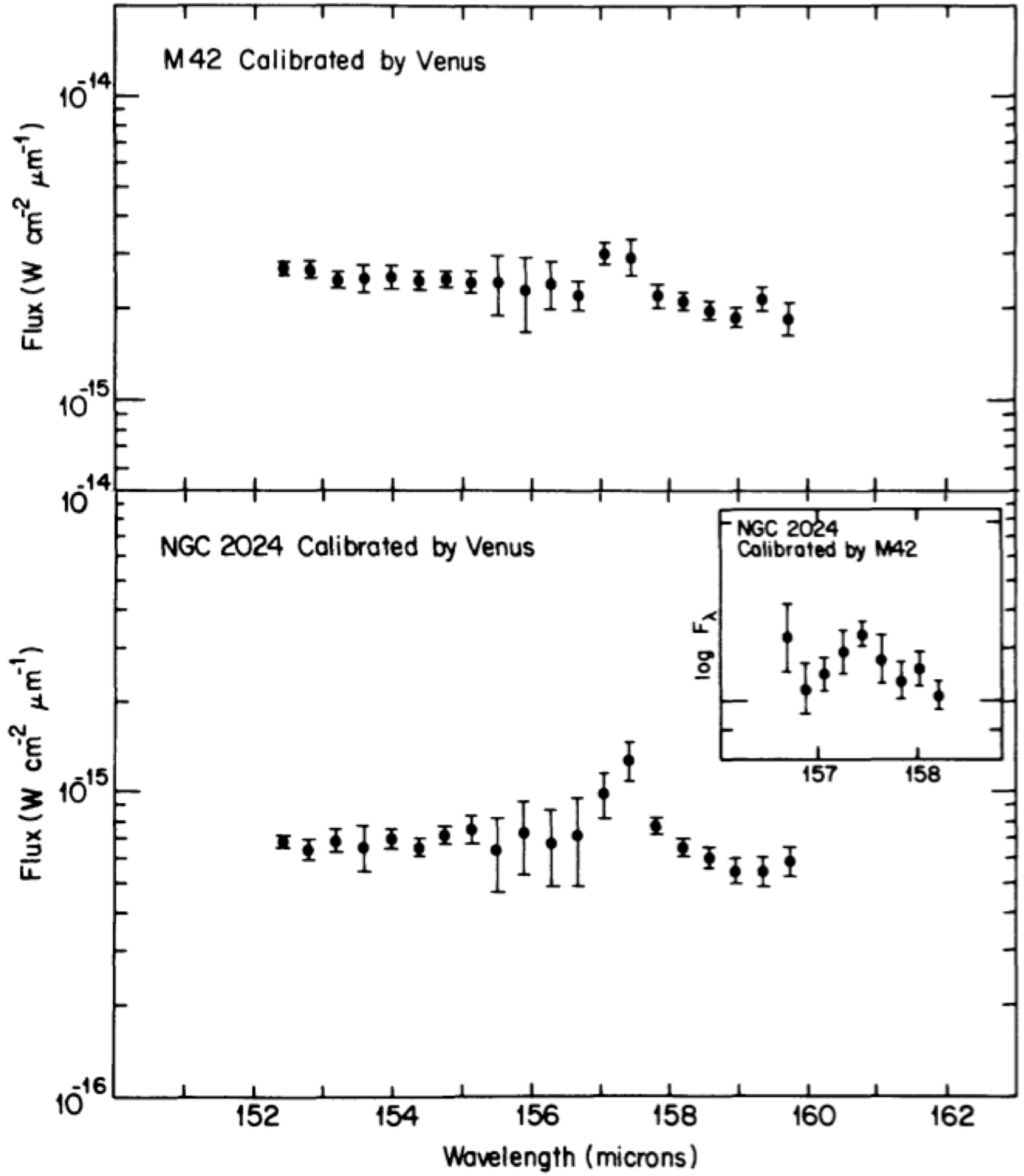
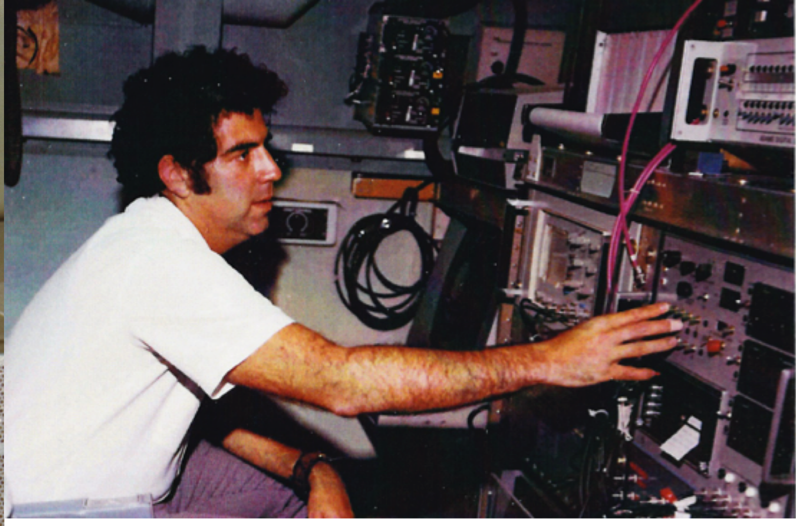


FIG. 1.—Spectra of NGC 2024 and M42 from 152 to 160 μm. The data have been calibrated by comparison with data on Venus, assuming Venus emits like a 245 K blackbody at these wavelengths.

Ray W. Russell. Gary Melnick, George E. Gull & Martin Harwit, ApJ 240 L99-103, 1980

The Kuiper Airborne Observatory, KAO. The telescope looked out through the square aperture behind the pilots' cabin.

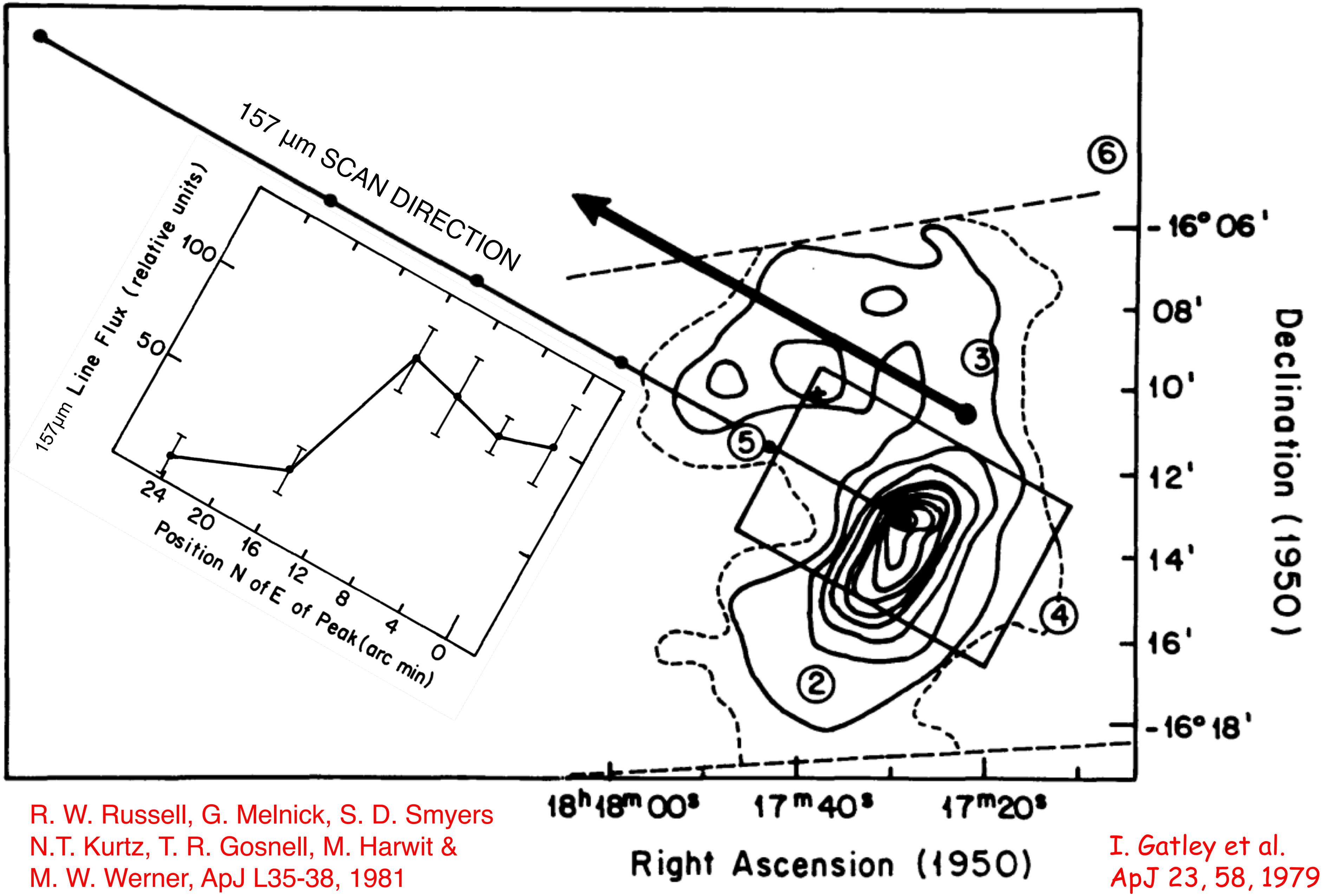


1980 attempt to observe the 158 µm C^+ emission from M17 with the KAO 91-cm telescope.

Michael W. Werner (above) had KAO observing time which he shared with our Cornell Group at left.

(Left) Ray W. Russell seated behind George E Gull in the foreground. Standing are Gary J. Melnick with Martin Harwit at the back.

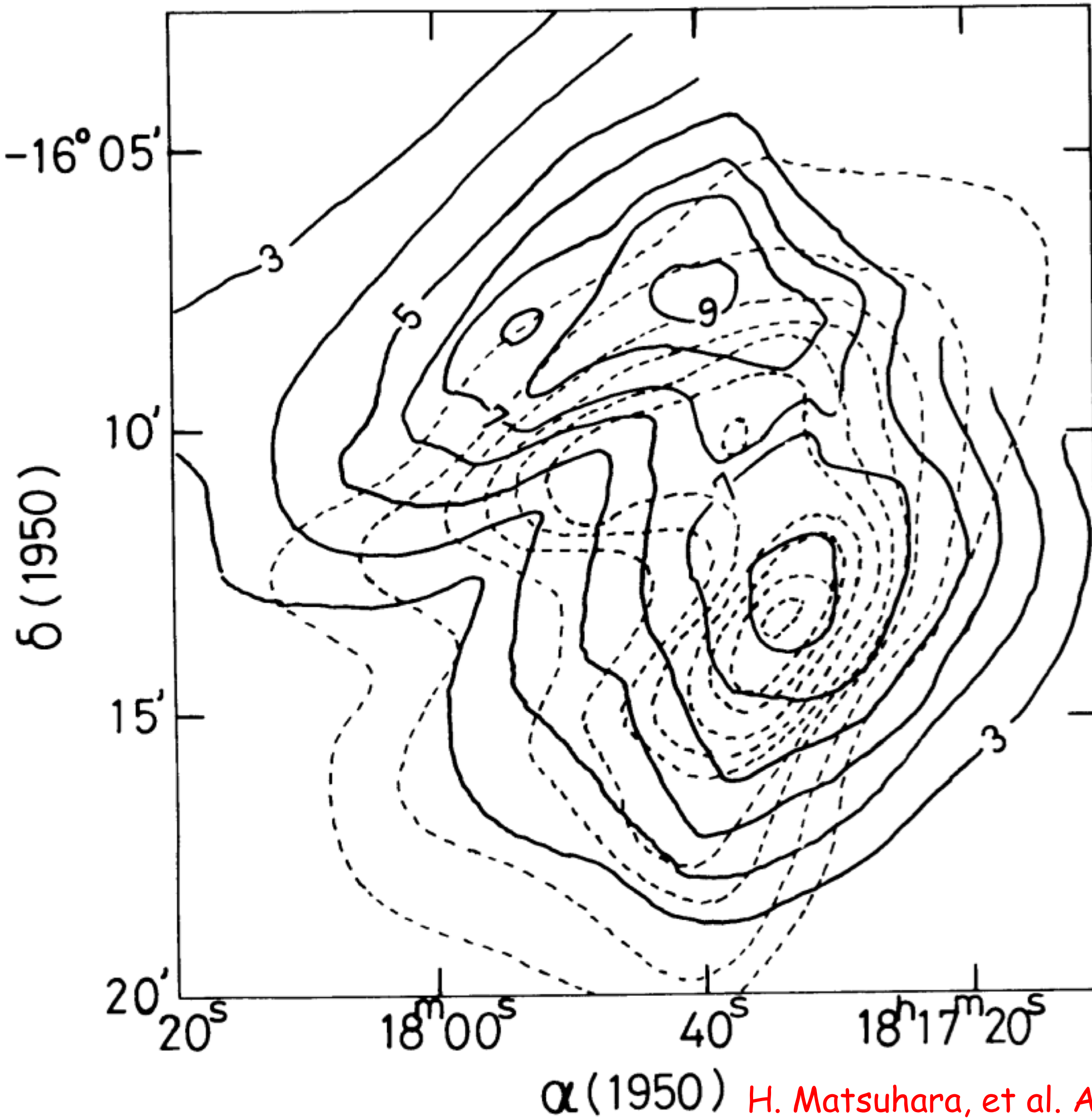
M17 Giant [CII] Halo Showing the Line Flux (in Insert) at 6 Locations, Indicated by 6 Dots on the Scan Direction across a 100μm Map of Gatley et al., 1979



R. W. Russell, G. Melnick, S. D. Smyers
N.T. Kurtz, T. R. Gosnell, M. Harwit &
M. W. Werner, ApJ L35-38, 1981

I. Gatley et al.
ApJ 23, 58, 1979

The central part of the contour map of M17 showing the [C II] line intensity superposed on a 3.5 cm radio map of T. L. Wilson et al., A&A 76, 86,1979, shown by the fainter dashed contours.



H. Matsuhara, et al. ApJ 339 L69-L70, 1989

Photo-Dissociation Regions

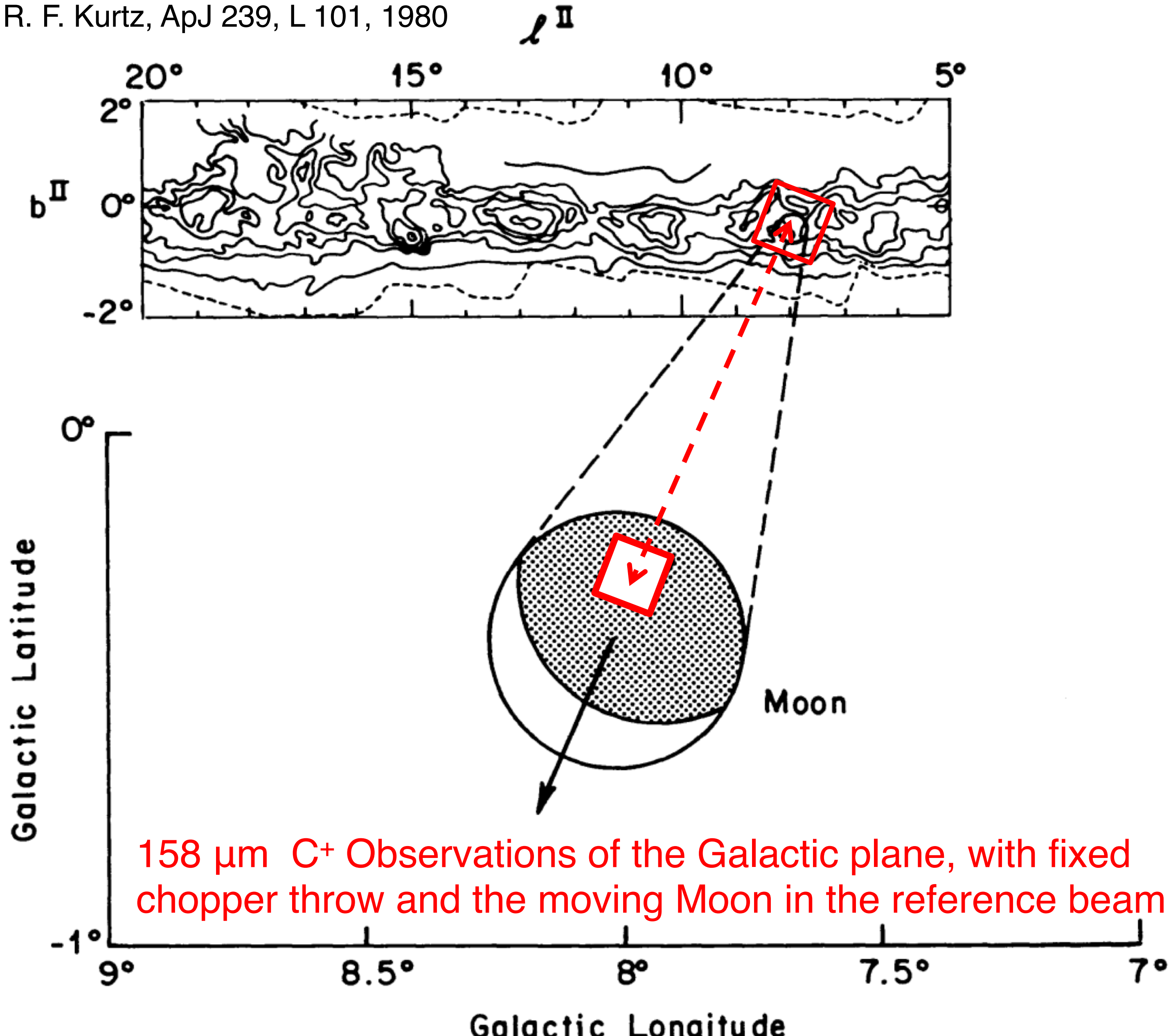
10.09 OI (63μ) and CII(157μ) Line Emission from Photodissociation Regions, D. J. Hollenbach, NASA/ARC

Observations of intense and extended OI(63μ) and CII(157μ) emission associated with several HII regions in the Galaxy have been made recently by several observers. The luminosity in these lines may be as much as 1% of the integrated far-infrared continuum luminosity (or stellar luminosity) from these regions. Photoelectric heating by 6eV - 13.6eV photons in the predominantly neutral atomic regions ("photo-dissociation regions") bounding the HII nebulae can account for such an efficient conversion of stellar luminosity to OI(63μ) and CII(157μ) line luminosity. Simple models are presented to demonstrate the conversion efficiency.

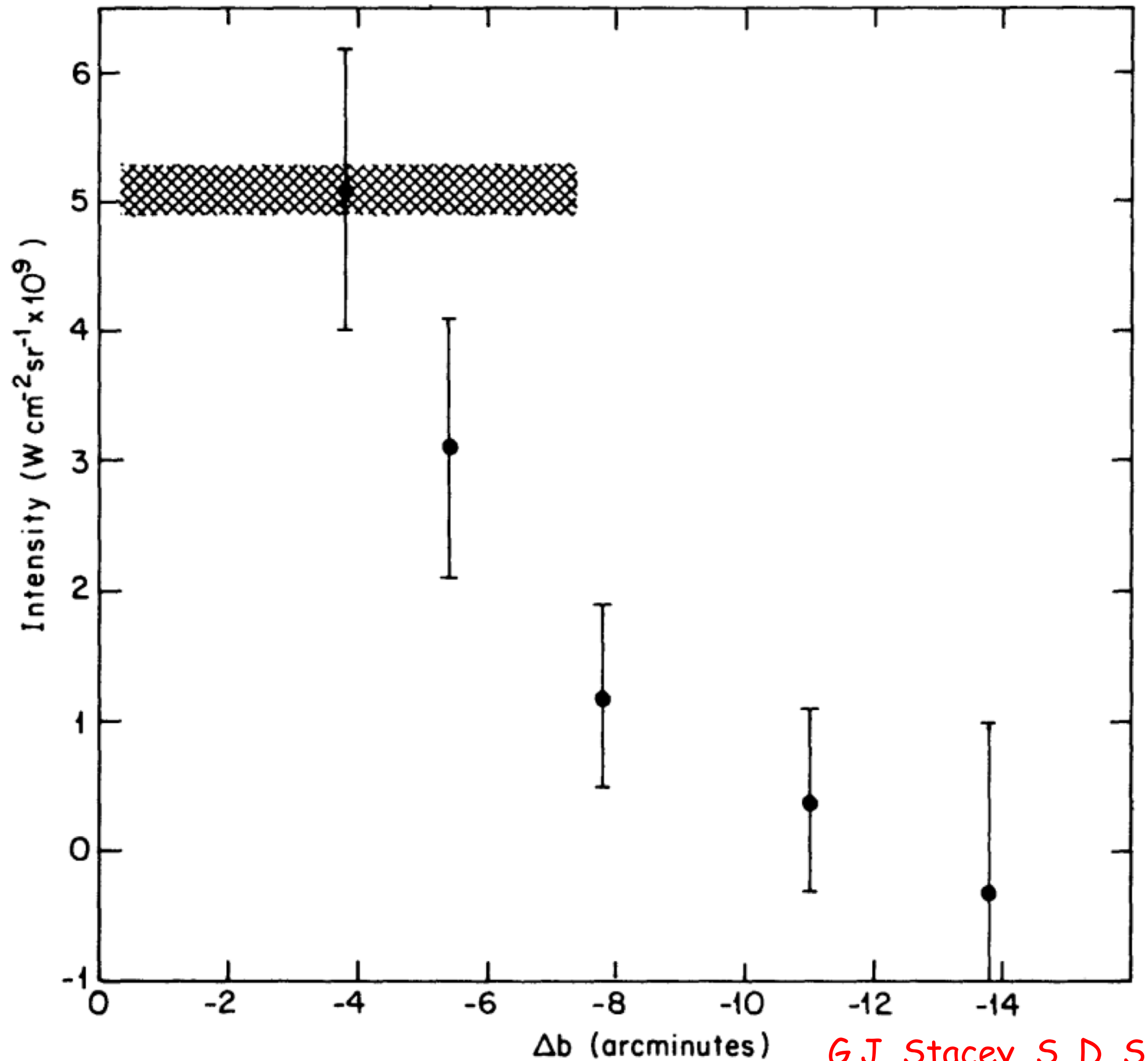
D. J. Hollenbach, BAAS, 159 the meeting of the AAS Boulder Colorado, 1981

Gordon Stacey waiting to reach altitude before starting observations of C^+ emission from the Galactic plane

Balloon-obtained 100-300 μm Map of the Galactic plane,
T. Nishimura, F. J. Low & R. F. Kurtz, ApJ 239, L 101, 1980



G.J. Stacey, S. D. Smyers, N. T. Kurtz & M. Harwit ApJ, 268, L99- L102, 1983



G.J. Stacey, S. D. Smyers, N. T. Kurtz & M. Harwit ApJ, 268, L99 – L102, 1983

FIG. 2.—The 157 μm [C II] fine-structure line emission observed as a function of latitude Δb, off the galactic plane. Error bars are 1 standard deviation from the mean. The cross-hatched strip represents the width of our field of view.

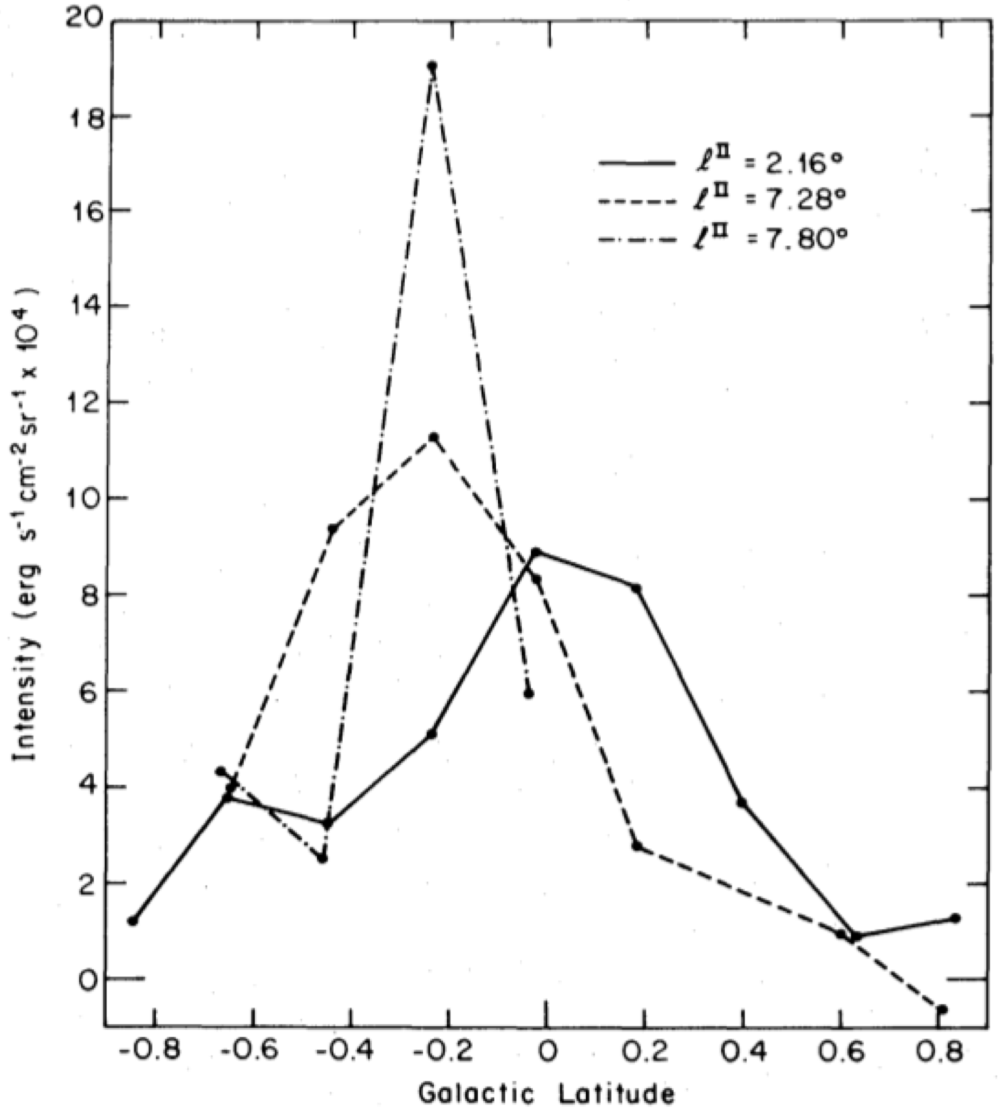


FIG. 2.—The 157 μm [C II] intensity at three galactic longitudes. Error bars have been omitted for clarity. Typical errors are $\pm 1.2 \times 10^{-4}$ ergs cm^{-2} s^{-1} sr^{-1} for the traces at $l^{II} = 2°16$ and 7°28, and $\pm 2.9 \times 10^{-4}$ ergs cm^{-2} s^{-1} sr^{-1} for the 7°80 trace. The quoted errors are one standard deviation from the mean.

G. J. Stacey, P. J. Viscuso. C. E. Fuller, \& N. T. Kurtz, ApJ 289, 803-806, 1985

Lamellar Grating Interferometer with one Fixed and one Movable Mirror used in tandem with our Lear Jet Spectrometer serving as monochromator

This device, though crude, increased our spectral resolving power to ~700 at 145.5 μm. It cost less than $2000 in parts and machining expenses and took only 7 weeks to design, construct, test, and fly on the KAO.

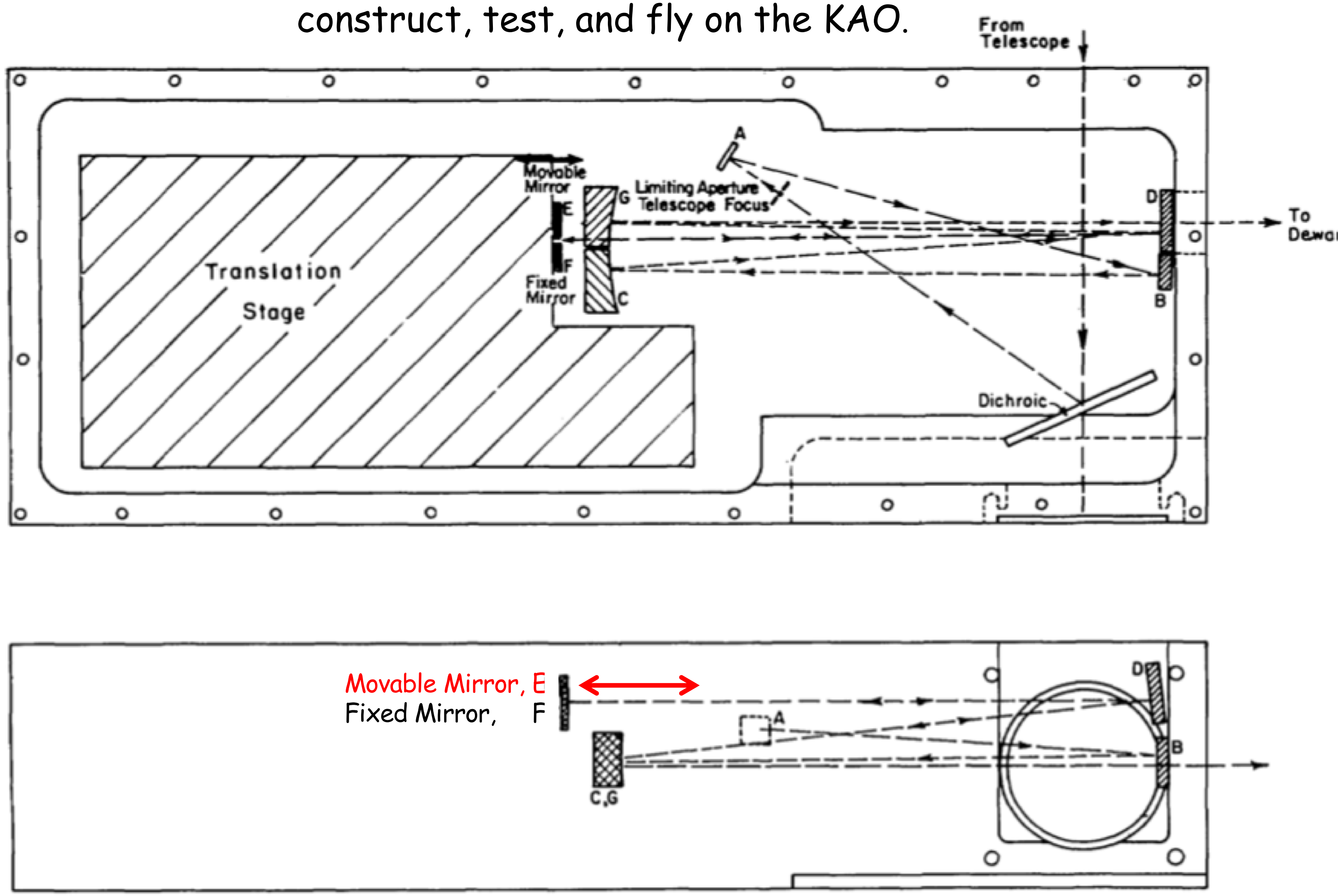
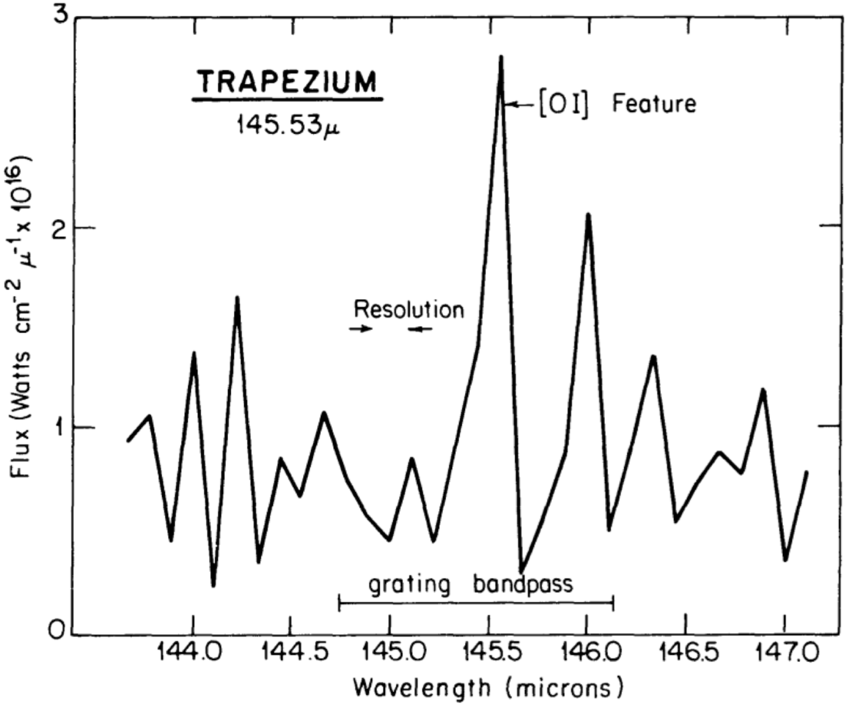
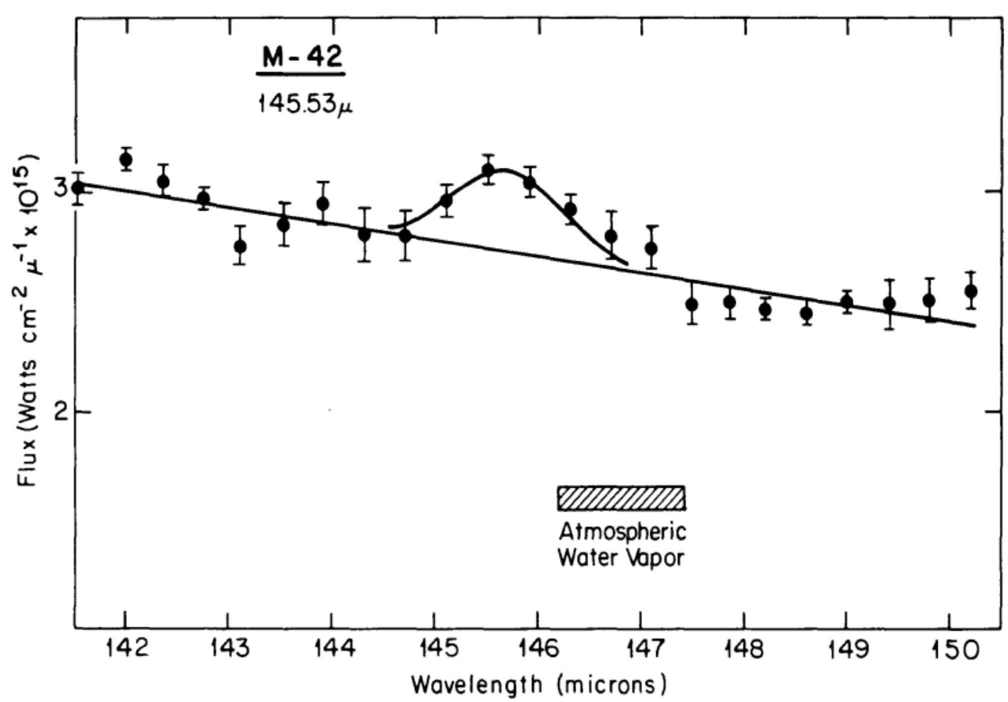


Fig. 1. Optical light path through the interferometric stage. Upper diagram shows the top view, the lower the side view.

Martin Harwit, Noel T. Kurtz, Ray W. Russell & Scott Smyers, Applied Optics, 20, 3792- 3796, 1981

First Observations of the 145.5μm [OI] Fine-Structure Line





In flights aboard the KAO conducted on January 14 and 15, 1982, with a new interferometric spectrometer having resolving power ~700 we observed a 1' x 1' field centered on the Orion Trapezium region. In five out of six spectra obtained, we detected excess radiation at the expected line position, relative to the continuum observed on Mars taken to compensate for atmospheric absorption at our aircraft altitude. The averaged spectrum shown Indicates an [OI] 145.5μm flux of 4.8+/-1.4 x 10^{-17} W/cm^2.

We followed up on the KAO observations with Lear Jet flights the next month, February 1982, where we observed the M42 145.5μm emission in our Instrument's 7'x7' full-width half-power beam. The line flux obtained on two flights yielding 15 spectra, each of which showed the feature, was 4.7+/-0.9 x 10^{-16} W/cm^2. We tried to account for the 145.5μm Trapezium flux in terms of available 63μm, C109α, and [CII], and concluded that the optical depth at 63μm would have to be τ≈2, to account for our 145.5μm observations.

Gordon J. Stacey, Scott D. Smyers, Noel T. Kurtz & Martin Harwit, ApJ 265, L7-11, 1983.

Fine-Structure Detections by Other Groups across the Spectrum

FAR-INFRARED:

[NIII] 57.3µm, A. F. M. Moorwood, P. Salinari, I. Furniss, R. E. Jennings, & K. J. King, A&A 90, 304, 1980

[NII] 122 µm, R. Rubin, M.R. Haas, E.F. Erickson, J. P. Simpson, & S. W. J. Colgan, BAAS 21. 1213R 76.0476.04, 1988

[NII] 205 µm, E. L. Wright, ApJ 381, 200-209, 1991 (COBE Preliminary Results)

SUB-MILLIMETER:

[CI] 370 µm, D. T. Jaffe, A. I. Harris, M. Silber, R. Genzel & A. L. Betz, ApJ 290, L59-62, 1985

[CI] 610 µm, T. G. Phillips., P. J. Huggins, T. B. H. Kuiper & R. E. Miller, ApJ 23, L103-106, 1980

MID-INFRARED, $\lambda > 15$ µm:

[NeIII] 15.5 µm, S. R. Pottasch et al., ApJ 278, L33-35, 1984 (IRAS Planetary Nebulae)

[SIII] 18 µm, J.-P. Baluteau, E. Bussoletti, M. Anderegg & A. F. M. Moorwood, ApJ 210, L45-48, 1976

[NeV] 24.3 µm, W. J. Forrest, J. F. McCarthy & J. R. Houck, ApJ 240, L37-41, 1980

[OIV] 25.9 µm, W. J. Forrest, J. F. McCarthy & J. R. Houck, ApJ 240, L37-41, 1980

[SIII] 33 µm, A. F. M. Moorwood, J.-P. Baluteau, M. Anderegg , N. Coron, Y. Biraud & B. Fitton, ApJ 238, 565, 1980

[NeIII] 36.0 µm, M. A. Shure, J. R. Houck, G. E. Gull & T. Herter, ApJ 281, L29-31, 1984

Charles H. Townes and Reinhard Genzel aboard the KAO in 1981

Rapid Advances Initiated by the UC Berkeley Group

By 1985, the group of Townes and Genzel at Berkeley was obtaining Kuiper Airborne Observatory [CI] 157 µm spectra of individual portions of nearby galaxies, M82, NGC 1068, M83, M51, as well as analyses of Galactic HII regions observed also in CO and IR continuum radiation. The era of discovery was giving way to deeper analyses of spectral line data. A new set of astrophysical tools was gaining acceptance!

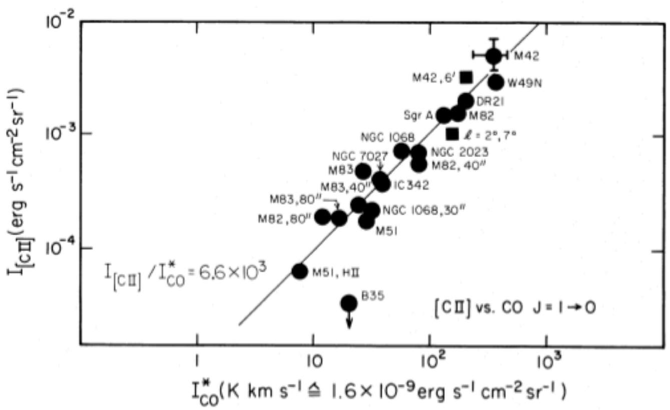
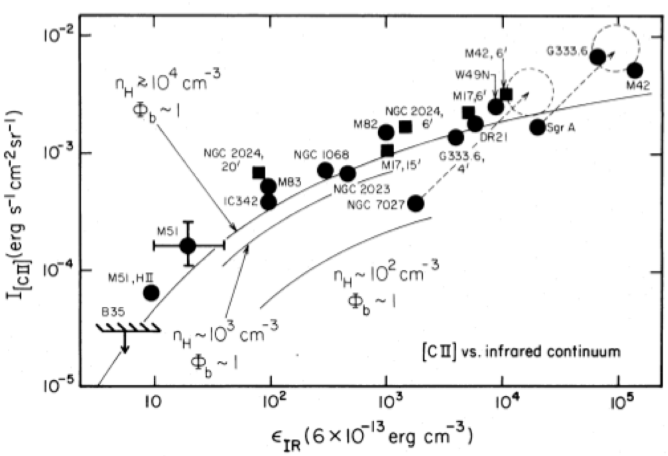
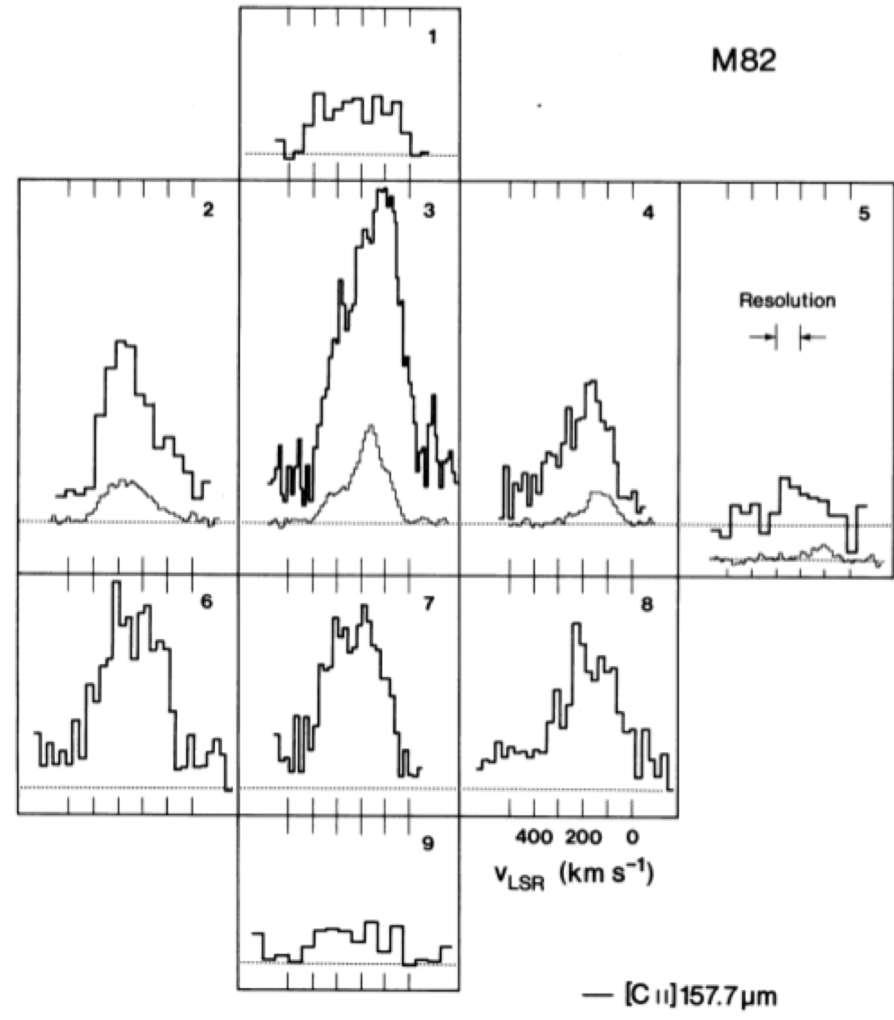
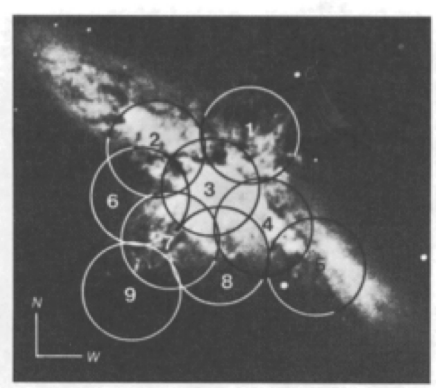


FIG. 5a







M. K. Crawford, R. Genzel
C. H. Townes, D. M. Wats
ApJ 291, 75, 1985

For text see Talks Folder: "Heidelberg fine structure text 2015"

For references and Background materials see: Completed Projects Folder: "Heidelberg Talk"