Airborne Infrared Astronomical Telescopes

Edwin F. Erickson, NASA Ames Research Center (retired)

Astronomy from aircraft began in the early 1920s, largely devoted to visible observations of solar eclipses and comets[1,2]. In 1957, infrared (1.0 – 6.5 μm) observations of the solar spectrum were made from a Canberra jet flying up to 14.6 km altitude[3].

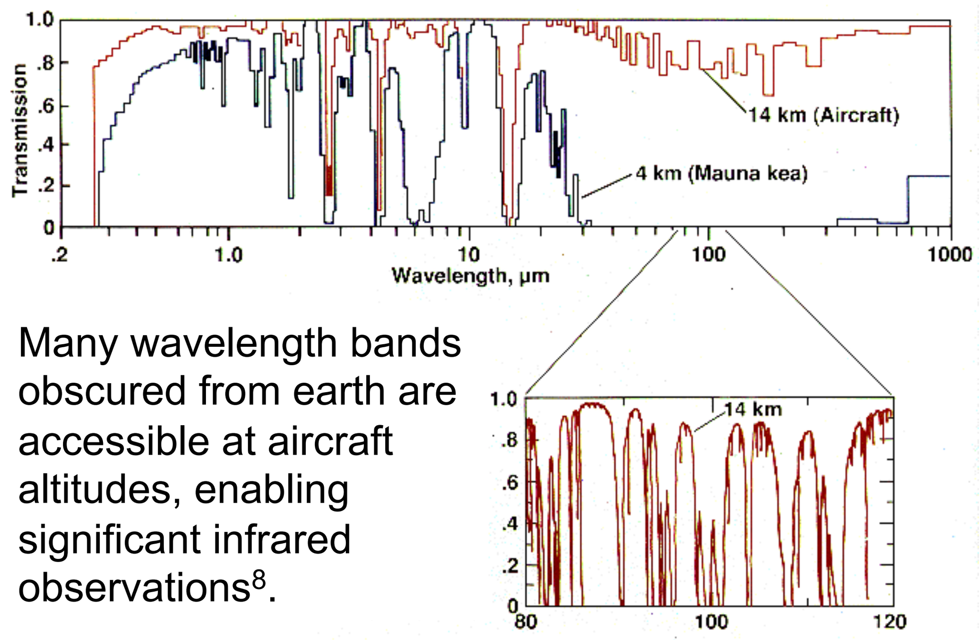
A Douglas A-3B aircraft operating up to 13.4 km was used in 1965 by G. P. Kuiper, P. St. Amand and C. M. Gillespie to examine the potential for planetary observations[4], and in 1966 and 1967 by F. J. Low and Gillespie to measure the solar brightness at 1mm[5].

However, the vast majority of infrared astronomy from aircraft has been done from three facilities based at NASA's Ames Research Center in California. These and the long anticipated Stratospheric Observatory for Infrared Astronomy (SOFIA)[6,7] are summarized below.

Airborne Astronomy Attributes:

- Visible to millimeter wavelengths
- Mobility: all sky, occultations, eclipses…
- Flexible observing program
- Variety of focal plane instruments
- New instrument technology opportunities
- Experience for young researchers
- Education and public outreach
- Co-location of observatory and staff
- Long facility lifetime
- Routine facility servicing

Atmospheric Transmission vs Wavelength



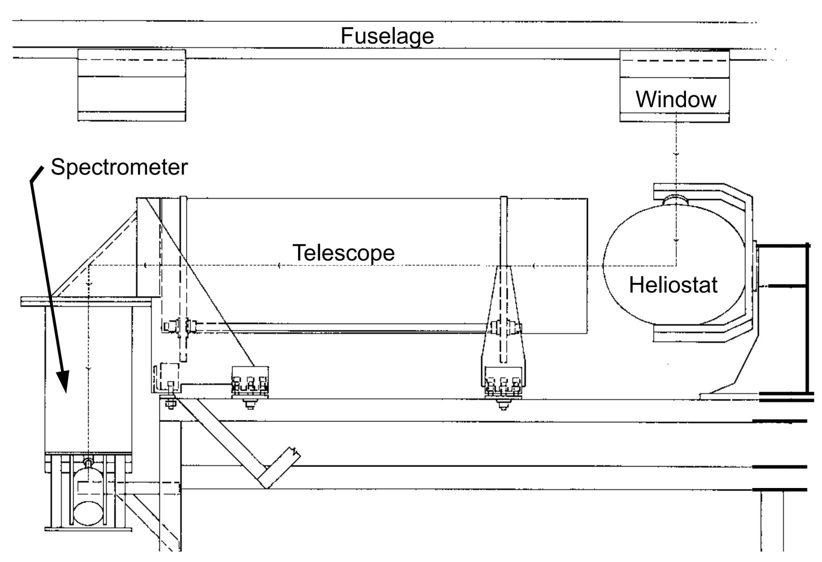
Many wavelength bands obscured from earth are accessible at aircraft altitudes, enabling significant infrared observations[8].

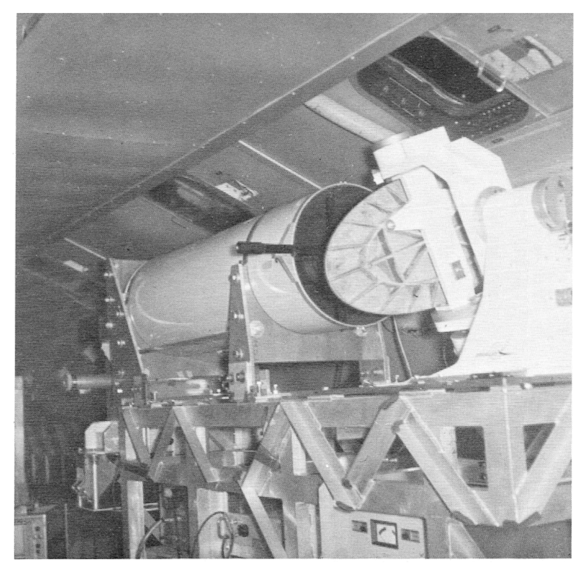
Comparison of Airborne Infrared Telescope Facilities

Facility	Years of Operation	Maximum Altitude	Primary Diameter	Wavelengths Accessed
Convair 990 – Galileo	1965 - 1973	12.4 km	30 cm	1 - 4 µm
Learjet Observatory – LJO	1966 – 1976 rarely to 1997	15.2 km	30 cm	0.3 - 250 µm
Kuiper Airborne Observatory – KAO	1974 - 1995	13.6 km	91 cm	0.3-1600 µm
Stratospheric Observatory for Infrared Astronomy – SOFIA	2014 - 2034 (design life)	13.6 km	270 cm	0.3-1600 µm (planned)

The Convair 990 "Galileo"

Kuiper and Forbes' Telescope and Spectrometer and NASA Heliostat Installed on the Convair 990





No Water in Venus Clouds!

In 1967 Gerard P. Kuiper and Frederic F. Forbes[9] installed a gyro-stabilized heliostat mirror with a 30-cm telescope and a Fourier transform spectrometer on the NASA Ames Convair 990 aircraft. They measured the 1.0 – 2.5 µm spectrum of Venus, finding – surprisingly! –that its clouds were devoid of water. This pioneering work showed that airborne astronomy enables hands-on operation of current, innovative technology to make observations precluded from the ground by telluric water vapor.

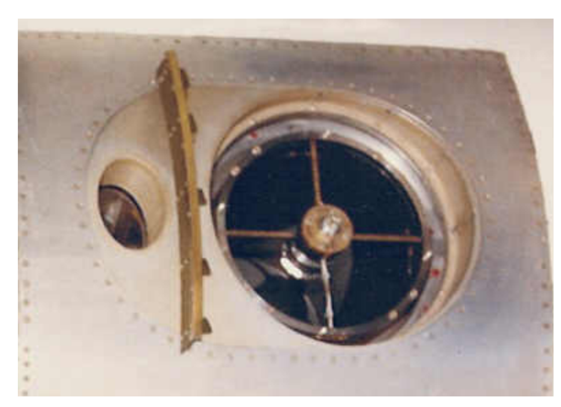
The Far Infrared

In 1968, Low[5] initiated a program of far-infrared observations from aircraft using bolometer detectors he had developed, and the NASA Ames Learjet. His clever 30-cm open-port telescope included the first chopping secondary mirror. This, with synchronous demodulation of the detector output, permitted measurement of astronomical signals 10^4 to 10^6 times fainter than radiant power received from the sky and telescope. In the early 1970's, an improved Learjet telescope[10] was developed at Ames to accommodate additional instrument teams.

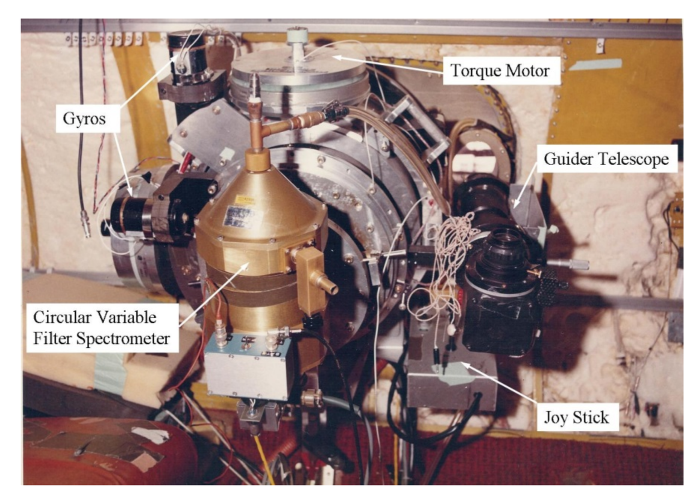
The Learjet Observatory "LJO"

Some Learjet Science:

- Luminosities of star-forming molecular clouds
- Evidence for concentrated sulfuric acid as the major aerosol in Venus' clouds
- First detection of the major interstellar medium (ISM) cooling C^+ line at 158 µm.



The gimbal-mounted telescope had a controlled-leak, a spherical air seal at the fuselage that permitted articulation.



Observers guided using a 7.6-cm optical telescope.

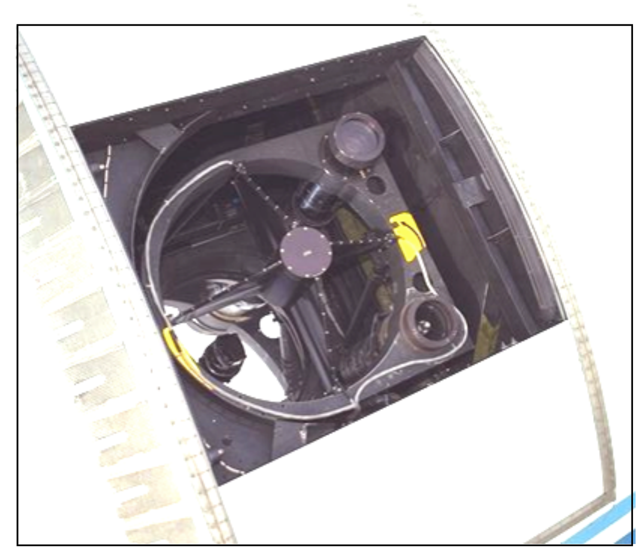
The Kuiper Airborne Observatory "KAO"

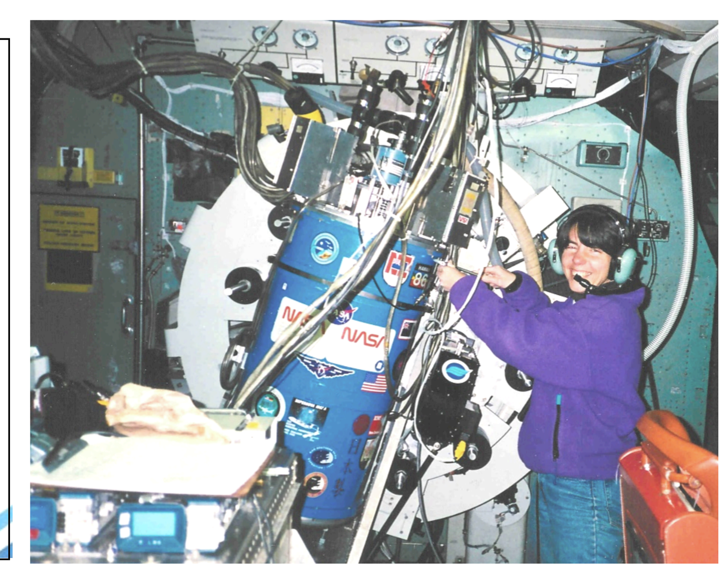
KAO 21-Year (Lifetime) Science-Program Summary

Instrument Teams	Instruments Flown	Instruments Flown/Year	Principal Investigators	Total Investigations	Investigations per year	Total Publications
33	>50	~10	>126	>510	>25	>1000

A Few KAO Science Discoveries and Revelations[11]

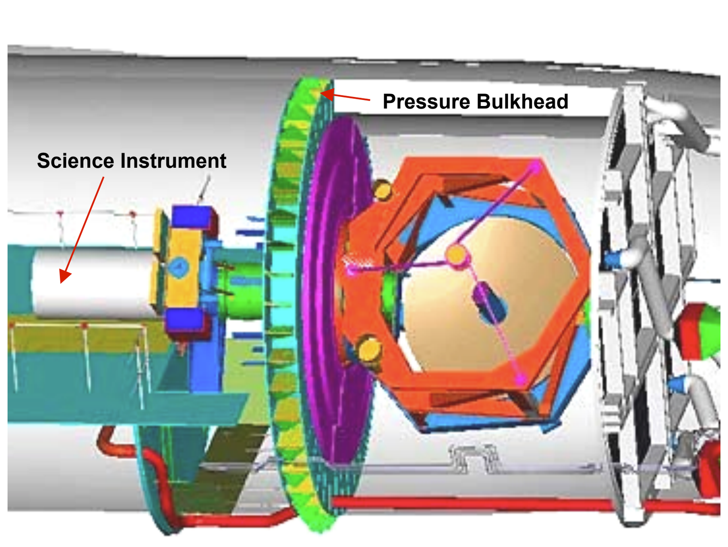
- Rings of Uranus
- Intrinsic luminosities of Jupiter, Saturn, and Neptune
- Water in Jupiter's atmosphere
- Early evidence for a black hole at our Galactic Center
- Properties of Photo-Dissociation Regions (PDRs)
- Over 70 new spectral features from atoms, ions, molecules, and grains
- Star-forming cores in Bok globules
- Far infrared luminosities of galaxies comparable to their visible luminosities
- Fe, Co, Ni, and Ar created in supernova SN1987A
- Detection of astronomical far-infrared lasers
- Spectral signatures of potentially prebiotic polycyclic aromatic hydrocarbon (PAH) molecules in the ISM

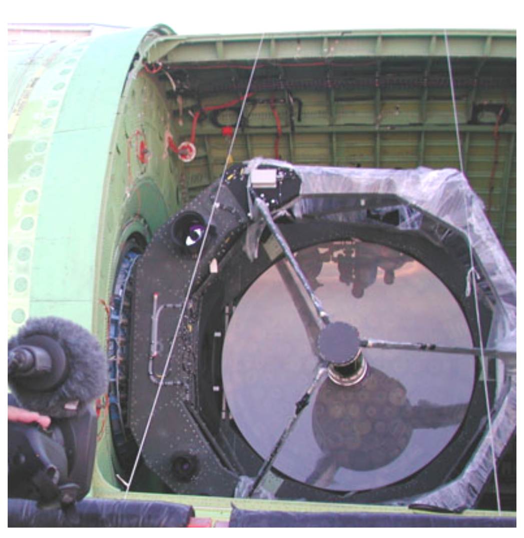




The KAO featured a door and aperture that tracked the telescope to provide open-port viewing throughout its 20 to 60° elevation range. The telescope is a "bent Cassegrain" configuration: light from the secondary was reflected from a tertiary to pass through the telescope-supporting spherical air-bearing and on to the focal plane instrument in the pressurized cabin[12]. The gyro/star-tracker system achieved a telescope stability of 0.25 arc seconds RMS.

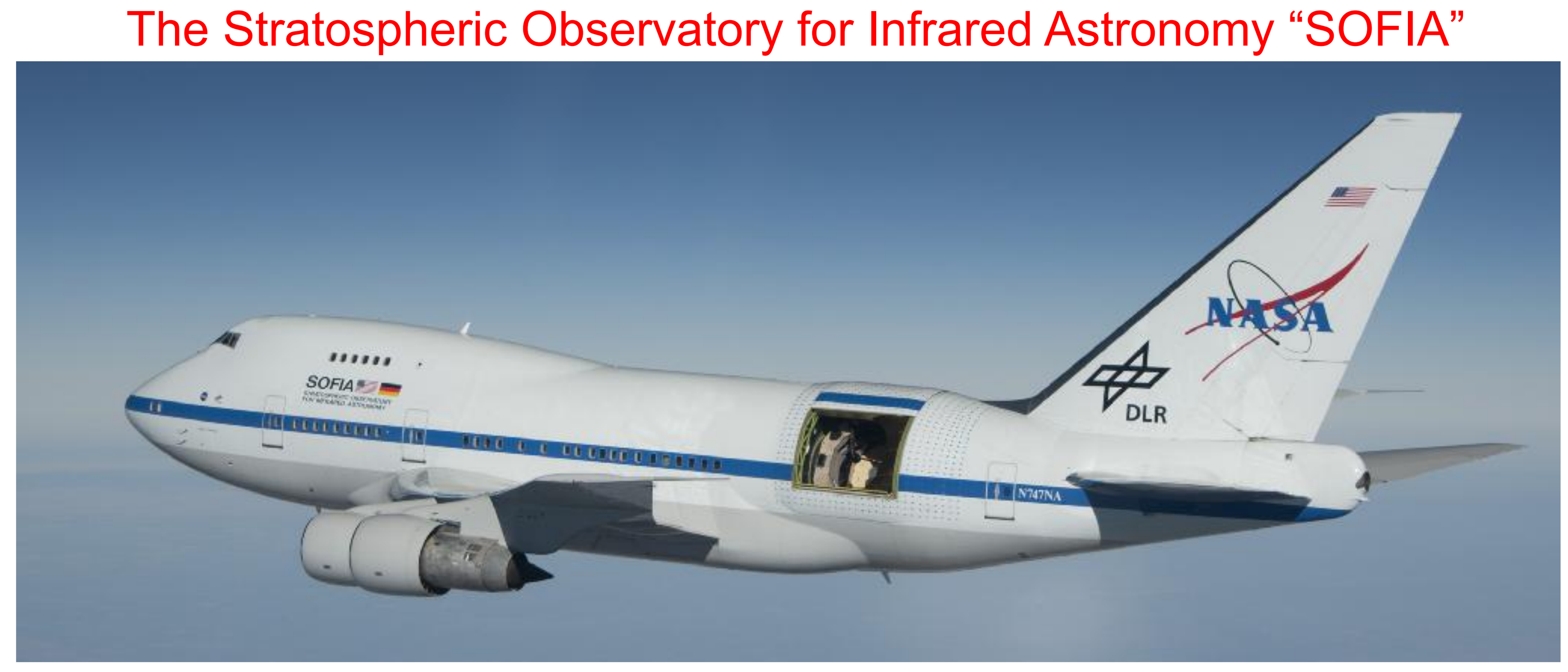
The Stratospheric Observatory for Infrared Astronomy "SOFIA"





The SOFIA telescope[13] was built in Germany by an industrial consortium sponsored by NASA's SOFIA partner, the German Aerospace Center (DLR). The telescope is installed on a full pressure bulkhead aft of the wing in a Boeing 747SP aircraft. The fuselage behind the bulkhead is unpressurized. A moveable door and aperture provide an open port for the telescope, as on the KAO. The telescope is supported on a spherical hydraulic bearing through which infrared and visible beams pass to the focal plane science instrument and facility guiding camera in the cabin.

SOFIA's visible-light high-speed imaging photometer HIPO is shown above on the telescope during first-light ground-based tests in WACO Texas in 2004[14]. The blue structure is the telescope, the black is HIPO.



SOFIA became fully operational in June 2014. Science highlights include visible/near infrared occultations of Pluto and mid-infrared observations of the Galactic Center. http://sofia.usra.edu.

-- References --

1. Craine, Eric R. ,"The Beginnings of Airborne Astronomy: 1920 - 1930 An Historical Narrative", *NASA Conference Publication* ***2353*****,** Airborne Astronomy Symposium Proceedings, Harley A.Thronson and Edwin F. Erickson editors, 1984.
2. Dolci, Wendy Whiting,"Milestones in Airborne Astronomy: From the 1920's to the Present" AIAA 975609, 1997.
3. Houghton, J. T., Moss, T. S., Seely, J. S., and Hawkins T. D. F., "Some Observations of the Infrared Solar Spectrum from a High Flying Aircraft", Nature **180,** 1187, 1957.
4. Kuiper, G. P., Forbes, F. F., and Johnson, H. L., "A Program of Astronomical Infrared Spectroscopy from Aircraft", U. Arizona Comm. Lunar and Planetary Lab. **93**, 155, 1967.
5. Low, Frank J., "Airborne Infrared Astronomy: The Early Days" *NASA Conference Publication* ***2353*** Airborne Astronomy Symposium - Harley A.Thronson and Edwin F. Erickson editors, 1984.
6. Erickson E. F., and Davidson, J. A., "SOFIA: The Next Generation Airborne Observatory", ASP Conference Series, **73**, 707, 1995
7. Becklin, E.E., Tielens, A.G.G.M., Gehrz, R.D., and Callis, H.H.S., "Stratospheric Observatory for Infrared Astronomy (SOFIA)", *Sensing and Instrumentation XV* (Proceedings of SPIE), 2008 in press.
8. Erickson, E. F., "Effects of Telluric Water Vapor on Airborne Infrared Observations", PASP **110**:1098, 1998.
9. Kuiper, G. P. and Forbes, F. F., "High Altitude Spectra from NASA CV 990 Jet I: Venus, 1-2.5 Microns, Resolution 20 cm-1, U. Arizona Comm. Lunar and Planetary Lab. **95**, 177, 1967.
10. Erickson, E. F., Goorvitch, D., Dix, M. G., and. Hitchman, M. J., "Learjet Telescope System", NASA TM X-62,389, 1974.
11. Haas, M. R., Davidson, J. A., and Erickson, E. F.,editors: *Airborne Astronomy Symposium on the Galactic Ecosystem: From Gas to Stars to Dust*, ASP Conference Series, **73**, 1995.
12. Cameron, R. M., Bader, M., and Mobley, R. E., "Design and Operation of the NASA 91.5-cm Telescope", Applied Optics **10**, 2011, 1971.
13. Kaercher, H. J., Erickson, E. F., Krabbe, A., Wagner, J. "SOFIA Design History", Proc. SPIE 9906, 2016
14. Dunham, Edward, "Airborne Stellar Occultations with HIPO on SOFIA" EPSC Abstracts,**3**, EPSC2008-A-005 79, 2008

American Astronomical Society
229th Meeting, Grapevine Texas
January 3-7, 2017