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Historical Review of Airborne Astronomy: Science Highlights from the Convair 990, Learjet, KAO and SOFIA

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Outline of Material

- Convair 990 (Galileo) Science
- Learjet Highlight Science
- KAO Science Highlights
- SOFIA Science Highlights
- Summary and a special Thank You!!

Science with the Convair 990

- **The Convair 990 (Galileo) started operation in 1965 with several small telescopes**
- **Fink, Larson, Kuiper and Popper studied the Water Vapor on Venus using a Fourier Transform Spectrometer. (Icarus, 1972, v17 p617)**
- **Several Solar Eclipse Observations**
- **In Nov 1966, Munch, Neugebauer and McCammon detected [Si X] and [Mg VIII] at 1.43 and 3.03 microns in the Solar Corona (ApJ, 1967, v149)**

Science with the Learjet

- **In about 1968 Frank Low placed a ~12 inch open port telescope in a NASA Learjet. Discoveries by Low etal included internal heat from Jupiter and Saturn, IR Galaxies and IR from star formation [HII] regions. ApJL, 1969, 157, L69; ApJL, 1970, 169, L79; ApJL, 1971, 165, L9.**

- **From Spectroscopy came the discovery of extensive [C II] and [OI] lines at 158 and 63 microns by the Cornell group led by Martin Harwit. ApJL, 1980, 240, L99; ApJL, 1979, 227, L29.**

- **Discovery by Pollack, Erickson etal of sulphuric acid in the clouds of Venus. Icarus 1974, v23, p8.**

Frank Low in the NASA Learjet

Early Science with the KAO

- **The first published imaging science from the KAO was of W51 by Paul Harvey, Bill Hoffmann and Murray Campbell. (ApJL 1975 196 L31)**
- **Additional Imaging science with the KAO began with Al Harper and his students at several Far IR wavelengths; Galaxies, HII regions and Planets. Also included work in collaboration with Werner, Gatley and Becklin. (ie ApJL 203, L51; ApJ 204 p420 and ApJ 205 p136)**
- **Spectroscopic results came from Fink, Larson, Fink and Gautier III, who discovered Water Vapor on Jupiter using a Fourier Transform Spectrometer in the 1 to 5 micron region. (ApJL, 1975, 197 L140)**
- **The first astrophysics far infrared spectroscopy of star forming regions were obtained by Erickson etal ApJ 1977 212, p696.**
- **The first special experiment with the KAO came when Elliott etal discovered the rings of Uranus in 1977. Nature 1977,267,p228.**

Gerry Neugebauer fixing the Dewar on the KAO

Figure C12. Graduate student Ian Gatley, Eric Becklin, Gerry Neugebauer, and Gordon Forrester (Caltech), 1976, making in-flight repairs to their far-infrared photometer.

Some additional examples of Highlight Science with the KAO

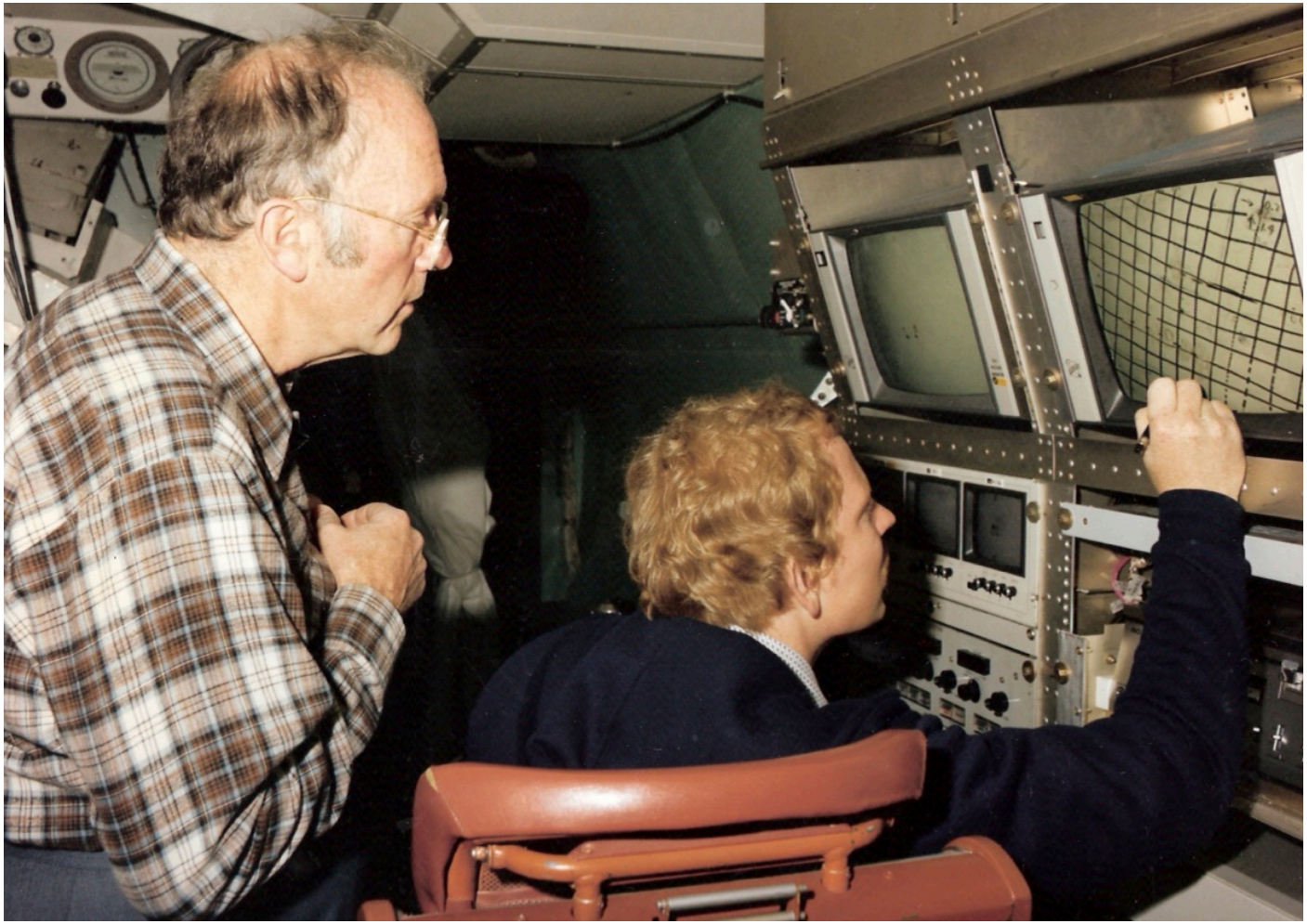
- **Townes, Genzel and collaborators obtained the first detection of high J CO and OH in the ISM, as well as first detection of OI, OIII and CII in External Galaxies**

- **Phillips etal detected and mapped the ground state CI line at 610 microns in many molecular clouds.**

- **Betz and Boreiko measured the CII, OI and high J CO (9-22) lines with high spectral resolution**

- **Discovery and analysis of PAH molecules in space by many people including Tielens, Witteborn, Allamandola, Sandford and others.**

Charlie Townes and Reinhard Genzel on the KAO



Later Highlight Science with the KAO

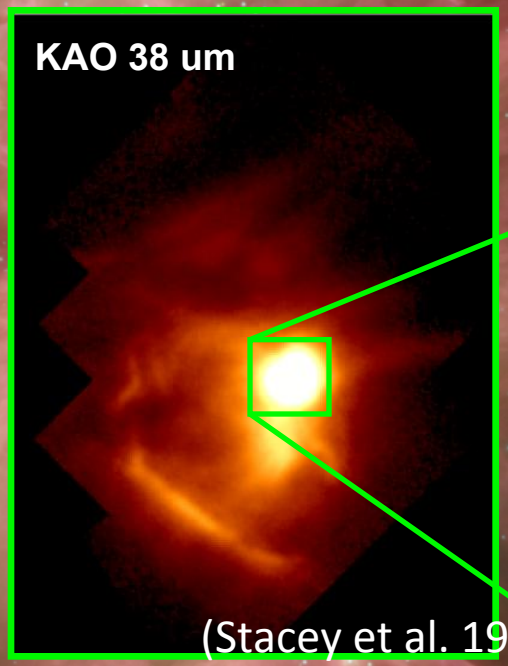
- **Hildebrand and students made the first measurements of Far Infrared polarization measurement of the dust continuum. Used to determine the direction and size of the magnetic fields in regions where stars are forming.**

- **Observations of the Core Collapse Super Nova in the LMC, SN1987A, increased our understanding of both dust formation and iron, cobalt, nickel and argon formation in a Type II supernova.**

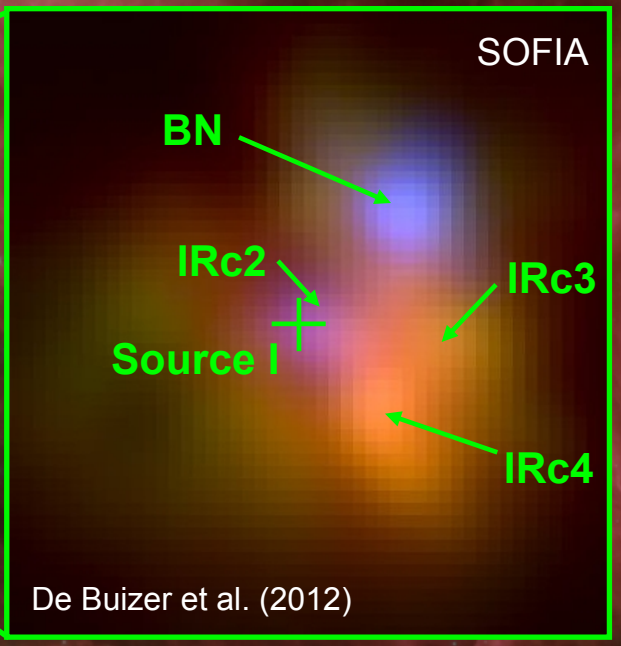
- **Discovery of the first astronomical far-infrared laser was made by Erickson etal.**

Science Highlights with SOFIA

- SOFIA is making unique imaging, spectroscopic and special observations
- You have heard or will here of many science highlights from SOFIA at this conference
- I will show a few additional examples.

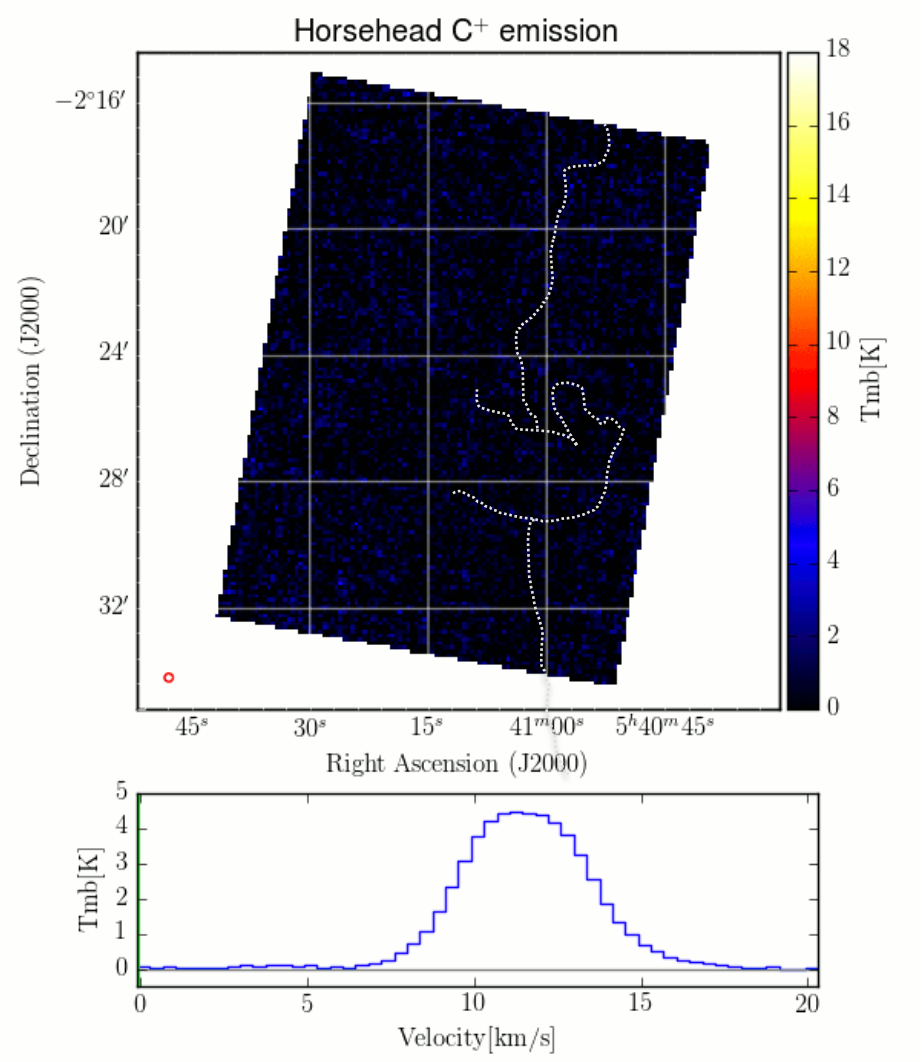


BN/KL Region
Blue=19um Green=31um Red=37um



Background Image

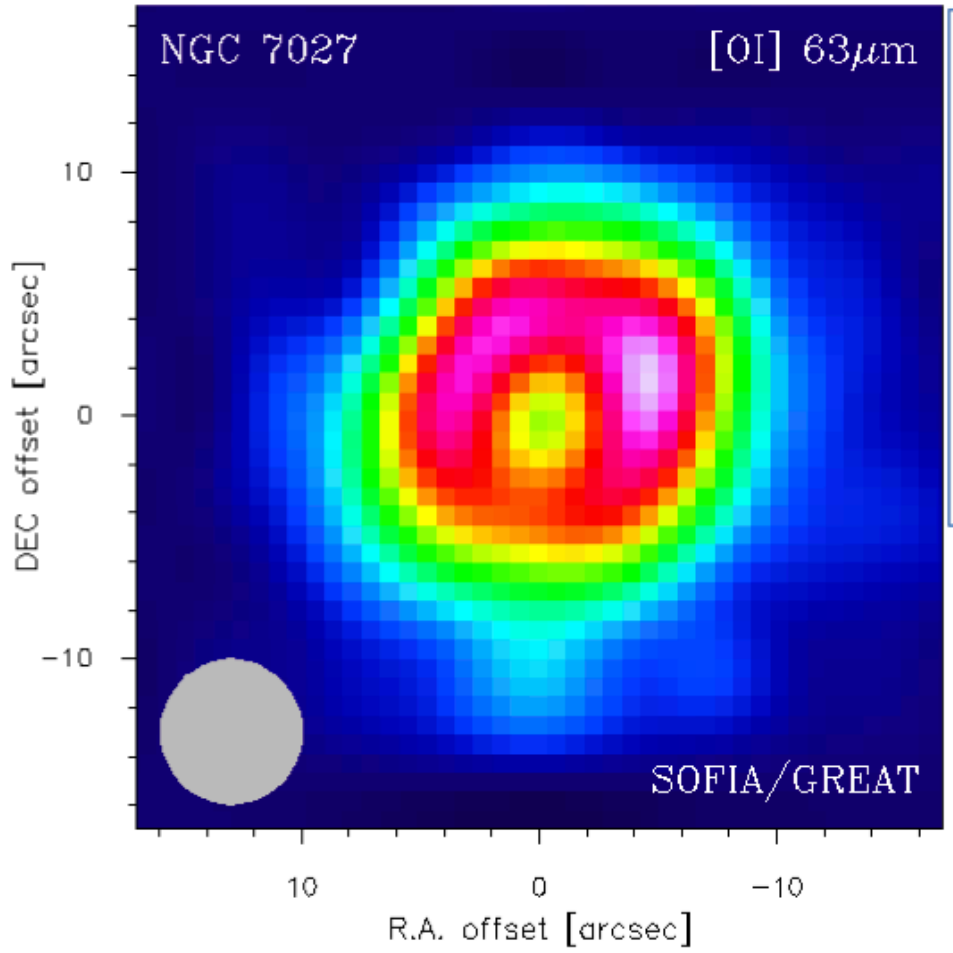
upGREAT [C II] Map

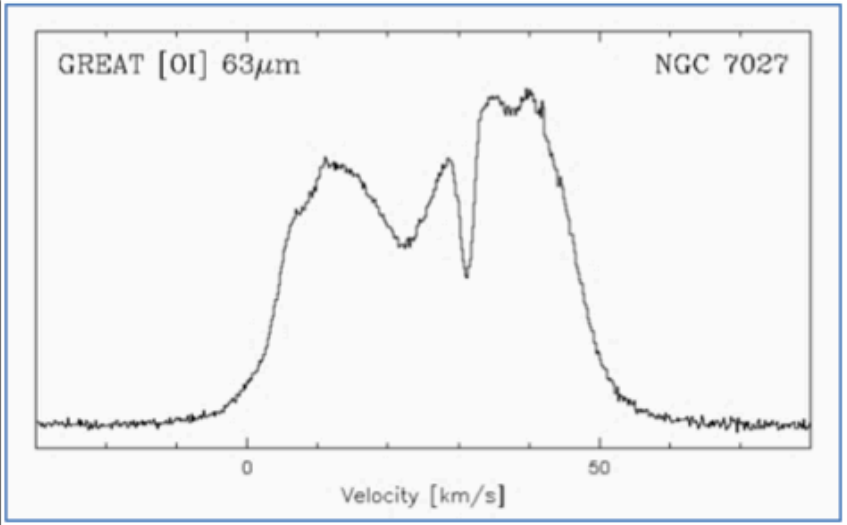


Averaged line profile over mapped region.
Smoothed to 0.76 km/s velocity resolution

50 times faster than Herschel Space Telescope

GREAT [OI] at 63 microns





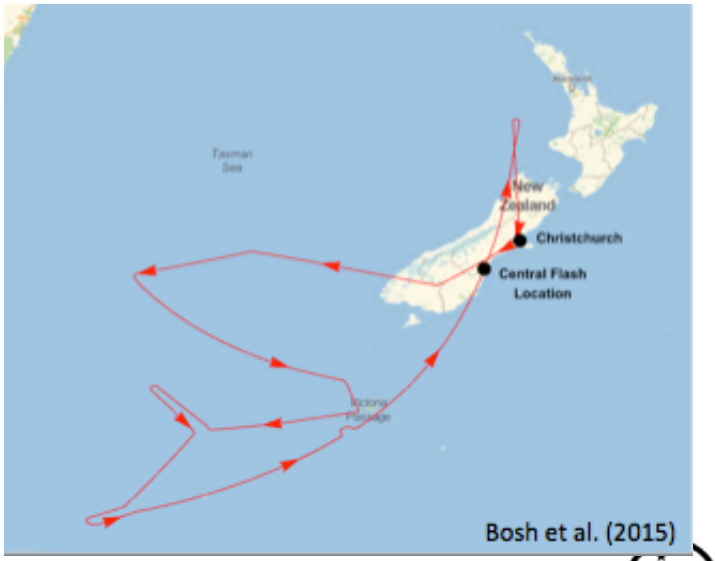
(Rolf Güsten & the GREAT Team)

Note Atmospheric OI line.

Also study of OI on Mars

Pluto Occultation on 29 June 2015

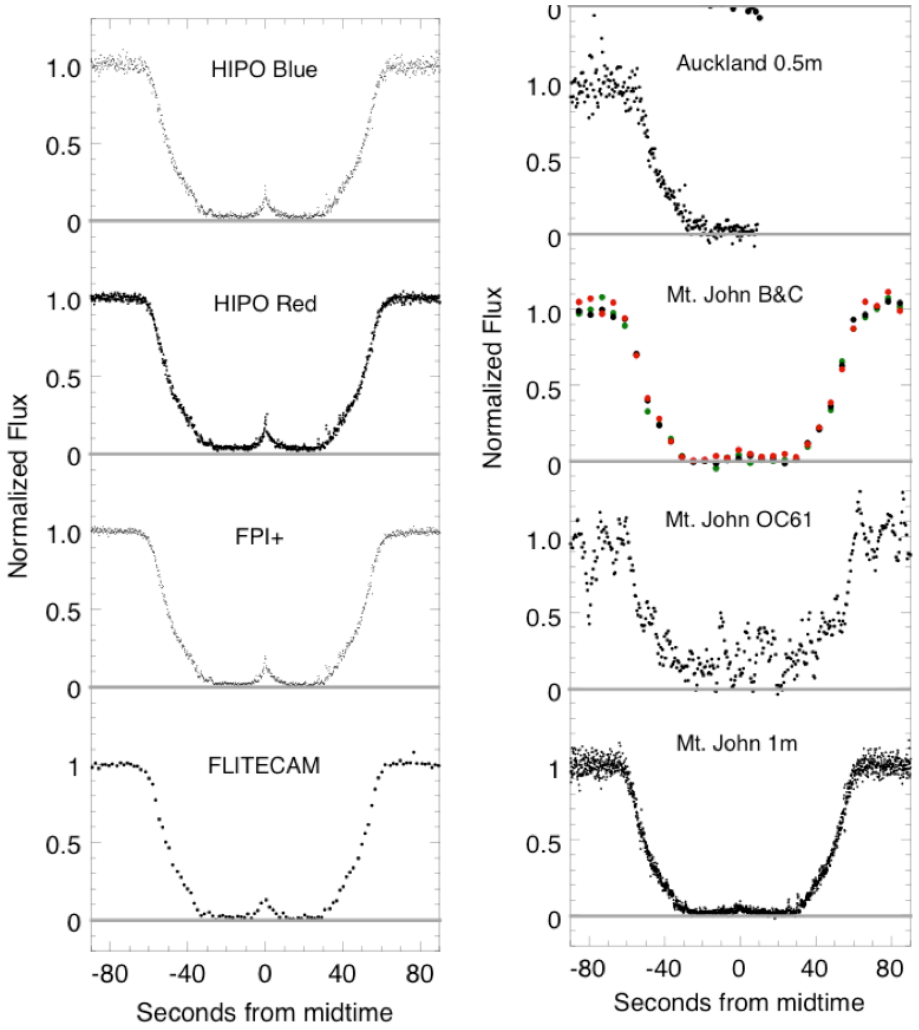
- Occultation of 12-mag star by Pluto on 2015 June 29 in support of New Horizons.
- Goal was to be within 25 km of center of Pluto shadow of 2400 km. (1 milli-arcsec and 100 milli-arcsec)
- Ground shadow moves 24 Km/s. Plane 0.3 Km/s.
- Final ground-based shadow updates required course adjustments of 200 km (8 milli-arcsec)
  - Updates to shadow path kept coming even after the plane took off.
  - Mobility of SOFIA was key to getting the observation



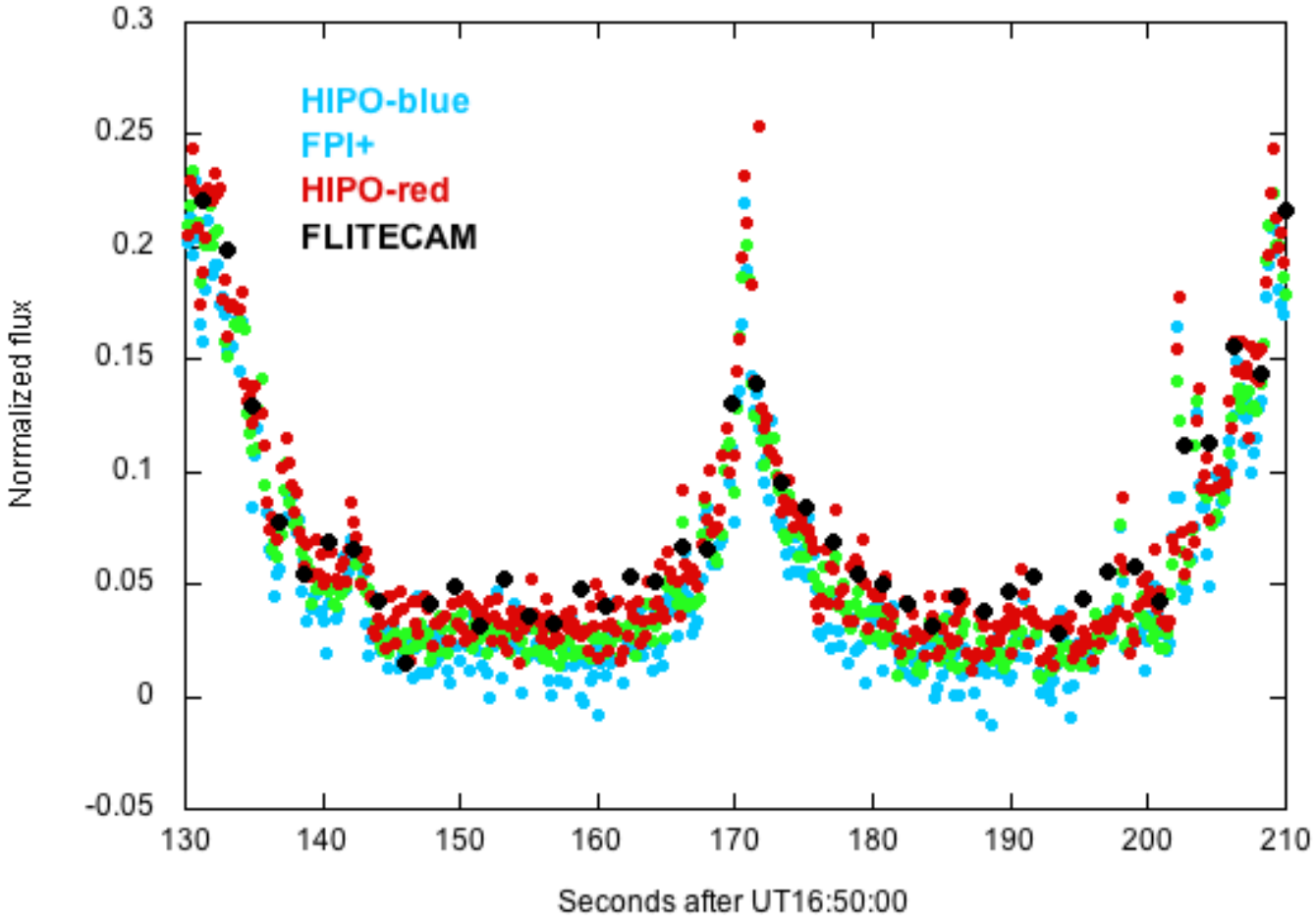
FliteCam team during Occultation

Science Highlight: Pluto Occultation

- Detection of strong “central flash” confirms accuracy of course corrections (within ~20 Km of Pluto center)
- Light curves show effect of mostly refraction in the atmosphere.
- Stability of Pluto’s atmosphere over last 15 years determined.
- Comparison of multi-wavelength observations allows detailed analysis of atmospheric profiles and aerosol or haze content.



Light curve minimum flux



Summary

- SOFIA is a 2.5-m aperture airborne telescope that provides the world astronomical community with access to wavelengths obscured by water vapor, particularly in the infrared and sub-millimeter
- SOFIA has a wide array of scientific instruments with imaging and spectroscopic capabilities
- SOFIA is able to deploy to distant locations, particularly the Southern Hemisphere as required by the science
- SOFIA is operational and producing important science in a many astronomical areas.

A Memorial Thank You

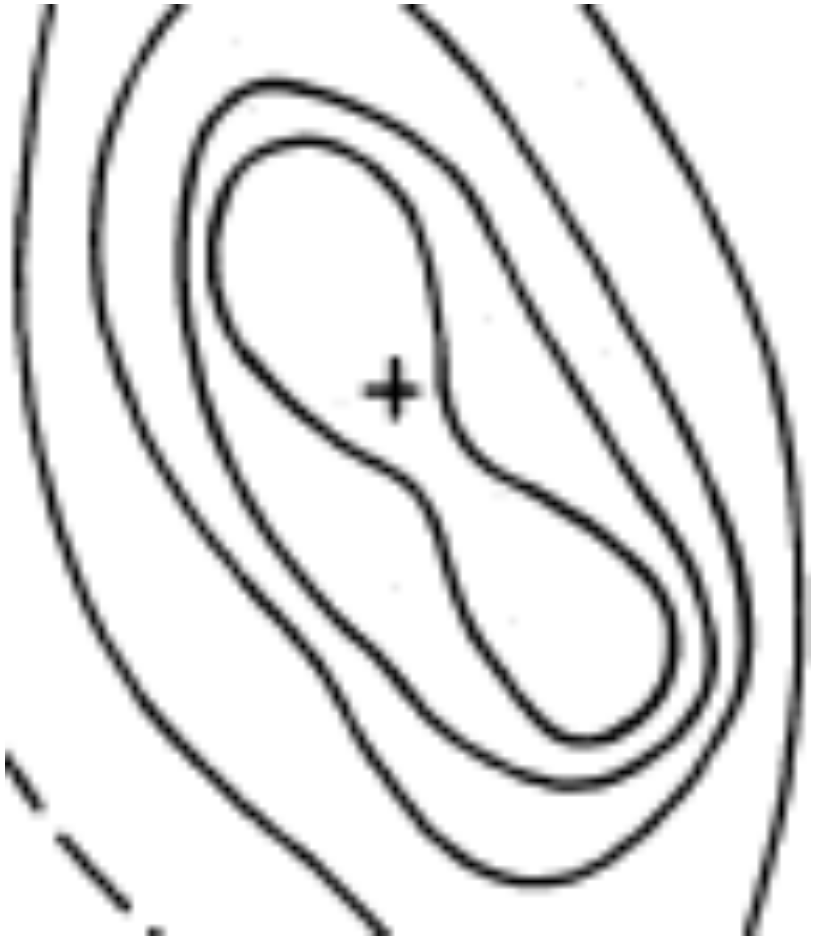
- SOFIA would not have been possible without years of tireless work and genius of Hans-Peter Roeser (DSI Stuttgart) and Nans Kunz (NASA Ames)
- Both started working on SOFIA in the 1980's
- Both passed way within the last year

Special Thank You

- There are certain people that put in a special dedicated effort on what ever they do.
- On SOFIA for the past 8 years we have had such a person.
- On the occasion of his retirement as SMO Director, I want to give a special thank you to Erick Young for his tireless efforts at getting SOFIA successfully operational!!
- Thank you Erick!!

Backup

Left KAO 50 microns, Right SOFIA 37, 31 and 19 microns



CNR at 19(blue), 31(green) and 37(red) microns

This is the highest resolution image of the Circumnuclear ring ever obtained with ~3 arcsec FWHM

- White central emission is from the hot dust heated by ionized gas of the northern and eastern arms
- Almost perfect 1.5 pc radius ring is seen in cooler dust (T~100K) centered on the Massive Black Hole and tilted about 18 degrees to the line of sight and The Galaxy
- The ring is resolved with a width of about 0.3 pc
- There is interesting small structures along the ring, almost periodic in nature.