First Science on SOFIA with FORCAST GREAT and HIPO

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Outline

- FORCAST High Resolution Imaging of Orion
- FORCAST Imaging of Galactic Center Circumnuclear Ring
- GREAT Probing Infall during Star Formation
- GREAT Discovery of OD in the Interstellar Material
- HIPO and Fast Diagnostic Camera measurements of the Pluto Occultation of 2011 June 23

Inside the Observatory with FORCAST

Science with FORCAST

- FORCAST produced sharp images from 6 to 37 µm on thirteen 10-hour science flights in Nov/Dec 2010 and in May-Jun 2011.

- Observations included several regions where massive stars are forming: Orion and Galactic Center.

- Eight papers have been published in ApJ Letters Vol 749 (2012)

Orion Nebula

- Orion Nebula is the closest region of Massive Star Formation to the Earth.
  - Distance = 415 pc
  - It contains both optically visible stars (Trapezium) and embedded star formation (OMC 1/BNKL)

- Studied on SOFIA with FORCAST the dust at 6 to 37 µm

  -- Sharpest angular resolution at 37 µm to date!

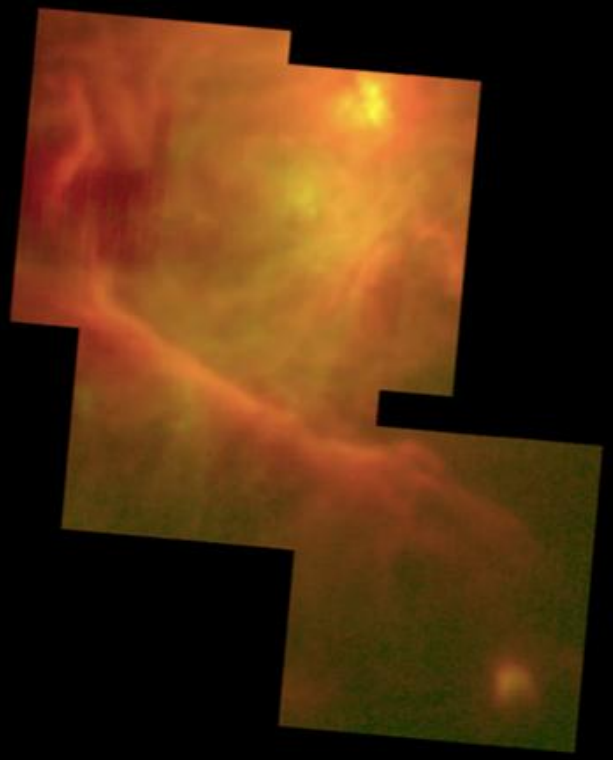
  -- BNKL: De Buizer et al. 2012, ApJ Letters, 749, L23.

  -- How many and where are luminous stars forming?

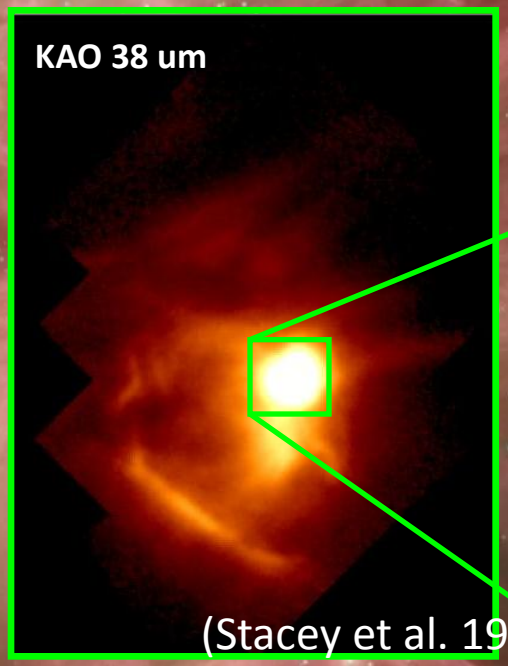
20 (Green) and 37 (Red) Micron Data of Orion Nebula

Visible light
(HST, C. O'Dell and S. Wong)

Near infrared
(ESO, M. McCaughrean)



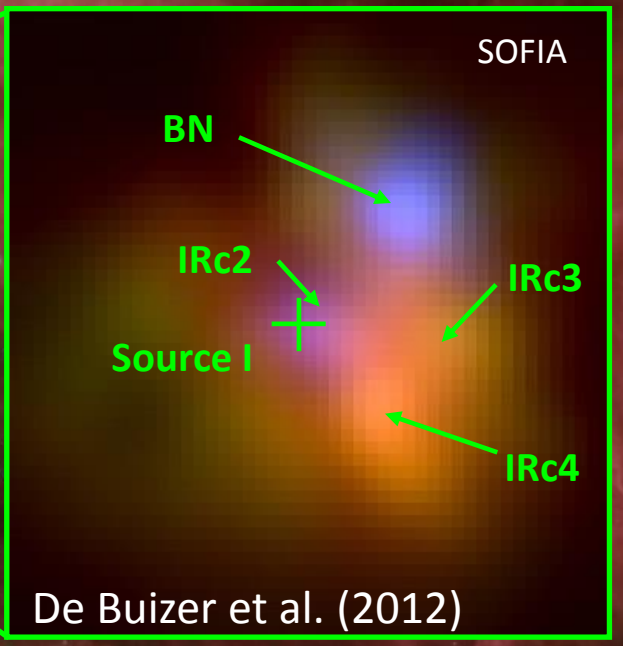
SOFIA mid infrared
(SS02)



(Stacey et al. 1995)

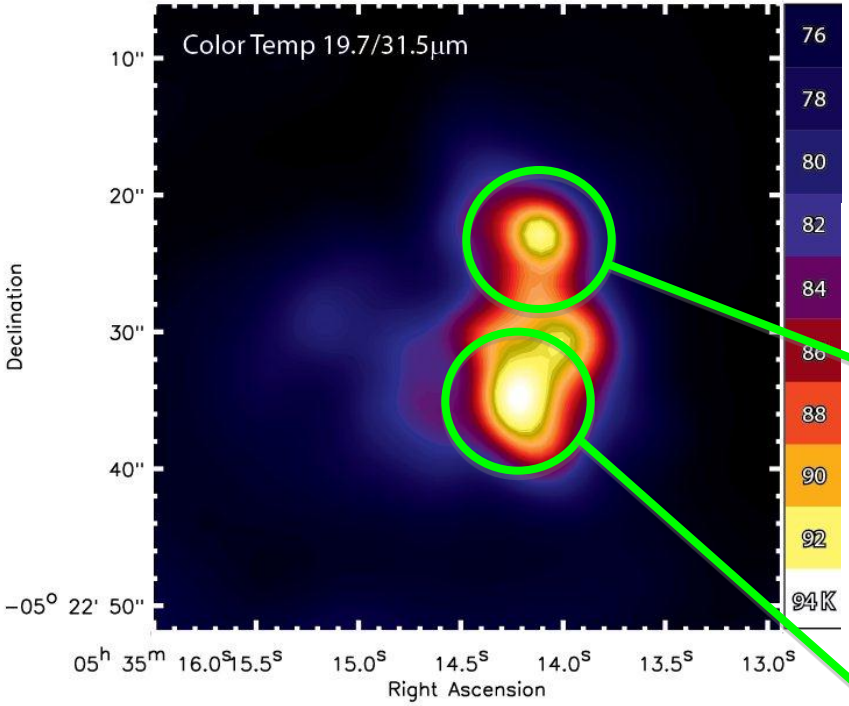
BN/KL Region

Blue=19um Green=31um Red=37um

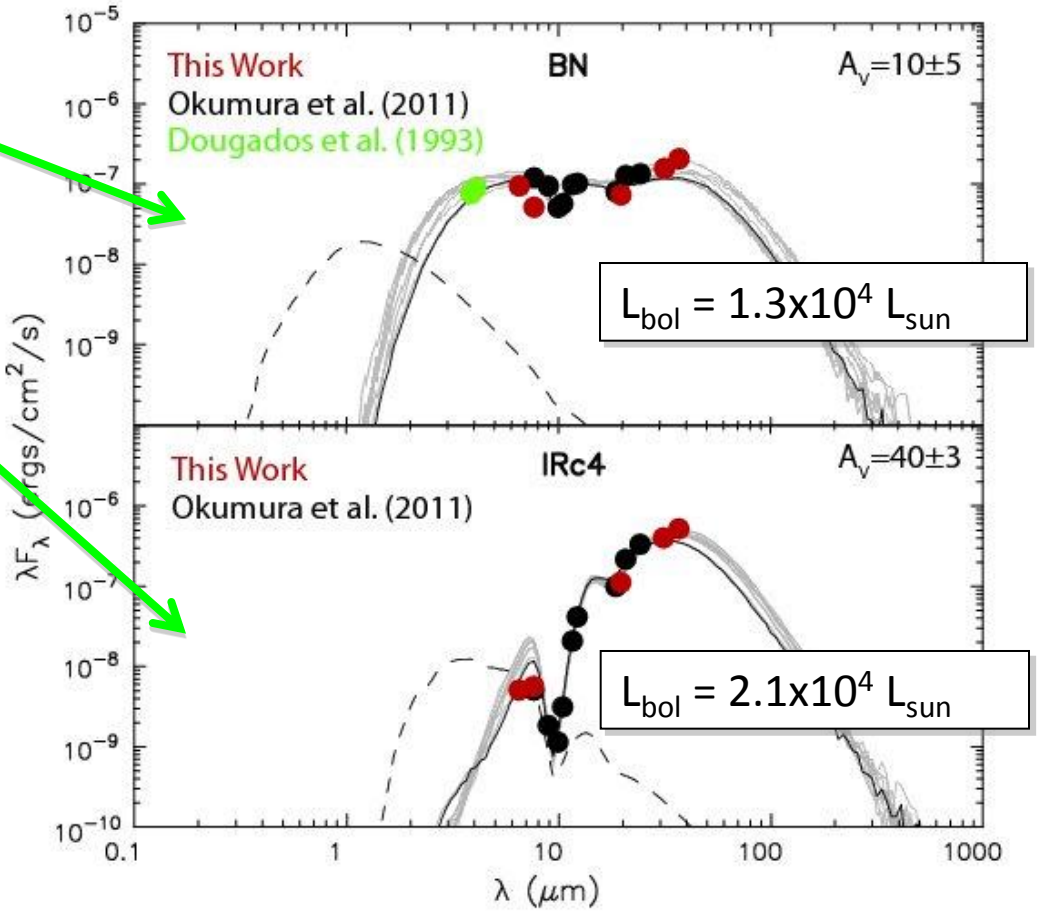


De Buizer et al. (2012)

Background Image:Spitzer



Like BN, IRc4 is a self-luminous source



IRc4 luminosity is too high to be caused by external heating

BN+IRc4 accounts for ~50% of the ~10^5 L_{sun} of the BN/KL region

De Buizer et al. (2012)

The Center of the Milky Way

- At the very core of our Galaxy, the Milky Way, exists a very massive Black Hole with $M \sim 4 \times 10^6 M_{sun}$
  - Distance = 8 kpc
  - It contains the Black Hole, young and old stars, and dust and gas.

- With SOFIA we studied the dust with FORCAST at 19, 31 and 37 µm

  -- Sharpest and deepest 37 micron image to date

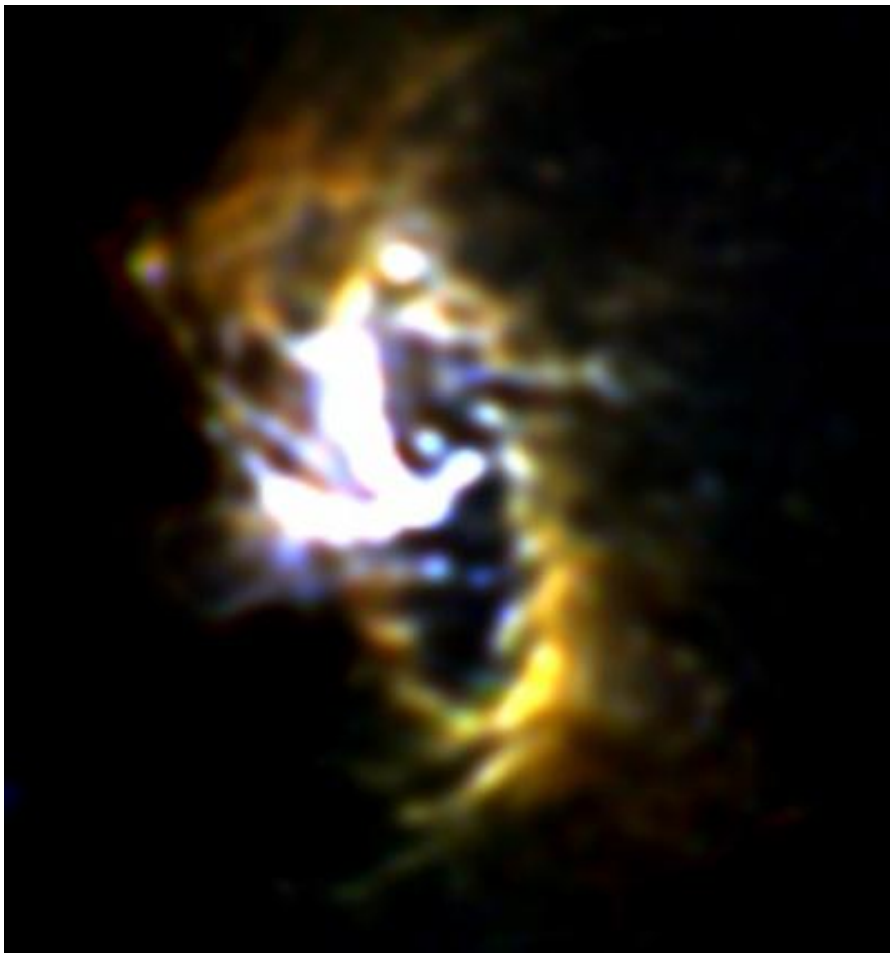
  --The central region around the Black Hole

  -- A region where massive stars are thought to be forming

Circumnuclear Ring at 19, 31 and 37 μm

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

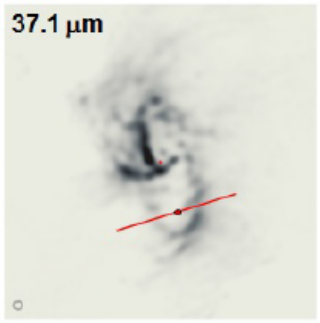
- White central emission is from the hot dust heated by ionized gas of the northern and eastern arms
- Almost perfect 1.5 pc radius ring is seen in cooler dust (T~100K) centered on the Massive Black Hole and tilted about 18 degrees to the line of sight and The Galaxy
- The ring is resolved with a width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

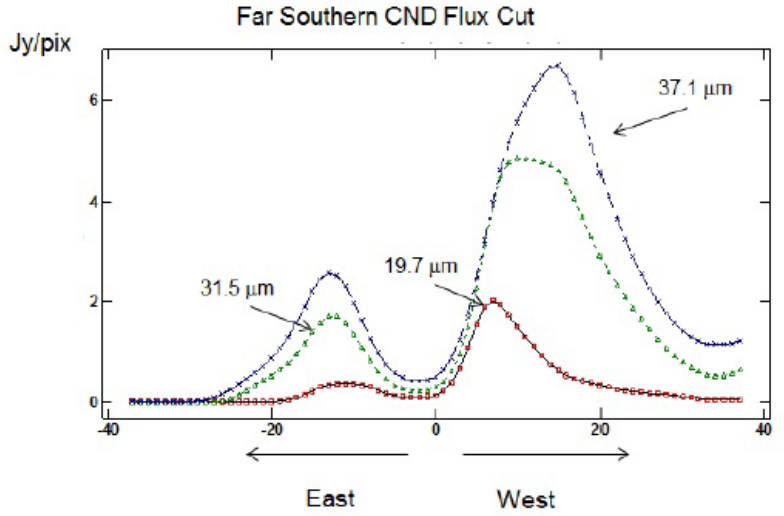


Lau et al. 2013

19 μm, 31 μm and 37 μm FORCAST Composite Image

Line Cuts along the CNR in the South





- Line cuts across the center clearly show a color gradient from the inside of the ring moving outward
- This implies centrally heated, probably by young bright stars near the BH
- Western arm of the ring brighter than eastern arm
- Poster yesterday on the results (Ryan Lau et al.). See Ryan after this session for a copy of the poster.

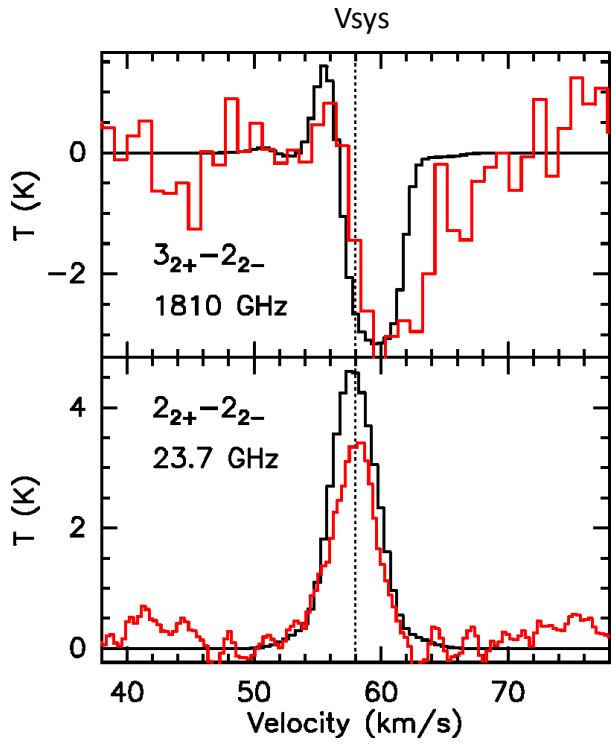
Science with GREAT

GREAT Heterodyne Spectrometer 1.4 to 2.5 THz (120 to 240 μm)

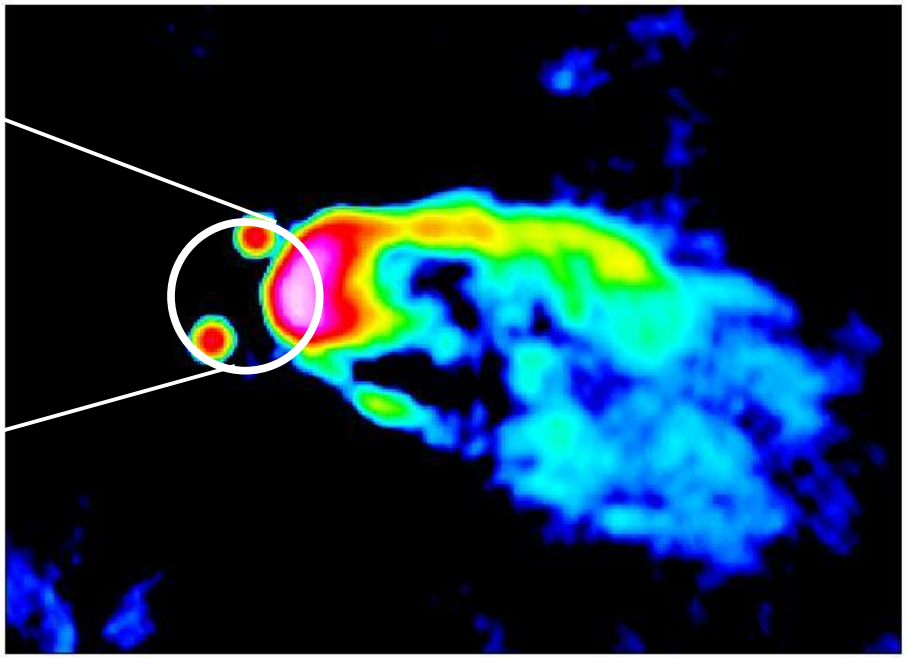
- GREAT is a Heterodyne Spectrometer with R~10^6
- About 16 GREAT flights were made in 2011 April-Nov.
- 22 papers in a A&A Letters Vol. 542, June 2012.
  -- Infall of material on to a forming stars (Wyrowski et al.)
  -- First Detection of OD in the Interstellar Medium. (Parise et al.)

Science Results: Probing Infall

- Probing infall with ammonia absorption against dust continuum
  - -- case study: UCHIIR G34.3 → red-shifted absorption detected
  - -- modeled with infalling envelope with a high accretion rate



Wyrowski et al. 2012

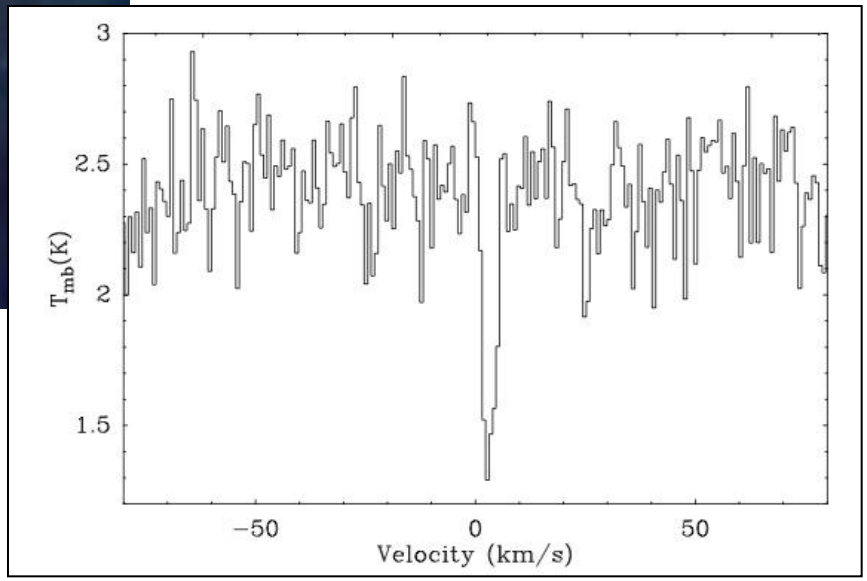


G34.26+0.15 VLA 3.6 cm

Detection of OD Toward the Low-Mass Protostar IRAS 16293-2422

Detection of the OD ground state line at 1.39 THz in absorption toward the line-of-sight of a low-mass protostar.

First detection of OD outside of the solar system.

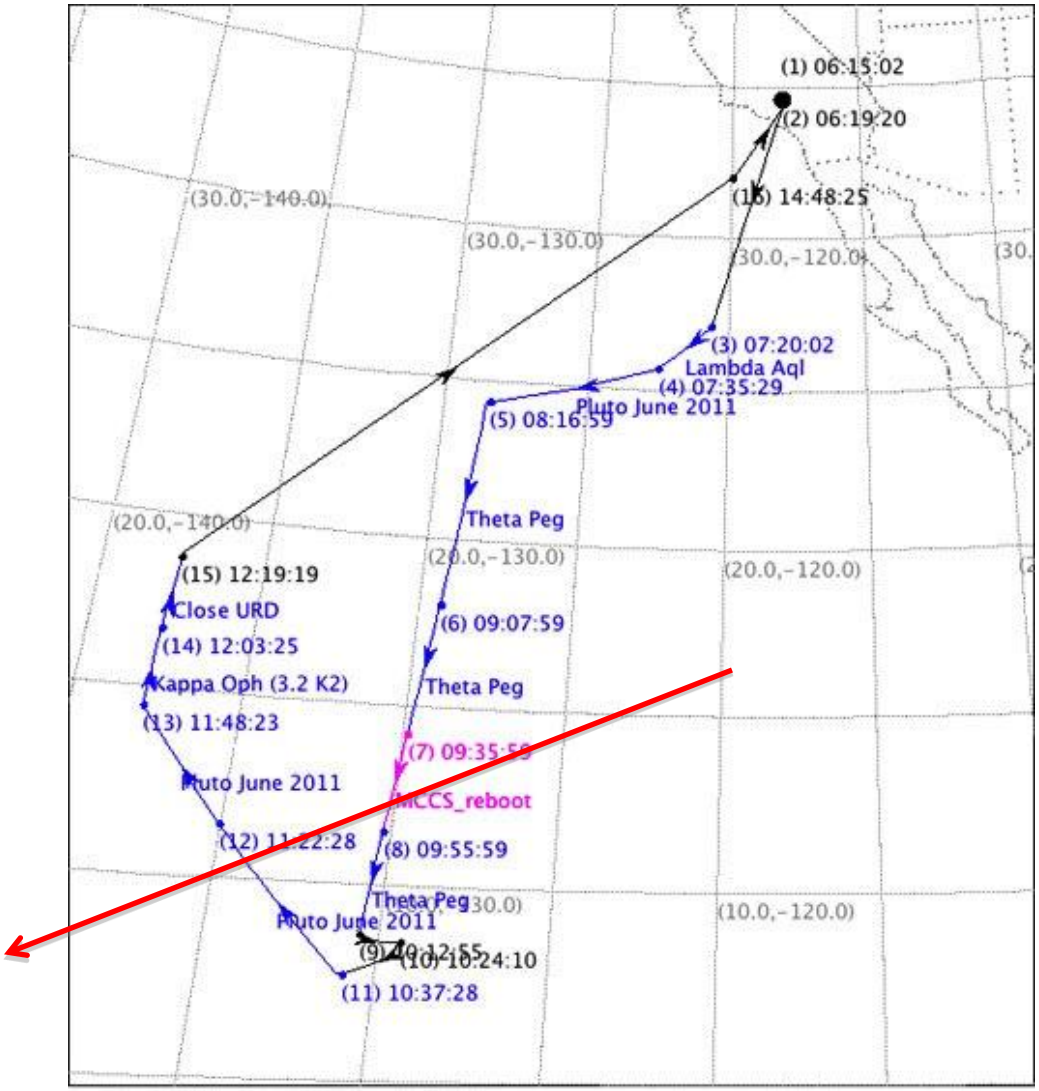


Analysis is ongoing, but high OD abundance suggests a higher than predicted OH fractionization

Work of B. Parise and the GREAT Team

Pluto Occultation with HIPO and the Fast Diagnostic Camera

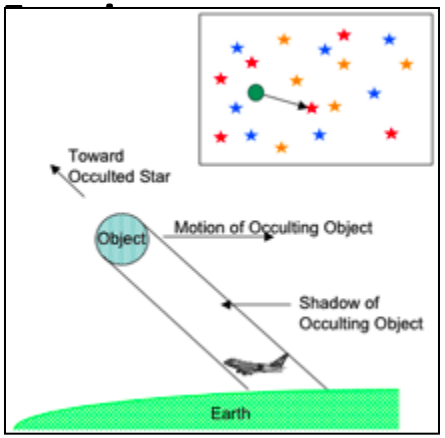
HIPO and FDC spots Pluto Eclipsing a Star



- Observed with HIPO in two channels and the FDC.

- Shadow travels at 85,000 kph (52,800 mph); SOFIA flew 2,900 km (1,800 miles) to capture the occultation

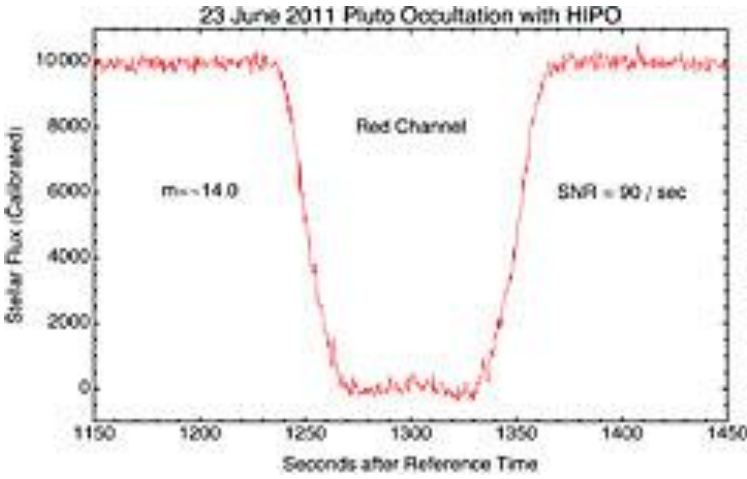
- **Hit center-line of occultation to within 100 km**



What Does This Mean for Pluto's Atmosphere?

Atmospheric pressure/temperature unchanged since 2006 measurement - atmosphere doesn't show signs of the expected collapse

Asymmetric central flash indicates significantly elliptical atmosphere → strong global winds



Ted Dunham,
Lowell Observatory,
HIPO instrument

Summary

- Early Science with FORCAST, GREAT and HIPO on SOFIA has produced outstanding science
  - 8 Letters in a special edition of ApJ Letters.
  - The Galactic Center results are spectacular
  - GREAT has many discoveries and 22 papers in a special edition A&A Letters
  - Occultation of a star by Pluto shows the potential of SOFIA

- SOFIA will be one of the primary facilities for far-IR and sub-millimeter astronomy for many years.