First Stellar Occultation Observation with SOFIA

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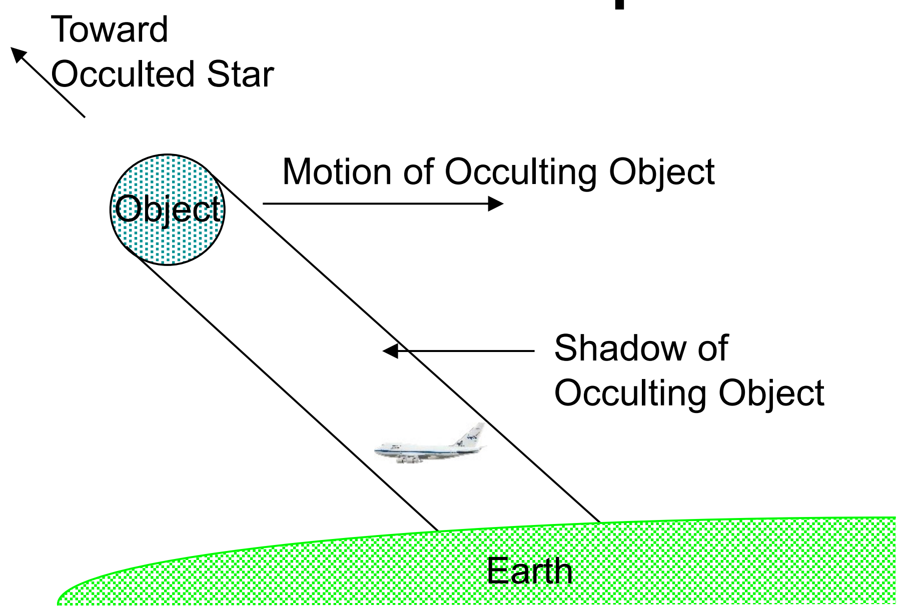
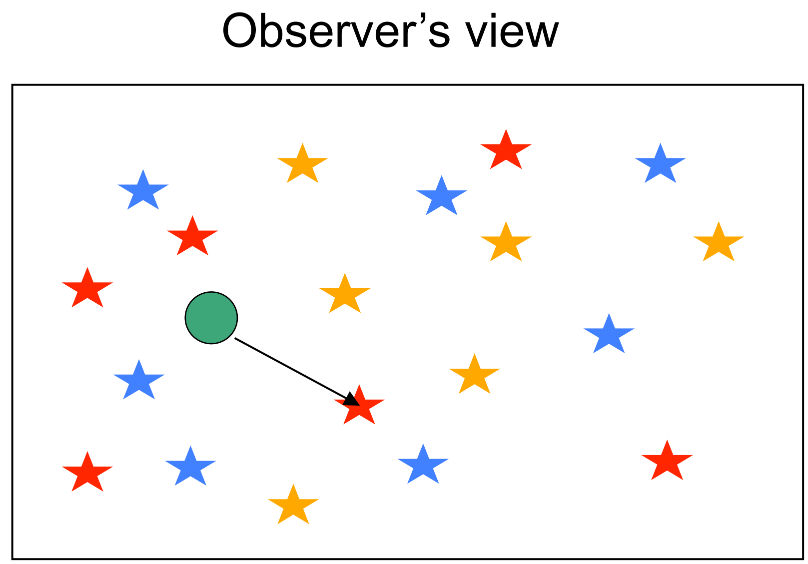
Special acknowledgement to the late Jim Elliot and Jim Darwin

Atmospheric Stellar Occultations

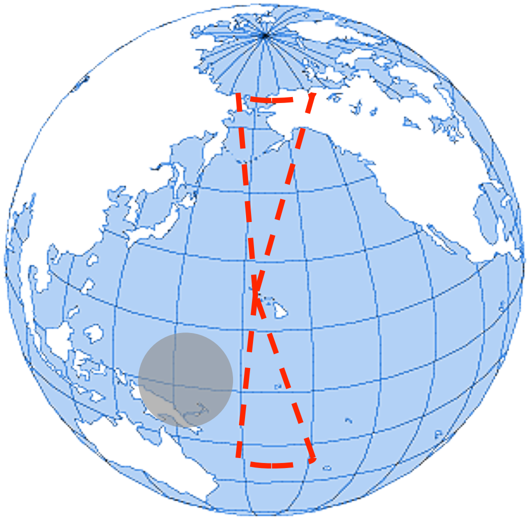




- Atmospheric sounding & accurate sizes of solar system objects
  - Pressure, density, temperature at microbar atmospheric levels
    - Central flash sensitive to global structure and extinction at lower altitudes
  - Vertical and horizontal atmospheric structures can be resolved
  - Repeated occultations can track changes in atmospheric structure

Why SOFIA?

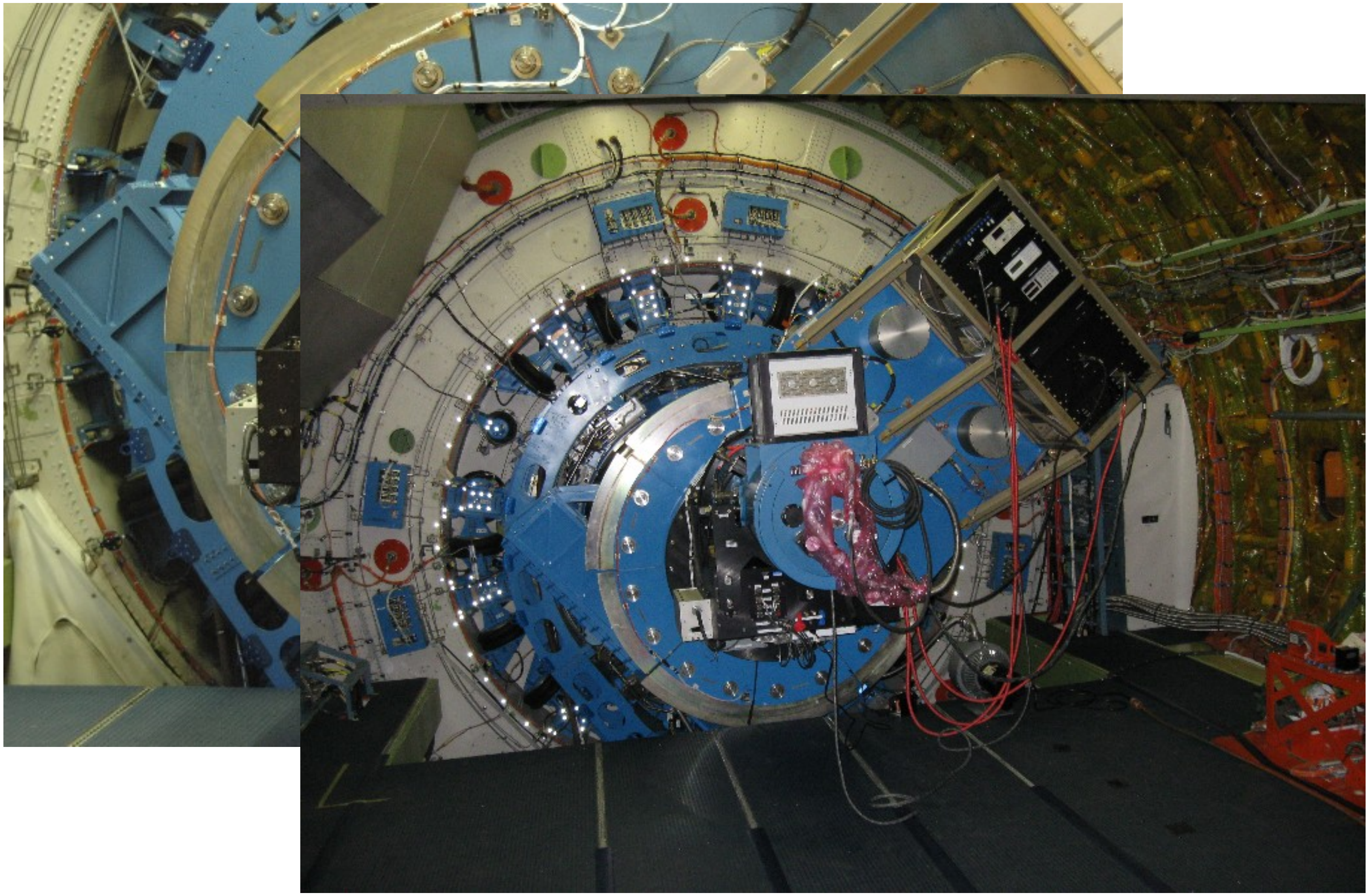
- 2.5 meter telescope
  - Largest "portable" telescope ever
- Boeing 747SP aircraft
  - Long range aircraft, ~0.7 D_{Earth} coverage from single base
  - Allows in-flight prediction update
    - Targeted occultations possible
  - Flexible Deployment Options
    - No *natural* restrictions
      - Safe aircraft operation limits
      - Fiscal, political & security limits
- Clouds exceedingly rare
- Low scintillation noise level
- Stable stratospheric transmission
- Smooth PSF (but with wide wings)



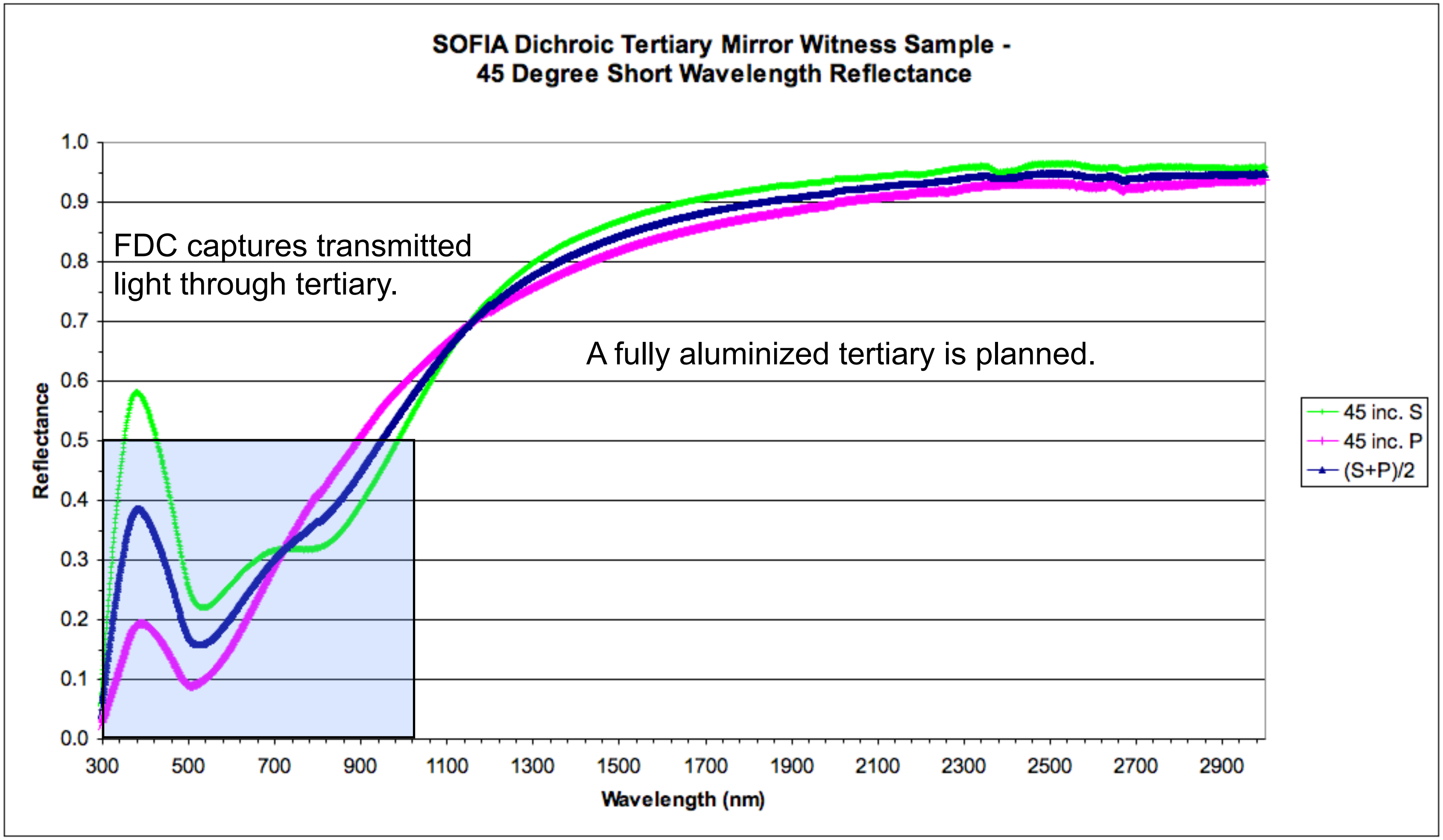
Related Considerations

- HIPO is a CCD instrument, not in SOFIA's IR 'sweet spot'
  - Rationale for airborne work:
    - Mobility, ephemeral events
    - Precise photometry
      - Low scintillation
      - Stable long-term photometry (a work in progress)
- "Custom" observations
  - Flexibility of configuration essential
  - Modifications may be needed to optimize the observation
- Therefore HIPO is a Special Purpose Science Instrument
  - Avoids the rigidity of a facility instrument
  - Co-mount with FLITECAM for simultaneous optical/IR work
  - Collaboration with Fast Diagnostic Camera (FDC) team
  - Collaboration with team(s) needed for best use of instrument(s)

HIPO (June & December) and FLIPO (August & October)



A Fly in the Ointment

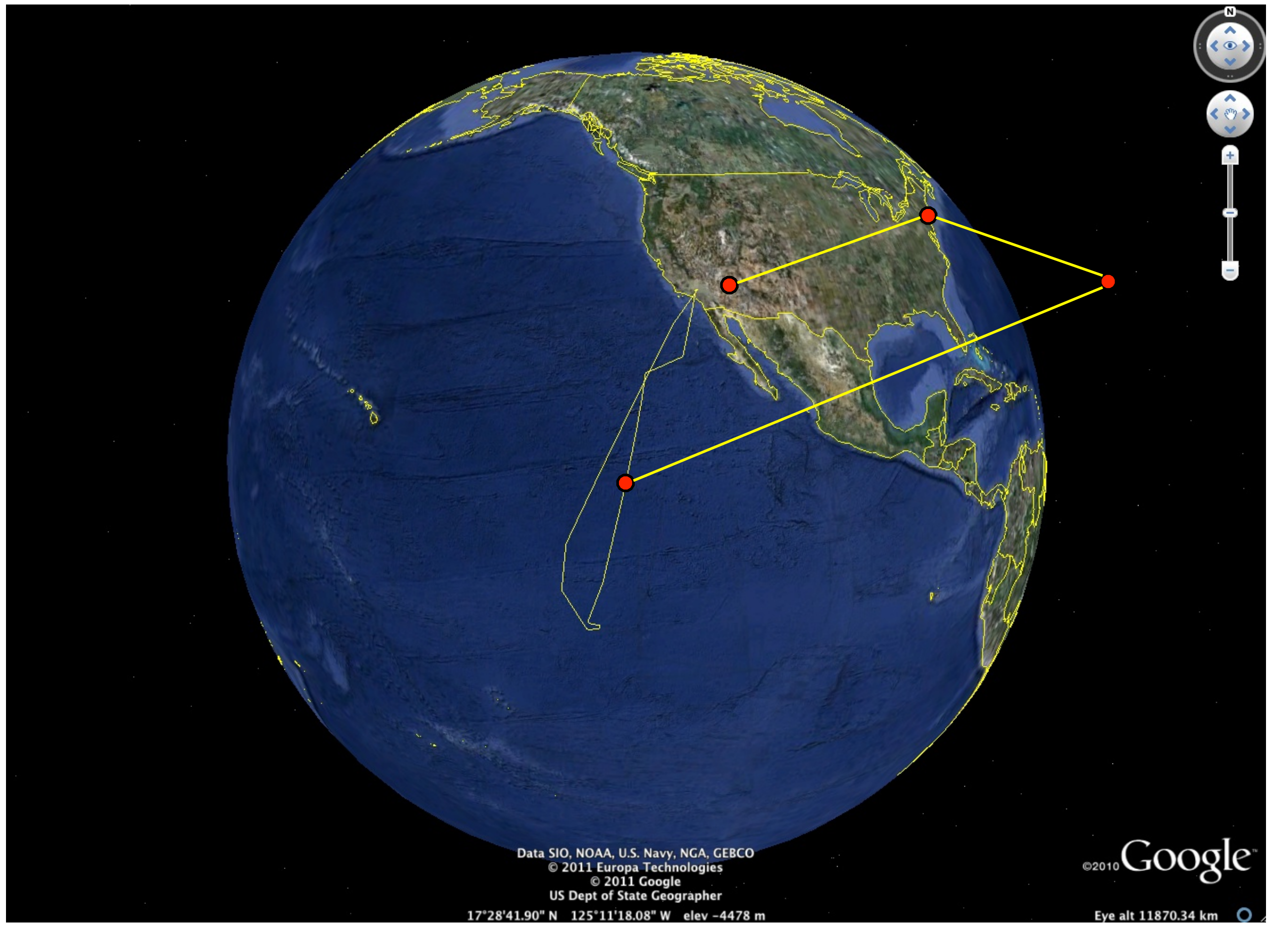


Pluto Occultation Programmatic Circumstances

- Occultation opportunity arose early in year
  - Timing fit in with the early science and V&V activities
    - Also propitious timing for New Horizons flyby preparation
- Process to decide whether to attempt observation
  - Proposal submitted and reviewed; tentatively approved
  - Simultaneous FDC data proposed to avoid tertiary loss
  - Unfortunately FLITECAM was not available
  - Targeted the central flash:
    - Richest possible dataset
    - Difficult prediction! Aimed for 100 km at 30 AU => 4 mas
    - Required in-flight prediction update
  - Early prediction work key to establish feasibility
    - Aircraft fuel performance only partially known at the time
- First SOFIA flight into remote waters
  - Pluto leg equidistant from Palmdale, Honolulu, and Tahiti

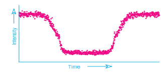
Pluto Occultation Observational Circumstances

- Plan of attack:
- Early calibration leg
- Test work
- Final prediction
  - Data from USNO Flagstaff Station
  - ftp to MIT for instant analysis
  - Iridium telephone update to flight deck
  - Flight plan updated
- Turn at updated time
- Observe event
- Test work on the way home till sunrise



Old Slide of 1988 KAO Pluto/P8 Light Curve

- Differential refraction is the main cause of fading of the star



- Extinction by aerosols *might* occur

Isothermal

Steep gradient?

Extinction?

- Refractive lightcurves can be inverted to provide temperature profiles in a region between UVS and radio occultations.

Pluto/P8 occultation, 1988

- Emphasis is shifting to central flash events.

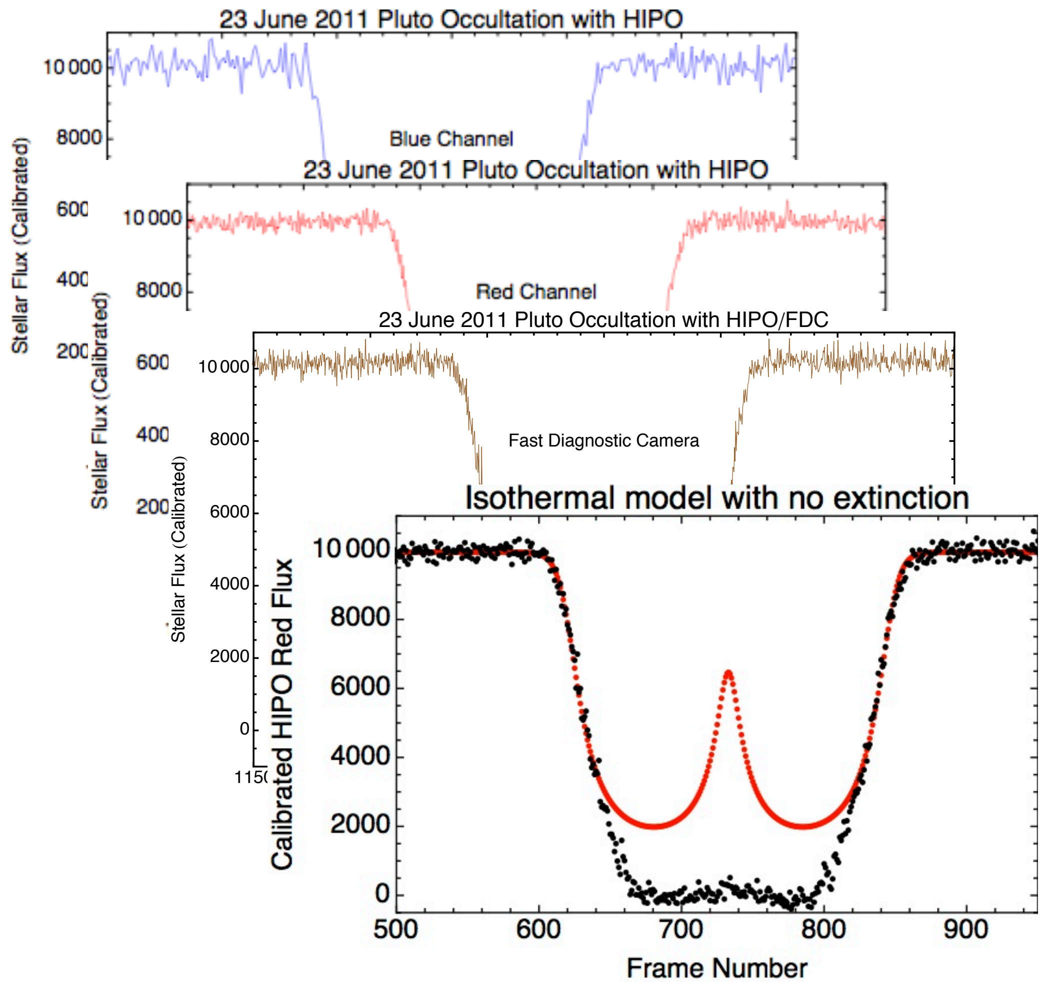
Elliot, *et al. Icarus* **77**, 148-170 (1989)

- Spatial resolution is limited by diffraction, (~ 1-2 km), the angular diameter of the occulted star, and the lightcurve S/N ratio

Examples of airborne planetary atmosphere occultation results:
- Discovery of the central flash phenomenon
- Discovery of Pluto's unusual atmospheric structure

2011 Pluto Occultation Light Curves

- Central brightening seen in all lightcurves
- Post-event fit to two chords indicates impact parameter ~100 km
  - Solution supported by USNO observation at high airmass
- Expected to see a much brighter and sharper central flash than this
  - Strong thermal inversion?
  - Extinction?
    - If so, episodic
  - Atmospheric asymmetry?
    - Easy to distort central flash, hard to move it.



Summary

- Unambiguous but weak, broad central brightening seen
- SOFIA chord ~100 km from the center of the shadow
- Central flash strongly attenuated
  - Probably in part due to thermal inversion
  - Almost certainly some extinction involved also
  - Possible, but unlikely, that central flash is significantly offset
- Precisely targeted occultation work demonstrated
- Next Steps:
  - Monitor atmospheric structure as New Horizons flyby nears
    - Attempt central chords for best understanding
    - Determine timescales for variability
    - FLIPO observations to search for particle size effects

We thank the SOFIA program for its willingness to attempt this challenging observation at such an early stage of SOFIA science operations and the US Naval Observatory Flagstaff Station for allowing us to use their facilities to obtain our prediction astrometry observations.

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Questions?