Occultation Work with SOFIA & the University of Stuttgart's 60 cm Telescope "ATUS"

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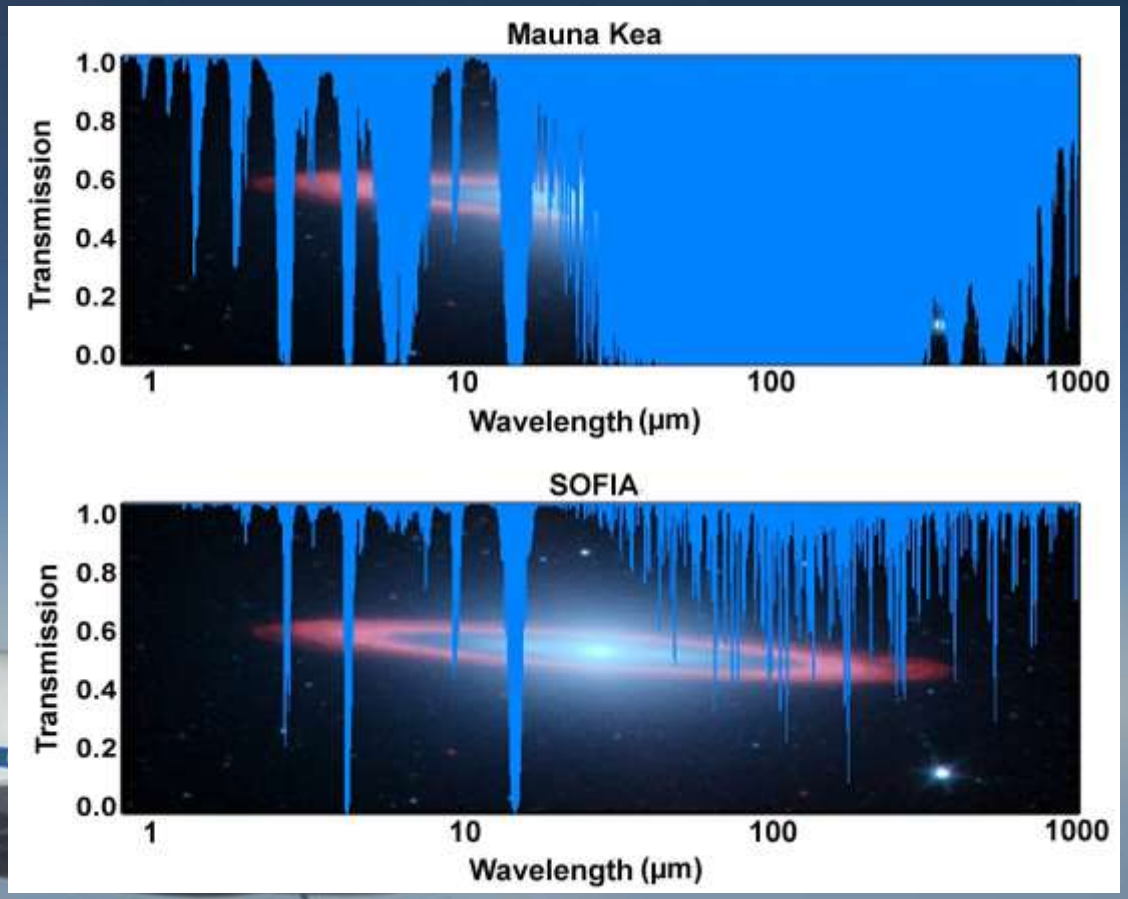
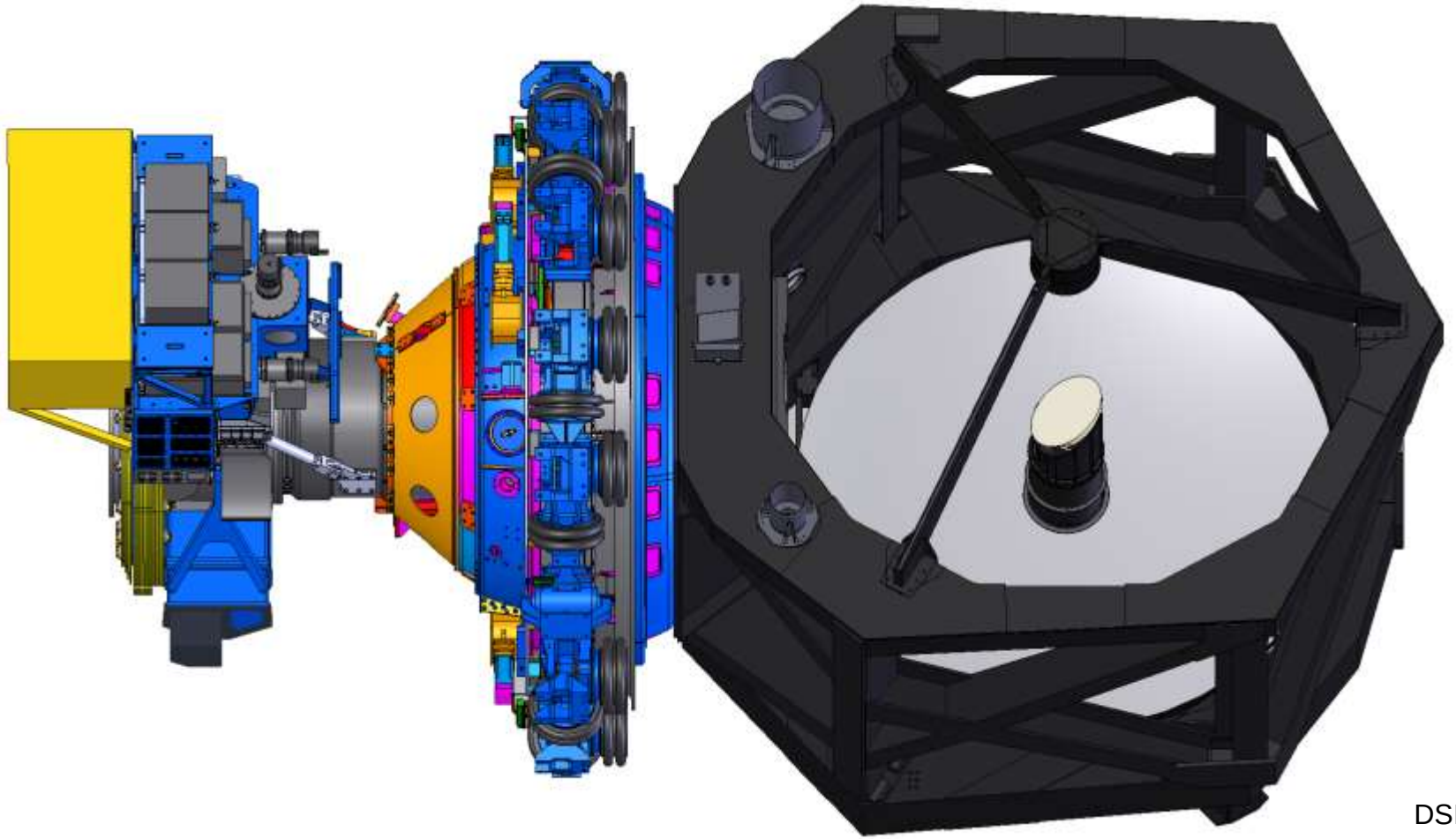
Outline

1. A quick overview on SOFIA
2. SOFIA‘s observations of stellar occultations by Pluto in 2011 & 2015
3. Our groundbased 60 cm telescope at SRO
4. Future plans

Stratospheric Observatory For Infrared Astronomy



The SOFIA Telescope

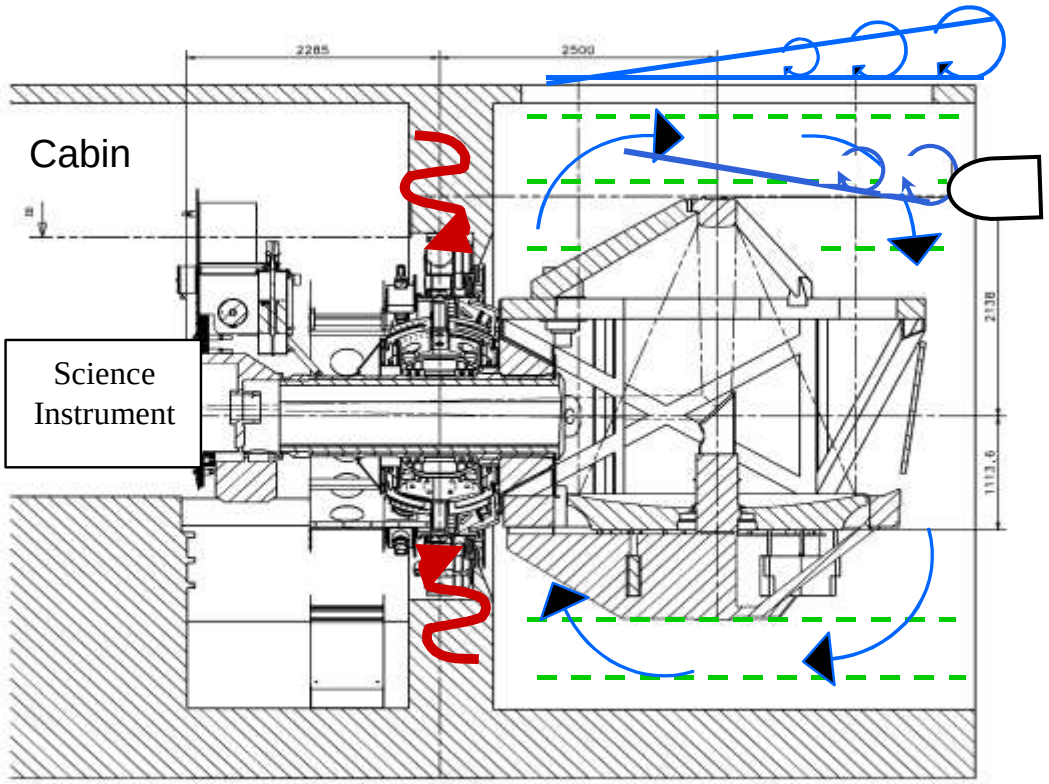


DSI

Cabin
~+20ºC, 0.8 bar

Cavity
~ - 40ºC, 0.1 bar

Dynamic Environment in the Cavity



Shear Layer at Cavity Opening

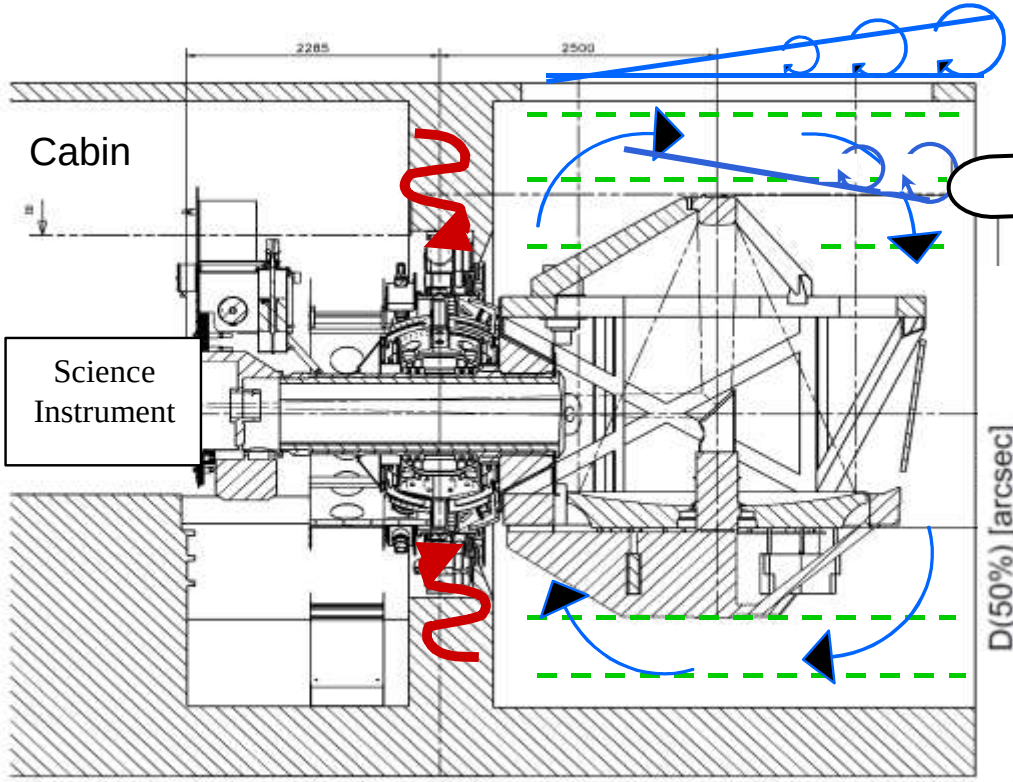
Standing Waves Excited by the Shear Layer

Wind in Cavity Induced by the Shear Layer

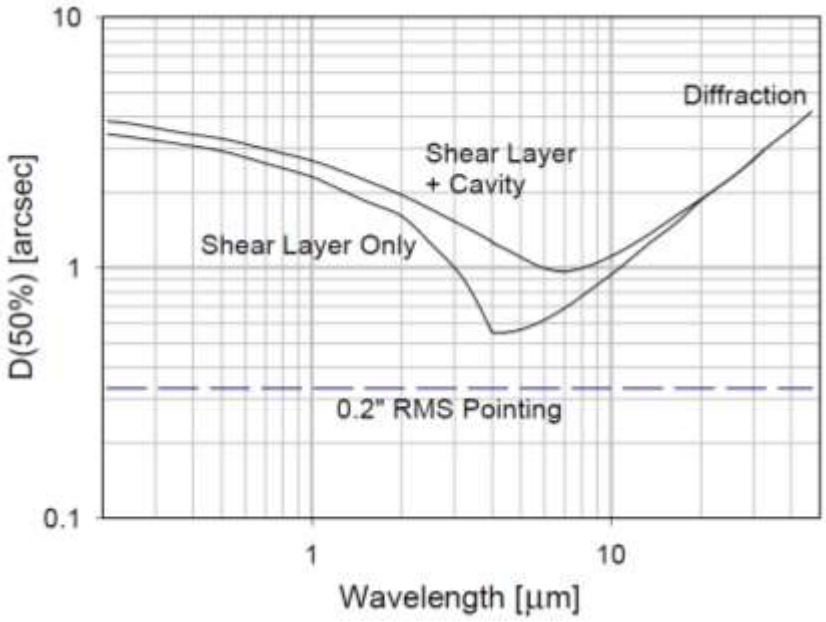
Aircraft Vibrations

SOFIA Program

Dynamic Environment in the Cavity



Shear Layer at Cavity Opening



Erickson & Dunham 2000

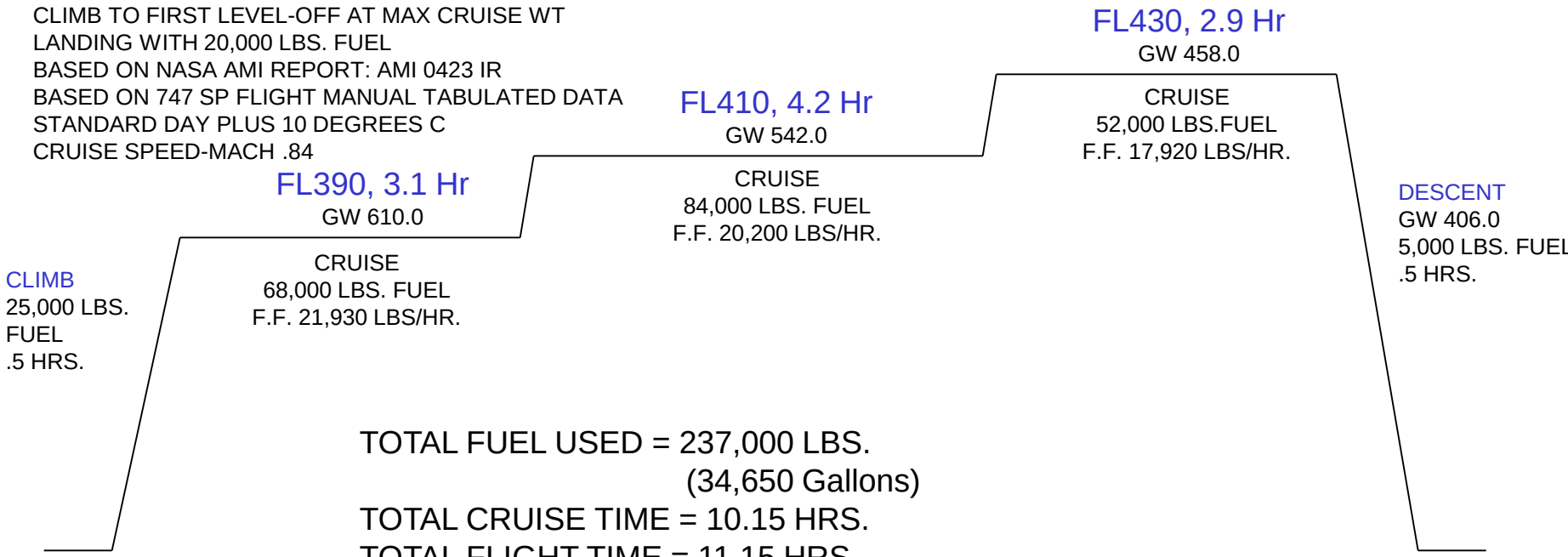
SOFIA Program

Flight Profile

ASSUMPTIONS

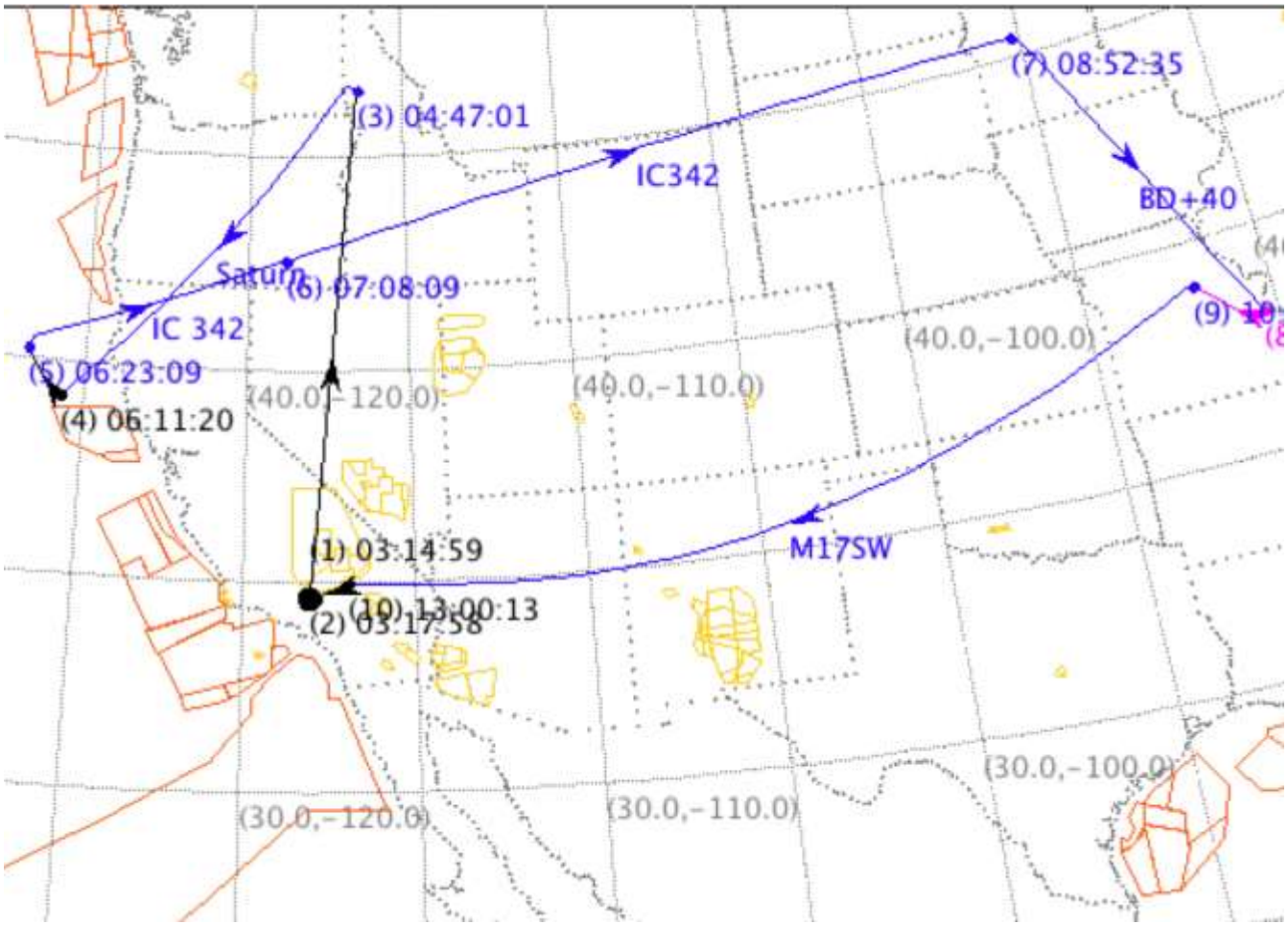
ZFW 381,000 LBS.
ENGINES OPERATE AT 95% MAX CONT THRUST AT CRUISE
25,000 LBS. FUEL TO FIRST LEVEL OFF
CLIMB TO FIRST LEVEL-OFF AT MAX CRUISE WT
LANDING WITH 20,000 LBS. FUEL
BASED ON NASA AMI REPORT: AMI 0423 IR
BASED ON 747 SP FLIGHT MANUAL TABULATED DATA
STANDARD DAY PLUS 10 DEGREES C
CRUISE SPEED-MACH .84

Performance with P&W JT9D-7J Engines:
Observations – start at FL390, duration 10.2 h



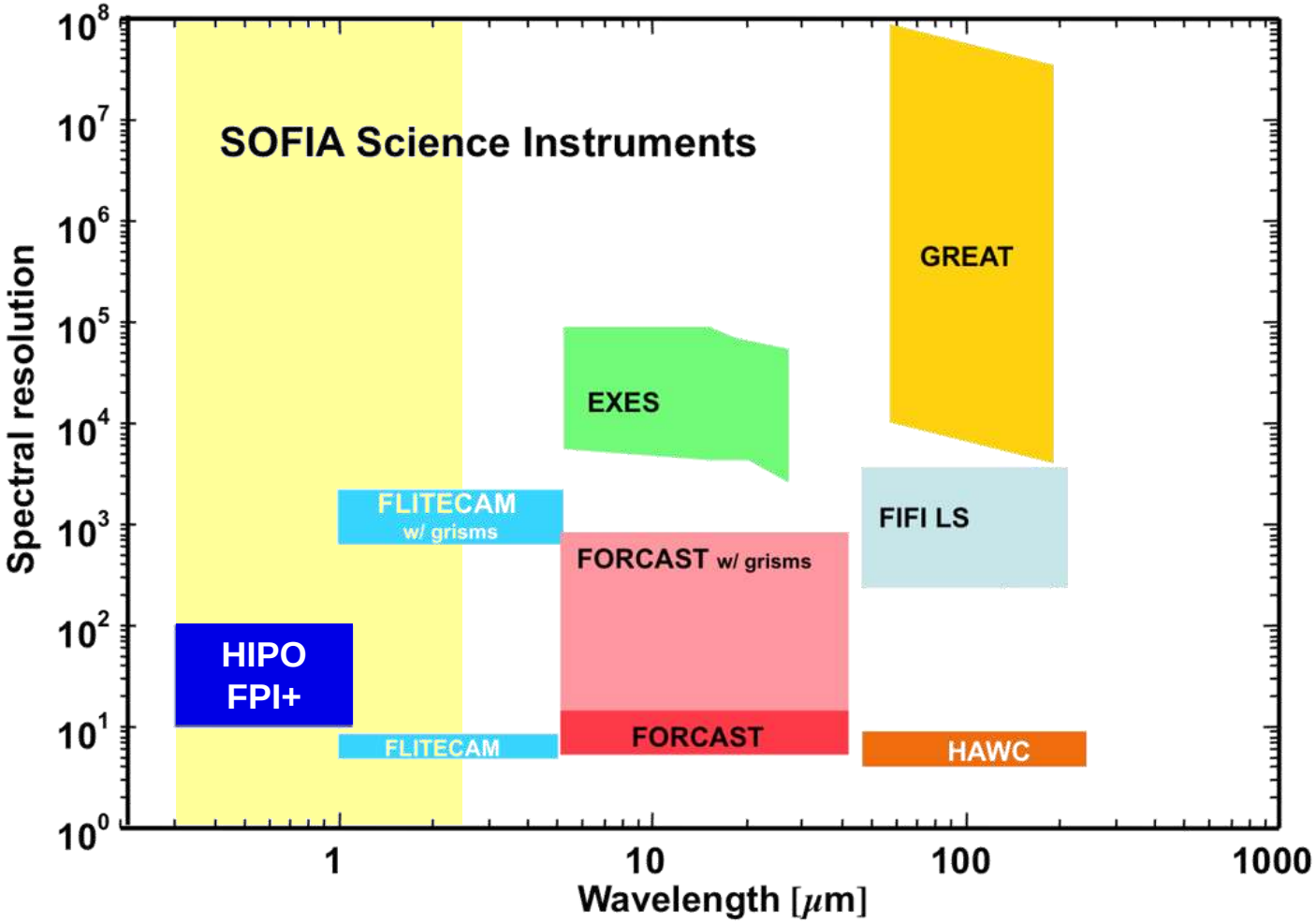
TOTAL FUEL USED = 237,000 LBS.
(34,650 Gallons)
TOTAL CRUISE TIME = 10.15 HRS.
TOTAL FLIGHT TIME = 11.15 HRS.

Flight Planning

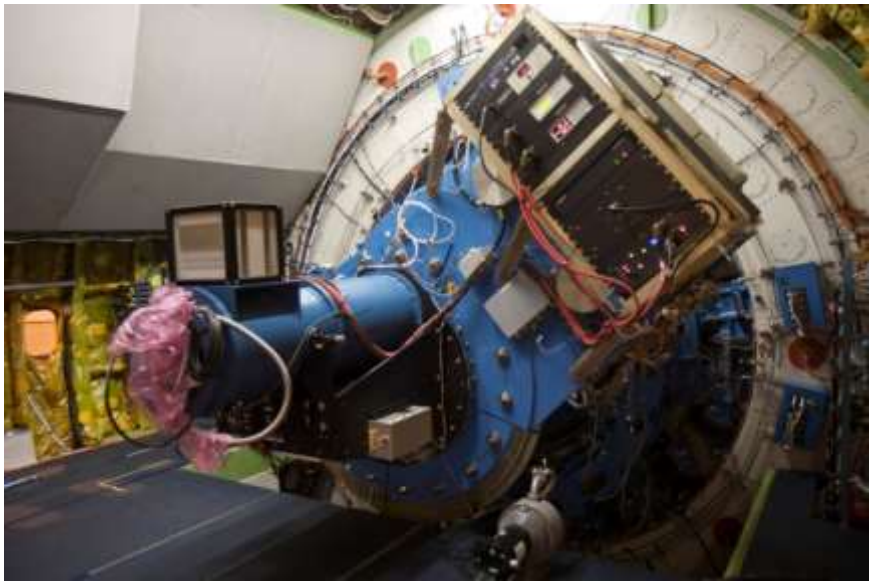


SOFIA Program

Available Instruments



FLITECAM
First Light Infrared Test Experiment CAMera



HIPO and FLITECAM co-mounted on the Telescope

- **λ = 1- 5.5 µm**
- Detector: Raytheon ALADDIN III InSb Array, 1024 x 1024
- FOV: Ø 8‘
- 0.46“ per pixel
- **Available filters for imaging**: J, H, K, L, M. Pa α, Pa α continuum, Water ice (3.08 µm), PAH (3.29 µm), L_{narrow}, M_{narrow}
- Grism spectroscopy, spectral resolution: 1000 – 2000 (2“ / 1“ entrance slit)
- Read noise: ≤ 40 electrons
- Quantum efficiency: ~ 80 %
- Cooled by double liquid helium and nitrogen cryostat

Principal Investigator:
Ian S. McLean, UCLA, Div. Astronomy, Los Angeles, California

HIPO
High Speed Imaging Photometer for Occultations

HIPO in the lab at Palmdale

- λ = 0.3 – 0.6 µm (blue channel)
  λ = 0.4 – 1.1 µm (red channel)
- FOV: 5.6‘ x 5.6‘
- 0.33 arcsec/pixel (with reimaging optics) / 0.055 arcsec/pixel (without)
- Maximum frame rate: 10/20 ms for three 80x80 pixel sub-frames
- Detectors: 1024 x 1024 e2v CCD47-20 frame transfer CCDs, on chip binning possible
- Read noise: ≤ 6 / 3 electrons
- Quantum efficiency: 40 – 80 %
- Available filters: Johnson, Sloan, Methane

Simultaneous high-speed time resolved imaging photometry in two channels (FLIPO = HIPO & FLITECAM = + NIR channel)

Principal Investigator:
Dr. Edward W. Dunham; Lowell Observatory, Flagstaff, Arizona

FPI+
Upgraded Focal Plane Imager

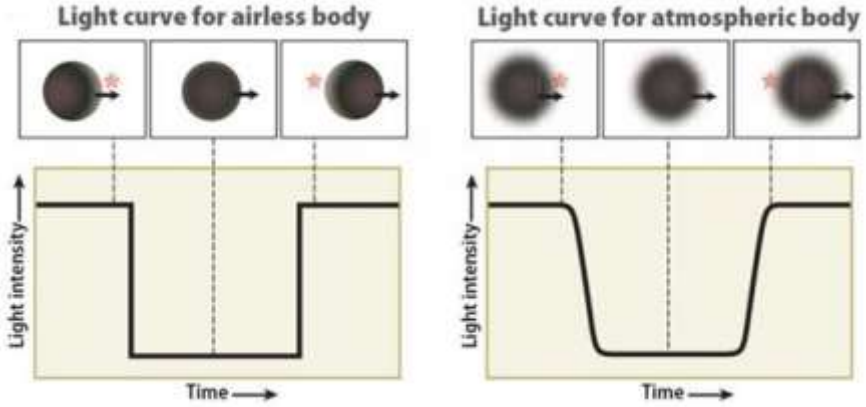

New double filter wheel


Andor DU-888 as FPI+ at SOFIA telescope

- FPI+ is permanently mounted to SOFIA telescope
- Andor iXon DU-888: Back-Illuminated, frame transfer EMCCD
- Diagnostic tool to measure telescope jitter: 426 fps 32x32 AOI 4x4
- Tracking down to V = 16 mag and fainter
- Permanently available as a very precise photometer
- Double filter wheel with Sloan and neutral density filters
- Facility Science Instrument since Cycle 4

Stellar Occultations & TNOs

SOFIA can be positioned almost anywhere, free from clouds and scintillation noise



- Size
- Presence of satellites or a ring system
- Presence of an atmosphere
  - Refraction in atmosphere
  - Presence of aerosols or dust particles
  - Variation in gas temperature with altitude
  - Surface/atmosphere interactions

Pluto Occultation June 23, 2011

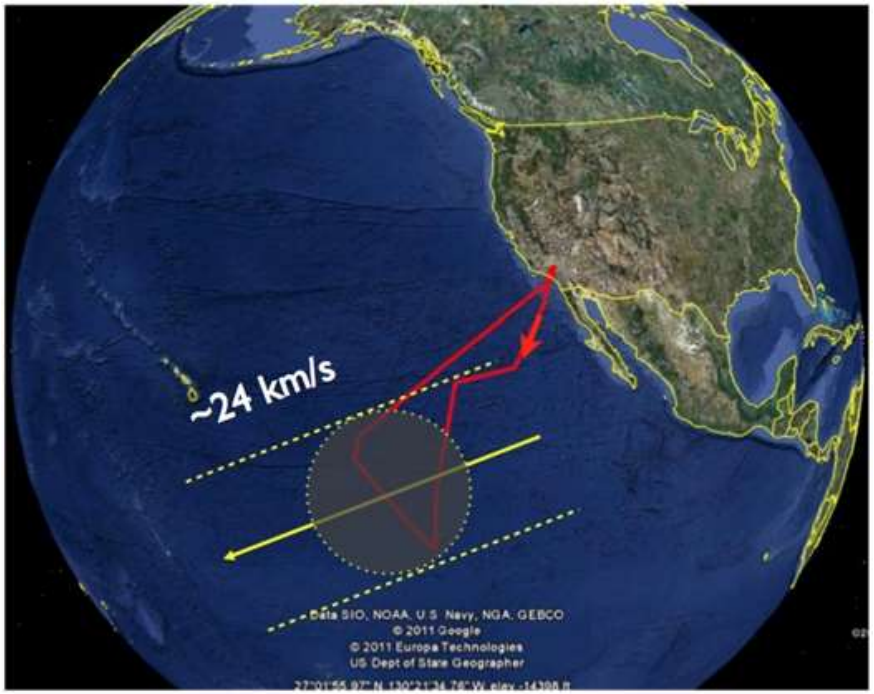
Scientific goals

- Measure temperature profile of Pluto's atmosphere
- Test atmospheric freeze-out models
- Target central flash – global atmospheric shape, possible extinction

To enable observation on the central chord, it was necessary to update the shadow path prediction and change the flight plan accordingly after take-off!

SOFIA met the shadow of Pluto in the mid-Pacific

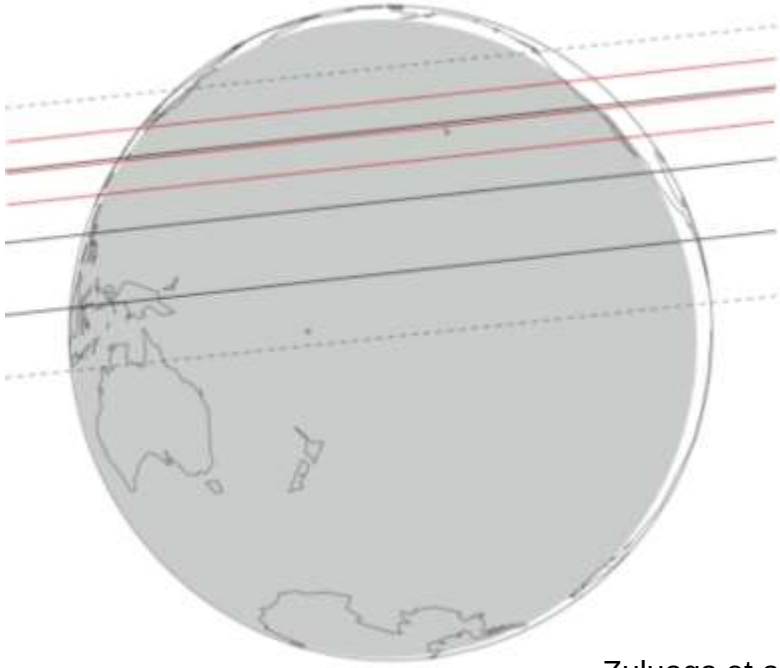
- **space-critical (within 100 km)**
- **time-critical (within 1 min)**



SOFIA Program

Pluto Occultation June 23, 2011

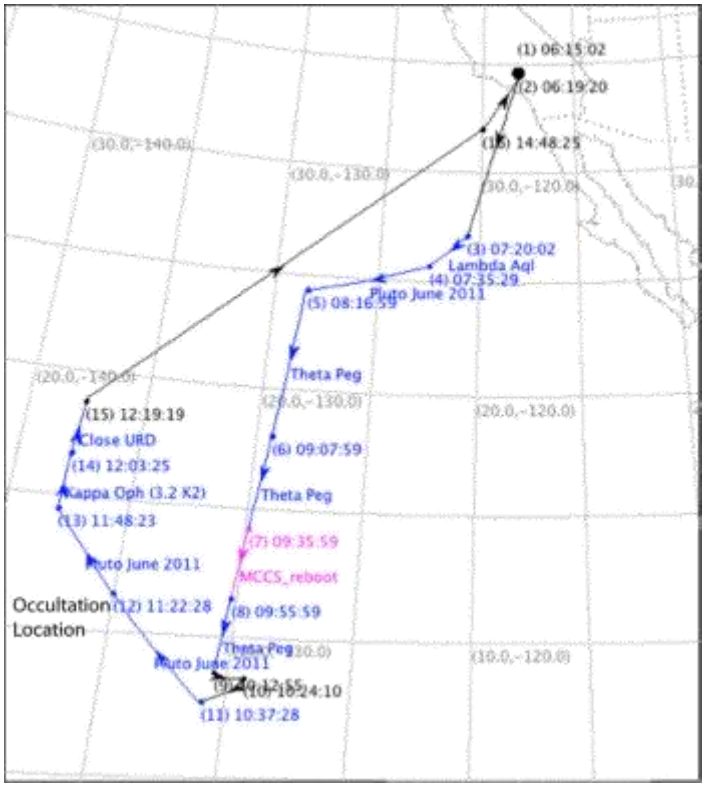
SOFIA Program



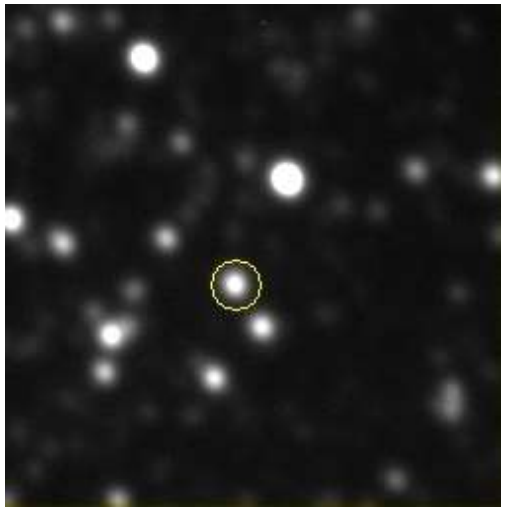
Zuluaga et al. 2011

Pluto: V~14 mag, Star (2UCAC 24677089): V=14.6 mag

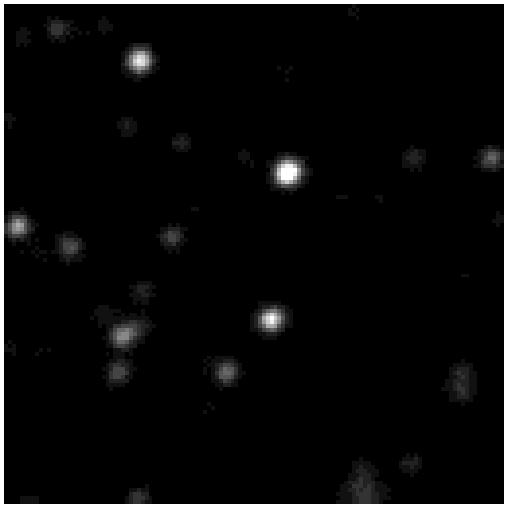
Pluto Occultation June 23, 2011



SOFIA Program / Person et al. AJ 146, 2013



Pluto approaching star



Occultation video
10x real time

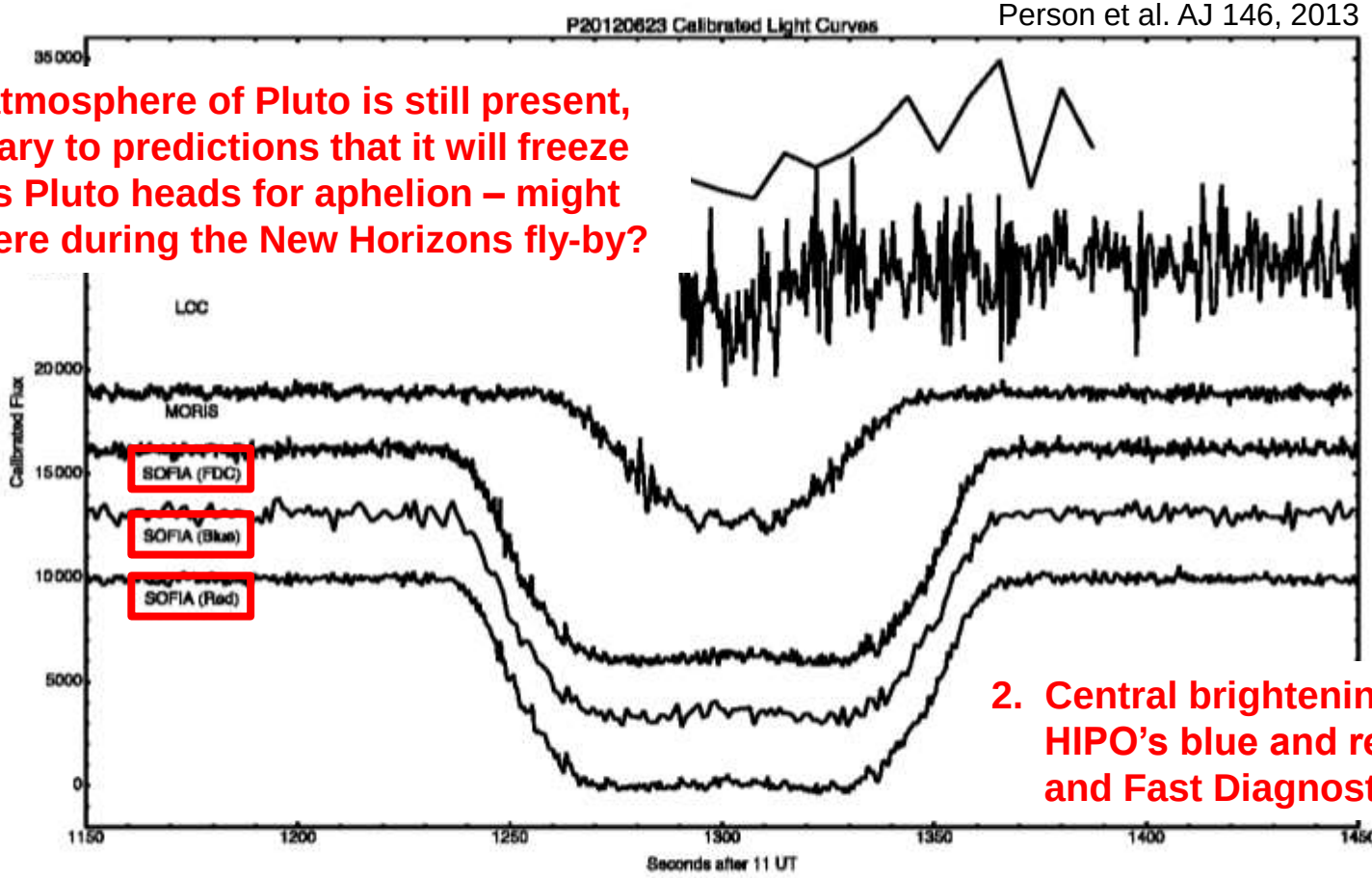
Pluto: V~14 mag, Star (2UCAC 24677089): V=14.6 mag

HIPO and FPI+ observed light curve of the occultation simultaneously
Proved that SOFIA can be in the right place at the right time

Pluto Occultation June 23, 2011

Person et al. AJ 146, 2013

1. **The atmosphere of Pluto is still present, contrary to predictions that it will freeze out as Pluto heads for aphelion – might be there during the New Horizons fly-by?**



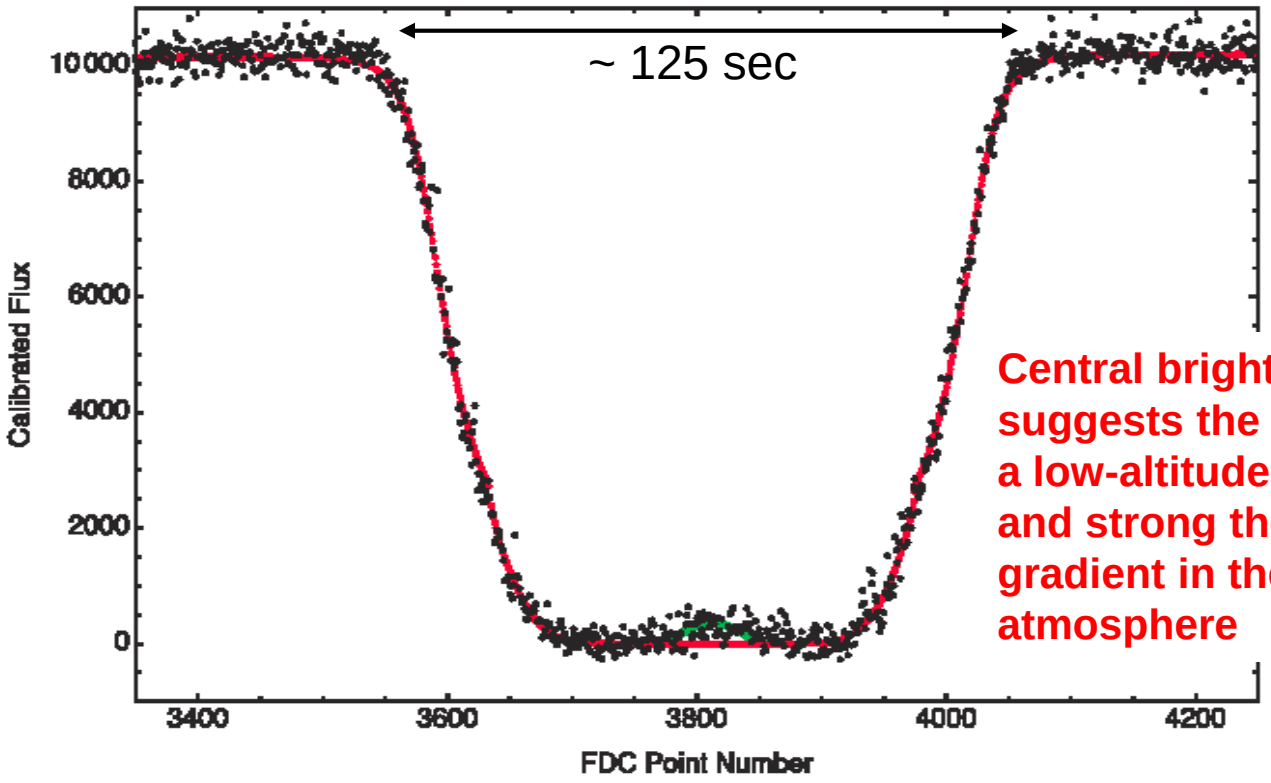
2. **Central brightening seen in HIPO's blue and red channel and Fast Diagnostic Camera**

Figure 5. All Pluto light curves obtained. Plotted above are all light curves obtained in this effort, each normalized from 0 to 10,000 counts. Light curves are ordered from north to south and offset from each other by 3000 counts for clarity of comparison; the LLC and USNO-FS light curves are offset by 6000 counts due to their higher noise). Note that all three of the SOFIA light curves show a wide but shallow central bulge slightly offset to the right. See also the change in slope between the upper and lower portions of the SOFIA light curves. This occurs at about the same location as that seen in the 1988 Pluto light curve (Millis et al. 1993) but changes in the opposite direction becoming suddenly shallower rather than steeper with increasing atmospheric depth.

Pluto Occultation June 23, 2011

Central flash due to atmospheric refraction

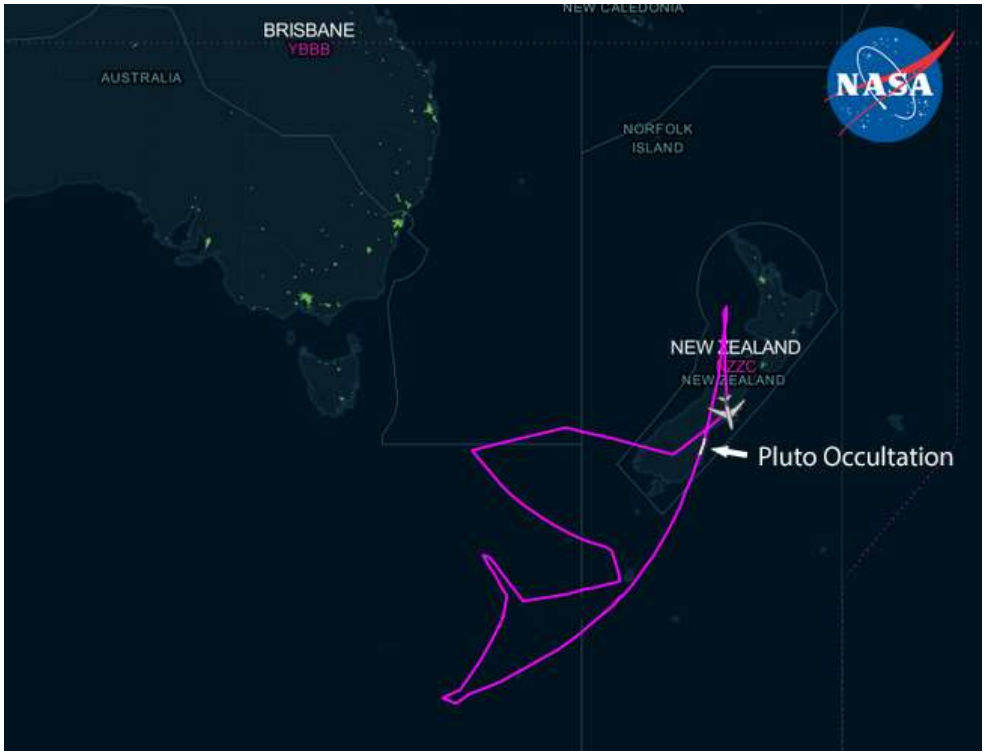
Person et al. AJ 146, 2013



Central brightening suggests the presence of a low-altitude haze layer and strong thermal gradient in the lower atmosphere

Figure 12. Central flash fit. Here, the FDC light curve is plotted in black, with the best-fitting lower atmospheric haze model overplotted in red. In the bottom 10% of the light curve this is overplotted in green by the simple evolute model with a strong thermal gradient (see text). The thermal gradient model follows the flux increase in the central portion of the light curve reasonably well, while the haze model is almost flat throughout this region. This best-fitting evolute has a fitted ellipticity of 0.06 ± 0.01 for isobars in Pluto's atmosphere in the region probed (approximately 1200 km radius).

Pluto Occultation June 29, 2015

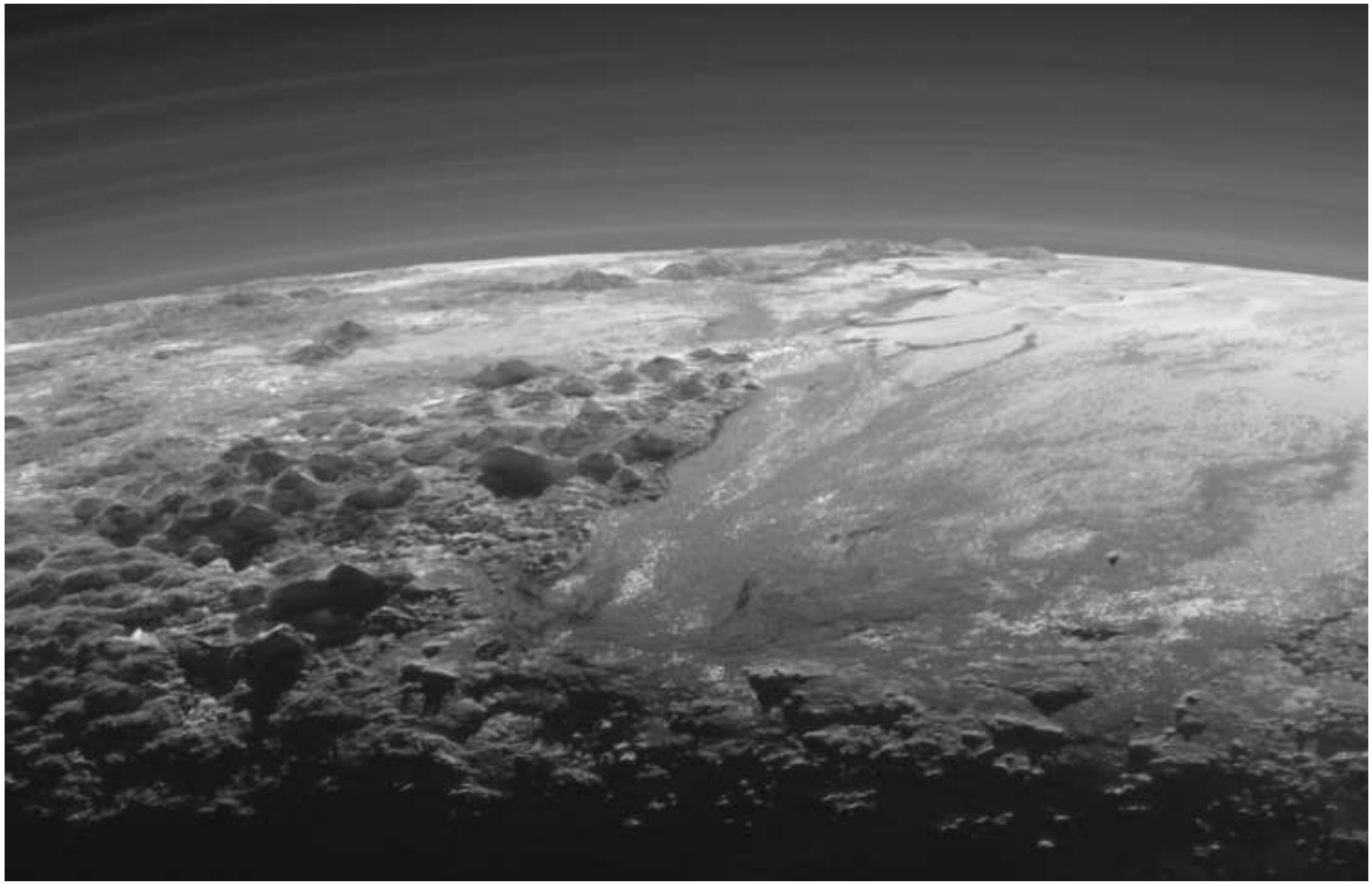


NASA

Pluto: V=14.4 mag, Star (UCAC4 347 165728): V=12.1 mag

During this year's Southern hemisphere deployment (June 15 to July 24)
Two weeks before New Horizon's Flyby

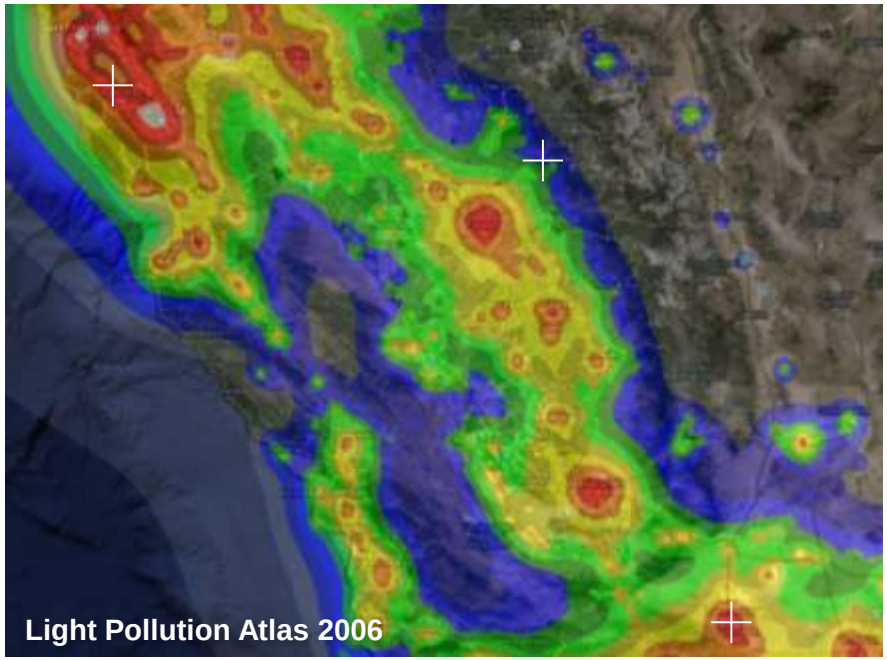
... after New Horizons



Courtesy NASA, Johns Hopkins Univ./APL, Southwest Research Institute

Sierra Remote Observatories

Google Earth


Light Pollution Atlas 2006

- 37˚ 4’ N, 119˚ 24’ W, 1406 m altitude
- ≈ 237 clear nights per year
- Good seeing (1 … 1.5 arcsec during summer)
- Low light pollution (Bortle Scale = 3)

Sierra Remote Observatories

PlaneWave / YouTube

ATUS at SRO

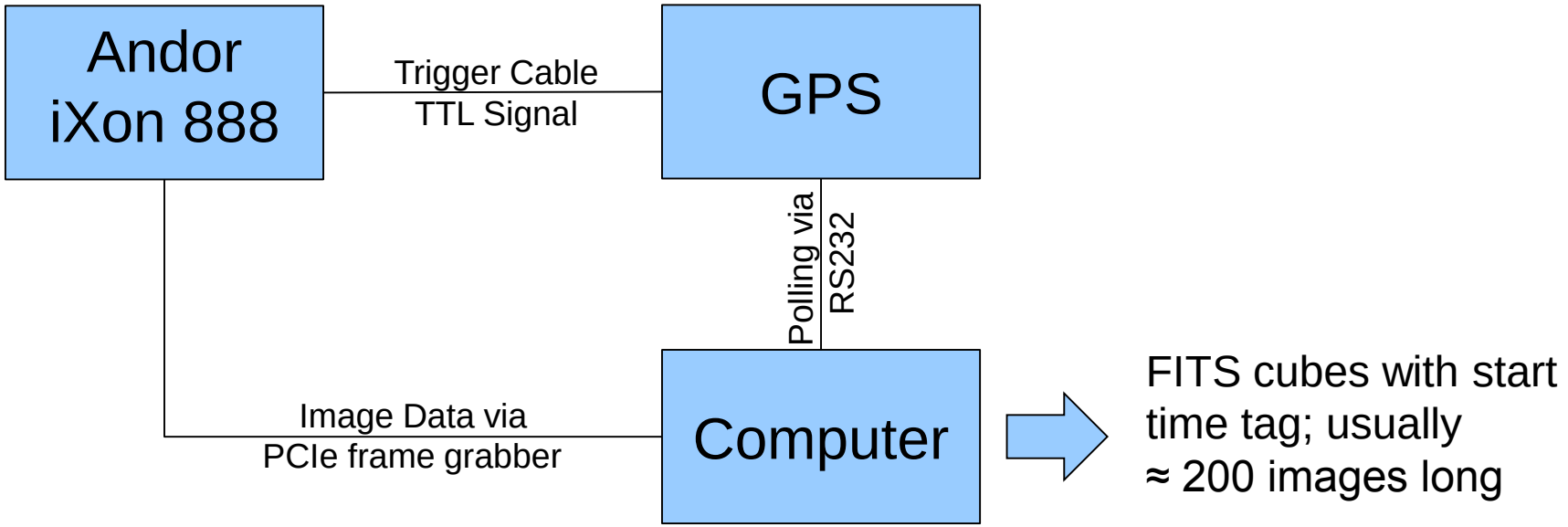
- Officina Stellare Ritchey-Chretien
  D = 600 mm, f = 4740 mm (f/8)
- Mirror substrates made from OHARA CLEARCERAM-Z (low expansion glas ceramics)
- Light weighted M1
- CFRP truss tube
- Focusing via motorized M2
- Fans, mirror heaters, M1 mirror dust cover

- Fast, very sensitive EMCCD camera:
  Andor iXon^{EM+} DU-888 BI, 1024 x 1024 Pixel
- Guide scope (soon): 130 mm f/6,2 with SBIG ST-10XME
- Wide Field Imager: Canon 135 mm f/2 Objektiv + FLI ProLine mit e2v CCD47-20

- AP3600 GTO PE mout with precision encoders
- Pointing <1 arcmin; >8 min imaging unguided

Observing Occultations with ATUS

- Re-Use of former Fast Diagnostic Camera (FDC) / FPI+ pathfinder
- Very precise GPS time stamp (Spectrum Instruments TM4)
- Frame-transfer CCD = virtually gap free imaging (3.4 ms)
- Sensor thermo-electrically cooled down to -80ºC
- Unbinned (0.56“/pixel): 8.7 fps full frame … 202 fps 32x32 AOI
- 2x2 binned (1.12“/pixel): 34 fps full frame

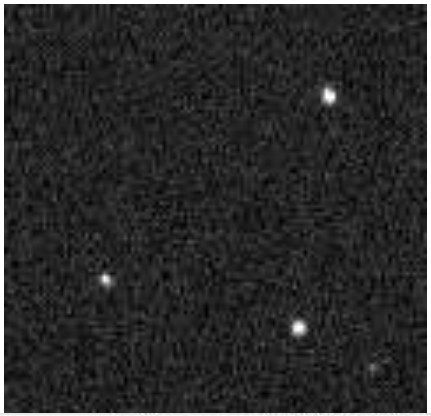


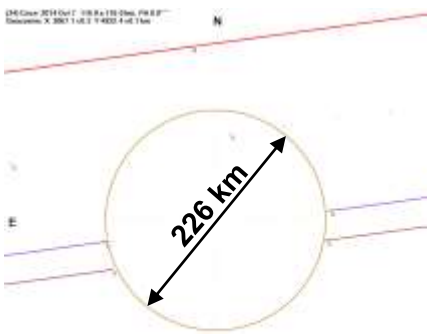
Motivation

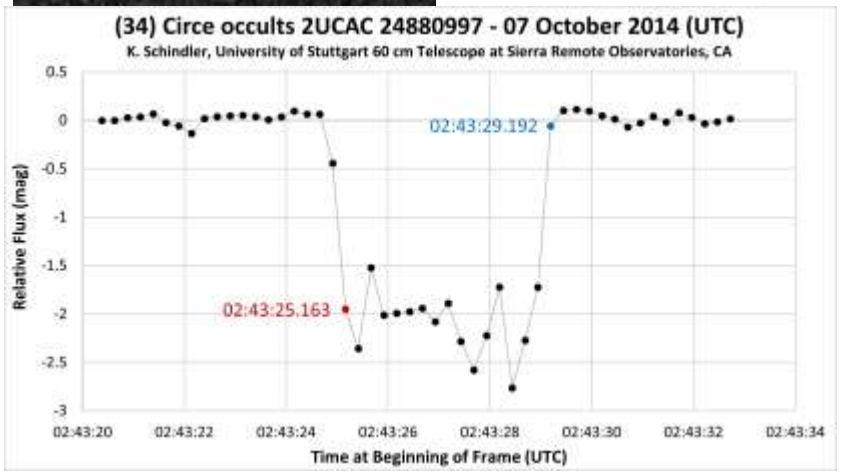
- Accessible for students for engineering and science
- Software & hardware test platform for SOFIA
- Preperatory or parallel observations for SOFIA flights
  - Photometry (flight planning)
  - Astrometry
- Time domain observations:
  - Occultations (16 events since Sept. 2014)
  - Exoplanet transits
  - Variable stars
- Lectures and MSc level lab work from Stuttgart (-9 h ☺)

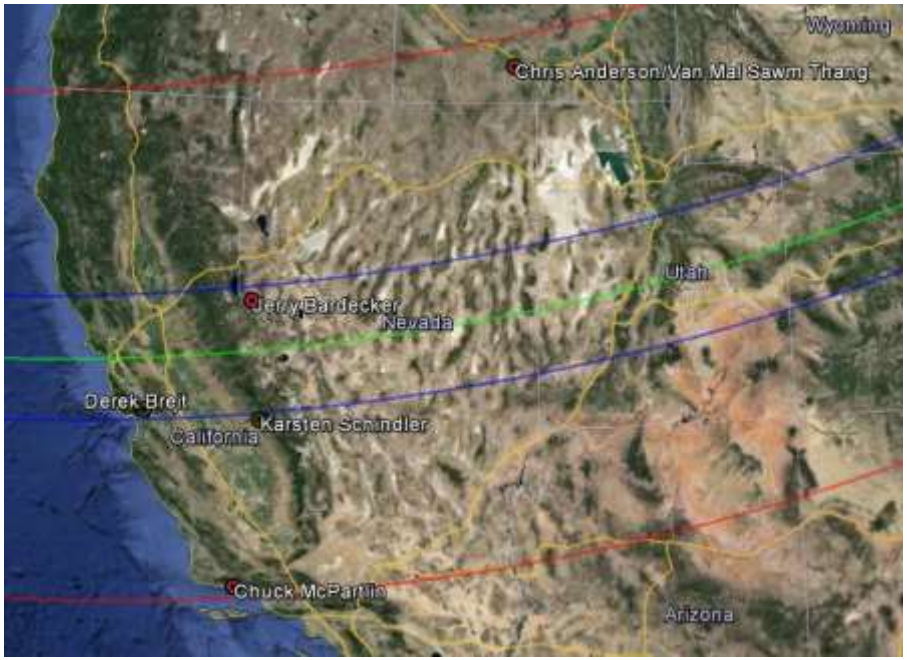
First positive occultation: (34) Circe

06.10.2014, 19:43:26 (PST), 2UCAC 24880997, 2.1 mag drop







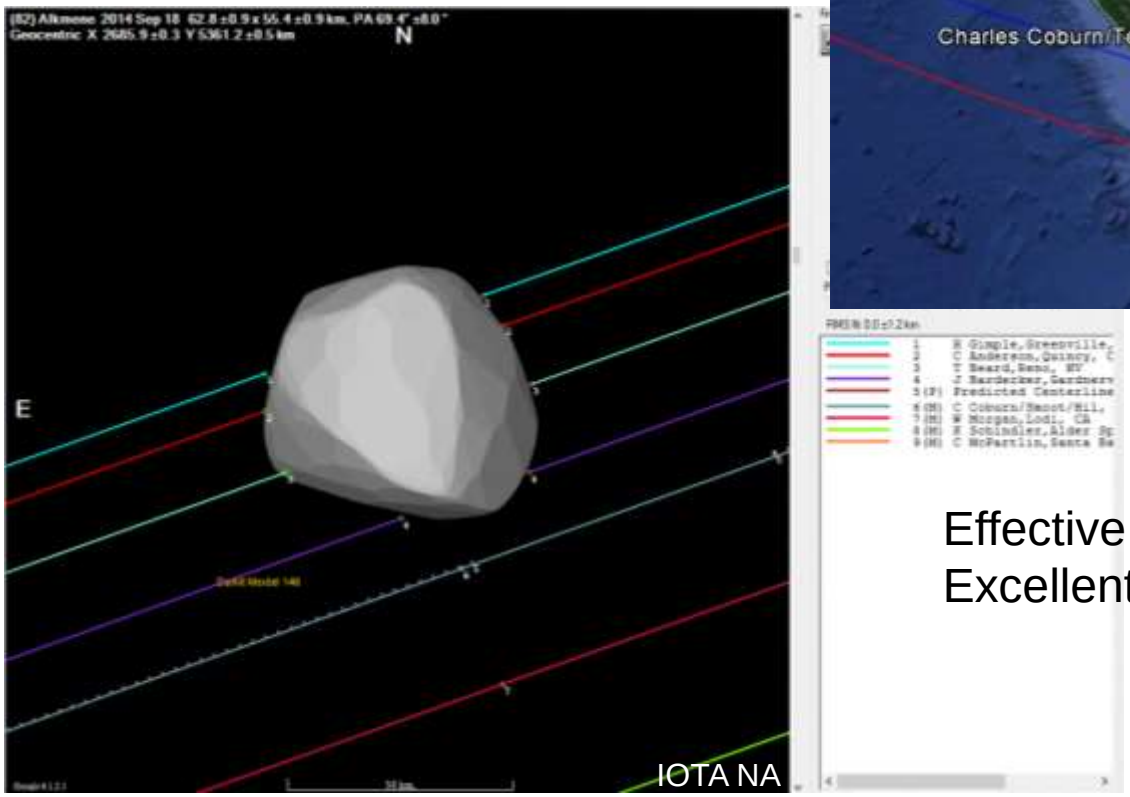


IOTA NA

Size and Shape of (82) Alkmene

HIP 99229
6.2 mag drop
17.09.2014, 23:35:21 (PST)

IOTA NA



IOTA NA

Effective diameter: 61±2 km
Excellent fit of DAMIT shape model

What is next?

SOFIA

- Cycle 4 Proposal for German queue:
  Stellar Occultations by Trans-Neptunian Objects and Centaurs
  - Up to five events with the FPI+ triggered as Targets of Opportunity
  - No dedicated flights – only a 30 min leg on a flight of another SI
  - Waiting for TAC results (”mid-October”)
  - If successful, amateurs can contribute significant science

ATUS

- Finish that 2007 UK126 paper!
- Participation in (more) IOTA events (with help from students?)
- Size estimates of Jovian irregular satellites
- Evaluation towards supporting astrometric prediction work for TNOs
  - Monitoring of targets to refine orbits and shadow predictions
  - Lots of telescope time necessary in the weeks before an event

More Information

Official ATUS Website:

www.dsi.uni-stuttgart.de/forschung/atus.html

Deutsches SOFIA Institut (DSI)

www.dsi.uni-stuttgart.de

SOFIA Science Center (USRA)

www.sofia.usra.edu

Youtube, search for:

“SOFIA Captures Pluto Occultation”

“RC600 SRO”

NASA AFRC