Airborne Stellar Occultations with HIPO and FLITECAM on SOFIA

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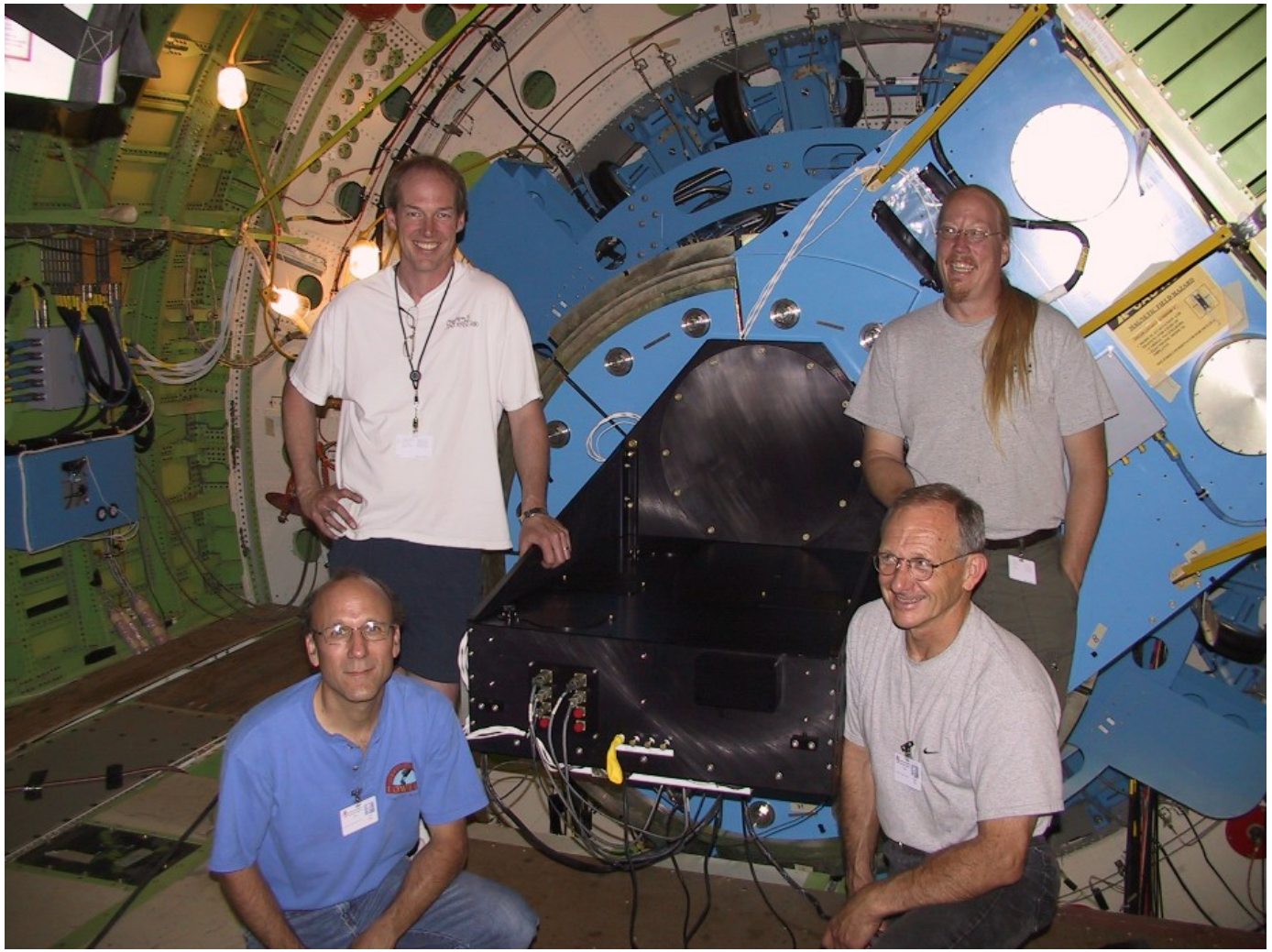


HIPO mounted on the SOFIA telescope, 2004

Outline

- Outline and purpose of the talk
  - Describe an upcoming opportunity
  - You and your good observing ideas can fly on SOFIA
- Summary of occultation science results
- Brief outline of requirements for occultation observations
  - Other applications, e.g. precise photometry, not addressed
- Characteristics of SOFIA and HIPO that address occultation work
  - Airborne photometry and imaging
  - HIPO details
- FLITECAM opportunities
- Programmatics and Status
- Questions?

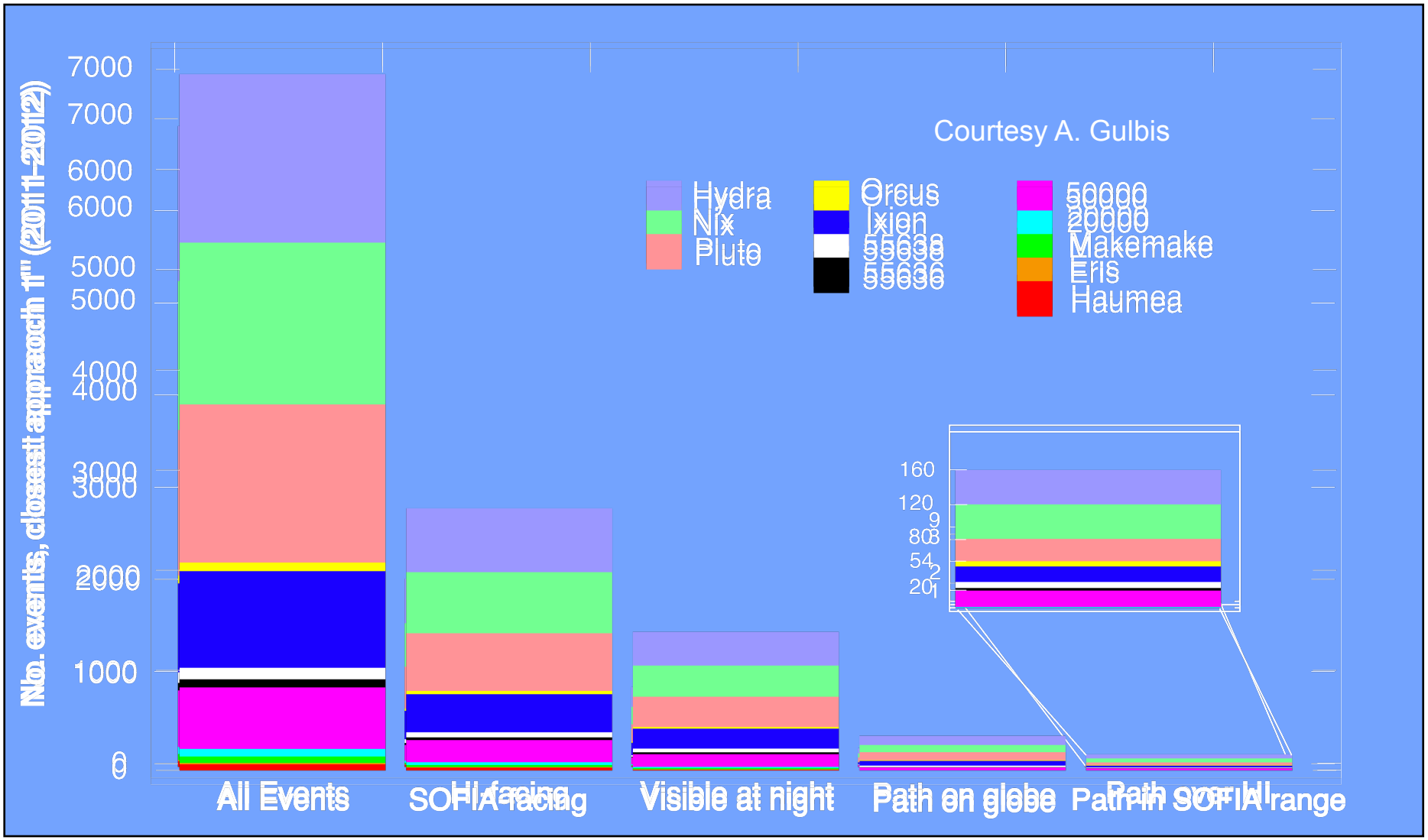
Occultation Science Summary

- Accurate size measurements
  - Spatial resolution of a few km at 30 AU
    - Multiple chords can determine object shape
    - Calibrate radiometric diameters of KBOs
  - Ring edges can be better - limited by S/N ratio
- Sensitive atmospheric probe
  - Pressure, density, temperature at microbar atmospheric levels
  - Vertical and horizontal atmospheric structures can be resolved
  - Central flash sensitive deeper in the atmosphere
    - Central flash morphology dependent on global atmospheric shape
  - Mainly sensitive to refraction, but extinction can be detected too.
  - Repeated occultations can track atmospheric changes

Occultation Observational Requirements

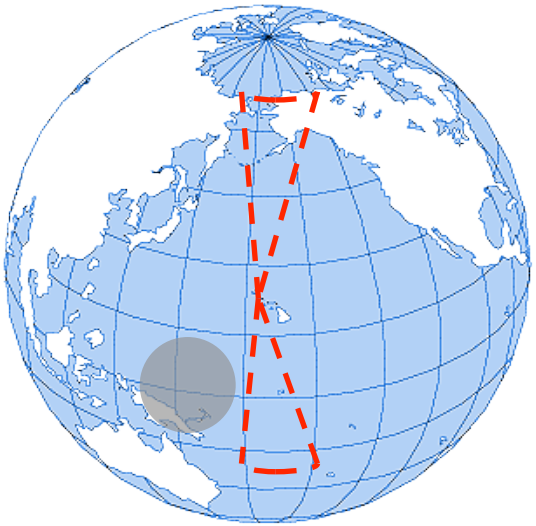
- Must be in the occultation track, object above the horizon, sun below it, and with good weather
- Time and position resolution and accuracy
  - 20-50 ms resolution to resolve Fresnel zone in some cases
  - ~1 ms time and ~30 meter position accuracy for high S/N ring events
- Reliable, redundant instrument to ensure data are obtained
- Two or three wavelength observations often desirable
- Imaging photometry desirable
  - Simultaneous observation of field standards if available
  - Subtract complex backgrounds
- Largest possible telescope and maximum throughput
  - Optimize S/N for a fixed event velocity
  - Maximize number of events observable with high S/N
- Flexible optical, filter, and readout configurations to optimize for particular events
- Observations straightforward, but completely unforgiving of error

TNO Event Statistics

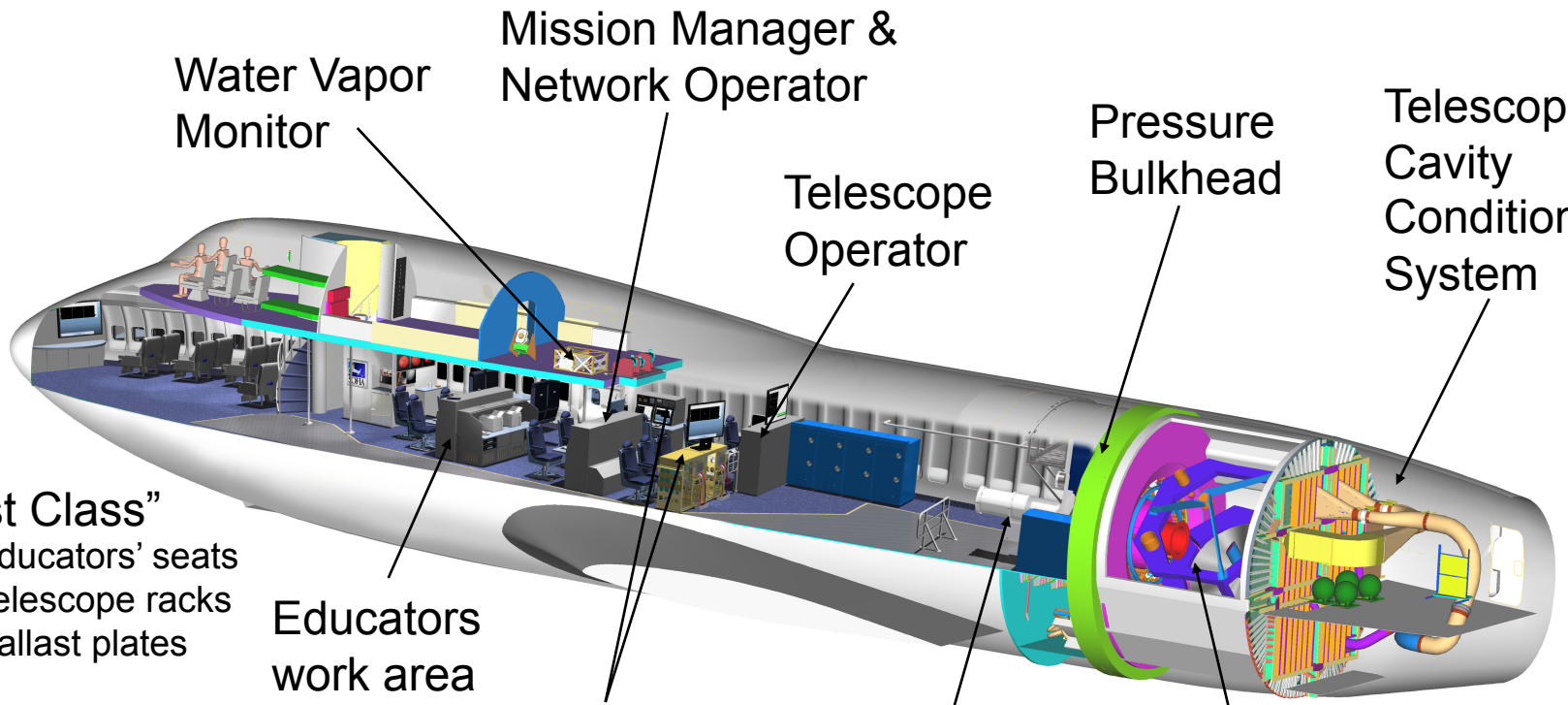


SOFIA Characteristics

- Joint NASA/DLR project
- 2.5 meter telescope
- Boeing 747SP aircraft
  - Long range aircraft, ~0.7 D_{Earth} coverage from operation base (probable, but not certain)
  - Allows for late prediction updates
  - Flexible Deployment Options
    - No *natural* restrictions
      - Safe aircraft operation limits
      - Political & security restrictions
    - Commercial airfield operations
- Clouds very rare
  - High tropopause at low latitude
  - Turbulence in ITCZ



SOFIA Characteristics, Cont'd

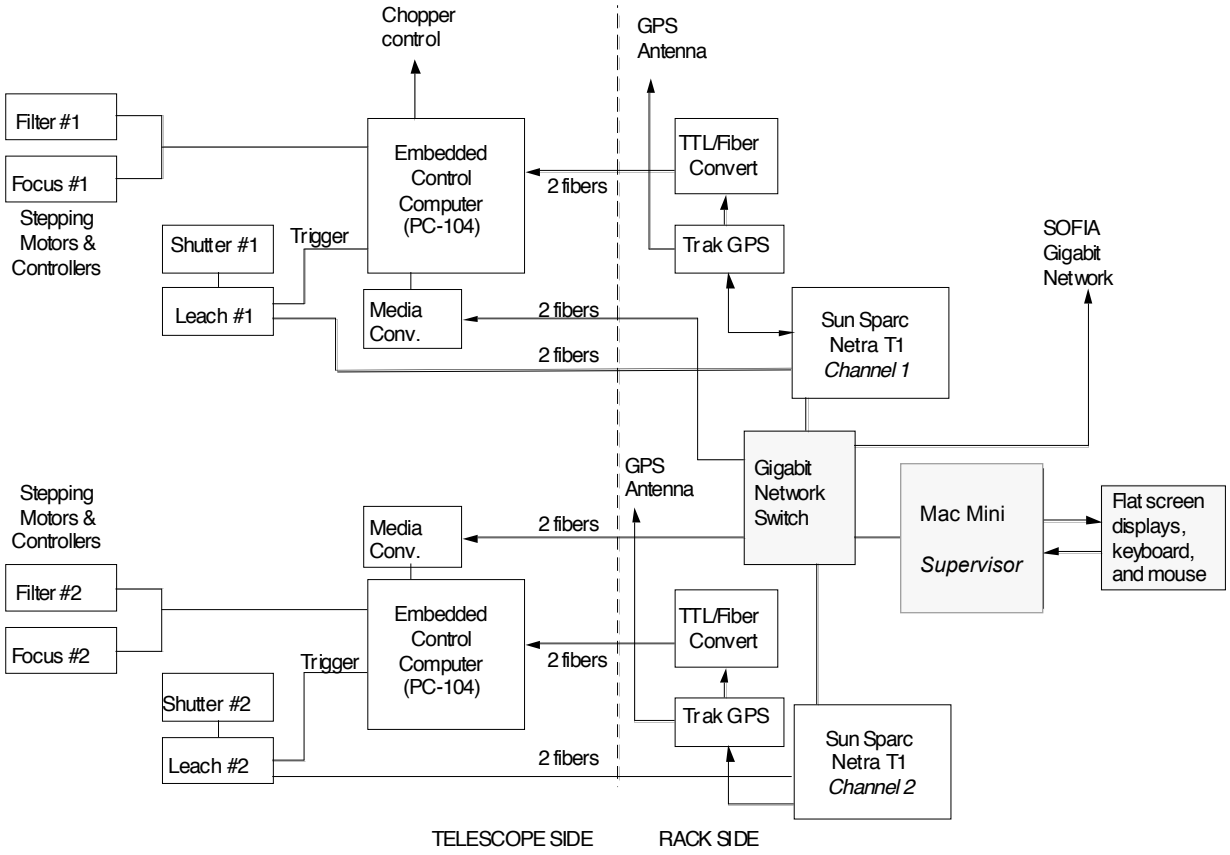


HIPO Characteristics

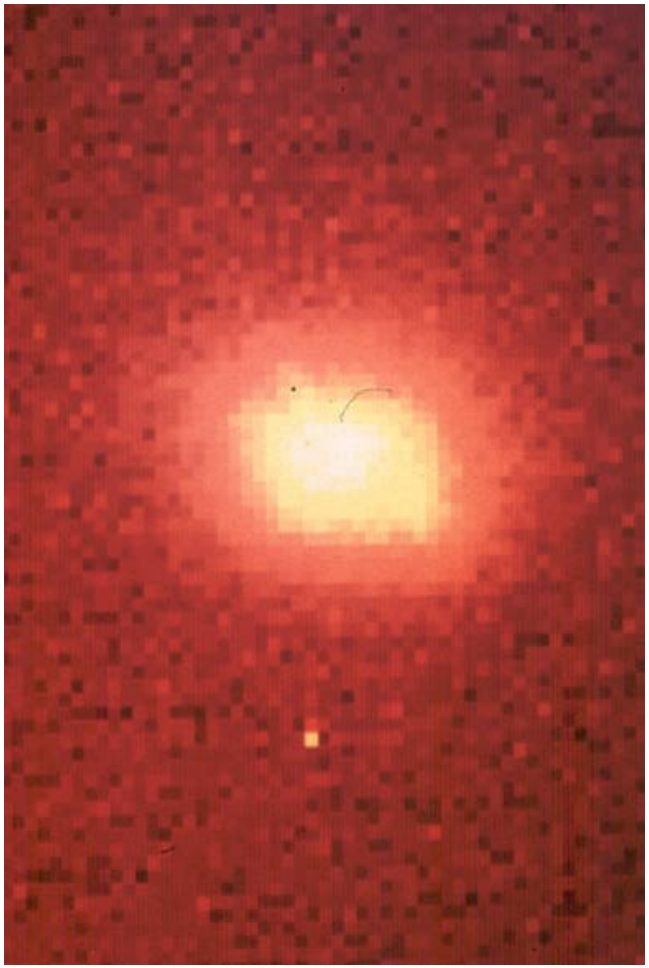
- Redundant design

- Two Channels
- GPS time/pos'n
- Hardware timing
- Flexible readouts
- Mounted spares for single string items
  - Network Switch
  - Mac Mini
  - Netra T1s
- Full spares set
- Fallback options

HIPO High-Level System Design - Electronics & Data System



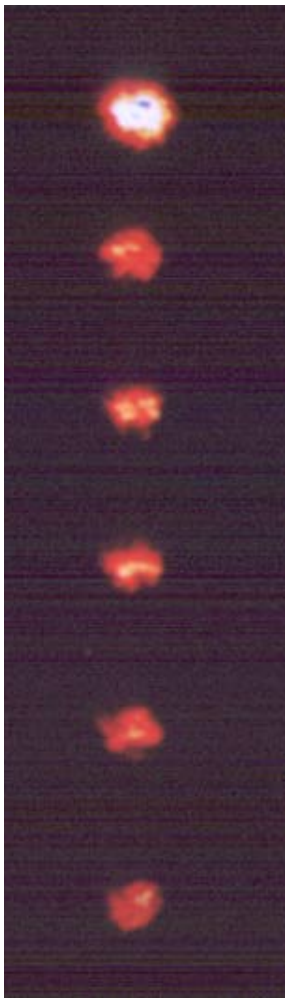
Airborne Photometry, I. (KAO images)



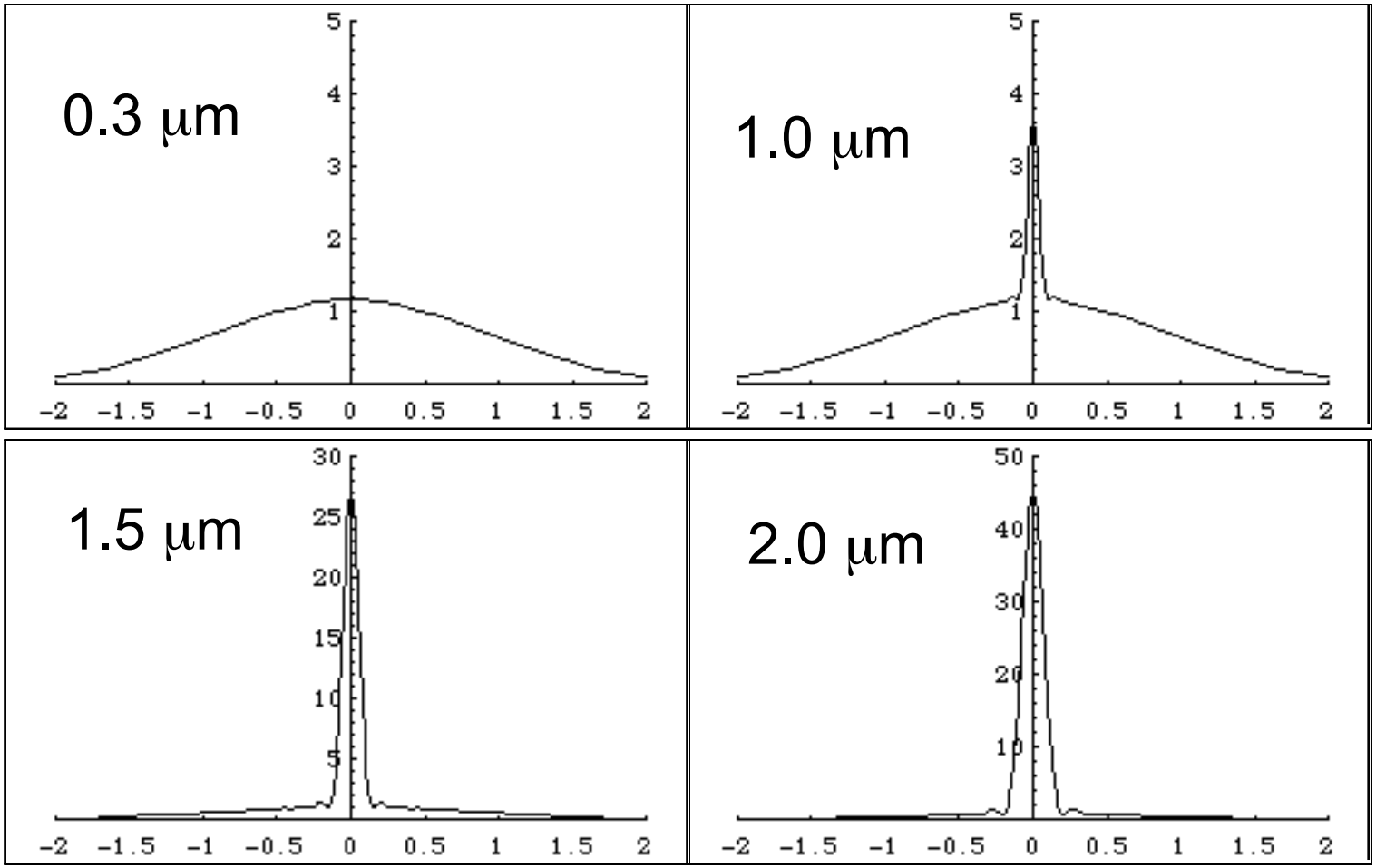
- Shear layer seeing - FAST!
- Telescope cavity seeing

- Long Exposure PSF (> 10 ms)
  - Large PSF, 3”-5” FWHM
  - Non-Gaussian, broad wings
  - Very stable shape and size
  - Smooth intensity profile

- Short Exposure PSF (< 1 ms)
  - Large PSF, 3”-5” FWHM
  - Unstable speckle profile



Airborne Photometry, II.

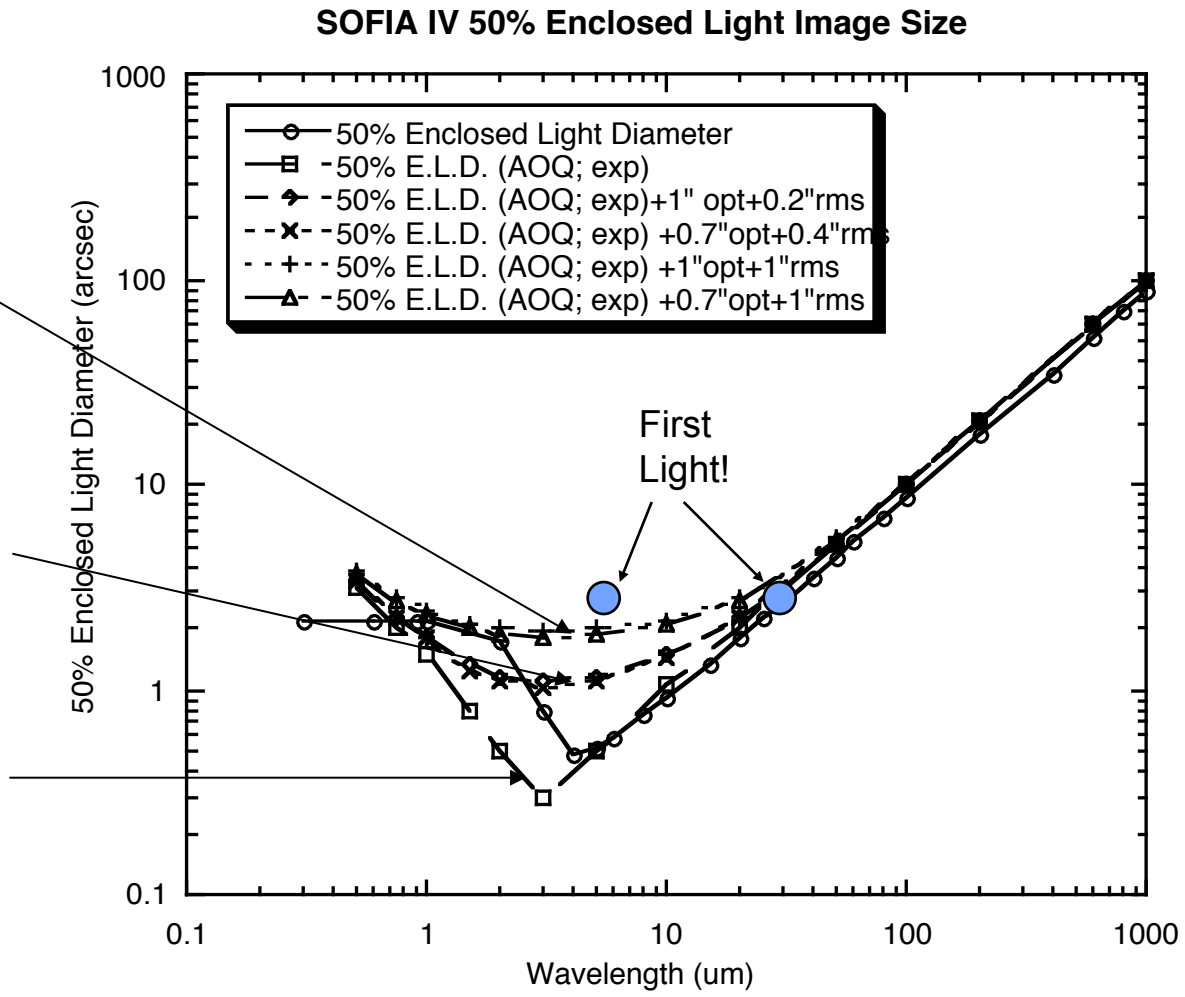


Airborne Photometry, III

Expected behavior of SOFIA images from wind tunnel test results and telescope FEM.

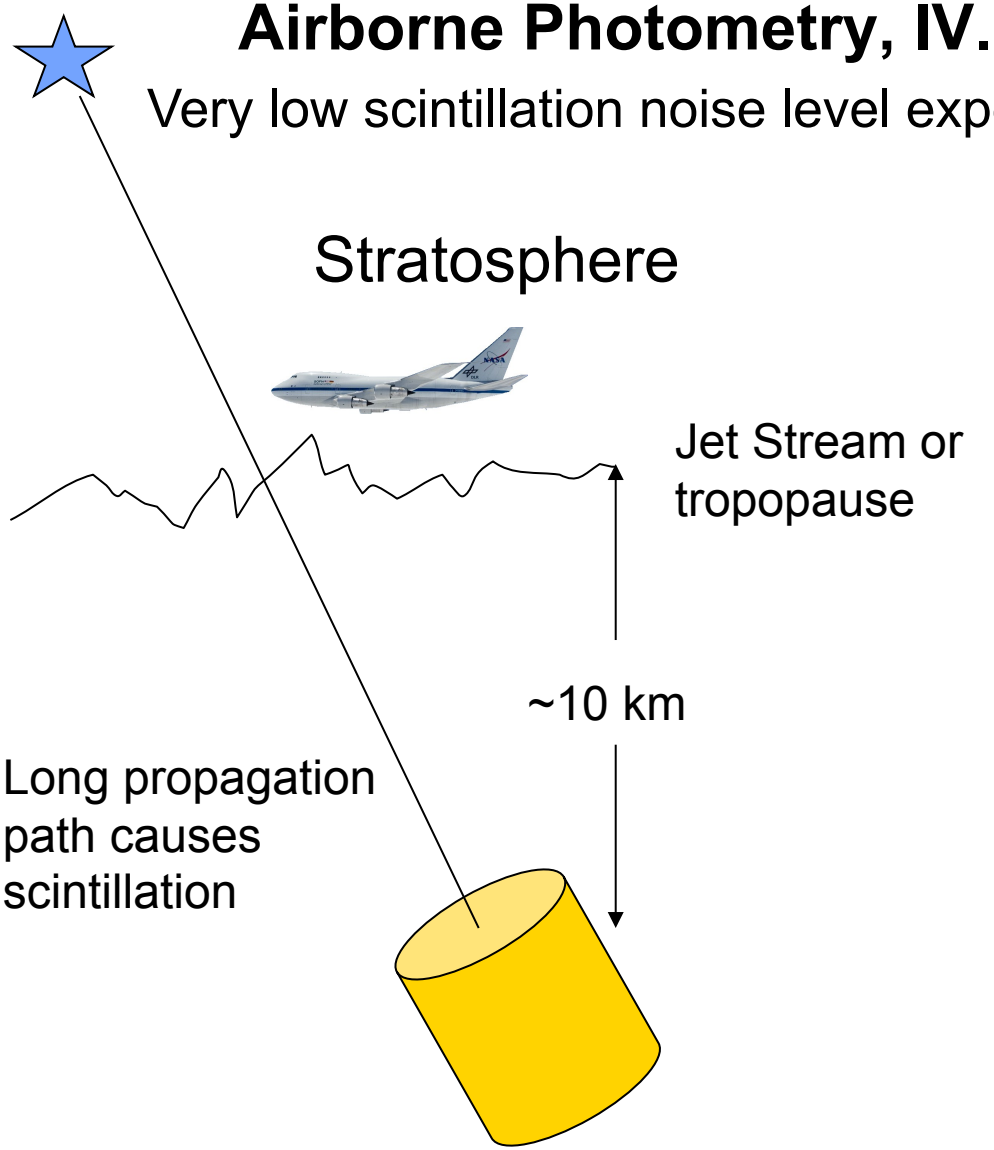
Later improvement in pointing stability

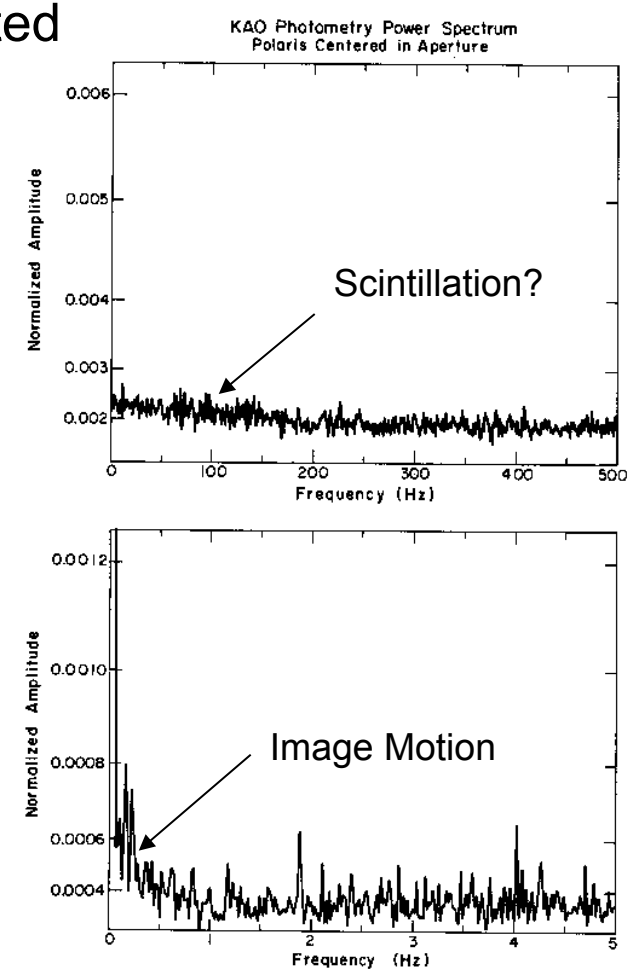
Shear layer and diffraction only



Airborne Photometry, IV.

Very low scintillation noise level expected

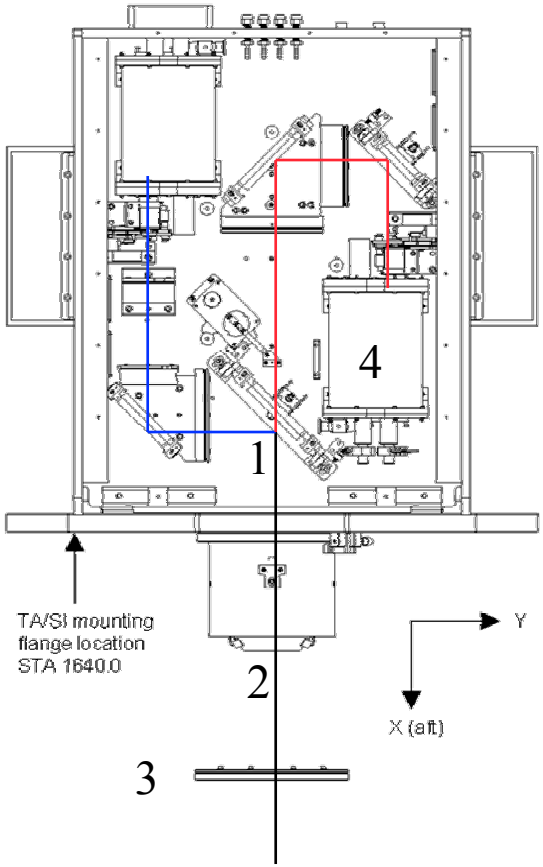




Dunham & Elliot, *PASP* **95**, 325-331 (1983)

HIPO Configuration

- Configuration Options
  - 1. One or two optical channels
    - Dichroic beamsplitter
  - 2. FLITECAM co-mount
    - Gold dichroic beamsplitter
    - Throughput reduction
  - 3. Gate valve window
    - Eliminates possible seeing issue
  - 4. Bare CCD (no reimaging optics)
    - Major reconfiguration, not shown
    - ~30% better throughput
    - ~1' field at 0.055"/pixel
    - Binning speed penalty



HIPO Performance

Parameter	Discussion
Read Noise	3 e^- at 200 kpx/sec and 8 e^- at 1 Mpx/s, both unbinned. 11 e- at 1 Mpx/s binned 3x3. Sky limited in most cases.
Time Accuracy	3.5 microsecond delay in DSP trigger loop
Position accuracy	5 meters (SA off), GPS limited
Read rate	11-22 Hz, 3 80x80 subframes binned 3x3 depending on pos'n 80 Hz, 1 80x80 subframe binned 3x3 in pipelined occ. mode
Optics Throughput	Blue side: 66-73% for 0.34 - 0.64 micron range Red side: 72-82% for 0.46 - 1.0 micron range
CCDs	e2v CCD47-20 1K frame transfer, thinned back-illuminated e2v CCD67 256x256 frame transfer, thinned back-illuminated
Field of View	5.7' square, 0.33 "/pixel (unbinned) w/ reimaging, CCD47 2.8' square, 0.66 "/pixel (unbinned) w/ reimaging, CCD67
Potential upgrades	Special filters, low-resolution grism, new CCDs, IMC, …

Reference: Dunham, et al., *Proc SPIE* **7014**, 164-173 (2008)

HIPO Observing Modes

Mode Name	Comments
Find	Repeated readout, used for field acquisition
Single Frames	**Ordinary CCD imaging; most cameras only do this**
Basic Occultation	**Time series with full readout flexibility, multiple subframes.**
Fast Occultation	Better duty cycle than basic occultation at high frame rates but only a single subframe can be supported
Pipelined Occultation	Faster integration interval than fast occultation, but only certain special subframes can be supported
Fast Dots	Very fast, uses CCD as analog storage so limited duration. Used for telescope test work.
Slow Dots	Not very useful with frame transfer CCDs.
Strip Scanning	Used for prediction astrometry and telescope test. Often called TDI mode.

Reference: Dunham, et al., *Proc SPIE* **7014**, 164-173 (2008)

FLITECAM

- InSb (Aladdin III) Imager/Spectrometer. Ian McLean, PI.
  - 1-5 micron wavelength range
  - Same electronics as SpEX, so same occultation capability
  - Fast single subframe capability
  - Two slit widths for R~1000 & R~2000 grism spectroscopy
- Facility Instrument
  - See www.sofia.usra.edu
  - Instrument hardware and software are complete
    - Considerable ground-based experience at Lick 3-meter
  - Instrument configuration fairly static
- Co-mounts with HIPO or mounts alone
  - Three channel observations possible
    - Co-mount demonstrated at Lowell in 2004
  - Single channel IR observations have better sensitivity

FLITECAM Co-Mount (at Lowell, May 2004)

Programmatics and Status

- SOFIA Status
  - Envelope expansion flights complete, first light achieved
  - Early science flights this winter and spring
- Instrument Status
  - HIPO used for ground testing of SOFIA in 2004 & 2008
  - Both instruments used in many ground-based observing runs
  - Anticipate commissioning HIPO and FLITECAM during Observatory engineering/test period, summer 2011
- Programmatics
  - NASA's 80% share of SOFIA time is open to foreign proposers
  - Science flight rate limited, ramping up between 2012 and 2015
  - Deployments not envisioned prior to 2012 or 2013
  - HIPO is a Special Purpose Science Instrument
    - Close collaboration between General Observers and HIPO team
  - FLITECAM is a Facility Instrument
    - No collaboration necessary unless co-mounted observations

Questions?