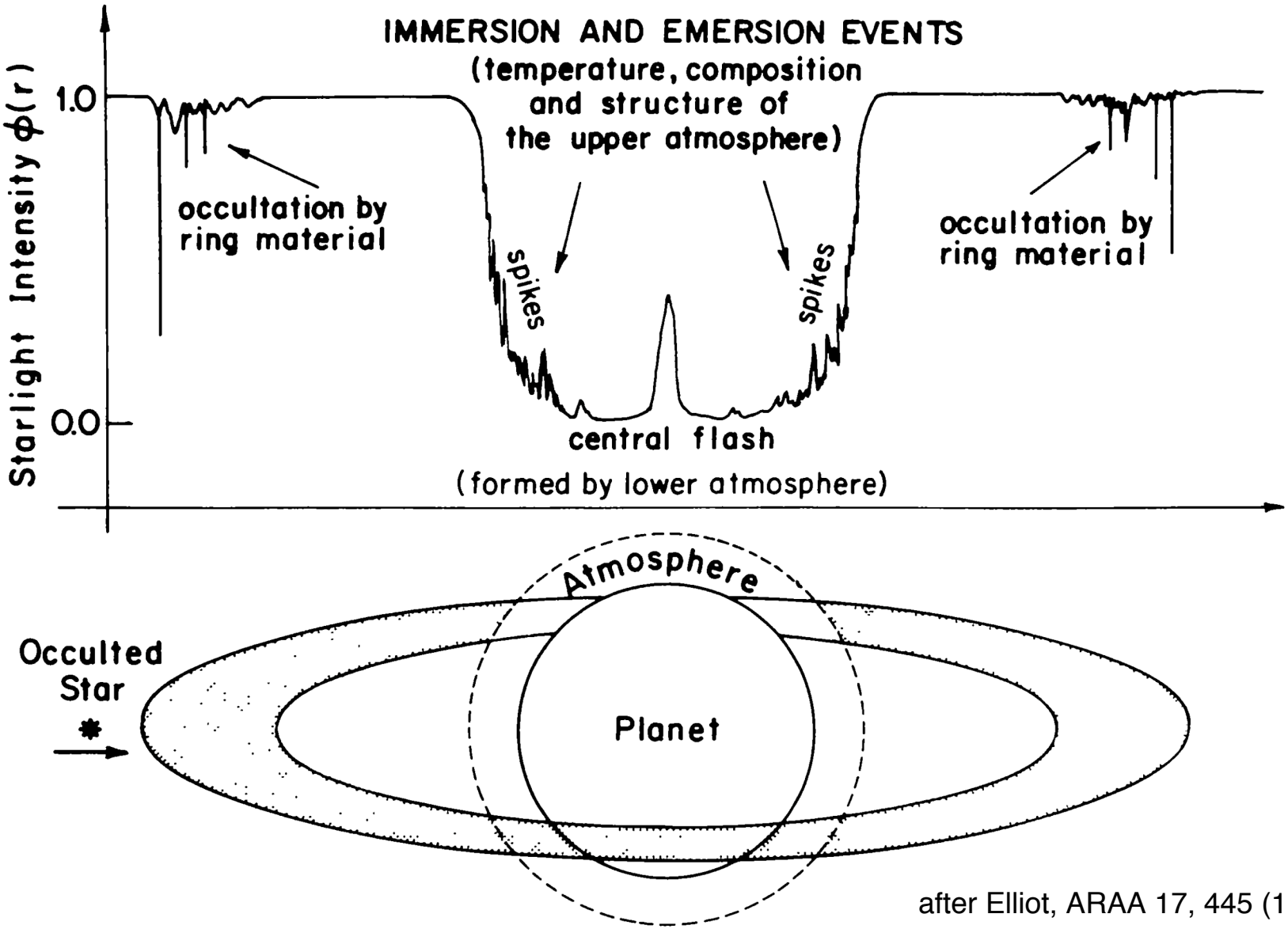
OCCULTATIONS WITH SOFIA

HIPO Team
SOFIA Community Task Force
2009-02-18

SCHEMATIC OCCULTATION



after Elliot, ARAA 17, 445 (1979)

STELLAR OCCULTATION OBSERVATIONS

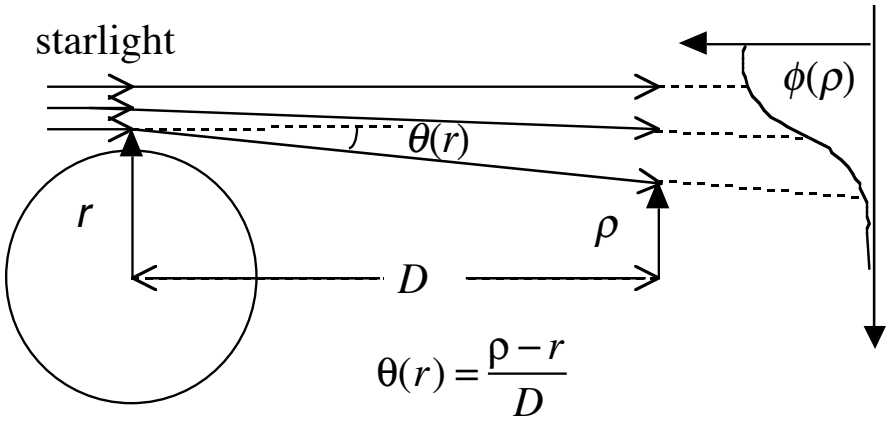
- Probe refraction of atmospheres
  - Measure scale height of the density
  - Deduce T/μ if gravity known; deduce pressure if μ known
- Probe extinction of rings and atmospheric material
  - Measure optical depth (along the line of sight to the star)
- High spatial resolution (few km)
  - Limited by Fresnel diffraction (not atmosphere or telescope)
- Global information from central flash
- Long time baselines possible (years & decades)
- Can be observed from virtually any platform
  - *e.g.* telescopes of any size (amateur to GMT, airborne, and in space)

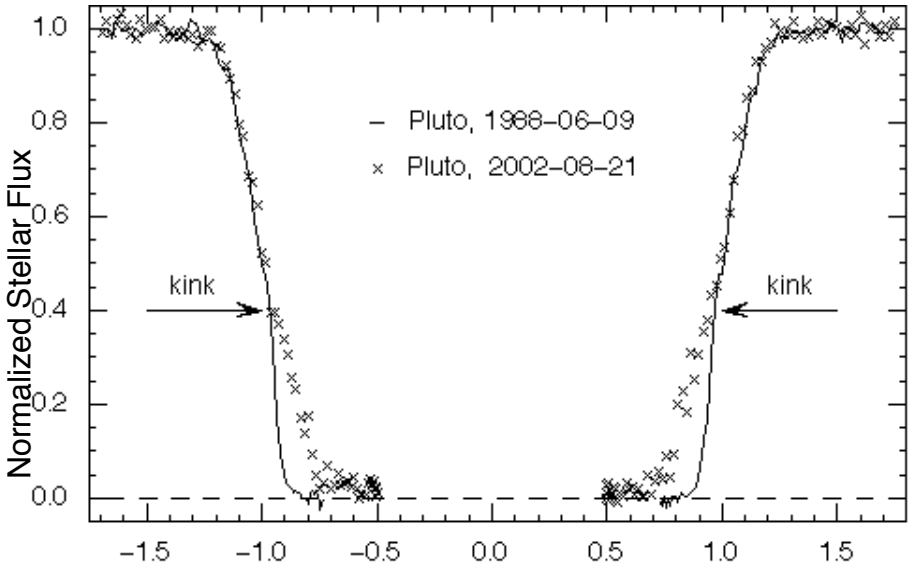
DESIRED OCCULTATIONS FOR HIPO AND FLITECAM

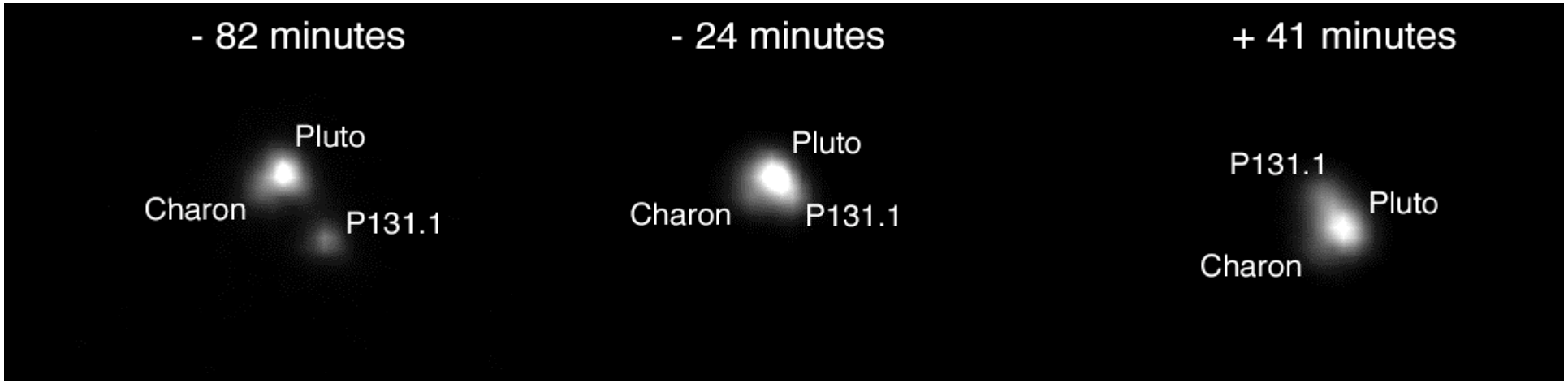
- Occultations
  - Pluto
    - » Central flash
    - » Graze (waves)
  - KBO occultation
  - Neptune central flash
  - Uranus central flash
  - Venus central flash
  - Rings
    - » Uranian
    - » Neptune
- Transits
  - Extrasolar planets

STELLAR OCCULTATIONS BY PLUTO (1988, 2002)

- Probe atmospheres with spatial resolution of a few kilometers



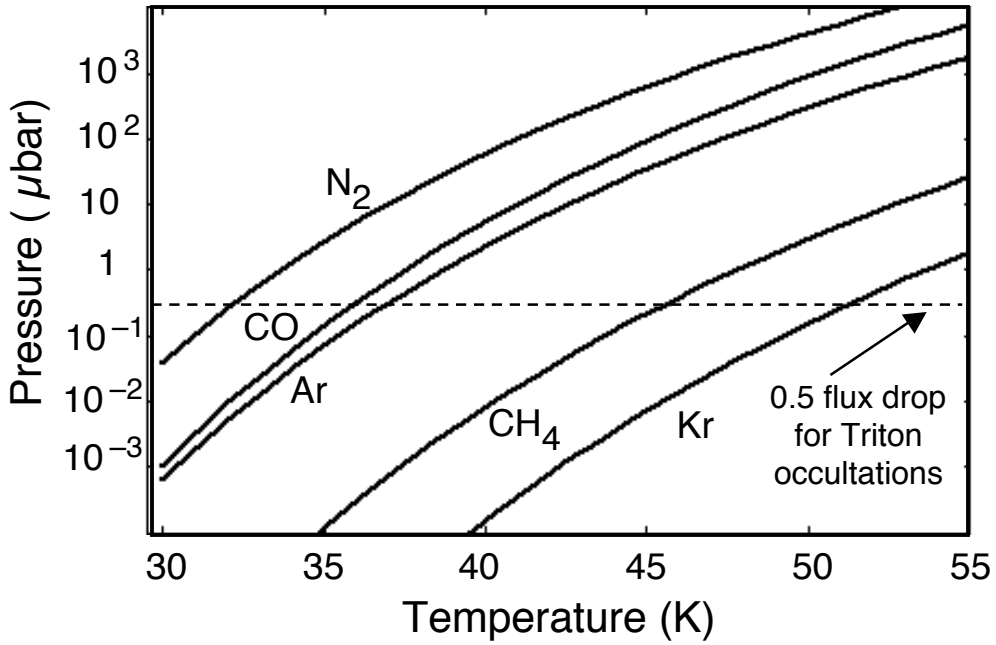




Pluto occultation images from Williams College; light curves adapted from Elliot et al., Nature **424**, 165 (2003)

REQUIREMENTS FOR AN ATMOSPHERE

- Appropriate surface volatiles
  - N_2, CO, CH_4, NH_3, Ne, Ar, Kr
  - Primordial, or replenished



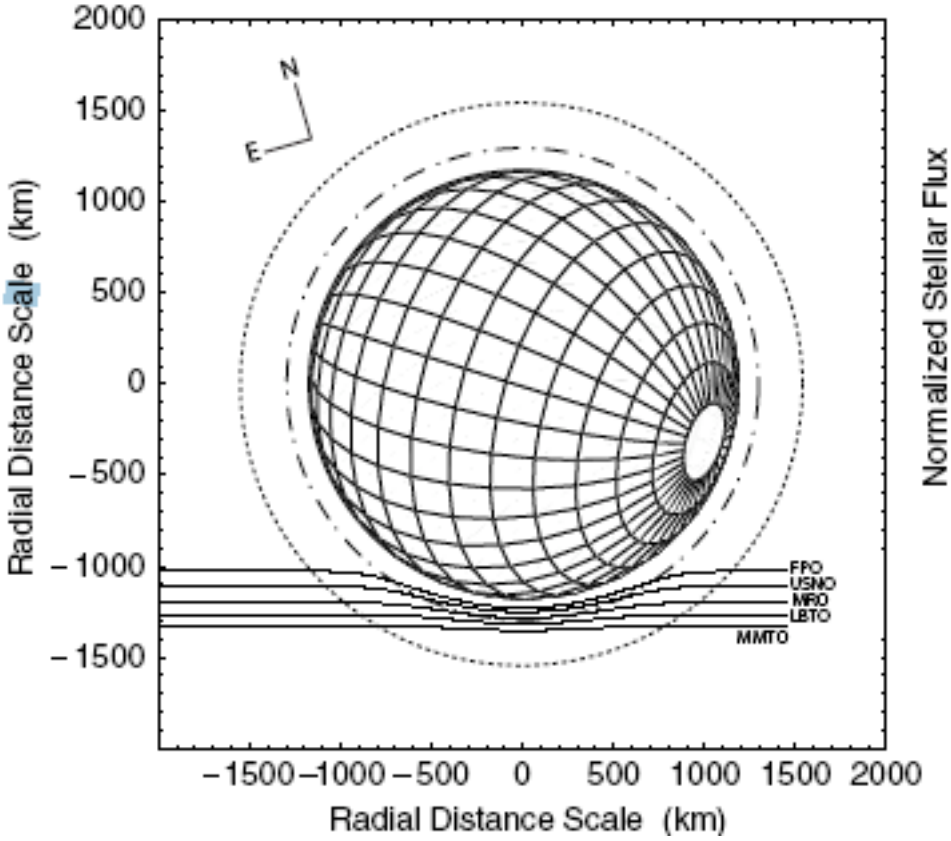
Data from Brown & Ziegler 1980

- Right temperature
  - Not too warm
    - Volatiles escape
  - Not too cold
    - Not enough sublimation
  - Blackbody temperature for 30AU is about 50K
- Sufficiently massive
  - How massive?

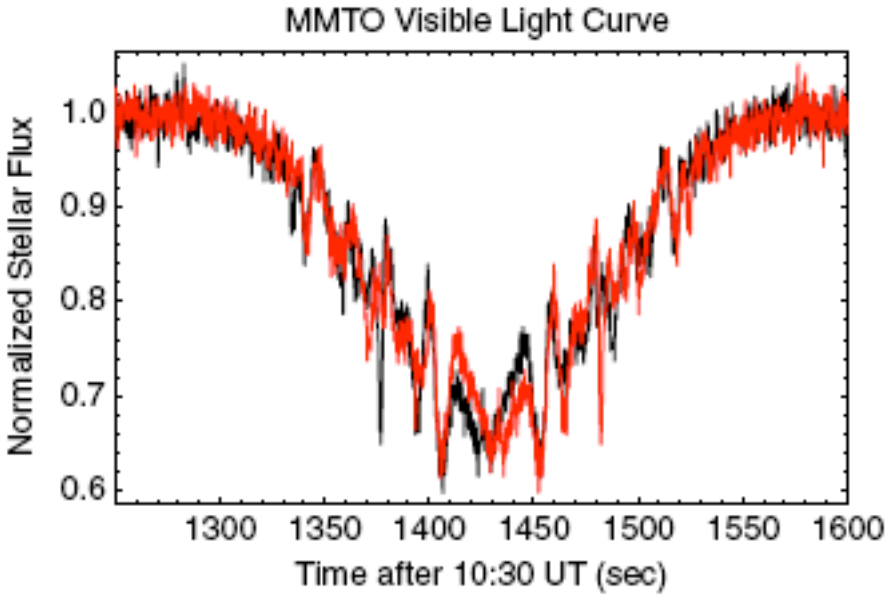
$$\lambda = (GM/k)(m\mu/rT)$$

  - Mass overcomes escape (*e.g.* Titan)
  - Kr atmosphere on less massive objects?

WAVES IN PLUTO'S ATMOSPHERE



Chords for the 2007-03-18 Pluto occultation., Visible in North America.

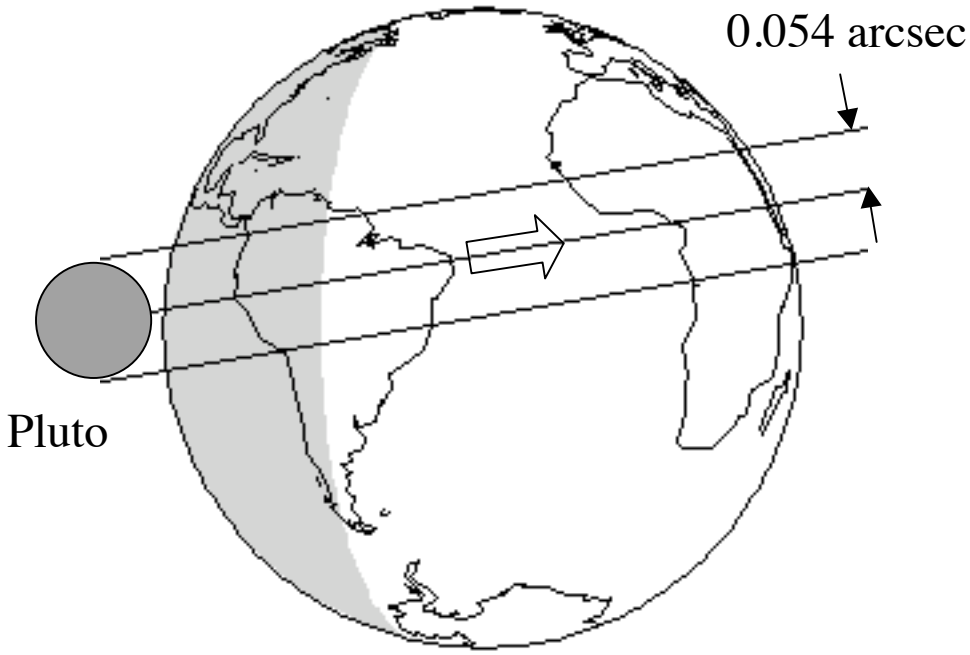


MMT Observatory visible light curve folded back on itself. Note the high degree of symmetry. The undulations are likely caused by atmospheric gravity waves (Hubbard *et al. Icarus*, submitted)..

Figures 3 and 4 from Person *et al. Astron. J.* **136**, 1510-1518 (2008)

PLUTO OCCULTATION 2010-03-03

- Allowable prediction error depends on the angular radius of the body
  - Example Pluto occultation
- Distances on Earth for 0.01 arcsec
  - ~200 km for object at 30 AU
  - ~400 km for object at 60 AU
  - ~600 km for object at 90 AU



Pluto Occultation, March 3, 2010
Star: 2MASS 591338134 (R = 12.7, K_s = 9.7)
Geocentric Mid-time: 09:34:55 UT
Geocentric shadow velocity: 17.2 km s^{-1}

KBO OCCULTATIONS WITH SOFIA

- Objectives
  - Establish accurate diameters
  - Search for close companions
  - Search for atmospheres
- Approach
  - Brightest KBOs as targets
  - Events accessible from Dryden
  - Optical/IR observations
- Prediction Strategy
  - Improve orbits for the largest KBOs (~30)
  - Maintain list of possible events
  - Refine astrometry for the best possibilities
  - Select events to observe (error ≤ 1500 km)
  - Final prediction refinement in flight

Typical Pluto shadow path
(early P126 prediction)

CHIRON OCCULTATION RESULTS (KAO & SAAO)

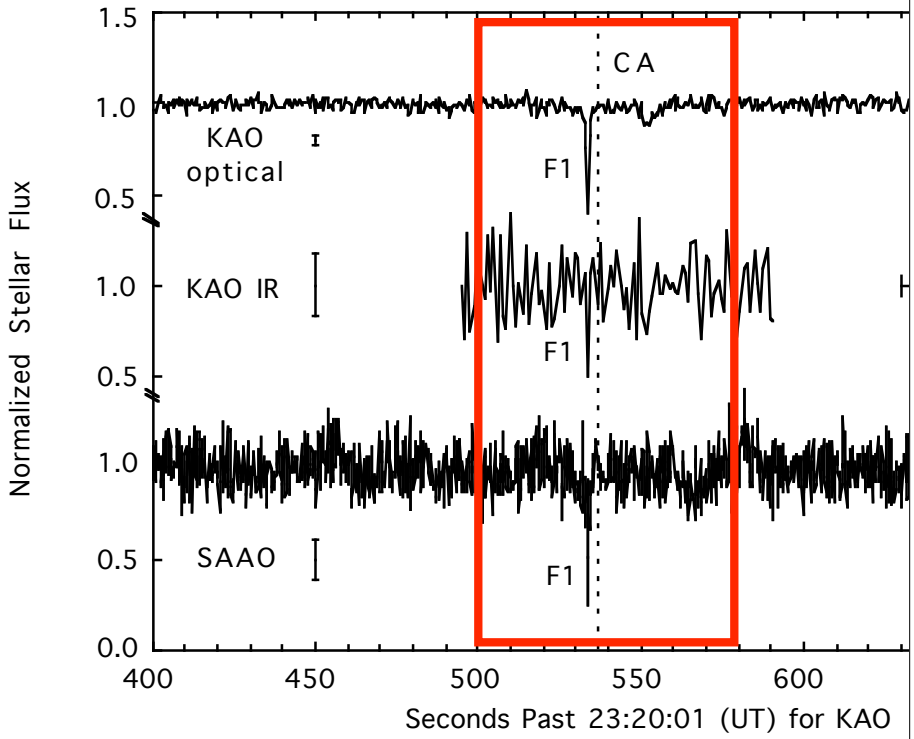


Figure 1 (Elliot et al.)

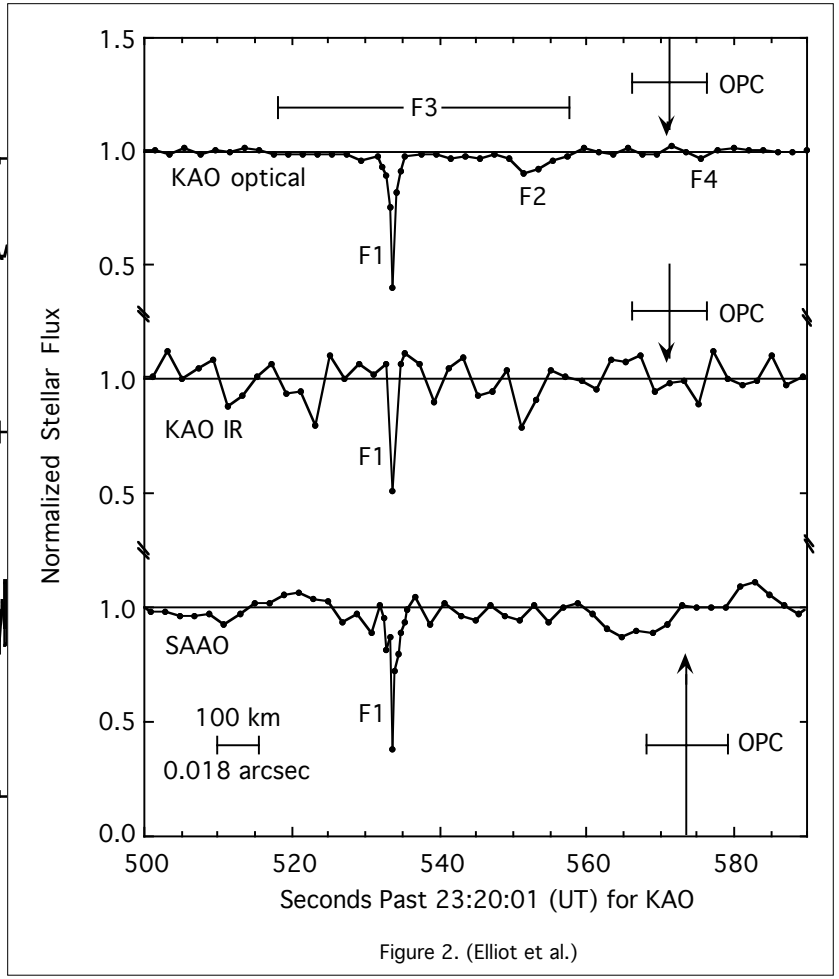


Figure 2. (Elliot et al.)

Adapted from Elliot et. al. Nature 373, 46 (1995)

CHARACTERISTICS OF AIRBORNE OCCULTATION OBSERVATIONS

- Advantages versus ground-based
  - Low scintillation noise
  - Above clouds
  - Virtually any location
  - State of the art instrumentation

- Disadvantages versus ground-based
  - Poor image quality
  - Scheduling
  - Instrument changes more difficult ("fast diagnostics camera*"?)

•"… could interleave an occultation measurement in any flight with any instrument."(Jurgen Wolf)

SUMMARY OF SUCCESSFUL KAO OCCULTATION MISSIONS

Body	Observations (land/water)	Results
Mars	water	Pre-Viking atmospheric probe; upper limit on Ar; central flash
Uranus	water	Rings discovered; atmospheric probe
Triton (Tr60)	water	Atmospheric probe
Triton (Tr148)	water	Atmospheric probe; atmosphere expanding
Jupiter ring	water	Upper limit on optical depth
Neptune ring search	water	No rings detected
Chiron	land	Nuclear jets
Pluto	water	Atmosphere detected and probed