Portable Occultation Systems for Studies of Pluto and Triton

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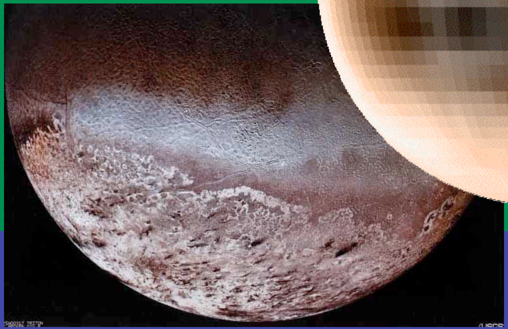
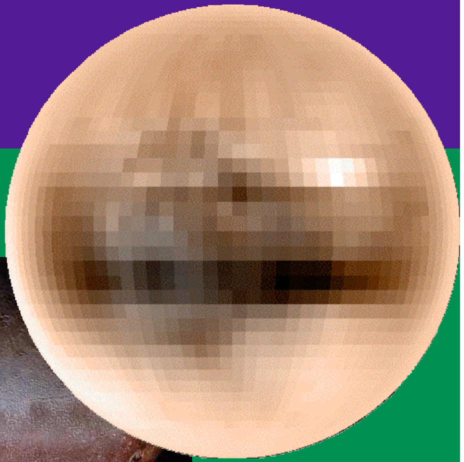
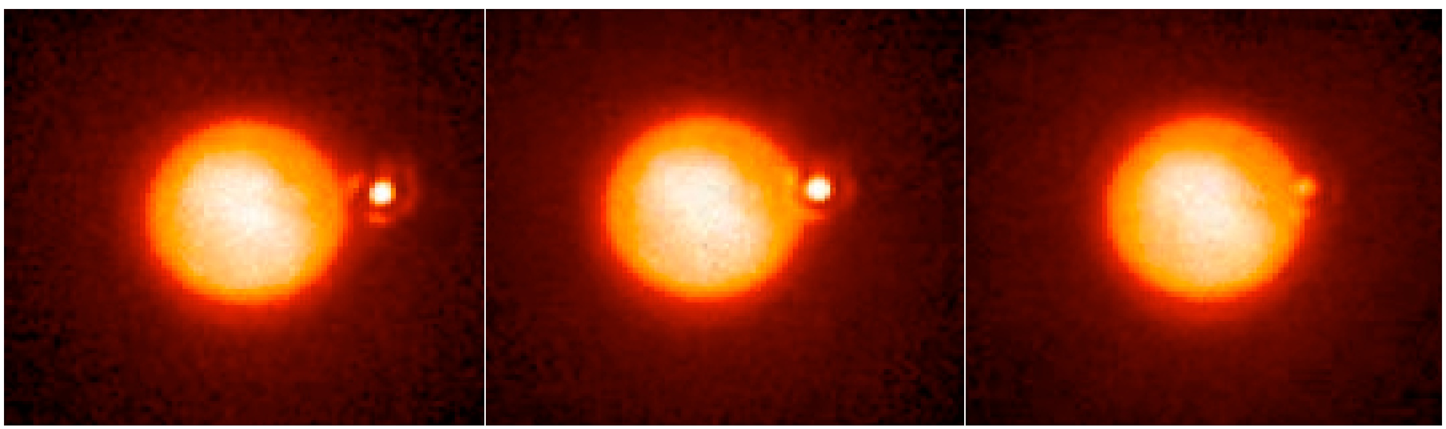




Lightbucket Astronomy Conference
Waimea, Hawaii, January 1, 2011

What is a Stellar Occultation?

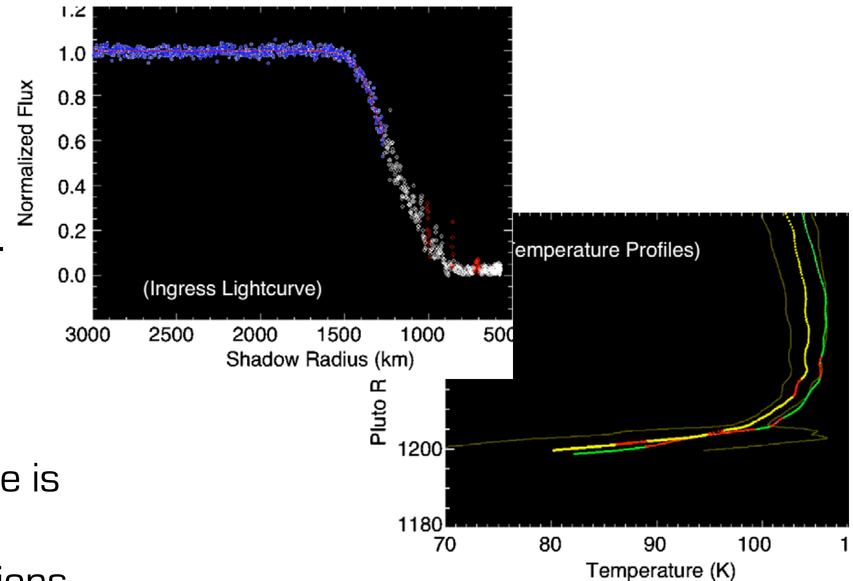
- A **stellar occultation** occurs when an object passes between an observer and a distant star.
- For bodies with atmospheres, like Pluto, **differential refraction** defocuses starlight, leading to a gradual dimming of the stellar flux.
- For bodies with no atmosphere, such as Pluto's moons Charon or Hydra, the stellar flux drops to zero abruptly when it is cut off by the solid **surface**.
- Given **multiple chords** across an object, we can reconstruct the exact location of the passage of the occultation shadow over the Earth and the size and shape of the occulting object.



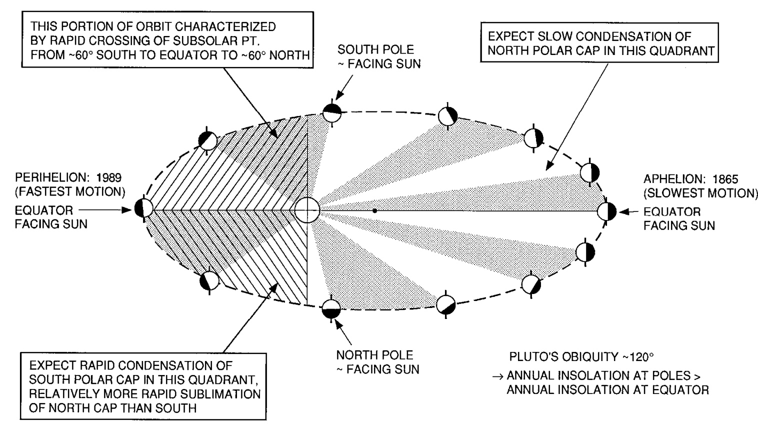
Three frames of a time series showing Saturn's moon Titan (disk) occulting a star (point source with diffraction pattern) as seen with adaptive optics from Palomar, 2001-Dec-20. Bouchez et al. 2003, SPIE 4839, 1045.

Why Observe Stellar Occultations of Pluto and Triton?

- Atmospheric pressure and temperature
  - Occultations probe atmospheric pressures and temperatures at sub-km scales, which lets us investigate atmospheric energetics and dynamics.
- Seasonal variation
  - Insolation and surface temperatures on Pluto and Triton vary seasonally due to its large orbital eccentricity and/or obliquity. The surface pressure is a function of frost temperature and may change seasonally by orders of magnitude. Using occultations, we found that Pluto's atmosphere doubled between 1988 and 2002, with slower change from 2002 to 2010. Triton's atmosphere doubled between 1989 and 1997. Continued occultations give the best constraints on models of atmospheric change.
- Context for NASA's mission to Pluto
  - *New Horizons* will give a snapshot of Pluto during its 2015 flyby. We need a temporal context to fully interpret the *New Horizons* data. Occultations will provide this context.



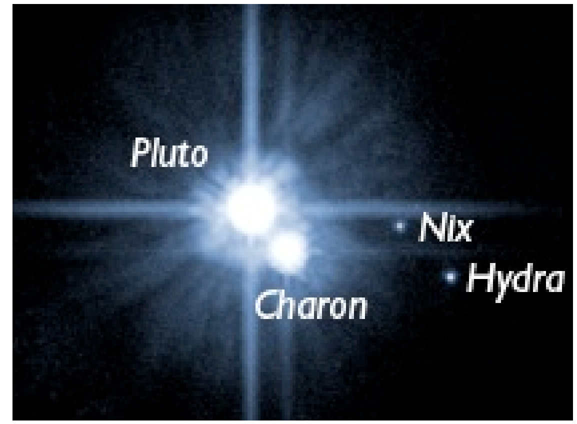
Pluto occultation of 2006 June 12. Top: Light curve.. Bottom: temperatures vs. radius. From Young et at. 2008, AJ 136, 1757.



Schematic of Pluto's orbit and insolation patterns. From Hansen and Paige 2006, Icarus, 120, 247.

Why Observe Stellar Occultations of Charon and Hydra?

- Sizes
  - Pluto's large moon, Charon (1200 km diameter), subtends only 50 milliarcsec. Its small moons, Nix and Hydra (50-150 km diameter), subtend about 5 milliarcsec. Occultations are the only way to directly measure the sizes of the small moons.
- Orbits
  - If Pluto and a moon occult the same star, then their *relative* positions can be measured very accurately. This will improve our knowledge of their orbits around the Pluto-system barycenter, which can be used to constrain the masses of Nix and Hydra, and origin scenarios.
- Support for NASA's mission to Pluto
  - The orbits of Nix and Hydra are currently uncertain enough that some of the highest-resolution images may miss their targets unless the orbits are improved. We have plans to do this with images taken with *New Horizons* itself in the weeks before encounter. Improved orbits now would make our flyby more robust.



Pluto and its moons Charon, Nix, and Hydra, as images from HST on 2006, Feb 15. Pluto and Charon are barely resolved, and Nix and Hydra are unresolved. "Size" of the objects indicate their relative brightness. Credit: NASA, ESA, H. Weaver (JHU/APL), S. Stern (SwRI), and the HST Pluto Companion Search Team.

PHOT: A team, a goal, some hardware

Southwest Res. Inst.

- Leslie Young
- Eliot Young
- Cathy Olkin
- Marc Buie

Wellesley College

- Dick French

Lowell Observatory

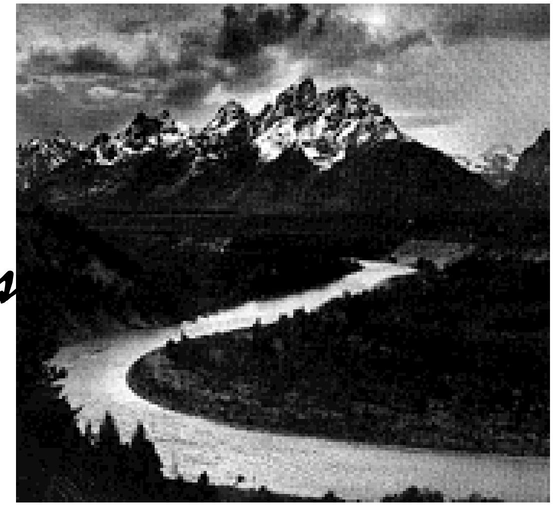
- Larry Wasserman

Pluto goals: observe one or more Pluto event per year, with multiple wavelengths and high SNR where possible.

4 MicroMax Cameras, bought in 2005

Henri Cartier-Bresson

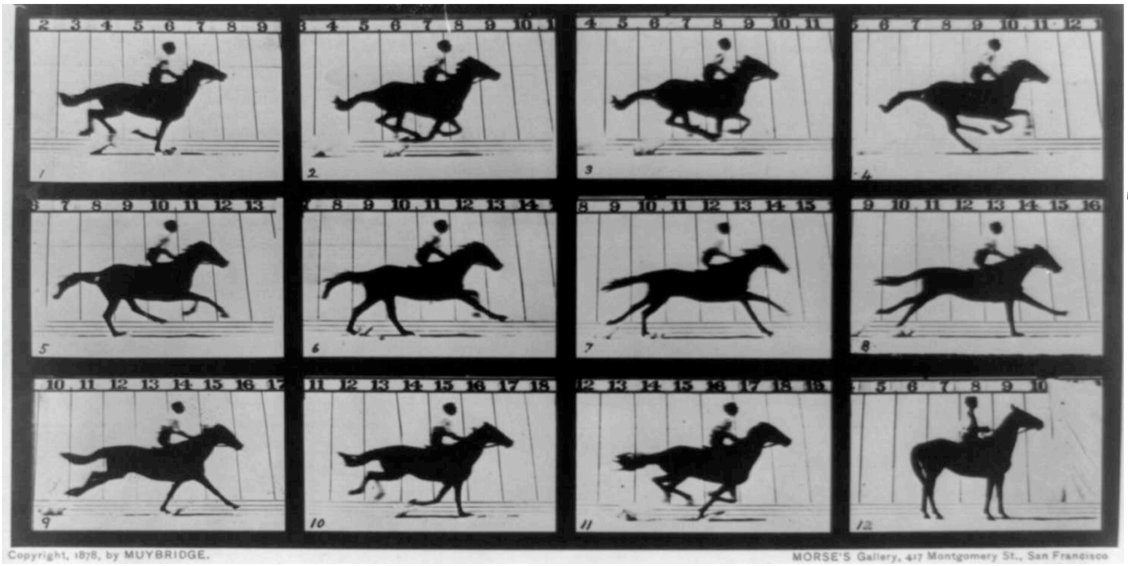
Ansel Adams



Dorothea Lange

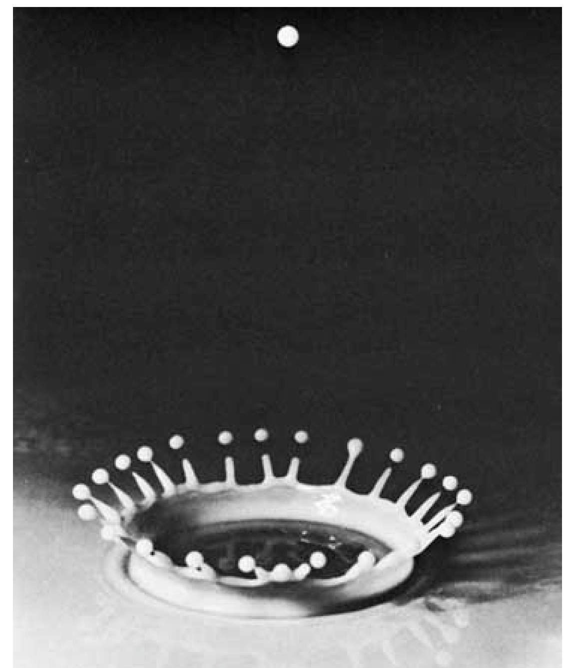
Walker Evans

3 PhotonMax Cameras, bought in 2007



Eadweard Muybridge

Gjon Mili



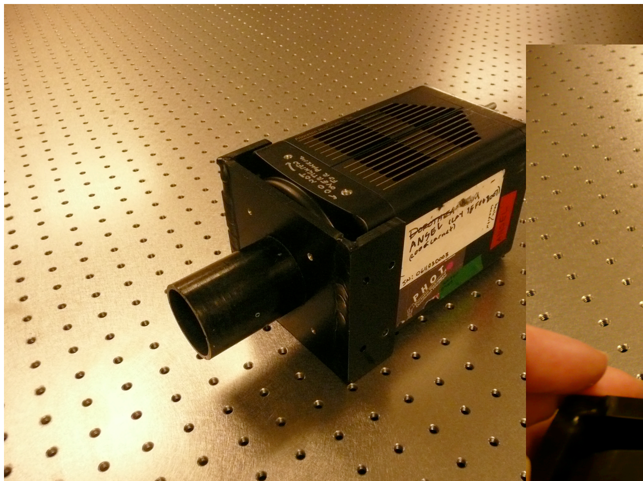
Doc Edgerton

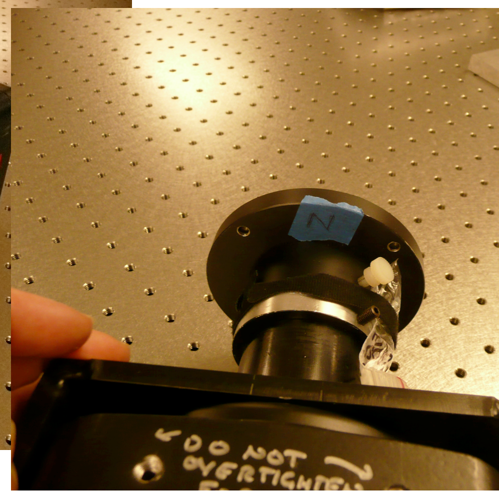

PhotonMax
MicroMax
Remove before using
This lens for test only
ROPER SCIENTIFIC, Inc.

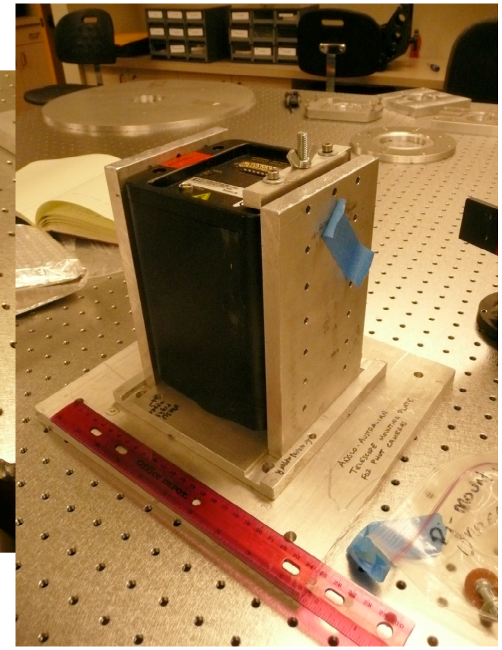
Characteristics of PHOT cameras

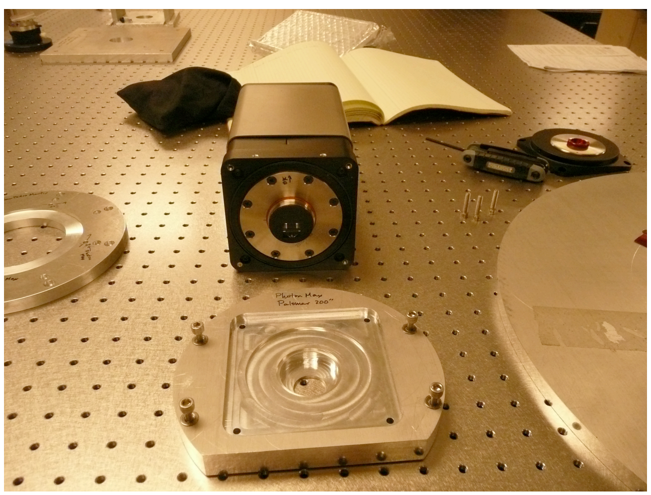
	MicroMax	PhotonMax
Field of View	512x512 13 μm pixels	512x512 16 μm pixels
Frame Transfer	Yes	Yes
Digitization rate	100 KHz & 1 MHz	1 MHz and 10 MHz
Read Noise	3 e- at 100 KHz 12 e- at 1 MHz	7 e- at 1 MHz
Thermelectricly Cooled	To -45 C	To -70 C
Quantum efficiency	>90%	>90%
Externally Triggerable	Yes	Yes

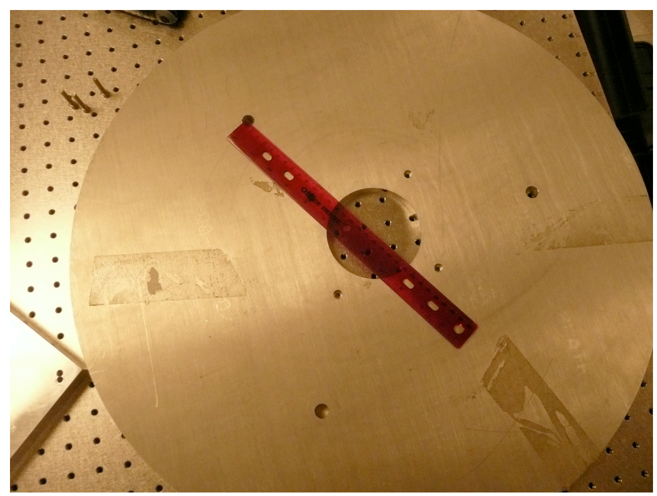
PHOT cameras have been mounted on 25 different telescopes in 10 countries



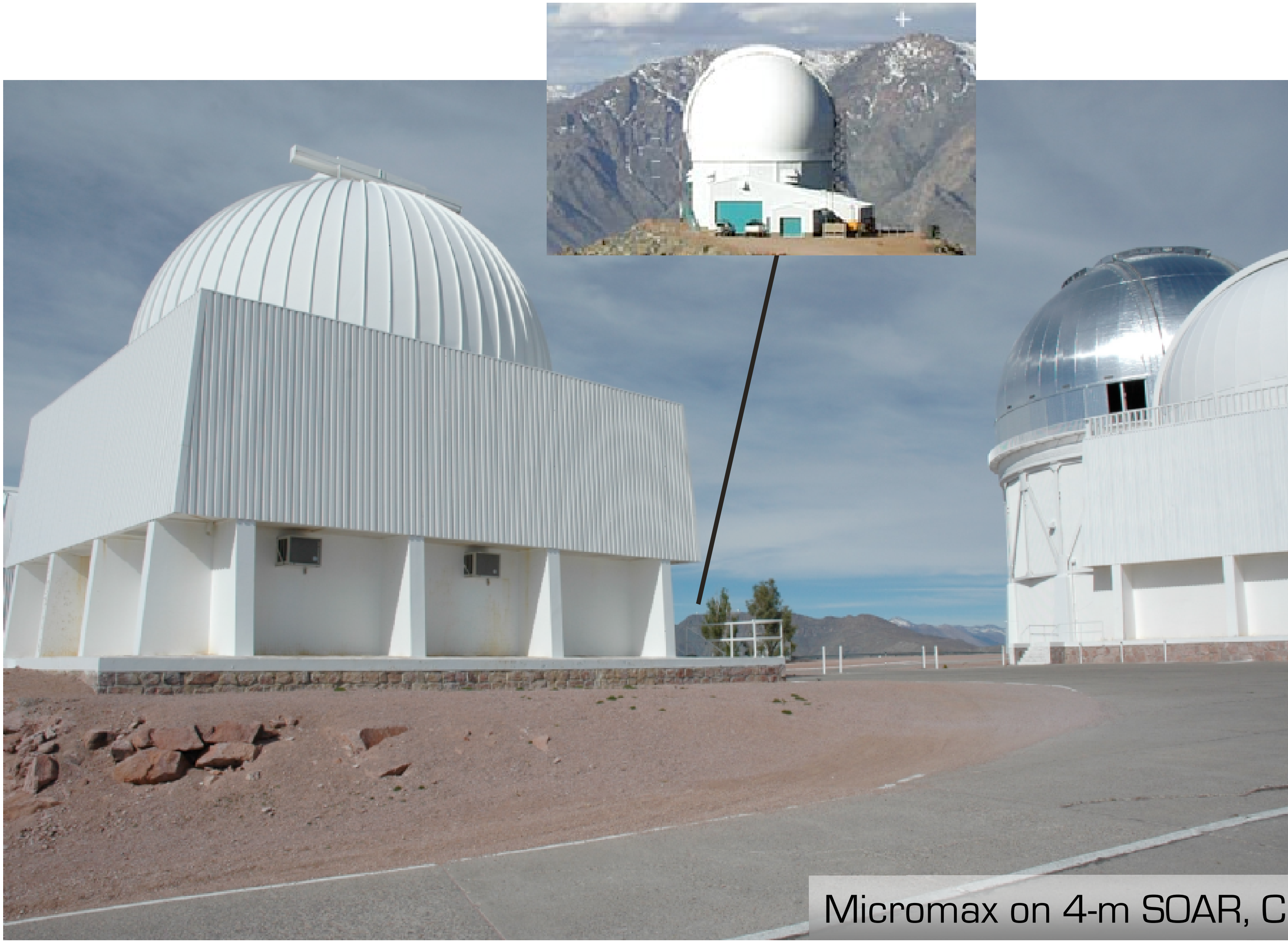






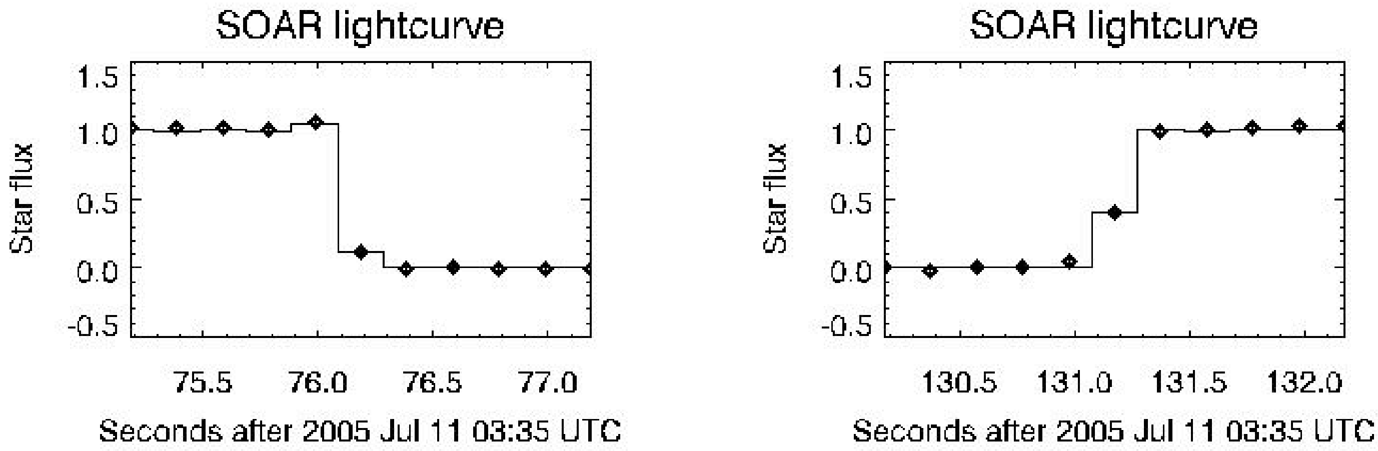


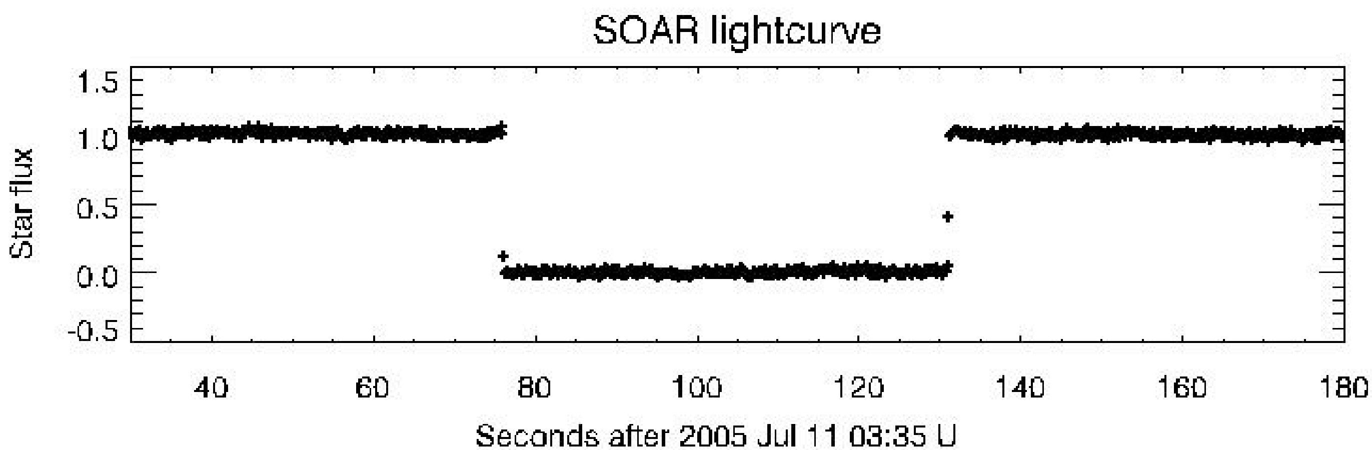
Charon-2005 July 11
Chile



Micromax on 4-m SOAR, Chile

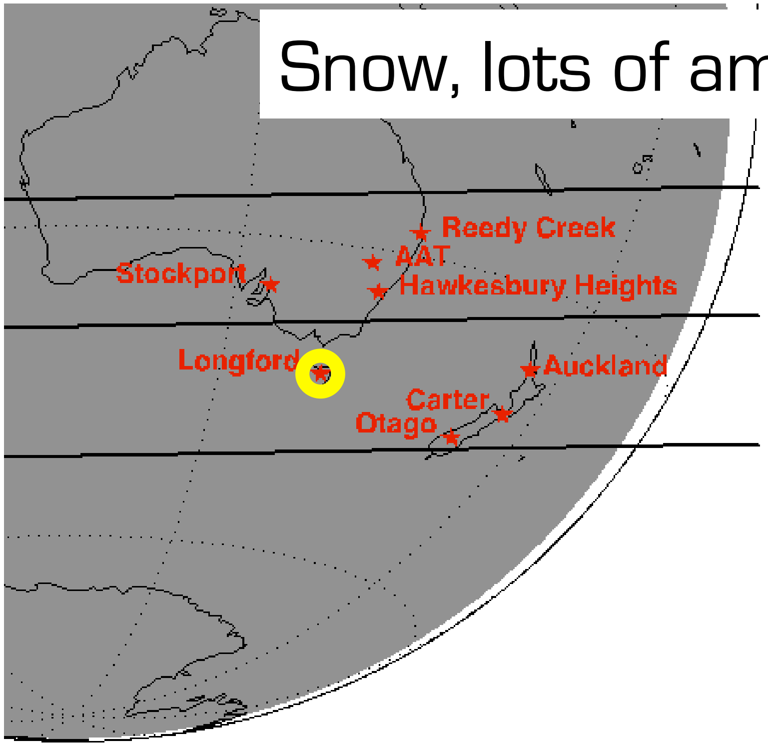
SOAR lightcurve of Charon, 2005

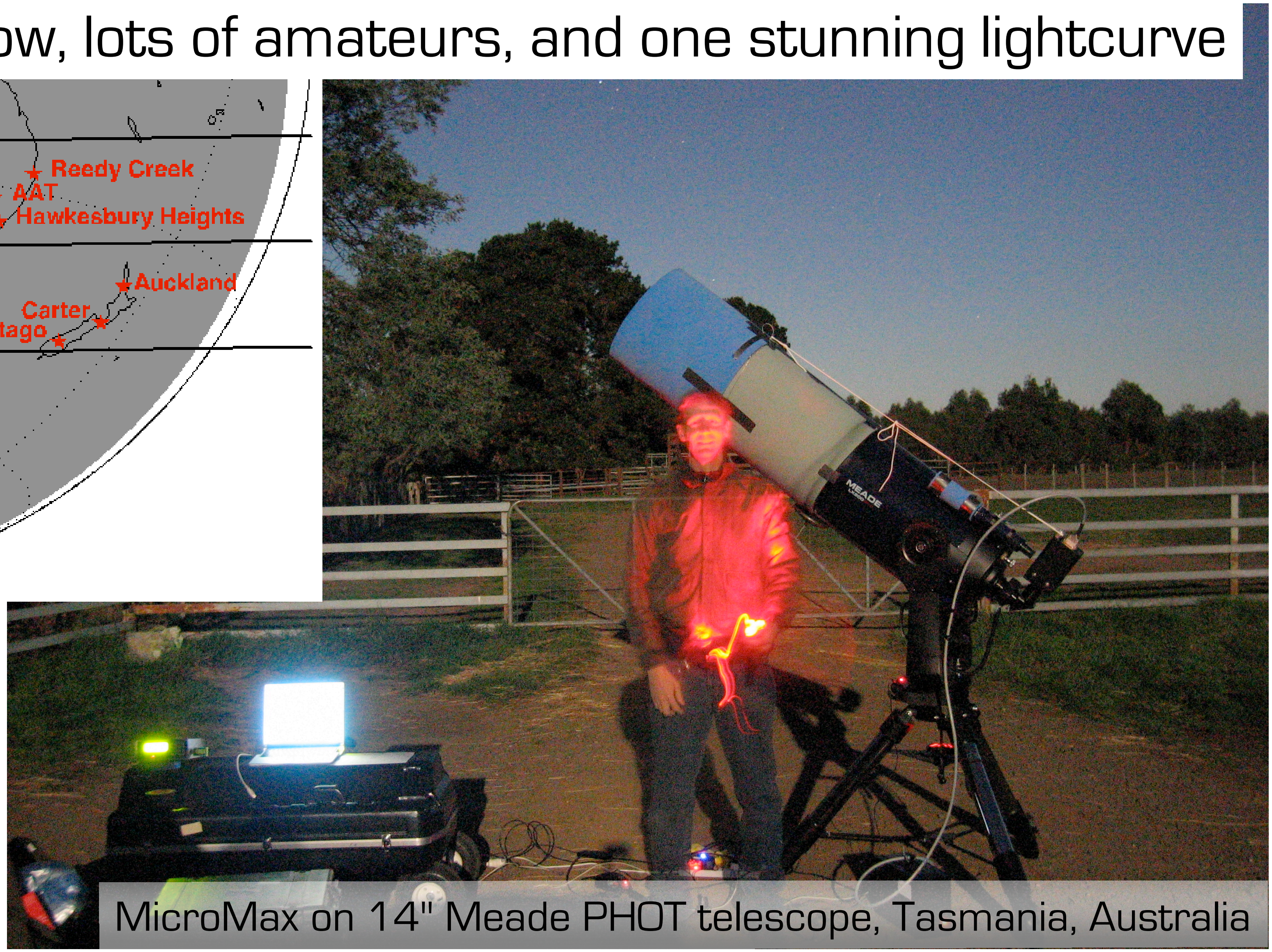




Pluto-2006 June 12
Australia & New Zealand

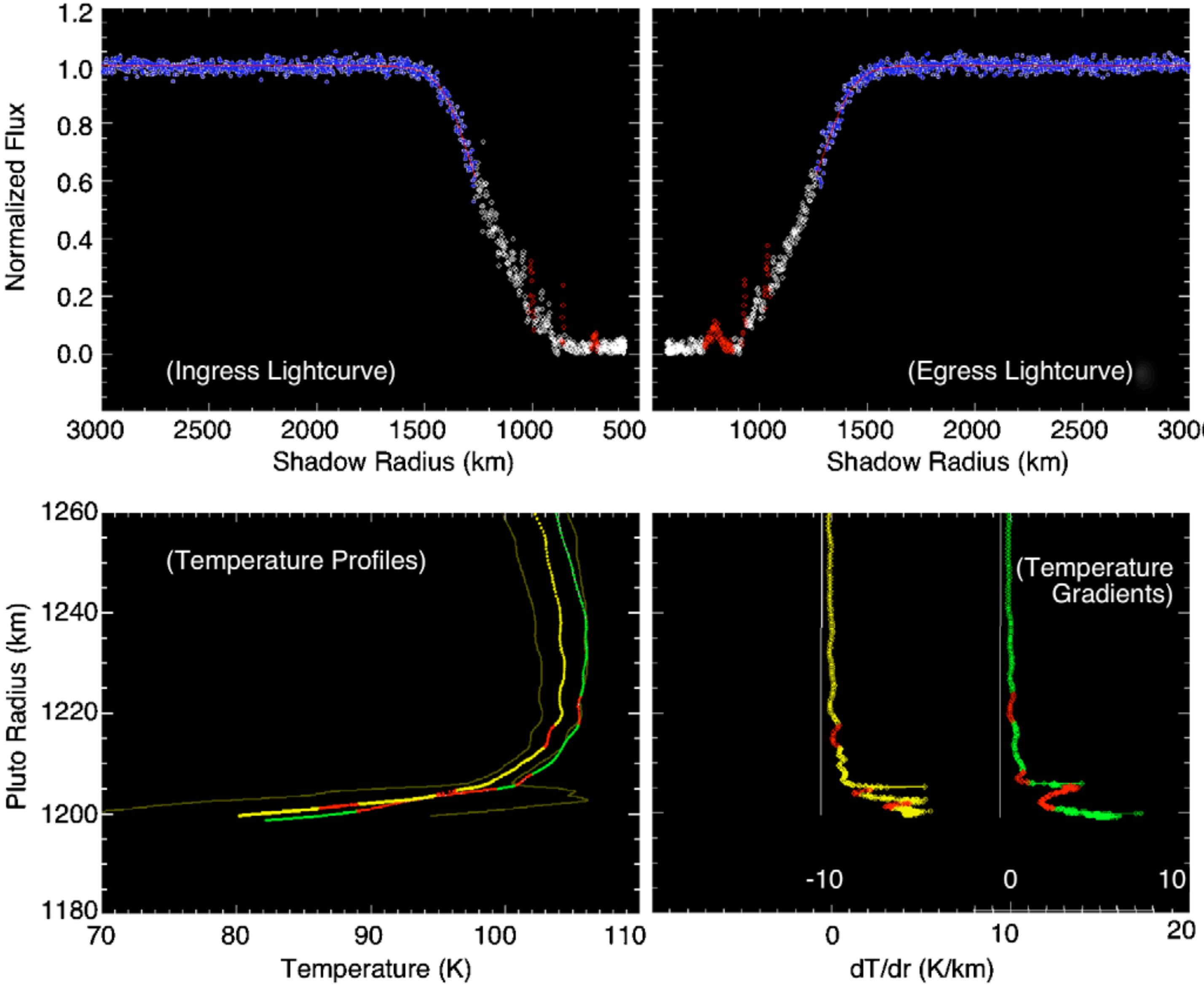
Snow, lots of amateurs, and one stunning lightcurve





MicroMax on 14" Meade PHOT telescope, Tasmania, Australia

Occultations measure temperature profiles



AAT 4-m telescope

Frame Rate: 10 Hz

Signal to Noise Ratio per point: 62

Signal to Noise Ratio per 60 km: 331

GPS-based absolute timing accuracy better than 100 *μ*second.

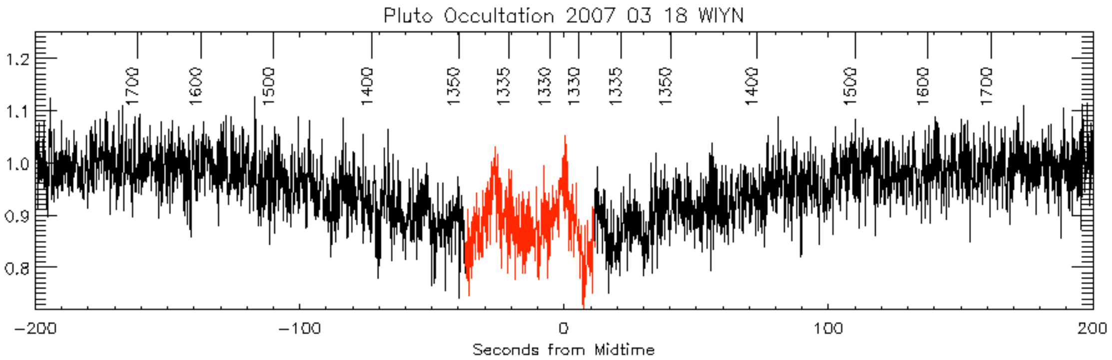
Spikes are resolved, differ in detail between ingress/egress

Pluto-2007 March 18
Western US and Baja

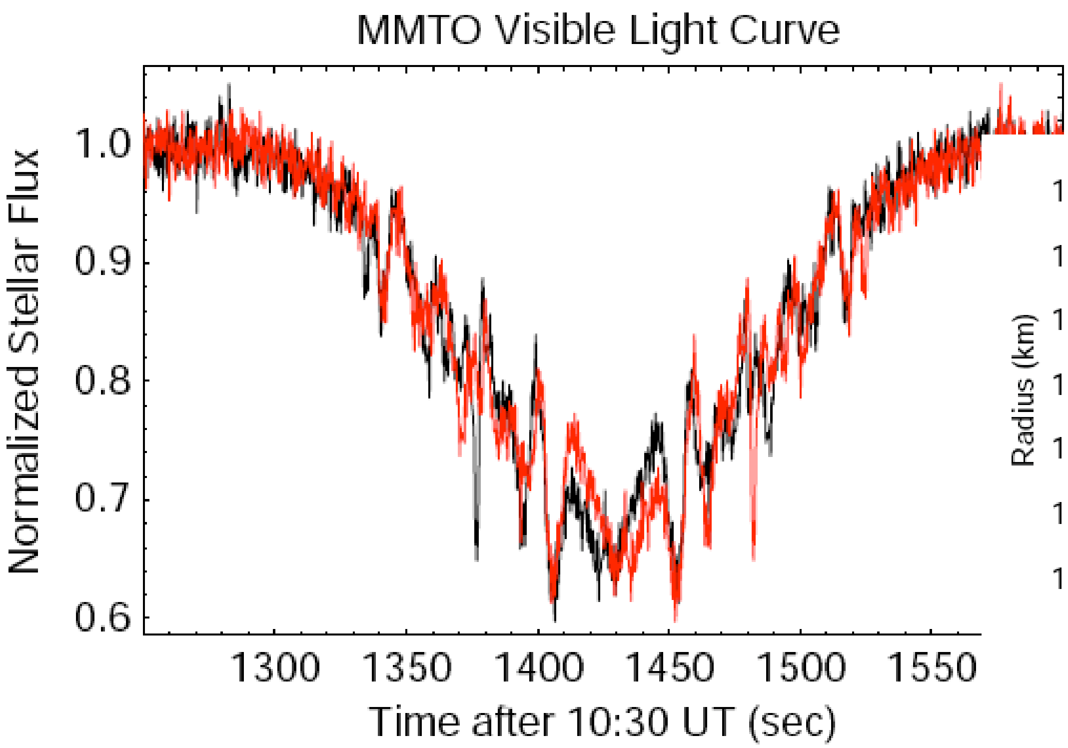
Eighteen telescopes! Visible and infrared!

PhotonMax on 1.5-m at San Pedro Martir, Baja, Mexico

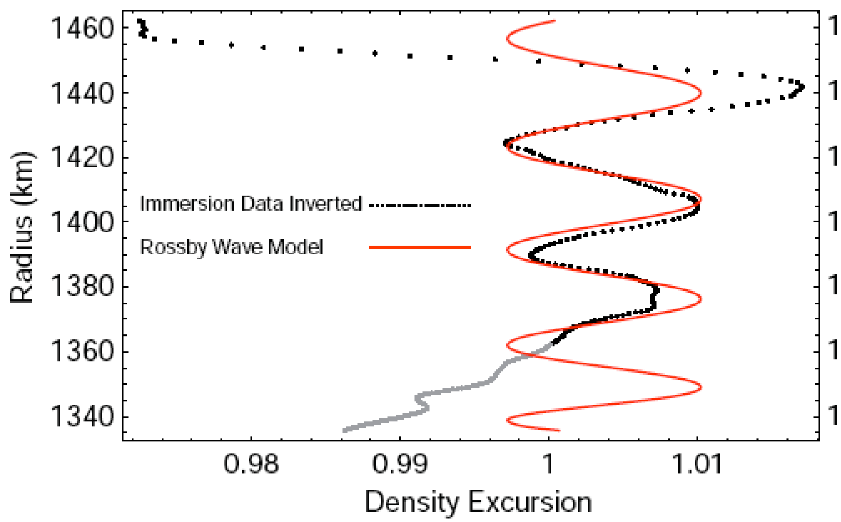
"Fangs" indicate high-altitude waves



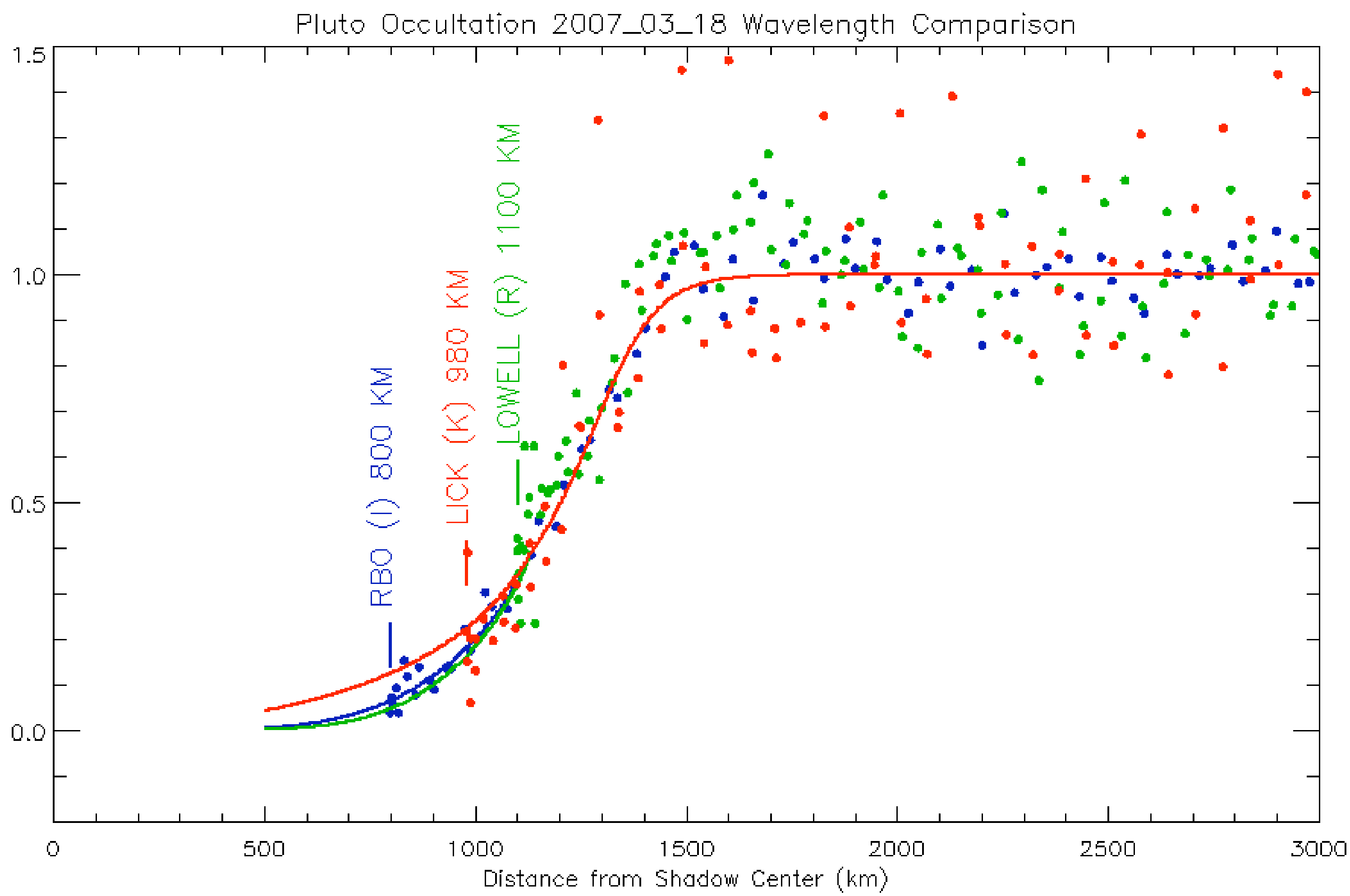
Pluto, Mar 18, 2007 (Young et al in prep)



Pluto, Mar 18, 2007 (Person et al 2008)

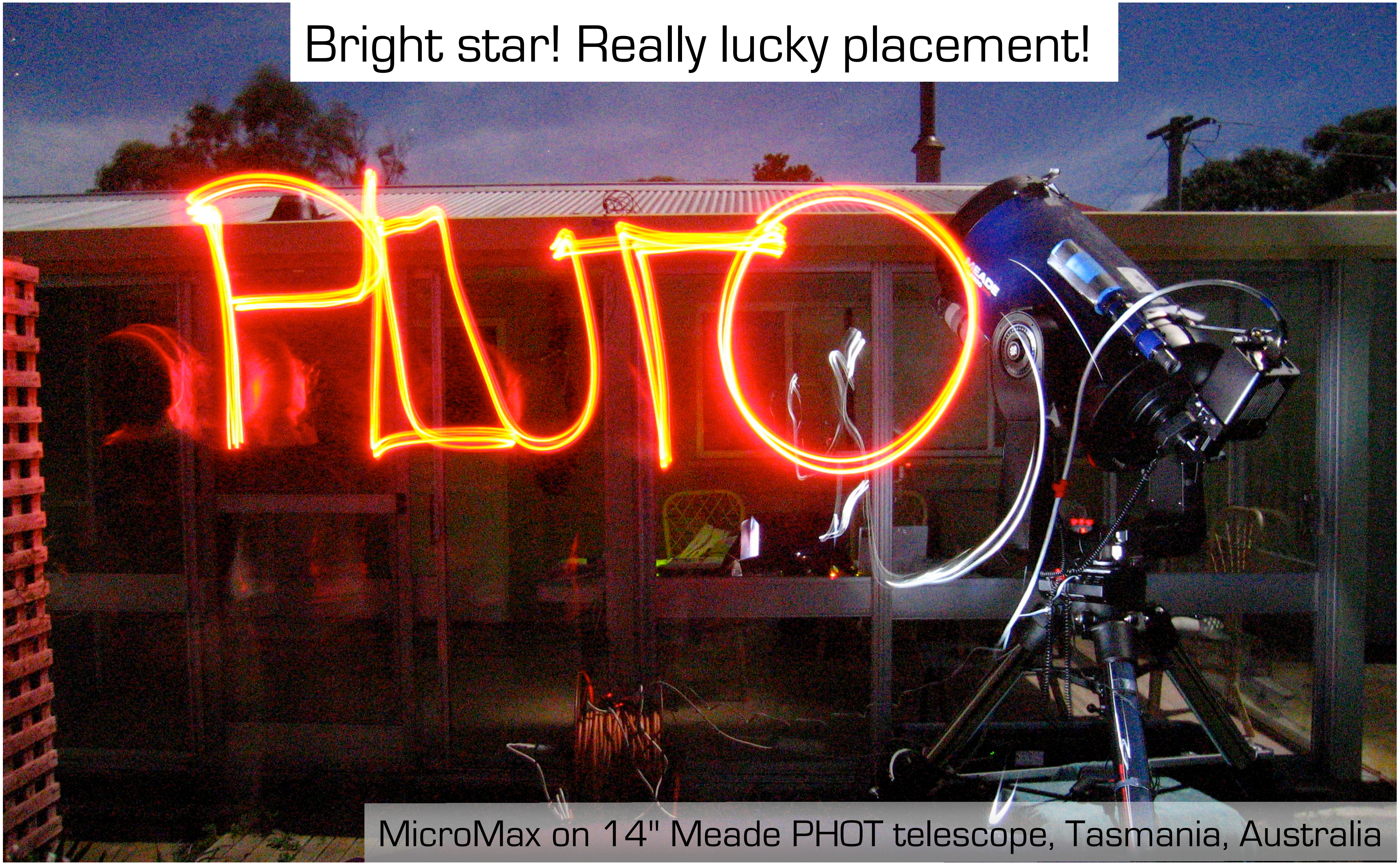


Occultation at different wavelengths constrain hazes



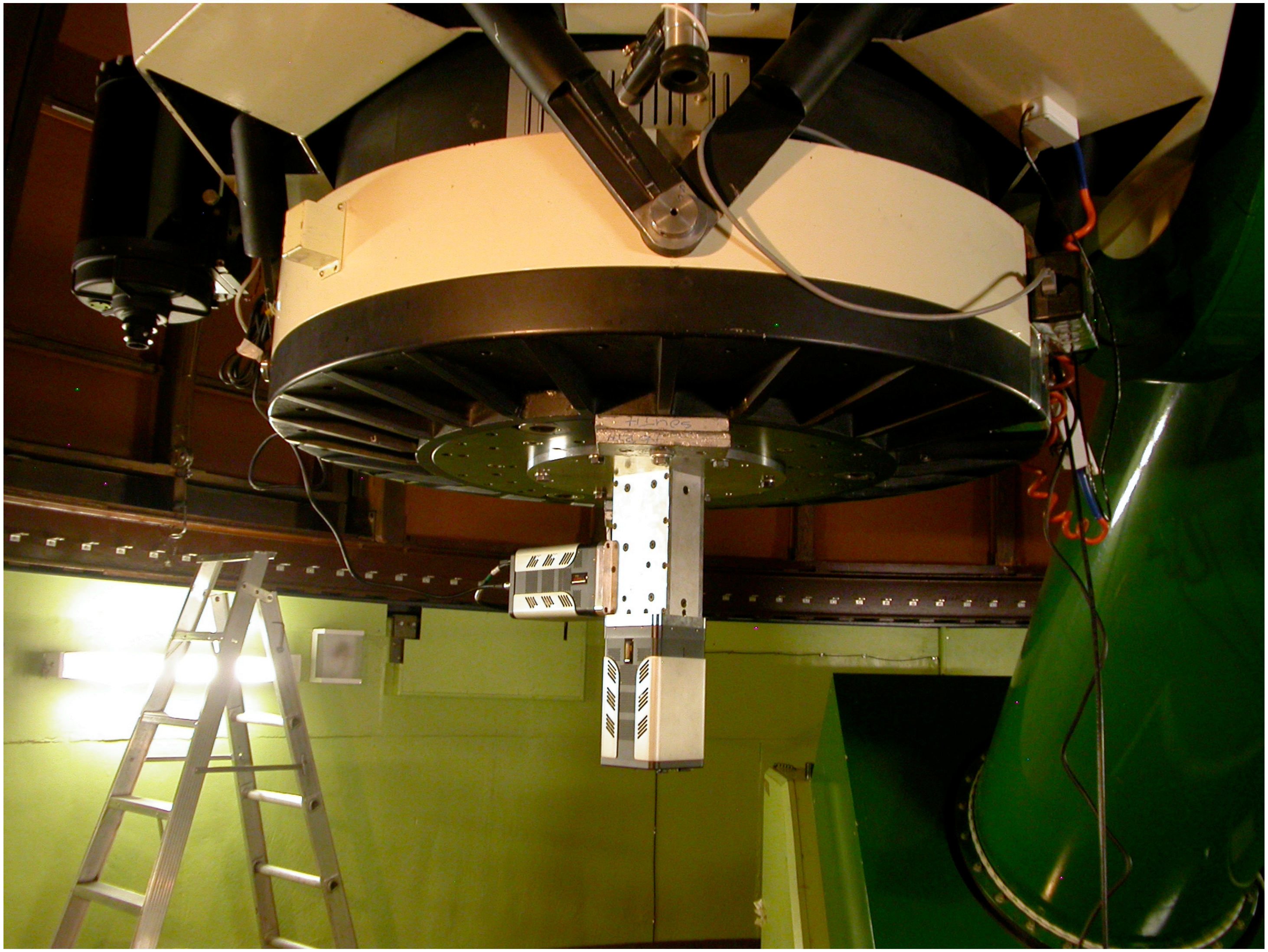
Pluto-2007 July 31
Return to Australia & New Zealand

Bright star! Really lucky placement!



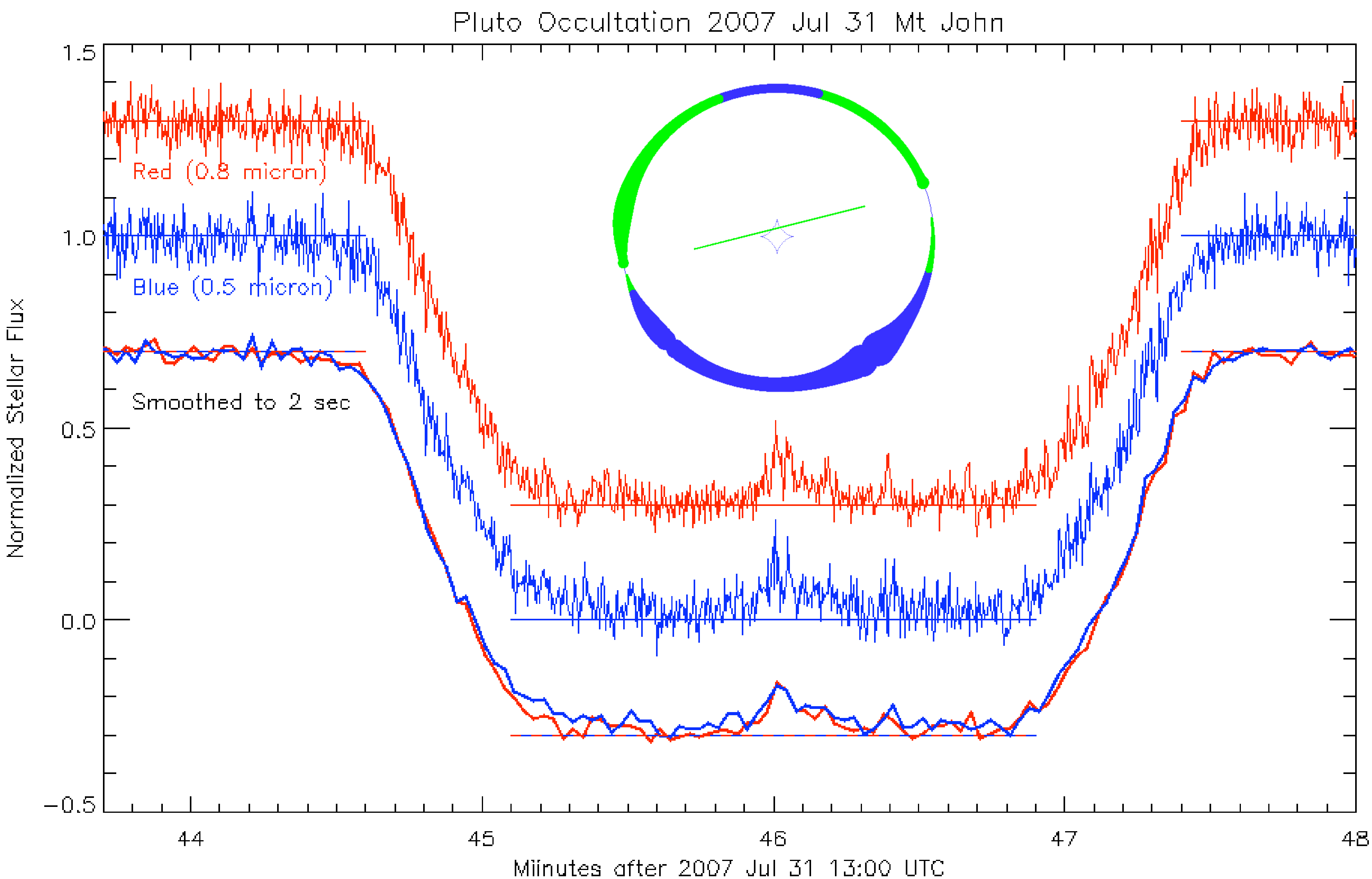
MicroMax on 14" Meade PHOT telescope, Tasmania, Australia

Pluto-2007 July 31
Return to Australia & New Zealand



2 PhotonMax's with a dichroic on 1-m telescope, Mount John, New Zealand

Occultations crossing the evolute are sensitive to the atmosphere's shape

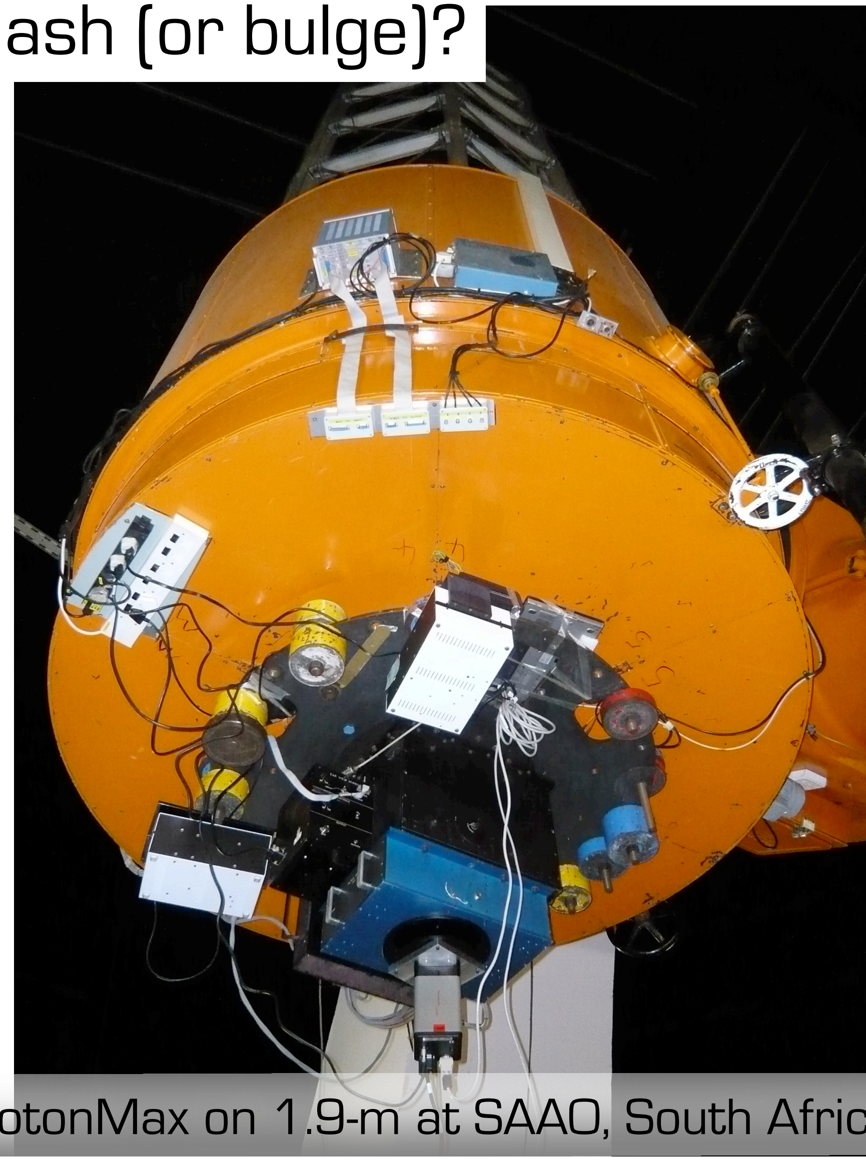


Pluto-2008 Aug 25 Western US again

Pluto-2009 Apr 21 Southern Africa

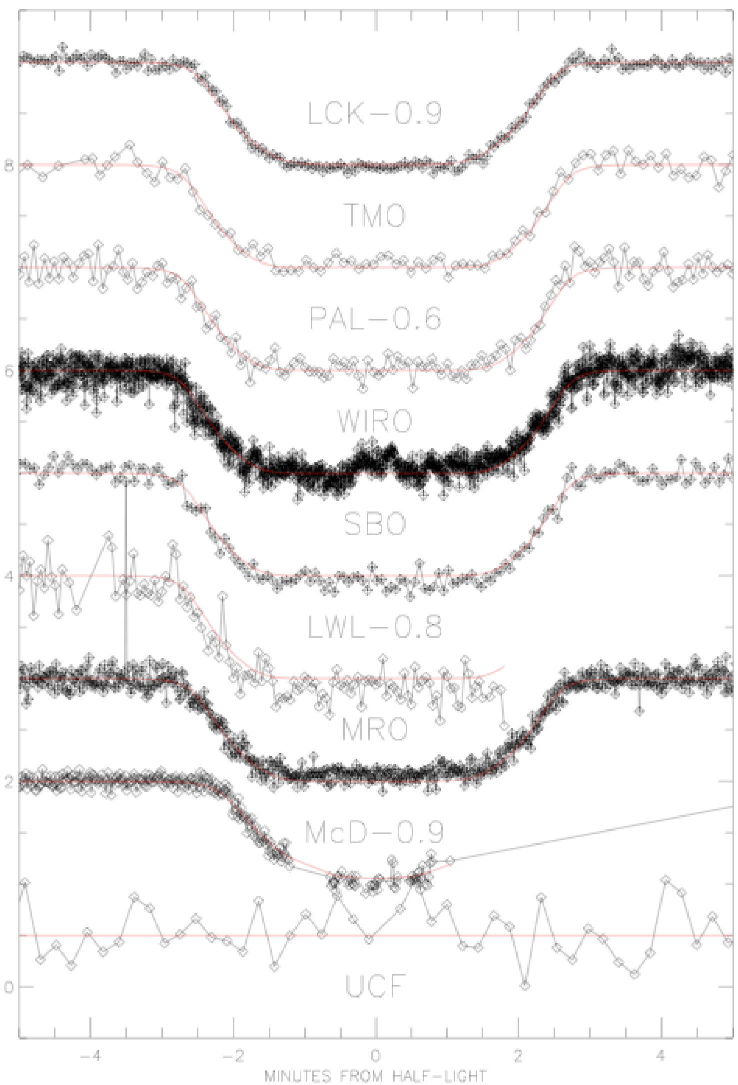
Possible central flash (or bulge)?

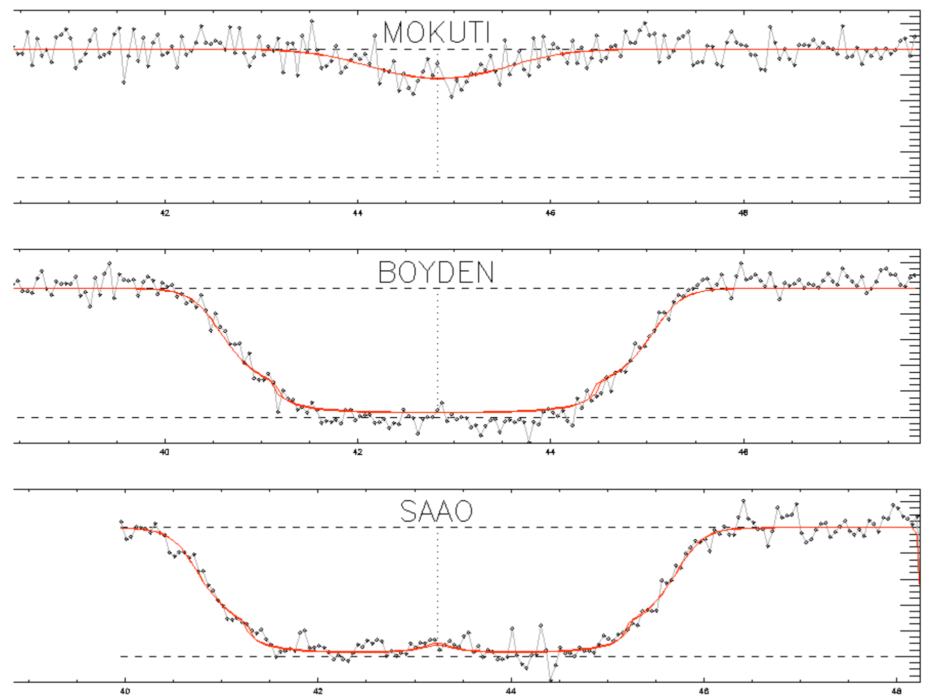
MicroMax on 36" Crossley, Lick, CA



PhotonMax on 1.9-m at SAAO, South Africa

Occultations near shadow center are sensitive to lower altitudes

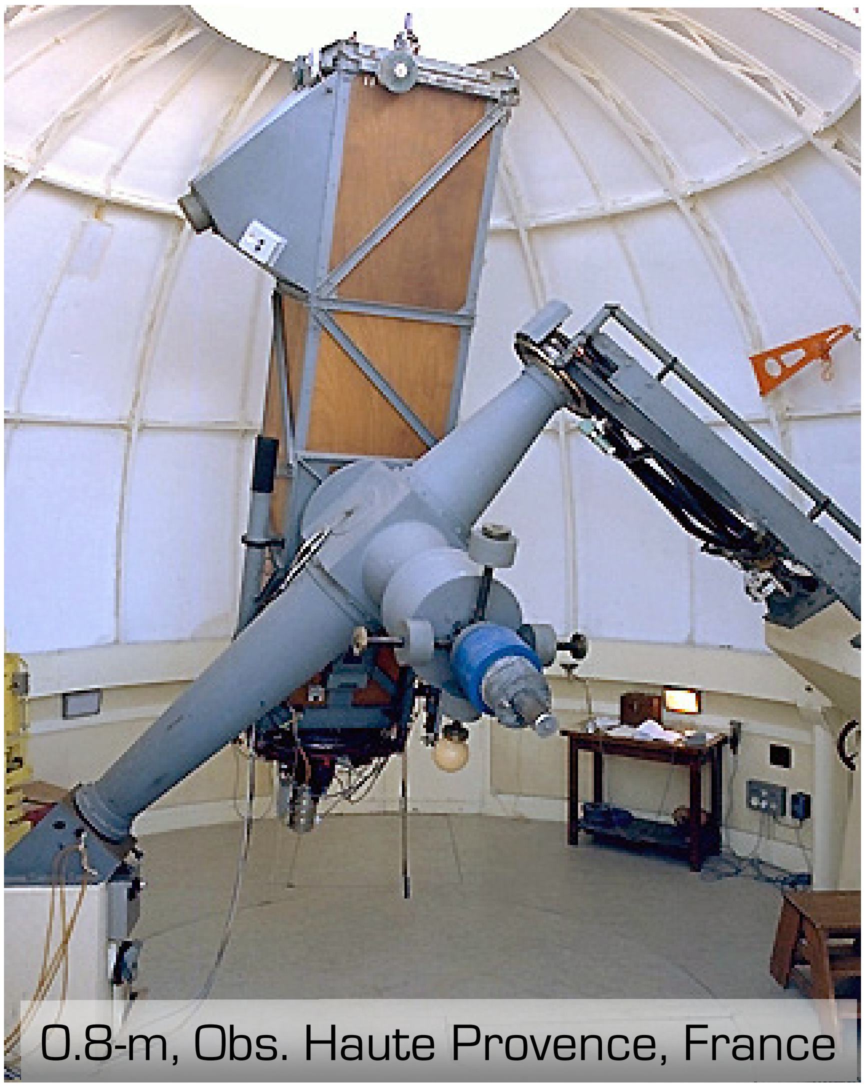




Pluto-2010 Feb 14 First time to Europe

Pluto-2010 July 4 South Africa

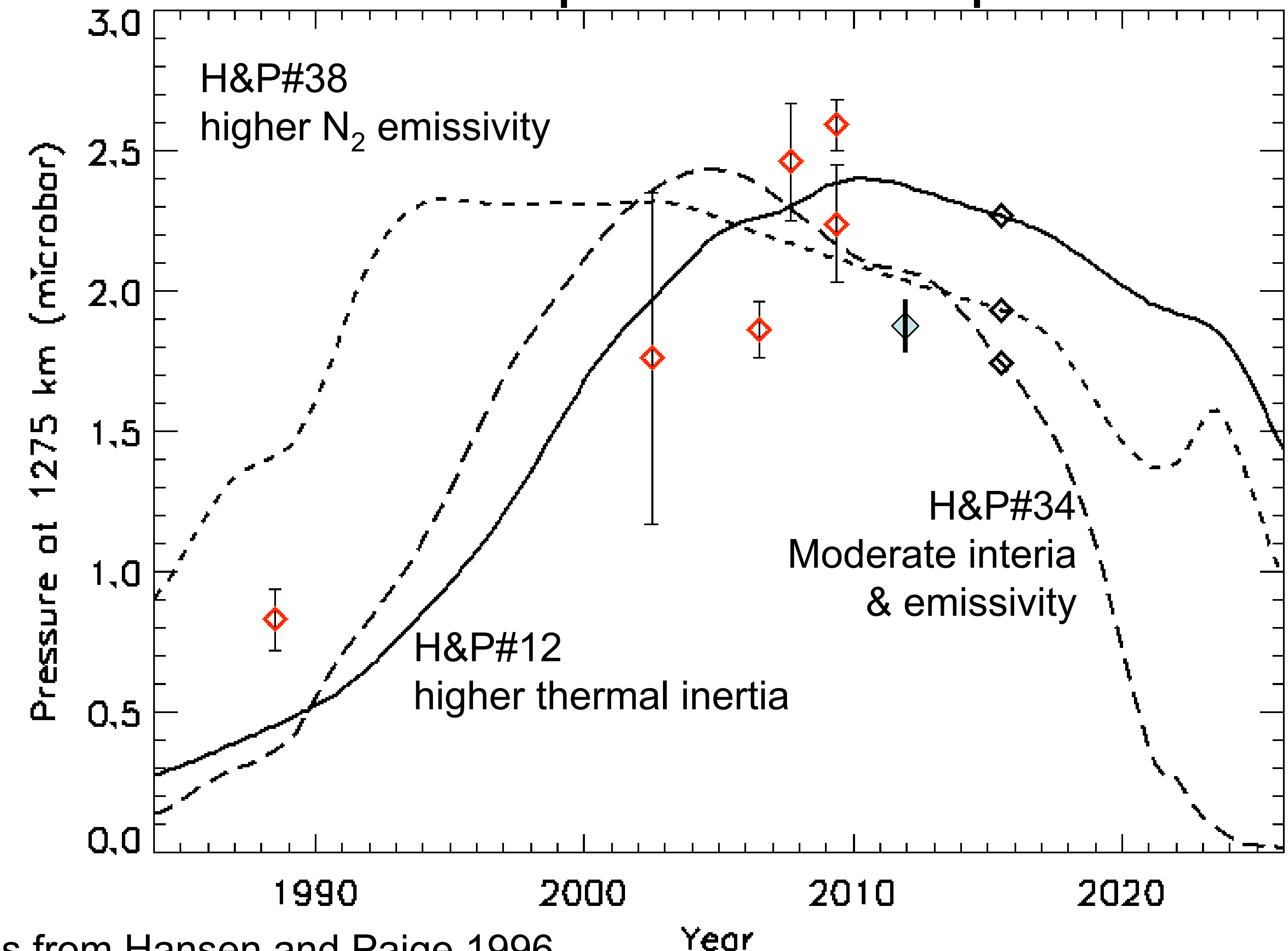
Collaborations, odd telescopes, poor weather.



0.8-m, Obs. Haute Provence, France

0.65-m, Aloe Ridge, South Africa

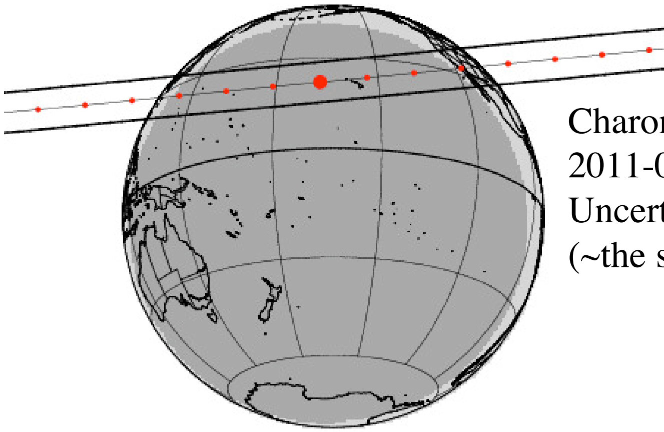
Occultations measure pressure vs. time that can be compared with predictions



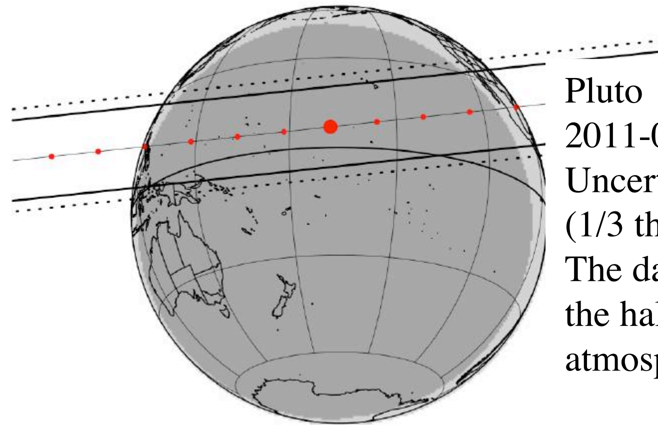
Models from Hansen and Paige 1996,

Pluto-Charon-Hydra 2011 June 23&27
First time to much of the Pacific

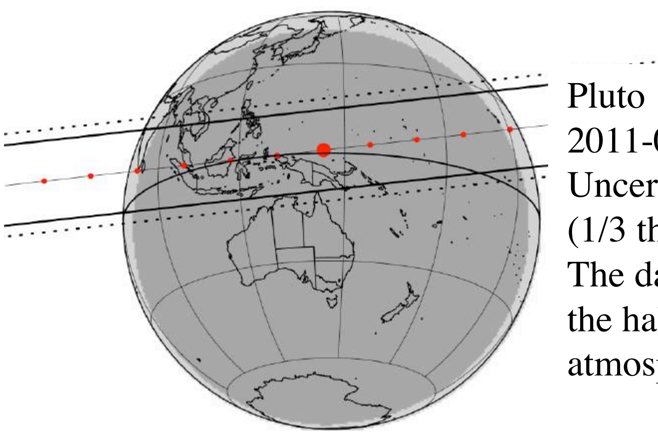
Date (UT)	Targets	RA (J2000)	Dec (J2000)	V	I	K
June 23 11:00-11:40	Charon/Pluto	18:25:55.4750	-18:48:07.015	15.2	12.7	9.7
June 27 14:04-15:07	Pluto/Hydra	18:25:29.0100	-18:48:47.570	13.7	13.0	11.9



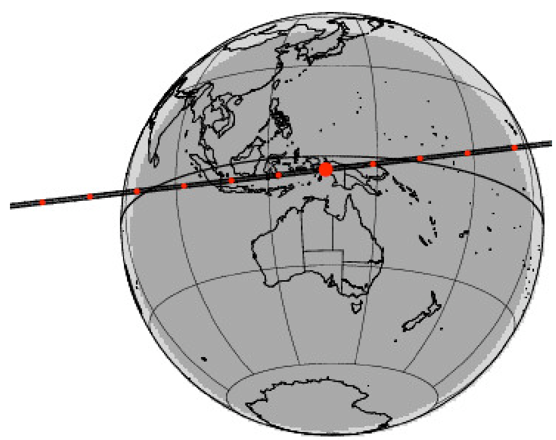
Charon
2011-06-23 11:15 UT
Uncertainty ~1200 km
(~the shadow width).



Pluto
2011-06-23 11:25 UT
Uncertainty ~800 km
(1/3 the shadow width).
The dashed line indicates the half-flux level of the atmospheric occultation.



Pluto
2011-06-27 14:19 UT
Uncertainty ~800 km
(1/3 the shadow width).
The dashed line indicates the half-flux level of the atmospheric occultation.

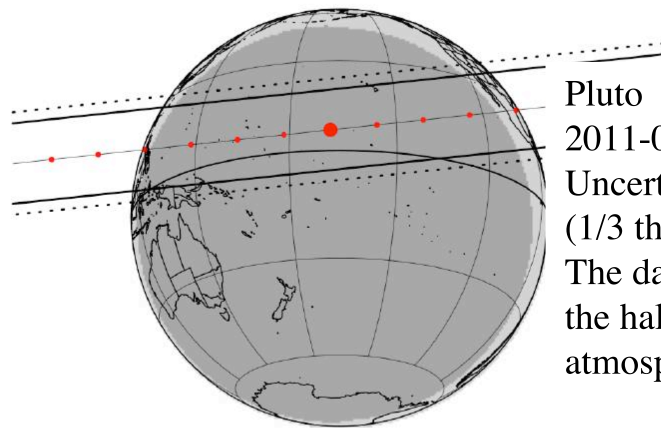


Hydra
2011-06-27 14:53 UT
Uncertainty ~2000 km
(20x the shadow width).
This is a high-risk, high-payoff observation for little additional effort.

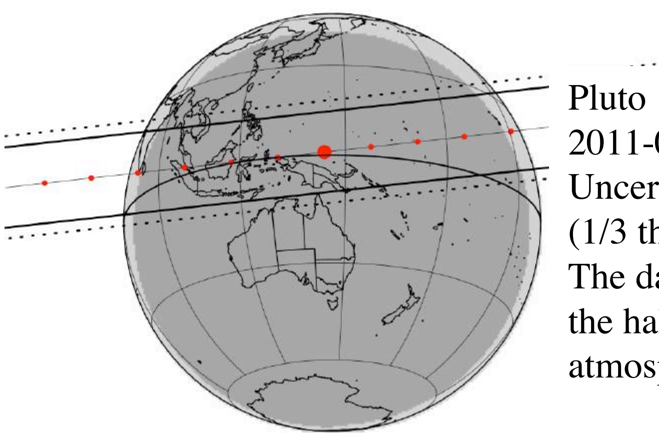
Pluto-Charon-Hydra 2011 June 23&27
First time to much of the Pacific

Date (UT)	Targets	RA (J2000)	Dec (J2000)	V	I	K
June 23 11:00-11:40	Charon/Pluto	18:25:55.4750	-18:48:07.015	15.2	12.7	9.7
June 27 14:04-15:07	Pluto/Hydra	18:25:29.0100	-18:48:47.570	13.7	13.0	11.9

Plans for California, Mexico, Hawaii (Mauna Loa, Maui, maybe Oahu & Kauai), Kwajalein, Papua New Guinea, Indonesia, Phillipines, and Australia.



Pluto
2011-06-23 11:25 UT
Uncertainty ~800 km (1/3 the shadow width).
The dashed line indicates the half-flux level of the atmospheric occultation.



Pluto
2011-06-27 14:19 UT
Uncertainty ~800 km (1/3 the shadow width).
The dashed line indicates the half-flux level of the atmospheric occultation.

We may be able to use telescopes or cameras in Hawaii, Papua New Guinea, or Indonesia. See Eliot Young's talk for more information.