Limits on Pluto Rings from the June 12 2006 Stellar Occultation

Henry Throop, R. G. French, K. Shoemaker, C. R. Ruhland, L. A. Young, C. B. Olkin

Pluto System on The Eve of New Horizons - APL, July 2013

Two ways to Search for Pluto's Rings Remotely

1. Direct Imaging

- Diffraction limit of telescope: r = 1500 km (HST)
- Sensitive to broad, dusty rings
- Limiting factor is stray light from Pluto / Charon
- Yields 2D imaging of system

2. Stellar Occultations

- Fresnel limit: r = $\sqrt{30\ \mathrm{AU}\ \lambda/2}$ = 2 km
- Ideal for detection of narrow and/or dense rings
- Gives 1D cut across system
- Can detect debris arcs and individual bodies that

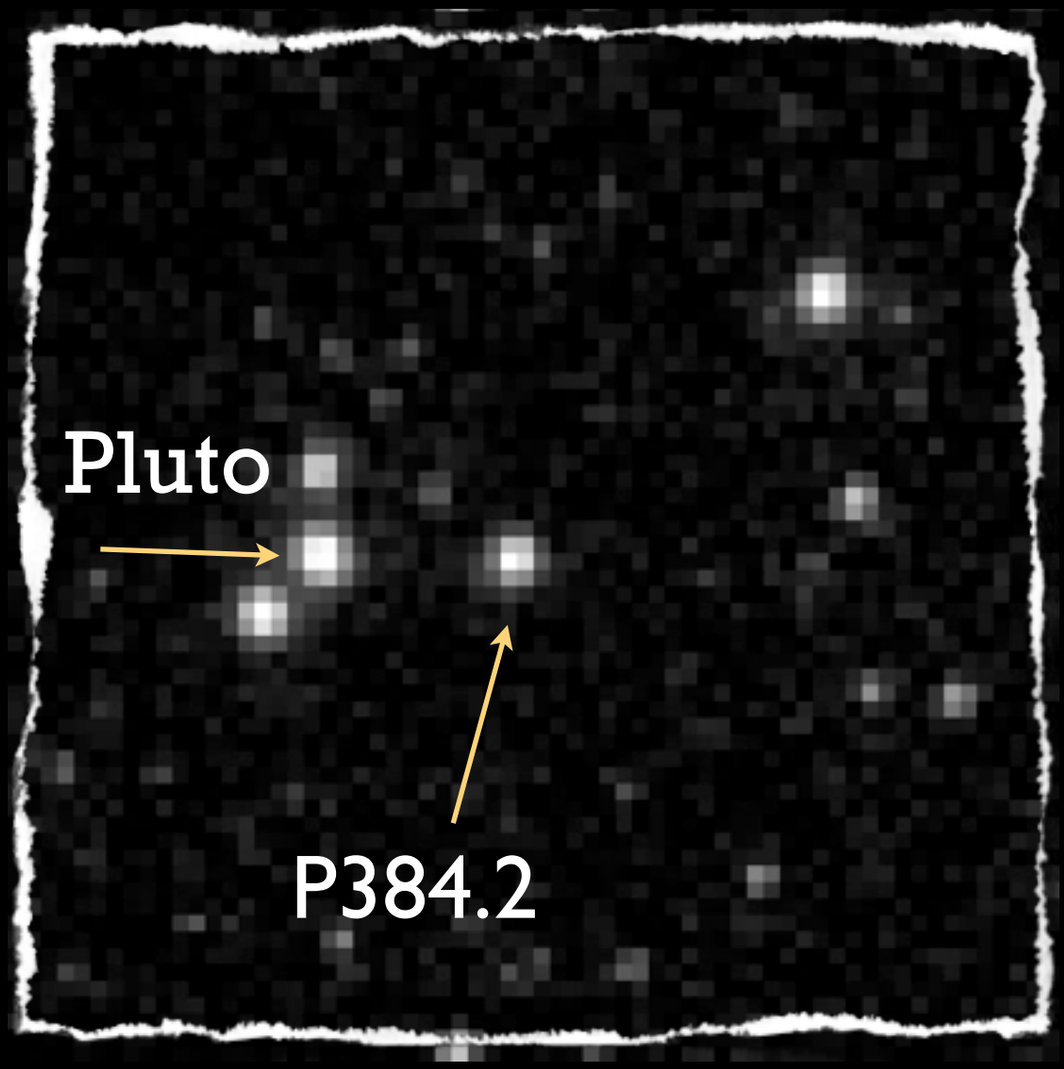
Anglo-Australian Telescope 3.9 m

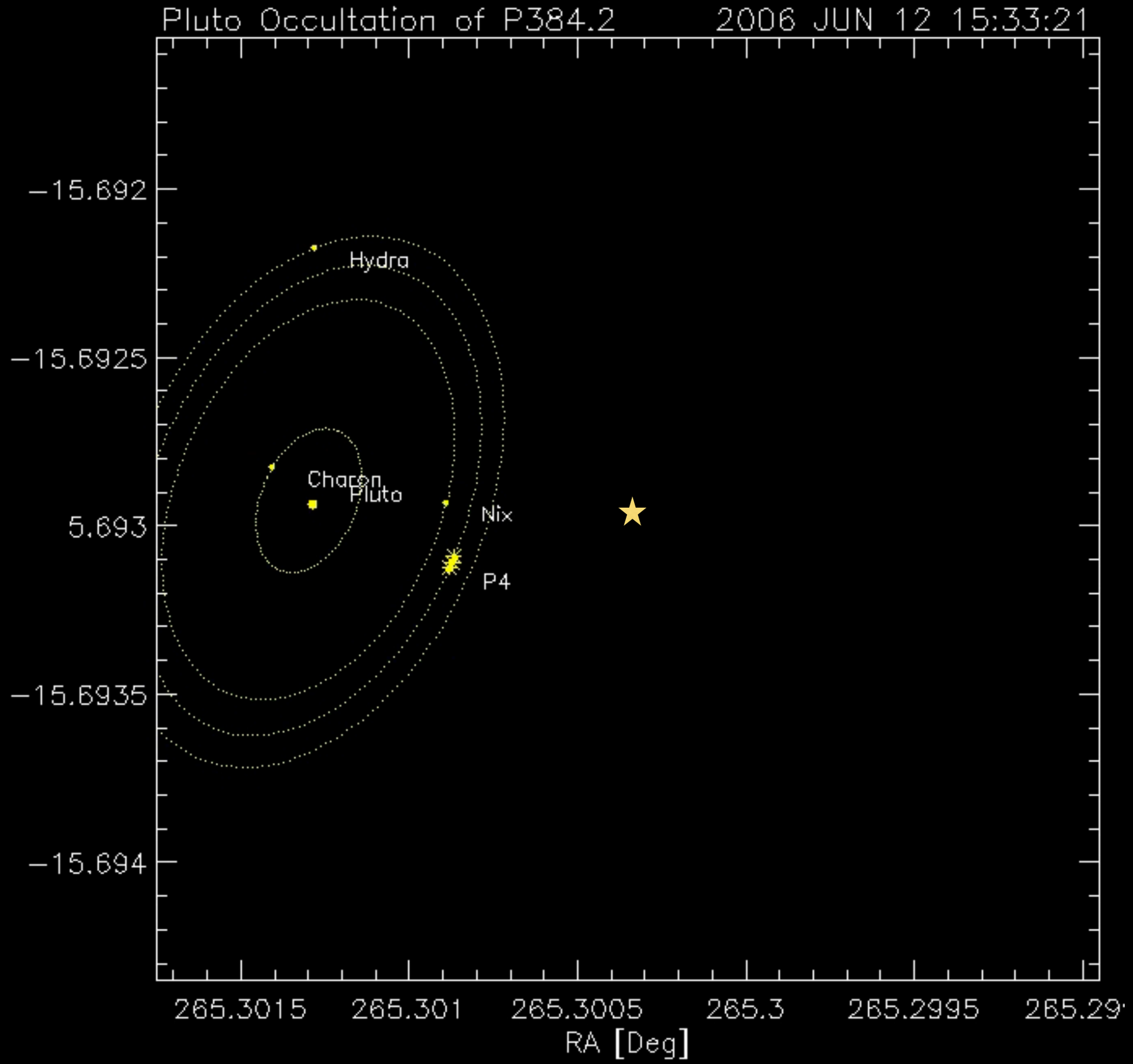
2006 Jun 12 Pluto Occultation

- Pluto system occulted 15.5 mag star, P384.2
- Shadow velocity = 27 km/sec
- AAT 3.9 m, observed by R. French & K. Shoemaker.

Observation Details

- Data taken at 10 Hz for 2.5 hours.
  - 64 x 64 pixels, binned on-chip
  - Low readnoise CCD
- 85,800 frames total.
- SNR ~ 300 per scale height
- Until now, only the central Pluto occultation in AAT dataset had been analyzed (e.g., E. Young *et al* 2008)
- High frame rate, long time base, and low noise data make this a great dataset for searching for rings!

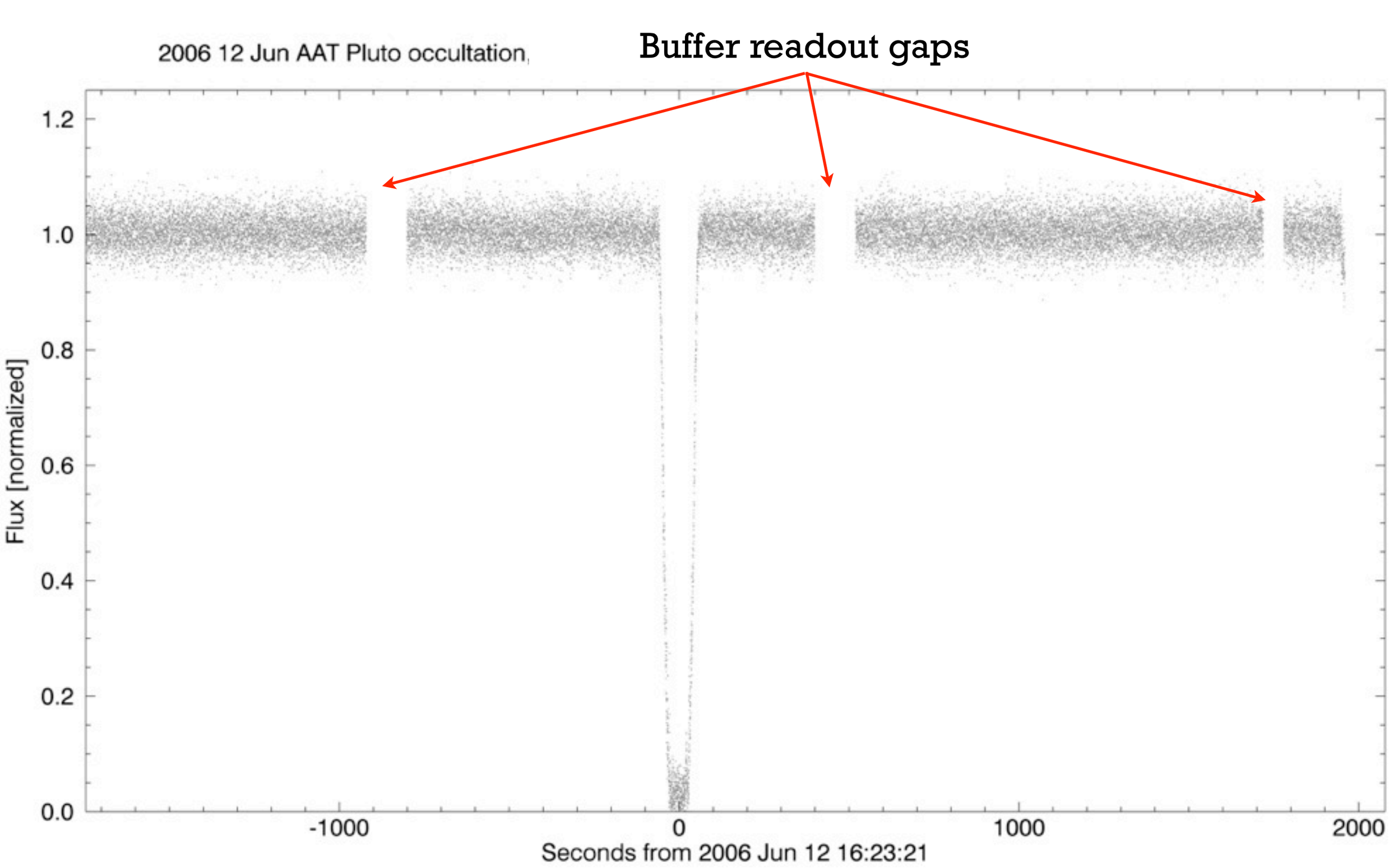




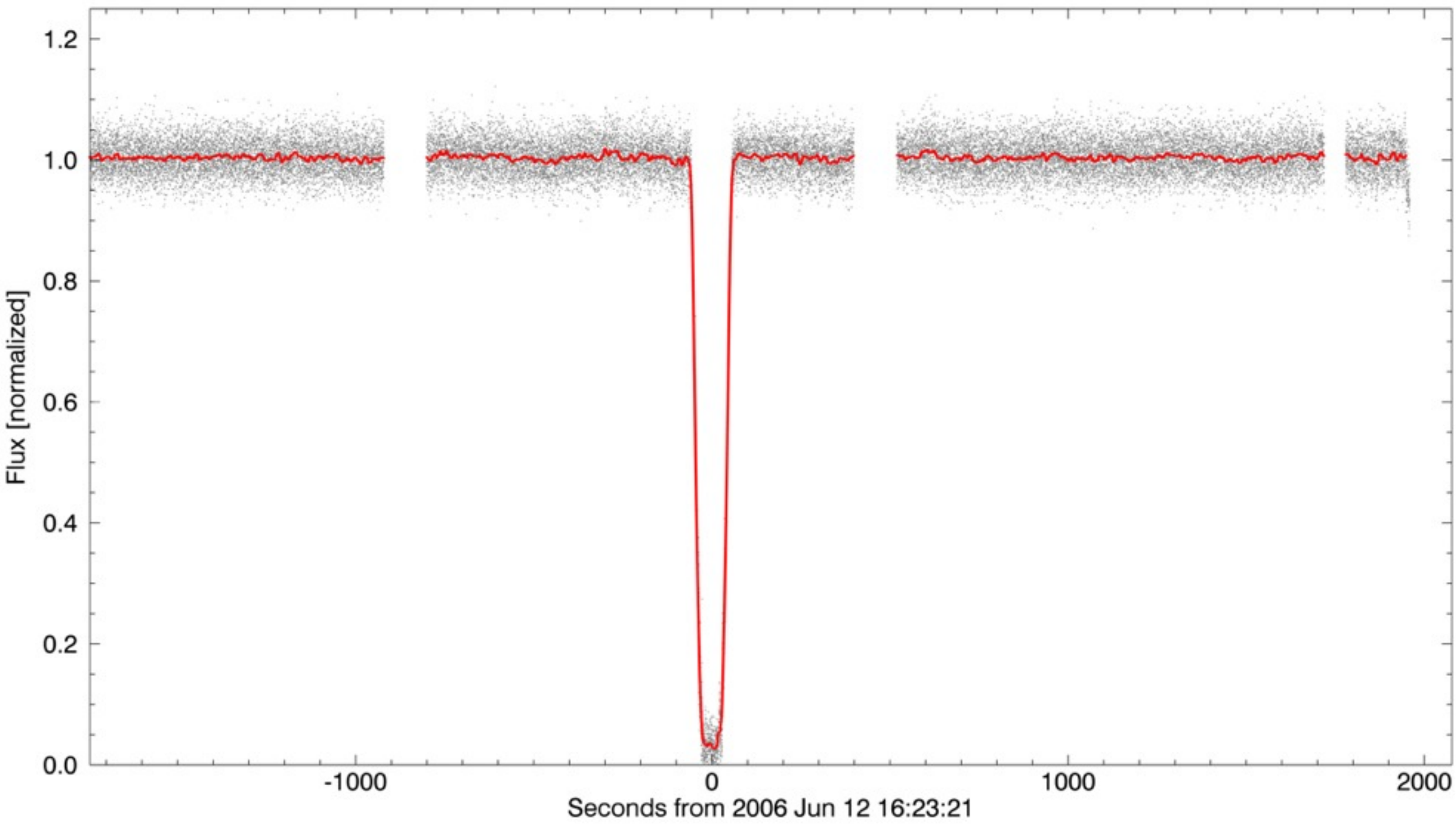
ie made with GeoViz, http://soc.boulder.swri.edu/nhgv

Analysis Pipeline

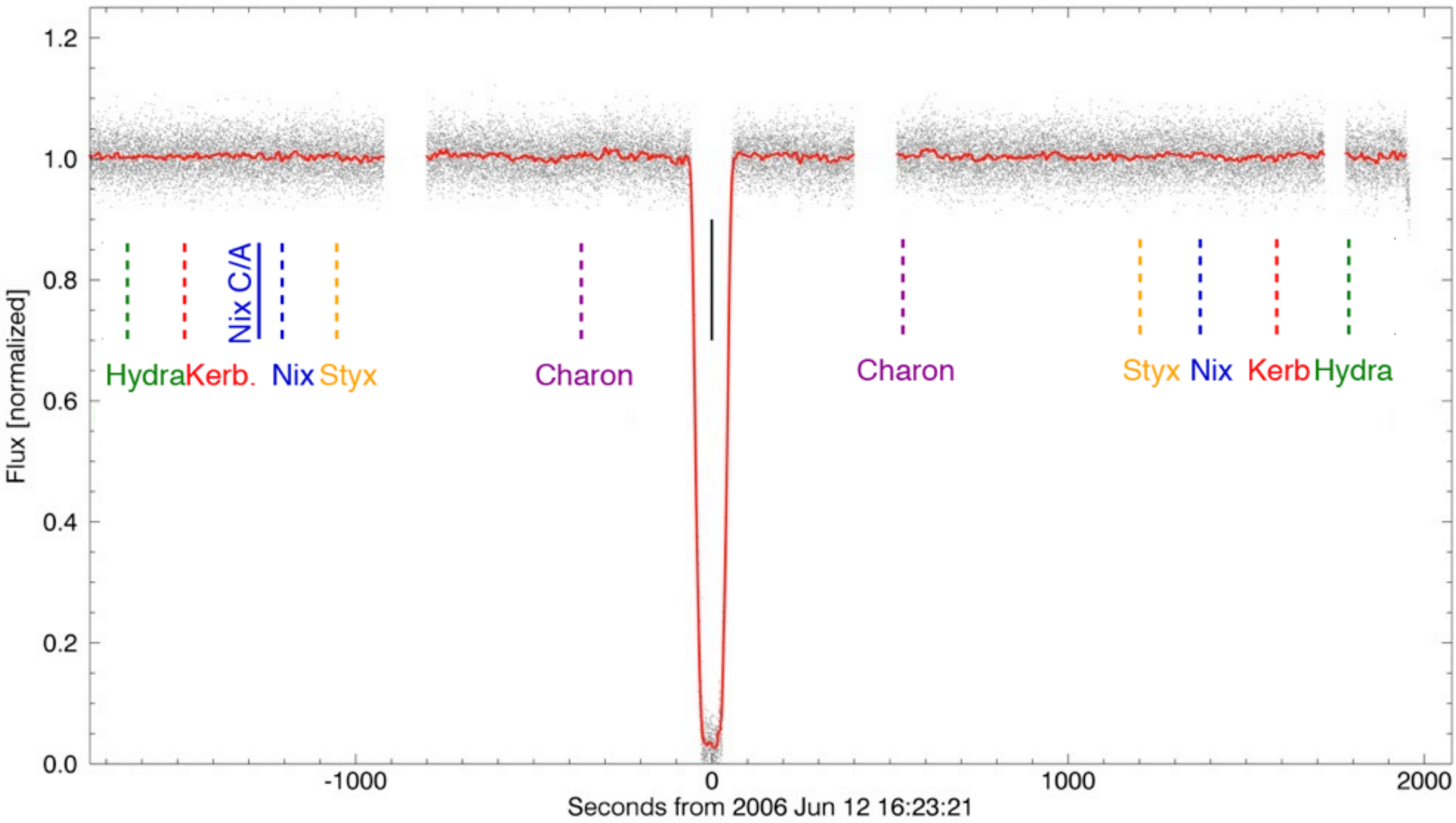
- Aperture photometry on all 85,800 individual frames
- Adjusted for frame-to-frame variation using flux from two reference stars in field
- High-pass filter used to flatten final curve, remove slow sky variations
- Used SPICE and post-occultation corrections to determine orbit crossing times.



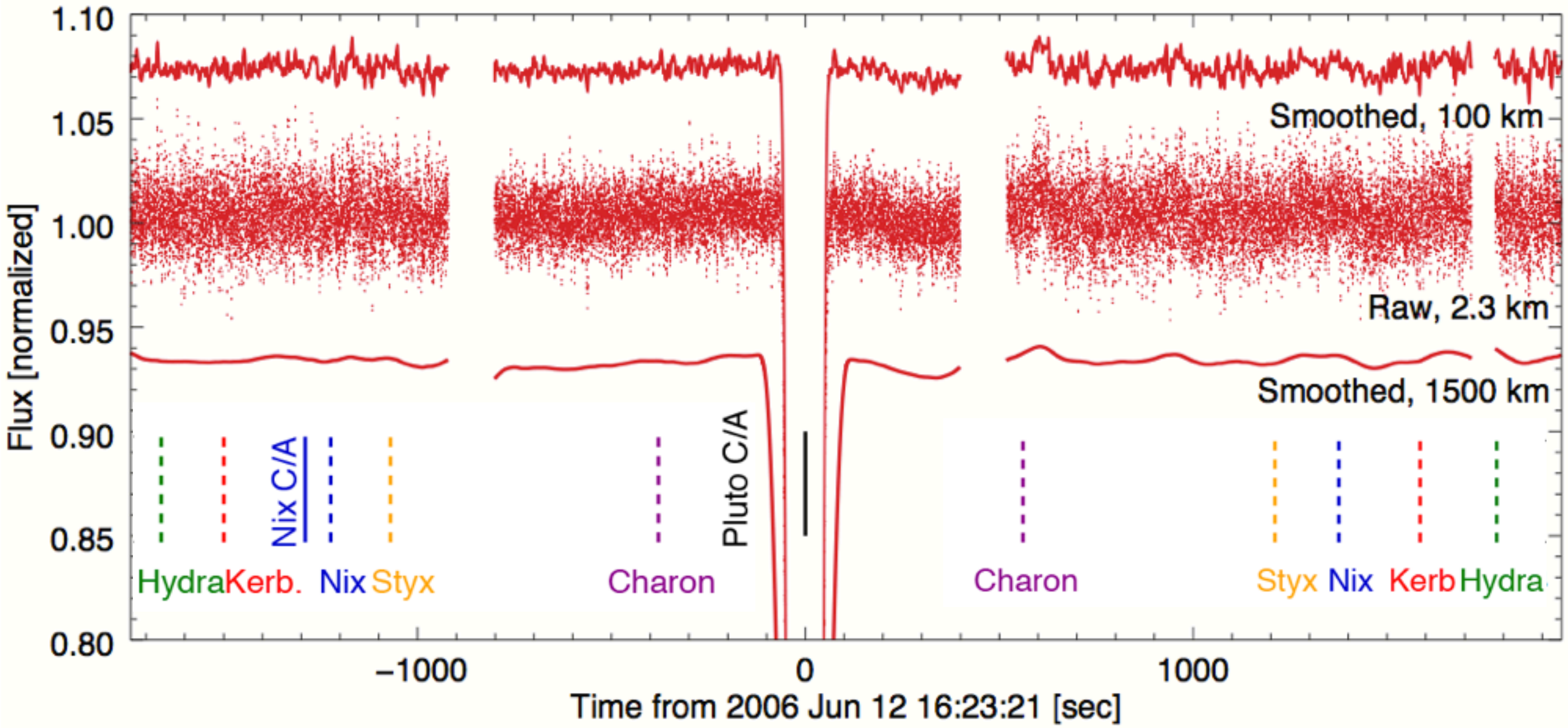
Central hour of data



Central hour of data



Smoothed, 500 km



No evidence for any rings or debris at any binning size

Optical Depth Limits

Throop et al 2013 (this talk)

- Upper limit on 2 km rings: $\tau < 0.07$ (all 4 σ)
- Upper limit on 50 km rings: $\tau < 0.015$
- Upper limit on 1500 km rings: $\tau < 0.007$
- Individual bodies: None occulted with r > 200 m

Steffl & Stern 2007 (HST)

- Upper limit on 1500 km rings: $\tau < 10^{-5}$ -10^{-6}

Showalter 2012 (HST)

- Upper limit on 1500 km rings: $\tau < 3 \times 10^{-7}$

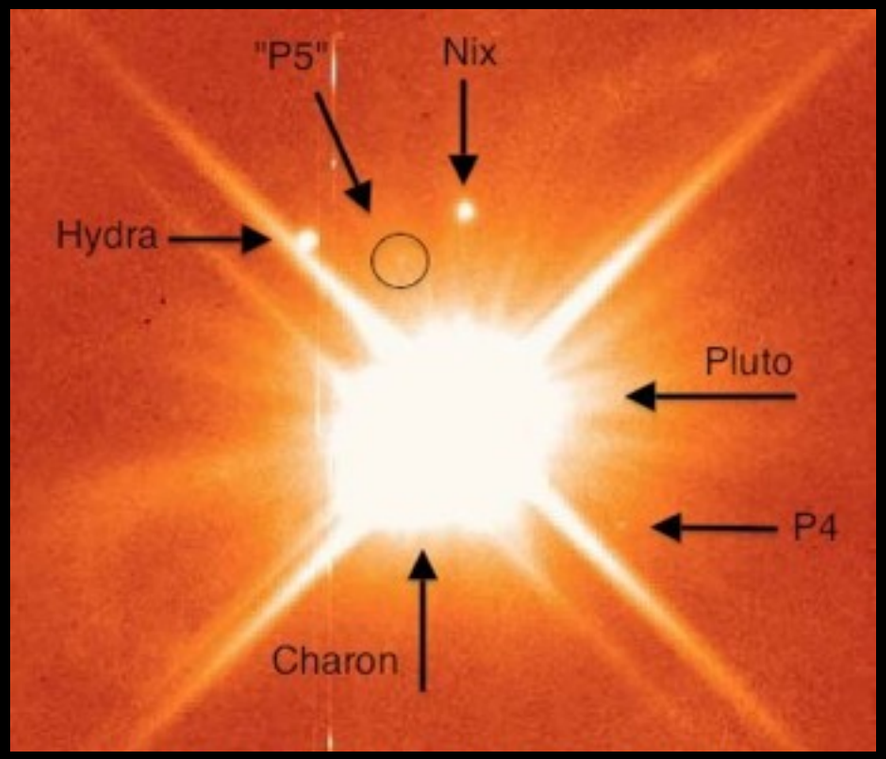
Pasachoff & McKay 2006 (AAT)

- $\tau < 0.1$

Boissel *et al* 2013 (2006-2007 occultations, Chile)

- Individual bodies: None occulted with r > 250 m

New Horizons Ring Hazard



All the new satellites are great, but satellites systems are often accompanied by rings, so…

New Horizons spacecraft can be disabled by direct hits from dust grains of critical mass $m_c = 10^{-4}$ g (~0.2 mm)

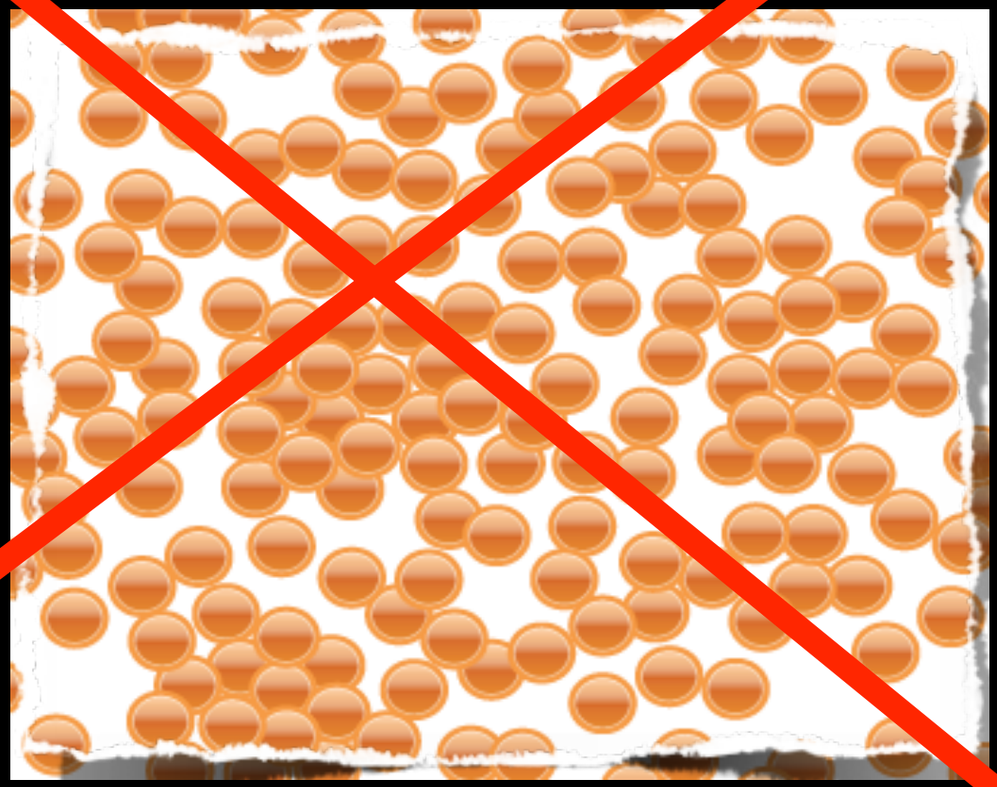
Mission requirement: N < 0.1 impacts of size m_c during encounter

Mission "desirement": N < 0.01 impacts of size m_c during encounter

November 2011

New Horizons Ring Hazard

- Most conservative case:
  - We assume that 100% of the unseen ring mass (as constrained by the ring searches) is in grains of size r_c



- Conclusion: N ~ 500 hits during encounter

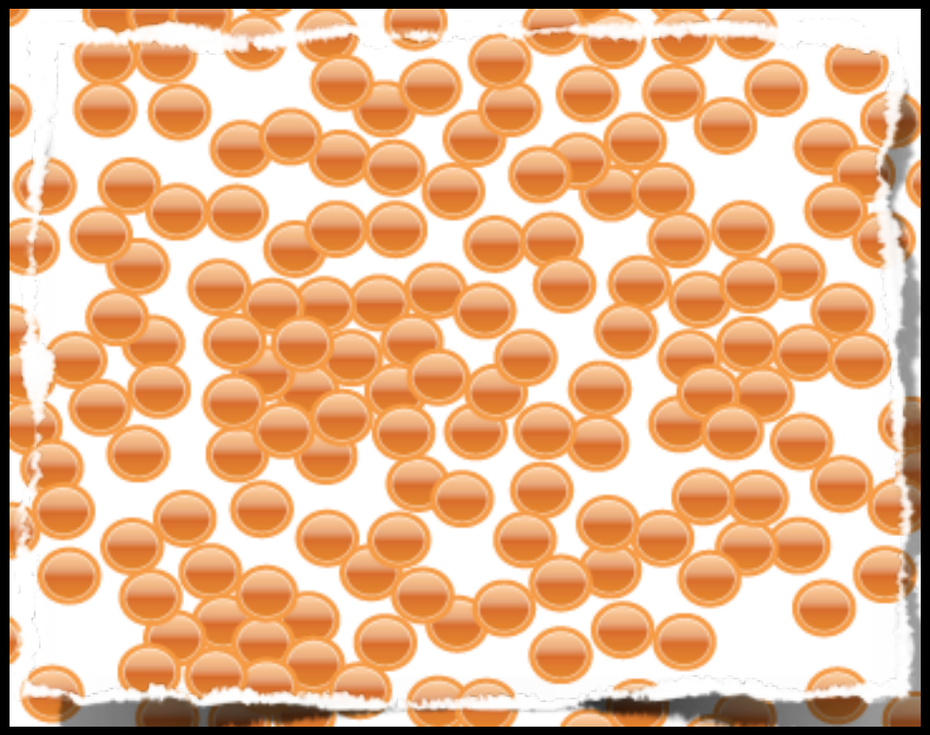
Not a Useful Result!!!

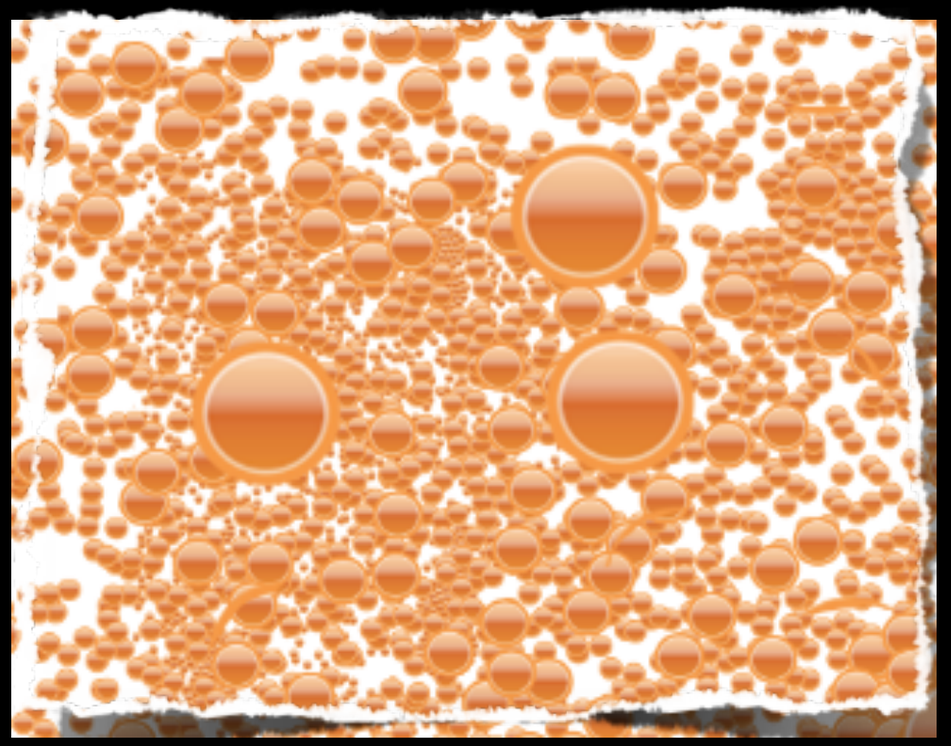
New Horizons Ring Hazard

We know that particles in real rings are not single-sized, but have a size distribution, usually a power law.

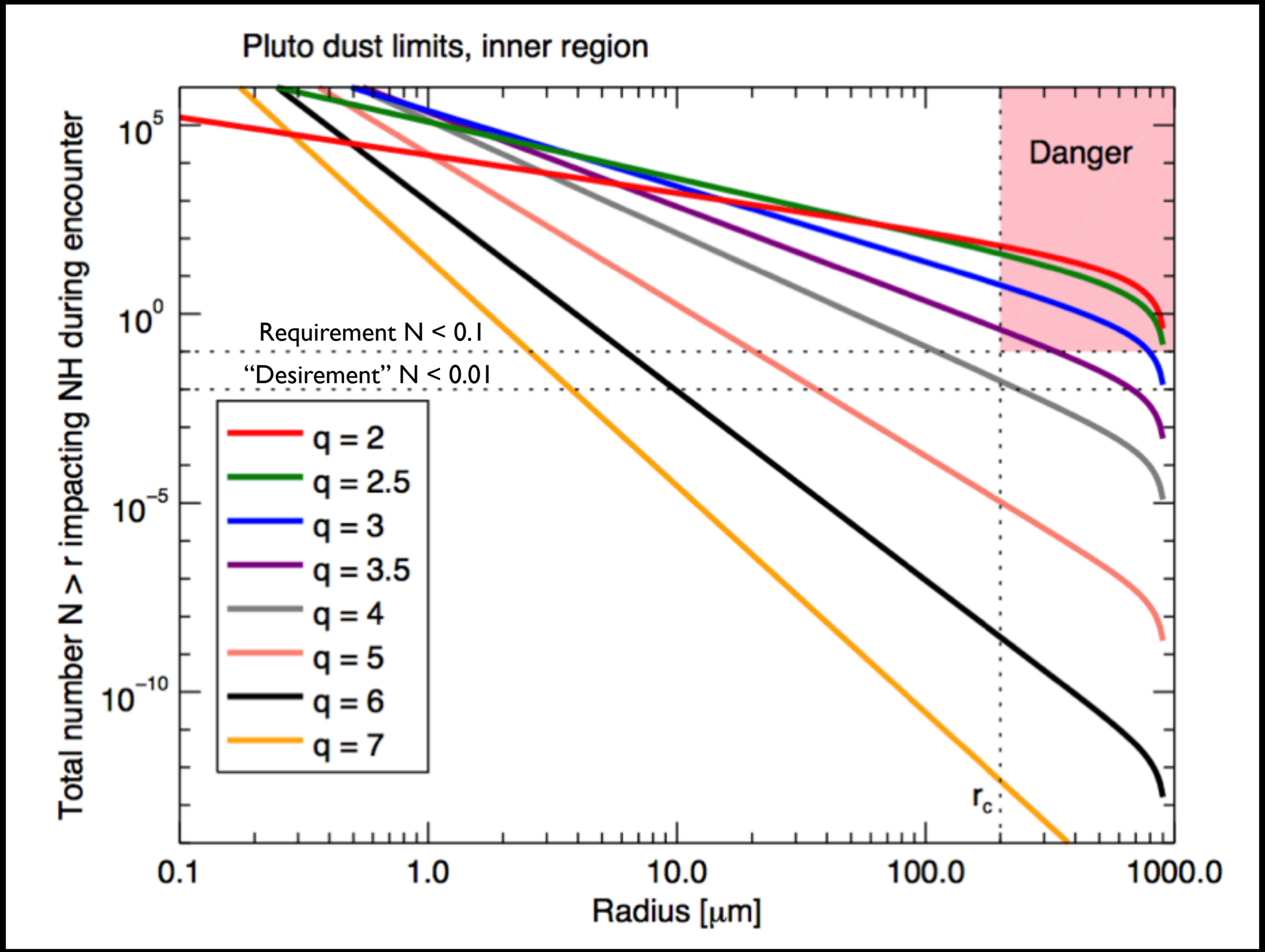
So, we consider a range of power laws:

$$n(r) \sim r^{-q} \qquad q = \{2, 2.5, \ldots 6.5, 7\}$$

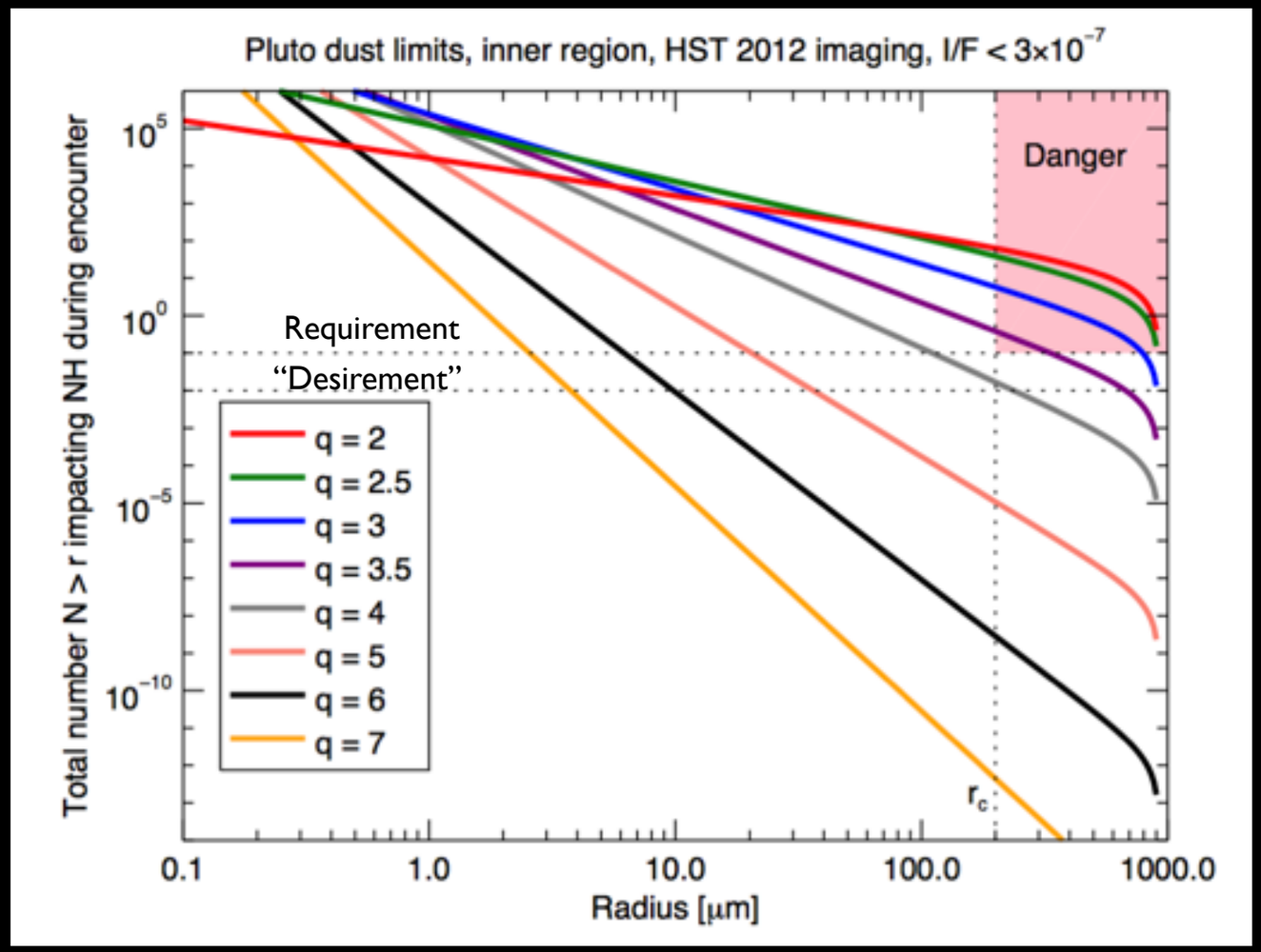




New Horizons Ring Hazard



New Horizons Ring Hazard

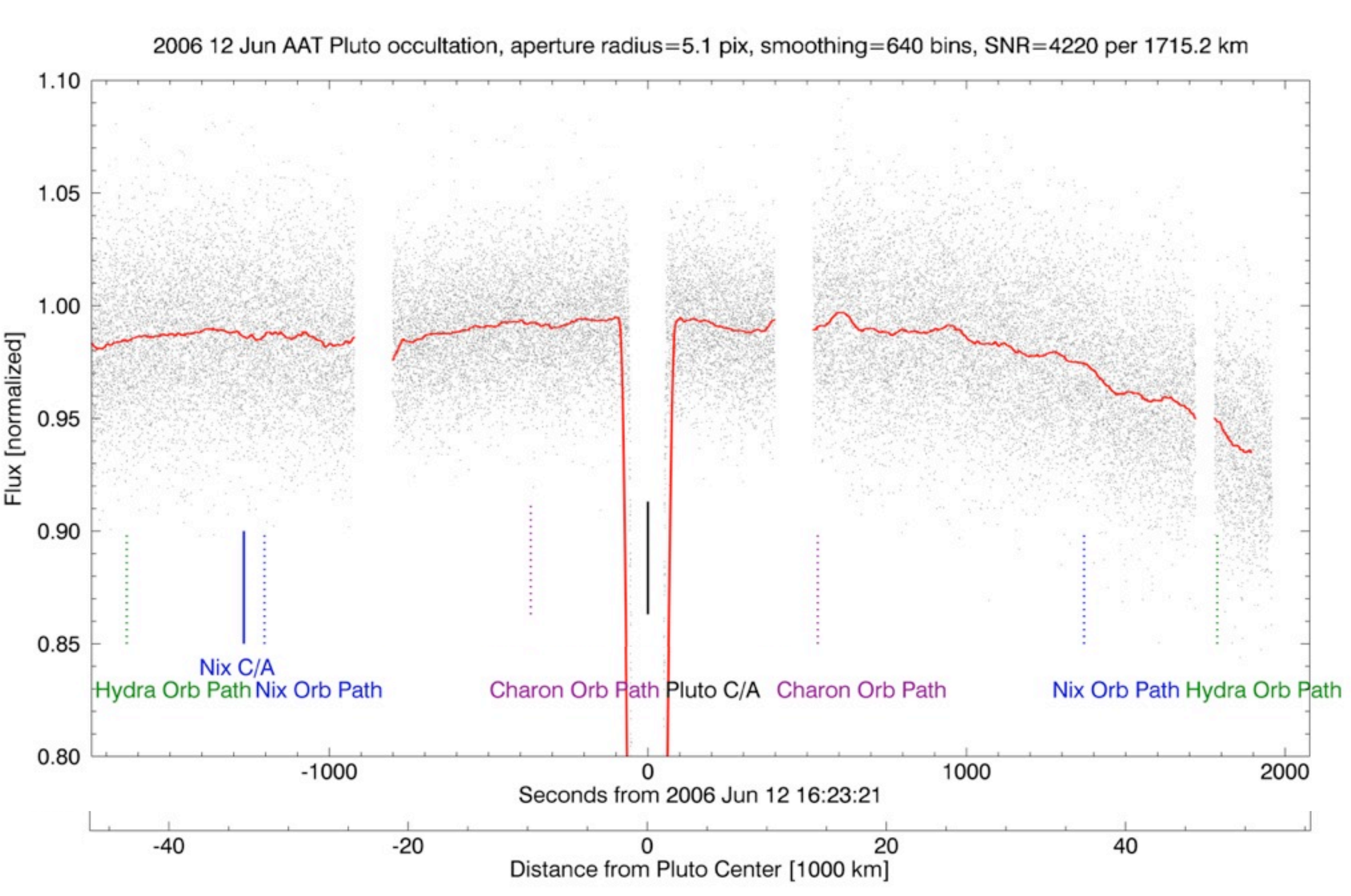


- Rings observations reduced impact risk, but could not put us entirely out of danger zone as of 2012.
- Subsequent s/c damage susceptibility testing has increased r_c from 0.25 mm to 0.5 mm, decreasing danger zone
- Subsequent dynamical modeling has also put much tighter constraints on N (Pires dos Santos, Kaufmann, etc.)

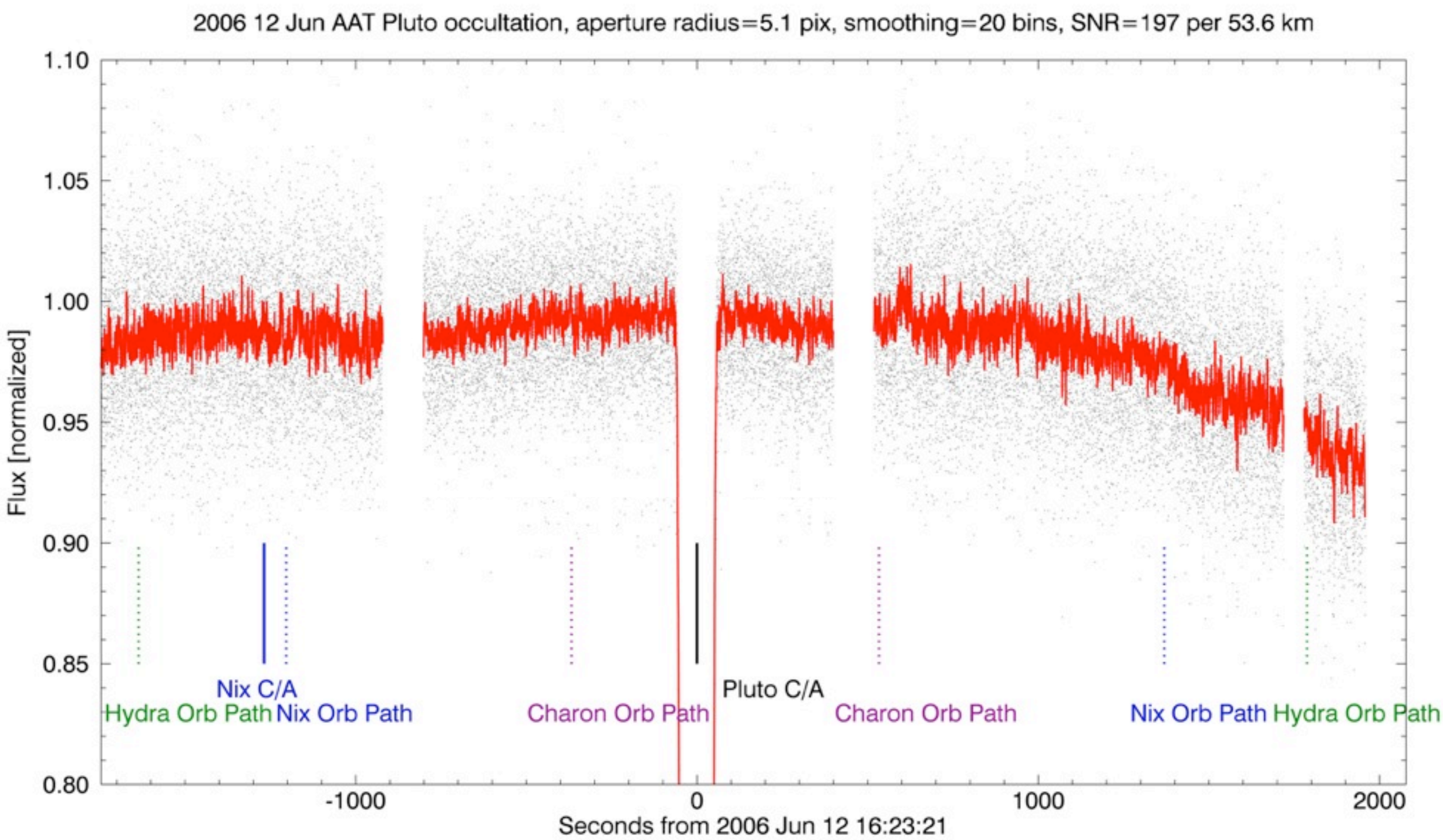
NH's high-phase rings observations will search 10^4x deeper than current observational limits!

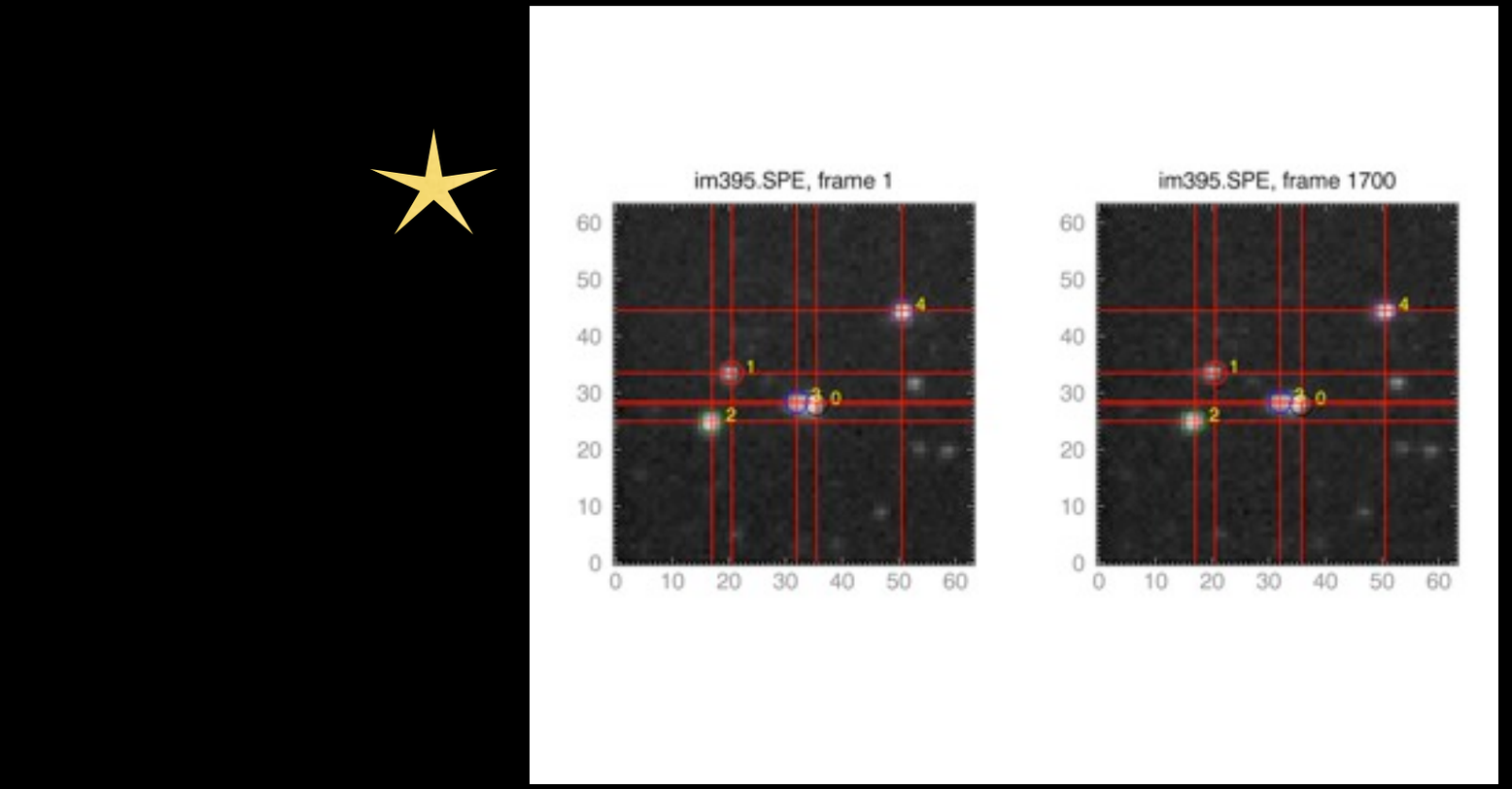
- From our observations and our knowledge of rings, we can't rule out n_crit < ~ 10 hits
- n_crit has been reduced from this value substantially by dynamical modeling. Grains in the Pluto-Charon region have short lifetimes due to unstable orbits.
- n_crit

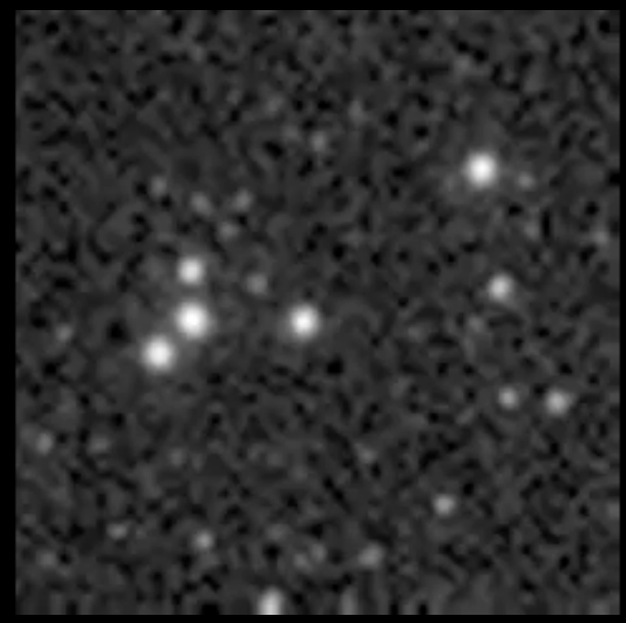
Search for broad rings: 1500 km



Searching for narrow rings: 50 km OLD




im395.SPE, frame 1
im395.SPE, frame 1700
0
10
20
30
40
50
60
1
2
3
0
4



2006 JUN 12 14:21:00 .. 2006 JUN 12 16:53:0

−15.691

−15.692

−15.693

−15.694

Dec [Deg]

Pluto start

Plu

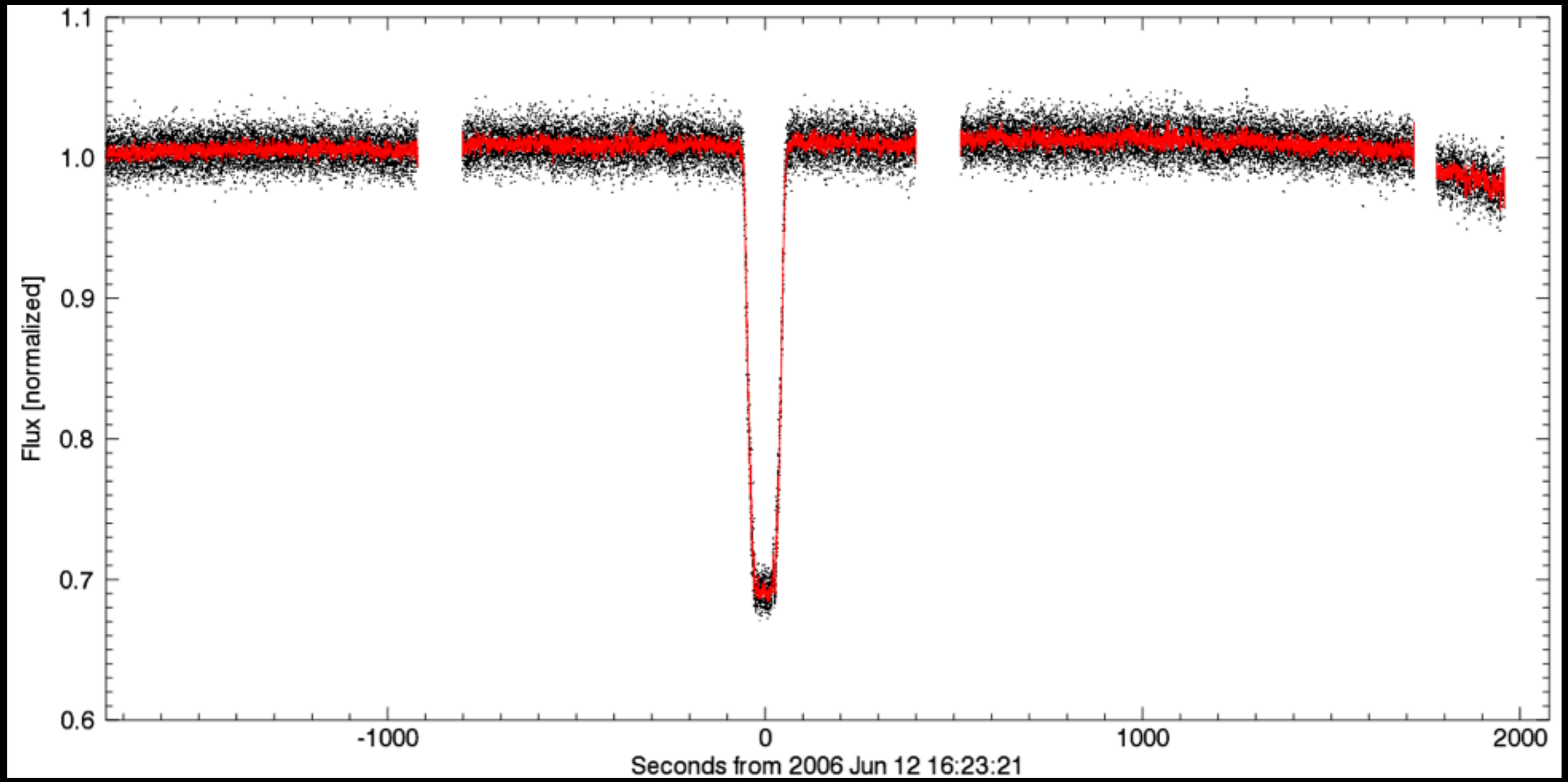
2006 Pluto Occultation

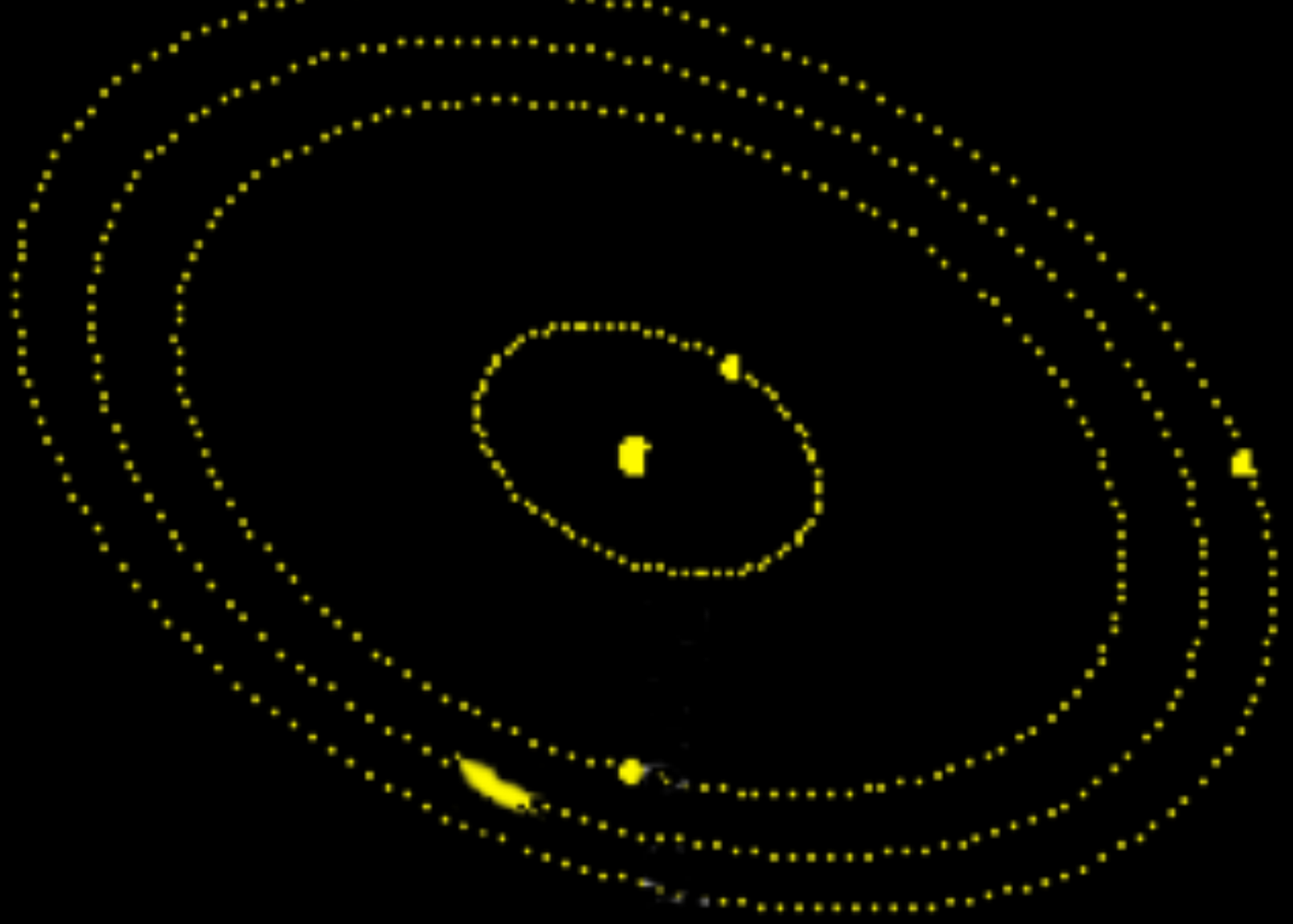
- Occultation star: P384.2, R=14.8.
- Motion of Pluto against stars: 27 km/sec
- Star P384.2 was observed for ~3 hours total surrounding occultation.
- Occultation was observed by 10 groups in southern hemisphere. AAT 3.9m was the largest aperture and highest-quality data.

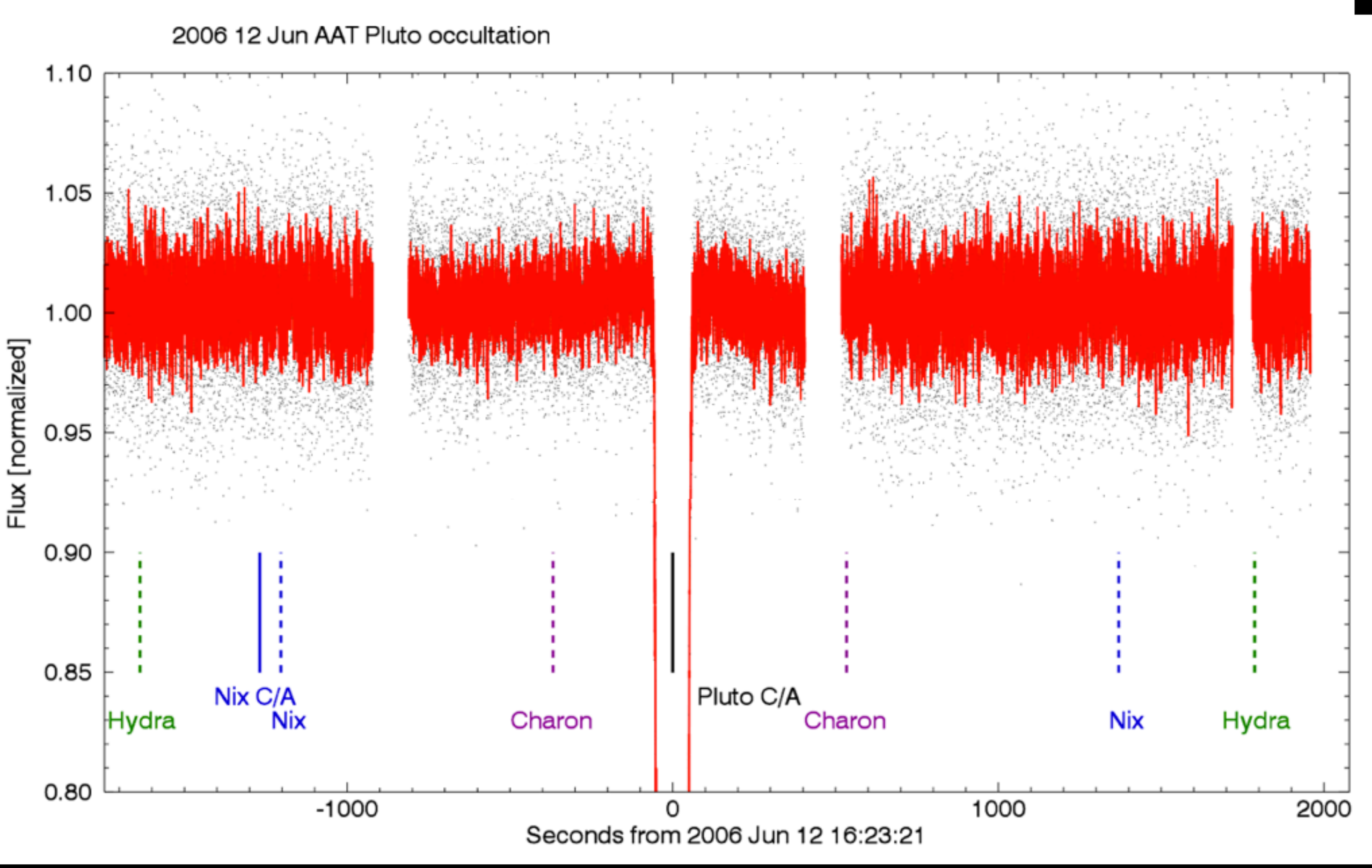
Occultations

- High resolution.
  - Fresnel limit = sqrt(30 au / 500 nm) = 2 km.
    - We sample at 20 km
- Assuming large grains, tau = 2 x opacity
- Equivalent Width
- Motivated by discovery of Nix, Hydra, and P4 in Pluto system.

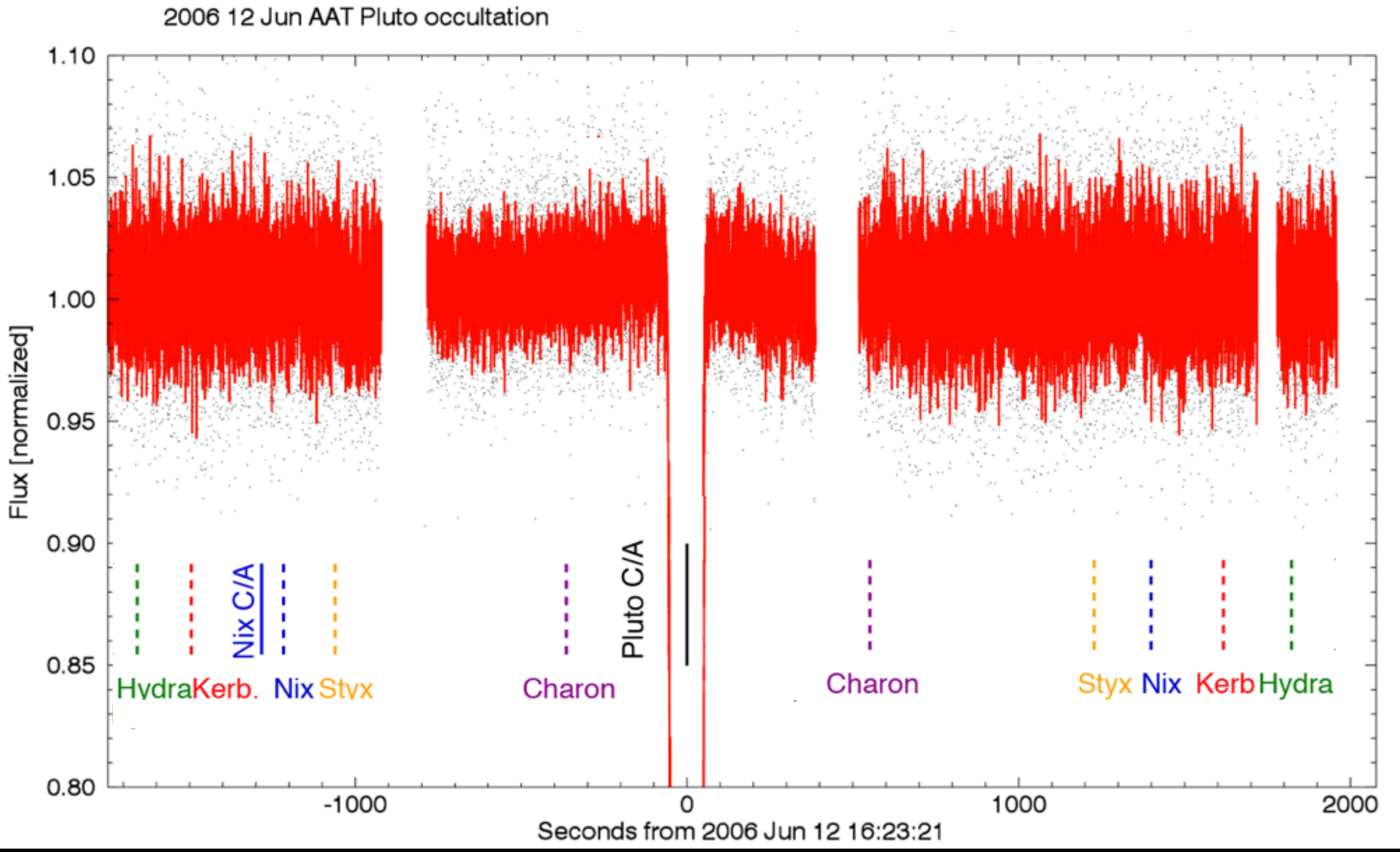
Central 90 Minutes of Occultation



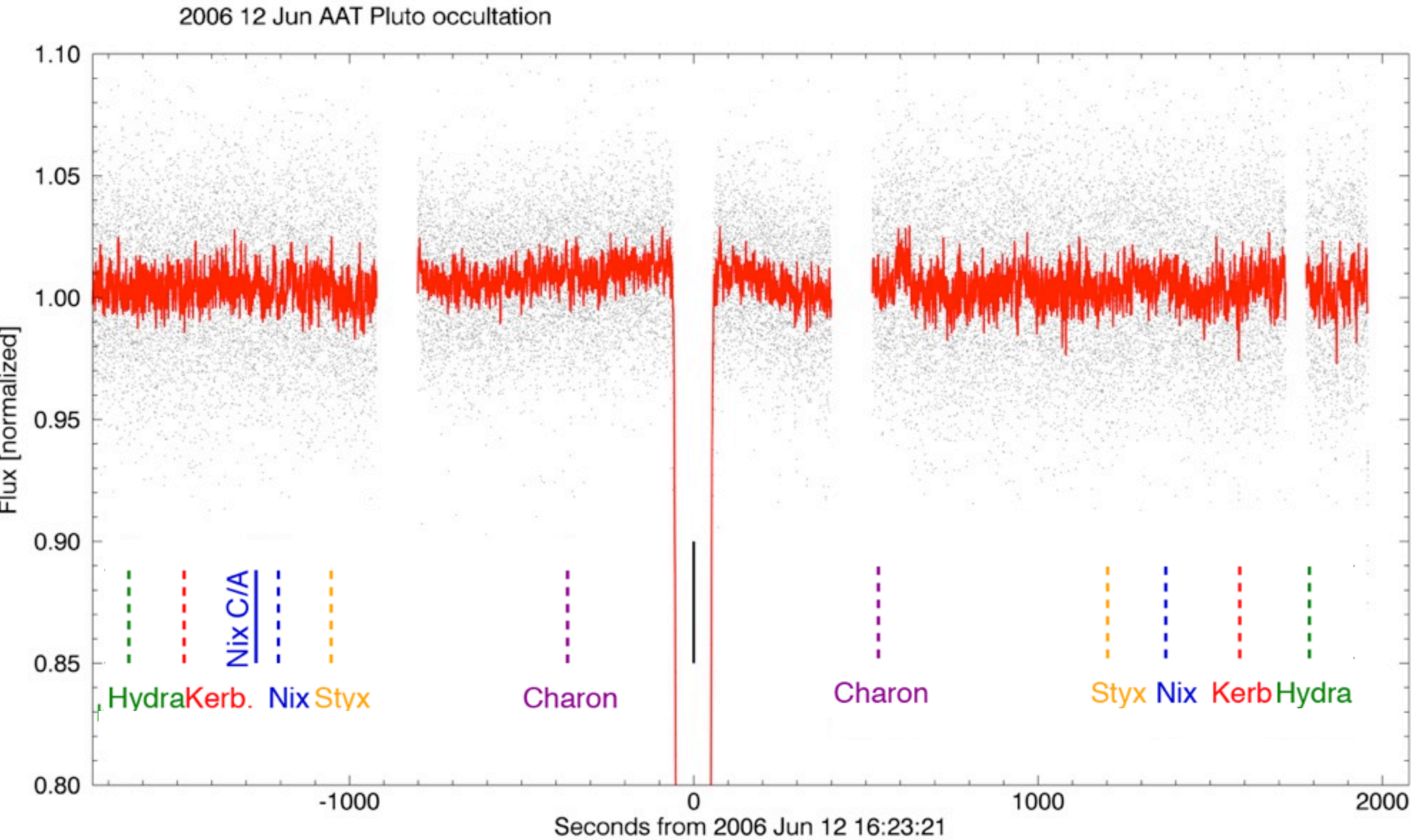




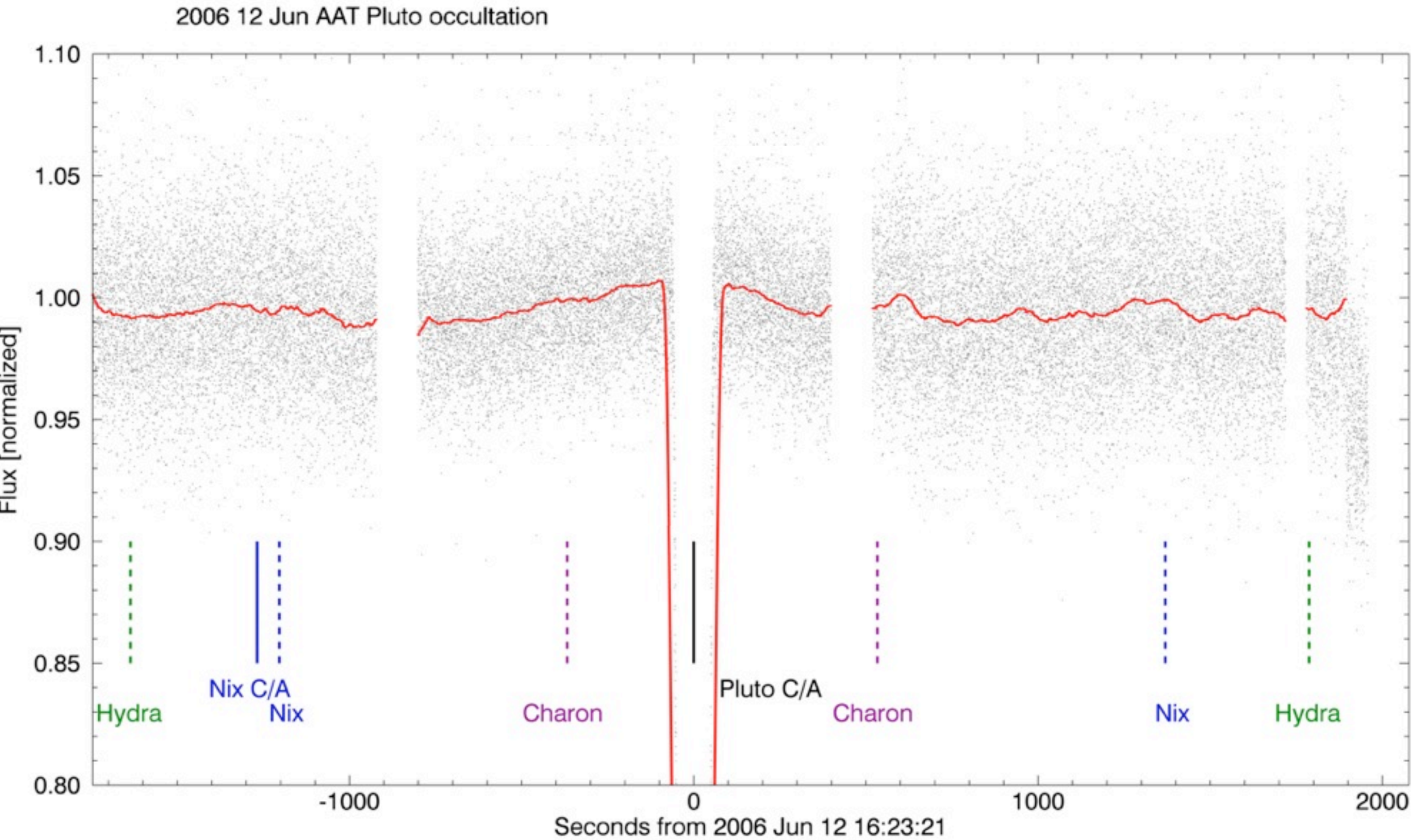
Smoothed, 7 km



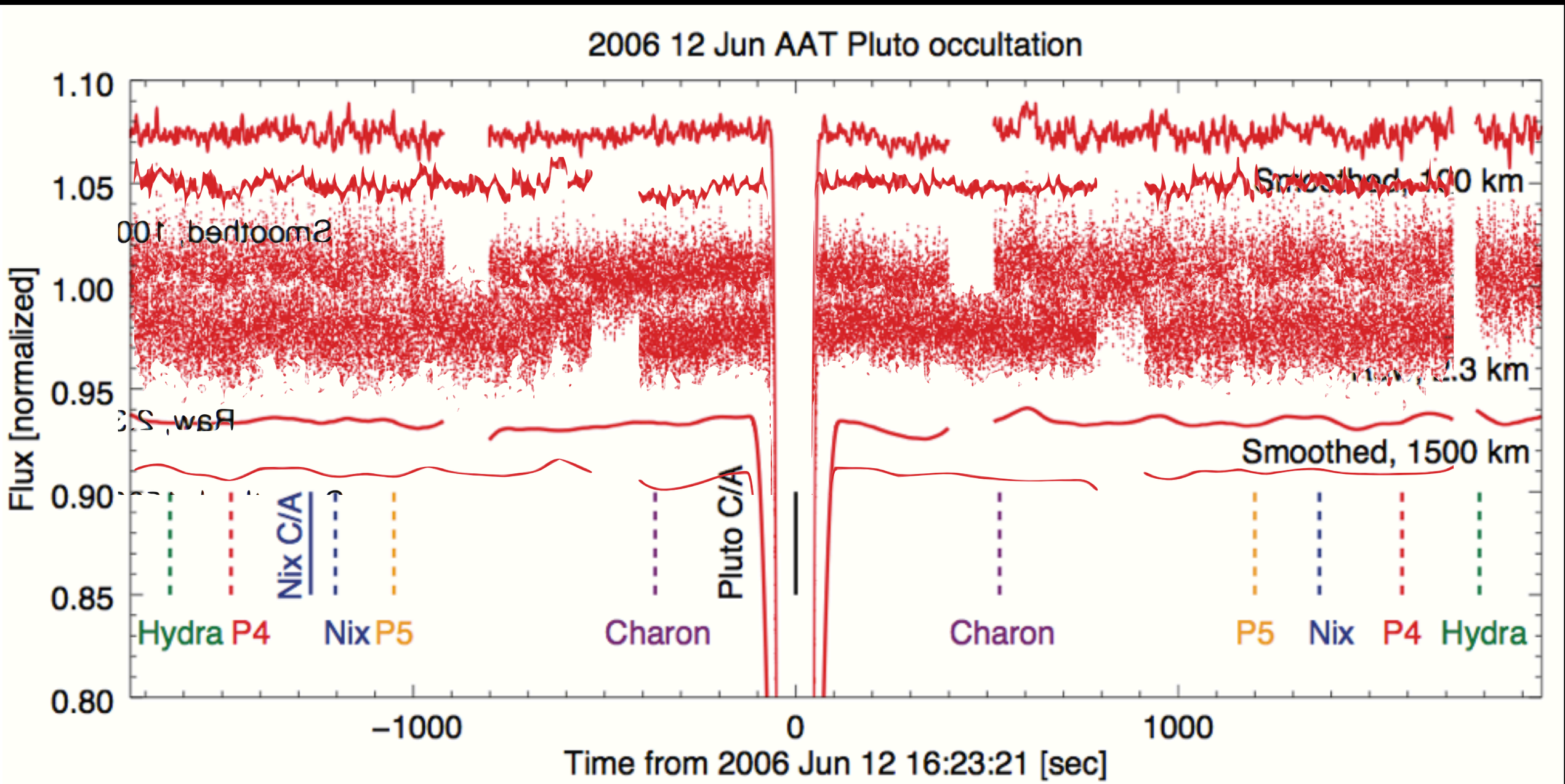
Smoothed, 5 km

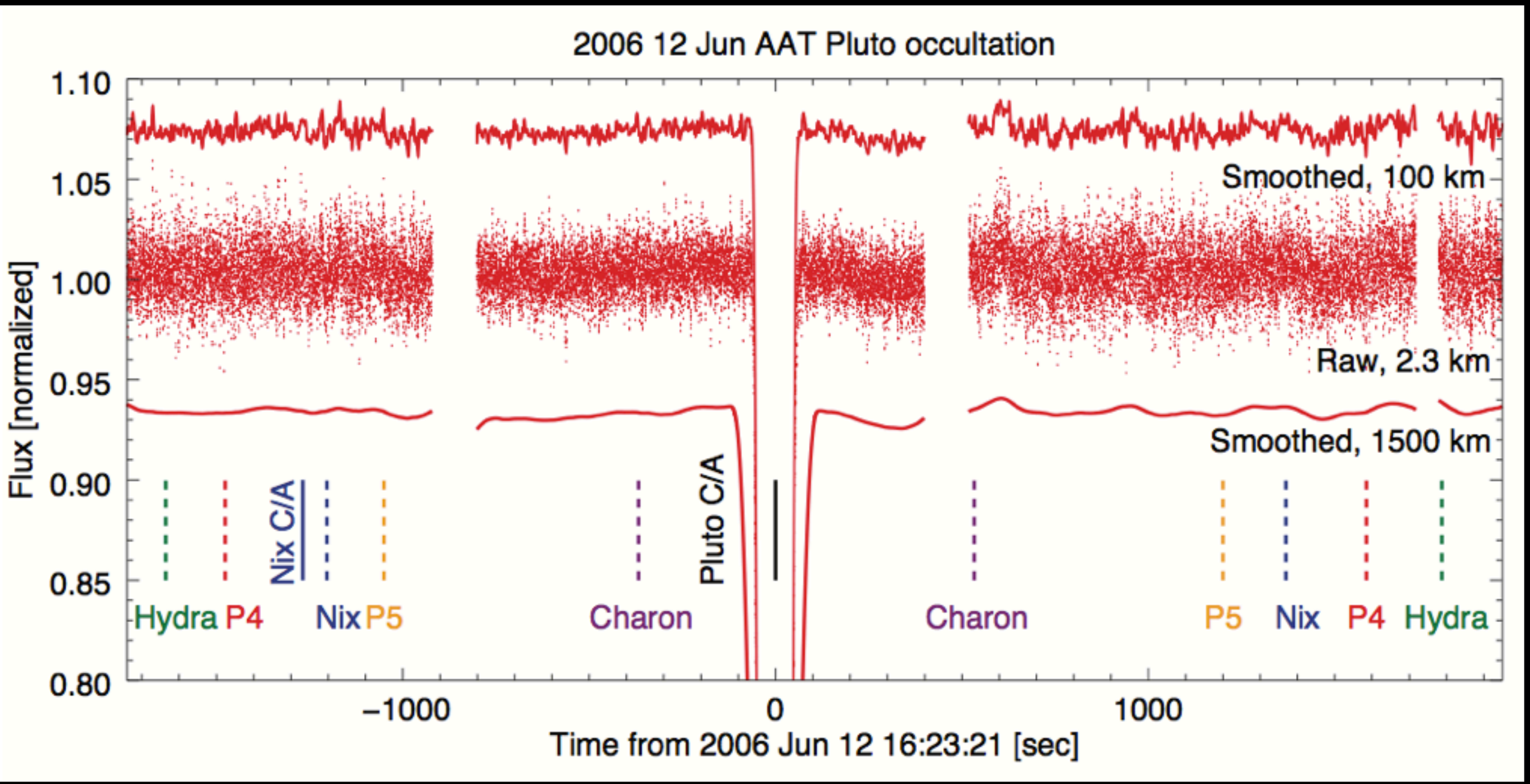


Smoothed, 50 km



Smoothed, 1500 km


2006 12 Jun AAT Pluto occultation
1.10
1.05
1.00
0.95
0.90
0.85
0.80
Flux [normalized]
Smoothed, 100 km
Smoothed, 1500 km
Nix C/A
Pluto C/A
Hydra
P4
Nix
P5
Charon
Charon
P5
Nix
P4
Hydra
−1000
0
1000
Time from 2006 Jun 12 16:23:21 [sec]


2006 12 Jun AAT Pluto occultation
1.10
1.05
1.00
0.95
0.90
0.85
0.80
Flux [normalized]
Smoothed, 100 km
Raw, 2.3 km
Smoothed, 1500 km
Nix C/A
Pluto C/A
Hydra
P4
Nix
P5
Charon
Charon
P5
Nix
P4
Hydra
−1000
0
1000
Time from 2006 Jun 12 16:23:21 [sec]