The Detection of a sub-km sized Kuiper Belt object by stellar occultations using HST

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Science with the Hubble Space Telescope III

FGS Collaboration:

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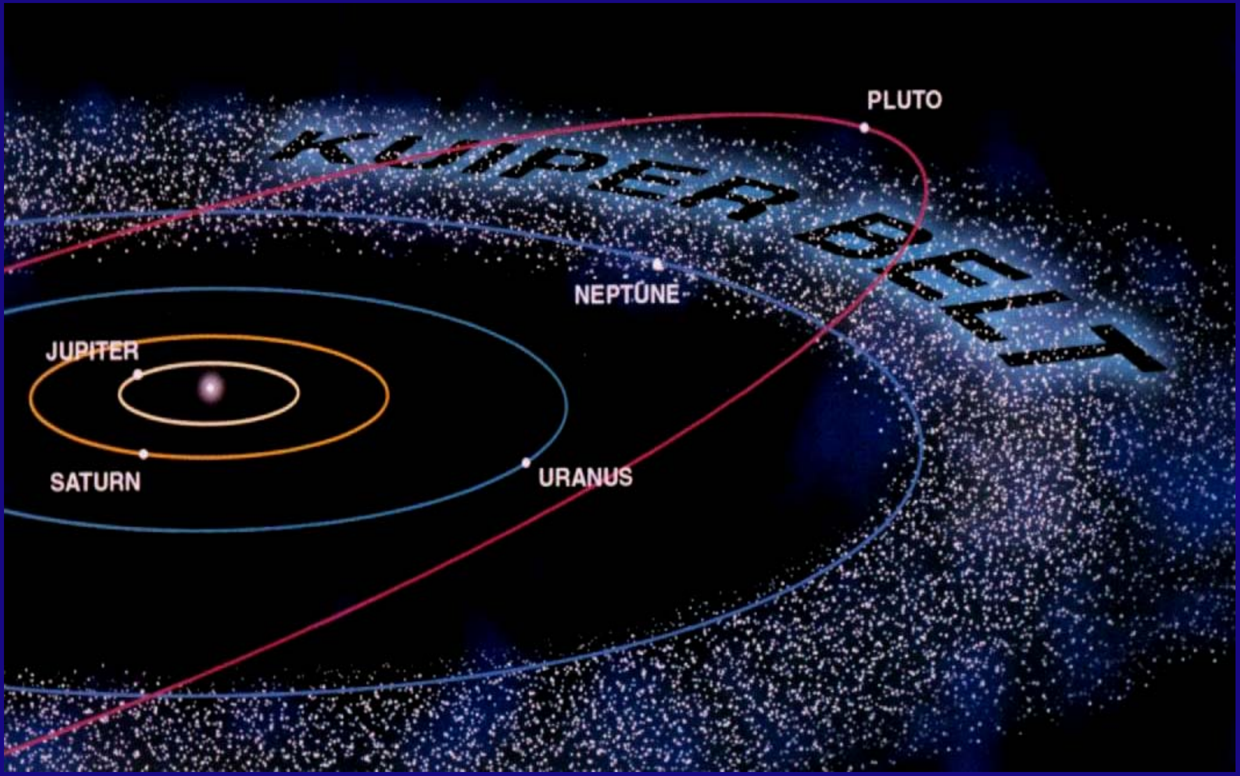
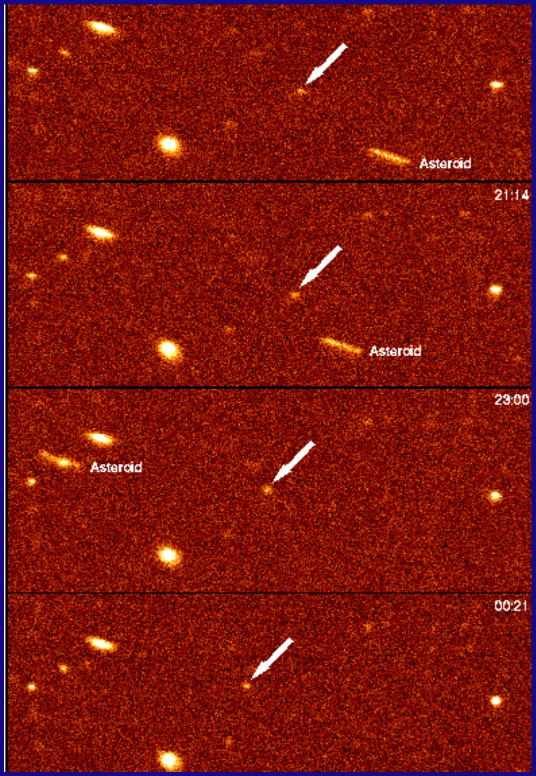
Kuiper Belt

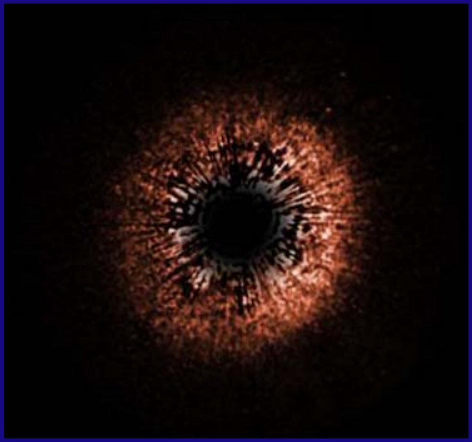
- ~40 AU from the Sun
- Source of the short period comets
- ~1000 detected objects
- Different dynamical classes (classical, scattered, resonant)
- Size estimates based on brightness
  - Typical radius R=100km





Debris Disks

- Kupier Belt solar system debris disk
- Smallest bodies must be constantly replenished
- Link between larger Kuiper belt objects and dust producing debris disk

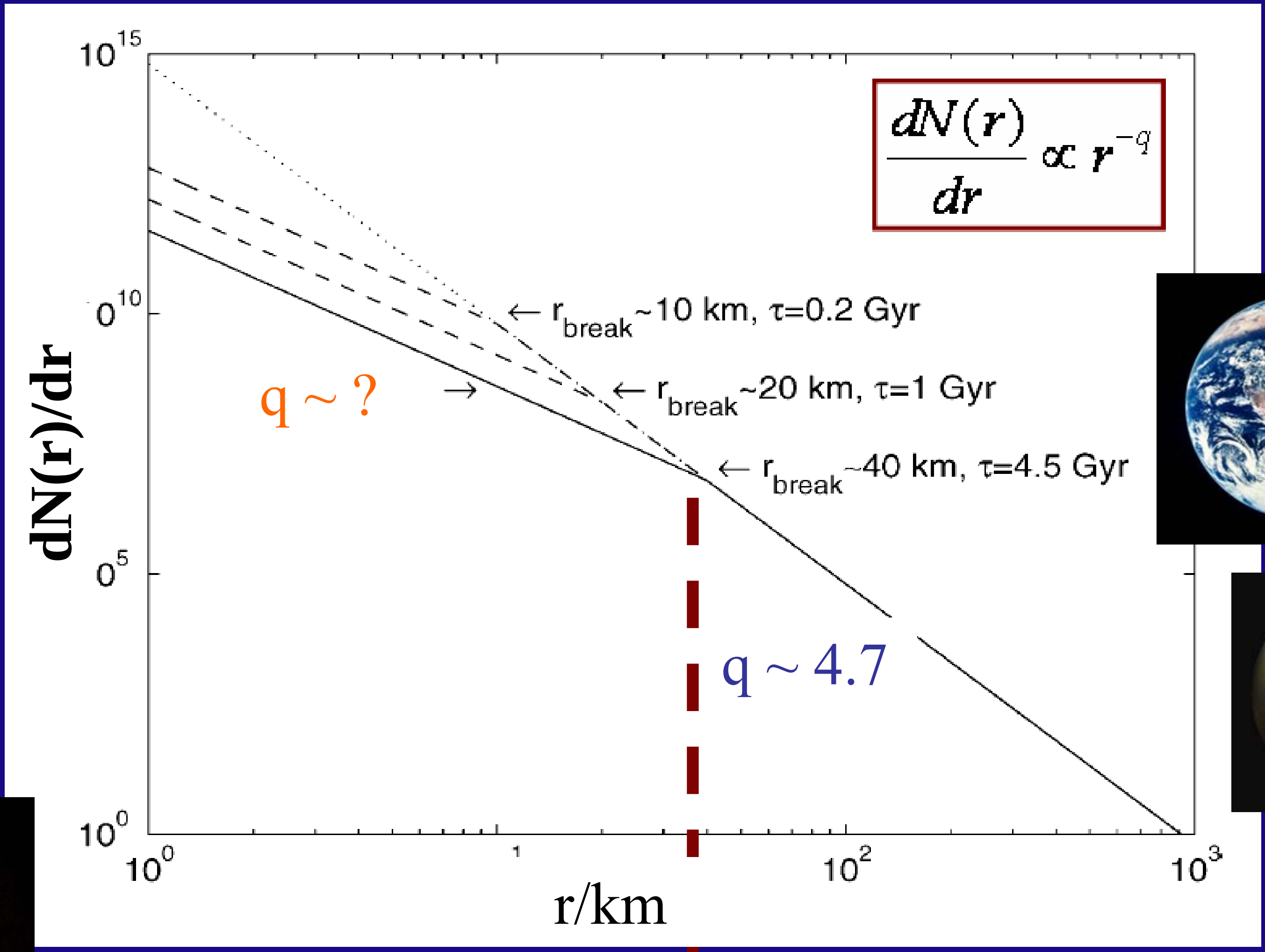


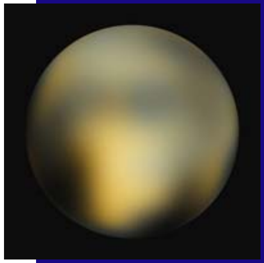
Comets

- Kuiper Belt source of the short period comets
- Link between KBOs – Centaurs – Jupiter Family Comets:

  - Supply rate
  - Size distribution

The Kuiper Belt Size Distribution





Evolved

Primordial

Power law index below the break, q_2

$q_2 \sim 4.7$ → no break → no collisional evolution

(Fuentes et al. 2008, Fraser et al.2008)

$q_2 \sim 3.5$ → break → collisional evolution, Dohnanyi spectrum, KBOs held together by material strength

(Dohnanyi 1969)

$q_2 \sim 3$ → break → collisional evolution, Rubble piles (i.e. lack significant material strength & held together predominantly by gravity)

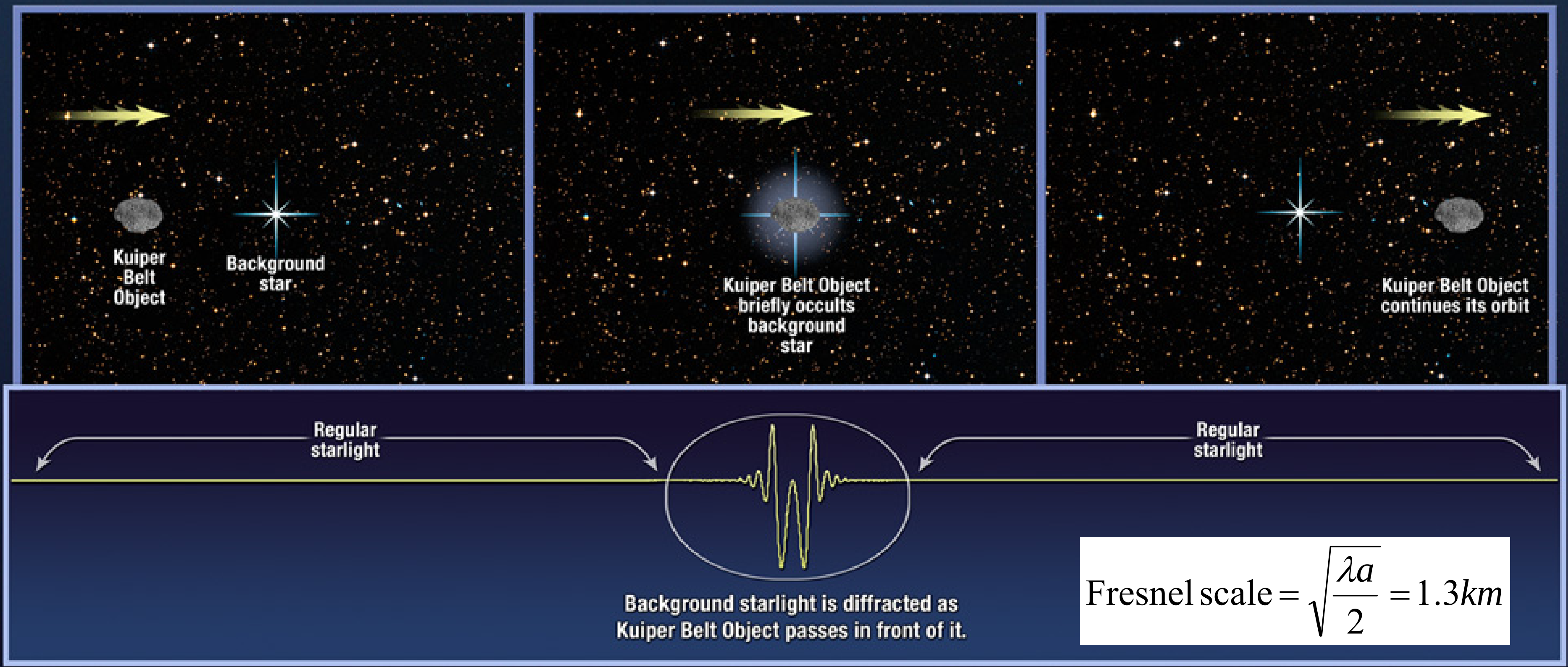
(Pan & Sari 2005)

Transiting Kuiper Belt Objects

KBOs < 10km too small to be detected directly

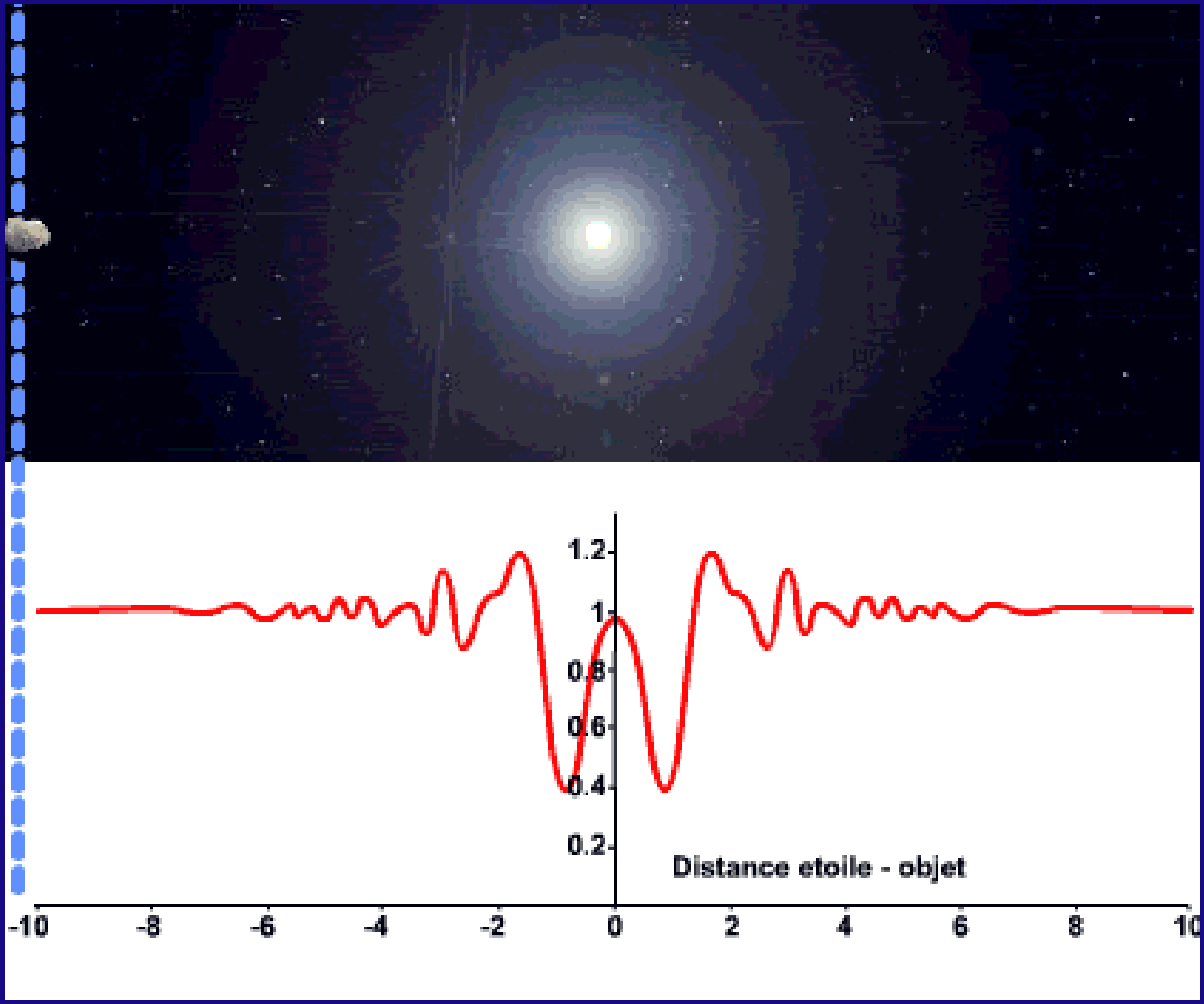
→ Observe indirectly using stellar occultations

(Dyson 1992, Axelrod et al. 1992)



$$\text{Fresnel scale} = \sqrt{\frac{\lambda a}{2}} = 1.3km$$

Transiting Kuiper Belt Objects



(Roques)

Kuiper Belt Size Distribution: Small Bodies

Event Duration ~ $3km/v_{earth}$ ~3km/30km/s ~ 0.1 s!

Occultation events produced by KBOs are rare & of short duration → Large number of star hours & high frequency

Ground Based Surveys:

- TAOS (Alcock et al. 2003, Lehner et al. 2008, Zhang et al. 2008,Bianco et al. 2010)
- Paris Team (Roques et al. 2003, 2006)
- UNSW/AA Program (Georgevits 2006)
- The Canadian Project (Bickerton et al. 2008)

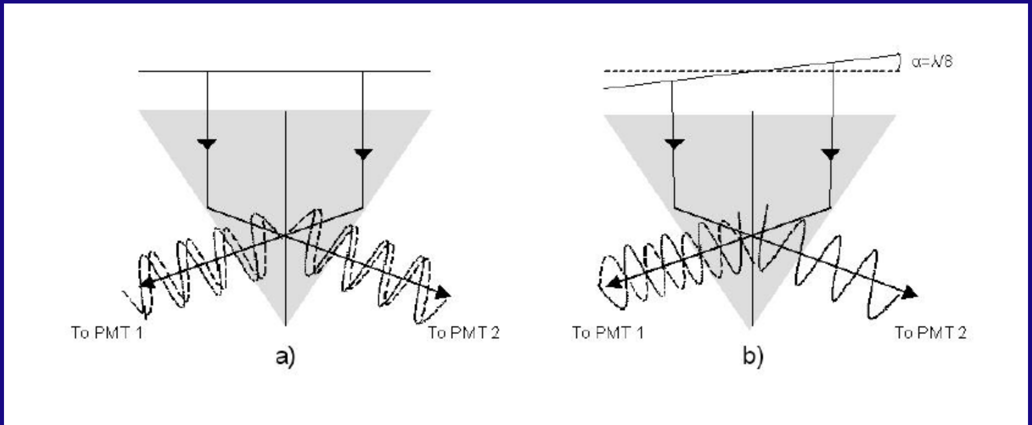
Space Based Surveys:

- RXTE (Chang et al. 2006, 2007)
- Our archival HST/FGS survey

Fine Guidance Sensors

- HST has 3 FGSs
- Wavelength range: 400nm -700nm
- Each FGS consists of 4 Photomultipliers
- Data recorded continuously at 40 Hz
- 5 x 5 arcsec aperture

- FGS observations are ideal because
  1) 40 Hz sampling frequency
  2) long baseline: 16 years
  3) space based
  4) good control sample



Dual axis white light shearing interferometer, consisting of a polarizing beam splitter followed by two Koester prisms

Our Expectations

- ~ 40,000 Star hours of observations with $i < 20$ deg
- Typical size that can be detected $r \sim 250$m

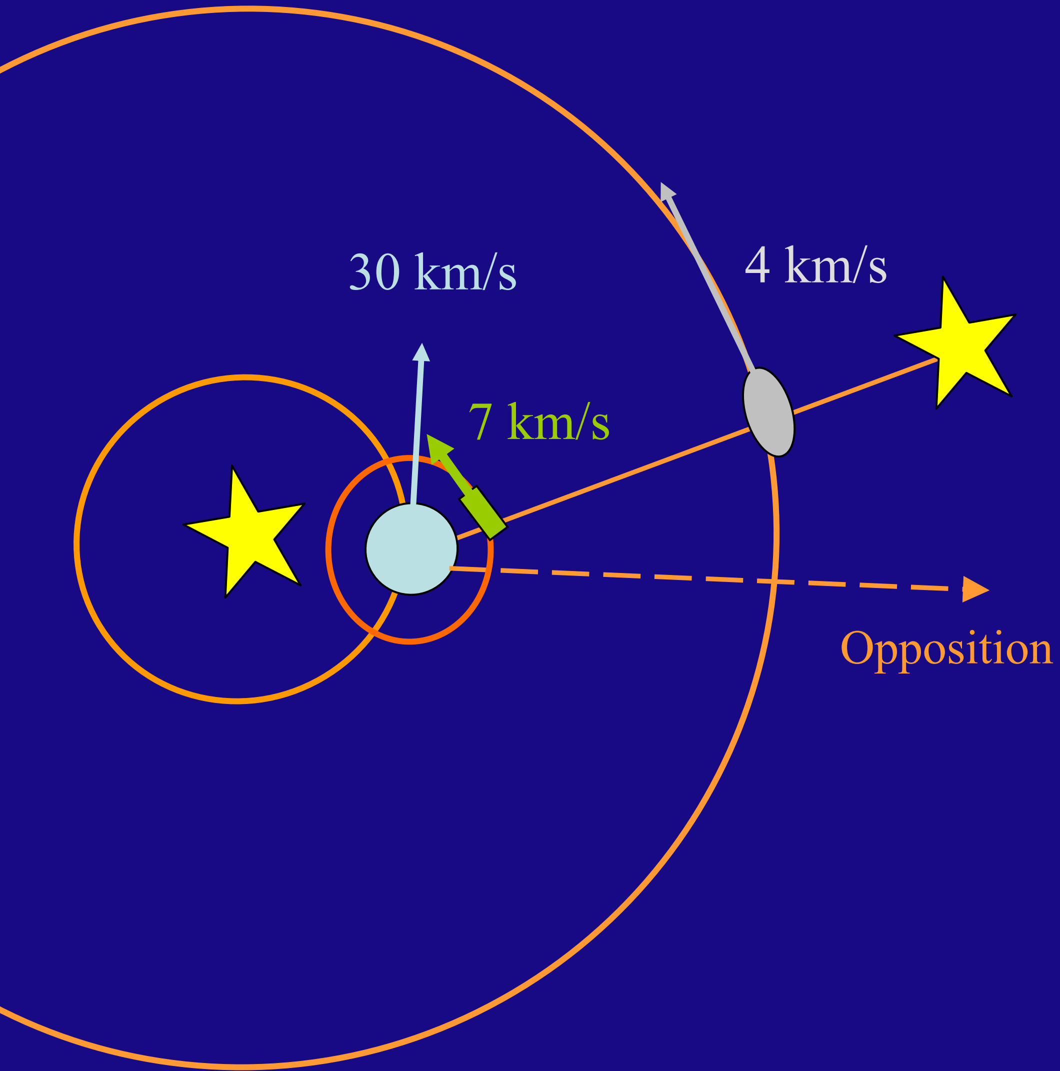
→ Expected number of events = $n_{KBO} v_{rel}\, 2R_{eff}\, t_{FGS} (r_{min}/r_{break})^{-q+1}$

$q_2 \sim 4.5$	~180 events	no break
$q_2 \sim 3.5$	~1 event	break
$q_2 \sim 3$	no events	break

Assuming:

1) break radius $r_{break} \sim 45$km, $N(>r_{break}) \sim 5.4$ deg^{-2} *(Fuentes, George & Holman 2008)*
2) *KBO ecliptic latitude distribution form Elliot et al. 2005*

Detection Method



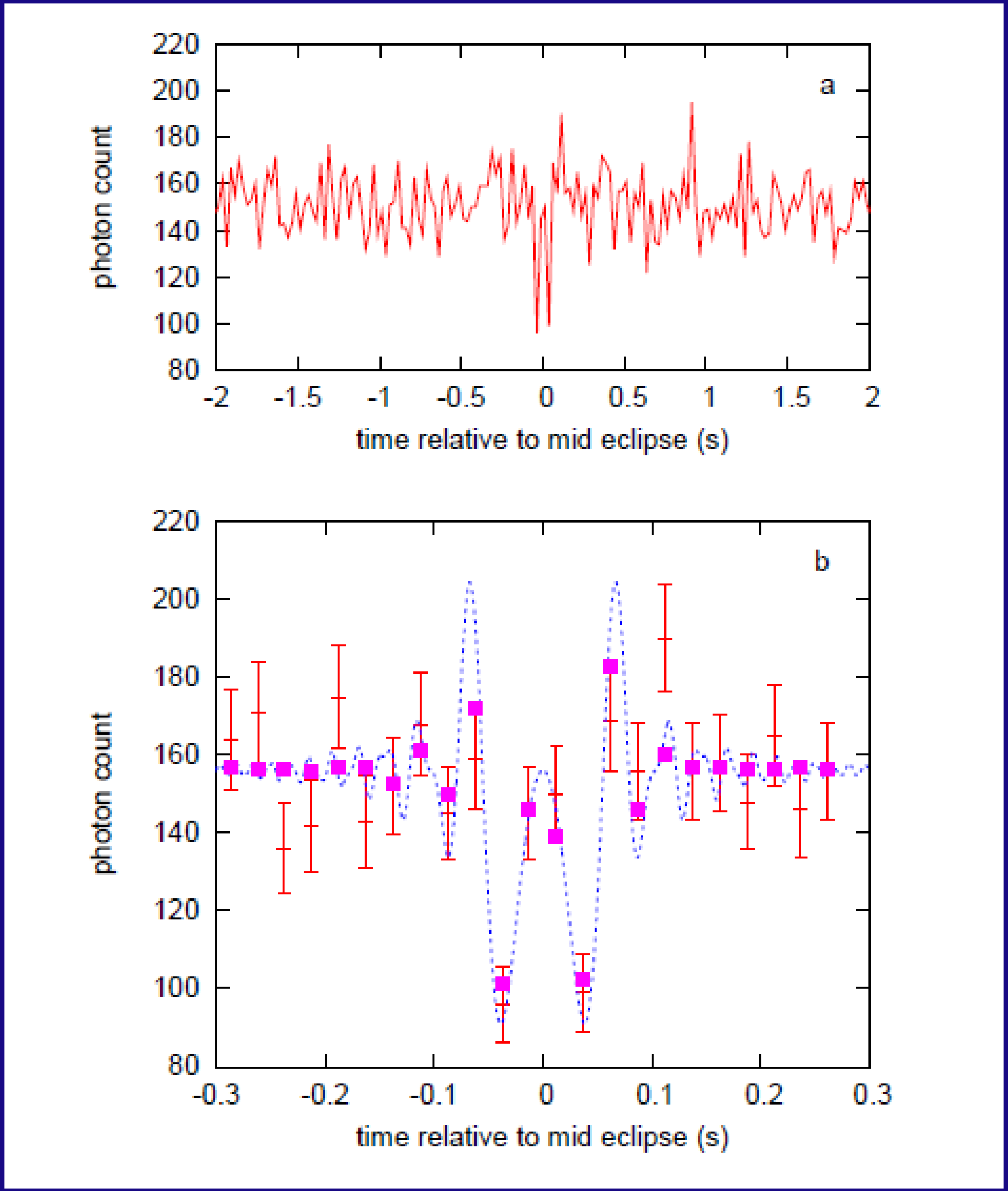
1) Search for events by fitting Fraunhofer Light curve template (3 free parameters, velocity, amplitude, mean)

2) For significant events we check

   - guide stars properties (position & subtend angular size)

   - compare velocity of best fit with velocity for observation geometry (assuming e<<1)

3) Compare with event rate in control sample, check for instrumental artifacts



Schlichting et al. 2009, Nature

Best fit values:

r ~ 520 m

a ~ 45 AU

$$r \propto \sqrt{amplitude}$$

Chi-squared fit:

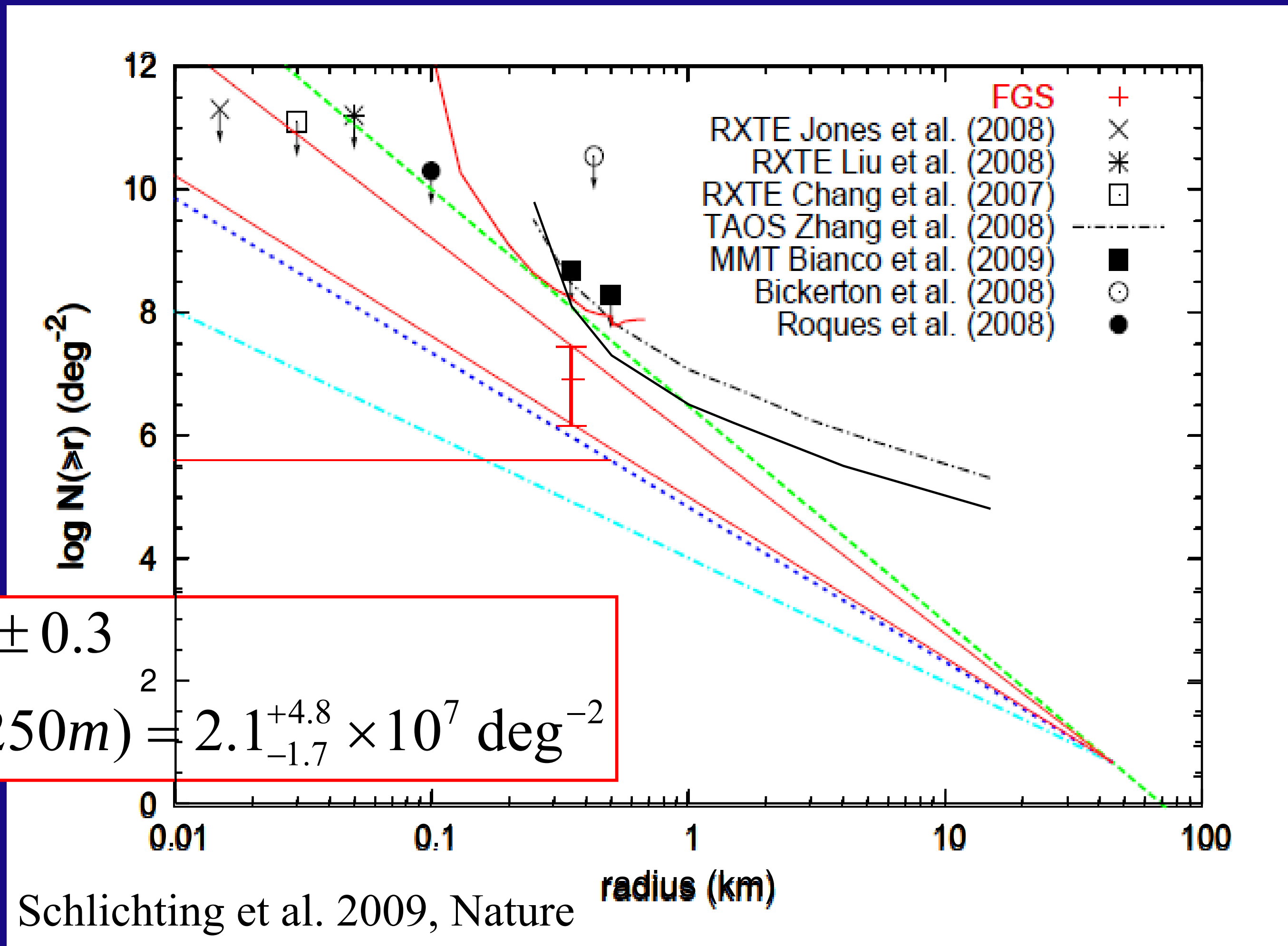
χ^2 /dof=20.1/21

From the observations we know:

- $\theta_{Star} / \theta_{Fresnel} \sim 0.3$
- Ecliptic latitude +14 deg

- Compared PMT readings
- Checked second FGS
- No correlated noise
- Examined the engineering telemetry for HST
- Less than 2% chance to be false-positive

Cumulative KBO size distribution



$$q = 3.9 \pm 0.3$$

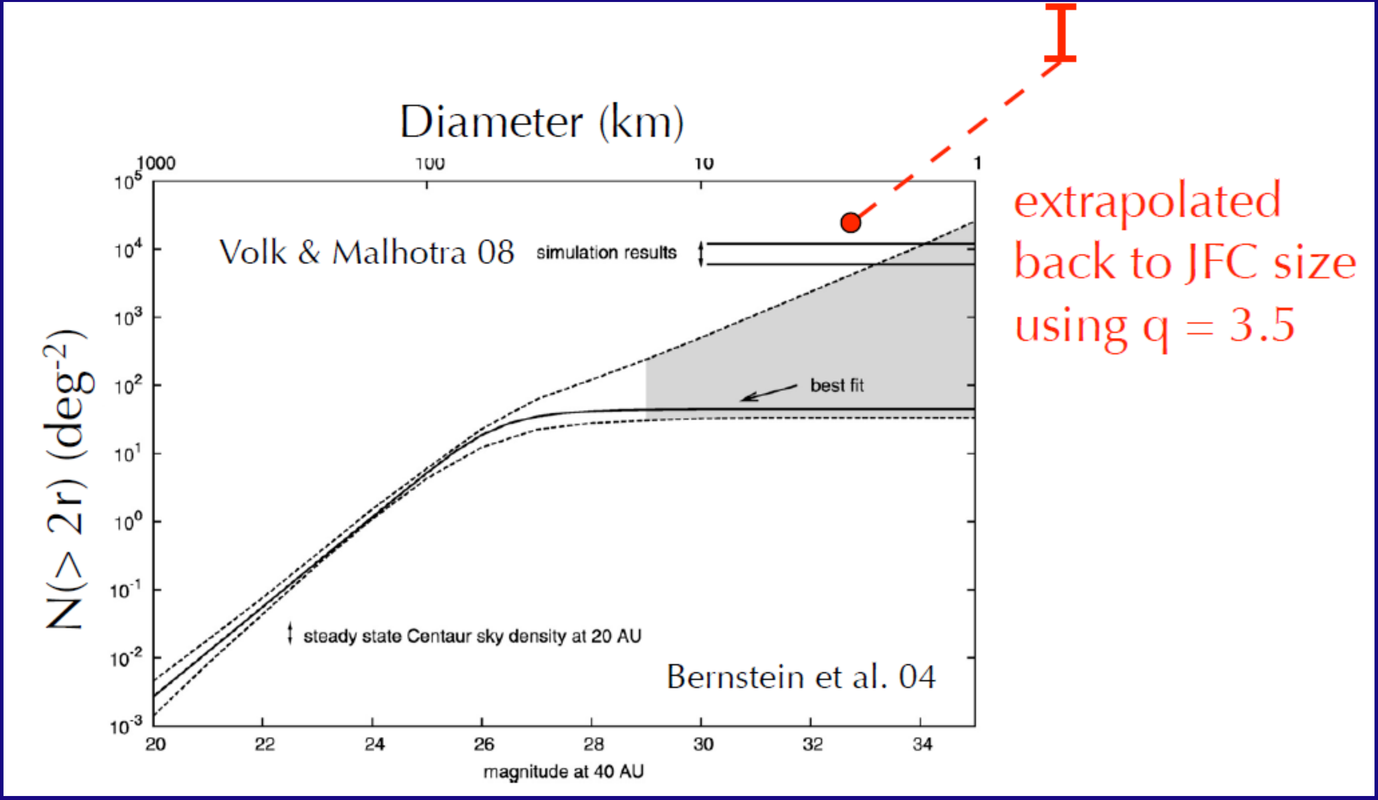
$$N(r > 250m) = 2.1^{+4.8}_{-1.7} \times 10^{7}\ \mathrm{deg}^{-2}$$

Schlichting et al. 2009, Nature

Rule out inferred KBO surface densities from previous claimed detections (Roques 2006, Chang 2006, 2007) by more than 5σ!

Implications

- Break in KBO Size Distribution → Collisional evolution
- Small KBO size distribution similar to Centaurs (q ~ 4, Sheppard et al. 2000) → Kuiper Belt source region of Centaurs
- Inferred KBO abundance consistent with required supply rate for Jupiter Family Comets (Volk & Malhotra 2008, Chiang & Pan 2010)



Questions

•Why is size distribution of comets (q ~ 2.9 +/- 0.3, e.g. Lamy et. al, 2004) different from Centaurs (q ~ 4, Sheppard et al. 2000) & small KBOs (q ~ 3.9 +/- 0.3, Schlichting et al. 2009)?

→ Modified due to mass loss and splitting?

•What is the inclination distribution of small KBOs?

Future

•Analyze the remaining 70% to the data

•Improve detection algorithm