The Taiwanese-American Occultation Survey (TAOS)

Matthew Lehner

ASIAA

The TAOS Institutional Partners:

The TAOS science team:

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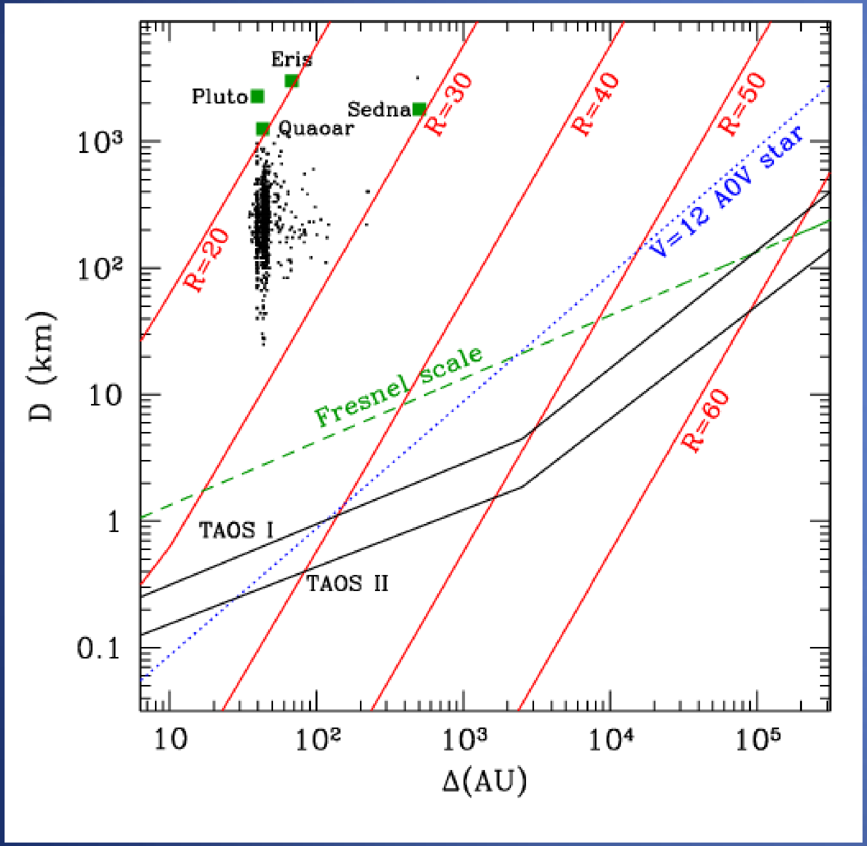
W.-P. Chen (NCU)
Nate Coehlo (UC Berkeley)
K. Cook (LLNL)
R. Dave (Harvard)
J. Giammarco (Eastern)
D.-W. Kim (Yonsei)
S.-K. King (ASIAA)
T. Lee (ASIAA)
M. Lehner (ASIAA)
J. Lissauer (NASA Ames)
S.L. Marshall (SLAC)
S. Mondal (NCU)
I. de Pater (UC Berkeley)
R. Porrata (UC Berkeley)
P. Protopapas (Harvard)
J. Rice (UC Berkeley)
J.-H. Wang (ASIAA)
S.-Y. Wang (ASIAA)
C.-Y. Wen (ASIAA)
Z.-W. Zhang (NCU)

Why attempt an occultation survey?



- Direct searches well-suited to objects larger than R ~30 km
- Much of the mass may be in smaller objects
- Models predict a major change in size distribution for smaller objects
- Occultations of bright stars can reveal smaller and/or more distant objects!

Challenges

- Rapid photometric measurements (5 Hz)
- Follow enough stars (500 - 1000) for significant rate
- Credible result
    - Require detection in multiple telescopes

Occultation Events

Fresnel Scale:

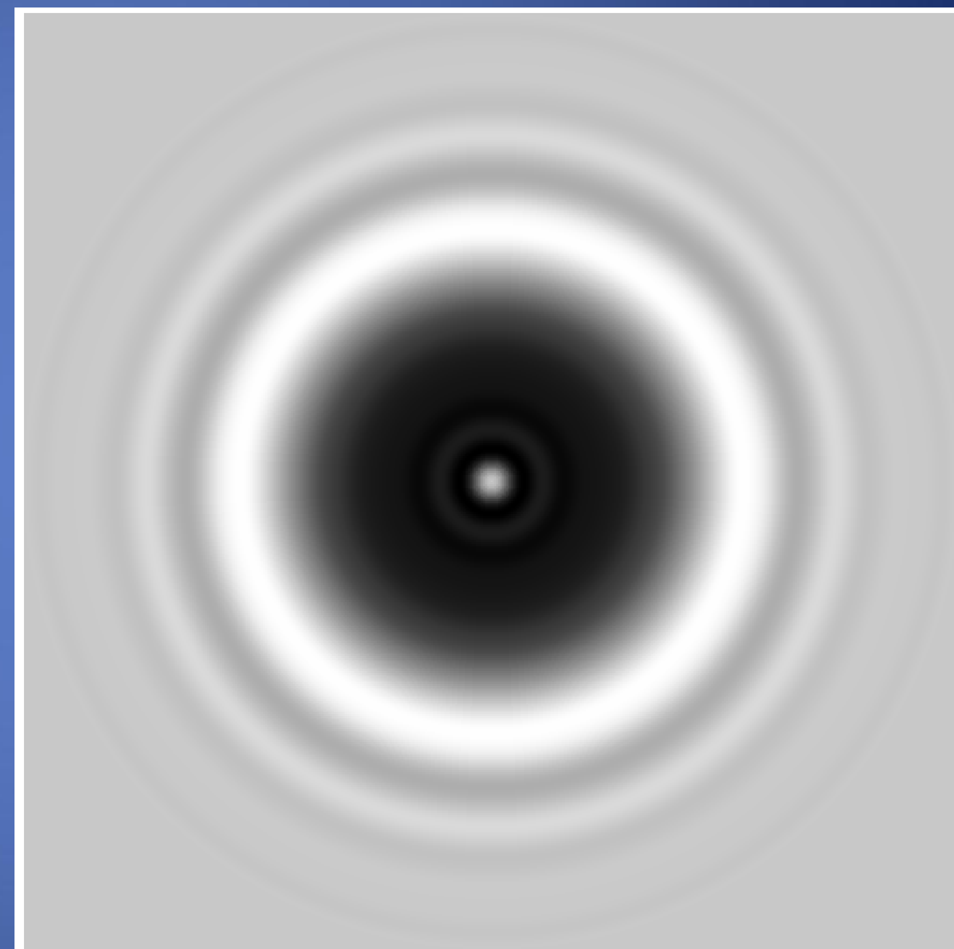
$$F = \sqrt{\lambda a / 2}$$

F = 2 km at 50 AU

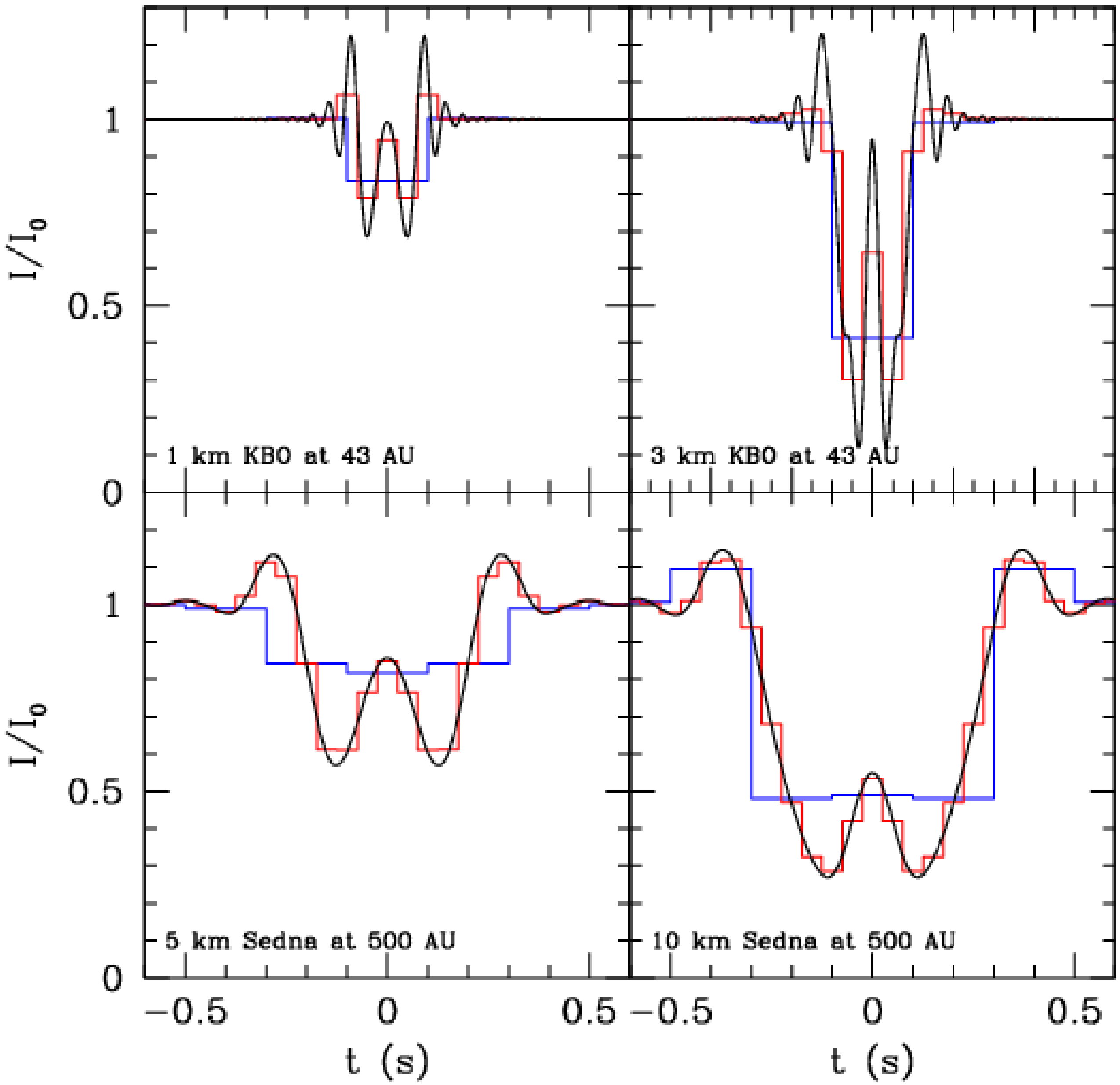
Objects in relative motion,

v ~ 25 km/sec

Event timescale ~200ms!

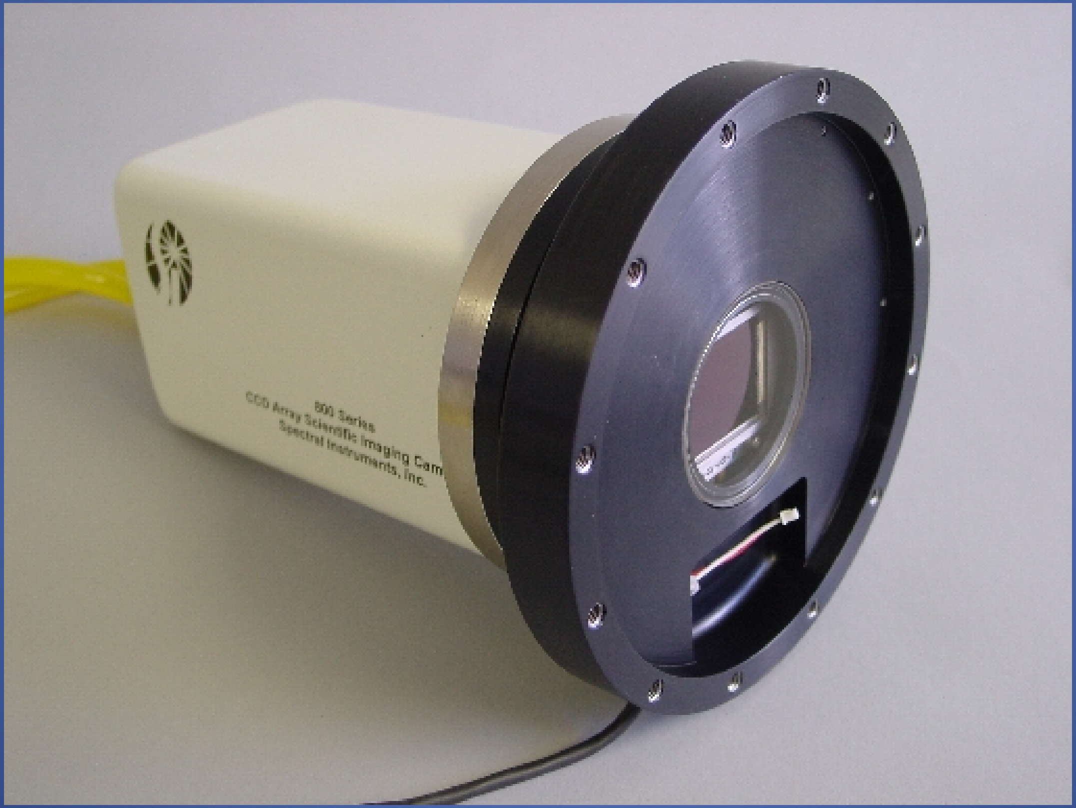


10 km



I/I0
1
0.5
0
1 km KBO at 43 AU
3 km KBO at 43 AU
5 km Sedna at 500 AU
10 km Sedna at 500 AU
−0.5
0
0.5
t (s)

Spectral Instruments SI-800 thinned, backside illuminated, 2048×2052 CCD cameras:



Readout time of 2.5 seconds, want 5 Hz sampling

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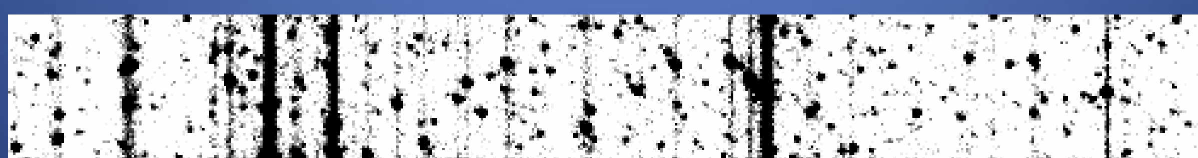
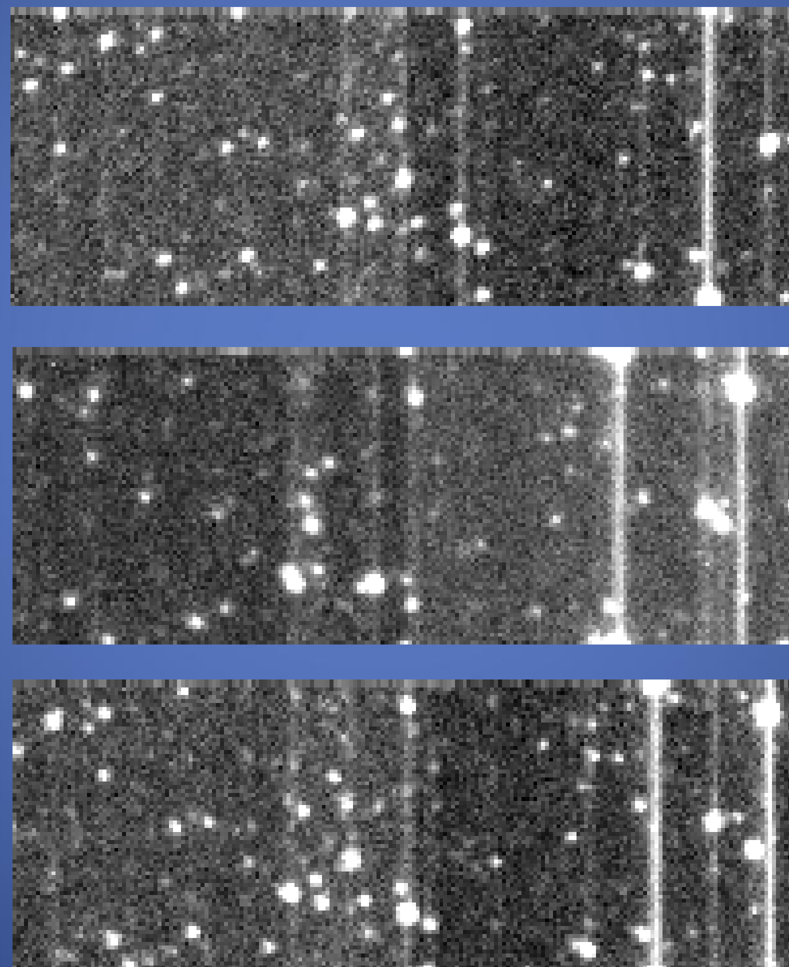
“Zipper Mode”

- 27 “rowblocks” × 76 rows
- Sky background 27 times as bright
- Streaks from bright stars
- **Readout every star in image at 5 Hz**



512×76 rowblock

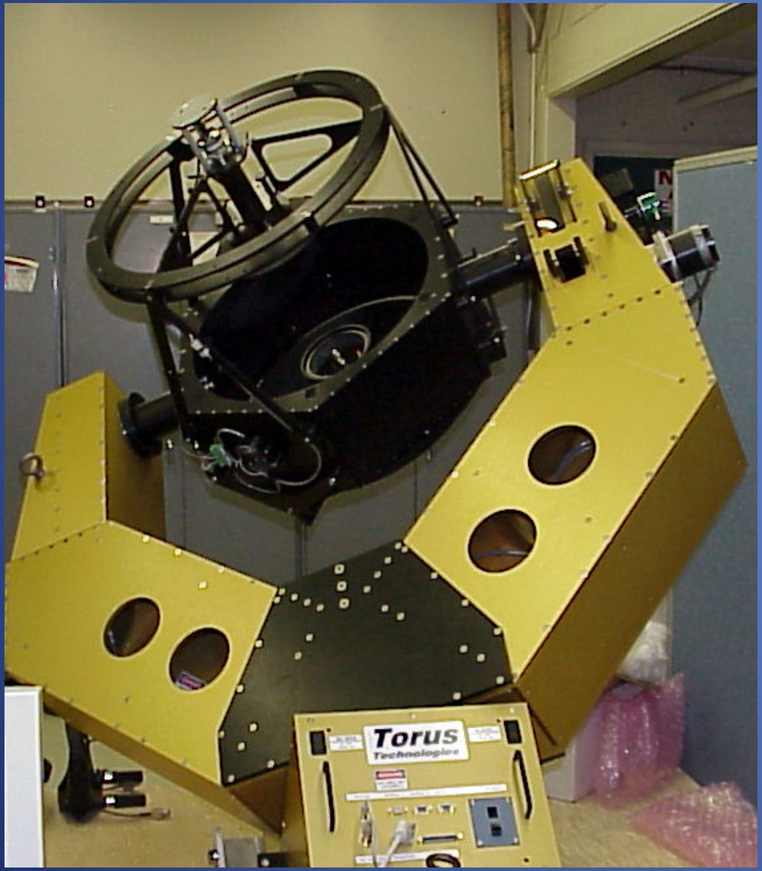
Occultation by (286) Iclea
2006 February 6



Need ~1000 stars for significant rate

- 5 Hz sampling, 27 times sky background
- Dim stars lost in noise
- Need wide field of view or large aperture, dark sky

TAOS: four small robotic telescopes



- 50 cm aperture
- F/2.0
- 3 square degree field
- Robotic operation
- Synchronized imaging

The telescopes operate at the Lu-Lin Observatory in Central Taiwan

- Moderate elevation (2850 meters)
- Dark sky (comparable to Kitt Peak)
- 100-200 clear nights per year

The telescopes will operate at the Lu-Lin Observatory in Central Taiwan

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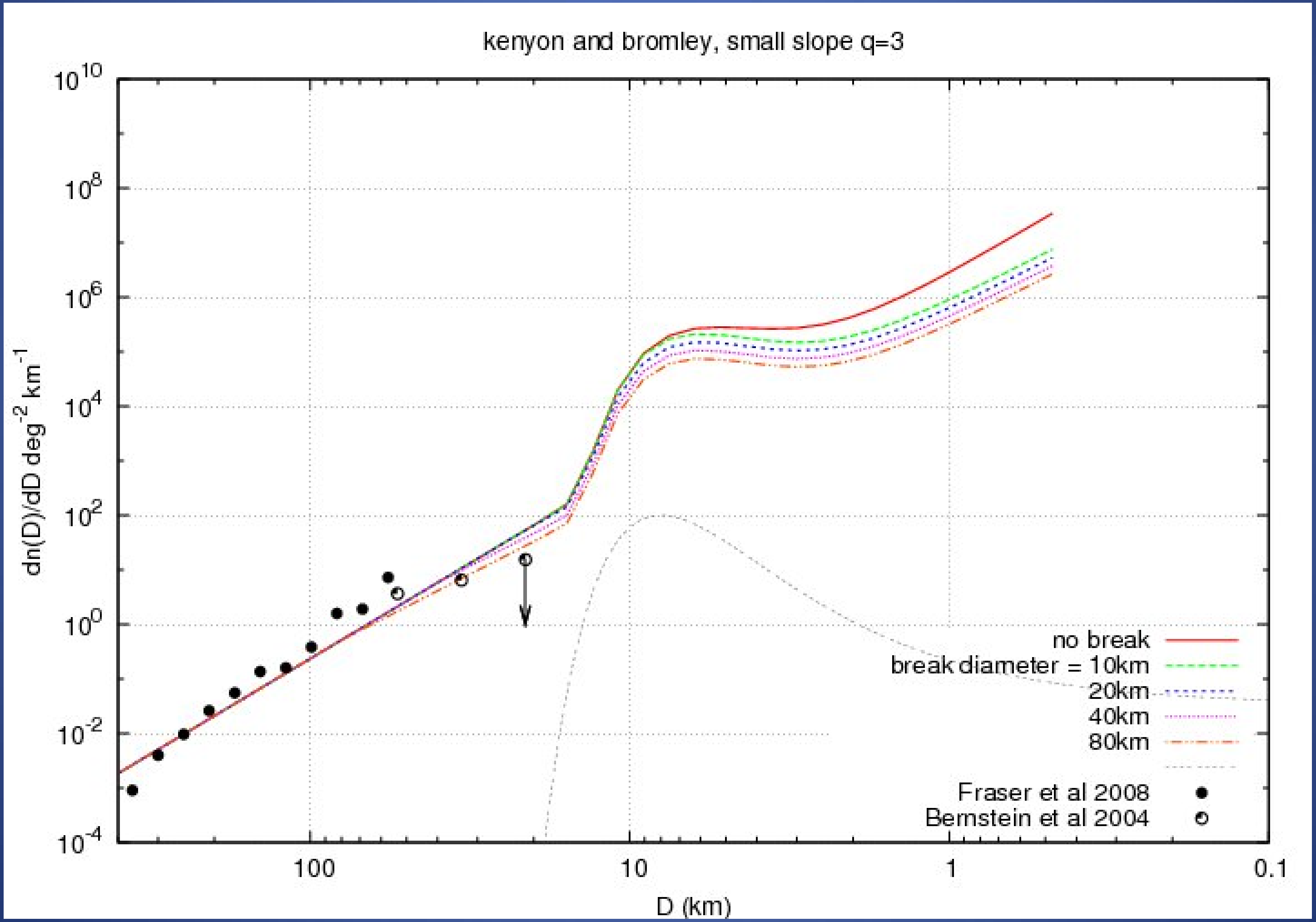
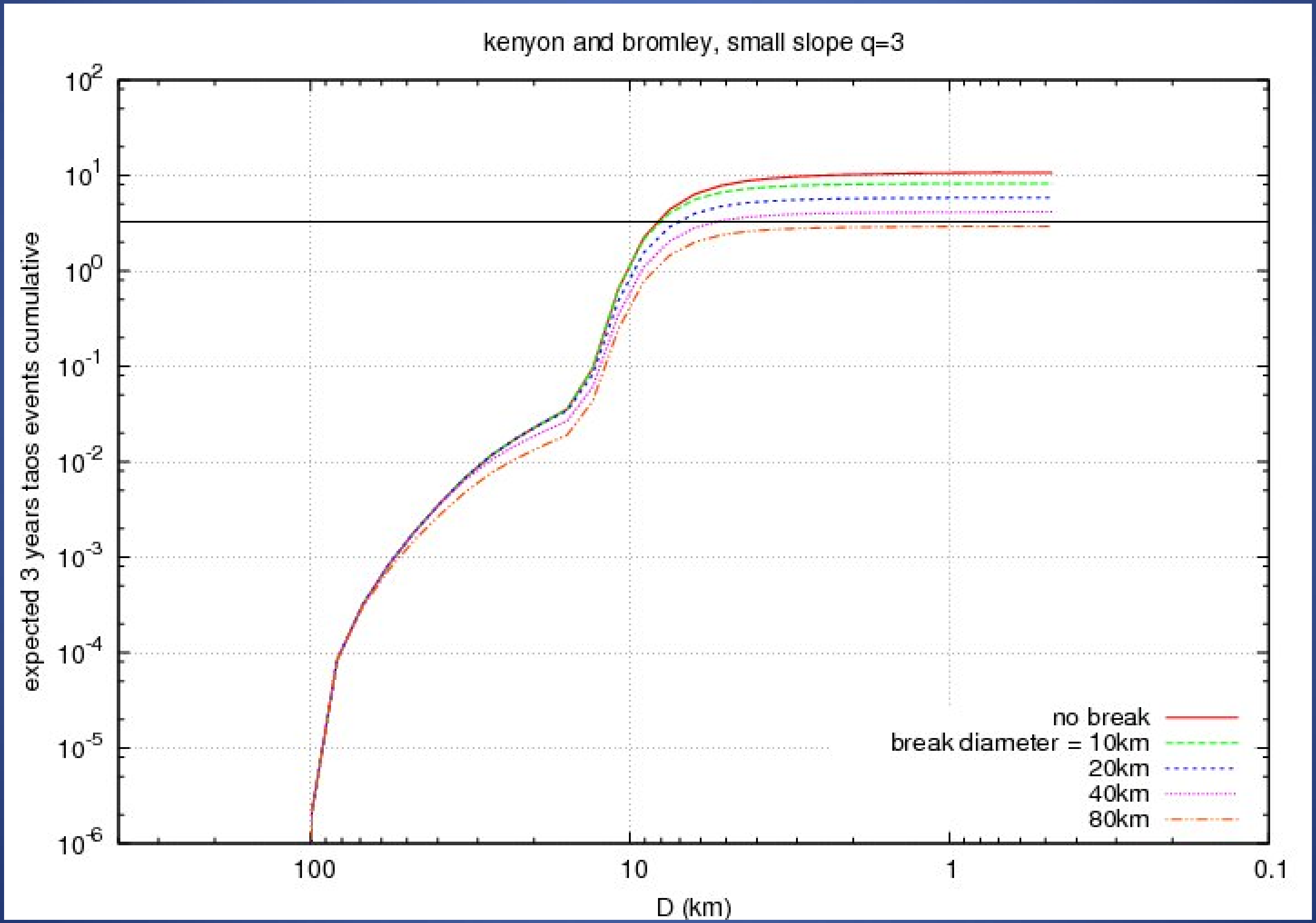
Bianco et al. (2009)



Bianco et al. (2009)



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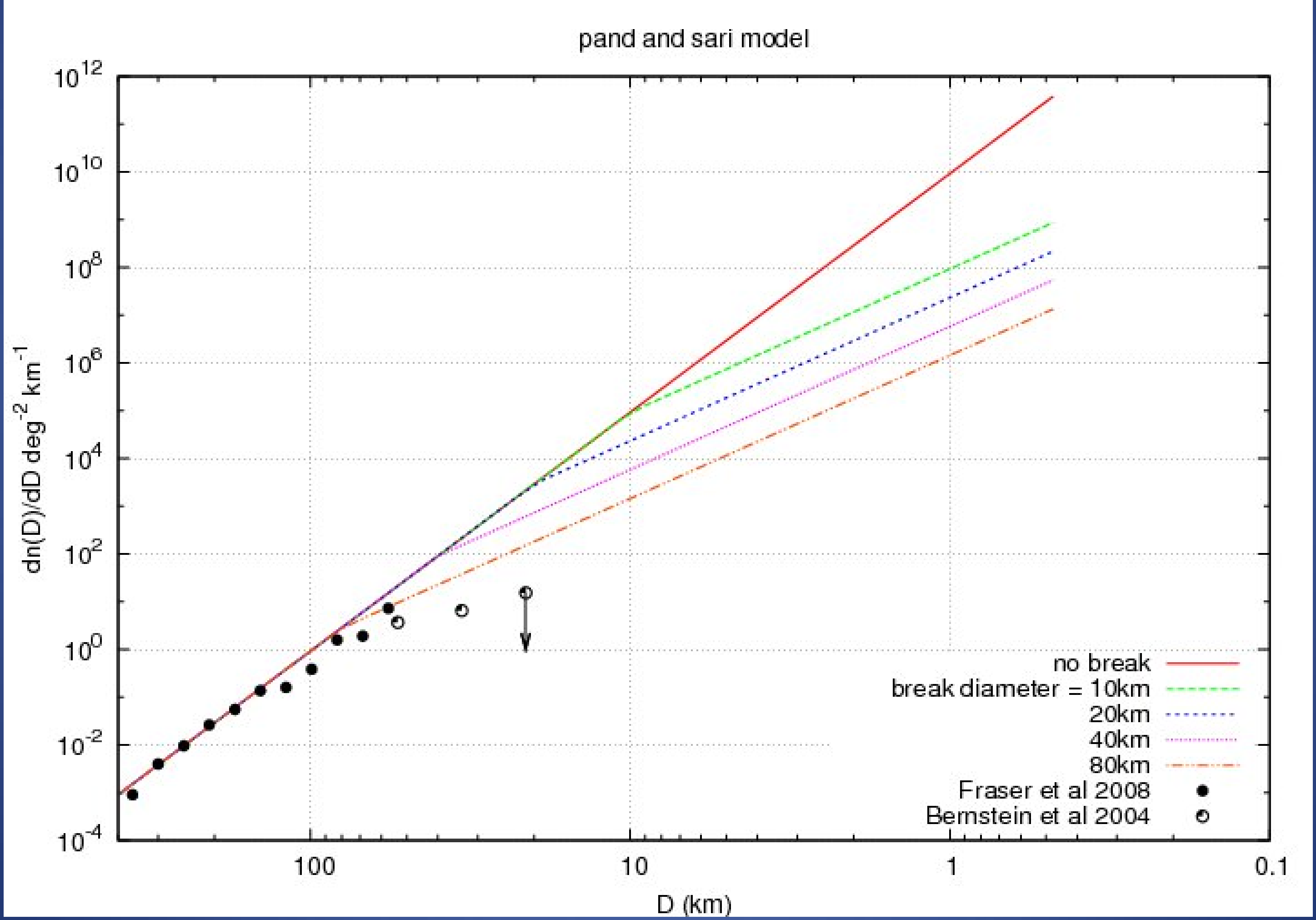

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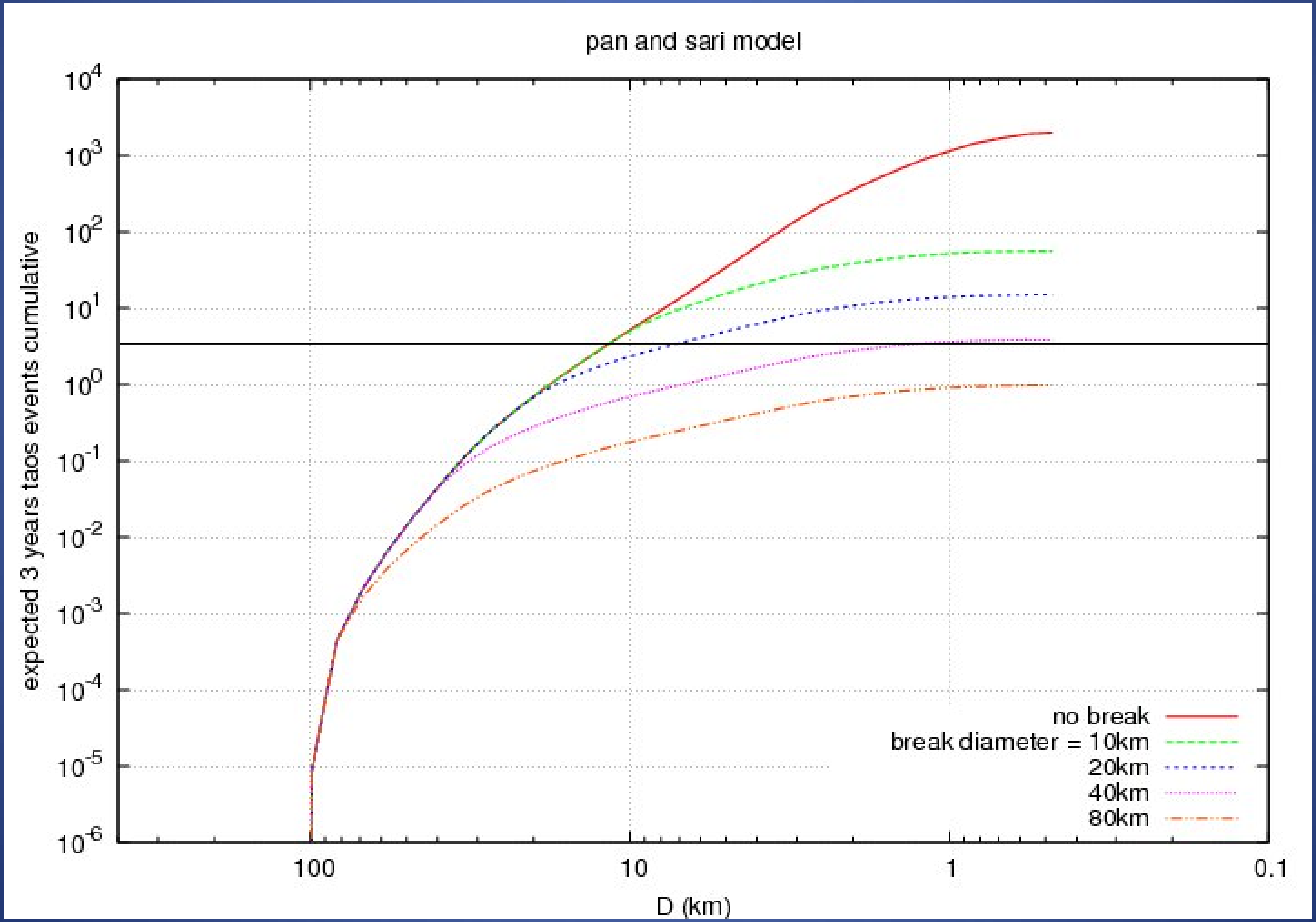
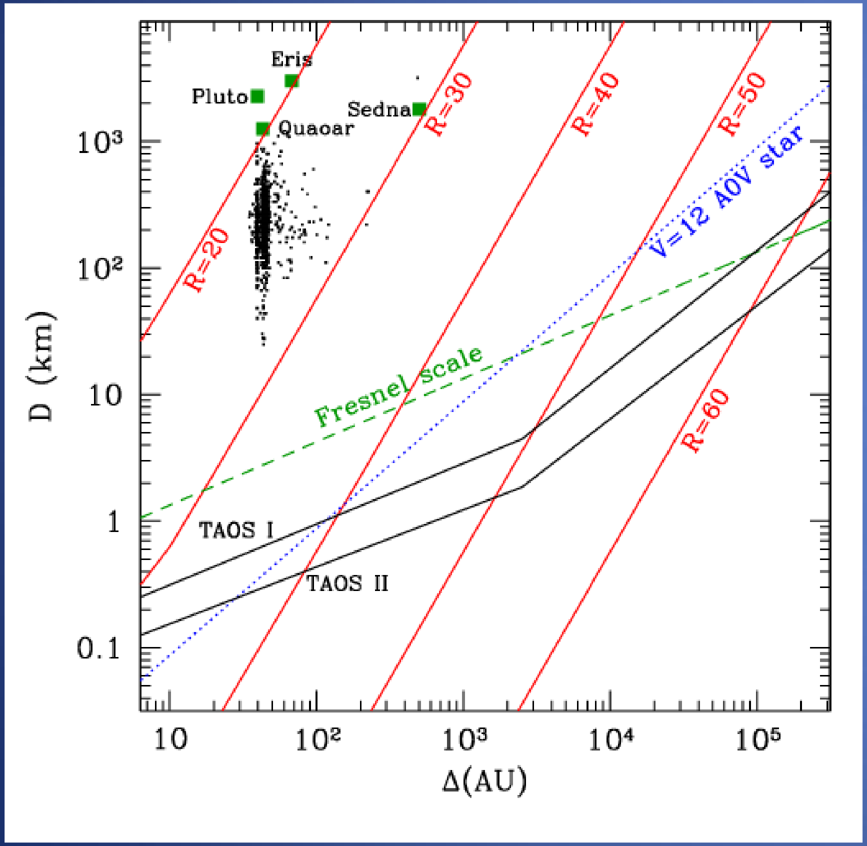


Why attempt an occultation survey?



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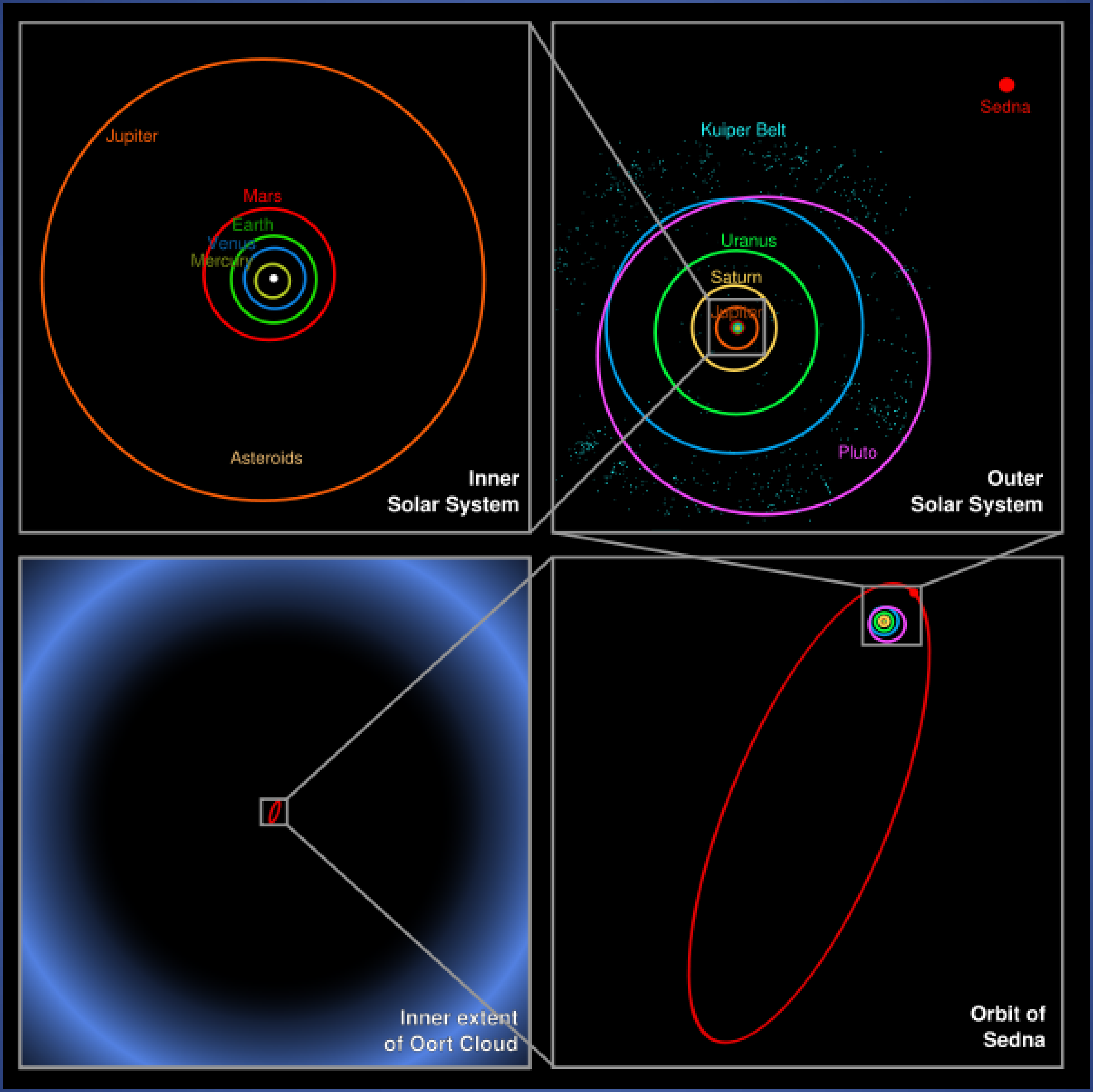
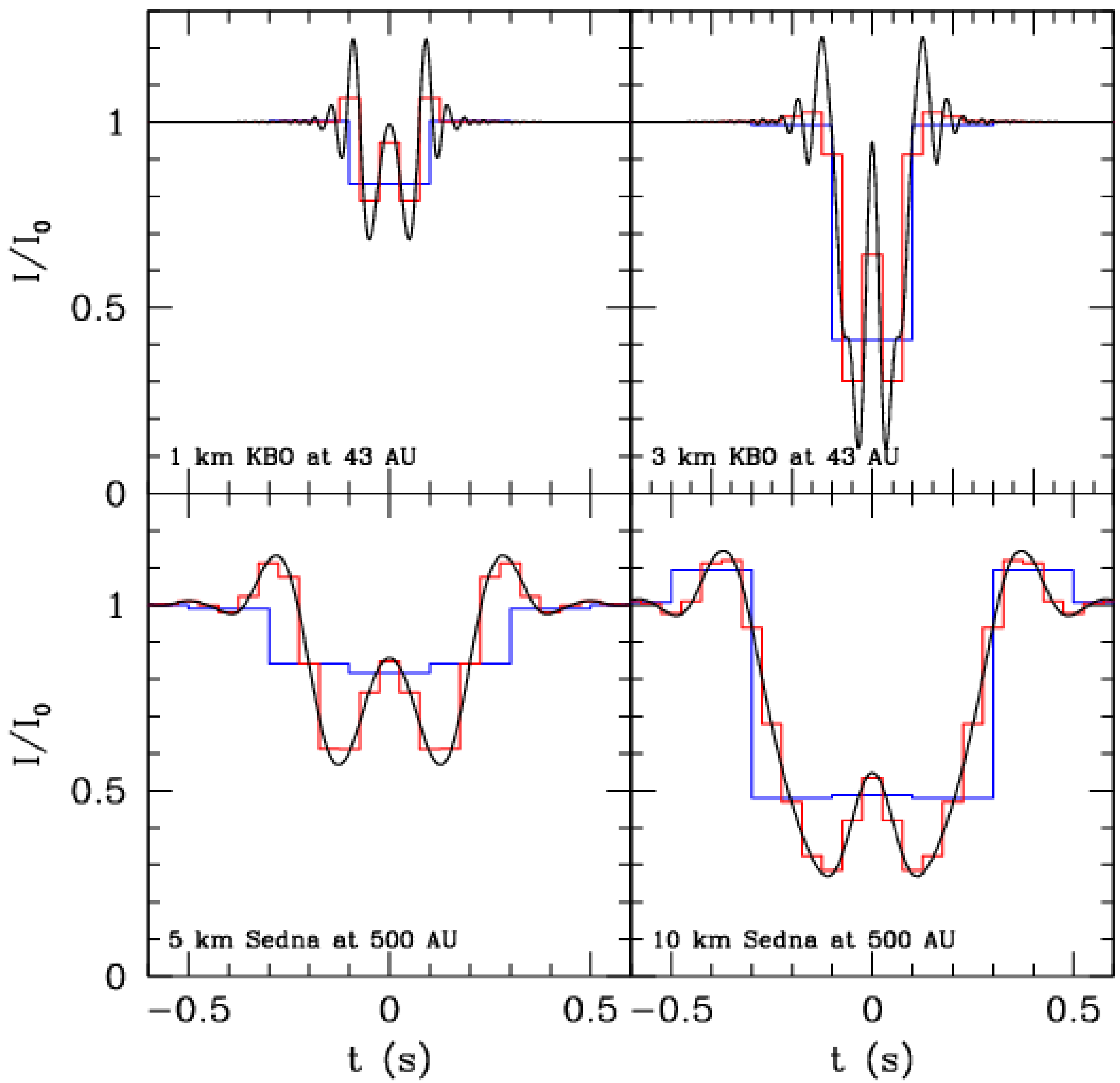
Beyond the Kuiper Belt: 100-1000 AU

- Sedna: very eccentric orbit
- Perihelion at 76 AU, Aphelion at 976 AU
- Discovered near perihelion, where it spends little time
  - 5 Earth masses???
- How did it get into this orbit? (not perturbed by gas giants, molecular clouds, galactic tidal forces)
- Passing stars?
- Difficult to put Sedna in this orbit without putting many other objects in this region.


Jupiter
Mars
Earth
Venus
Mercury
Asteroids
Inner
Solar System
Sedna
Kuiper Belt
Uranus
Saturn
Jupiter
Pluto
Outer
Solar System
Inner extent
of Oort Cloud
Orbit of
Sedna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TAOS II

- Next generation occultation survey
- Design Goal: 100 times the event rate of TAOS I
- Better site, better telescope, larger focal plane, 20 Hz sampling cadence

A factor of 100

- 5 times more of observing time
  - 250 observable nights/yr
- 1-5 times higher event rate (model dep.)
  - 20 Hz sampling, higher S/N → smaller objects
- 10 times more stars monitored
  - R_{limit}= 17.5 with 1/2 FOV
  - 40 times higher SNR needed
    - Larger aperture
    - Better seeing
    - No zipper mode!

Telescope (first choice)

- DFM Engineering
- F/4 1.3 m
- 1.7° FOV
- Equatorial mount

Camera

- High speed readout with ultra low noise
- High duty cycle

EMCCD

- 20 MHz readout
- <2e$^-$ read noise
- Frame transfer buffer
- Standard product
- Under testing at IAA

Monolithic CMOS

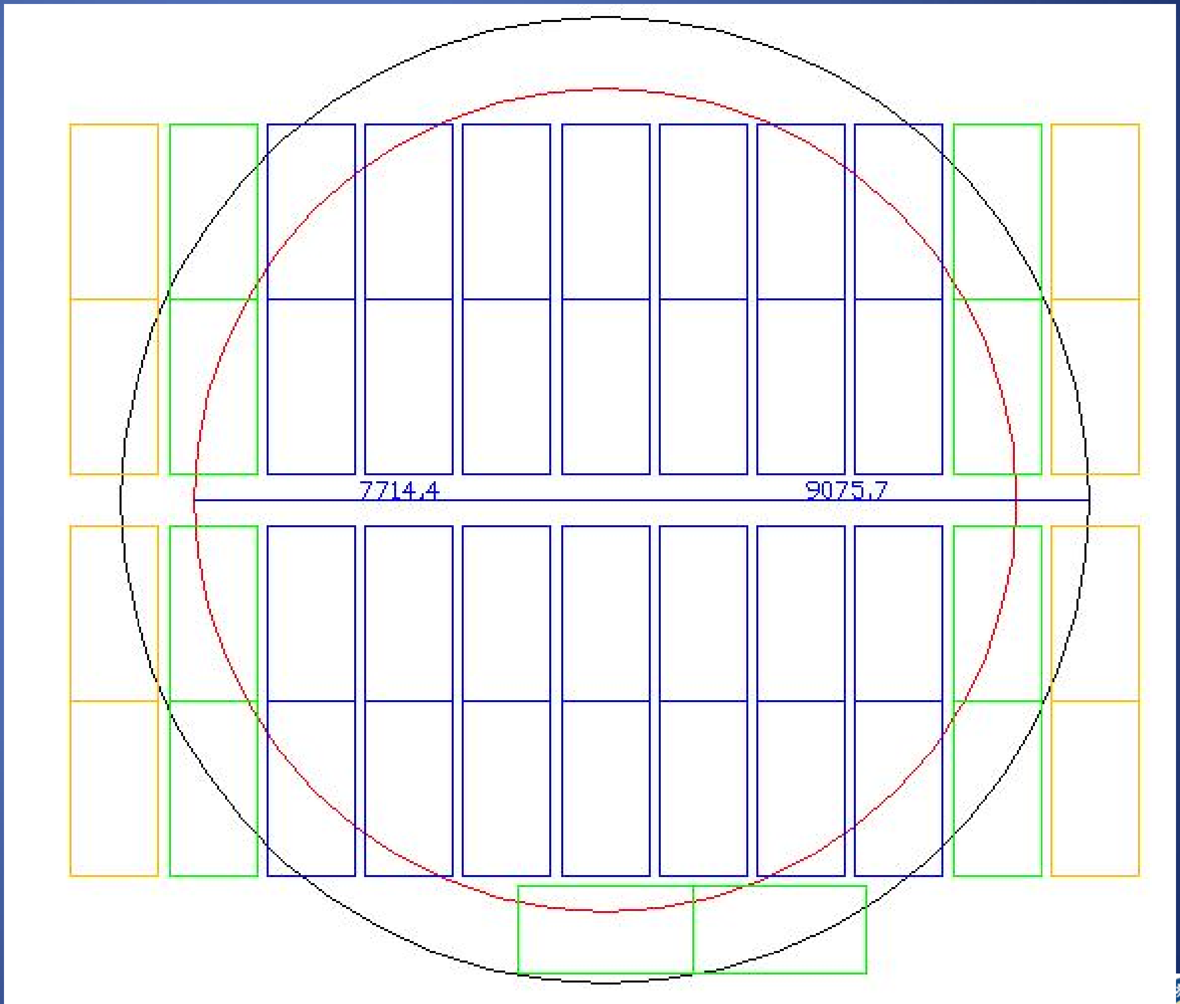
- New technology
  - Back-illuminated
- 200 KHz readout
- 2e$^-$ read noise
- Large format under development

Focal Plane with EMCCD

Custom designed Frame Transfer EMCCD

14 4.5k × 2k 16 μ m pixels

Effective FOV 1.0 sq. deg. (1.4 sq. deg.)



TAOS II Site

- High quality astronomical site needed
- >250 clear nights per year
- <1” median seeing
- large baseline (>100 m)

- Mauna Loa
- San Pedro Martir (Plan B)

TAOS: Other Science

- GRB afterglow
- Supernovae detection
- Exoplanet search
- Variable and other transient events