Graduate Institute of Astronomy, NCU
國立中央大學天文研究所

The Taiwan-America Occultation Survey (TAOS) Project --- Current Status

Wen-Ping Chen（陳文屏）
(National Central University, Taiwan)
on behalf of the TAOS collaboration

2005.06.03@CAST

Outlines

- A Quick Overview of the Project
  --- Concept and Experimental design
- Current Status

What do we get to hear from the TAOS talks in the sessions

Collaborators

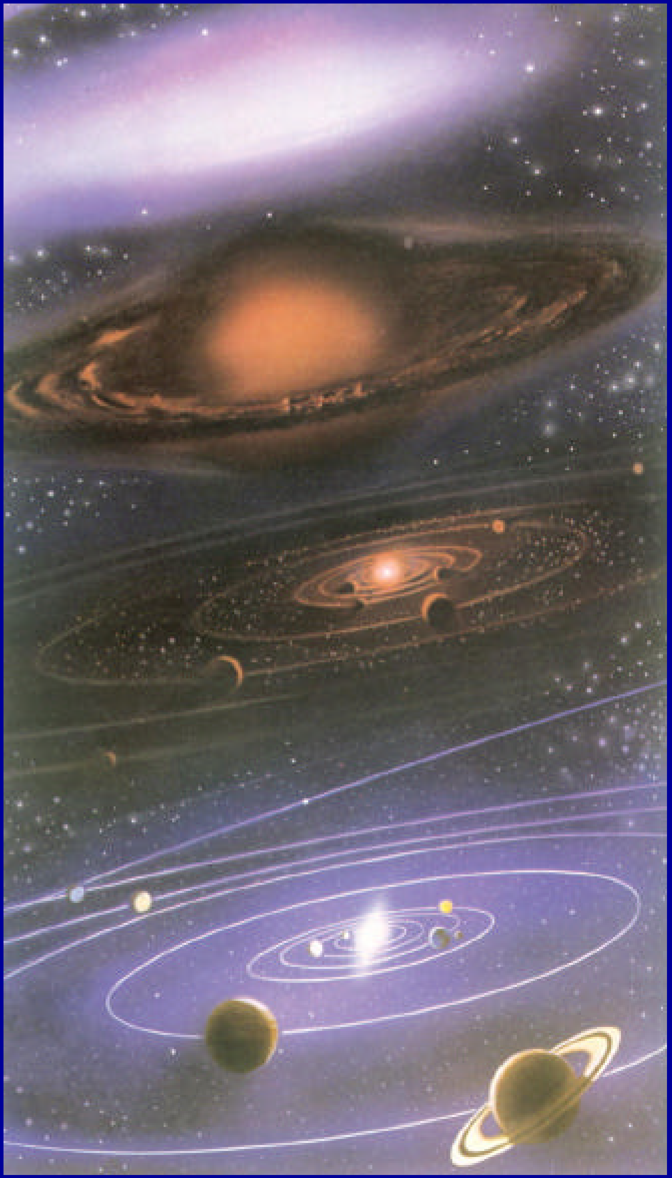
- **USA**
  C. Alcock, Federica Bianco **(*CfA*)**
  Rahul Dave, Joe Giammarco, Matt Lehner, Megan Schwamb **(*U. Penn)***
  K. Cook, Rodin Porrata **(*LLNL*)**
  S. Marshall **(*SLAC*)**
  I. de Pater, J. Rice ***(UC/Berkeley*)**
  J. Lissauer **(*NASA/Ames*)**
- **Taiwan**
  T. Lee, C.Y. Wen, S.K. King, A. Wang, S.Y. Wang **(*ASIAA*)**
  W.P. Chen, W. Ip, Y.H. Chang, D. Kinoshita, H. C. Lin, Soumen Mondal, Z. W. Zhang **(*NCU*)**
- **Australia** T. Axelrod **(*U Arizona*)**
- **Korea** Y. I. Byun **(*Yonsei U*)**

Solar System Formation in a Nutshell

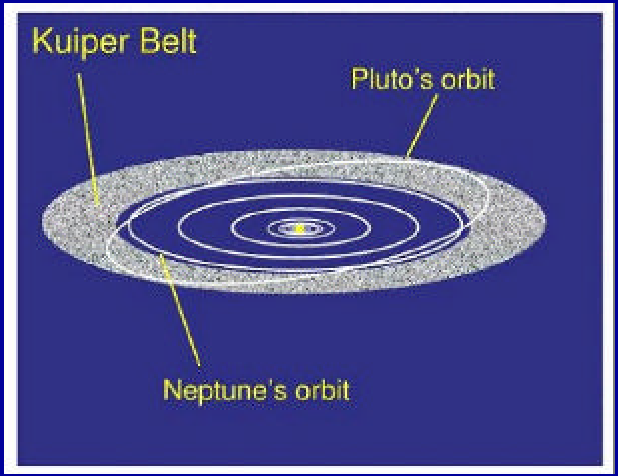
The Sun and planets were formed out of an interstellar molecular cloud.

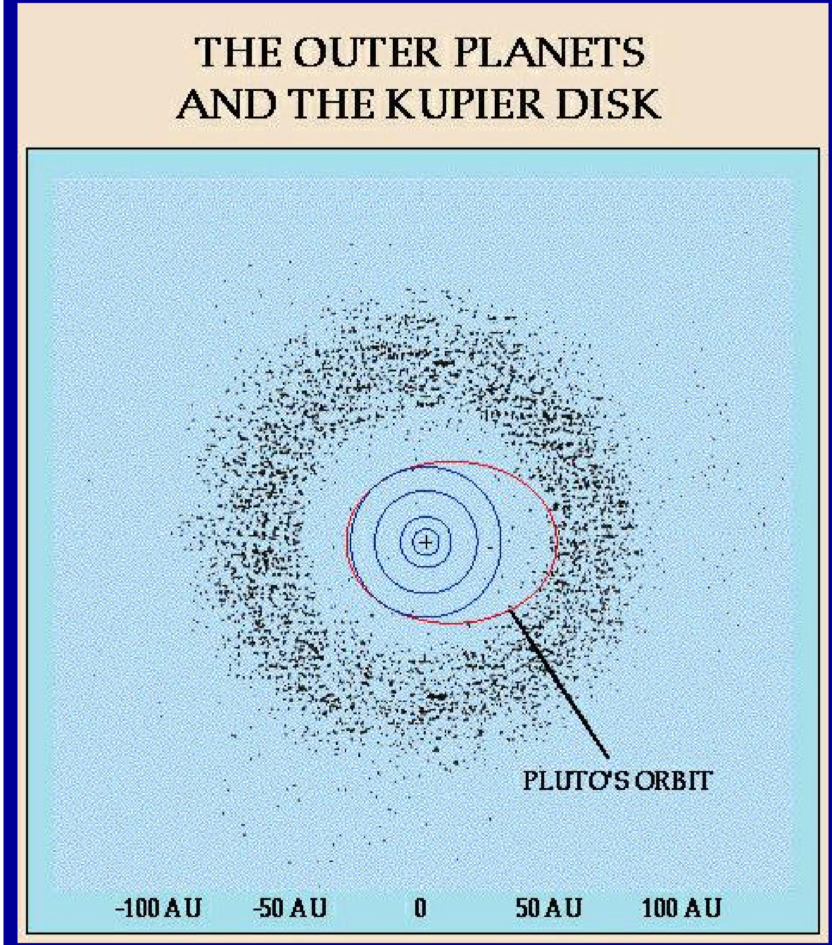
Cloud collapsed
$\rightarrow$ central T $\uparrow$ $\rightarrow$ nuclear fusion
➔ **Sun**
$\rightarrow$ dust coagulated in circumstellar disk
➔ **planetesimals** (asteroids)

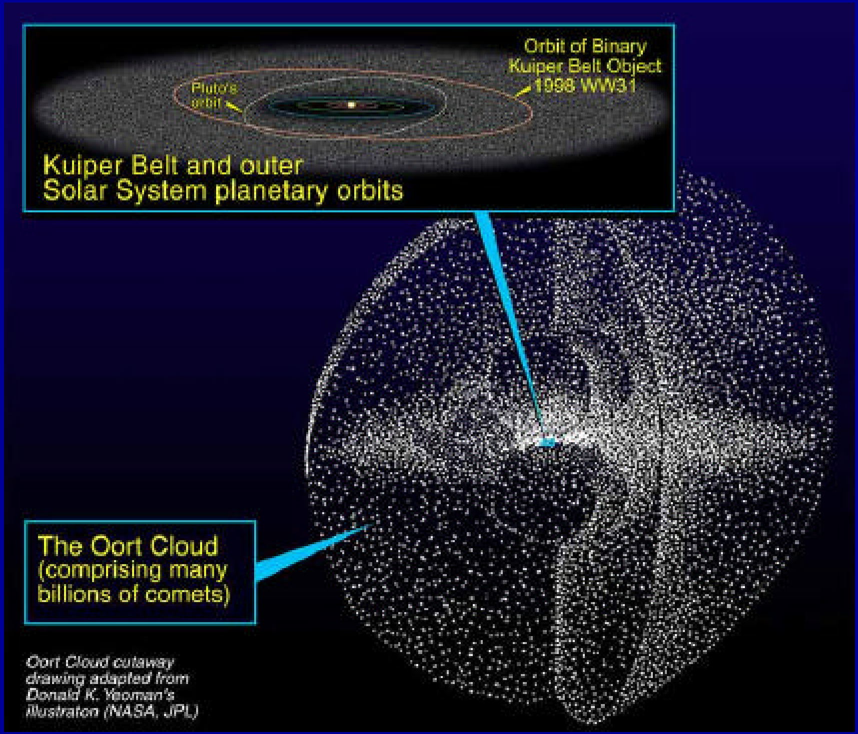
Heavy bombardments shaped the planets and satellites ...

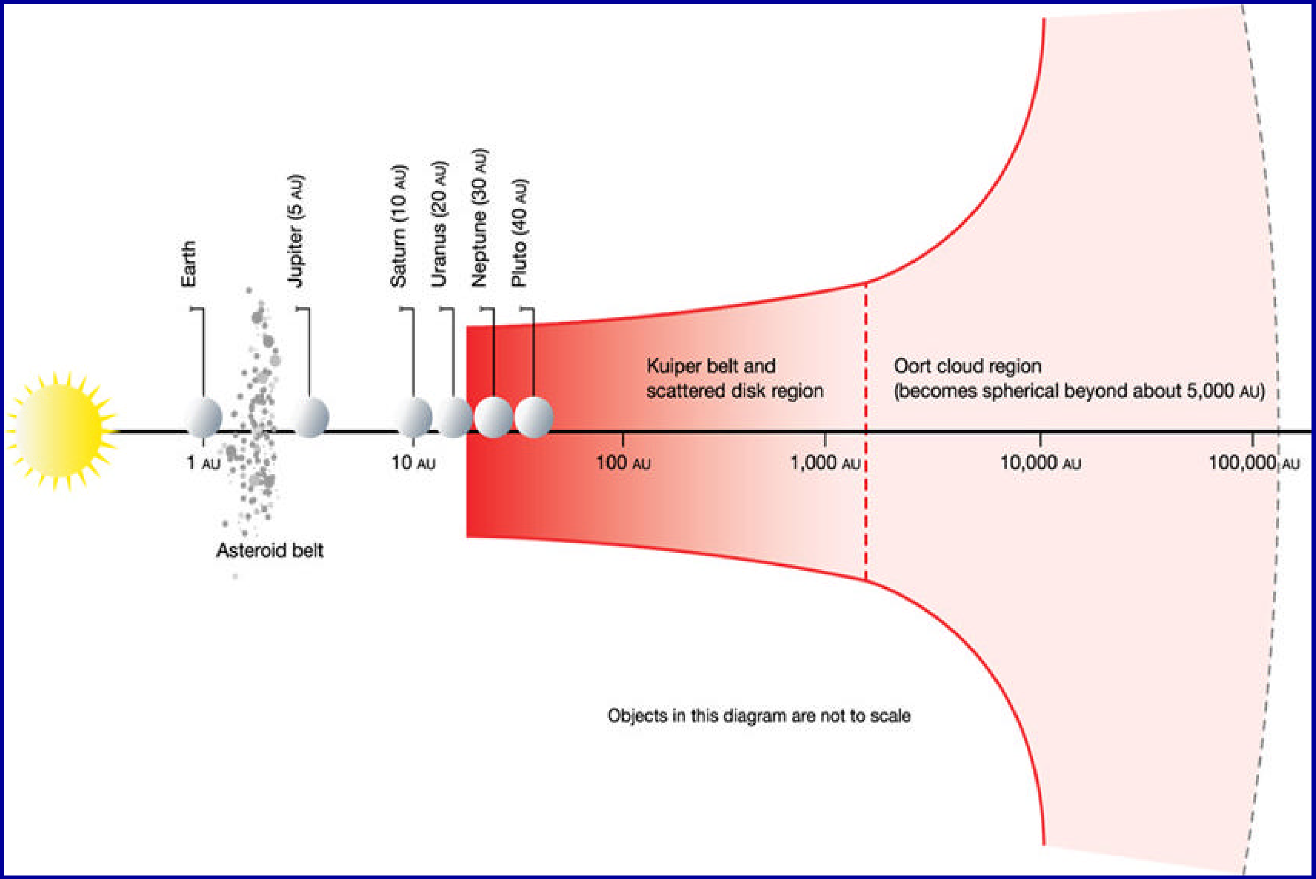


The surplus material and plantesimals become the Kuiper disk or Kuiper belt .





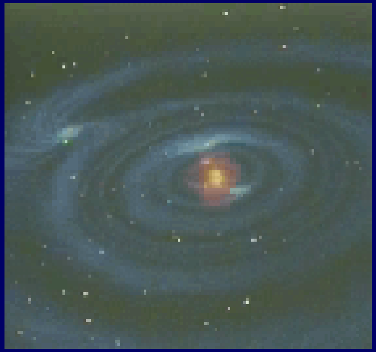


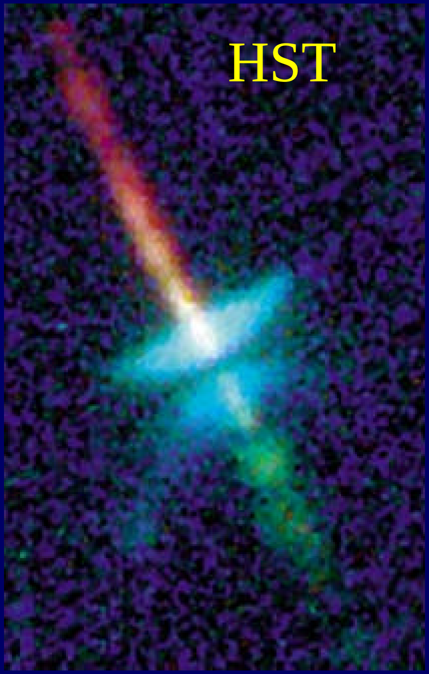


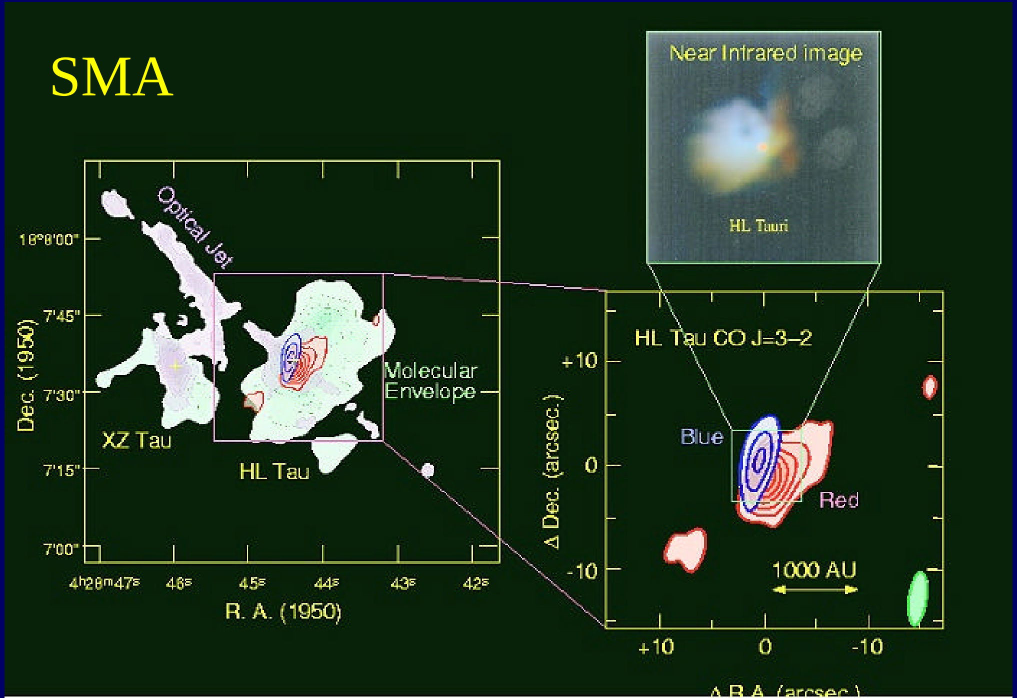
The Kuiper belt is the remnant planetary disk extending beyond Naptune to perhaps > 1,000 AU.

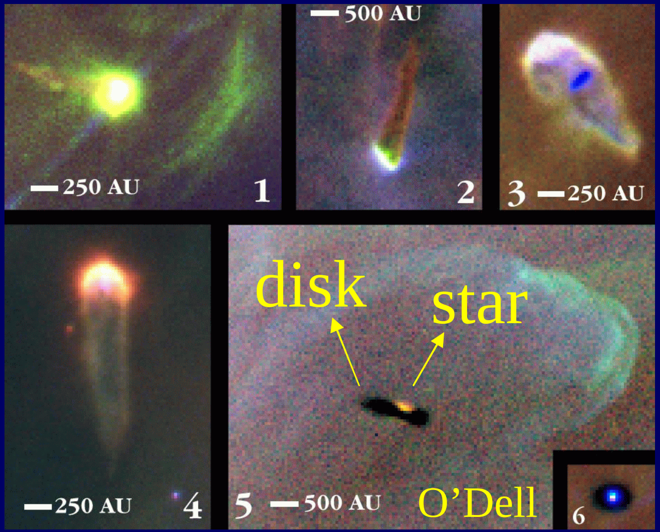
Stern (2003)

Circumstellar disks are ubiquitous among sunlike young stars …



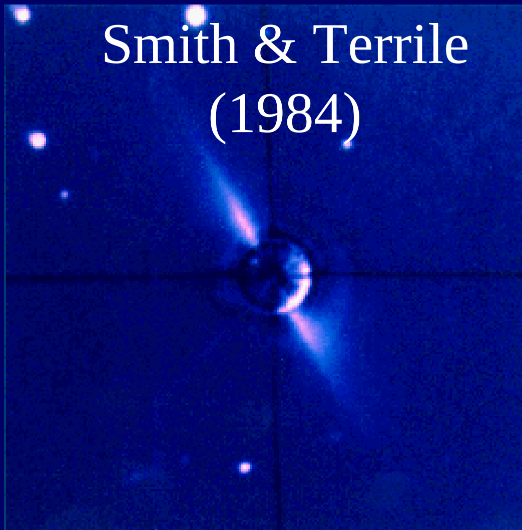


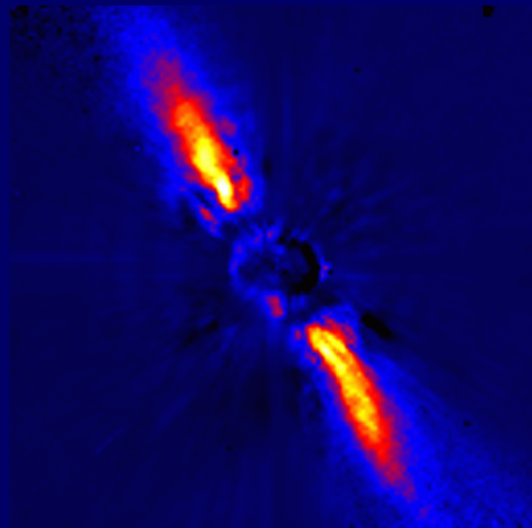


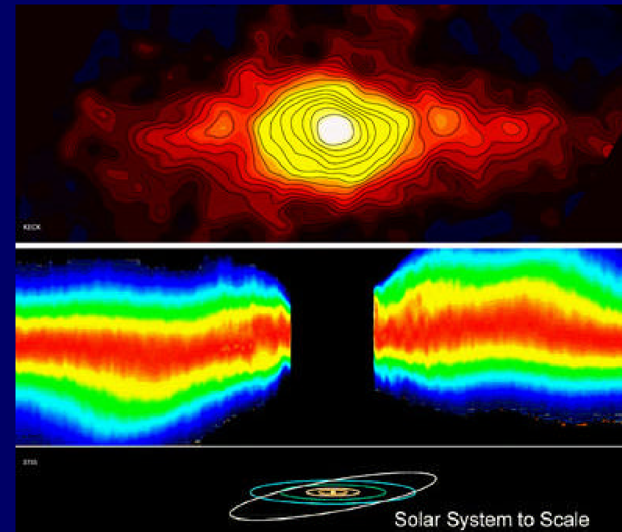


http://www.asiaa.sinica.edu.tw/news/SMAPR/hl_c.html

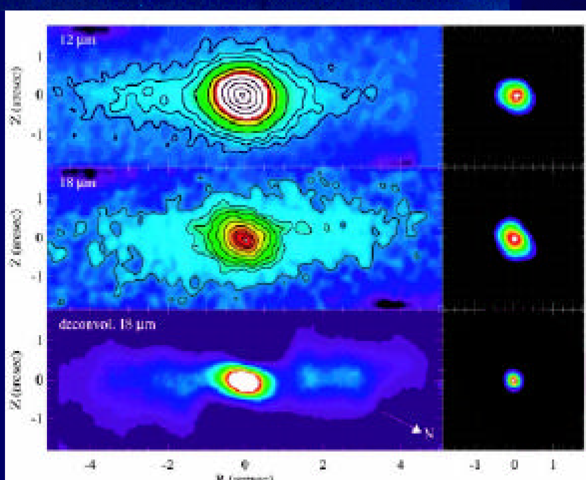
Debris planetary disk around Beta Pictoris

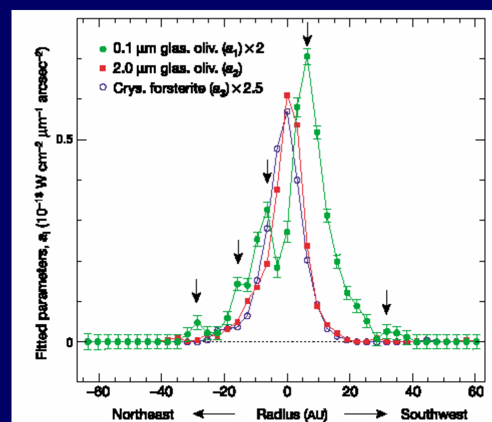


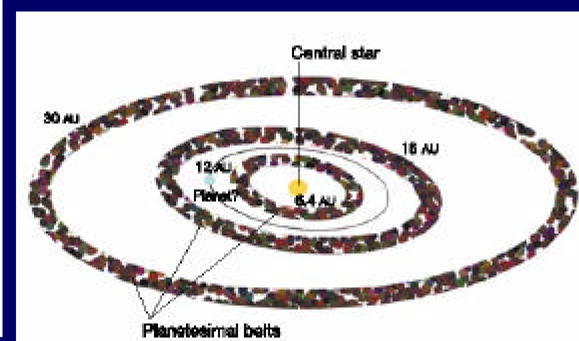




Schultz & Heap







11.7 & 17.9 micron images (Weinberger et al 2003)

Dust emission has peaks at 6, 16, and 30 AU (Okamoto et al. 2004)

Kuiper-belt population in our Solar System is known to exist.

Distant EKOS --- *The Kuiper Belt E-Newsletter*

(http://www.boulder.swri.edu/ekonews/)

As of 2005/06

Current number of TNOs: 886 (and Pluto & Charon, and 12 other TNO binary companions)

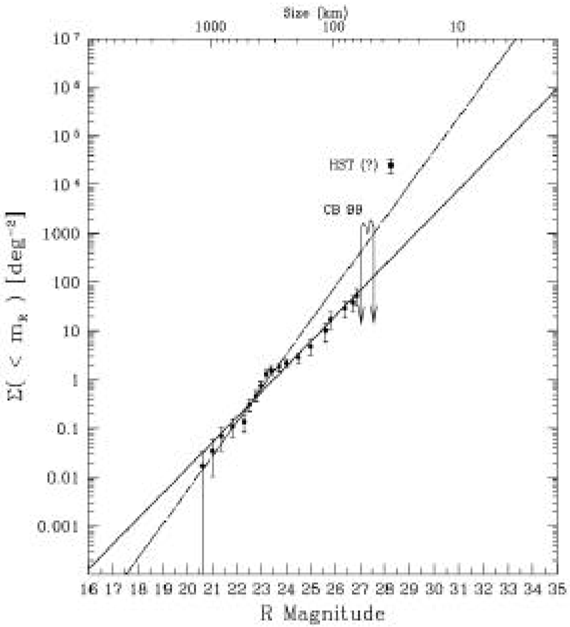
Current number of Centaurs/SDOs: 151

Current number of Neptune Trojans: 2

Out of a total of 1039 objects:

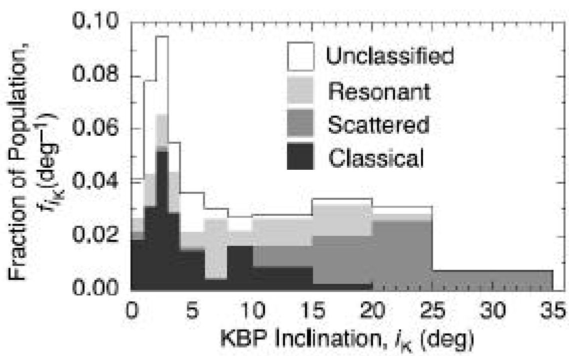
- 500 have measurements from only one opposition
- 410 of those have had no measurements for more than a year
- 203 of those have arcs shorter than 10 days

Kuiper-belt objects (KBOs) = Edgeworth-Kuiper Objects (EKOs)
= Transneptunian Objects (TNOs)



Statistical studies now become possible

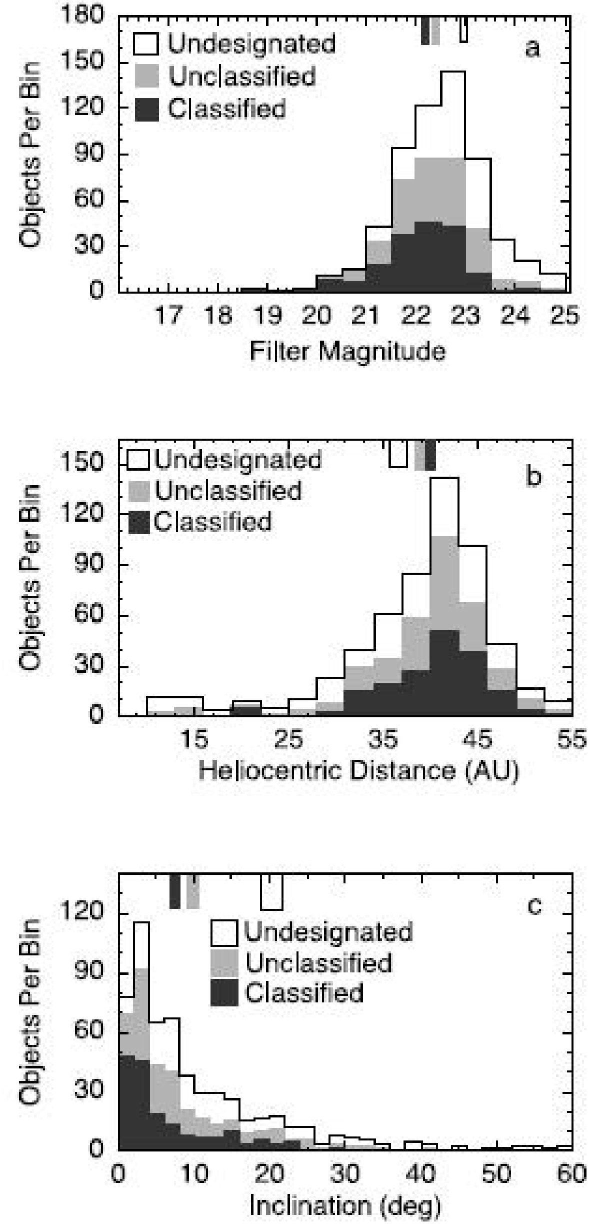
A deficit at small-size end?

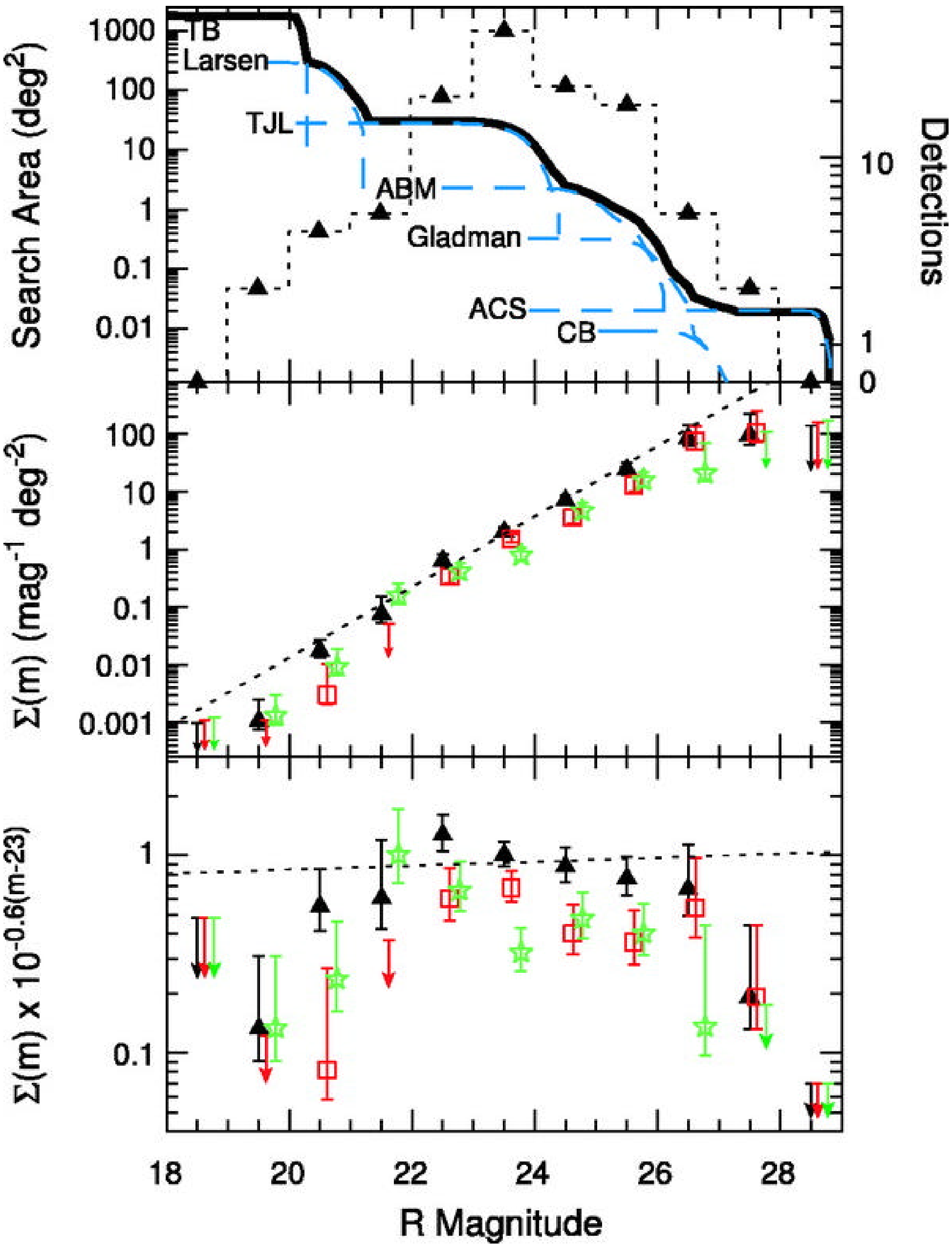


Distinctly different populations!

FIG. 17.—The unbiased KBP inclination distribution as a function of KBO classification. The fraction of objects in the sample per degree of inclination is the same as Fig. 16, with each bin shaded to reflect the proportion of objects by classification. Unclassified objects are represented by open areas, Resonant objects are light gray, Scattered (Near and Extended) objects are dark gray, and Classical objects are black. The low-inclination "core" is primarily composed of Classical objects, while the higher inclination "halo" is primarily Scattered objects. Along the KBP inclination axis, the boundary between Classical and Scattered objects is not distinct.

← Elliot et al. 2005 →





HST/ACS with 22 ks per pointing found 3 KBOs, with the faintest of 28.3 mag, corresponding to a size of 25 km!

Deficit in both large and small bodies

Classical KB and Excited KB are different

CKBOs mostly 100 km bodies with a second peak <10 km

Largest EKBOs=Pluto

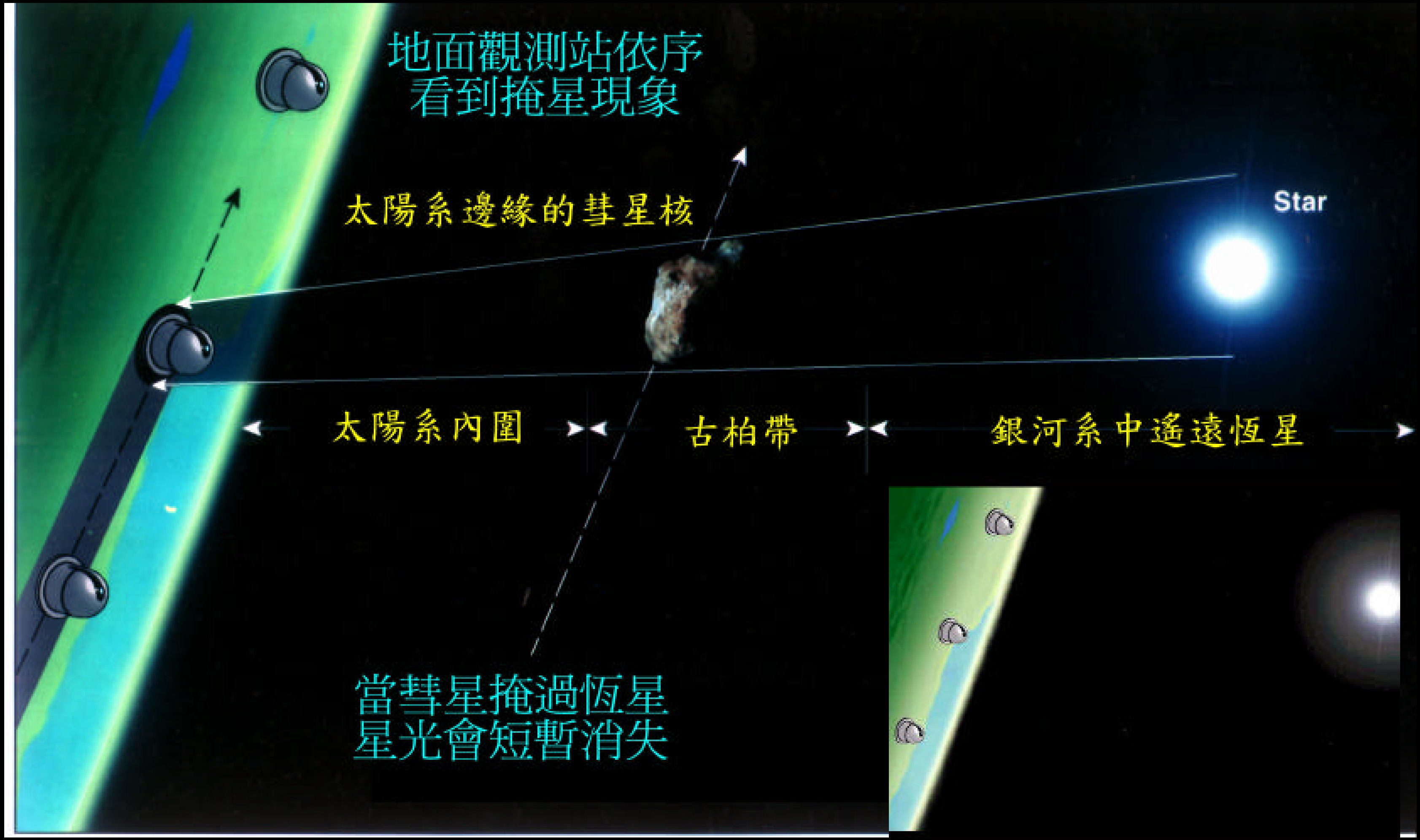
Burnstein et al. (2004)

- ✓ KBOs are building blocks of planets/satellites, so bear much information of formation and evolution history of the Solar System.
- ✓ But they can be studied only when come near the Sun/Earth and display cometary behavior.
- ✓ Otherwise they are extremely faint ***B*** µ **[size]^2(*1/d*)*2* (*1/d*)*2***
- ✓ Only the largest (> a few tens km) can be seen by reflected sunlight
- ✓ Smaller ones (~km), though likely much numerous on theoretical grounds (e.g., Kenyon & Bromley 2004), cannot be seen even with the largest telescopes.

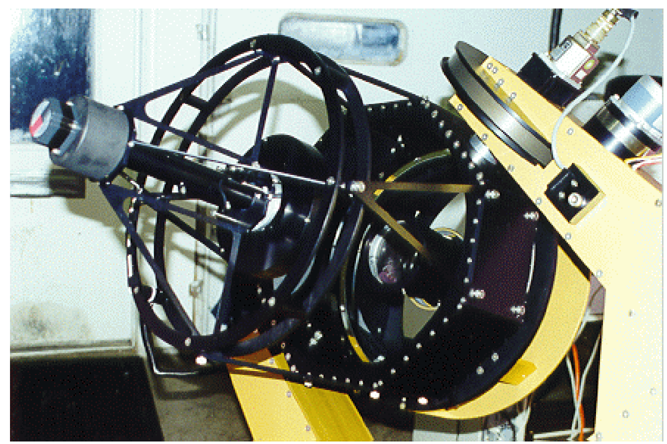
➔ We just begin to learn about their spatial distribution, sizes, composition. But we really do not even know **their total number,** especially the small ones (collisional fossils?)

Hence the TAOS project --- to 'see' them by blocking starlight

TAOS will detect KBOs by stellar occultation



TAOS has been a highly challenging project!!



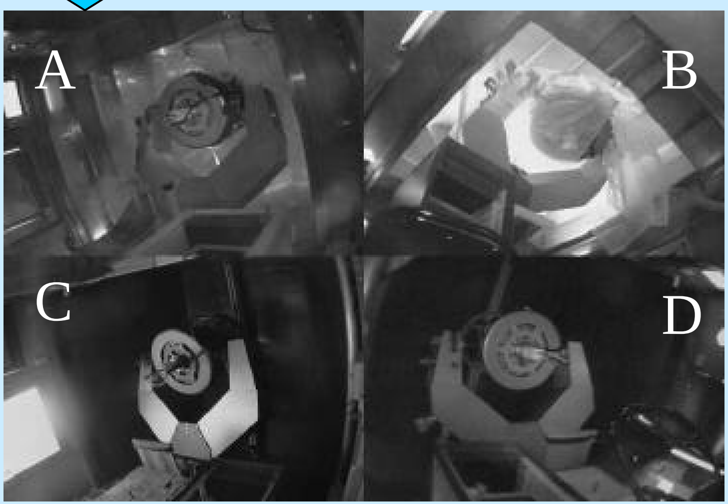
TAOS telescope: D=0.5 m; f/1.9

Hardware

- 50 cm f/1.9 Cassegrain by Torus
- SI800 camera (2K sq EEV) by Spectral Instruments
- Self-designed, customer-made enclosure

×4

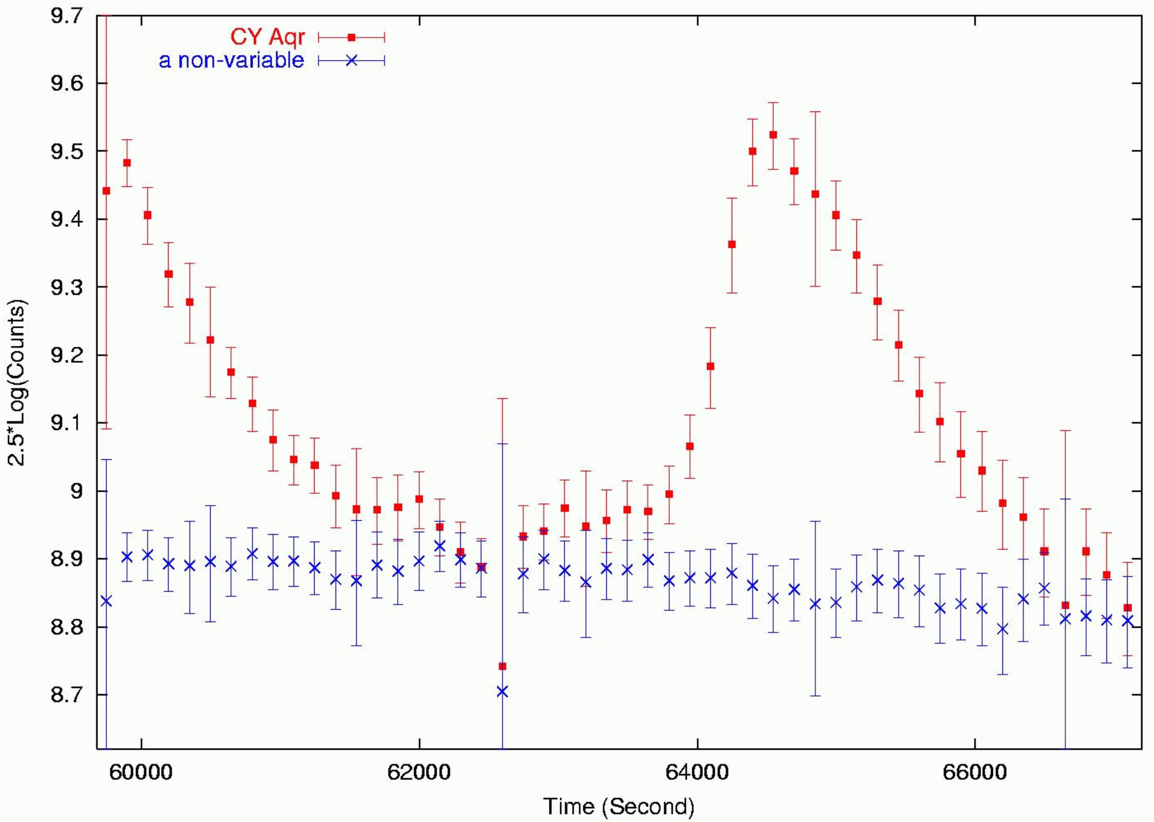
by SK King (15 Oct. 2004)



Real-time webcam images of the 4 TAOS telescopes (by SK King, 26 Oct. 2004)

TAOS Telescopes

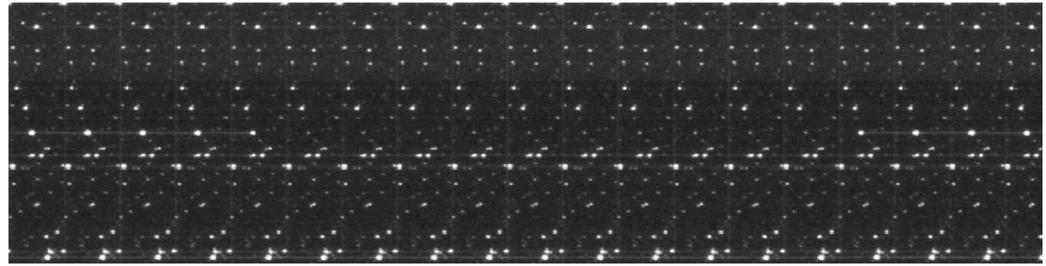
TEST DRIVE 1

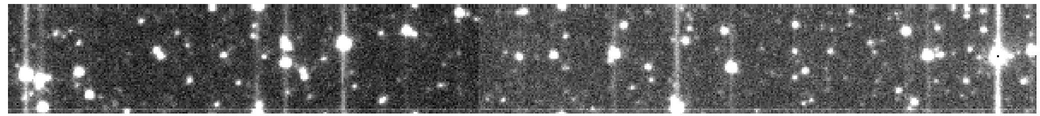


CY Aqr, a known Delta-Scuti star with P~88 min, was observed by TAOS on 2003 September 16 with 0.3 s sampling, here binned to 150 s for illustration.

➔ **time-domain astrophysics**

TEST DRIVE 2

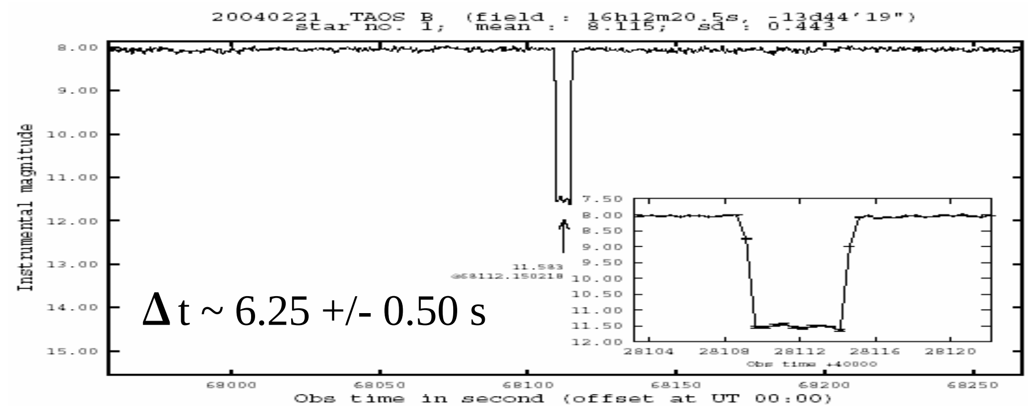


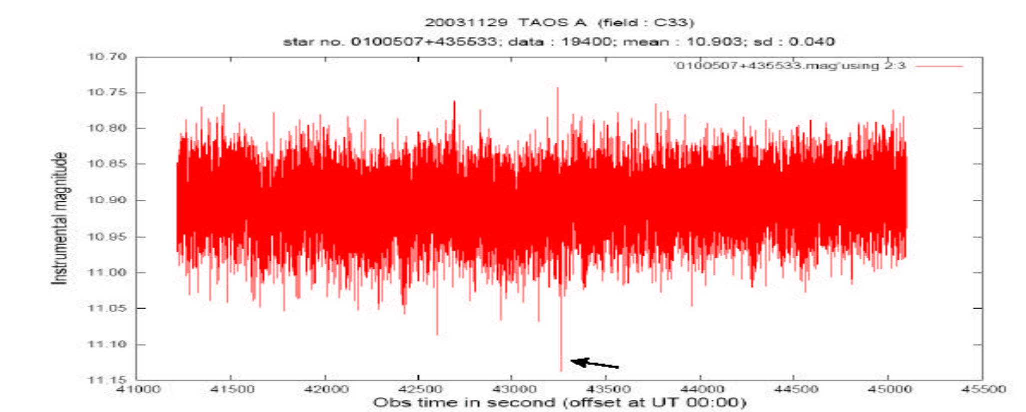


2004 February 21
TAOS detected the occultation event of HIP 079407, m_V=8.8 mag) by **(51) Nemausa** (m_V=11.9)

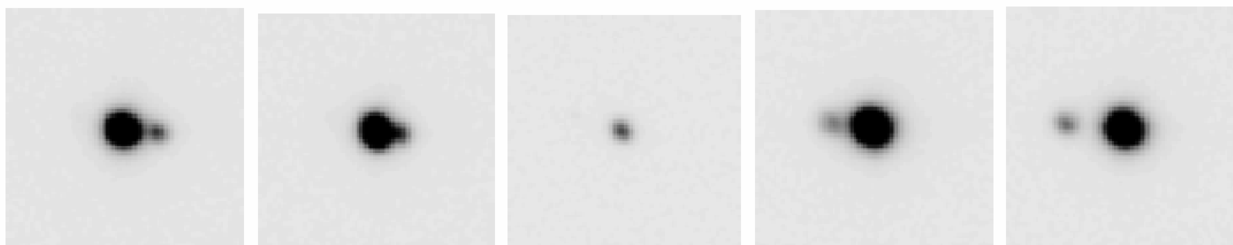
Prediction by Isao Sato (左藤勳)

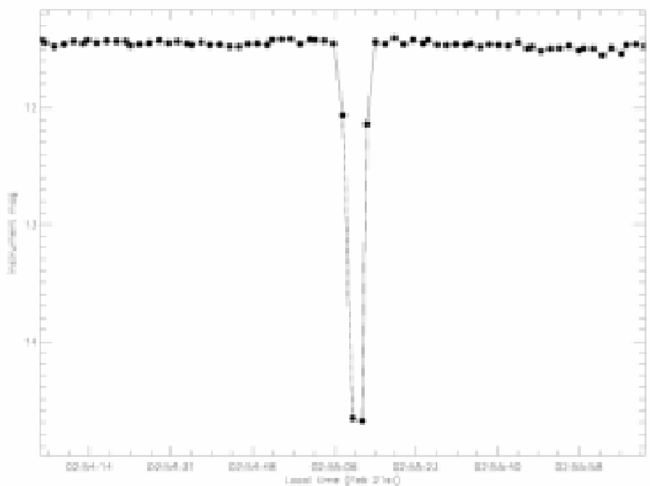
D~150 km





The 1 m telescope at Lulin also detected the same event with traditional CCD imaging.



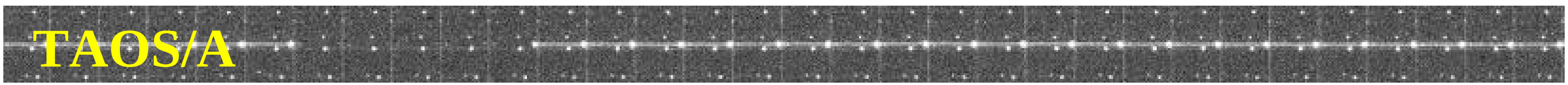


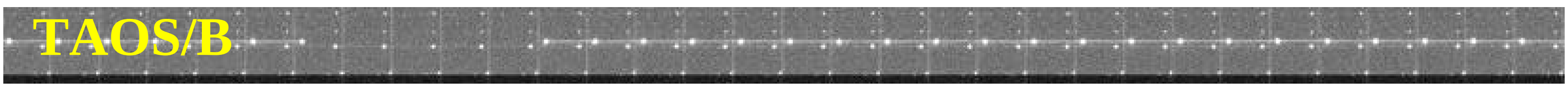
t_{exp} =1 s
t_{ro} < 2 s

By A. Chen

TEST DRIVE 3

2004 June 05 TAOS detected the occultation of HIP 050525 (m_V~8.46 mag) by **(1723) Klemola** (m_V~15.7 mag; D~31 km) with two telescopes





Enclosure opened by a resident assistant and observations carried out remotely from Taipei

TAOS Talks to Look Out For

- 09:30—09:45 **Ib-1** W. P. Chen
  The TOAS Project – Current Status
- 09:45—10:00 **Ib-2** Z. W. Zhang
  TAOS Photometry Pipelines and Event Detection Algorithms
- 10:00—10:15 **Ib-3** Matt Lehner
  Photometry --- EM Principles and Example
- 11:30—11:45 **IIb-3** S. K. King
  TNO occultation survey: event rate, simulation & interpretation
- 11:45—12:00 **IIb-4** C. Y. Wen
  TAOS Software Overview: A Robotic System
- 10:00—10:15 **IIIb-3** S. Mondal
  Stellar angular diameters and occultation by KBOs
- *11:15—11:30 **IVb-2** J. S. Liang
  X-Ray Source as a TNO Occultation Survey Target
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  Possible Improvements of TAOS Performance

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  TAOS Software Overview: A Robotic System

Events short, with duration typically ~0.2 s

→ **high-speed photometry**

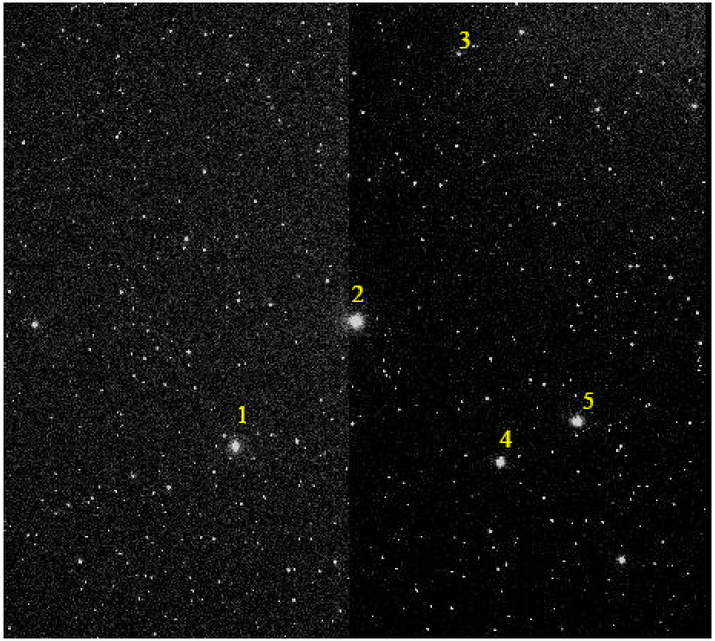
Events expected extremely rare

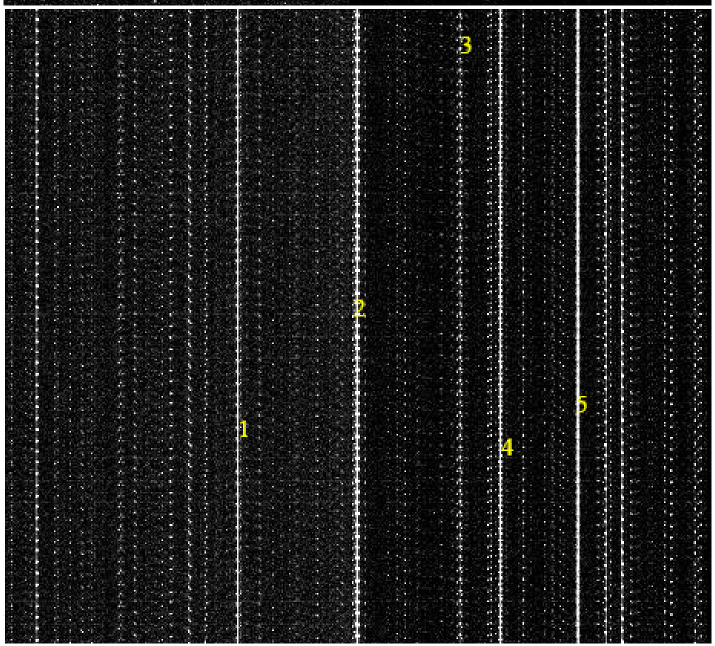
→ **A large number of targets**

HUGE DATA VOLUME (up to 100 GB/night)

➔ Challenges in data acquisition hardware and software

➔ Challenges in data analysis, storage, and archival

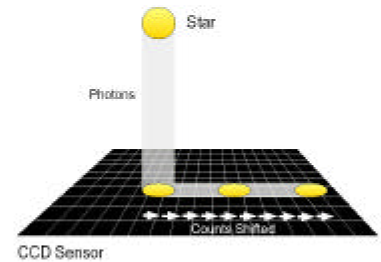




Data Acquisition

Typical CCD imaging

Every star, together with surrounding skies, get exposure at the same time

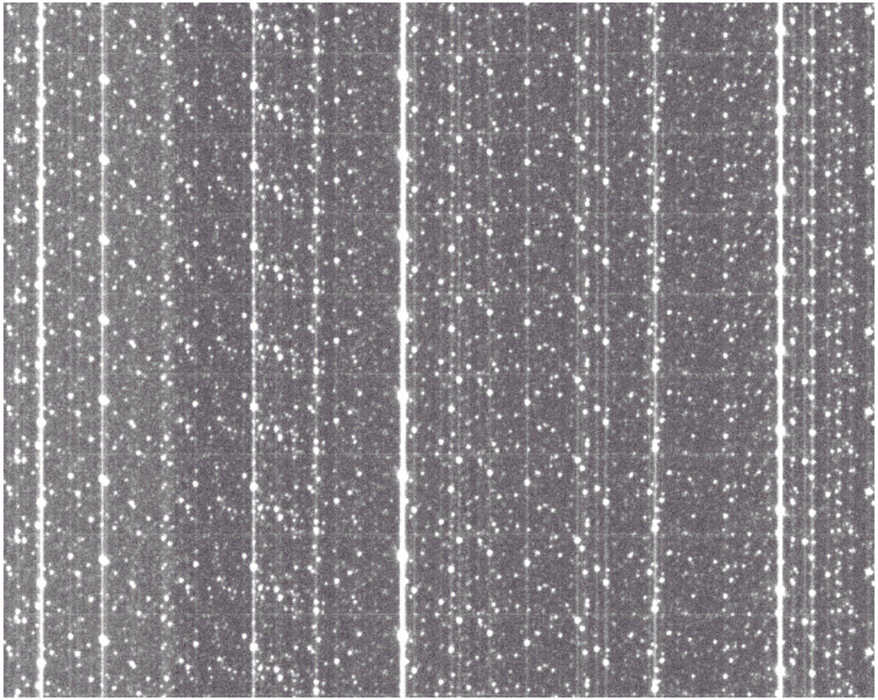


TAOS data

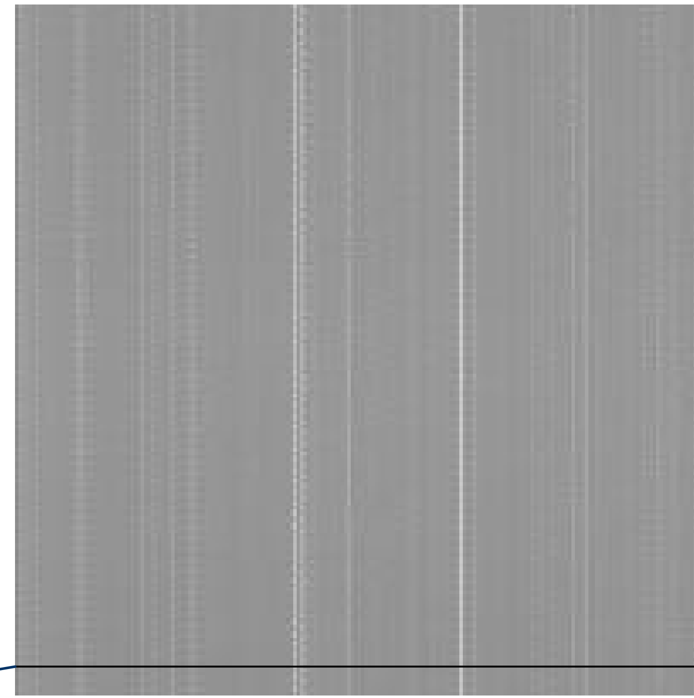
Integrate for 200 ms and then read out 32 rows of pixels, with the shutter remains open

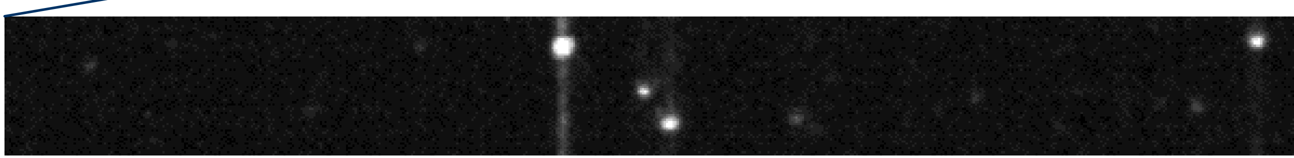
The sequence continues, so each star appears as a series of dots ➔ 'zipper'

'Fake' neighboring stars and skies!



A section of an actual
TAOS zipper image





Event Detection --- Rank Statistics

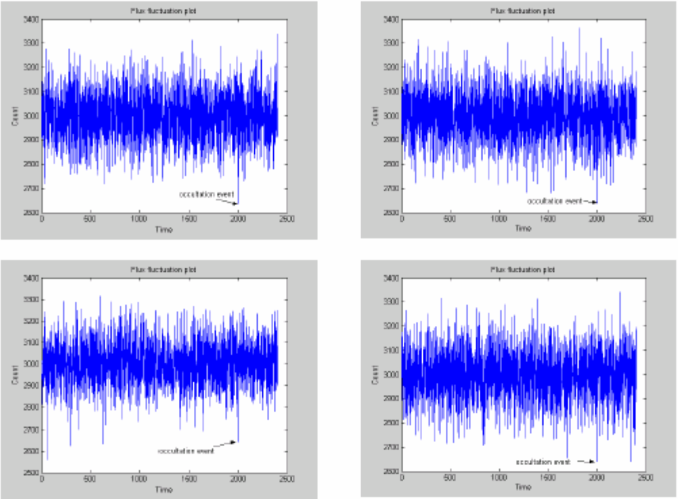
- Use the rank, instead of the flux, to quantify the light curve

$$Z_w = \log_{10}(S^4) - \log_{10}(\prod_{i=1}^{4} W_i)$$

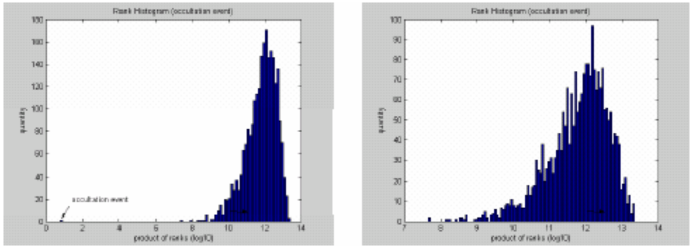
- A true occultation event should have the lowest rank in **all** telescopes

no need for highly accurate flux
➔ speed

conditional probability
➔ low false rates

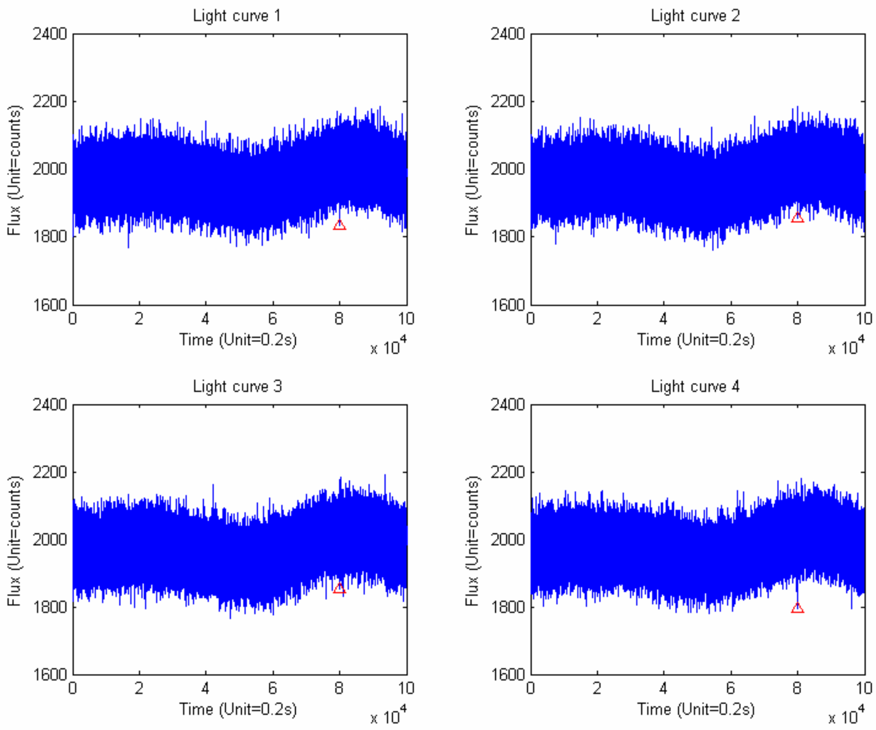


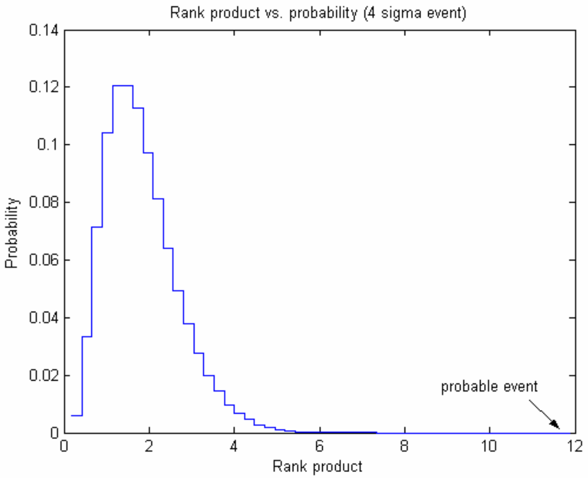
Simulated light curves by each of the four telescopes



With occultation *Without*

Ranking statistics





← Higher ranking

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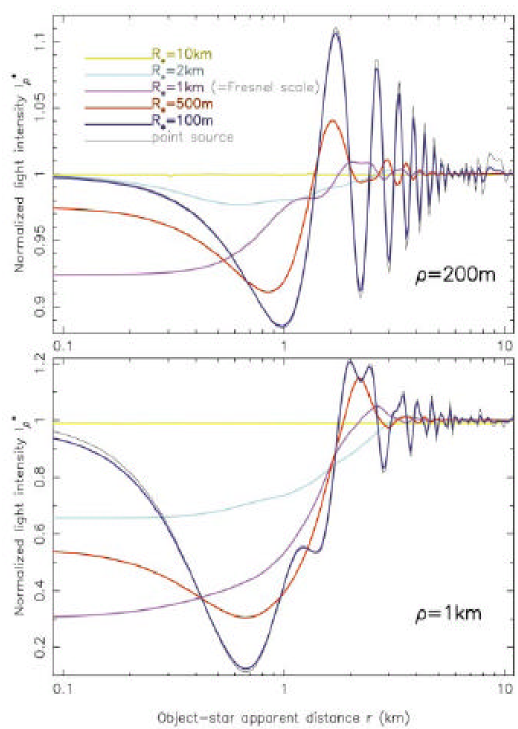
  Stellar angular diameters and occultation by KBOs

Alas, an occultation is not a simple block of starlight.

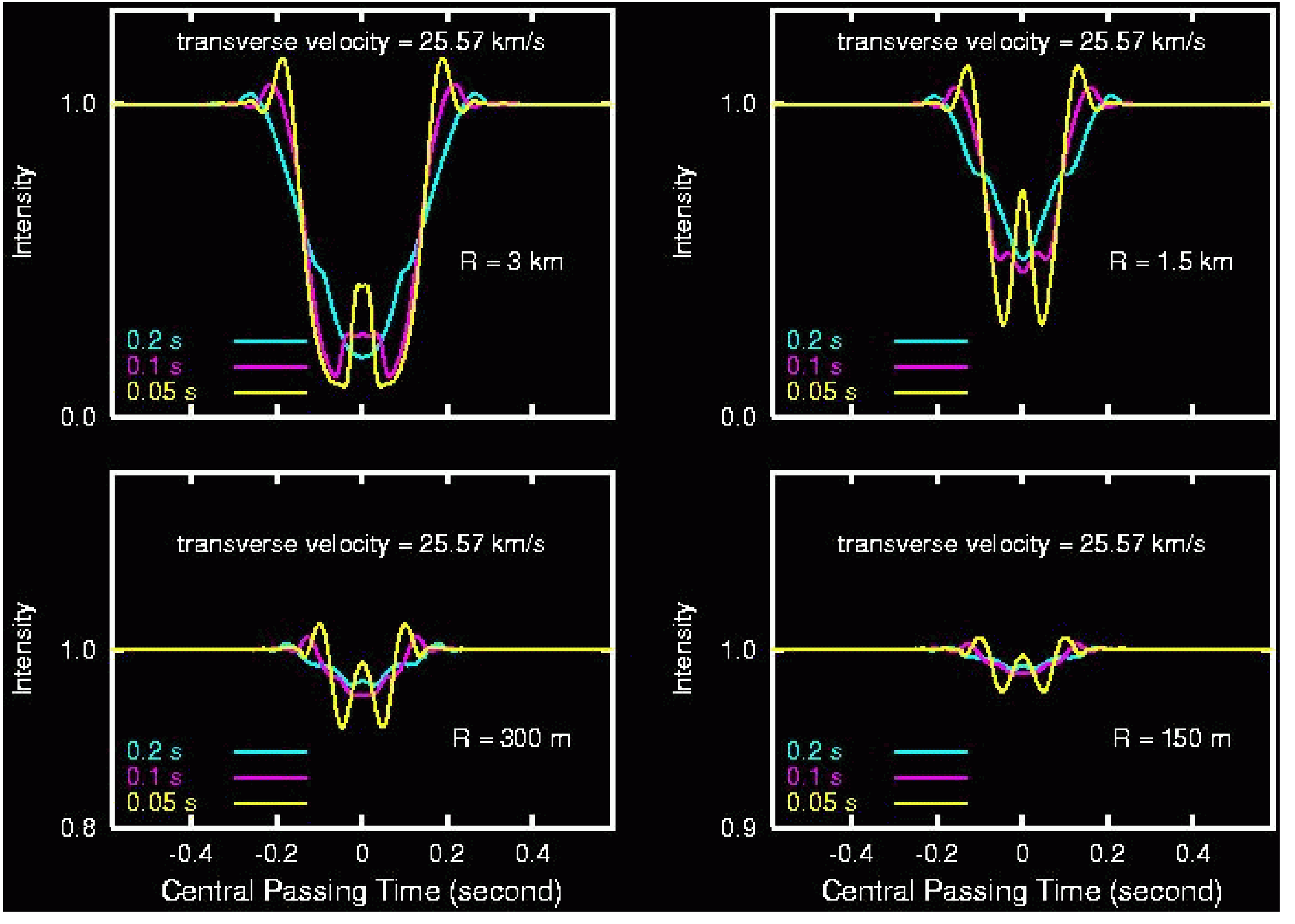
If the KBO has a small angular size (a small diameter or a large heliocentric distance) compared to the background star
➔ (Fresnel) diffraction effects



Roques et al. 2000

KBO: circular @ 50 AU, Target star: A0 (T=9790 K, black body)

Spectral properties + different sampling rate + point source



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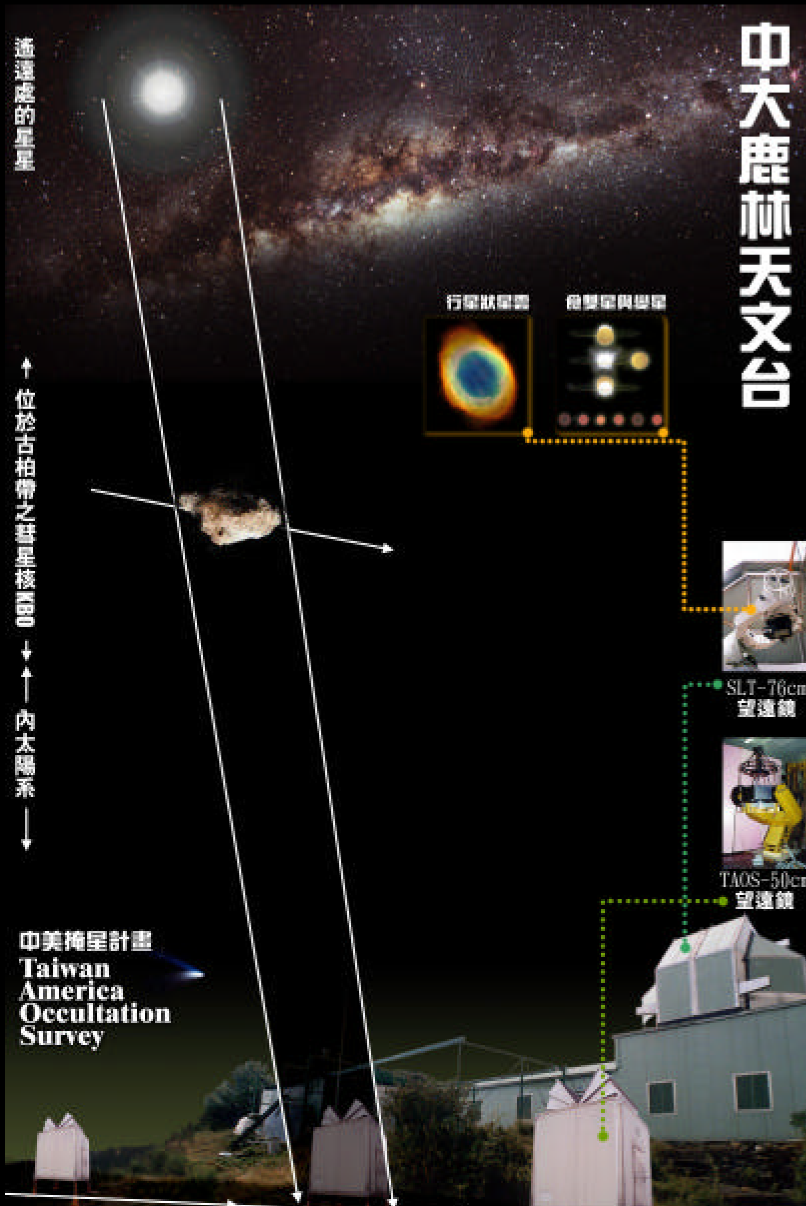
  Possible Improvements of TAOS Performance

A much efficient camera system --- the frame-transfer CCD

Better telescope optics

…



The TAOS systems have been taking scientific data since last winter.

Routine survey with 4 telescopes will begin by this fall.

The system will also respond to GRB alerts.

Stellar variability on (sub)second time scales can be explored.

Stay tuned!