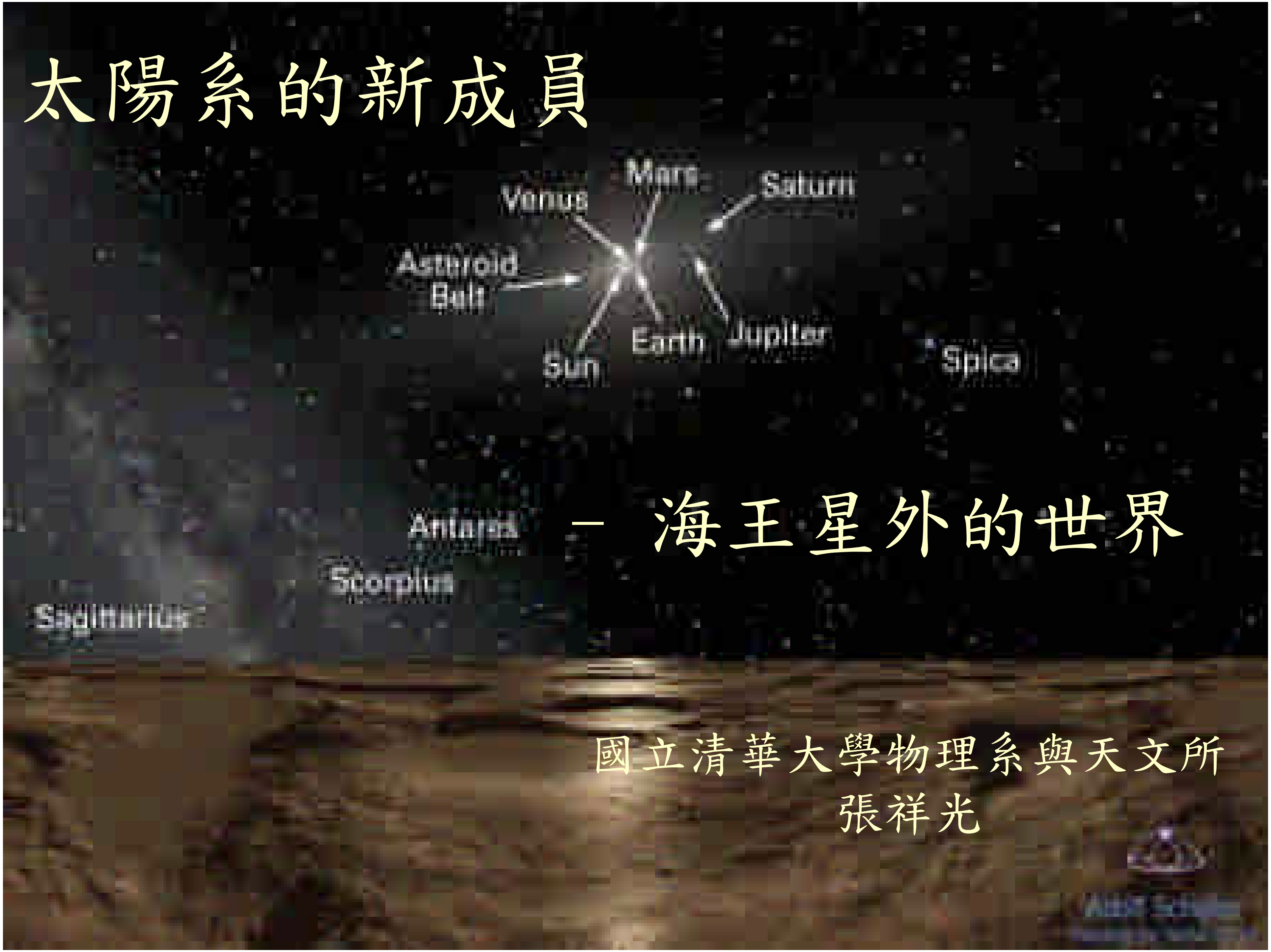
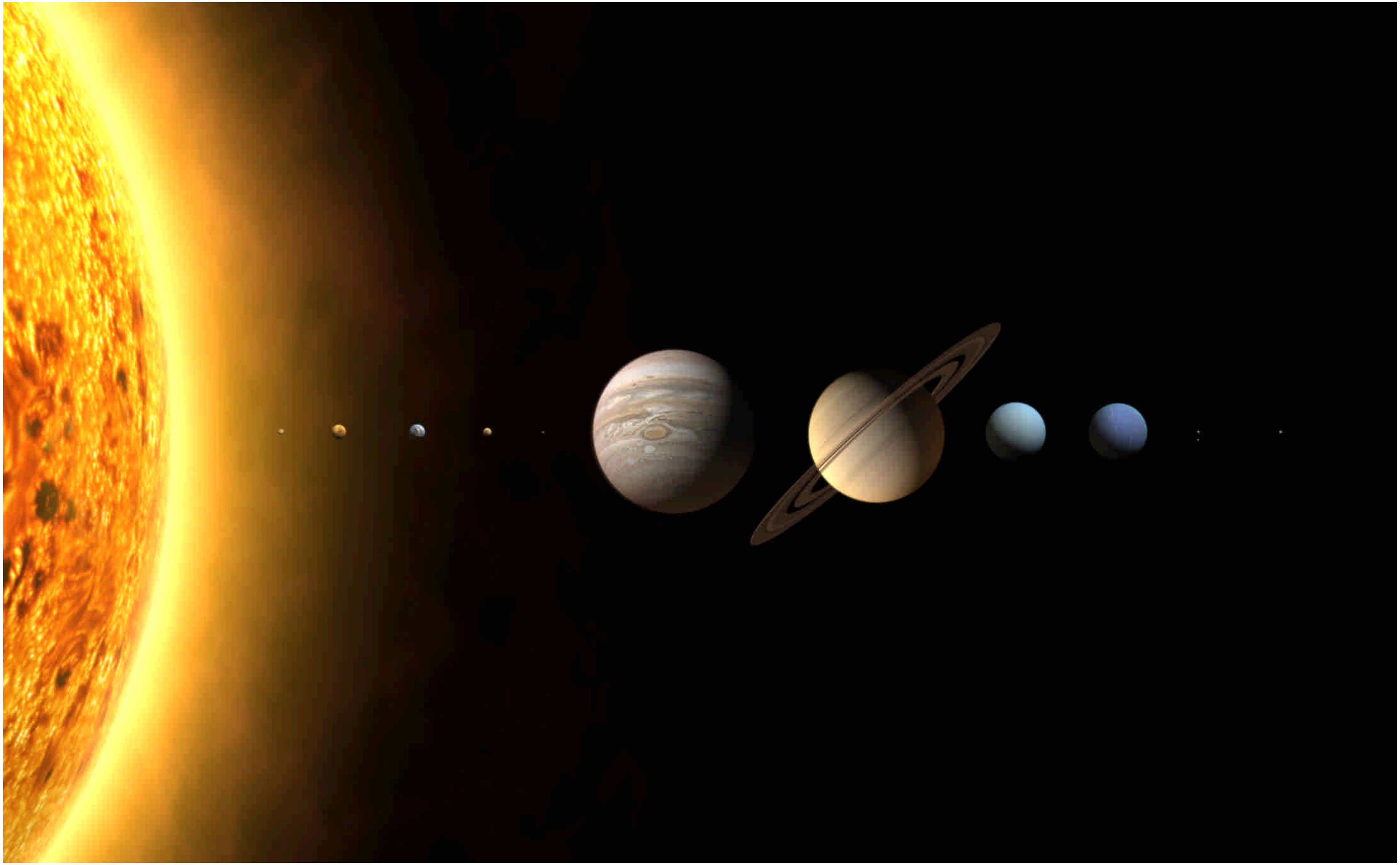


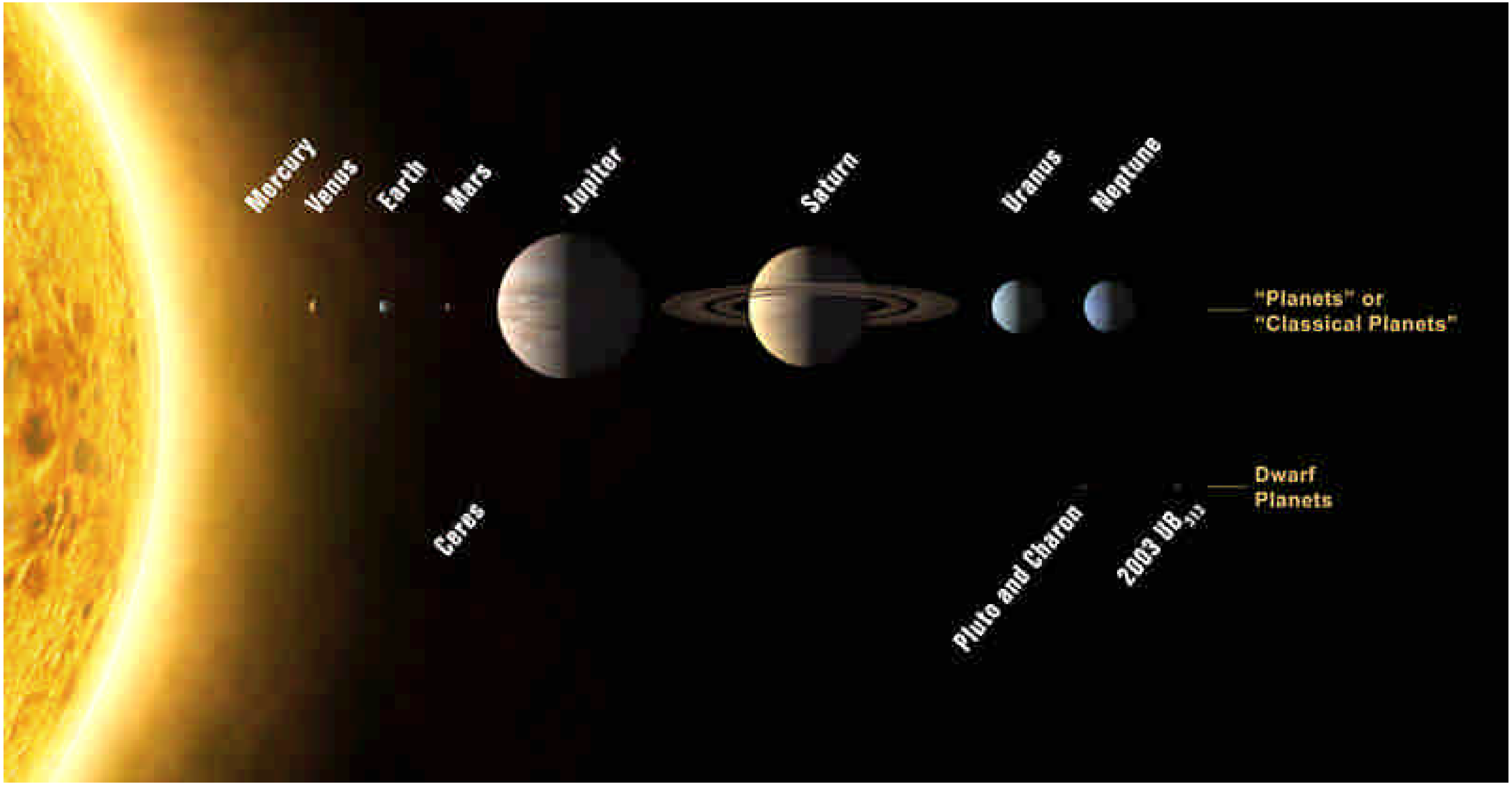
太陽系的新成員

– 海王星外的世界

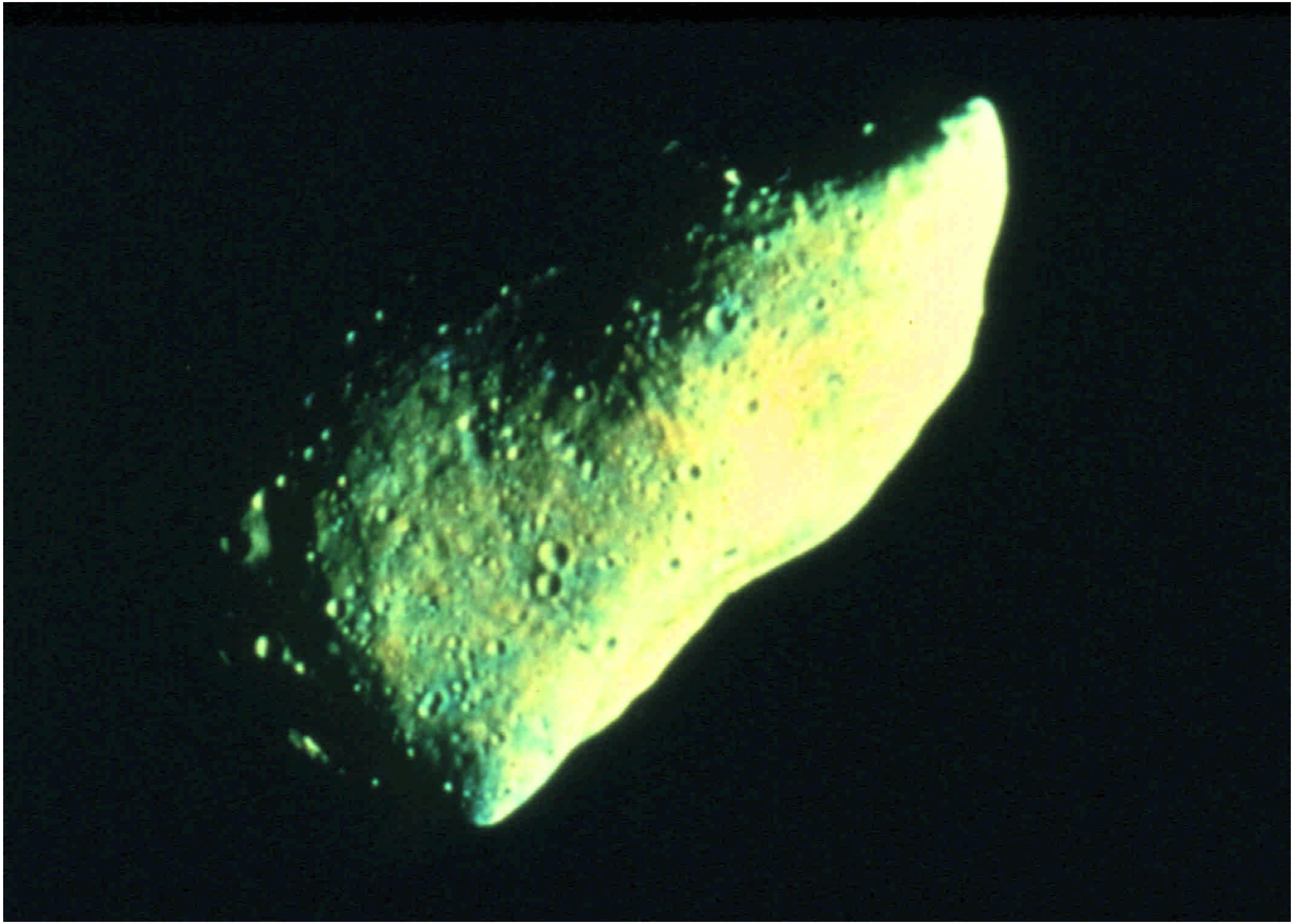
國立清華大學物理系與天文所
張祥光

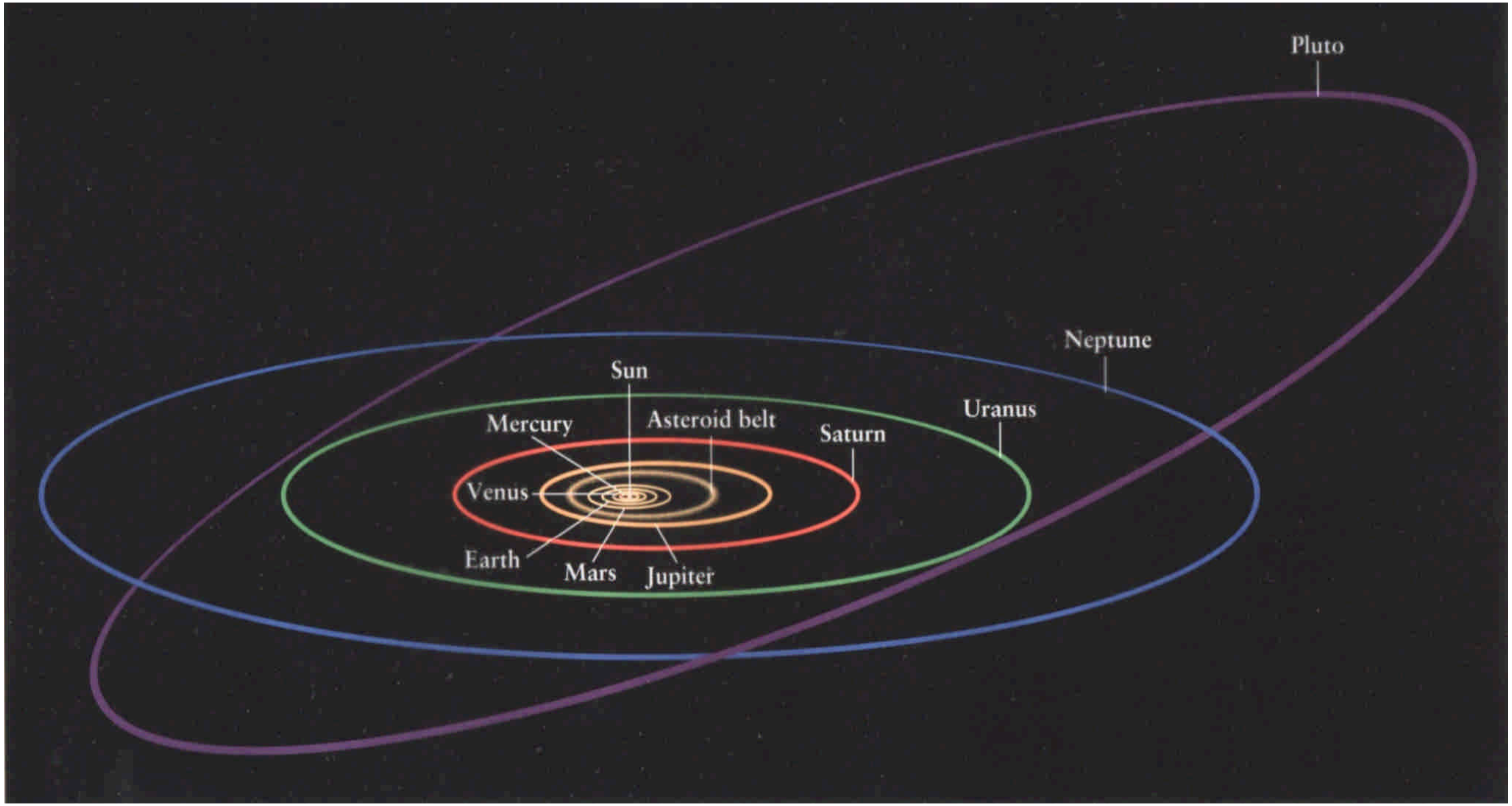


The 26th IAU General Assembly, Session 2, Prague, Aug 24, 2006

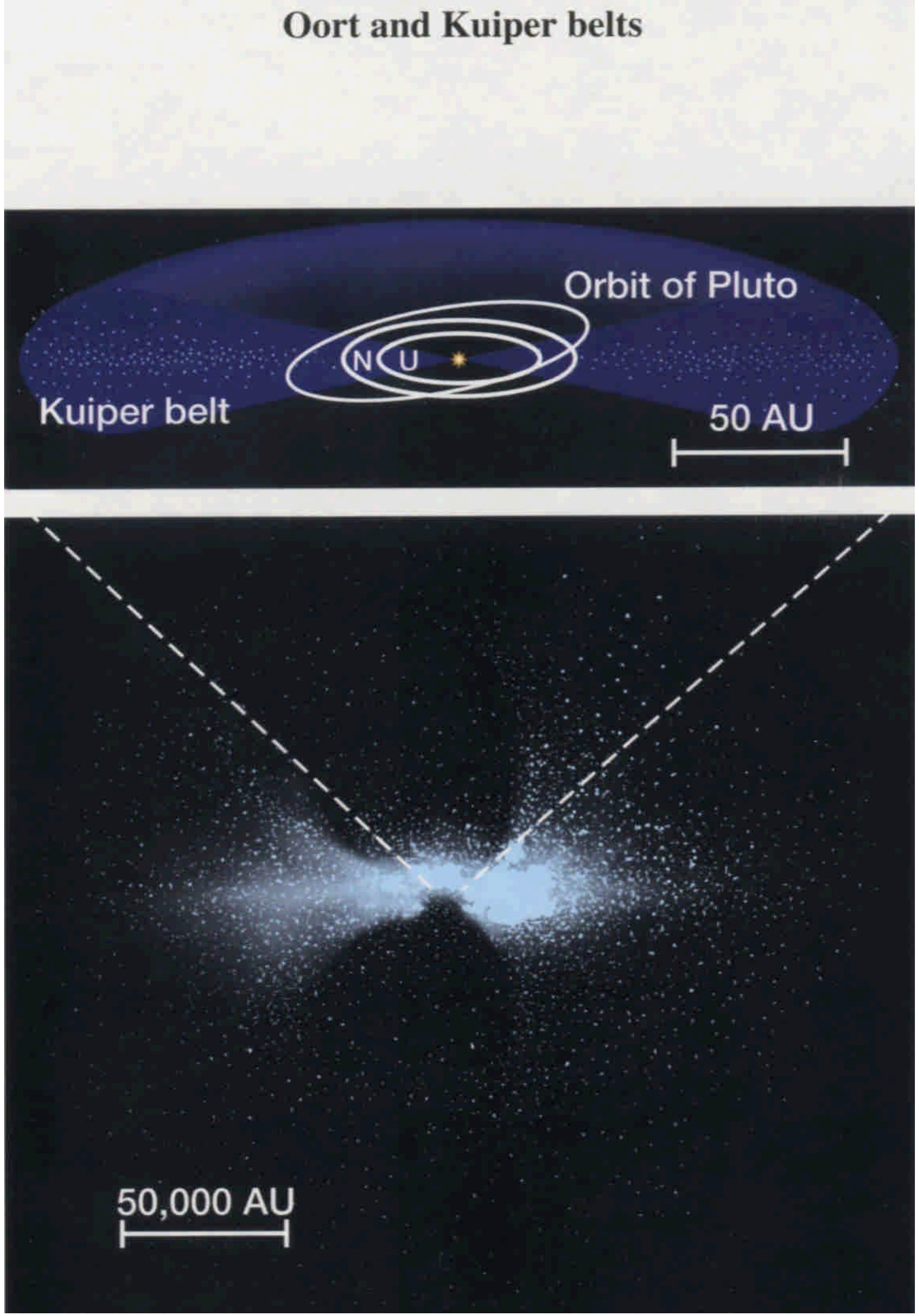


依據國際天文聯合會（IAU）2006年大會決議，太陽系中的天體(衛星除外)分為三類:
行星（planets)、
矮行星（dwarf planets)、
小型太陽系物體（small solar-system bodies)。
<http://www.iau.org/iau0603.414.0.html>





The solar system we know as of 1930.



古柏帶

(Kuiper Belt)

古柏帶物體

(Kuiper Belt Objects, KBOs)

奧特雲

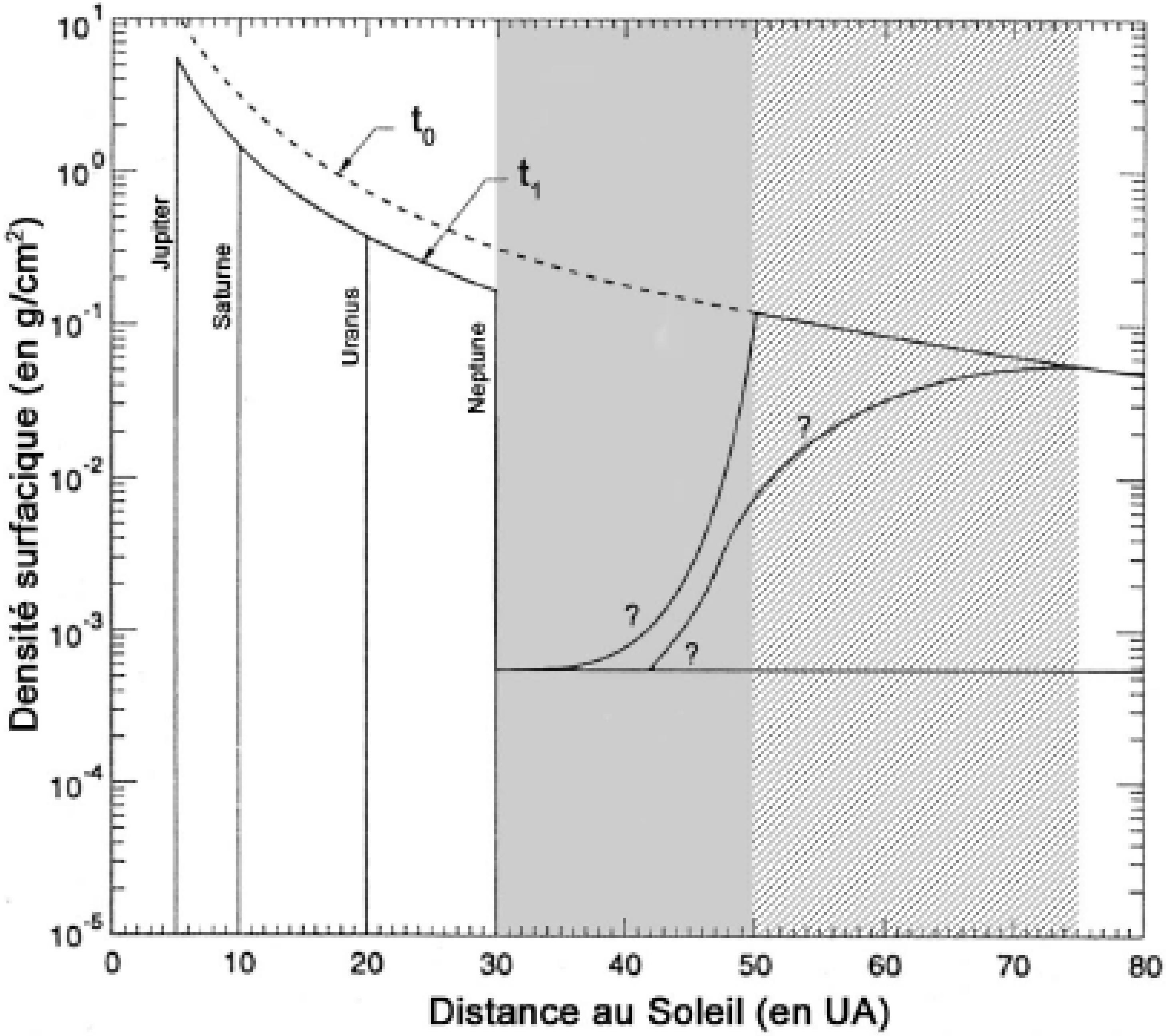
(Oort Cloud)

proposed by
Leonard (1930),
Edgeworth (1943, 1949),
Oort (1950),
Kuiper (1951)

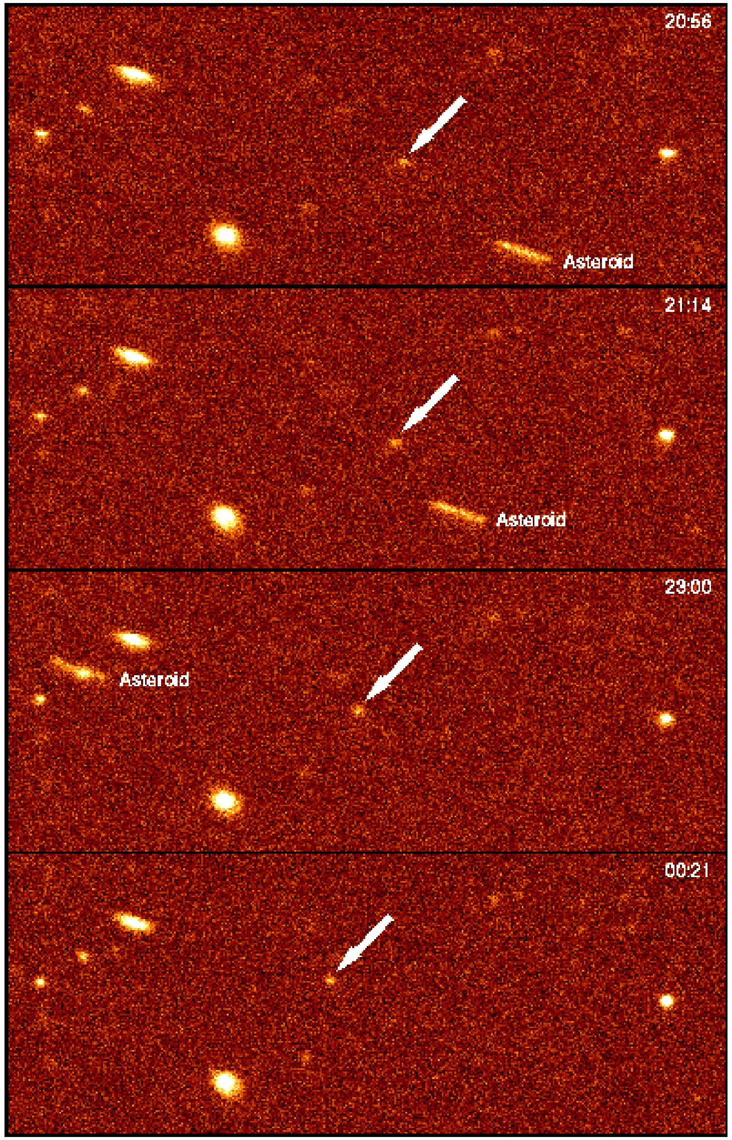
So, sometimes EKB, EKBOs.

Trans-Neptunian region

Trans-Neptunian Objects (TNOs)



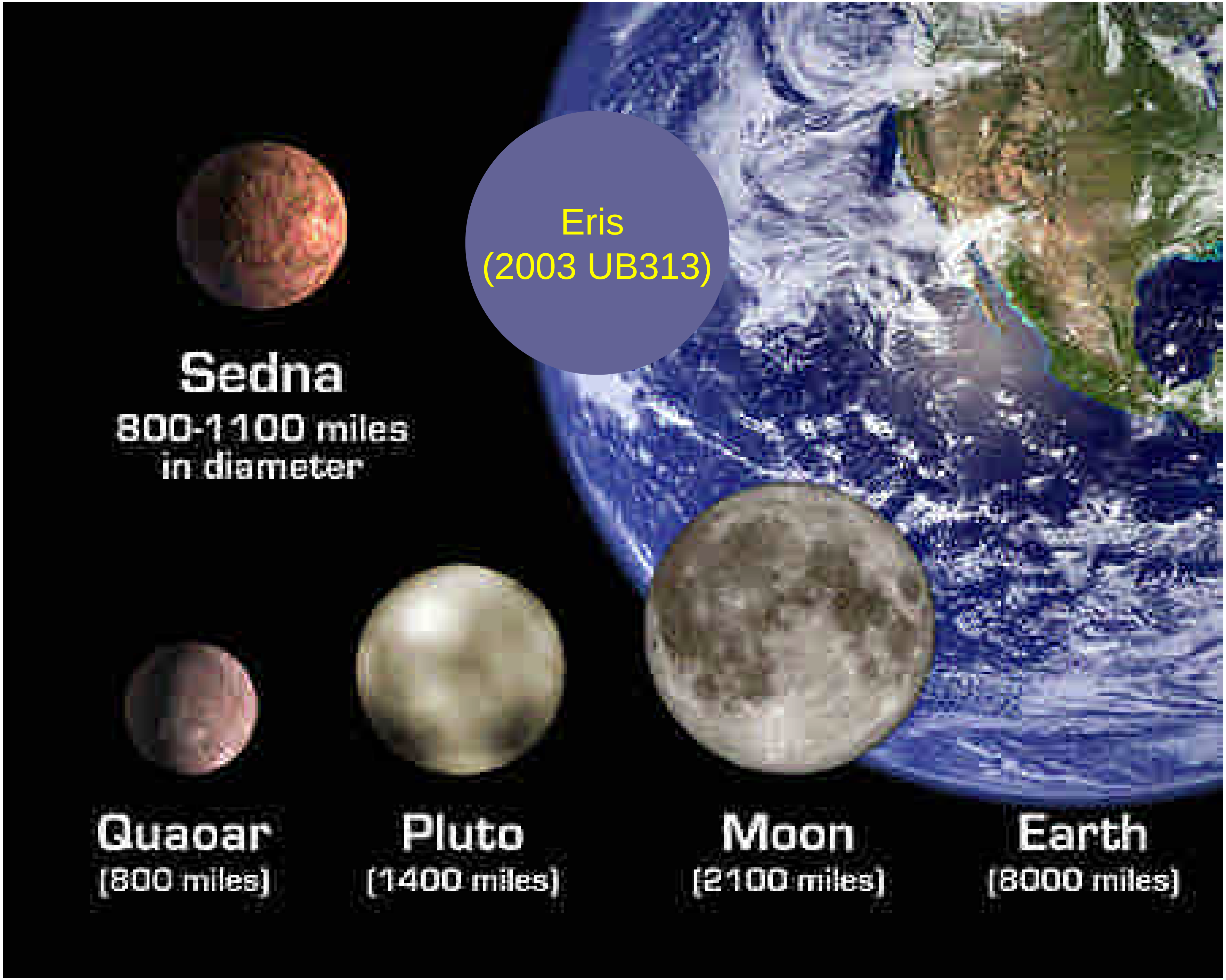
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Densité surfacique (en g/cm^2)
0
10
20
30
40
50
60
70
80
Distance au Soleil (en UA)
t_0
t_1
Jupiter
Saturne
Uranus
Neptune
?
?
?



The first object in the trans-Neptunian region, beside Pluto, was discovered in 1992.

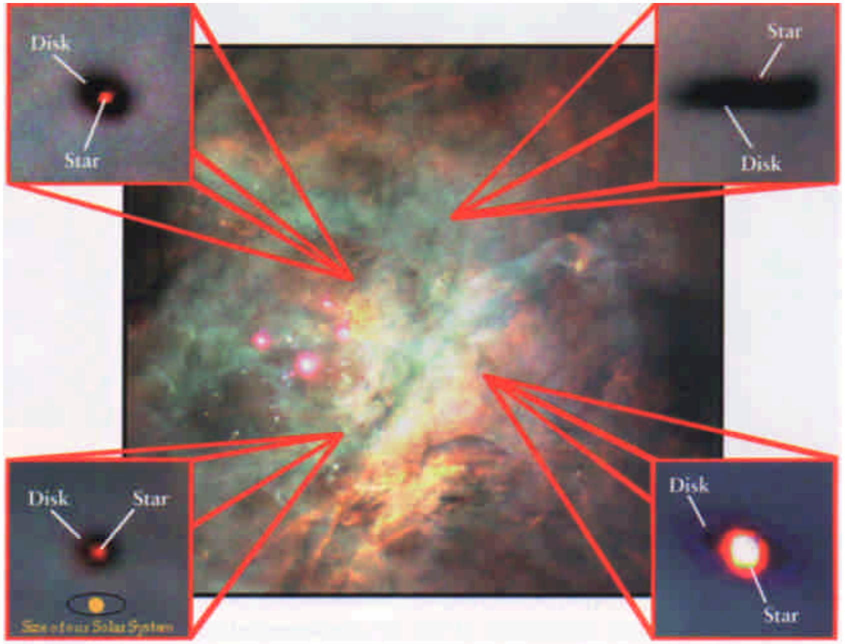
D. Jewitt & J. Luu

IAUC 5611 (1992.09.14)


Sedna
800-1100 miles
in diameter
Eris
(2003 UB313)
Quaoar
(800 miles)
Pluto
(1400 miles)
Moon
(2100 miles)
Earth
(8000 miles)

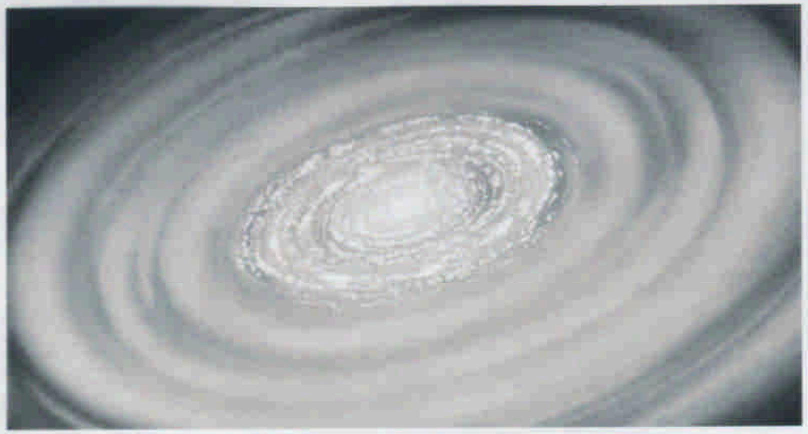
Alain Doressoundiram


Mars
Venus
Saturn
Asteroid Belt
Sun
Earth
Jupiter
Spica
Antares
Scorpius
Sagittarius

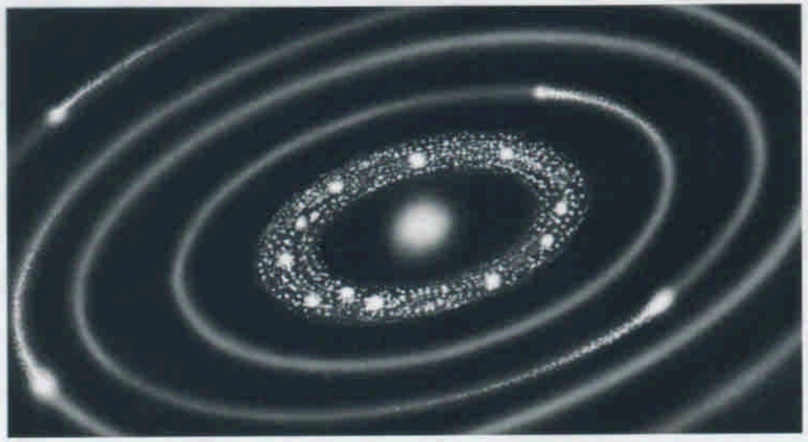


星際間的分子雲氣重力塌陷形成恆星

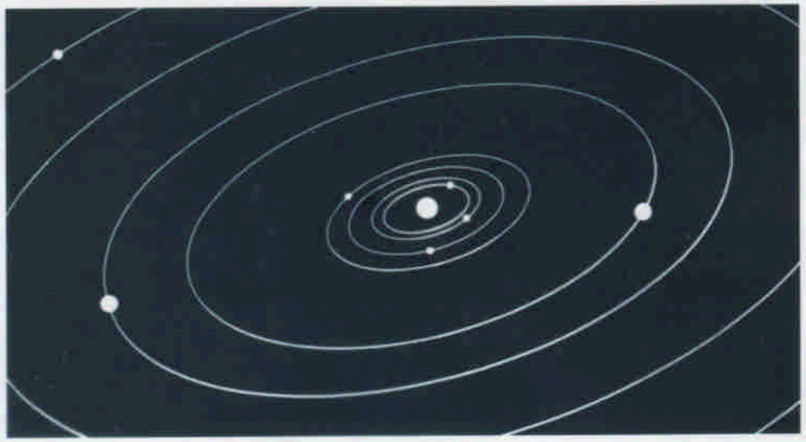
形成中的恆星常伴隨著充滿固體
微粒塵埃與分子雲氣的拱星盤



a



b

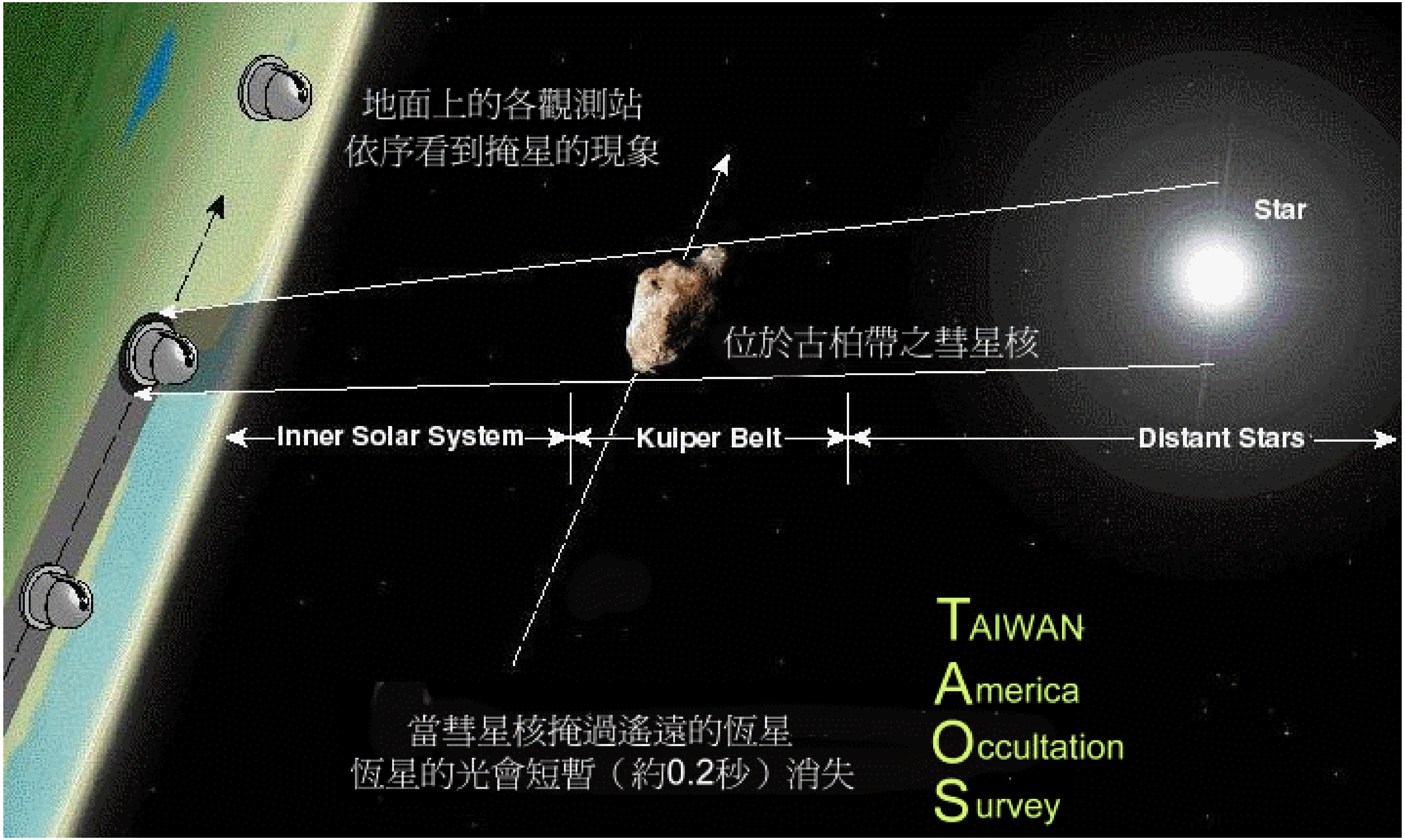


c

拱星盤中的固體微粒塵埃與分子雲氣漸漸凝結、碰撞、合併、碎裂，而形成今天的行星系統。

近年來發現的海王星外天體可以進一步幫助我們了解當時的形成過程。

不過，較小的海王星外天體因為太遠太小，沒有辦法被直接觀測到。


地面上的各觀測站
依序看到掩星的現象
Star
位於古柏帶之彗星核
Inner Solar System
Kuiper Belt
Distant Stars
當彗星核掩過遙遠的恆星
恆星的光會短暫（約0.2秒）消失
TAIWAN
America
Occultation
Survey

Optical occultation search:

French – Roques et al. Paris Observatory

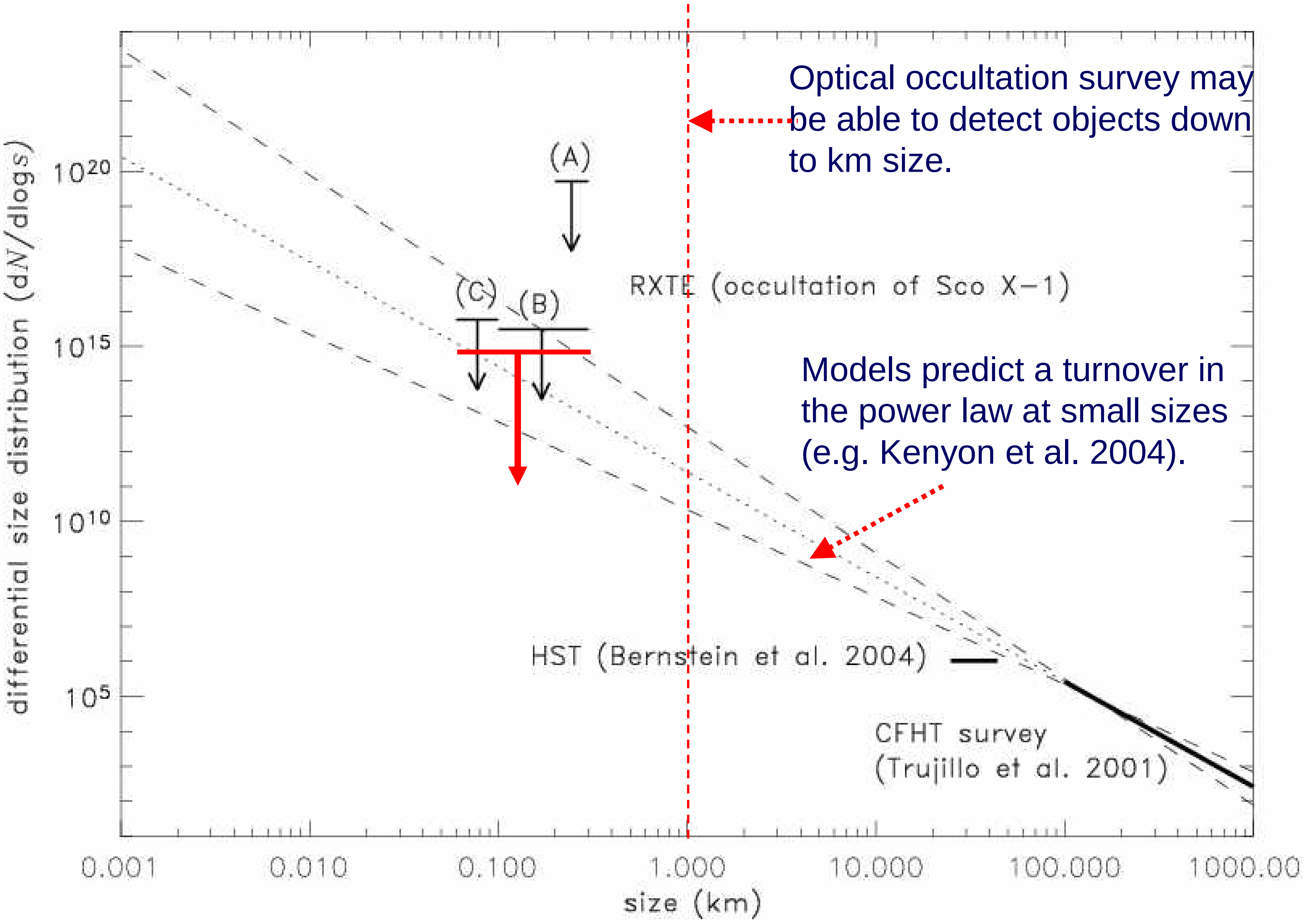
Australian – Georgevits et al. U of New South Wales

Canadian – Kavelaars et al., Herzberg Instutue of Astrophysics

TAOS – CfA, NCU, ASIAA No definite detections so far……

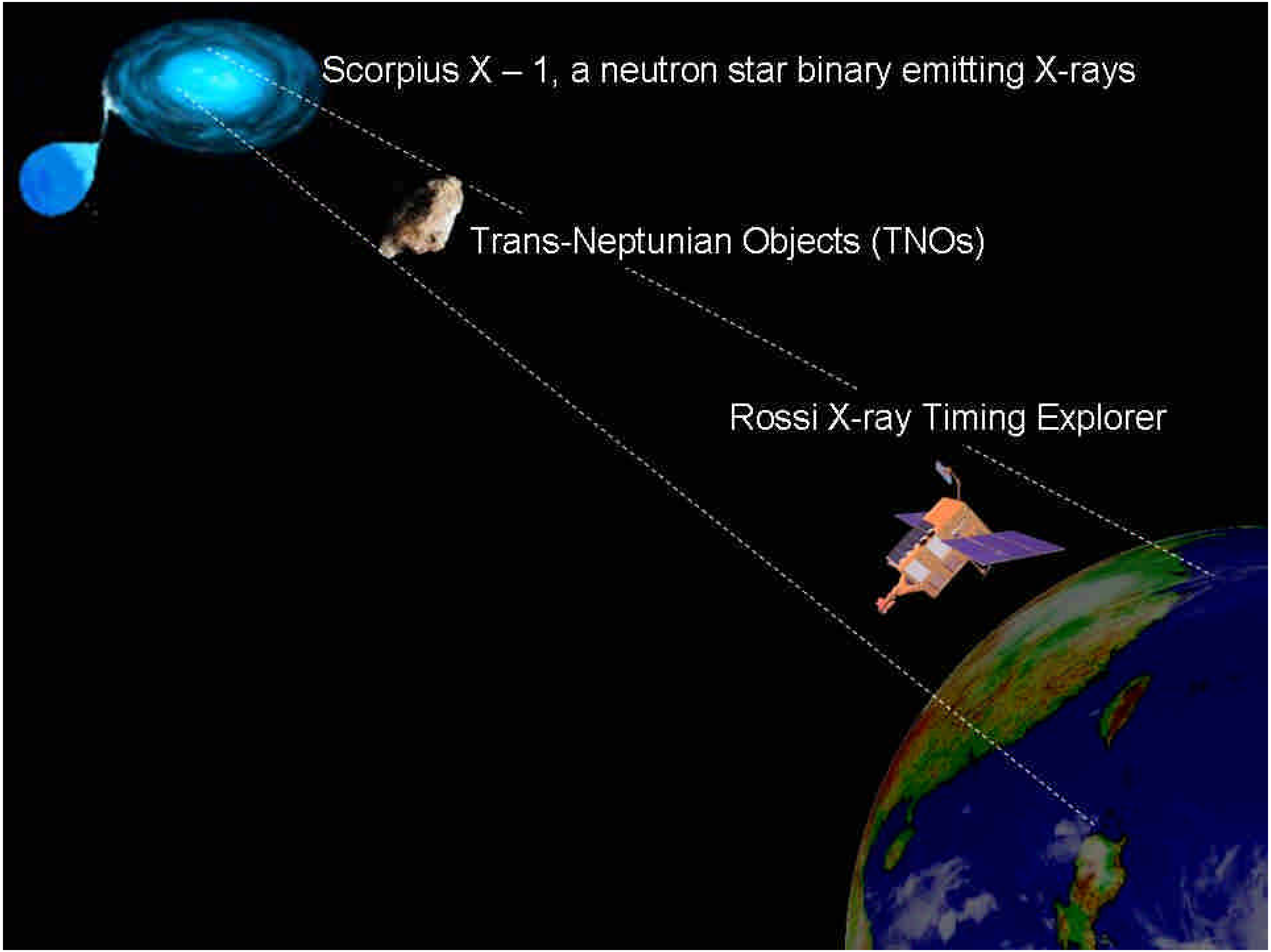
UltraPhot – Paris Observatory, NTHU

(Whipple – CfA, JPL)
(OCLE-DOCLE – Canada)



Optical occultation survey may be able to detect objects down to km size.

Models predict a turnover in the power law at small sizes (e.g. Kenyon et al. 2004).



Scorpius X – 1, a neutron star binary emitting X-rays

Trans-Neptunian Objects (TNOs)

Rossi X-ray Timing Explorer

Why X-ray occultation?

faster photometry
less diffraction → shorter events → smaller bodies → better chance to detect

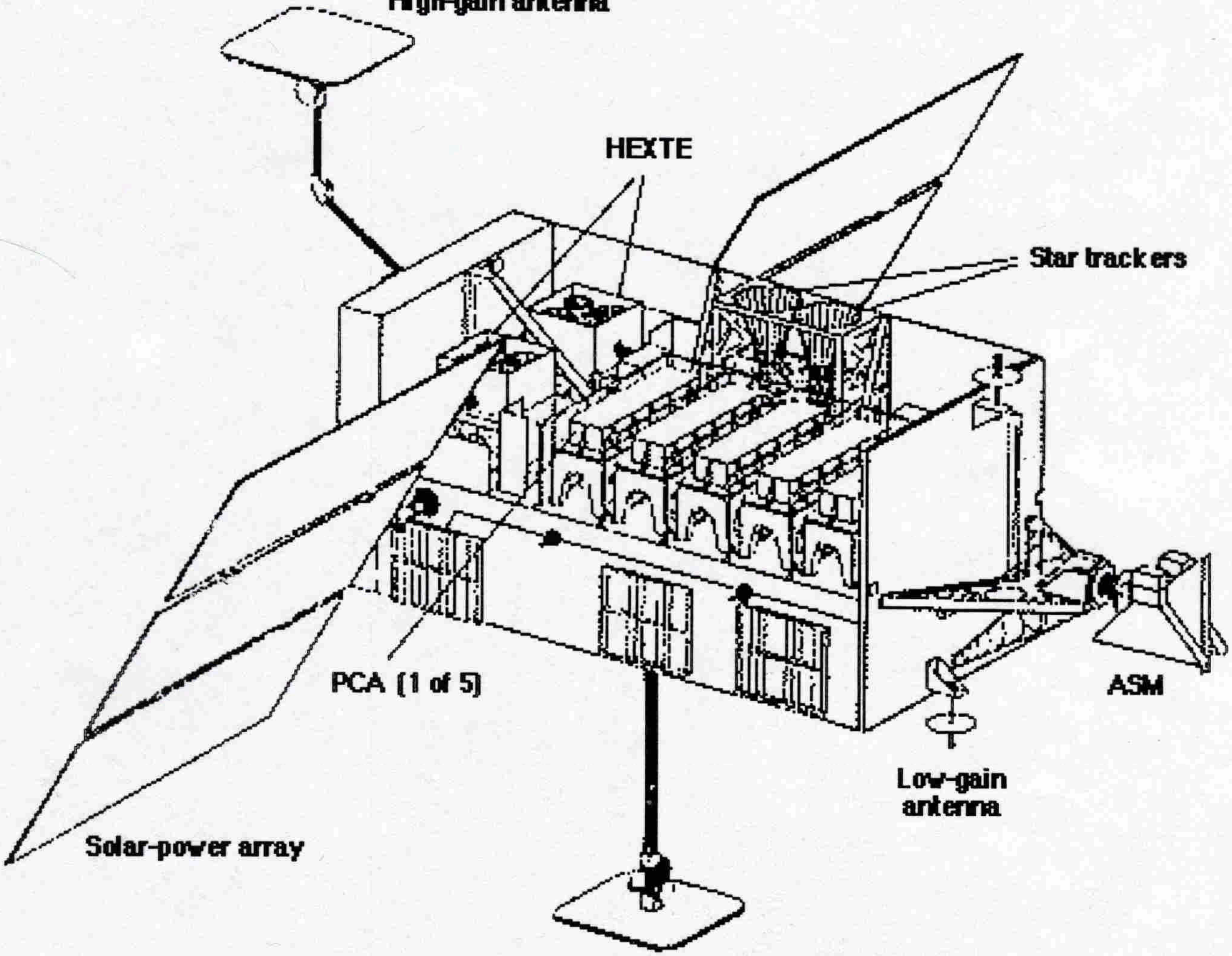
* The background X-ray source needs to be bright enough.

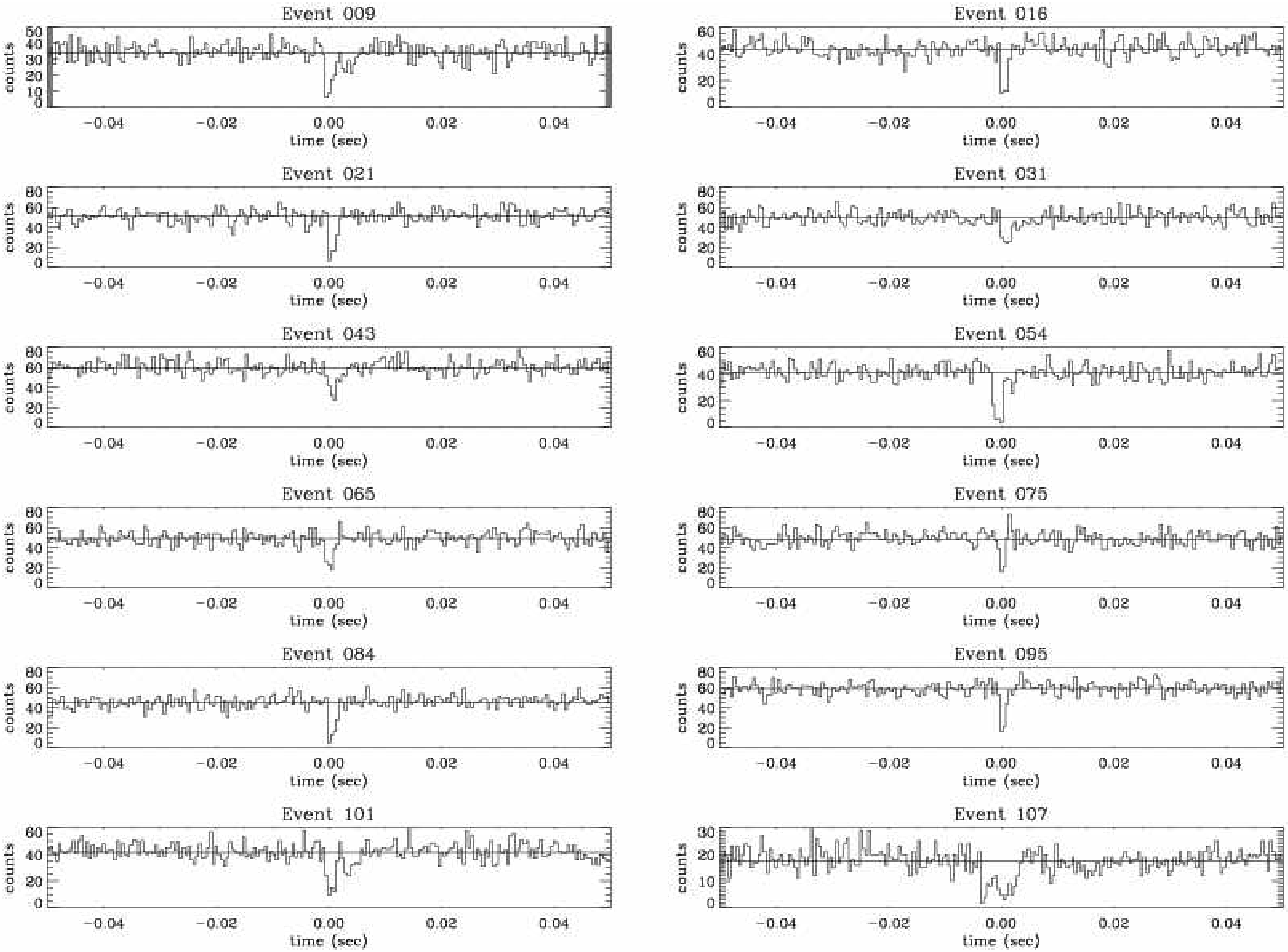
* Sco X-1 is the brightest in the Sky.

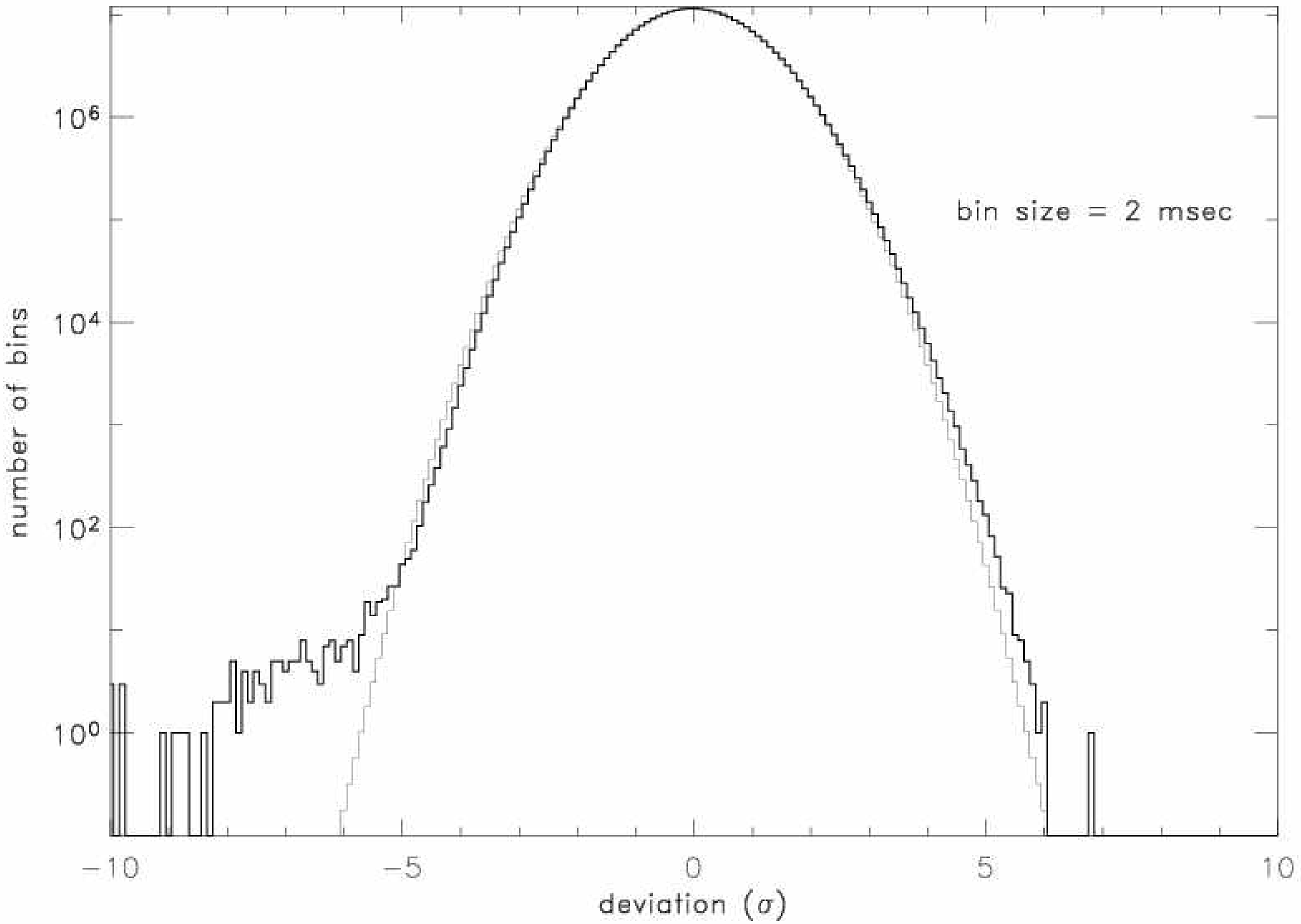
* RXTE/PCA has the largest effective area.

* The typical PCA count rate of Sco X-1 is 10^5 cps.
* Detection of msec time-scale occultation is possible.

XTE Spacecraft




Event 009
Event 016
Event 021
Event 031
Event 043
Event 054
Event 065
Event 075
Event 084
Event 095
Event 101
Event 107
counts
time (sec)
-0.04
-0.02
0.00
0.02
0.04
0
10
20
30
40
50
60
80

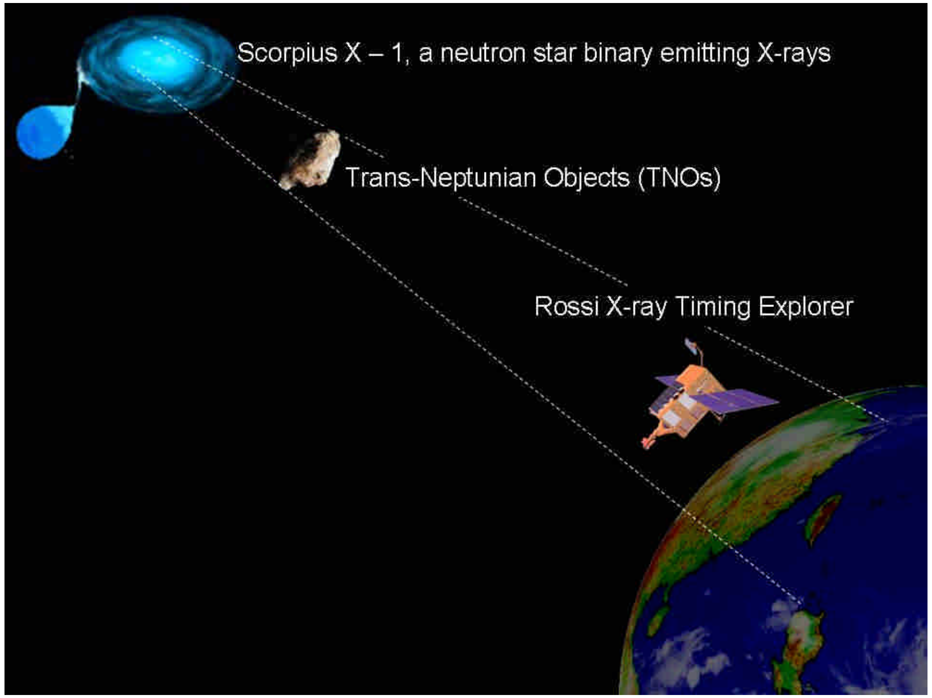


* The RXTE/PCA data used in this search spans over 7 years from 1996 to 2002. The total exposure is 564.3 ksec.

In the 564-ksec data, 107 events were found.

What are they if not instrumental???

- Intrinsic variation of Sco X-1?
- Objects moving around Sco X-1?
- Objects in the interstellar space moving across the line of sight?
- The main belt asteroids?



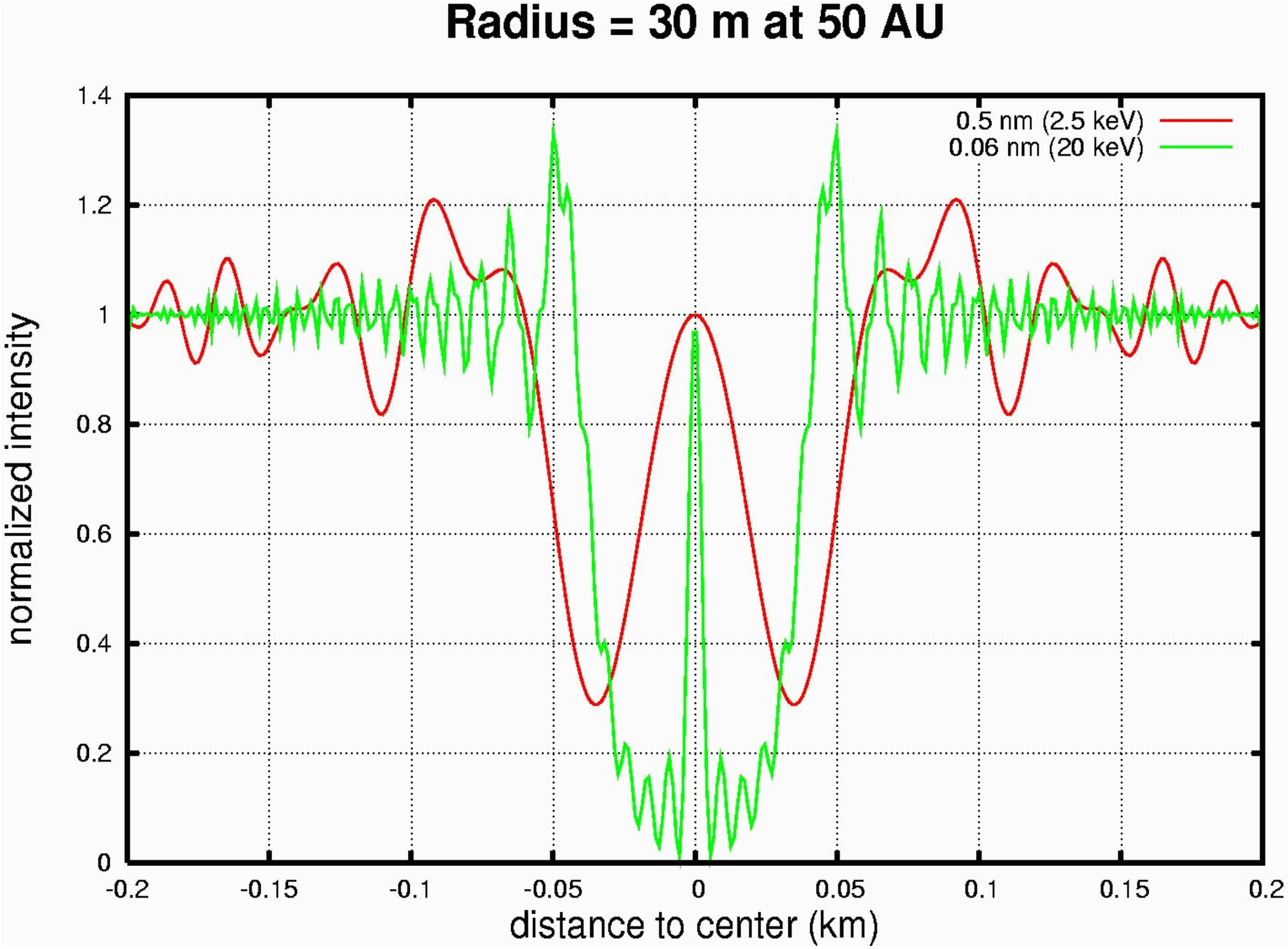
The Fresnel scale : $F = (\lambda d / 2)^{1/2}$

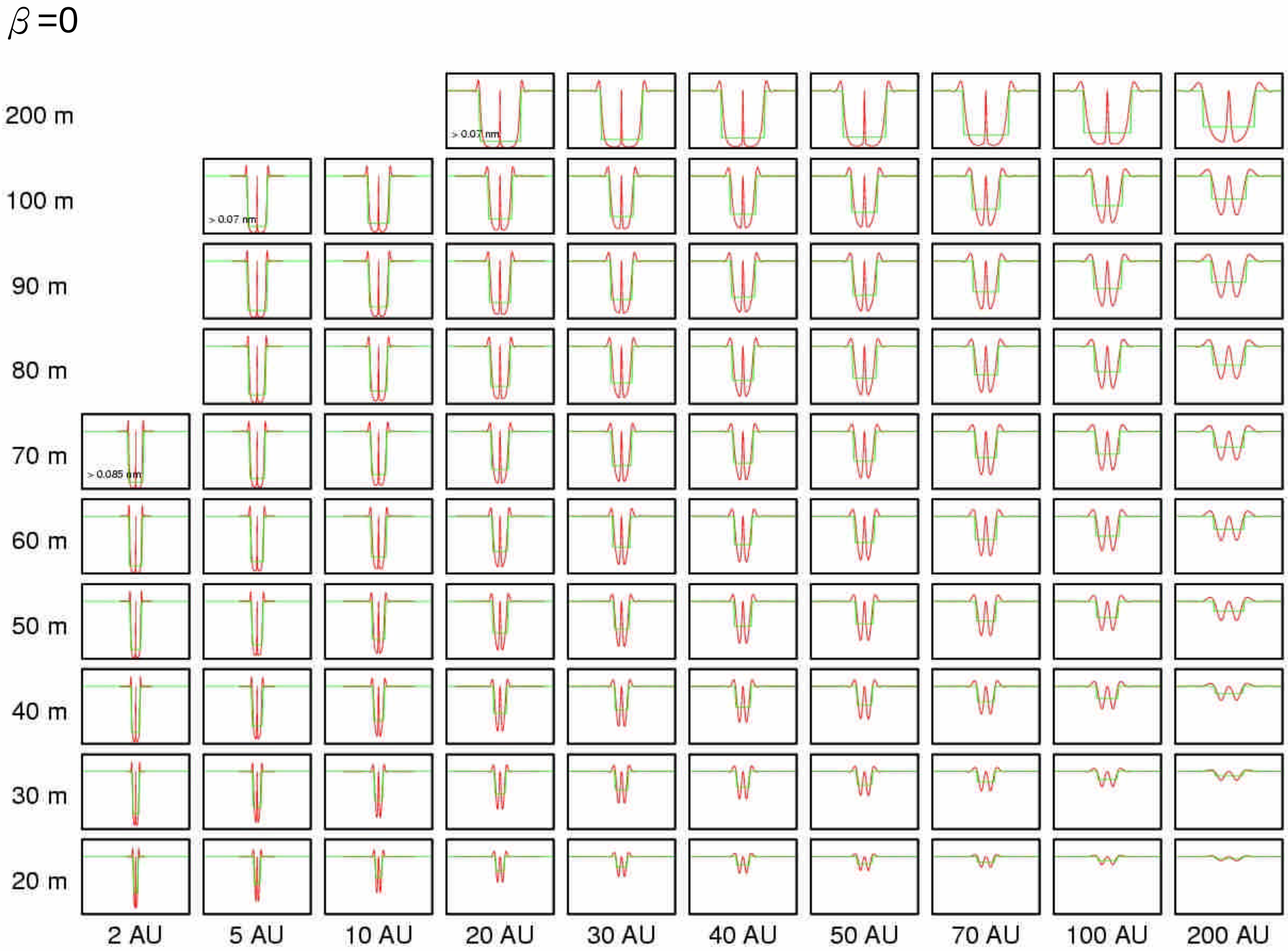
For λ =0.3 nm (4 keV)

F ~ 30 m @ 40 AU
~ 500 m @ 10,000 AU
~ 100 km @ 2.8 kpc

Most likely, occultation by objects within about 1000 AU.

Diffraction Pattern (mono-chromatic)




β =0
200 m
100 m
90 m
80 m
70 m
60 m
50 m
40 m
30 m
20 m
> 0.07 nm
> 0.07 nm
> 0.085 nm
2 AU
5 AU
10 AU
20 AU
30 AU
40 AU
50 AU
70 AU
100 AU
200 AU

nature Vol 442|10 August 2006|doi:10.1038/nature04941

LETTERS

Occultation of X-rays from Scorpius X-1 by small trans-neptunian objects

Hsiang-Kuang Chang[1,2], Sun-Kun King[3], Jau-Shian Liang[1], Ping-Shien Wu[2], Lupin Chun-Che Lin[1] & Jeng-Lun Chiu[1]

Since the discovery[1] of the trans-neptunian objects (TNOs) in 1992, nearly one thousand new members have been added to our Solar System[2,3], several of which are as big as—or even larger than—Pluto[4,5]. The properties of the population of TNOs, such as the size distribution and the total number, are valuable information for understanding the formation of the Solar System, but direct observation is only possible for larger objects with diameters above several tens of kilometres. Smaller objects, which are expected to be more abundant, might be found when they occult background stars[6–10], but hitherto there have been no definite detections. Here we report the discovery of such occultation events at millisecond timescales in the X-ray light curve of Scorpius X-1. The estimated sizes of these occulting TNOs are $\leq$100 m. Their abundance is in line with an extrapolation of the distribution[2] of sizes of larger TNOs.

Because of the photon-counting nature of X-ray observations, X-ray occultation may stand a good chance of revealing the existence of small TNOs as long as the background X-ray source is bright enough to allow statistically meaningful determination at short timescales. Scorpius X-1 is the brightest and first-discovered X-ray source outside our Solar System[11]. It has been extensively studied and observed, particularly by the Rossi X-ray Timing Explorer (RXTE). In addition, Sco X-1 is only about 6° to the north of the ecliptic, making it the best target for a TNO occultation search. RXTE is a NASA mission launched at the end of 1995, providing the largest effective area of all X-ray satellites[12].

The Proportional Counter Array (PCA) instrument (2–60 keV) onboard RXTE registers a raw count rate of about 10^5 counts per second from Sco X-1. Although PCA, with a one-degree field of view, has no imaging capability, the extremely high count rate from the point source Sco X-1 makes the sky and instrumental background both negligible. This high count rate also enables us to perform an examination on its light curve at timescales as short as one millisecond to search for possible occultation.

To search for occultation events, we examine all the time bins in the available RXTE/PCA archival data of Sco X-1 and compute their deviation distribution (Fig. 1). The deviation distribution of all the time bins in the light curve should be poissonian, modified by the dead-time and coincidence-event effects if all the fluctuations are random and there is no occultation event. The PCA data we used span over seven years from 1996 to 2002 and the total exposure time is about 322 ks. A log of all these data are listed in Supplementary Table 1.

In our search, we found obvious excess at the negative-deviation end in the deviation distribution. The excess becomes less significant for cases of larger bin sizes. Two of these distributions are plotted in Fig. 1. To check whether these negative-deviation excesses are instrumental, we performed the same search with PCA data for the Crab nebula, which is an extended X-ray source and is thus most suitable for checking whether those excesses are instrumental rather than due to occultations. Although the PCA count rate of the Crab nebula is about one-eighth of that of Sco X-1, a similar excess should still be detectable with enough data if it is instrumental in origin. From our search on 380-ks PCA data of the Crab nebula, no such excess was found. We also searched the PCA data of a candidate

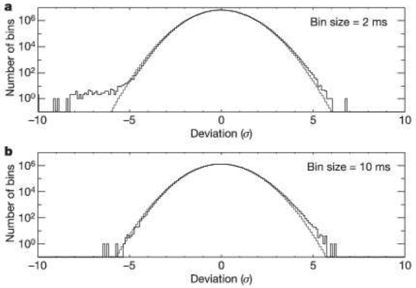


Figure 1 | Deviation distributions of the Sco X-1 RXTE/PCA light curve. The 'deviation' is defined for each time bin in the data as the difference between the photon number counts of that time bin and the mean counts per bin in a time window encompassing and running with the time bin in question. The 'deviation' is further expressed in units of the standard deviation of the photon counts per bin in the associated running window. In practice, the size of the running window should be large enough to have enough bins for the determination of the running mean and the standard deviation. However, it should not be too large, or the intrinsic flux level change of Sco X-1 will be involved. An adequate window size can be determined from comparing simulated distributions with computed (theoretically expected) ones. Searches for large deviation have been performed with all the available RXTE archival data, using different time-bin sizes from 1 to 10 ms with a window size of 8 s and time-bin sizes from 11 to 20 ms with a window size of 16 s. Here we show the deviation distributions for bin sizes of 2 ms (**a**) and 10 ms (**b**). Thick histograms are from the 322-ks RXTE/PCA data of Sco X-1 and thin histograms are gaussian distributions, plotted for comparison. To show the relatively small number of dip events, the ordinate is plotted in logarithmic scales. The excess at the negative deviation end in **a** is obvious. It becomes insignificant when the bin size increases to 10 ms. The small excess at the positive deviation part in both panels and the tiny deficiency between about -3σ and -5σ are due to the Poisson nature of the observed photons.

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Abstractions

SENIOR AUTHOR

In 1996, 20 neuroscience students in Iran signed their names in blood, pledging their commitment to studying the brain despite limited funding and facilities and US sanctions limiting travel and trade (see *Nature* **465,** 264-265; 2005). In the same year, Hossein Esteky, an Iranian who earned a PhD in Texas and did a fellowship in Japan, returned home to Tehran. He and several of the students who had taken the pledge joined forces, set up an electrophysiology lab and began studying cognition in monkeys. Their work shows how electrical stimulation of a few key neurons can help monkeys better perform facial recognition and categorization tasks (see page 692). *Nature* caught up with Esteky to discuss his work.

What obstacles did this research face?

It was hard. We didn't have the basic research infrastructure, and no one else in Iran was working with non-human primates. It took me about a year and a half to set up the first lab. Most of the equipment had to be obtained from the United States. Fortunately, medical instruments are not on the sanctions list.

Have you had any difficulties keeping in touch with research in the West?

We have tried to stay in touch. I've visited the United States several times since I left, but I have to go through Dubai in order to get a visa because there is no US embassy in Iran. Some of my students have not been able to get visas to attend US conferences.

How have your students progressed?

To begin with, I had to oversee the surgery on the monkeys that was required for the experiments, but the students soon learned to operate alone. Many of them are now in the United States. Seyed-Reza Afraz, the first author on the paper, is doing a PhD at Harvard University.

Why did you return to Iran after success in the United States and Japan?

To be with my family. I love my country. The brain drain going on the world is not healthy.

How do you think the current Middle East conflict is affecting research in the region?

At the moment Iran is relatively stable, and as a result science has been able to grow. Fifteen years ago, Iranians published 300-400 papers a year. Last year, we published about 4,000. But there are still few top-tier papers.

How has your work been received in Iran?

During the past five days I've been on TV and radio, up to six times a day. The public's understanding of the need for scientific progress is increasing here. Science can help us to improve our standard of living. ■

MAKING THE PAPER

Hsiang-Kuang Chang

How a neutron star can spot small rocks over long distances.

Beyond Neptune lies the Kuiper belt, an area of the Solar System that astronomers believe is made up of billions of rocks. These are thought to be the result of collisions, and some are huge, measuring 1,000 kilometres or more in diameter. Well-known examples include Pluto and its moon Charon. Although astronomers believe they exist, the smaller rocks have been harder to find. Now, a team of researchers has hit on a new way of looking for them (see page 660).

The use of optical methods has not been particularly successful in the hunt for the smaller members of the Kuiper belt. So, a group of astronomers led by Hsiang-Kuang Chang at Taiwan's National Tsing Hua University looked for an alternative. They came up with the idea of using X-rays from Scorpius X-1, a neutron star 9,000 light years away. From time to time, the number of X-ray photons reaching an observing satellite from Scorpius X-1 dips significantly. The researchers thought that these dips might result from small bodies passing in front of the star. Such dips are known as occultations.

Much shorter occultations can be detected with X-ray than optical methods, and this is crucial for finding tiny bodies. Whereas visible-light occultation events of 0.1 or 0.2 seconds might be detectable, researchers can detect X-ray occultations as short as one millisecond. This is because the instrument they used, NASA's Rossi X-ray Timing Explorer (RXTE) satellite, can process incoming data much faster than optical instruments.

Chang and his colleagues analysed seven years' worth of publicly available archive data from the RXTE. They used a computer program to sift through each time bin — a prescribed time interval during which the total number of photons was recorded. This was a much more thorough analysis than usual. "No one has ever looked into every time bin," Chang says.

The researchers found records of 58 occultation events. On the basis of their findings, they estimate that the Kuiper belt contains some 10^{15} small bodies (of 100 metres or less in diameter). Initially, however, they couldn't be sure that the effects they were seeing were not the result of instrumental error. So they turned to another batch of RXTE data, reporting observations of another major X-ray emitter, the Crab nebula, as a control.

Because of its large size, the Crab nebula is an extended source of X-rays. Scorpius X-1 is a point source. So whereas the tiny Kuiper-belt bodies would all but completely block Scorpius X-rays, they would barely obscure any of the Crab nebula's. The team reasoned that if there was an instrumental effect, both the Crab and the Scorpius data would contain similar dips in photon count. If there were none, only the Scorpius data would reveal the X-ray photon dips. They found the latter to be true.

In future work, Chang hopes to pin down the distance to these small bodies. The key could be in their diffraction effects. Although diffraction levels are much lower with X-rays than with optical light, diffraction effects are still seen in X-rays and can be used to determine how far objects are from Earth. This should lead to a better estimate of the size of these occulting bodies. Chang will also look at data from future RXTE observations in order to find more occultation events and to improve the accuracy of estimates of the size distribution of the Kuiper belt's rocks. ■

KEY COLLABORATIONS

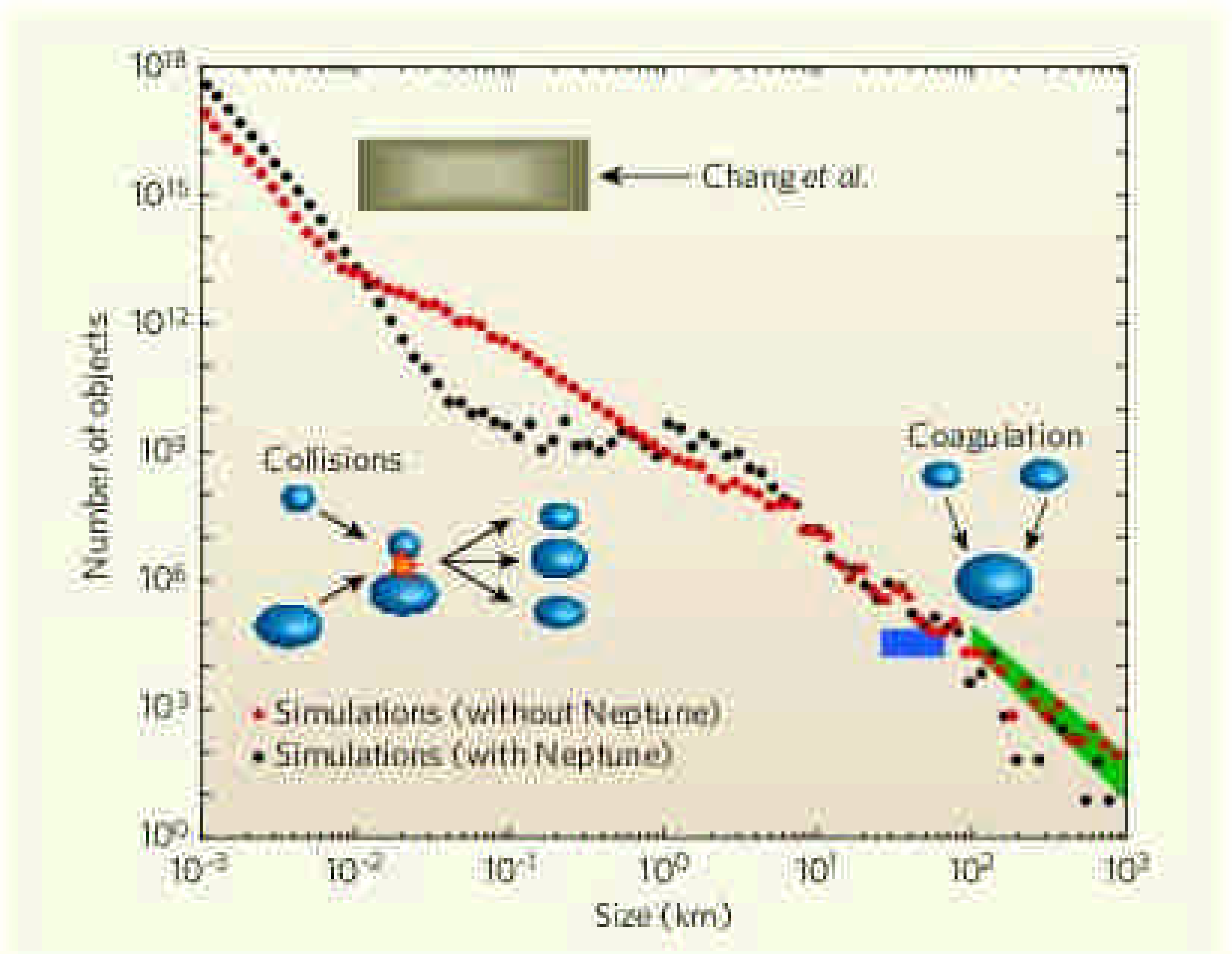
The success of a team that produced three-dimensional images of prehistoric embryos (see page 680) is down to the group's tenacity, says Philip Donoghue, an Earth scientist at the University of Bristol, UK.

The field caught the interest of another Earth scientist, XI-Ping Dong of Peking University in China, during a visit to Harvard University in 1996. "He didn't discover these embryos by chance," says Donoghue. "He saw presentations of other rare embryo finds, and wanted to find some himself. It got him thinking about biology rather than geology."

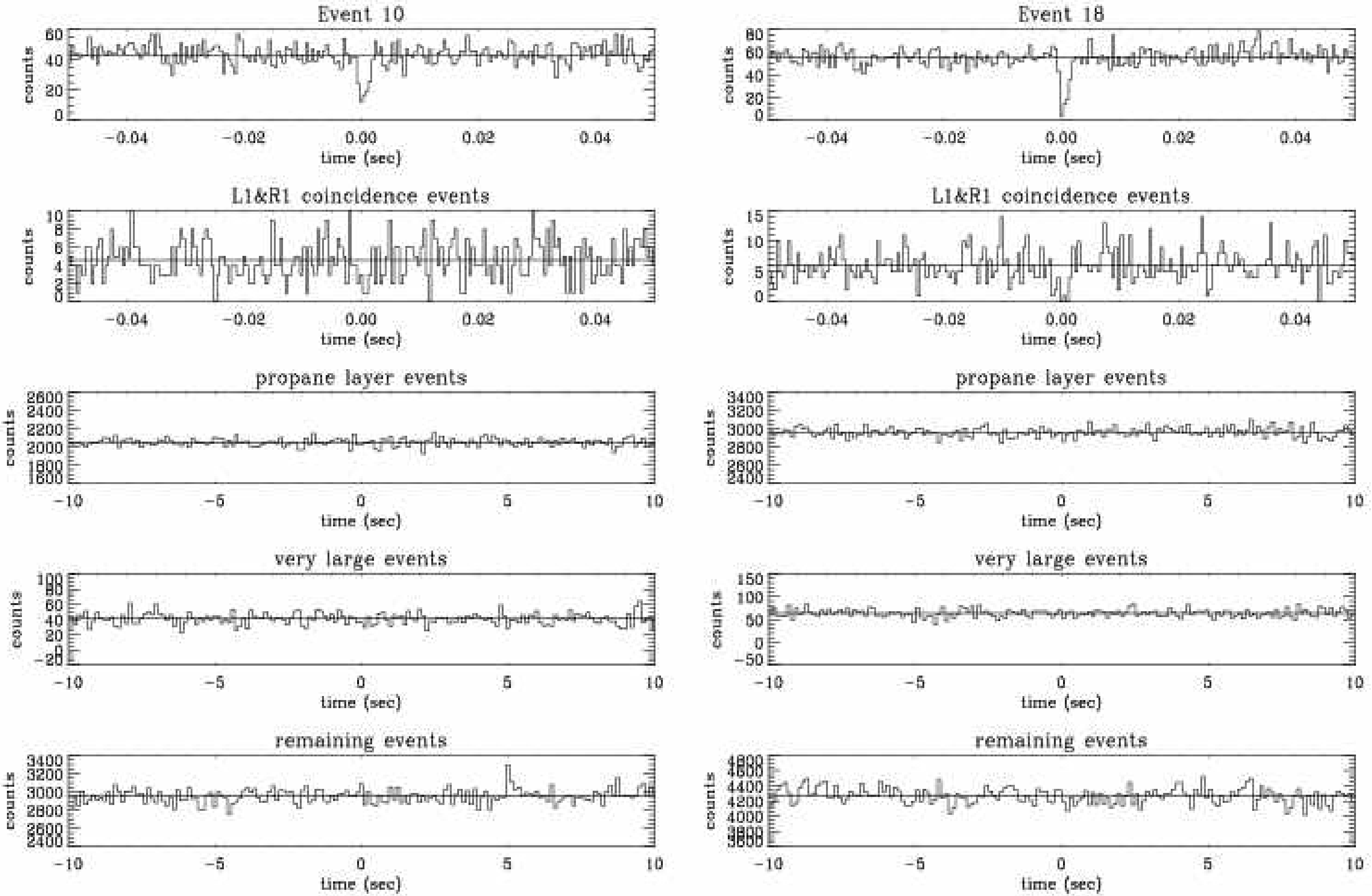
Dong teamed up with Donoghue, who has expertise in scanning electron microscopy. They began by looking at conodonts — tiny eel-like creatures dating back 510 million years. By chance, Dong found embryos of a prehistoric segmented worm in his samples. He eventually processed 12 tonnes of rock into sand-like particles and found five embryos.

A 2004 paper then drew the attention of Marco Stampanoni at the Swiss Light Source near Zurich. He had developed a technique in 3D X-ray tomography that held promise for imaging the tiny fossils in great detail. Stampanoni invited Donoghue to Zurich and gave him 24 hours of beam time.

Donoghue, who never used to work on embryos, now devotes much of his time to them. ■



(Cooray 2006, Nature 442, 640)



Event 10
Event 18
L1&R1 coincidence events
propane layer events
very large events
remaining events
counts
time (sec)
-0.04
-0.02
0.00
0.02
0.04
-10
-5
0
5
10

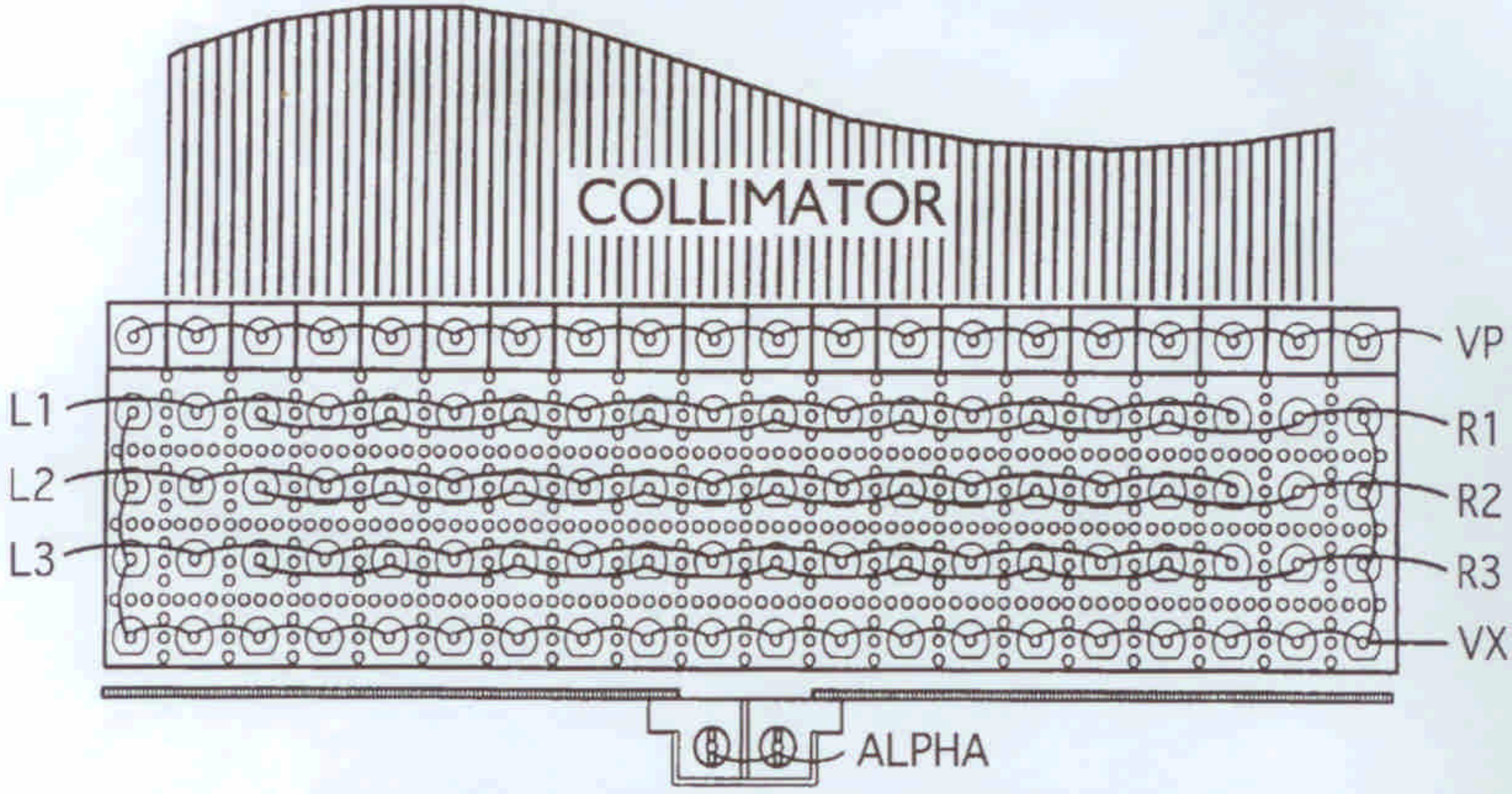
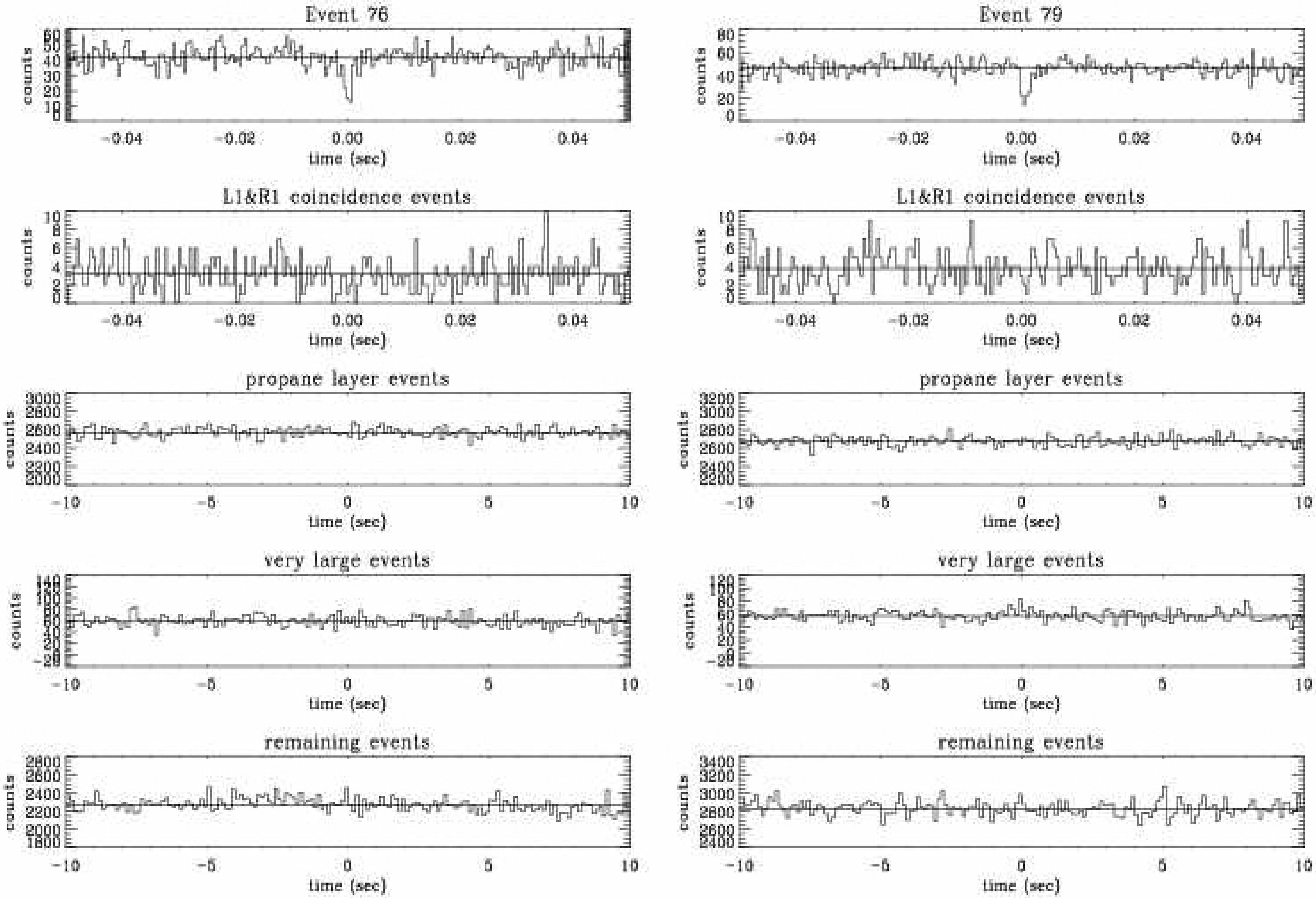


Fig. 4.2 The anode and signal connections for the 9 independent channels of analog electronics. The interleaved anodes provide rejection of charged particle background.

RXTE PCA Very Large Events (VLEs) are those events which deposit more than 100 keV in any one of the 6 active xenon layers or the propane layer.


Event 76
Event 79
L1&R1 coincidence events
propane layer events
very large events
remaining events
counts
time (sec)
-0.04
-0.02
0.00
0.02
0.04
-10
-5
0
5
10
0
10
20
30
40
50
60
80
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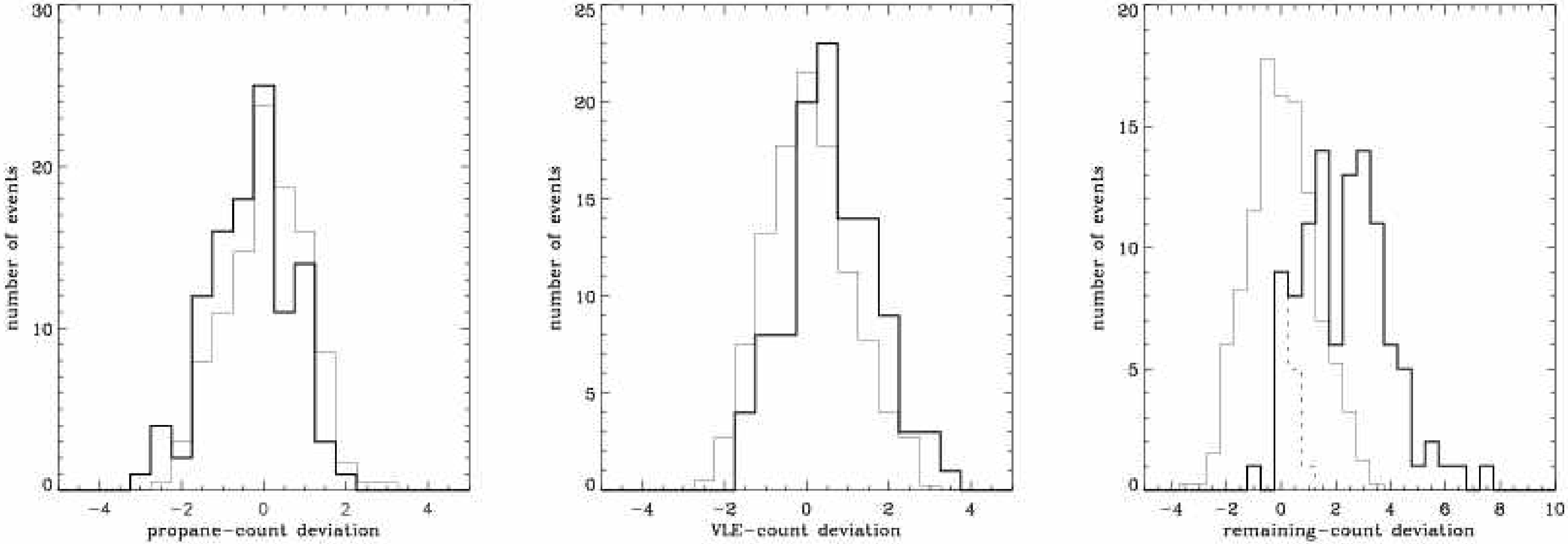
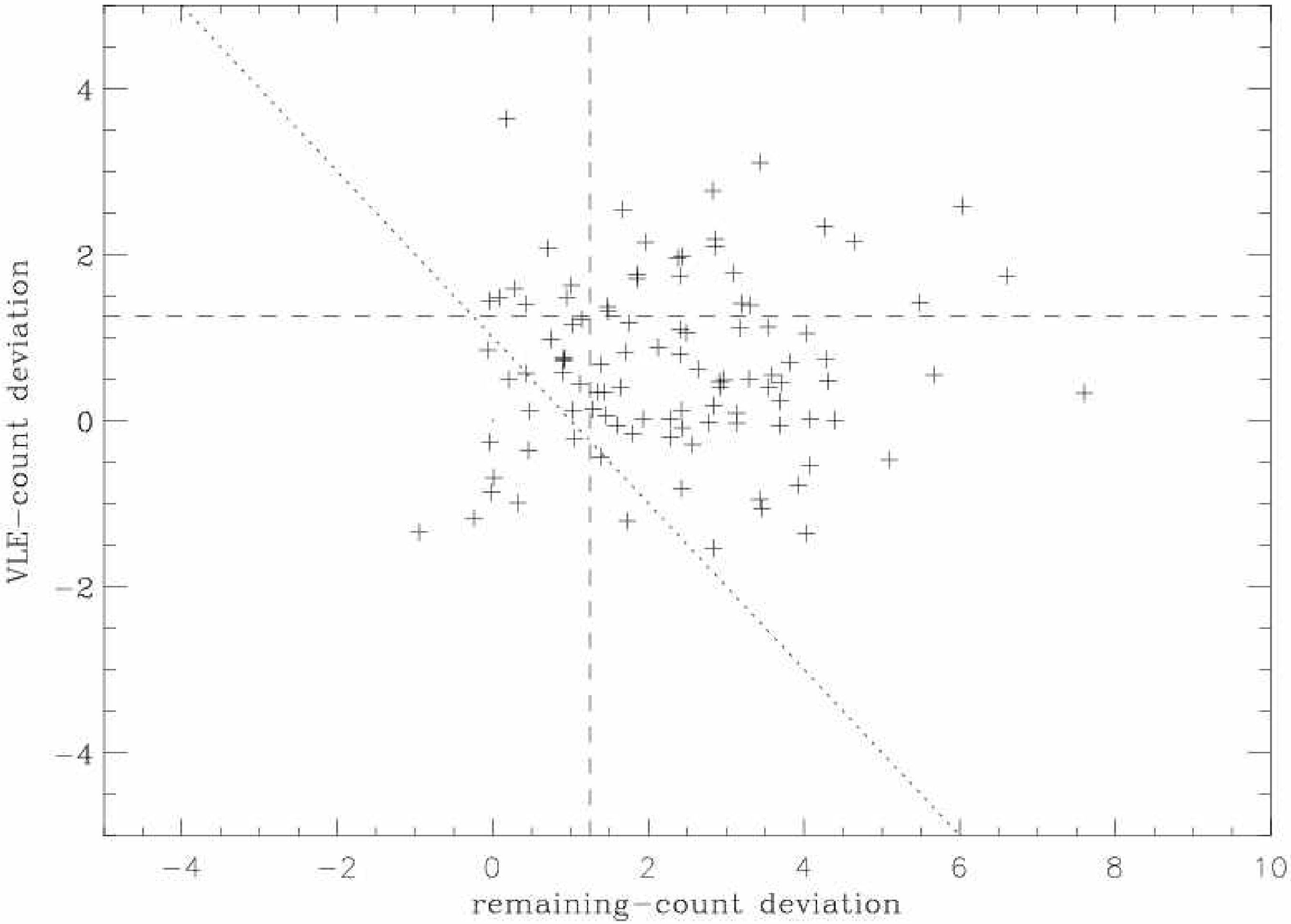
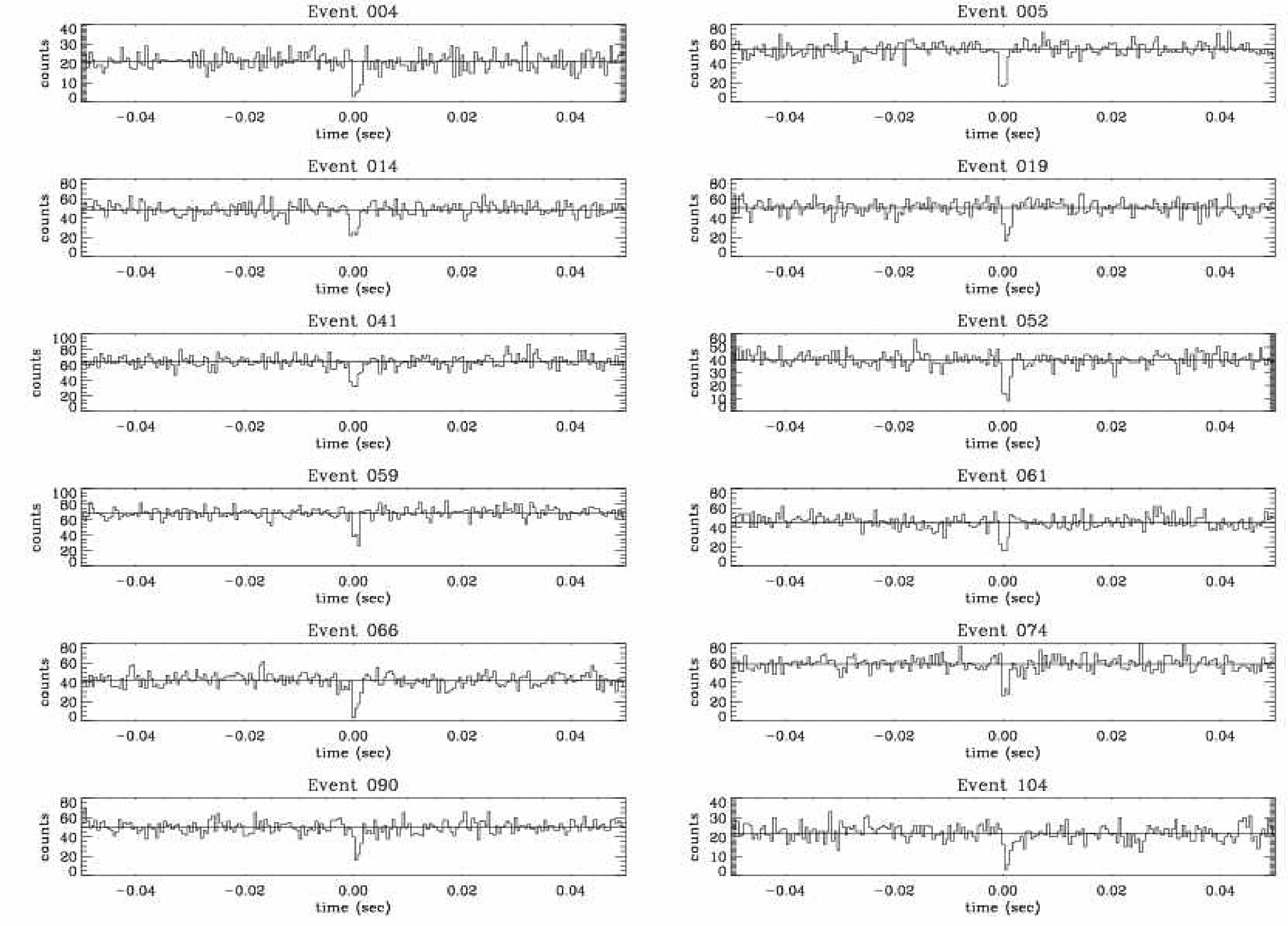
4
6
8
2000
2200
2400
2600
2800
3000
3200
3400
1800
-20
100
120
140


number of events
30
20
10
0
−4
−2
0
2
4
propane−count deviation
number of events
25
20
15
10
5
0
−4
−2
0
2
4
VLE−count deviation
number of events
20
15
10
5
0
−4
−2
0
2
4
6
8
10
remaining−count deviation


VLE-count deviation
remaining-count deviation
4
2
0
−2
−4
−4
−2
0
2
4
6
8
10



Light curves of the 12 probable non-instrumental events
(no anomaly in ‘remaining’ and ‘VLE’ counts)

In the first attempt……

RXTE/PCA data of Sco X-1, 1996-2002, 564 ksec

- * 107 significant dips were found.
- * There are signatures indicating that most, if not all, of them could be due to some possible instrumental effects, which are previously unknown.
- * Those signatures allow 10% of the dip events to be non-instrumental.

To pin down the distance and the size of each occulting body more accurately for all the events is an important issue but requires further analysis on the dead-time-corrected light curves, diffraction patterns and different orbital inclinations and eccentricities.

For an approximate estimation of the occulting-object sizes at this stage, we contend ourselves by considering a typical relative speed of 30 km s^{-1} between the occulting TNOs and *RXTE* and a random crossing through the shadow. The average crossing length of a random crossing is $\pi/4$ times that of a central crossing, assuming a circular shadow.

We therefore set the size range of these 12 objects to be from 60 to 100 m for durations from 1.5 to 2.5 ms.

For a background point source, the event rate is

$$\frac{N}{T} = \frac{\int_{s_1}^{s_2} \left(\frac{\mathrm{d}N}{\mathrm{d}s}\right) s v \,\mathrm{d}s}{d^2 \Omega_\mathrm{A}} \quad , \tag{1}$$

where N is the number of detected events (assuming a 100% detection efficiency), T the total exposure time, $\left(\frac{\mathrm{d}N}{\mathrm{d}s}\right)$ the differential size distribution, v the typical relative speed, d the typical distance to the TNOs, and Ω_A the total solid angle of the sky distributed with TNOs. To derive $\left(\frac{\mathrm{d}N}{\mathrm{d}s}\right)$ from the event rate, a function form of the distribution needs to be assumed. On the other hand, if the integration is only over a small range of the size, we may consider to derive an average value at that size. Noting that $\frac{\mathrm{d}N}{\mathrm{d}\log s} = \frac{\mathrm{d}N}{\mathrm{d}s}\, s \ln 10$, we have

$$\int_{s_1}^{s_2} \left(\frac{\mathrm{d}N}{\mathrm{d}s}\right) s v \,\mathrm{d}s = \left(\frac{\mathrm{d}N}{\mathrm{d}\log s}\right)_{s_1<s<s_2} \frac{v(s_2 - s_1)}{\ln 10} \quad , \tag{2}$$

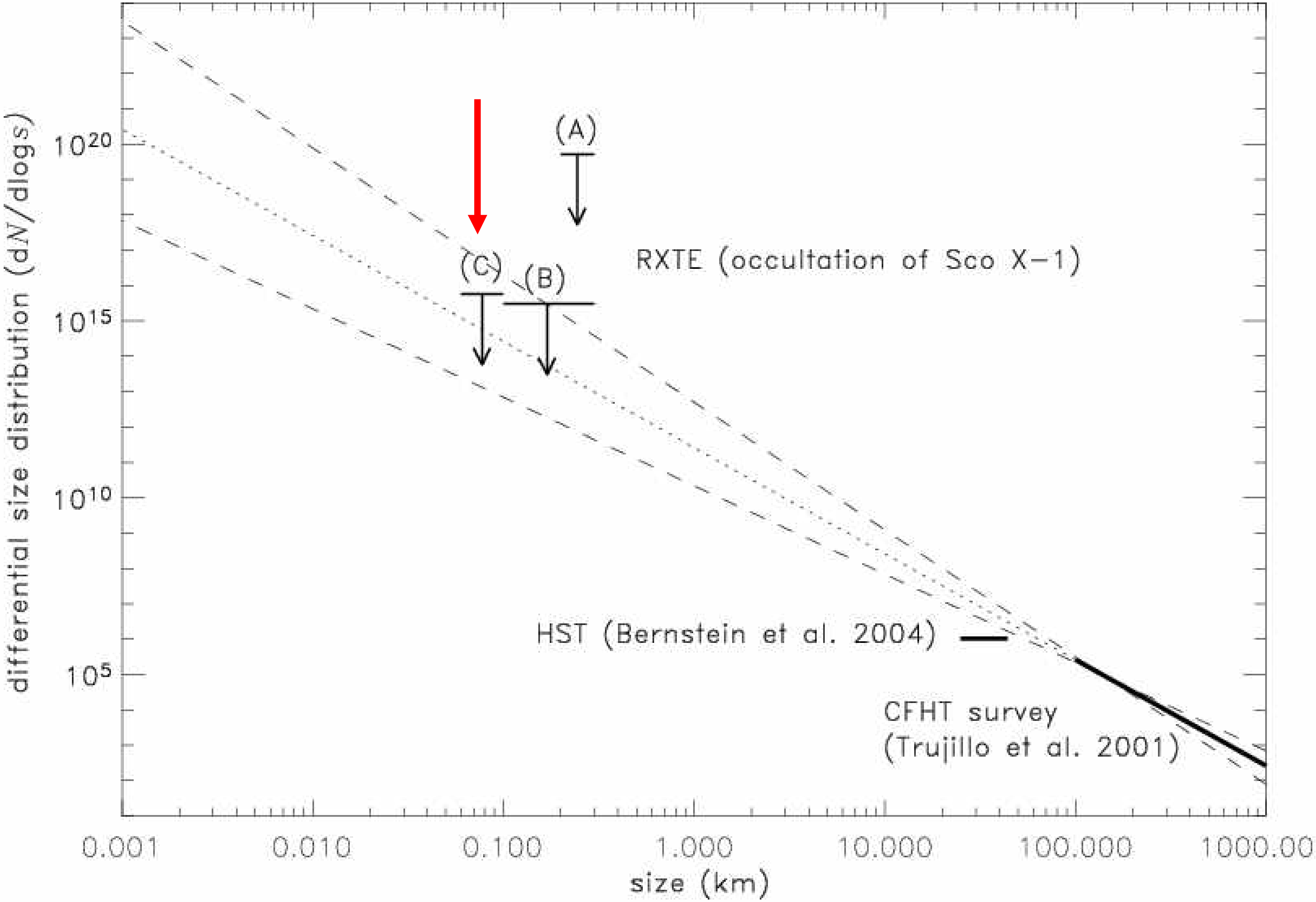
and

$$\left(\frac{\mathrm{d}N}{\mathrm{d}\log s}\right)_{s_1<s<s_2} = \frac{d^2 \Omega_\mathrm{A}}{v(s_2 - s_1)} \frac{N}{T} \ln 10 \quad . \tag{3}$$

We can estimate Ω_A with the inclination distribution obtained from the CFHT survey (Trujillo et al. 2001), which reported a 20° half-angle of an assumed gaussian distribution. This half-angle in the inclination distribution translates to about 12.8° for a corresponding half-angle in the apparent ecliptic latitude distribution, assuming circular orbits. Sco X-1 is 5.5° north of the ecliptic. To use the detection rate in the direction toward Sco X-1 to represent the whole TNO population, the equivalent sky area is a zone occupying ±15.5° in latitude. Therefore, $\Omega_\mathrm{A} = 360 \times 31 \times (\frac{\pi}{180})^2 = 3.4$. Assuming a typical distance $d = 43$ AU, a typical relative sky-projection speed $v = 30$ km/s, and $T = 564.3$ ks, we have in the size range from 60 m to 100 m

$$\left(\frac{\mathrm{d}N}{\mathrm{d}\log s}\right) \approx 5.7 \times 10^{15} \quad . \tag{4}$$

The total number of TNOs in that size range is about 1.3×10^{15}.


differential size distribution (dN/dlogs)
10^20
10^15
10^10
10^5
0.001
0.010
0.100
1.000
10.000
100.000
1000.00
size (km)
(A)
(B)
(C)
RXTE (occultation of Sco X-1)
HST (Bernstein et al. 2004)
CFHT survey
(Trujillo et al. 2001)

In the second attempt ……

RXTE/PCA data of Sco X-1, 2007/2008/2009, 240 ksec

* New event modes for recording the so-called ‘very large events’ (VLEs) were designed, in the hope to identify clearly the instrumental effect associated with dip events.

* The arrival time of each VLE is recorded with 125-μs resolution. The identification of anodes which detect the recorded VLE is also known.

The RXTE/PCA VLE types

According to the number of anodes triggered, we classify VLEs as the following:

RXTE PCA Very Large Events (VLEs) are those events which deposit more than 100 keV in any one of the 6 active xenon layers or the propane layer.

Type A: no anodes are triggered!!!
Type B: all anodes are triggered.
Type C: more than one but not all are triggered.
Type D: only one anode is triggered.

The average count rate is

for all VLEs	90.5 ± 19.2 counts per sec per PCU;
for Type A	1.73 ± 0.29 counts per sec per PCU;
for Type B	34.5 ± 11.2 counts per sec per PCU;
for Type C	44.8 ± 9.80 counts per sec per PCU;
for Type D	9.44 ± 2.27 counts per sec per PCU.

The RXTE/PCA dip events

39 ‘significant’ dips are found in the 240-ks data (June 2007 – Oct 2009).

According to the types of VLEs detected ‘near’ the dip event epoch, we classify dip events as the following:

Group A: with Type A VLE	34
Group B: with Type B VLE	2
Group C: with Type C VLE	2
Group D: with Type D VLE	0
Group E: no VLE	1

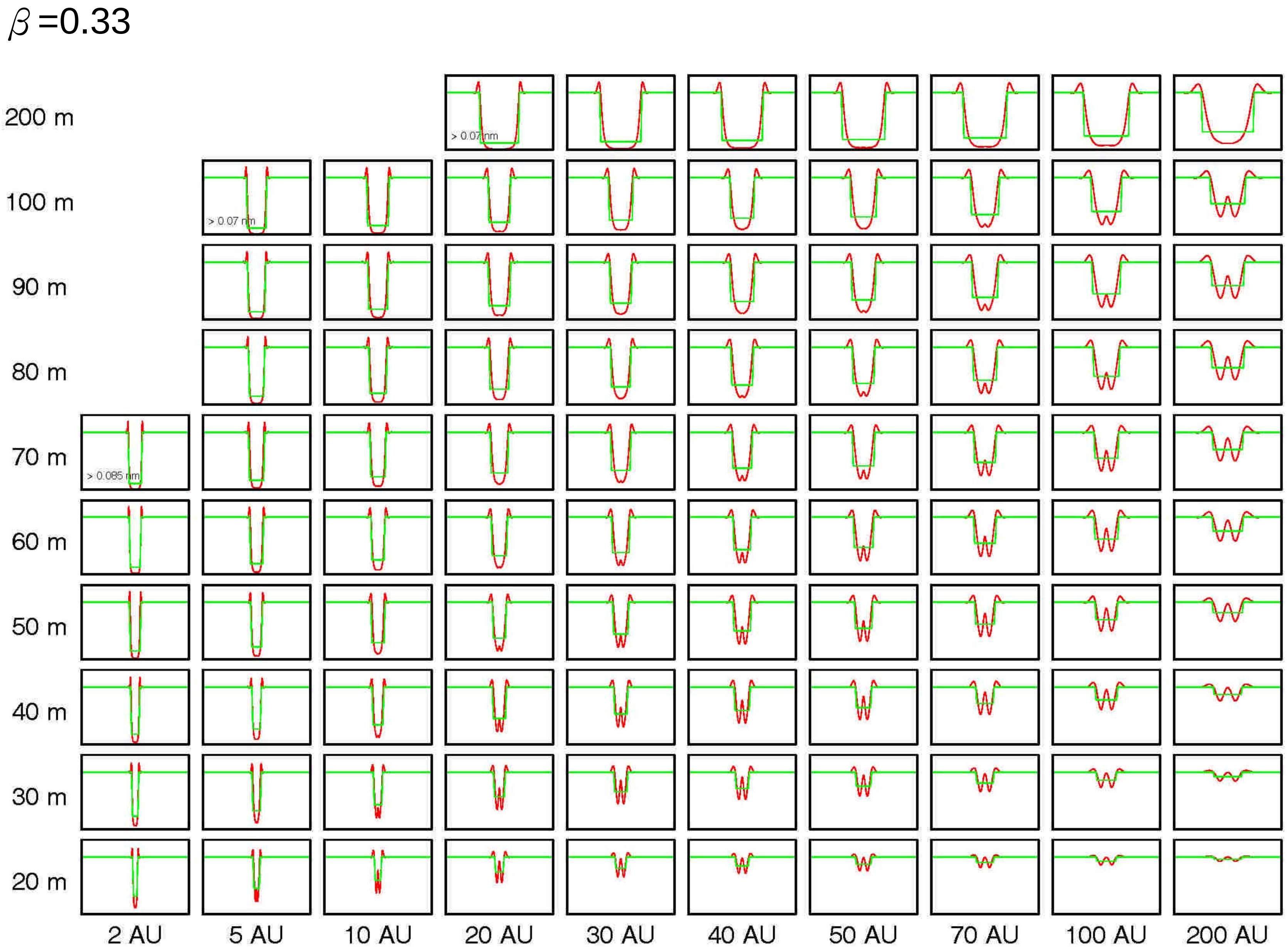
The RXTE/PCA dip events

253 ‘less significant’ dips are found in the 240-ks data (June 2007 – Oct 2009).

According to the types of VLEs detected ‘near’ the dip event epoch, we classify dip events as the following:

Group A: with Type A VLE	34	125
Group B: with Type B VLE	2	94
Group C: with Type C VLE	2	23
Group D: with Type D VLE	0	3
Group E: no VLE	1	8

Assuming a Gaussian distribution, the number of bins with counts less than 5 σ below the average is about 34.4, for 2-ms bins in 240-ks data.


β =0.33
200 m
100 m
90 m
80 m
70 m
60 m
50 m
40 m
30 m
20 m
> 0.07 nm
> 0.07 nm
> 0.085 nm
2 AU
5 AU
10 AU
20 AU
30 AU
40 AU
50 AU
70 AU
100 AU
200 AU

The most recent result is like this …

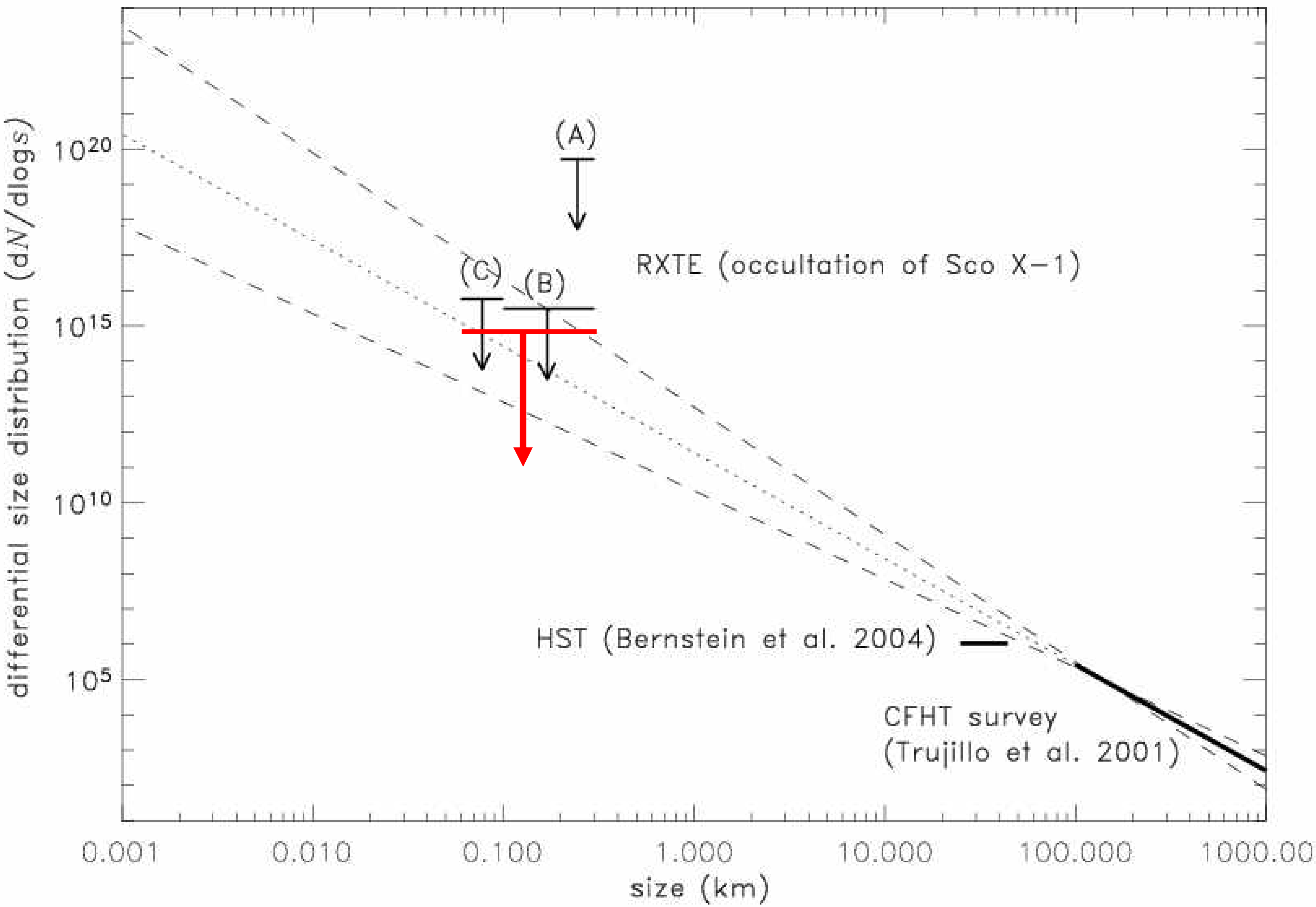
From RXTE/PCA data of Sco X-1, 2007/2008/2009, 240 ksec

* 39 significant dips were found, but 36 of them are associated with some particular types of VLEs, whose presence indicates instrumental effects. The remaining 3 deserve further investigation.

* 253 less-significant dips were identified, 219 of which are associated with those particular VLEs. The remaining 34 are consistent with random fluctuations.

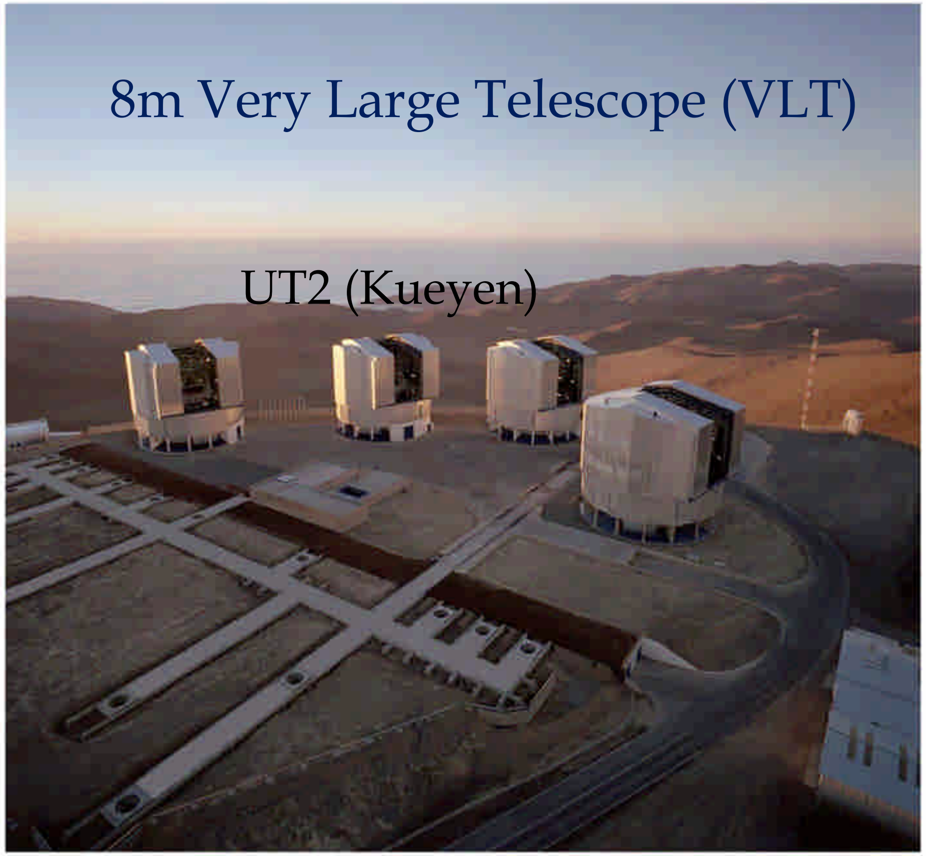
In the future

ASTROSAT/LAXPC observation of Sco X-1 ???
AXTAR, 10 times more sensitive than RXTE ???


(A)
(B)
(C)
RXTE (occultation of Sco X-1)
HST (Bernstein et al. 2004)
CFHT survey
(Trujillo et al. 2001)
differential size distribution (dN/dlogs)
10^{20}
10^{15}
10^{10}
10^{5}
size (km)
0.001
0.010
0.100
1.000
10.000
100.000
1000.00

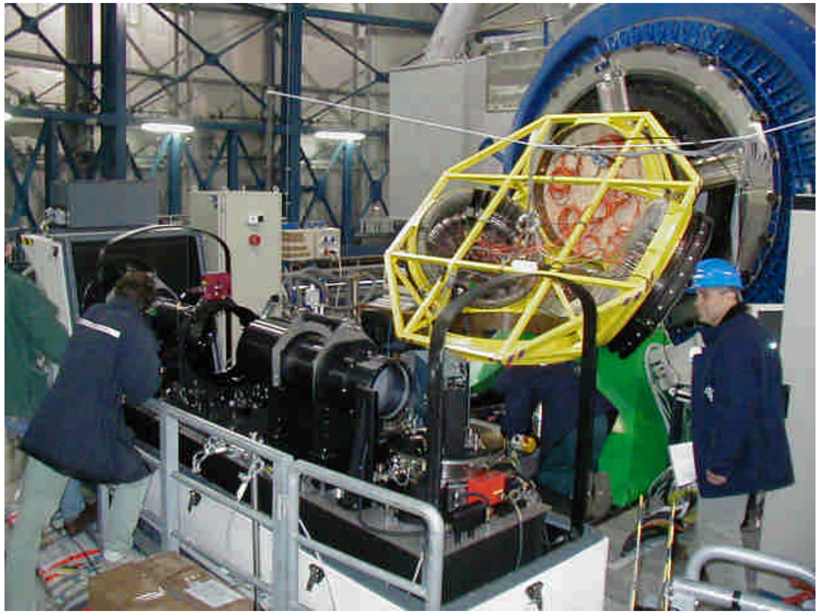
UltraPhot: 超快測光儀

A collaboration between NTHU and Paris Observatory



The VLT Array on the Paranal Mountain

ESO PR Photo 14a/00 (24 May 2000)



FLAMES, a multi-object spectrograph, including OzPoz, the fiber positioner (yellow), and GIRAFFE, the spectrograph (black).

UltraPhot will operate in a photometric mode for FLAMES on the VLT UT2.