天狗也吃恆星嗎：掩星

辜品高
師大地科系
中研院天文所

Thanks to the good weather, we observed Mercury transit on Nov. 9th!

一個天體遮住另一個天體的光

1. 日蝕(solar eclipse)：月球遮住太陽
2. 凌日(transit)：行星或其他較小天體通過我們與太陽之間(小遮大)
3. 掩星(occultation)：視直徑大的遮視直徑小的(大遮小)
4. 蝕雙星(eclipsing binary)：當雙星的軌道面朝向我們

Conditions for Eclipses

日蝕發生在新月(大約初一)
但初一時，日蝕並不一定發生。
因為月球軌道與地球軌道不共面

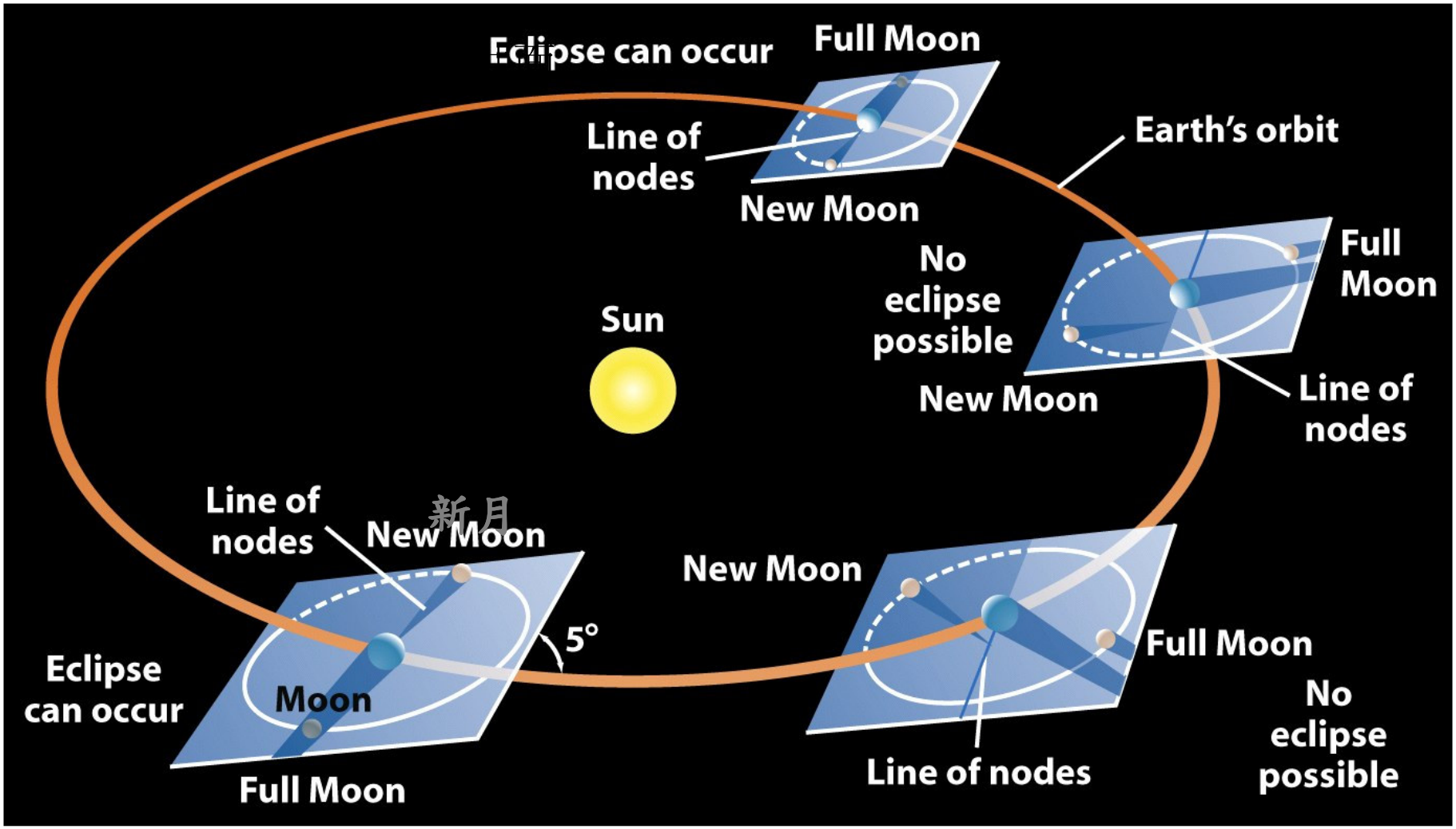
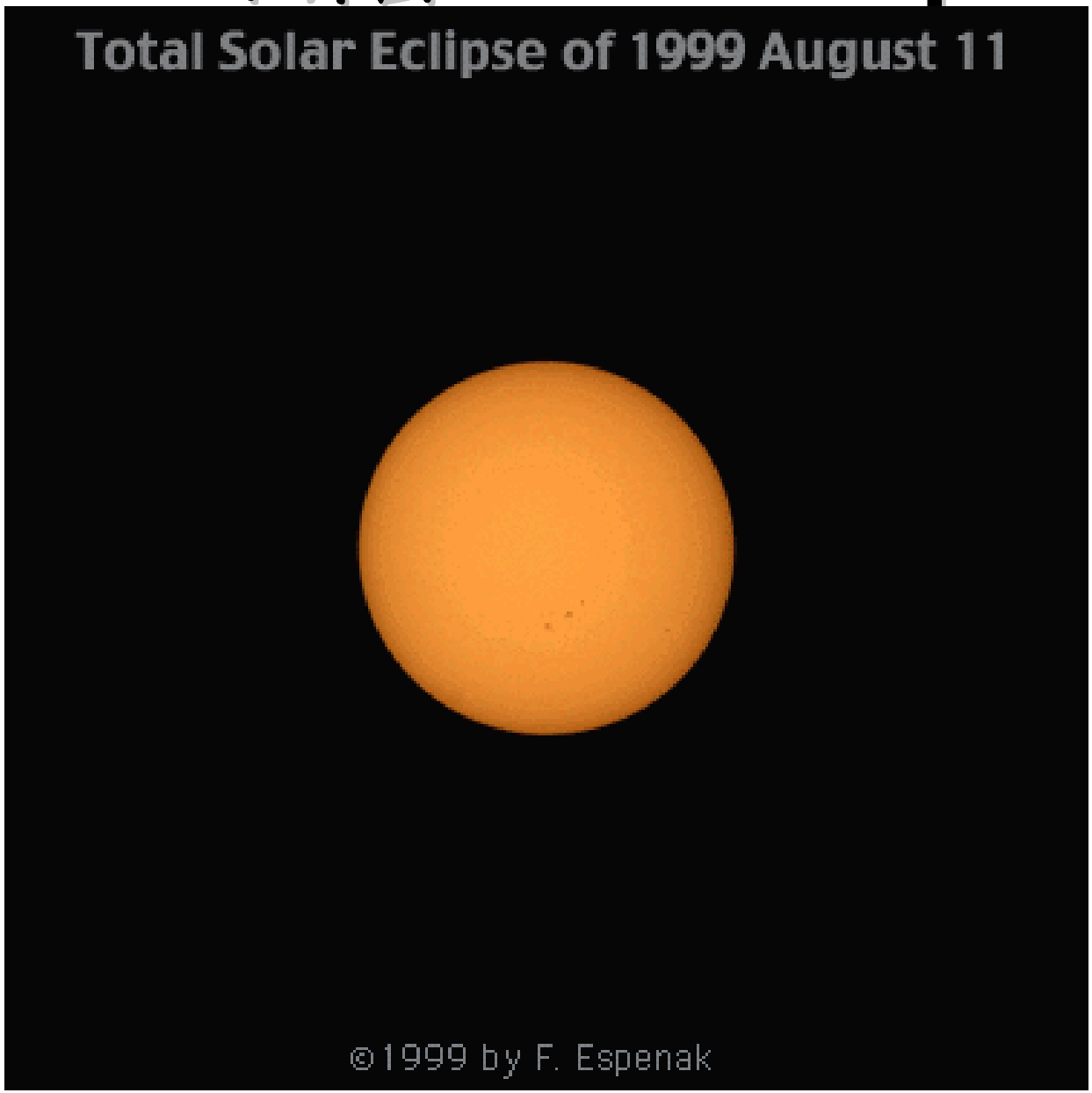


Figure 1-26
Discovering the Universe, Seventh Edition

日蝕 Solar eclipse



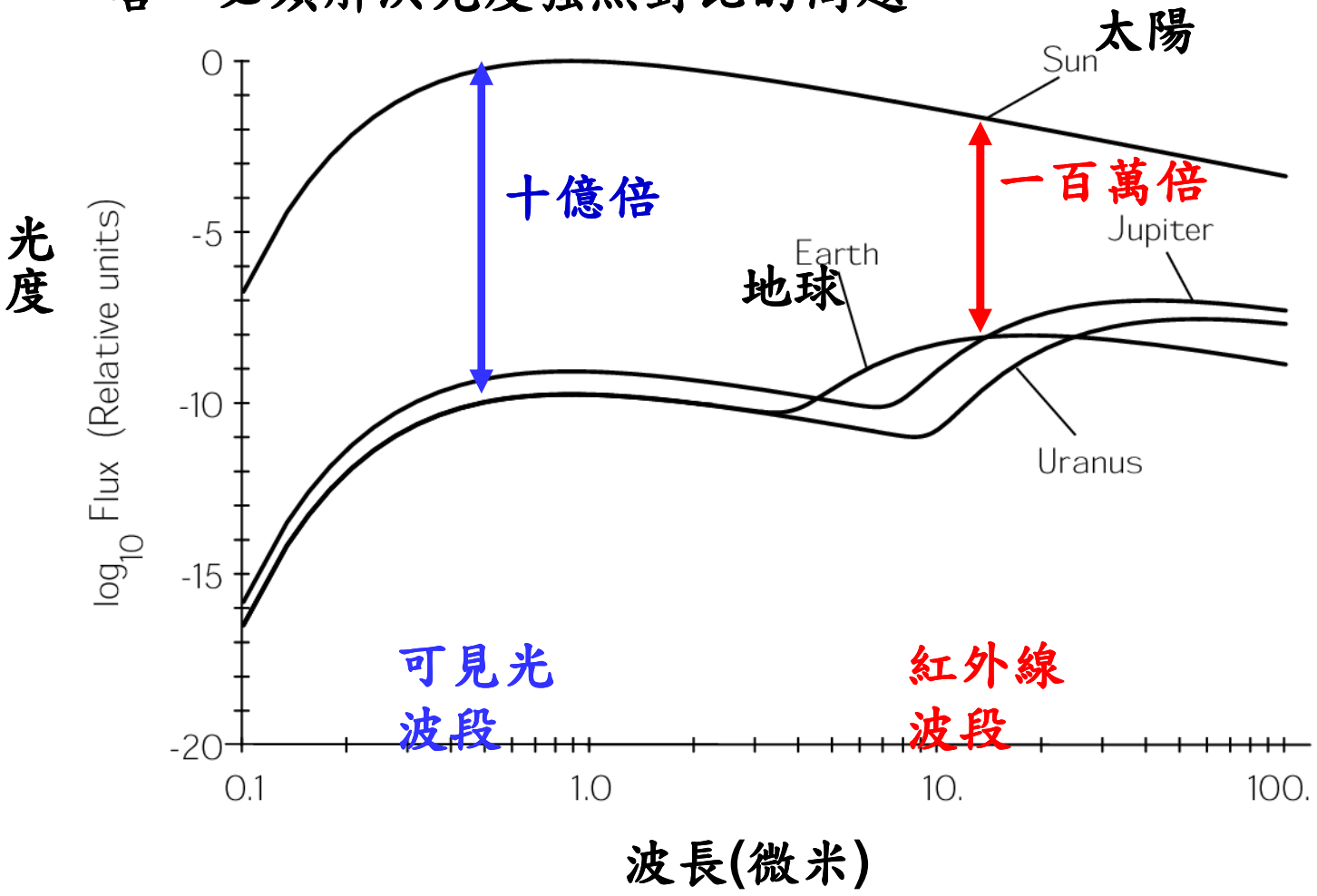
Pay attention to solar corona (日冕) when the sun is totally blocked by the Moon.

Solar corona is the outermost part of Sun's atmosphere.

母恆星的光是一種「光害」！

是否能直接觀測到行星?

答：必須解決光度強烈對比的問題



日冕儀：人工日全蝕器

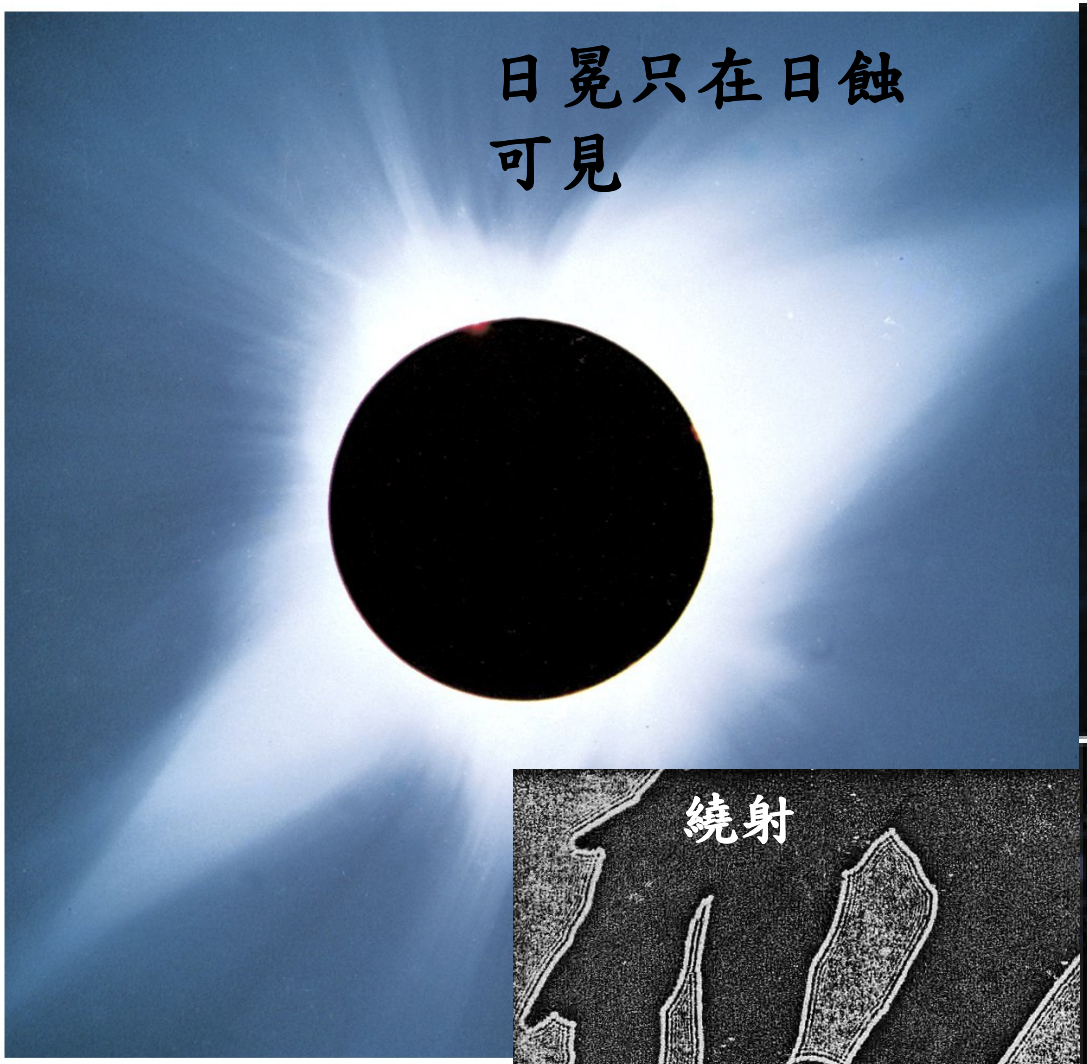
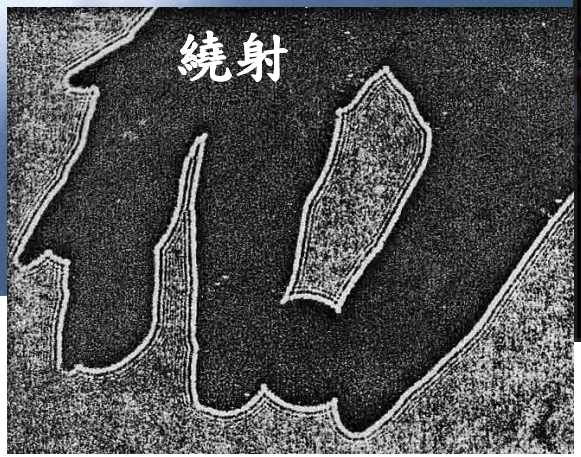
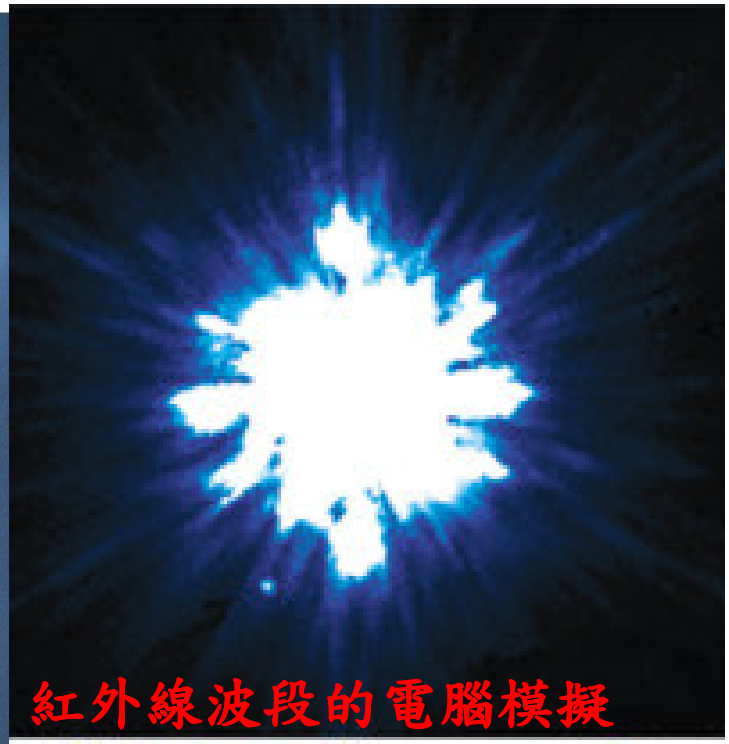
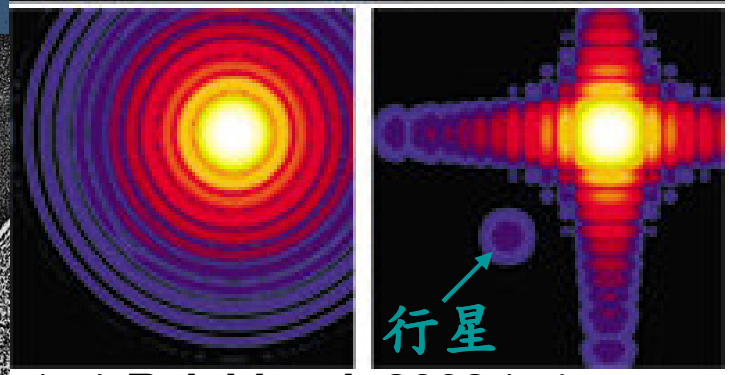


Figure 10-6a
Discovering the Universe, Seventh Edition



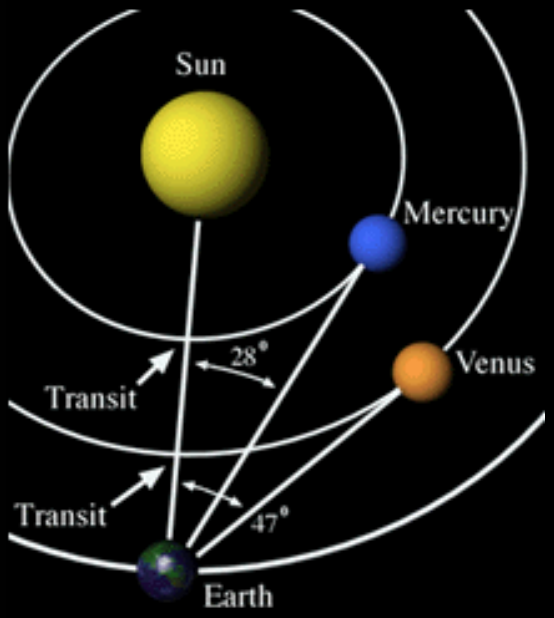


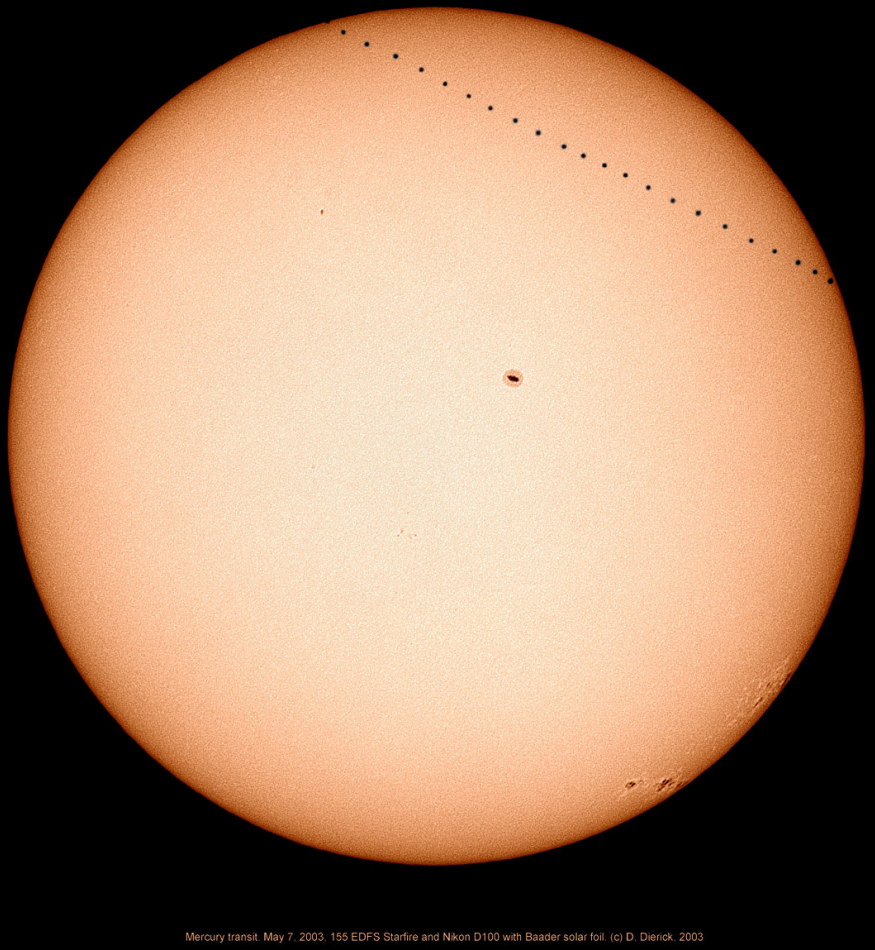


摘自Reichhardt 2002自然雜誌
Nisenson & Papaliolios 2001
天文物理期刊

2003年水星凌日(小日蝕)

凌日(transit)





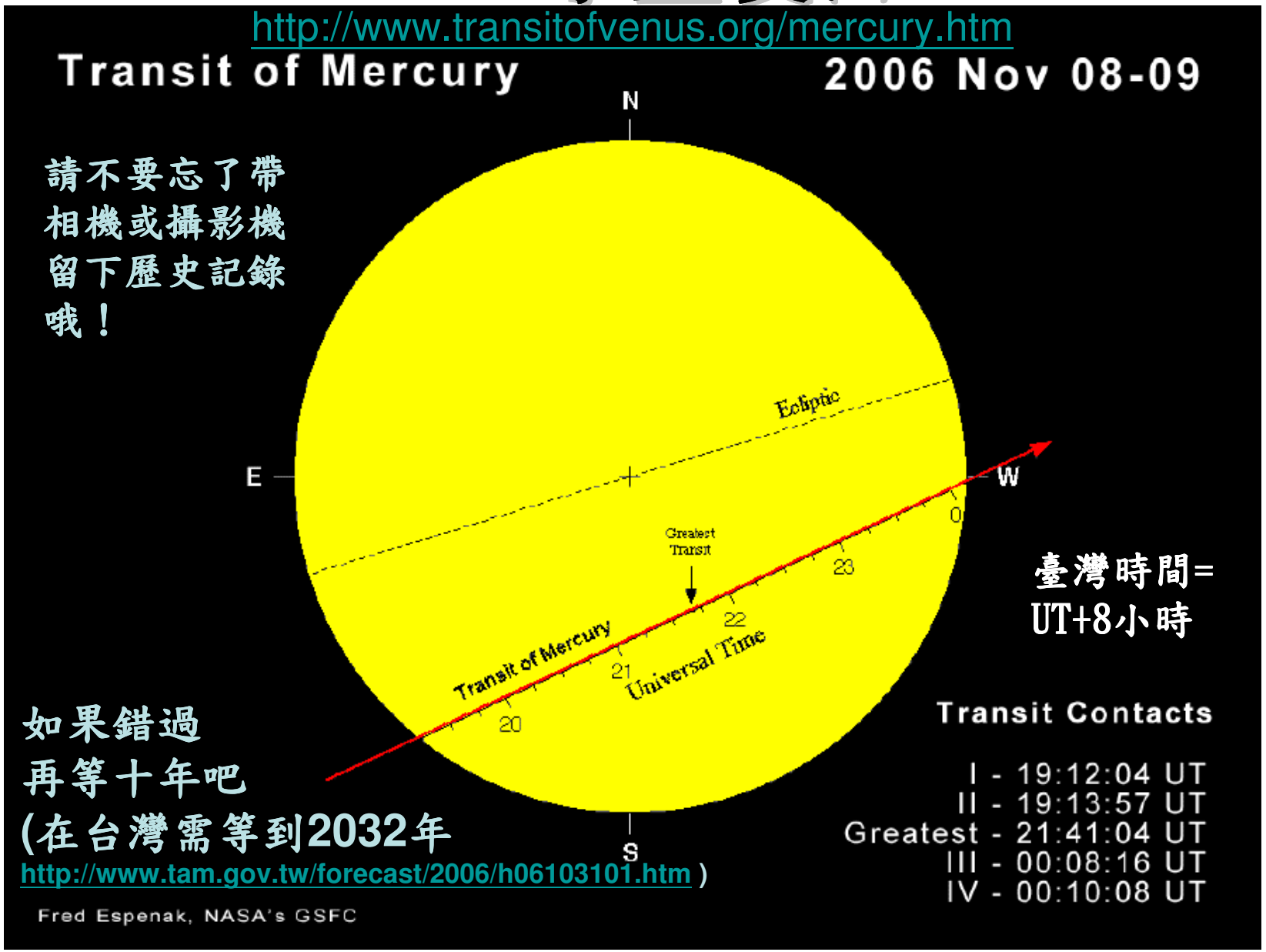
Mercury transit. May 7, 2003. 155 EDFS Starfire and Nikon D100 with Baader solar foil. (c) D. Dierick, 2003

今年11月9日
日出至上午
8點台灣可見

http://antwrp.gsfc.nasa.gov/apod/ap030527.html

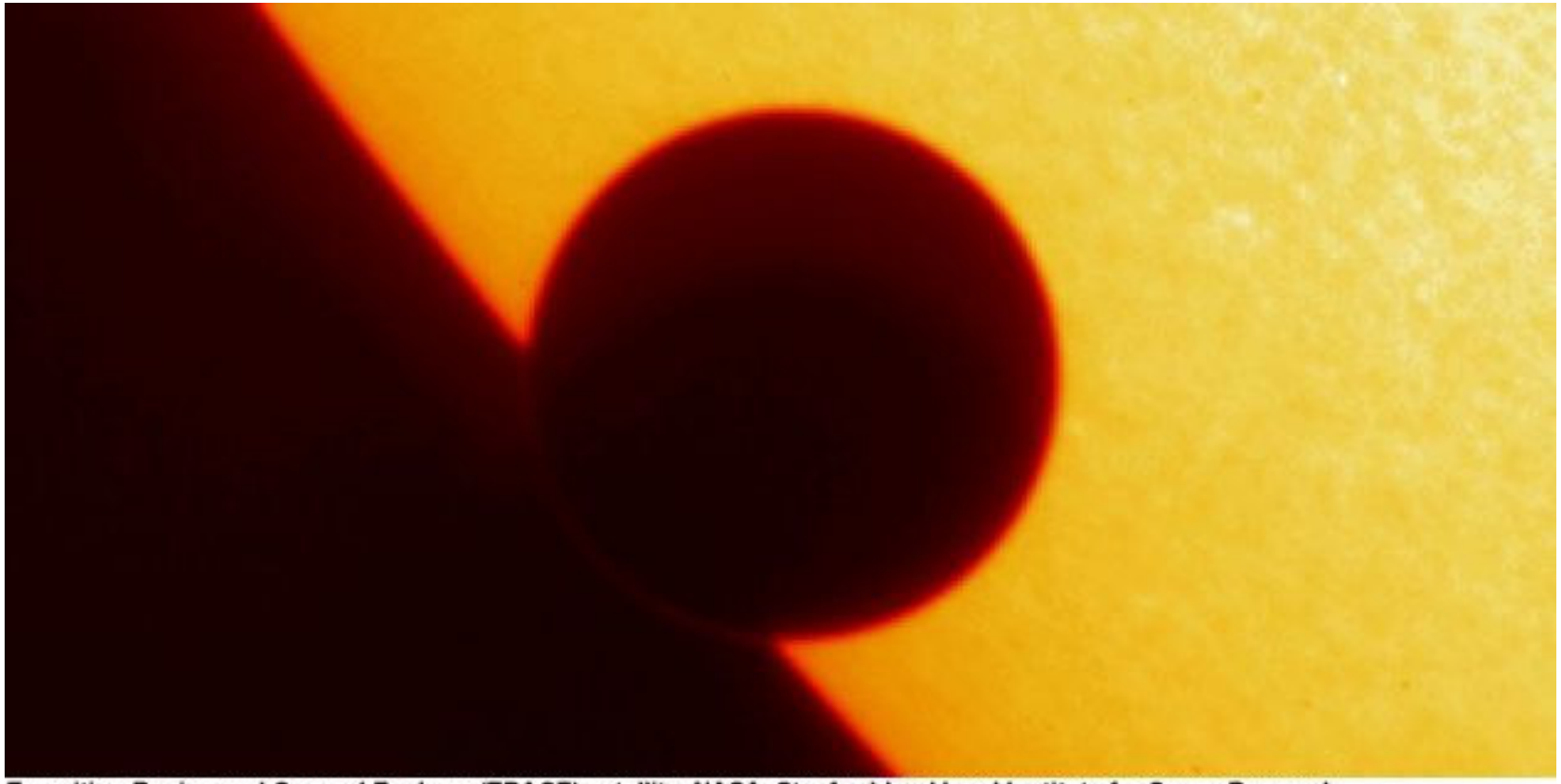
2006水星凌日

http://www.transitofvenus.org/mercury.htm



凌日可以用來研究大氣

2004金星凌日　下一次於2012



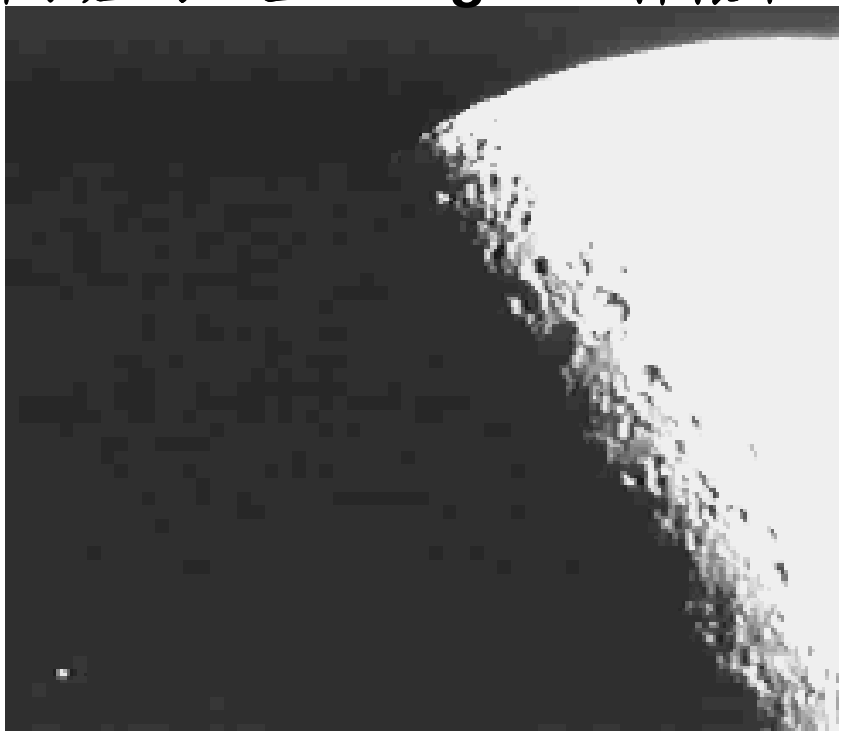
Transition Region and Coronal Explorer (TRACE) satellite, NASA, Stanford-Lockheed Institute for Space Research

note

A student asked me in the class about the period of Mercury transit. I said that there are some sort of periods but there is no definite period because the ecliptic orbit of Mercury is precessing due to the gravity of the Sun and other planets. Of course, the transit period should slightly alter if the orbit changes slowly with time. However, what I explained using orbital precession is actually a small effect for a timescale of a few hundred years. The main reason why there exist a number of periods for Mercury (or Venus) transit is just because of some complex results from the orbital inclination and orbital eccentricity even though we ignore orbital precession (i.e. even if we assume that the orbits are fixed with time). For more info, please refer to
http://sunearth.gsfc.nasa.gov/eclipse/OH/transit06.html

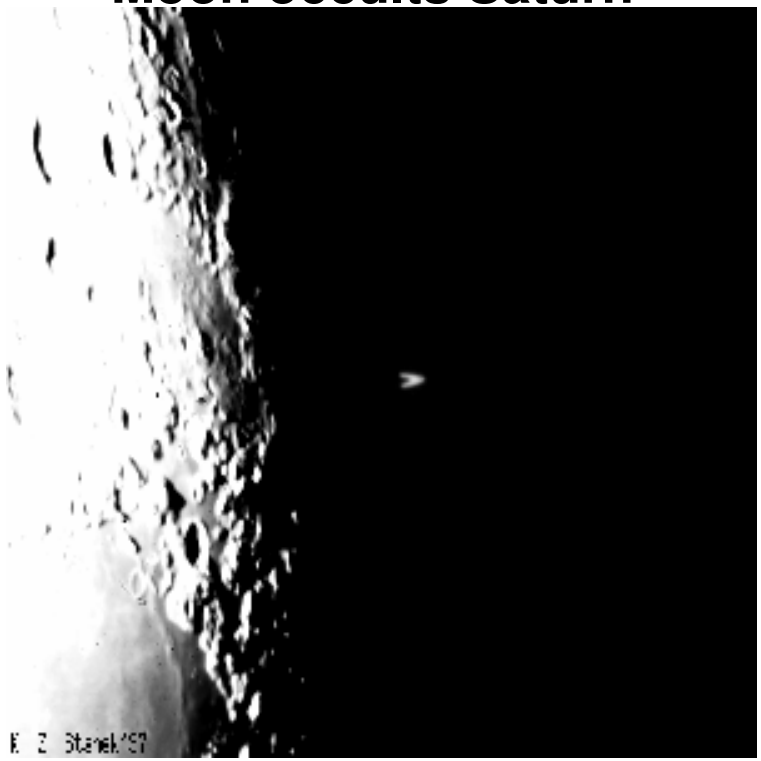
掩星 (occultation)

例子：月球運行，遮掩背景的恆星
(獅子座的α星：Regulus 軒轅十四)



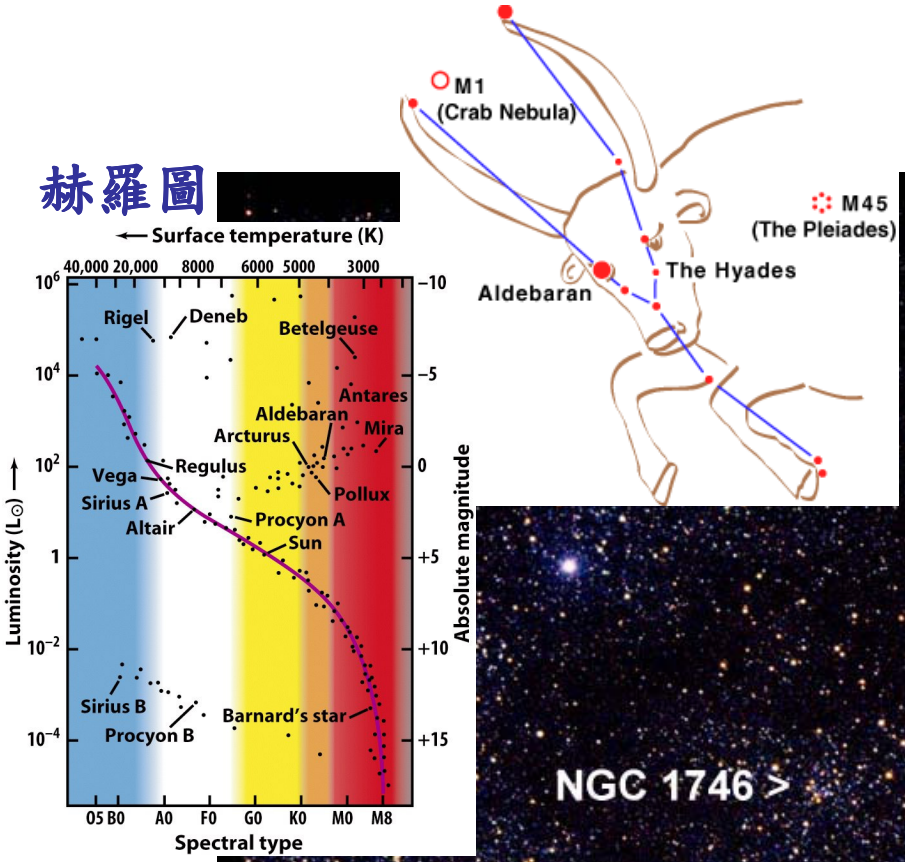
http://spacescience.spaceref.com/newhome/headlines/ast03jun99_1.htm

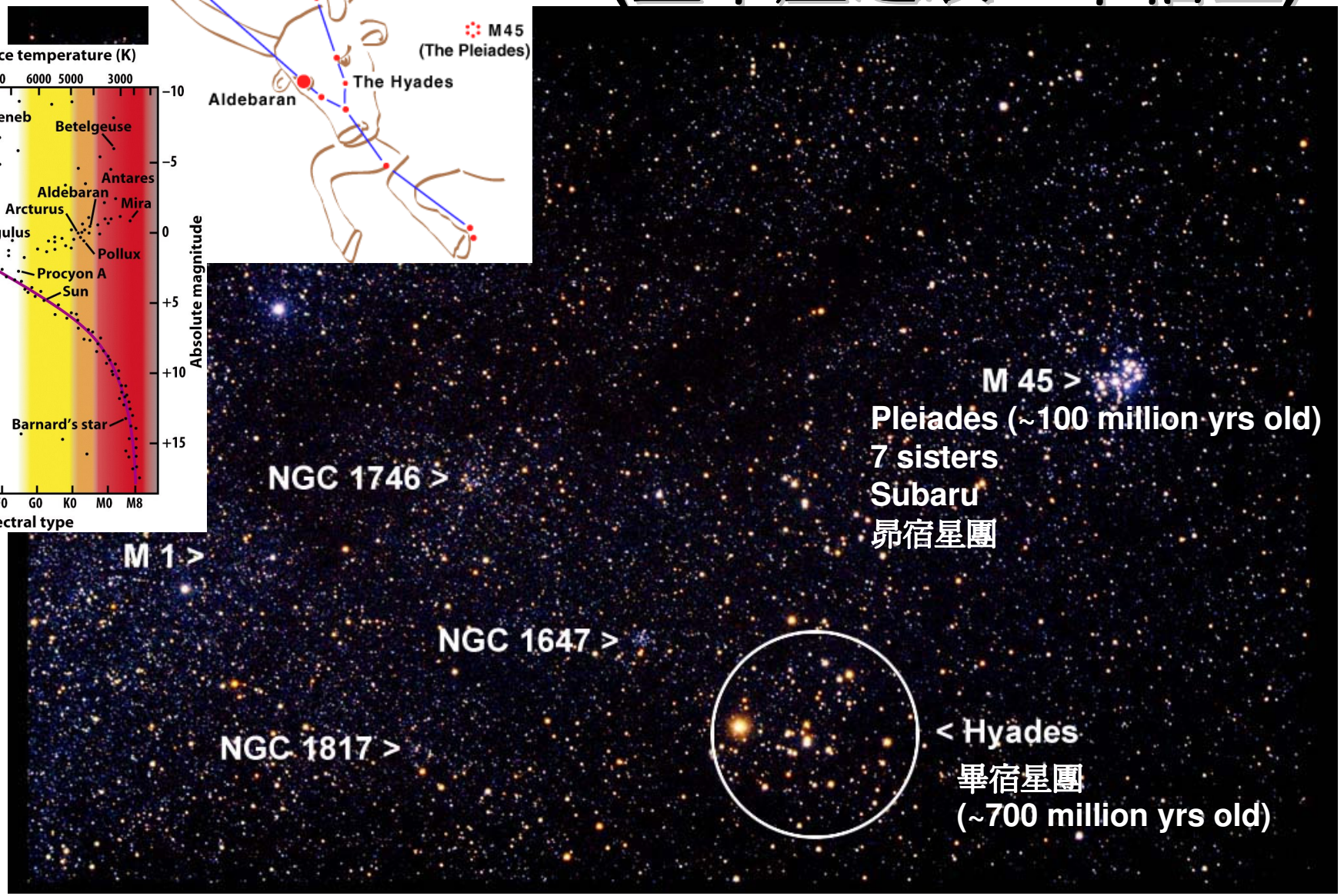
Moon occults Saturn



http://antwrp.gsfc.nasa.gov/apod/ap990508.html

Aldebaran in Taurus
(金牛座之眼：畢宿五)





Determining Aldebaran's Size

Brown et al. 1979

比較：肉眼可分辨的角度下限≈ 1'

Table 1. Results derived from the occultation.

Date	1978 August 26
Time of disappearance (UT)	$2^h\,14^m\,51^s.4 \pm 0^s.1$
Time of reappearance (UT)	$2^h\,36^m\,0^s.818 \pm 0^s.010$
Duration of emergence (u = 0.99)	176 ± 4 ms
Duration of emergence (u = 1.0)	176 ± 4 ms
Duration of emergence (u = 0.0)	154 ± 4 ms
Lunar rate	0.139 ± 0.004 arcsec/s
Angle of emergence	18° ± 0.5
Angular diameter (u = 0.99 and 1.0)	0.023 ± 0.004 arcsec
Angular diameter (u = 0.0)	0.021 ± 0.004 arcsec
Radius	$52 \pm 10\,R_\odot$
Mass	$1.9 \pm 0.7\,M_\odot$
Effective temperature	3650 ± 350 K

176 ms x 0.139 arcsec/s
= 0.023 arcsec
0.023 arcsec x distance
= 52 solar radii (紅巨星)

Δt=176 ms → 推測被遮天體的大小

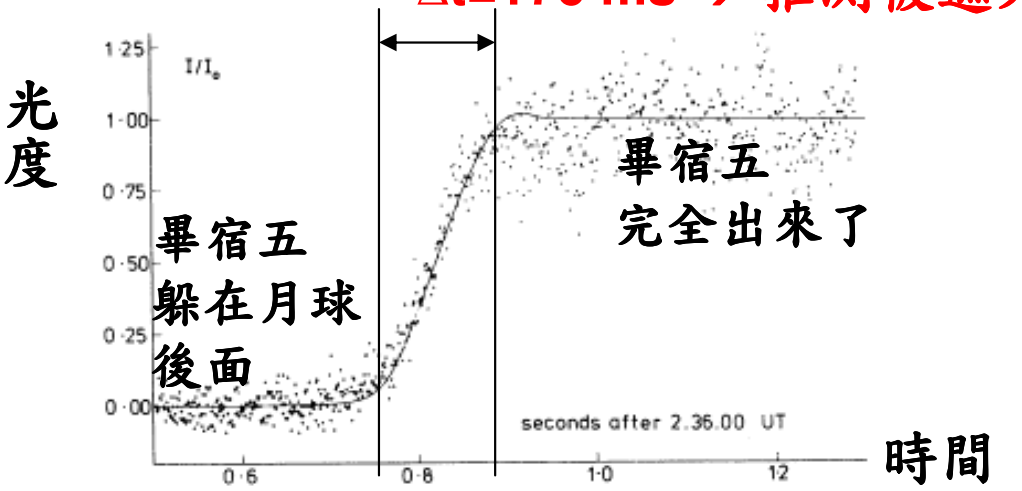


Figure 1. The occultation light curve. The solid line is the theoretical fit for a fully limb-darkened star with an angular diameter of 0.023 arcsec. Each dot represents a 1 ms observation. The ordinate is the measured intensity normalized to the intensity of the star outside occultation, while the abscissa is the time in seconds after 2.36.00 UT.

Uranus 天王星 & Neptune 海王星

Methane (甲烷) absorbs red light.

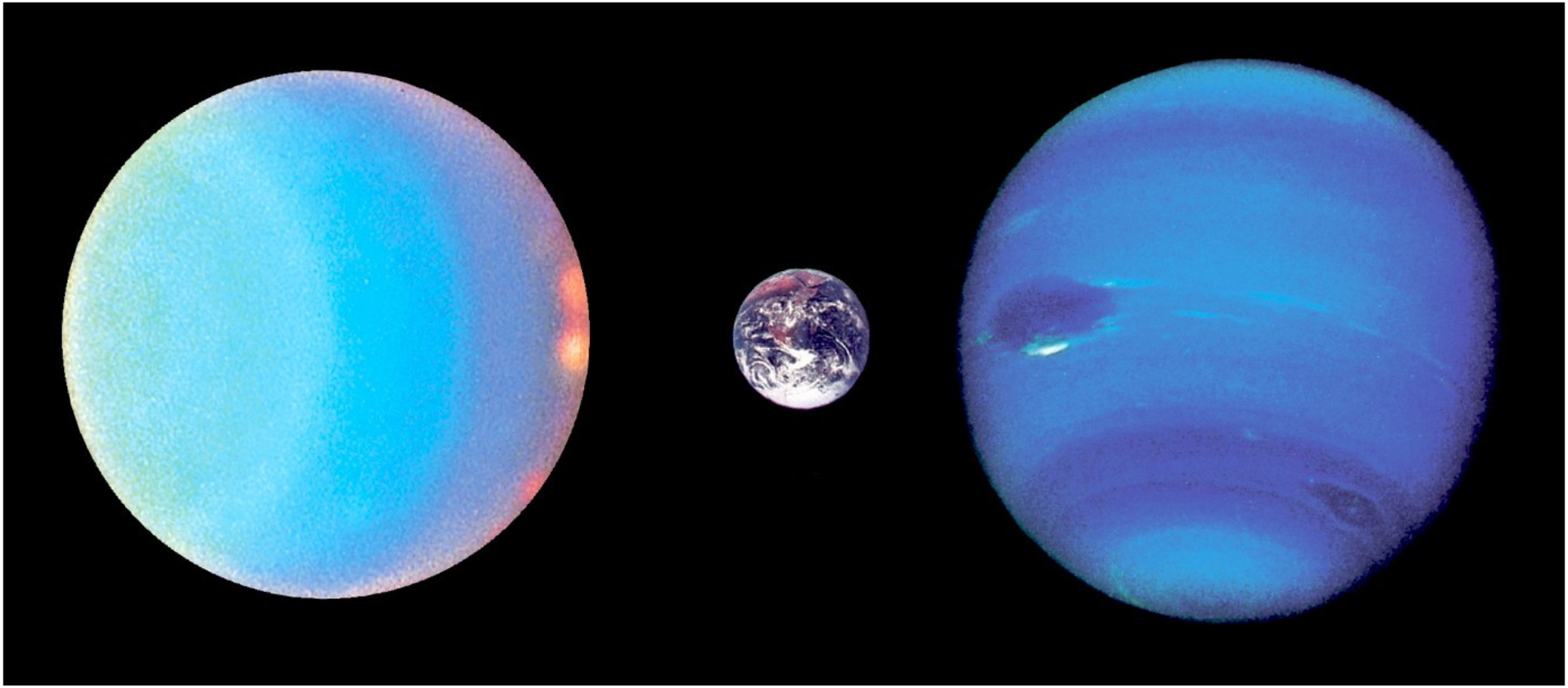


Figure 8-28 part 2
Discovering the Universe, Seventh Edition

Exaggerated seasons on Uranus

天王星自轉軸倒在軌道上，故四季變化劇烈

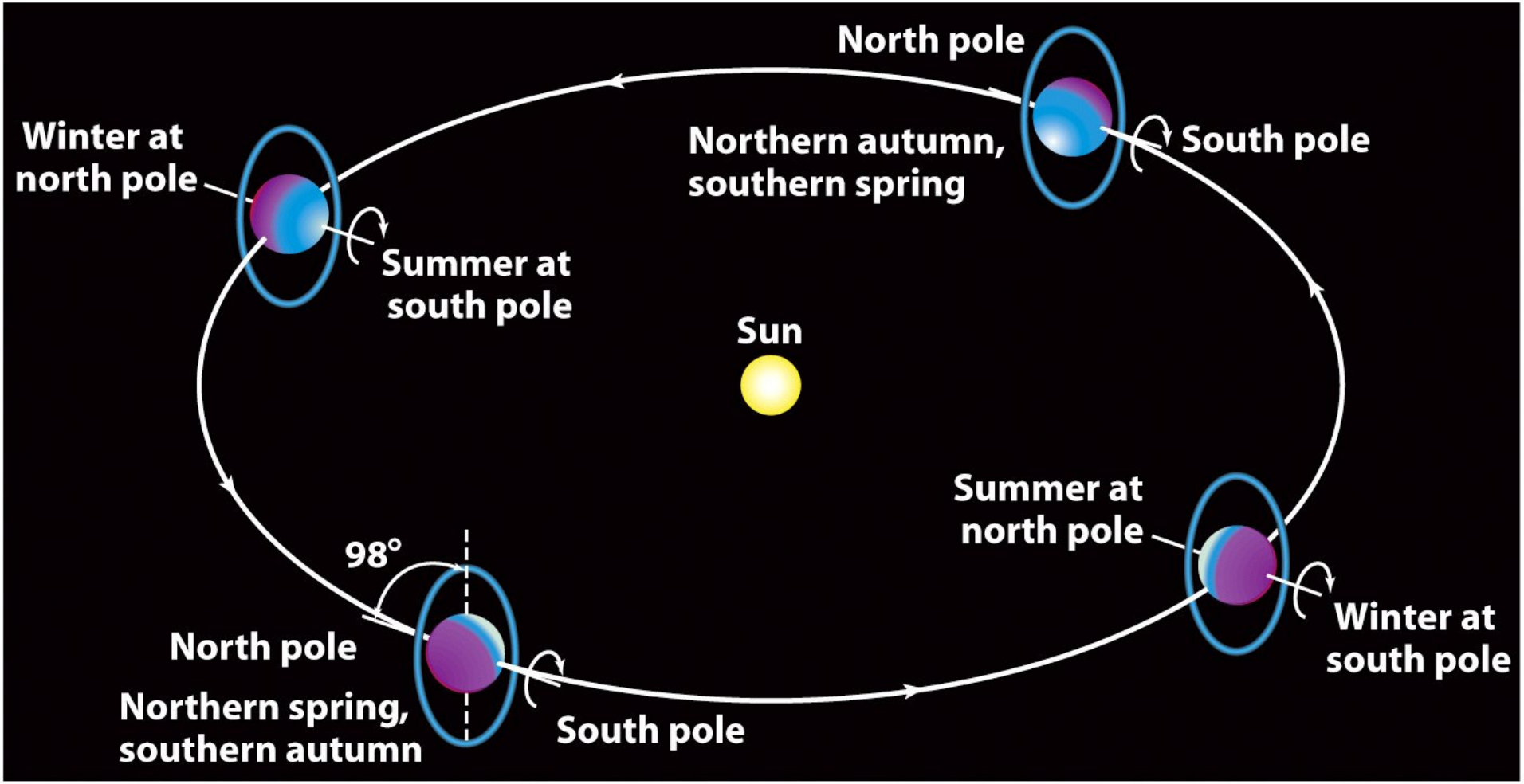


Figure 8-29
Discovering the Universe, Seventh Edition

Discovery of the Rings of Uranus

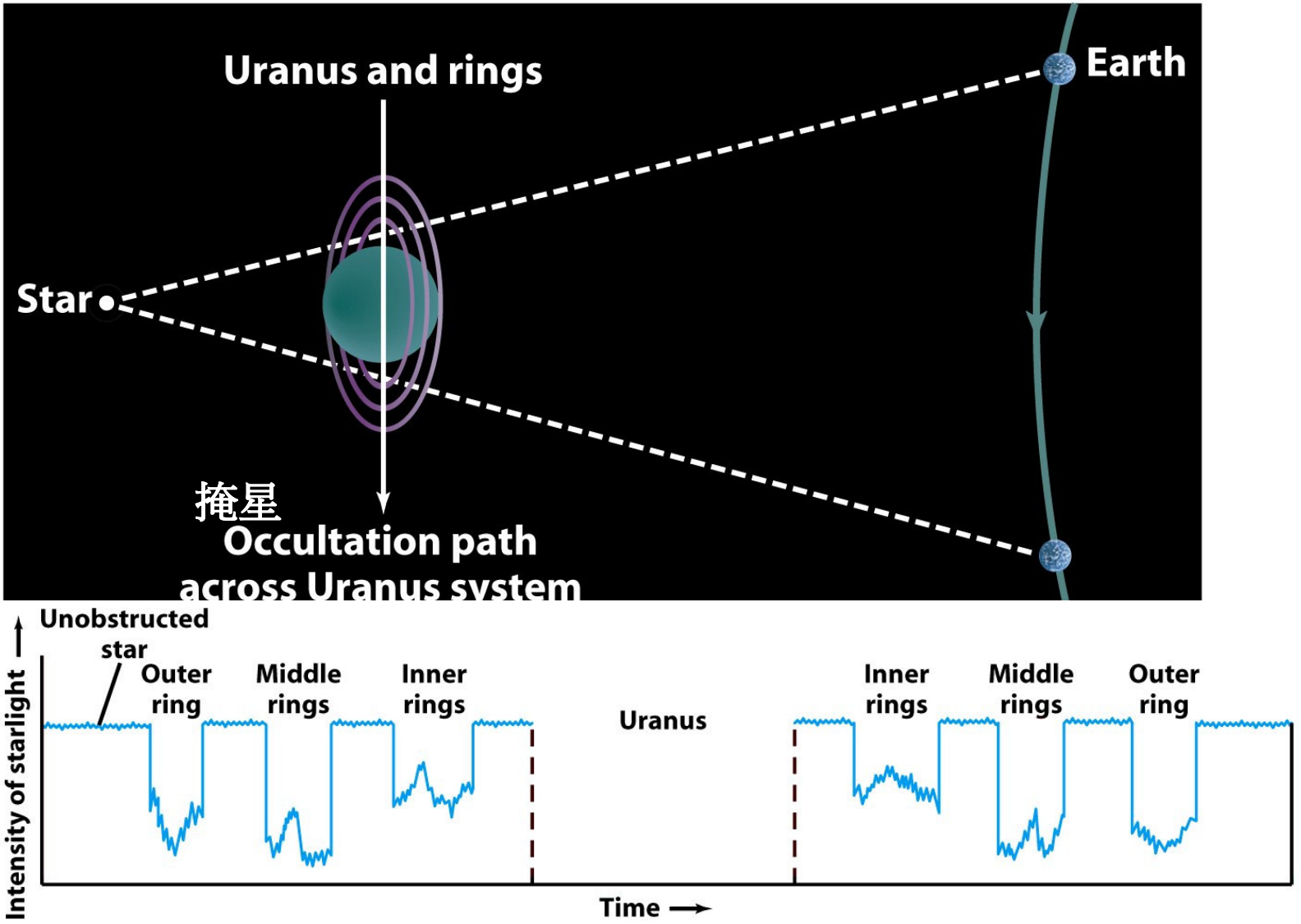


Figure 8-32b
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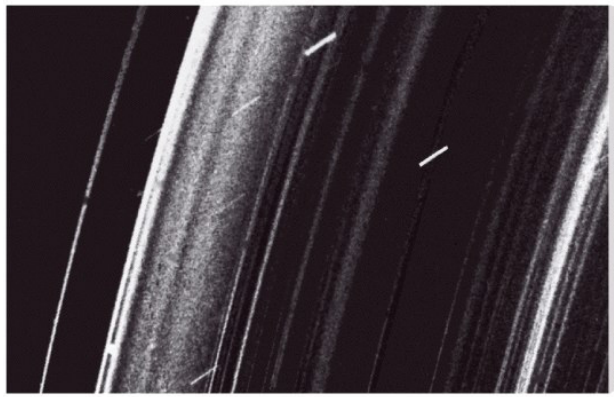
Rings and moons of Uranus

By Voyager 2



外行星(Jupiter, Saturn, Uranus, Neptune)皆有環

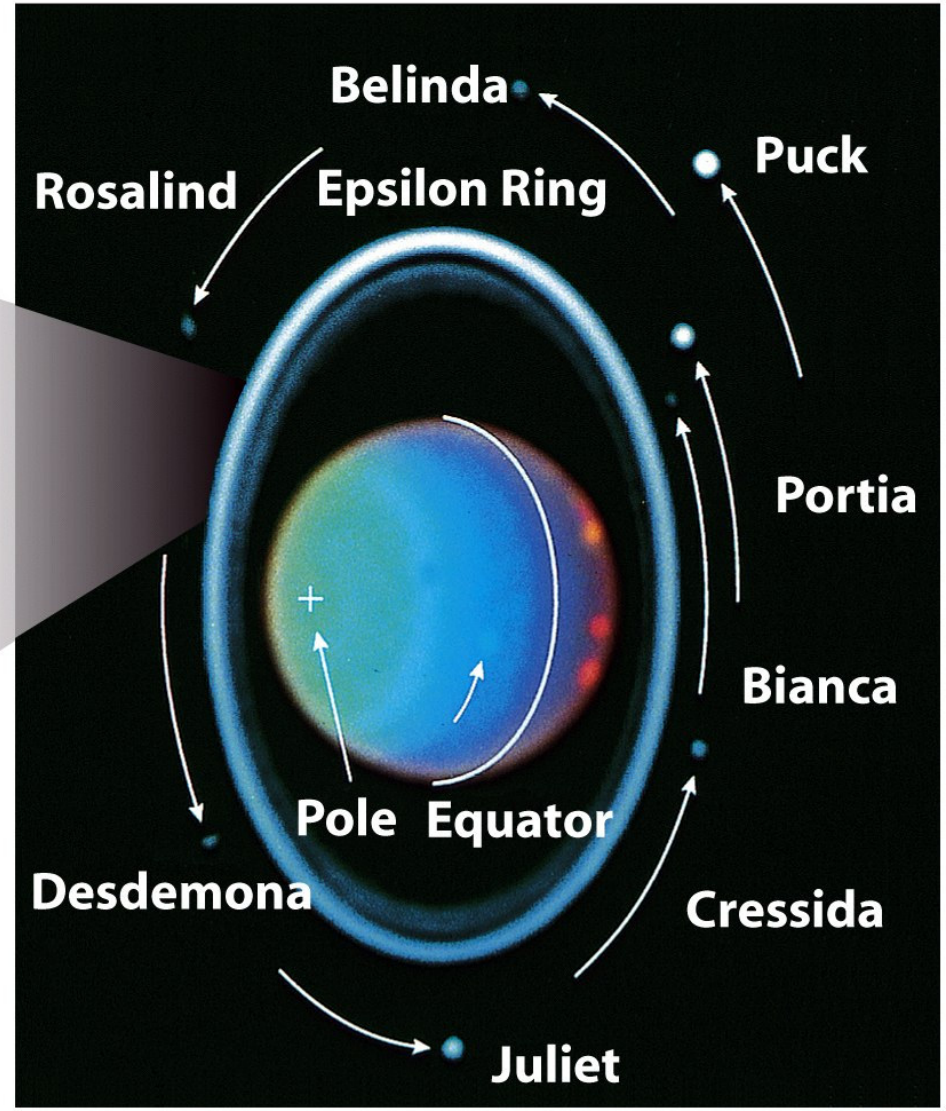


Figure 8-33
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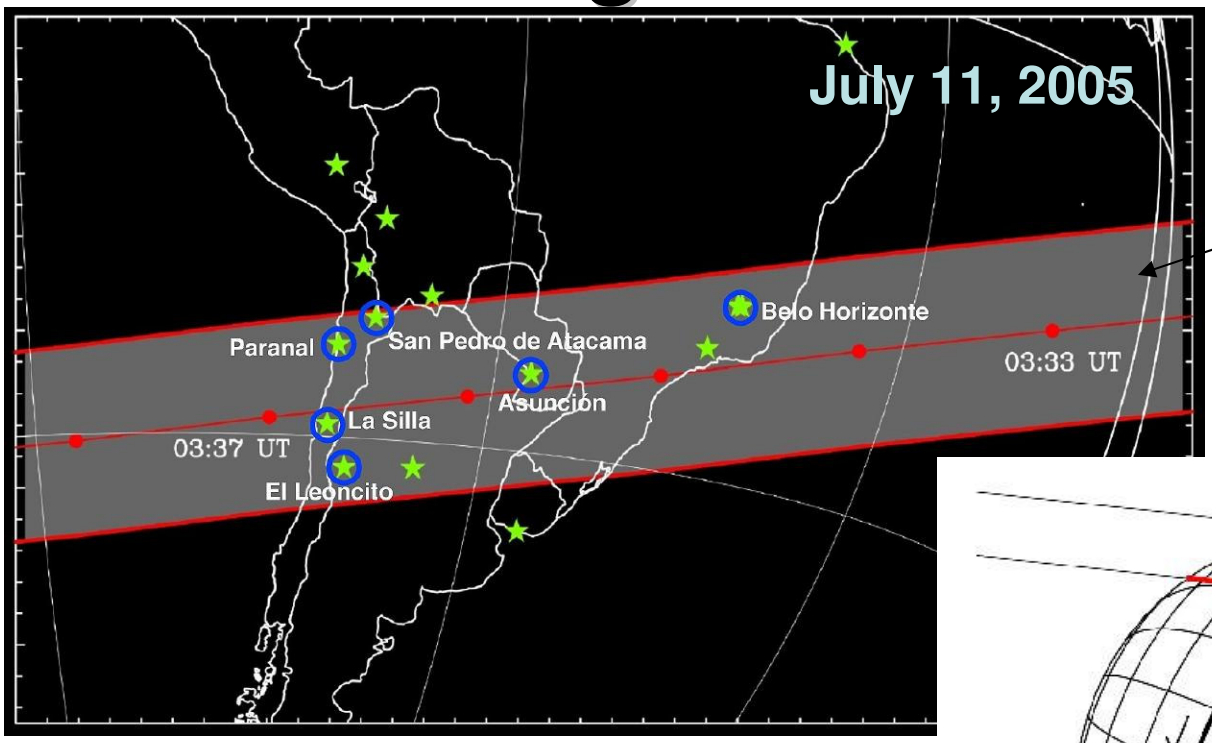
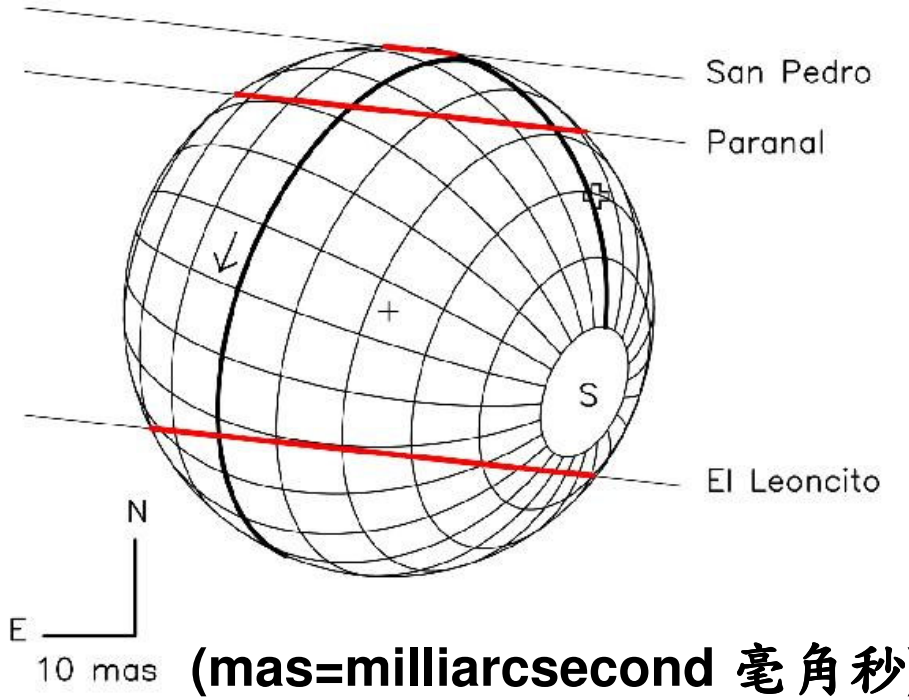
Determining Charon's Size & Density



當Charon在地球和某一恆星之間，Charon 遮住該星光所造成的影子落在地球

http://www.obspm.fr/actual/nouvelle/dec05/charon.en.shtml



(mas=milliarcsecond 毫角秒)

掩星發生的時間 →

半徑=603.6 +/- 5 km

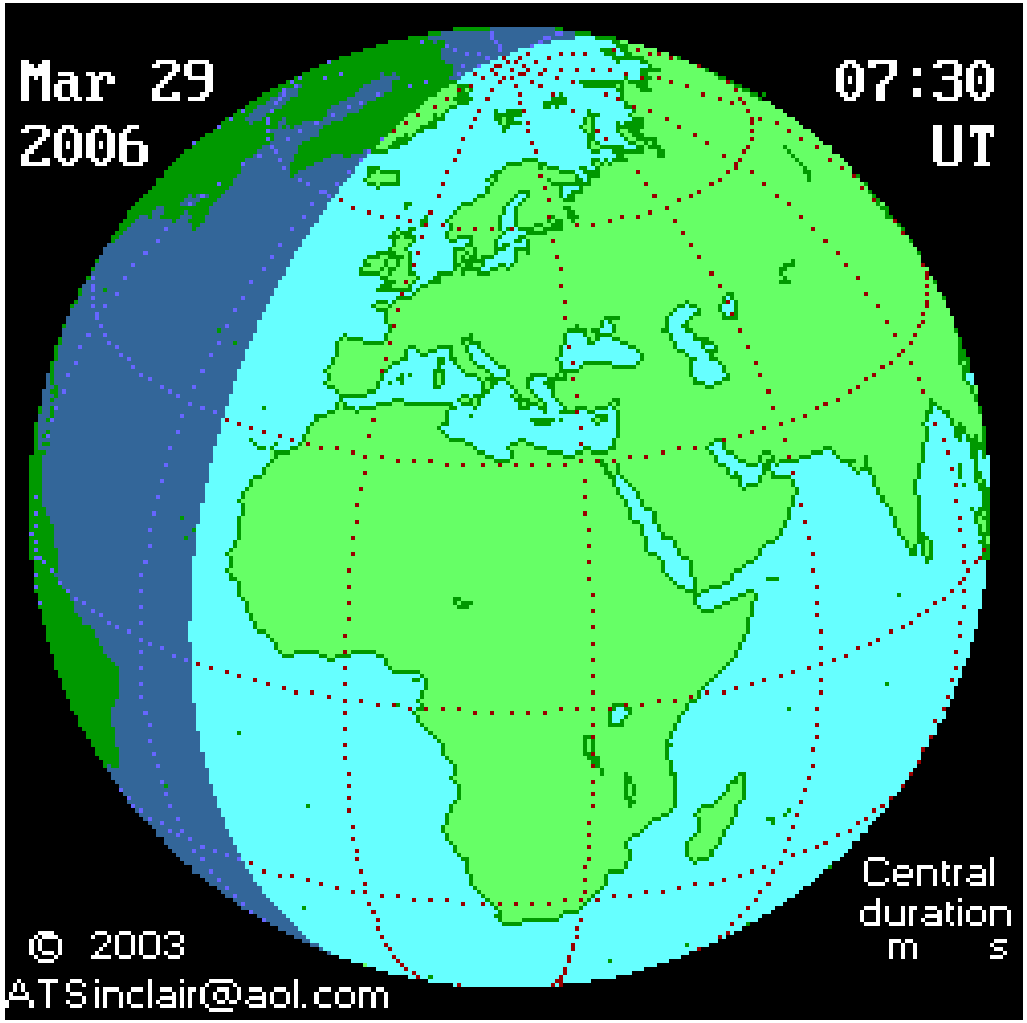
平均密度(=質量/體積)=

1.71 +/- 0.08 g/cm^3 →

contains ice & rock

Solar eclipse

http://www.flycapers.com/tours/voyages/2006/2006Eclipse/eclipse.html




30
新中橫・玉山國家公園
高程表
0 200 500 1000 2000 3000 4000 公尺
往水里
沙里仙工作站
阿里山森林遊樂區
阿里山舊站
沼平
觀日樓
祝山 2489
往阿里山
阿里山氣象所
阿里山鄉
信義鄉
萬年神木
林馬燮班溪
神木林道
出水溪
東埔隧道
第一迴頭彎觀景點
玉山景觀公路
東埔山觀景點
夫妻樹
東埔山 2782
信
義
鄉
沙里仙溪
陳有蘭溪
和社溪
塔塔加遊客中心
玉山北北峯 3833
玉山北峯 3858
玉山氣象測站
金門峒大斷崖
八通
新中橫公路
自忠
雪峰護管所
雪峰派出所
雪峰小隊
國家公園界碑
石山服務站
東埔山莊
大鐵杉
塔塔加鞍部
南投縣
嘉義縣
玉山前峯 3239
West Peak
玉山西峯 3467
玉山 3952
玉山東峯 3869
Pai Yun Retreat
排雲山莊
西峯下山屋
南投縣
高雄縣
自忠山 2606
東水山 2611
玉山口
石山 2682
麟芷山口
麟芷山 2854
鹿林山莊
鹿林山自然公園
玉山林道
鹿林前山 2845
鹿林山
Lulin
林務局楠溪工作站
阿里山鄉
桃源鄉
阿里山鄉
石水山 2800
北霞山 2472
博博猶溪
巴伊車留山 2241
玉山南峯 3844
玉山小南山 3582
玉山東小南山 3711
南玉山 3383
霞山
楠梓仙溪
楠溪
A
B
C
D
E
F
23°30′

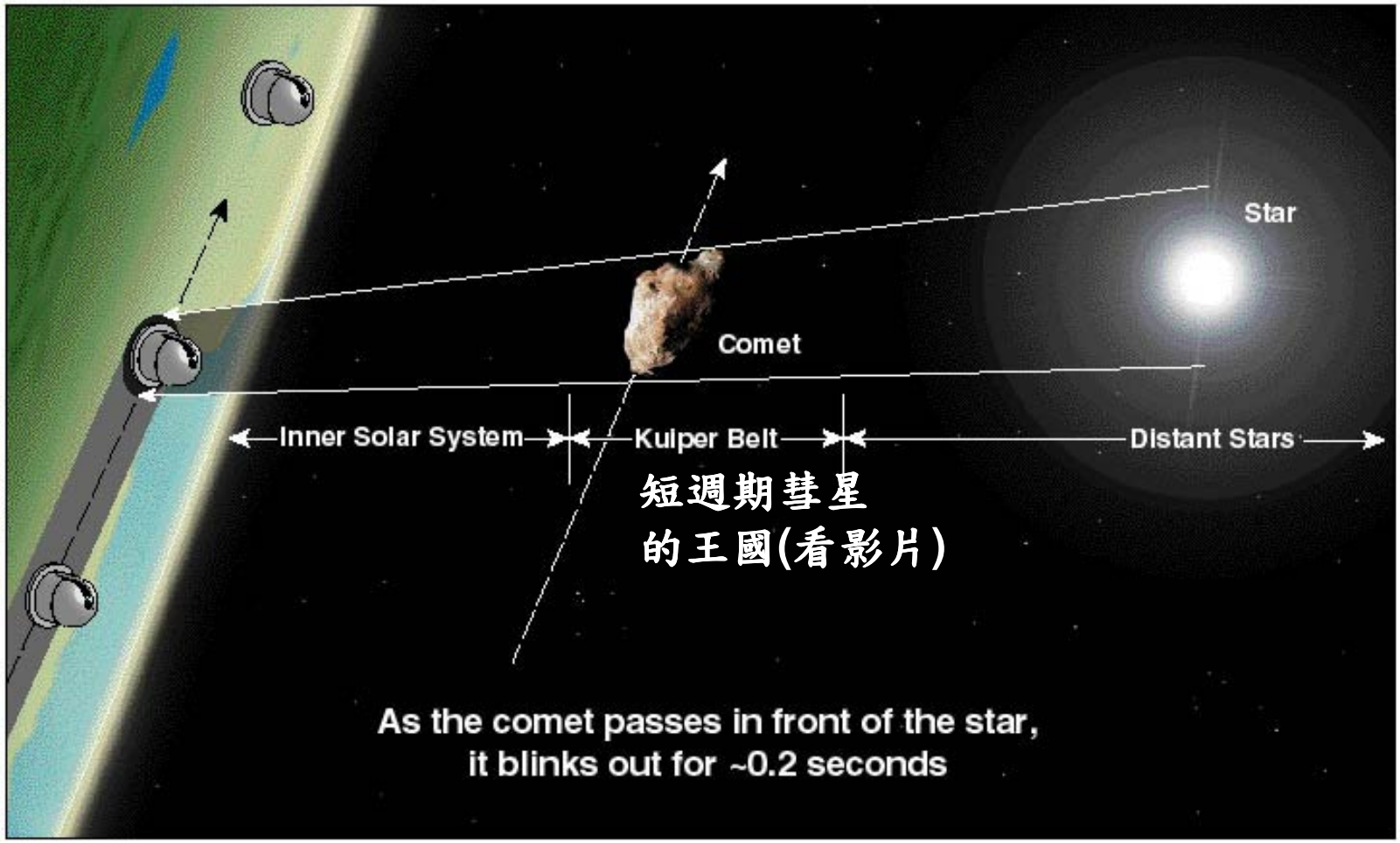
TAOS telescopes

臺美掩星計畫 (Taiwan-America Occultation Survey, a.k.a. TAOS):
http://taos.asiaa.sinica.edu.tw/
中央研究院
中央大學
美國勞倫斯利物摩國家實驗室
美國賓州大學
韓國延世大學
4 telescopes
0.5m in diameter
Search for Kuiper belt objects(the source of comets)

Taiwan-America Occultation Survey (TAOS)

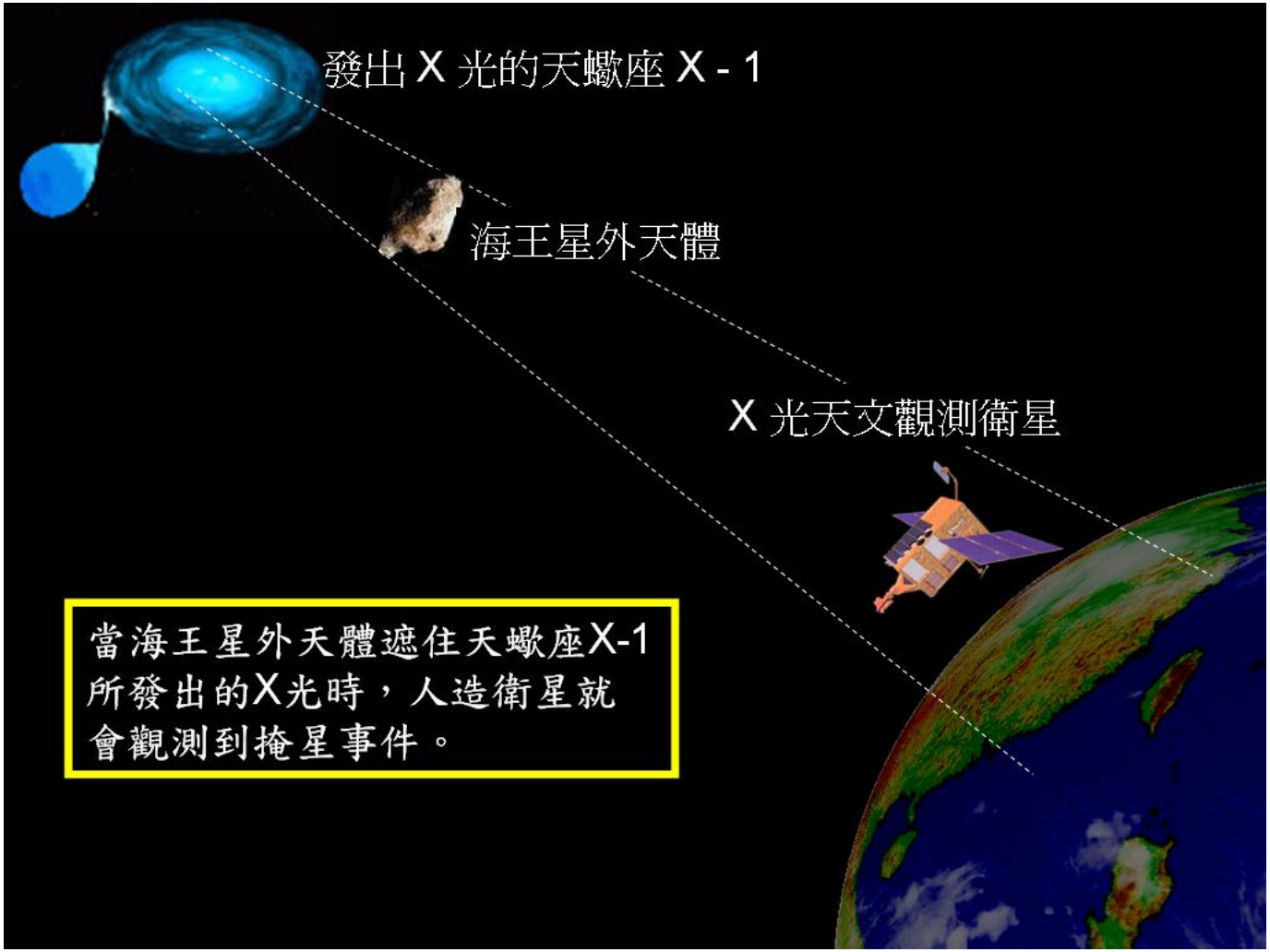
Counting Kuiper Belt objects using occultations (掩星)

Most of Kuiper Belt objects are too small to see!



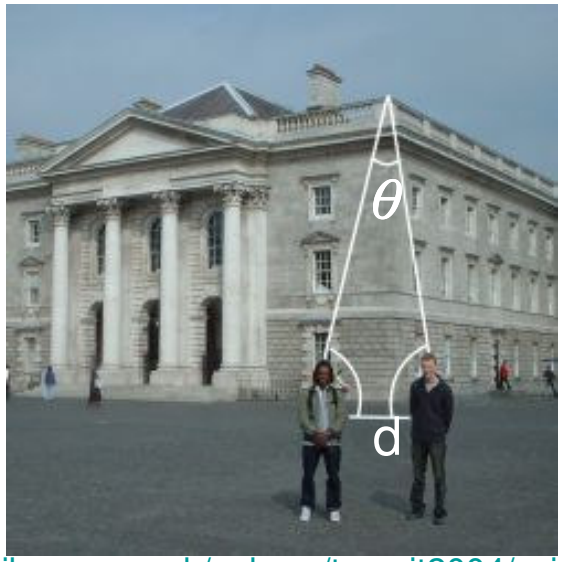
X-ray 的掩星

http://astro.phys.nthu.edu.tw/

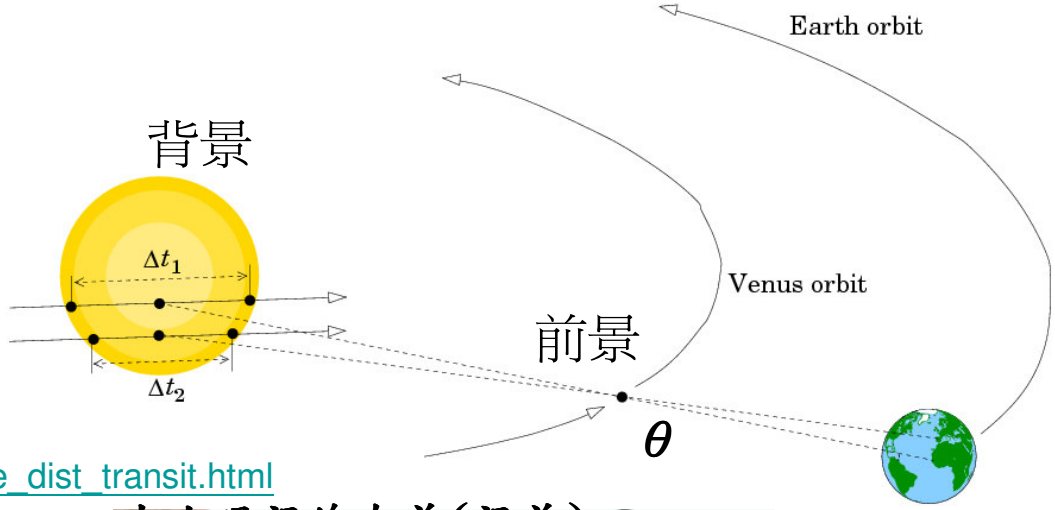


這些掩星事件大部分持續二到三毫秒，最長的是七毫秒。它們所對應的海王星外天體大小則是幾十公尺到一百公尺左右。根據這些事件，清大張祥光團隊估算出太陽系中這種尺度大小的海王星外天體總數至少有一千兆個以上。

Measuring the distance between the earth & the Venus



http://en.wikipedia.org/wiki/Transit_of_Venus



http://www.jb.man.ac.uk/~slowe/transit2004/science_dist_transit.html

parallax 視差
triangulation 三角測量

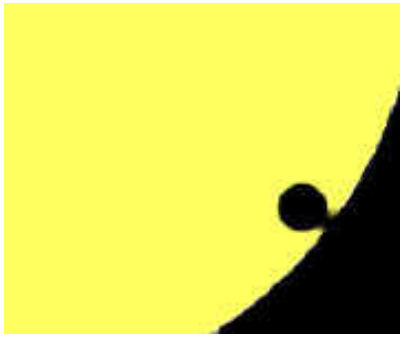
d固定，θ越小 ，
目標物距離越遠

How does a 3-D movie or picture work?

黑滴(black drop)現象

http://www.transitofvenus.org/blackdrop.htm

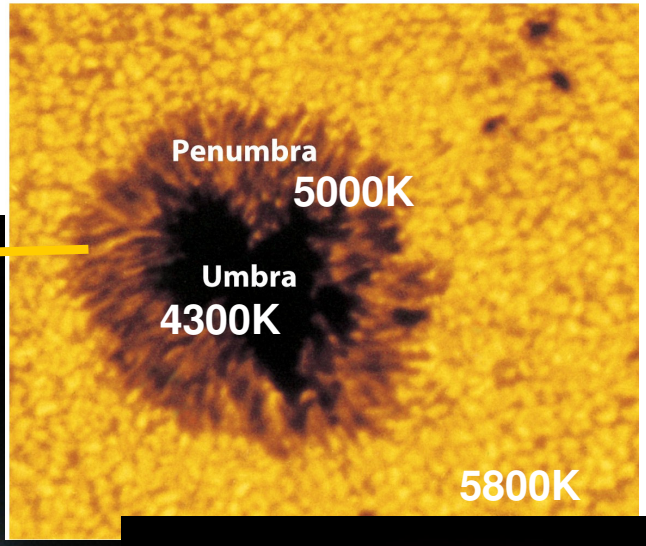
http://www.tam.gov.tw/forecast/2006/h06103101.htm

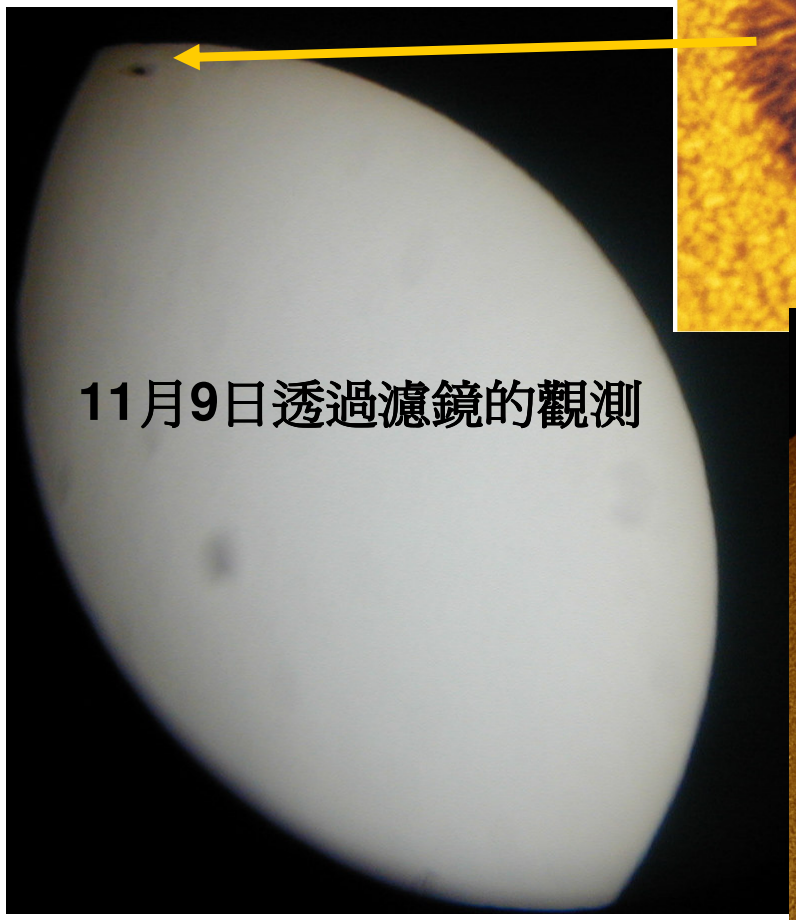


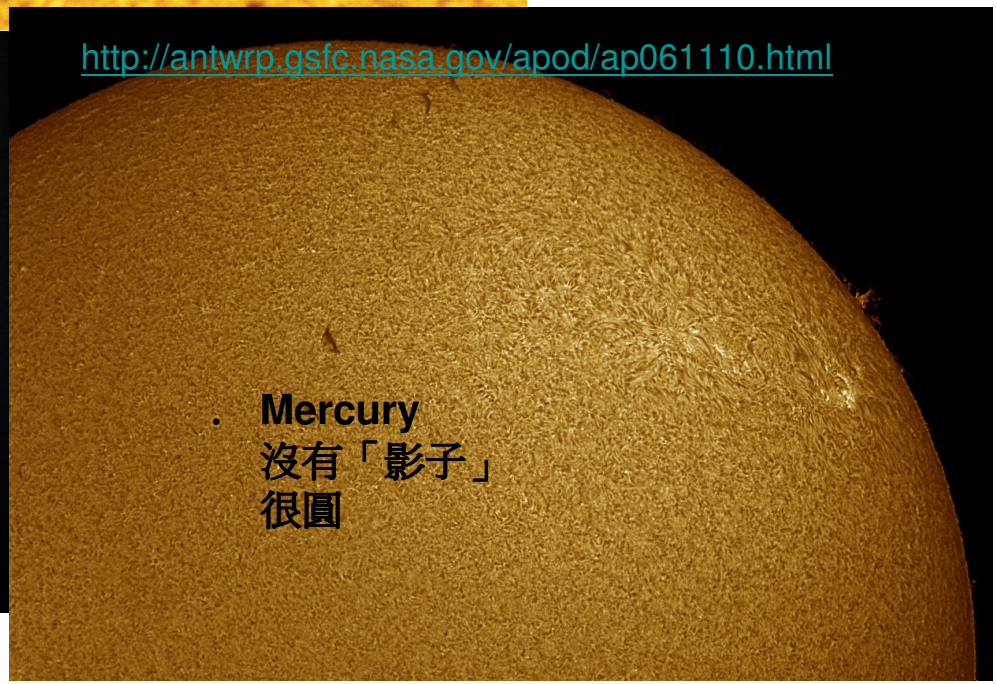
主因：繞射

Other small factors:
Limb darkening
Planet's atmosphere

如何分辨 Sunspot (太陽黑子) & Planet Transit (行星凌日)



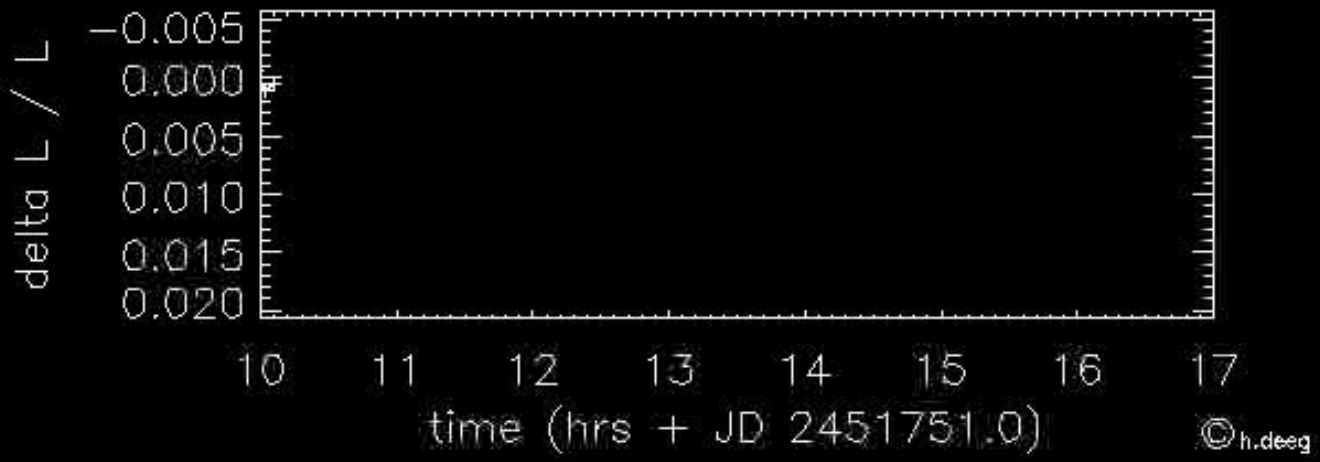




系外行星穿越它的太陽(行星凌日)

無法鑑別 →

實際可以看到的 →

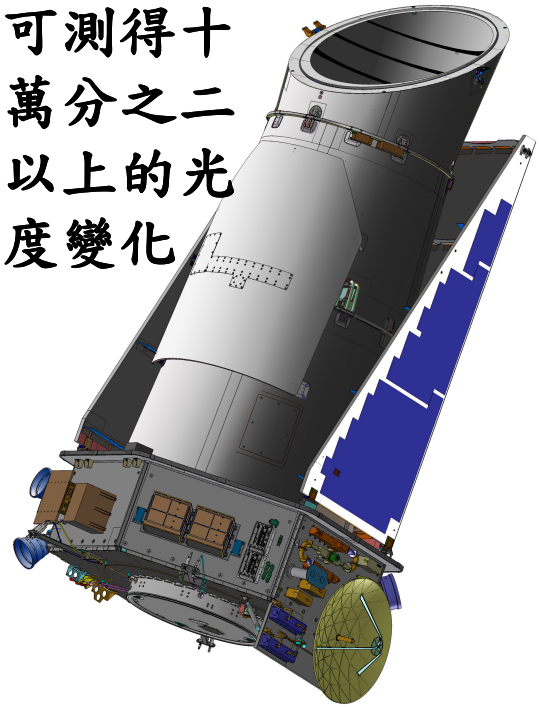


http://www.iac.es/proyect/tep/transitanim.html

刻卜勒1米太空望遠鏡 (2008?)

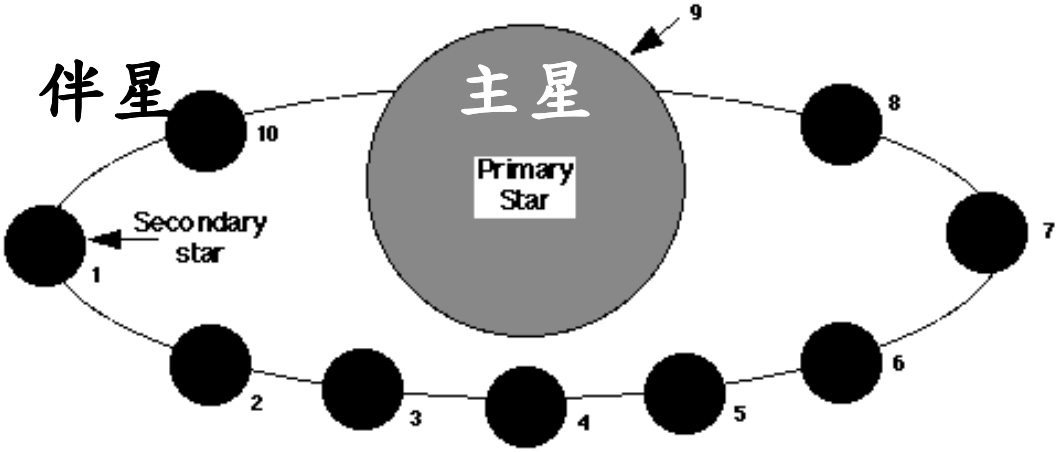
美國太空總署
四年不間斷地觀測
十萬個類似太陽的恆星

可測得十萬分之二以上的光度變化

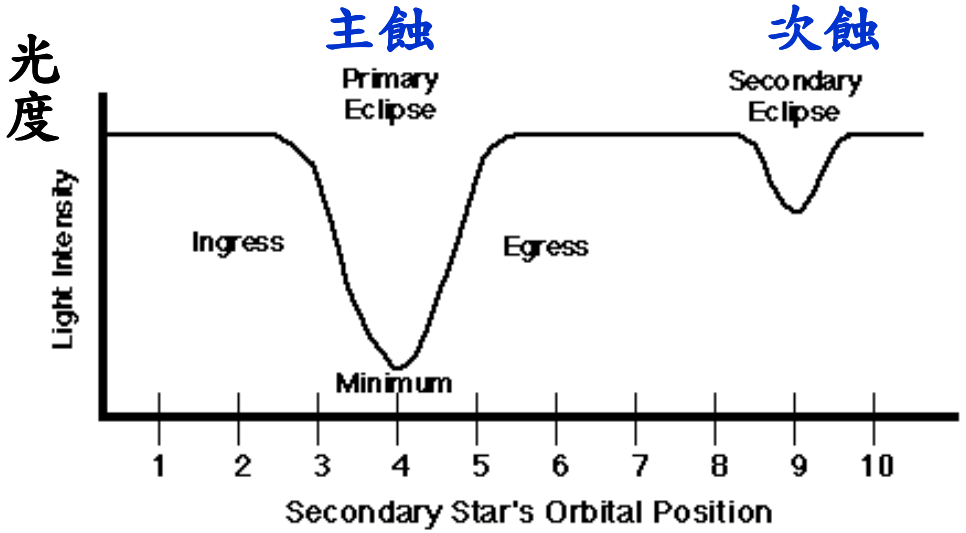


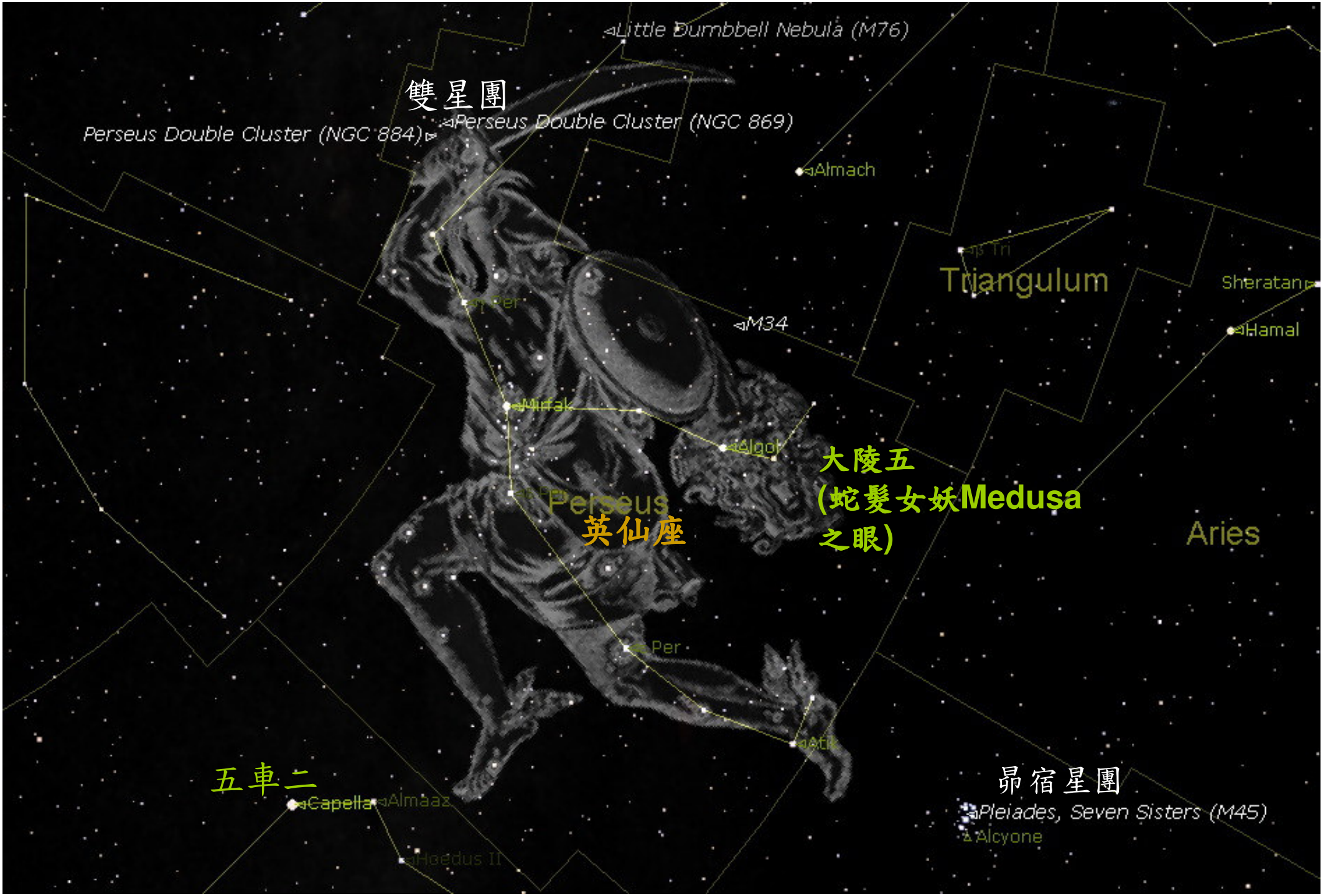
蝕雙星 Eclipsing Binary

ECLIPSING BINARY STAR SYSTEMS



www.hposoft.com/Astro/PEP/eclipsingbinaries.html




Little Dumbbell Nebula (M76)
雙星團
Perseus Double Cluster (NGC 869)
Perseus Double Cluster (NGC 884)
Almach
Triangulum
Sheratan
Hamal
M34
Mirfak
Algol
大陵五
(蛇髮女妖Medusa
之眼)
Perseus
英仙座
Aries
Per
五車二
Capella
Almaaz
Hoedus II
昴宿星團
Pleiades, Seven Sisters (M45)
Alcyone

close binaries

英仙座大陵五
蝕變星 →

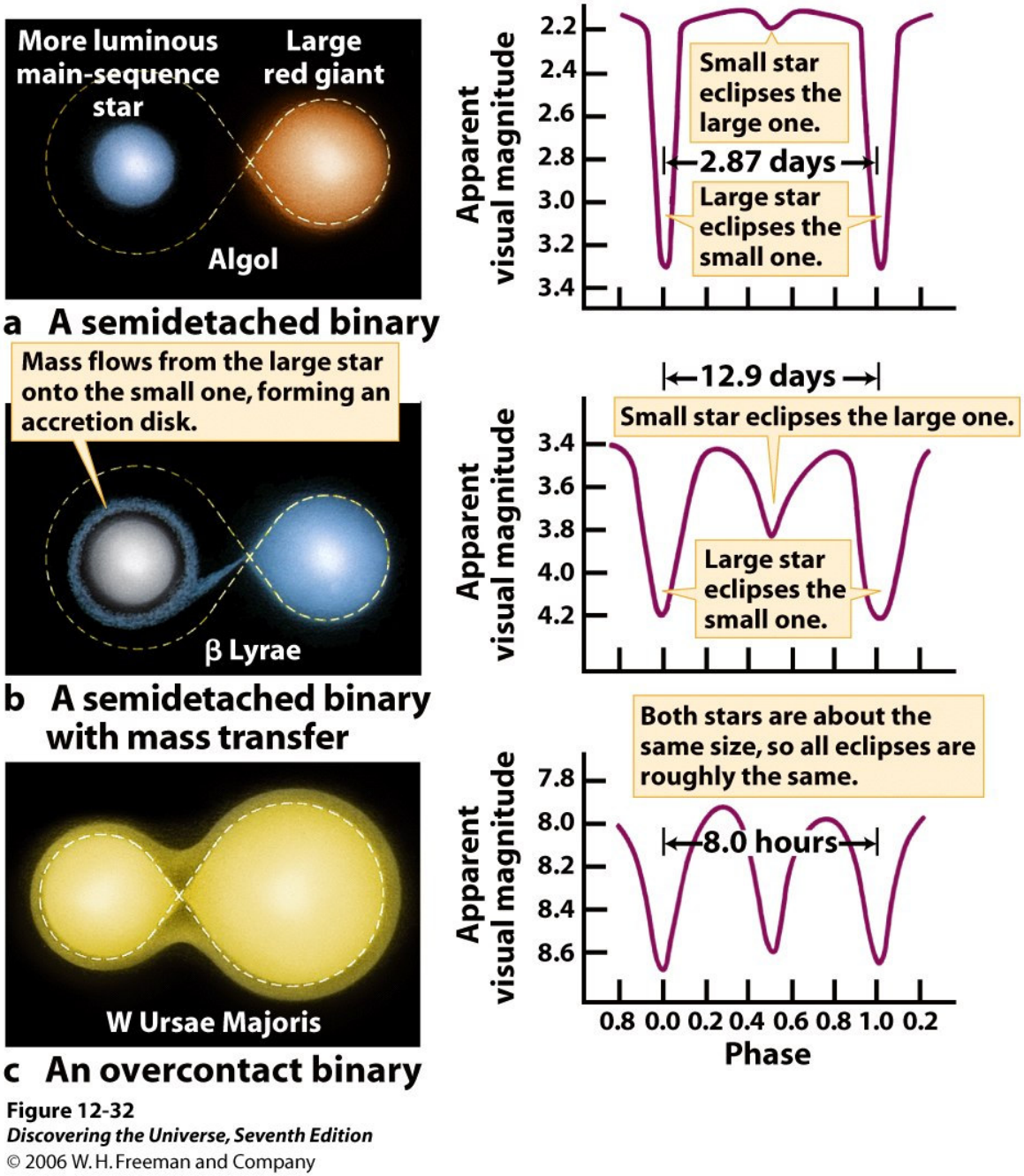


Figure 12-32
Discovering the Universe, Seventh Edition

MERCURY: VITAL STATISTICS 水星(辰星)

Average distance from Sun:	0.387 AU = 5.79 × 10^7 km
Maximum distance from Sun:	0.467 AU = 6.98 × 10^7 km
Minimum distance from Sun:	0.307 AU = 4.60 × 10^7 km
Eccentricity of orbit:	0.21
Average orbital speed:	47.9 km/s
Sidereal period of revolution:	88.0 Earth days = 0.24 Earth year 公轉
Sidereal rotation period:	58.7 Earth days 自轉
Solar rotation period (day):	176 Earth days
Inclination of equator to orbit:	0.5°
Inclination of orbit to ecliptic:	7° 00' 16"
Radius (equatorial):	2439 km = 0.382 Earth radius
Mass:	3.30 × 10^{23} kg = 0.0553 Earth mass
Average density:	5430 kg/m^3 = 0.984 Earth density
Escape speed:	4.3 km/s
Surface gravity (Earth = 1):	0.38
Albedo:	0.12 因幾乎無大氣，反射率低
Average surface temperatures:	Day: 350°C = 662°F = 623 K Night: −170°C = −274°F = 103 K
Atmosphere:	Very thin, transient H, He, K, Na, O

1AU=一個天文單位
=earth-to-Sun distance

自轉週期：公轉週期
= 2：3

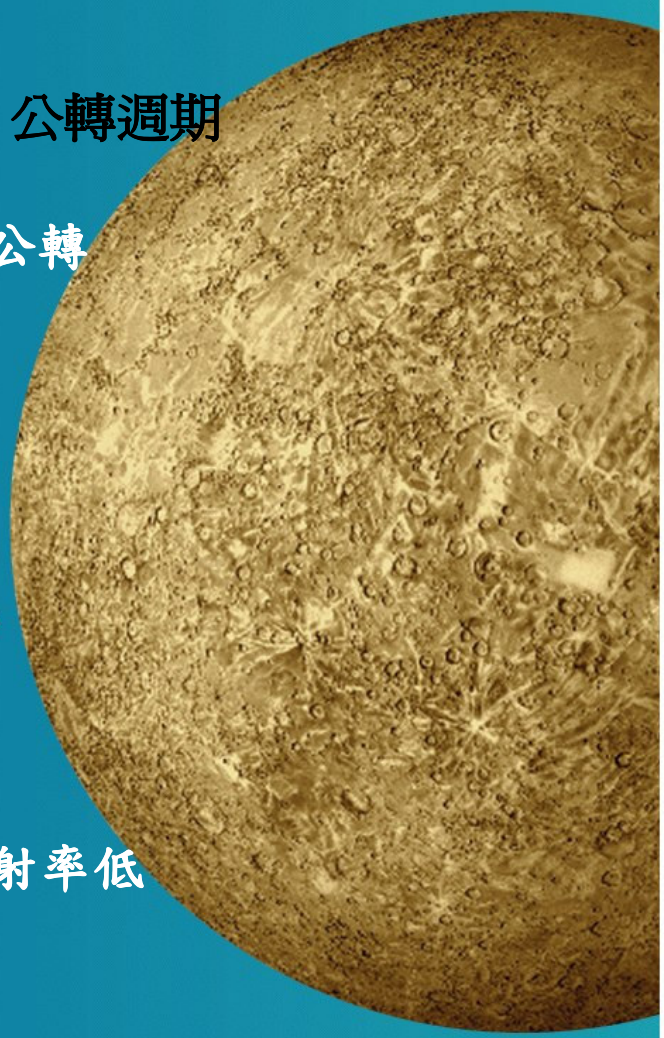


Figure 7-1
Discovering the Universe, Seventh Edition

1974: Mariner 10 (photograph only 40% of Mercury)

Mercury is almost dead (no volcanic activities)
☹

Mercury: no maria?

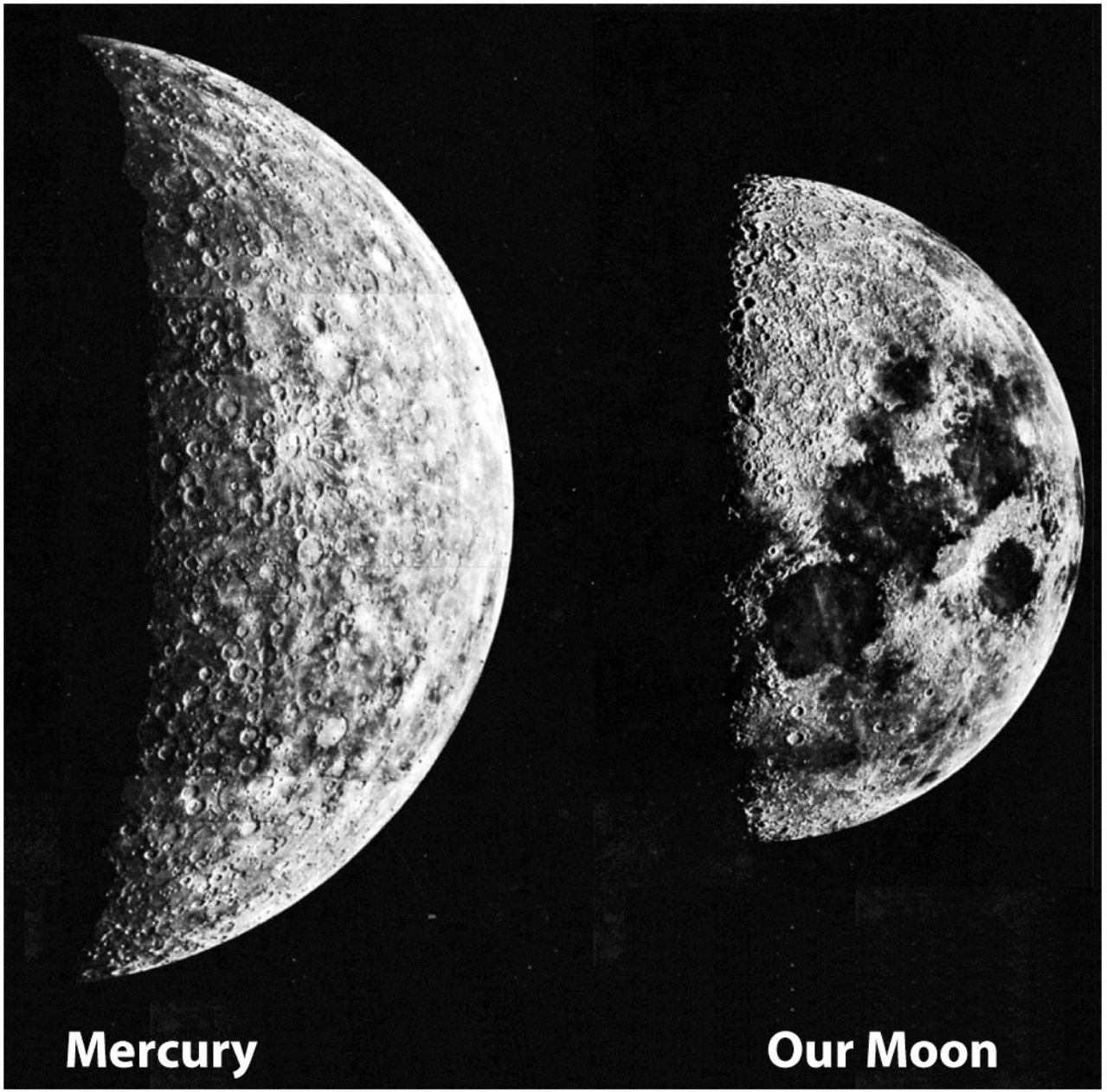


Figure 7-2
Discovering the Universe, Seventh Edition

Caloris Basin: a huge impact basin

Probably created in the era of heavy bombardment; i.e. older than lunar maria → erase marialike feature

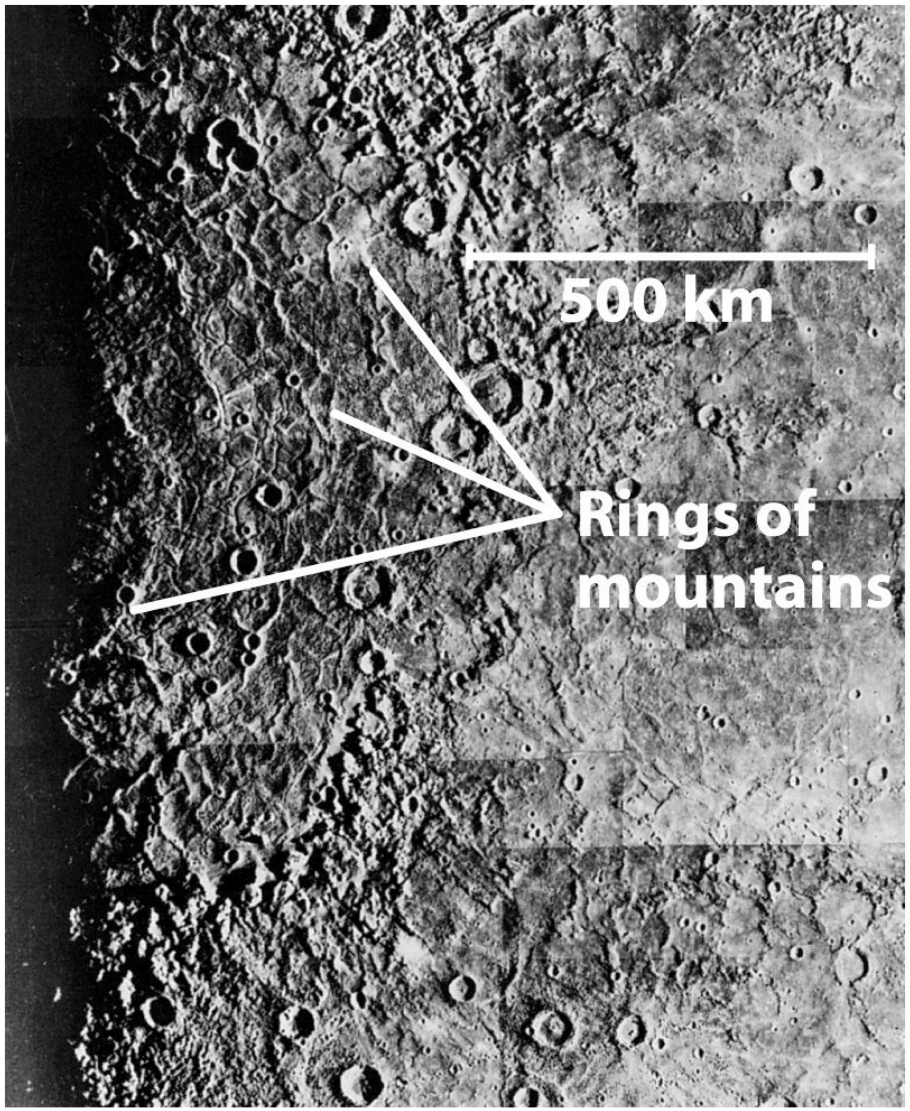


Figure 7-3a
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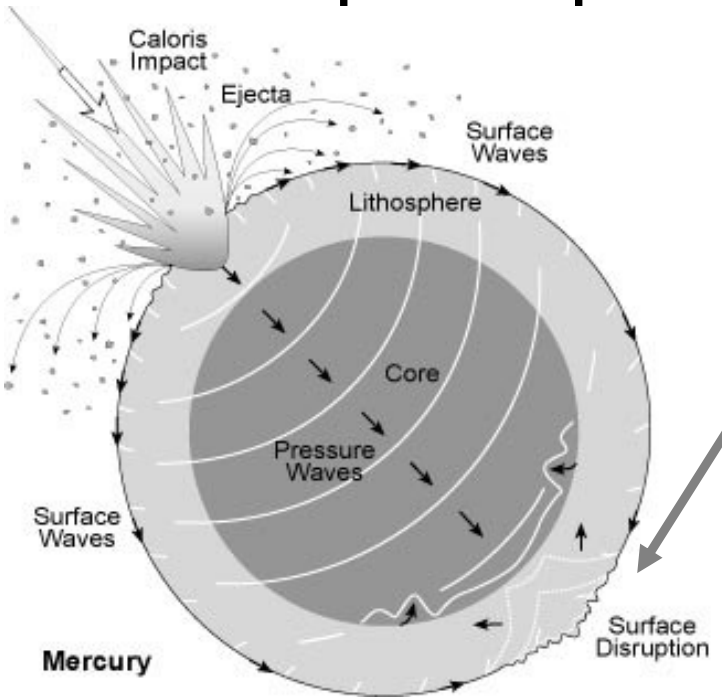
Hilly Terrain

On the opposite side of the Caloris Basin

Big impact
→ Caloris basin
→ energy propagates to the other side & get focused
→ surface is pushed up



http://ase.tufts.edu/cosmos/view_picture.asp?id=309

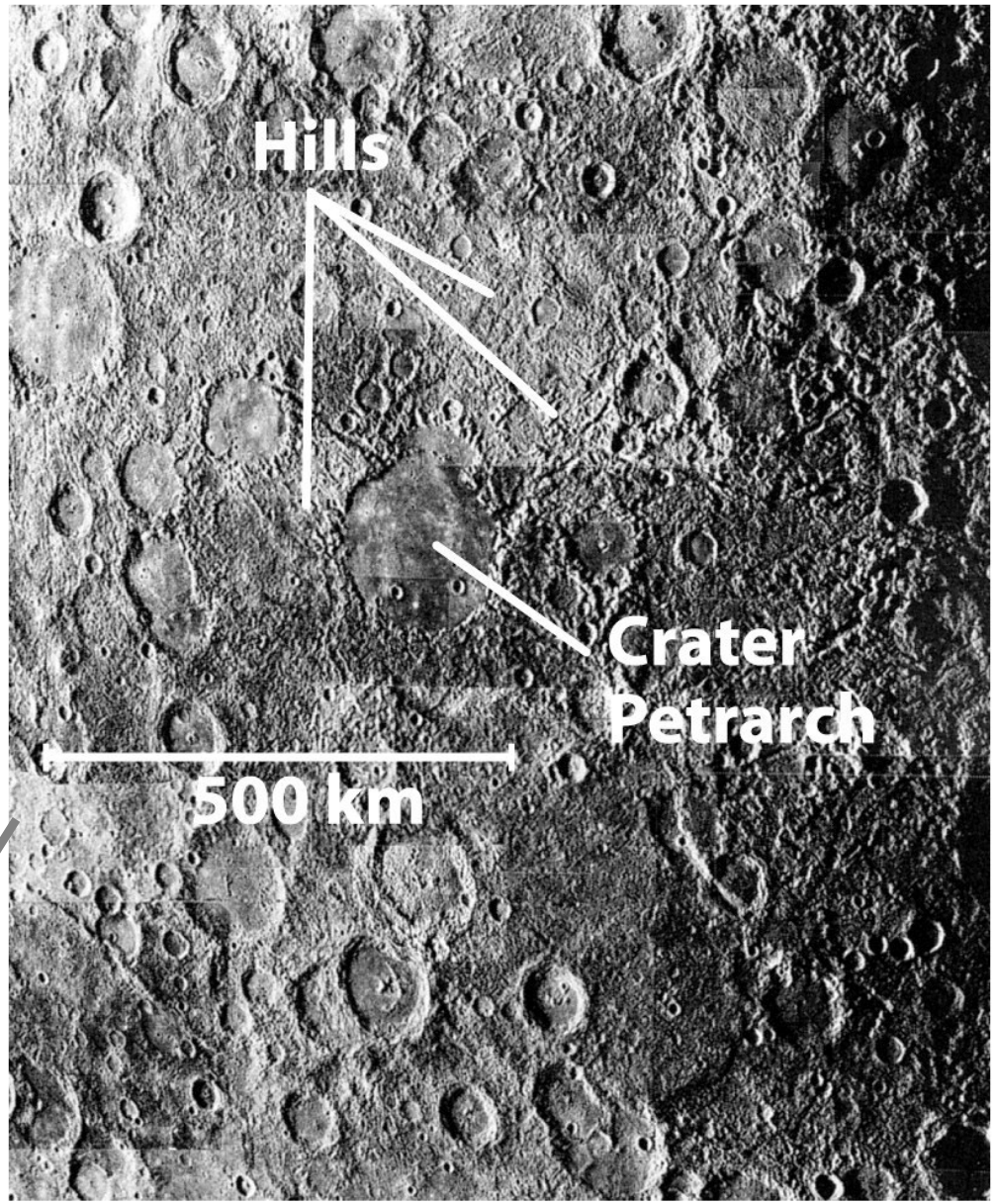


Figure 7-3b
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Mercury is iron-rich

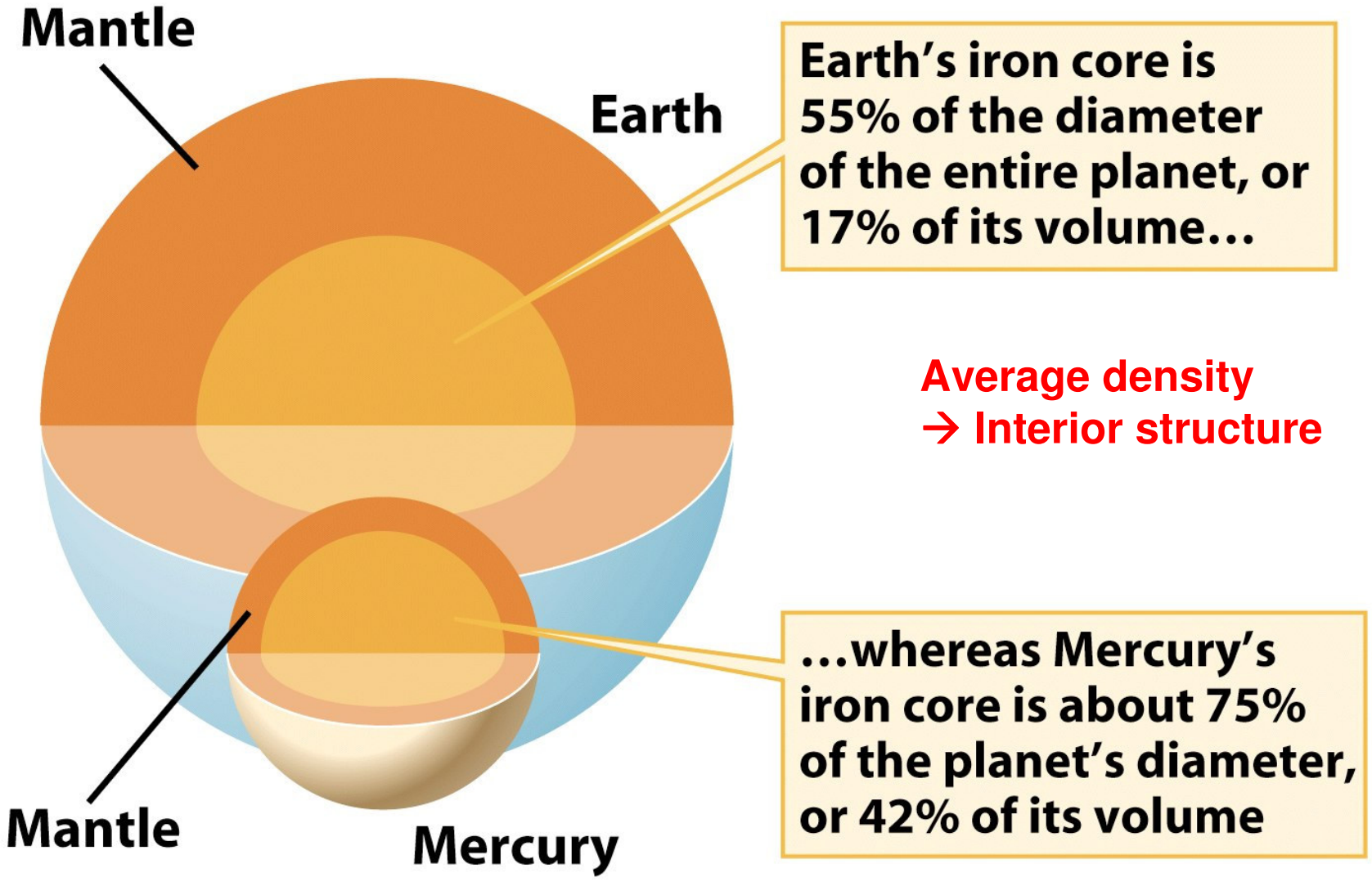

Figure 7-6
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Collision model

Similar to earth-moon formation, but no moons form for Mercury

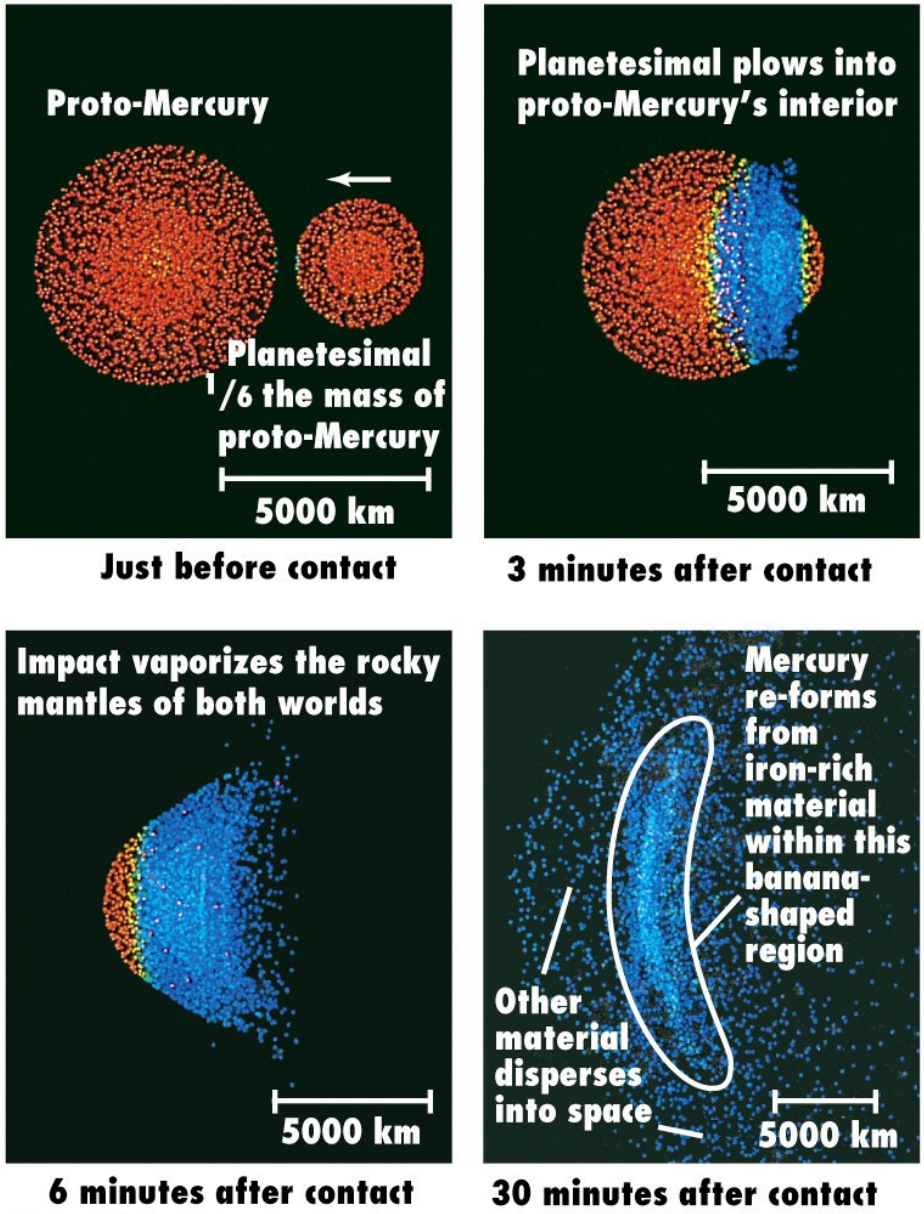
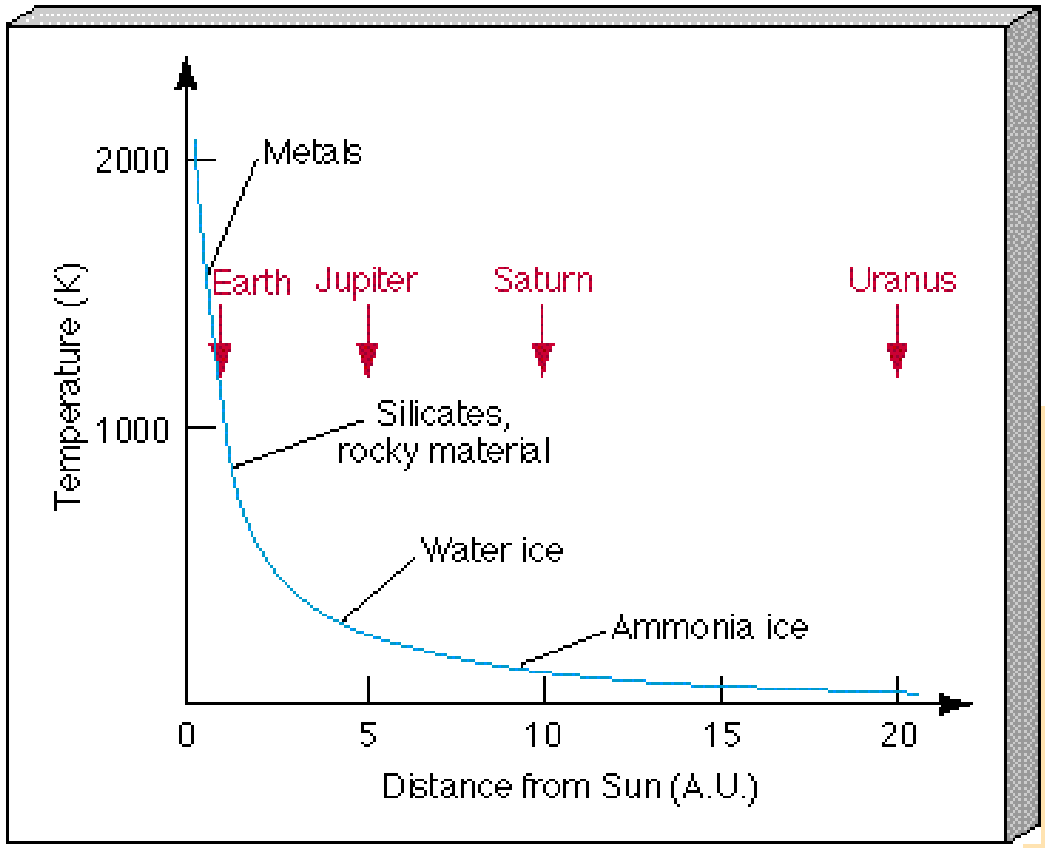


Figure 7-7
Discovering the Universe, Seventh Edition

Condensation sequence



273K=0°C

http://ircamera.as.arizona.edu/astr_250/Lectures/Lec_21sml.htm
http://inverse.astro.uwo.ca/ast21/slides20/slide2.html

Planets form in a proto-stellar disk around a protostar.

Table 19-3 The Condensation Sequence

Temperature (K)	Condensate	Planet (Estimated Temperature of Formation; K)
1500	Metal oxides	Mercury (1400)
1300	Metallic iron and nickel	
1200	Silicates	
1000	Feldspars	Venus (900)
680	Troilite (FeS)	Earth (600)
		Mars (450)
175	H_2O ice	Jovian (175)
150	Ammonia–water ice	
120	Methane–water ice	
65	Argon–neon ice	Pluto (65)

summary

- 為什麼日蝕發生在朔？
- 為什麼日冕儀可以幫忙找系外行星？
- 為什麼水星和月球一樣已「死」並且幾乎無大氣？
- 為什麼水星含有大量的鐵？
- 除了水星和金星，其他太陽系的行星可以凌日(transit)嗎？
- 什麼是太陽黑子(sunspot)？
- 如何利用掩星(occultation)去測量視直徑很小天體的大小？
- 臺美掩星計畫(TAOS)是為了找什麼？為什麼要用掩星的方式？
- 系外行星也凌它們的太陽嗎？
- 為什麼視差(parallax)可以用來測量距離？
- 如何得知蝕雙星(eclipsing binary)的軌道週期？