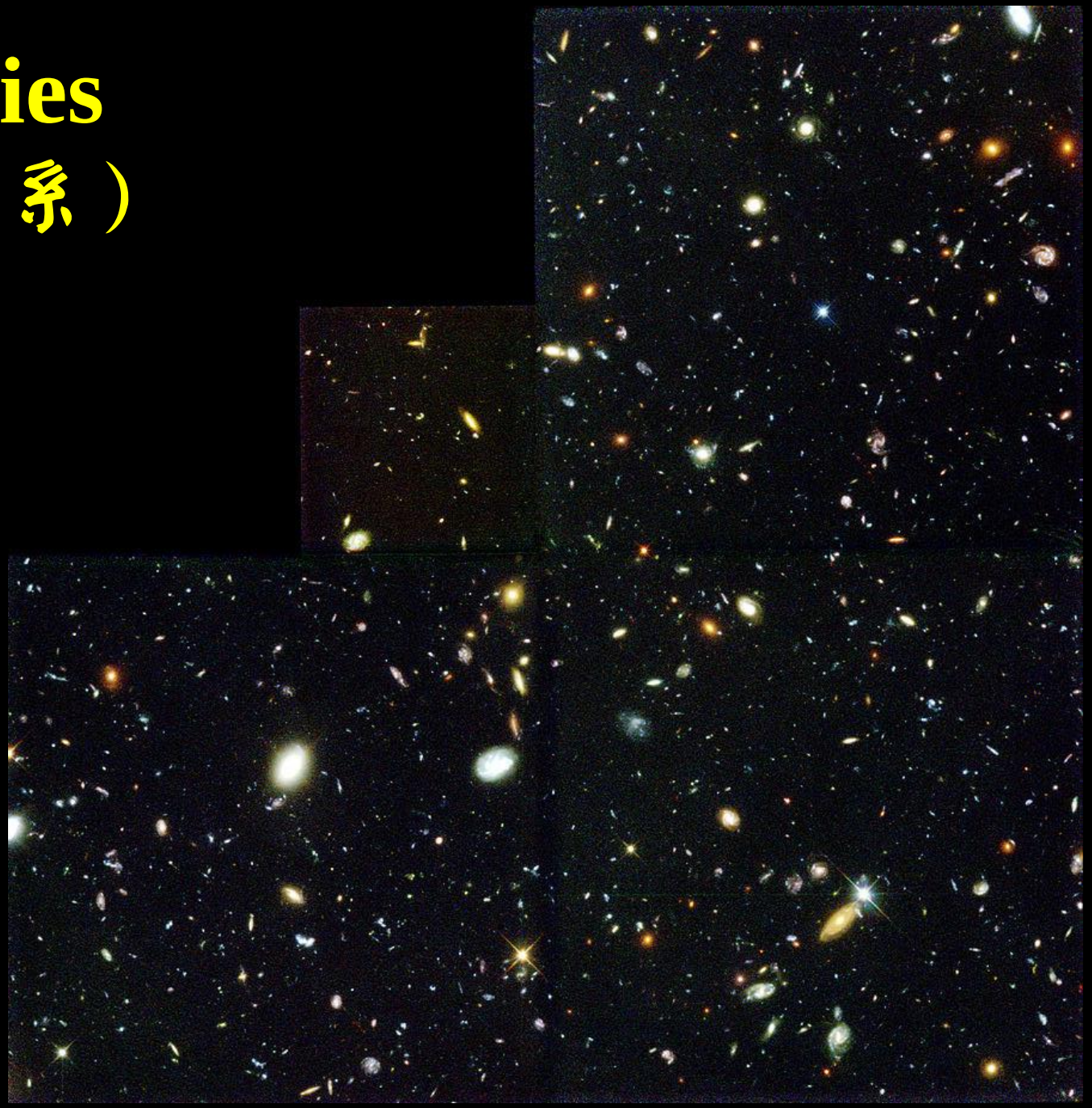
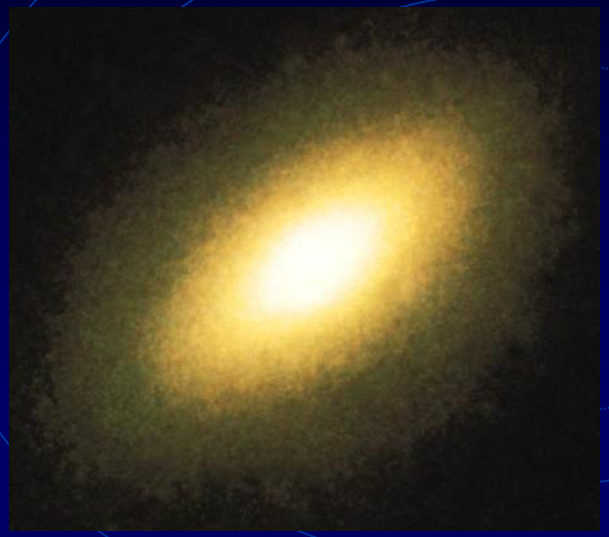
Galaxies
（各式星系）



你覺得呢？

- 所有星系都有螺旋臂嗎？
- 對於螺旋星系，恆星大多分佈在旋臂上嗎？
- 星系是孤立的系統嗎？
- 其他星系是怎麼運動的呢？和銀河系之間的相對運動為何？

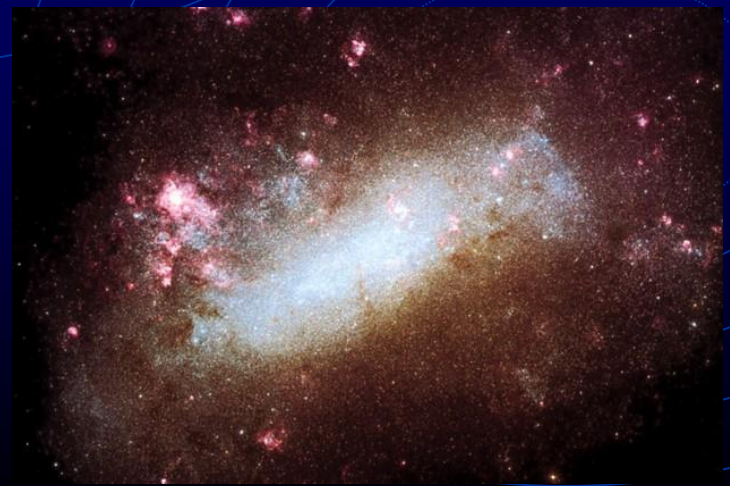
星系外觀



橢圓星系
(elliptical)

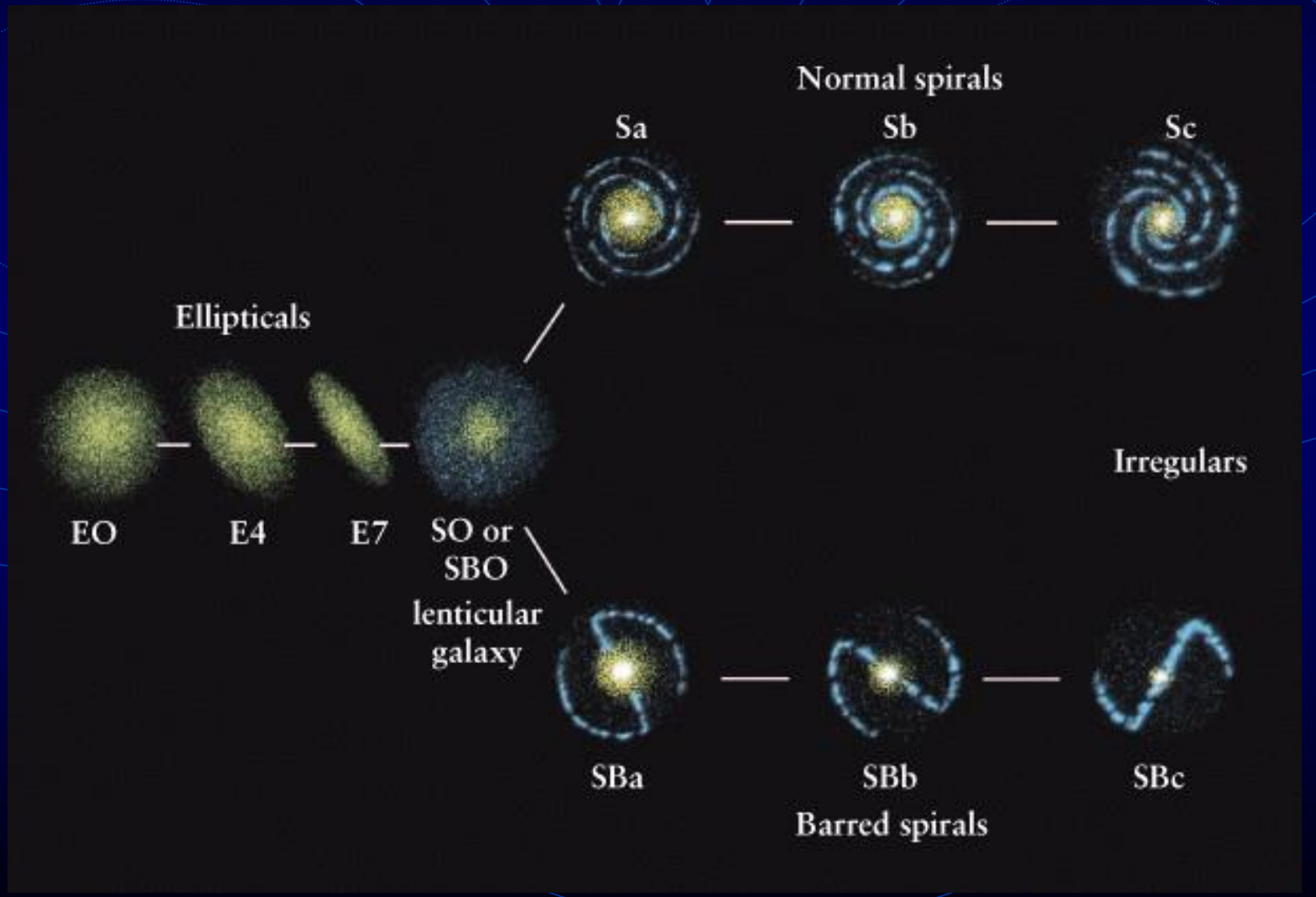
螺旋星系
(spirals)

棒旋星系
(barred spirals)



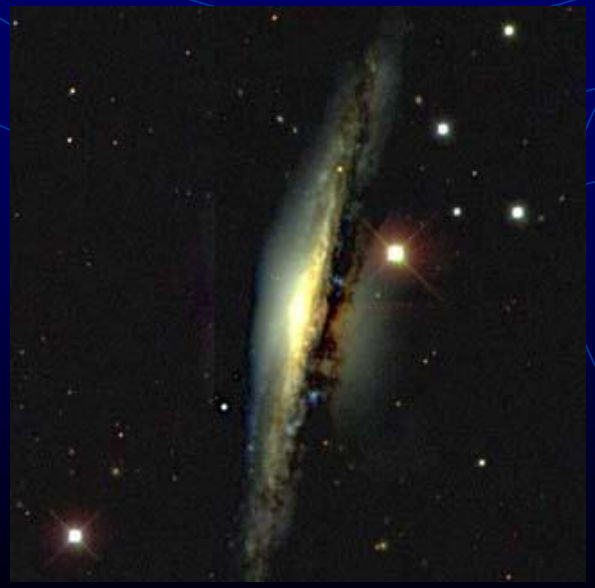
不規則星系
(irregulars)

Hubble's "tuning fork" diagram for types of galaxies



螺旋星系

- 例如銀河系、仙女座星系 (M31)
- 外觀上有旋臂，有中央突起
- 螺旋臂繞得越緊，中央突起越明顯
- 有豐富氣體 → 恆星形成活躍



側向 (edge-on) 著我們的螺旋星系
M104 可以看到核心突起的部分

螺旋星系由旋臂緊繞的程度與中央突起的大小來分類

(a) Sa (NGC 1357)

(b) Sb (M81)

(c) Sc (NGC 4321)

Sa 旋臂纏繞得緊、寬廣而連續，中央突起最大

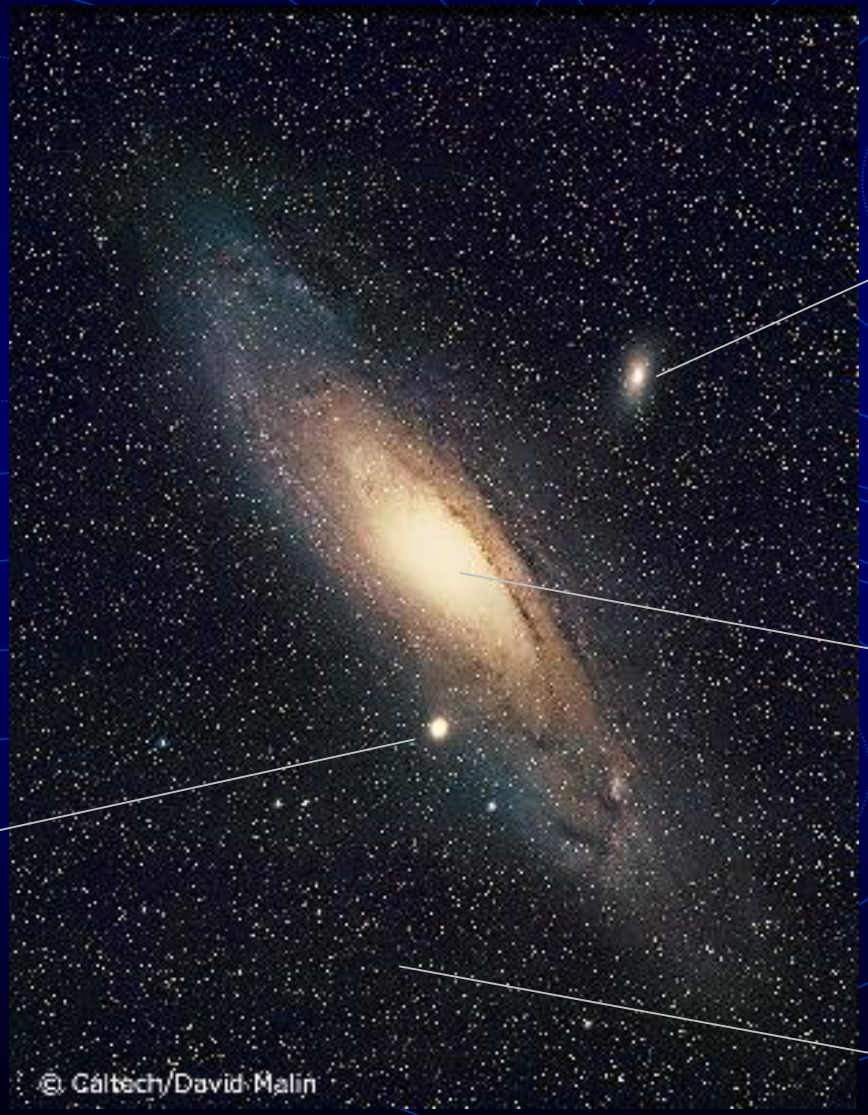
Sb 次之

Sc 旋臂最鬆散，中央突起最小

仙女座星系

北半球天空唯一
裸眼可見非銀河
系內的天體

Andromeda “Nebula” (Galaxy)
(M31=NGC 224)

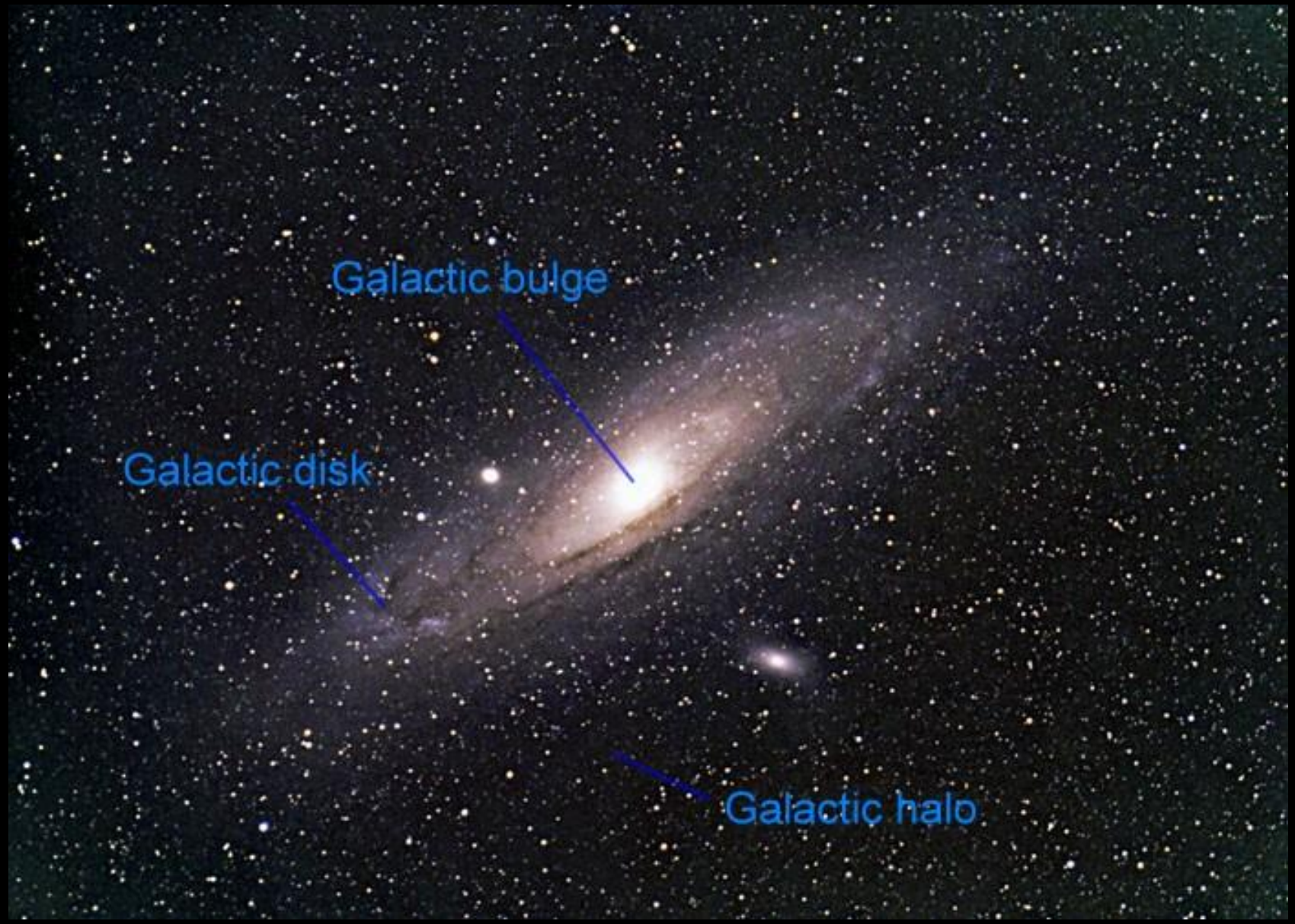


M110 = NGC 205

M31 = NGC 224

M32 = NGC 221

Stars in our own
Milky Way


Galactic bulge
Galactic disk
Galactic halo

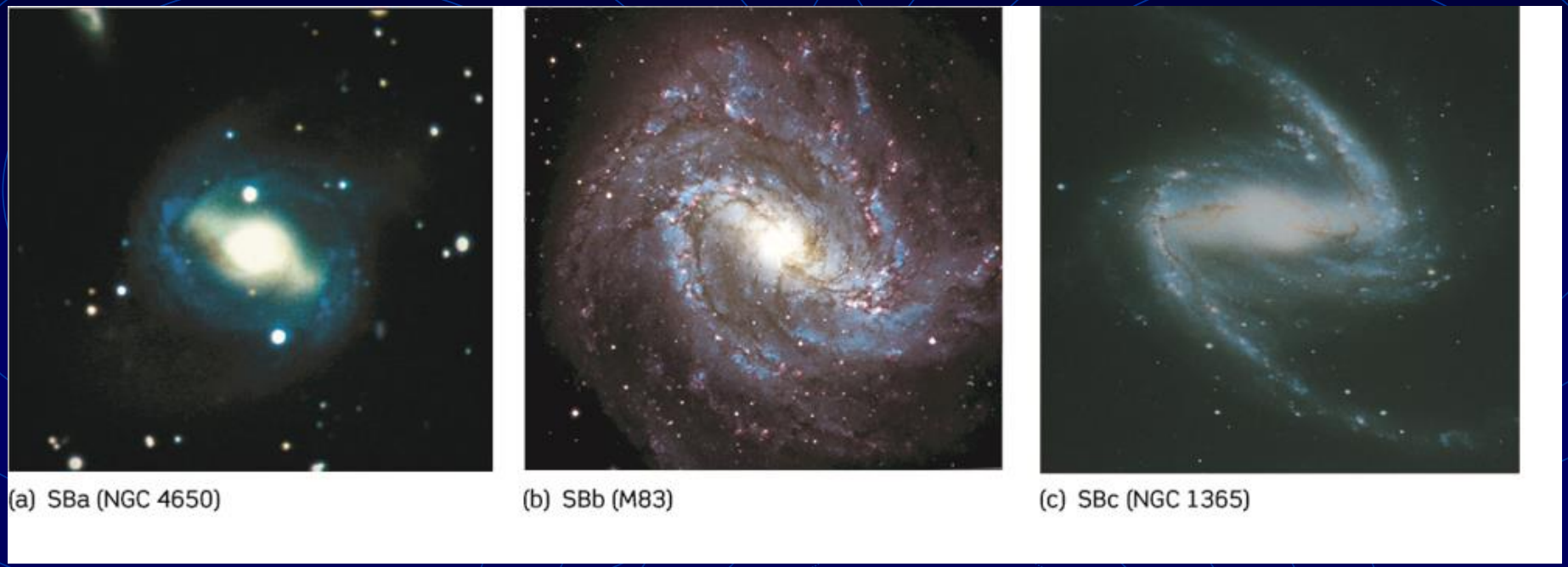
M74 的旋臂
清晰可見

M33 的旋臂則不明顯，如絨毛般

形成旋臂的不同機制？

e.g., 恆星爆發形成 flocculent spirals？
而密度波形成 grand design spirals？

棒旋星系

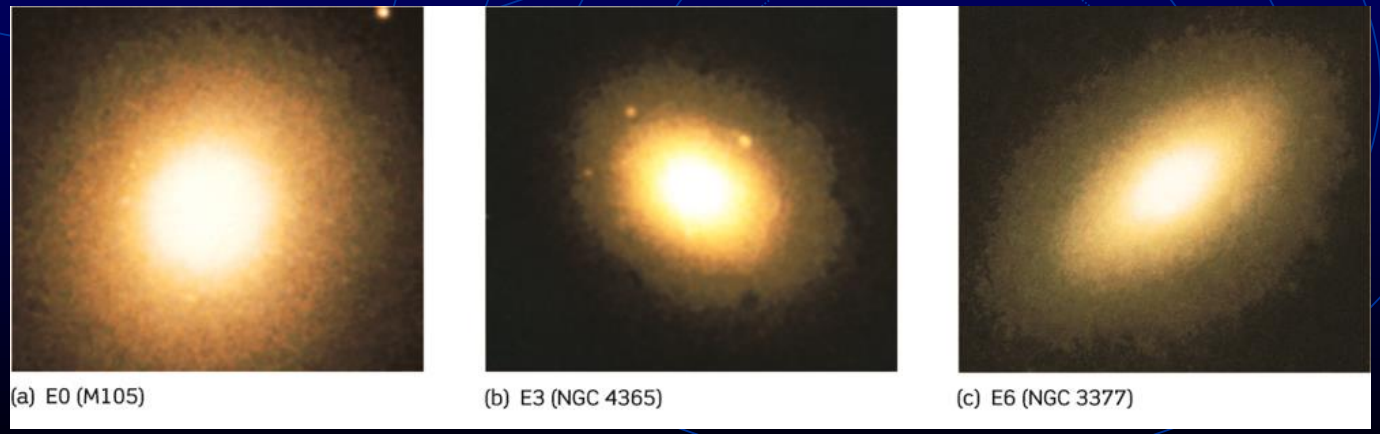


(a) SBa (NGC 4650)　(b) SBb (M83)　(c) SBc (NGC 1365)

與螺旋星系一樣，棒旋星系也由旋臂緊繞的程度與中央突起的大小來分類。SBa 旋臂纏繞得最緊，突起最大；SBb 次之；SBc 螺旋最鬆散，中央突起最小

橢圓星系

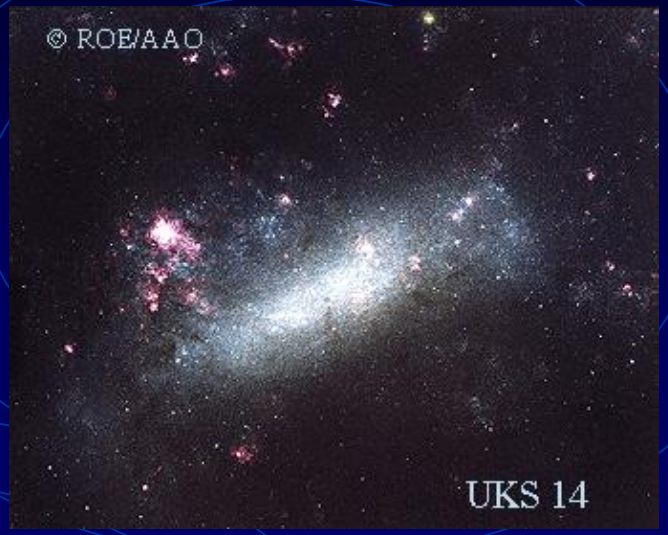
- 例如 M105
- 外觀上有的比較圓 (E0)，有的明顯扁橢 (E7)
- 各種大小與質量
- 缺乏氣體，已經沒有恆星形成活動 恆星早就做完了
- 星系團中央常存在大型橢圓星系

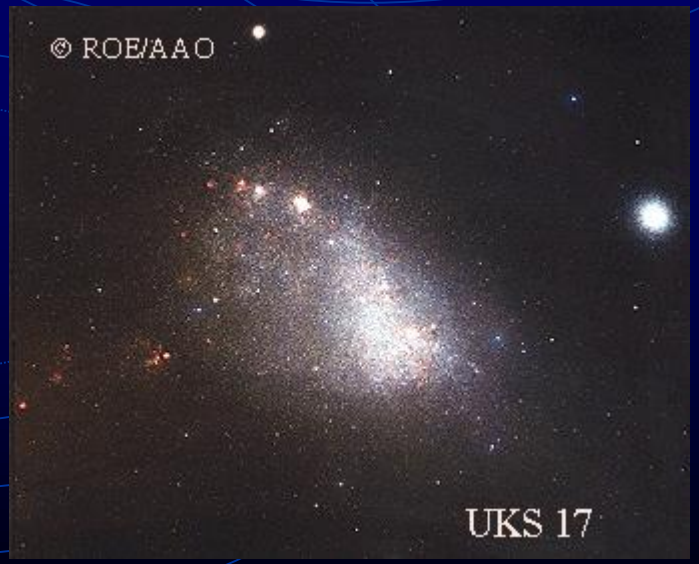


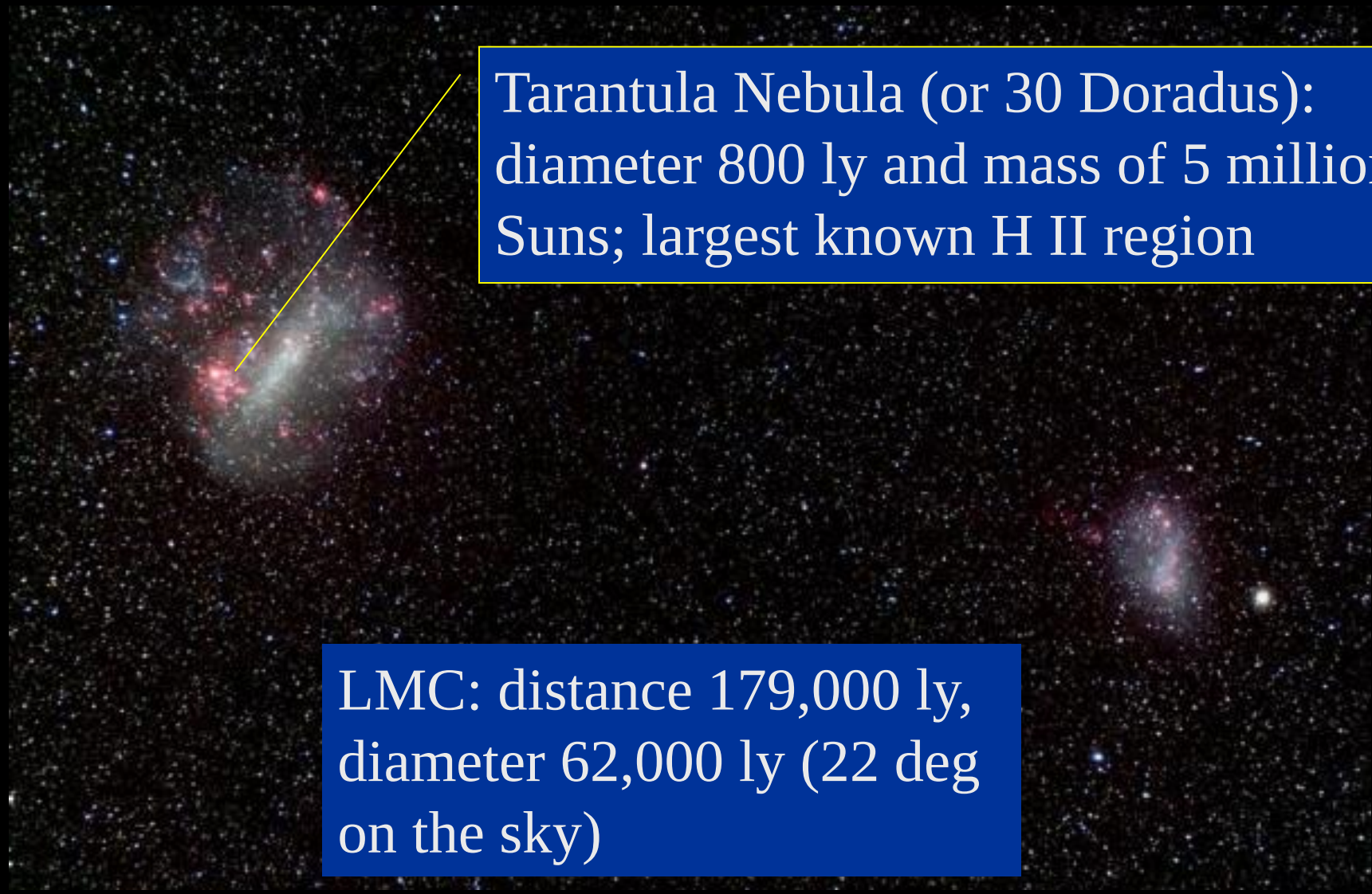
Virgo cluster 中央的大型橢圓星系。室女座星系團距離我們約5千萬光年，包含超過 2000 個星系

不規則星系

- 例如大、小麥哲倫星雲
  （其實是星系）
  Large Magellanic Cloud (LMC),
  Small Magellanic Cloud (SMC)
- 含有大量氣體，劇烈恆星形成活動



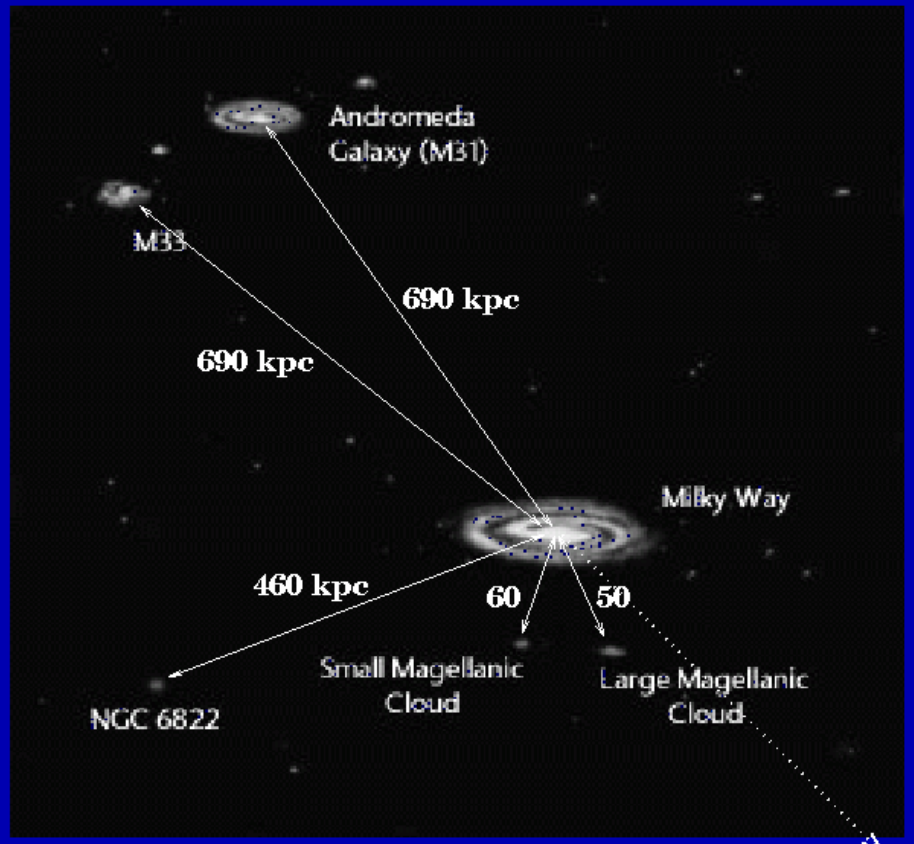



Tarantula Nebula (or 30 Doradus): diameter 800 ly and mass of 5 million Suns; largest known H II region
LMC: distance 179,000 ly, diameter 62,000 ly (22 deg on the sky)

LMC and SMC

© Akira Fujii/DMI

Local Group of Galaxies



1 kpc = 3260 光年

本星系群

Local Group (of Galaxies)

我們本身（銀河系）所在的星系群體，涵蓋了大約方圓 3 Mpc（1千萬光年）之內的體積，目前知道超過54個星系成員

除了銀河系，還包括 M31、M32、 M33、LMC、SMC，以及一些矮星系 (dwarf galaxies)


© Akira Fujii/DMI


© 1997 Jerry Lodriguss

星系團
(cluster of galaxies)

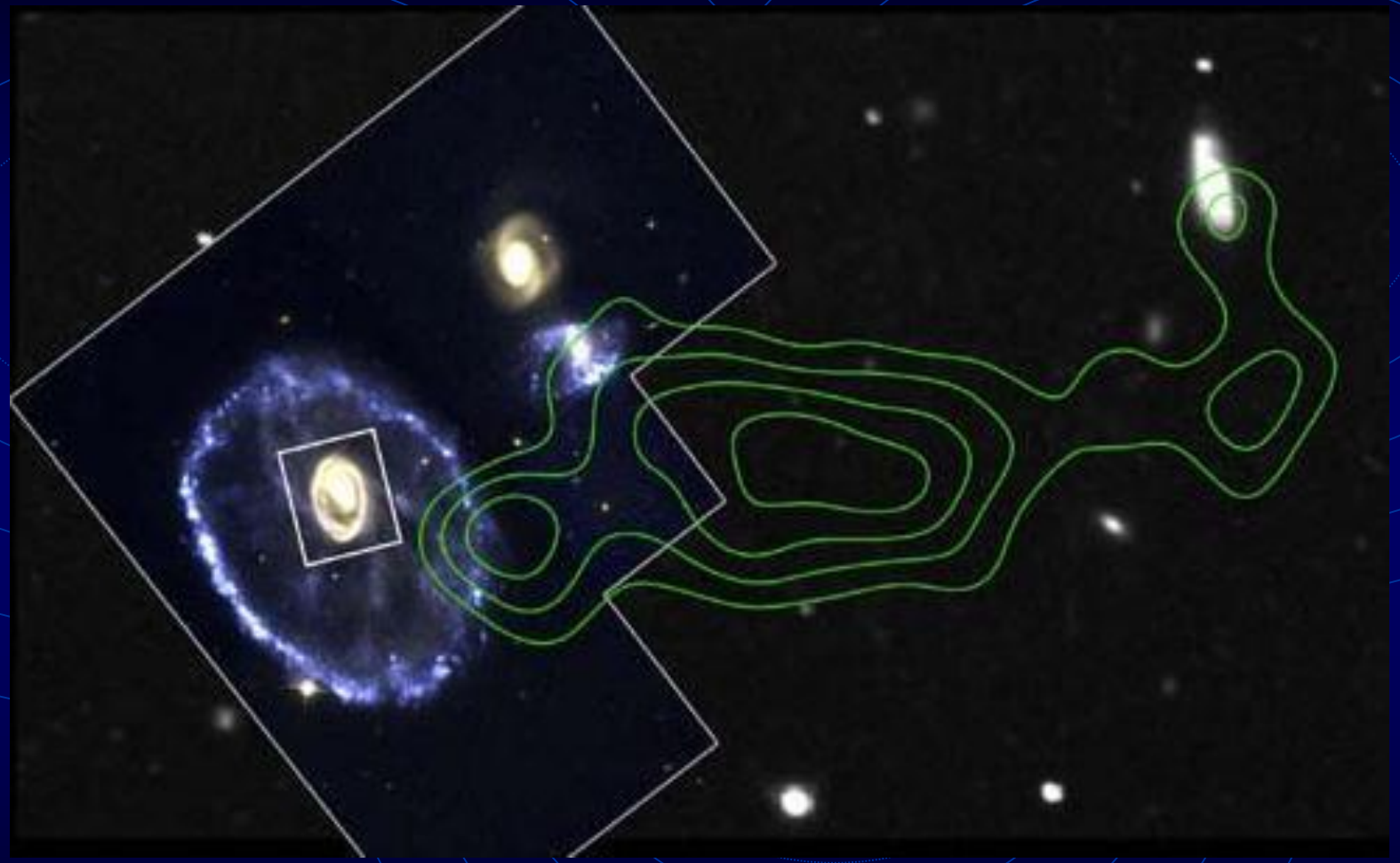
Virgo cluster 距離我們 5 千萬光年，擁有超過2000個成員星系。這張照片只涵蓋了中央部分，包括兩個最大的巨型橢圓星系 M84 與 M86

星系會從某個種類演化成另一種嗎？

星系會不會相撞？例如螺旋星系撞了以後，雲氣被擾動後消散，成為沒有雲氣的橢圓星系？

太陽直徑：140萬公里
$(1.4 \times 10^6$ km)
鄰近恆星距離：4光年
$(3 \times 10^{13}$ km)
➔ 比例 ~ 10^7

銀河系大小：10萬 ly
鄰近星系距離：數十萬 ly
➔ 比例 ~ 10

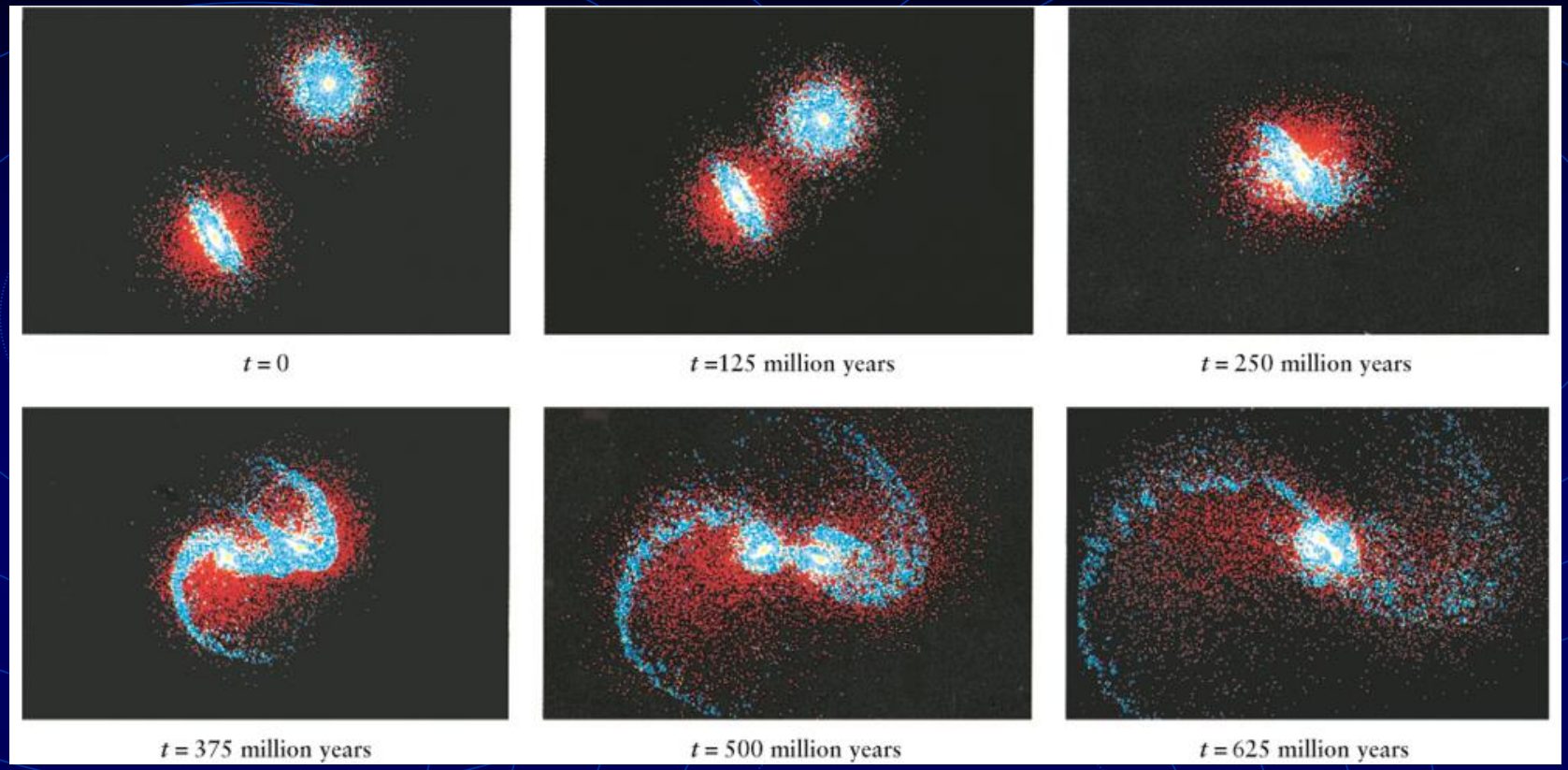


穿越後擾得烏煙瘴氣、雲氣裊裊

星系碰撞

NGC4038/4039

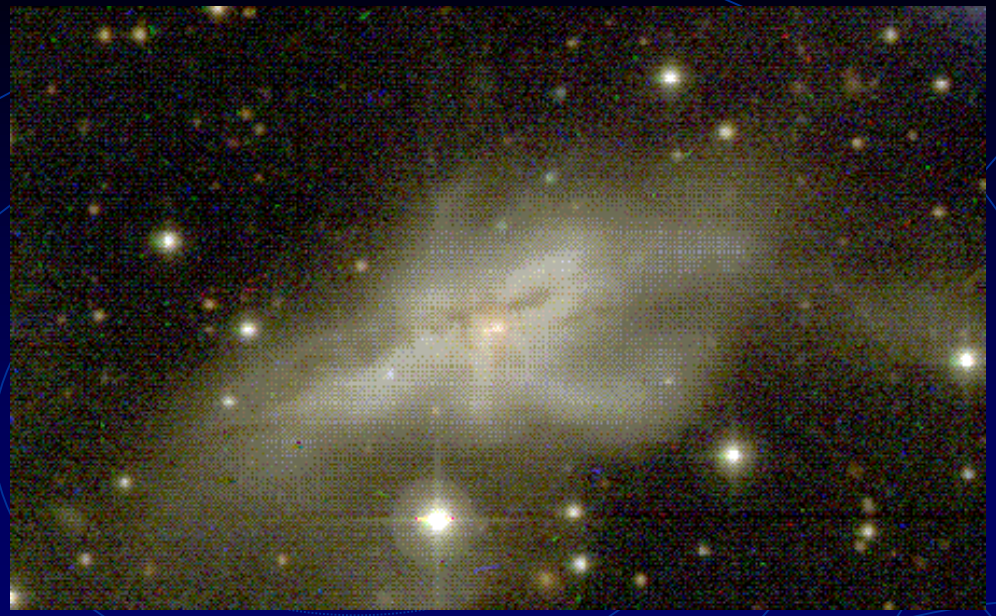
「觸角」星系（Antennae galaxies)



A Simulated Collision between Two Galaxies

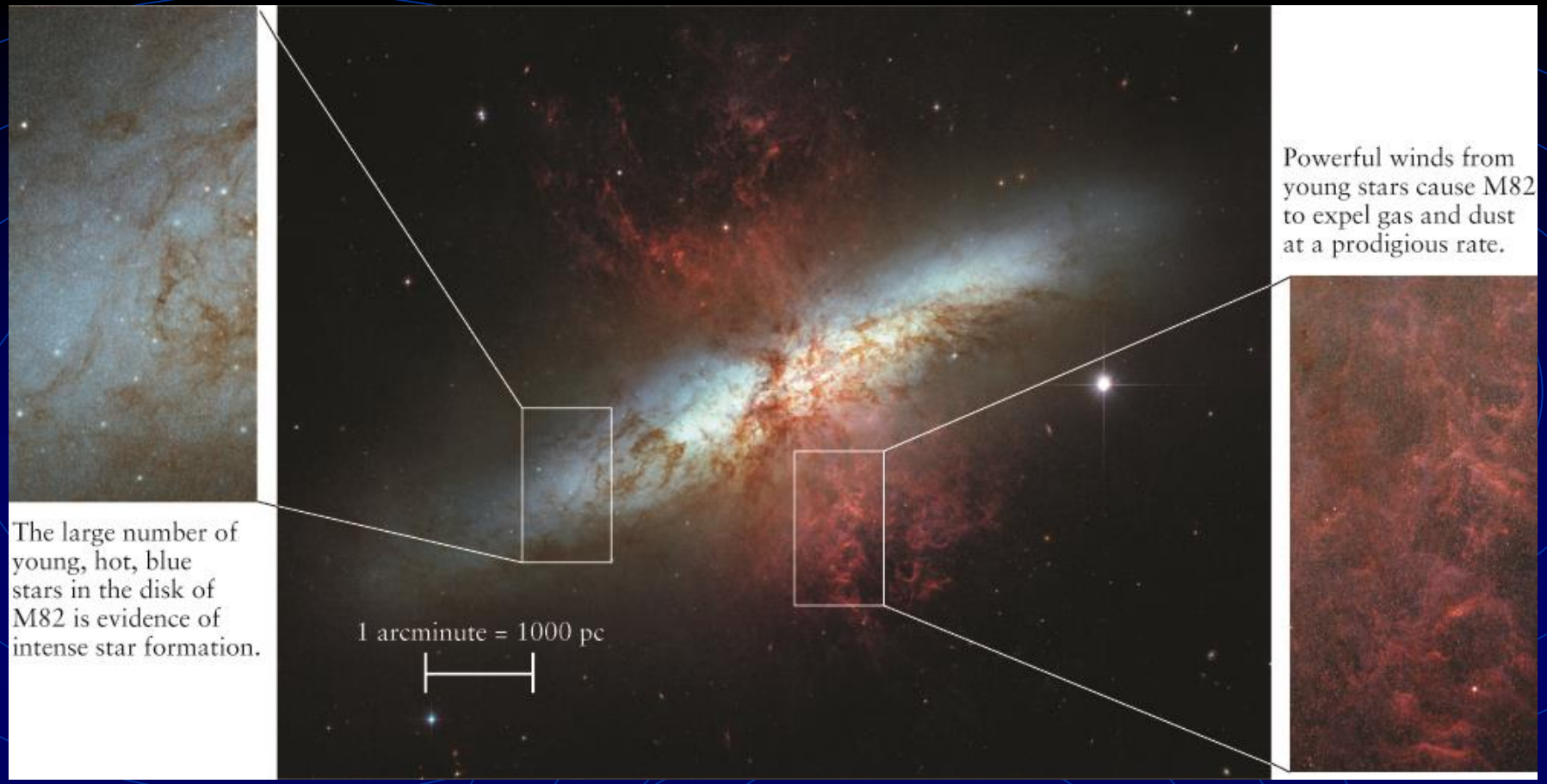
(by a supercomputer; blue=disk stars; yellow=bulge stars; red=dark matter)

IC 2163 and NGC 2207 are tidally interacting.

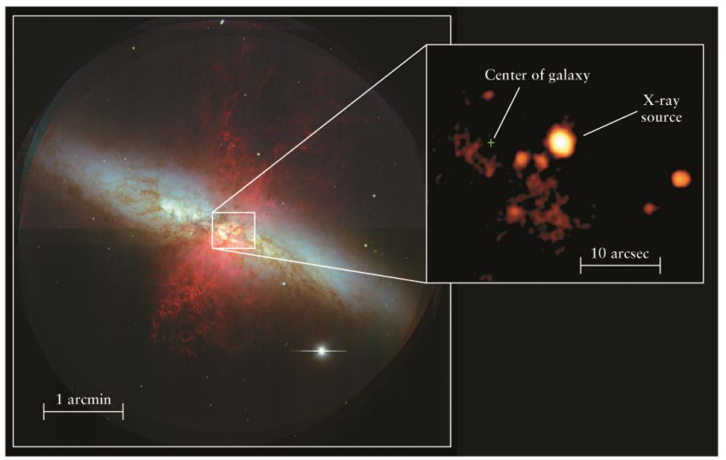


← **NGC6240**
星系的核心恆星正以
高速運動

M64/NGC4826
（又稱「睡美人星系」）
的核心與星系其他部分
運動方向相反 →



A Starburst Galaxy: M82

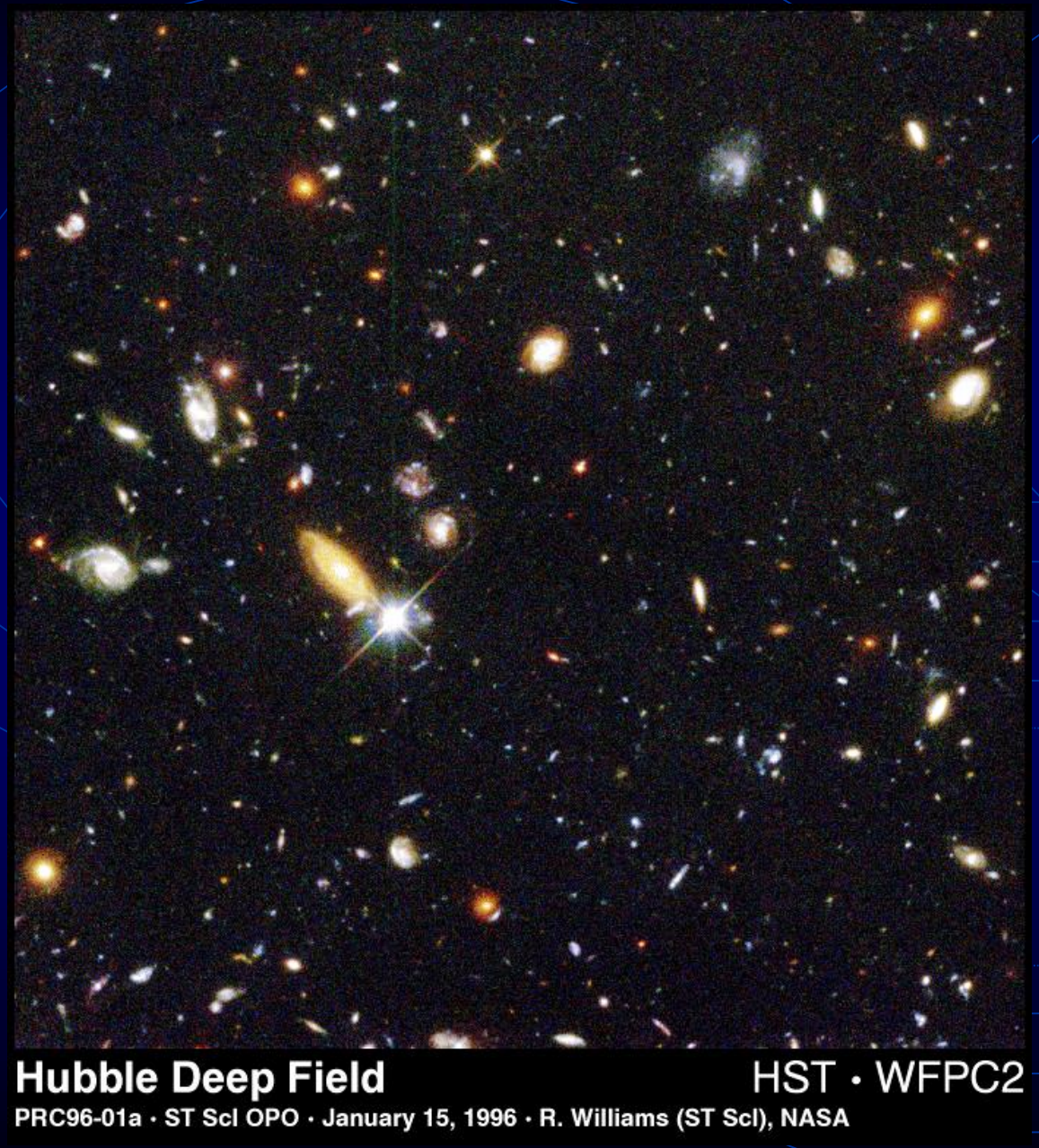


An unusual X-ray source in M82: an intermediate-mass BH?

SN 2014j type Ia supernova in Messier 82 (the “Cigar Galaxy”)

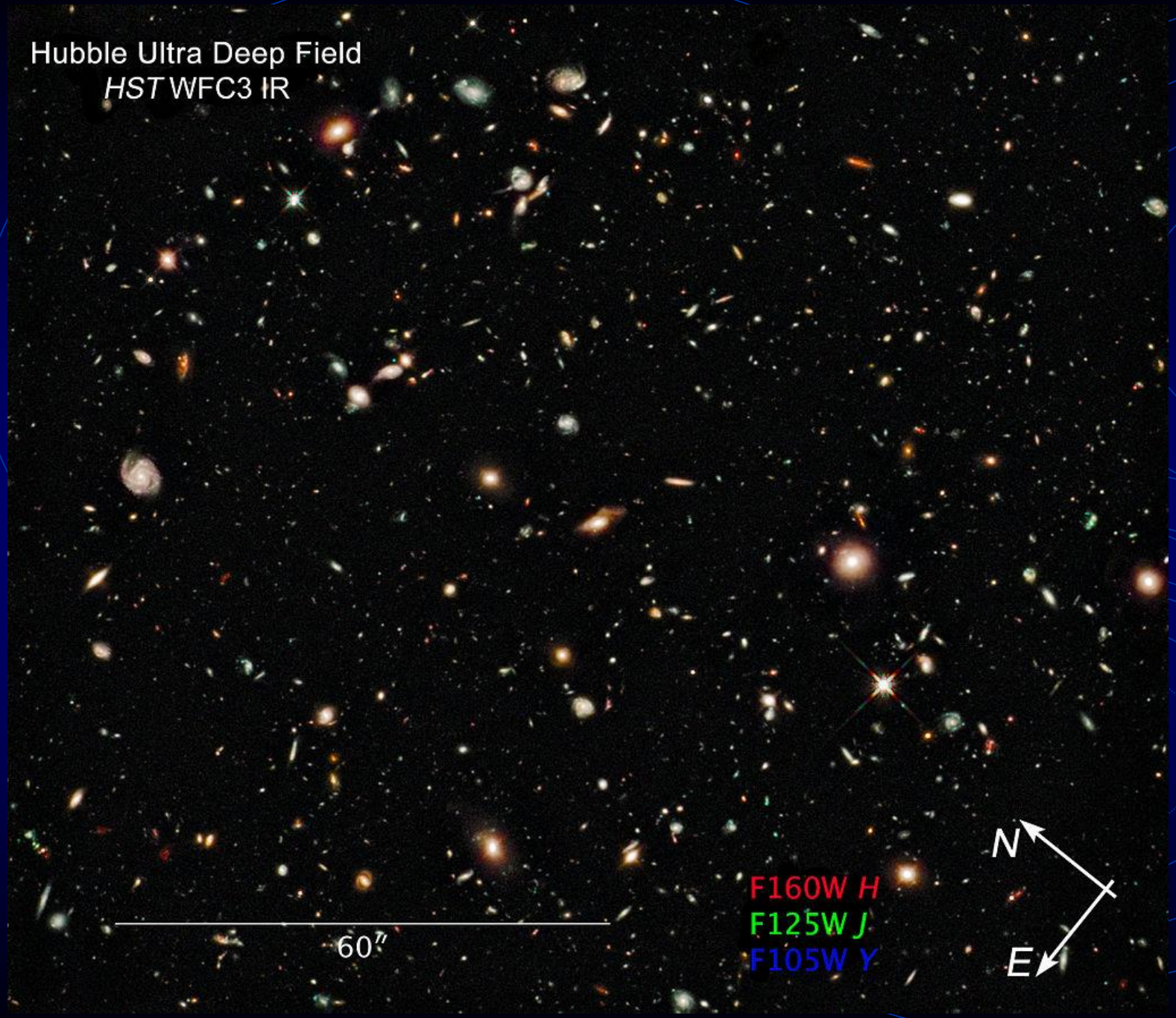
$d = 3.5 \pm 0.3$ Mpc

First image: 10 December 2013
Second image: 22 January 2014.



Hubble Deep Field（哈柏深景影像）看到的是古老宇宙

相當於10天的曝光時間，可以看到約30等的天體



Hubble Ultra Deep Field 2014

UV-optical-IR

… into a few 100 Myr after the Big Bang

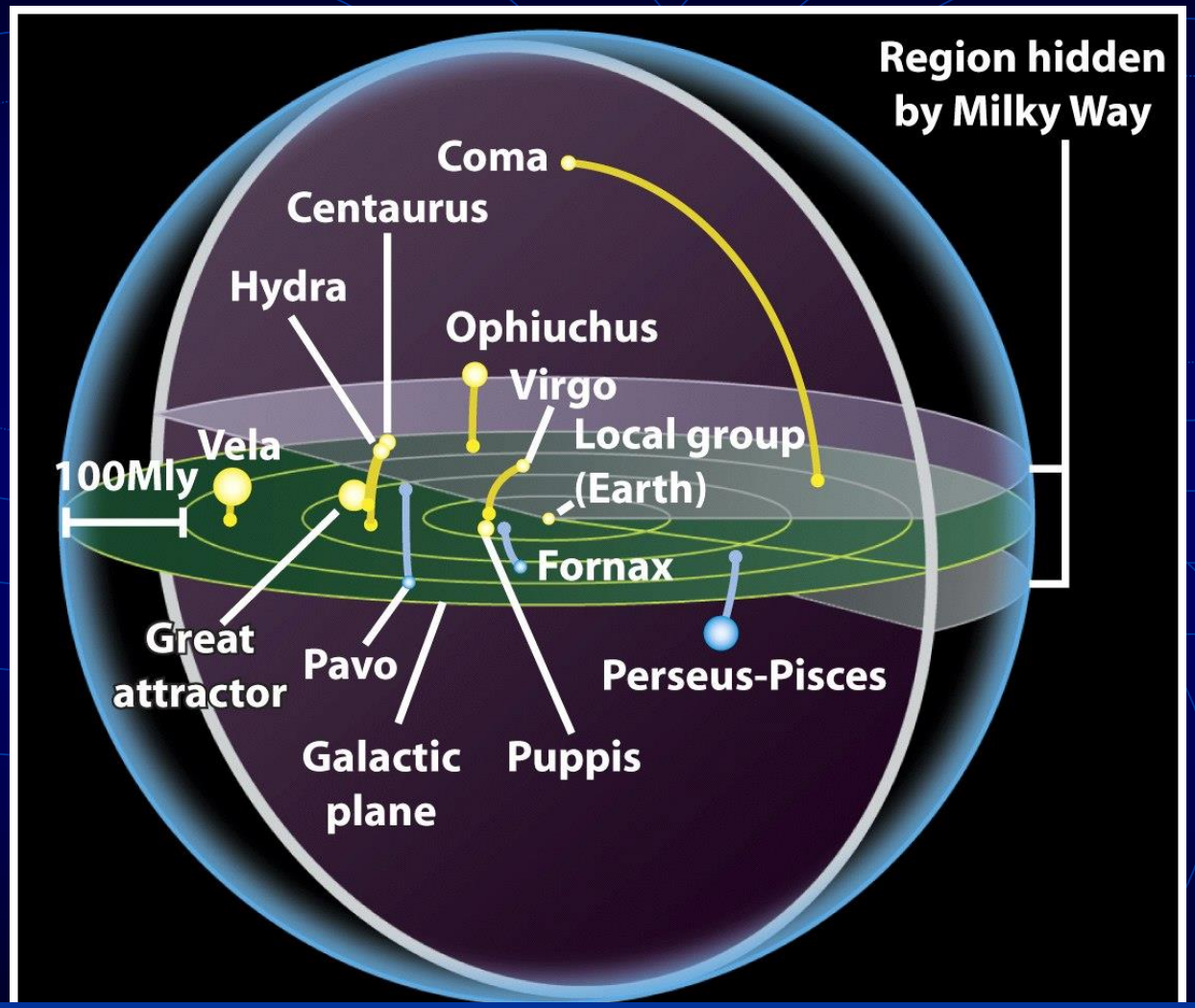
星系的性質

Some Properties of Galaxies

	Spiral (S) and barred spiral (SB) galaxies	Elliptical galaxies (E)	Irregular galaxies (Irr)
Mass ($M_\odot$)	10^9 to 4×10^{11}	10^5 to 10^{13}	10^8 to 3×10^{10}
Luminosity ($L_\odot$)	10^8 to 2×10^{10}	3×10^5 to 10^{11}	10^7 to 10^9
Diameter (ly)	1.6×10^5 to 8×10^5	3×10^3 to 6.5×10^5	3×10^3 to 3×10^4
Stellar populations	disk: young Population I central bulge and halo: Population II and old Population I	Population II and old Population I	mostly Population I
Percentage of observed galaxies	77%	*20%	3%

*This percentage does not include dwarf elliptical galaxies that are as yet too dim and distant to detect. Hence, the actual percentage of galaxies that are ellipticals is likely to be higher than shown here.

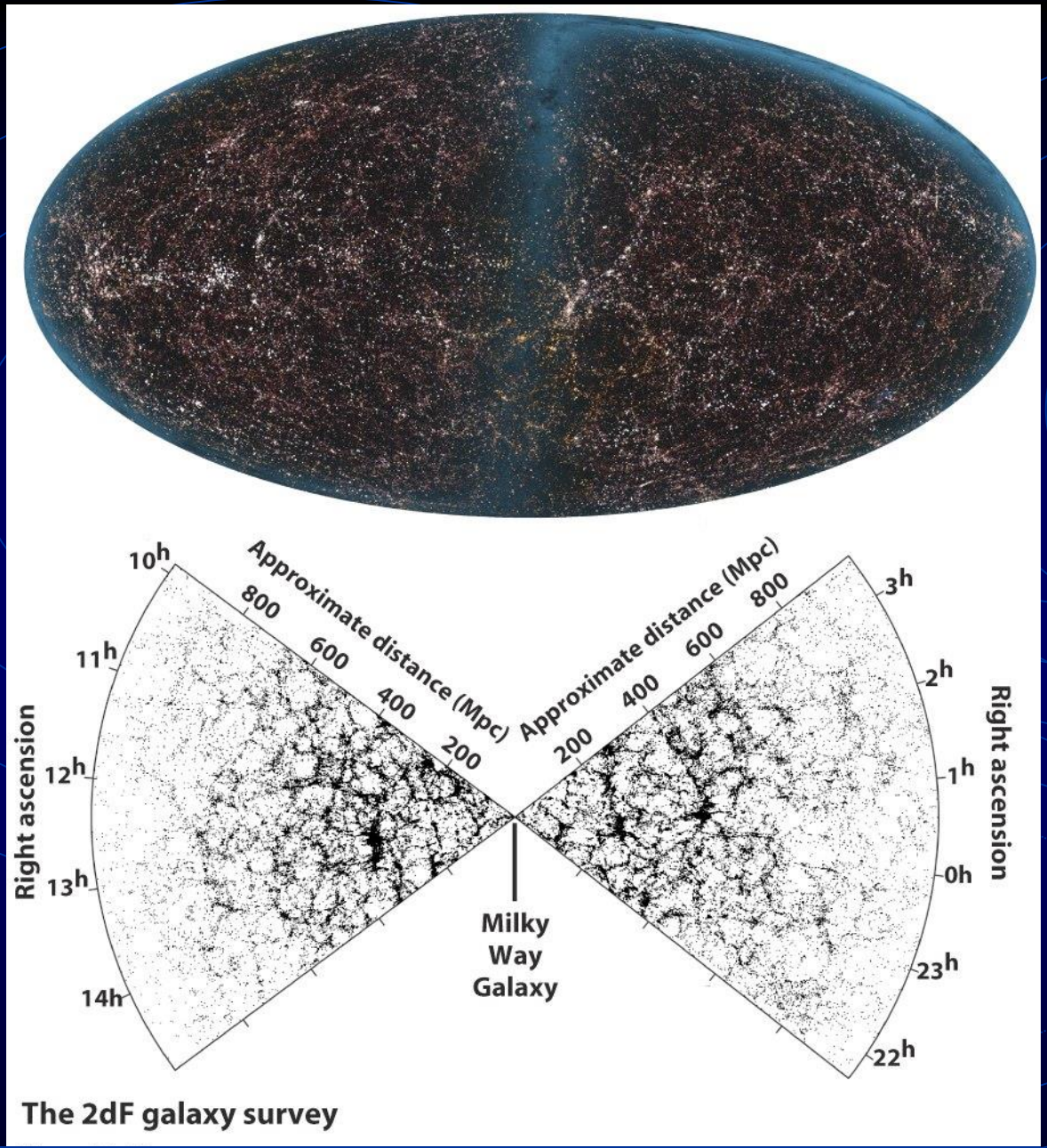
本星系群周圍的星系團



250 Mpc (800 M ly) 方圓之內的星系團

超星系團 (superclusters)

- 星系團群聚成為超星系團。每個超星系團包含約十數個星系團，所佔空間直徑約1億5千萬光年。我們所在的這個，稱為 Local Supercluster（Virgo cluster 之內）
- Most superclusters are not gravitationally bound; superclusters are all moving away from each other.
- 超星系團之間存有 voids，這些「空洞」大致成球形，大小約1-4億光年。很多星系分佈在空洞的表面。



1.6 million galaxies by 2MASS

注意絲狀結構當中缺乏星系的「空洞」，以及包圍在空洞四周滿是星系的分佈

62,559 galaxies by 2dF, in two wedges extending out in opposite directions from the Earth

Large Scale Structure of the Universe

Gravitational Lens in Abell 2218

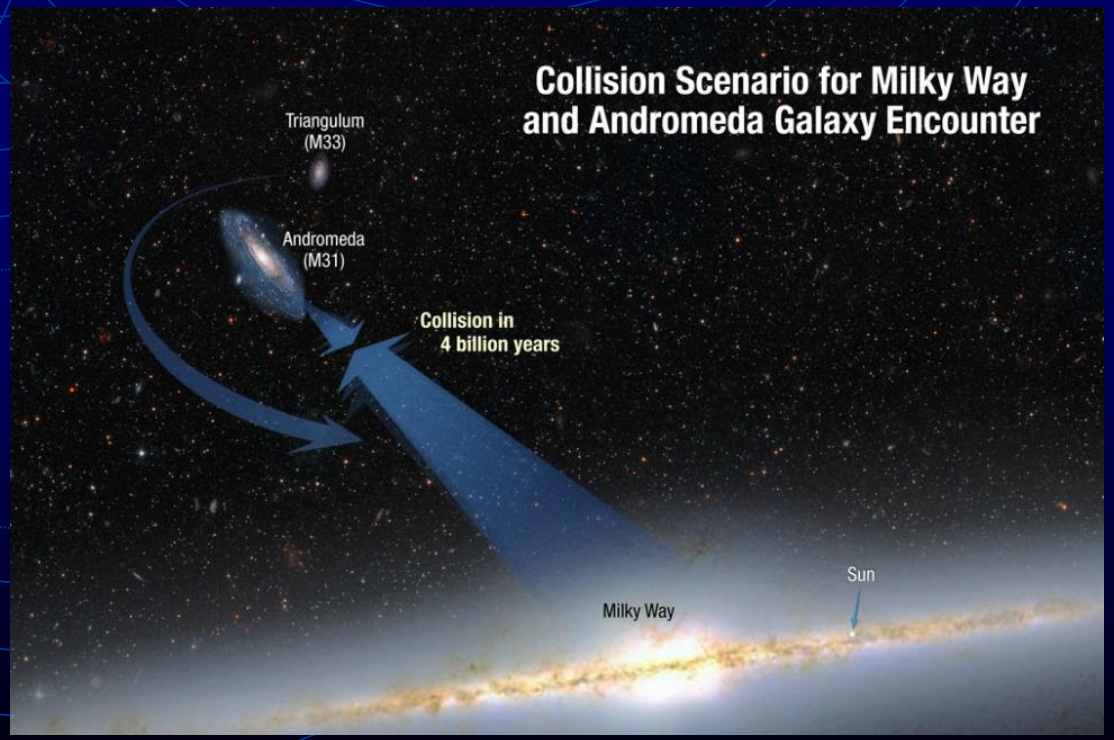
HST • WFPC2

PF95-14 · ST ScI OPO · April 5, 1995 · W. Couch (UNSW), NASA

Superclusters in Motion

- 1920 年代，Edwin Hubble and Milton Humason 使用加州 Mount Wilson 的100吋望遠鏡記錄星系的光譜
- 他們發現這些星系都在遠離我們
- 以都卜勒效應，可以計算出這些星系「後退」的速度
- 利用例如造父變星的亮度變化，可以求出某些星系的距離
- 哈伯發現**遙遠星系團中的星系**比**近距離星系團中的星系後退的速度較快** ➔ **Hubble flow**

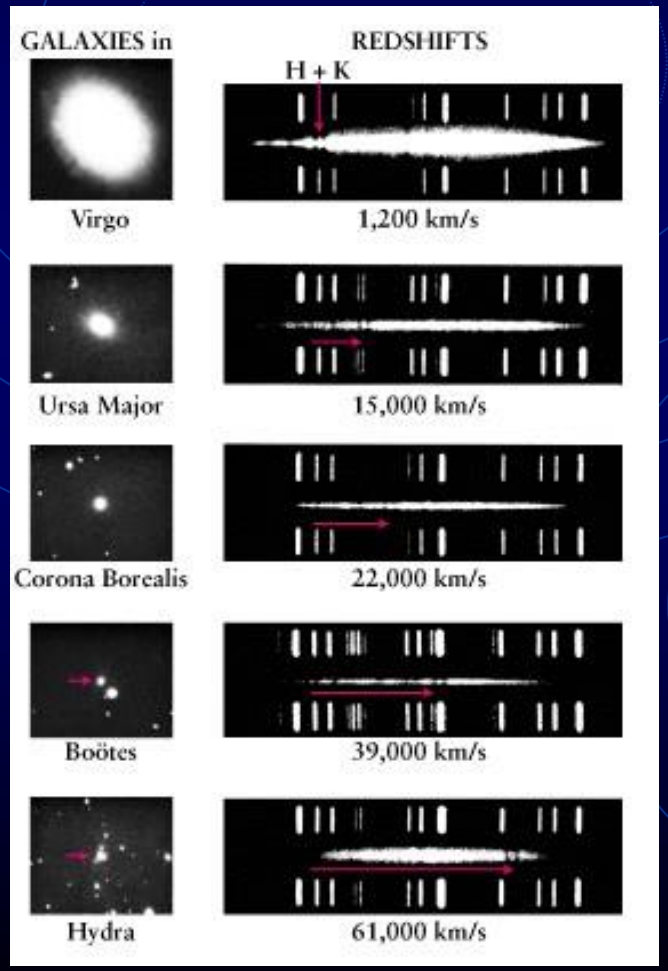
- Not every galaxy is moving away from us.
- Each galaxy has its own neighbor-induced intrinsic motion.
- For nearby galaxies, the intrinsic motion is more important than the Hubble flow, e.g., M31 is approaching us (blue shifted) at a speed of 110 km/s.
- With a relatively small tangential velocity, a collision is likely to happen in 4 billion years.

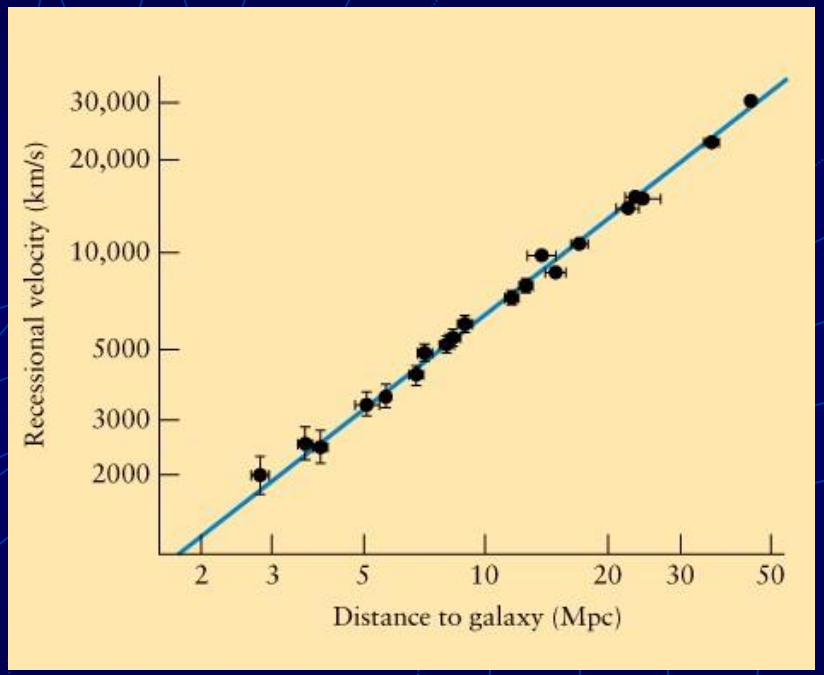


Animation MW and M31

Hubble Law（哈伯定律）

遙遠星系【後退速度】 ＝ H_0 ×【距離】





哈伯定律可以算是廿世紀最重要的天文發現

H_0 ：哈伯常數 (Hubble constant)

$v = H_0 \times d$

- Usually v is in [km/s], and d in [Mpc]
- Modern determination $H_0 \sim 73 \pm 4$ km/s/Mpc

Ex 1. A galaxy following the Hubble flow at 1 Mpc from us is receding at a speed of

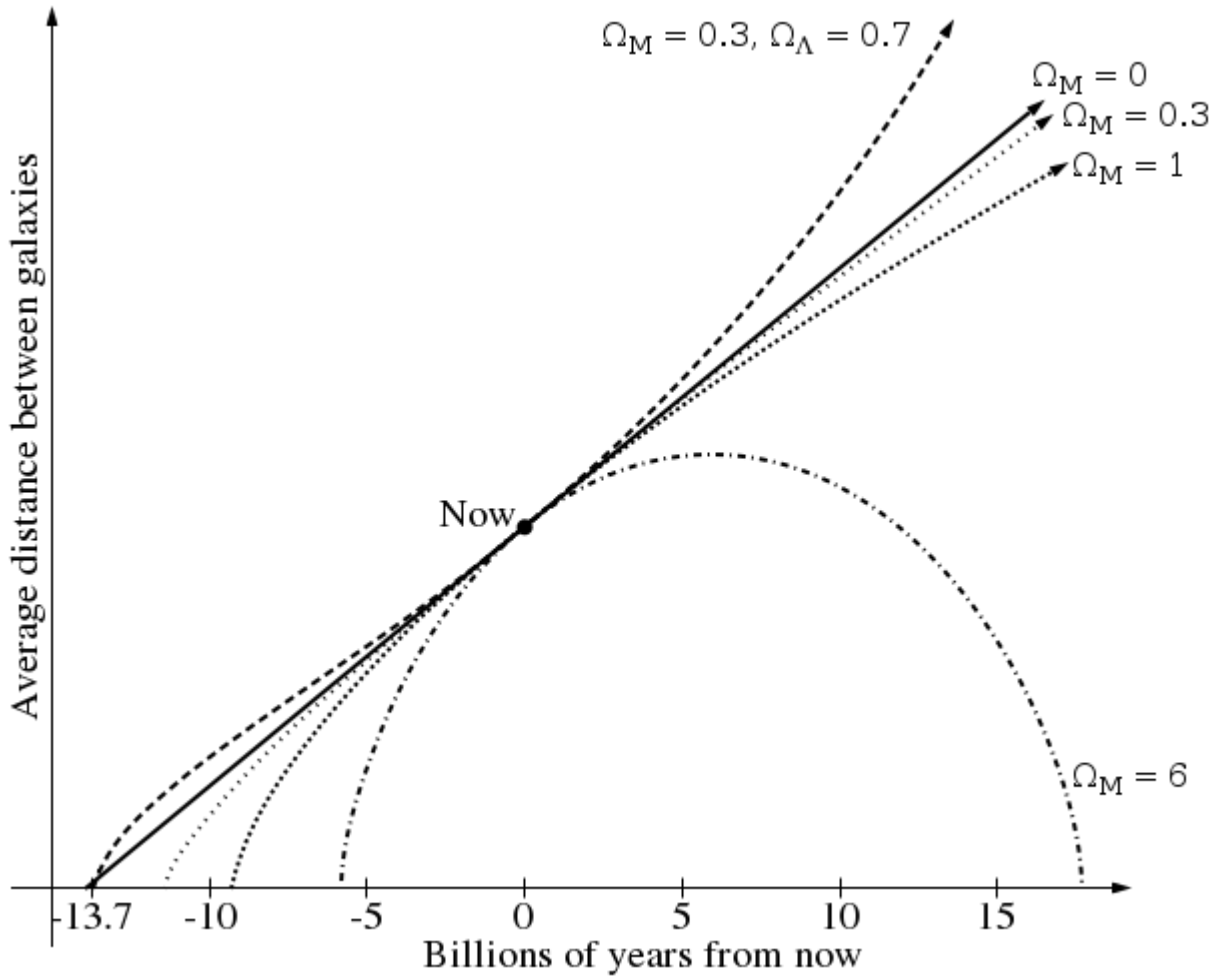
v = 73 km/s/Mps × 1 Mpc = 73 km/s

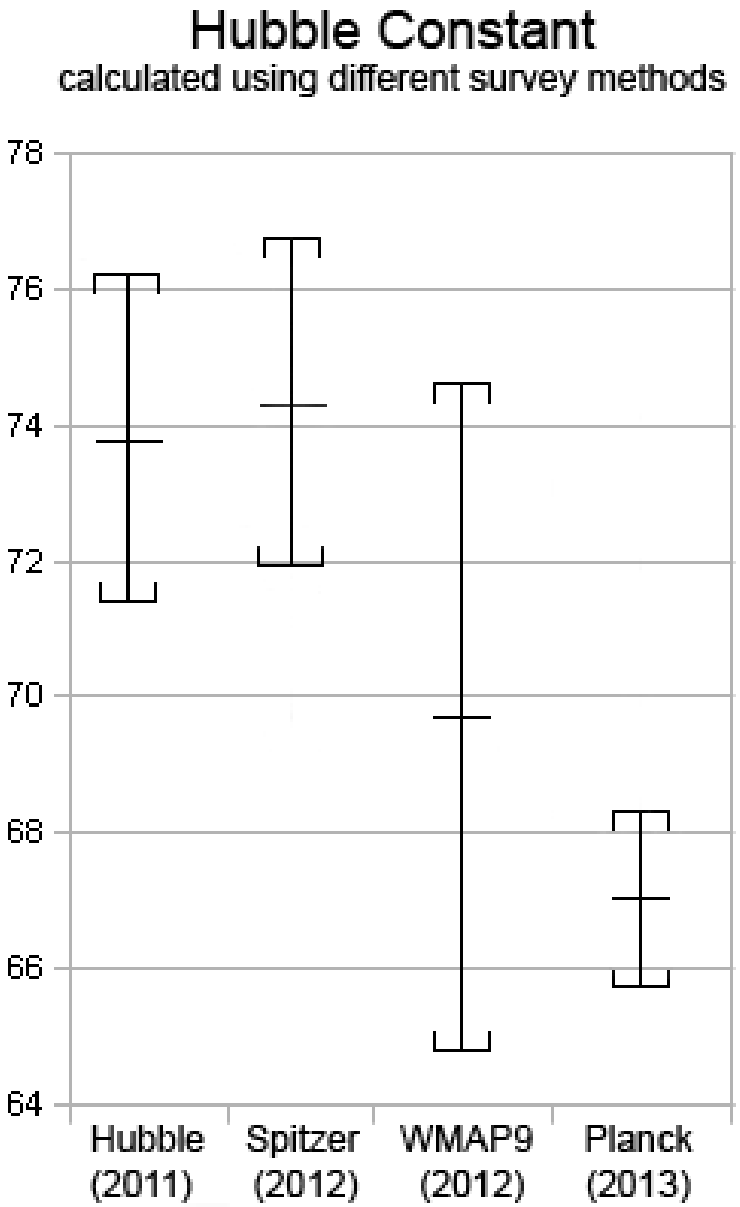
Ex 2. A supercluster of galaxies 10 Mpc away recedes at 730 km/s. In comparison, the solar system orbits the Galactic center at 230 km/s.

Ex 3. A galaxy located 100 Mpc from Earth rushes away with a speed of 7300 km/s.

Q: How fast is a galaxy 8 billion light-years away moving away from us? What if H_0 is 50 km/s/Mpc?

$1/H_0$ = Hubble time
= age of the Universe if
expansion had been linear





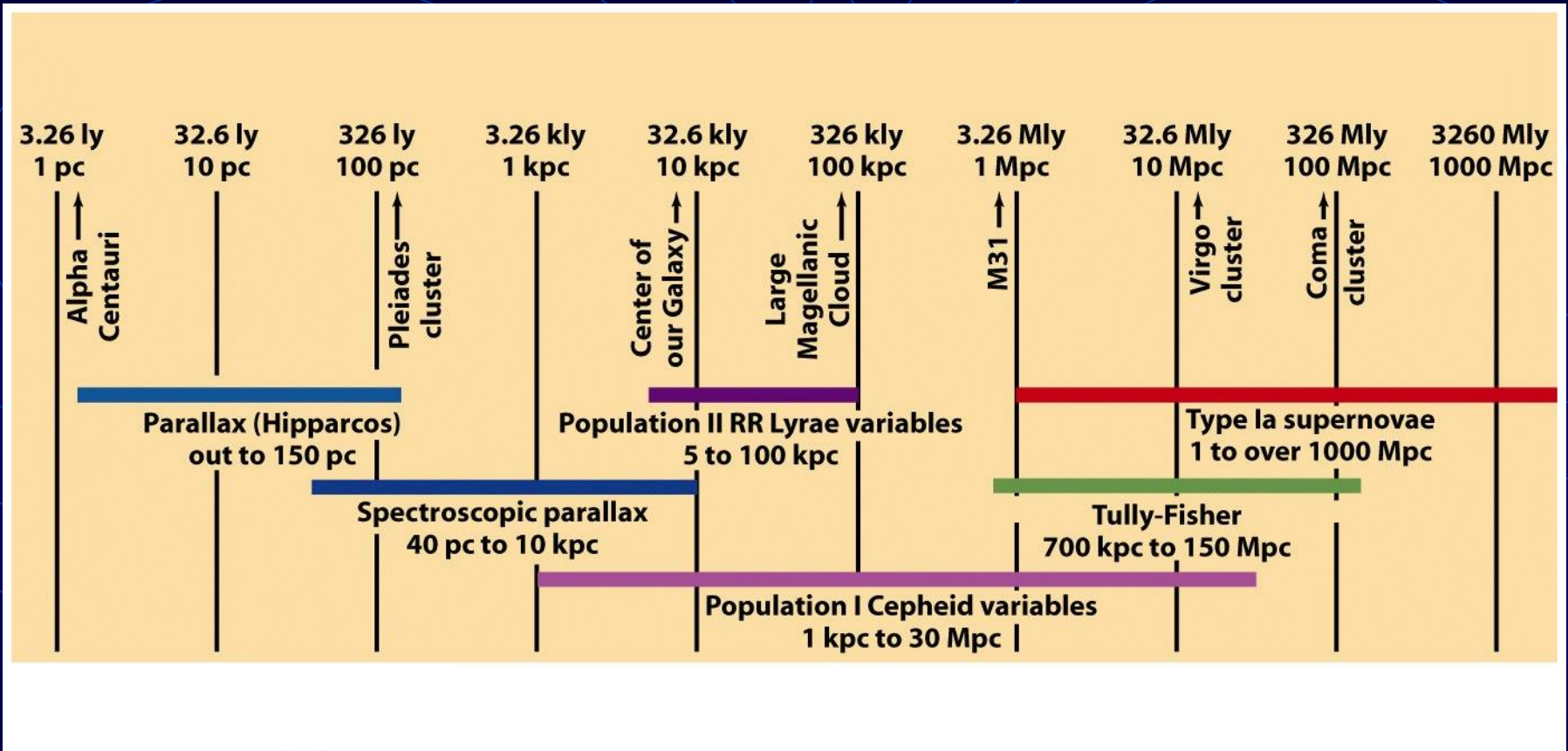
Distance Ladder

測量天體的距離（尺度）

- Parallax (< 150 pc)
- Spectroscopic parallax (< 10 kpc)
- RR Lyrae variables (5 to 100 kpc)
- Pop I Cepheid variables (1 kpc to 30 Mpc)
- Type Ia supernovae (1 to over 1000 Mpc)
- Tully-Fisher method (0.7 to 150 Mpc)
- Hubble law

絕對星等已知的天體

➔ **標準燭光 standard candle**


3.26 ly
1 pc
32.6 ly
10 pc
326 ly
100 pc
3.26 kly
1 kpc
32.6 kly
10 kpc
326 kly
100 kpc
3.26 Mly
1 Mpc
32.6 Mly
10 Mpc
326 Mly
100 Mpc
3260 Mly
1000 Mpc
Alpha Centauri
Pleiades cluster
Center of our Galaxy
Large Magellanic Cloud
M31
Virgo cluster
Coma cluster
Parallax (Hipparcos)
out to 150 pc
Population II RR Lyrae variables
5 to 100 kpc
Type Ia supernovae
1 to over 1000 Mpc
Spectroscopic parallax
40 pc to 10 kpc
Tully-Fisher
700 kpc to 150 Mpc
Population I Cepheid variables
1 kpc to 30 Mpc

Tully-Fisher Relation

- 1970s, Brent Tully and Richard Fisher
  ➔ **21 公分發射線越寬的螺旋星系越明亮**
- 原因是質量越大的螺旋星系，亮度越大（絕對星等越小），當中的恆星與雲氣也運動得越快，速度的範圍也就越大，使得21公分譜線的寬度越大
- 譜線的寬度很容易測量 → 星系的絕對星等 ←→ 星系視星等 ➔ 星系的距離

Special Theory of Relativity

Time Dilation

$$\tau = \frac{\tau_0}{\sqrt{1-(v/c)^2}}$$

Lorentz Transformation for time

τ_0: proper time (not moving) with the phenomena

Ex. If τ_0 = 1 min, then for an observer moving at v = 0.98 c,

τ = 5 min

高速運動者，時間變慢

Length Contraction

$$L = L_0 \sqrt{1 - (\frac{v}{c})^2}$$

Lorentz Transformation for length

L_0: proper time (not moving) with the phenomena

Ex. If L_0 = 1 m, then for an observer moving at v = 0.98 c,

L = 20 cm

高速運動者，長度縮短

Relativistic Redshift

Doppler Redshift

$$z = \frac{\lambda - \lambda_0}{\lambda_0} = \frac{\Delta\lambda}{\lambda_0}$$

$z > 0$ redshift

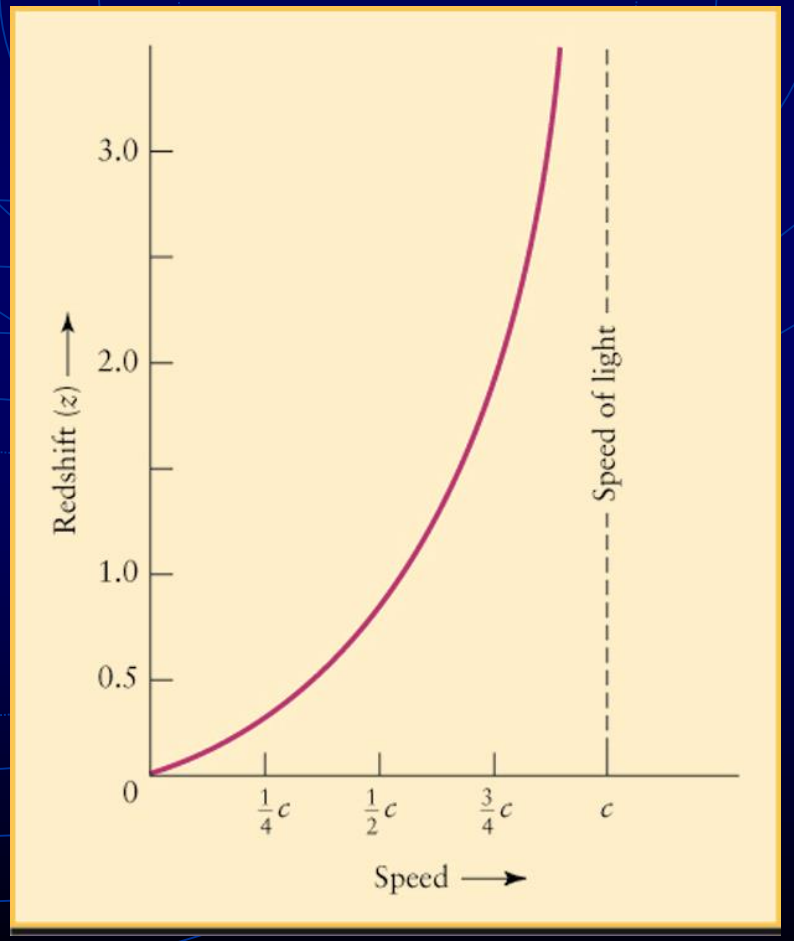
$z < 0$ blueshift

For $v << c$ $\quad z = \frac{v}{c}$

For $z > 0.1$ $\quad z = \sqrt{\frac{c+v}{c-v}} - 1$

In general, $\frac{v}{c} = \frac{(z+1)^2 - 1}{(z+1)^2 + 1}$

$$1 + z = \frac{\lambda}{\lambda_0} = \sqrt{\frac{1+\beta}{1-\beta}}, \quad \beta = \frac{v}{c}$$



Q: The K line of singly ionized calcium measured in a lab has λ_0 = 393.3 nm. But in NGC 4889, this spectral line has λ = 401.8 nm. Using H_0 = 73 km/s/Mpc, find the distance to this galaxy.

A: The redshift is z = (401.8 – 393.3)/393.3 = 0.022. This is less than 0.1 so no relativistic treatment is ok, i.e., $v = cz$, so $v = 0.022*3*10^5$ km/s = 6480 km/s.

Given H_0 = 73 km/s/Mpc, d = v /H_0 = 6480 / 73 = 89 Mpc or about 290 Mly

Q: In 1997, a type Ia supernova, SN 1997ff was measured $z = 1.7$. Using the Hubble law to find the distance to this supernova.

A: The redshift is large, so we need to use the relativistic formula,

$$v/c = [(1.7 + 1)^2 - 1] / [(1.7 + 1)^2 + 1] = 0.76$$

So the recessional speed is 0.76 c or 2.3×10^5 km/s.

Using the Hubble law, the distance to the supernova is

$$d = v / H_0 = 2.3 \times 10^5 / 73 = 3200 \text{ Mpc} = 10^{10} \text{ ly}$$

Supernovae probe the distant and early Universe!