星團 ── 恆星的社會組織

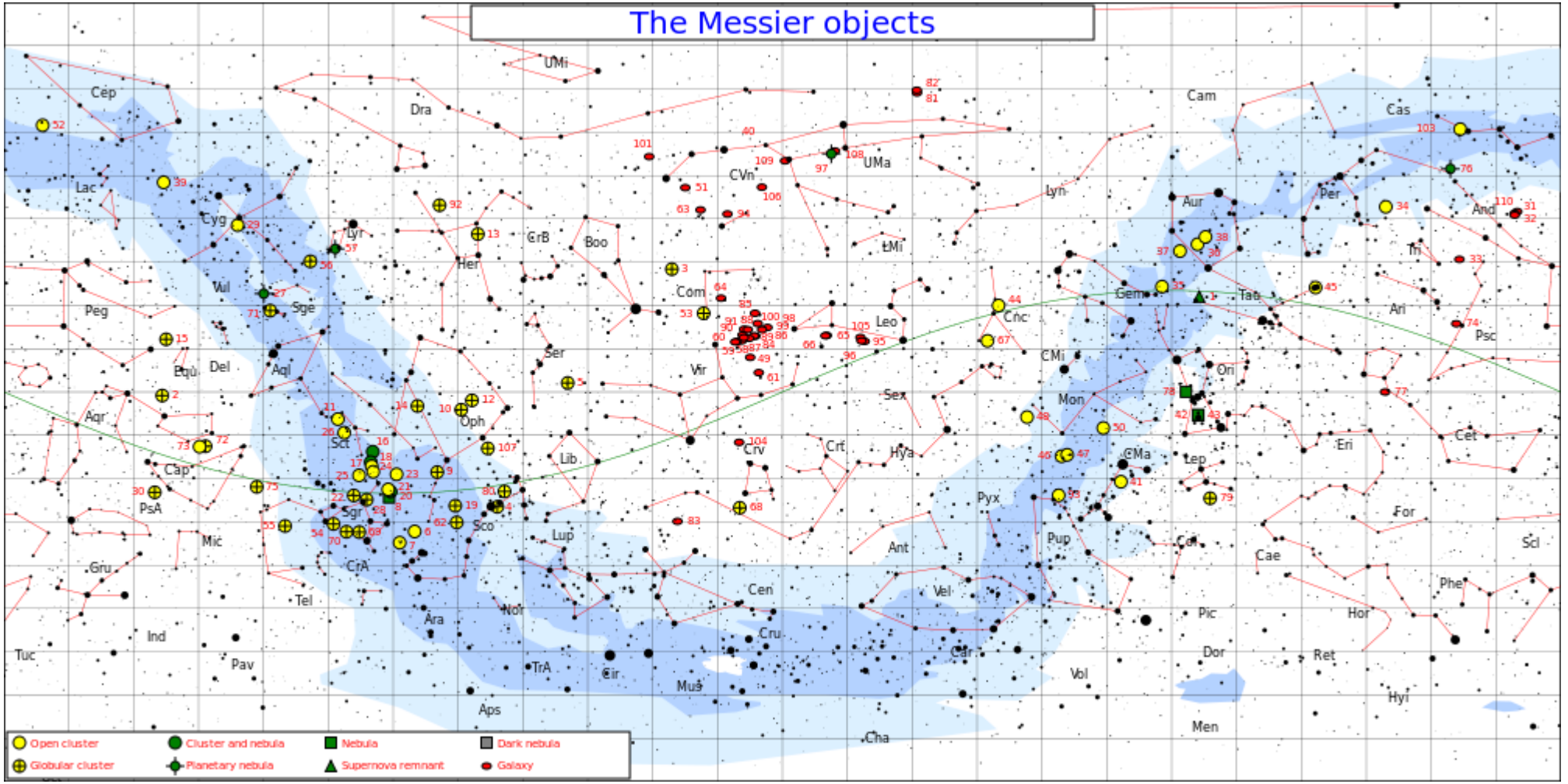
- 恆星成群形成
- 了解星團
- 利用星團

陳文屏
中央大學 天文所

2021.07.16 中學教師 online lecture

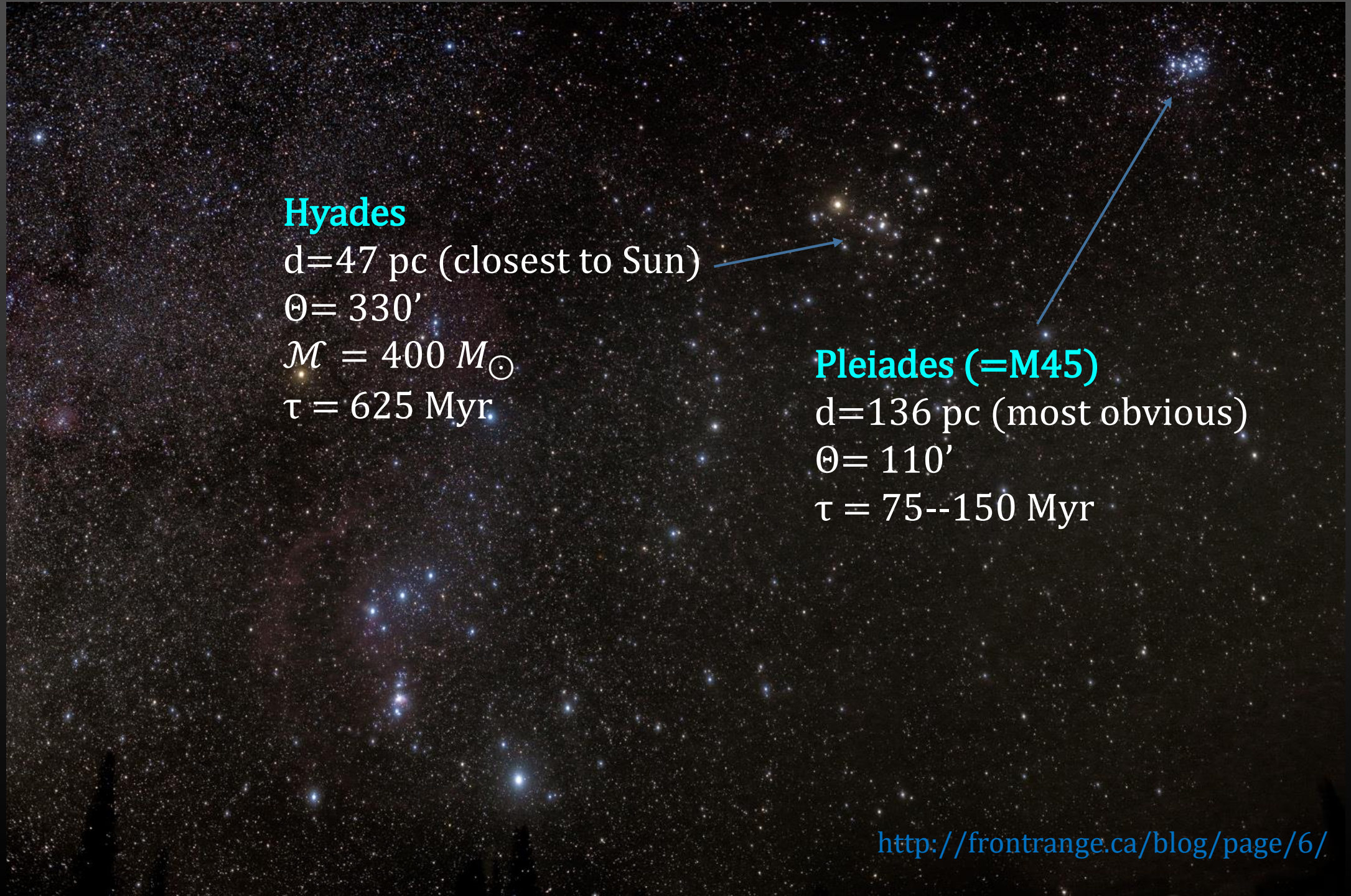
https://www.astro.ncu.edu.tw/~wchen/Courses/StellarEvo/starClusters.pdf

星團 --- 肉眼可見，恆星、行星以外，人類最早注意到的天體



OCs: 26
GCs: 29

Messier "*Catalogue des Nébuleuses et des Ams e'Étoiles*" ("Catalogue of Nebulae and Star Clusters" (1771)


Hyades
d=47 pc (closest to Sun)
Θ= 330’
$\mathcal{M} = 400\ M_\odot$
τ = 625 Myr
Pleiades (=M45)
d=136 pc (most obvious)
Θ= 110’
τ = 75--150 Myr
http://frontrange.ca/blog/page/6/

畢宿星團

昴宿星團

Praesepe (=M44=Beehive)

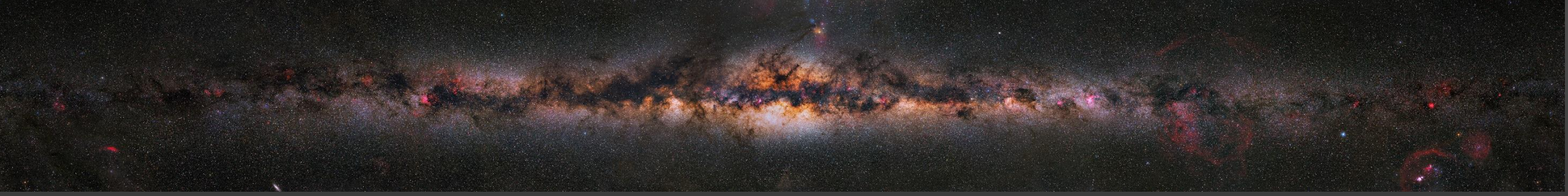
d=177 pc

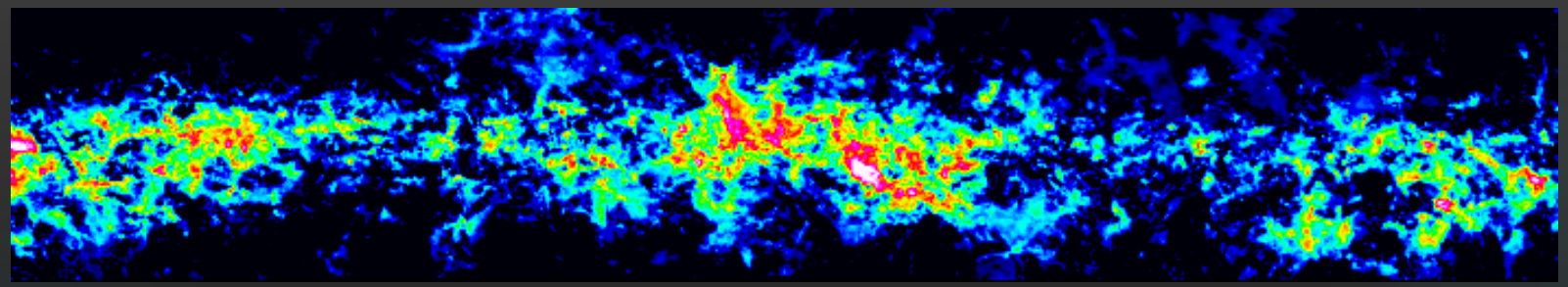
$\Theta = 95'$

$\mathcal{M} = 500 - 600\, M_{\odot}$

$\tau = 600 - 700$ Myr

鬼宿星團





Giant Molecular Clouds
（巨型分子雲）

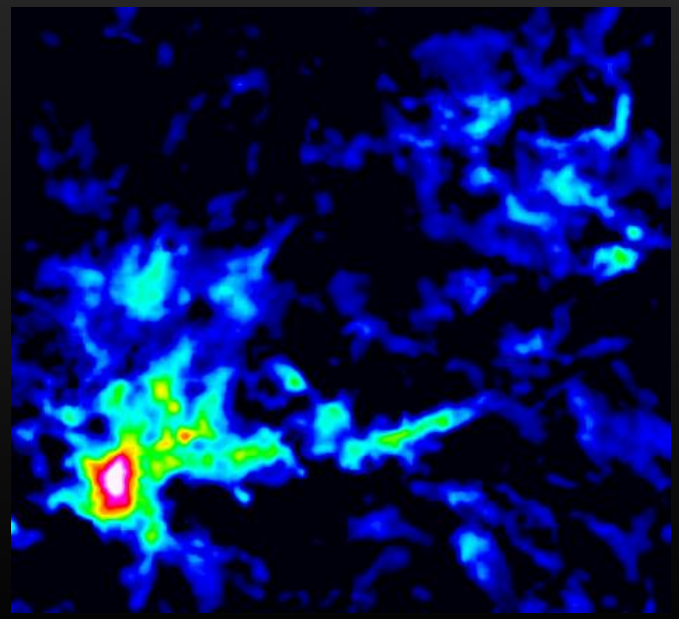
D=20~100 pc

$\mathcal{M} = 10^5 \sim 10^6\ \mathcal{M}_\odot$

$\rho \approx 10 \sim 300\ \mathrm{cm}^{-3}$

$T \approx 10 \sim 30\ \mathrm{K}$

$\Delta v \approx 5 \sim 15\ \mathrm{km}^{-1}$



Molecular clouds/clumps
（分子雲）

$n \sim 10^3\ \mathrm{cm}^{-3}$, $D \sim 5$ pc,
$M \sim 10^3\ \mathrm{M}_\odot$

Dense molecular cores
（分子雲核）

$n \geq 10^4\ \mathrm{cm}^{-3}$, D ~ 0.1 pc,
$M \sim$ 1-2 $\mathrm{M}_\odot$

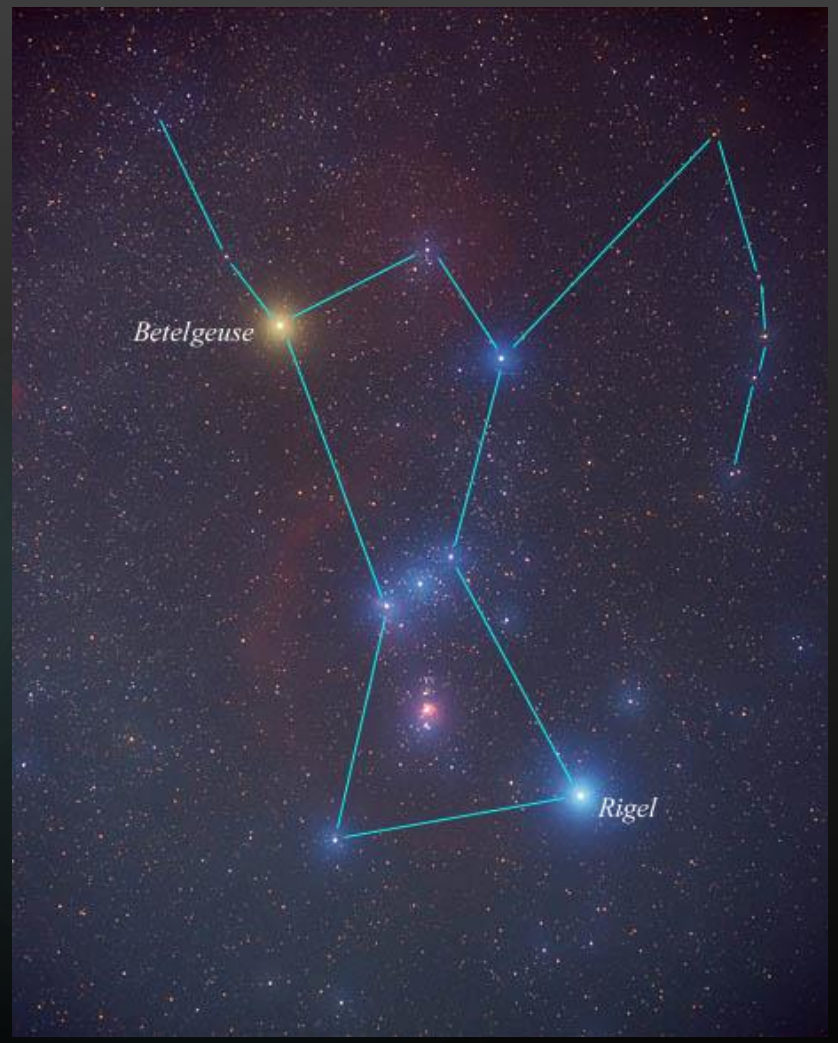
Barnard 72 in Ophiuchus

蛇夫座方向的暗雲

http://www.robgendlerastropics.com/B72JMM.jpg

Orion in visible light

獵戶座可見光照片



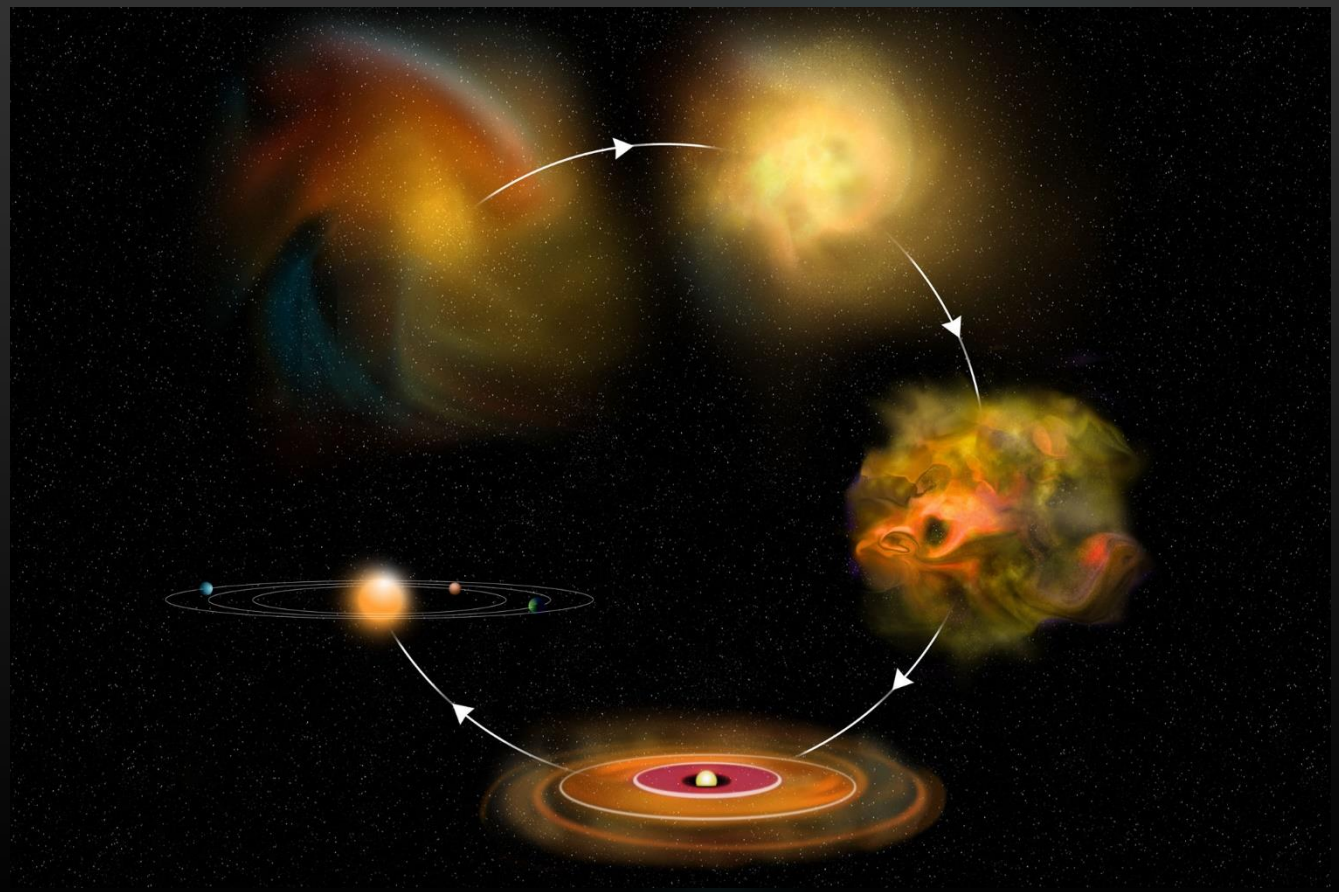
… and in CO

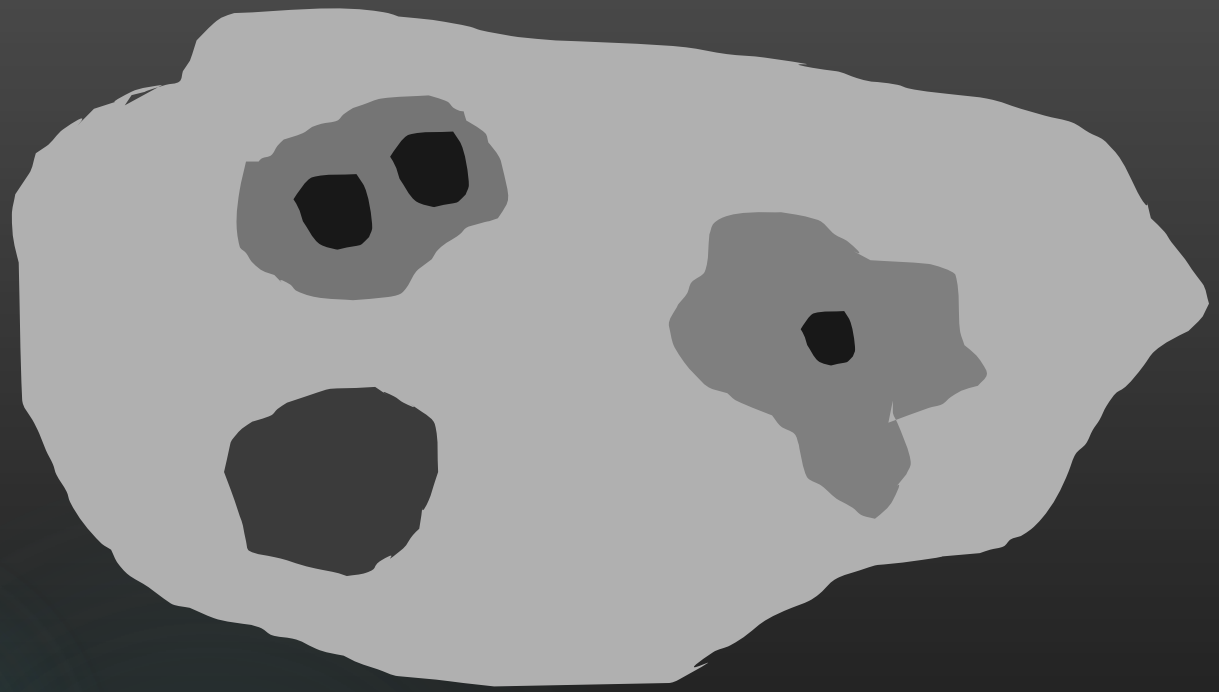
獵戶座分子輻射假色圖

濃厚的分子（暗）雲與塵埃

{密度高（引力強）
{溫度低（壓強弱）

雲氣收縮 → 會怎麼樣？





分子雲收縮 ⟶ 溫度下降 ⟶ 繼續收縮 ⟶ 雲氣分裂

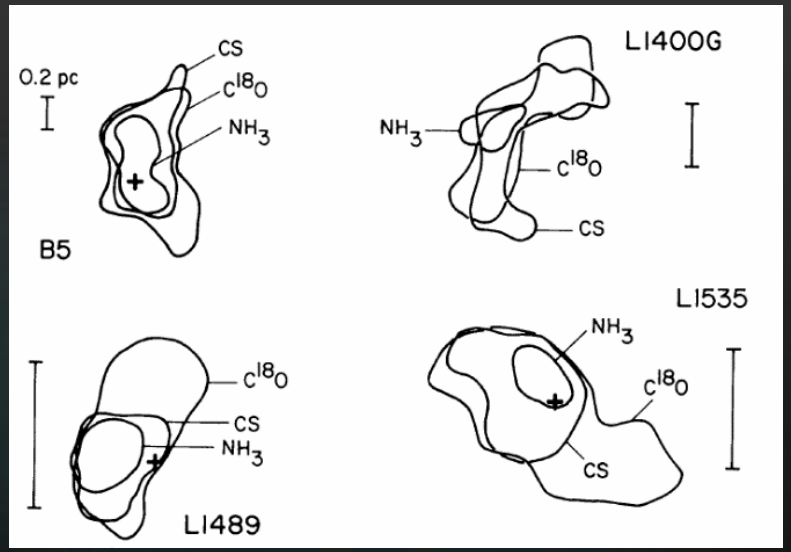
個別雲核收縮 ⟶ 密度高 $\xrightarrow{\text{不再透明}}$ 溫度上升、夠熱 ⟶ 恆星

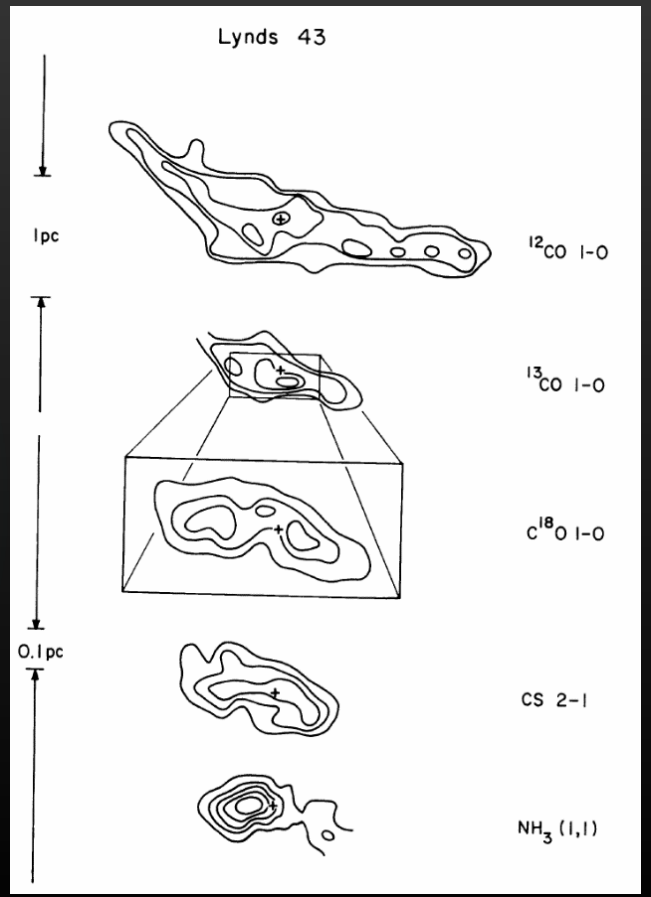
⟹ 一群恆星

恆星形成 ＝ 雙星形成 ＝ 星團形成

恆星在分子雲中成群誕生；而行星則在年輕的環星盤中凝聚形成

金牛座分子雲與初生恆星





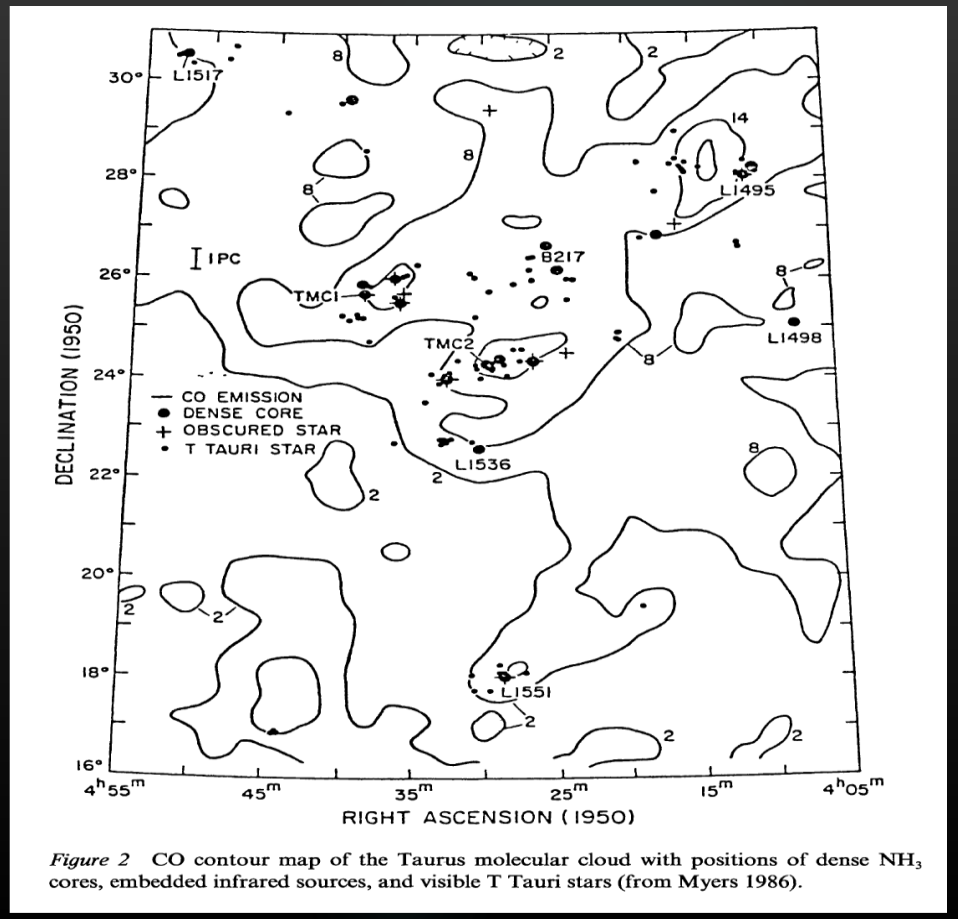


Figure 2 CO contour map of the Taurus molecular cloud with positions of dense NH_3 cores, embedded infrared sources, and visible T Tauri stars (from Myers 1986).

不同種類的分子譜線
探測不同環境
（密度、溫度）

NGC 6520

Barnard 86

星團大略分為兩類

◘ 疏散星團

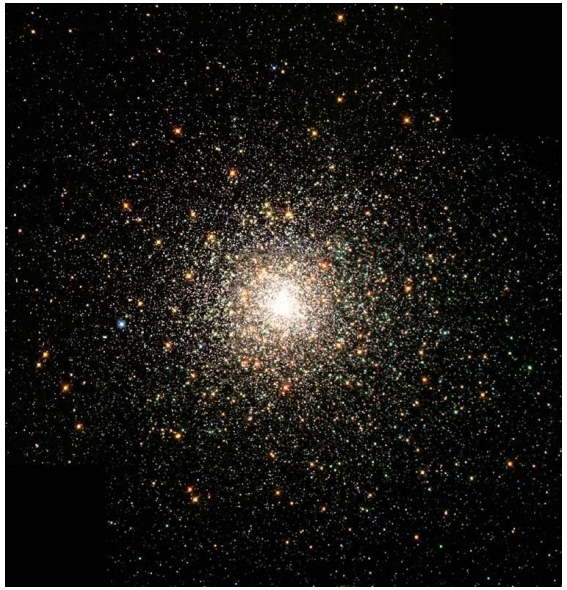
- ✓外觀鬆散
- ✓半徑 1~10 pc 內數百到數千顆星
- ✓成員星年輕到老；富含「金屬」
- ✓目前知道數千個；都在太陽系附近
- ✓在銀盤中繞銀心

NGC 290 HST

LMC-NGC 2093 ESO 2.2 m

◘ 球狀星團

- ✓外觀呈球形；往中央高度集中
- ✓數 pc 內包含 10^4 to 10^6 顆星
- ✓成員星年齡大 Pop II (metal poor)
- ✓銀河系約150個
- ✓在銀暈中繞銀心

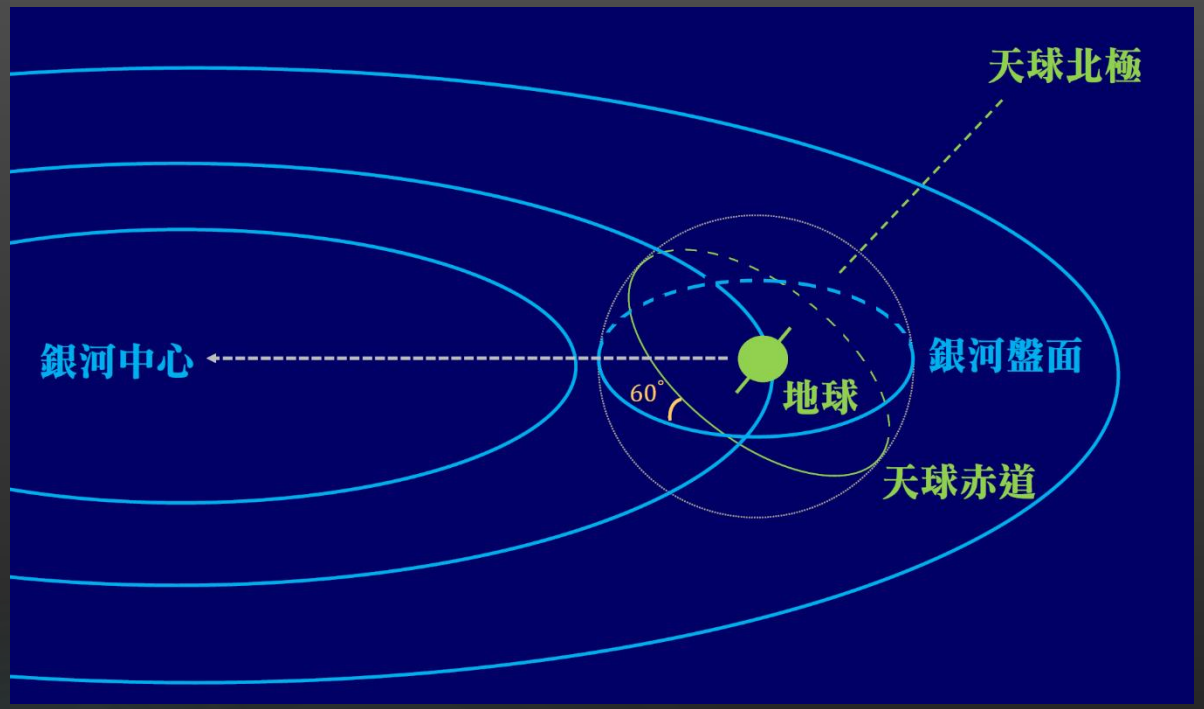


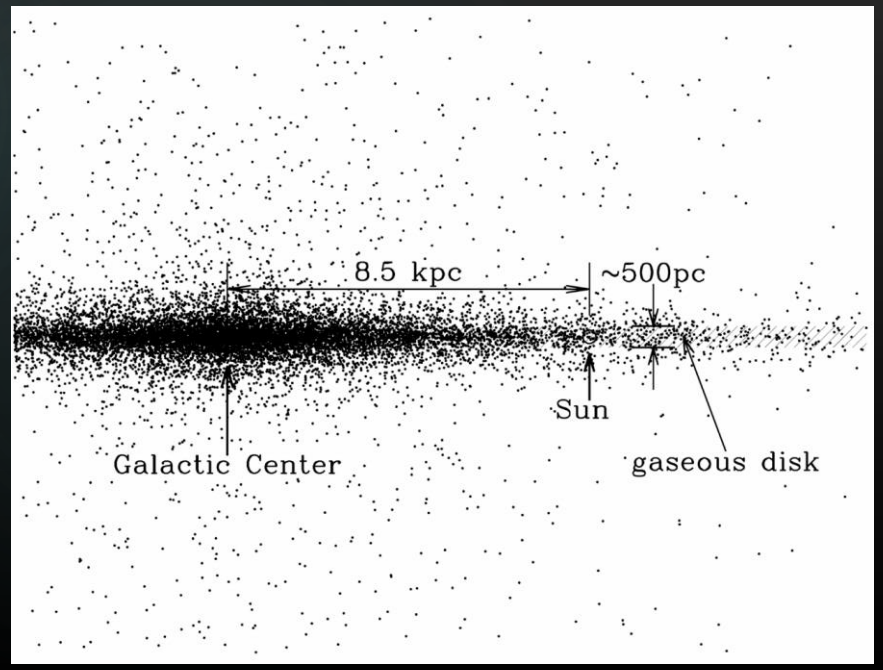
M80 HST

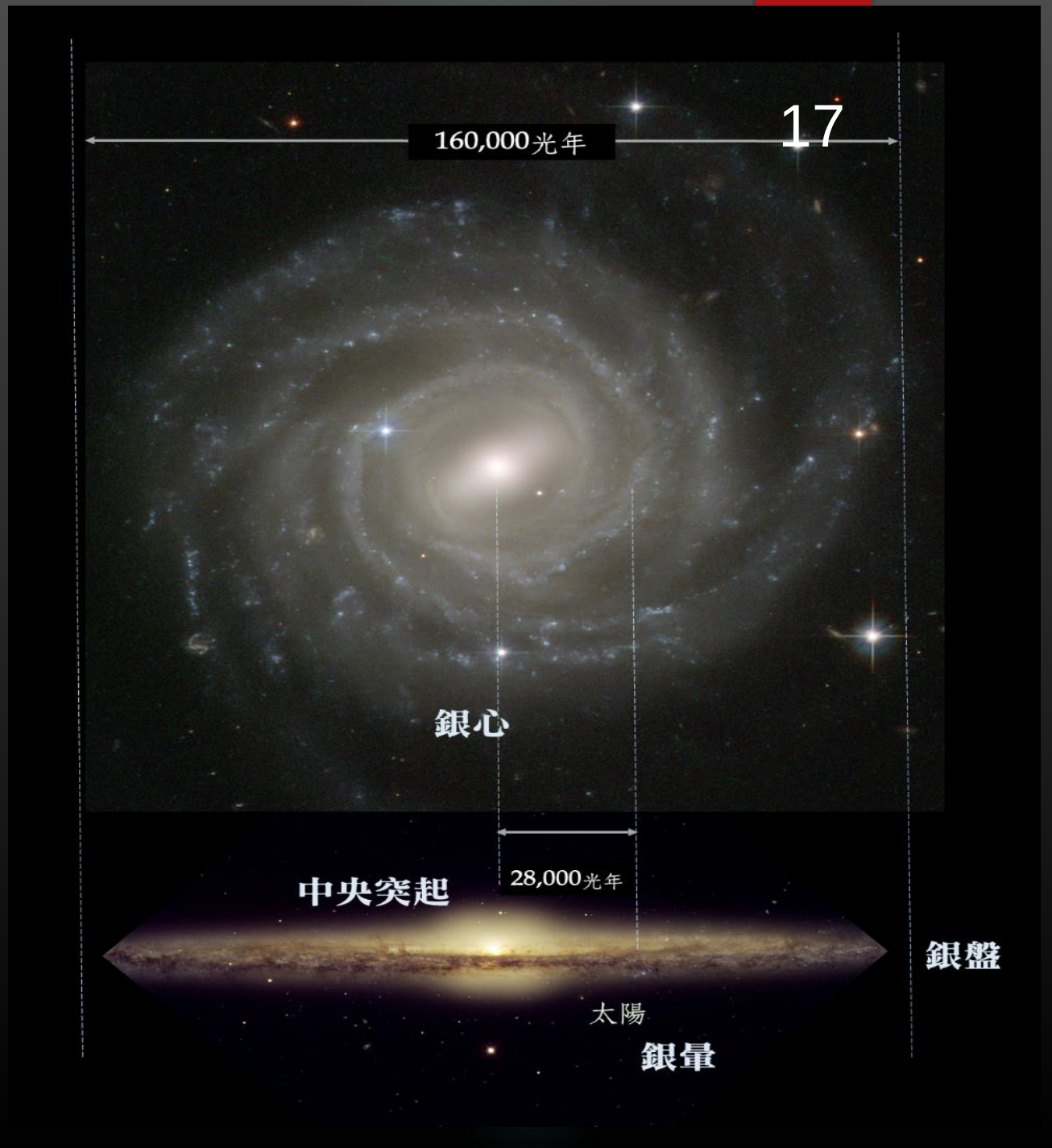
M31-G1 HST

M35
$d = 860$ pc
$\tau = 150$ Myr

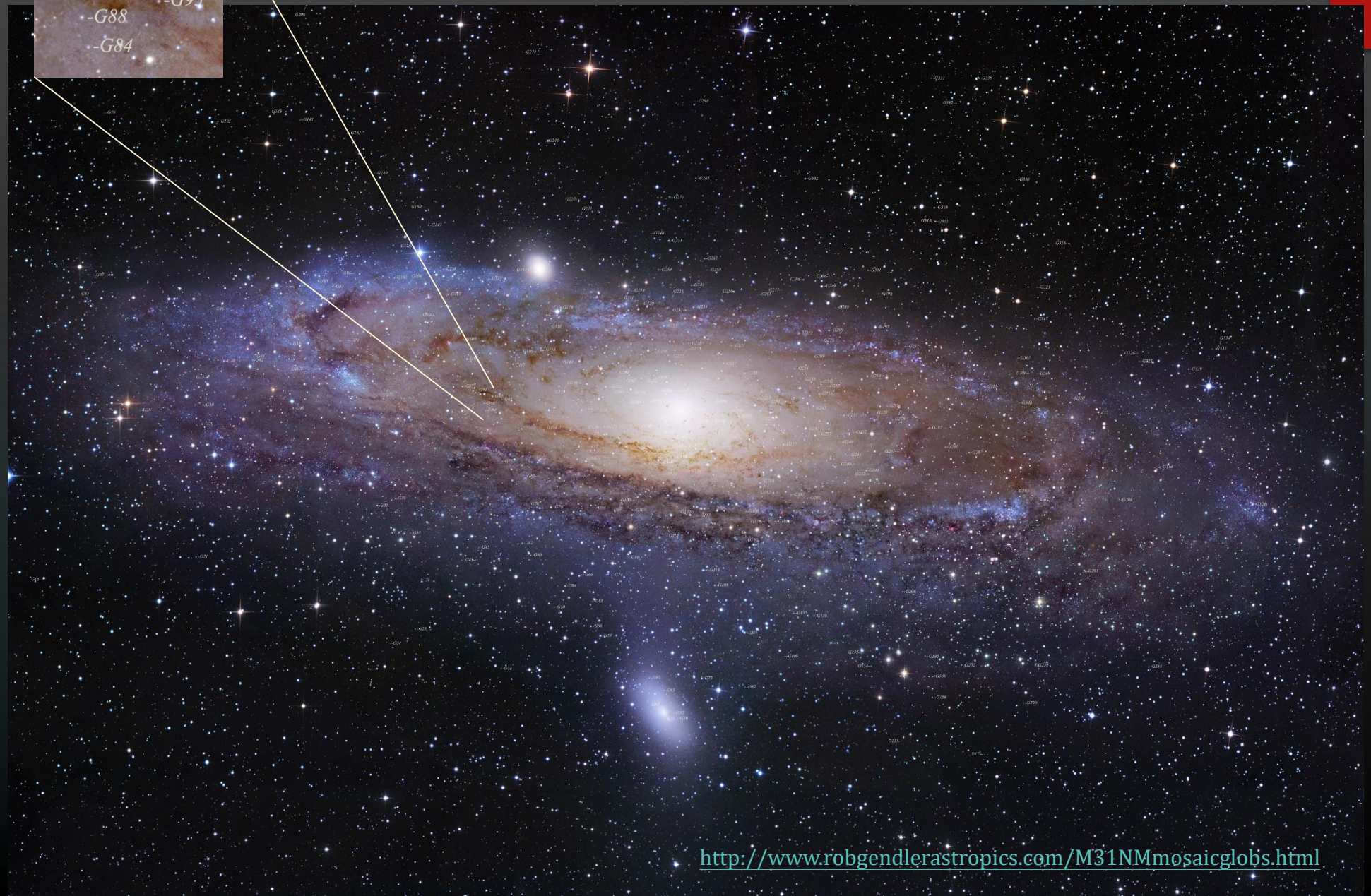
NGC 2158
$d = 5200$ pc
$\tau = 1.05$ Gyr


天球北極
銀河中心
銀河盤面
60°
地球
天球赤道


8.5 kpc
~500pc
Sun
Galactic Center
gaseous disk

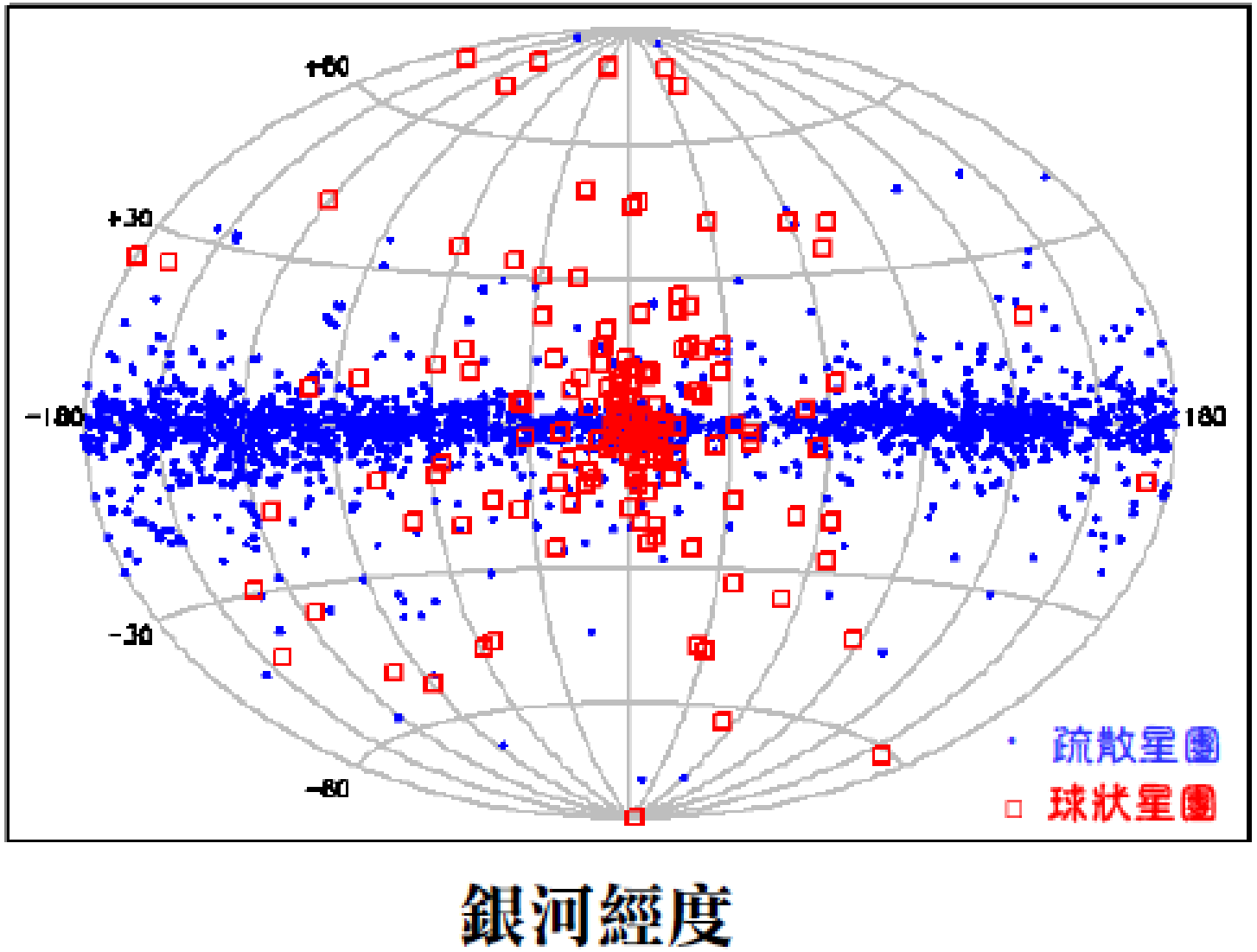

160,000光年
銀心
28,000光年
中央突起
銀盤
太陽
銀暈

Globular Clusters in M31

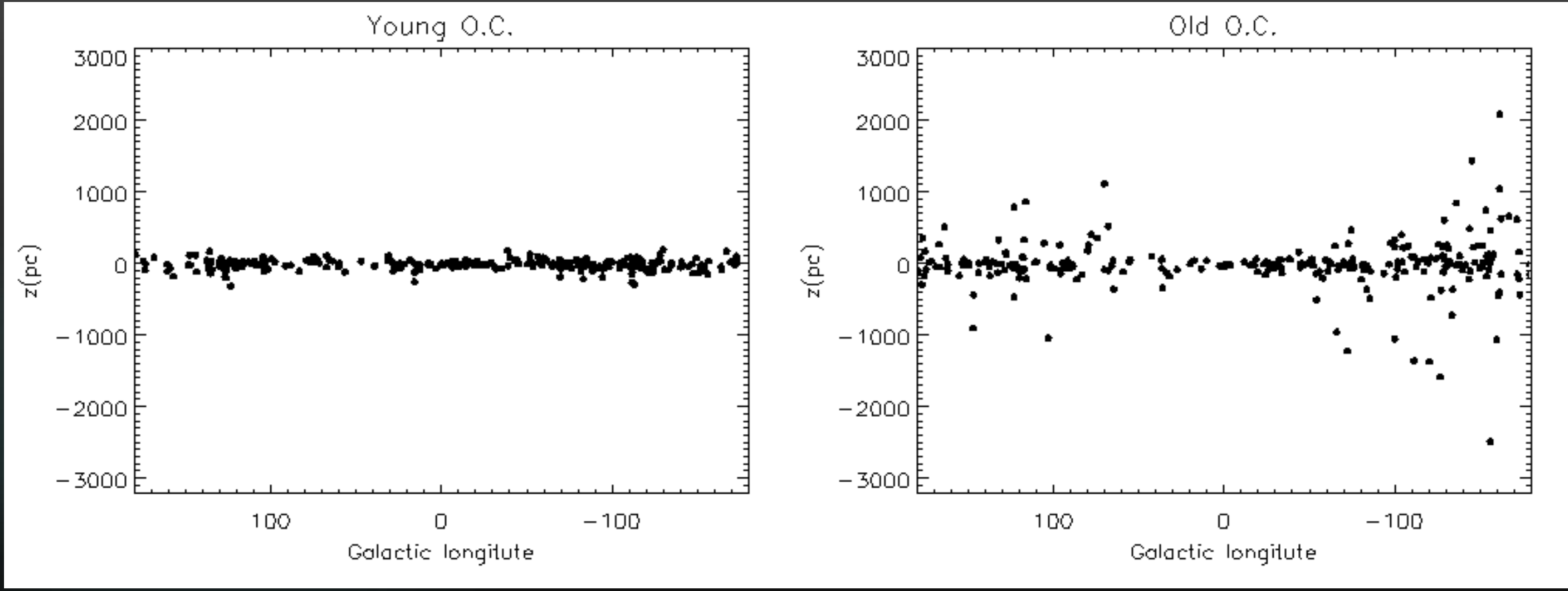


http://www.robgendlerastropics.com/M31NMmosaicglobs.html

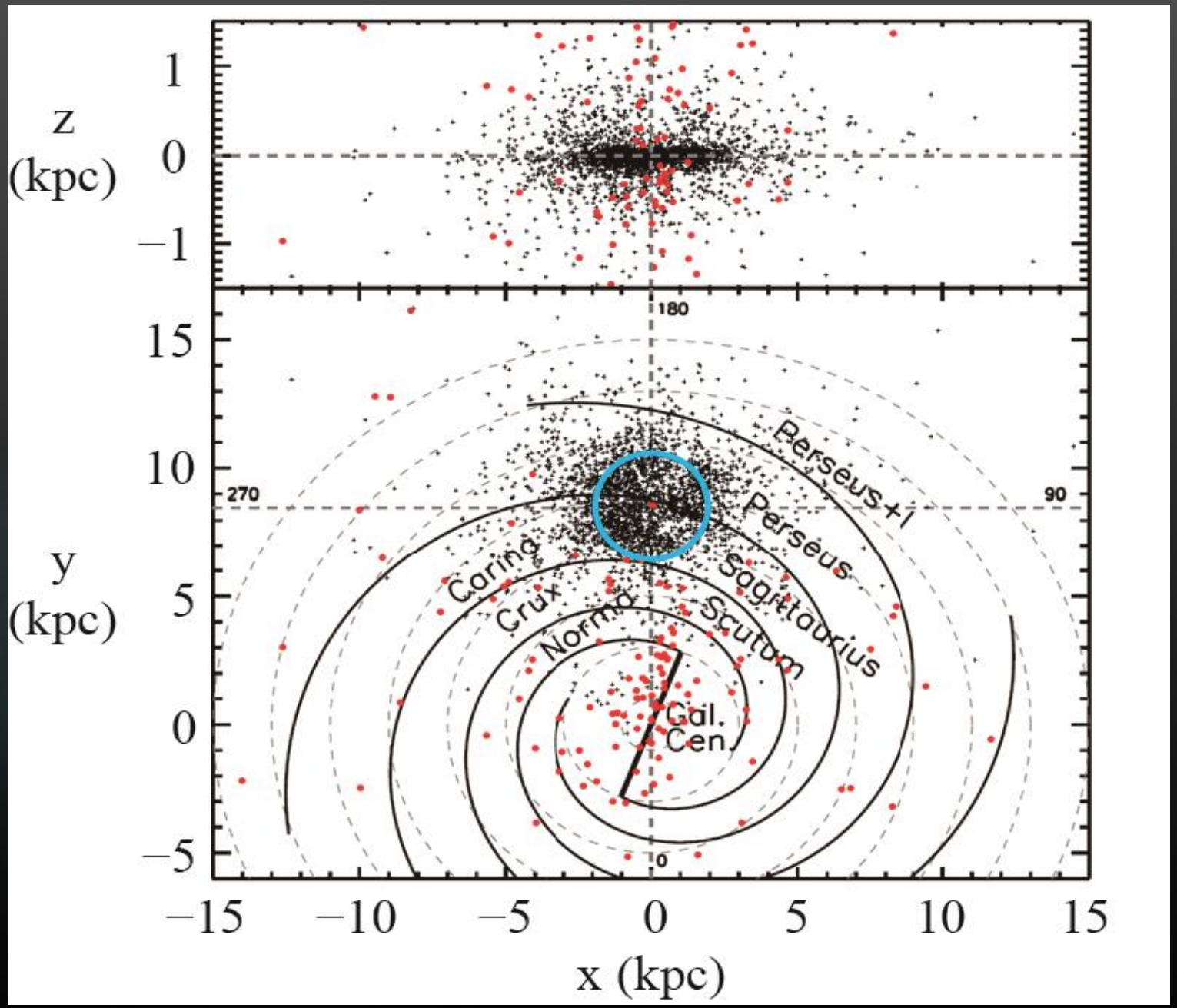
疏散星團集中於銀盤



球狀星團分布於銀盤上下



年輕的 (< 100 Myr) 疏散星團更集中於盤面（爲什麼？）



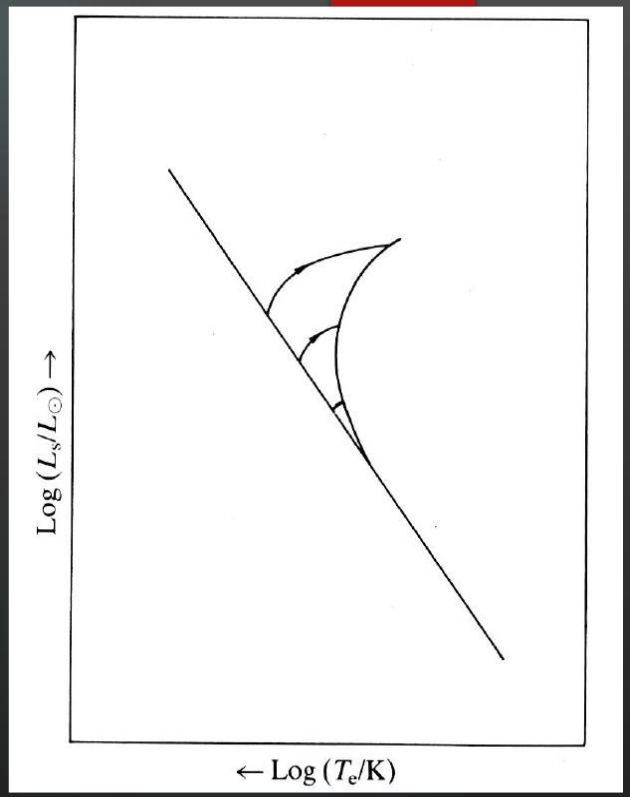
已知疏散星團距離太陽
1~2 kpc 之內
（爲什麼？）

多半位於銀河旋臂附近
（爲什麼？）

星團當中的成員星誕生於同一團星際雲氣

✓ 距離、年齡、成分（幾乎）相同
✓ 但不同質量的恆星演化快慢不同
⟹ 恆星演化展示場

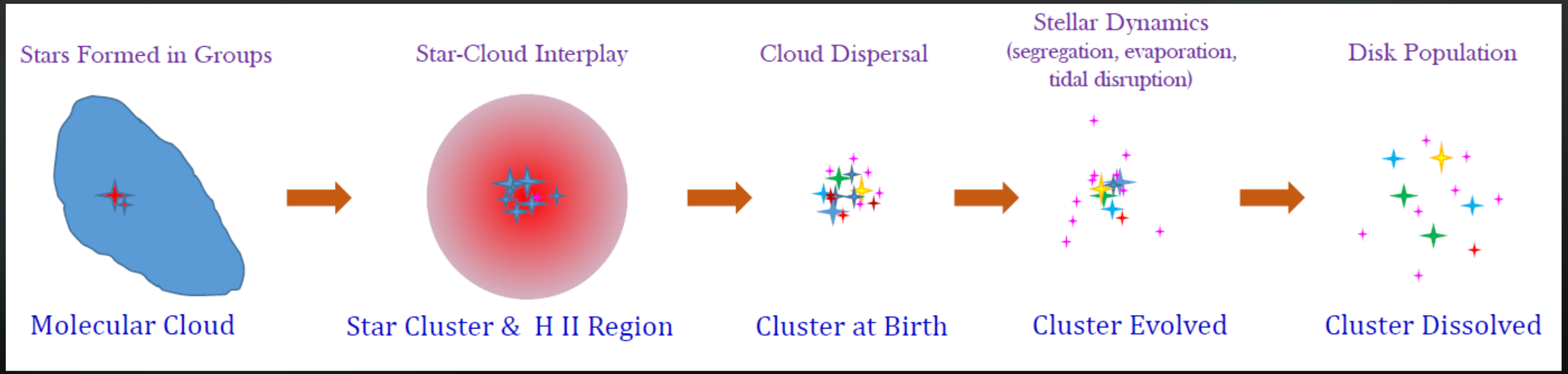
星團演化 ＝ 恆星演化



- 當某星團（成員星）老化，質量越大的恆星越早演化離開主序
- 主序依照恆星質量順序，逐漸「剝離」上半部
- 只剩下低質量恆星還在主序
- 「轉折點」main sequence turn-off ⟶ 星團年齡

星團的動力演化

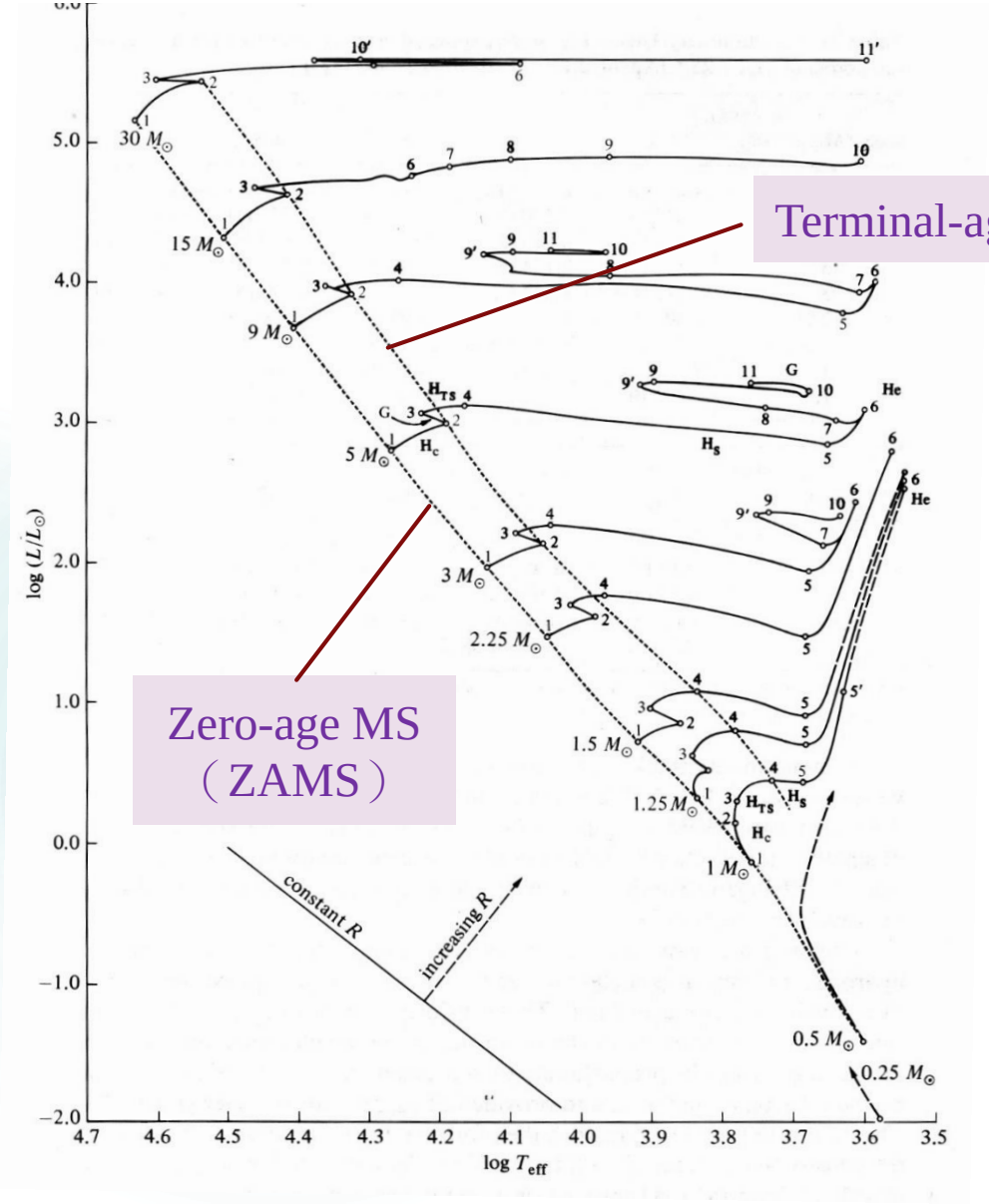
星團當中的成員星彼此重力作用、整體受到外界環境影響
⟹ 研究動力學（銀河系形成、結構、物質分布）



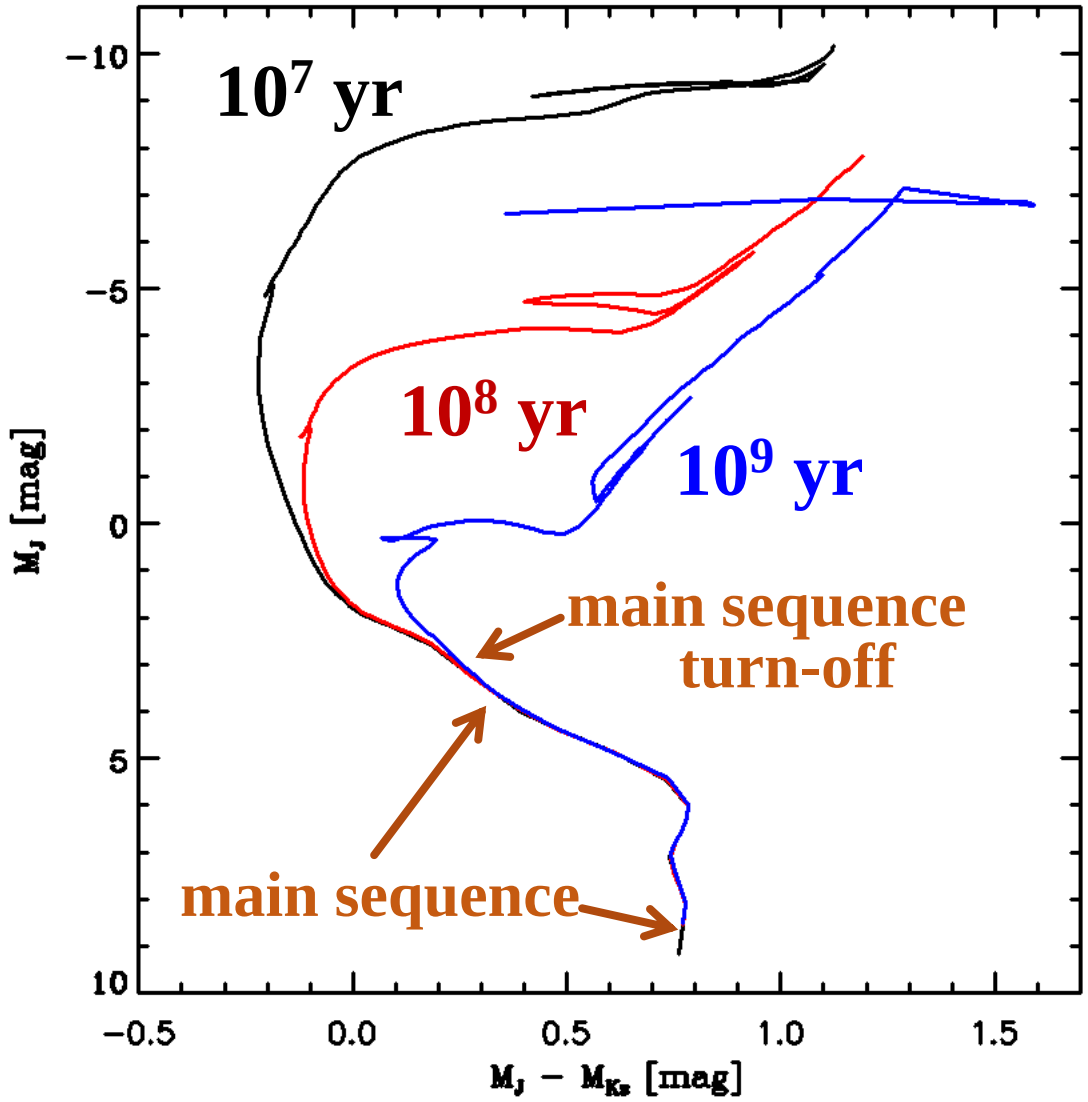
恆星成群形成　　星球與雲氣相互影響　　星團逐漸散開

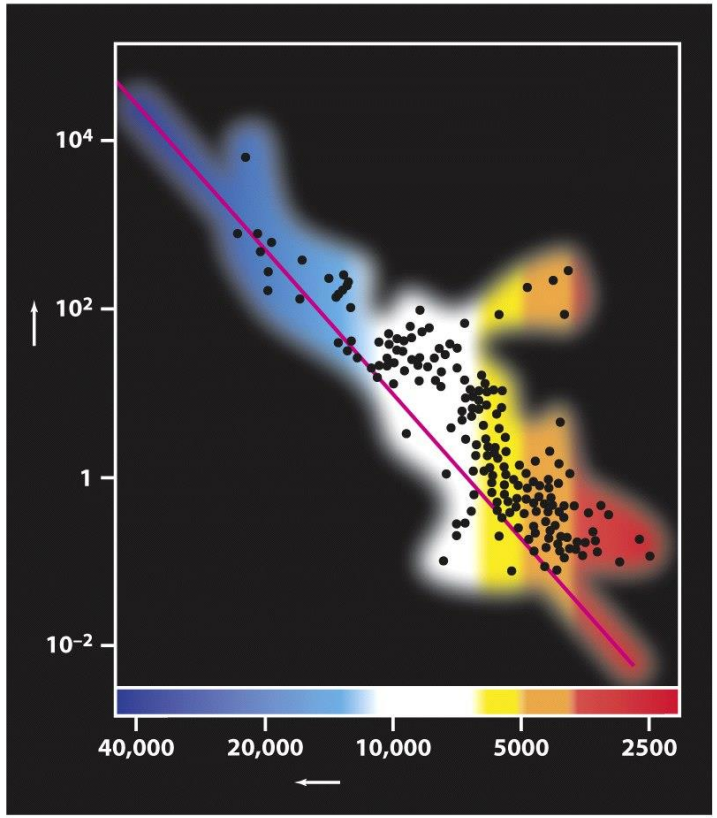
多半不久就散去　　雲氣消散、星團存活　　星團瓦解

不同質量個別恆星的演化

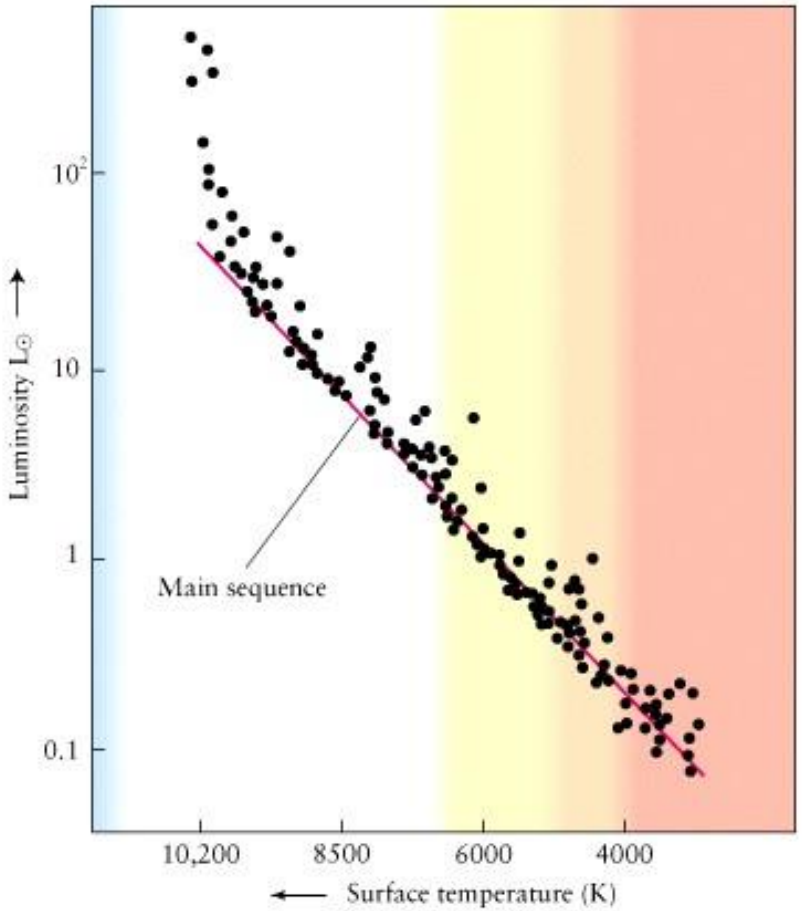


整個星團的等年齡演化線

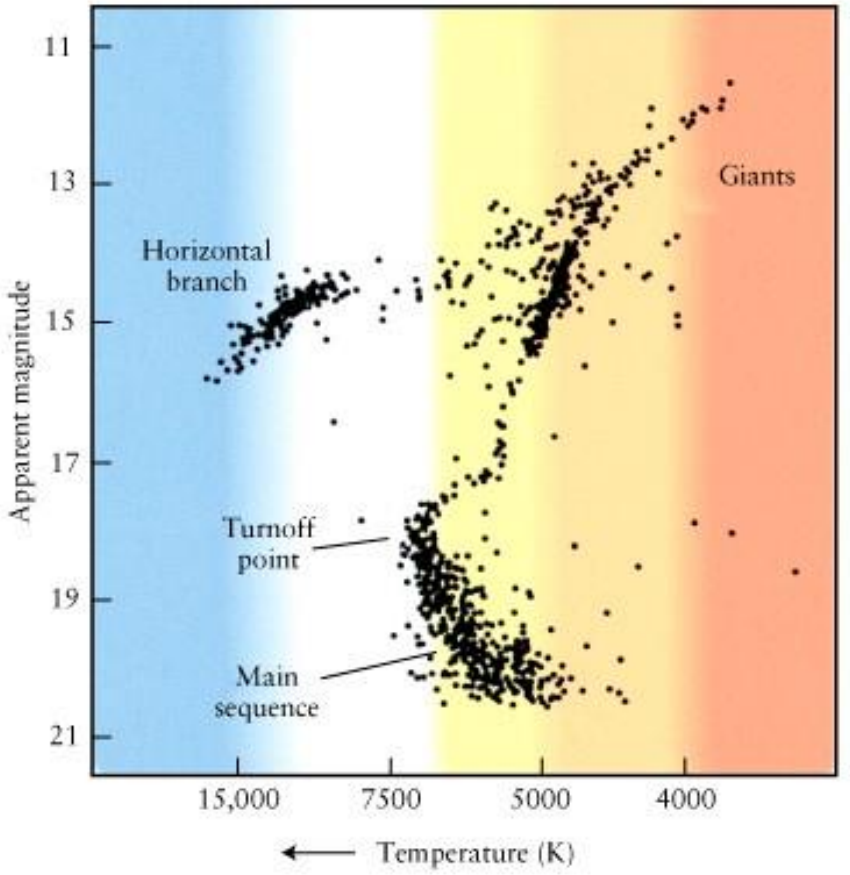




剛誕生的星團
（埋在雲裡）
低質量成員星尚未
進入主序

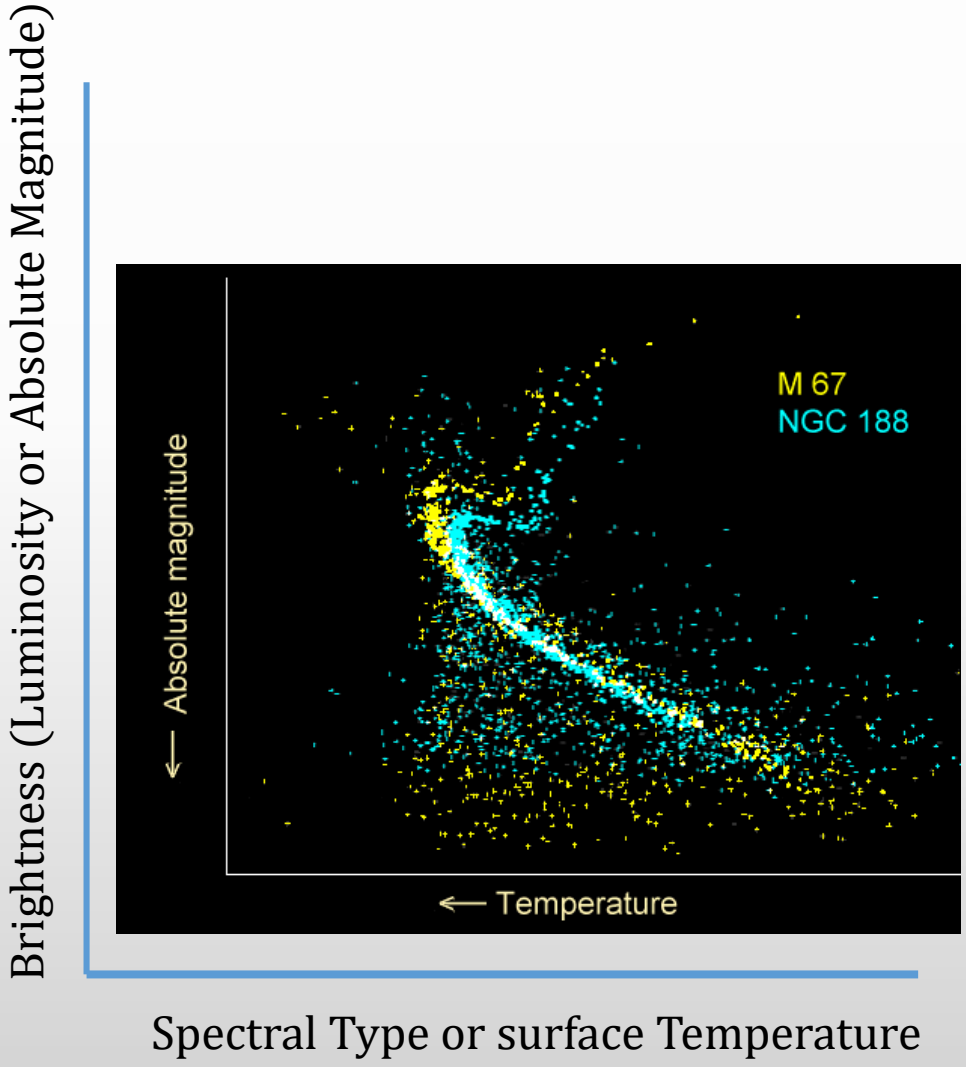


年輕的星團
大質量成員星將
要離開主序

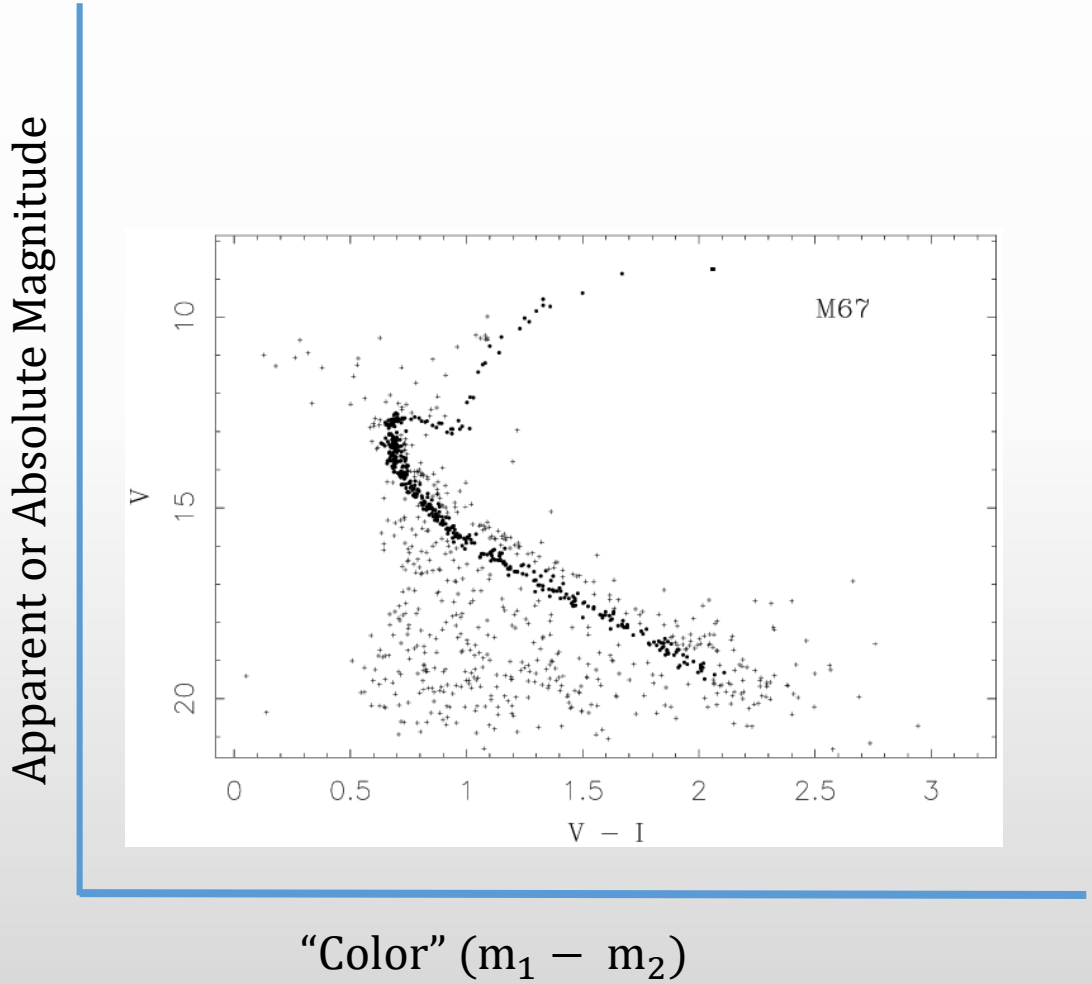


年老的星團
除了最小質量成員星
其他都已經離開主序

Hertzsprung-Russell Diagram
(physical)



Color-Magnitude Diagram (CMD)
(observational, a proxy of the HRD)



星團的主序

Main Sequence Fitting

$$m_\lambda - M_\lambda = 5\log d_{\rm pc} - 5 + A_\lambda$$

$$(m_{\lambda 1} - m_{\lambda 2}) = (M_{\lambda 1} - M_{\lambda 2}) + E(\lambda 1 - \lambda 2)$$

$$E(\lambda 1 - \lambda 2) \equiv A_{\lambda 1} - A_{\lambda 2}$$

距離越遠 → 變暗且變紅

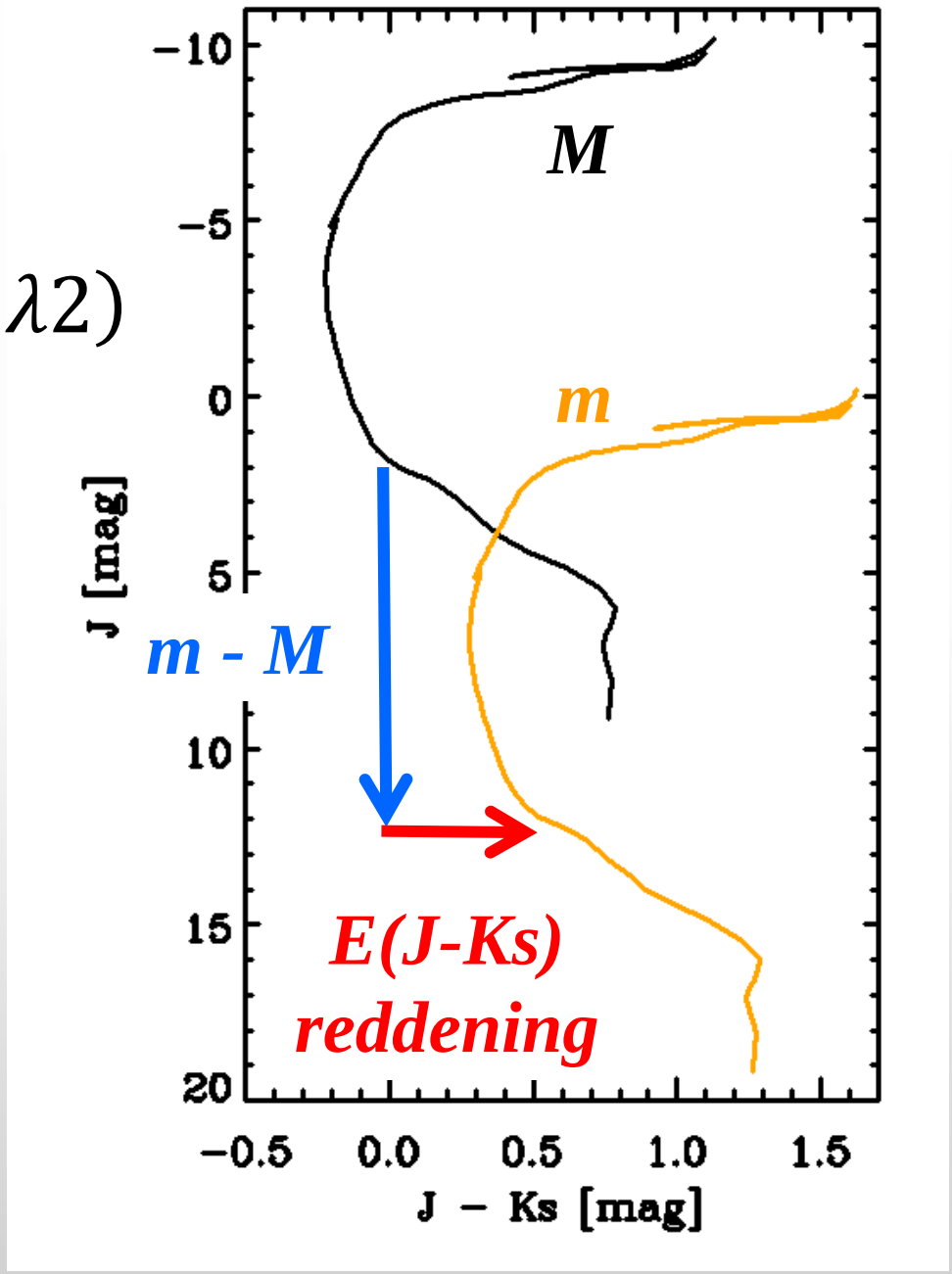
ISM "**Reddening law**" (Rieke & Lebofsky 1985)

$$A_B = 1.324\, A_V$$

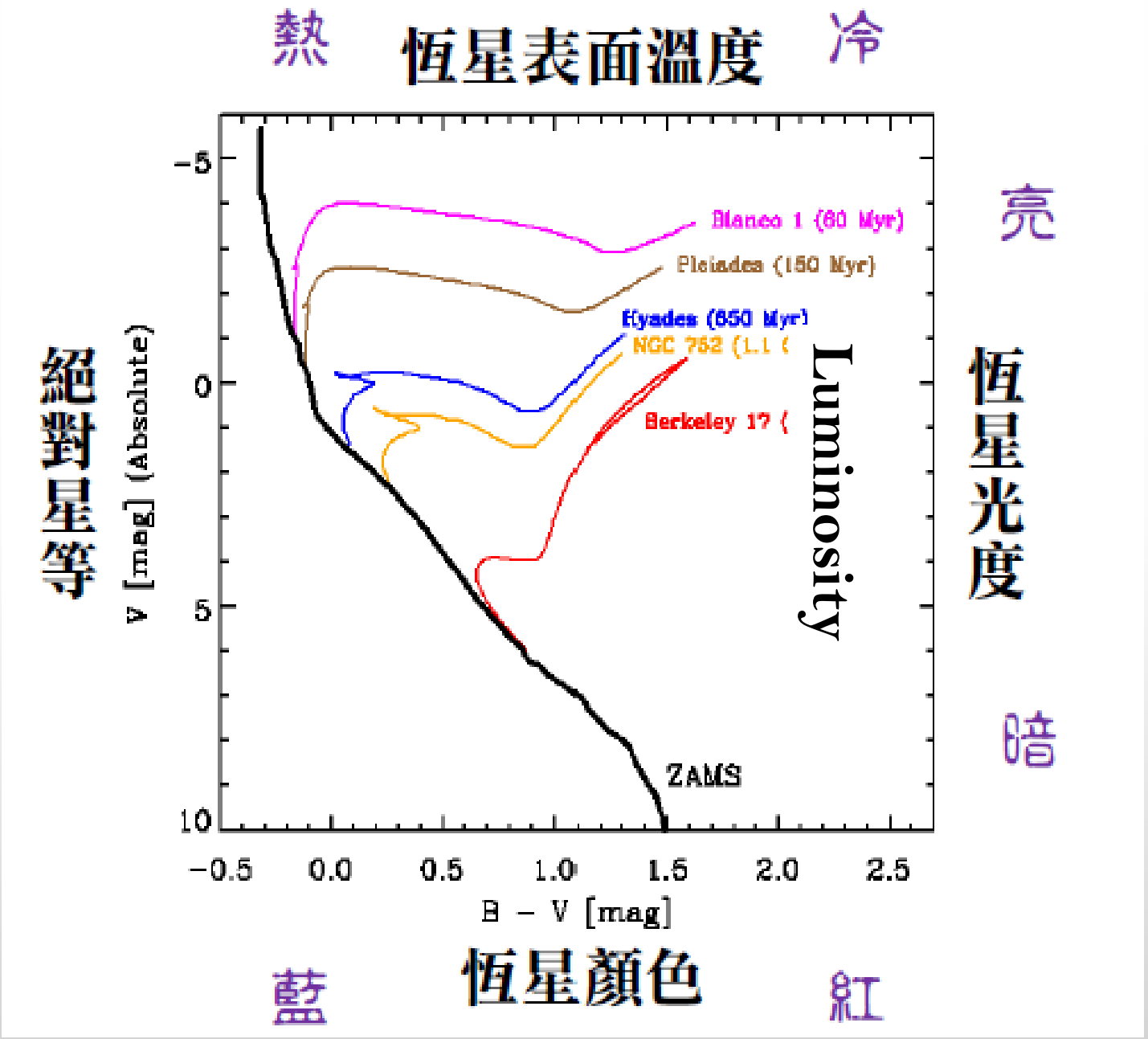
$$A_J = 0.282\, A_V$$

$$A_K = 0.112\, A_V$$

$$R \equiv A_V / E(B-V) \approx 3.1$$



觀測到的星團 CMDs


熱
恒星表面溫度
冷
亮
恒星光度
暗
絕對星等
V [mag] (Absolute)
Luminosity
Blanco 1 (60 Myr)
Pleiades (150 Myr)
Hyades (650 Myr)
NGC 752 (1.1
Berkeley 17
ZAMS
−5
0
5
10
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
B − V [mag]
藍
恒星顏色
紅

HB stars

He core burning,
RR Lyrae variables

He core fusion; H shall fusion

Blue stragglers

An extension of MS beyond the MSTO. They should not exist per "standard" stellar evolution theories.

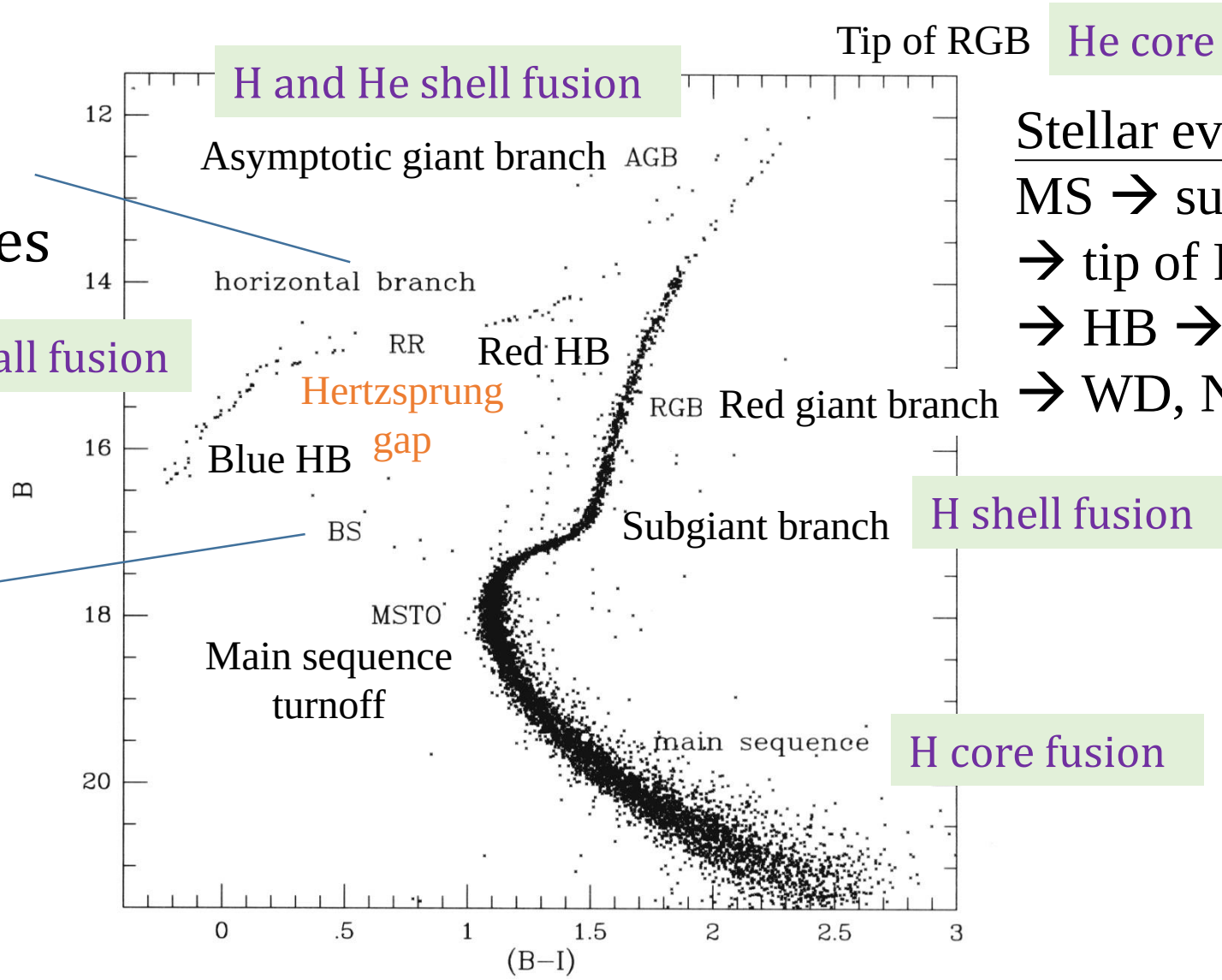
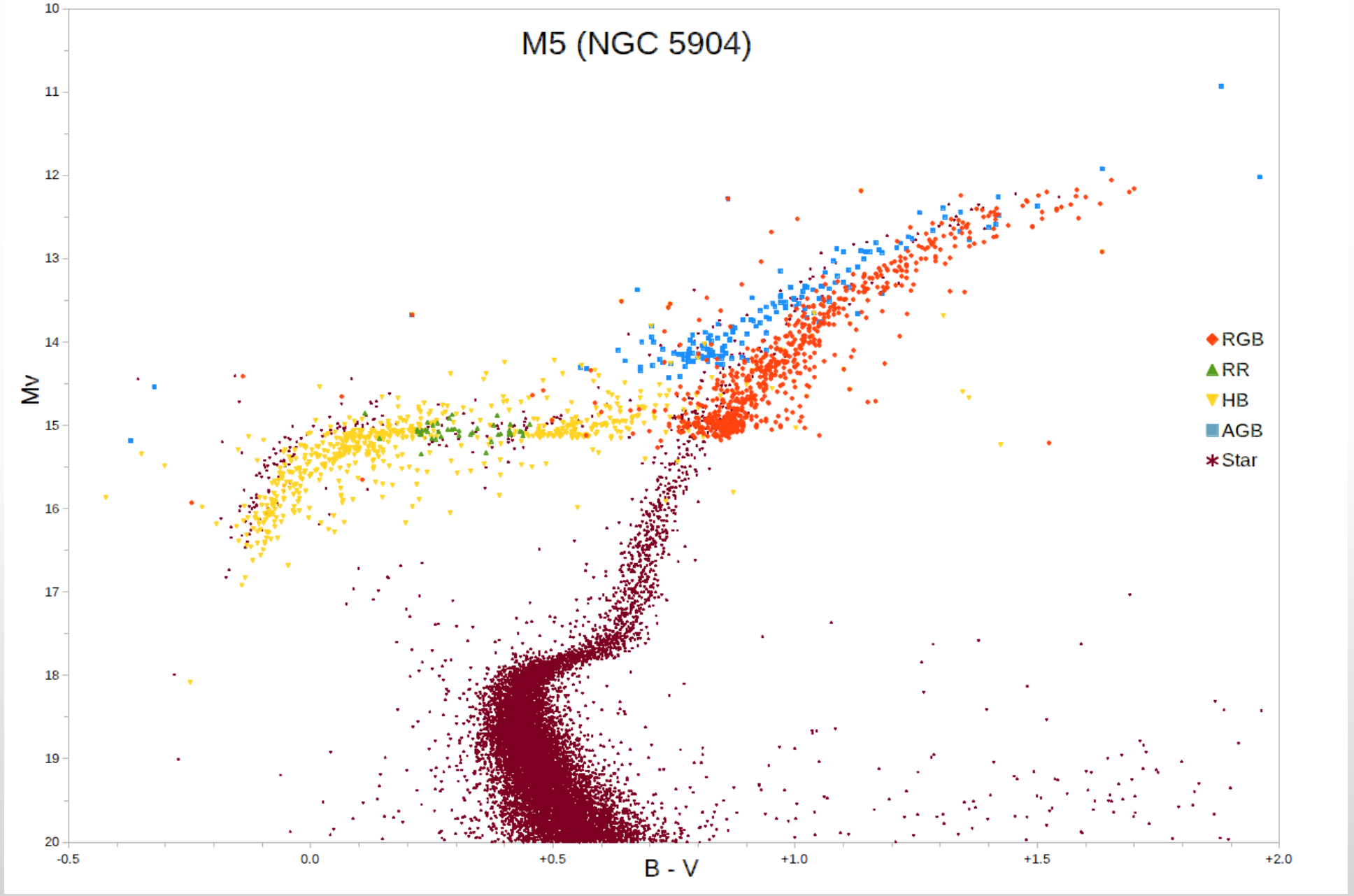


Fig. 2.1. The color–magnitude diagram of M5. The horizontal branch and main sequence are labeled. Also shown are: the RR Lyrae gap or instability strip (RR); the Red Giant Branch (RGB); the asymptotic giant branch (AGB); the main-sequence turn-off (MSTO); and blue stragglers (BS). (From data supplied by M. Bolte.)

Stellar evolution

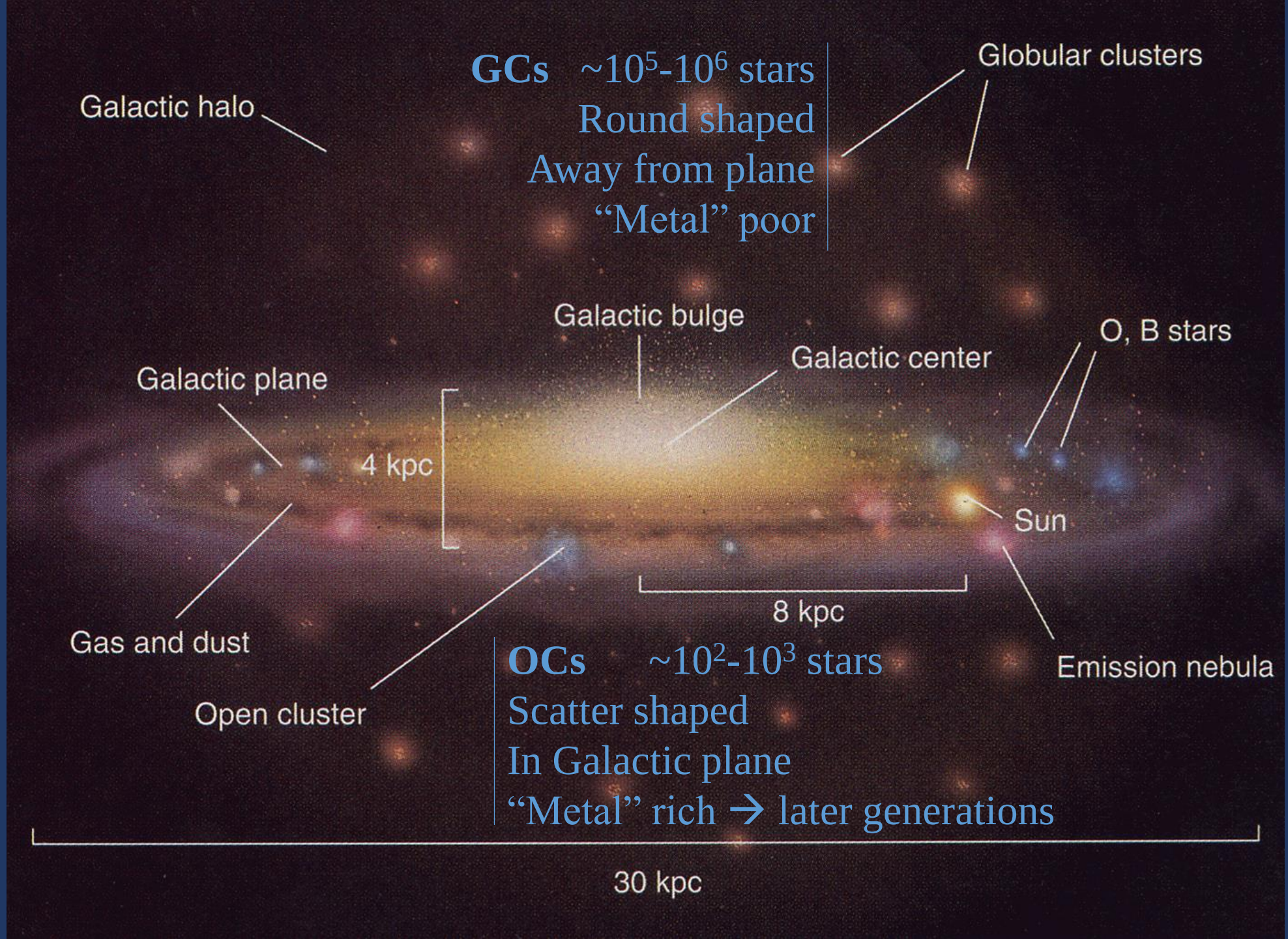
MS → sub-GB → RGB
→ tip of RGB (He flash?)
→ HB → AGB → (PN, SN)
→ WD, NS, BH

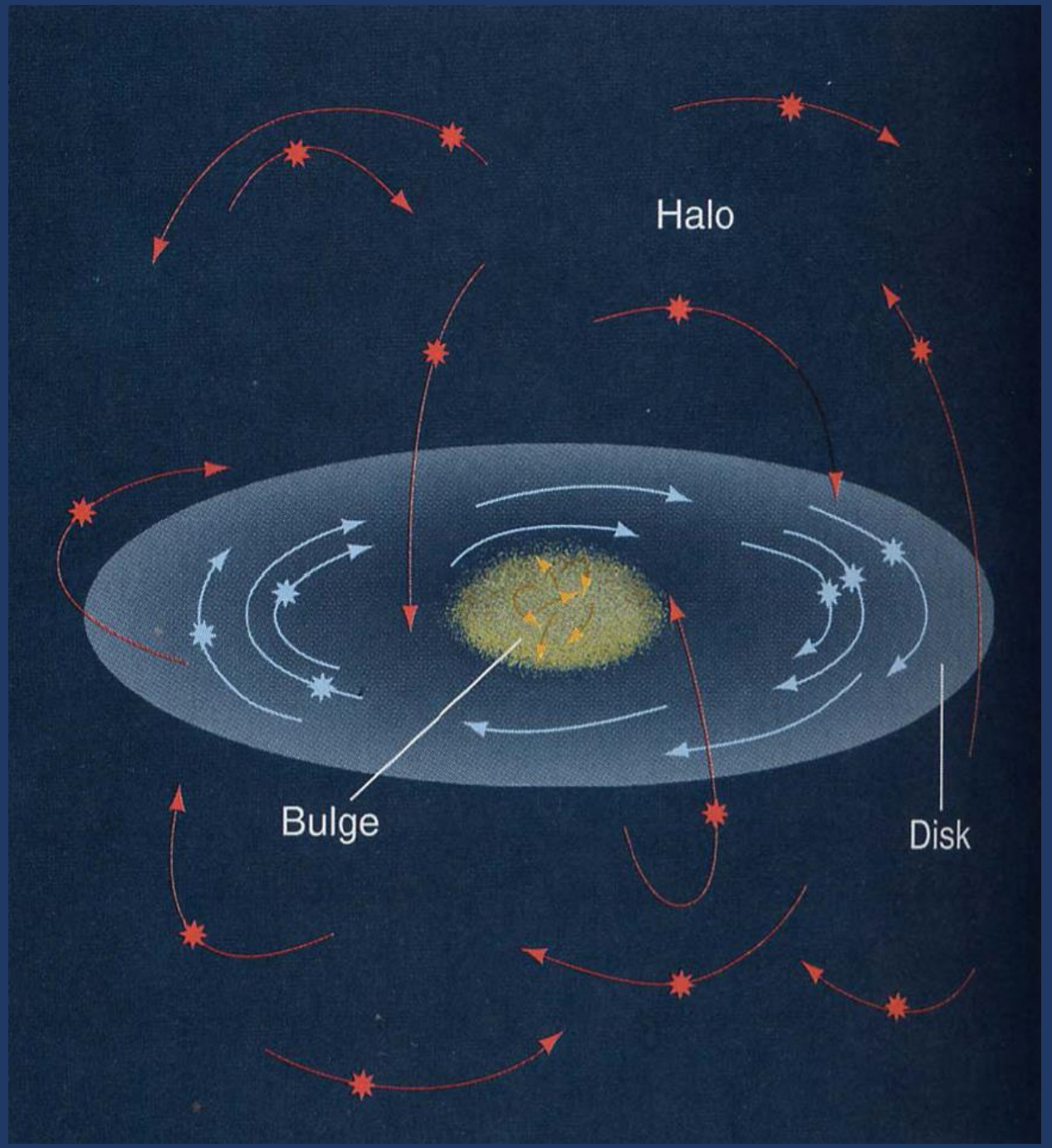
Ashman & Zepf (1998)


M5 (NGC 5904)
Mv
B - V
10
11
12
13
14
15
16
17
18
19
20
-0.5
0.0
+0.5
+1.0
+1.5
+2.0
RGB
RR
HB
AGB
Star

- 宇宙早年形成銀河系的巨大雲氣，誕生的恆星缺乏「金屬」
- 這團「星系雲氣」然後收縮，旋轉變快導致扁平
- 早年形成的星團留在「銀暈」；引力拉成球體
- 「銀盤」當中雲氣持續產生代代恆星，成分越發複雜
- 後期形成的星團在盤中運行，持續受到環境干擾（差動自轉、潮汐力），容易瓦解
- 最近才解散的系統，只在太陽系附近看得出來，成為「共行星群」(moving star groups)
- 瓦解的星團成員成為銀盤中的「場星」
- 近來發現高、富、帥的「超級星團」

Westerlund 1


GCs ~10^5-10^6 stars
Round shaped
Away from plane
"Metal" poor
Globular clusters
Galactic halo
Galactic bulge
Galactic center
O, B stars
Galactic plane
4 kpc
Sun
8 kpc
Gas and dust
Open cluster
OCs ~10^2-10^3 stars
Scatter shaped
In Galactic plane
"Metal" rich → later generations
Emission nebula
30 kpc


Halo
Bulge
Disk

結論

https://www.astro.ncu.edu.tw/~wchen/Courses/StellarEvo/toolsStarClusters.pdf