Stellar Properties

- positions and velocities – astrometry
- luminosities
  - inverse-square law
    - $f = \frac{L}{4\pi D^2}$
  - filters – photometry
    - $f_C = \int f(\lambda)\, t_C(\lambda)\, d\lambda$
  - the magnitude scale
    - $m_1 - m_2 = -2.5 \log_{10}\left(\frac{f_1}{f_2}\right) = 2.5 \log_{10}\left(\frac{f_2}{f_1}\right)$
    - $m - M = 5 \log_{10} D(\mathrm{pc}) - 5$
  - colors
    - $U - V \equiv m_U - m_V = 2.5 \log_{10}\left(\frac{f_V}{f_U}\right)$, etc.

Some Magnitudes

Sun: $m_V = -26.7,\ D = 1\,AU \implies M_V = 4.8\ (\rightarrow L_\odot)$

α Centauri AB: $m_V = -0.27,\ D = 1.37\ \text{pc} \implies M_V = 4.1\ (1.9\ L_\odot)$

α Centauri A: $m_V = 0.01,\ D = 1.37\ \text{pc} \implies M_V = 4.4\ (1.4\ L_\odot)$

α Centauri B: $m_V = 1.33,\ D = 1.37\ \text{pc} \implies M_V = 5.7\ (0.4\ L_\odot)$

Sirius A: $m_V = -1.47,\ D = 2.6\ \text{pc} \implies M_V = 1.4\ (23\ L_\odot)$

Sirius B: $m_V = 8.44,\ D = 2.6\ \text{pc} \implies M_V = 11.4\ (2.3{\times}10^{-3}\ L_\odot)$

α Orionis: $m_V = 0.5,\ D = 222\ \text{pc} \implies M_V = -6.2\ (2.5{\times}10^{4}\ L_\odot)$

M87: $m_V = 9.6,\ D = 16\ \text{Mpc} \implies M_V = -21.4\ (3.0{\times}10^{10}\ L_\odot)$

3C273: $m_V = 12.9,\ D = 750\ \text{Mpc} \implies M_V = -26.5\ (3.3{\times}10^{12}\ L_\odot)$

Stellar Properties

- positions and velocities – astrometry
- luminosities
- temperatures
  - "effective" blackbody temperature
  - colors
  - spectra

$$\frac{n_2}{n_1} = \frac{g_2}{g_1}\, e^{-\Delta E_{12}/kT}$$ (Boltzmann)

- composition
- radii
- masses

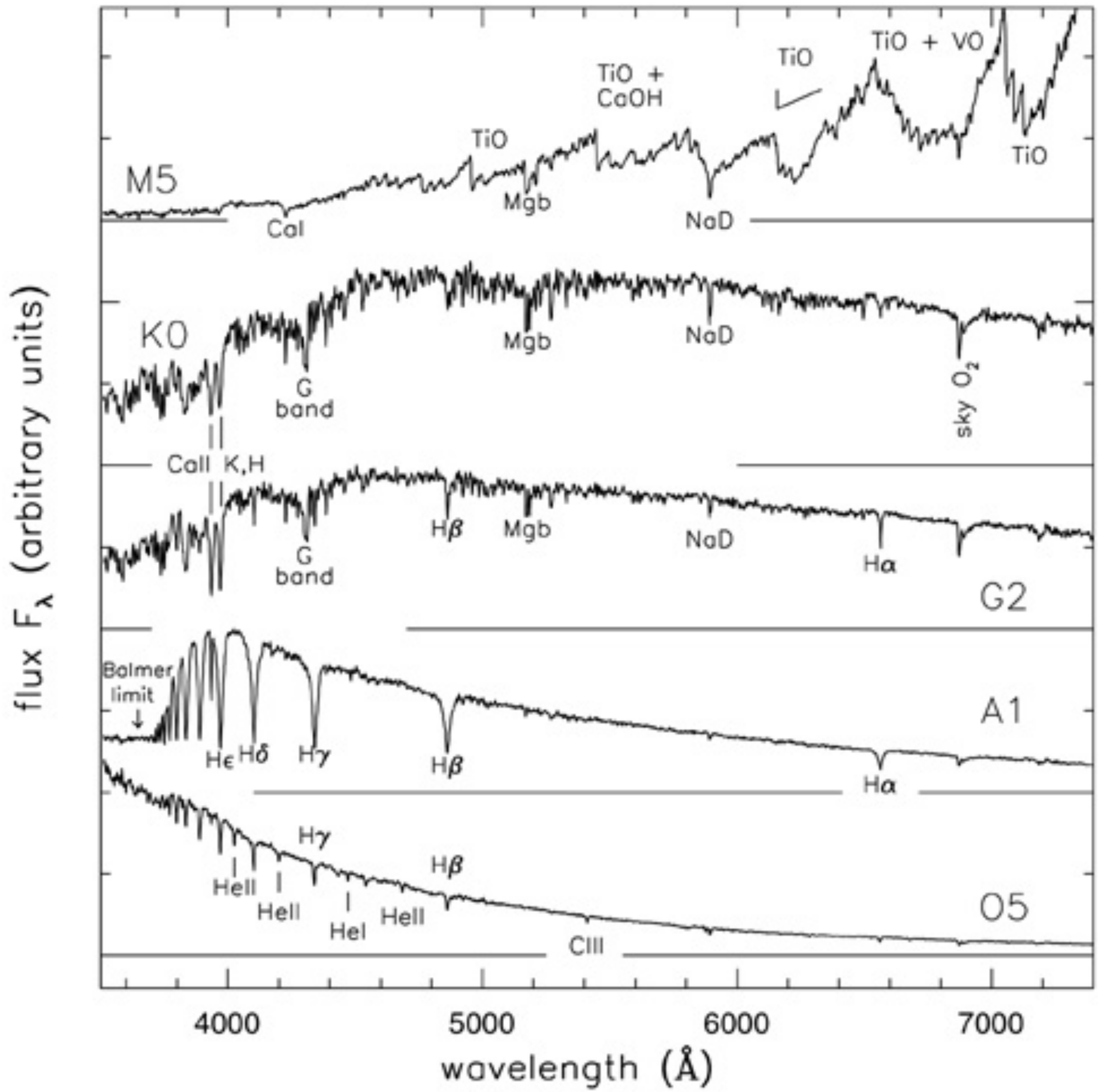


Fig 1.1 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

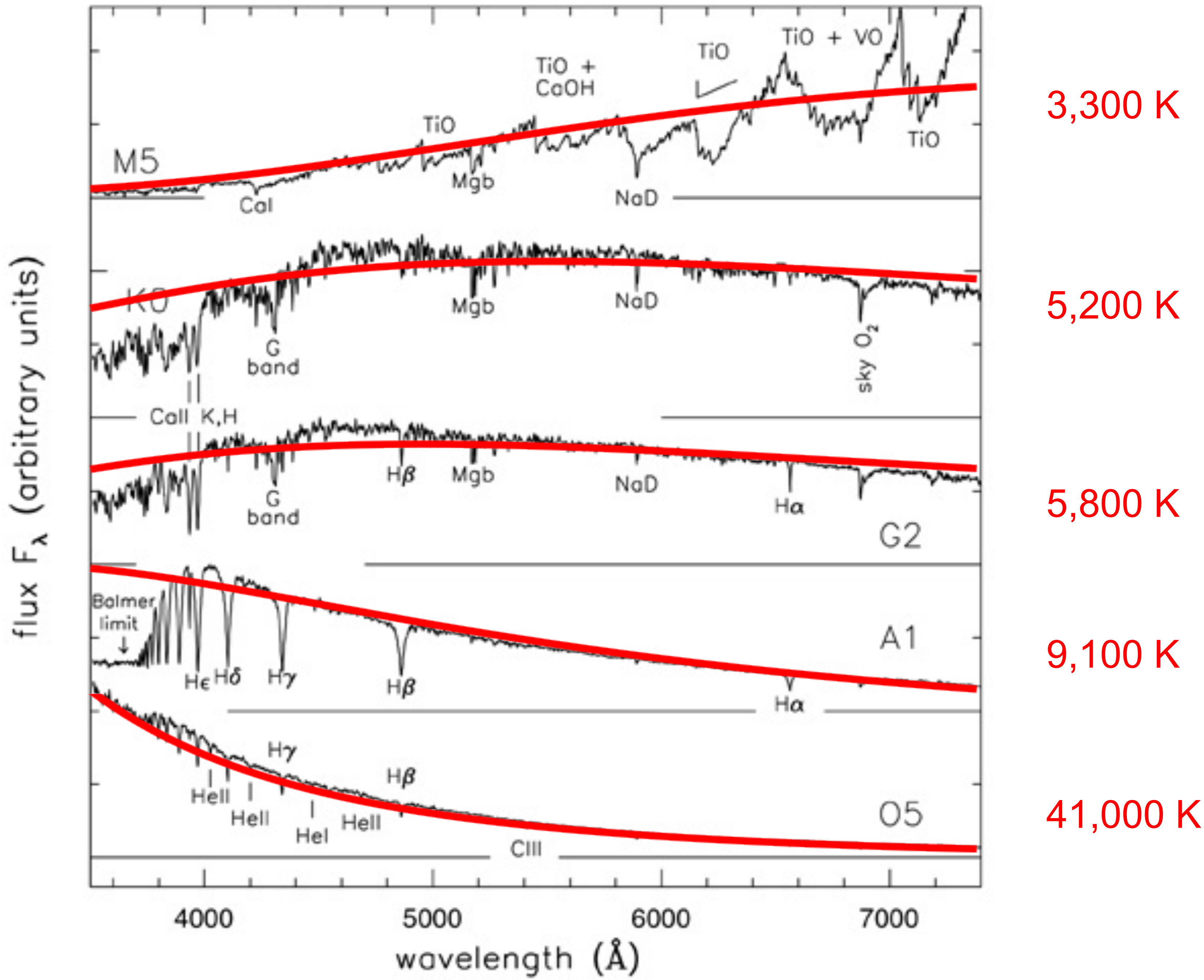
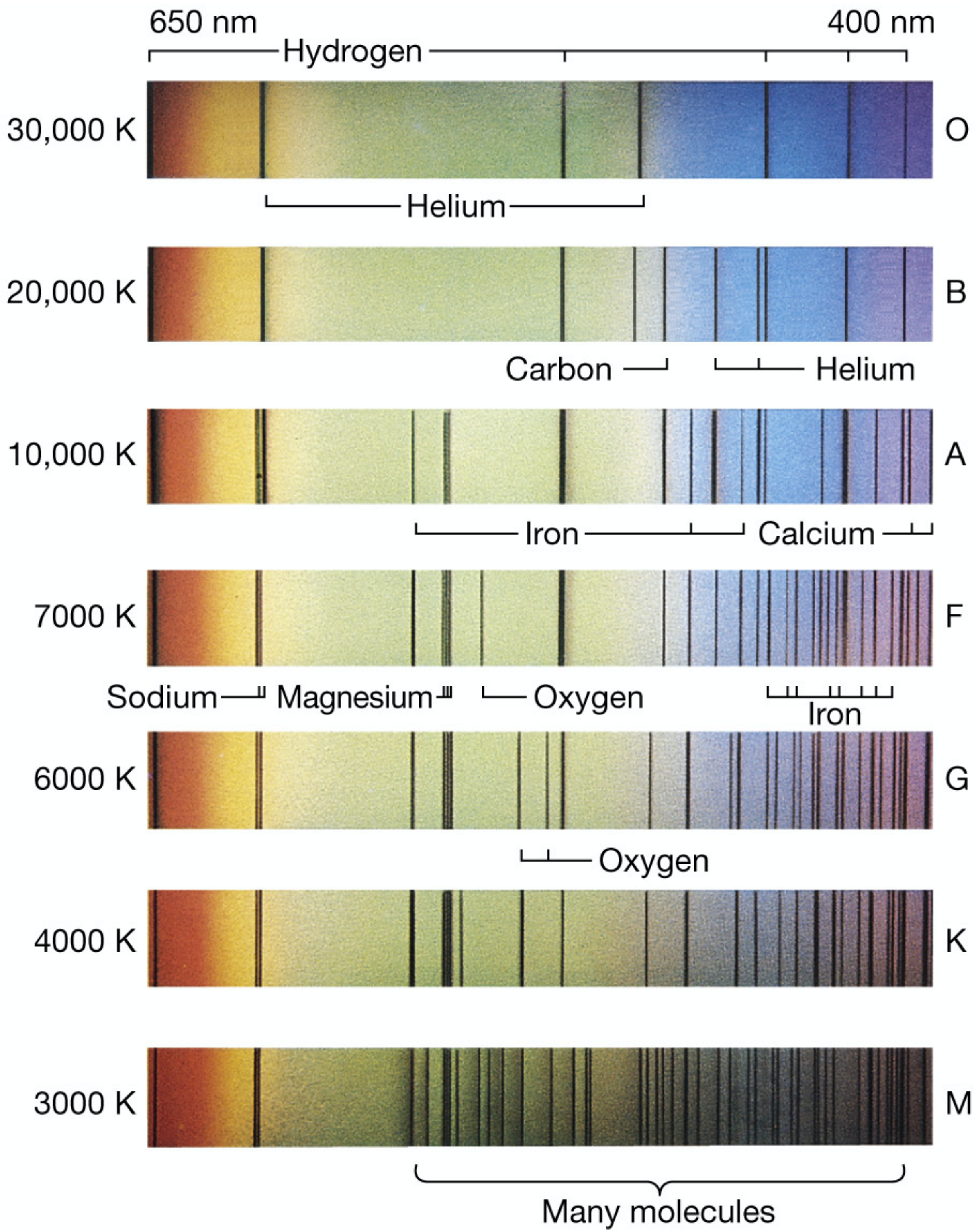


Fig 1.1 'Galaxies in the Universe' Sparke/Gallagher CUP 2007


650 nm
400 nm
Hydrogen
30,000 K
O
Helium
20,000 K
B
Carbon
Helium
10,000 K
A
Iron
Calcium
7000 K
F
Sodium
Magnesium
Oxygen
Iron
6000 K
G
Oxygen
4000 K
K
3000 K
M
Many molecules

Spectral Type	Surface Temperature	Distinguishing Features
O	> 25,000K	H; HeI; HeII
B	10,000-25,000K	H; HeI; HeII absent
A	7,500-10,000K	H; CaII; HeI and HeII absent
F	6,000-7,500K	H; metals (CaII, Fe, etc)
G	5,000-6,000K	H; metals; some molecular species
K	3,500-5,000K	metals; some molecular species
M	< 3,500K	metals; molecular species (TiO!)
C	< 3,500K	metals; molecular species (C2!)

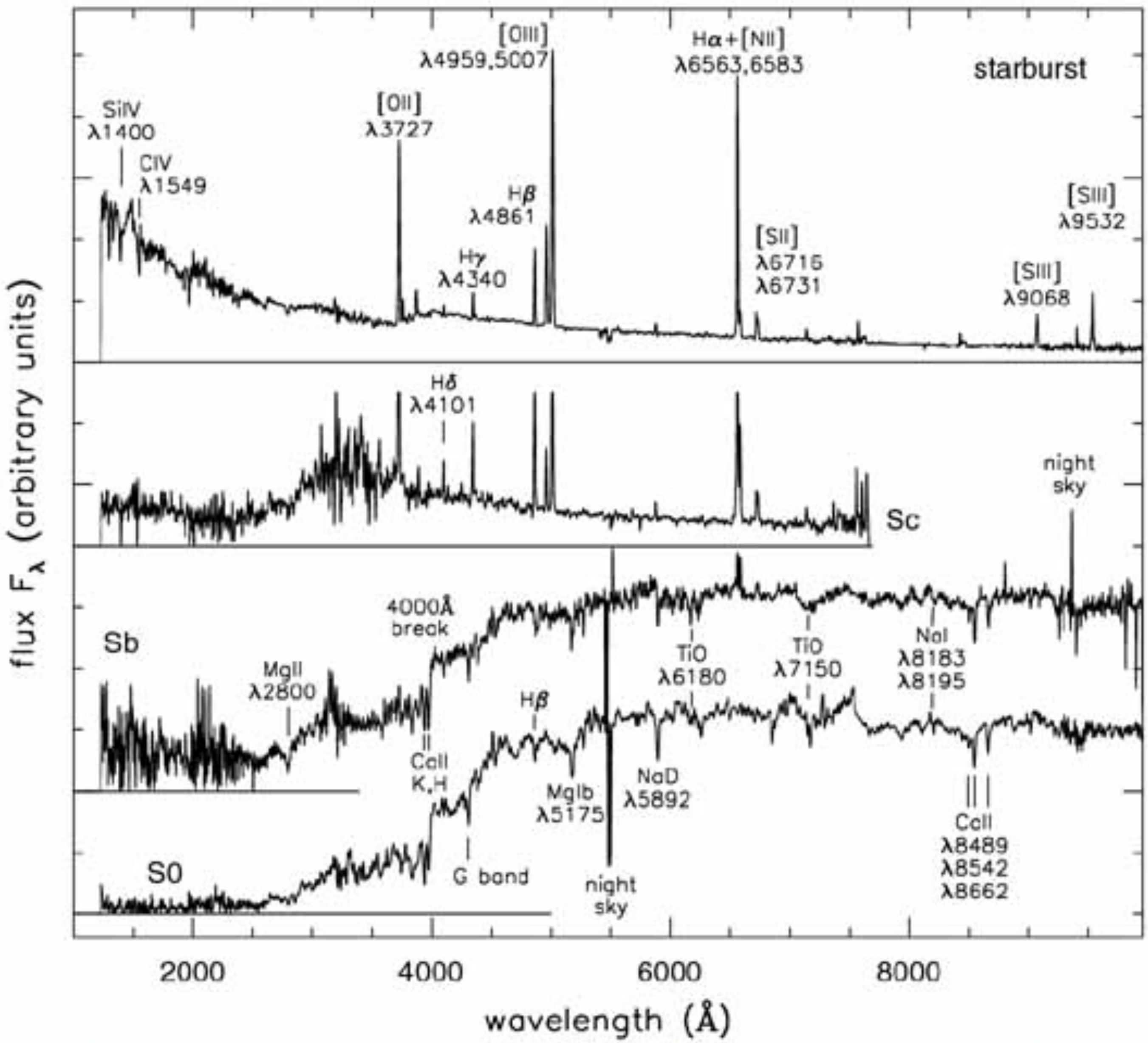


Fig 5.24 (A. Kinney) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Stellar Properties

- positions and velocities – astrometry
- luminosities
- temperatures
- composition

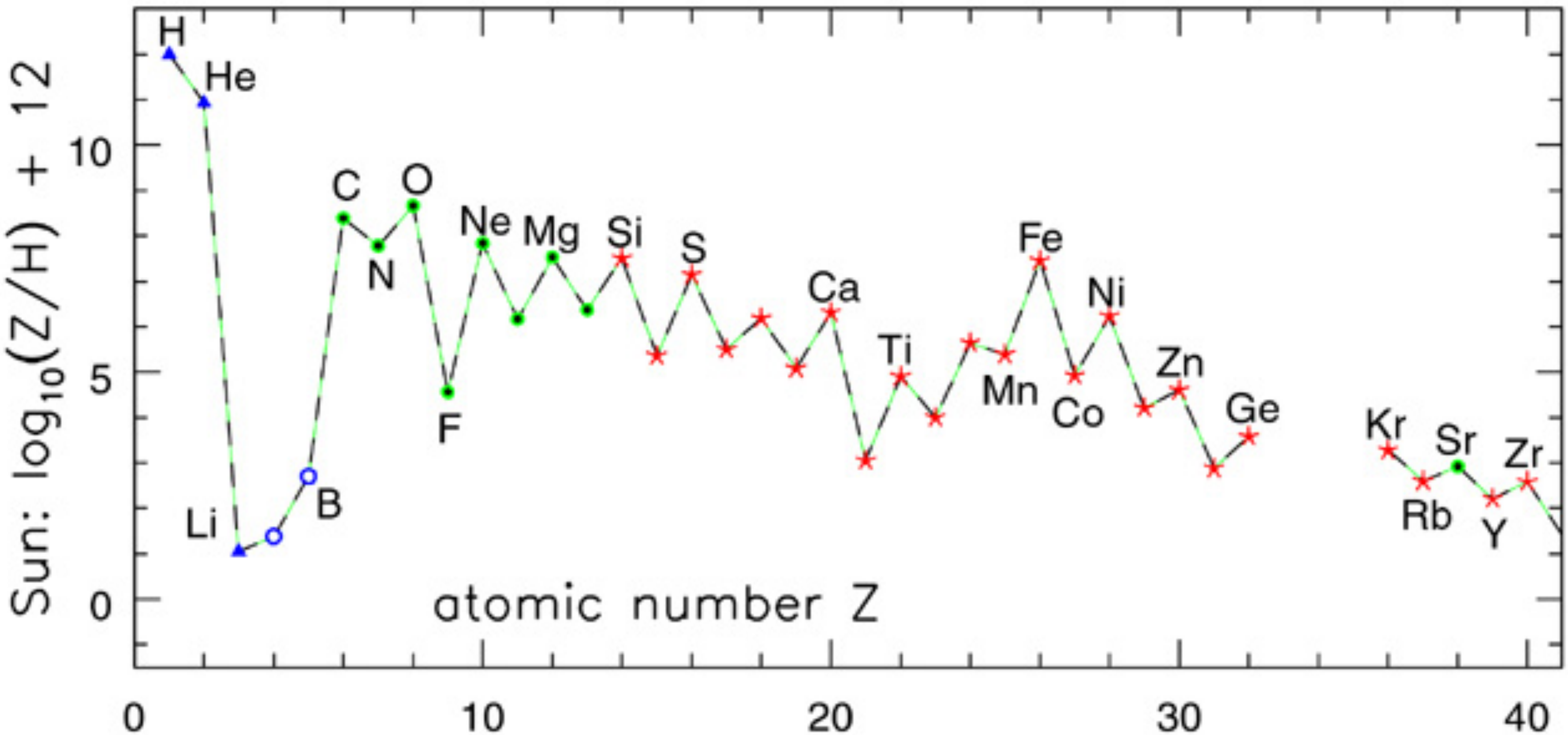


Fig 1.3 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Stellar Properties

- positions and velocities – astrometry
- luminosities
- temperatures
- composition
- radii
  - direct measurement: $R = D\,\Delta\theta$
  - radiation laws: $L = 4\pi R^2\,\sigma T^4$
  - red giants and white dwarfs

Stellar Radii

Sun at 10 pc: $R_\odot = (10\text{ pc})\Delta\theta \implies \Delta\theta = 4.6 \times 10^{-4}$ arcsec

α Ori at 200 pc: 4 AU $= (200\text{ pc})\Delta\theta \implies \Delta\theta = 0.02$ arcsec

$$L = 4\pi R^2\,\sigma T^4\,, \qquad L_\odot = 4\pi R_\odot^2\,\sigma T_\odot^4$$

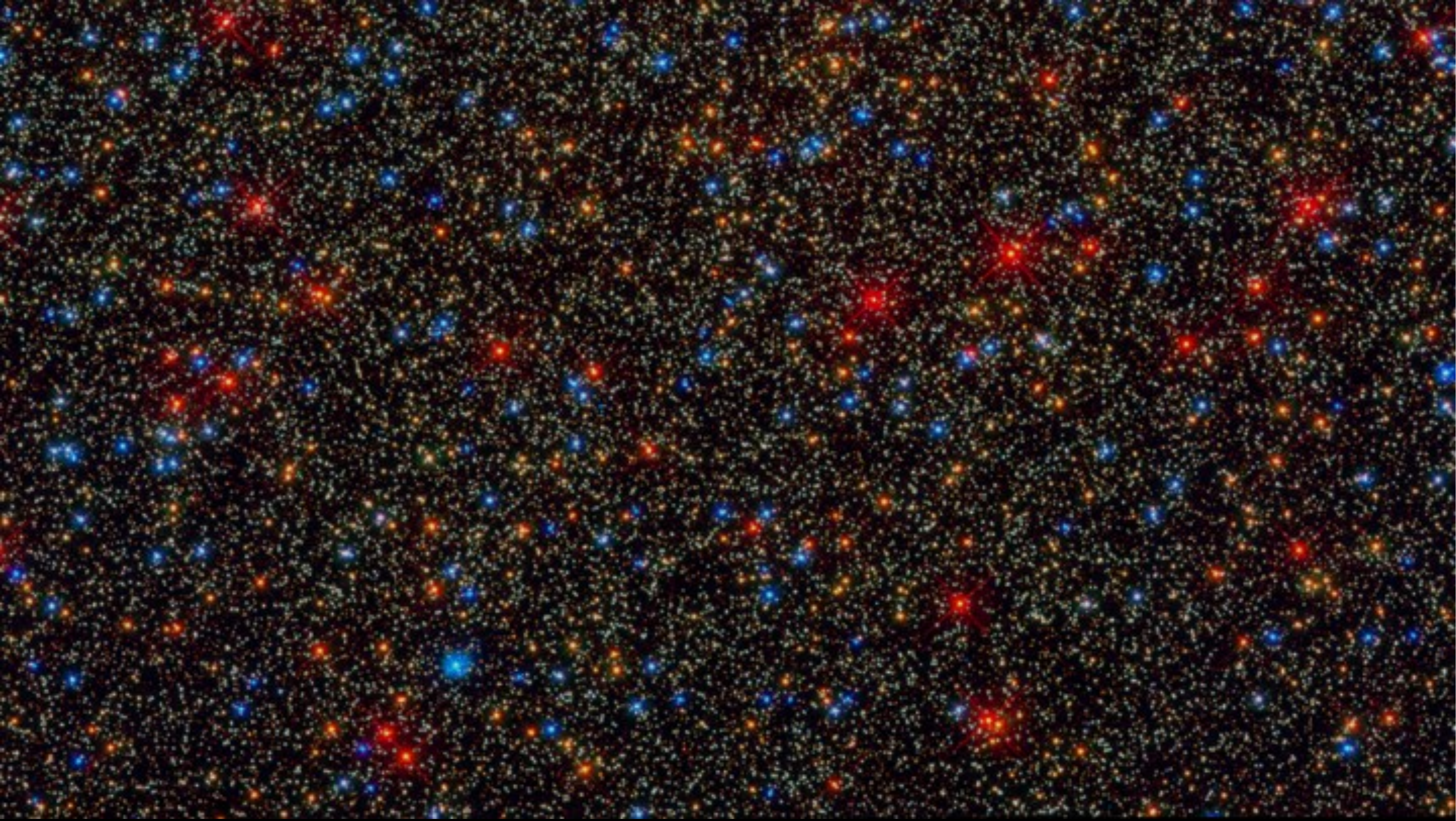
$$\implies \frac{L}{L_\odot} = \left(\frac{R}{R_\odot}\right)^2 \left(\frac{T}{T_\odot}\right)^4 \implies \frac{R}{R_\odot} = \left(\frac{L}{L_\odot}\right)^{\frac{1}{2}} \left(\frac{T}{T_\odot}\right)^{-2}$$

$L = 10^3 L_\odot, T = 3000\ K \implies R = 126\ R_\odot = 0.6$ AU RED GIANT

$L = 10^{-3} L_\odot, T = 10^4\ K \implies R = 0.011\ R_\odot = 1.2\ R_\oplus$ WHITE DWARF

Stellar Properties

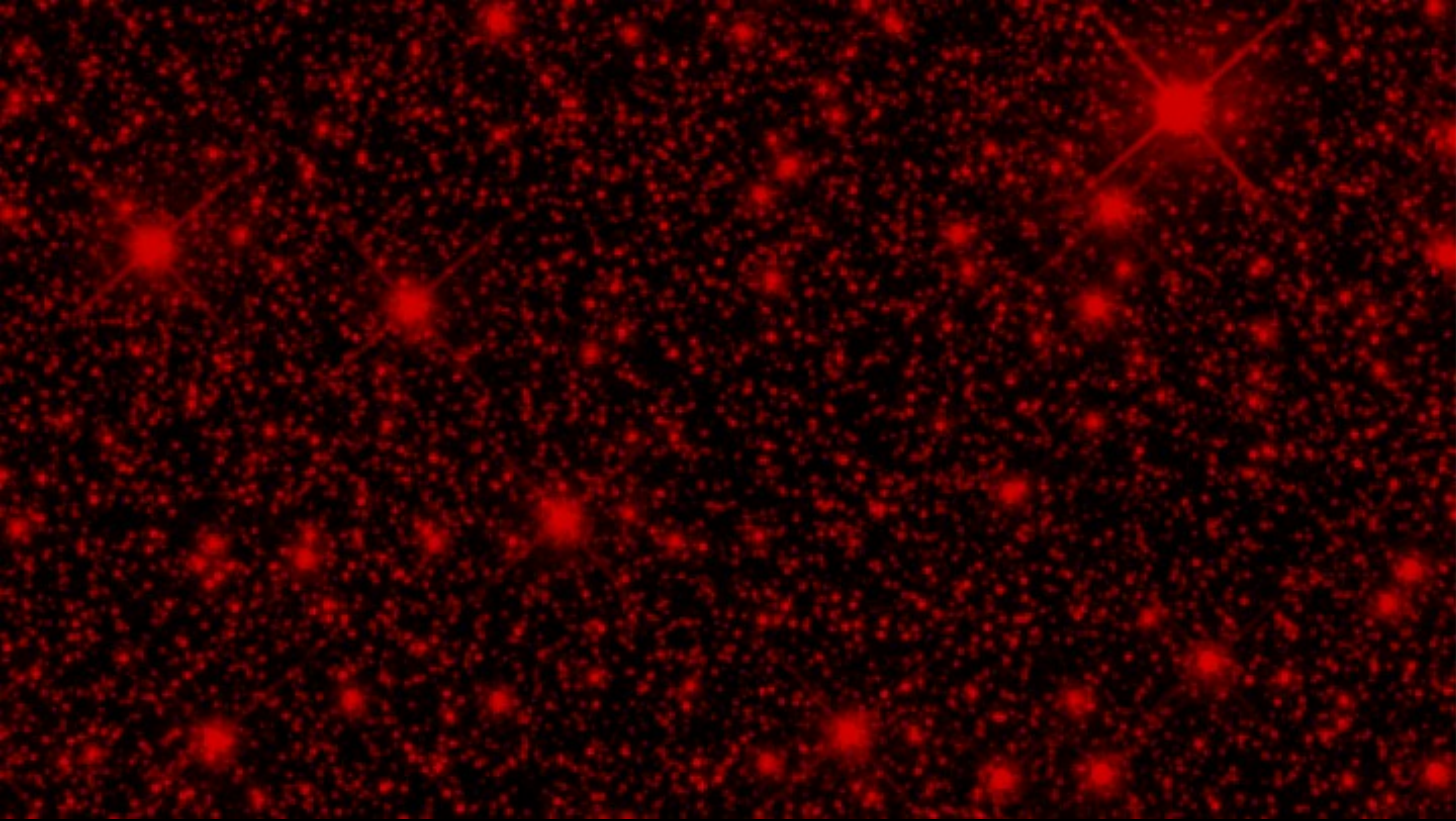
- positions and velocities – astrometry
- luminosities
- temperatures
- composition
- radii
- masses
  - need dynamics
  - binary stars



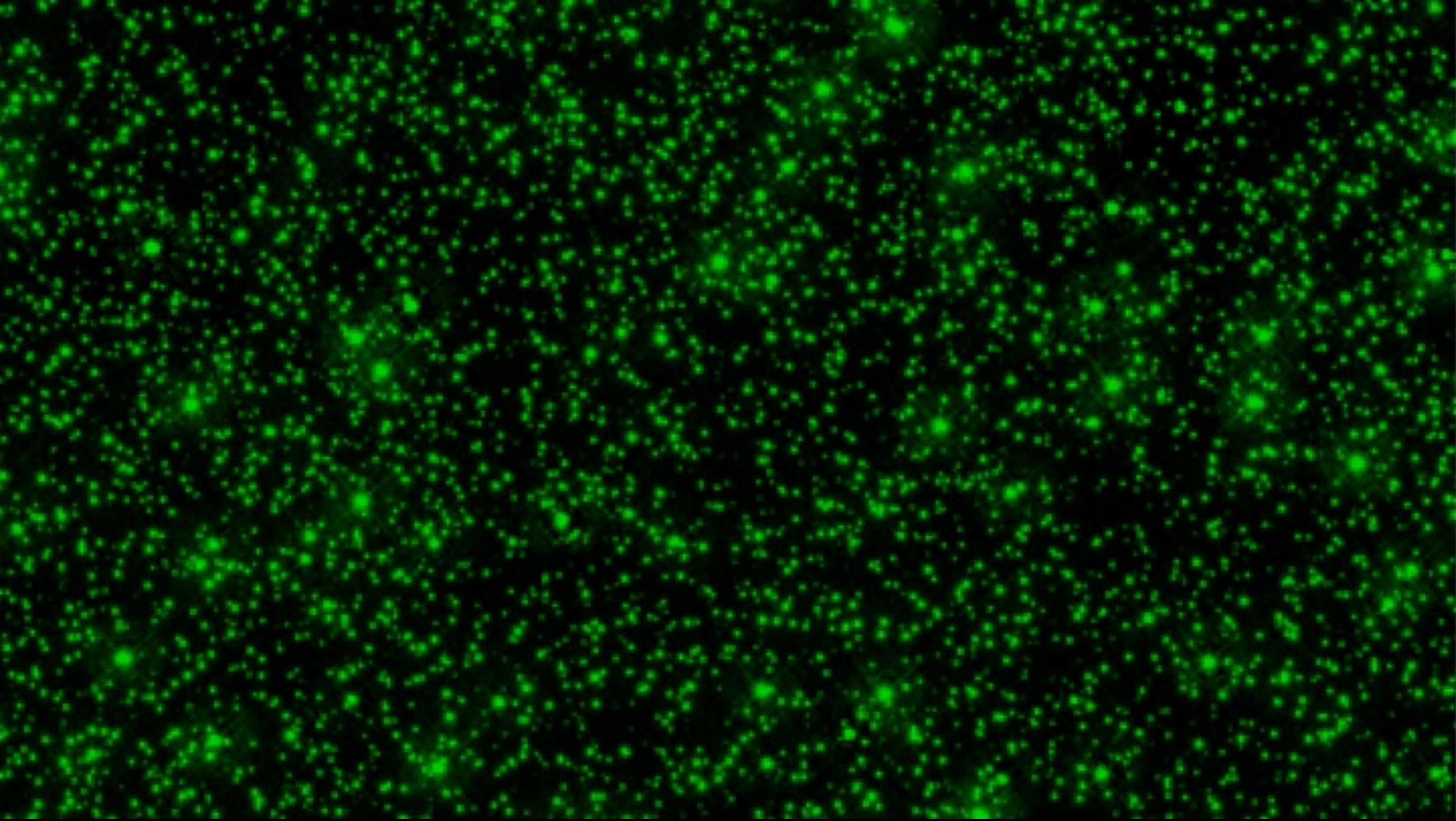
http://hubblesite.org/gallery/wallpaper/pr2009025q/

Early-Release Image of Omega Centauri, taken by WFC3/UVIS on board the Hubble Space Telescope (HST)

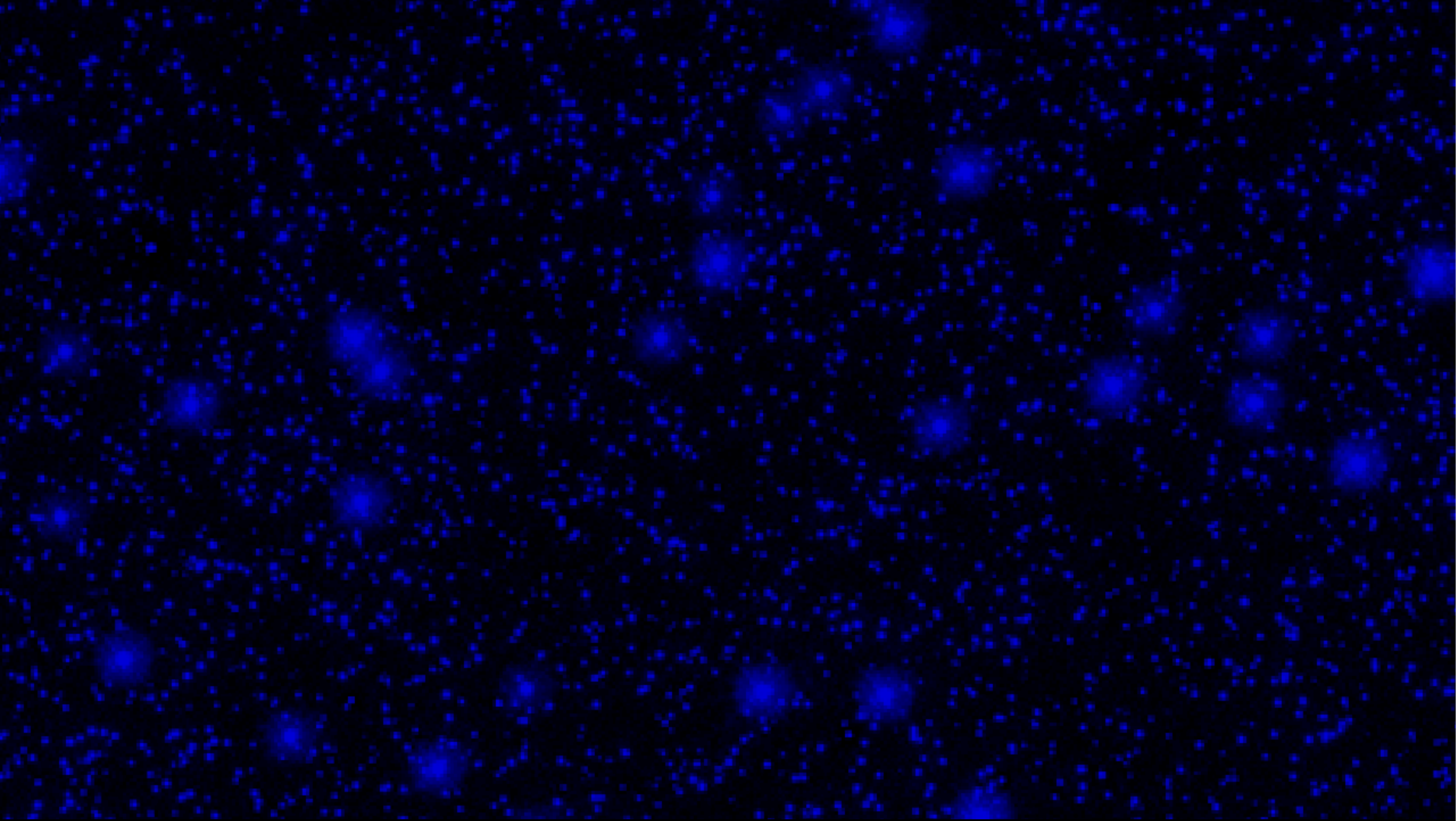
A close-up of the central region. This image was made by combining separate red, green, and blue images



The **red** image is from filter F814W, which sees only very red light.

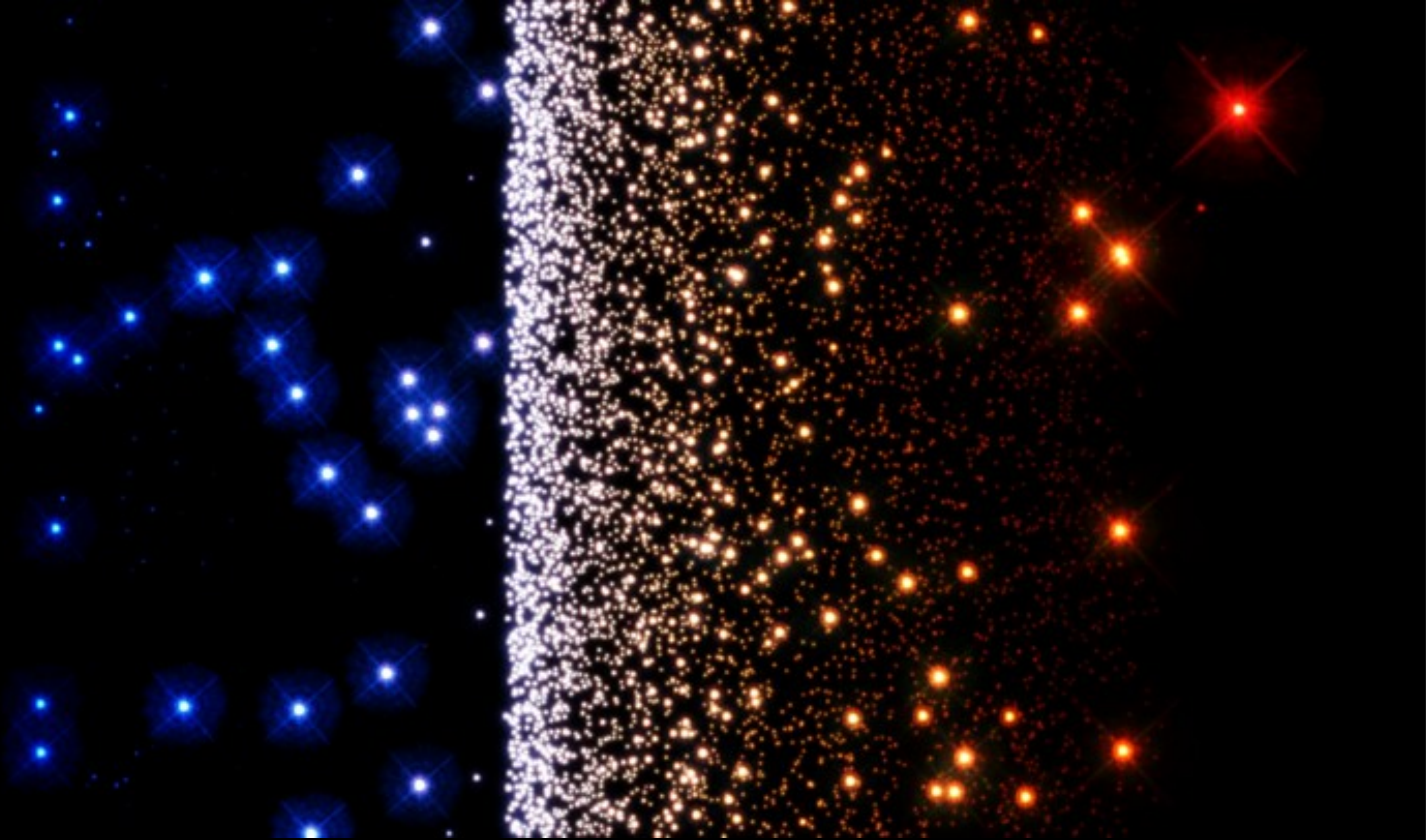


The **green** image is from filter F336W, which sees only blue light.

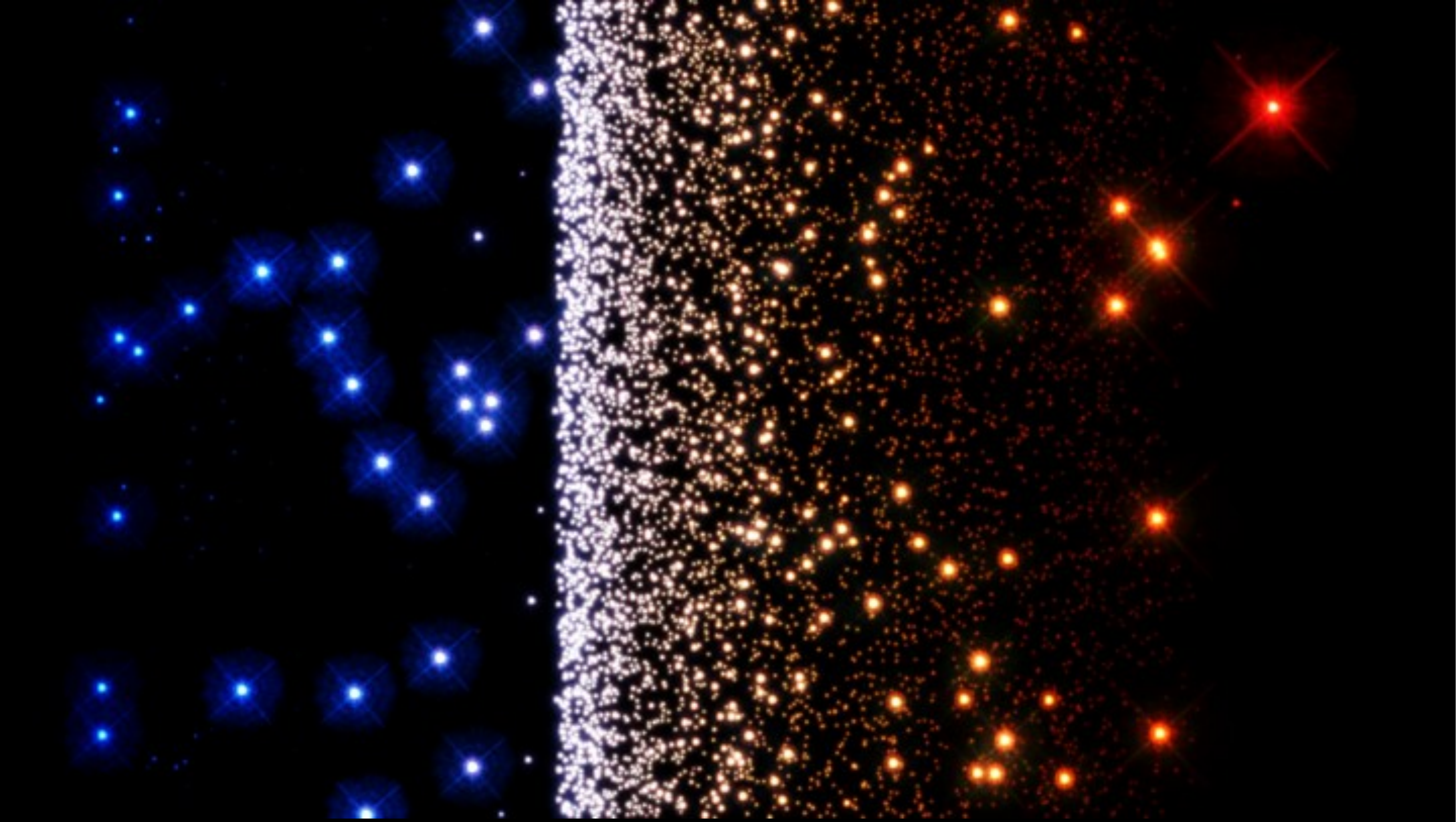


The **blue** image is from filter F225W, which sees only ultraviolet light.

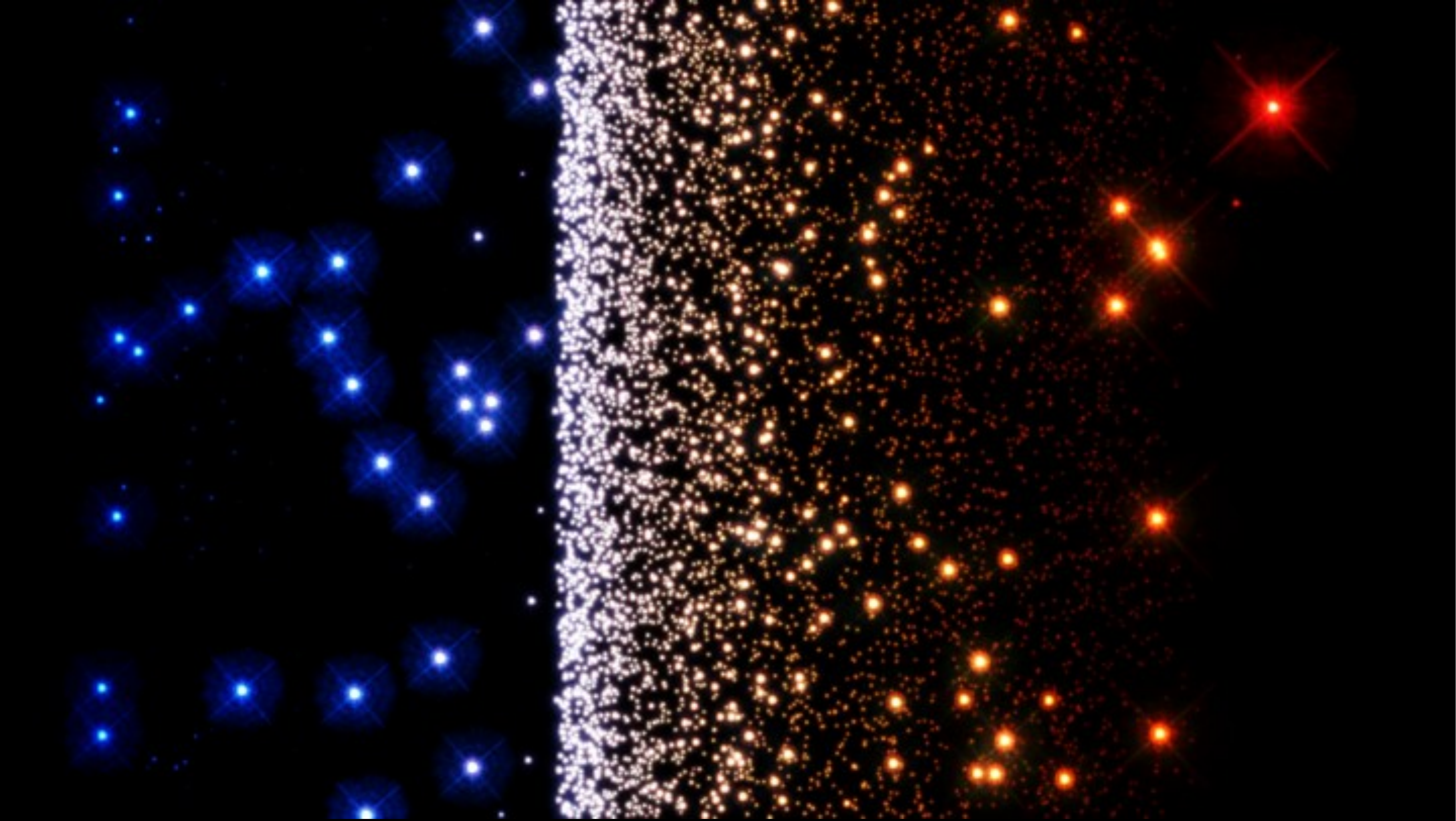
Let’s sort the stars by color, putting the **blue** stars on the left and the **red** stars on the right.



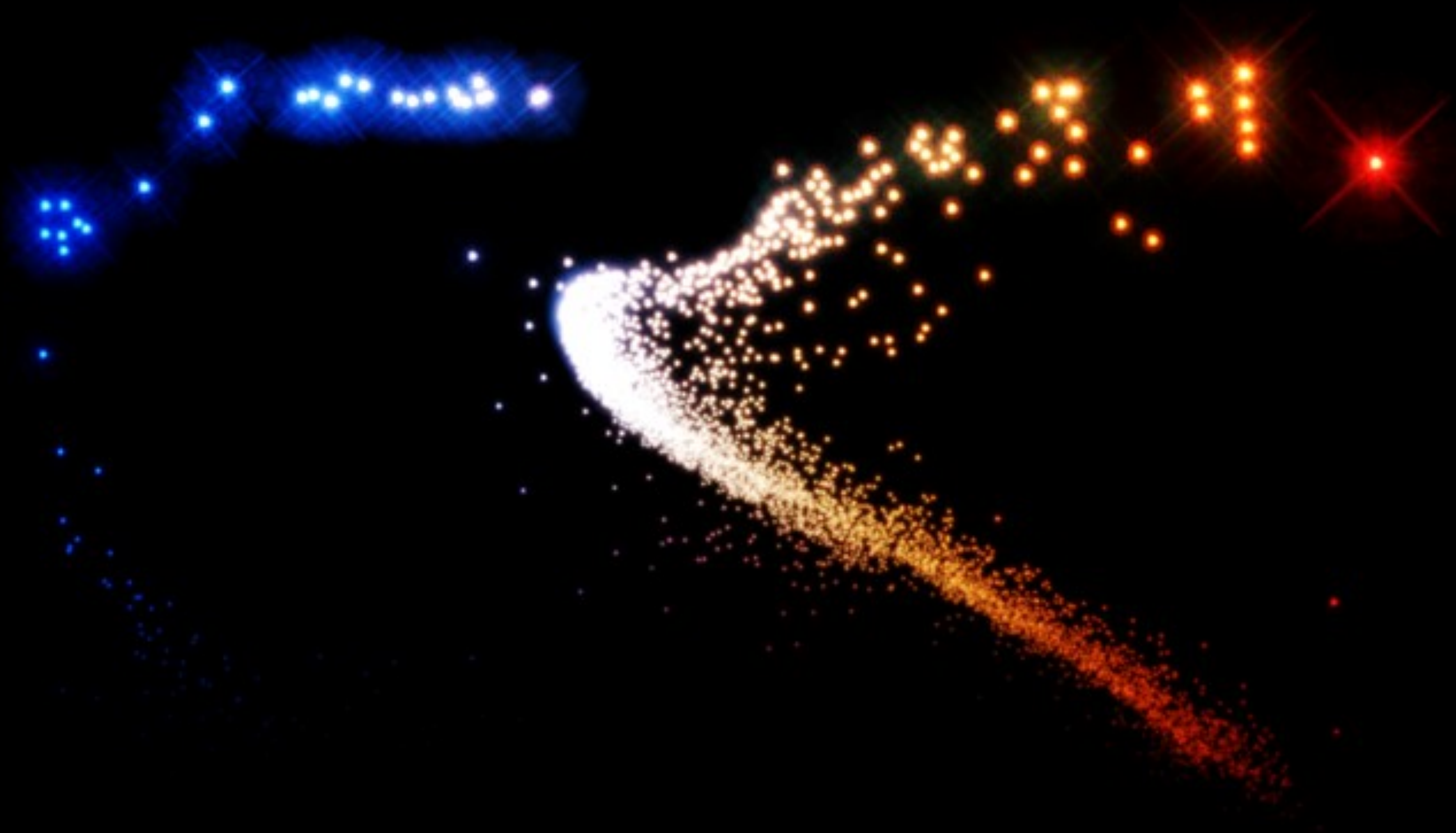
Note that most stars are nearly **white**.



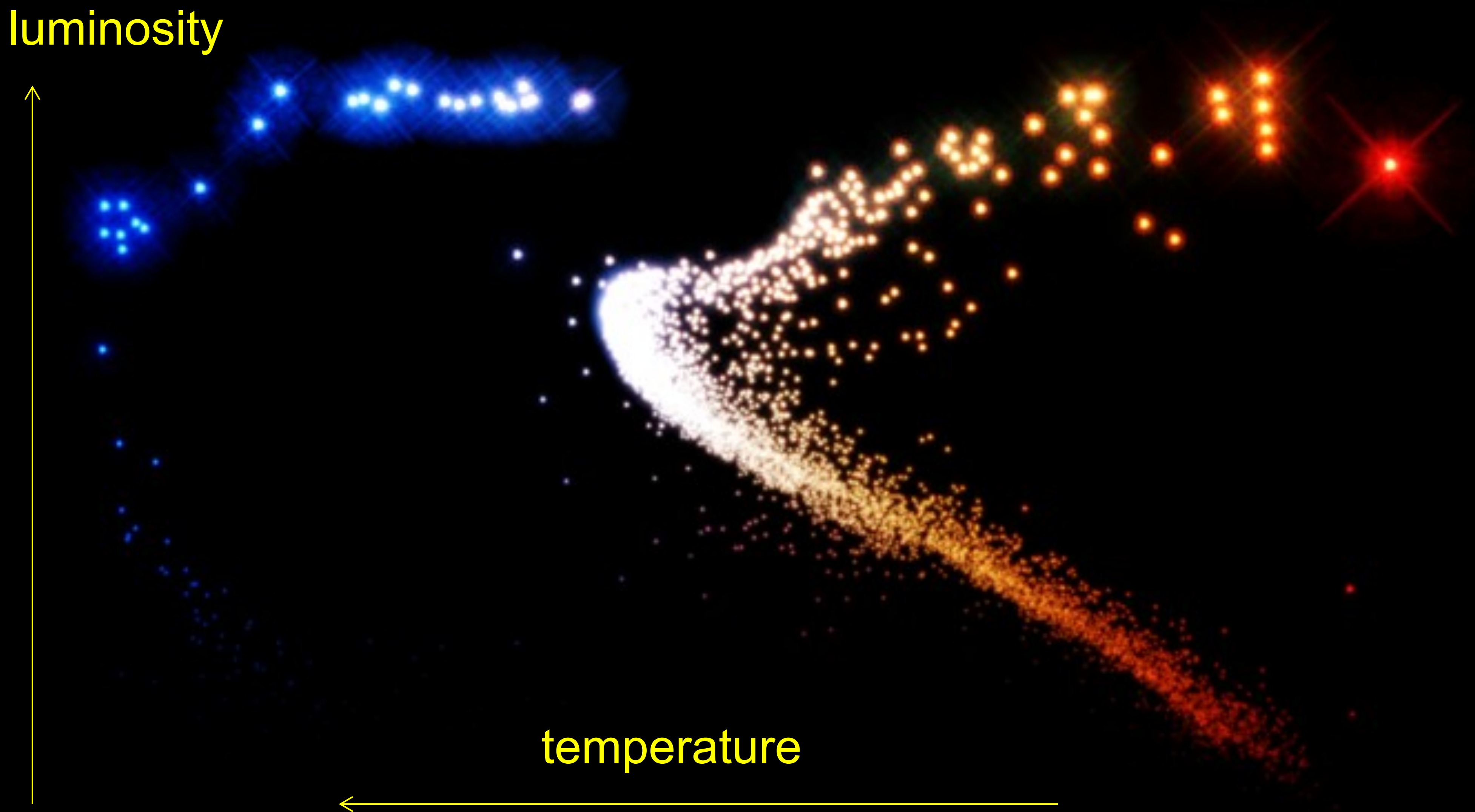
Astronomers also characterize stars in terms of brightness.



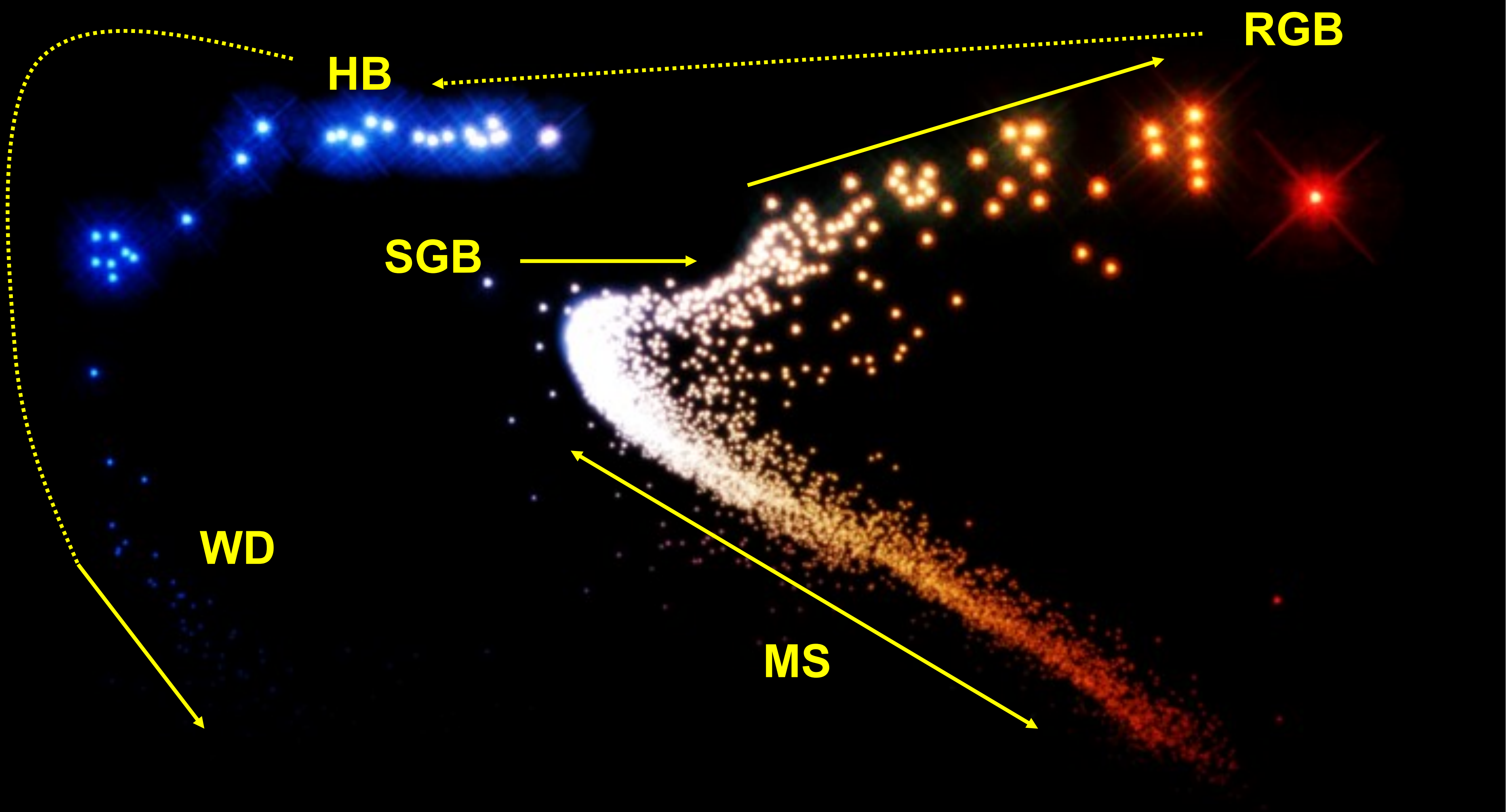
Let’s sort the stars, putting the **bright** stars on top and the **faint** stars on the bottom.



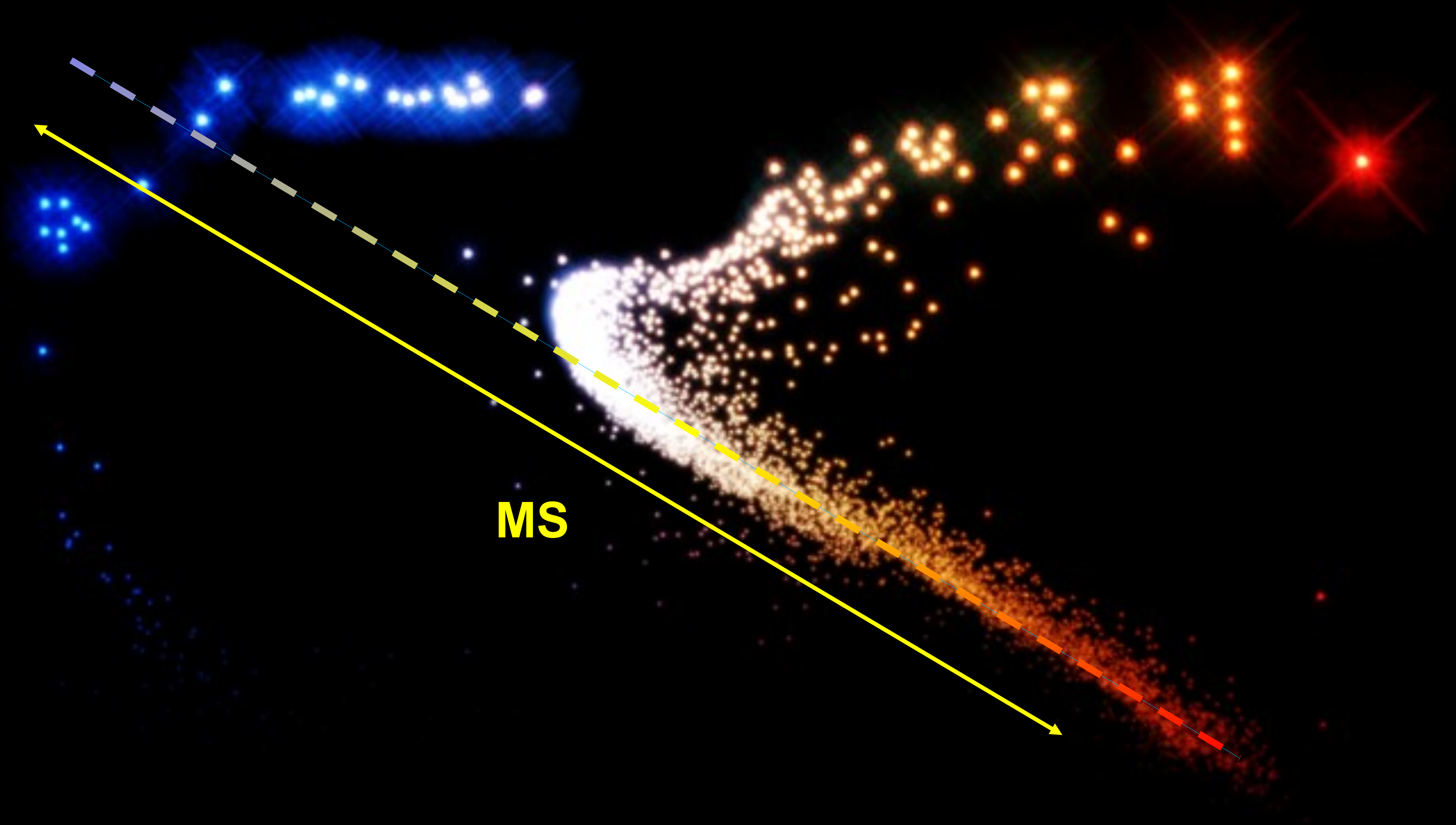
This is called a Hertzsprung-Russel (H-R) Diagram.



The unmistakable order in diagrams like this led astronomers to develop theories to explain stellar evolution.



Stars lie along a few well-defined sequences.



The vast majority of stars lie along the

Main Sequence (MS)

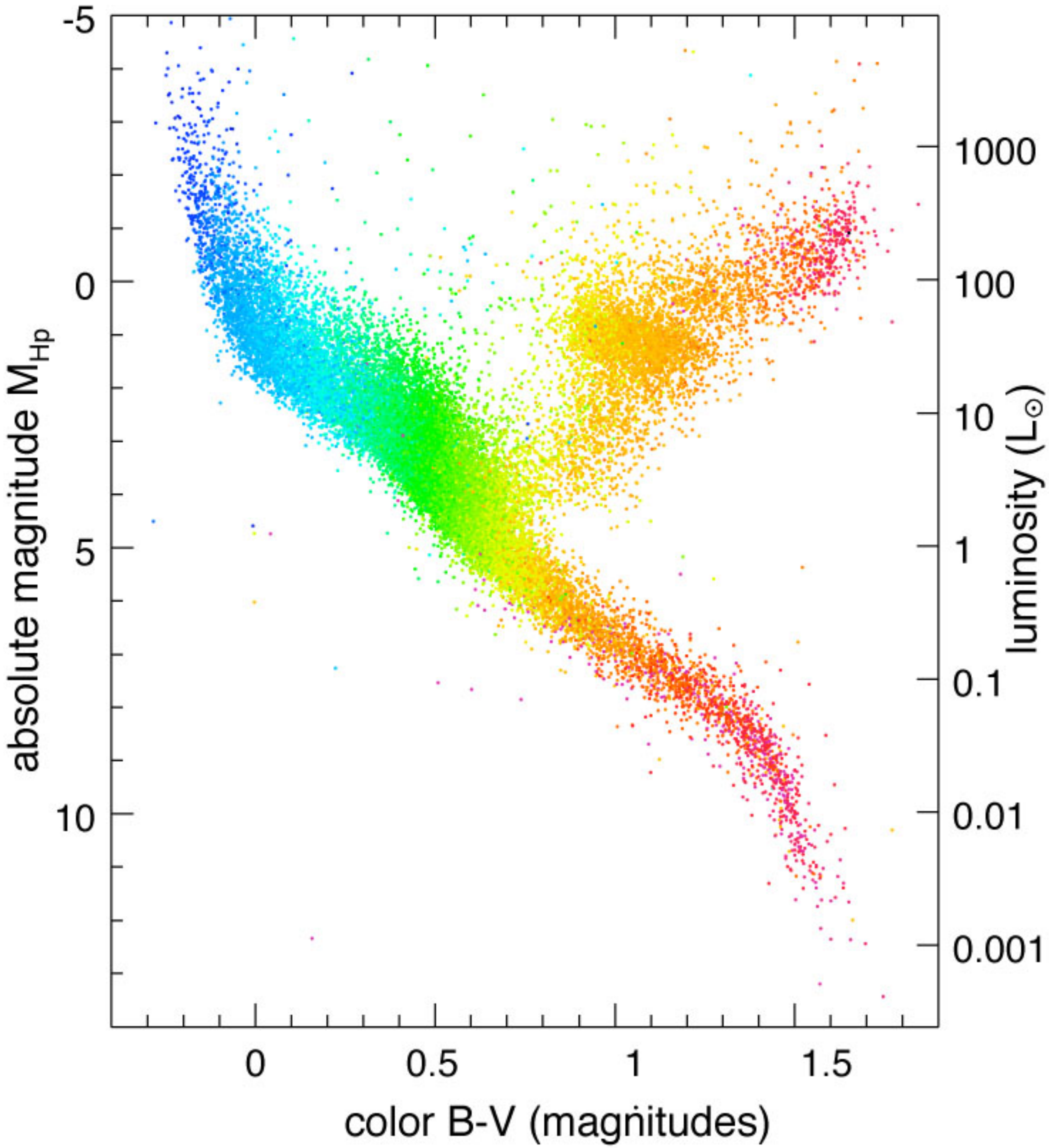
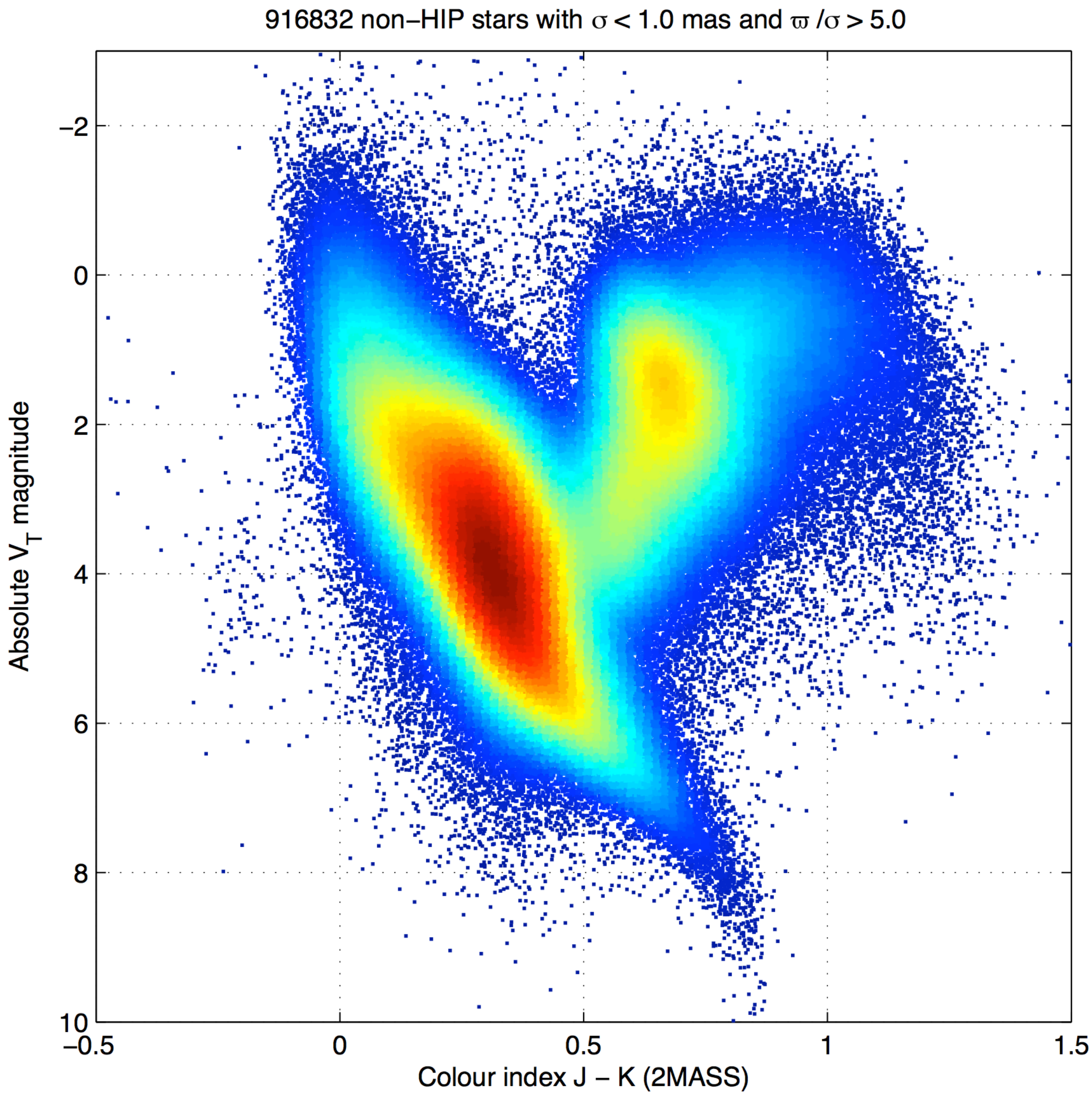
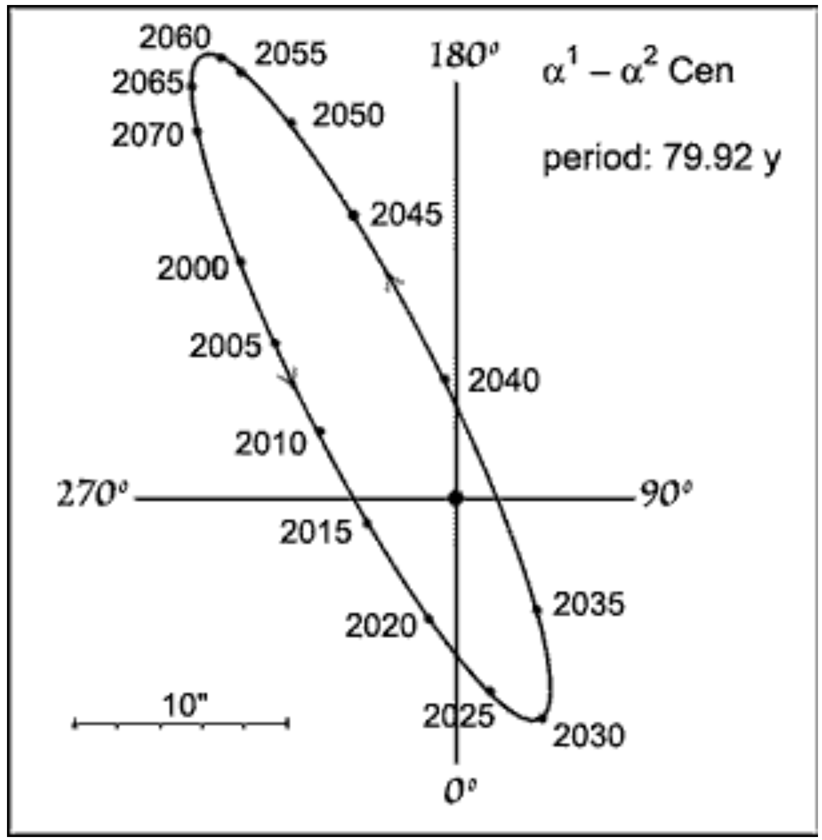


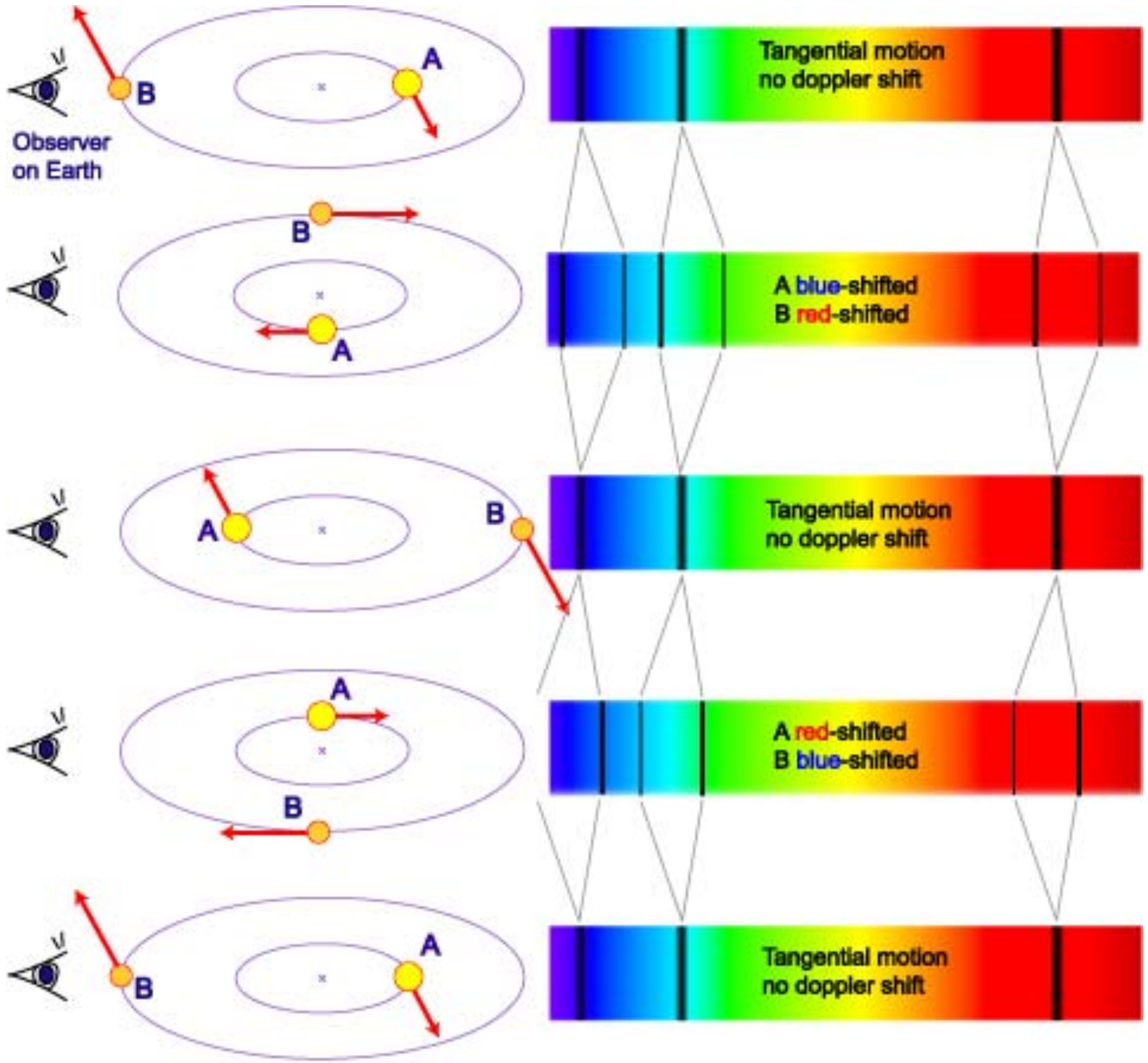
Fig 2.2 (F. van Leeuwen) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007



916832 non−HIP stars with σ < 1.0 mas and ϖ /σ > 5.0
Absolute V_T magnitude
Colour index J − K (2MASS)
−2
0
2
4
6
8
10
−0.5
0
0.5
1
1.5

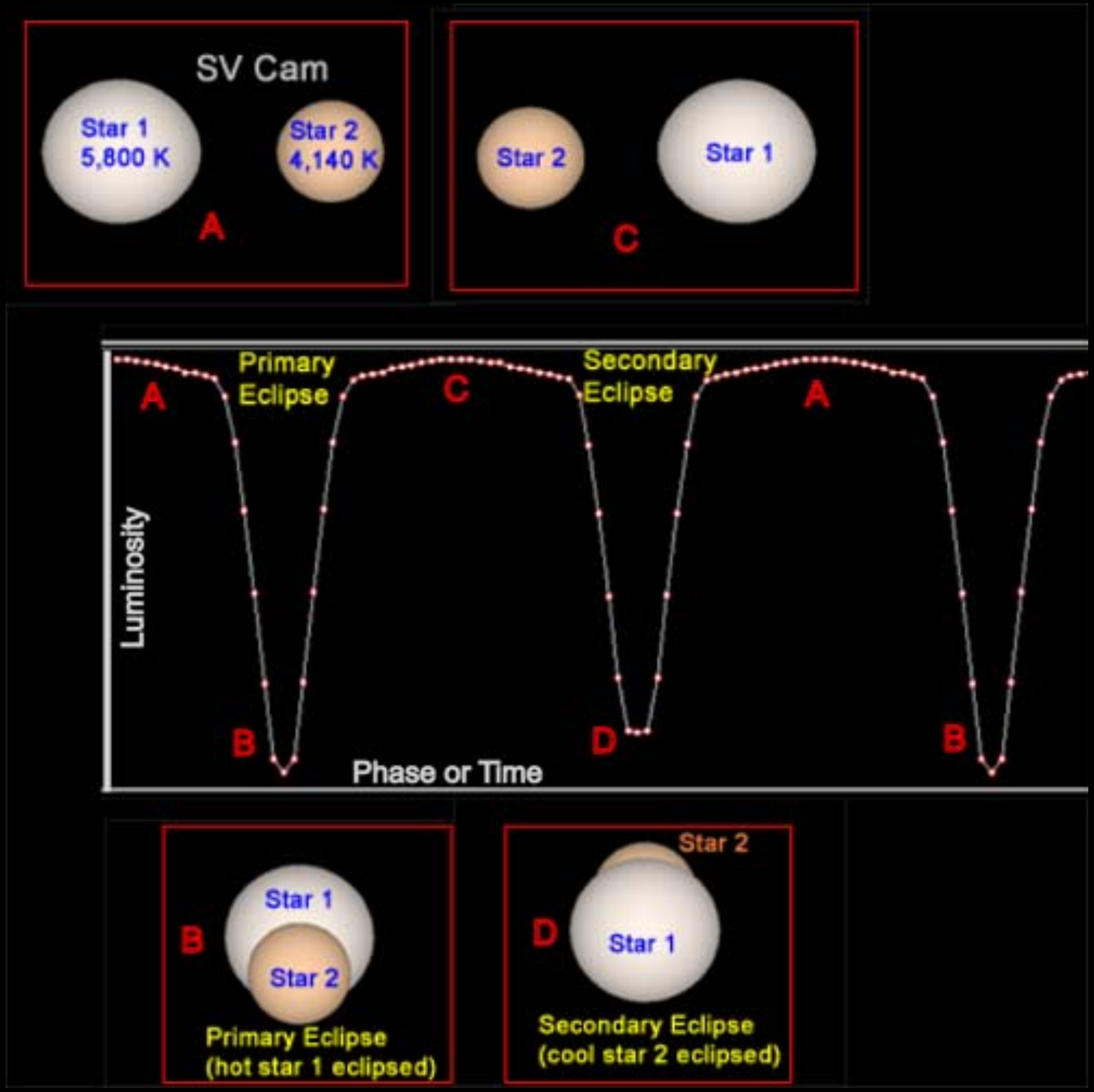


α1 – α2 Cen
period: 79.92 y
180°
90°
0°
270°
10"
2060
2055
2065
2050
2070
2045
2000
2005
2040
2010
2015
2035
2020
2025
2030



A Spectroscopic Binary System

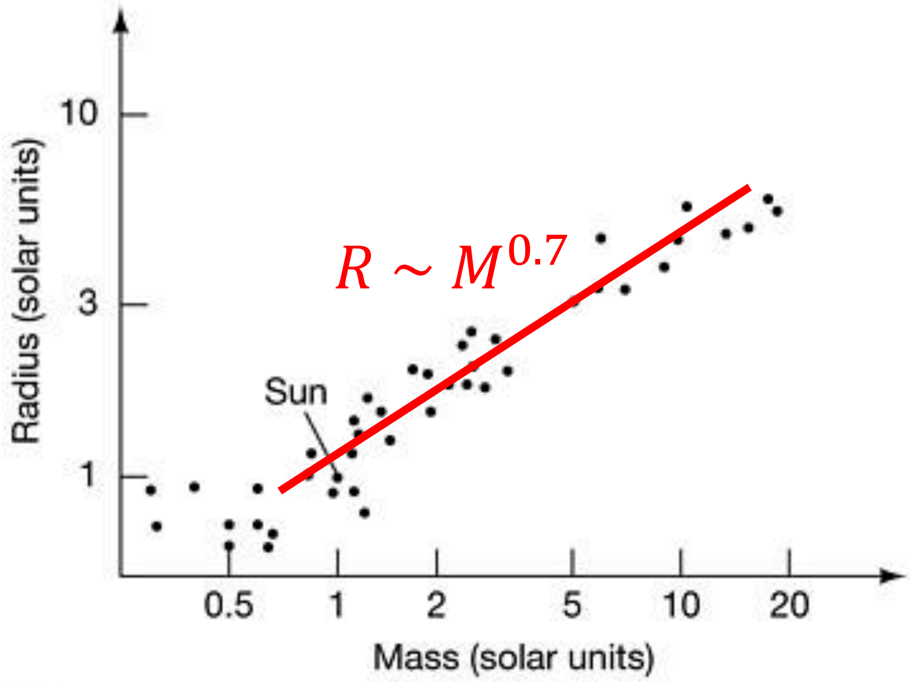
High-mass star A and lower-mass B orbit around a common centre of mass. The observed combined spectrum shows periodic splitting and shifting of spectral lines. The amount of shift is a function of the alignment of the system relative to us and the orbital speed of the stars.

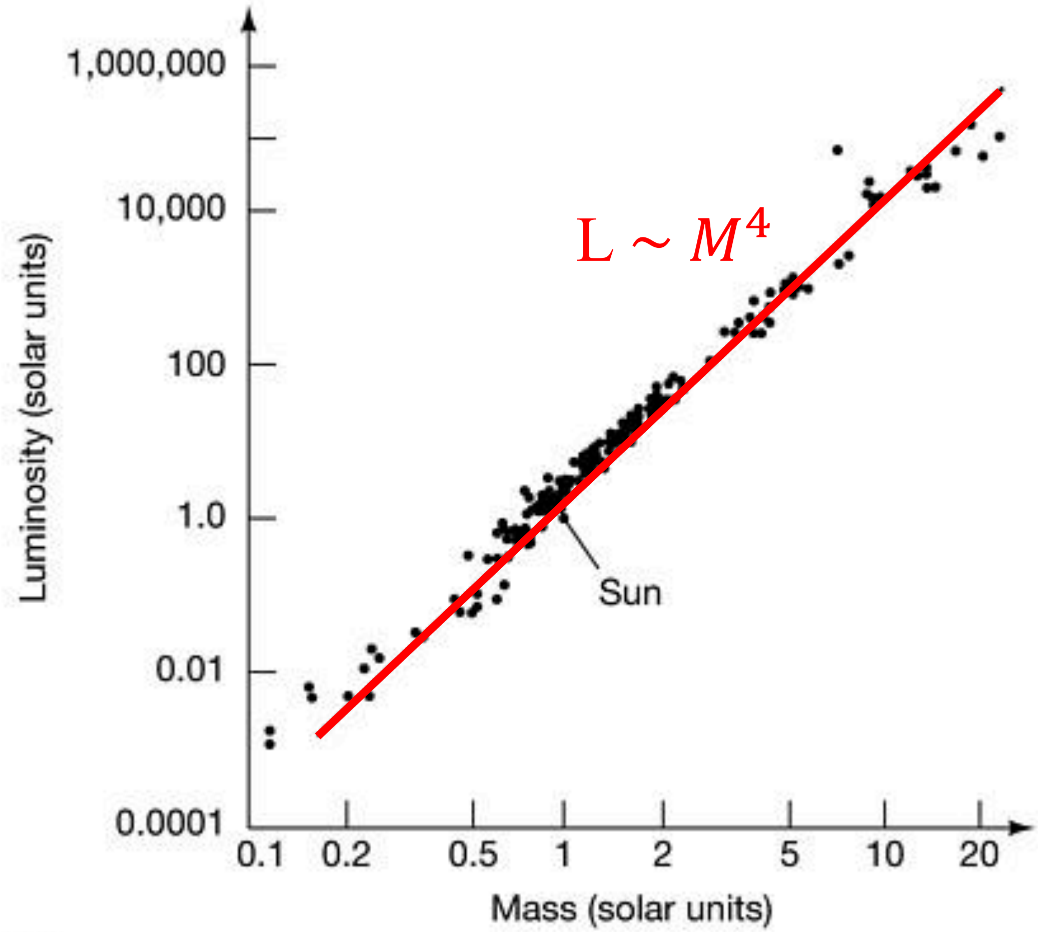

SV Cam
Star 1
5,800 K
Star 2
4,140 K
A
Star 2
Star 1
C
Luminosity
Primary
Eclipse
C
Secondary
Eclipse
A
A
B
D
B
Phase or Time
B
Star 1
Star 2
Primary Eclipse
(hot star 1 eclipsed)
D
Star 2
Star 1
Secondary Eclipse
(cool star 2 eclipsed)

Stellar Properties

- positions and velocities
- luminosities $10^{-4} - 10^{4}\ L_{\odot}$
- temperatures $3000 - 30000$ K
- composition $0.001 - 10$ solar
- radii $0.1 - 20\ R_{\odot}$ at birth

  WD: 10^{4} km; RG: >1 AU
- masses $0.1 - 100\ M_{\odot}$ at birth





stellar lifetime ~ M/L ~ M^{-3}

Key Nuclear reactions – Main Sequence

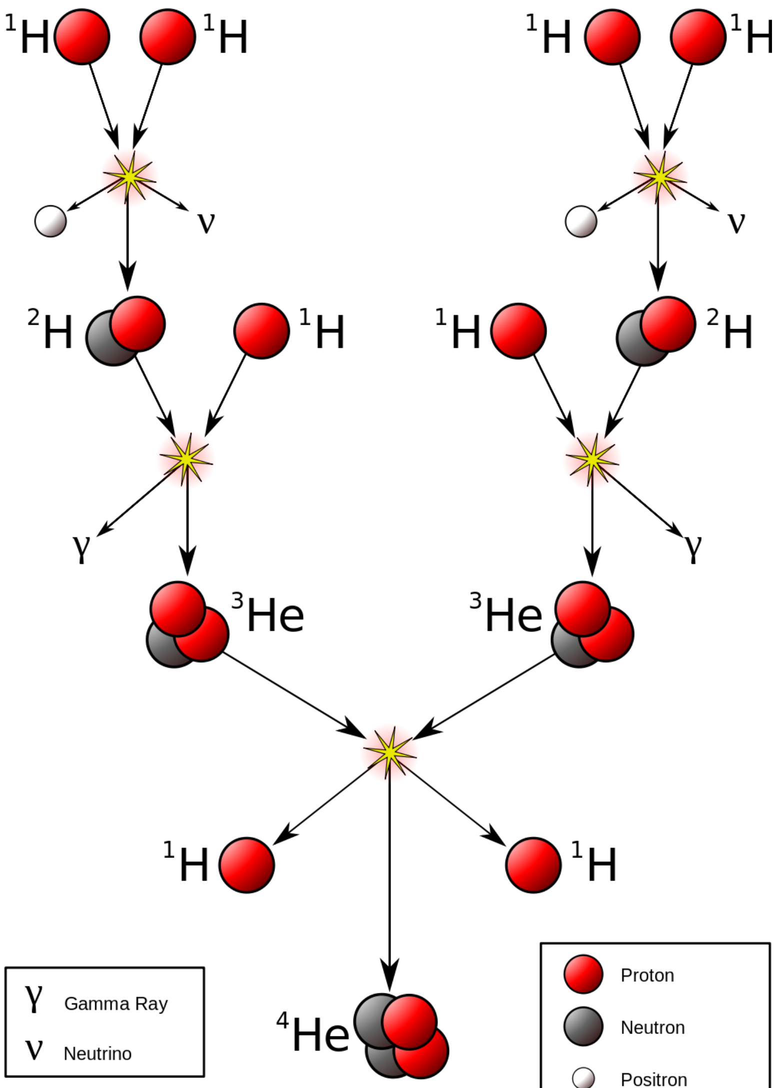
Proton-proton chain

$^{1}_{1}H + ^{1}_{1}H \rightarrow ^{2}_{2}He \rightarrow ^{2}_{1}H + e^{+} + \nu_{e}$

$^{2}_{1}H + ^{1}_{1}H \rightarrow ^{3}_{2}He$

$^{3}_{2}He + ^{3}_{2}He \rightarrow ^{4}_{2}He + 2\ (^{1}_{1}H)$

$4\ (^{1}_{1}H) \rightarrow ^{4}_{2}He + 2\ e^{+} + 2\nu_{e} + 24\ MeV$



Key Nuclear reactions – Main Sequence

CNO cycle

$^{12}_{6}C + ^{1}_{1}H \rightarrow ^{13}_{7}N + \gamma$

$^{13}_{7}N \rightarrow ^{13}_{6}C + e^{+} + \nu_{e}$

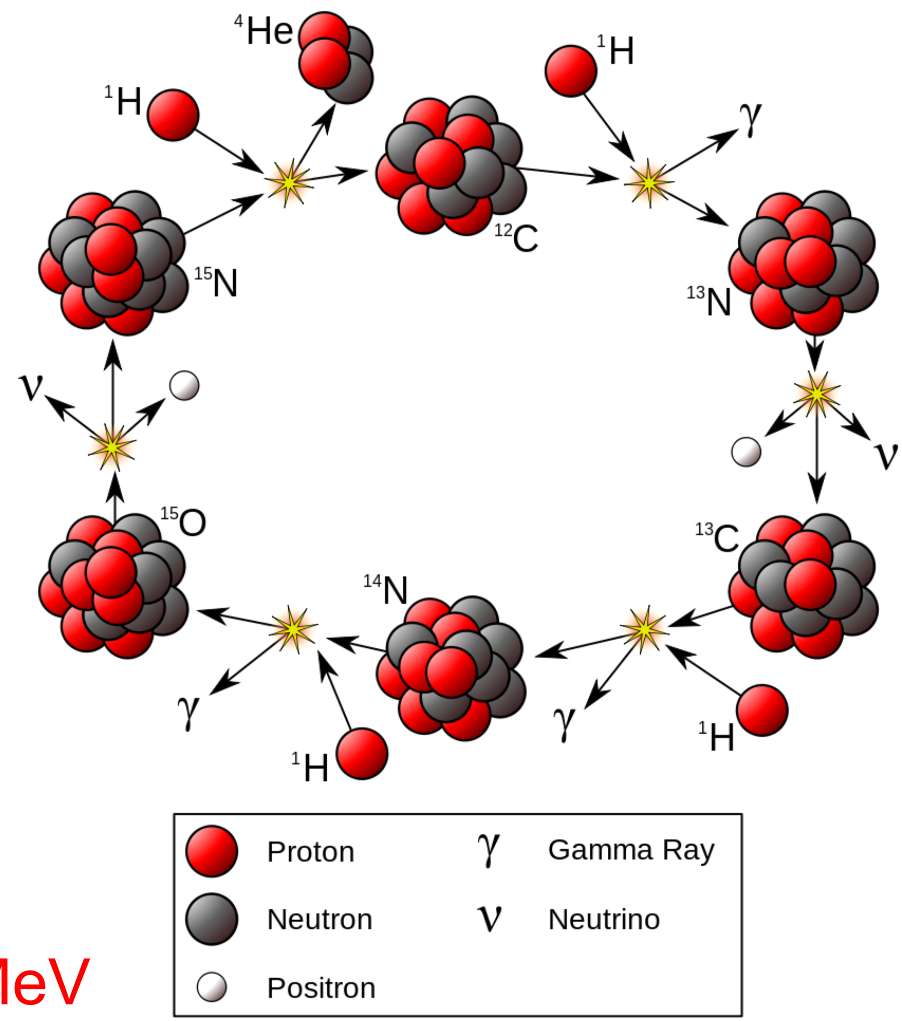
$^{13}_{6}C + ^{1}_{1}H \rightarrow ^{14}_{7}N + \gamma$

$^{14}_{7}N + ^{1}_{1}H \rightarrow ^{15}_{8}O + \gamma$

$^{15}_{8}O \rightarrow ^{15}_{7}N + e^{+} + \nu_{e}$

$^{15}_{7}N + ^{1}_{1}H \rightarrow ^{12}_{6}C + ^{4}_{2}He$

$4\,(^{1}_{1}H) \rightarrow ^{4}_{2}He + 2\,e^{+} + 2\nu_{e} + 24\text{ MeV}$

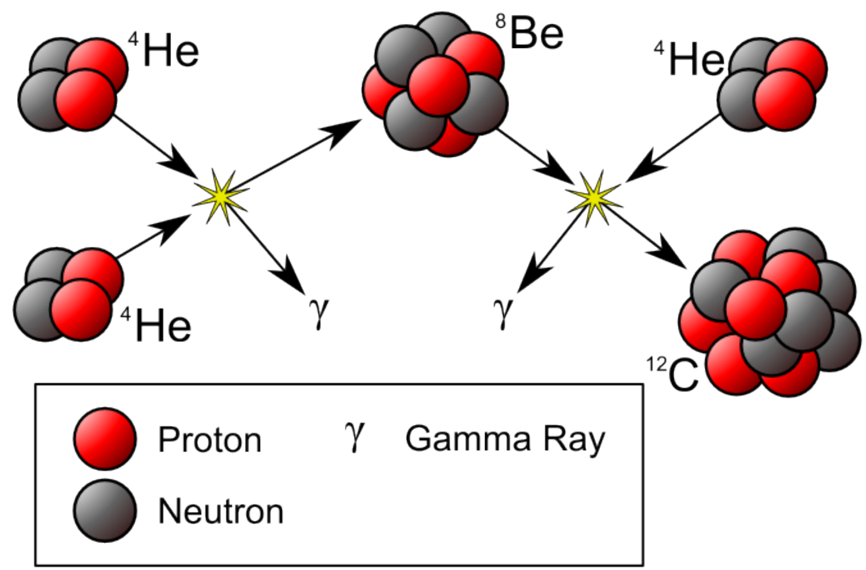


Key Nuclear reactions – Post-Main-Sequence

Triple-alpha process

$^{4}_{2}He + ^{4}_{2}He \rightarrow ^{8}_{4}Be - 94\ keV$

$^{8}_{4}Be + ^{4}_{2}He \rightarrow ^{12}_{6}Be + 7.4\ MeV$



Alpha capture

$^{12}_{6}C + ^{4}_{2}He \rightarrow ^{16}_{8}O + 7.2\ MeV$

$^{16}_{8}O + ^{4}_{2}He \rightarrow ^{20}_{10}Ne + 4.7\ MeV$

$^{20}_{10}Ne + ^{4}_{2}He \rightarrow ^{24}_{12}Mg + 9.3\ MeV$

etc.

$$t_{MS} \sim \frac{M}{L} \sim M^{-3}$$

$$\sim 10^{10}\ \mathrm{yr} \left(\frac{M}{M_\odot}\right)^{-3}$$

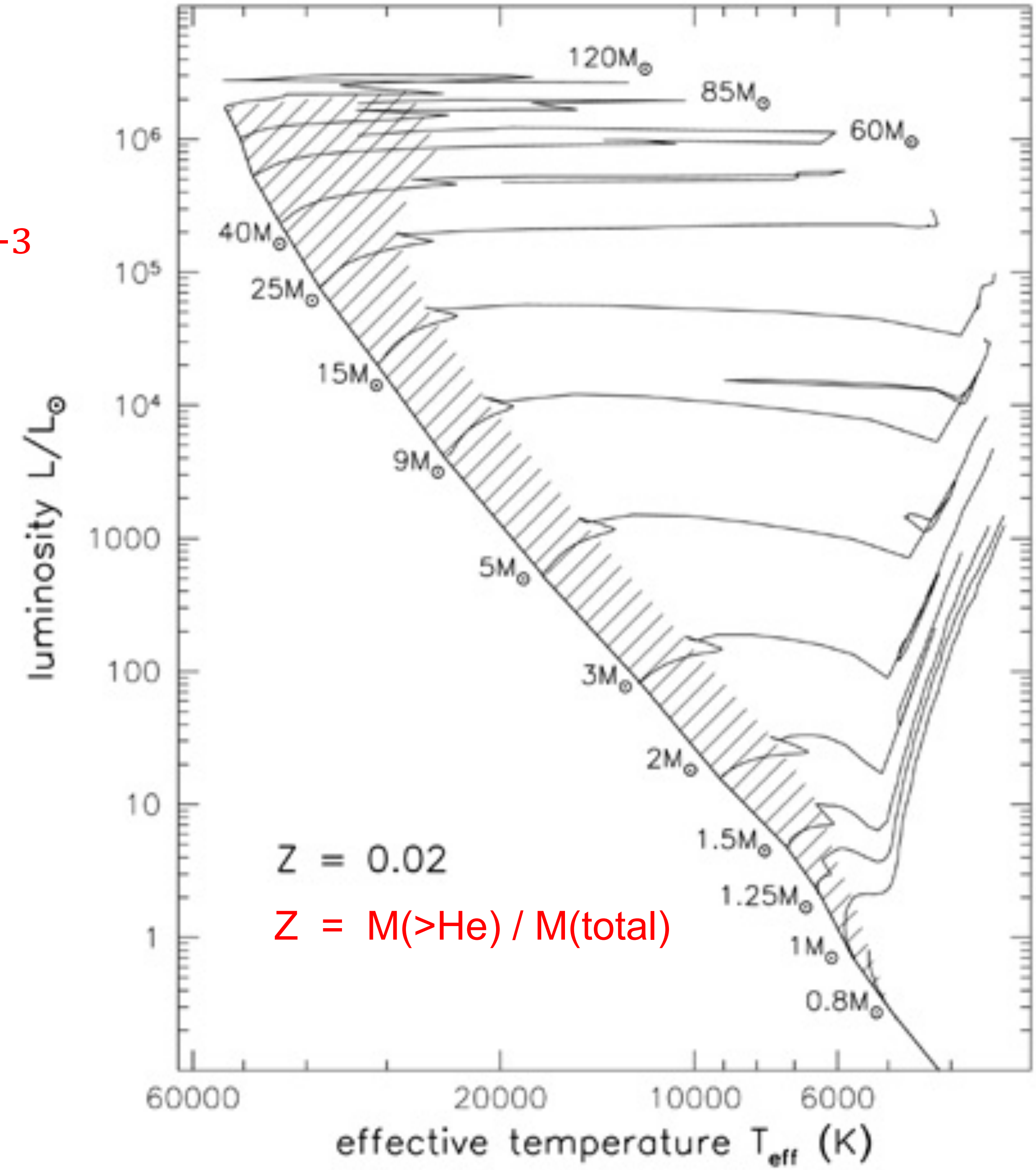


Fig 1.4 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Endpoints of Stellar Evolution

$< 0.08\ M_\odot$	brown dwarf (degenerate H)	
$0.08-0.25\ M_\odot$	He white dwarf	
$0.25-8\ M_\odot$	CO white dwarf	$t \sim 10^{10}$ yr $(M/M_\odot)^{-3}$
$8-12\ M_\odot$	NeO white dwarf	
$12-20\ M_\odot$	supernova/neutron star	$t \sim 3\text{-}20 \times 10^6$ yr
$>20\ M_\odot$	supernova/black hole	