The Death of Stars: Neutron Stars, Black Holes and Beyond

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UNIVERSITY OF BIRMINGHAM

CONACYT
Consejo Nacional de Ciencia y Tecnología

Science Seminars of the Mexican Society at UoB
October 13, 2017

Outline

- What is a star?
- The life of (single) stars
- The death of stars
- Beyond
- Encore

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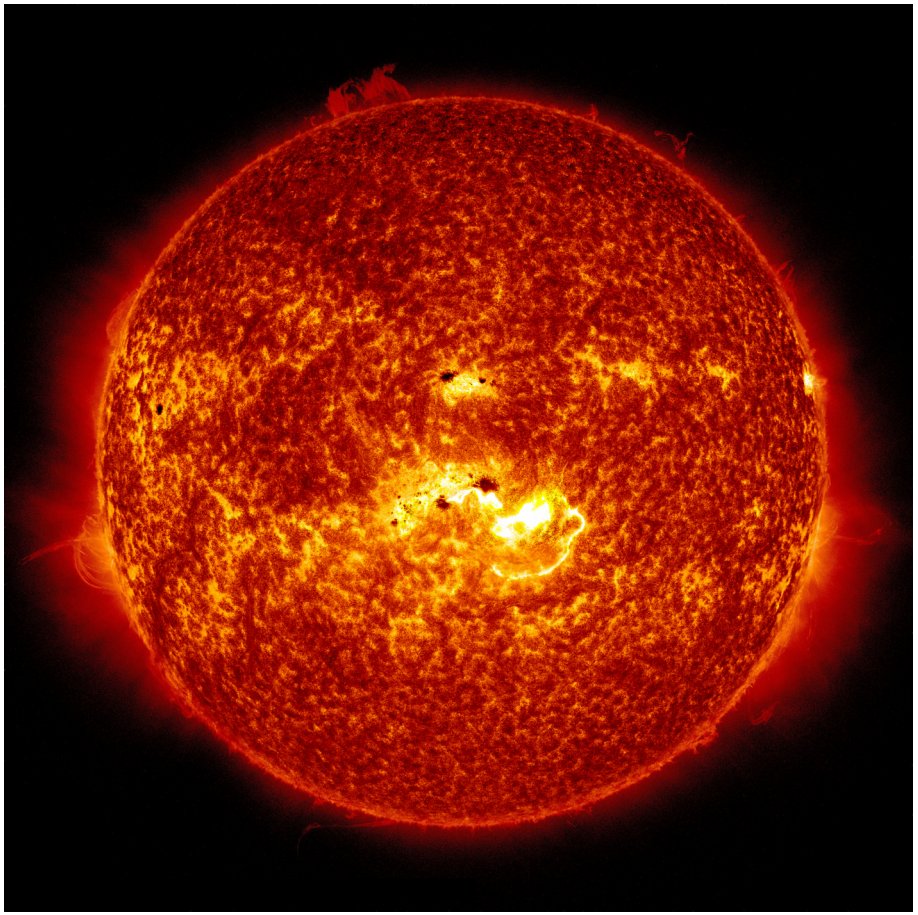
What is a Star?

- “A fixed **luminous** point in the night sky which is a large, remote **incandescent** body **like the sun**.” - Google

- “A star is a **luminous sphere** of plasma **held together by its own gravity**.” - Wikipedia

Self-gravitation: matter pushes inwards

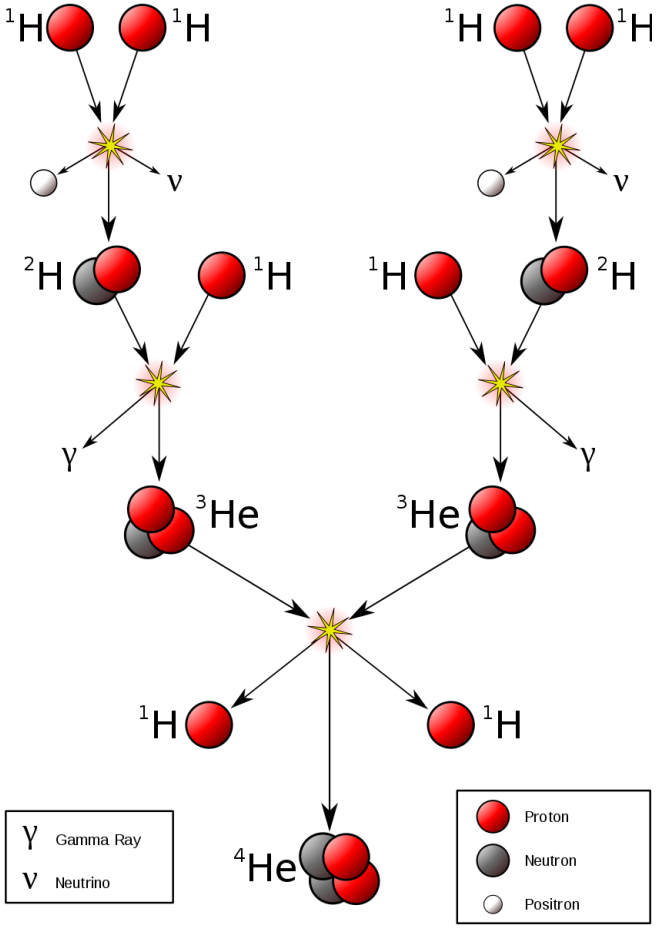
Earth
Mass: 5.972×10^{24} kg
Surface gravity (g): 9.807 m/s²

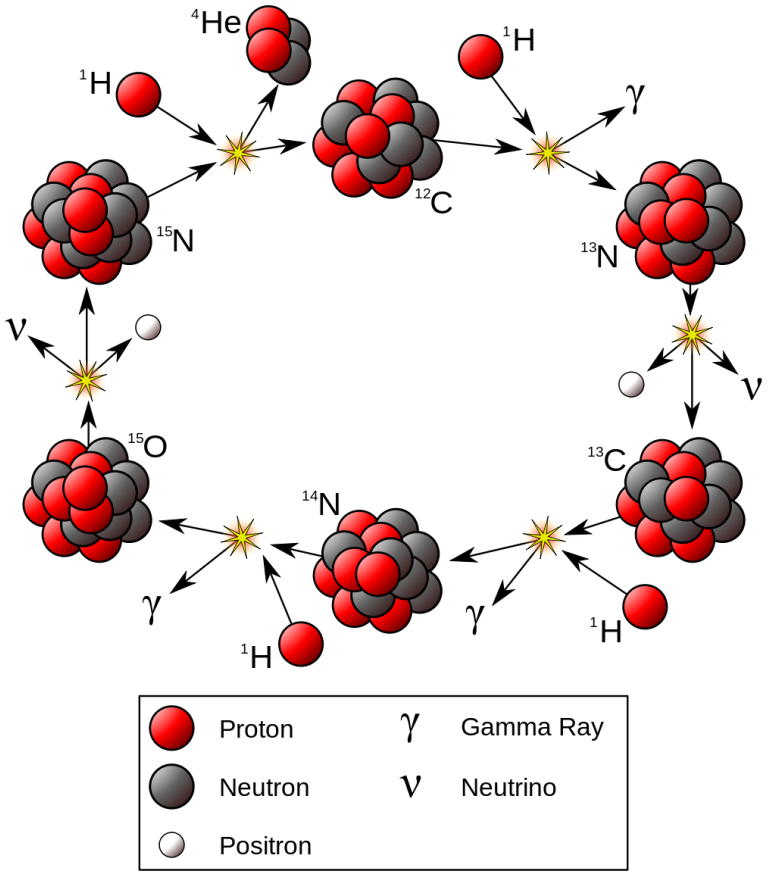


Sun
Mass: 1.989×10^{30} kg
Surface gravity: 28.02g

Credit: NASA

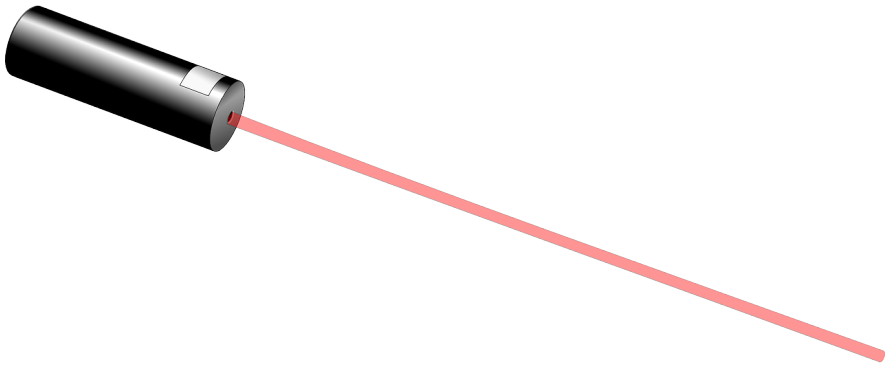
Nuclear Burning: a star gets hot and begins burning





Credit: Wikipedia

Radiation Pressure: photons push outwards



$$p_\gamma = \frac{h}{\lambda}$$

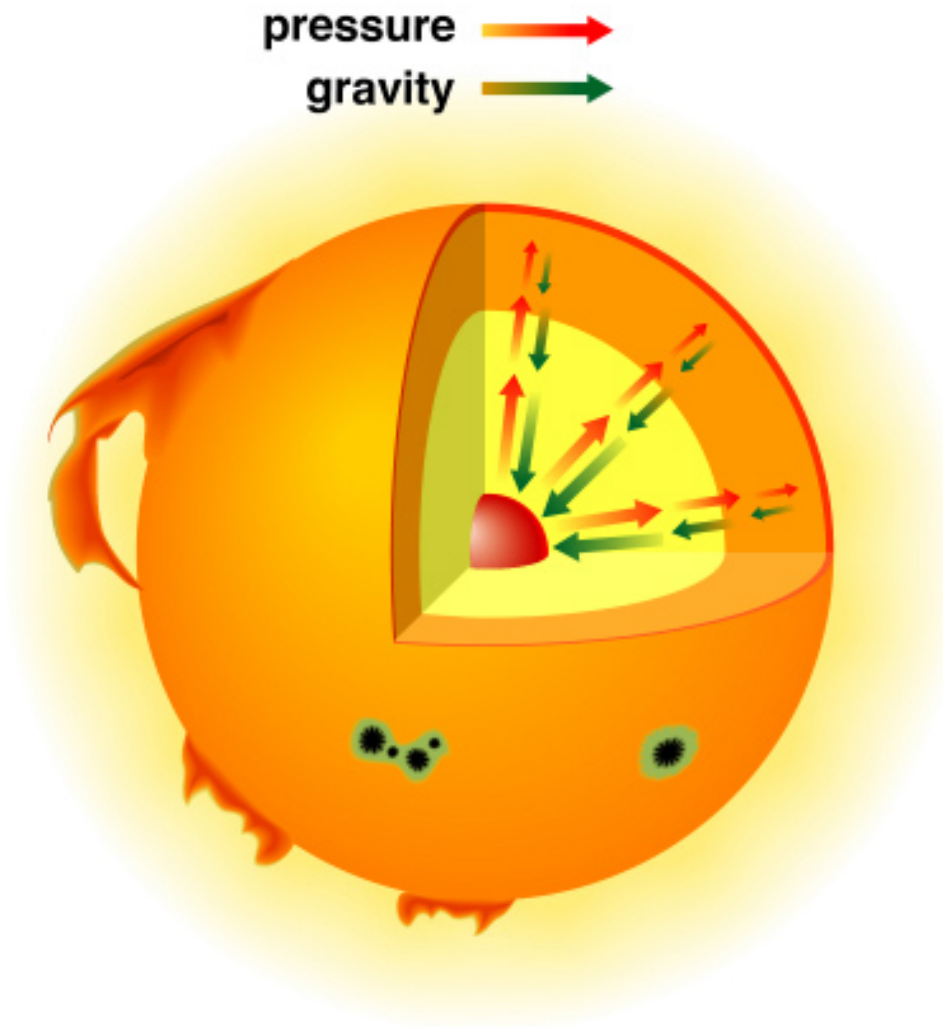
$$p_{\gamma,\mathrm{red}} = 9.47 \times 10^{-28} \mathrm{kg\ m/s}$$

$$p_{\mathrm{ball}} = m_{\mathrm{ball}} \times v_{\mathrm{ball}}$$

$$p_{\mathrm{ball,fast}} \approx 25.50\ \mathrm{kg\ m/s}$$

Credit: Wikipedia

Hydrostatic Equilibrium



https://ryanoursun.wikispaces.com/file/view/hydro.jpg/62193798/hydro.jpg

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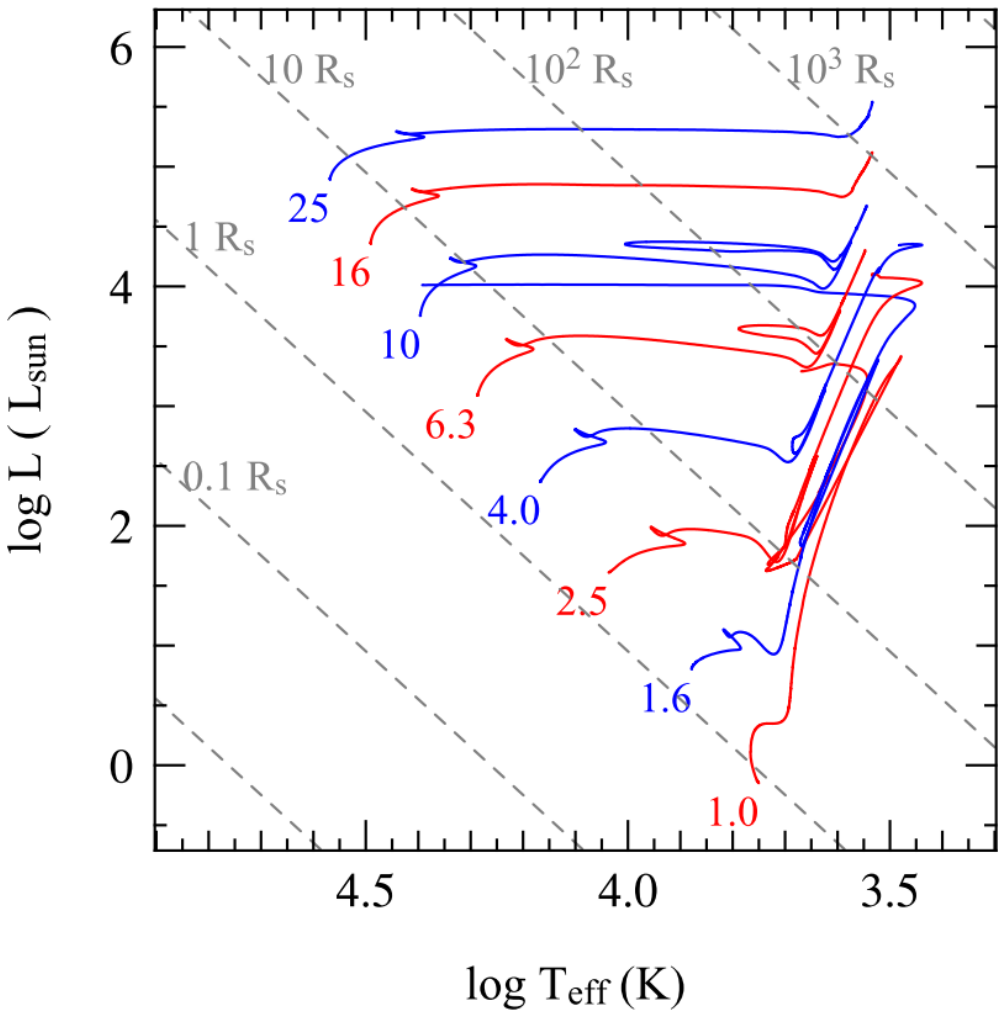
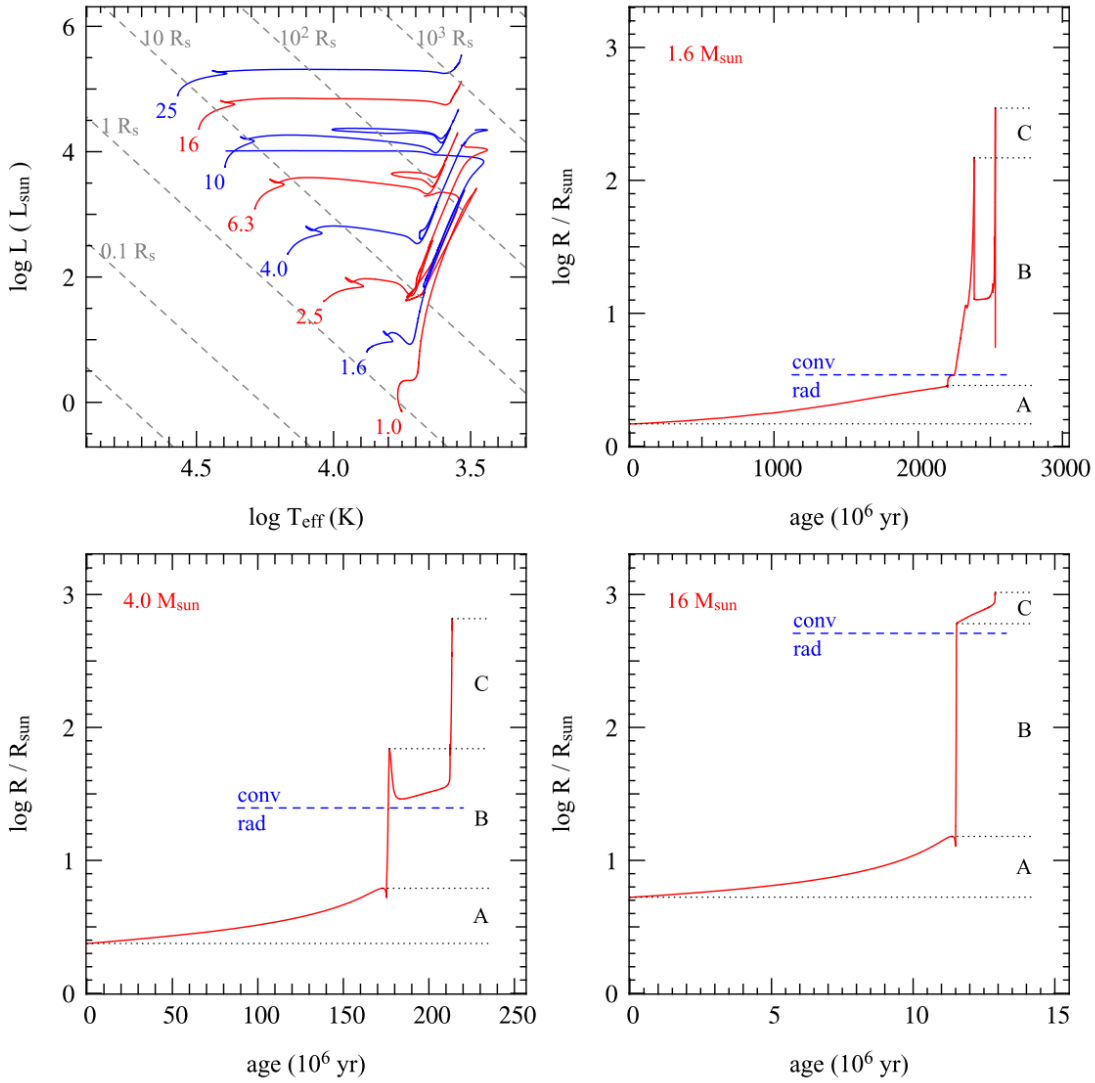
The Life of (Single) Stars



The Life of (Single) Stars



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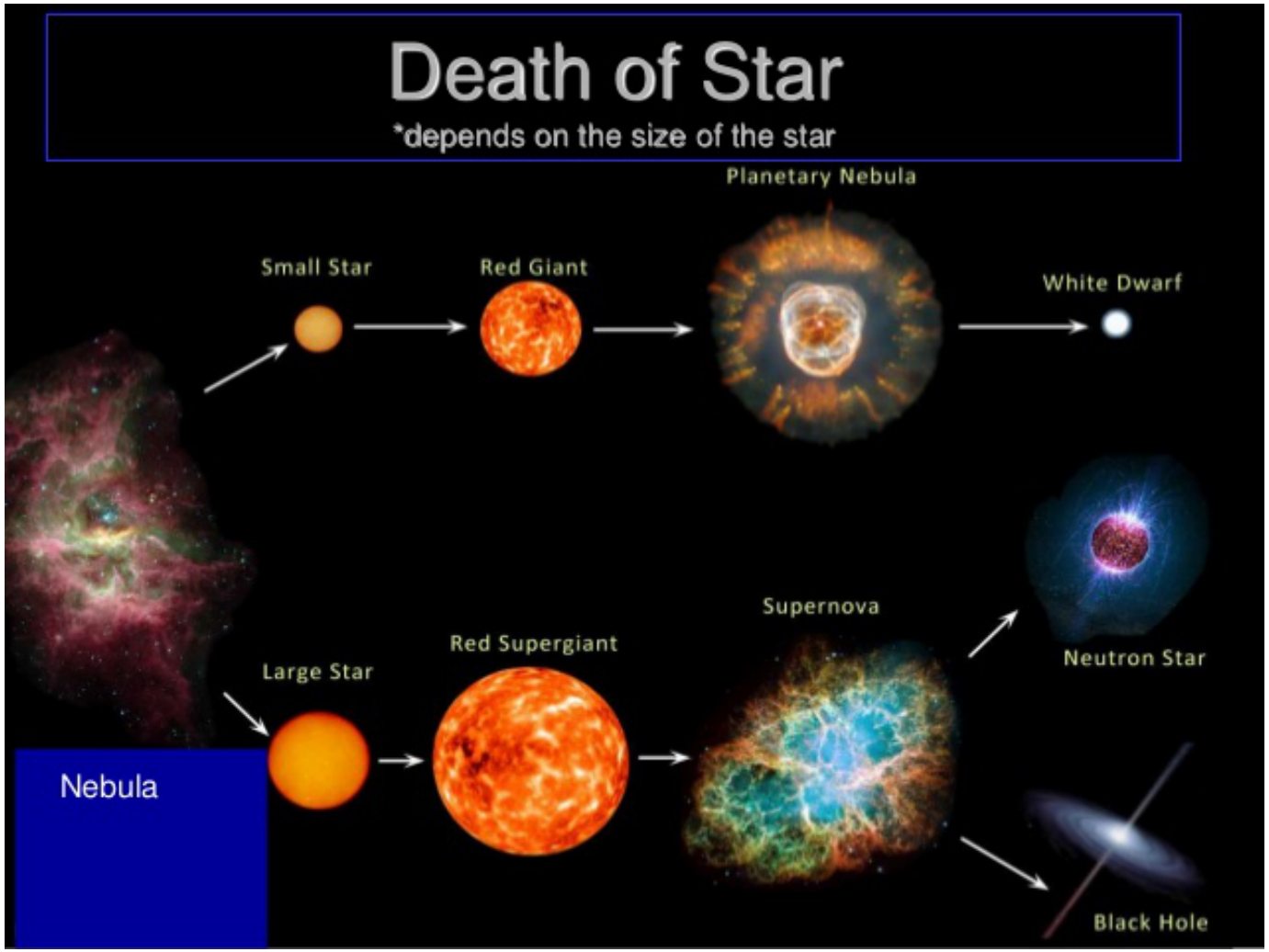
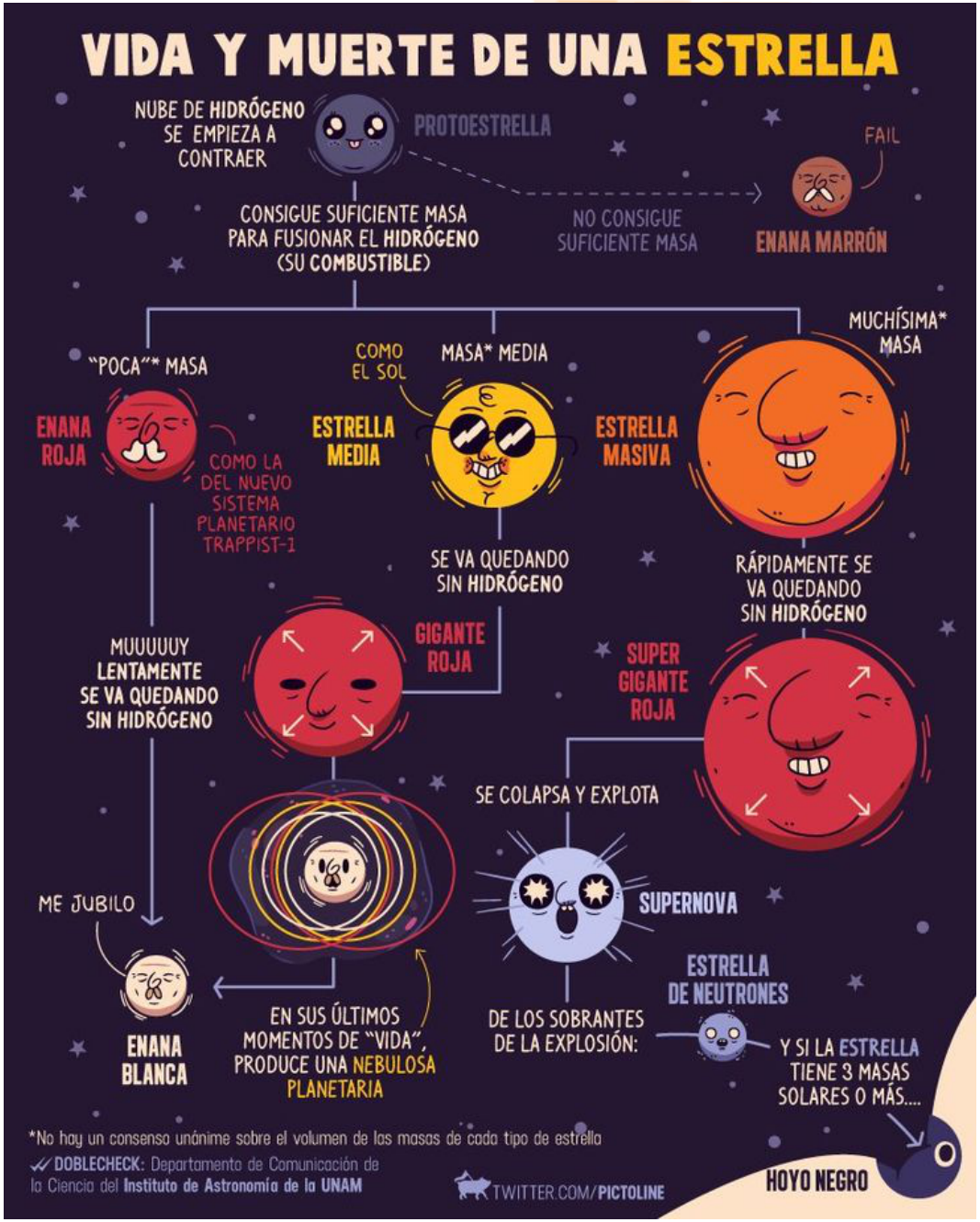
The Death of Stars:
White Dwarf (WD), Neutron Star (NS) and Black Hole (BH)



https://www.slideshare.net/hazwanialias/form-3-chapter-9-stars-and-galaxies


VIDA Y MUERTE DE UNA ESTRELLA
NUBE DE HIDRÓGENO SE EMPIEZA A CONTRAER
PROTOESTRELLA
FAIL
NO CONSIGUE SUFICIENTE MASA
ENANA MARRÓN
CONSIGUE SUFICIENTE MASA PARA FUSIONAR EL HIDRÓGENO (SU COMBUSTIBLE)
"POCA"* MASA
COMO EL SOL
MASA* MEDIA
MUCHÍSIMA* MASA
ENANA ROJA
COMO LA DEL NUEVO SISTEMA PLANETARIO TRAPPIST-1
ESTRELLA MEDIA
ESTRELLA MASIVA
SE VA QUEDANDO SIN HIDRÓGENO
RÁPIDAMENTE SE VA QUEDANDO SIN HIDRÓGENO
MUUUUUY LENTAMENTE SE VA QUEDANDO SIN HIDRÓGENO
GIGANTE ROJA
SUPER GIGANTE ROJA
SE COLAPSA Y EXPLOTA
SUPERNOVA
ME JUBILO
ESTRELLA DE NEUTRONES
DE LOS SOBRANTES DE LA EXPLOSIÓN:
Y SI LA ESTRELLA TIENE 3 MASAS SOLARES O MÁS....
ENANA BLANCA
EN SUS ÚLTIMOS MOMENTOS DE "VIDA", PRODUCE UNA NEBULOSA PLANETARIA
HOYO NEGRO
*No hay un consenso unánime sobre el volumen de las masas de cada tipo de estrella
DOBLECHECK: Departamento de Comunicación de la Ciencia del Instituto de Astronomía de la UNAM
TWITTER.COM/PICTOLINE

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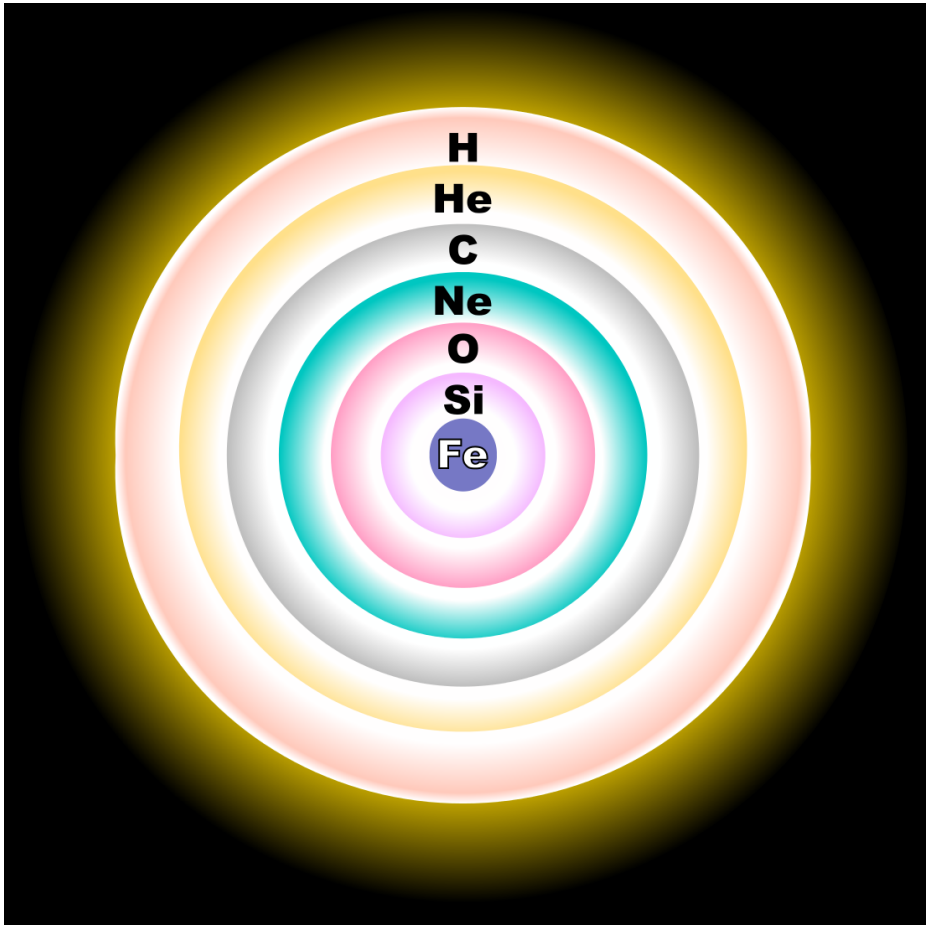
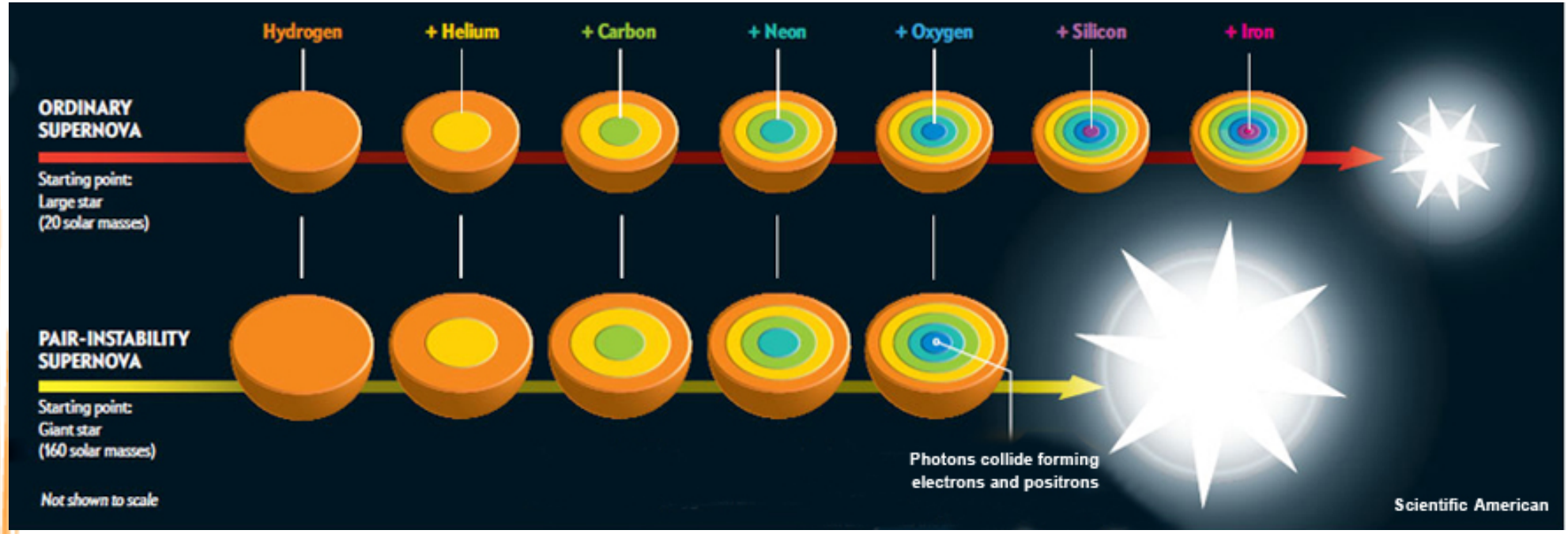
Beyond:
Pair-instability Supernova (PISN)



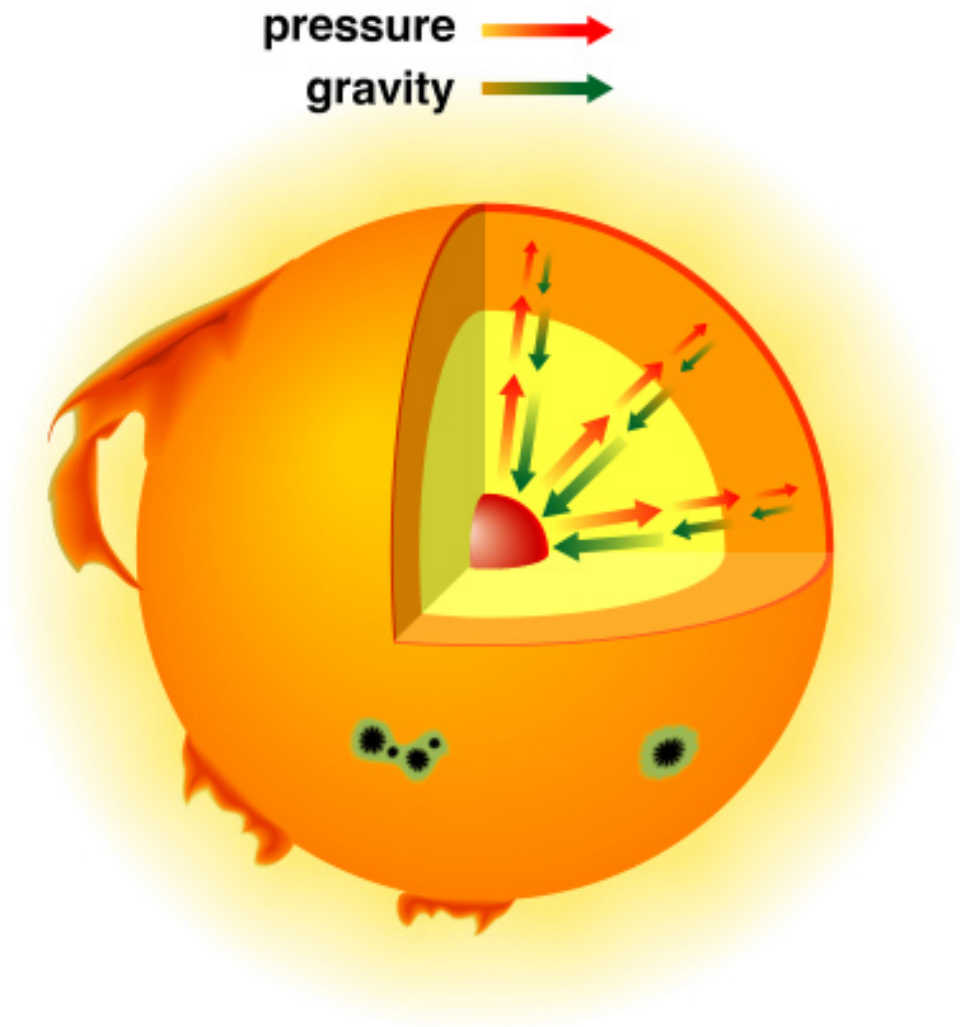
Credit: Wikipedia

PISN: How do you make one?



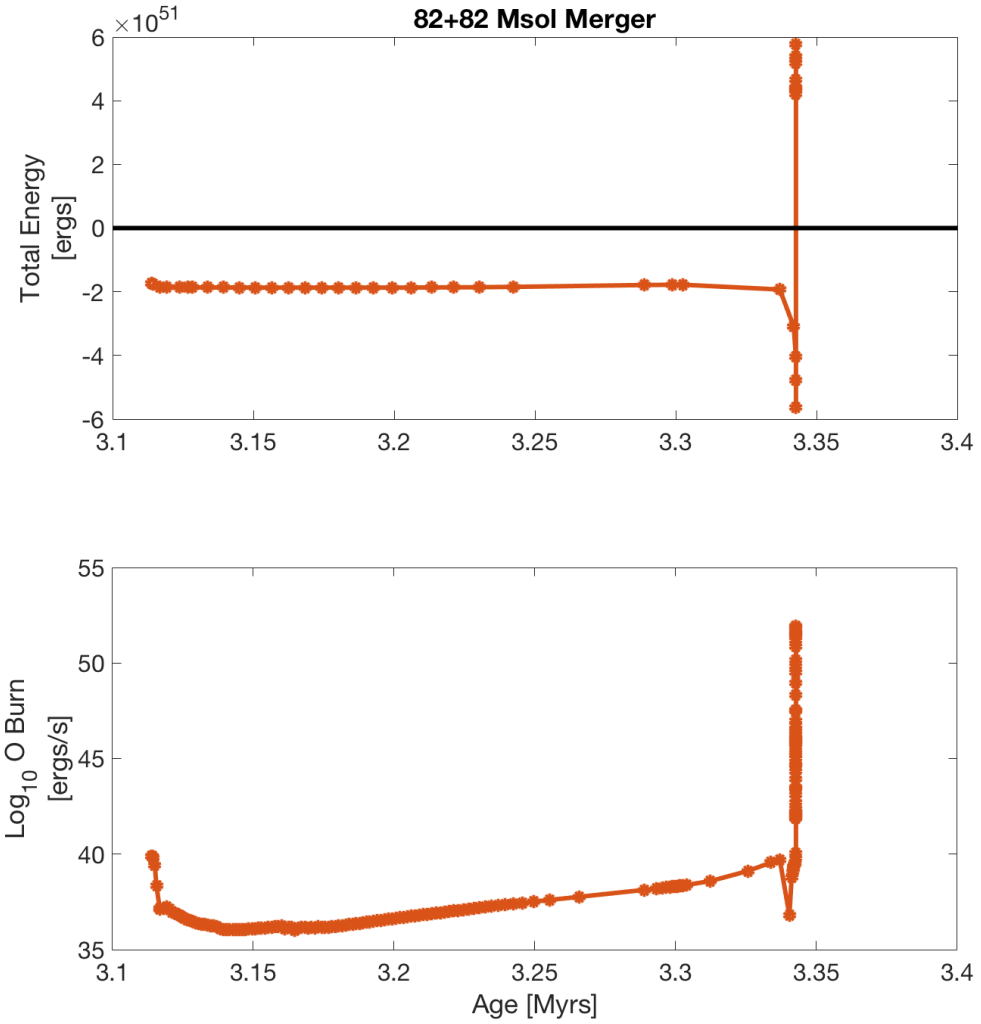
Barkat+1967, Rakavy+1967, Fraley 1968

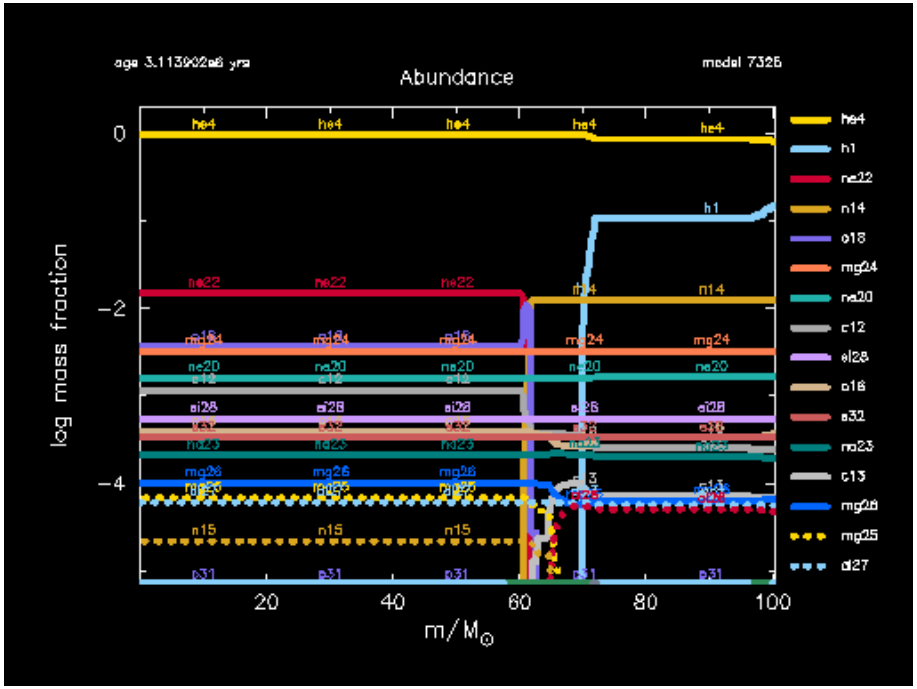
PISN: not in hydrostatic equilibrium



https://ryanoursun.wikispaces.com/file/view/hydro.jpg/62193798/hydro.jpg

PISN: Model


82+82 Msol Merger
×10^51
Total Energy [ergs]
Log10 O Burn [ergs/s]
Age [Myrs]


Abundance
log mass fraction
m/M⊙

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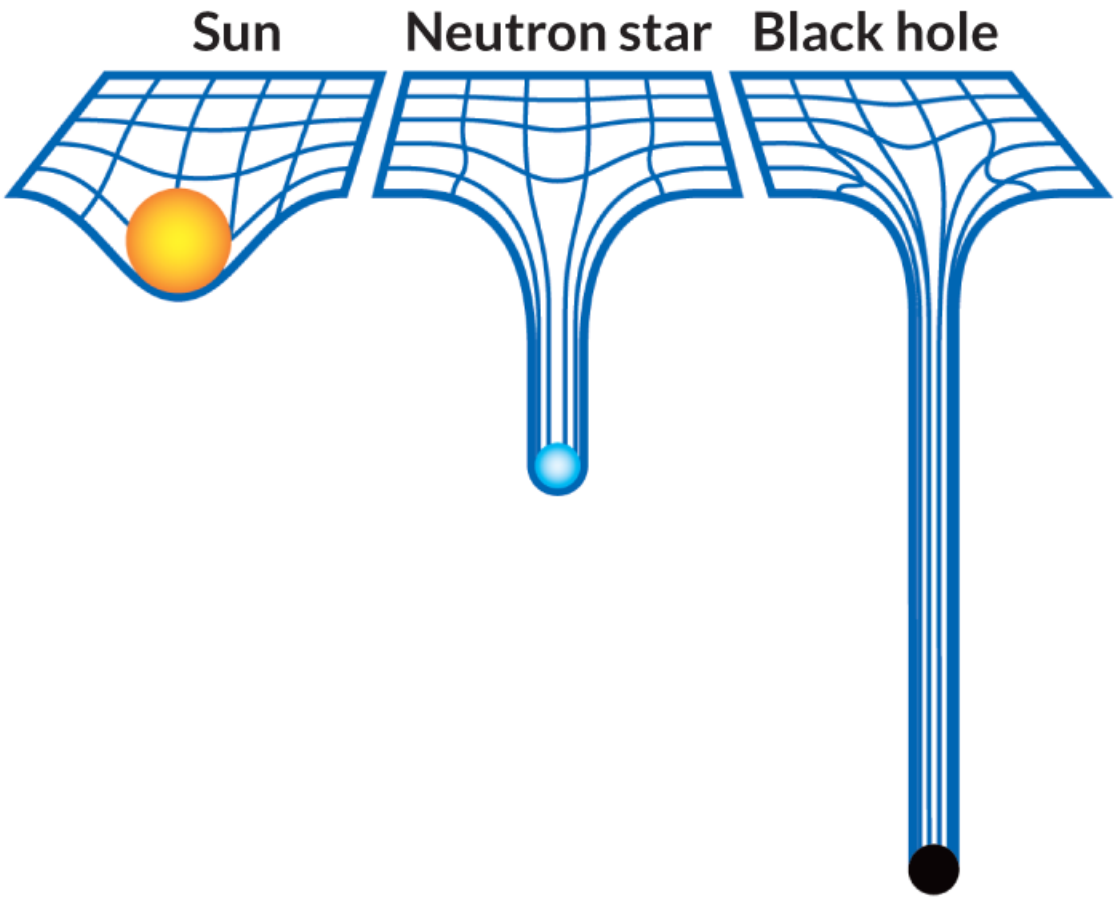
Spacetime



Equations to Model a Star

$$\frac{\partial r}{\partial m} = \frac{1}{4\pi r^2 \rho} \tag{7.1}$$

$$\frac{\partial P}{\partial m} = -\frac{Gm}{4\pi r^4} - \frac{1}{4\pi r^2}\frac{\partial^2 r}{\partial t} \tag{7.2}$$

$$\frac{\partial l}{\partial m} = \epsilon_{\text{nuc}} - \epsilon_\nu - T\frac{\partial s}{\partial t} \tag{7.3}$$

$$\frac{\partial T}{\partial m} = -\frac{Gm}{4\pi r^4}\frac{T}{P}\nabla \qquad \text{with} \qquad \nabla = \begin{cases} \nabla_{\text{rad}} = \dfrac{3\kappa}{16\pi acG}\dfrac{lP}{mT^4} & \text{if } \nabla_{\text{rad}} \le \nabla_{\text{ad}} \\ \nabla_{\text{ad}} + \Delta\nabla & \text{if } \nabla_{\text{rad}} > \nabla_{\text{ad}} \end{cases} \tag{7.4}$$

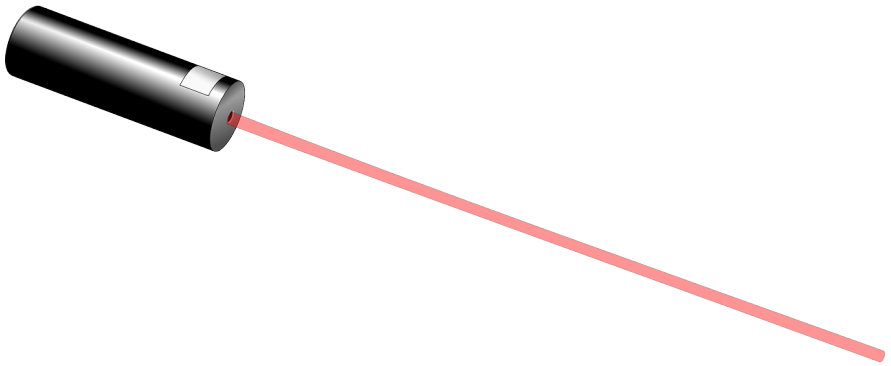
$$\frac{\partial X_i}{\partial t} = \frac{A_i m_u}{\rho}\left(-\sum_j (1+\delta_{ij})\, r_{ij} + \sum_{k,l} r_{kl,i} \right) \quad [+ \text{ mixing terms}] \qquad i = 1 \ldots N \tag{7.5}$$

Conclusions

- What is a star?: “A star is a **luminous sphere** of plasma **held together by its own gravity**.” - Wikipedia
- The life of (single) stars: they burn lighter elements into heavy elements, growing a core, and they expand.
- The death of stars: WD, NS, BH...
- Beyond: ...and PISN.
- Encore: Spacetime and stellar models

Appendix

Radiation Pressure: photons push outwards



$$p_\gamma = \frac{h}{\lambda}$$

γ : *photon*

h: Planck's constant

λ : *wavelength*

$h = 6.63 \times 10^{-34}\ m^2\ kg/s$

$\lambda_{red} \approx 700.00\ nm$

$p_{\gamma,red} = 9.47 \times 10^{-28} kg\ m/s$

$$p_{ball} = m_{ball} \times v_{ball}$$

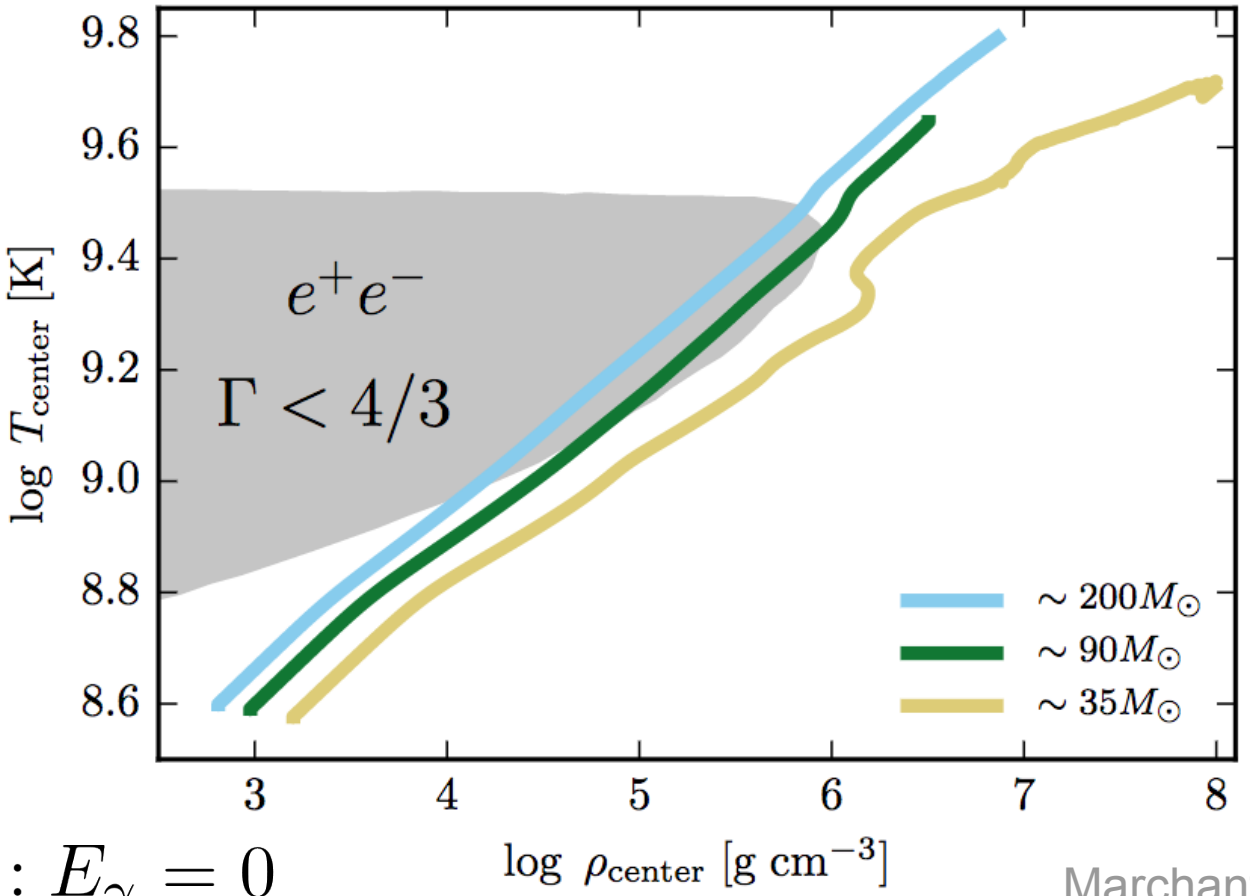
$m_{ball} \approx 0.15\ kg$

$v_{ball,fast} \approx 170.00\ m/s$

$p_{ball,fast} \approx 25.50\ kg\ m/s$

Credit: Wikipedia

PISN: How do you make one?



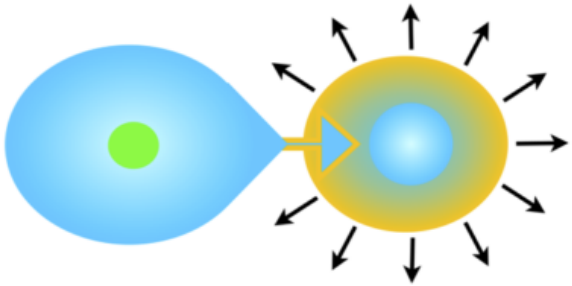
$Z = Z_\odot/50$

$35\ M_\odot : E_\gamma = 0$
$90\ M_\odot : E_\gamma > E_{\rm bind}$
$200\ M_\odot : E_\gamma < E_{\rm bind}$

Marchant+2016

Mergers (PISN Progenitors)

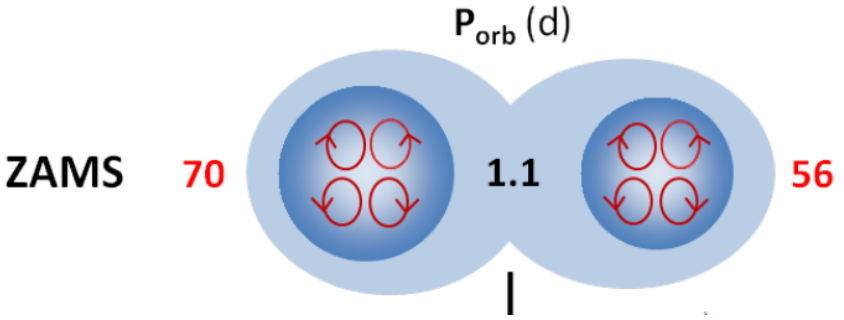
Case B with q ~ 1



Rates: Lower

See: Justham+2014

Massive Overcontact Binaries



Rates: Higher

See: Marchant+2016

$$Rates_{\mathrm{Single},Z_\odot} = 0$$
$$Rates_{\mathrm{Binary},Z_\odot} > 0$$