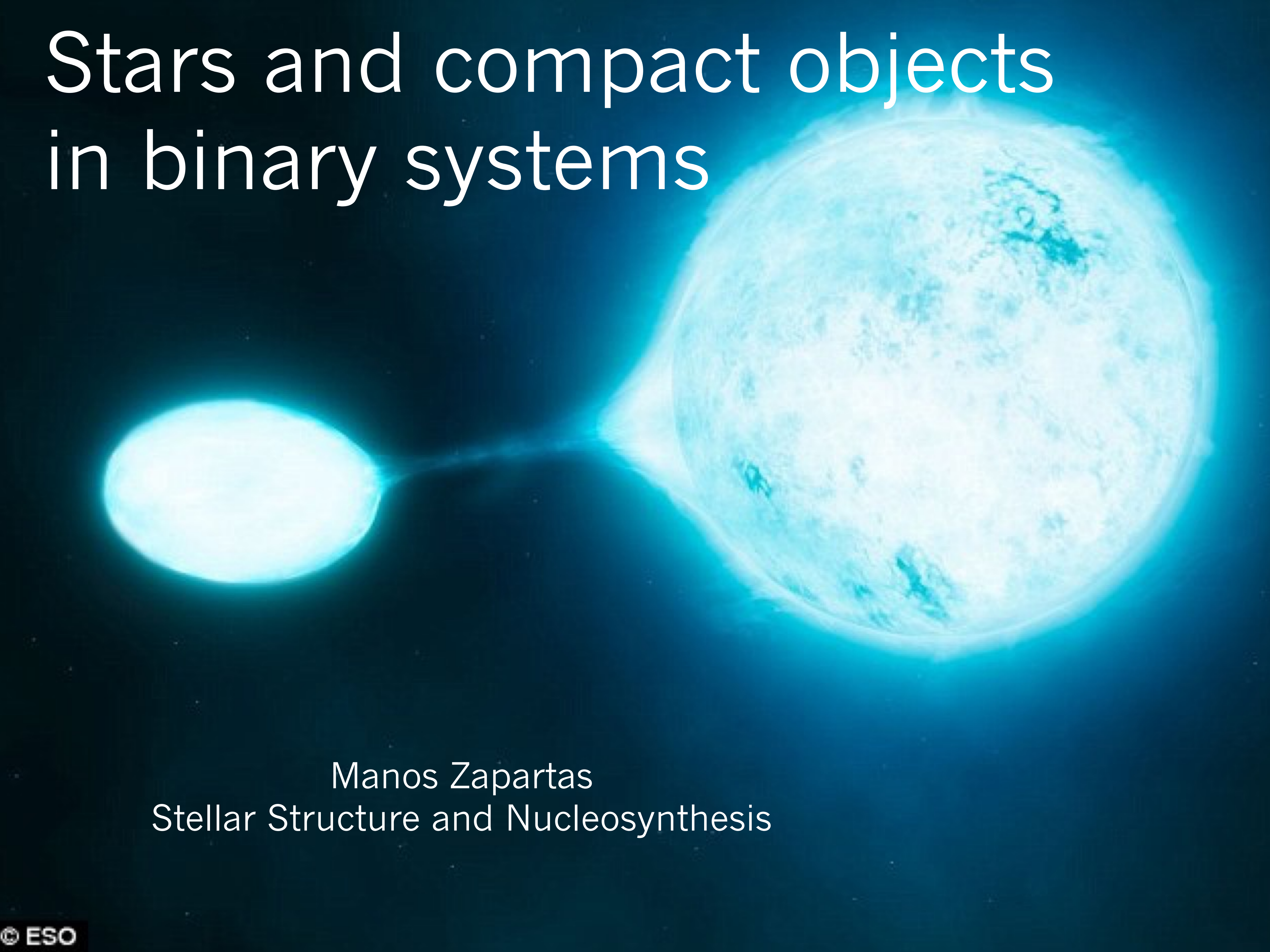
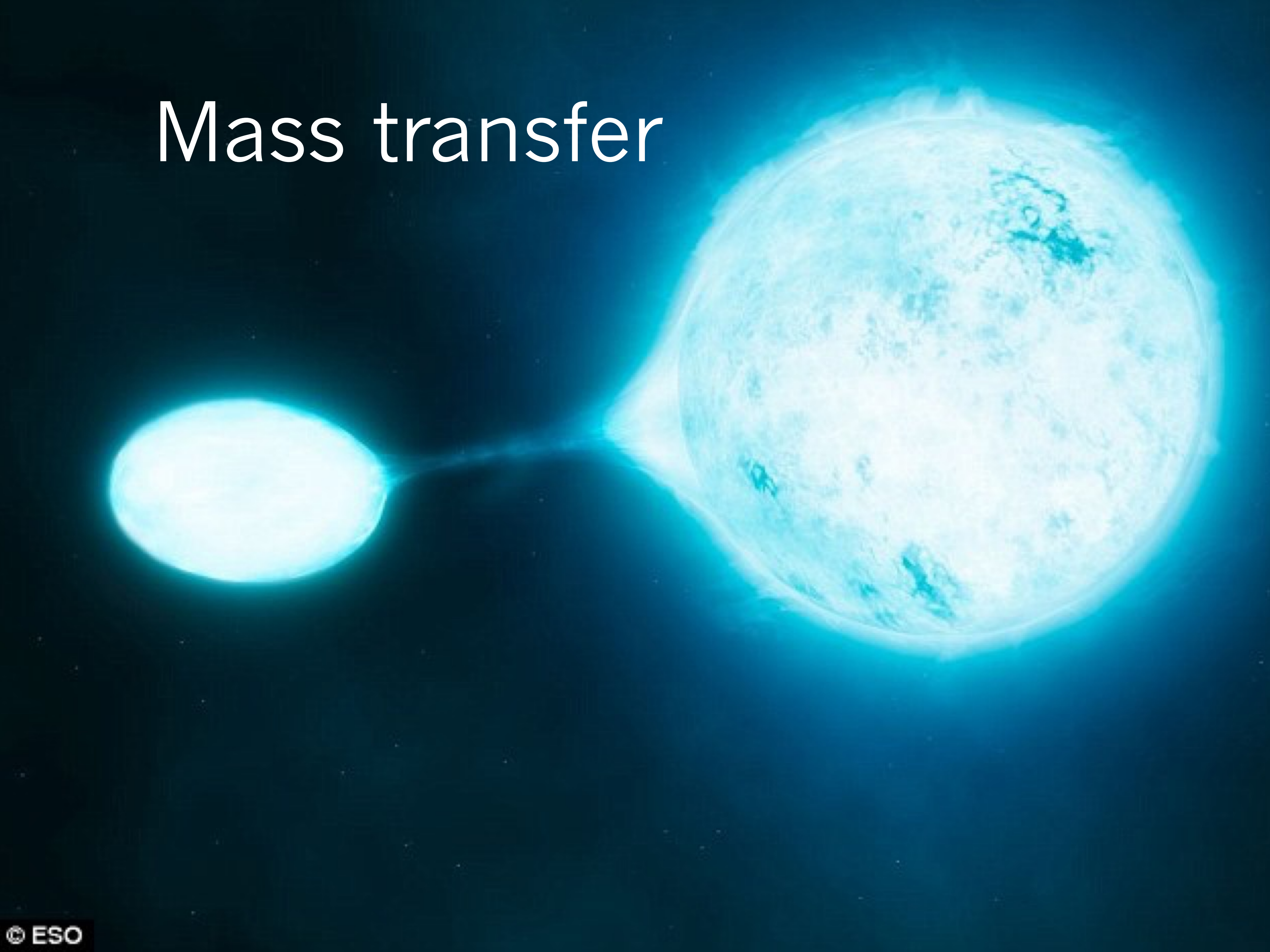
Stars and compact objects in binary systems



Manos Zapartas

Stellar Structure and Nucleosynthesis

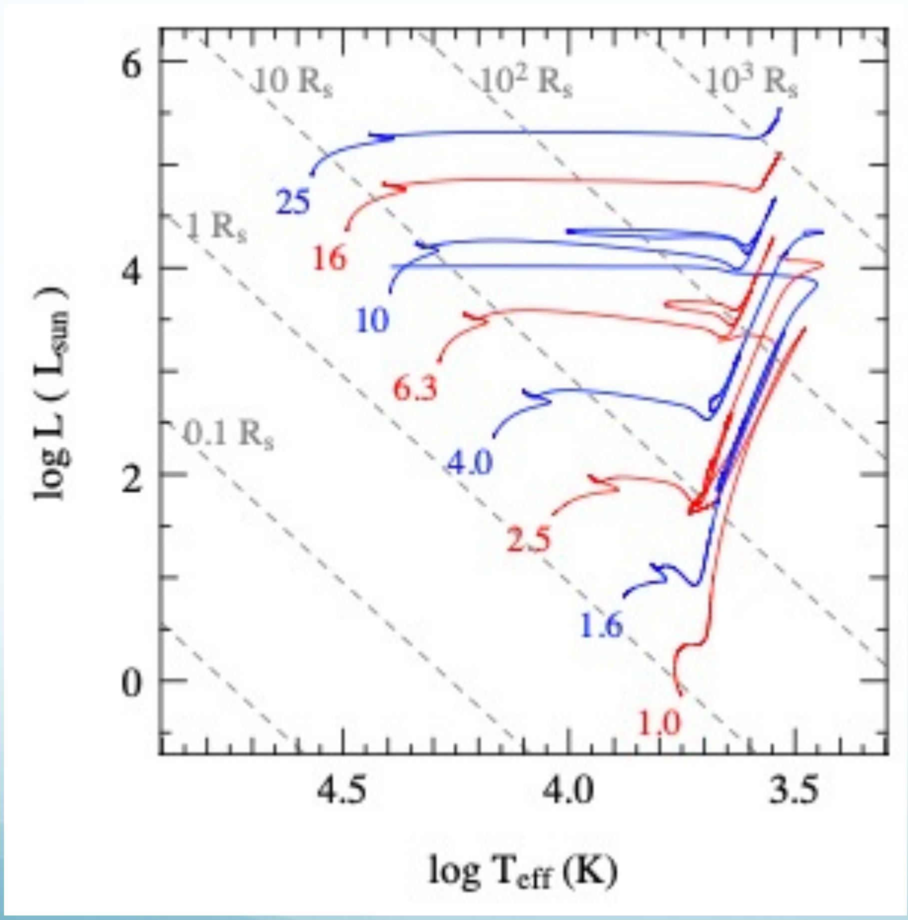
Mass transfer

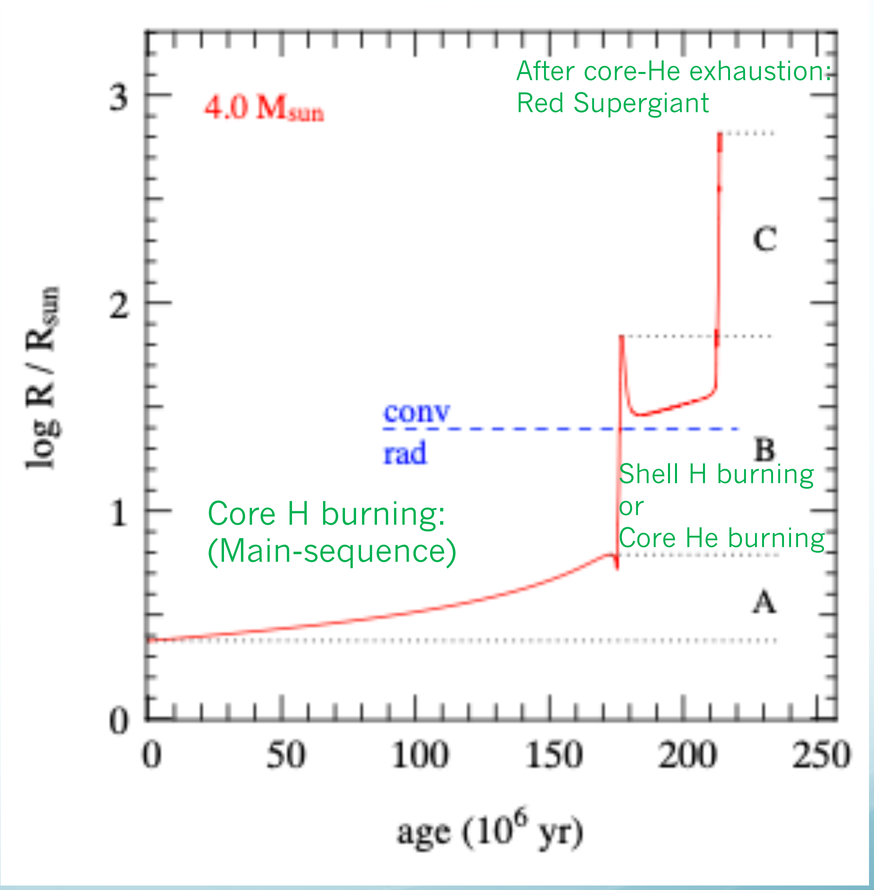


Mass transfer


Stripped star

Different evolution of a stripped star





HRD of a stripped star

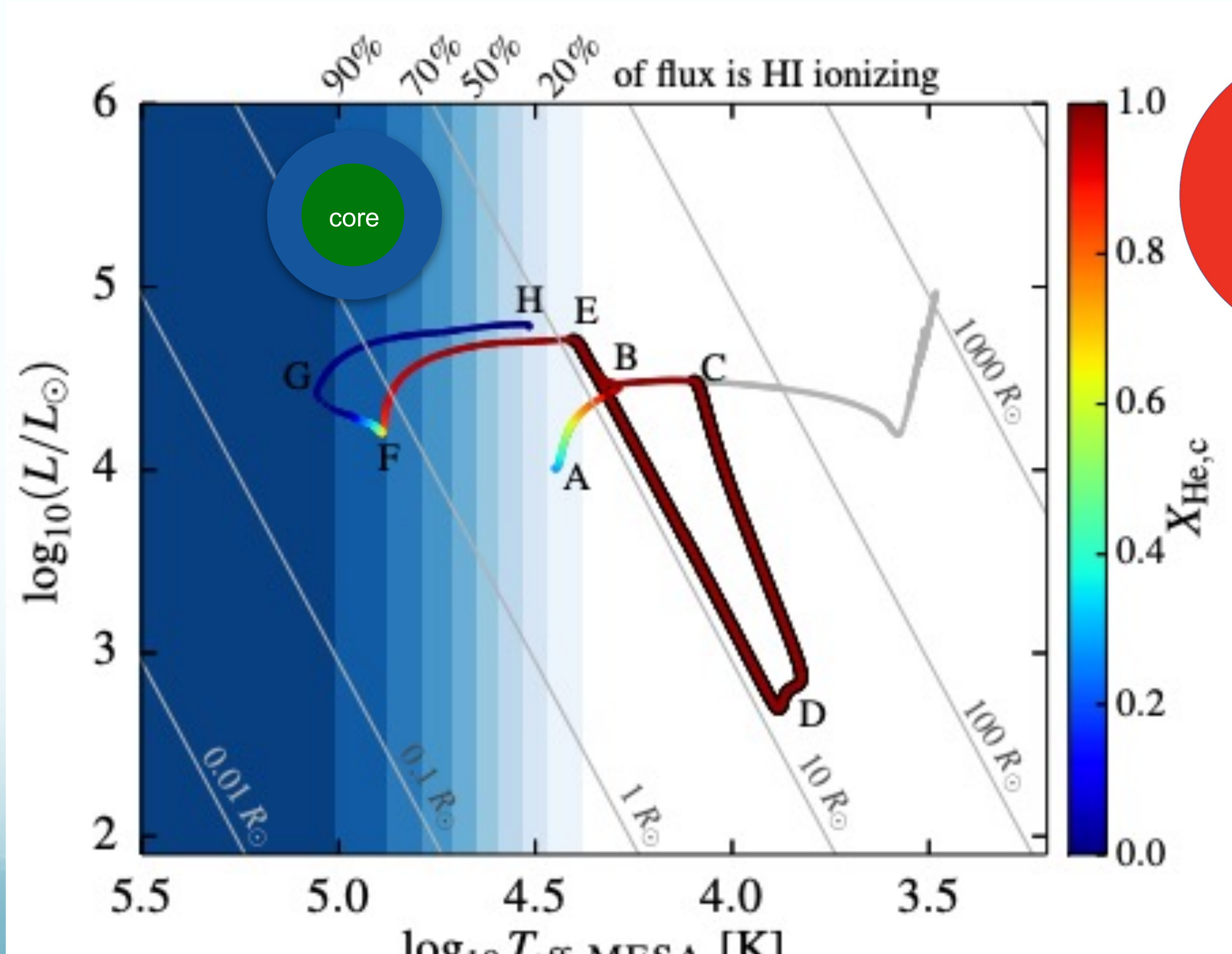
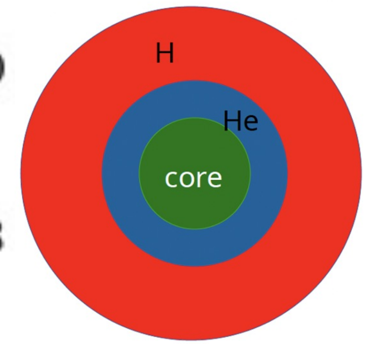


Figure from Götberg et al (2017)




Mass transfer
mass
gaining
© ESO

Mass accretor (gainer)

- Gain of mass
  - acceleration of evolution
- Rejuvenation
  - New fuel in the center
- spin up!
  - *(De Mink+2013)*

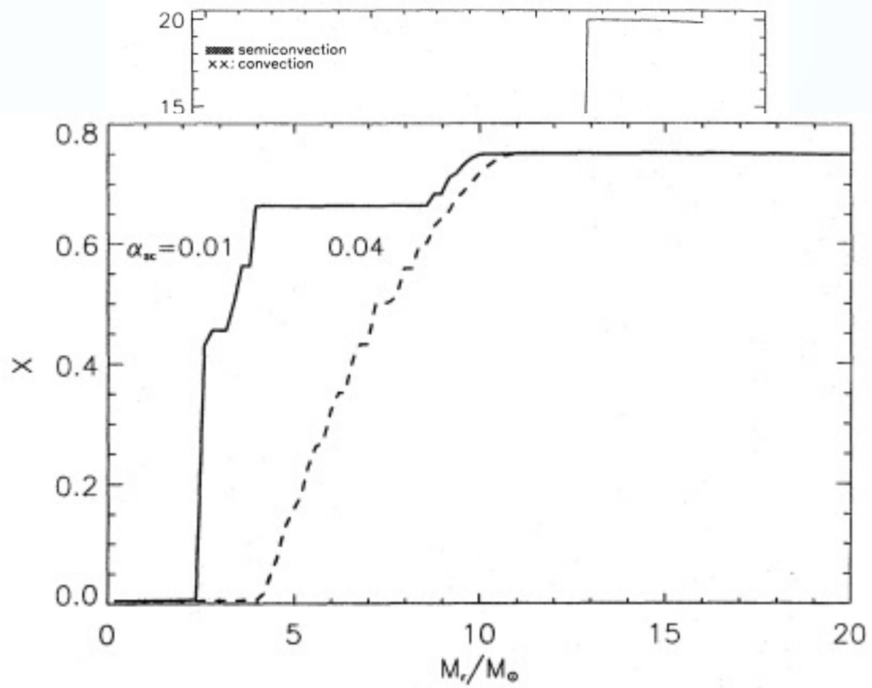
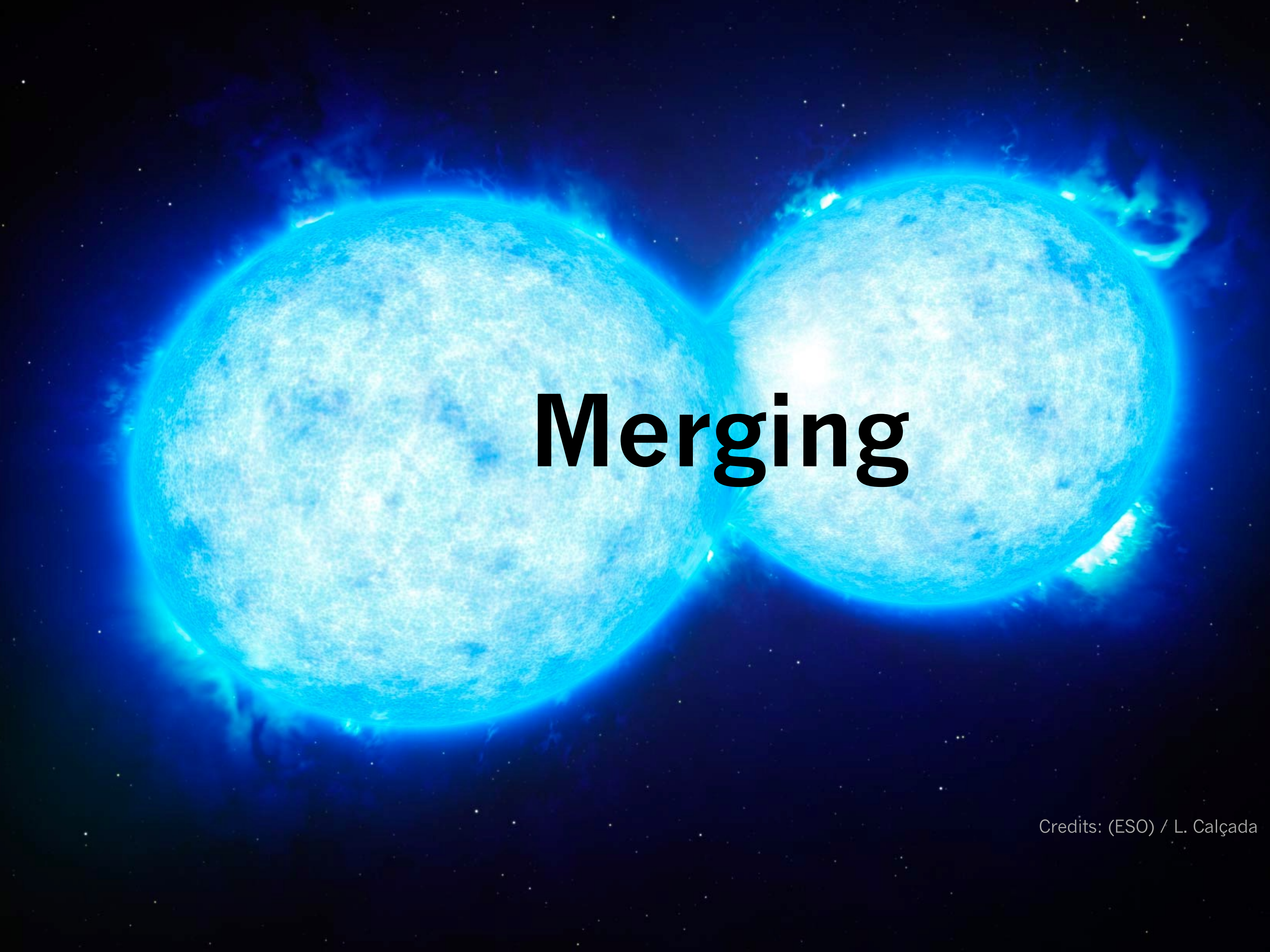


Fig. 2. Hydrogen profile at the end of core hydrogen burning of a $12M_\odot$ star accreting $8M_\odot$ for the cases $\alpha_{sc} = 0.04$ (Seq. #1) and $\alpha_{sc} = 0.01$ (Seq. #3). The central helium mass fraction at onset of accretion is $Y_{acc} = 0.7$. Due to the rejuvenation, the hydrogen profile in the case $\alpha_{sc} = 0.04$ is similar to that of a $20M_\odot$ single star

Fig. 1a and b. Convective and semiconvective structure of a $12M_\odot$ star which accretes $8M_\odot$ of matter at a time where its central helium mass fraction is $Y_{acc} = 0.7$. In Fig. 1a (upper panel), the semiconvective efficiency parameter is adopted as $\alpha_{sc} = 0.01$ (Seq. #3), while in Fig. 1b it is $\alpha_{sc} = 0.04$ (Seq. #1)

Merging

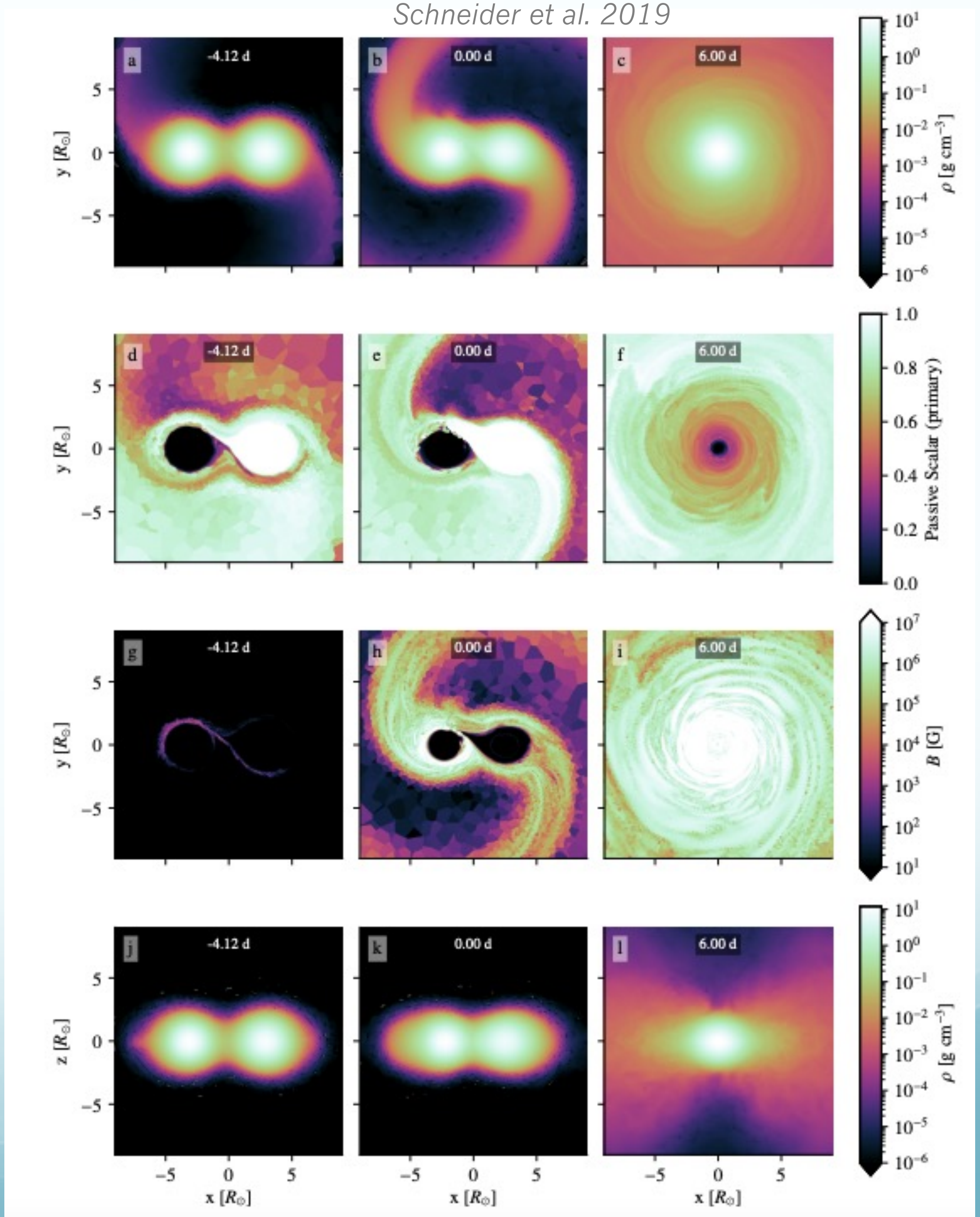


Credits: (ESO) / L. Calçada

Hydrodynamical simulations of merging

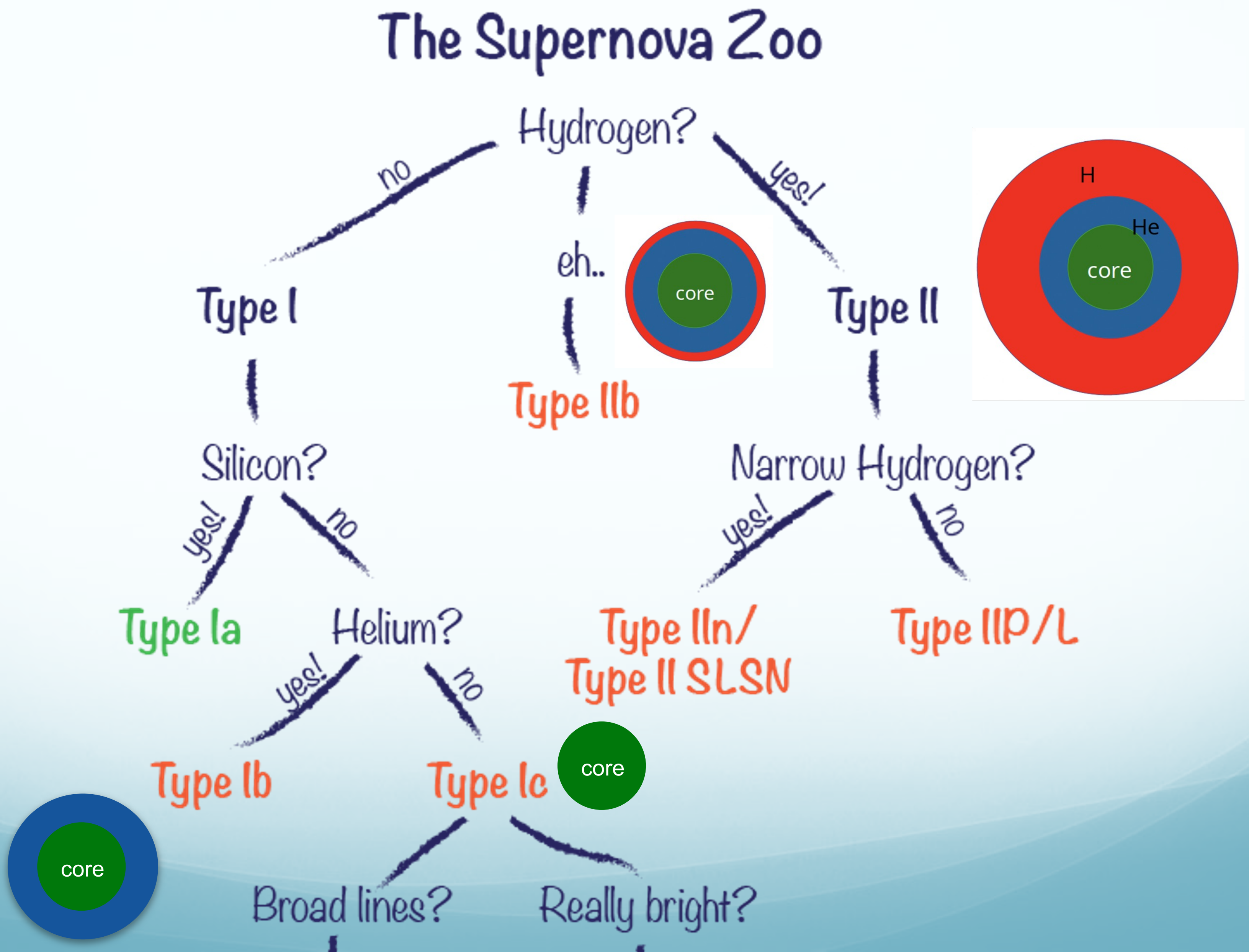
Looking the binary face-on
(from above the orbit)

Schneider et al. 2019

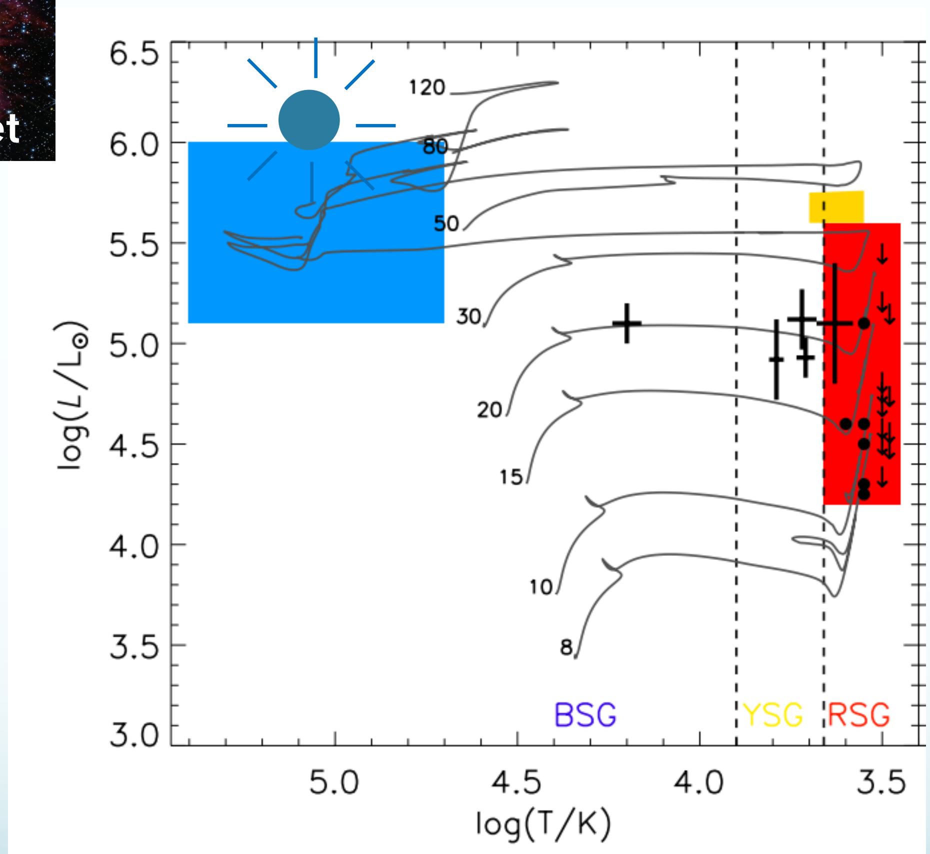


Looking the binary edge-on
(from inside the orbital plane)

Core collapse supernovae



Core collapse supernovae

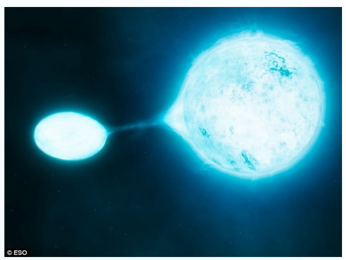


Type II SN (H-rich)

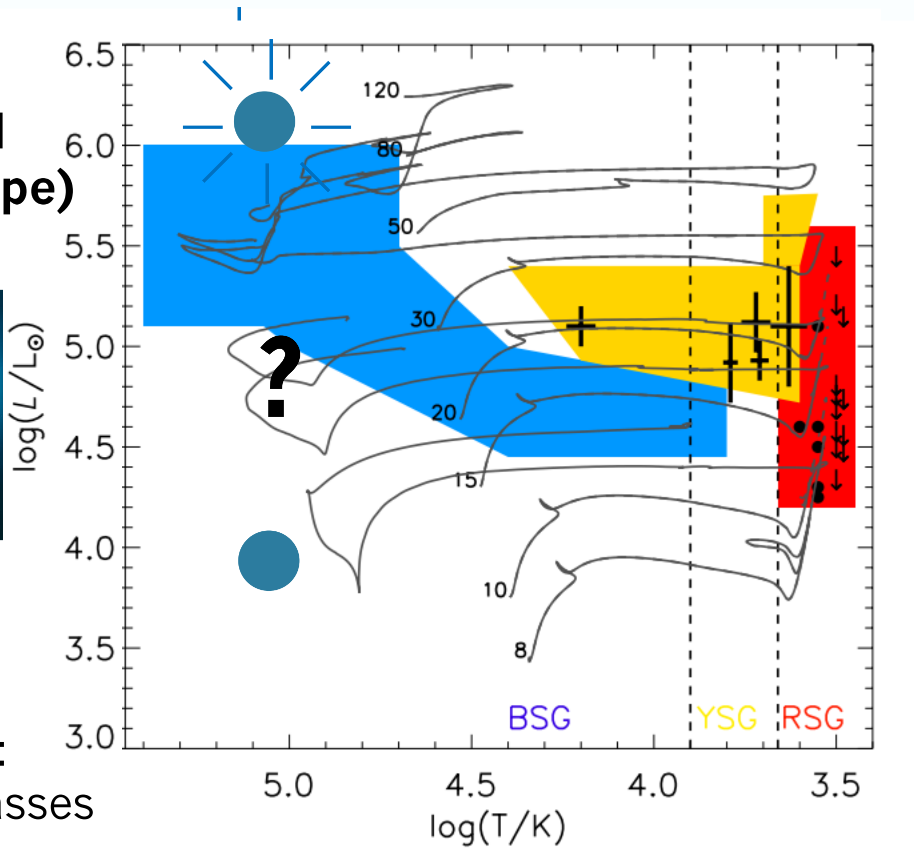
Figure from Eldridge+2013

Core collapse supernovae from binaries

Type Ib, Ic SN (stripped-envelope)



BINARIES!



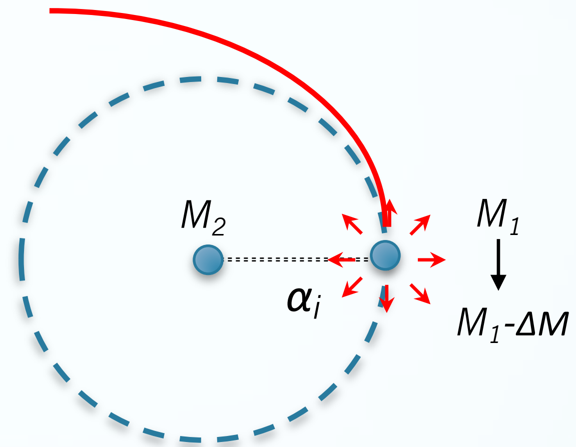
Type II SN (H-rich)

Figure from Eldridge+2013

help explain also:

- Low ejecta masses
- High relative rates
- binary companions detected

Supernova in binaries?
Possible binary disruption



$$a_i = (1 - e)a_f$$

periastron distance

$$v^2 = G(M_1 + M_2)\left(\frac{2}{r} - \frac{1}{a}\right)$$

Velocity in eccentric orbit

$$\frac{G(M_1 + M_2)}{a_i} = \frac{G(M_1 + M_2 - \Delta M)}{a_f}\frac{1 + e}{1 - e}$$

eq. (10.2) Pols notes

$$e = \frac{\Delta M}{M_1 + M_2 - \Delta M}$$

eq. (10.3) Pols notes

For e>1: $\Delta M > (M_1 + M_2)/2$

if no intrinsic kick at the compact object during the collapse

But intrinsic kicks during the supernova explosion

(due to asymmetries in the explosion)

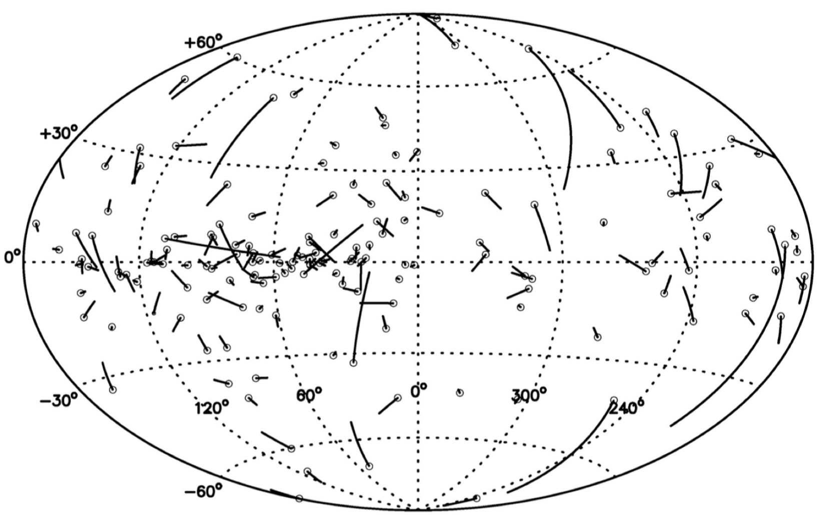
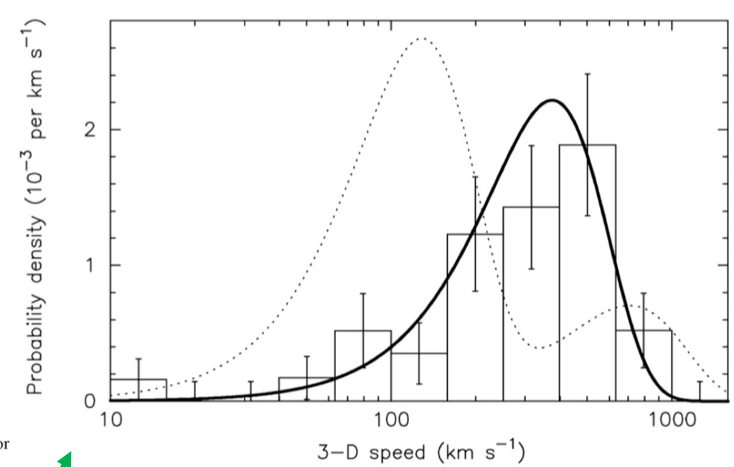
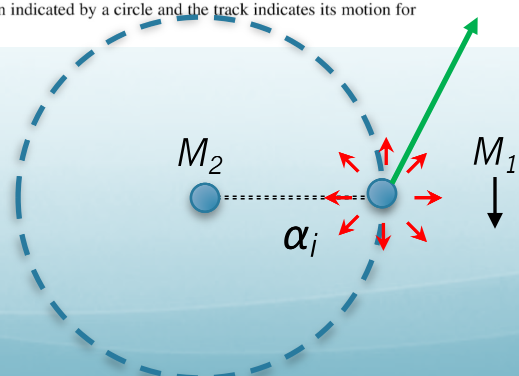
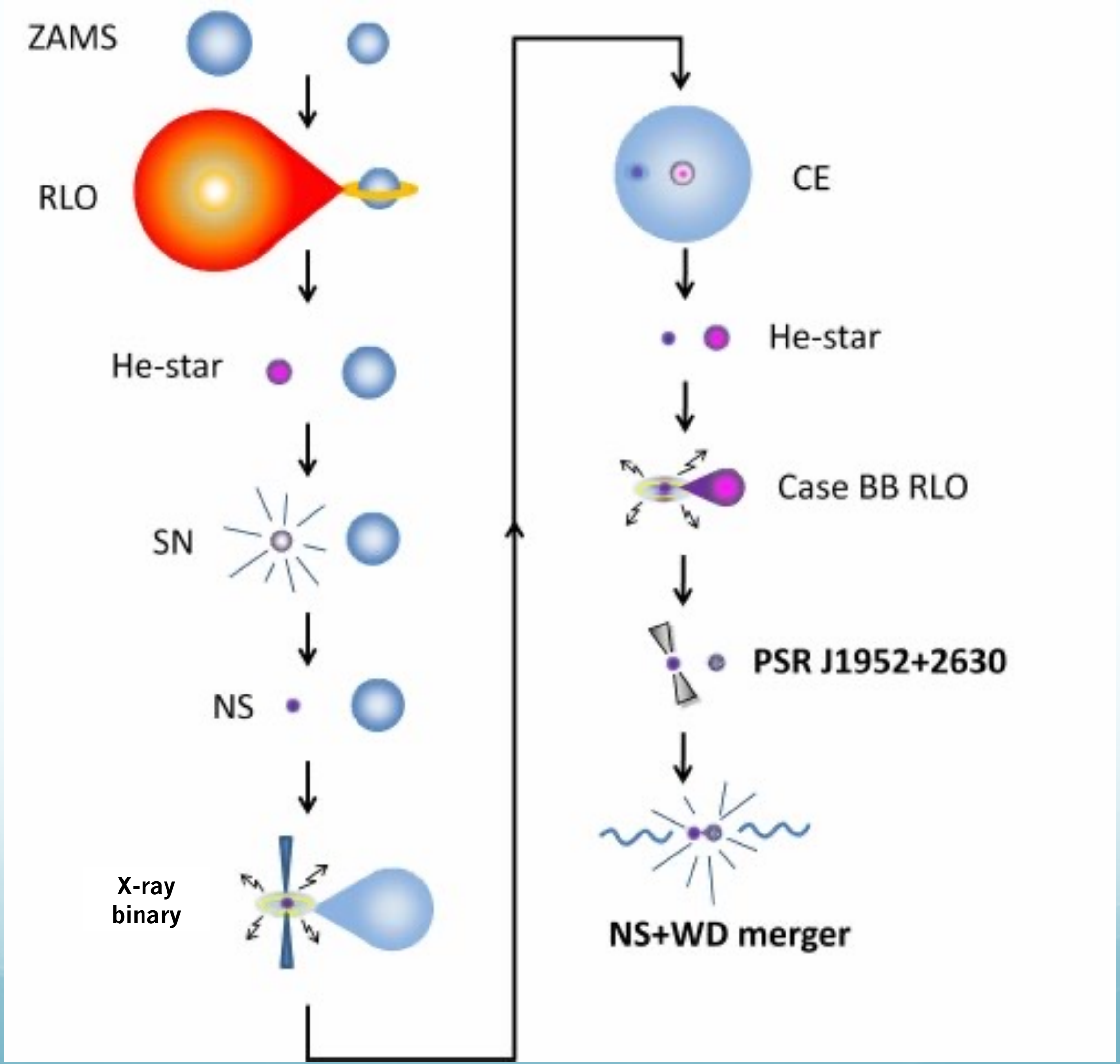


Figure 1. The Galactic motions of the pulsars in our sample. A pulsar is currently at the position indicated by a circle and the track indicates its motion for the last 1 Myr assuming no radial velocity.

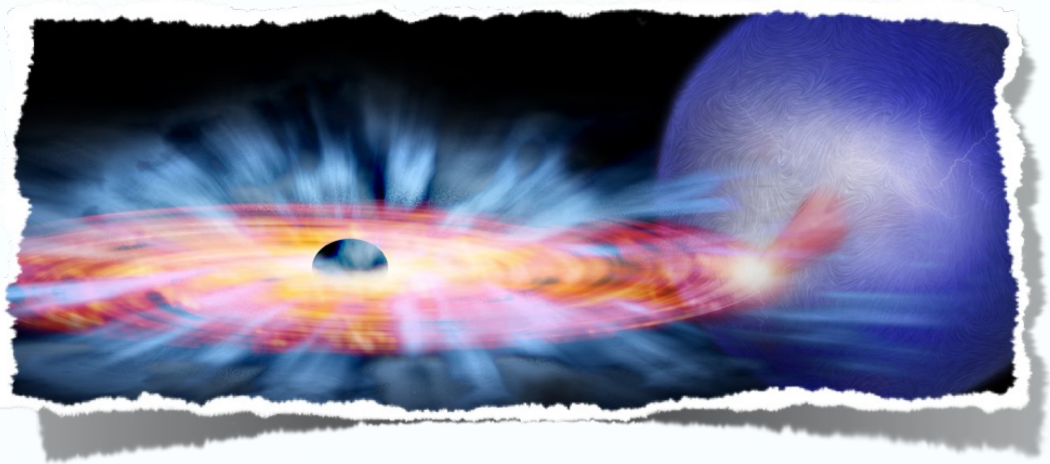




If the binary survives the SN and it does get disrupted

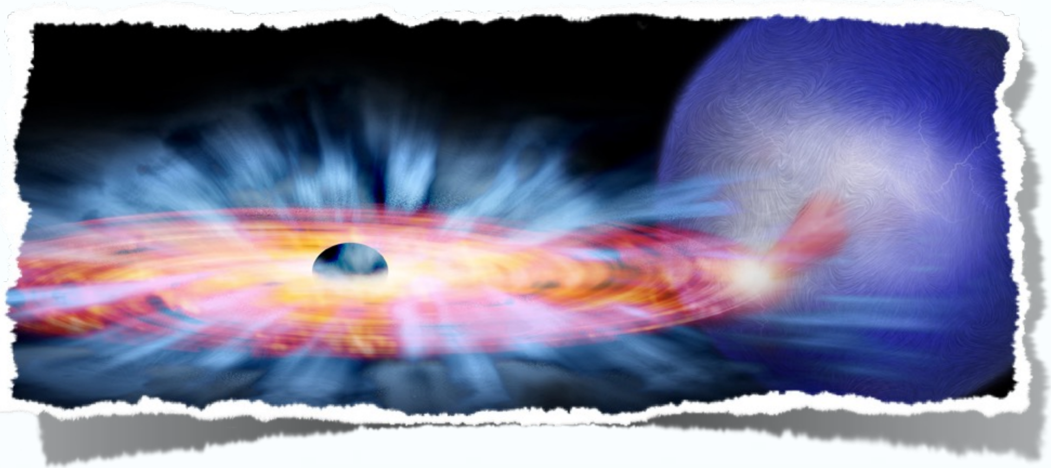


If binary survives the supernova: Potentially X-ray binary



$$E_{\mathrm{grav}} = \frac{GM_{\mathrm{co}}m}{R_{\mathrm{co}}} \approx \frac{10^{20}\mathrm{erg}}{\mathrm{gram\ of\ m}} \qquad E_{\mathrm{nuc}} = 0.007mc^2 \approx \frac{6 \cdot 10^{18}\mathrm{erg}}{\mathrm{gram\ of\ m}}$$

If binary survives the supernova: Potentially X-ray binary

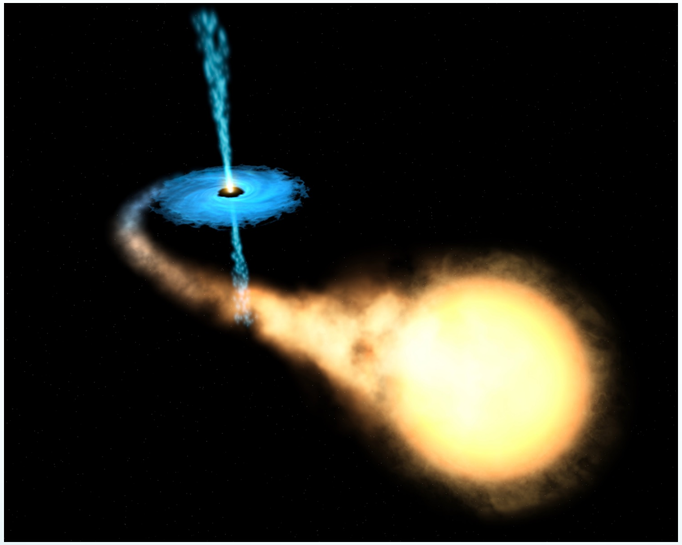


$$L = \frac{\mathrm{d}E_{\mathrm{grav}}}{\mathrm{d}t} = \frac{GM_{\mathrm{co}}\dot{m}}{R_{\mathrm{co}}}$$

$$\approx 2 \cdot 10^{36} \left(\frac{\dot{m}}{10^{-10}\mathrm{M}_\odot/\mathrm{yr}}\right)(M_{\mathrm{co}}/\mathrm{M}_\odot)(10\ \mathrm{km}/\mathrm{R}_{\mathrm{co}})\ \mathrm{erg\ s}^{-1}$$

$$\begin{aligned} L_{\mathrm{Edd}} &= 4\pi G M m_{\mathrm{p}} c/\sigma_{\mathrm{T}} \\ &\cong 1.3 \times 10^{38} (M/M_\odot)\ \mathrm{erg\ s}^{-1} \end{aligned}$$

If binary survives the supernova: Potentially X-ray binary



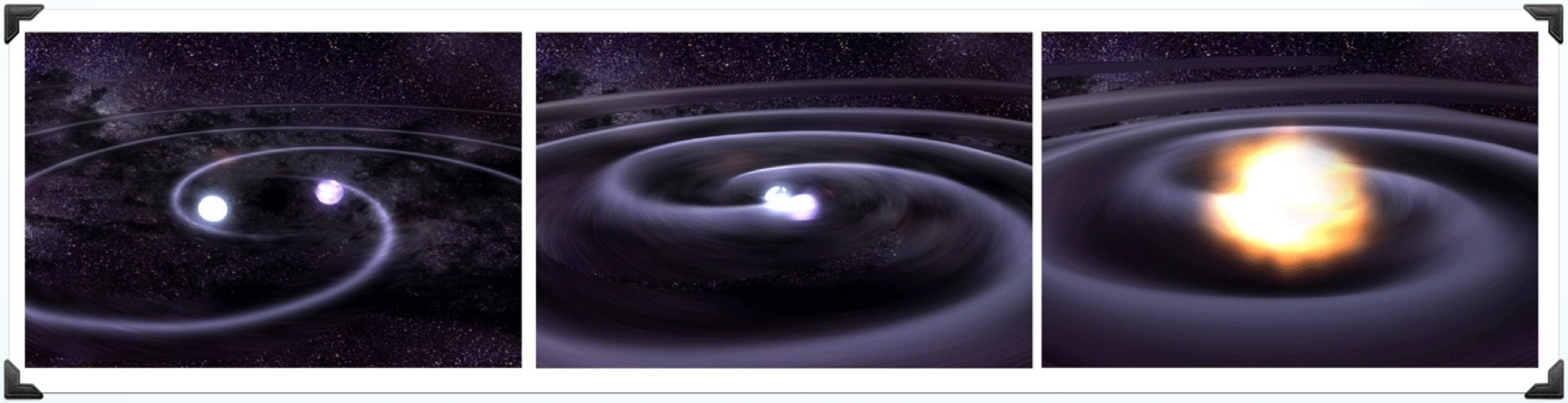
Low mass X-ray binary

- Low mass donor
- Roche lobe overflow

High mass X-ray binary

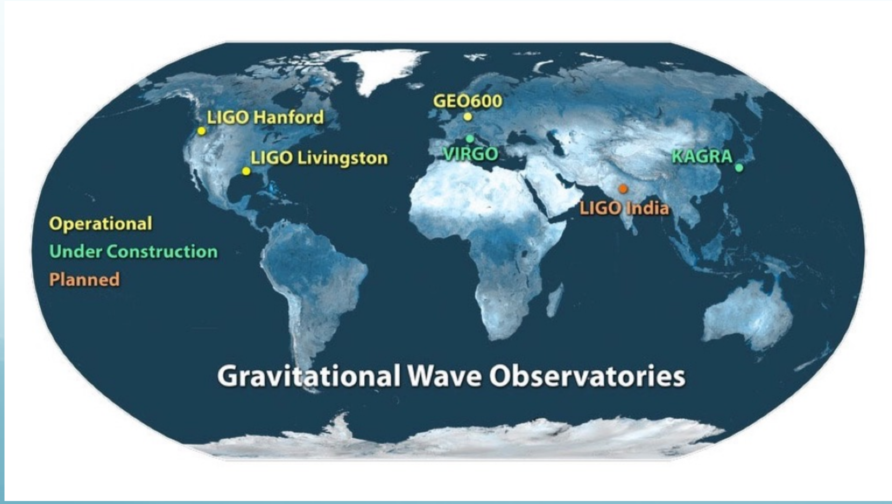
- High mass donor
- Wind-fed accretion

Gravitational waves from coalescing compact objects!



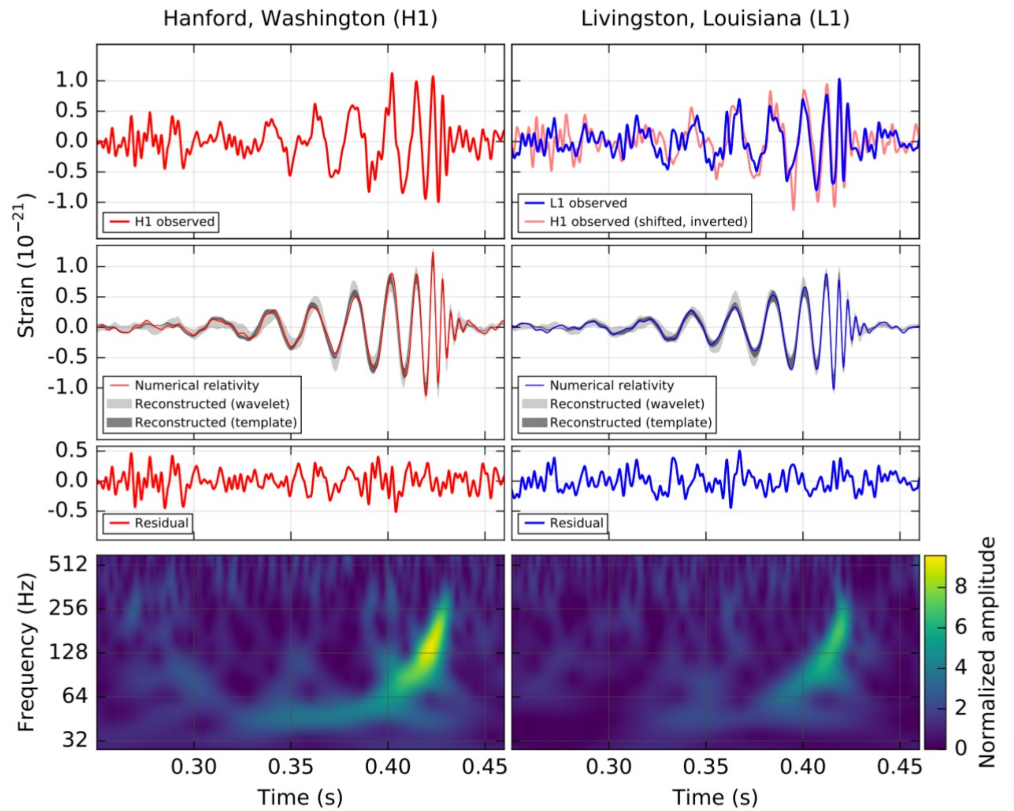
Laser interferometer

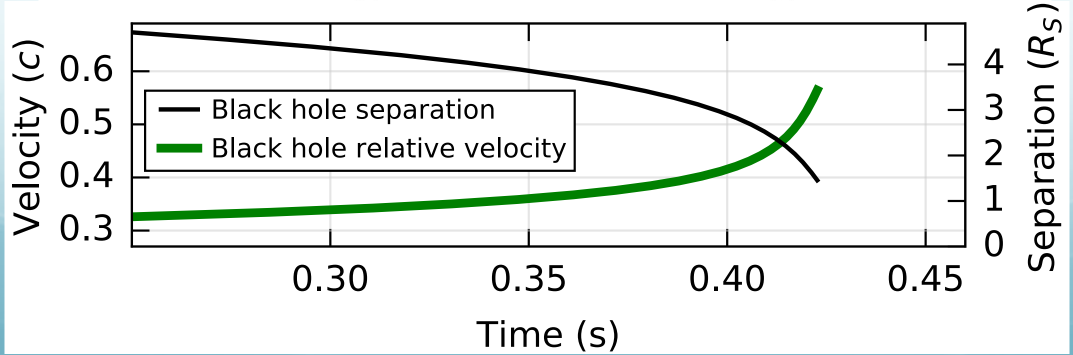
LIGO observatories in the United States



First detection of binary black holes merging

GW150914





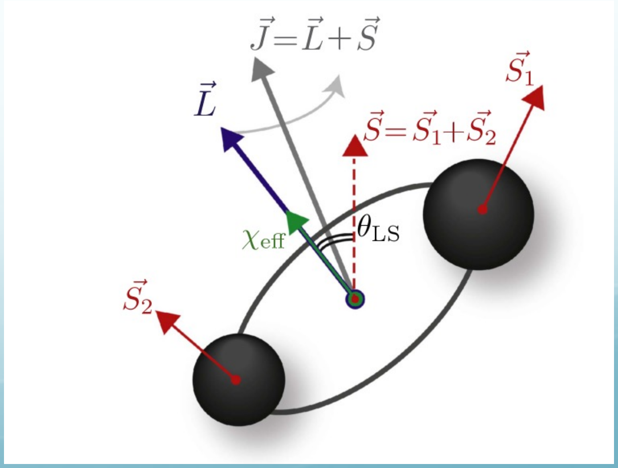
Two important observational constraints

Chirp mass

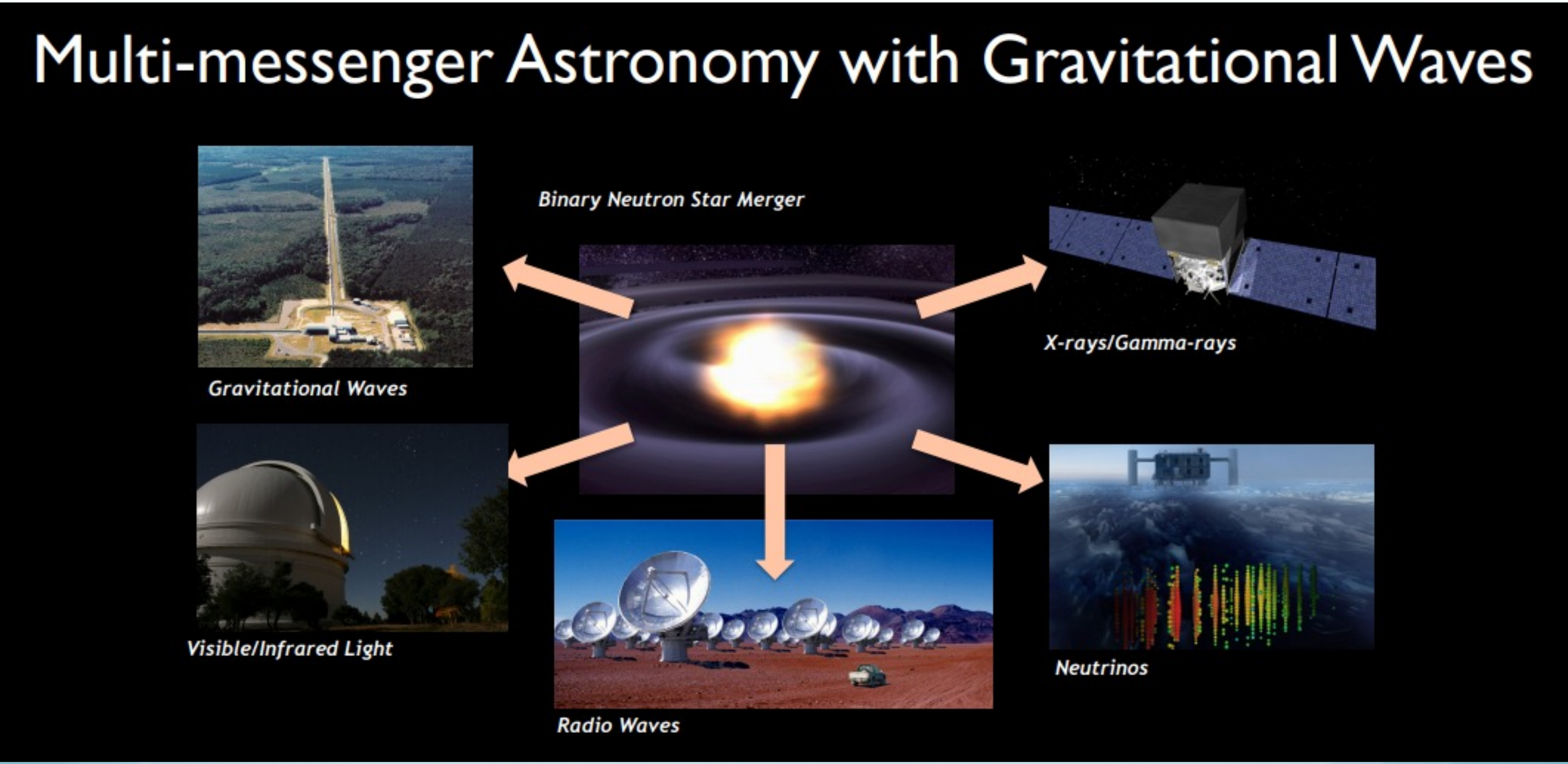
$$M_c = \frac{(m_1 m_2)^{3/5}}{(m_1+m_2)^{1/5}}$$

Effective inspiral spin parameter

$$\chi_{\text{eff}} = \frac{m_1\bar{S}_1 + m_2\bar{S}_2}{m_1+m_2}\,\hat{\boldsymbol{L}}$$



Electro-magnetic counterpart in double neutron star mergers

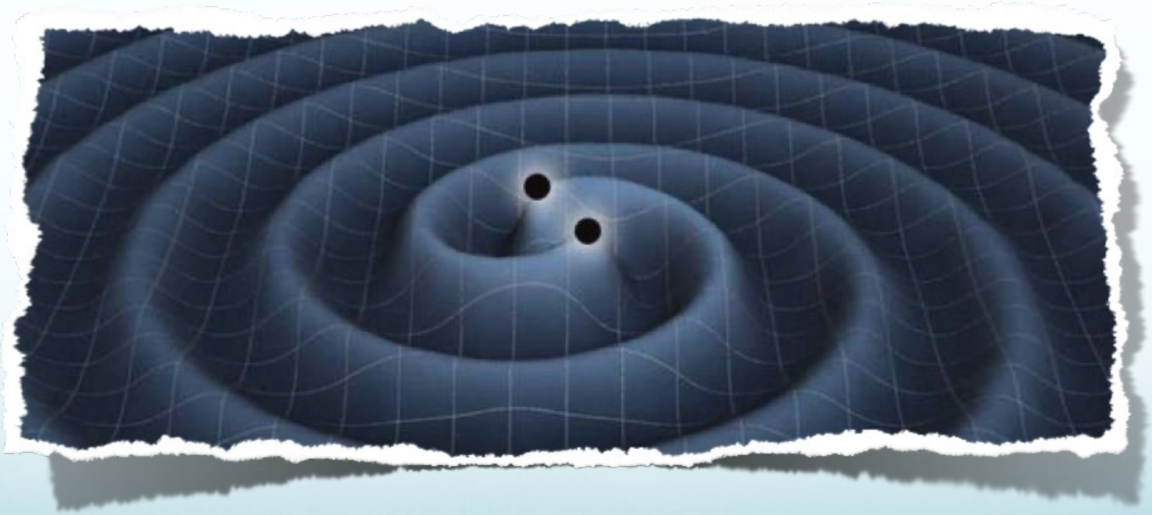


e.g. GW170817

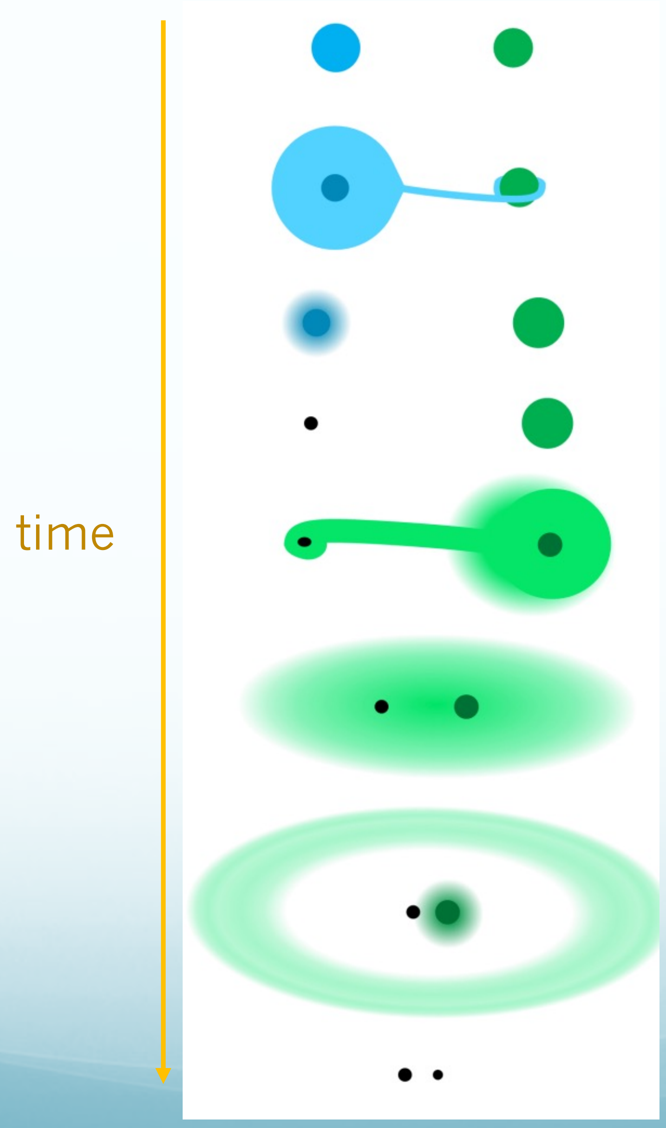
Image credit: Laura Cadonati, Georgia Tech LIGO Scientific Collaboration

How do we find compact objects in close orbits?

- Orbits of ~10-100s $R_{\odot}$
- Progenitor radii of ~1000 $R_{\odot}$

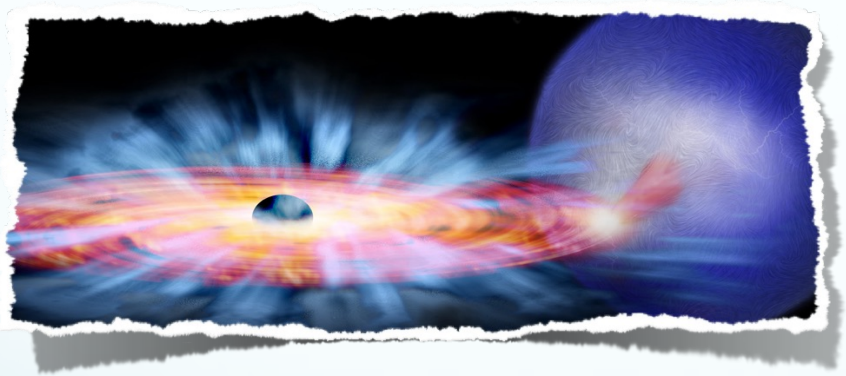


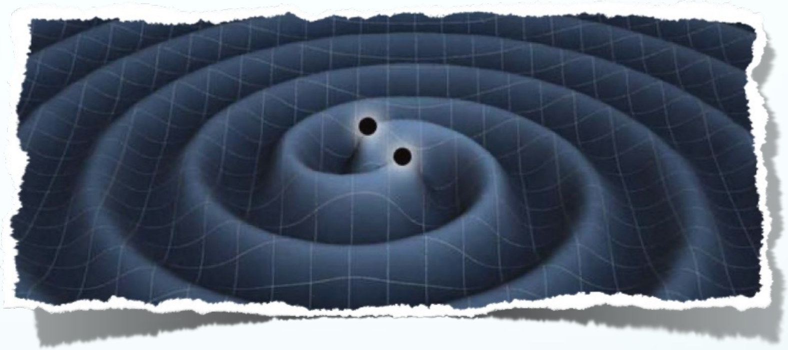
How do we find compact objects in close orbits?



Stellar black holes are observed in binary systems!

- Else they are invisible
  - (unless gravitational lensing)





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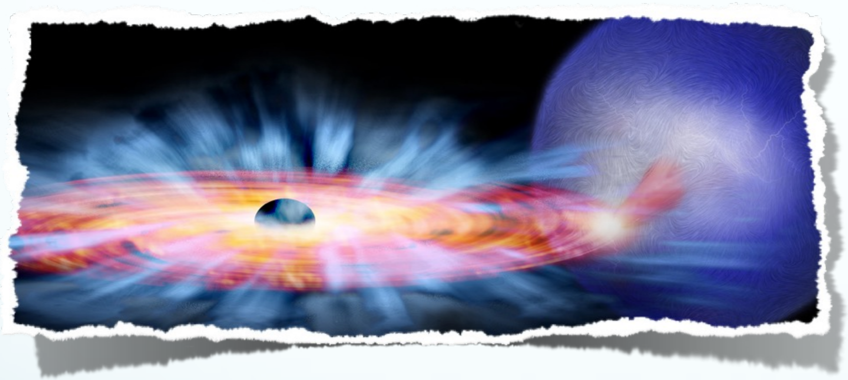


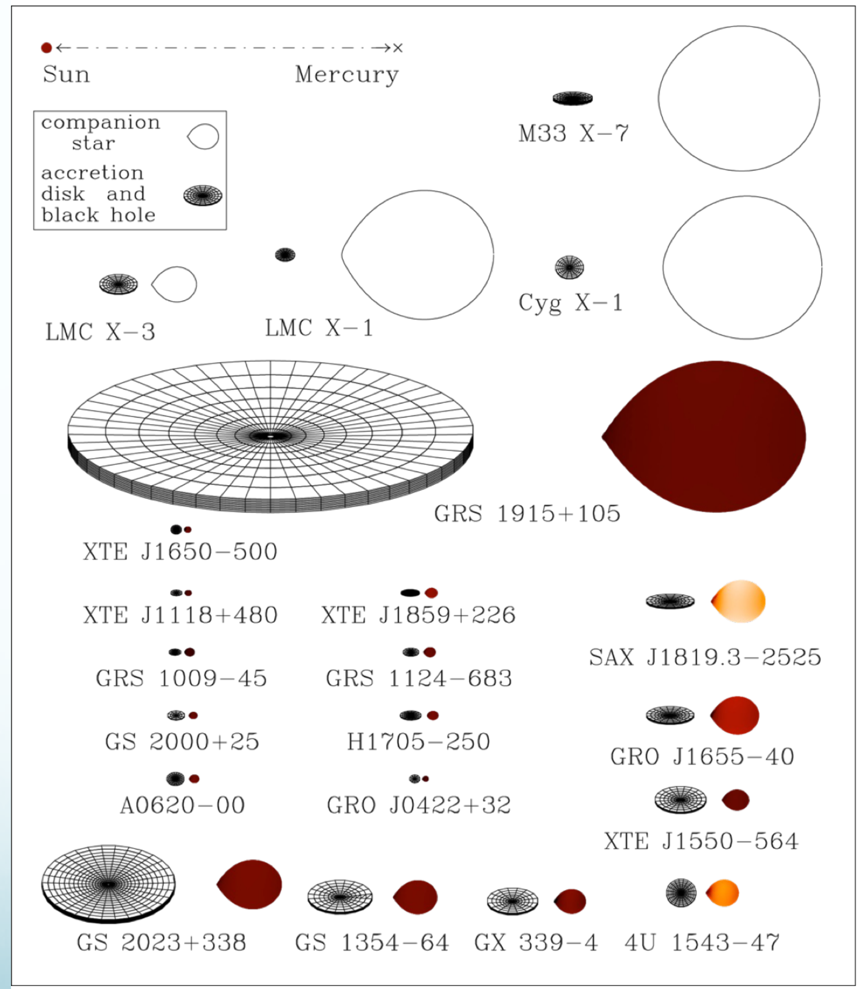
•Bolton (1972), Webster & Mardin (1972)

•21 BHs with dynamical mass measurement

McClintock &Remillard 2006, Casares & Jonker 2014

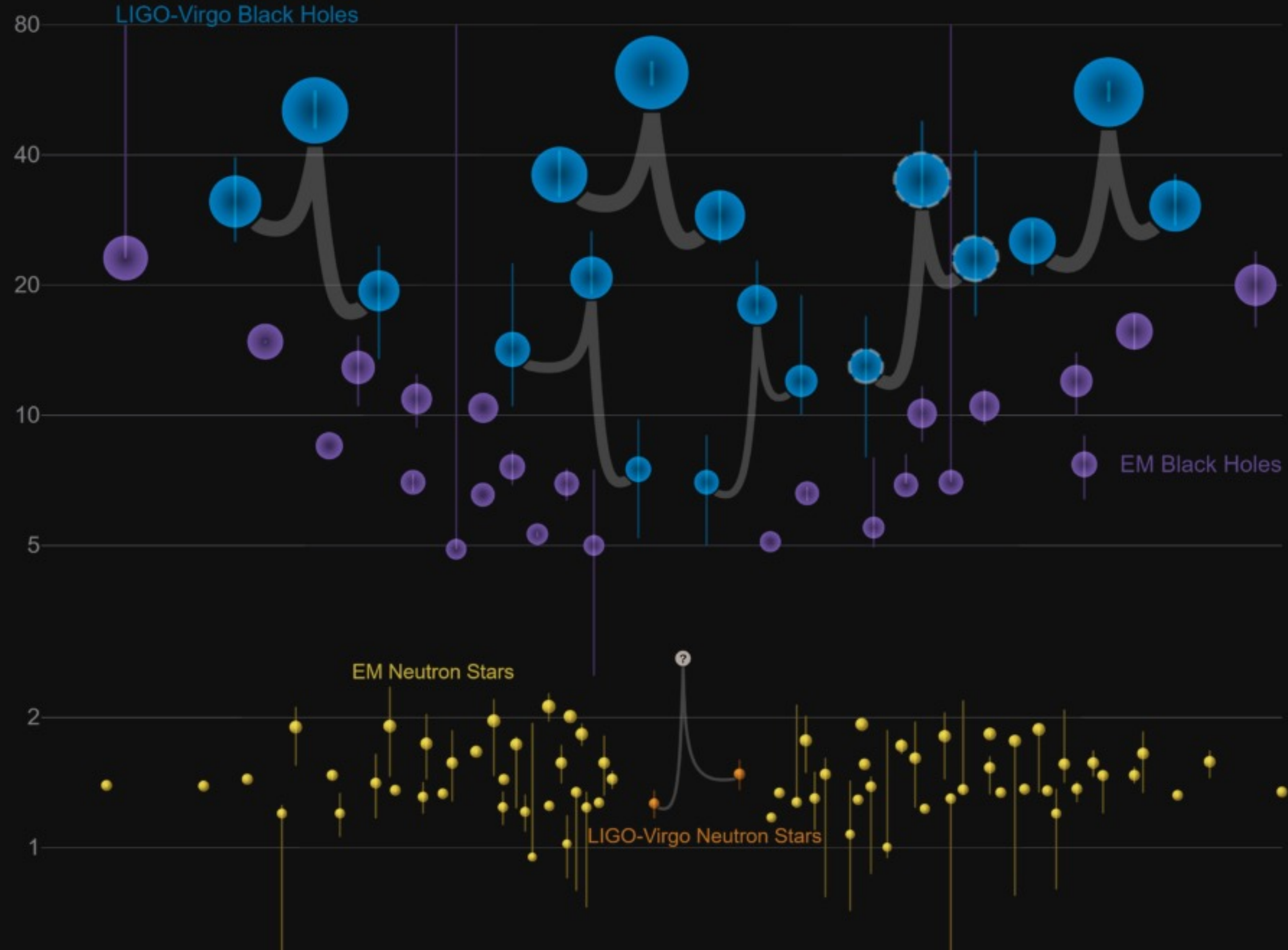
•18 Galactic, 3 in nearby galaxies

•33 more BH candidates

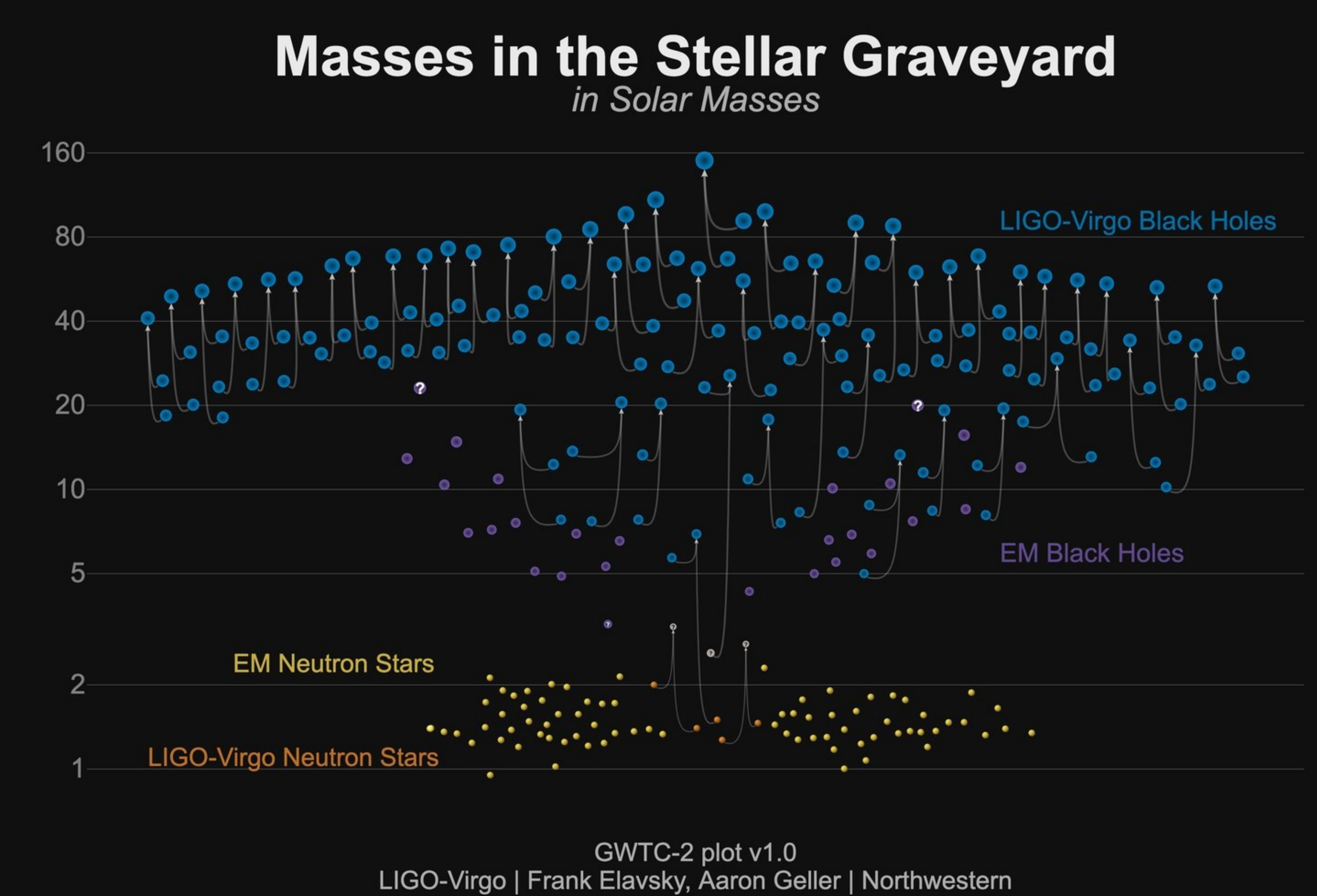


Masses in the Stellar Graveyard

in Solar Masses



Doubling the sample of known BH masses




Questions?