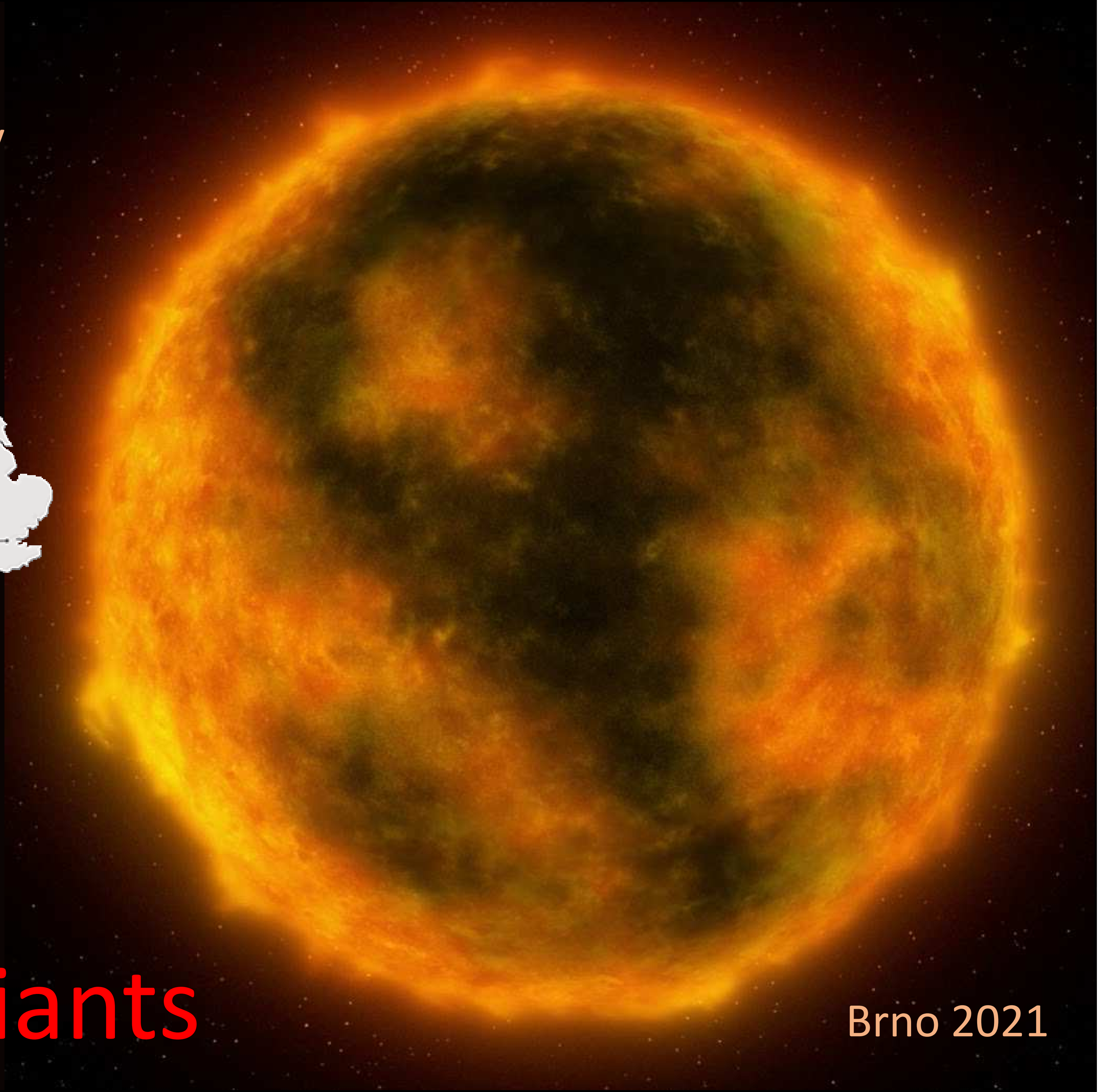
Jacco van Loon
Keele University

Red supergiants

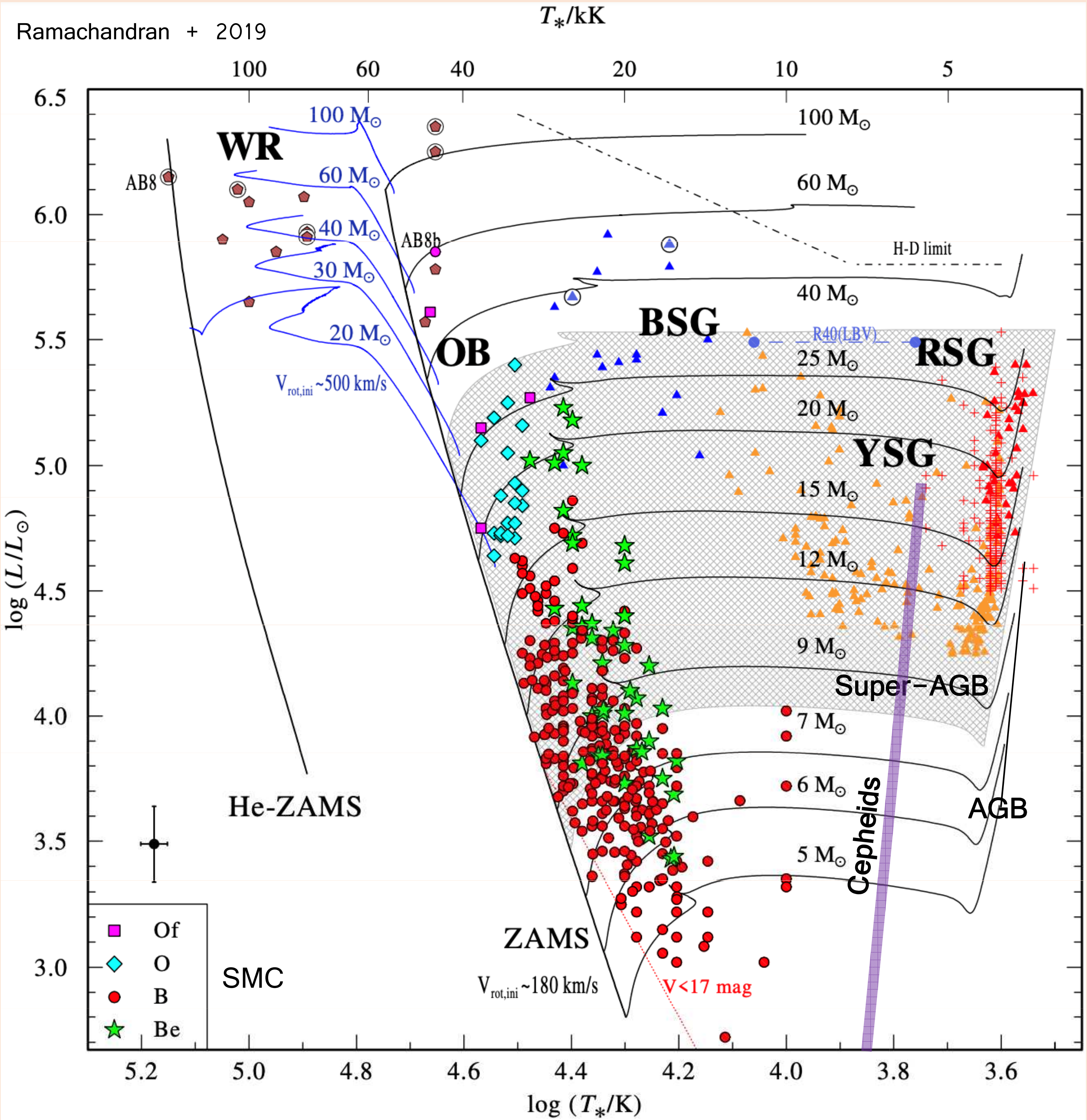


Brno 2021

Plan for this seminar:

- What are red supergiants… and what are not?
- Why should we care about red supergiants?
- Mass loss from red supergiants
- The peculiar (or typical?) case of Betelgeuse
- Red supergiants as progenitors of supernovae
- My favourite red supergiant

Feel free to interrupt! We can discuss binary evolution…



What are red supergiants?

- Post-OB evolution ("inverse Henyey"), core He burning, convective mantle ("inverse Hayashi")

… and what are not?

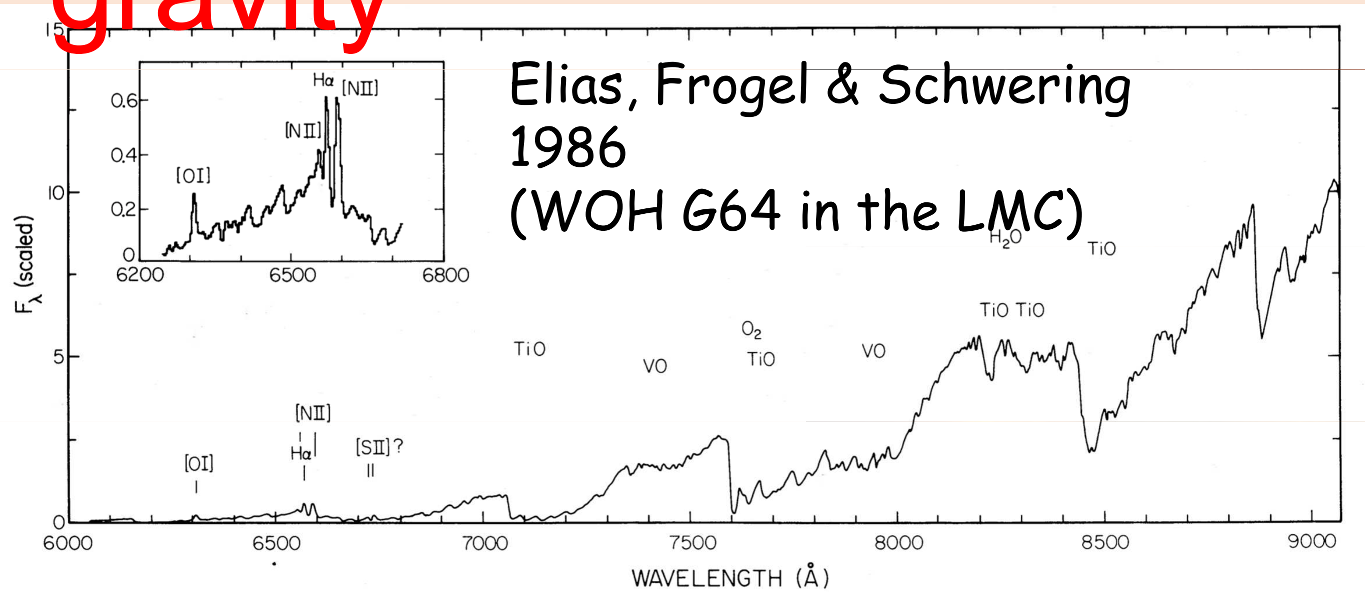
- Yellow SuperGiants (Blue Loop stars ⇒ post-YSG RSGs?)
- (shell-burning) AGB or super-AGB stars

complications

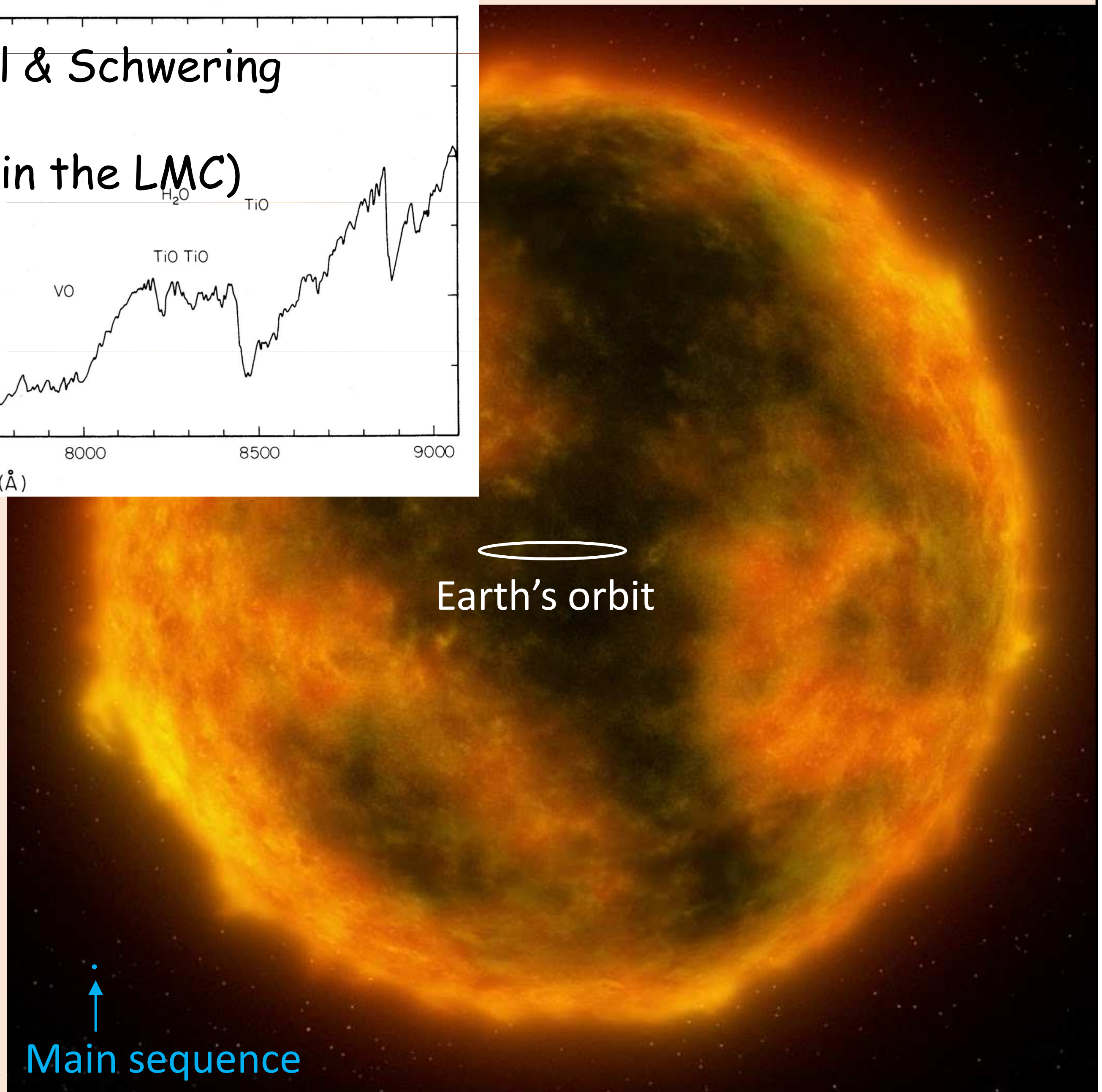
- rotation
- overshoot
- binary interaction

red ⇔ low surface temperature

supergiant ⇔ low surface gravity

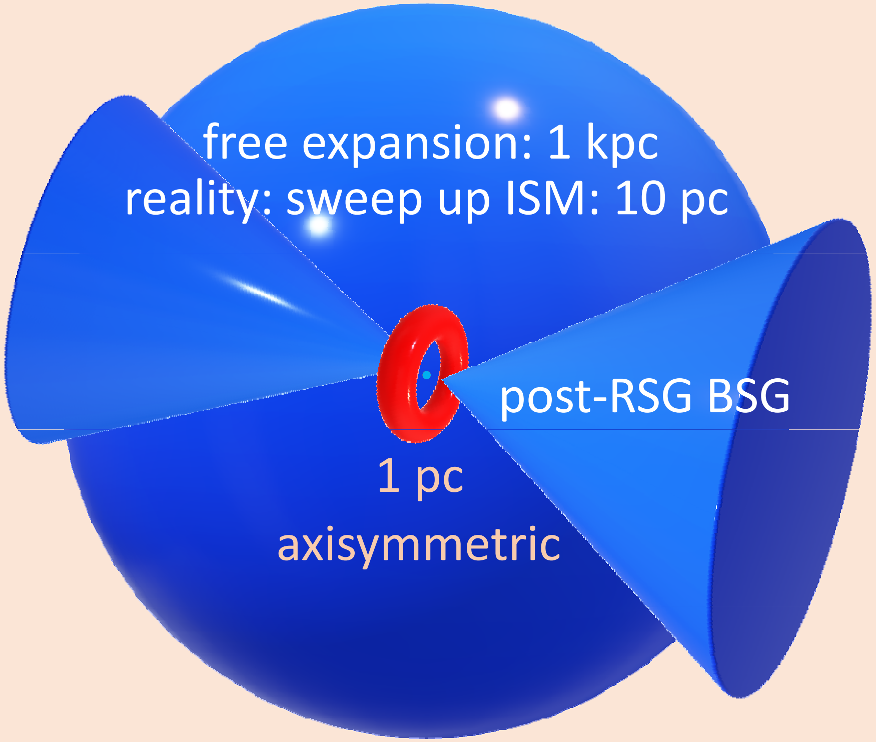


- motions of few–tens km/s
- dynamical timescales year(s)
- rotation, convection, pulsation, collapse, binary motion, wind…



Why should we care about red supergiants?

Why?	pro	con
Tracers of stellar populations	Luminous Peak around 1 µm	Rare (lifetime few % of main sequence) Complicated analysis (spectrum, variability)
Feedback on ISM	Mass return Dust production	Energetically unimportant (radiation, mechanical) Relatively little dust (< 1 % $M_\odot$) may not survive
Supernovae Neutron stars Black holes	Proven link to SNe Probable link to NSs Possible link to BHs	Limited to < 30–40 $M_\odot$ No warning of imminent SN (?) Link to black holes unproven



$$P_{ram} = \rho\, v^2$$

$$\rho = \frac{1}{4\pi r^2}\frac{dM}{dr} = \frac{1}{4\pi v^2(\Delta t)^2}\frac{dM}{vdt}$$

$$\Rightarrow P_{ram} = \frac{1}{4\pi v(\Delta t)^2}\frac{dM}{dt}$$

BSG: 10^{-6} $M_\odot$/yr, 10^6 yr, 1000 km/s
RSG: 10^{-5} $M_\odot$/yr, 10^5 yr, 10 km/s

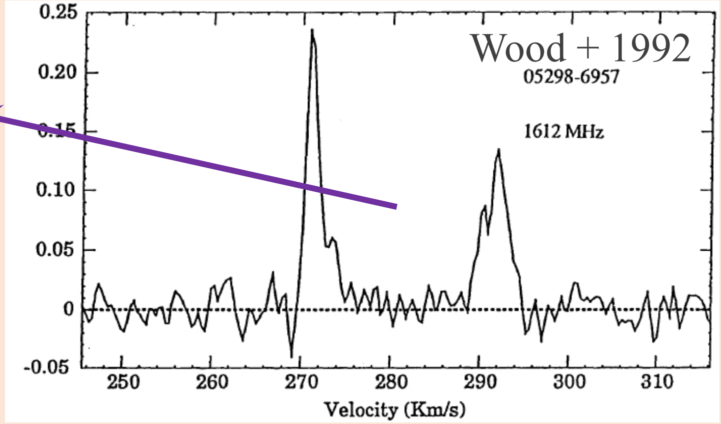
$$\Rightarrow P_{RSG\ (pc)} = 10^5 P_{BSG\ (kpc)}$$

Mass loss from red supergiants – method

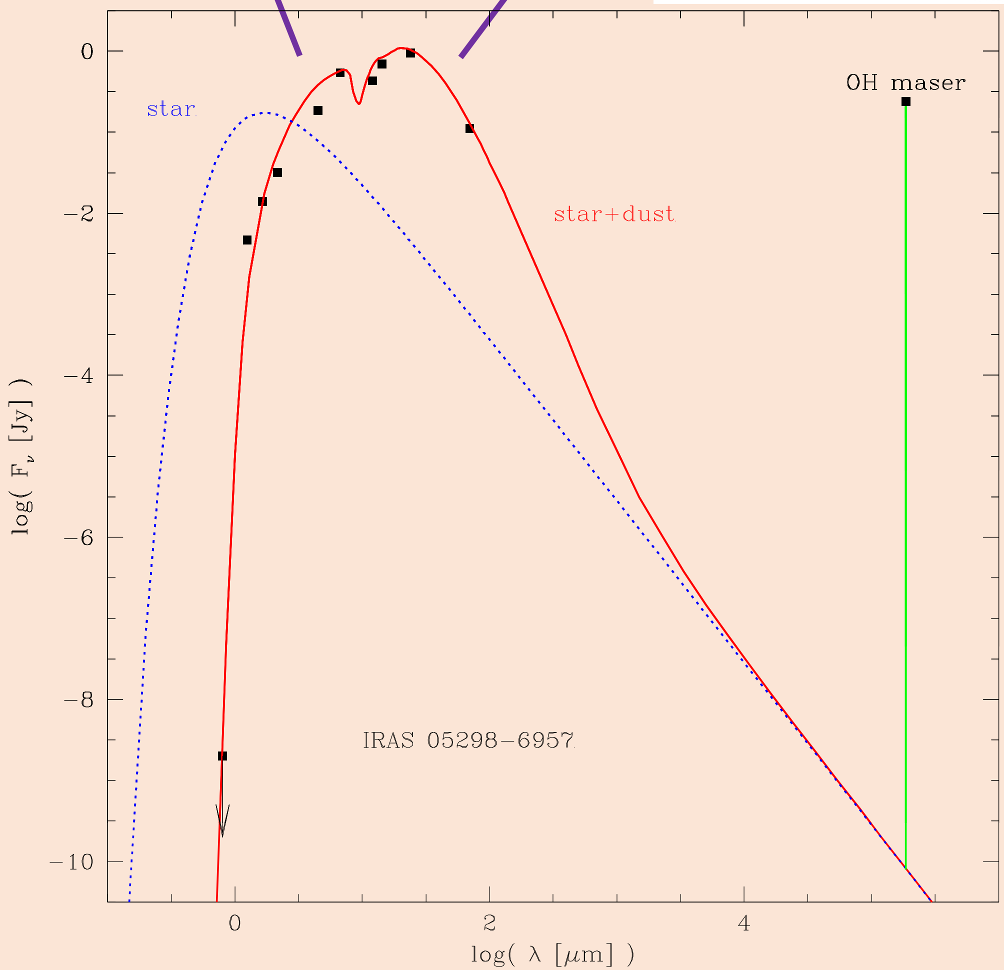
$$r_{gd}^{-\frac{1}{2}}\ L^{\frac{1}{4}} = v_{exp}$$

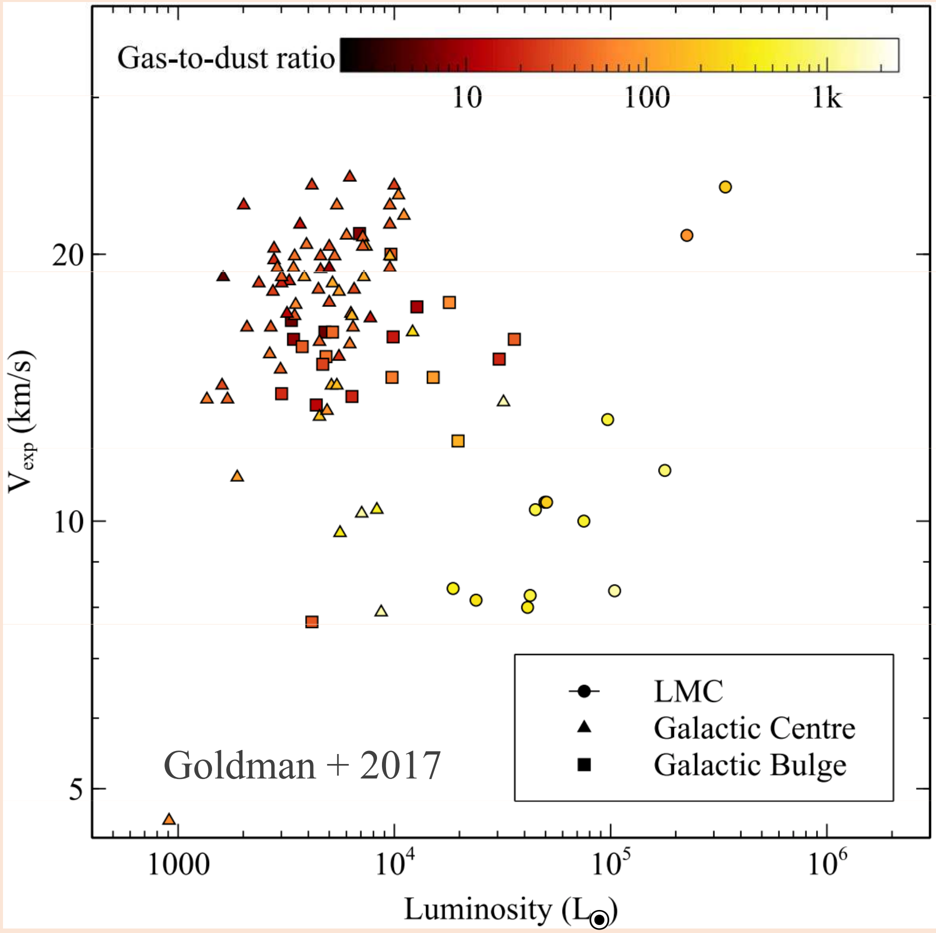
Marshall + 2004

$$\frac{dM}{dt} = \tau(\lambda)\ r_{gd}\ v_{exp}\ L^{\frac{1}{2}}$$

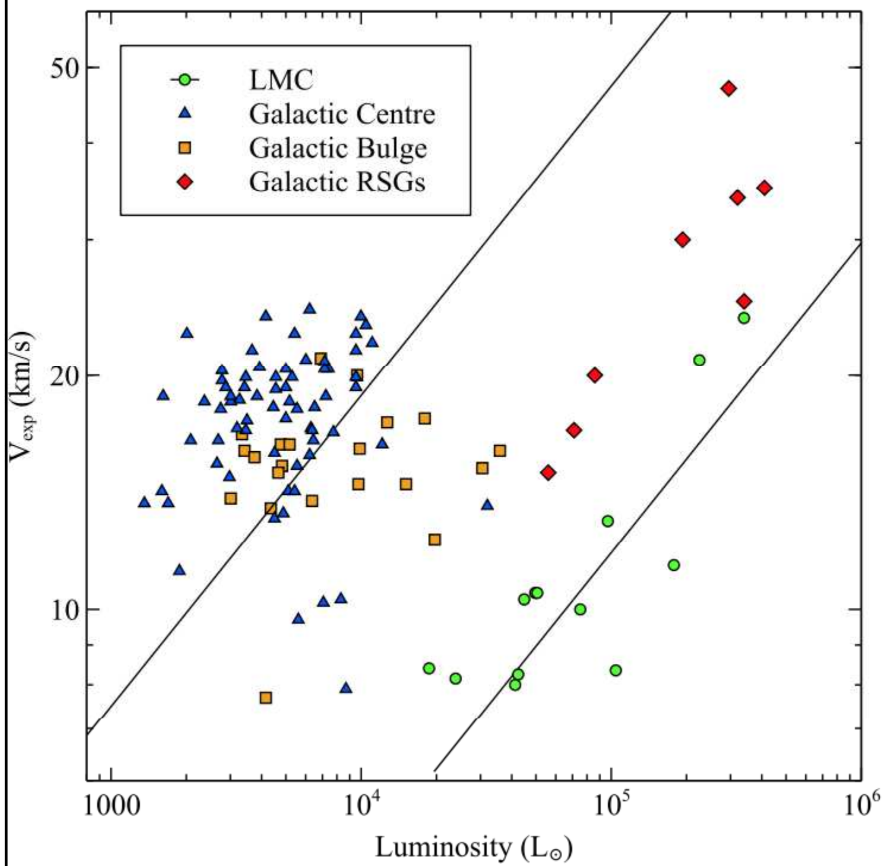


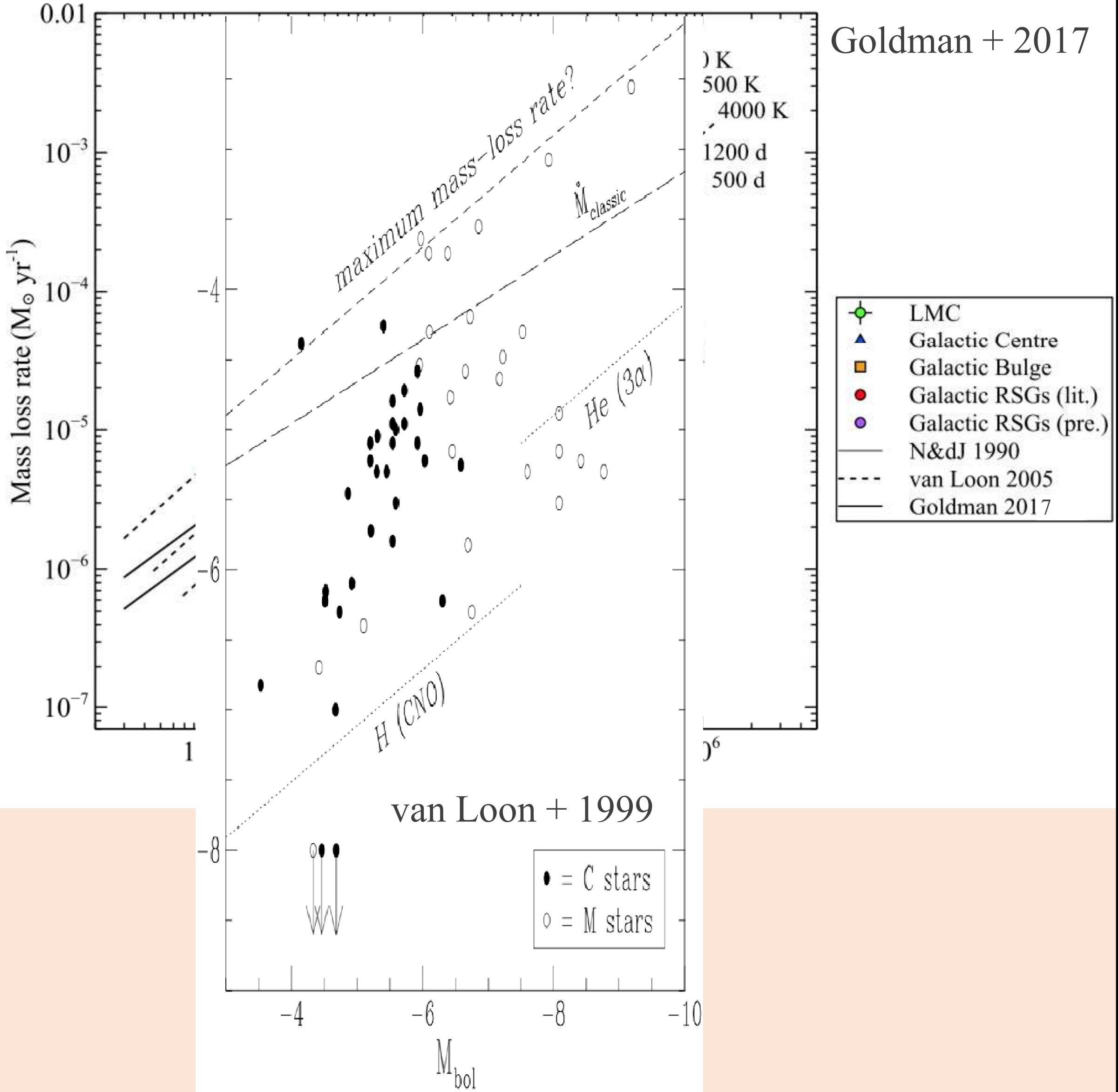
- if dusty !
- if opacities known
- if geometry known
- alternatively model atomic line profiles





Mass loss from red supergiants – results



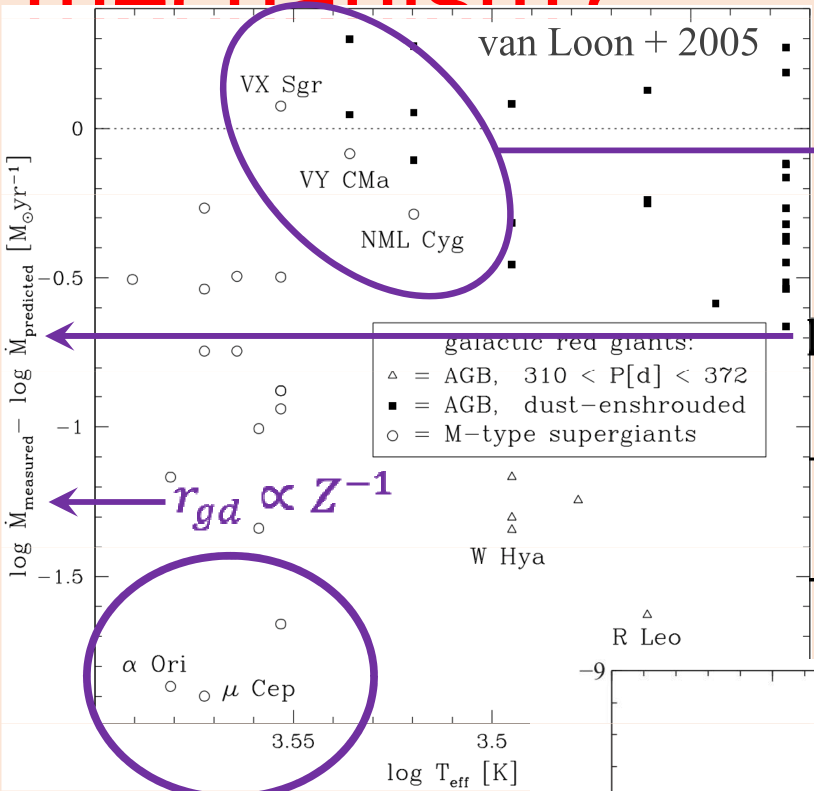


$$\log\left(\frac{dM}{dt}\right) = -5.0 + 0.9\log\left(\frac{L}{10^4}\right) + 0.75\log\left(\frac{P}{500d}\right) - 0.03\log\left(\frac{r_{gd}}{200}\right)$$

no direct metallicity dependence

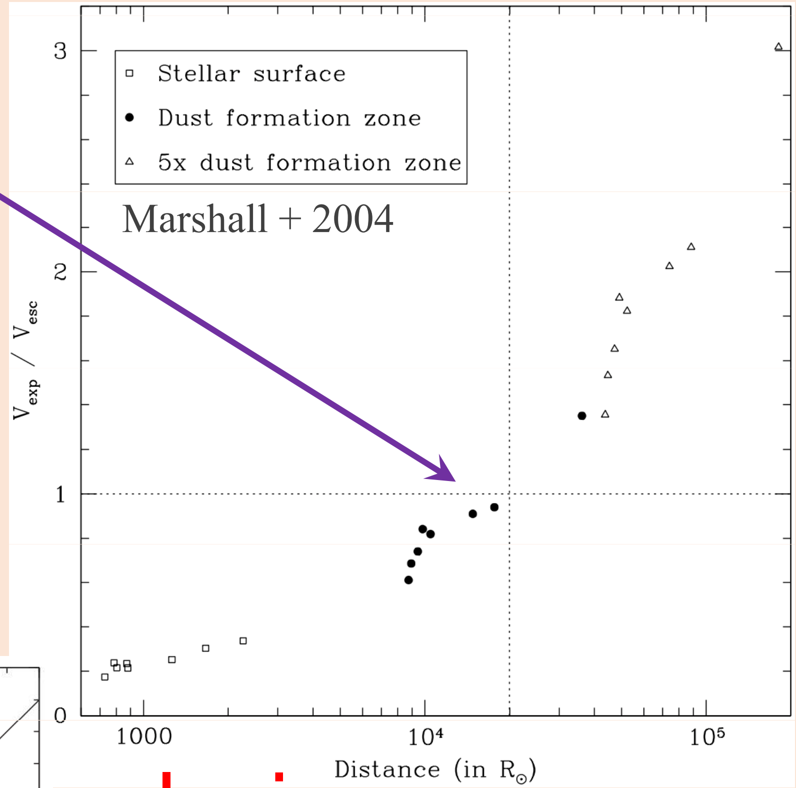
- RSG mass loss generally at nuclear burning rate
- + possible superwind

Mass loss from red supergiants – mechanism?



pulsation + dust driven mass loss?

$$\log\left(\frac{dM}{dt}\right) = -5.65 + 1.05\log\left(\frac{L}{10^4}\right) - 6.3\log\left(\frac{T_{eff}}{3500}\right)$$



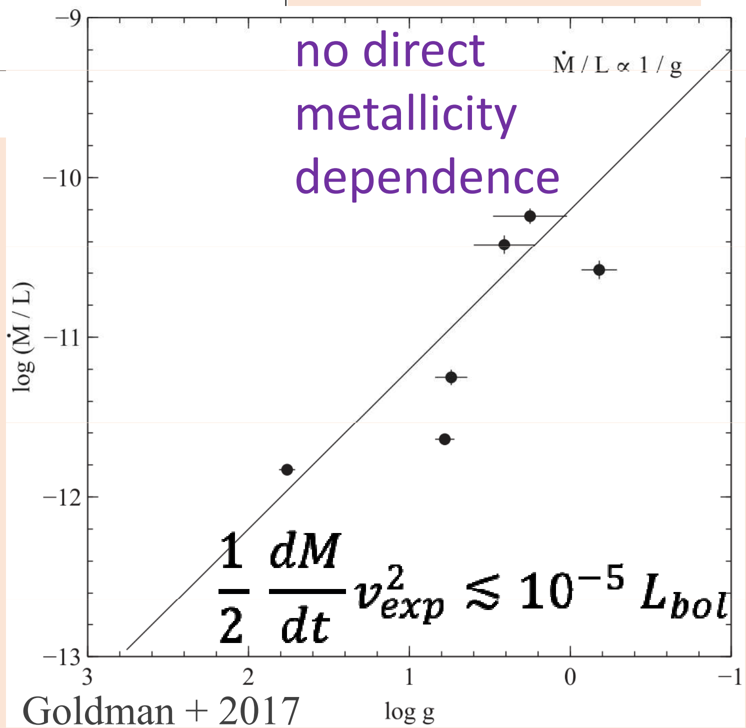
$r_{gd} \propto Z^{-1}$

abnormally high r_{gd}

chromospheric driving?

cf. $L_X \lesssim 10^{-3}\, L_{bol}$

Judge & Stencel 1991



no direct metallicity dependence

$$\frac{1}{2}\frac{dM}{dt}v_{exp}^2 \lesssim 10^{-5}\, L_{bol}$$

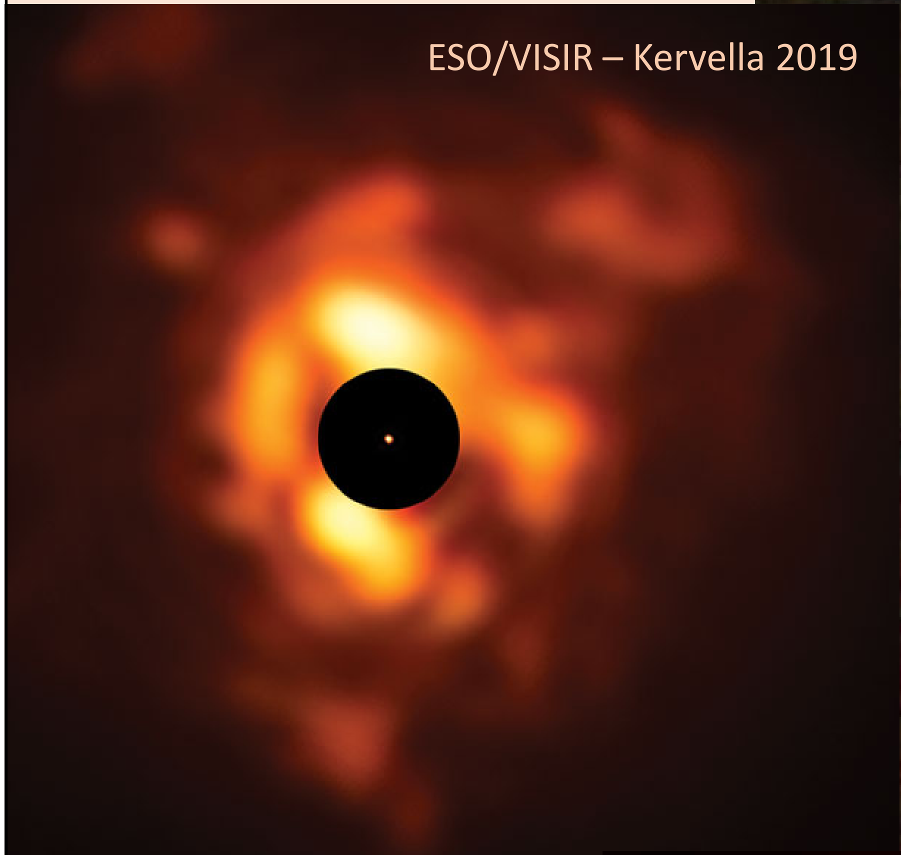
closing remark

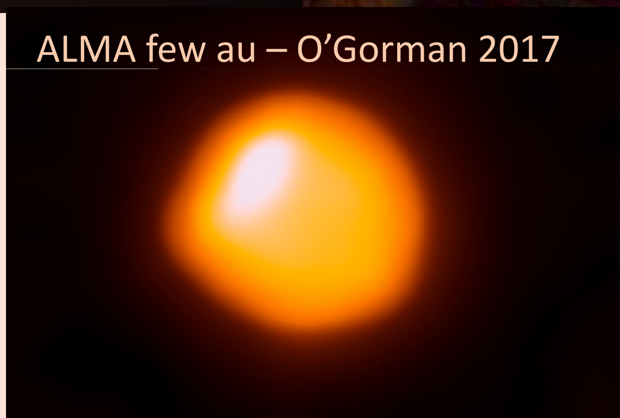
Energetically trivial

cf. when gravity does work:

- Roche Lobe overflow
- Common Envelope
- core collapse

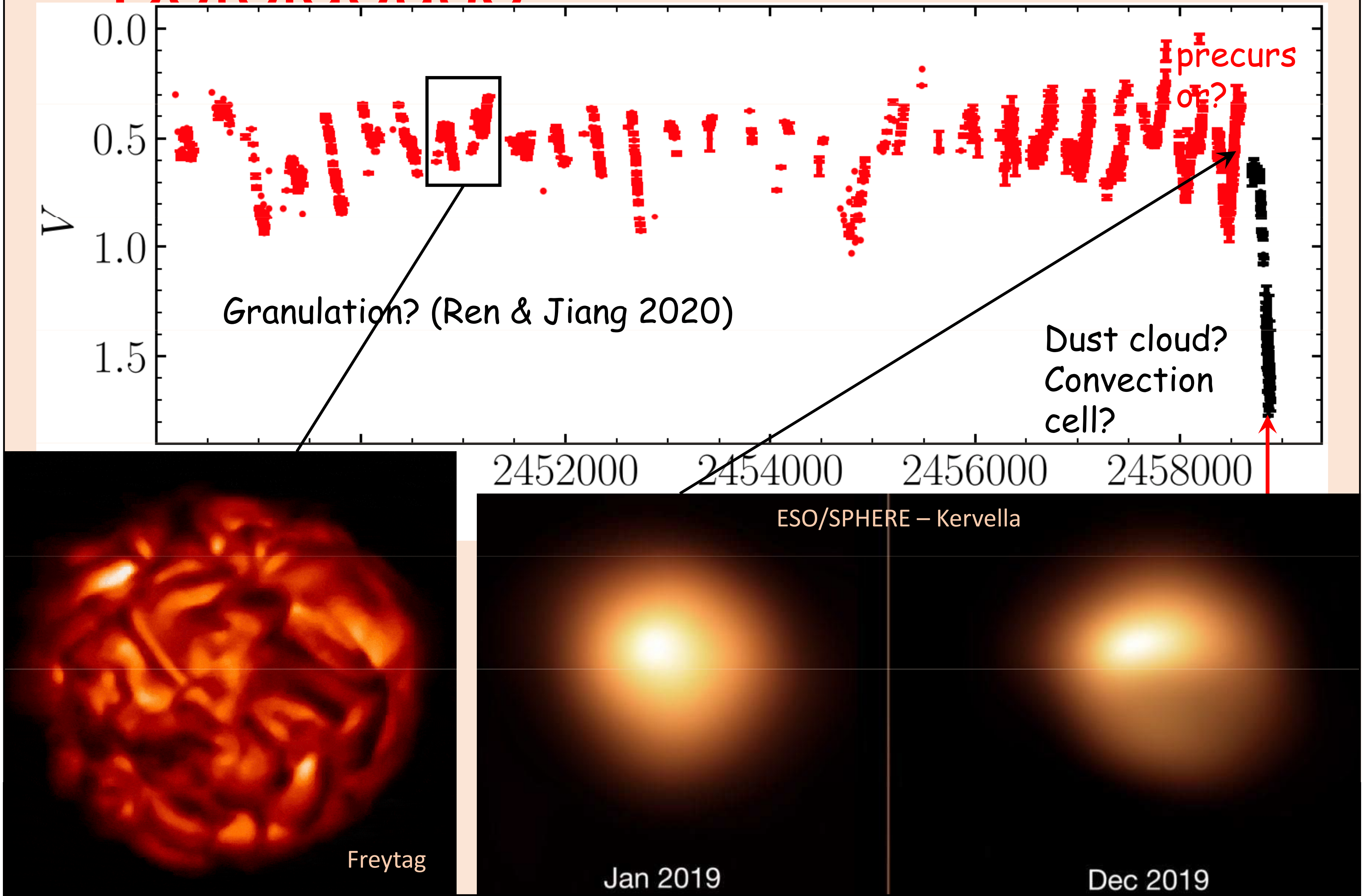
The peculiar (or typical?) case of Betelgeus



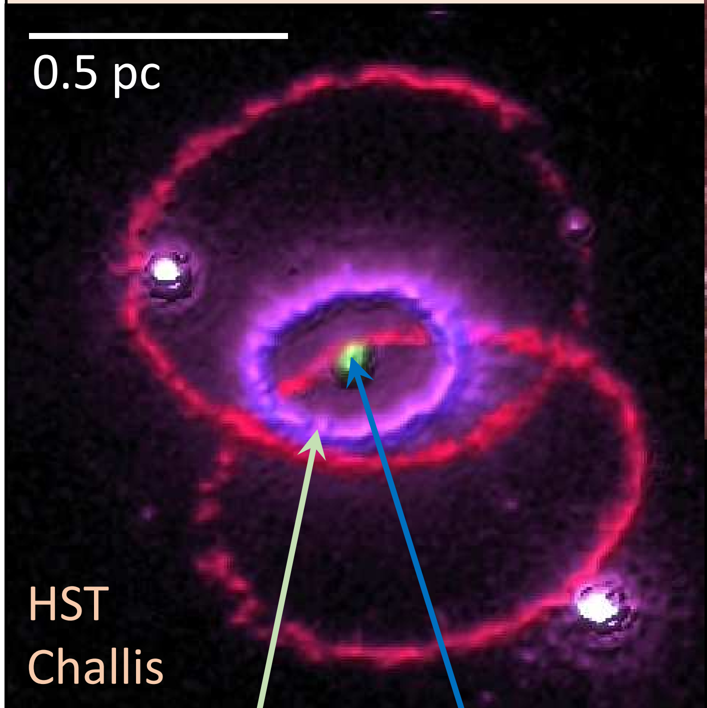


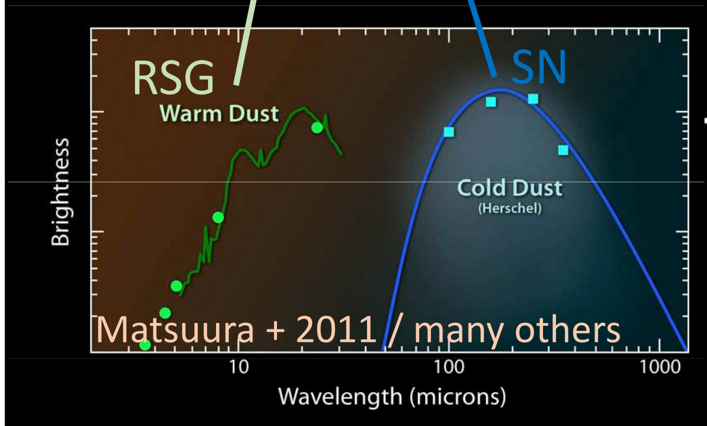
- runaway (whence?)
- fast rotator (15 km/s)
- not very dusty
- chromosphere

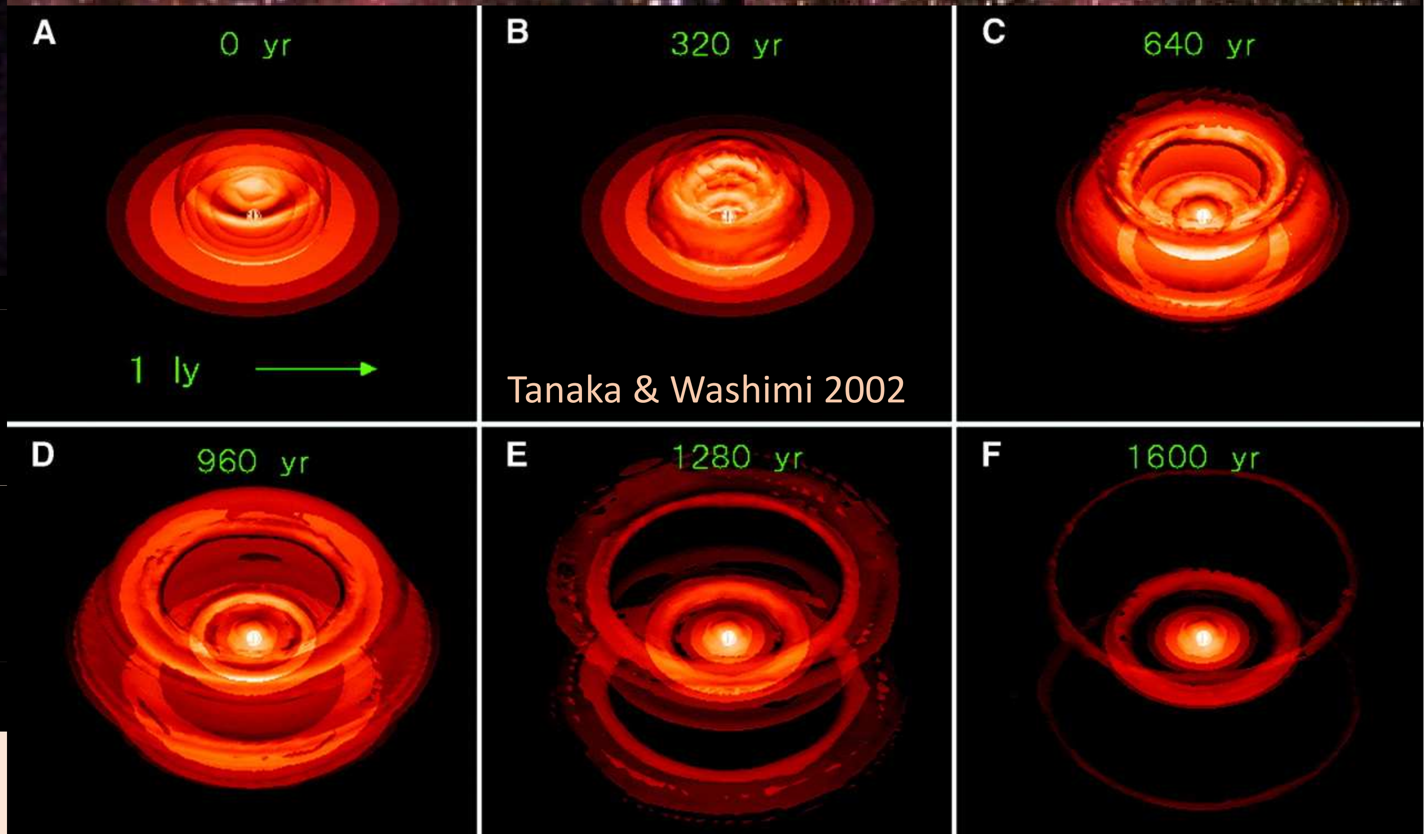
The Great Dimming of Betelgeuse



Red supergiants as progenitors of supernovae

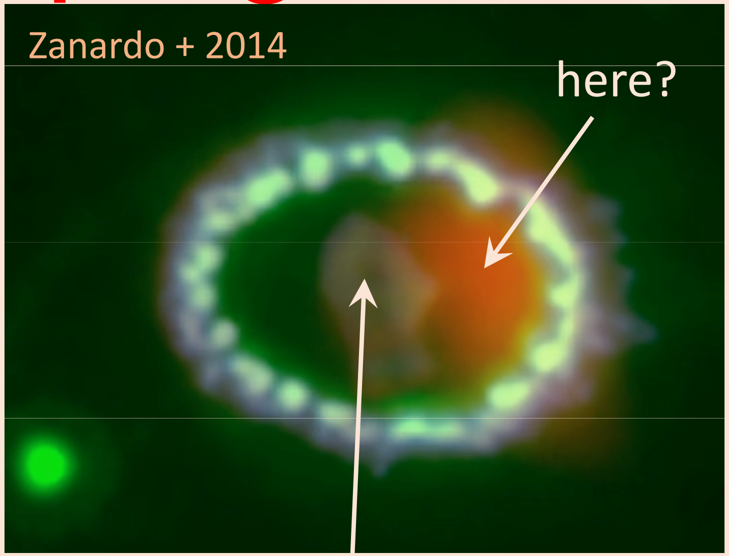


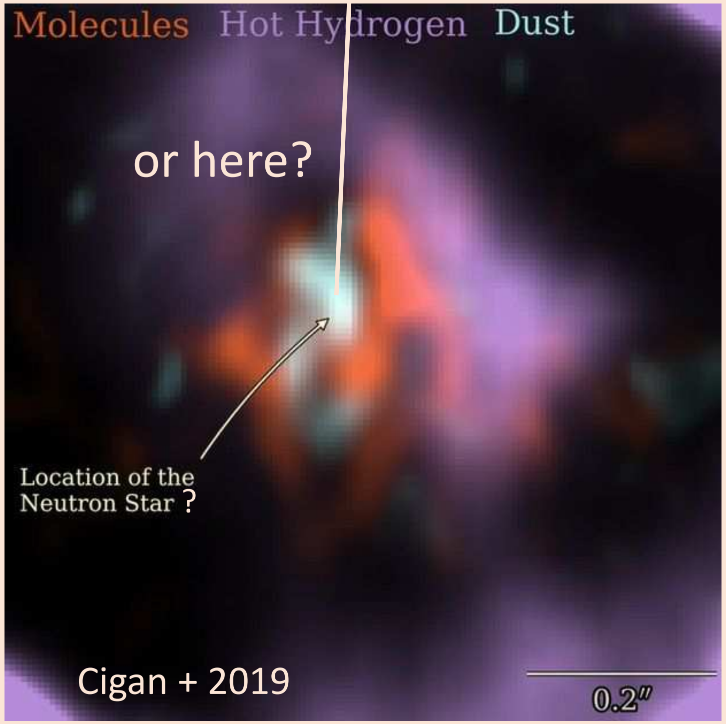


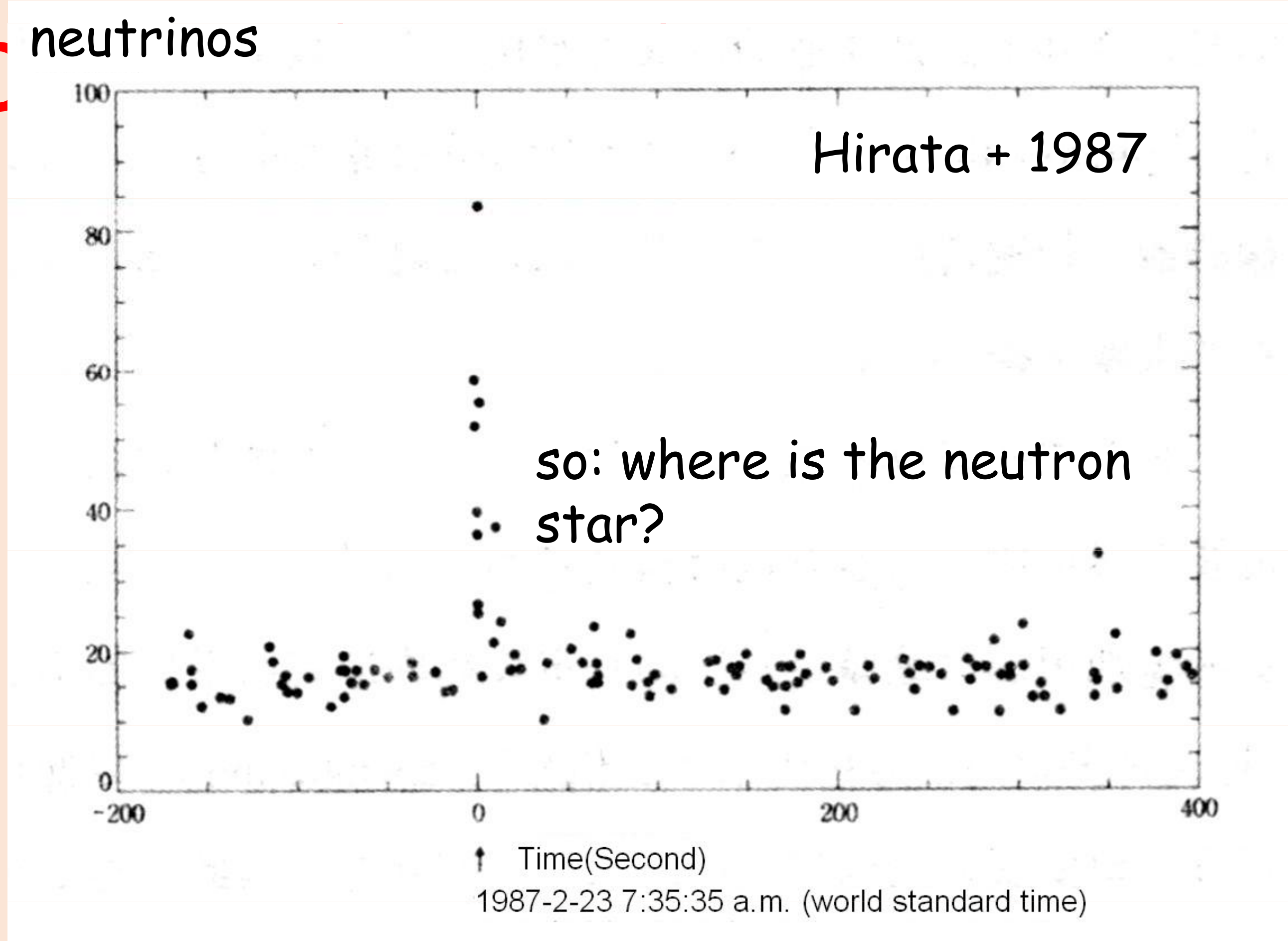


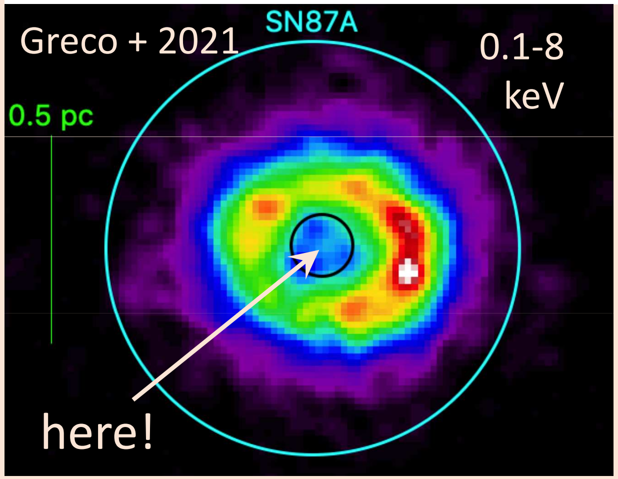
- post-red supergiant !

Red supergiants as progenitors c





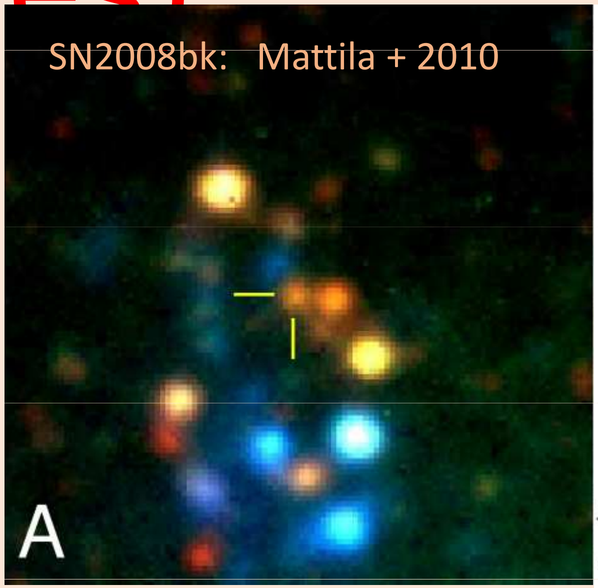




evidence?

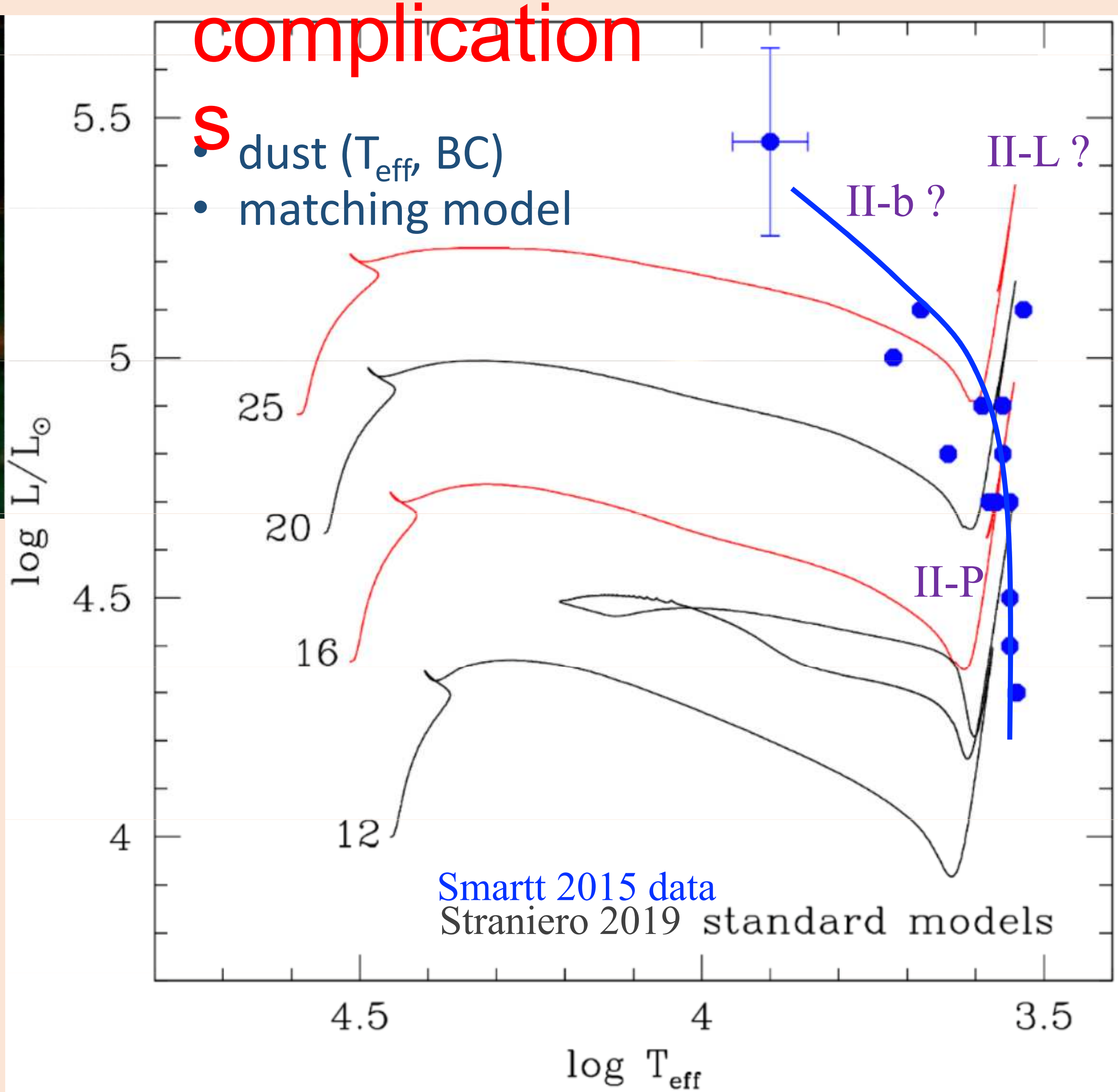
- neutrinos (black hole?)
- source of dust heating
- no pulsar detected

Red supergiants as progenitors of supernovae (and possibly black holes)

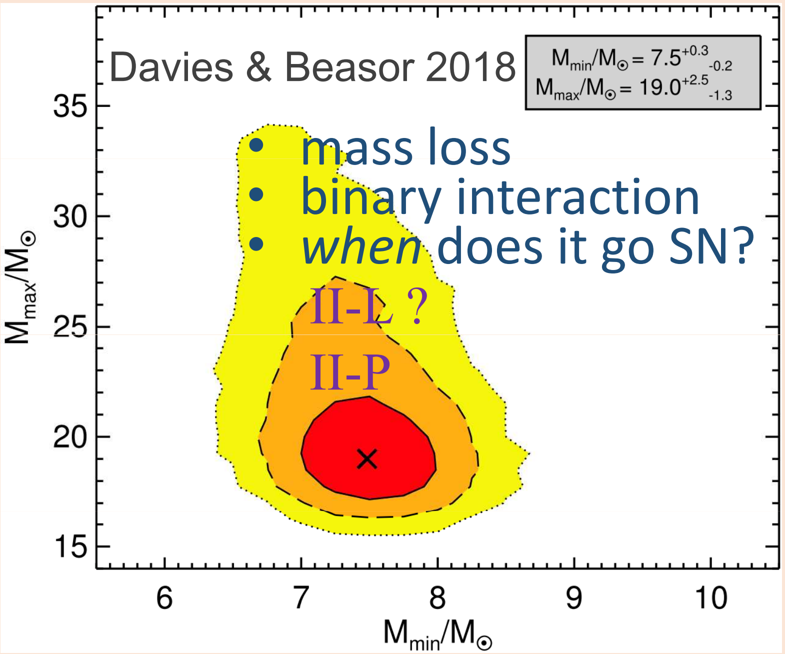


complications

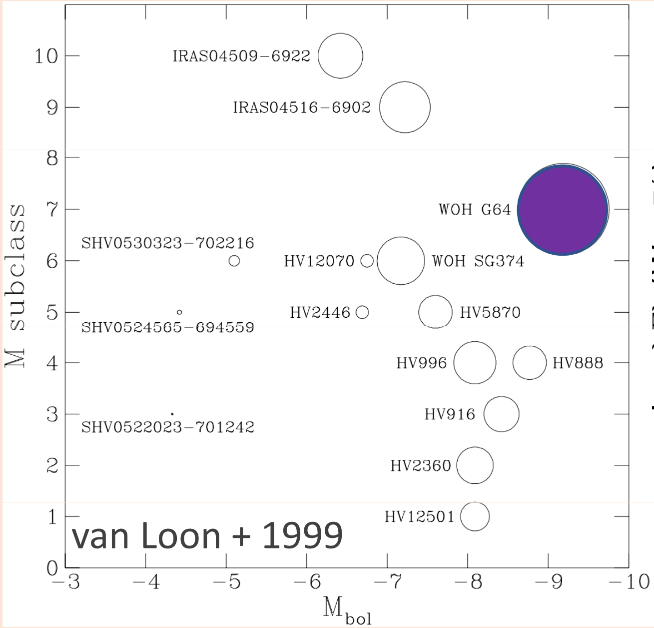
- dust (T_{eff}, BC)
- matching model

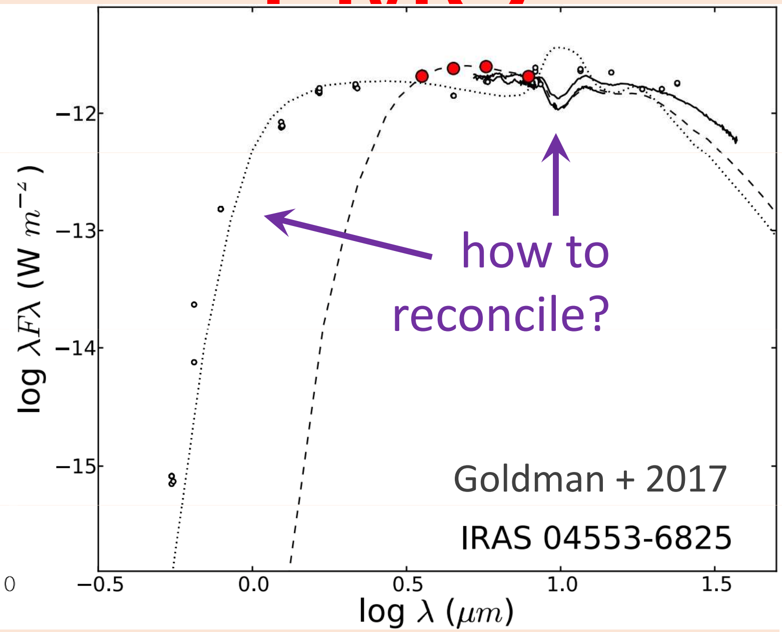


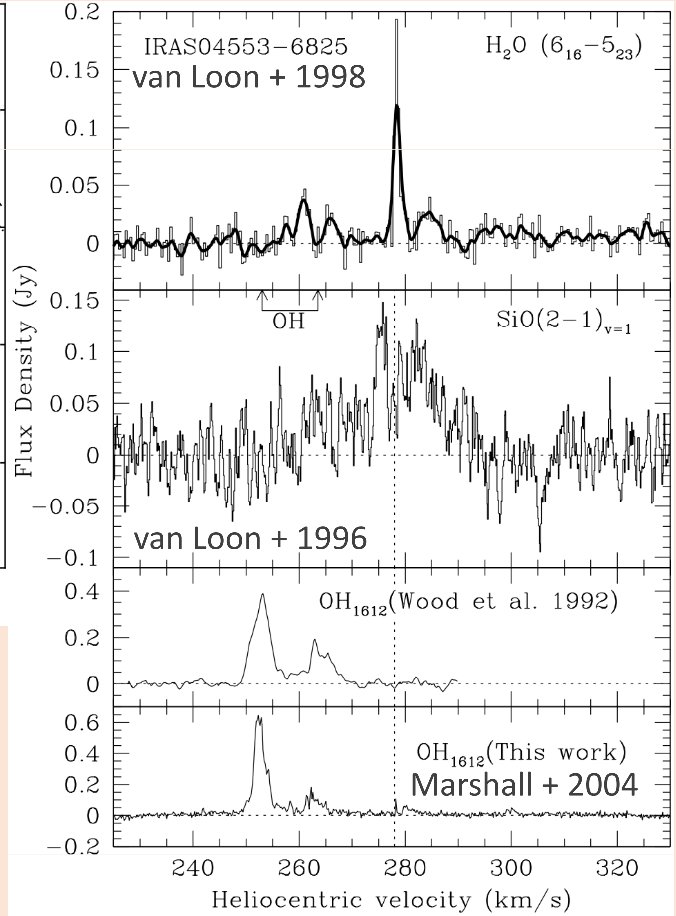
- mass loss
- binary interaction
- *when* does it go SN?

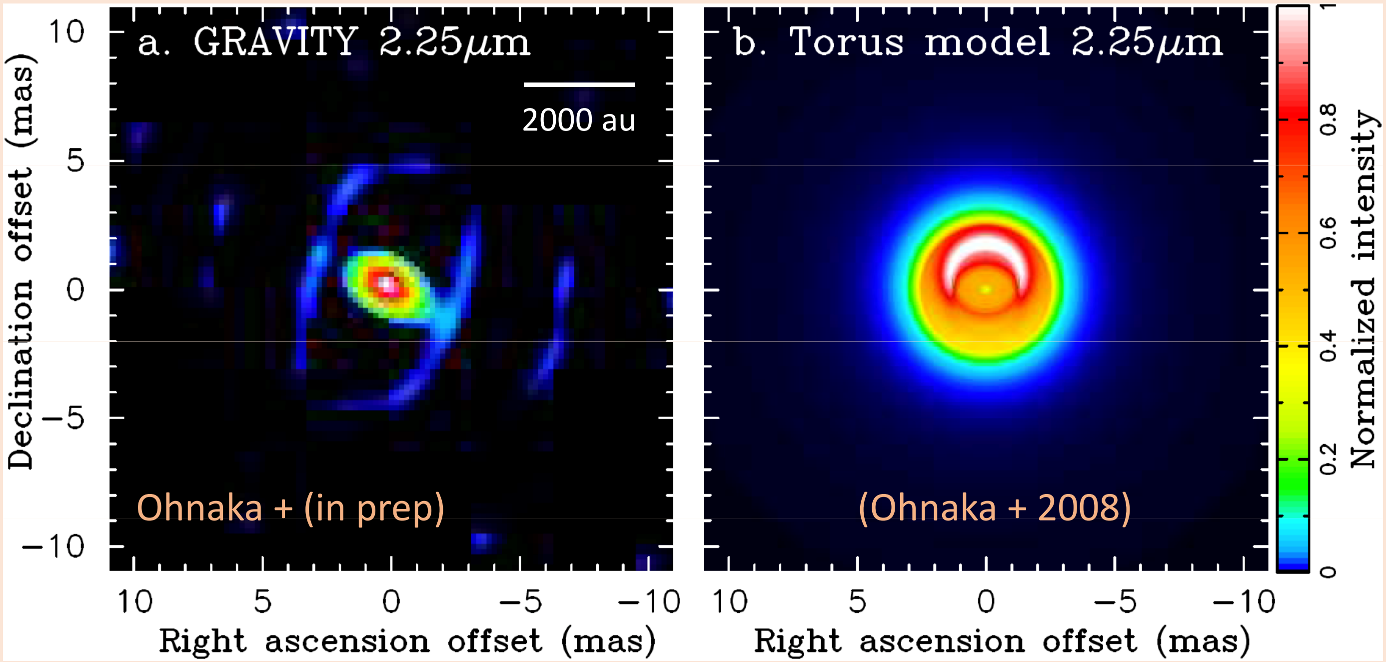


My favourite RSG: WOH G64 in the LMC



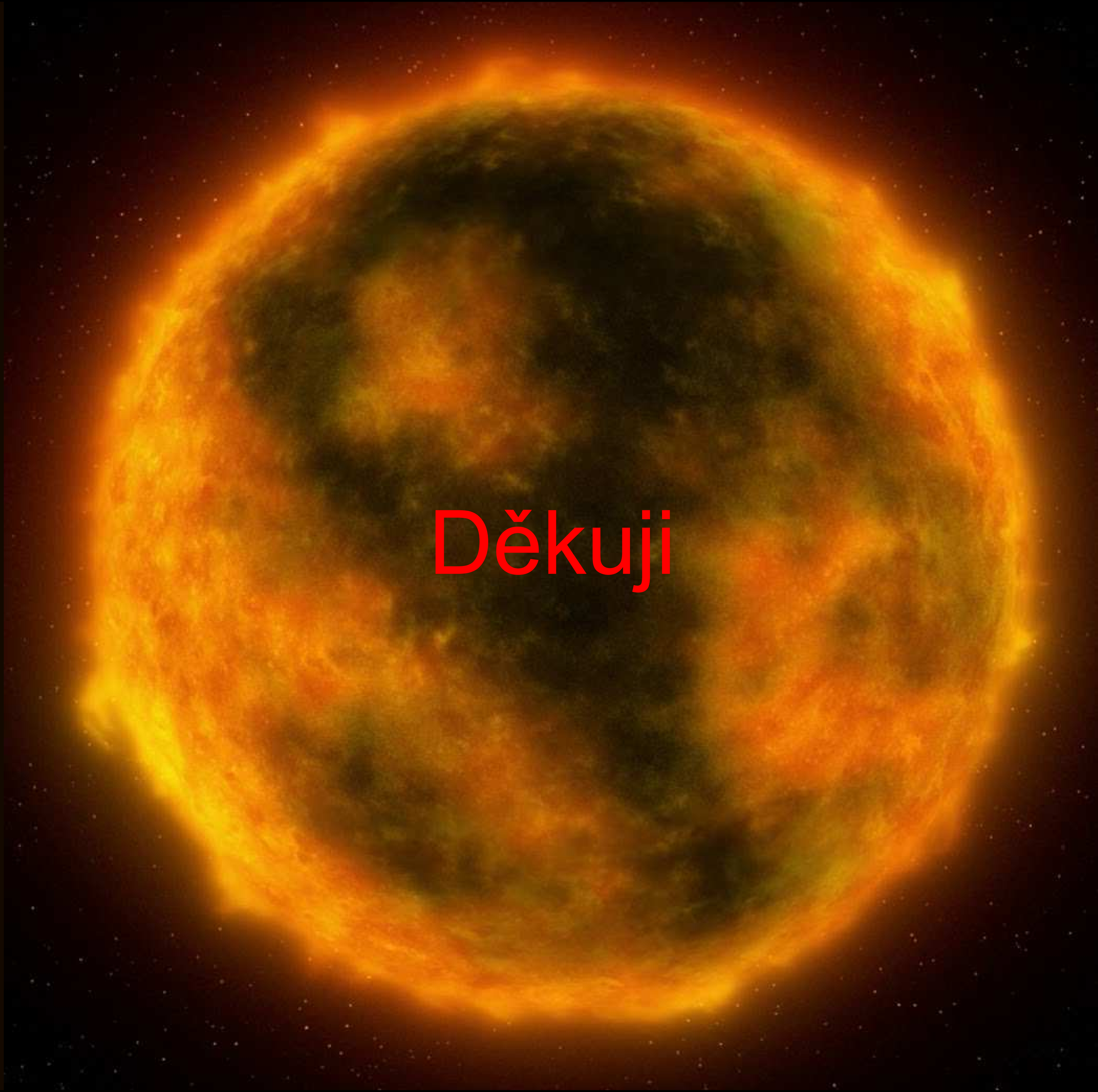






questions

- where is the dust?
- why is it axisymmetric?
- will it mimic SN1987A?



Děkuji