Betelgeuse

يد الجوزا

and (other) red supergiants

What do we know?

What don't we know?

What could we do?

Is Betelgeuse typical?

- yes

  (in the absence of evidence for it to be atypical)

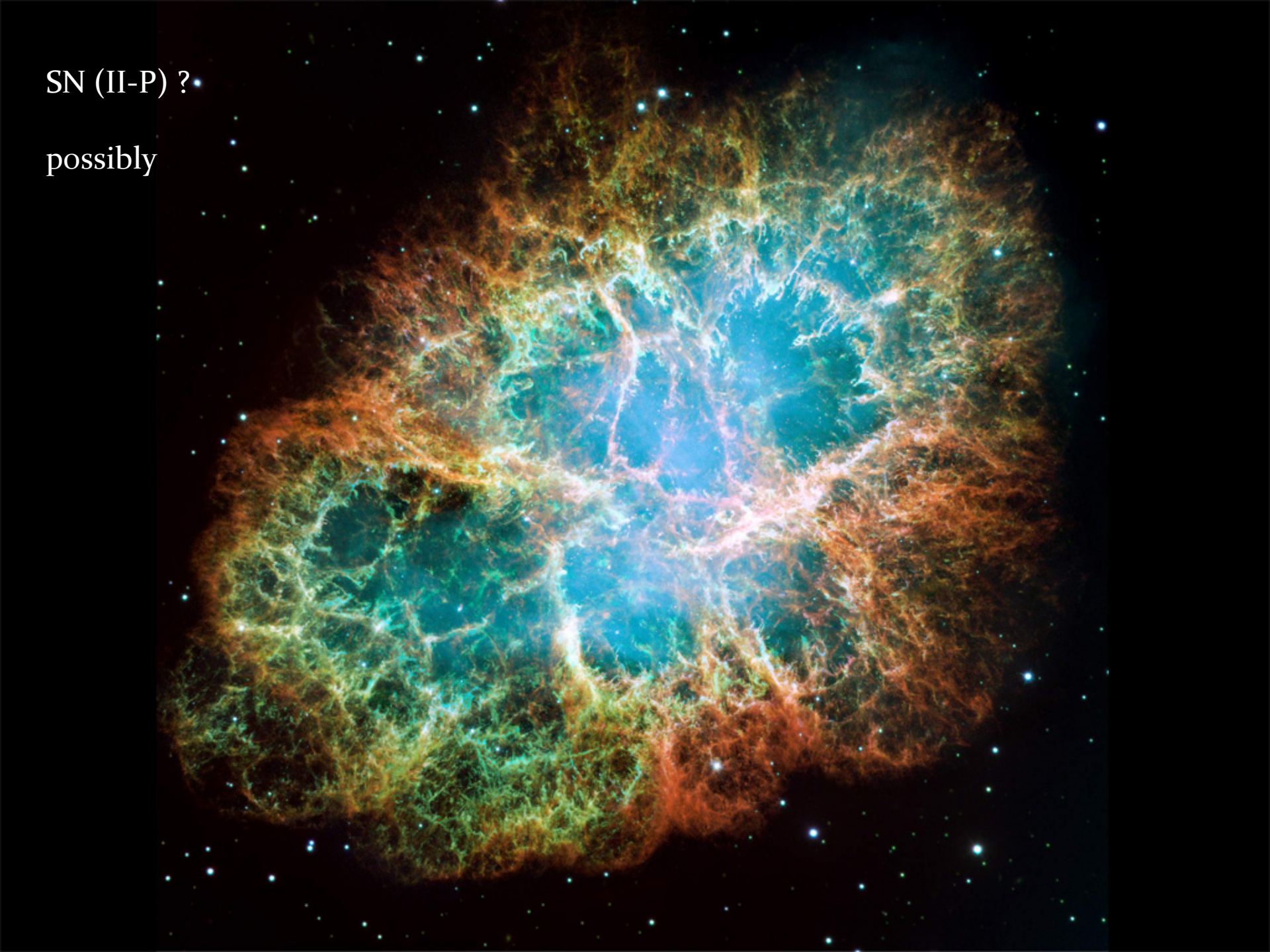
- “any well observed star is a peculiar star” (G. Meynet)

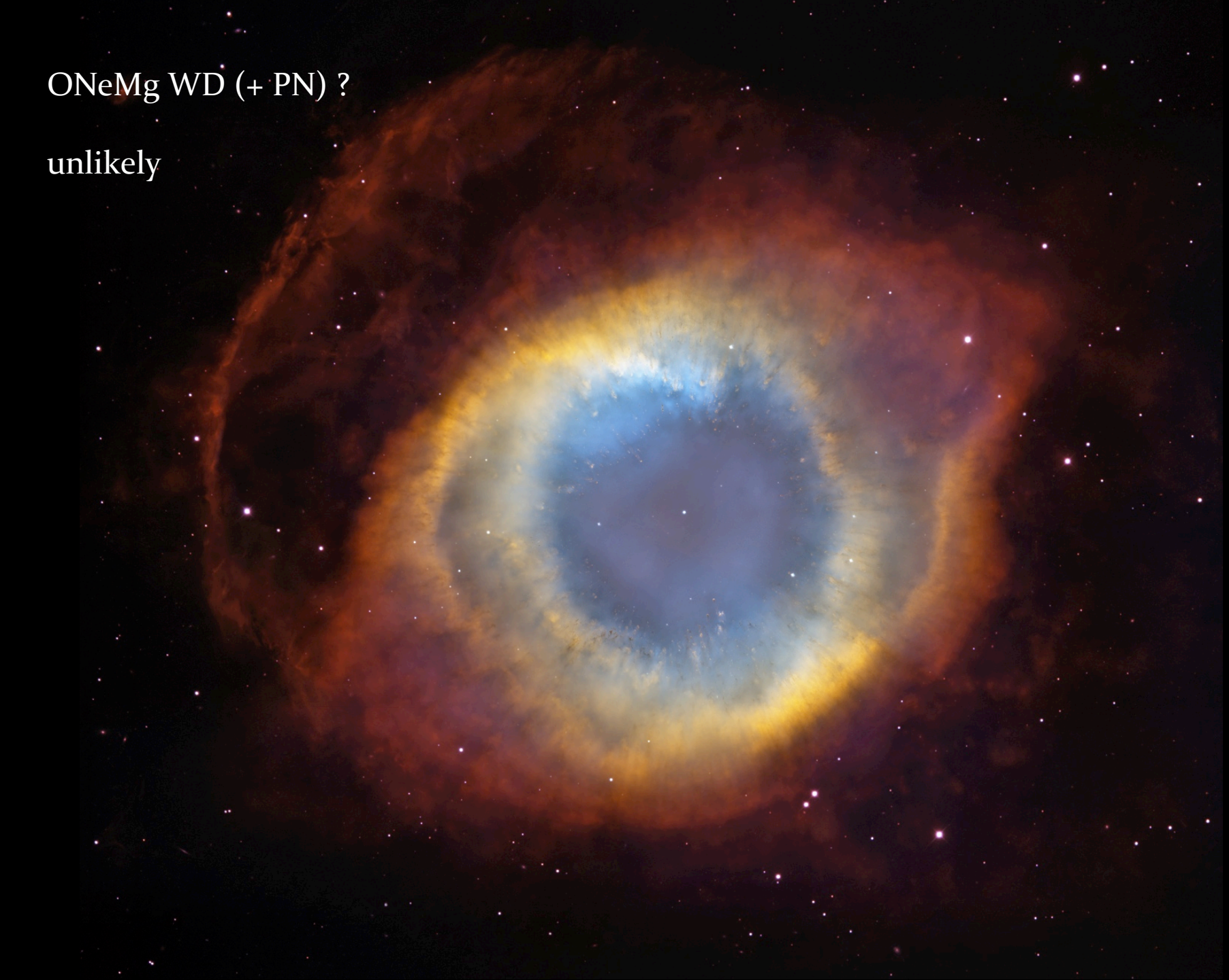
- “nothing is peculiar once we understand it”

- It probably even was a binary once upon a time…

SN (II-P) ?

possibly




ONeMg WD (+ PN) ?
unlikely

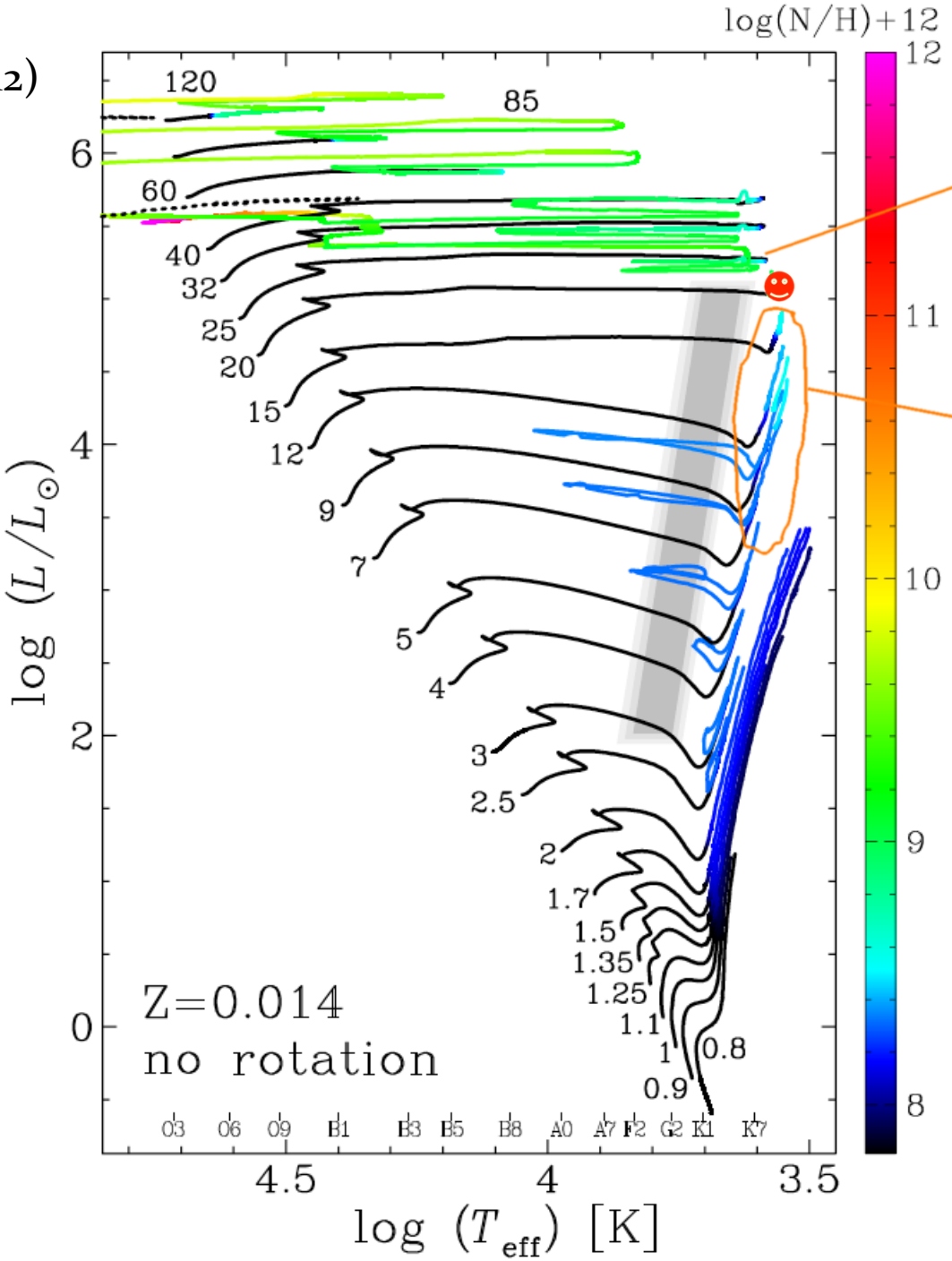
?

(no)

What is the mass of Betelgeuse?

- "15 M_{sun}"
- $\log(T_{eff}) \sim 3.56$ $\log(L_{bol}) \sim 5.1$
- distance: 150-250 pc = ~0.4 dex in luminosity

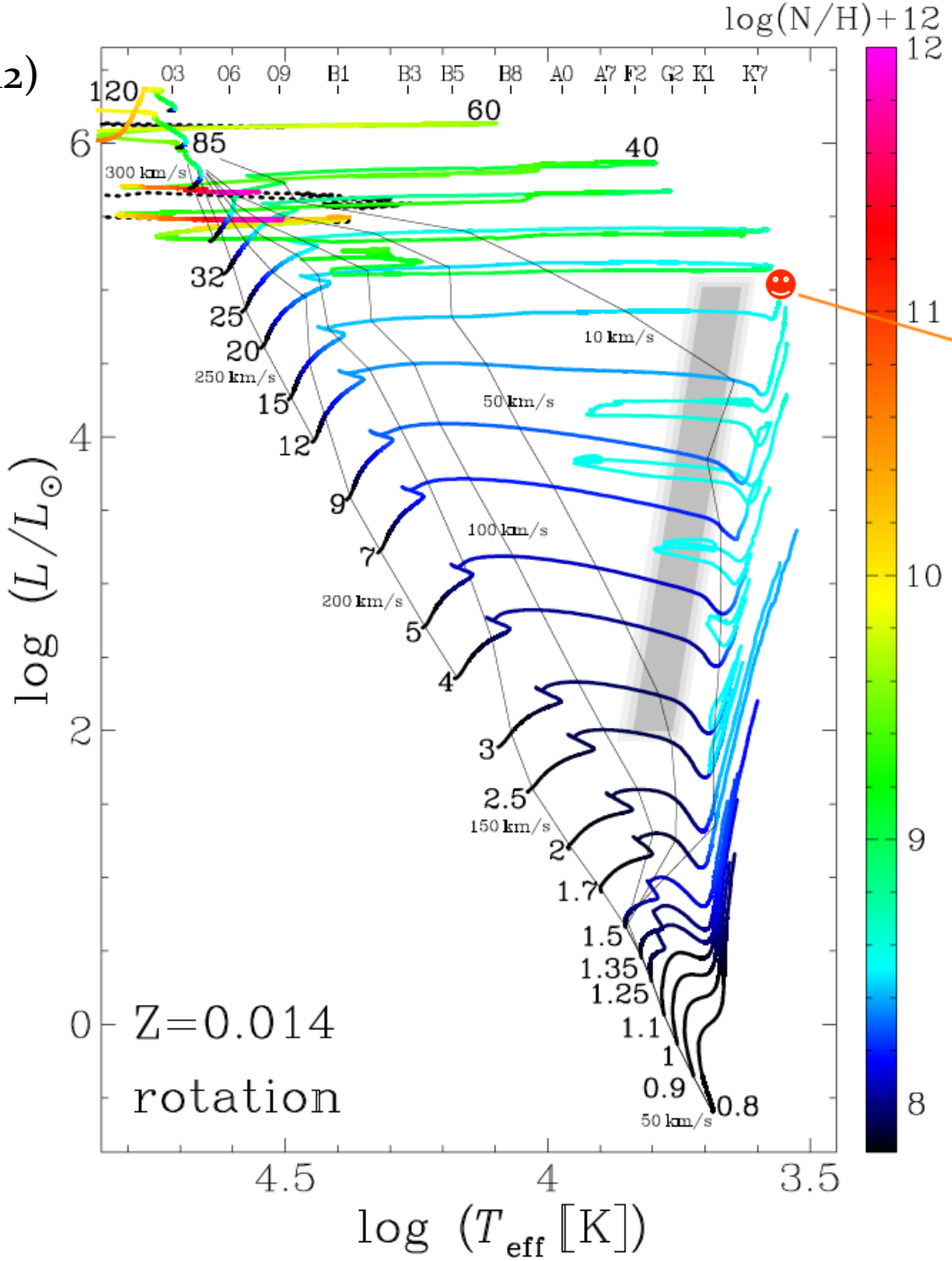
Ekstrom et al. (2012)



Exact T_{eff} is critical for convection, pulsation, dust formation, mass loss...

ambiguous

Ekstrom et al. (2012)



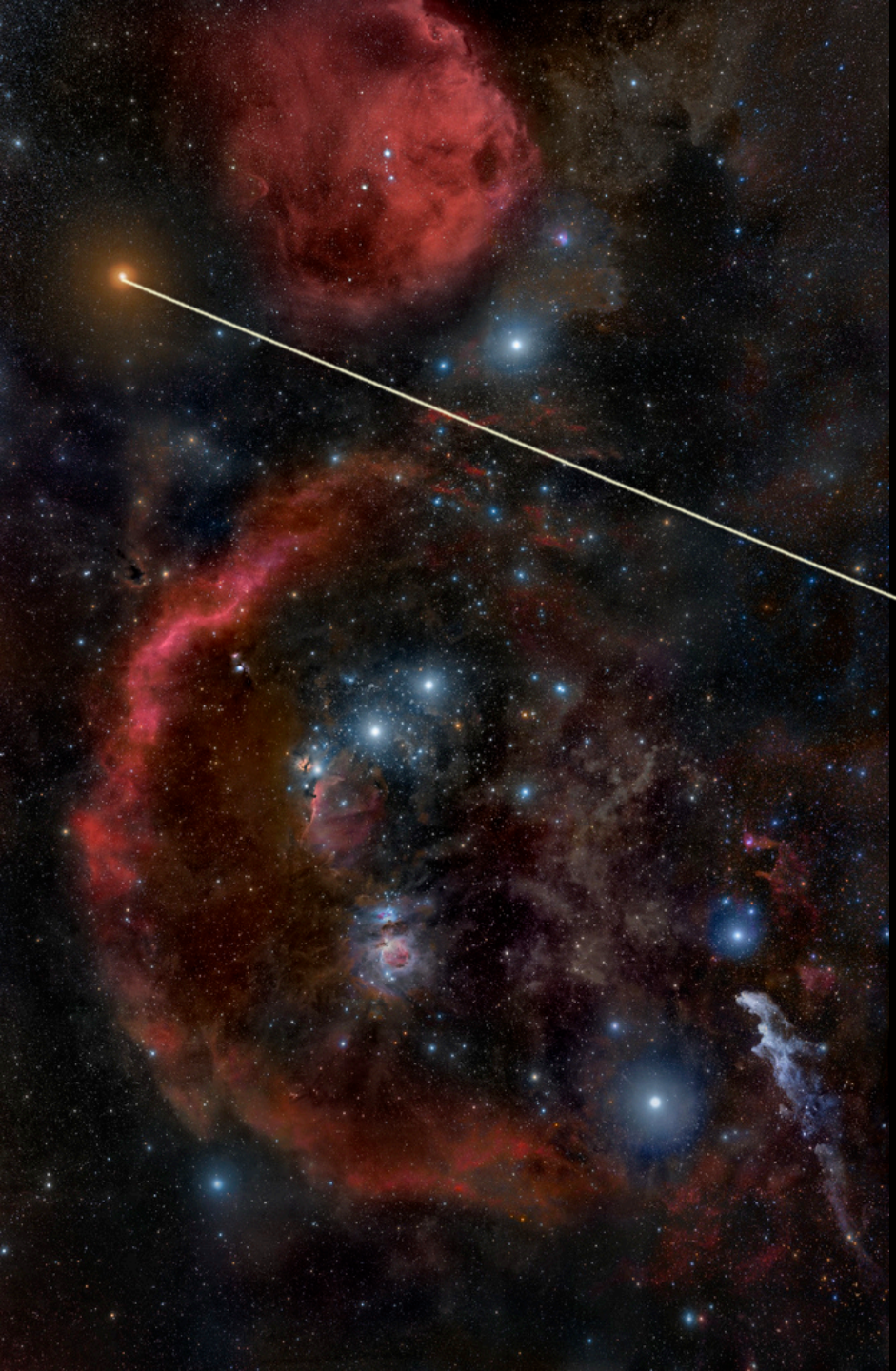
unlikely at tip of RSG of a 15 M_{sun}

What is the mass of Betelgeuse?

- "15 M_{sun}"
- $\log(T_{eff}) \sim 3.56$ $\log(L_{bol}) \sim 5.1$
- distance: 150-250 pc = ~0.4 dex in luminosity
- 15-25 M_{sun} possible
- 20 M_{sun} (Ekstrom et al. 2012):

model	RSG starts (Myr)	RSG duration (Myr)	mass at RSG start (M_{sun})	RSG mass loss (M_{sun})
no rotation	8.1	0.55 (then SN)	17.3	8.7
v/v_{crit} =0.4	9.3	0.3 (then BSG)	15.7	6.0

- but other models differ (e.g., "Bonn") – why?

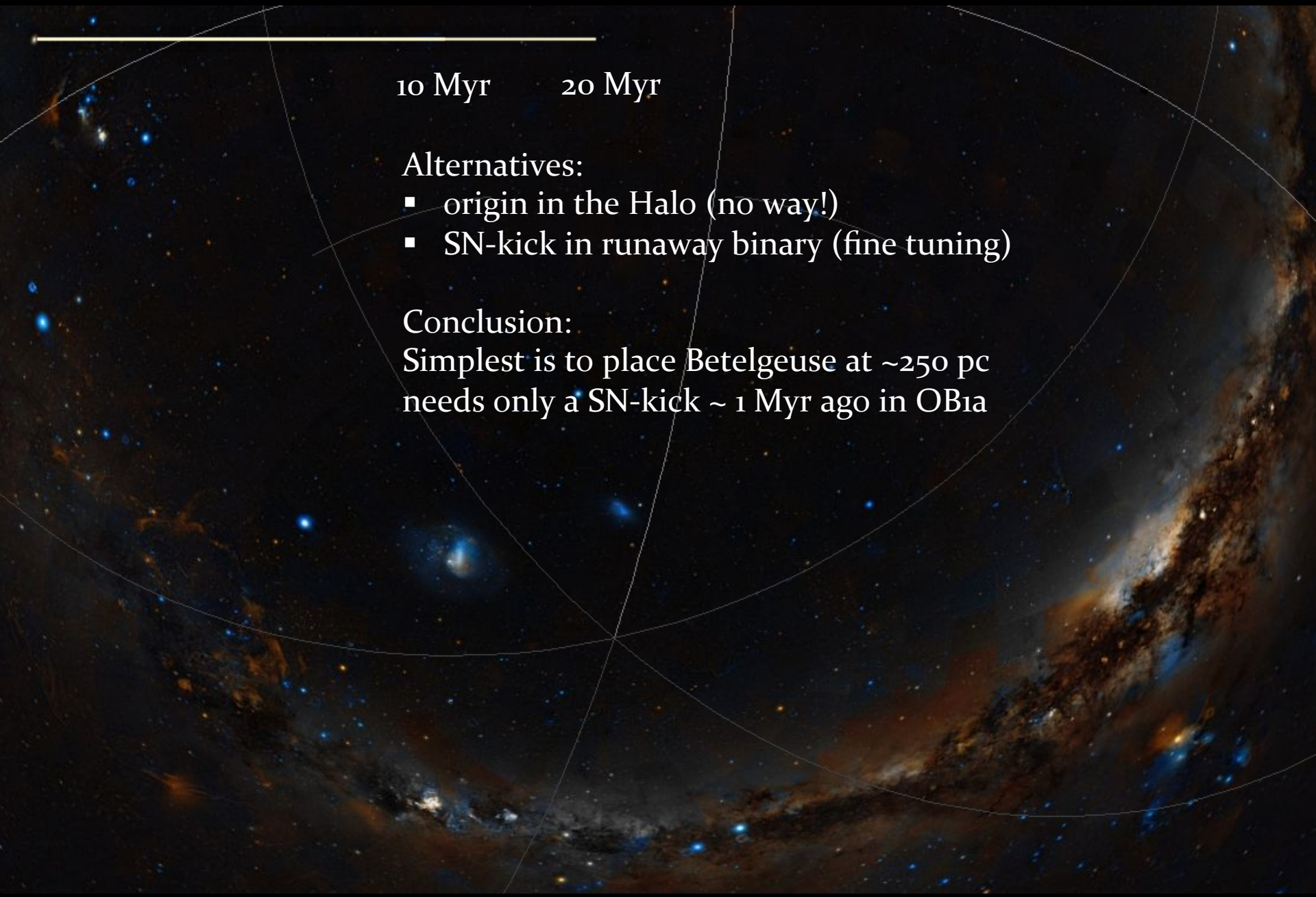


Betelgeuse:
Distance 150-200 pc (parallax ~6 mas)
Proper motion 25 km/s (30 mas/yr)
Radial velocity +22 km/s

“Orion” (North: ~10 Myr; N. Przybilla):
Distance ~250 pc (parallax ~4 mas)
Proper motion negligible
Radial velocity < 20 km/s

Conclusion:
Betelgeuse was moving towards Orion!
Unless parallax ~4 mas (more massive!)

This is likely within the uncertainties!
(surface brightness variations!)



10 Myr 20 Myr

Alternatives:

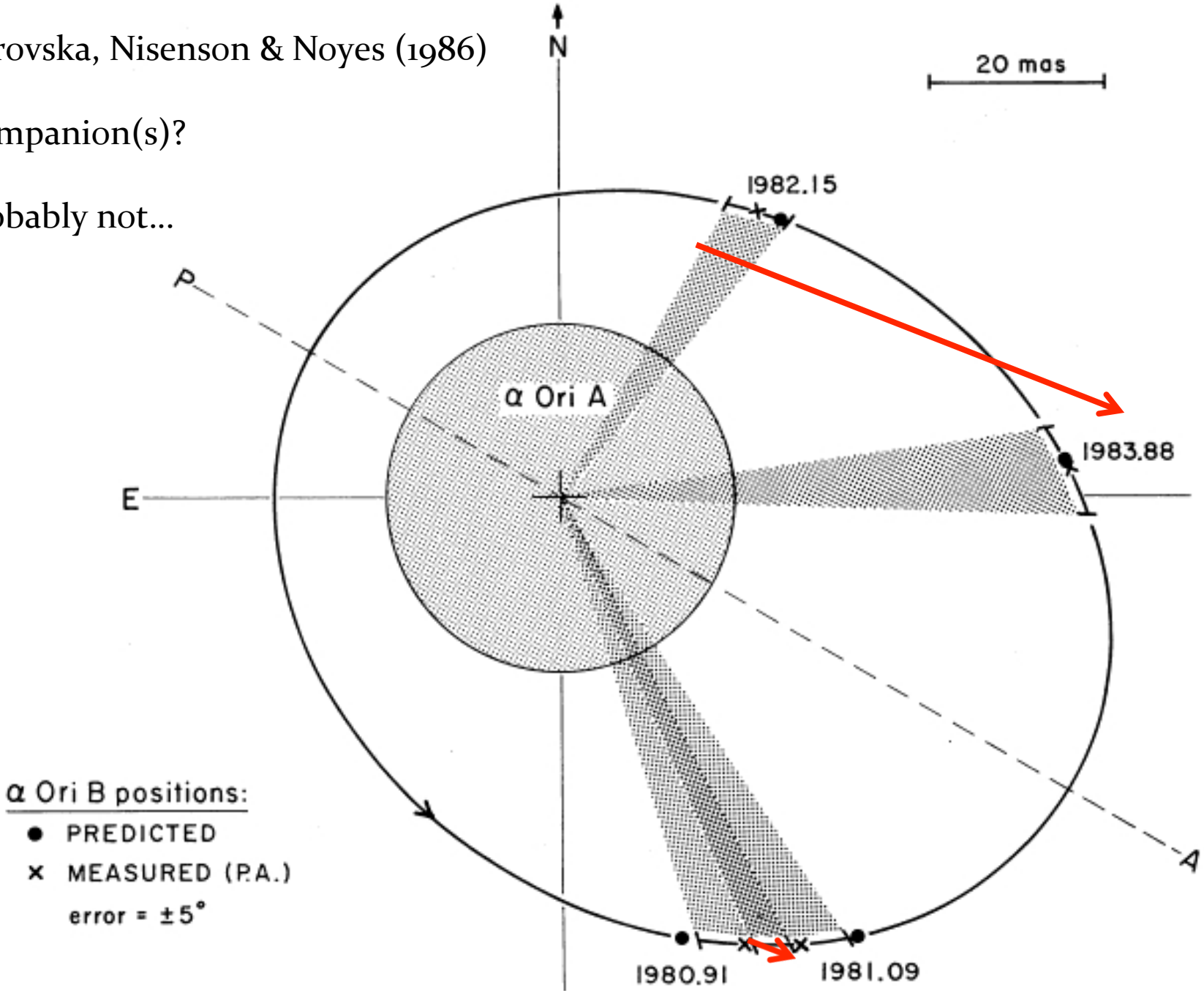
- origin in the Halo (no way!)
- SN-kick in runaway binary (fine tuning)

Conclusion:
Simplest is to place Betelgeuse at ~250 pc
needs only a SN-kick ~ 1 Myr ago in OB1a

Karovska, Nisenson & Noyes (1986)

Companion(s)?

Probably not...

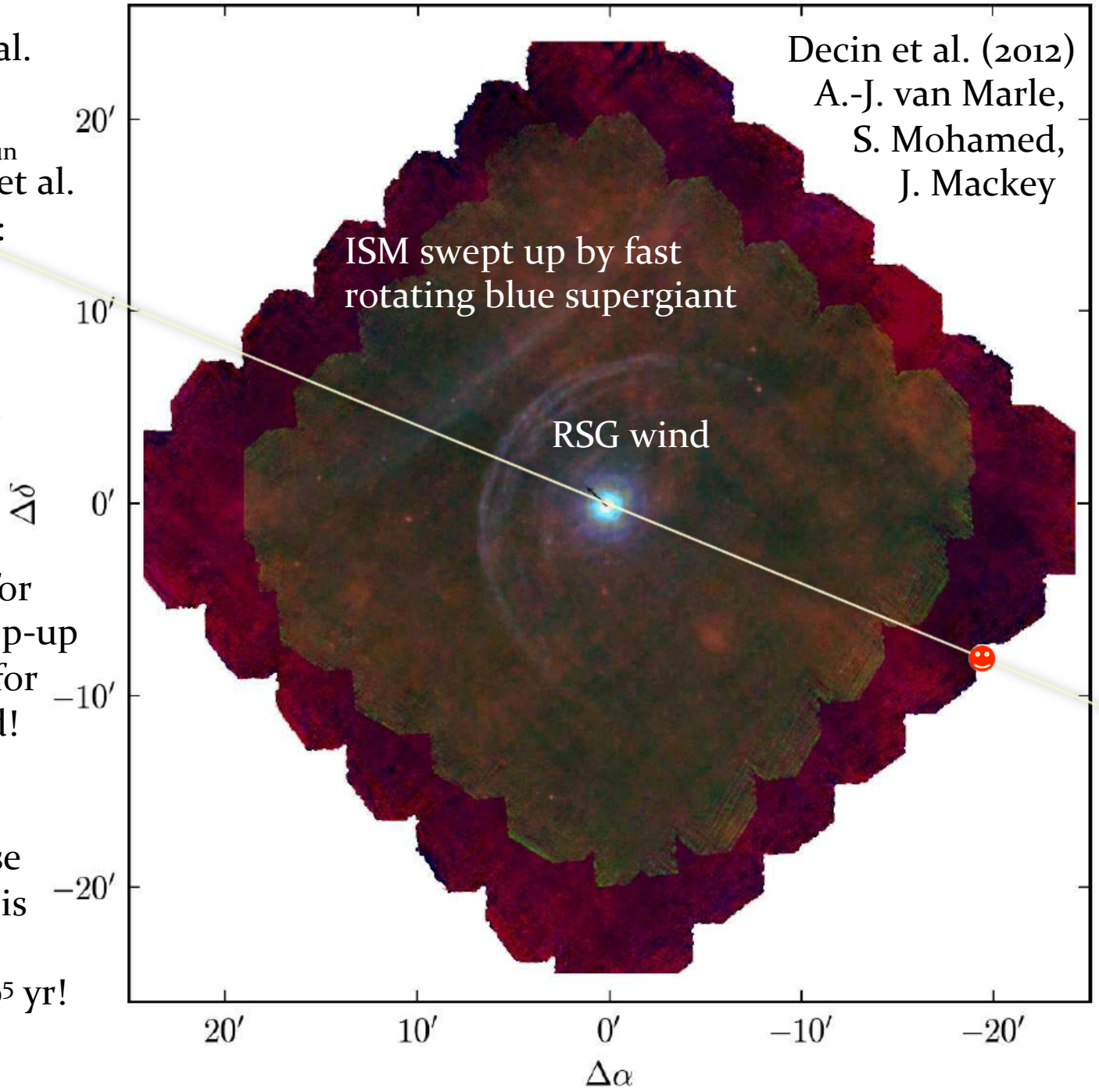


Decin et al. (2012) IR: 0.003 M_{sun}
LeBertre et al. (2012) HI: 0.05 M_{sun}

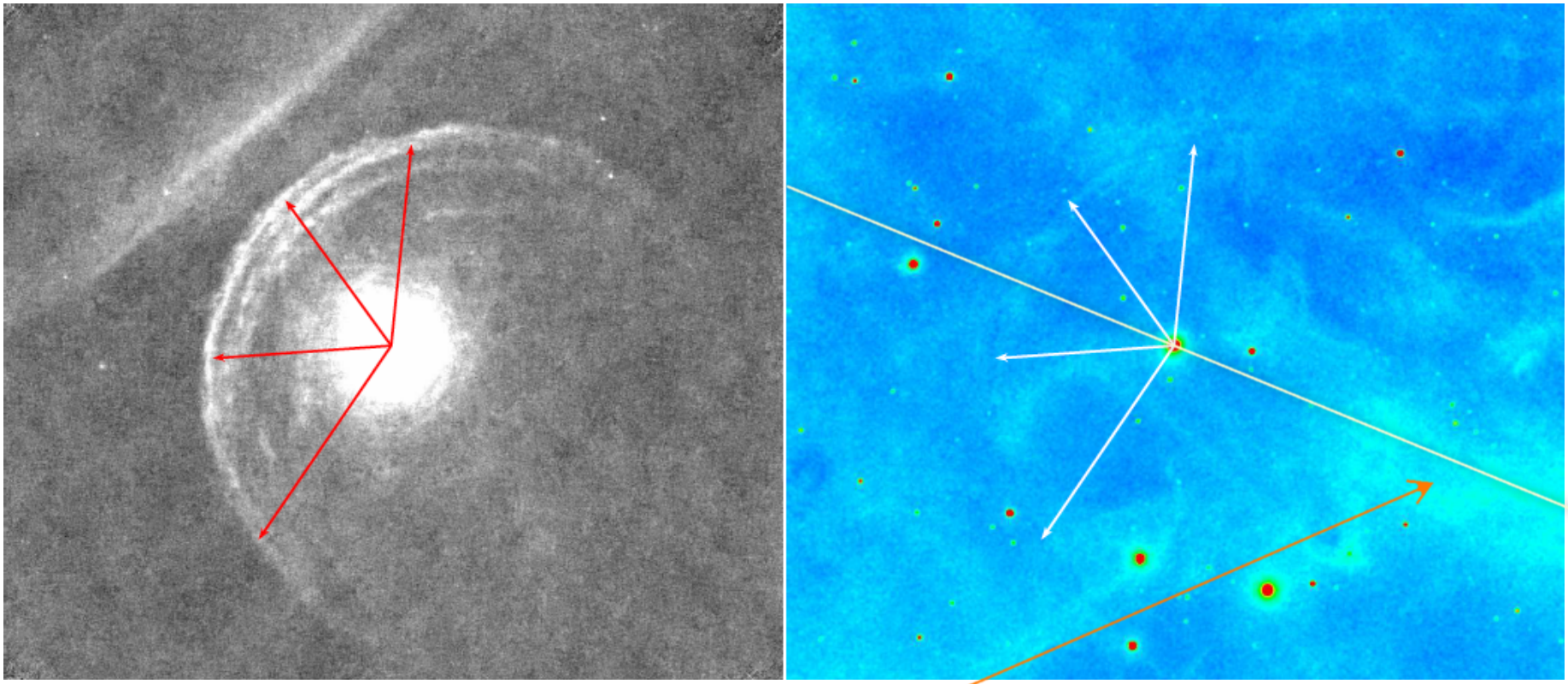
R_0~0.3 pc
R_1 ~0.5 pc

~$10^{4\text{-}5}$ yr for ISM sweep-up and also for RSG wind!

Betelgeuse probably is only RSG since < 10^5 yr!



Decin et al. (2012)

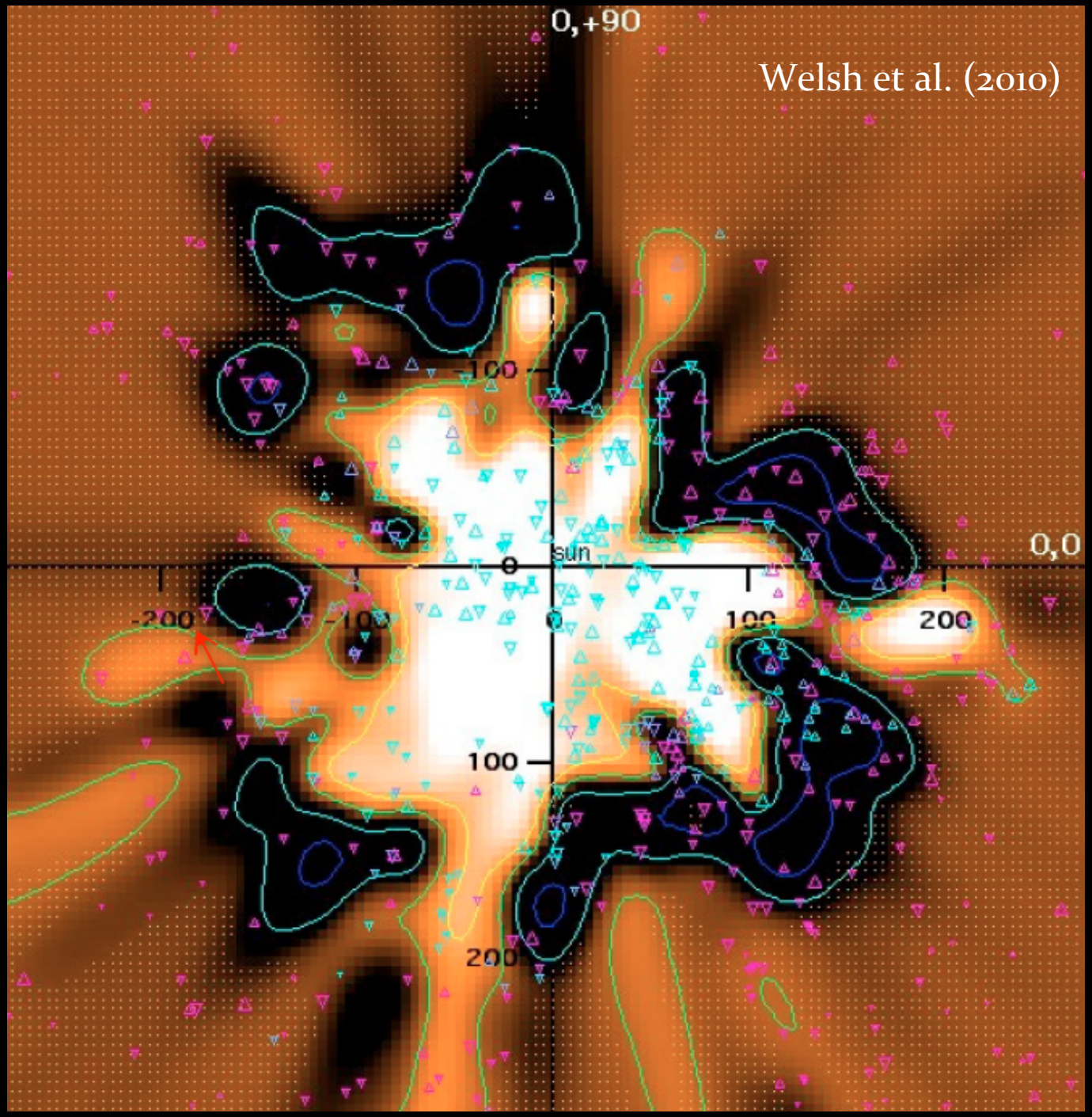


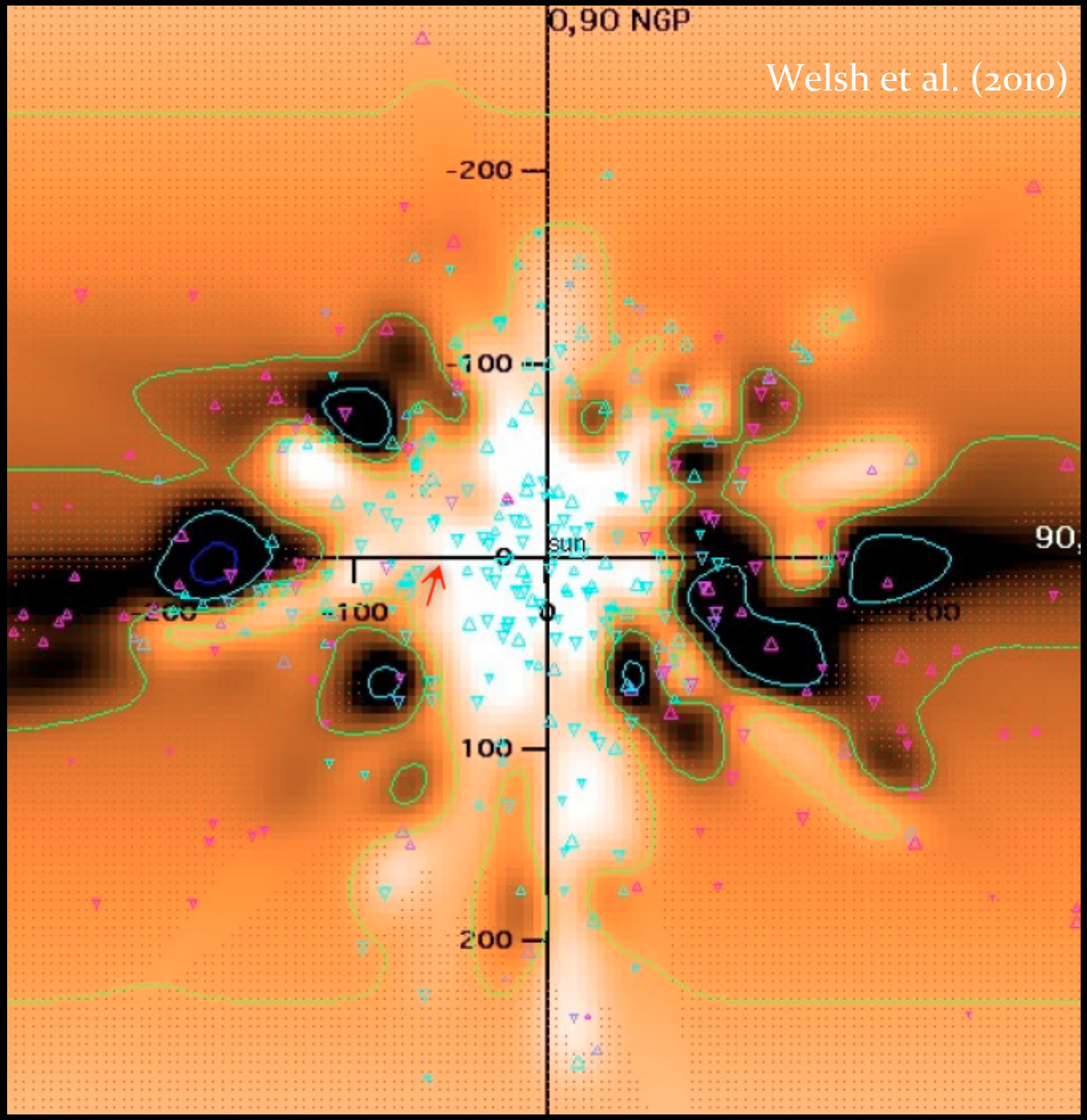
70 micron

GALEX

Blue supergiant wind
falling back into
under-pressured wake:
heated

Jonathan Mackey: “like tree rings showing climate history”


0,+90
Welsh et al. (2010)
-100
sun
0,0
-200
-100
0
100
200
100
200

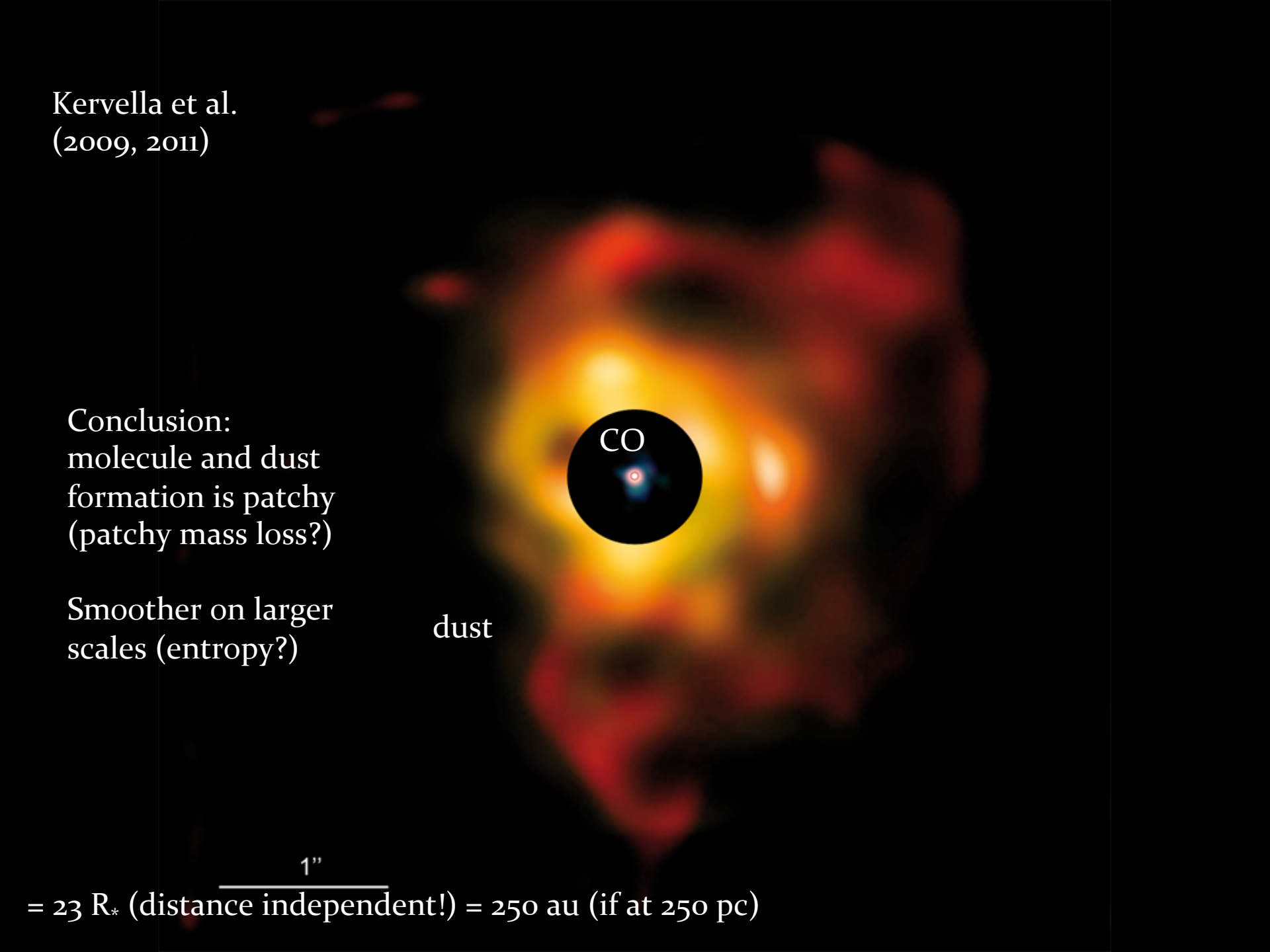


Welsh et al. (2010)

How does Betelgeuse lose mass?

- $2 \cdot 10^{-6}$ M_{sun}/yr (within factor 2?)
- consistent: dust, CO, HI, H_{alpha}, free-free, bowshock…

Kervella et al.
(2009, 2011)

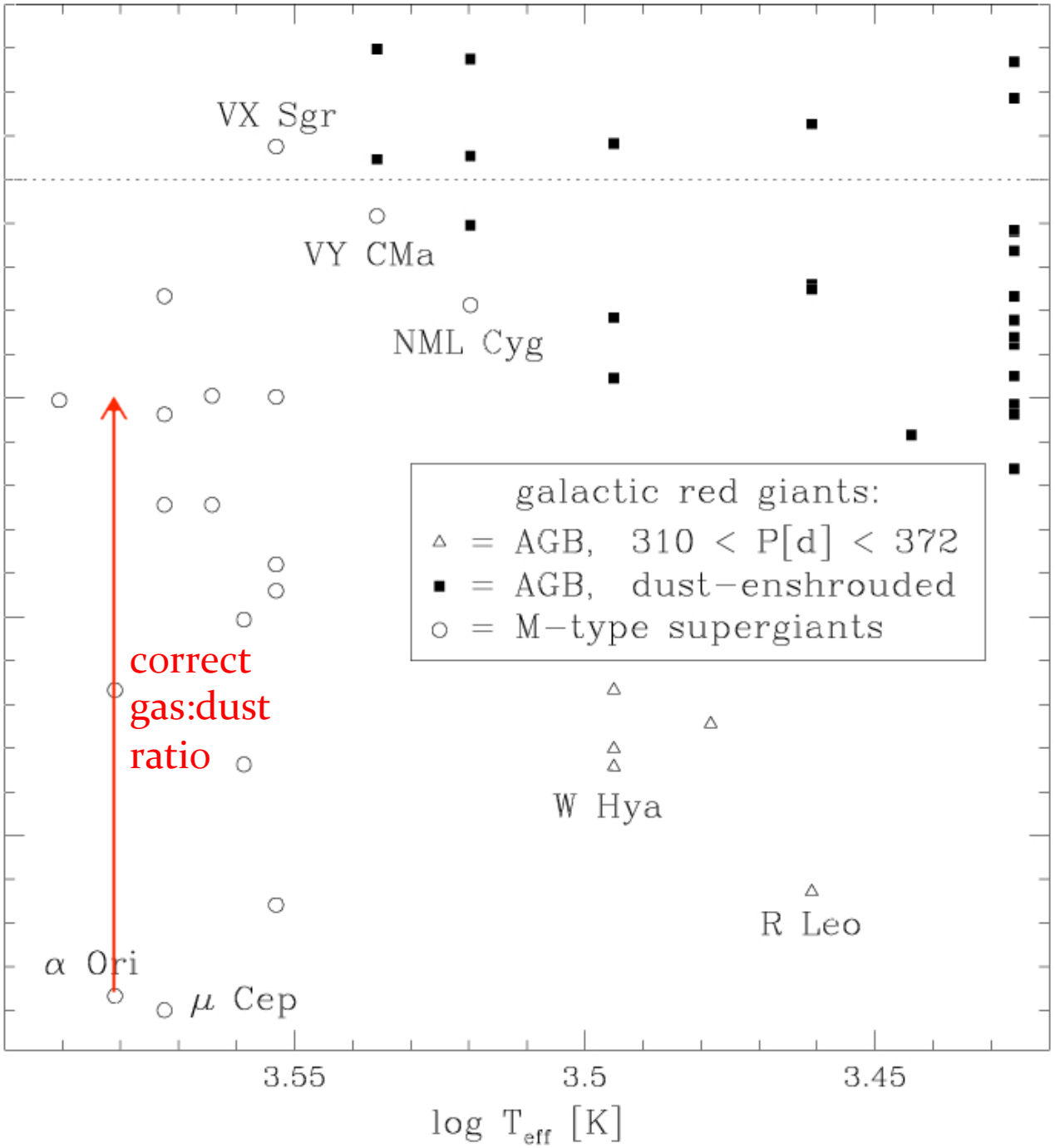


Conclusion:
molecule and dust formation is patchy (patchy mass loss?)

Smoother on larger scales (entropy?)

= 23 R_* (distance independent!) = 250 au (if at 250 pc)

van Loon et al. (2005)



from formula $f(T_{eff}, L)$

from dust assuming complete condensation

correct gas:dust ratio

Conclusion: dust traces, not drives (Betelgeuse)

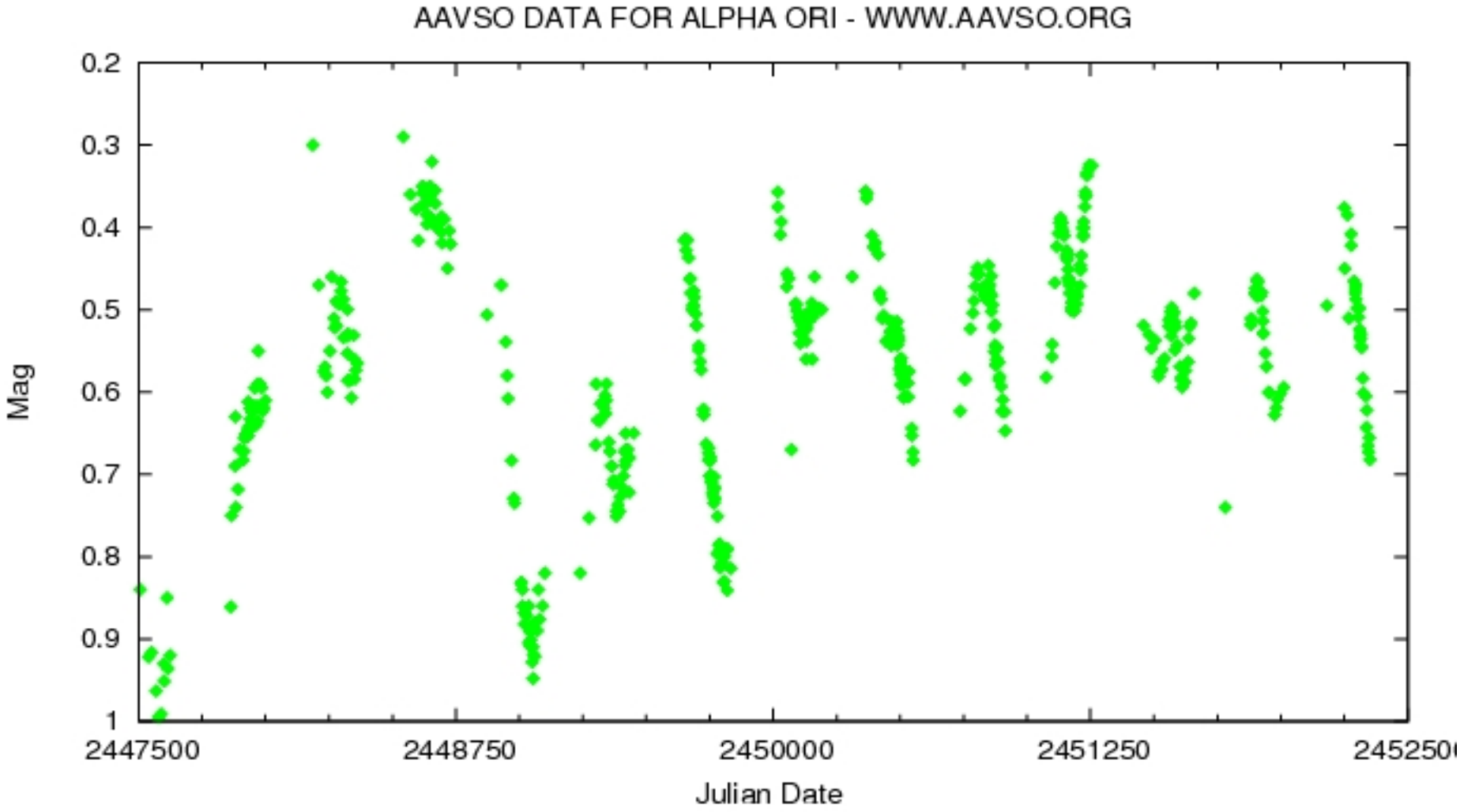
How does Betelgeuse lose mass?

- $2 \cdot 10^{-6}$ M_{sun}/yr (within factor 2?)
- consistent: dust, CO, HI, H_{alpha}, free-free, bowshock…
- little dust, low density: little coupling, large drift

Do we know why?

Yes:

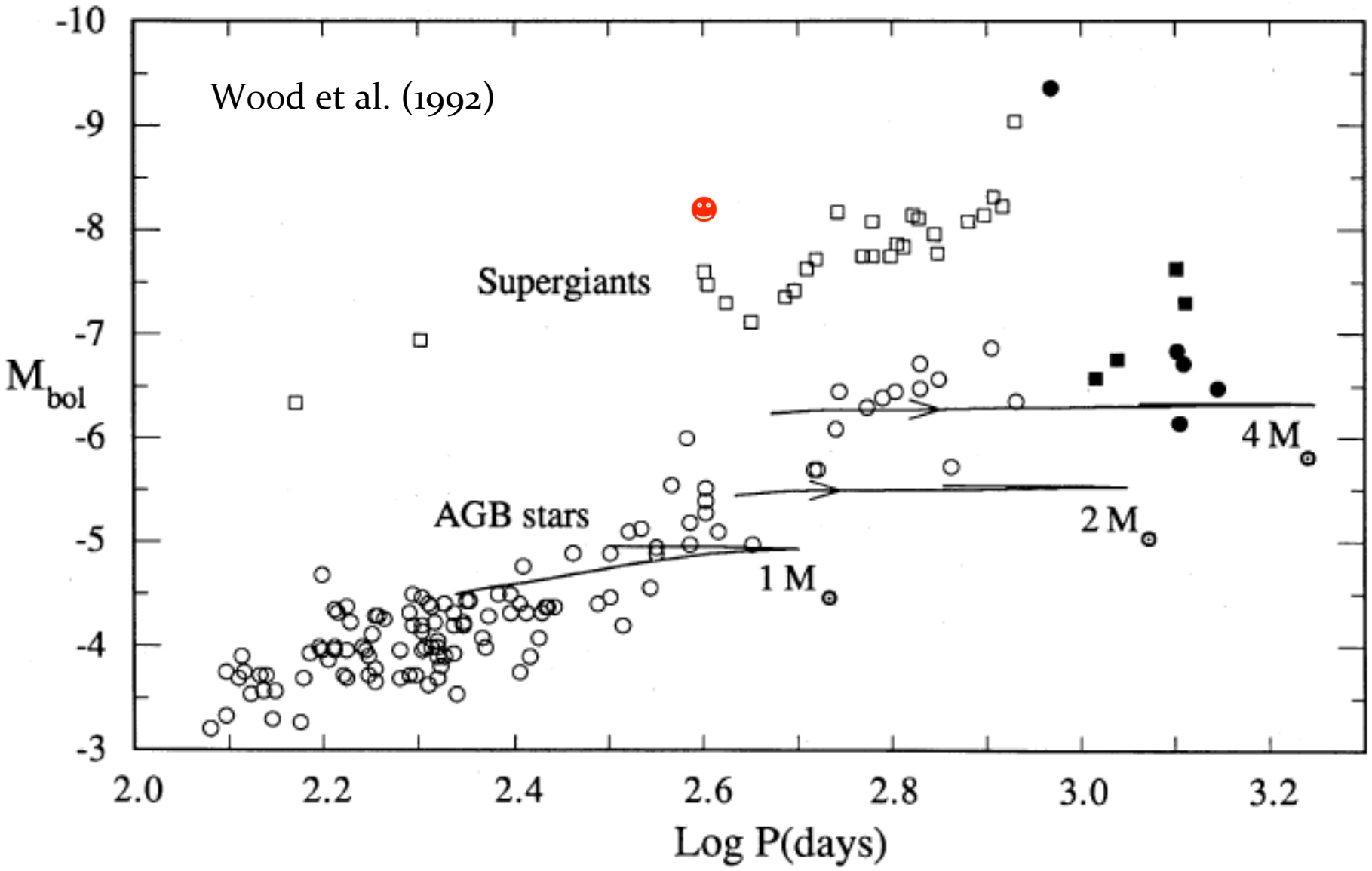
- Cherchneff: no water, no clusters (hence no dust)
- Betelgeuse: CO, but little water hence little dust
- Cherchneff: water forms in post-shock region
- Betelgeuse: weak pulsation hence little water



5-6 yr: convection (Kiss et al. 2006; Stothers et al. 2011); <200 d: granulation
(are these periods and amplitudes reproduced by hydro models?)

~400 d periodicity: pulsation? Semi-regular because of convection?
(small amplitude in V but luminous hence large energy amplitude; but high v_{esc})

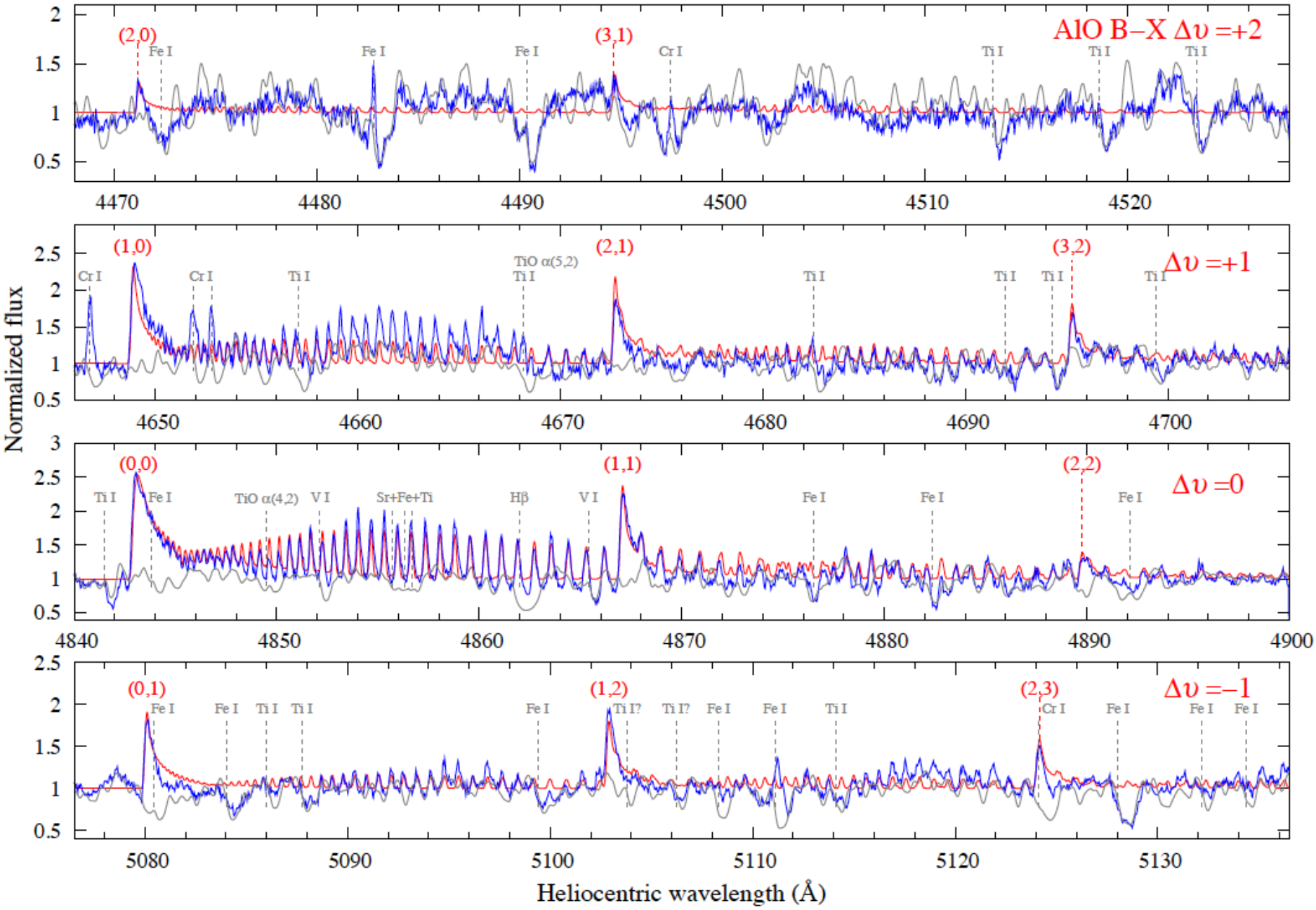
Chromospheric mass loss? (Judge & Stencel 1991: smooth transition to pulsation)



cf. Groenewegen et al. (2009), Bonanos et al. (2010), Mauron & Josselin (2011)

VY CMa

Humphreys, Helton & Jones (2007)



Kaminski, Schmidt & Menten (2012)

Also: resolved TiO and TiO_2 !

VY Canis Majoris

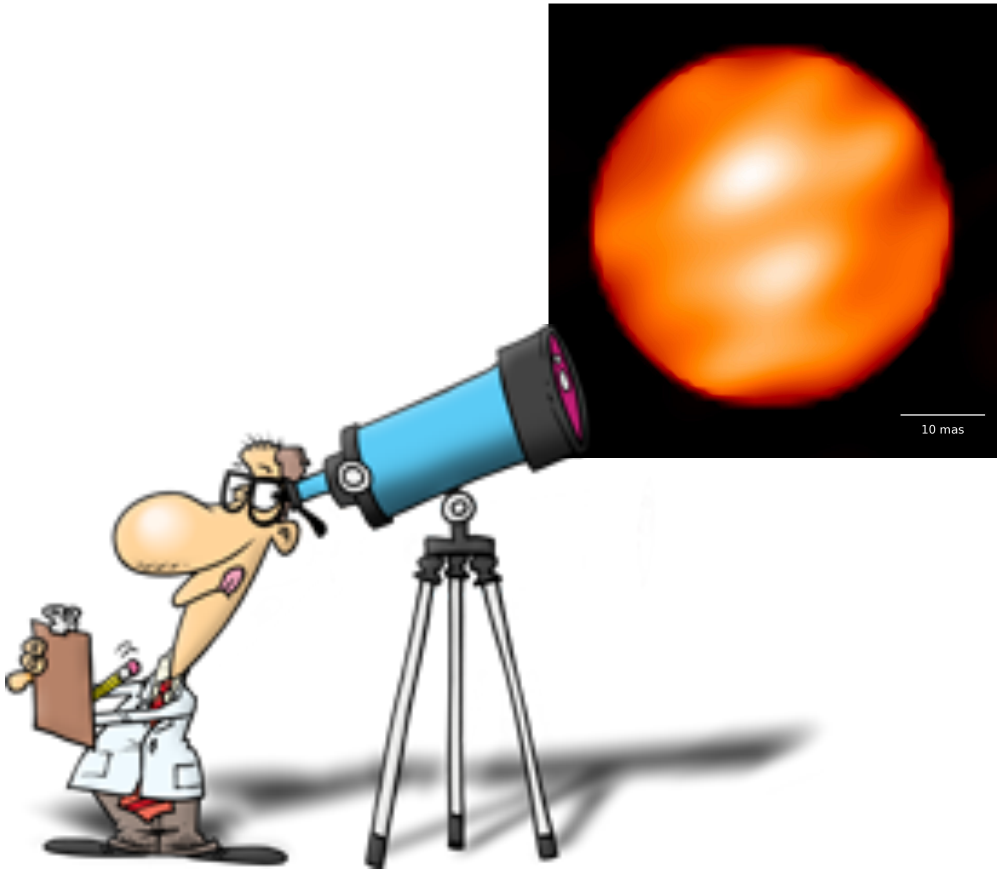
- 100 x higher mass-loss rate than Betelgeuse
- Much stronger pulsation
- Much dustier
- Basic molecules, water and clusters are present
- Masers support acceleration by radiation pressure
- Hence better understood

- Is the base of mass loss as chaotic as Betelgeuse's?
- Will Betelgeuse turn into a "VY Canis Majoris"?

Seeing and making the photosphere

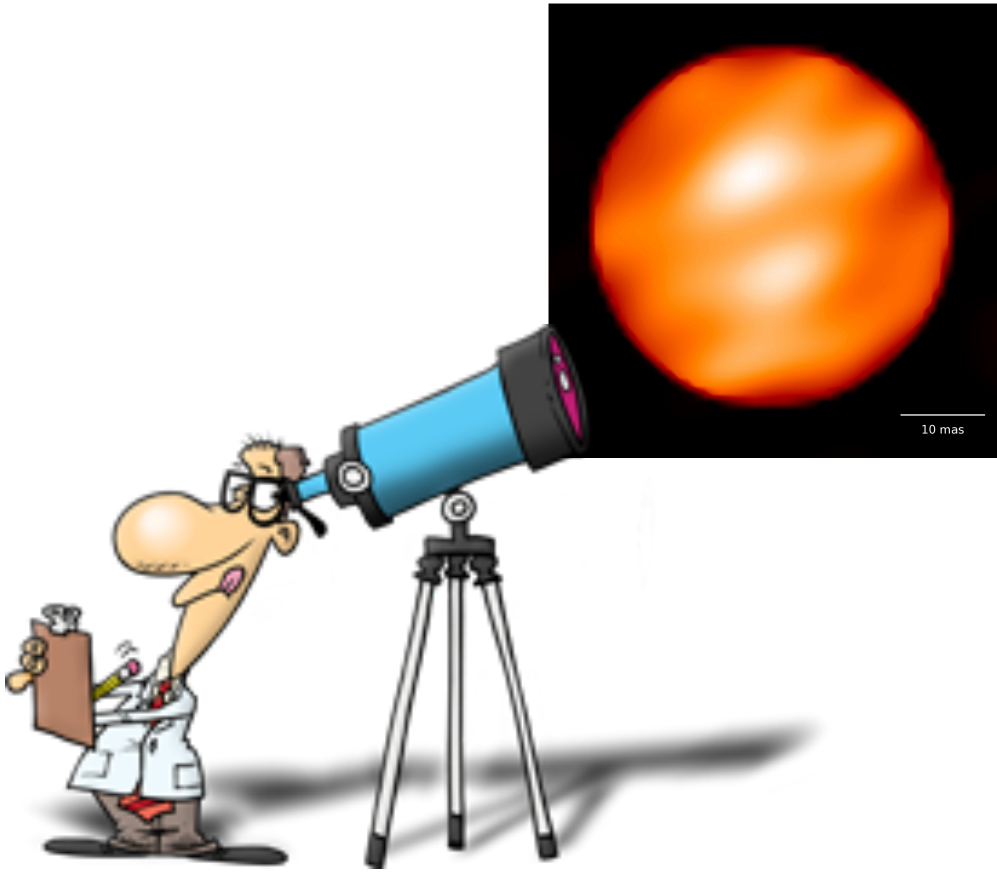
- Links stellar models to observations
- Links stellar models to circumstellar models

The imaginary world



The real world

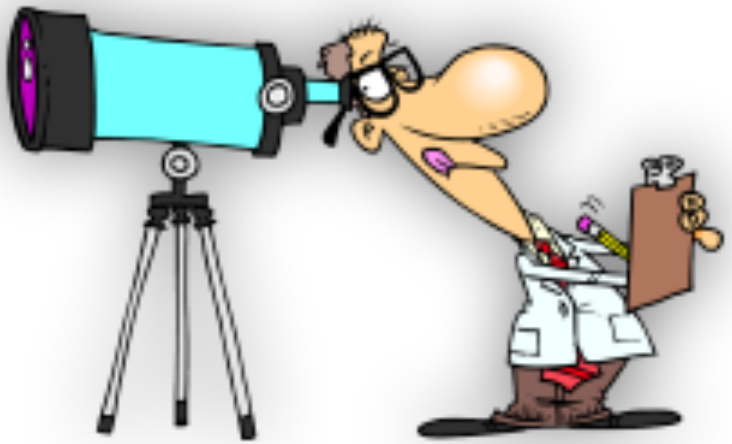
The real world



The imaginary world

“all models are wrong, some models are useful” (Bernd Freytag quoting someone else)

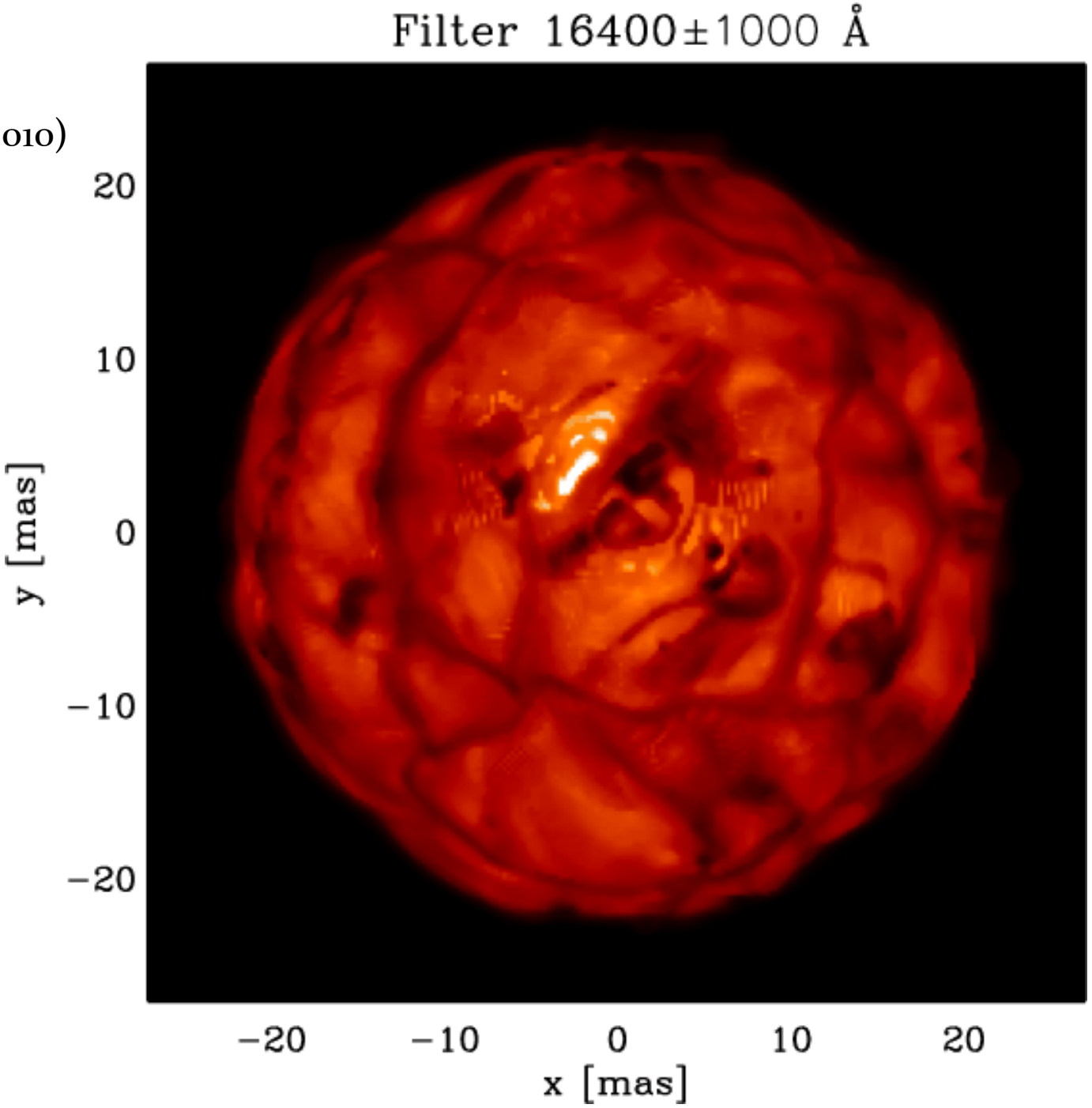
“sometimes theorists are right and observers are wrong”



Real imagination?

“if you say it often enough it becomes reality” (Ben Davies)

Chiavassa et al. (2010)

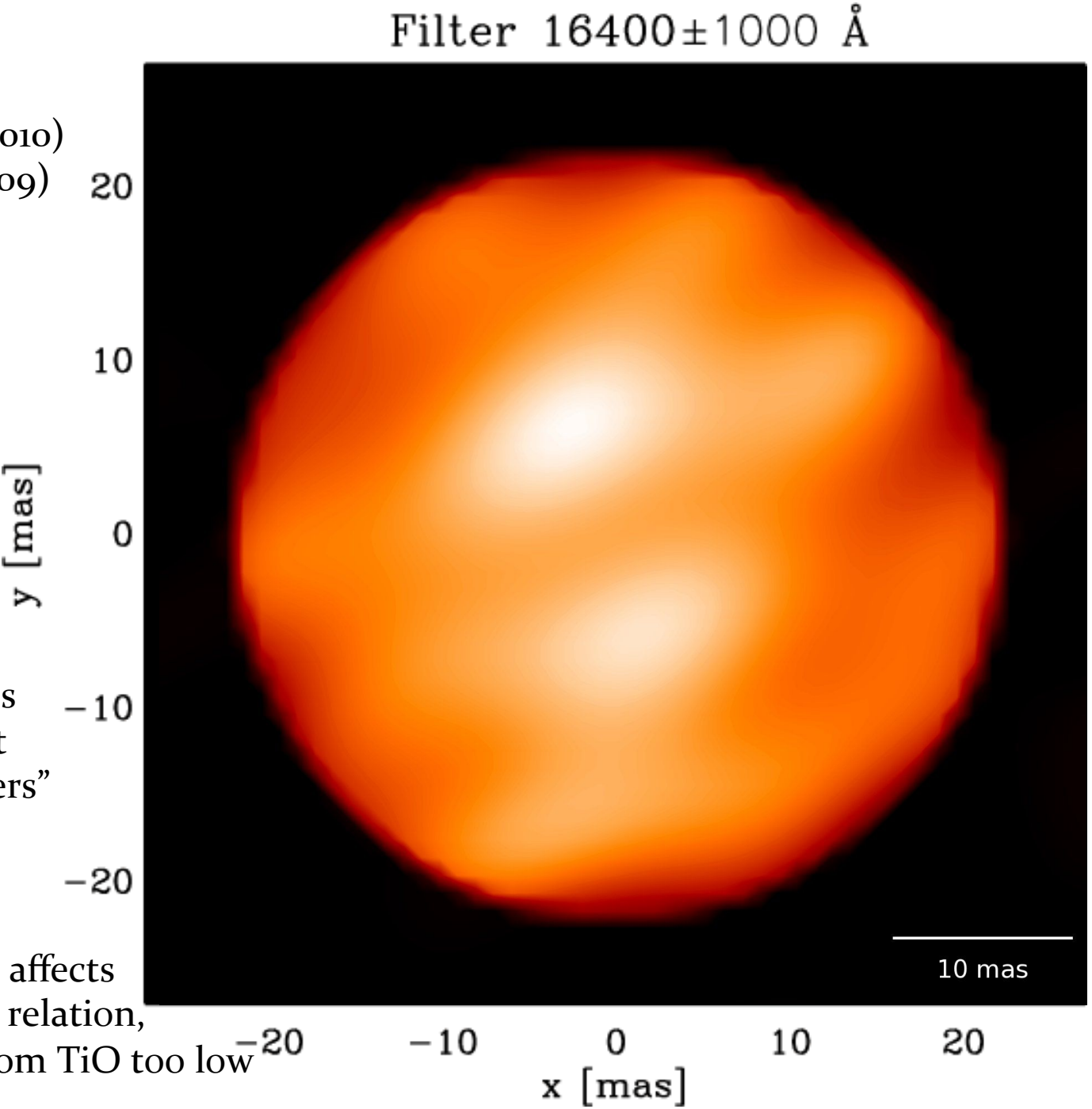


Chiavassa et al. (2010)
Haubois et al. (2009)
43 mas diameter

Also:
Andrea Dupree,
Keiichi Ohnaka…

Conclusions:
- convection cells
- outflow/indraft
- molecular “layers”
- v_{eq}~15 km/s?

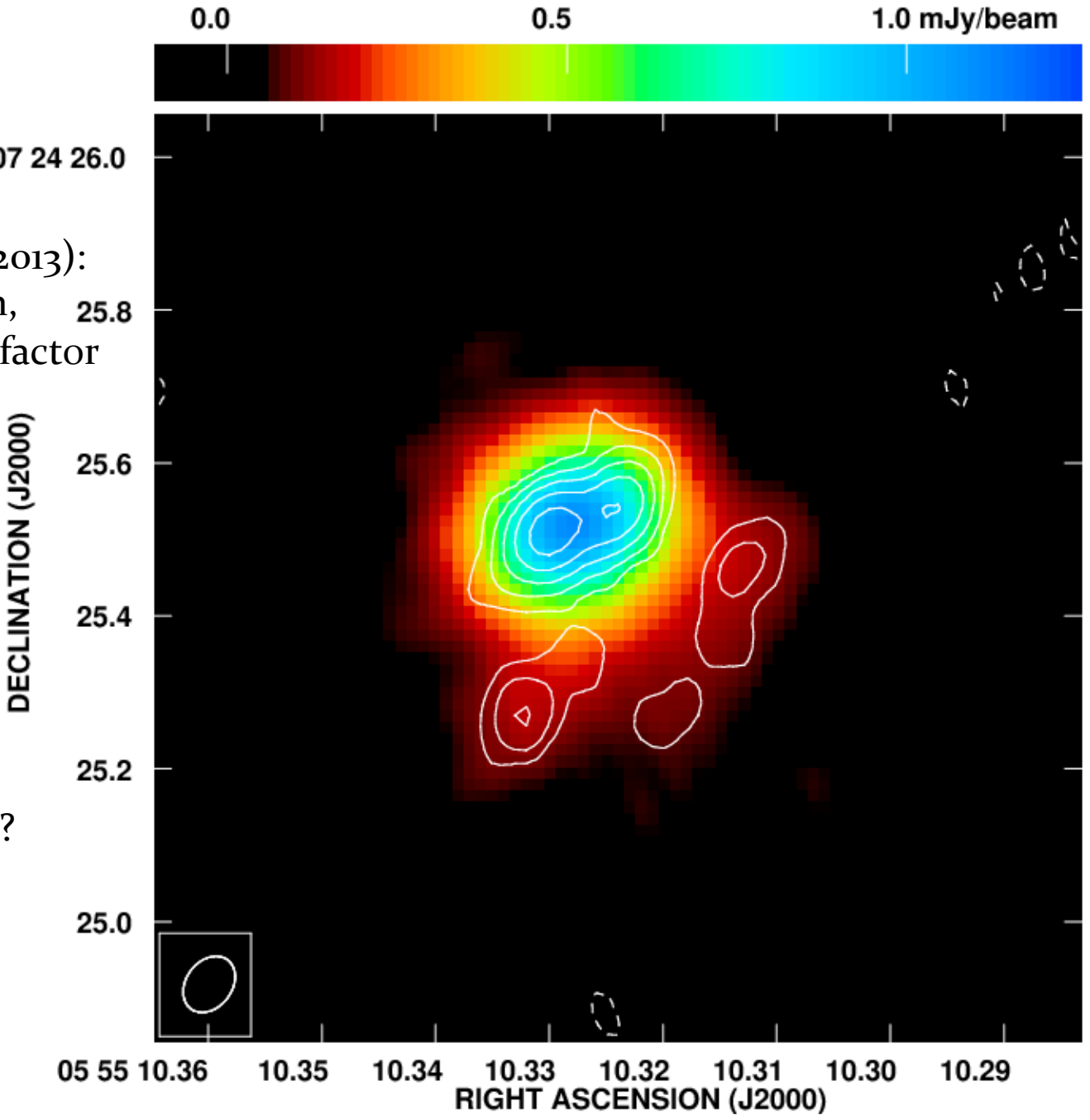
Non-uniform disc affects radius-luminosity relation,
Ben Davies: T_{eff} from TiO too low



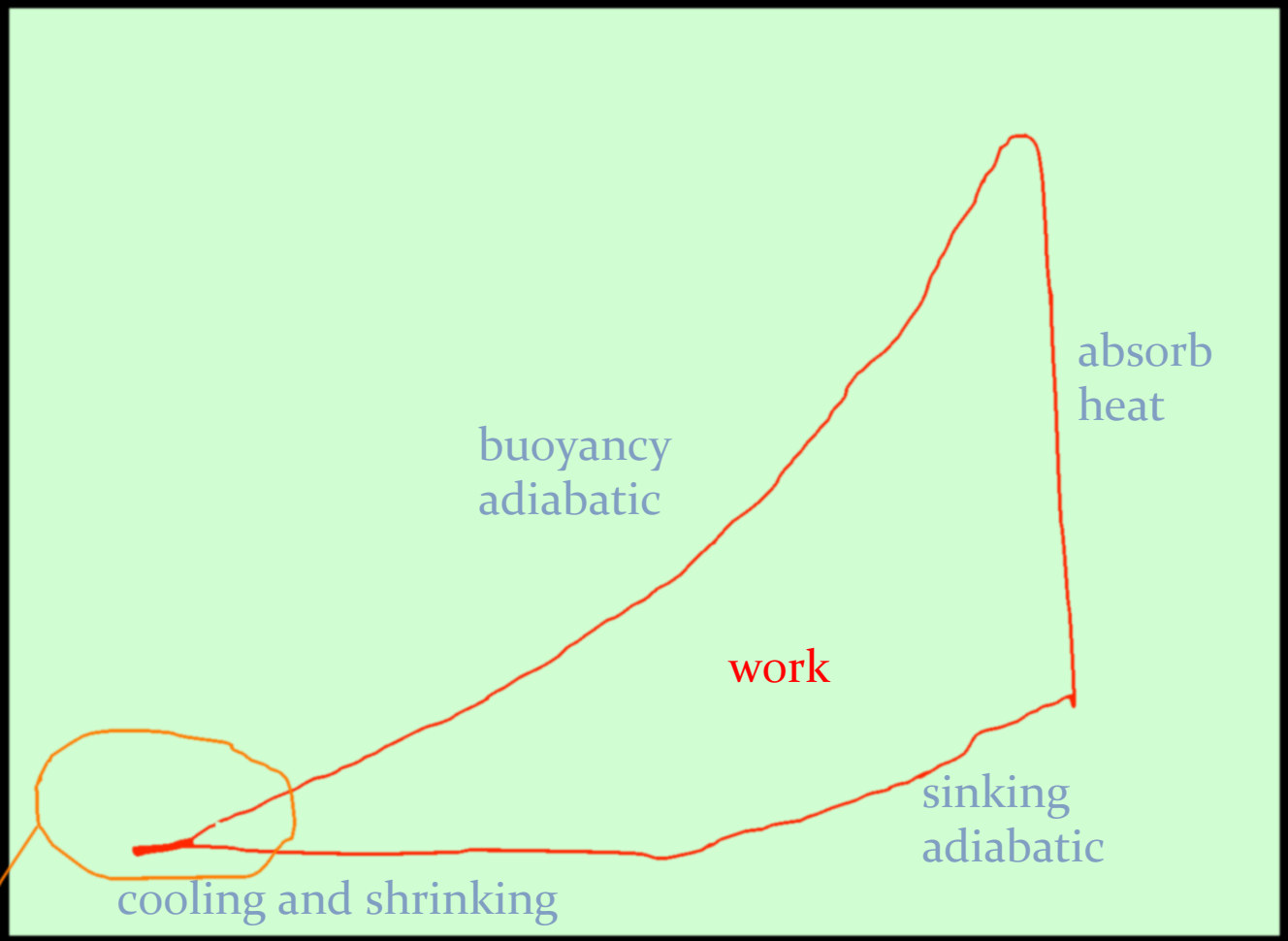
Richards et al. (2013):
5.75 GHz

Brown, Harper et al. (2013):
cool free-free emission,
ionised gas low filling factor

non-thermal emission?
Auriere et al. (2010):
magnetic field ~1 G!

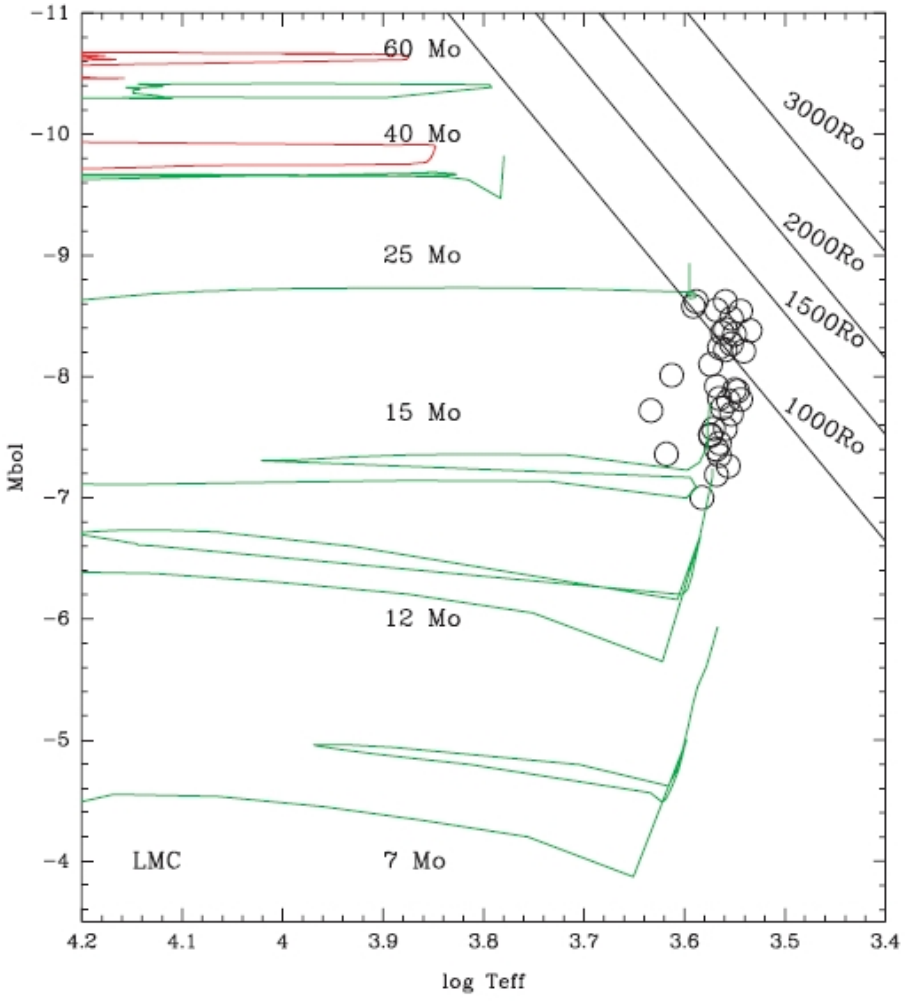


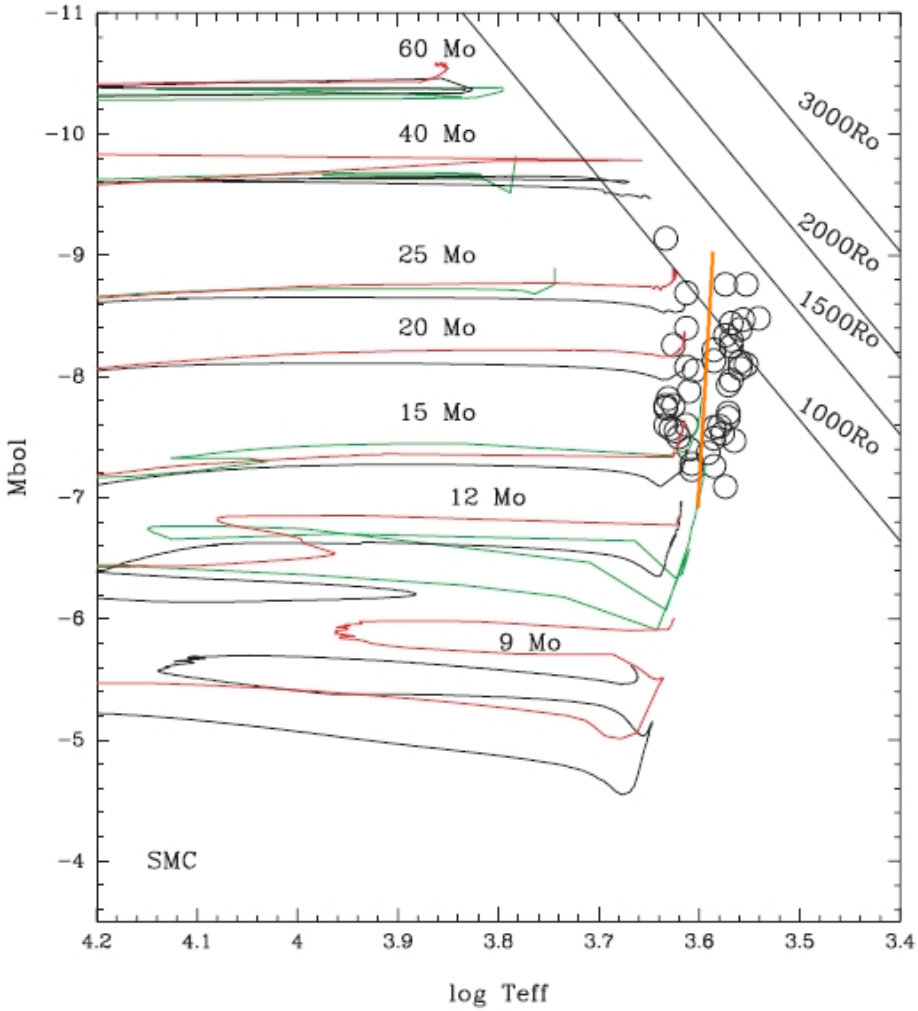
Convection as a heat engine



(gravity is a conservative field so no net work is done by it)

Red supergiant populations

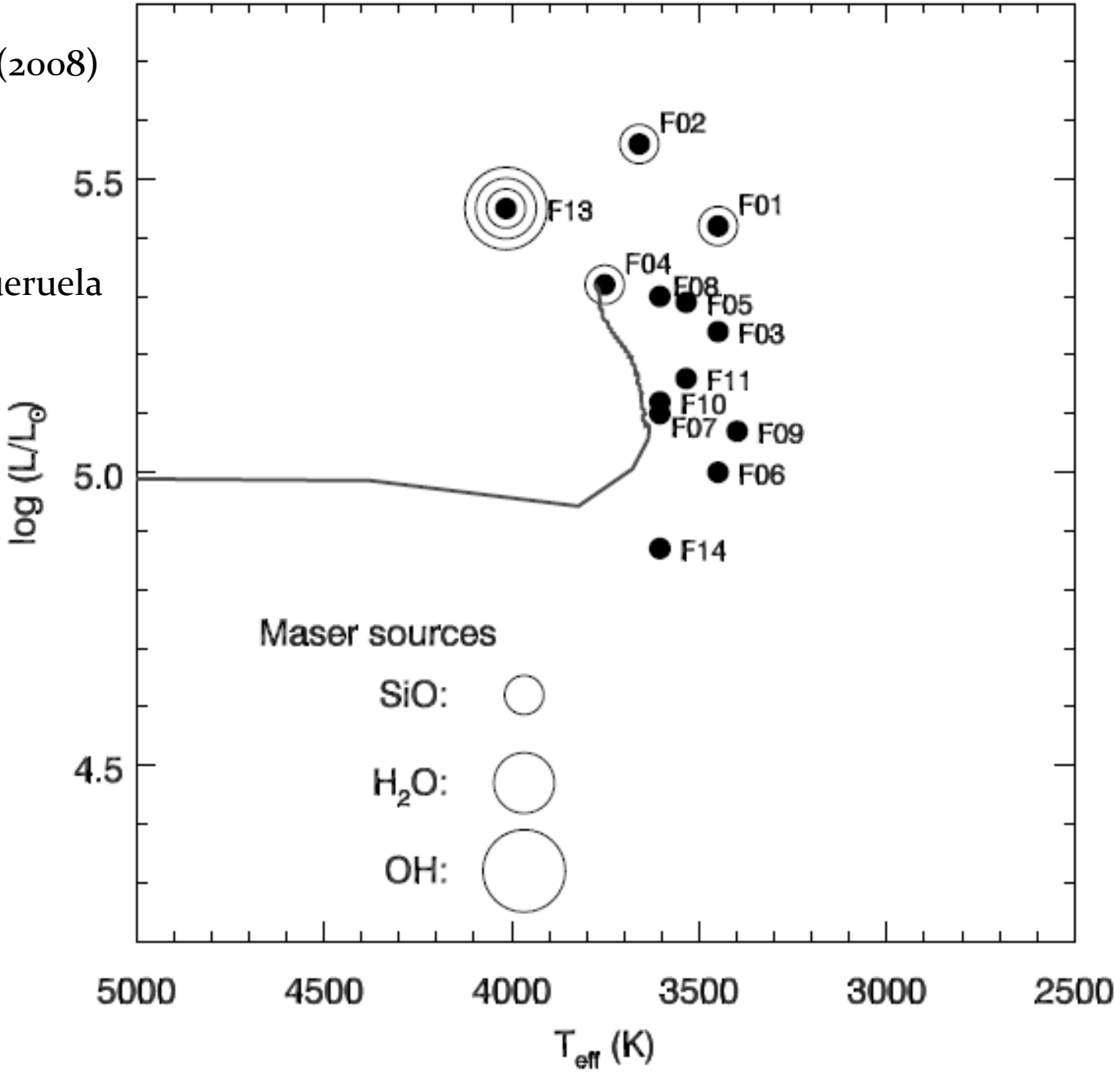




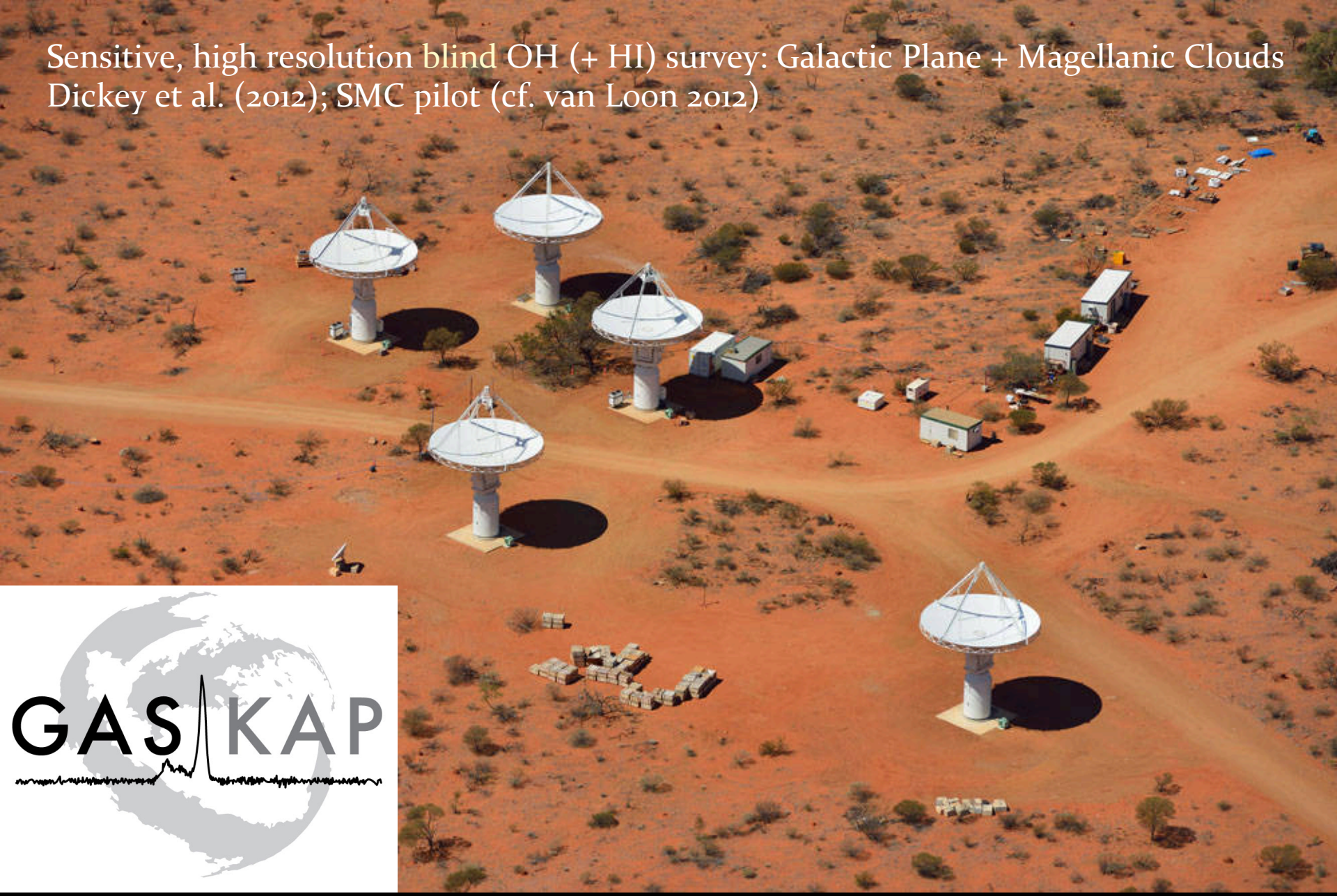
Levesque et al. (2005)
M33 (optical: Drout, Massey & Meynet 2012; infrared: Javadi et al. 2011a,b, 2013)
Reconcile T_{eff}, L; lifetimes

Davies et al. (2008)
RSG-C1

also
Ignacio Negueruela



Sensitive, high resolution blind OH (+ HI) survey: Galactic Plane + Magellanic Clouds
Dickey et al. (2012); SMC pilot (cf. van Loon 2012)



Wish list for modeling people:

- NLTE feedback on atmospheric structure
  (cf. Maria Bergemann, Julien Lambert, Bertrand Plez)
- High-altitude molecular layers (haze? clouds?)
- Hydro models to produce a "mixing length"
- Include a wind (pulsation, acoustic/Alfven waves?)
- Hydro models to include magnetic field, rotation

- Ben Davies: whence the disagreement between groups?
- Rotation profile: differential or solid body?
- Why is ratio of blue/red supergiants not reproduced?

Wish list for watchers of the sky:

- Betelgeuse!
- Antares!
- E. Griffin: other binaries! (R. Humphreys: VV Cep!)
- maser observations (Betelgeuse?)
- spectroscopic monitoring (cf. Sophie Van Eck)
- CNO and He abundance, rotation, magnetic field
- Complete samples RSGs in clusters and galaxies (masses, timescales) (cf. E. Levesque, I. Negueruela) out to z~0.1 (cf. B. Davies, R.-P. Kudritzki)
- SN progenitors/afterglows (blue loops, RSG mass loss)

And one for all:

- Reconcile the modeled and observed effects of binarity

IAU Commission 35: “Stellar structure and evolution”

IAU Task Group: “Red giants and red supergiants”

IAU Working Group: “Stellar hydrodynamics” (John Lattanzio)

AGB Newsletter: www.astro.keele.ac.uk/AGBnews (also red supergiants!)


Thank you all!
and especially:
Thibaut Le Bertre
Pierre Kervella
Guy Perrin
(Apologies if I did not mention you – all participants made this workshop a big success)