The spectacular lives and deaths of Massive Stars

and future UVOIR Space Astronomy

Credit background NASA Paresce., Design E. Bununk

Massive Star Tarantula Consortium

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Challenges

Rare and short lived
→ Need for larger and larger distances

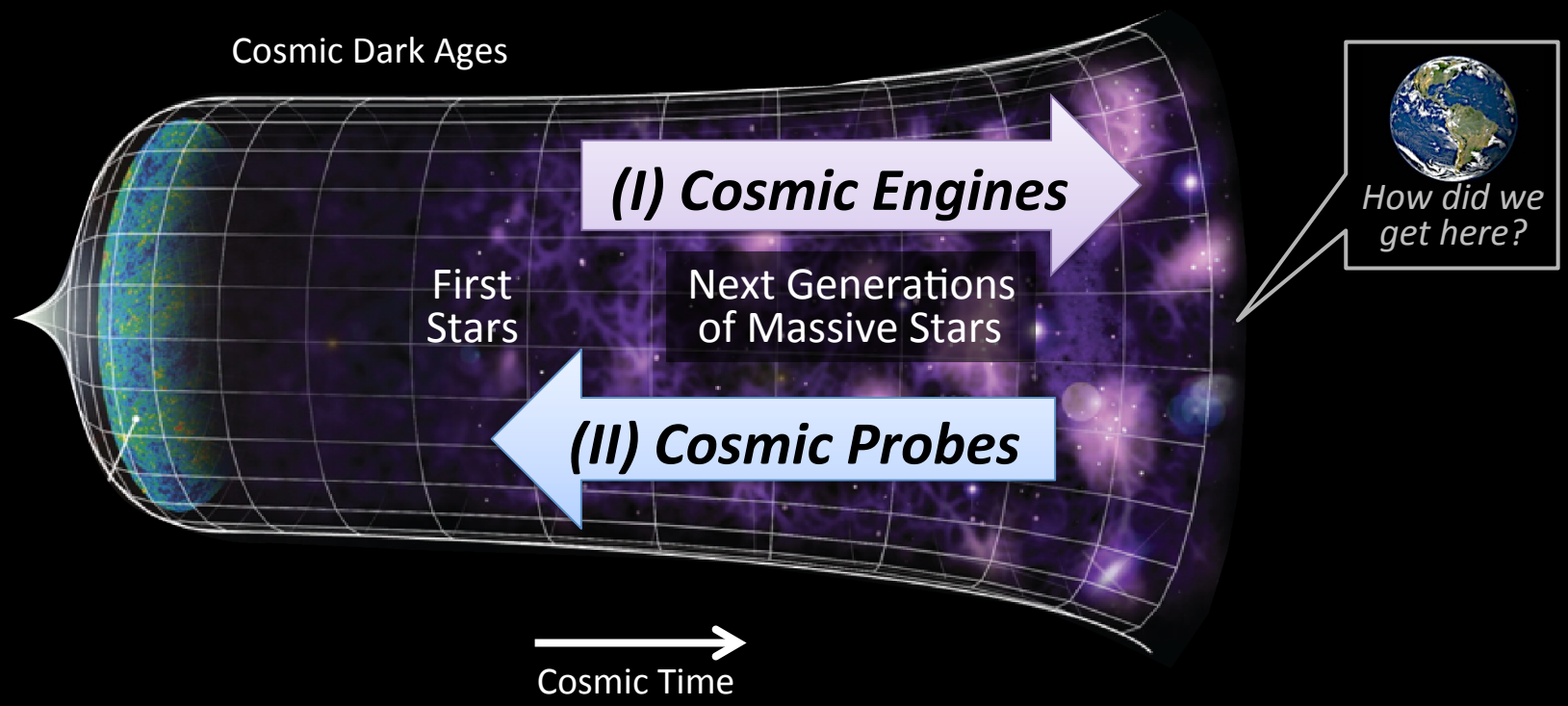
Emit most of their light in the UV
→ Need for Space

Form in crowded regions with companions
→ Need for superb spatial resolution

Bin Cosmos

1. Introduction and motivation

Many roles of Massive Stars in Astrophysics



Many roles of Massive Stars in Astrophysics

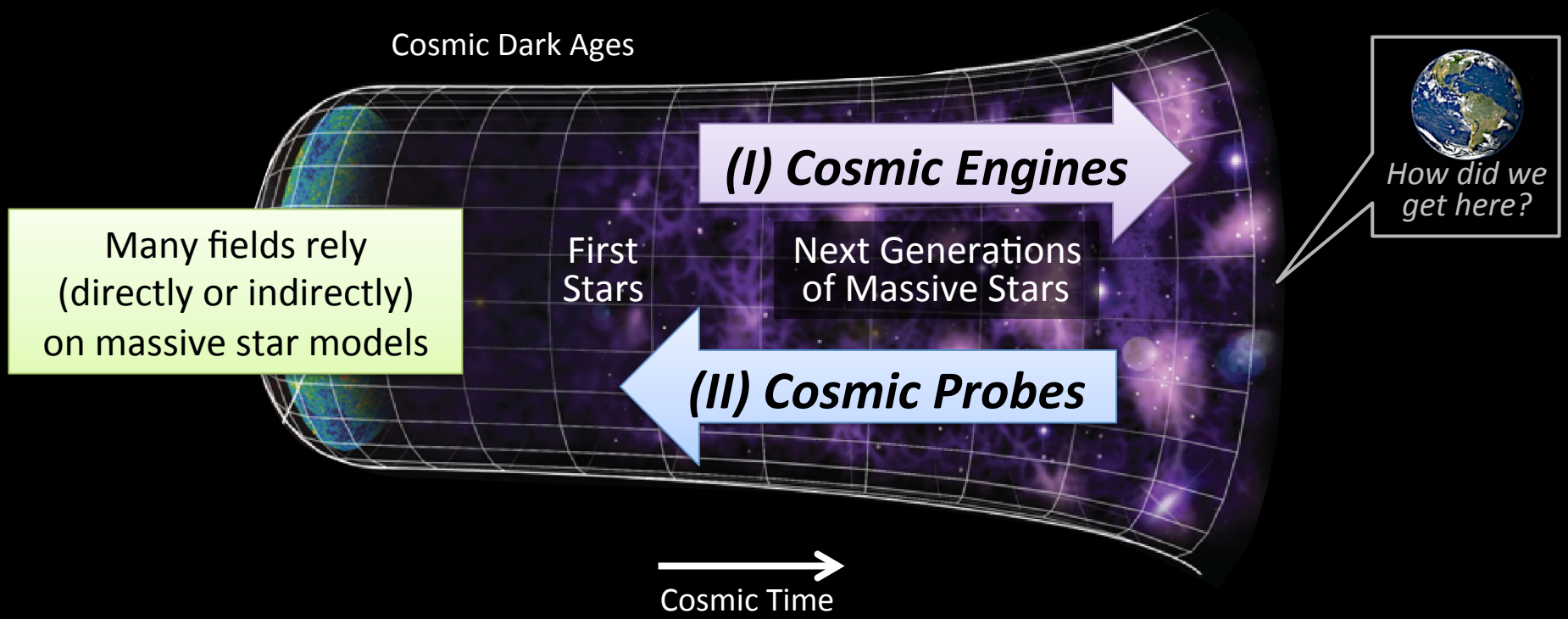
Reionization

Chemical enrichment

Heating

Seeding turbulence

Galactic-scale outflows



Many fields rely (directly or indirectly) on massive star models

High redshift galaxies: Star formation history, IMF

Most energetic explosions

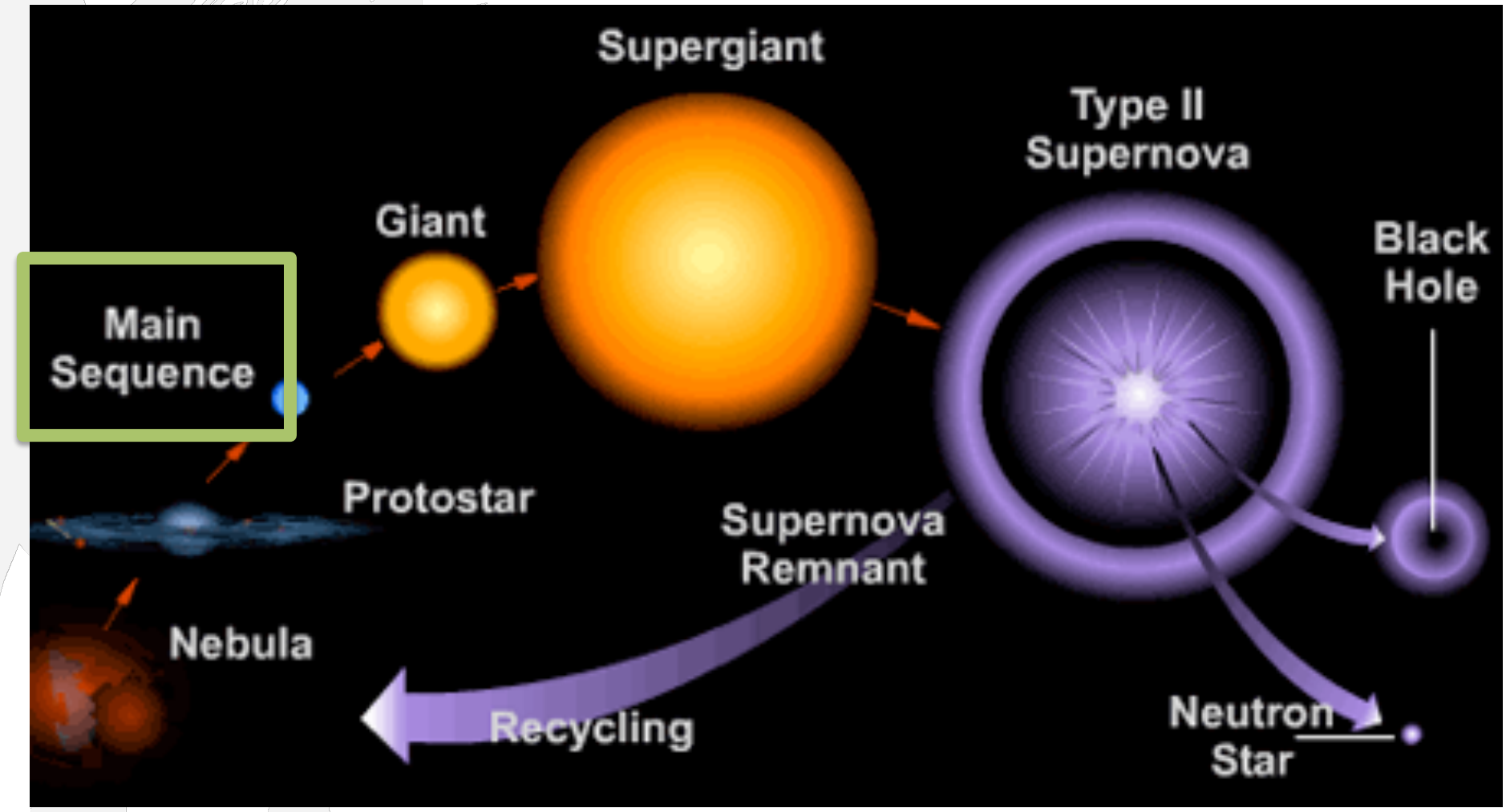
Extreme physics of NS & BHs

Nearby stellar populations

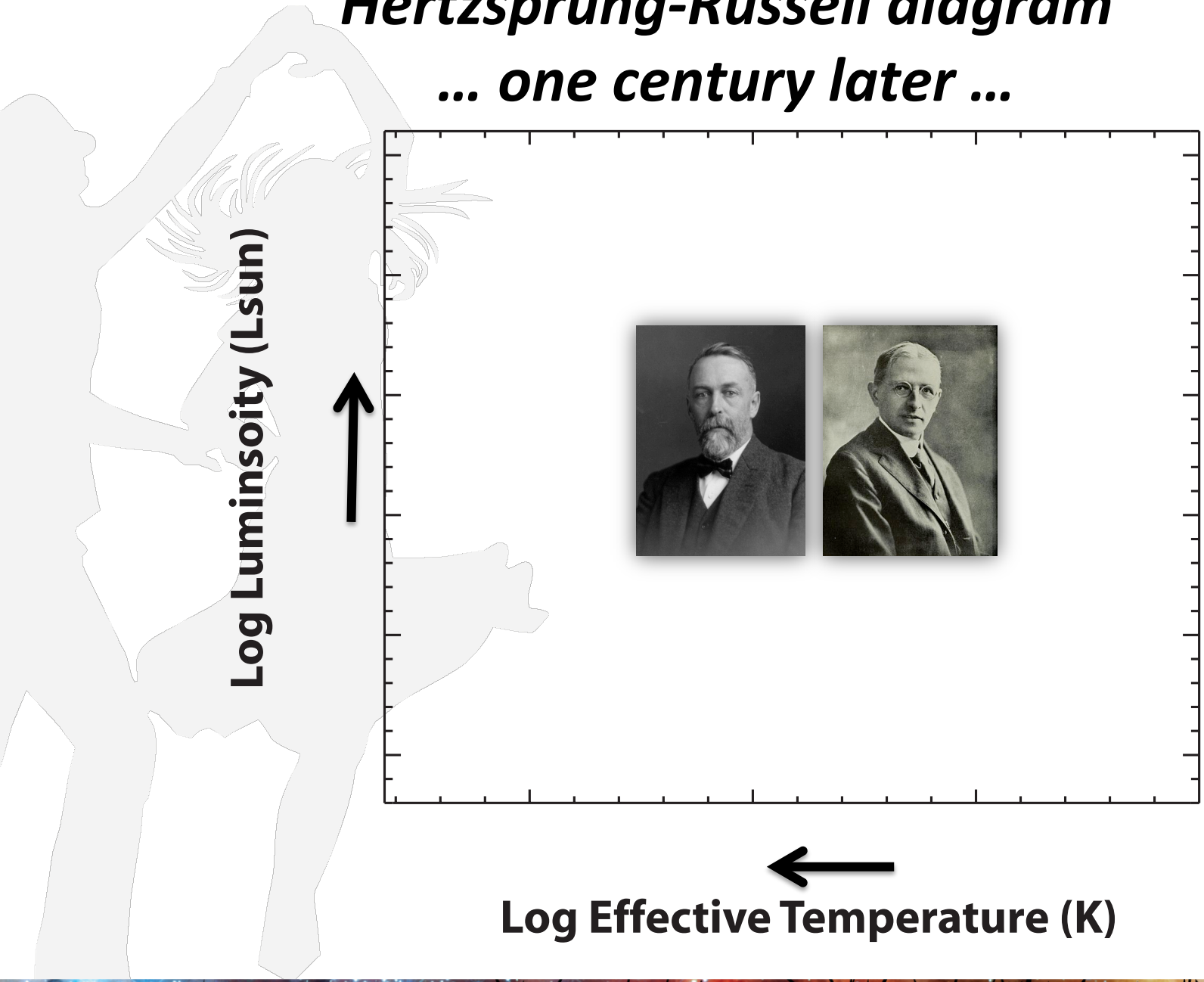
Probes of intervening gas (IGM, ISM)

What we tell our students …

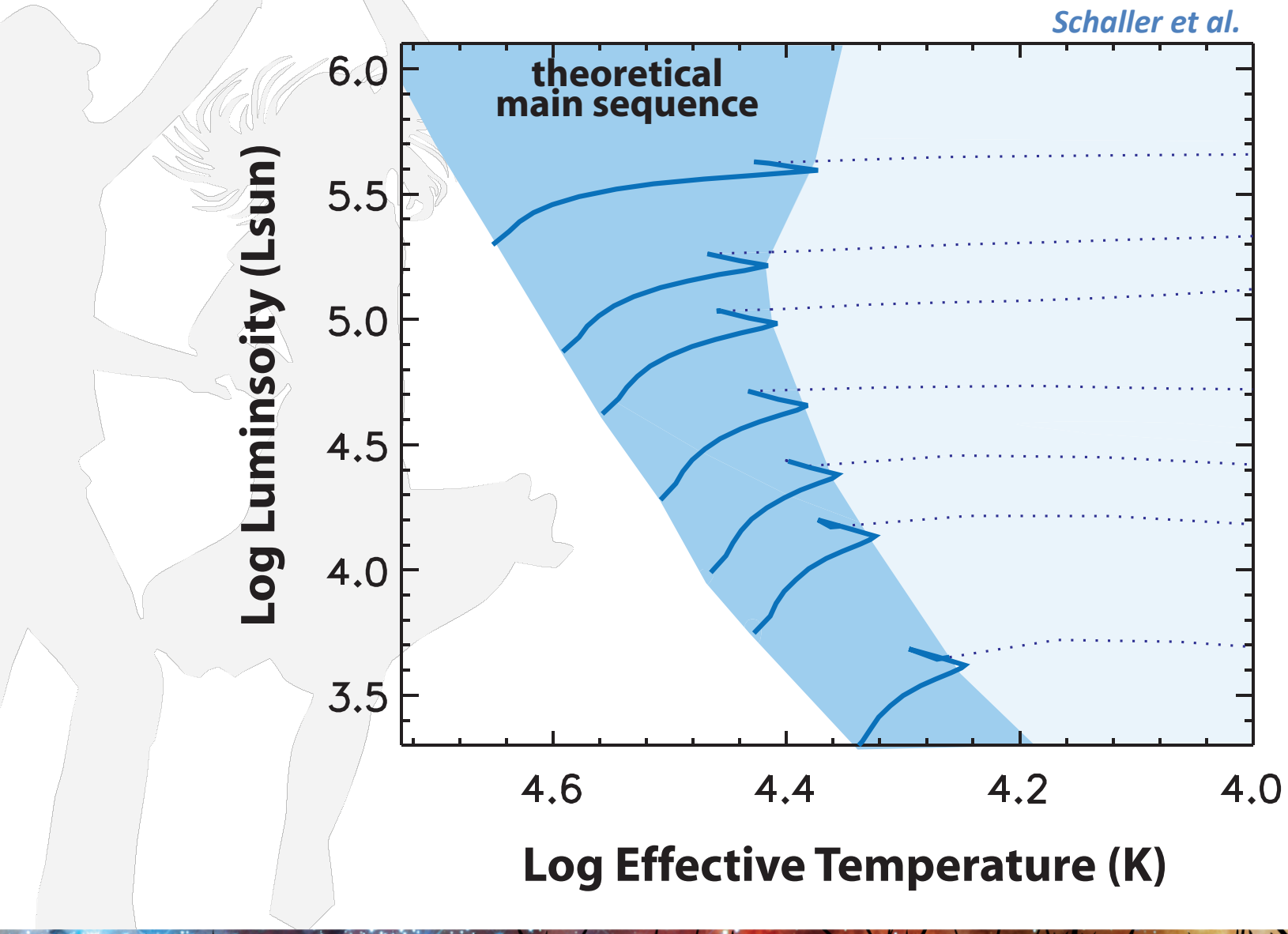
(the classic models that are widely used in astrophysics)



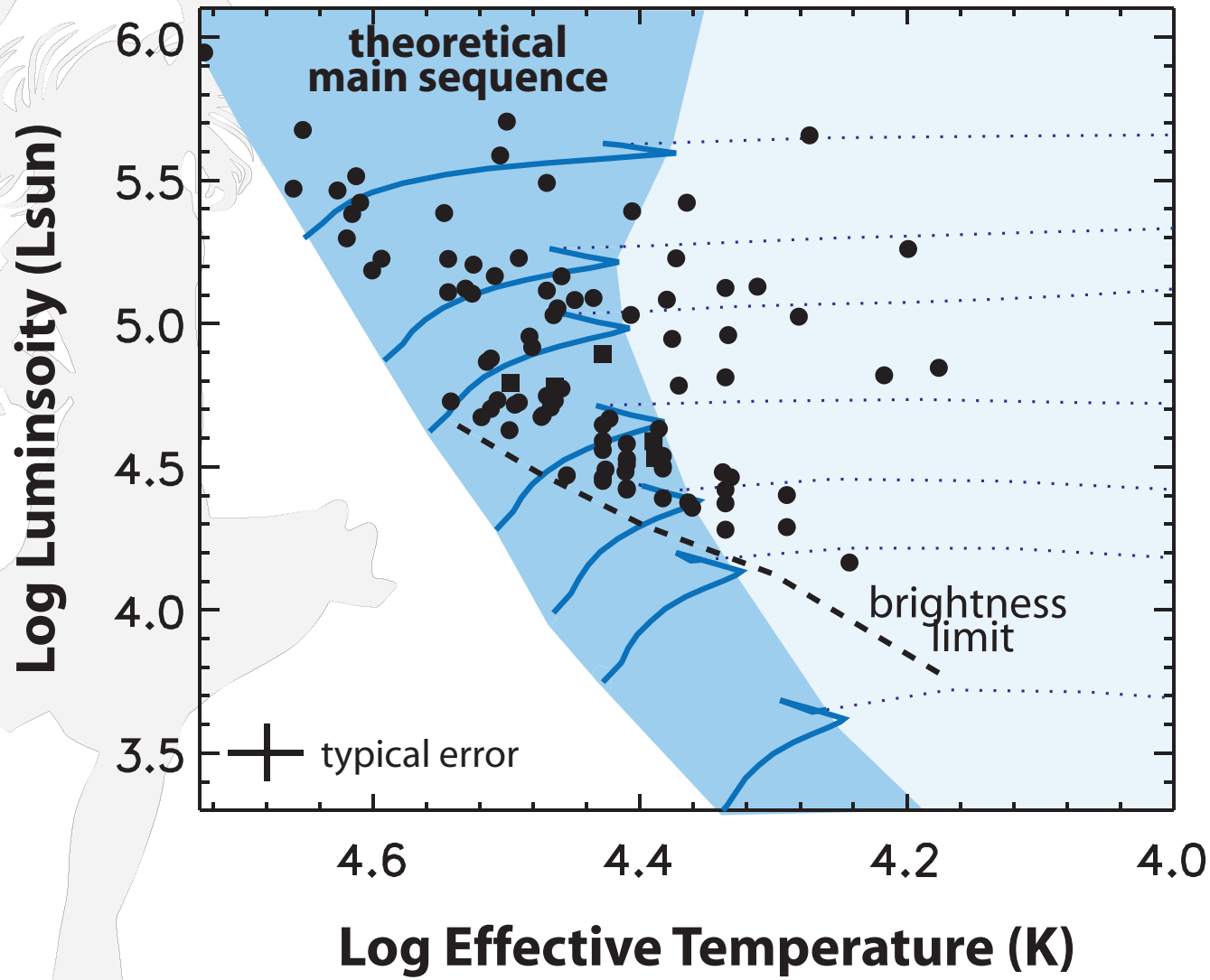
Hertzsprung-Russell diagram
... one century later ...



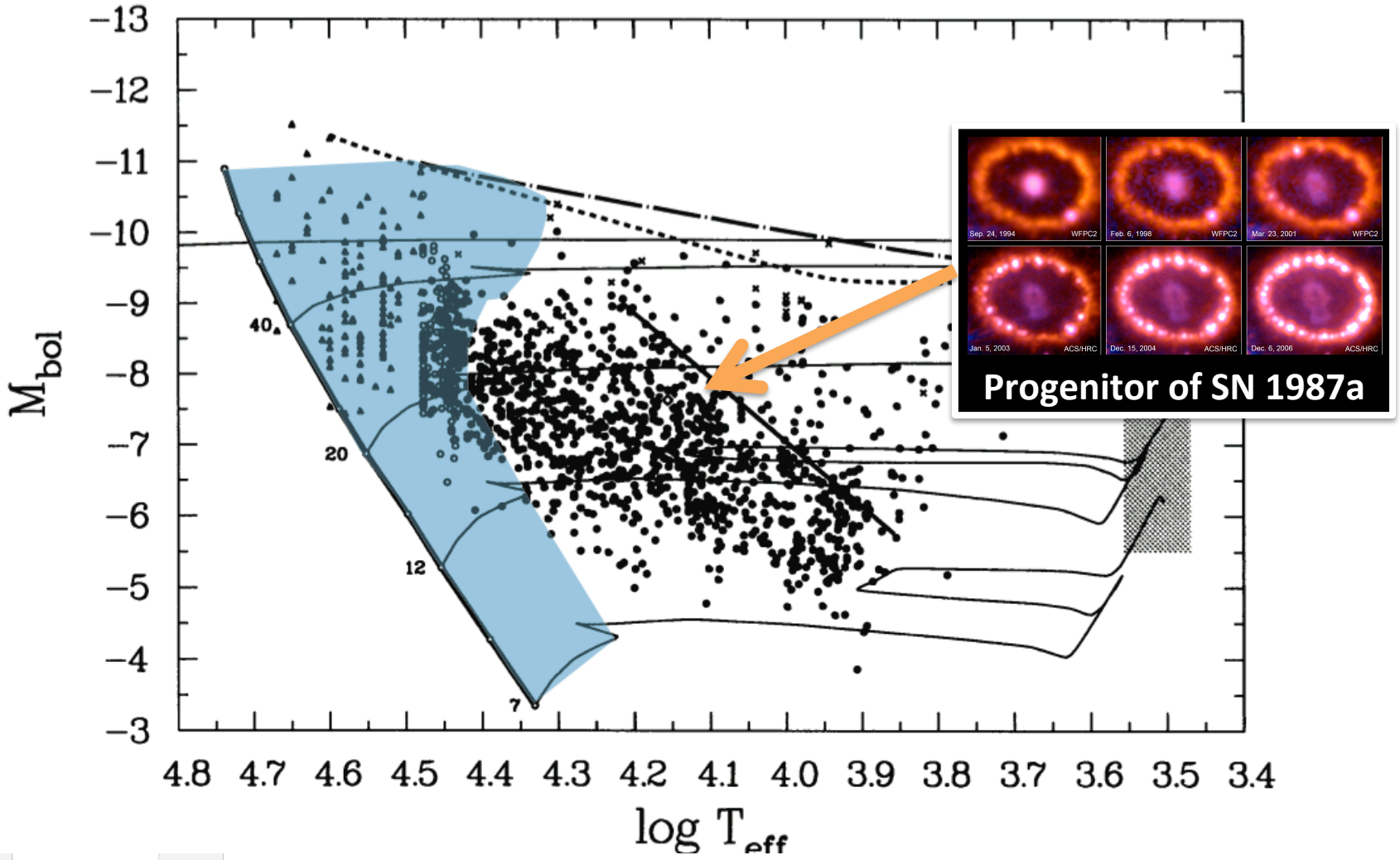
How well do the classic widely used models do?



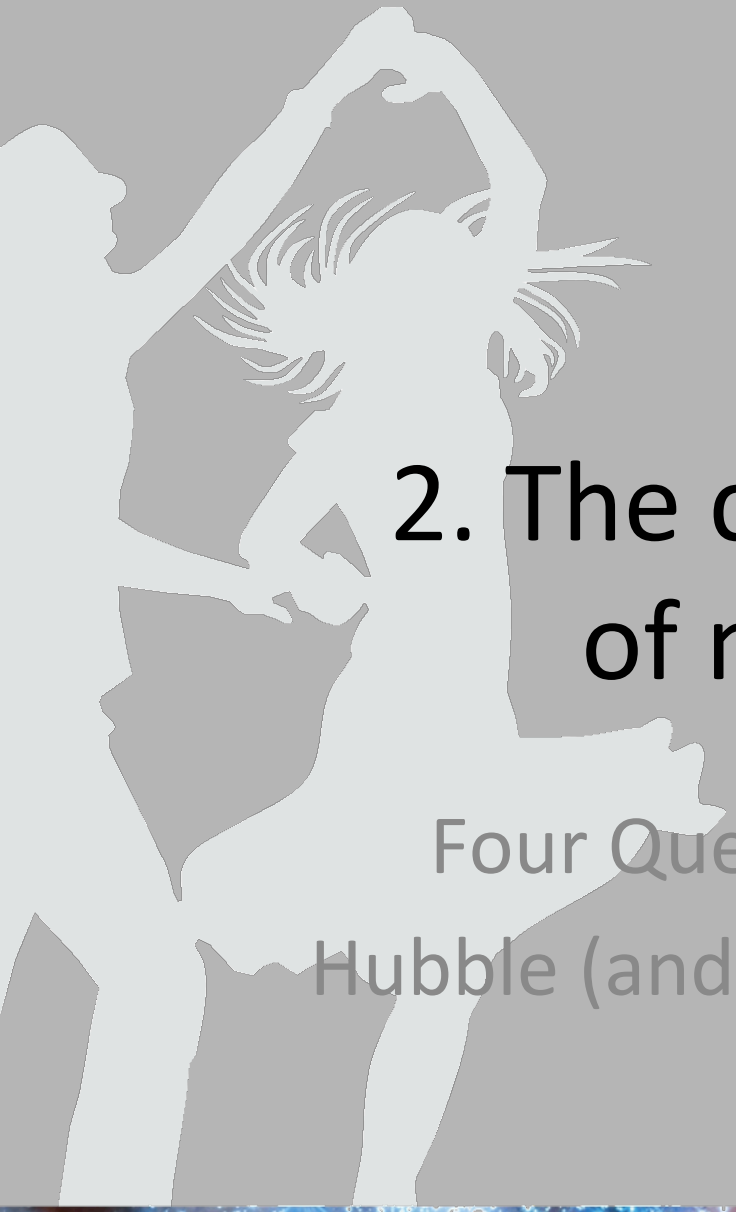
Data: VLT-FLAMES Survey of Massive Stars (Evans et al. 2006)



Data: Stars in the Large Magellanic Cloud (Fitzpatrick & Garmany, 1990)



S.E. de Mink

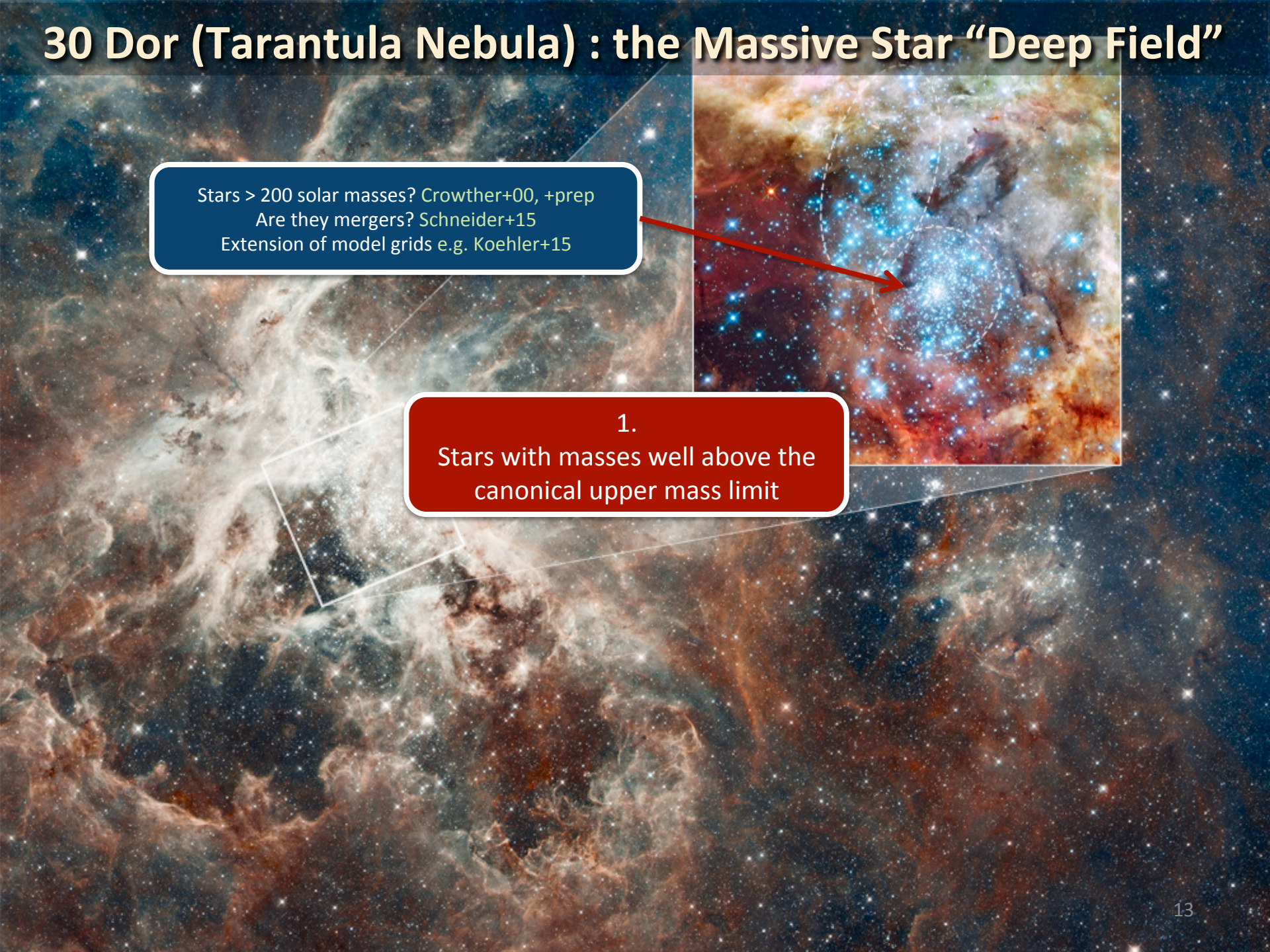


2. The complicated lives of massive stars

Four Questions triggered by Hubble (and VLT) observing 30 Dor

30 Dor (Tarantula Nebula) : the Massive Star "Deep Field"

30 Dor (Tarantula Nebula) : the Massive Star "Deep Field"



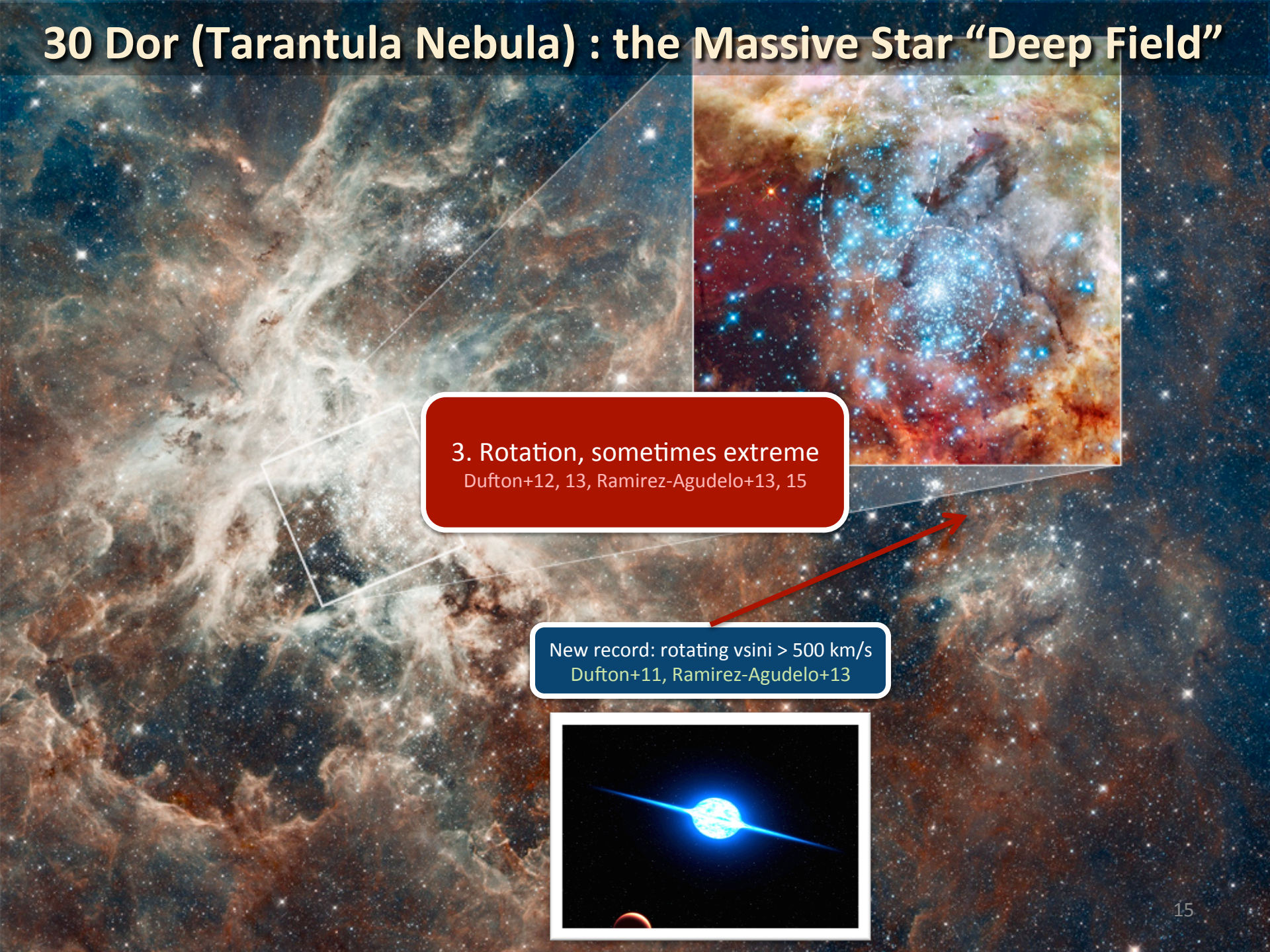
30 Dor (Tarantula Nebula) : the Massive Star "Deep Field"

2.
Majority in very close Binaries.
~7 out of 10 will interact
Sana+12+13, Dunstall+15

New records

- **Most massive over contact system** Almeida+15
- **First X-ray binary in 30 Dor,** Clark+15
- Most massive binary w/ O giants: Taylor+11

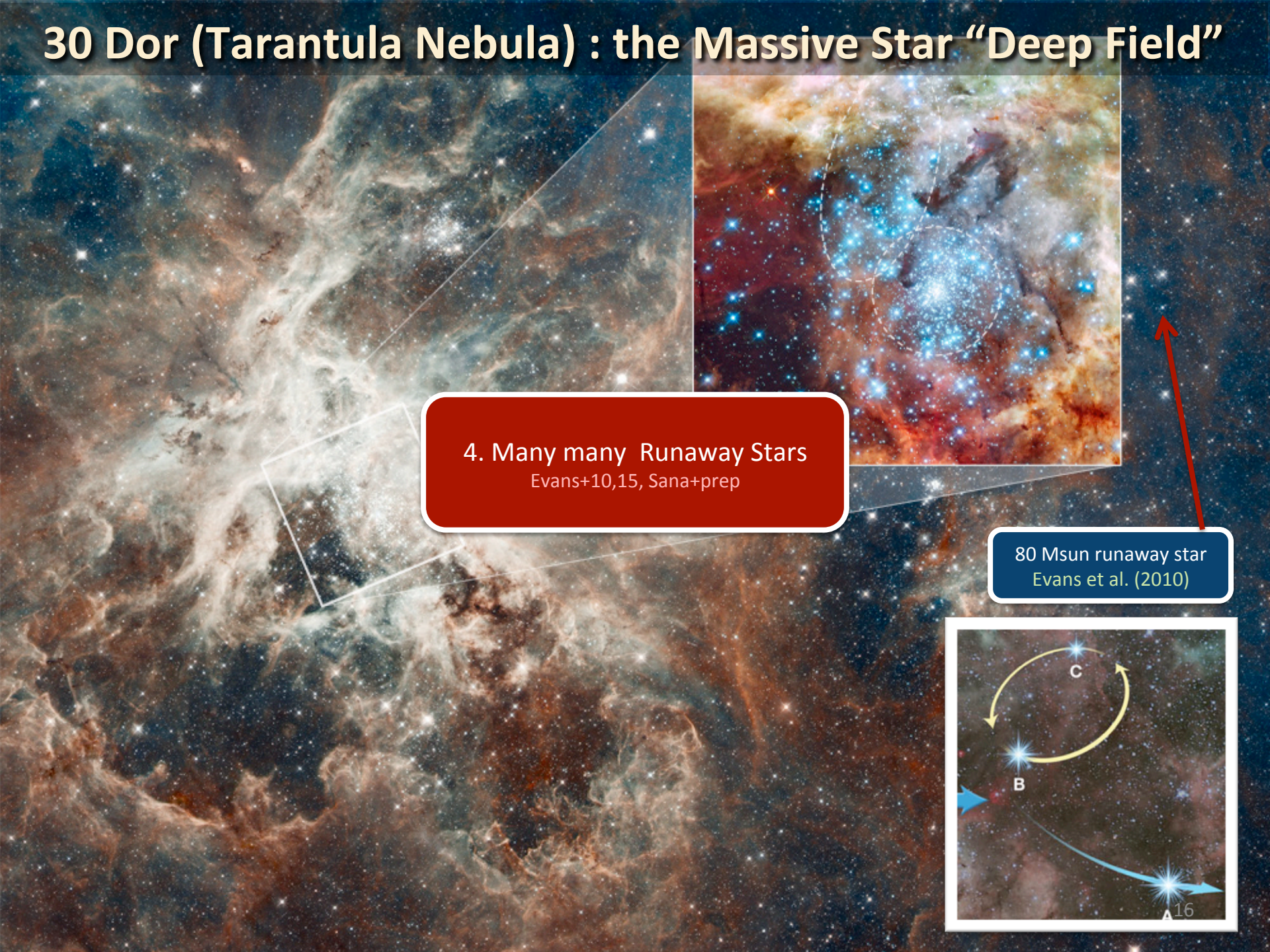
30 Dor (Tarantula Nebula) : the Massive Star "Deep Field"



3. Rotation, sometimes extreme
Dufton+12, 13, Ramirez-Agudelo+13, 15

New record: rotating vsini > 500 km/s
Dufton+11, Ramirez-Agudelo+13

30 Dor (Tarantula Nebula) : the Massive Star "Deep Field"



4. Many many Runaway Stars

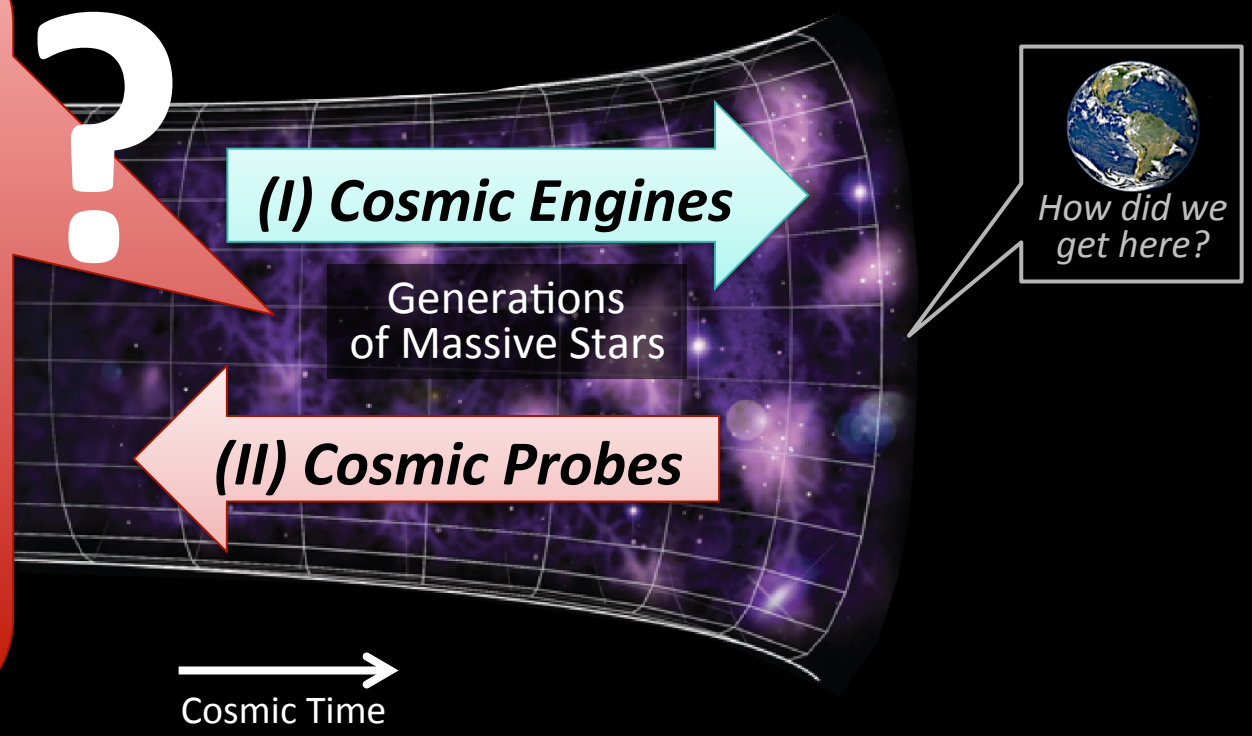
Evans+10,15, Sana+prep

80 Msun runaway star
Evans et al. (2010)

Raising many new questions …

1. Is there a Universal upper stellar mass limit?
2. High binary fraction Universal?
3. What are the origin and consequences of rotations?
4. Runaway stars.

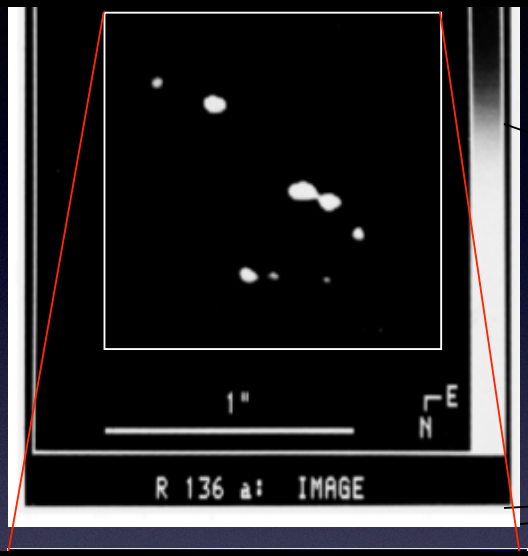
… …



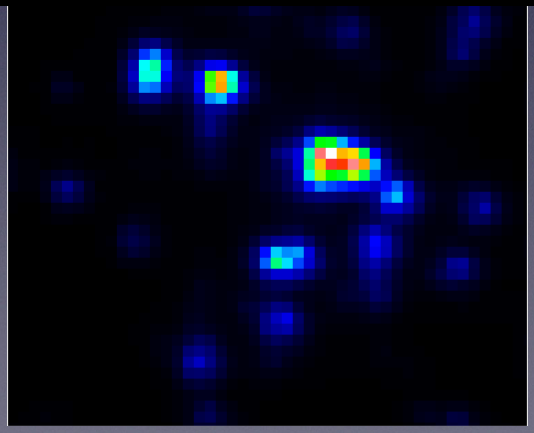
2.I Example
Finding the most massive stars

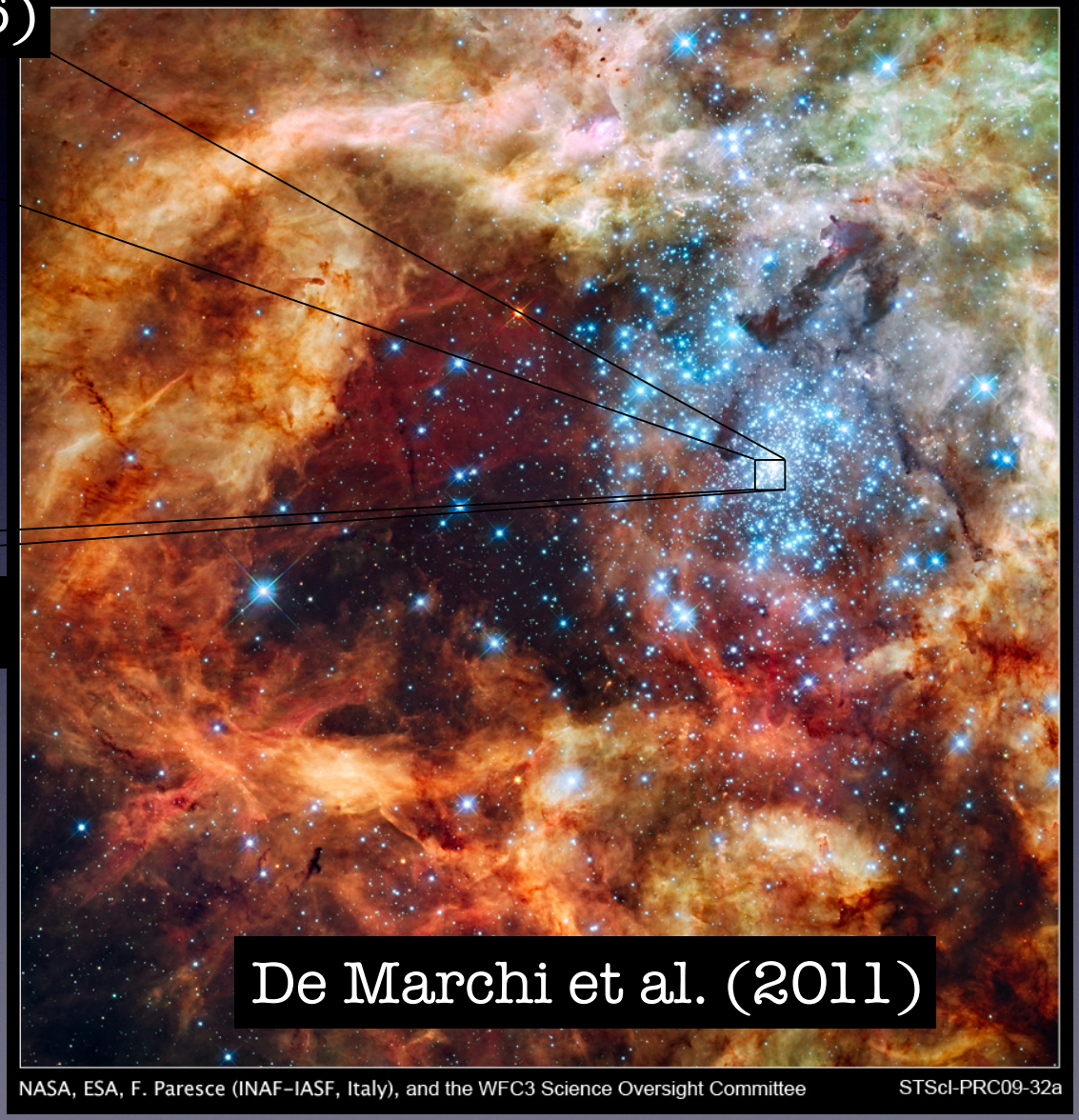
R136: ionizing star cluster

Weigelt & Baier (1985)



Hunter et al. (1995)





De Marchi et al. (2011)

Slide w/ courtesy of Paul Crowther

The 4 "super stars" in R136

Crowther et al. 2010

Name	a1	a2	a3	c
BAT99	108	109	106	112
$M_{\rm init}$ $(M_\odot)^b$	320^{+100}_{-40}	240^{+45}_{-45}	165^{+30}_{-30}	220^{+55}_{-45}
$M_{\rm current}$ $(M_\odot)^b$	265^{+80}_{-35}	195^{+35}_{-35}	135^{+25}_{-20}	175^{+40}_{-35}

Separated by
~0.1 arcsec (about 5000 AU)

Based on ***HST UV/Optical Spectra*** **(**Ebbets, Heap, Massey) **and near IR VLT spectra (**Schnurr)

Can we do better …dissecting R136 w/ Hubble

HST/STIS

39 HST orbits, 17 slits, 0.2'' width

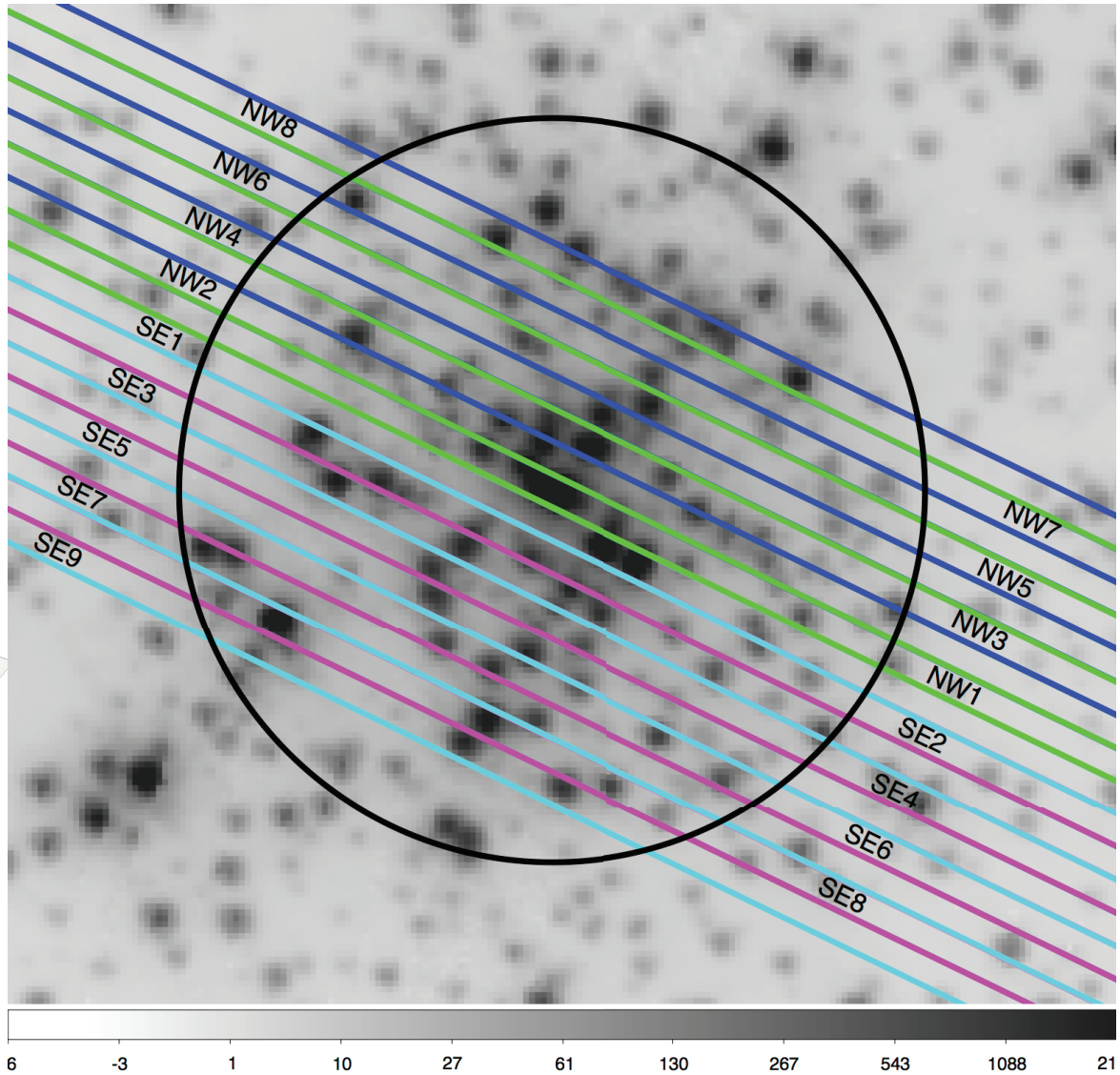
(PI: Crowther)

Crowther, Caballero-Nieves et al. in prep.

HST/FGS:

(PI: de Mink/Caballero-Nieves)

Caballero-Nieves, Nelan, de Mink et al. in prep.

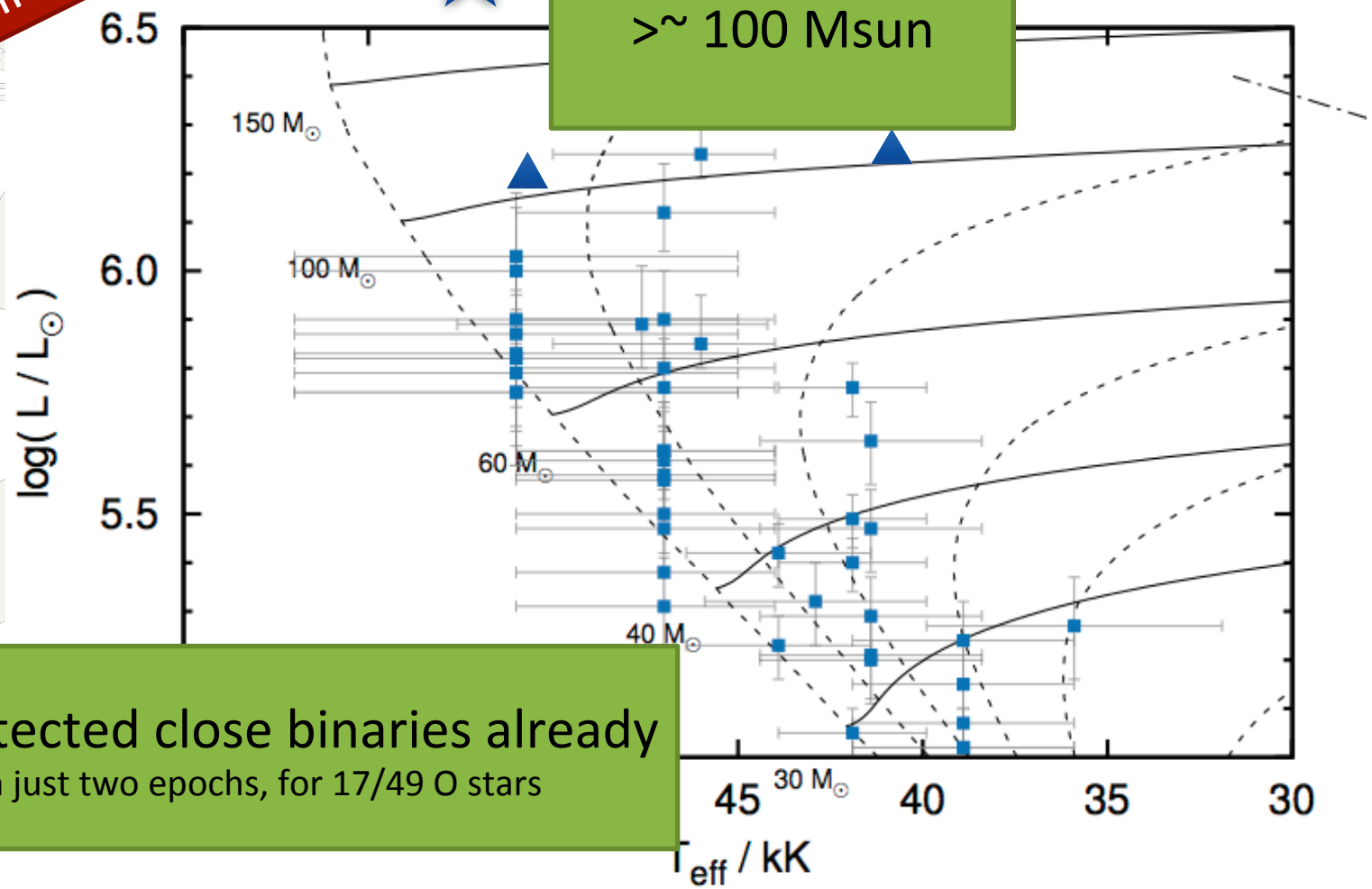


… Yes, they are still extremely massive …

Preliminary

7 stars
>~ 100 Msun

w/ courtesy of P. Crowther
& S. Caballero-Nieves



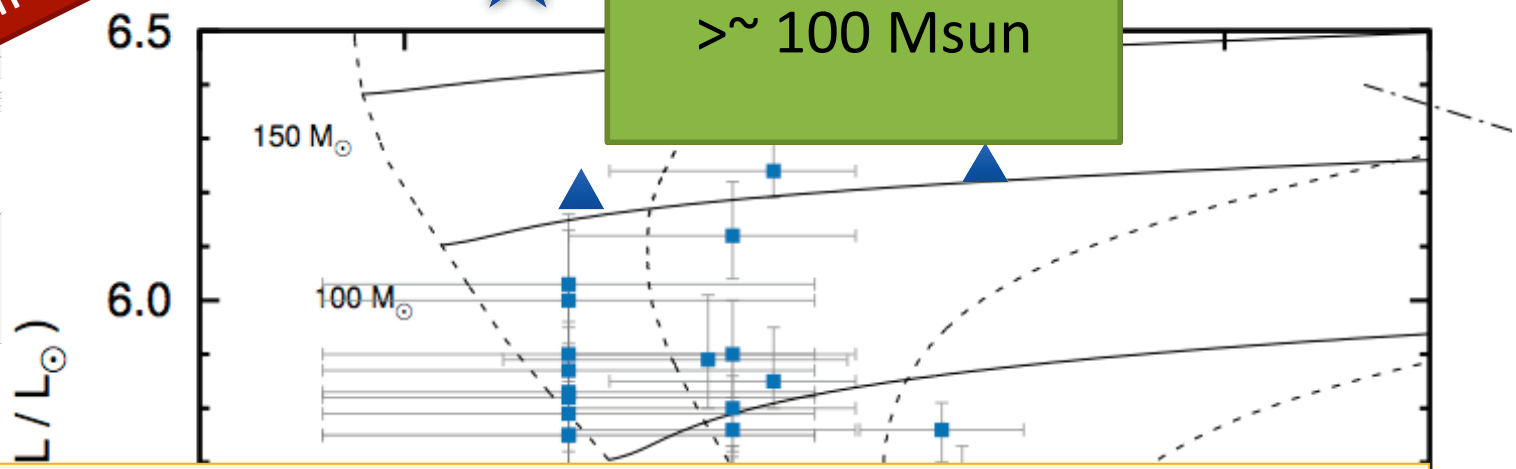
35% detected close binaries already
with just two epochs, for 17/49 O stars

… Yes, they are still extremely massive …

Preliminary

7 stars
>~ 100 Msun

w/ courtesy of P. Crowther
& S. Caballero-Nieves



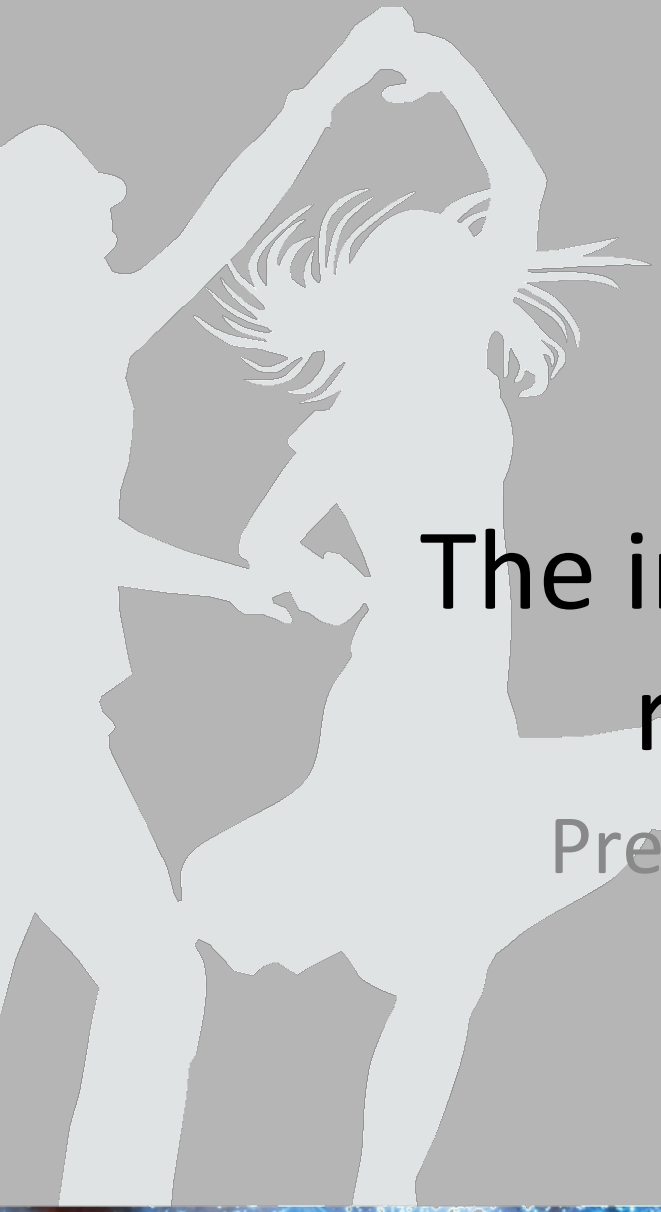
Implications: 100 + M_{sun} stars and disproportionally contribute to ionizing radiation and strong spectral features (He II 1640 emission)

- Omitting these leads to (e.g. Starburst99, BPASS)
  - Under estimating **ionizing fluxes**
  - Over estimating the **age**
  - Over estimating the **metallicity**

Questions for ATLAST/HDST/LUVOIR ….

- **Is there a (Universal) Upper mass limit?**
- **Resolving 100 pc everywhere in the Universe? → What features do we see in the integrated (UV) spectra of "resolved" starbursts**

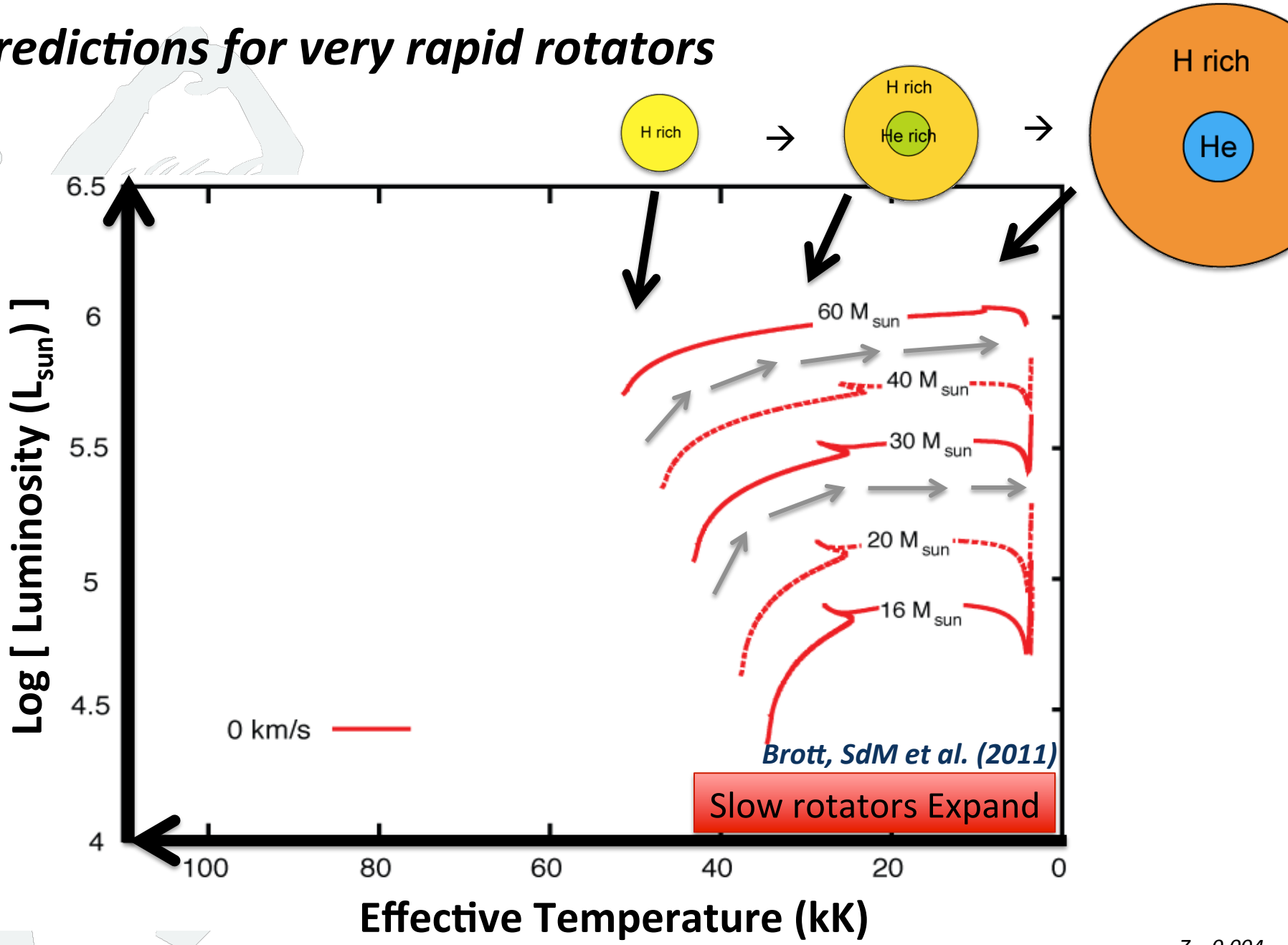
de Mink



2.II Example
The impact of extreme rotation rates

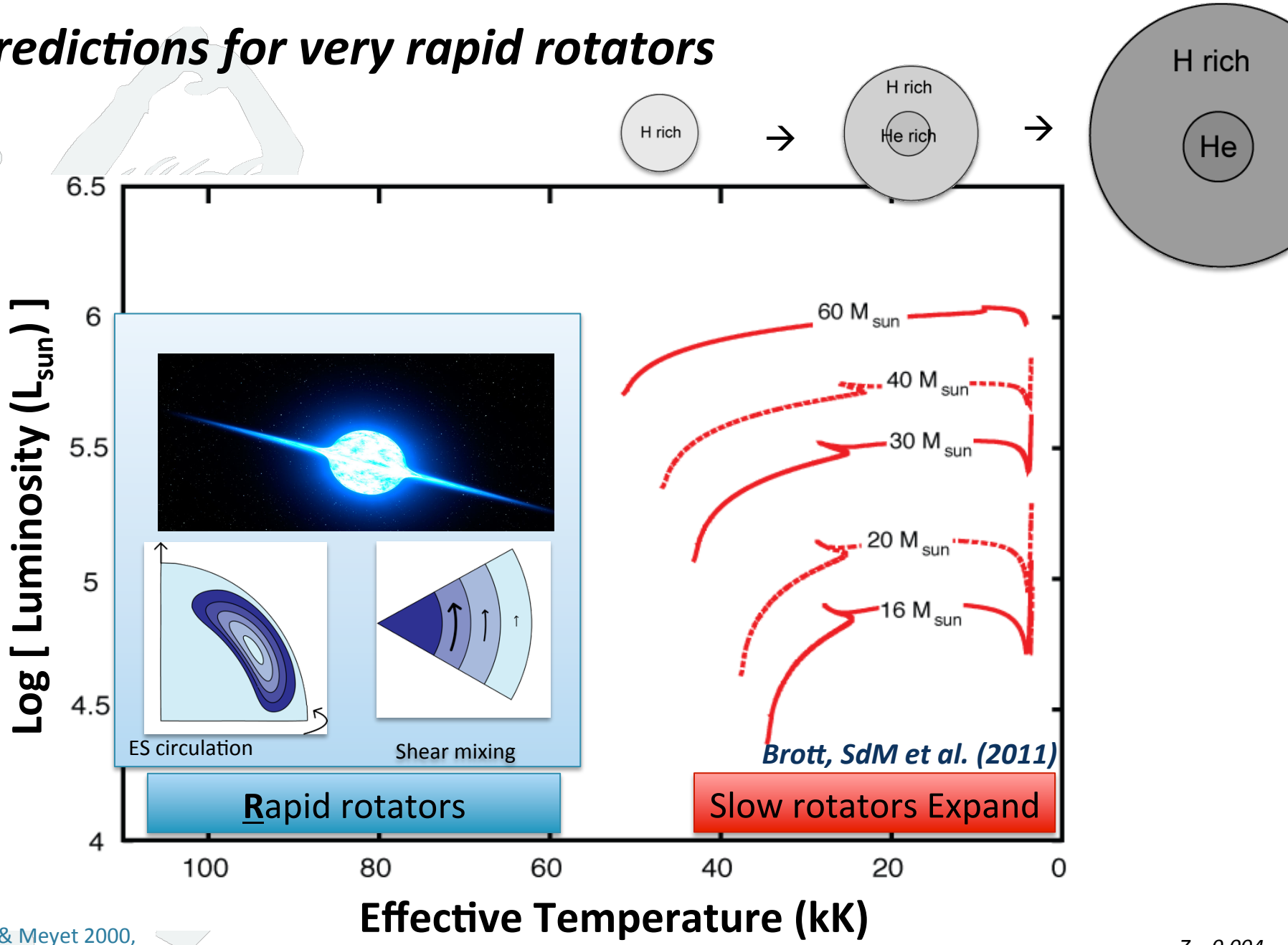
Predictions from theory

Predictions for very rapid rotators



Z = 0.004

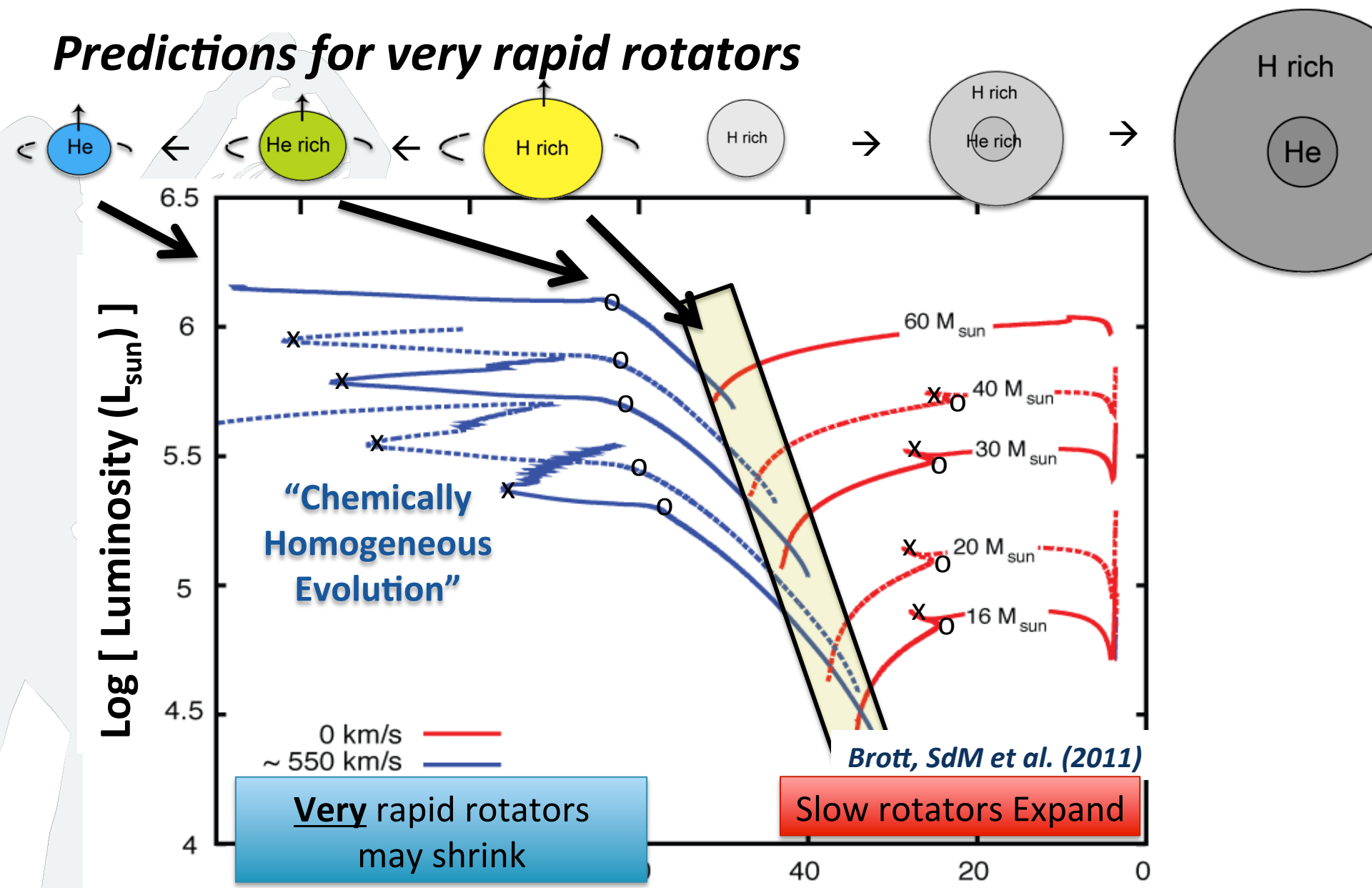
Predictions for very rapid rotators



Maeder & Meyet 2000,
Heger et al 2000, Yoon et al 2006,Hirschi 2007, Ekstroem et al 2012, Georgy et al. 2014, Kohler et al. 2015

Z = 0.004

Predictions for very rapid rotators



Maeder89, Yoon+05/06

Maeder & Meyet 2000,
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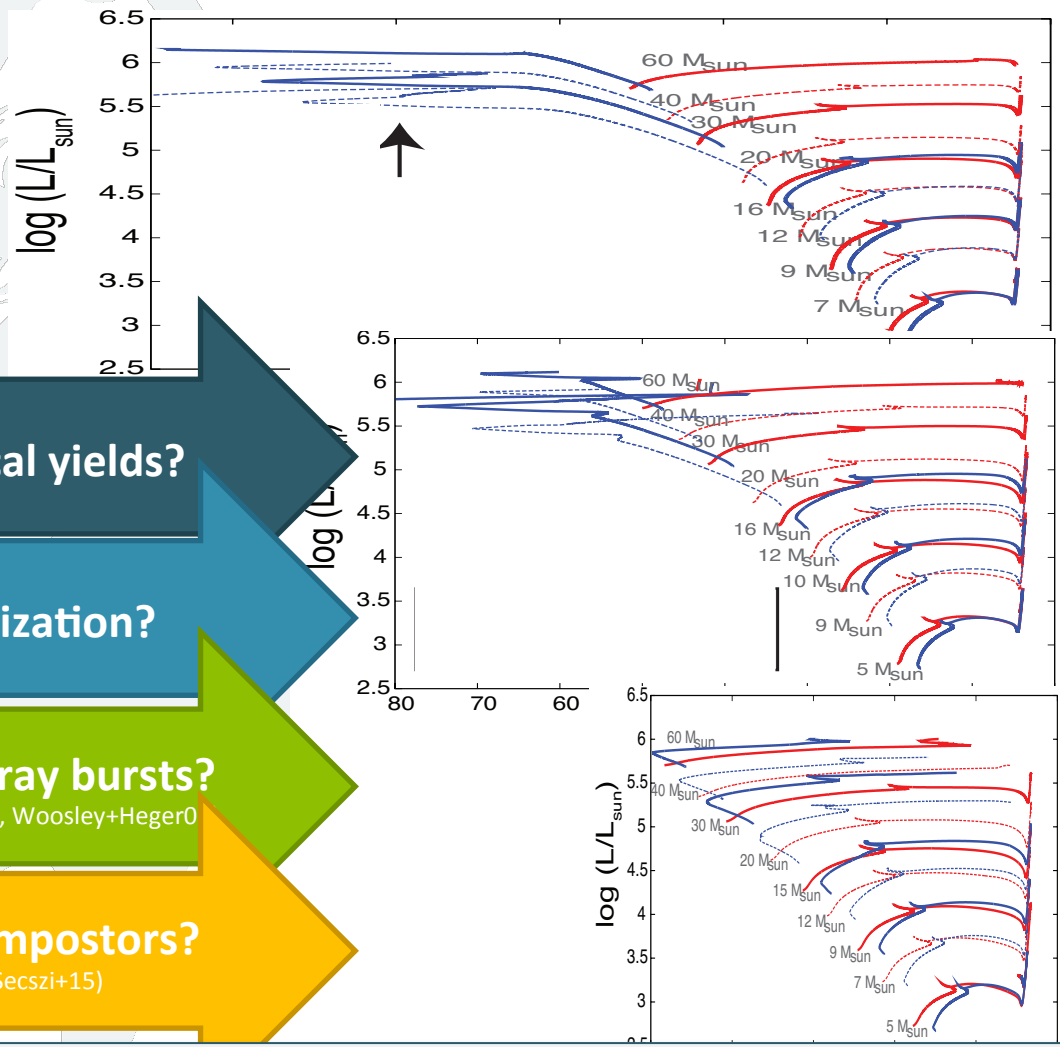
Z = 0.004

Stronger effects at low metallicity (in the early Universe)

Brott, SdM et al. 2011, Yoon+2006



Z = 0.004
(Small Magellanic Cloud)

Z = 0.008
(Large Magellanic Cloud)

Z = 0.012
(Solar Neighborhood)

Chemical yields?

Reionization?

Gamma-ray bursts?
(Yoon+Langer05, Woosley+Heger0

Pop III impostors?
(e.g. Secszi+15)

ATLAST/HDST/LUVOIR ….

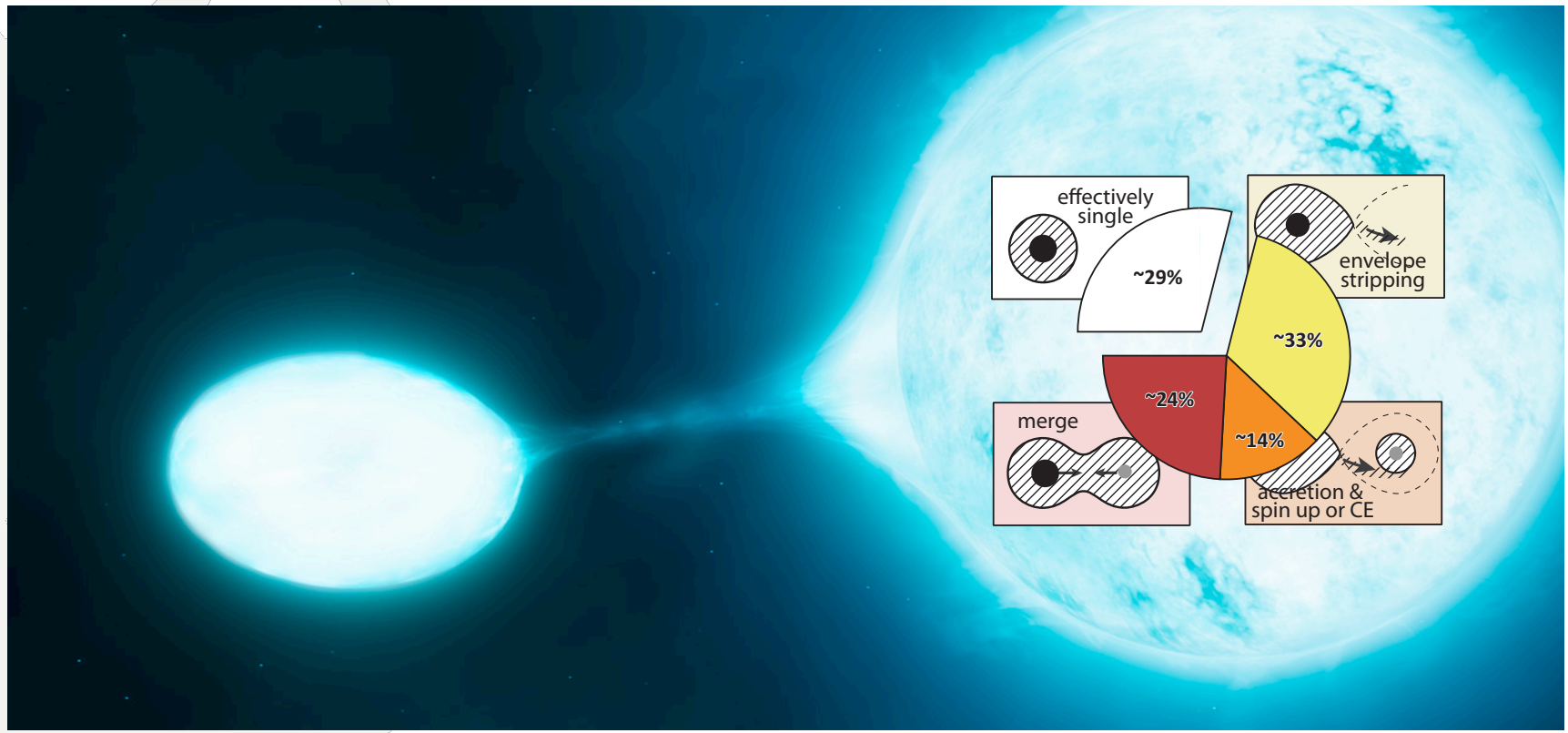
- **Allow to test lower metallicities: e.g. the irregular galaxy I Zw 18 (~20 Mpc)**
  Getting closer to the very first stars
- **Imprints on the UV of more distant starbursts**

de Mink

2.III Example
Massive Stars do not live alone

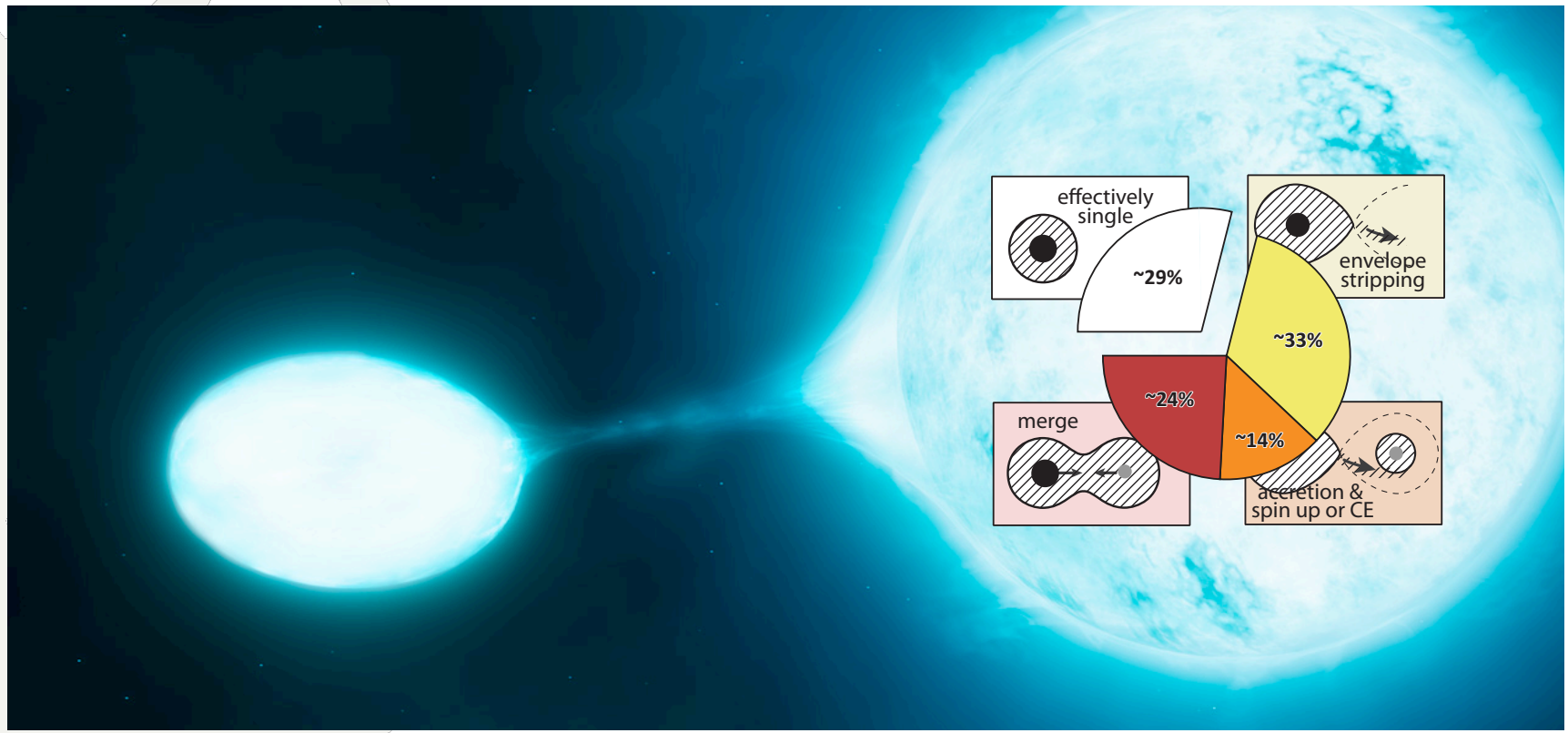
Is the binary fraction universal

Sana, de Mink et al., Science 2012



7 out of 10 massive stars severely interact before they die

Sana, de Mink et al., Science 2012

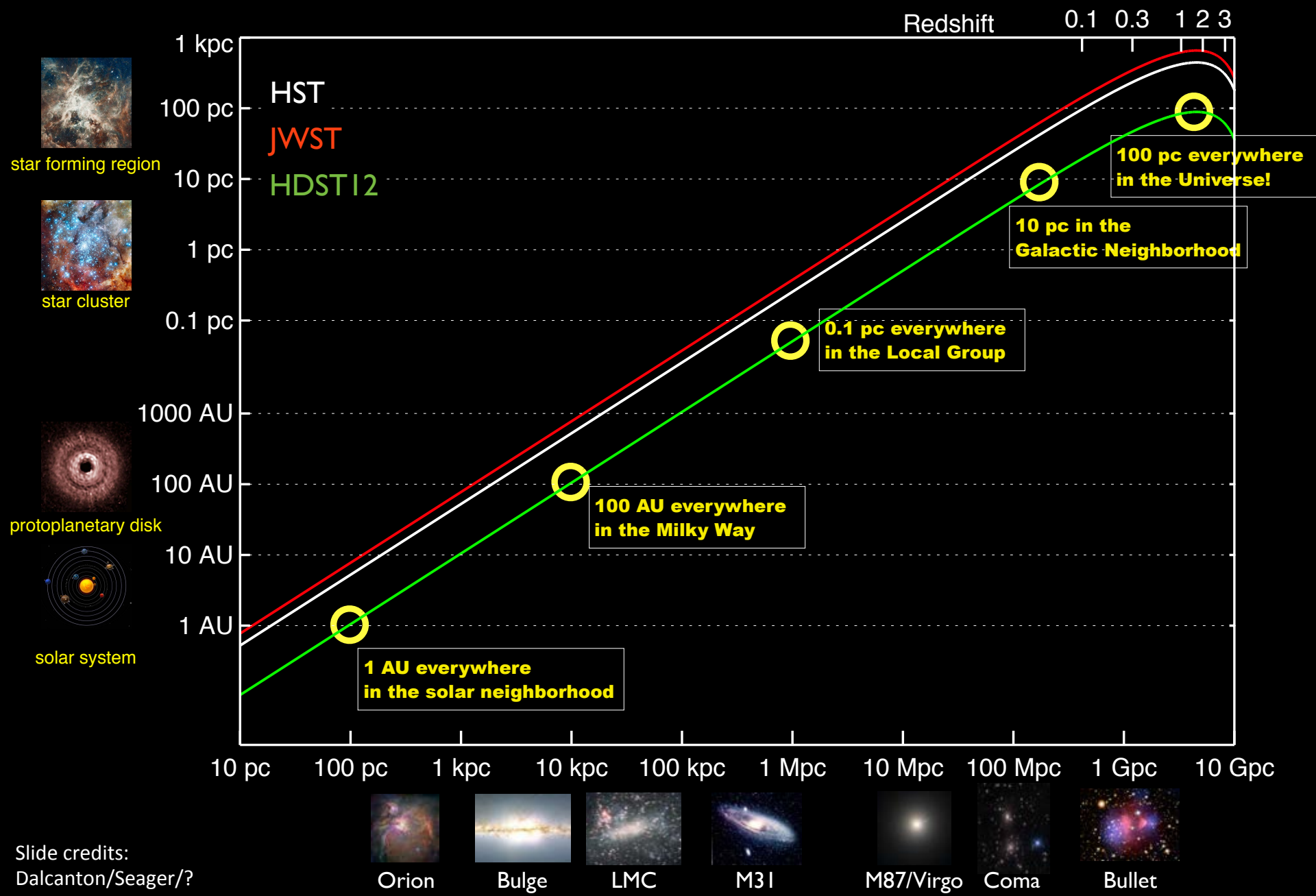


Questions for ATLAST/HDST/LUVOIR ….

- **Is the binary fraction universal (e.g. in dense regions, low Z)**
- **Probing extreme low mass companions. (Like finding a planet)**
- **Imprints of binary products in UV spectra of distant populations**

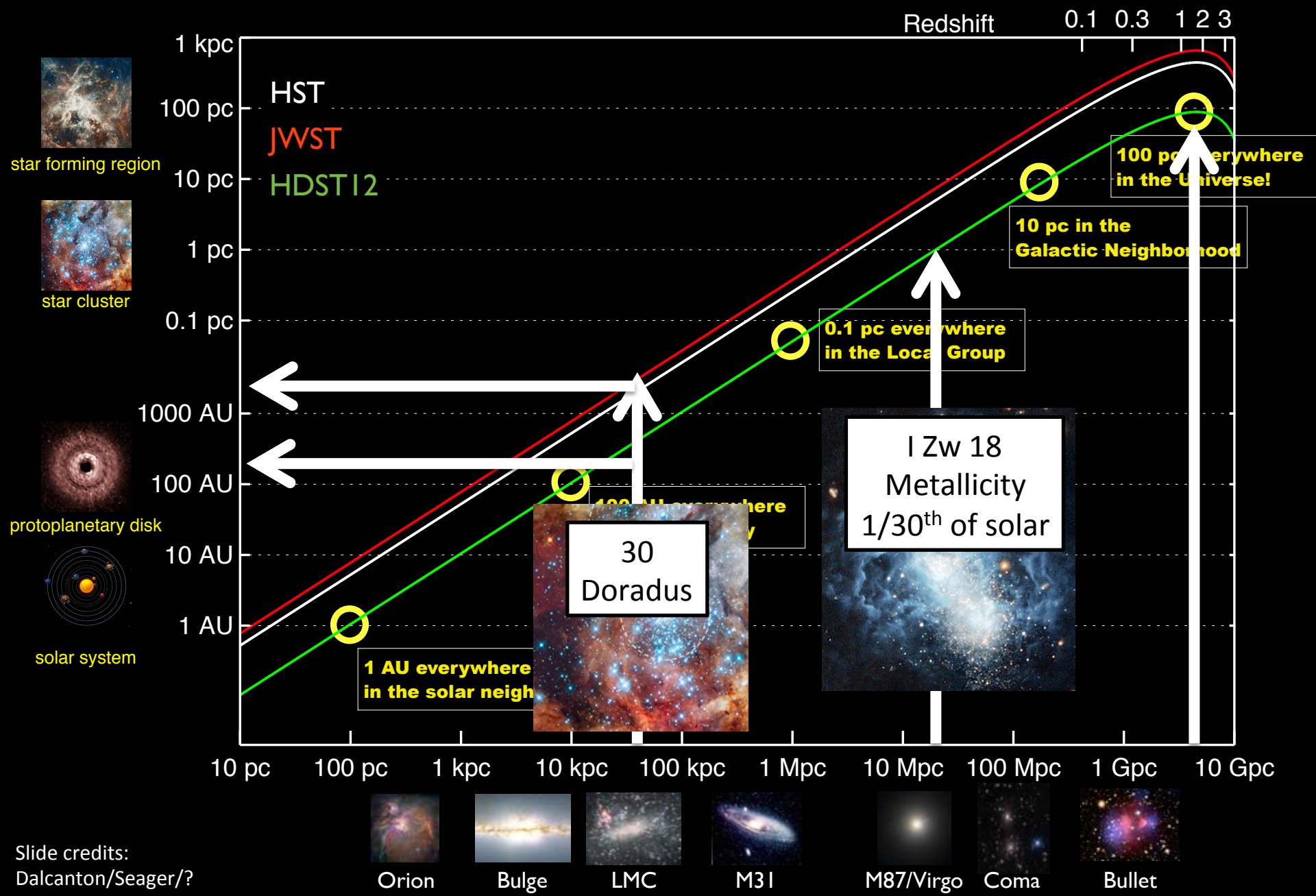
Questions in the context of a future UVOIR space telescope

HDST: Breaking Resolution Barriers



Slide credits:
Dalcanton/Seager/?

HDST: Breaking Resolution Barriers



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Raising many new questions …

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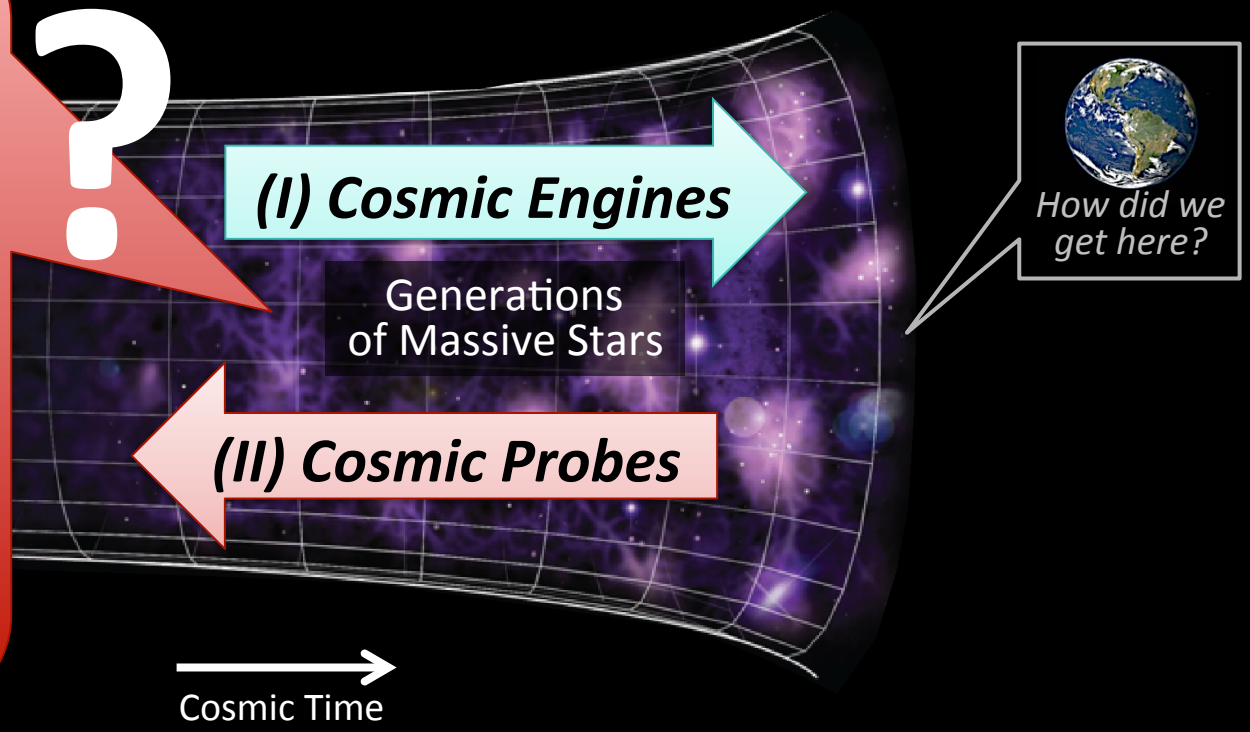
… …



Lower metallicity environments

Thank you