Runaway Survivors from Thermonuclear Supernovae

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White Dwarfs from Physics to Astrophysics @ KITP – 11/17/2022

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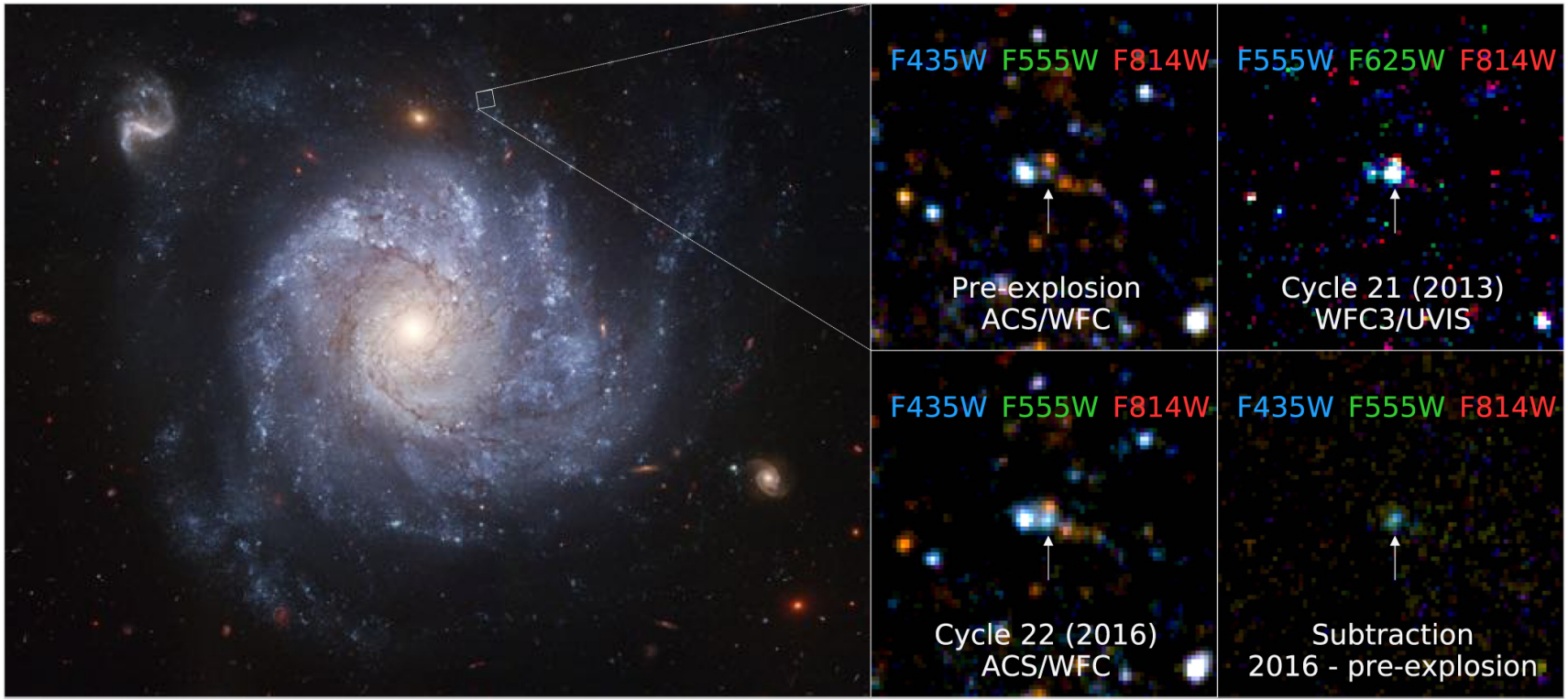
Outline

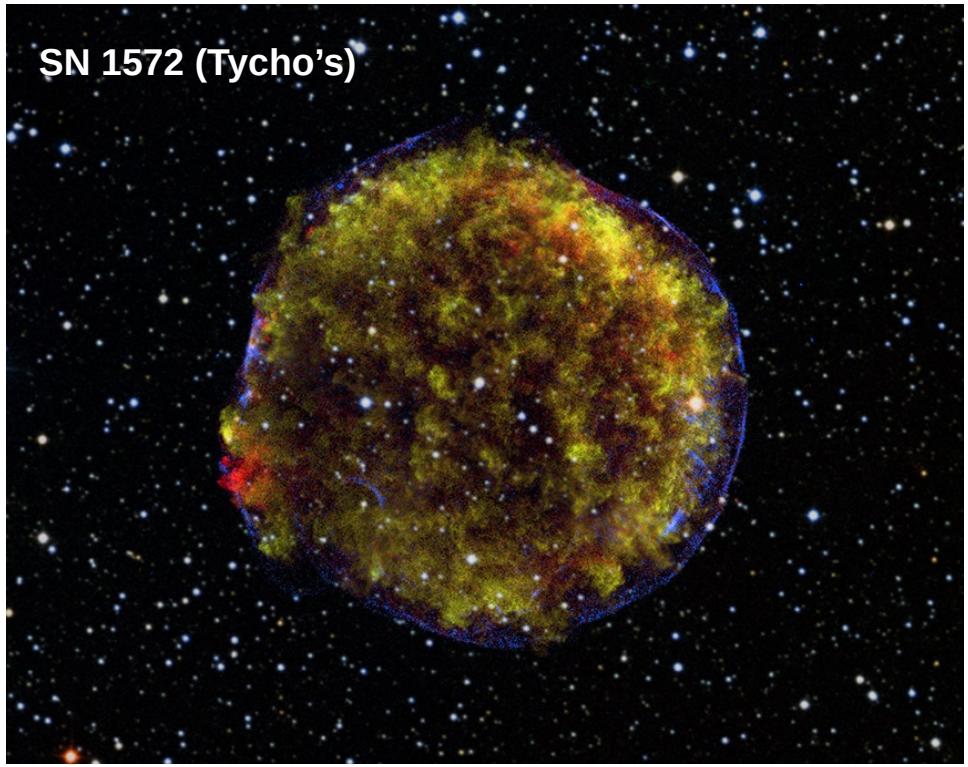
- ☆ Properties of runaway thermonuclear supernova survivors
- ☆ Formation and evolutionary scenarios
- ☆ Future prospects
- ☆ Summary

Extragalactic identifications

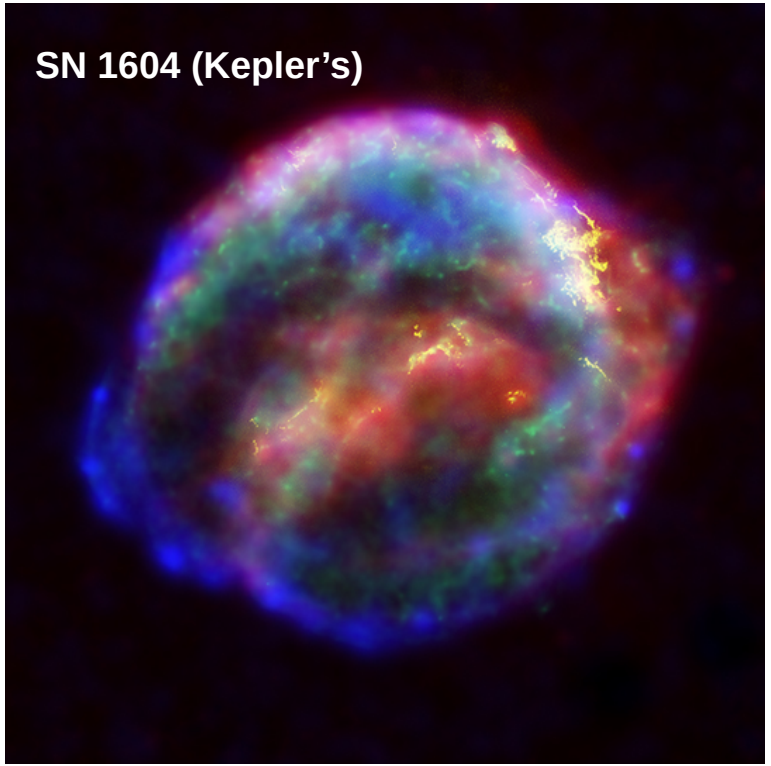


McCully et al. (2014), Nature, 512, 54; McCully et al. (2022), ApJ, 925, 138

Galactic supernovae

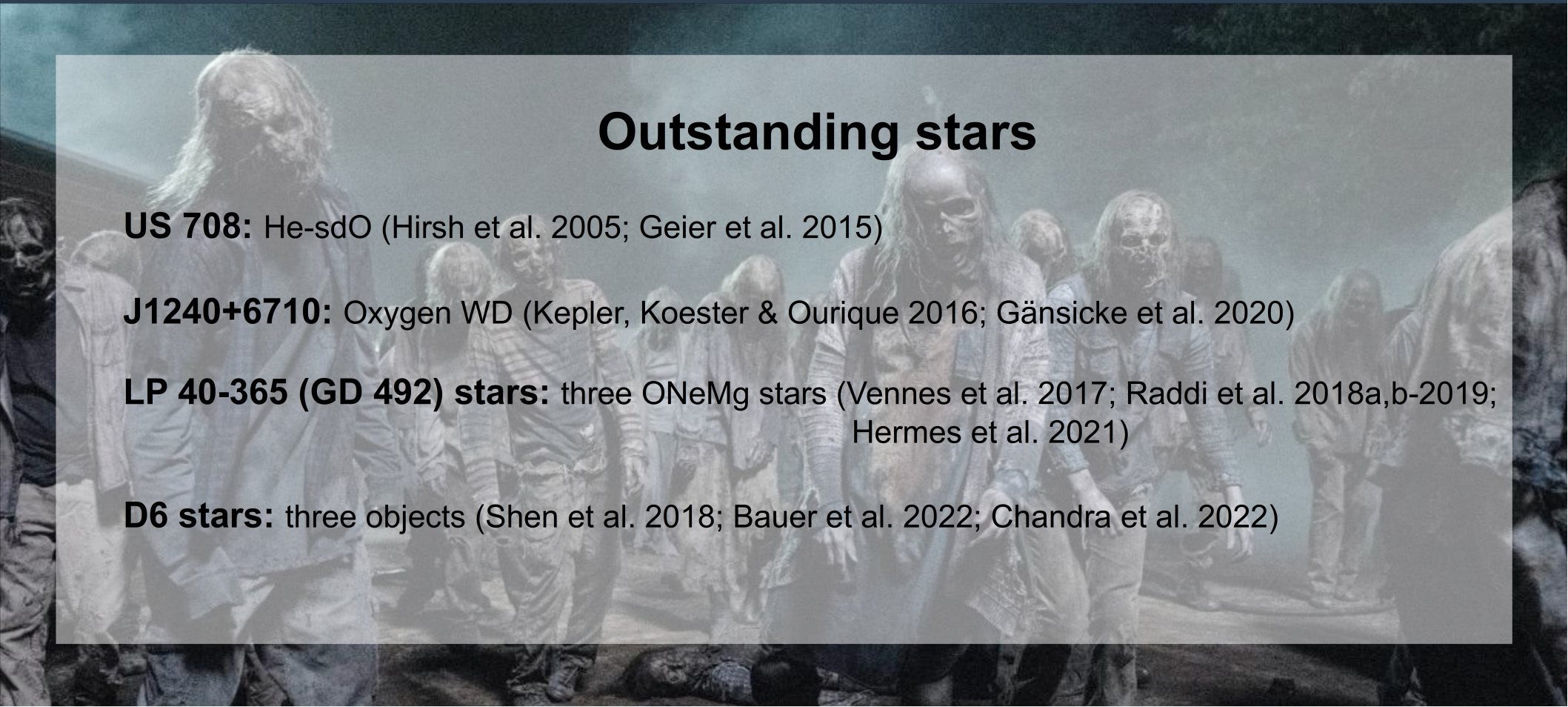


Williams et al. (2016), ApJL, 823, L32



Credit: NASA/ESA/JHU/R.Sankrit & W.Blair

THE RUNNING DEADS



Outstanding stars

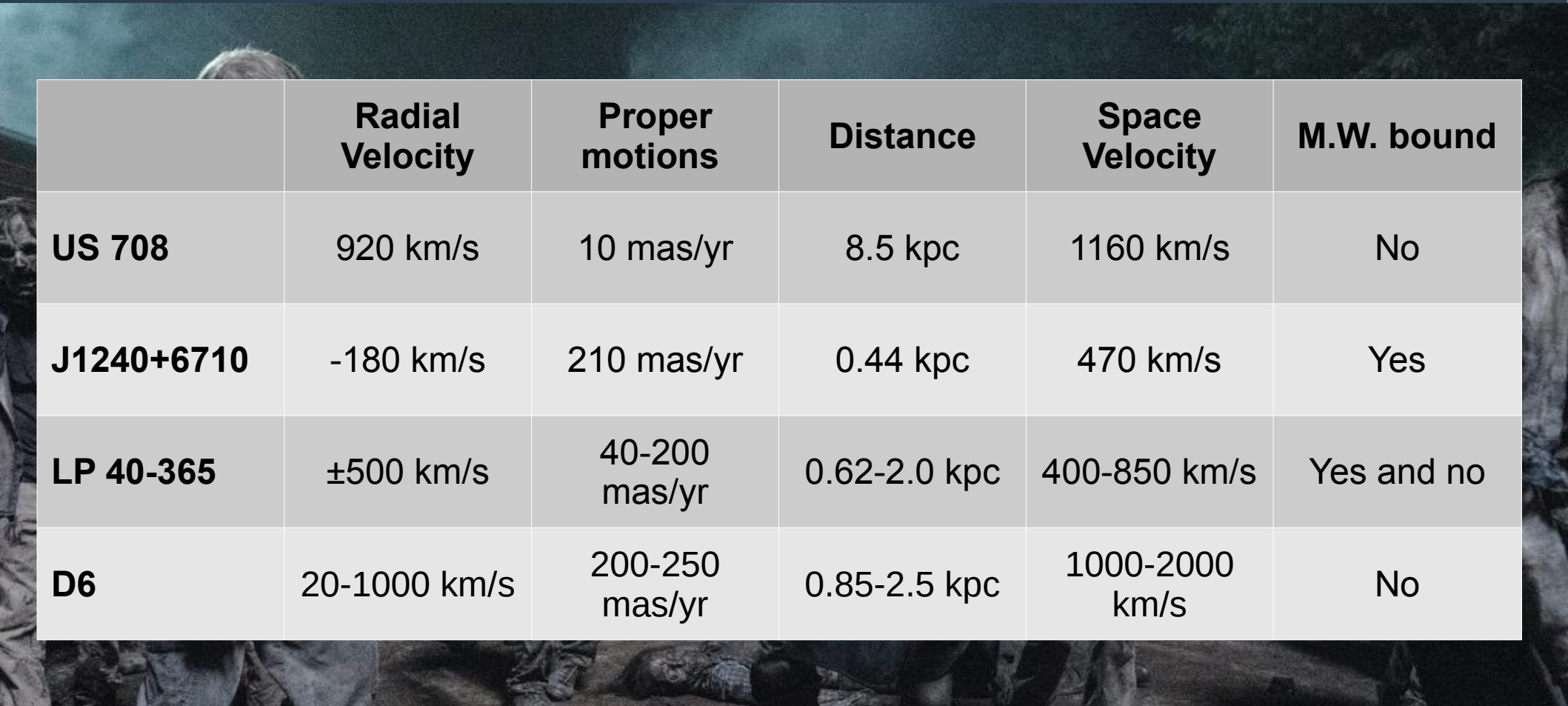
US 708: He-sdO (Hirsh et al. 2005; Geier et al. 2015)

J1240+6710: Oxygen WD (Kepler, Koester & Ourique 2016; Gänsicke et al. 2020)

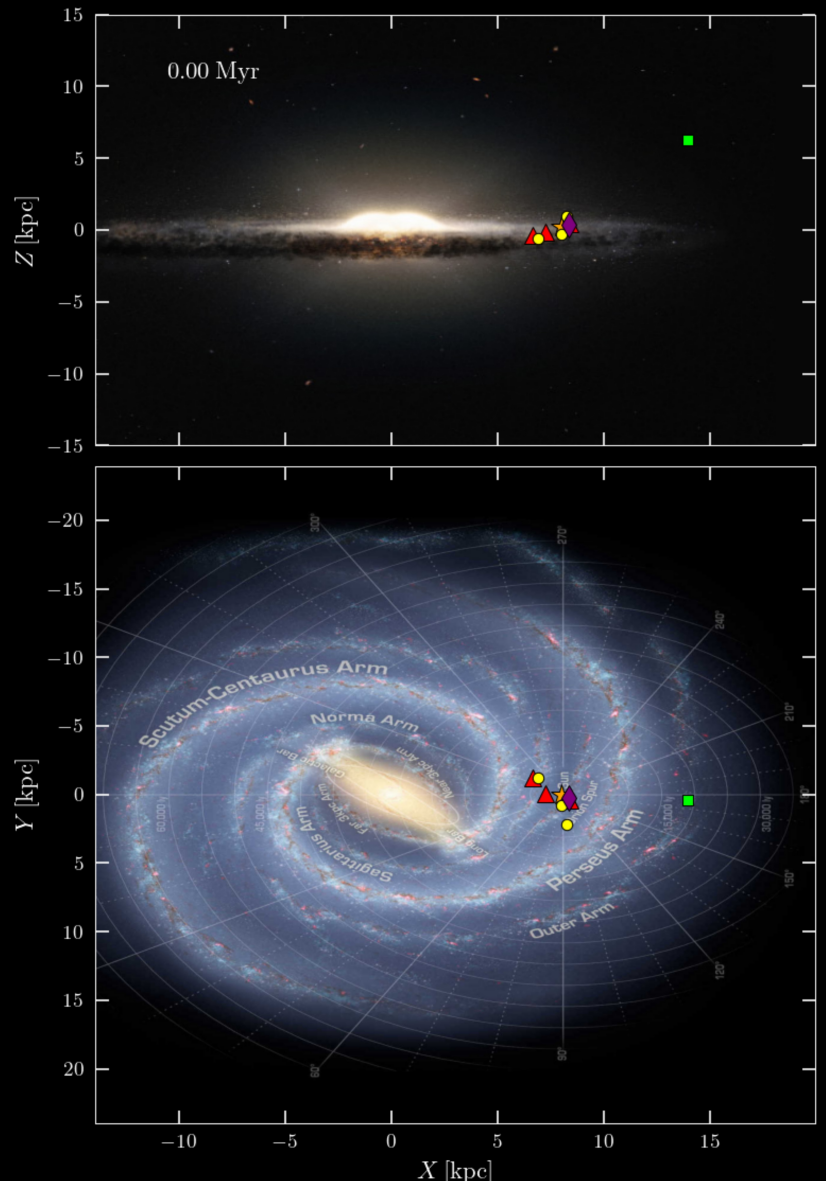
LP 40-365 (GD 492) stars: three ONeMg stars (Vennes et al. 2017; Raddi et al. 2018a,b-2019; Hermes et al. 2021)

D6 stars: three objects (Shen et al. 2018; Bauer et al. 2022; Chandra et al. 2022)

THE RUNNING DEADS



	Radial Velocity	Proper motions	Distance	Space Velocity	M.W. bound
US 708	920 km/s	10 mas/yr	8.5 kpc	1160 km/s	No
J1240+6710	-180 km/s	210 mas/yr	0.44 kpc	470 km/s	Yes
LP 40-365	±500 km/s	40-200 mas/yr	0.62-2.0 kpc	400-850 km/s	Yes and no
D6	20-1000 km/s	200-250 mas/yr	0.85-2.5 kpc	1000-2000 km/s	No



Extreme kinematics

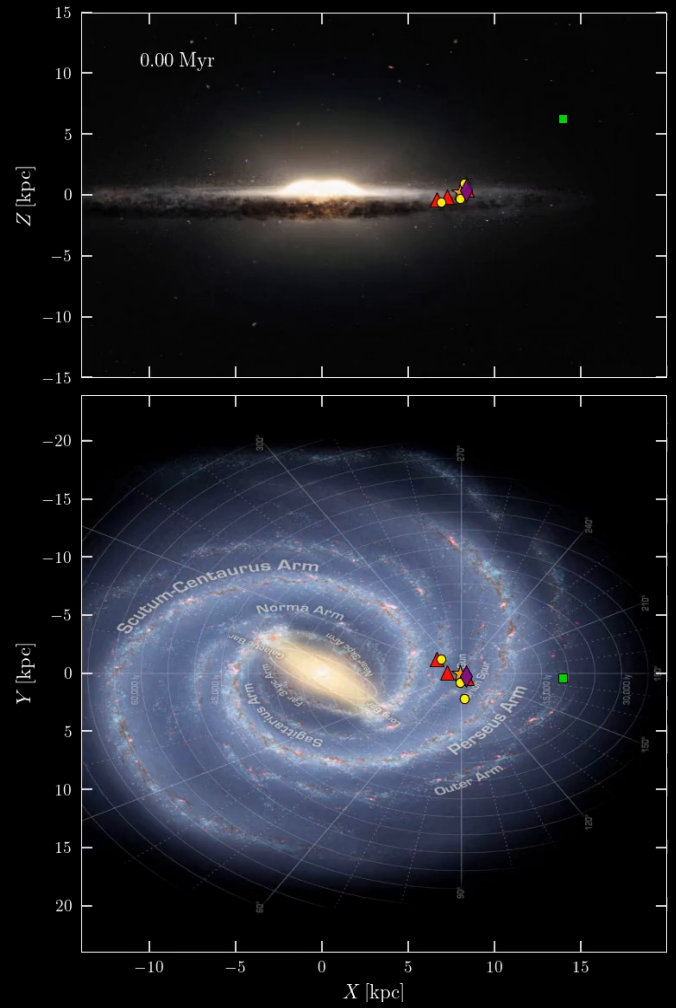
Orange star: the Sun

Green square: US 708

Purple diamond: J1240+6710

Three red triangles: LP 40-365 stars

Three yellow circles: D6 stars



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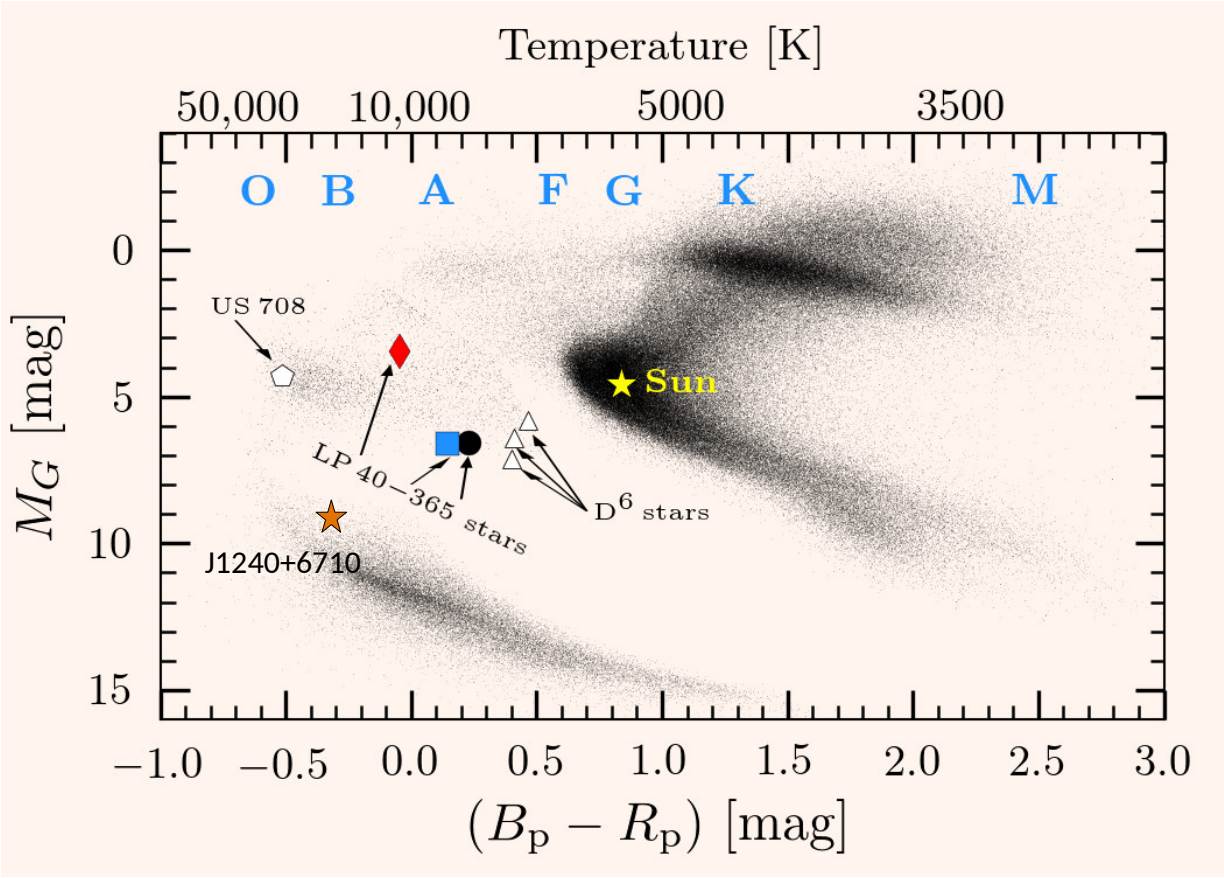
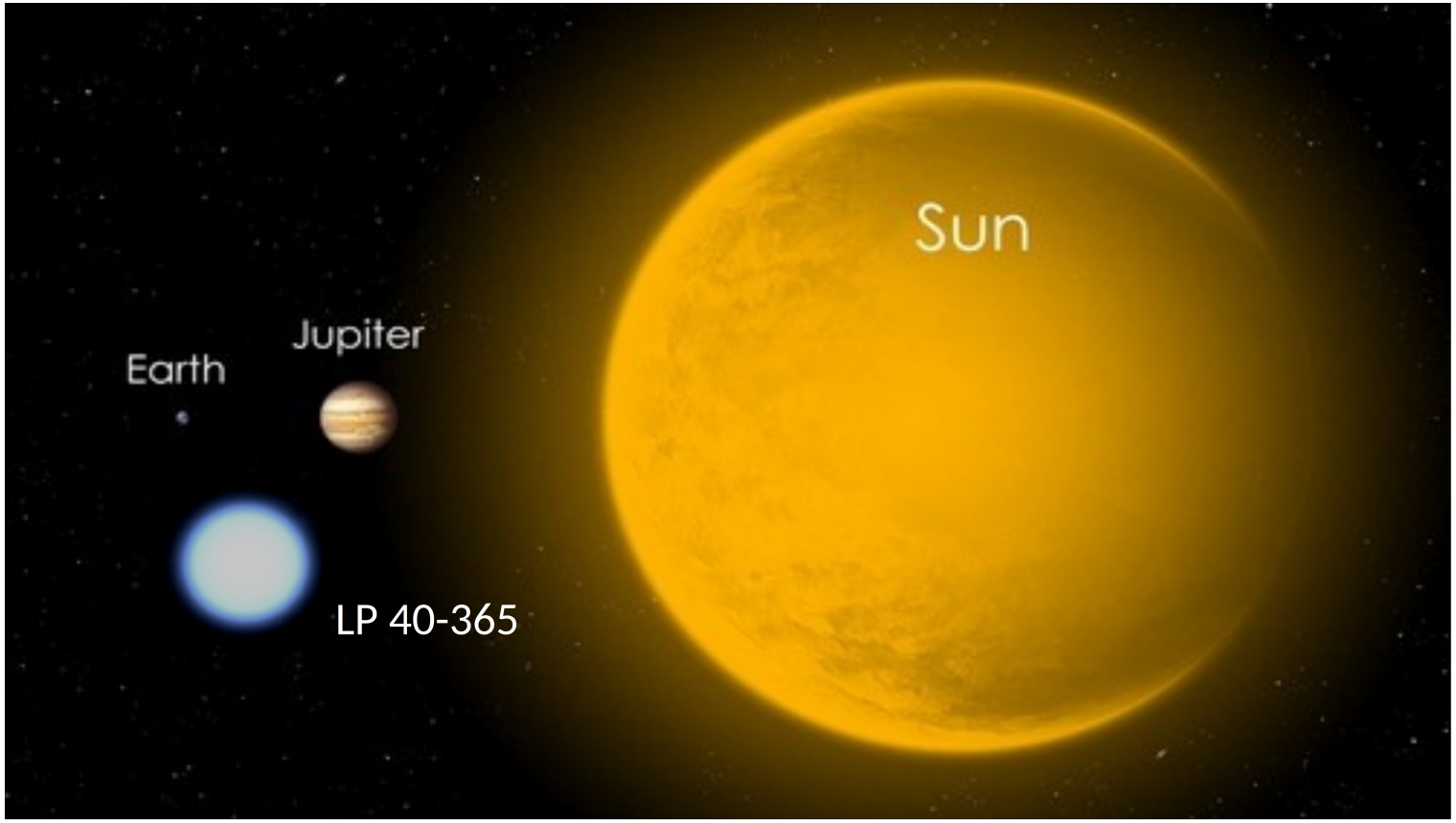
Gaia DR2 colour-magnitude diagram

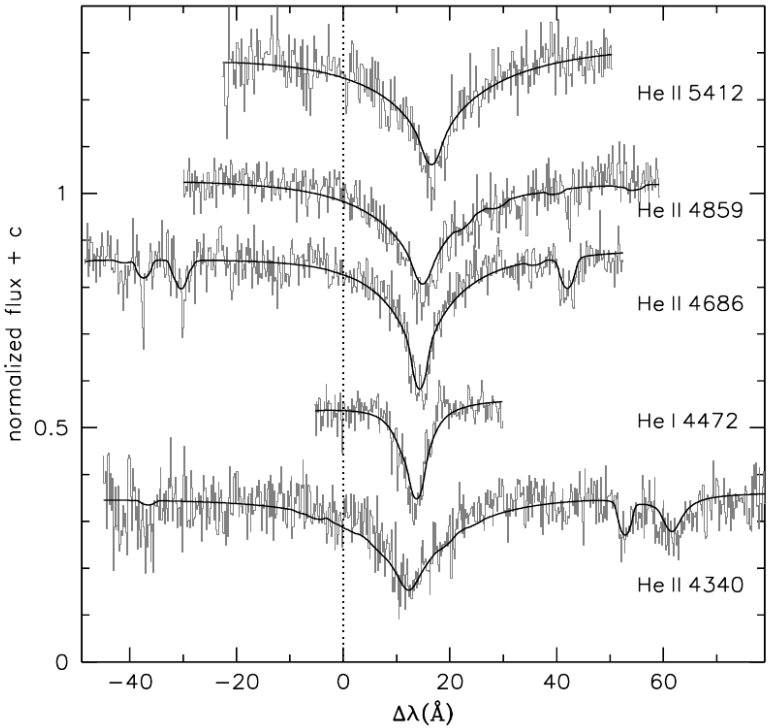


Parallax means radius



Peculiar spectral appearence (US 708)

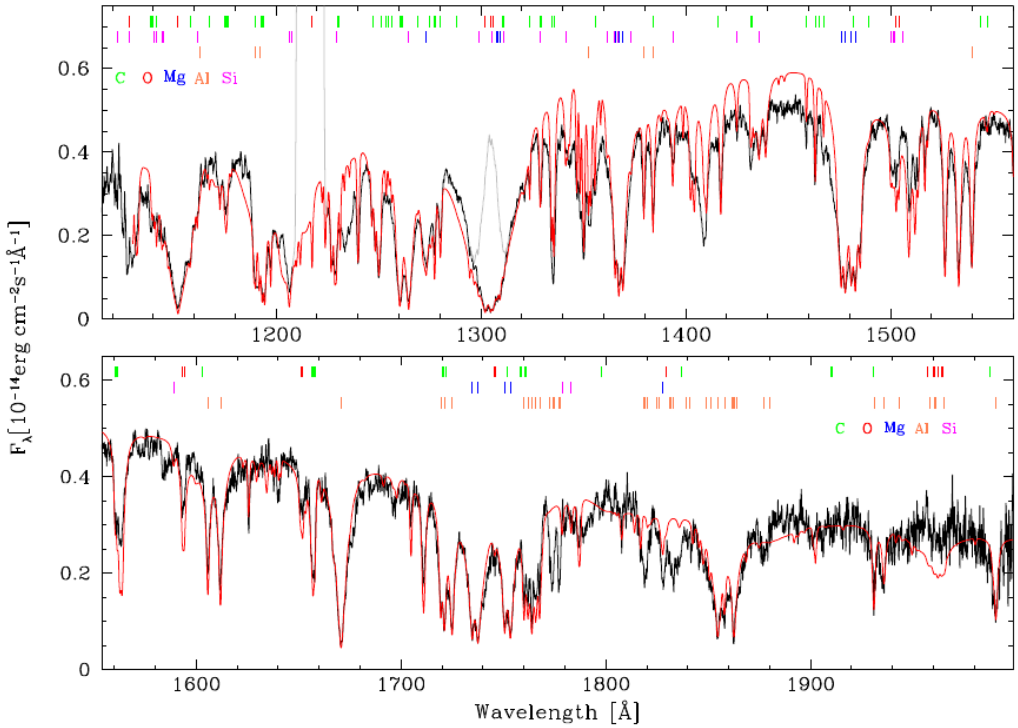
- ⭐ Teff = 47,000 K; logg = 5.7 (0.3 Msun)
- ⭐ Helium and nitrogen rich
- ⭐ Fast rotators (*vsini* = 115 km/s)



Geier et al. 2015, Science, 347, 1126

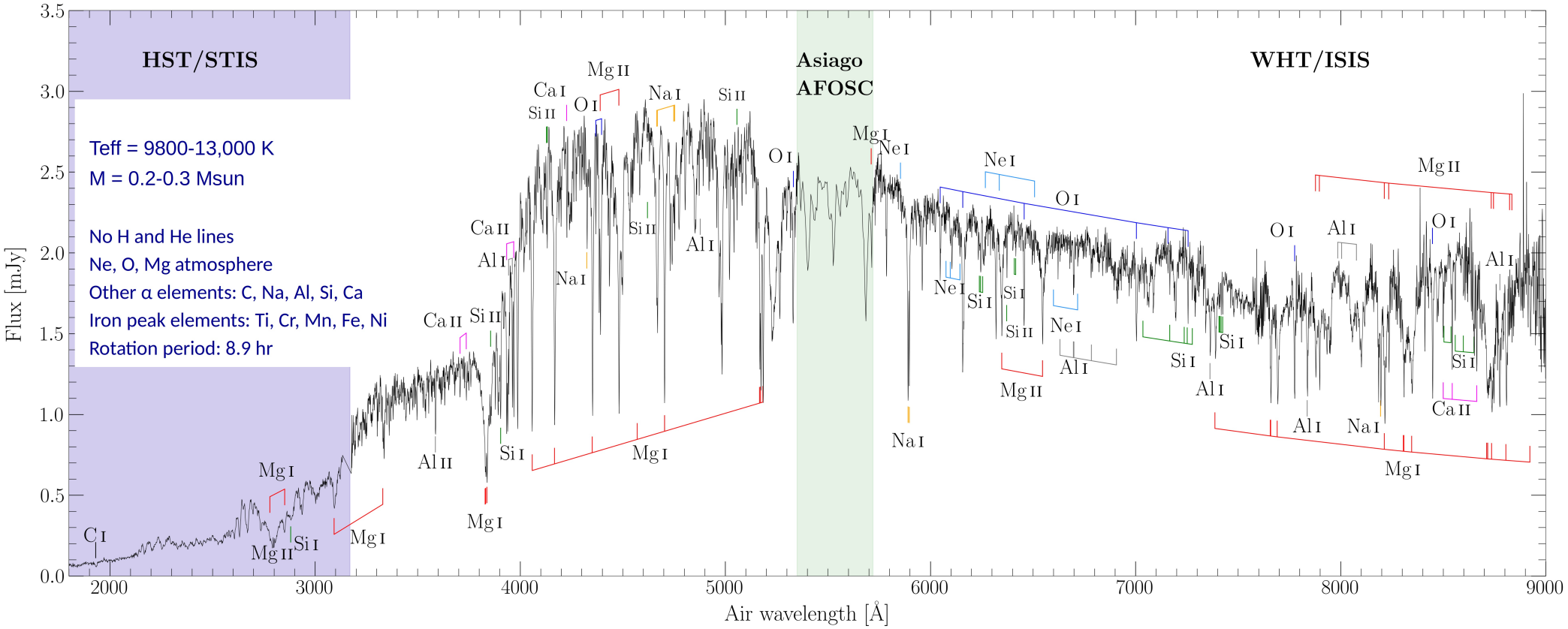
Peculiar spectral appearence (J1240+6710)

- ⭐ Teff = 20,500 K, 0.4 Msun
- ⭐ Oxygen dominated atmosphere
- ⭐ C, Ne, Na, Mg, Al, Si
- ⭐ H, He undetected



Gänsicke et al. 2020, MNRAS, 496, 4079

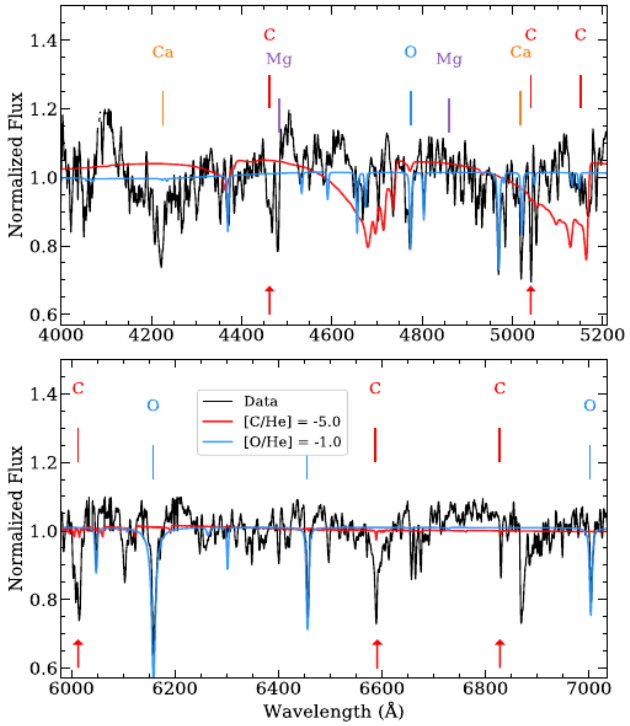
Peculiar spectral appearence (LP 40-365 and friends)



Peculiar spectral appearence (D6 stars)

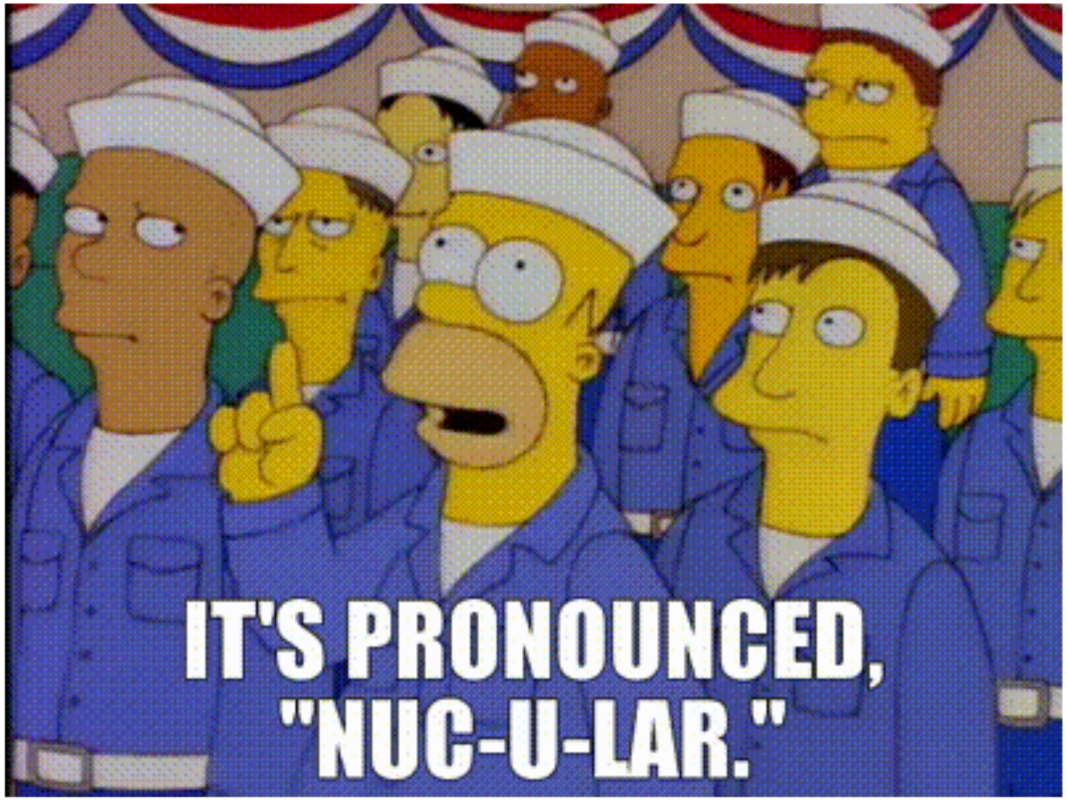
- ⭐ Teff = 7500 K, logg = 5.5 (0.2-0.8 Msun)
- ⭐ Carbon-oxygen dominated atmosphere
- ⭐ Circumstellar material
- ⭐ Rotation period: 15.4 hr
- ⭐ H, He undetected
- ⭐ Linked to SN remnant (~10^5 yr old)

LP 398-9 (D6-2)



Chandra et al. 2022, MNRAS, 512, 6122

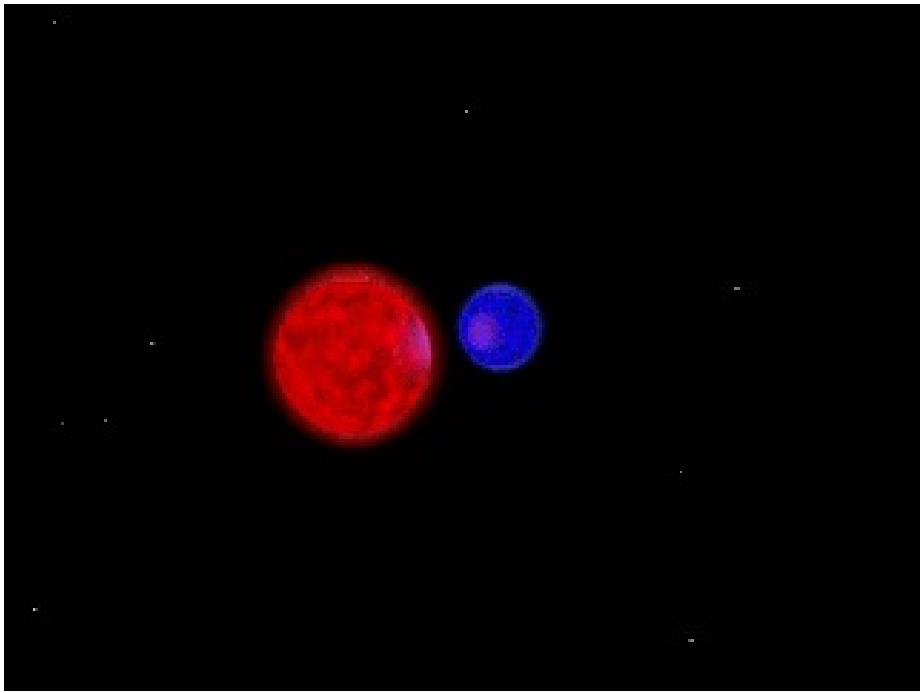
Formation scenarios: thermonuclear supernovae



Binary ejection mechanism

- ⭐ Core collapse supernova
- ⭐ Mass loss and binary unbinding

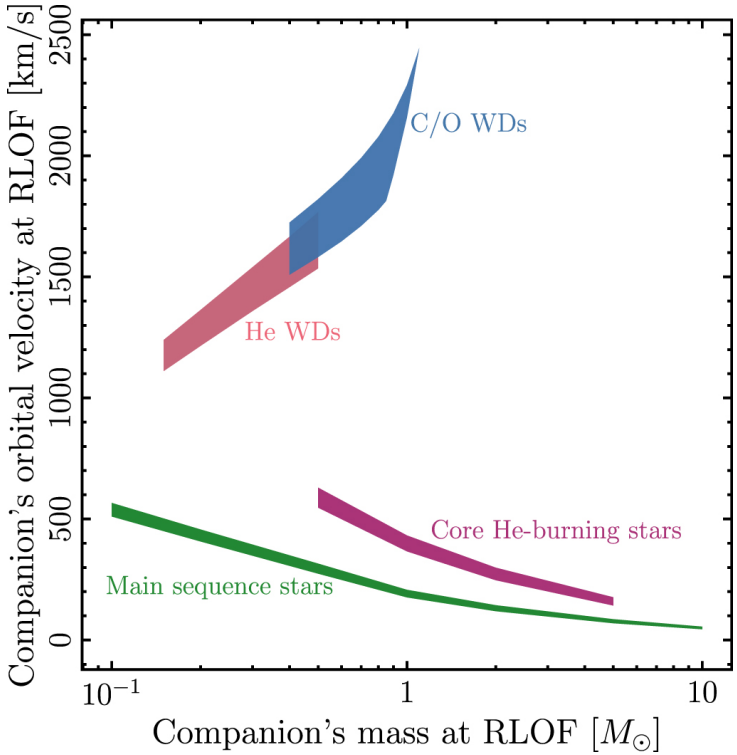
(Blaauw 1961, Hills 1983, Tauris et al. 2015)



Credit: Andreas Irrgang (Dr Remeis Sternwarte)
Shen et al. 2018, ApJ, 865, 15

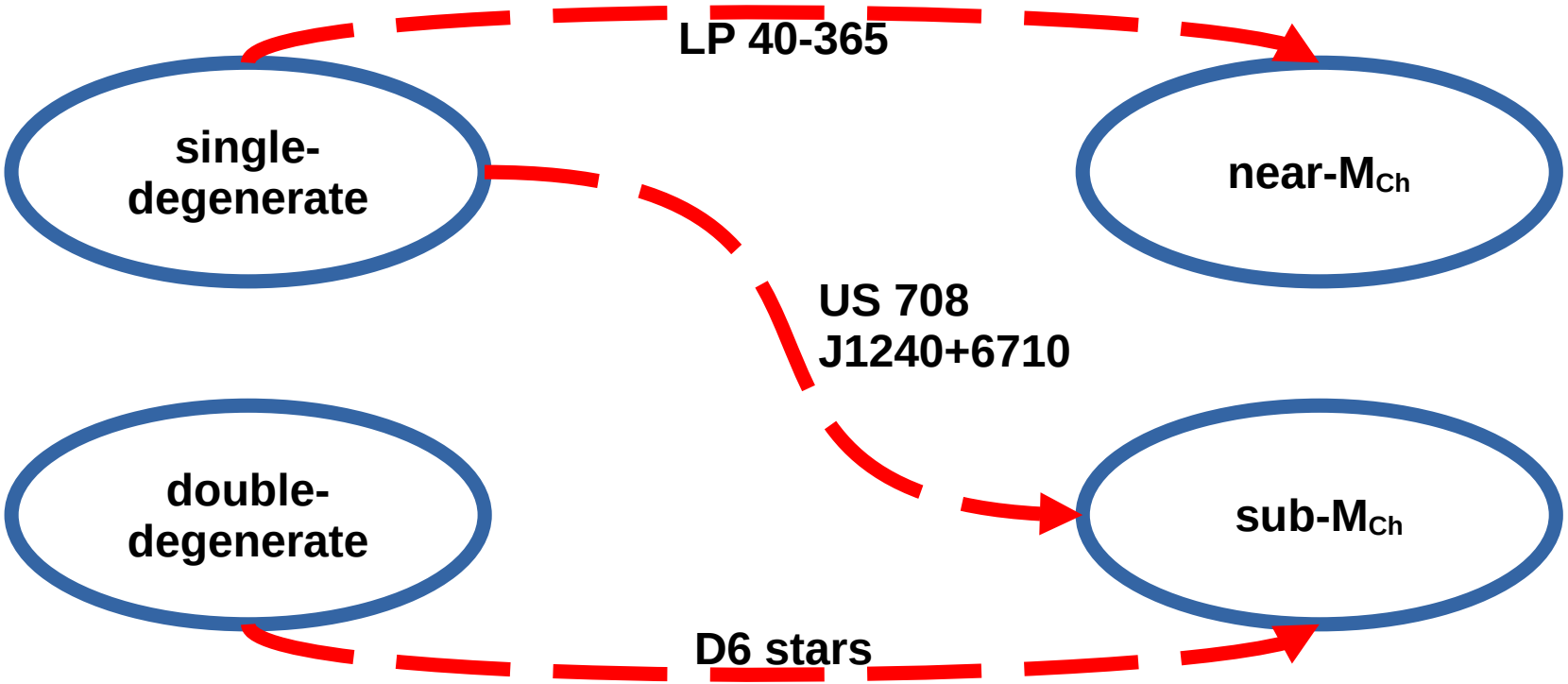
Binary ejection mechanism

- ⋆ Double-degenerate progenitors →
- ⋆ Single-degenerate progenitors →



Shen et al. 2018, ApJ, 865, 15

Progenitor and explosion scenarios



Former donors in thermonuclear supernovae

- ⭐ **US 708:** double-detonation, He-star donor channel
  - Wang et al. 2009; Justham et al. 2009

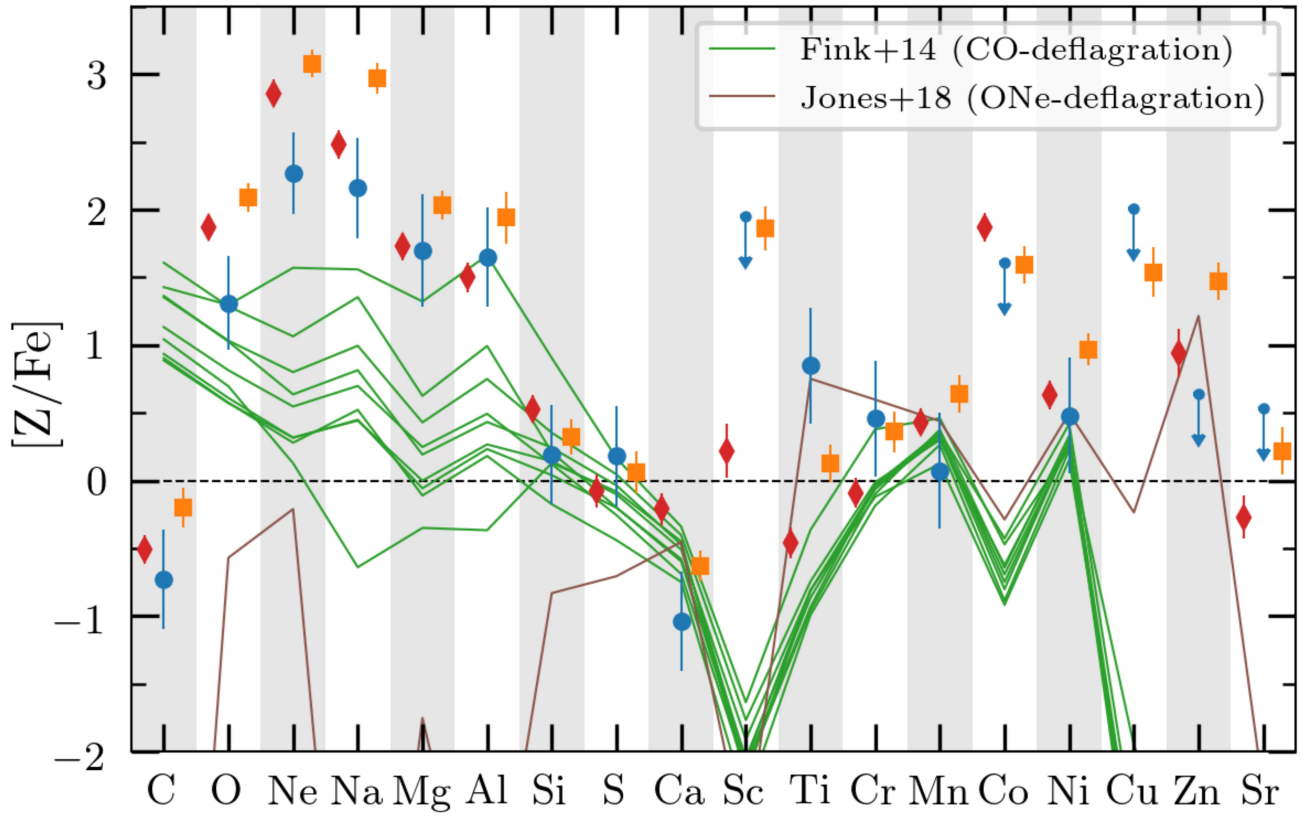
- ⭐ **D6 stars:** double-detonation occurring before merger
  - Shen et al. 2017, 2018a,b

Former WD-accretors in thermonuclear supernovae

- ⭐ **J1240+6710:** double-detonation, partial burning, low-Ni production, accretion of thick helium shell
  - Polin et al. 2019

- ⭐ **LP 40-365:** deflagration, single degenerate donor, partial burning
  - SN Iax: Jordan et al. 2012; Kromer et al. 2013, 2015; Fink et al. 2014
  - thermonuclear electron-capture SN (tECSN): Jones et al. 2016, 2019

Abundance pattern of LP 40-365 and friends



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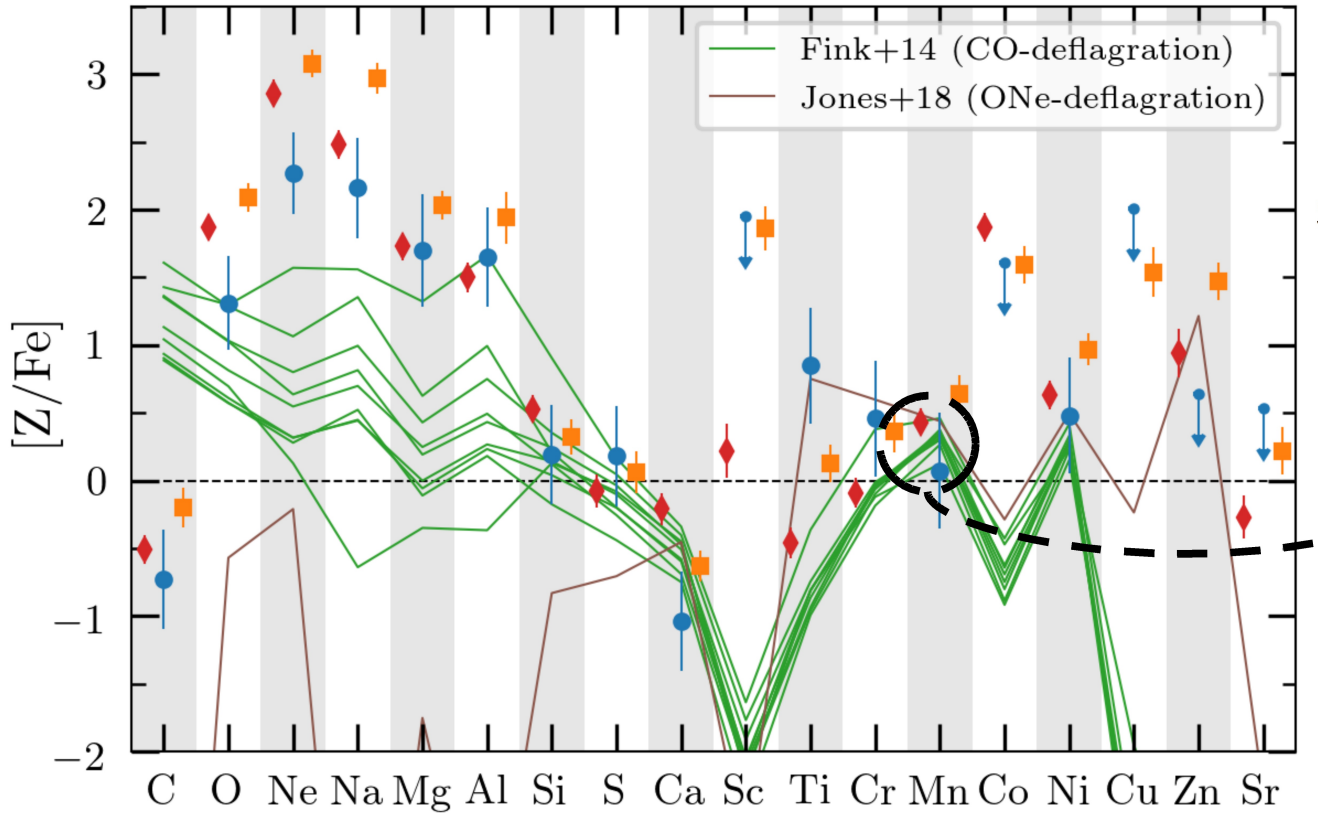
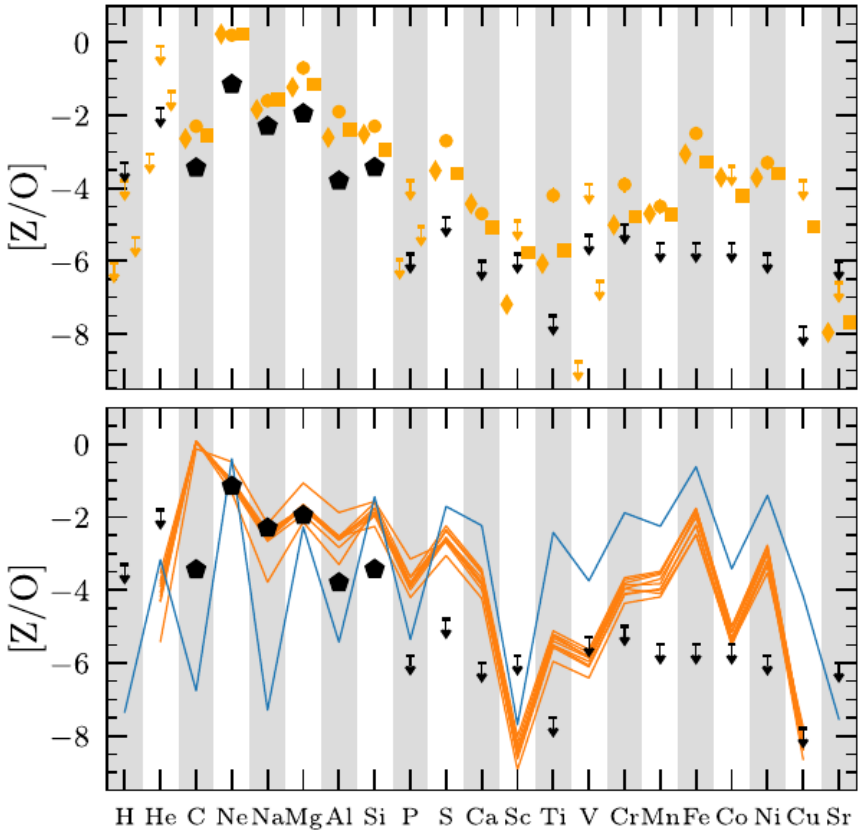


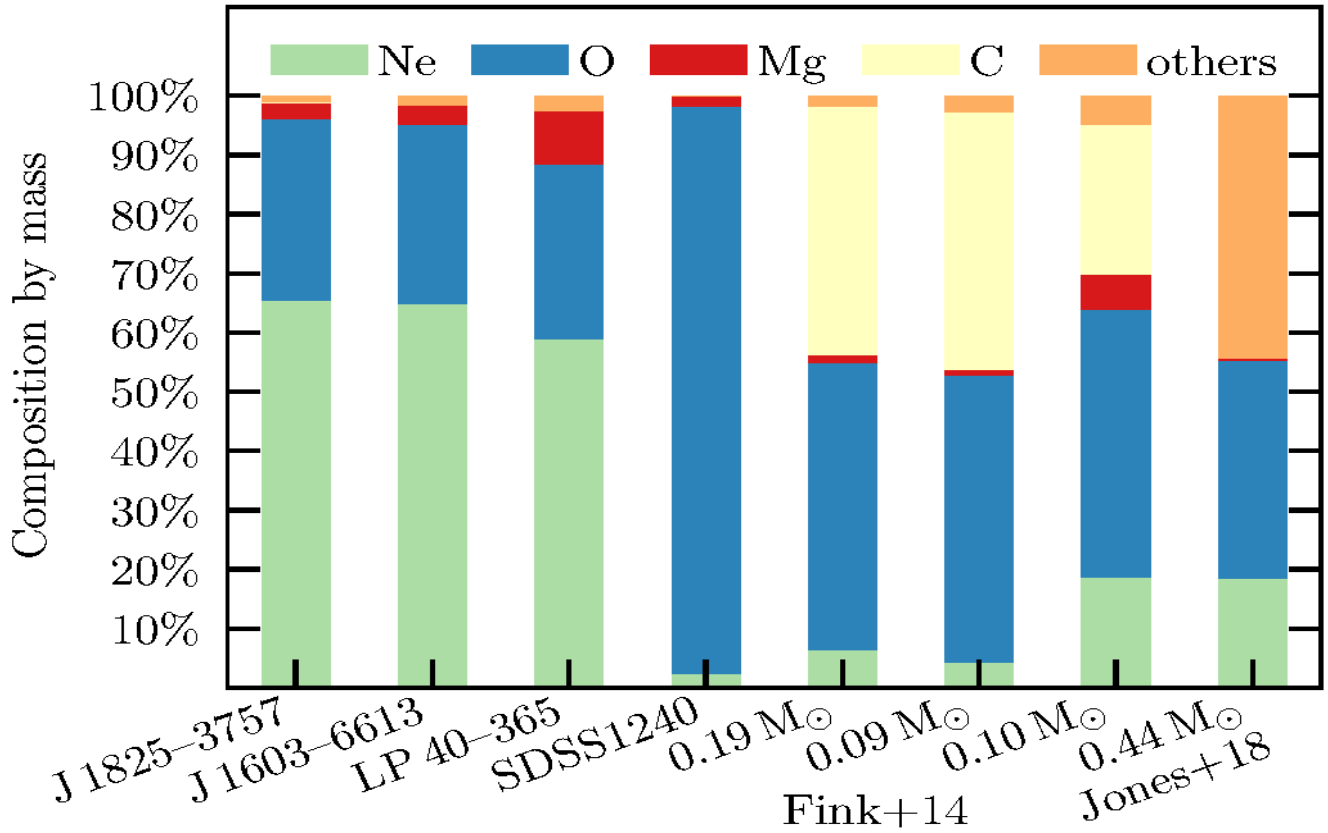
[Mn/Fe] super Solar
See Seitenzahl et al. 2013

Comparison with J1240+6710



Gänsicke et al. 2020, MNRAS, 496, 4079

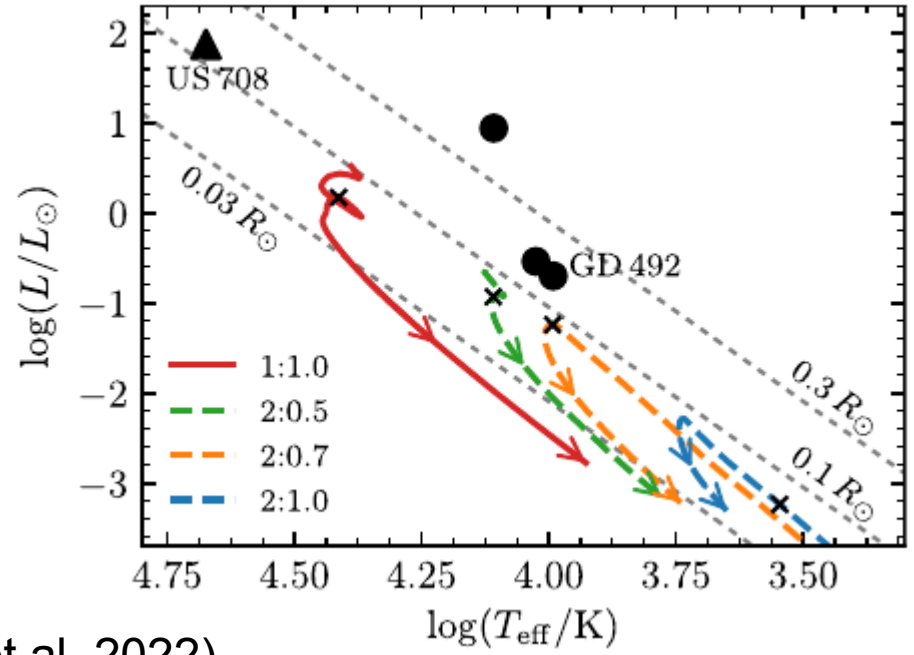
Atmospheric vs bulk composition



Evolution and open questions

- ⭐ Long evolutionary timescales
- ⭐ Heavy elements in the atmosphere
- ⭐ Progenitors and ejection velocities
- ⭐ Velocity distribution

(Bauer et al. 2019, Zhang et al. 2019; Neunteufel et al. 2022)

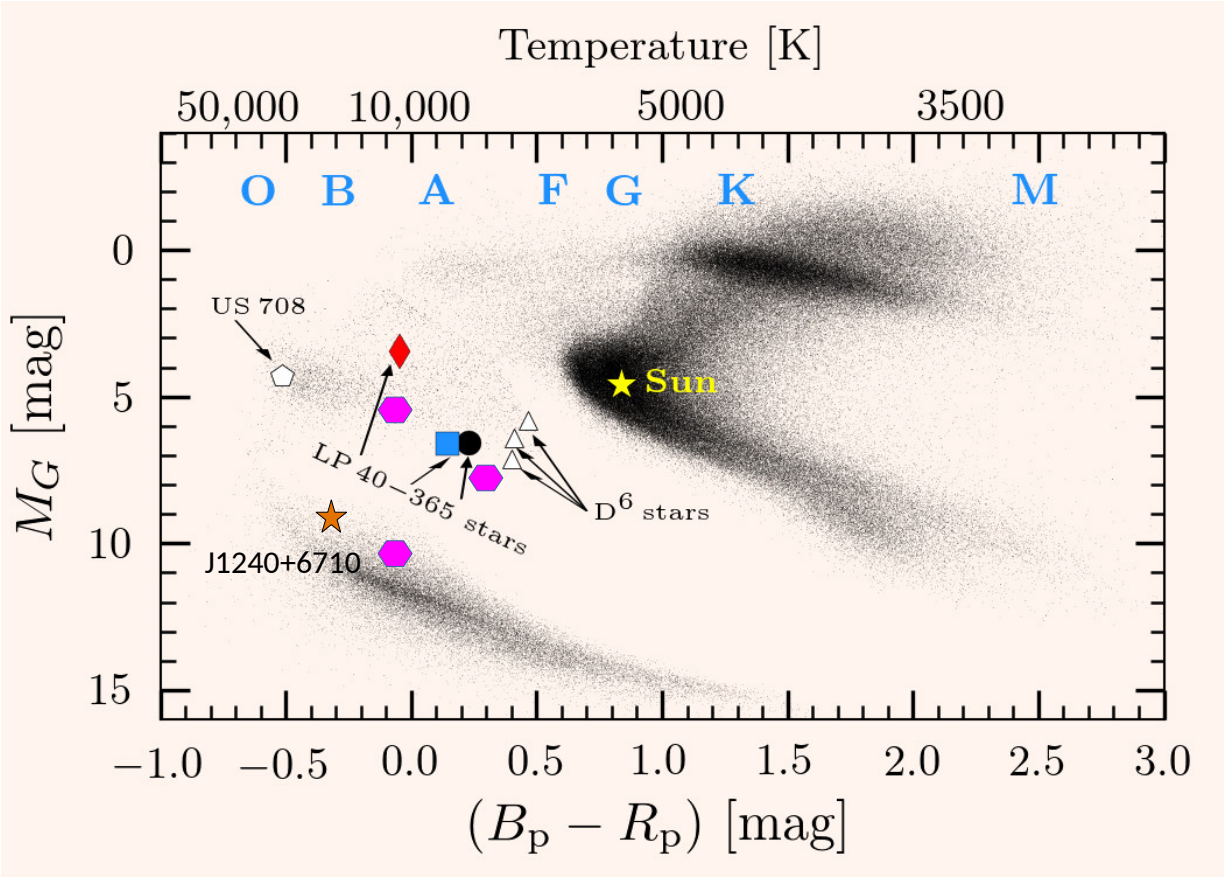


Bauer et al. 2019, ApJ, 887, 68

New candidates and “contaminants”

- **Candidate supernova survivors**
  - MW-bound US 708 twin in Geier et al. (2015)
  - MW-unbound LP 40-365 twin in Raddi et al. (2019)
  - Two hotter metal-rich stars (Raddi et al. 2019; Fantin et al. 2021)
- **Very likely contaminants**
  - LP 29-31 (DQ; Ruffini & Casey 2019; Kawka et al. 2020)
  - WD 0810-353 (DAH; de la Fuente Marcos et al. 2022)

Where are the new candidates



Summary

- ☆ Eight well characterized supernova survivors
- ☆ Variety of thermonuclear supernova progenitors and explosion mechanisms
  - single and double-degenerates
  - double-detonation, deflagration
- ☆ Need for improved analysis and modelling of future/past evolution
- ☆ More discoveries to come from multi-fibre spectroscopic surveys