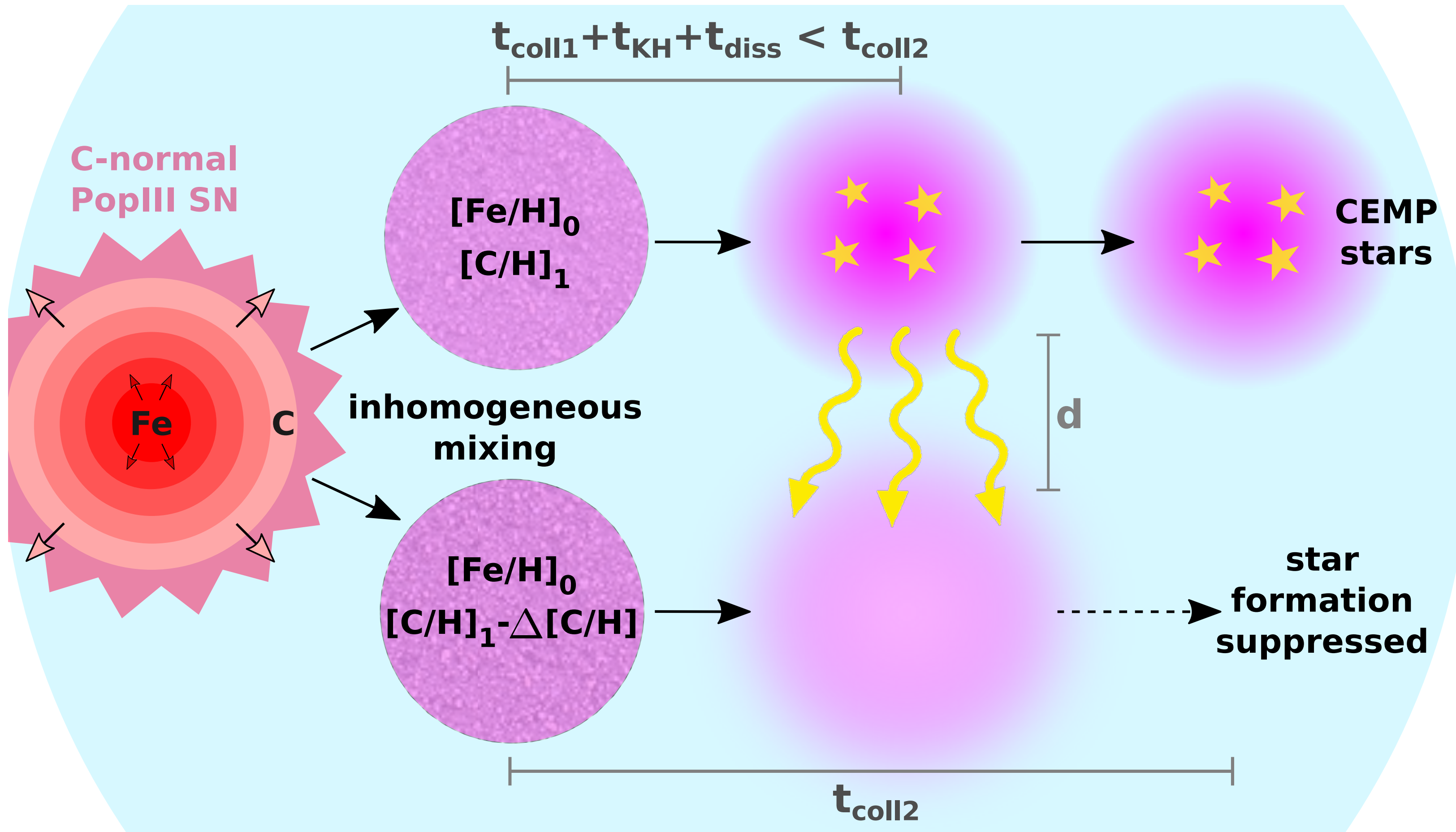
Carbon-enhanced metal-poor stars as a consequence of inhomogeneous metal mixing



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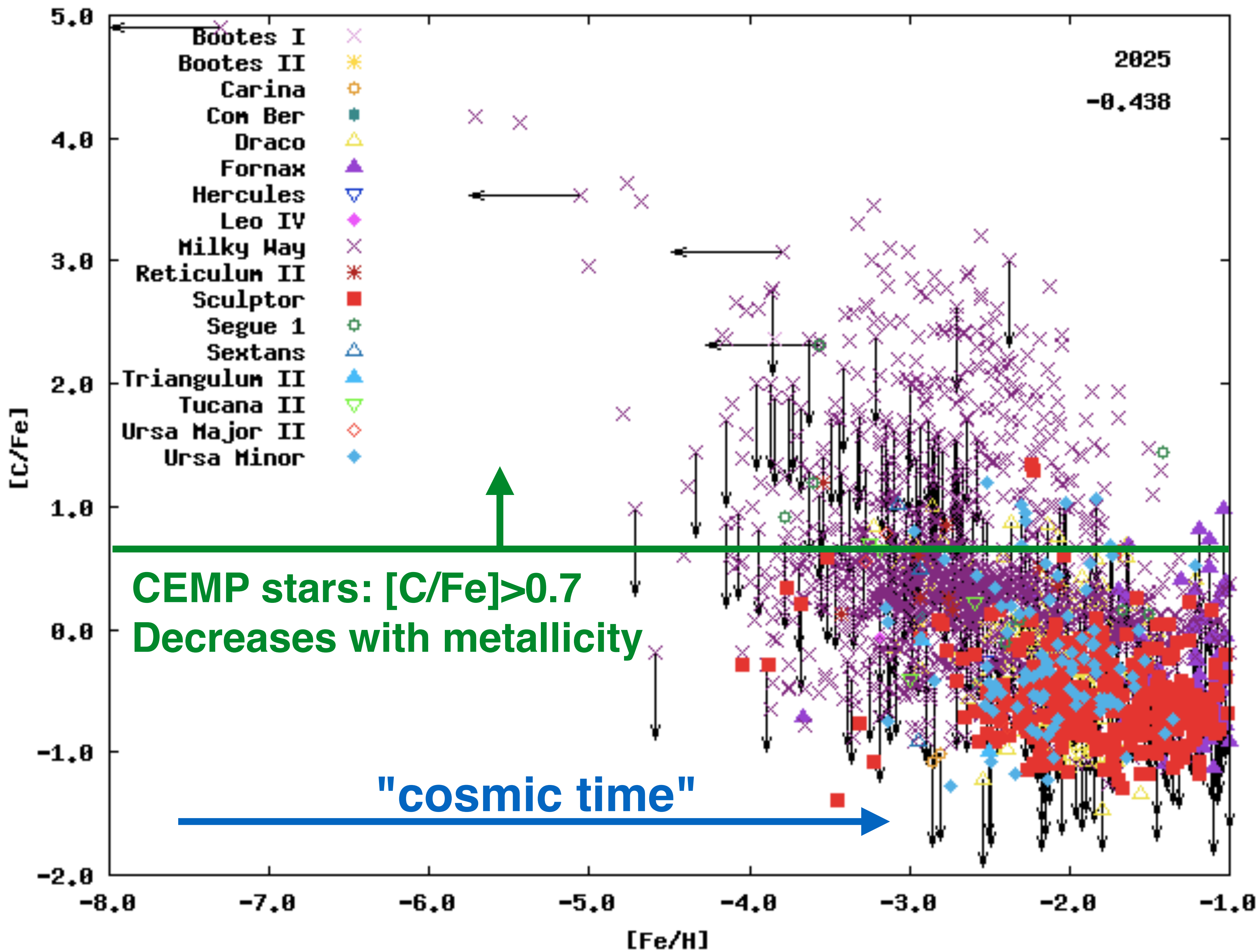
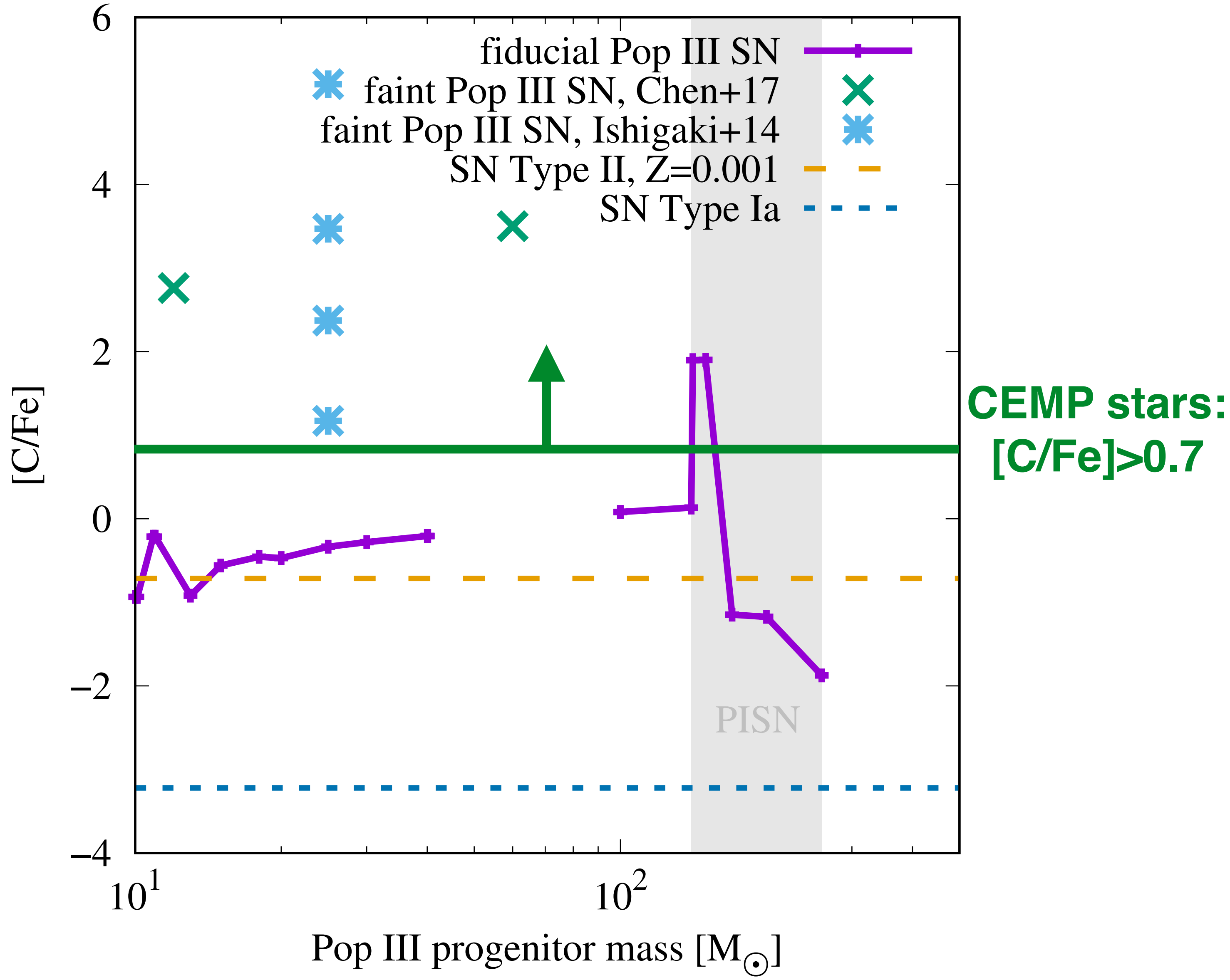


Saga database, Suda-san

Are faint SNe the progenitors of CEMP stars?

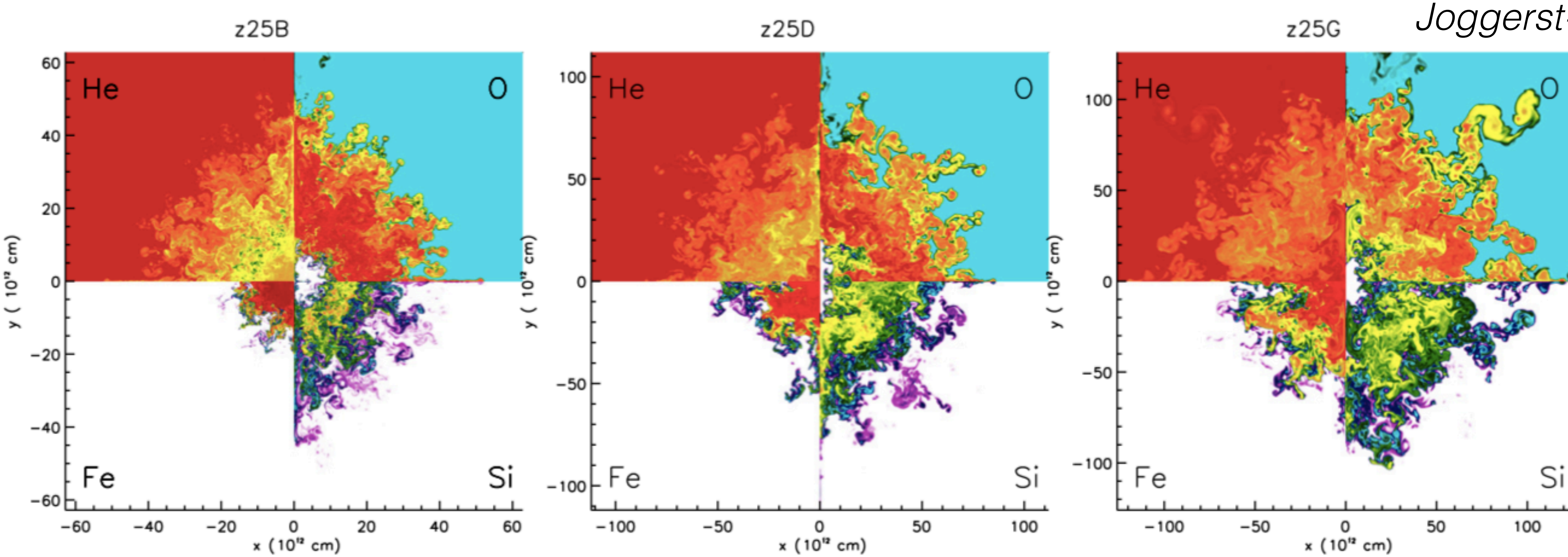


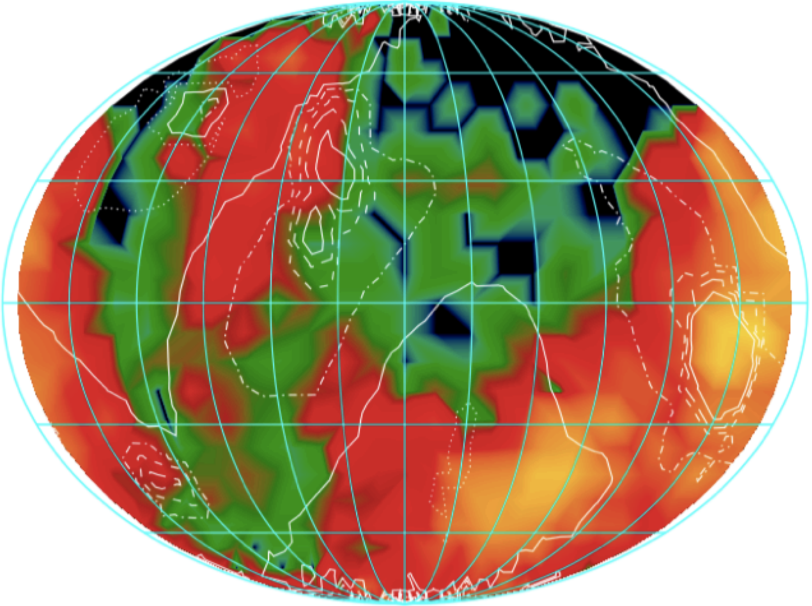
Hartwig+18

- Semi-analytical models: **50-80% faint** (Ji+15, de Bennassutti+16, Hartwig+18a)
- Fitting 200 observed EMP stars with theoretical SN yields: **10% faint** (Ishigaki+18)
- SN rate is only half the SFR: ~**50% faint?** (Horiuchi+11)
- 11 CEMP-no stars in **binaries** (Arentsen+18)

Is iron well mixed with alpha-elements?

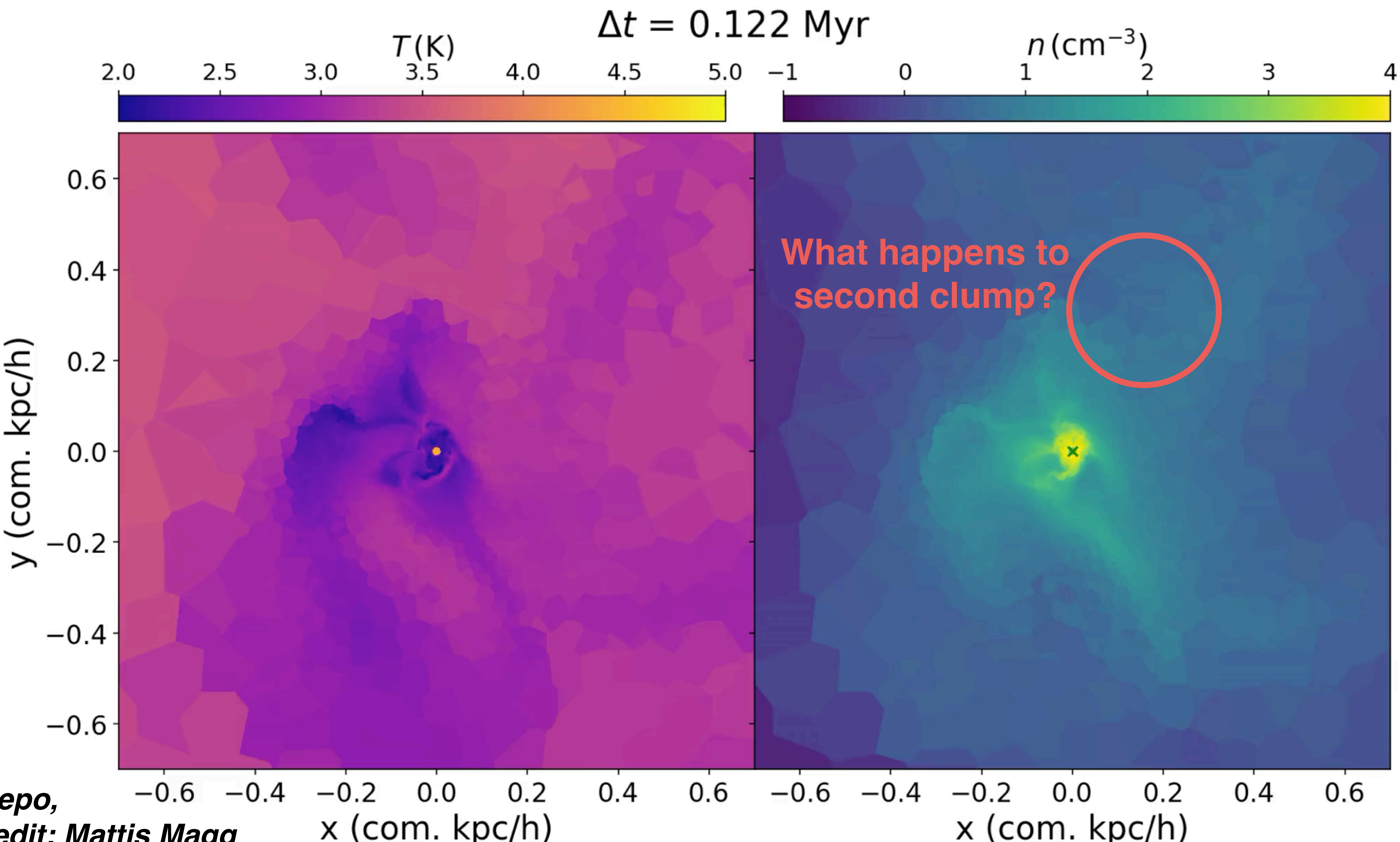
Joggerst+10





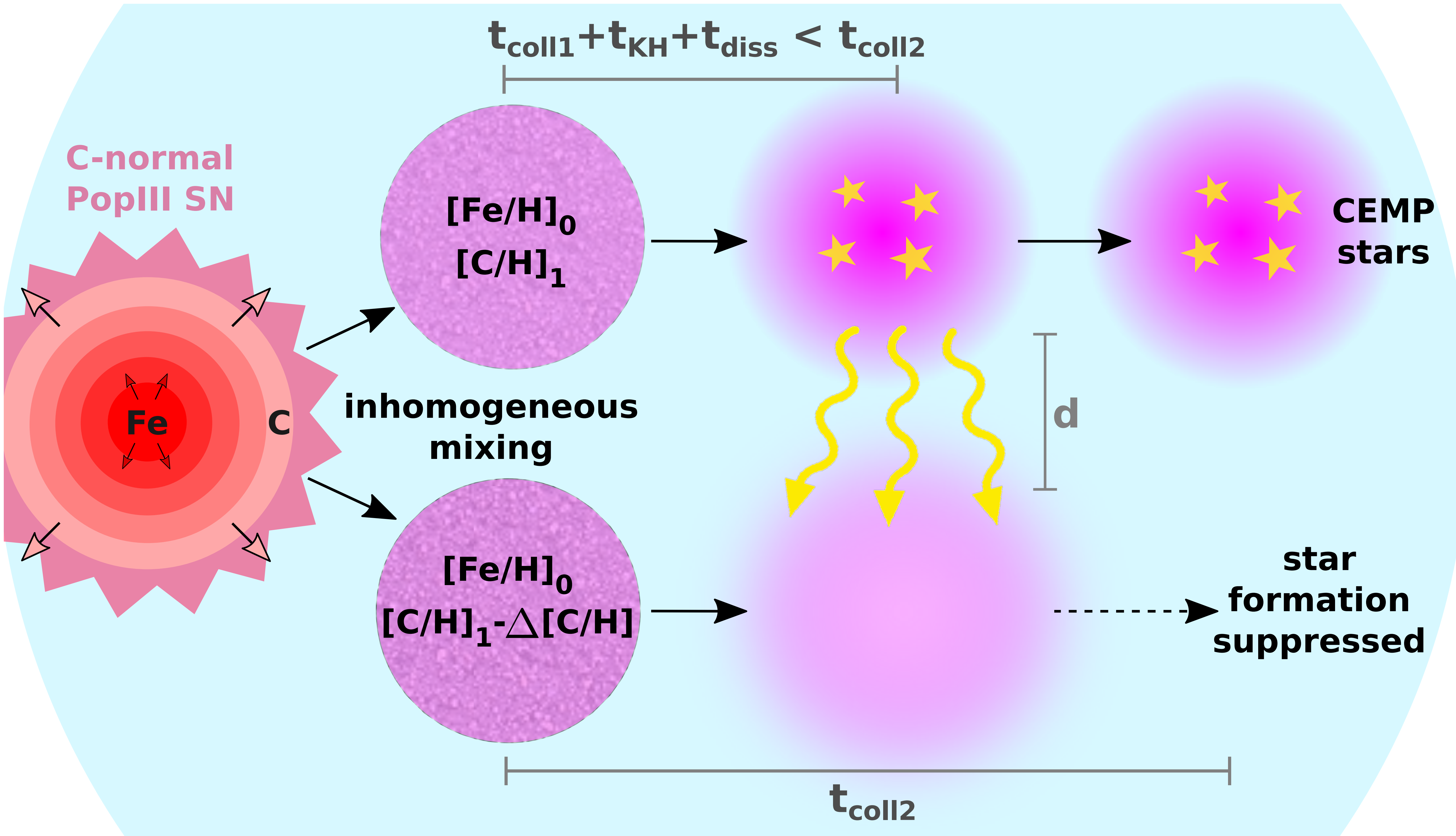
Probability that ejected elements are corporated into second-generation star (Sluder+16)

After PopIII SN: several clumps may form



Arepo, credit: Mattis Magg

Carbon-enhanced metal-poor stars as a consequence of inhomogeneous mixing of metals in the interstellar medium?



New Scenario

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Characteristic Timescales

Kelvin-Helmholtz: $t_{\rm KH} = 0.1\,{\rm Myr} \left(\frac{M_*}{10\,{\rm M}_\odot}\right)^2 \left(\frac{R_*}{5.3\,{\rm R}_\odot}\right)^{-1} \left(\frac{L_*}{5750\,{\rm L}_\odot}\right)^{-1}$

LW dissociation: $t_{\rm dis} = 0.2\,{\rm Myr} \left(\frac{M_{\rm clump}}{1000\,{\rm M}_\odot}\right)^{1/3} \left(\frac{n}{10^3\,{\rm cm}^{-3}}\right)^{2/3} \left(\frac{D}{10\,{\rm pc}}\right)^2$

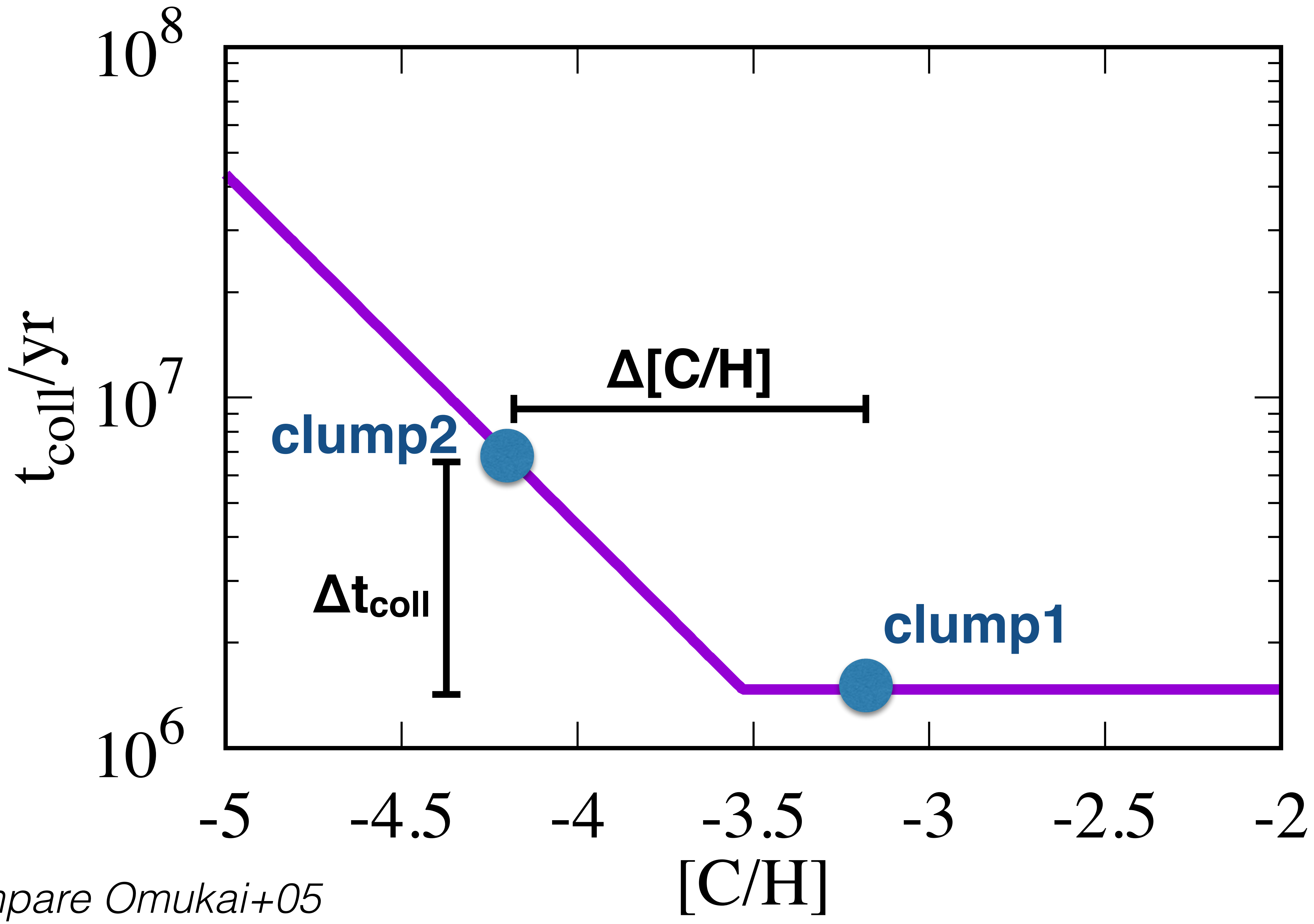
Collapse time: $t_{\rm coll} = \max(t_{\rm ff}, t_{\rm cool})$

Cooling Rate: $\frac{\Lambda_{\rm CII}}{\rm erg\,cm^{-3}\,s^{-1}} = 4.8\times10^{-21} \left(\frac{n_H}{10^3\,{\rm cm}^{-3}}\right)^2 \exp\left(-\frac{92\,{\rm K}}{T}\right)$ x $10^{[{\rm C/H}]}$

Condition: $\mathbf{t_{coll1} + t_{KH} + t_{diss} < t_{coll2}}$

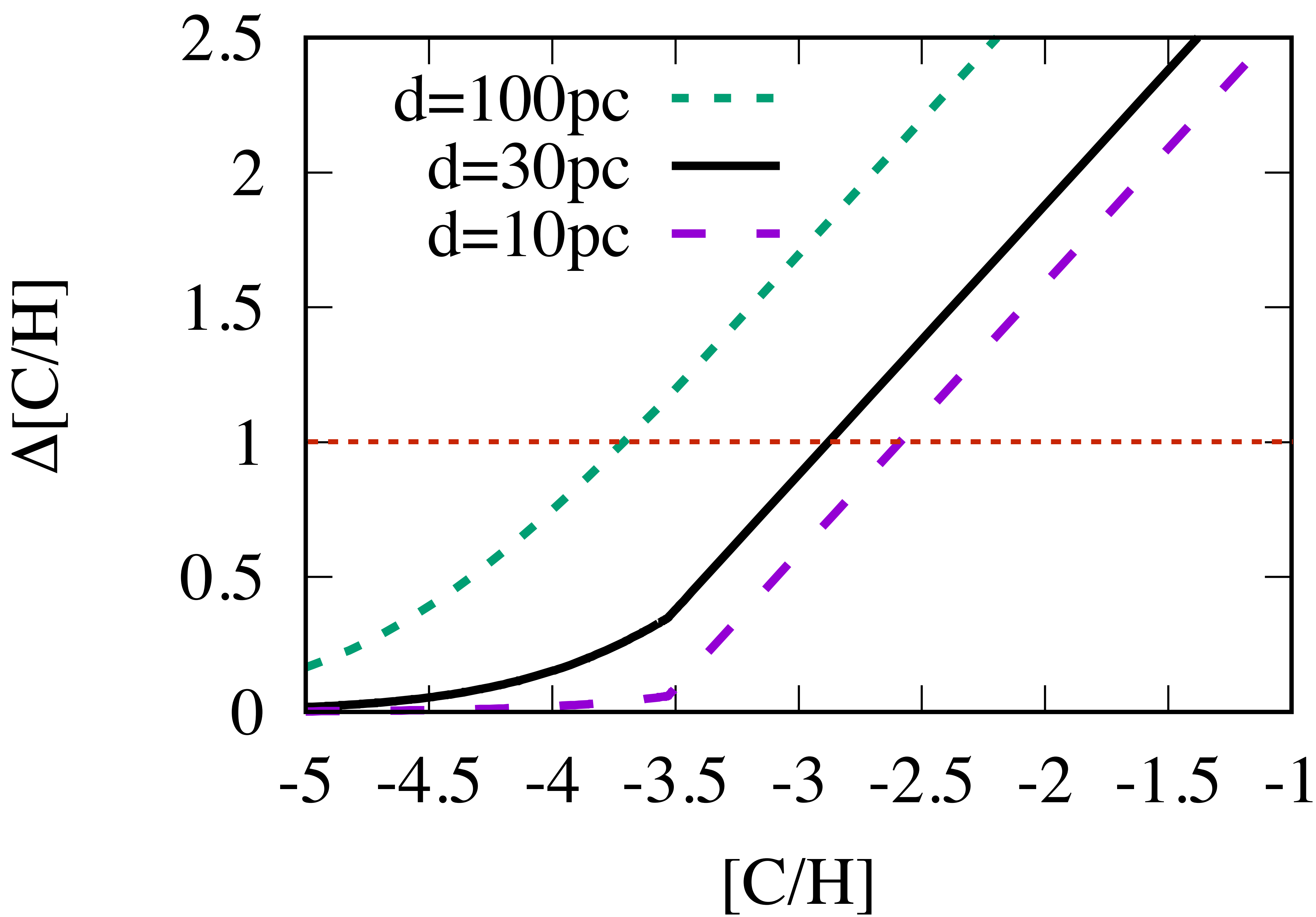
$$\Delta[{\rm C/H}] > [{\rm C/H}] + 3.6 + \log_{10}\left(\frac{13000 + 2\times10^5 d_{10}^2 n_3^{2/3} + 1.5\times10^6 n_3^{-1/2}}{1.7\times10^6} n_3\right)$$

Characteristic Timescales, illustrated



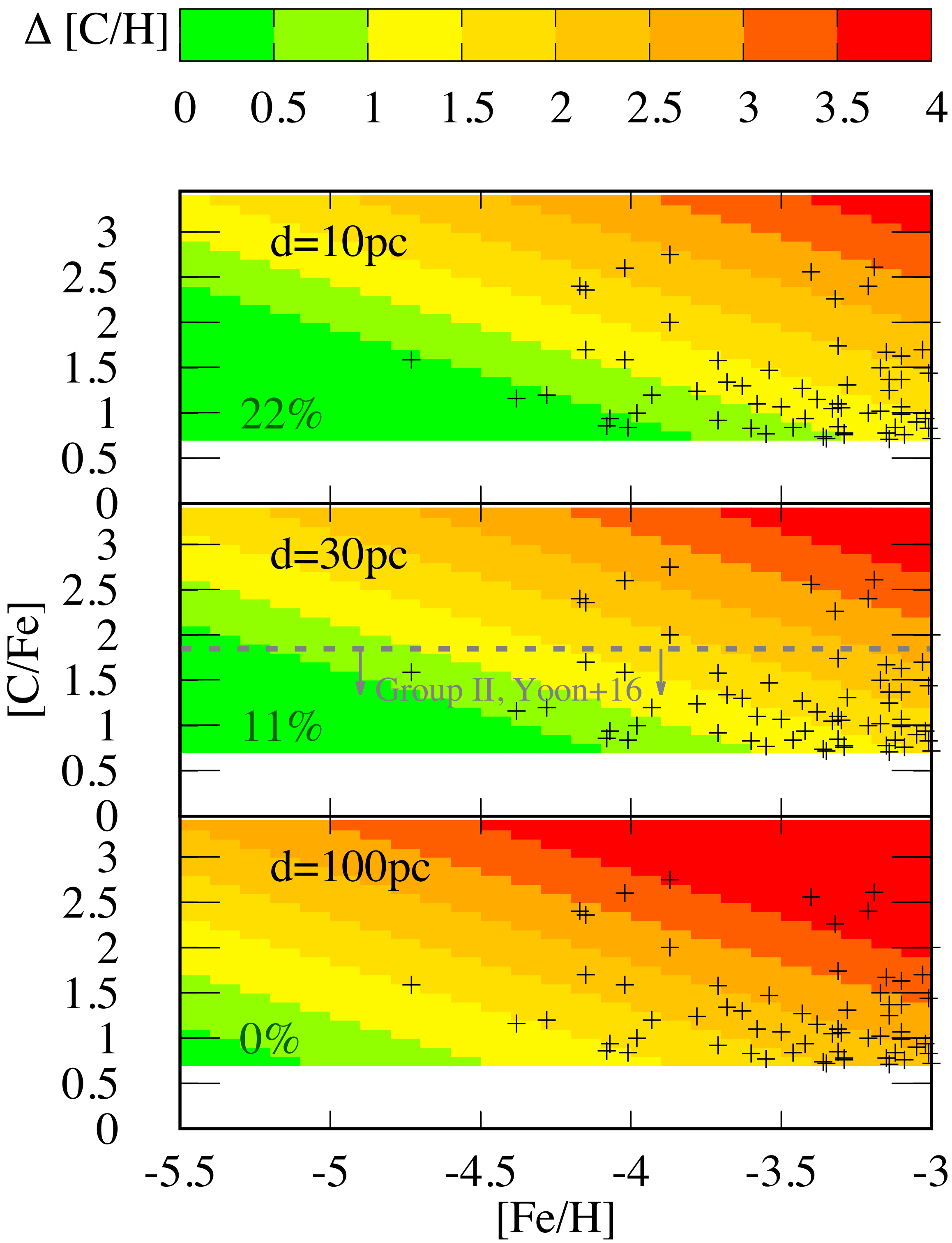
compare Omukai+05

Required Inhomogeneity



Δ[C/H]~1 is reasonable (Sluder+16)

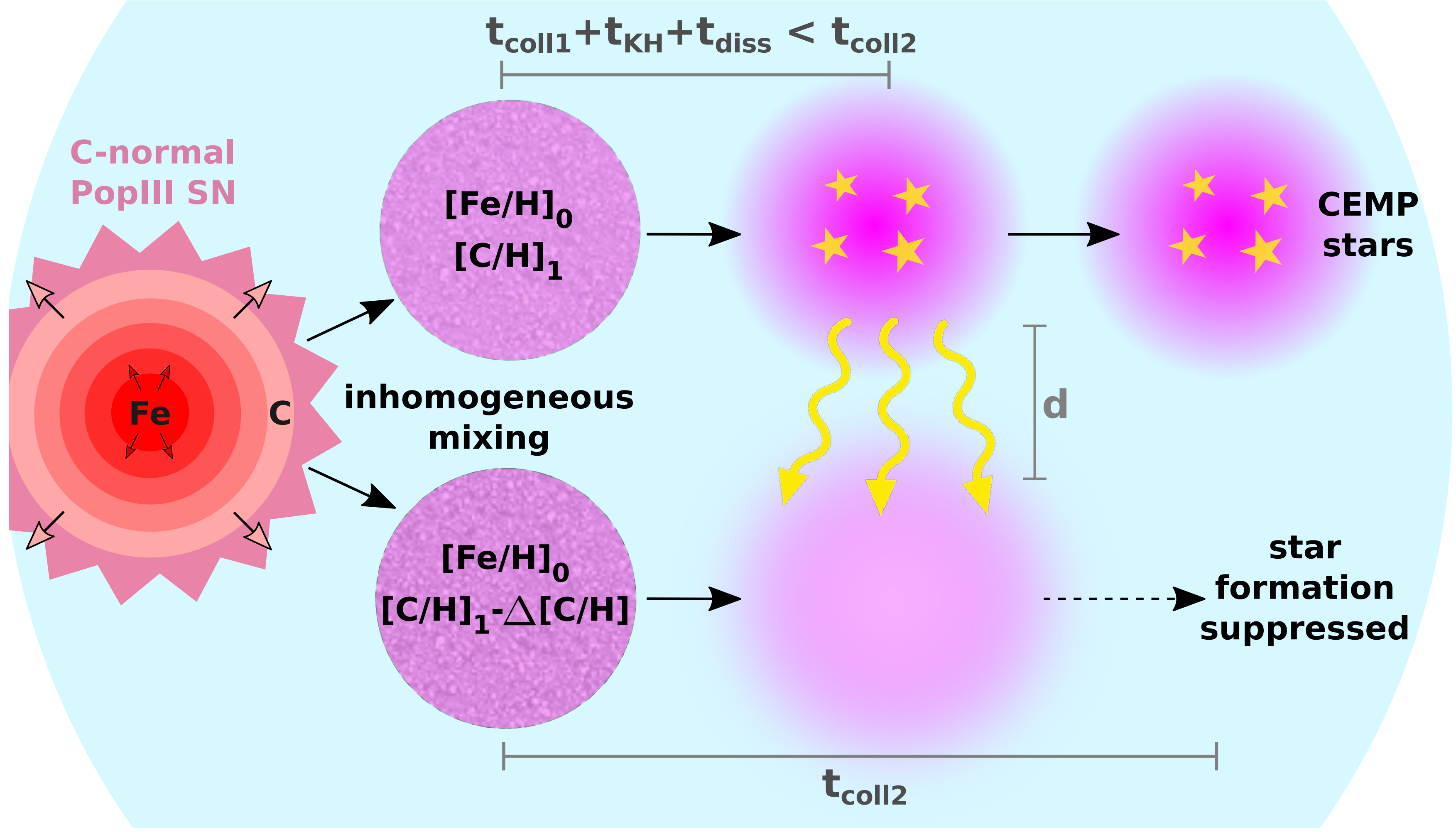
Comparison to Observations



- 0-22% of CEMP-no stars can be explained for Δ[C/H]~1
- Up to 89% for Δ[C/H]~2
- Follow-up simulations with Arepo
- General importance of inhomogeneous mixing for interpretation of EMP stars

A novel formation scenario for carbon-enhanced metal-poor stars

- 0-89% of CEMP-no stars could have formed by inhomogeneous metal mixing
- Caveats: only carbon (no dust or oxygen), simplistic analytical treatment
- Next step: 3D simulations
- Inhomogeneous metal mixing: general importance for interpreting stellar abundance patterns



Summary

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