Supernova enrichment and dynamical histories of solar-type stars in clusters

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Parker, Church, Davies & Meyer (2014)
MNRAS **437** 946

Gustafsson, Church, Davies & Rickman
(submitted to *A&A*)

TWO QUESTIONS

Can we pollute the Solar System
and yet,
not clobber the planets?

Could the Sun have come from
the open cluster M67?

Pollution from massive stars

Meteorites contain decay products of radioactive isotopes ^{26}Al and ^{60}Fe.

Lee et al. (1976)

Most likely source of ^{26}Al and ^{60}Fe is a supernova close to the Sun whilst it still has a planet-forming disc.

e.g. Chevalier (2000)

The Sun should be between 0.1 and 0.3 pc away from the supernova.

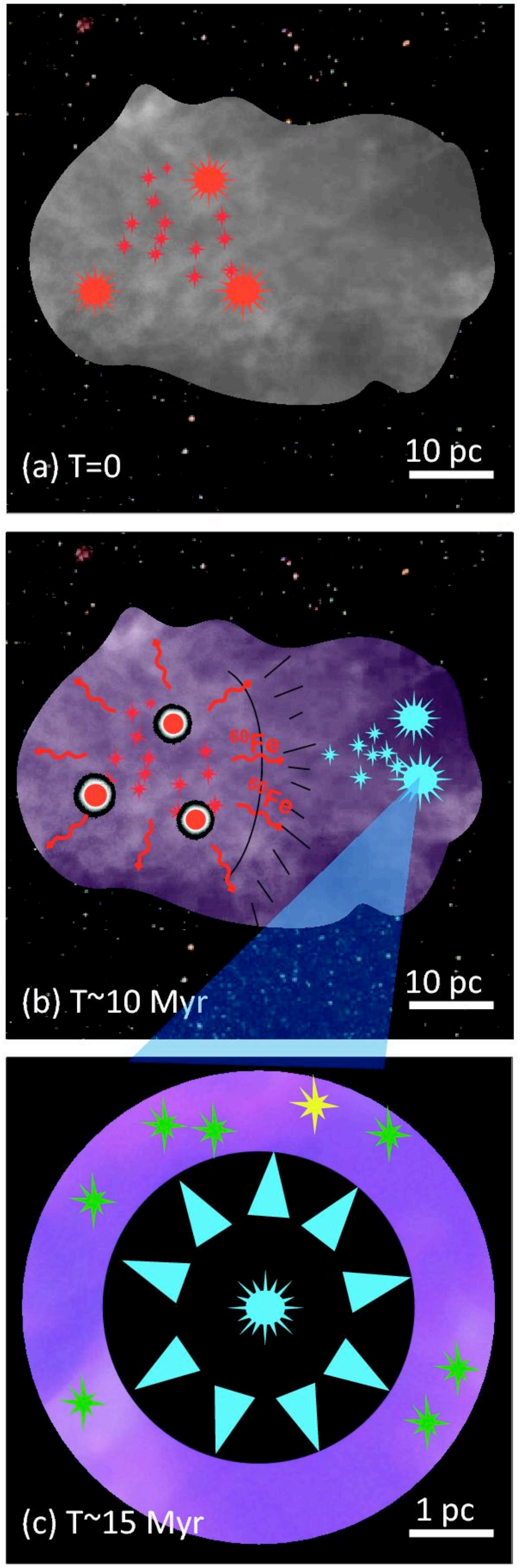
Adams et al. (2011)

If the isotopes come from a single supernova the progenitor star's mass should be about $25\,M_\odot$.

Wasserburg et al. (2011)

So put the Sun in a cluster of about 2100 stars

Pollution in two phases?



Get ^{60}Fe from SNe in first generation and ^{26}Al from single massive star in second generation.

Gounelle & Meynet (2012)

...but the Sun is still in a CROWDED PLACE

Crowdedness matters

Dynamical encounters in planetary systems can be very dangerous for planetary systems:

Close encounters can remove planets (that's the clobbering).

Remaining planets end up on eccentric, inclined orbits that may destabilise the planetary system.

Close encounters of protoplanetary discs with cluster stars can truncate or evaporate the discs.

The Sun is probably one of the ~15% of "singleton" stars that has always been single and never had an encounter.

e.g. Malmberg et al. (2007a, 2007b, 2011)

Star and cluster masses

Relationship between cluster mass and maximum stellar mass:

May have a physical origin i.e. low-mass clusters with high-mass stars are impossible

(Weidner & Kroupa 2006)

May have a statistical origin; i.e. low-mass clusters with high-mass stars are rare

(Parker & Goodwin 2007; Maschberger & Clarke 2008)

We adopt a cluster model that is consistent with both approaches (2100 stars, one $25\,M_\odot$ star, 96 G-dwarfs).

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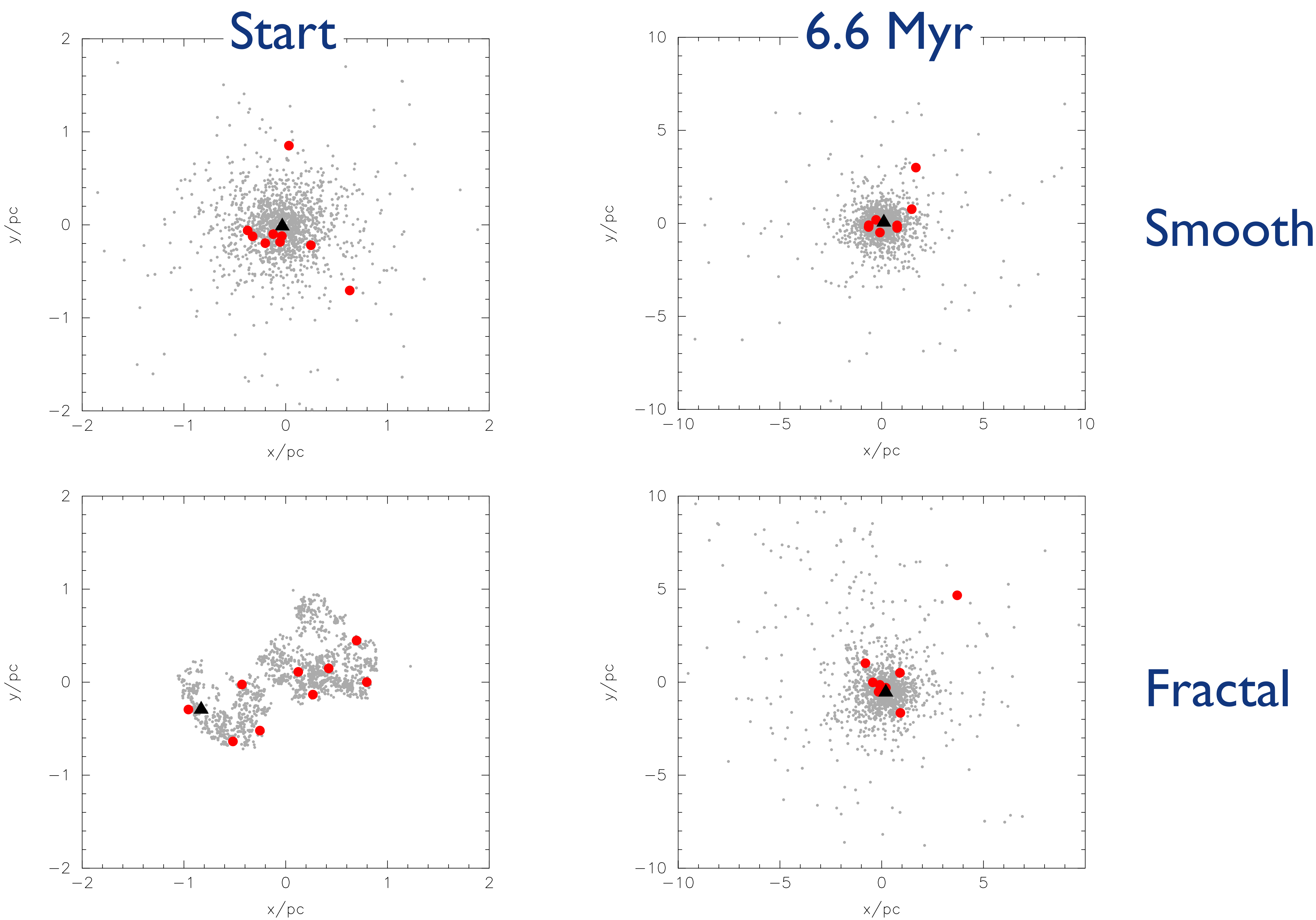
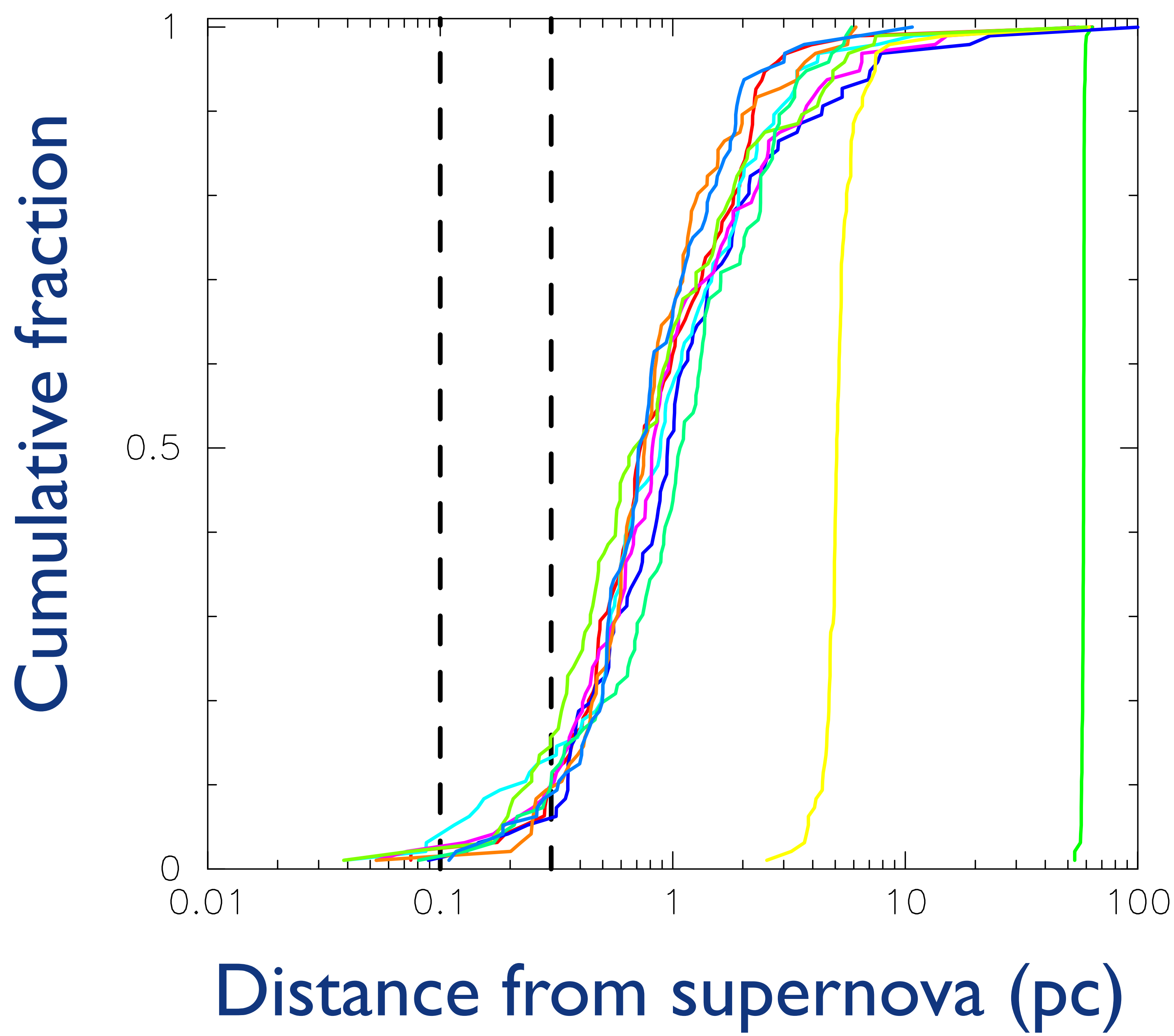
Dynamics removes substructure

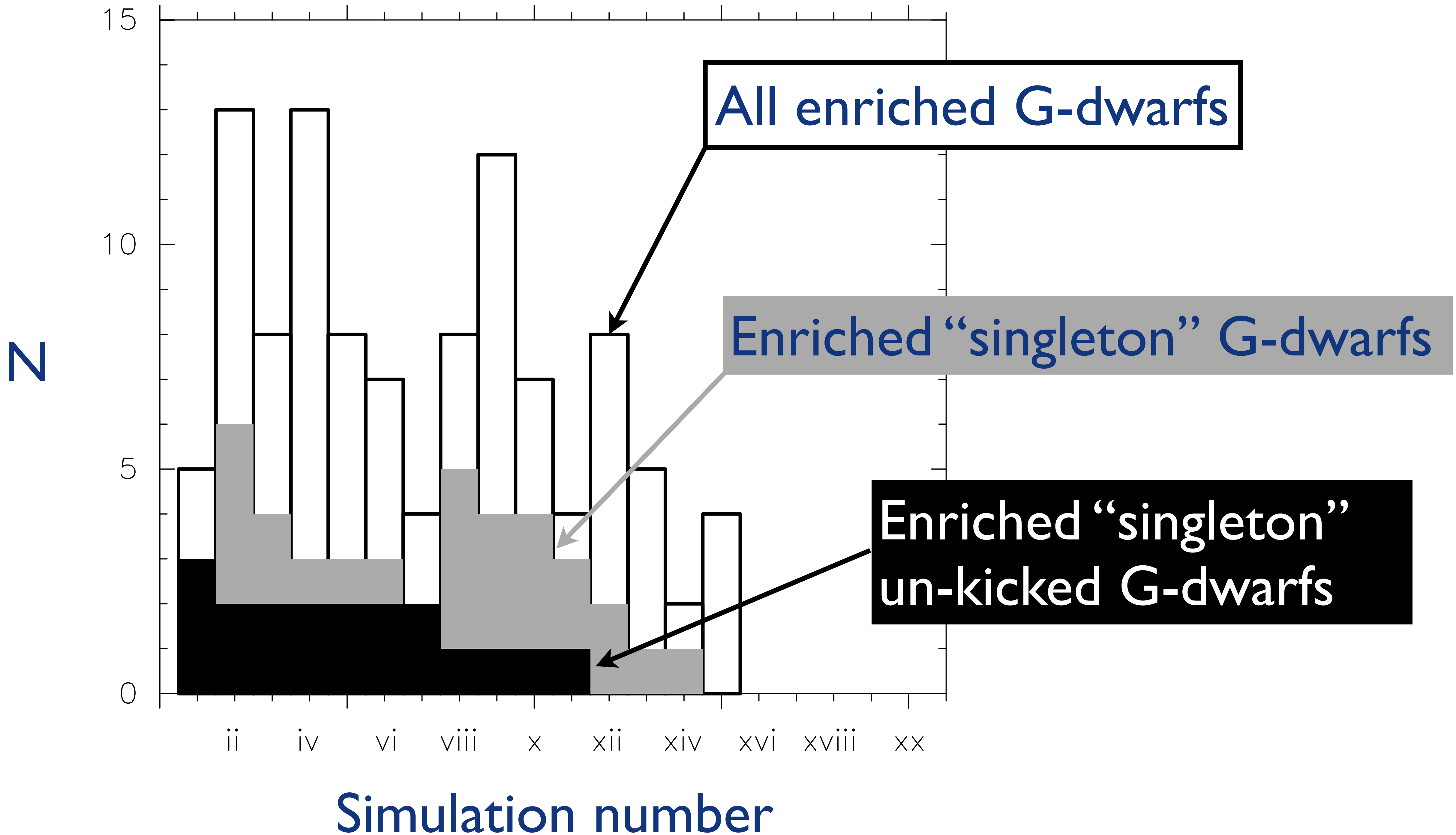


Distances from supernova



Typically about 10% of G-dwarfs are enriched

Dynamical effects



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Bottom line

A typical 2000-star cluster contains a massive star suitable to enrich the Solar System.

On average a few G-dwarfs are close enough to be enriched.

Roughly one per cent of G-dwarfs are enriched and unperturbed singletons.

Planetary systems like the Solar System should be unusual but not horribly rare.

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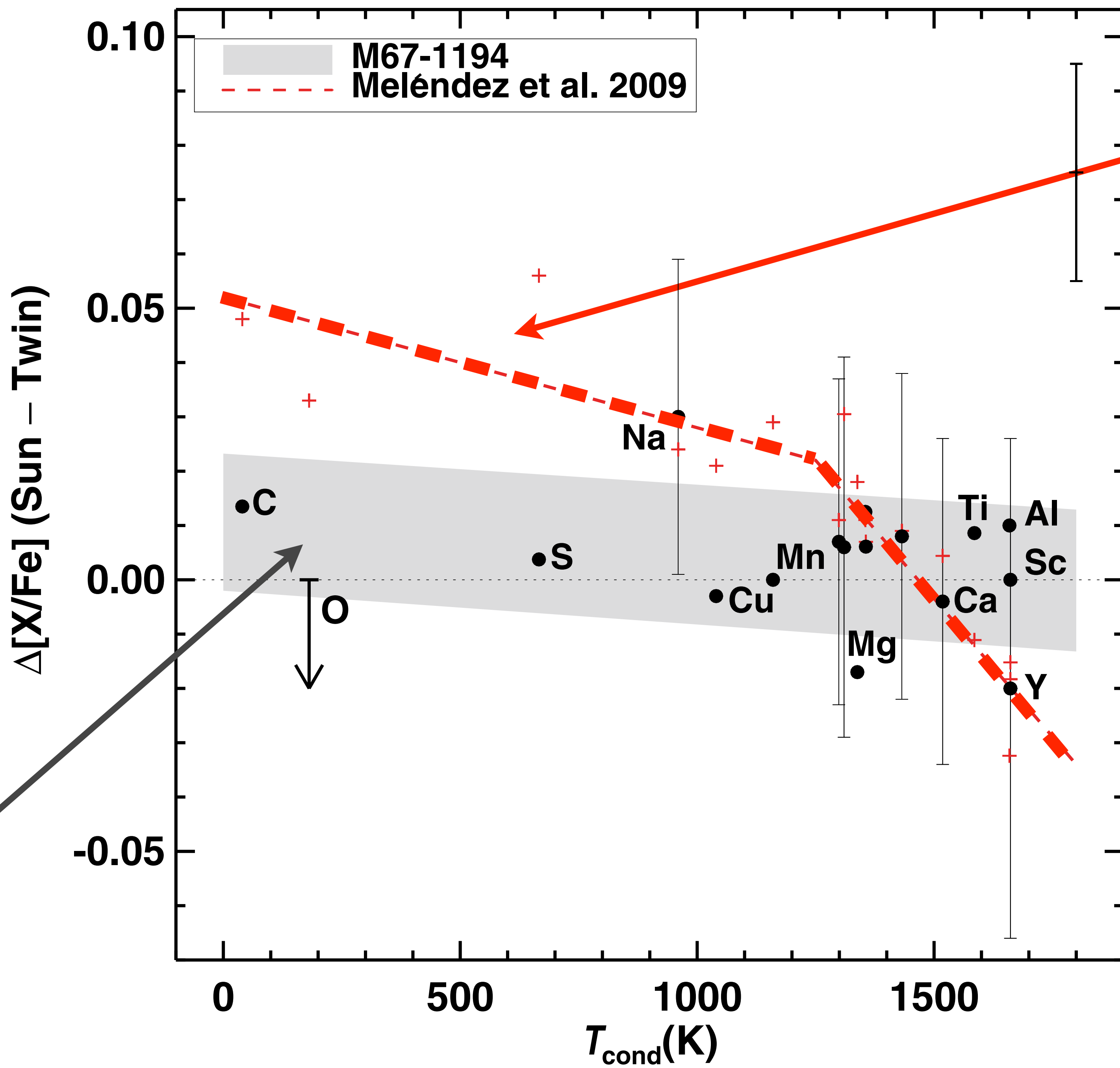
Did the Sun come from M67?

Solar twins and M67

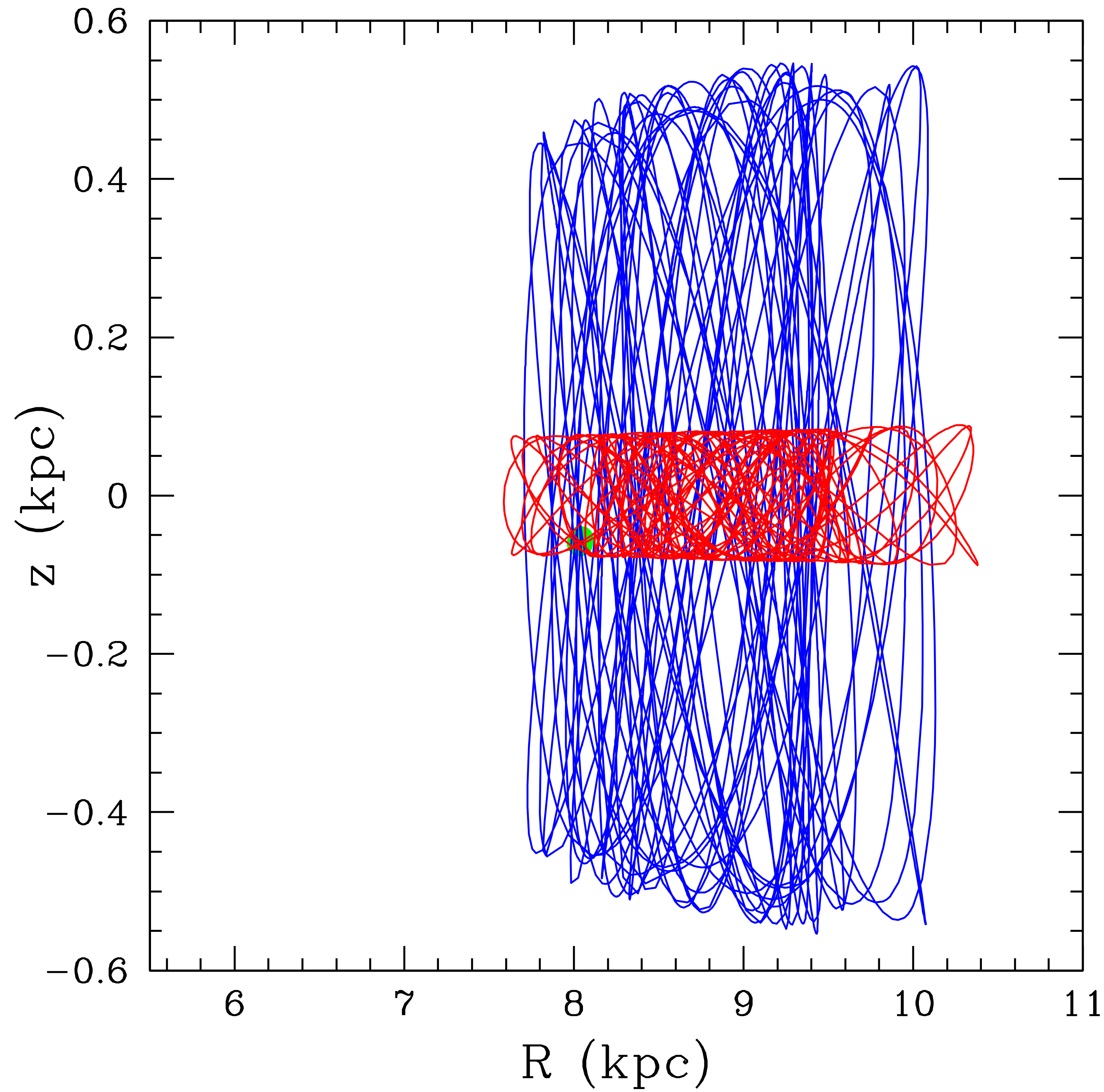


Trend for solar twins outside M67

Range of trends for M67-1194

Önehag et al. (2011) *A&A* **528** 85

The Sun's orbit differs from M67's



Pichardo et al. (2012) *AJ* **143** 73

Scattering M67 off a giant molecular cloud

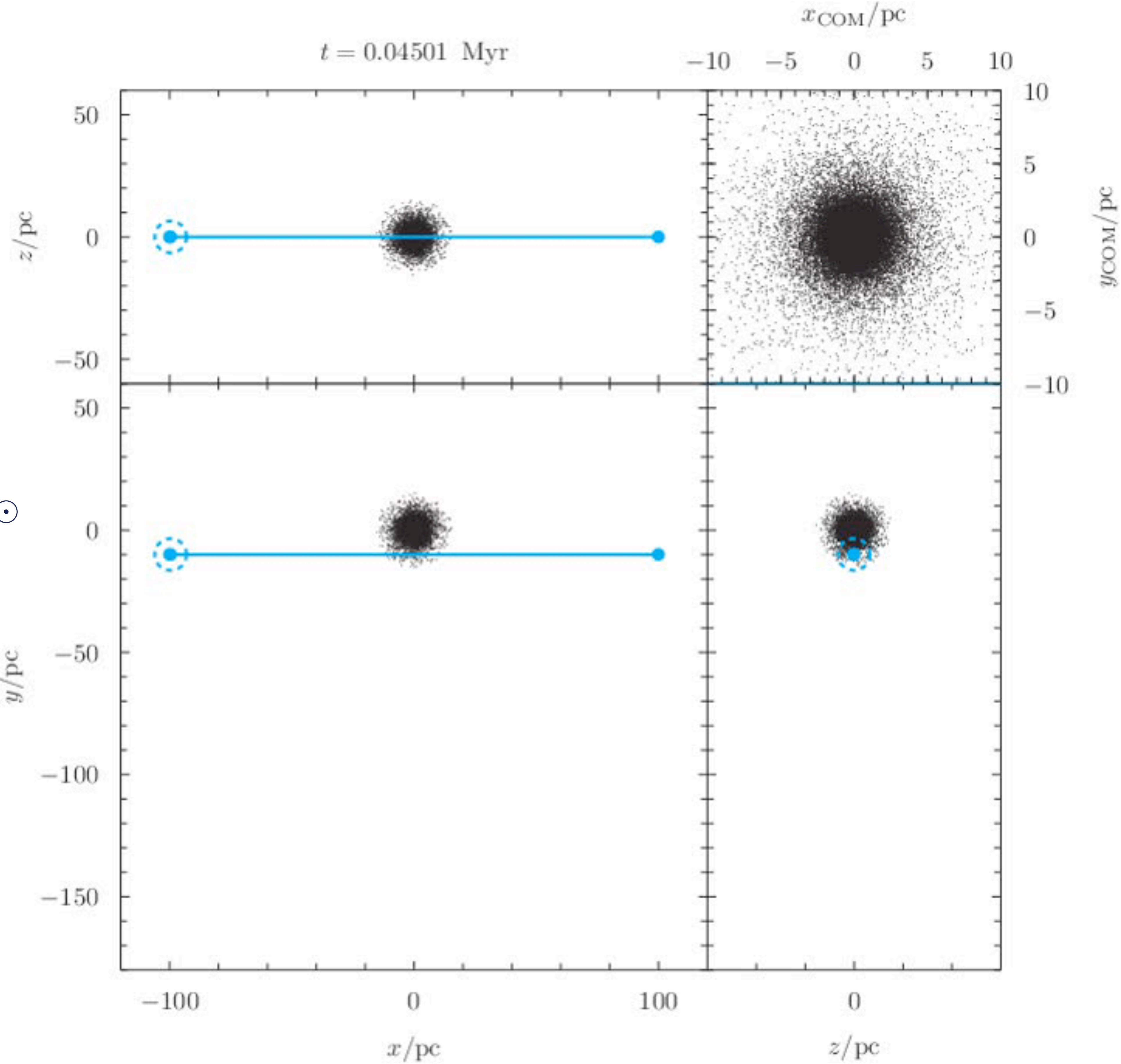
$$M = 3 \times 10^5\, M_\odot$$

$$b = 10\,\mathrm{pc}$$

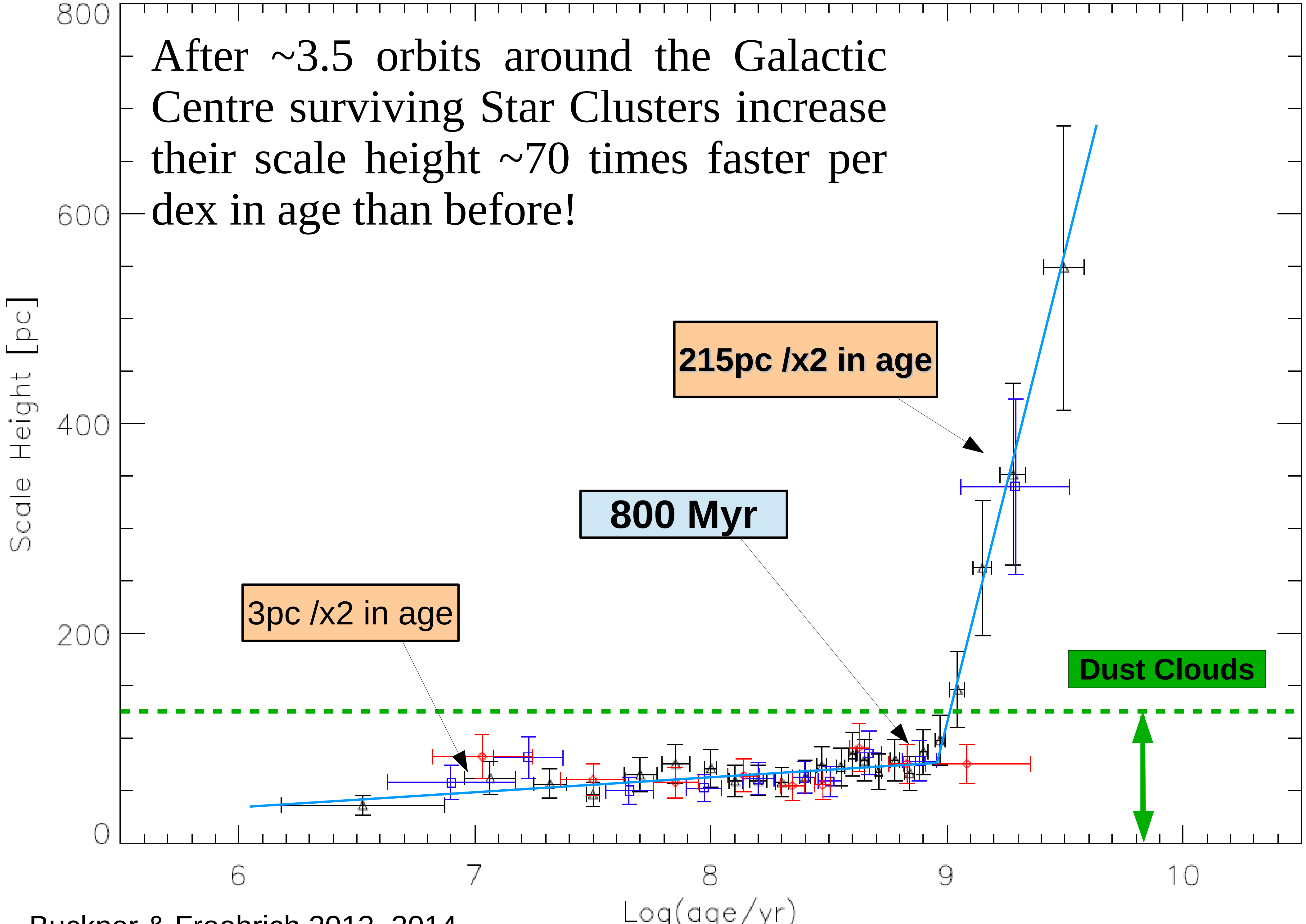
$$r_\mathrm{h} = 2\,\mathrm{pc}$$

$$v_\infty = 10\,\mathrm{km\,s^{-1}}$$

$$\frac{\Delta E}{E} \simeq 0.25$$



Interesting to note: Anne Buckner's Poster



Buckner & Froebrich 2013, 2014

Bottom line

M67 did not form on its current orbit.

We show that it could have survived being scattered from the disc into its present orbit by encounters with giant molecular clouds.

Careful abundance analysis suggests M67 is an interesting candidate for the birthplace of the Sun.

Gustafsson, Church, Davies & Rickman (submitted to *A&A*)

Summary

Meteoritic abundances suggest that the Sun probably formed in a stellar cluster.

Unperturbed G-dwarfs form in 2000-star clusters, but are relatively unusual.

The stars with the most solar-like abundances are in M67.

A solar origin in M67 is not ruled out by dynamical arguments.