Gravitational scattering in the Galactic Disc
and
Old High-Altitude Open Clusters

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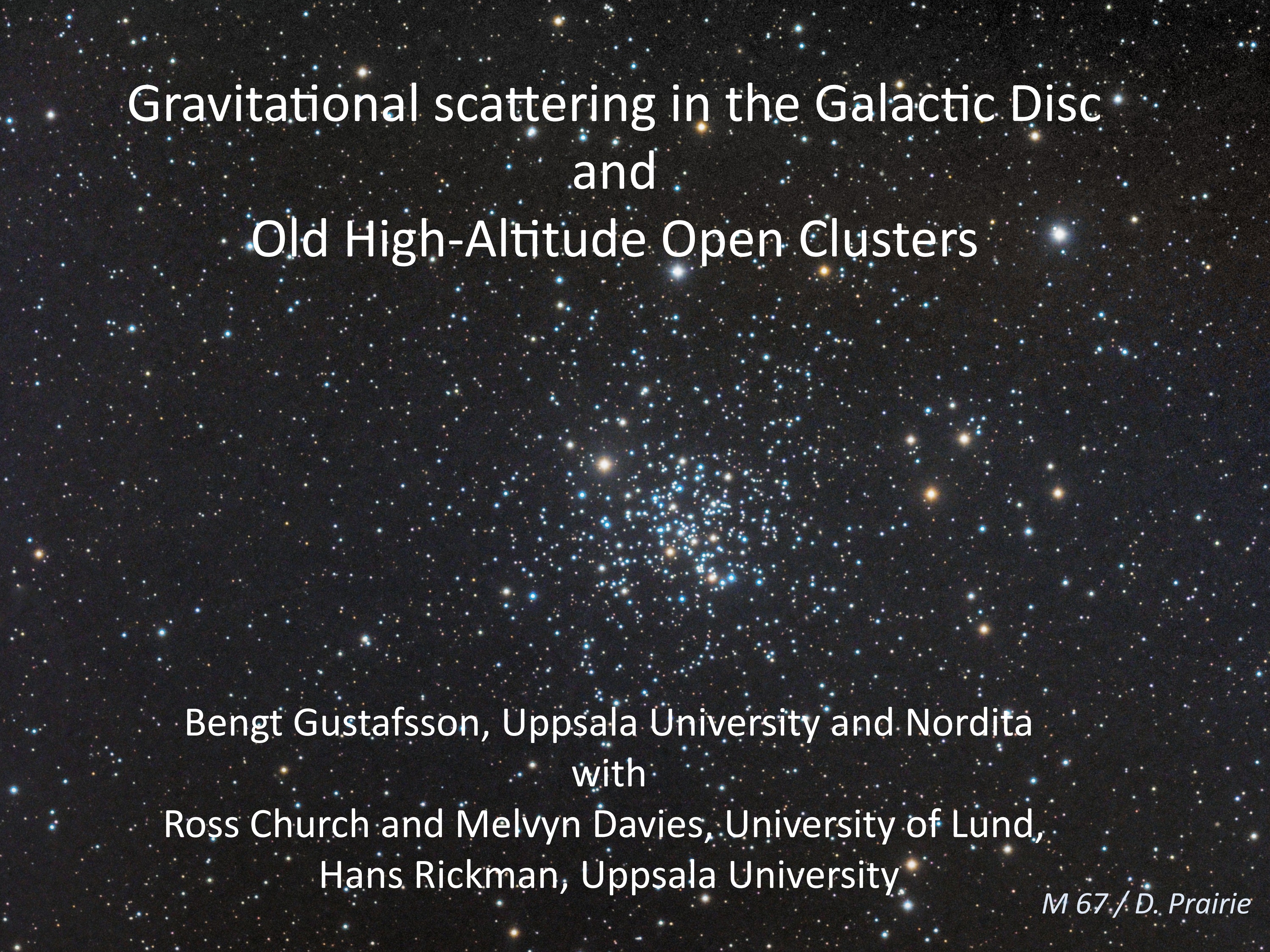


M 67 / D. Prairie

Starting point: Sun vs ”Solar twins”

Meléndez et al. (2009)

Correlation with condensation temp.

Various hypotheses:

…

Pre-solar cloud dust-cleansed by hot stars.

Check: Go to cluster! M67:

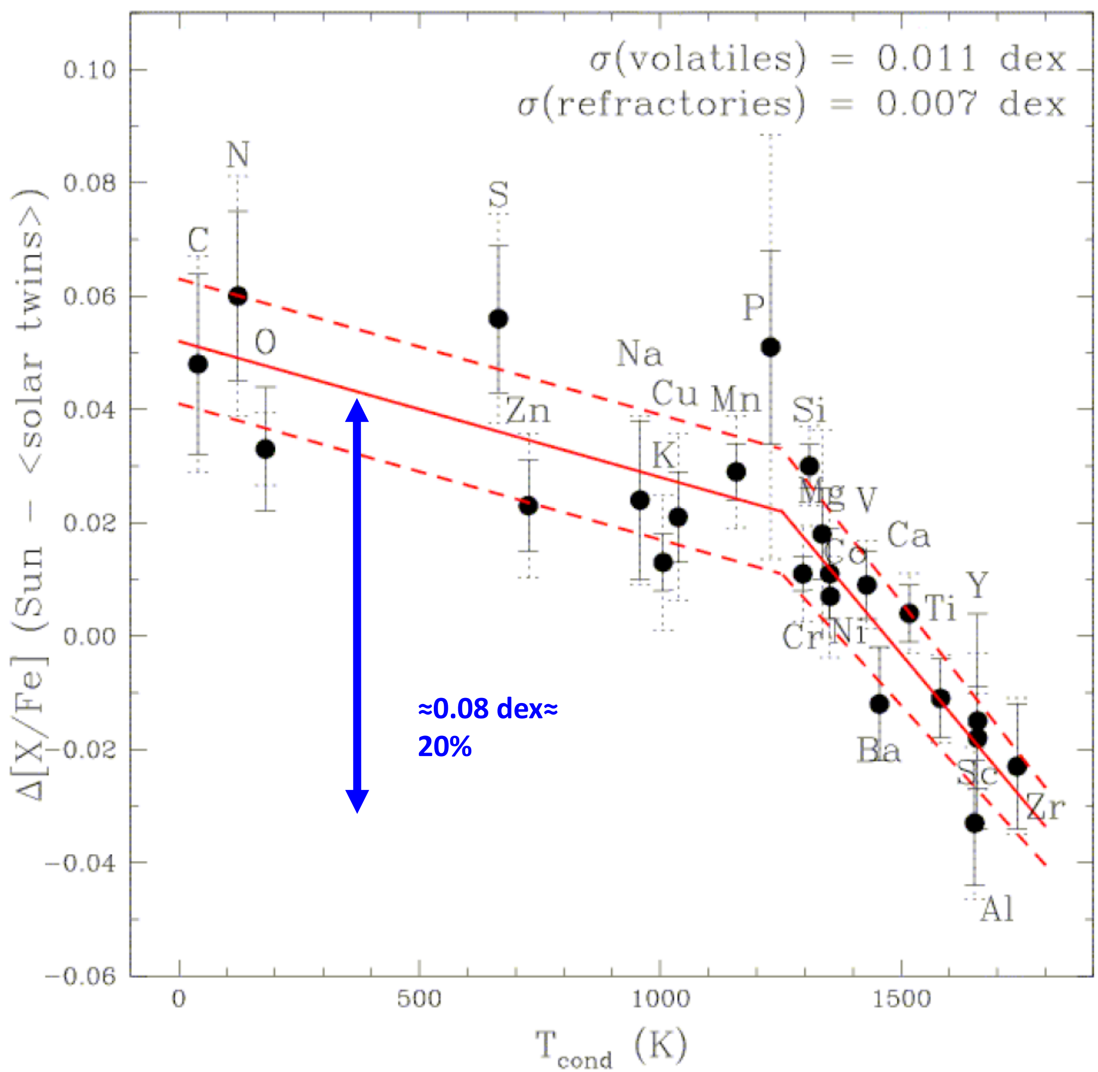
Age and metallicity solar like. Indeed:

Önehag et al. ((2011, 2014) found its stars to have Solar abundance profiles!

But – how did it get up there?

Exotic scenarios:

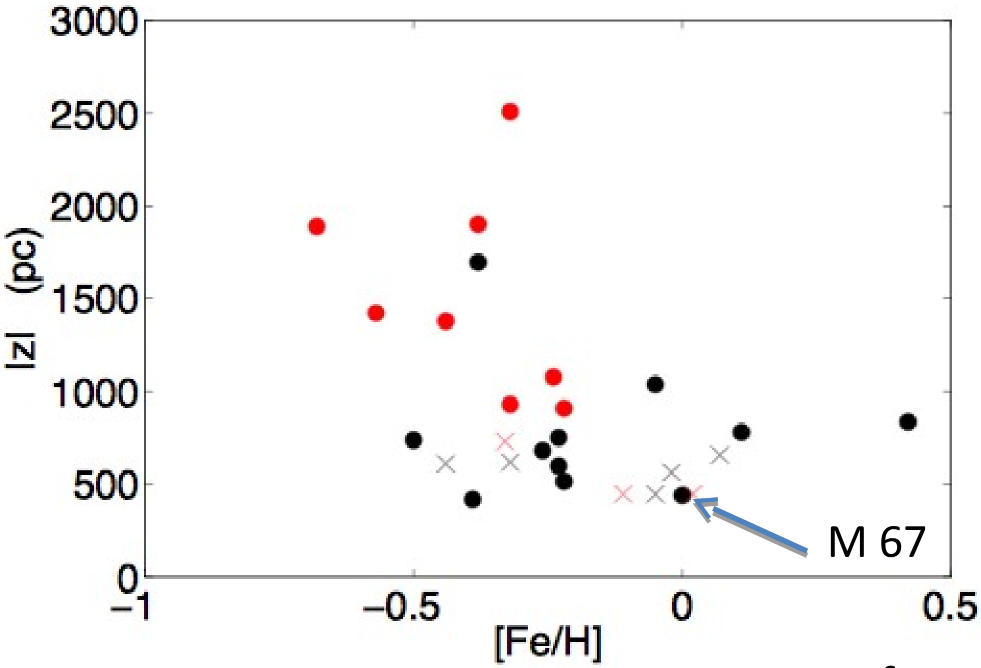
See Putte et al. (2012) But …



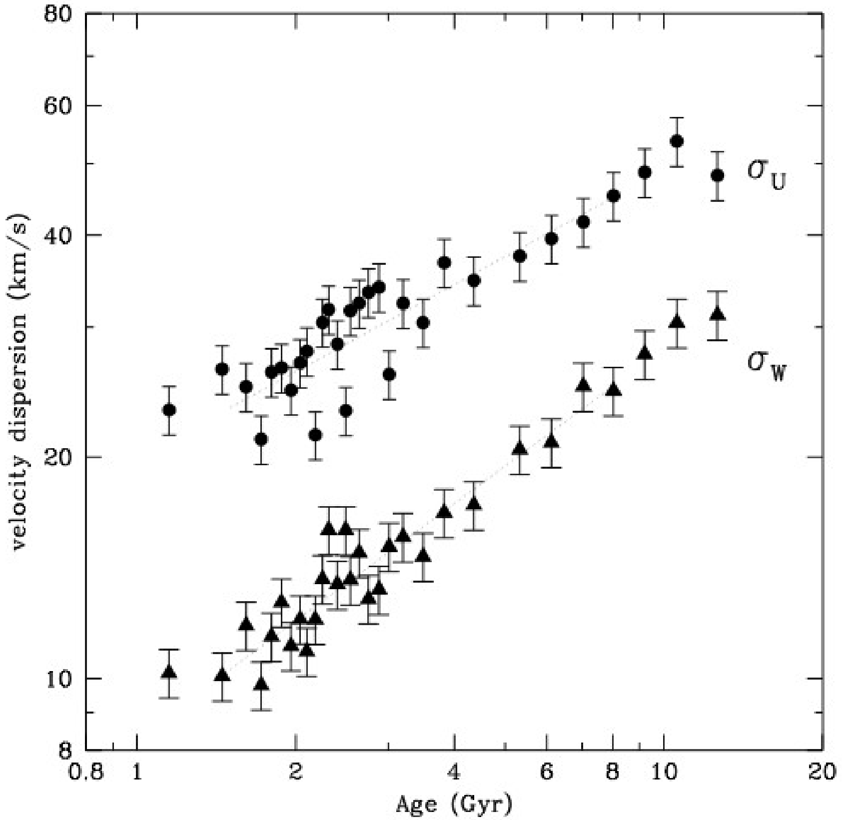
Questions

(1) Could OHAOCs be up there due to gravitational scattering?

(2) What are the mechanisms heating the Disc?



Data from *Heiter et al. (2014)* …



Holmberg et al. (2009)

(3) Does (1) constrain (2)?

(4) Could the solar birth-cluster still exist?

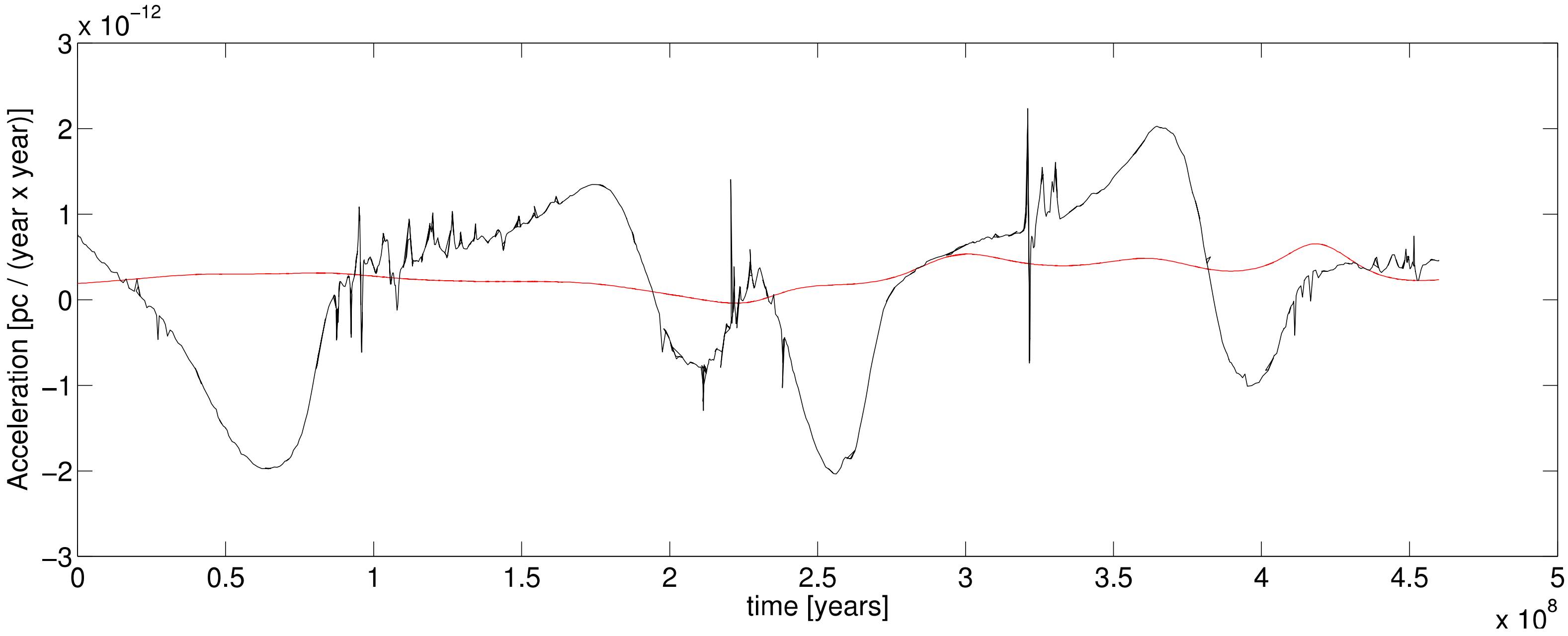
Methods: 1

- Integration of orbits of test particles (stars, clusters) in Galactic potential with rotating stationary spiral arms and Bar and with soft spherical GMCs
- GMCs mass distribution (*Hopkins et al. 2012*)

$$N(M)\, dM = \text{const} \times M^{-1.8}\, dM,\ 10^5 \leq M_{max}/M_{sun} \leq 10^7$$

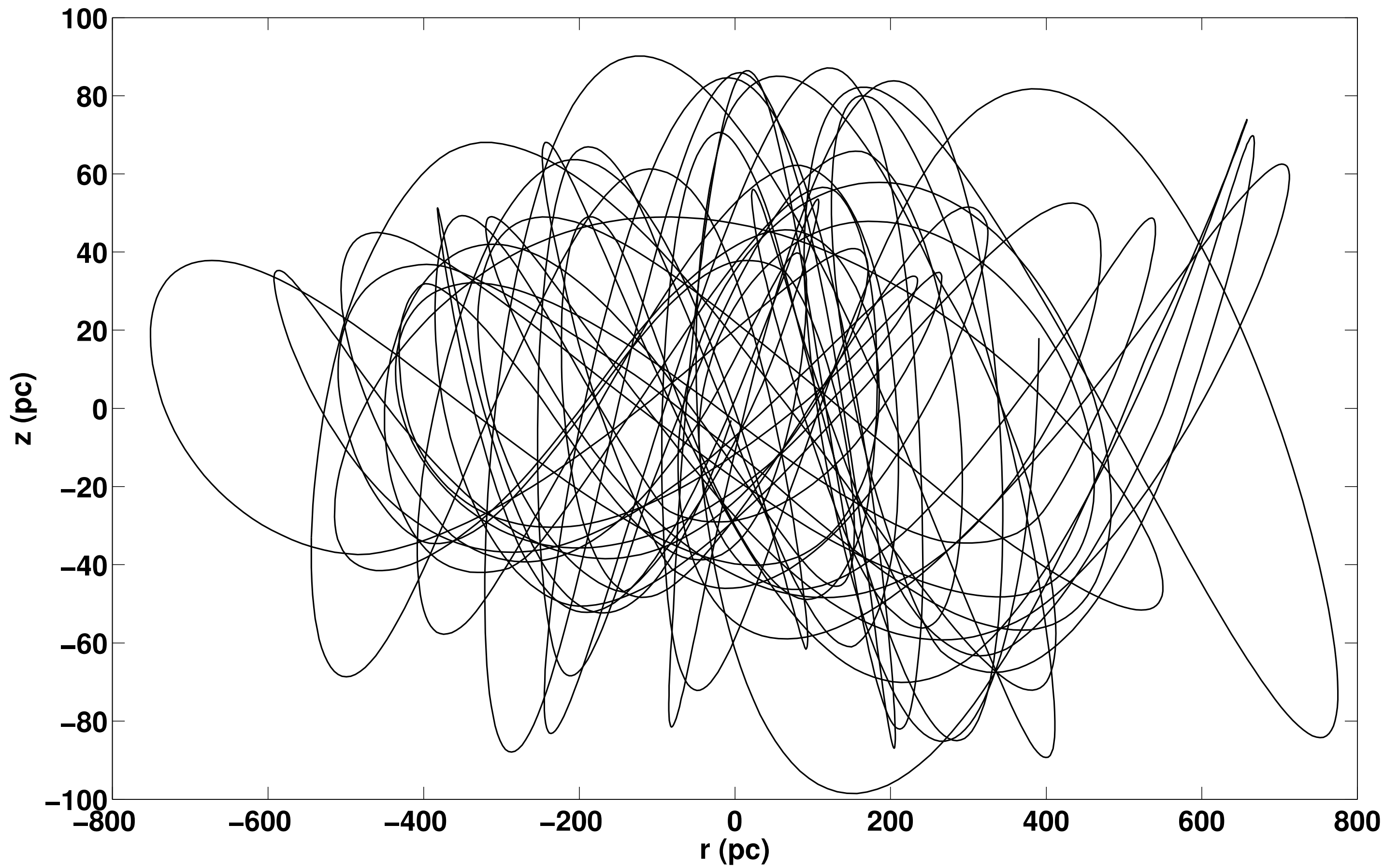
$$\Sigma M = 10^9\, M_{sun},\ \Sigma N = 300{,}000 \text{ (\textit{Williams \& McKee 1997})}$$

- GMC mass with linear growth and decline with time, in 40 million years
- GMCs formed in spiral arms with velocity scatter with $\sigma_v = 7$ (alt.) km/s, orbits integrated

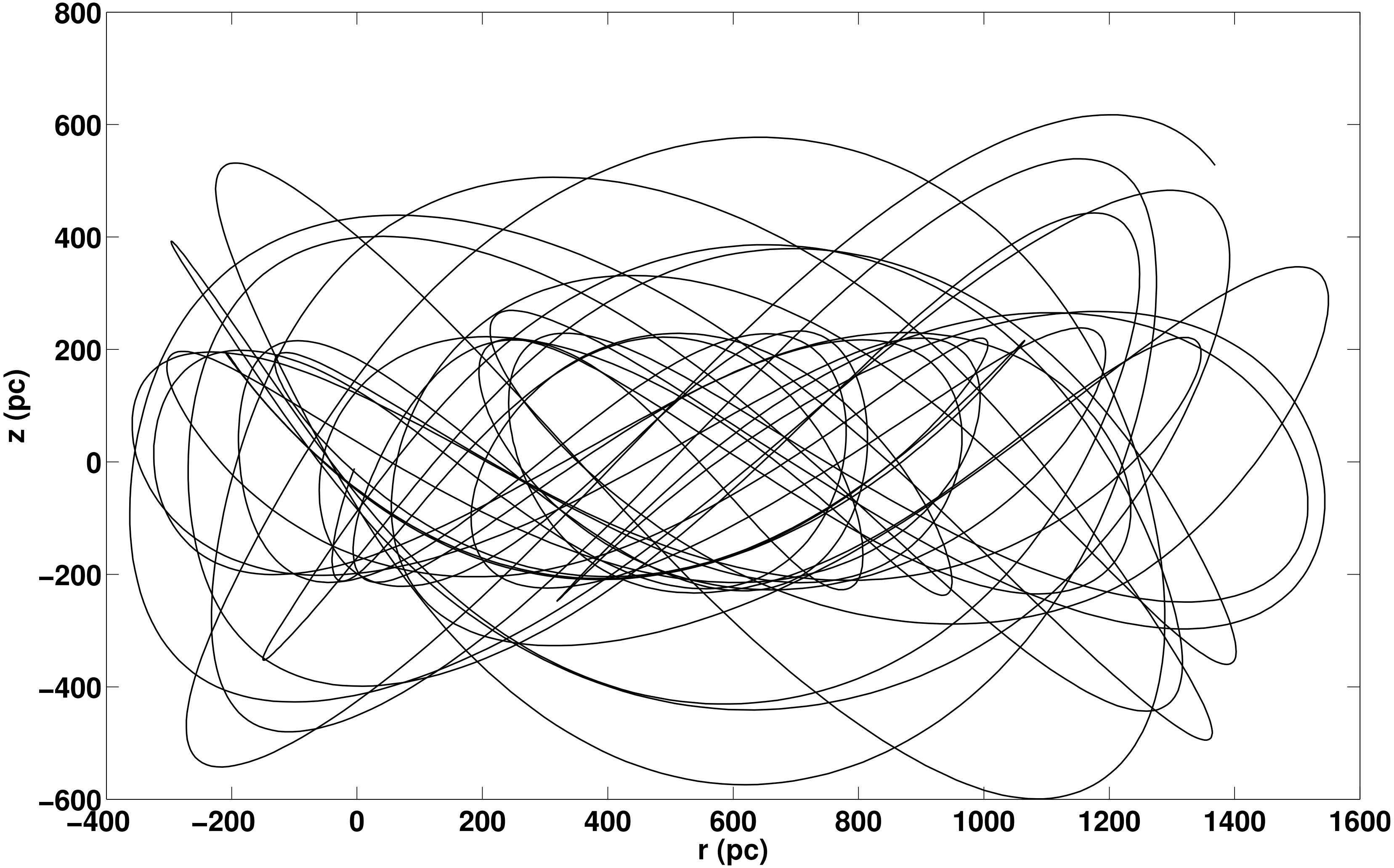


Methods: Orbit example

in co-rotating frame

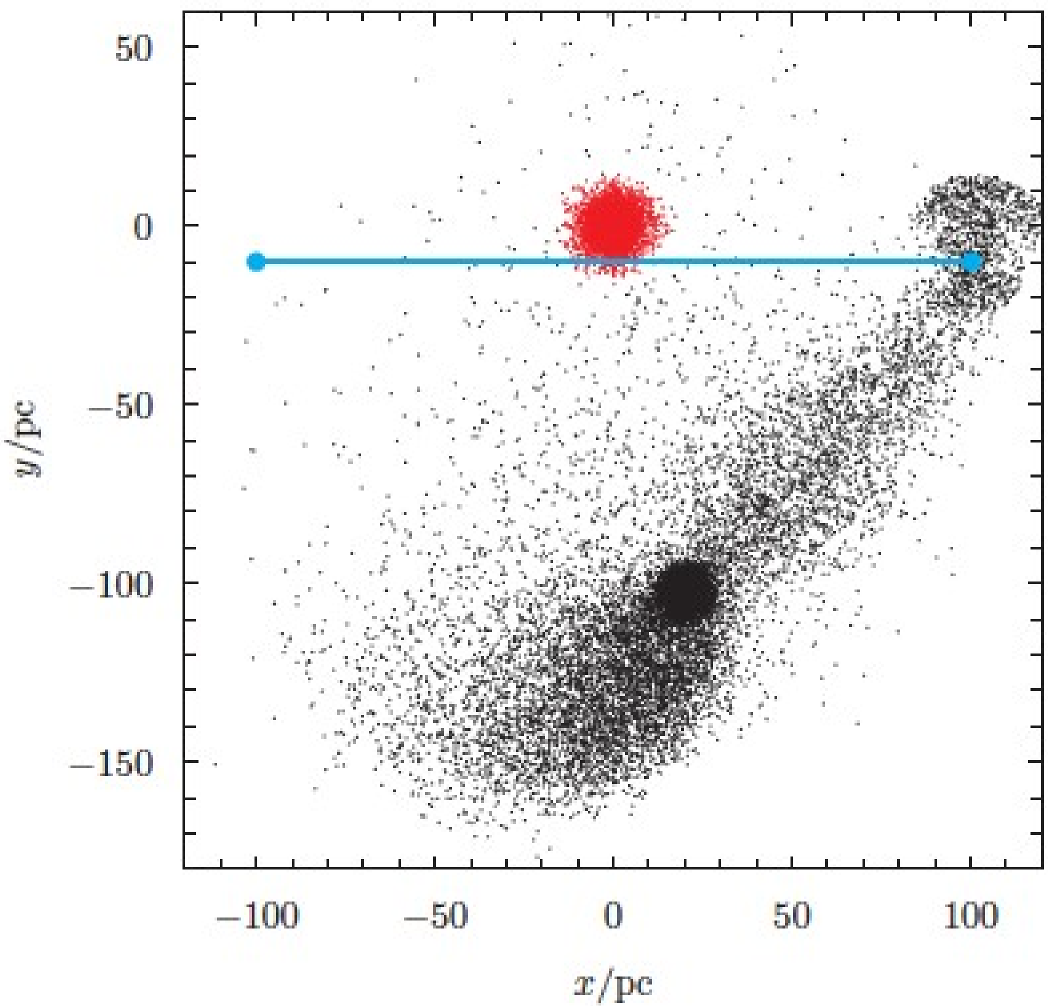


Methods: Orbit example 2

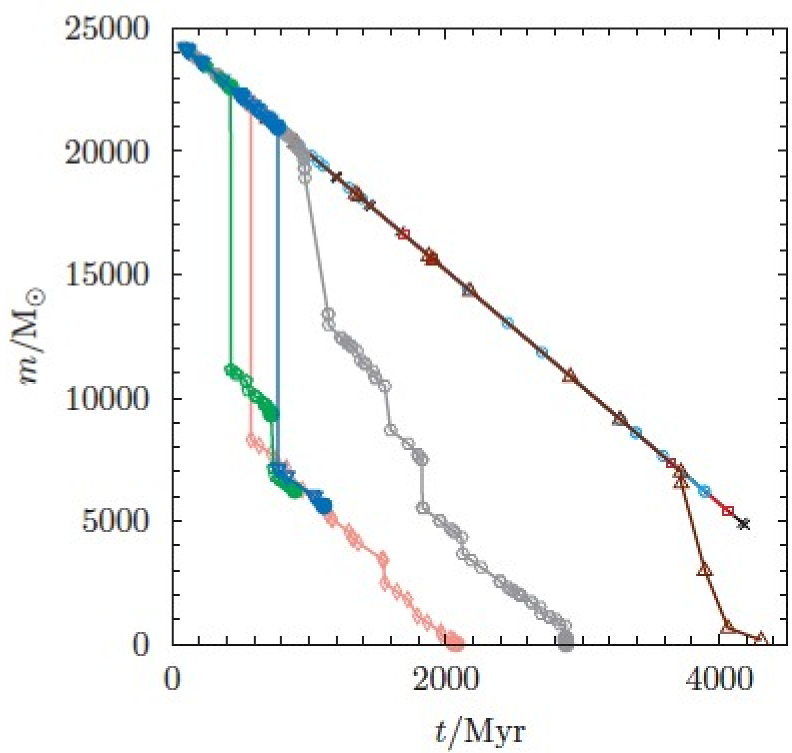


Methods: Cluster destruction

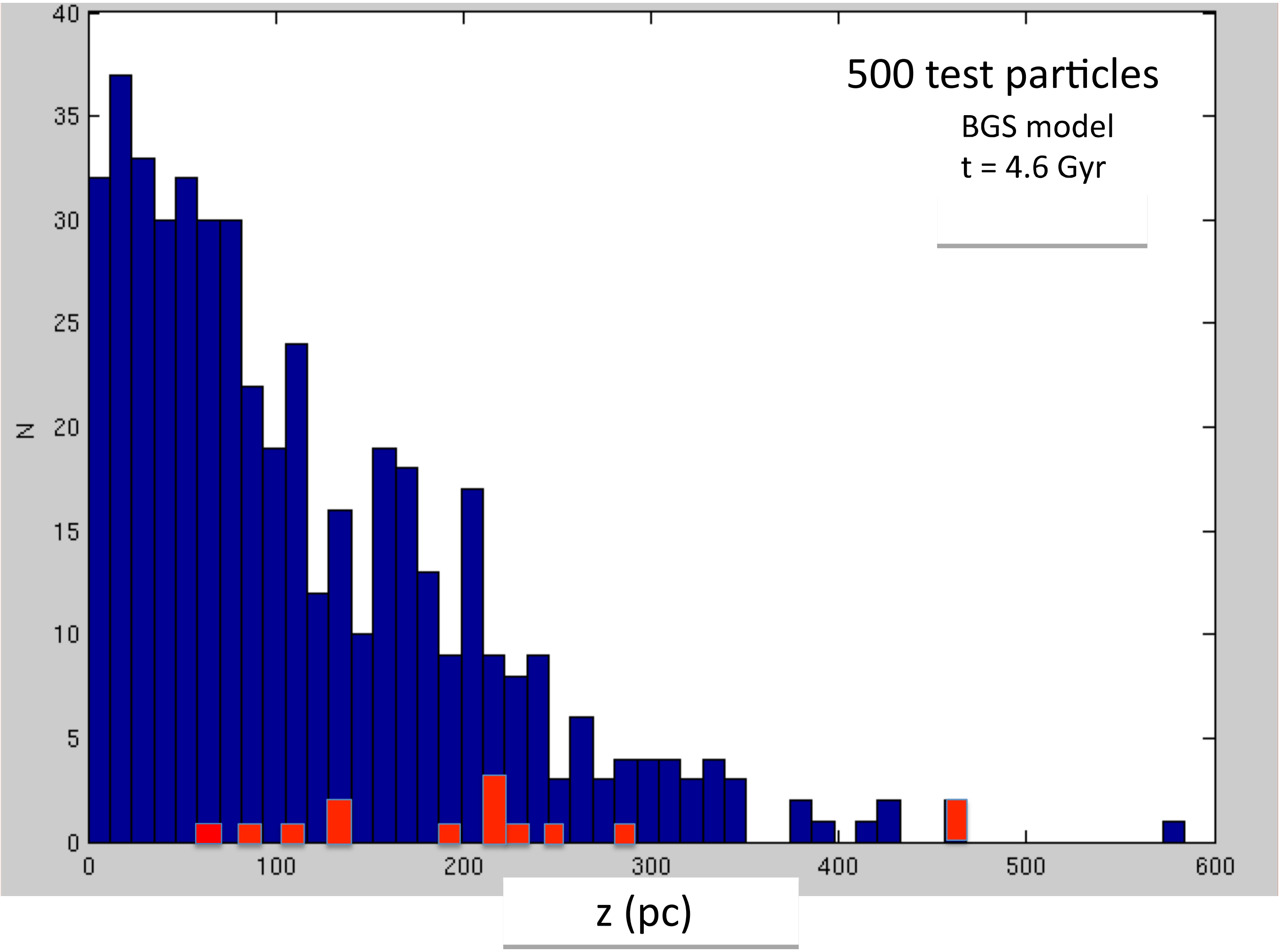
$$b_{crit} = 16\text{pc}\frac{(M/10^6\,\mathrm{M}_\odot)^{1/2}}{(m/10^4\,\mathrm{M}_\odot)} \cdot \frac{(r_s/\,1\,\text{pc})^{3/4}}{(V_0/10\,\text{km/s})^{1/2}}.$$



Detailed N-body simulations with NBODY6 (*Aarseth 2003*).



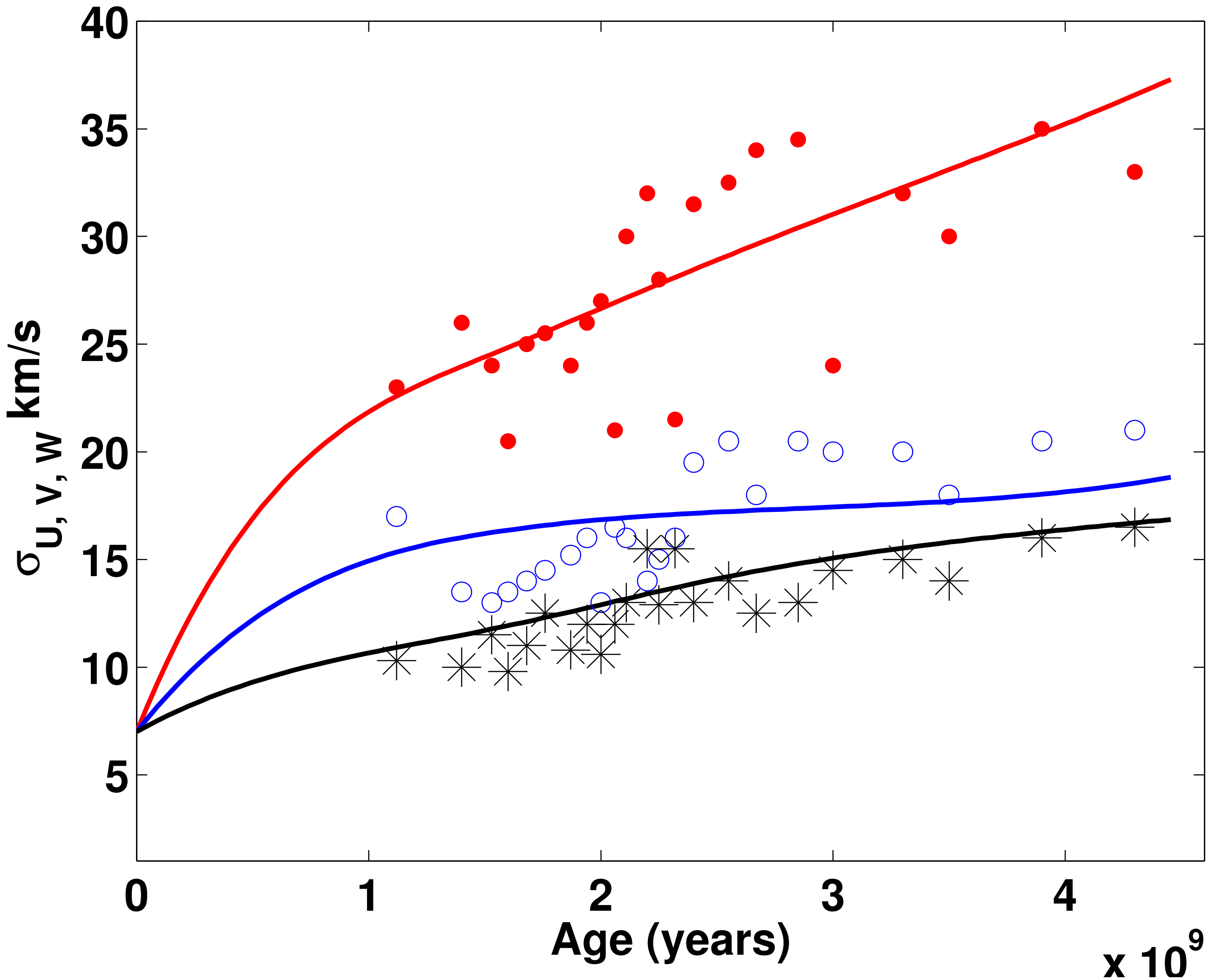
Example run: z distribution after 4.6 Gyr



Red: surviving clusters. *Full consistency between approx. and N-body-simulation of cluster destruction*

Results …

(1) Disc heating explained by GMCs and spiral arms



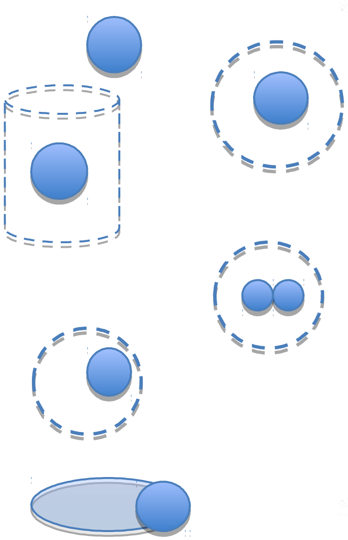
Limiting assumptions

- Stationary model Galaxy (as of today)
- Only last 5 Gyr (as yet)
- Simplified model GMCs

Velocity scatters at R = 8 kpc (km/s)

Frac. of particle with z ≥ 400 pc

GMC repres.



Model	σ_{U8}	σ_{V8}	σ_{W8}	f_{400} [%]
Standard BGS	37.5	18.9	16.9	1.8
"spherical shielding"	28.4	13.4	9.1	< 0.2
"cylindrical shielding"	33.1	14.8	12.9	0.5
"dumbbell30"	30.0	15.6	10.5	< 0.2
"dumbbell100"	30.3	15.5	12.2	< 0.3
"cloud displacement"	40.8	15.7	18.4	2.2
"reservoir clouds"	47.9	20.6	20.0	2.9

What matters? Bar, GMCs or Spiral arms?

Just rot. sym. potential

At solar circle

Mean for all stars

Quantity	BGS	BS		Φ
σ_{U8} [km/s]	37.5	24.8		17.1
σ_{V8} [km/s]	18.9	14.0		7.7
σ_{W8} [km/s]	16.9	8.8		9.1
σ_{U8}/σ_{W8}	2.21	2.82		1.88
σ_{Ua} [km/s]	58.0	47.9		13.5
σ_{Va} [km/s]	38.6	35.2		7.7
σ_{Wa} [km/s]	19.8	10.9		10.1
$< \delta R >$ [pc]	74	-256		85
$\sigma_{\delta \mathbf{R}}$ [pc]	1161	1020		409
$< R_0 >$ [pc]	7440	7700		7830
f_{400} [%]	1.8	0.2		< 0.2
S_{400}	2/6	1/1		-

In our model, GMCs are most important for σ_w , and important for σ_u at R_{sun}, while Spiral arms are more significant for σ_u , in particular inside the Solar Circle.

Results …

(1) Heating of Thin disc explained by GMCs and spiral arms

(2) Existence of OHAOCs consistent with (1)

Fraction of test particles with z > 400 pc at 4.6 Gyr is about 1.8%.

About 1/3 of corresponding rich clusters survive for that time.

With present observed birth-rate of open rich clusters in the Galaxy we expect about 4 OHAOCs of ages > 1 Gyr within a Galactic cylinder with R = 4 kpc. *Agrees with observed value.*

(3) GMC scattering is decisive, but detailed GMC structure and internal dynamics are important.

(4) Effects of ”turbulence” in Early Disc may be vital for heating

See *Gustafsson et al. (2016), arXiv:1605.02965, A&A in press*