Early History of the Solar System

K.Vincke, S. Pfalzner

Max-Planck-Institut für Radioastronomie, Bonn

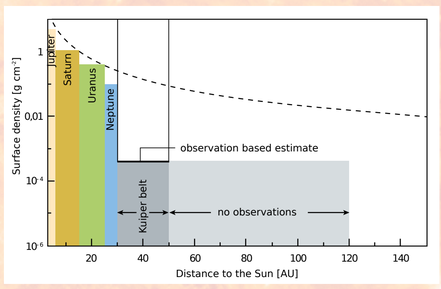
Match young massive cluster types to present day properties of solar system

Solar System Properties

Most stars do **not** form in isolation but in groups[1]. Different indications exist that the Sun was born in a stellar cluster.

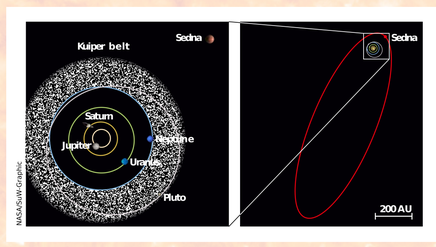
Part of the meteorite Allende, found in Mexico, 8. Feb. 1969.

- Presence of isotopes ^{26}Al and ^{60}Fe[2] $\Rightarrow$ Sun formed near supernova[3]
- Supernova progenitor: $\sim 25\ M_\odot$ [3]



Surface density of our Solar system as a function of distance to Sun.

- Outside Neptune orbit: significant drop of surface density (factor 0.01)
- Stellar encounters[4] one probable culprit



Solar system, Kuiper belt, and orbit of Kuiper belt object Sedna.

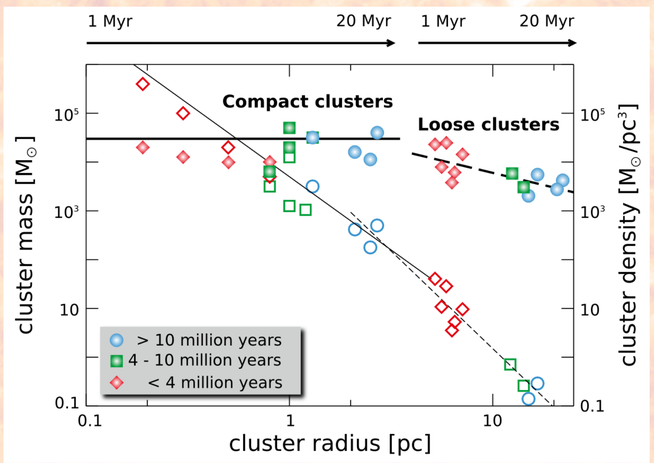
- Kuiper belt object Sedna: very eccentric orbit (e = 0.8527)
- Explanation: encounter[5]

⇒ **Sun: part of stellar cluster with > 1 000 stars**

⇒ **Not too many high mass stars: < 100 000 stars**

⇒ **Average stellar density of cluster: 10 - 10 000 $M_\odot pc^{-3}$**

Cluster Evolution

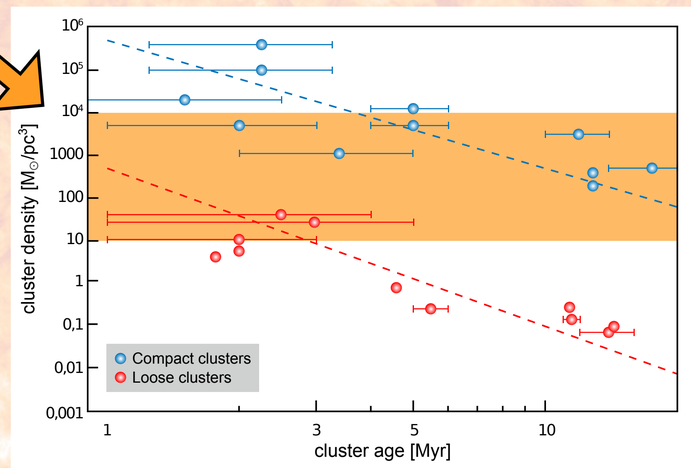


Mass (filled) and density (open) evolution of stellar clusters.

- 2 types of massive clusters: compact clusters & loose clusters
- **For same cluster age: significant difference in stellar density between both types!**

In which environment did the Sun form?

Solar Birth Environment

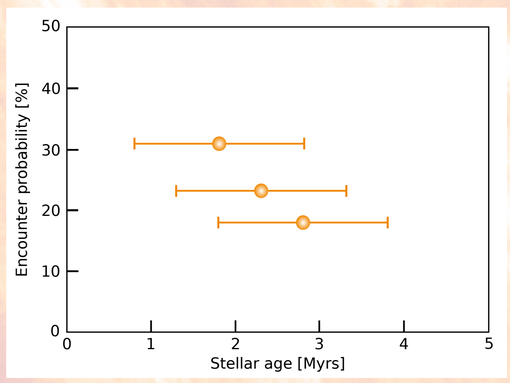


Stellar cluster density as a function of cluster age.

- Both cluster types fulfil conditions at some point of development
- **But:** very violent interactions in compact clusters during first Myrs! $\Rightarrow$ Protoplanetary discs are largely destroyed!

$\Rightarrow$ **Sun formed most probably in loose cluster**

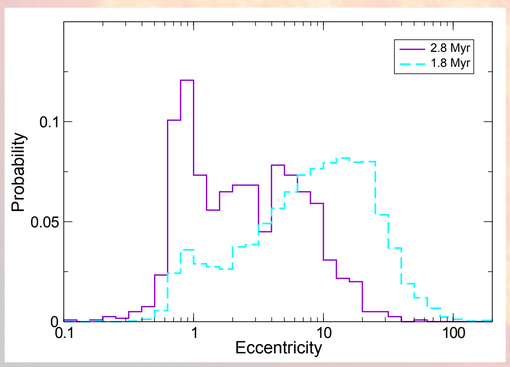
Probability of Solar System Forming Encounter



Encounter probability for Sun as function of Sun age.

Clusters become less dense with age
$\Rightarrow$ (close) encounters less probable with time!

$\Rightarrow$ **Probability for solar system forming encounter decreases with time**
$\Rightarrow$ **Encounter happened in early forming phase**



Encounter probability as function of eccentricity.

Cluster properties (e.g. size, density) change significantly during evolution

Encounter type changes:
> 2 Myrs (dense): **hyperbolic, low mass ratio**
< 3 Myrs (sparse): **parabolic, high mass ratio**

Conclusion

- **2 types of clusters: Compact clusters & loose clusters**
- **Sun formed most probably in loose cluster environment**
- **Close stellar encounter disturbed disc in early formation phase**

References

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[4] S. Pfalzner, P. Vogel, J. Scharwächter, C. Olczak. Parameter study of star-disc encounters. *A&A*, 437:967–976, 2005.

[5] A. Morbidelli, H. F. Levison. Scenarios for the Origin of the Orbits of the Trans-Neptunian Objects 2000 CR105 and 2003 VB12 (Sedna). *Astronomical Journal*, 128:2564–2576, 2004.

For further information, please ask me, visit www.mpifr-bonn.mpg.de/staff/spfalzner or: