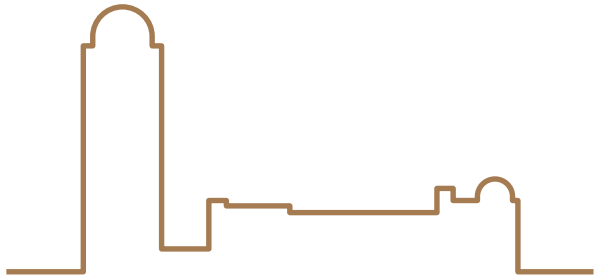


LUNDS
UNIVERSITET

Making exotic objects in stellar clusters

Ross Church
Department of Astronomy and Theoretical Physics, Lund

Melvyn B. Davies, Anders Johansen, Serge Nzoke, Michiel Lambrechts, Alexey Bobrick, Daniel Carrera, Kalle Jansson, David Lundberg, Elvijs Matrozis, Katrin Ros

The solar neighbourhood is a peaceful place

4 light-years to the nearest star

~9000 times the size of the Solar System

The Sun will not have a close encounter in its remaining 4.5 Gyr lifetime.

Photo by Max Westin

Stellar clusters are busy places!

In stellar clusters stars come close to one another

Close encounters manufacture exotic objects.

Photo by Chris Beckett

Three types of stellar cluster...

Young star-forming clusters...

Three types of stellar cluster...

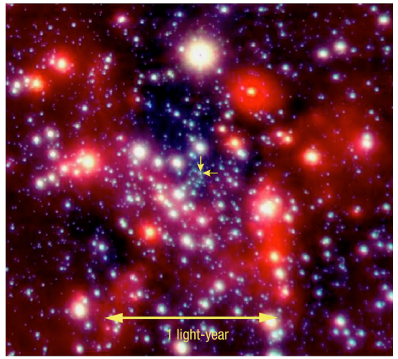
Young star-forming clusters...

Old globular clusters...

Three types of stellar cluster...

Young star-forming clusters...

Old globular clusters...



Galactic centre clusters...

...three types of exotic object

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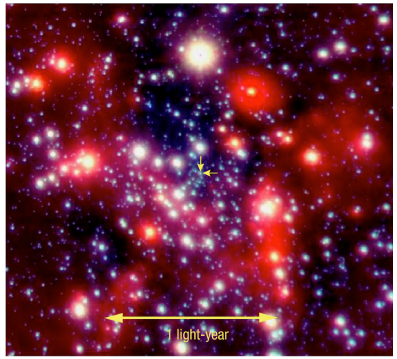

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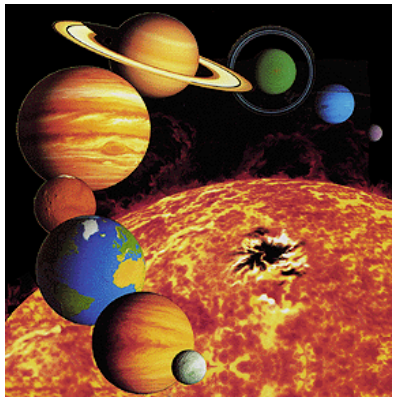
...make planetary systems



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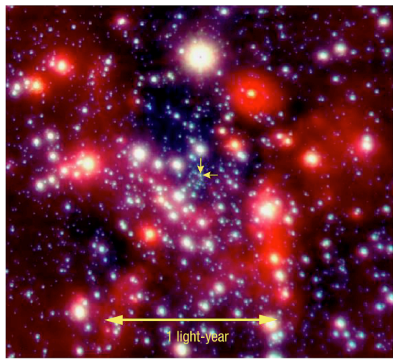

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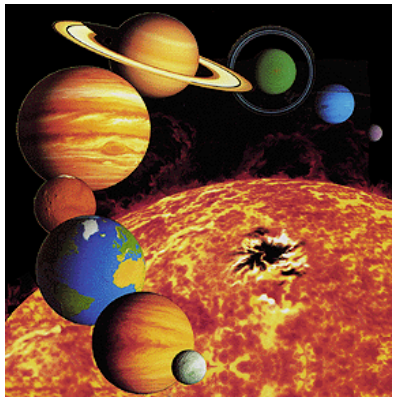
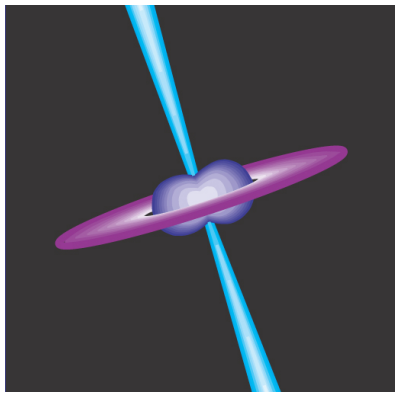
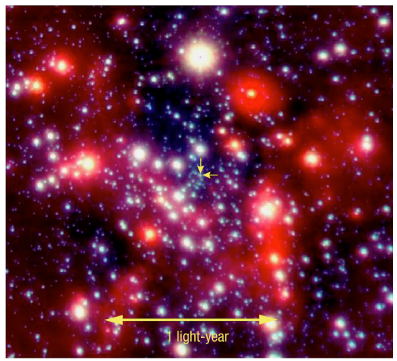


Old globular clusters...

...make gamma-ray bursts





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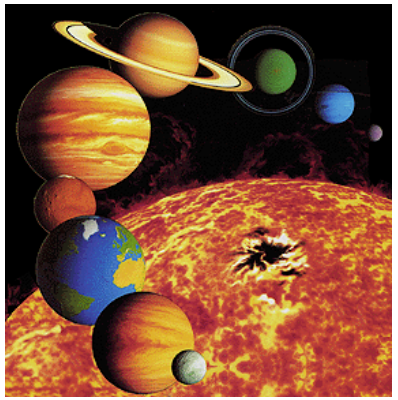

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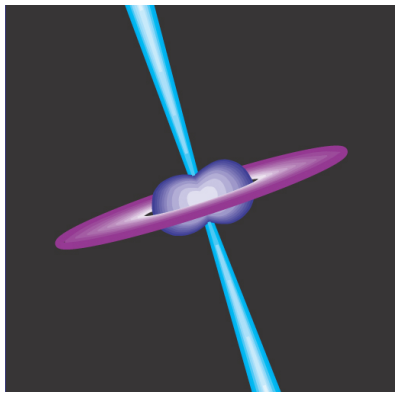
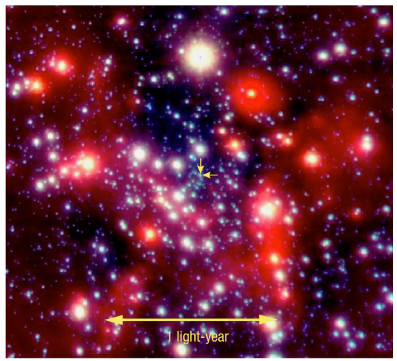
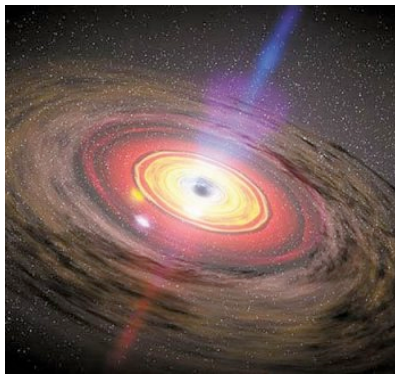




Galactic centre clusters...

...make super-massive black holes



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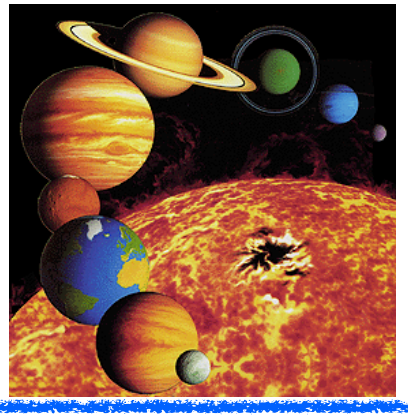

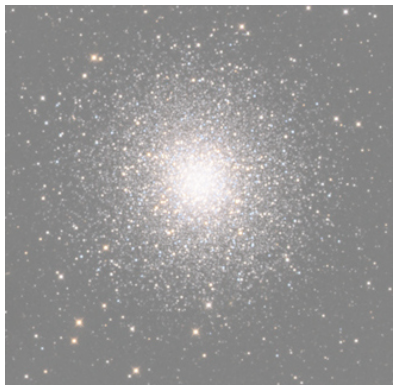

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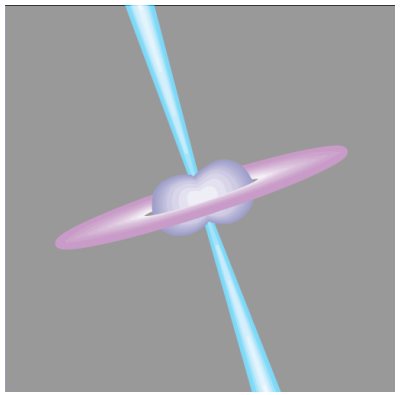

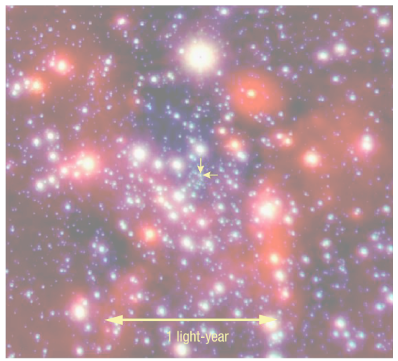

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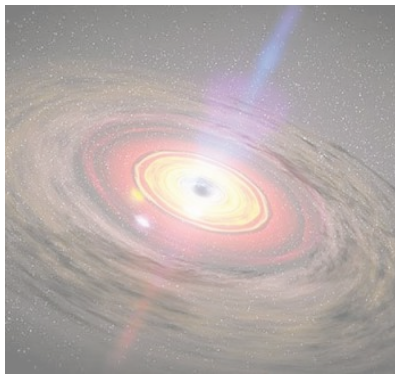
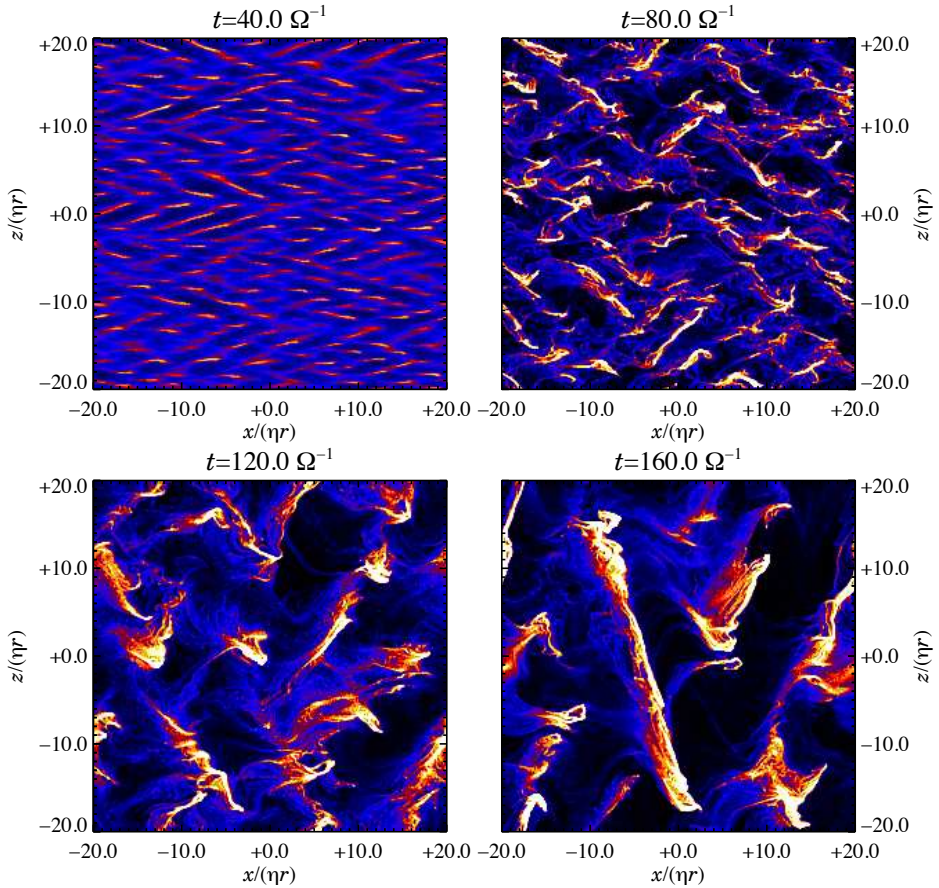


Building planets in a computer



Streaming instability causes particles to clump together

Relies on interactions between gas and dust phases, and magnetic fields.

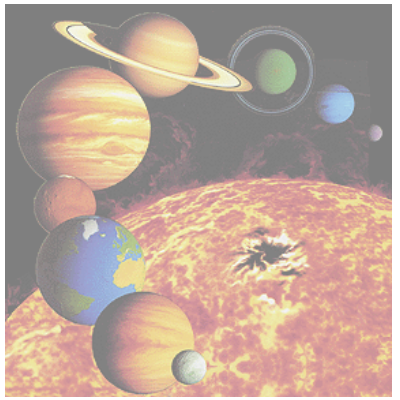
$3^3+4^3+5^3$
PLATON

Interactions in young stellar clusters change planetary systems that form into those we observe

Three types of exotic object

Young star-forming clusters...

...make planetary systems



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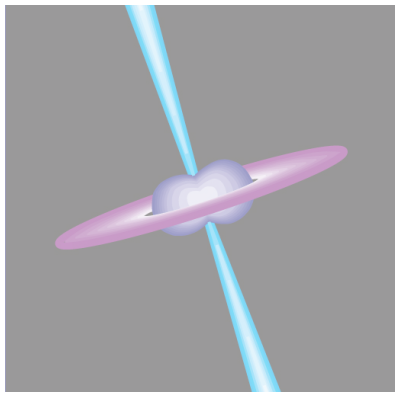

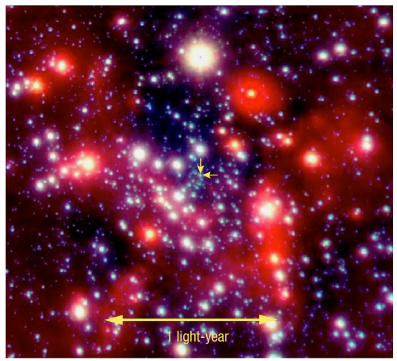

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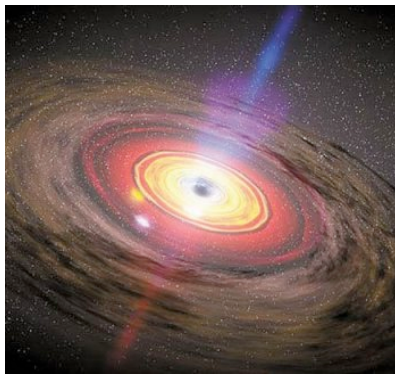
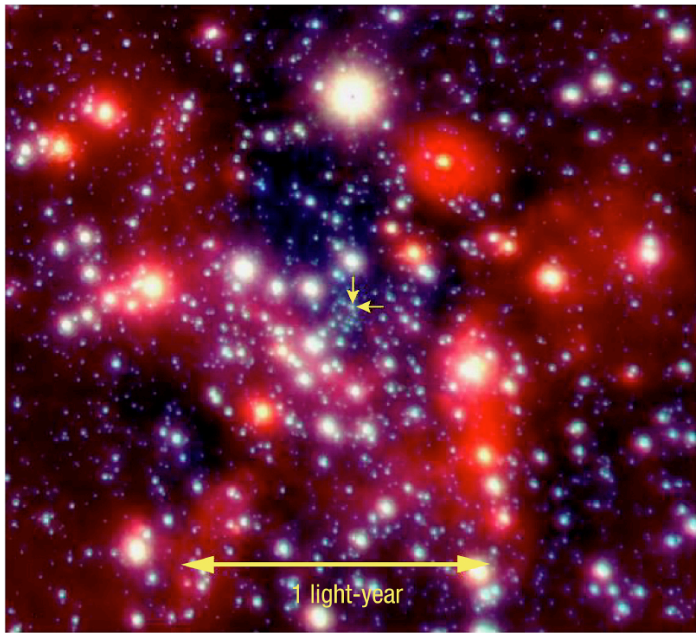
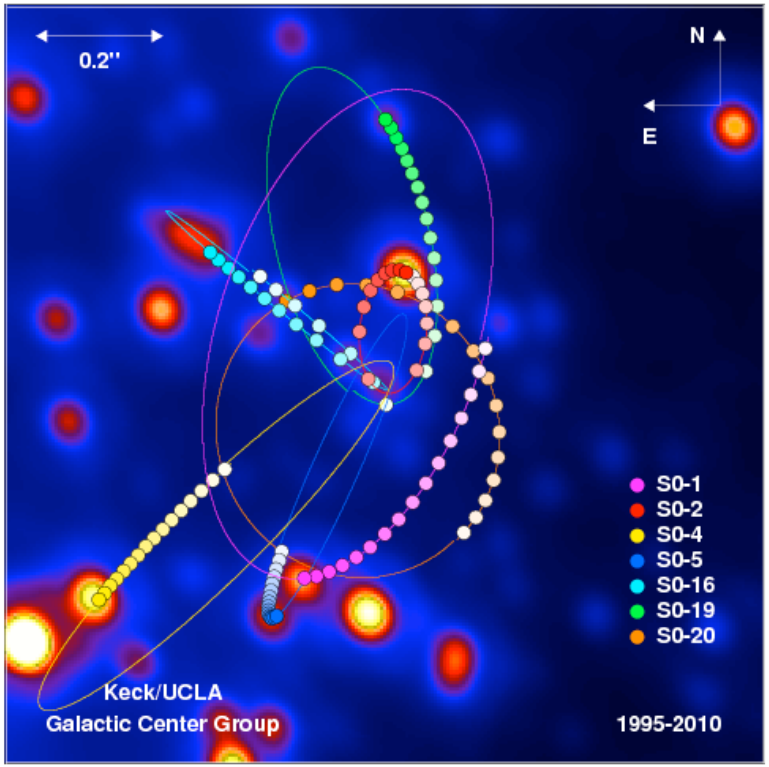


Galactic centre clusters



The most massive star cluster in our Galaxy is at its centre

The orbits of the central stars imply the presence of a 10^6 solar mass black hole

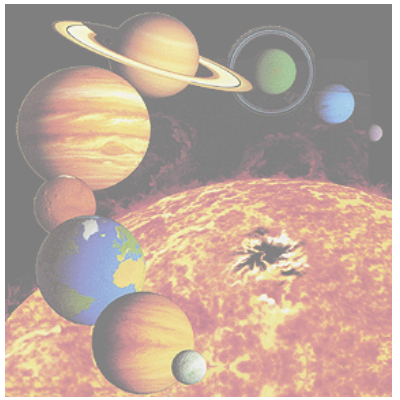


In the early Universe, the flow of a very large quantity of gas into a galactic centre stellar cluster could produce a super-massive black hole (Davies et al. 2011)

...three types of exotic object

Young star-forming clusters...

...make planetary systems



Old globular clusters...

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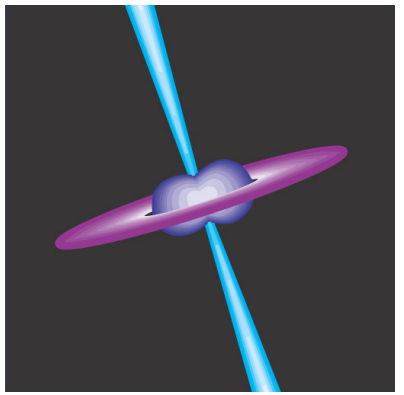

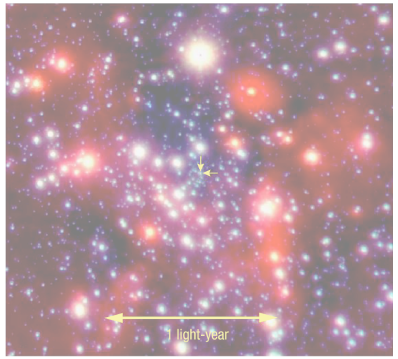

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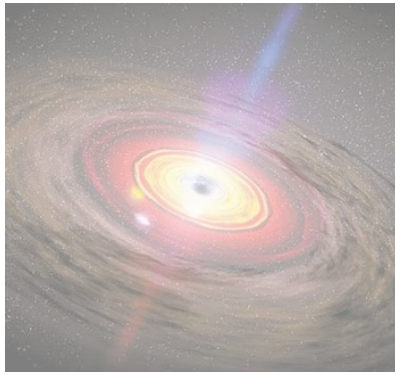
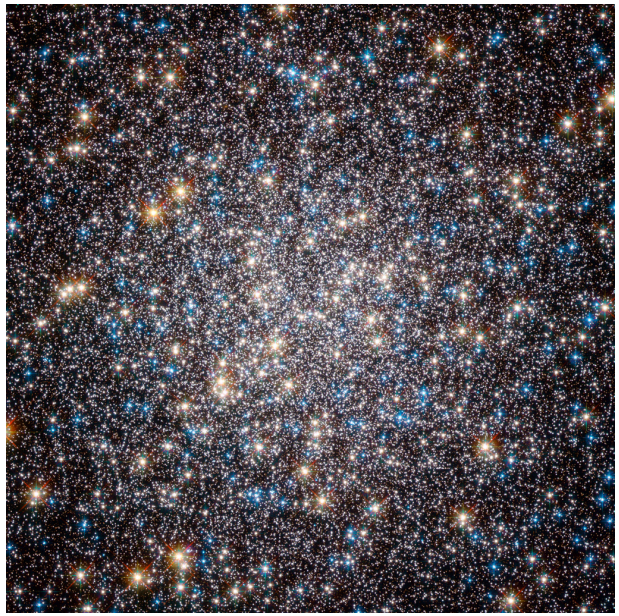


Globular clusters

Whole cluster

Central regions



Central number density can reach 10^6 stars / cubic parsec
Total of 10^6 stars, a few parsec in diameter

(1 parsec = 3.25 light years = 3×10^{13} km)

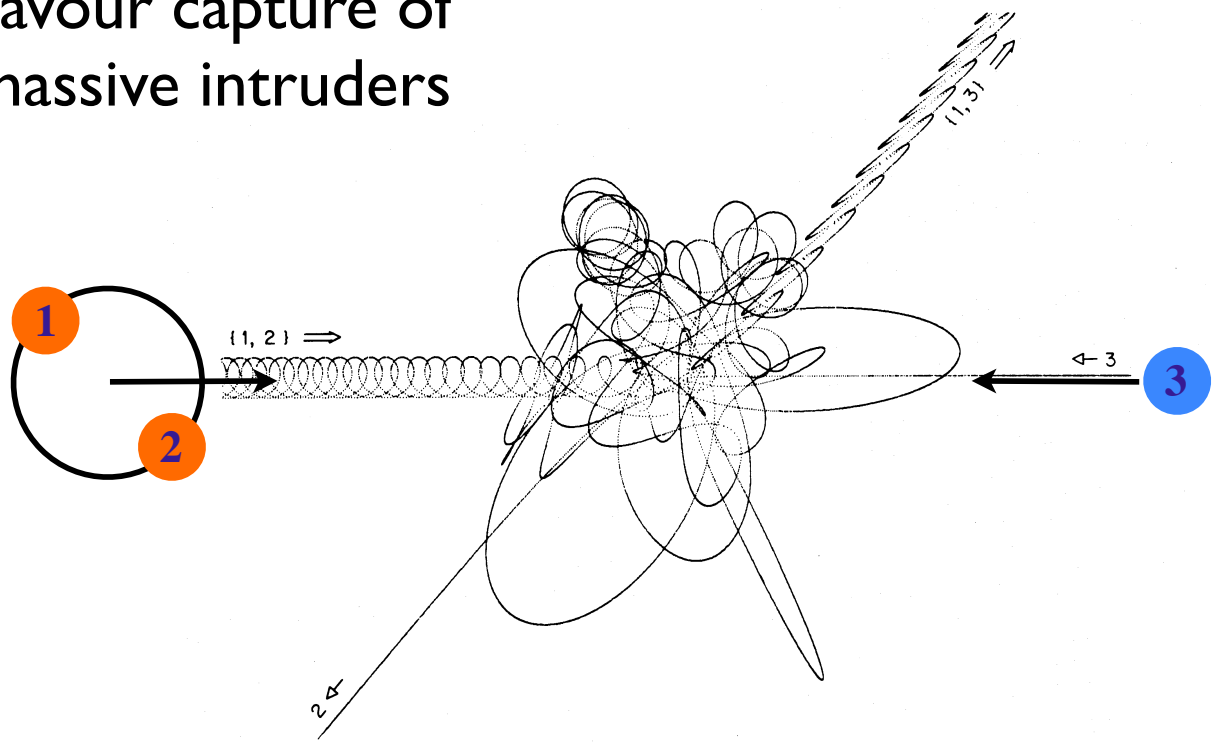
Switching partners

Binary-single encounters favour capture of massive intruders

Figure from Hut & Bahcall (1983)

Switching partners

Binary-single encounters favour capture of massive intruders



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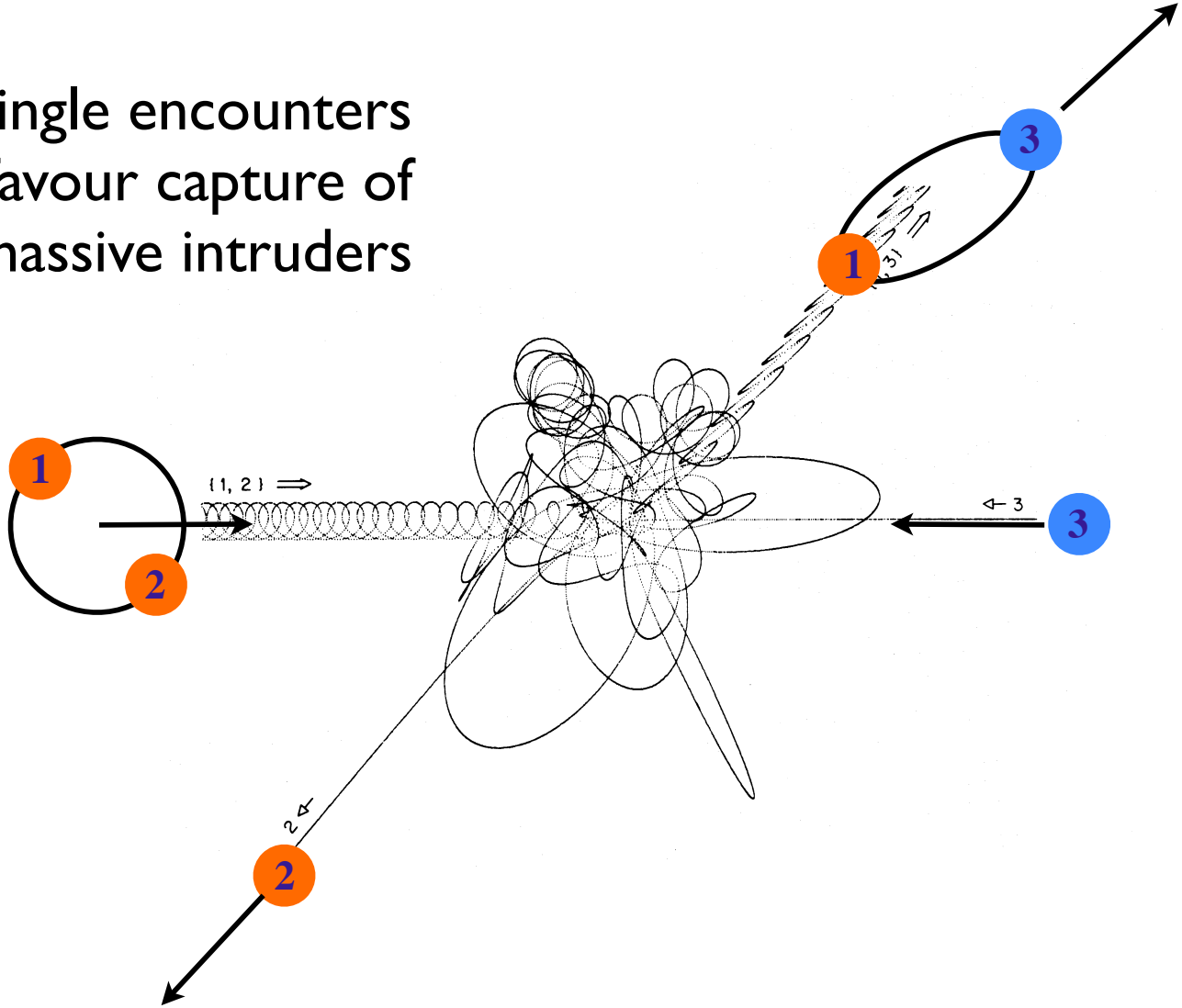
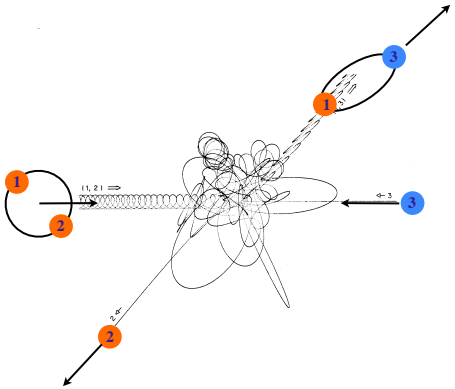


Figure from Hut & Bahcall (1983)

Going out with a bang

Neutron stars (1.4 Solar mass spheres of nuclear density material) sink to the centre of stellar clusters and exchange into binaries.



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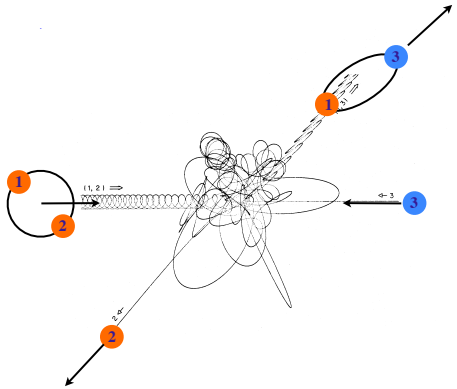

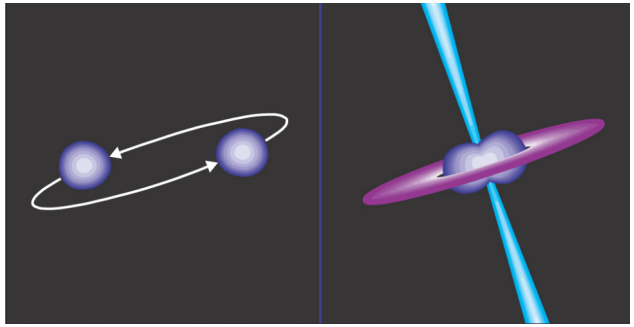

These double neutron star binaries emit gravitational waves and spiral together to merge in highly-energetic gamma-ray bursts.

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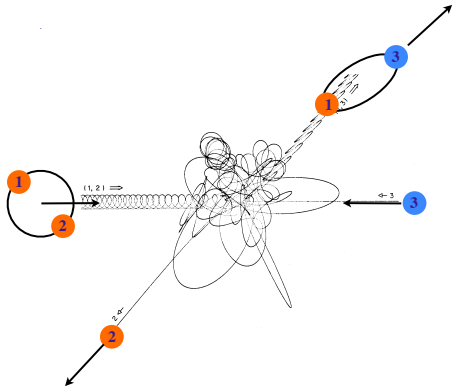

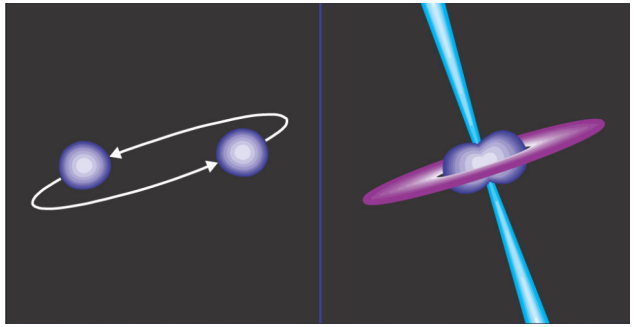

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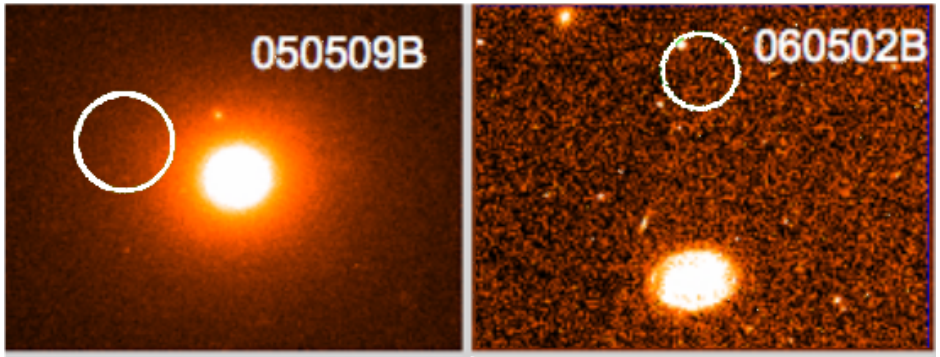
We have observed these bursts well outside their host galaxies, matching a cluster origin.



Globular clusters in the computer

A (deceptively simple) set of differential equations

$$\ddot{\vec{\mathbf{r}}}_i = \sum_j -\frac{Gm_j\vec{\mathbf{r}}_{ij}}{r_{ij}^3}$$

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Timescales range from hours to Gyr.

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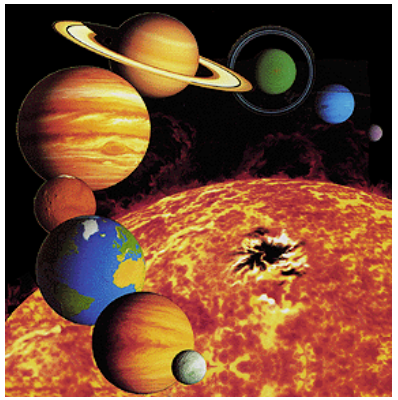
A range of numerical techniques (individual timesteps, regularisation, neighbour schemes).

Special purpose hardware (GRAPE, GPU).

Summary

Young star-forming clusters...

...make planetary systems



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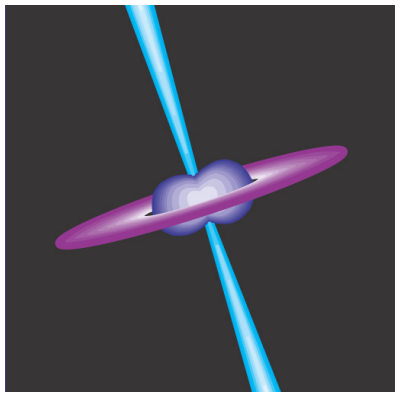

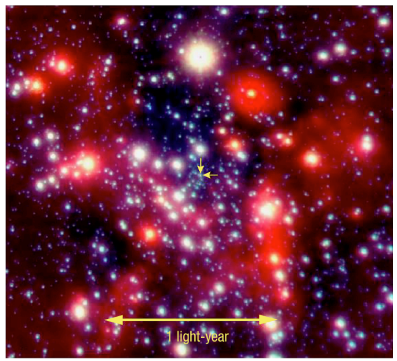

Galactic centre clusters...

...make super-massive black holes