Binary star formation

So far we have ignored binary stars. **But**, most stars are part of binary systems:

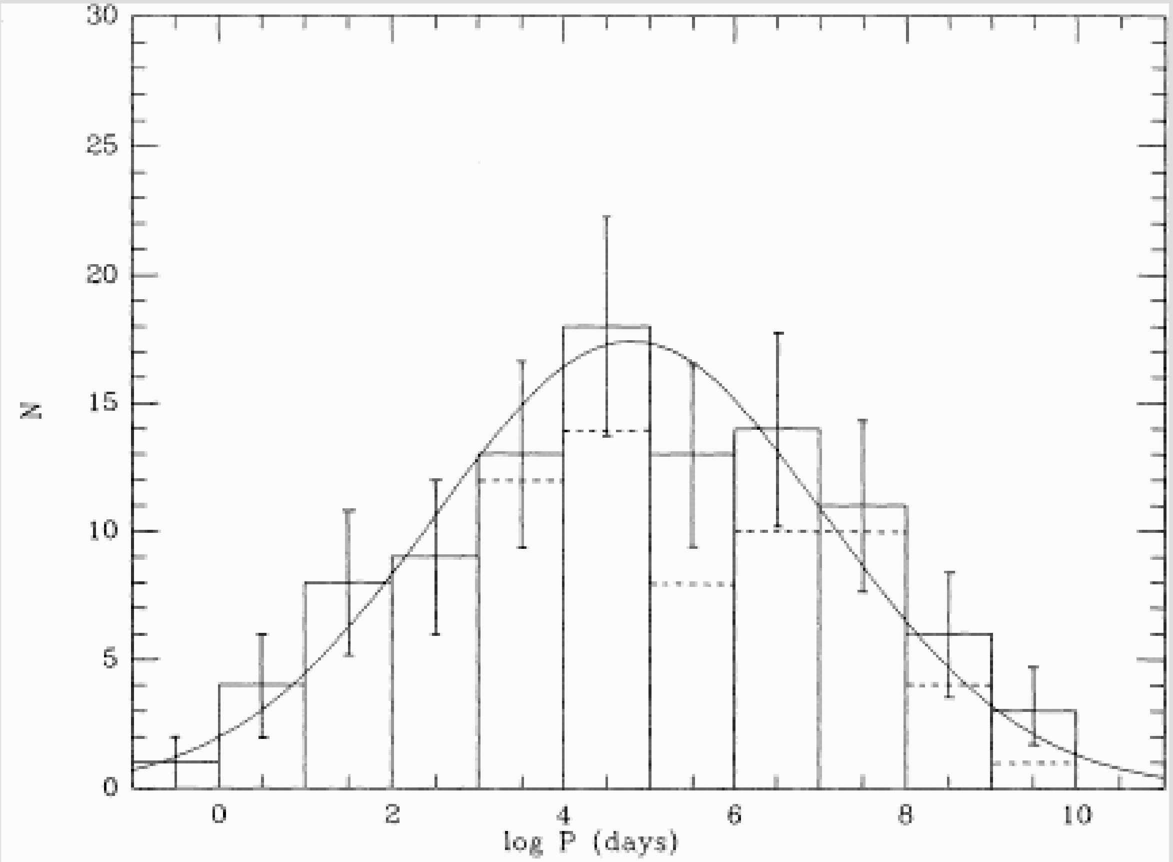


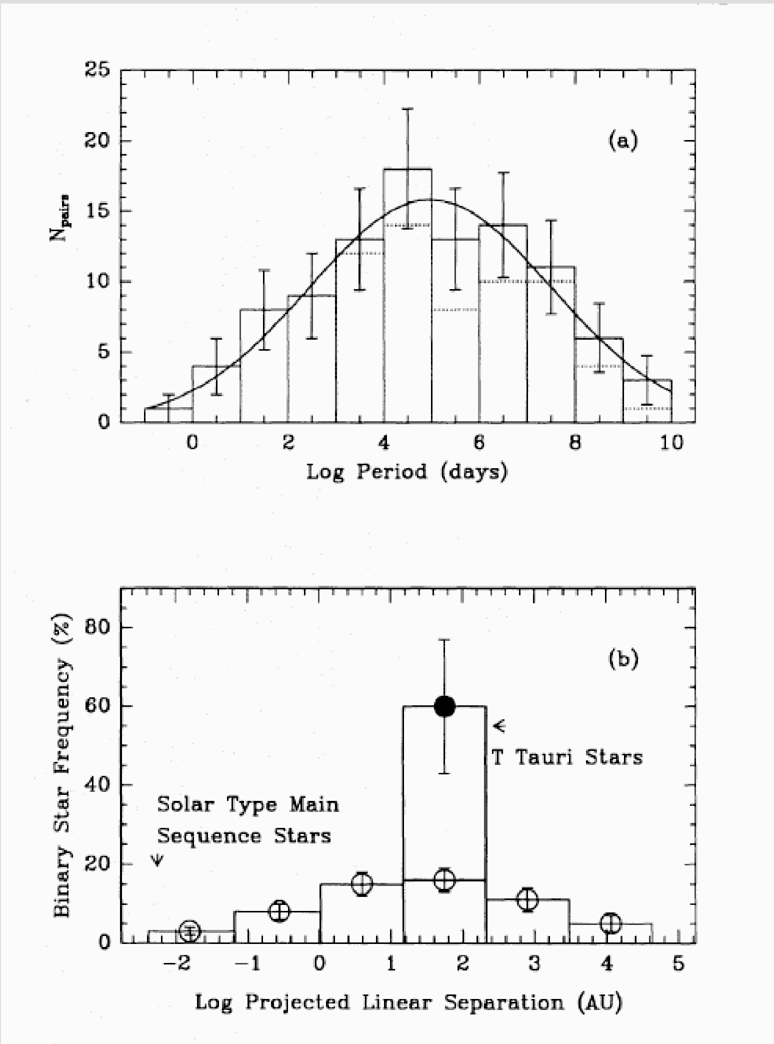
Fig. 7. Period distribution in the complete nearby G-dwarf sample, without (dashed line) and with (continuous line) correction for detection biases. A Gaussian-like curve is represented whose parameters are given in the text

Solar mass stars: about 2 / 3 are part of binaries

Separations from:

- < 0.1 au
- $> 10^3$ au

Wide range of separations makes it hard to detect and measure all binaries - especially if the mass ratio is not close to unity and the system is far away.



Most estimates of the binary frequency in star forming regions suggest the number is *at least* as large as the main sequence - binaries are formed early.

Angular momentum problem of star formation

Consider a uniform spherical cloud:

- radius R = 0.1 pc
- mass $M = M_{sun}$
- uniform rotation, with angular velocity $\Omega = 10^{-14}\ s^{-1}$

Ratio of rotational energy to gravitational energy is **small**:

$$\beta = 0.004$$

Angular momentum of cloud: $L = I\Omega \approx 7 \times 10^{53}\ \mathrm{g\ cm^2\ s^{-1}}$

Angular momentum of Sun: $L_{sun} \approx 2 \times 10^{48}\ \mathrm{g\ cm^2\ s^{-1}}$

Enormous amount of `excess' angular momentum. Very reasonable to expect that binary formation could be one way to get around this problem of too much angular momentum…

Mechanisms for binary star formation

Although very common, not obvious how to form binary stars:

- Never observed the process happening
- Wide range of scales involved in different binaries

Possible mechanisms that have been suggested:

- **Fission** - one star splits into two
- **Capture** - one star captures another initially unbound star into a bound orbit
- **Cloud fragmentation** - collapsing cloud breaks up into several pieces during collapse, each of which forms a separate star
- **Disk fragmentation** - form one star + disk, which subsequently breaks up

Fission

Idea: protostars are initially rather large - contract as they evolve toward the main sequence. Consider how the gravitational and rotational energy evolve during the contraction.

Star radius R, mass M, angular velocity ω:

Angular momentum $L = I\omega$ is conserved, where I is the moment of inertia of the star.

$$I = kMR^2$$

…with k a constant. If L is conserved, $\omega \propto M^{-1}R^{-2}$

Energies: $E_{grav} = \frac{GM^2}{R}$

$$E_{rot} = \frac{1}{2}I\omega^2$$

Ratio of rotational to gravitational energy is:

$$\square = \frac{\frac{1}{2} I \square^2}{\frac{GM^2}{R}} \quad \frac{MR^2 \square^2}{M^2 / R} \quad \frac{R^3 \square^2}{M}$$

Substitute for the angular velocity:

$$\square \quad \frac{1}{M^3 R} \quad \frac{1}{R}$$ …if no mass is lost

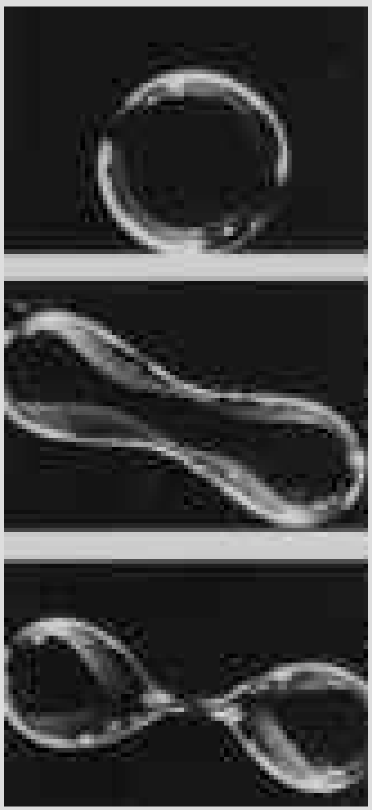
Rotational energy becomes increasingly important as the star contracts toward the main sequence - spin up toward the break up velocity.

Equilibrium shapes of rotating bodies of *incompressible* fluids are well known (but very complicated to work out!):

Sphere ⇨ **Oblate spheroid** ⇨ **Ellipsoid**

⟶

increasing values of □

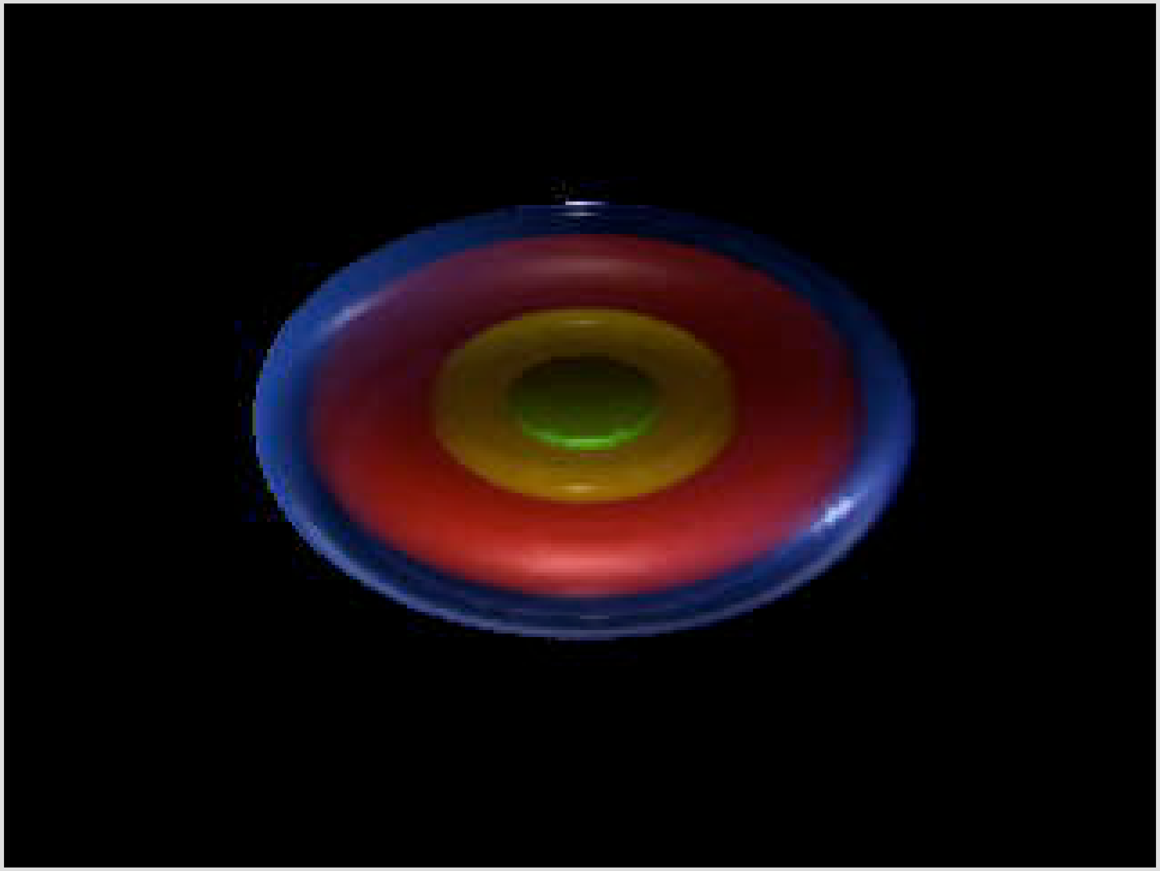


Water *is* an incompressible fluid

Droplets spun up in zero gravity behave the way predicted by classical theory, and eventually fission into two.

Is this a way to form binary stars?

Difference: stars are compressible - much denser near the center than at the outside. Try spinning a star up…



Conclude: stars don't fission - lose angular momentum in spiral arms instead…

Capture

Consider two stars isolated from all other stars. If we can ignore the internal structure of the stars then:

- Total energy = Potential energy + Kinetic energy is conserved
- If $E_{total} < 0$: stars are **bound** (don't need to form a binary - we have one already!)
- If $E_{total} > 0$: stars are **unbound** and will remain so

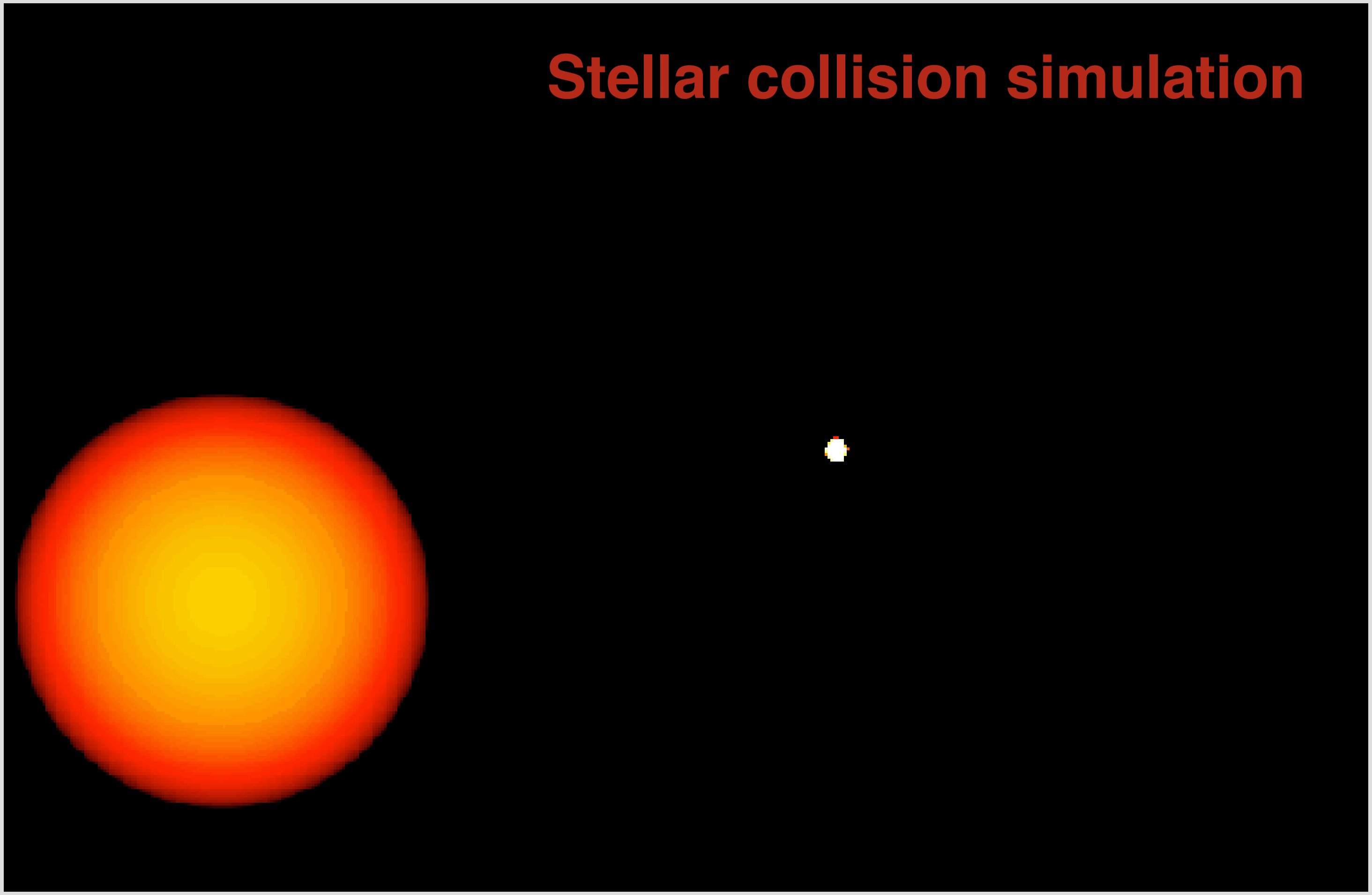
For one star to capture another and form a binary, need to somehow lose energy from the system.

- into internal energy / fluid motion of the stars

- give energy to a third star

A very close approach can lead to:

- tidal distortion of the stars
- energy loss into internal energy within the stars
- formation of a bound system - **tidal capture**



As noted before: requires extremely high stellar densities for collisions and near misses to happen.

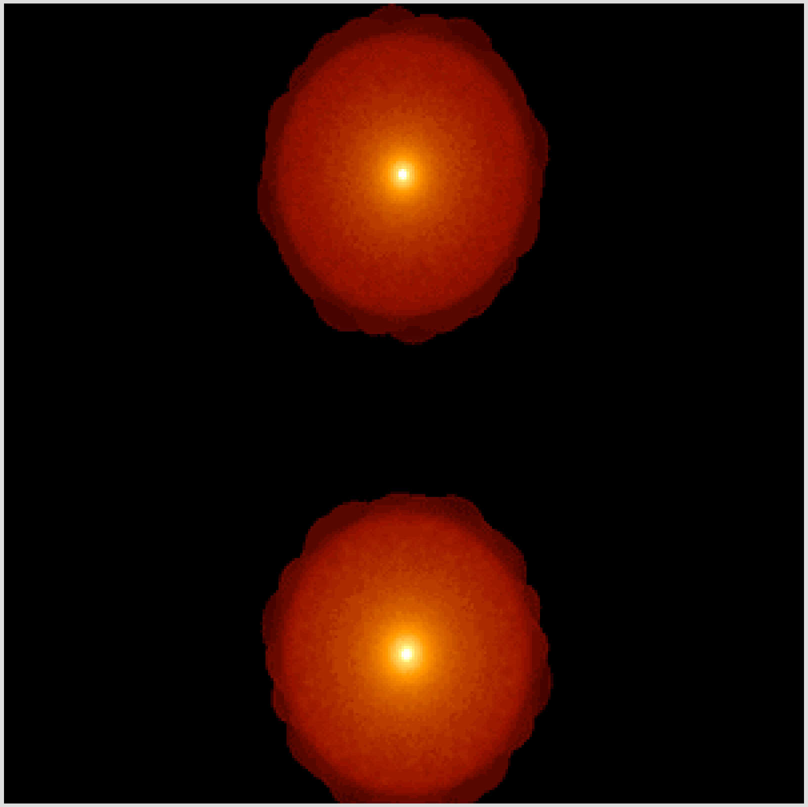
Also requires careful choice of parameters:

- Too close an approach: **merger**
- Too distant: **insufficient energy dissipation to form binary**

Possible as a formation route for rare objects in the cores of globular clusters, but not as a general binary formation process.

What about three star interactions, or binary + single star encounters?

Another idea is to make the stars larger targets - form binaries via capture early on when the stars still have massive disks around them:



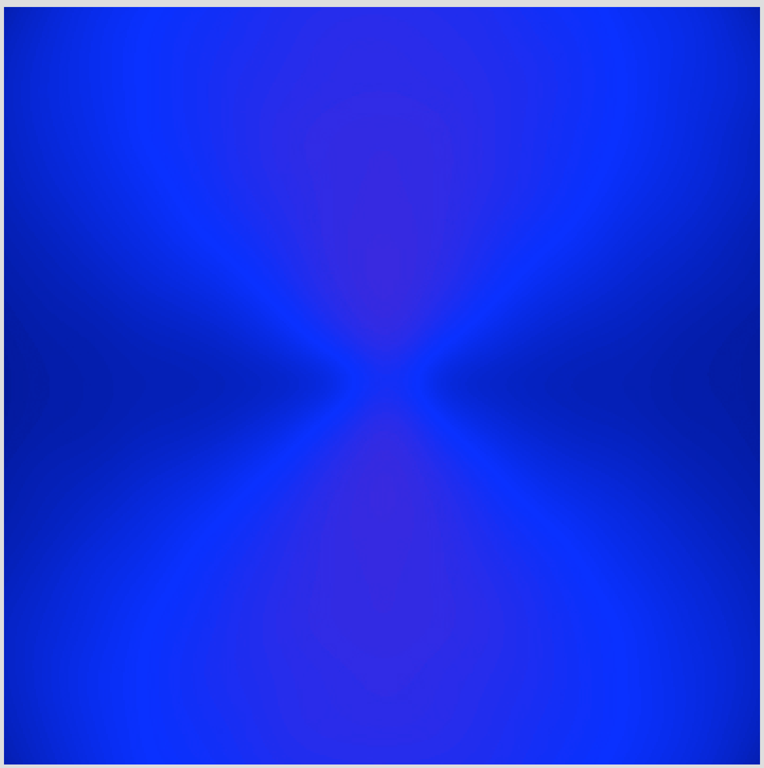
Still requires high densities of stars but may be feasible in young, small clusters.

Fragmentation

Recall scaling of the Jeans mass: $M_J \propto T^{3/2}\rho^{-1/2}$

Initial isothermal phase of collapse (T = constant) is most favorable for fragmentation.

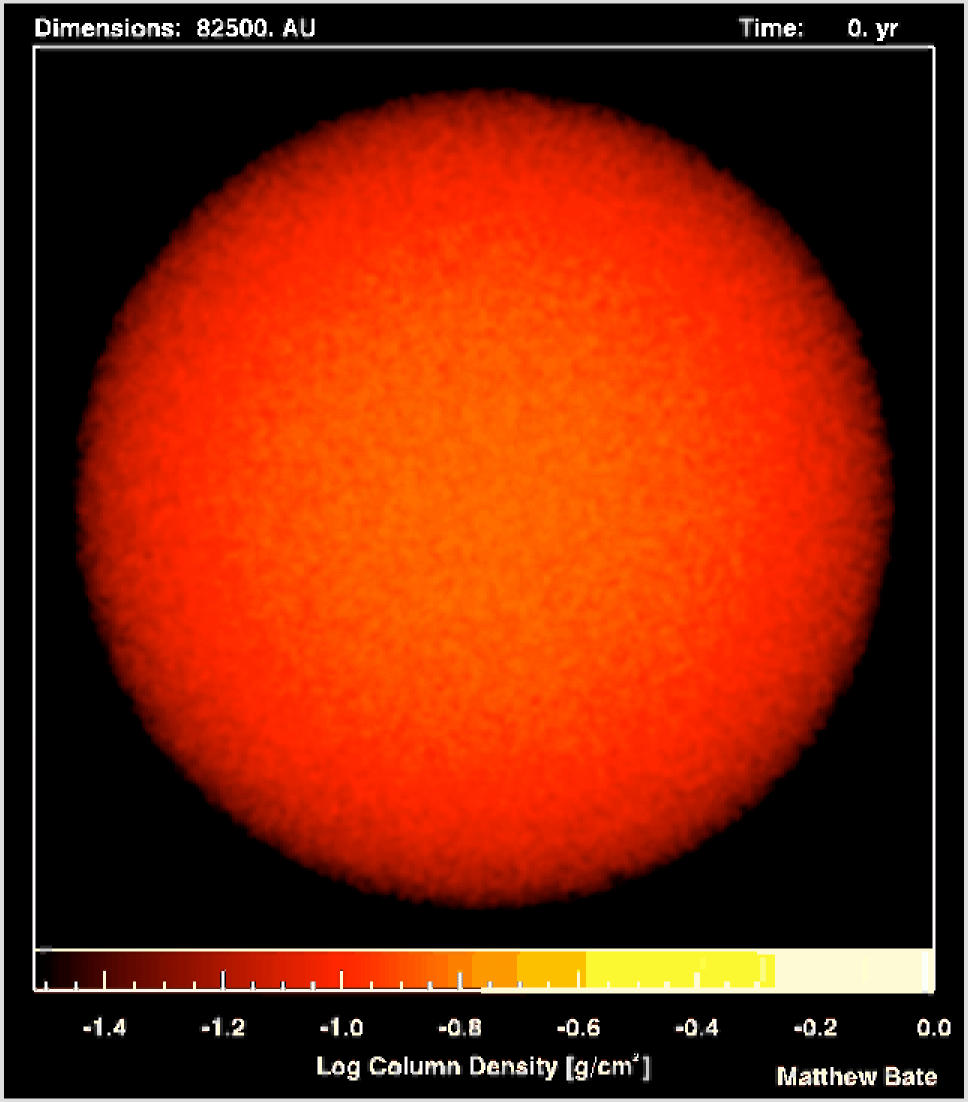
But, unless fragments form quickly collapse will cause them to merge again later…



Need to *start* from initial conditions (pre-collapse) that are:

- not too strongly centrally concentrated
- have significant departures from spherical symmetry

Most favorable case is one in which there are large density variations in the molecular cloud to start with - sometimes called *prompt fragmentation*.



Forms binaries rather efficiently…