Collapse of Molecular Cloud Fragments to Form Stars and Planets

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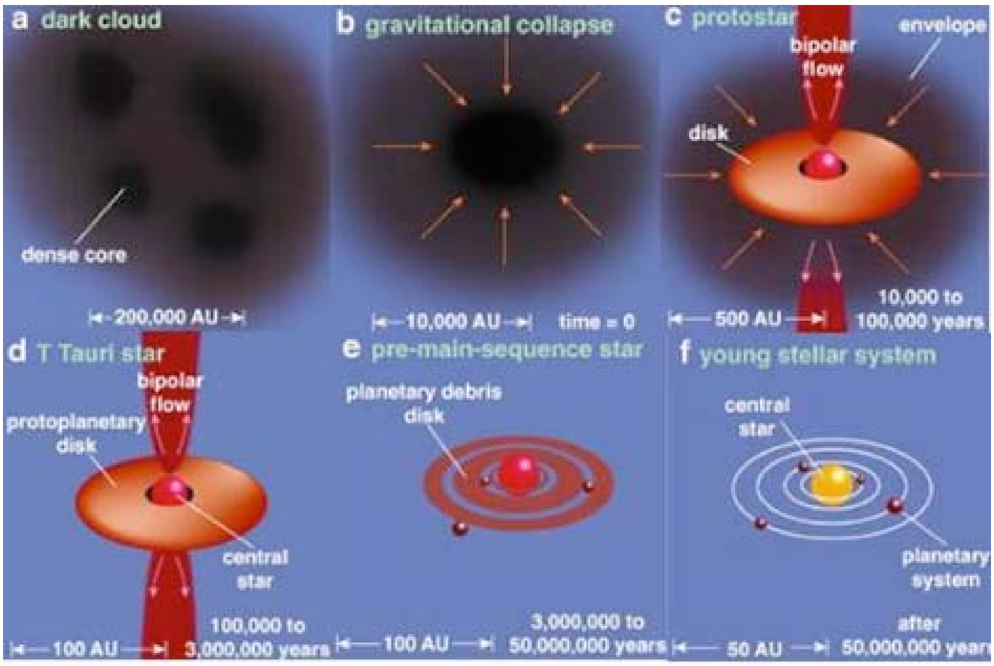
Milky Way molecular cloud RCW 49
Spitzer Space Telescope ssc2004-08a

Galaxies contain myriads of stars and vast molecular clouds. They are dynamic places – dying stars return dust and gas to the clouds and new stars are born within the clouds. Various factors, including supernova explosions and radiation pressure of O-B Association stars affect the composition, compression and turbulence of molecular clouds and trigger portions to collapse. This essay summarises, in a general way, some details of the gravitational collapse of molecular cloud fragments to form stars and planets.

An early stage of the gravitational collapse process is the generation of a spinning disk enclosing a central core object. The flattening of cloud matter into a spinning disk is a direct result of the angular momentum of the particles drawn into the collapse.

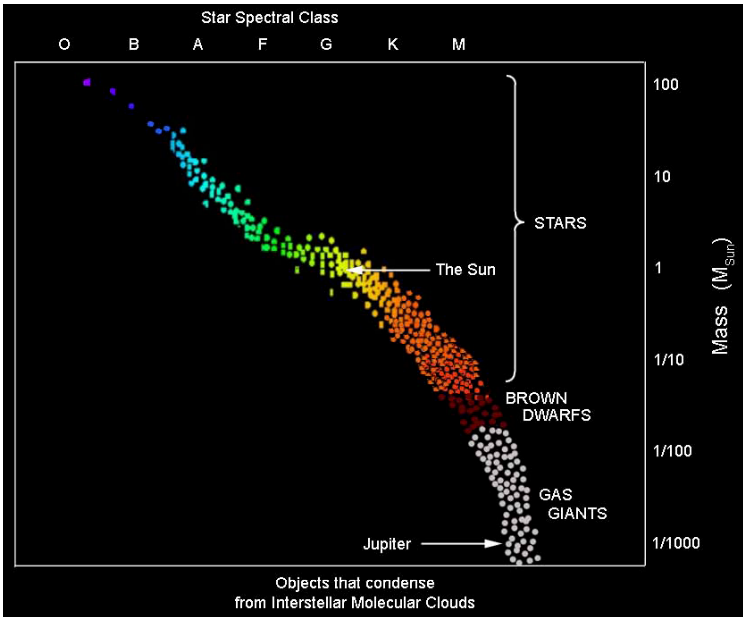


Stages in the formation of a star with a planetary system
Source: http://ssc.spitzer.caltech.edu/documents/compendium/galsci/

As they are drawn in, the collapsing cloud particles interact and shed angular momentum. A massive amount of energy is generated. This is shed by heating and radiation emission. Young stellar objects are much more luminous than the stars and planetary systems they become. Because they form deep in clouds, observation must be by telescopes sensitive to radiation that reaches us: radio waves, infrared, ultraviolet and X-rays. Strong bipolar outflows are observed in newly forming young stellar objects, but our knowledge of such phenomena is in its infancy and current theories do not adequately explain the nature of the processes that generate the bipolar jets.

The amount of material available in a collapsing cloud fragment determines the nature of the object that results. End products include bodies with a wide range of masses:

- O, B, A, F, G , K, M stars
- Brown dwarfs
- Gas giants
- Icy bodies



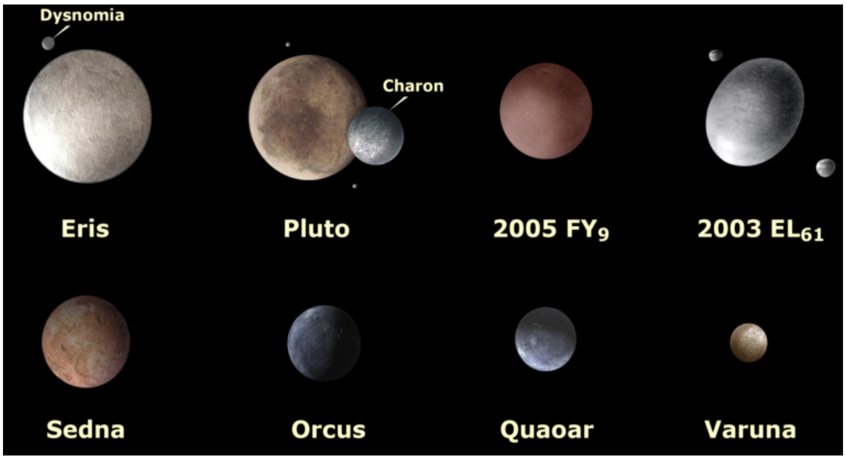
Rather than isolated bodies, however, collapsing cloud fragments more commonly produce gravitationally bound systems:

- Binary stars
- Binary brown dwarfs
- Multiple star systems
- Stars with planetary systems
- Brown dwarfs with planetary systems
- Giant planets with moon systems

Masses of Objects Produced by Gravitational Collapse of Molecular Cloud Fragments. Sun = 1

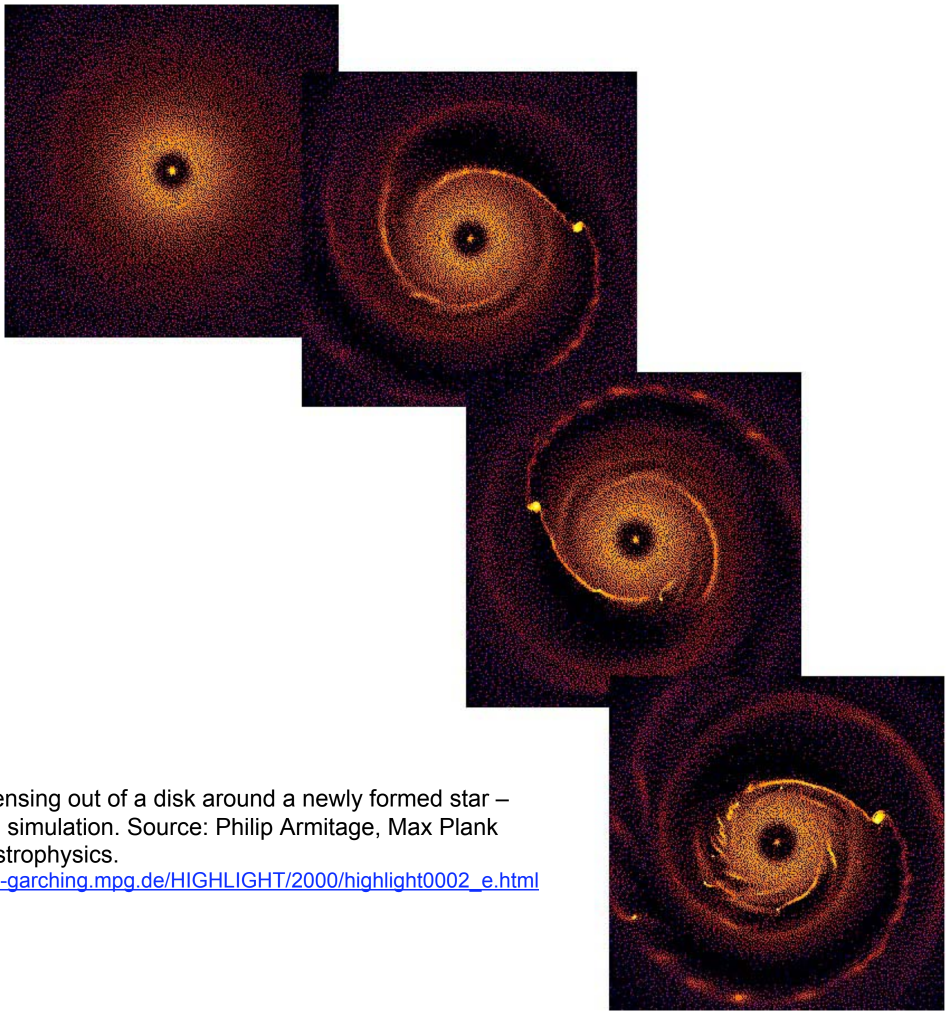
100	Largest stars
10	Large stars
1	Sun
0.1	Small stars
0.08	Smallest stars
0.013	Smallest brown dwarfs
0.010	Large planet
0.001	Jupiter
0.0003	Saturn
0.00005	Neptune
0.000003	Earth
0.00000007	Pluto

There is currently much interest in the formation processes of icy bodies such as Kuiper Belt and Oort Cloud objects. Evidence is accumulating that they form before stars and planet systems, by a different process. When a stellar system formation process begins, pre-formed icy bodies may be available to supply material to objects forming in the disk. The New Horizons Mission to Pluto and the Kuiper Belt will gather data that allows us to test theories of where, when and how such icy bodies form.



Since 1992, Pluto has been joined by many newly discovered outer solar system icy bodies
Source: http://en.wikipedia.org/wiki/Eris_(dwarf_planet)

Planets form in the spinning disks enclosing the protocore of the central object of a new-formed system. Portions of the main disk form smaller disks around the protocores of larger planets. Moon systems form from planet encompassing disks. Extended space missions to the planets have and are gathering essential data for teasing out the detail of such processes. And now, we no longer have only our own Solar System to examine. Since 1995, several hundred exoplanets have been found in orbits round other stars. The first light from several of those planets has been gathered. Programs to closely observe newly forming stars and young stars with evolving planetary disks are now being put in place.



Planets condensing out of a disk around a newly formed star – frames from a simulation. Source: Philip Armitage, Max Plank Institute for Astrophysics.
http://www.mpa-garching.mpg.de/HIGHLIGHT/2000/highlight0002_e.html

There are many unanswered questions regarding the collapse of molecular clouds. How do the formation processes of giant stars, sun-sized dwarf stars and substellar objects differ? Do jupiter-sized bodies formed in protoplanetary disks differ from jupiter-sized bodies formed directly from molecular cloud fragments? How do jupiter-sized bodies form in close proximity to stars? Do rocky bodies only form in protoplanetary disks by collision and accretion of protoplanets? Is there an upper limit to the size of a rocky body?

Our knowledge of how molecular cloud fragments collapse to form stars, planets etc is in its infancy. The latest generation of telescopes is gathering hard data on star and planet formation processes. Mathematicians are scrambling to develop techniques to adequately model observed processes. New space and ground-based telescopes are being planned to provide the resolving power that will enable us to examine processes in more detail. We are slowing creating the tools to obtain detailed answers to such questions as: How did Earth and the Solar System form? Are there places like ours elsewhere?