An introduction to
Star Formation

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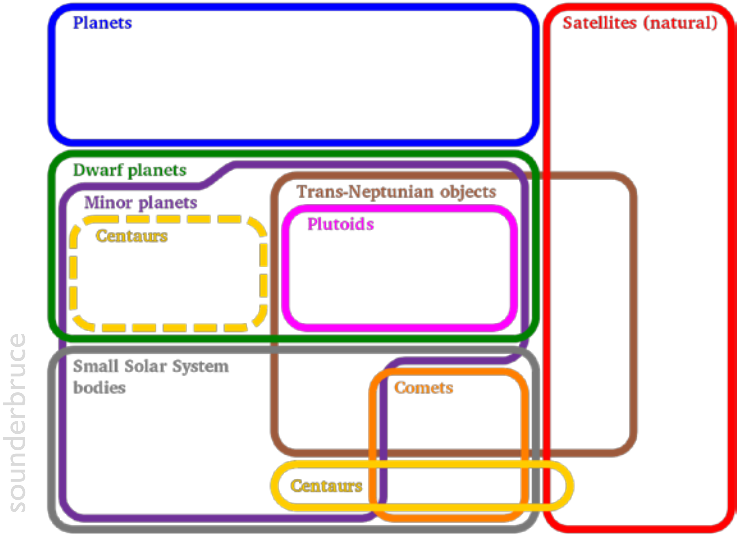
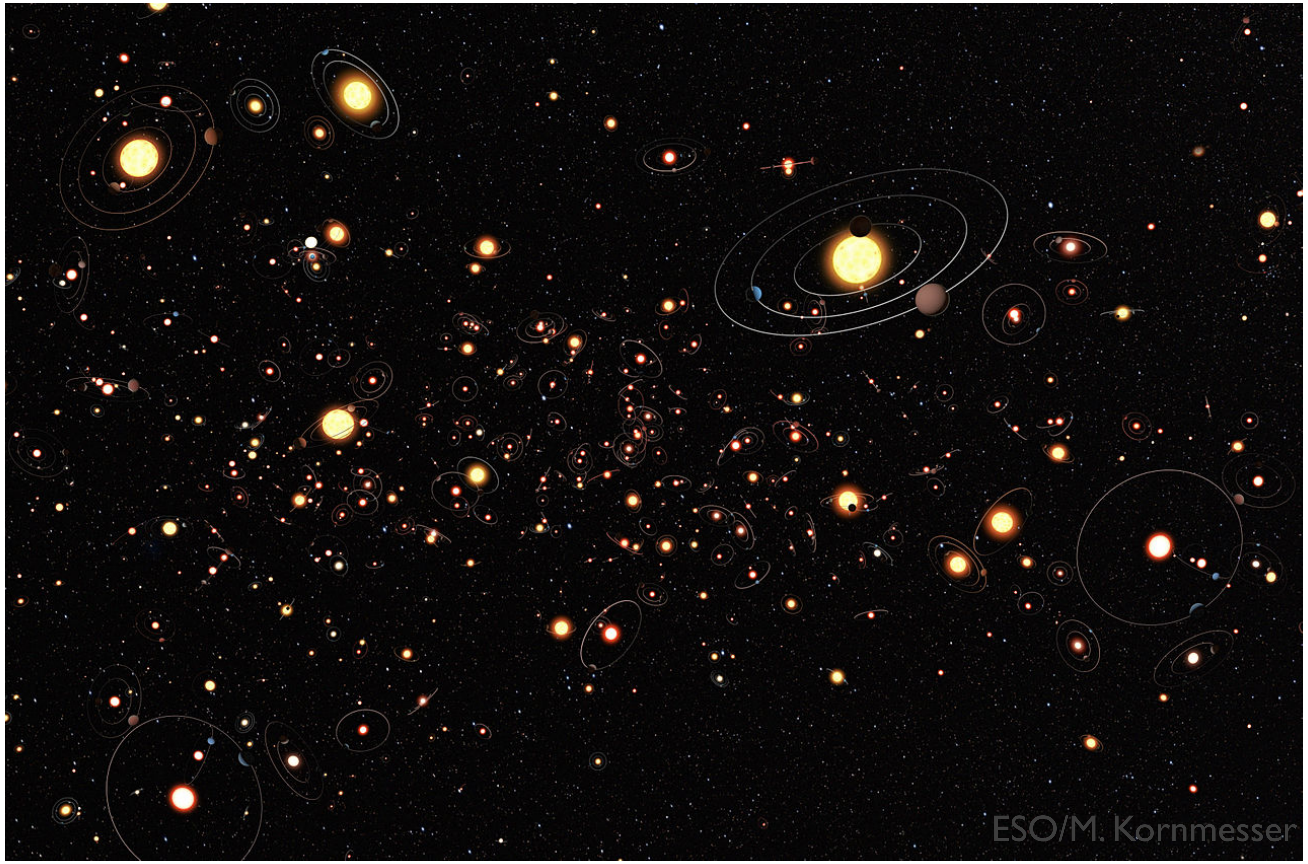
Many stellar systems exist

*In 1600, Giordano Bruno was burned at the stake for spreading the idea that numerous planetary systems existed beyond our solar system. It is now our turn to study stellar systems.**

in homage to "States of Matter" by Goodstein

- "stellar system" = star(s) + planet(s)
- The majority of stars have planets. Where a planet:
  1. orbits a star
  2. is massive enough that its self-gravity results in a roughly spherical shape
  3. has cleared its own orbital path

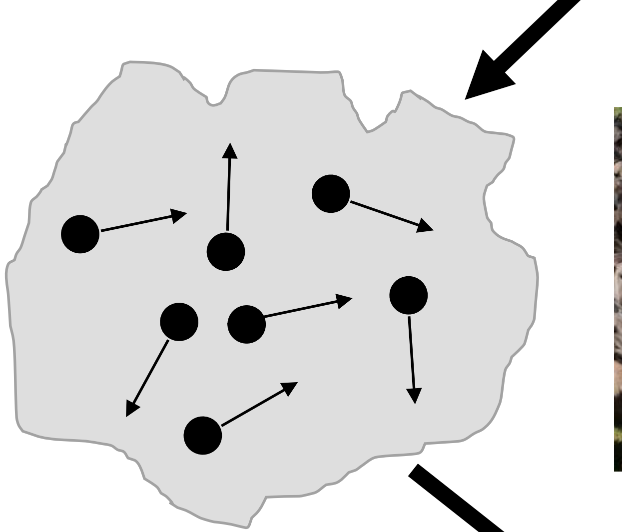


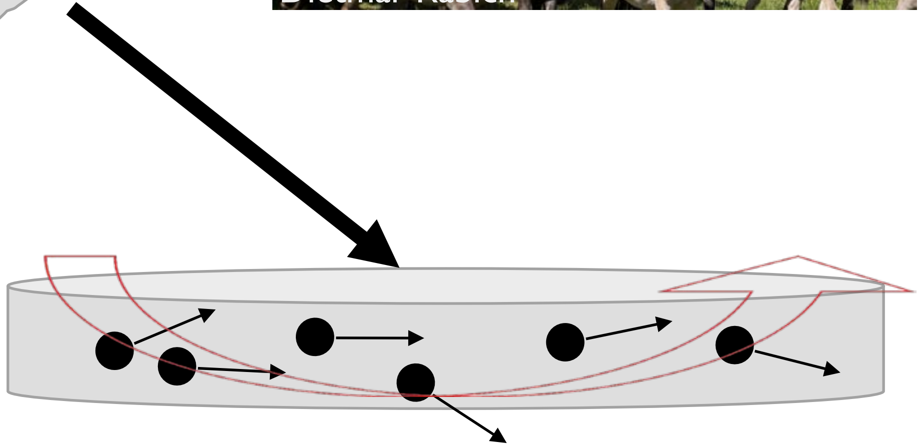


Collapse of a gas cloud

see *Intro to Milky Way Formation*

- Cool, higher-density regions exist, where the local gravity results in a gas cloud collapsing
- Particles in the cloud will have random motion, where the average motion is likely not zero.
  i.e. there will be some net rotation
- As gas particles collide, fewer and gentler collisions will happen to particles moving in the direction of rotation
- Thus, after some time, the collapsing clump will form a disk, though with a substantial spherical core
- The disk is the material from which planets will form



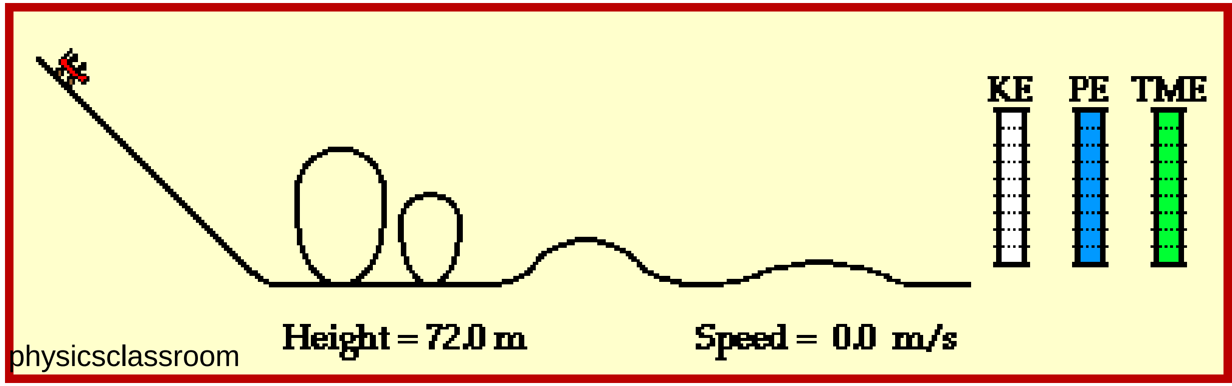


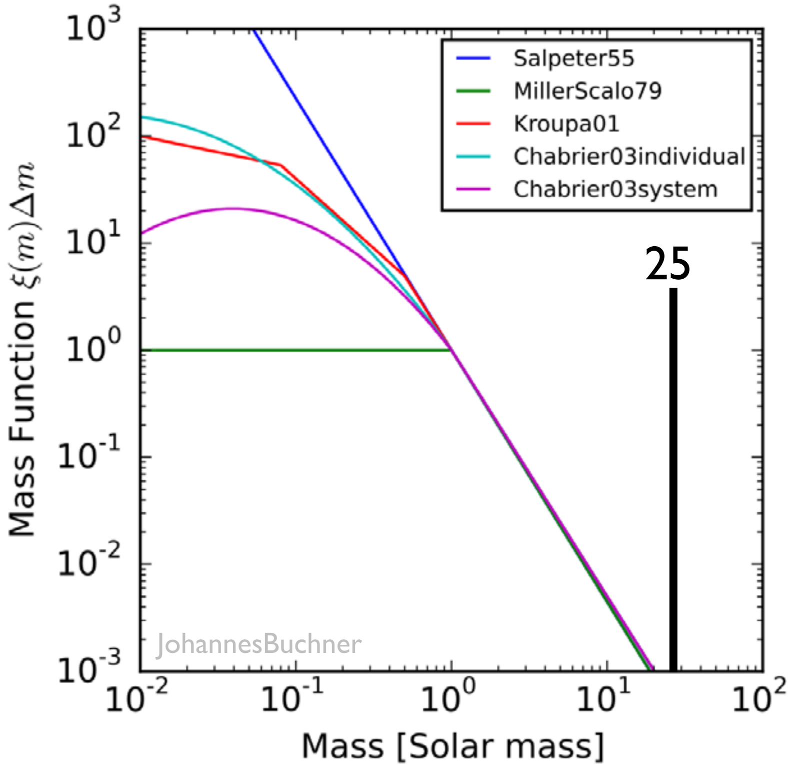
When does collapse happen? *the Jeans Criterion*

- A cloud of gas has (gravitational) potential energy and (from motion) kinetic energy
- If the gravitational potential can overpower the kinetic energy, the gas cloud will collapse
- After some relatively straight-forward estimates (take ASTR 4201), we find that collapse will occur for a cloud of molecular hydrogen (H_2) when:

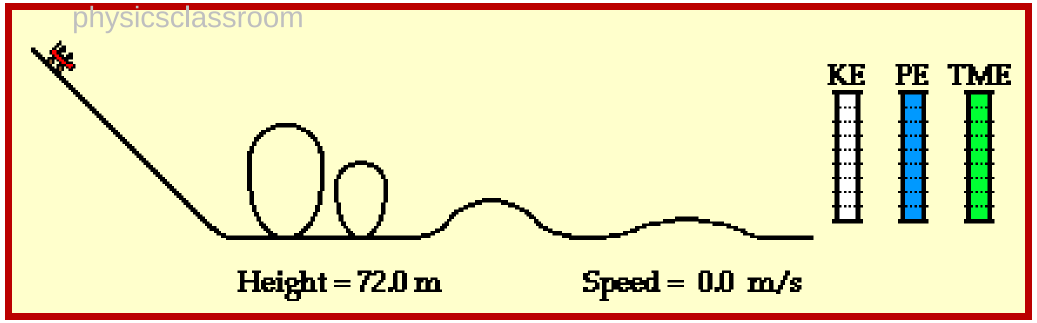
  $M_J \approx 25\sqrt{\frac{T^3}{n}} M_\odot$,

  where T is the temperature in Kelvin and n is the number density in molecules/cm^3.
- Typical conditions in a star forming nebula are $T{\sim}10$ K and $n{\sim}10^3 \frac{\text{molecules}}{\text{cm}^3}$ (so $M_J{\sim}25\ M_\odot$)
- Fragmentation leads to smaller stellar masses

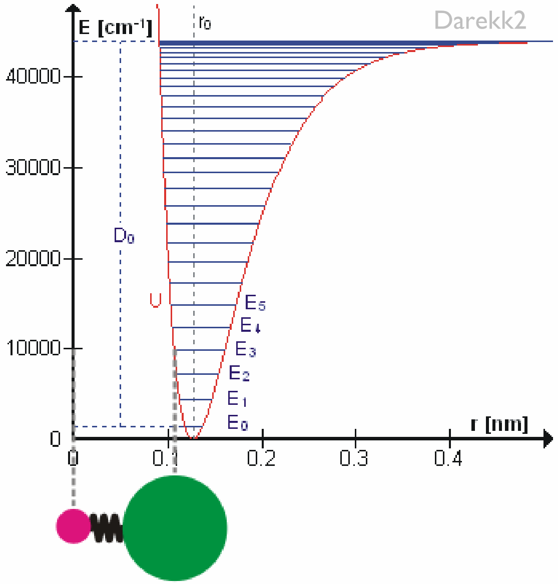




Keeping cool



- There's on issue with the picture we just presented: When collapse occurs, potential energy is converted to kinetic energy.
  - So, when collapsing, the cloud heats up
  - But, M_J increases when T increases! So the cloud would no longer have enough mass for the gravitational potential to overpower the kinetic energy.
- Solution: Cooling must happen for stars to form.
- The mechanism is kinetic energy converting to radiation
  - Molecules (usually CO):
    Collisions result in an excitation [rotational, vibrational, electronic], followed by a de-excitation. Some fraction of those photons escape the cloud, cooling it.
  - Dust (few molecules to several microns):
    Collisions result in a dust grain getting heated, which then radiates thermally. This is only relevant at high enough densities.



Star Formation on the HR Diagram

- The gas-cloud collapses in a free-fall until molecular hydrogen is dissociated and molecular cooling is no longer efficient.
- Then, the object is a protostar (no core H fusion yet)
- The protostar cools on the Kelvin-Helmholtz timescale (see Intro to Stellar Equilibrium)
- As the cloud collapses, it gets hotter, but we also see a shorter way into the star because it is denser (see Intro to Stellar Energy Transport).
  - So, the surface temperature is ~constant.
  - The radius decreases, so luminosity decreases.
  - This is the **Hayashi track**
- Eventually (very soon for high-mass), the collapse is so slow that the star is nearly in hydrostatic equilibrium (see Intro to Stellar Equilibrium), so luminosity is barely changing. This is the **Henyey track**