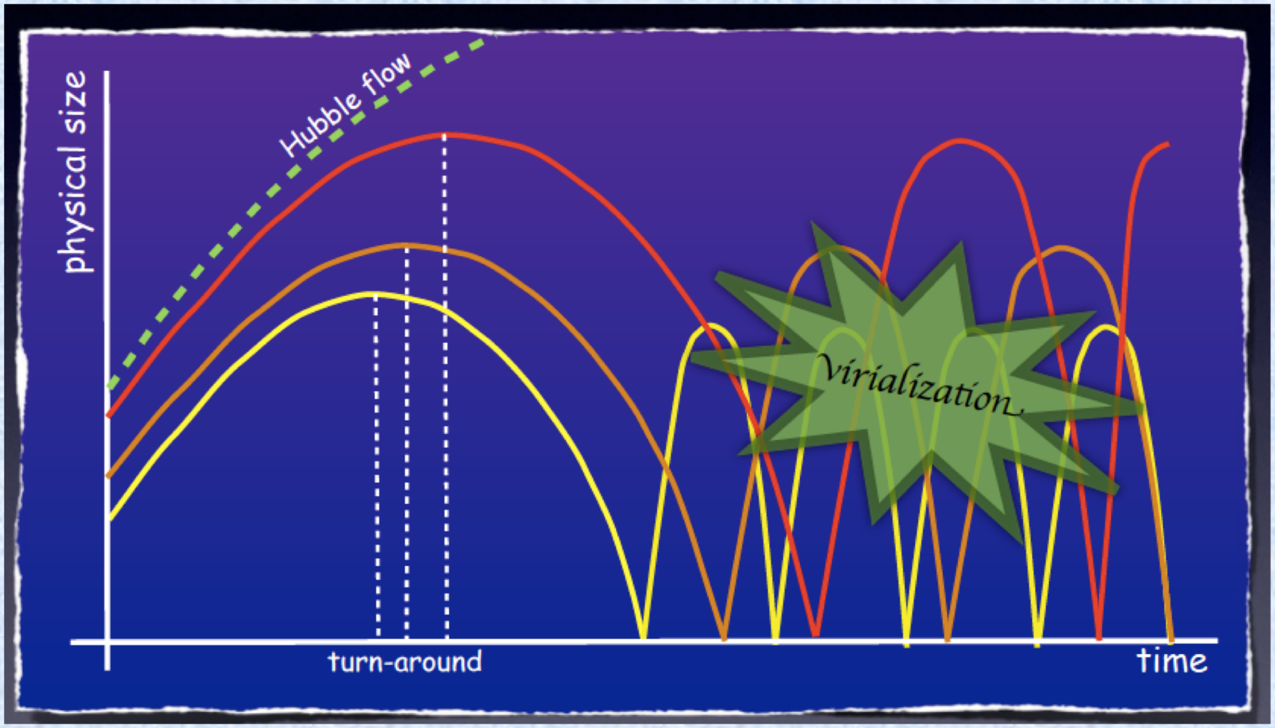
Physics 133: Extragalactic Astronomy and Cosmology



We will learn how galaxies are made.

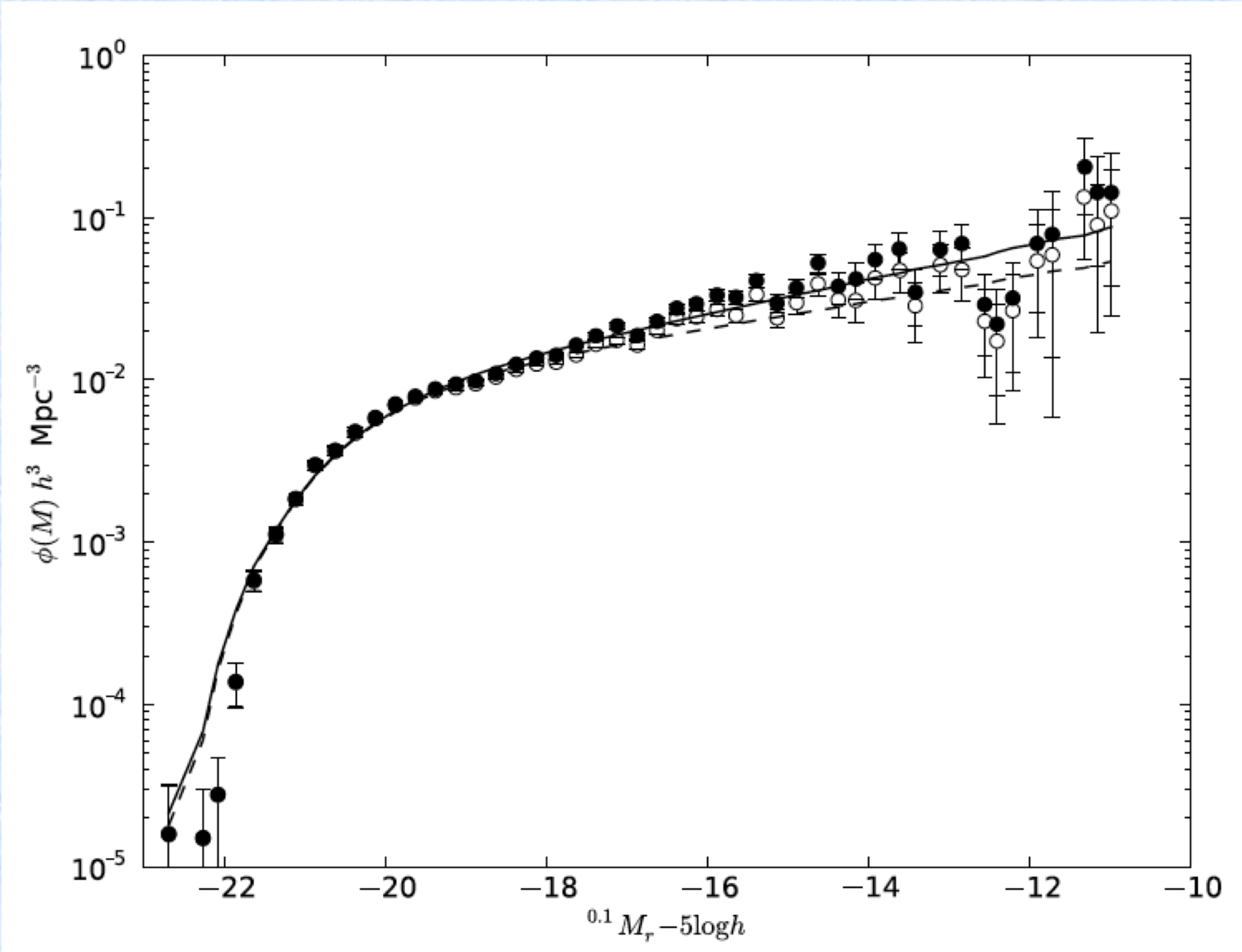
Week 10

Outline for Week 10

- Galaxy formation (starting with the dark matter)
- The observed galaxy luminosity function - HW 10 [R 12.1].
- What is a galaxy in context of structure formation?
- How long does it take to make a galaxy?
  - Minimum timescale in [R 11.4]
  - Analytic description of non-linear collapse is highly simplified but provides a definition of when galaxy formation begins.
- Use virial theorem to define a galaxy
  - Halo radius
  - Halo temperature
- Power spectrum at matter-radiation equality provides the starting point for structure growth
- Baryon physics further shape the galaxy properties.

Galaxy Luminosity Function

GAMA Survey (Loveday+2012)



Luminosity Function with friendlier units…

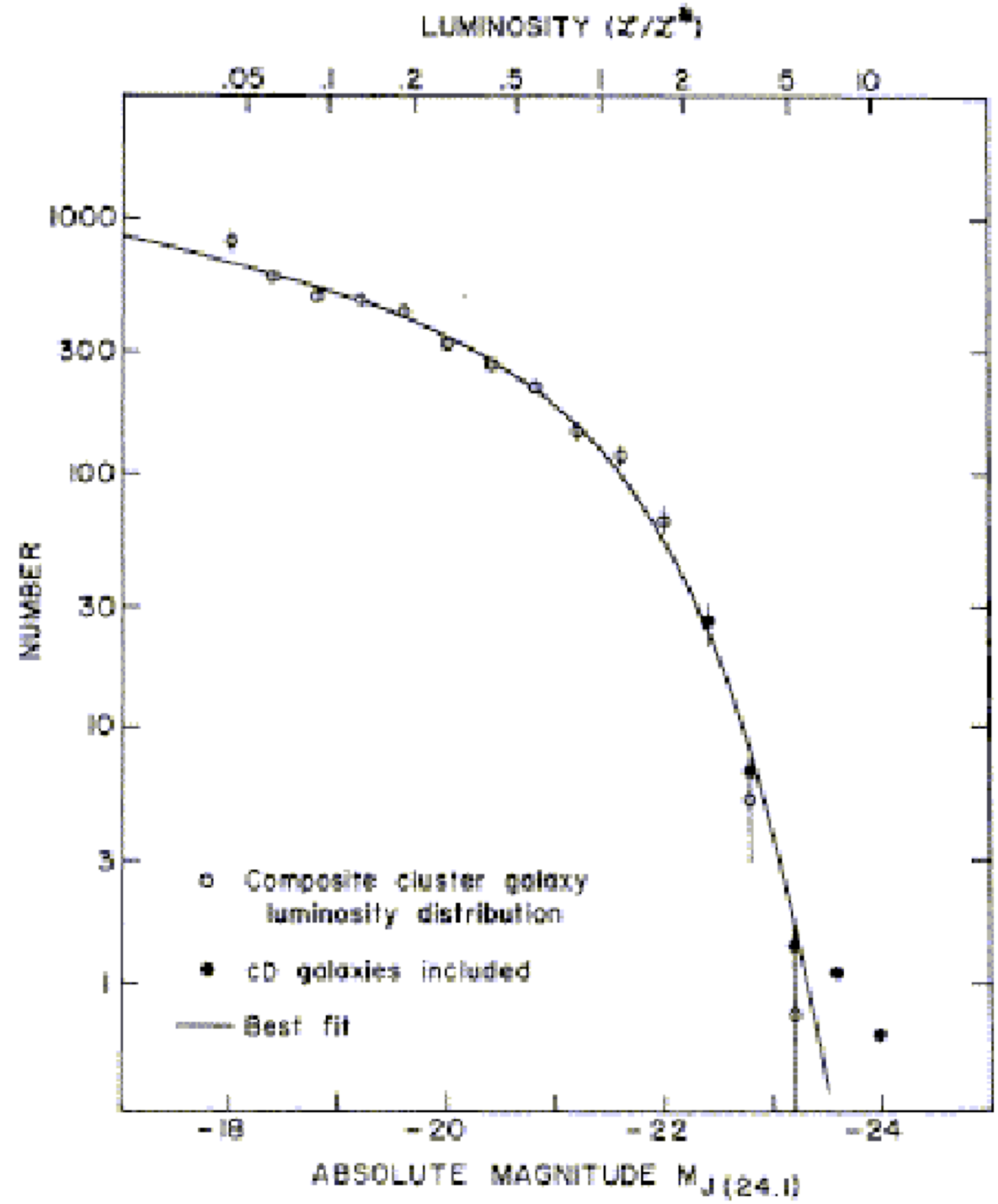


FIG. 2.—Best fit of analytic expression to observed composite cluster galaxy luminosity distribution. Filled circles show the effect of including cD galaxies in composite.

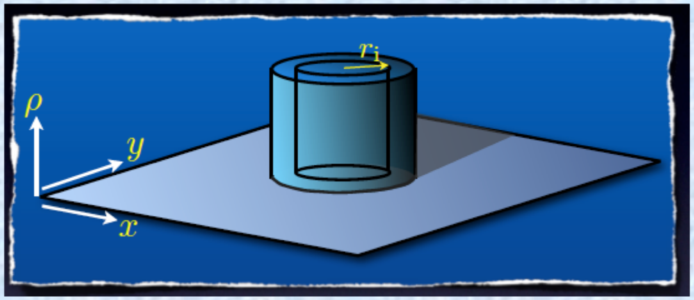
What defines a galaxy?

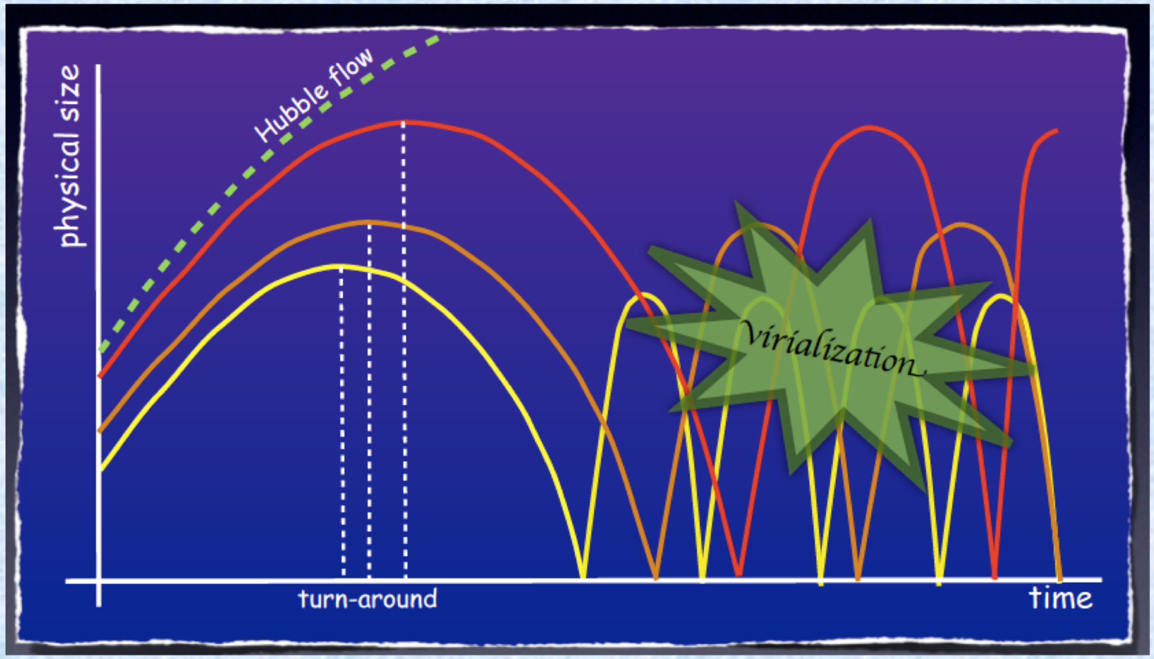
Non-linear Evolution. I. Schematic Picture

- Galaxies and galaxy clusters have densities many orders of magnitude larger than the cosmic mean; hence $\delta >> 1$.
- Linear perturbation theory obviously fails as δ approaches unity.
- Computer simulations are required to obtain an accurate solution.
- Oversimplified analytical tools can help us interpret what happens in the simulations.
  - Minimum collapse timescale
  - Spherical top-hat collapse
  - Minimum overdensity of a virialized galaxy (or galaxy cluster) defines where a galaxy ends, i.e. the virial radius.

Minimum Overdensity of Virialized Structure

- Turn around radius defined by top-hat spherical collapse model.





At turnaround,
$1 + \delta(t_{ta}) = 5.5$.
At virialization, $t_v = 2\, t_{ta}$

- The minimum density at virialization is 8 times higher than the density at turn around. [Blackboard]
- The expansion of the universe during the interval from turn around to virialization further dilutes the background density, giving $\delta(t_{Vir}) = 8 * 5.5 / (1/2)^2 = 176$. [Blackboard]

Small Galaxies Formed First and Super-clusters Formed Last

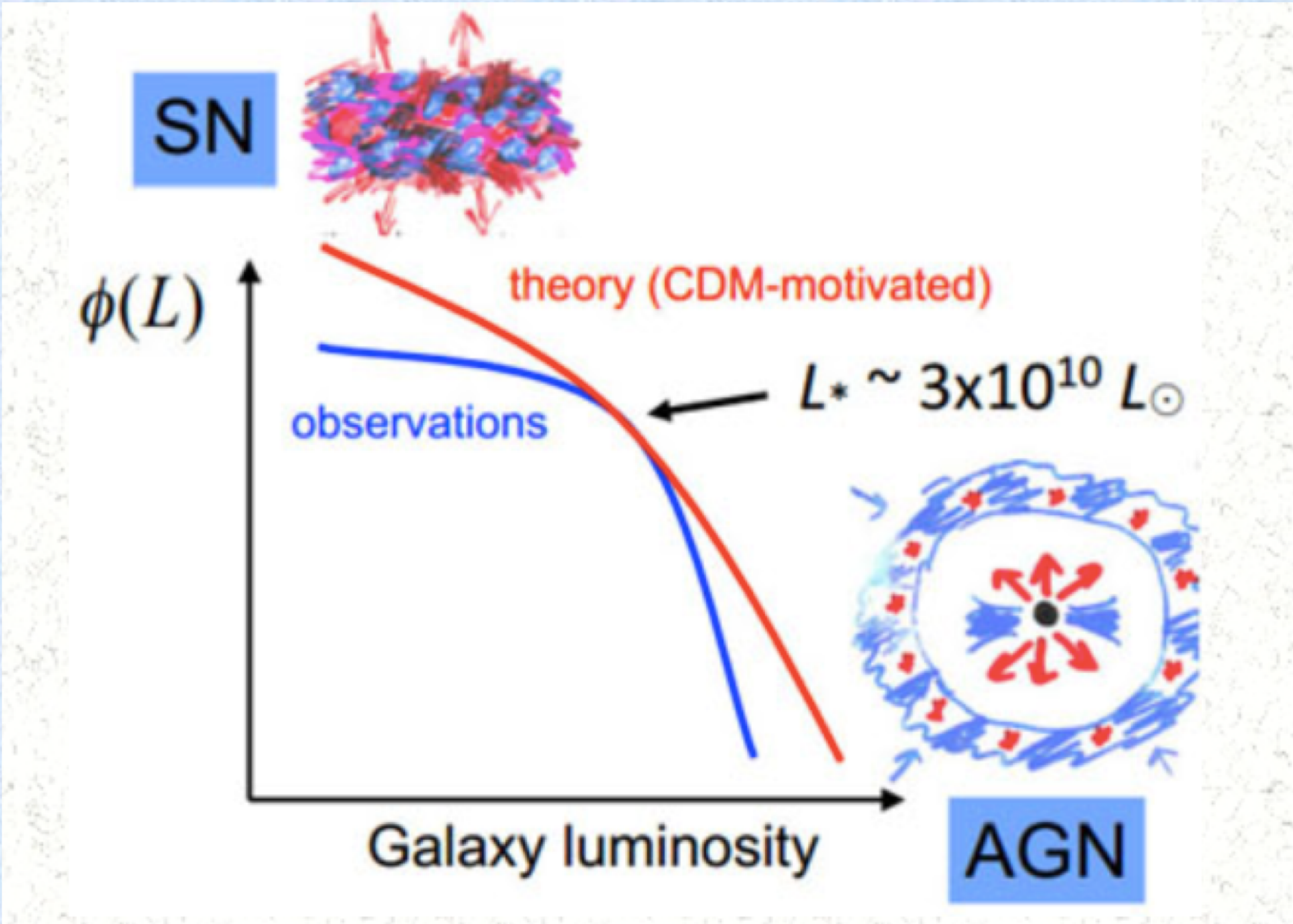
- From the average density of a virialized galaxy, you can compute when it started to collapse (i.e., turn around).

$$\rho(t_{vir}) = 8\ (1+\delta_c)\bar{\rho}_{m,0}(1+z_c)^3$$

$$1 + z_c \approx 6\ V_{230}^{2/3} R_{150}^{-2/3}$$

M_{halo} / M_o	z_c	T_V (K)
10^{10}	6.7	7×10^4
10^{12}	3.4	9×10^5
10^{14}	1.0	9×10^6

How baryons populate the dark matter halos could be an entire course!



Final Exam

- Final Exam, Monday June 7, 2021 at 4 pm.
  - 6 problems covering chapters 7-12.
  - 2 problems reviewing concepts from ch 1-6.
- **Bring a calculator. No cell phones.**
- **Print equation sheet on a single piece of paper.**
- **Be prepared to scan and upload papers.**
- Review
  - Homework problems and quizes
  - Midterm problems.
  - Summaries at the end of each lecture
  - Extra problems at the end of the chapters