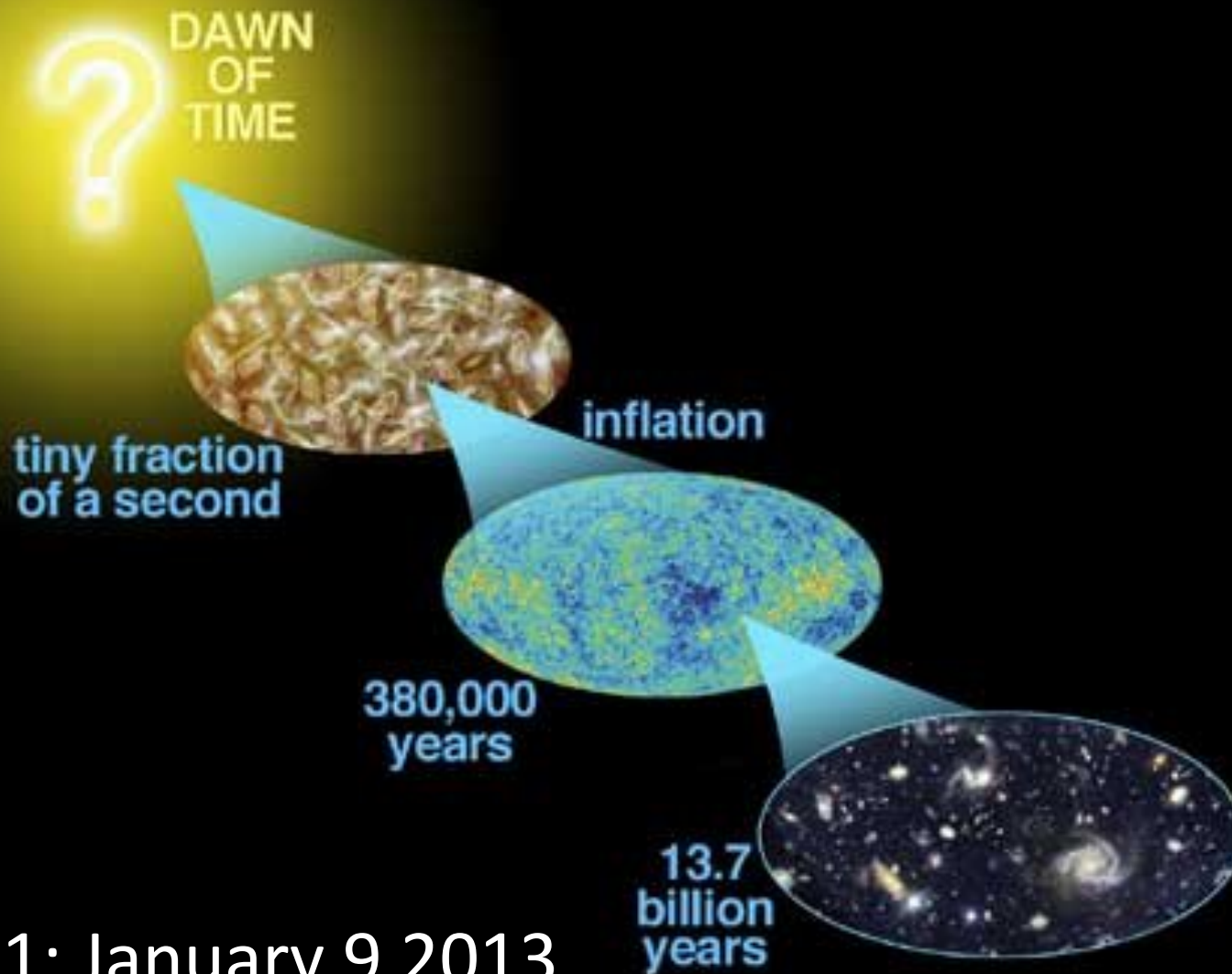


# Cosmology W13



Lecture 1: January 9 2013

# Physics 236

- Instructor: Prof. Tommaso Treu
  - Lectures: MW 12:30-1:45 HSSB 3202
  - Office hours: MW 2-3 Broida 2015F
- MIDTERM:
  - February 11 2013
- CLASS PRESENTATIONS:
  - March 11/12 2013
- FINAL EXAM:
  - March 19 2013 12-3PM

# Physics 236

- Textbook:
  - **Galaxy formation**, Malcom S Longair
- Website: [web.physics.ucsb.edu/~tt/PHYS236](http://web.physics.ucsb.edu/~tt/PHYS236)
- Power point files, homework, and reading assignments will be found on the website

# Physics 236

- Grading:
  - Class participation 10%
  - Homework 20%
  - Midterm Exam 20%
  - Final Exam 20%
  - Presentations 20%
  - Participations to your colleagues' presentations 10%
- Homework:
  - assigned on wednesday, due the following Monday
  - Graded by pairs of students (sign up!)

# Physics 236: the big question

COSMOLOGY MARCHES ON



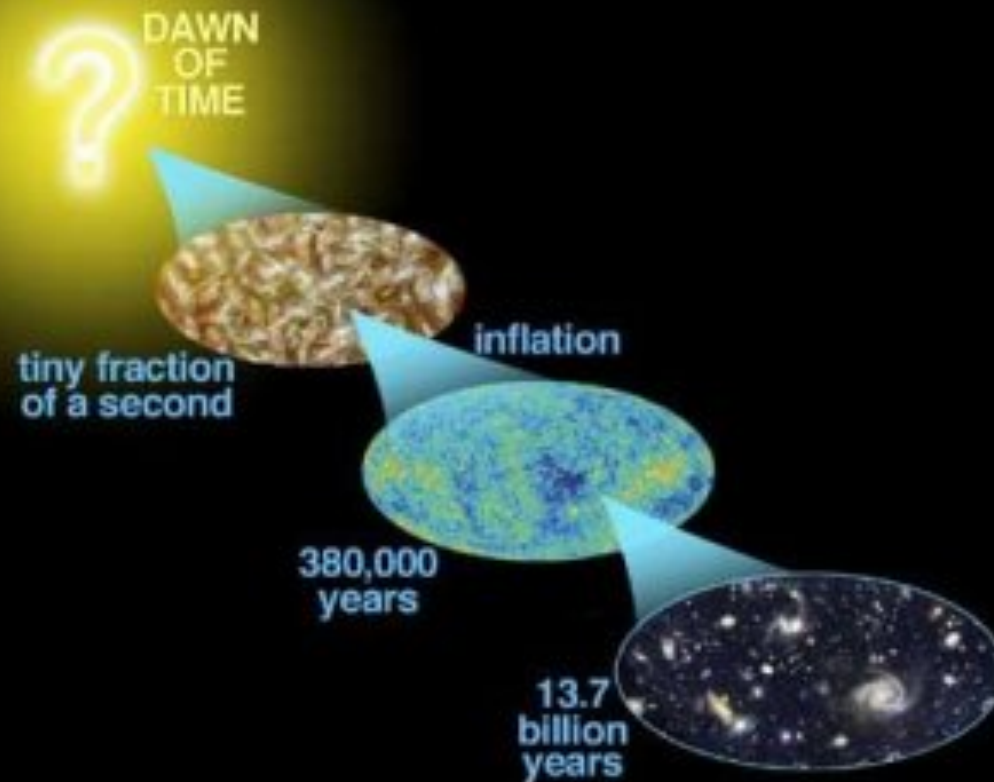
# Physics 236: more specifically

- Is the Universe evolving?
- If so, how and when did it form?
  - How and when did galaxies and black holes form? (see PHYS235 taught in the spring by Prof Martin)
- How big/old is the universe?
  - What's the geometry of the Universe? Dynamics?
- *Can we put together a physical model of the universe and its contents, capable of reproducing the observations and predicting falsifiable observations? The best we could come up so far is the so-called Standard Cosmological Model (by analogy with particle physics' Standard Model), or Big Bang Theory*

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# Physics 236: the big bang theory



# Traditional Observational Foundations of the Big Bang Theory

- Olbers' Paradox
- Hubble's Law
- The cosmic microwave background
- He abundance in stars
- And many many many more awesome observations at later times

# Physics 236: open problems with BB

- The horizon problem
- The flatness problem
- The baryon asymmetry problem
- The primordial fluctuations problem
- The fine tuning problem
- What is the universe made of?
  - What are dark energy and dark matter?

# Physics 236: open problems with BB

- The horizon
- The flatn
- The bary
- The prim
- The fine
- What is t
  - What a



# Some epistemological issues

- The subject of the discipline is unique: we only have one Universe, we cannot replicate/alter/reproduce our “sample”
- We can only do experiments and measurements from one specific point in time and space
- Yet we would like to construct a scientific theory that describes the universe everywhere and at all times.

# Cosmological Principle

- Physicists postulate a universal principle: our local sample of the universe is no different from more remote and inaccessible places
  - A.k.a. Cosmological or Copernican Principle
- This postulate is deeply rooted in two fundamental principles of physics:
  - The laws of physics (whatever they are!) do not depend on space and time
  - Physical explanations of natural phenomena should be as simple as possible (Ockham's razor)

# Plan

- Part 0: basic phenomenology (today; L2-4)
- Part I: the (smooth) average universe (L5-10)
- Part II: the growth of fluctuations (L11-L15)
- Part III: very early universe (L20)
- Part IV: class presentations

# Some useful concepts/units

- Parsec (pc) = distance that gives a parallax of 1 arcsecond  $\sim 3.08e16m$
- Solar Mass =  $2e30kg$   $M_{\odot}$
- Solar Luminosity =  $3.8e26 W$
- Redshift  $z = \lambda/\lambda_0 - 1$

# Some useful concepts/units

- Apparent magnitudes: flux in “funny” units
  - Magnitude  $m = -2.5 \log F/F_0$ ; e.g.  $F_0$  can be flux of Vega
  - Letters indicate band, i.e. through a standard filter. For example B=blue band, V=visual, g=green. There is a whole zoology of bands
- Absolute Magnitude is luminosity in funny units, defined as the apparent magnitude of an object at a distance of 10 pc
  - Sun is  $M_V = -4.83$
  - Andromeda  $M_V \sim -20$

# Olbers' paradox. The night sky

- What strikes you of the night sky?
- It is dark!!
- This apparently superficial statement (formulated by Heinrich Olbers in the early 1800s) has very profound consequences and is one of strongest pieces of evidence in favor of the big bang



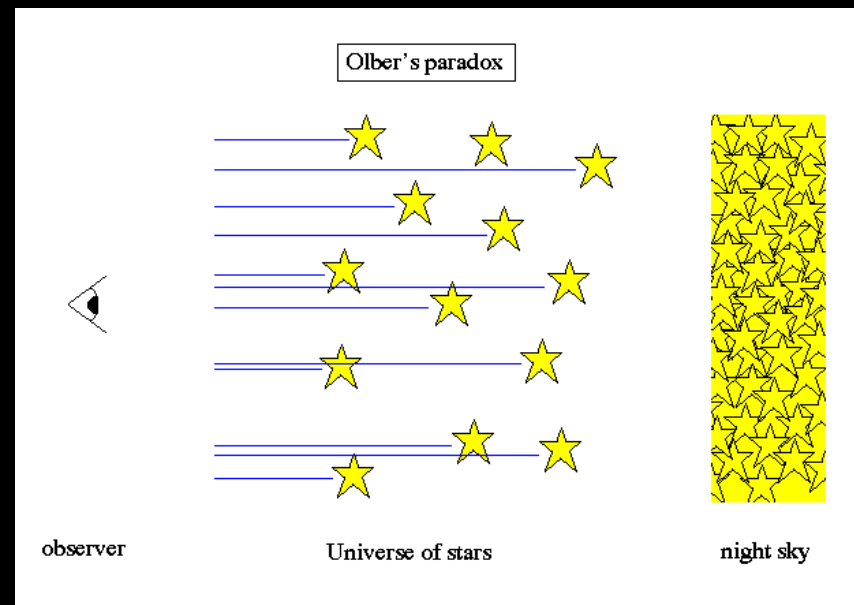
# Olbers' paradox. A step back..

- Newton's model of the universe was:
- Eternal
- Infinite (otherwise it would collapse gravitationally)
- Flat Space
- Time independent of space



# Olbers' paradox. What does the sky look like in Newton's model?

- For every line of sight sooner or later you find a star
- Surface brightness is independent of distance for a Euclidean flat space (draw on the blackboard)
- This would mean that the sky should have the same surface brightness of the sun, your average Joe star.



# Olbers' paradox. Olbers' solution.

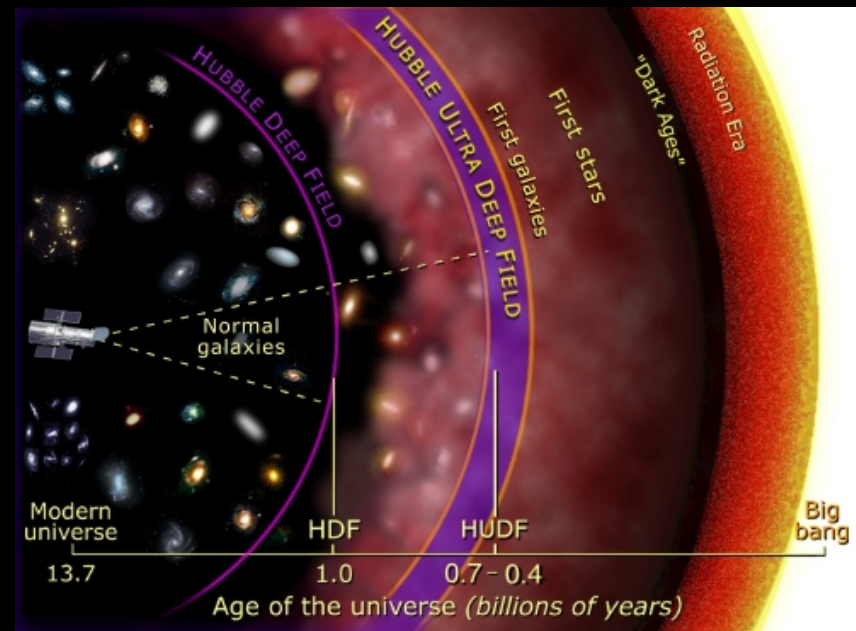
- Olbers postulated that the Universe was filled with an absorbing medium, like fog
- However, if light is absorbed it will also re-radiate, producing light albeit at different wavelengths, so this doesn't work!



# Olbers' paradox.

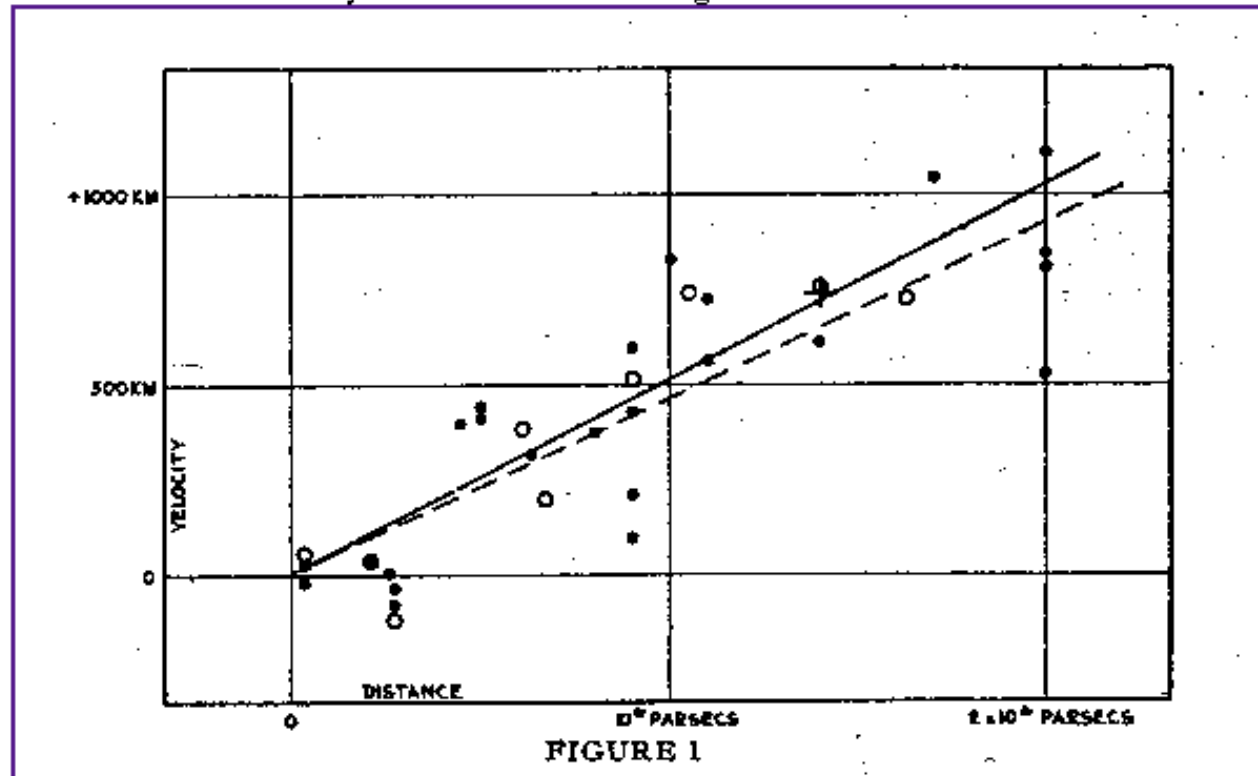
## The Big-Bang solution

- In the Big Bang model the Universe is finite in TIME (13.7 billion years)
- This means that we can only see as far away as light has had time to travel
- Furthermore stars were not always shining (the sun for example is 4.5 Gyrs old).



# Hubble's Law

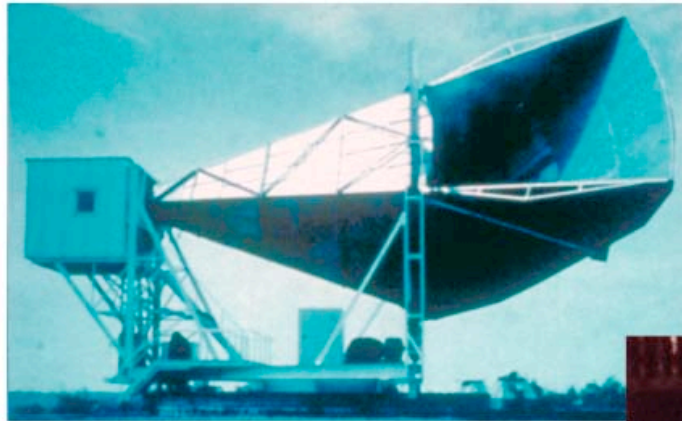
Velocity-Distance Relation among Extra-Galactic Nebulae.



**Figure 1:** Radial velocities, corrected for solar motion, are plotted against distances estimated from involved stars and mean luminosities of nebulae in a cluster. The black discs and full line represent the solution for solar motion using the nebulae individually; the circles and broken line represent the solution combining the nebulae into groups; the cross represents the mean velocity corresponding to the mean distance of 22 nebulae whose distances could not be estimated individually.

# Cosmic Microwave Background

## DISCOVERY OF COSMIC BACKGROUND

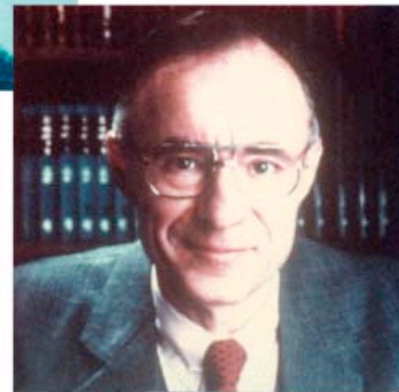


Microwave Receiver



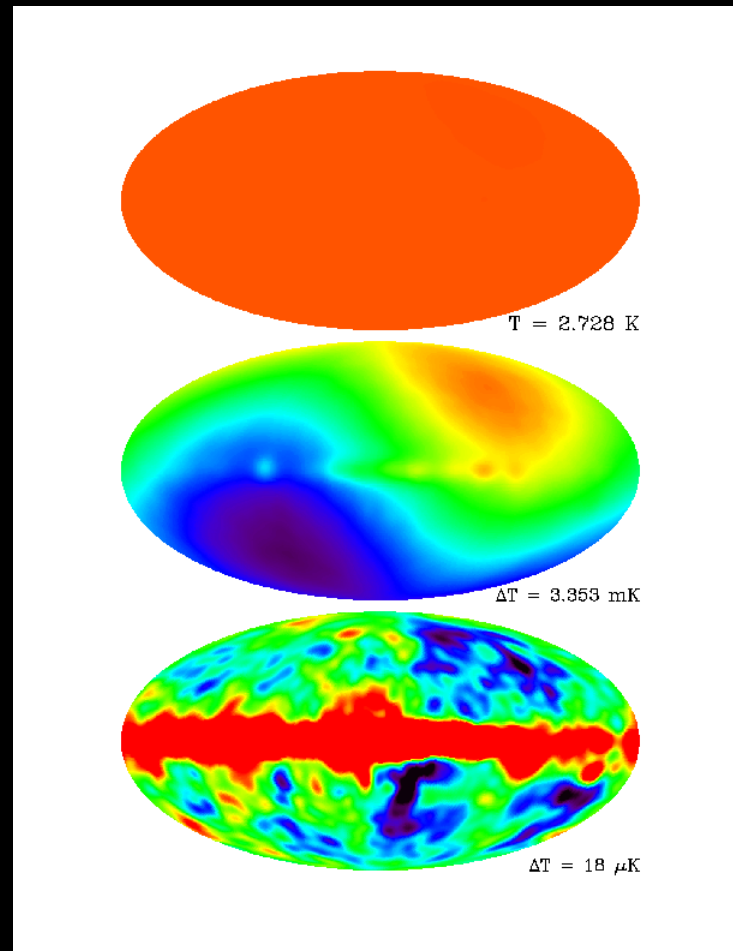
MAP990045

Robert Wilson

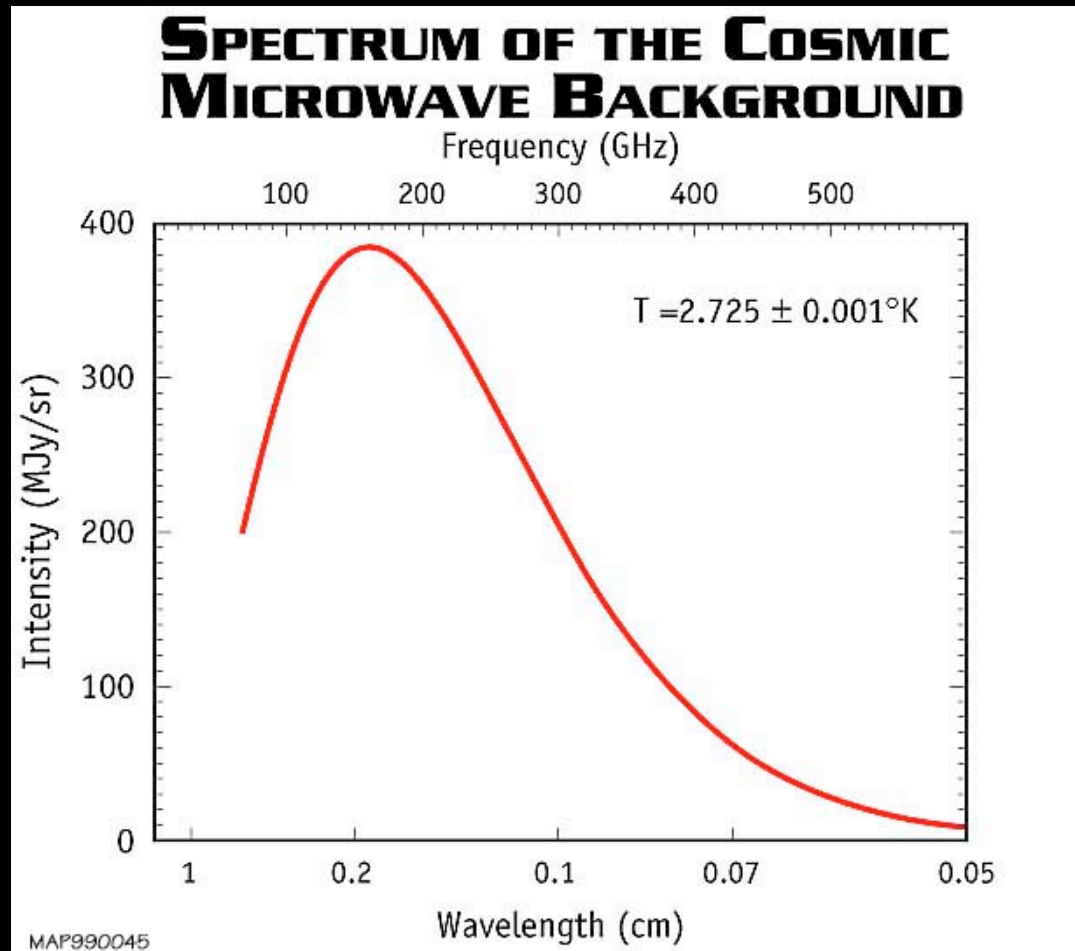


Arno Penzias

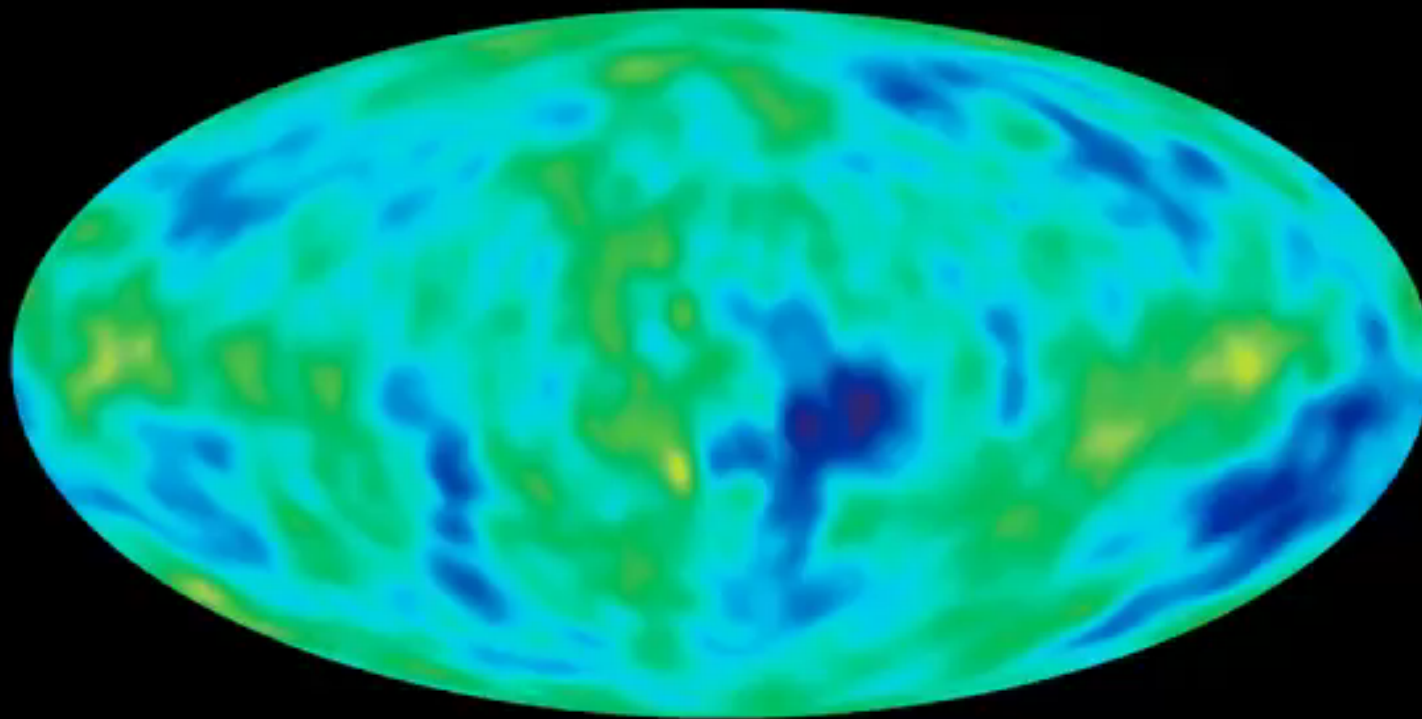
# Cosmic Microwave Background



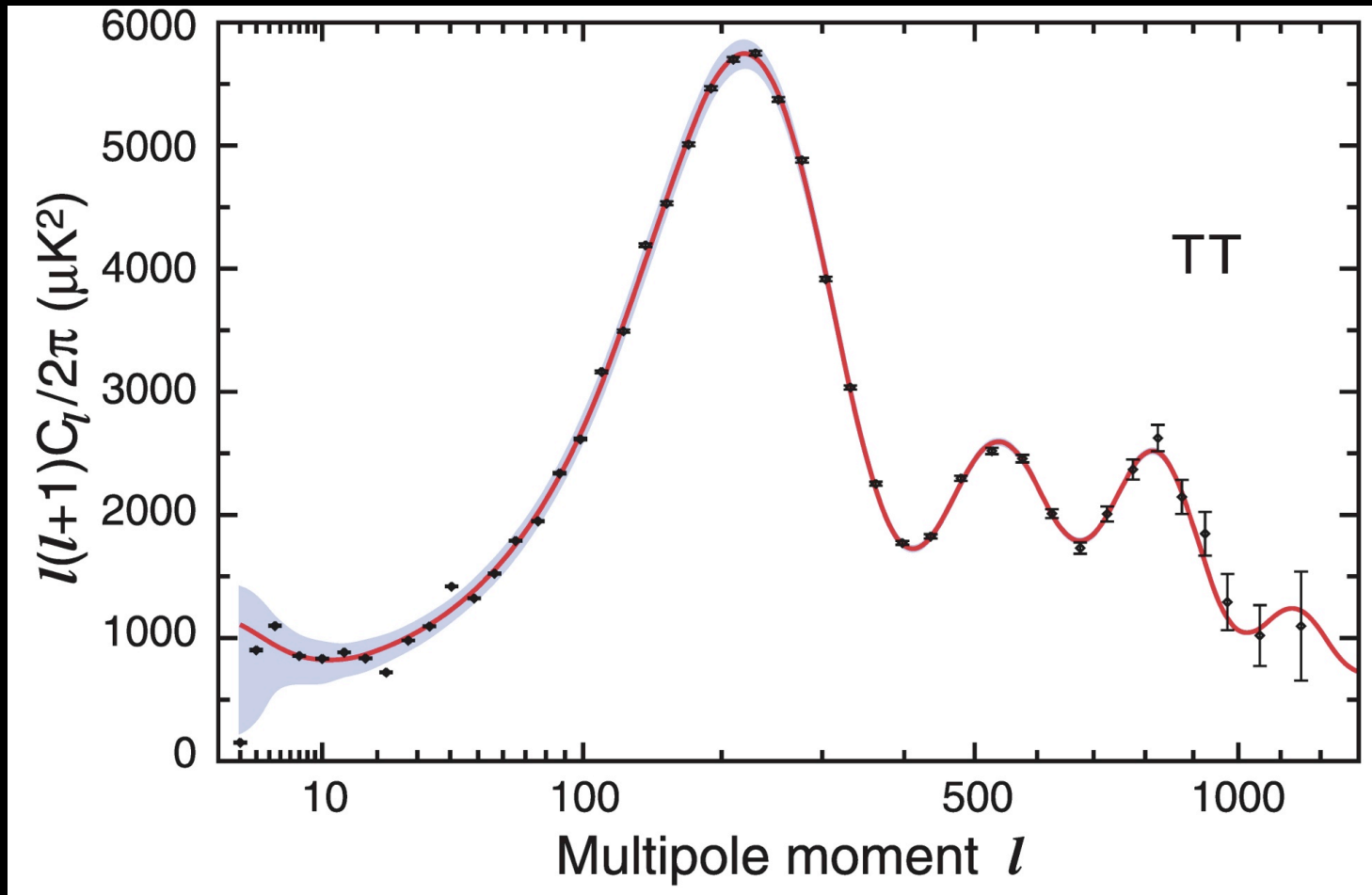
# Cosmic Microwave Background



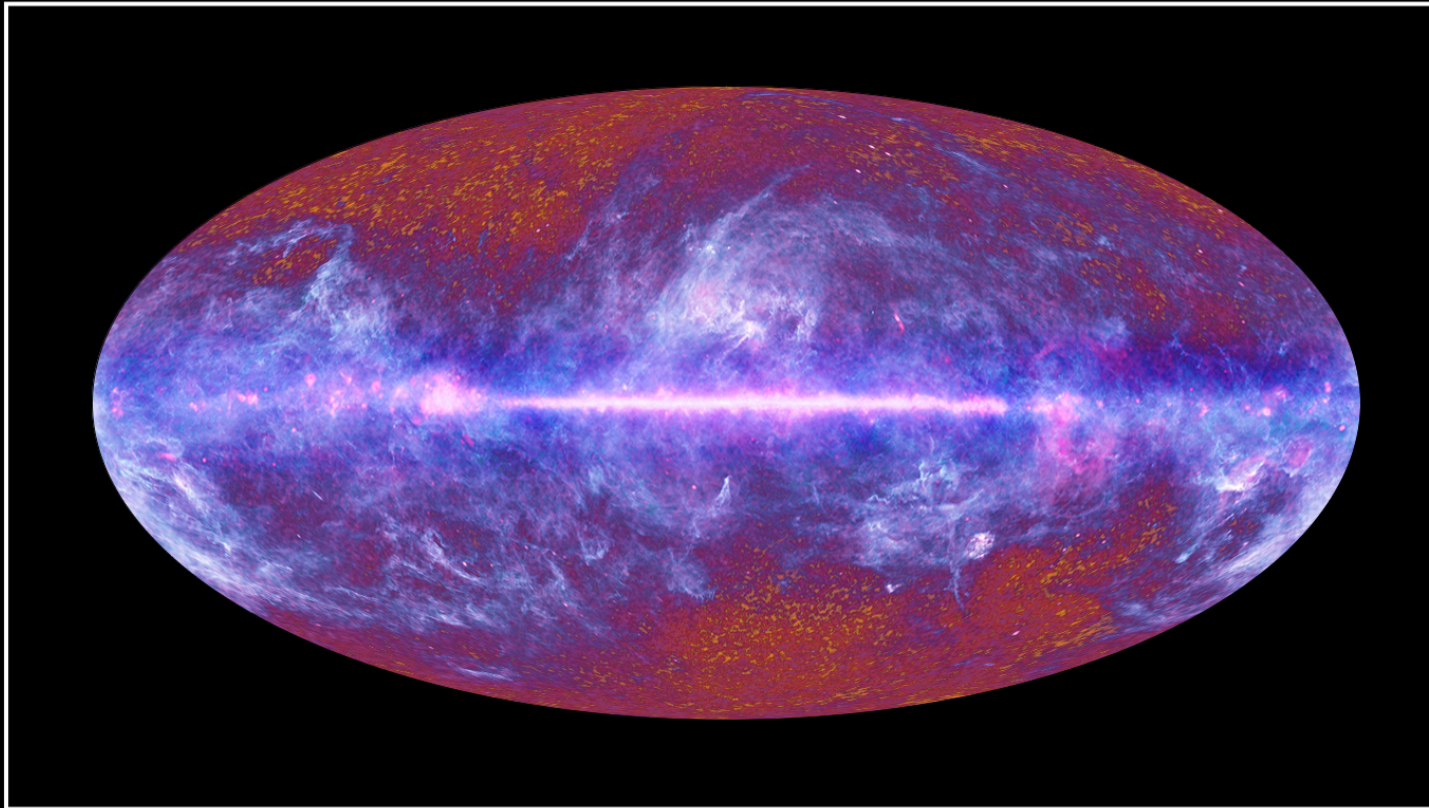
# Anisotropies of the CMB



# Anisotropies of the CMB



# Planck CMB mission



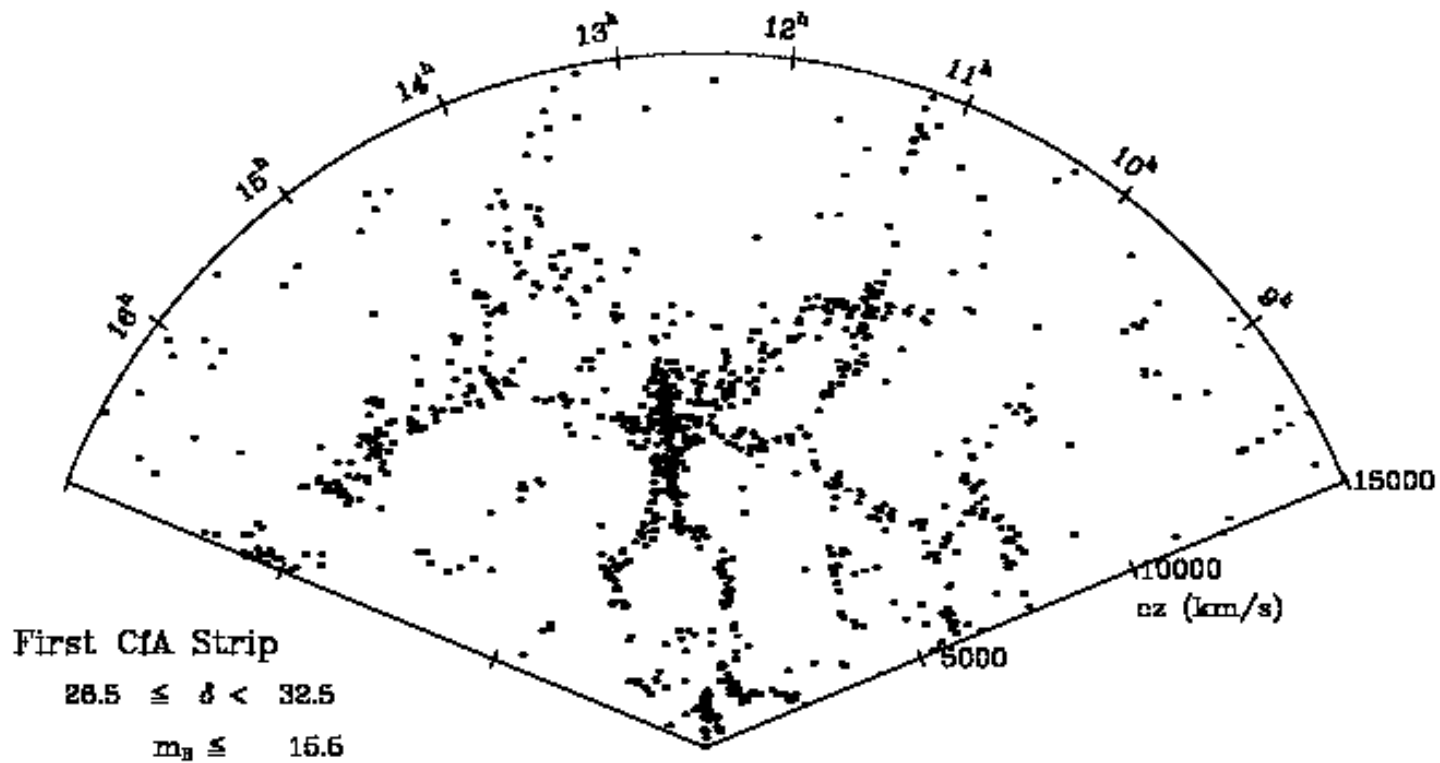
The Planck one-year all-sky survey



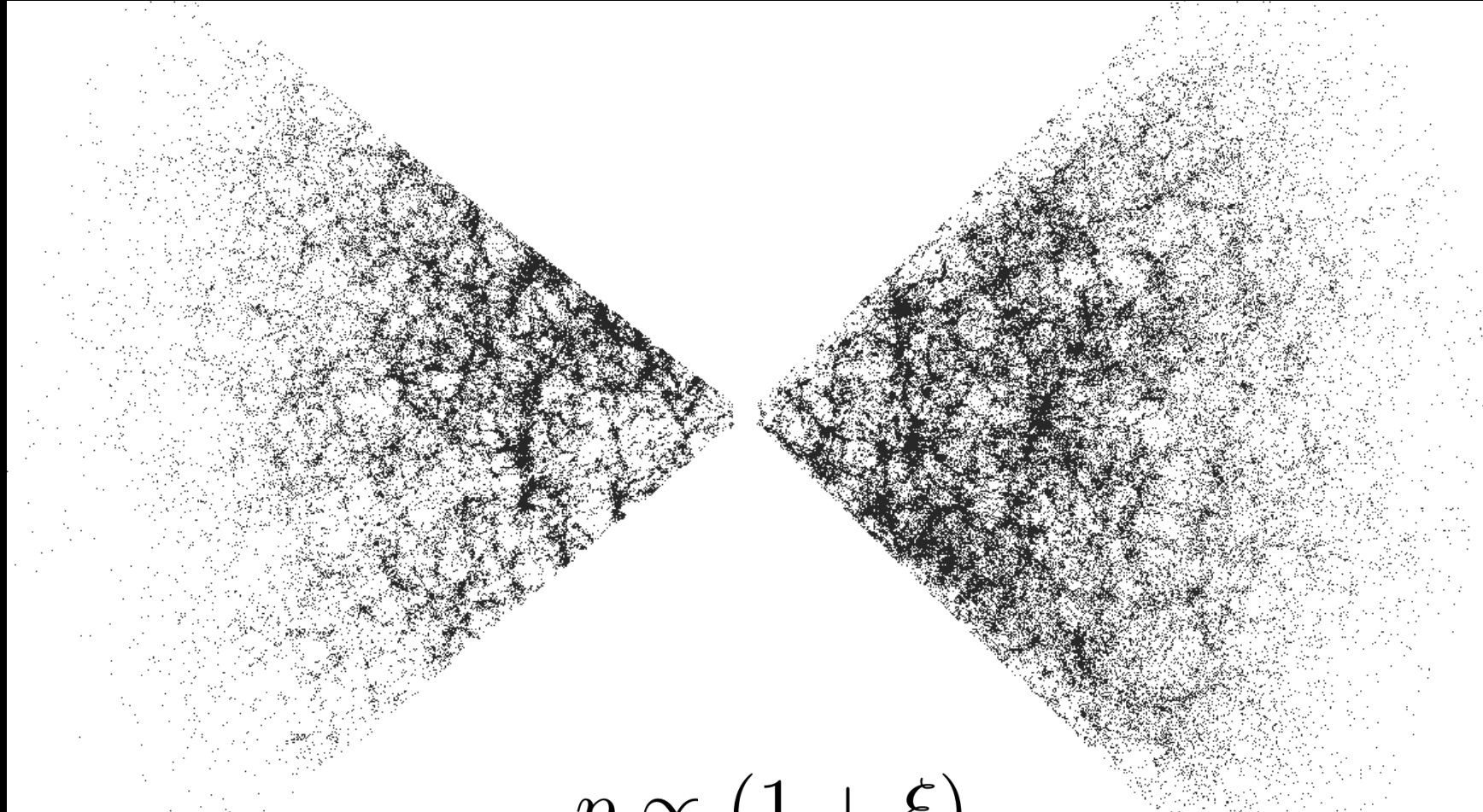
(c) ESA, HFI and LFI consortia, July 2010

Cosmology results should come out soon!!!

# Basic Phenomenology: LSS



# Basic Phenomenology: LSS



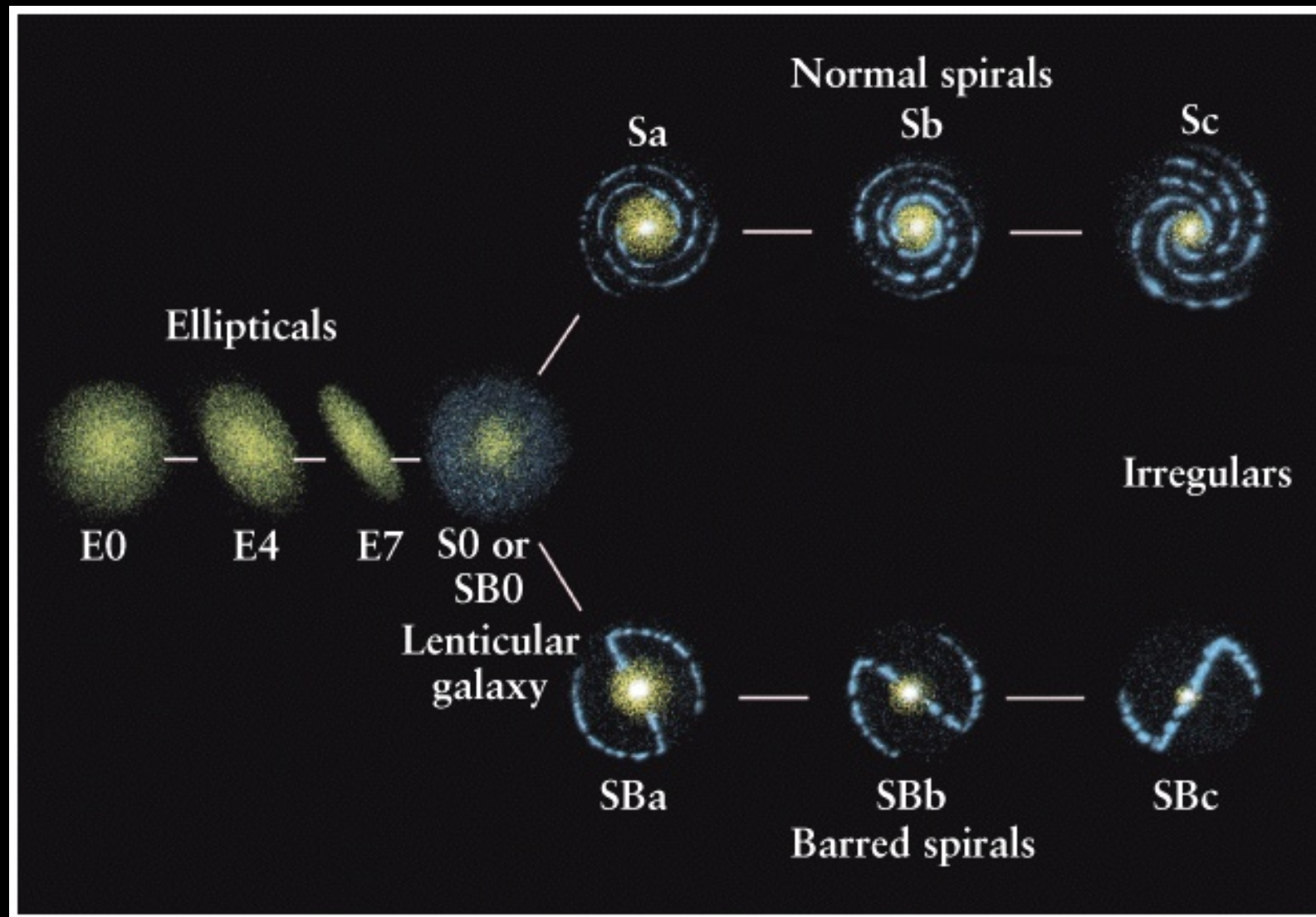
Galaxies are clustered:

$$p \propto (1 + \xi)$$
$$\xi \propto r^{-\gamma}; \gamma \approx 2$$

# Basic Phenomenology: galaxies

- Galaxies are:
  - Self gravitating sets of stars, gas, and dark matter
    - Typical size is kpc for the baryons 100s of kpc for the halo
  - Most of the mass is in dark matter (so called halo)
    - Halo mass ranges from  $>10^7$  to  $10^{13}$  solar masses
    - Upper limit set by collapse of structures
    - Lower limit set by ?? Dark matter physics?
  - Mass in stars is at most a few percent
  - Majority of baryons are in gas (cold and hot), the so-called interstellar medium
  - Galaxies are believed to have many satellites and dark subhalos

# Basic Phenomenology: galaxies



# Basic Phenomenology: galaxies

- Morphological types roughly map into spectral types
  - Elliptical galaxies have typically old stars, and no star formation, and are therefore said to be “red” and dead
  - Spiral galaxies have typically younger stars and active star formation. Sometimes called “blue” galaxies

# Basic Phenomenology: massive elliptical galaxies

- Most massive galaxies up to  $10^{12}$  Msun in stars
  - Typically found at the center of groups/clusters
  - Hot X-ray emitting halo
  - Highly clustered
  - Pressure supported (blackboard)
  - Devaucouleurs profiles (blackboard)
- There are smaller version, down to dwarfs
  - Younger stellar ages
  - Increased rotational support
  - Seric profiles with  $n \rightarrow 1$  (blackboard)

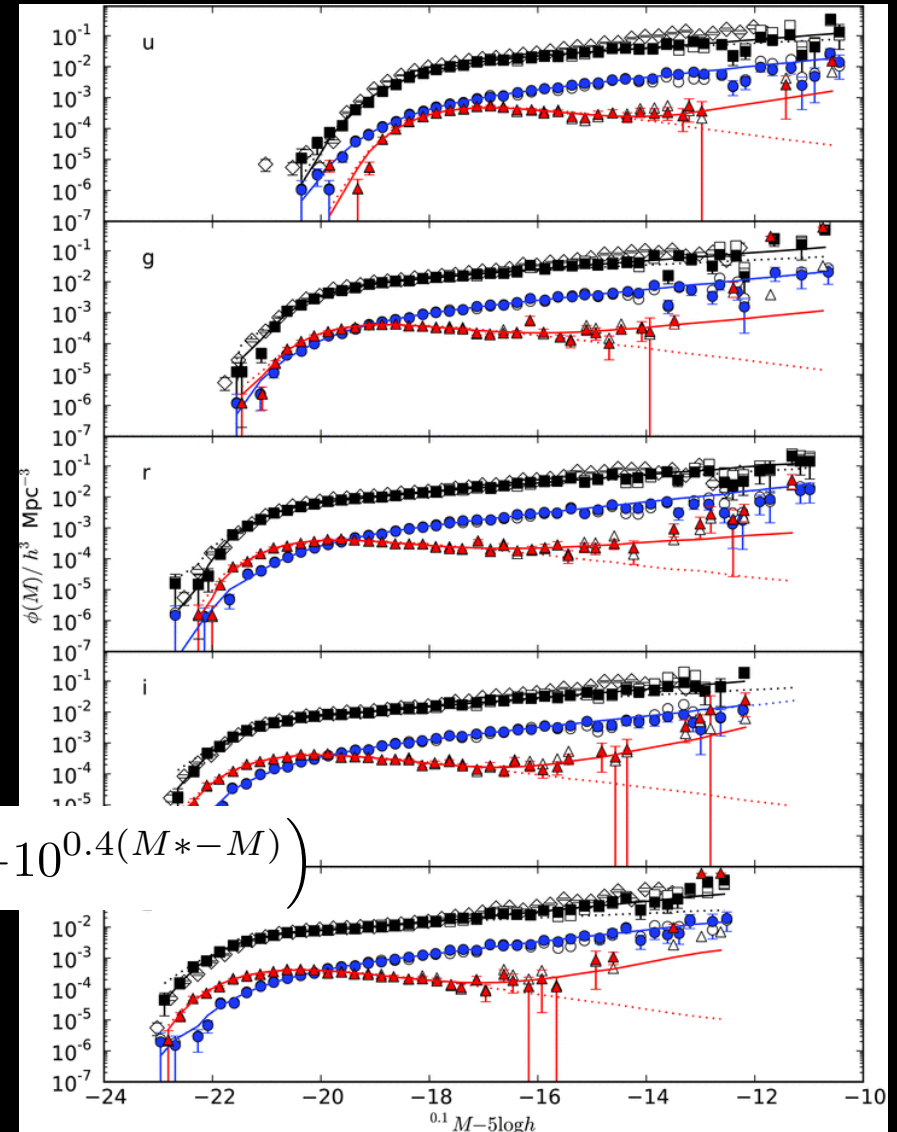
# Spiral galaxies

- Like our very own Milky Way and Andromeda
  - Rotation supported
  - Rich in cold gas
  - Typically star forming
  - Spiral density waves
  - Two main baryonic components
    - Bulge (and/or pseudobulge)
    - Disk

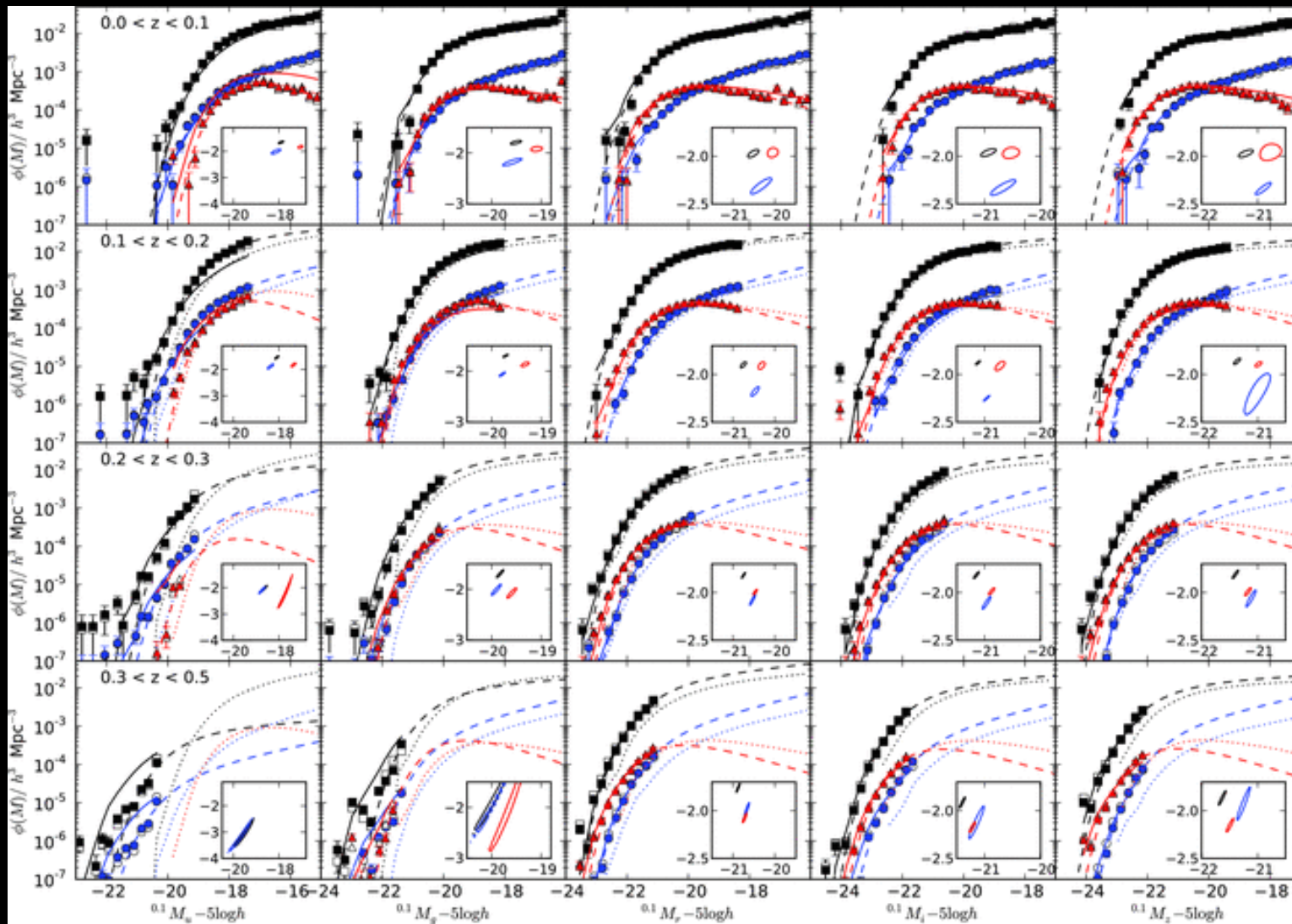
# Luminosity function

- Depends on band
- Type of galaxy (in this case Loveday et al. 2011 blue and red galaxies)
- Evolves with redshift (see next slide)
- Usually described as a powerlaw + exponential cutoff known as Schechter function

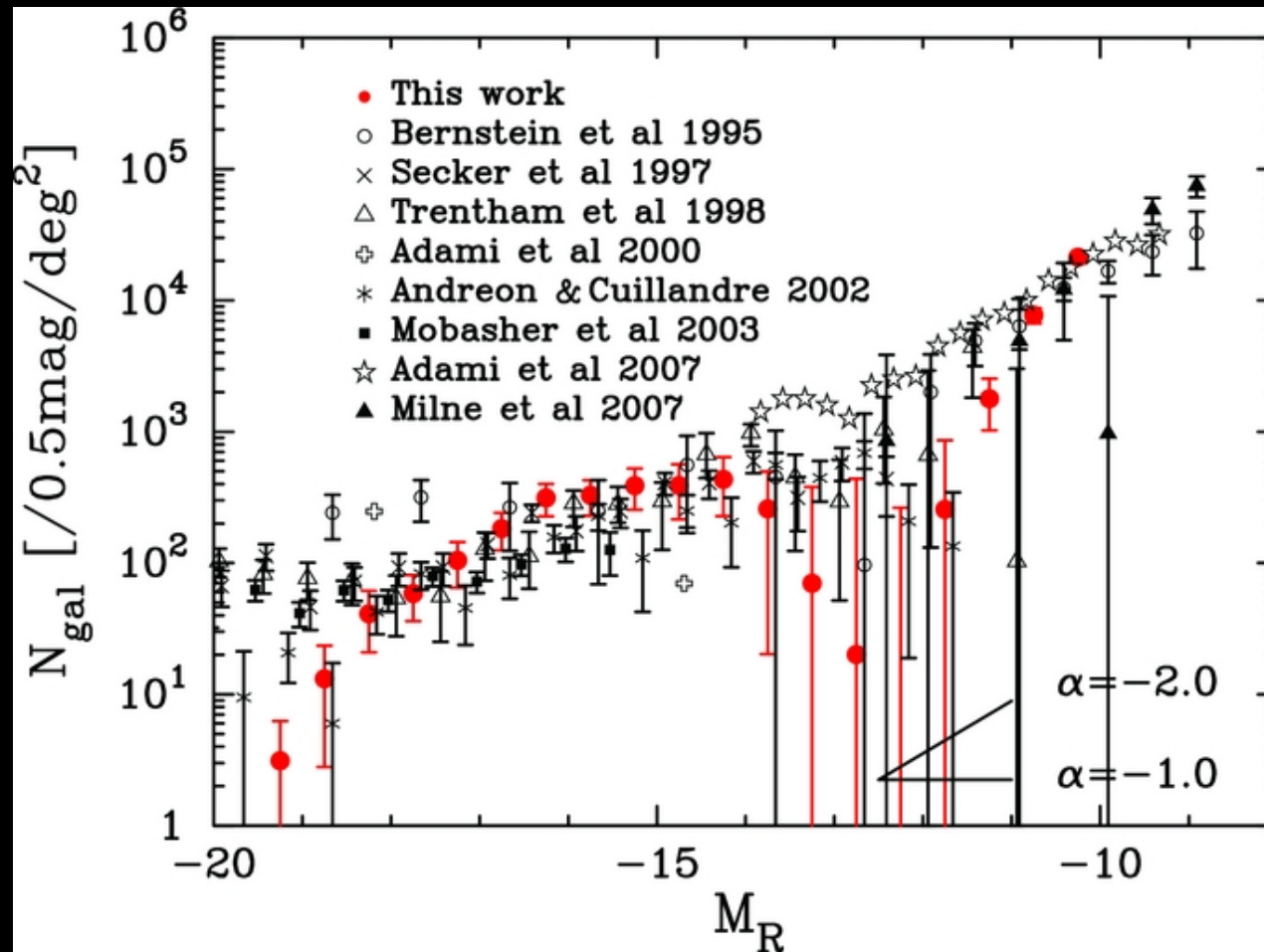
$$\phi(M) = 0.4 \ln \phi^* \left( 10^{0.4(M^* - M)} \right)^{1+\alpha} \exp \left( -10^{0.4(M^* - M)} \right)$$



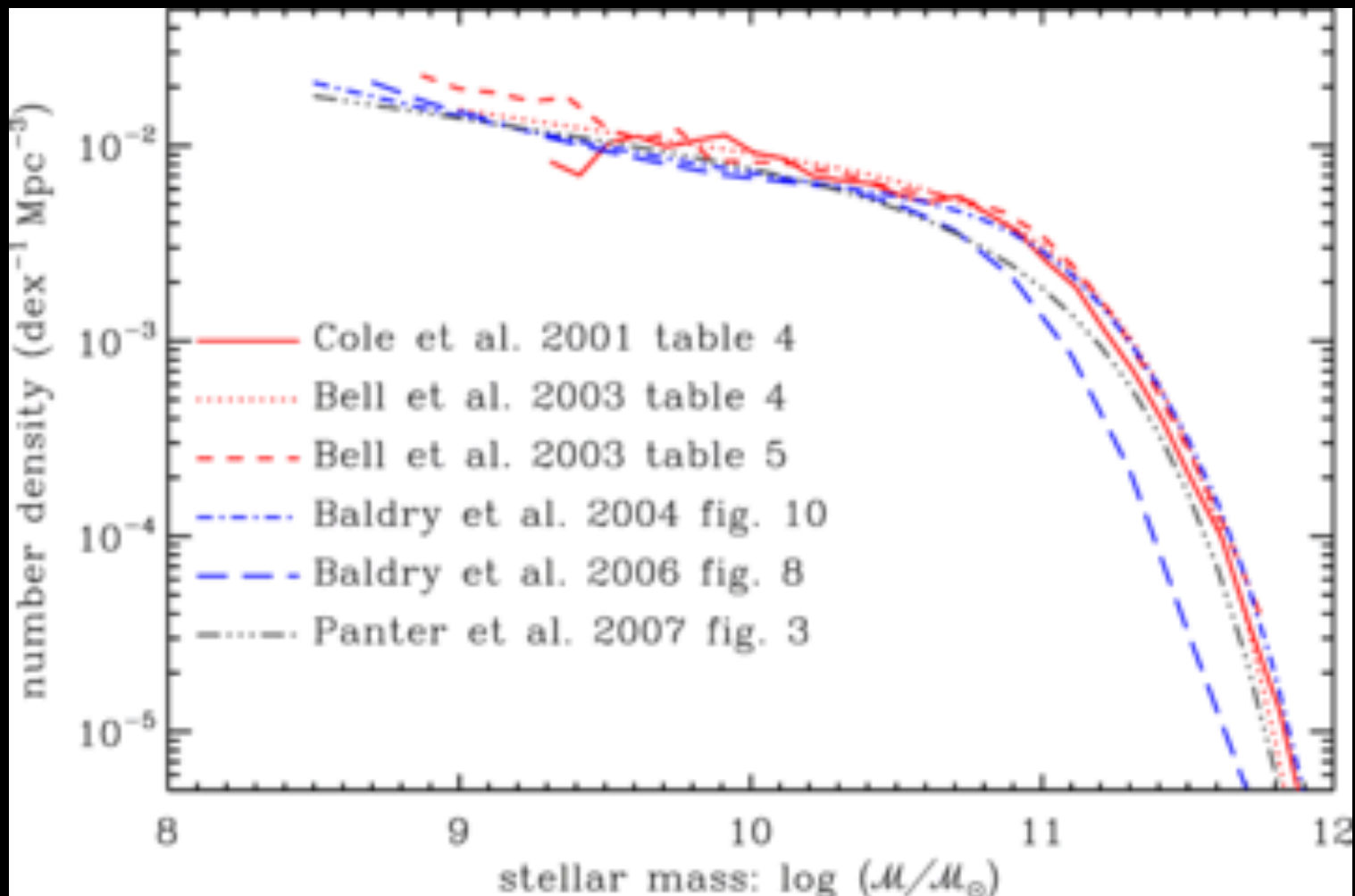
# Luminosity function



# Luminosity function



# Stellar mass function

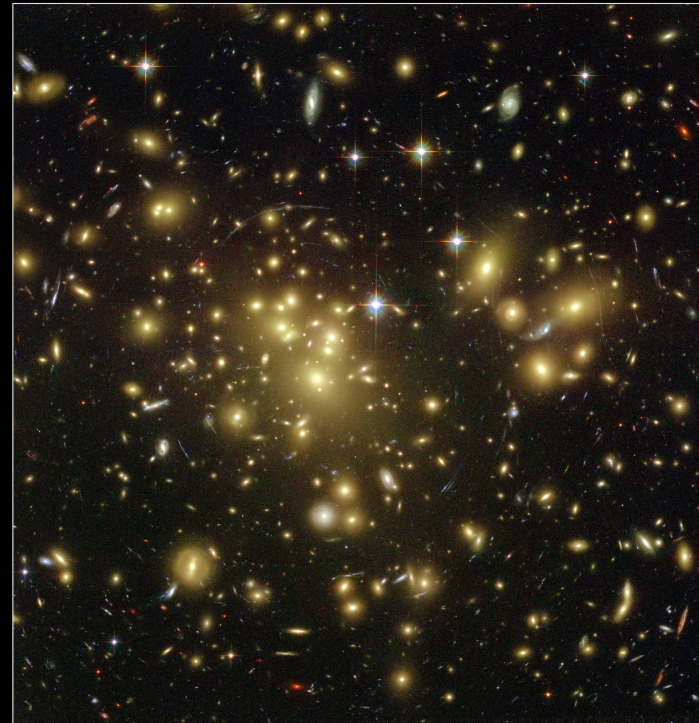


What about halo mass function?

Baldry et al. 2008

# Clusters of galaxies

- Massive systems, typically above  $10^{14}$  Msun
- Typically contain very hot gas  $kT \sim \text{keV}$  and above (but not always)
  - Free free emission in the X-ray
- Gas is believed to be mostly pressure supported (write hydro equilibrium eq on blackboard)
- Act as gravitational lenses (basic of gravitational lensing will be covered later)
- Kinematics in clusters was first evidence of dark matter (virial theorem)
- Sunyaev-Zeldovich Effect (blackboard)



**Galaxy Cluster Abell 1689**  
Hubble Space Telescope • Advanced Camera for Surveys

NASA, N. Benitez (JHU), T. Broadhurst (The Hebrew University), H. Ford (JHU), M. Clampin (STScI), G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory), the ACS Science Team and ESA  
STScI-PRC03-01a

# Examples of cluster in the optical

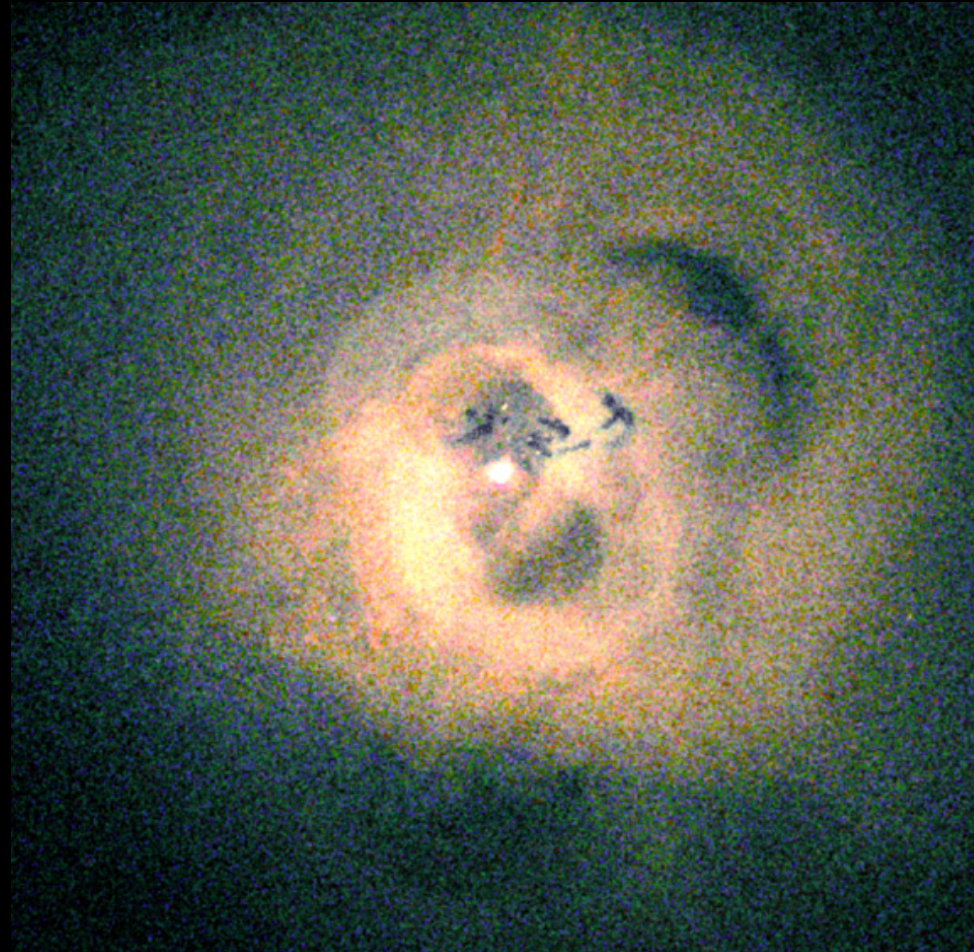


**Galaxy Cluster Abell 2218**

NASA, A. Fruchter and the ERO Team (STScI) • STScI-PRC00-08

**HST • WFPC2**

# Examples of cluster in the X-ray



Perseus cluster; Fabian et al

# Examples of cluster in the X-ray



Abell 383; recent PR from Newman and Morandi

# Homework for 1/14

- Read and memorize 😊 Chapters 1-4 of the Longair's textbook.

The end