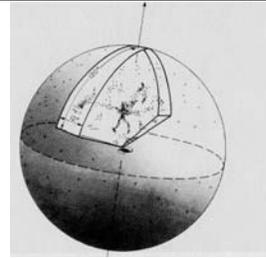
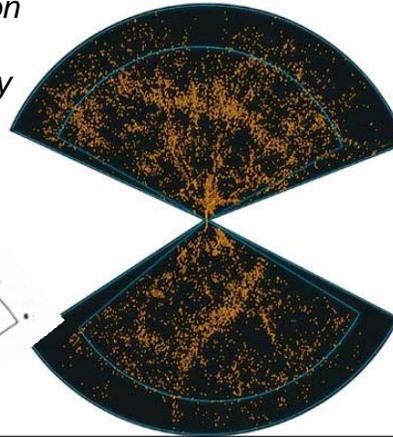
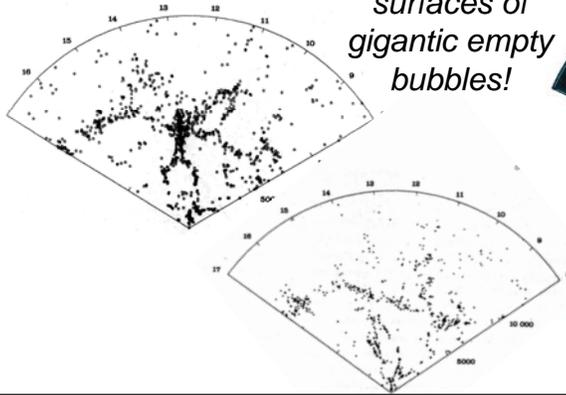


Large-Scale Structures: A Slice of the Sky

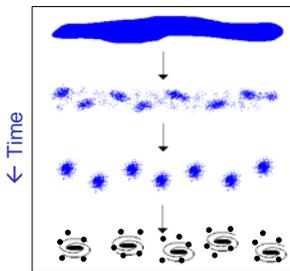
[see Fig 16.13]



*Galaxies are on
surfaces of
gigantic empty
bubbles!*



Dark Matter and the Formation of Structure

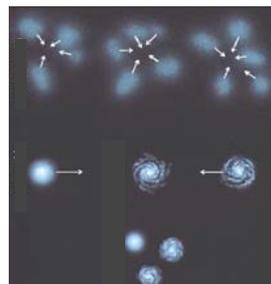


Top-Down:

Large structures (e.g. galaxy superclusters, clusters) form first
Then fragment into galaxies
Then globular clusters, etc form within galaxies.

Predicted for Hot Dark Matter

Predicted for Cold Dark Matter



Bottom-up:

Small structures form first

- Dwarf galaxies
- Globular Clusters

Galaxies grow by cannibalism

Galaxy clusters form last

The Cosmic Microwave Background

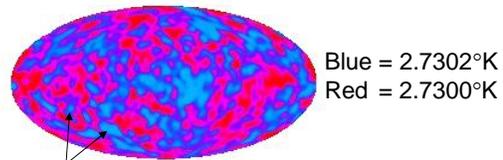
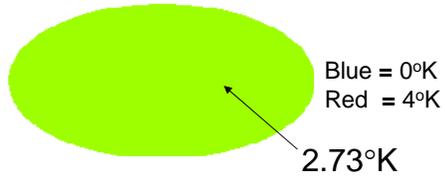
Comes from all directions

COBE satellite (1989)



Whole-Earth Map

Whole-Sky Maps



Seeds of future galaxies and galaxy clusters

$R = 6.0 \text{ Mpc}$ $z = 10.155$

In "proper" coordinates

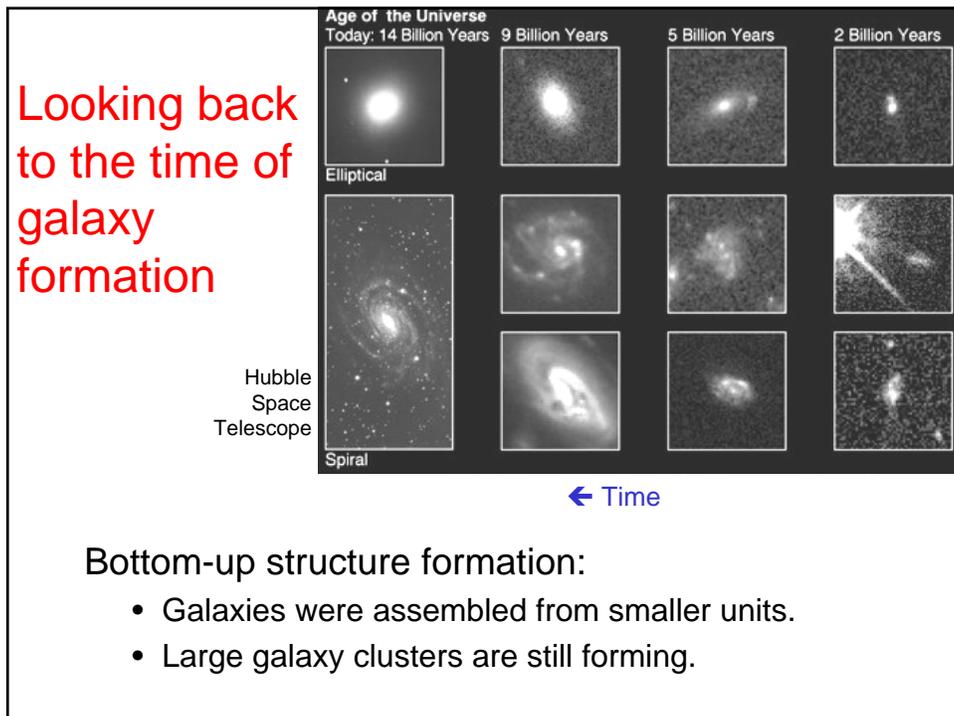
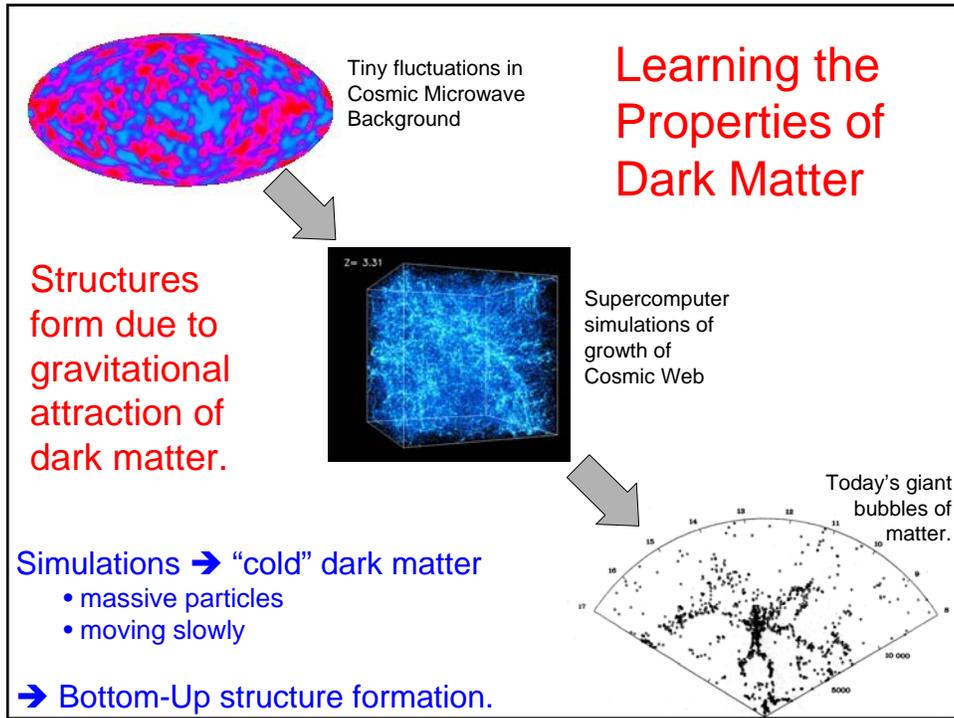
$a = 0.090$ diemand 2003

**The Structure of the Universe:
The "Cosmic Web"**

Observed : Giant Bubbles

$Z = 28.62$

In co-moving coordinates



Life in the fastlane...

Colliding galaxies

Meanwhile, in a galaxy close, close to home...

The Milky Way Meets Andromeda

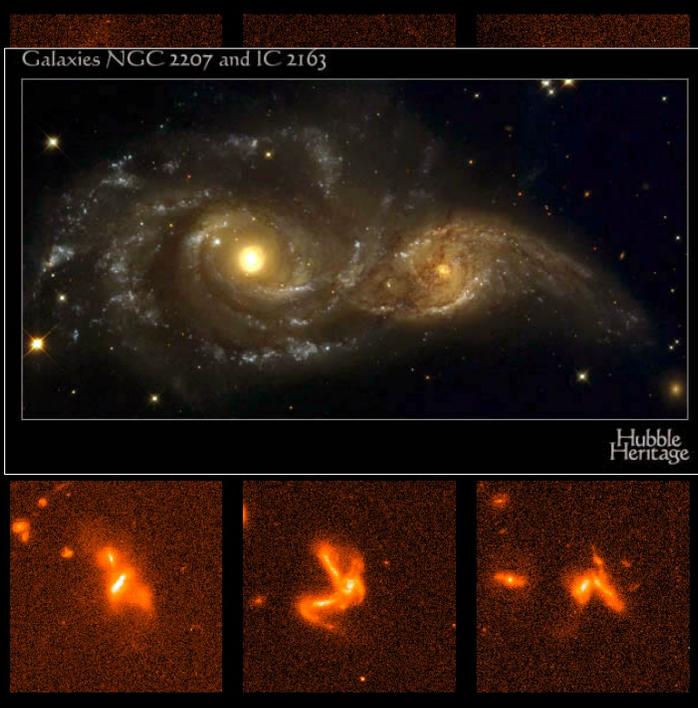
2.5 million ly away

Approaching at 500,000 km/hr

→ Collision in 3 billion yrs

Movie lasts 1.3 billion yrs.

play

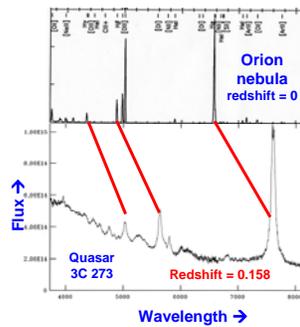
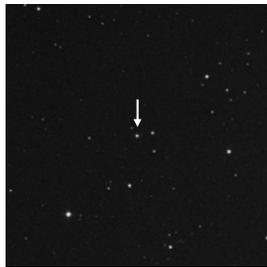


Quasars

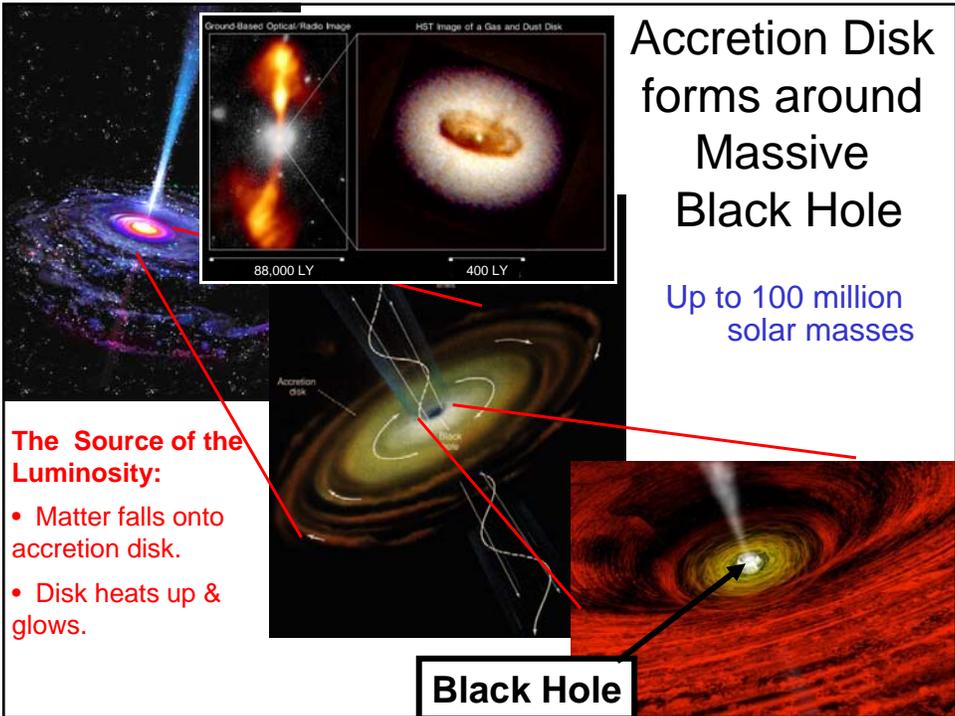
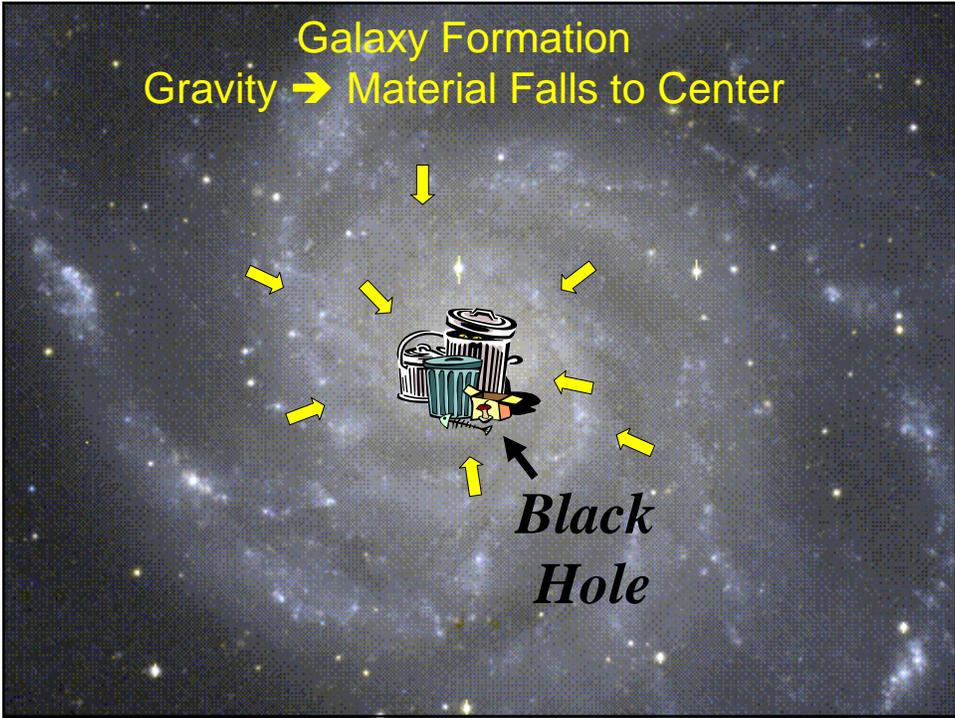
Quasi-Stellar Radio Sources

The Most Energetic Objects in the Universe

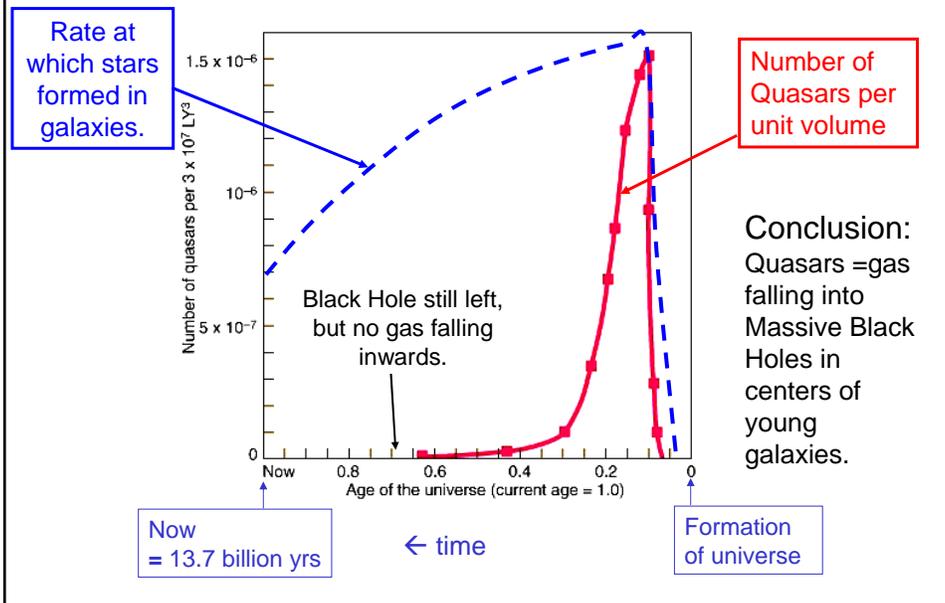
Look like medium-brightness stars, but 1000 times more luminous than our galaxy.



- *Luminosity* = flux x distance²
- *Distance*: from redshift + Hubble's Law.
→ huge distance → huge luminosity!



Most Quasars Lived and Died Long Ago



The Black Hole at the Galactic Center

1 million M_{\odot}

Measure mass using

$$P^2 = \text{constant} \times \frac{a^3}{m_1 + m_2}$$

A few Schwarzschild radii

Latest data follows complete orbits to within 60AU from black hole.

