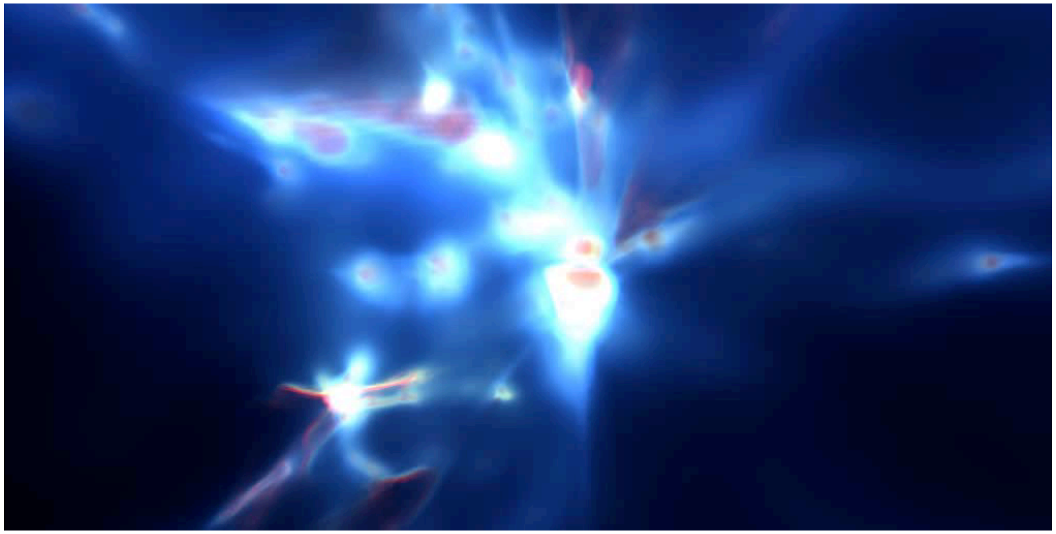
The First Things in the Universe



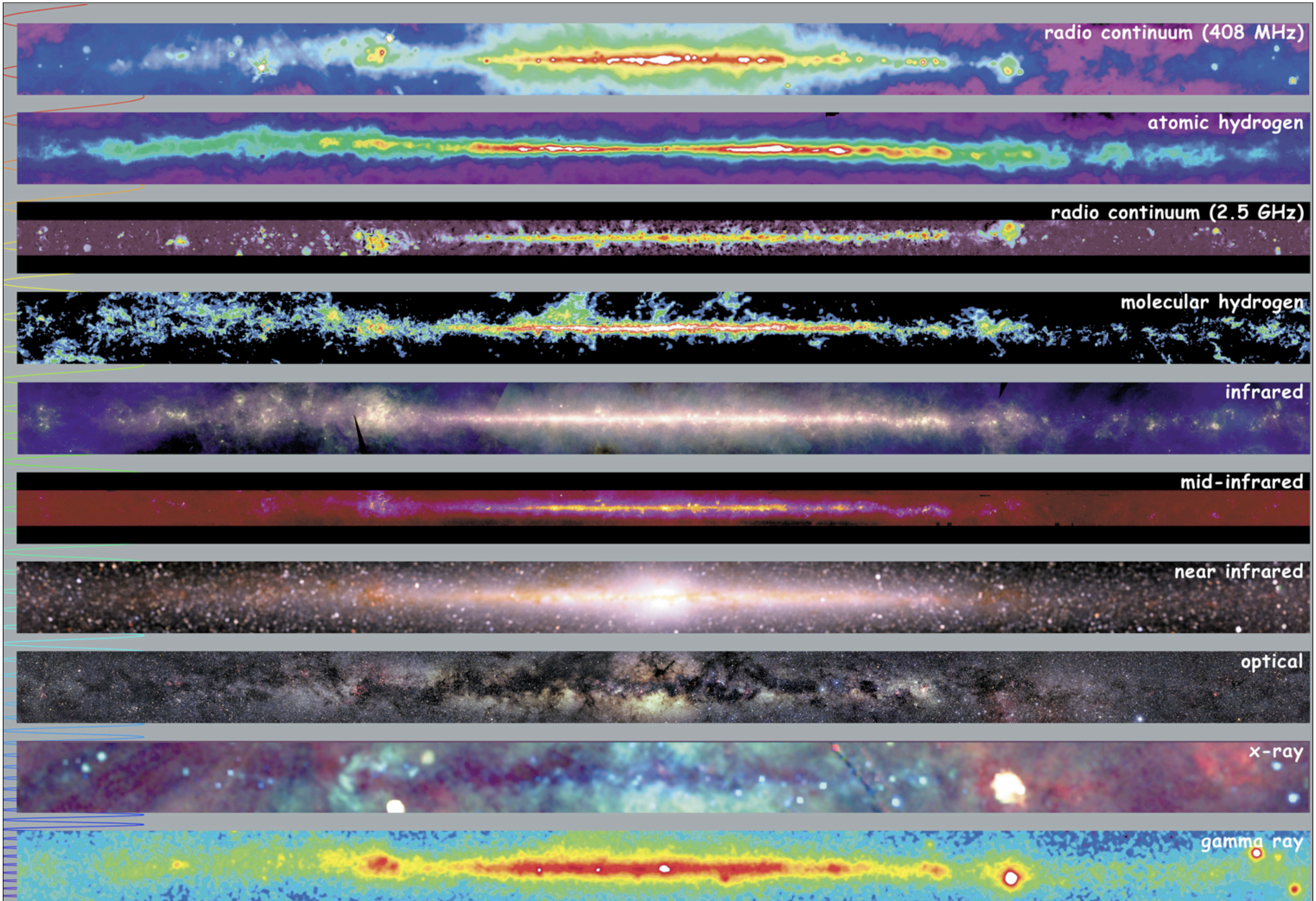
Simulation: Marcelo Alvarez, John Wise & Tom Abel 2007
Visualization: Ralf Kähler, Alvarez & Abel

Outwards into space: Our place in the Universe
Obvious Dark Matter
Baby pictures of the Universe:
Starting from the beginning with the biggest supercomputers:
First things first!
Taking it personal.

- Tom Abel
  Kavli Institute for Particle Astrophysics and Cosmology
  Stanford Linear Accelerator Center & Stanford University

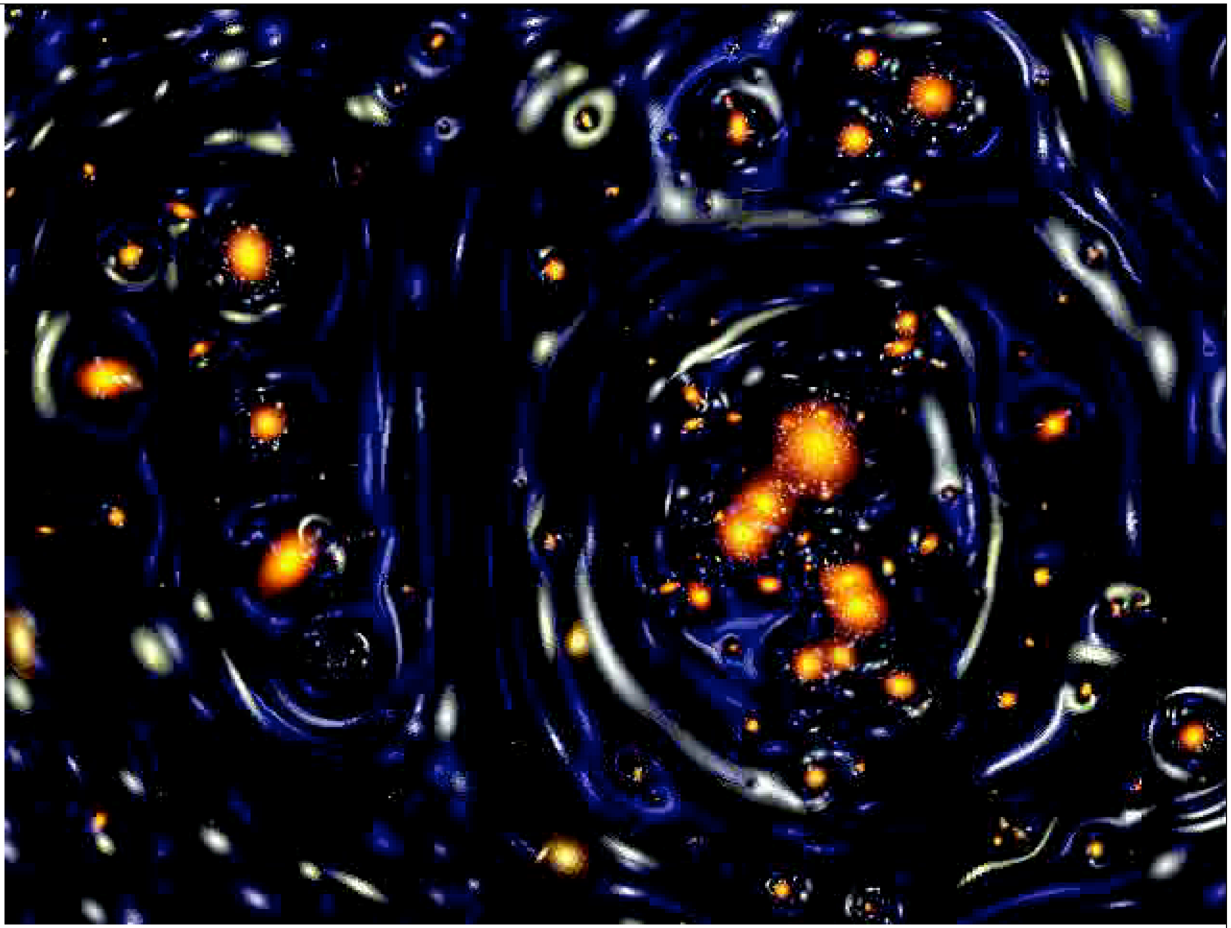
Today

Tom Abel
KIPAC



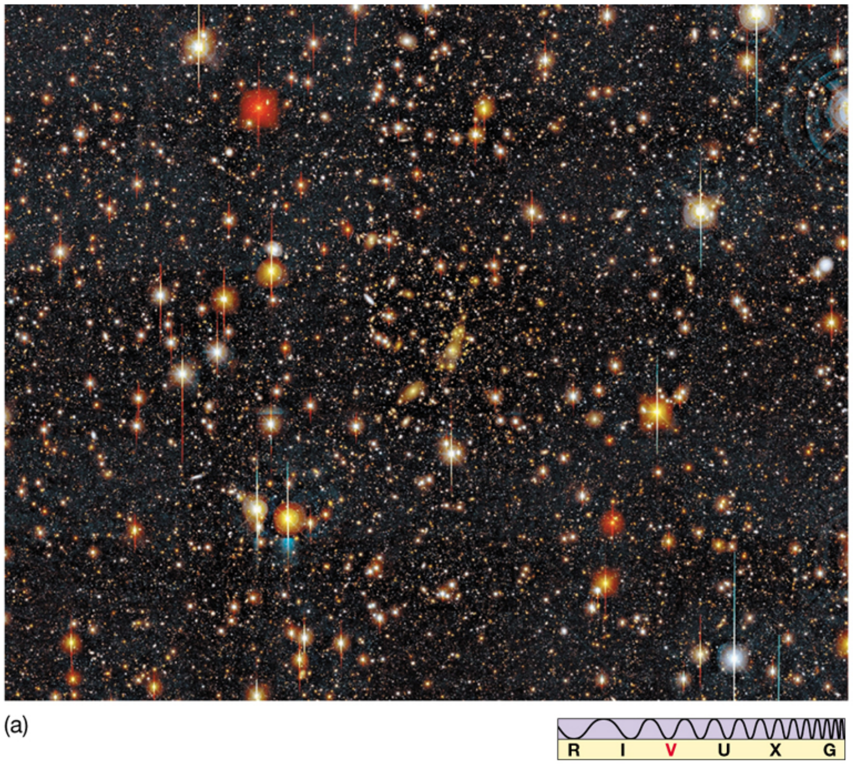
Multiwavelength Milky Way

Strong Gravitational Lensing

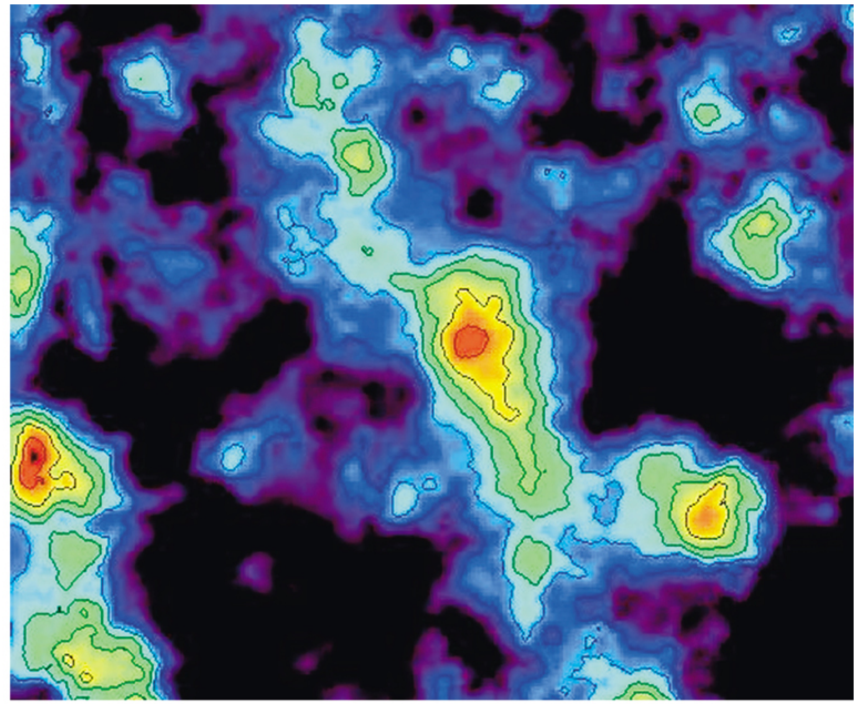


When light rays from a distant source bend around both sides of a massive object and cross near Earth, the effect is called "strong gravitational lensing." Strong lensing magnifies and distorts light from the source, and in some cases also produces multiple images of the source. This movie shows a simulation of strong lensing by a massive cluster of galaxies containing huge amounts of both visible matter and "dark matter." The light distortion effects are exaggerated in the movie, but generally speaking such effects are common since rich clusters of galaxies are the largest concentrations of matter in the universe. In fact, the patterns of distortion help astronomers determine the amount of dark matter in clusters, and how that matter is spread in the cluster - both of which tell a great deal about the behavior of matter in the cosmos as a whole.

Weak Gravitational Lensing
Dark Matter Map



(a)



(b)

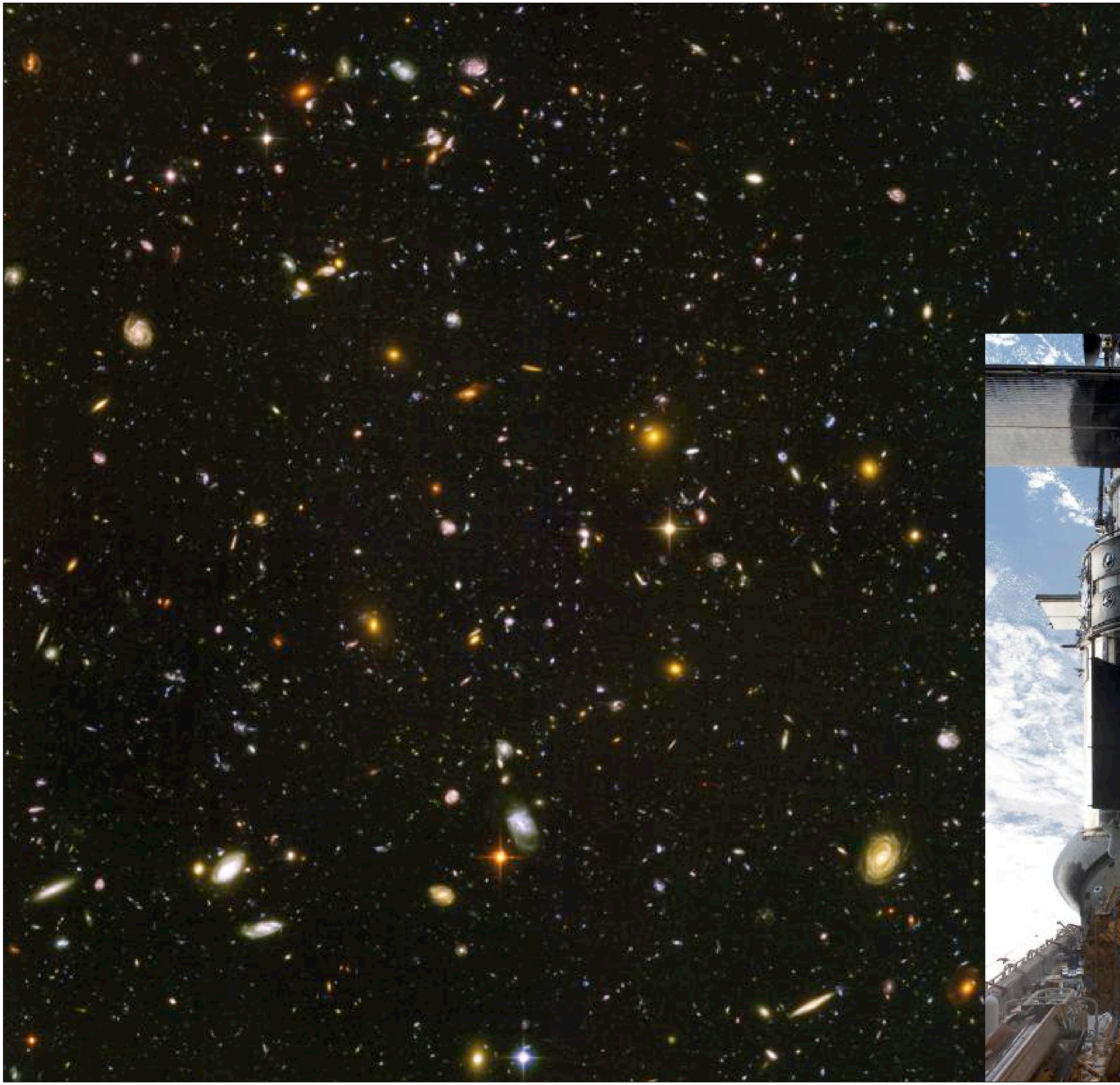
Dark matter & Gravity dominate on large scales

Clowe, Bradac, et al. 2007

collision speed 2600 km/s
mass ratio ~1/10
Cluster: 1E0657-56
~ 10 million lyrs across
~ 10 billion lyrs from earth

Simulation: John Wise & Tom Abel
for Marusa Bradac, 2007 aired on Fox News


Ancient globular star cluster M80



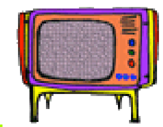
HST:
A Time Machine

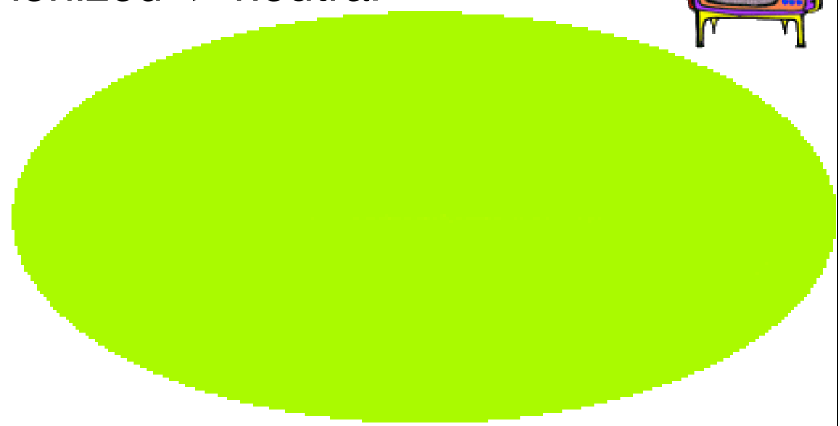
Best Time machine uses radio waves gives Baby Pictures of Universe

Universe at 400,000 years of Age

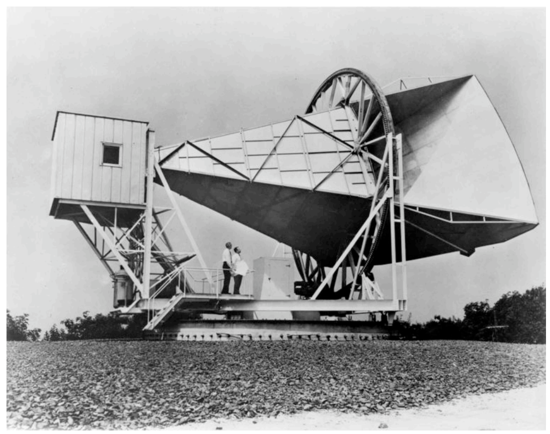
13.7 billion years

ionized -> neutral

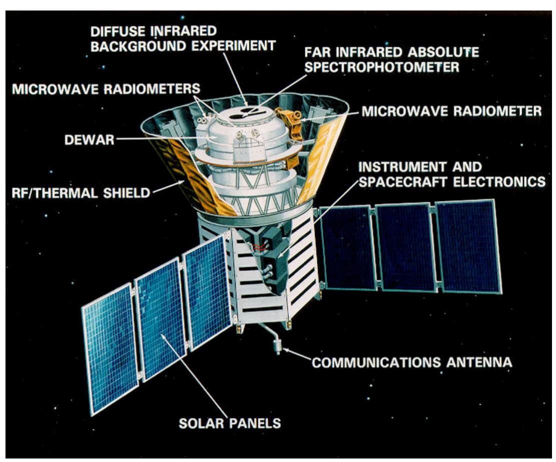


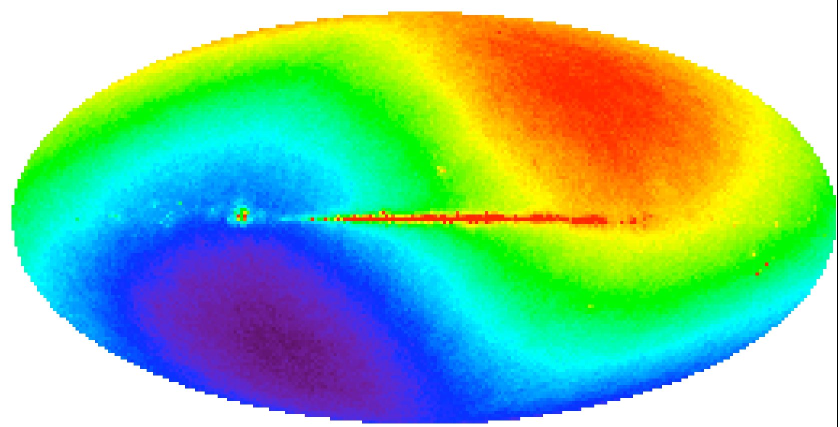


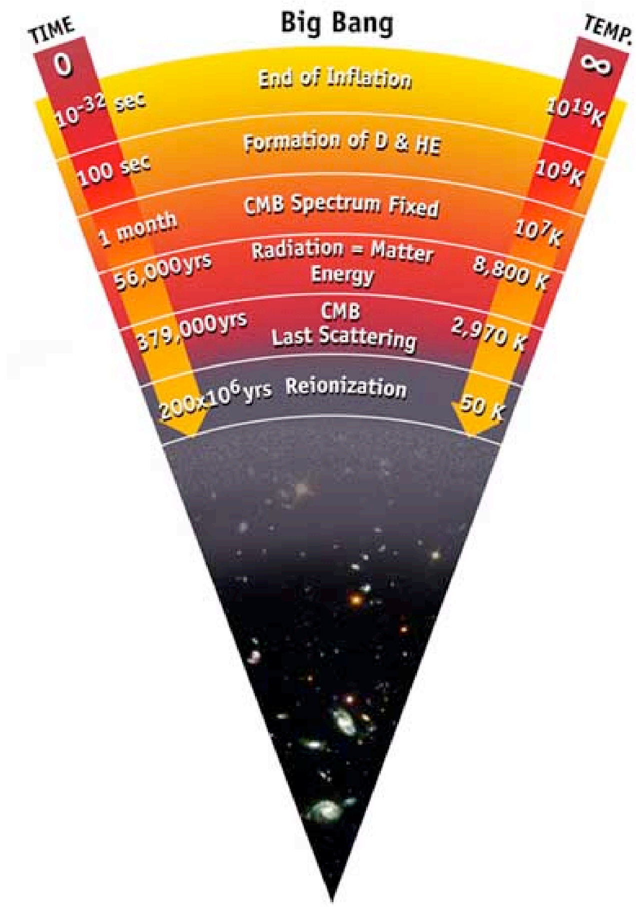
Nobel 1978:
Penzias & Wilson



Nobel 2006:
Mather & Smoot

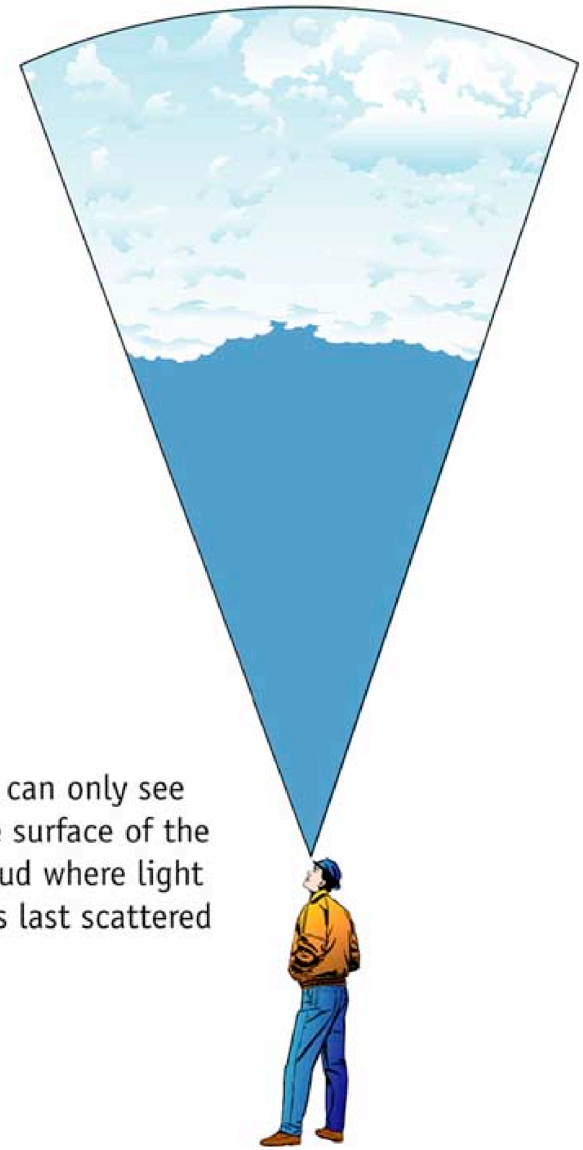






PRESENT
13.7 Billion Years
after the Big Bang

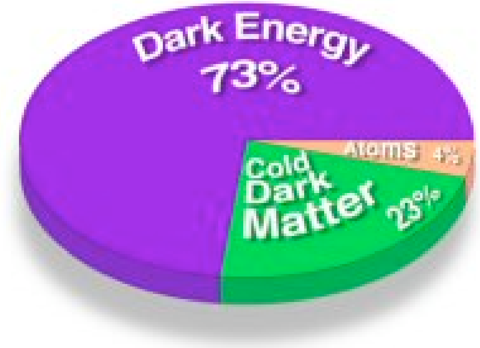
The cosmic microwave background Radiation's "surface of last scatter" is analogous to the light coming through the clouds to our eye on a cloudy day.



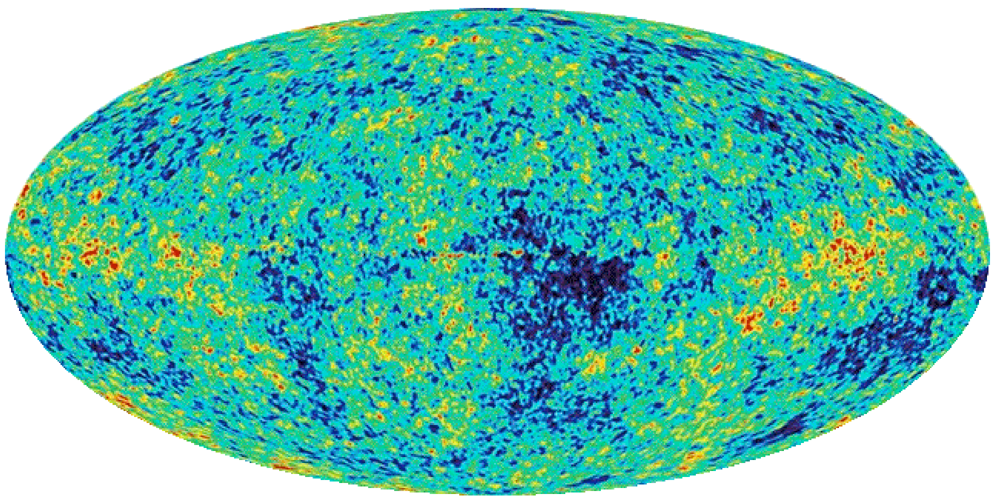
We can only see the surface of the cloud where light was last scattered

knowing hydrogen & observing CMB
tells us how much universe expanded since then

So we know what it looked like then, but what happened next?



- 13.7 billion years ago:
  - Hydrogen, Helium Primordial Gas 17% of total matter content
    Dark Matter the rest. About 25% of total energy density in the universe today.
  - Densest “Objects” in the Universe less than 1.01 of the average density
  - Gravitational instability of pre-existing density variations leads to formation of Structure and eventually us



Simple!

- Initial Conditions from observations of the cosmic microwave background radiation
- Physics: Gravity, fluids, chemistry, radiation, etc.
- Transition from Linear to Non-Linear; fancy for easy to difficult
- Using patched based structured adaptive (space & time) mesh refinement
- Differs from current day star formation:
  - Complete initial conditions known
  - all physical processes are understood

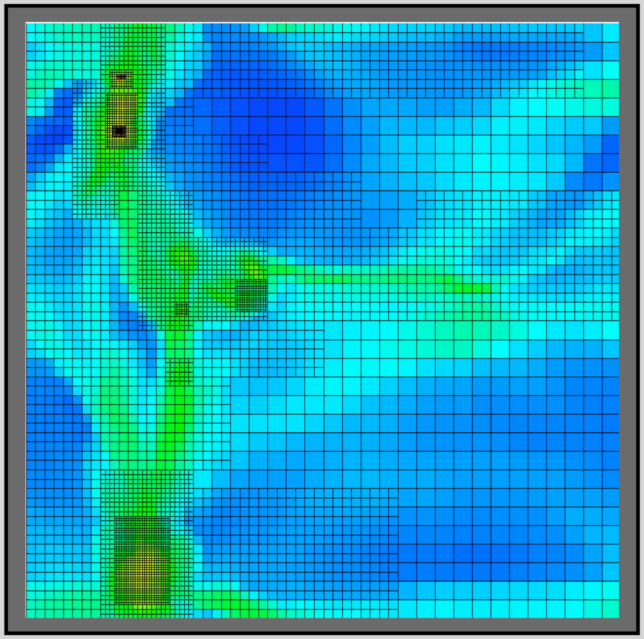
Ralf Kähler & Tom Abel for PBS Origins. Aired Dec 04

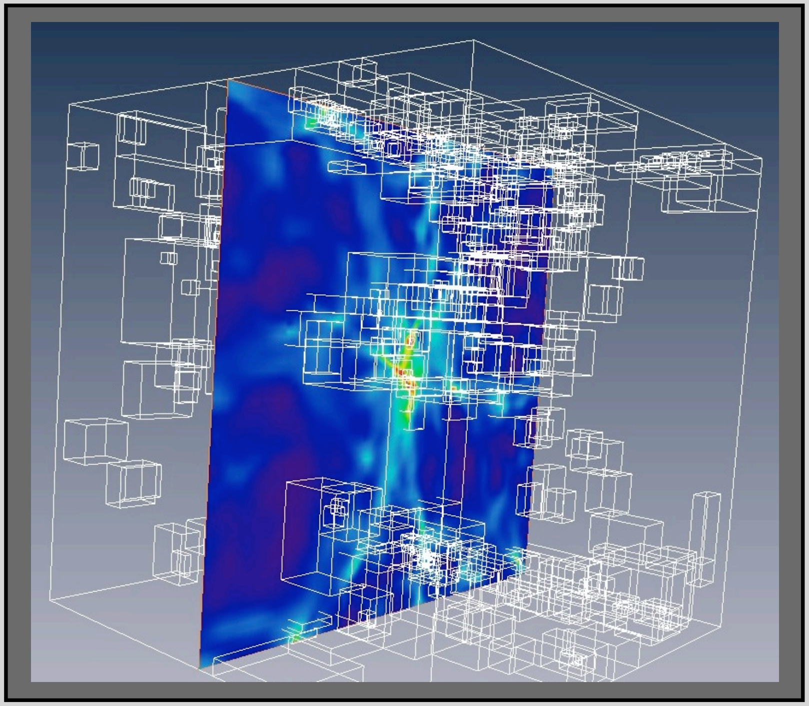
$$\frac{R_{\odot}}{R_{\mathrm{MilkyWay}}} \approx 10^{-12}$$

$$\frac{P_{\odot,\mathrm{Kepler}}}{t_{\mathrm{Hubble}}(z=30)} \approx 10^{-12}$$

Cosmological Adaptive Mesh Refinement

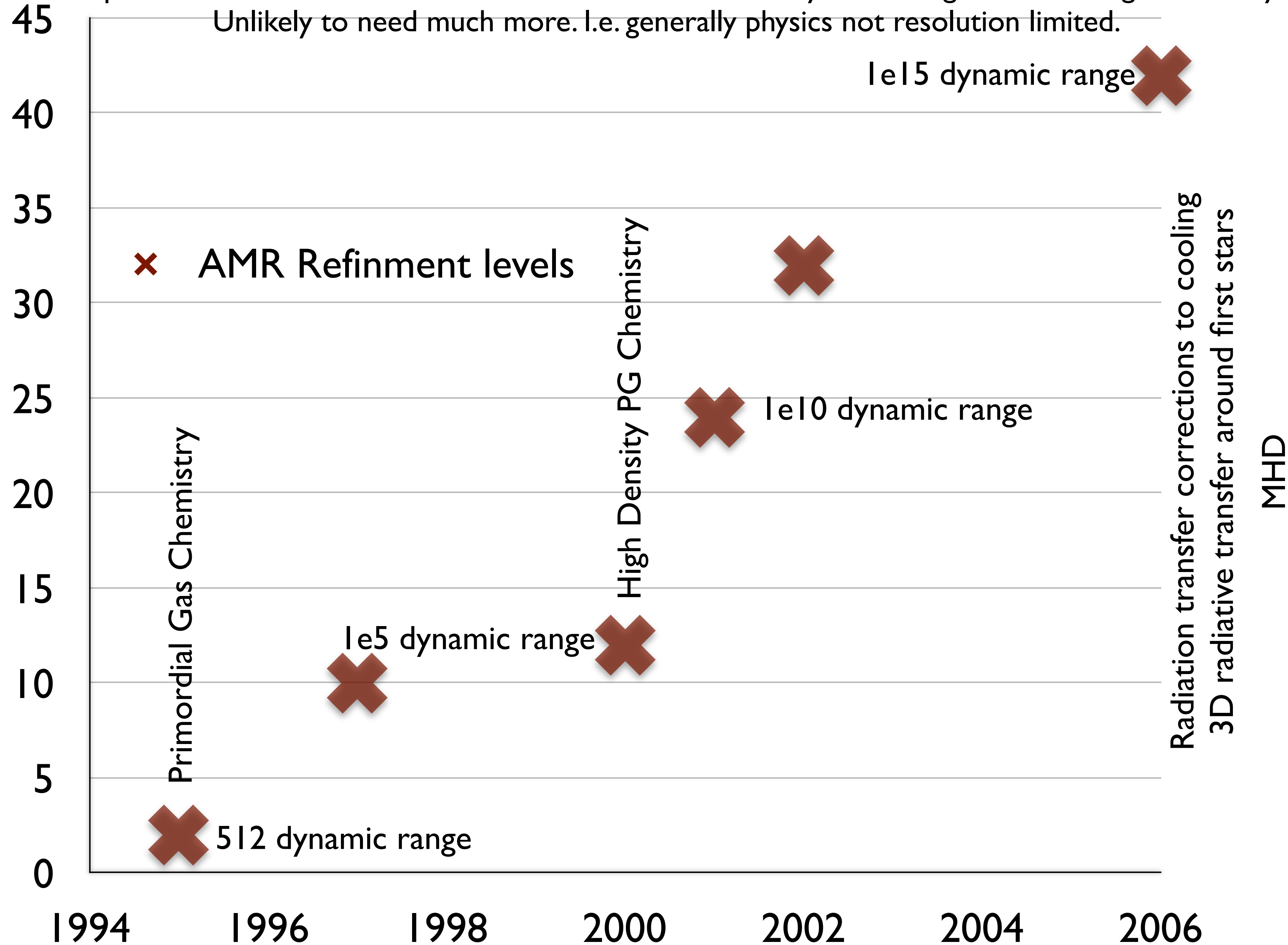
- **Enzo:** Bryan and Norman 1997-; Abel et al 97; Anninos et al 97; Bryan, Abel & Norman 2002; O'Shea et al; Abel, Wise & Bryan 2006
  - 87,000 lines of code in C++ and F77
  - Cosmological Radiation Hydrodynamics adapting in space and time
  - Dynamic range up to 1e15 using quadruple precision coordinates in space and time
  - Dynamically load balanced parallel with MPI
  - Gravity, DM, Gas, Chemistry, Radiation, star formation & feedback
  - Current new Developments at KIPAC: exact 3D radiation transport, very high density chemistry, HD & fine structure line cooling, relativistic hydro, passive MHD, new visualization toolkit

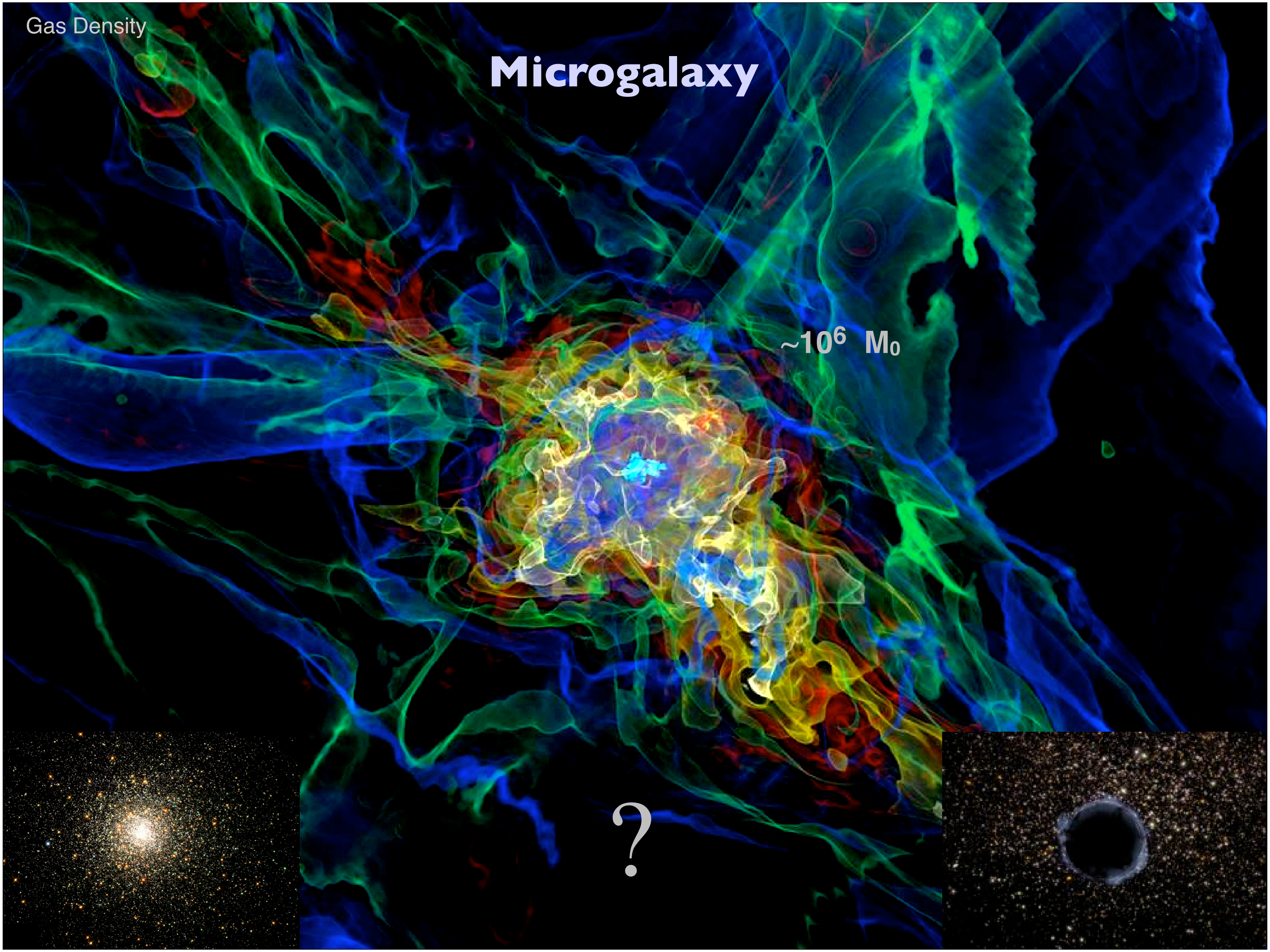




Technical Progress with *Enzo*

1Mpc - 3e9cm = 0.1 ls i.e. 40 cells across the Sun = 1e15 dynamic range. >1e25 range in density
Unlikely to need much more. I.e. generally physics not resolution limited.




Gas Density
Microgalaxy
~10^6 M0
?

The first 100 million years in one sentence

Small dark matter halos form first, gas follows, hydrogen molecules form and make the gas shine, it collapses 10 million times further, ignites hydrogen fusion, makes a massive star, radiation disperses birth-cloud, explodes in a supernovae which releases carbon, oxygen, etc., collapses again, makes more stars, more explosions, more than 10 million massive stars later: **us**

Custom GPU based volume renderer for adaptive grids by Ralf Kähler, John Wise & Tom Abel

Simulation: John Wise & Tom Abel
Visualization: Ralf Kähler, Wise & Abel


CALIFORNIA NEBULA, NGC1499
500 pc = 1,500 light years away
30 pc long
Xi Persei, منكب mankib, Shoulder of Pleiades:
O7.5III
330,000 solar luminosities
~40 solar masses, Teff=3.7e4K

3D Cosmological Radiation Hydrodynamics

Focus on point sources

Early methods: Abel, Norman & Madau 1999 ApJ; Abel & Wandelt 2002, MNRAS; Variable Eddington tensors: Gnedin & Abel 2001, NewA

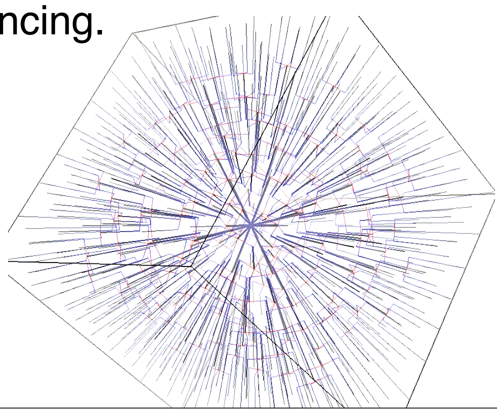
Latest: Abel, Wise & Bryan 06 astro-ph/0606019. Keeps time dependence of transfer equation using photon package concept from Monte Carlo techniques, yet not using any random numbers.

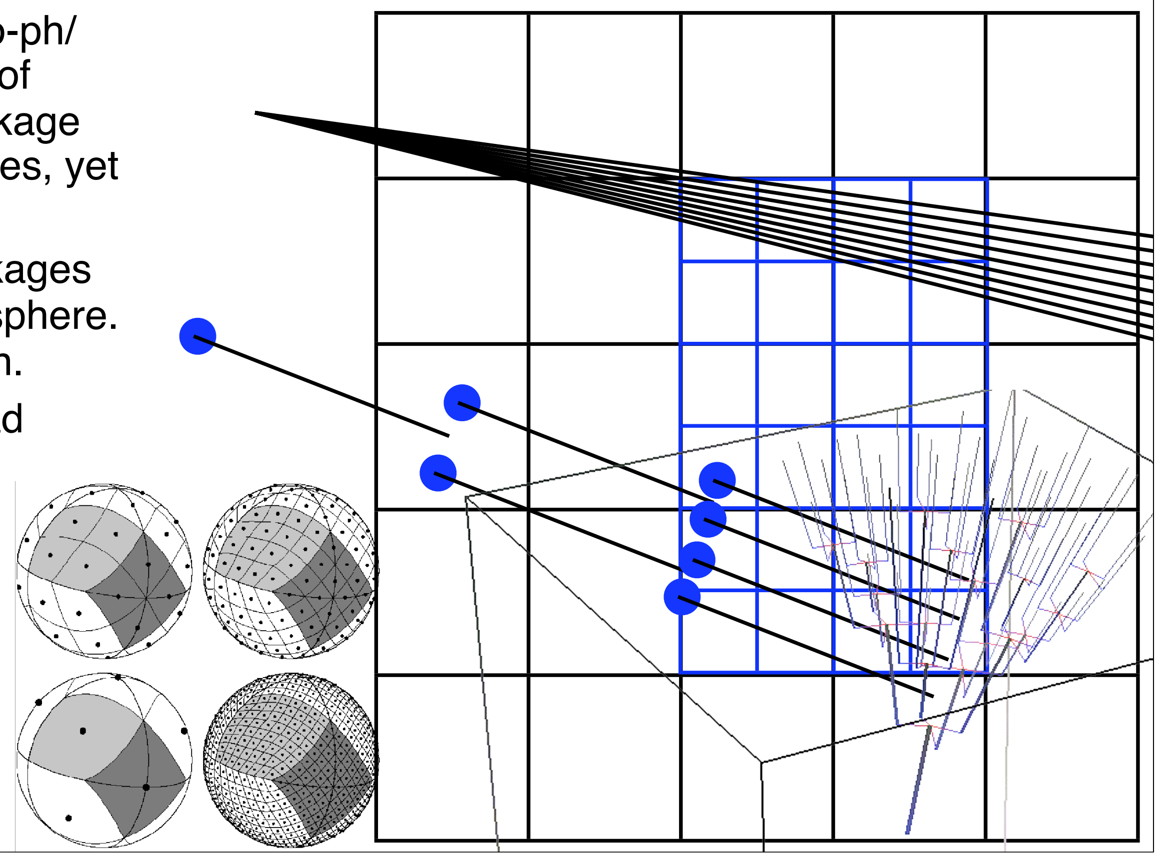
Adaptive ray-tracing of PhotonPackages using HEALPIX pixelization of the sphere. Photon conserving at any resolution.

Parallel using MPI and dynamic load balancing.

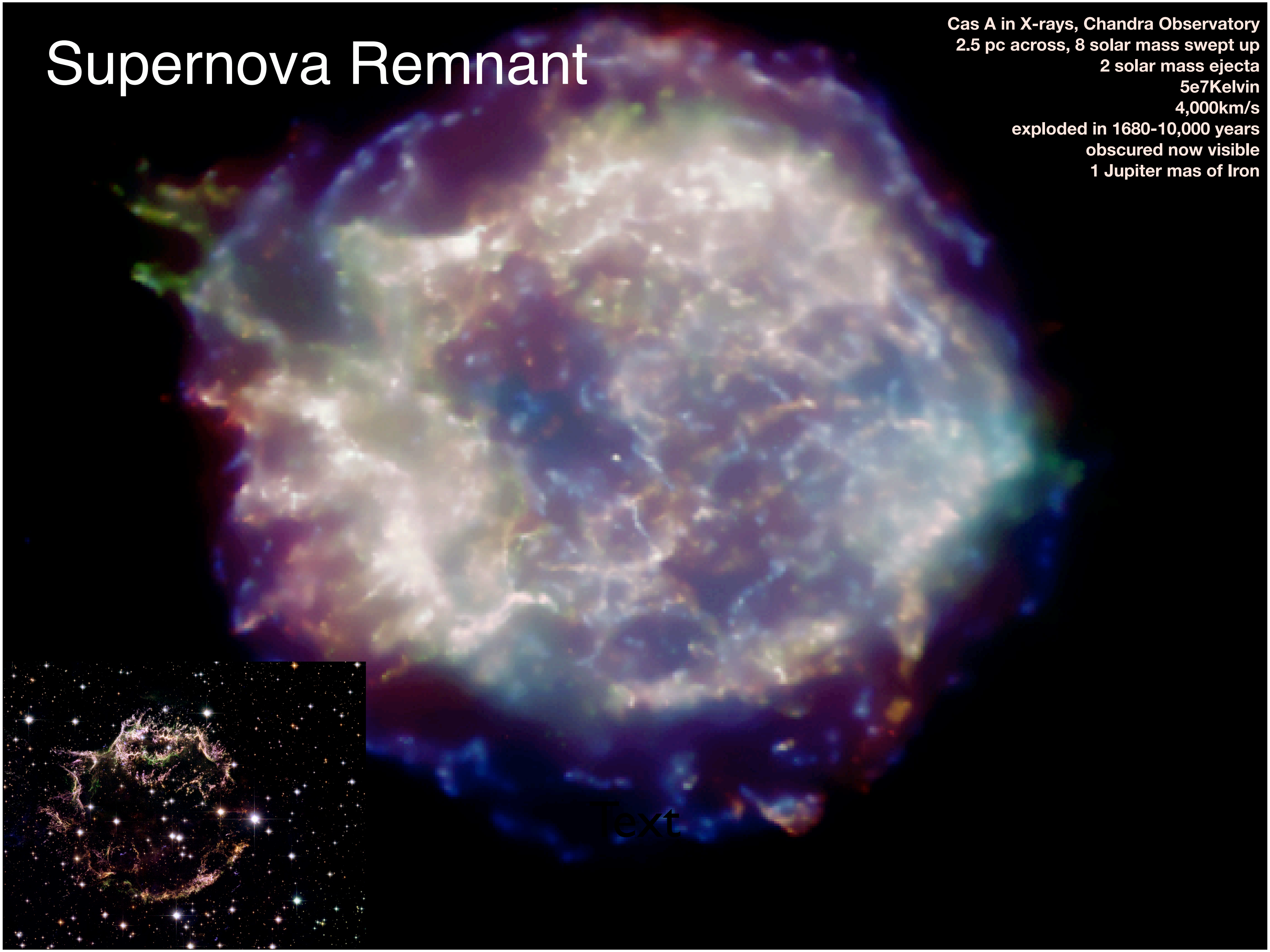
$$\frac{1}{c}\frac{\partial I_\nu}{\partial t} + \frac{\partial I_\nu}{\partial r} = -\kappa I_\nu$$

Transfer done along adaptive rays
Case B recombination

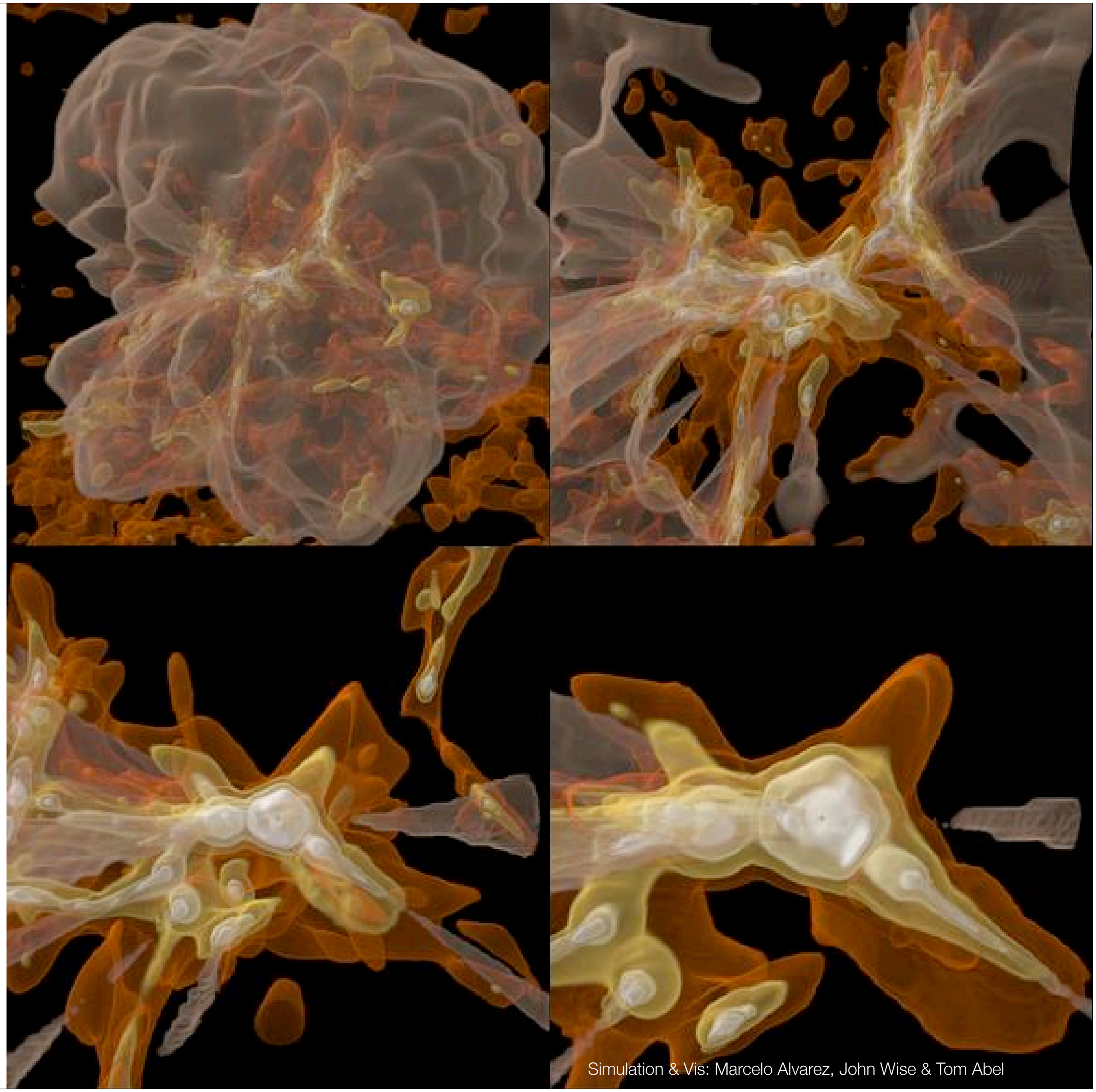




Supernova Remnant

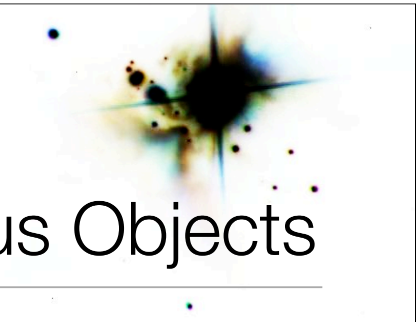


Leave black holes behind?!



>1,000 lyrs across
evolves for
~ 100 million years

Leave
black
holes
behind?!



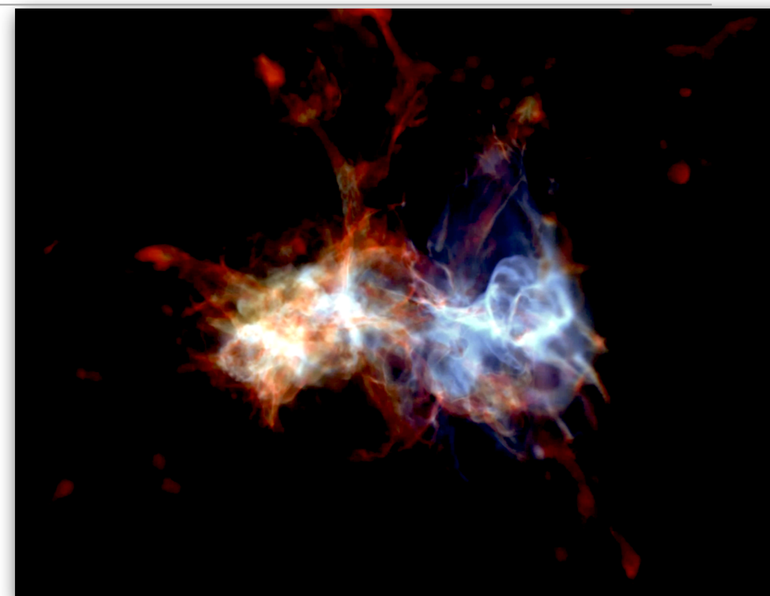
Massive Isolated Stars are the First Luminous Objects

- “Discovered” with supercomputer not telescope.
- Initial proto-star of 10 Jupiter masses accretes same amount every year
- ~ 30 - 300 $M_\odot$ within 10^5 years
  1,000,000 solar luminosities
  2,700,000 years life expectancy
  (~4,000 times shorter than the sun)

Matt Turk & Tom Abel (KIPAC)

- Not around today!
  Some of their black holes though are.
- Consistent with all current observational clues yet no direct observational proof.

Galaxies, one star at a time



John Wise & Tom Abel (KIPAC)

~20,000 light years

First few hundred million years: Cosmic Fireworks

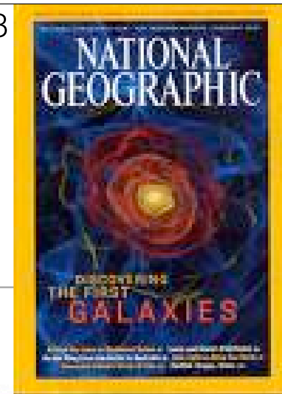
10,000 such
patches make
Milky Way
~ 1e5 first star remnants
early element enrichment

John Wise & Tom Abel (KIPAC)

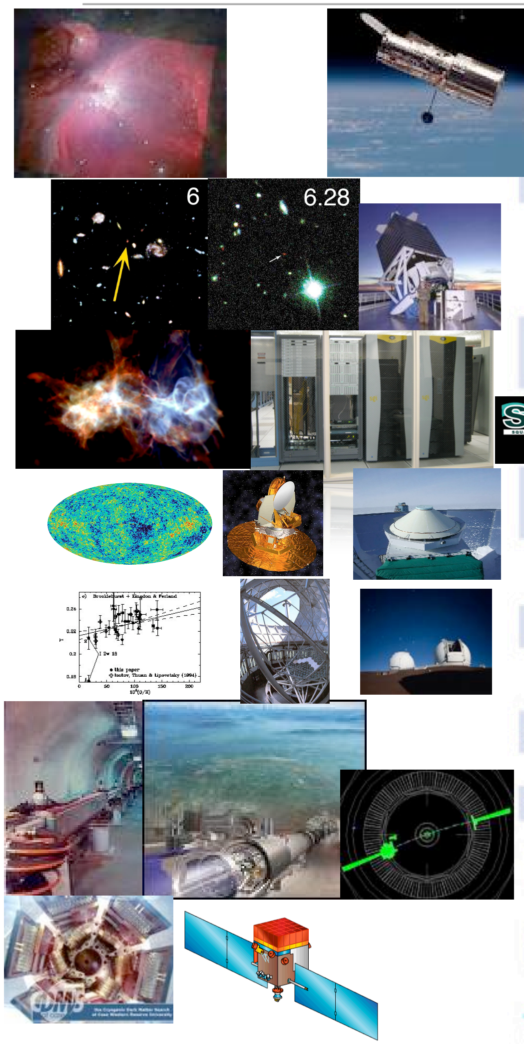

Simulation: John Wise & Tom Abel
Visualization: Ralf Kähler, Wise & Abel

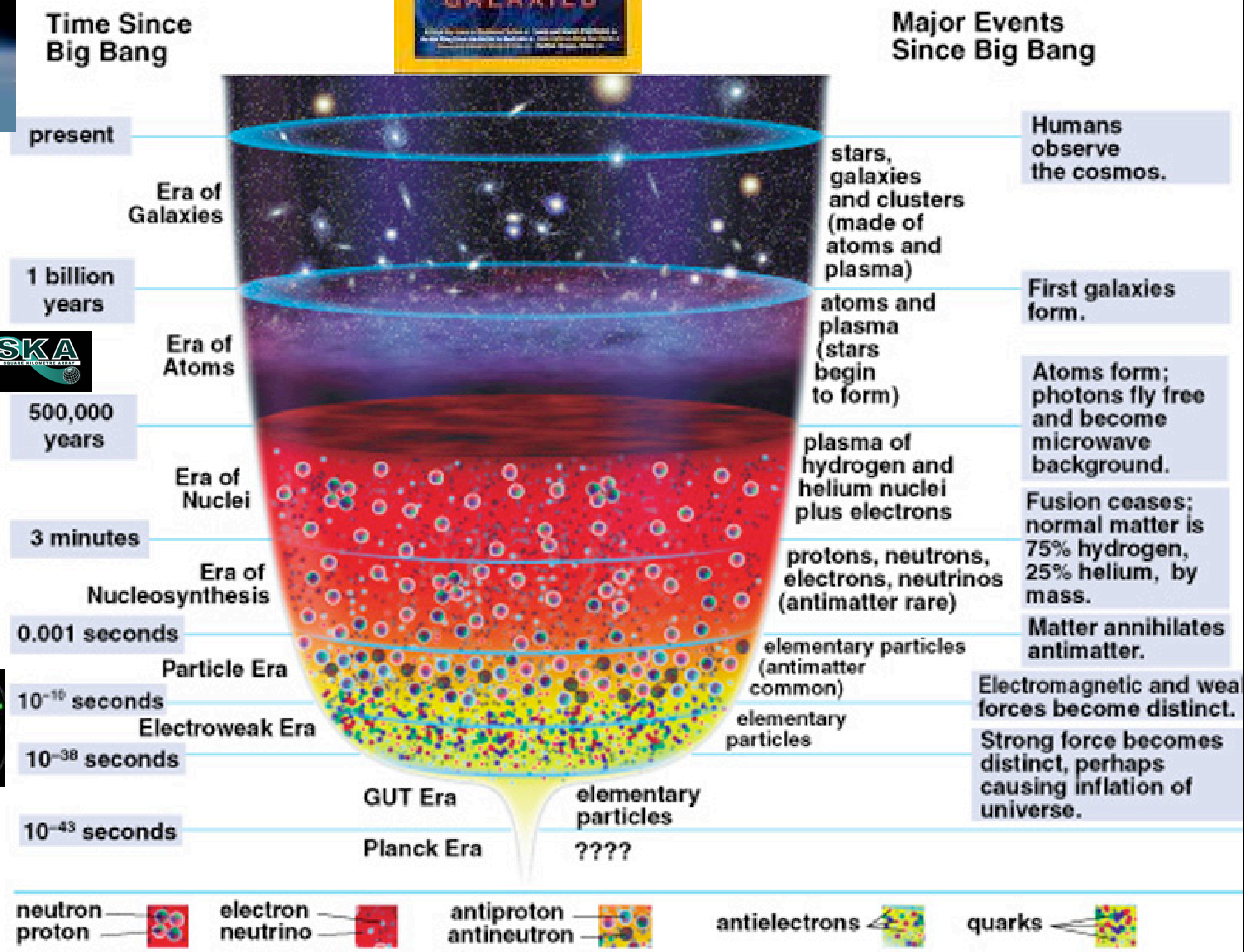
How we find things:

Feb 2003



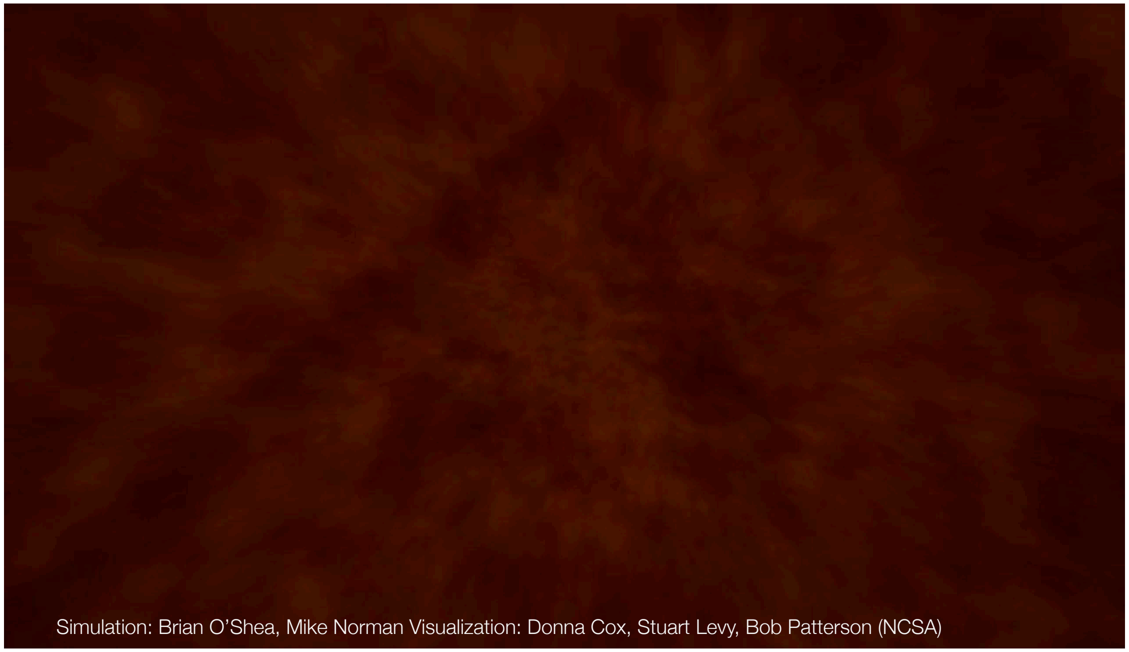
Discovery by Computer?





Taking it personal

- Much of you is 13.7 billion years old
- practically nothing of you is younger than 4.5 billion years
- somewhere between 10,000 and ten million massive stars have helped in making you
- about the amount of one of your fingers came from the earliest stars
- you used to be almost a million light years across



Simulation: Brian O'Shea, Mike Norman Visualization: Donna Cox, Stuart Levy, Bob Patterson (NCSA)

Summary

- The physics of the Universe is explored not only with telescopes but also with supercomputers
- The first stars were massive, short lived and their remains are in you.
- Cosmologists are predicting the past and also are predicting what the next generation of telescopes should see. Now is the time!
- Please do take this personal!