Simulating Galaxies, Stars, and Black Holes

Philip Hopkins

Miller Lunch
09/28/10

Eliot Quataert, Lars Hernquist, T. J. Cox, Kevin Bundy, Jackson DeBuhr, Volker Springel, Dusan Keres, Alison Coil, Gordon Richards, Josh Younger, Desika Narayanan, Paul Martini, Adam Lidz, Tiziana Di Matteo, Yuexing Li, Adam Myers, Patrik Jonsson, Chris Hayward, Chung-Pei Ma

Lars Hernquist

Volker Springel

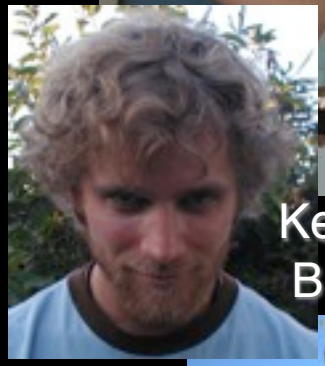
TJ Cox

Eliot Quataert

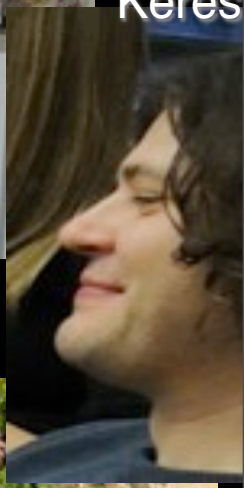
Rachel Somerville

Josh Younger

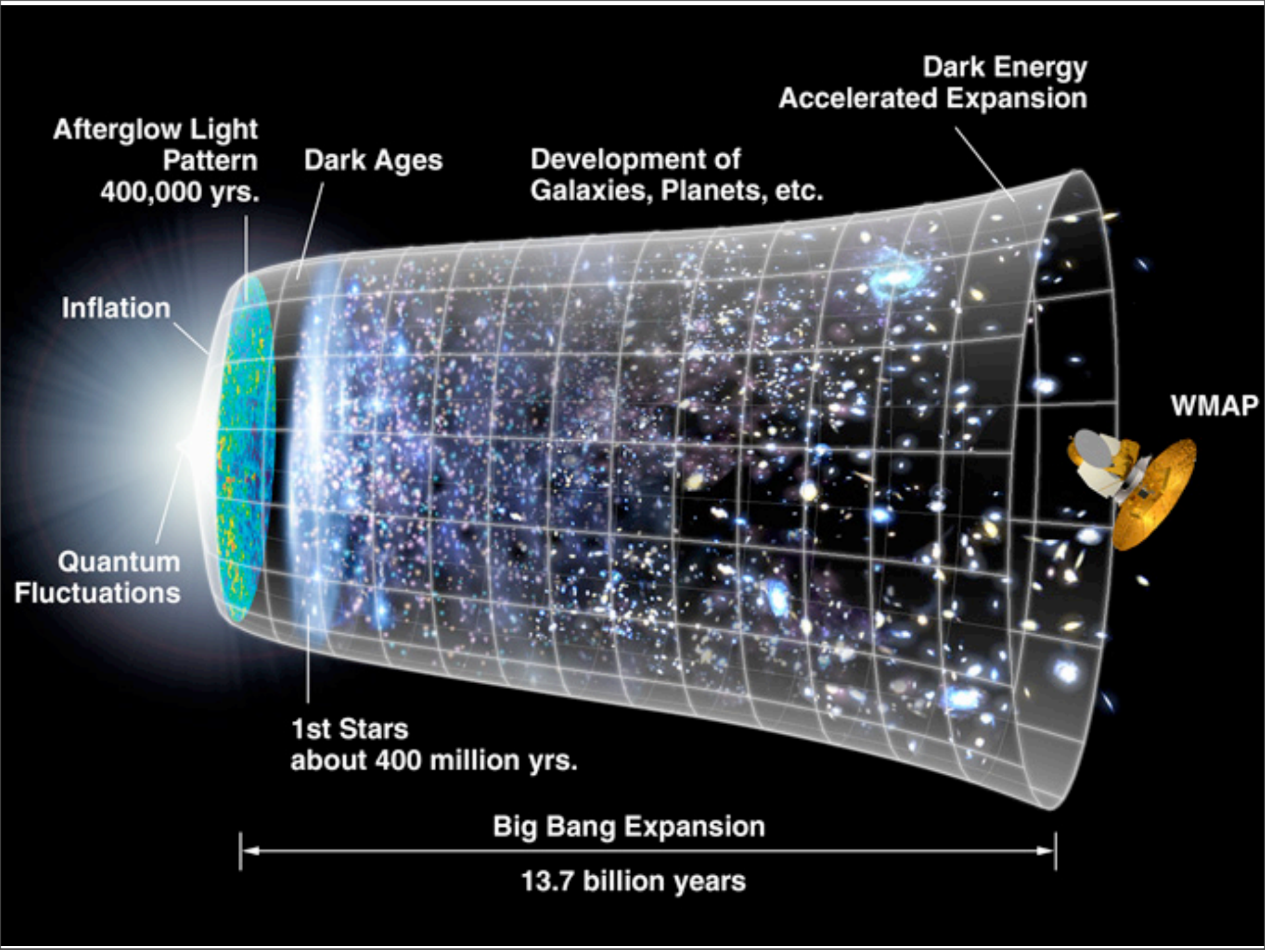
Dusan Keres

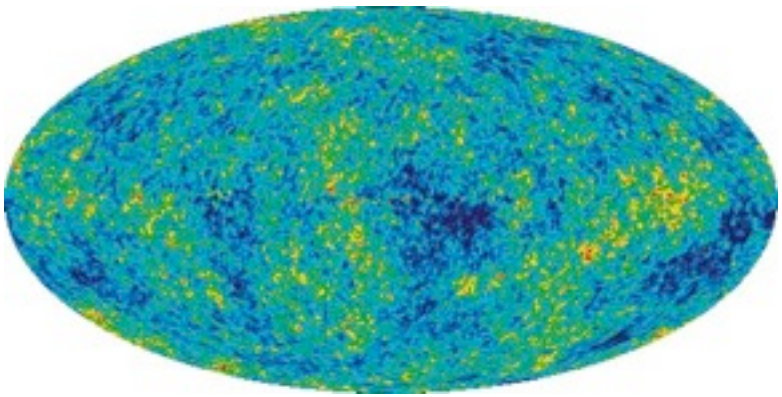


Kevin Bundy



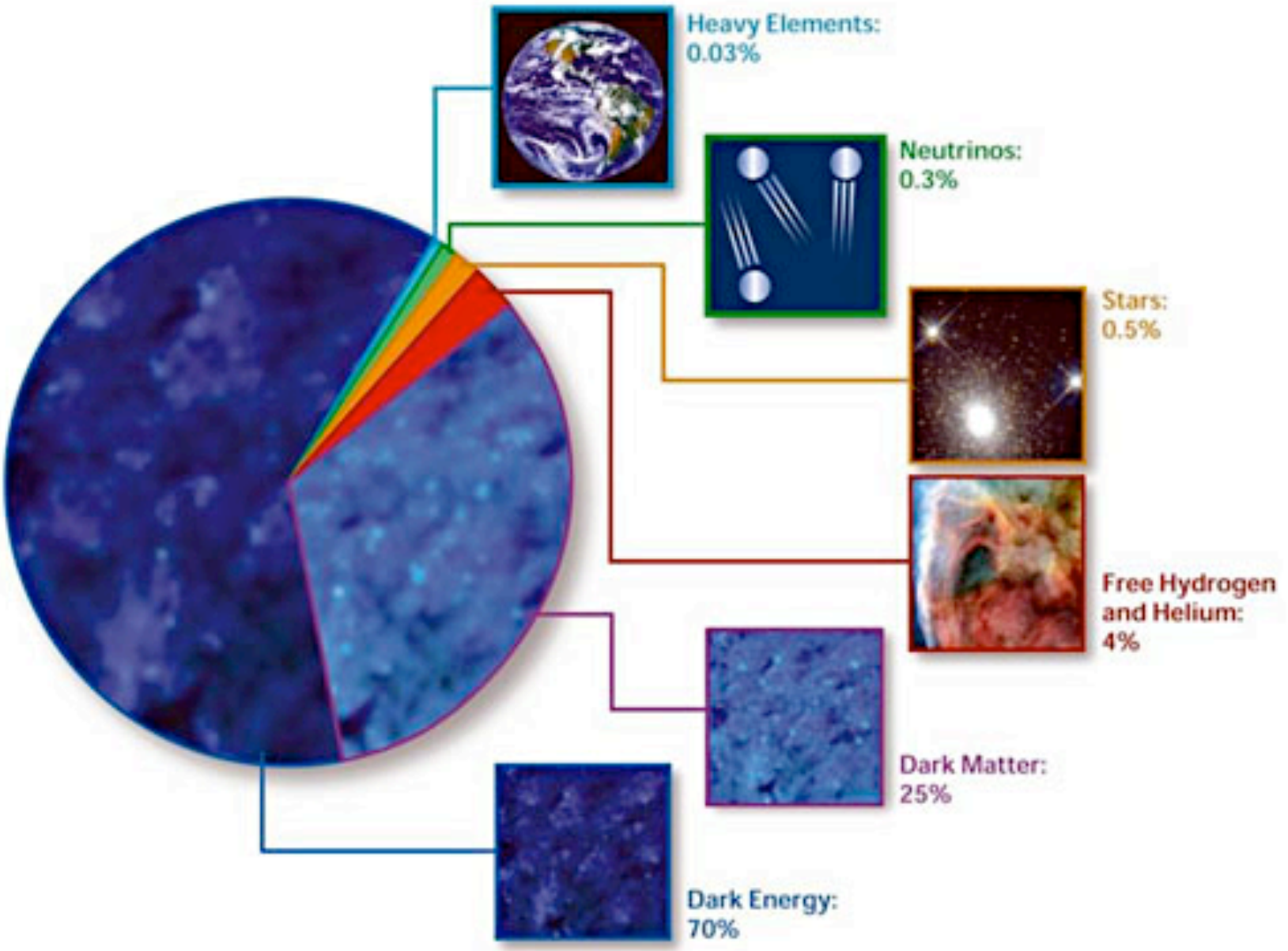
Chris Hayward

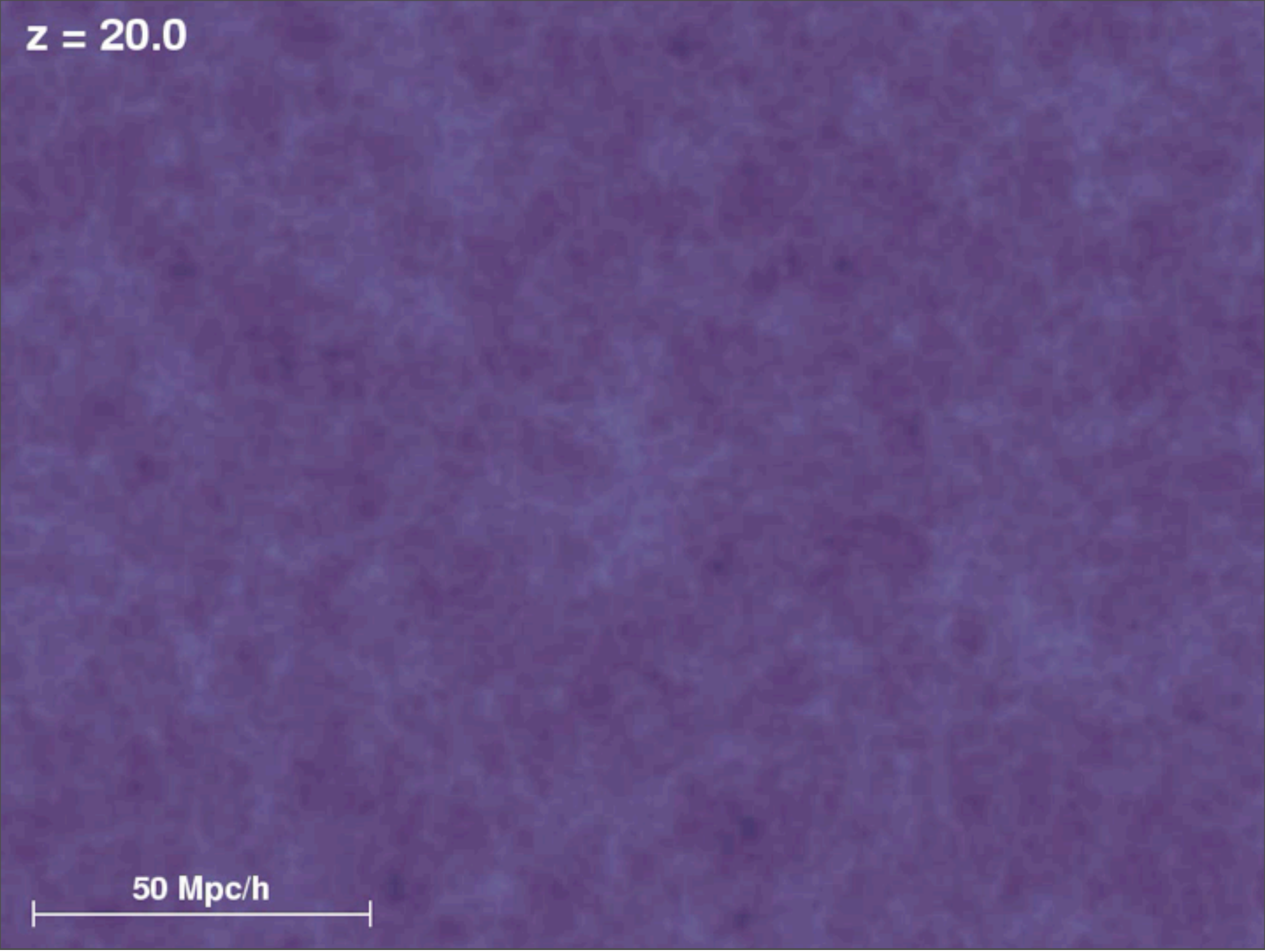

Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

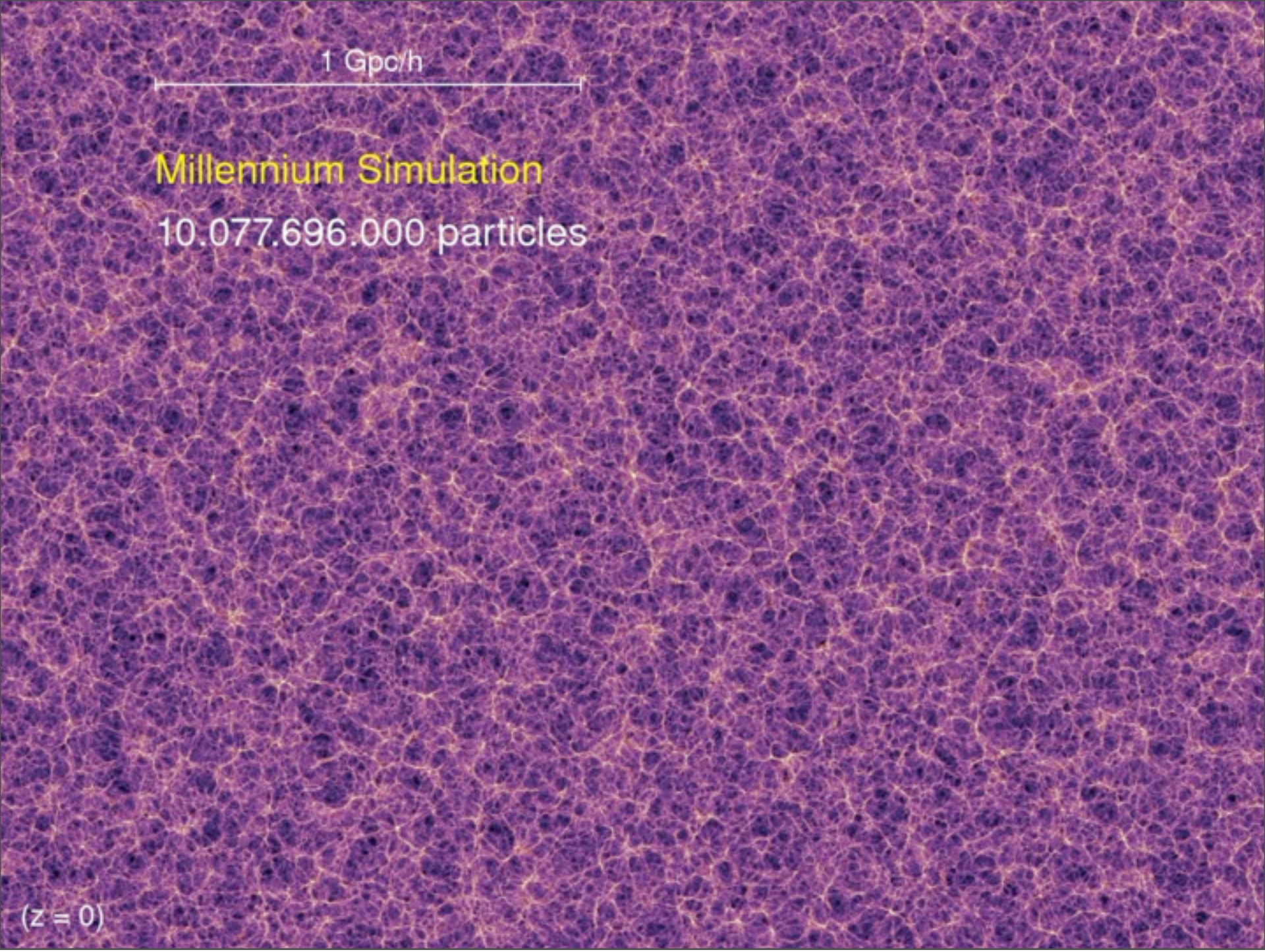


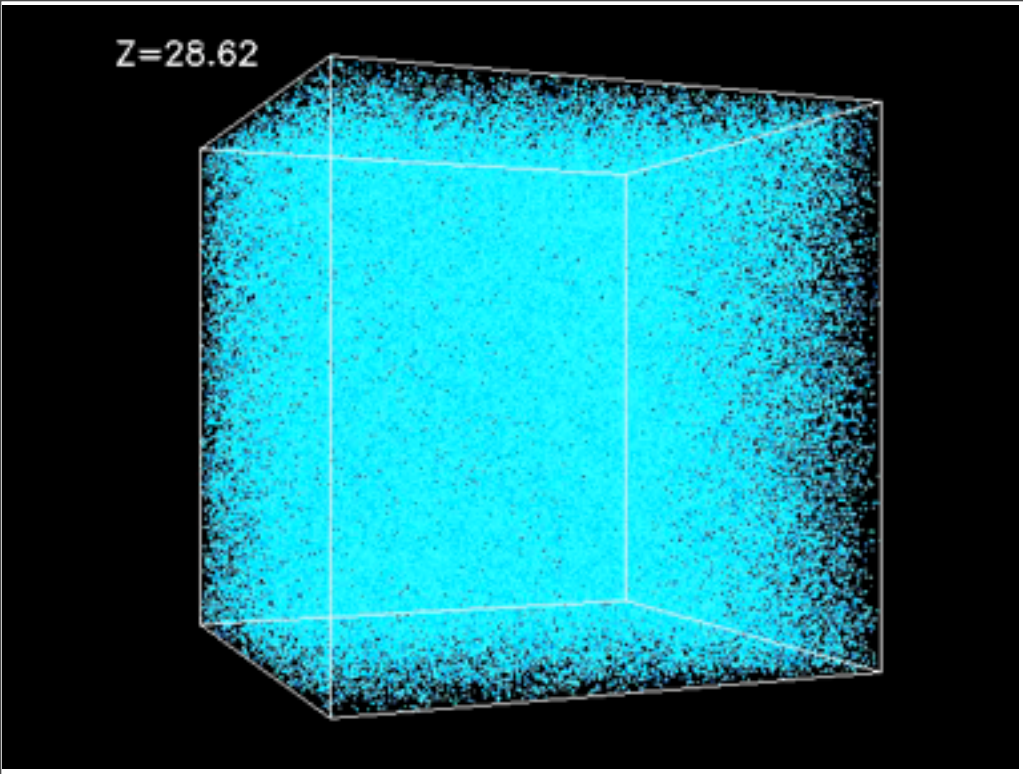
?

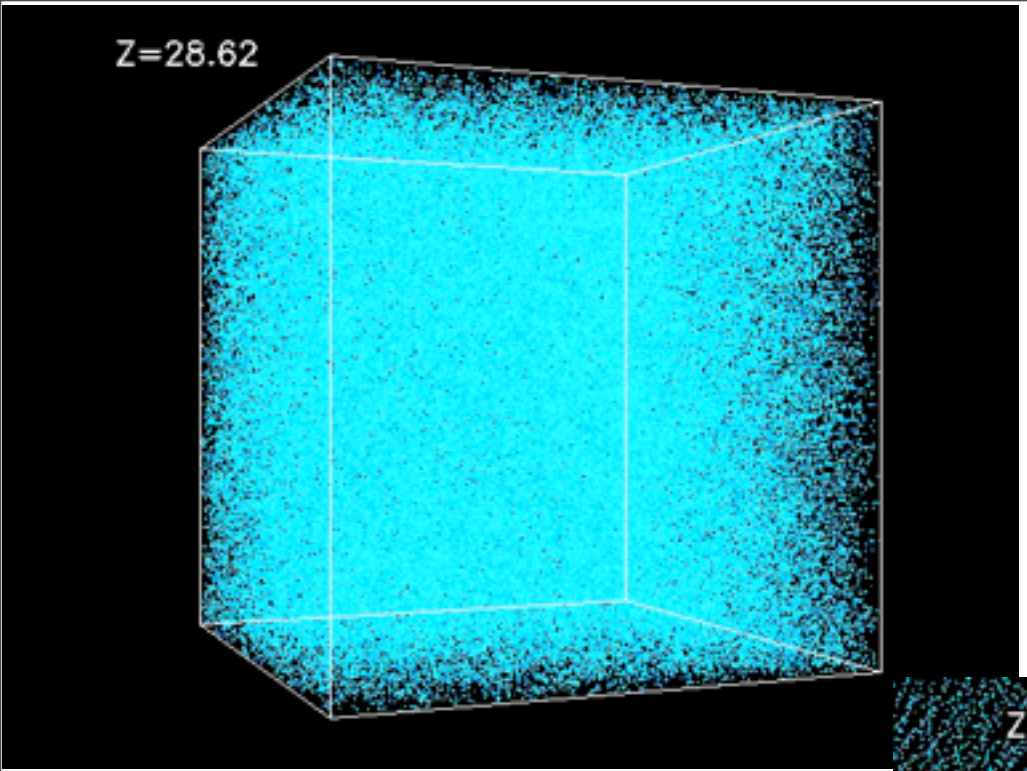
COMPOSITION OF THE COSMOS




z = 20.0
50 Mpc/h


1 Gpc/h
Millennium Simulation
10.077.696.000 particles
(z = 0)


Z=28.62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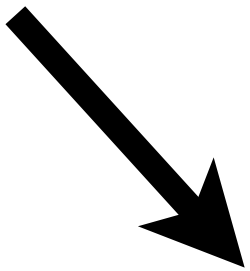

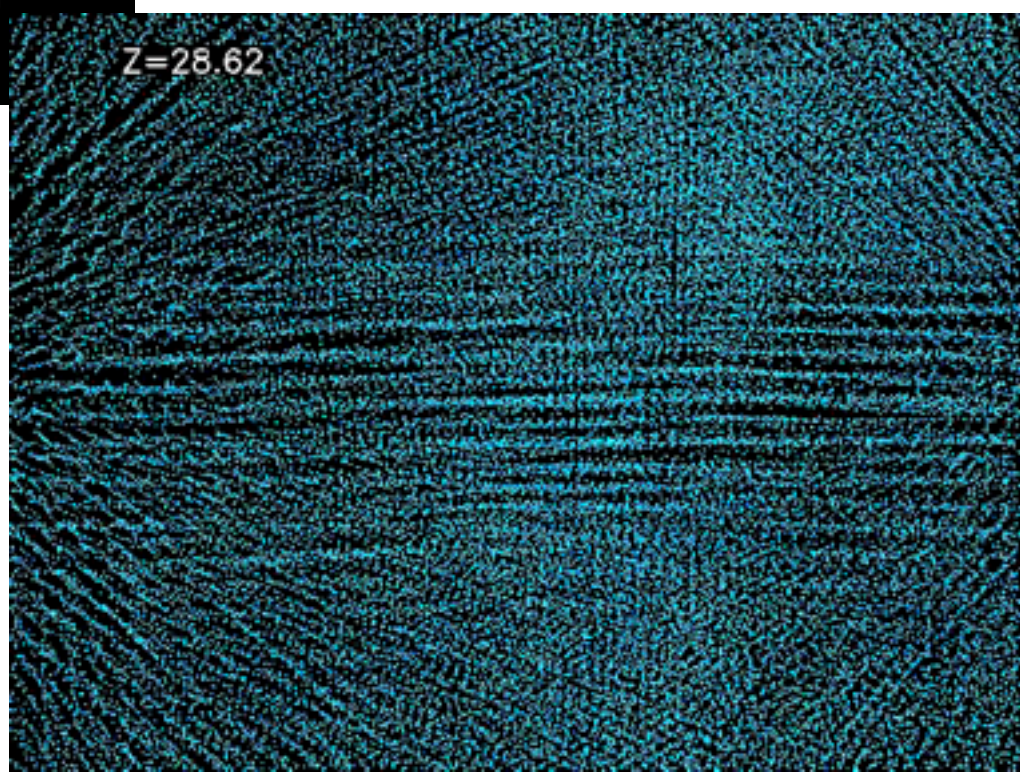
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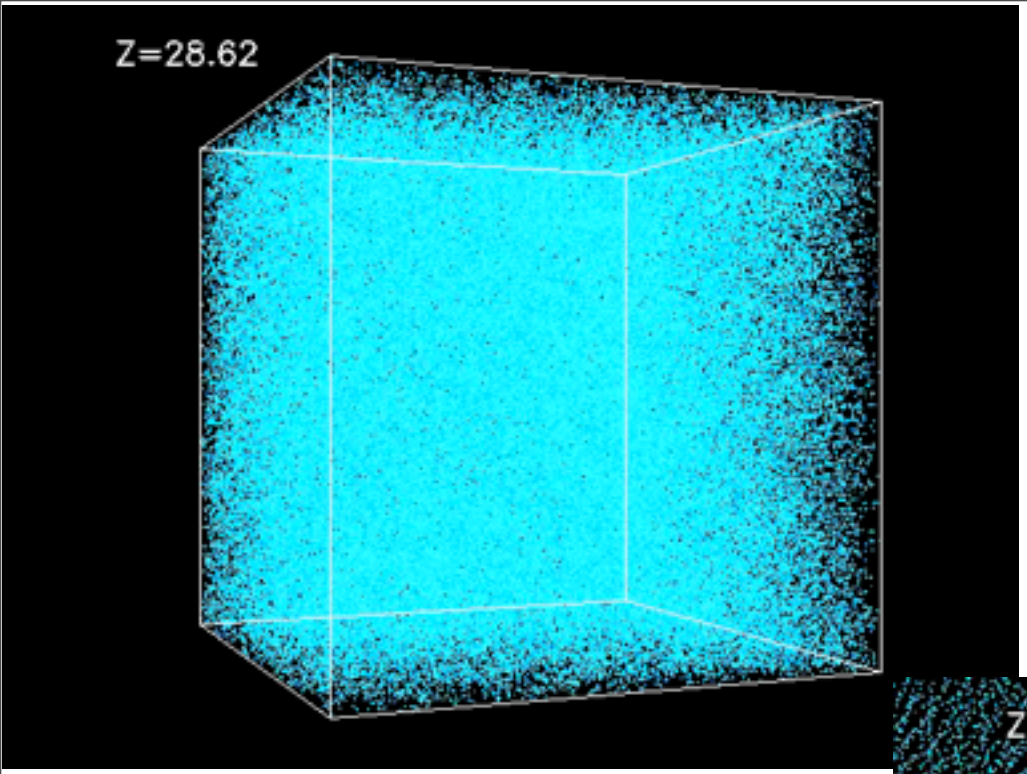
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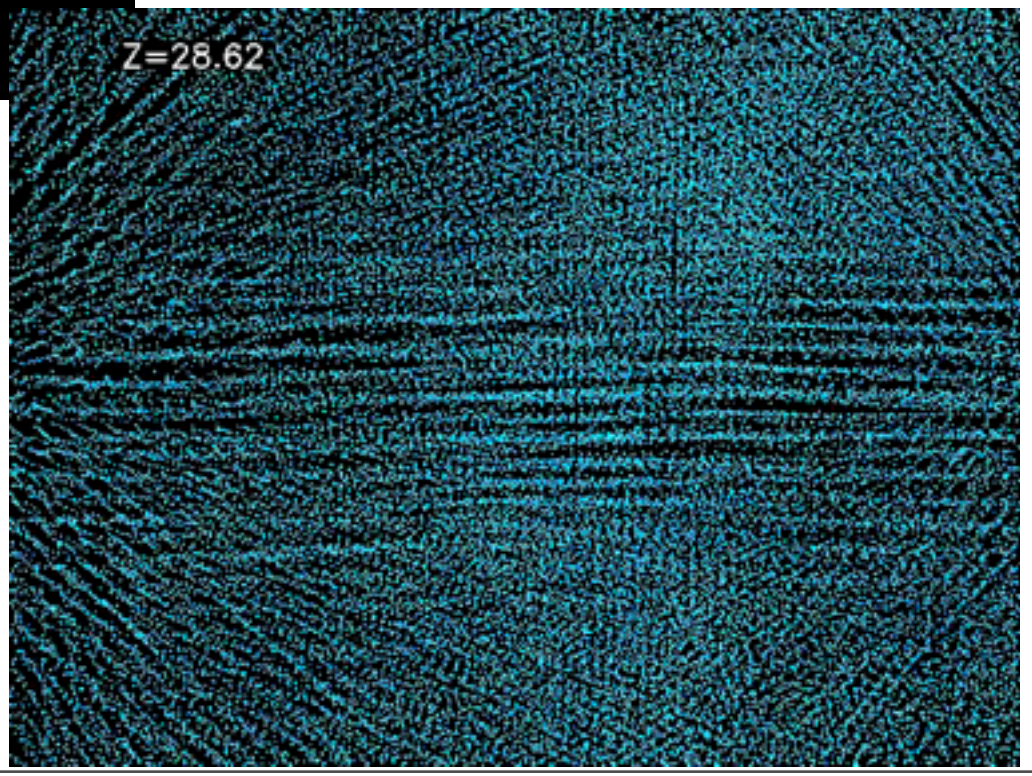
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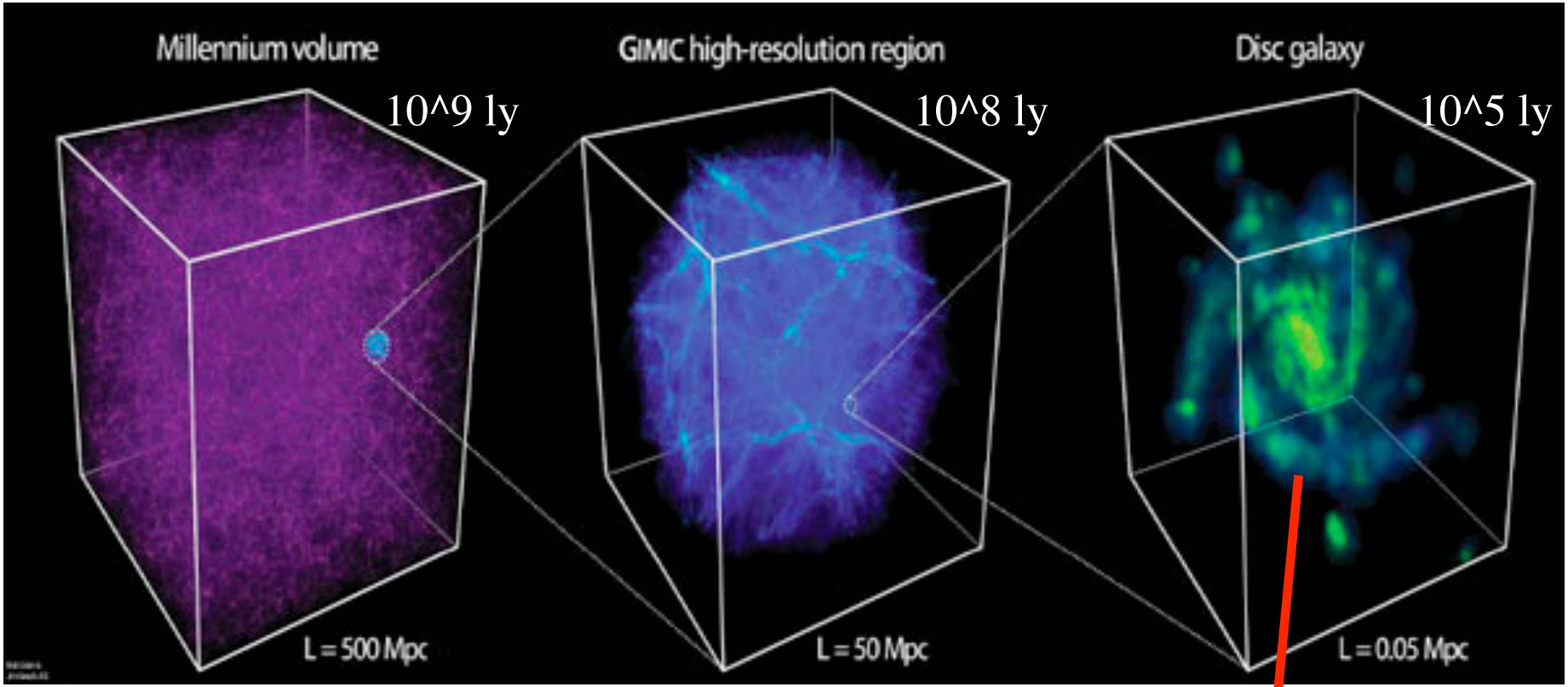

Star-forming cloud:
~10-1000 ly

Cluster of stars/single supernovae "blast region":
~1 ly

Size of a solar system:
~ 10^-5 ly

- Have to go "sub-grid"

How Do We Make Disks In the First Place?

- Fortunately, some simple rules apply:
  - Gas cools via well-understood atomic transitions
  - Above some threshold density, gas turns into stars about ~1% per dynamical time $\sim (G\,\rho_{\rm gas})^{-1/2}$

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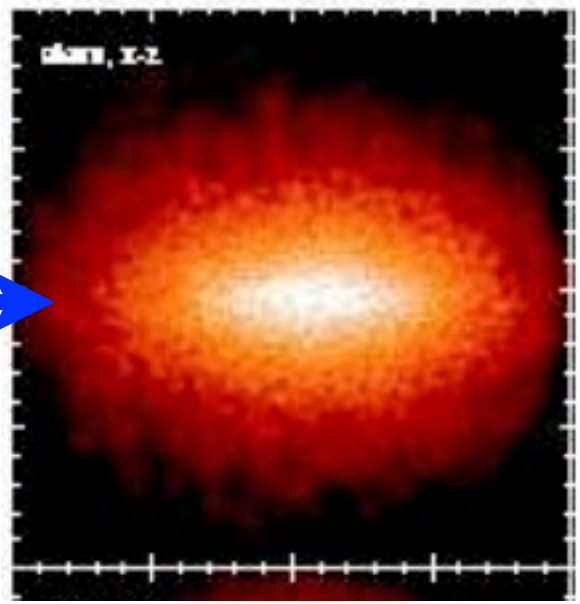
“disk”

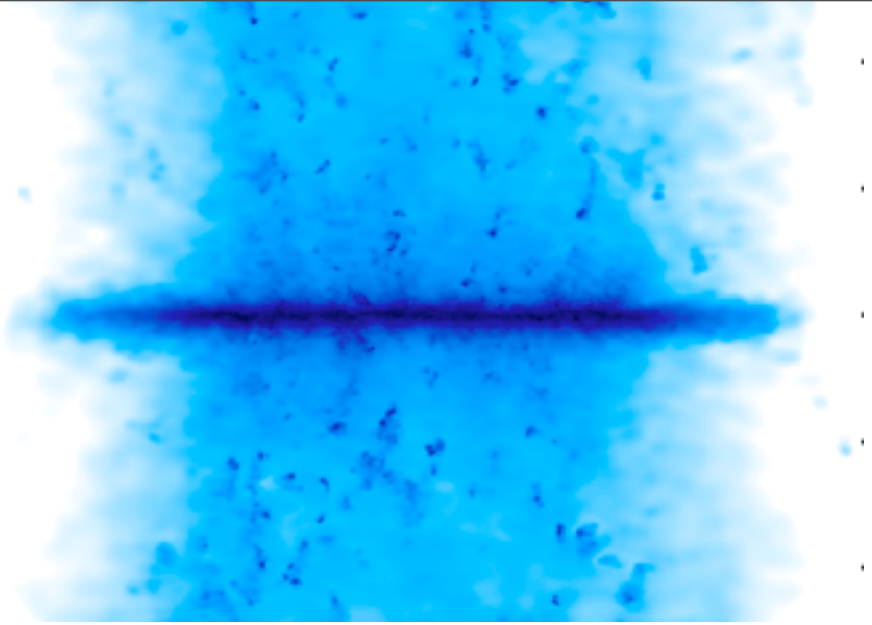


What happened?!?!?

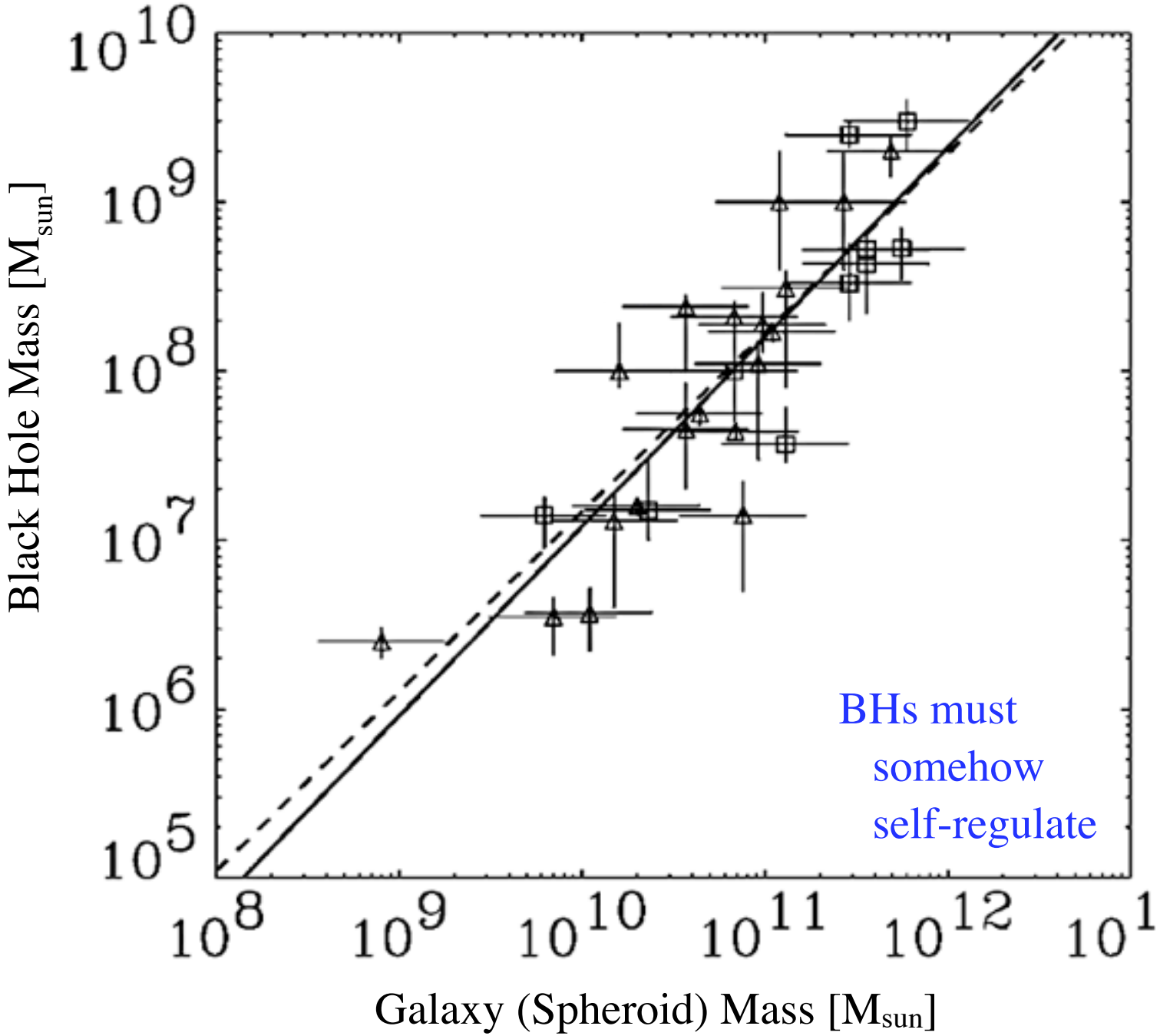
What happened?!?!? -- Galaxy histories are *violent*


What happened?!?!?
ESA

What happened?!?!?

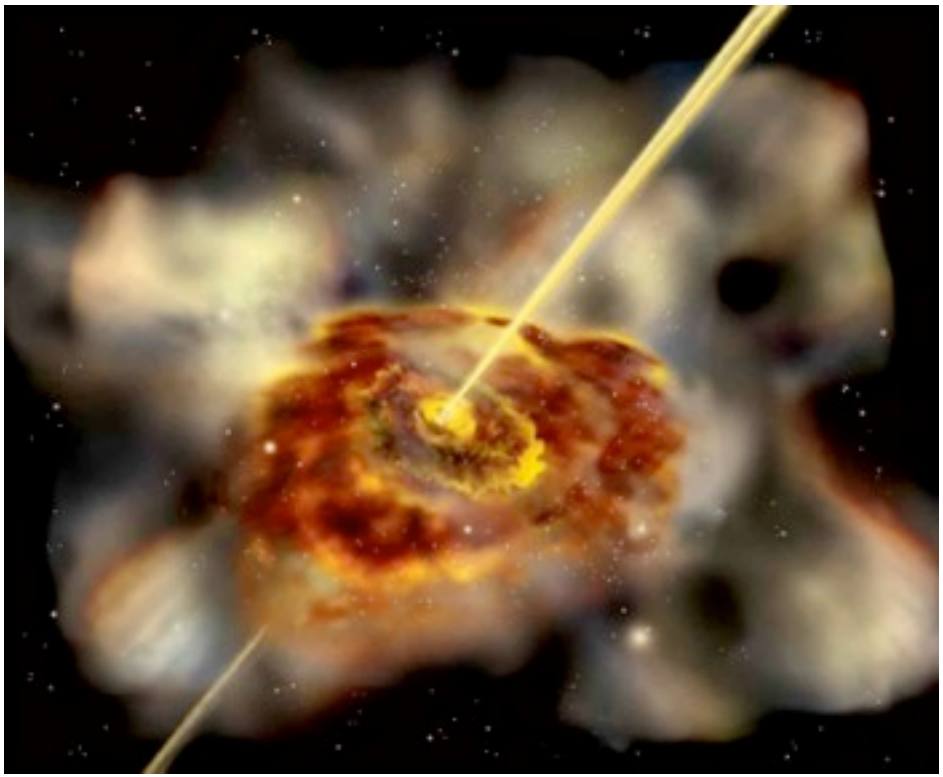


- *Feedback* is critical
  - Supernovae
  - Stellar winds
  - Ionization by starlight
  - Photon radiation pressure


Black Hole Mass [M_{sun}]
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
10^{1}
Galaxy (Spheroid) Mass [M_{sun}]
BHs must somehow self-regulate

- Every massive galaxy hosts a supermassive black hole

(scale ~ 0.1 ly)



- These BHs are “fossil” quasars

FEEDBACK ENERGY/MOMENTUM BALANCE

- Accretion disk radiates:

$$L = \epsilon_r \, (\mathrm{d}M_{\rm BH}/\mathrm{d}t) \, c^2 \quad (\epsilon_r \sim 0.1)$$

- Total energy radiated (typical ~10^8 $M_{\rm sun}$ system)

$$\sim 0.1 \, M_{\rm BH} \, c^2 \sim 10^{61} \, \mathrm{ergs}$$

- Compare to gravitational binding energy of galaxy:

$$\sim M_{\rm gal} \, \sigma^2 \sim (10^{11} \, M_{\rm sun}) \, (200 \, \mathrm{km/s})^2 \sim 10^{59} \, \mathrm{erg}$$

- If only a few percent of the luminous energy coupled, it would unbind the baryons!

- Turn this around: *if* some fraction f ~ 1-5% of the luminosity can couple, then accretion stops when

$$M_{\rm BH} \sim (1/f\epsilon_r) \, M_{\rm gal} \, (\sigma/c)^2 \sim 0.002 \, M_{\rm gal}$$

Gas Rich Mergers and Disk Galaxy Formation

Galaxy formation simulations created at the

N-body shop

makers of quality galaxies

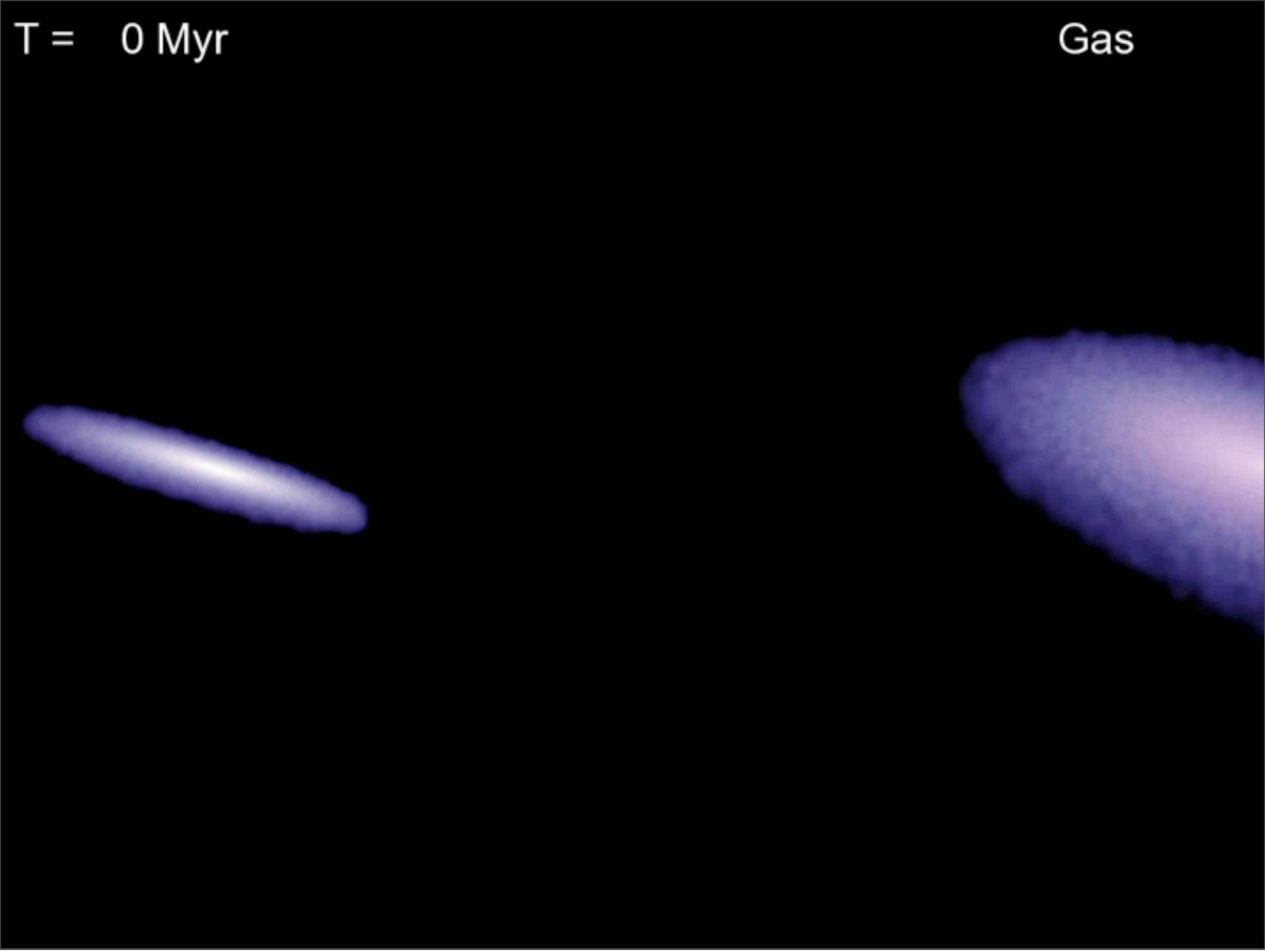
key: gas- green new stars- blue old stars- red

credits:

Fabio Governato (University of Washington)
Alyson Brooks (University of Washington)
James Wadsely (McMaster University)
Tom Quinn (University of Washington)
Chris Brook (University of Washington)

Simulation run on Columbia (NASA Advanced Supercomputing)

contact: fabio@astro.washington.edu


T = 0 Myr
Gas

Summary

- Galaxy formation is a complicated, multi-scale problem
  - Evolution of individual stars and black holes matters!
- We can understand the Universe at lowest-order quite well with a very simple model of dark matter + baryons, with (mostly Newtonian) gravity dominating the forces
  - "Gastrophysics" messes it up, though!
- The order we see today is probably the product of complex "feedback loops" between gravity, cosmological gas inflows, and the explosions of stars and feeding of black holes
- Where is the field going?
  - Better direct observational tests
  - More physics of star formation & stellar feedback
  - No more artificial separation of feedback from stars/quasars/galaxies
- Thanks!