Dark Matter

ASTR 333/433
Fall 2013
MoTu 4:00-5:15pm
Sears 552

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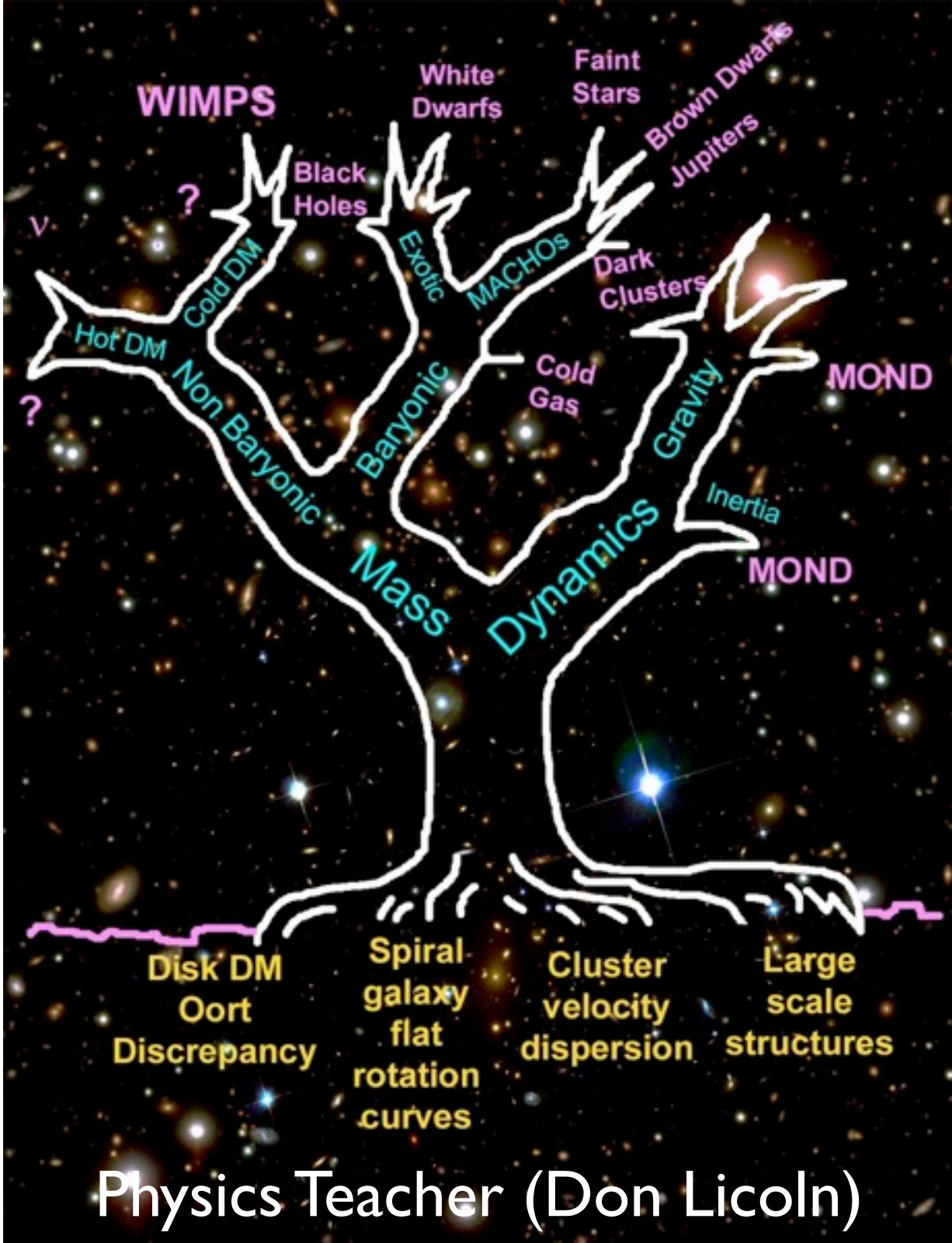


Physics Teacher (Don Licoln)

This course will address

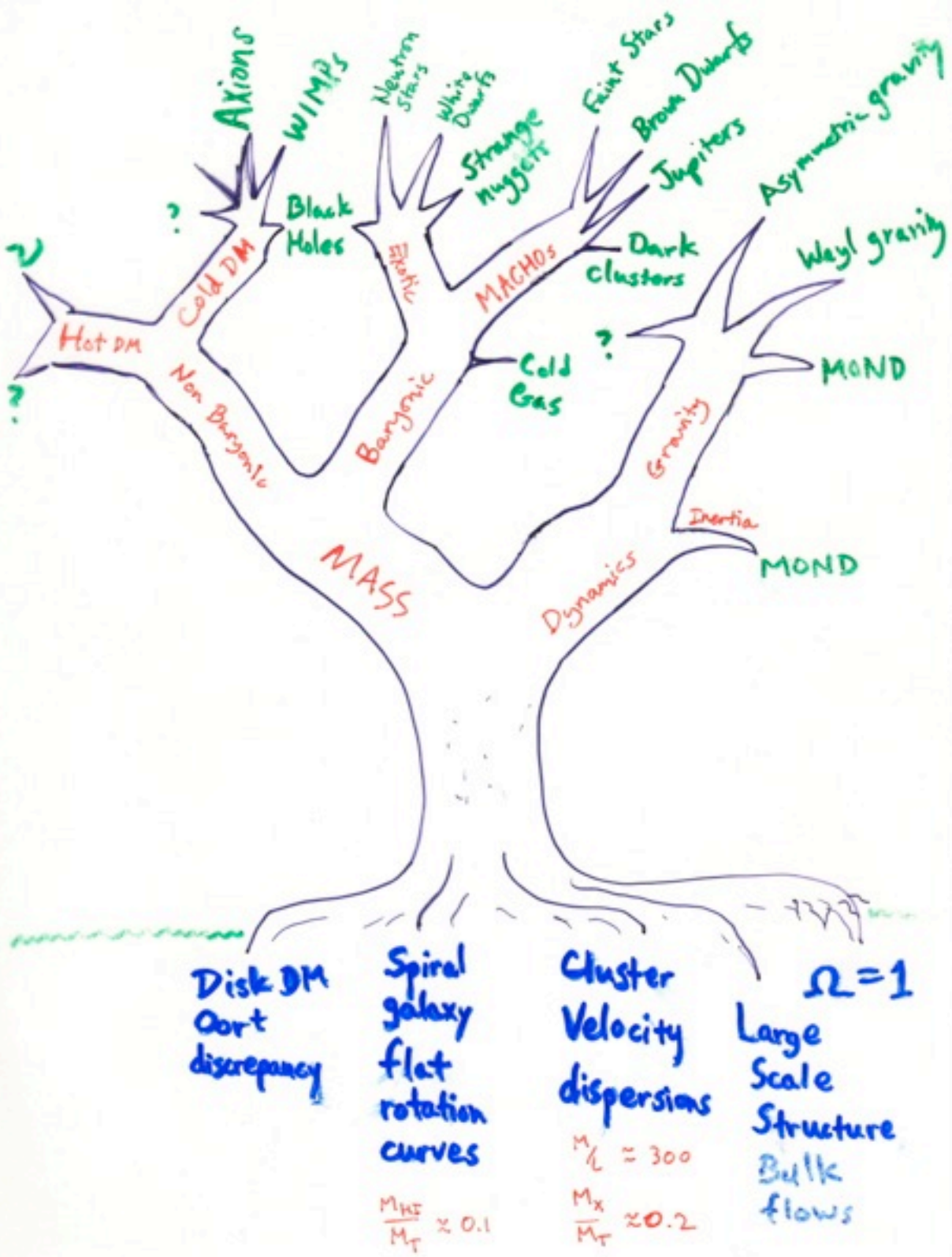
Some Great Questions

of modern physics & astronomy:

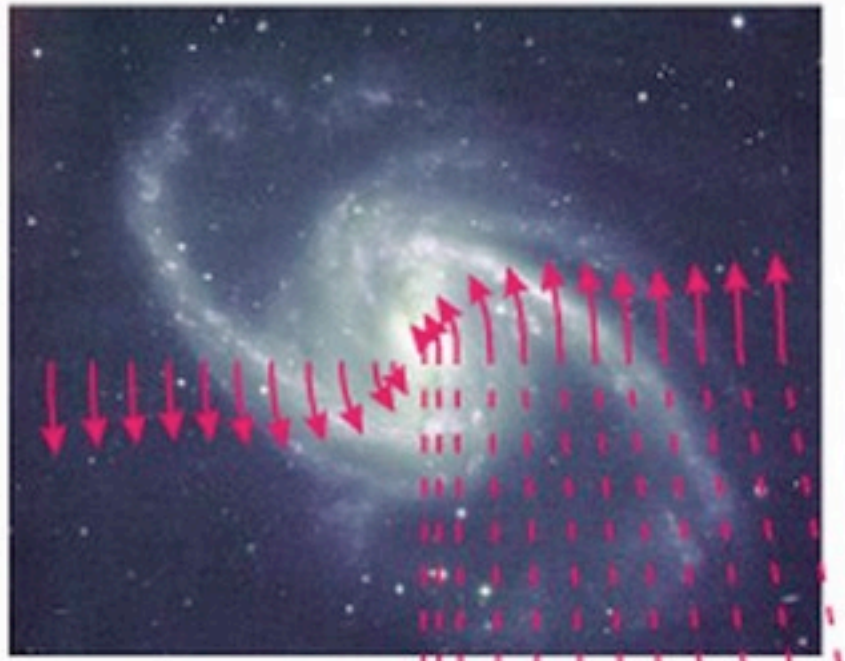
What is the solution to the missing mass problem?
What is the dark matter?
Is it necessary to modify the law of gravity?

and offer a multiplicity of answers,
of which at most one can be correct.

First we will cover the empirical evidence that indicates the existence of mass discrepancies

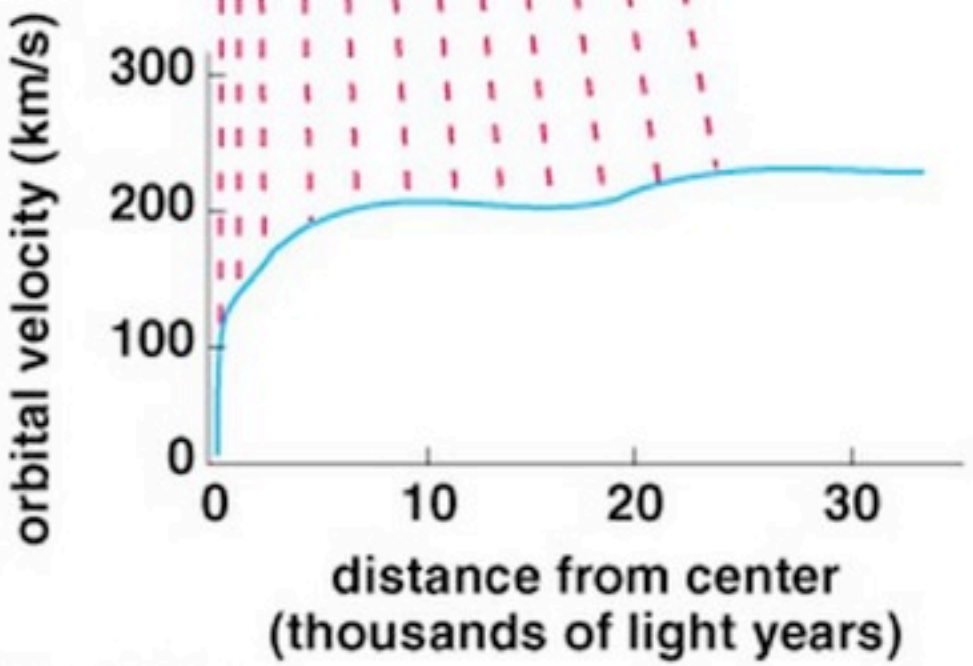

Axions
WIMPs
Neutron stars
White Dwarfs
Strange nuggets
Faint Stars
Brown Dwarfs
Jupiters
Asymmetric gravity
Weyl gravity
MOND
MOND
Black Holes
Cold DM
Hot DM
Baryonic
Non Baryonic
MACHOs
Dark clusters
Cold Gas
Gravity
Inertia
Dynamics
MASS
Disk DM
Oort discrepancy
Spiral galaxy flat rotation curves
$\frac{M_{HI}}{M_T} \times 0.1$
Cluster Velocity dispersions
$\frac{M}{L} \simeq 300$
$\frac{M_X}{M_T} \simeq 0.2$
Large Scale Structure
Bulk flows
$\Omega = 1$

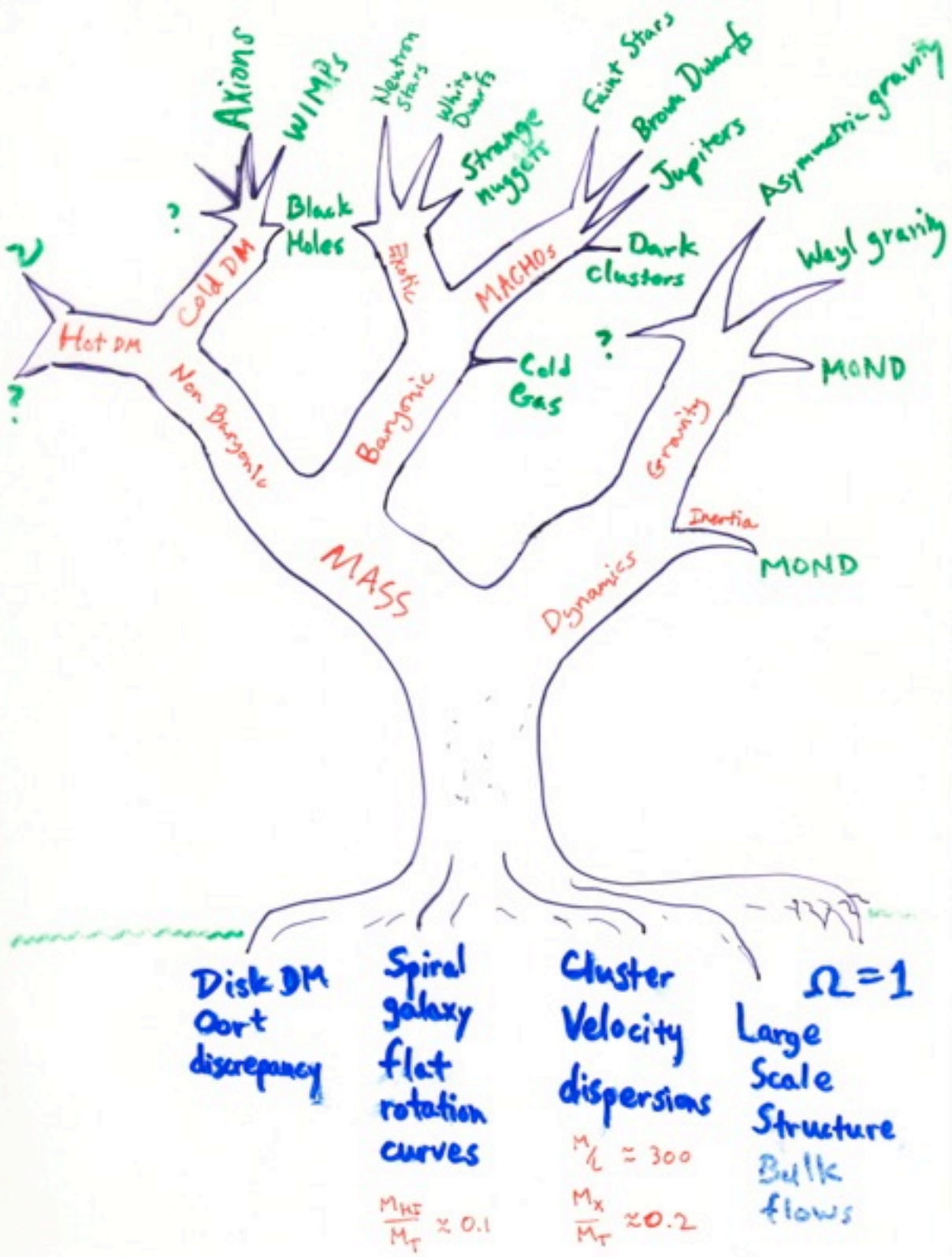
Spiral
Galaxy



Longer arrows represent larger orbital velocities.

Rotation
Curve

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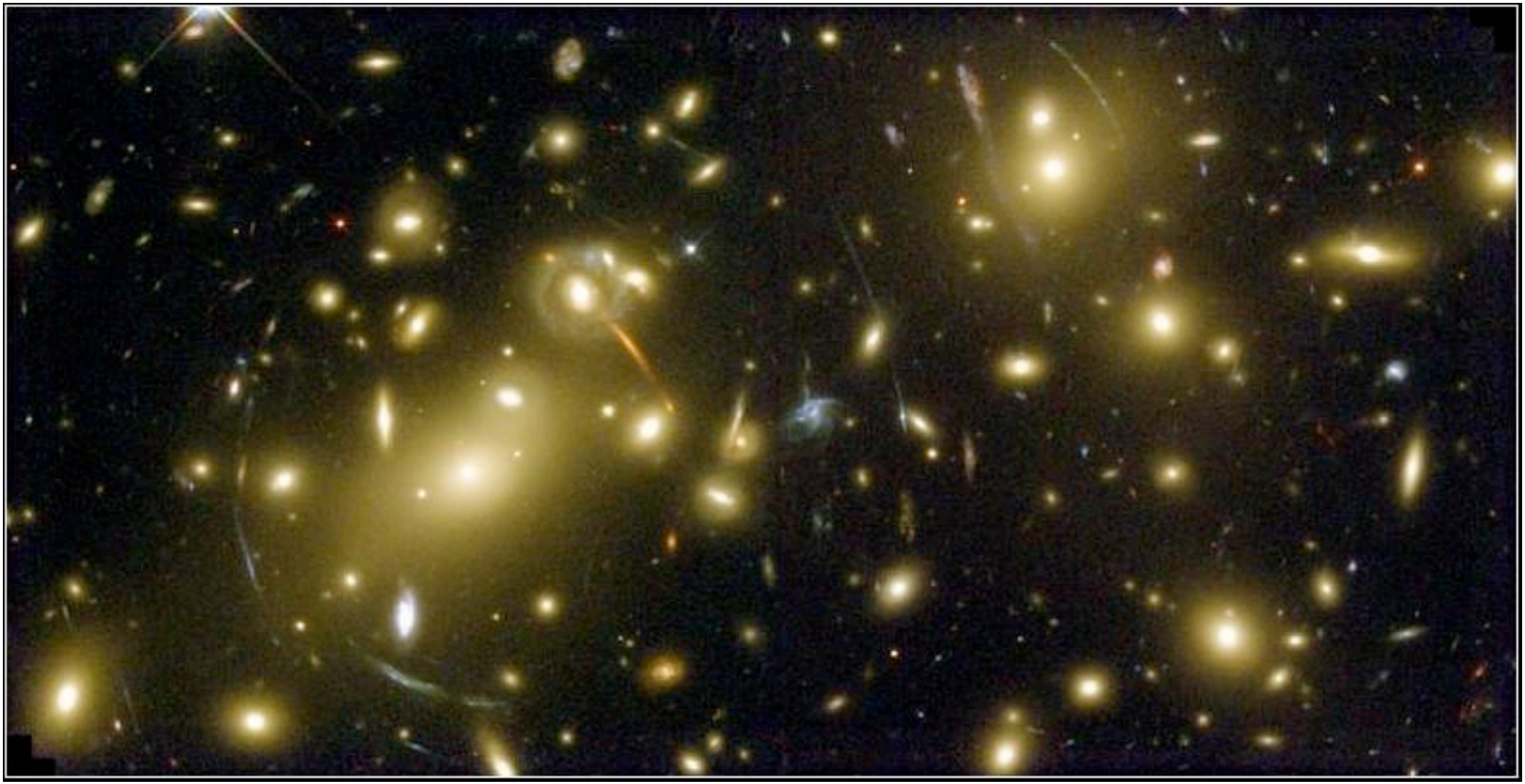
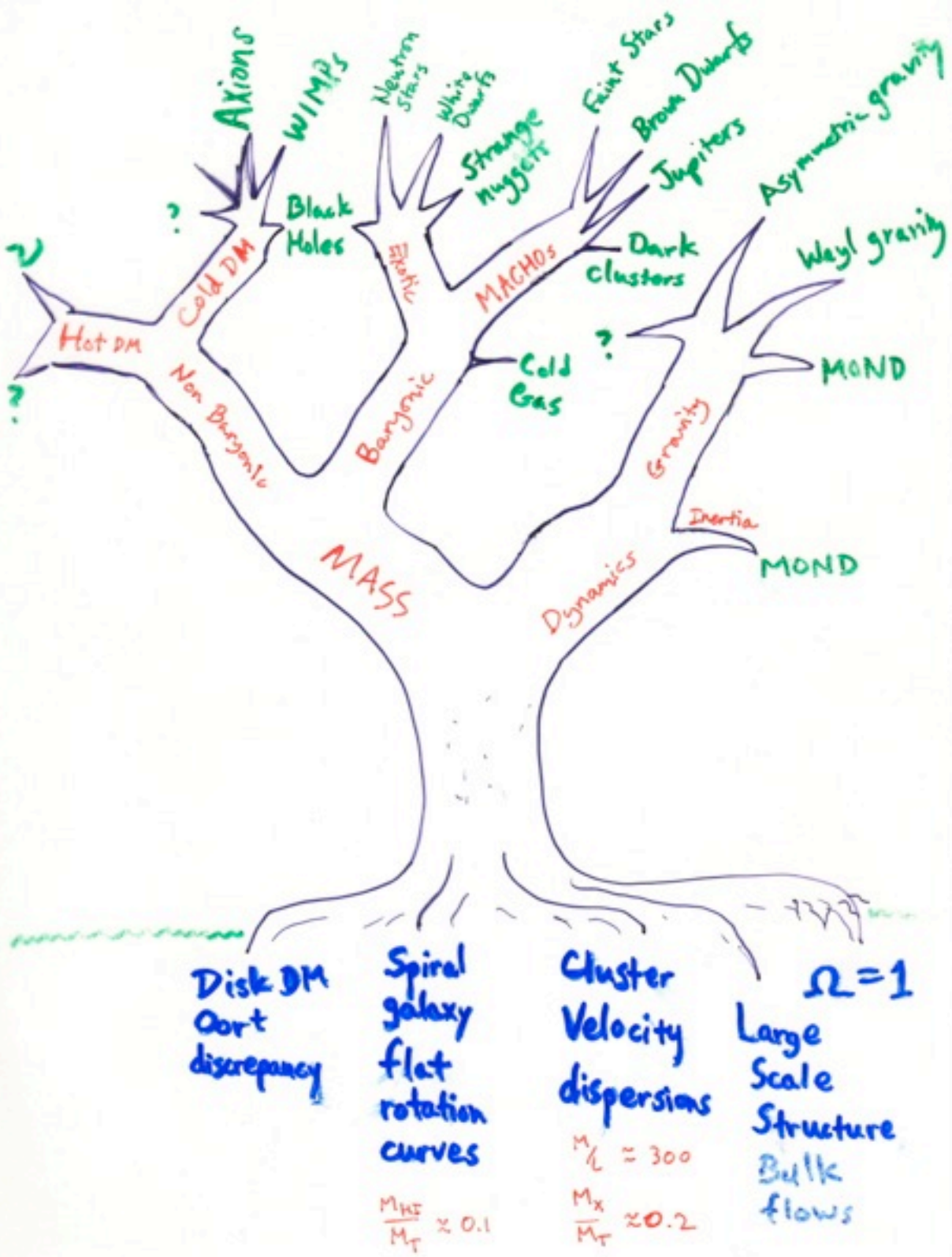
Galaxy Cluster



3 distinct measures: velocity dispersion, gravitational lensing, and hydrostatic equilibrium of X-ray gas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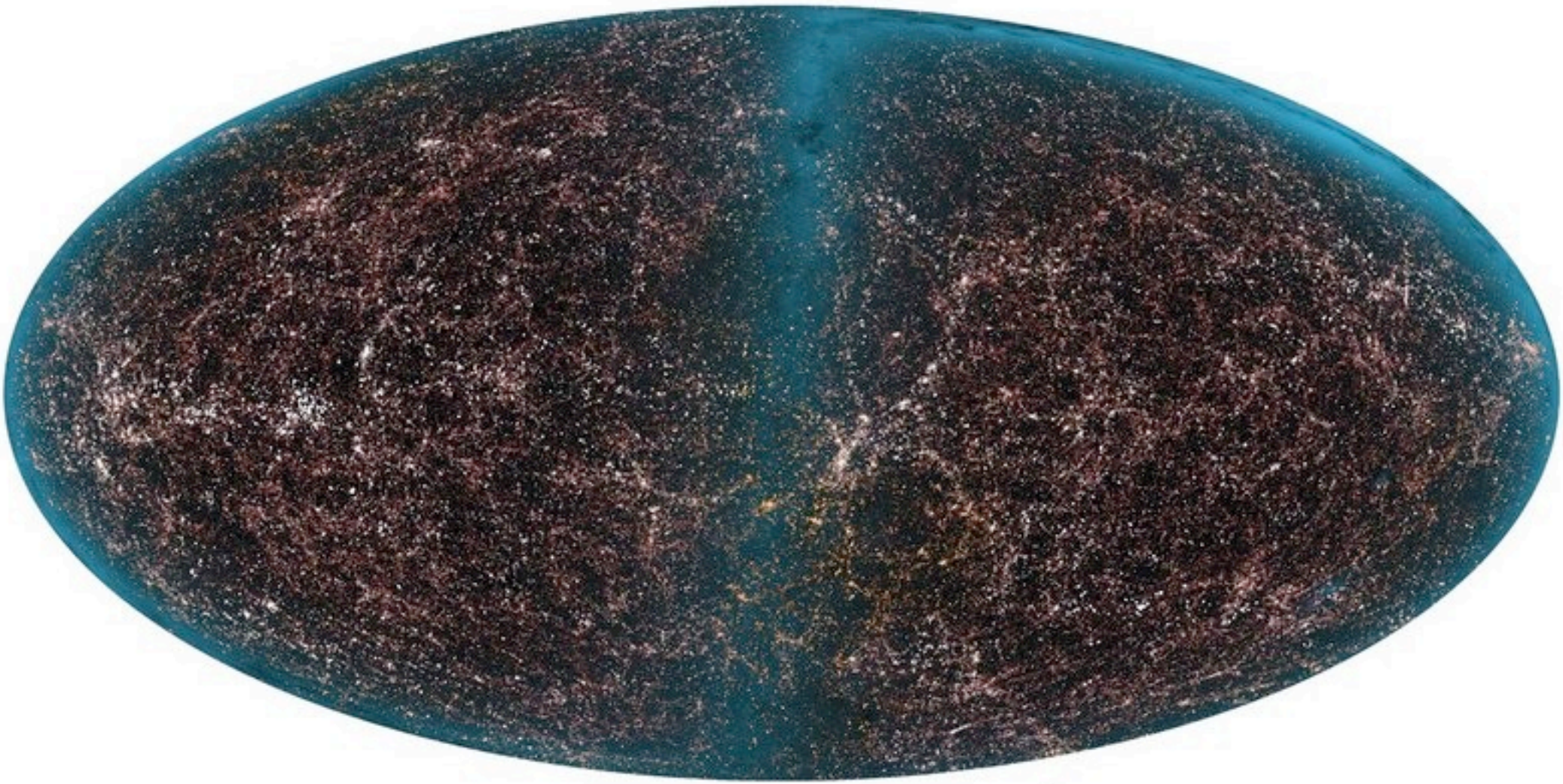
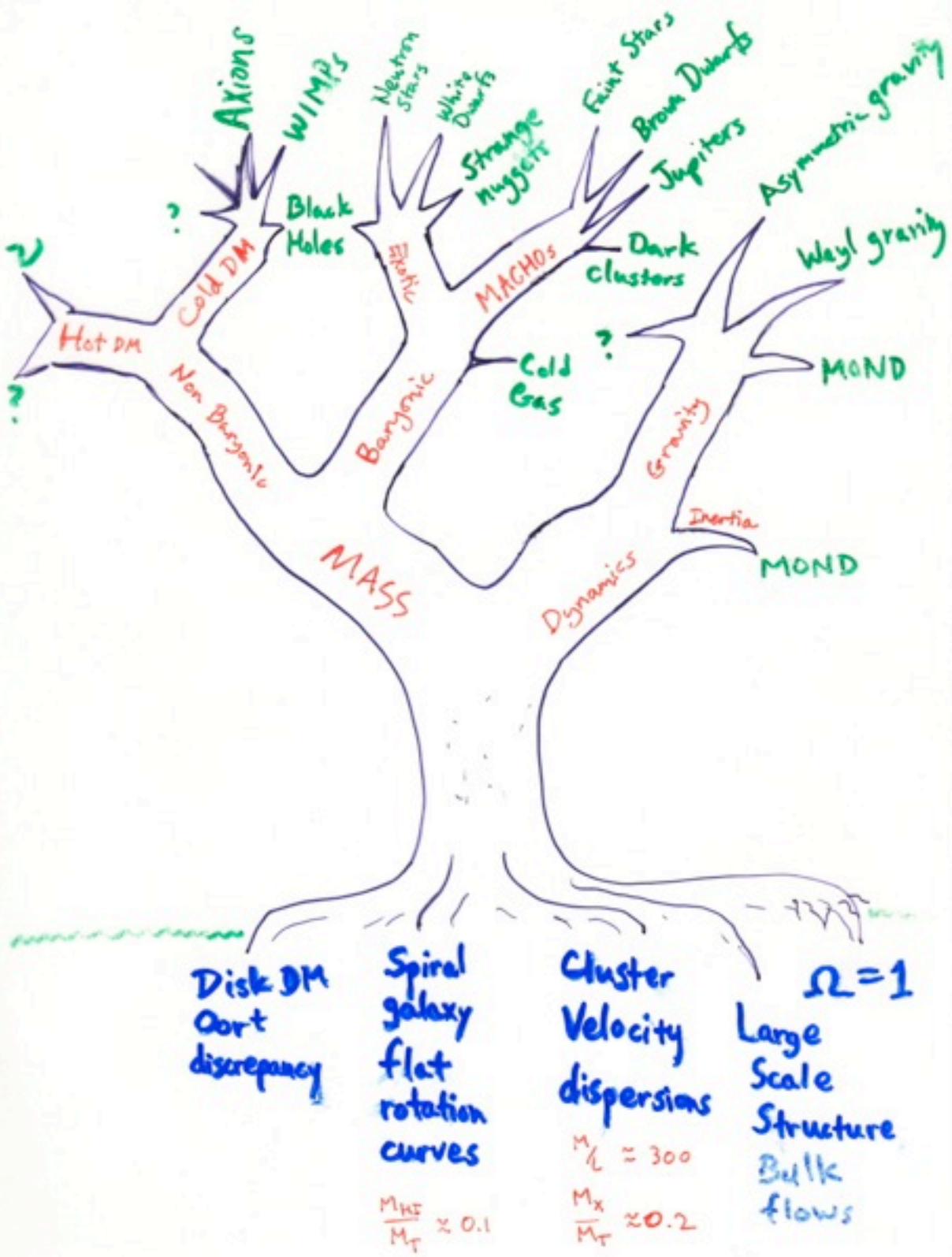
Large Scale Structure

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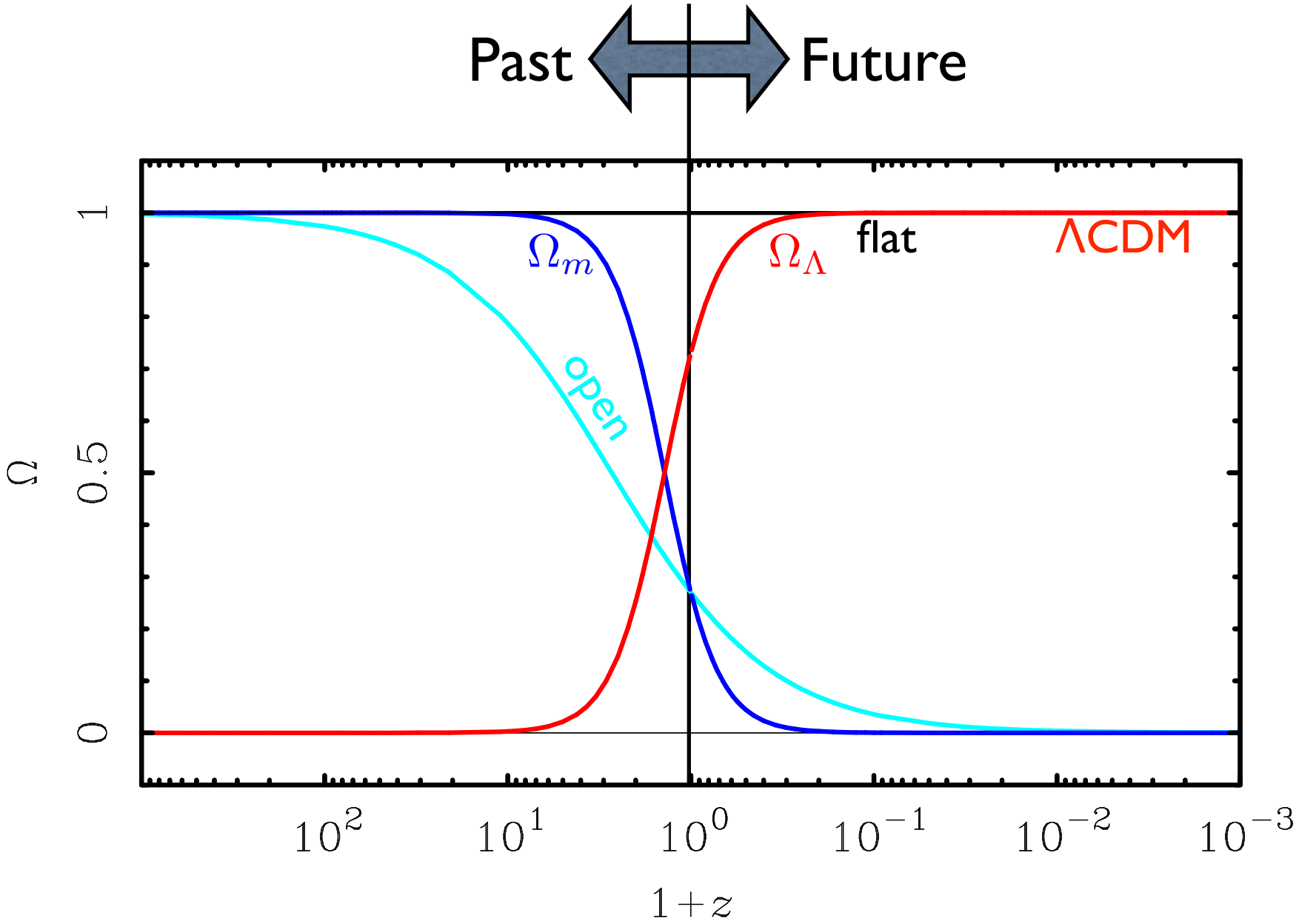
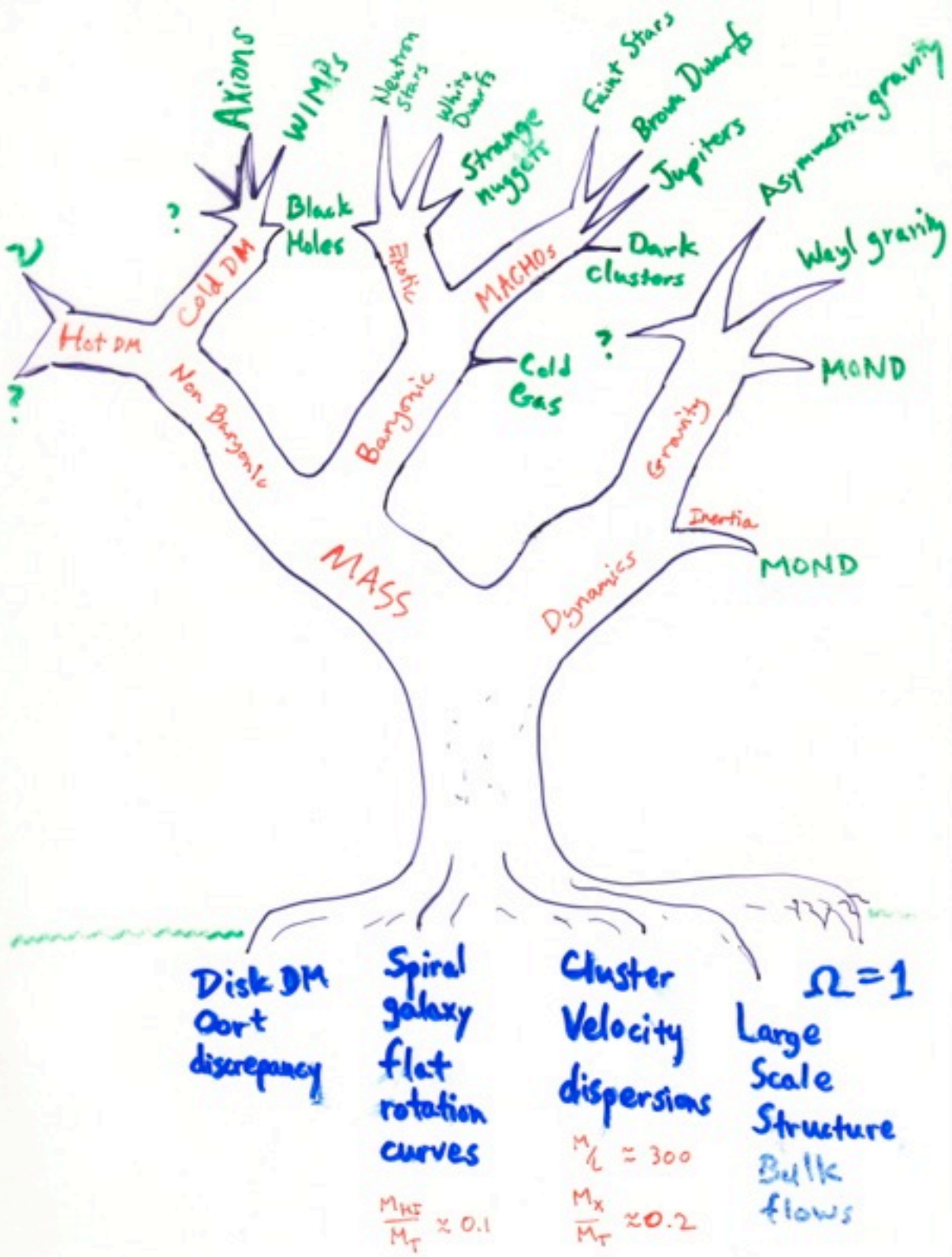


Coincidence/flatness problem:
why is the density parameter of order unity?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Pruning the tree

Baryonic Dark Matter

Many candidates:
- brown dwarfs
- Jupiters
- very faint stars
- very cold molecular gas
- warm (~10^5 K) ionized gas

Can usually figure out a way to detect them: most have been ruled out.

Pruning the tree

Hot Dark Matter (HDM)

Obvious candidate:
neutrinos

neutrinos got mass!...
...but not enough.

Also
- neutrinos suppress structure formation
- can't crowd together closely enough
(phase space constraint)

Pruning the tree

Cold Dark Matter (CDM)

Some new particle, usually assumed to be
WIMPs (Weakly Interacting Massive Particle)
don't interact electromagnetically, so very dark.

Two big motivations:

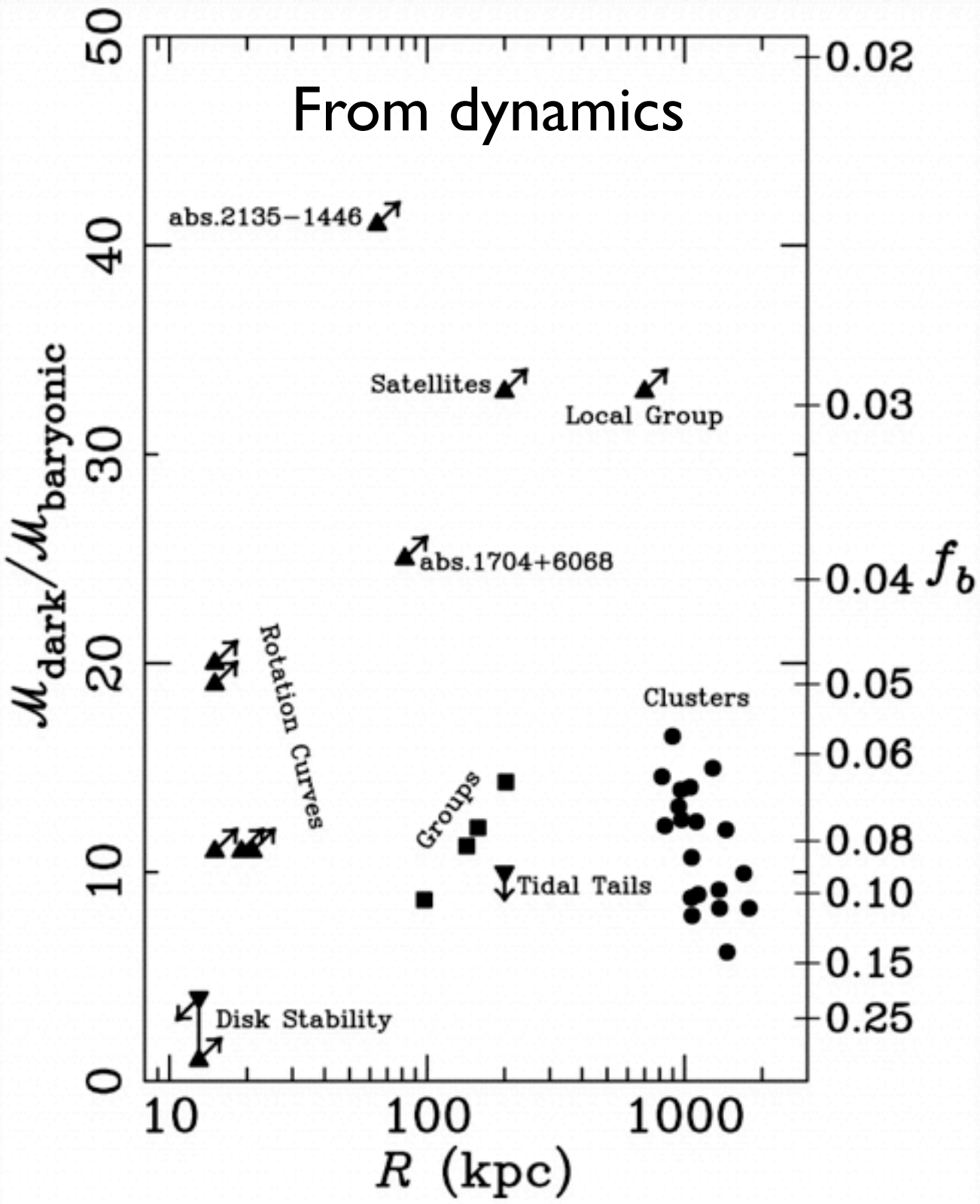
1) total mass outweighs normal mass from BBN

2) needed to grow cosmic structure

(1) There's more dark mass than baryons.

From cosmology

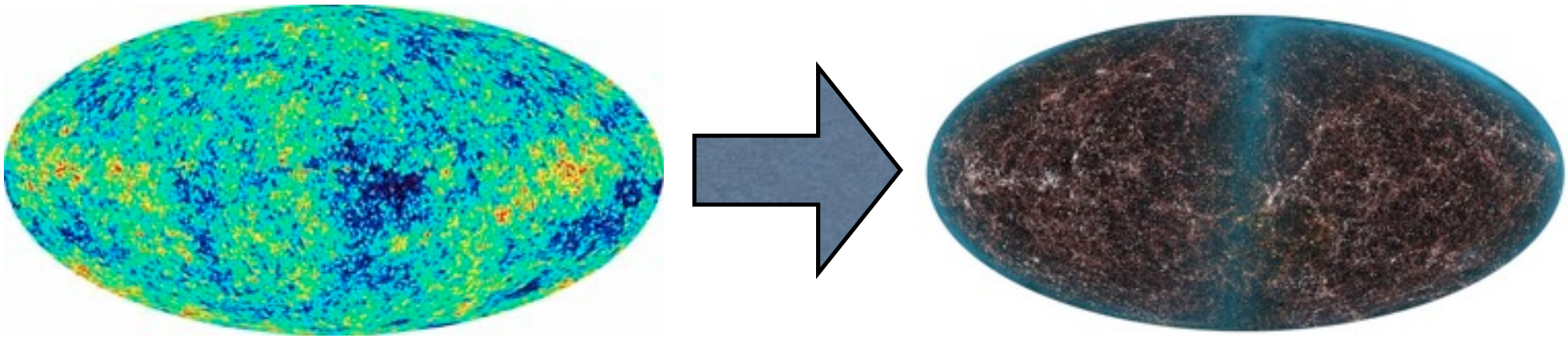
$\Omega_m \approx 6\Omega_b$



(2) There isn't enough time to form the observed cosmic structures from the smooth initial conditions unless there is a component of mass independent of photons.

$t = 3.8 \times 10^5$ yr

$t = 1.4 \times 10^{10}$ yr



very smooth: $\delta\rho/\rho \sim 10^{-5}$

very lumpy: $\delta\rho/\rho \sim 1$

$$\delta\rho/\rho \propto t^{2/3}$$

These considerations made CDM the dominant paradgim

Only requirement to be CDM is

- dynamically cold (slow moving)
- non-baryonic (no E&M interactions)

could be
WIMPS
(or some other particle)
or
Black Holes
(masses of ~ 10^5 $M_\odot$ conceivable)

Lots of particle candidates for CDM:

WIMPs
Axions
Light dark matter
wimpzillas

Can imagine other candidates as well:

Warm DM
Self-interacting DM
Light DM
etc.