DARK MATTER

ASTR 333/433
FALL 2013
MOTU 4:00-5:15PM
SEARS 552

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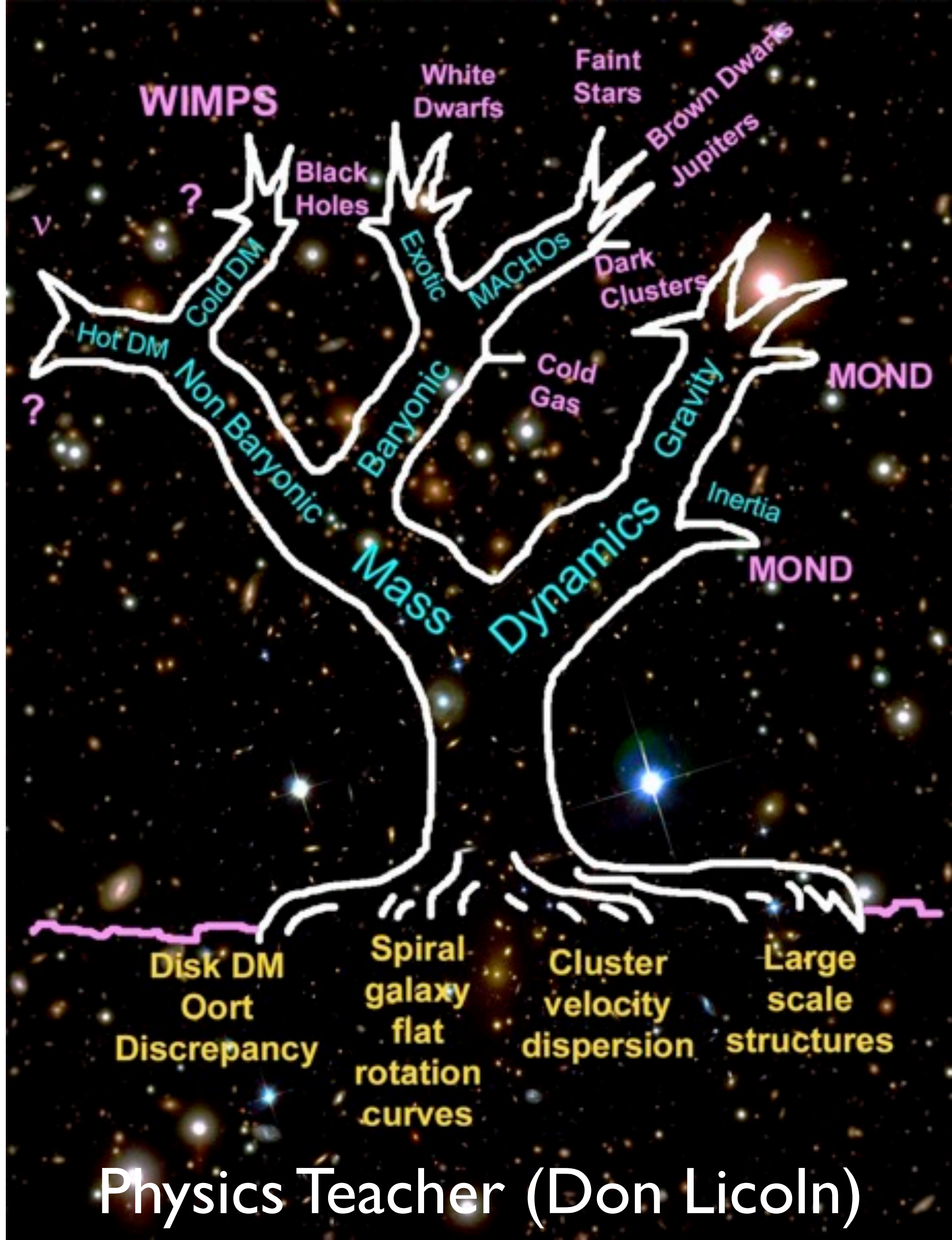
http://astroweb.case.edu/ssm/ASTR333

CASE WESTERN RESERVE UNIVERSITY EST. 1826



Physics Teacher (Don Licoln)

This course will address

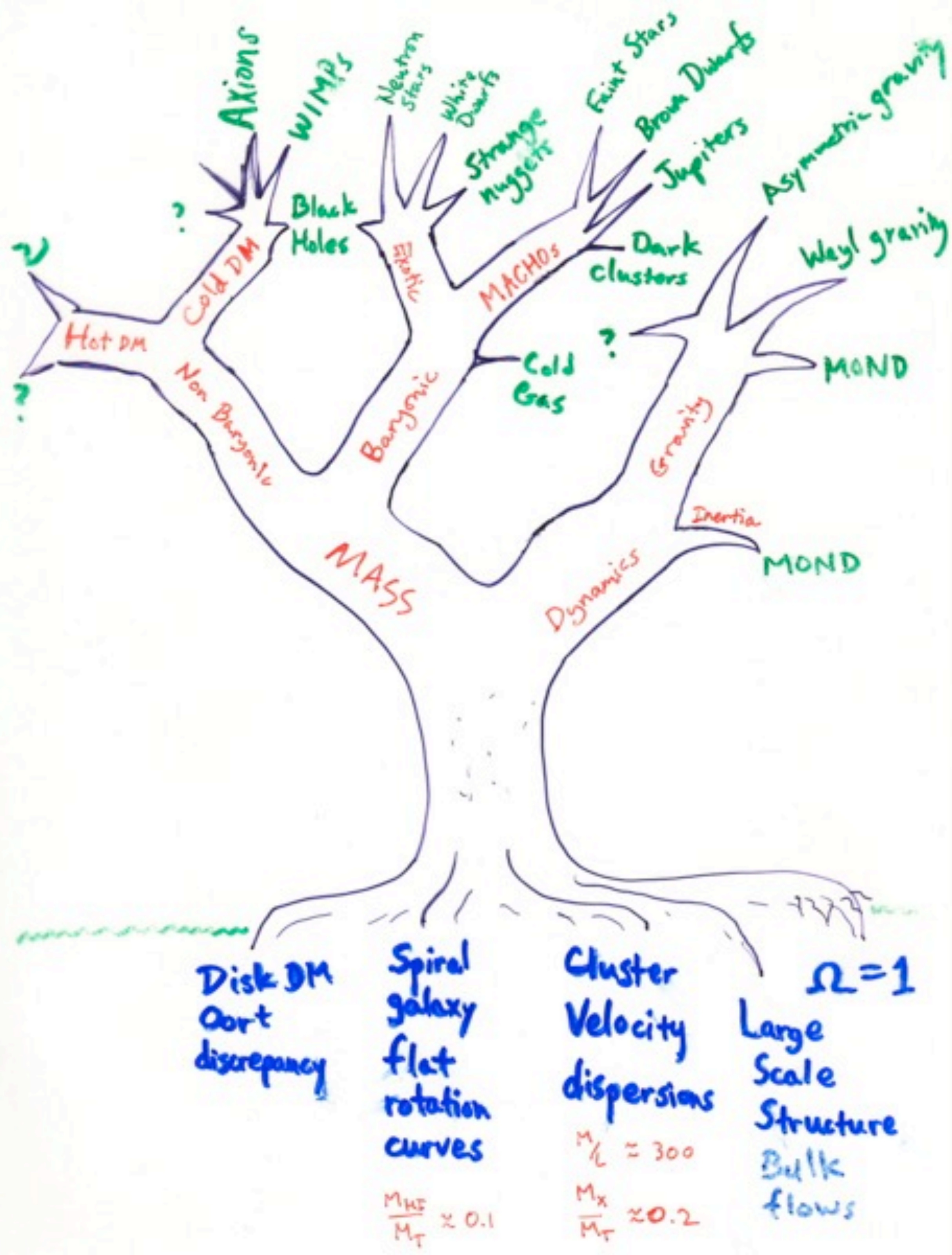
Some Great Questions

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
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Spiral galaxy flat rotation curves
$\frac{M_{HI}}{M_T} \approx 0.1$
Cluster Velocity dispersions
$M/L \approx 300$
$\frac{M_X}{M_T} \approx 0.2$
$\Omega = 1$
Large Scale Structure
Bulk flows

BULLETIN OF THE ASTRONOMICAL INSTITUTES OF THE NETHERLANDS.

1932 August 17 | Volume VI. | No. 238.

COMMUNICATION FROM THE OBSERVATORY AT LEIDEN.

The force exerted by the stellar system in the direction perpendicular to the galactic plane and some related problems, by *J. H. Oort.*

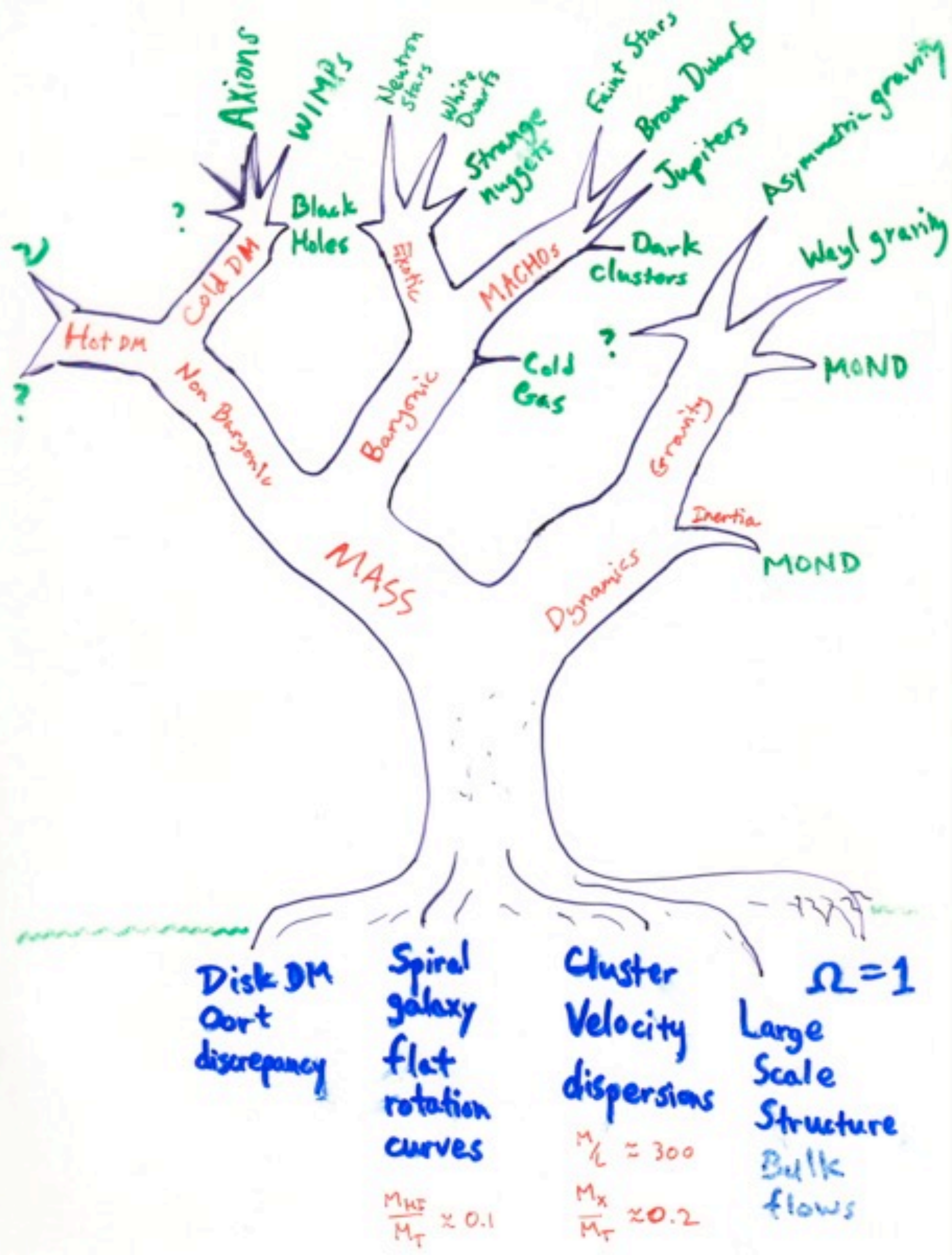
Notations.

- z distance from the galactic plane,
- Z velocity component perpendicular to the galactic plane,
- Z_0 the value of Z for $z = 0$,
- l modulus of a Gaussian component of the distribution of Z (formula (5), p. 253),
- $K(z)$ the acceleration in the direction of z,
- Δ the star-density,
- ρ the distance of a star from the sun,
- $\Phi(M)$ the number of stars per cubic parsec between $M - \frac{1}{2}$ and $M + \frac{1}{2}$,
- $A(m)$ the number of stars per square degree between $m - \frac{1}{2}$ and $m + \frac{1}{2}$,
- b galactic latitude,
- ϖ distance to the axis of rotation of the galactic system,
- δ $\partial \log \Delta / \partial \varpi$.

Summary of the different sections.

4. From VAN RHIJN's tables in *Groningen Publication* No. 38 the density distribution $\Delta(z)$ has been computed for four intervals of visual absolute magnitude (Table 13 and Figure 1). Figures 2 and 3 show $\log \Delta(z)$ for A stars and yellow giants, as derived by LINDBLAD and PETERSSON.

5. With the aid of the data contained in the two preceding sections I have computed the acceleration $K(z)$ between $z = 0$ and $z = 600$. The computations were made by successive approximations; the B stars were eliminated first. The results are in Table 14 and Figure 4, $K'(z)$ giving the values finally adopted. The good agreement between the practically independent values of $K(z)$ derived from the separate absolute magnitude groups is a strong argument in favour of the approximate correctness of the data up to $z = 400$. The result may be summarized by stating that the absolute value of $K(z)$ increases proportionally with z from $z = 0$ to $z = 200$; between $z = 200$ and $z = 500$ it remains practically constant and equal to $3{\cdot}8 . 10^{-9}$ cm/sec².



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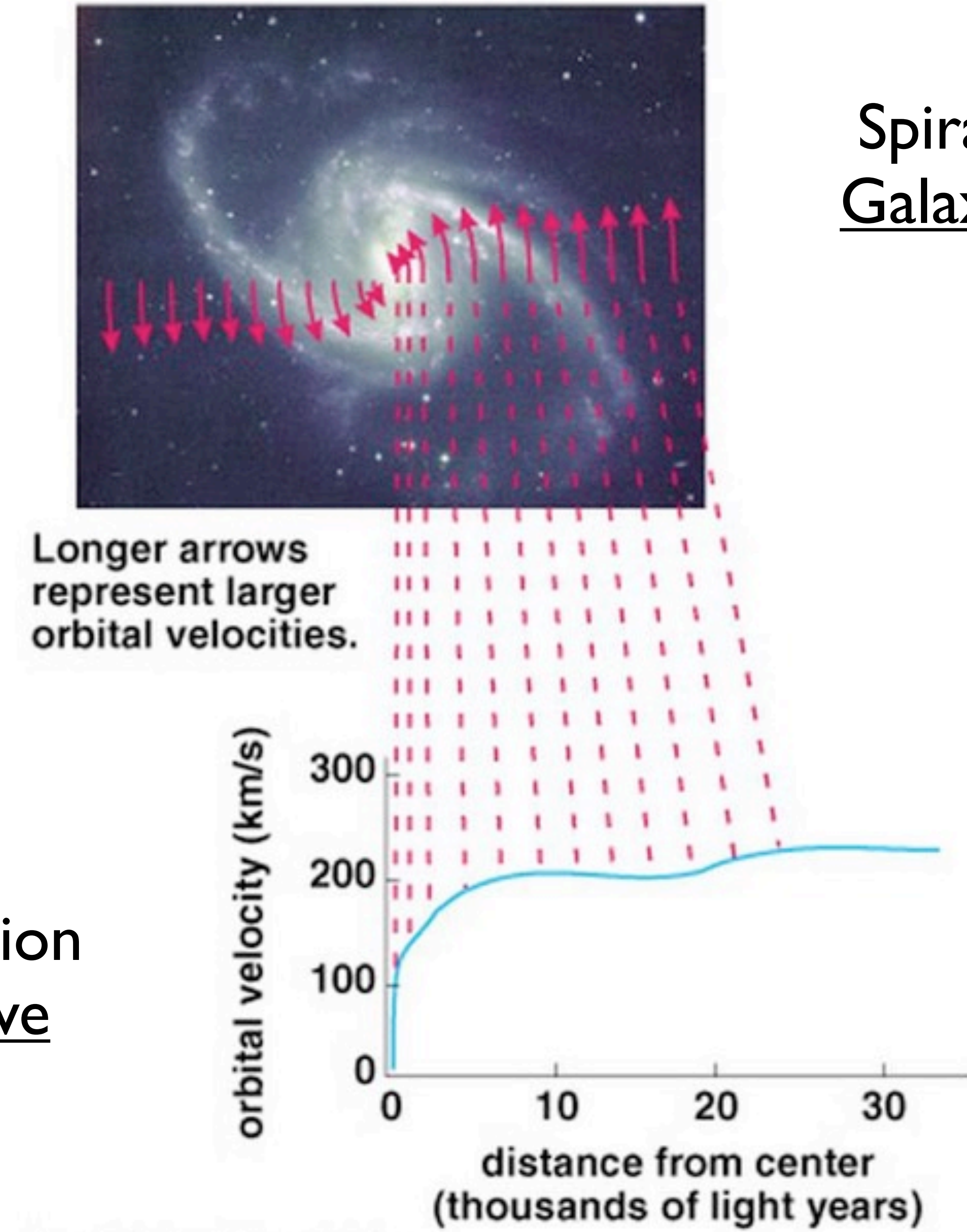
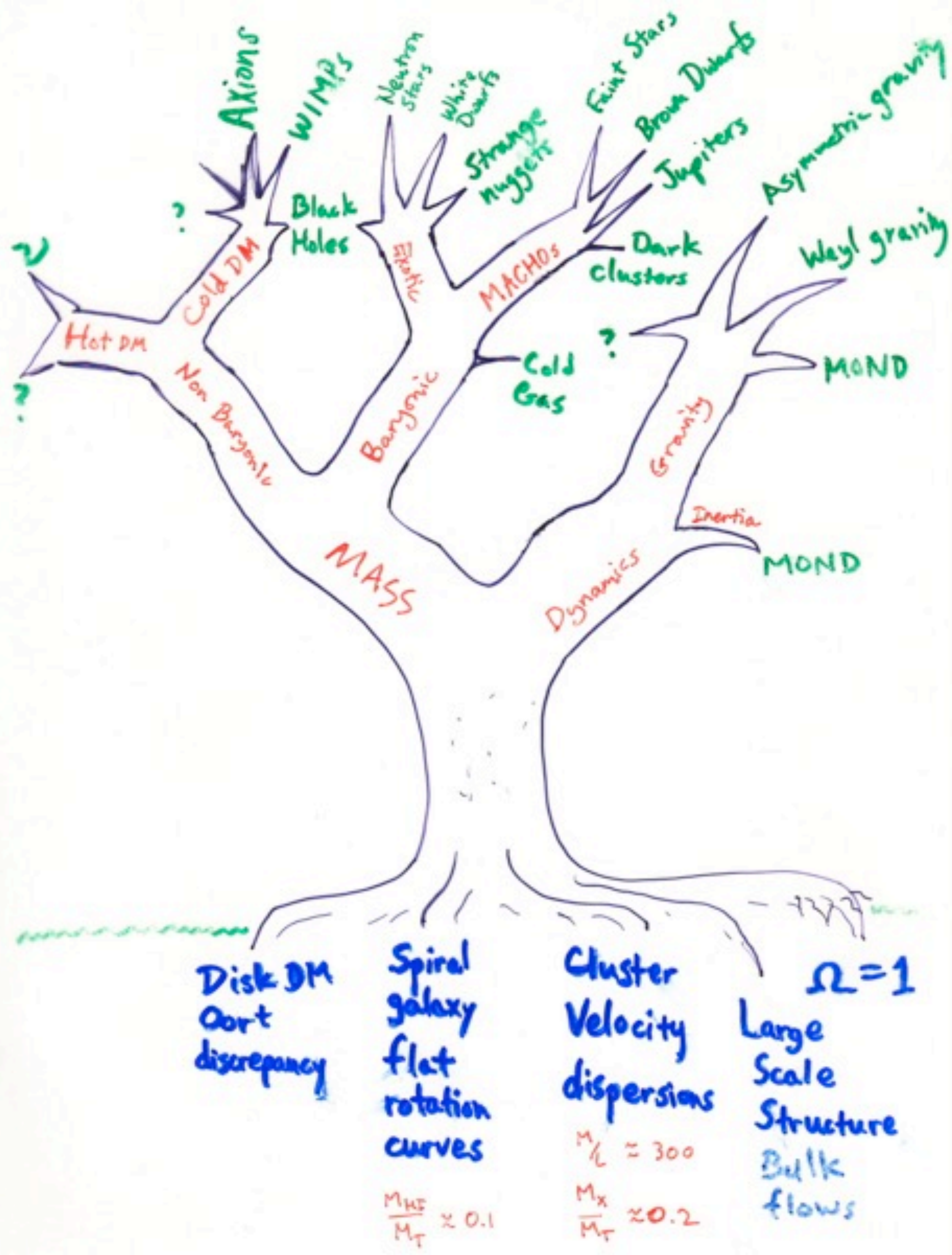
Spiral Galaxy



Rotation Curve



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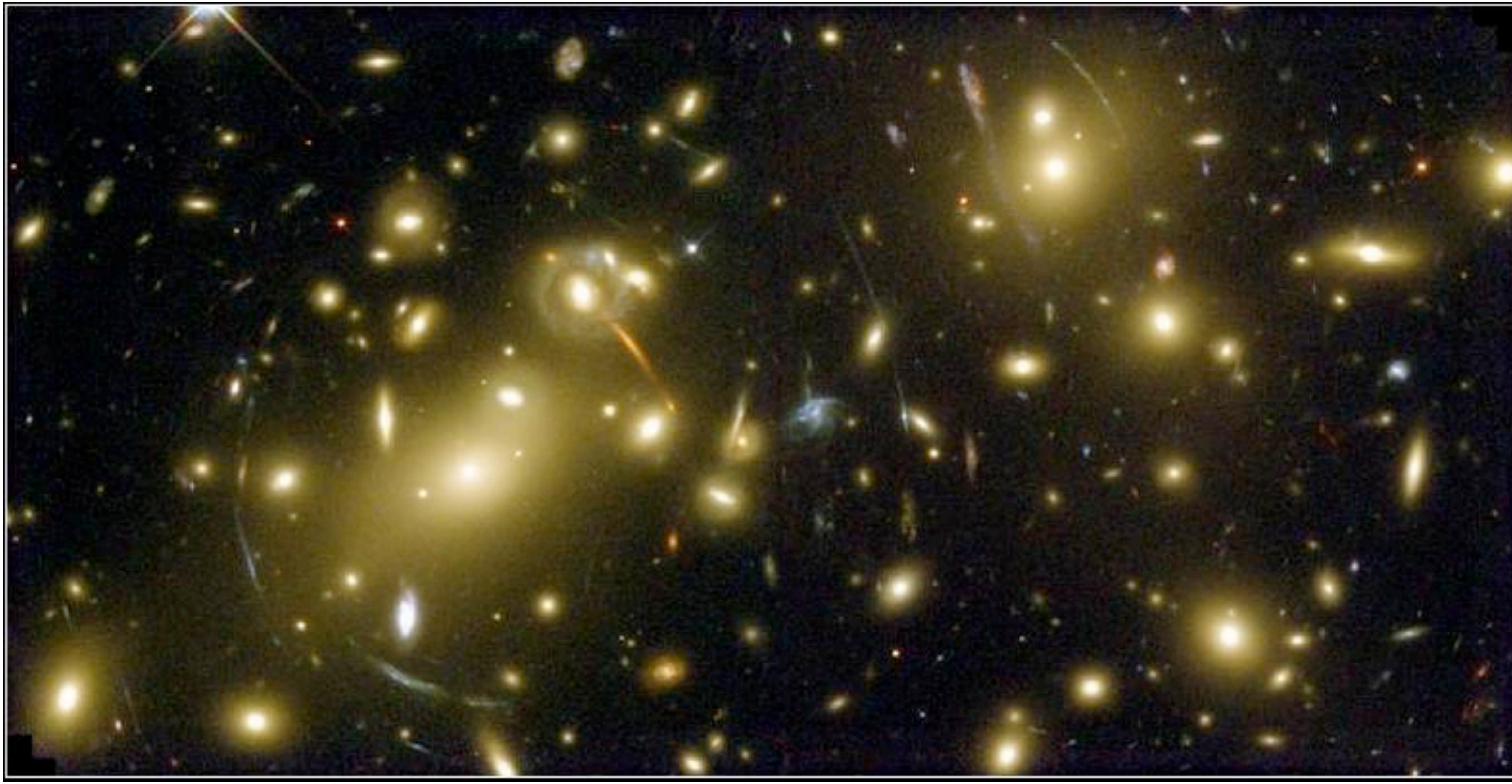
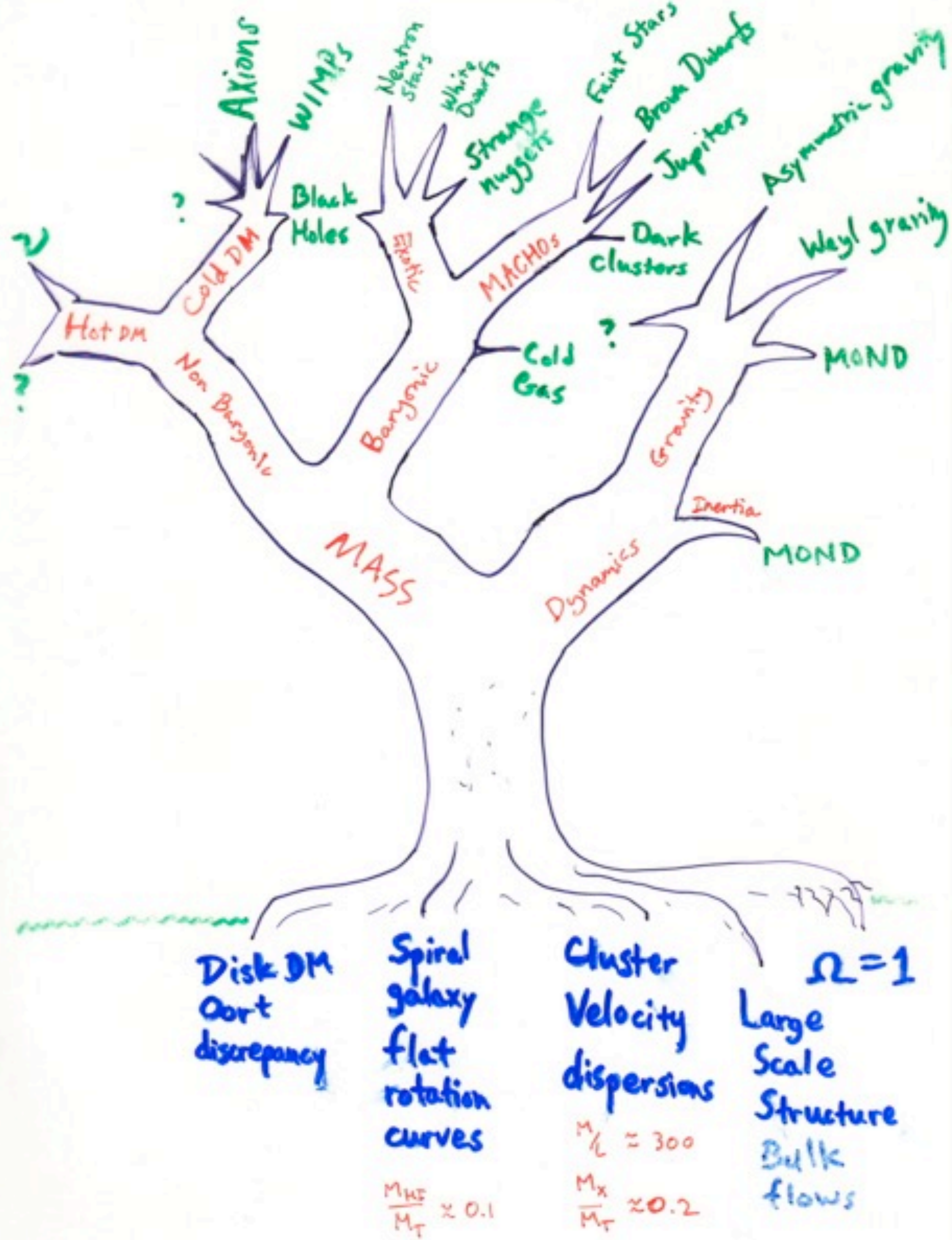
<u>Galaxy Cluster</u>

Zwicky 1933, 1937



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



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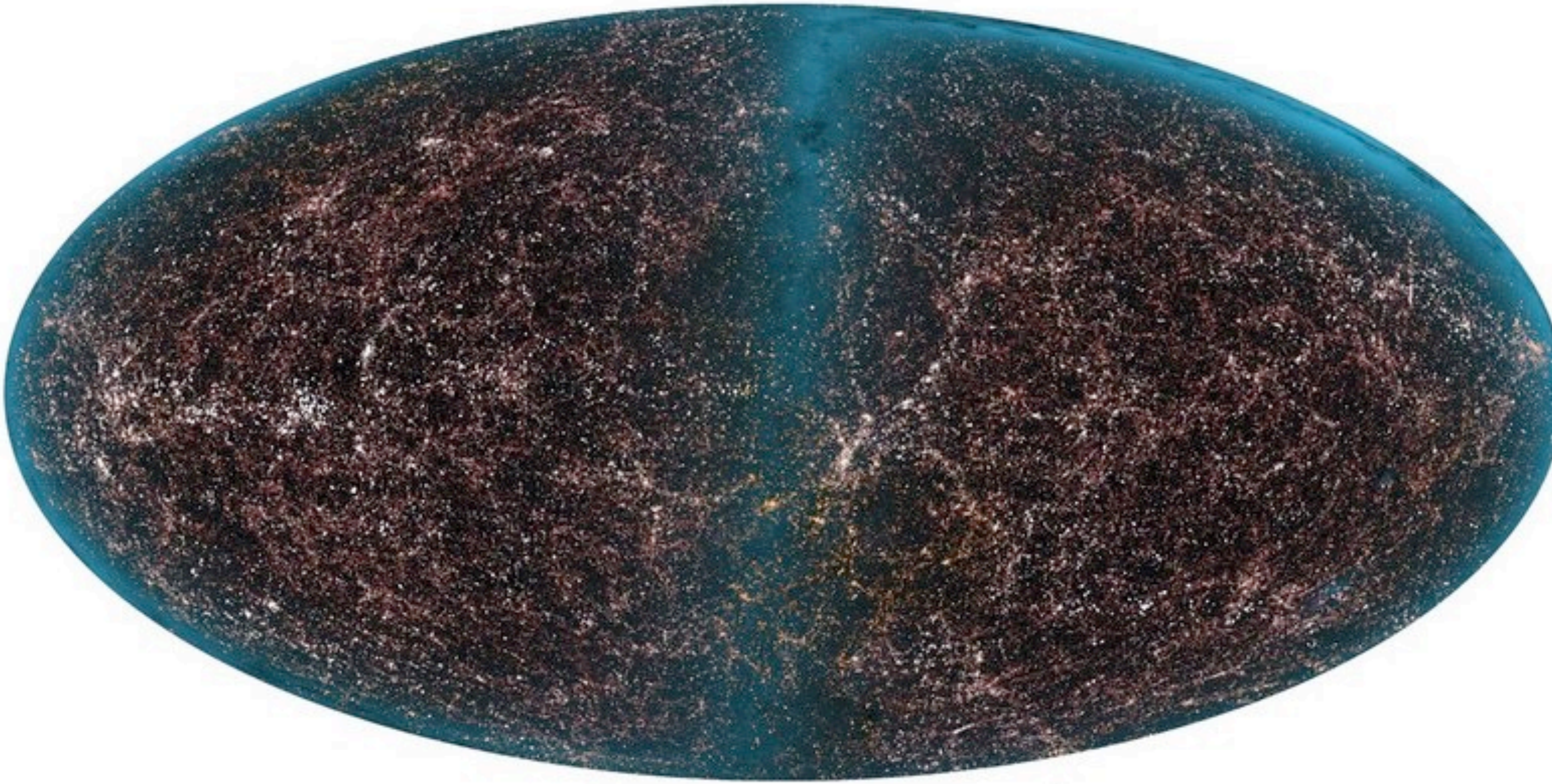
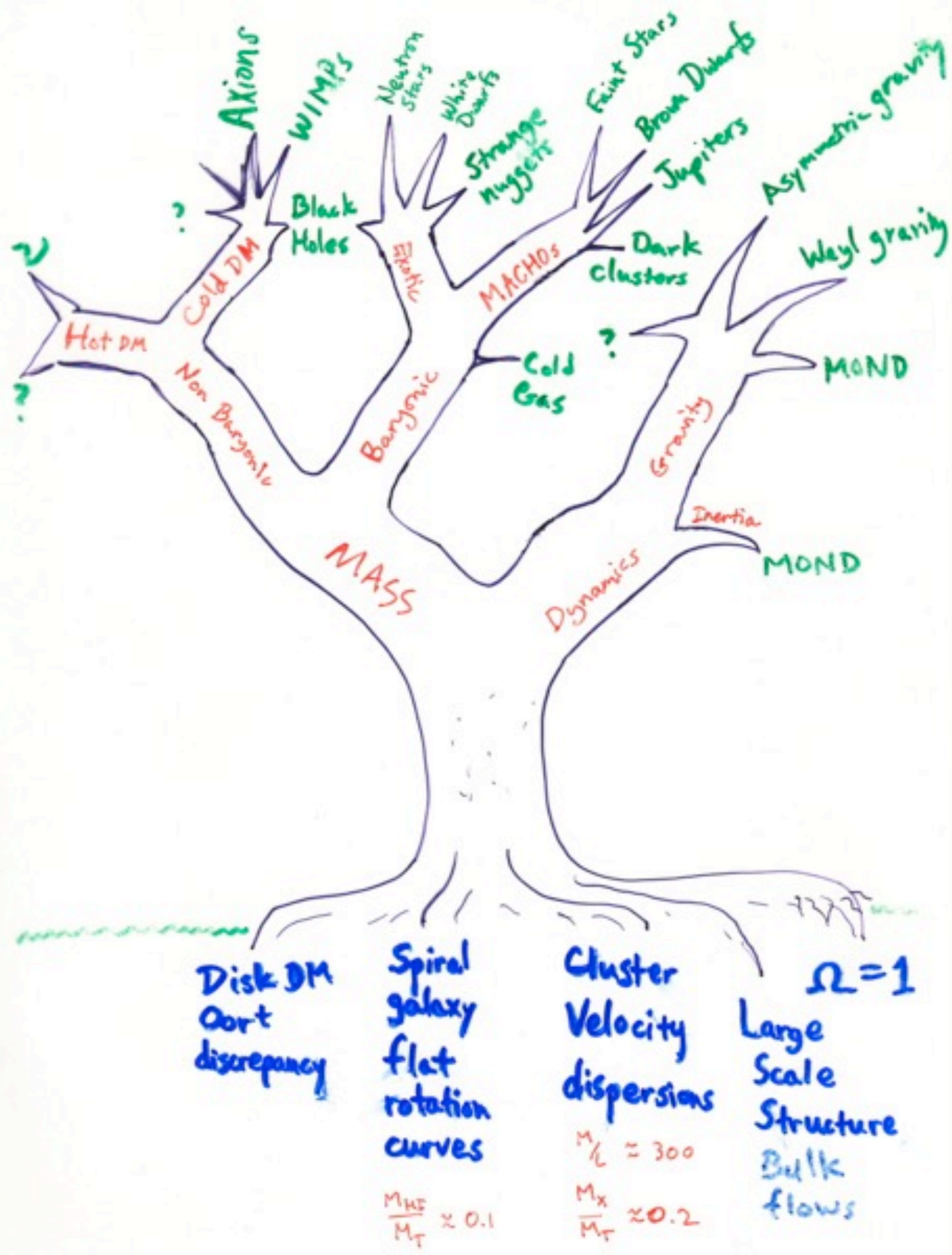
Large Scale Structure





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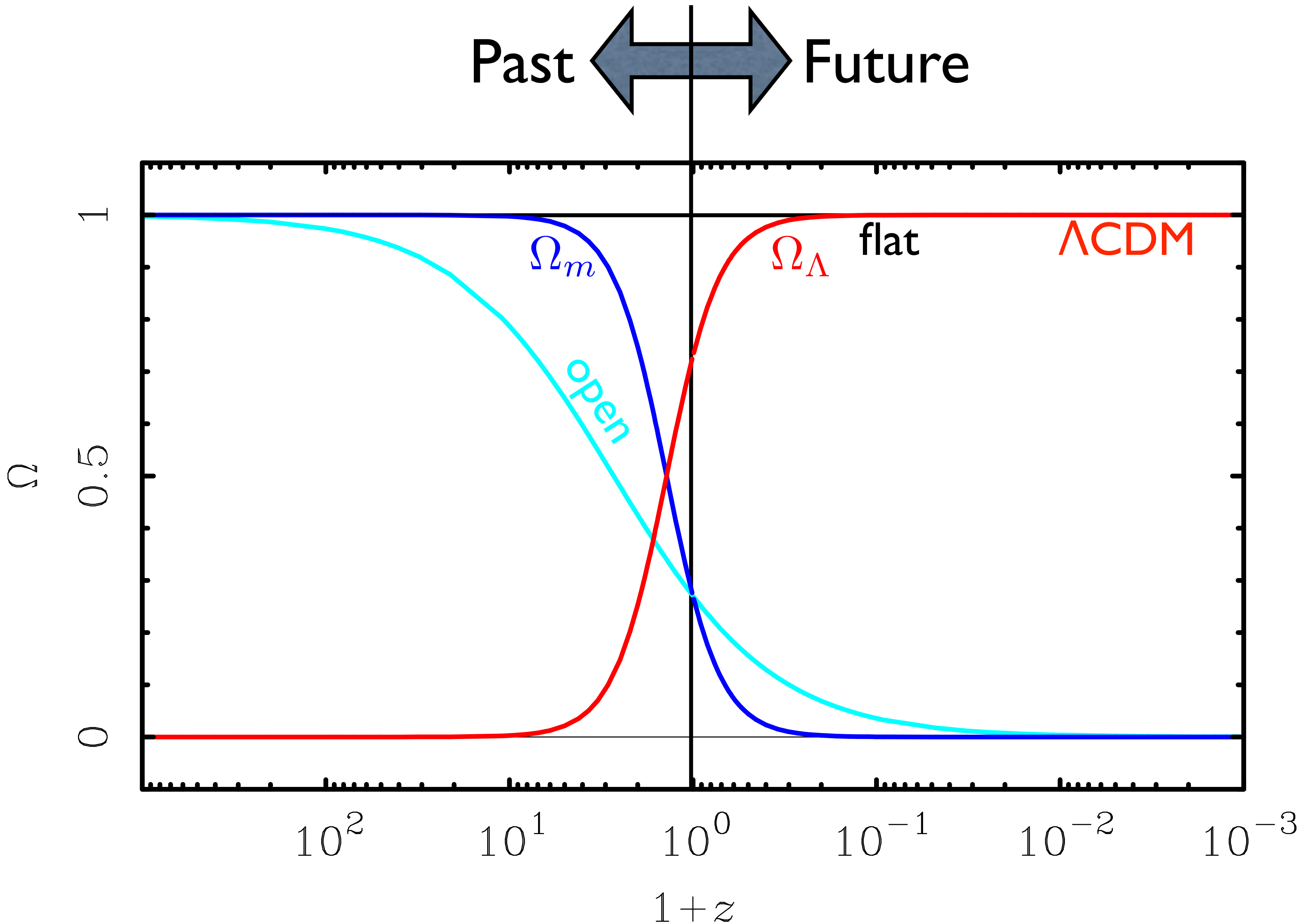
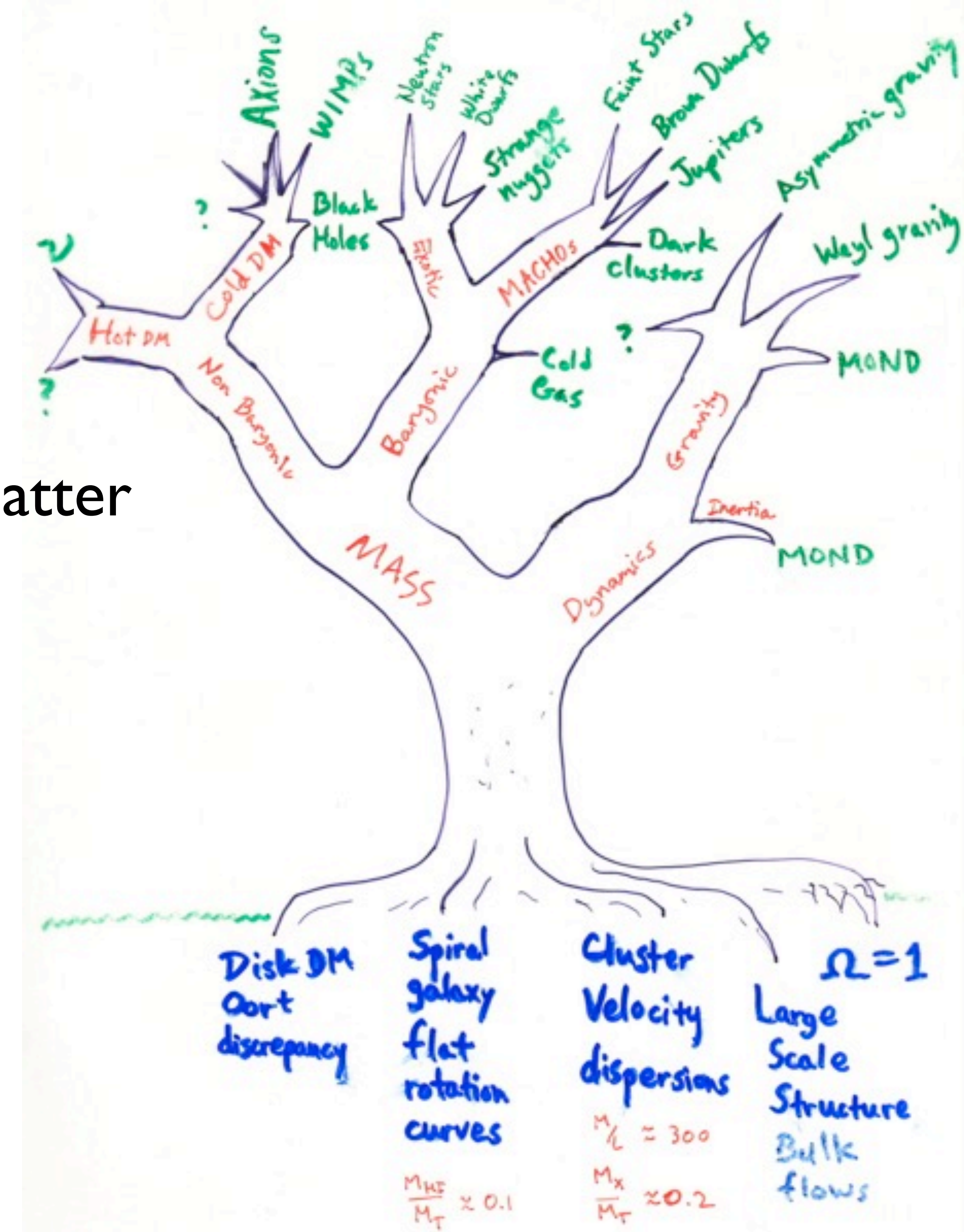


Coincidence/flatness problem:
why is the density parameter of order unity?

Modified Gravity

Dark Matter



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