

# DARK MATTER

ASTR 333/433

SPRING 2020

T R 11:30AM-12:45PM

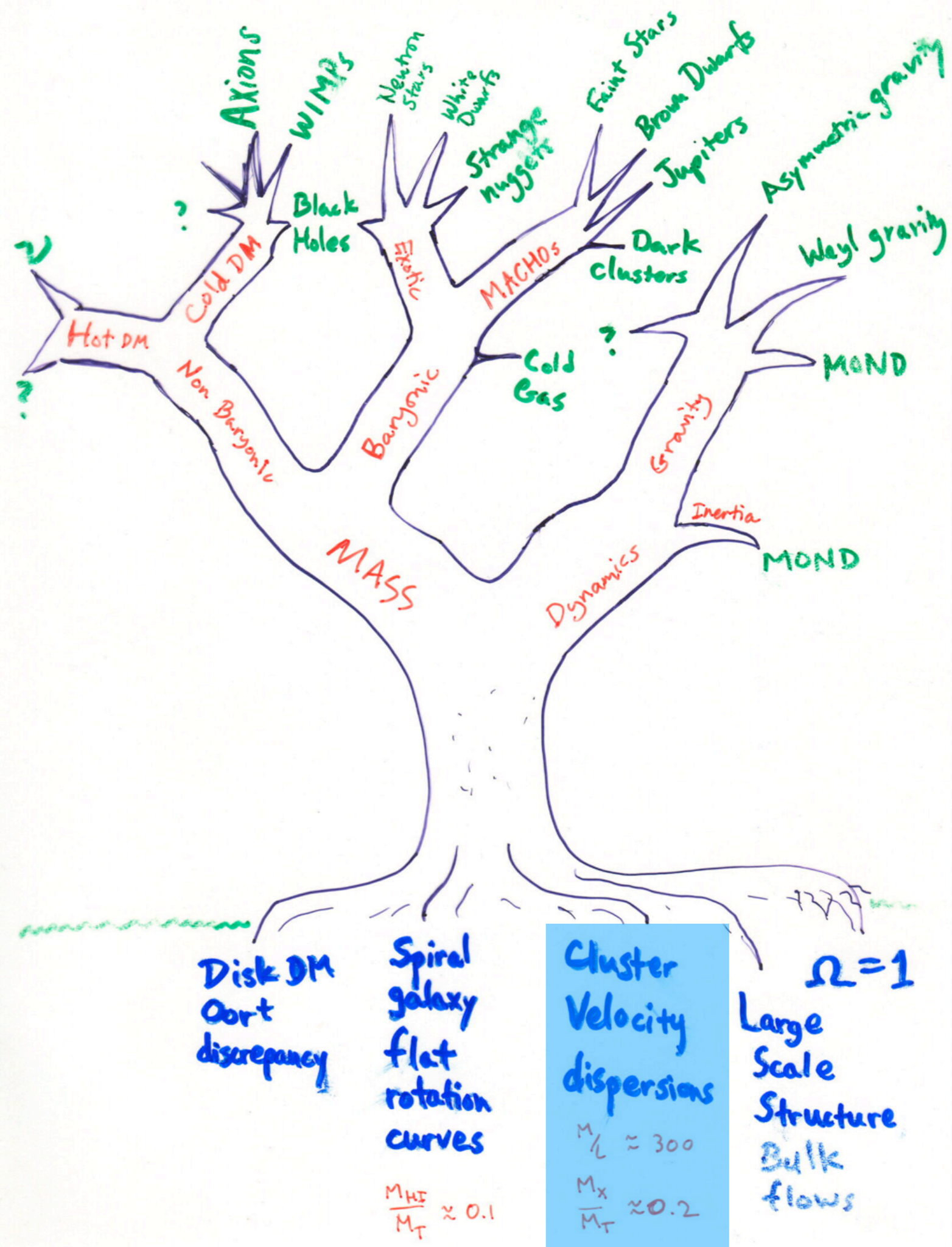
SEARS 552

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

PROF. STACY MCGAUGH

SEARS 558

368-1808



# Hypothesis Testing

Observed Reality

Theoretical Interpretation

Natural Phenomena

Hypothesized Explanation

Predictions

Experimental Tests

Ambiguous  
result

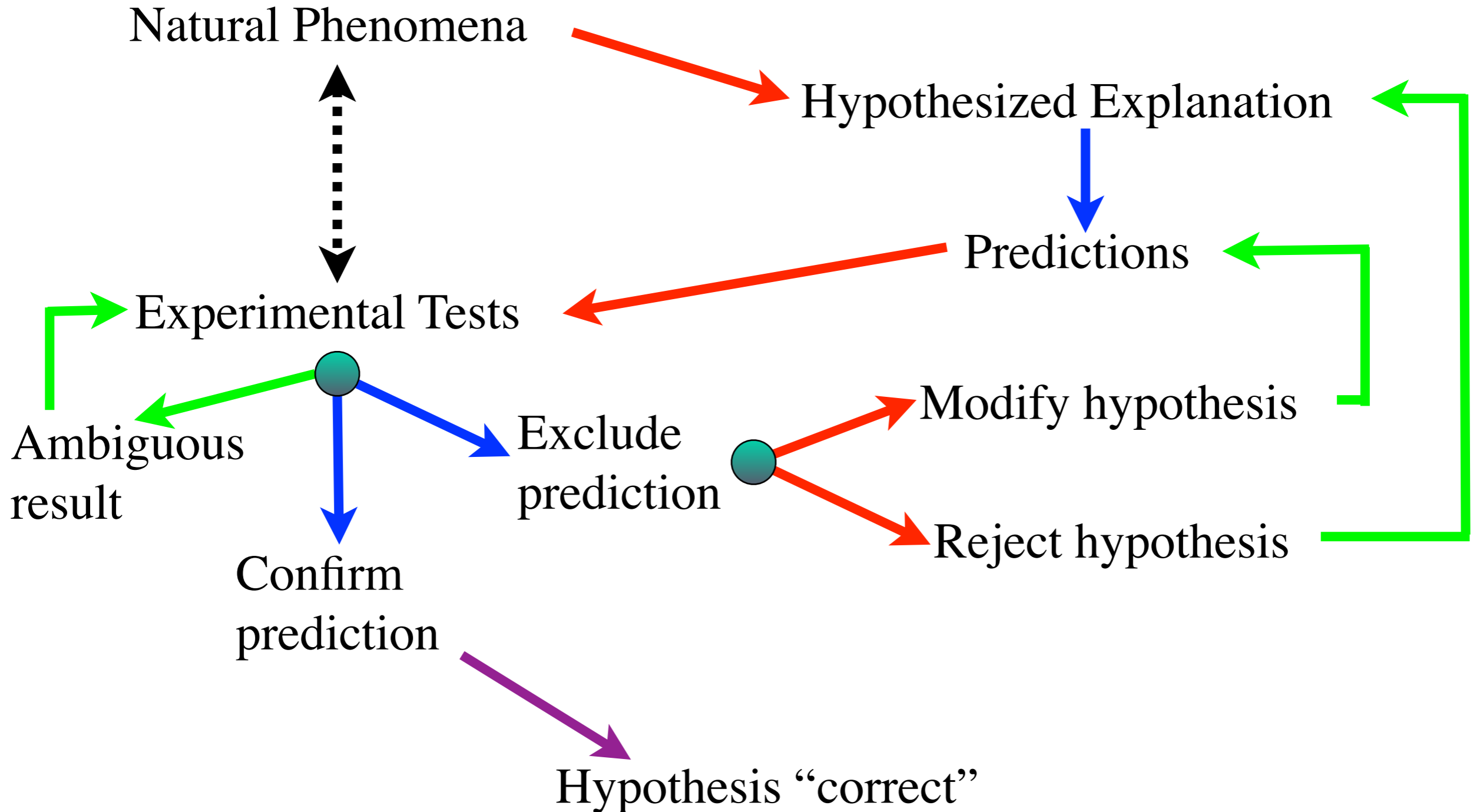
Exclude  
prediction

Modify hypothesis

Reject hypothesis

Confirm  
prediction

Hypothesis "correct"



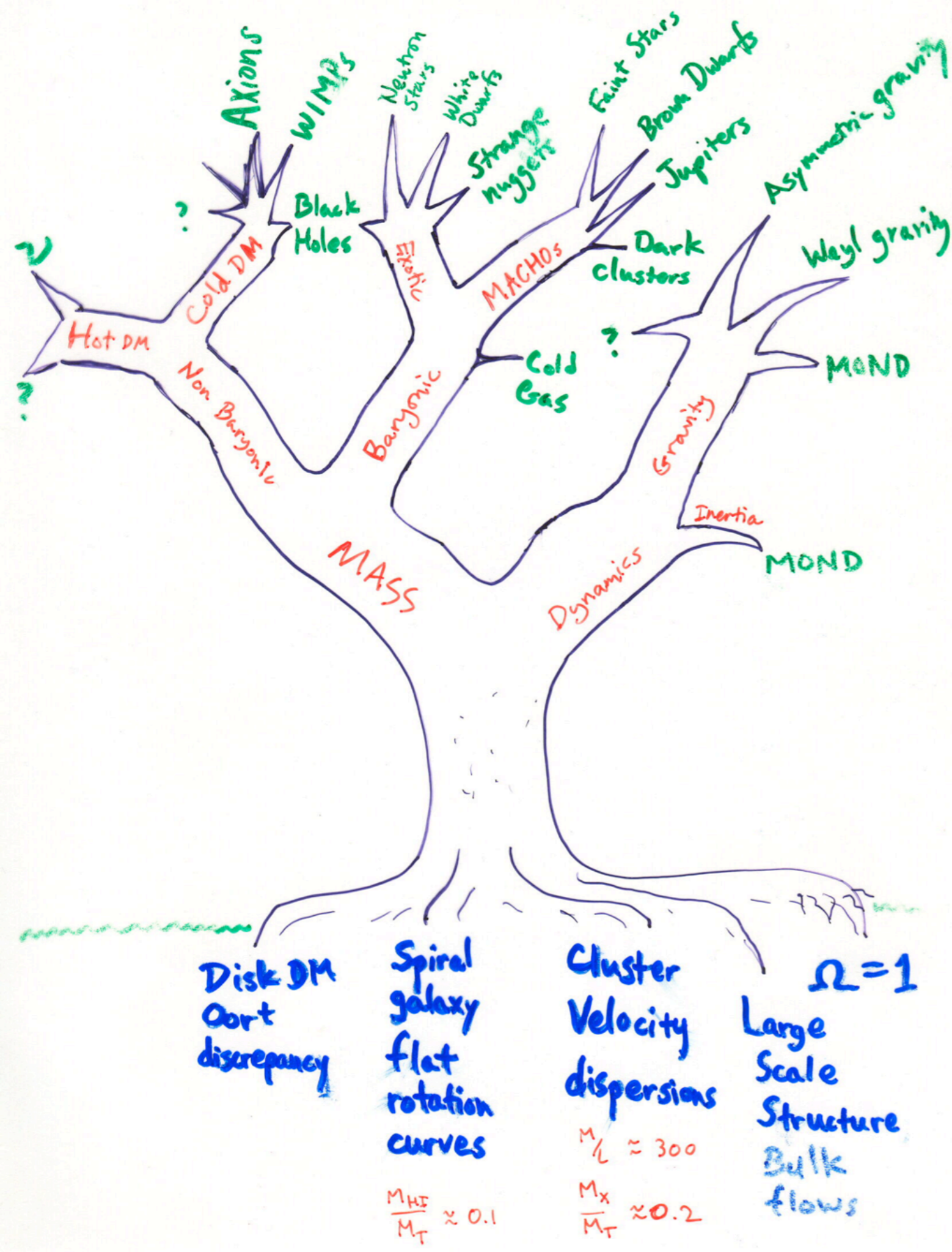
# The Principle of Doubt

- Hypotheses can be *rejected* but never completely *confirmed*.
- At best, a theory can be *adequate* for describing a specific set of phenomena.
- Do not trust - verify through experiment.
- Simple theories are preferable to complicated theories (Occam's Razor)
  - Any theory can be made complicated enough to explain anything. It isn't useful unless it can predict new things.
  - If a theory has its predictions come true, we are obliged to acknowledge its efficacy, even if it means rejecting something we formerly believed.

# Measurement Uncertainty

- No experiment is perfect
- Experimental uncertainty is often the difference between rejecting a hypothesis and an ambiguous result
- It is important to quantify both measurements AND their accuracy
- This is virtually impossible in astronomy
  - there are often systematic uncertainties that are not easily quantifiable: we can't put the universe in a box and control the experiment.





## Back to observations

Dark Matter has always been driven by data - specifically, astronomical observations of large structures like galaxies, clusters of galaxies, and the universe as a whole.



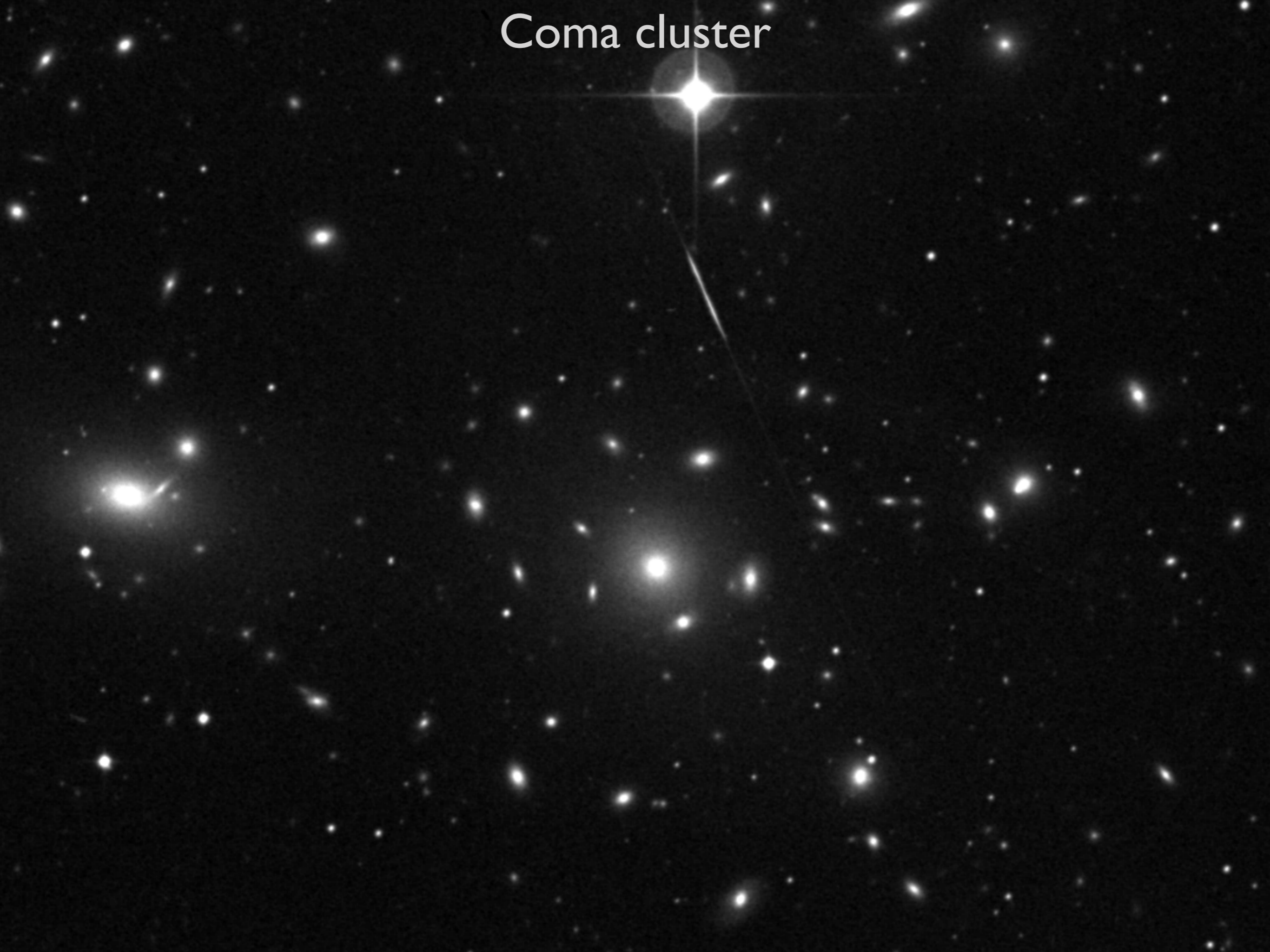
Zwicky's problem: clusters of galaxies

Coma cluster





# Coma cluster



# Coma cluster velocity dispersion

## Colless & Dunn 1996

DYNAMICS OF COMA CLUSTER

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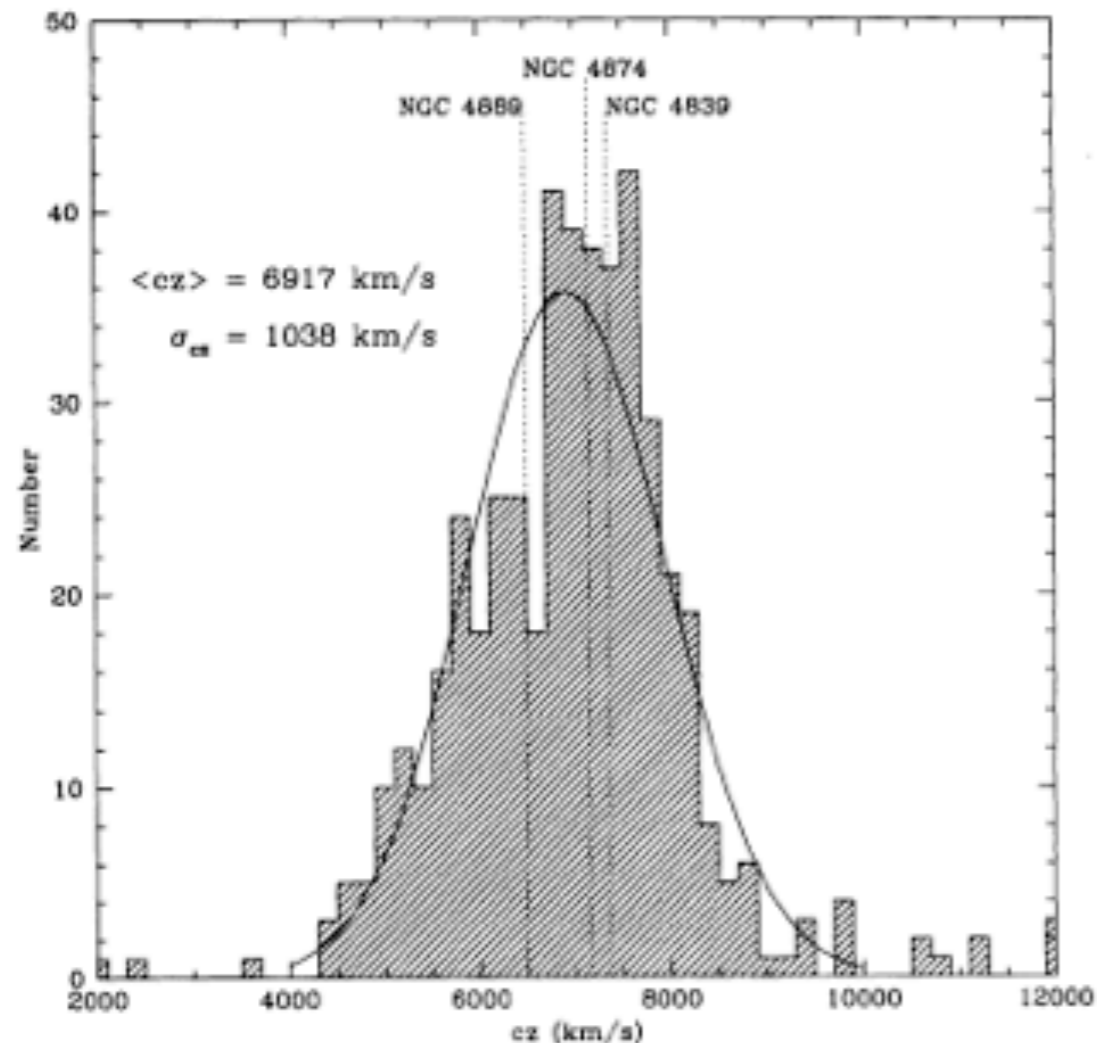


FIG. 5.—Distribution of radial velocities for galaxies in the Coma cluster. The curve is a Gaussian with mean  $6917 \text{ km s}^{-1}$  and standard deviation  $1038 \text{ km s}^{-1}$ . The velocities of the three dominant cluster galaxies are indicated.

Cluster observations are usually interpreted with the **Virial Theorem**.

This assumes the system is “virialized,” which is to say, relaxed to an equilibrium configuration.

Galaxy clusters form late by the merger of smaller groups; it is not obvious that they have achieved this state.

See also the “Review literature” course web page <http://astroweb.case.edu/ssm/ASTR333/revlit.html>

the relative richness of the subclusters from this analysis. An alternative visualization of the subclustering is provided by Figure 10, which shows the smoothed density of galaxies as a function of velocity and distance from the cluster center along the NE-SW diagonal [i.e.,  $(X + Y)/2^{1/2}$ , with NE

projected galaxy distribution in the core of the Coma cluster. NGC 4874 and NGC 4889, it is no surprise to see that these two dominant galaxies are projected in the spatial dimension onto the primary and secondary peaks, respectively, in the core galaxy distribution. Contrary to naive expectation, however,

## Coma (smoothed)

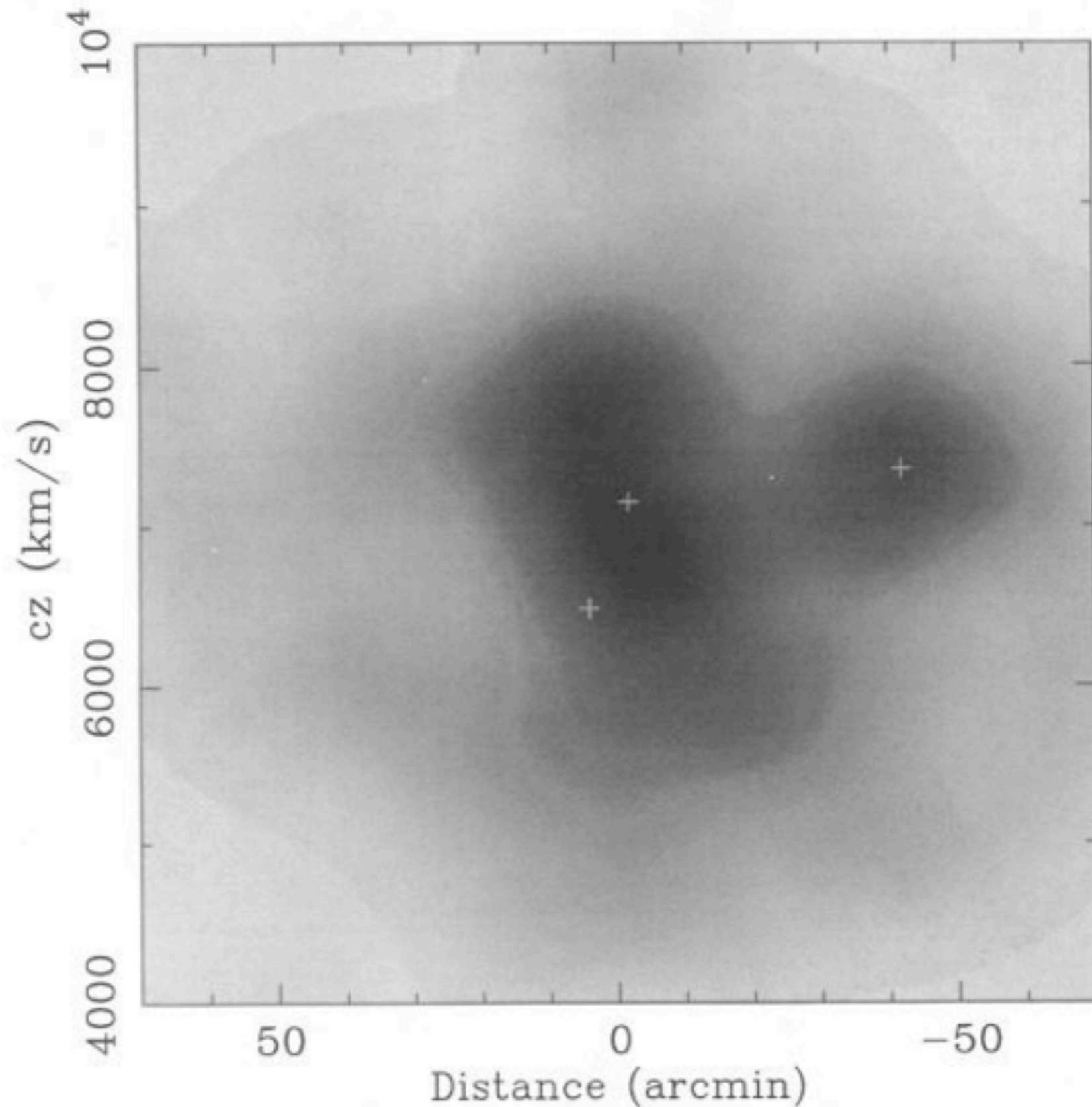


FIG. 10.—Galaxy density distribution projected onto the plane of radial velocity versus projected distance from the cluster center along the NE-SW diagonal (NE positive). The density is smoothed with a Gaussian of dispersion  $8'$  in the spatial dimension and  $300 \text{ km s}^{-1}$  in the velocity dimension. The positions of the three dominant galaxies are marked by crosses (left to right: NGC 4889, NGC 4874, NGC 4839). The gray scale is linear with density and runs from zero to the maximum.