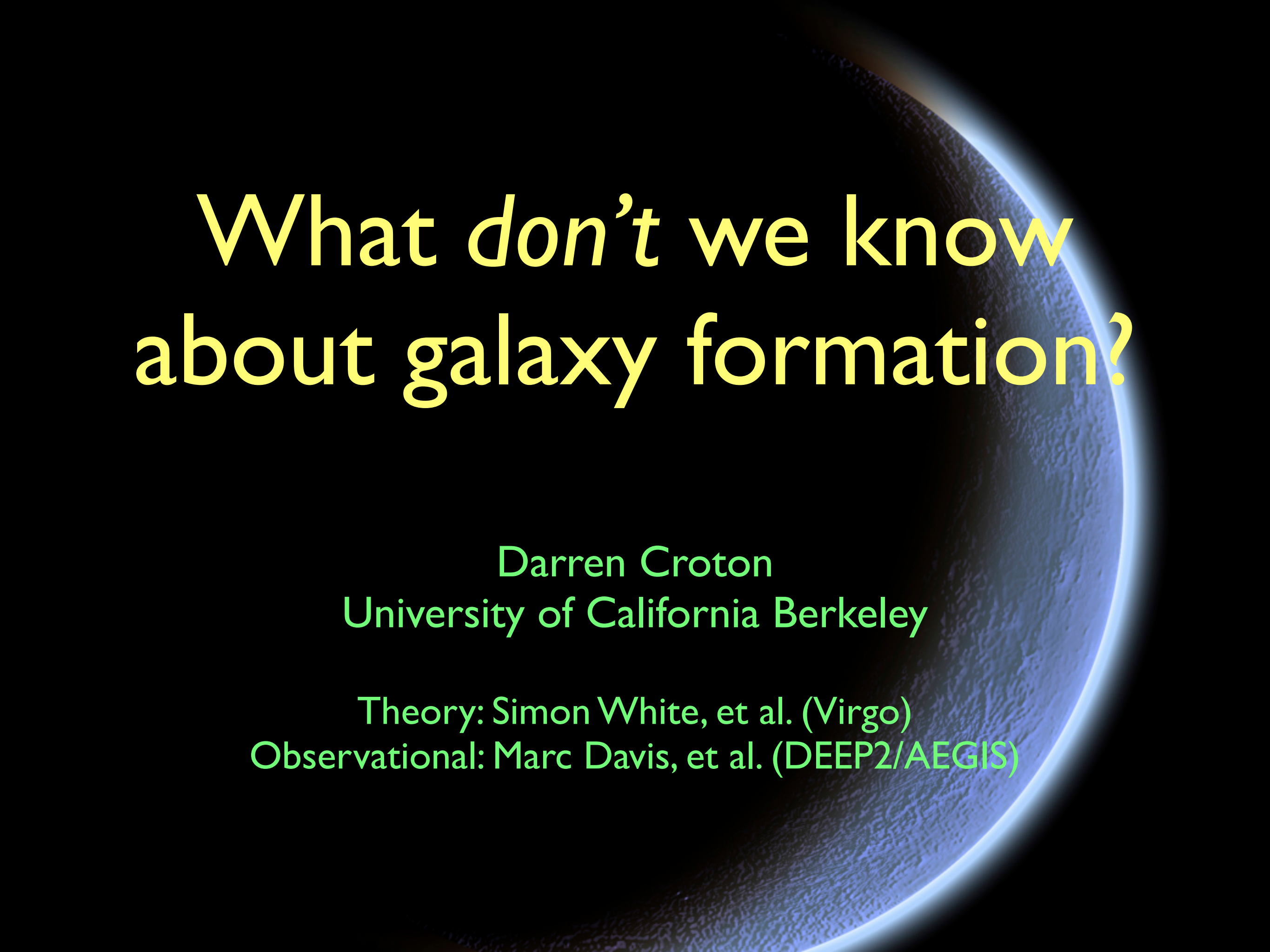




What *don't* we know about galaxy formation?

Darren Croton
University of California Berkeley

Theory: Simon White, et al. (Virgo)
Observational: Marc Davis, et al. (DEEP2/AEGIS)

Galaxies, why we care ...

- highly non-linear evolution
- home of internal phenomena
- shaped by external influences

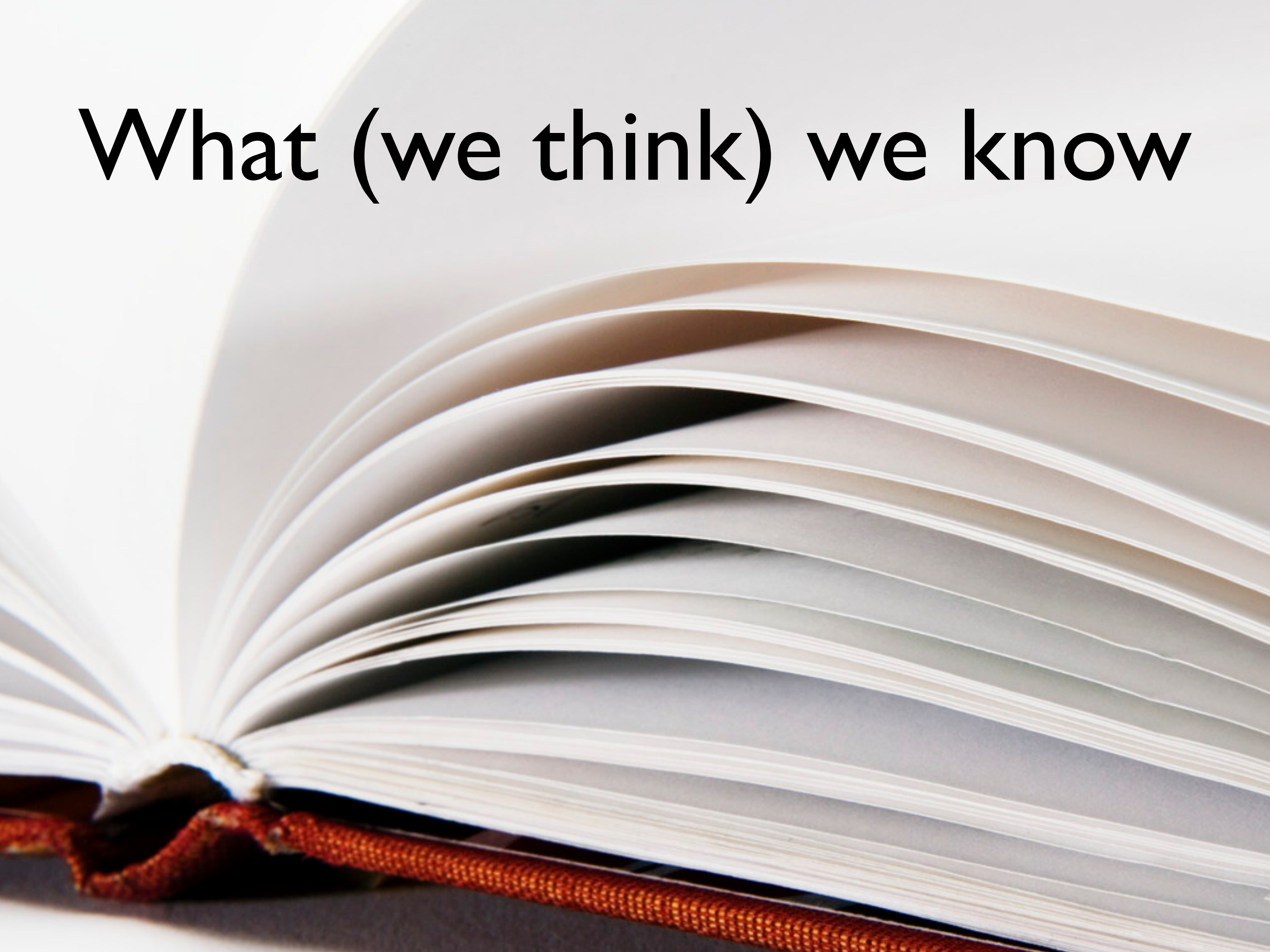




Outline

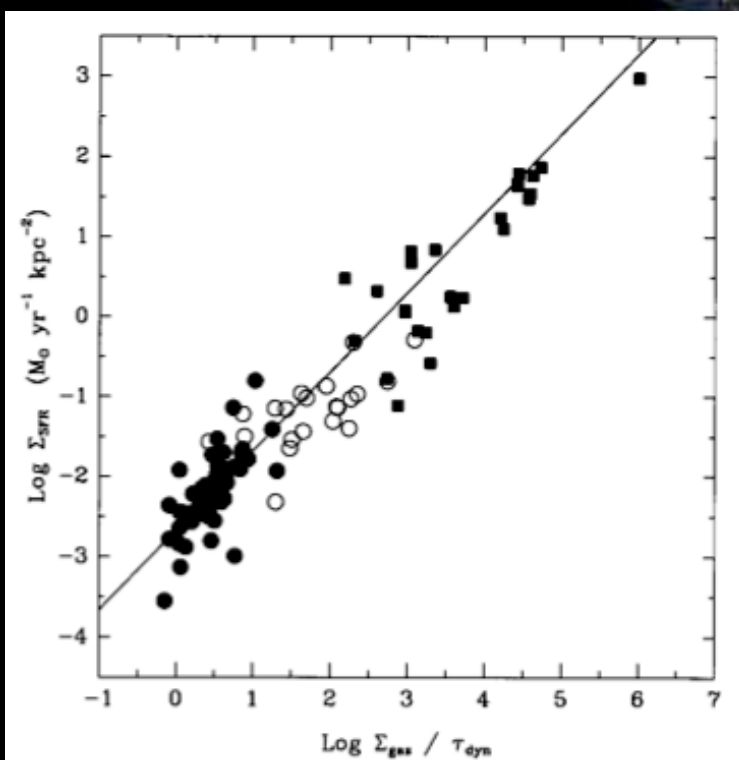
1. What we think we know
2. What we think we don't know
3. Next generation surveys

What (we think) we know



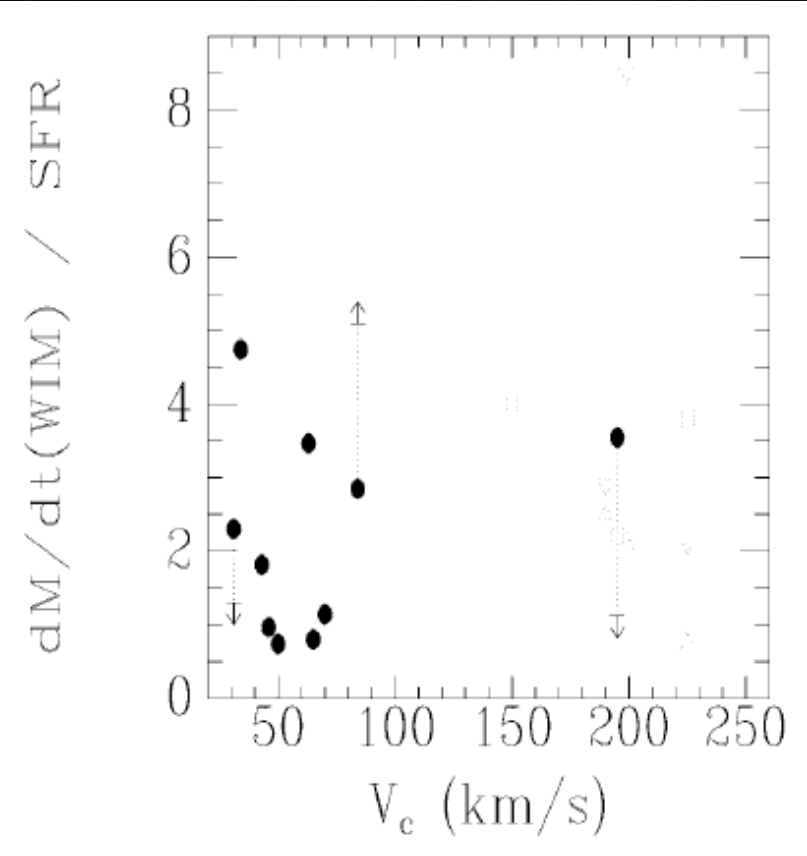
Star formation

Kennicutt 1998



M31

M82

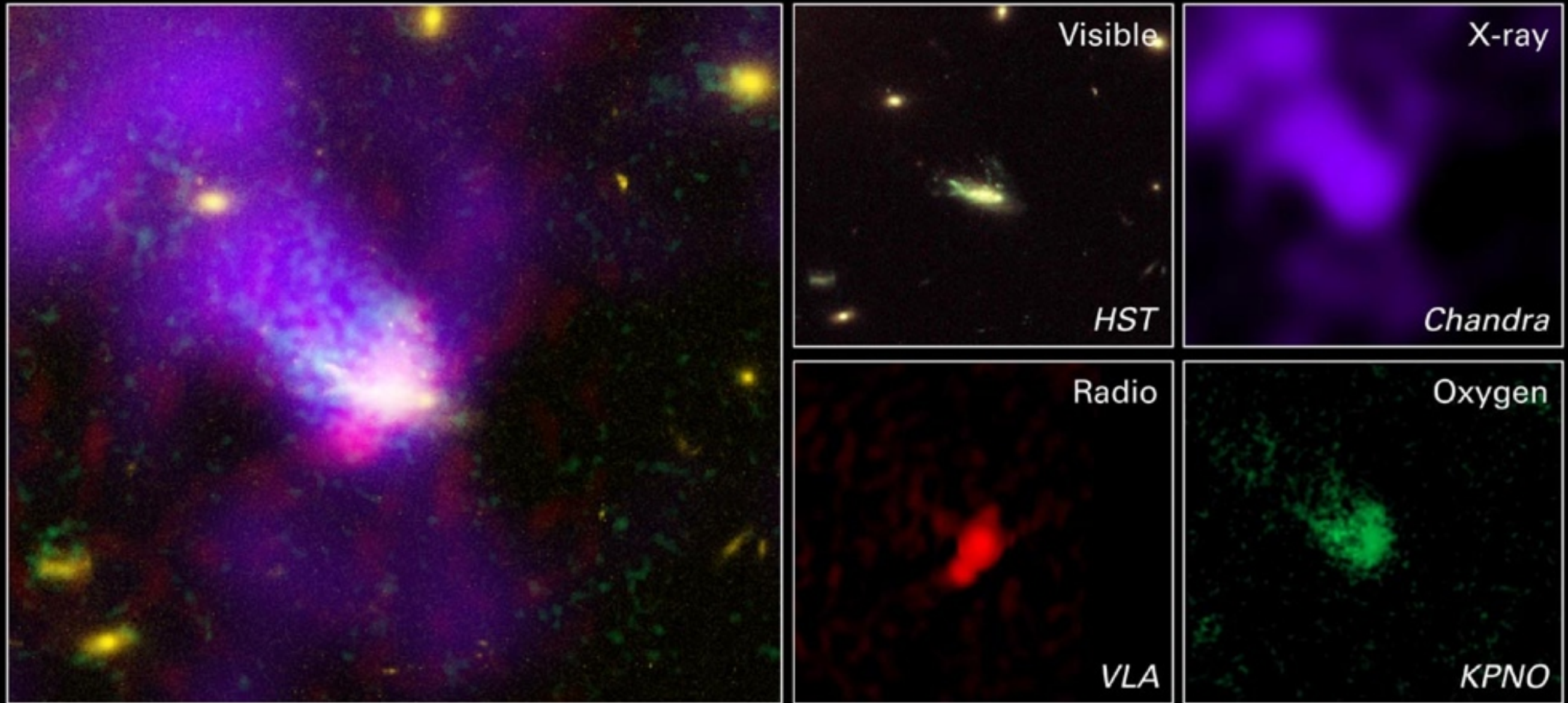


Martin 1999

Supernova feedback

Satellite infall

Galaxy C153 in Cluster Abell 2125



NASA, W. Keel (University of Alabama), F. Owen (National Radio Astronomy Observatory),
M. Ledlow (Gemini Observatory) and D. Wang (University of Massachusetts)

STScI-PRC04-02a

Morphological evolution



NGC 2207 & IC 2163

... and assembly



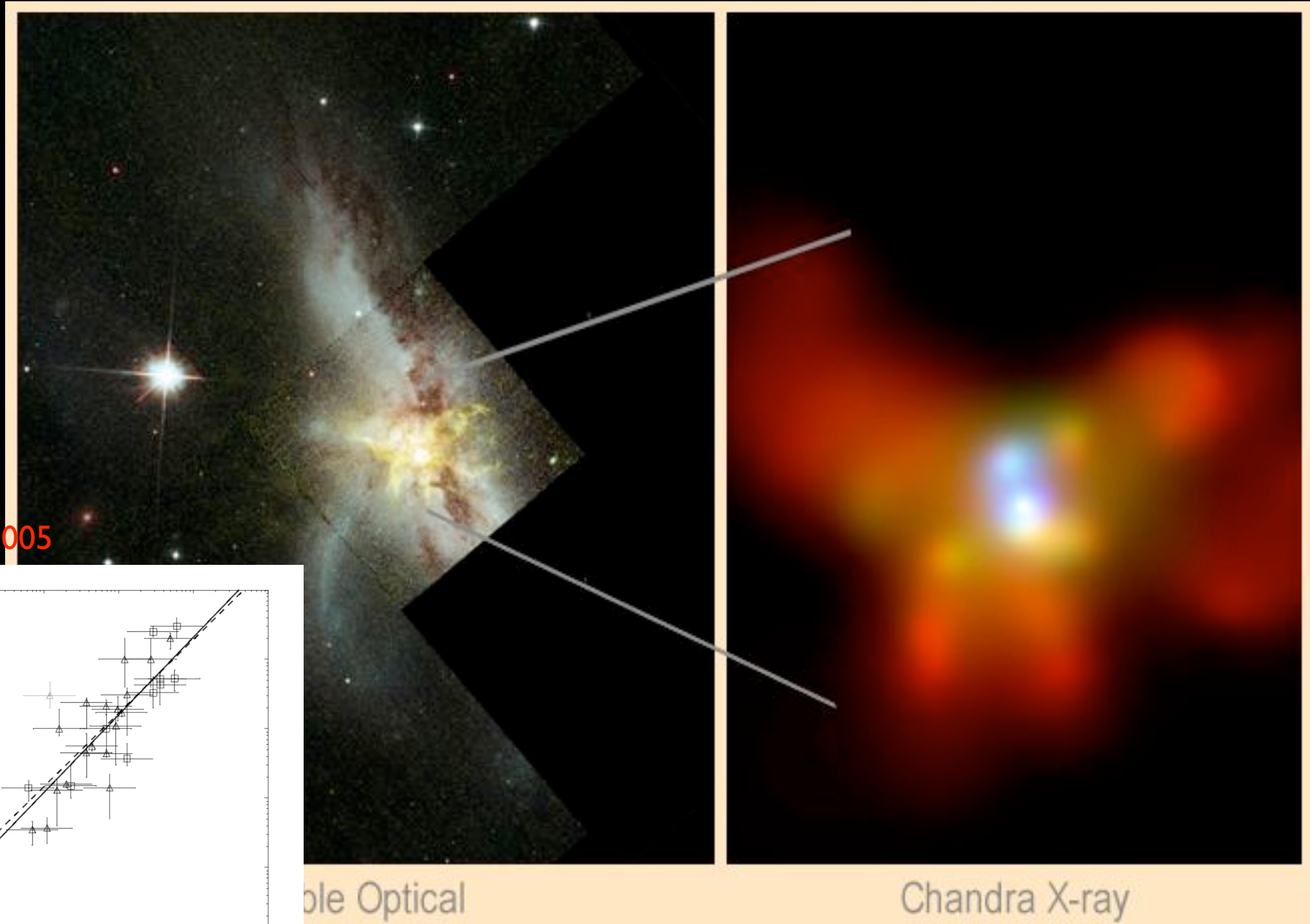
Seyfert's Sextet

A deep-field astronomical image of the Virgo cluster (M87). The image shows a dense field of stars and galaxies against a black background. A bright, yellowish-white star is prominent in the center, surrounded by a dense field of smaller stars. The text "... and death" is overlaid in a light blue color.

... and death

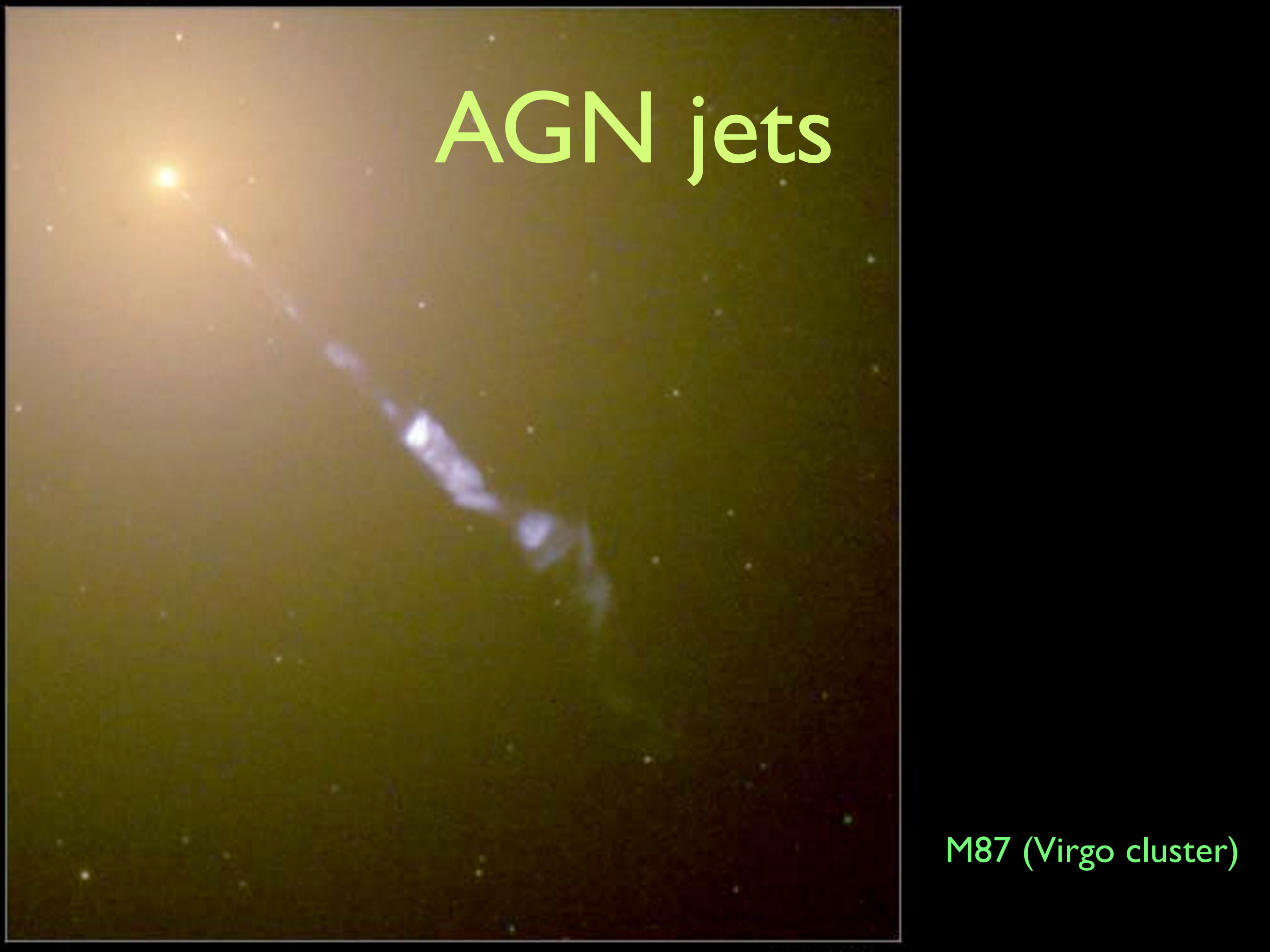
M87 (Virgo cluster)

Black holes



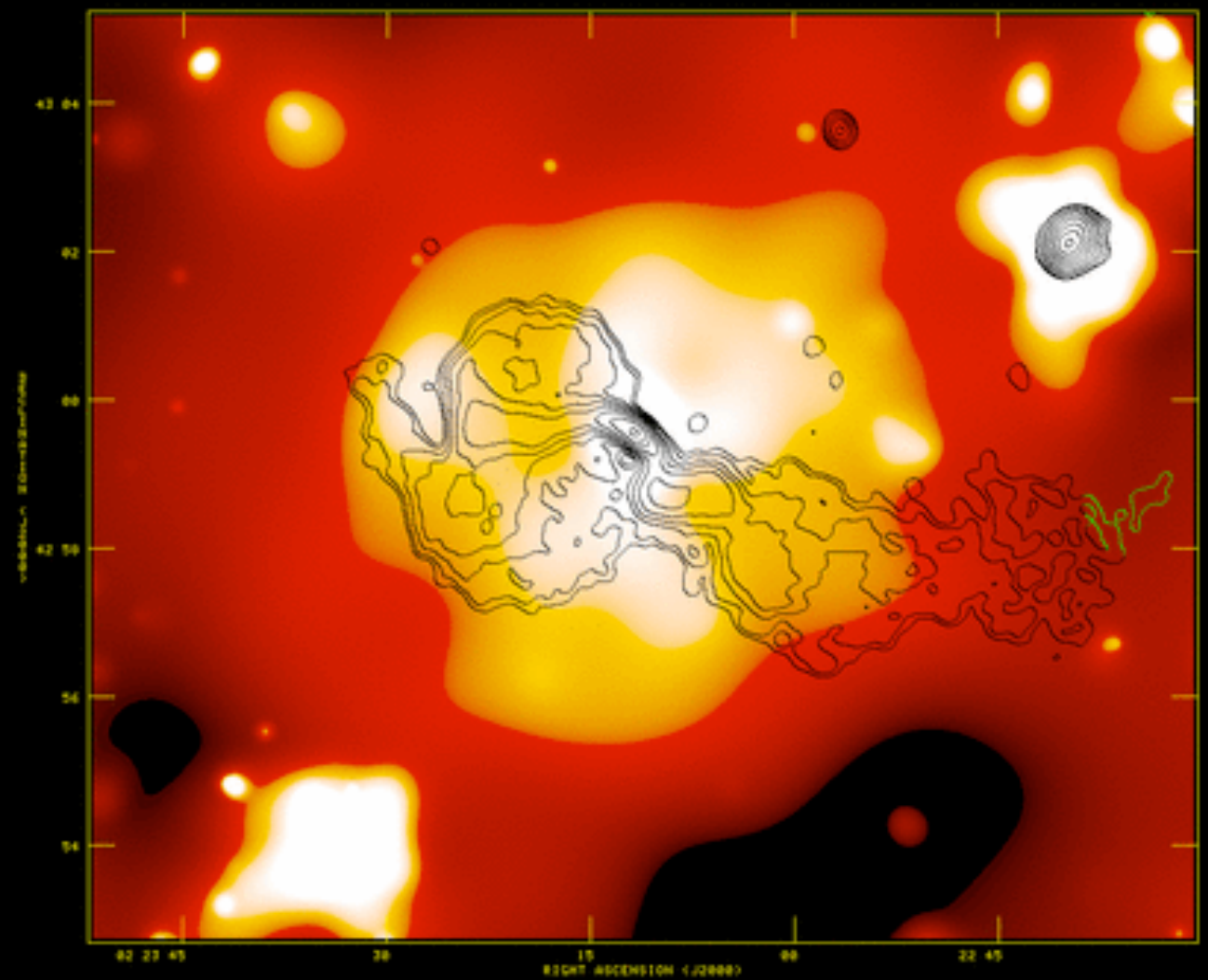
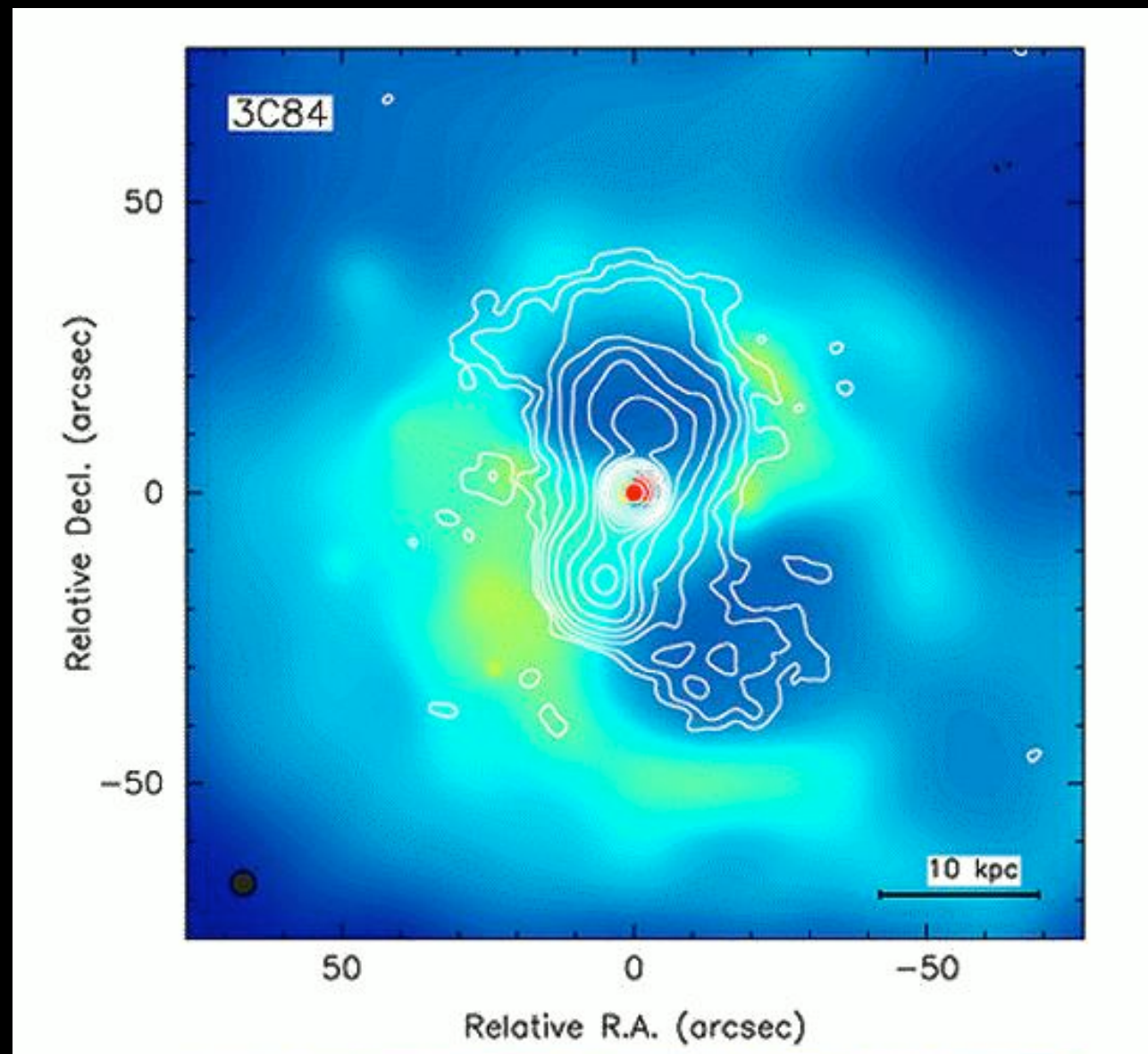
NGC 6240

AGN jets

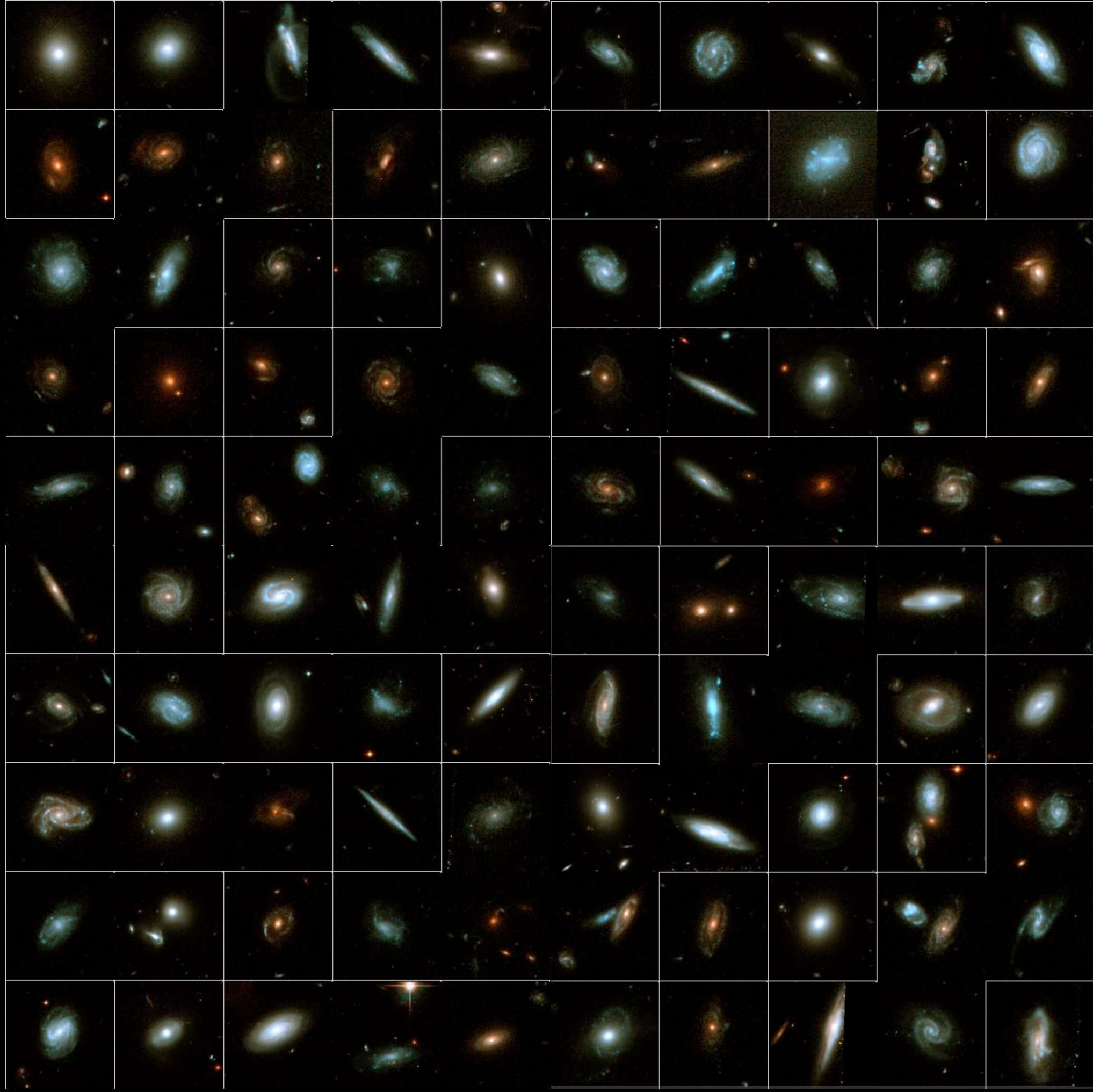
The image shows a bright, yellowish-white point source in the upper left corner, representing the nucleus of the galaxy M87. A long, narrow, and slightly curved jet of light extends from this source towards the lower right. The jet is composed of several distinct, brighter knots or lobes separated by darker regions. The background is a dark, deep blue space filled with numerous small, distant stars.

M87 (Virgo cluster)

AGN bubbles



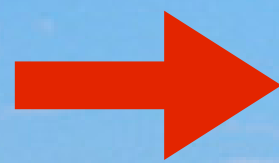
GEMS (Rix et al. 2004)



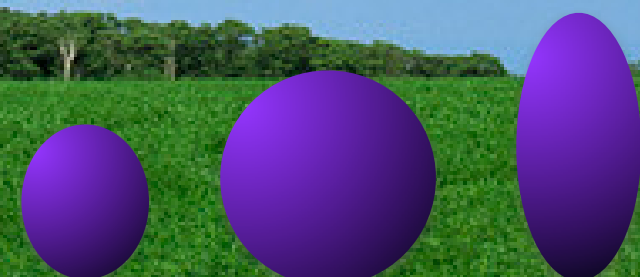
making sense of this with
models

Alien invasion

height & shape,
density, pressure,
gravity, ...



flexibility, running,
jumping,
disintegration
resistance



(human)

Our model is only as good as the questions
we ask

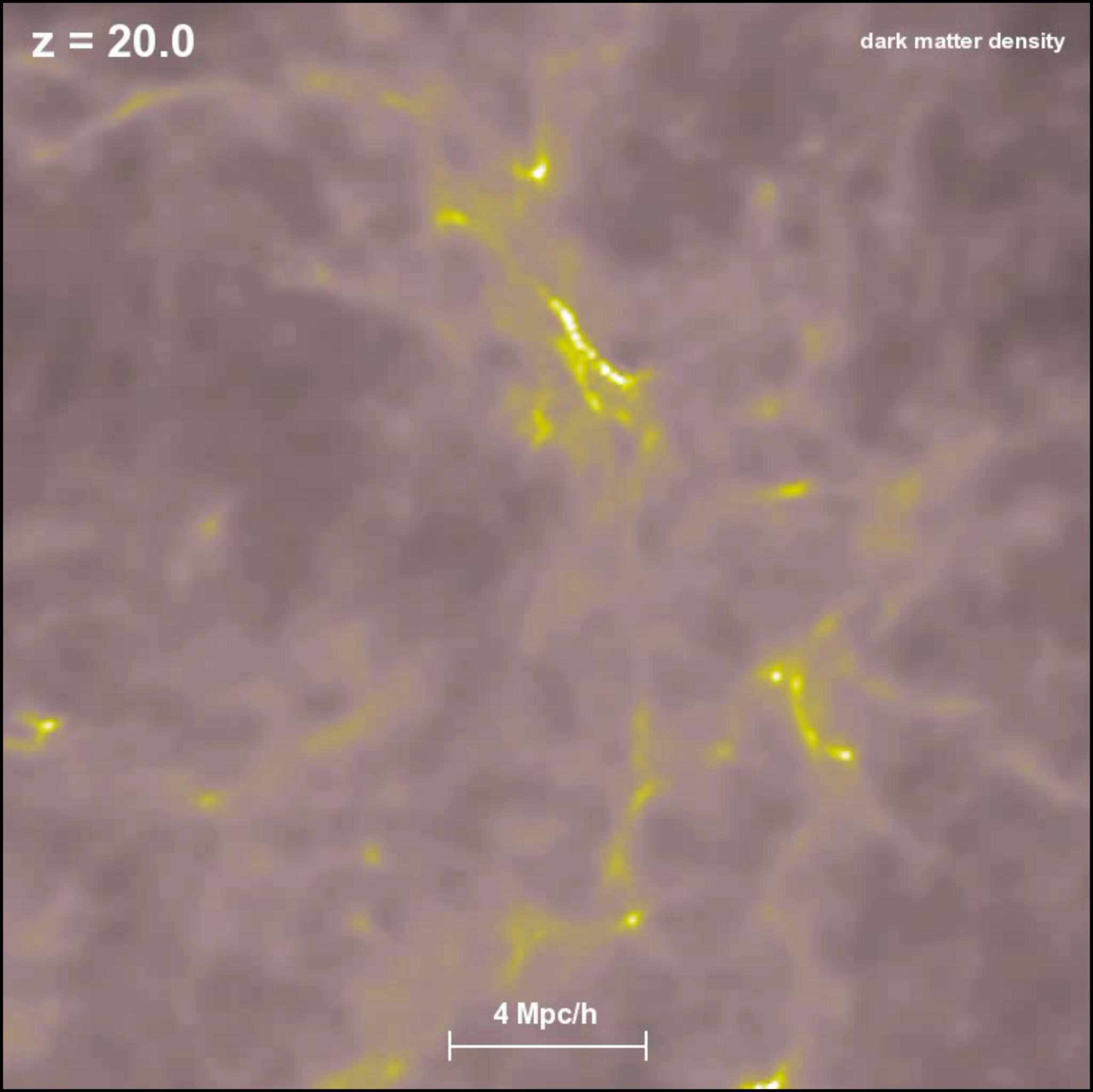


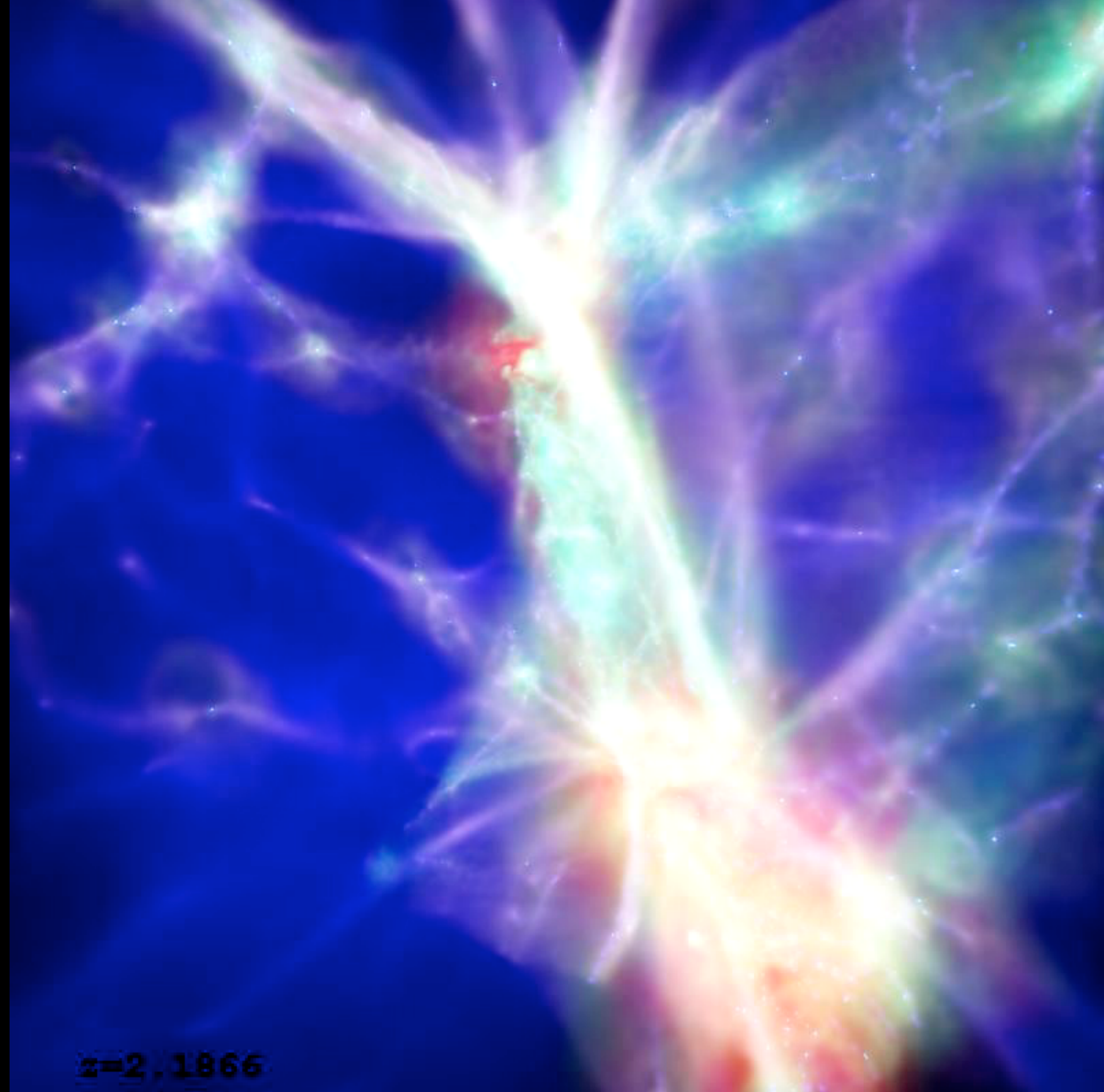
For systems with infinite levels of complexity,
our model can never be “correct”

$z = 20.0$

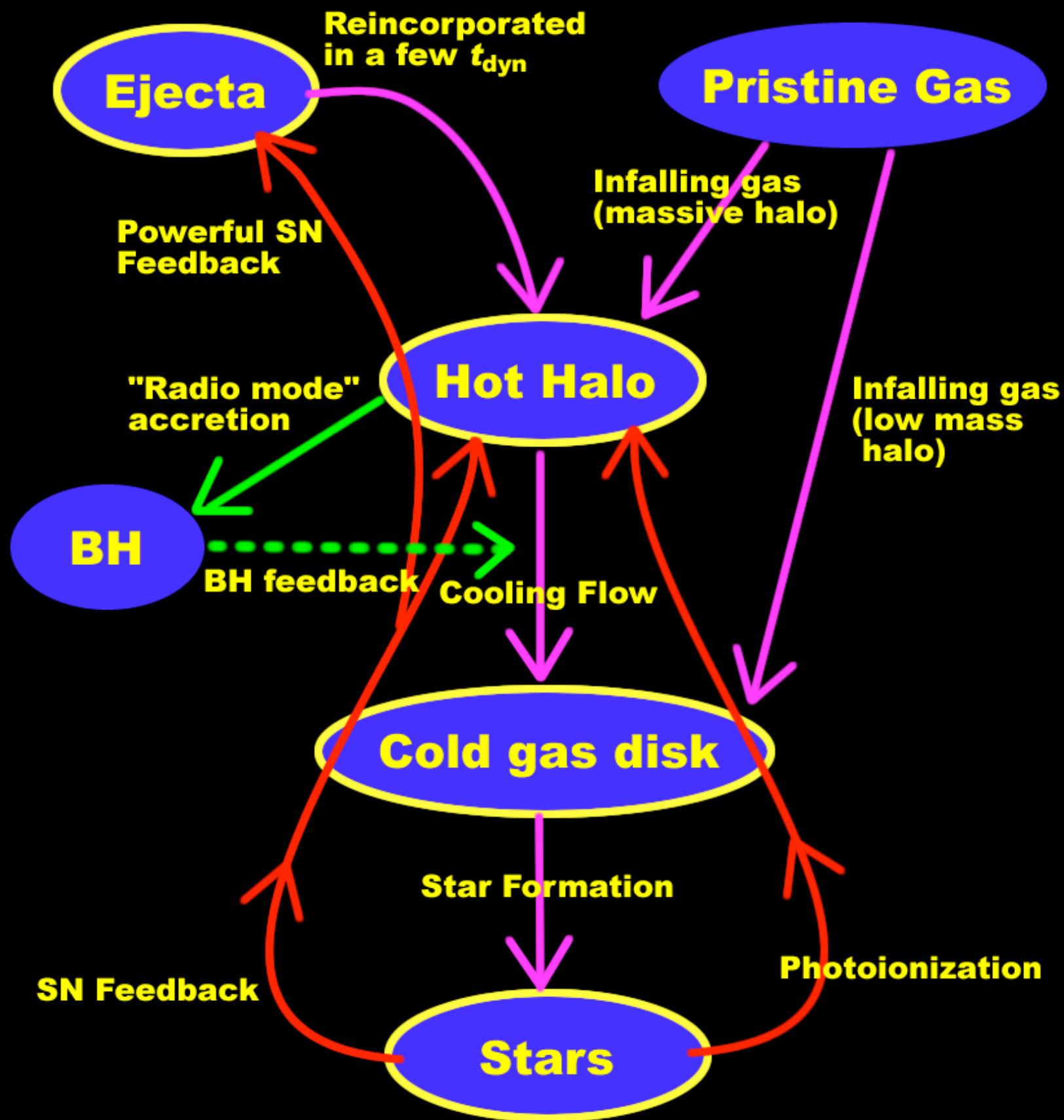
dark matter density

4 Mpc/h





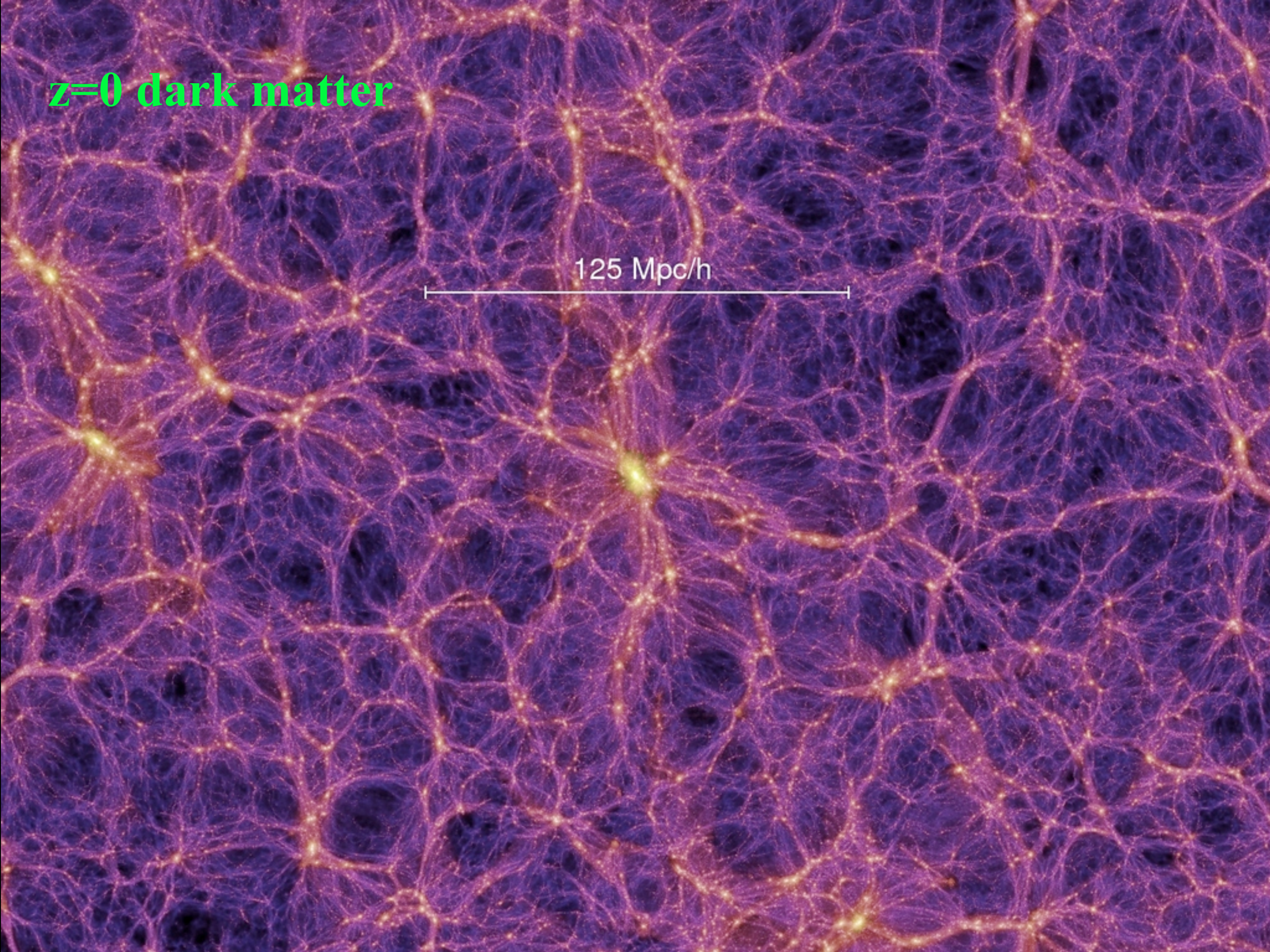
$z=2.1866$



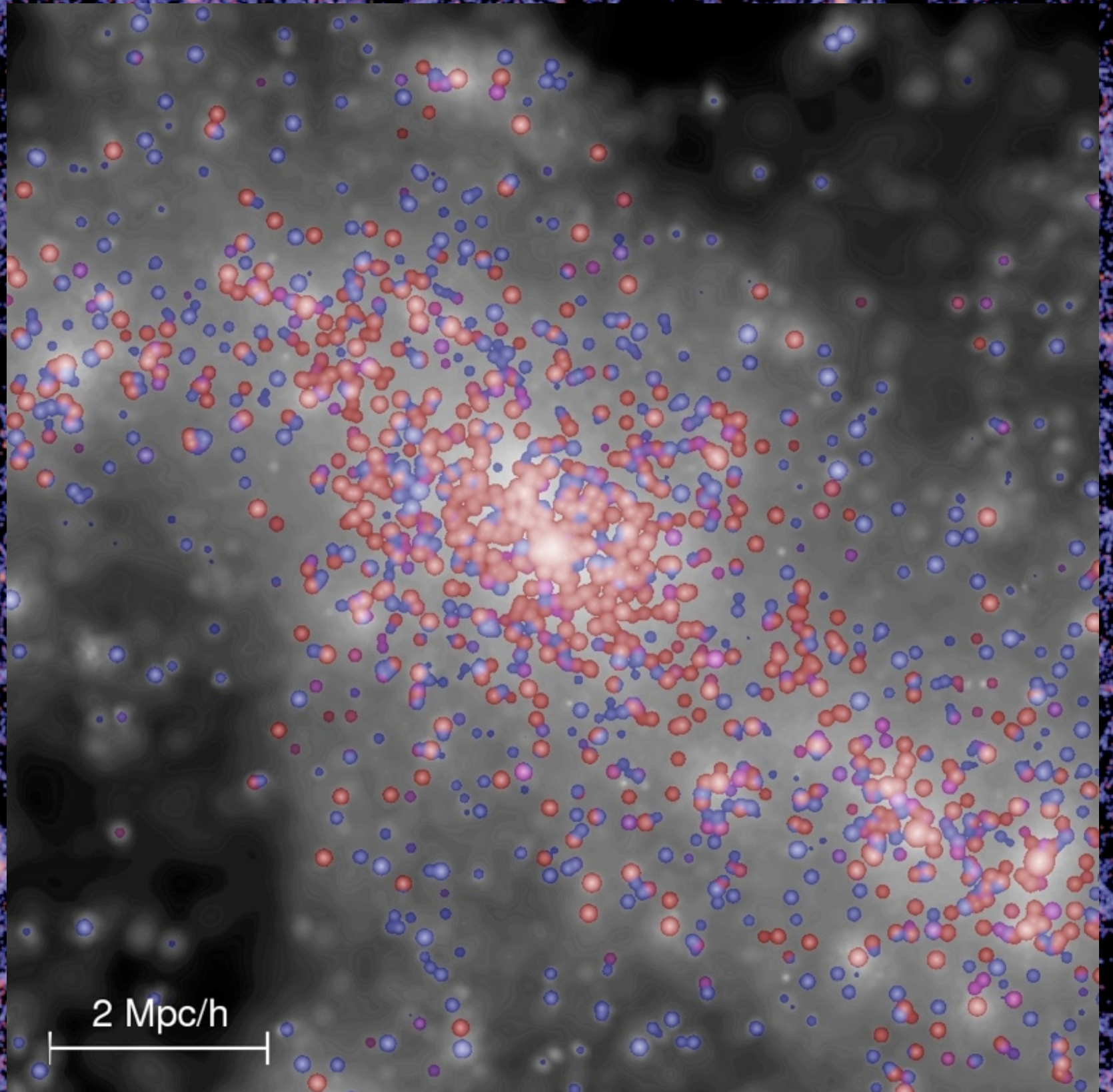
- Schmidt law star formation
- SFR dependent SN winds
- satellite gas stripping
- morphological transformation
- assembly through mergers
- starbursts through mergers
- Magorrian relation BH growth
- jet & bubble AGN feedback

$z=0$ dark matter

125 Mpc/h

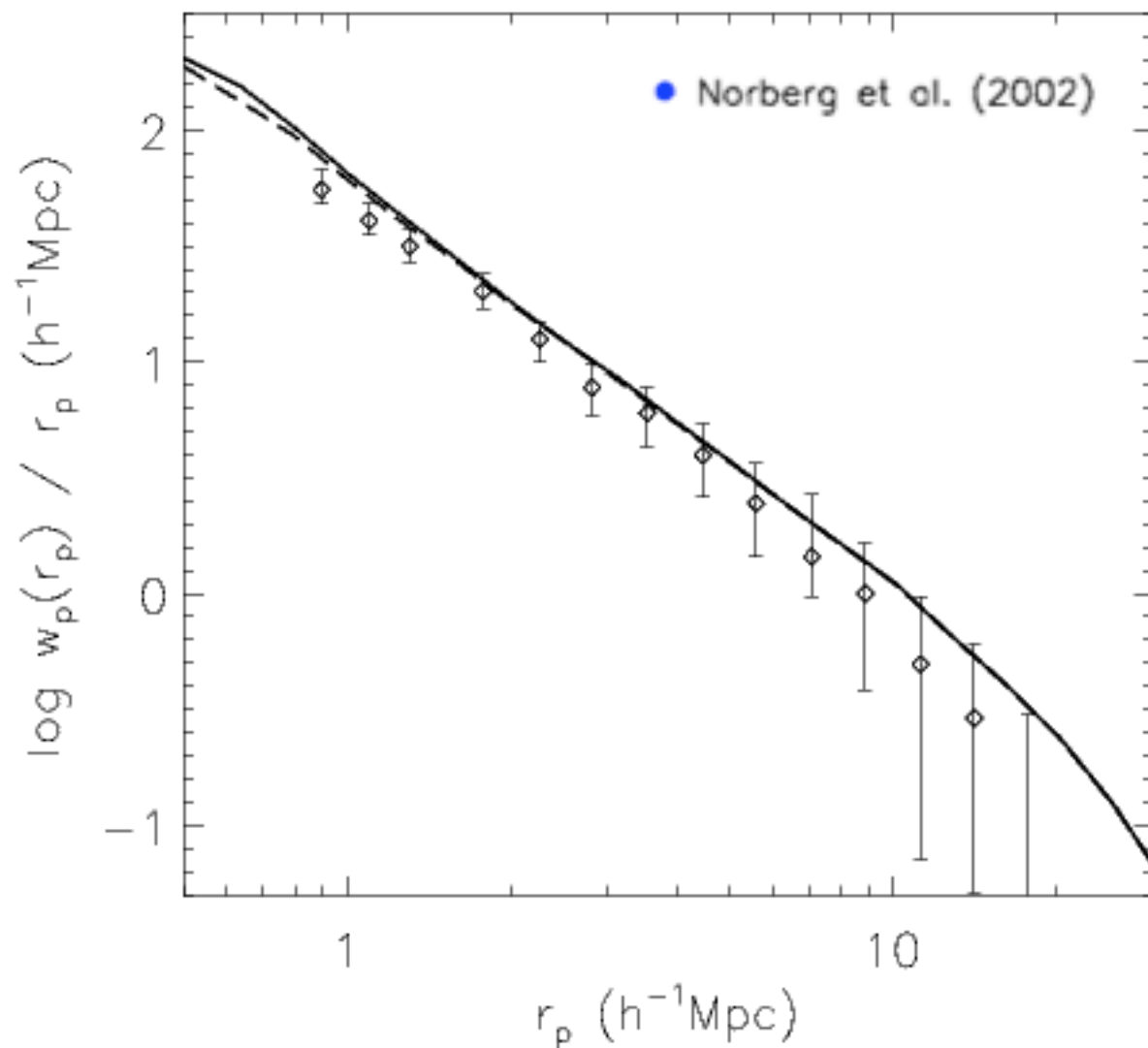
The image displays a dense, interconnected network of dark matter particles at redshift z=0. The particles are represented as small dots, with their density and velocity fields visualized using a color gradient from dark blue to bright yellow. The structure is highly filamentary, with numerous branching filaments and dense clusters of matter. A horizontal scale bar with vertical end-caps is positioned in the upper-middle section, labeled '125 Mpc/h', providing a reference for the physical size of the structures shown.

$z=0$ galaxy light

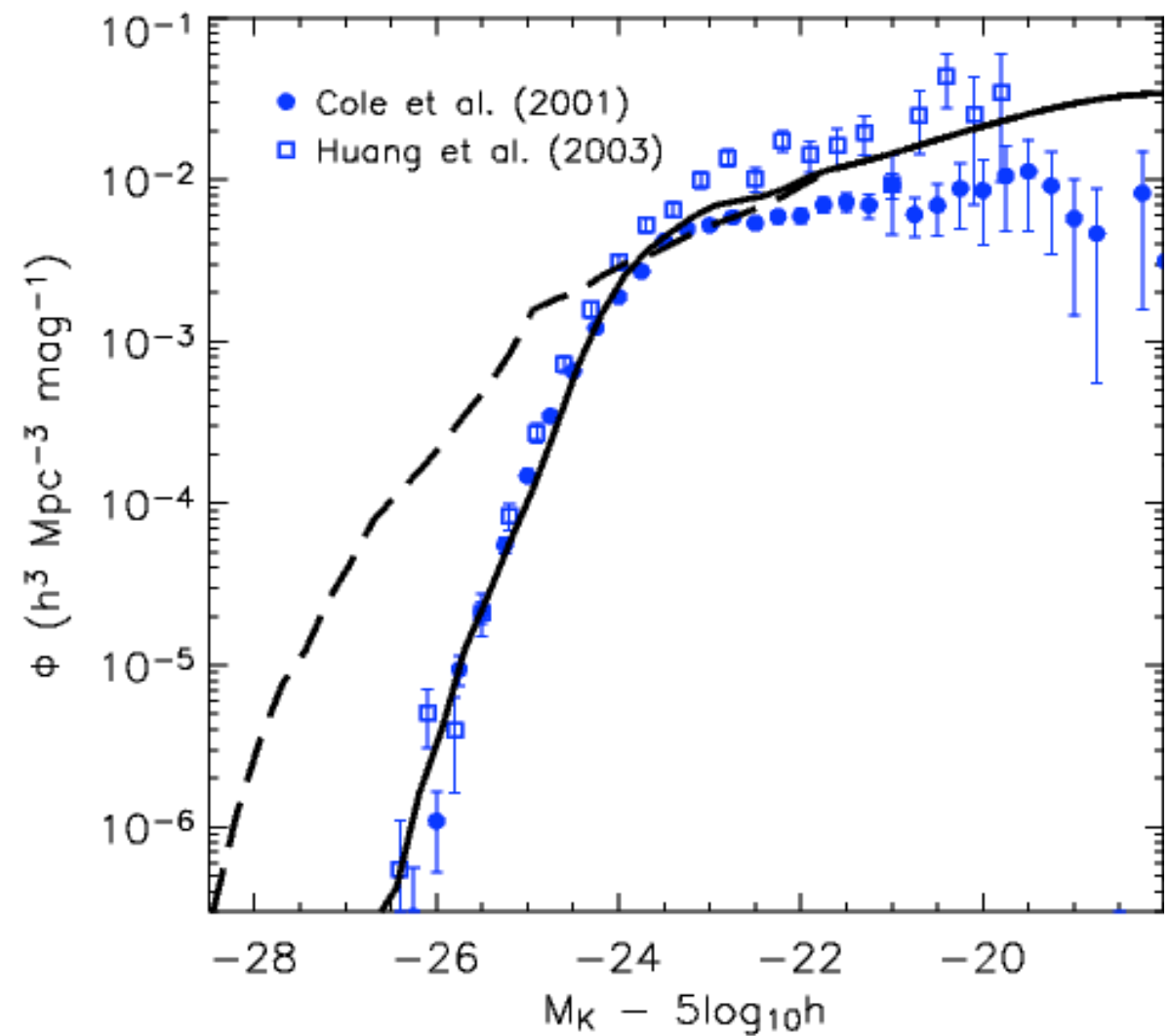


STATISTICS

Do our galaxies have the right distribution and abundance?



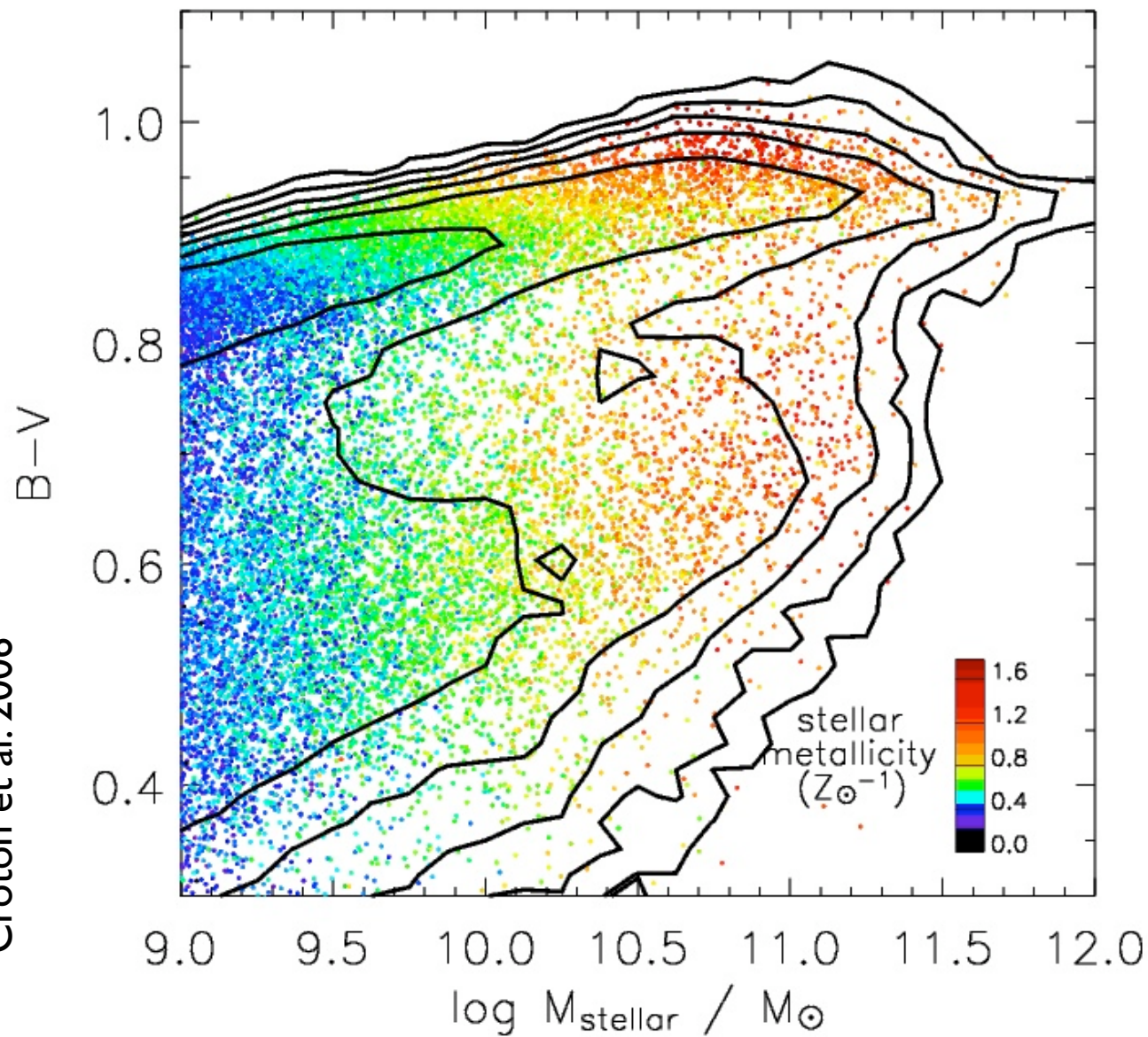
< clustering >



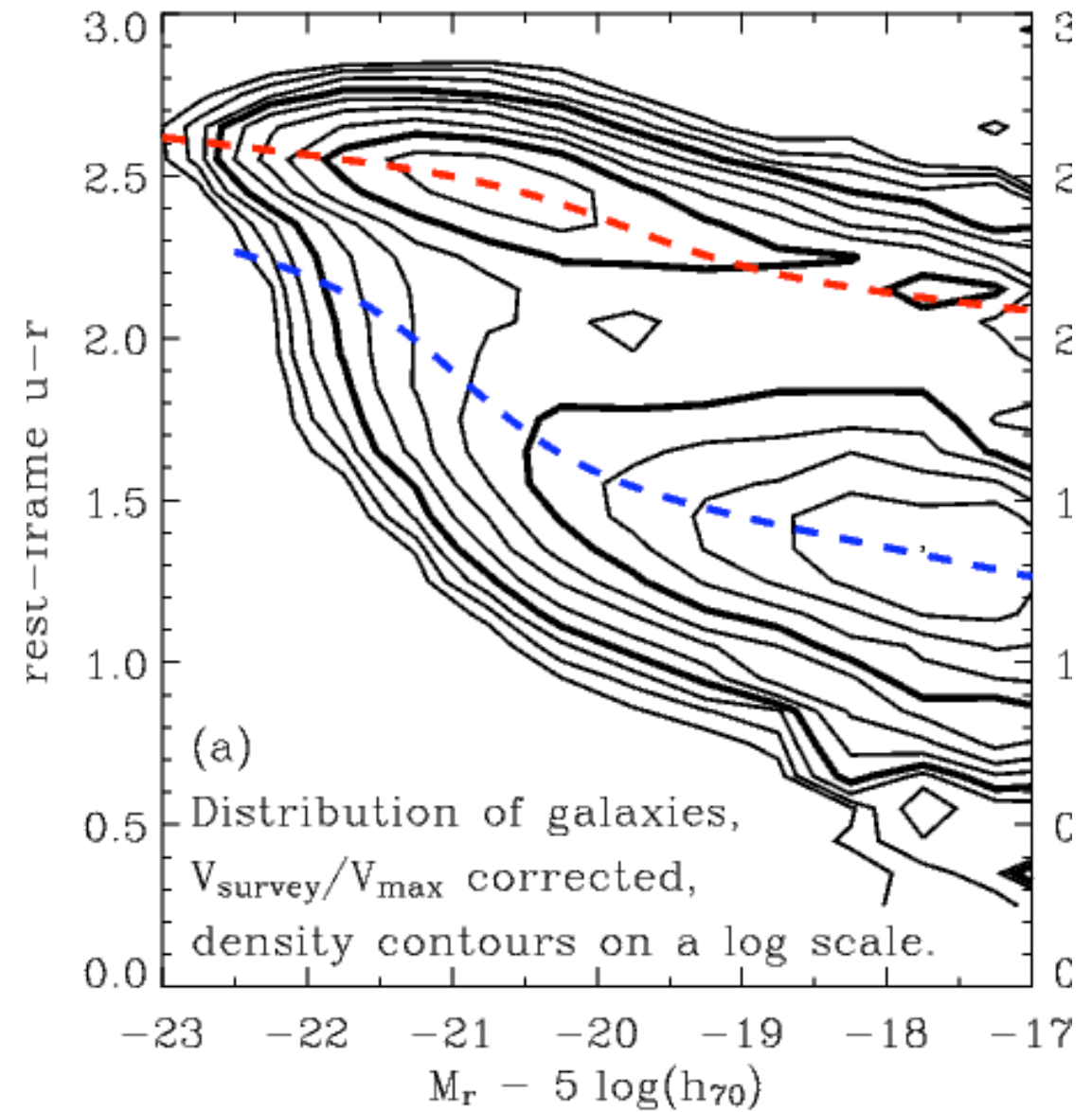
< luminosity function >

... and the right colours?

Croton et al. 2006



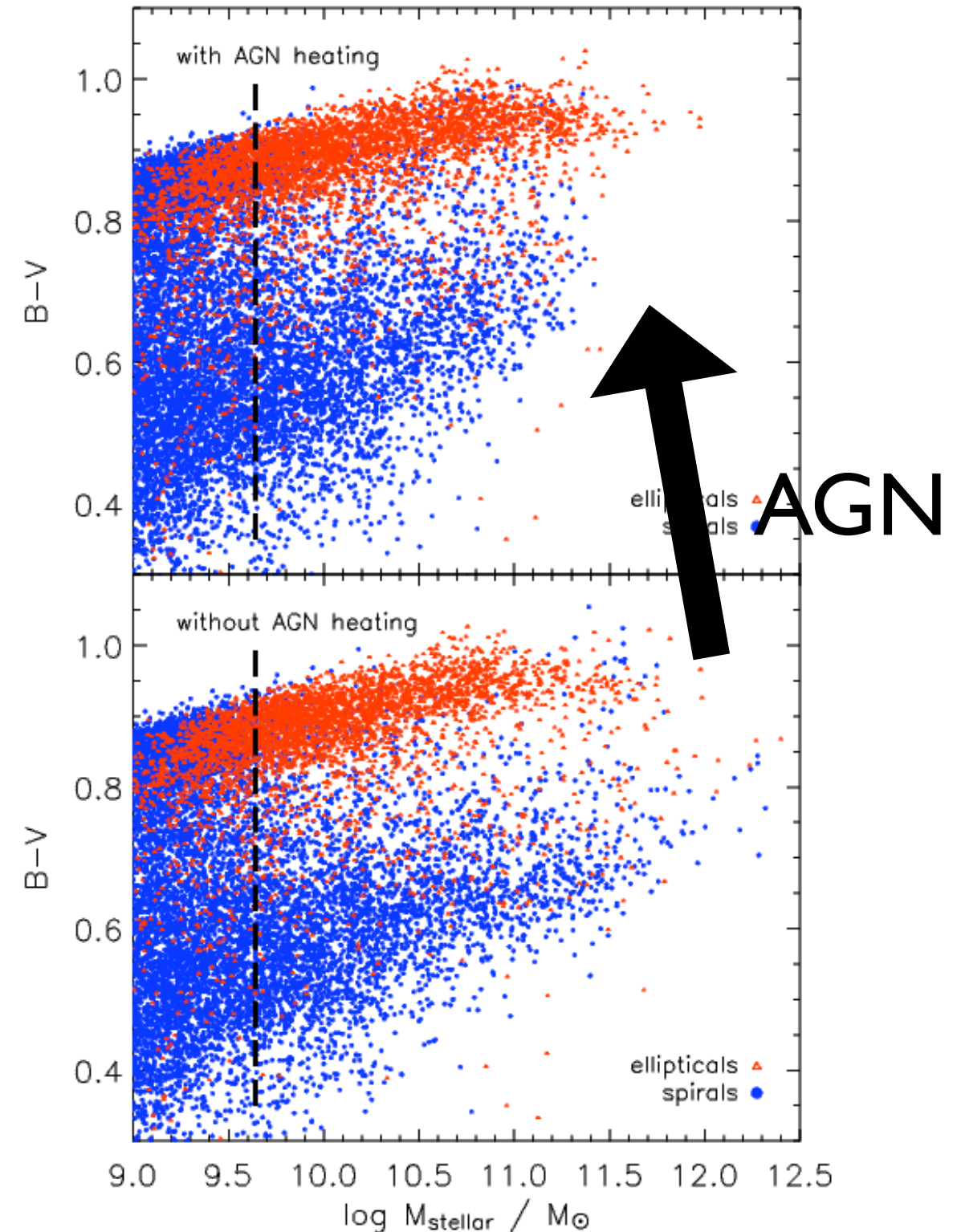
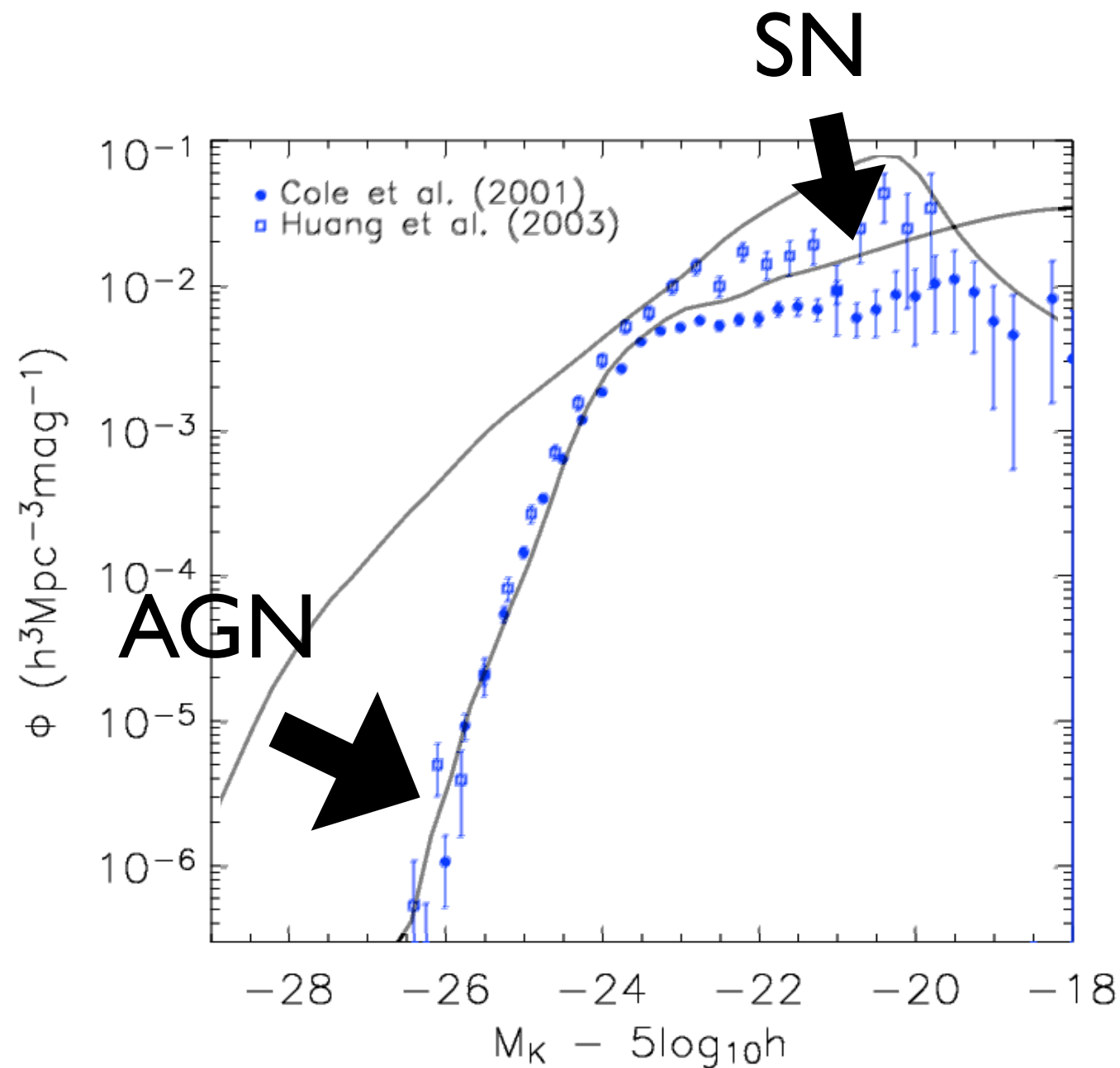
< model >



< SDSS >

Baldry et al. 2005

Physical consequences





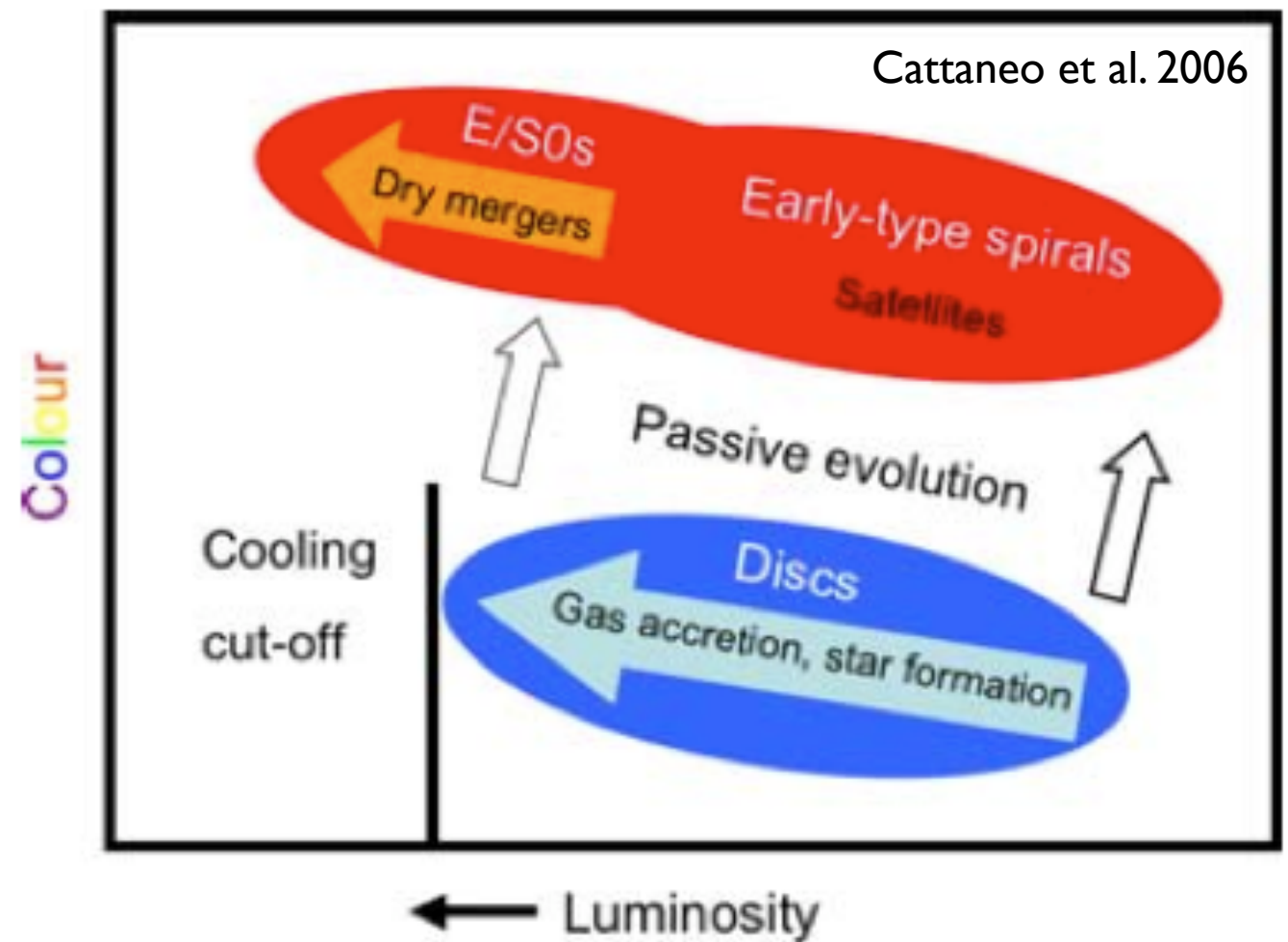
What we think we don't
know

What really shuts down star formation?

(or: how do galaxies evolve across the CMD?)

(or: to what degree is AGN even needed?)

- Important, why?
- Current understanding?
- Solutions?

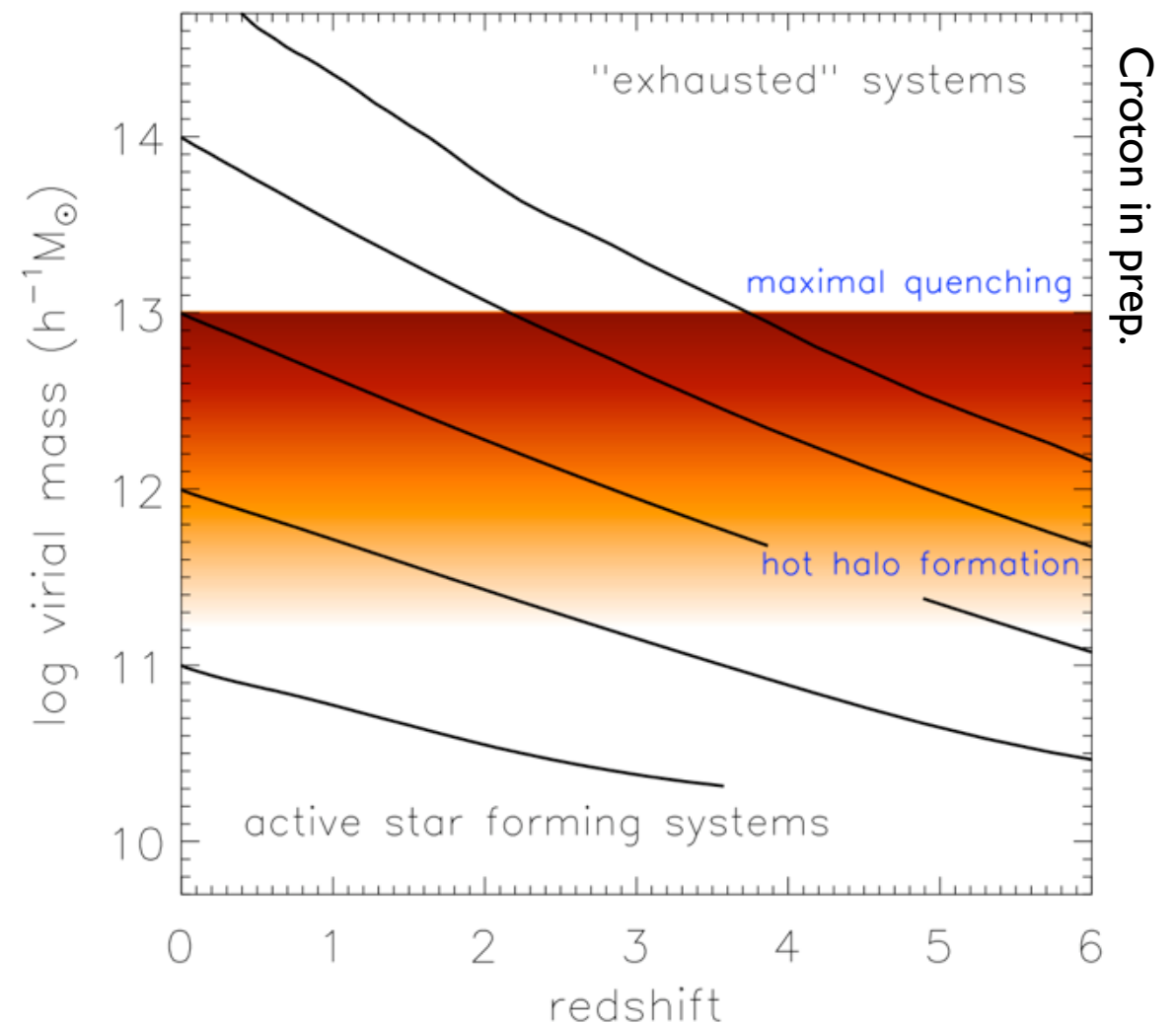


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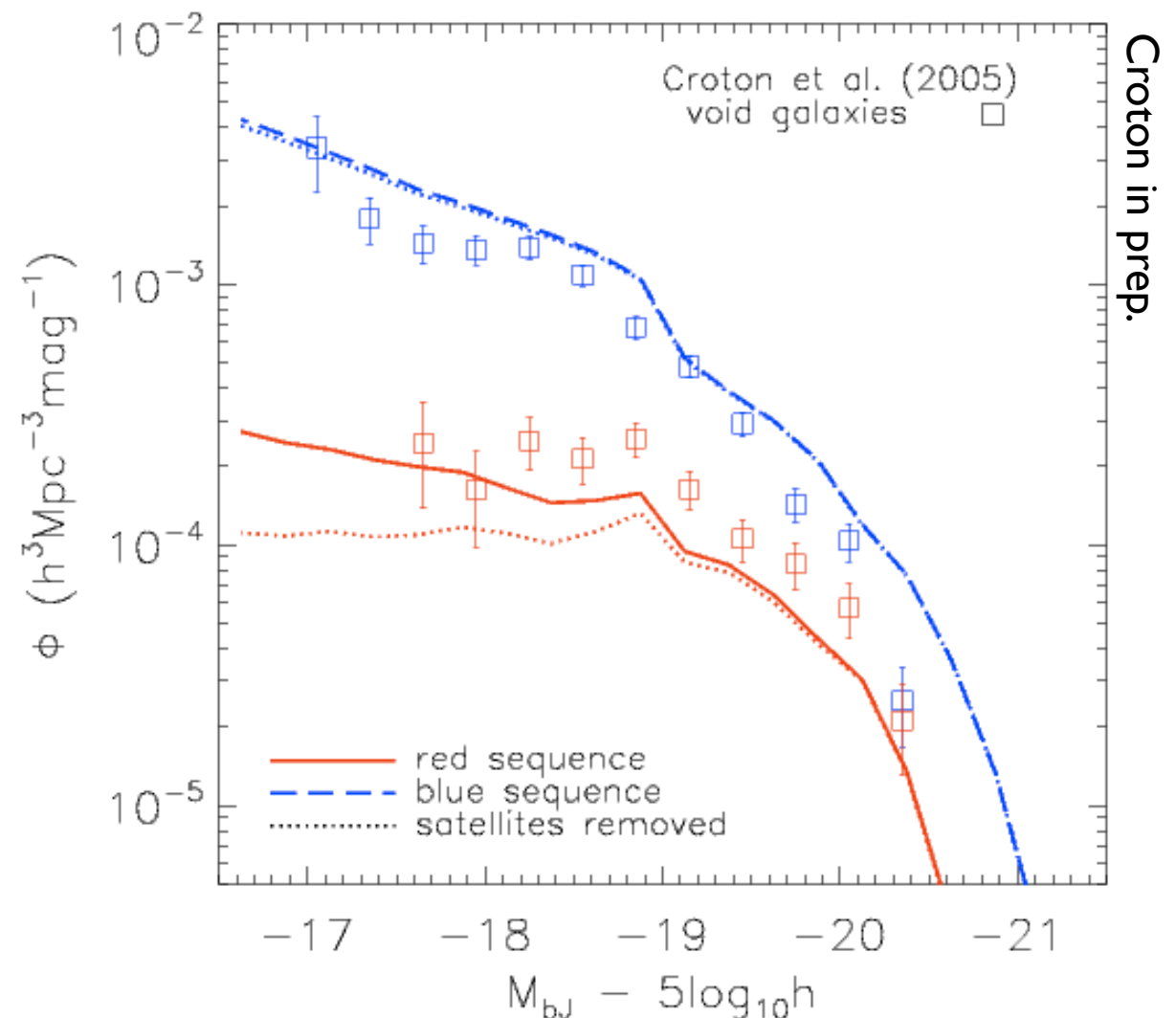


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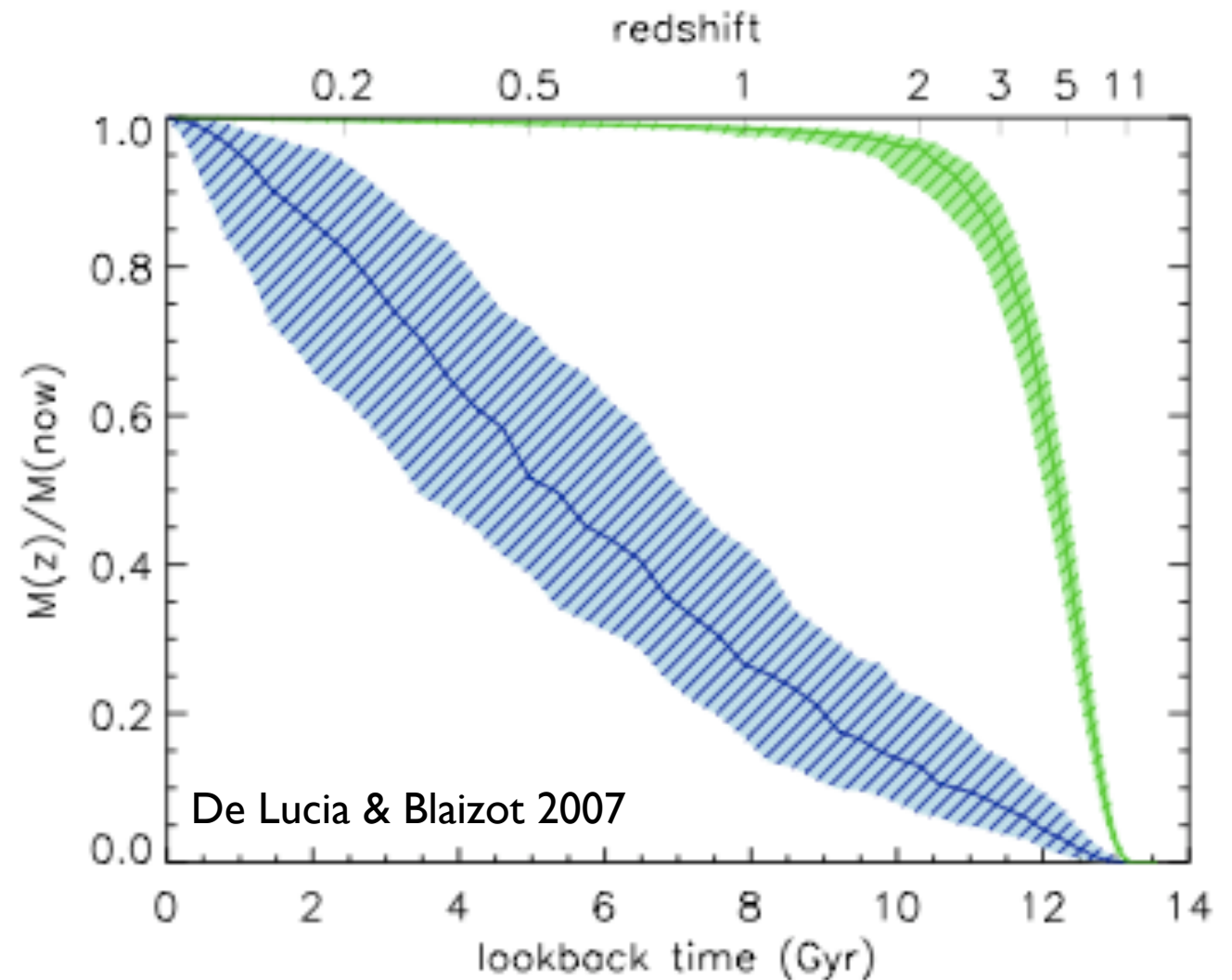
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The assembly of massive galaxies?

(or: at what point does DM & baryon growth de-couple?)
(or: monolithic or hierarchical? a problem for CDM?)

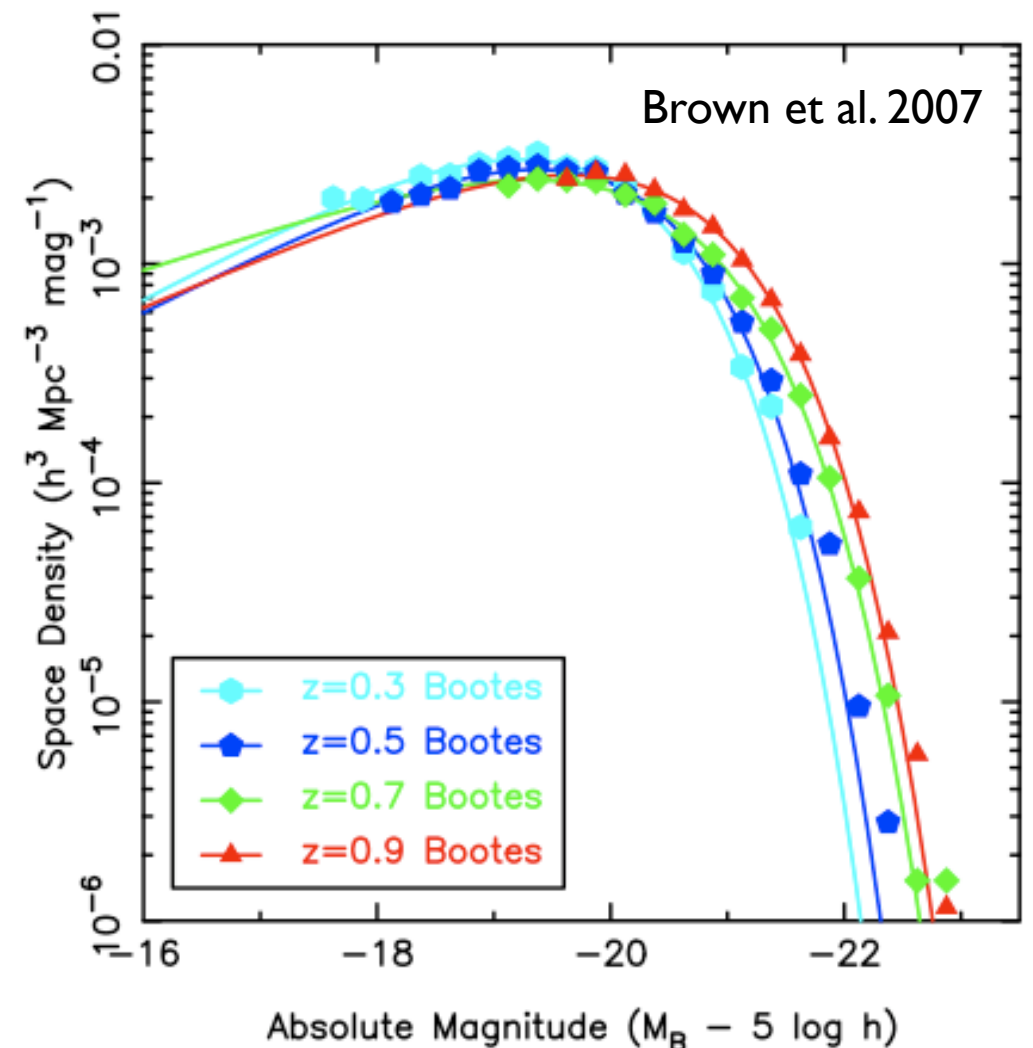
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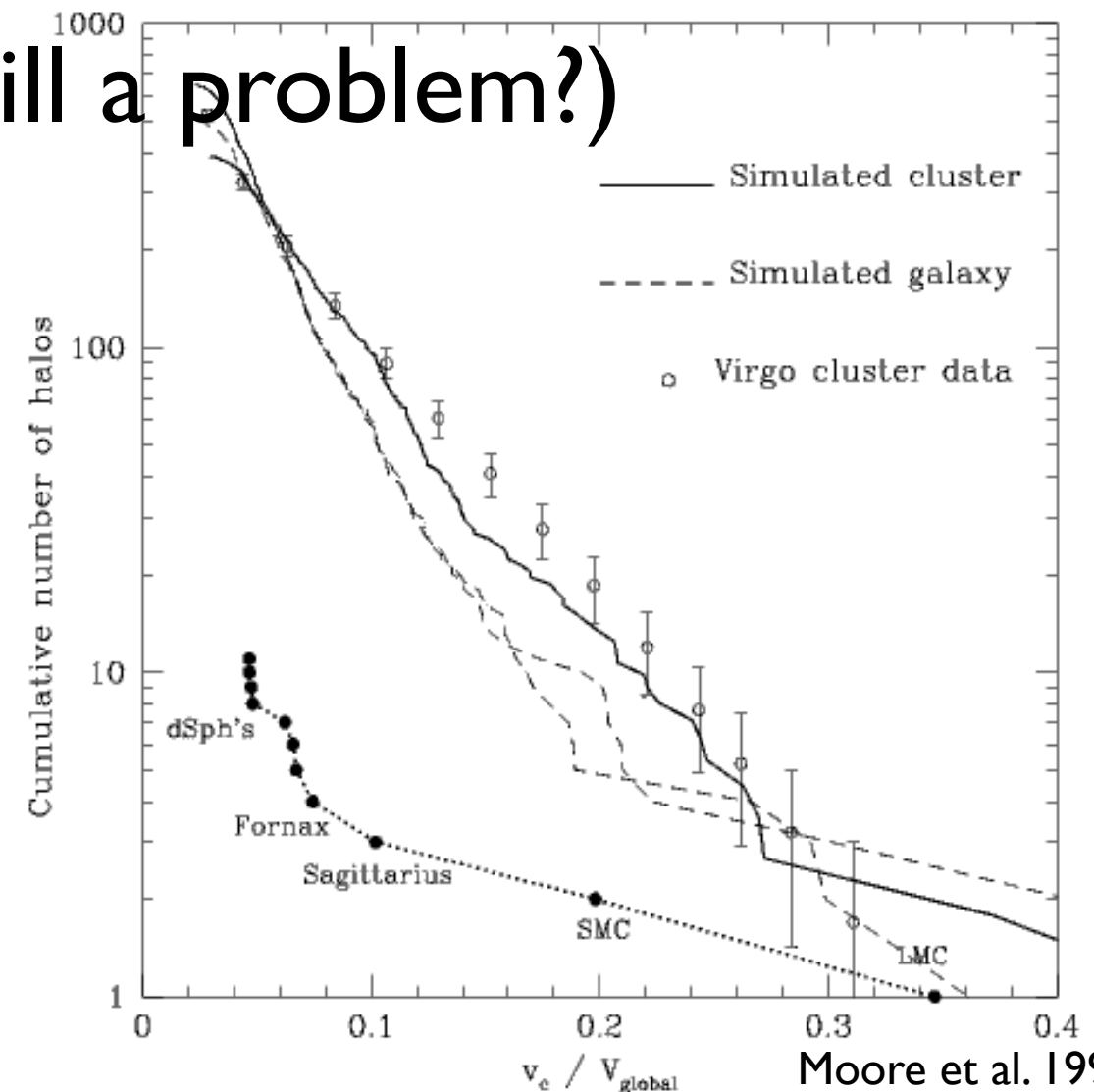
Satellite galaxy evolution?

(or: do central and satellite galaxies evolve differently?)

(or: merging vs. ICL?)

(or: is sub-structure still a problem?)

- Important, why?
- Current understanding?
- Solutions?



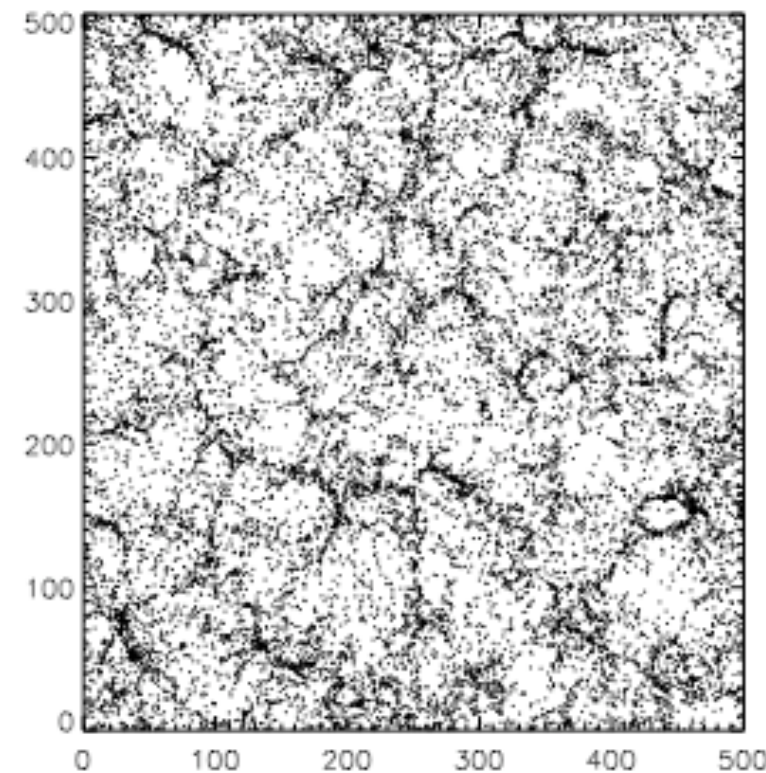
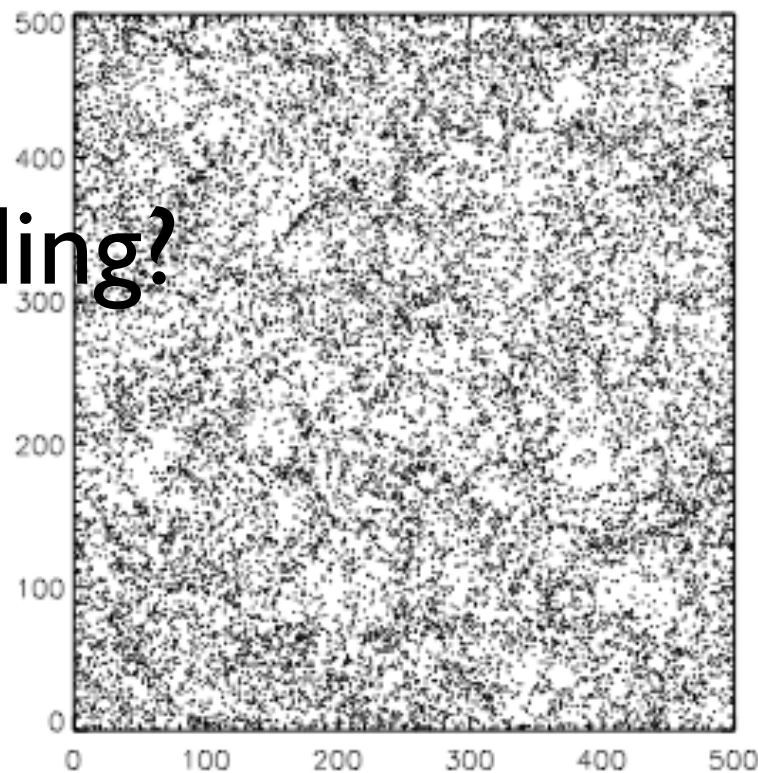
The role of environment?

(or: how important for cosmological measures?)

(or: is halo mass the fundamental property?)

- Important, why?
- Current understanding?
- Solutions?

Gao et al. 2005

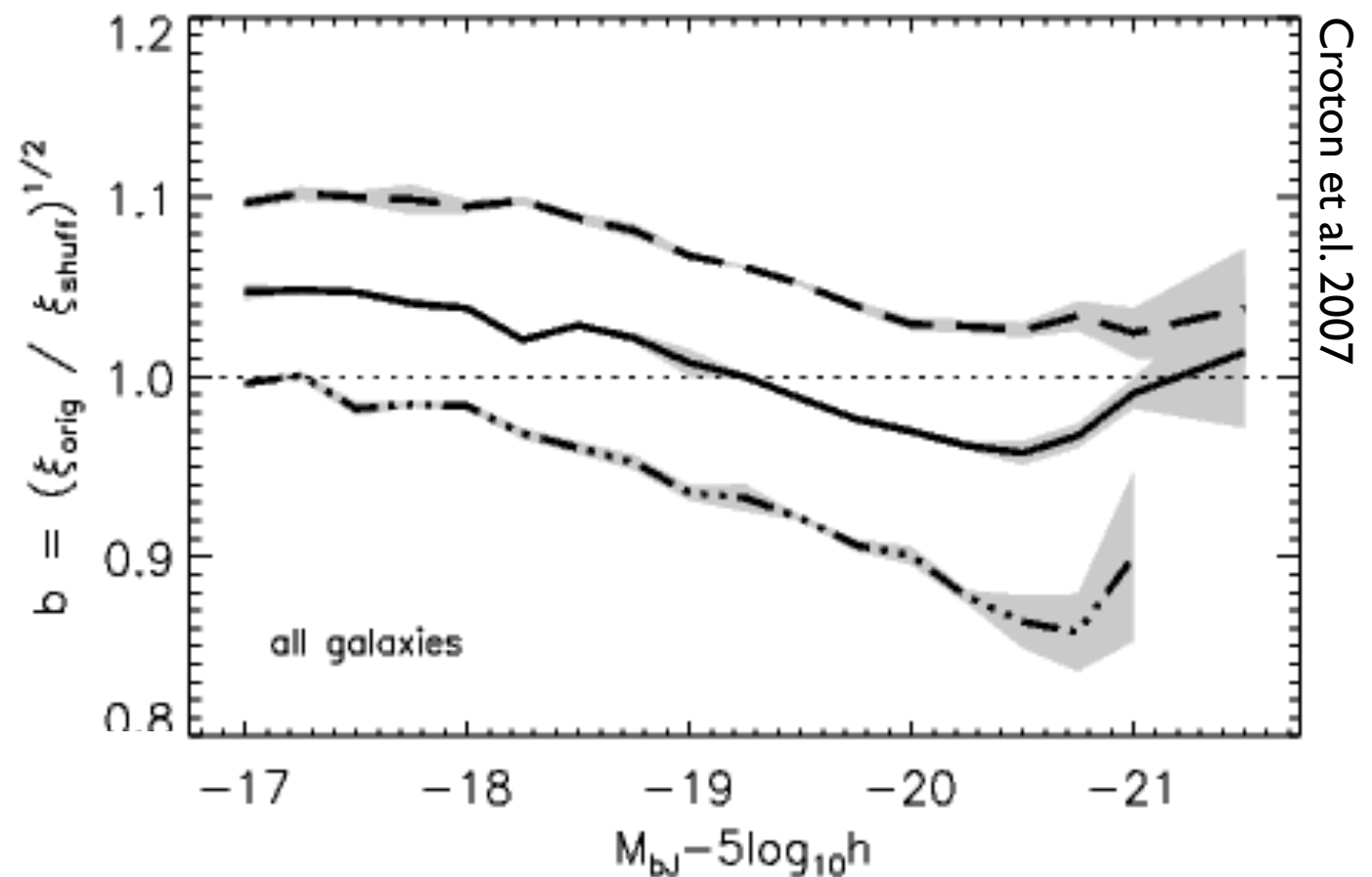


The role of environment?

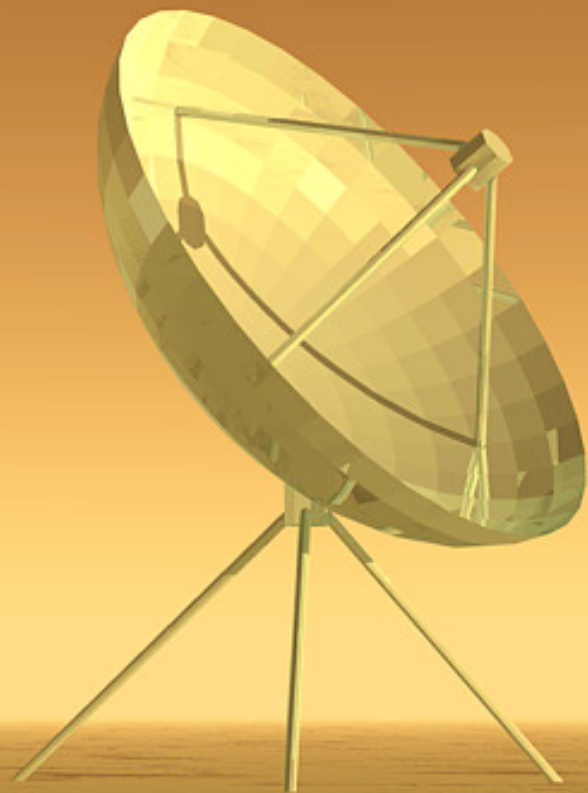
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Next generation surveys



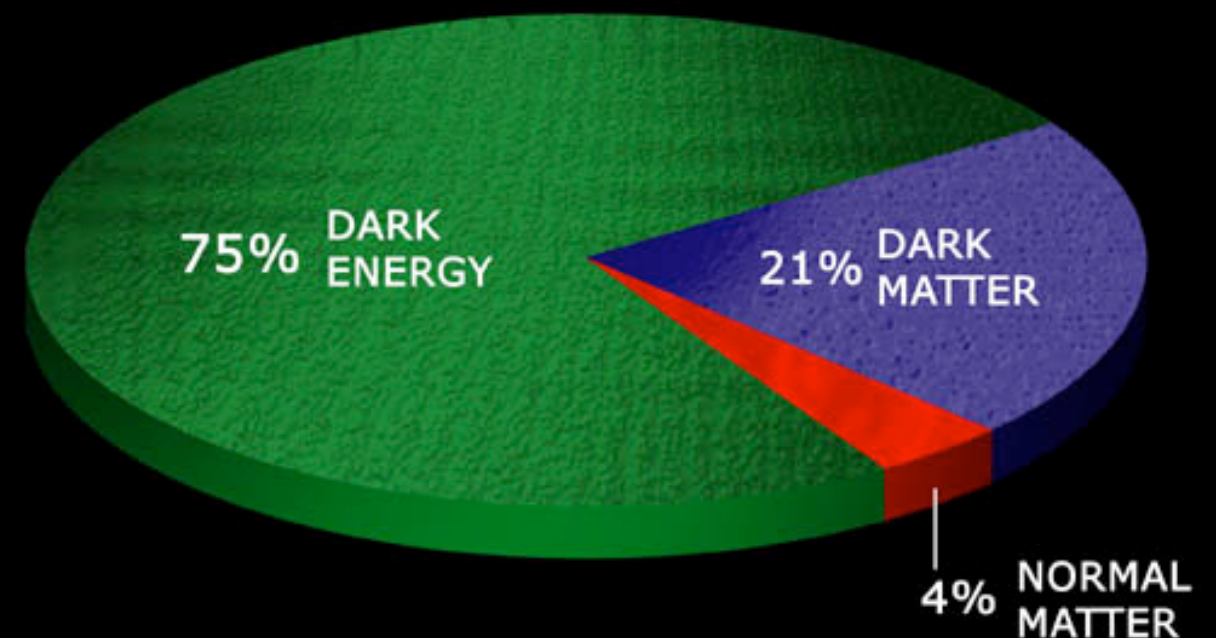
Probing dark energy

Weak & strong lensing

BOA's

Cluster counts

Supernova



- ◎ DES: ~**300 million galaxies** across 5,000 sq-degrees out to $z \sim 1.3$ in 4 bands ($r < 24.1$).
- ◎ LSST: **billions of galaxies** across 20,000 sq-degrees out to $z \sim 4$ in 6 bands ($AB < 29.0$).
- ◎ Other surveys/instruments: PanSTARRS, SKA, JWST, GLAST, ... will provide equivalent multi-wavelength data sets.

What can you do with millions/billions of galaxies?

Statistics:

SDSS volume limited catalogue of ~50k galaxies can at most be sub-divided 1-2 more times

Next generation catalogues can be sub-divided multiple times on any property of interest

What can you do with millions/billions of galaxies?

Objects:

Muilt-wavelength catalogues can be cross-correlated and studied together

Rare objects will become commonplace and will be analysed with statistical confidence

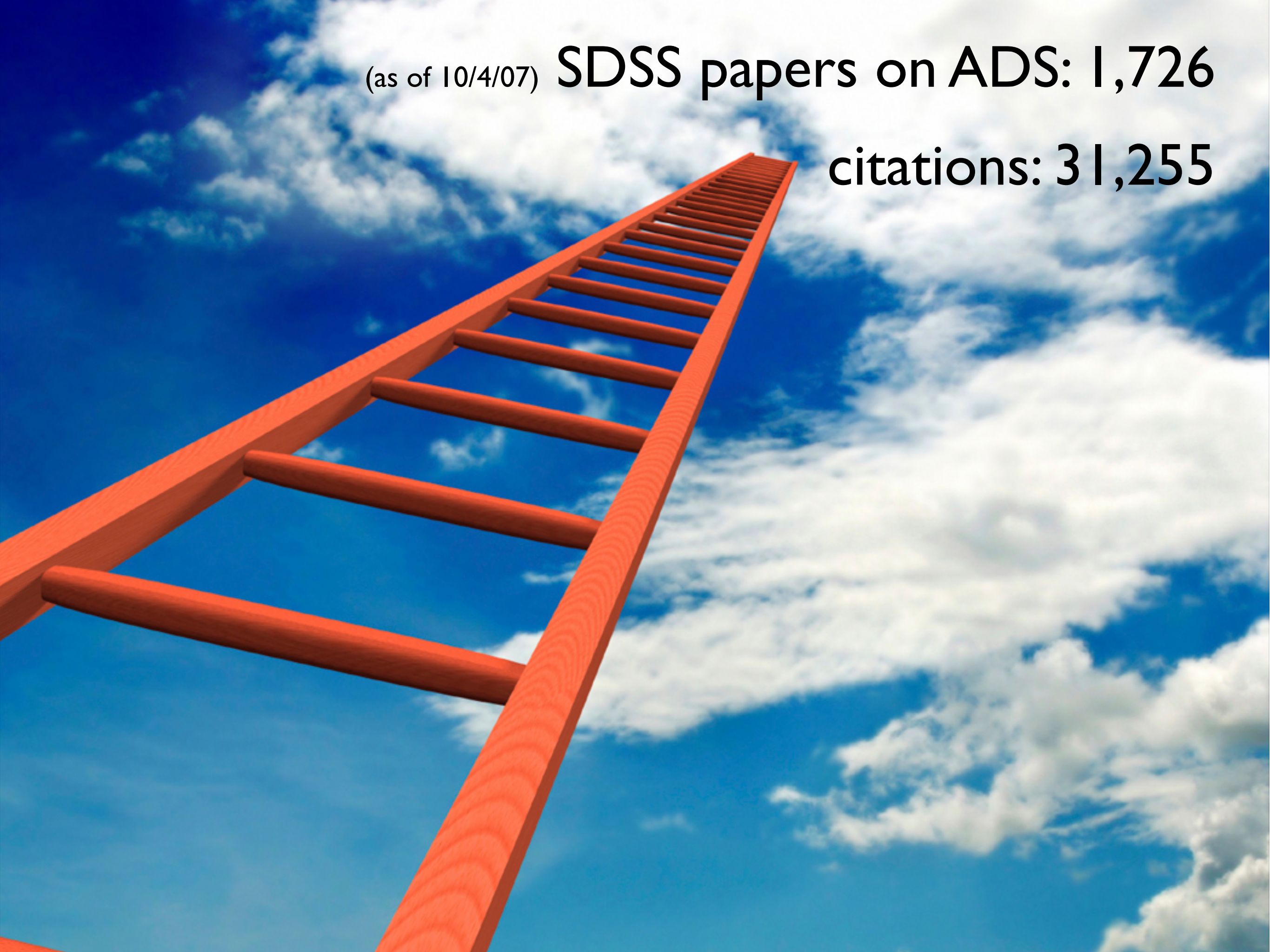
Extra-galactic astronomy covers a vast range of disciplines.

These data sets will produce vast amounts of science



(as of 10/4/07) SDSS papers on ADS: 1,726

citations: 31,255



Outlook

- (1) Simple models help interpret the data, and more complex observations require more complex modelling.
- (2) Our understanding of galaxy evolution is still mostly phenomenological.
- (3) Future surveys have the potential to overwhelm us with information, but also answer key questions.