

ASTRONOMÍA EXTRAGALÁCTICA

Marc HUERTAS-COMPANY

mhuertas@iac.es

TUTORIAS: LUNES Y VIERNES DE 11h a 13h
[CON PREVIO AVISO]

EVALUACIÓN

DOS PARTES:

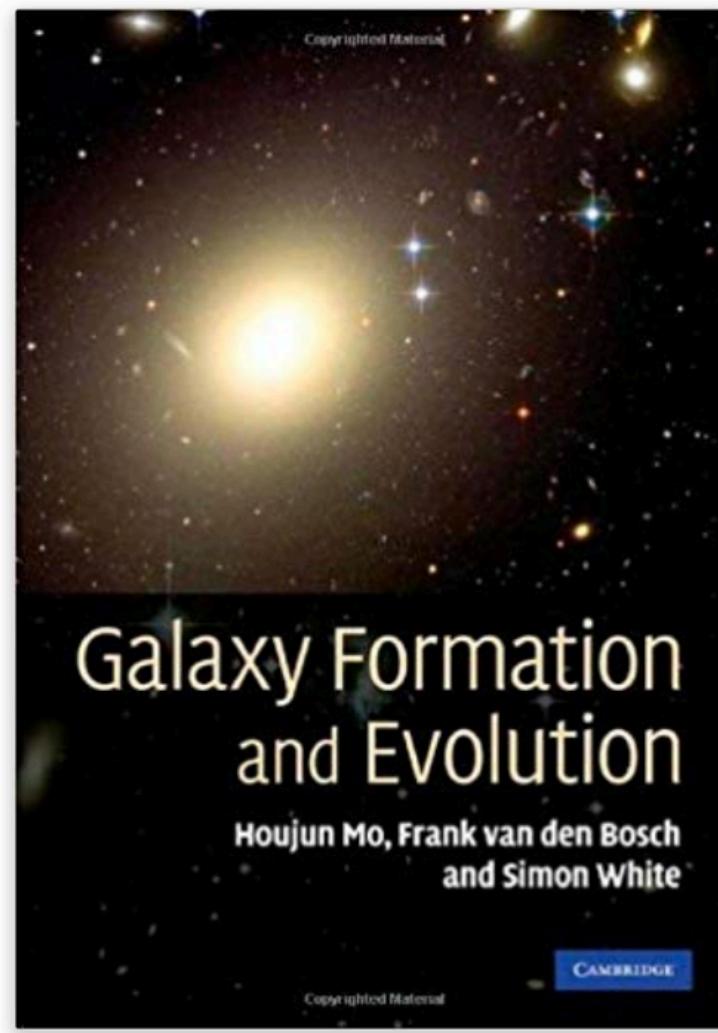
1. EVALUACIÓN CONTINUA: DOS PRÁCTICAS

2. EXAMEN ORAL: PRESENTACIÓN DE UN ARTÍCULO CIENTÍFICO

ONLINE
RESSOURCES:

<https://github.com/mhuertascompany/UllM1extragal>

BIBLIOGRAPHY



OBJECTIVES

**THIS INTRODUCTORY COURSE IS THOUGHT TO PROVIDE A GLOBAL
OVERVIEW OF THE FIELD OF GALAXY FORMATION IN A COSMOLOGICAL
CONTEXT**

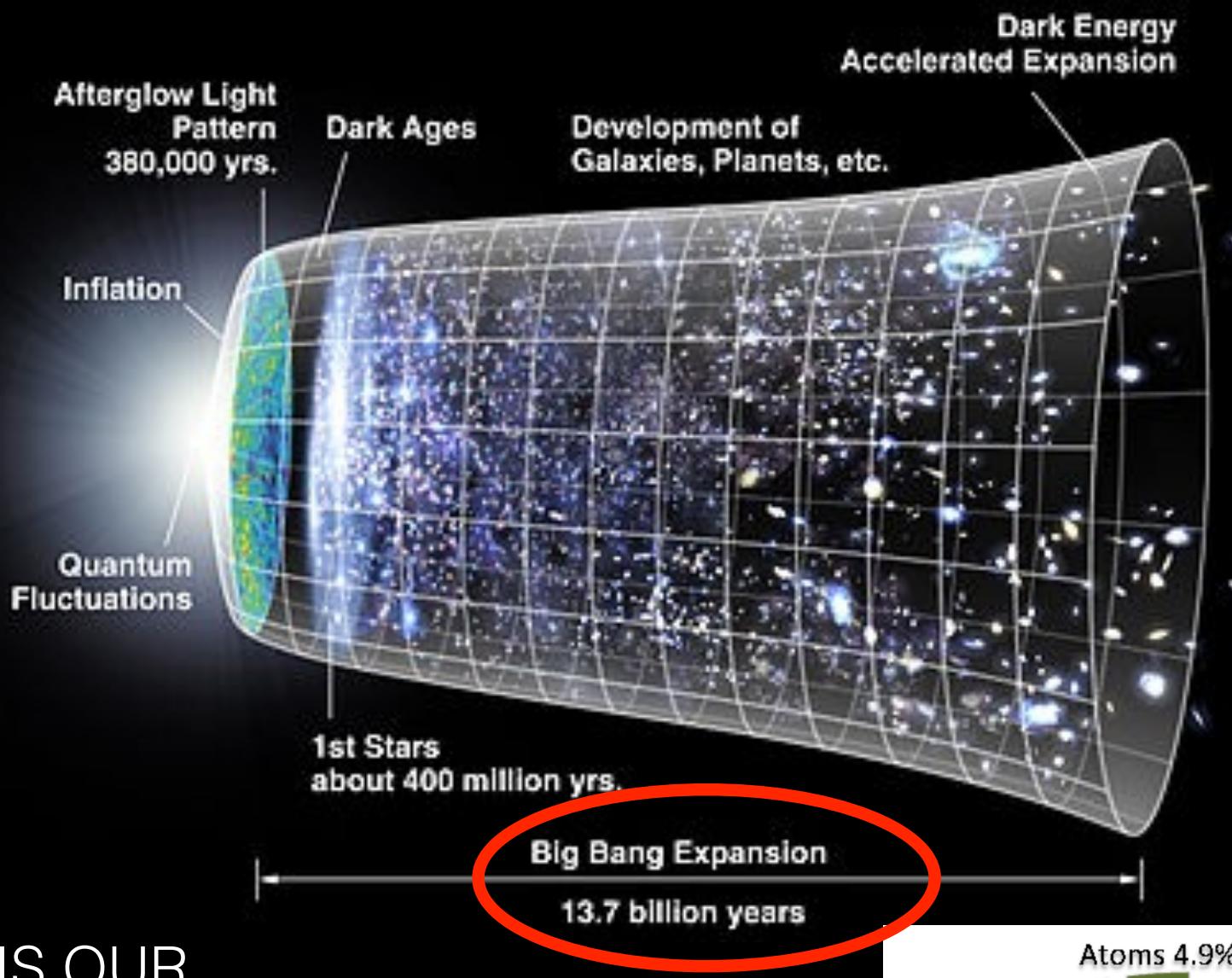
**WE WILL OVERVIEW THE MAIN CURRENT UNDERSTANDING AND
INGREDIENTS IN GALAXY FORMATION**

**MOST OF THE ELEMENTS WILL BE PRESENTED QUALITATIVELY WITHOUT
ENTERING IN THE EXACT DETAILS OF THE PHYSICAL PROCESSES**

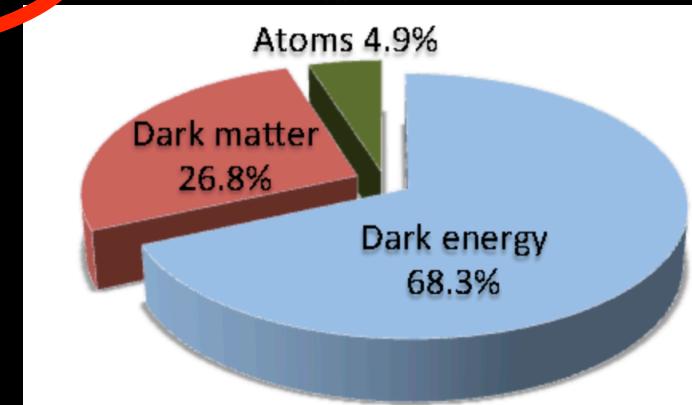
PROGRAM

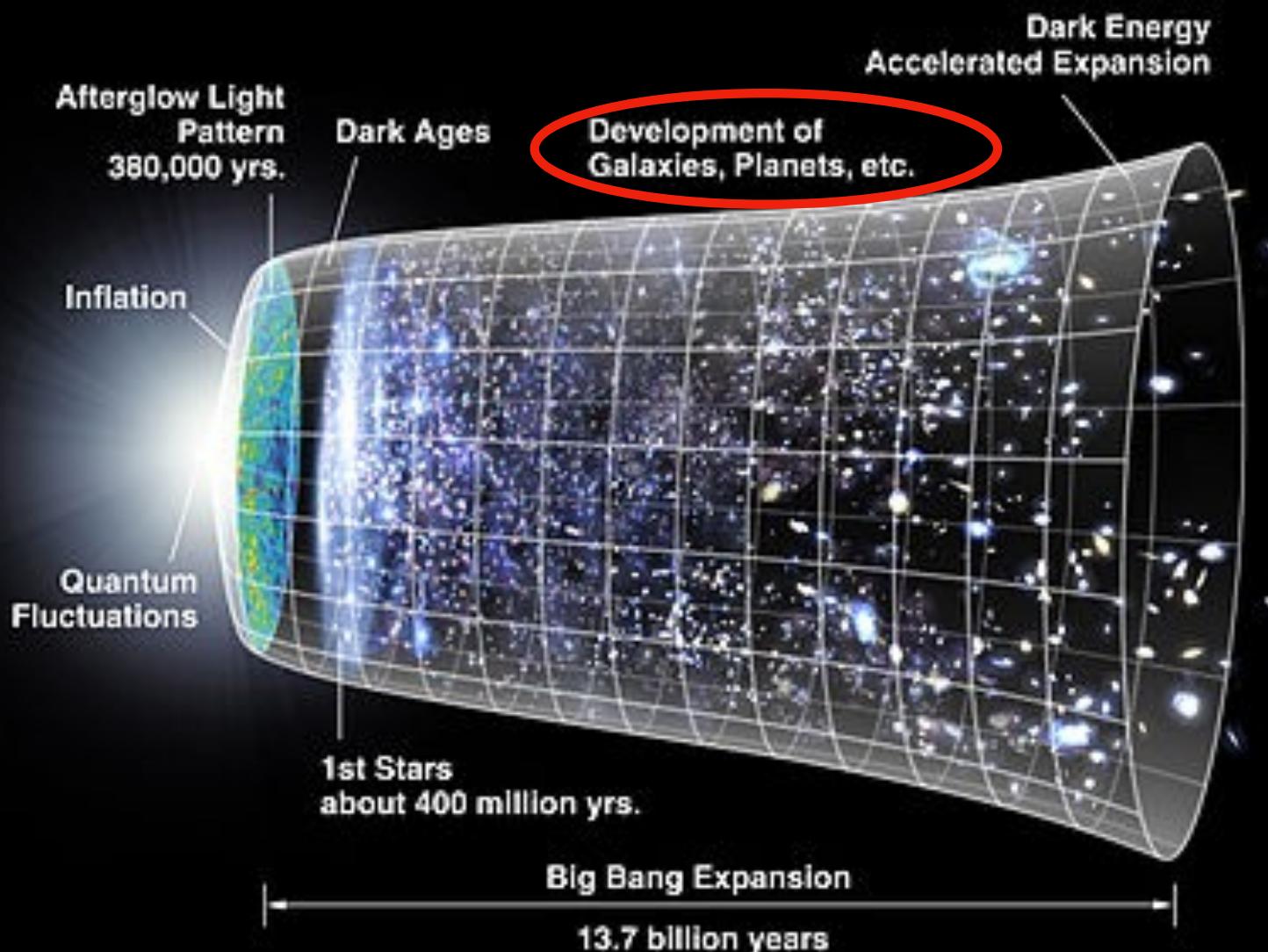
[Preliminary]

- A GLOBAL UPDATED OVERVIEW OF GALAXY FORMATION
- STAR FORMATION AND FEEDBACK
- GALAXY MERGERS
- QUENCHING
- ***METHODS:*** MACHINE LEARNING FOR GALAXY MORPHOLOGY ESTIMATION

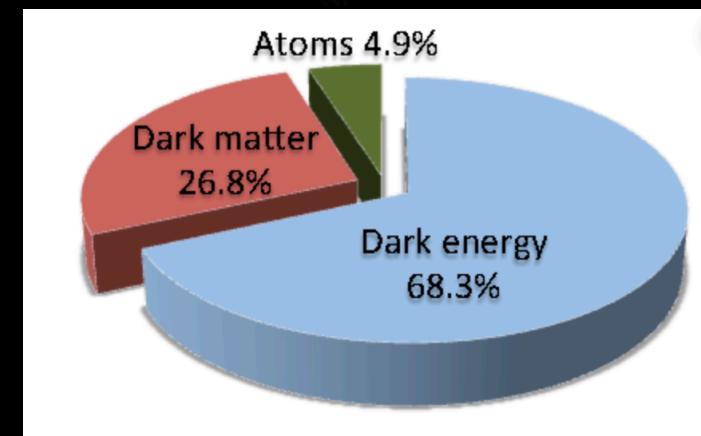


THIS IS OUR
CURRENT
UNDERSTANDING OF
THE HISTORY
OF THE UNIVERSE





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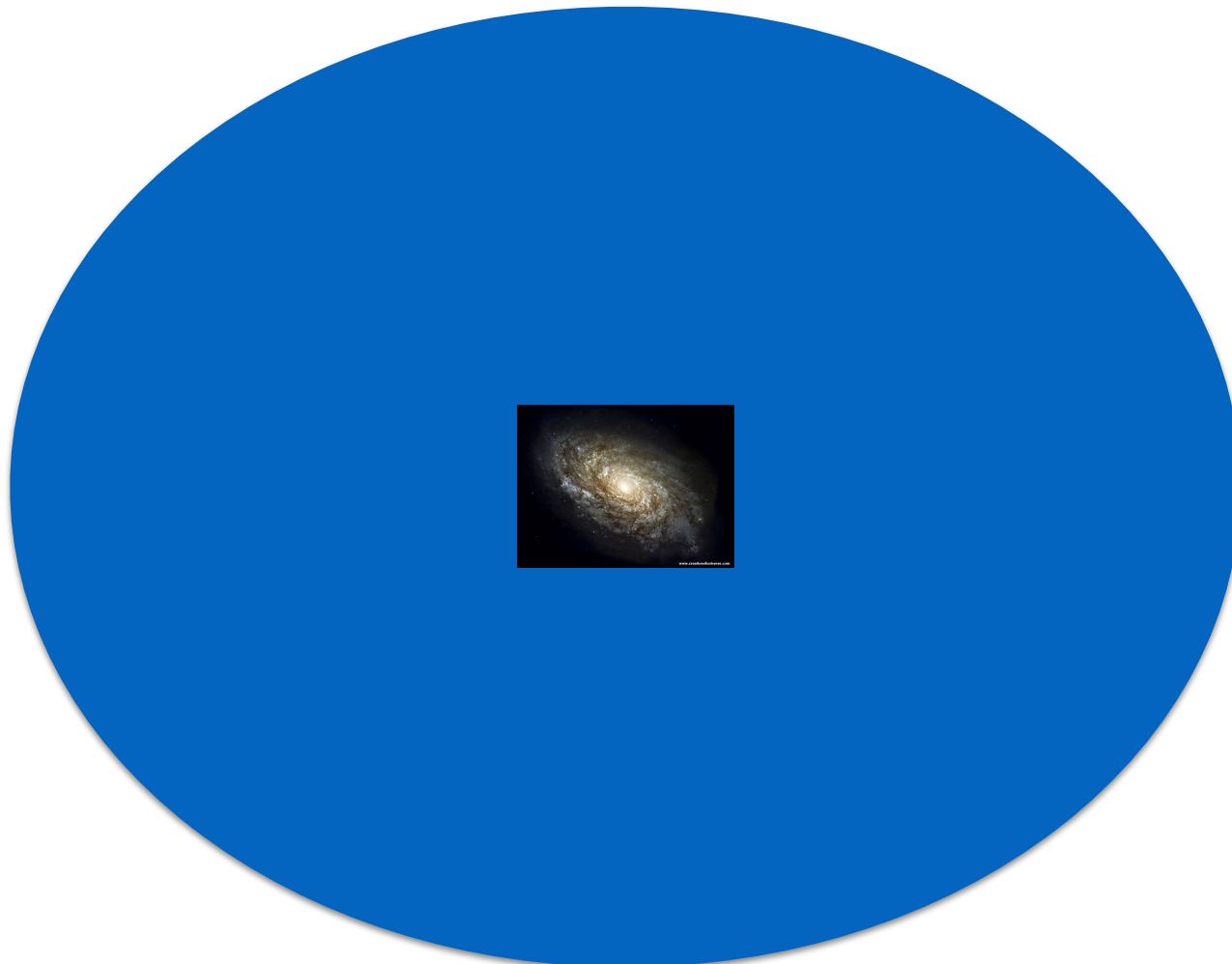


WHAT ARE GALAXIES?

**HUGE COLLECTION
OF GAS, STARS AND
DUST**

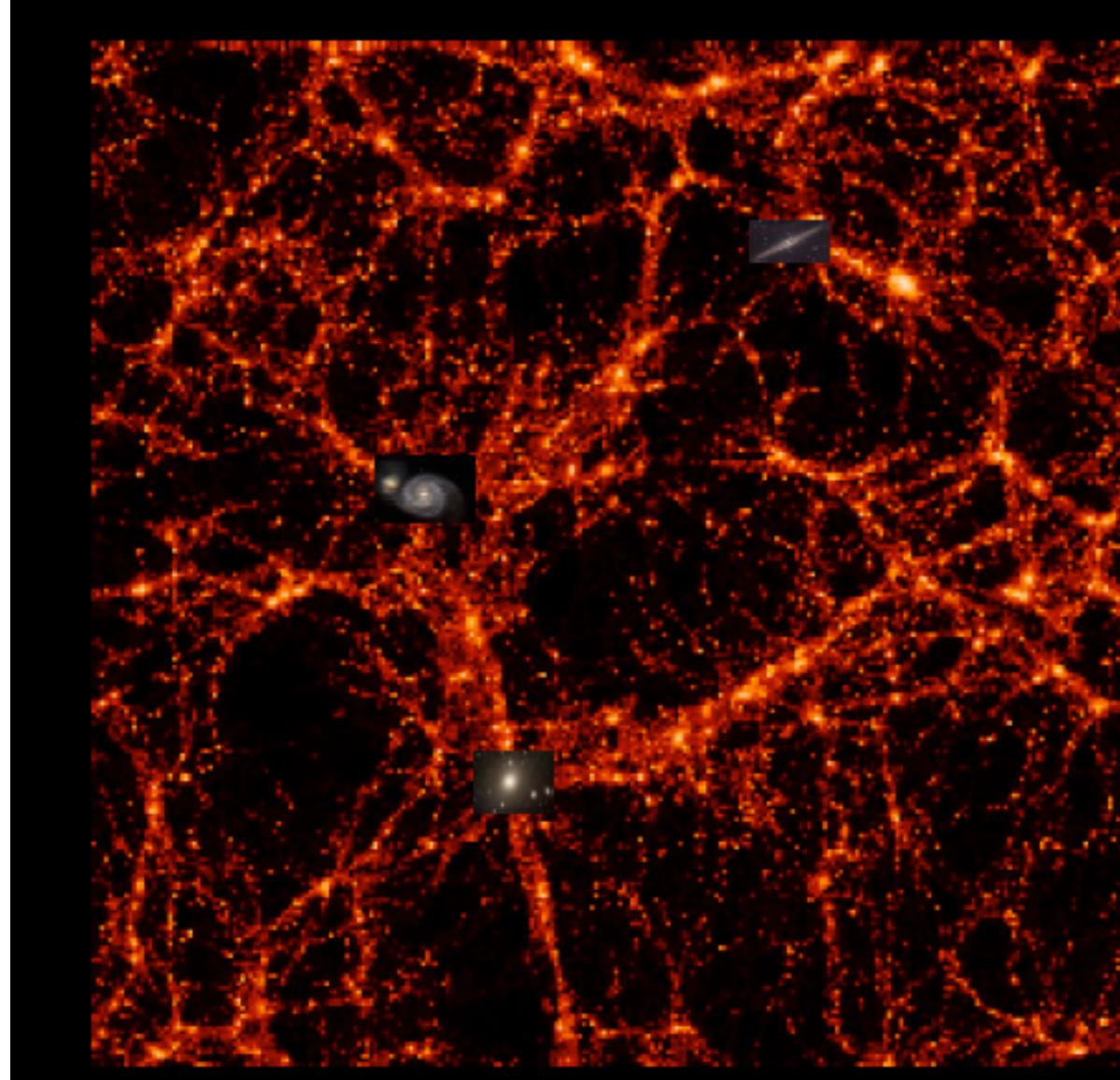


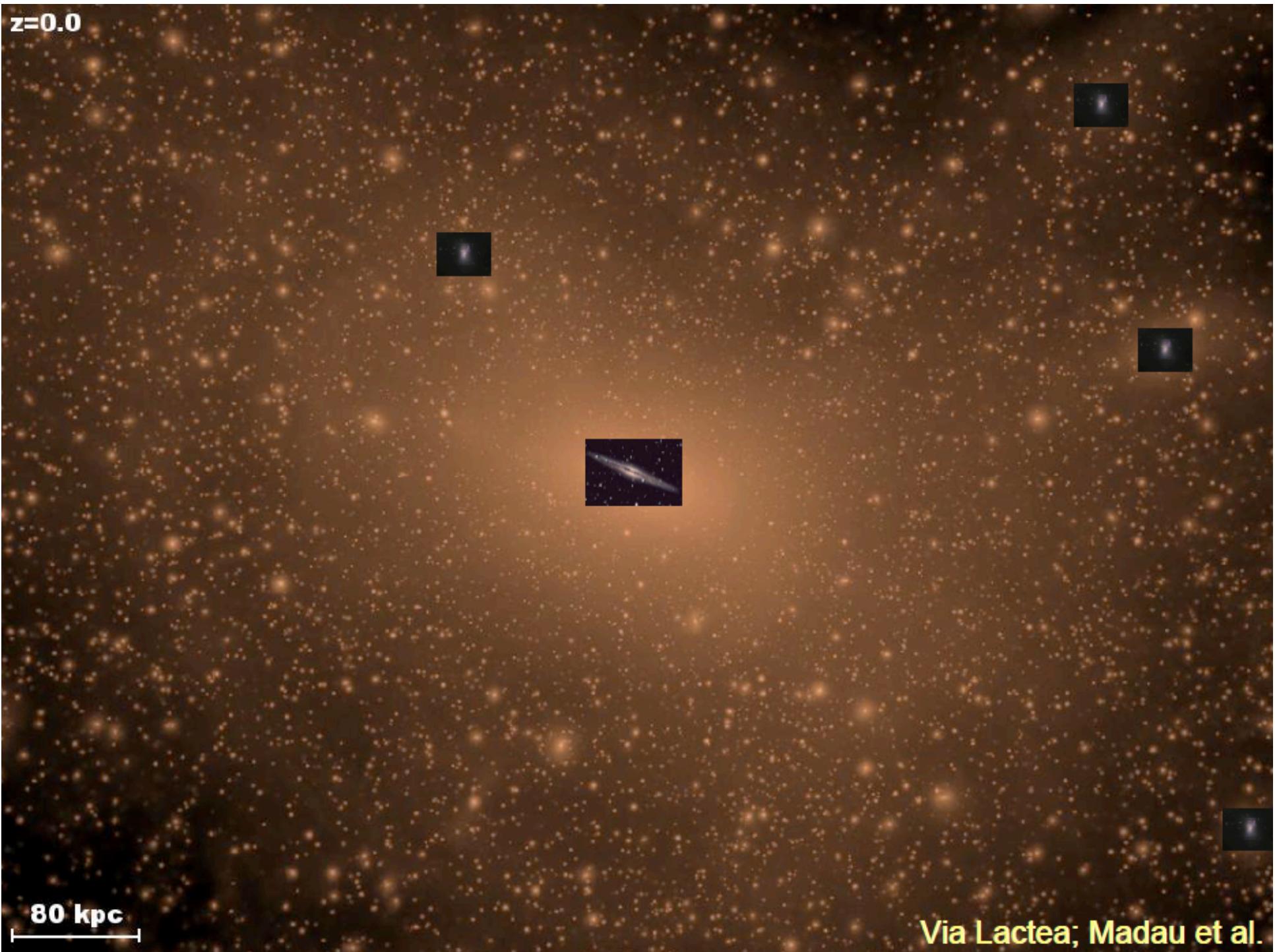
GALAXY



“A dark matter potential well with a small fraction of baryonic matter in the central regions”

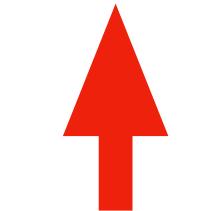
**SMALL “BLOBS” OF
NORMAL
MATTER IN A
HUGE DARK
MATTER HALO**



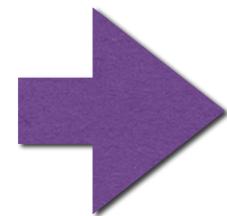


Via Lactea; Madau et al.

GAS IN
ASTRONOMY
MEANS
HYDROGEN...



GAS



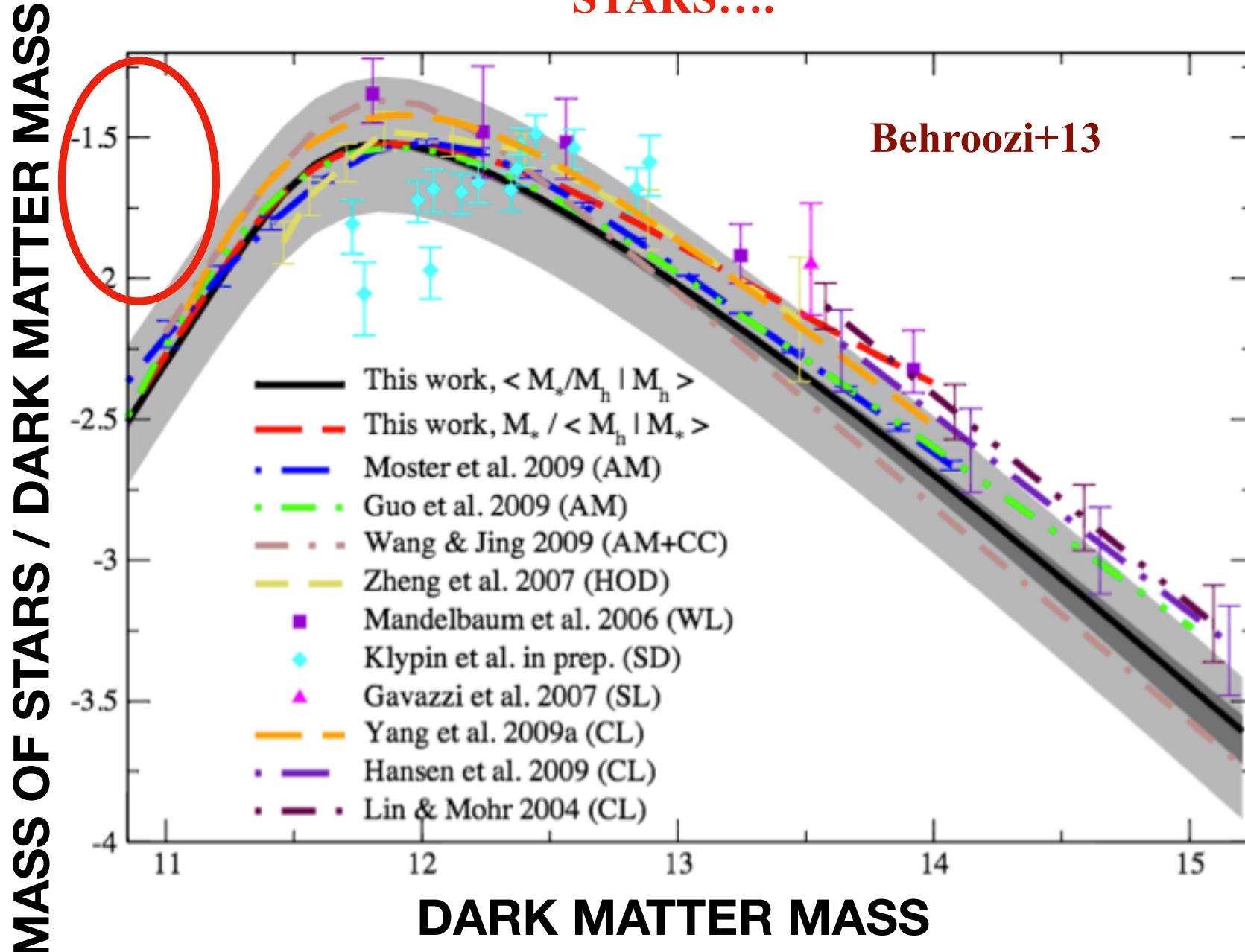
STAR-FORMATION RATE (SFR)
A KEY OBSERVABLE...
TYPICALLY MEASURED IN
“SOLAR MASSES / YEAR”



STARS

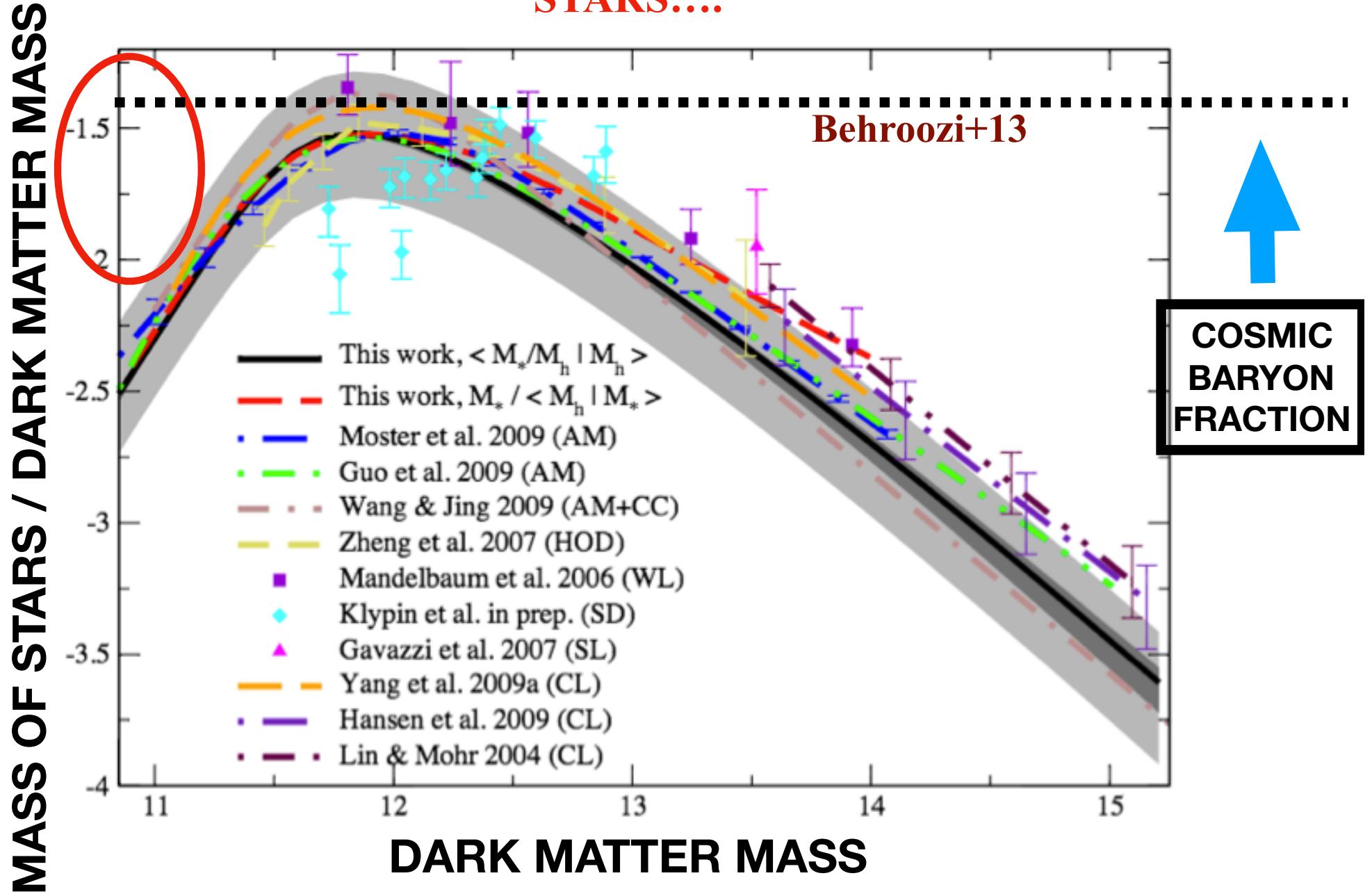
GALAXIES ARE “MACHINES” THAT FORM STARS

ONLY A SMALL FRACTION OF THE GAS IS CONVERTED INTO STARS....



... WE WILL COME BACK LATER TO THIS KEY PLOT...

ONLY A SMALL FRACTION OF THE GAS IS CONVERTED INTO STARS....



... WE WILL COME BACK LATER TO THIS KEY PLOT...

UNDERSTANDING GALAXIES...

**MEANS UNDERSTANDING THE
PROCESSES THAT TRANSFORM
GAS INTO STARS**

UNDERSTANDING GALAXIES...

MEANS UNDERSTANDING THE
PROCESSES THAT TRANSFORM
GAS INTO STARS

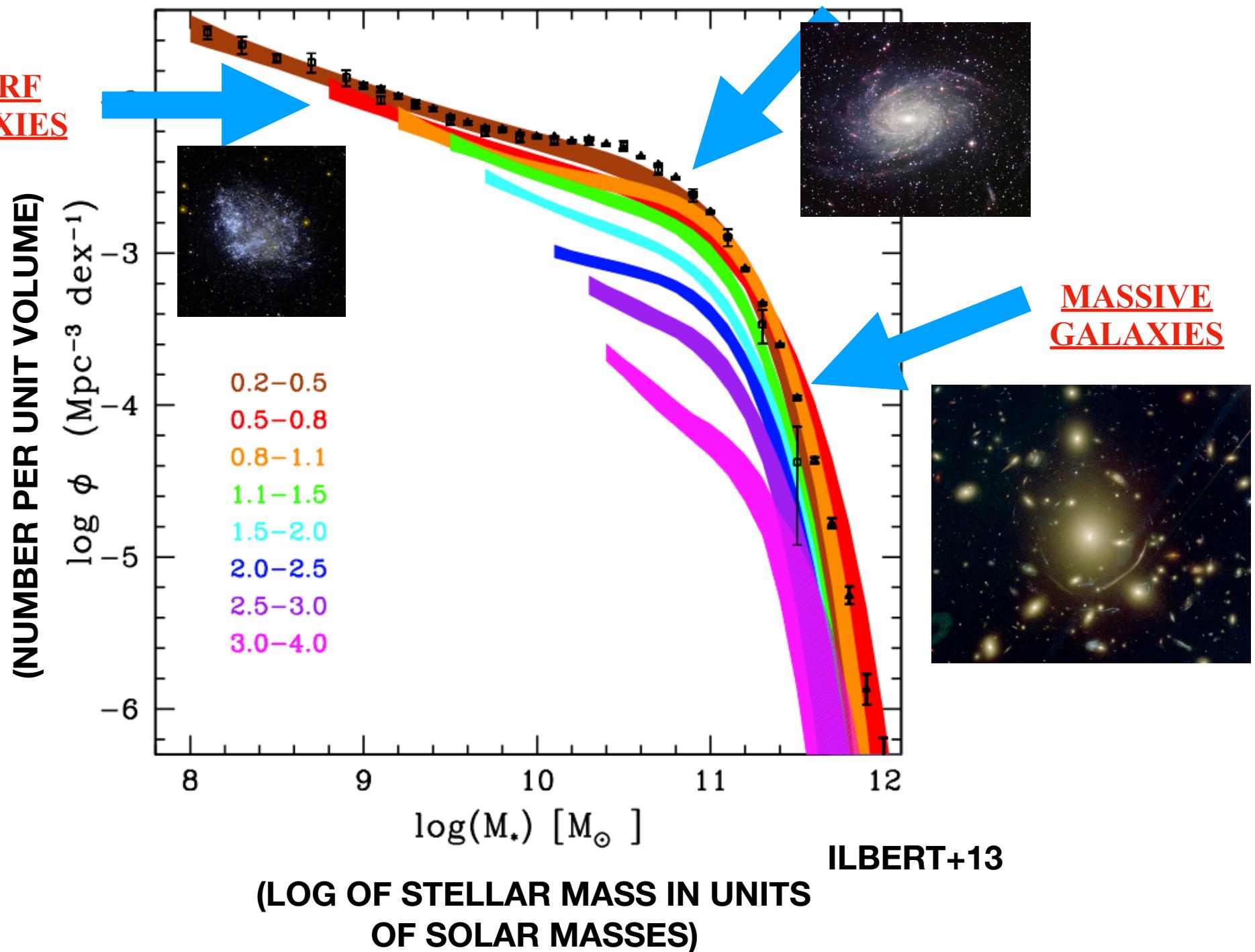


STELLAR MASS:
HOW MANY STARS HAVE BEEN
PRODUCED

GAS FRACTION:
AVAILABLE AMOUNT
OF FUEL TO *FEED* STAR FORMATION

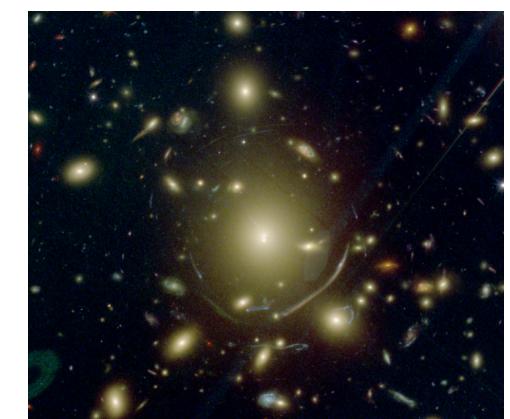
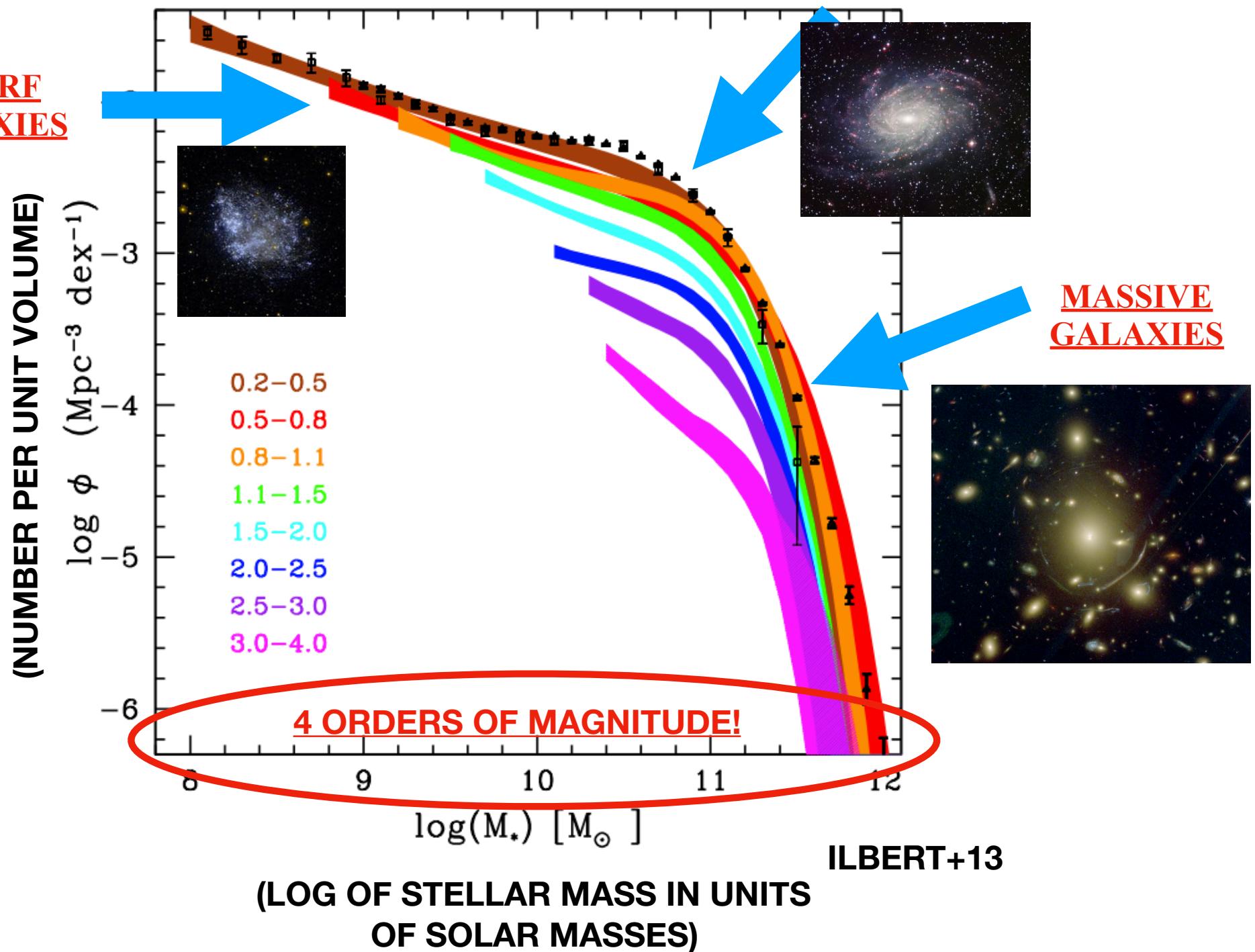
MILKY-WAY TYPE GALAXIES

DWARF
GALAXIES



MILKY-WAY TYPE GALAXIES

DWARF
GALAXIES

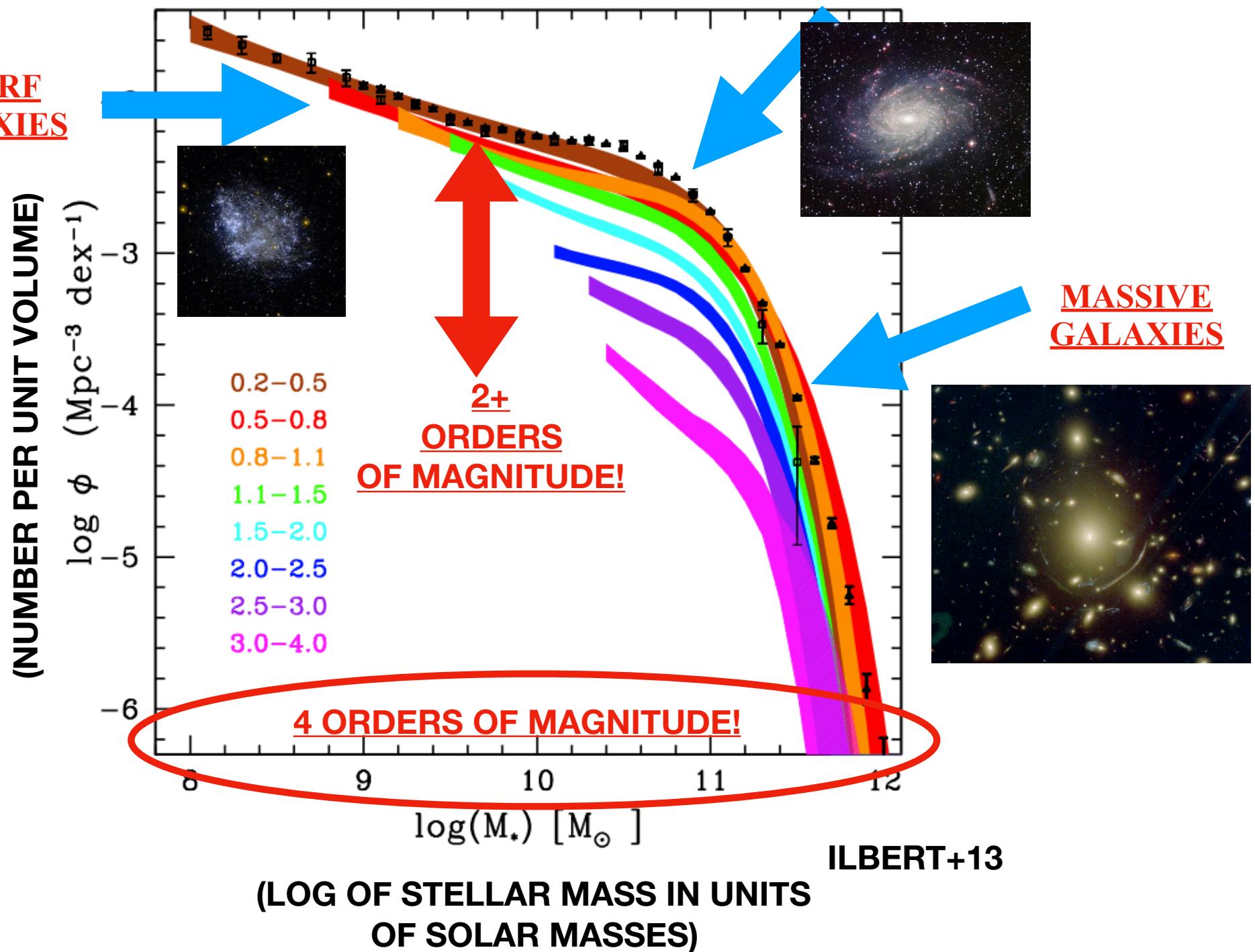


MASSIVE
GALAXIES

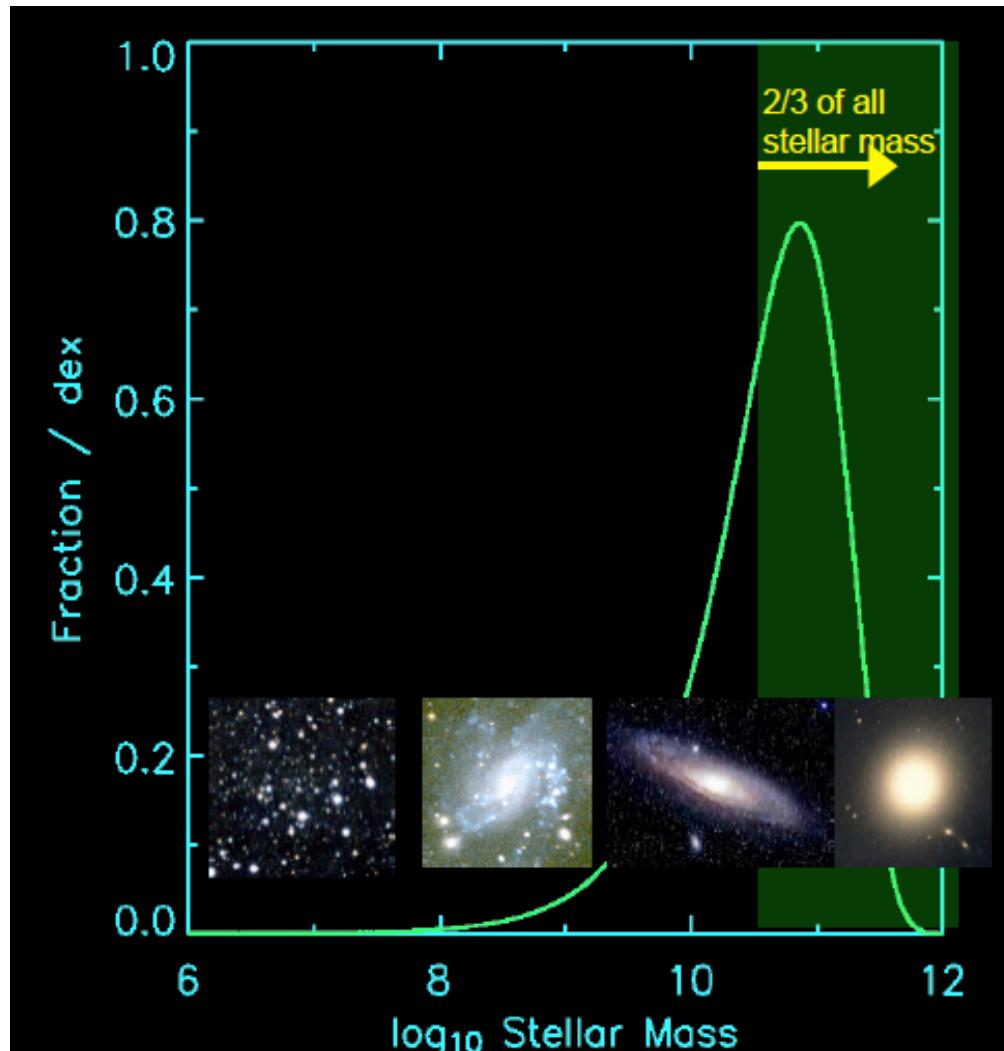
MILKY-WAY TYPE GALAXIES

DWARF
GALAXIES

MASSIVE
GALAXIES

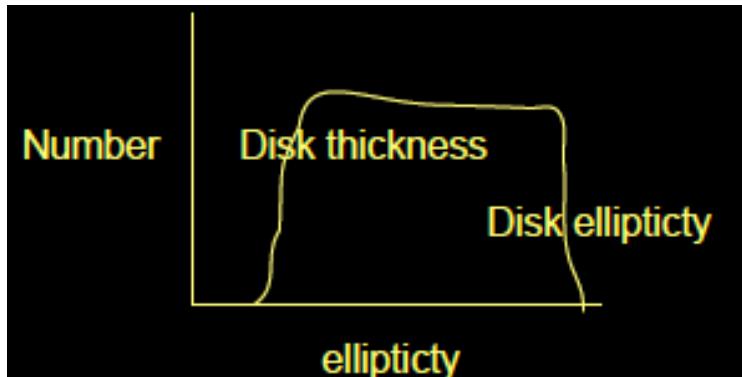


MASSIVE GALAXIES DOMINATE STELLAR MASS OF THE UNIVERSE [EVEN IF LESS ABUNDANT IN NUMBERS]

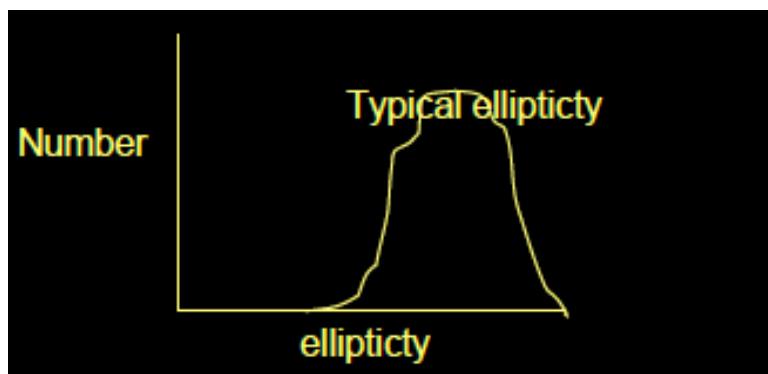


BELL+03

GALAXY STRUCTURE



*DISKS -
CONSERVED SOME ANGULAR MOMENTUM*

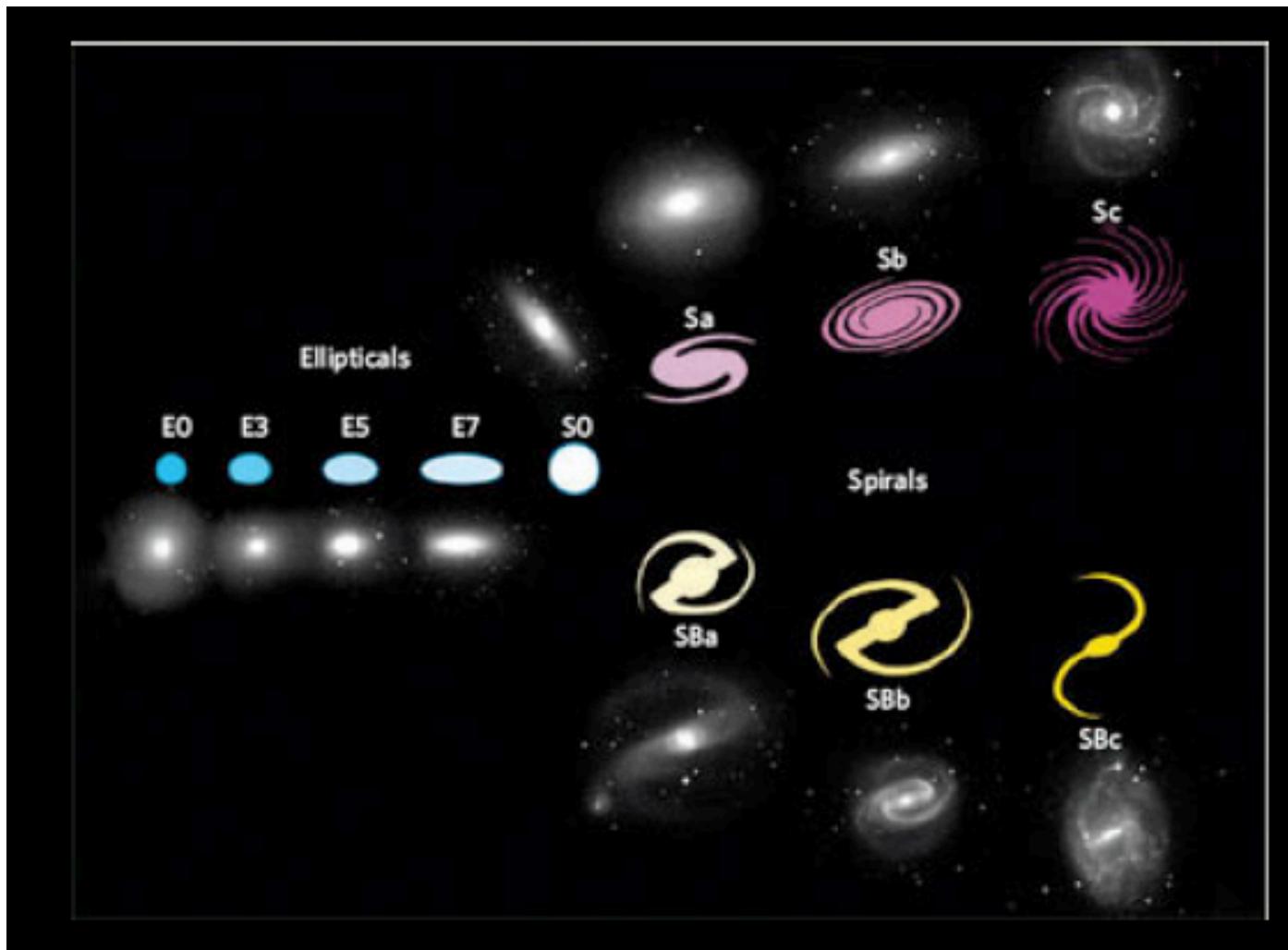


*SPHEROIDS -
LOST ALL ANGULAR MOMENTUM*



GALAXY STRUCTURE

THE HUBBLE SEQUENCE



WHAT ABOUT GAS?

**MAIN BODY OF GALAXIES (<30 Kpc) PRESENTS A WIDE RANGE
OF GAS CONTENTS...**

FROM ALMOST GAS FREE TO ~80% OF COLD GAS (HI/HII)
(ALSO CHANGES WITH TIME...)

WHAT ABOUT GAS?

**MAIN BODY OF GALAXIES (<30 Kpc) PRESENTS A WIDE RANGE
OF GAS CONTENTS...**

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(ALSO CHANGES WITH TIME...)

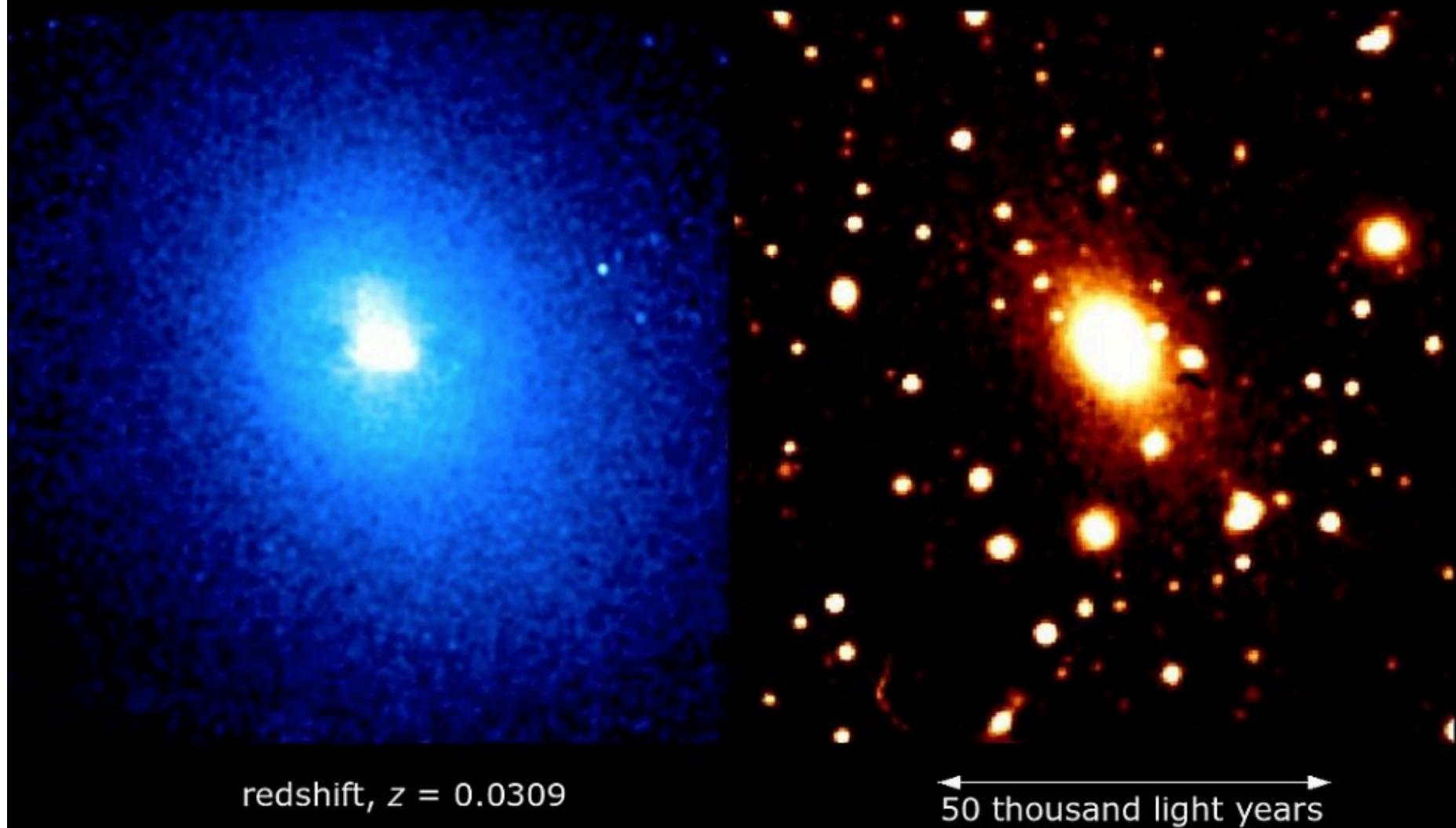
BUT, MOST OF THE GAS IS IN WARM/HOT STATE:

**80/90% OF THE BARYONS DO NOT FORM STARS!
FILAMENTS, EXTENDED GAS HALOS —> CLEARLY SEEN IN
CLUSTERS**

Abell 2199

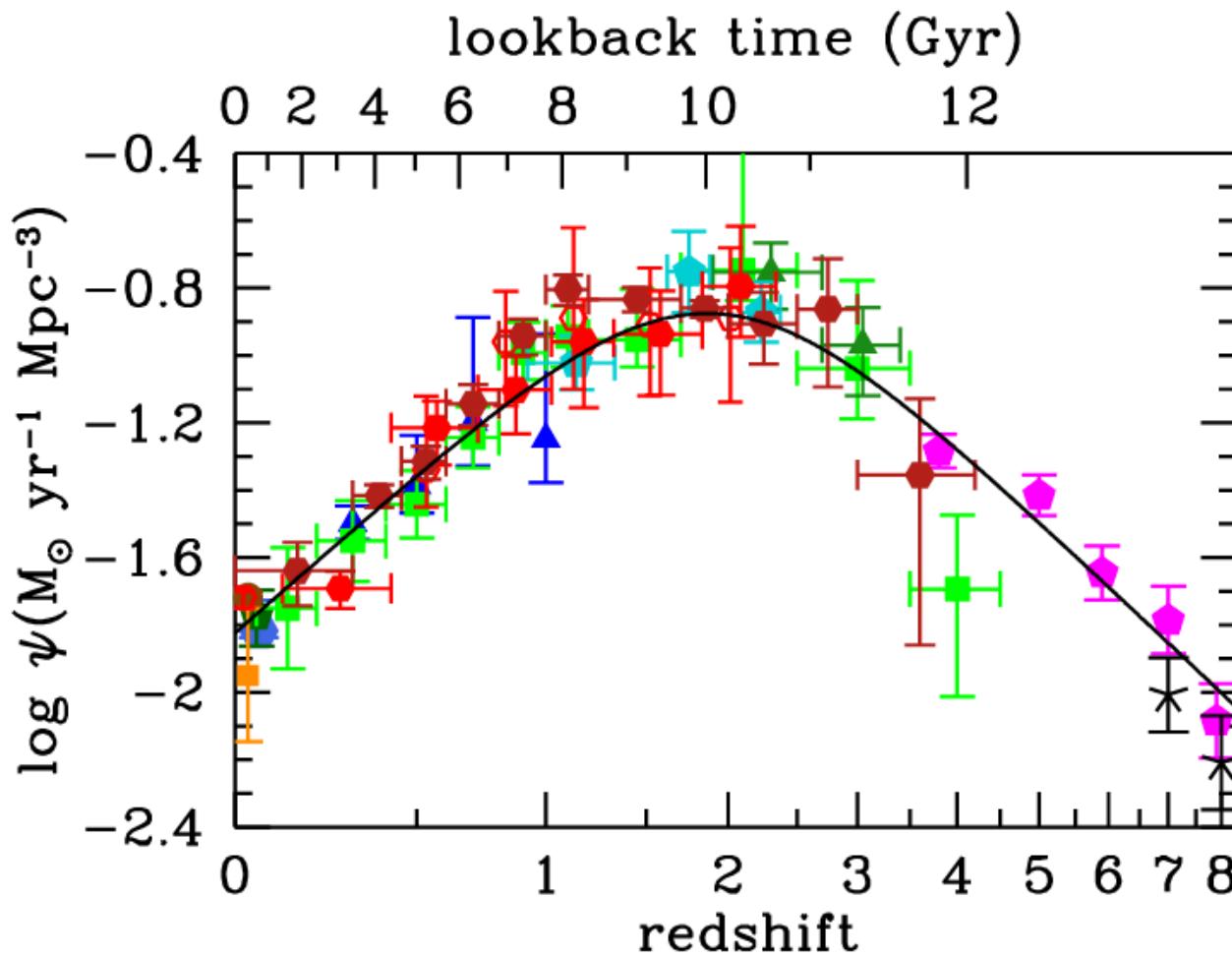
Chandra (X-ray)

DSS (Optical)



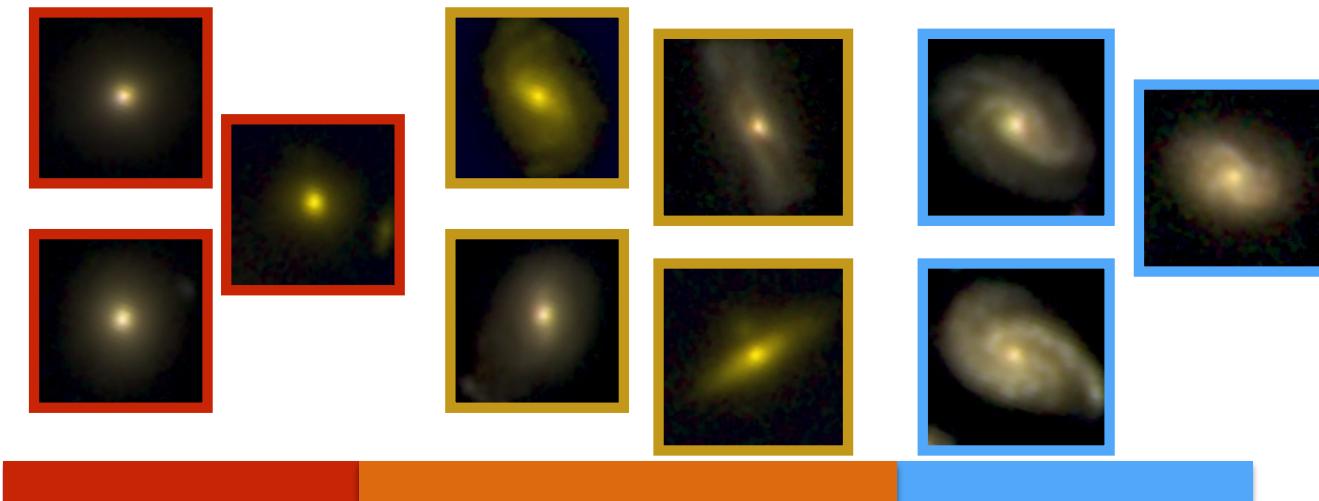
HOT GAS IS CLEARLY VISIBLE IN CLUSTERS OF GALAXIES

DON'T FORGET GALAXIES EVOLVE...



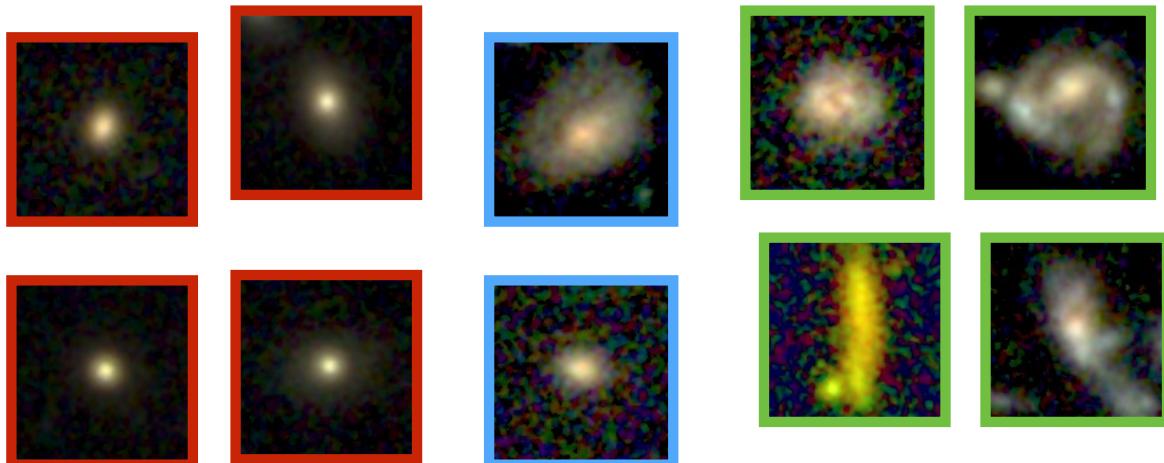
Madau&Dickinson+14

**~Milky Way+
progenitors**



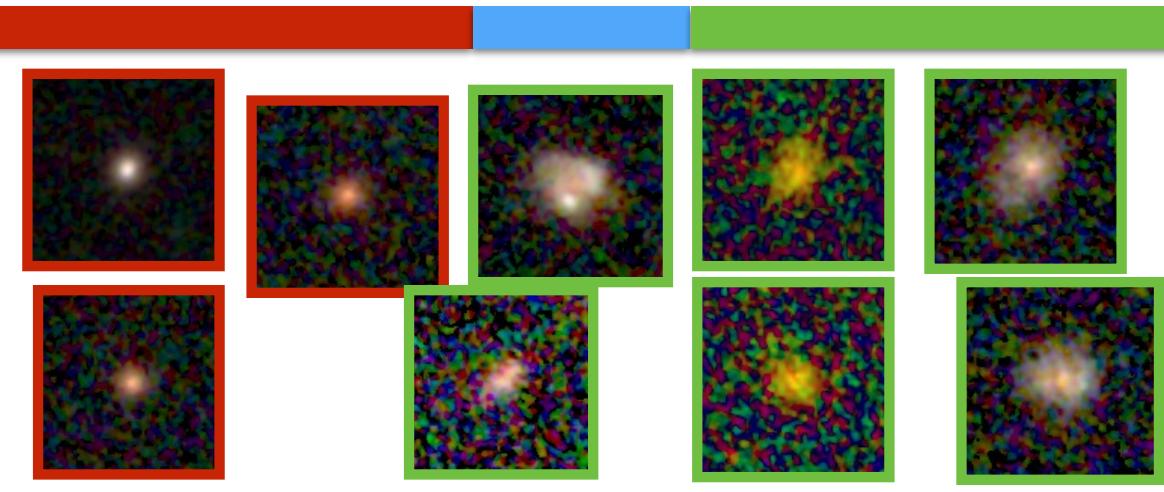
(7 Gyrs ago)

$z < 1$



(~9 Gyrs ago)

$1 < z < 2$



(~11 Gyrs ago)

$z > 2$

MHC+16

RECALL ...

- GALAXIES ARE STAR FORMATION ENGINES
- DM OVER-DENSITIES IN COSMIC WEB
- COMPLEX PHYSICAL SYSTEMS CONVERTING GAS INTO STARS
- LARGE DIVERSITY OF STELLAR MASSES, SHAPES WITH VERY DIVERSE ABUNDANCES [ORDERS OF MAGNITUDE]
- LARGE DIVERSITIES OF GAS FRACTIONS
- THE MAJORITY OF THE GAS IS IN HOT-WARM MODE —> MOST OF THE GAS IS NEVER CONVERTED INTO STARS

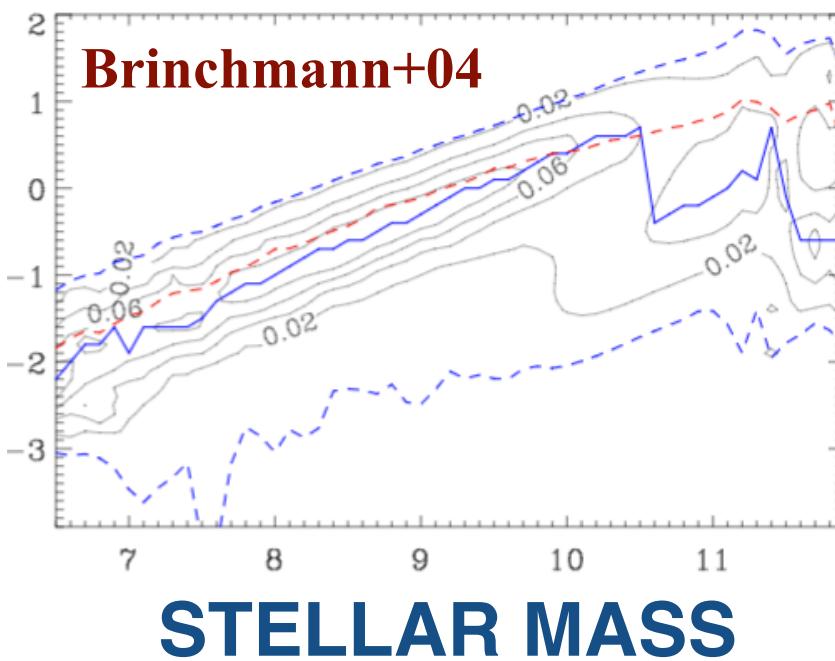
DESPITE BEING COMPLEX SYSTEMS ... ASTONISHING REGULARITY

GIVEN, e.g **STELLAR MASS** ONE CAN PREDICT:

- ROTATION, VELOCITY DISPERSION TO 30%
- STAR-FORMATION RATE TO 30%
- SIZE TO A FACTOR OF 2
- HALO MASS IN WHICH GALAXY LIVES
- CAN PREDICT BLACK HOLE MASS TO A FACTOR OF 3

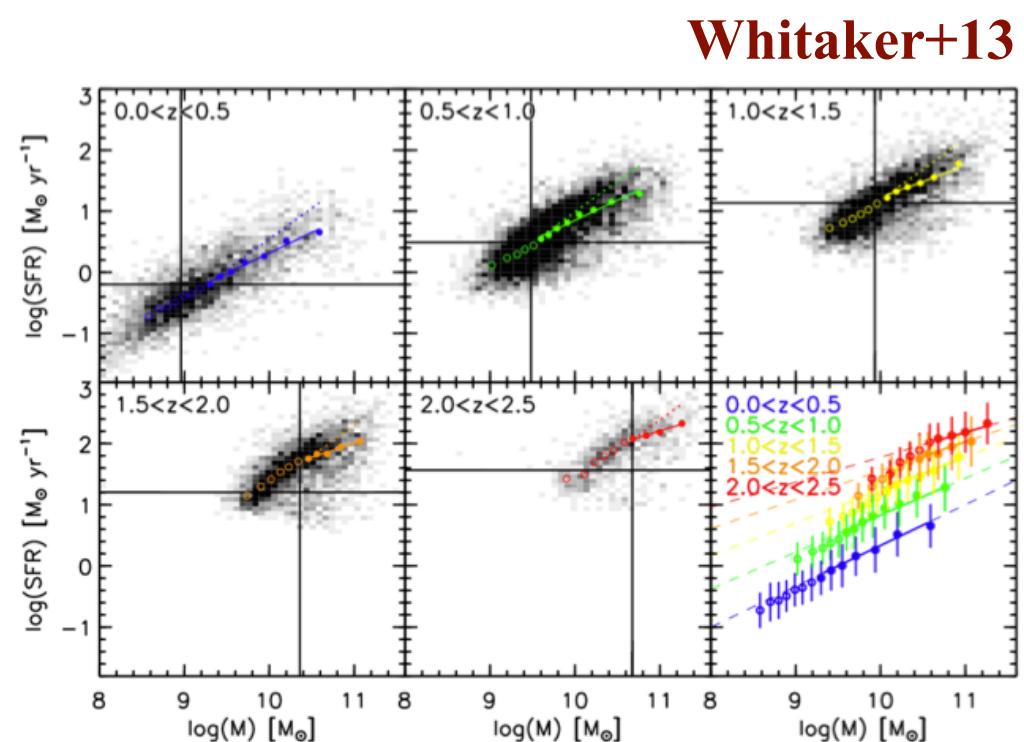
STAR FORMATION RATE

STAR FORMATION MAIN SEQUENCE

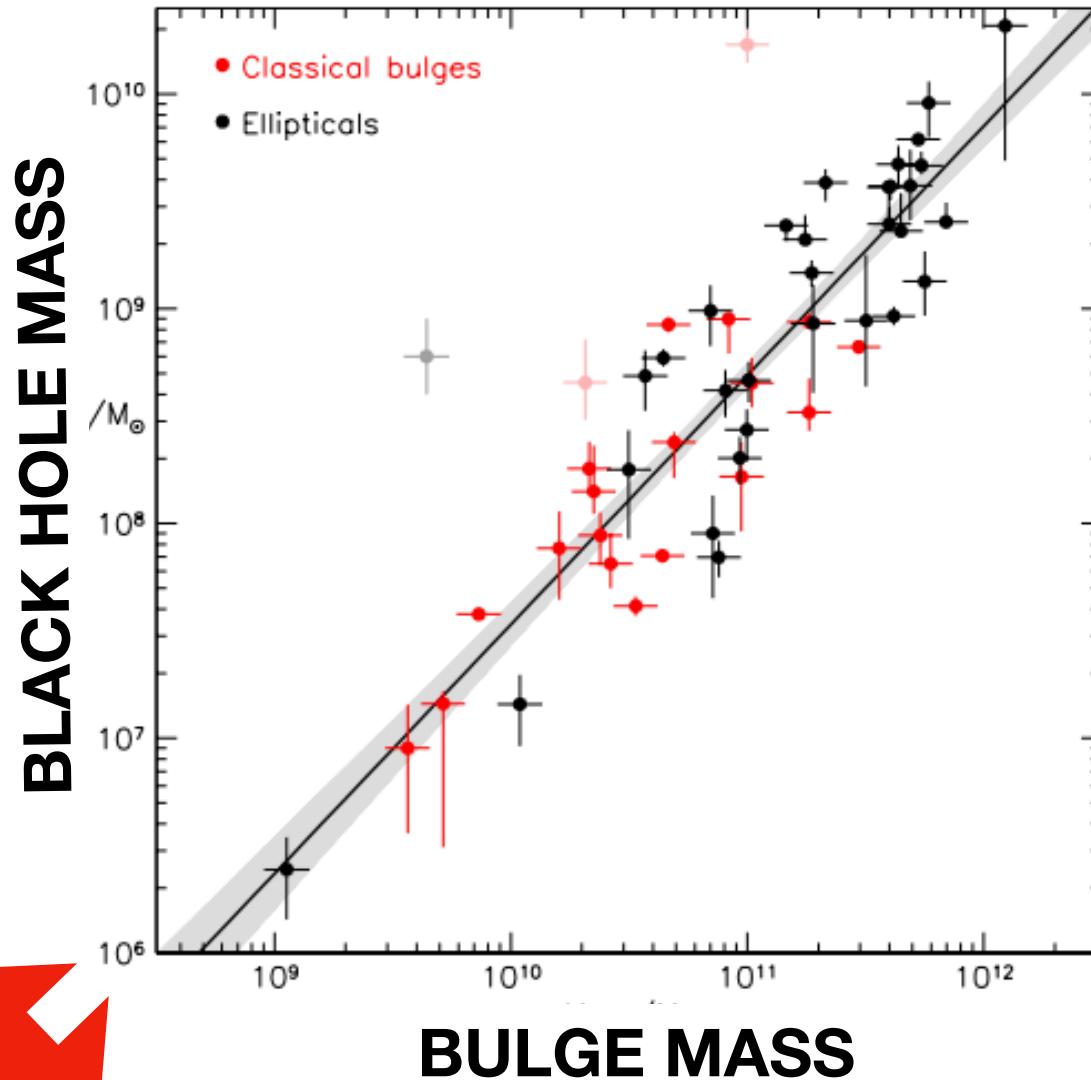


And also at higher
redshift
[HST legacy]

In the local Universe
[SDSS legacy]



MBH-MBULGE RELATION

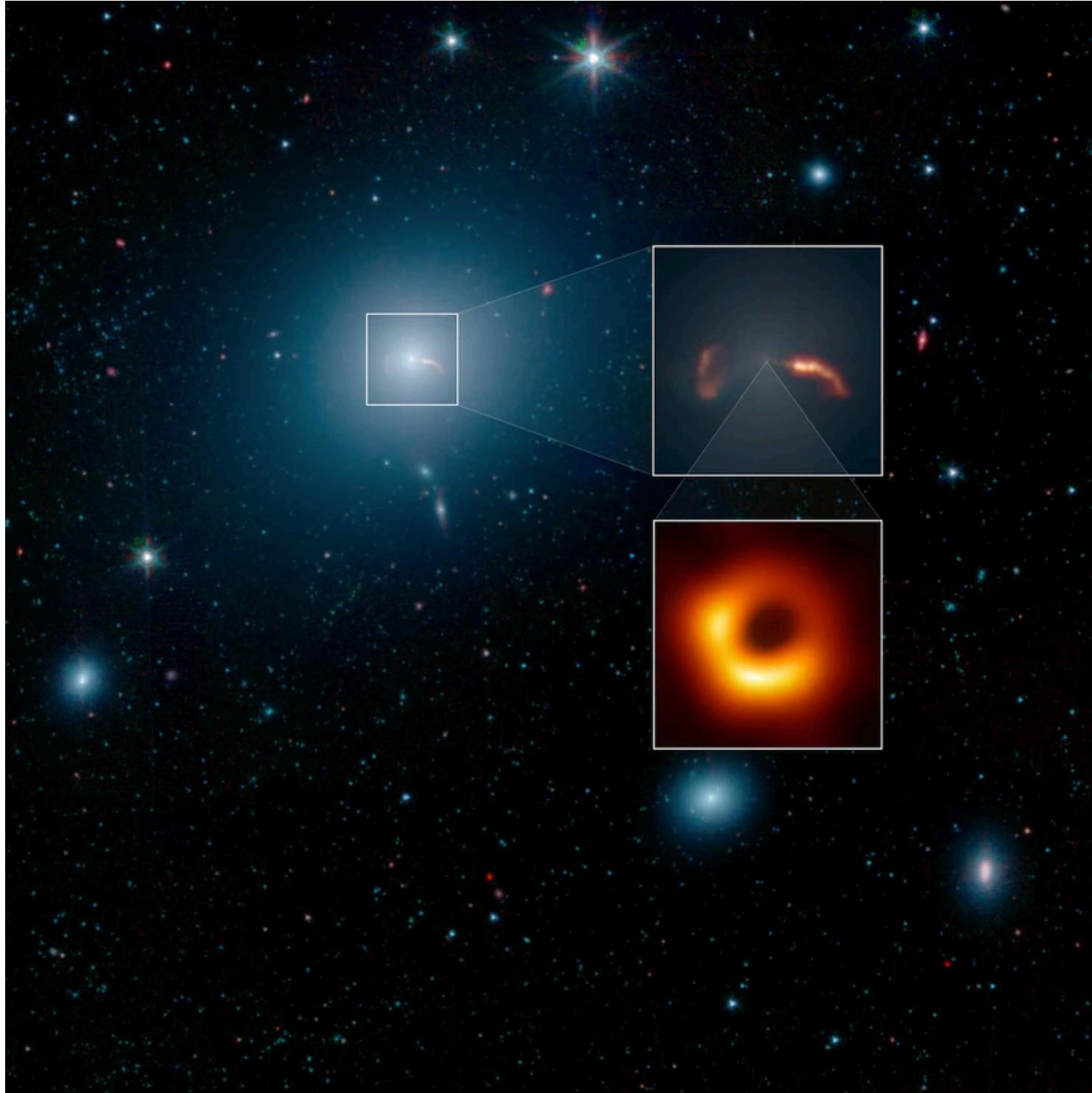


THREE
ORDERS OF
MAGNITUDE
DIFFERENCE!

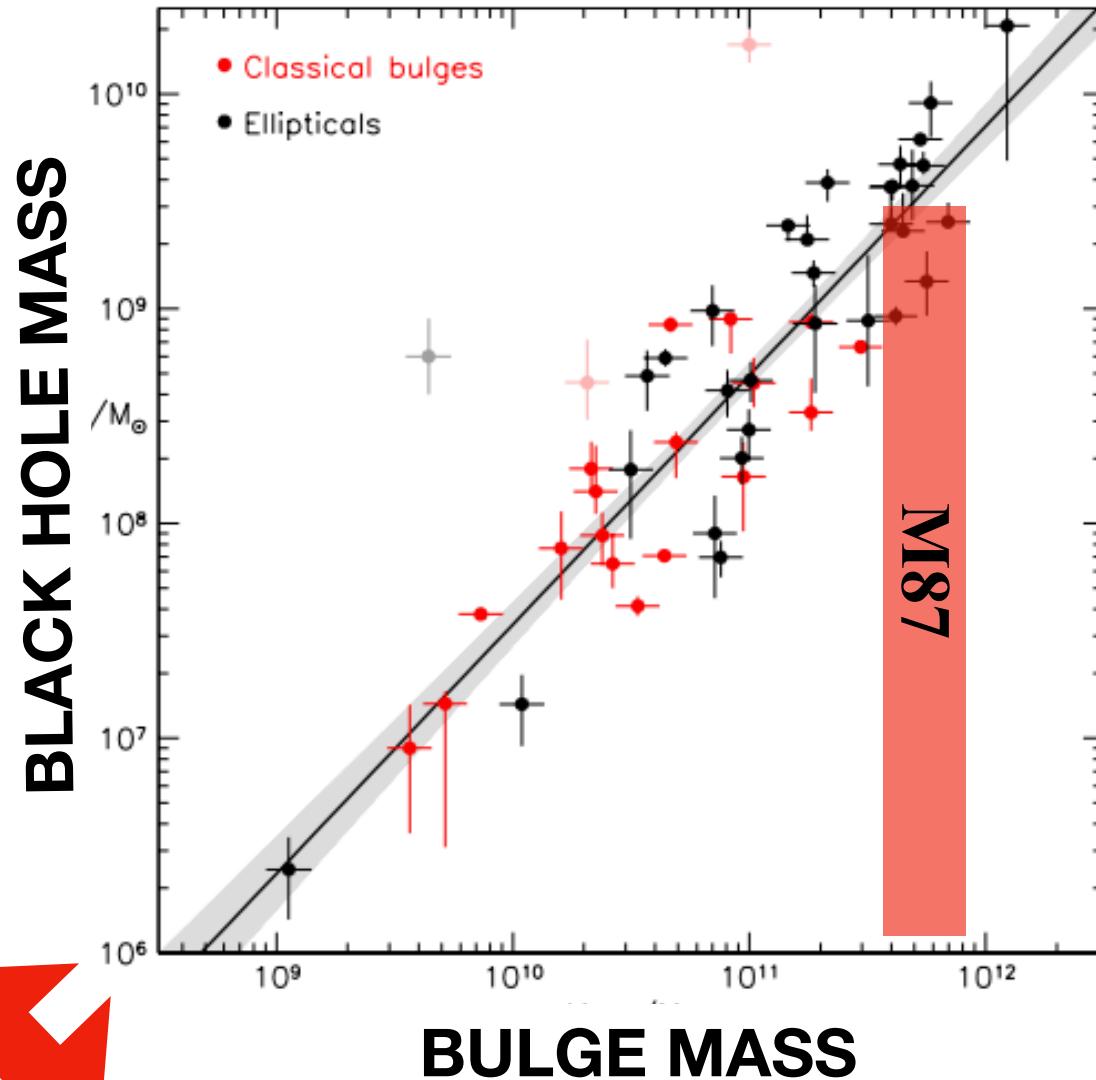


Kormendy&Ho+13

FIRST BLACK HOLE IMAGE IN M87



MBH-MBULGE RELATION



THREE
ORDERS OF
MAGNITUDE
DIFFERENCE!

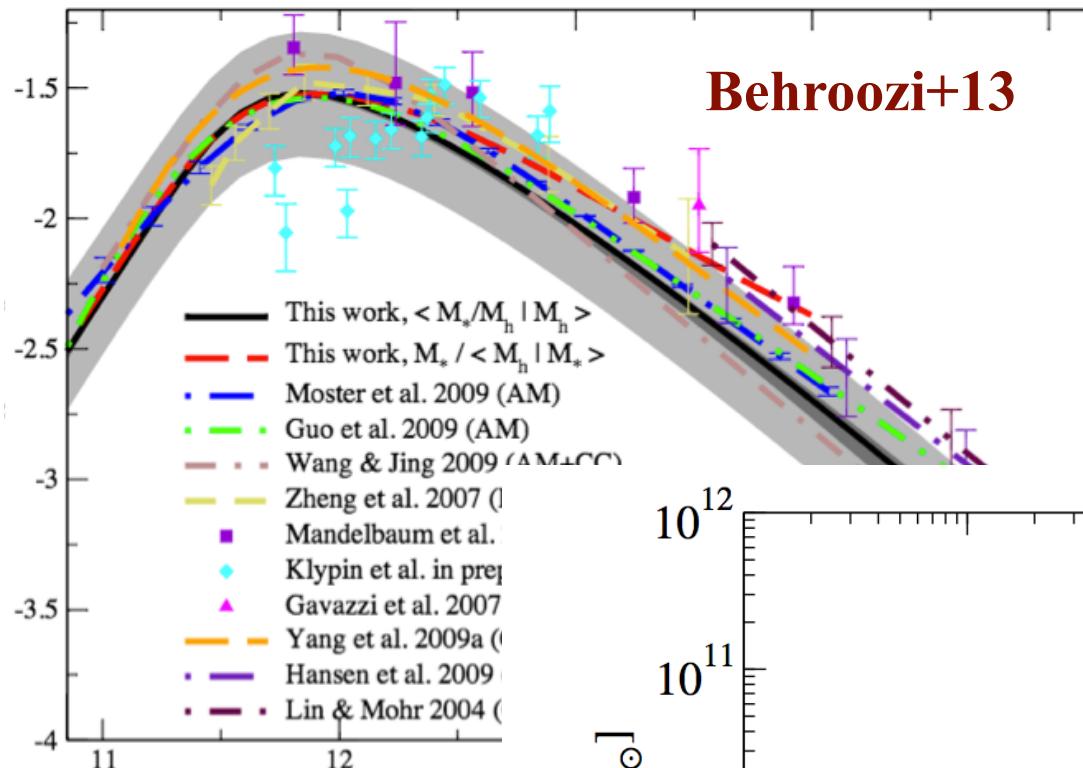
Kormendy&Ho+13

Black Hole at the center of the Milky Way

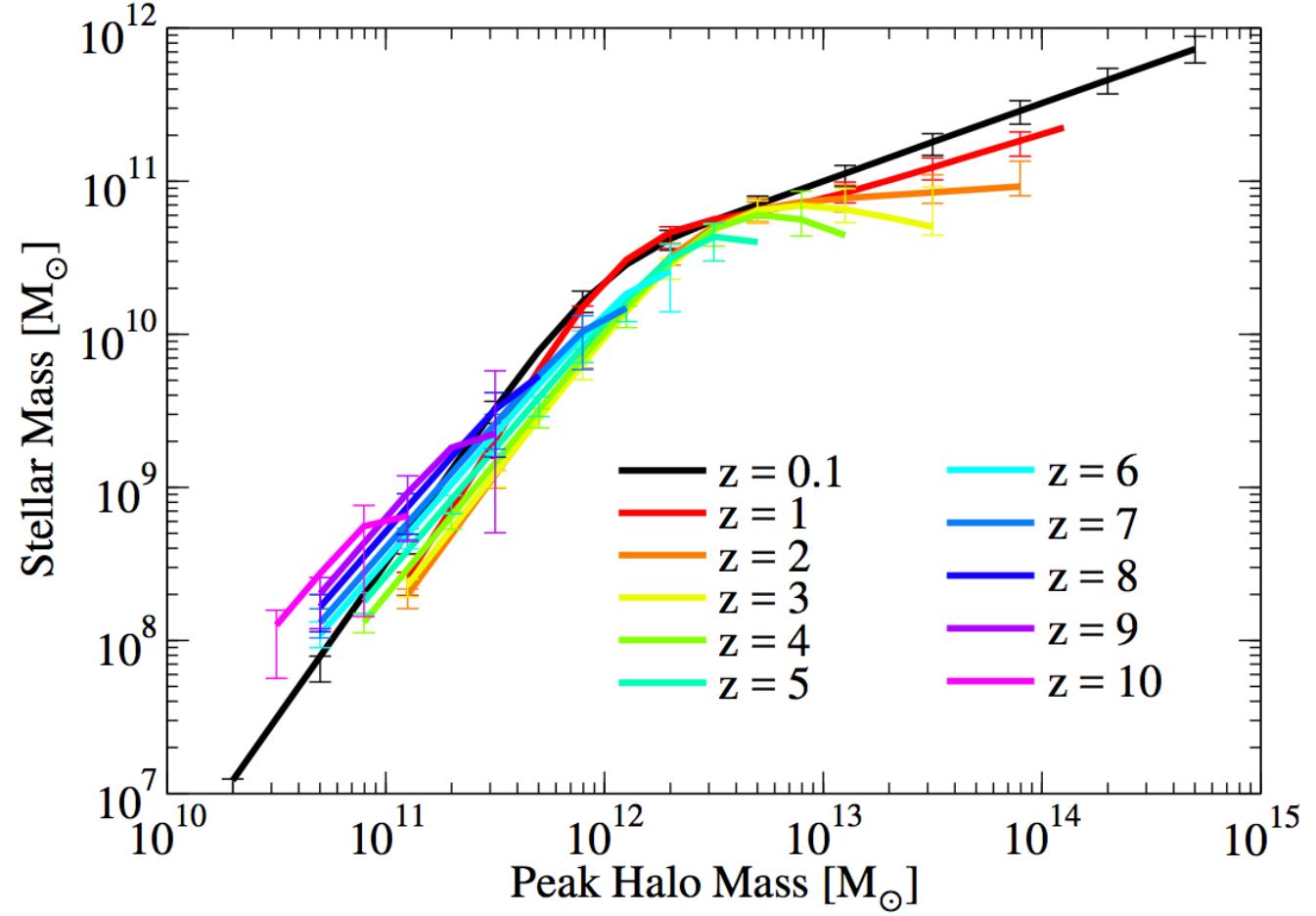
<https://www.youtube.com/watch?v=TF8THY5spmo>

MASS OF STARS / MASS OF DARK MATTER

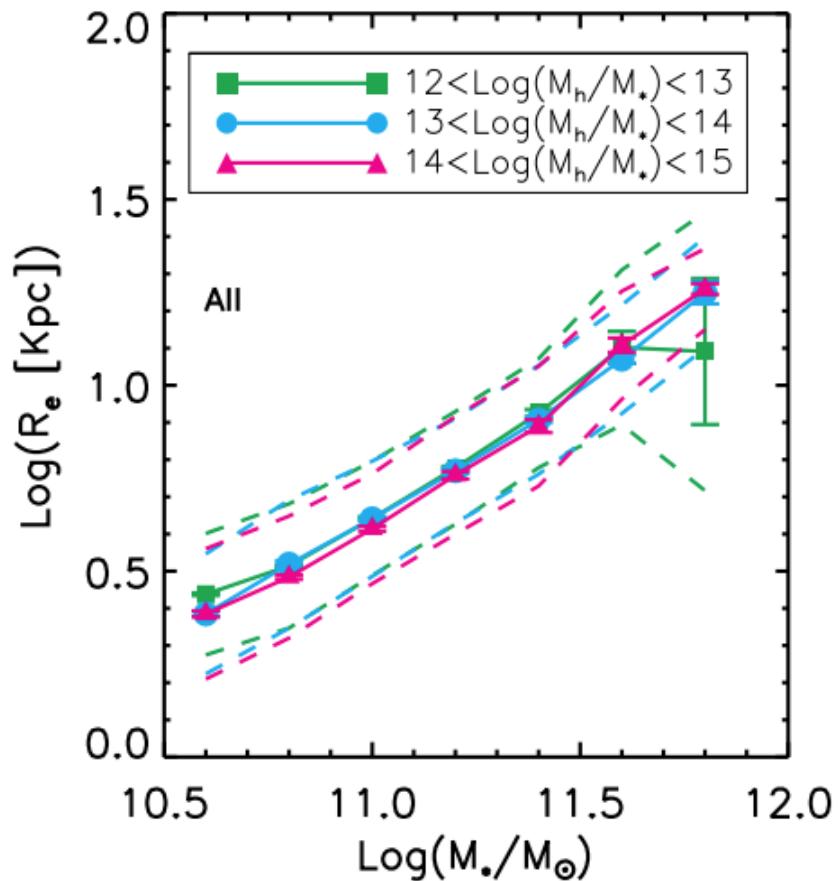
MASS-HALO RELATION



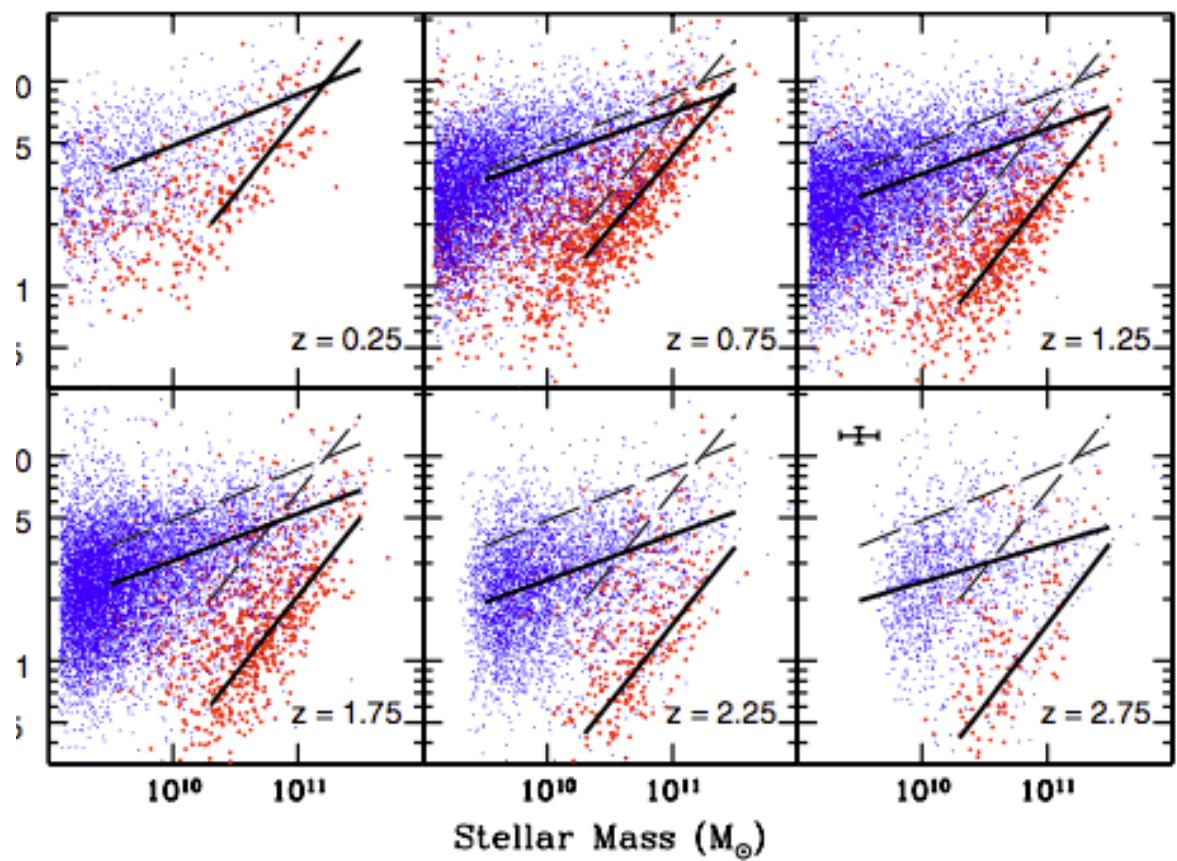
DARK MAT-



MASS-SIZE RELATION



MHC+13



van der Wel+13

HOW DO WE GET THESE TIGHT RELATIONS?

... THIS IS STILL MATTER OF CURRENT RESEARCH

CURRENT PICTURE OF GALAXY FORMATION (IN 5 BULLET POINTS)

- 1. FORMATION OF THE DARK MATTER HALO
- 2. GAS ACCRETION / COOLING
- 3. GROWTH THROUGH ACCRETION OF GAS
(SMOOTH, STUFF THAT CANNOT COOL INTO HALOS)
+ MERGING (WHERE STARS COLD / GAS ALREADY
FORMED)
- 4. STAR FORMATION IN THE COOLED GAS
- 5. FEEDBACK

- 1. FORMATION OF THE DARK MATTER HALO

GAS PRESSURE AT EARLY TIMES STOPS BARYONS FROM CLUMPING

DARK MATTER → NO PRESSURE → ACTS AS SEED FOR GALAXY FORMATION

<https://www.youtube.com/watch?v=jHoHz9fSGVI#action=share>

DEUS N-BODY SIMULATION

- 1. FORMATION OF THE DARK MATTER HALO

Gravitational instability scenario assumes the early universe to be almost perfectly smooth, with the exception of tiny density deviations with respect to the background density.

These small perturbations are accompanying by small velocity perturbation to the general Hubble expansion.

From the CMB observations:

$$\Delta T \sim 10^{-5} K$$

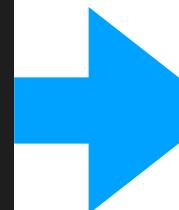
- 1. FORMATION OF THE DARK MATTER HALO

If the fluctuations are $\delta\rho/\rho \ll 1 \rightarrow$

they grow via gravity and can be described by linear perturbation theory.

When they grow so that $\delta\rho/\rho \sim 1 \rightarrow$

They are able to separate from the global expansion and collapse to form a bounded system.

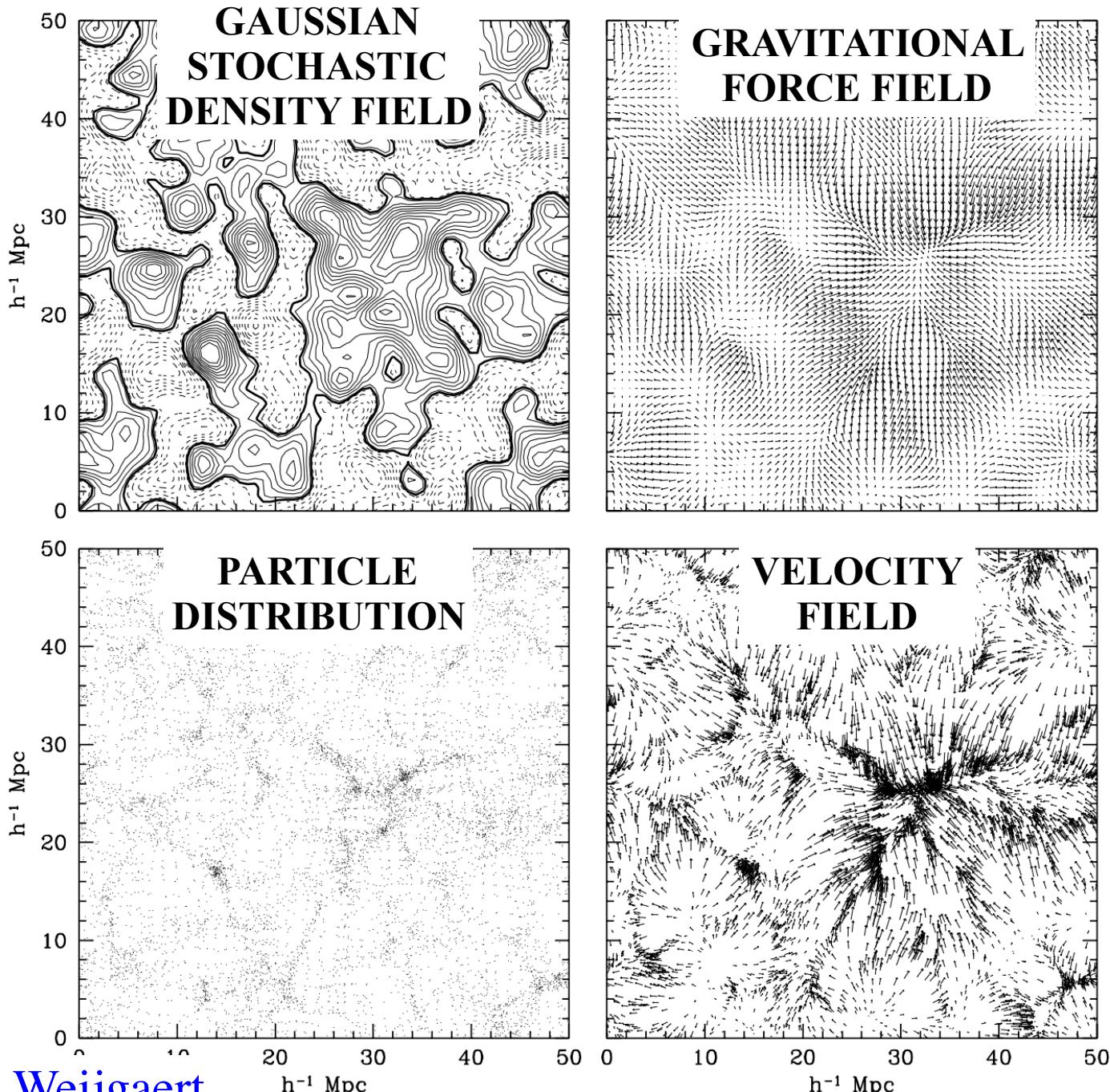


DARK MATTER HALO

At the turnaround radius, fluctuations reach its maximum radius and collapse, entering the non-linear regime.

Finally, the system will reach virialization.

- 1. FORMATION OF THE DARK MATTER HALO



GRAVITATIONAL INSTABILITY

DM HALOS HAVE A UNIVERSAL DENSITY PROFILE IN CDM (N-BODY SIMULATIONS)



A UNIVERSAL DENSITY PROFILE FROM HIERARCHICAL CLUSTERING

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CARLOS S. FRENK

Department of Physics, University of Durham, South Road, Durham DH1 3LE, England; c.s.frenk@uk.ac.durham

AND

SIMON D. M. WHITE

Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Strasse 1, 85740, Garching bei München, Germany;
swhite@mpa-garching.mpg.de

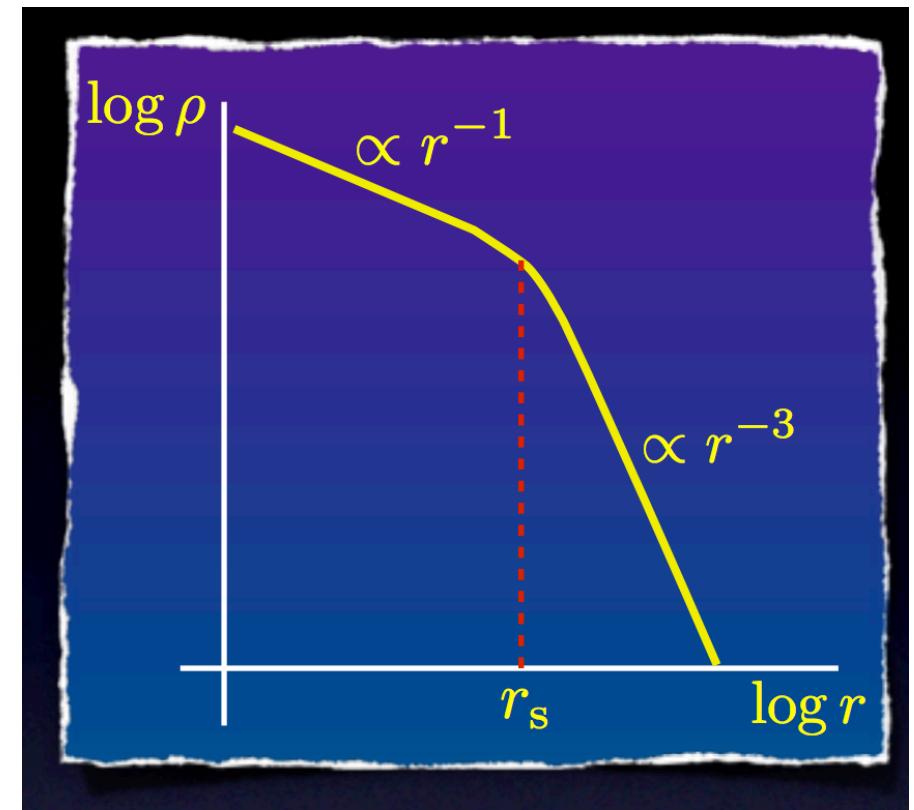
Received 1996 November 13; accepted 1997 July 15

ABSTRACT

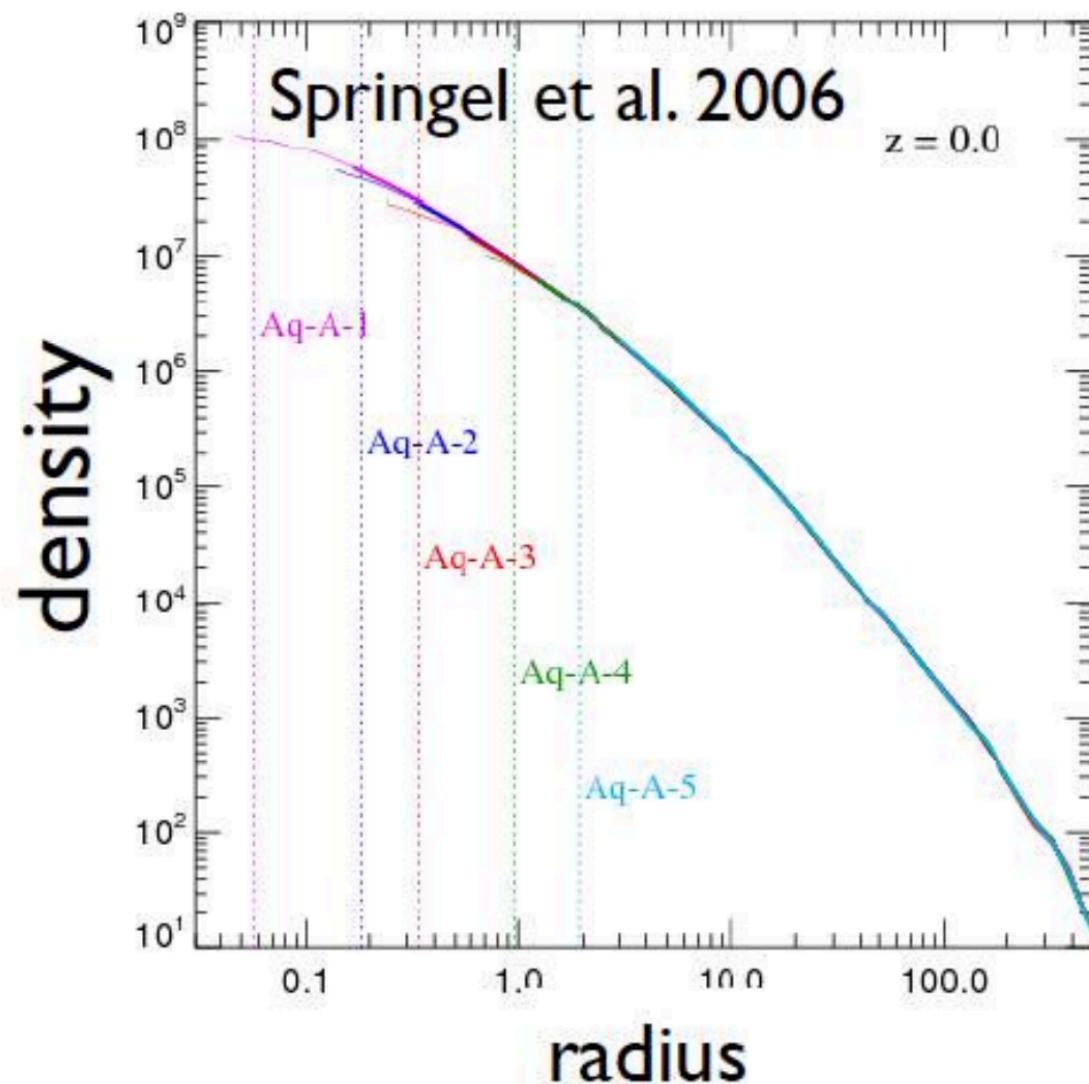
We use high-resolution N -body simulations to study the equilibrium density profiles of dark matter halos in hierarchically clustering universes. We find that all such profiles have the same shape, independent of the halo mass, the initial density fluctuation spectrum, and the values of the cosmological parameters. Spherically averaged equilibrium profiles are well fitted over two decades in radius by a simple formula originally proposed to describe the structure of galaxy clusters in a cold dark matter universe. In any particular cosmology, the two scale parameters of the fit, the halo mass and its characteristic density, are strongly correlated. Low-mass halos are significantly denser than more massive systems, a correlation that reflects the higher collapse redshift of small halos. The characteristic density of an equilibrium halo is proportional to the density of the universe at the time it was assembled. A suitable definition of this assembly time allows the same proportionality constant to be used for all the cosmologies that we have tested. We compare our results with previous work on halo density profiles and show that there is good agreement. We also provide a step-by-step analytic procedure, based on the Press-Schechter formalism, that allows accurate equilibrium profiles to be calculated as a function of mass in any hierarchical model.

THE NFW PROFILE

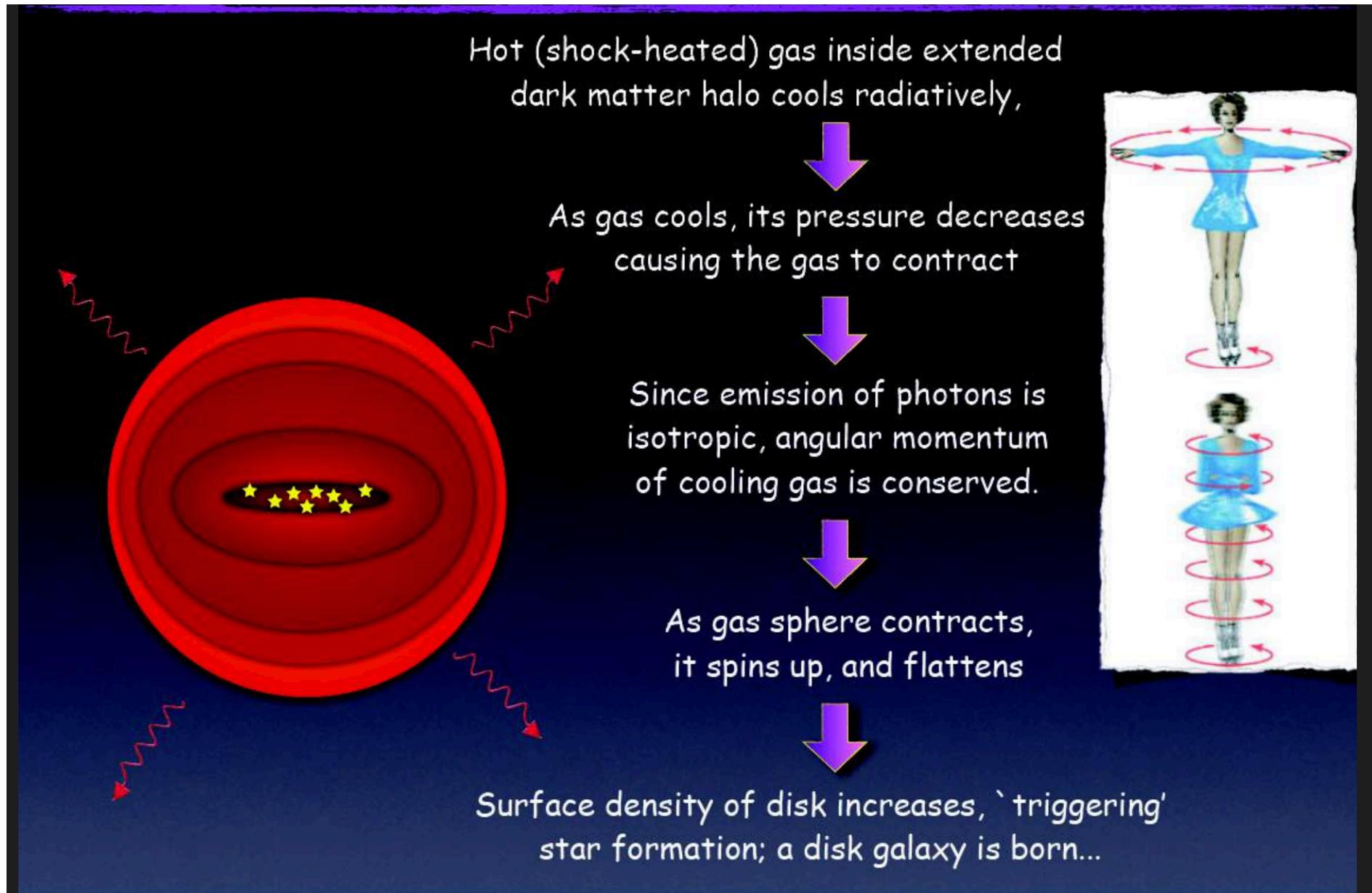
$$\rho(r) = \rho_{\text{crit}} \frac{\delta_{\text{char}}}{(r/r_s)(1+r/r_s)^2}$$



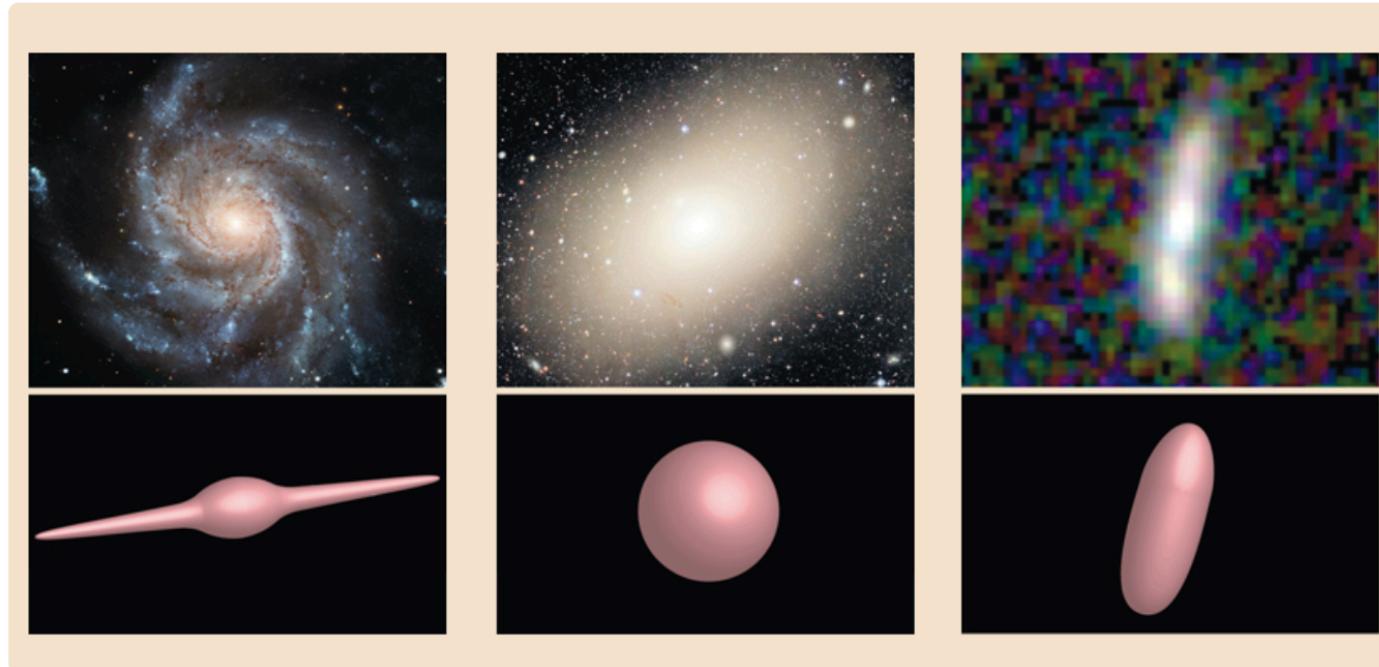
DARK MATTER PROFILES ARE SELF SIMILAR



- 2. GAS ACCRETION / COOLING
[THE CLASSICAL VIEW]



HOWEVER: NUMERICAL SIMULATIONS + OBSERVATIONS SHOW SOME GALAXIES START AS “PICKLES”



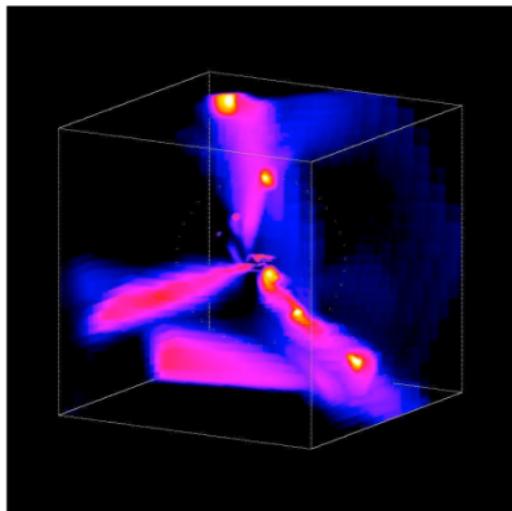
“Galaxies do not form in isolation; rather, they emerge along the long filaments of dark matter, called the *cosmic web*, that bind together the entire universe”

PRIMACK+

- 3. GROWTH THROUGH ACCRETION OF GAS (SMOOTH, STUFF THAT CANNOT COOL INTO HALOS) + MERGING (WHERE STARS COLD / GAS ALREADY FORMED)

ACCRETION COULD CONSERVE SOME ANGULAR MOMENTUM - COMES FROM TORQUES AS GALAXIES TURN AROUND AND COLLAPSE, E.G COFFEE CUP [MAO, MO, WHITE 98]

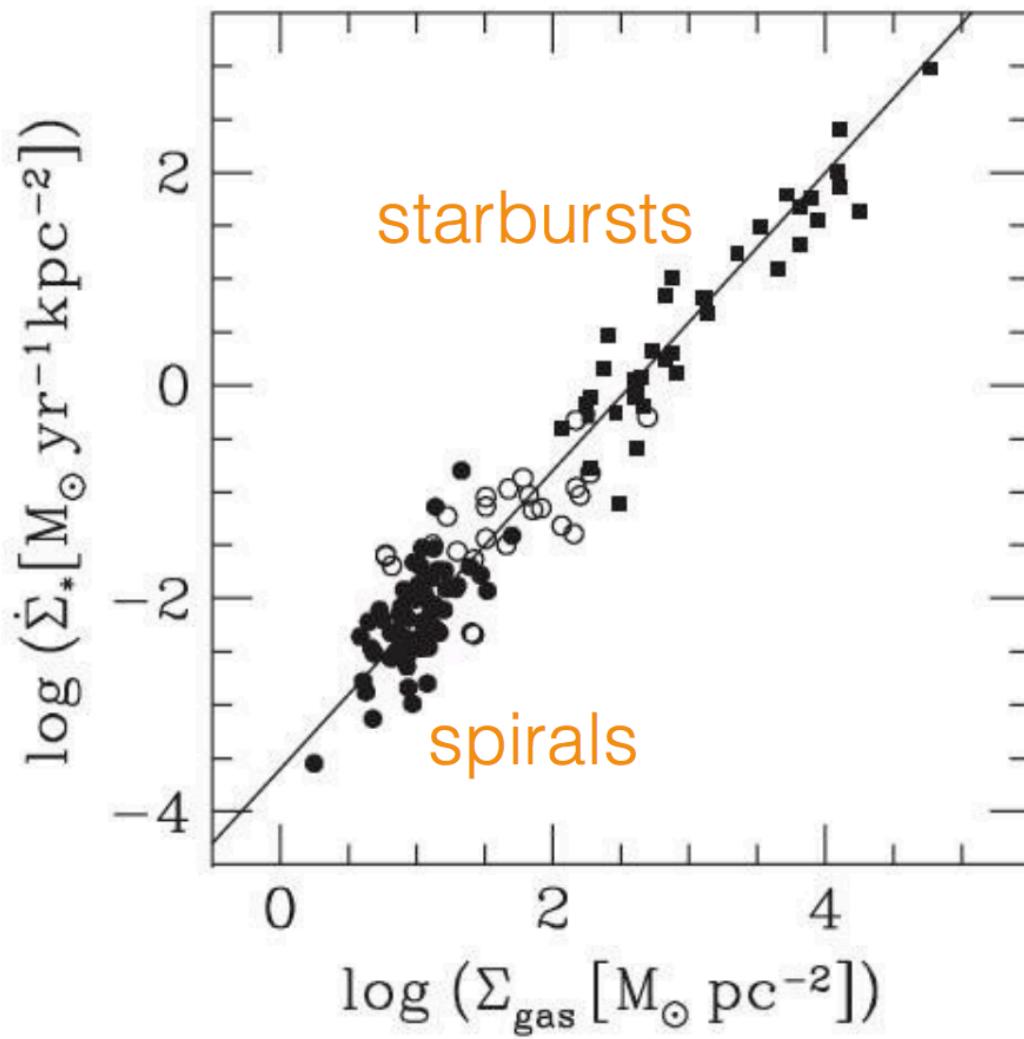
**MERGING RANDOMIZES ANGULAR MOMENTA
[TOOMRE&TOOMRE 72]**



<https://www.youtube.com/watch?v=CcopGM8iUCY>

- 4. STAR FORMATION IN THE COOLED GAS

$$\dot{\Sigma}_* = (2.5 \pm 0.7) \times 10^{-4} \left(\frac{\Sigma_{\text{gas}}}{M_\odot \text{ pc}^{-2}} \right)^{1.4 \pm 0.15} M_\odot \text{ yr}^{-1} \text{ kpc}^{-2}$$



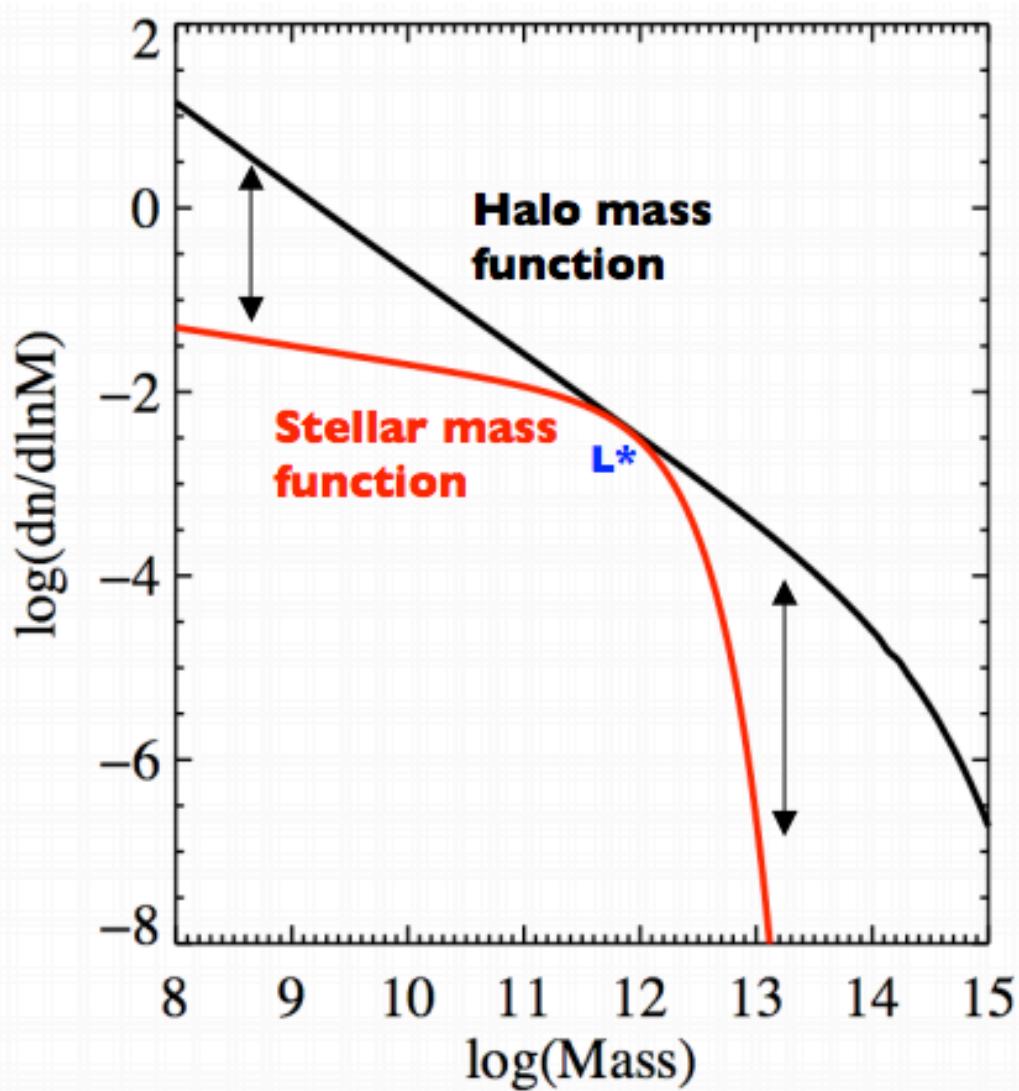
KENNICUT+98

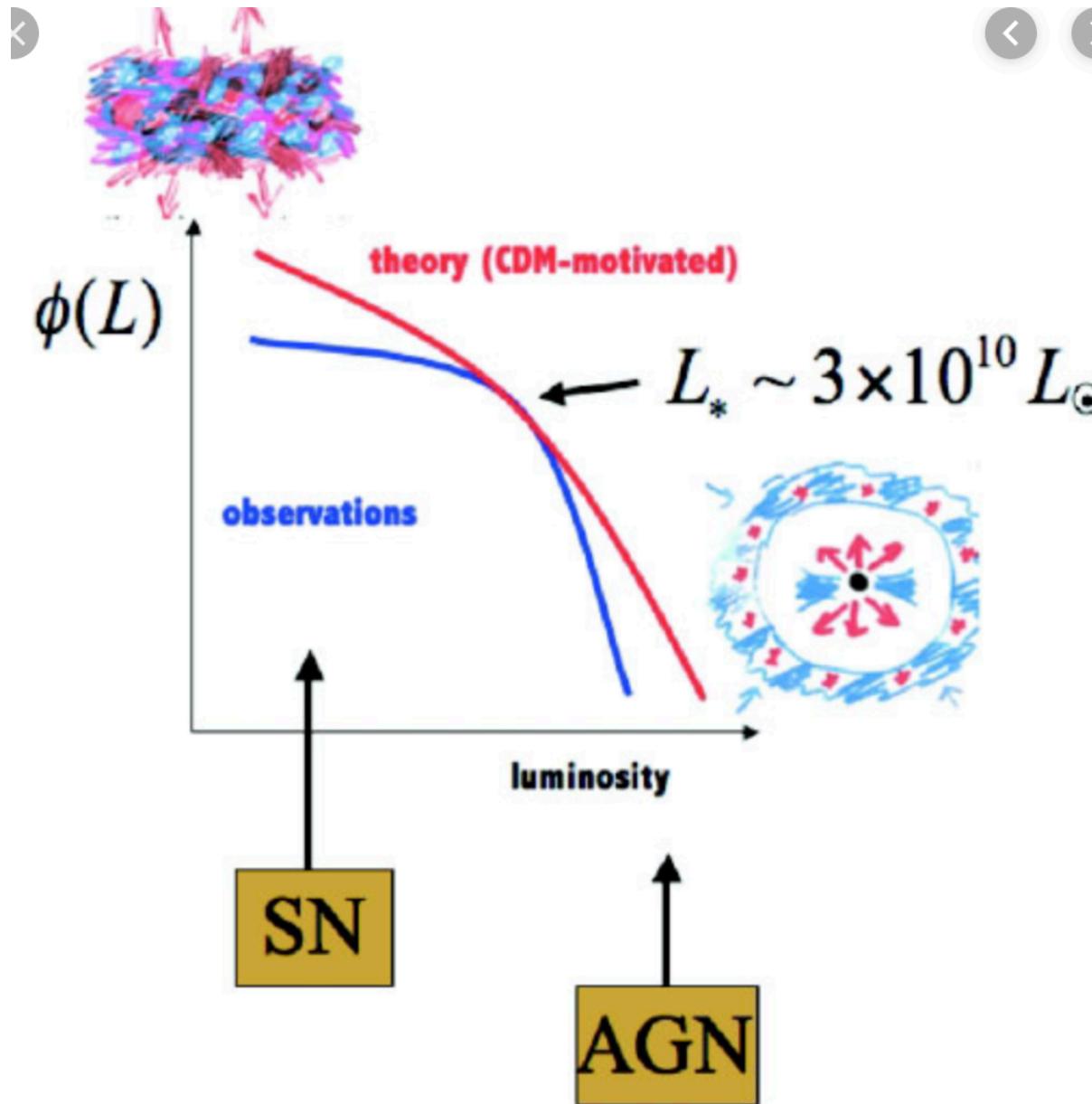
- 5. FEEDBACK

**SUPERNOVAE / STELLAR WINDS —> OUTFLOW OF HOT, METAL ENRICHED GAS
[DEKEL&SILK]**

WINDS CAUSED BY SUPER MASSIVE BLACK HOLES [AGNs]

WHY DO WE NEED FEEDBACK?

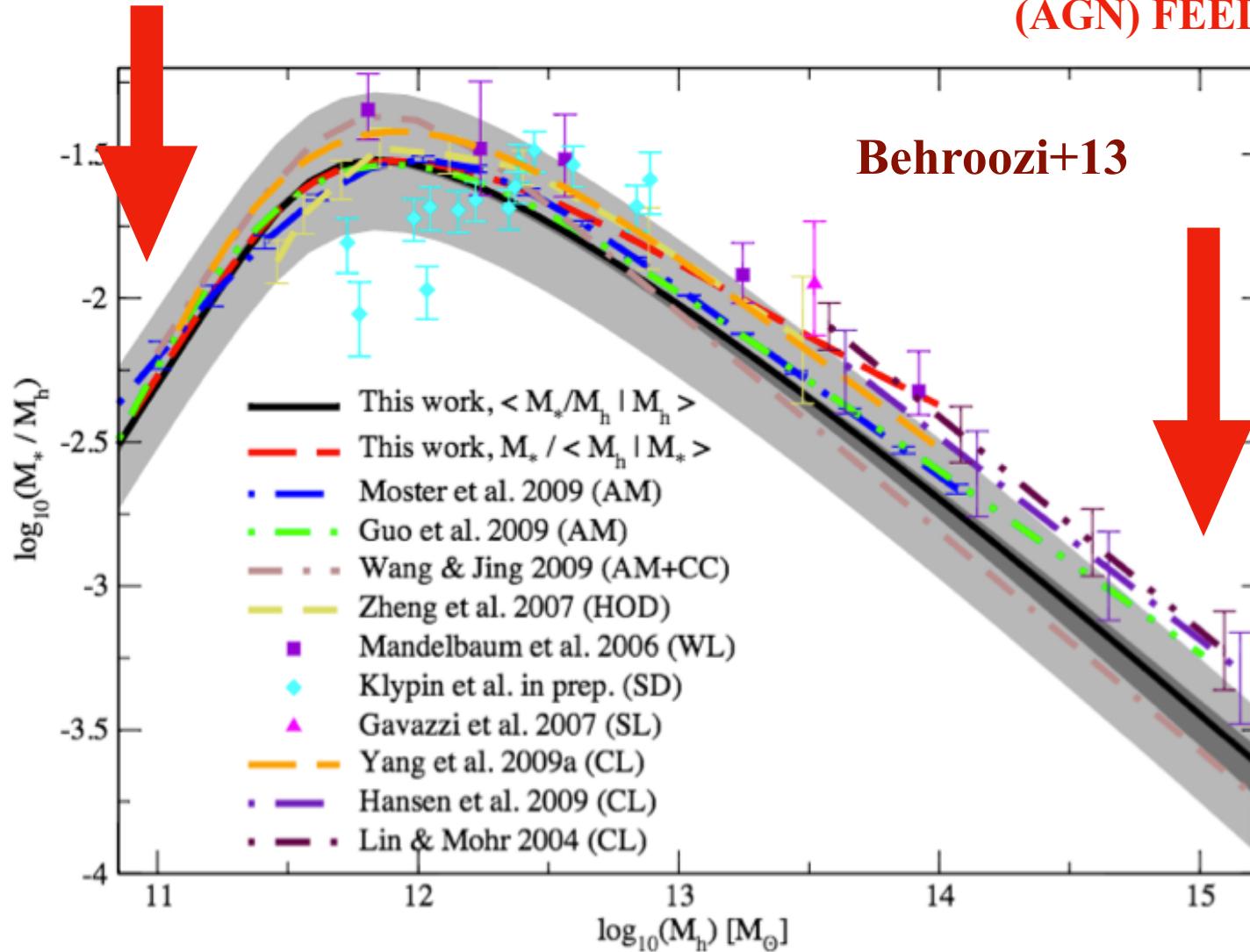




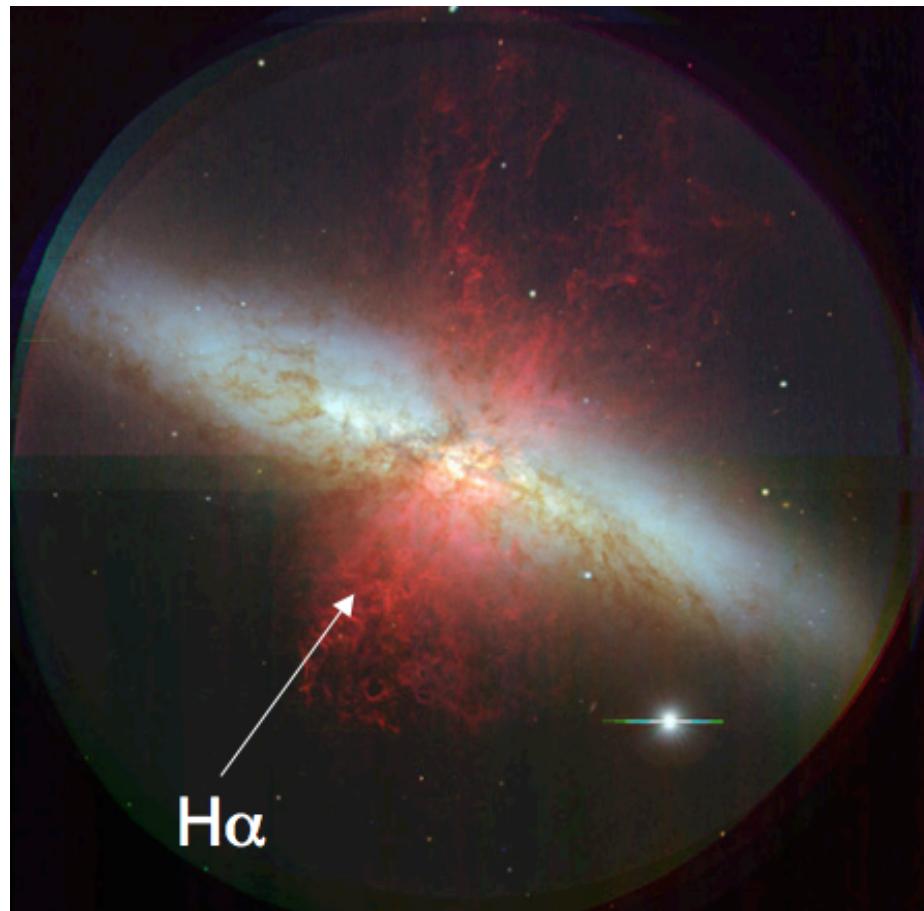
WHY DO WE NEED FEEDBACK?

SUPERNOVA FEEDBACK
(ENERGY INJECTED BY
EXPLOSION
OF MASSIVE STARS)

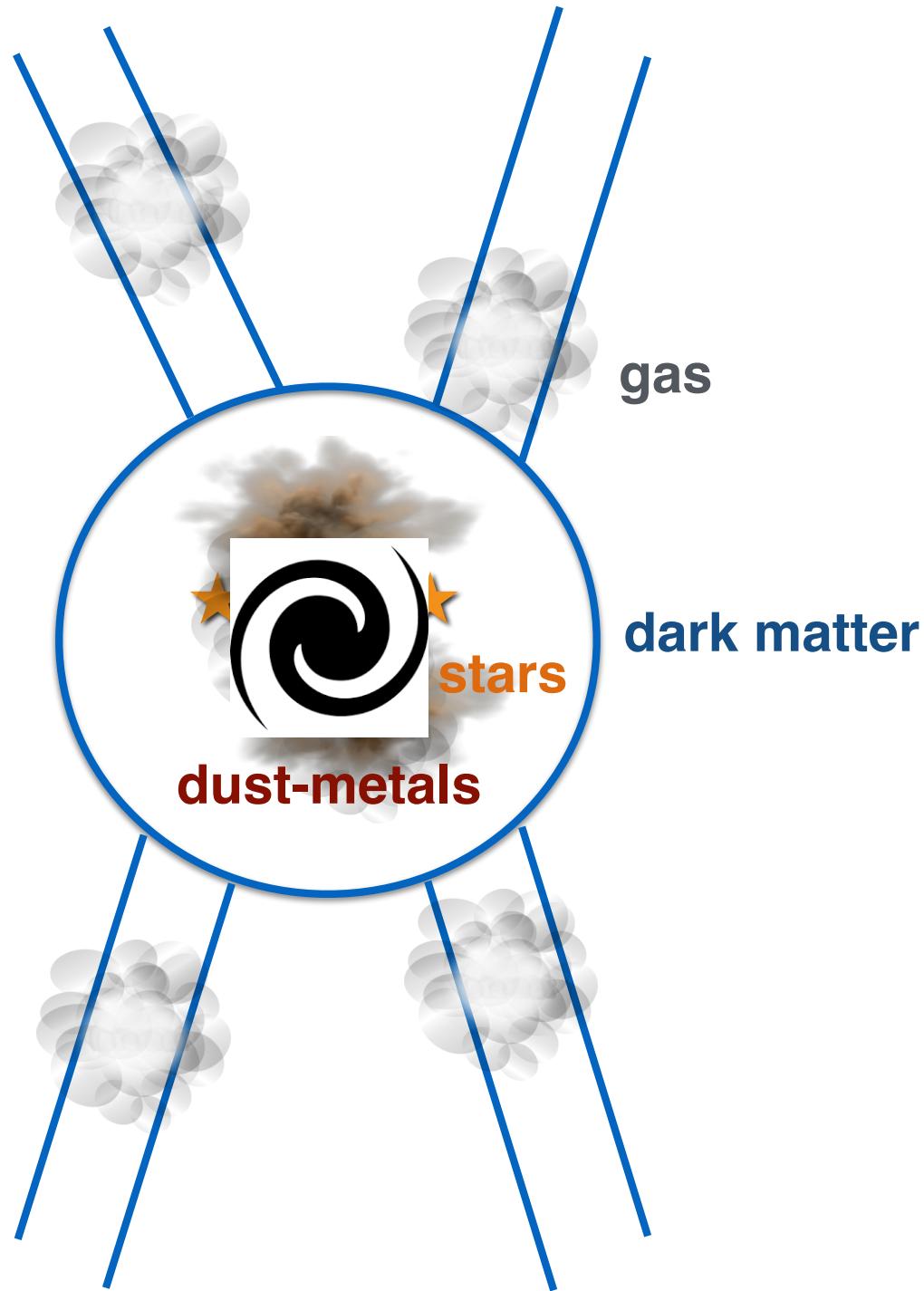
ACTIVE GALACTIC NUCLEI
(AGN) FEEDBACK



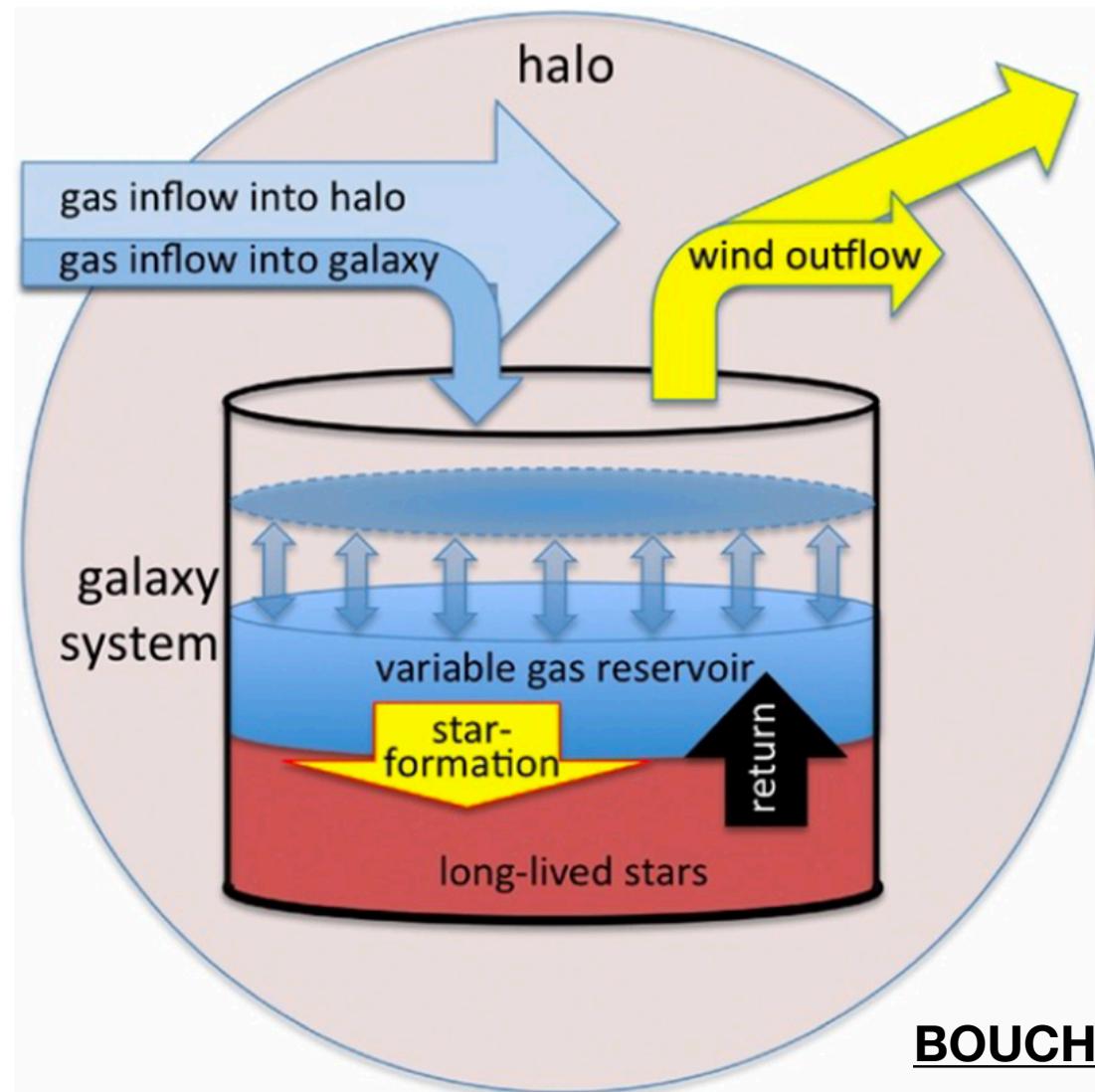
WE NEED MECHANISMS TO PREVENT THE GAS TO COOL....



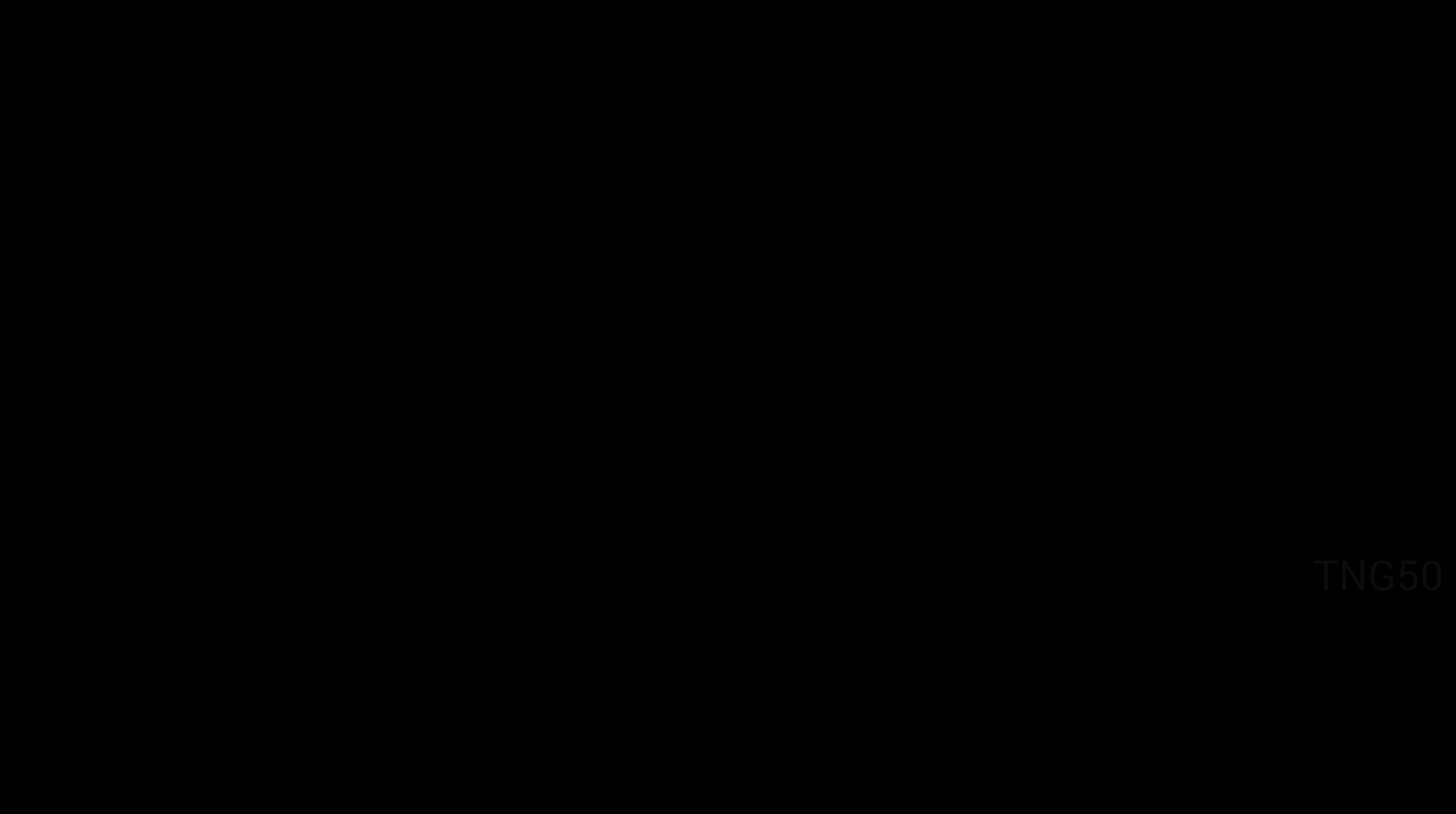
M82



THE BATHTUB MODEL OF GALAXY FORMATION

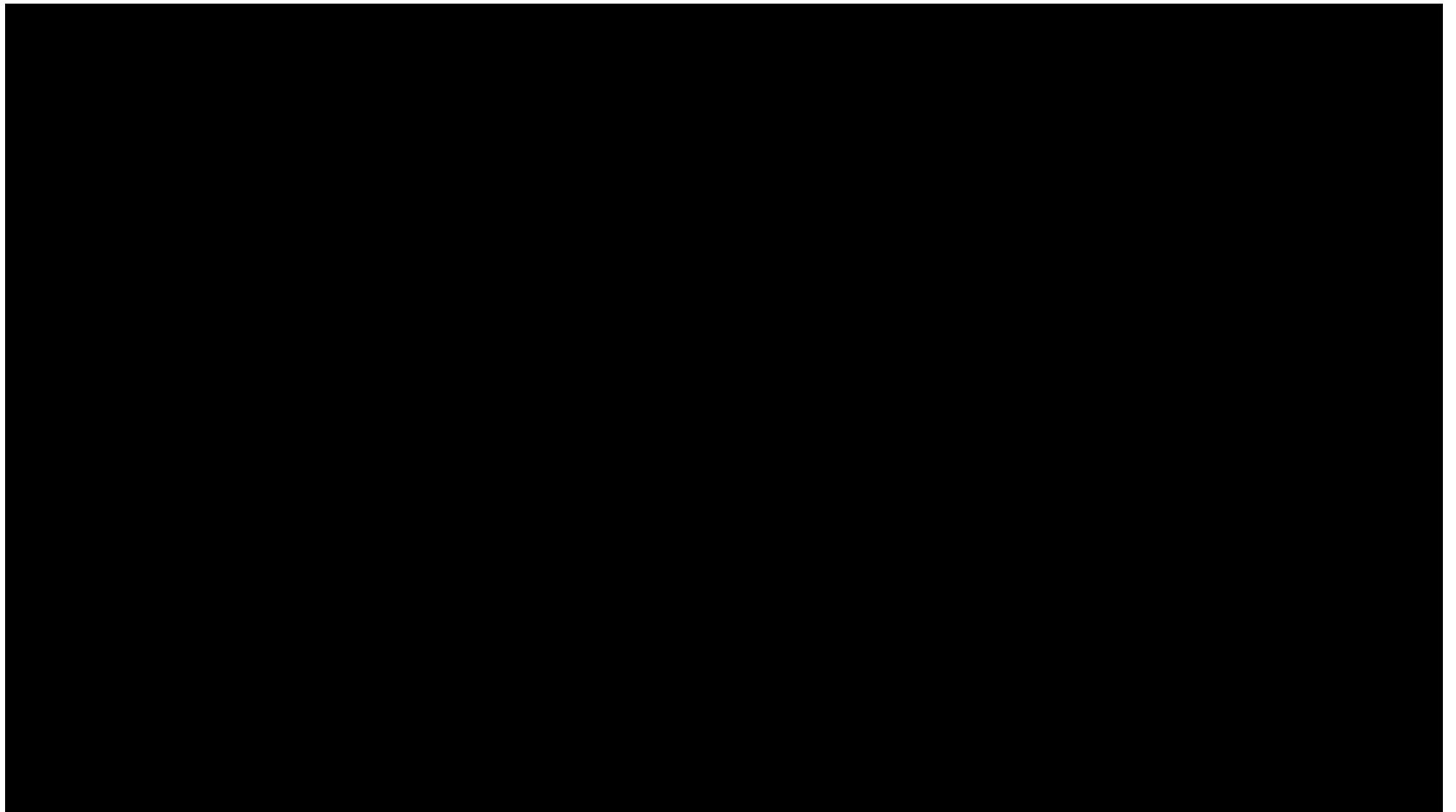


BOUCHE+, MAIOLINO+, LILLY+



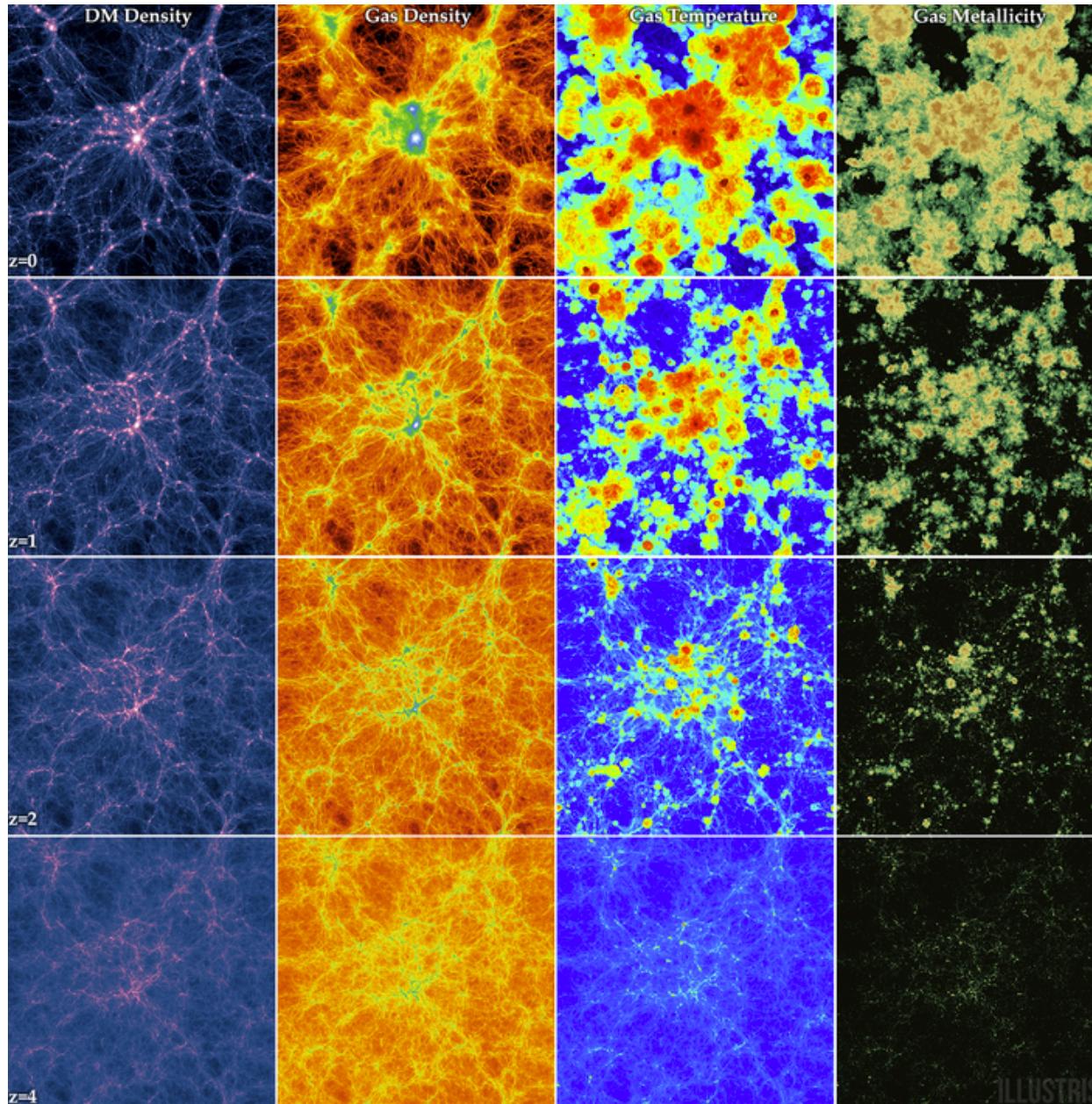
TNG50

[TNG50 simulation](#)



TNG100 simulation

DARK MATTER → GAS → STARS → METALS



Illustris Simulation (illustris-project.org)

TAKE AWAY...

- GALAXIES ARE BARYONIC RESIDUE IN CENTER OF DARK MATTER HALOS
- STARS + COLD GAS MASS FUNCTION DIFFERENT FROM DARK MATTER MASS FUNCTION
- MOST BARYONS ARE IN WARM MODE (NOT IN GALAXIES)
 - WHY? FEEDBACK...
- VIEWED FROM GLOBAL PROPERTIES...ASTONISHING REGULARITY BUT
- GALAXY FORMATION IS COMPLEX!