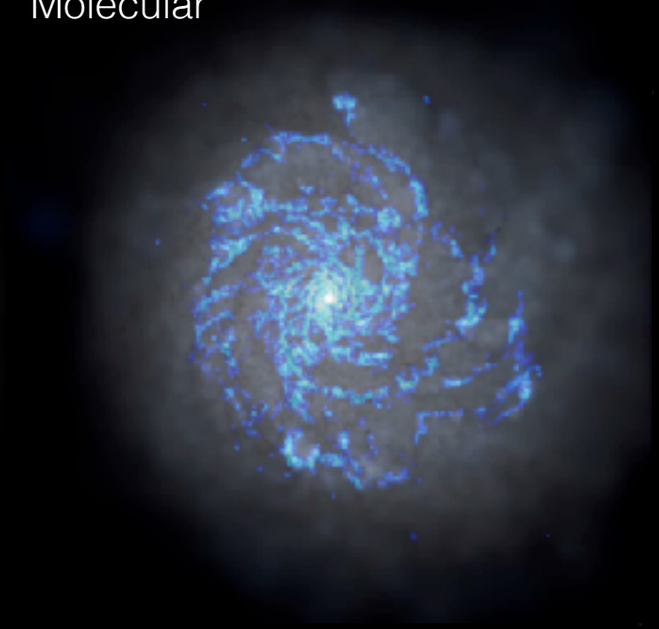
Failures No More: The Radical Effect of Stars on Galaxies

Observed Starlight

Molecular



Galaxy Merger

X-Rays

Star Formation

Phil Hopkins, Andrew Wetzel (Caltech) & the FIRE Team:

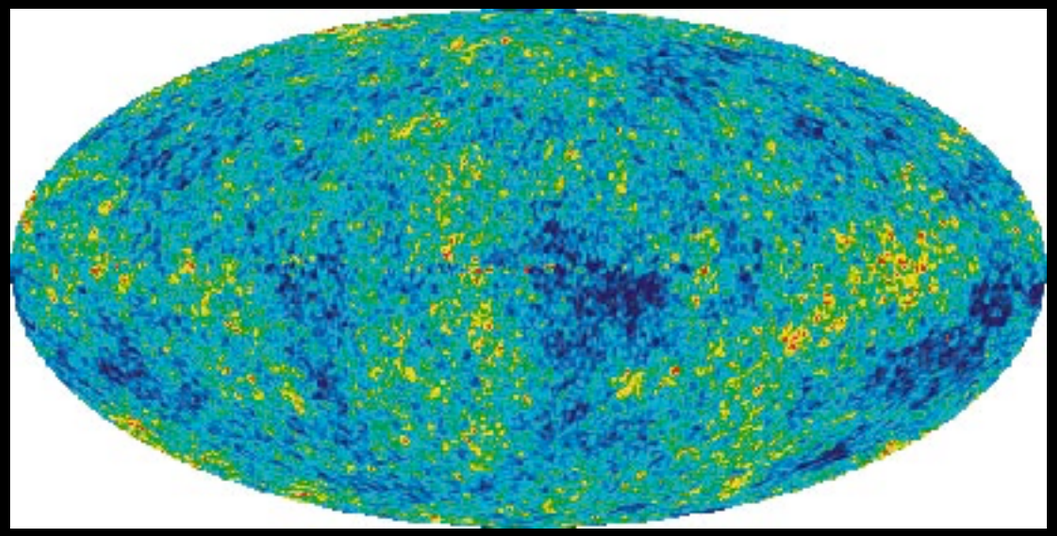
Dusan Keres, Eliot Quataert, James Bullock, Coral Wheeler, TK Chan,
Shea Garrison-Kimmel, Paul Torrey, Claude Faucher-Giguere, Xiangcheng Ma, Sasha Muratov

FIRE
Feedback In Realistic Environments

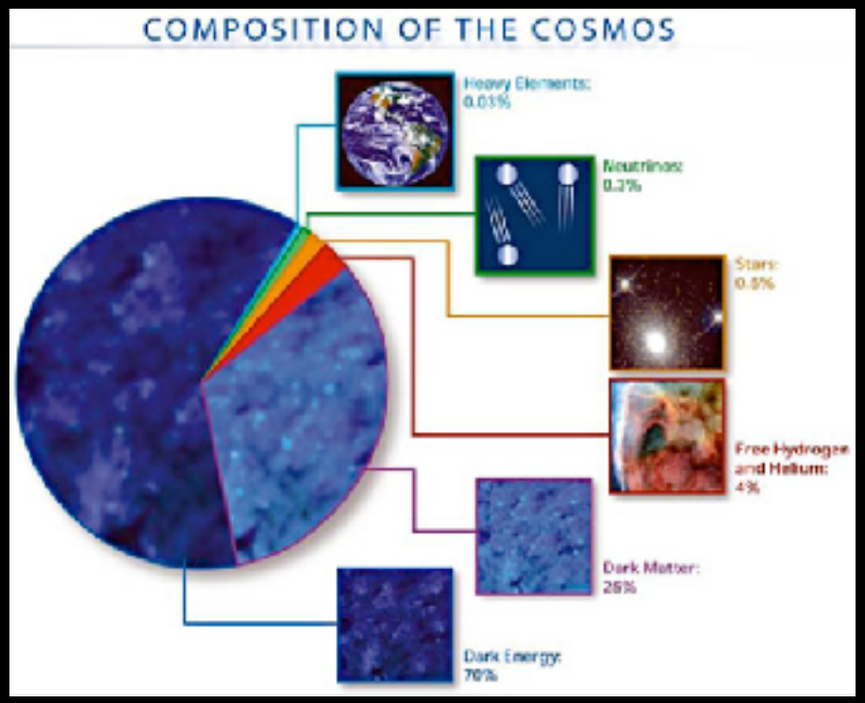
The Big Question:

HOW DO WE GO FROM BIG BANG TO MILKY WAY?

Today



?



z~1090
(t~400,000 yr)

The Big Question:

HOW DO WE GO FROM BIG BANG TO MILKY WAY?

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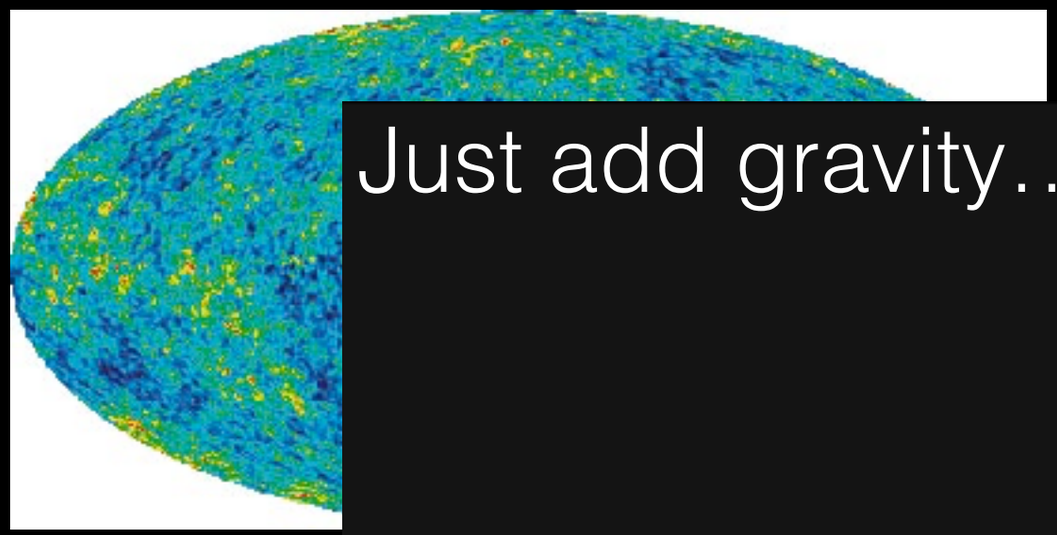
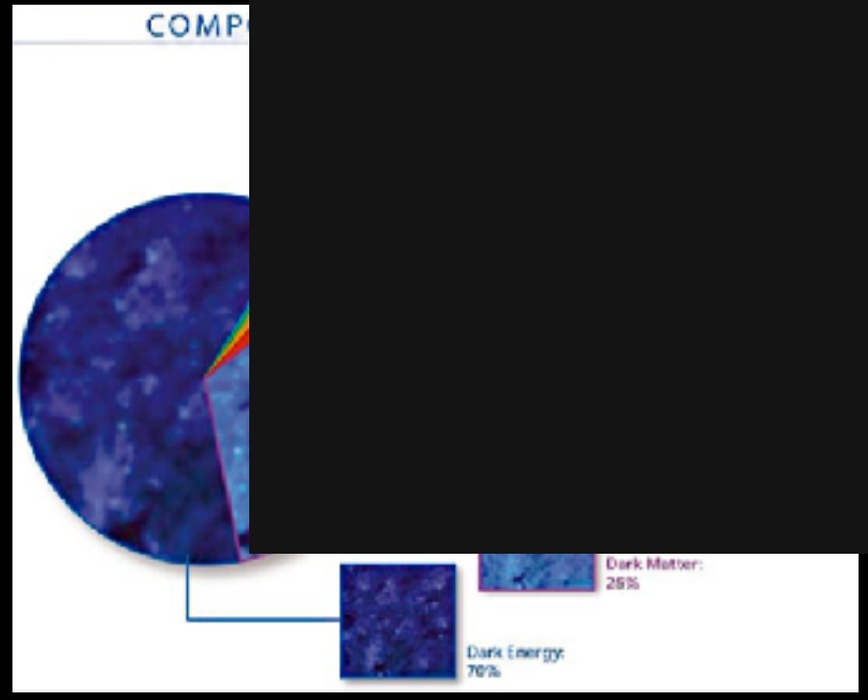


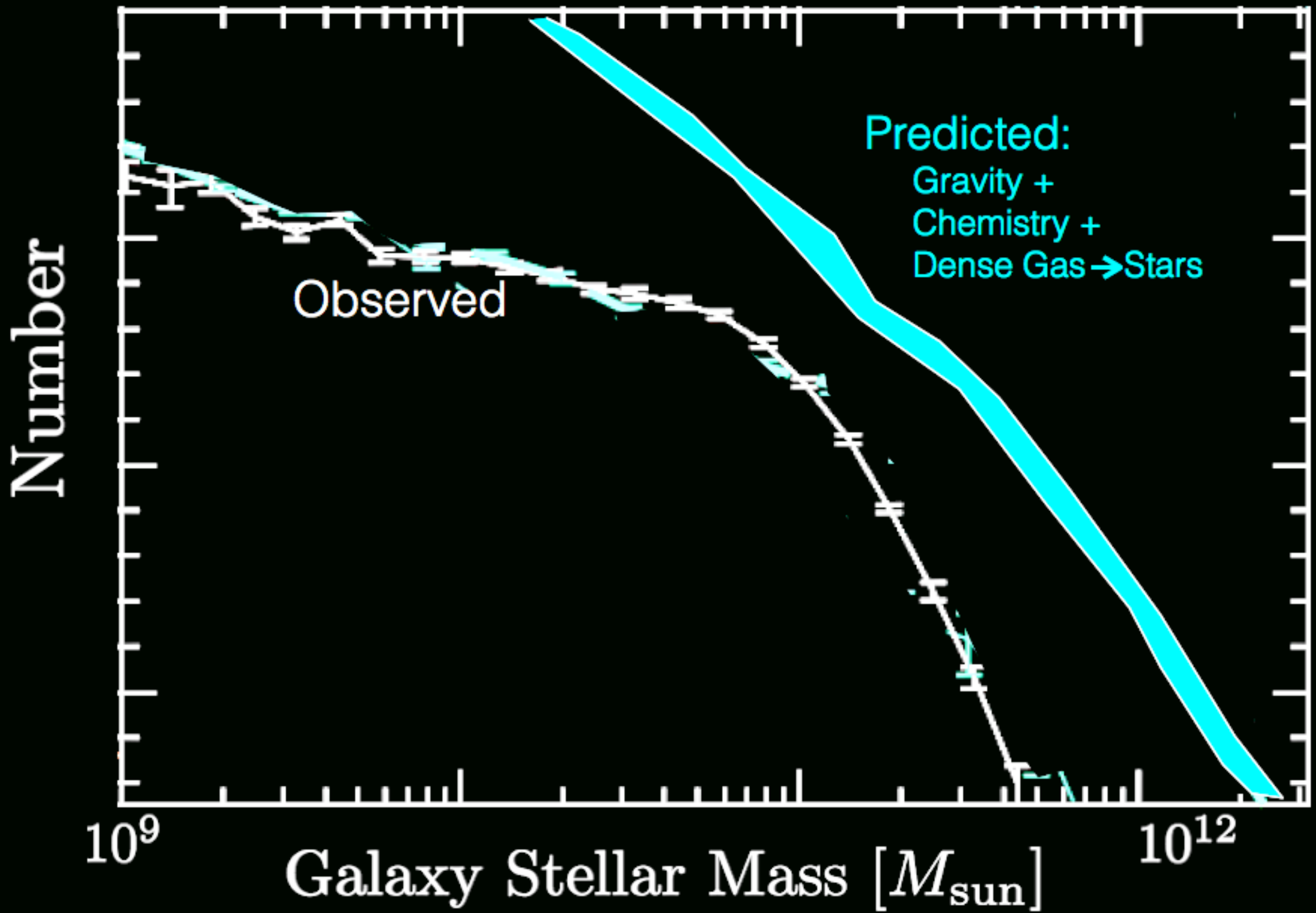
Just add gravity…



z~1090
(t~400,000 yr)

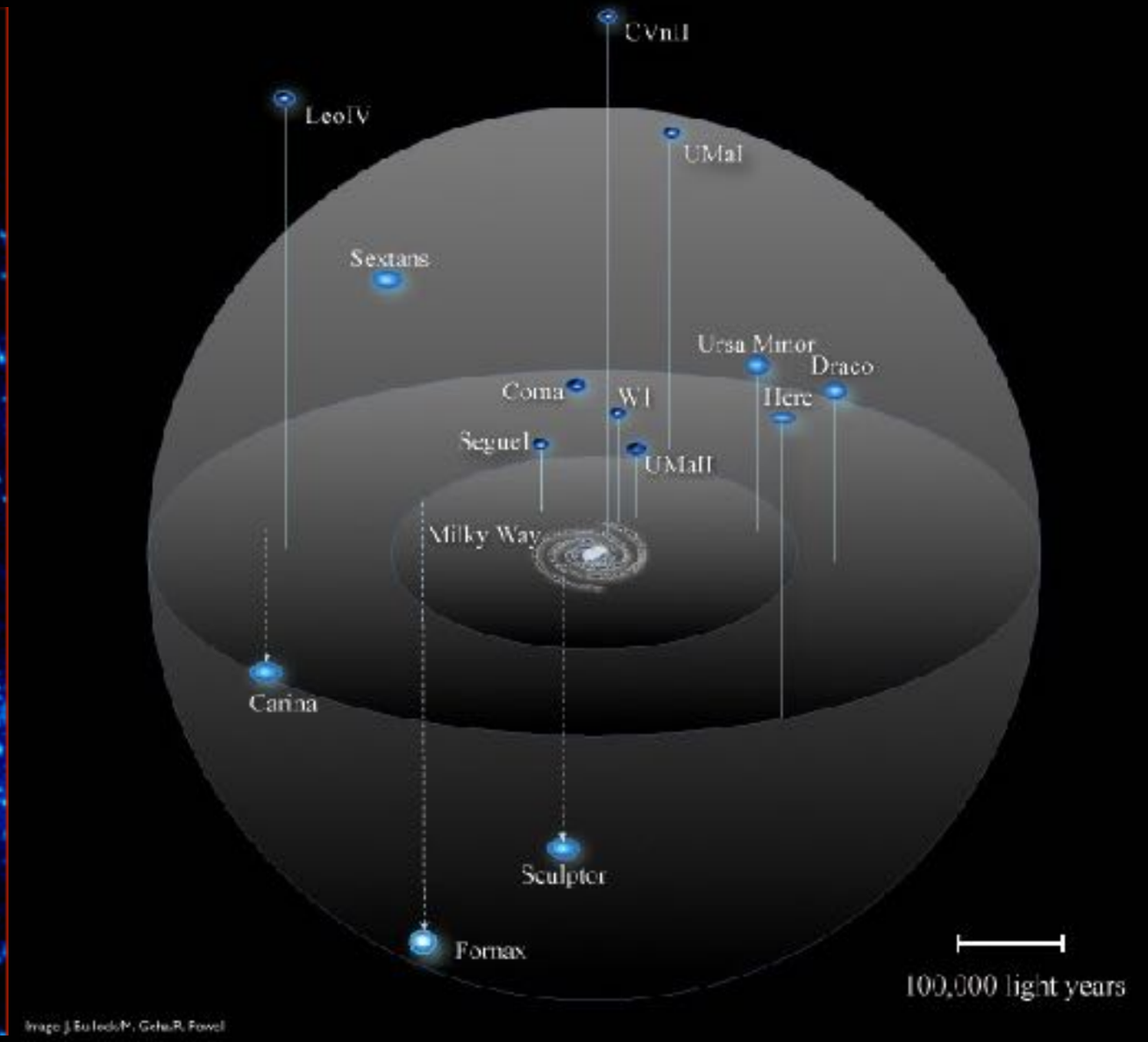
Problem:

WHY SO FEW GALAXIES & STARS?



Problem:
WHERE ARE THE "MISSING SATELLITES"?

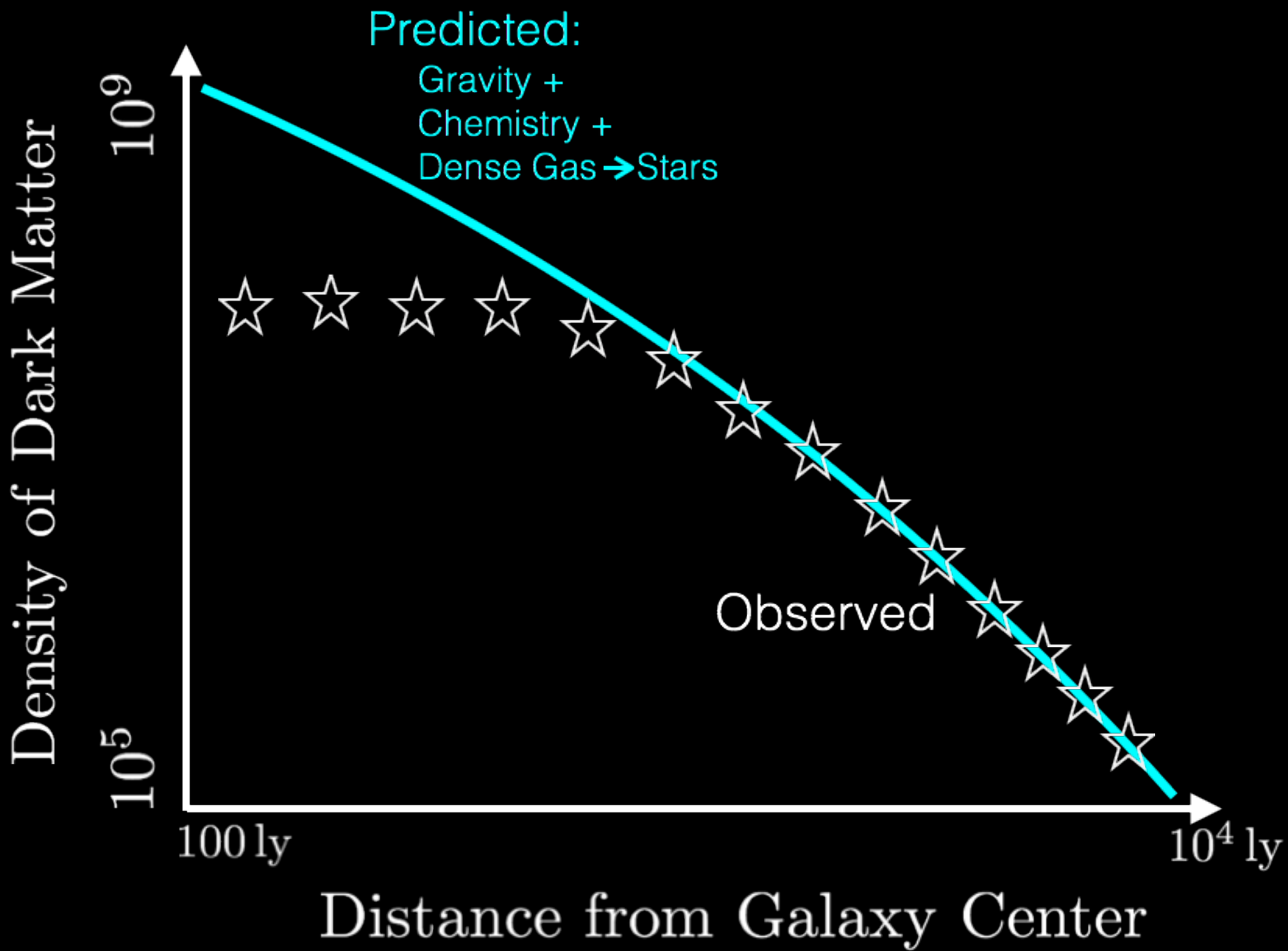
Predicted structure
(dark matter)



Observed
around us

Problem:

WHY ISN'T THERE MORE DARK MATTER?
("CUSP-CORE" or "TOO BIG TO FAIL")

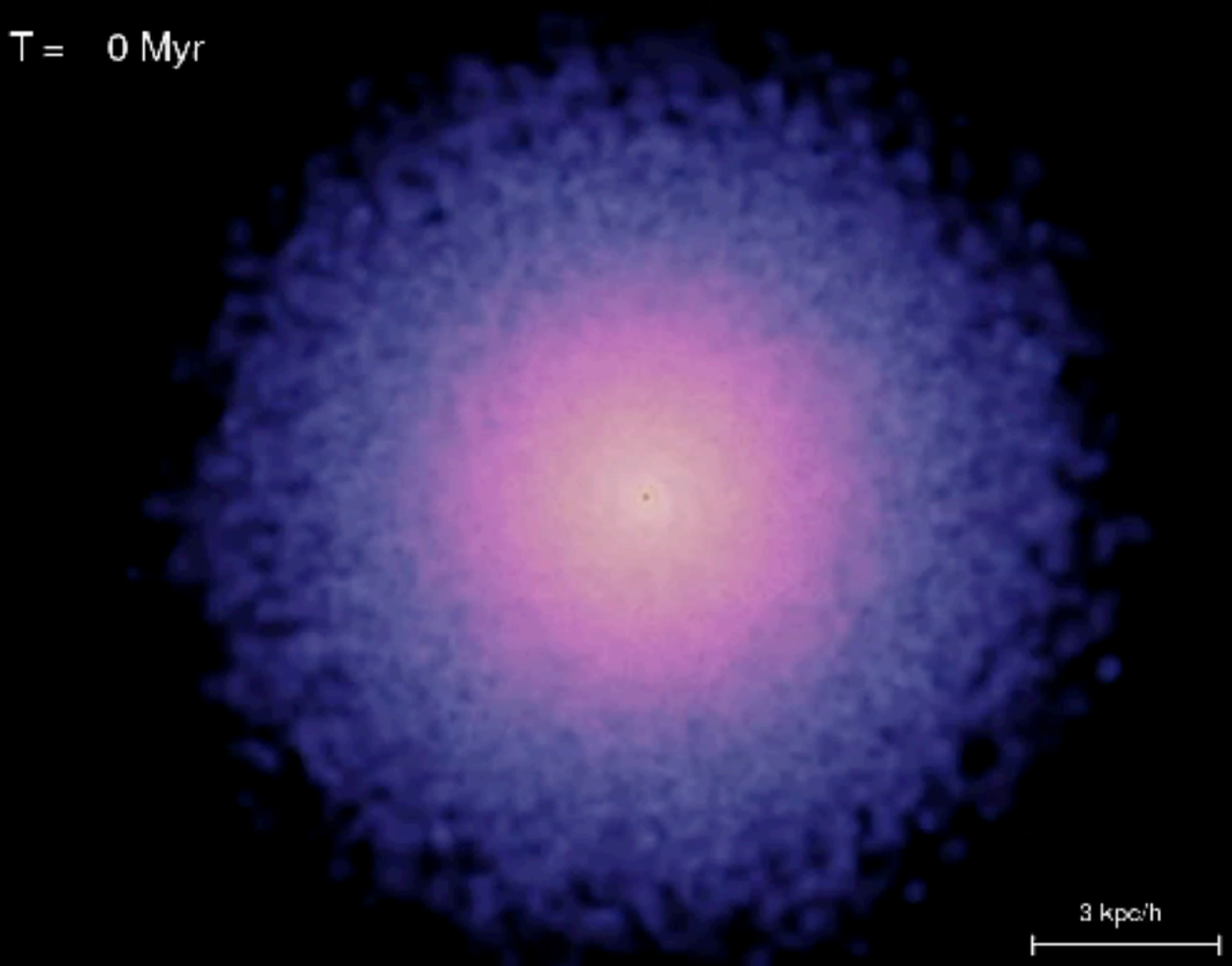


Stars Matter

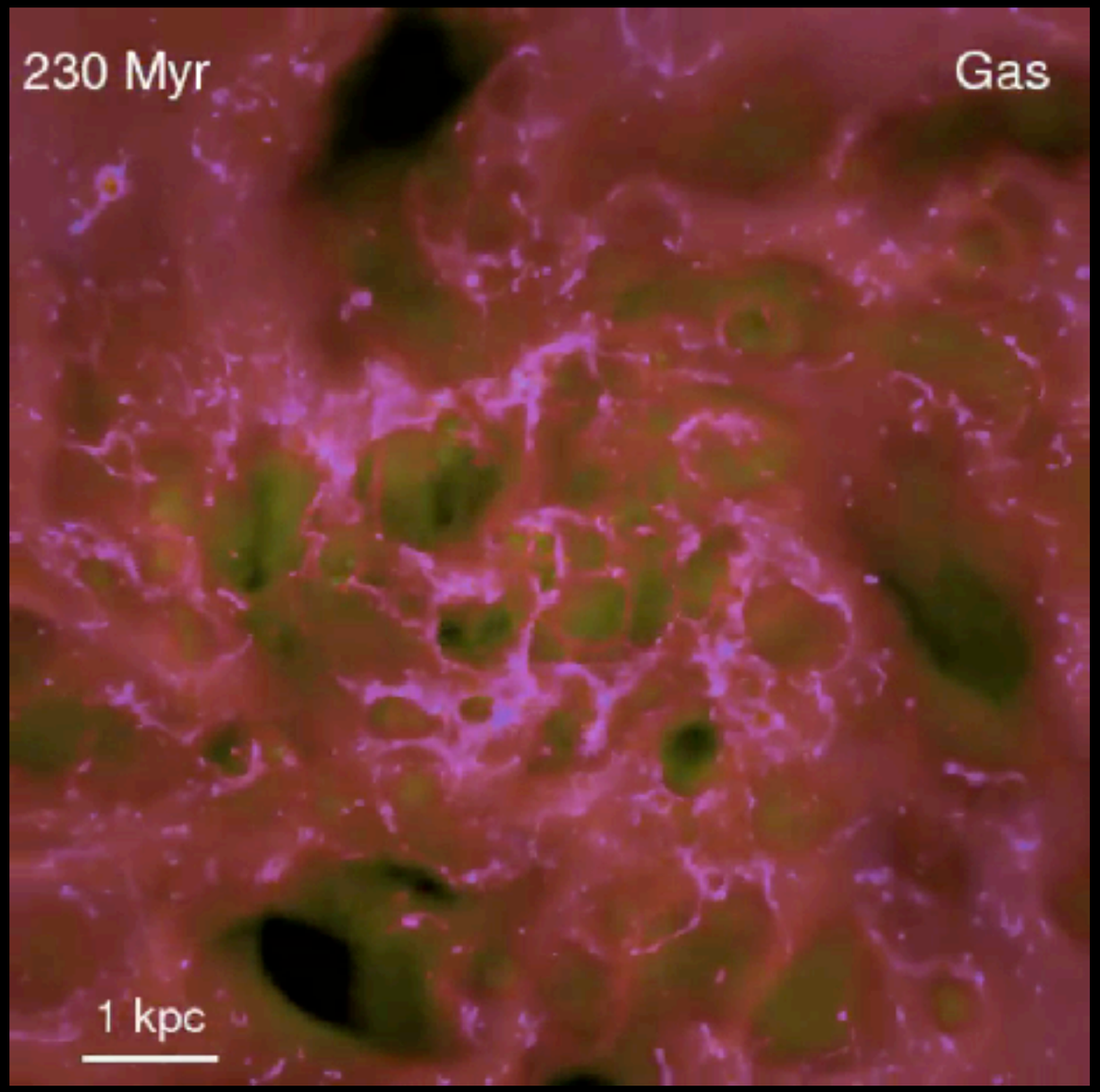
Stars Matter

NEED PHYSICS AND RESOLUTION TO MODEL THEM

Previous State-of-the-Art



Resolved Inter-Stellar Medium in FIRE



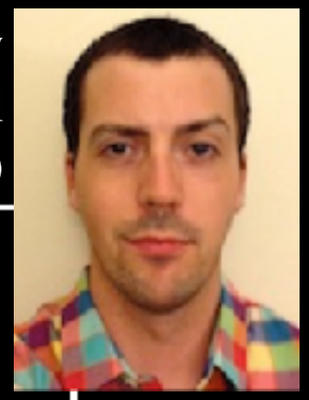
Yellow: hot (>10^6 K) **Pink: warm (ionized, ~10^4K)** **Blue: cold (neutral <10^4 K)**

- Supernovae
- Stellar Winds
- Radiation

The Future is Now

NEW PHYSICS AT NEW SCALES

Andrew Wetzel (arXiv:1602.05957)



Spatial Resolution [pc]

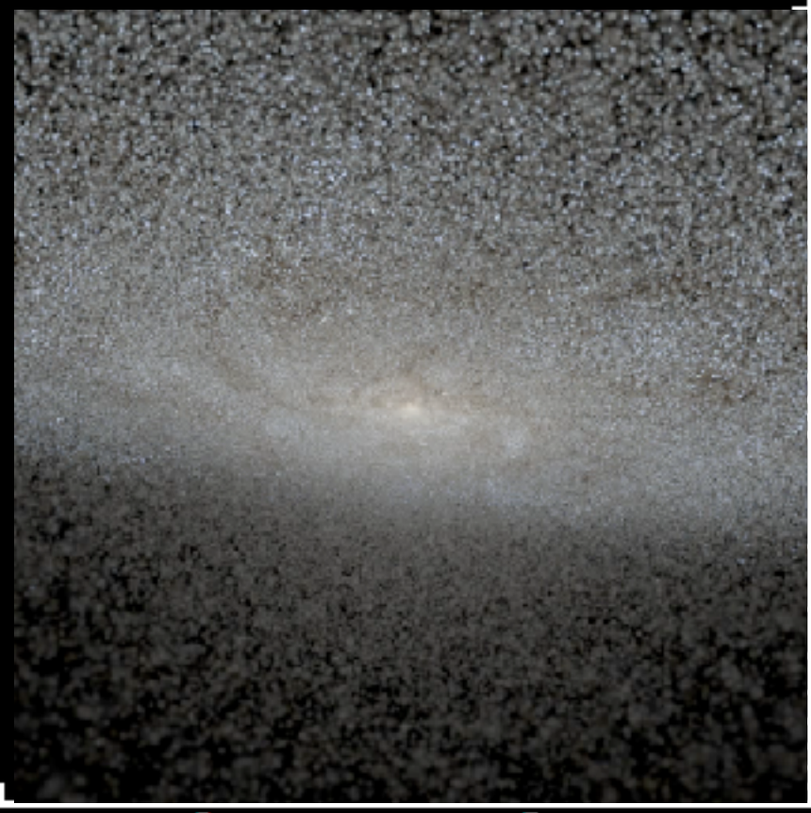
0.1
1
10
100
1000

Triple Latte

Latte (Milky Way on FIRE)

FIRE

Garrotxa
Agertz
Sawala
Eris
CLUES
Mollitor
MAGICC
GASOLINE
Nihao
Aquarius (AREPO)
Massive Black-II
Eagle
Illustris



10^7 10^6 10^5 10^4 10^3 10^2 10^1

Mass Resolution $[M_{\rm sun}]$

The Future is Now

NEW PHYSICS AT NEW SCALES

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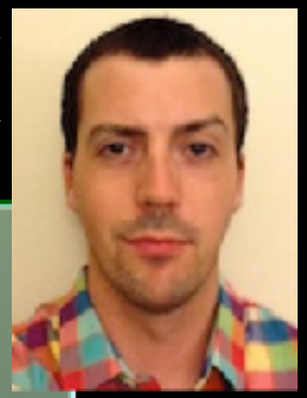


Cusp-core Problem

Triple Latte

Latte (Milky Way on FIRE)

SNe Cooling

FIRE

Molecular Clouds

Ultra-faint Dwarfs

Garrotxa

Agertz

Sawala

Eris

CLUES

Mollitor

MAGICC

GASOLINE

Nihao

Aquarius (AREPO)

Massive Black-II

Eagle

Illustris

0.1

1

10

100

1000

Spatial Resolution [pc]

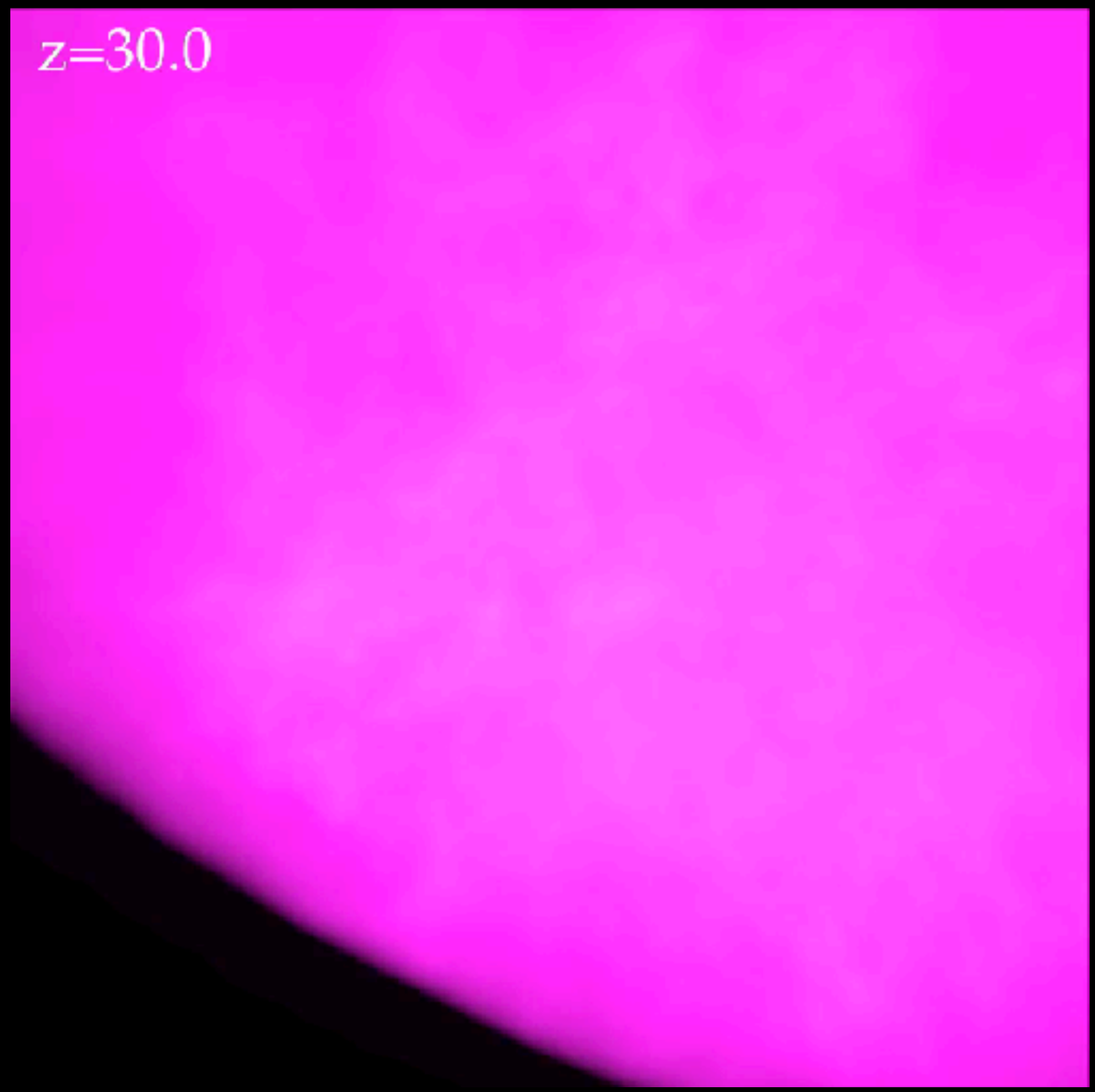
10^7 10^6 10^5 10^4 10^3 10^2 10^1

Mass Resolution [$M_{\rm sun}$]

(movies at fire.northwestern.edu)

z=30.0

10 kpc



Stars (Hubble image):

Blue: Young star clusters

Red: Dust extinction

Gas: Magenta: cold $(< 10^4\,K)$

Green: warm (ionized)

Red: hot $(> 10^6\,K)$

It Works!

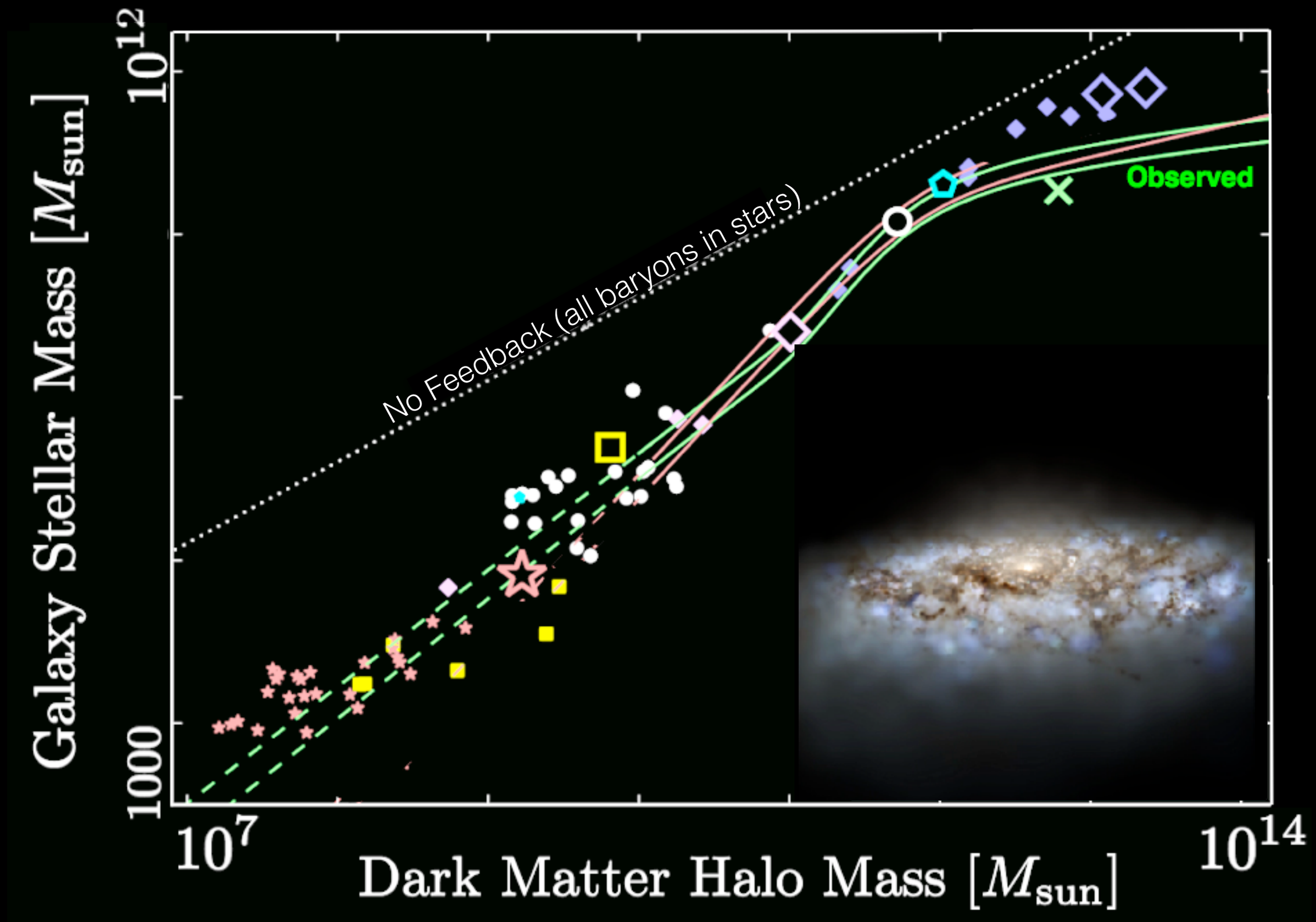
- Resolution ~pc , 100-10^4 M_{sun}
  Cooling ~10-10^{10} K
  SF in self-gravitating gas, $n_H > 1000$

- Feedback:
  - SNe (II & Ia)
  - Stellar Winds (O & AGB)
  - Photoionization (HII regions) & Photo-electric (dust)
  - Radiation Pressure (IR & UV)

Why Are Galaxies Such Lightweights?

GAS IS BLOWN OUT, INSTEAD OF TURNING INTO STARS

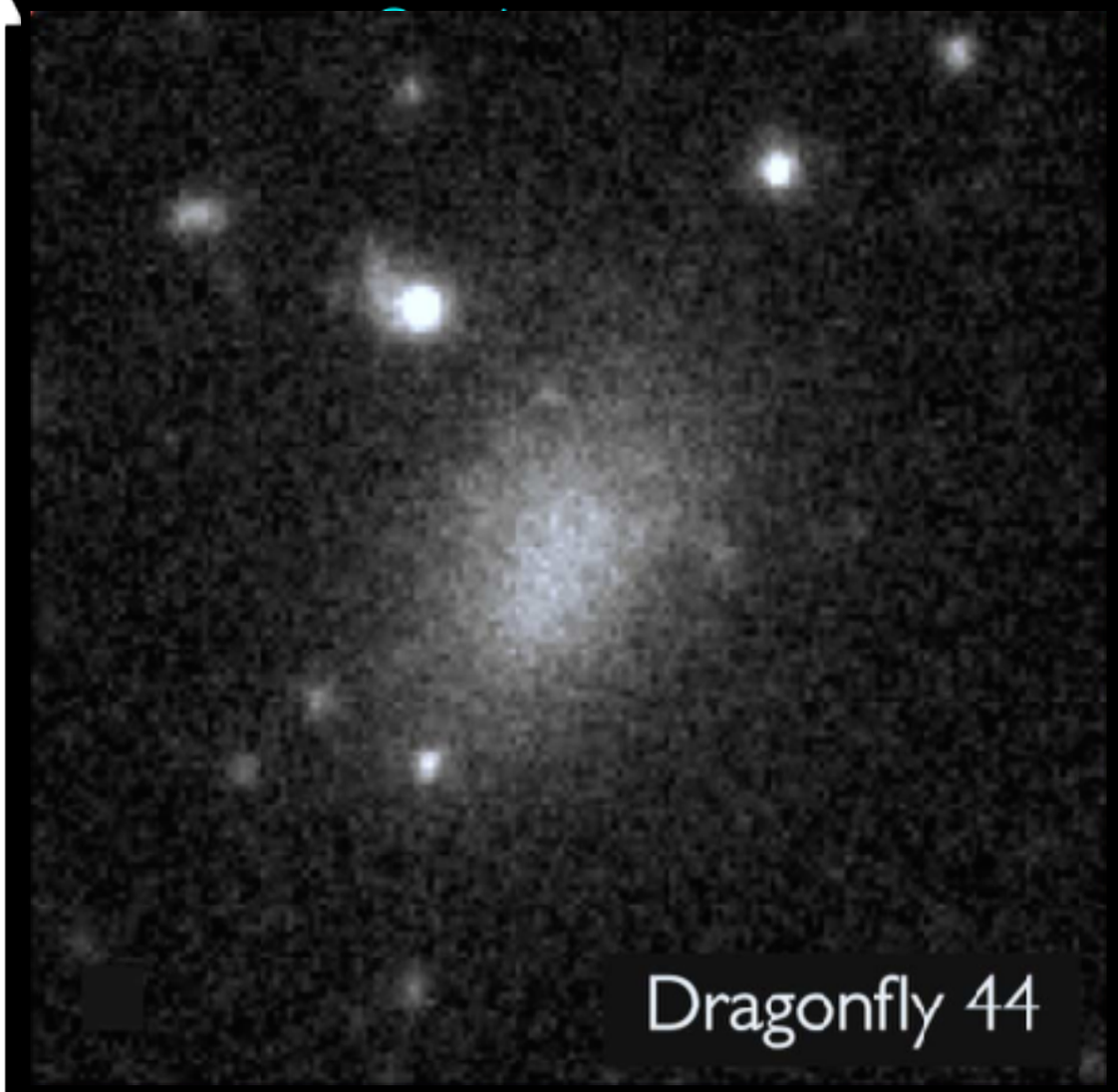
PFH et al.
(arXiv:1311.2073)



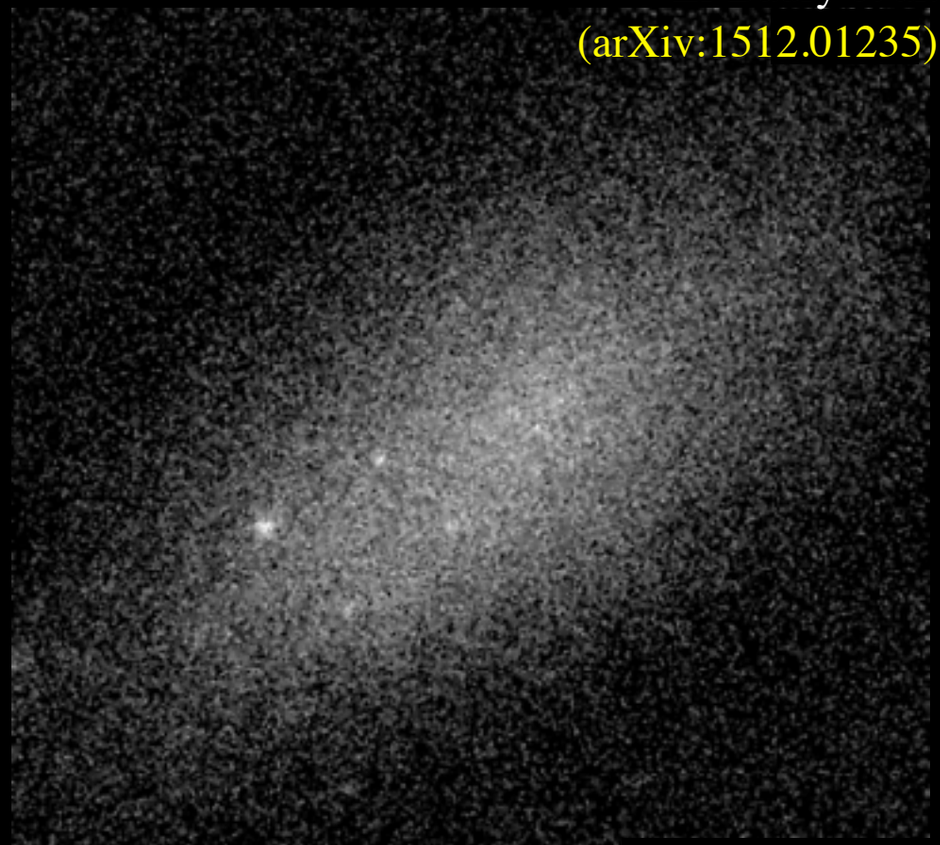
Feedback Saves Cold Dark Matter?

NO EXOTIC PHYSICS NECESSARY

Predicted:



El-Badry et al.
(arXiv:1512.01235)



Density of Dark Matter

10^9

10^5

100 ly

10^4 ly

Distance from Galaxy Center

Onorbe et al.
(arXiv:1502.02036)
Chan et al.
(arXiv:1507.02282)
El-Badry et al.
(arXiv:1512.01235)

Failures No More

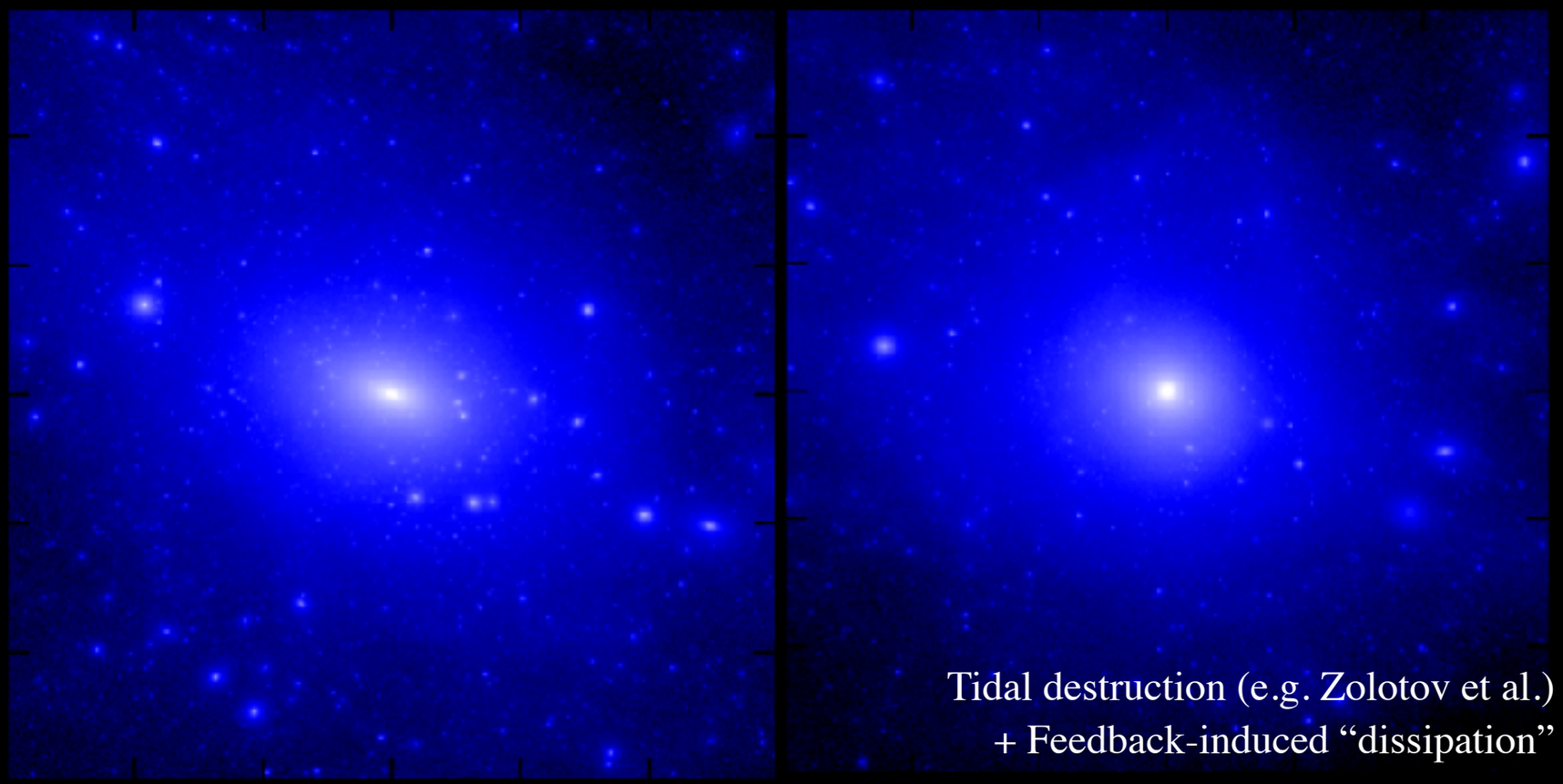
FEEDBACK EXPLAINS WHY SATELLITES ARE “MISSING”

Andrew
Wetzel
(arXiv:1602.05957)

Dark matter only simulation
(dark matter)

+ baryons & feedback
(dark matter)

+ baryons & feedback
(stars)



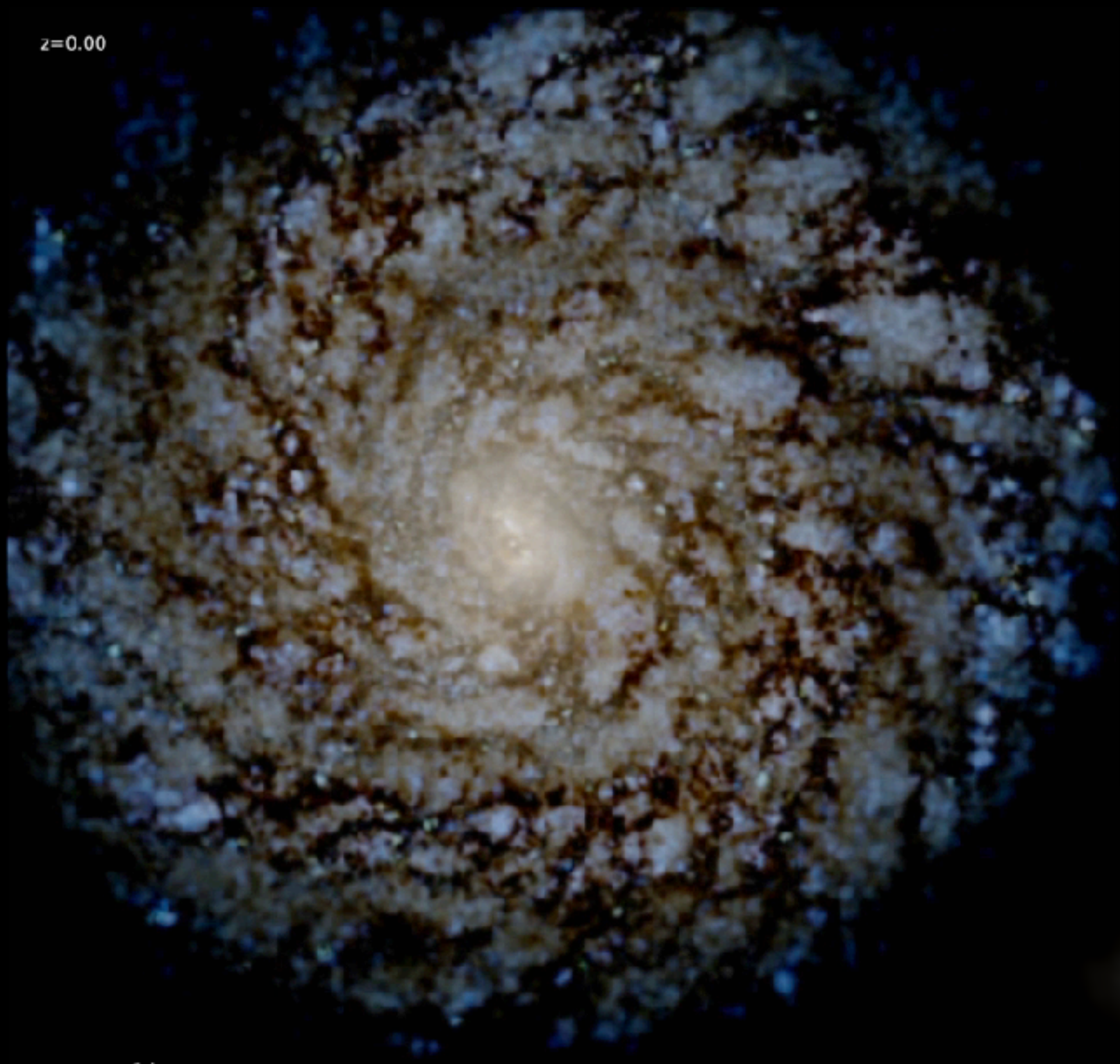
Tidal destruction (e.g. Zolotov et al.)
+ Feedback-induced “dissipation”

600 kpc

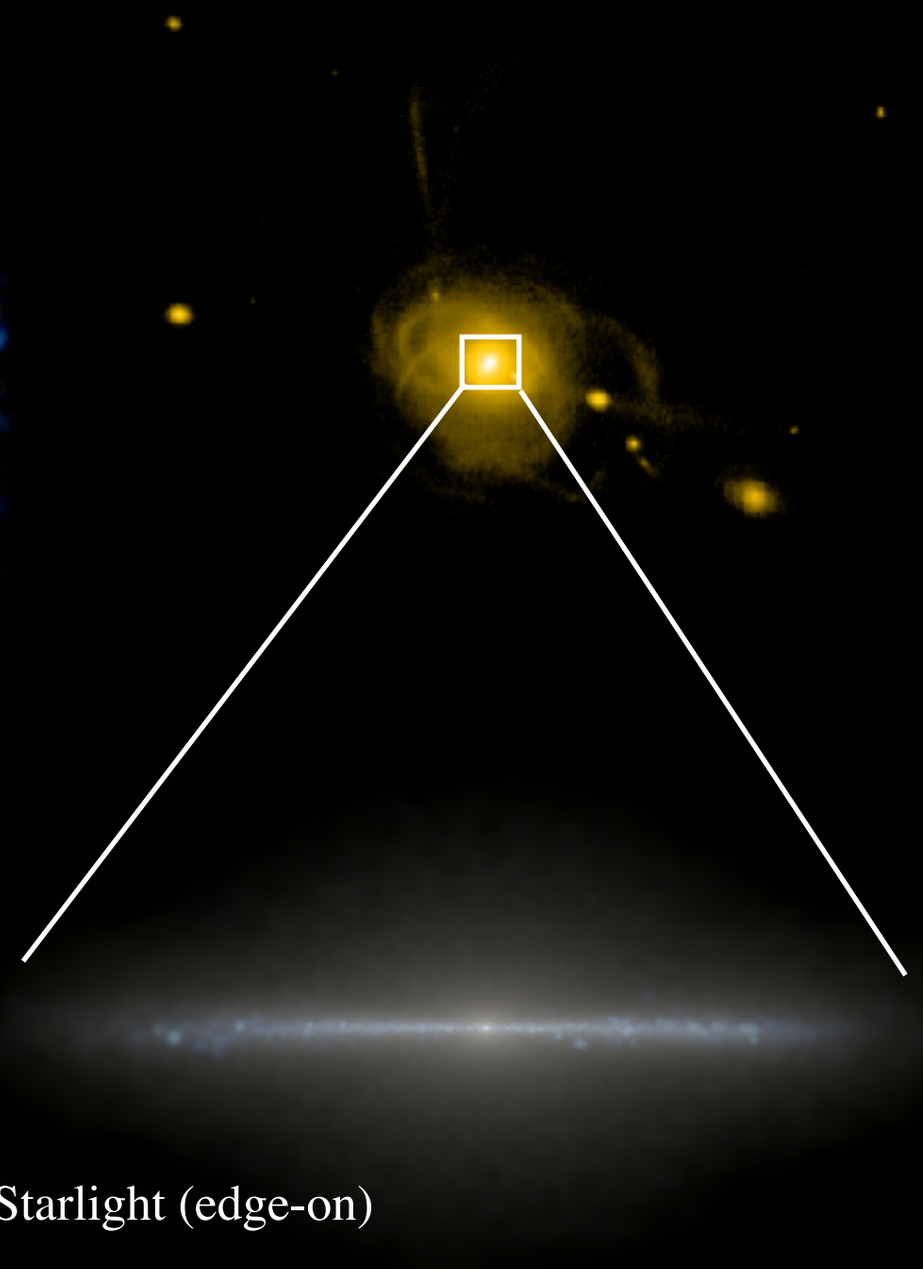
Failures No More

THIN GALAXY DISKS EMERGE NATURALLY

Garrison-Kimmel et al., in prep



+ baryons & feedback (stars)

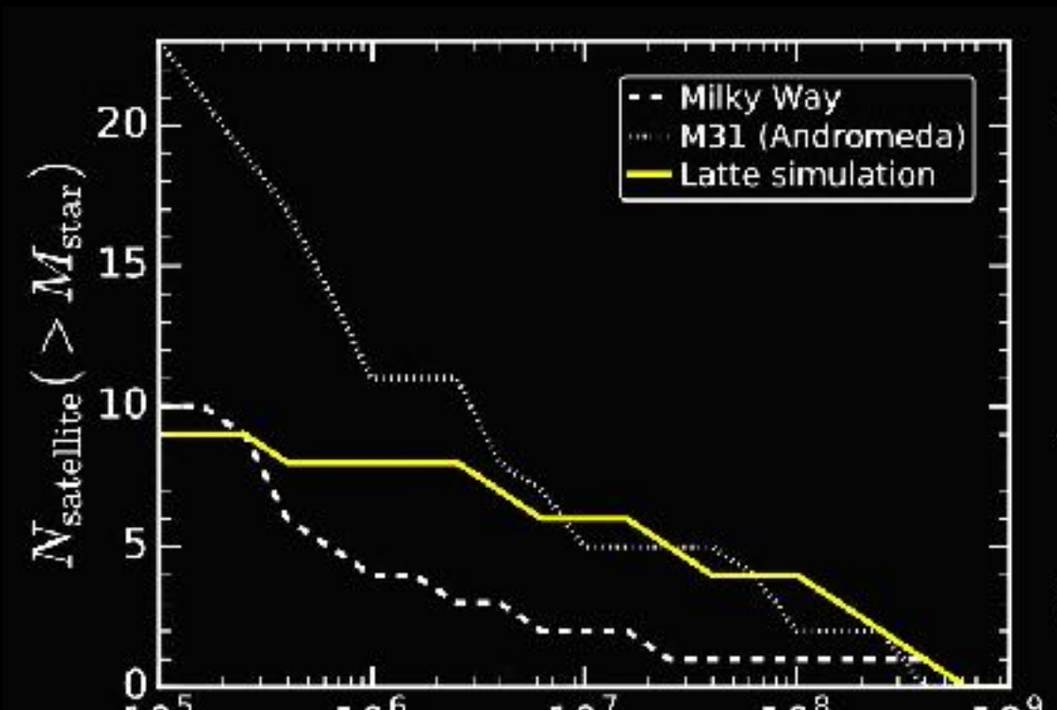


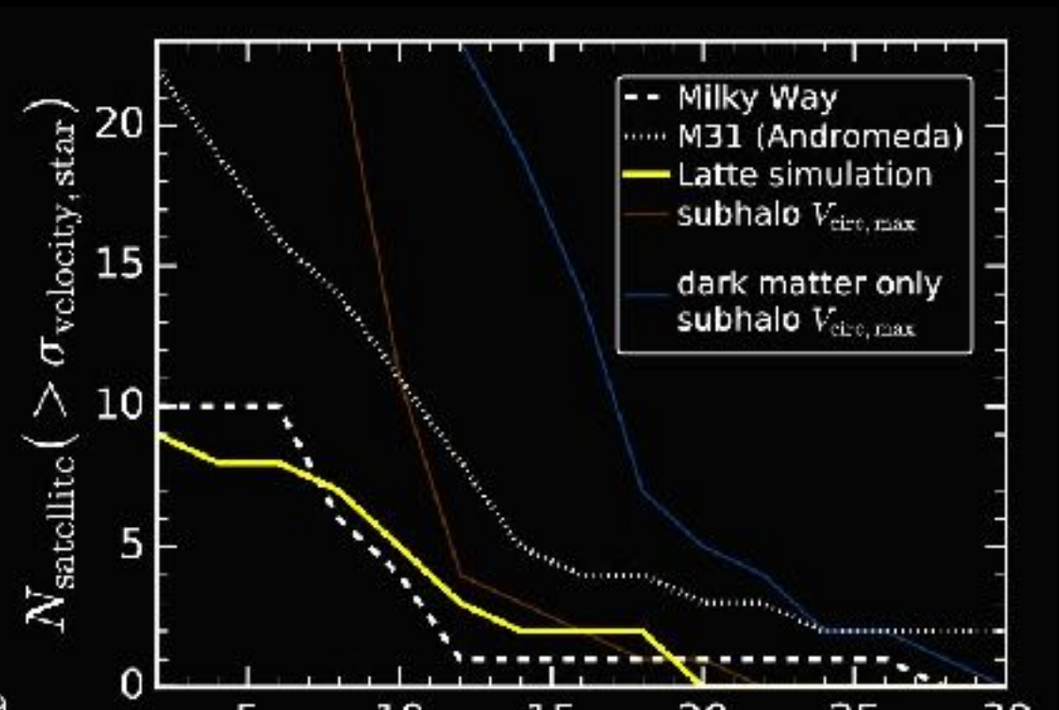
Starlight (edge-on)

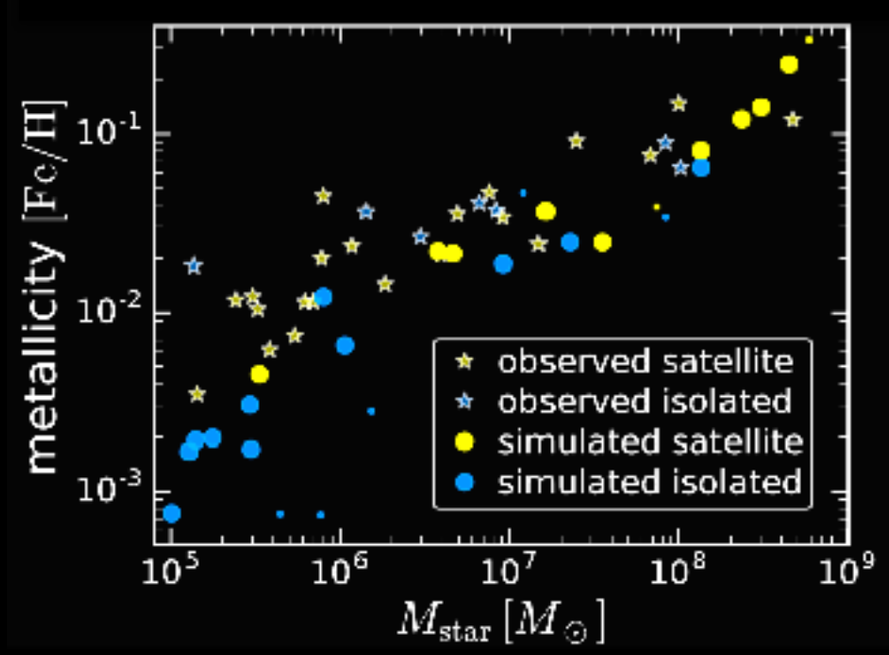
Failures No More

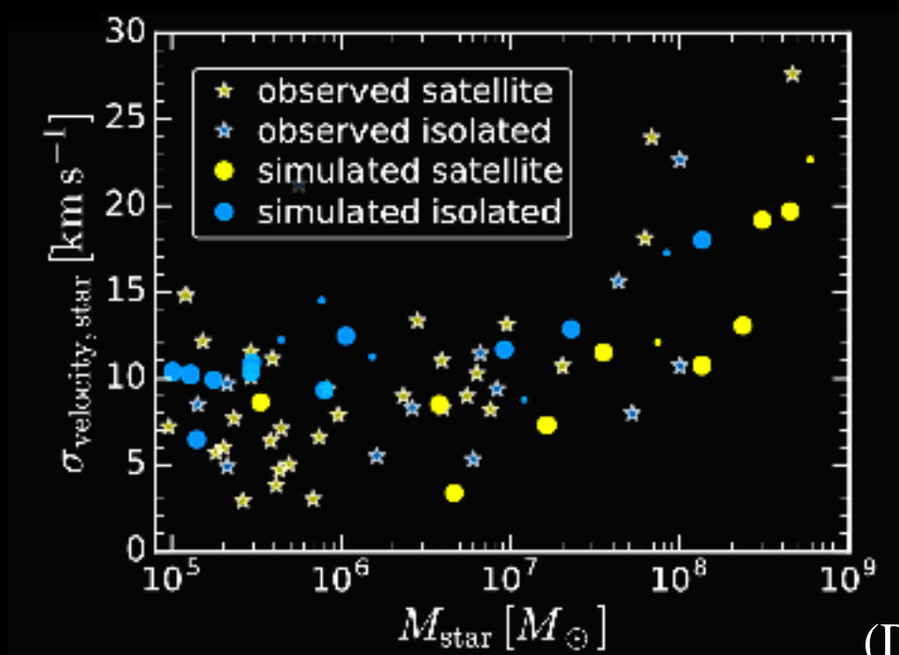
FEEDBACK SUPPRESSES STAR FORMATION AND DENSITIES

Andrew Wetzel (arXiv:1602.05957)









+ Escala (prep)
(Detailed abundance & SFH comparisons)