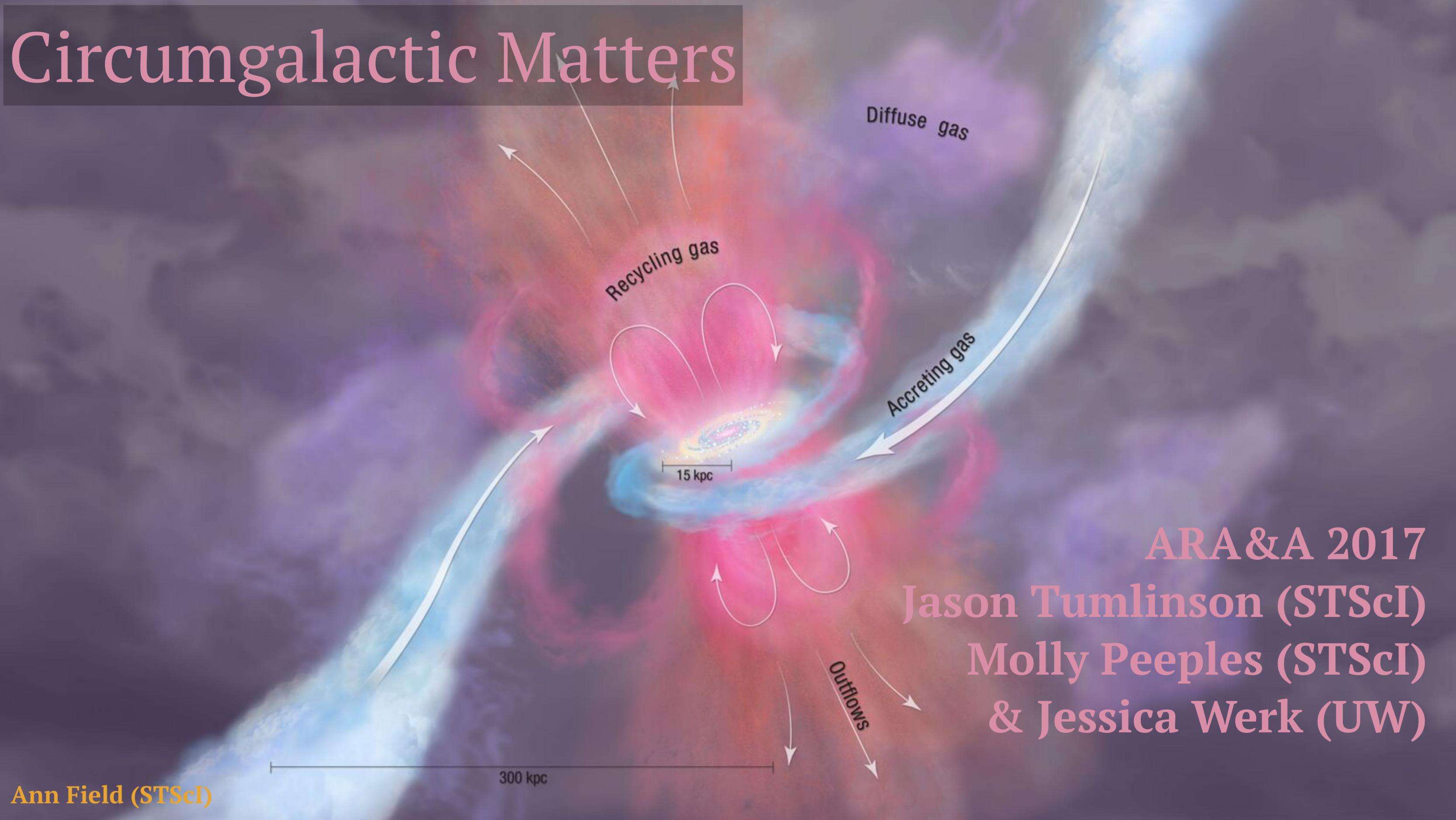


Circumgalactic Matters



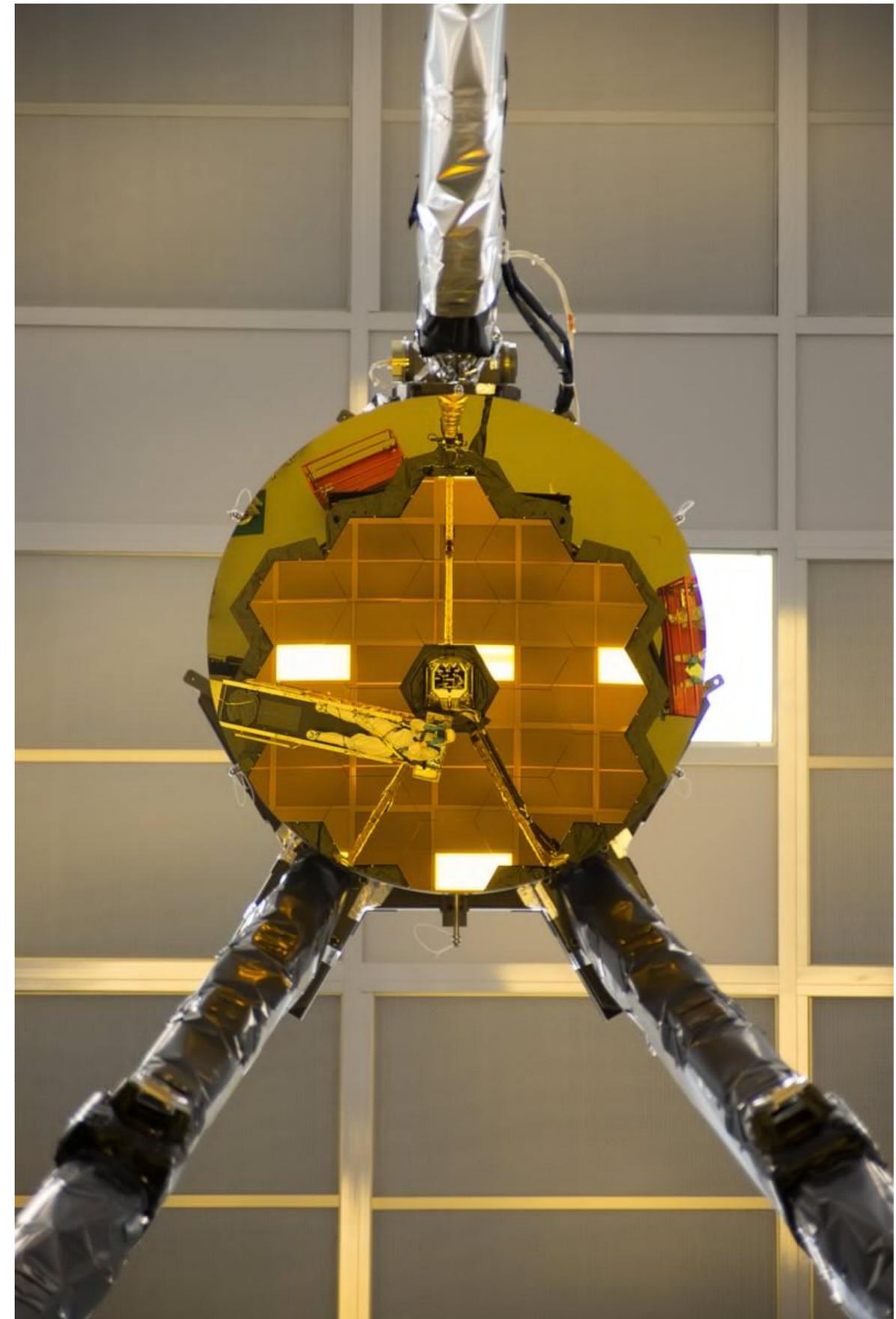
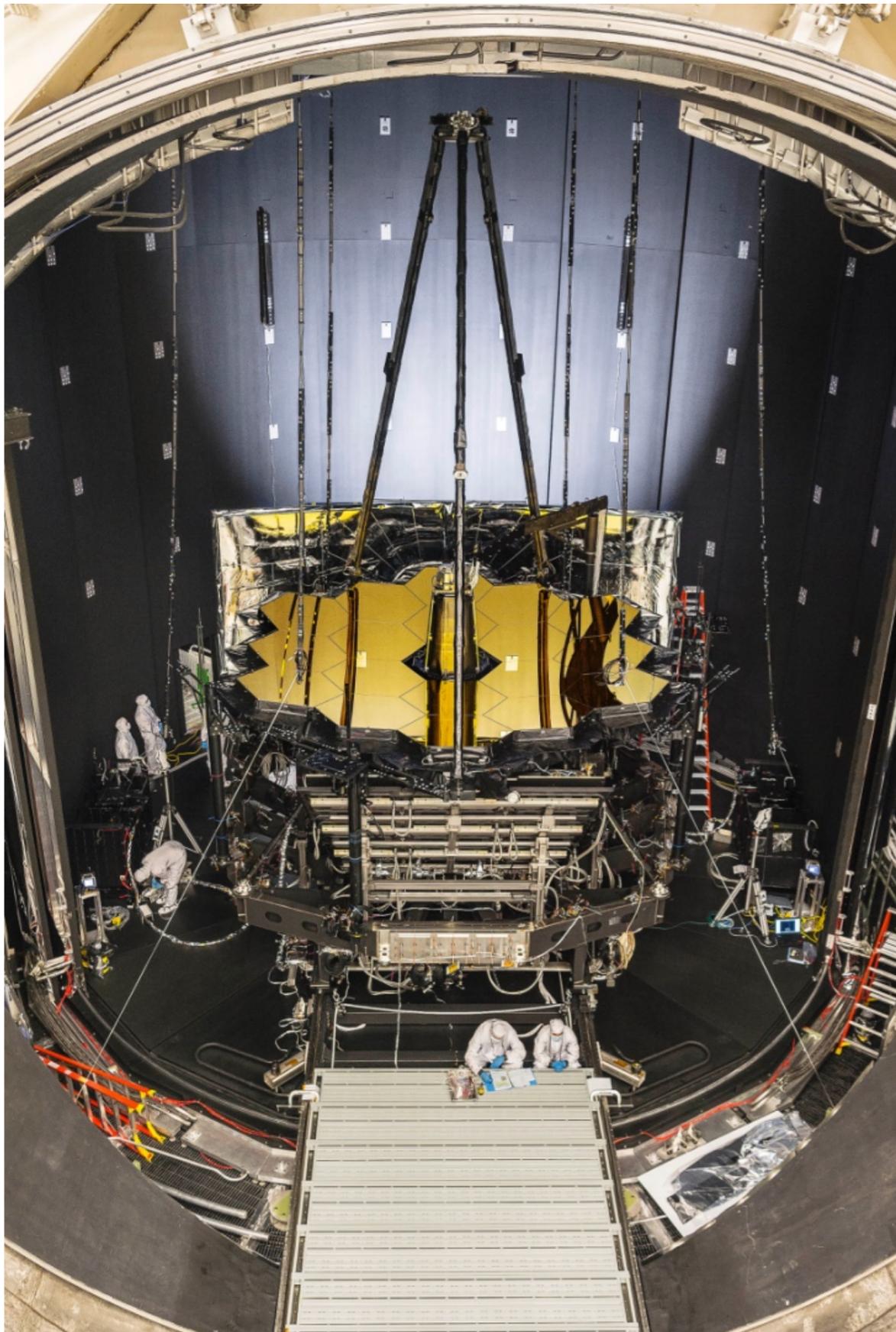
ARA&A 2017
Jason Tumlinson (STScI)
Molly Peeples (STScI)
& Jessica Werk (UW)

JWST

entering cryo tests at
Johnson Space Center
in Houston

Launch
Oct 2018

Cycle 1
proposals
due March 2018

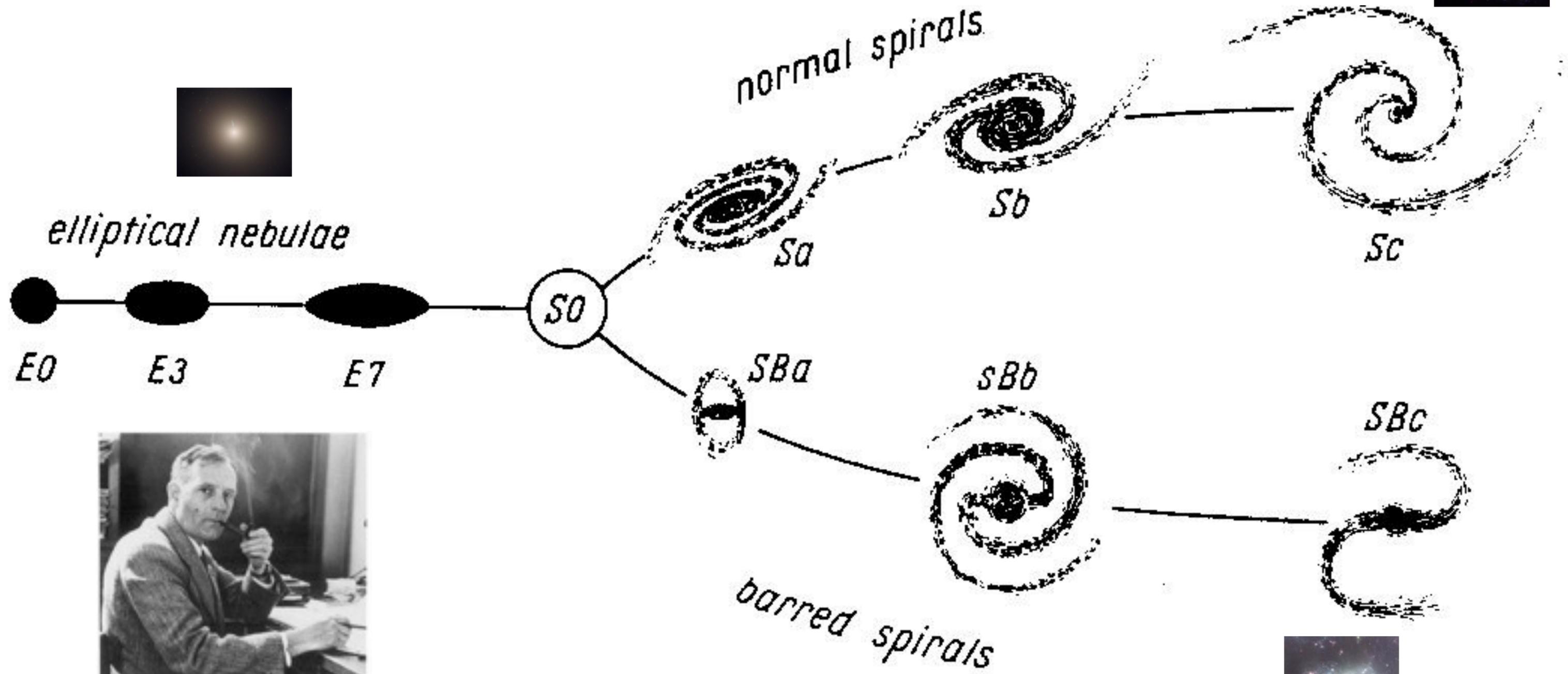


forge: v

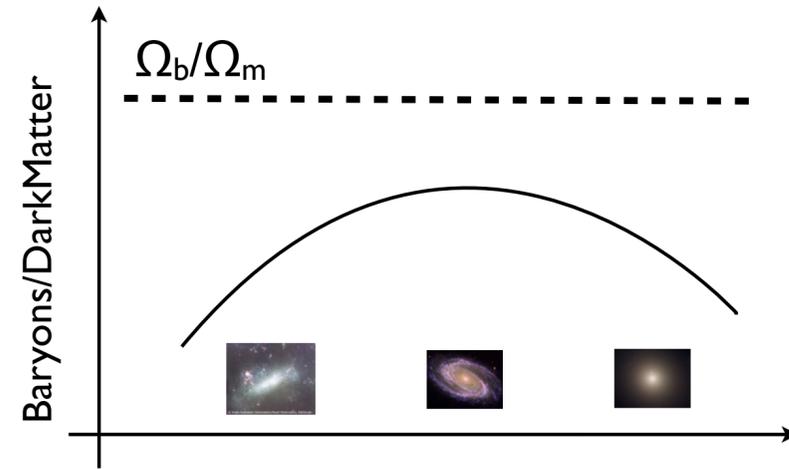
1. to make, fashion, frame, or construct
(any material thing)

2. To fabricate, frame, invent
(a false or imaginary story, lie, etc.);
to devise (evil).

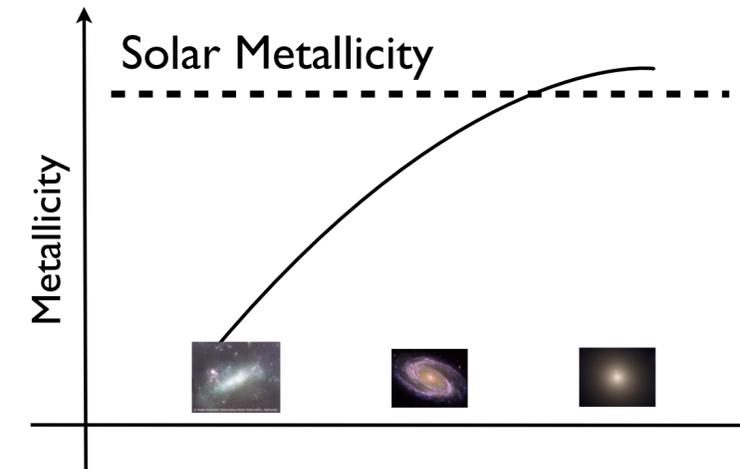
The Basic Puzzle: An early Hubble observation



Fundamental Problems in Galaxy Evolution

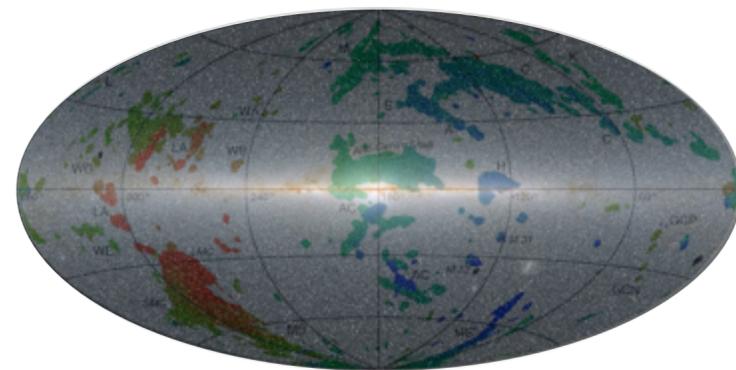


Why do galaxies appear to lack their full share of baryons?

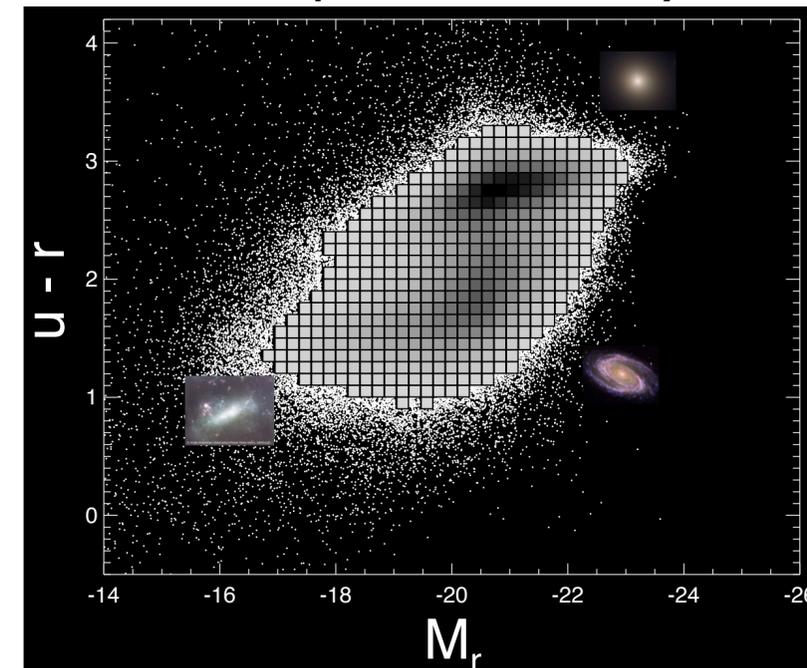


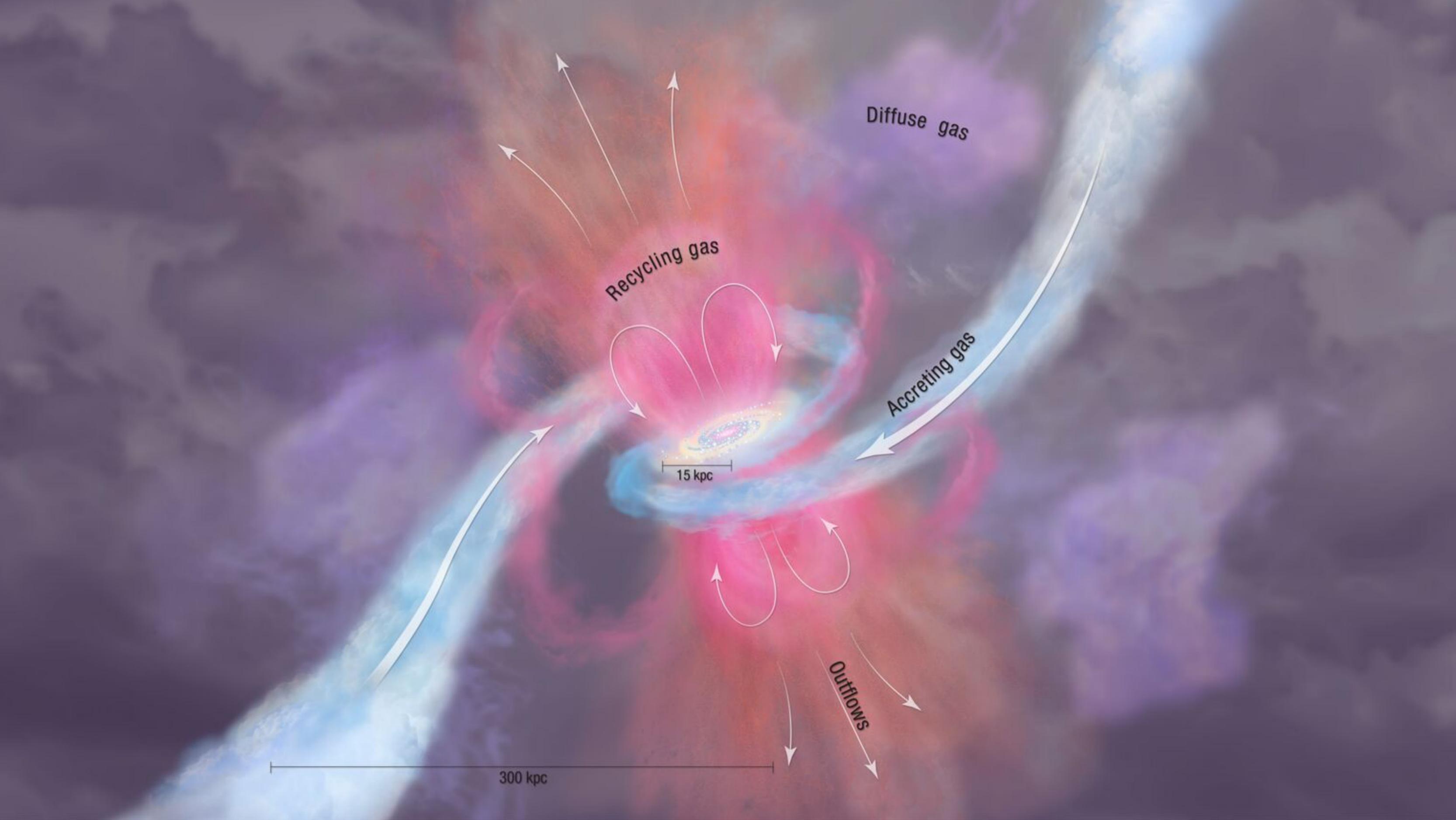
Why do galaxies follow a steep mass-metallicity relation?

How is star formation sustained for 10 Gyr, if only 1 Gyr of gas is present now?



What quenches galaxies and keeps them that way?





Diffuse gas

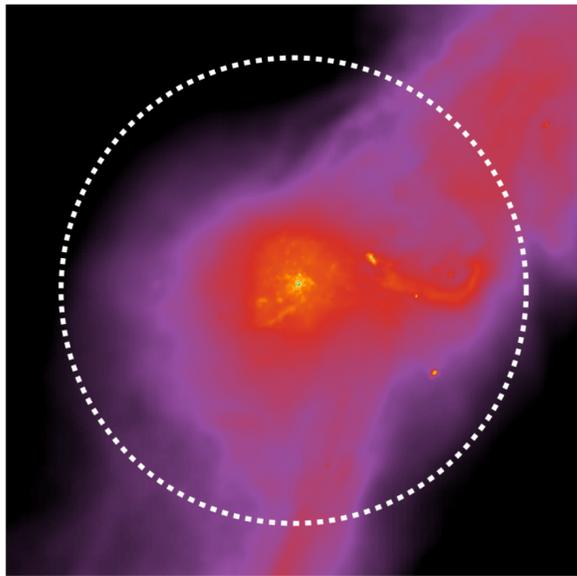
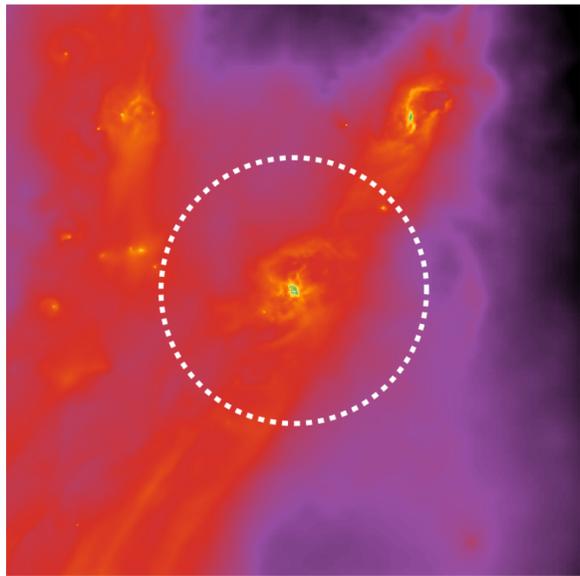
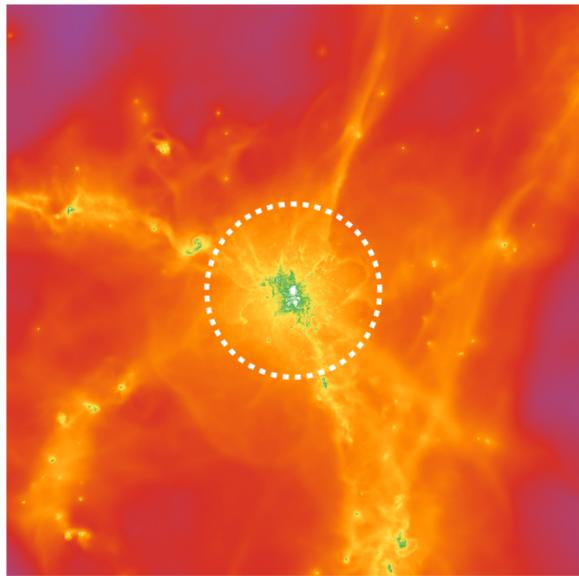
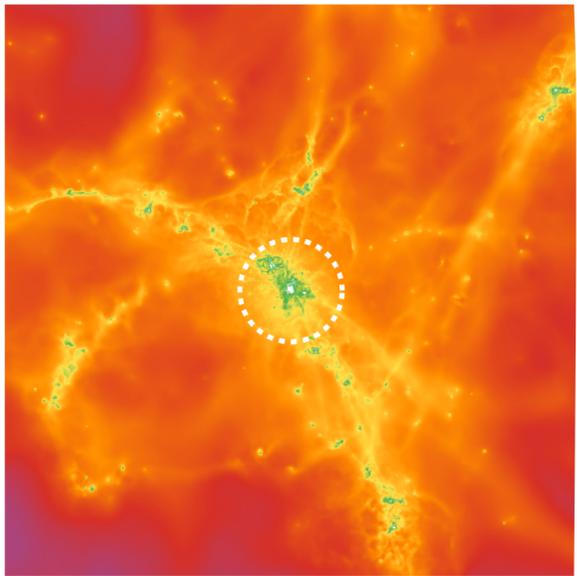
Recycling gas

Accreting gas

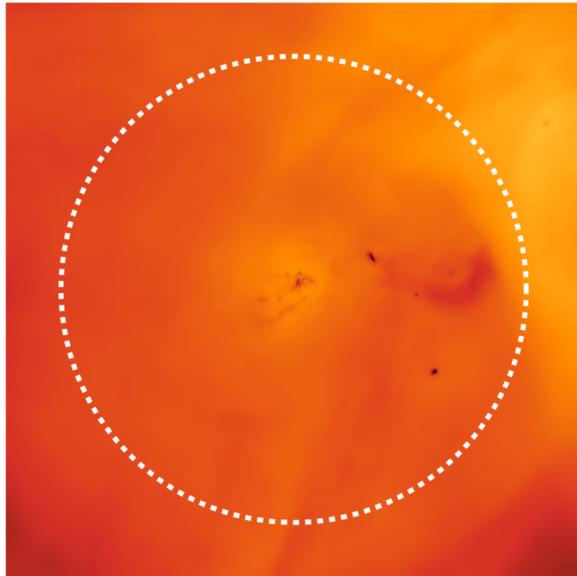
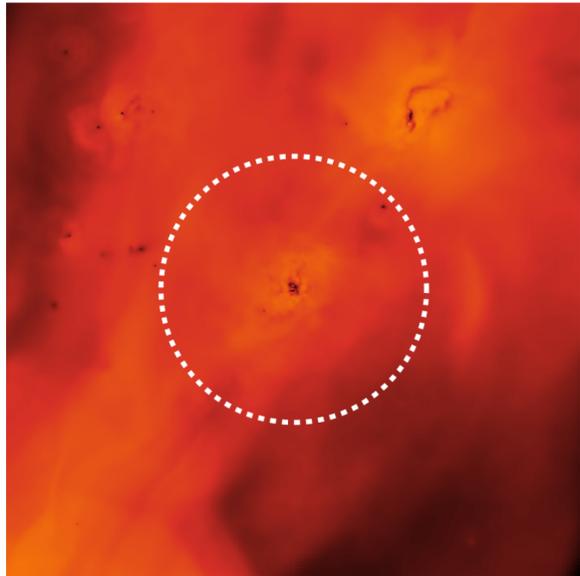
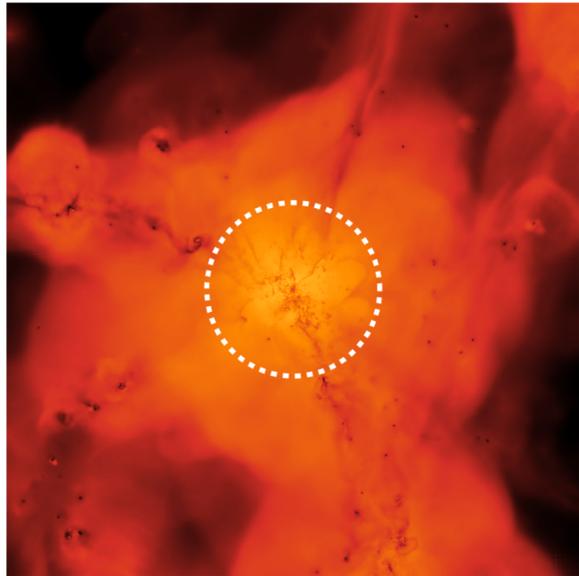
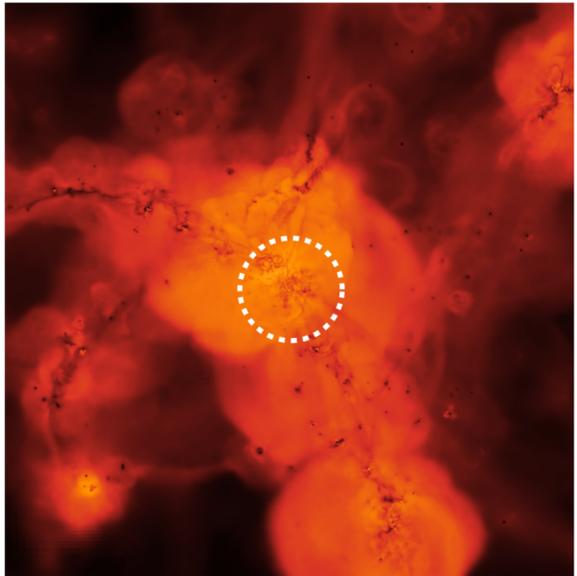
15 kpc

Outflows

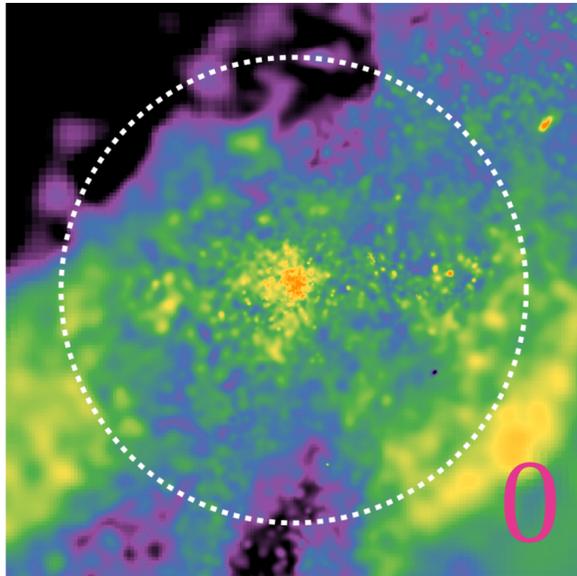
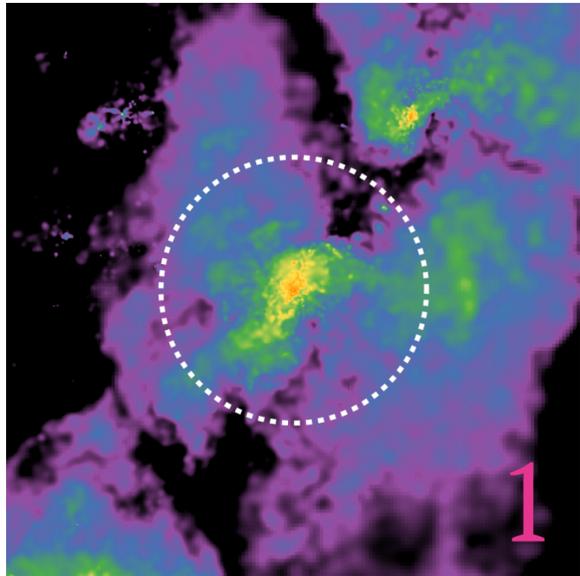
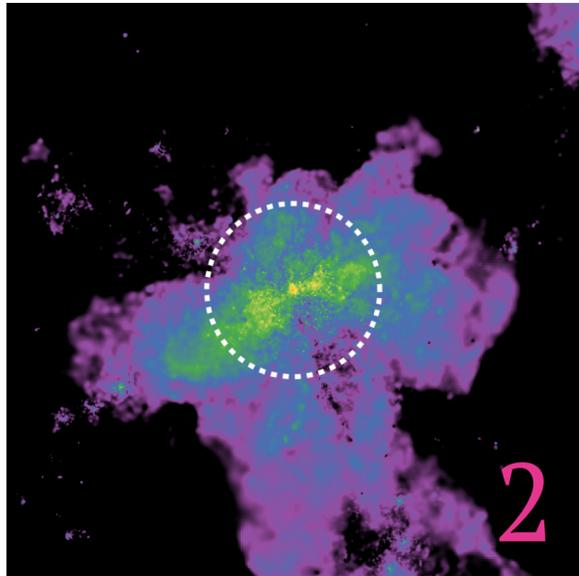
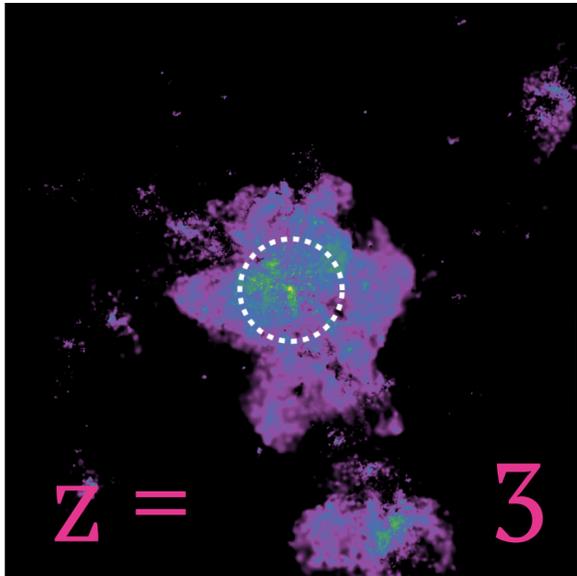
300 kpc



Density

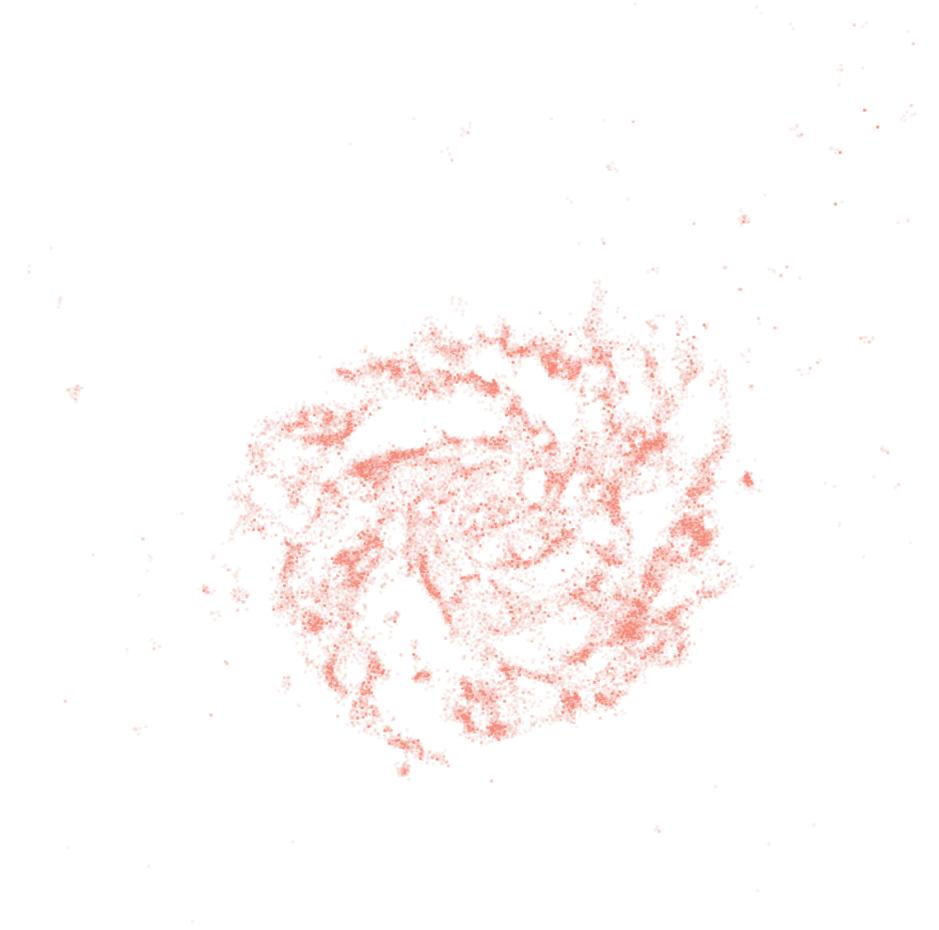


Temperature



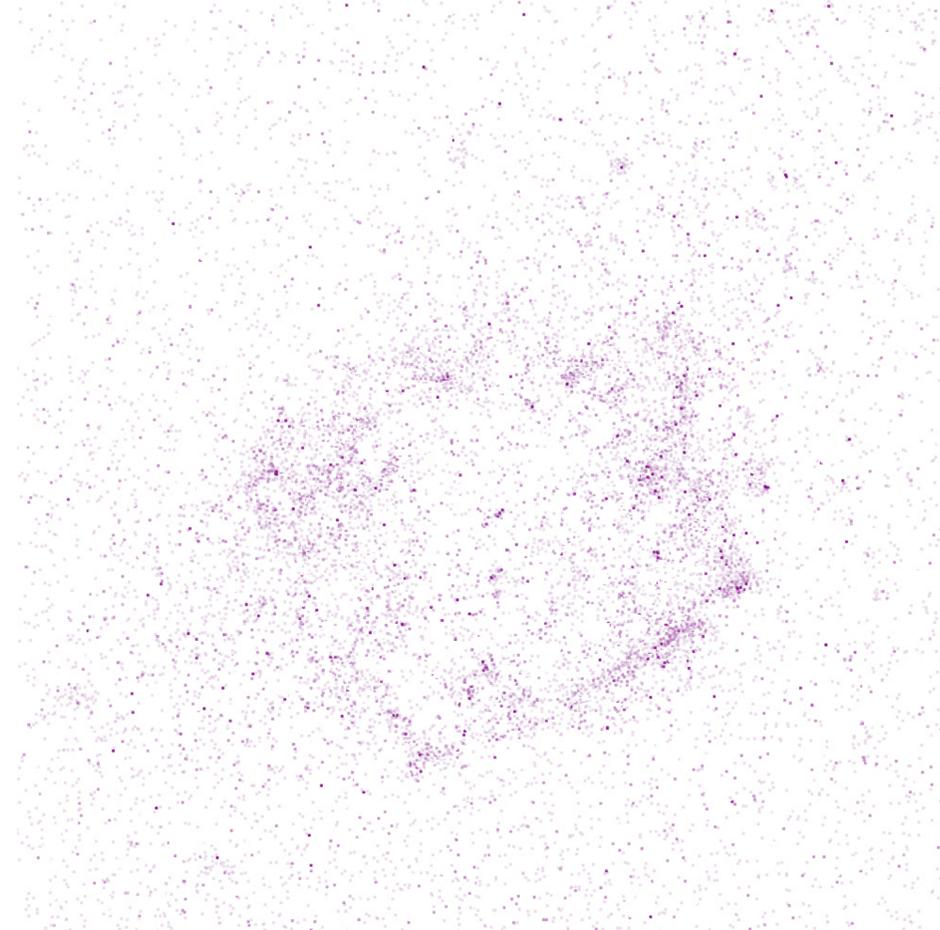
Metallicity

Hot



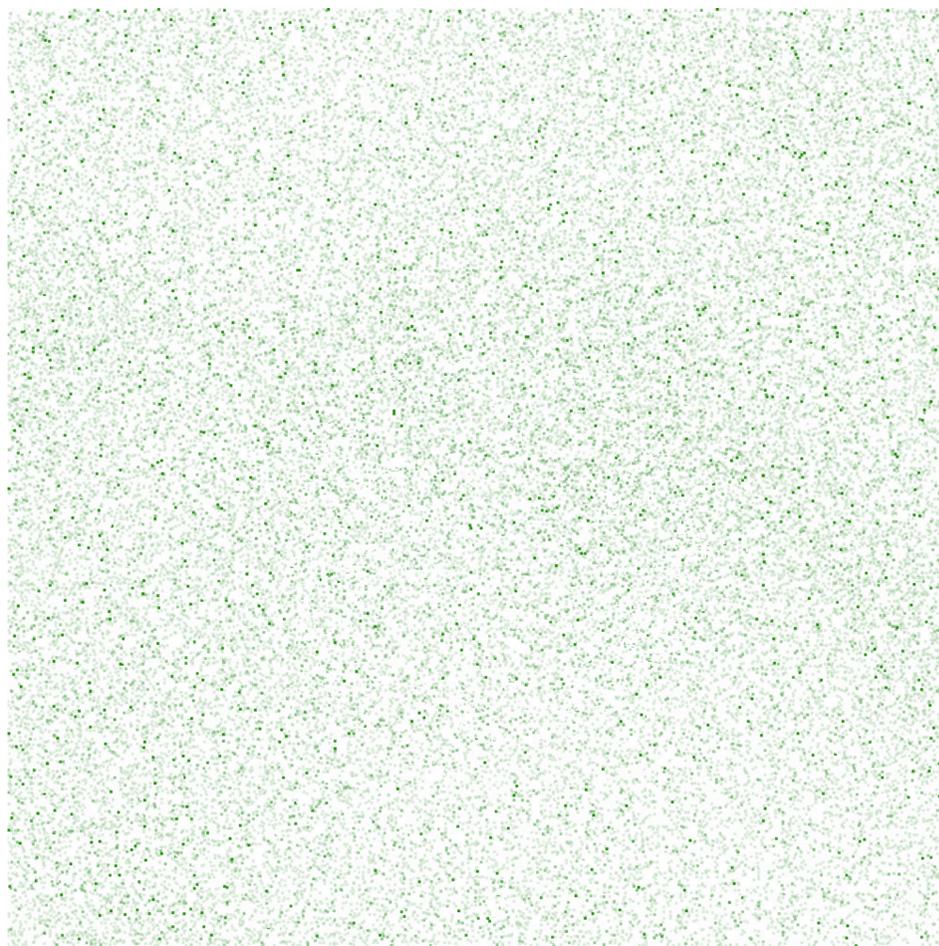
$>10^6$ K

Warm



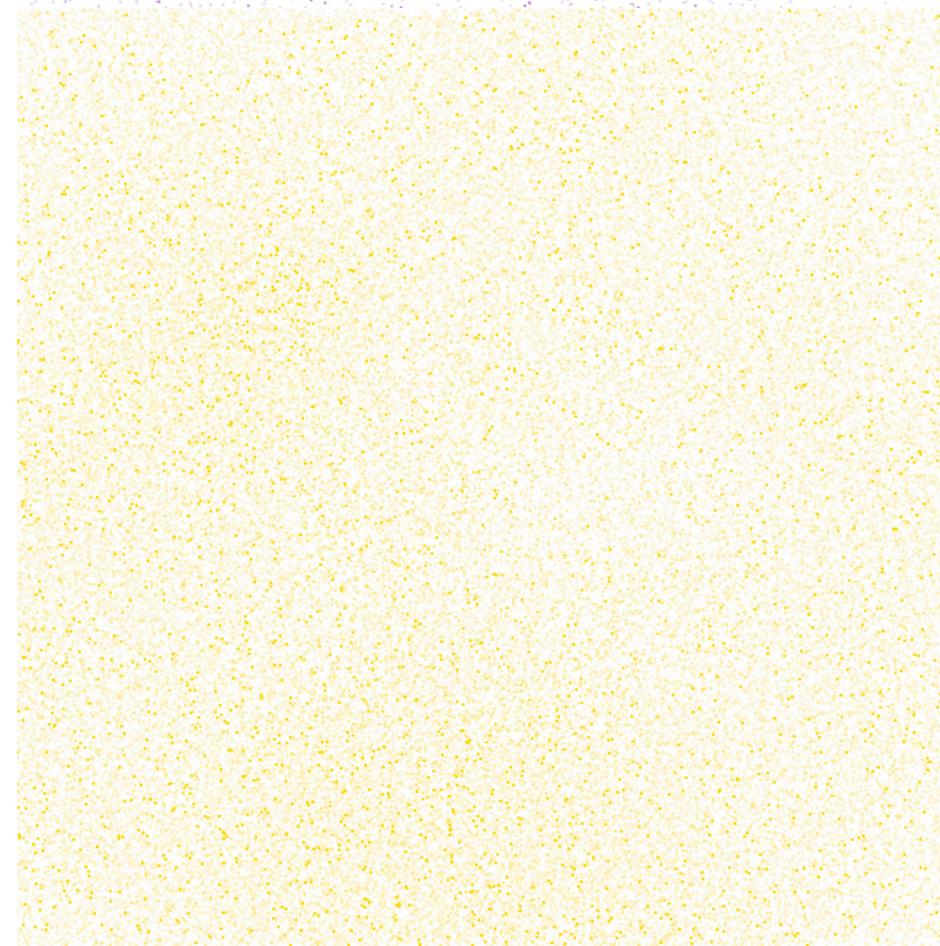
10^{5-6} K

Cool



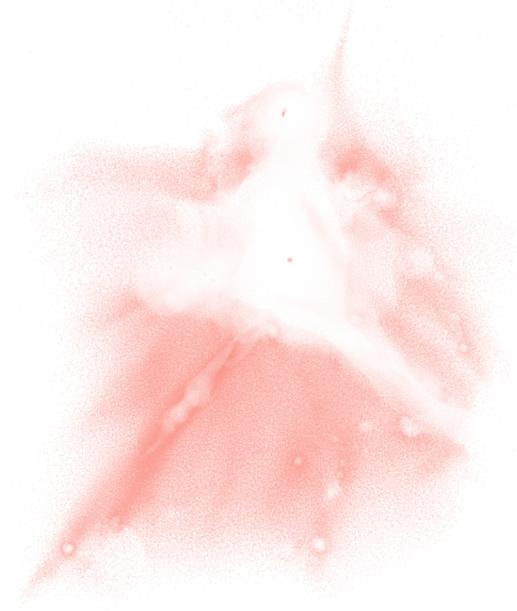
10^{4-5} K

Cold



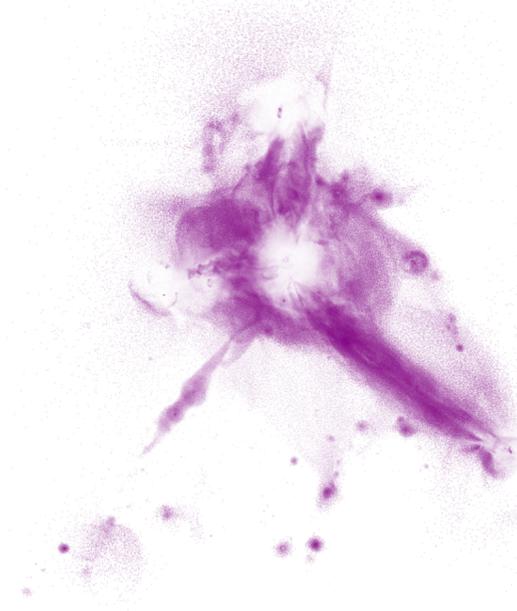
$<10^4$ K

Hot



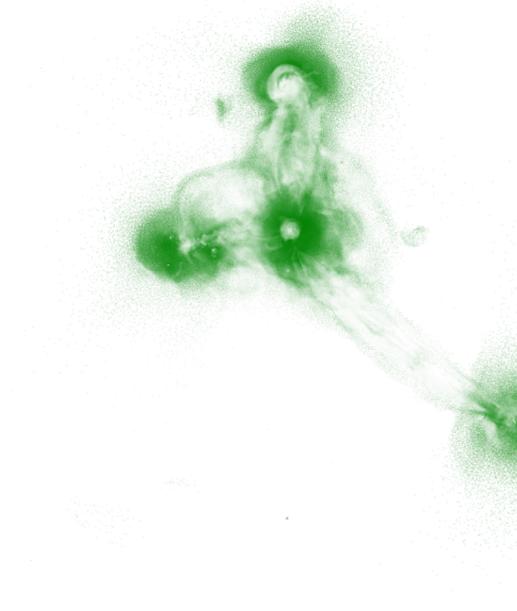
$>10^6$ K

Warm



10^{5-6} K

Cool



10^{4-5} K

Cold



$<10^4$ K

Hot

$>10^6$ K

Warm

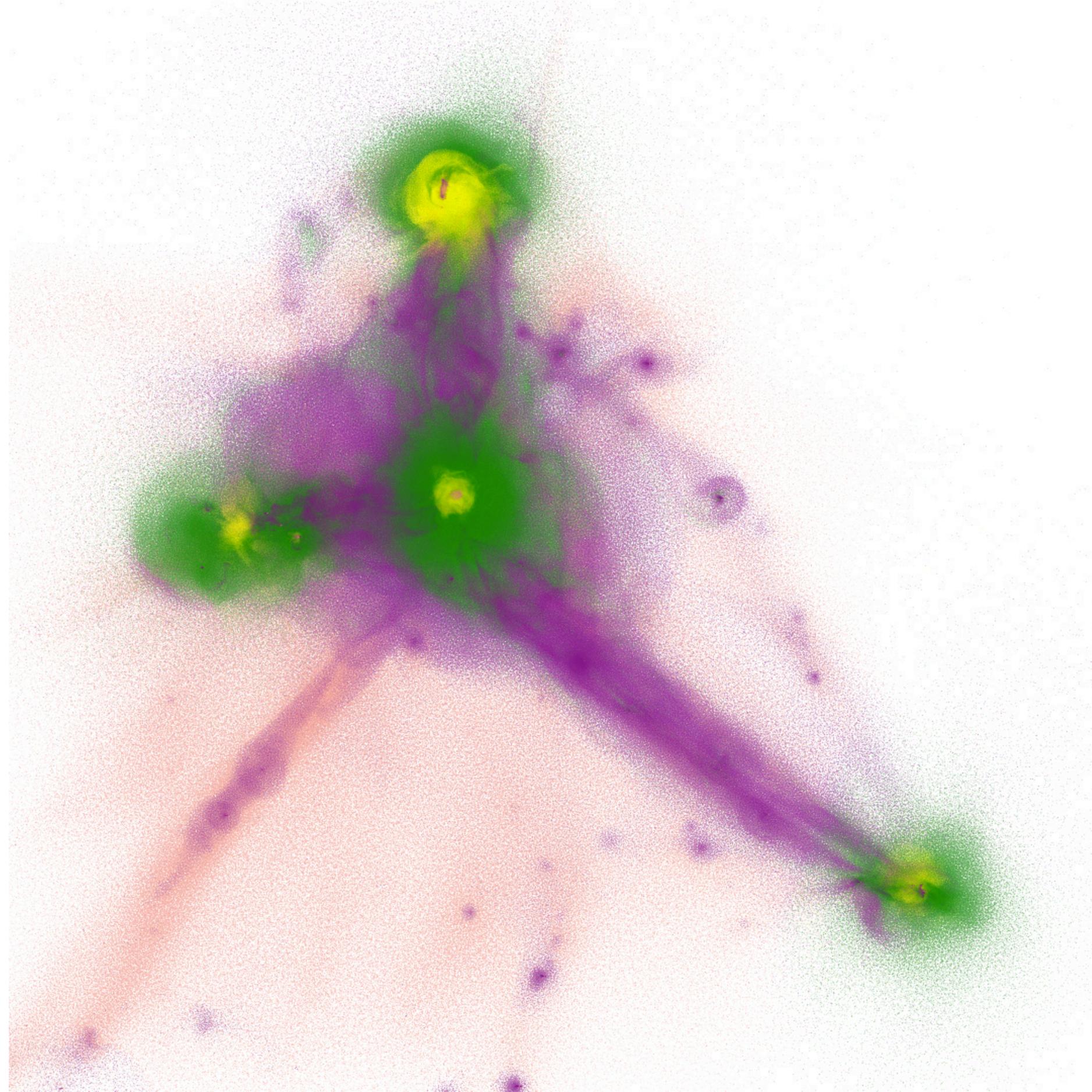
10^{5-6} K

Cool

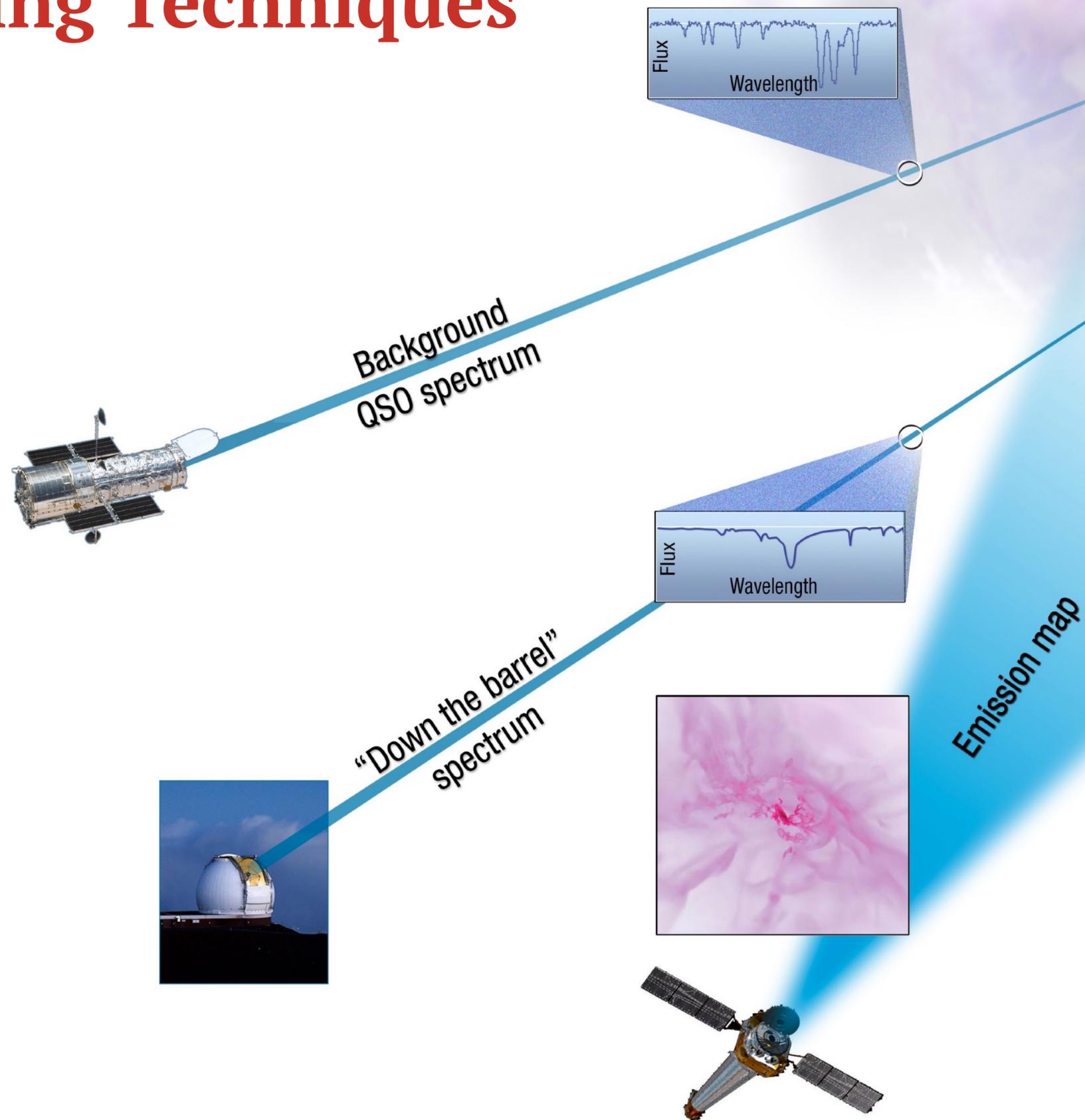
10^{4-5} K

Cold

$<10^4$ K



Observing Techniques



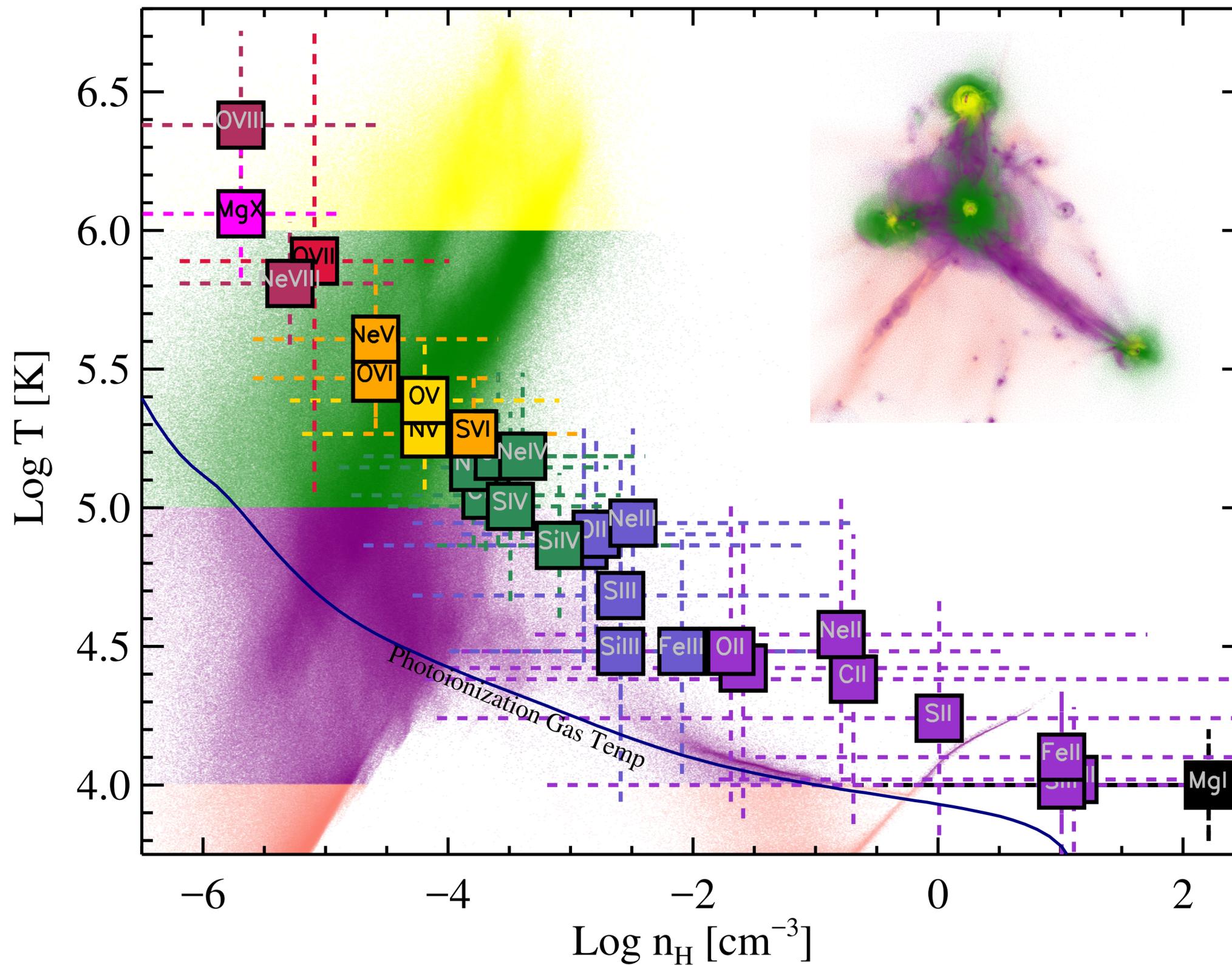
Phases and Diagnostics

Hot

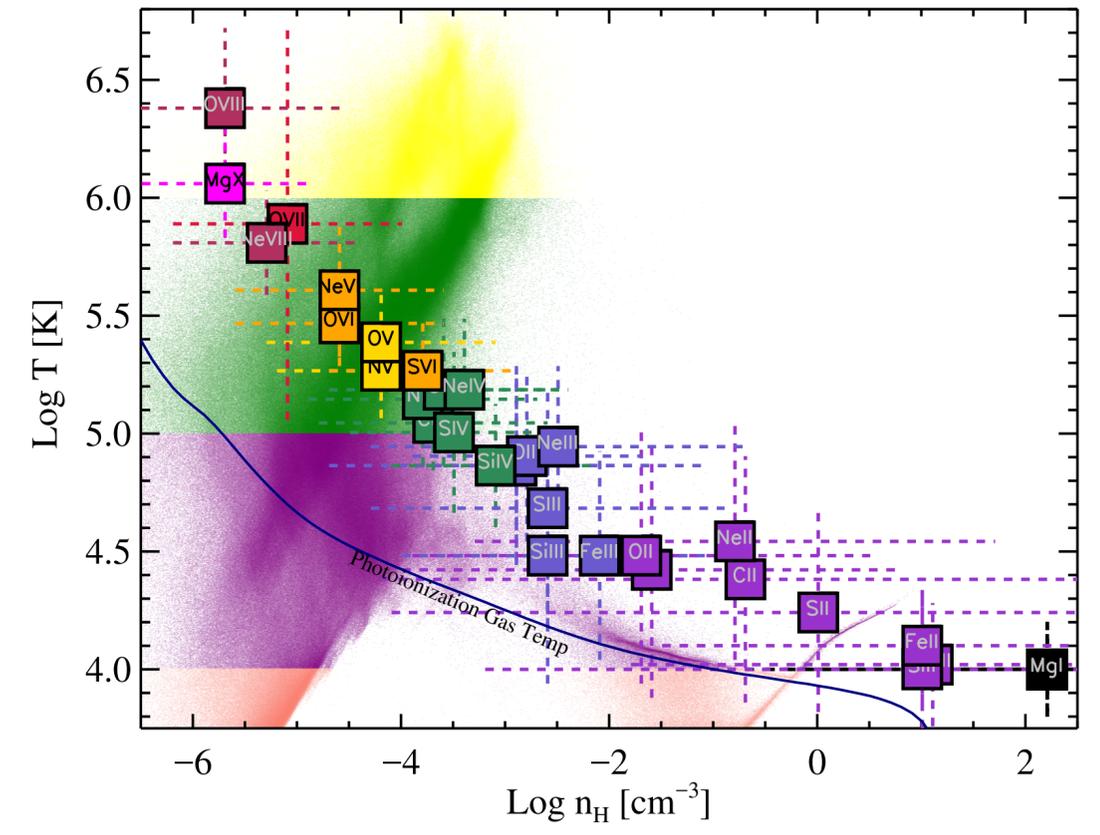
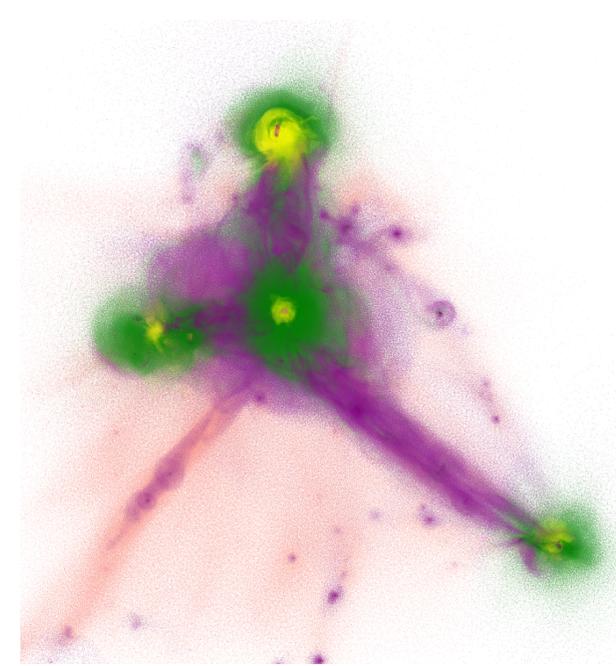
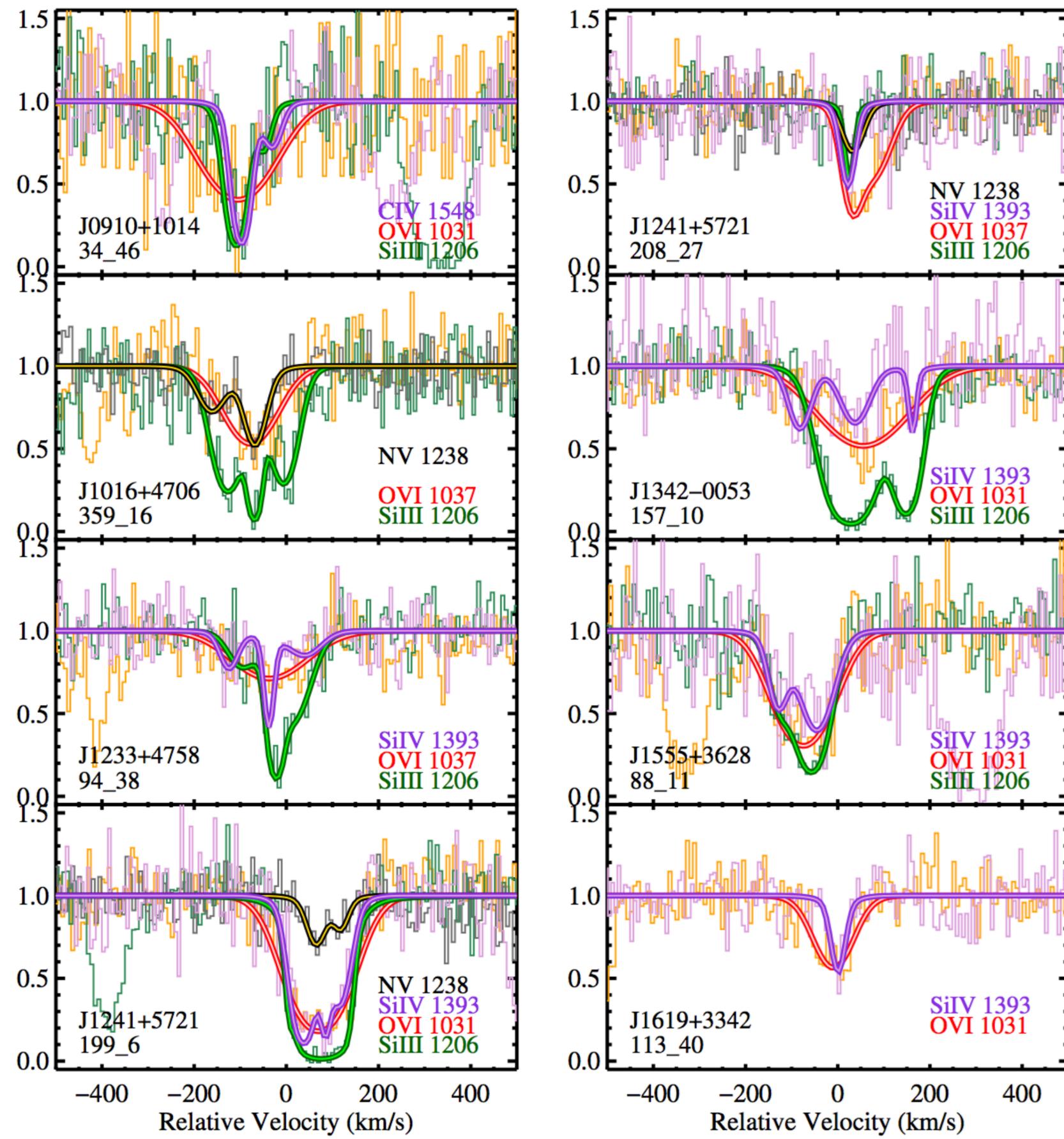
Warm

Cool

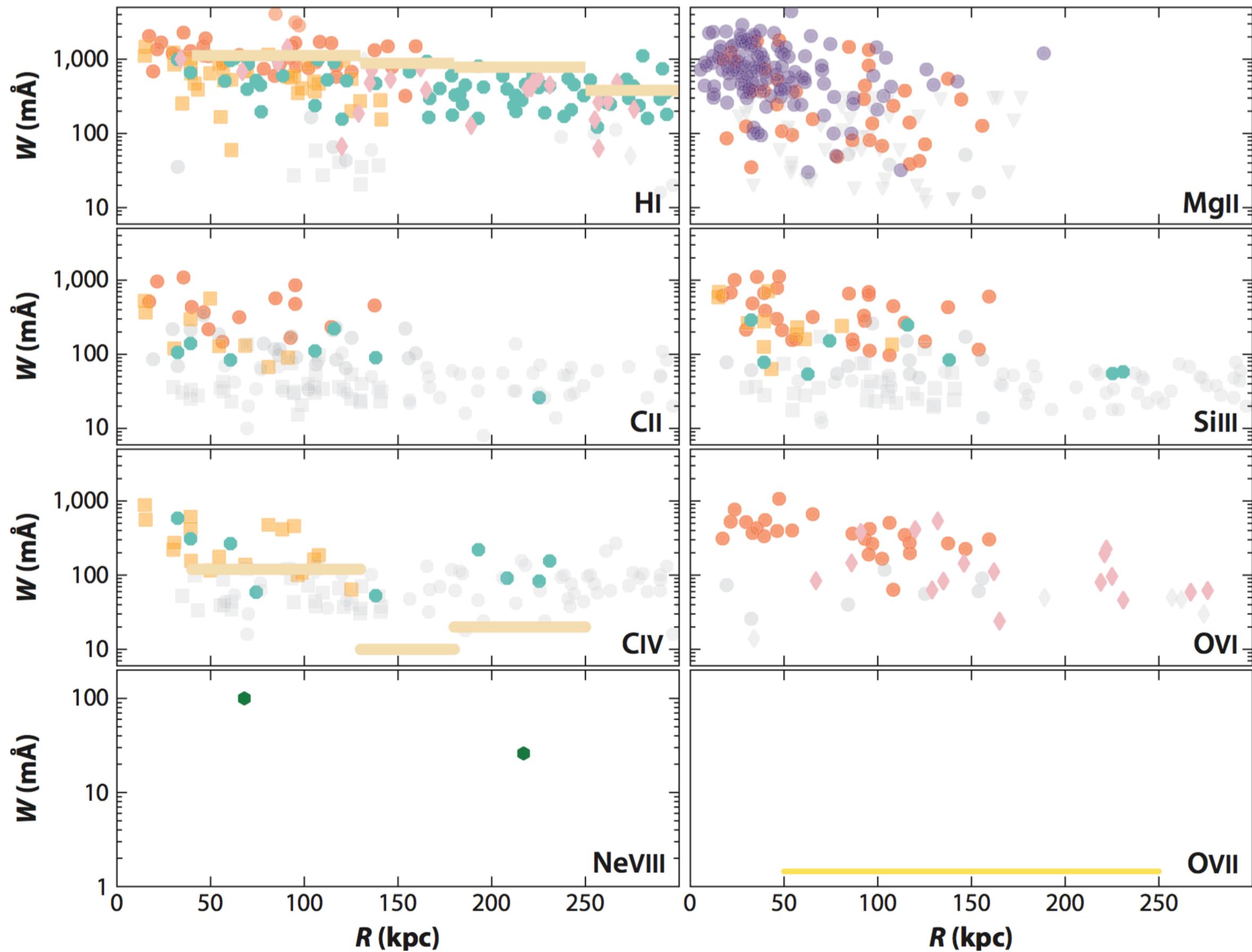
Cold



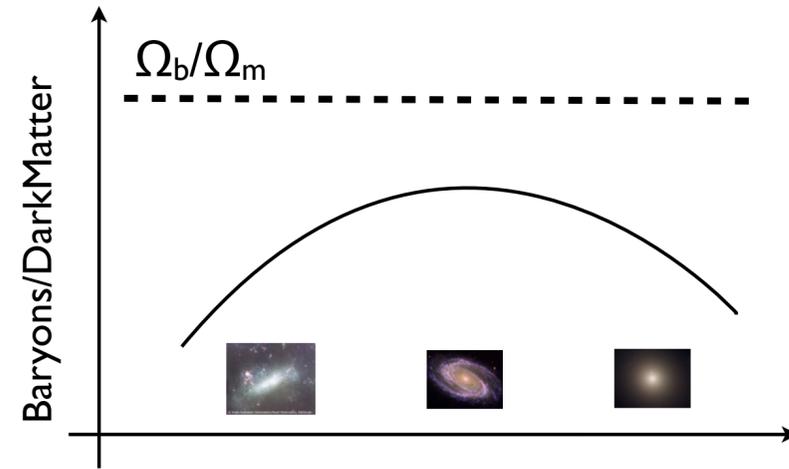
Absorbers and Phases



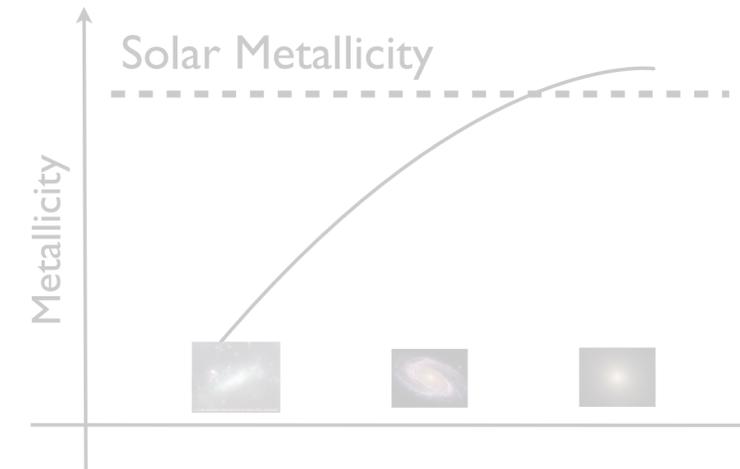
COS-Halos COS-Dwarfs MAGIICAT LC14 CASBaH Yao KBSS P11 COS-GASS



Fundamental Problems in Galaxy Evolution

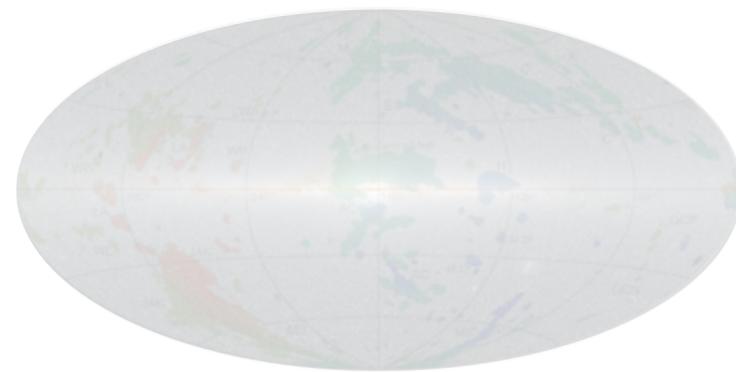


Why do galaxies appear to lack their full share of baryons?

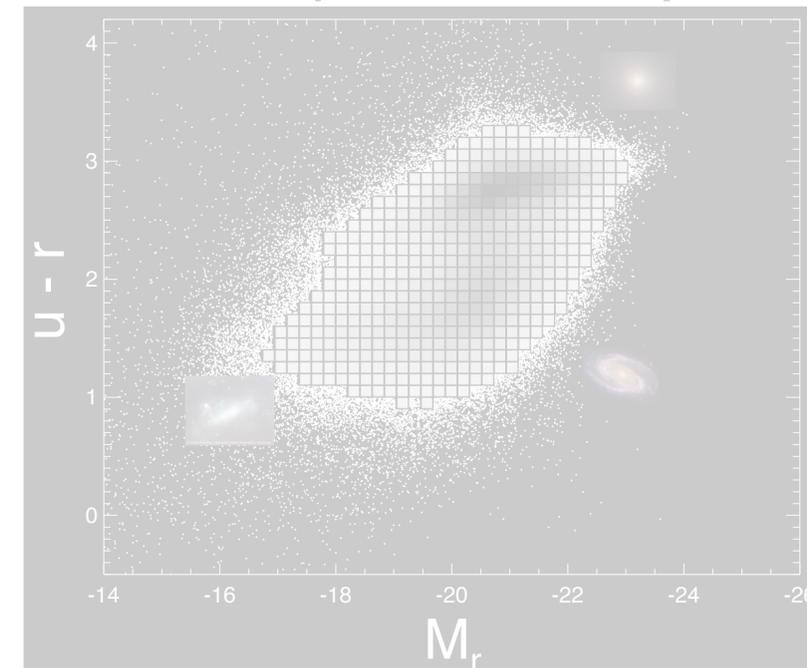


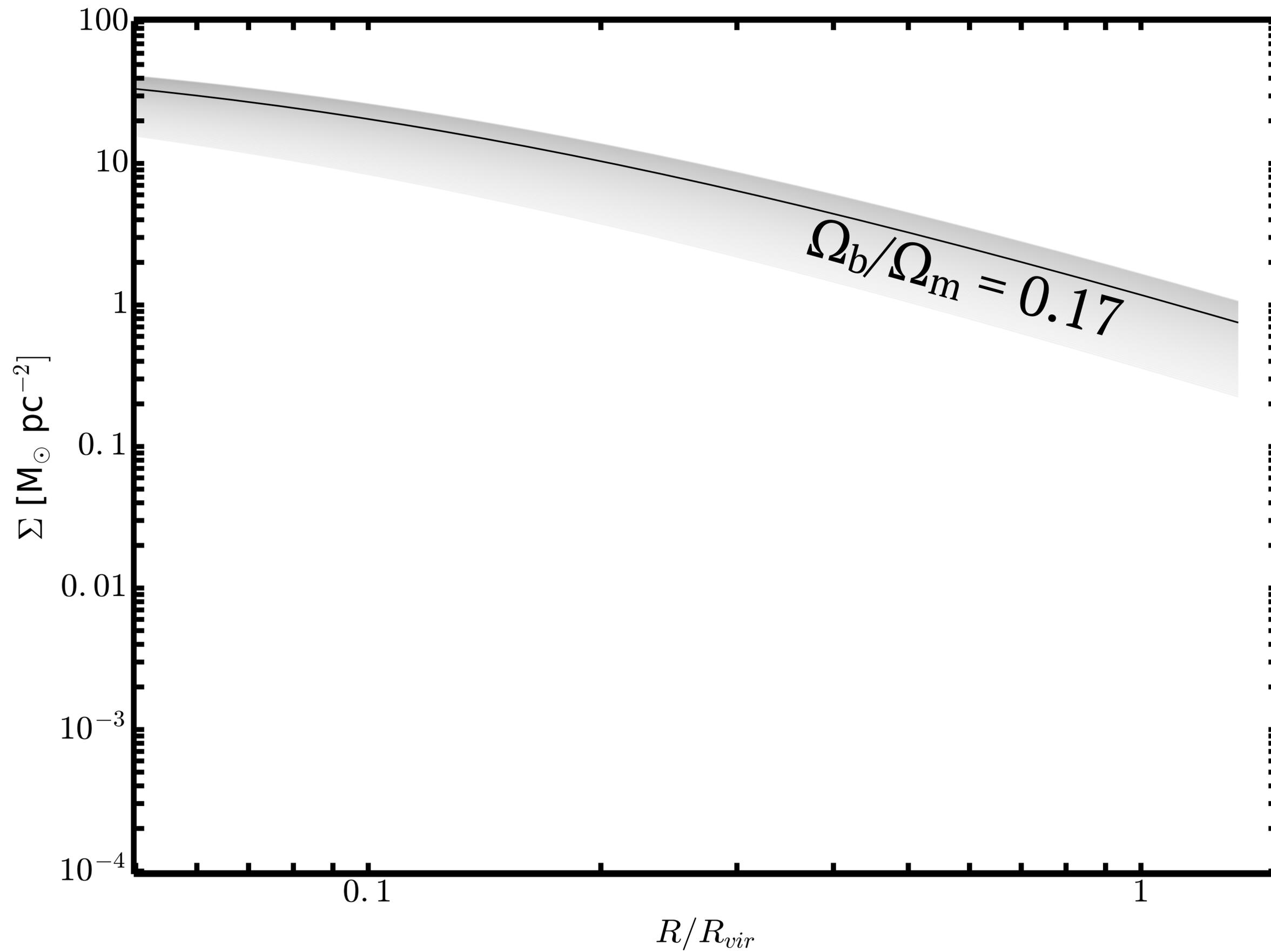
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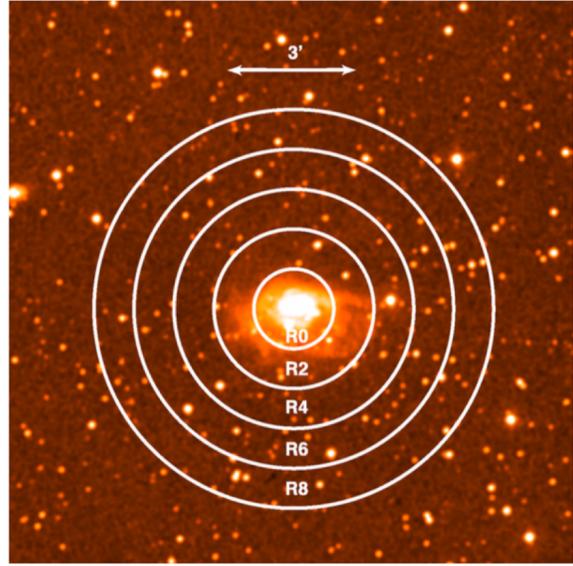


What quenches galaxies and keeps them that way?

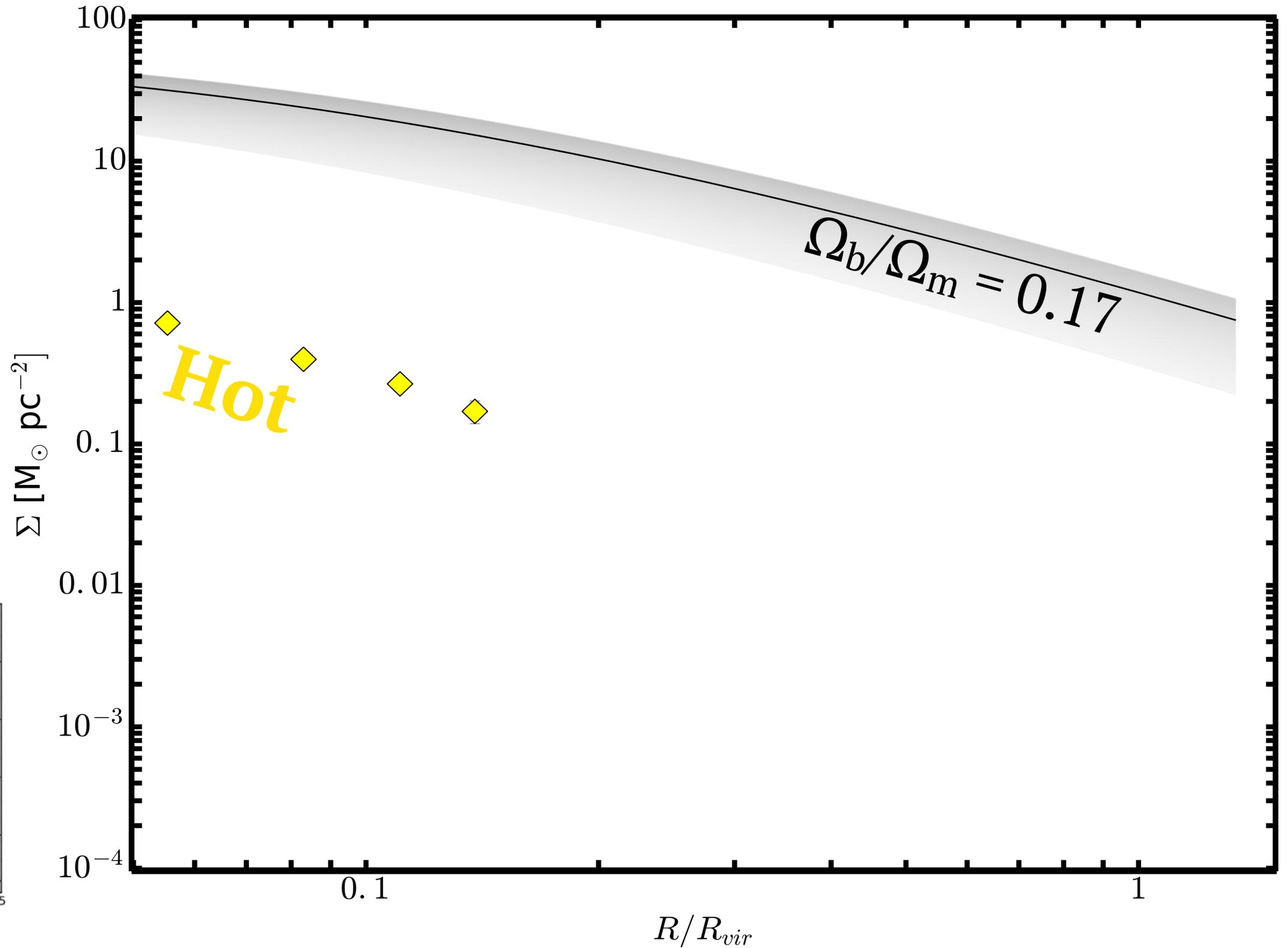
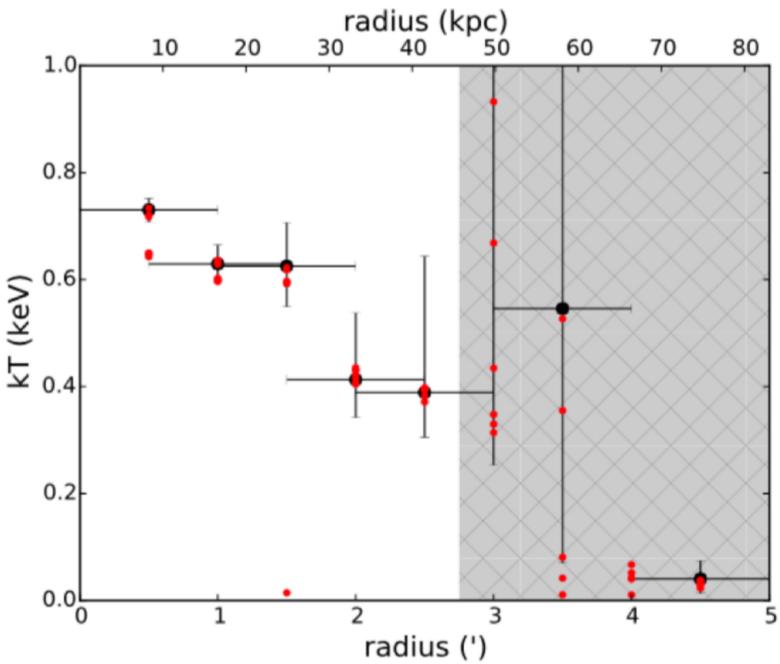




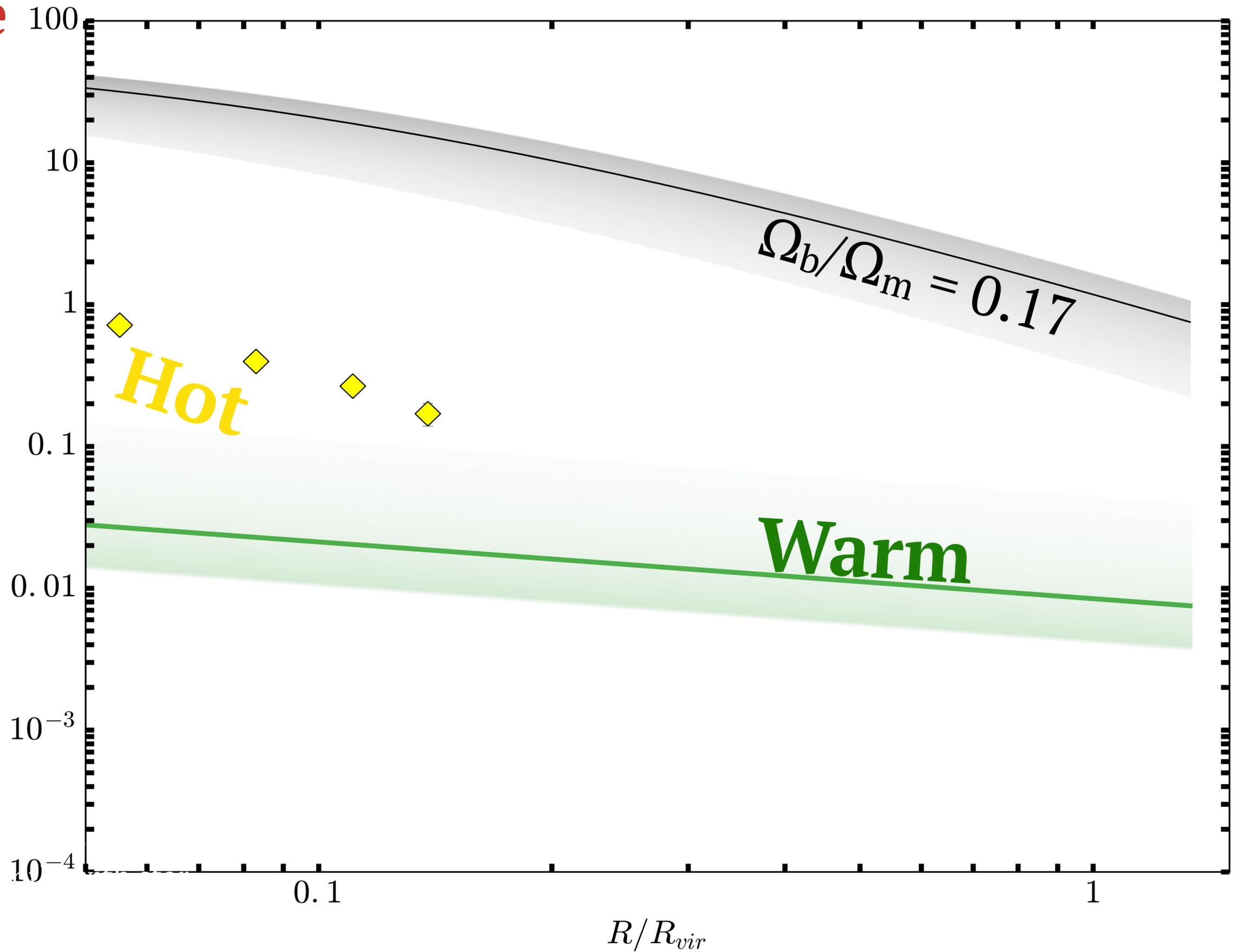
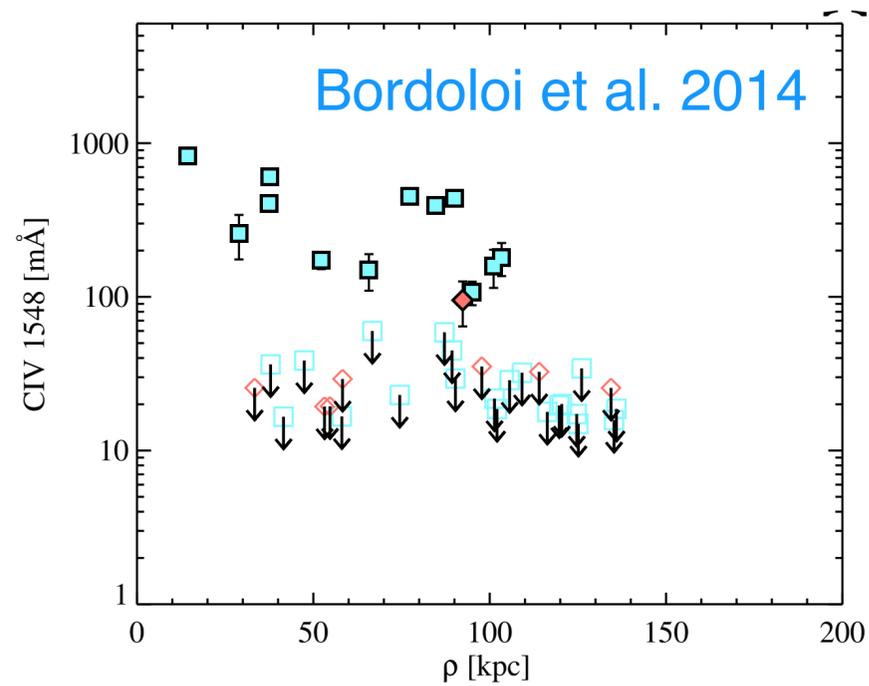
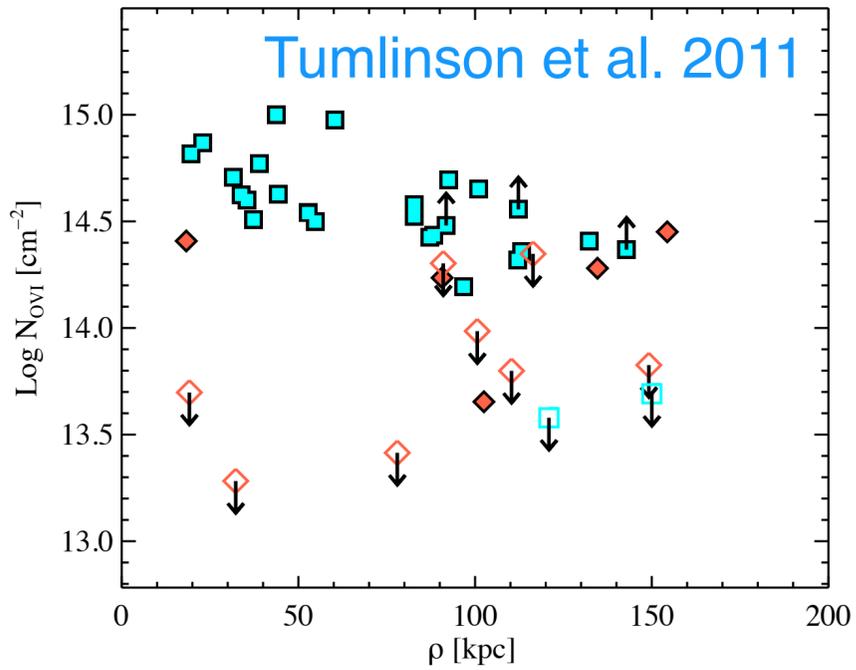
X-Ray Maps of Hot Gas



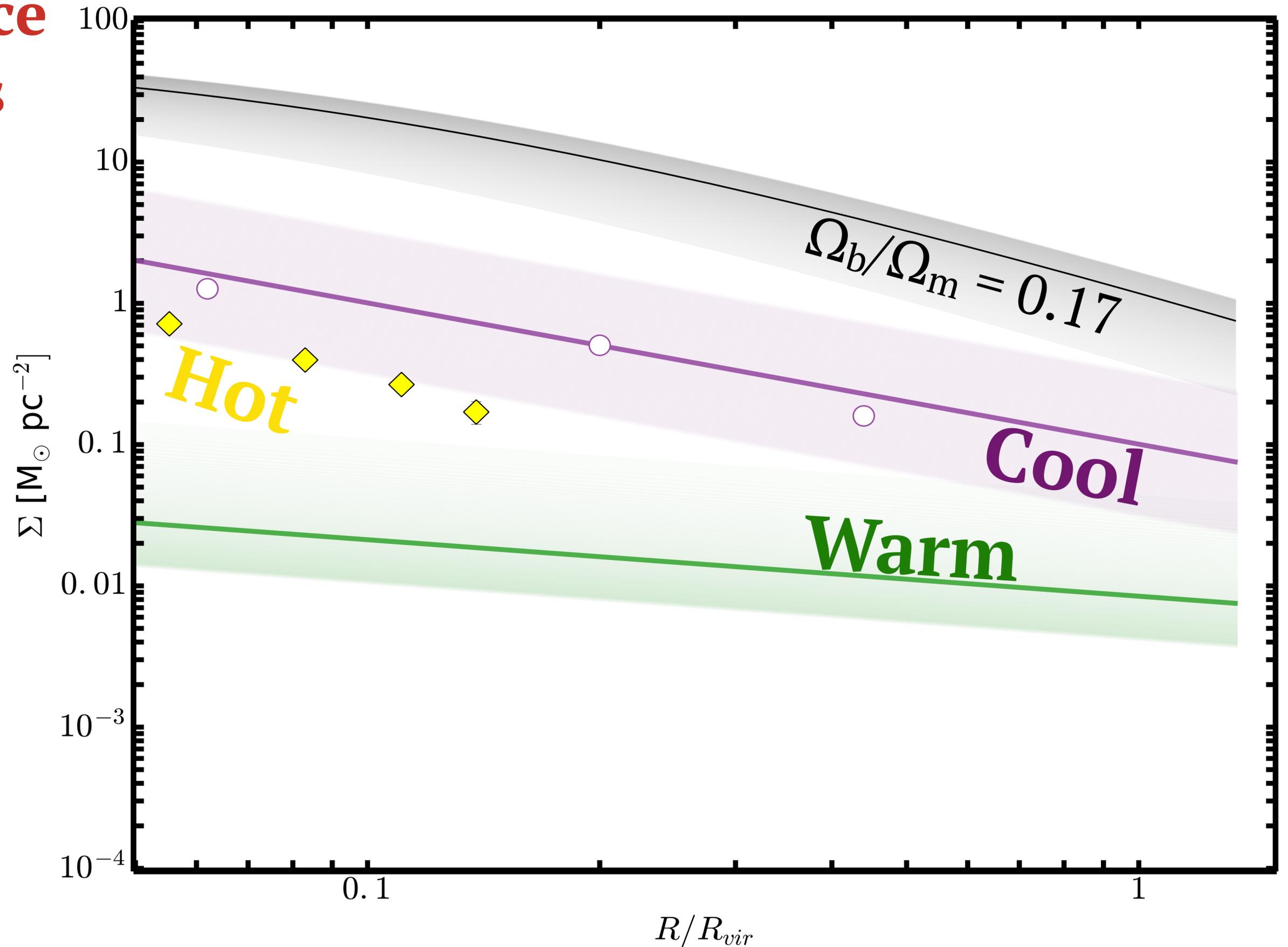
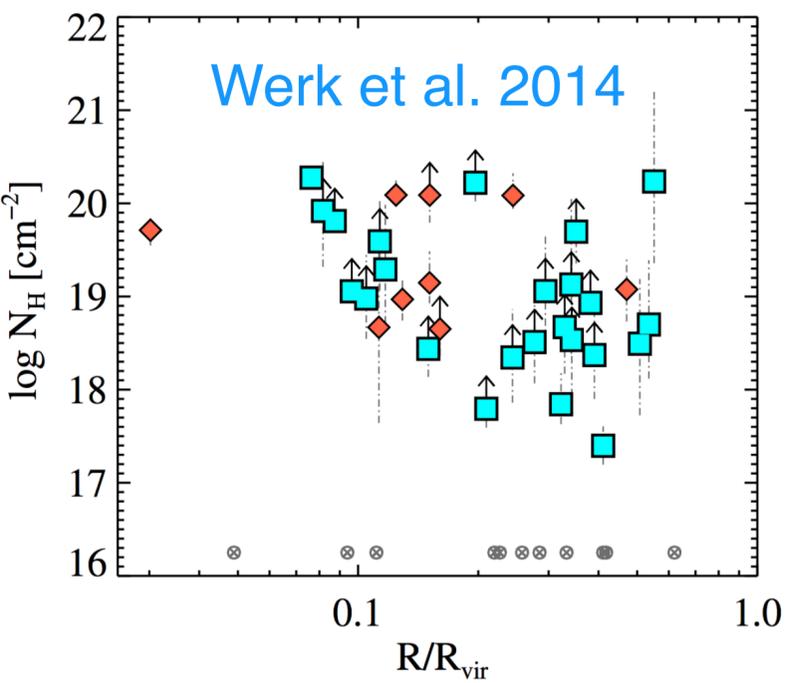
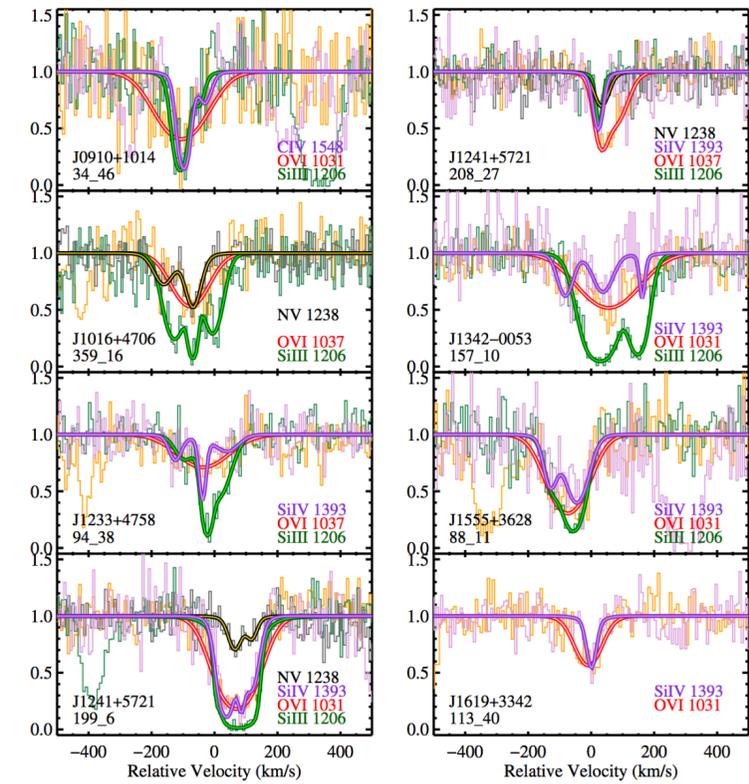
Anderson et al. 2013, 2016



High Ions Trace “Warm” Gas

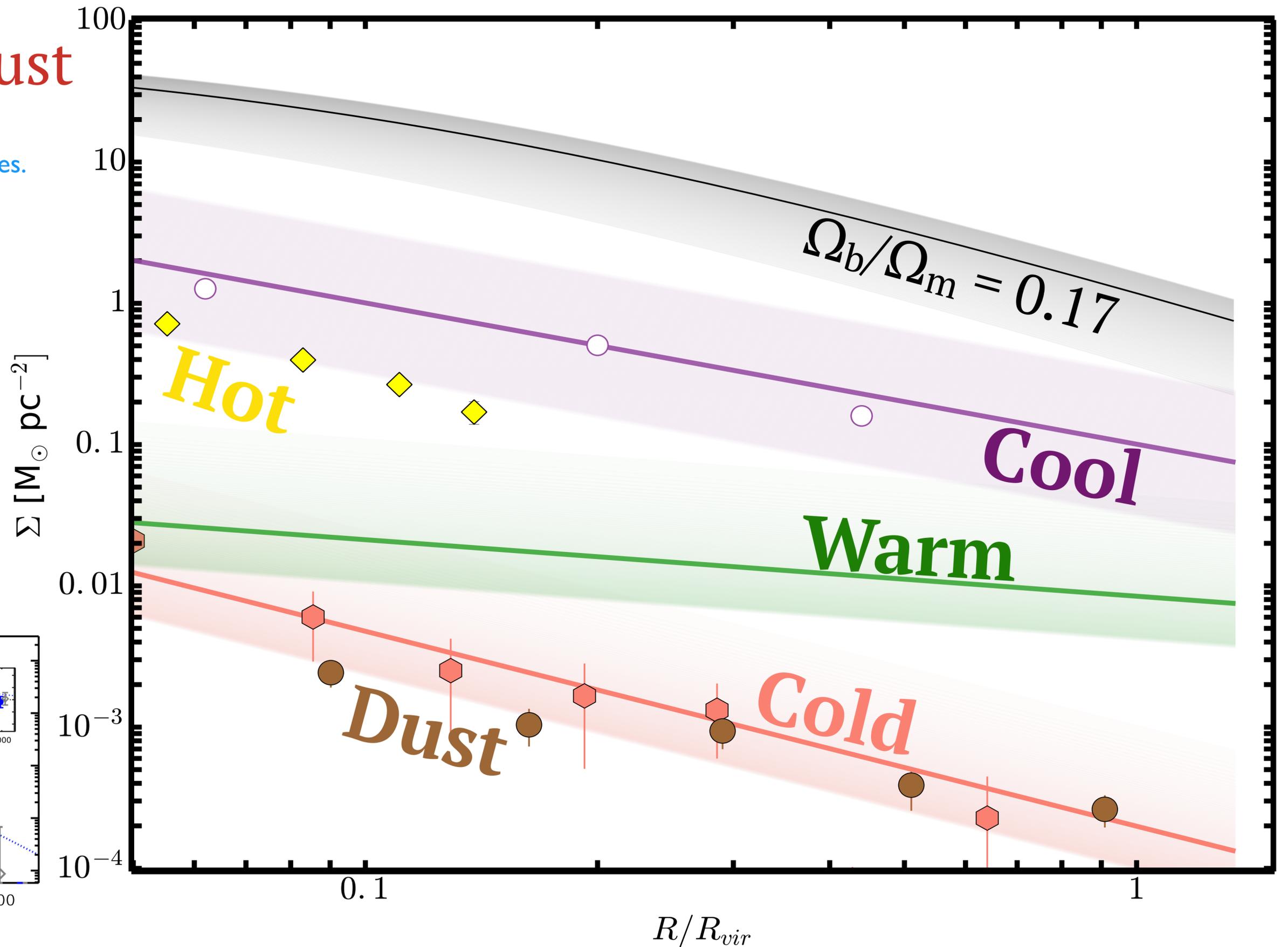
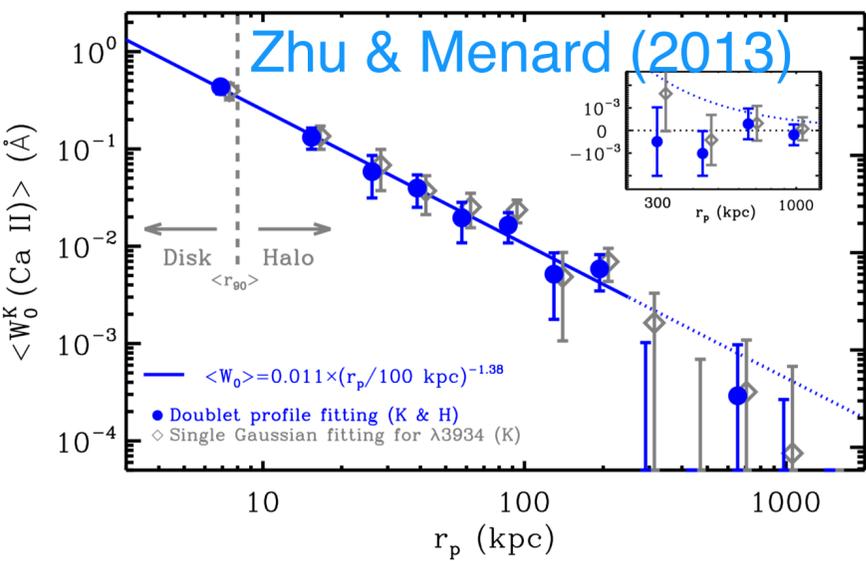
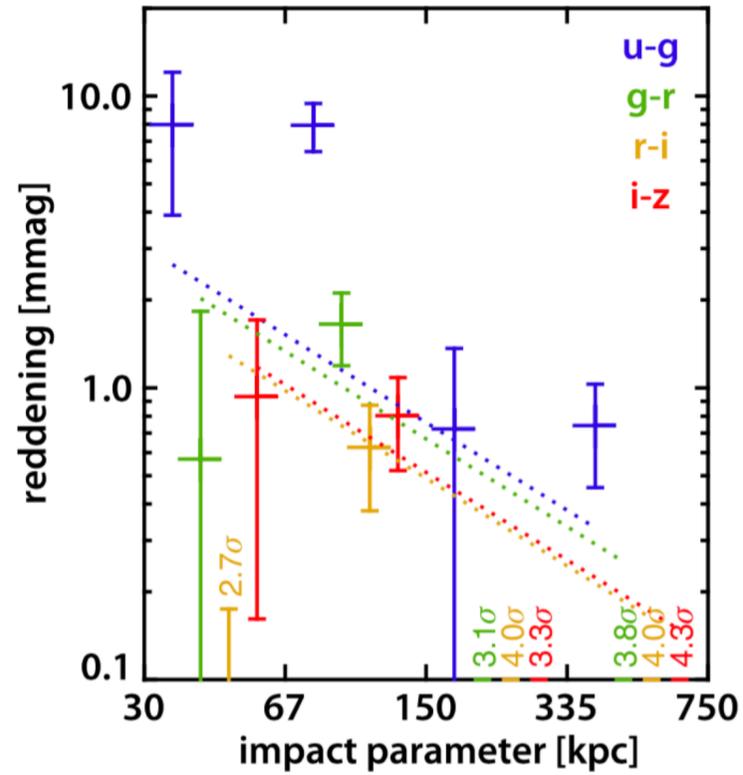


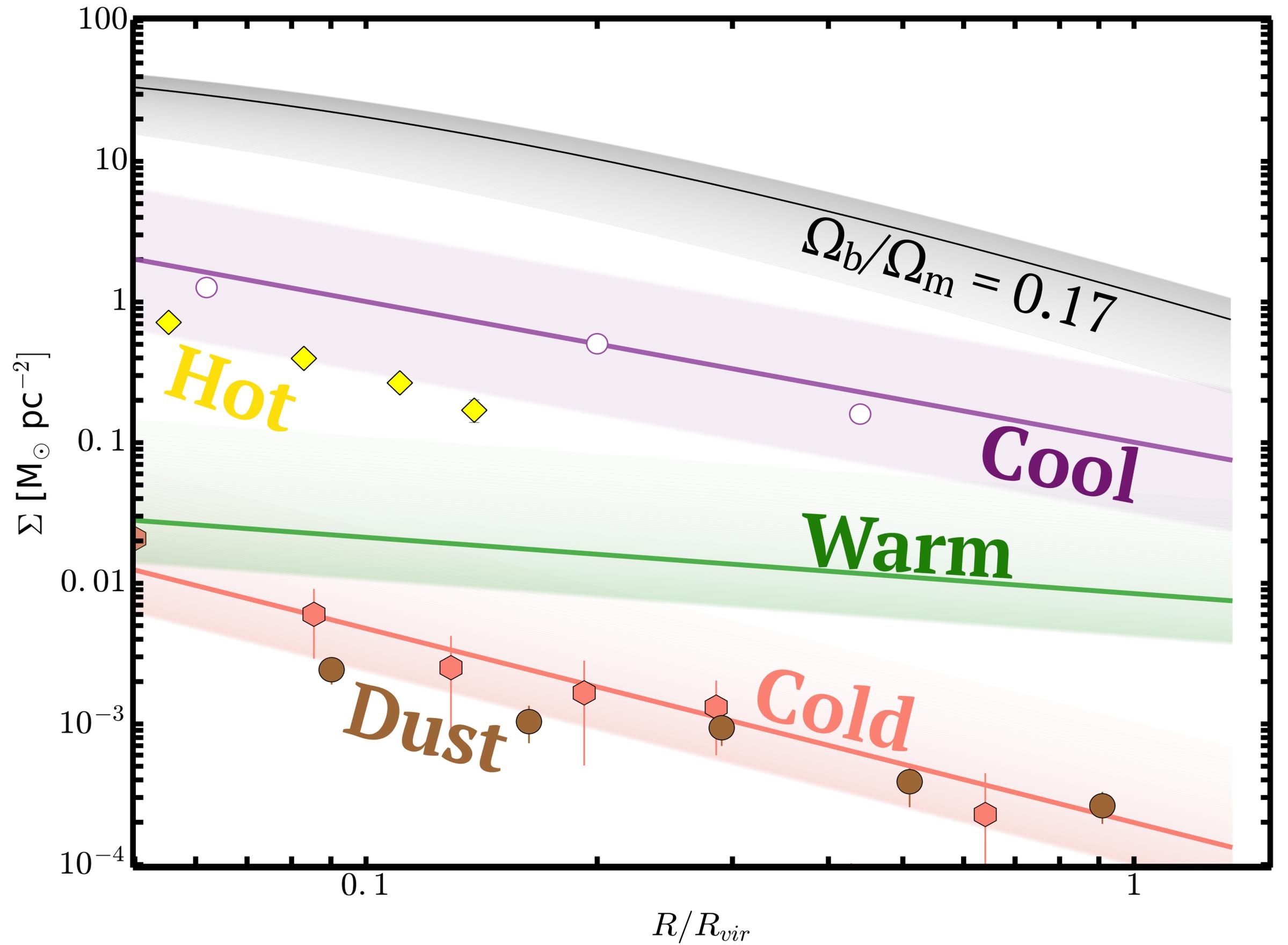
Low Ions Trace “Warm” Gas

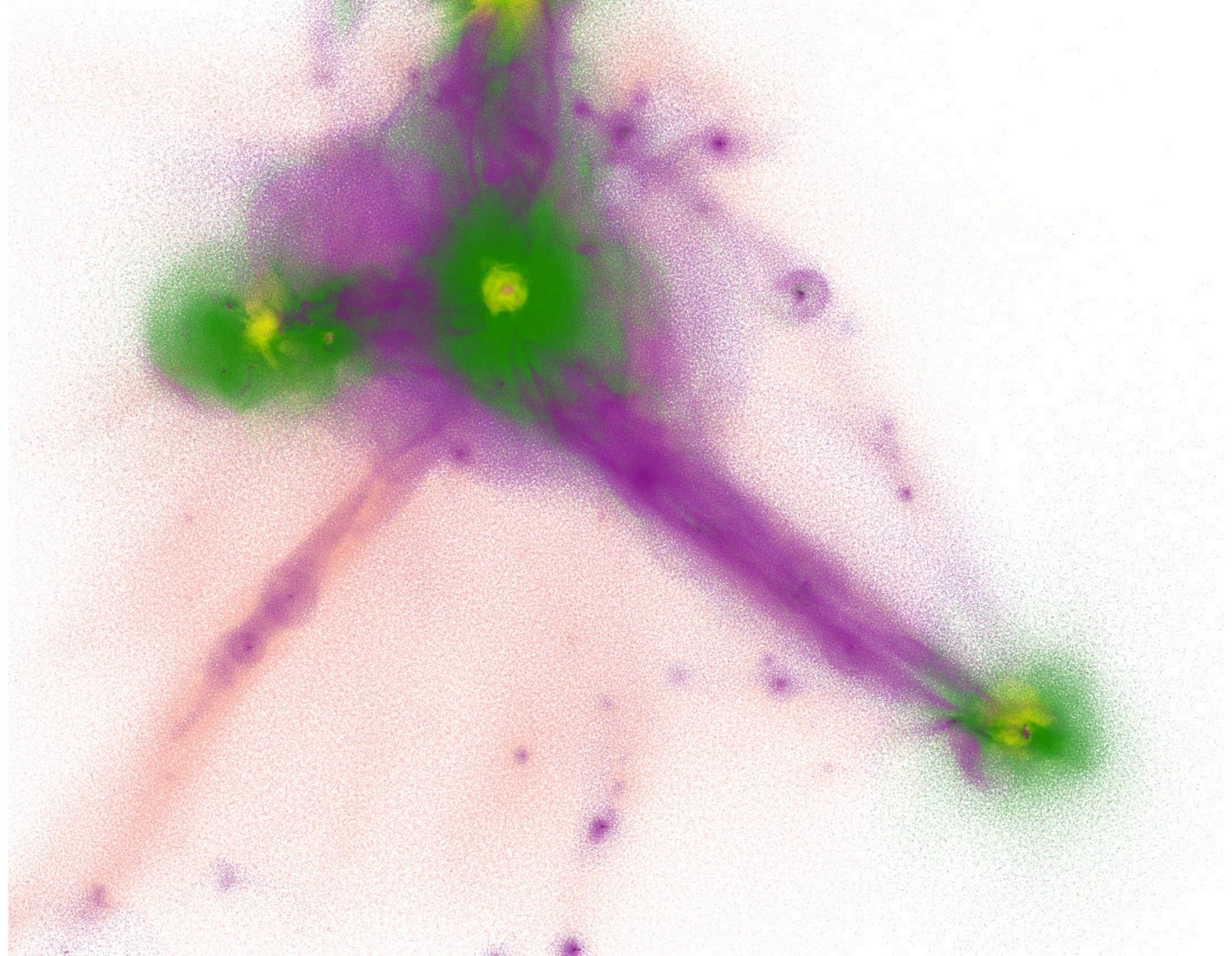


Cold Gas and Dust

Peek et al. (2015)
reddening of "standard crayon" galaxies.

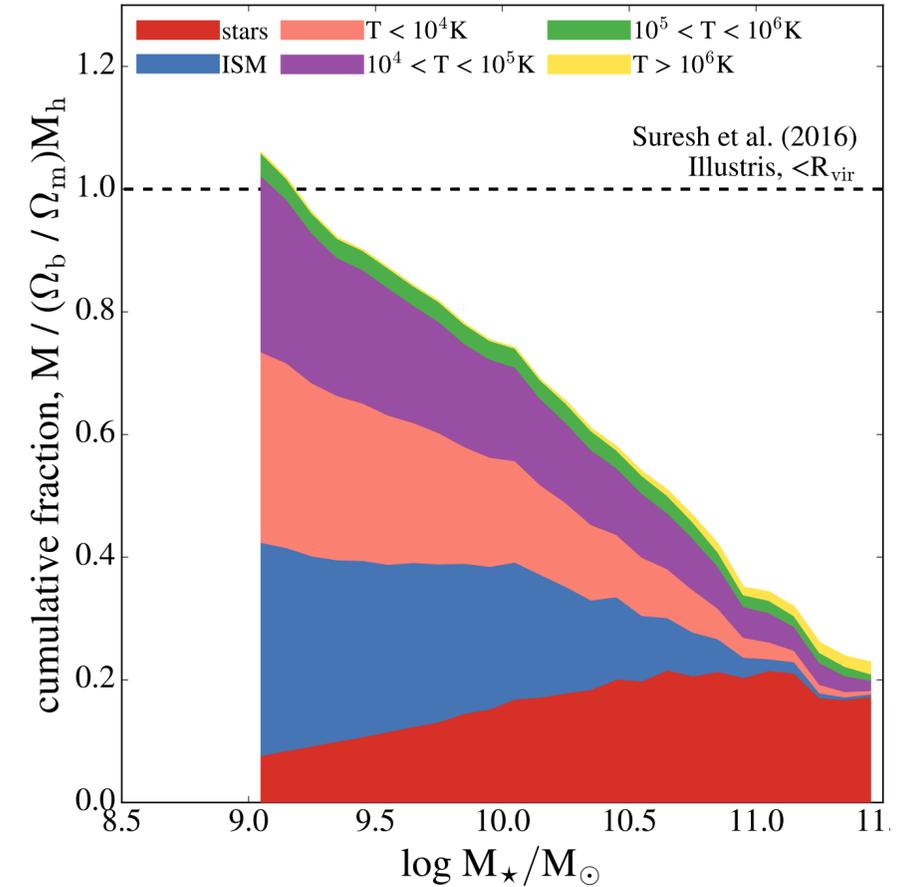
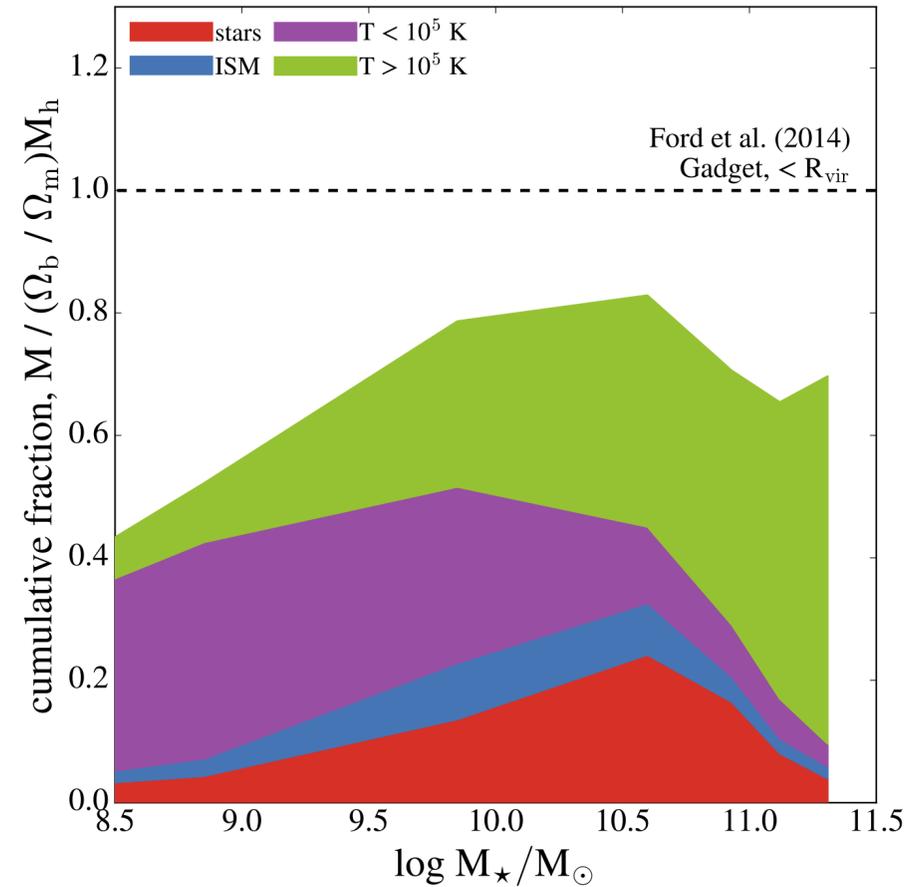
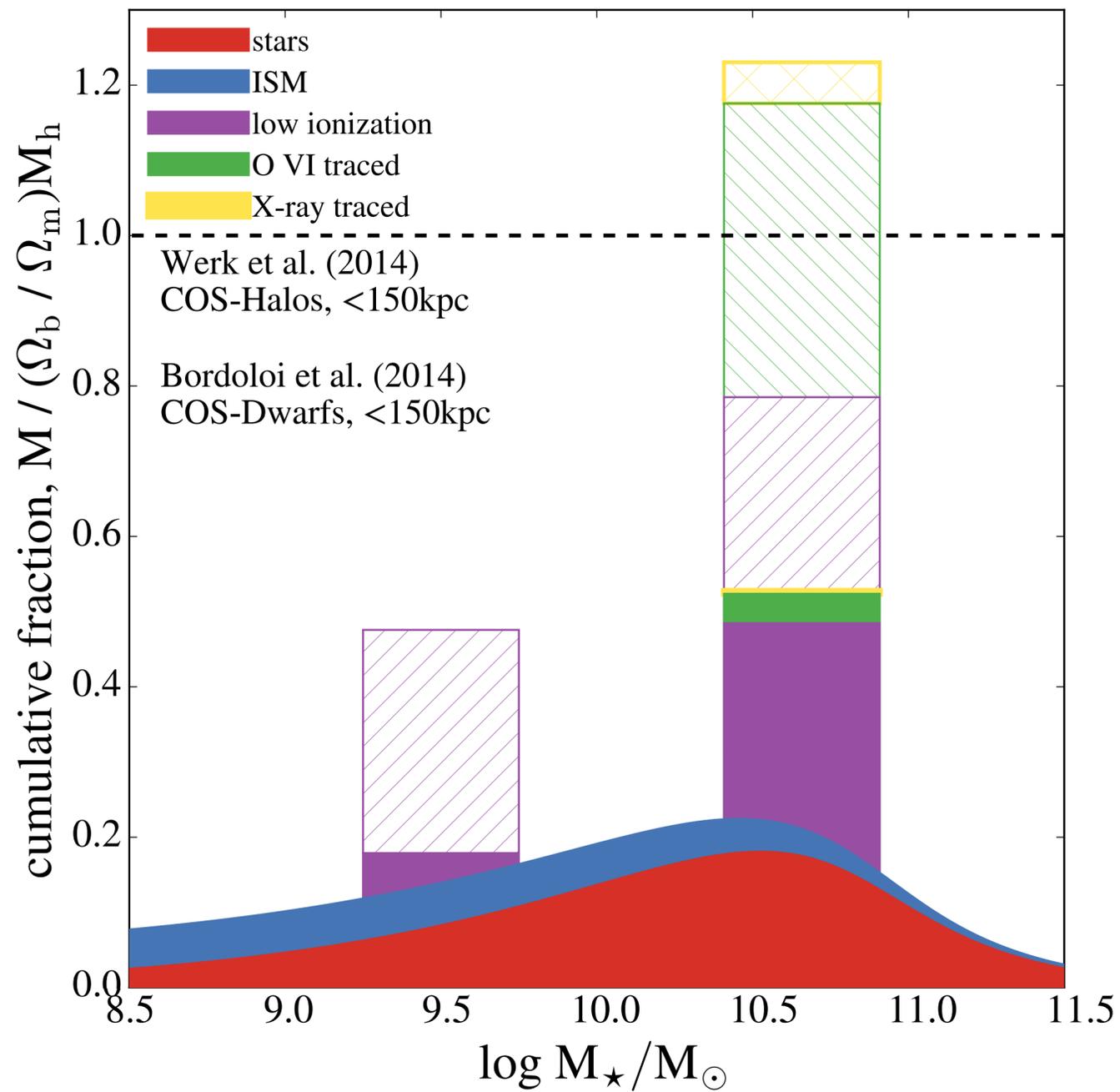






We now have a characterization of the mean surface density profile for the CGM of L^* galaxies (2010-now).

Baryon Census

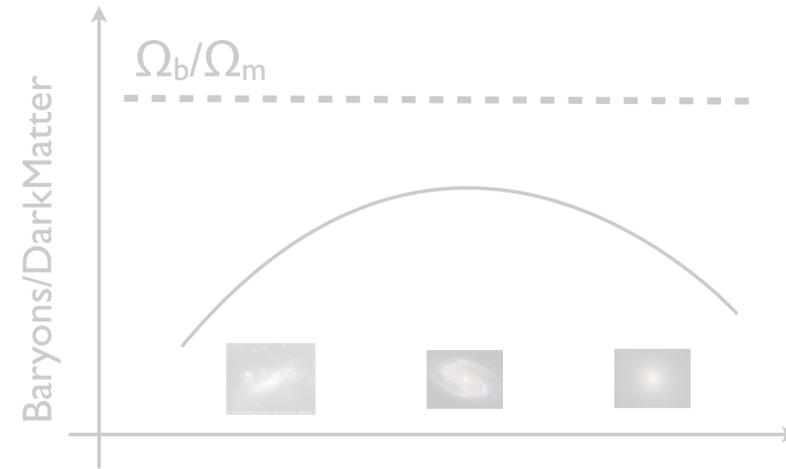


Nearly complete at L^*

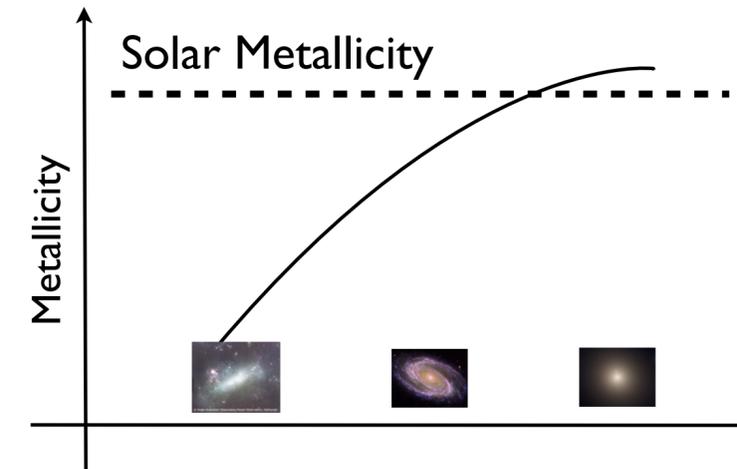
Still working on $< L^*$

Can constrain models,
but perhaps not very well at
the current level of precision.

Fundamental Problems in Galaxy Evolution

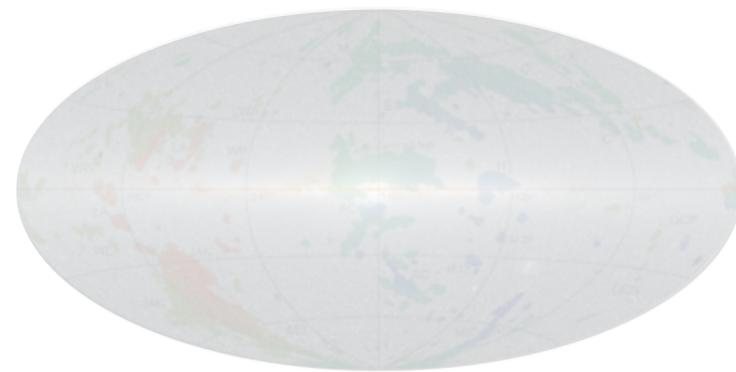


Why do galaxies appear to lack their full share of baryons?

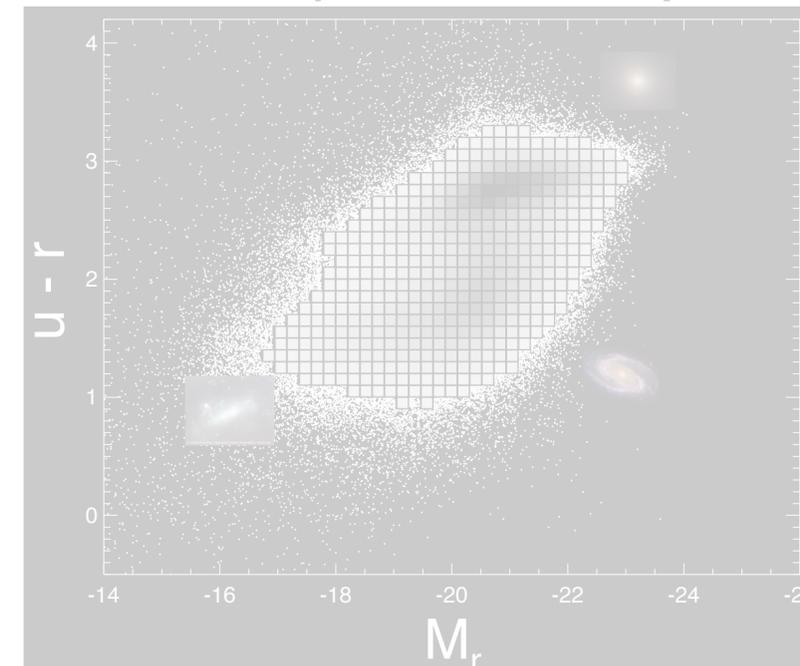


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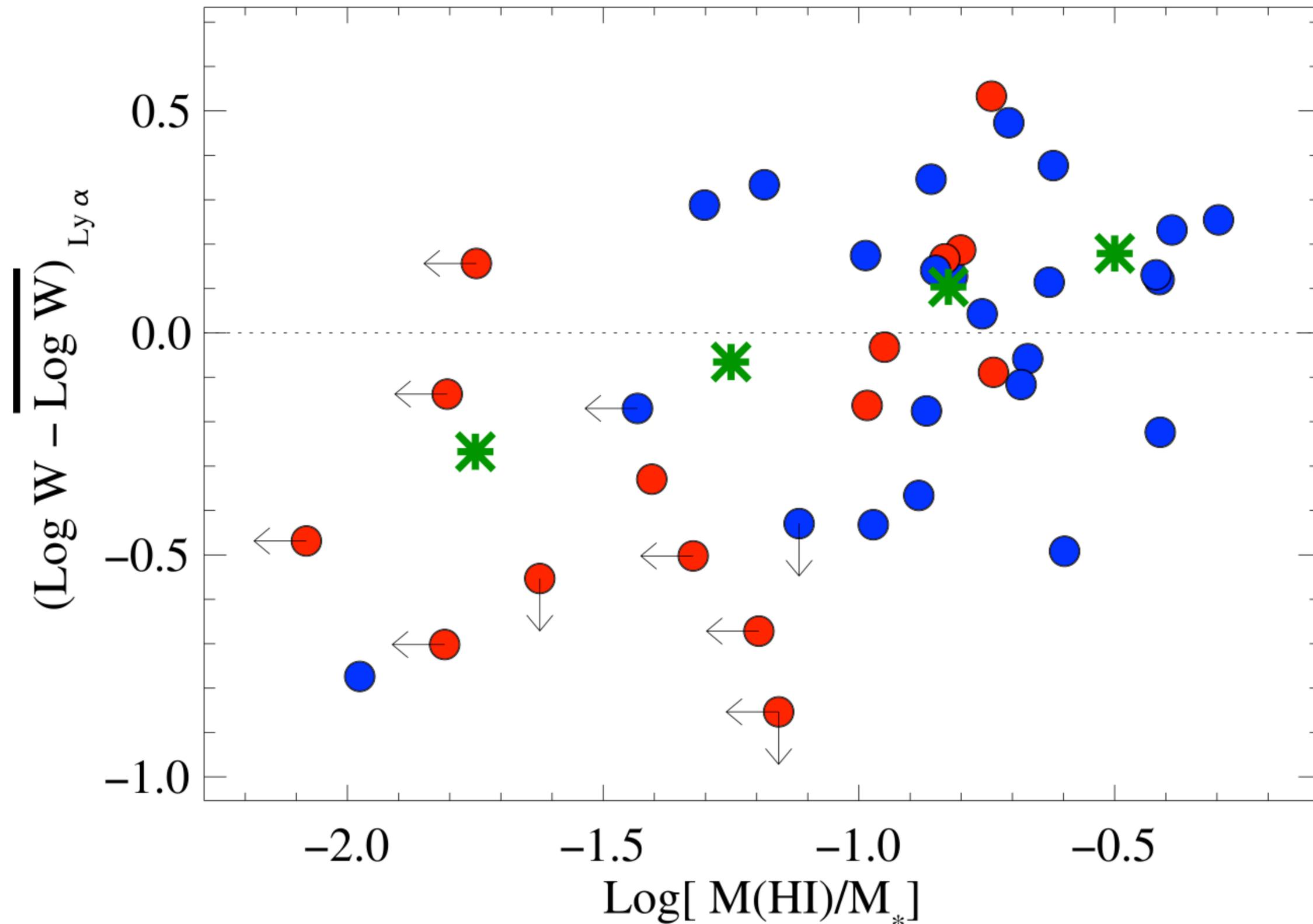
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Accretion vs. Feedback?

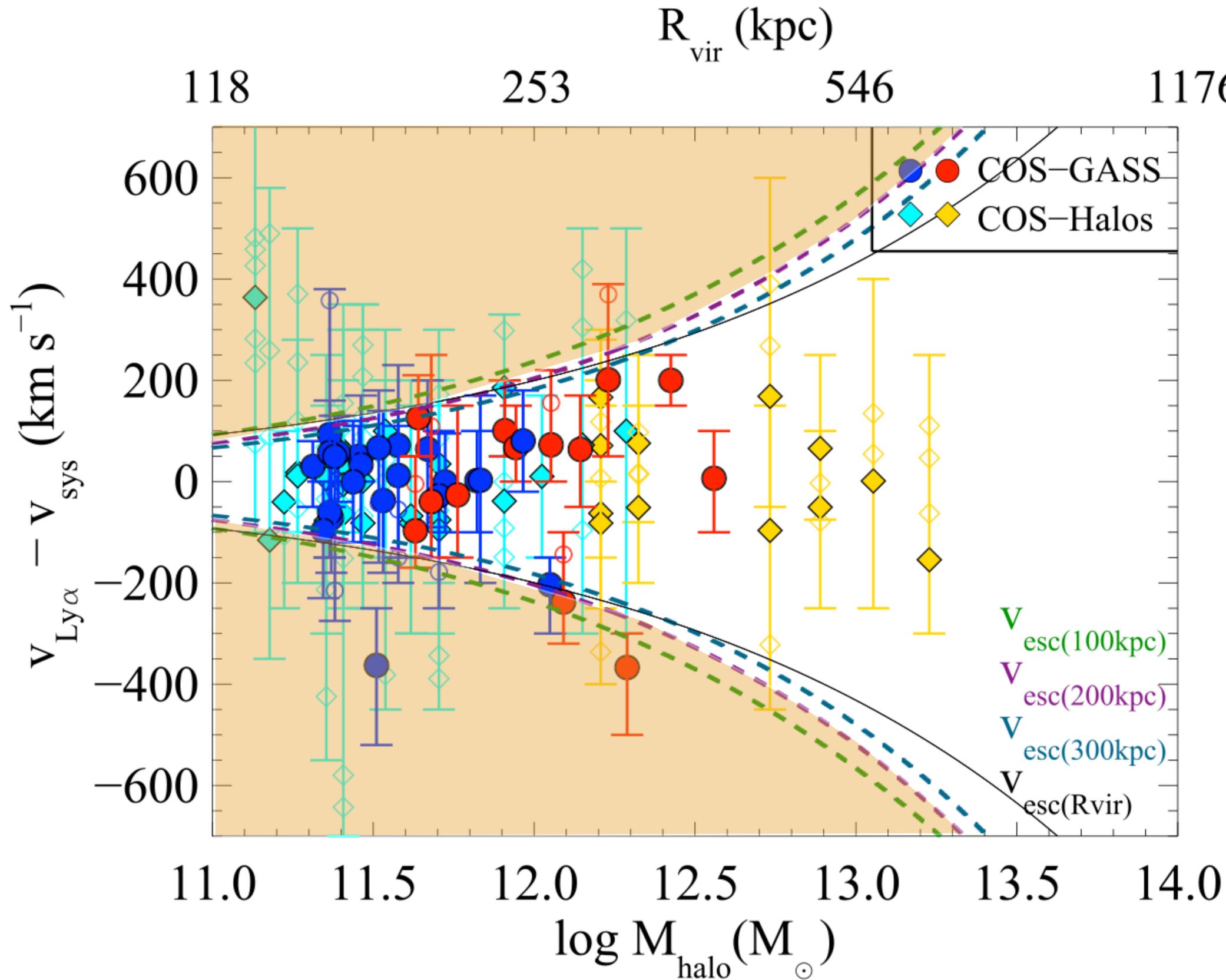


**Clues to
Accretion**

**more ISM
means
more CGM**

Plot by Borthakur et al. (2015; COS-GASS)

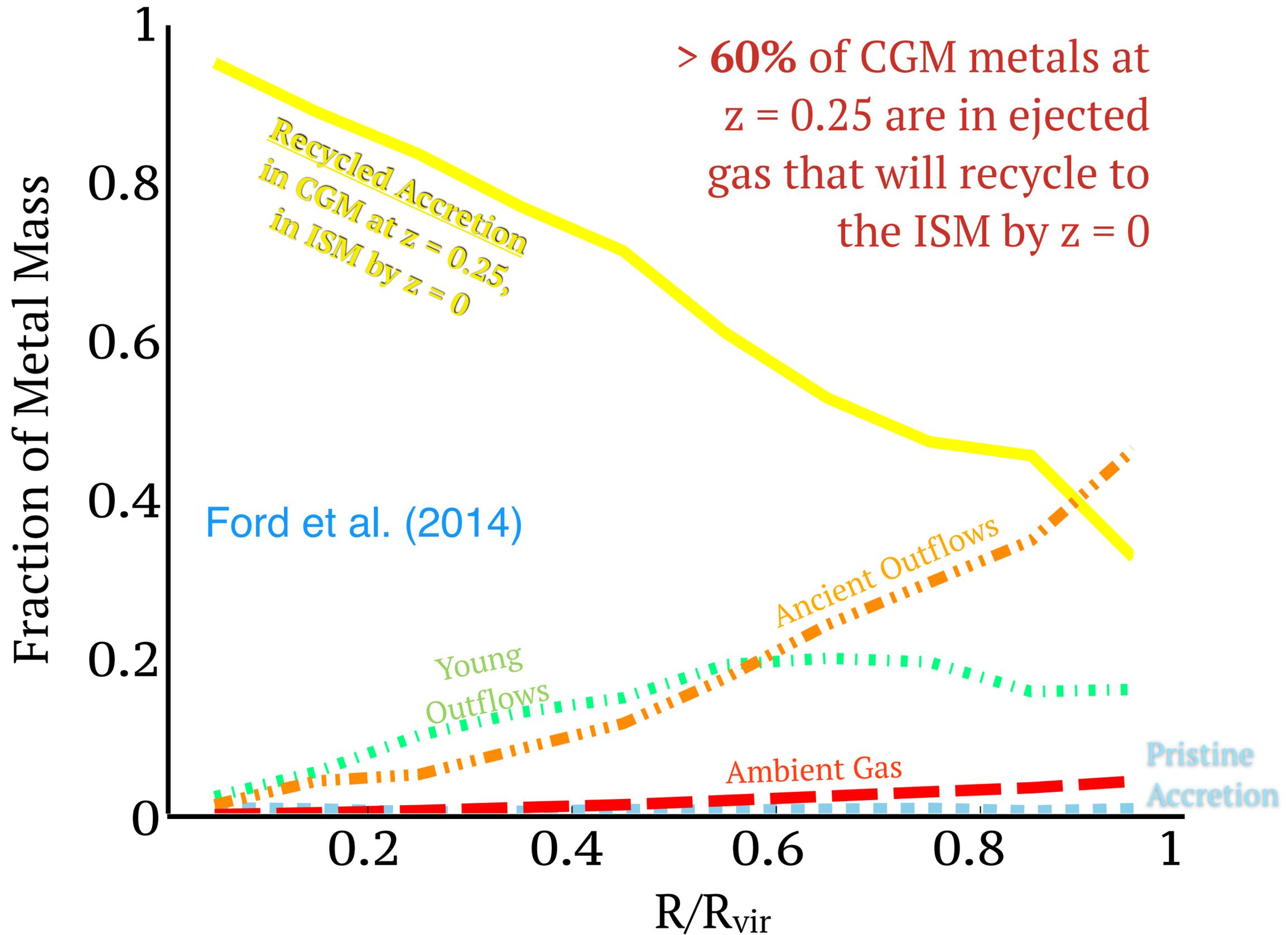
Clues to Accretion



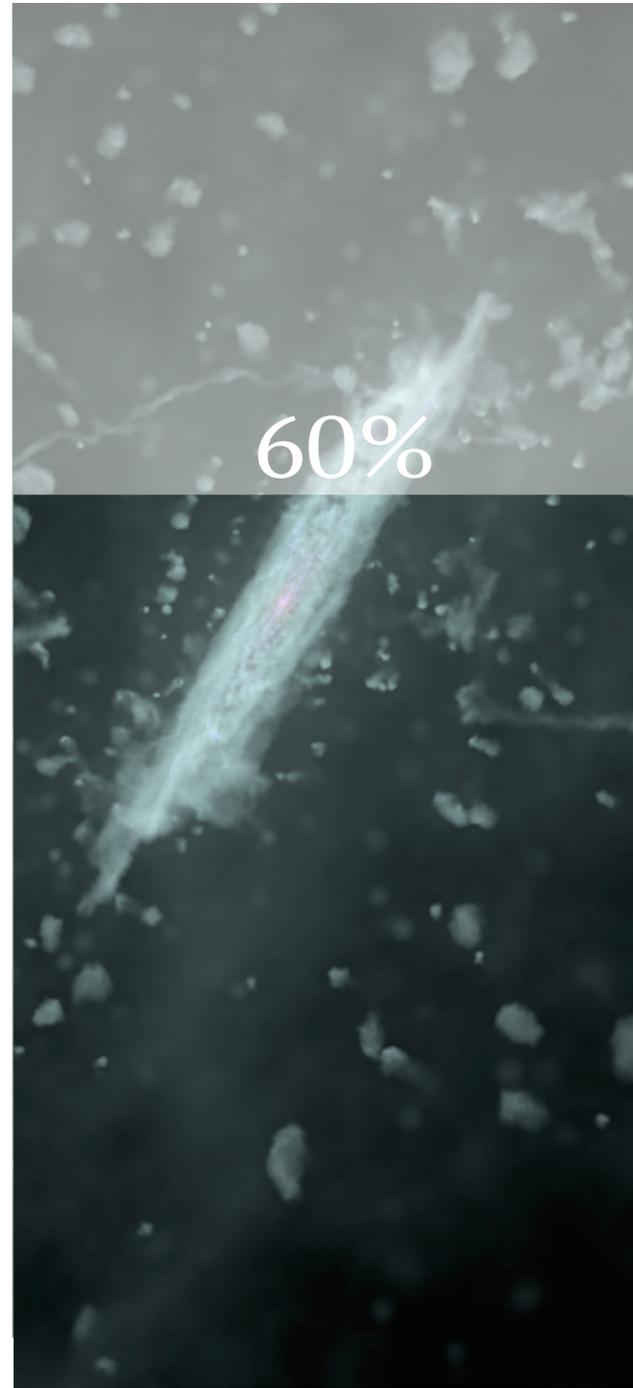
Nearly all the mass traced by HI is **BOUND**

A large mass of gas and metals at sub-escape velocity implies **RECYCLING**

Plot by Borthakur et al. (2015; COS-GASS)



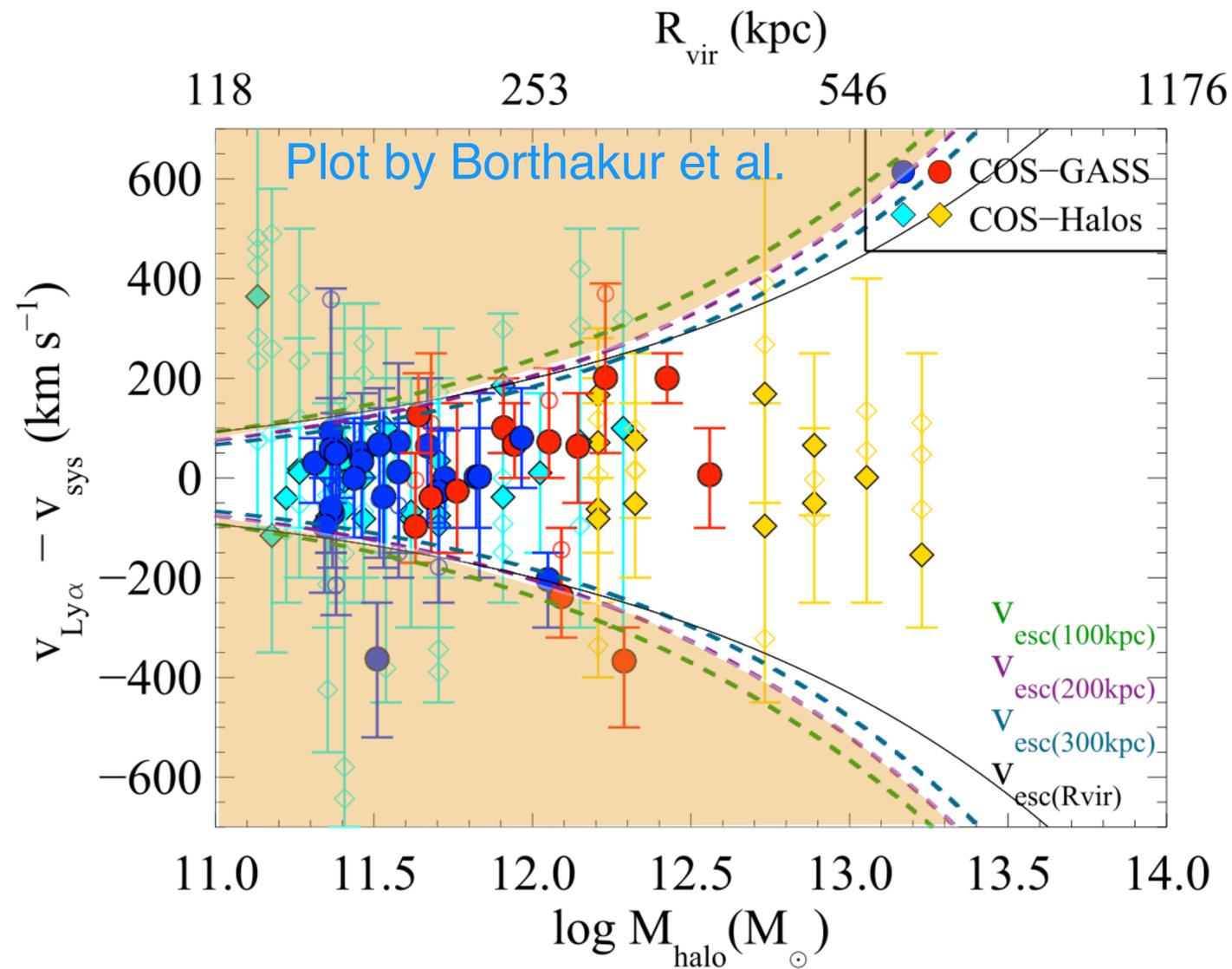
Fraction of gas in CGM at 3 Gyr ago that will recycle by $z = 0$



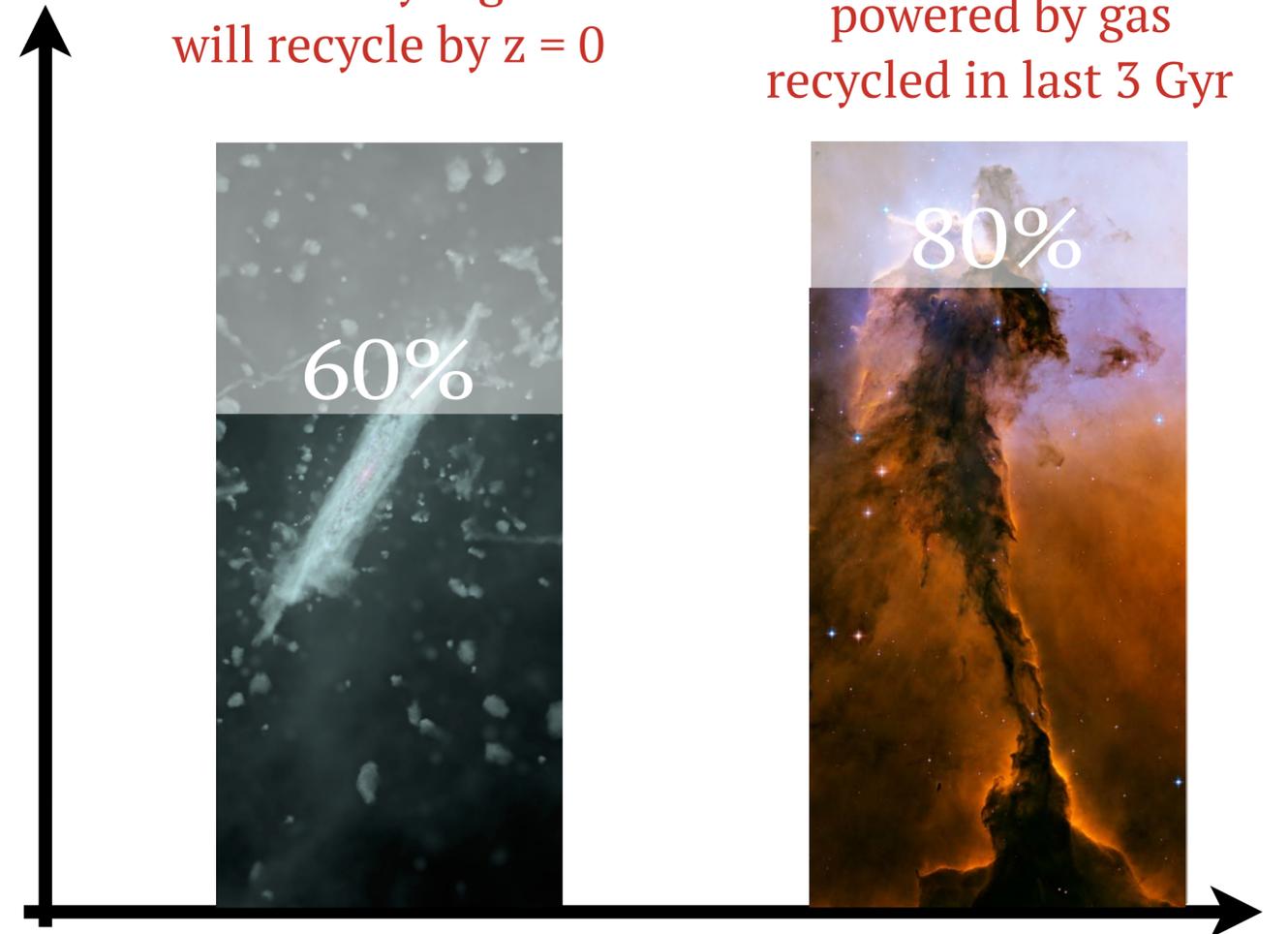
Fraction of present star formation powered by gas recycled in last 3 Gyr



forged connection one

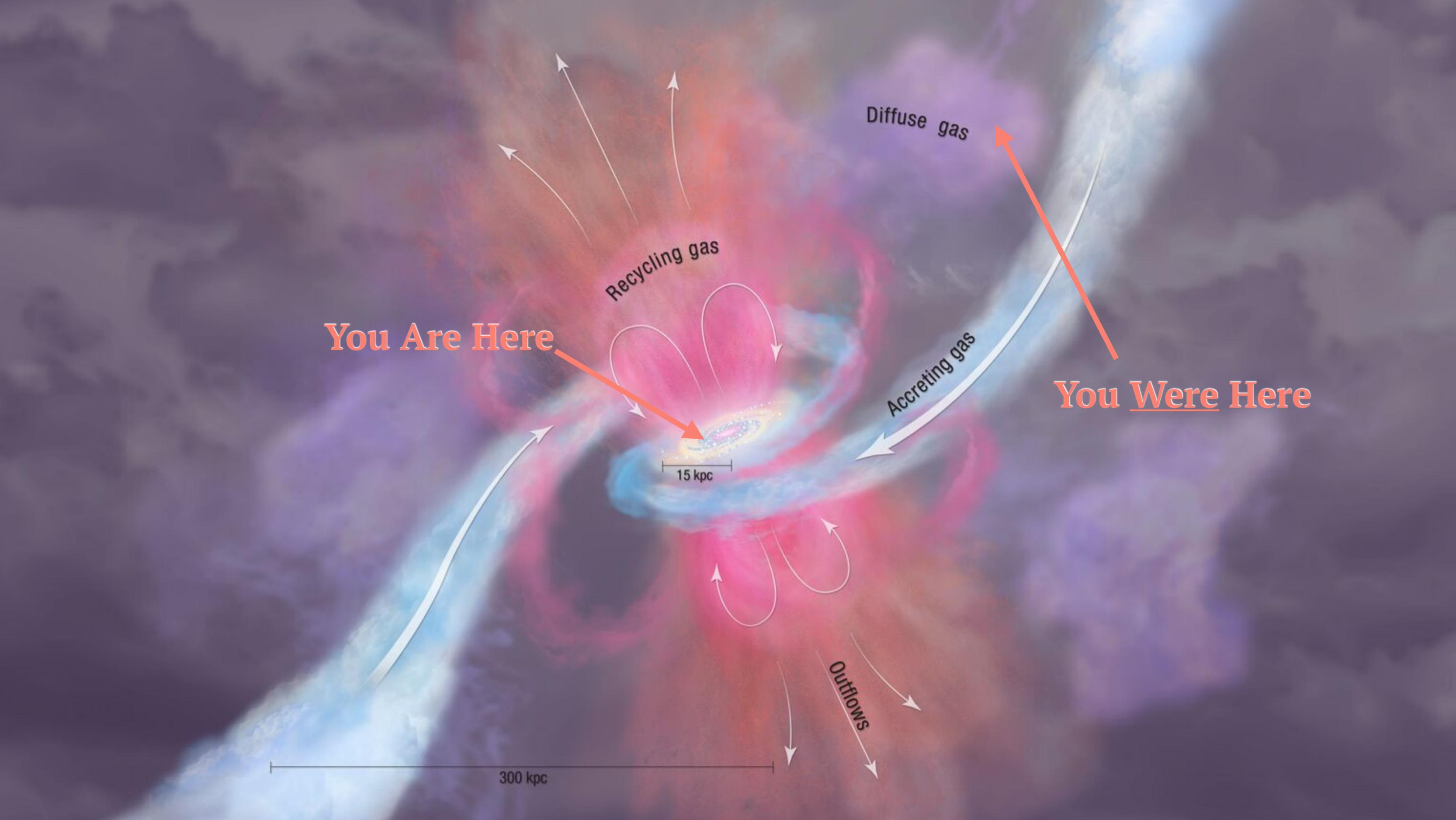


Fraction of gas in CGM at 3 Gyr ago that will recycle by $z = 0$



Fraction of present star formation powered by gas recycled in last 3 Gyr

Recycling through the CGM is a big factor!



Diffuse gas

Recycling gas

Accreting gas

You Are Here

You Were Here

15 kpc

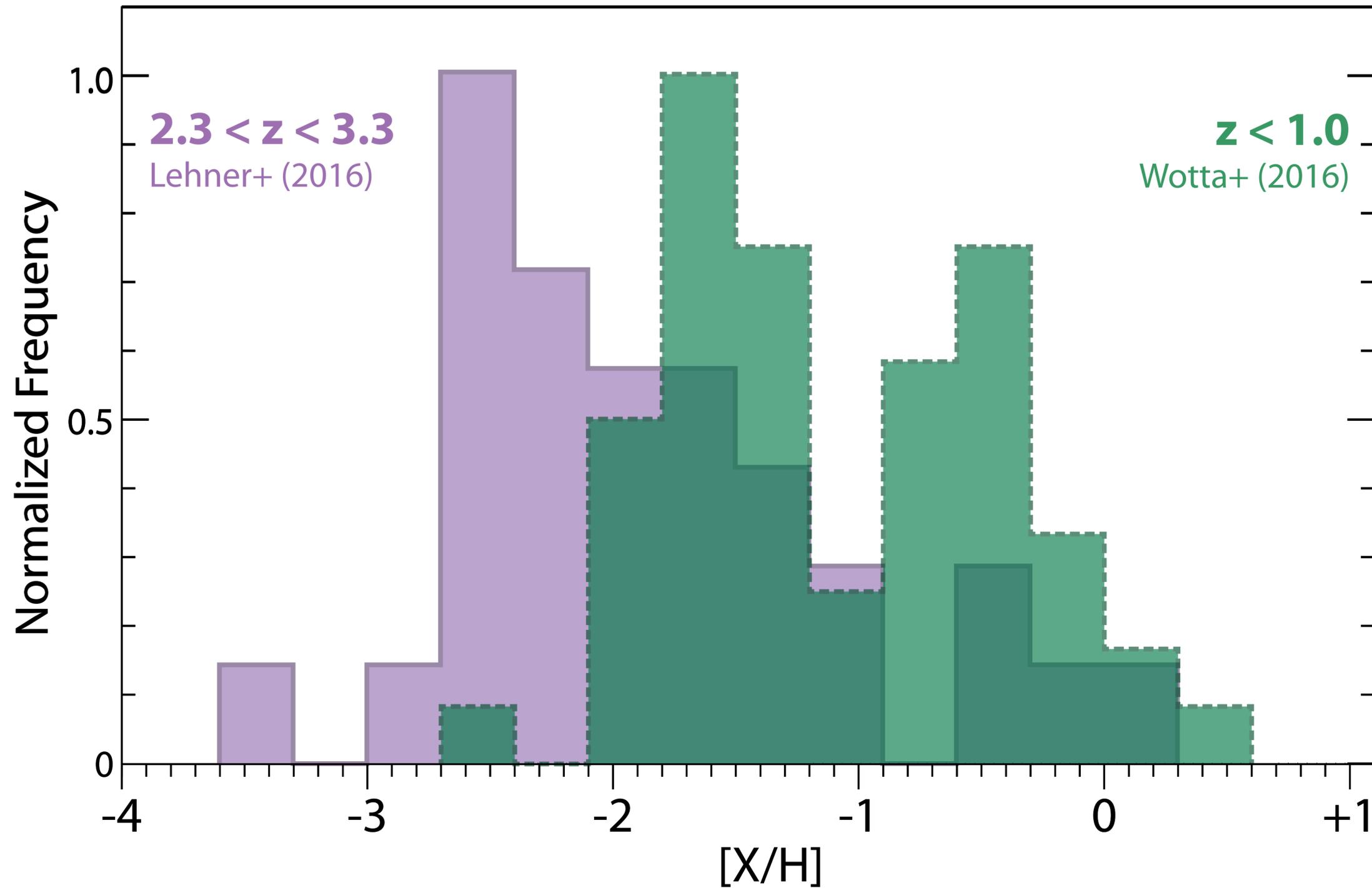
Outflows

300 kpc

To Understand Feedback, Follow the Metals

a.k.a. “Metals: the cause of, and solution to, all our problems.”

Feedback Gotta Feed Back

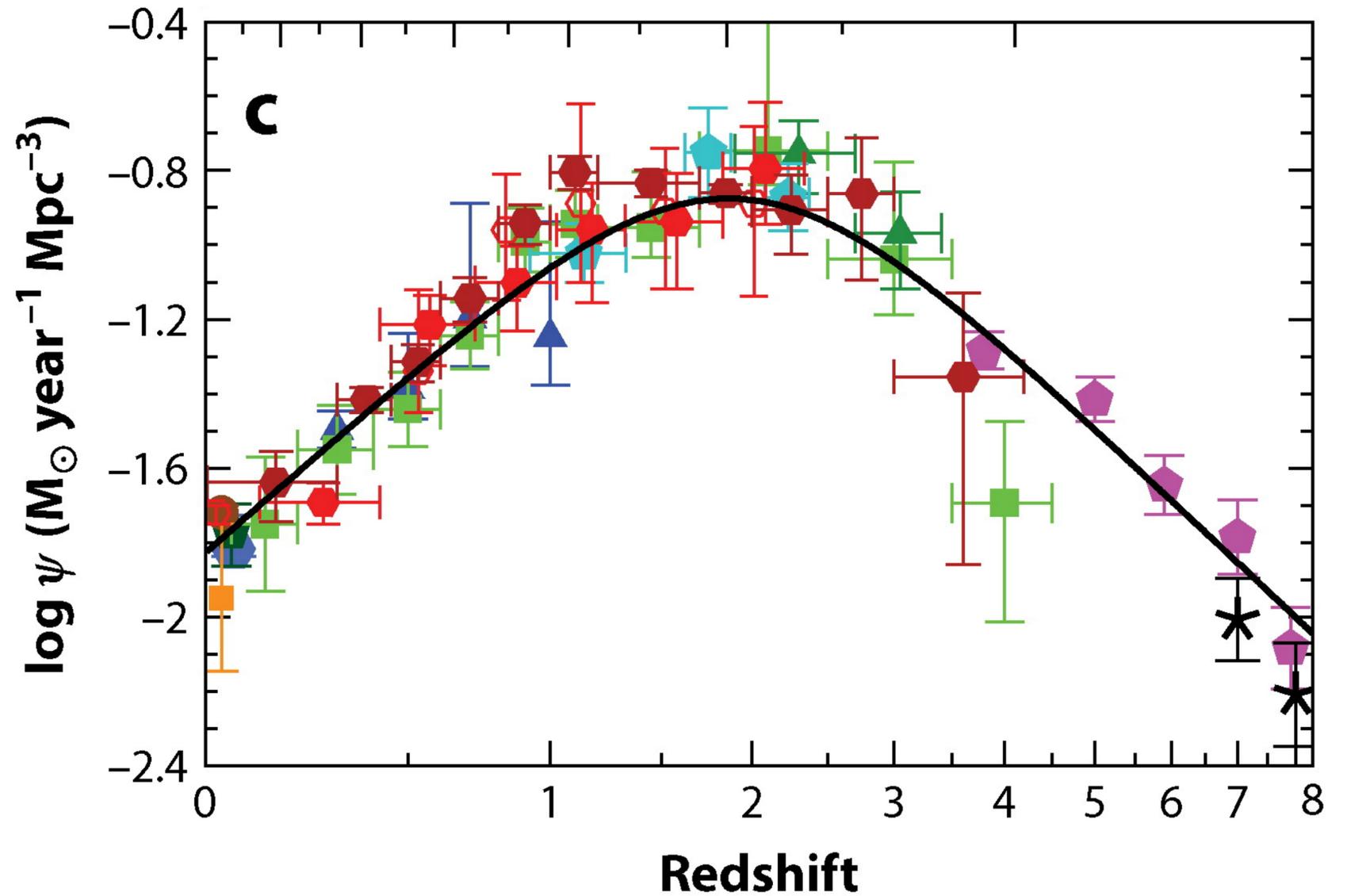
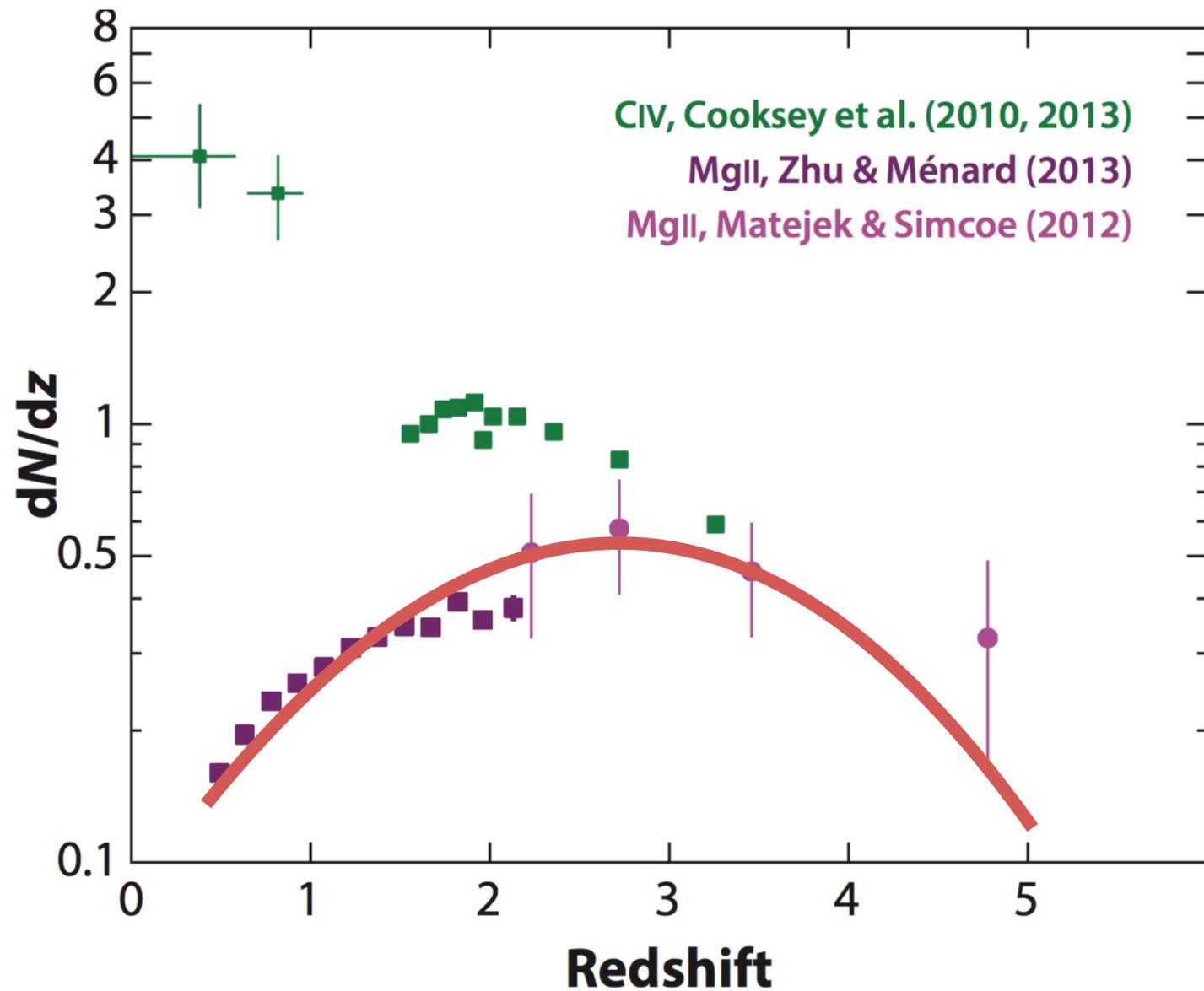


Metallicity of dense CGM is low at $z > 2$.

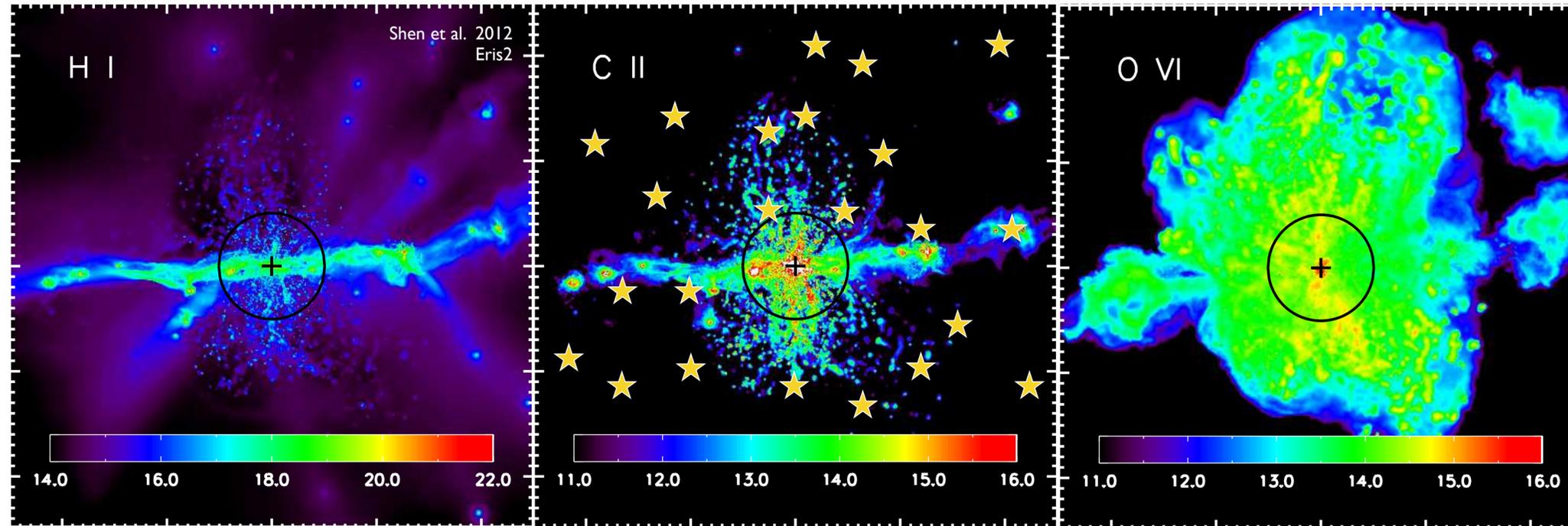
At low z , this distribution increases to higher metallicity, but...

Bimodality implies accretion and feedback are about even?

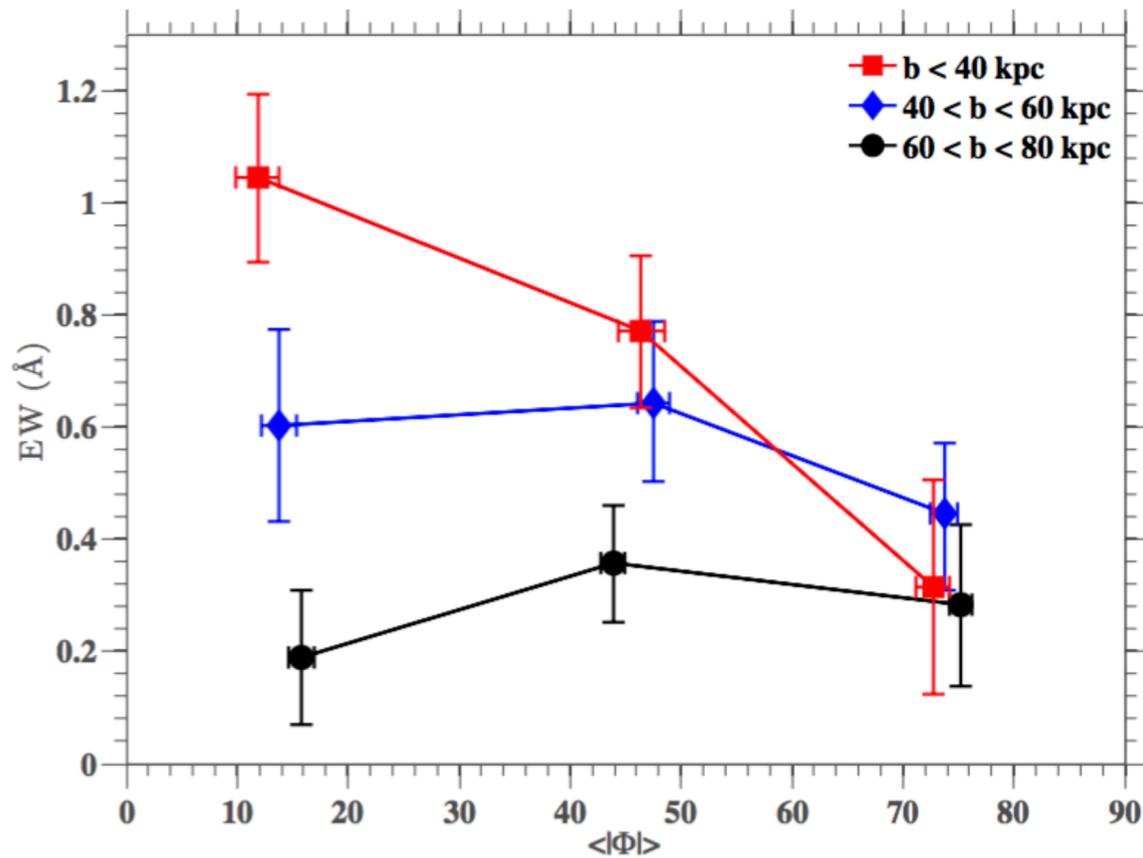
forged connection two



The CGM tracks with cosmic star formation!

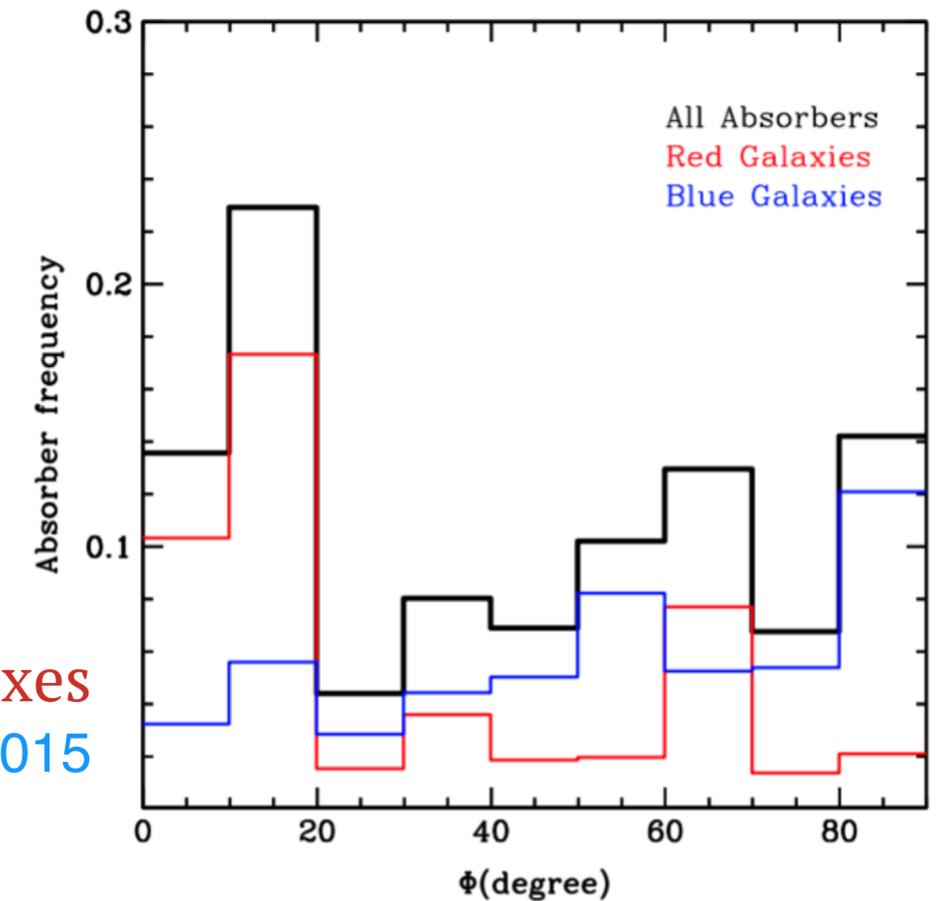


More clues
to feedback

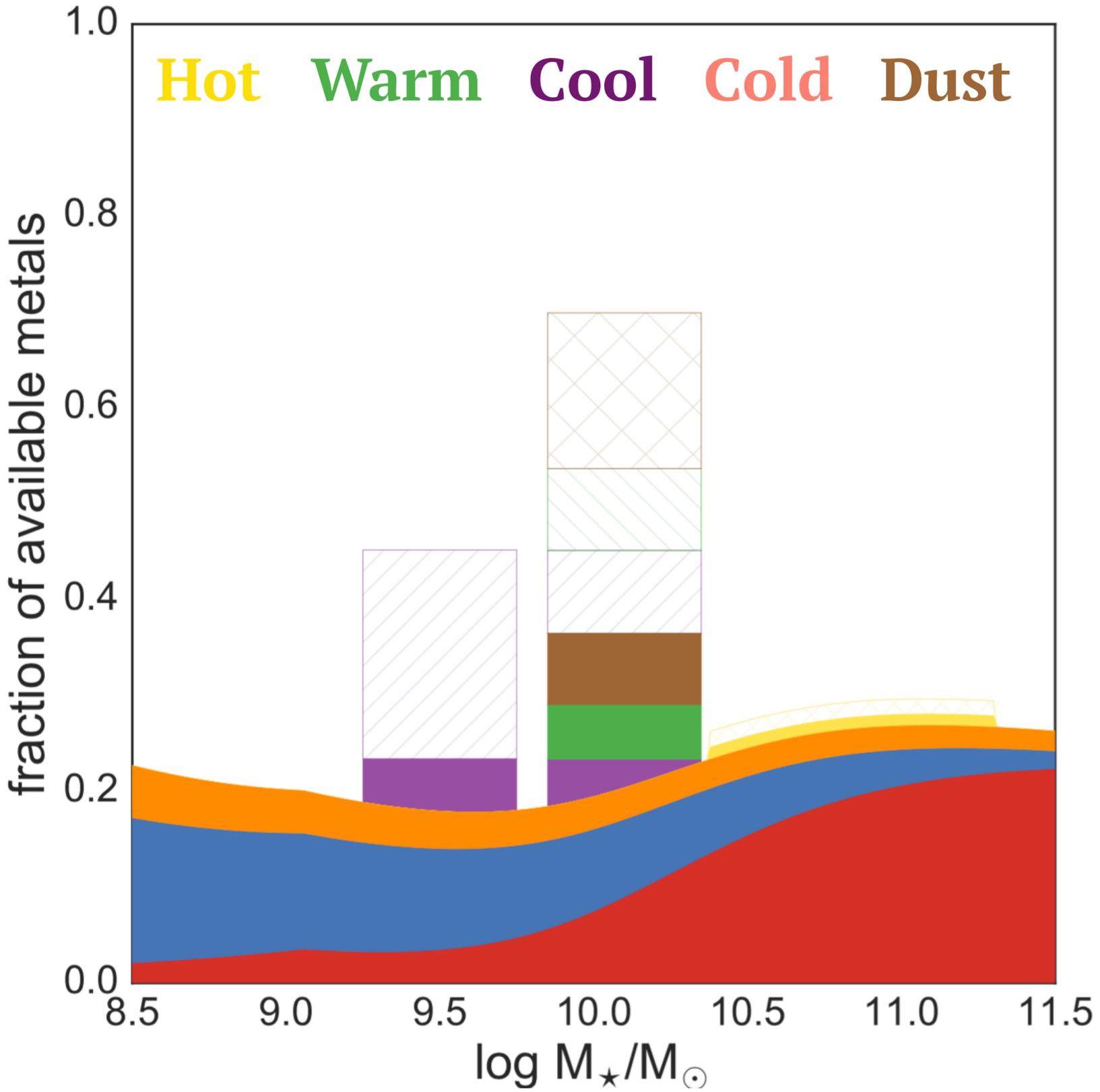


strong Mg II
prefers the semi-minor axis -
biconical outflows?
Bordoloi et al. 2011

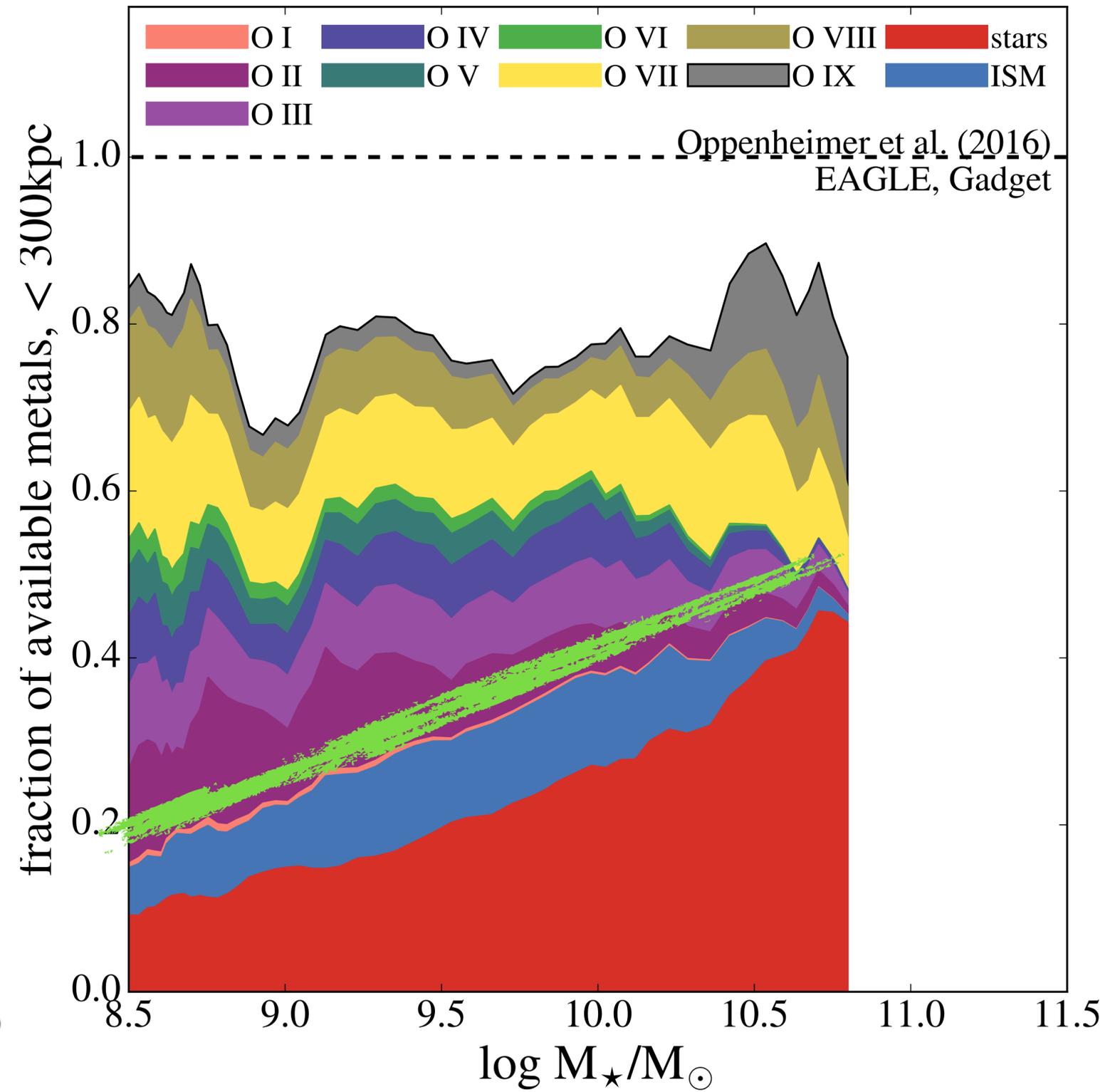
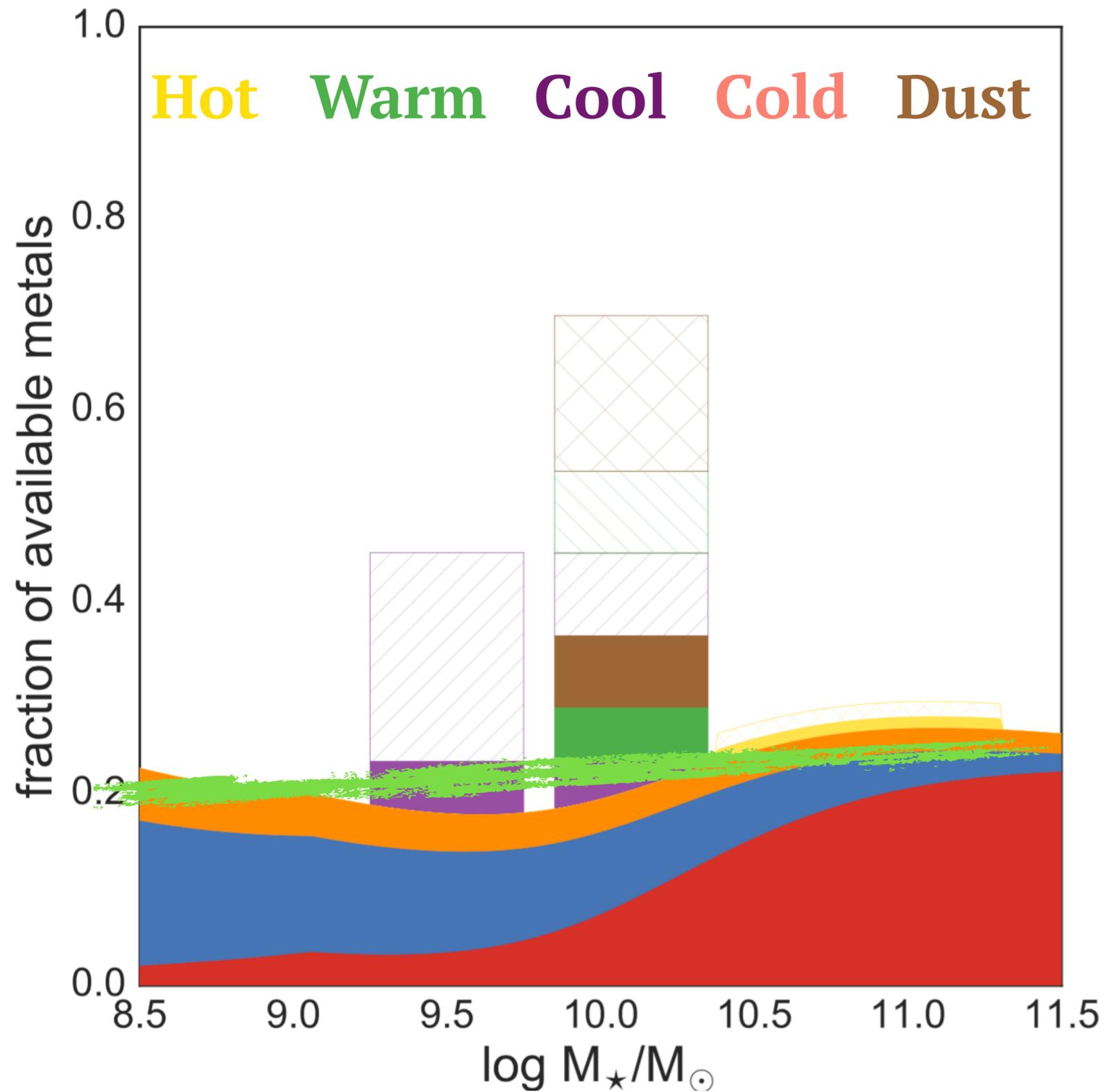
while O VI occurs along both axes
Kacprzak et al. 2015



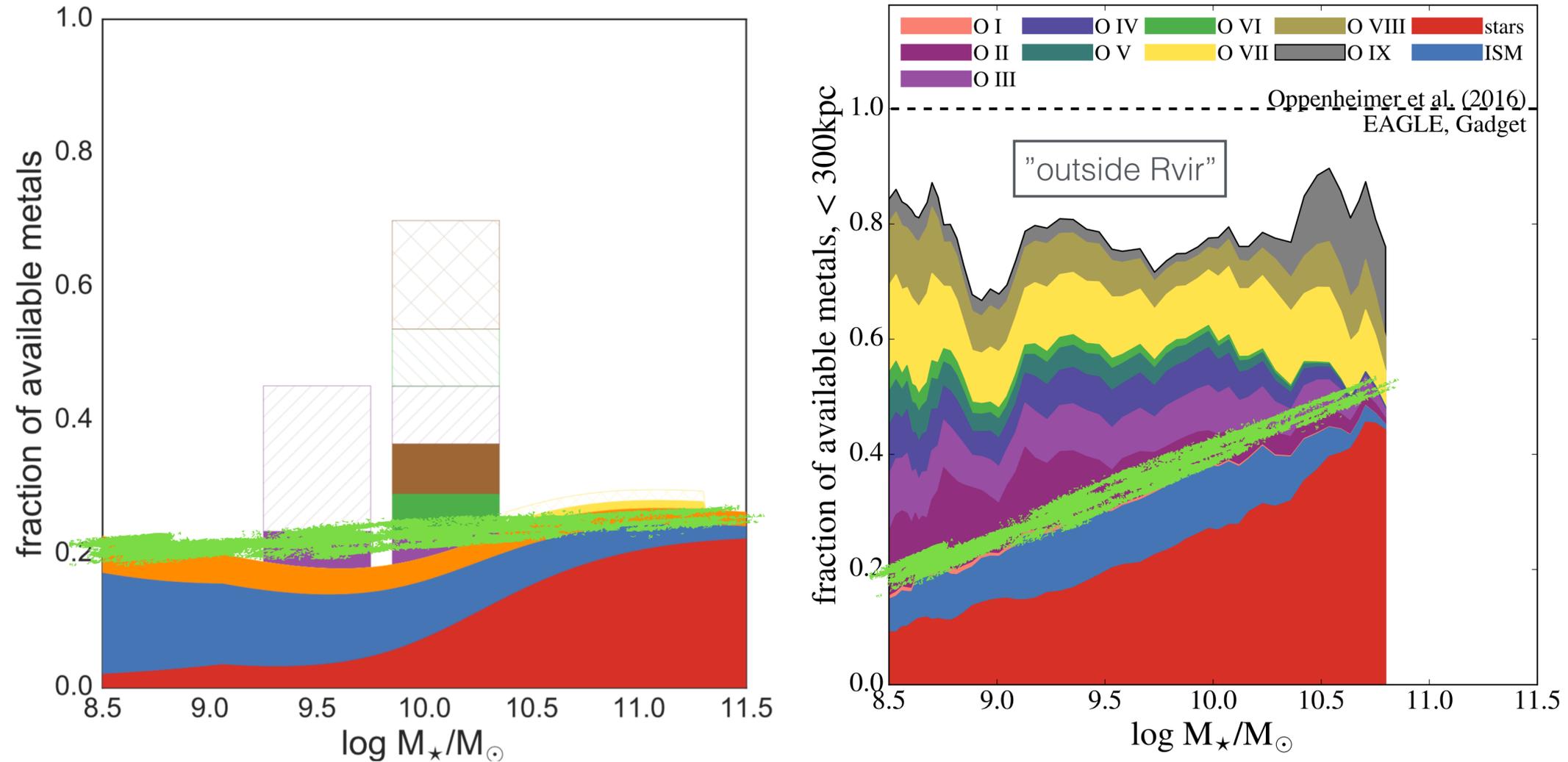
The Metals Census: Real and Mocked



The Metals Census: Real and Mocked

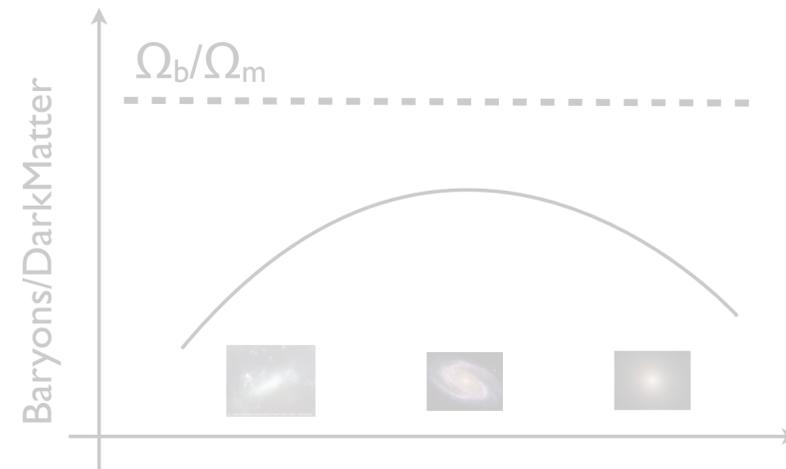


forged connection three

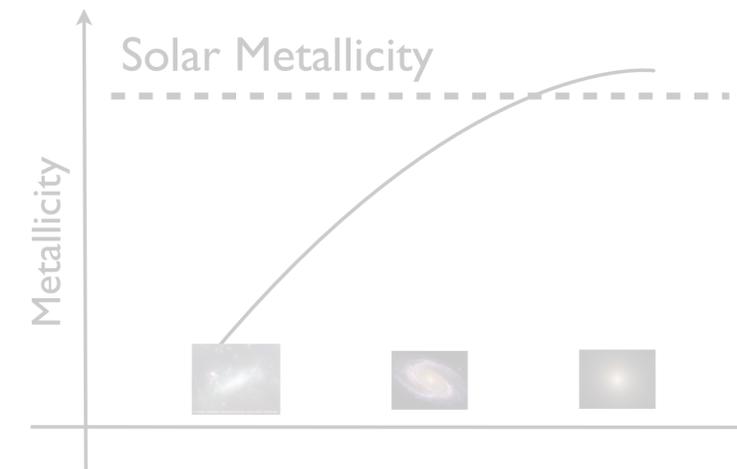


The CGM outweighs the ISM in metals!

Fundamental Problems in Galaxy Evolution

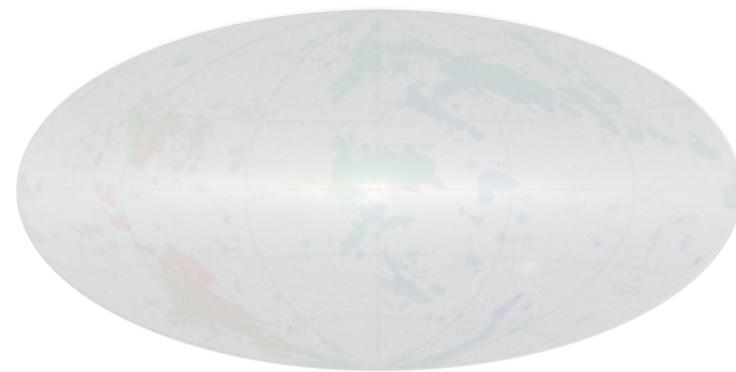


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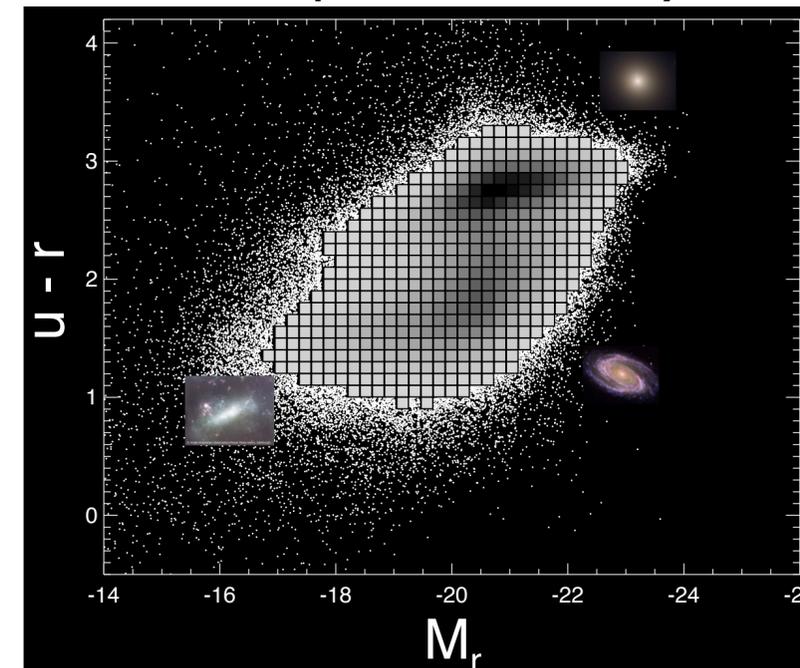


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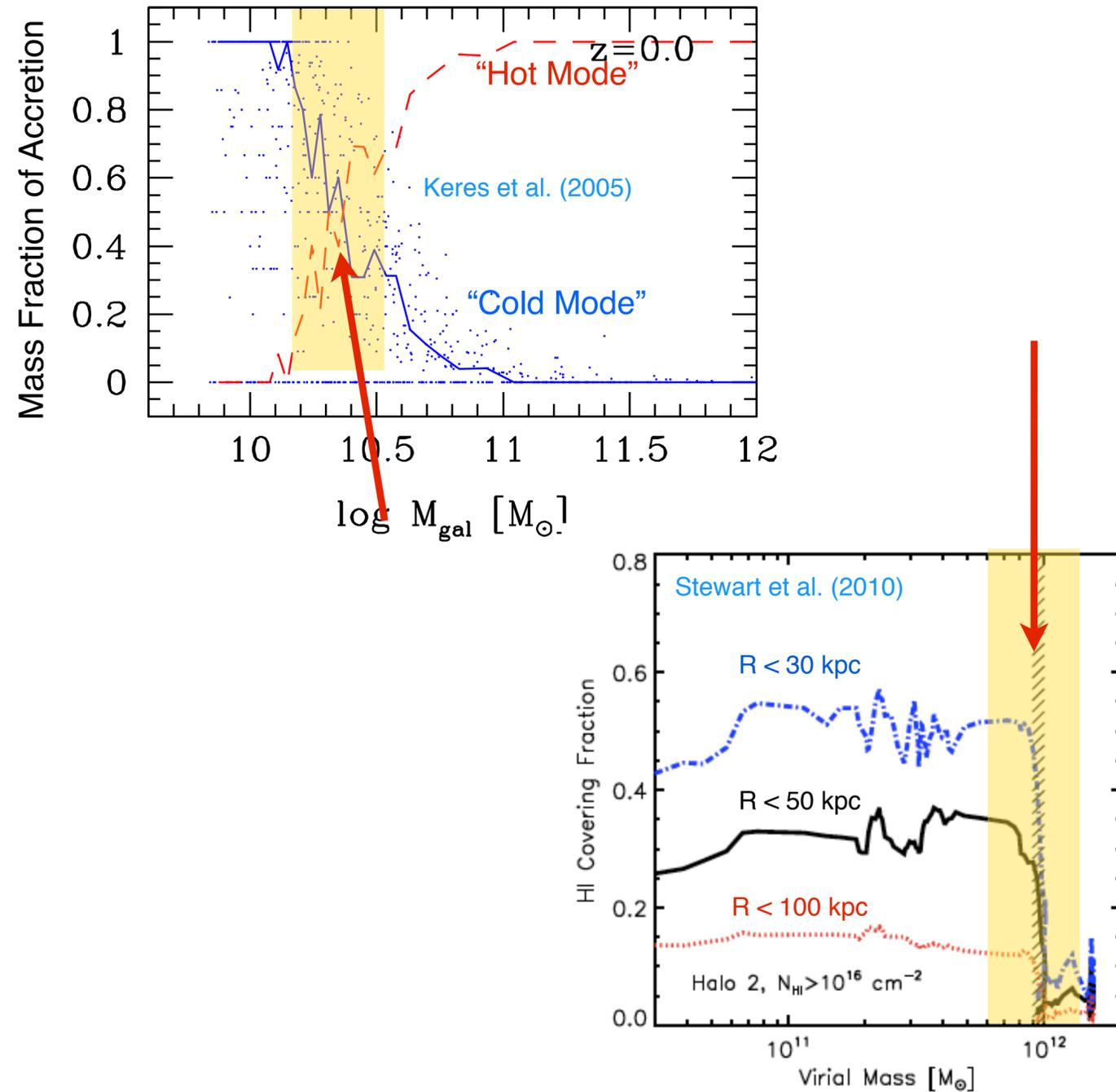


What quenches galaxies and keeps them that way?

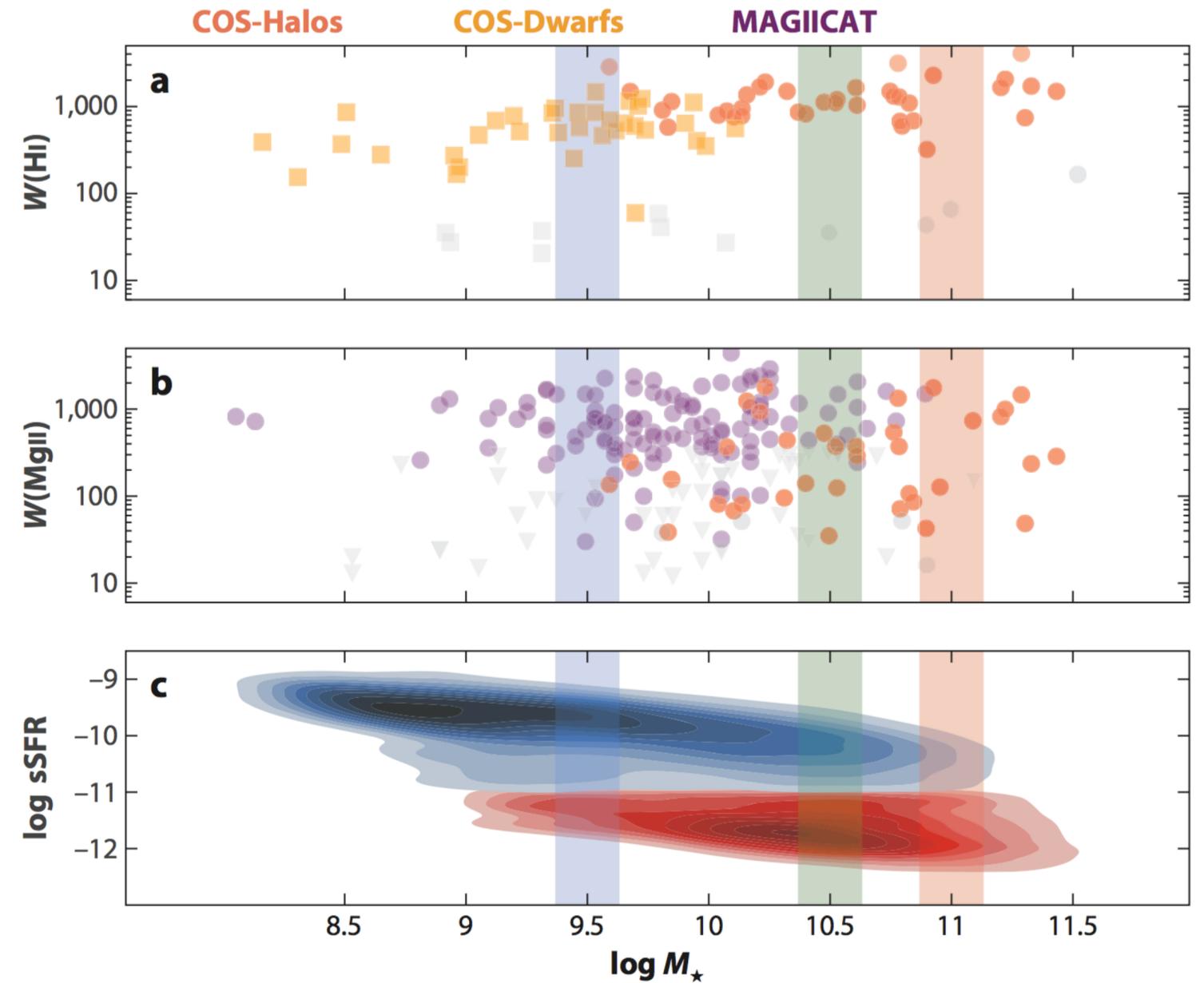


Quenching?

what was supposed to happen



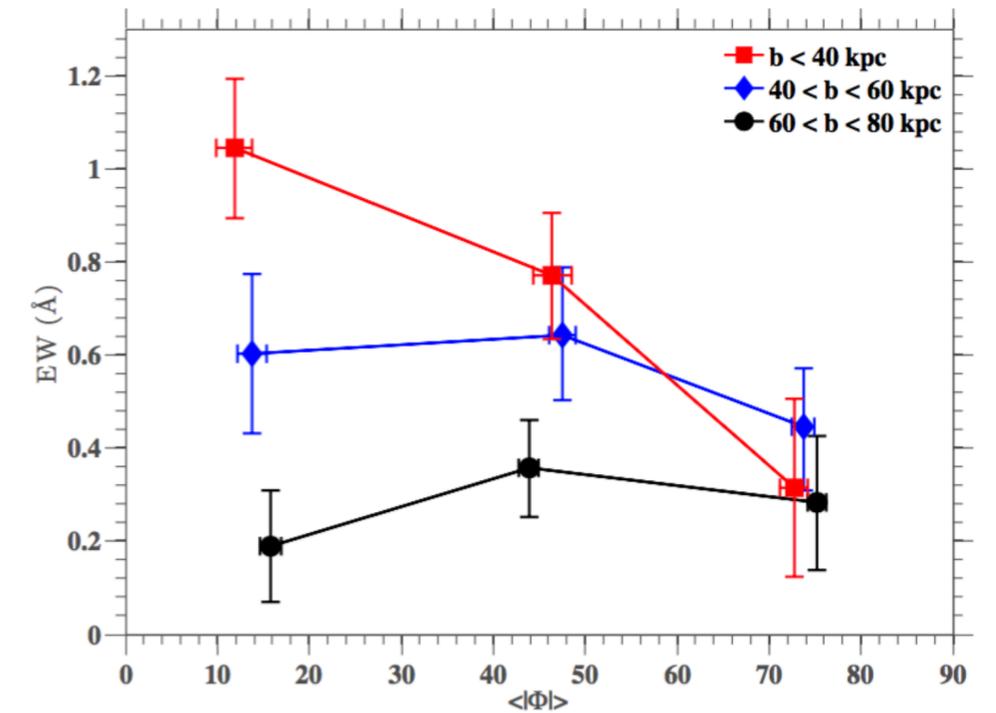
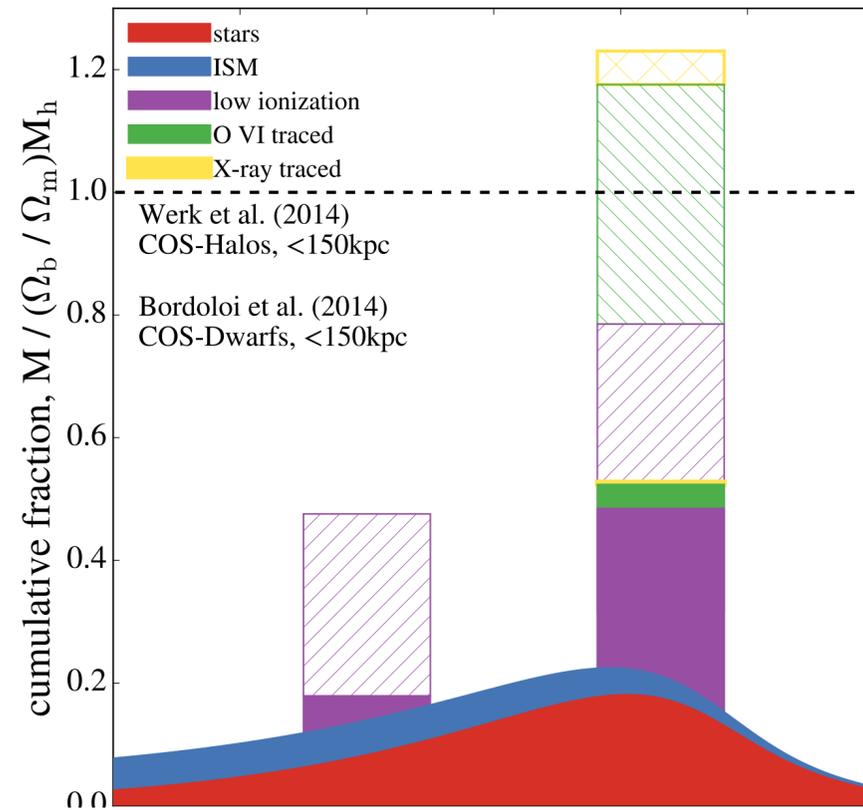
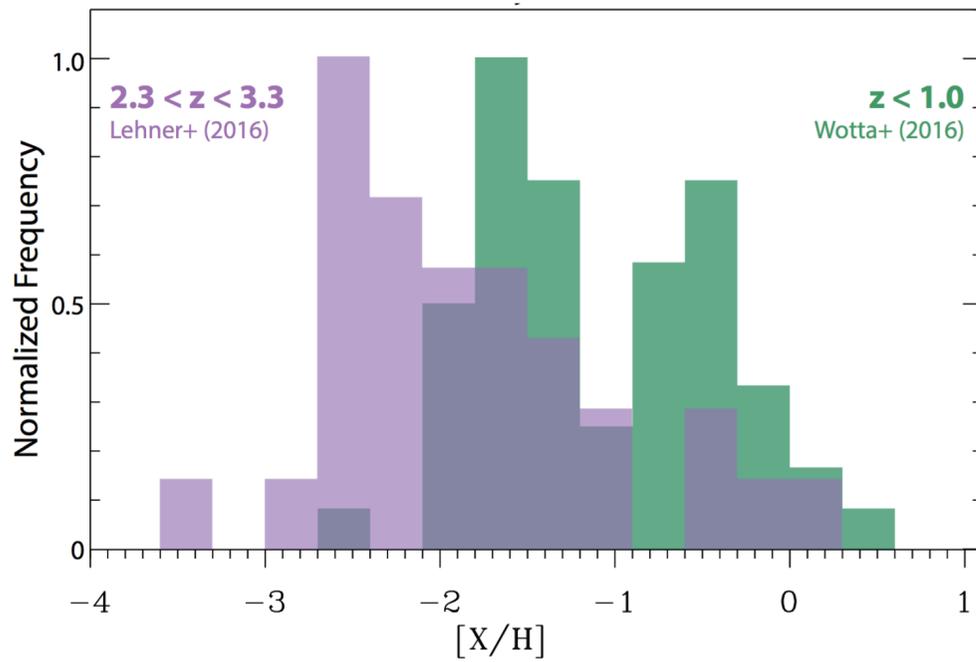
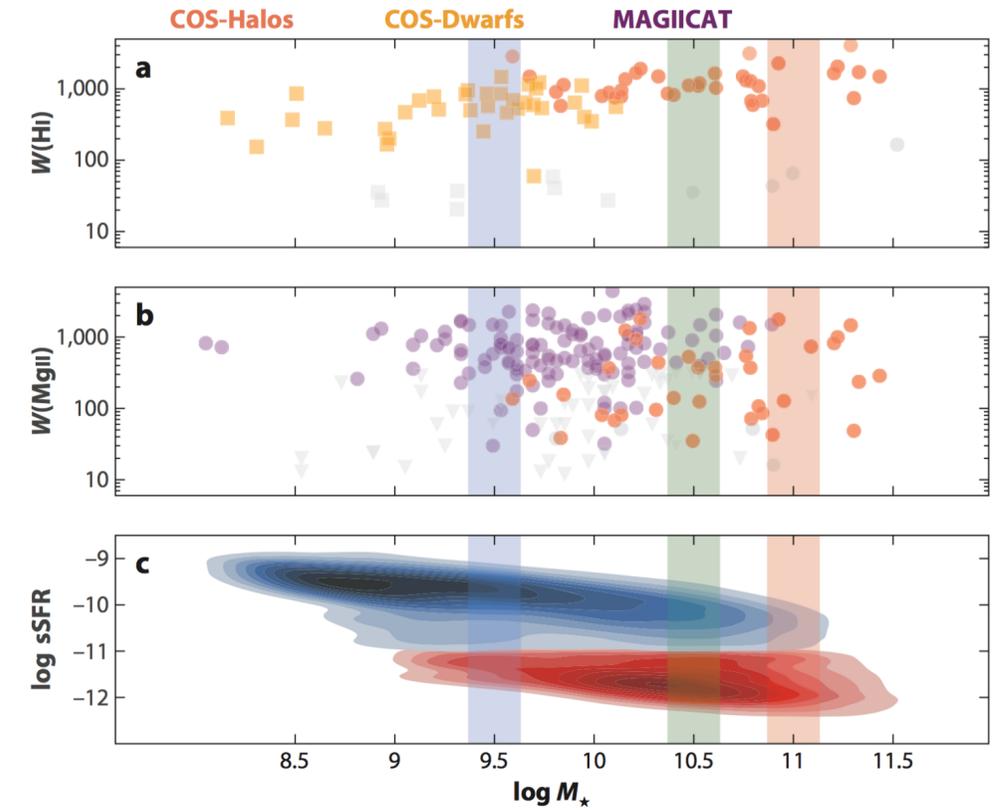
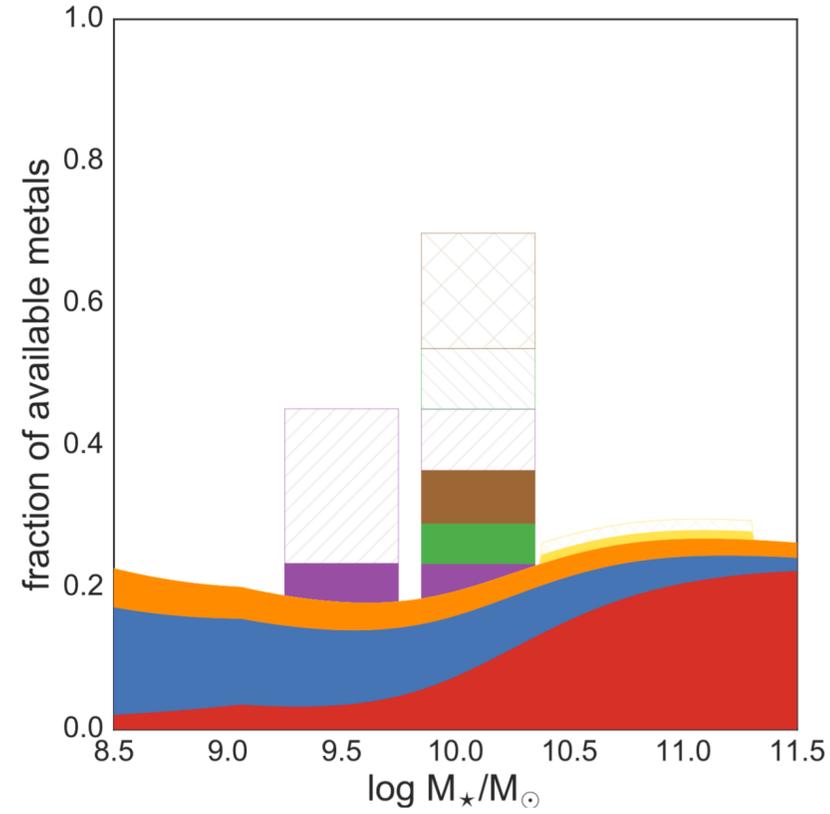
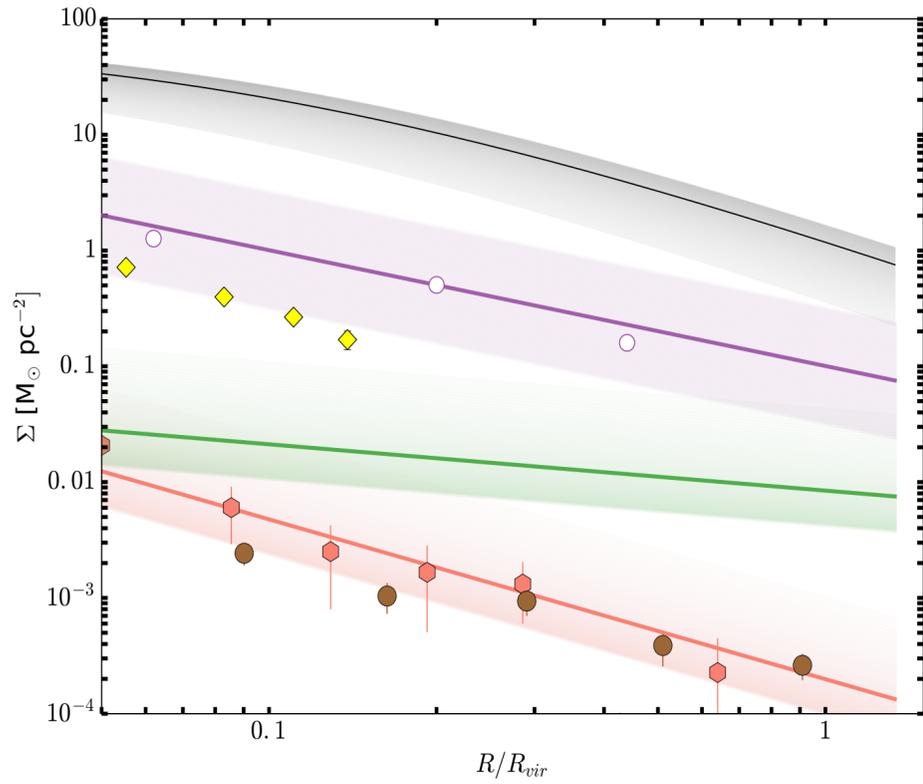
what actually happened



forged connection four

Like Charlie said, nobody understands why galaxies turn passive and remain that way.

What we have learned



forged connection five

The CGM is a critical venue for chemical evolution: just as important as the ISM!

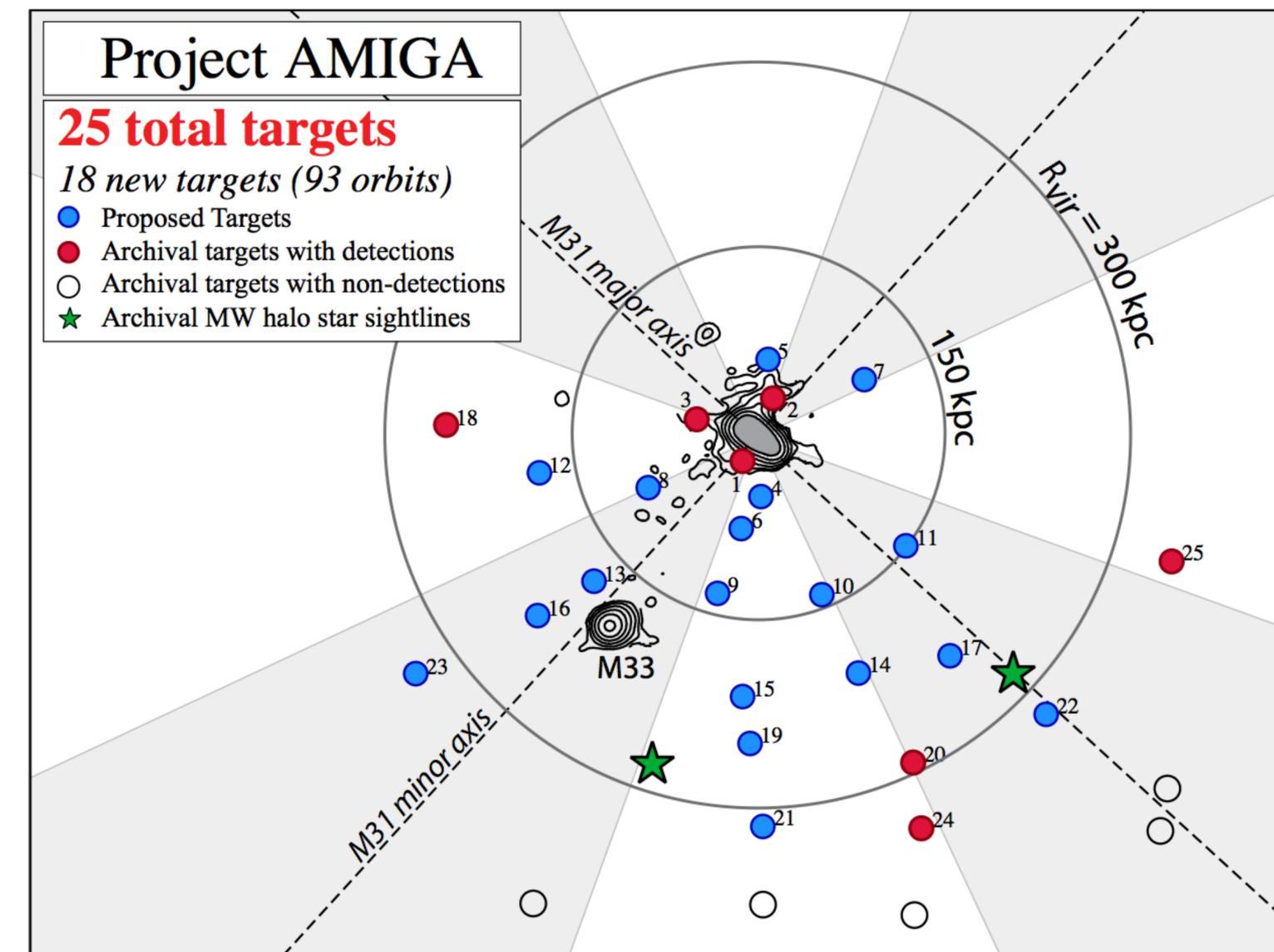
Outlook

AMIGA: Absorption Maps of Gas In Andromeda

(PI: N. Lehner, Notre Dame)

93 *Hubble* orbits with COS
+ parallel imaging with both WFC3 and ACS to map the *stellar* halo at roughly same locations

Data still being collected, but preliminary analysis of archival data reveal interesting trends within *one* halo versus what COS-Halos saw in aggregate.

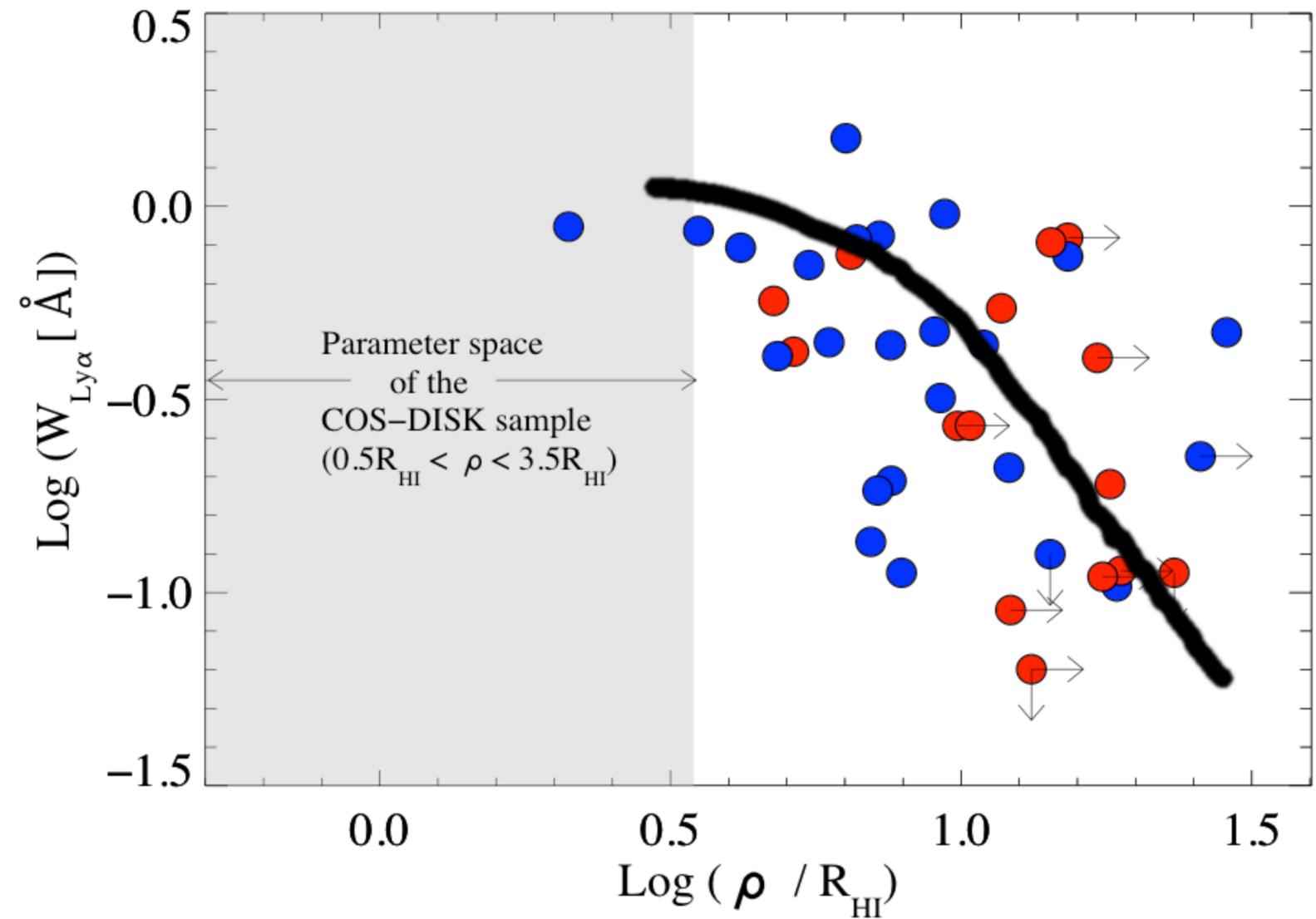


COS-Disks

(PI: S. Borthakur, Arizona State)

99 *Hubble* orbits with COS
supporting HI data from Arecibo, with star formation measures from SDSS, GALEX, and other sources.

Key goal is to map CGM gas in absorption as close as possible to the disk, address accretion where it happens and feedback where it starts.



FOGGIE

Figuring Out Gas & Galaxies In Enzo



Peeples



Corlies



JT



O'Meara



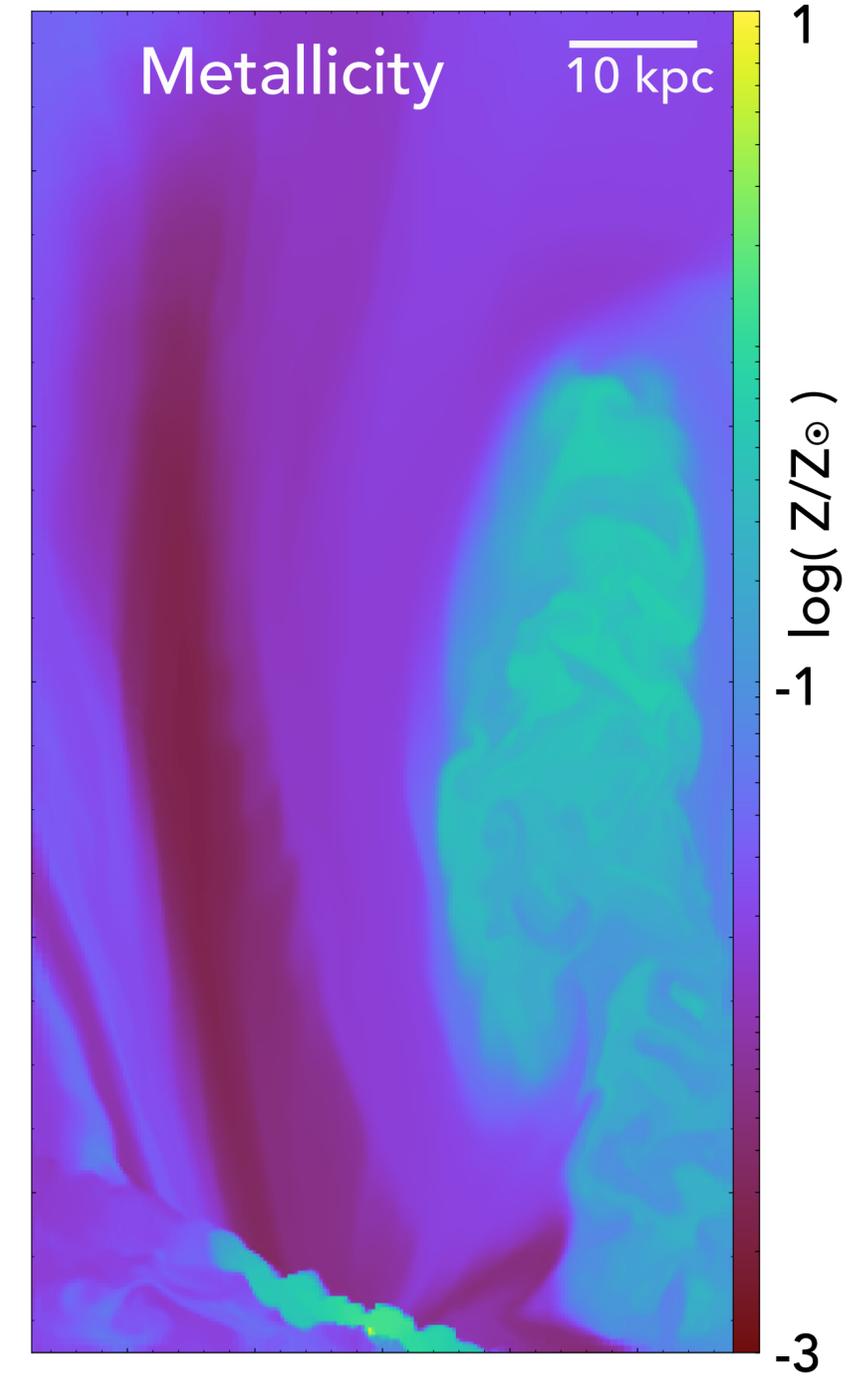
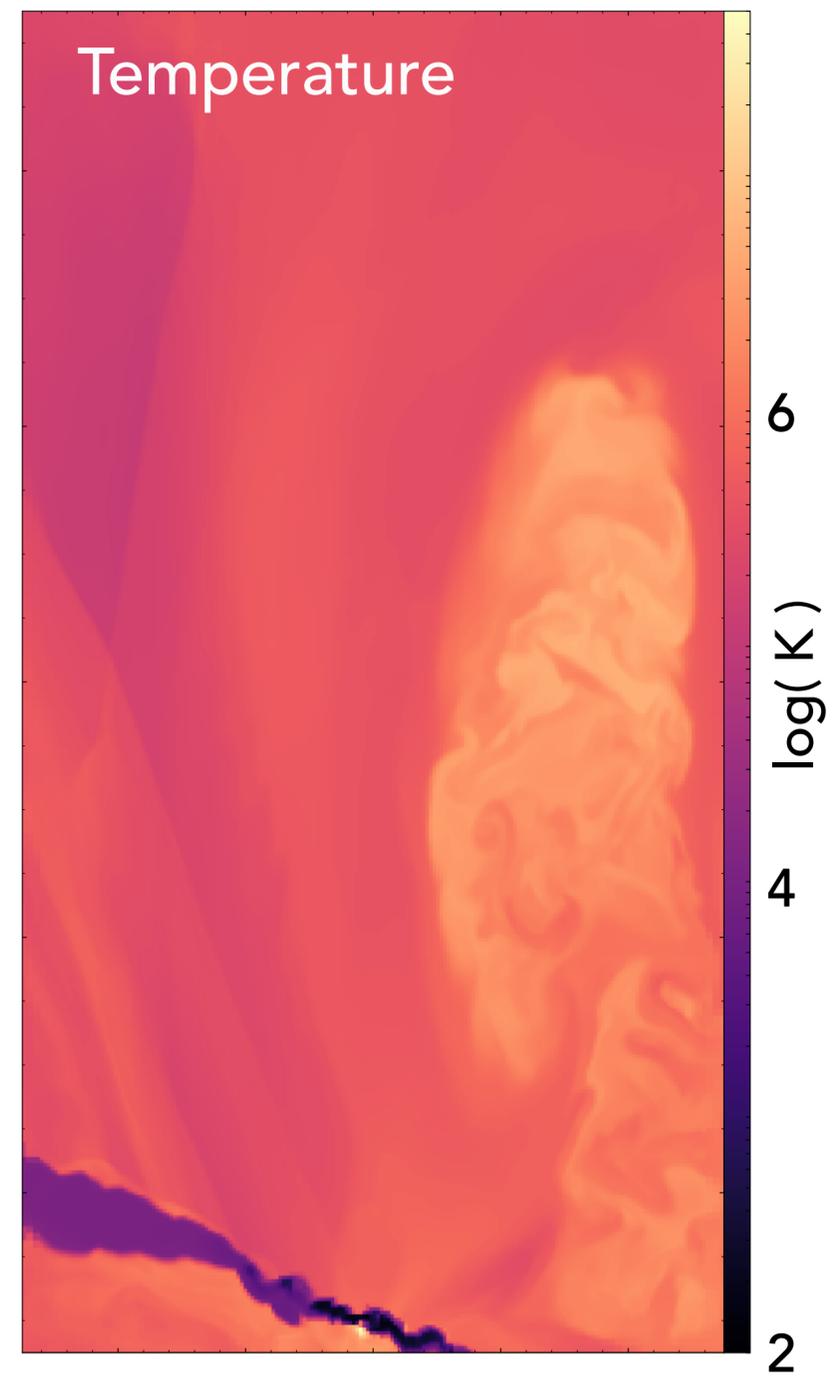
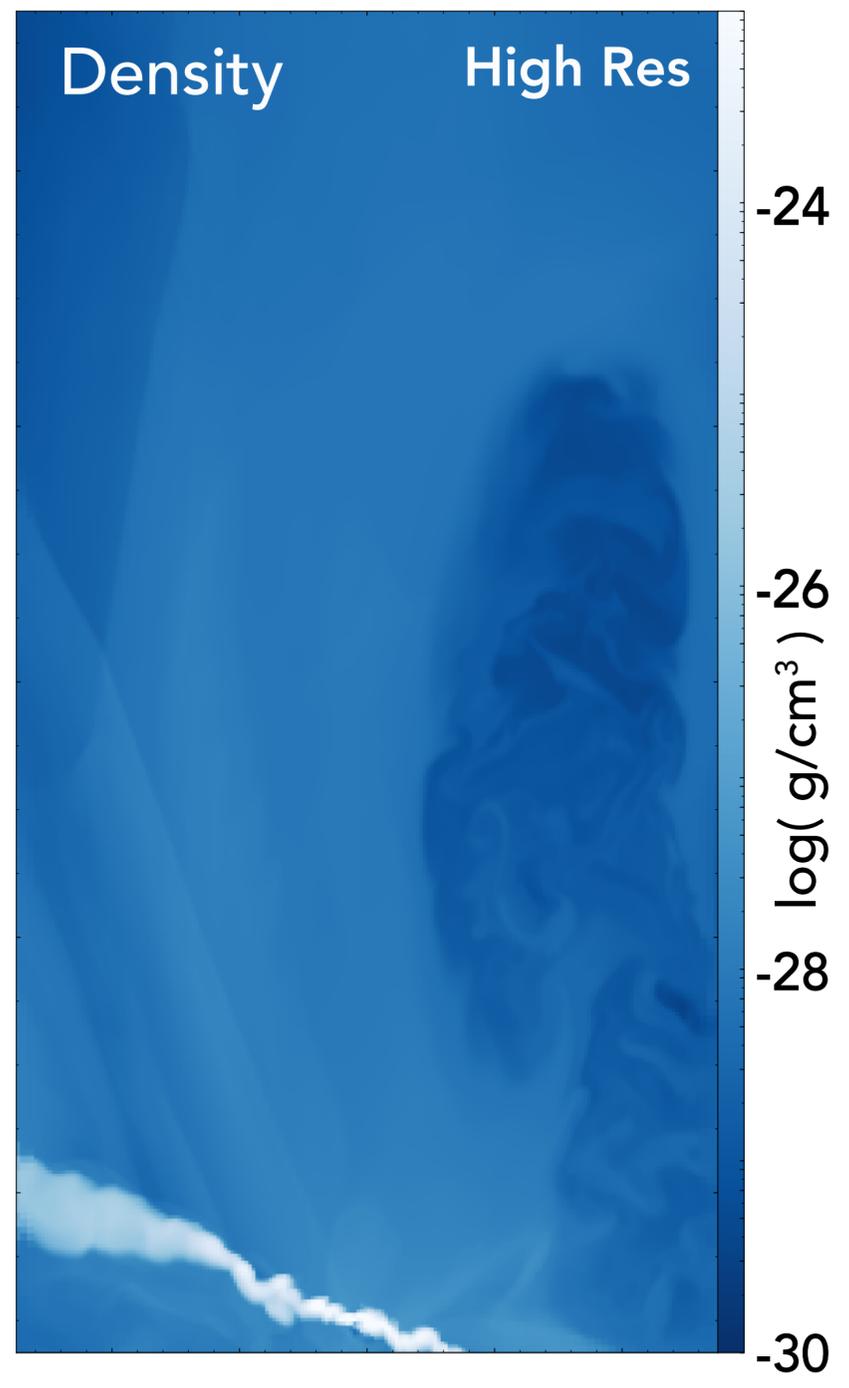
O'Shea



Lehner

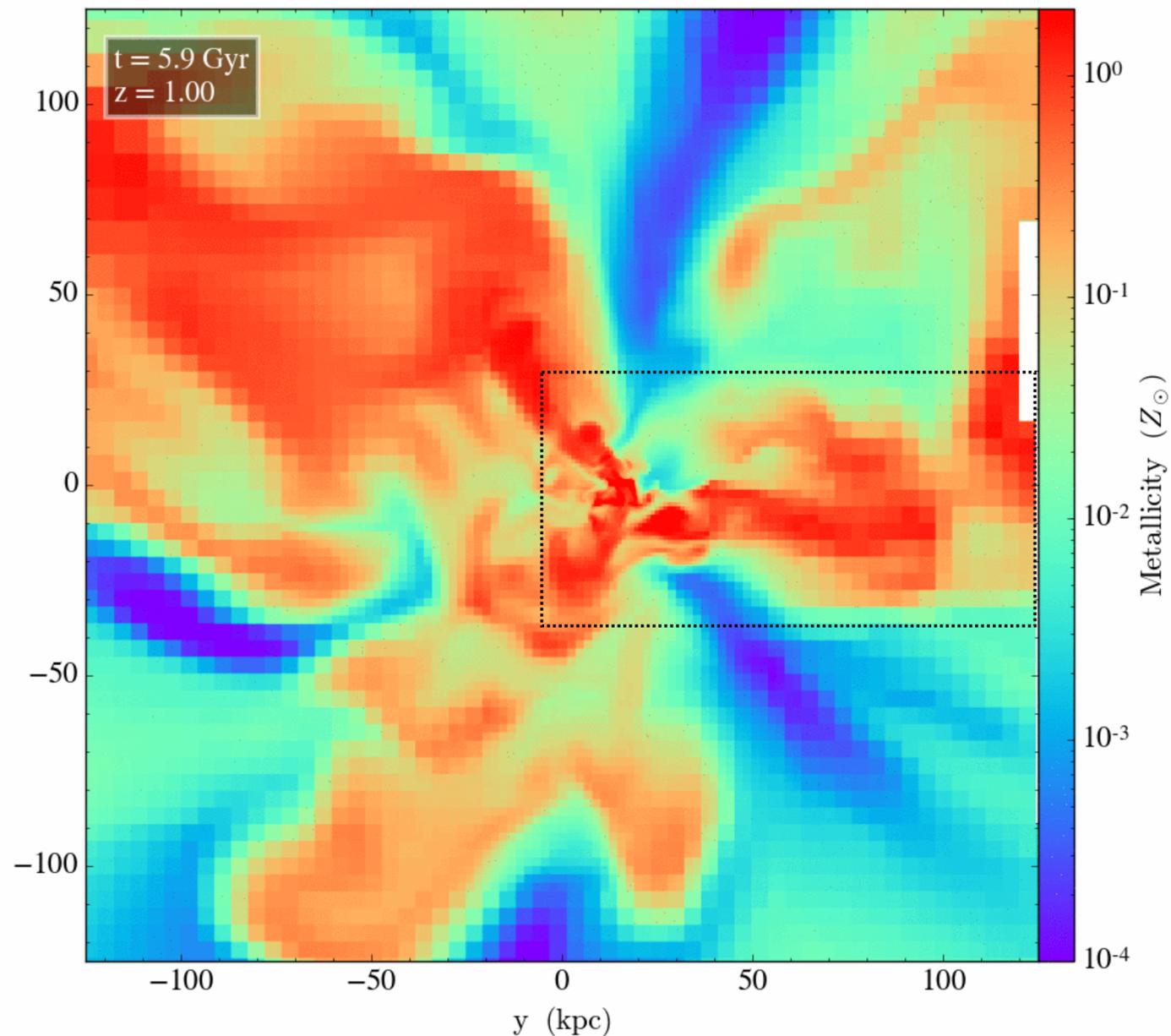
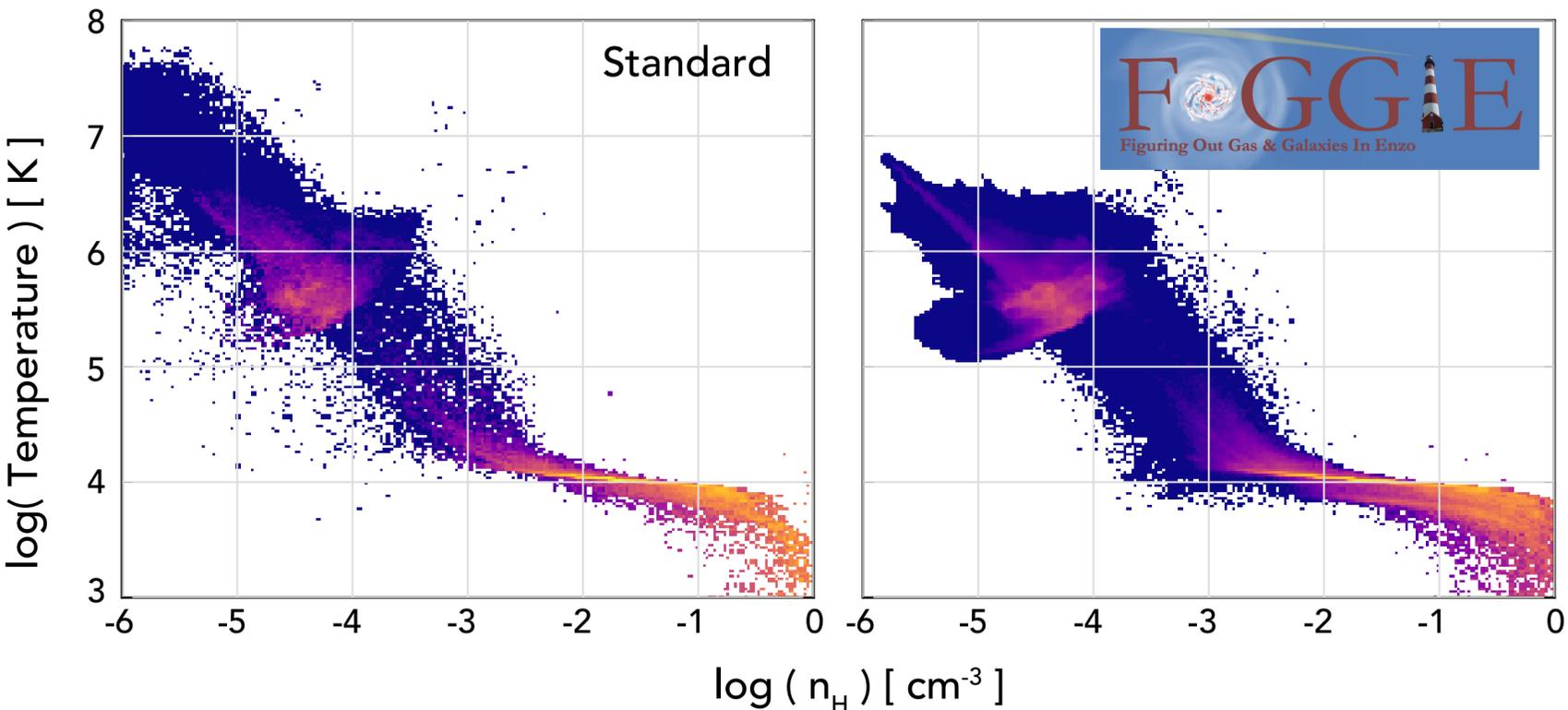
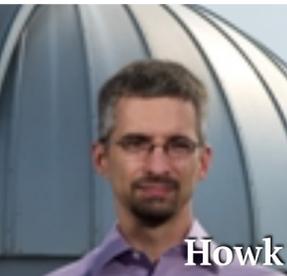
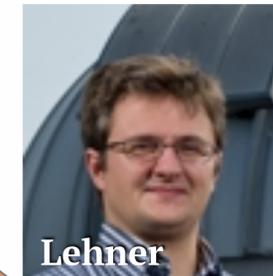


Howk



FOGGIE

Figuring Out Gas & Galaxies In Enzo



mass resolution

as low as $\sim 100\text{-}500 M_\odot$ in low density gas

cf. $10^{5-7} M_\odot$ in typical particle-based

simulations (such as FIRE/Latte)

Back to stars for a bit
[just for JB-H]

Hubble resolution at 100x FOV

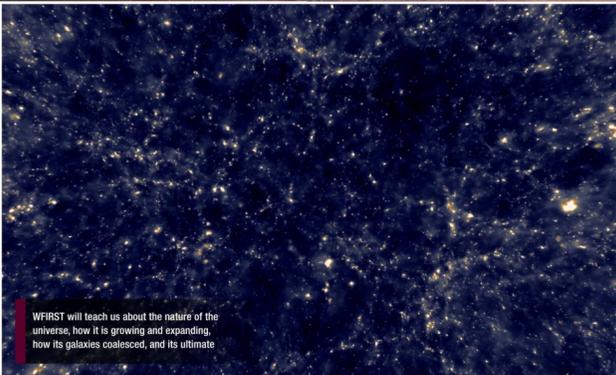
National Aeronautics and Space Administration 



WFIRST

Wide Field Infrared Survey Telescope

Determining our origins
Discerning our fate
Discovering new worlds



WFIRST will teach us about the nature of the universe, how it is growing and expanding, how its galaxies coalesced, and its ultimate fate.

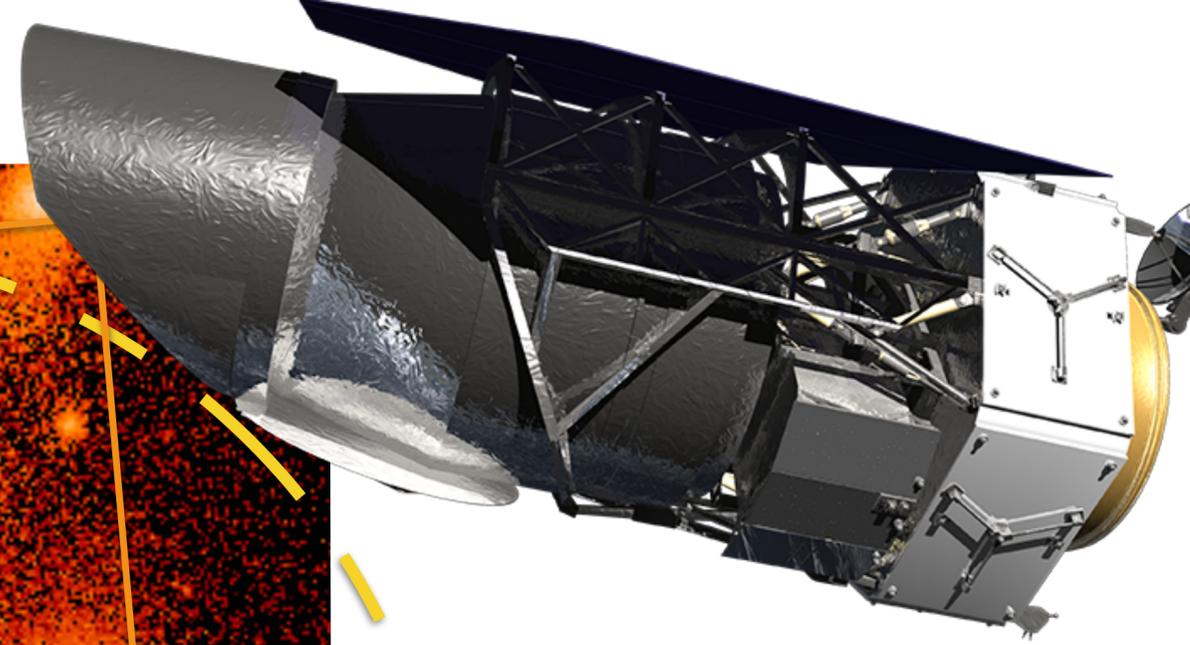
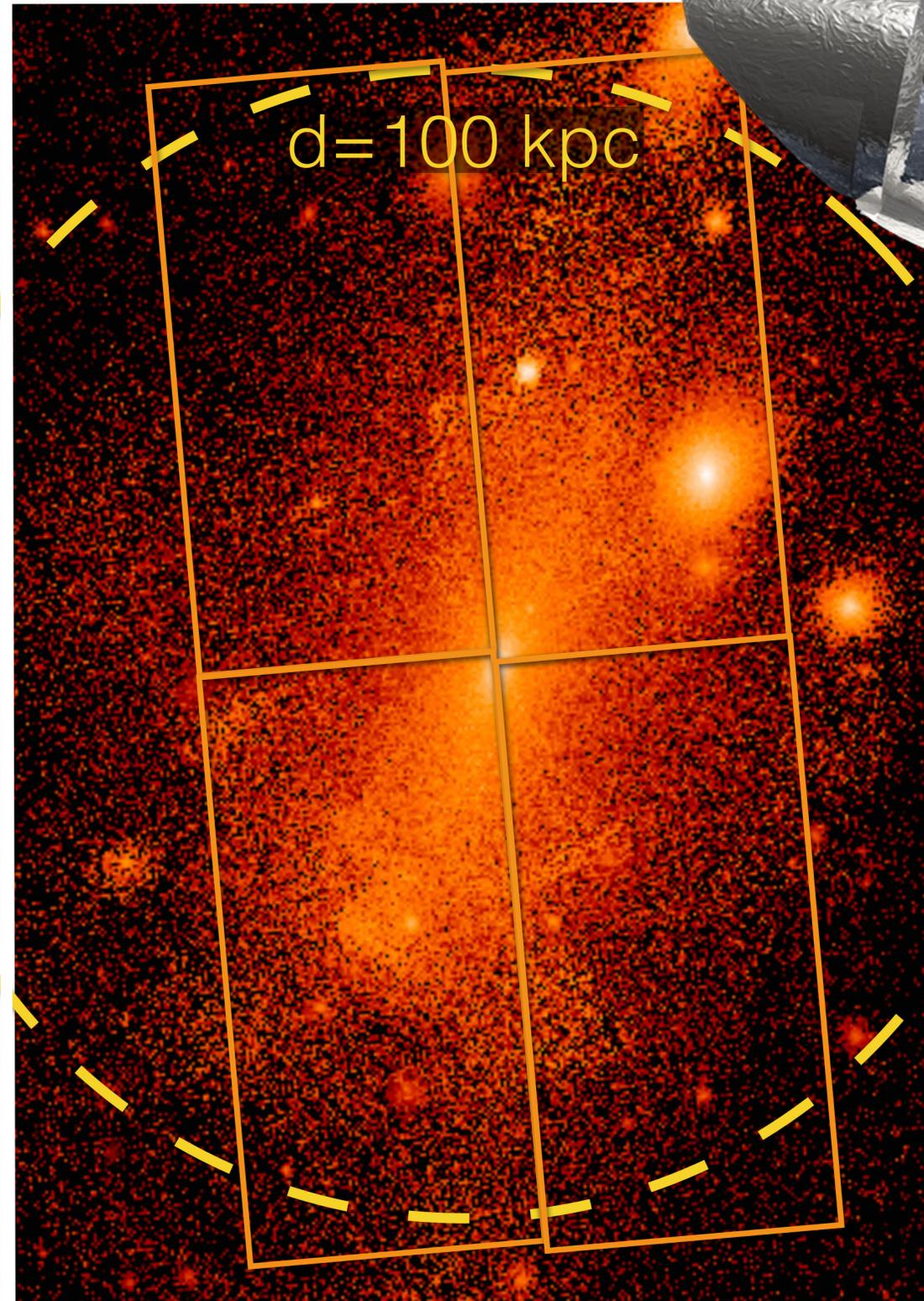
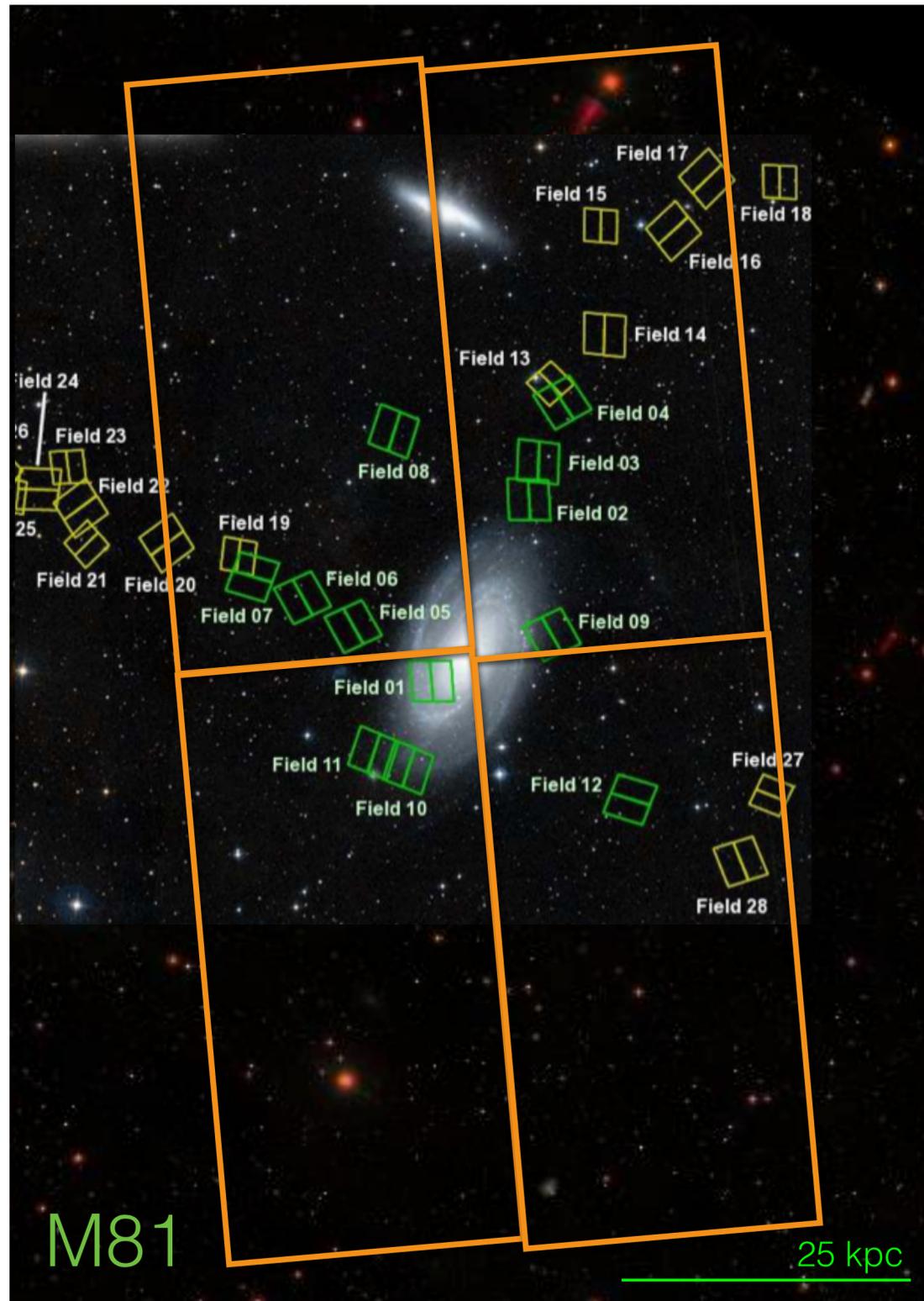


WFIRST will complete the census of exoplanets, finding planets around other stars at distances similar to what is found in our own solar system.

www.nasa.gov



2025 launch



4 fields
cover
M81
halo

LUVOIR: A NASA Study for the 2020 Decadal



Large UV / Optical / Infrared Surveyor (LUVOIR)

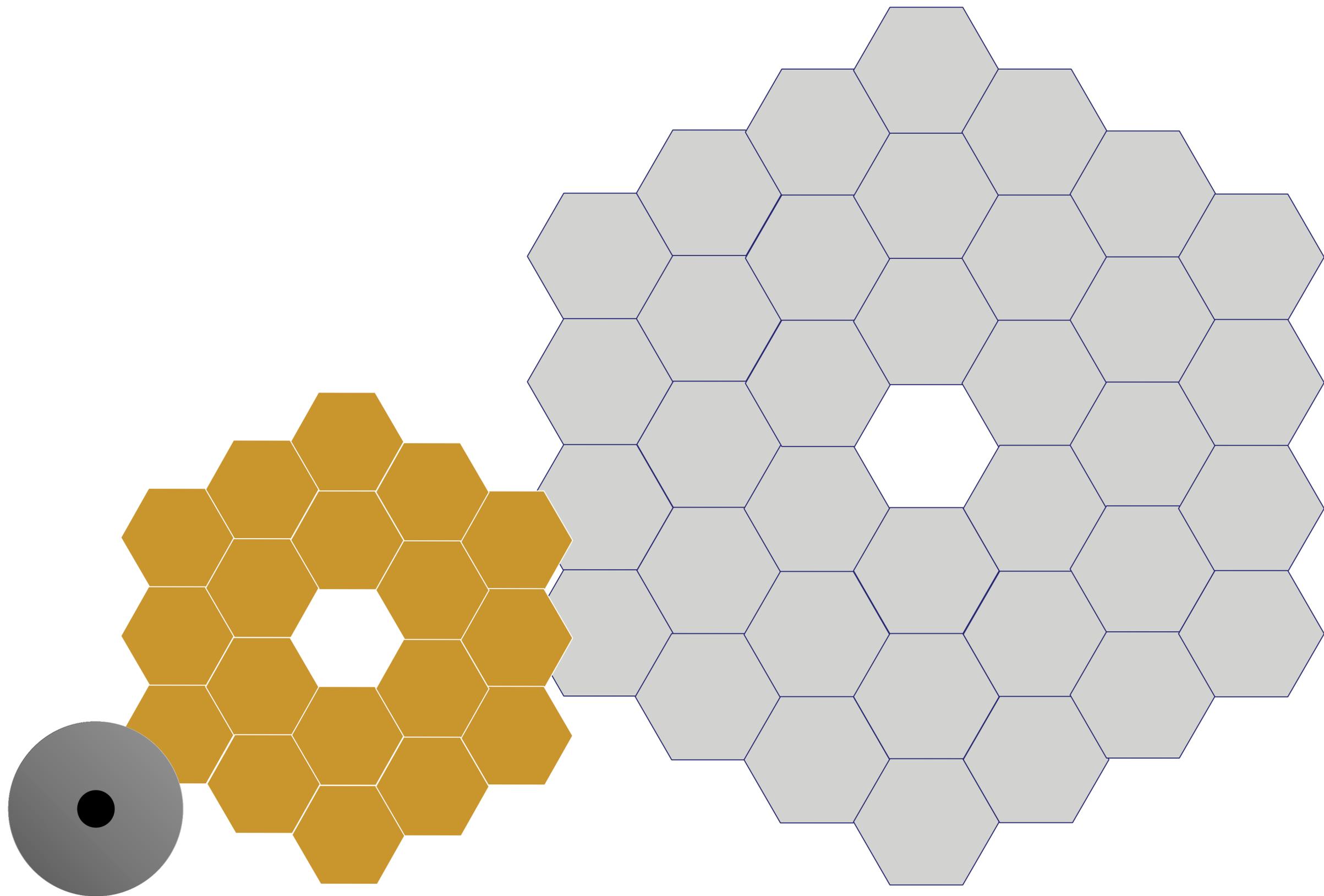
A space telescope concept in tradition of Hubble

- Broad science capabilities
- Far-UV to Near-IR bandpass
- ~ 8 – 16 m aperture diameter
- Suite of imagers and spectrographs
- Serviceable and upgradable
- Hubble-like guest observer program

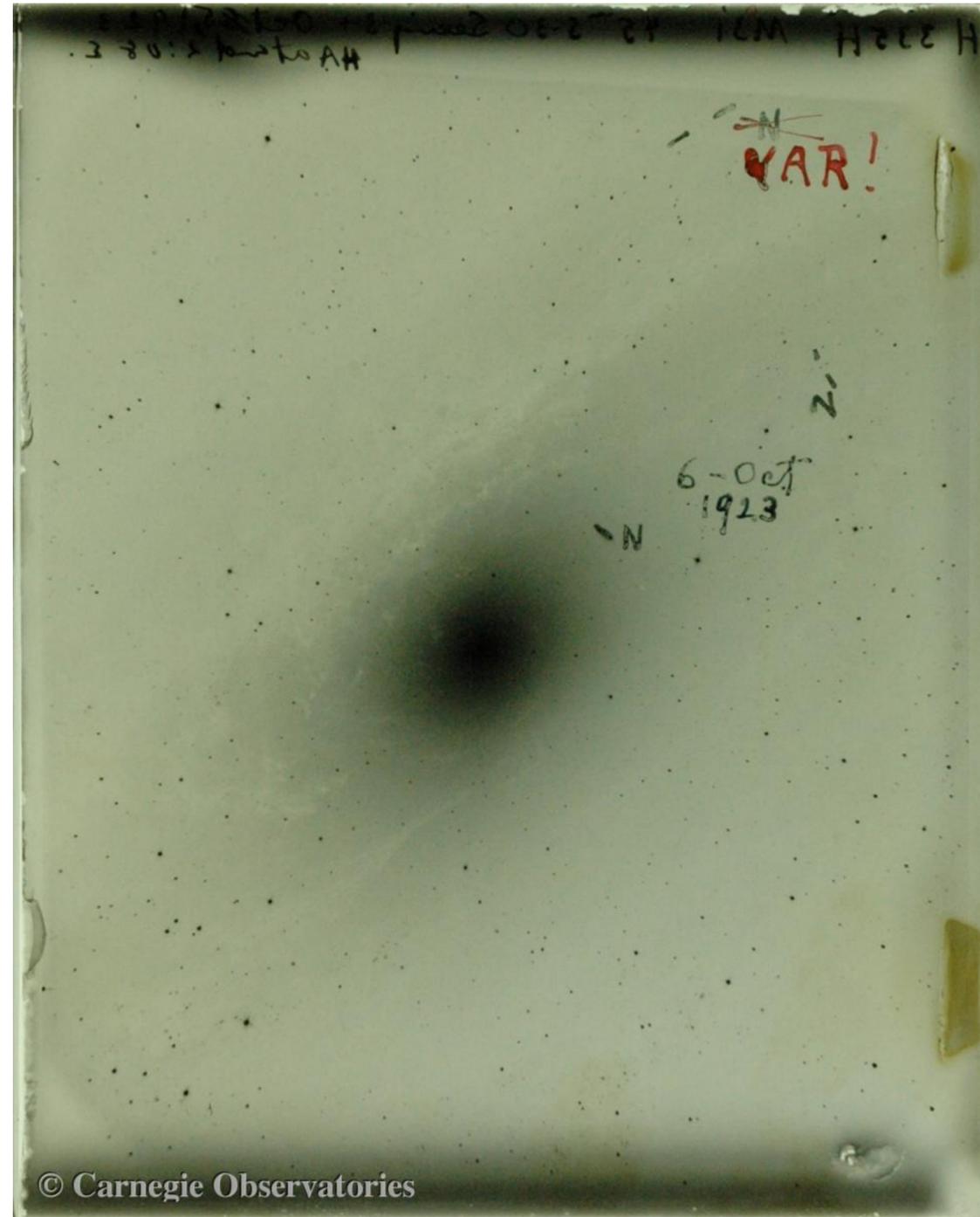
**Aimed for
2030 launch.**

“Space Observatory for the 21st Century”

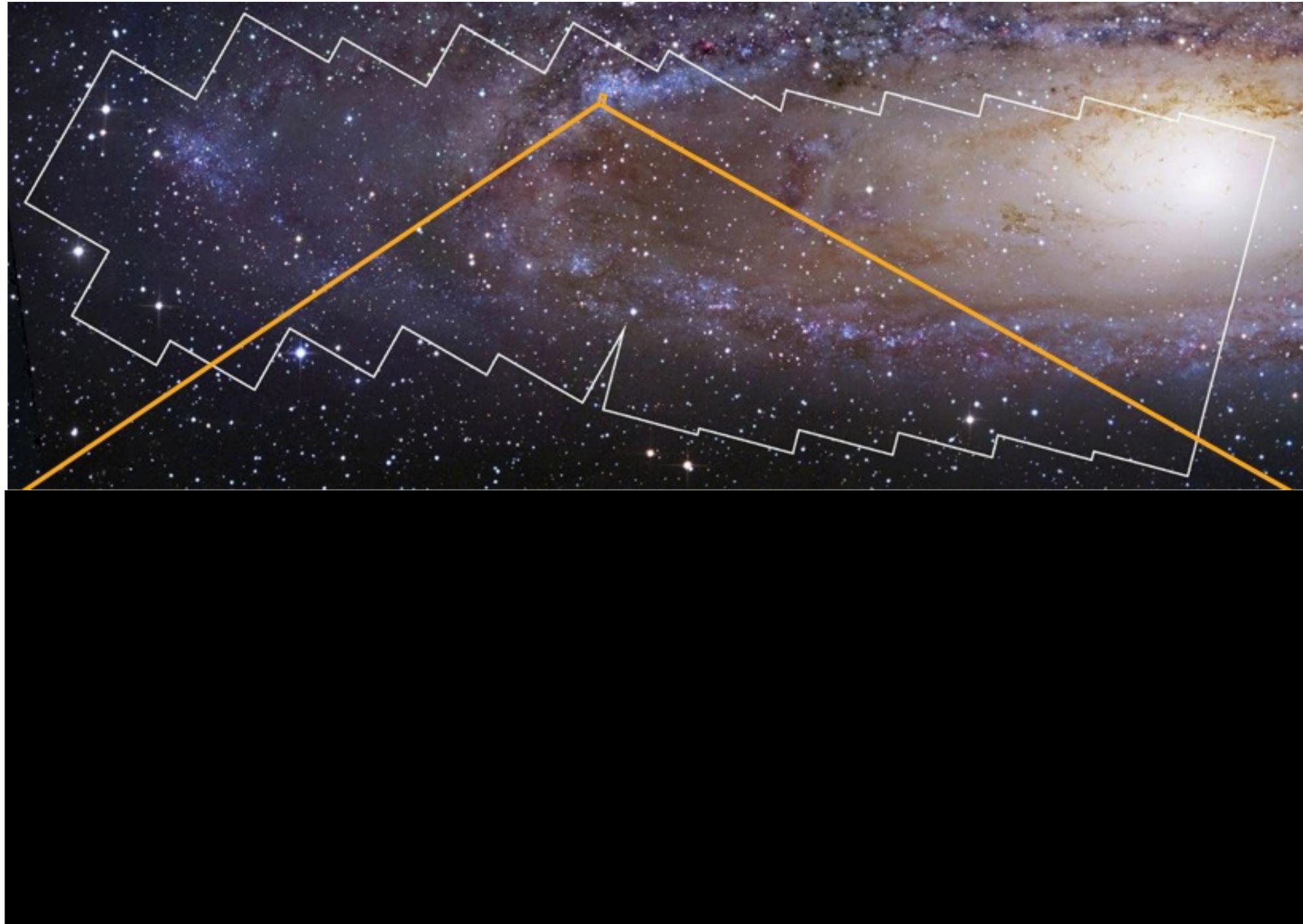
Ability to answer questions we have not yet conceived



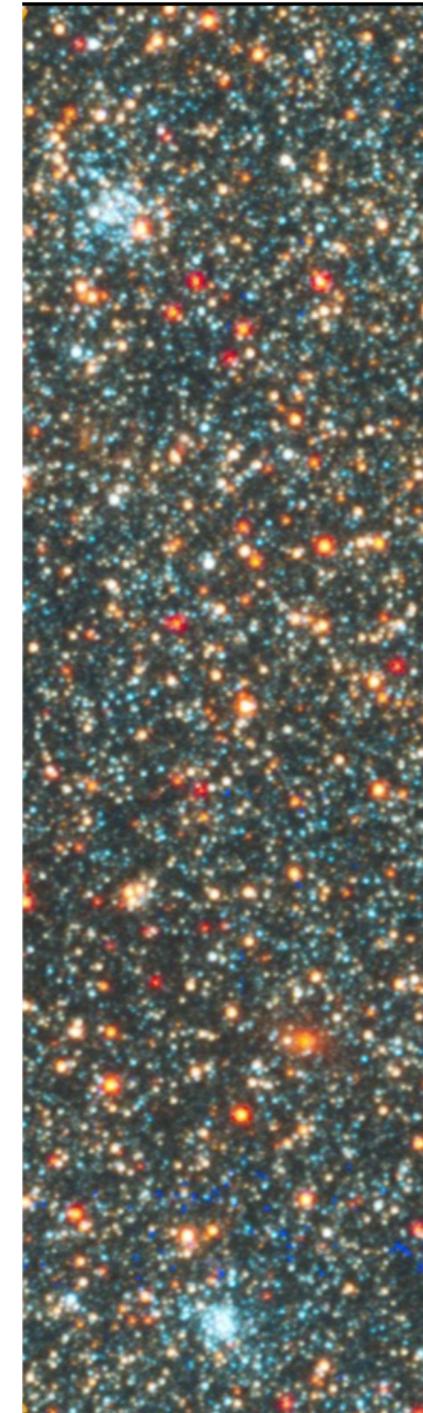
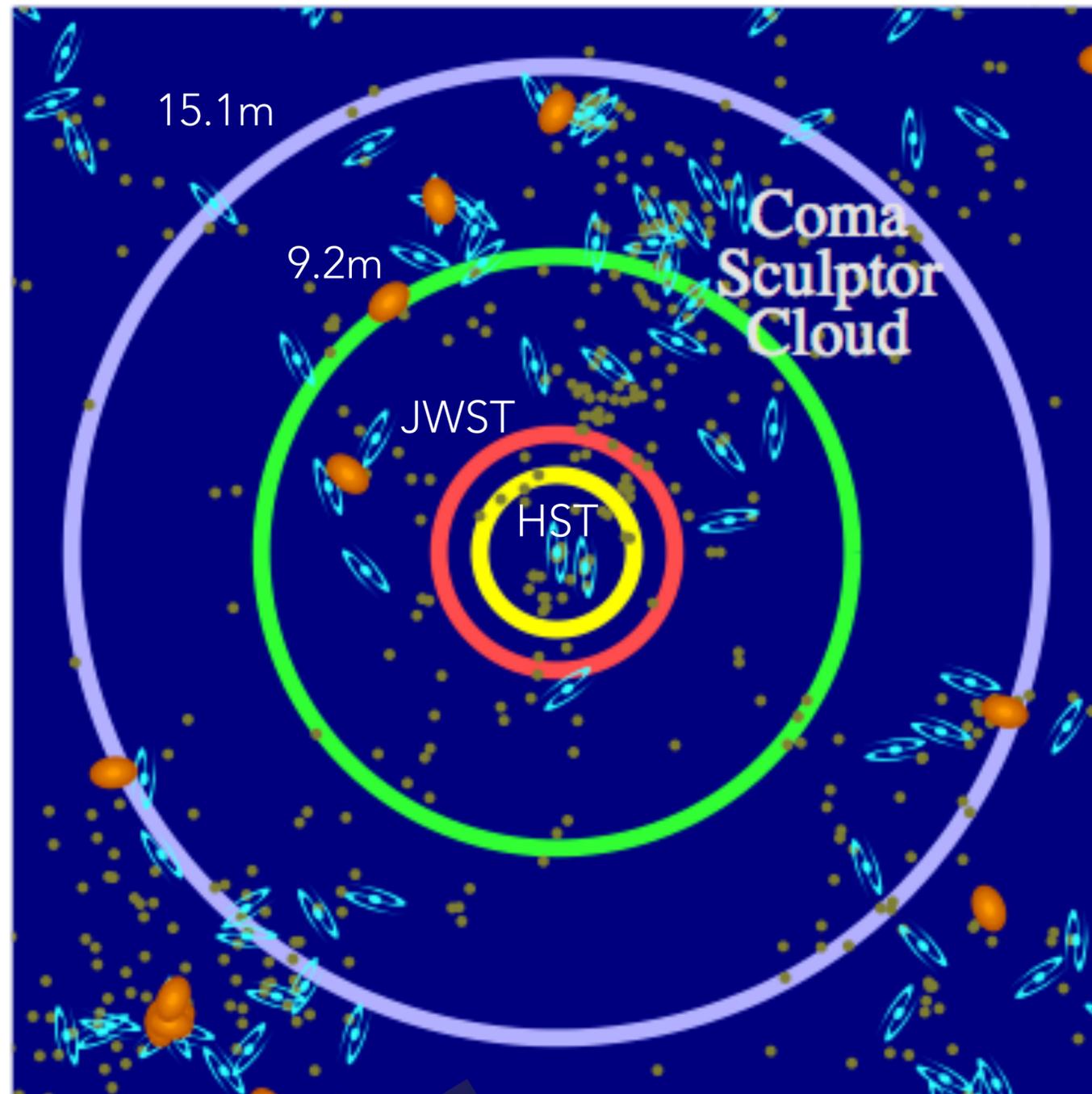
THE POWER OF APERTURE: OLD SCHOOL EDITION



GALACTIC ARCHAEOLOGY



GALACTIC ARCHAEOLOGY



● = Large Elliptical Galaxy

● = Large Spiral Galaxy

● = Dwarf Galaxy

Get involved with LUVOIR

<http://asd.gsfc.nasa.gov/luvoir/>

ETCs and simulation tools at:

<https://asd.gsfc.nasa.gov/luvoir/tools/>

Large UV/Optical/Infrared Surveyor (LUVOIR)

NASA National Aeronautics and Space Administration
Goddard Space Flight Center
Astrophysics Science Division • Sciences and Exploration

LUVOIR

Large UV/Optical/Infrared Surveyor

- Home
- Science
- LUVOIR Flyer
- Technology
- Seminars
- Events
- Meet the Team
- Working Groups
- Documents
- Images & Videos
- Simulation Tools

Large UV/Optical/Infrared Surveyor

The Large UV/Optical/IR Surveyor (LUVOIR) is a concept for a highly capable, multi-wavelength space observatory with ambitious science goals. This mission would enable great leaps forward in a broad range of science, from the epoch of reionization, through galaxy formation and evolution, star and planet formation, to solar system remote sensing. LUVOIR also has the major goal of characterizing a wide range of exoplanets, including those that might be habitable - or even inhabited.

LUVOIR is one of four Decadal Survey Mission Concept Studies initiated in Jan 2016. The study will extend over three years and will be executed by the Goddard Space Flight Center, under the leadership of a Science and Technology Definition Team (STDT) drawn from the community.

A brief description of LUVOIR science goals and capabilities are available in this [flyer](#).

News

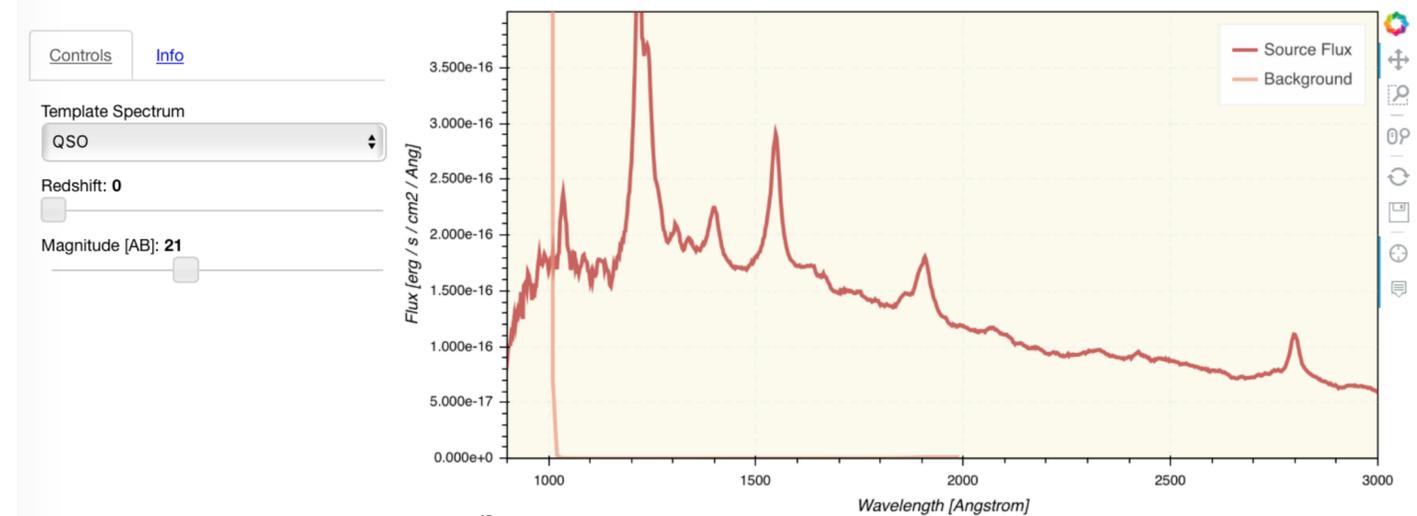
Fourth LUVOIR STDT Meeting

The fourth face-to-face team meeting took place at JPL in Pasadena CA on April 17 & 18, 2017. Meeting info can be found on the [Events](#) page.



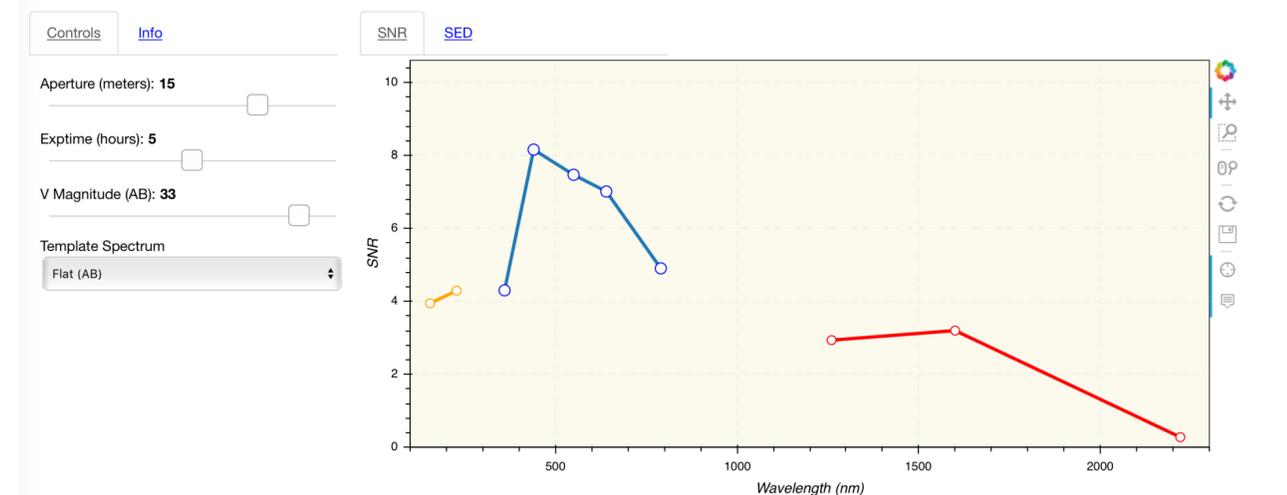
[LUVOIR: The Large UltraViolet Optical Infrared Surveyor](#)

LUVOIR UV MultiObject Spectrograph (LUMOS) ETC



[LUVOIR: The Large UltraViolet Optical Infrared Surveyor](#)

High Definition Imager (HDI) ETC



The

End

