The Cosmic Baryon Cycle

Science Drivers for the Habitable Galaxies Observatory

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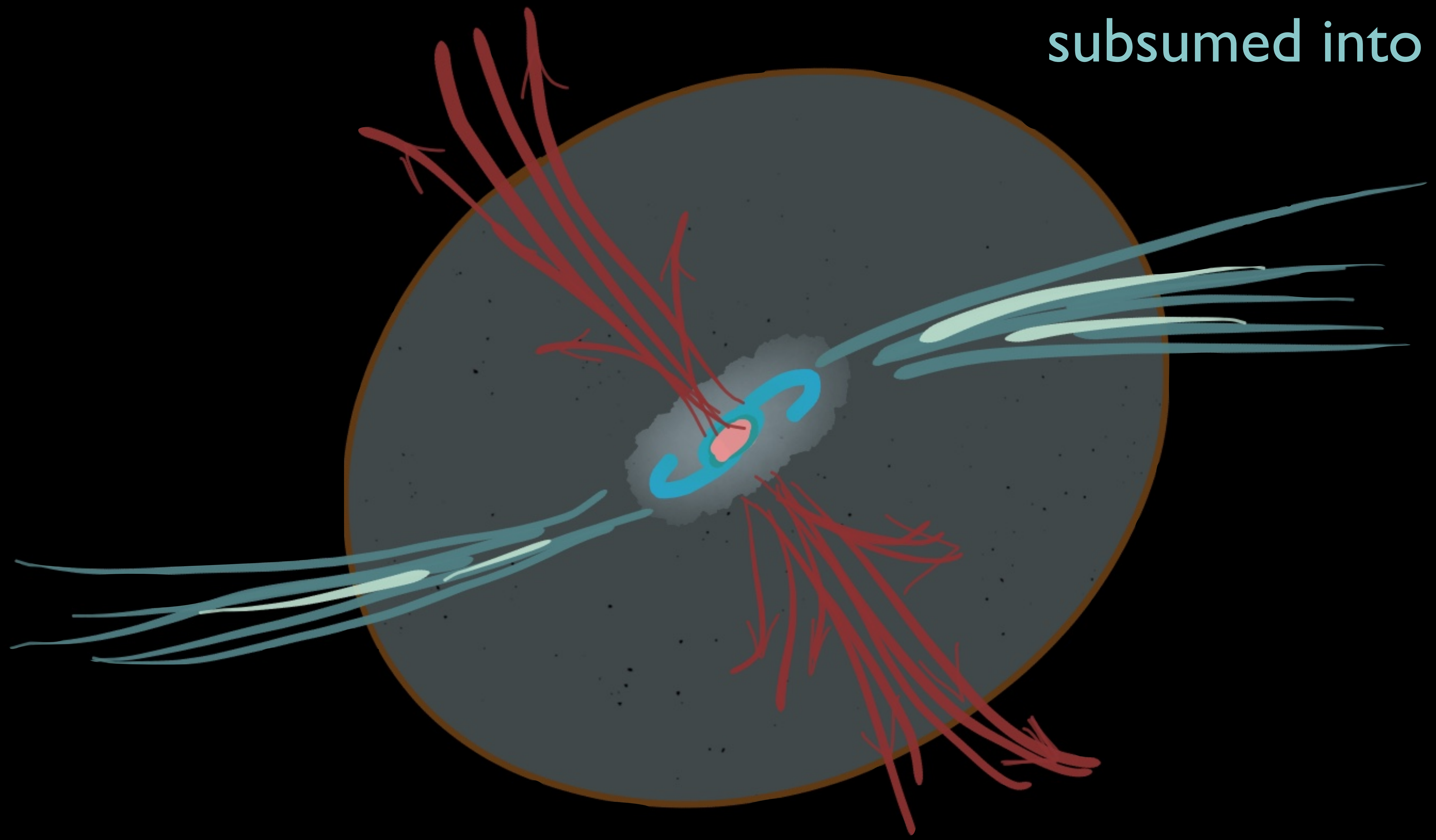
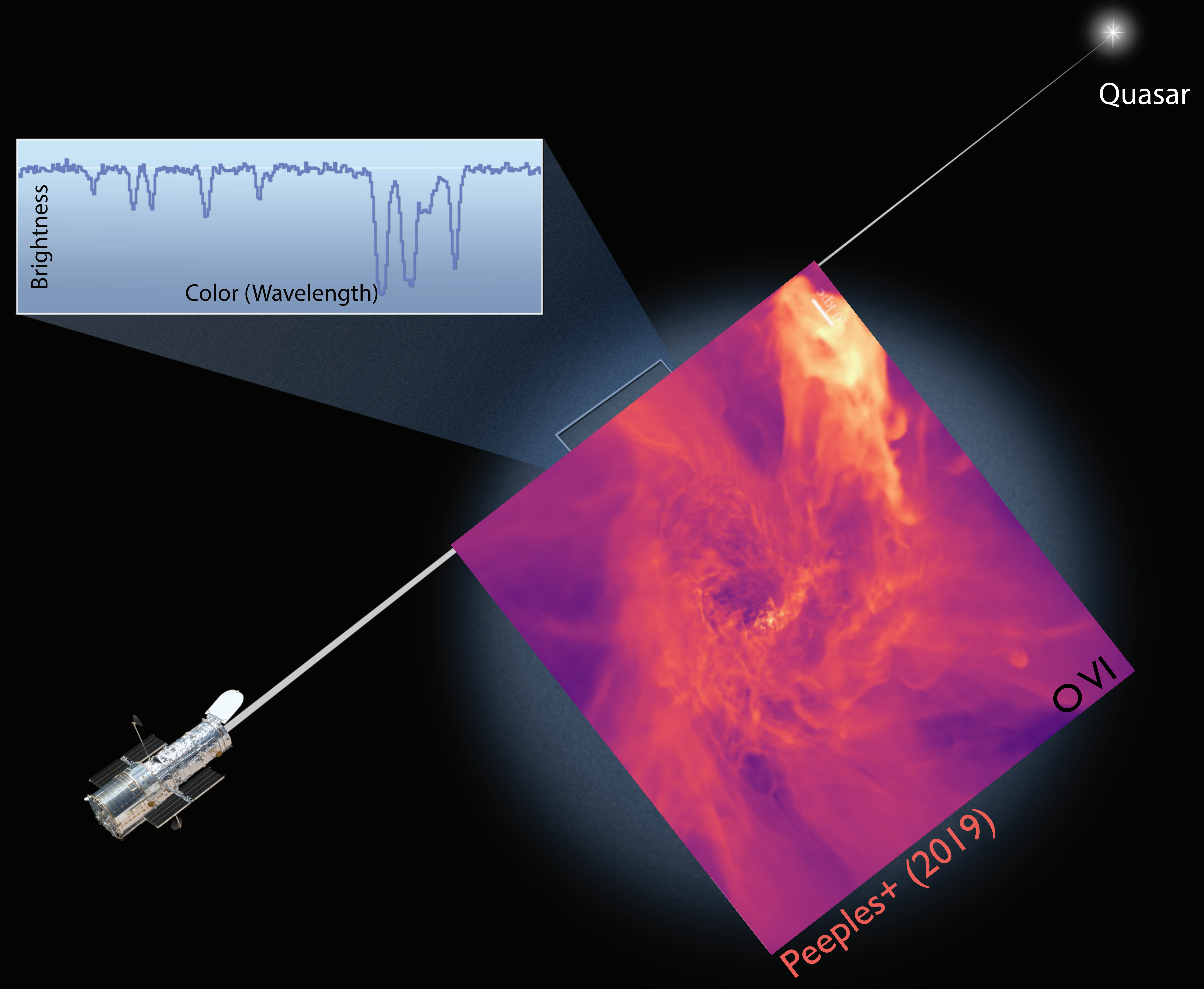
The visible **stars** in a galaxy trace only a portion of the baryonic matter important to its evolution.

Inflowing **pristine matter** from the intergalactic medium may fuel **star formation** in the disk or be heated, subsumed into the **corona**.

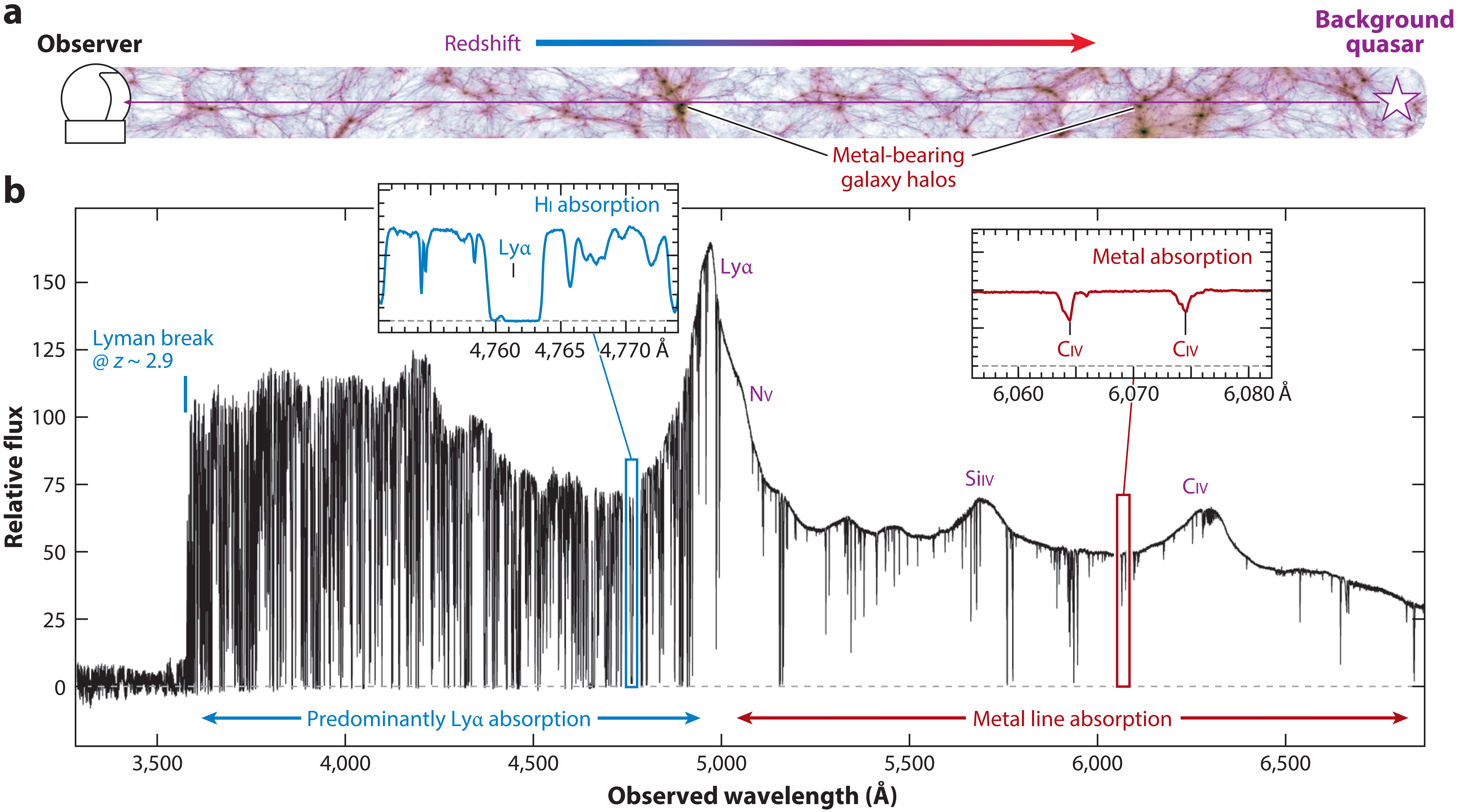


Outflows driven by star formation and/or AGN activity circulate **baryons, metals,** and **energy** into the **corona** (and perhaps beyond the halo).

An extended **corona** of gas may be a remnant of the collapse of the galaxy, perhaps near the virial temperature of the dark matter halo.



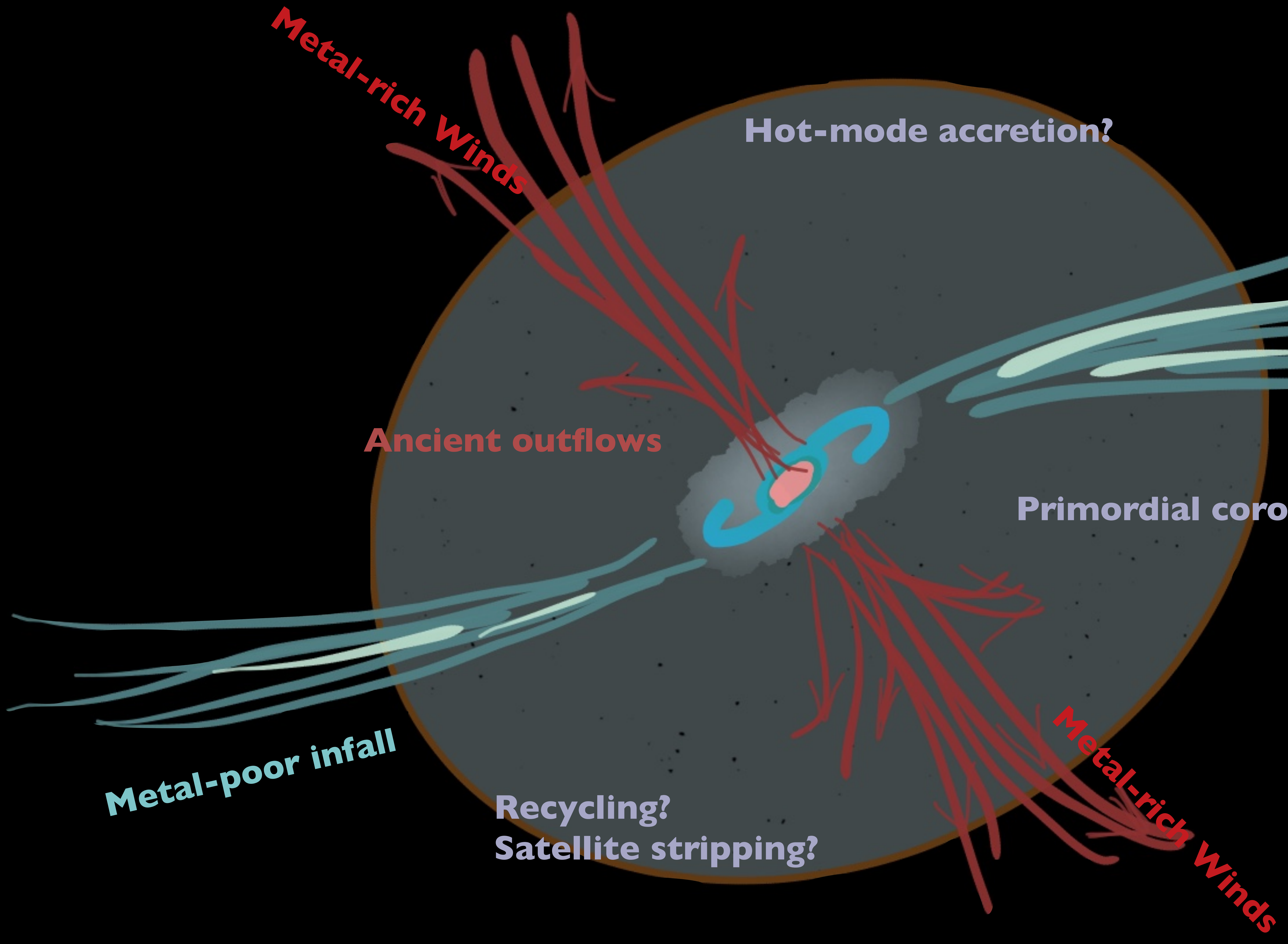
Quasar
Brightness
Color (Wavelength)
OVI
Peeples+ (2019)



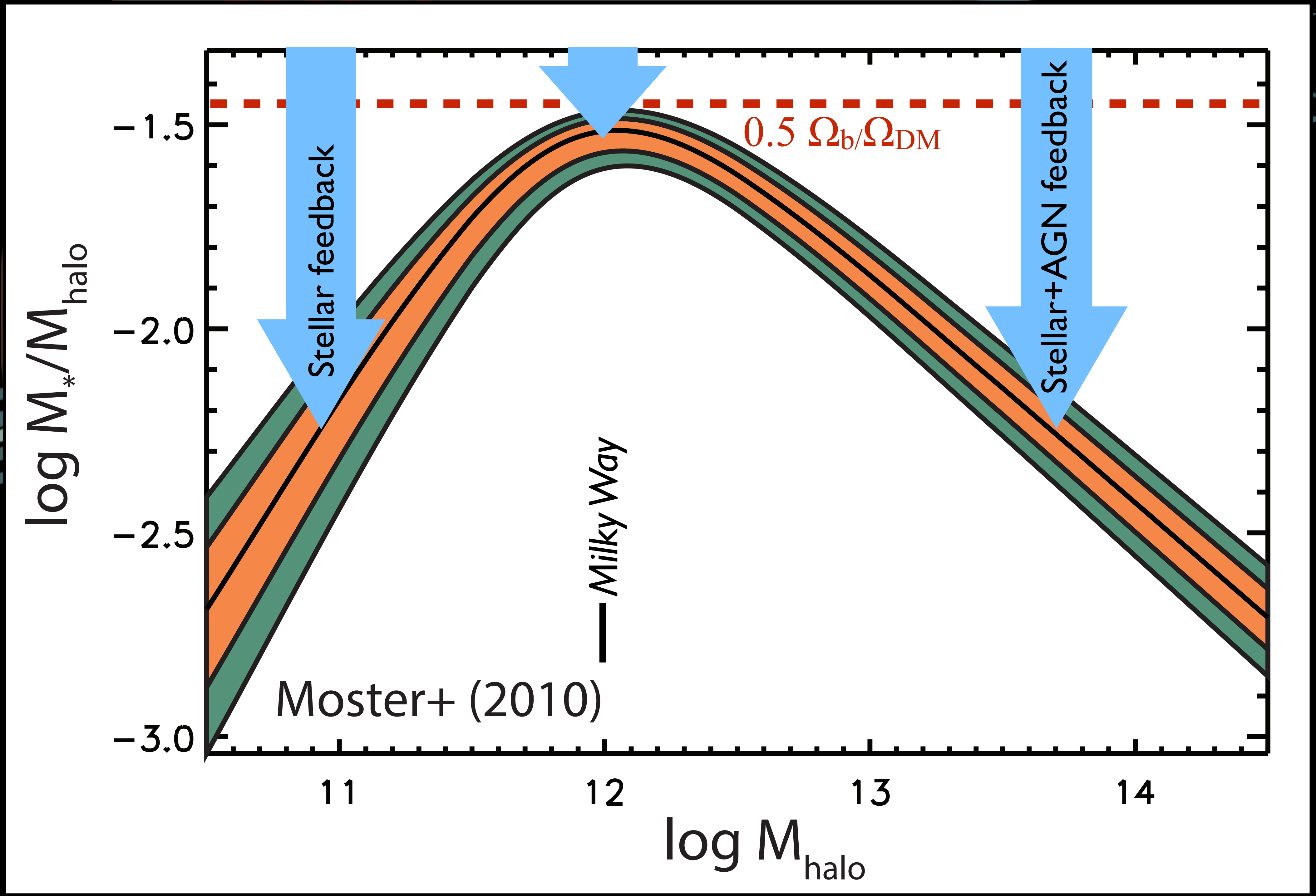
Péroux & Howk (2020)

Spectrum from D'Odorico+ (2016)

The circumgalactic medium plays a *fundamental role* in and potentially provides *unique constraints* on the baryon cycle that drives galaxy evolution.

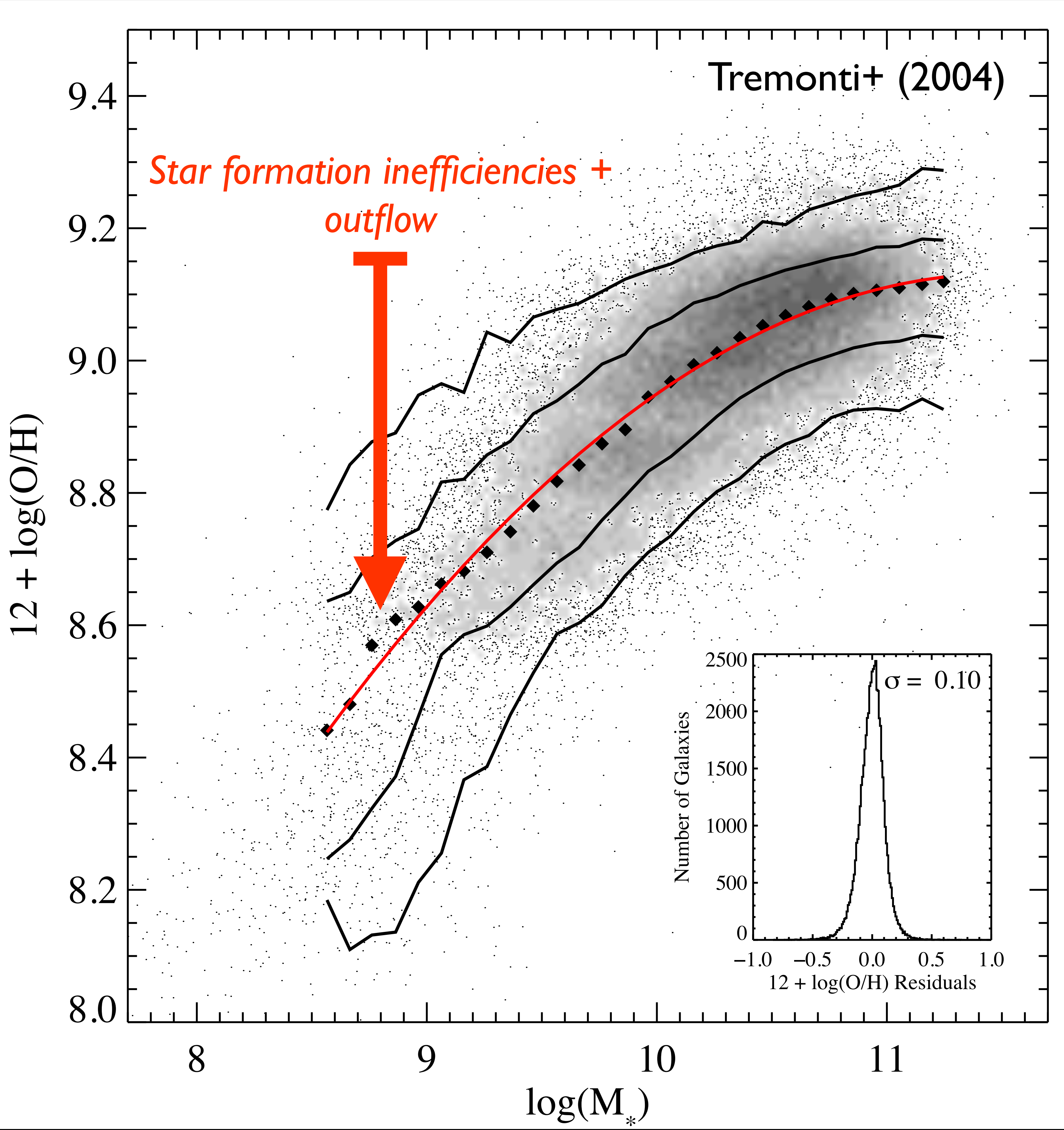


1. How does the CGM reflect galaxy evolution?

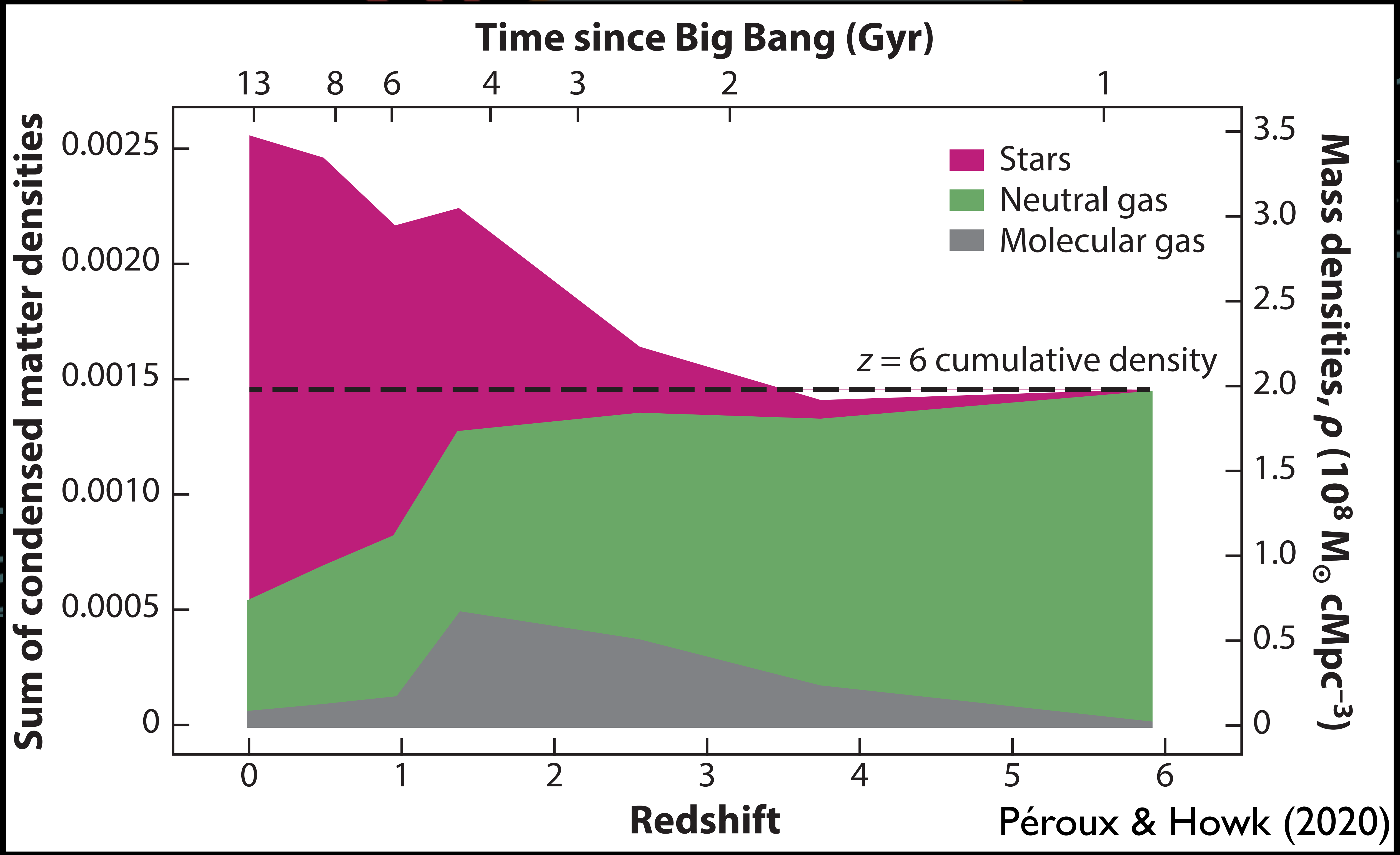


*Many baryons "missing" from galaxies are stored in the CGM, reflecting the outflows that shape the stellar mass-halo mass relationship.

*Metals ejected from galaxies by feedback, which shape the galactic mass-metallicity relationship, are stored in the CGM.



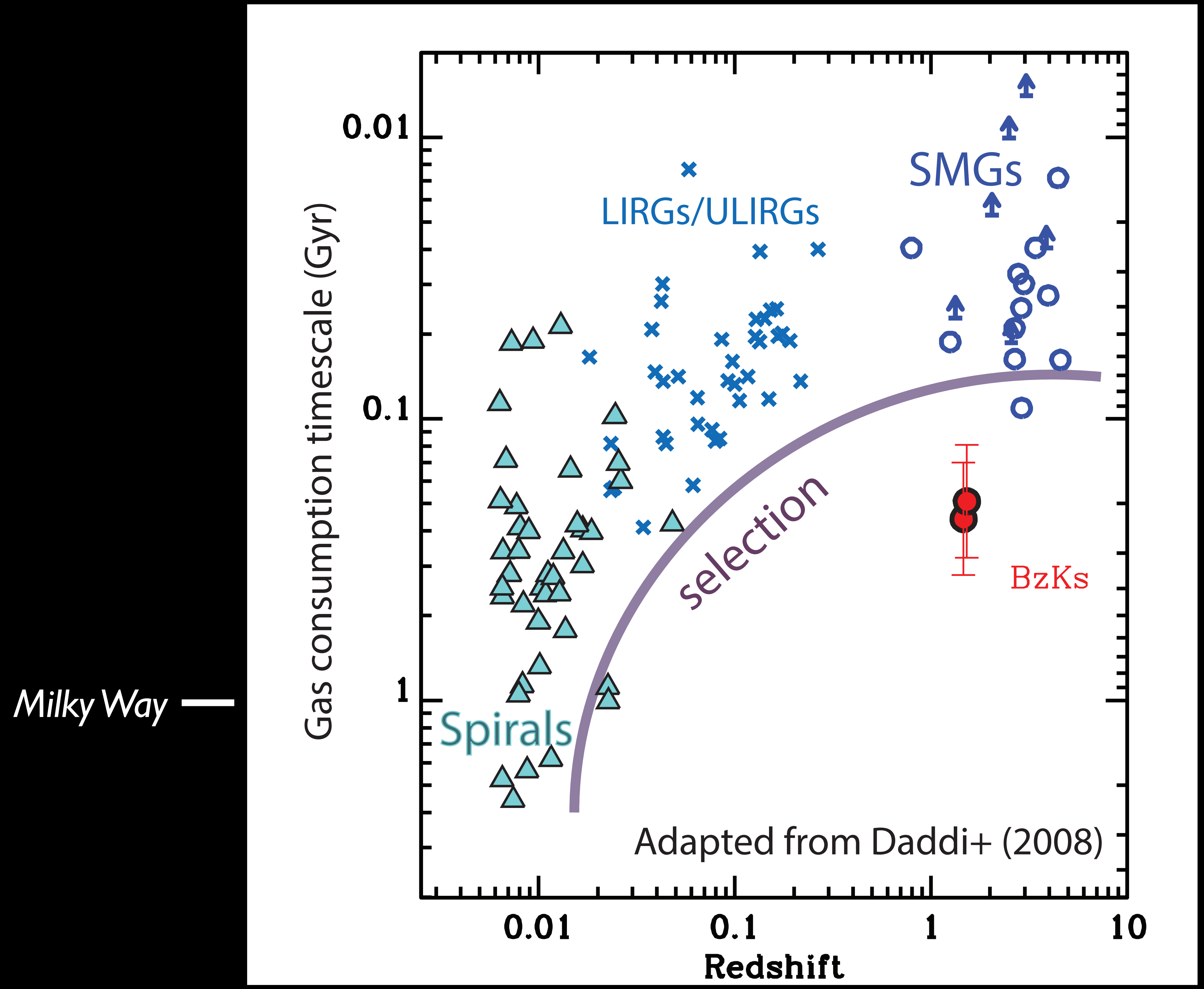
The baryonic and metal content of the CGM trace baryons collected from the **assembly** of the galaxy, **expelled** from the galaxy, and contributed by **satellites**.



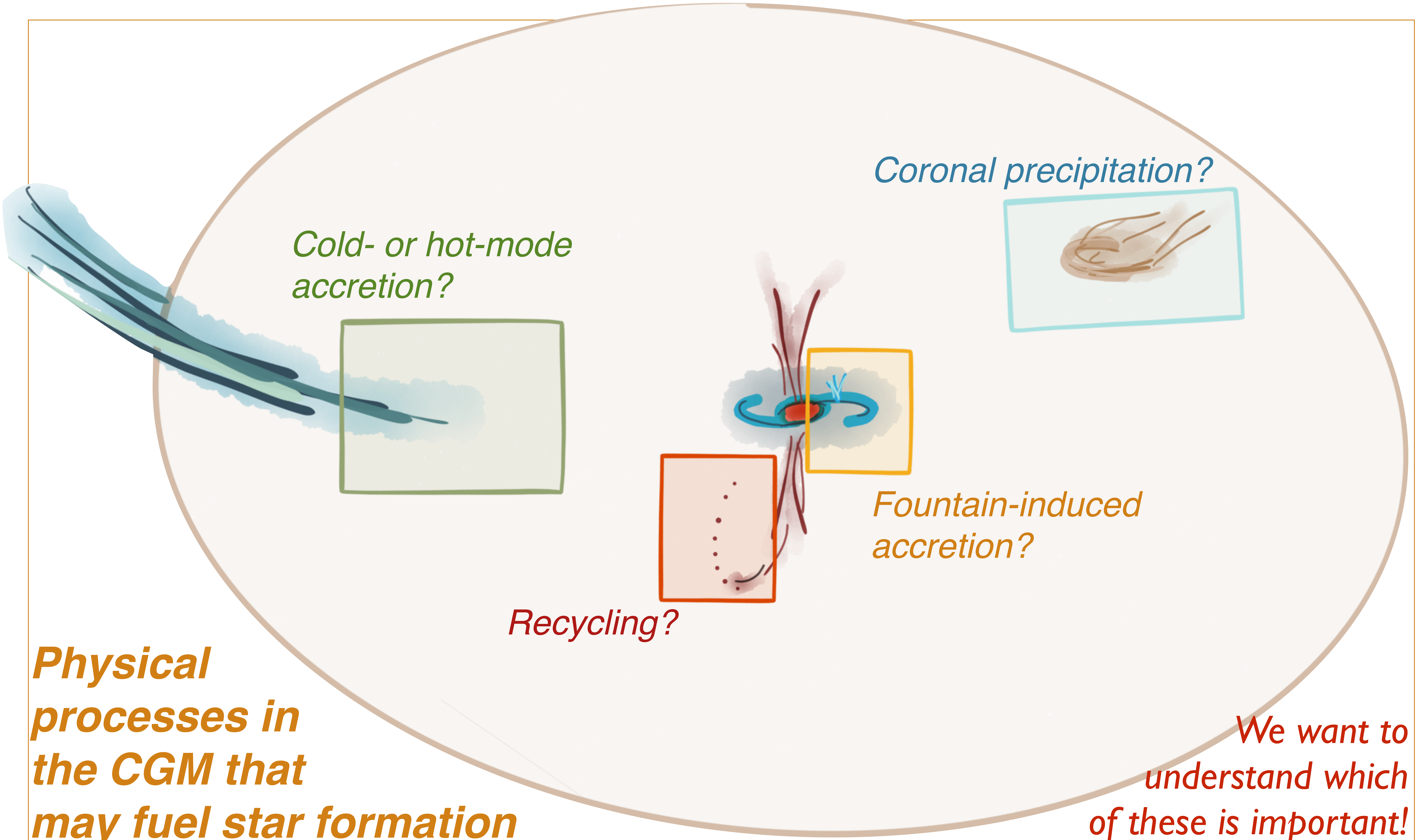
2. What role does the CGM play in shaping galaxies?

*Infall of IGM/CGM gas is required to fuel multi-Gyr star formation in galaxies.

*The need for conversion of CGM/IGM material into the fuel for star formation is a global phenomenon in the Universe.



Flows *through* or *from* the CGM provide fuel for star formation in galaxies.



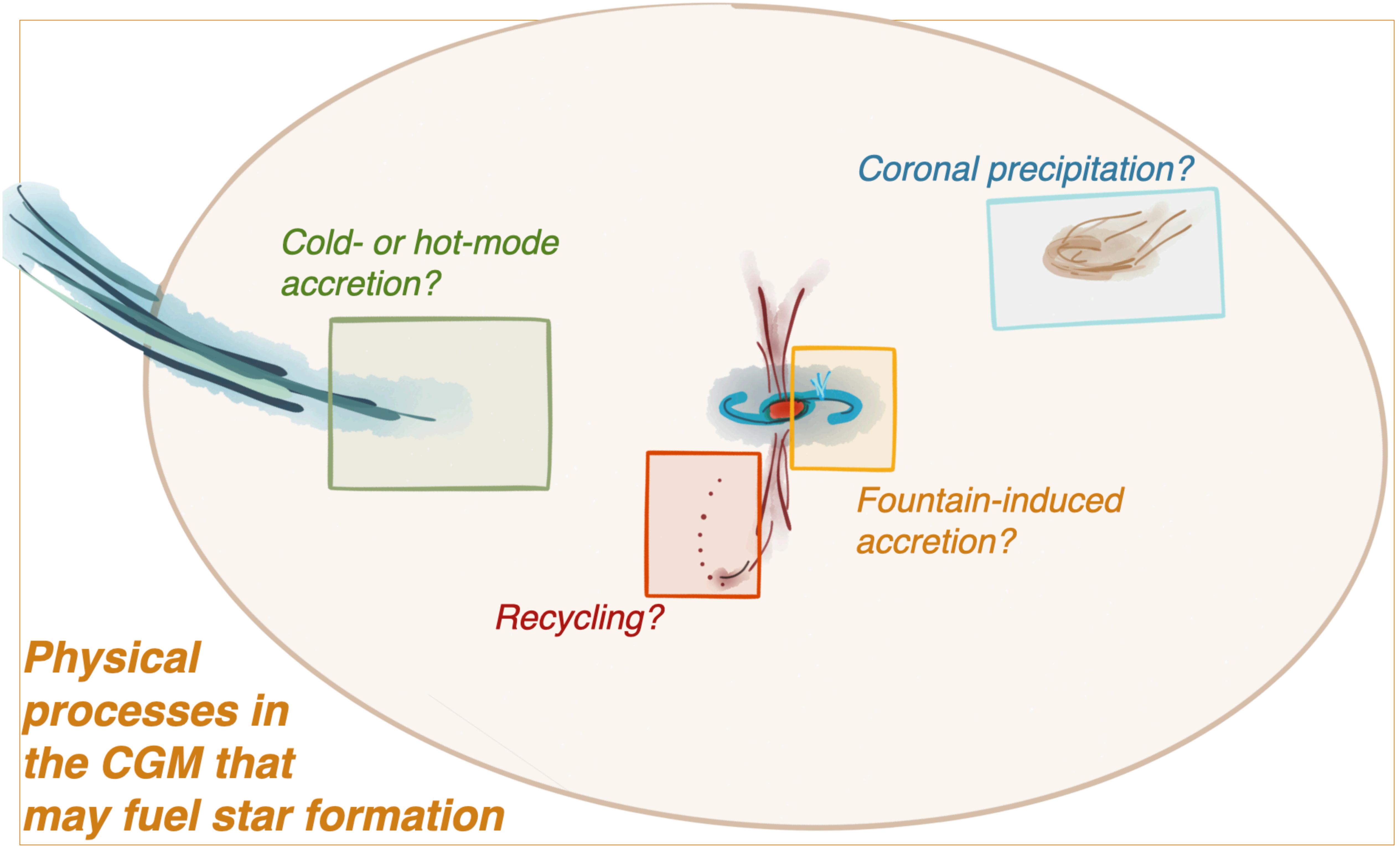
Physical processes in the CGM that may fuel star formation

We want to understand which of these is important!

What are the priorities for HWO for studying the flow of baryons and metals in and out of galaxies?

What technologies and requirements are most important?

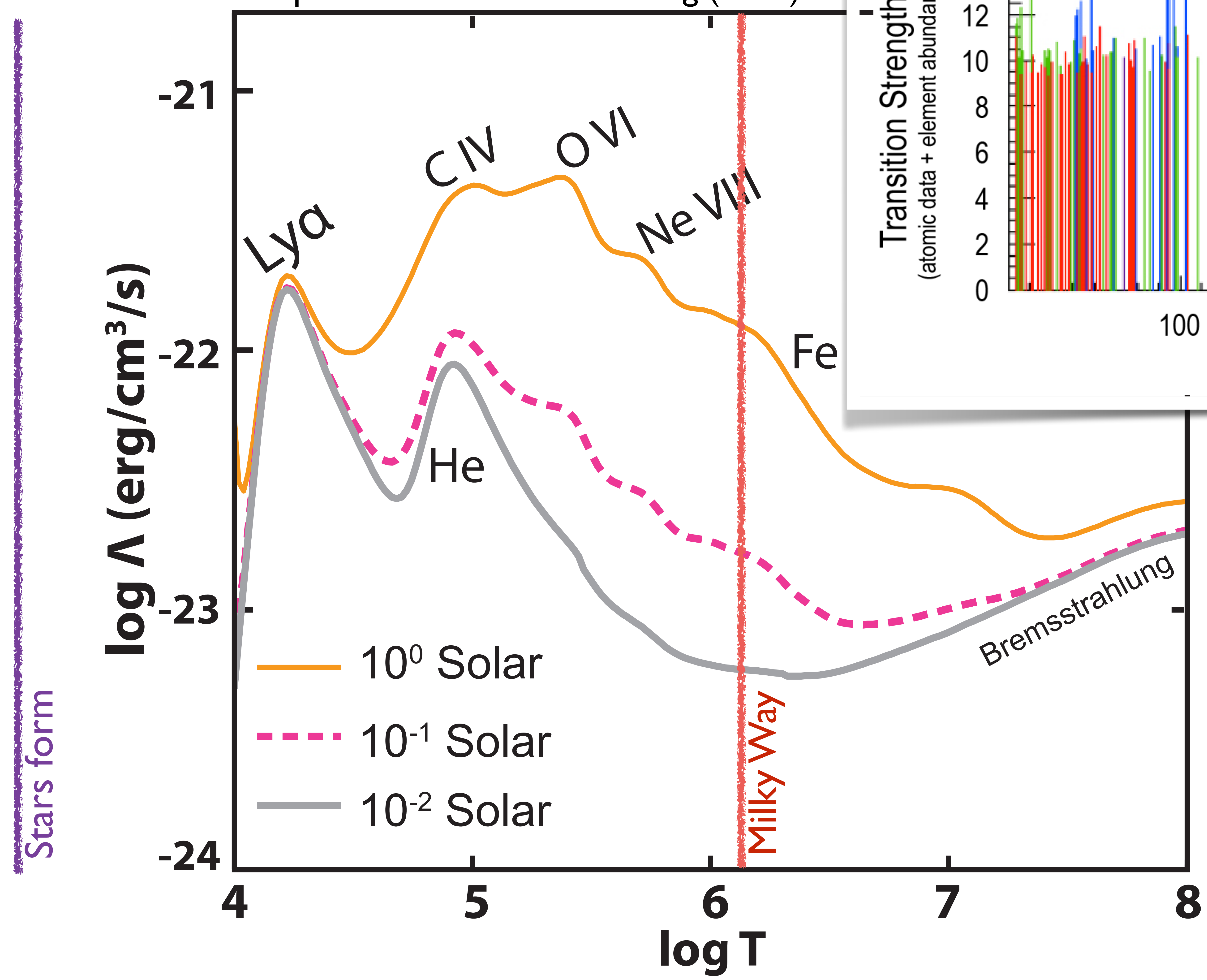
We want to trace the **mass reservoirs** of warm and hot ionized gas ***AND*** the processes that **transform** this into cold gas that can form stars.



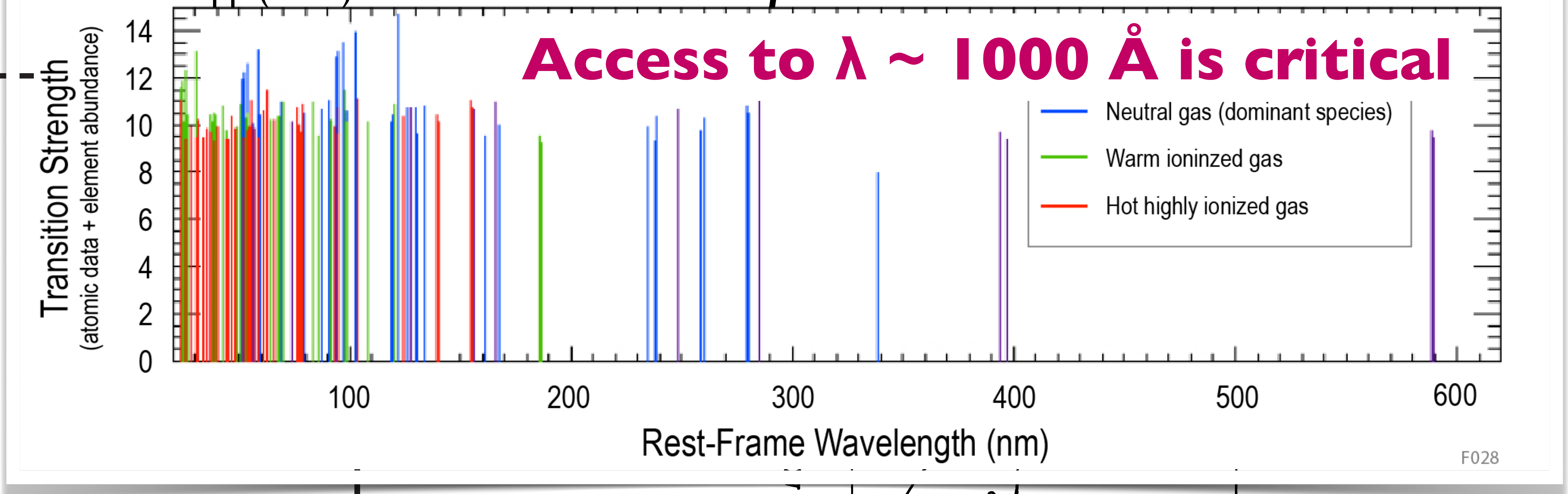
- FUV spectroscopy (<1200 Å)
- Diffuse imaging

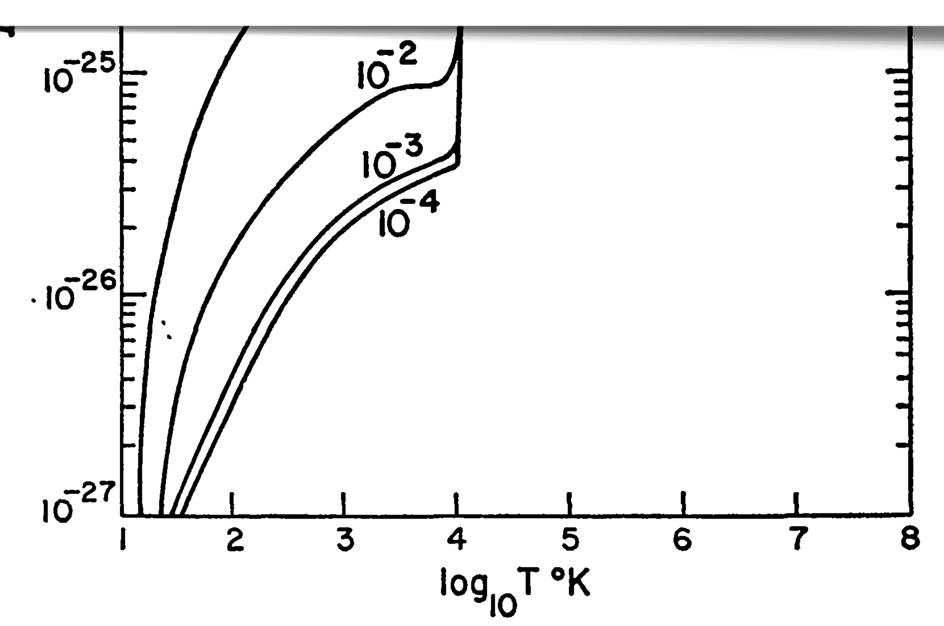
Understanding the baryon cycle requires access to the FUV

Adapted from Gnat & Sternberg (2007)



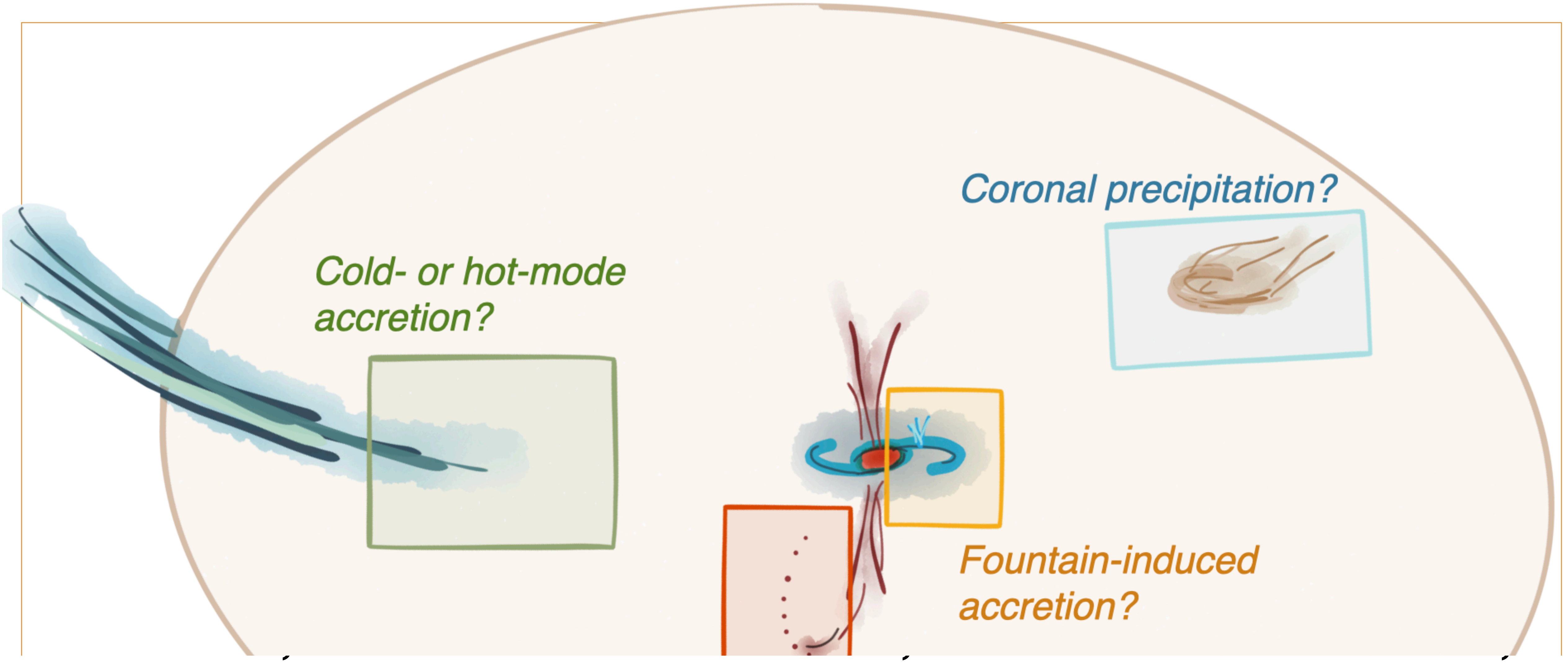
Tripp (2019) from the ***HabEx Final Report***

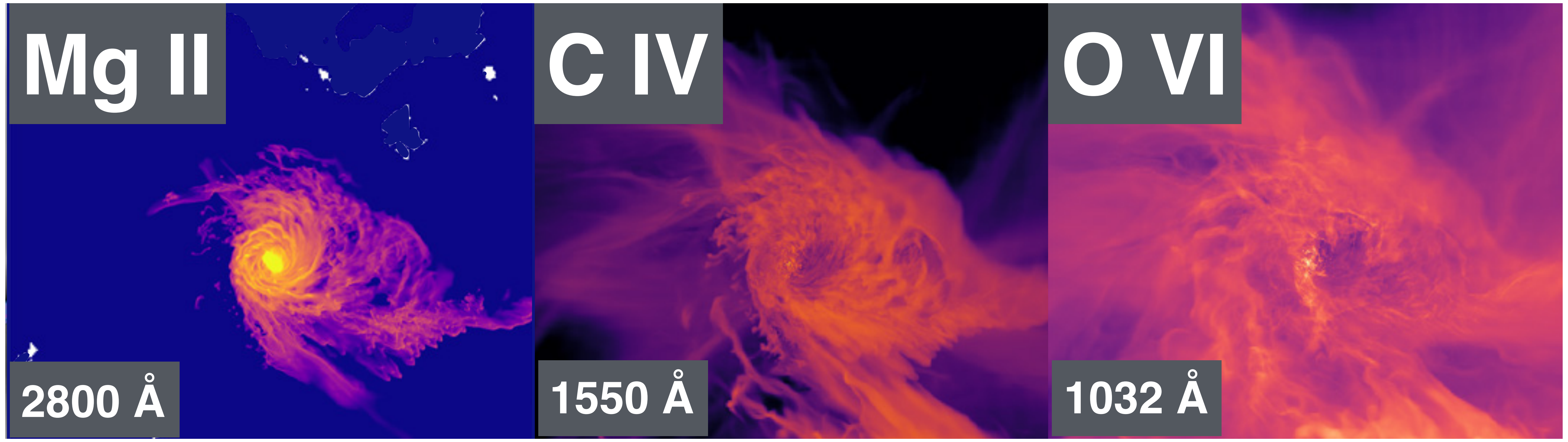




While the hottest gas may bear much of the mass, the ***ACTION*** is all in the EUV/FUV ions that cool the gas to the star-forming regime.

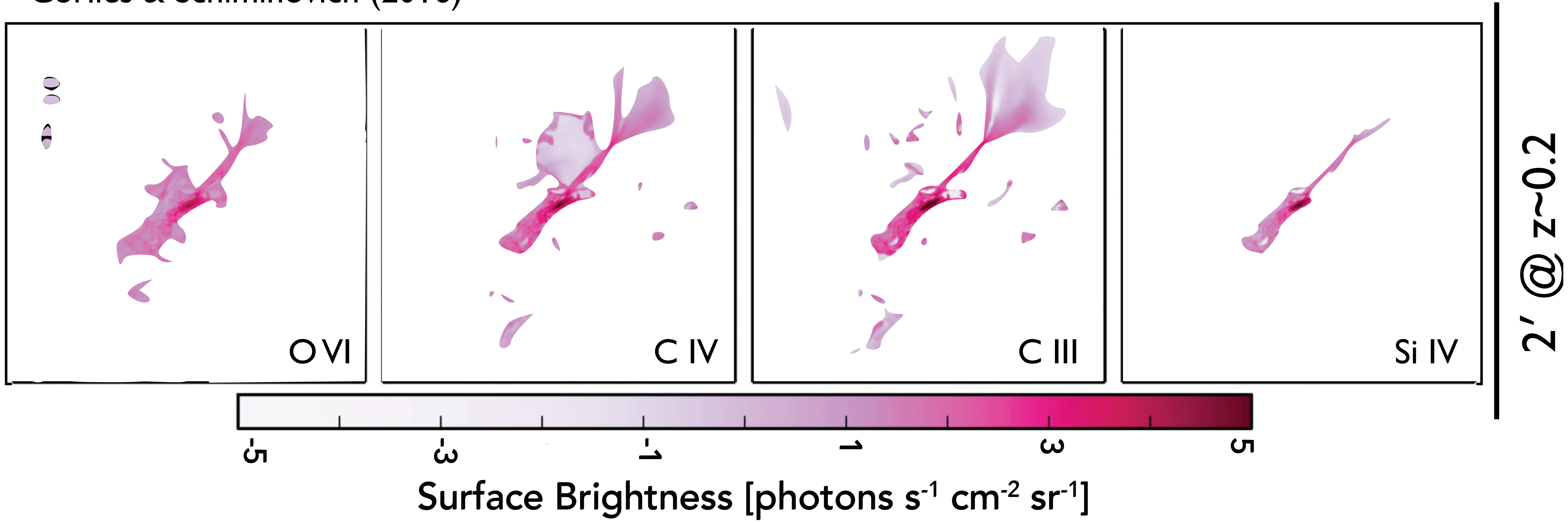
We want to **map** the morphology of the gas, tracing the **energy** and **mass exchange** through the CGM





- FUV spectroscopy (<1200 Å)
- Diffuse imaging
- Multiplexed spectroscopy
- Large aperture

Corlies & Schiminovich (2016)



Morphological information –

Where are the filaments and winds?

Cooling rates –

Do galaxies acquire their gas from the CGM?

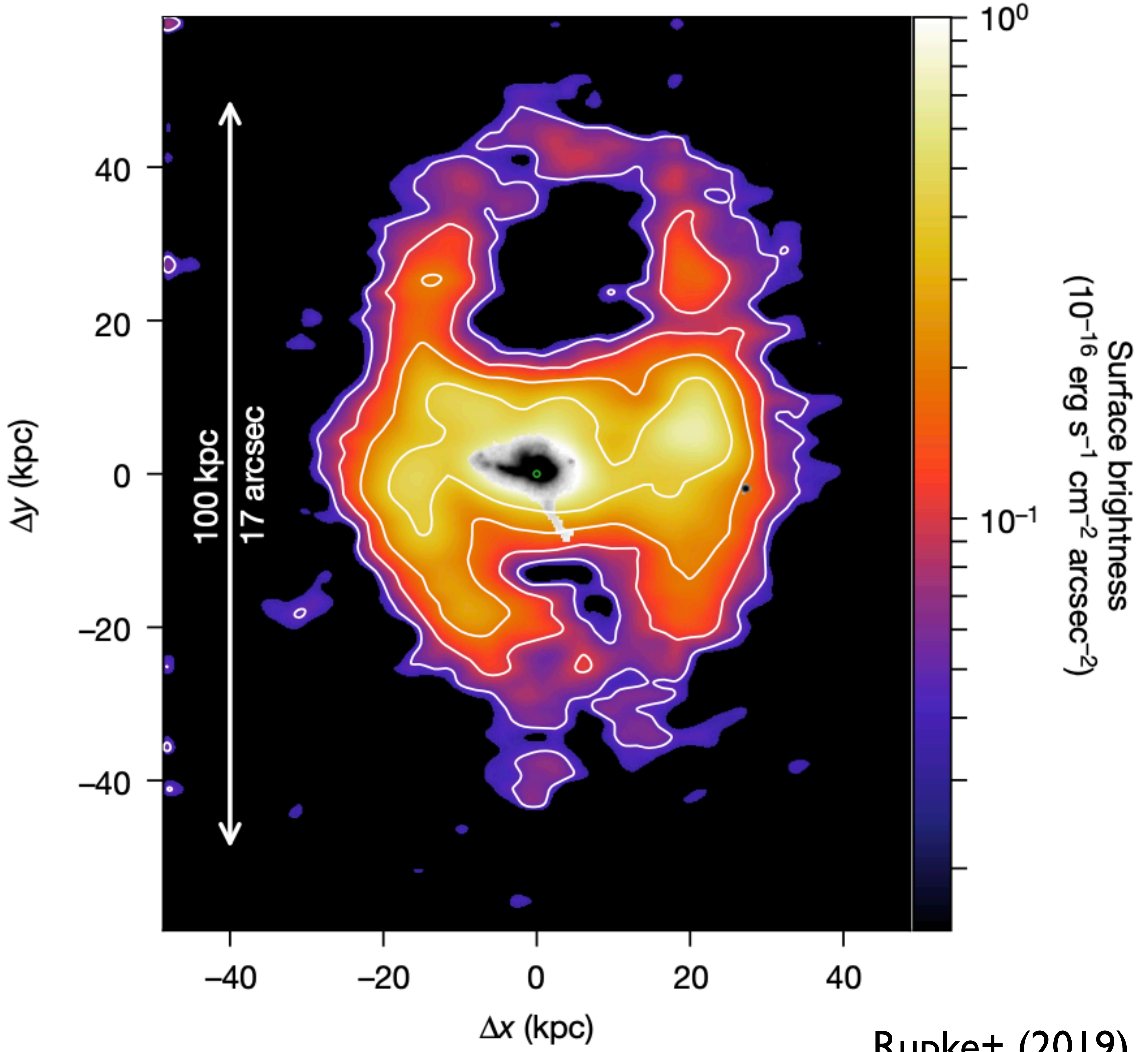
Do winds lose their energy to radiation?

Physical Scales –

What are the relevant length, density scales for halo structures? Pressures, temperatures?

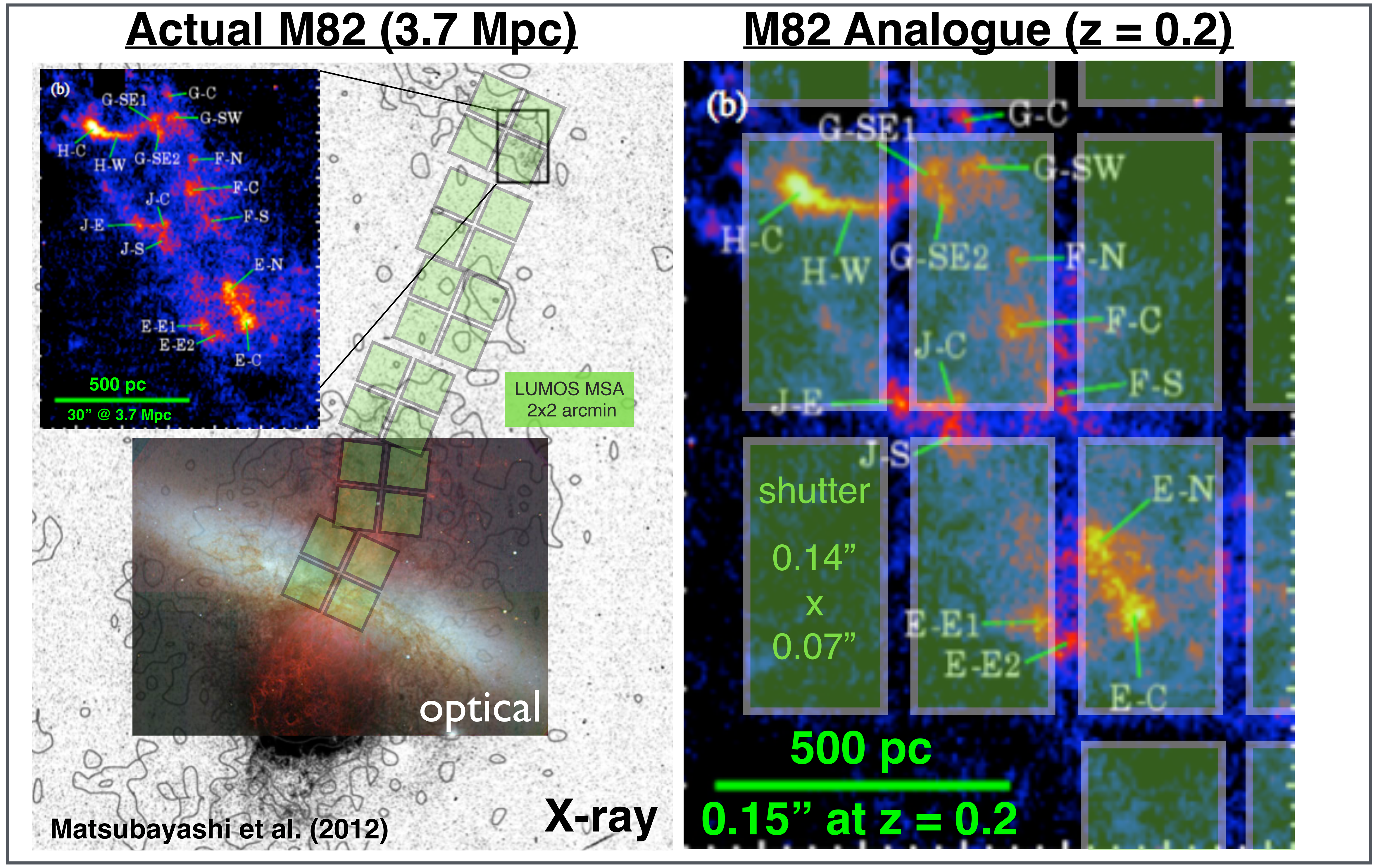
See also van de Voort & Schaye (2013), Bertone & Schaye (2012)

[O II] emission from *Makani*



Rupke+ (2019)

Spectral imaging technologies



Microshutter arrays

Vives+ (2008)

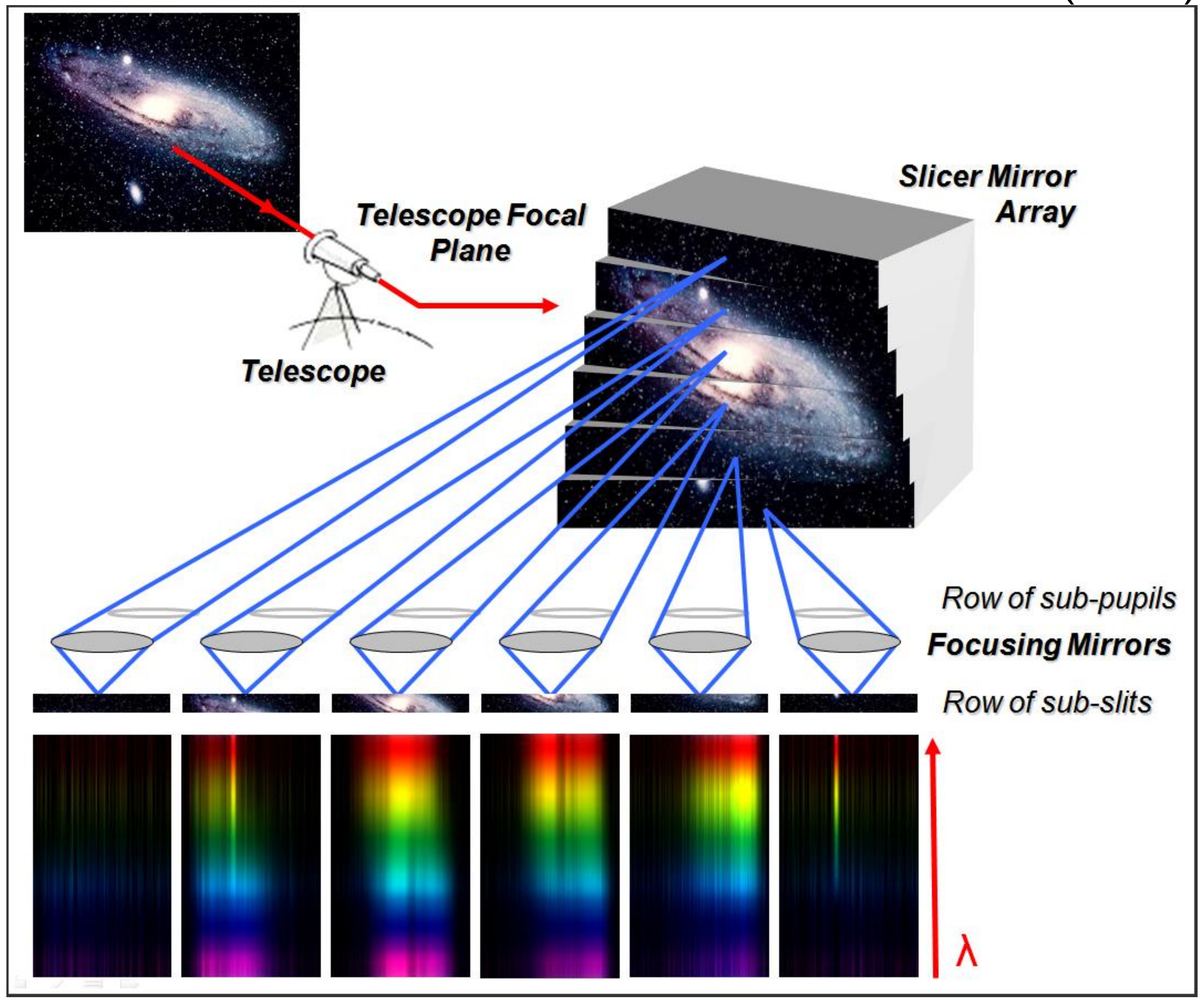
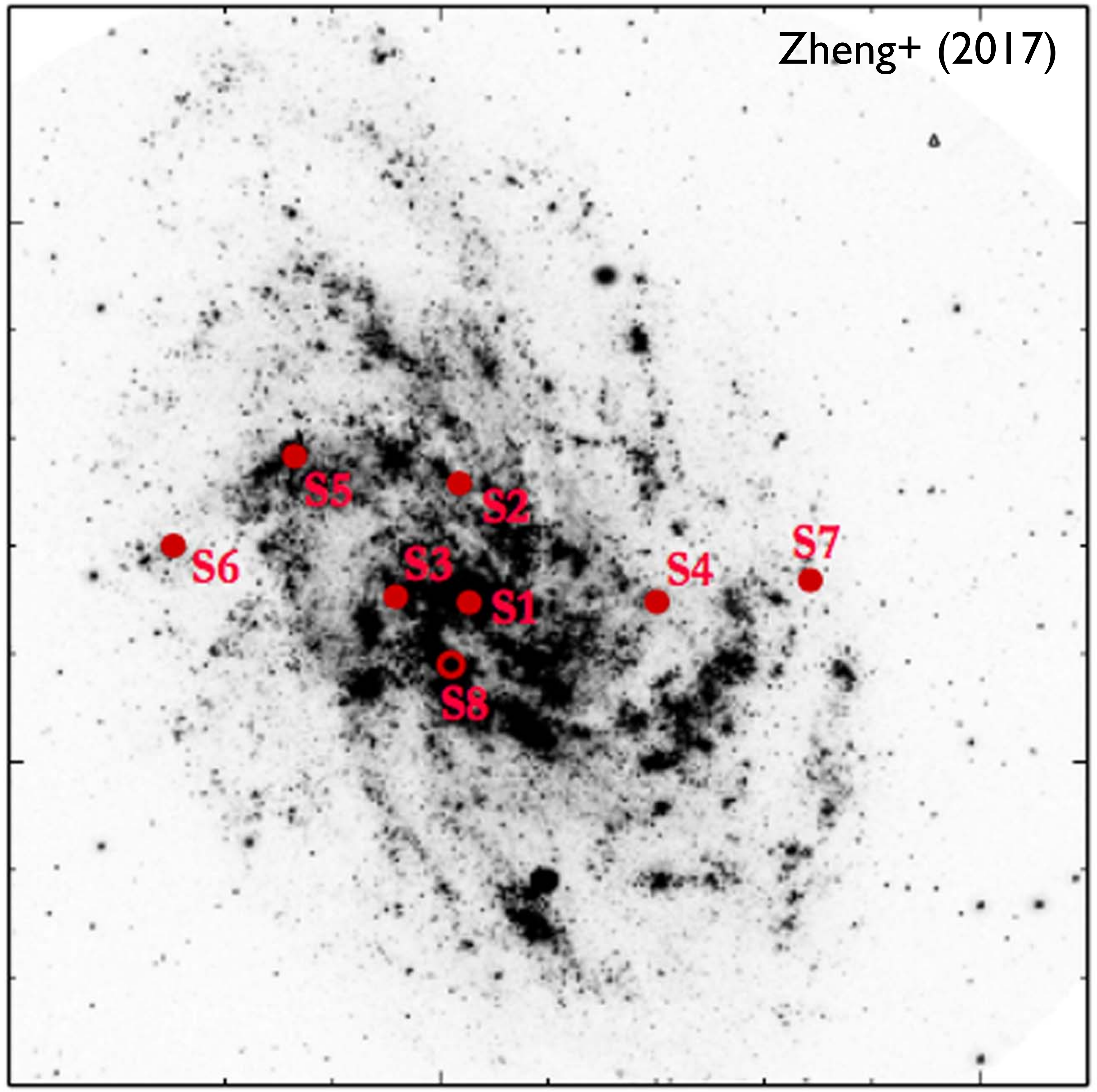
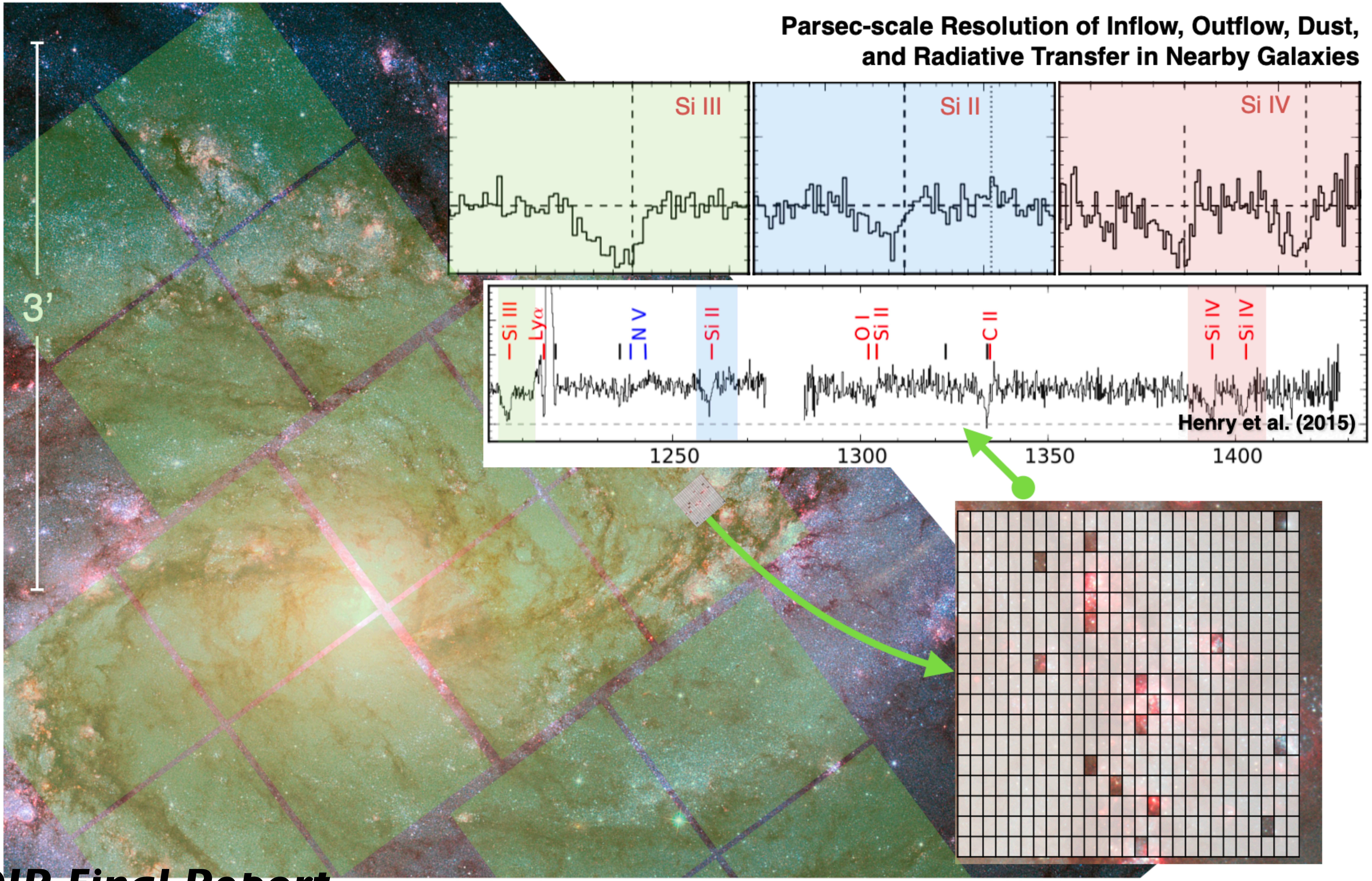


Image slicers?

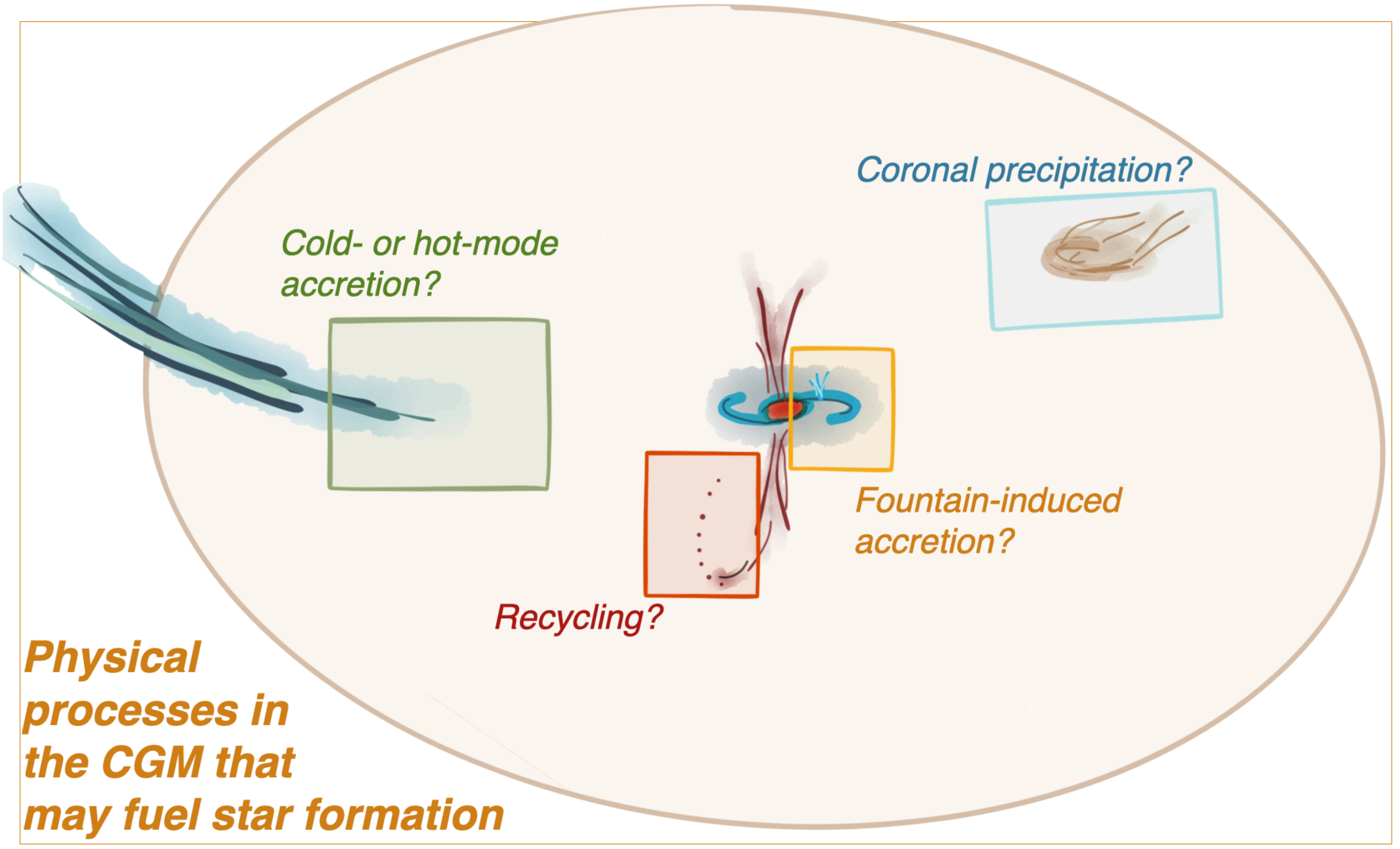
We want to use **multiobject spectroscopy** to understand the **energy requirements** for launching outflows.

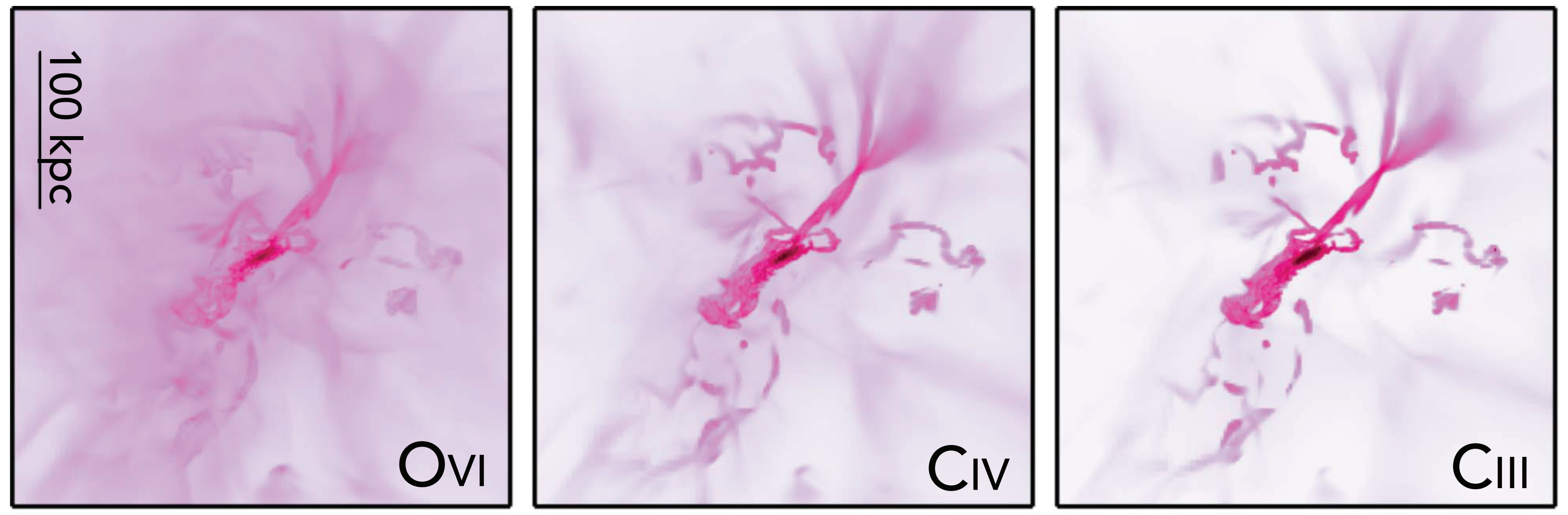


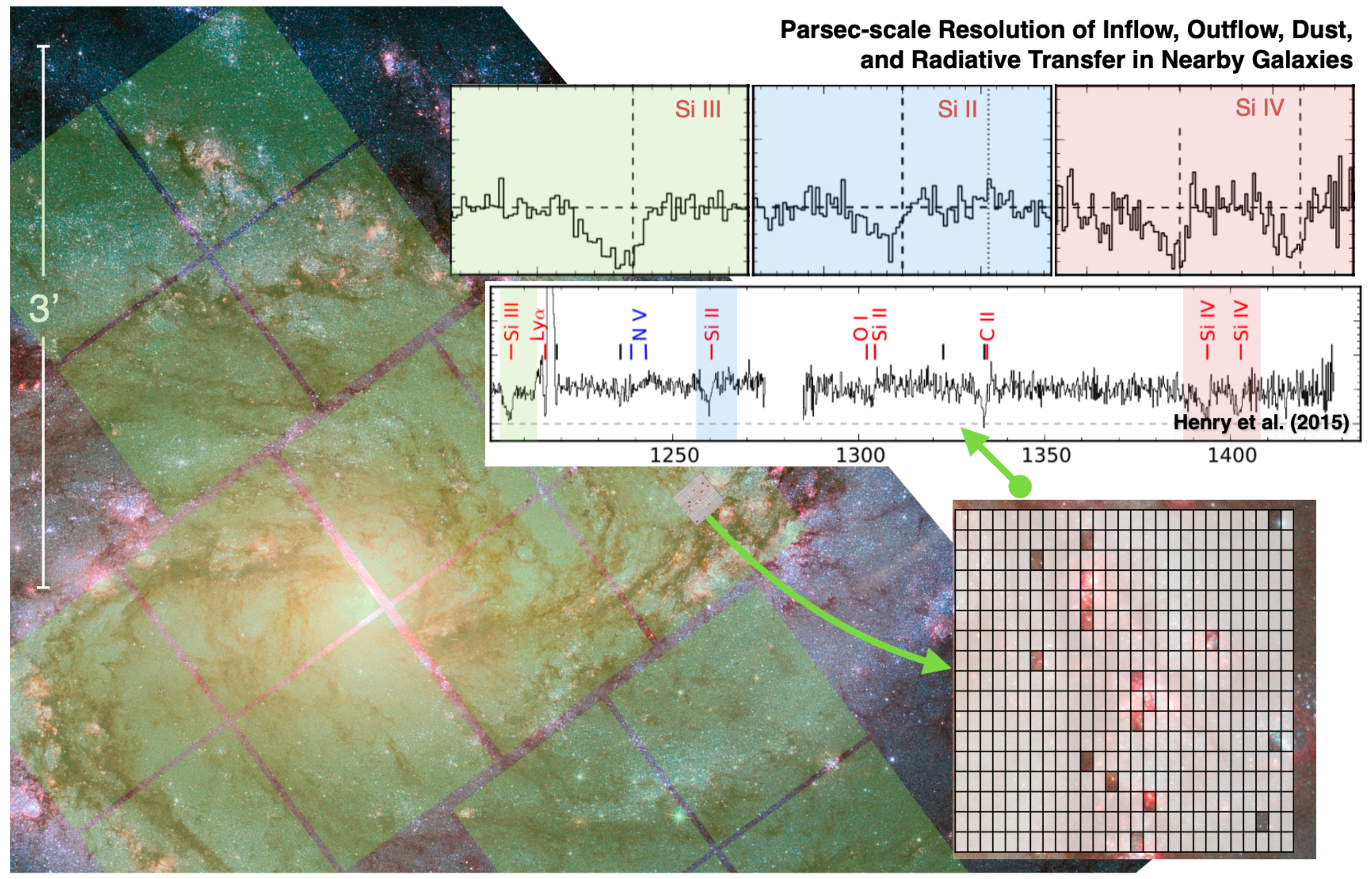
- FUV spectroscopy (<1200 Å)
- Multiobject spectroscopy



LUVOIR Final Report







The **cosmic baryon cycle** dictates the manner in which galaxies form stars (or cease forming stars).

HWO will allow us to probe the exchange of matter between a galaxy and its surroundings in ways we never could with Hubble.

HWO will provide the greatest advances with:

- Good sensitivity to **λ > 1000 Å**.
- Robust diffuse **imaging** capability.
- **Multiobject** spectroscopy in the UV.
- **High spectral resolution** (preferrably $R \gtrsim 50{,}000 - 100{,}000$)