Gas Flows in Galaxies

The Essential Role of UV Spectroscopy

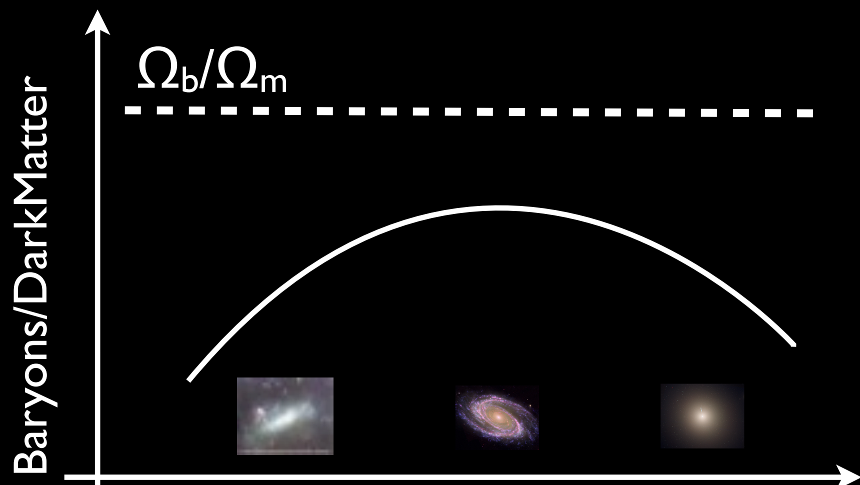
Moral of the Story:

UV spectroscopy provides unique tools for mapping the interstellar, circumgalactic, and intergalactic gas flows that drive galaxy evolution.

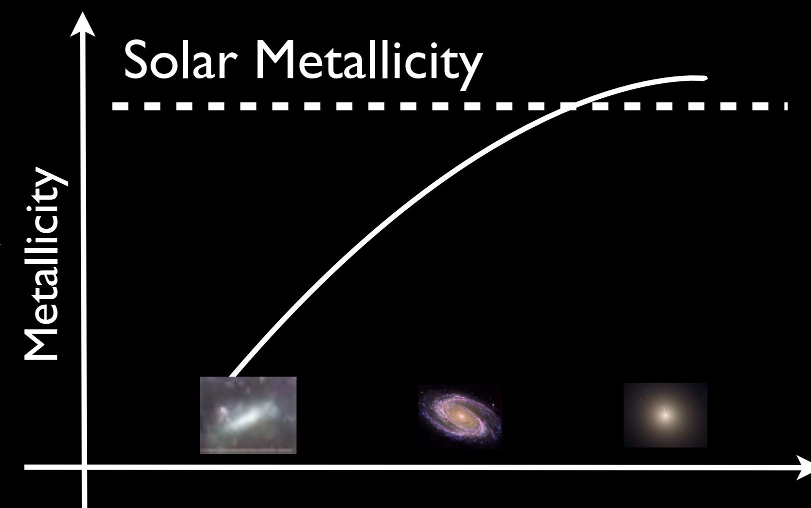
Jason Tumlinson
(STScI)

see also recent white paper "Unique Astrophysics in the Lyman Ultraviolet" (arXiv:1209.3272)

Big Puzzles in Galaxy Formation

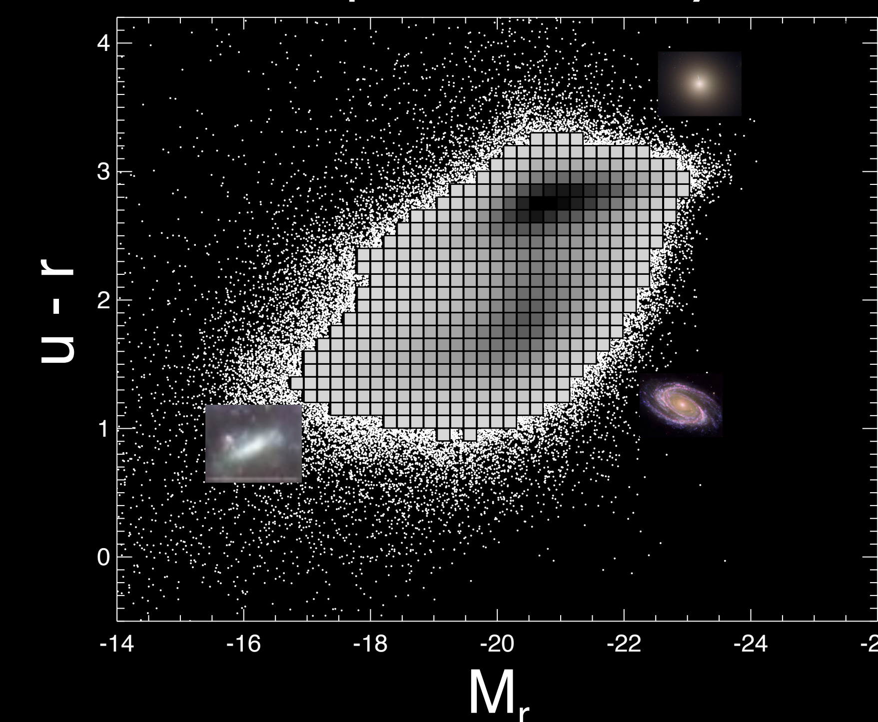


Why does the galaxy LF not follow the DM halo mass distribution?



What causes the galaxy mass-metallicity relation (MZR)?

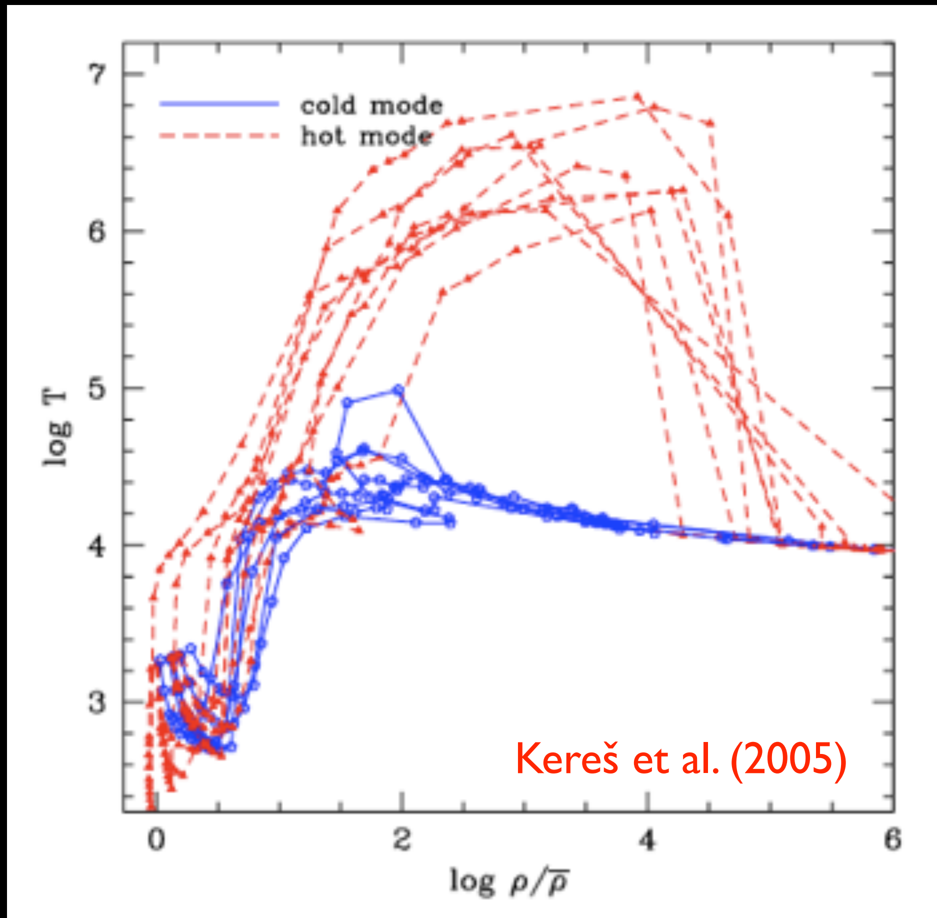
What quenches galaxies and keeps them that way?



How are galaxies transformed?

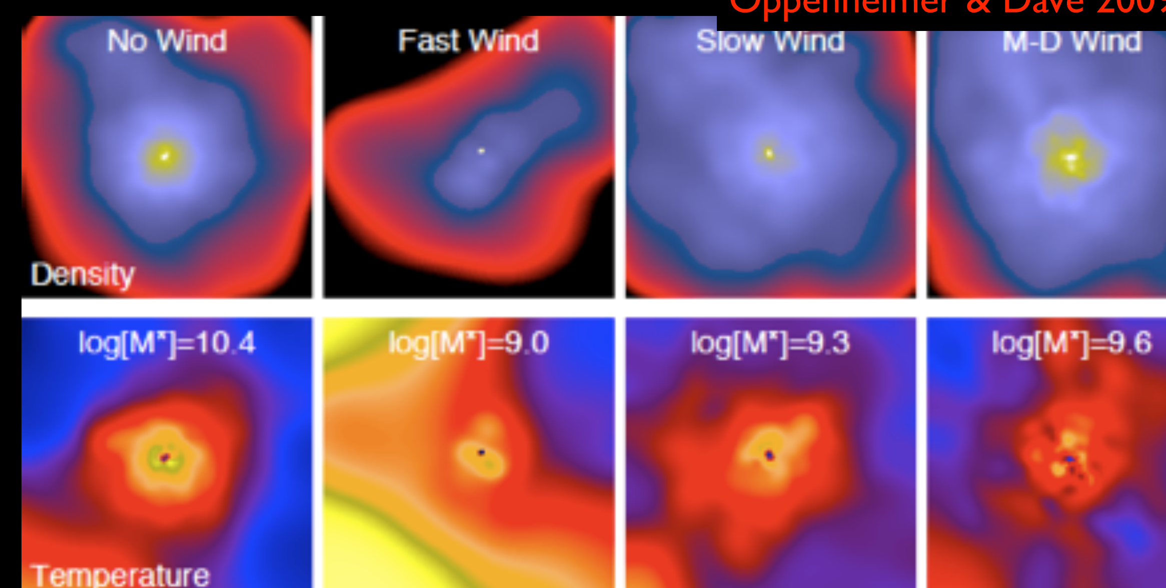
Gas Flows in Galaxies

ARE galaxy formation



Is bimodality related to gas accretion modes?

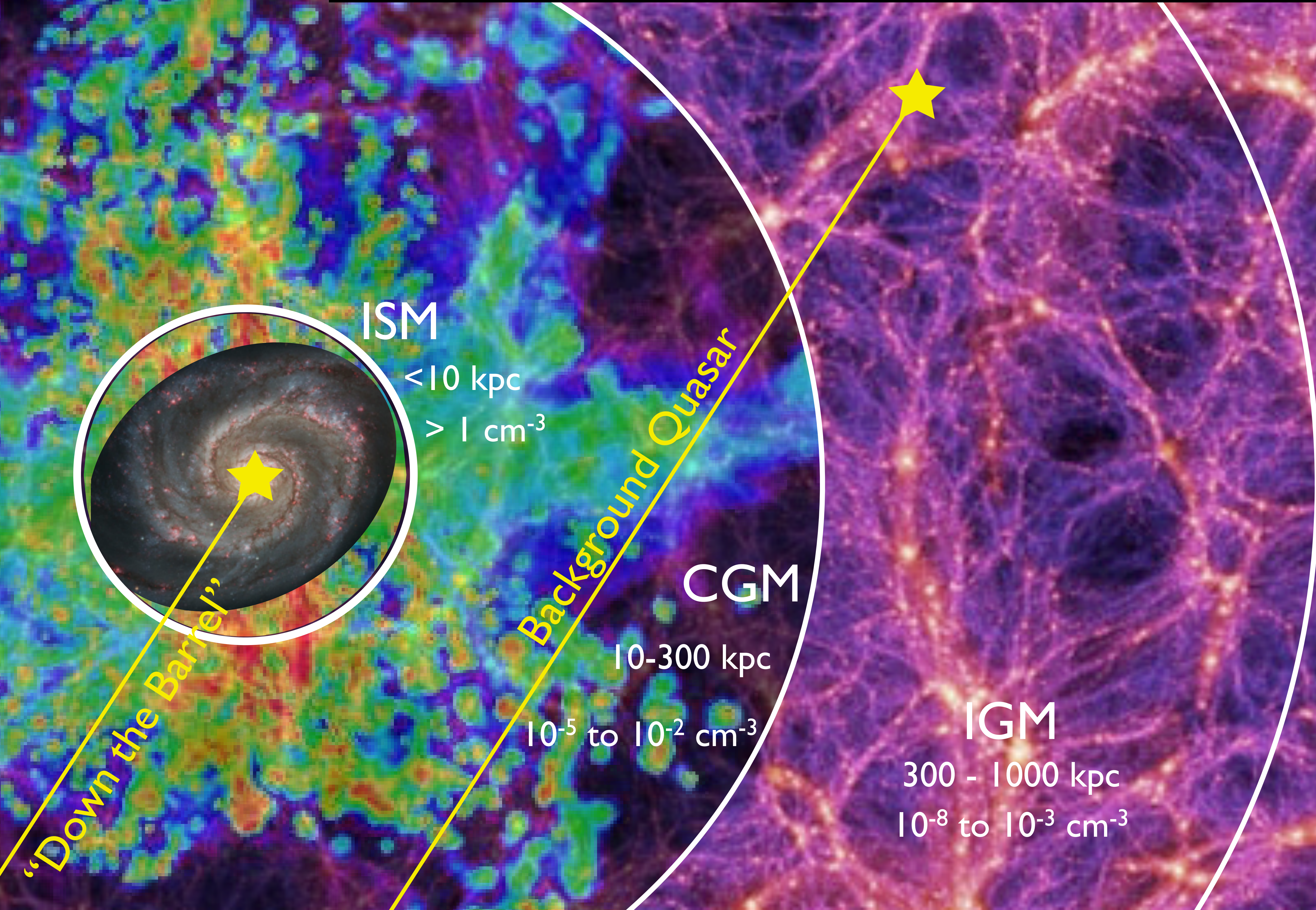
Oppenheimer & Davé 2009



Or to galactic "feedback" from star formation or AGN?

How do these gas flows work?
How much mass do they contain? transport?
How do they drive galaxy formation and evolution?

How We See Gas Flows



Why is UV Absorption so Critical for Studying Gas Flows?

1. UV covers a rich set of physical diagnostics simultaneously.

From densities $n_H = 10^{-7}$ to 1 cm^{-3}, and from T ~ 100 K to ~ 1 million K.

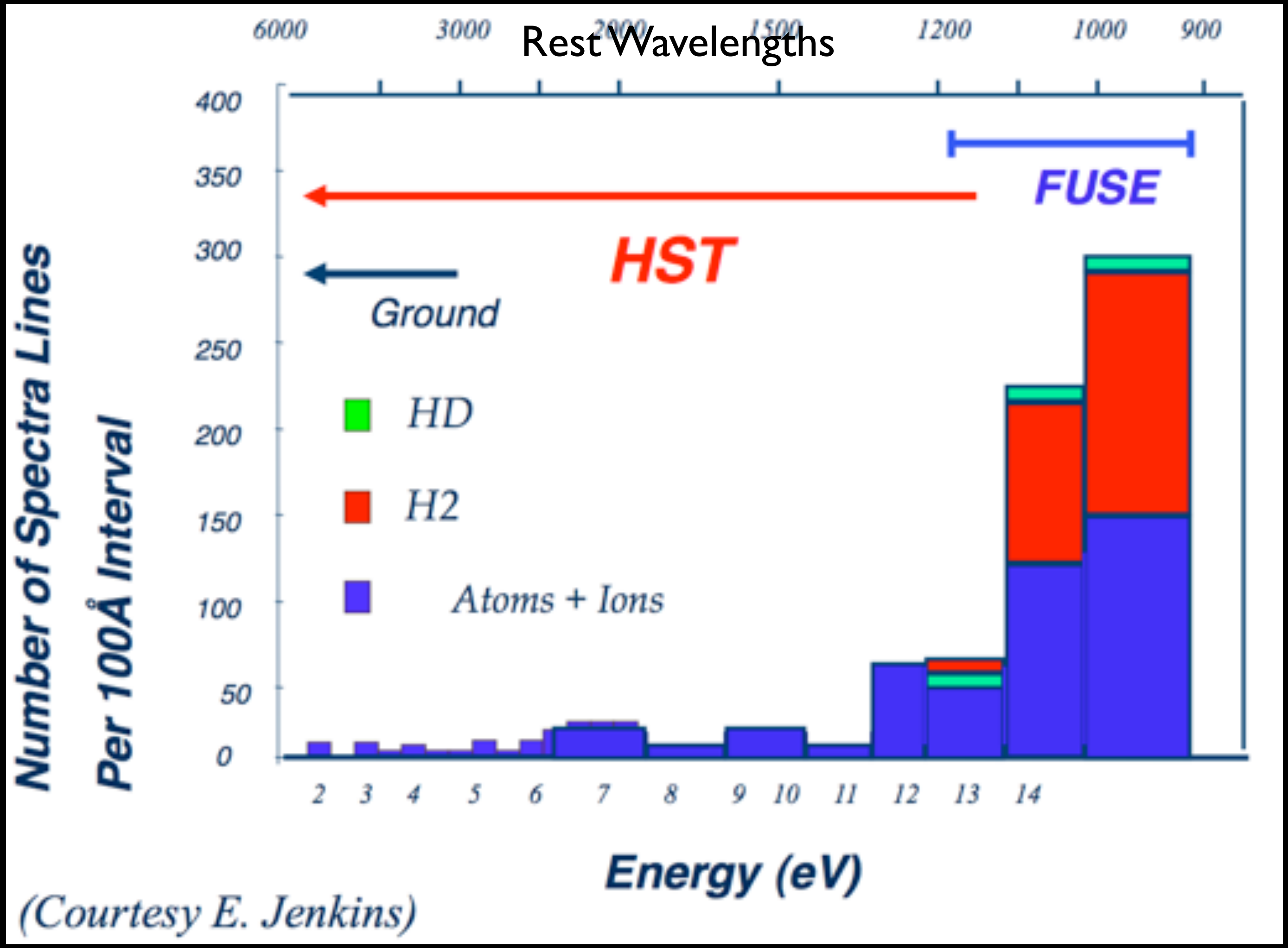
Rest-frame optical tracers (Mg II, Balmer lines) probe only cool neutral medium.

2. Available tracers cover all relevant densities:

IGM and CGM gas are too diffuse to image in emission

3. These tracers measure:

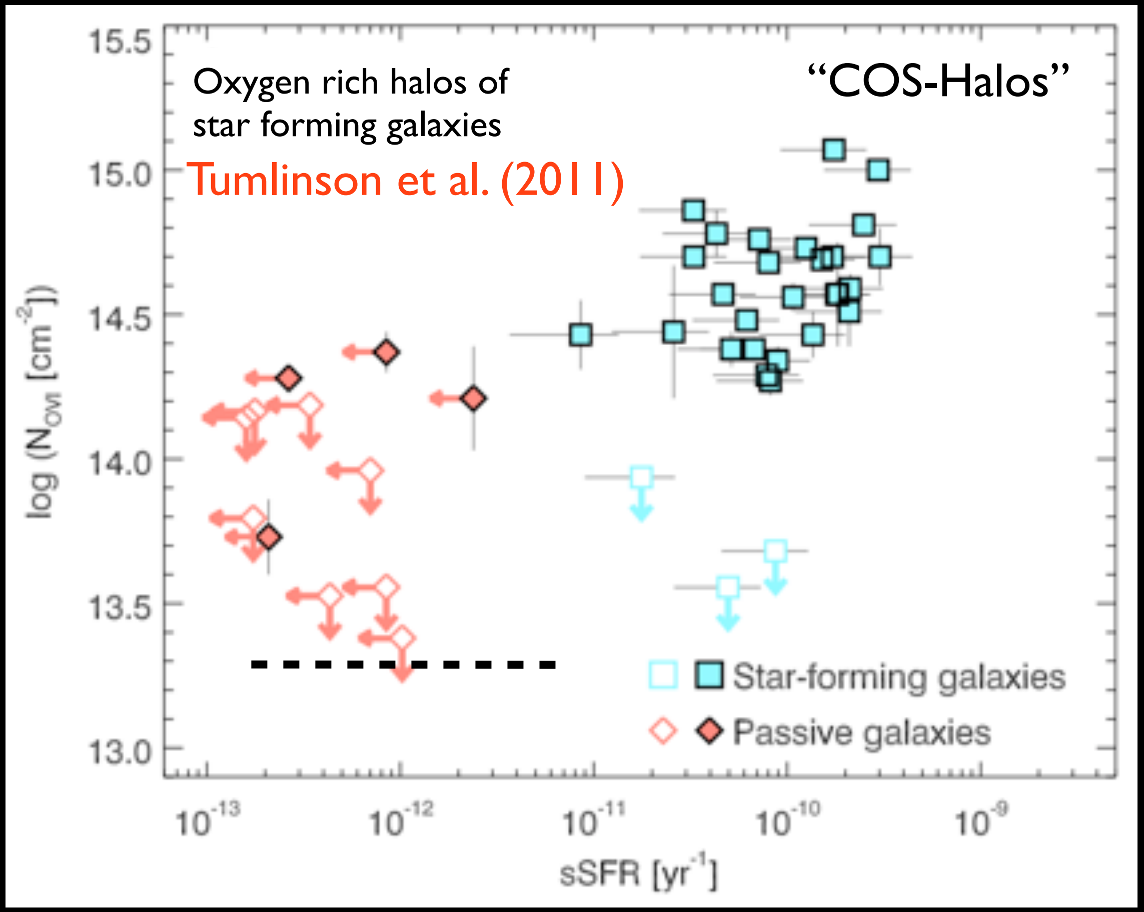
- Surface density.
- Physical density.
- Ionization state.
- Mass.
- Metallicity.
- Kinematics.

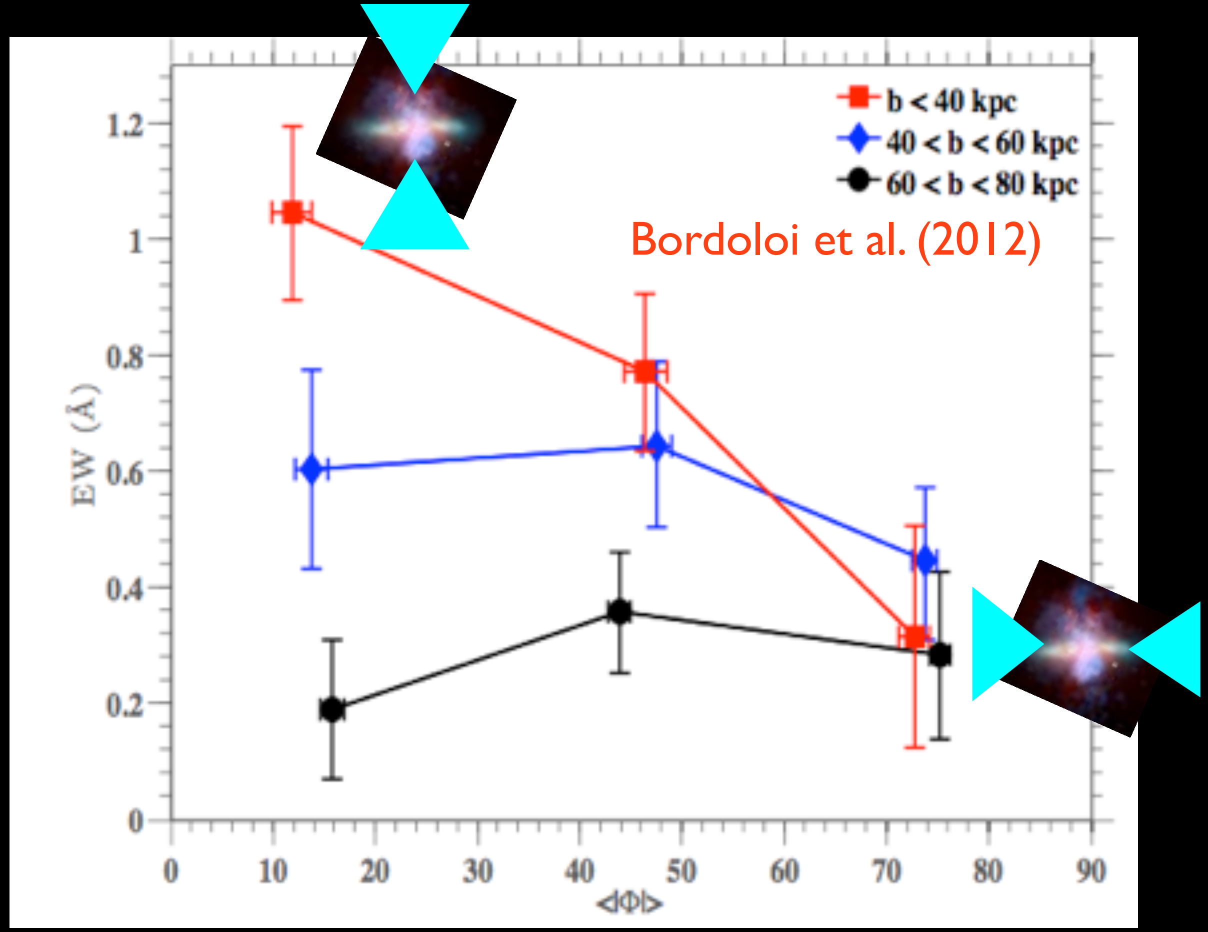


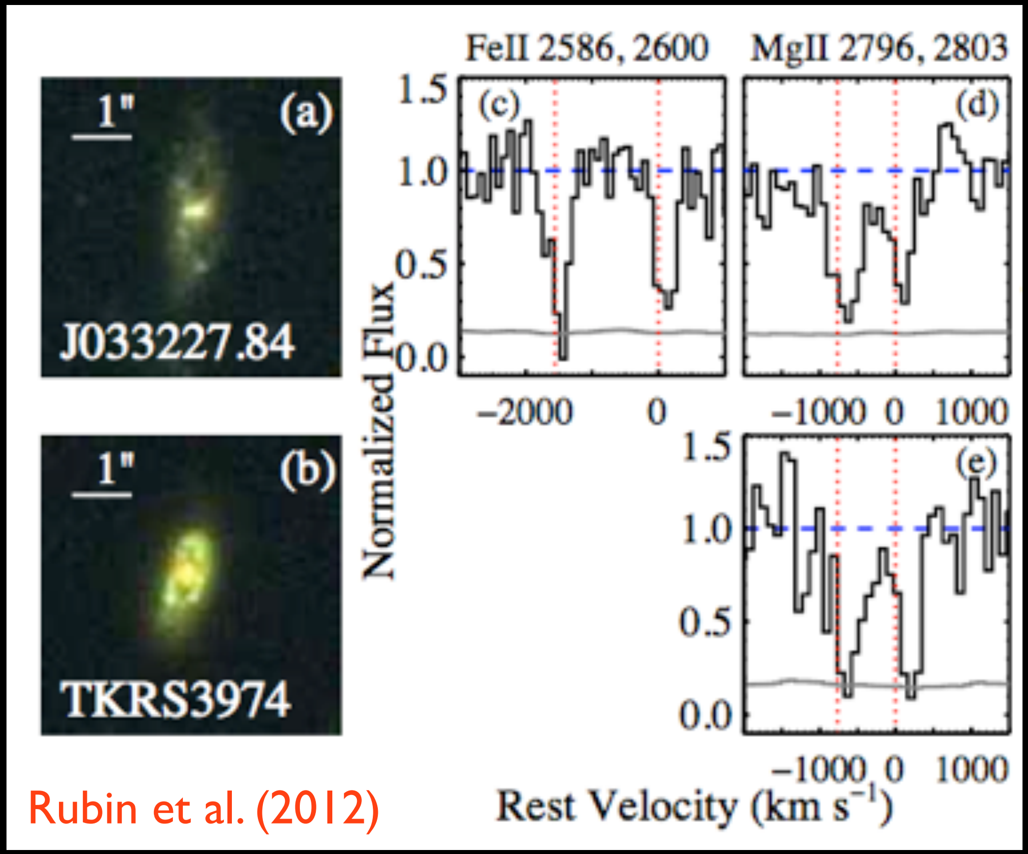
4. They can be used effectively at all redshifts z = 0 - 3.

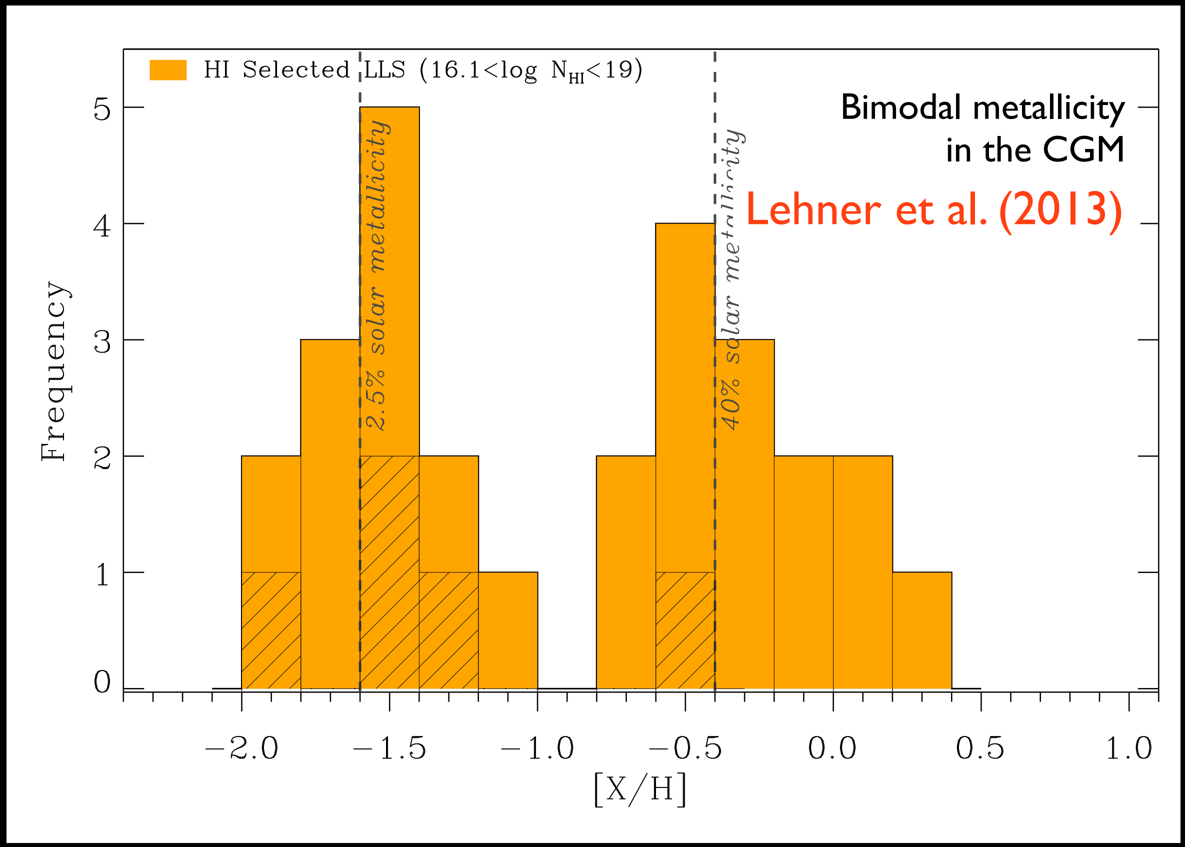
The lines used to probe galactic gas at z ~ 2-3 (e.g. Steidel / Rudie) are in the rest-frame UV.

The Current State of the Art









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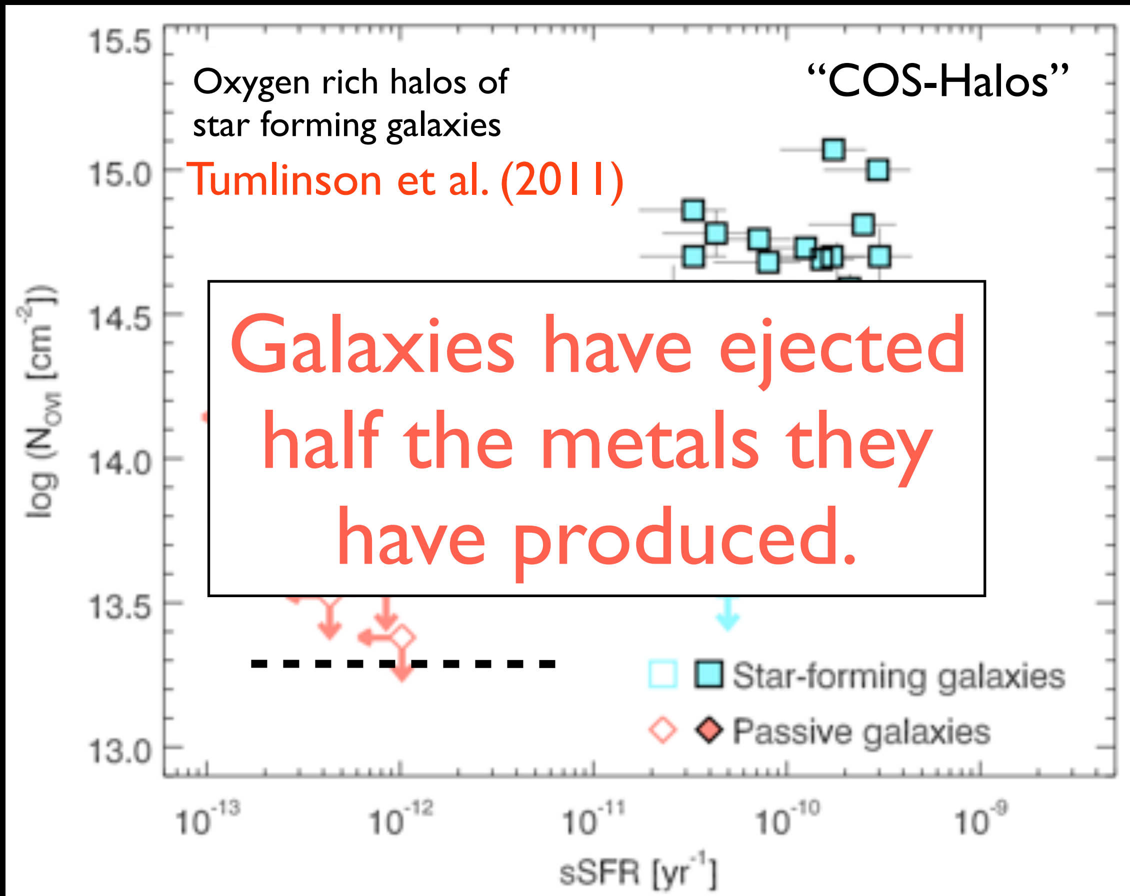

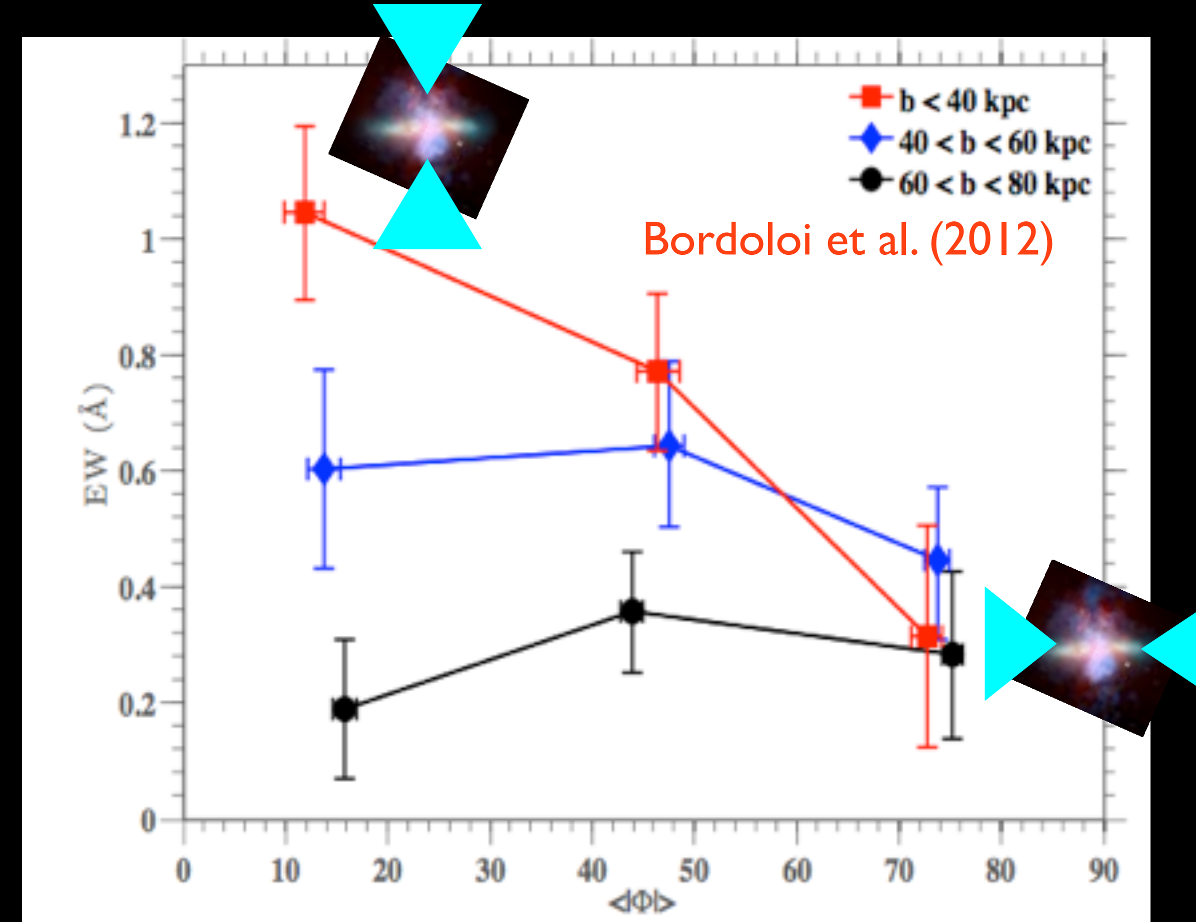

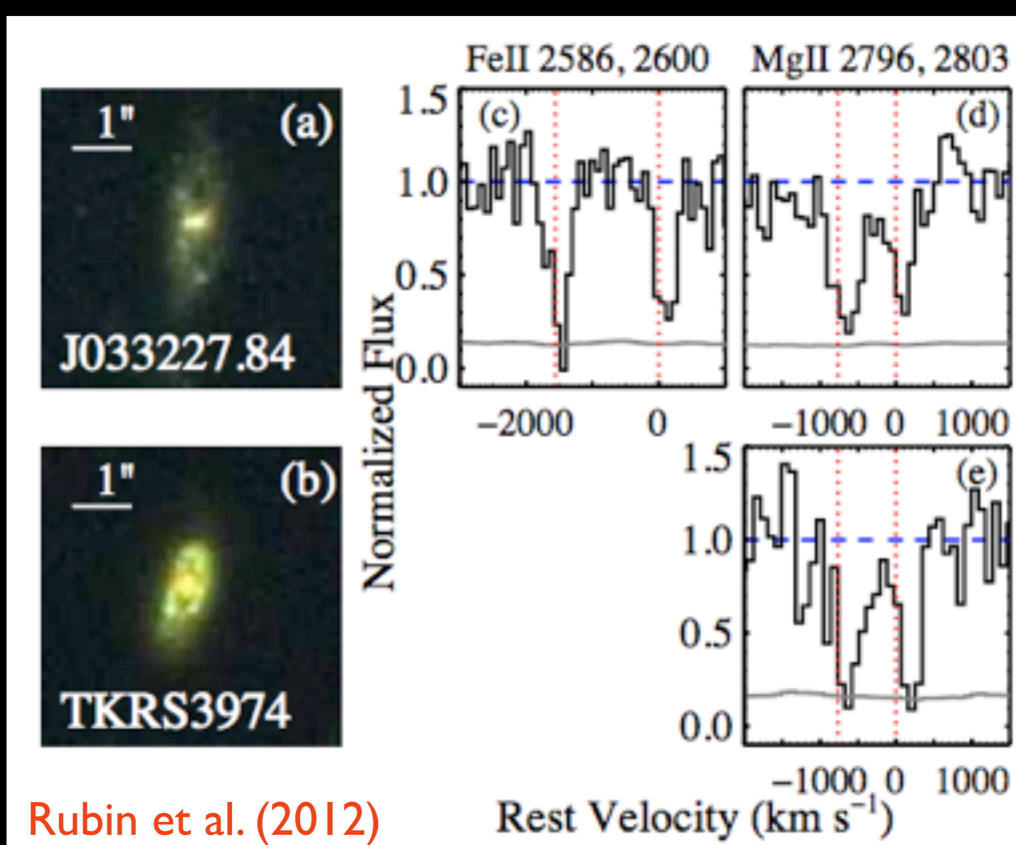

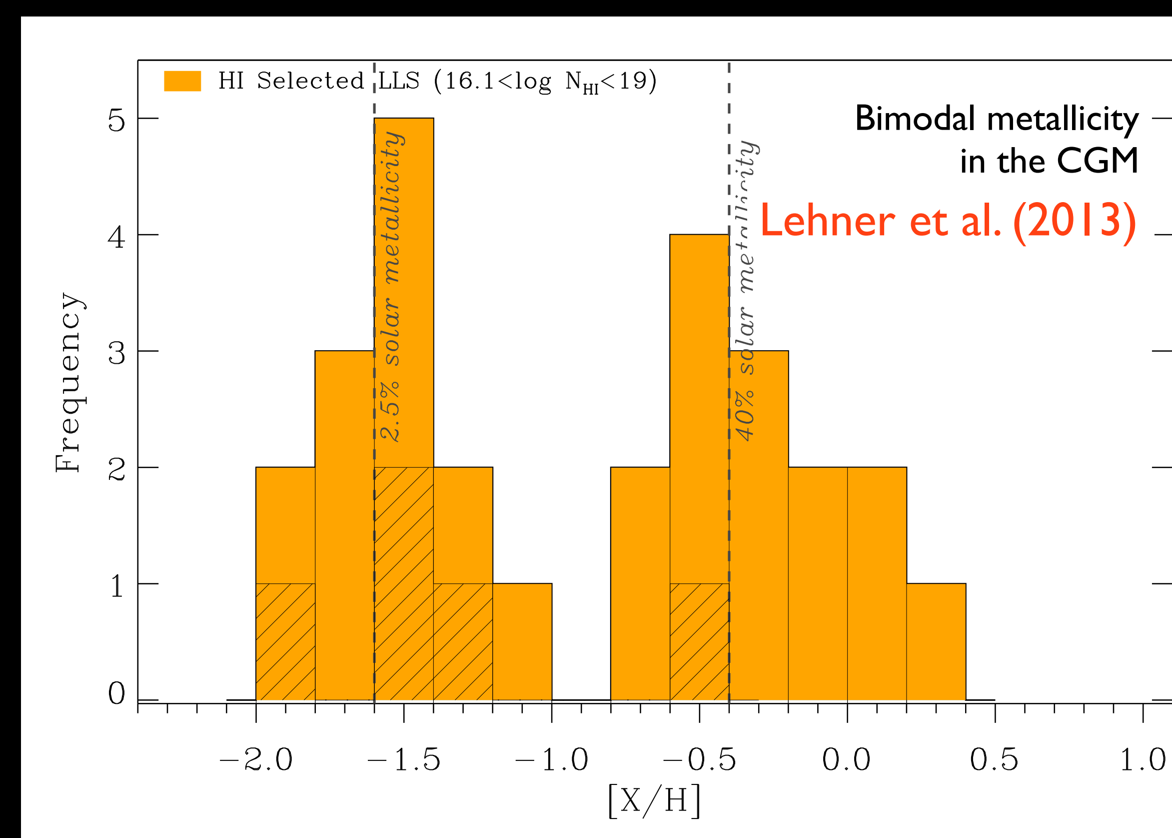

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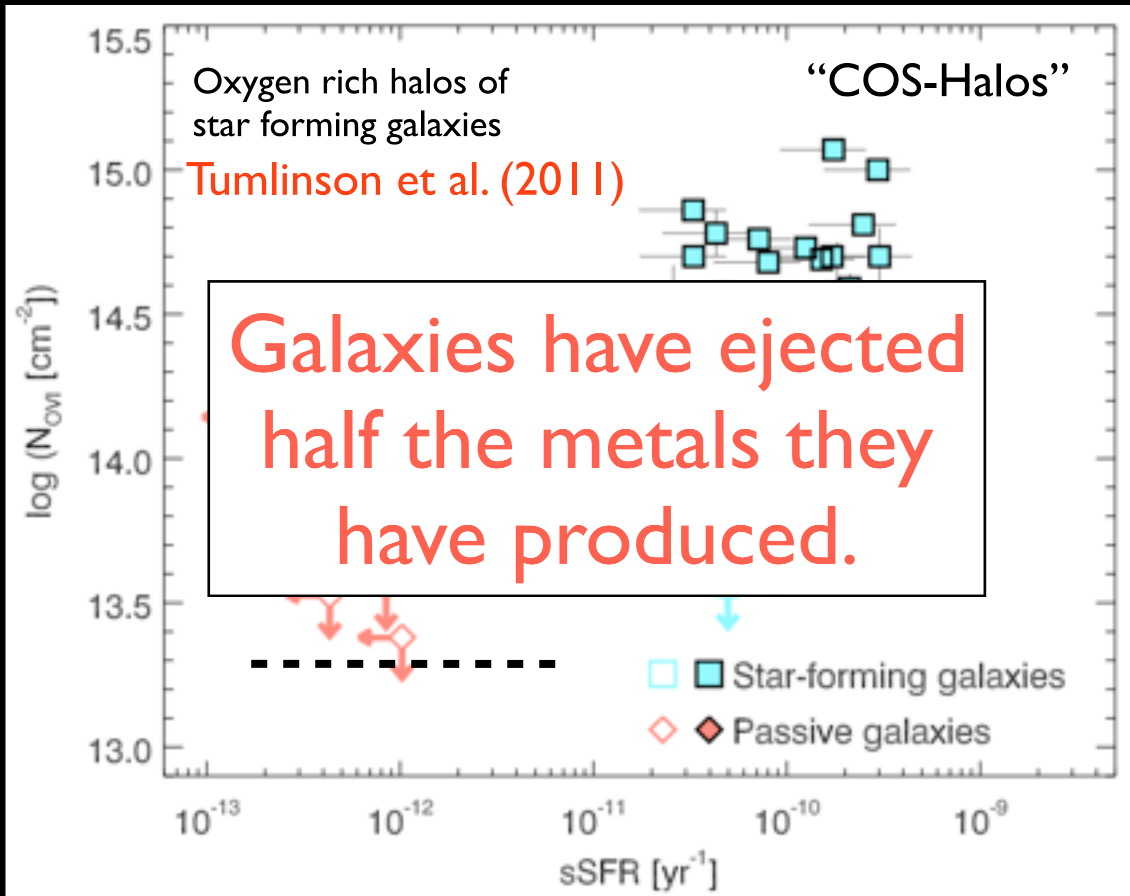

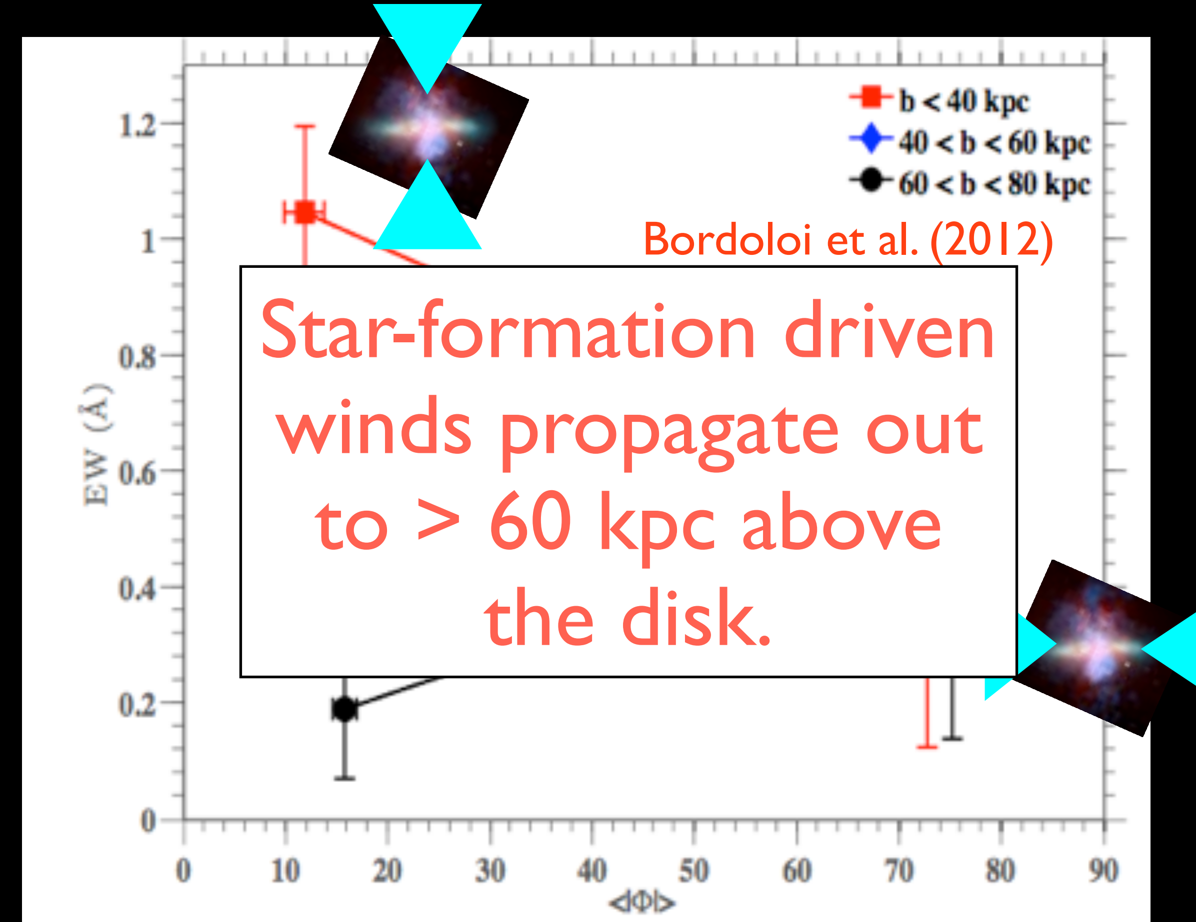

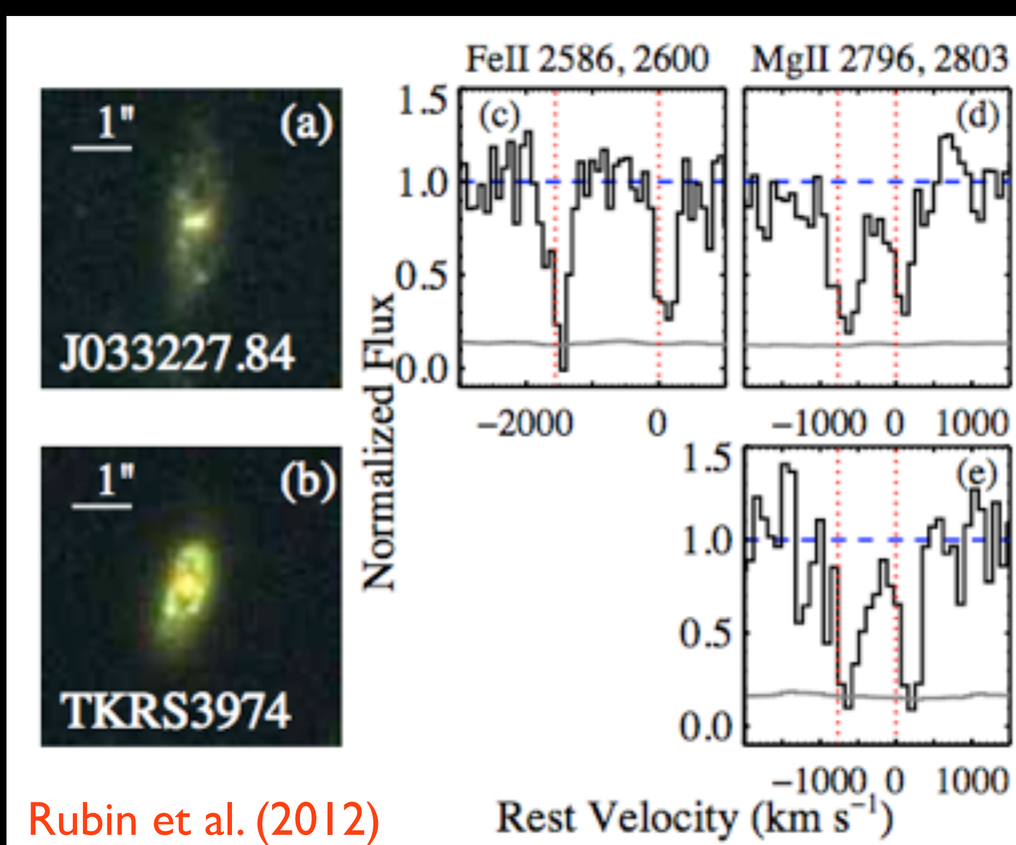

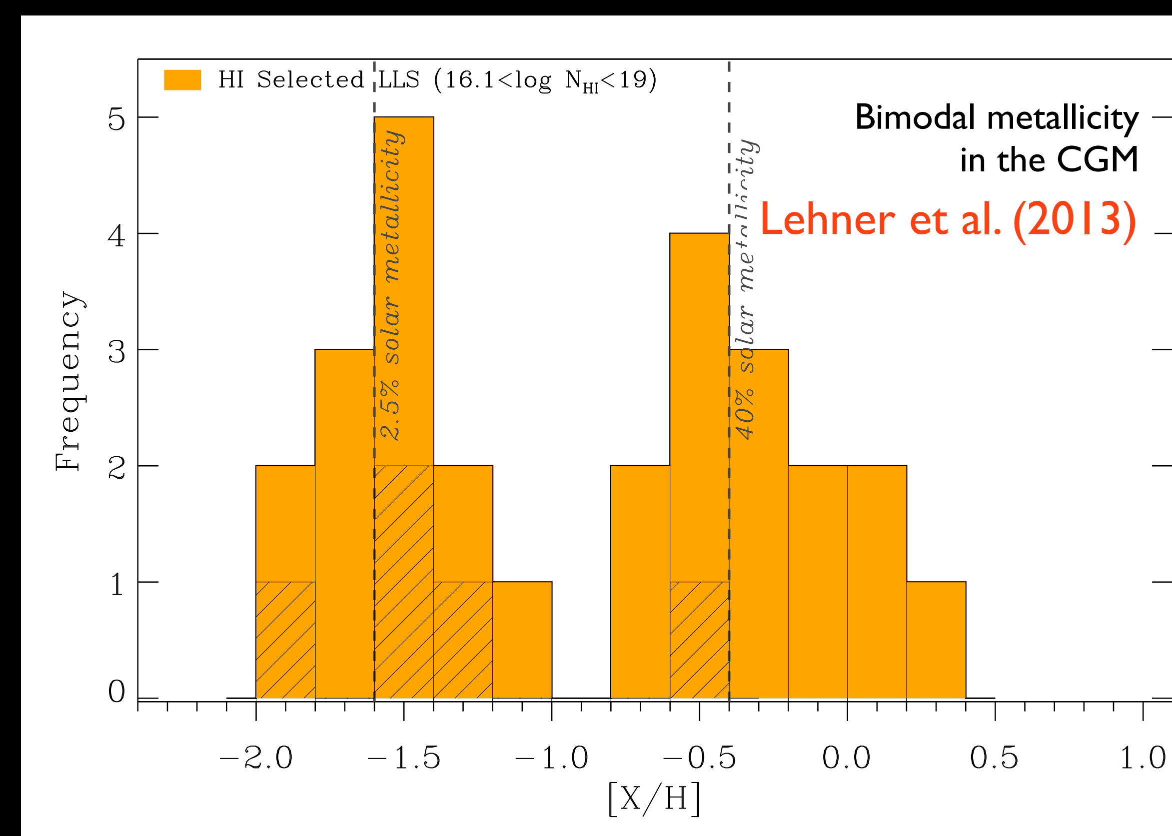

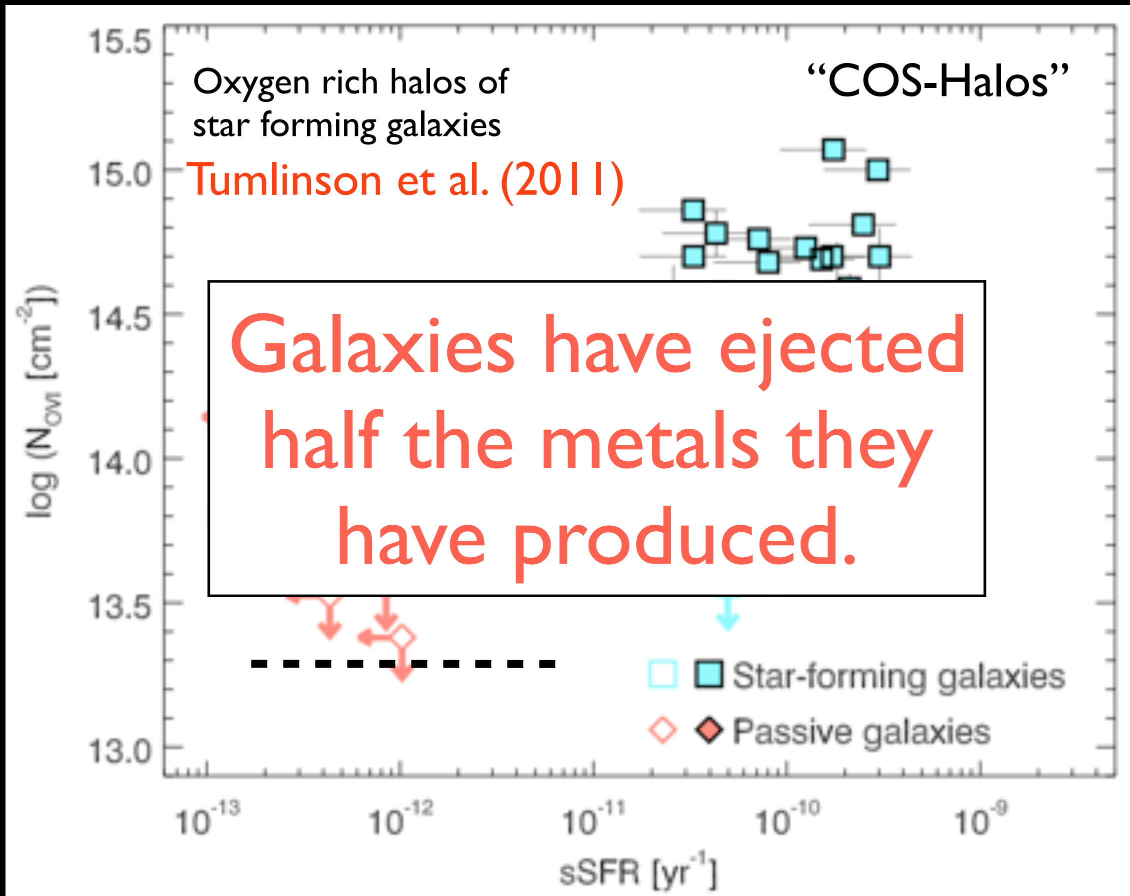

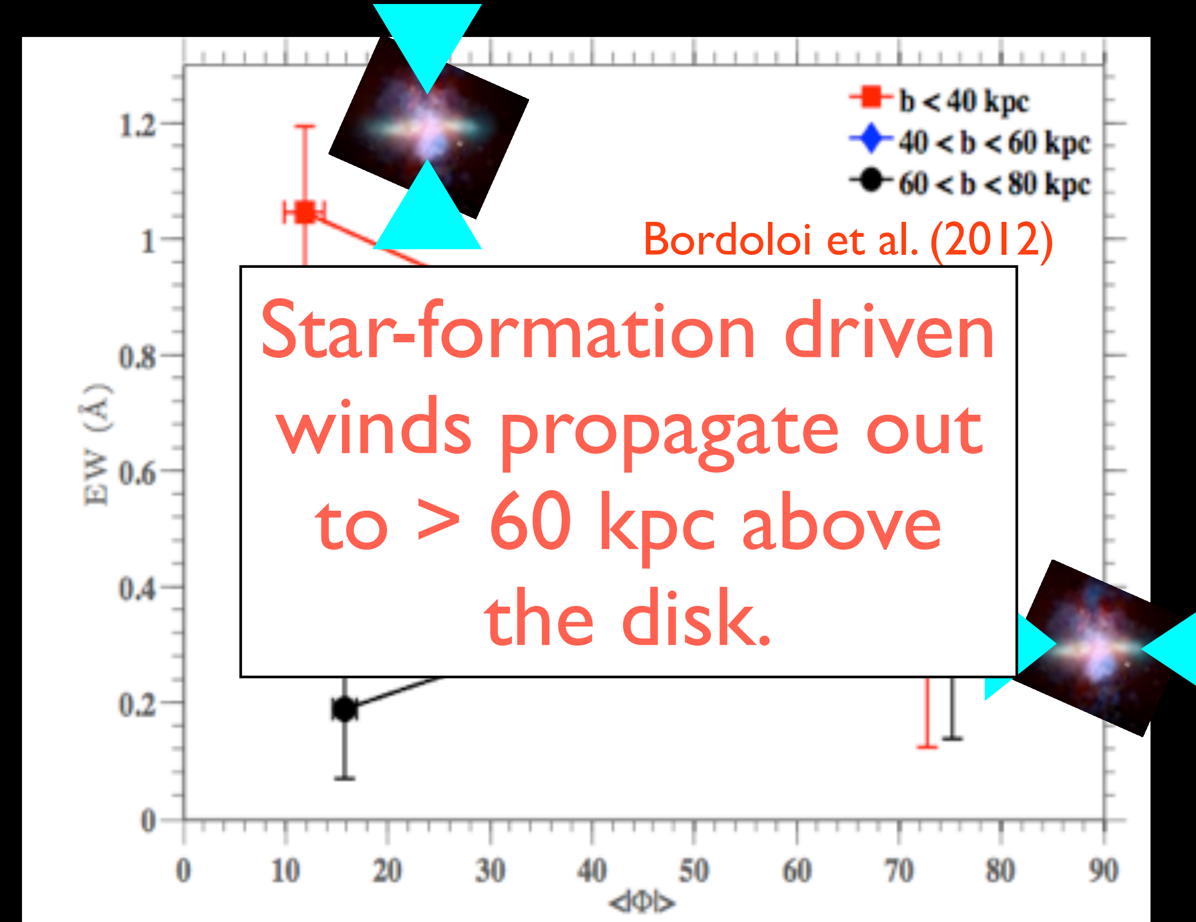

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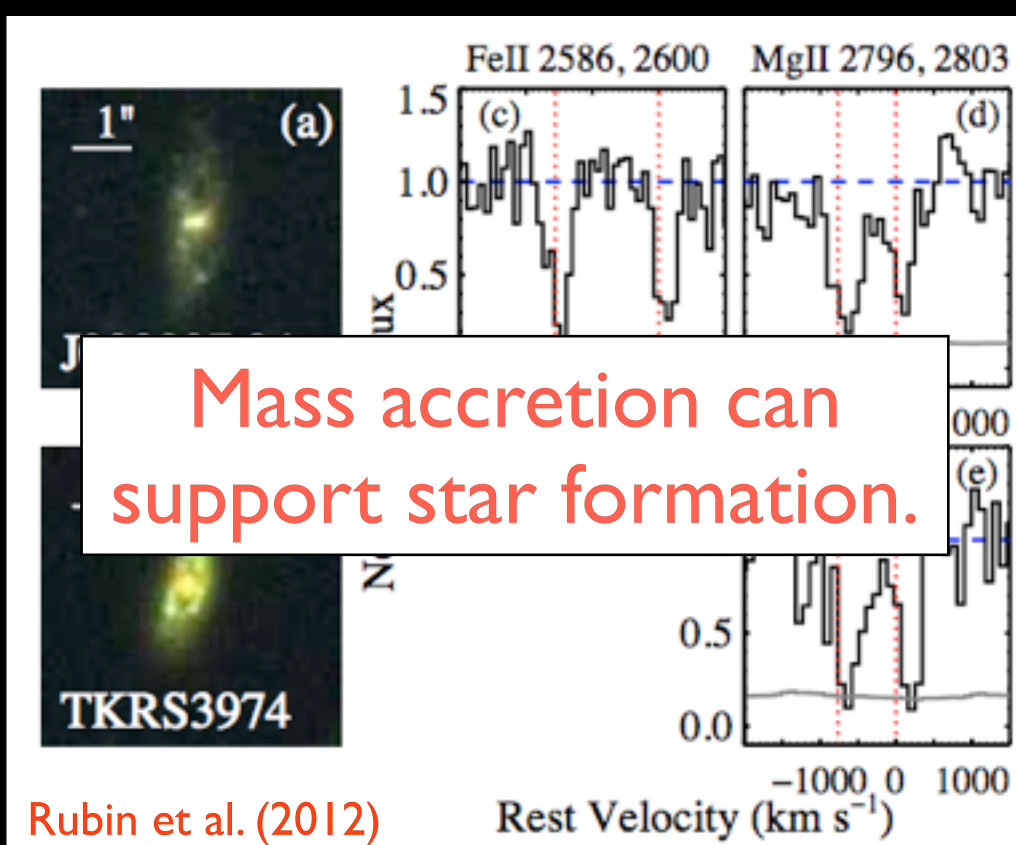

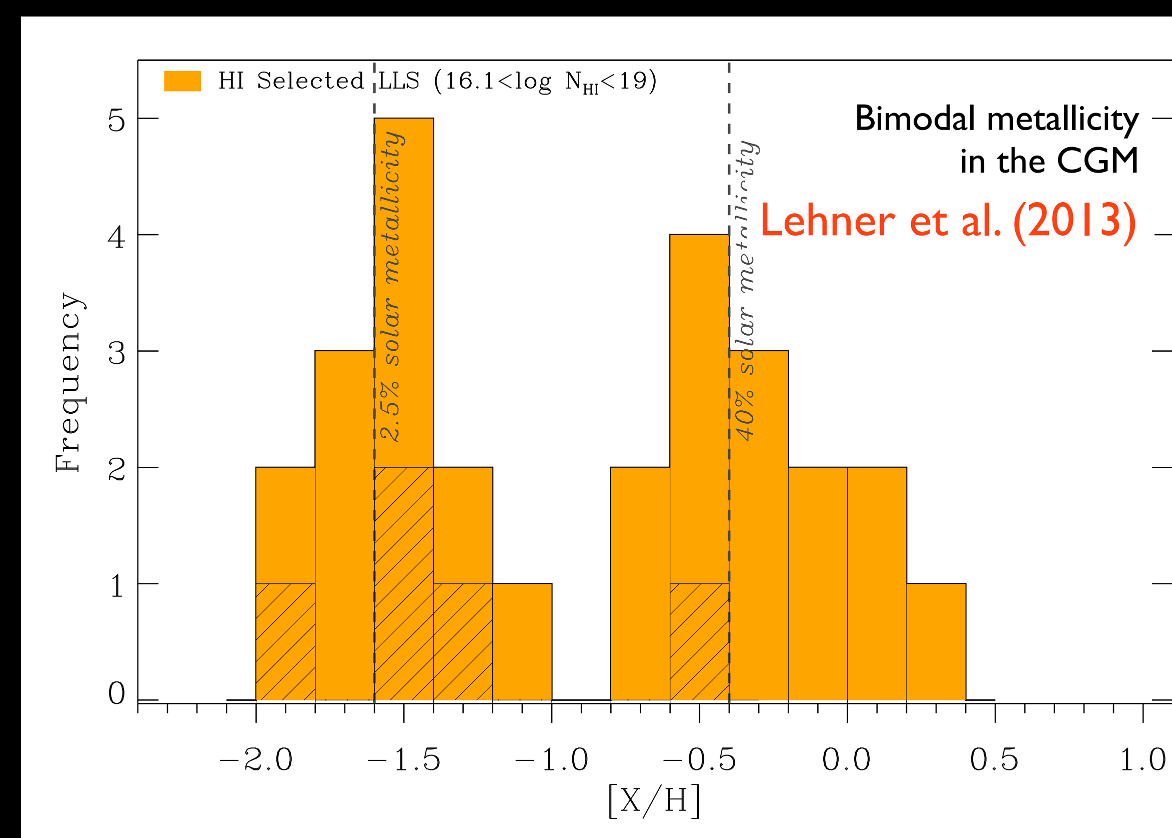

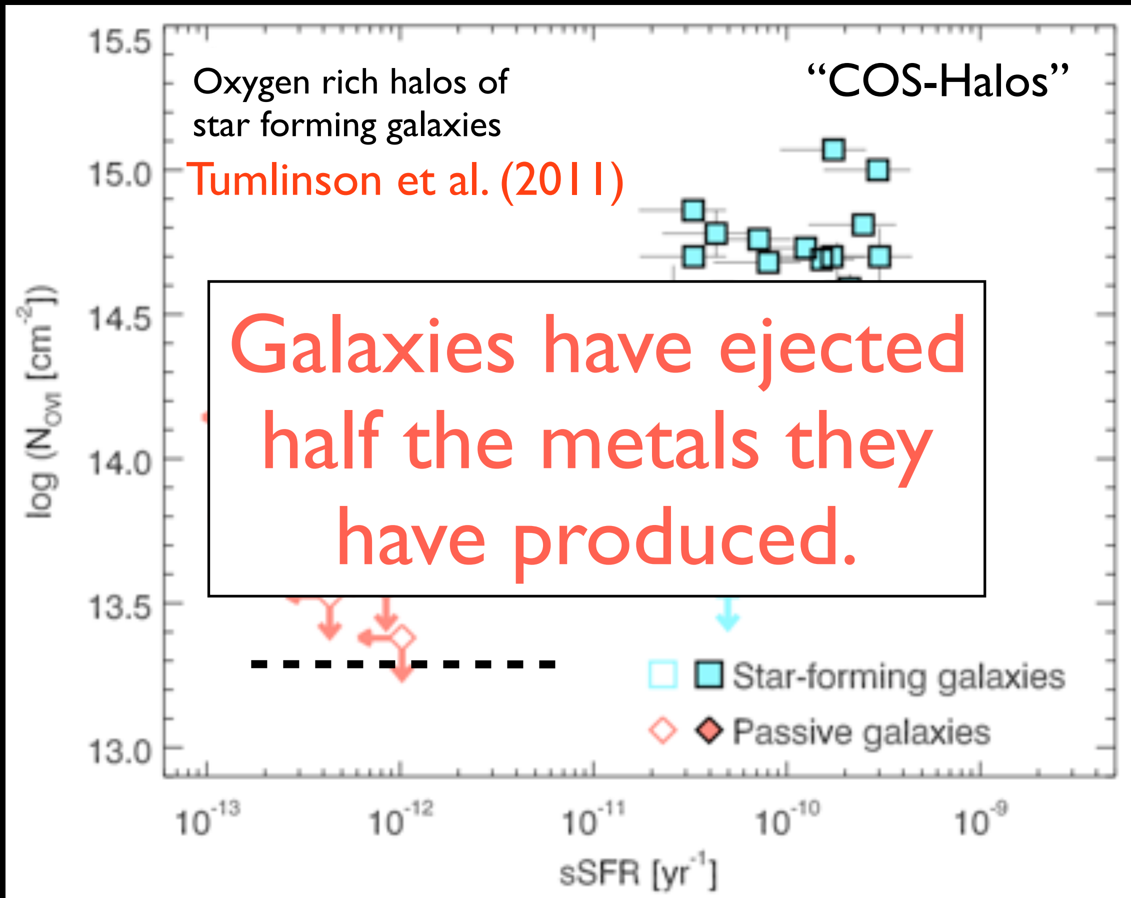

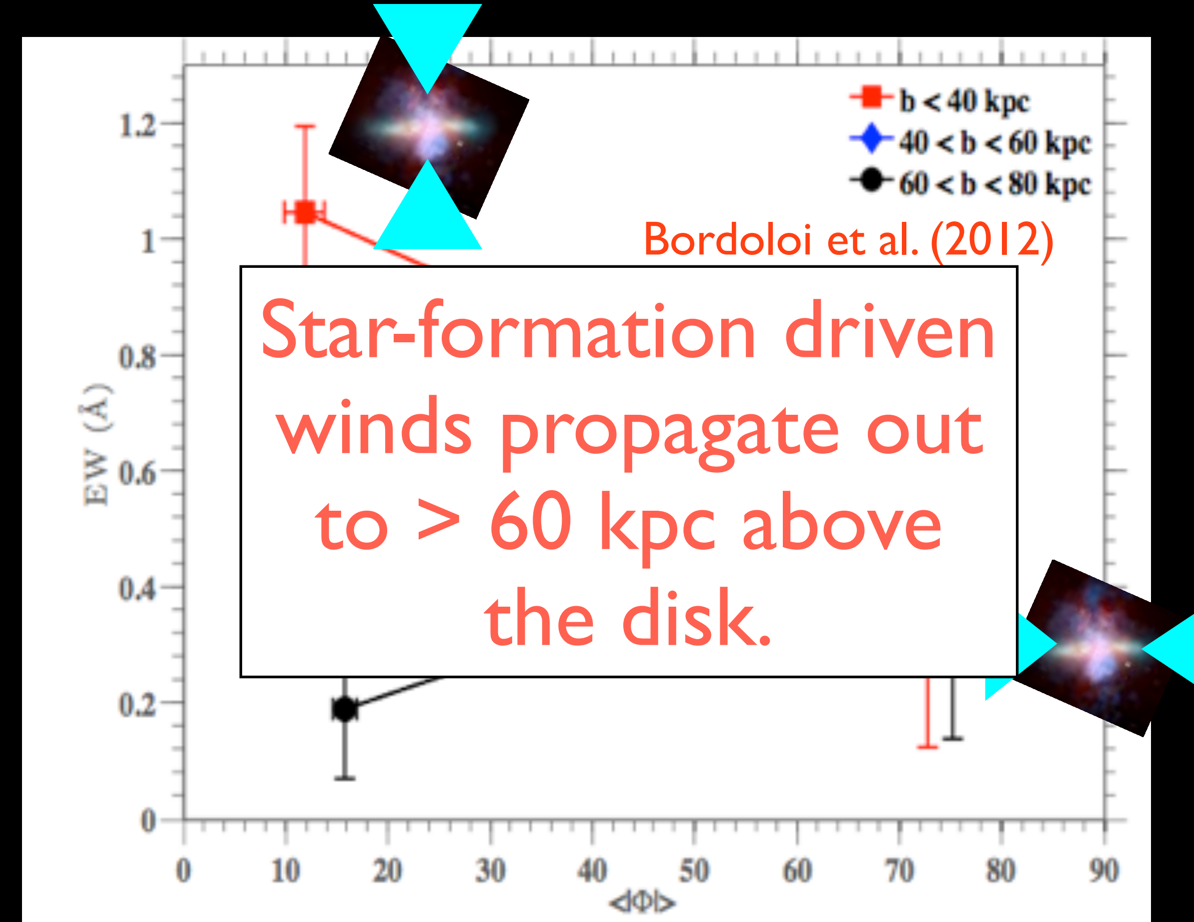

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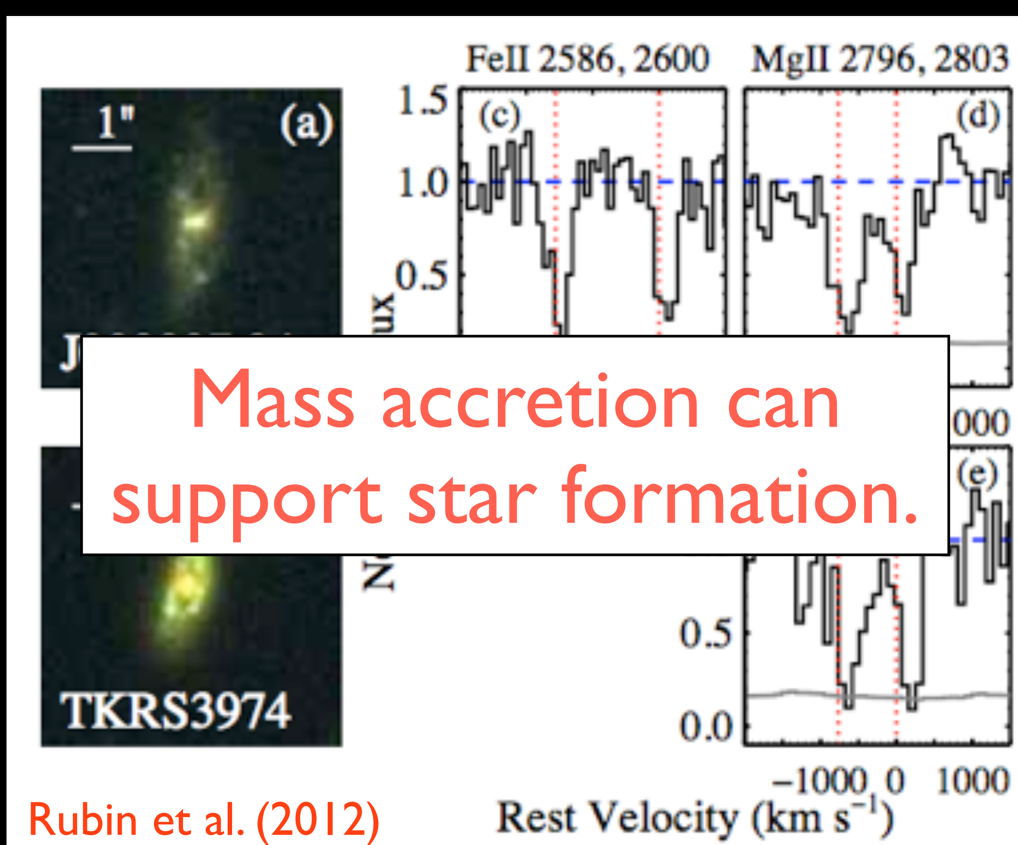
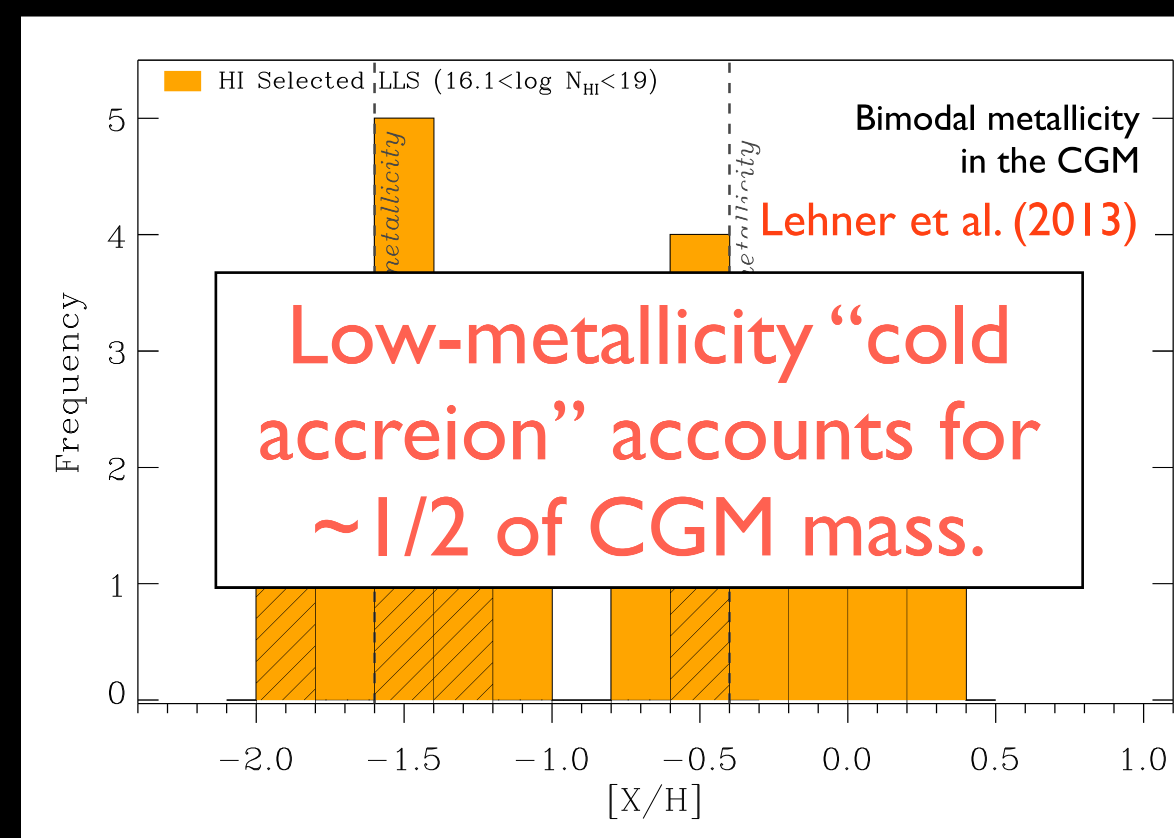
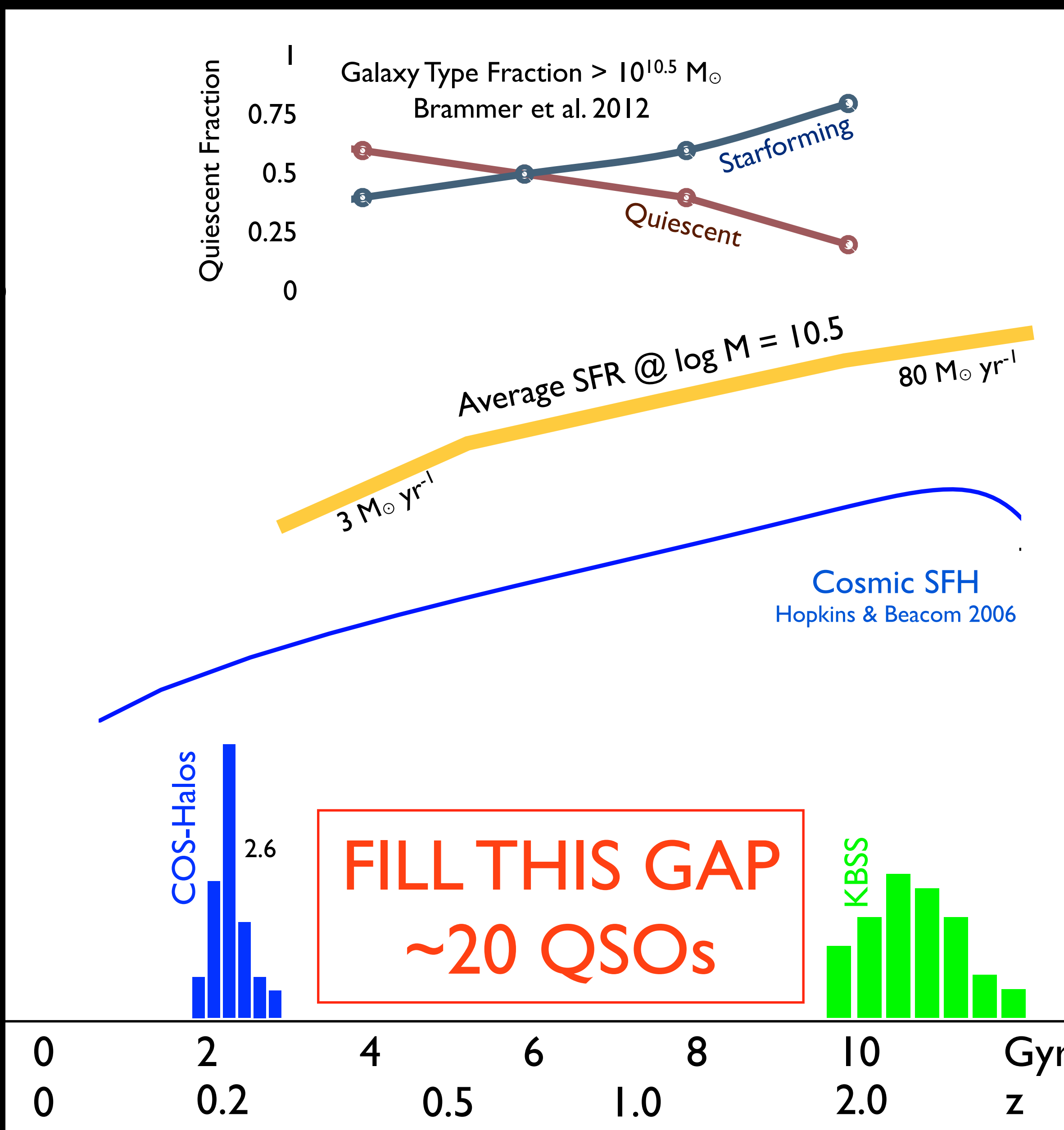




A Bright 10-year Outlook with HST

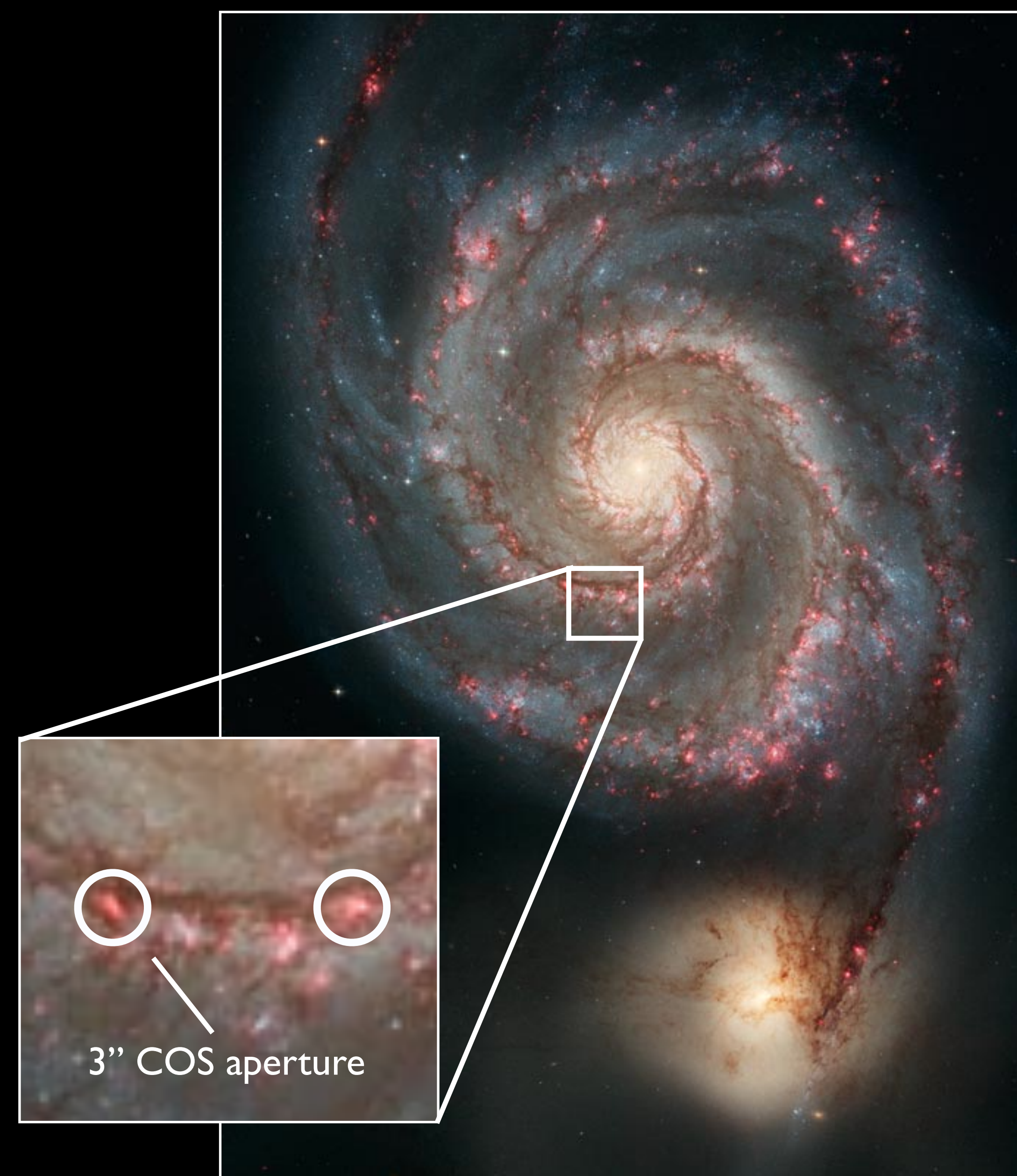
Push CGM Studies to z = 0.5 - 1

HST can reach ~30 QSOs in the era when the red sequence of galaxies was being assembled
Goal is to identify the outflows that quench star formation and keep it so.



Examine Galactic Winds As They Form

We can use "down the barrel" spectroscopy to examine blueshifted winds and redshifted accretion in (a few) nearby galaxies. Important first steps.



The 20-year outlook (without HST)

The 20-year outlook (apart from HST)

Explorer-scale missions could:

(1)
map the CGM emission for a few very nearby CGM/IGM filaments

(2)
Use GALEX-like low-resolution spectroscopy to statistically relate the high-column density CGM to galaxies of all types.

These are interesting capabilities but far less general than a new UV spectroscopic mission.

The 30-year Outlook

Long-term, major progress in this subject requires

(1) access to more background sources
(2) at higher density on the sky
(3) and higher redshift (up to z = 1-2)

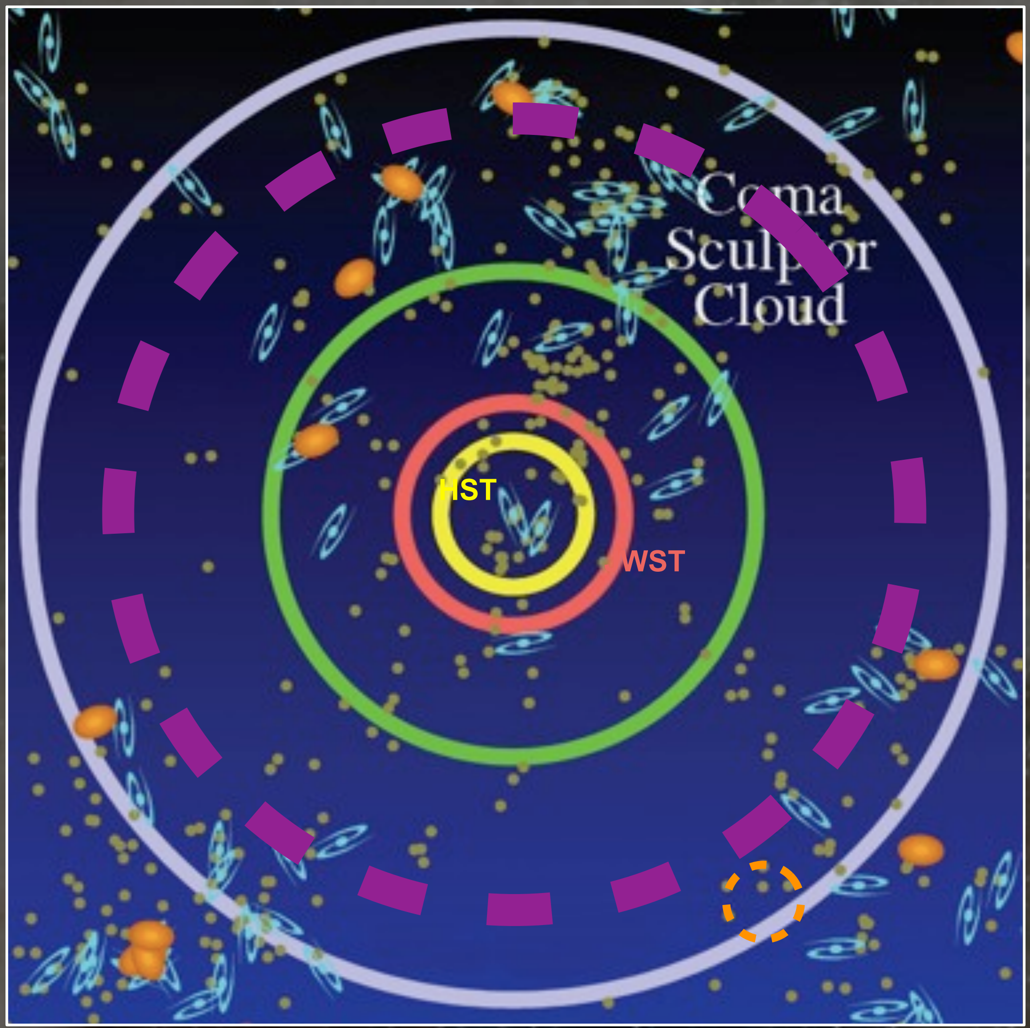
to expand survey volumes

AND

(4) a multiplexing advantage and/or
(5) spatially resolved spectroscopy

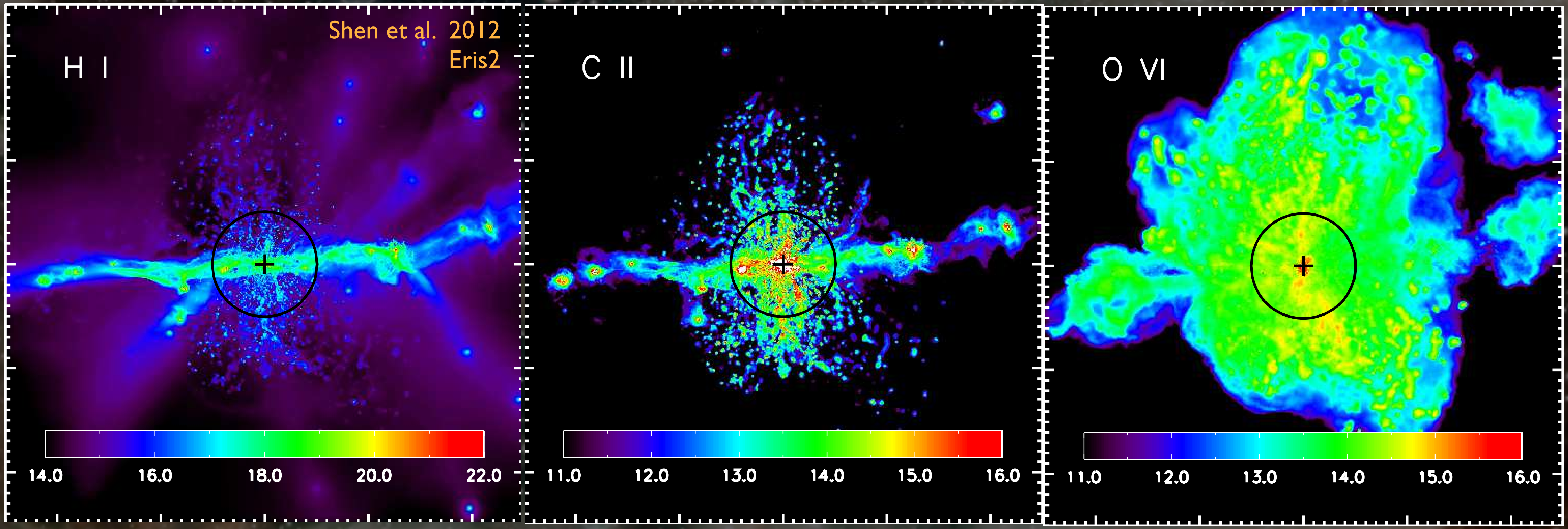
to enable resolved maps of nearby galaxies.

Future Challenge I: High-Def Mapping of the Richly Structured CGM

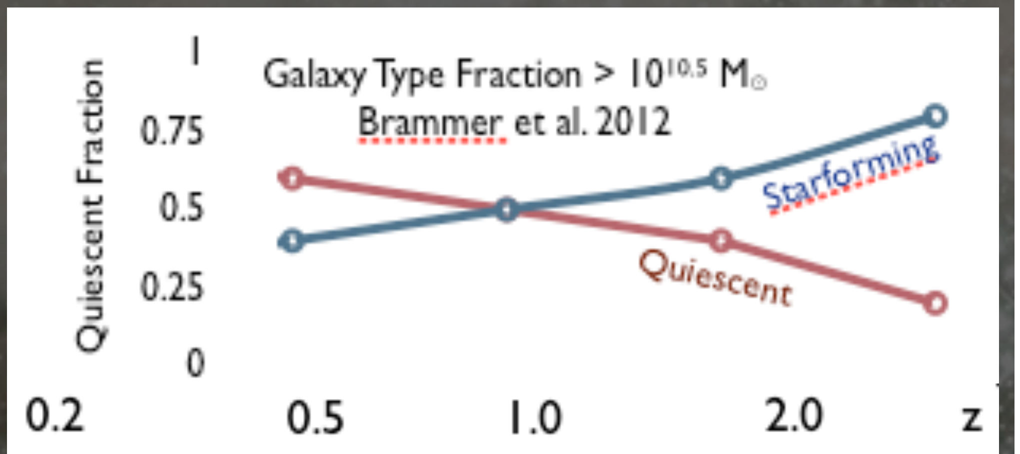


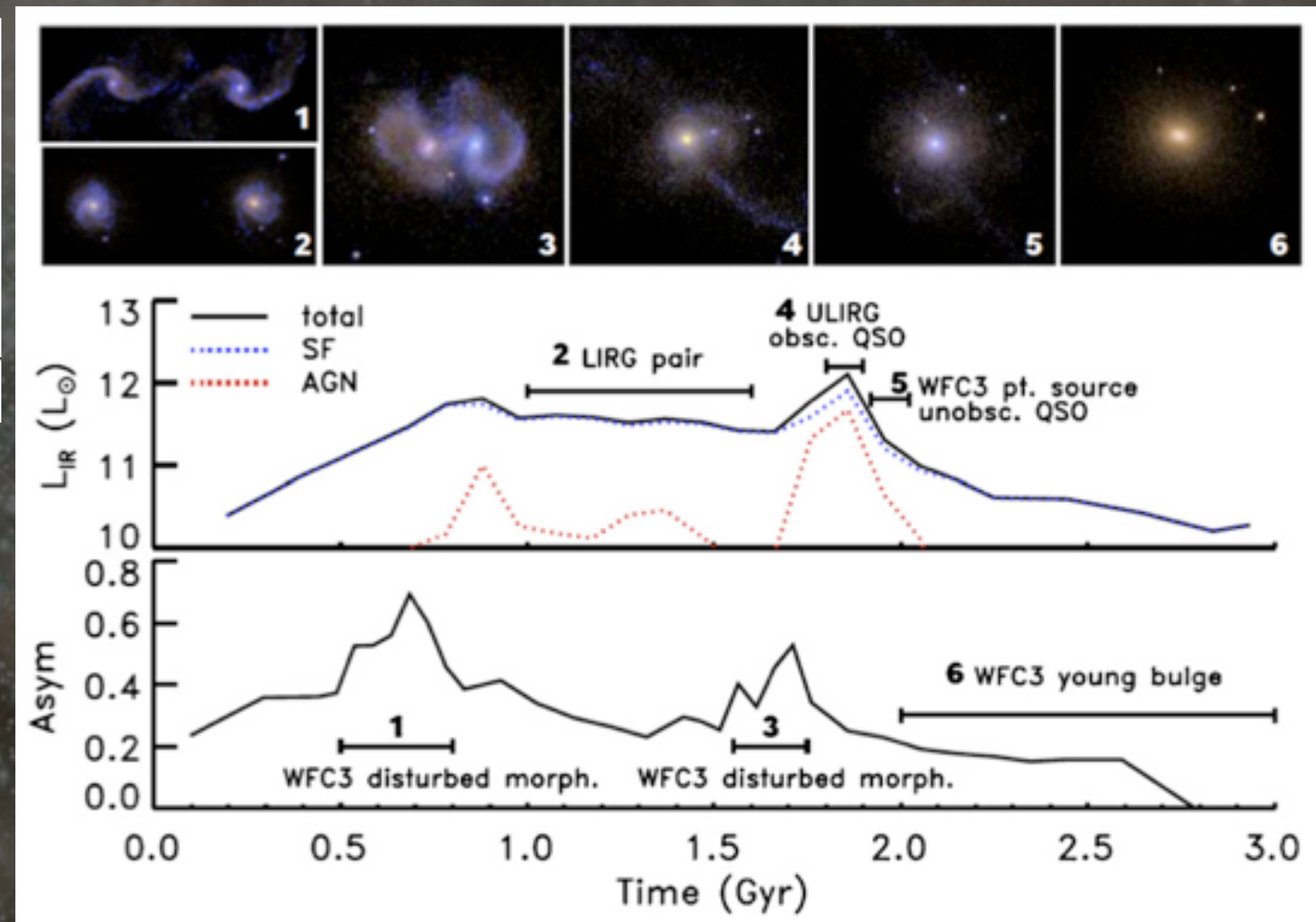
A facility with 10x the sensitivity of HST can reach ~10 QSOs behind all galaxies within ~ 10 Mpc and more than one QSO for all galaxies out to purple line.

We could therefore map the CGM in detail for all types of galaxies in the local Universe, for which we also can fully piece together the star formation history.



Future Challenge II: Map the Flows Driving the Epoch of Galaxy Transformation





HST surveys (e.g. GOODS, CANDELS) have now quantified the rate at which galaxies transform from star-forming to passive as a function of mass and redshift.

But where does the gas go? Does it get consumed or recycled? To answer, we need >100 of galaxies in each phase (before, during, and after transformations).

Reaching these numbers at the z = 0.5 - 1.5 epoch requires access to 500-1000 choice faint QSOs, not the ~20 that HST can reach.

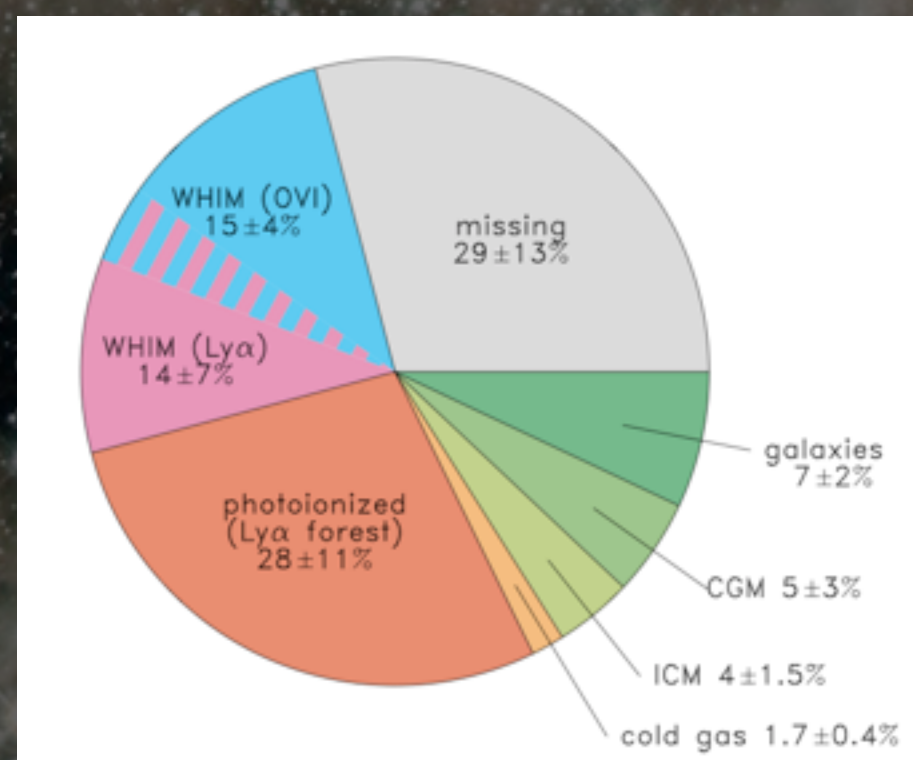
Future Challenge III: Find the Missing Baryons in the Hot IGM

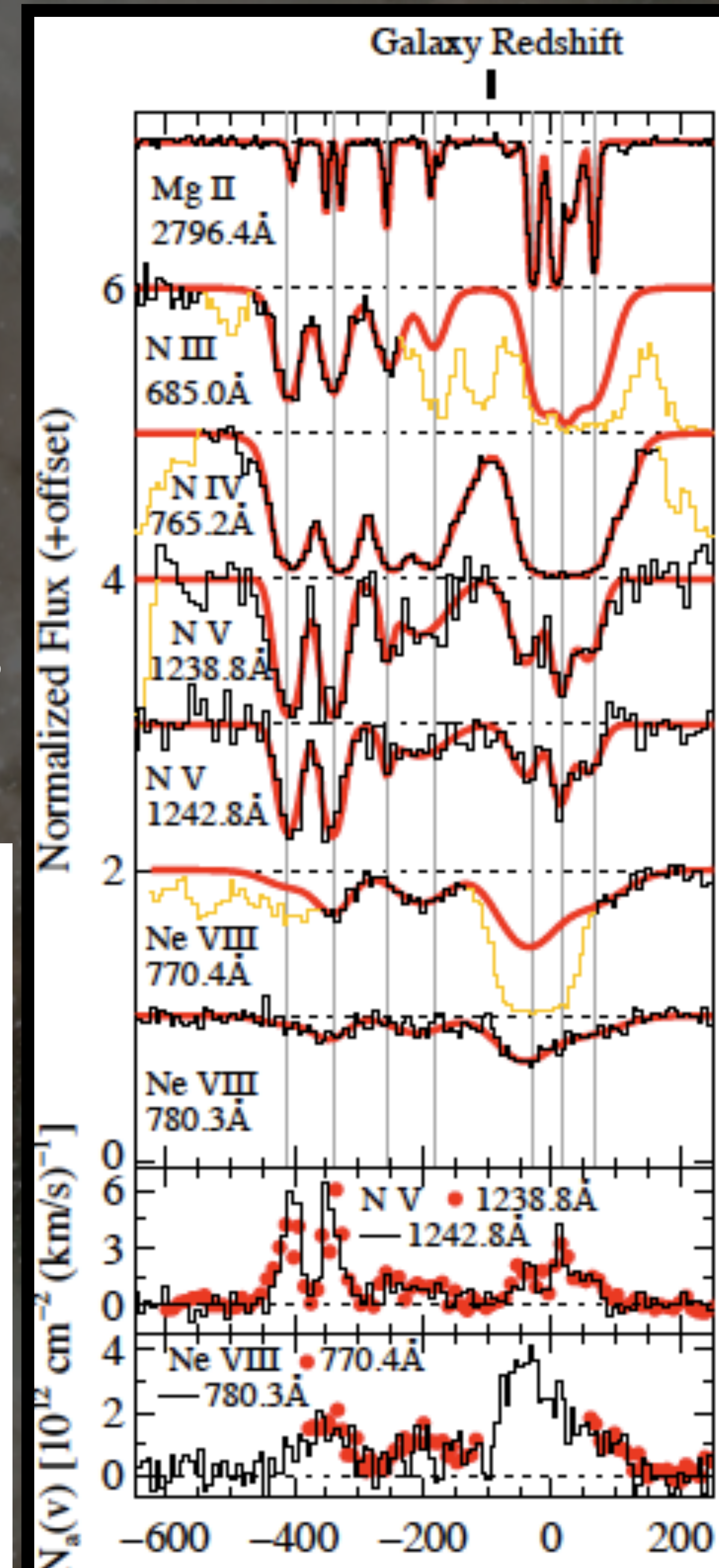
Up to 30% of all cosmic baryons at z < 1 reside in the low-density, hot IGM at ~ 1 million K (the so-called WHIM gas). This phase can be seen in the rest-frame lines of NeVIII and MgX, if observed at redshift z > 0.5.

These are extremely challenging observations for HST/COS, and so far only a few such absorbers have been found. (Tripp et al. 2011, at right, also Savage et al. 2010, 2011).

This gas is also accessible via O VII and O VIII lines in the soft X-ray, but only 6 QSOs on the entire sky are accessible to Chandra for this work.

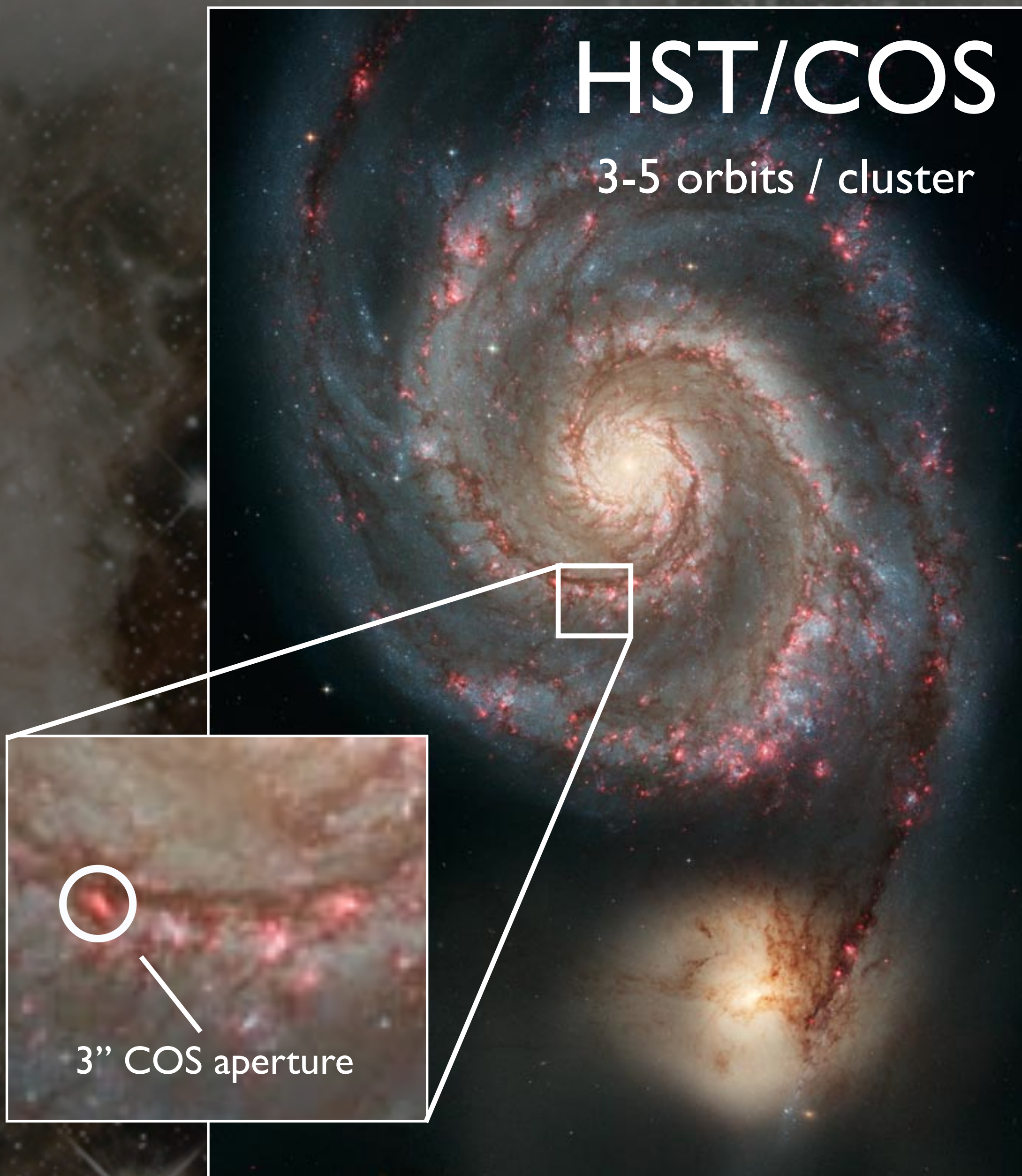
50-100x HST sensitivity would allow us to assess the baryon content of the hot IGM, in a temperature regime usually accessed through the X-ray.

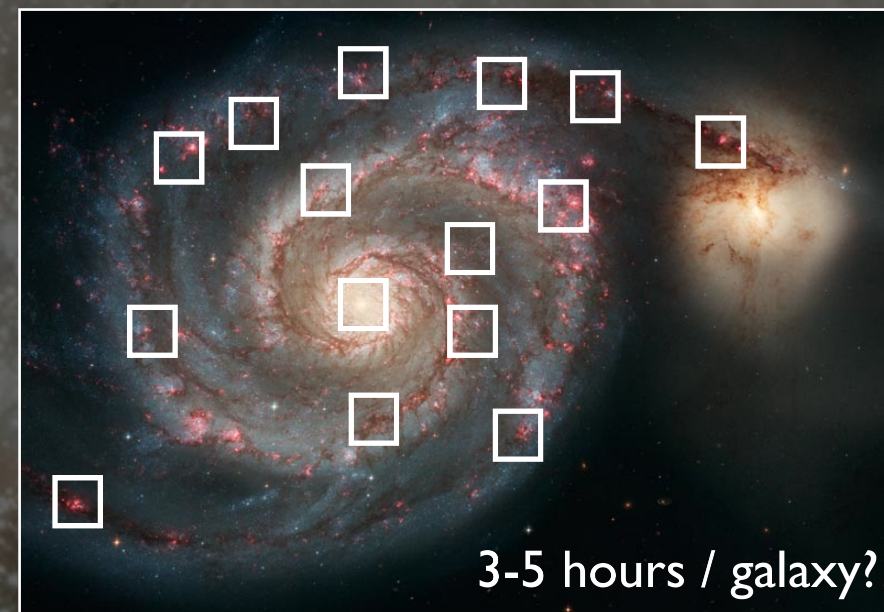




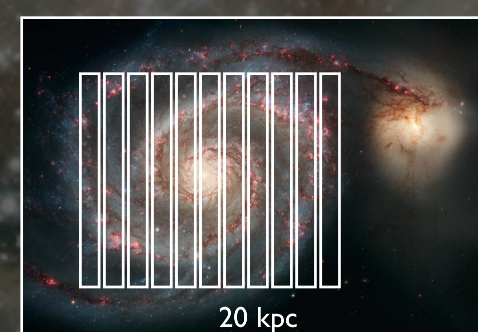
Future Challenge IV: Map Gas Accretion and Feedback Within Galaxies

A true multi-object / IFU capability in the UV would trigger a revolution in our ability to dissect gas flows and the stellar populations that give rise to them, with dense sampling of spatial variations and all relevant physical variables.





3′ MOS
at z ~ 0



3″ IFU
at z ~ 0.5

Would also support intensive spectroscopy of every Magellanic Cloud OB star.

Also would permit detailed mapping of UV continuum and line SFR metrics, spatially resolved, from z = 0 - 1.

Strategic Considerations

A Powerful Capability for many fields: UV capability that supports the study of gas flows addresses other topics as well:

- AGN physics (Kriss)
- exoplanet atmospheres
- hot stars: winds and atmospheres
- and much more

Compatibility with Design Requirements for other problems.

- The UV requires its own special detectors and optical coatings, but neither interferes with observations at other wavelengths (Hubble covers the far-UV to the NIR perfectly).

Complementarity with other facilities.

- UV provides unique access to some types of astrophysical objects.
- also complements, for instance, the NIR, where we use many rest-UV spectral features at high redshift.

Technology Considerations

Efficient UV Coatings:

- Need thinner, uniform MgF_2 or LiF (or novel materials), refine methods for coating primary and secondary mirrors for efficient UV performance.
- Fortunately most UV coatings also perform well in optical/NIR.
- Could accelerate existing NASA-funded development efforts.
- **Better coatings are essential to support instrument designs with more bounces, such as IFUs and MOS.**

Large Format UV Photon Counting Detectors:

- Current TRL9 large-size microchannel-plates (such as in COS) still limit the available wavelength / spatial coverage.
- Continue to support development efforts (e.g. Berkeley's 20x20 cm MCPs.)

IFU/MOS Optics:

- UV photons don't like to bounce, so need to develop optical designs that support MOS/IFU capabilities efficiently (trades directly against aperture).
- FOV needs to be arcminute scale to be useful, bigger is better.
- Investigate configurable aperture masks (e.g. microshutters, mirrors).

Key Points

UV Imaging/Spectroscopy capability supports a wide range of vital scientific investigations.

Critical problems in galaxy evolution - accretion, feedback, and transformation - are being addressed by HST but will likely remain unsolved beyond HST.

True MOS / IFU capability down to the far-UV would be revolutionary, allowing many-fold gains in survey speed and discovery space.

Mid-TRL technologies already exist to support large gains in optical performance, coatings, detector QE and detector area.

Altogether, these factors make a vast improvement in UV capability on a flagship mission in the next decade a compelling and feasible prospect.