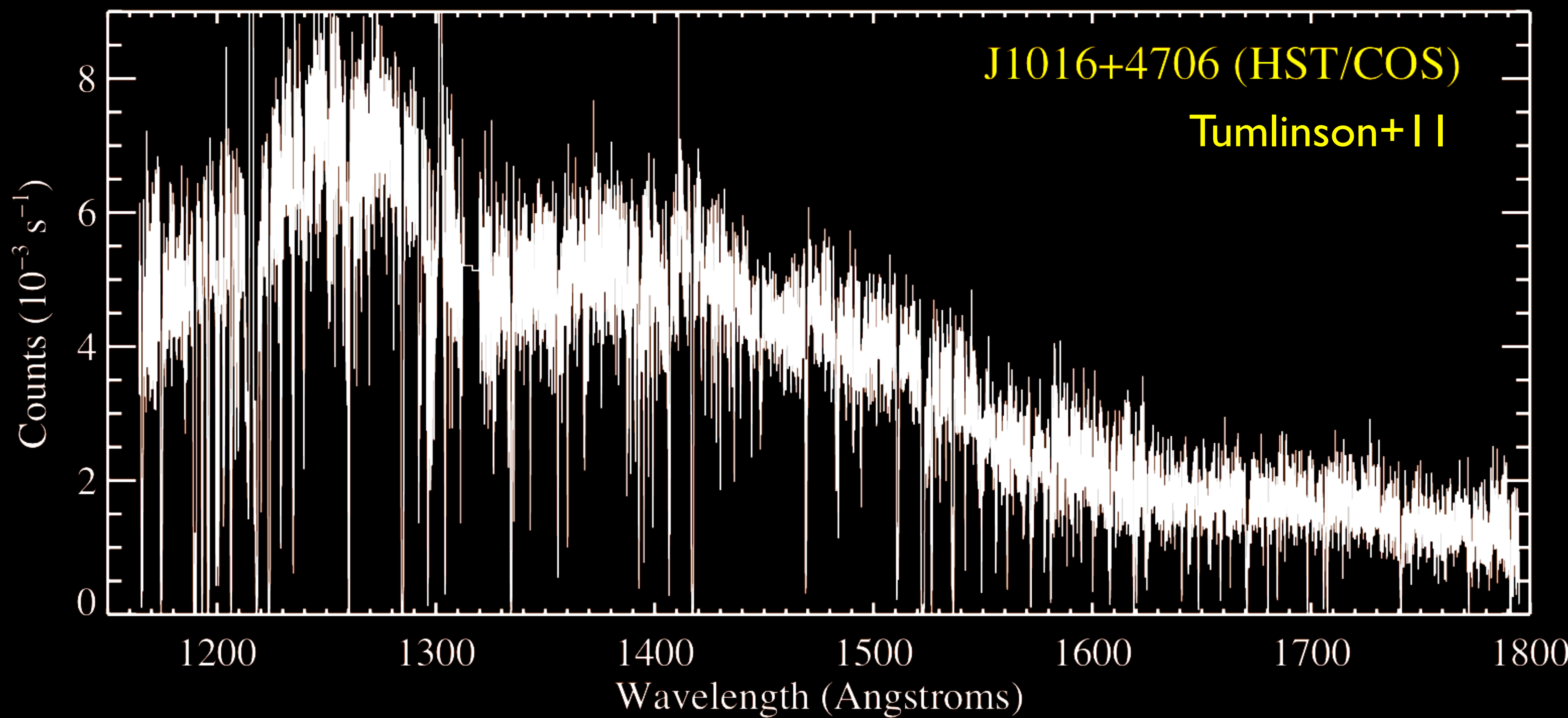
GAS IN GALAXY HALOS

Accretion, Feedback, and A New Reservoir of Cosmic Metals

The "COS-Large" Teams



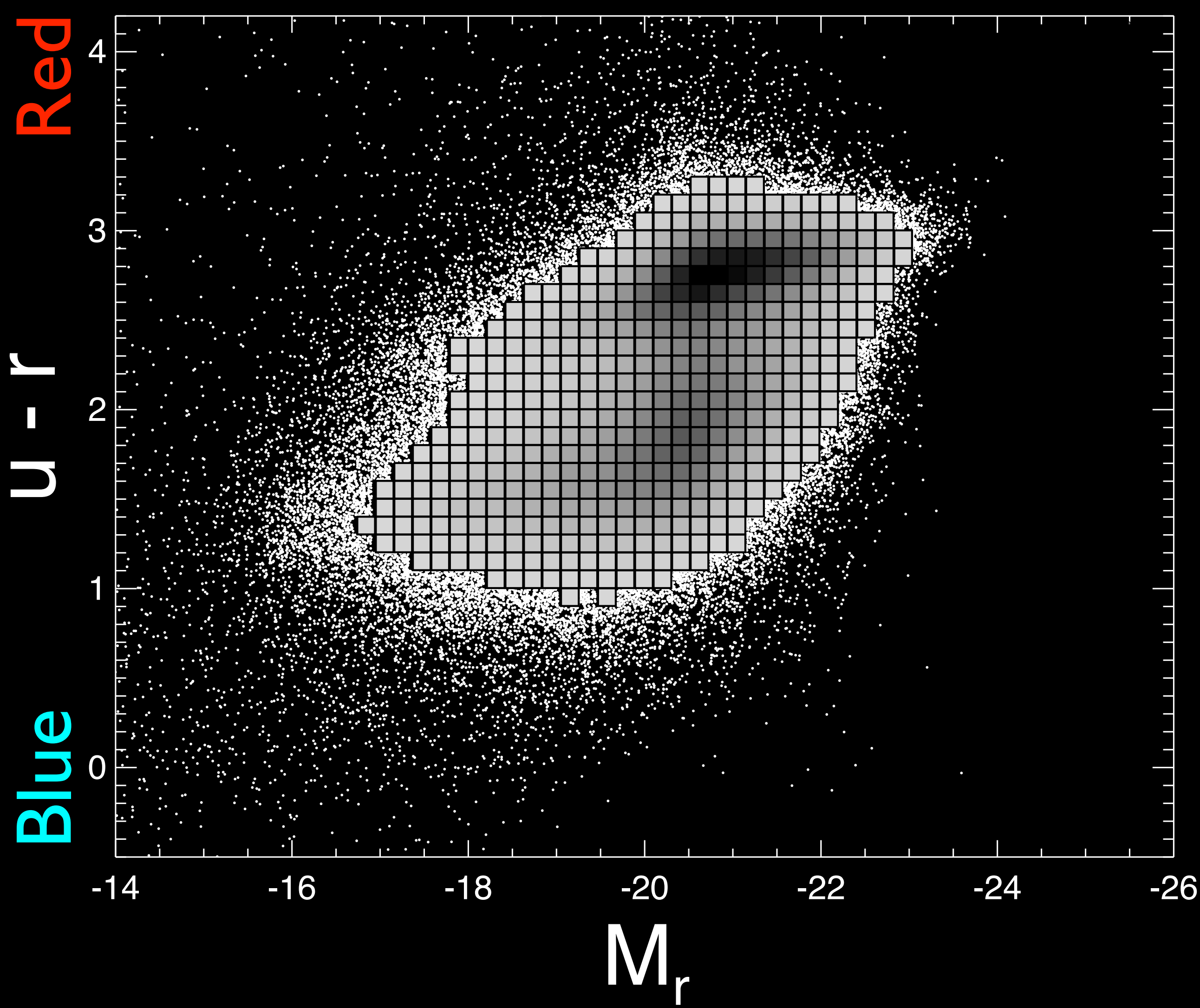
as told by: Jason et al.

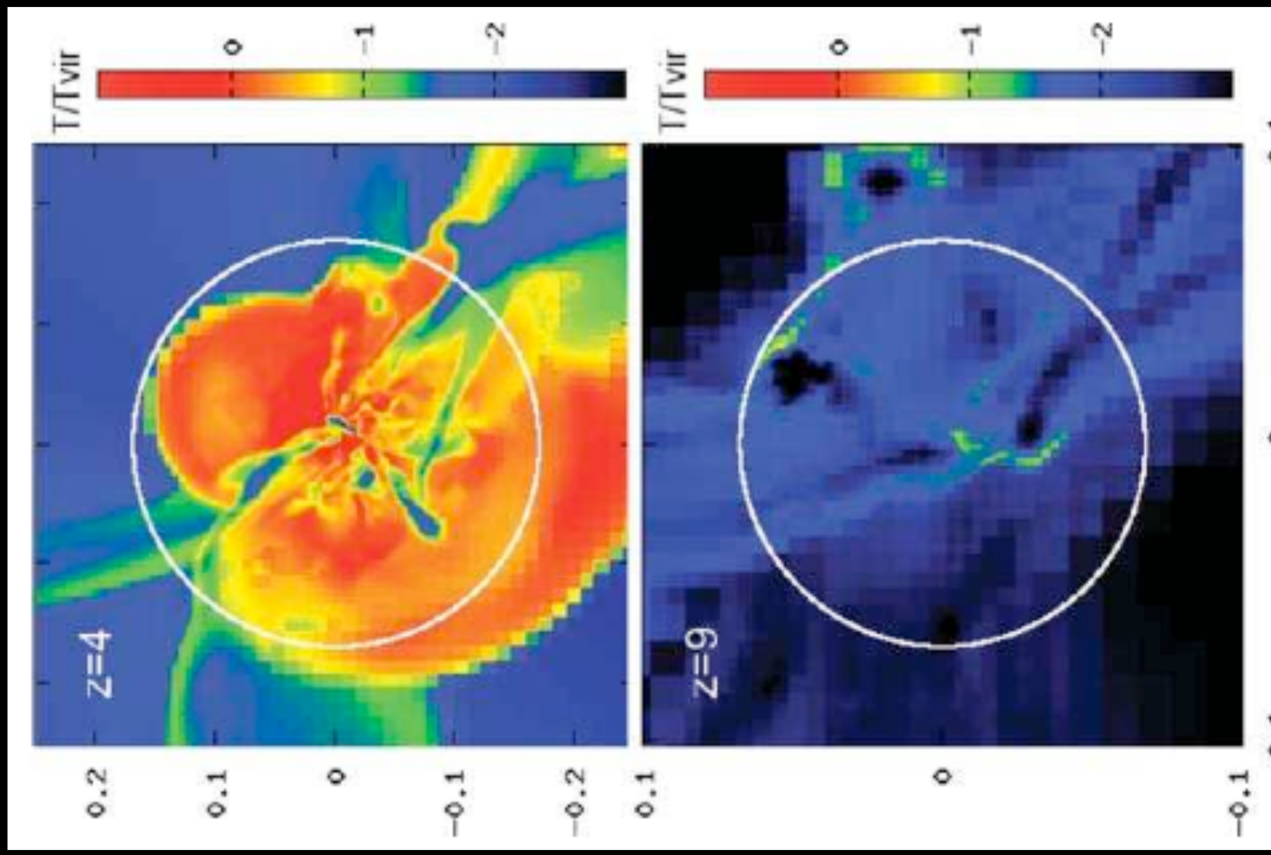
with major contributions from:

Chris Thom (STScI) + Jessica Werk (IMPS/UCSC)

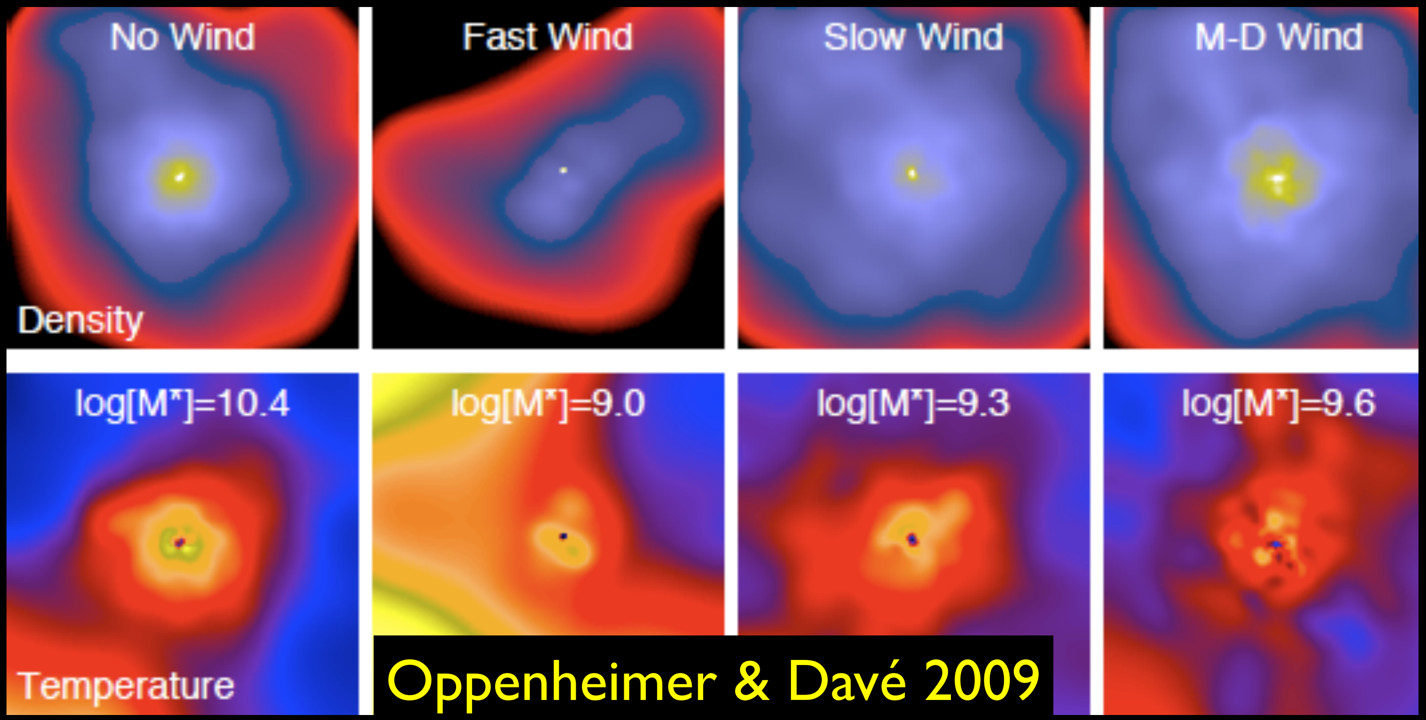
Is bimodality related to gas accretion physics?

Keres+05
Dekel & Birnboim (2006)
Fumagalli+11





. . or to the modes of galactic "feedback" from star formation or AGN?



Oppenheimer & Davé 2009

The Central Problem of the “Circumgalactic Medium”

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<1 galaxy halo (they're just too small!)

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too diffuse to be studied in emission, and

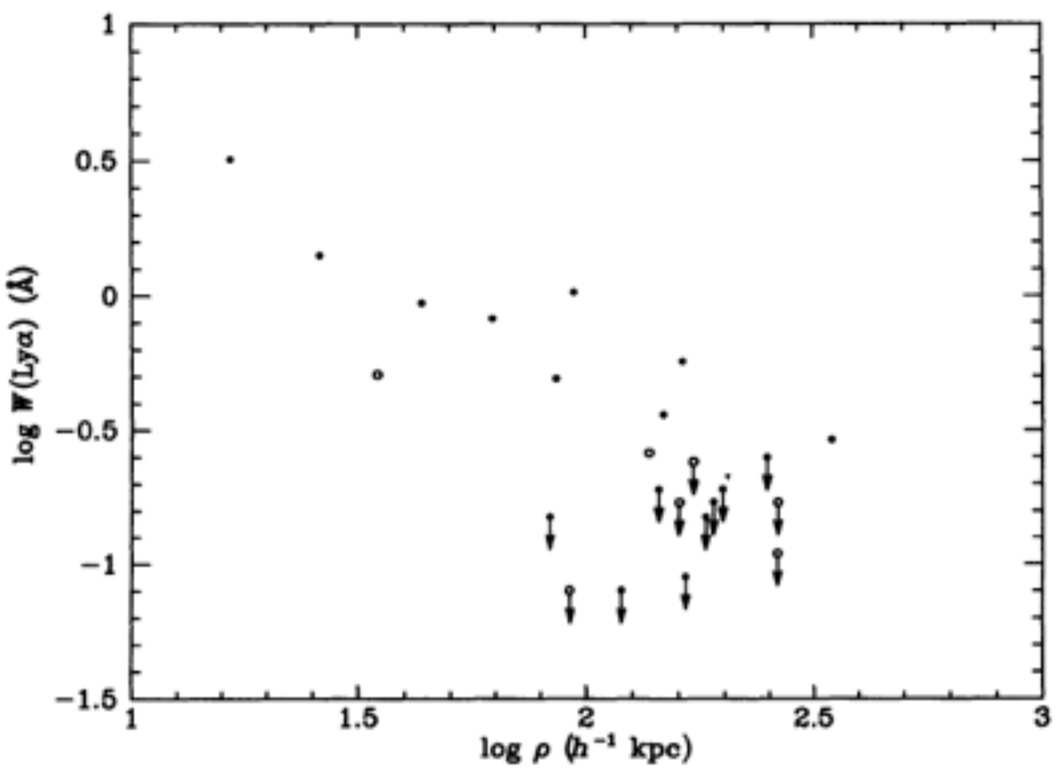
a random sightline through the IGM is intercepted by
<1 galaxy halo (they’re just too small!)

Thus, we need a new approach to direct
observations of galaxy accretion and outflows and
their relations to galaxy properties.

Galaxy (L~L*) halo gas through the years

HI

Lanzetta et al. (1995, ApJ, 442, 538)

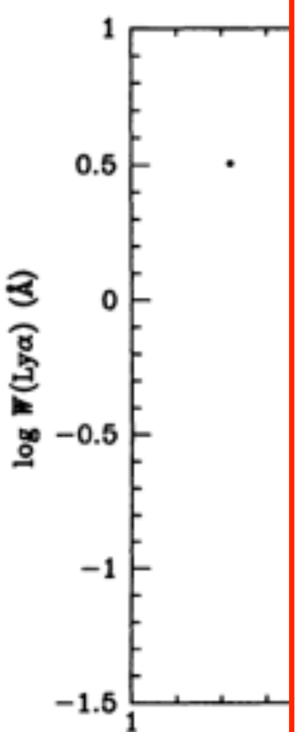


Lyα halo extends to 150-200 kpc, unity covering fraction inside there.

Galaxy (L~L*) halo gas through the years

HI

Lanzetta

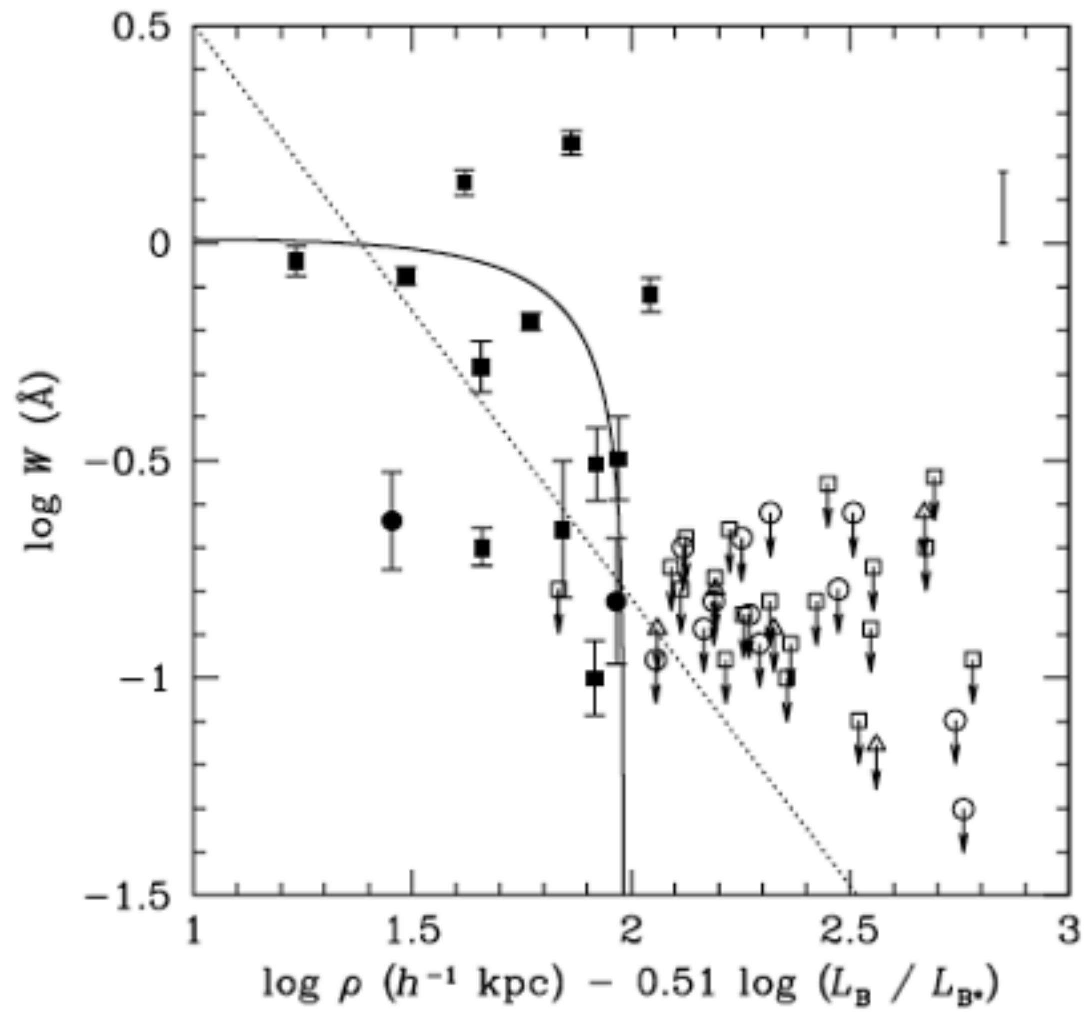


Lyα hal

unity cov

CIV

Chen, Lanzetta, & Webb (2001, ApJ, 556, 158)

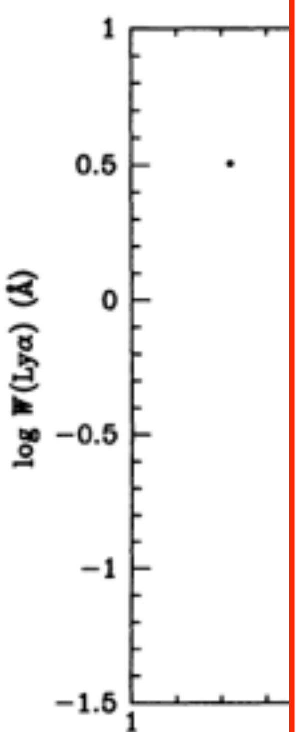


C IV halo sharply edged at 100 kpc,
unity covering fraction inside there.

Galaxy (L~L*) halo gas through the years

HI

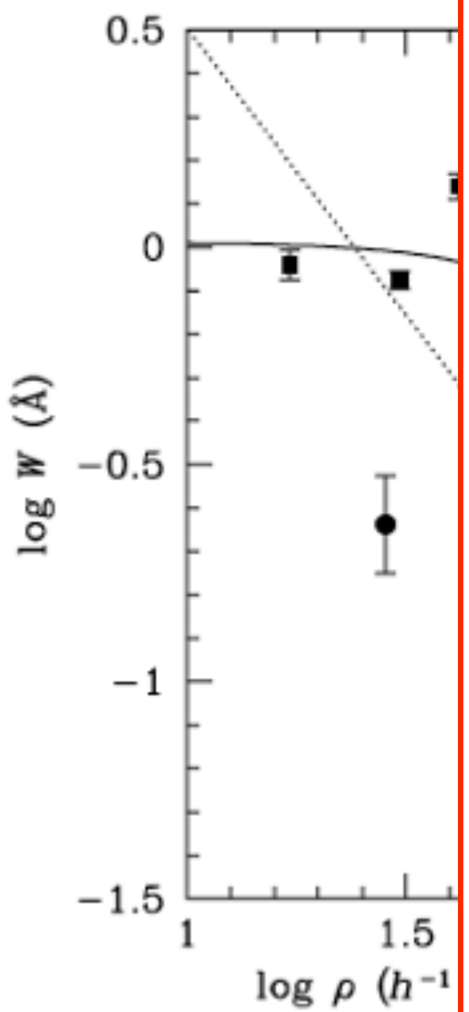
Lanzetta



Lyα hal
unity co

CIV

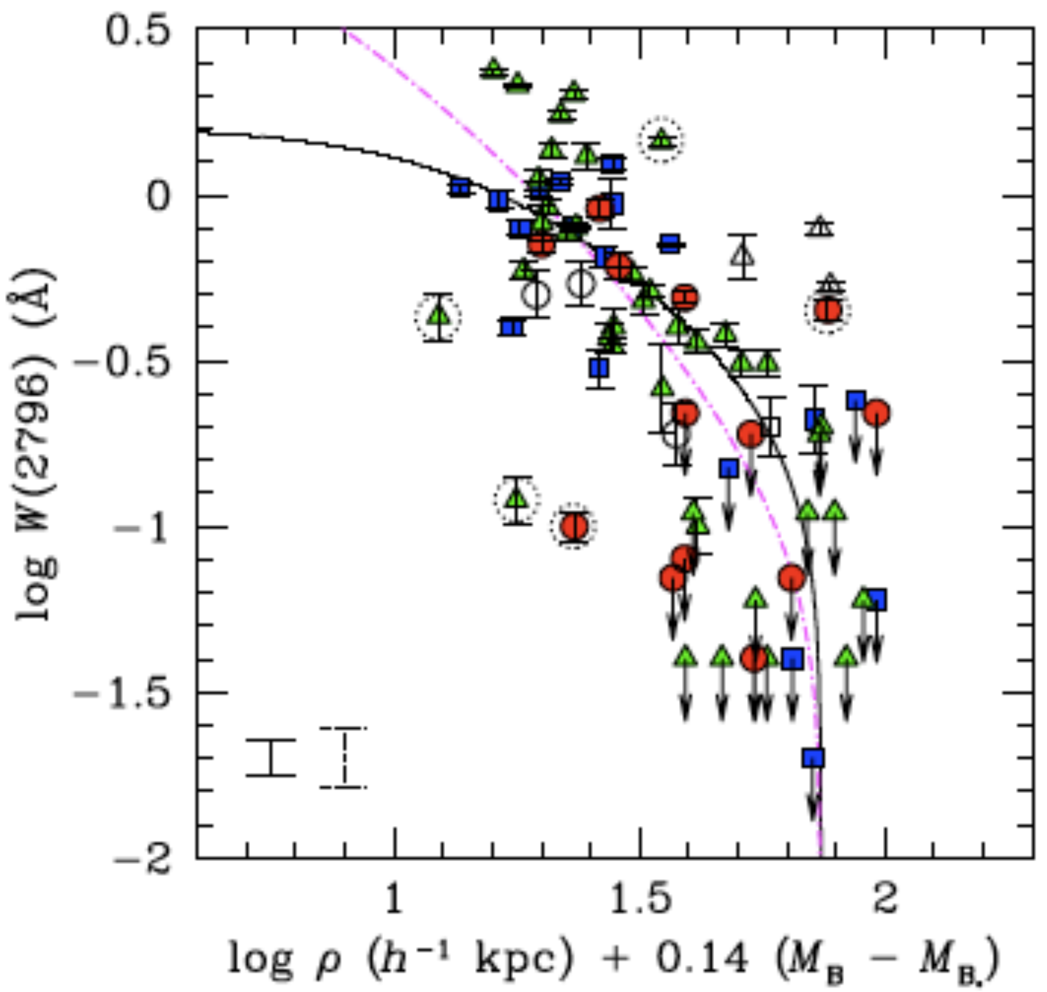
Chen, Lanzetta, & W



C IV halo shar
unity covering

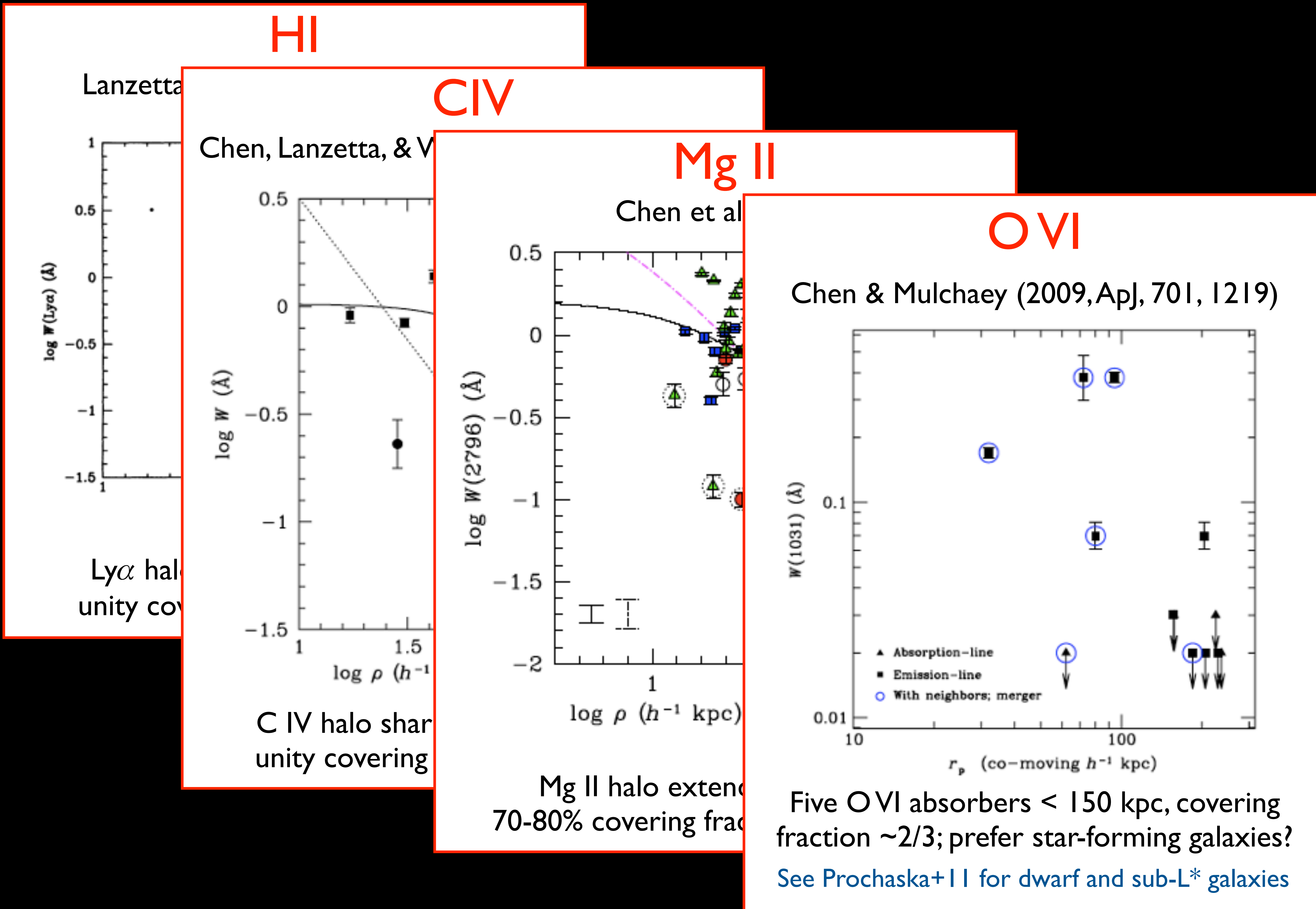
Mg II

Chen et al. (2010)

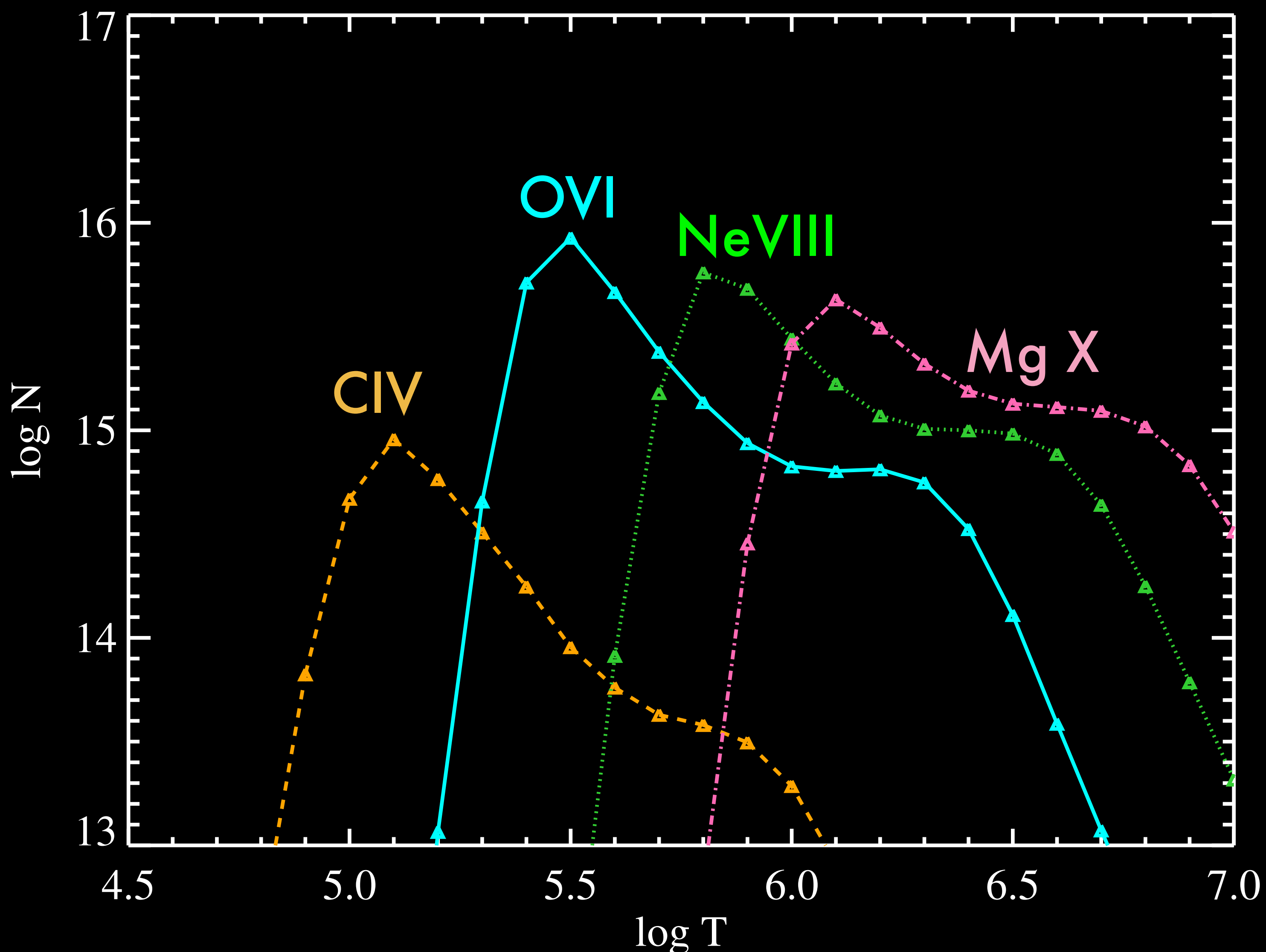


Mg II halo extends to ~50 kpc,
70-80% covering fraction inside there.

Galaxy (L~L*) halo gas through the years



Why O VI?



Advantages:

- highest T probe available in FUV
- strong doublet, easily detected
- IGM samples for comparison
- peak ionization fraction at T = 300,000K, still significant at 10^6 K
- *catches gas heating and/or cooling through coronal regime.*

O VI has also been widely used to count hot gas or "missing baryons", so general IGM samples are well characterized.

Tripp+08, Thom+Chen08,Danforth+Shull08

Disadvantages:

- must be redshifted to detect w/ HST (mirror absorbs at < 1150).
- peak abundance lies where rad cooling is efficient, so there are significant non-equilibrium issues.

Hubble Space Telescope   Cycle 17 GO Proposal   <ID>

How Galaxies Acquire their Gas: A Map of Multiphase Accretion and Feedback in Gaseous Galaxy Halos

Principal Investigator: Dr. Jason Tumlinson

Institution: ~~Yale University~~ STScI

"COS-Halos"

Data Division

Jessica Werk & Xavier Prochaska (Santa Cruz)

Joseph Meiring & Todd Tripp (UMass)

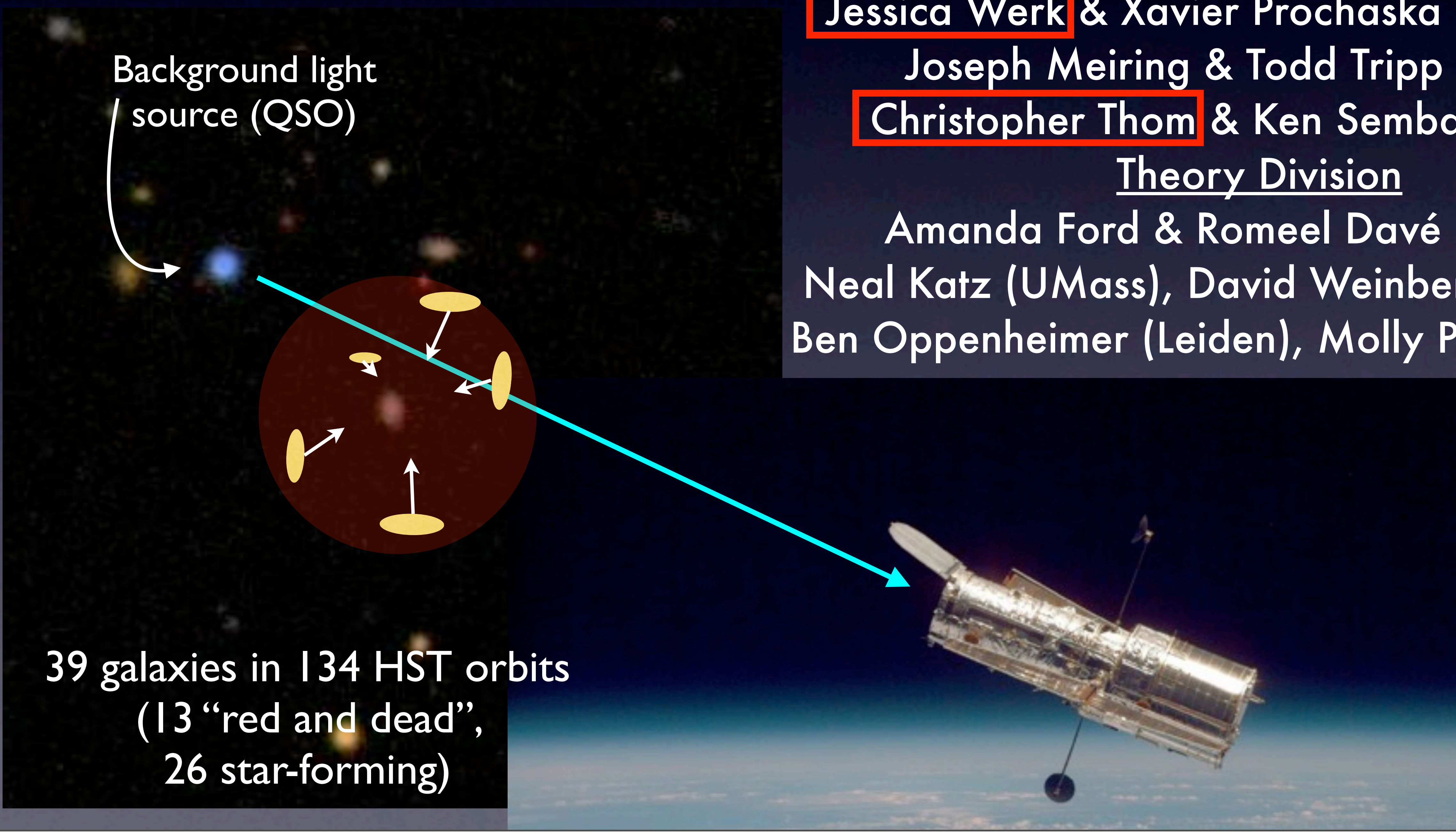
Christopher Thom & Ken Sembach (STScI)

Theory Division

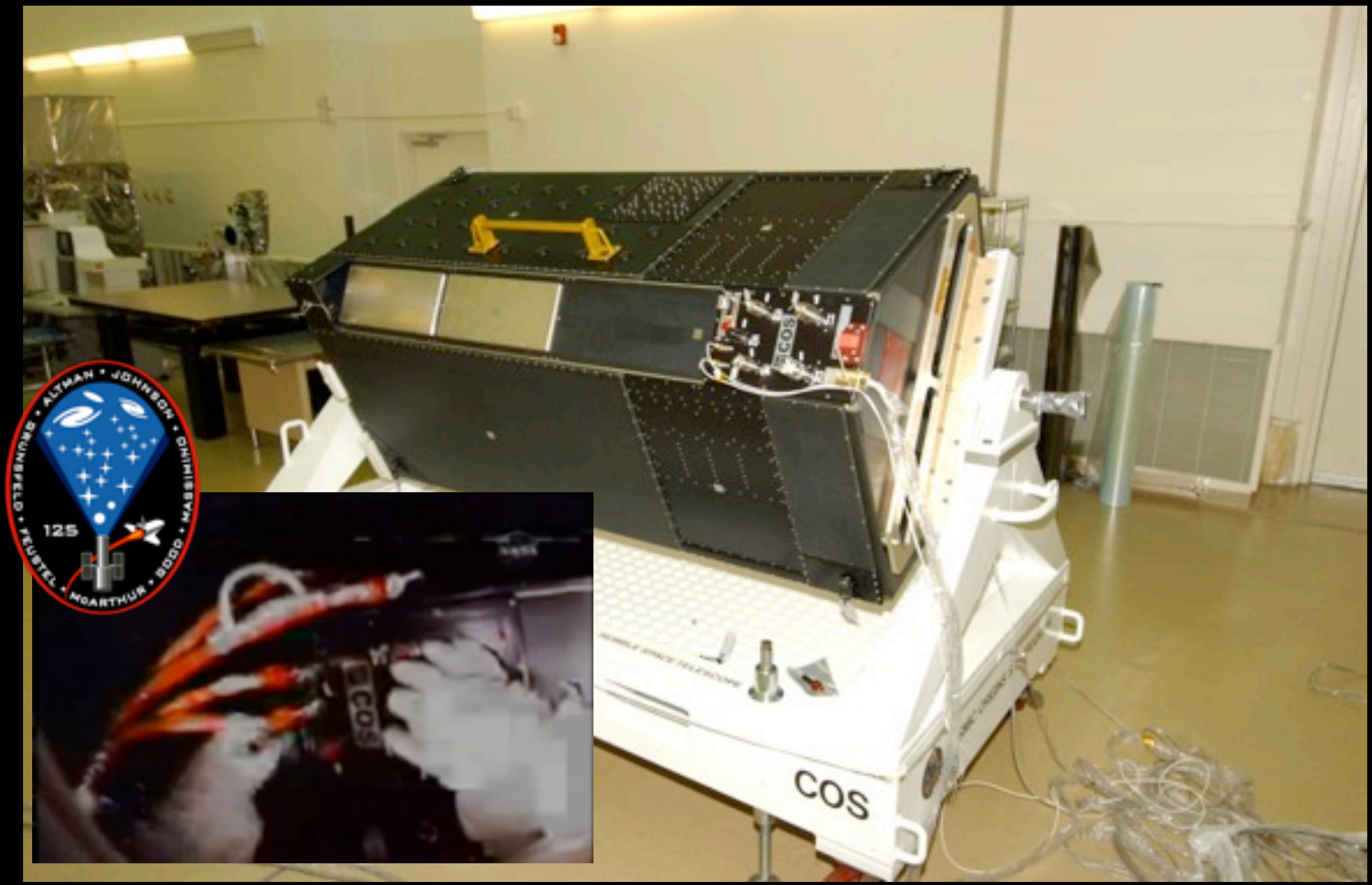
Amanda Ford & Romeel Davé (Arizona)

Neal Katz (UMass), David Weinberg (The OSU),

Ben Oppenheimer (Leiden), Molly Peeples (UCLA)



The Cosmic Origins Spectrograph

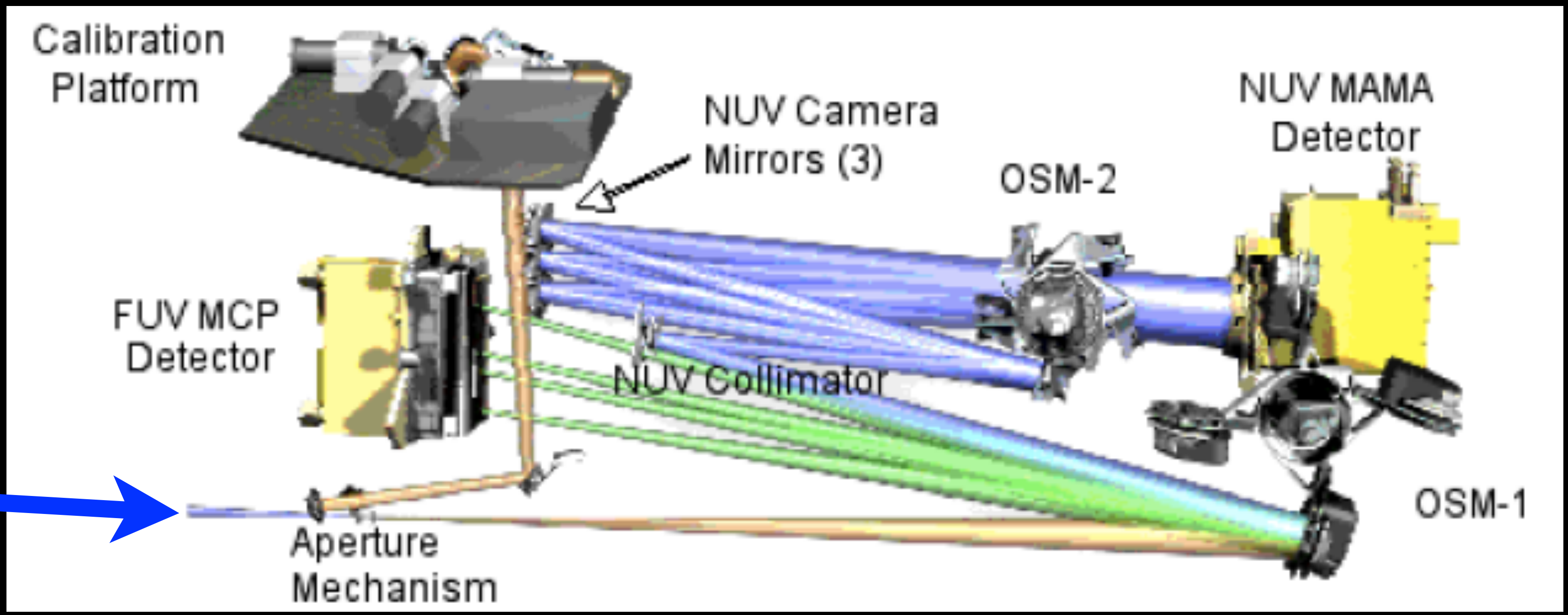


PI = Jim Green, U. of Colorado
Installed by John Grunsfeld & Drew Feustel on SM4, May 16, 2009

Optimized for UV spectroscopy, R = 2000 and R = 18000 gratings, low-background photon-counting detectors.

FUV Channel:
Effective area 10 - 20x that of STIS over 1150-1800 Å.

Light from
HST secondary



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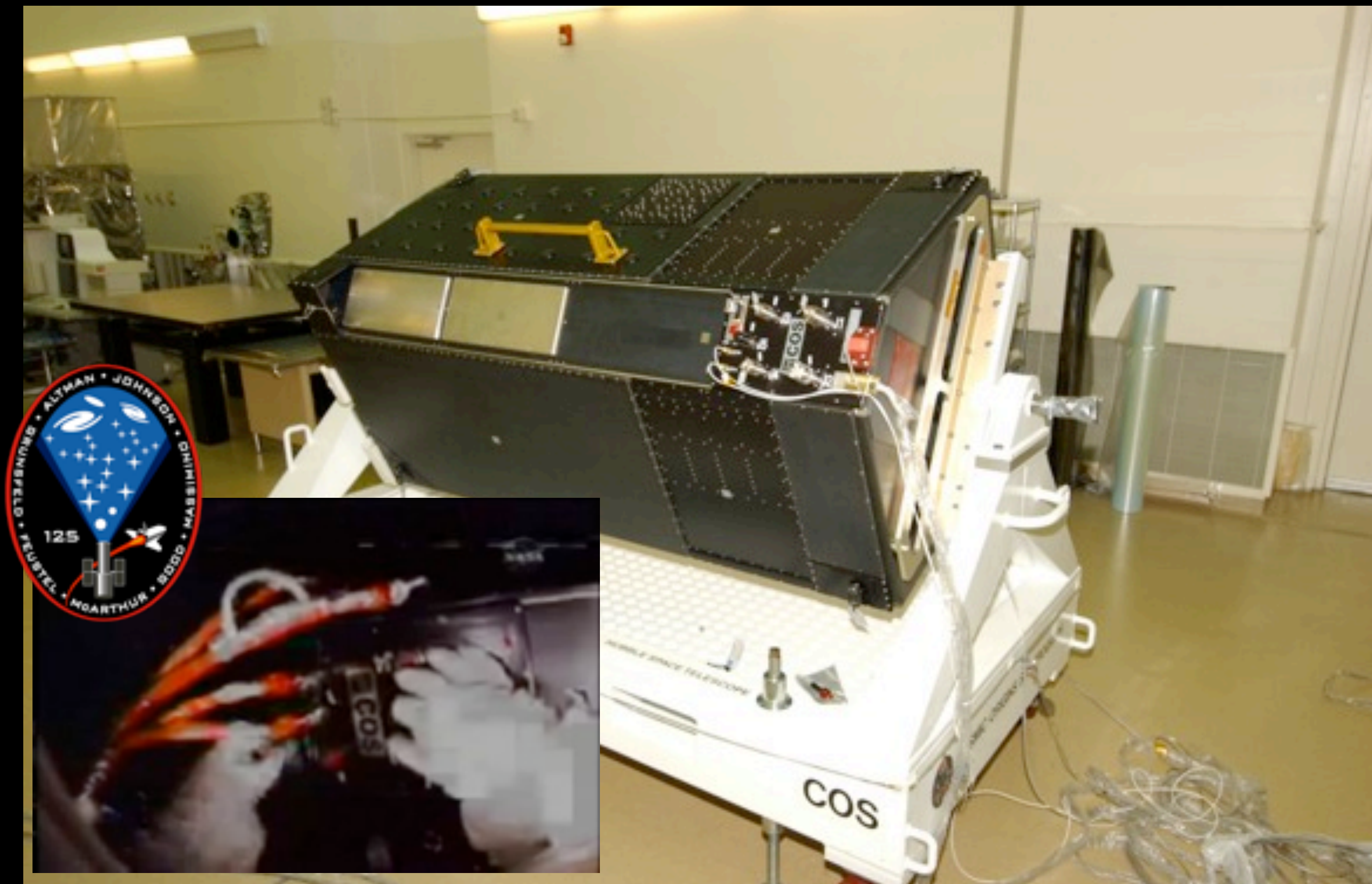

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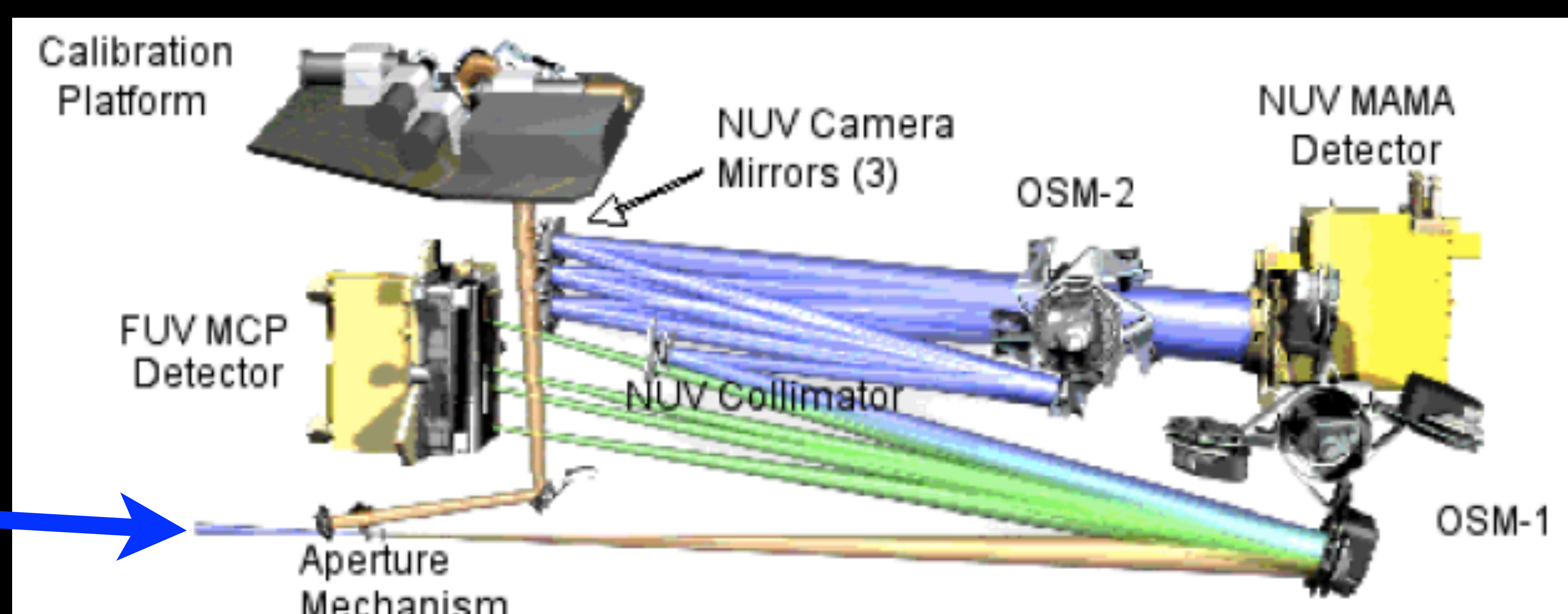


COS-Halos Survey Design:

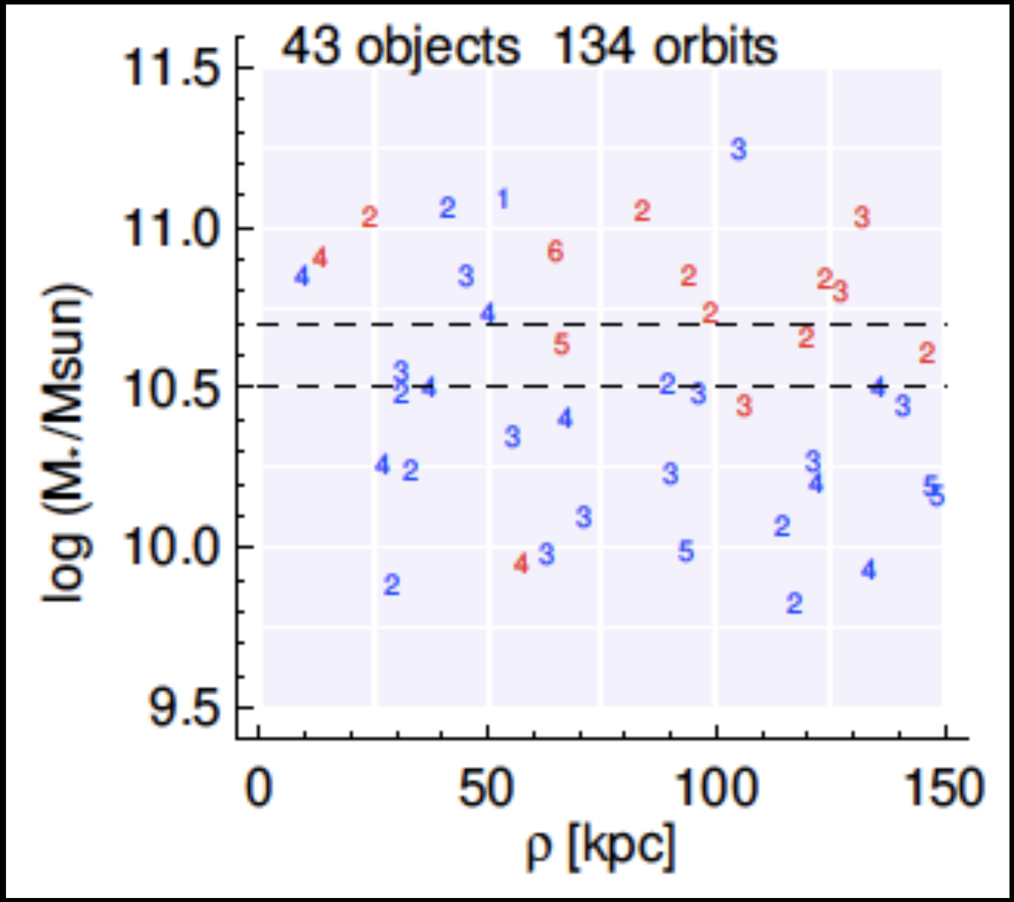
- O VI $\lambda\lambda$1032, 1036 must be redshifted to z > 0.11 to detect in HST band.

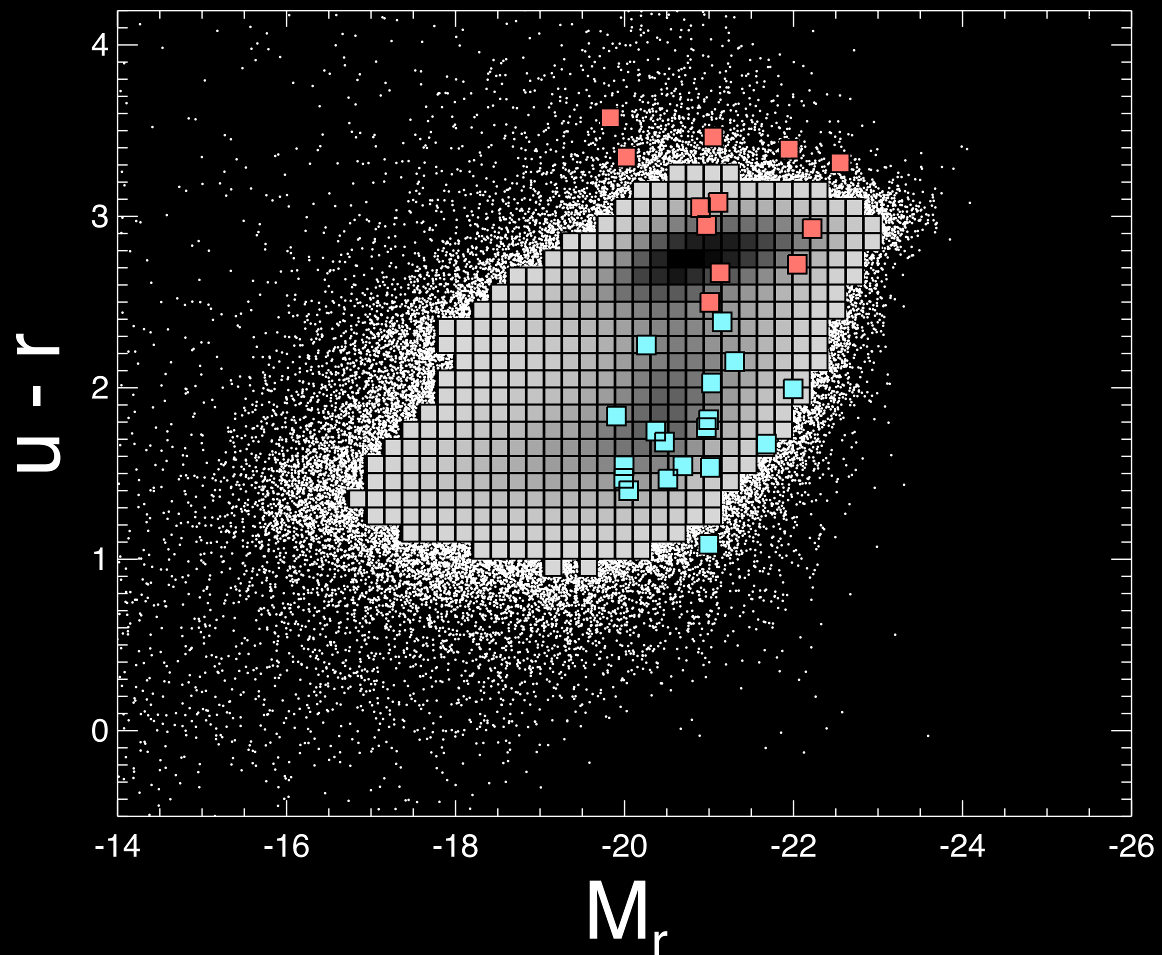
- The main SDSS spectroscopic galaxy survey is flux-limited to z ≤ 0.1, so select galaxies in foreground based on **photometric** redshift.

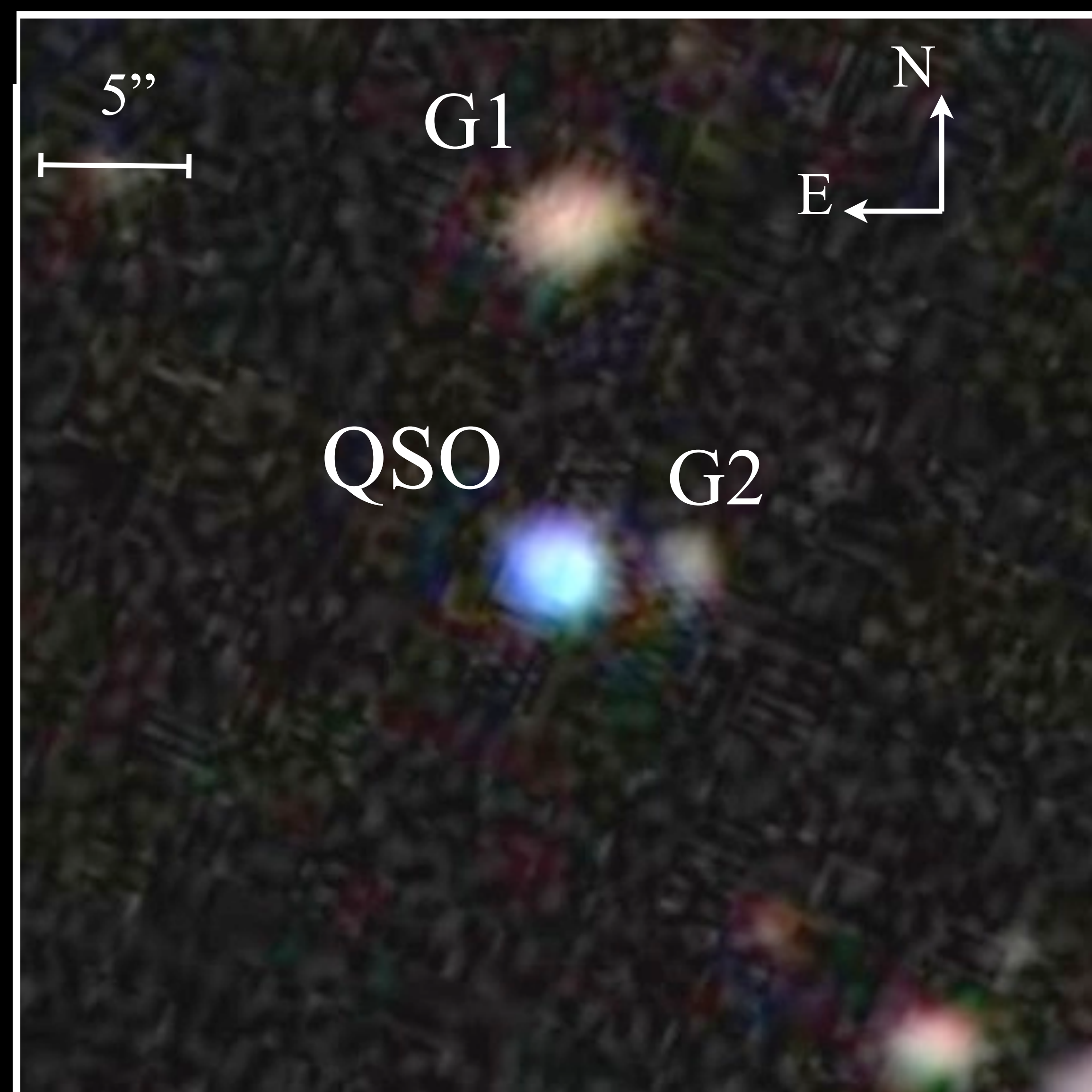
- Then obtain spectroscopic redshifts with Keck/LRIS (via CoI Prochaska+Werk).

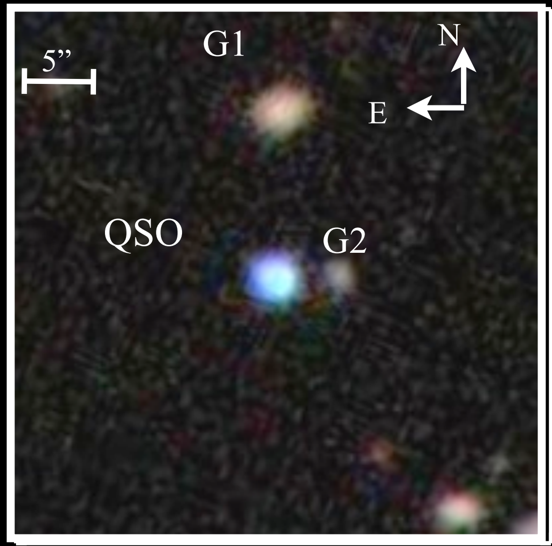
- Selection for galaxies at z > 0.1 limits the survey to ~ L*.

- Select background QSOs to obtain S/N ~ 10 with COS in 2-5 orbits.

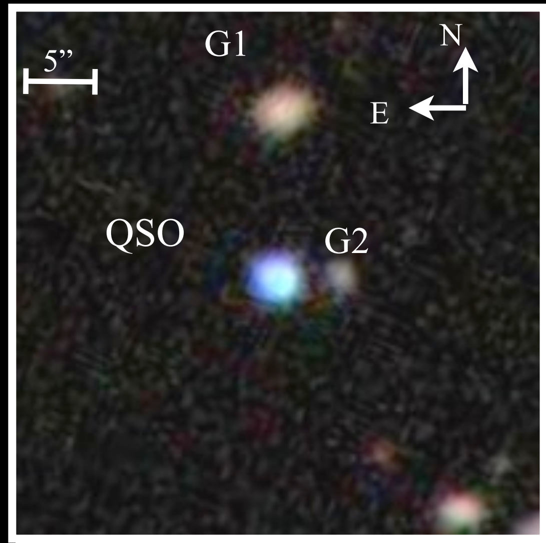


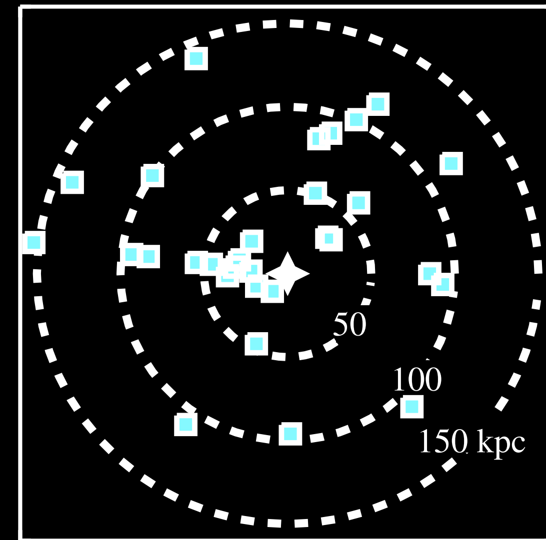



5”
G1
N
E
QSO
G2



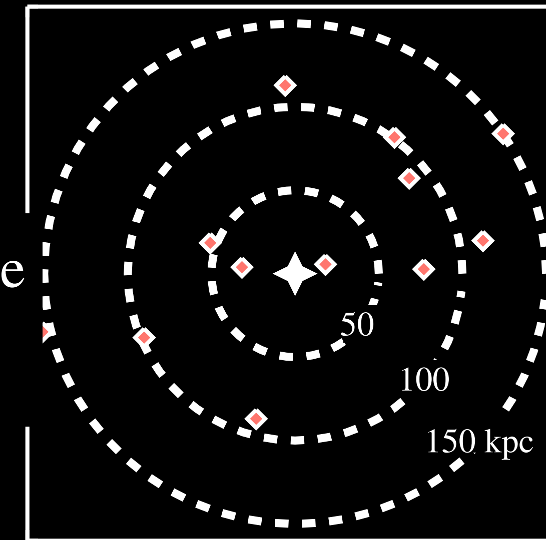
5"
G1
N
E
QSO
G2



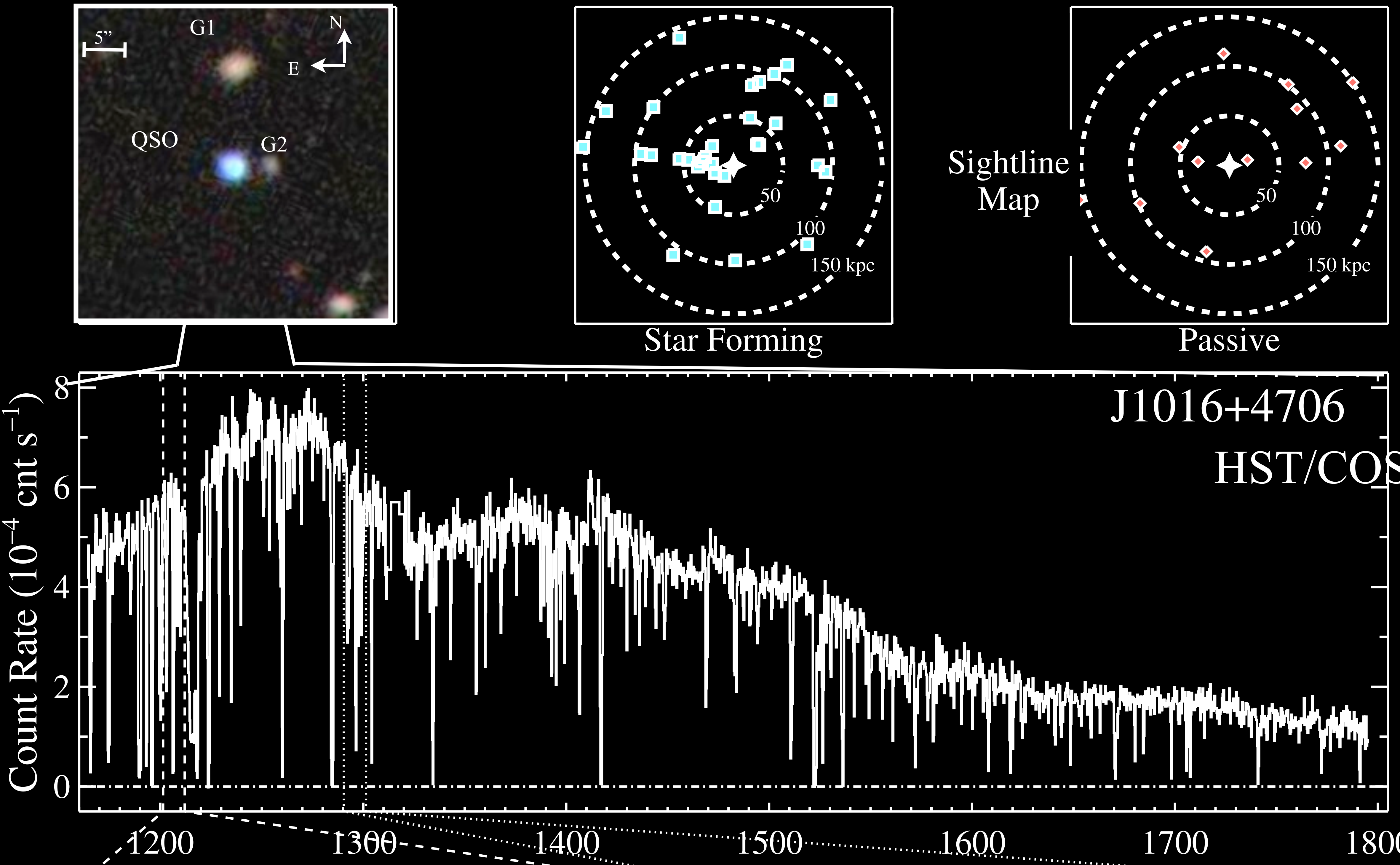


Star Forming

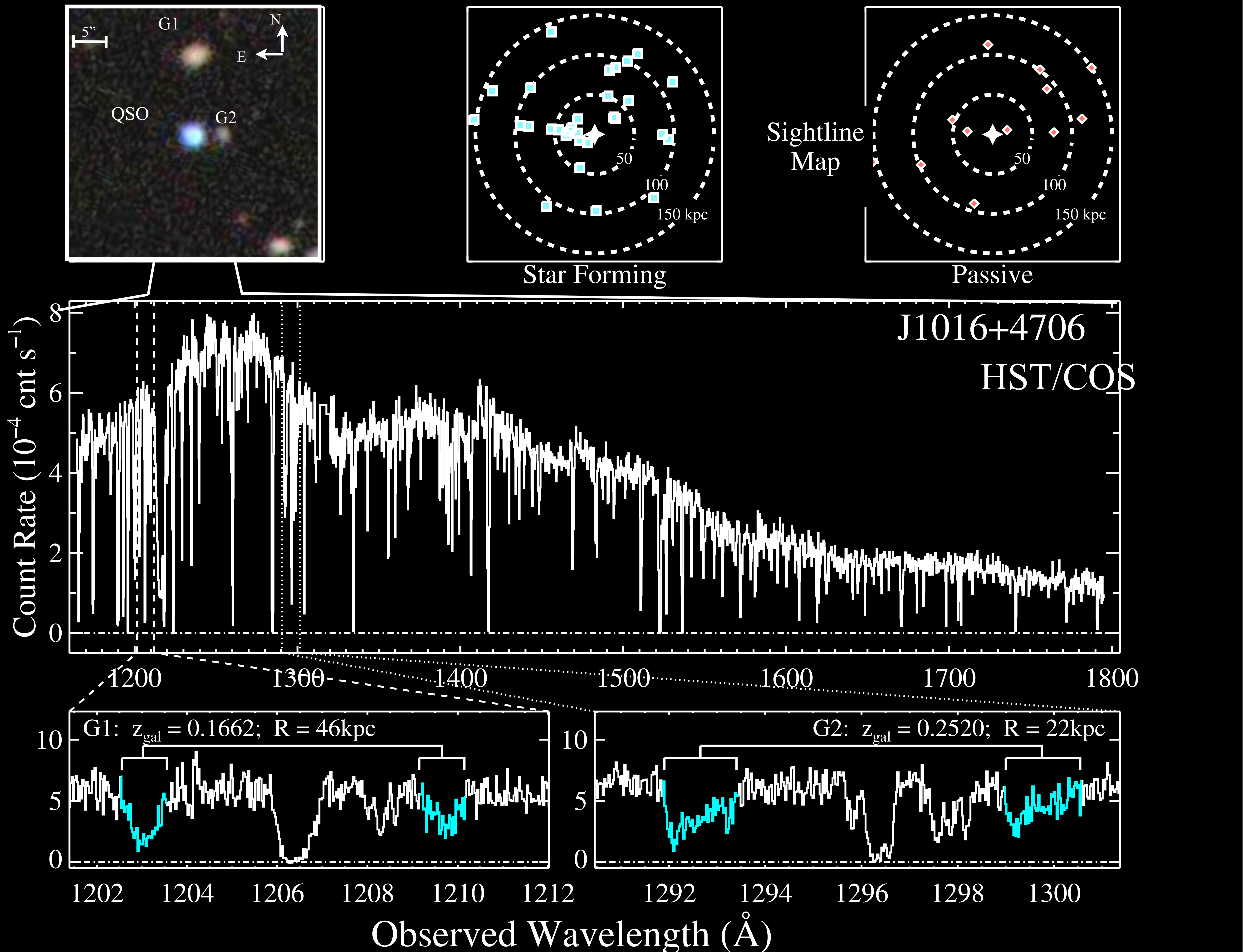
Sightline Map



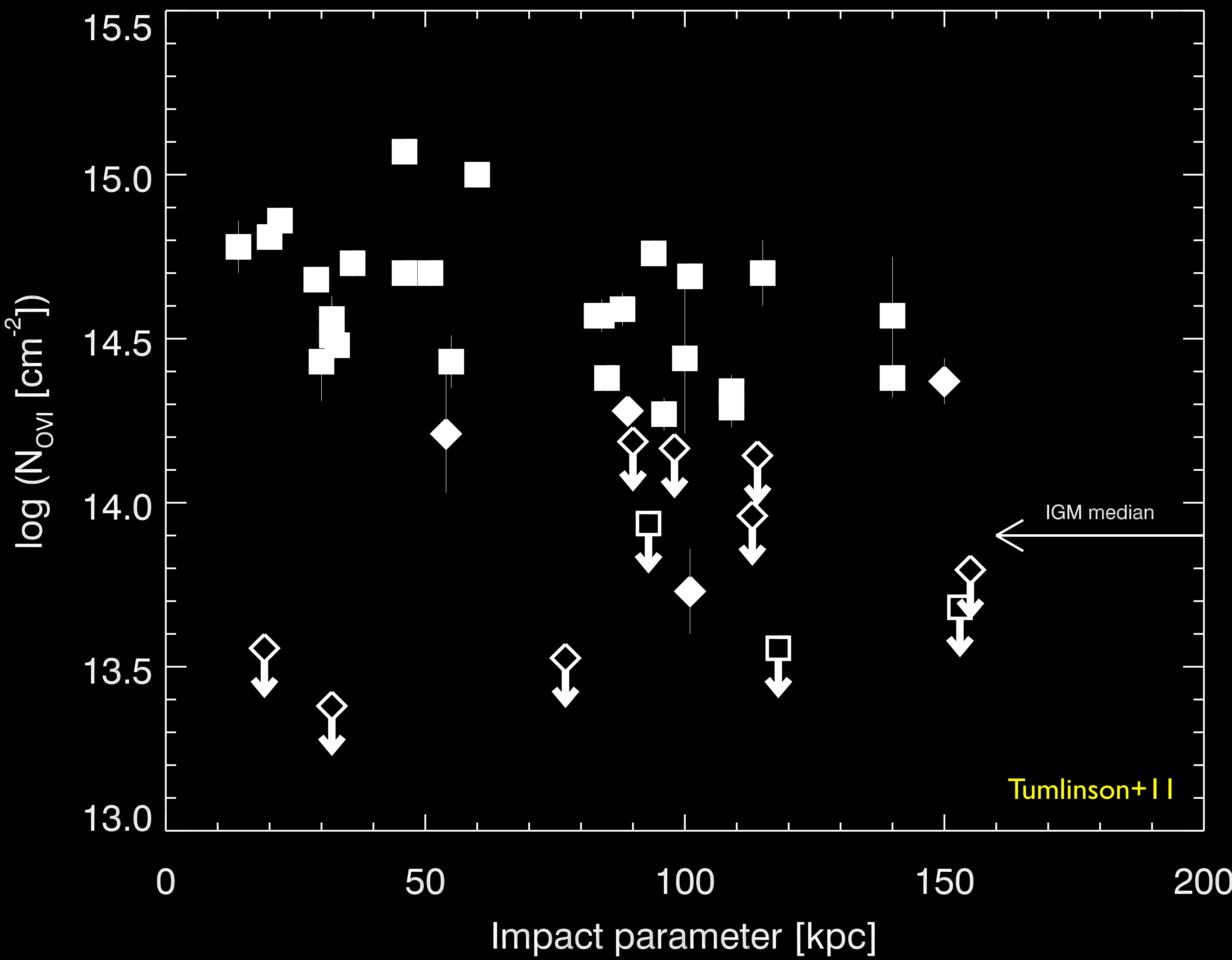
Passive



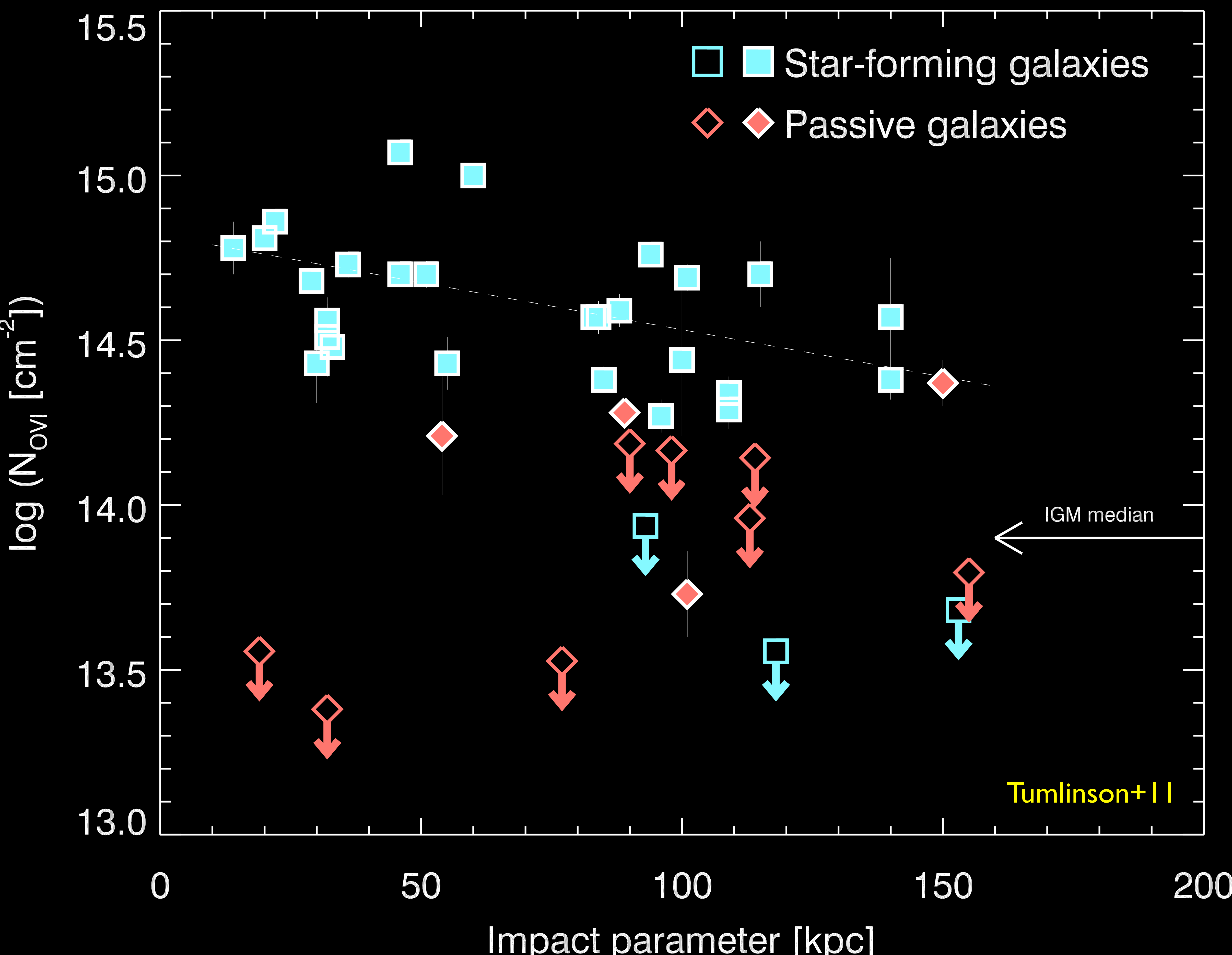
5"
G1
N
E
QSO
G2
50
100
150 kpc
Star Forming
Sightline Map
50
100
150 kpc
Passive
J1016+4706
HST/COS
Count Rate (10^{-4} cnt s^{-1})
0
2
4
6
8
1200
1300
1400
1500
1600
1700
1800



Sunday, June 26, 2011



15.5
15.0
14.5
14.0
13.5
13.0
log (N_{OVI} [cm^{-2}])
IGM median
Tumlinson+11
0
50
100
150
200
Impact parameter [kpc]



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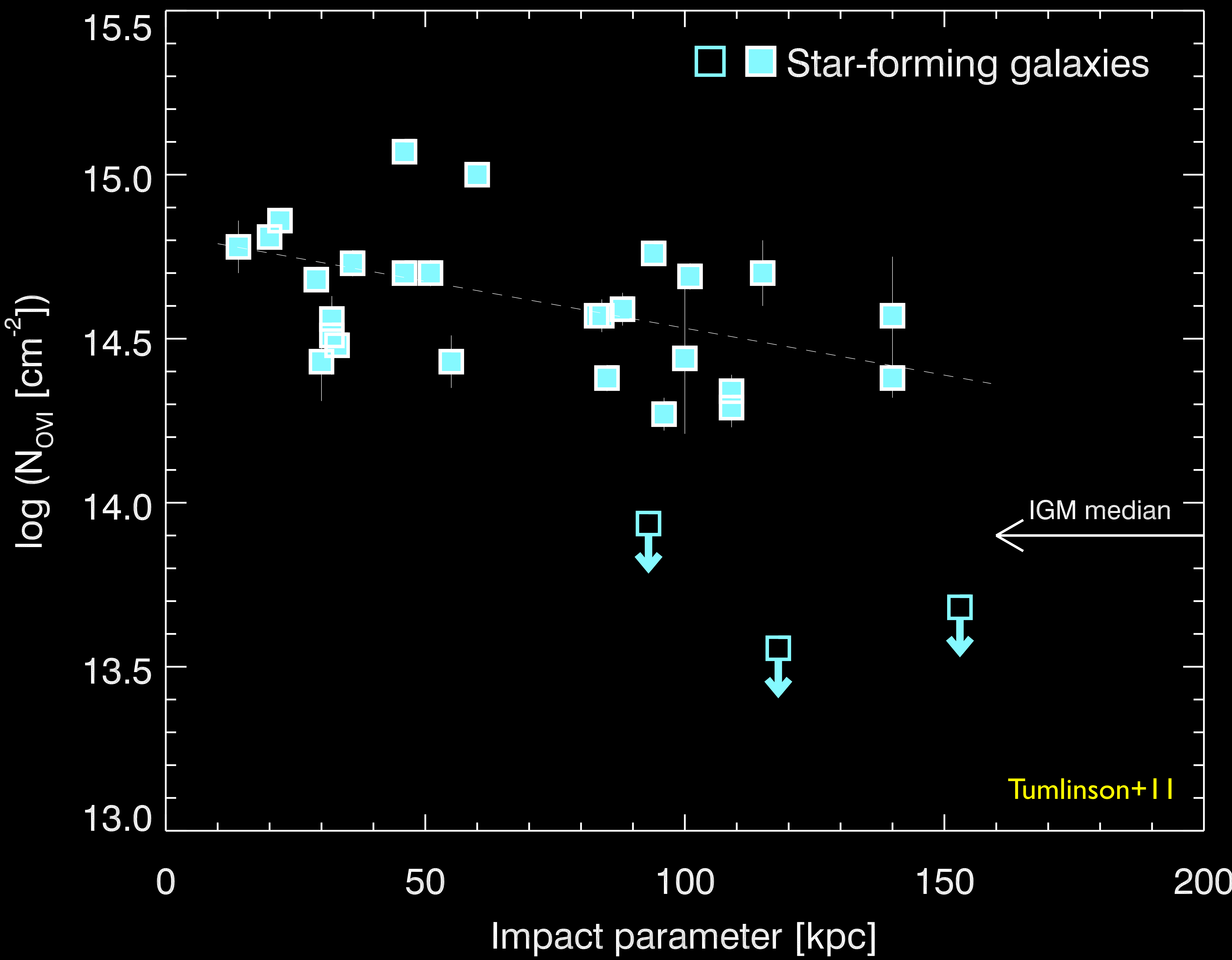
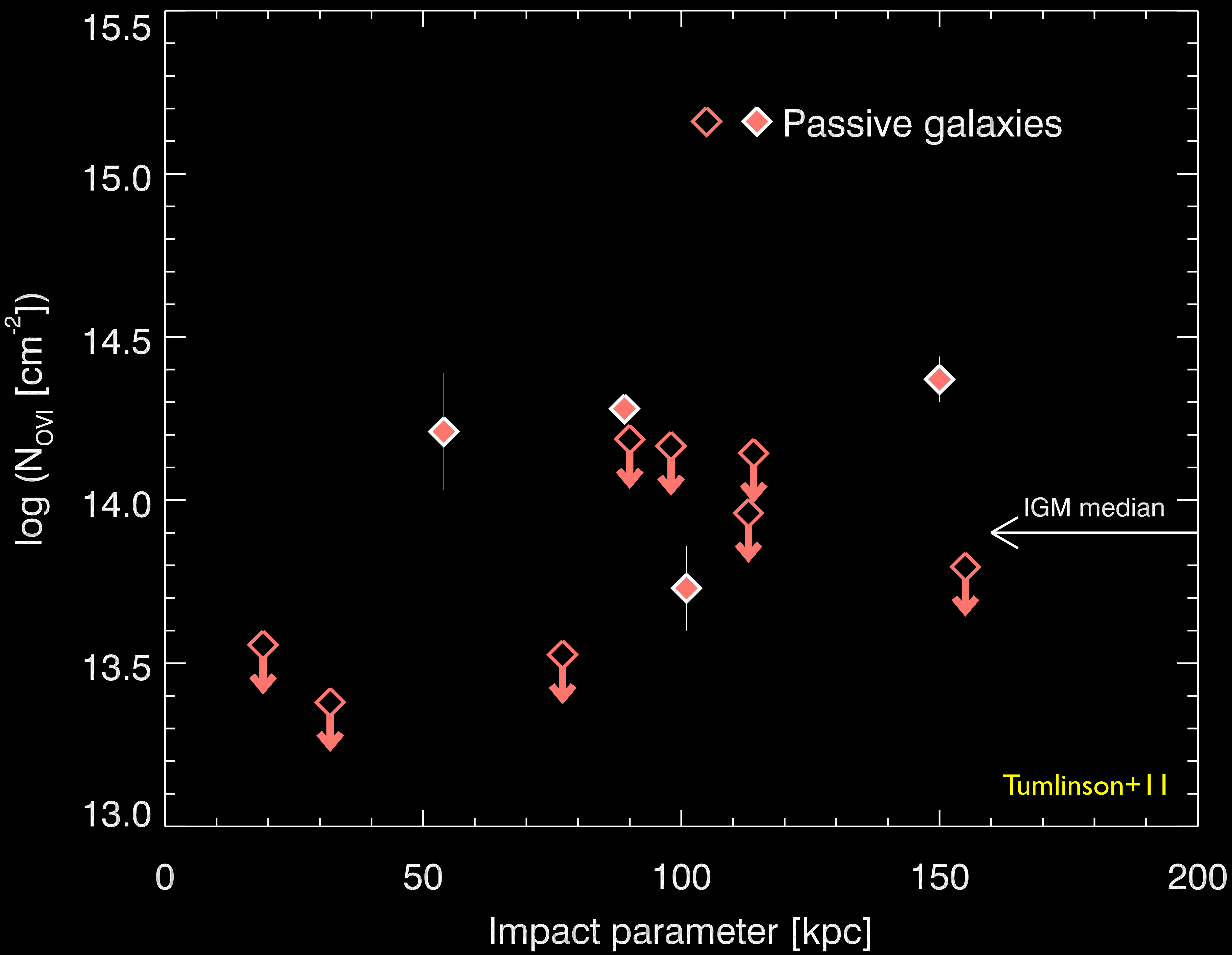


Star-forming galaxies
log (N_{OVI} [cm^{-2}])
15.5
15.0
14.5
14.0
13.5
13.0
IGM median
Tumlinson+11
0
50
100
150
200
Impact parameter [kpc]


15.5
15.0
14.5
14.0
13.5
13.0
log (N_{OVI} [cm^{-2}])
Passive galaxies
IGM median
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0
50
100
150
200
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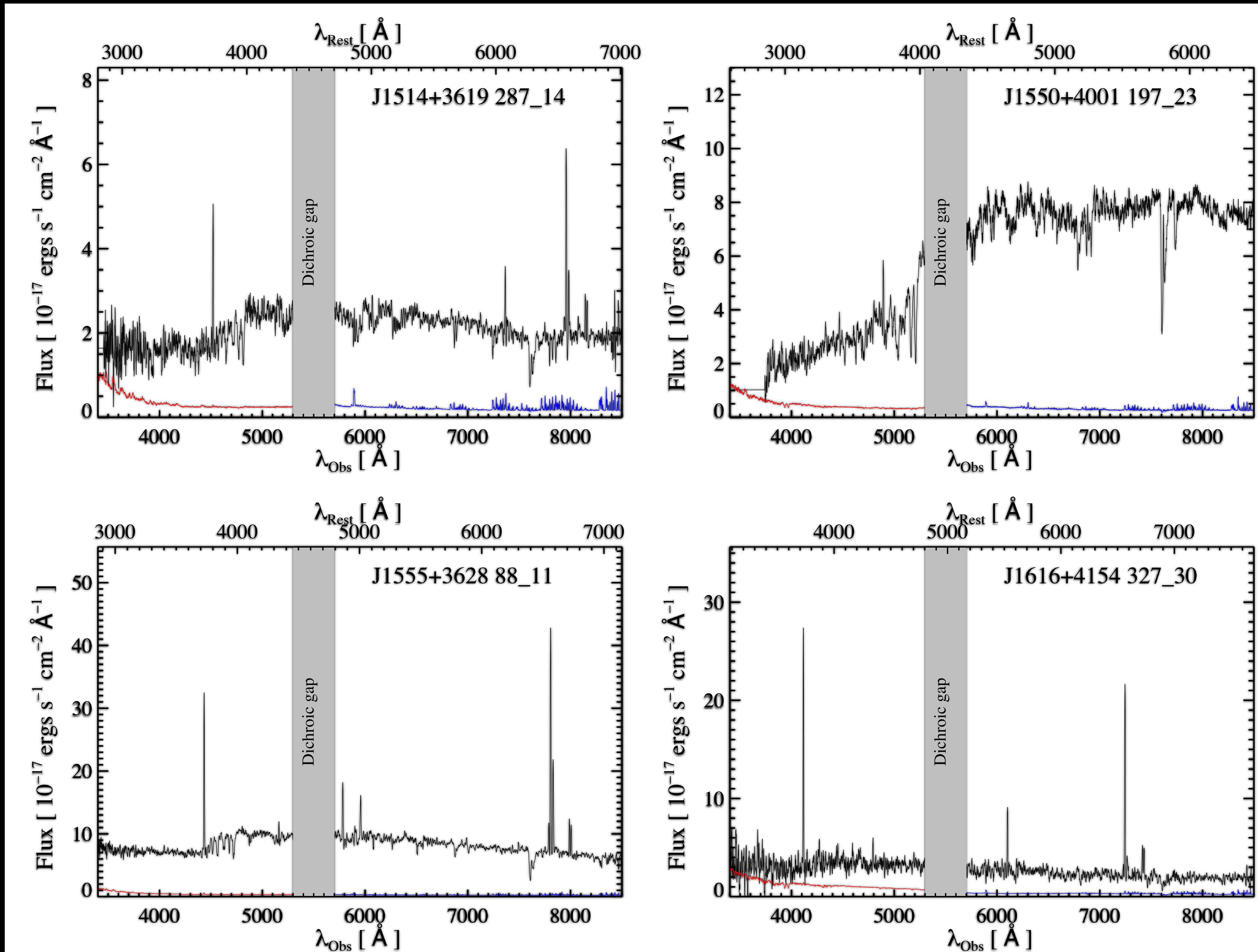
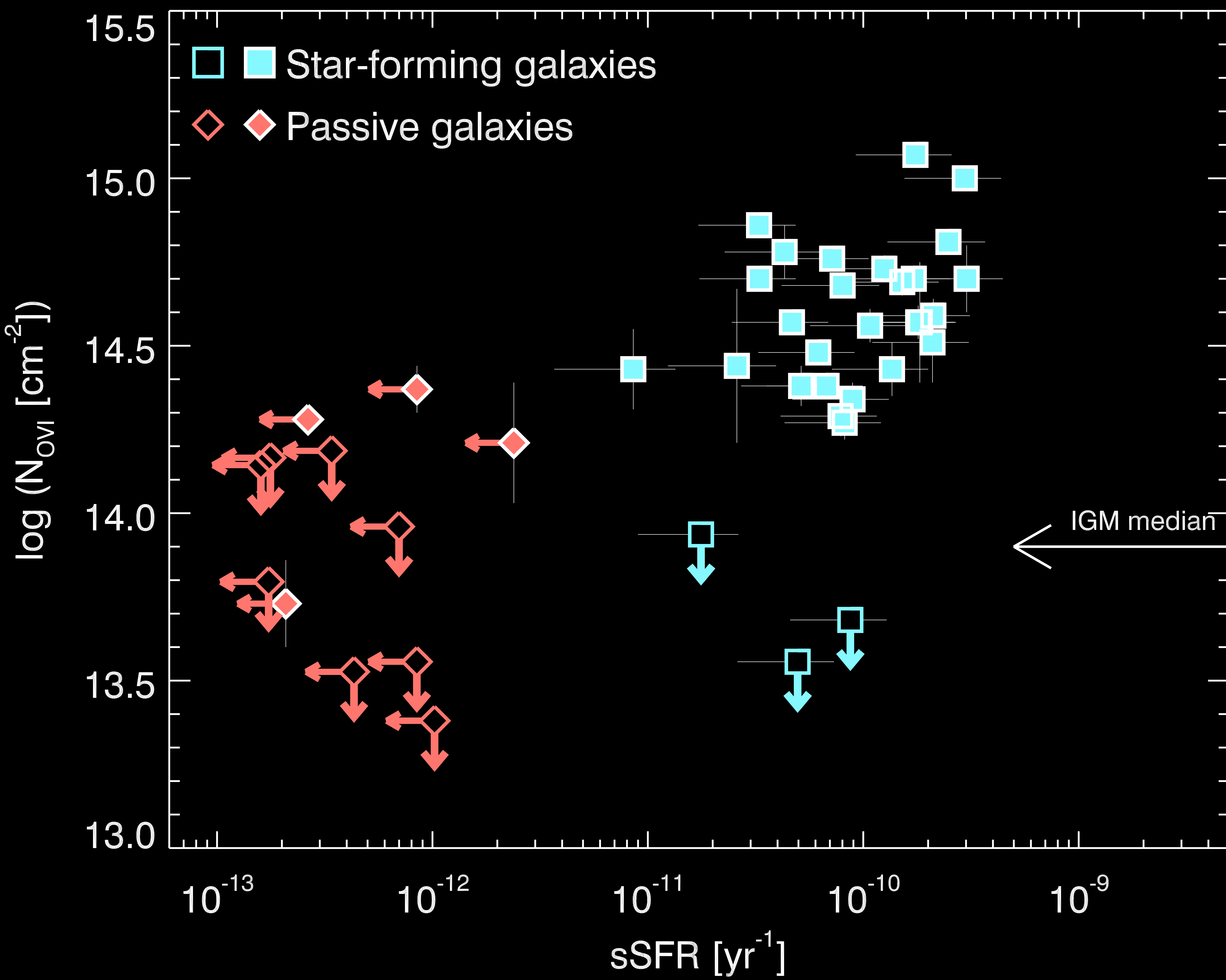
Keck/LRIS Galaxy Spectroscopy



Measure redshift, SFR, stellar mass, metallicity, environment, etc.

Werk+11



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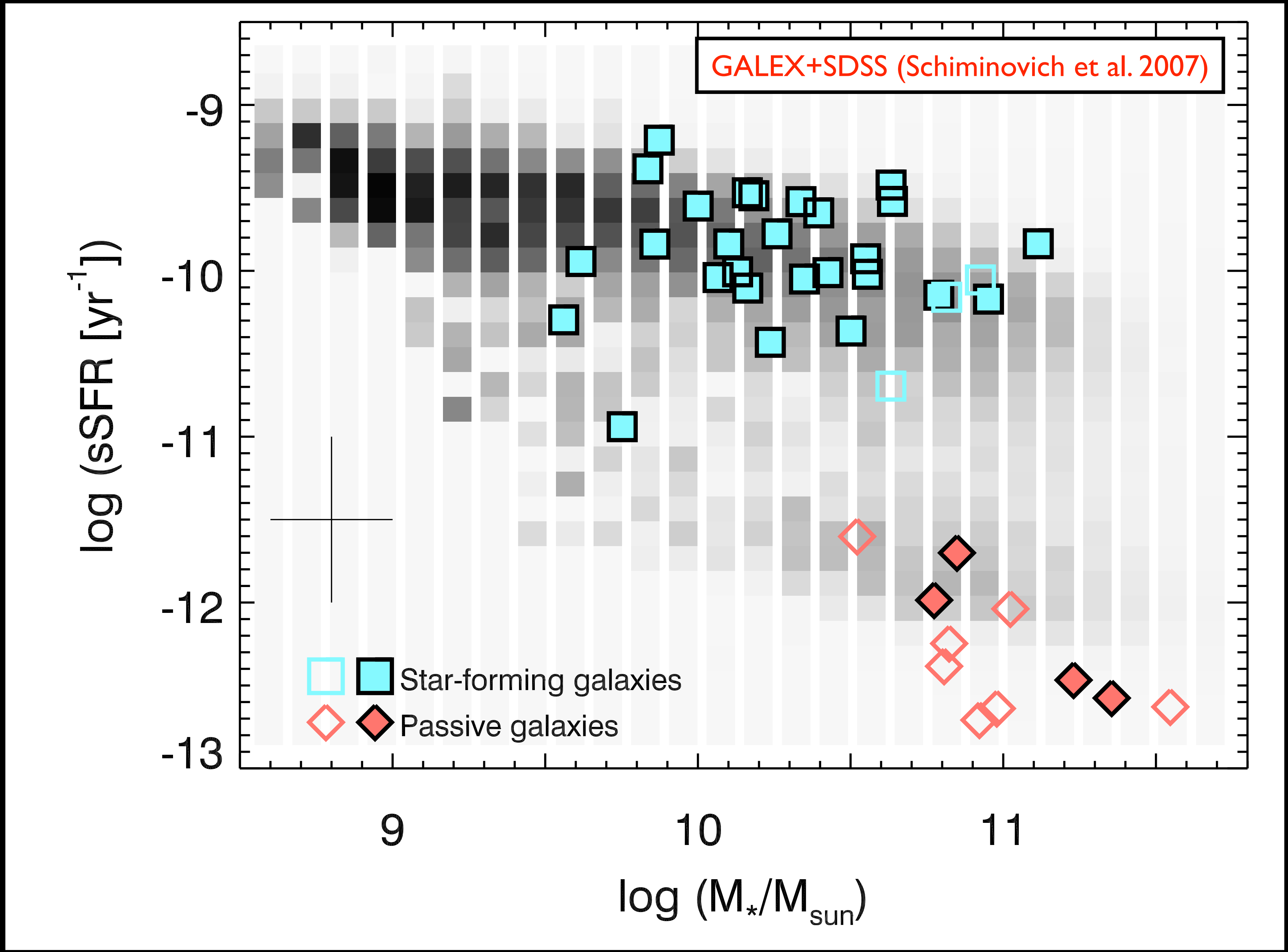
Gas Halos and Galaxy Bimodality



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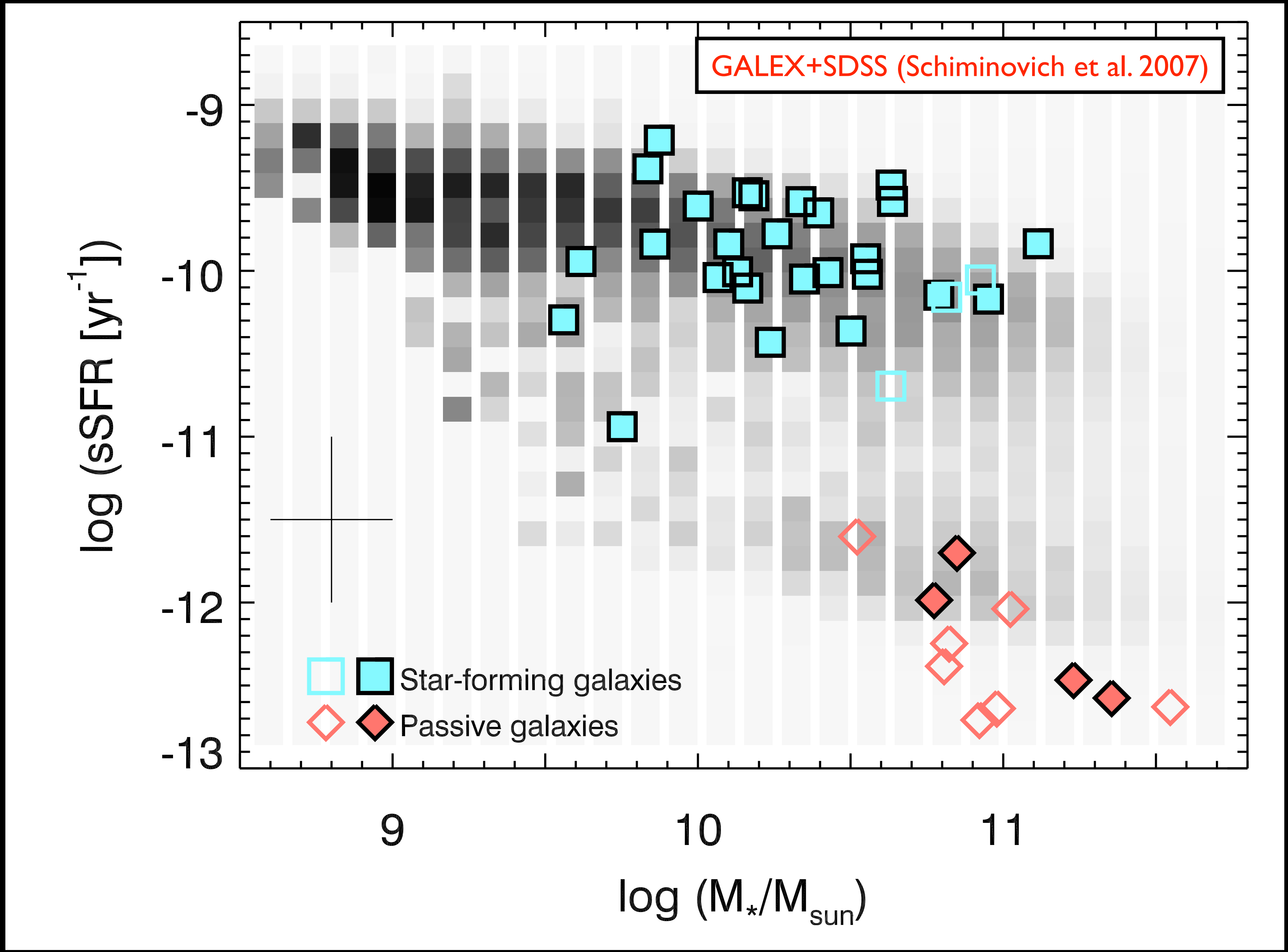

"Blue cloud" galaxies have 92% detection rate (100% inside 90 kpc)

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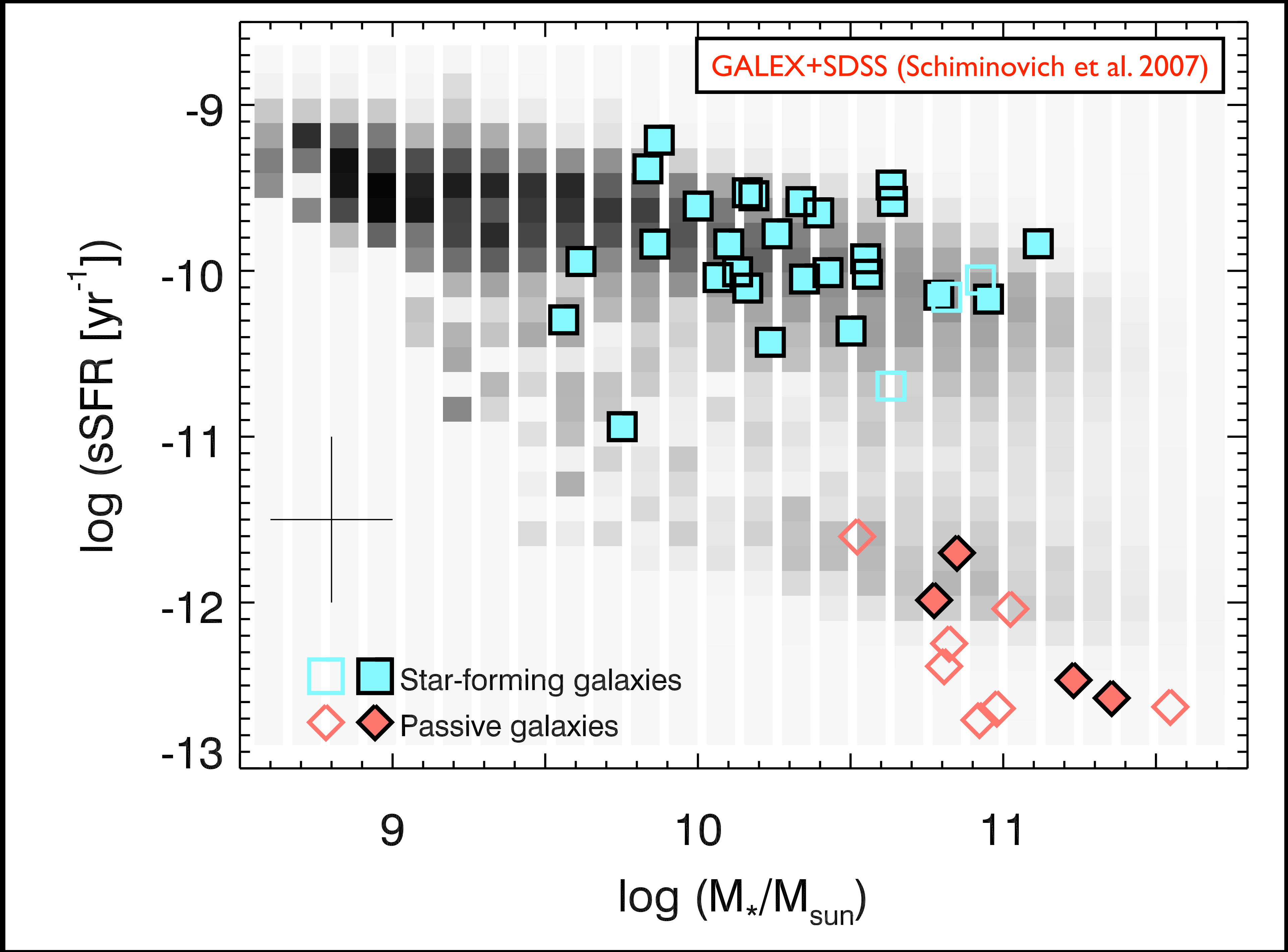
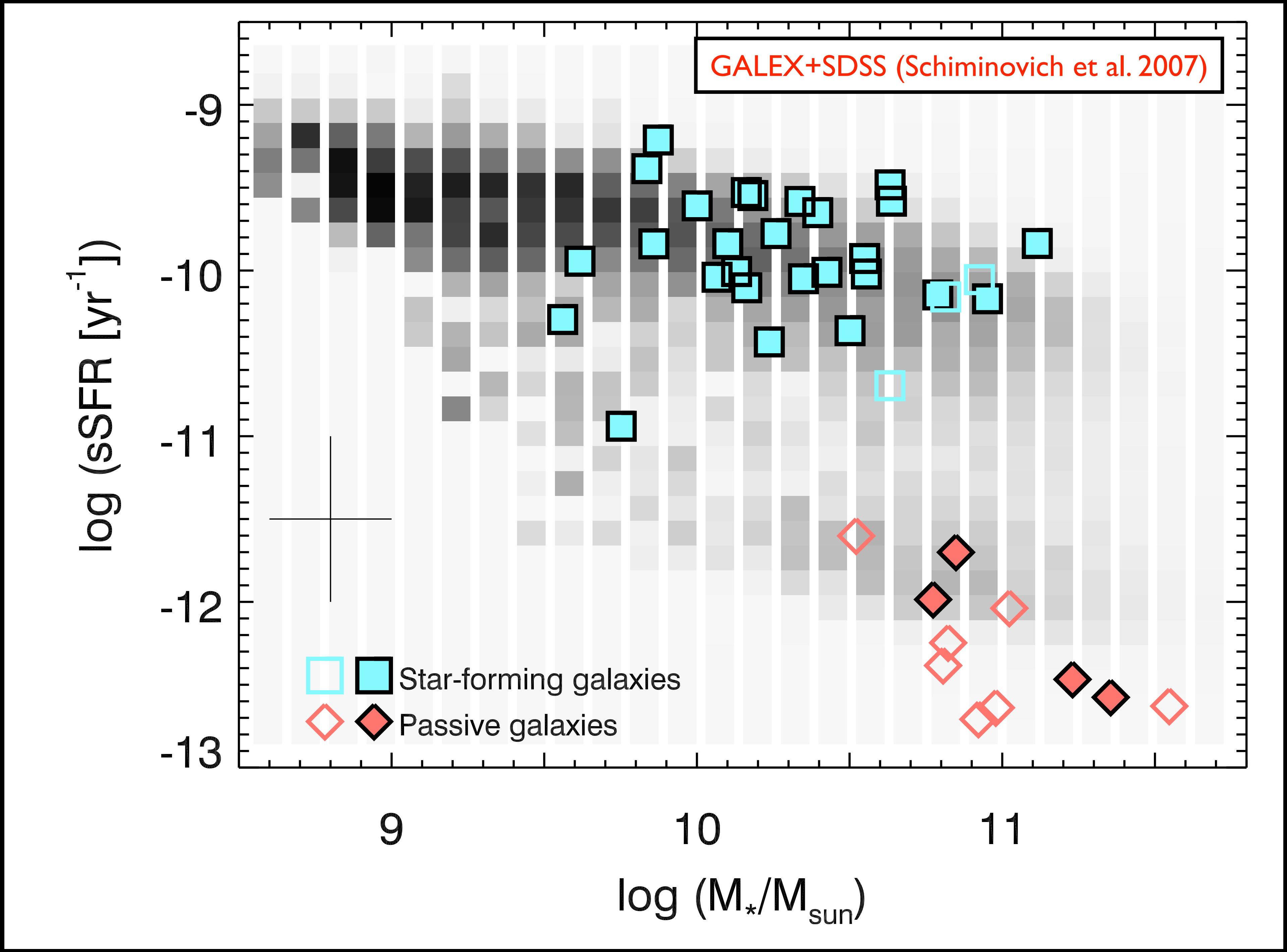


“Blue cloud” galaxies have 92% detection rate (100% inside 90 kpc)

“Red sequence” galaxies have 44% detection rate.

Gas Halos and Galaxy Bimodality



"Blue cloud" galaxies have 92% detection rate (100% inside 90 kpc)

"Red sequence" galaxies have 44% detection rate.

"Green Valley"… too few to tell. Get some more data?

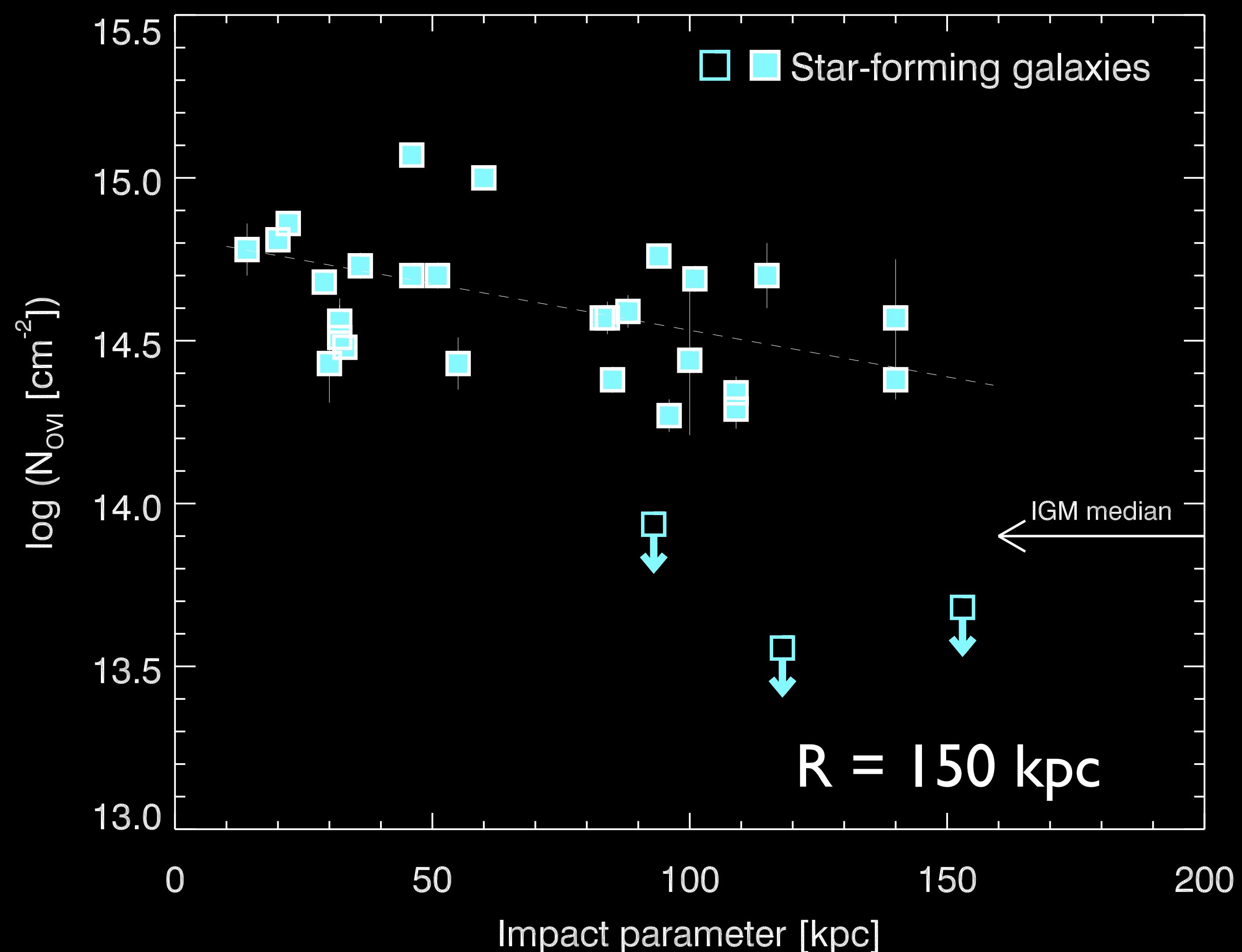
Star Forming Galaxy Halos: Lots of Oxygen Mass!

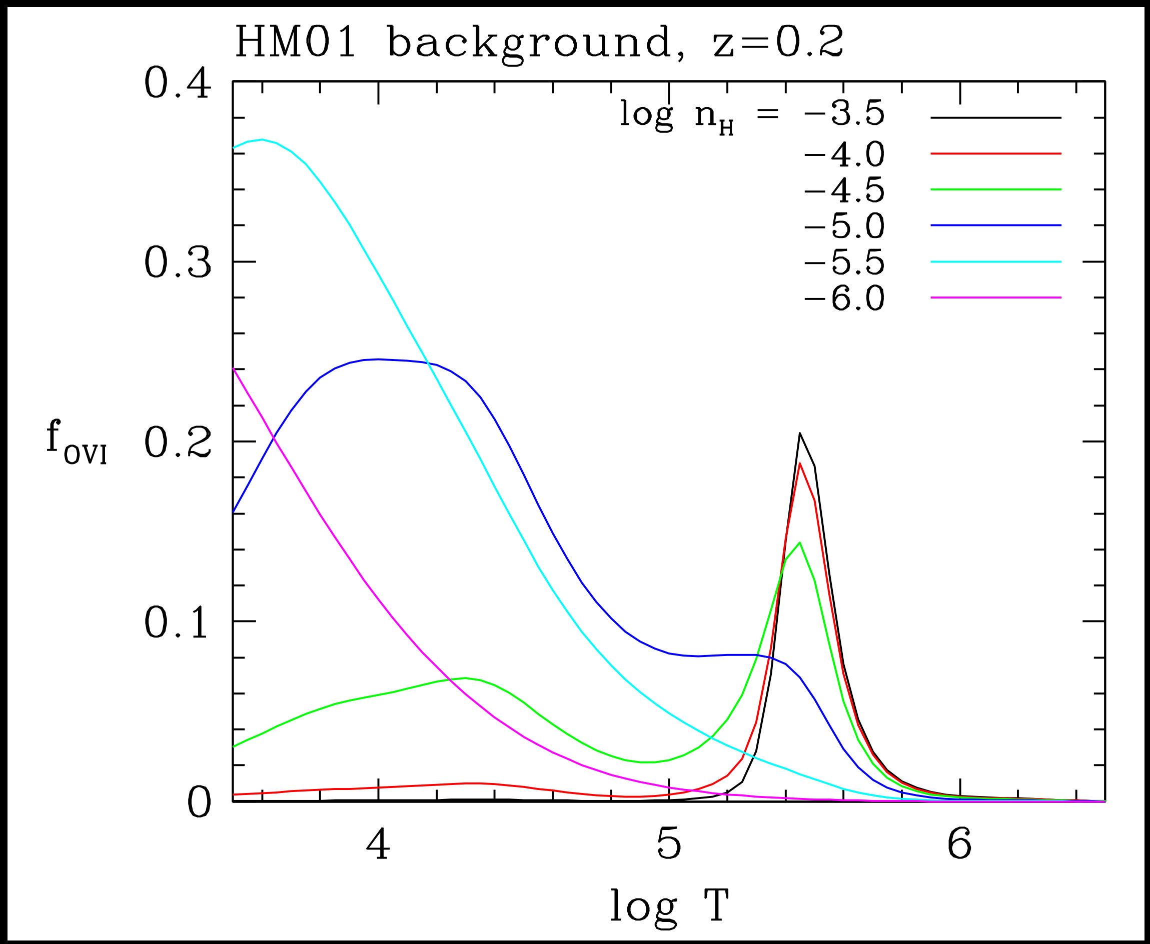
$$M_{OVI} = \pi R^2 N_{OVI} 16 m_H M_\odot$$

. . . then apply ionization correction f_{OVI}. . .

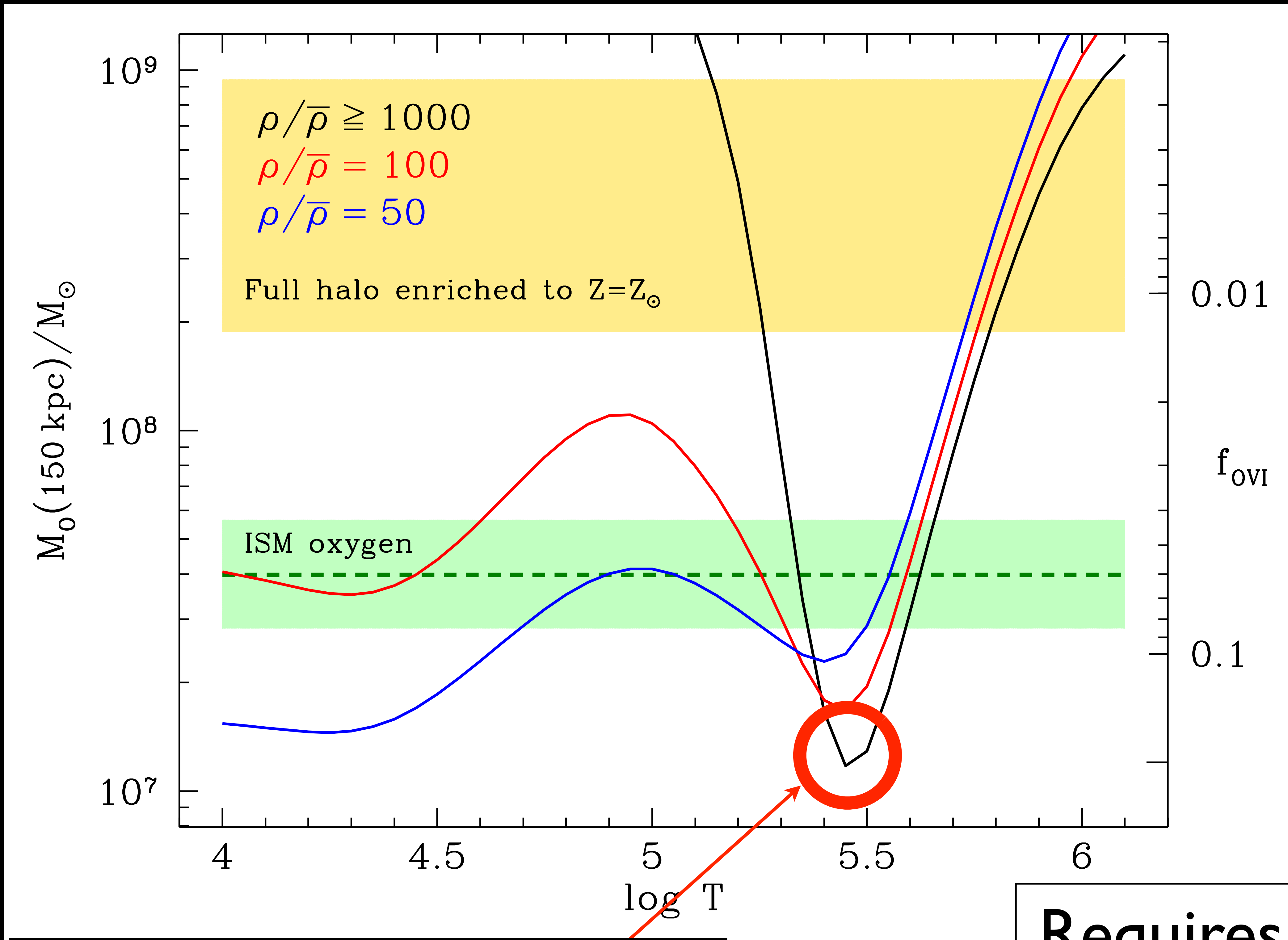
$$M_{Oxygen} = 1.2 \times 10^7 (0.2/f_{OVI}) M_\odot$$

$$M_{gas} = 2 \times 10^9 (Z_\odot/Z) (0.2/f_{OVI}) M_\odot$$





Oxygen and Gas mass in ionized halos may exceed the average ISM!



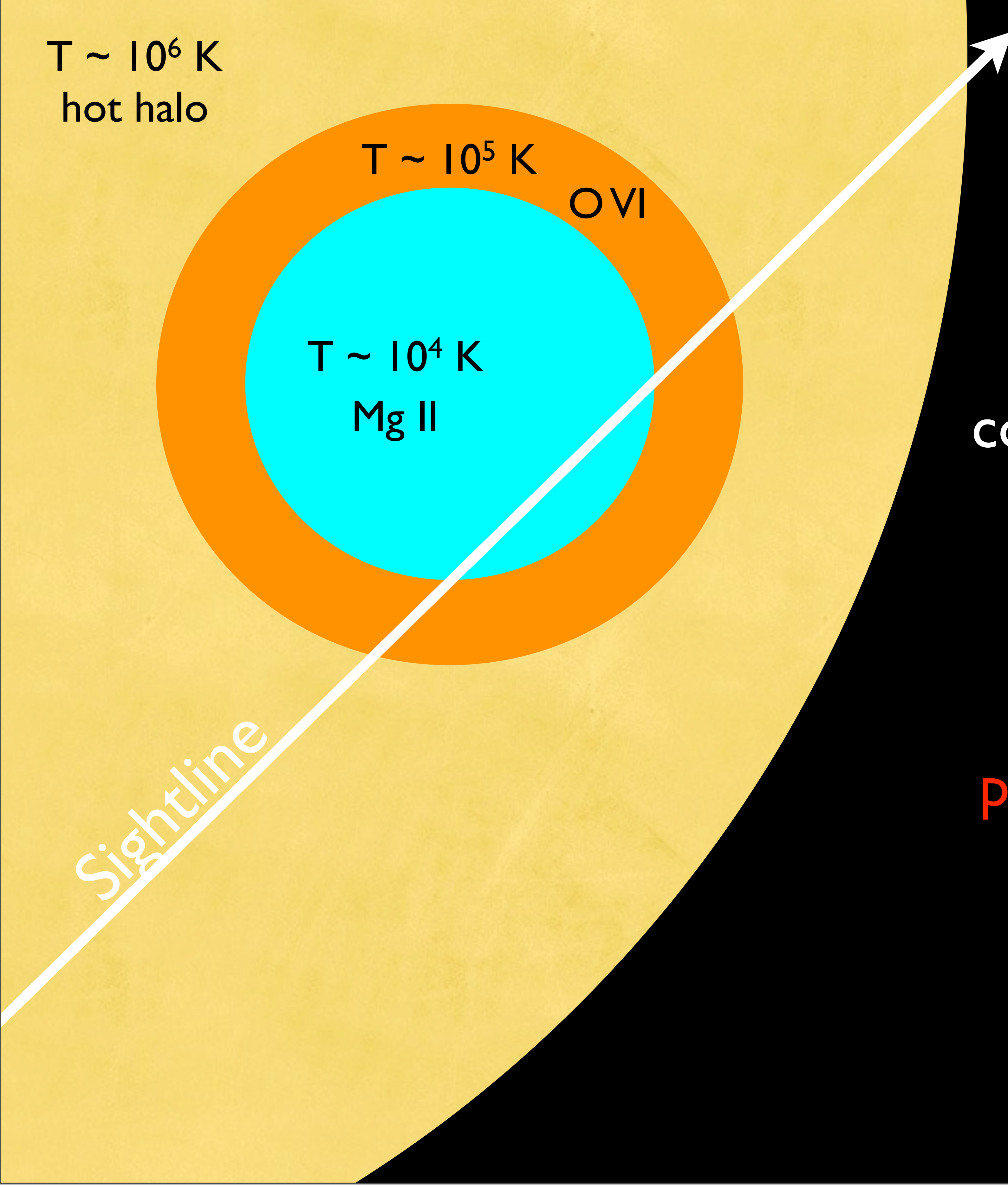
$M_{Oxygen} = 1.2 \times 10^7\ (0.2/f_{OVI})\ M_\odot$

$M_{gas} = 2 \times 10^9\ (Z_\odot/Z)\ (0.2/f_{OVI})\ M_\odot$

Requires $10^9\ M_\odot$ of total star-formation!

Sunday, June 26, 2011

Accretion Scenario for O VI?

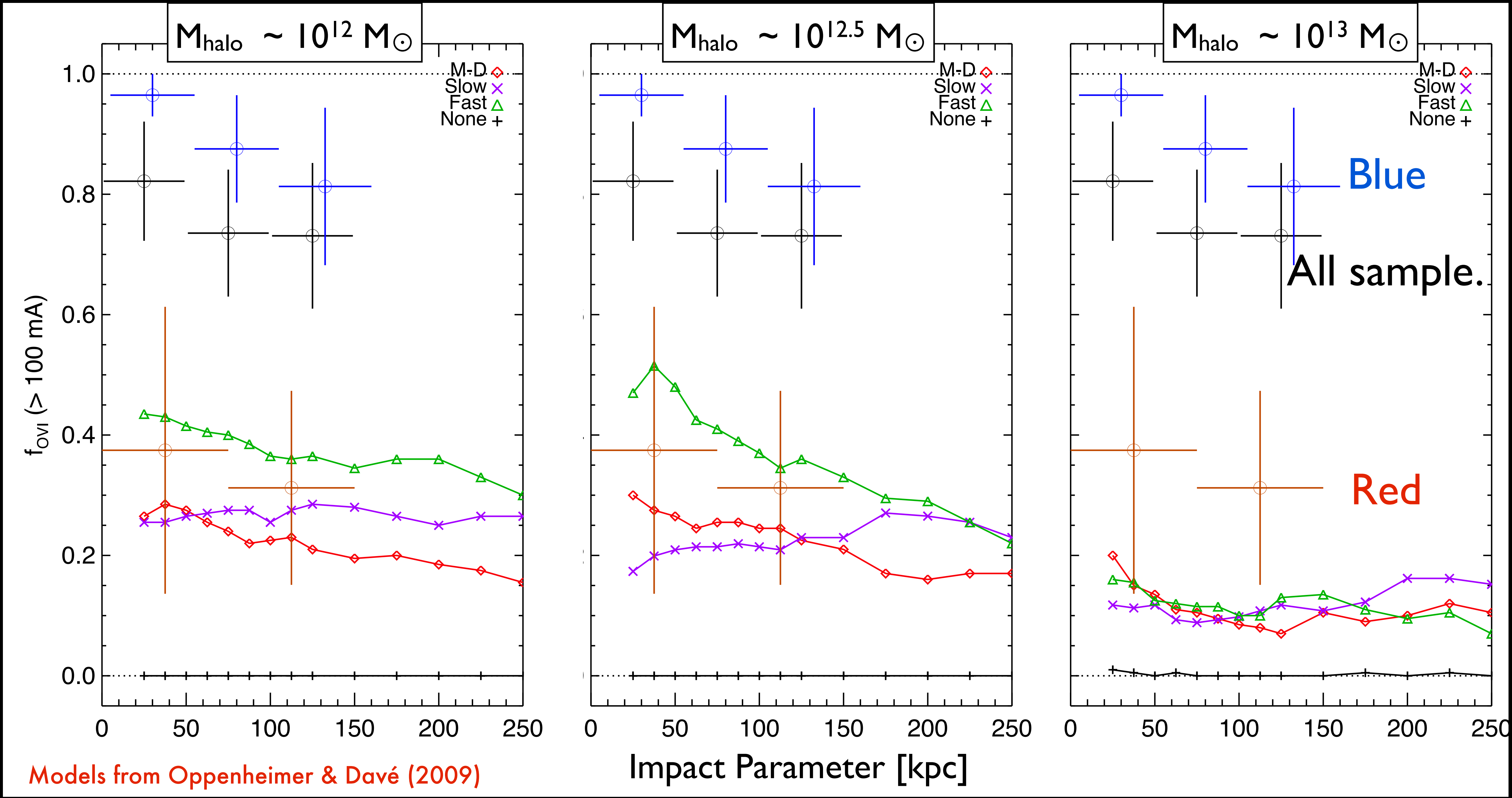


O VI can fit into the "Multiphase Accretion" scenario as the tracer of interface gas between the cooler condensed clouds and the hot coronal halo.

But the covering fraction predicted by "cold mode" or "multiphase" accretion is ~10-20%, not ~100%.

e.g. Keres&Hernquist 2009

So what about outflows?

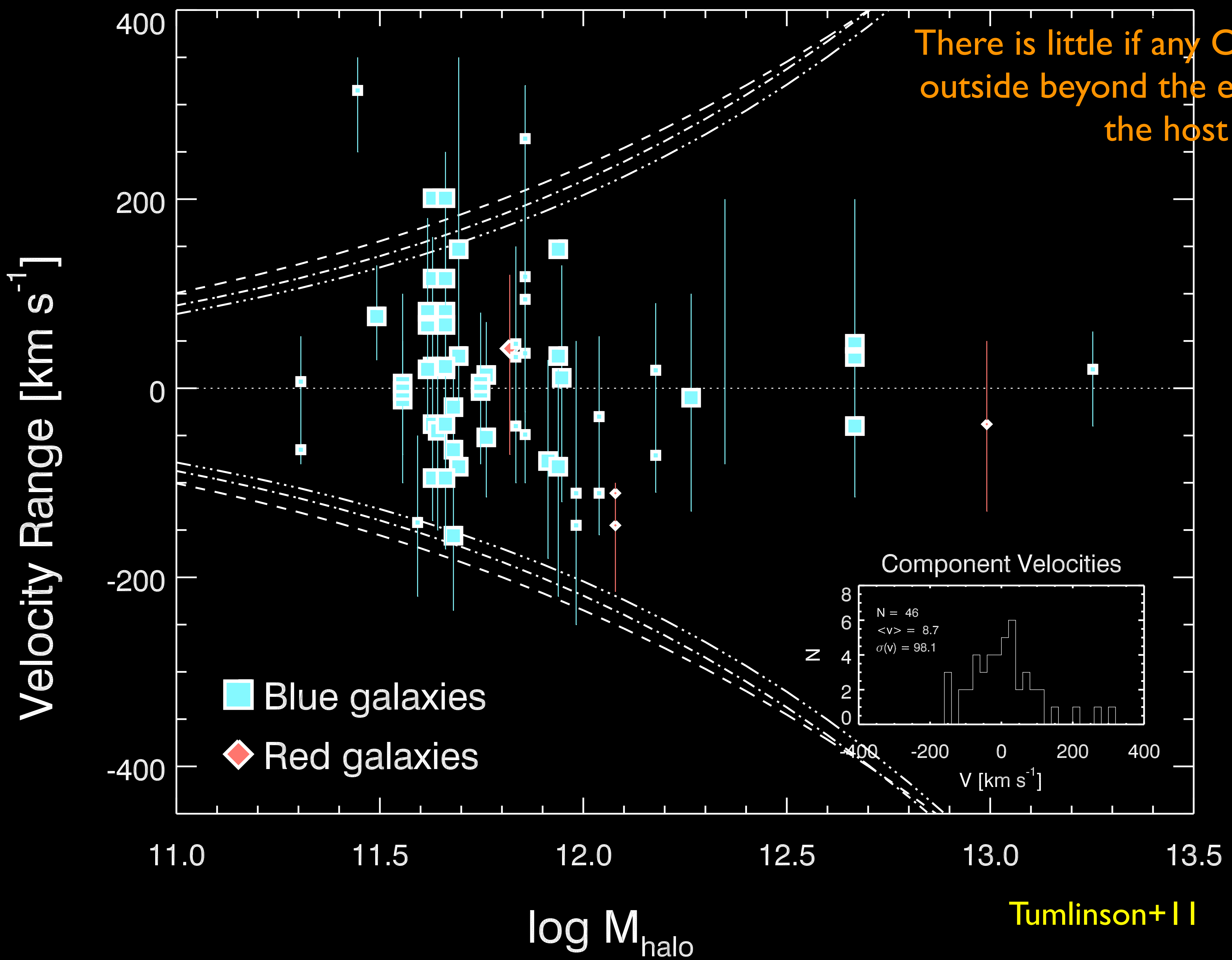


The large oxygen mass in the ionized halos of galaxies implies at least 1 Gyr worth of star formation and oxygen yield, efficiently transported out to > 150 kpc.

O VI Kinematics

O VI gets stronger by getting broader (not by getting optically thick and saturated).

There is little if any O VI-traced material outside beyond the escape velocities of the host halos.



Tumlinson+11

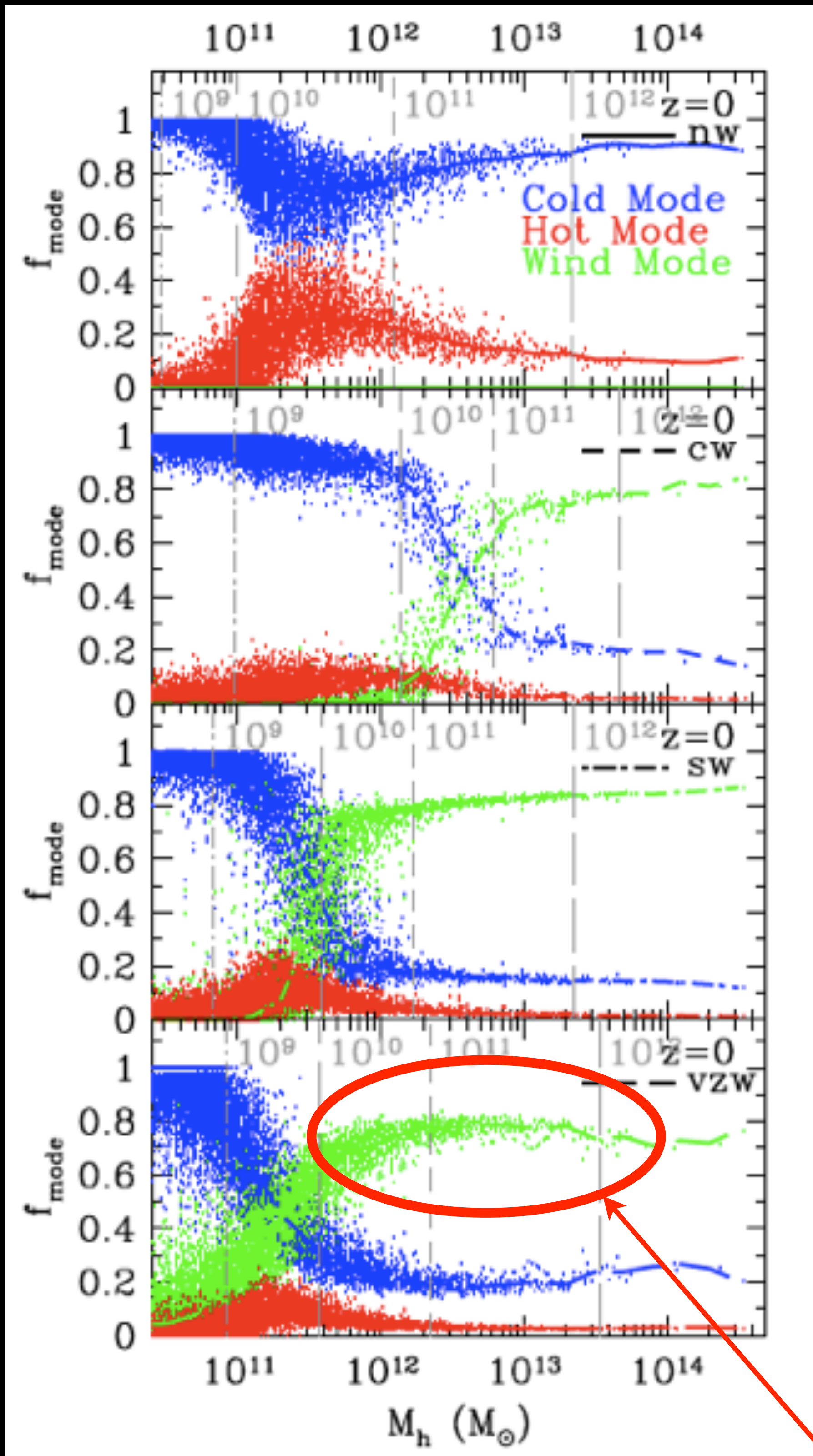
"Recycled winds" = half of accretion at z < 1?

No winds

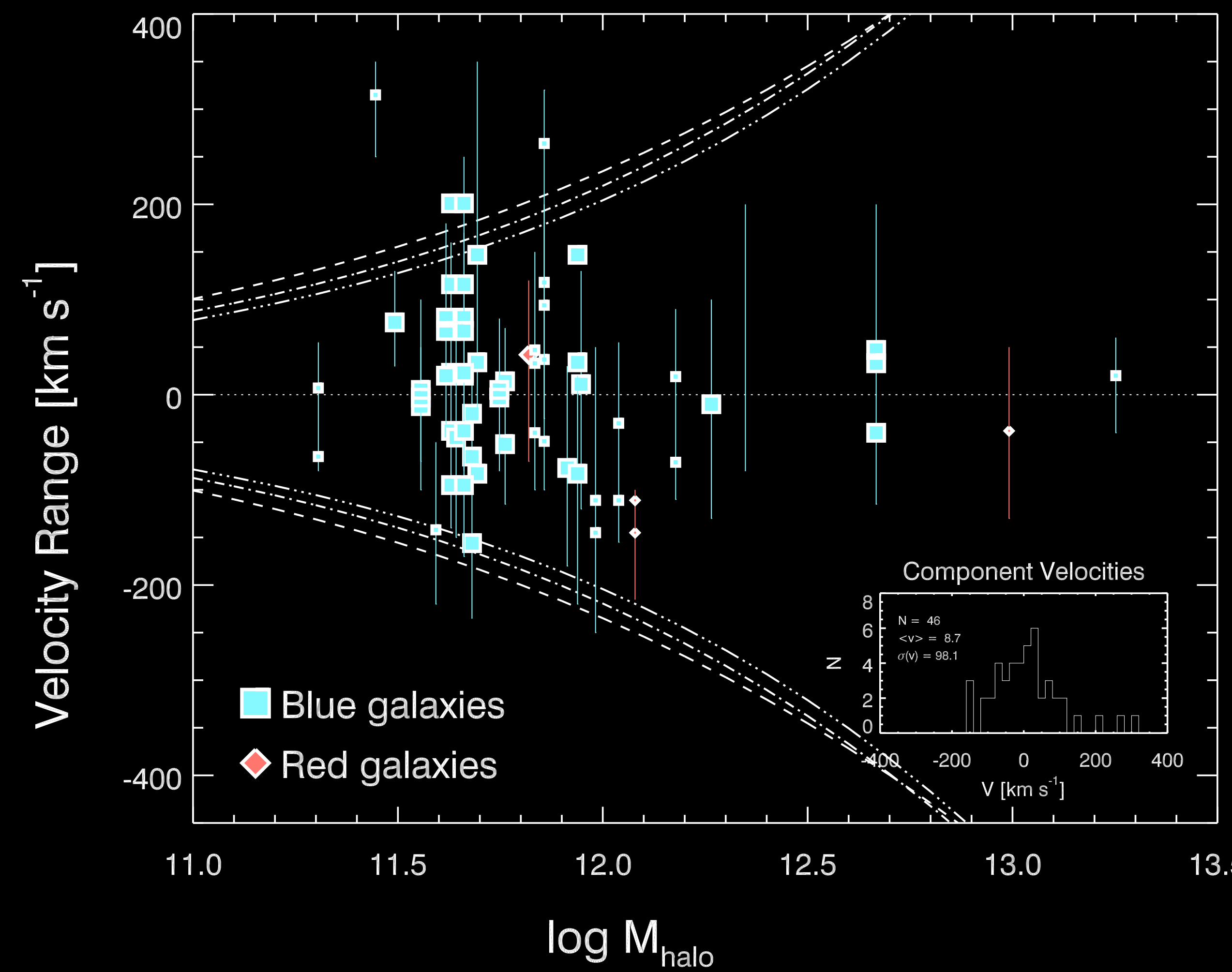
Fast winds

Slow winds

Mom-driven winds



Oppenheimer et al. 2010



The O VI we represents significant mass and metal outflow from galaxies, yet does not appear to exceed the escape velocity.

This finding is consistent with the expectation that much of z < 1 accretion is recycled outflows.

"Wind mode" is 80% of accretion for L* galaxies (in this simulation).

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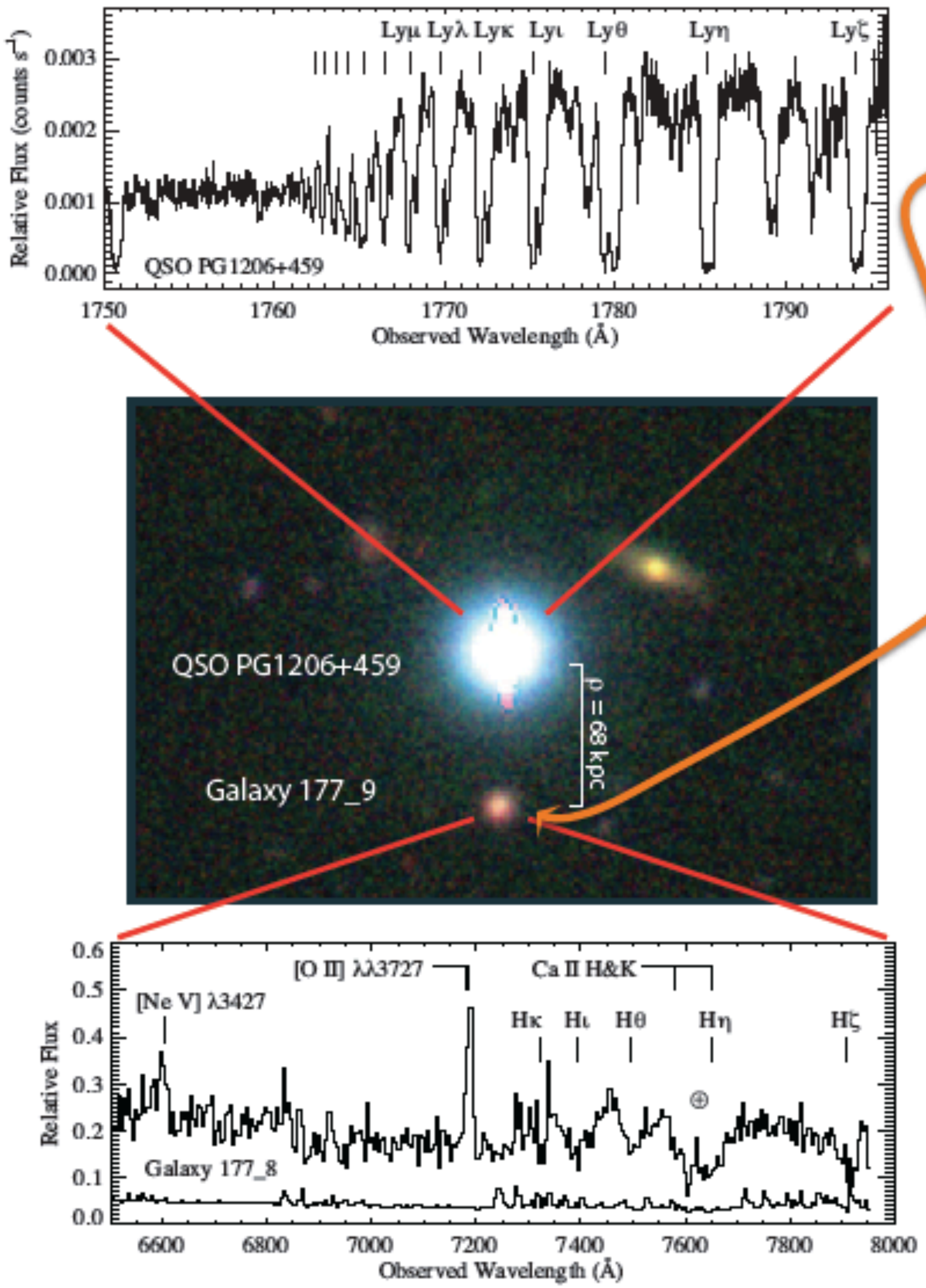
PG1206+459 z = 0.93

The galaxy – a "post starburst" (?) with an AGN



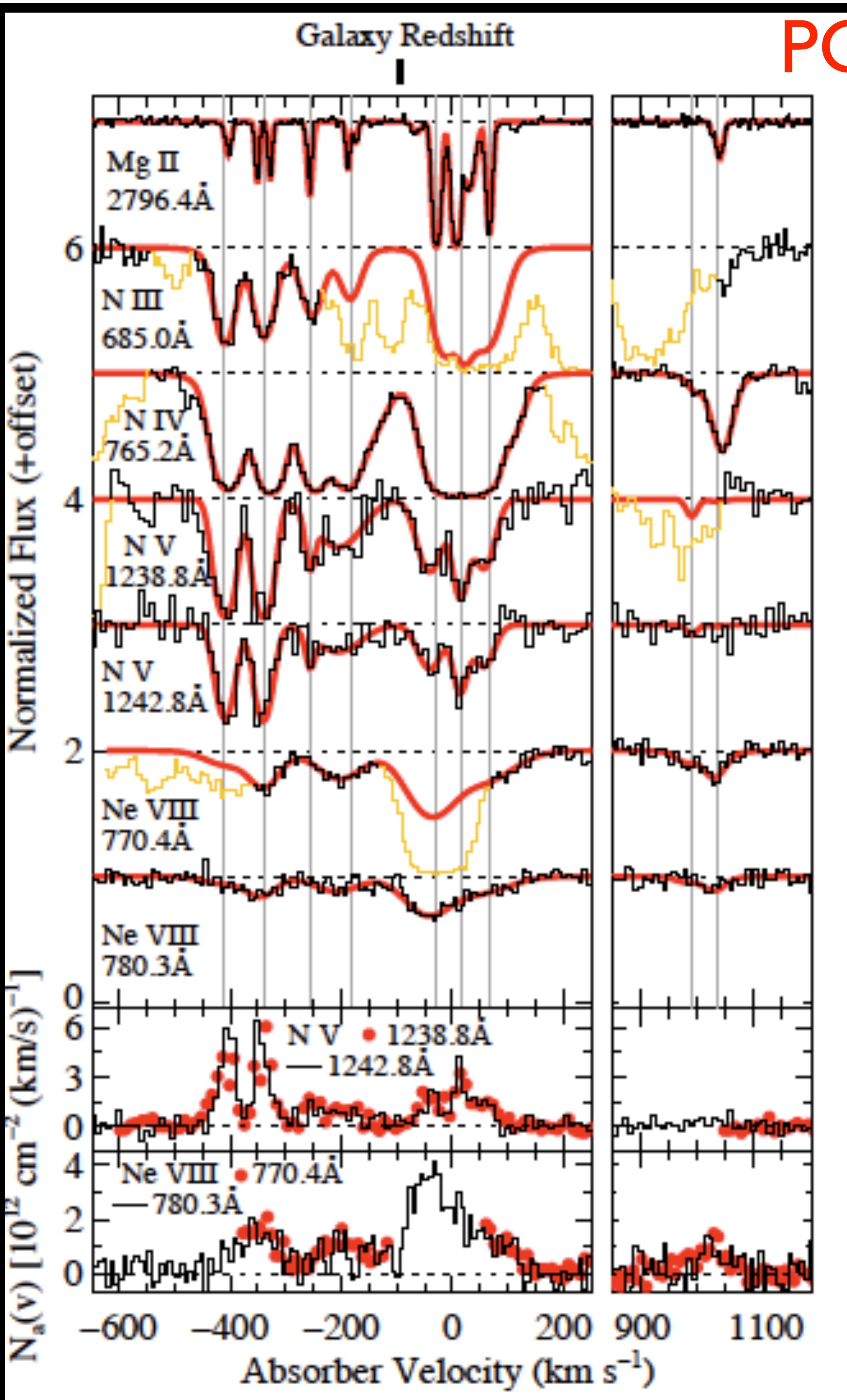
- Presence of [Ne V] emission is a strong indication of an active nucleus
- Strong Balmer absorption lines suggest "post-starburst" classification
- [O II] possibly (probably) due to AGN rather than star formation
- Galaxy is reminiscent of Tremonti et al. (2007) targets

Tripp et al. (2011, submitted)

PG1206+459 z = 0.93

e galaxy – a “post

rburst” (?) with an AGN



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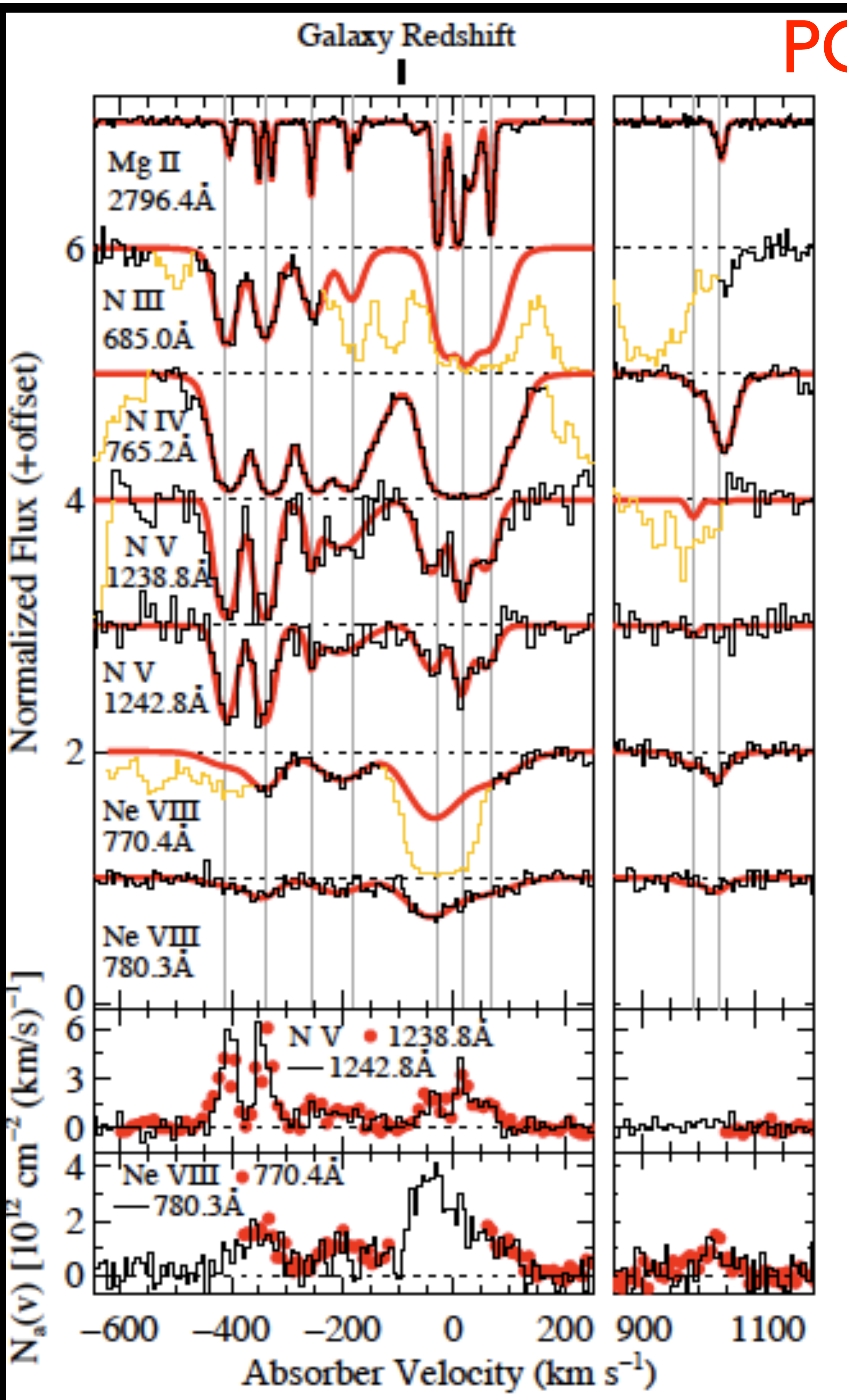


A wind caught in the act

Ten multiphase components (Δv~1600km/s), with ions ranging from Mg II (10^4 K) to Ne VIII (10^6 K).

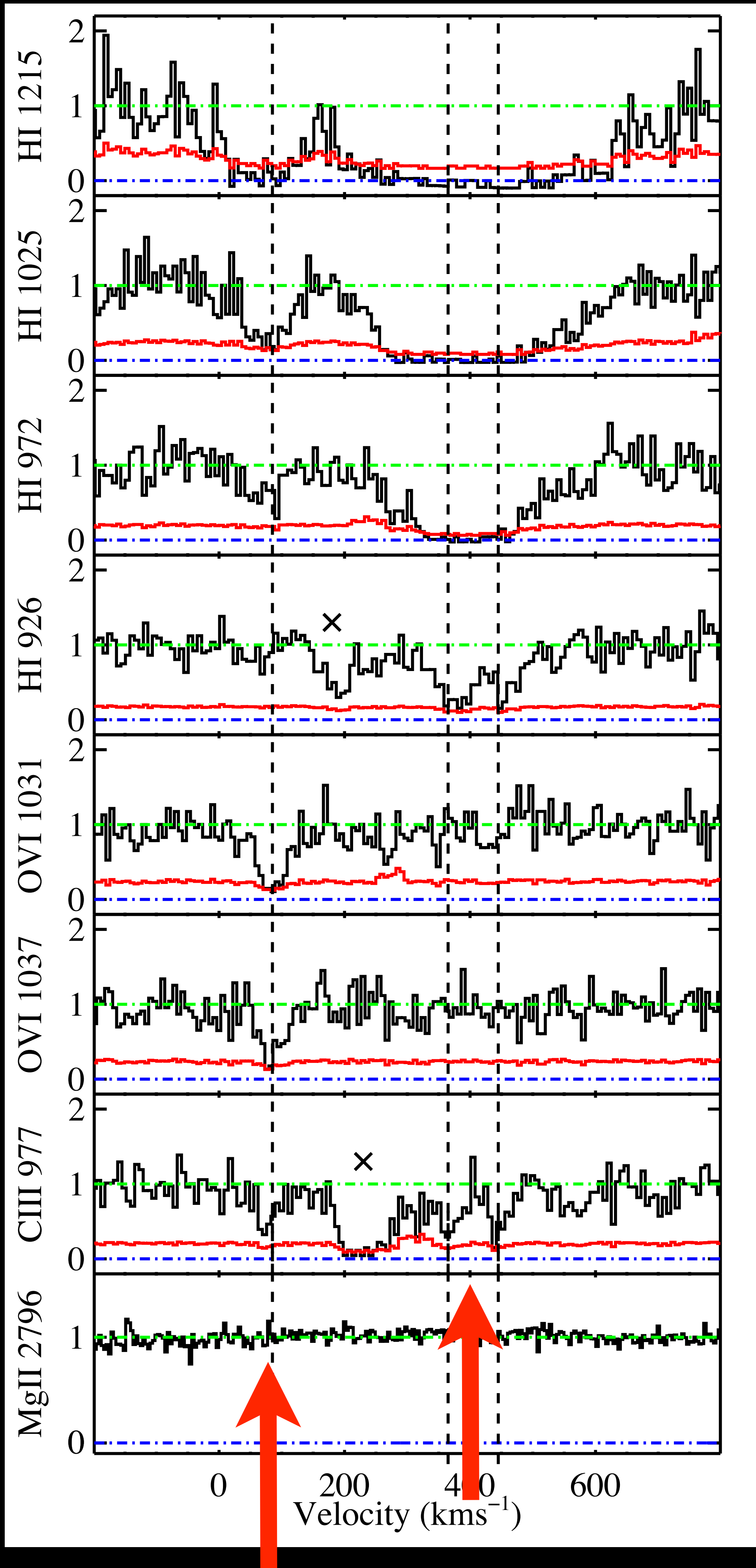
Cold gas can be photoionized by the extragalactic (HM) background.

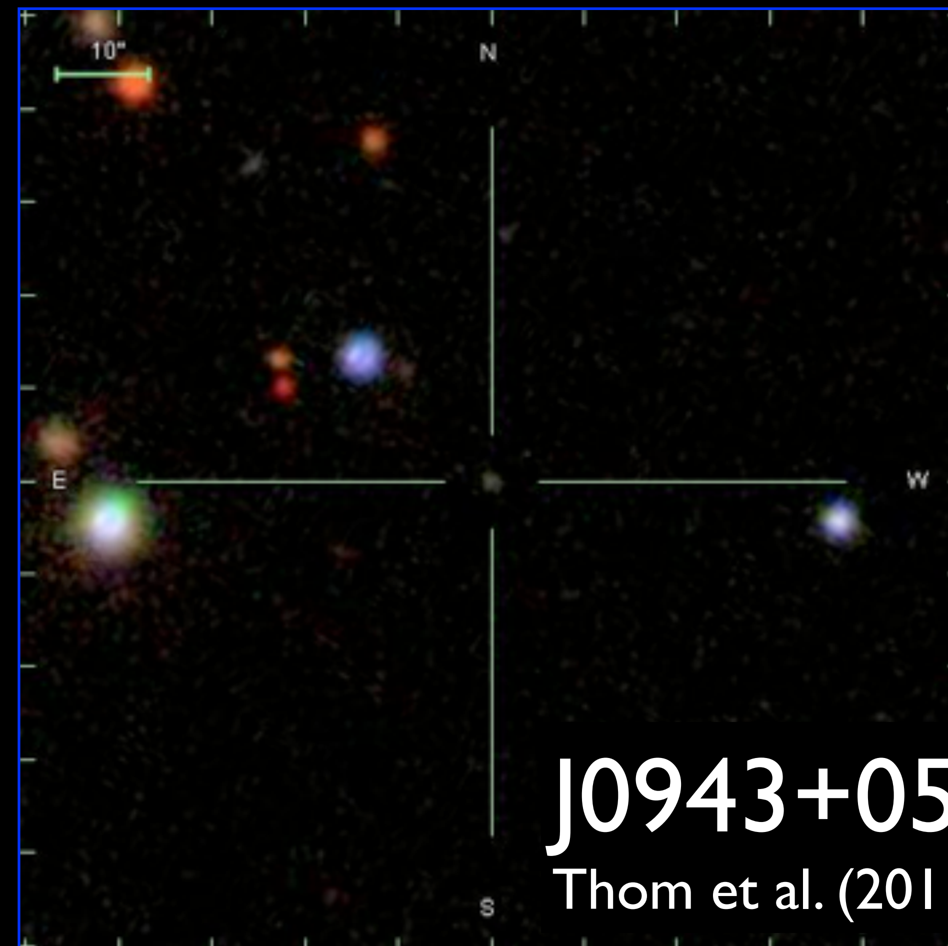
The hot gas is probably collisionally ionized, but closely tracks components in the colder material.

Total wind mass 10^8 - 10^9 $M_\odot$ inferred from ionization modeling and a shell geometry.

Tripp et al. (2011, submitted)

Evidence of Cold Accretion?





J0943+0513

Thom et al. (2011, arXiv:1105.4601)

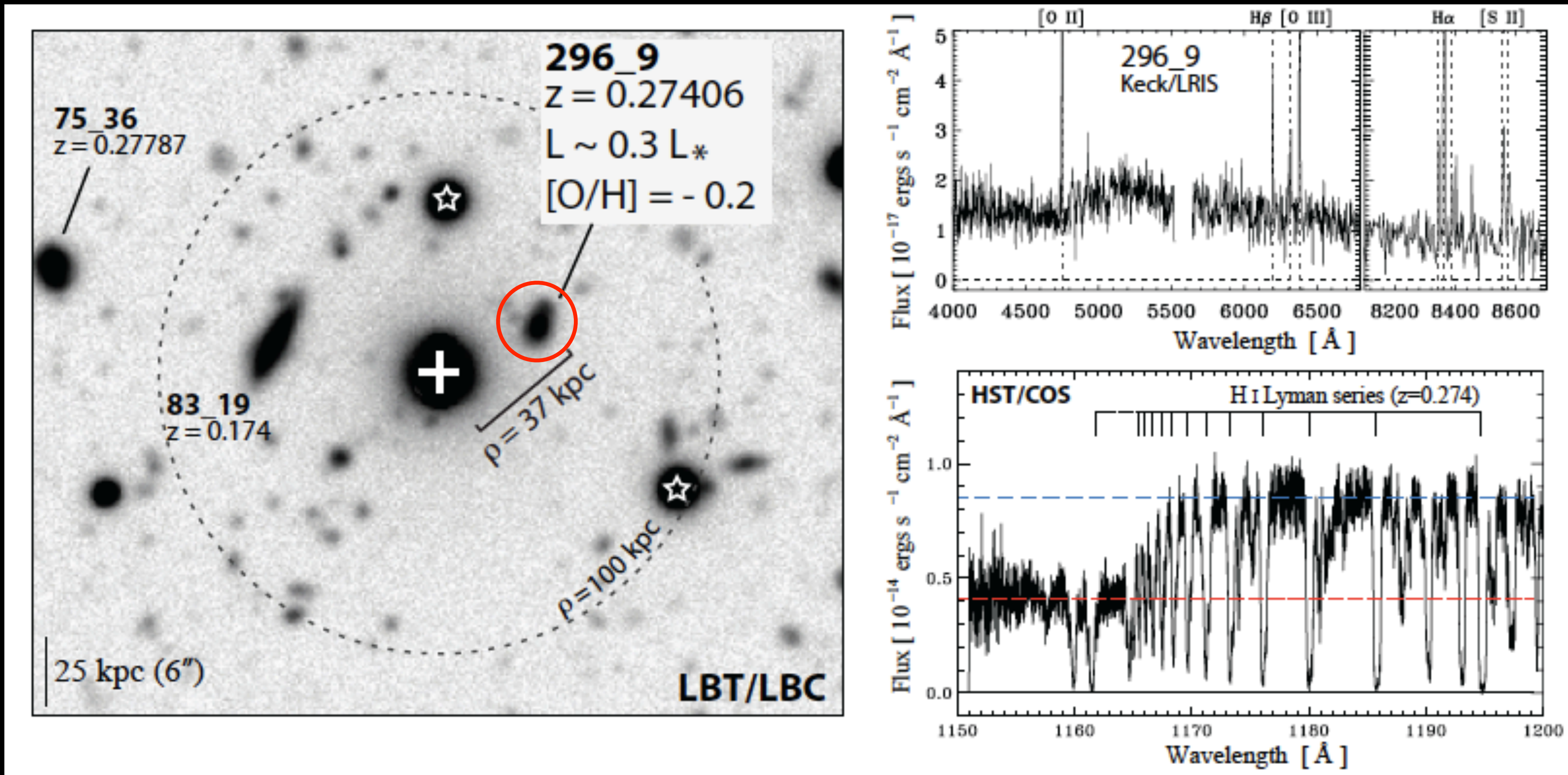
Two clouds:

- one at "low velocity", consistent with z = 0.1Z_{sun} photoionized filament gas. (+85 kms^{-1})

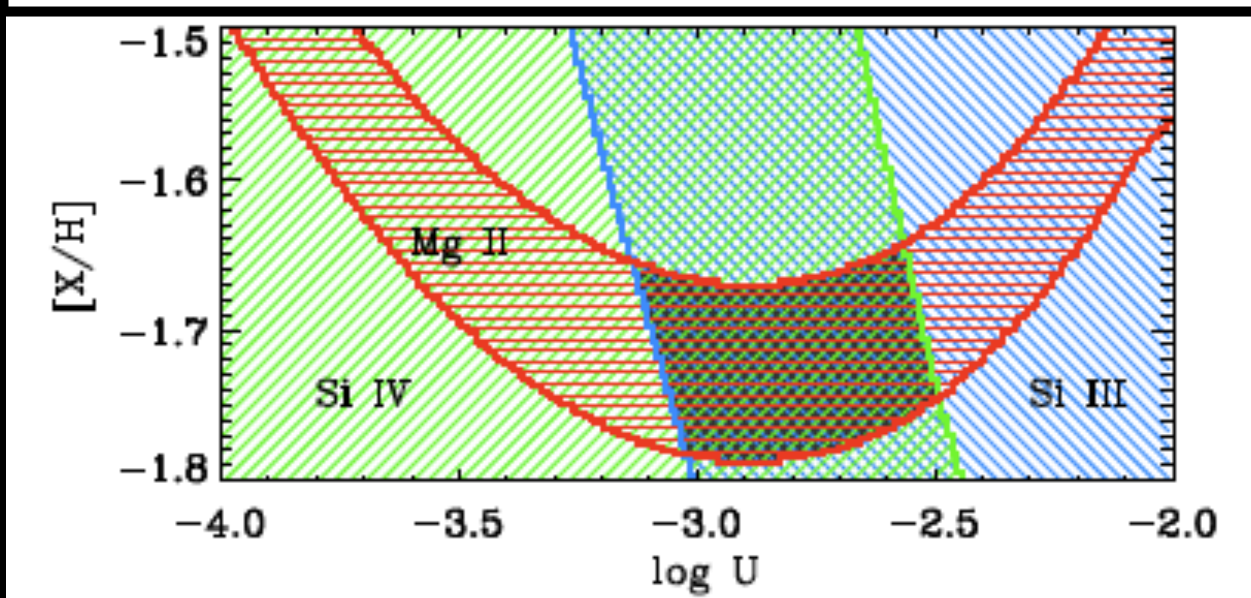
- another at high column density, but [Z/H] < -1.5, and likely falling into the galaxy.

The "Metal-poor cloud" could be low-metallicity, cold-stream gas (e.g. Stewart+11, Fumagalli+11)

More Cold Accretion?



Ribaudo et al. 2011
arXiv:1105.5381

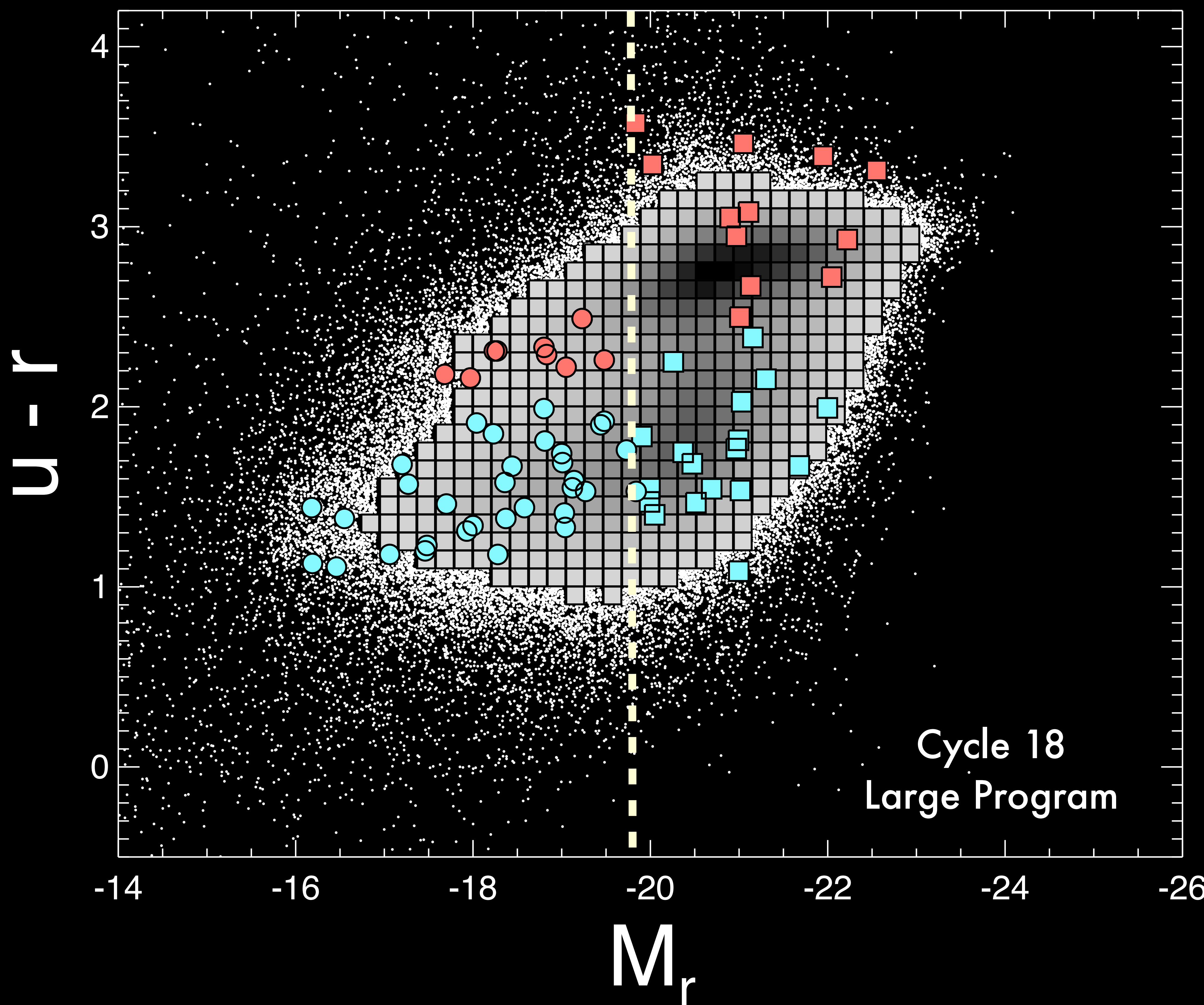


- a partial Lyman limit at z = 0.274

- [Z/H] < -1.7, and likely falling into the 0.3L* galaxy at 37 kpc.

- temperature constrained by linewidths to < 38000 K.

Unfinished business: COS-Dwarfs



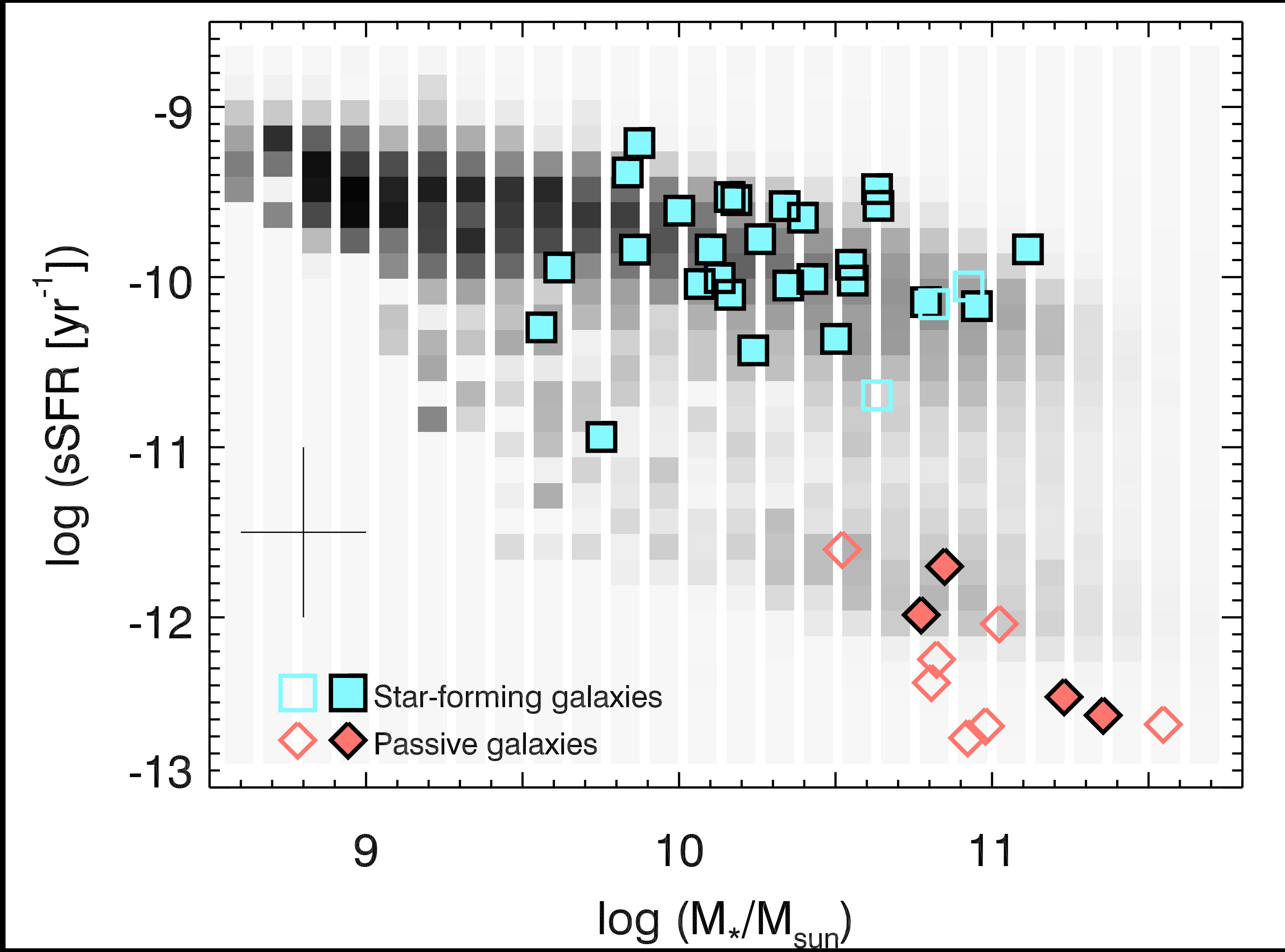
Using COS, we have mapped hot ionized gas in L~L* galaxy halos:

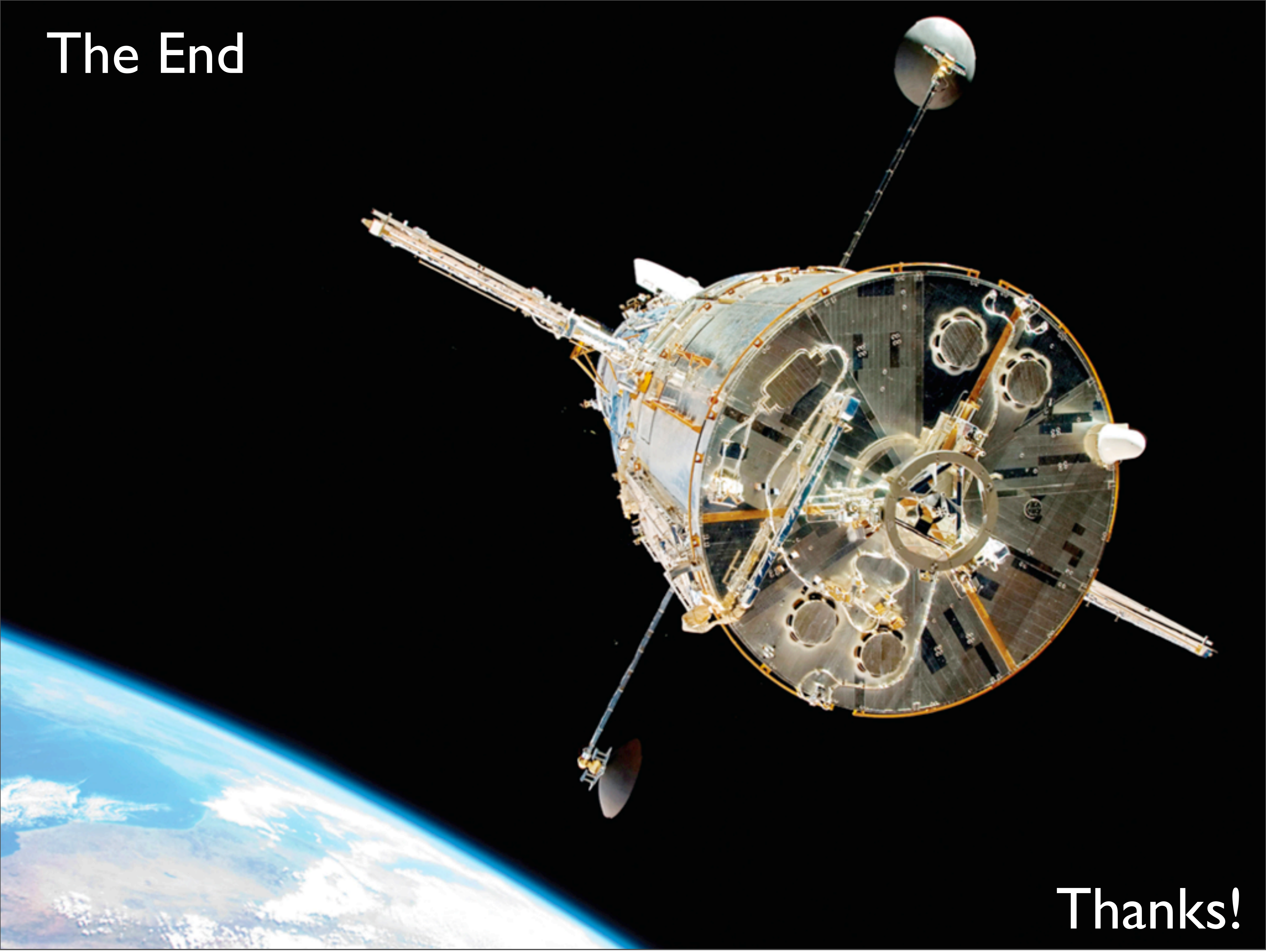
1. Hot ionized gas is as common in star-forming galaxy halos as in the Milky Way.
   External galaxy halos are also filled with "highly ionized HVCs".

2. O VI covers 90% of blue sequence galaxies; only 30% of red sequence galaxies.
   The dichotomy of galaxy colors appears directly in their gaseous halos.

3. The ionized halos of star-forming galaxies contain > 10^7 $M_\odot$ of oxygen and >10^9 $M_\odot$ of gas.
   These oxygen masses are comparable to a whole galaxy ISM and require 10^9 $M_\odot$ of star formation over ~1 Gyr. Outflows!?

4. Infall models fail on covering fraction, but if outflows exist the material does not exceed the escape velocity.
   The halos of star-forming galaxies are filled with accreting ionized gas, "galactic fountain" material from recent star formation, or some mixture.




The End
Thanks!