Probing the Co-Evolution of Galaxies and the CGM with Large Surveys

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with
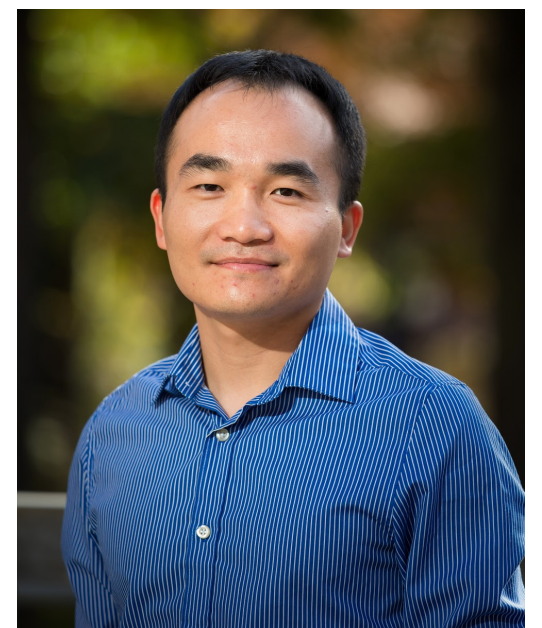
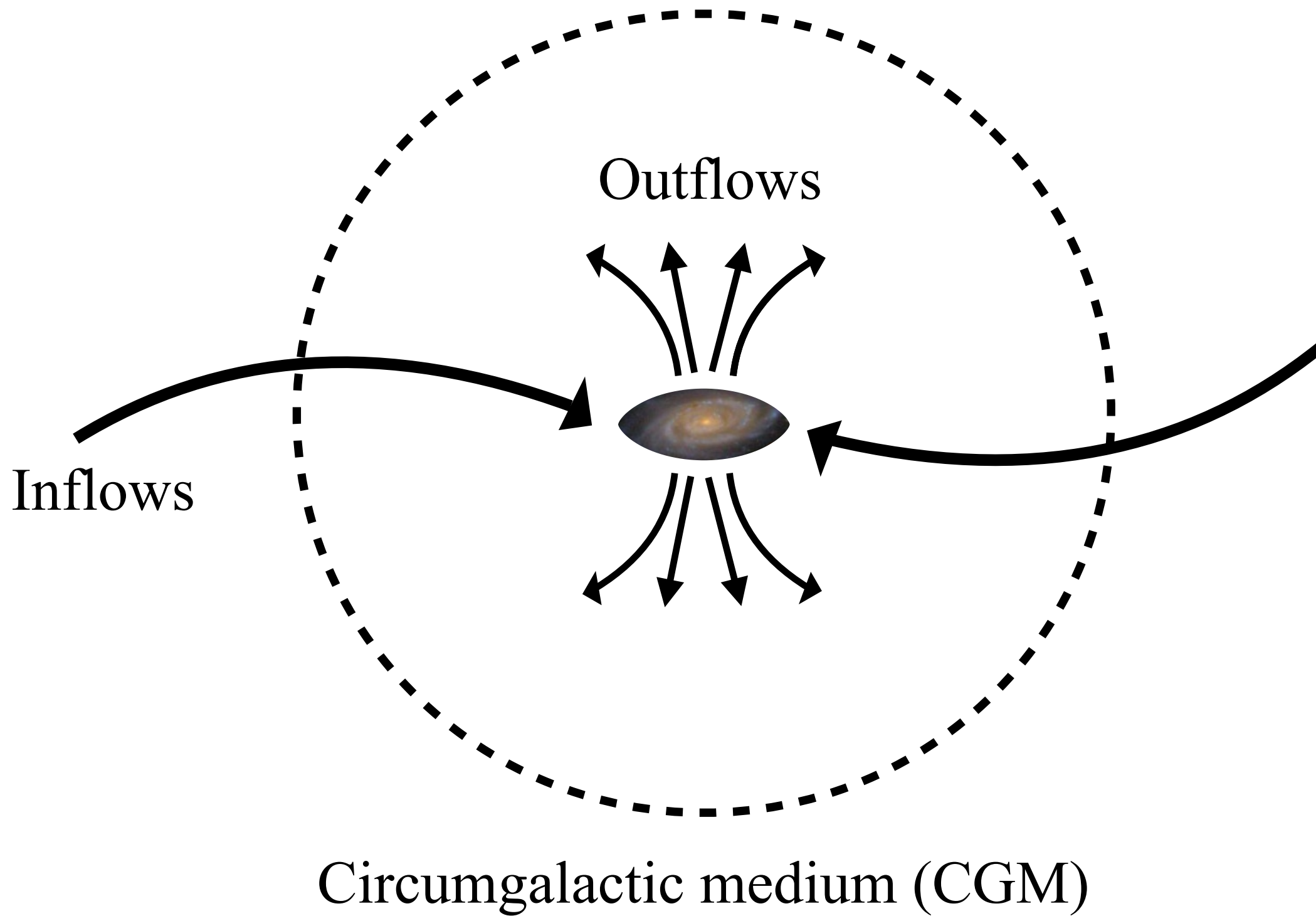Masataka Fukugita   Brice Ménard   Houjun Mo   Guangtun Zhu
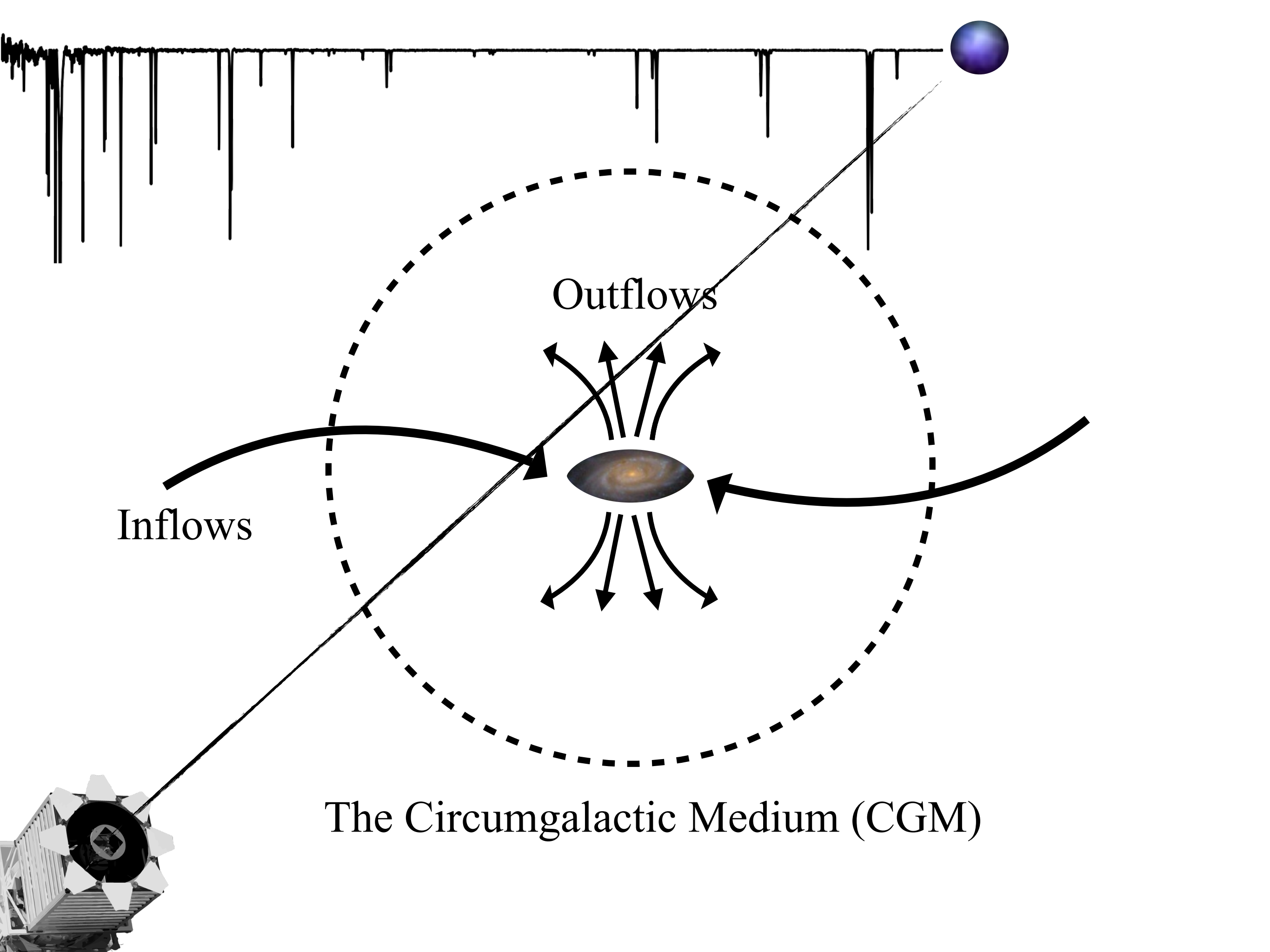
The dichotomy of galaxy types

Star-forming galaxies

Passive galaxies

Outflows

Inflows

Circumgalactic medium (CGM)

Outflows
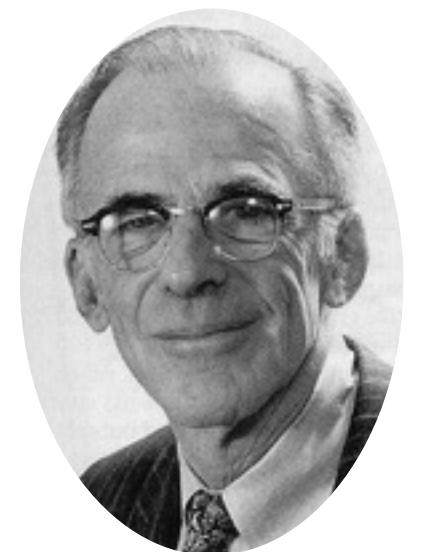
Inflows

The Circumgalactic Medium (CGM)

1969

Bahcall & Spitzer

ABSTRACT

We propose that most of the absorption lines observed in quasi-stellar sources with multiple absorption redshifts are caused by gas in extended halos of normal galaxies.

John Bahcall   Lyman Spitzer
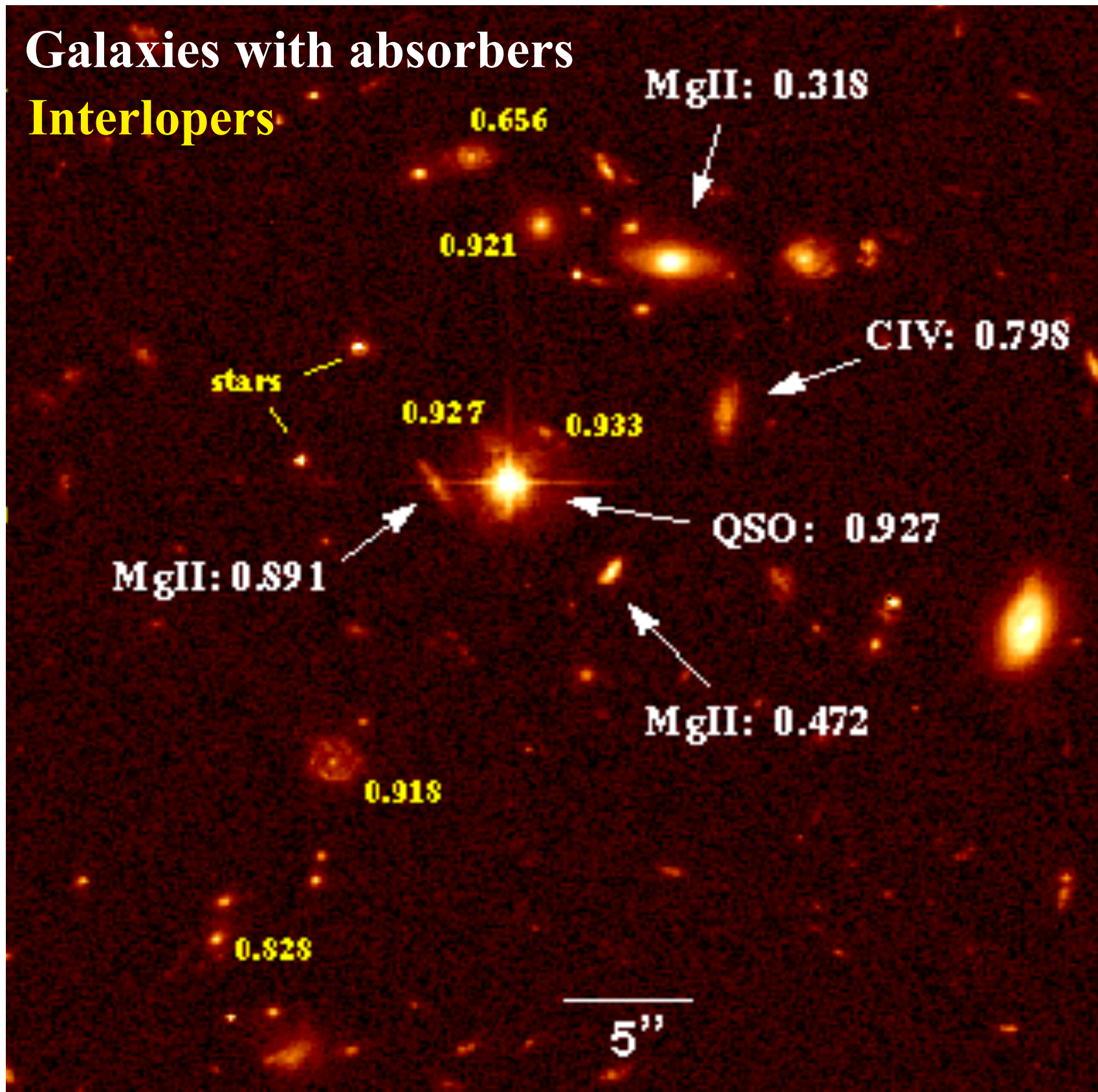
1986

1

Jacqueline Bergeron

galaxy-absorber pair

We found the first galaxy, close on the sky to a QSO with an absorption system, which redshift (z = 0.430) equals that of the absorber. This object is gas rich and lies 8.6arcsec or 64kpc north-east of the QSO. The uncertainty in our z estimate correspo[nds to] a velocity of 210 km s^{-1} at the absorber, valu[es in] the range observed for interstellar matter in [...] of a spiral galaxy. The V and red magnitud[es ...]
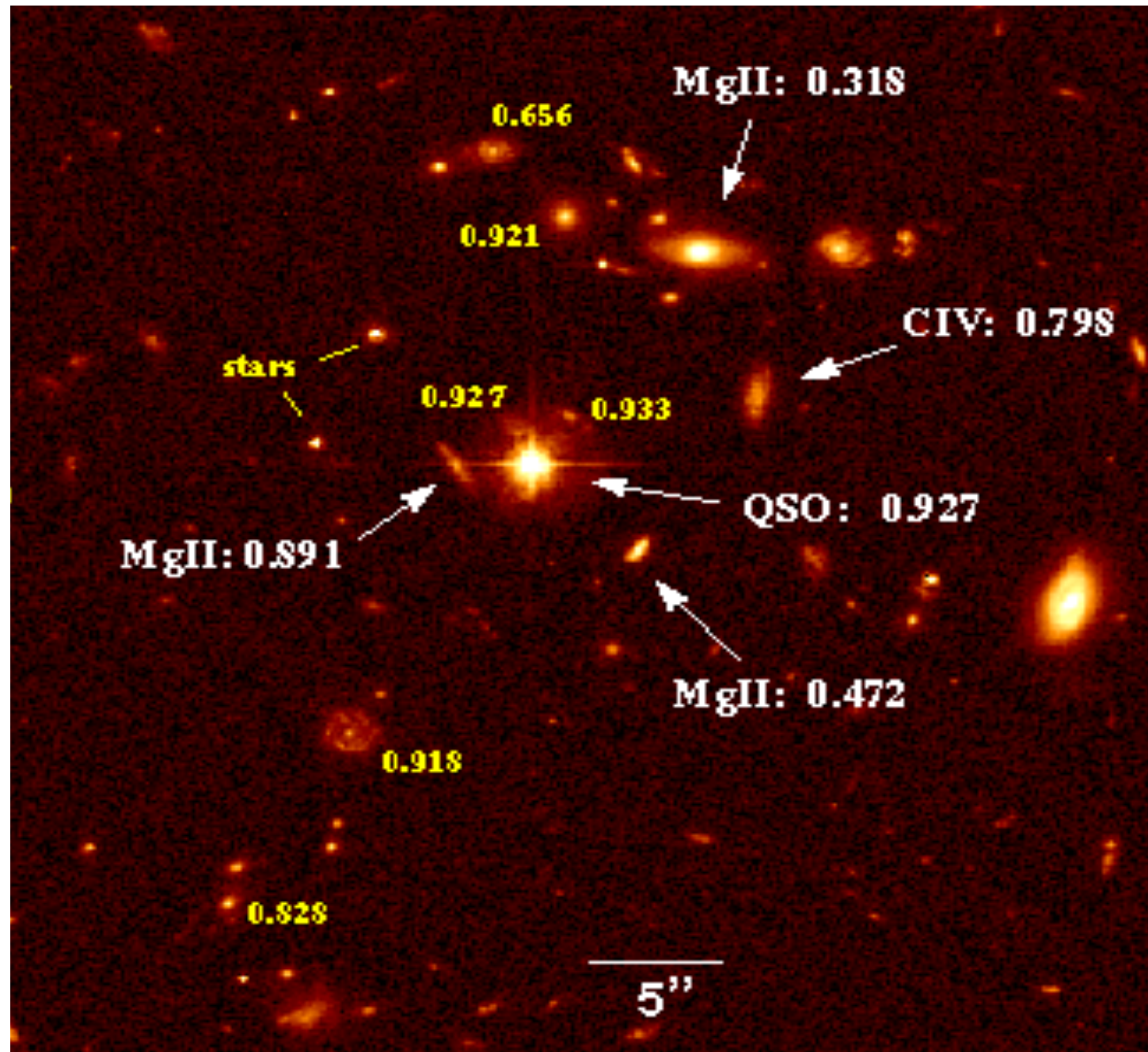

Jacqueline Bergeron

Searching for galaxy - absorber pairs

Steidel et al. (1997)

Searching for galaxy - absorber pairs

MgII: 0.318
0.656
0.921
CIV: 0.798
stars
0.927
0.933
MgII: 0.891
QSO: 0.927
MgII: 0.472
0.918
0.828
5"

1986   1   Bergeron

1995-2010   50   Steidel et al.
Churchill et al.
Chen et al.

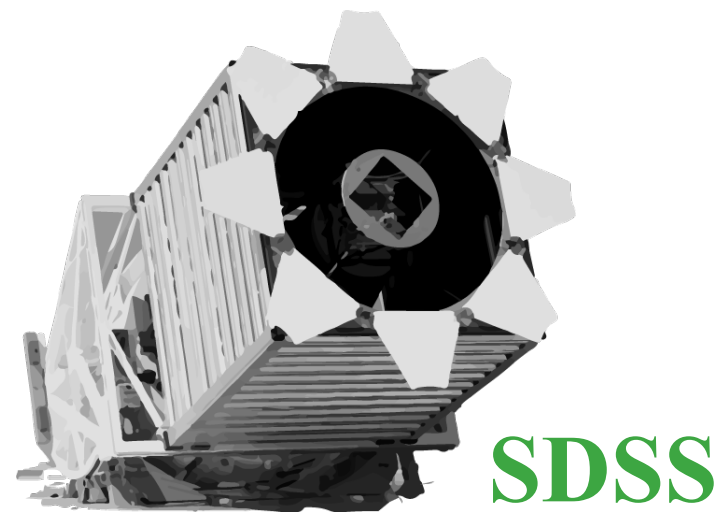2013   200   Nielsen et al.
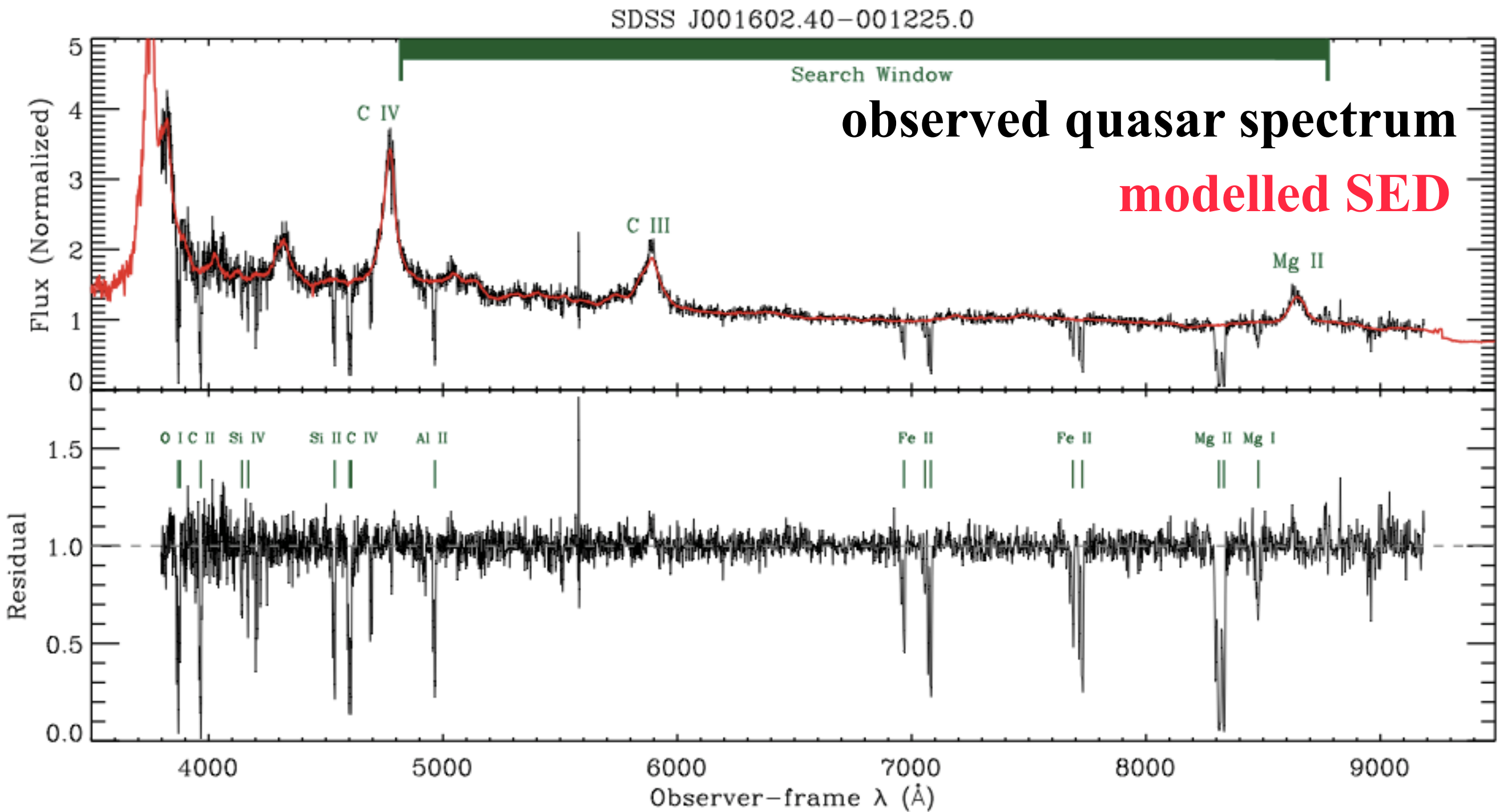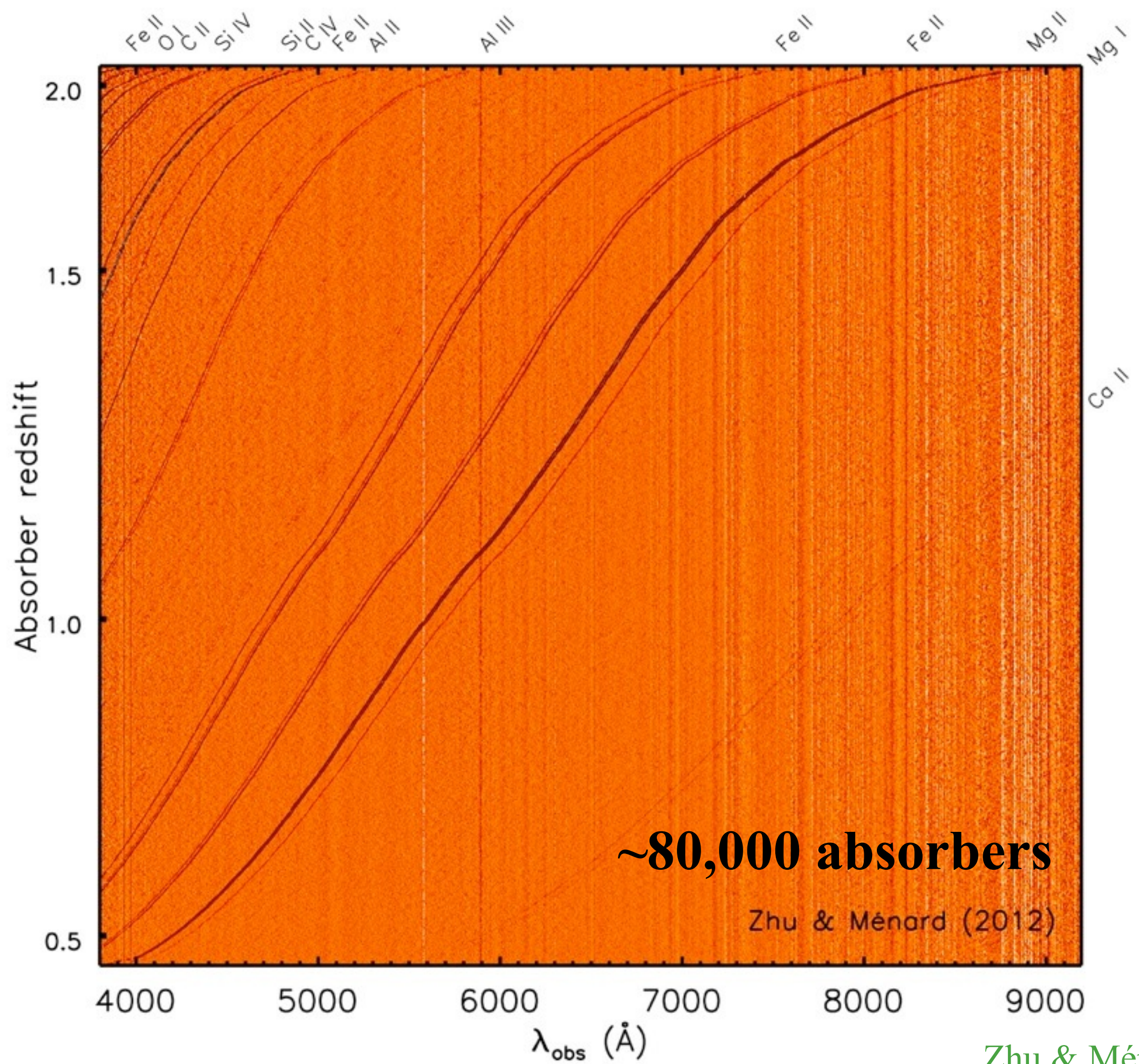
Steidel et al. (1997)

Is the dichotomy of galaxy types reflected in the CGM?

Is the evolution of galaxies reflected in the CGM?
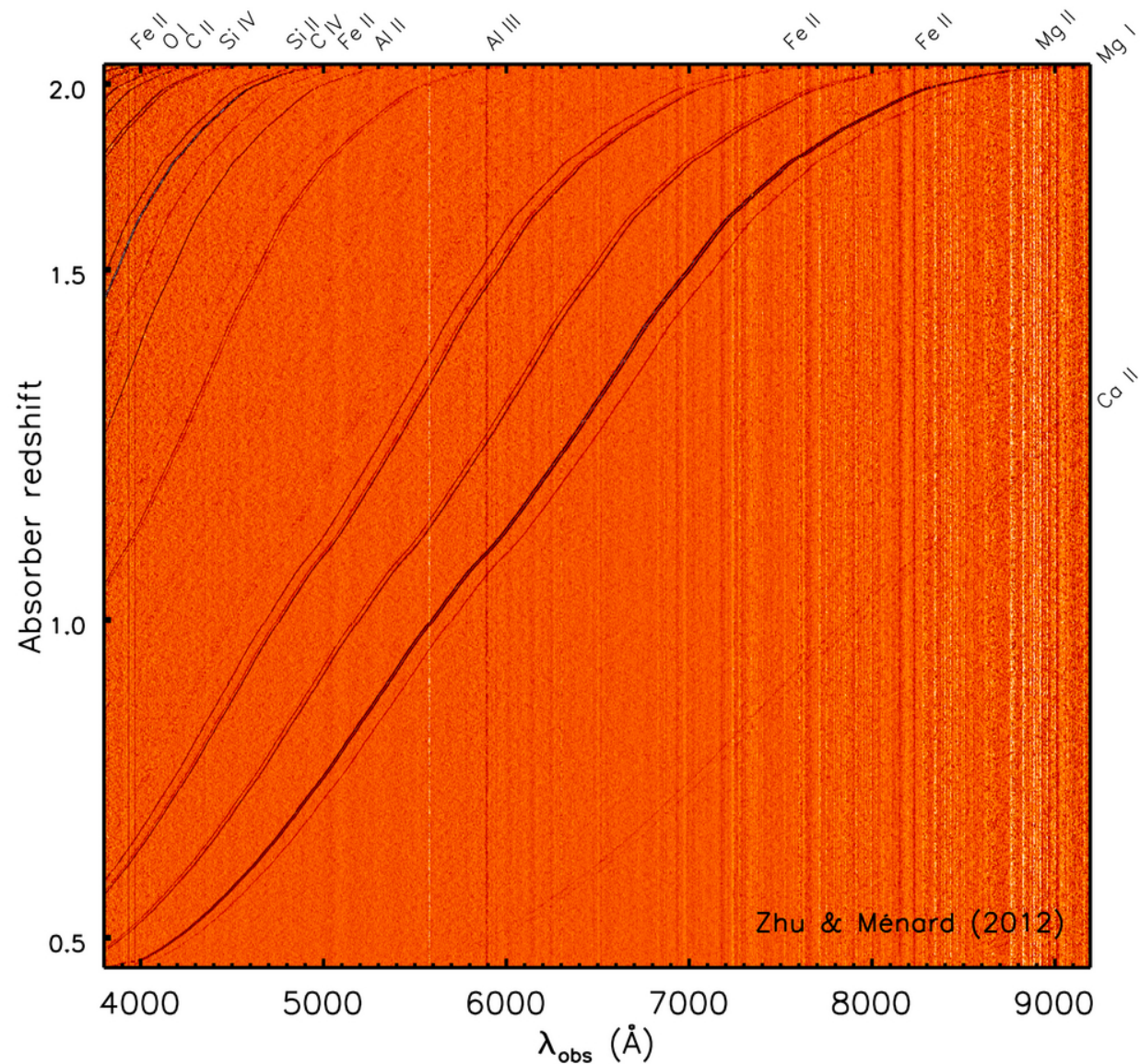
SDSS

Detecting MgII absorbers in SDSS quasar spectra
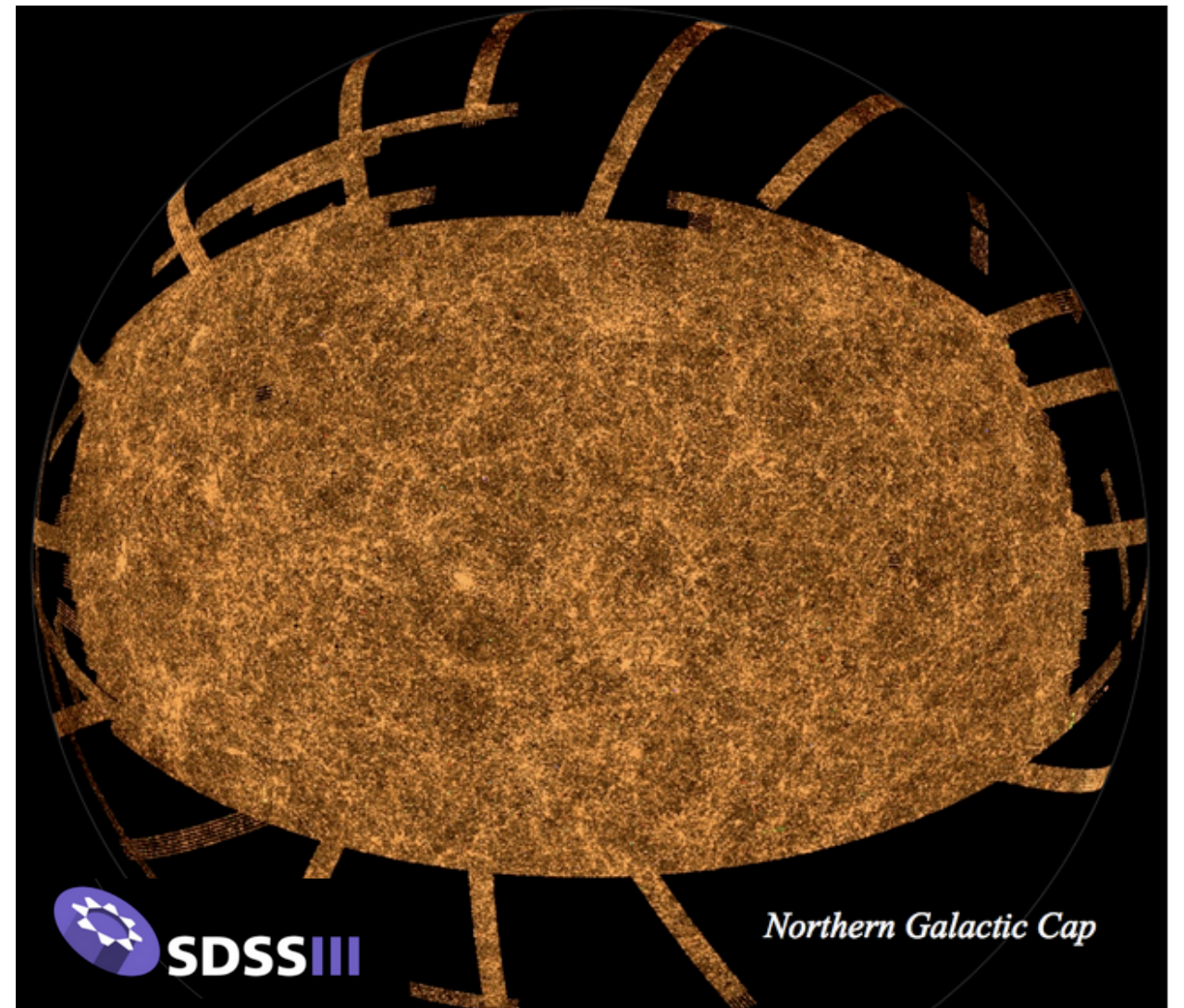
SDSS J001602.40−001225.0

Search Window

observed quasar spectrum

modelled SED

C IV

C III

Mg II

Flux (Normalized)

Residual

O I C II   Si IV   Si II C IV   Al II   Fe II   Fe II   Mg II Mg I

Observer−frame λ (Å)

~80,000 absorbers

Zhu & Ménard (2012)

Zhu & Ménard 2013

Probing the associated galaxies with a statistical approach

Metal absorbers

Zhu & Ménard (2012)
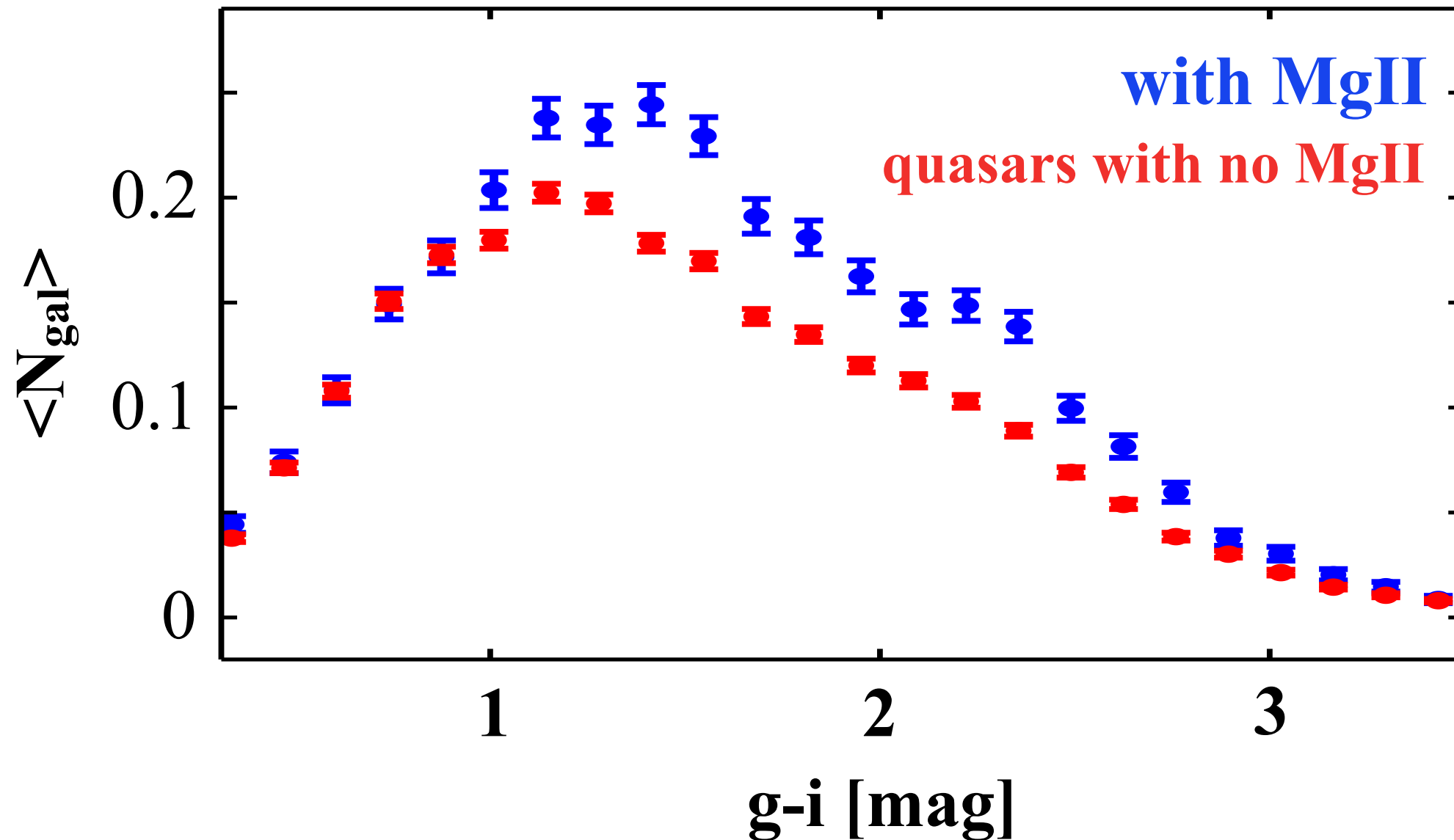
millions of photometric galaxies

SDSS photometric galaxies

$$\langle \delta_{\mathrm{MgII}} \cdot \delta \mathrm{N}_{\mathrm{gal}} \rangle$$

Probing the associated galaxies with a statistical approach

SDSS galaxies (<200 kpc) around 3,000 absorbers at z~0.5

with MgII

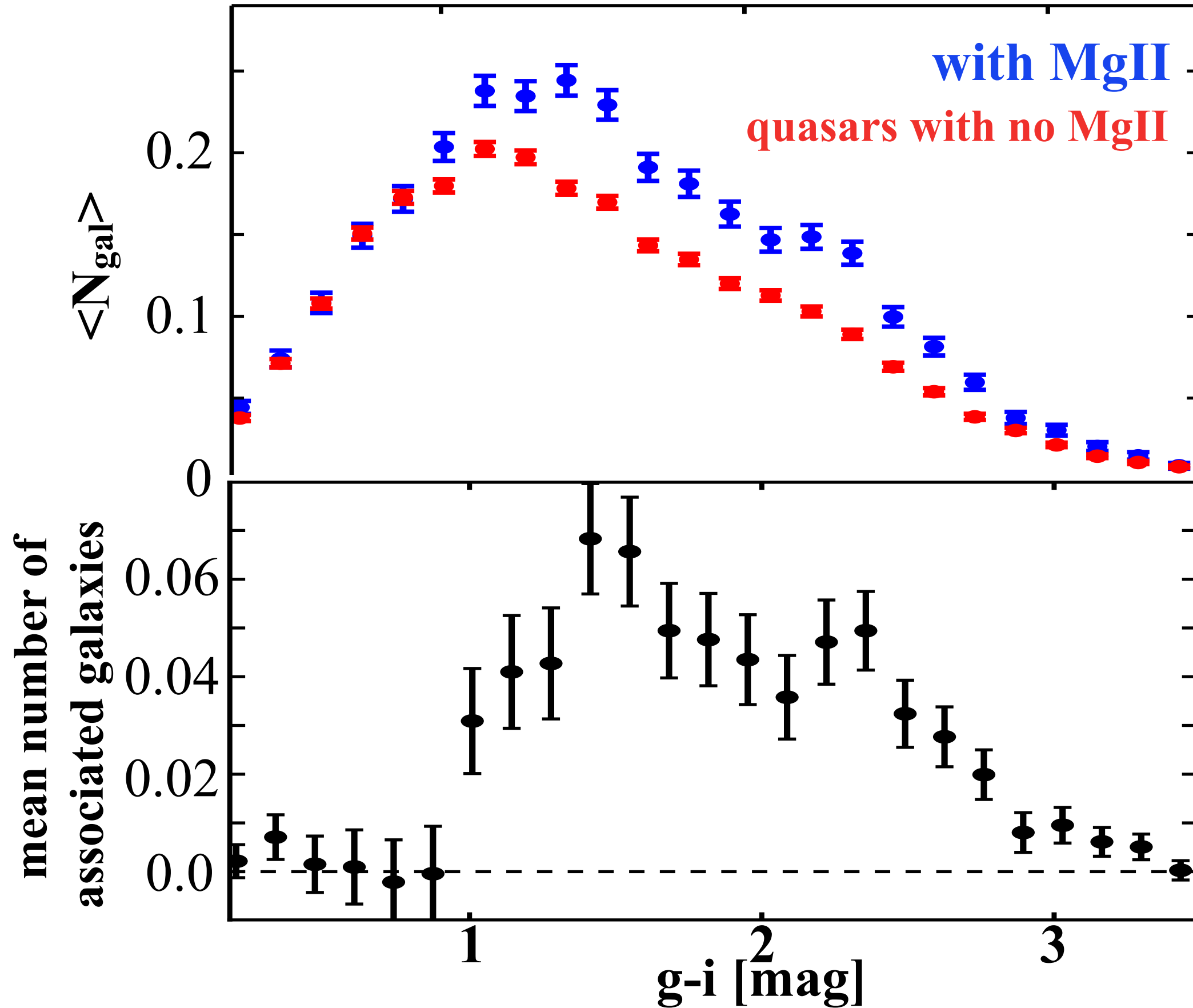quasars with no MgII

randomly-distributed
background galaxies
+
galaxies associated with MgII

randomly-distributed
background galaxies

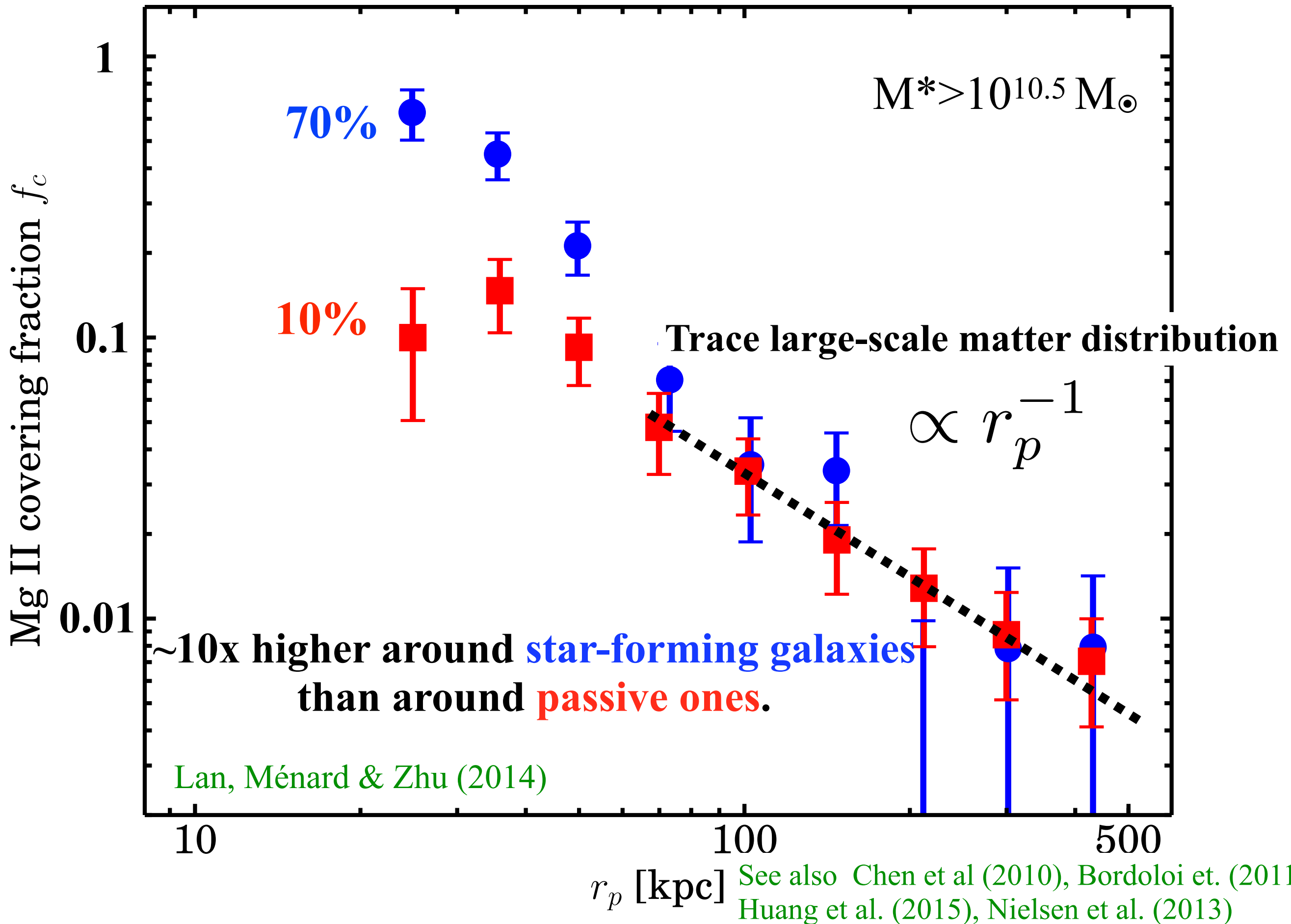# Probing the associated galaxies with a statistical approach
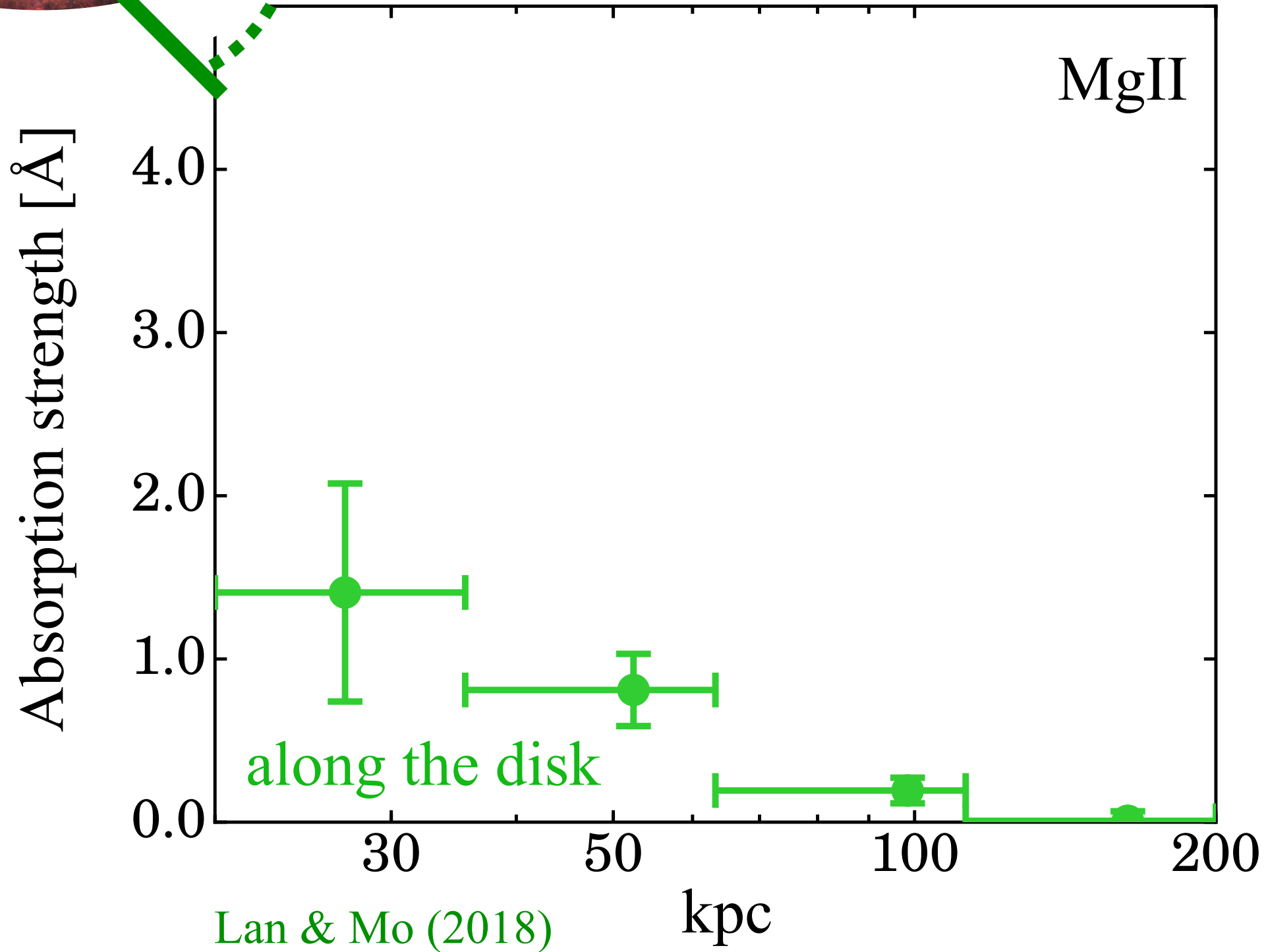
SDSS galaxies (<200 kpc) around 3,000 absorbers at z~0.5

with MgII

quasars with no MgII

$\langle N_{gal} \rangle$

mean number of associated galaxies

g-i [mag]

Mg II covering fraction   **W > 1 Å**

$M* > 10^{10.5}\,M_\odot$

70%

10%

Trace large-scale matter distribution

$\propto r_p^{-1}$

Mg II covering fraction f_c

~10x higher around **star-forming galaxies**
than around **passive ones.**

Lan, Ménard & Zhu (2014)

r_p [kpc]

10   100   500

See also Chen et al (2010), Bordoloi et. (2011)
Huang et al. (2015), Nielsen et al. (2013)

Azimuthal dependence

MgII

along the disk
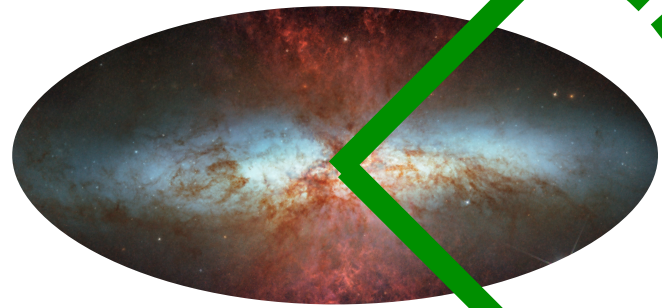
Lan & Mo (2018)

See also Bordoloi et al. 2011, Kacprak et al. 2011,
Bouche et al. 2012, Lan et al. 2014

Azimuthal dependence
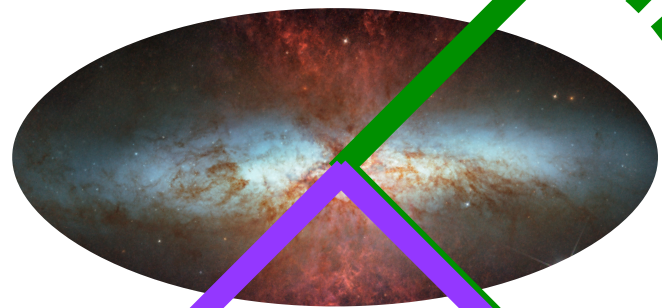
MgII

along the pole

along the disk
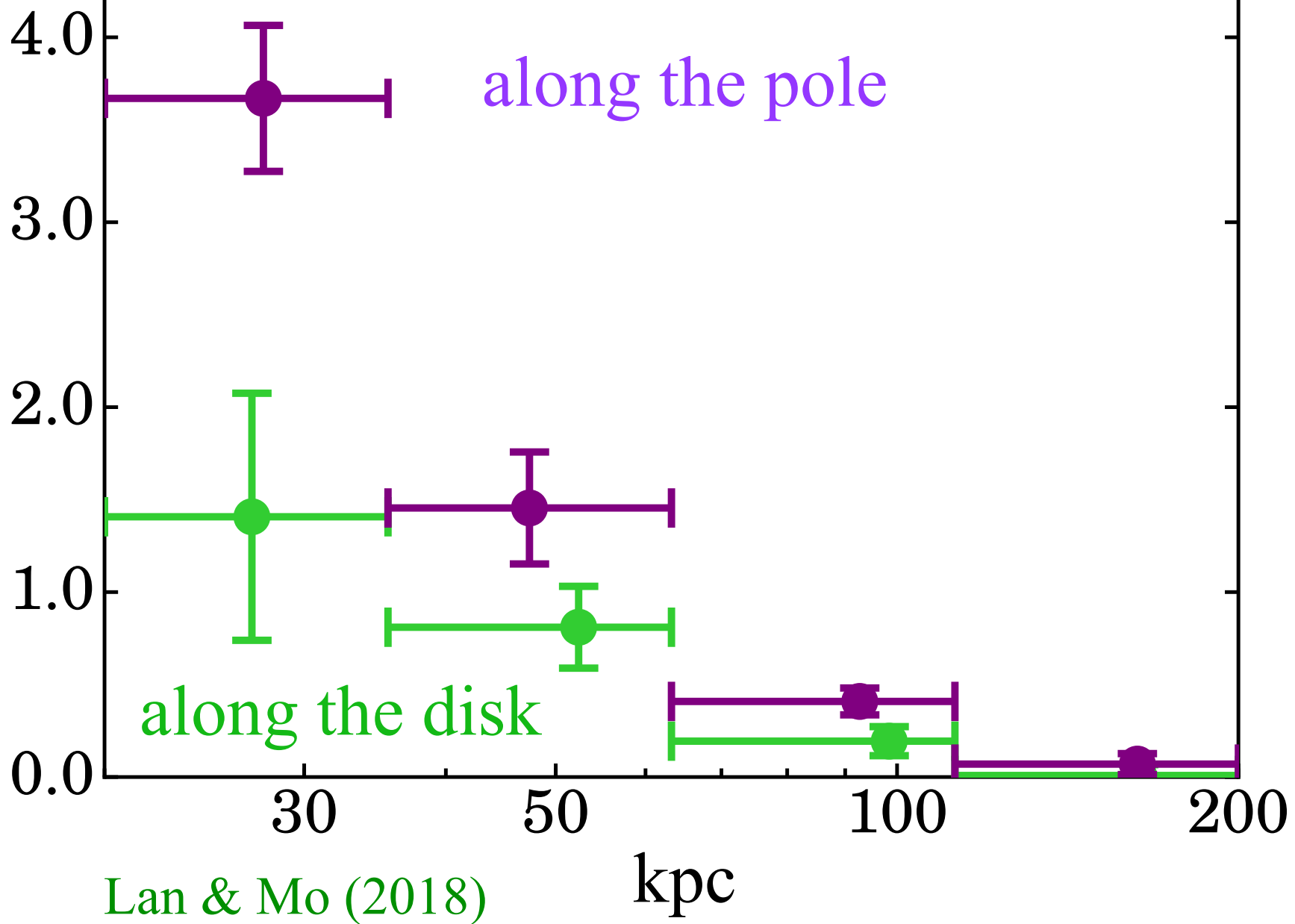
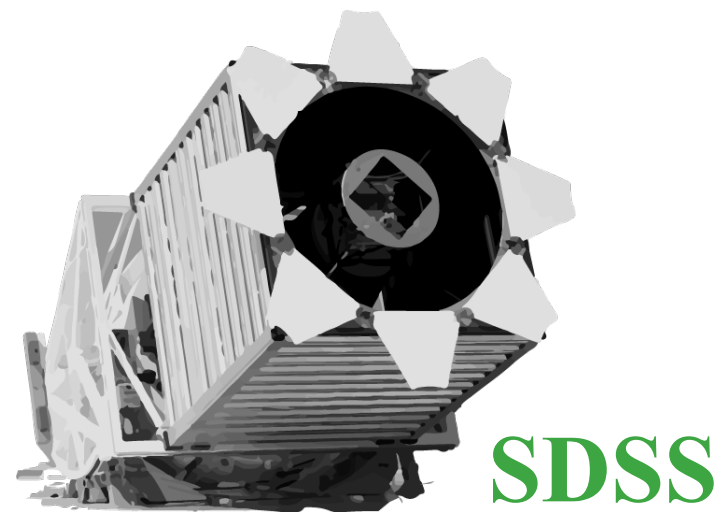Absorption strength [Å]

kpc

30   50   100   200

Lan & Mo (2018)

See also Bordoloi et al. 2011, Kacprak et al. 2011,
Bouche et al. 2012, Lan et al. 2014

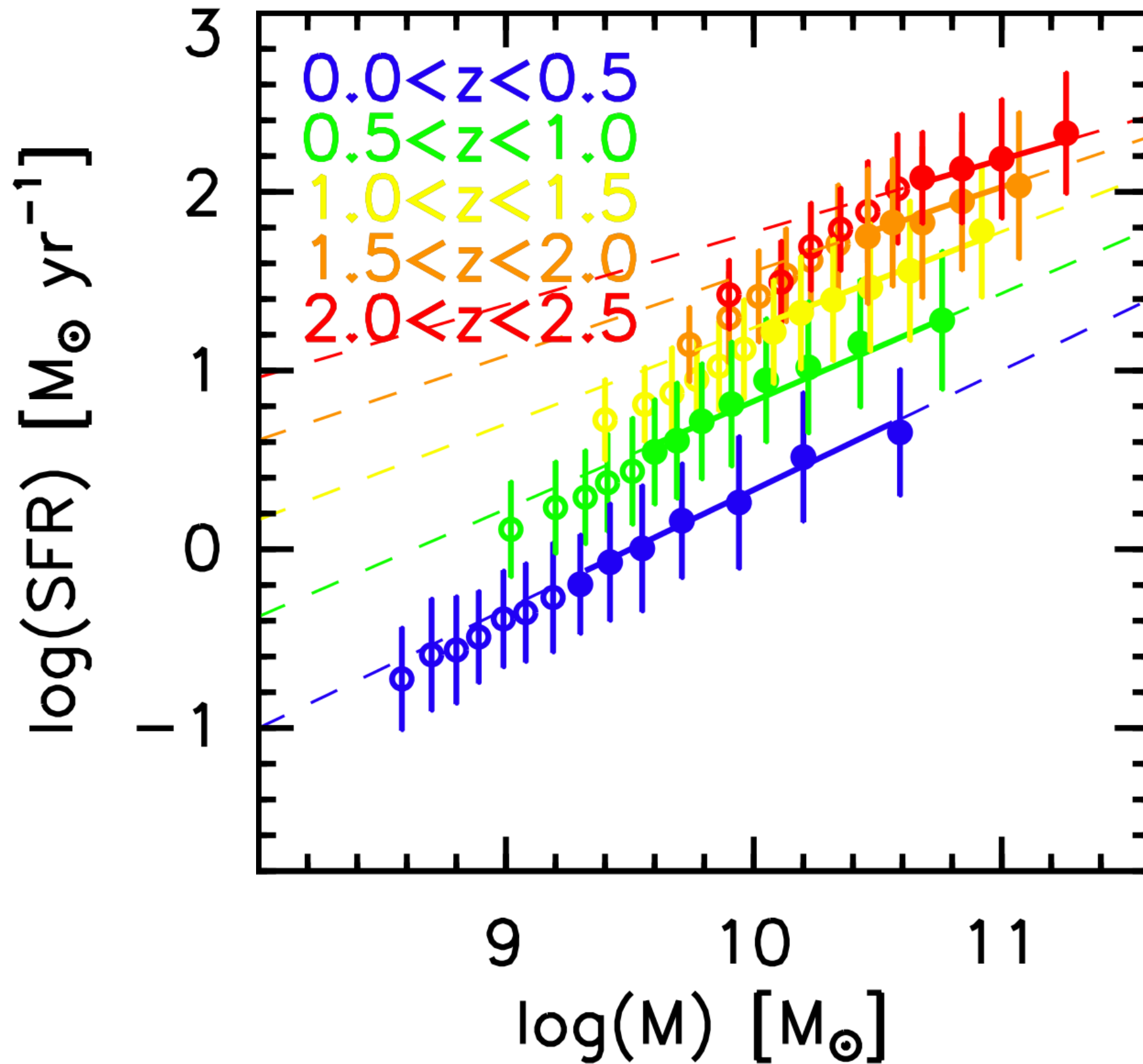**Is the dichotomy of galaxy types
reflected in the CGM?**

**Yes, cool gas is more abundant around
star-forming galaxies than around passive galaxies.**

Is the evolution of galaxies reflected in the CGM?

SDSS

Evolution of the SFR of galaxies

Whitaker et al. (2012)

Probing the associated galaxies with a statistical approach

Metal absorbers

Zhu & Ménard (2012)

millions of photometric galaxies

SDSS III — Northern Galactic Cap

SDSS photometric galaxies

$$\langle \delta_{\mathrm{MgII}} \cdot \delta \mathrm{N}_{\mathrm{gal}} \rangle$$

Probing the associated galaxies with a statistical approach

Metal absorbers

Zhu & Ménard (2012)

millions of photometric galaxies

Dey et al. (2019)

**DESI Legacy Imaging Surveys
2 magnitudes deeper than SDSS**

$$\langle \delta_{\mathrm{MgII}} \cdot \delta \mathrm{N}_{\mathrm{gal}} \rangle$$

Number of associated galaxies as a function of redshift

The DESI Legacy
Imaging Surveys z<22.5

SDSS z<20.7

~15,000 pairs statistically

Lan ApJ submitted
arxiv:1911.01271
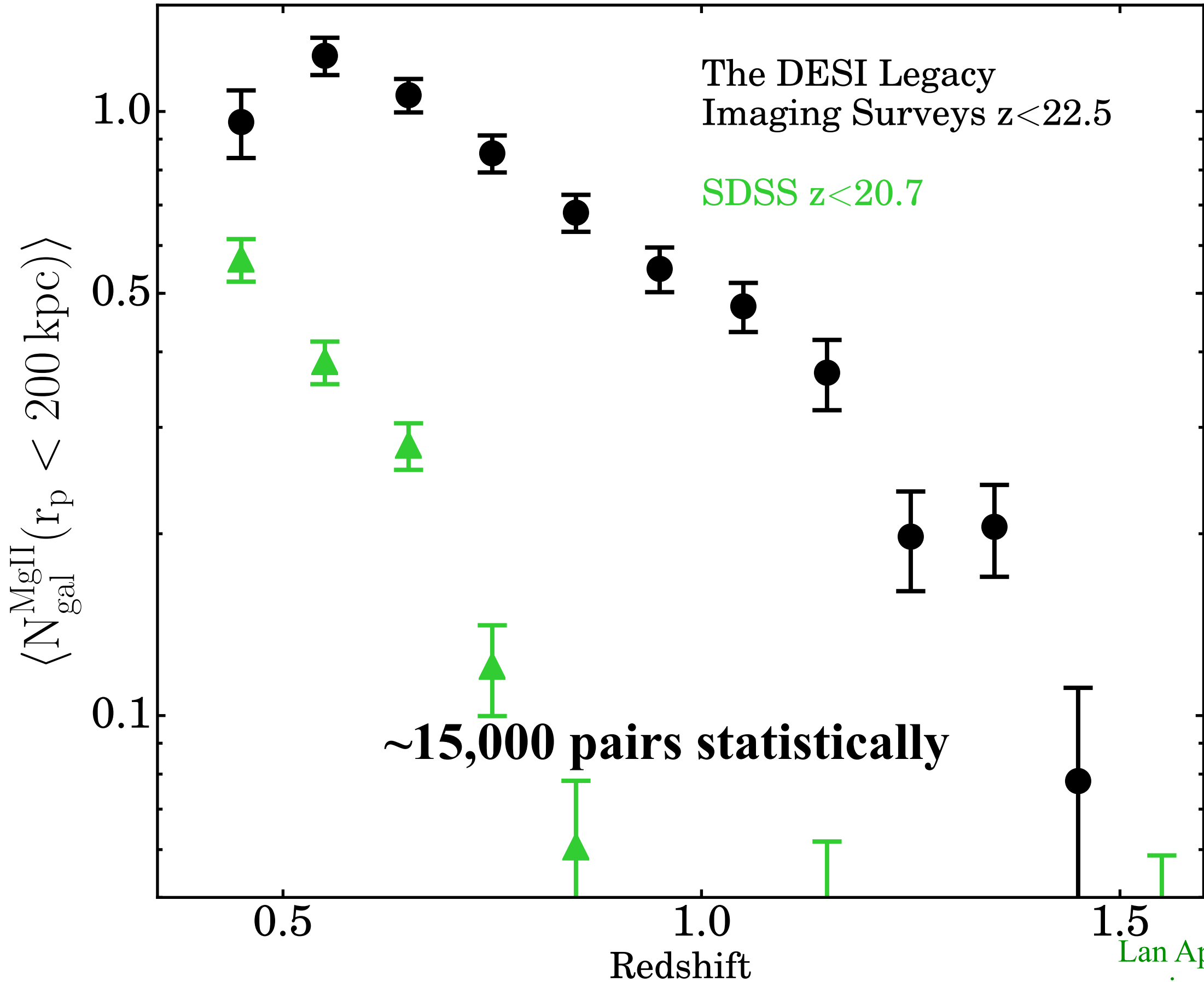
Stellar mass dependence   **W > 1 Å**

$10.5 < \log M_* / M_\odot < 11.0$

$10.0 < \log M_* / M_\odot < 10.5$

$9.5 < \log M_* / M_\odot < 10.0$

$9.0 < \log M_* / M_\odot < 9.5$

Covering fraction $f_c \left(W_{\lambda 2796} > 1\,\text{Å} \right)$

z~0.6

r_p [kpc]

Lan ApJ submitted
arxiv:1911.01271
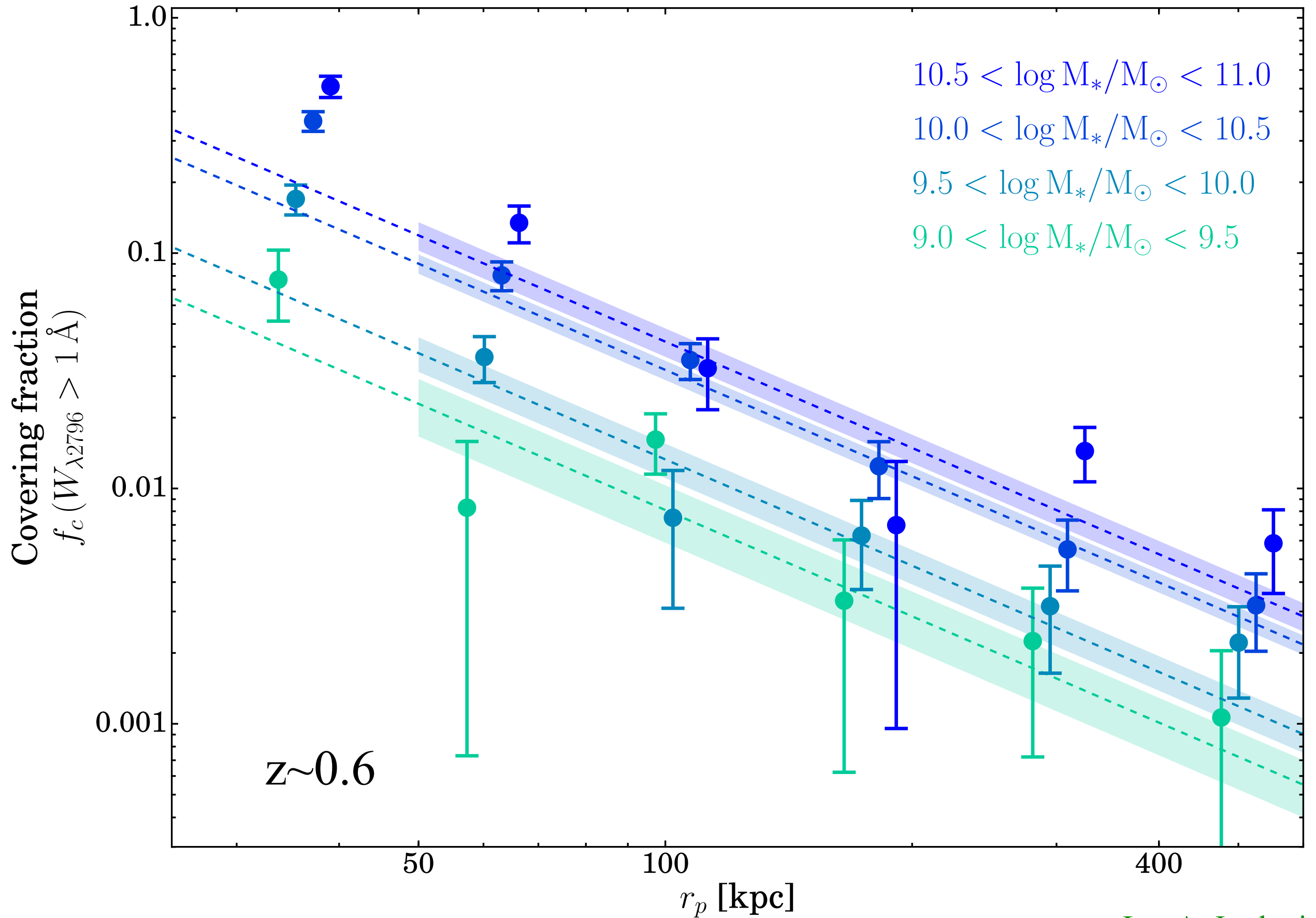
Gas distribution in dark matter halos W > 1 Å

Covering fraction $f_c (W_{\lambda 2796} > 1\,\text{Å})$

$10.5 < \log M_*/M_\odot < 11.0$

$10.0 < \log M_*/M_\odot < 10.5$

$9.5 < \log M_*/M_\odot < 10.0$

$9.0 < \log M_*/M_\odot < 9.5$

r_p/r_{vir}

z~0.6
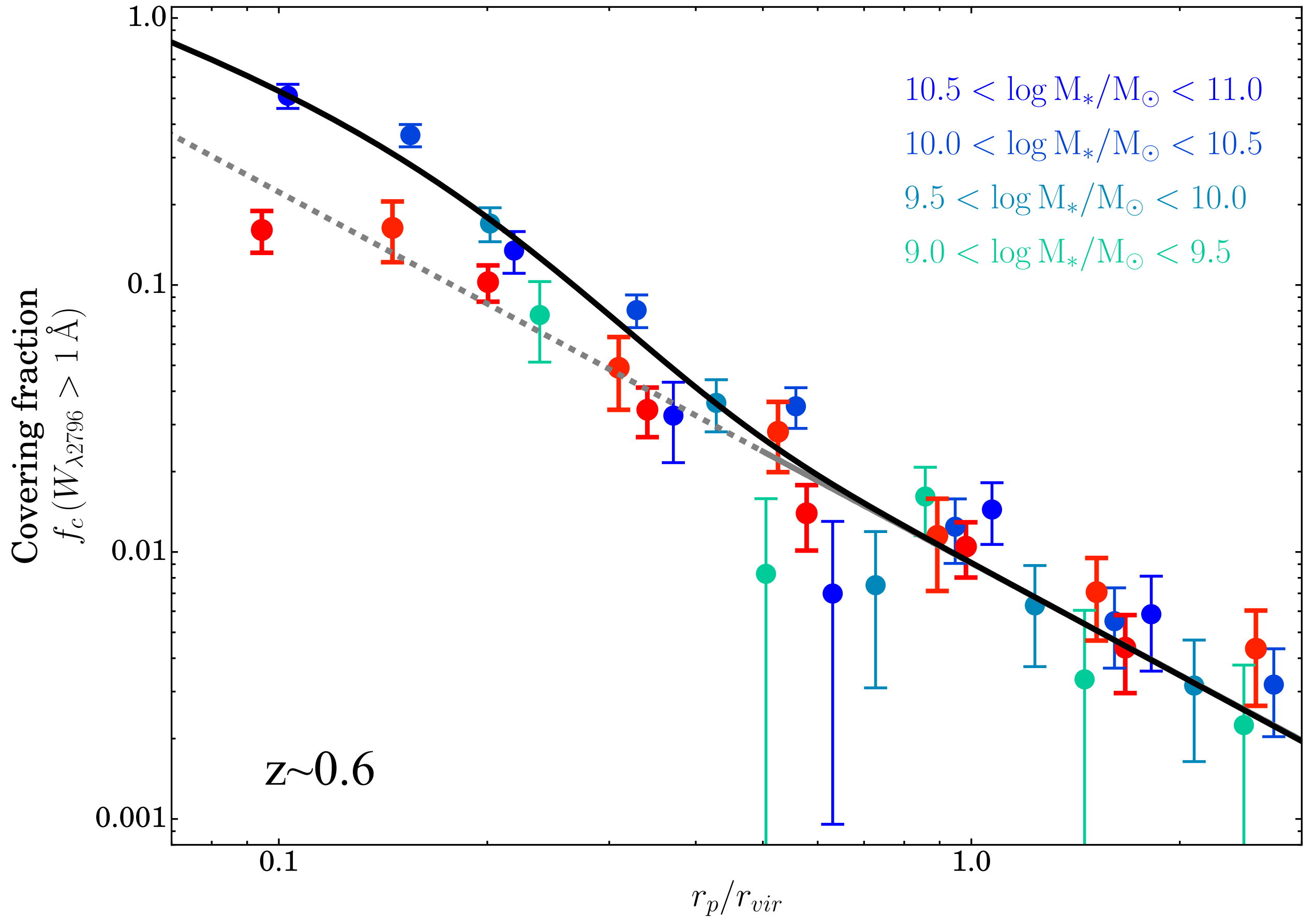
See also Churchill et al. 2012, 2013

Redshift evolution of gas profiles

Covering fraction $f_c\left(W_{\lambda 2796} > 1\,\text{Å}\right)$

r_p/r_{vir}

z~0.6

Redshift evolution of gas profiles

z~0.9

z~0.6

Covering fraction $f_c \left(W_{\lambda 2796} > 1\,\text{Å} \right)$

r_p / r_{vir}

Redshift evolution of gas profiles

Covering fraction $f_c\,(W_{\lambda 2796} > 1\,\text{\AA})$

z~1.2

z~0.9

z~0.6

r_p/r_{vir}

Lan ApJ submitted
arxiv:1911.01271

Redshift evolution of gas profiles

$$f_c = f_c^{exp} + f_c^{power}$$

Covering fraction $f_c\left(W_{\lambda 2796} > 1\,\text{Å}\right)$

r_p/r_{vir}

Redshift evolution of gas mass

$$M_{\rm HI} \propto \left(1+z\right)^{3.5} \times M_*^{0.7}$$

Axis labels: $M_{\rm HI}(< r_{vir})\ [M_\odot]$, $\log {\rm M}_*/{\rm M}_\odot$

Inset legend:
0.0<z<0.5
0.5<z<1.0
1.0<z<1.5
1.5<z<2.0
2.0<z<2.5

Inset axes: $\log({\rm SFR})\ [{\rm M}_\odot\ {\rm yr}^{-1}]$, $\log({\rm M})\ [{\rm M}_\odot]$

Gas mass vs SFR

$M_{\rm HI} \propto SFR$

$M_{\rm HI}(< r_{vir})\,[M_\odot]$

$\log {\rm SFR/M_\odot\,yr^{-1}}$
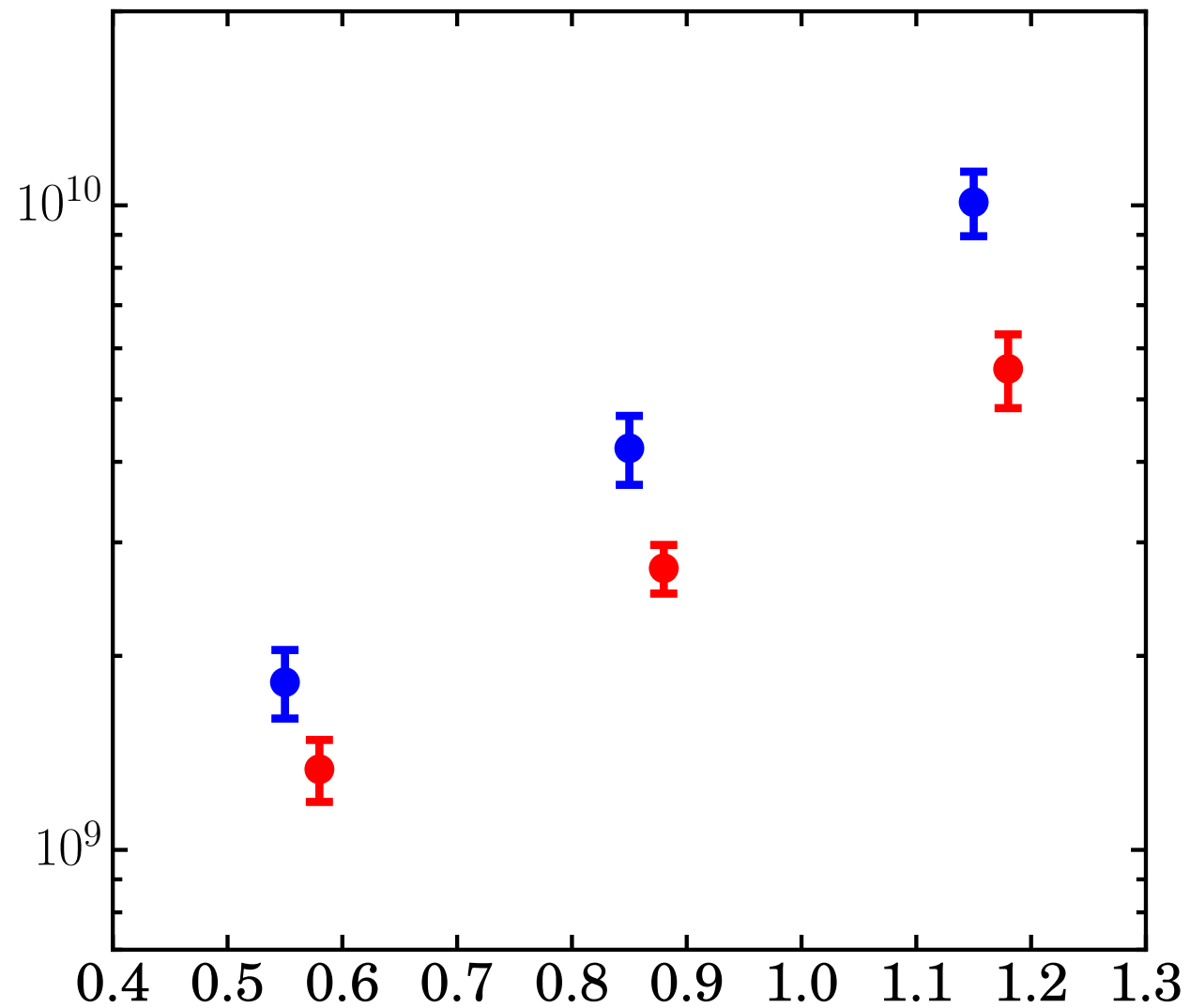
Gas mass in the CGM evolves consistently with the SFR of galaxies.
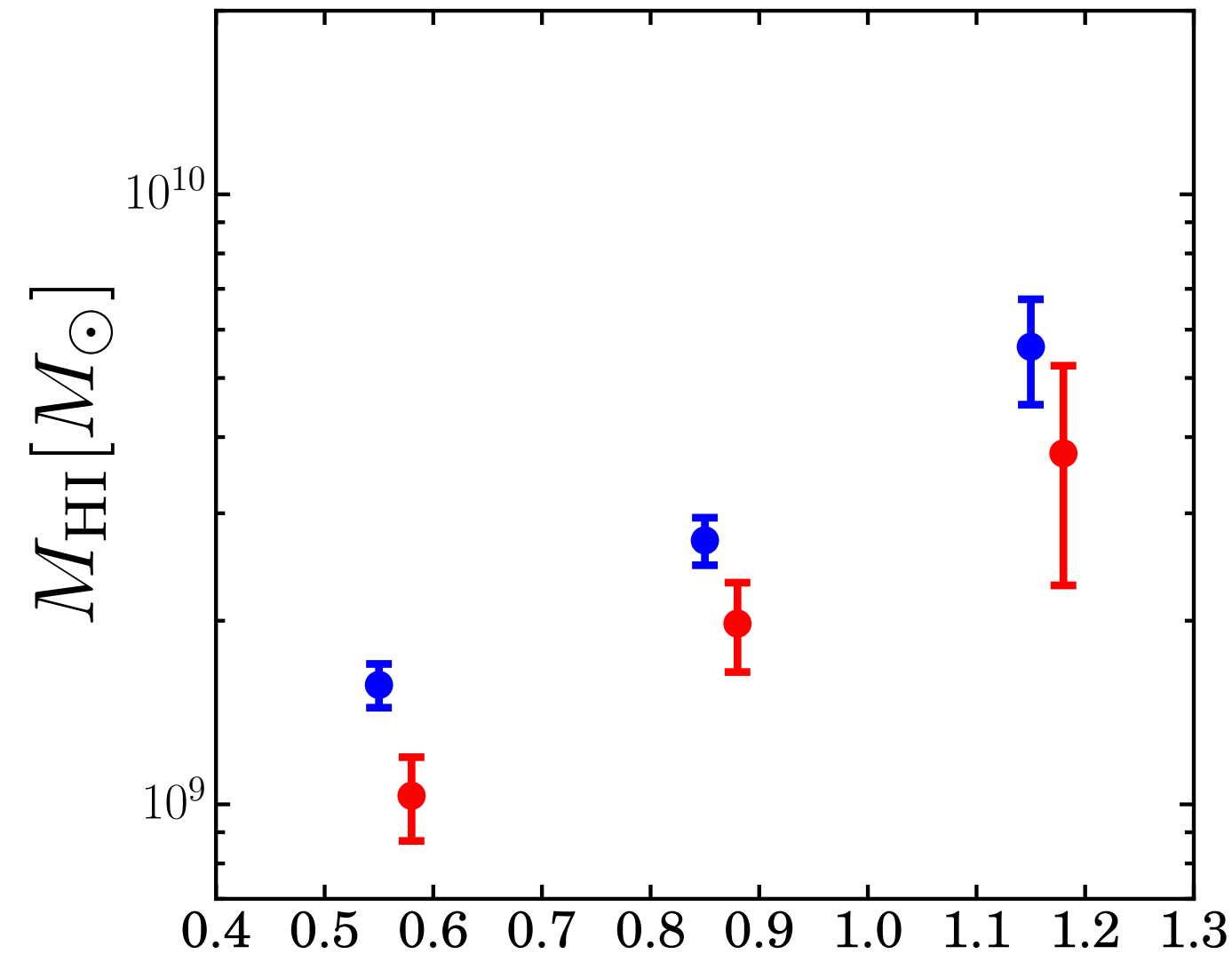
Redshift evolution of gas mass

$log\, M_*/M_\odot \sim 10.3$

$log\, M_*/M_\odot \sim 10.8$

$M_{\mathrm{HI}}\,[M_\odot]$
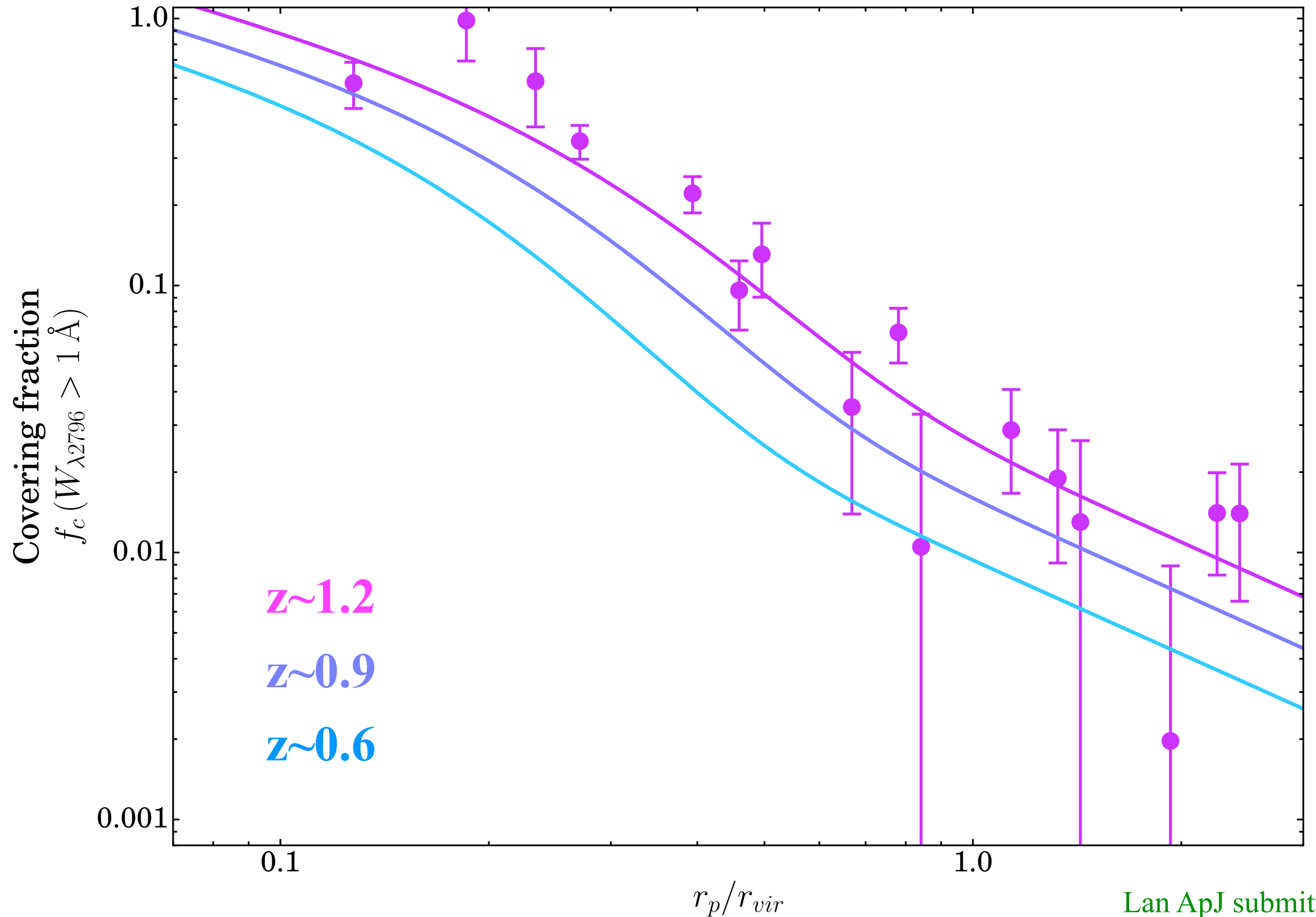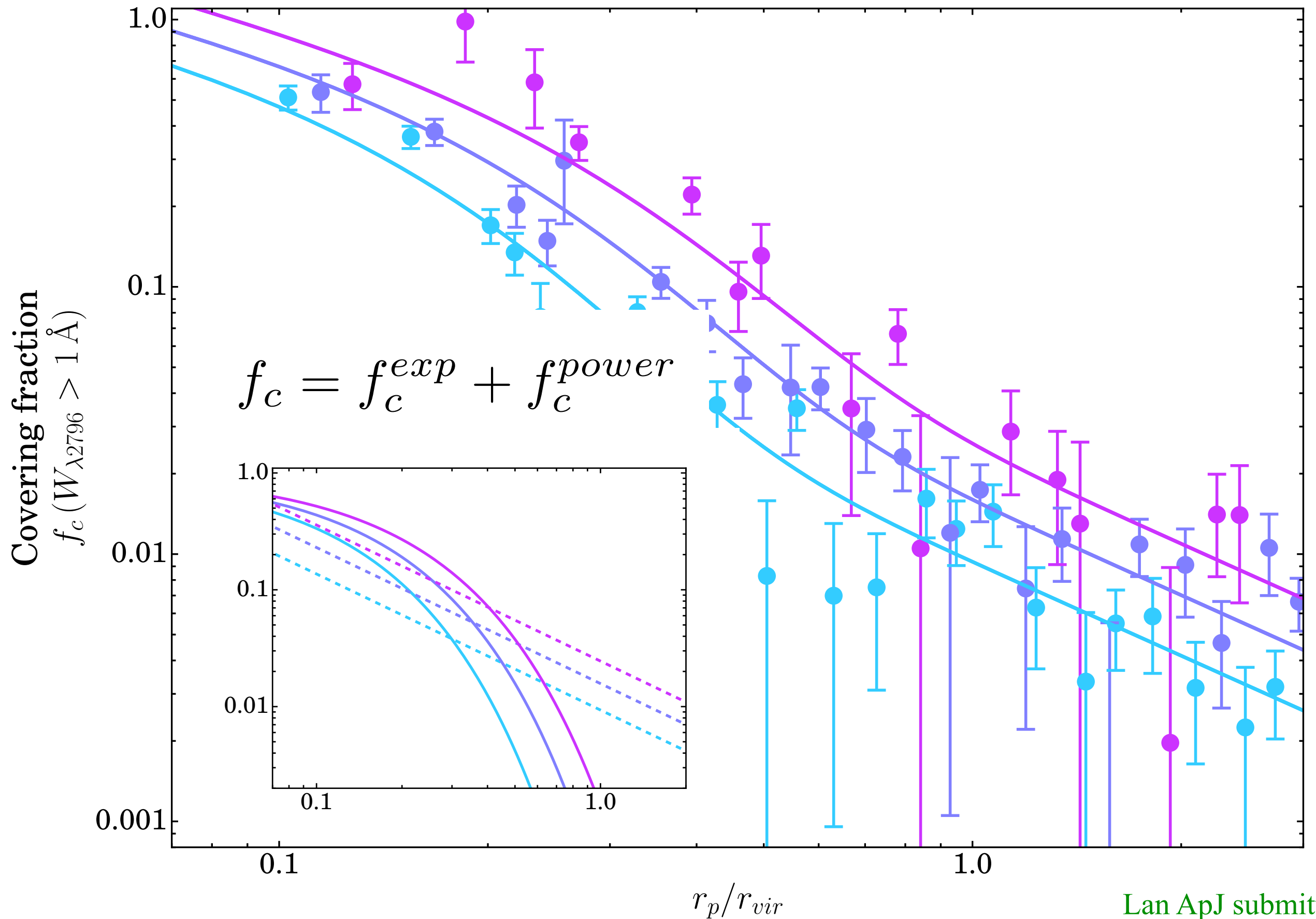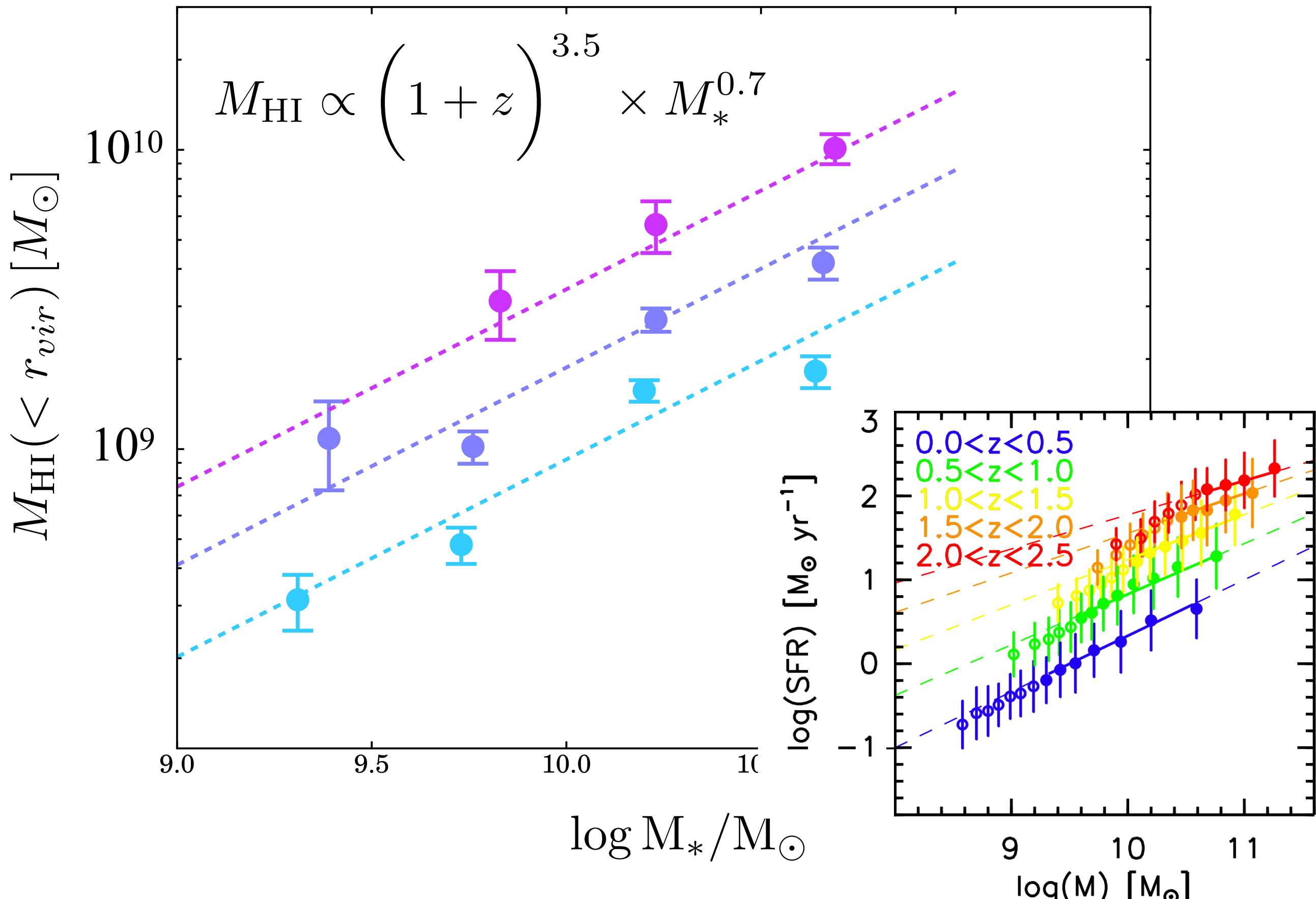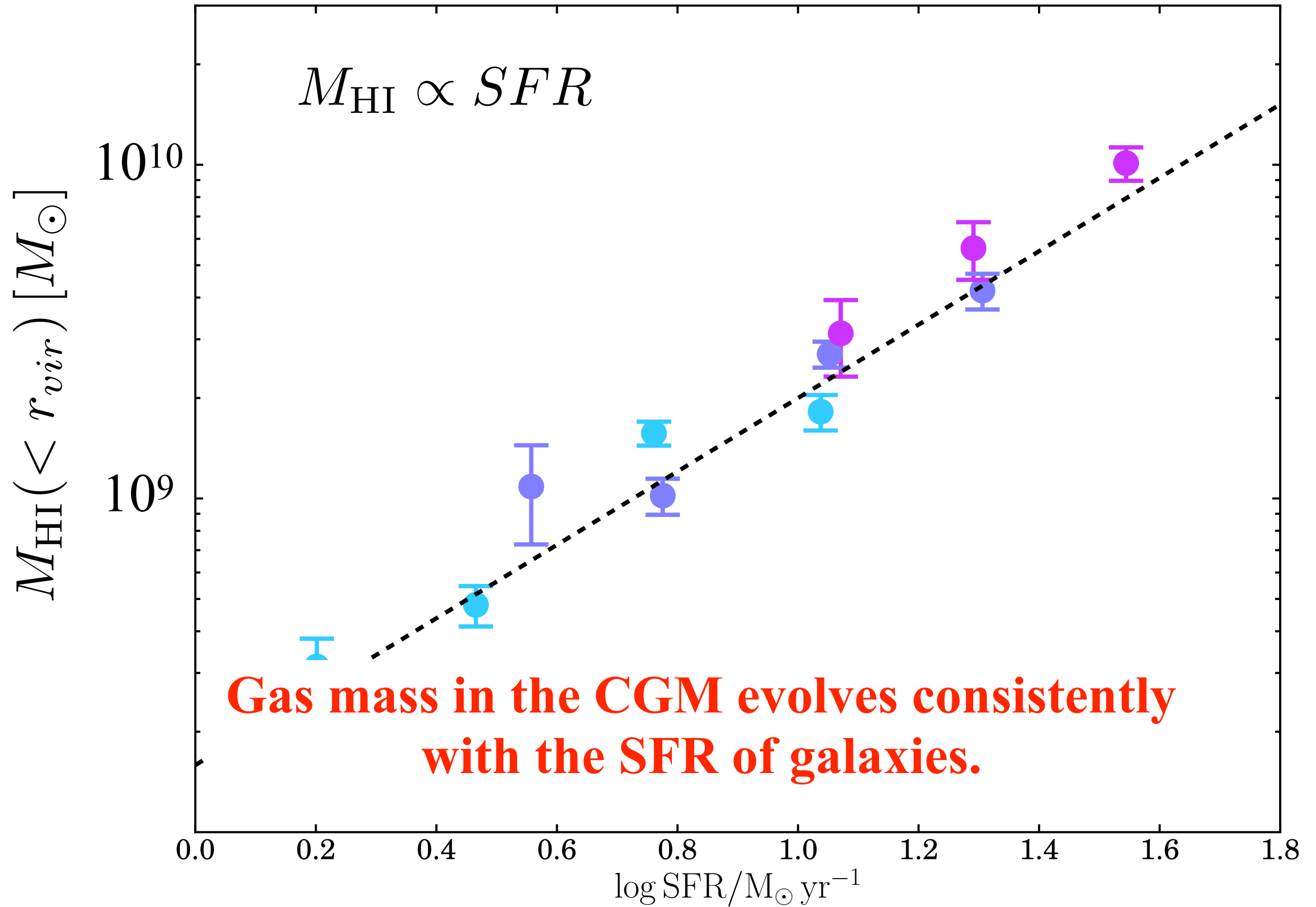
Redshift

Excess gas mass vs SFR

$\delta M_{HI} = M_{HI}^{\text{star-forming}} - M_{HI}^{\text{passive}}$

$\delta M_{HI} \propto \text{SFR}$

$\delta M_{HI}(< r_{vir})$ [M$_\odot$]

z~1.2

z~0.9

z~0.6
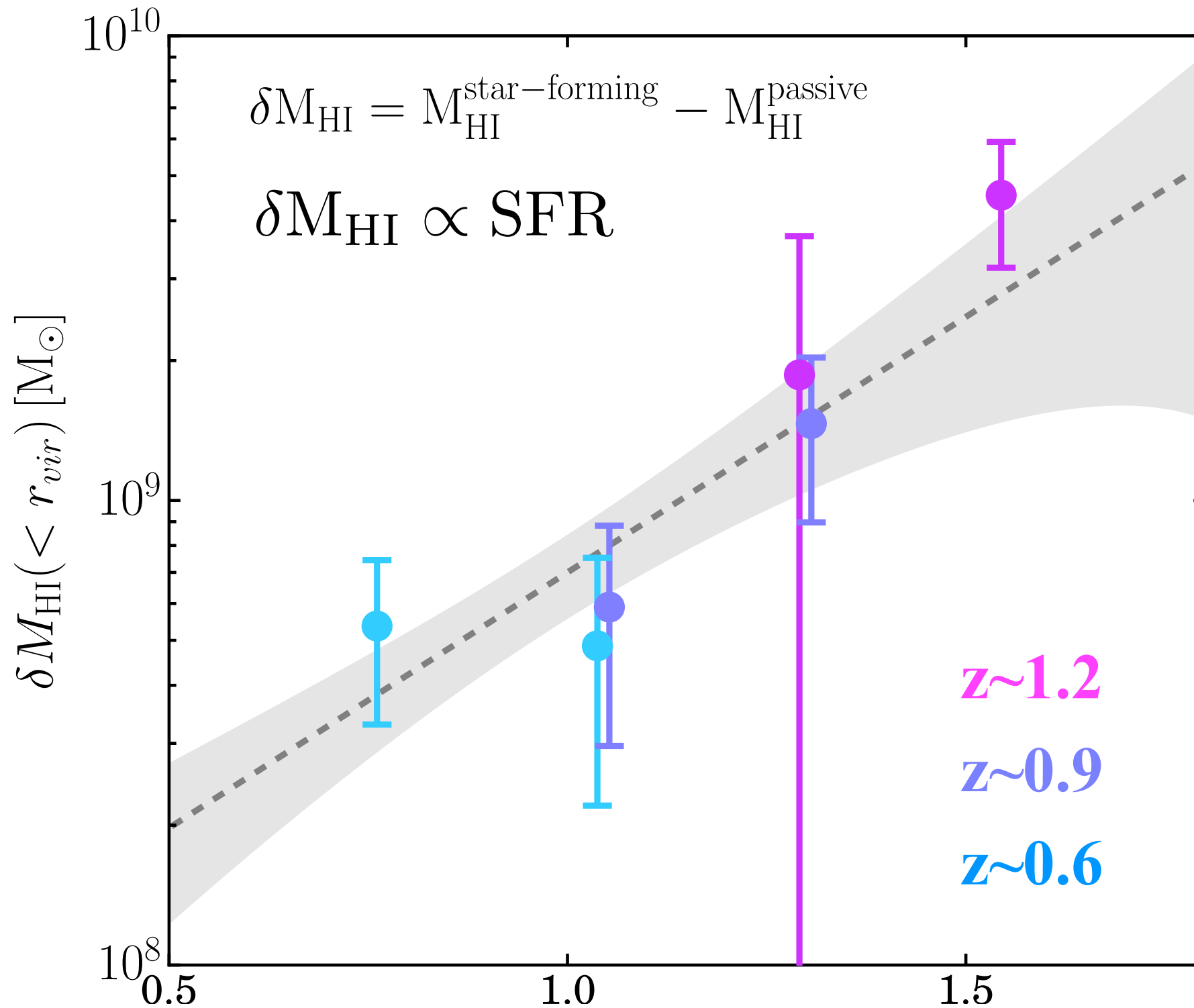
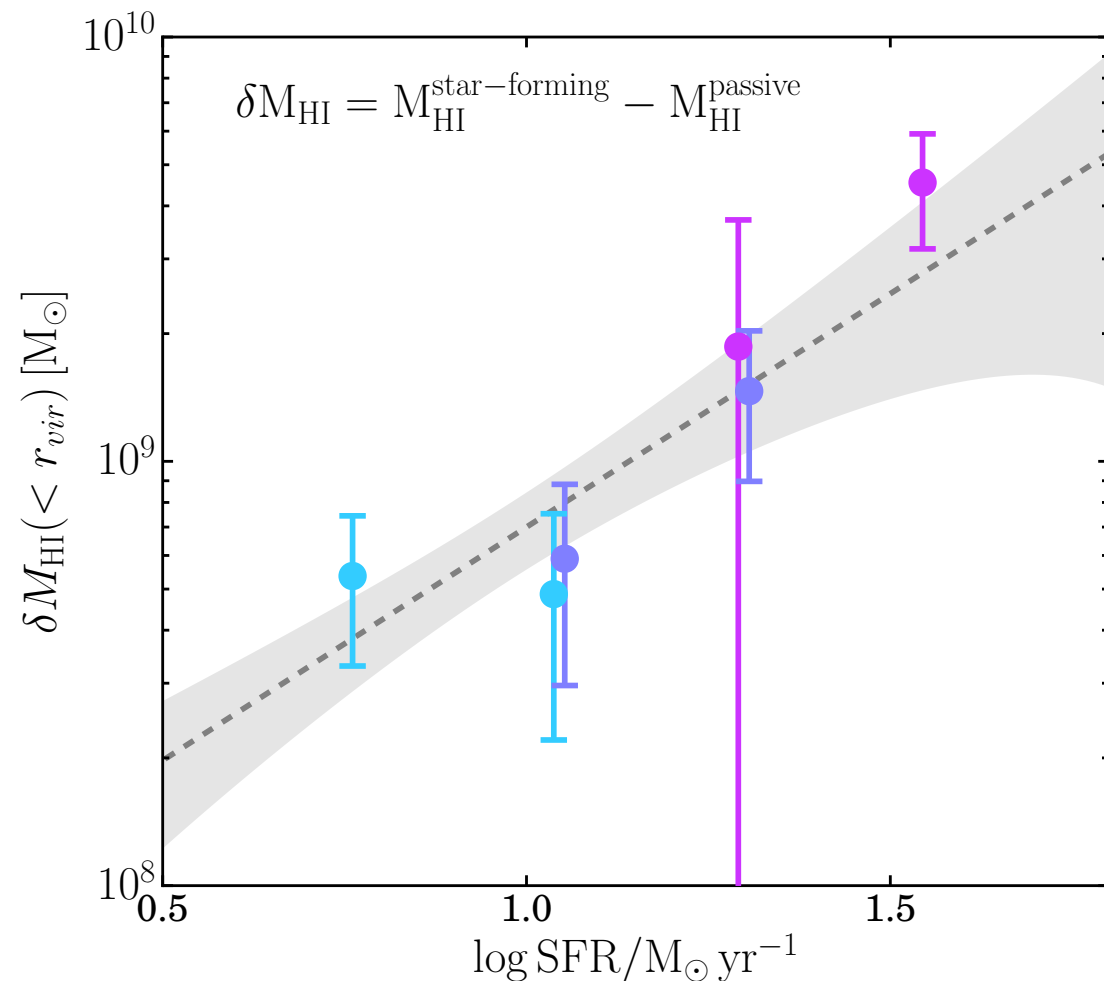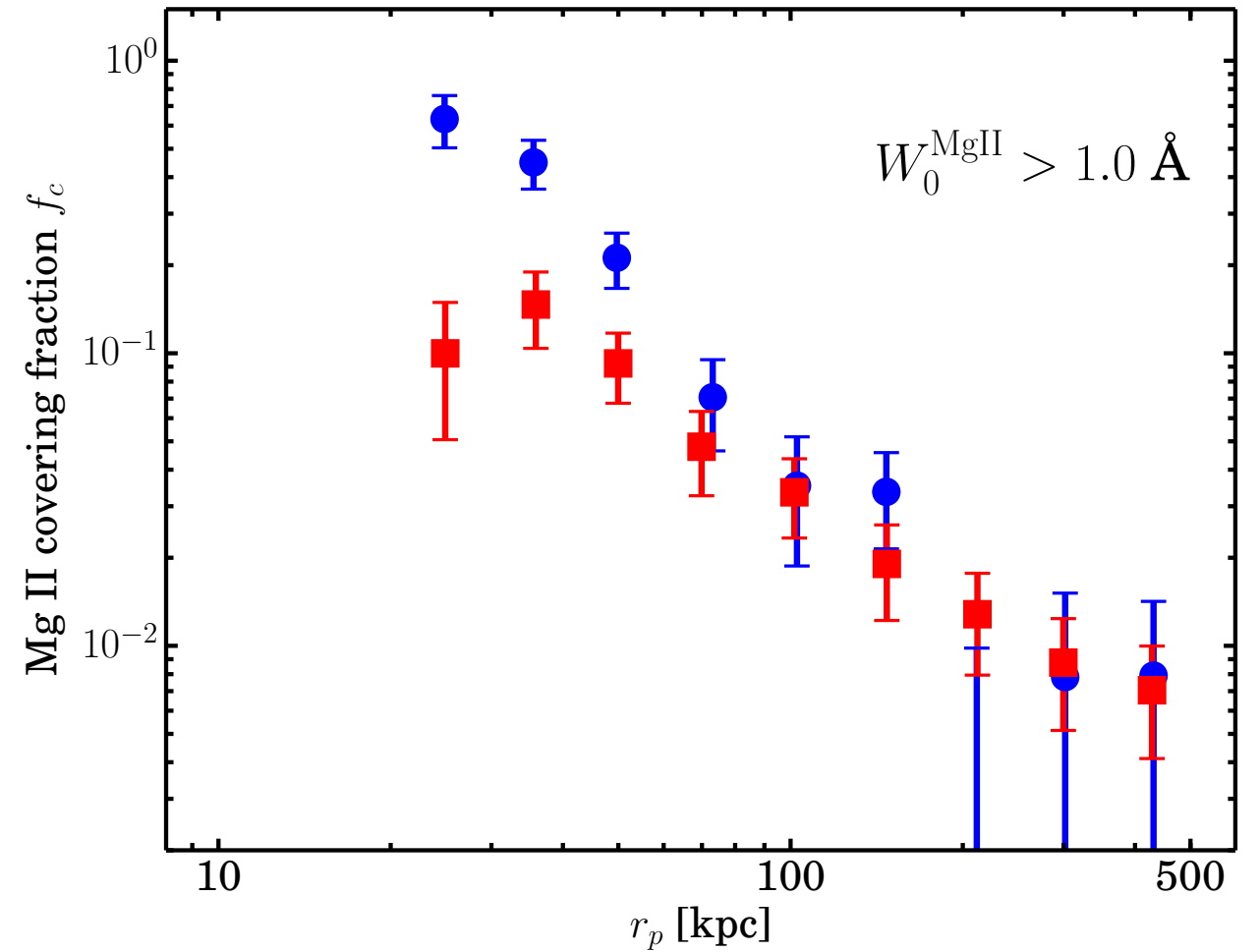**The cosmic evolution of SFR of galaxies is reflected in the properties of the CGM.**

Key questions

Is the dichotomy of galaxy types reflected in the CGM?

$W_0^{MgII} > 1.0$ Å

Mg II covering fraction f_c

r_p [kpc]

$\delta M_{HI} = M_{HI}^{star-forming} - M_{HI}^{passive}$

$\delta M_{HI}(< r_{vir})$ [$M_\odot$]

$\log SFR/M_\odot \, yr^{-1}$

Is the evolution of galaxies reflected in the CGM?