HI and metal absorption around LAEs at z=2-3

(Progress report on HETDEX Project #29)

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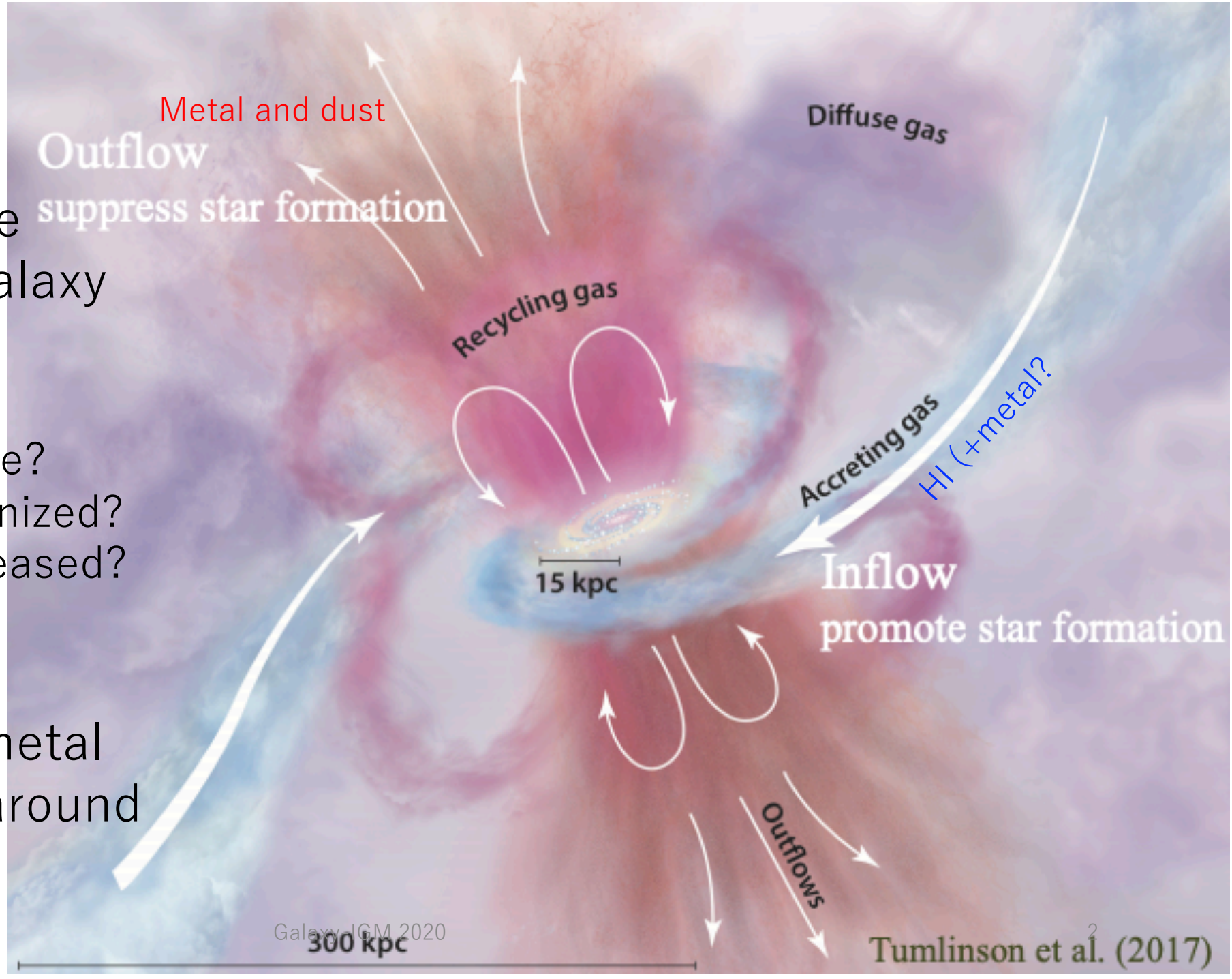
Ultimate Goal

Understanding of the interplay between galaxy formation and IGM

- How much HI accrete?
  - How much are ionized?
- How far metal is released?

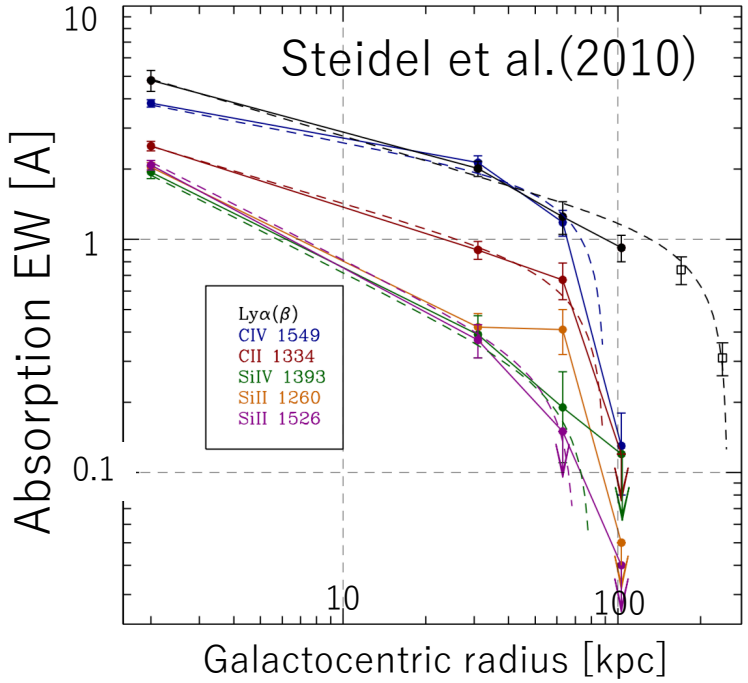
Immediate Goal

Mapping HI / HII / metal spatial distribution around galaxies



Introduction

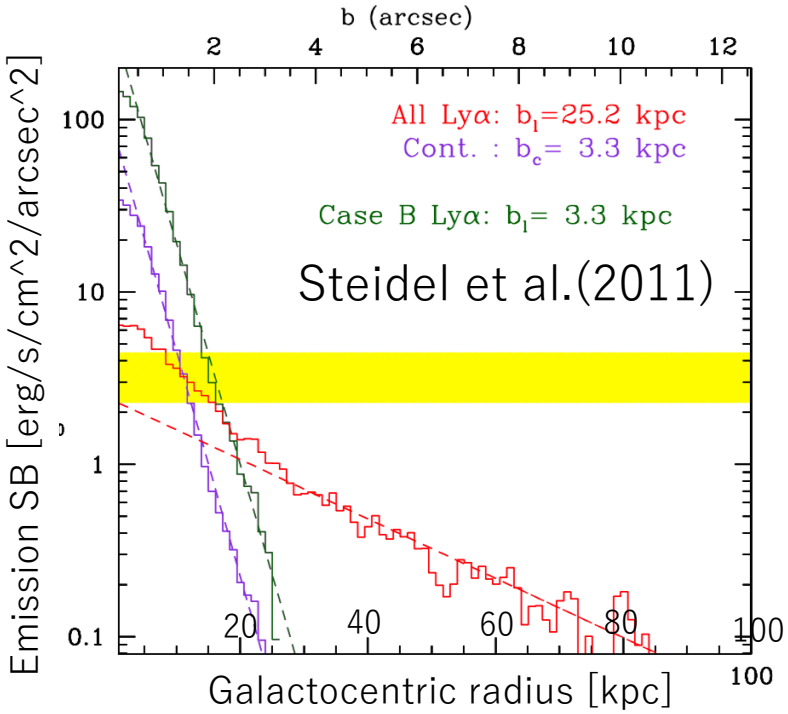
- HI and metal are imprinted in absorption lines of the background objects
- Ionized H is investigated via Lya emission



Problem

Still unclear at b > 100kpc,
due to poor quality of the observational data.
: object number & S/N of each object

HSC SSP, HETDEX

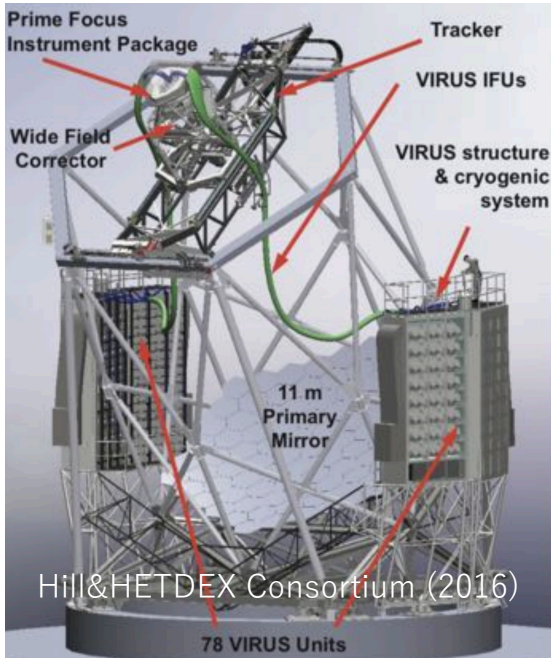


Used data

- LAEs from HETDEX HDR1 catalog
  - LAE Selection by plae_poii_hetdex_gmag>10
  - 8,742 LAEs at 1.9<z<3.6; 7,173 in Spring&EGS / 1,333 in Fall / 153 in COSMOS / 83 in GOODS-N

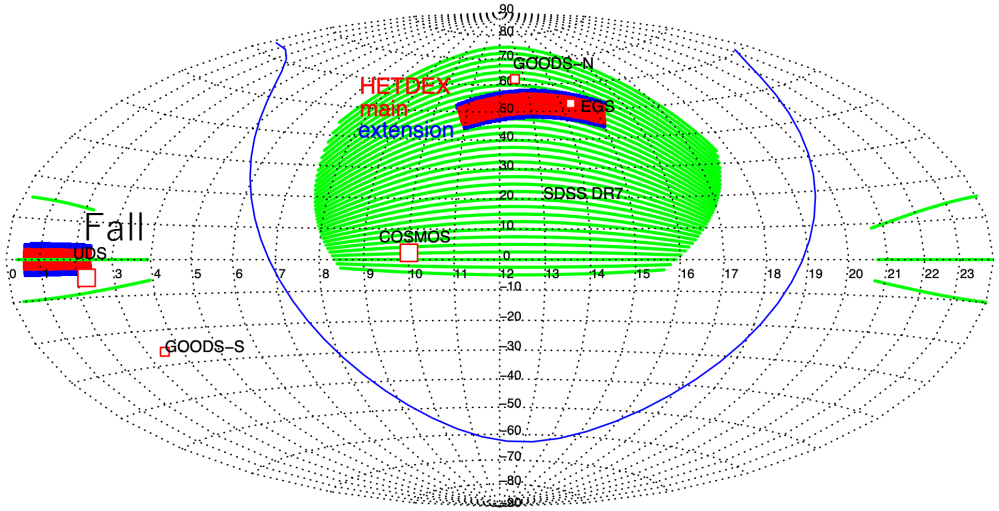
  LAE LF -> Y. Zheng talk
  Update on Cataloging w/ ML -> N. Sakai talk

- Background spectra from SDSS DR14 QSOs (Paris+18)
  - Selection for Lya /metal abs analysis
    - SN>2 at 1040< λ_{rest} <1185 (Lya) or 1250< λ rest<1600 (metal)
    - z_QSO > z_LAE
    - Within 10pMpc from the nearby LAEs
  - N_QSO ~ 1,300 (Lya) / 2200 (metal)



11m HET +
Opt IFU(R=750) VIRUS
↓
Blind spec survey of LAEs at 1.9<z<3.6 in 450deg^2

1,000,000 LAEs are expected!



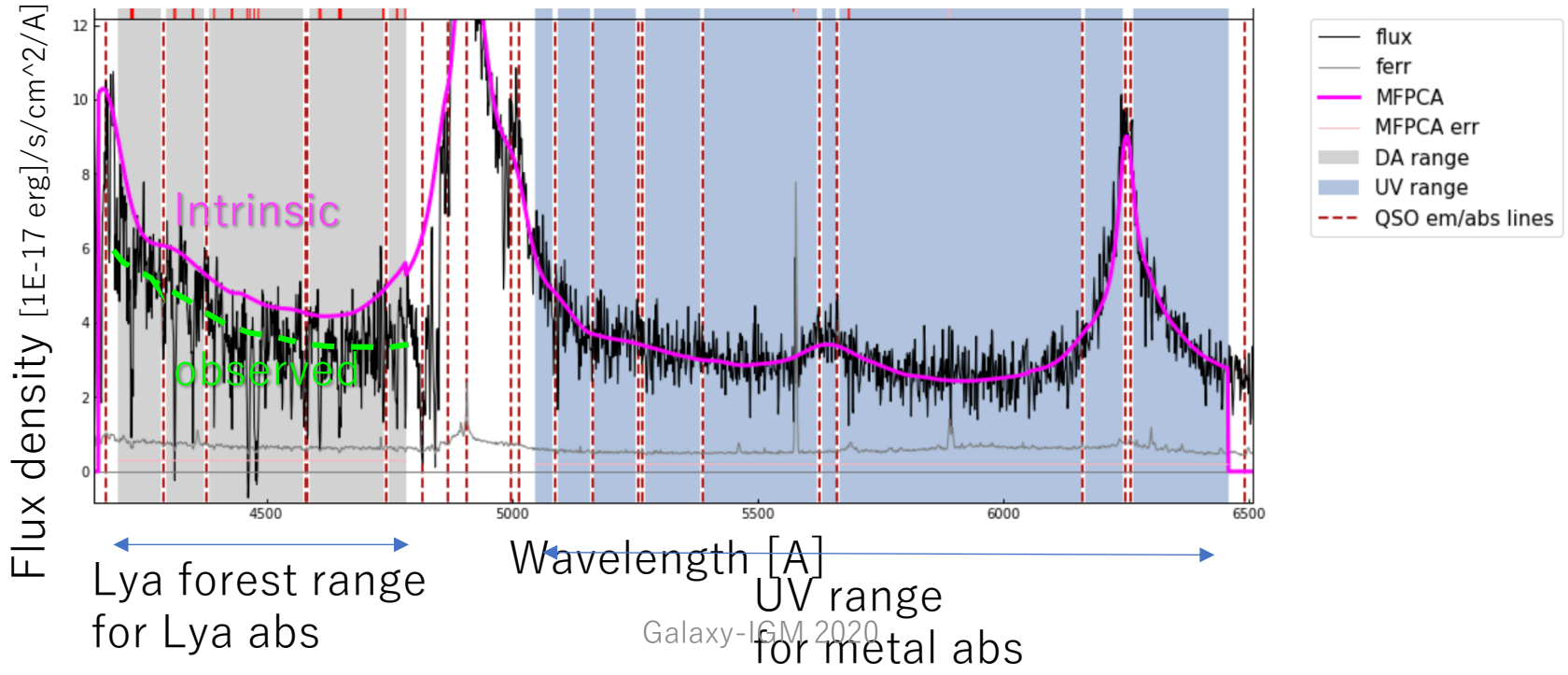
Mukae D thesis (2020)

Analysis: absorption lines in QSO spec

1. Intrinsic continuum extraction

- MFPCA fitting (Lee et al. 2012,2013,2014)
  - Step1. Template fitting to spectrum at $\lambda_{rest} > 1216$
  - Step2. Mean Flux regulation at $1040 < \lambda_{rest} < 1185$ (Lya forest range)

  : Lya forest spec (amp and slope) is tuned so that it can reproduce the redshift evolution of the cosmic average Lya-forest absorption (Faucher-Giguere+08)



Analysis: absorption lines in QSO spec

2. Absorption excess from cosmic average

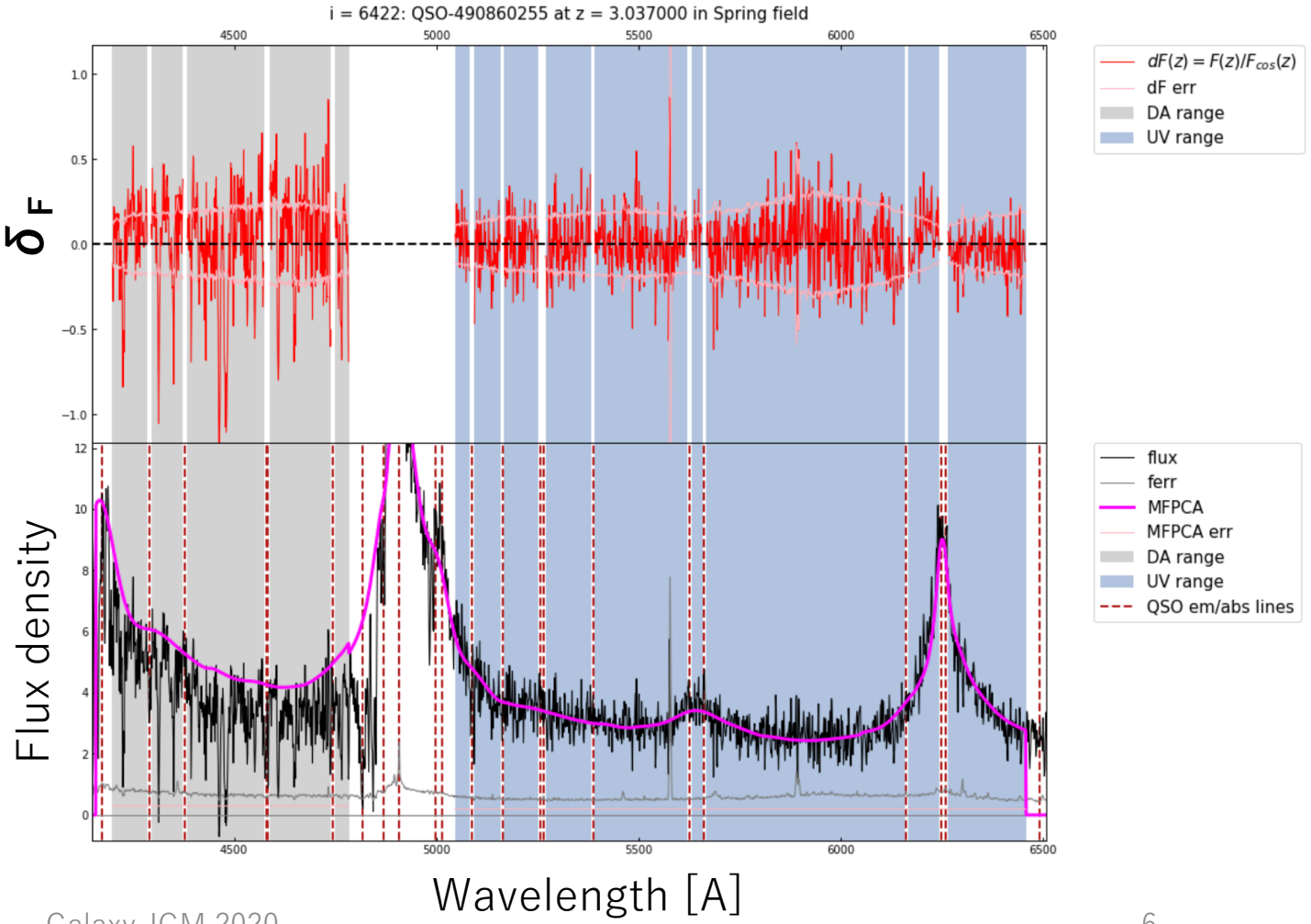
Observed spec

$$\delta_F = \frac{F_{obs}}{F_{cont} \times F_{cos}(z)} - 1$$

Intrinsic continuum

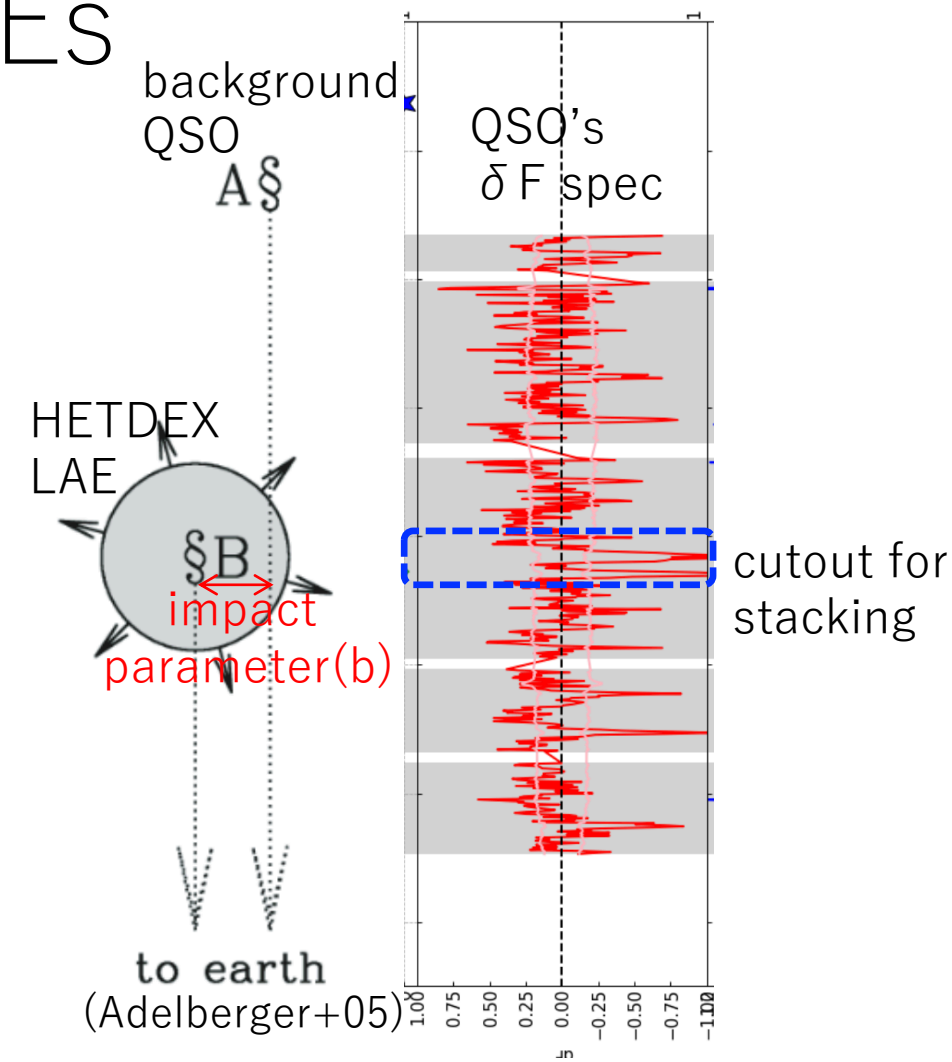
Cosmic Average transmission

$F_{cos}(z)$ is neglected for metal absorption in UV range

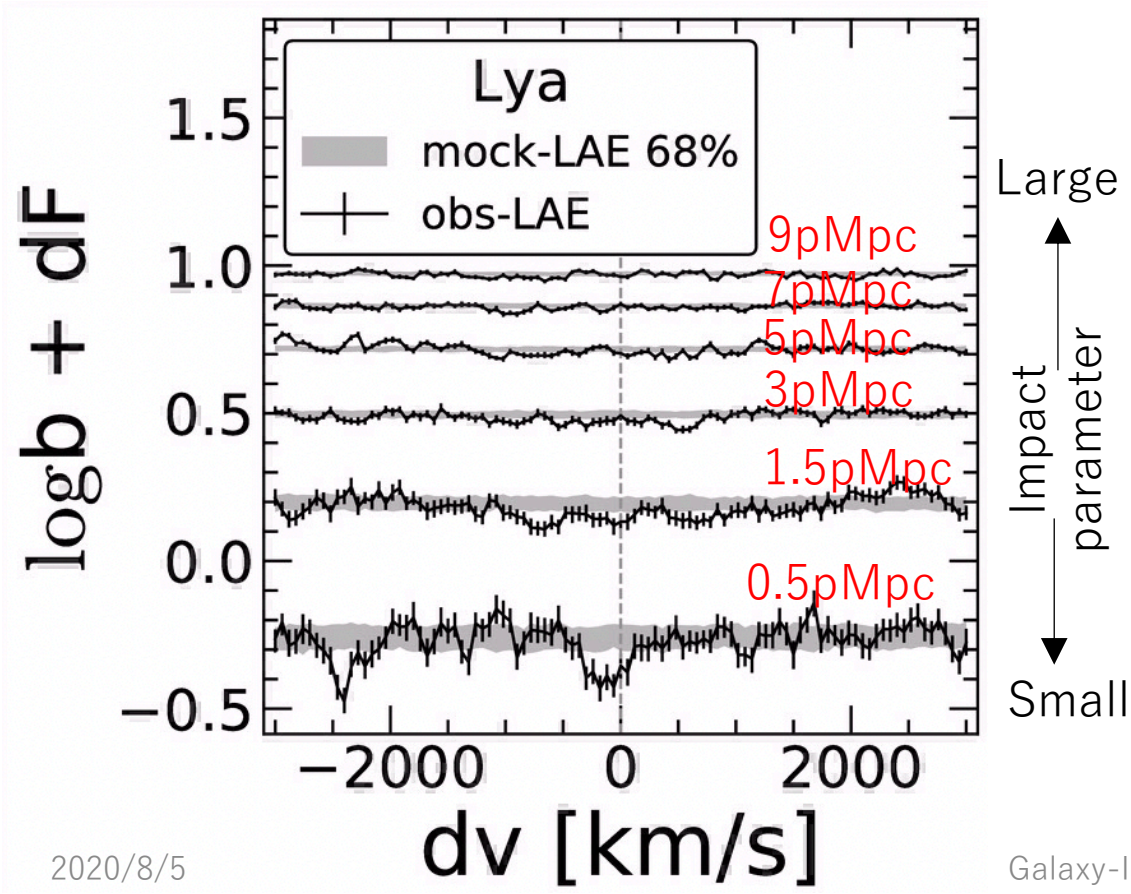


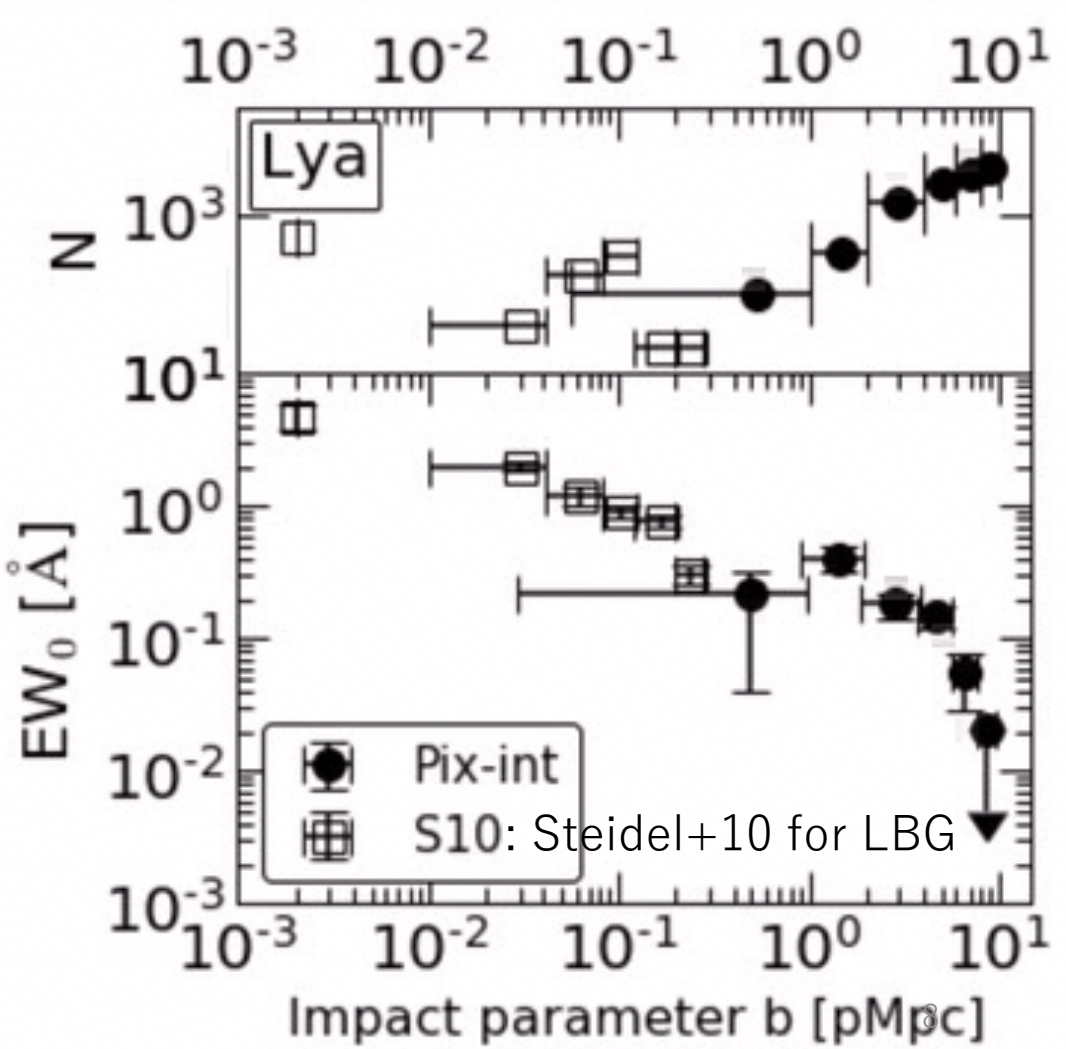
Stacking of absorption spectra in rest-frame wavelengths for HETDEX LAEs

- Extract QSOs' δF spec with velocity difference -3000 < dv[km/s] < 3000 from every individual LAEs' Lya (or metal) line
- The extracted QSOs' dF specs are stacked Tomography -> D. Sun talk
- The QSOs are grouped by impact parameters (b=0-10pMpc)



Stacking of absorption spectra in rest-frame wavelengths for HETDEX LAEs

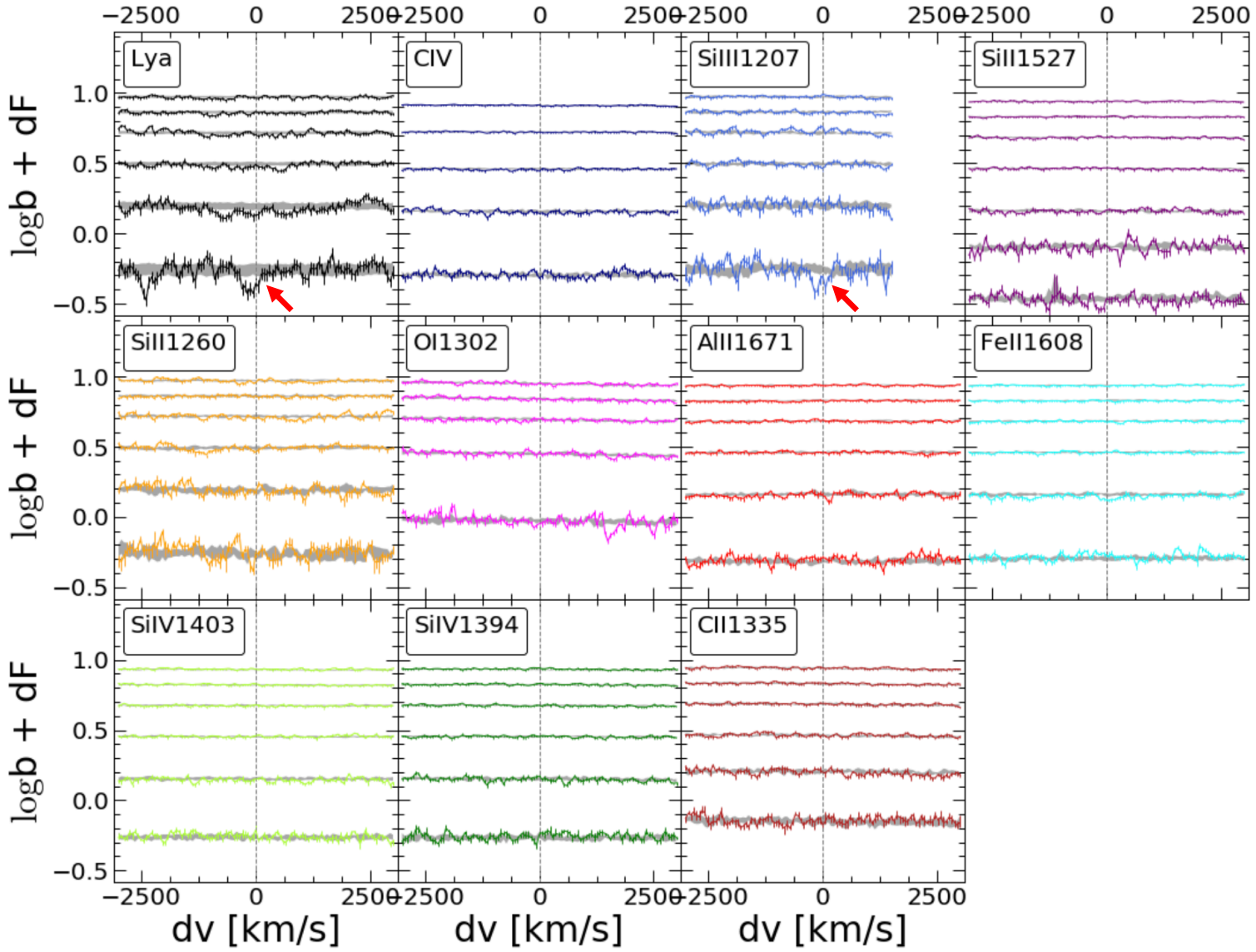




Stacking of absorption spectra in rest-frame wavelengths for HETDEX LAEs

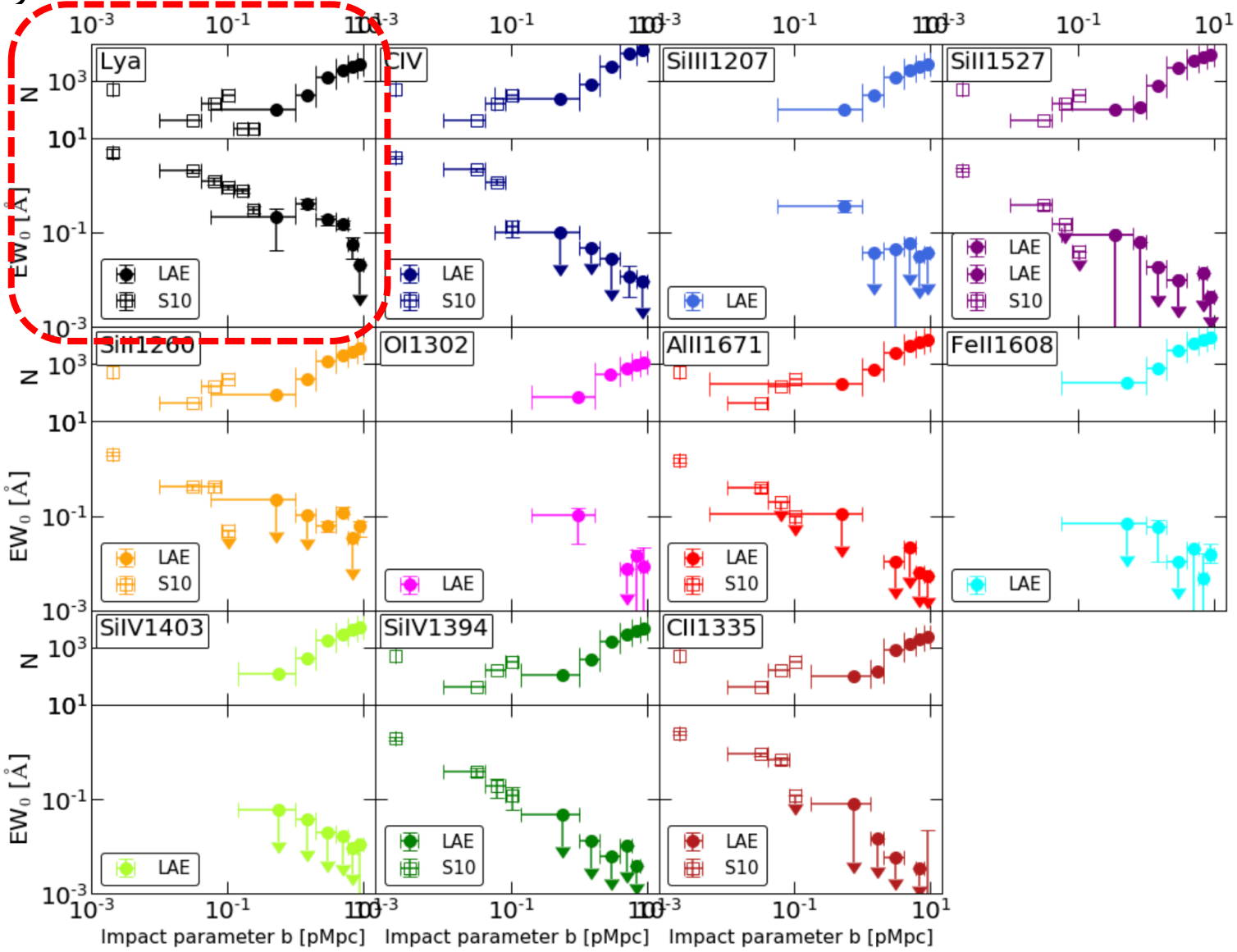
No notable absorption line other than
Lya and SiII1207…

The situation will be improved by
by HETDEX future data release, where LAE number increases x100.

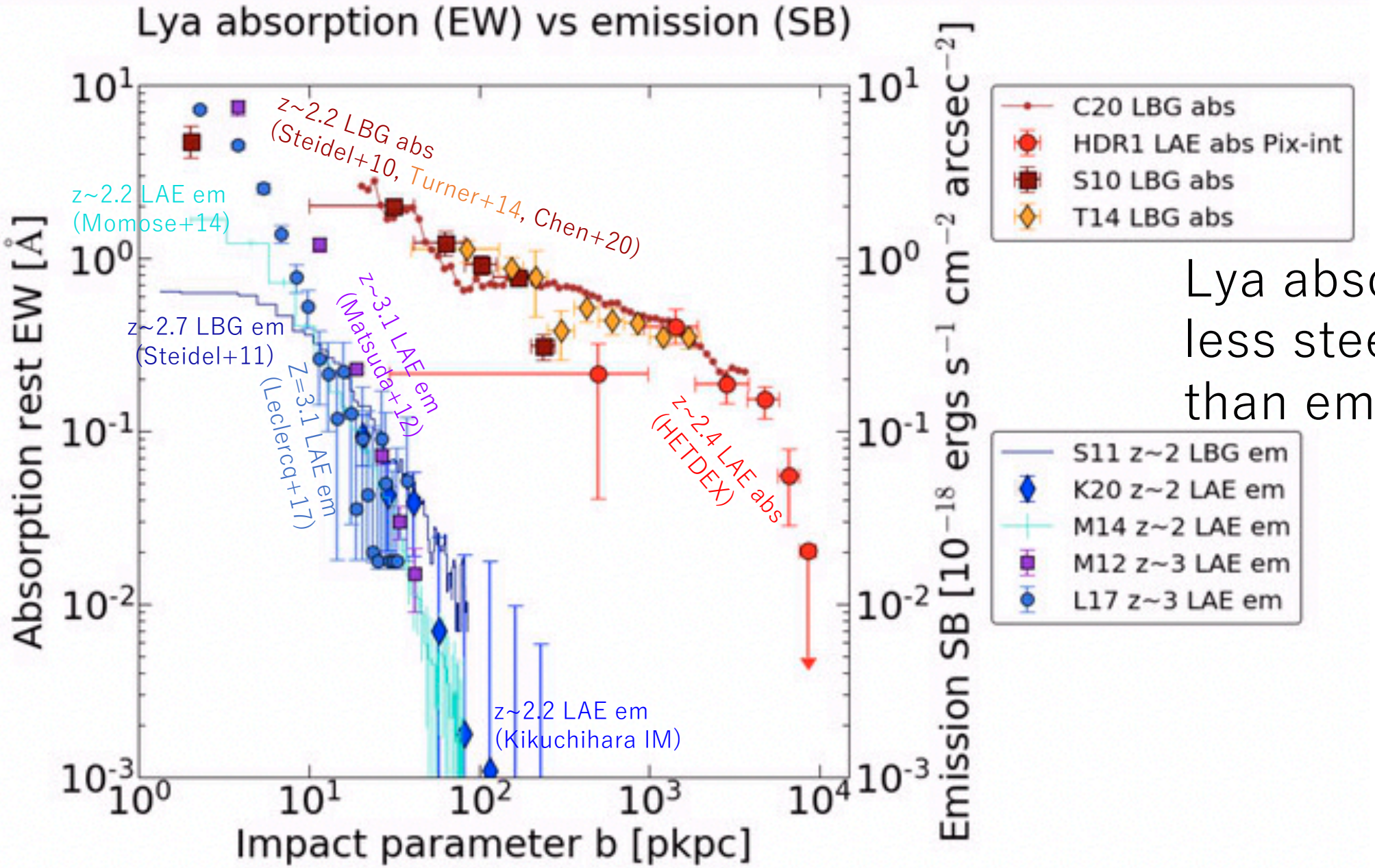


Stacking of absorption spectra in rest-frame wavelengths for HETDEX LAEs

Focus on Lya



Compilation of Lya abs/emission observations



Lya absorption is
less steep
than emission halo.

Analytic modeling for Lya emission&absorption

Covering fraction (fc) of HI absorbers that also scatter Lya photons determines the profile shapes (slope).

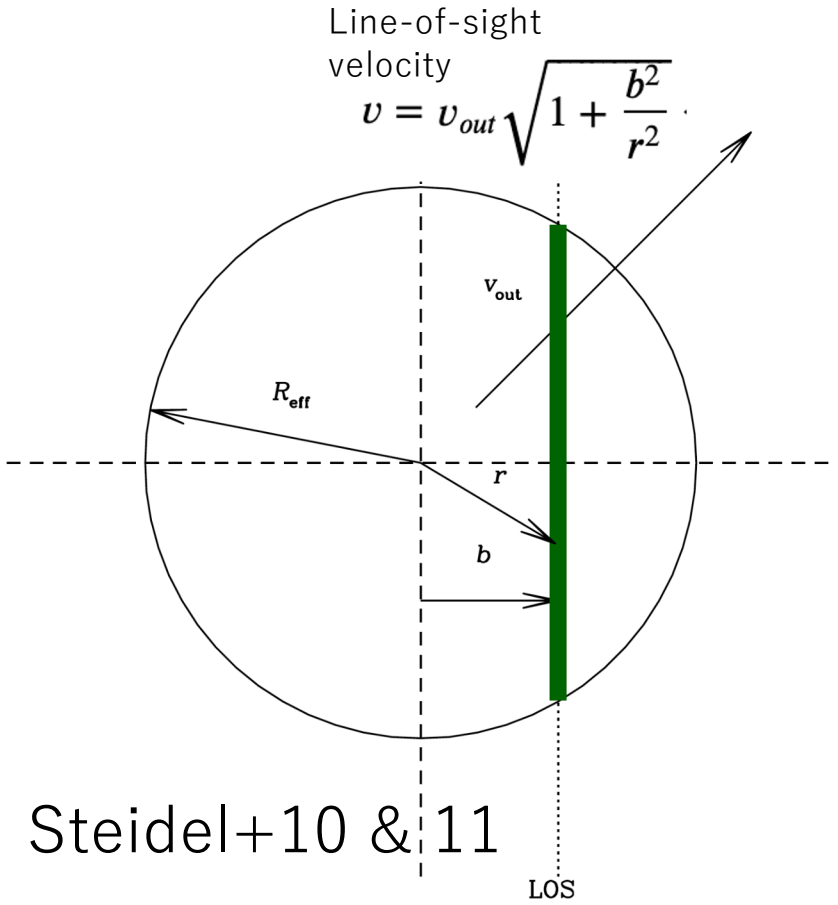


Figure 23. Diagram illustrating the simple model for estimating the relative IS absorption line strength W_0 as a function of impact parameter b used to produce the model curves in Figure 21. $R_{\rm eff}$ is the characteristic size of the gas distribution producing saturated lines of a particular transition. Any systematic dependence of $v_{\rm out}$ on radius has not been included in this model, but the covering fraction f_c of gas giving rise to the transition of interest is assumed to have a radial dependence $f_c(r) \propto r^{-\gamma}$ (see the text for additional details).

Covering fraction

$$f_c(r) = \left(\frac{r}{r_0}\right)^{-\gamma}, \text{ as a func of velocity, } f_c(v) = \left[\frac{b}{r_0}\left(1-\frac{v^2}{v_{out}^2}\right)^{-1/2}\right]^{-\gamma}$$

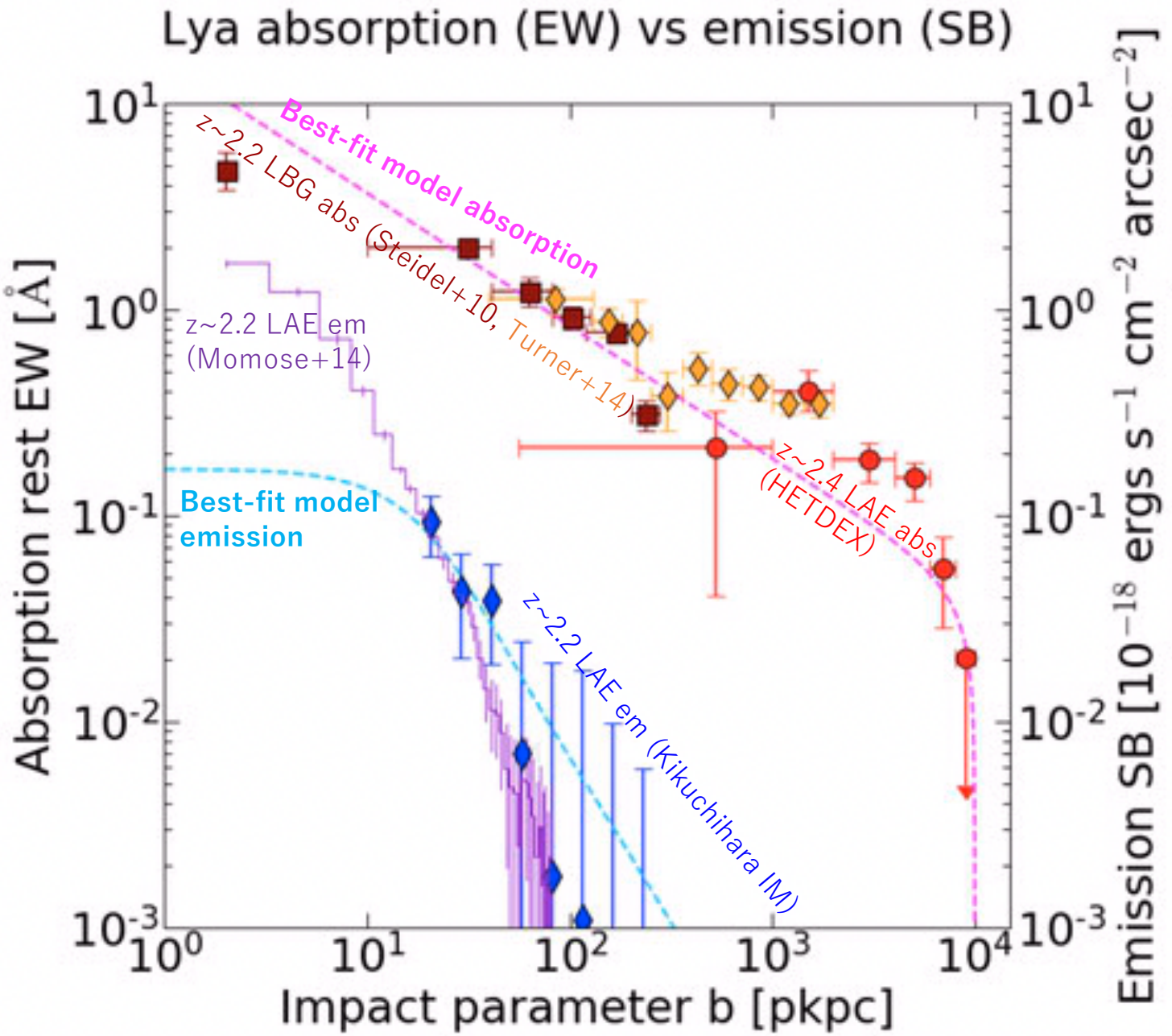
Lya "absorption"

$$EW = 2\int_0^{\Delta v_{max}} f_c(v)dv \quad \text{with} \quad \Delta v_{max} = v_{out}\left(1-\frac{b^2}{R_{eff}^2}\right)^{1/2}$$

Lya "emission"

$$S_{\rm Ly\alpha}(b) \propto S_0 \int_{-l_{\rm max}}^{+l_{\rm max}} \frac{f_c(r)[1-f_c(r)]}{4\pi r^2} dl, \quad \text{with} \quad l_{max} = \sqrt{R_{eff}^2 - b^2}$$

Fitting result



Model parameters

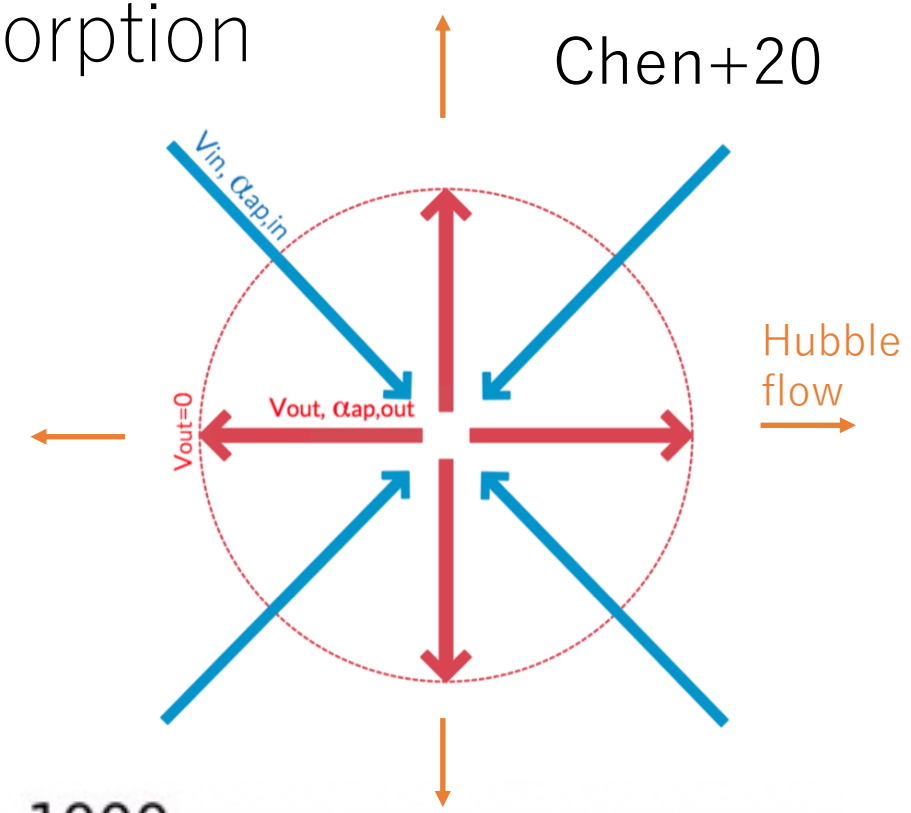
γ =0.64 (slope of covering fraction)
Reff = 10 pMpc (size)
v_out = 1000 km/s
r0 = 2.4 kpc (core radius)
S0 = 7.1×10^{-19} cgs/Hz (emi normalization)

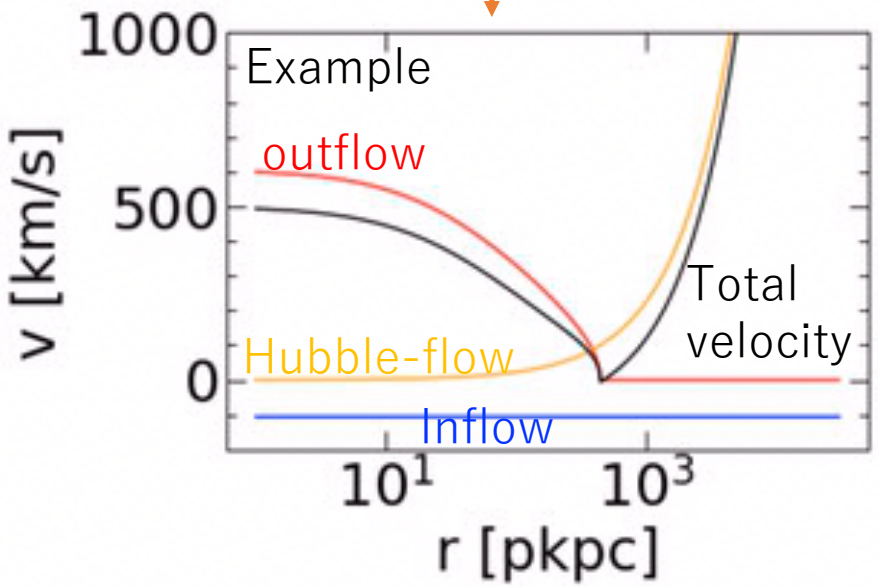
Analytic modeling for Lya emission&absorption

(TBC)
Velocity field: Outflow + Inflow + Hubble-flow

1. Outflow
   - Launch at 1kpc with v = v1
   - decrease as a func of radius in NFW potential
   - $$v_{out}(r) = \sqrt{v_1^2 + A\left(-\ln\frac{R_s+1}{R_s} + \frac{1}{r}\ln\frac{R_s+r}{R_s}\right)}$$
2. Inflow
   - Constant inflow velocity
   - v_in(r) = v_in0 = const
3. Hubble flow
   - v_H = H(z)*r

Chen+20





Conclusion

- Stacking analysis of Lya and metal absorption lines in ~2000 QSOs spectra around ~8000 HETDEX DR1 LAEs
- Metal absorptions are not detected other than SiII1207
- Lya absorption is detected up to ~ 7 pMpc
- Lya abs radial profile is more extended than Lya emission halo, which is qualitatively explained by the toy model

Next steps

- Use updated HETDEX LAE catalog -> metal abs detection
- Constract Lya emission halo from the same LAE sample as abs
- Sophisticated modeling