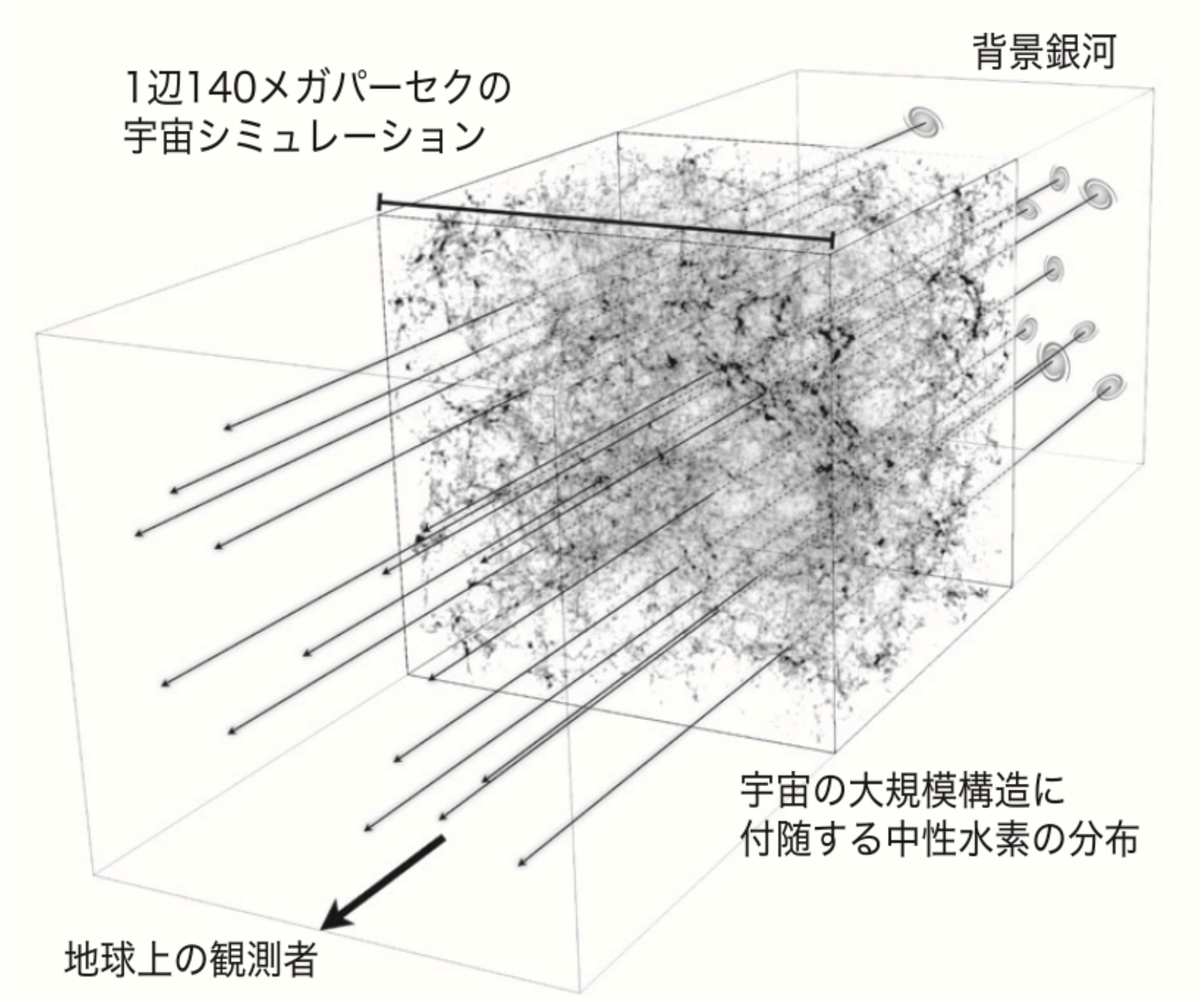
# Probing Feedback via Lyα forest & IGM tomography




**Ken Nagamine**
**(Osaka / K-IPMU / UNLV)**

**KN+21, ApJ, 916, 66**

**w/ Shimizu, Fujita, Suzuki, Lee, Momose+**

**(see also Momose-san's talk this afternoon)**

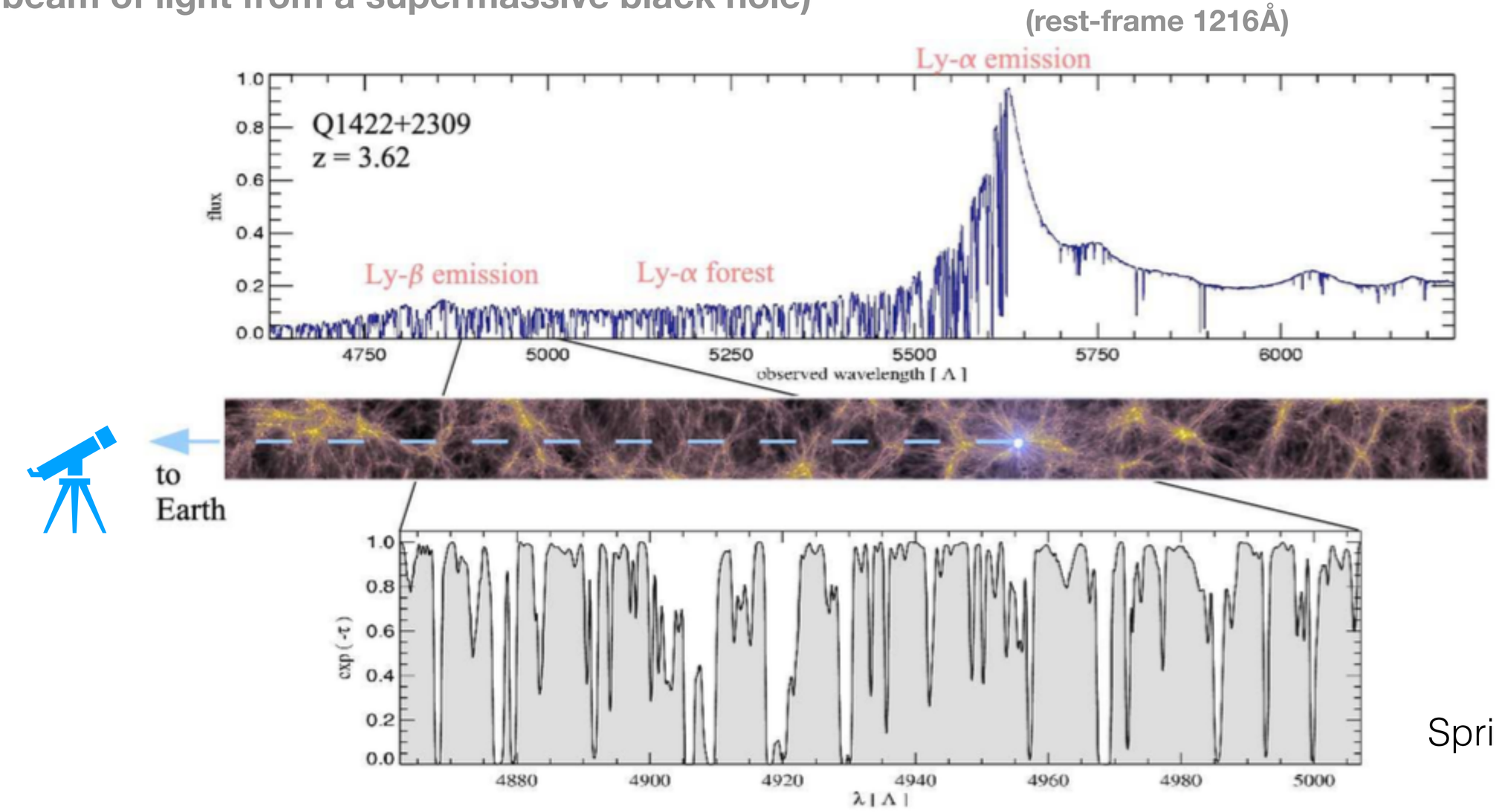
**Shimizu & KN; in TMT JP Science Book 2020**

# Outline

- **Lyα forest, IGM Tomography & Subaru PFS**
- How can we **probe the impact of feedback?**
- Various Lyα statistics: **Flux PDF, 1D $P_k$, Flux Contrast, 2D $P_k$(v)**

# Quasar (QSO) absorption line and Ly-α forest

(a beam of light from a supermassive black hole)




Springel+'05

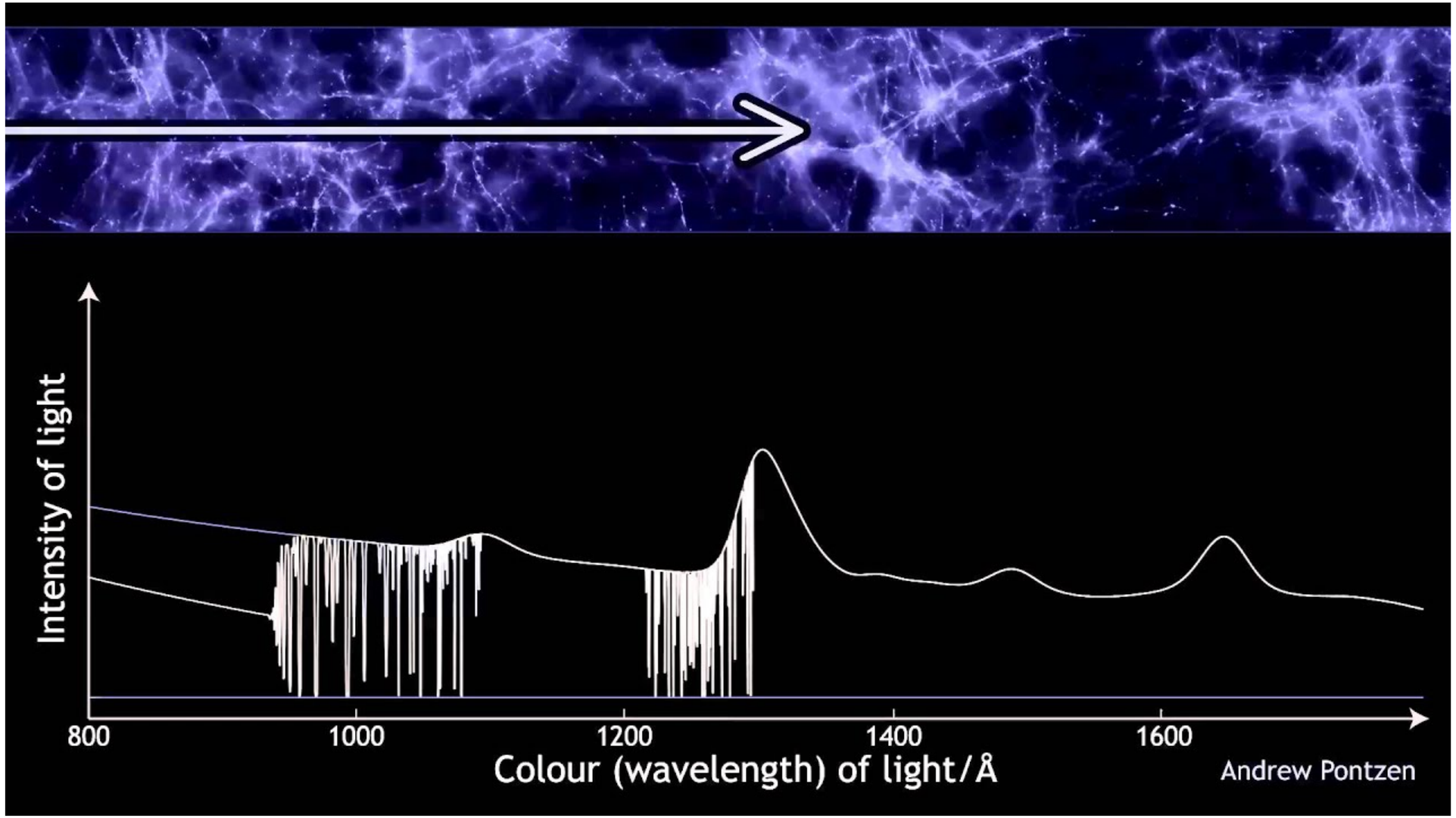
obs: Weymann+81; Cowie+95; Rauch+98

theory: Cen+94; Hernquist+96; Miralda-Escude+96; Croft+98; Zhang+97, 98

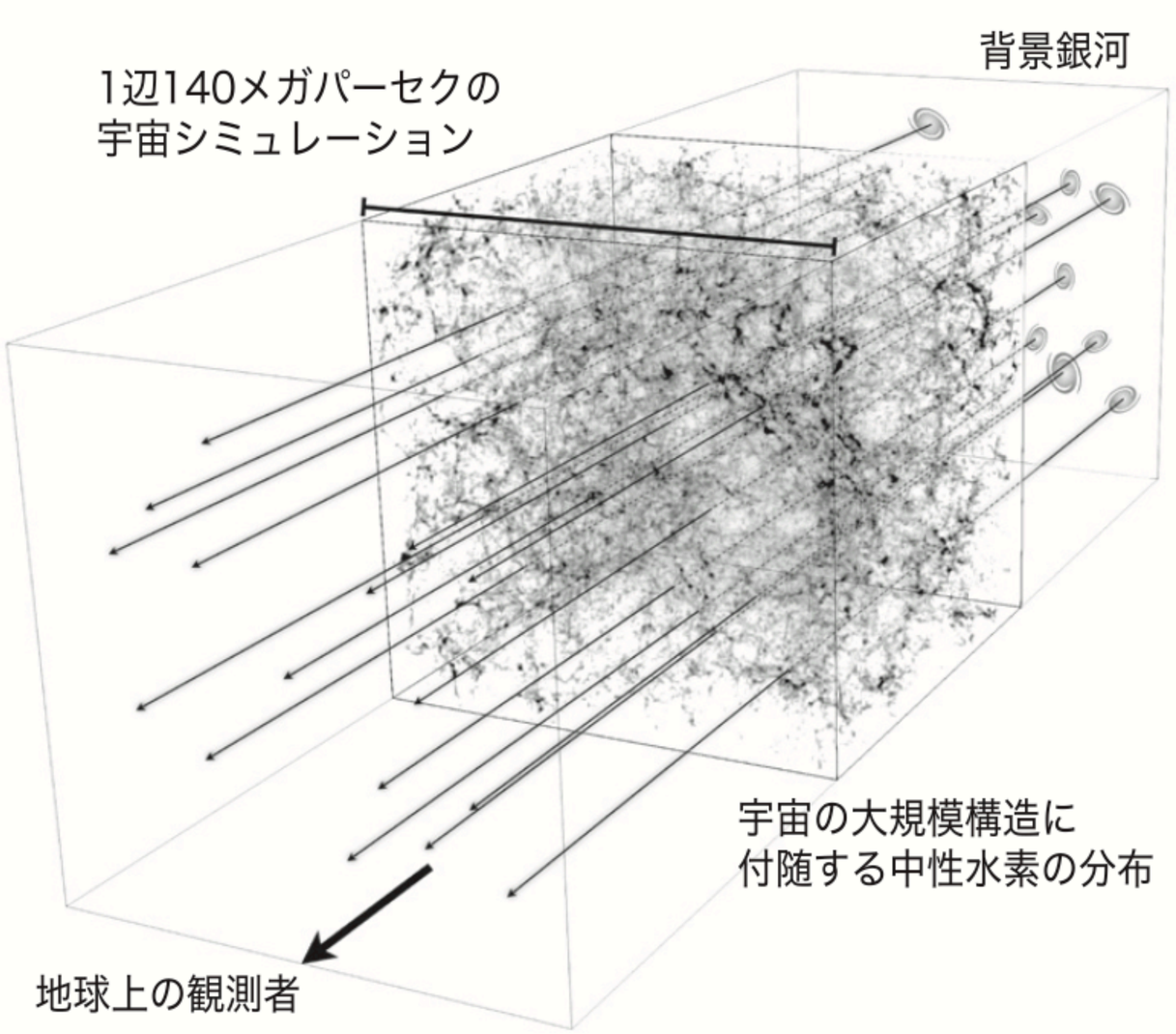
# Ly-α forest demonstration movie

Quasar

(very bright SMBH)



# IGM tomography




**Utilize numerous background star-forming galaxies**

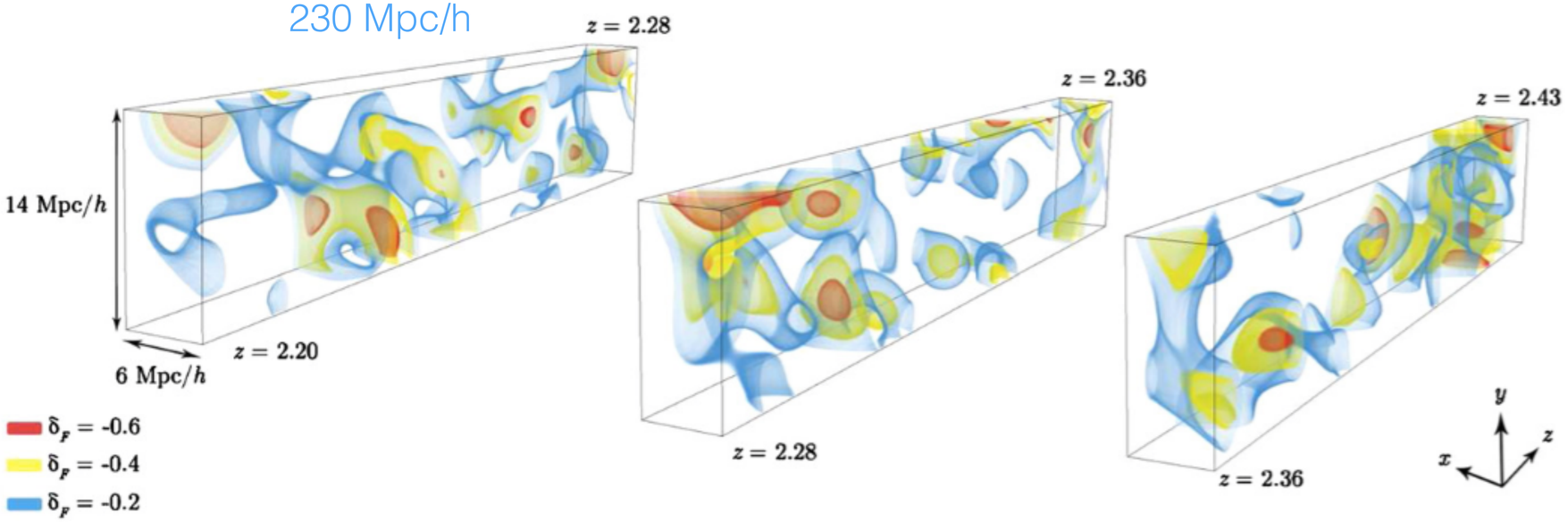
**Many Lyα forest skewers**

**Reconstruct baryon density field**

Shimizu & KN;  from TMT JP Science Book 2020

# Tomographic Reconstruction of 3D Lyα forest absorption

24 star-forming gals (SFGs) @ z~ 2.3 - 2.8




**Can we learn about feedback from this?**

**CLAMATO** survey **(Lee+ '14)**
(COSMOS Lyα mapping and tomography observations)

$z \sim 2.3$

$g \gtrsim 23$ star-forming gal.

eventually 1 deg$^2$
~1000 SFGs

moderate spec res. $R \equiv \frac{\lambda}{\Delta\lambda} \sim 1000$

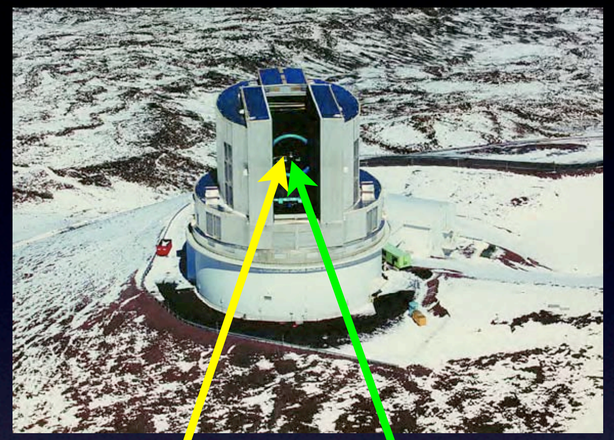
$\epsilon_{\rm 3D} \sim 2 - 5\ {\rm Mpc}/h$

(60Mpc/h)$^2$ x 300Mpc/h

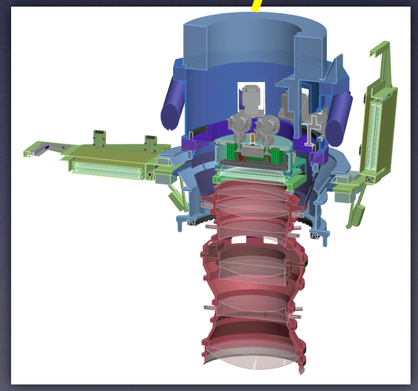
# SuMIRe /PFS

**(Subaru Measurement of Images and Redshift)**

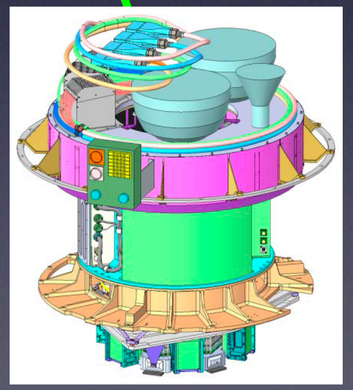
- a 5+5 year survey program
- exploiting FOV ~1.5° of 8.2m Subaru
- Imaging with Hyper-SuprimeCam (HSC)
  - 870M pixels
  - ~20M galaxy images, 1400 sq. deg.
  - 2014–2019, 300 nights
- spectroscopy with PrimeFocusSpectrograph (PFS) ≠ PSF
  - 2400 optical fibers
  - ~4M redshifts
  - ~~2019–2023~~? 300 nights? **2022~**
- *like SDSS on 8.2m telescope!*



Subaru



HSC



PFS

**slide credit:** *(H. Murayama)*

# Producing light-cone

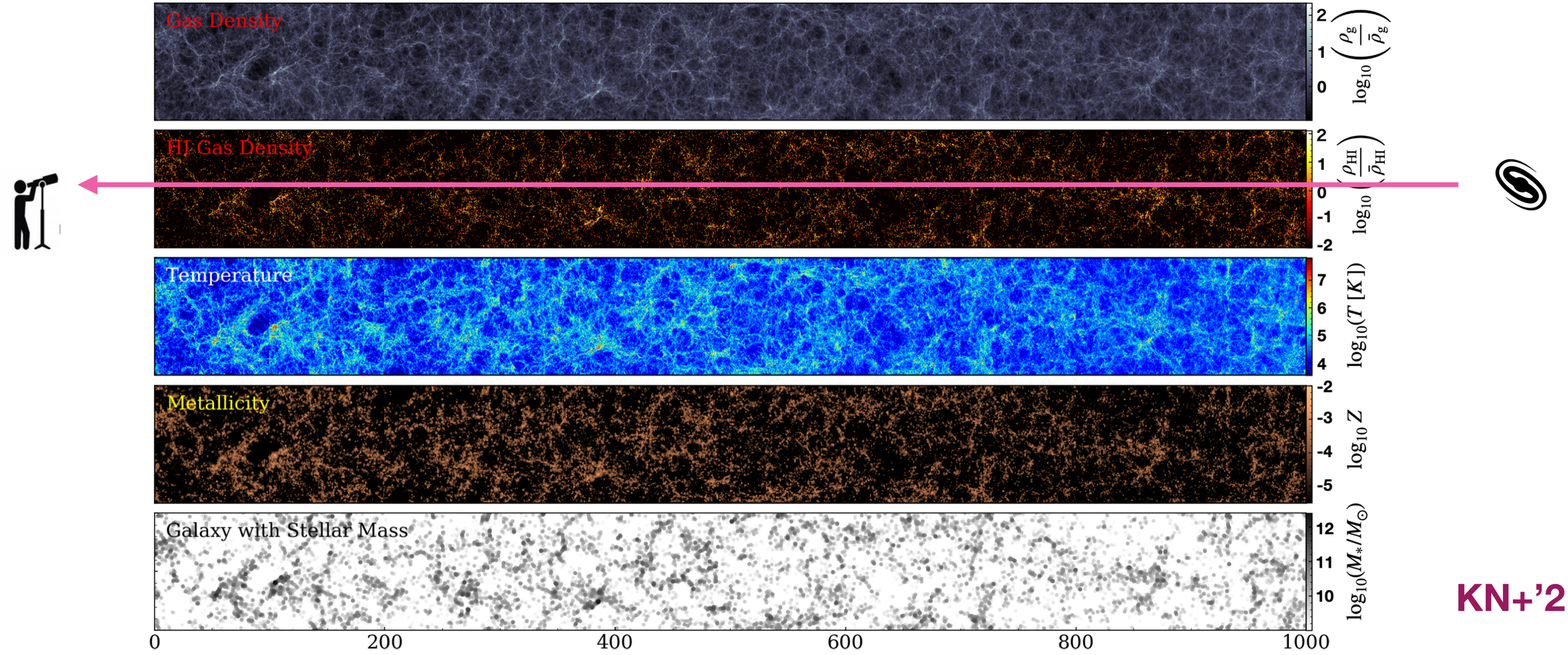
**GADGET3-Osaka cosmological simulation: $L_{box}$= 100 Mpc/h, N= 2 x $512^3$**

w/ various models

1. No-feedback
2. Const. wind velocity (Springel & Hernquist '03)
3. Osaka feedback model (Shimizu+'19)
4. FG09 vs. HM12 UVB,
5. Self-shielding or not.

(but no AGN FB yet)

**Light-cone @ z~2-3,** $100\,h^{-1}\mathrm{cMpc}\,(\mathrm{height}) \times 1\,h^{-1}\mathrm{cGpc} \times 10\,h^{-1}\mathrm{cMpc}\,(\mathrm{depth})$

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# Line-of-sight example (z=2.4 – 2.6)

(~ 2 connected simulation box)

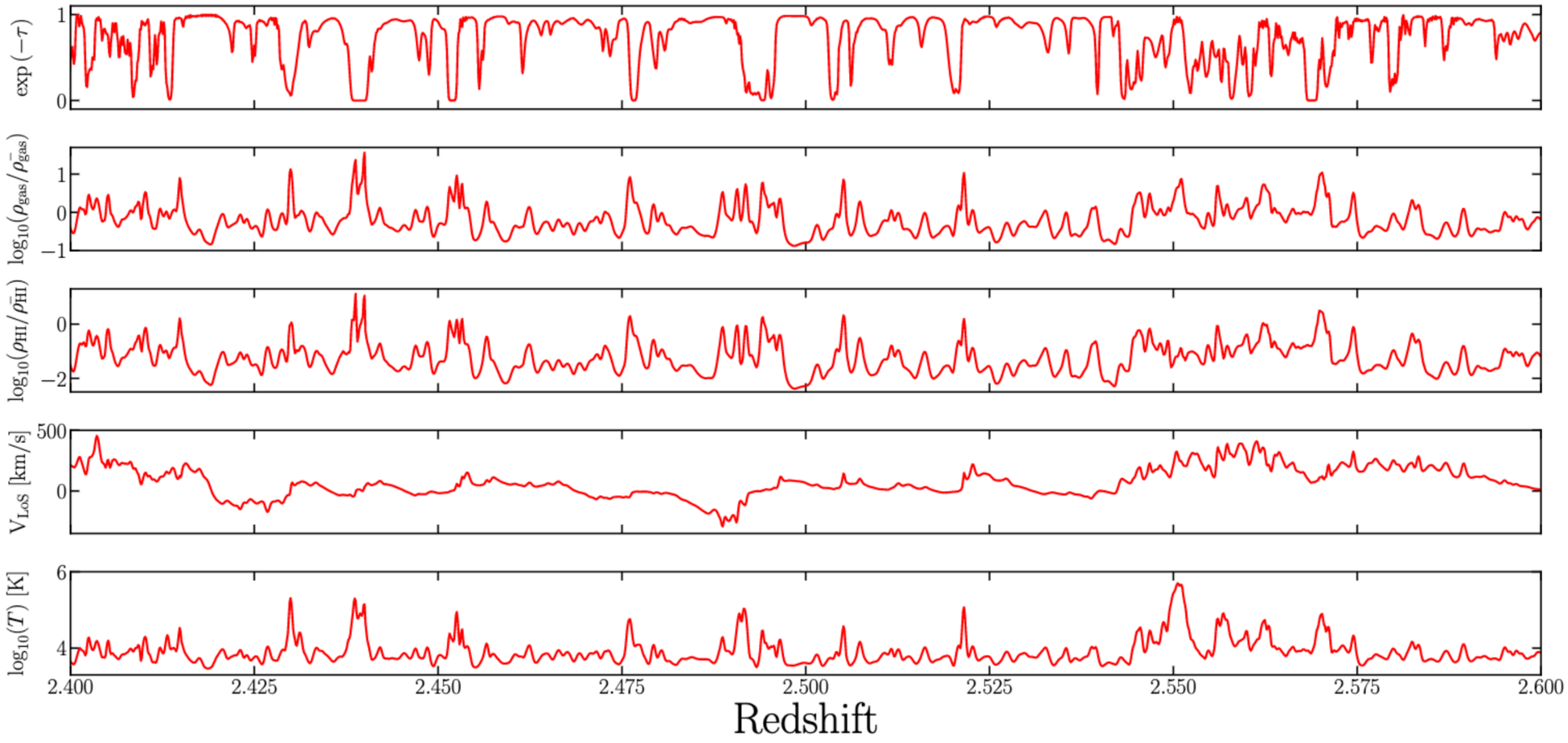
transmission

gas overdensity

HI overdensity

peculiar velocity

temperature




Various statistics can be computed from this: 1. Flux PDF, 2. 1D $P_k(v)$, 3. Flux contrast (1D, 2D)

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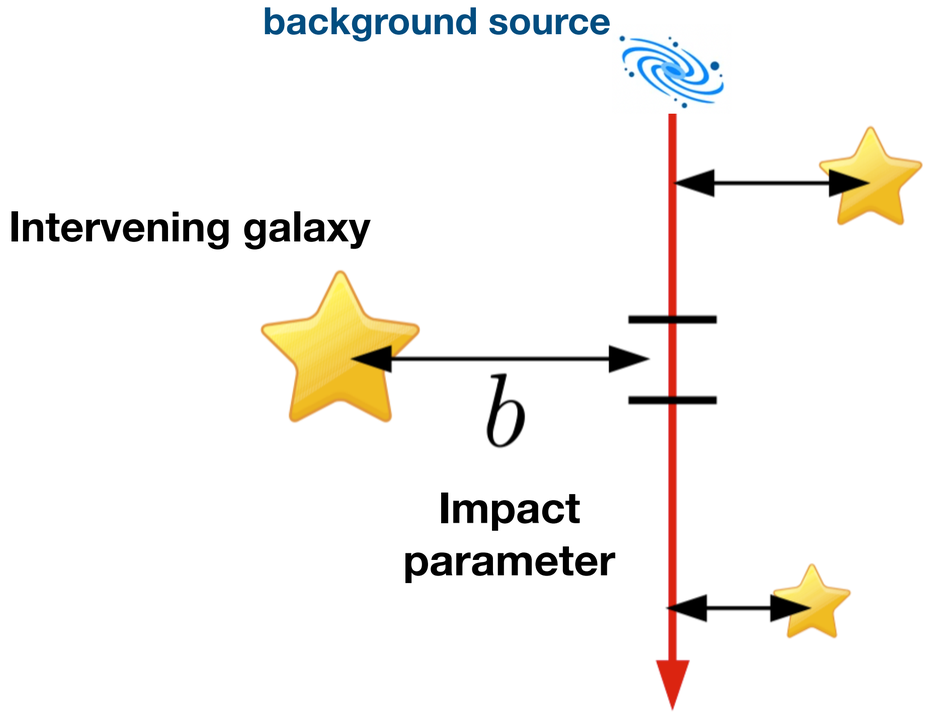
# Lyα forest mean flux contrast vs. Impact param.

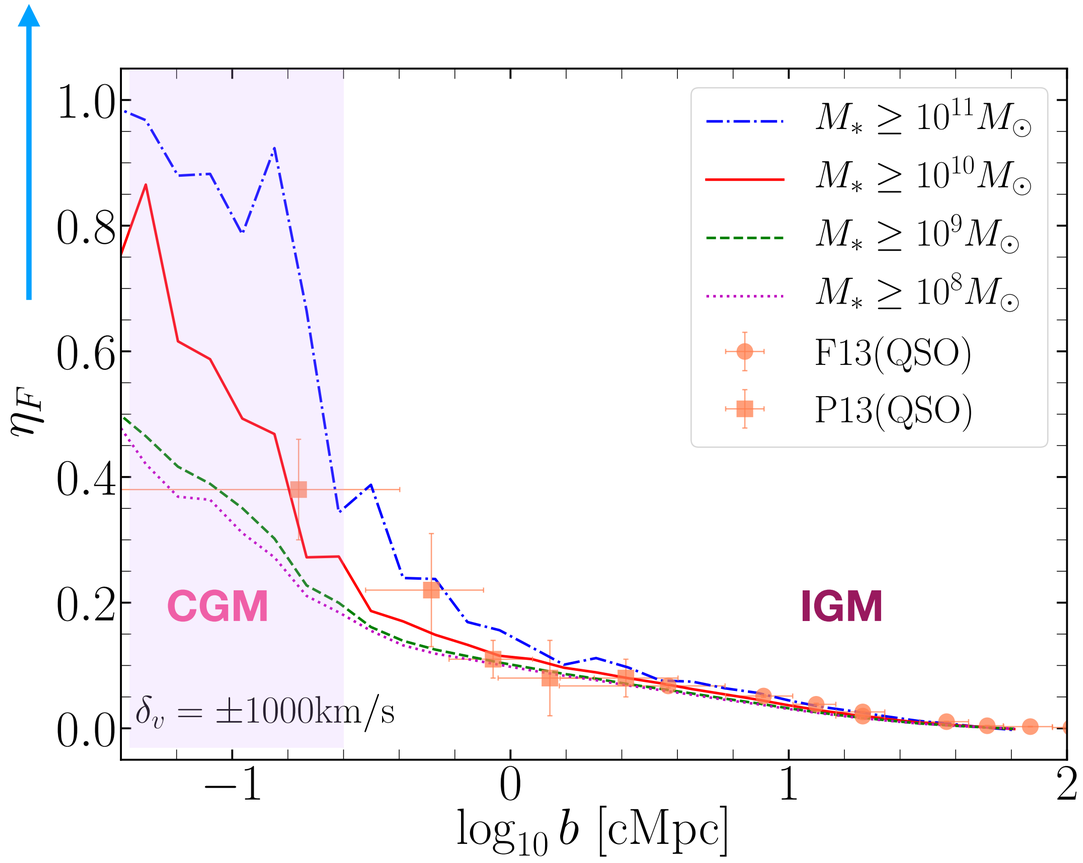
**Flux Contrast**

$$\eta_F \equiv -\delta_F = 1 - \frac{F}{\langle F \rangle}$$

$$F = e^{-\tau}$$



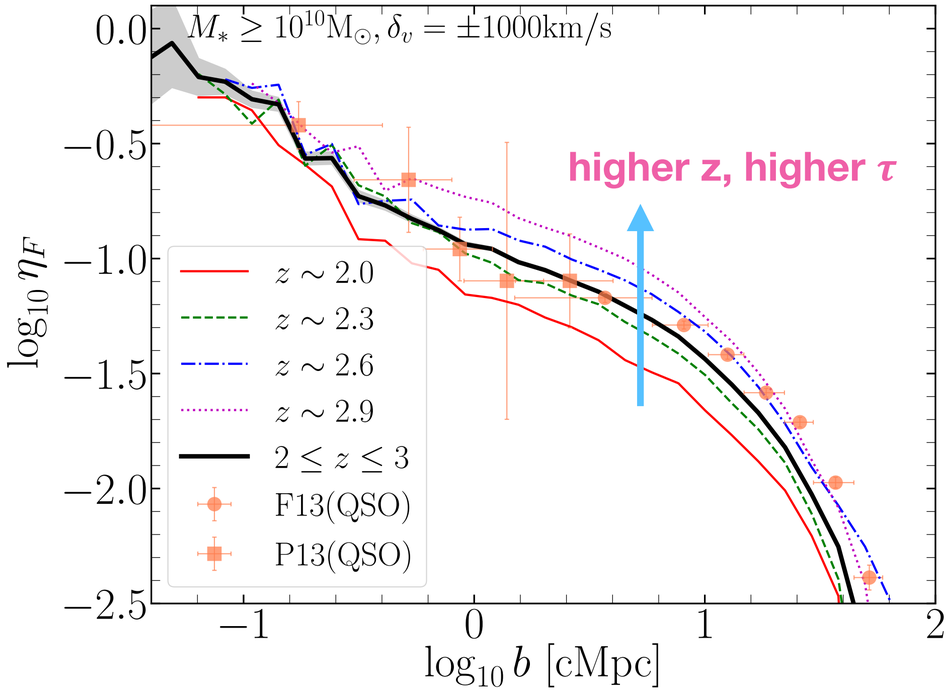

Stronger HI absorption




**Impact Parameter from galaxies**

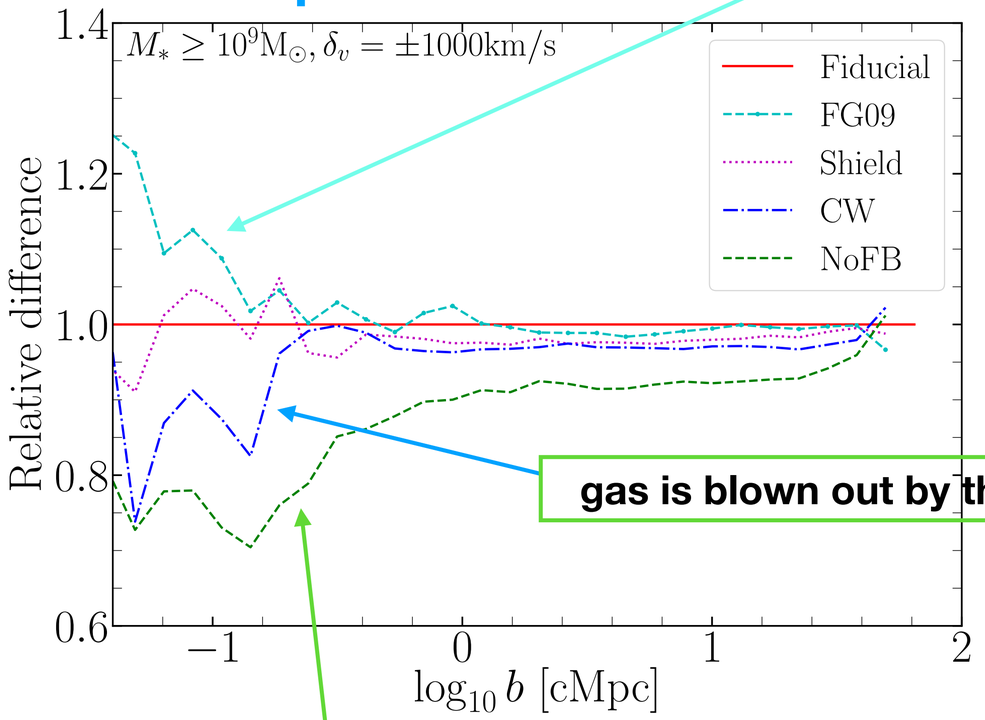
# Flux Contrast vs. Impact Parameter

## Redshift dependence




## Feedback model dependence

lower photoioniz. rate in FG09 than HM12




gas is blown out by the strong CW

much gas is consumed by SF

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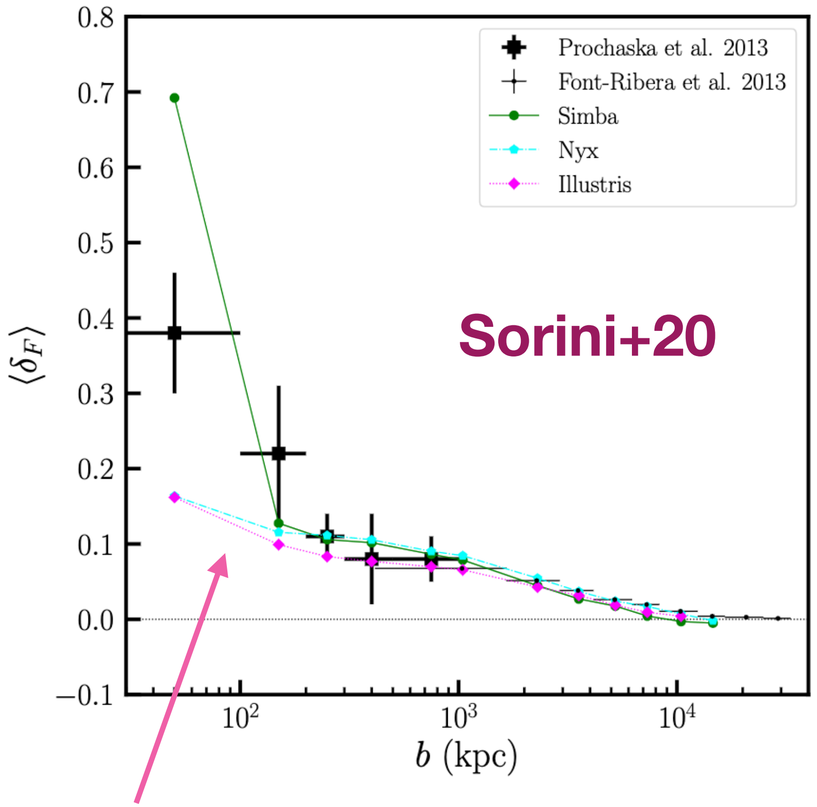
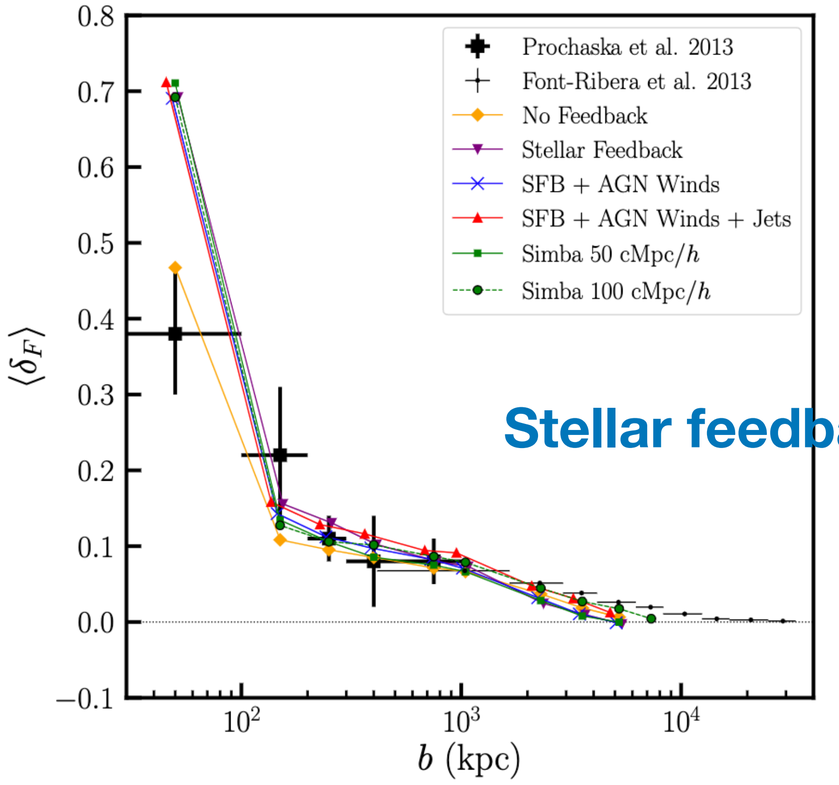



Sorini+20

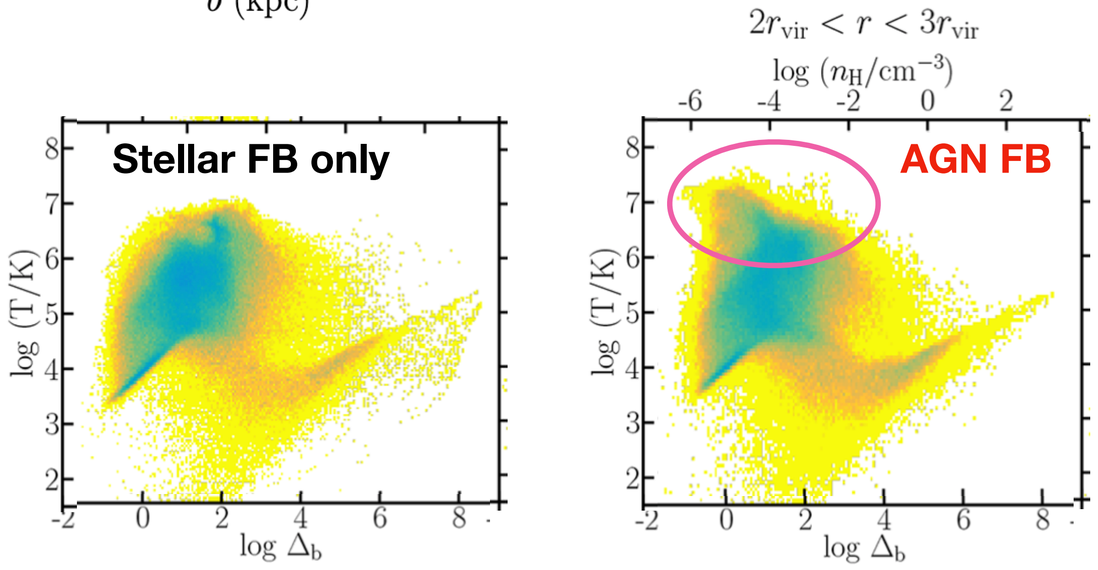
Nyx & Illustris underpredict.




Stellar feedback is the dominant driver.

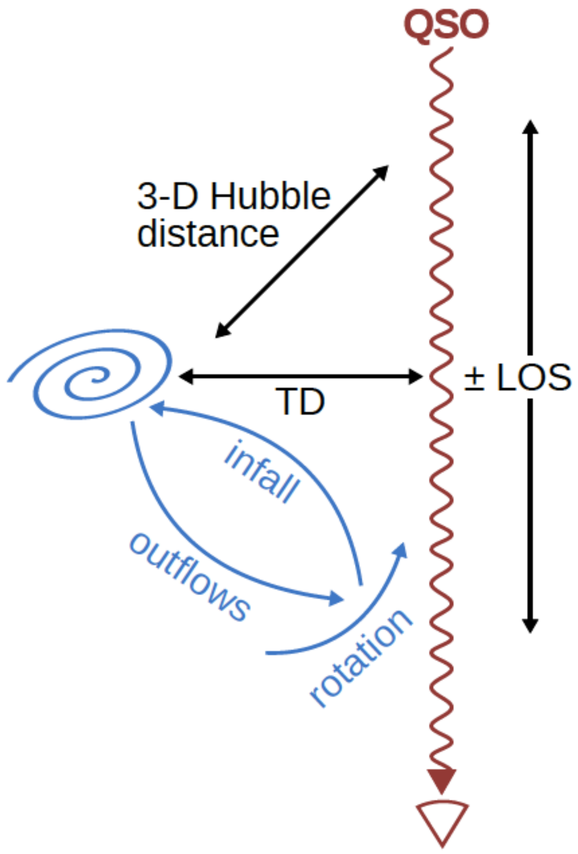
AGN subdominant.

Sorini+20

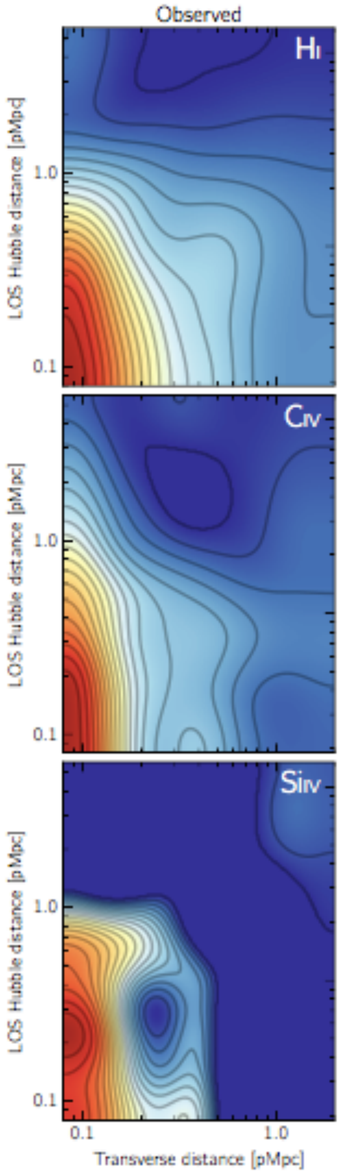


# 2D Velocity Structure

## Turner+'17 (KBSS): log(τ) in color

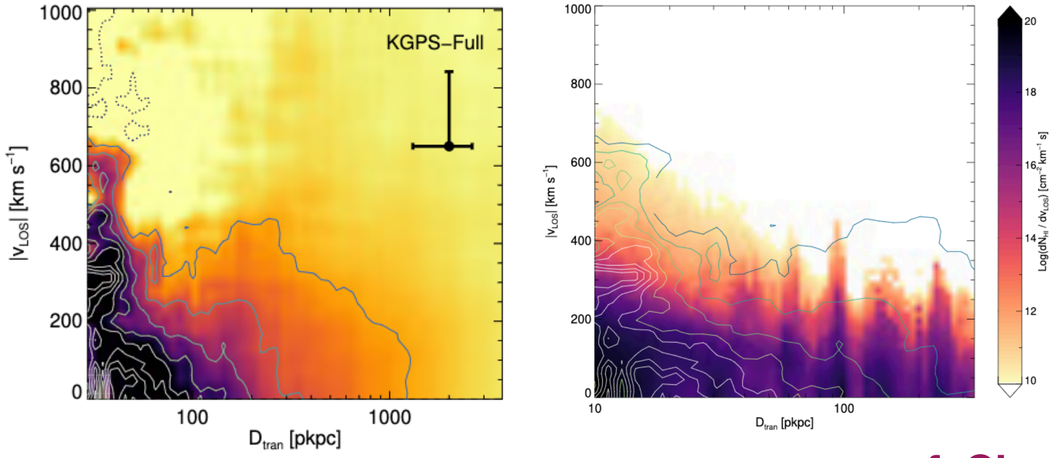



Turner+17

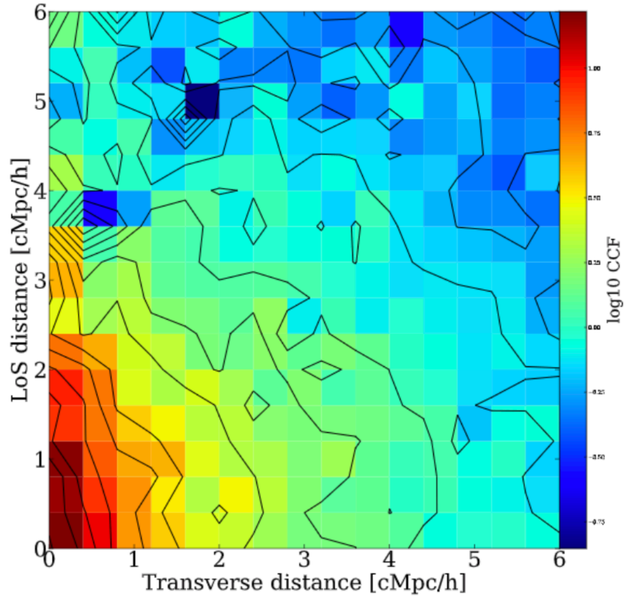



KBSS data

FIRE sim




cf. Chen+20

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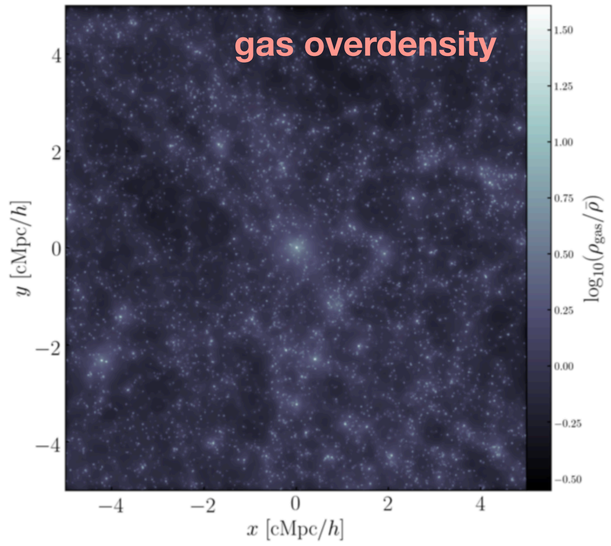
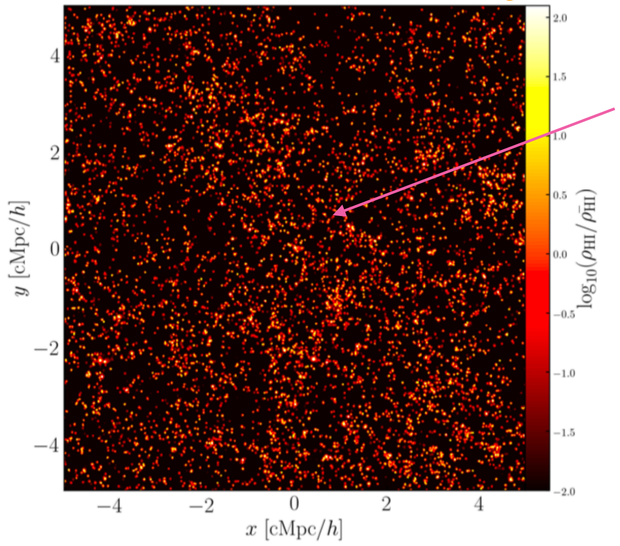
# Protocluster @ z~2.1

$M_h \sim 10^{14}\, h^{-1} M_\odot$

$R_{\rm vir} \sim 1\,{\rm cMpc}$

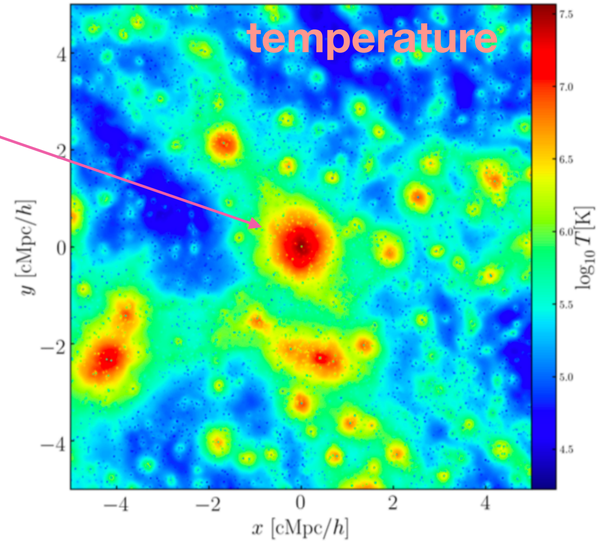


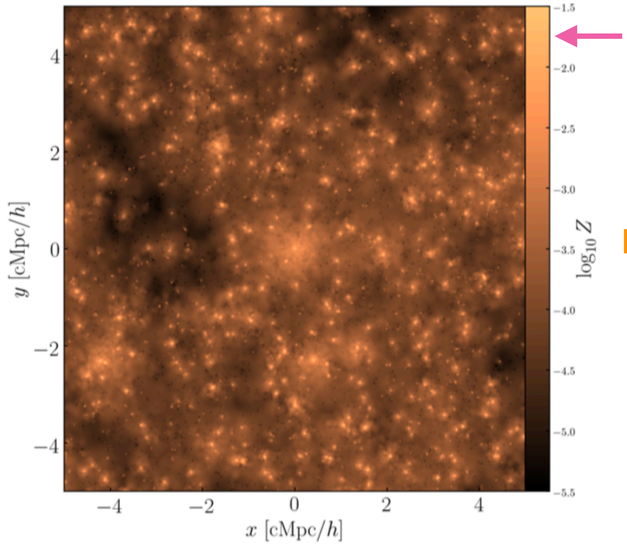

HI overdensity




HI gas contributed more by individual galaxies rather than diffuse ICM

hot X-ray emitting gas



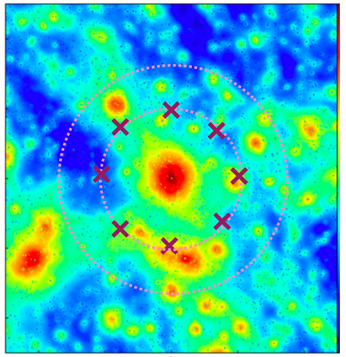

← solar

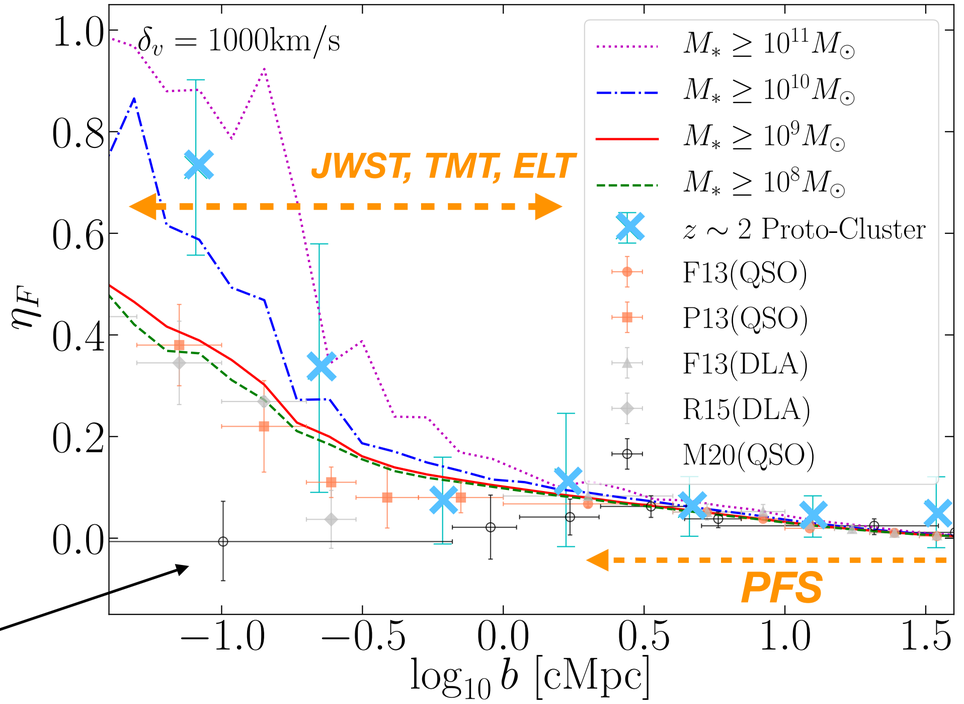
metallicity

KN+'21

# Flux contrast of a protocluster

z~2.2



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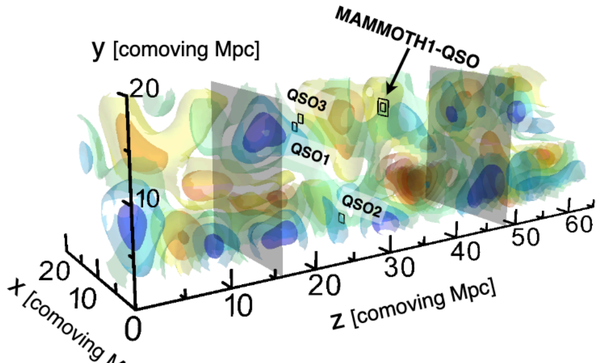
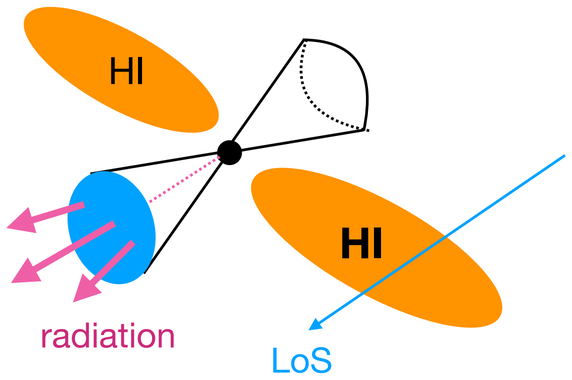
asymptote to cosmic IGM

Mukae+'20

MAMMOTH QSO region

proximity effect?




Consistent w/ Sorini+'18

→ support for ΛCDM

cf. Prochaska+13; Lee+14; Cai+16, 17; Liang+20; Miller+19

# Summary

- **Ly$\alpha$ absorption** flux contrast & **IGM tomography** — useful probe of feedback in the **CGM/IGM**
- 2D velocity structure could reveal gas dynamics in **CGM**
- AGN feedback effect — needs to be studied more.
- Proto-cluster flux contrast → *PFS, ELT/TMT, FOREVER22*

Yajima+'21

KN+21, ApJ, 916, 66