

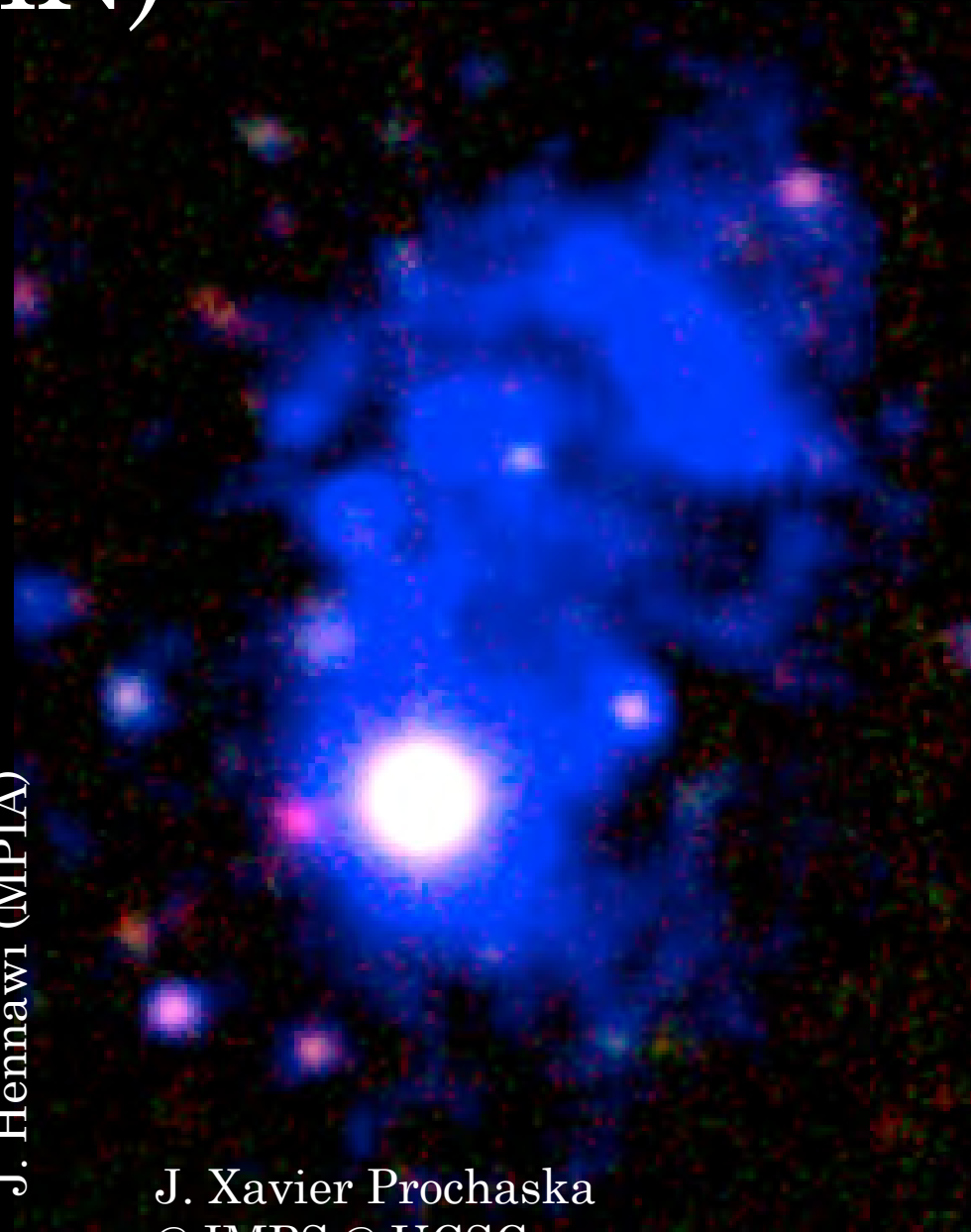
# The Rise of Enormous Ly $\alpha$ Nebulae (ELAN)



Fabrizio Arrigoni Battaia  
(ESO)



Camille Leibler  
(UCSC/IMPS)



S. Cantalupo (ETH)



J. Hennawi (MPIA)



J. Xavier Prochaska  
@ IMPS @ UCSC

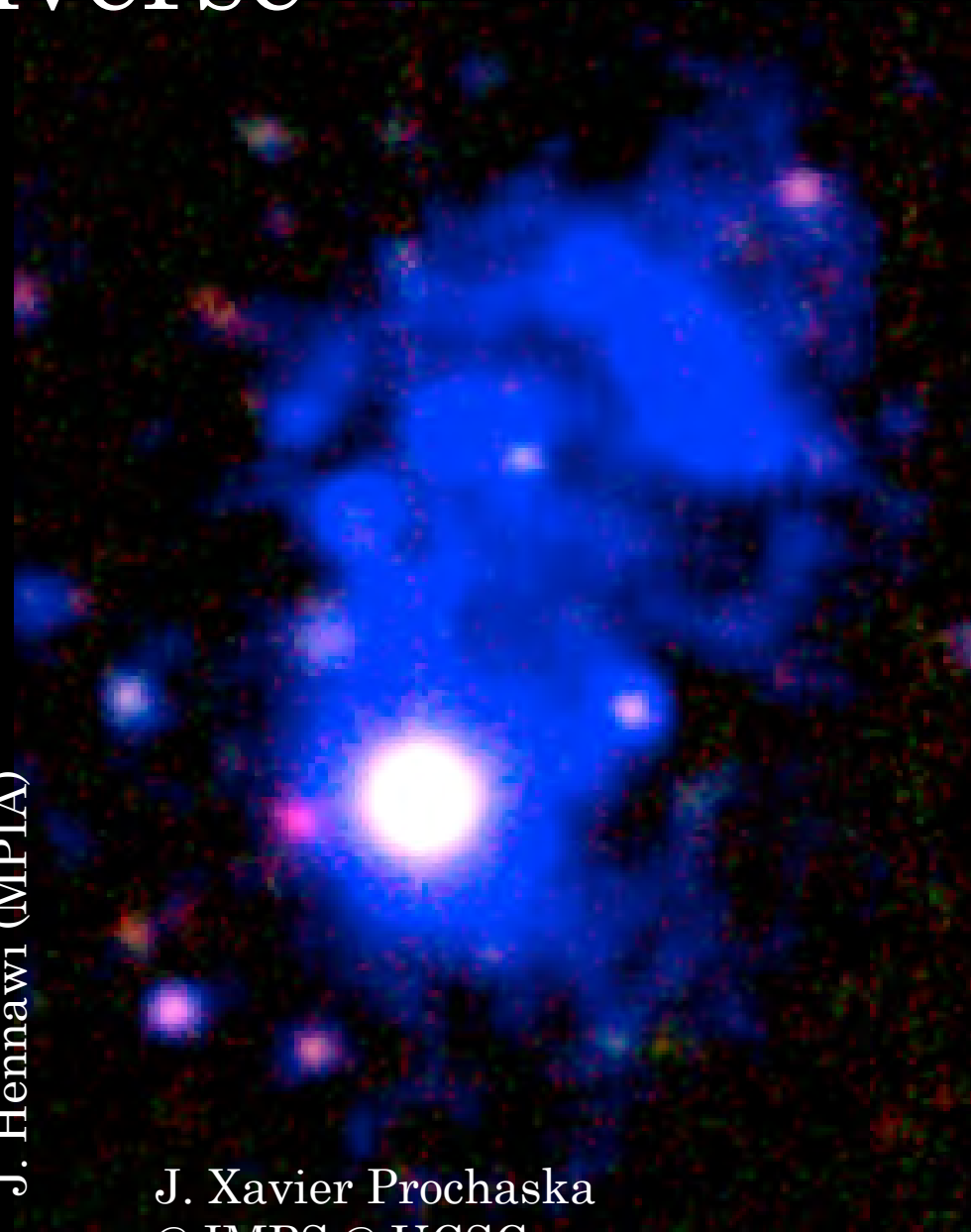
# Rise of the Proto-Galaxy System in the Universe



Fabrizio Arrigoni Battaia  
(ESO)



Camille Leibler  
(UCSC/IMPS)



S. Cantalupo (ETH)



J. Hennawi (MPIA)



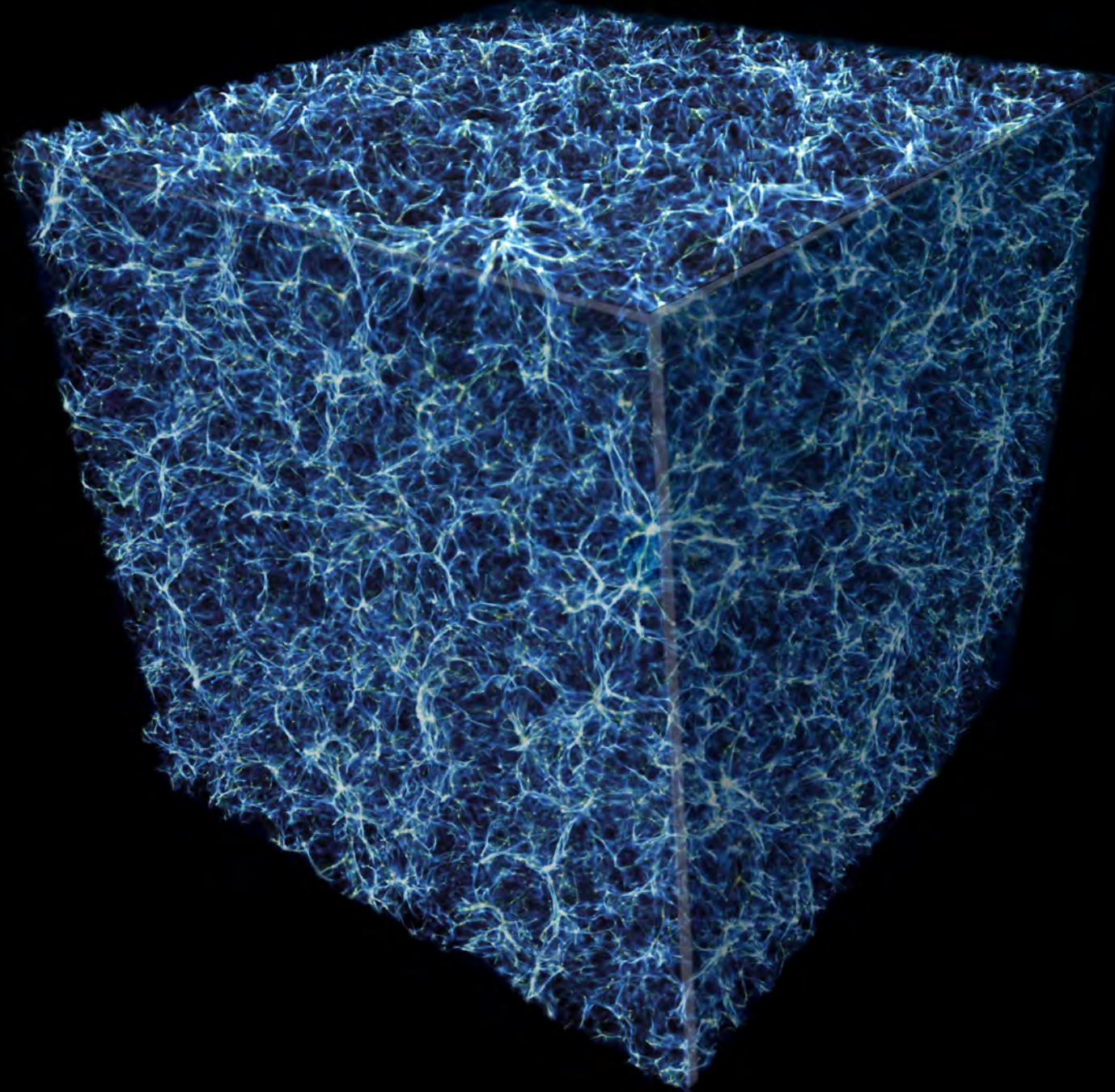
J. Xavier Prochaska  
@ IMPS @ UCSC

# A brief aside...



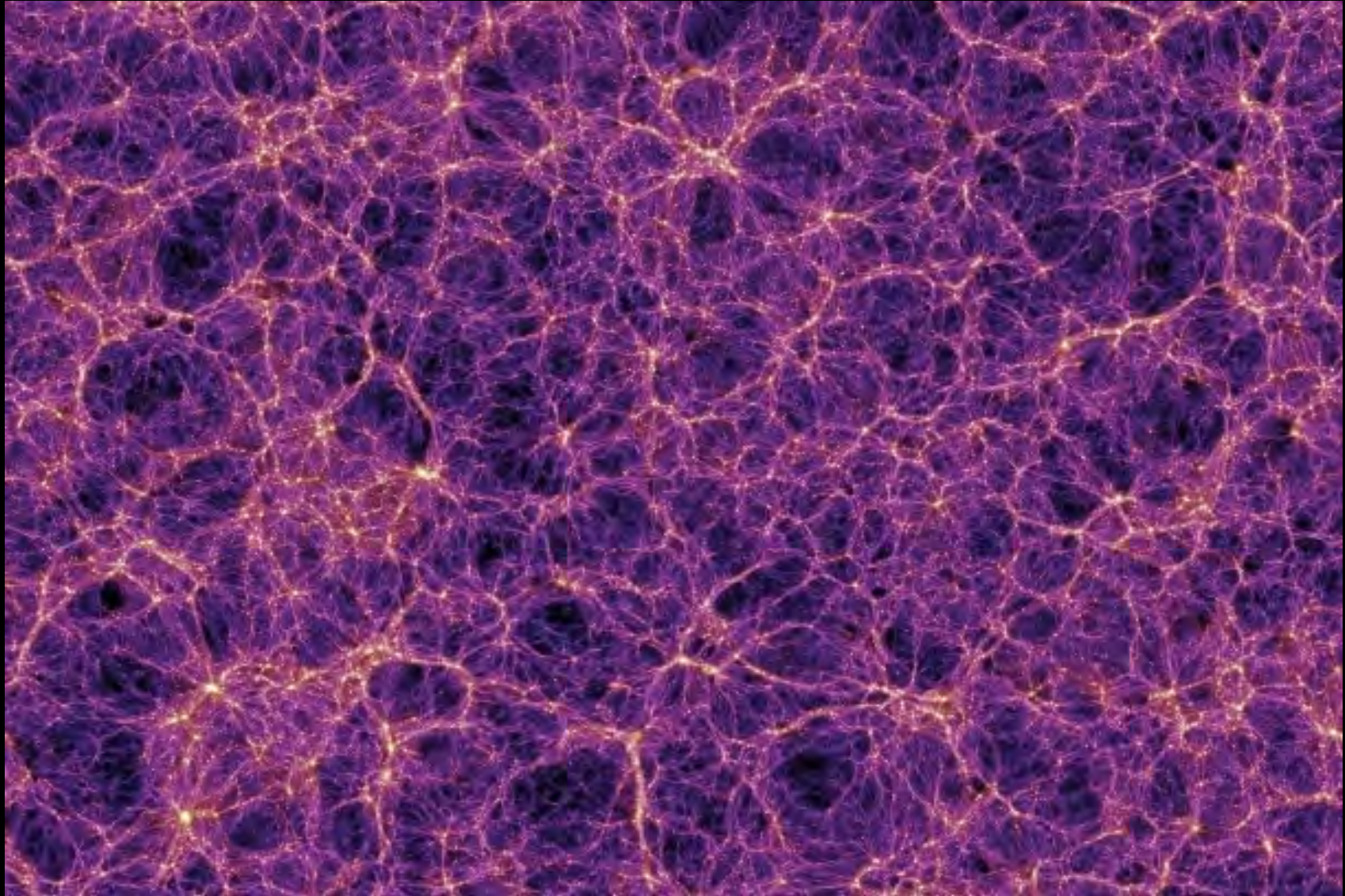


# The Cosmic Web



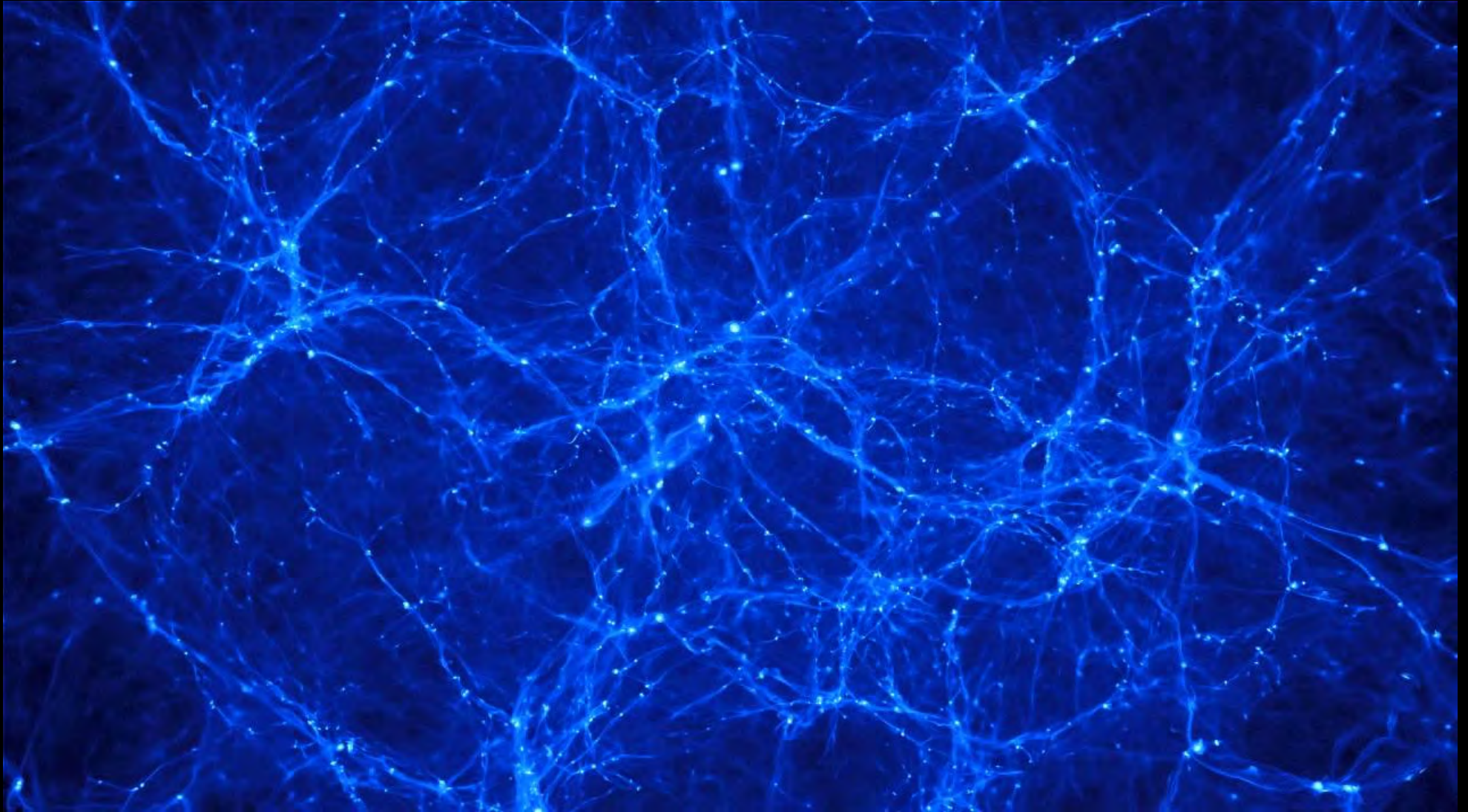


# The Cosmic Web



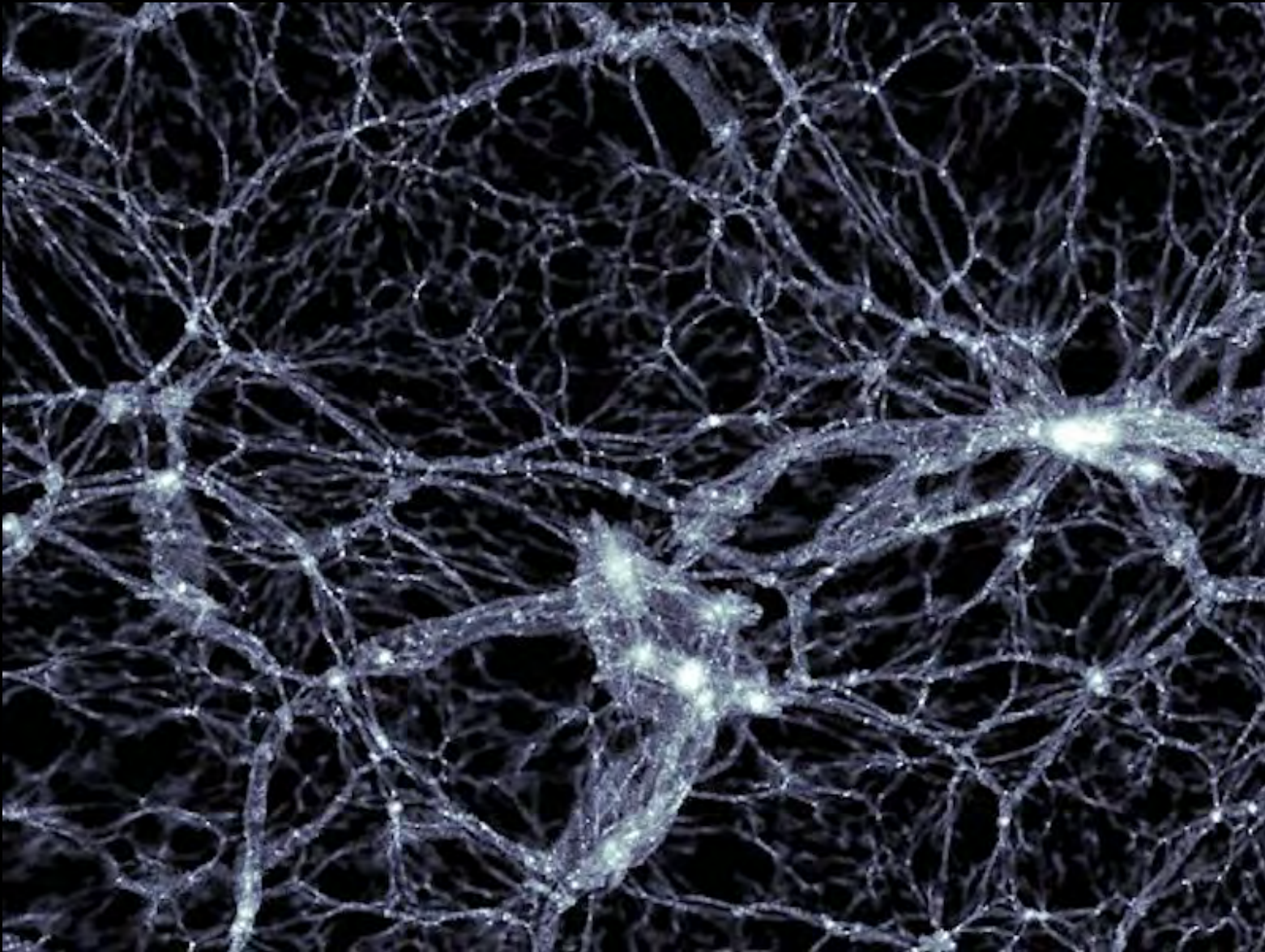


# The Cosmic Web

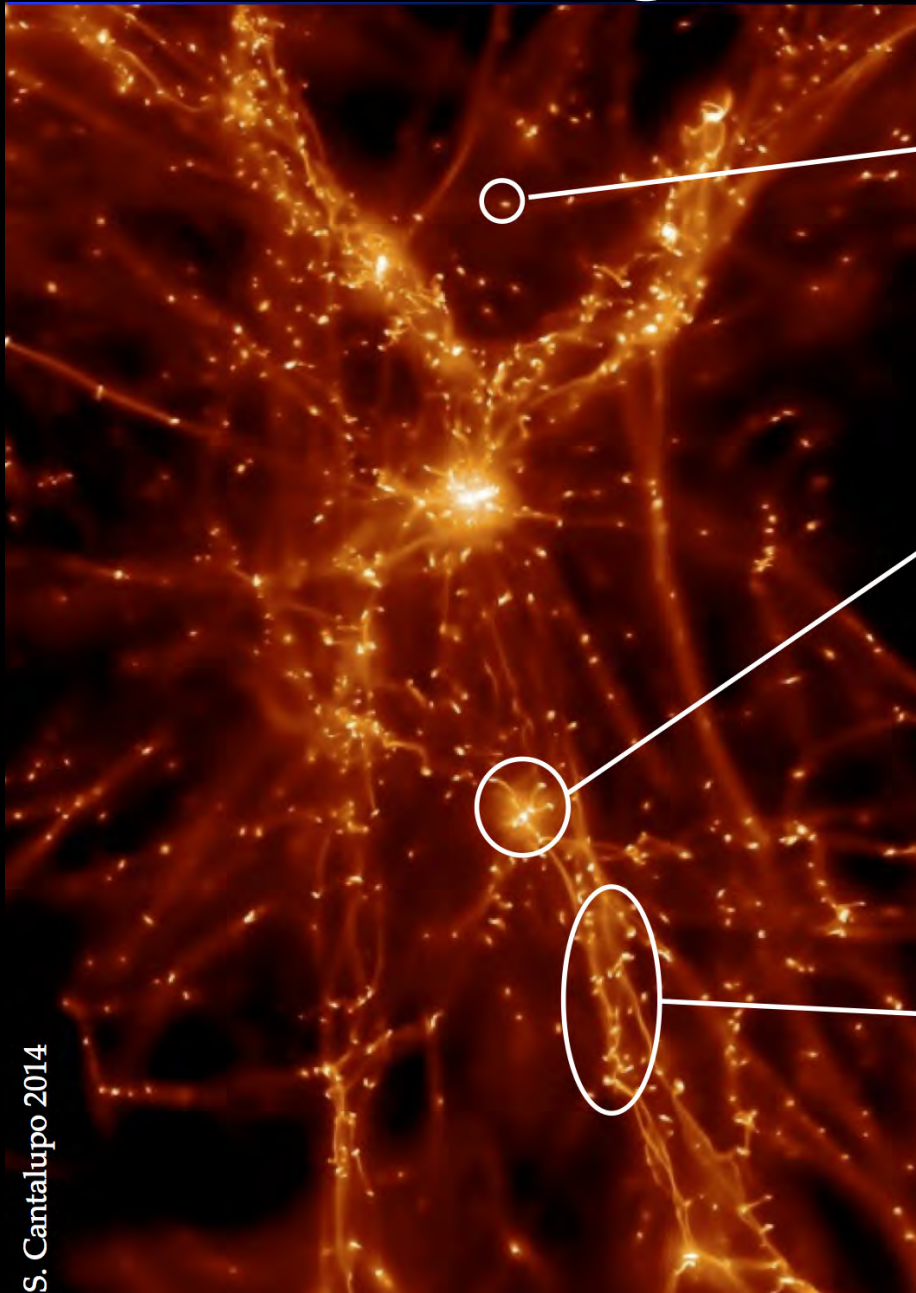




# The Cosmic Web (aka IGM)

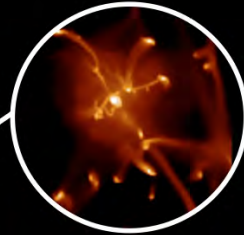


# Resolving the Universe's Web



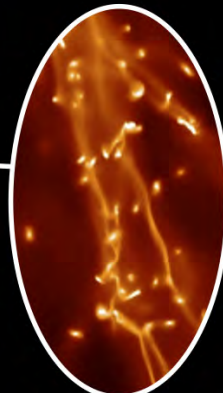
1-10 kpc

How is gas converted into stars?  
Is there a “dark” galaxy phase?



10-200 kpc

How do galaxies get their gas?  
What are the density and temperature of the “Circum Galactic Medium”?

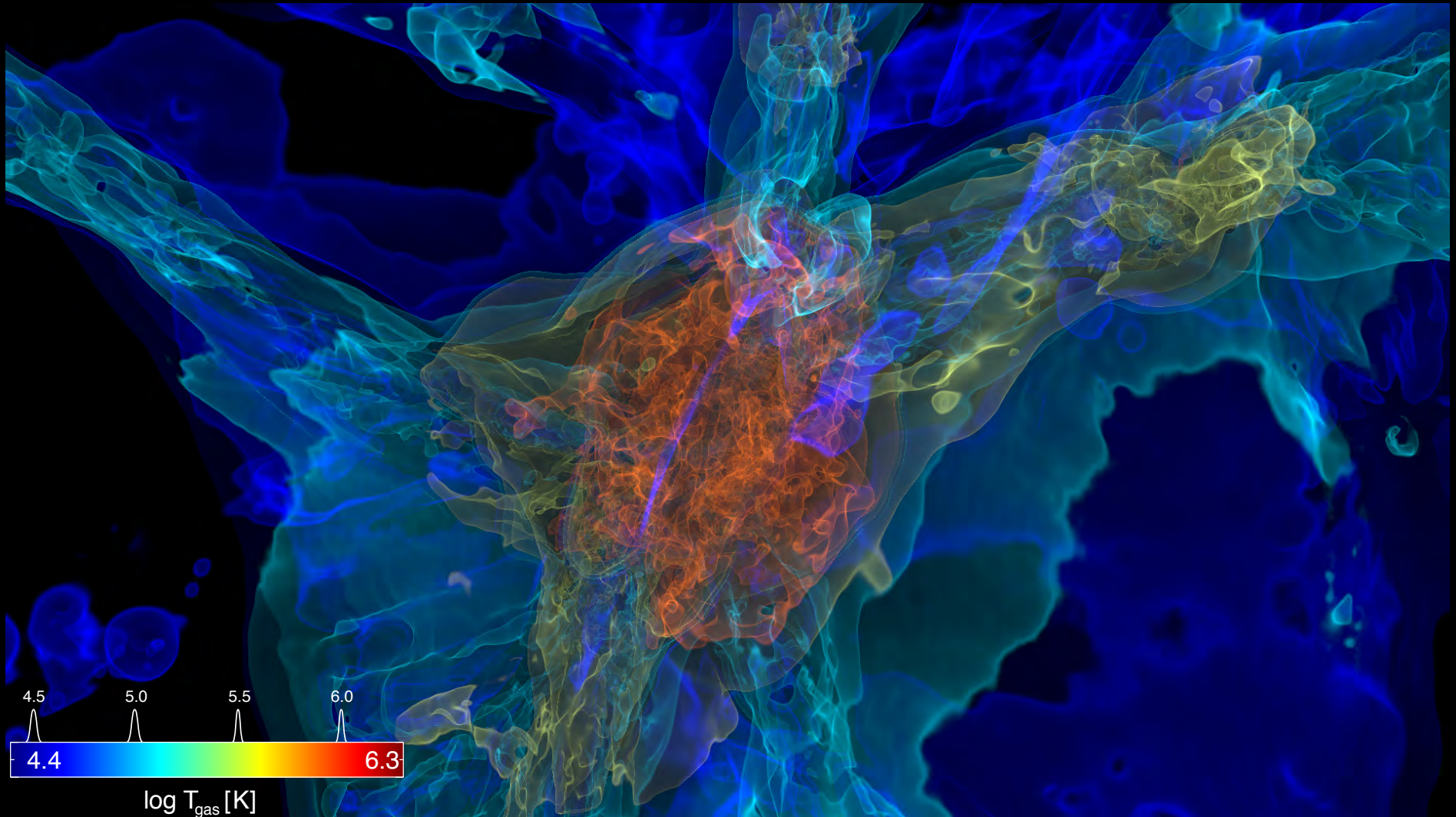


200-1000+ kpc

How are galaxies linked to each other?  
What are the morphology and the small scale properties of the “Cosmic Web”?

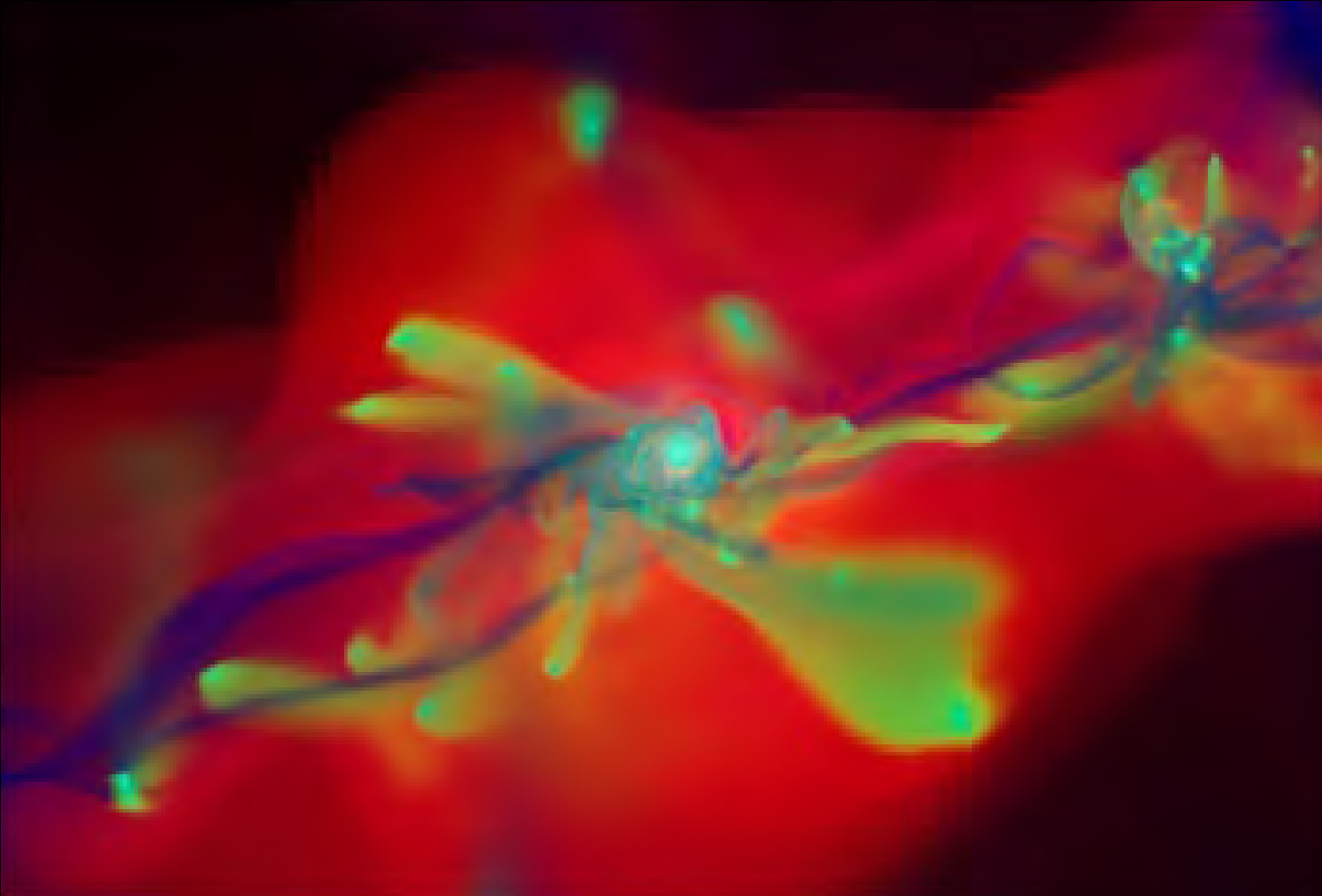


# The Baryonic Halo (aka CGM)



Nelson+15

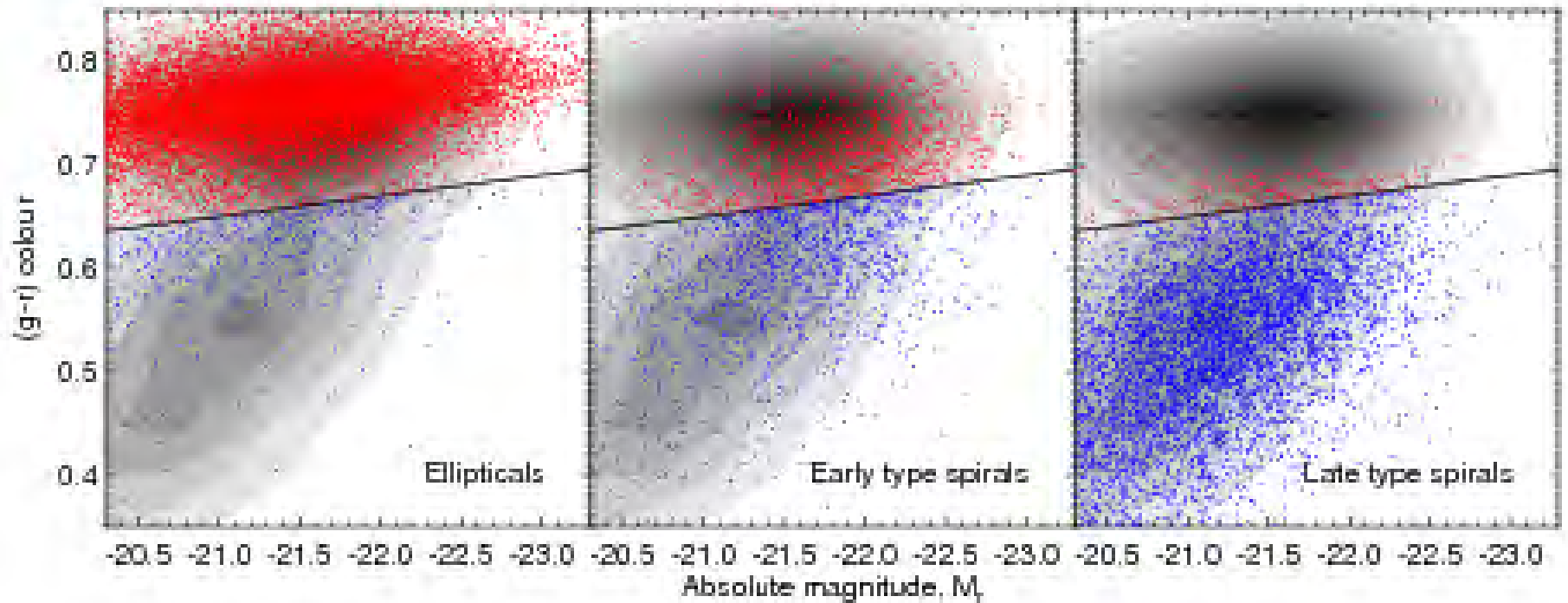
# How does this gas fuel galaxies?



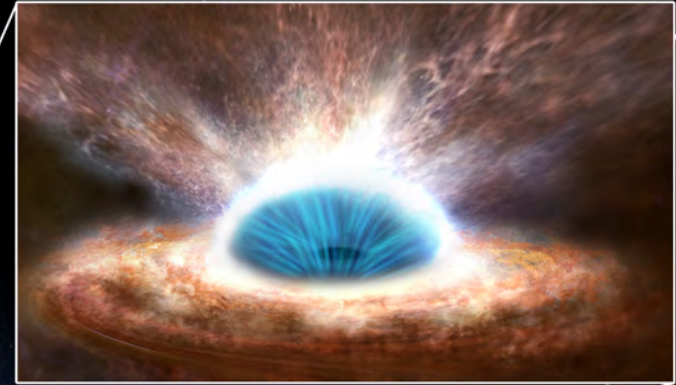
Agertz+12



# What 'Quenched' these Galaxies?



# What 'Quenched' these Galaxies?





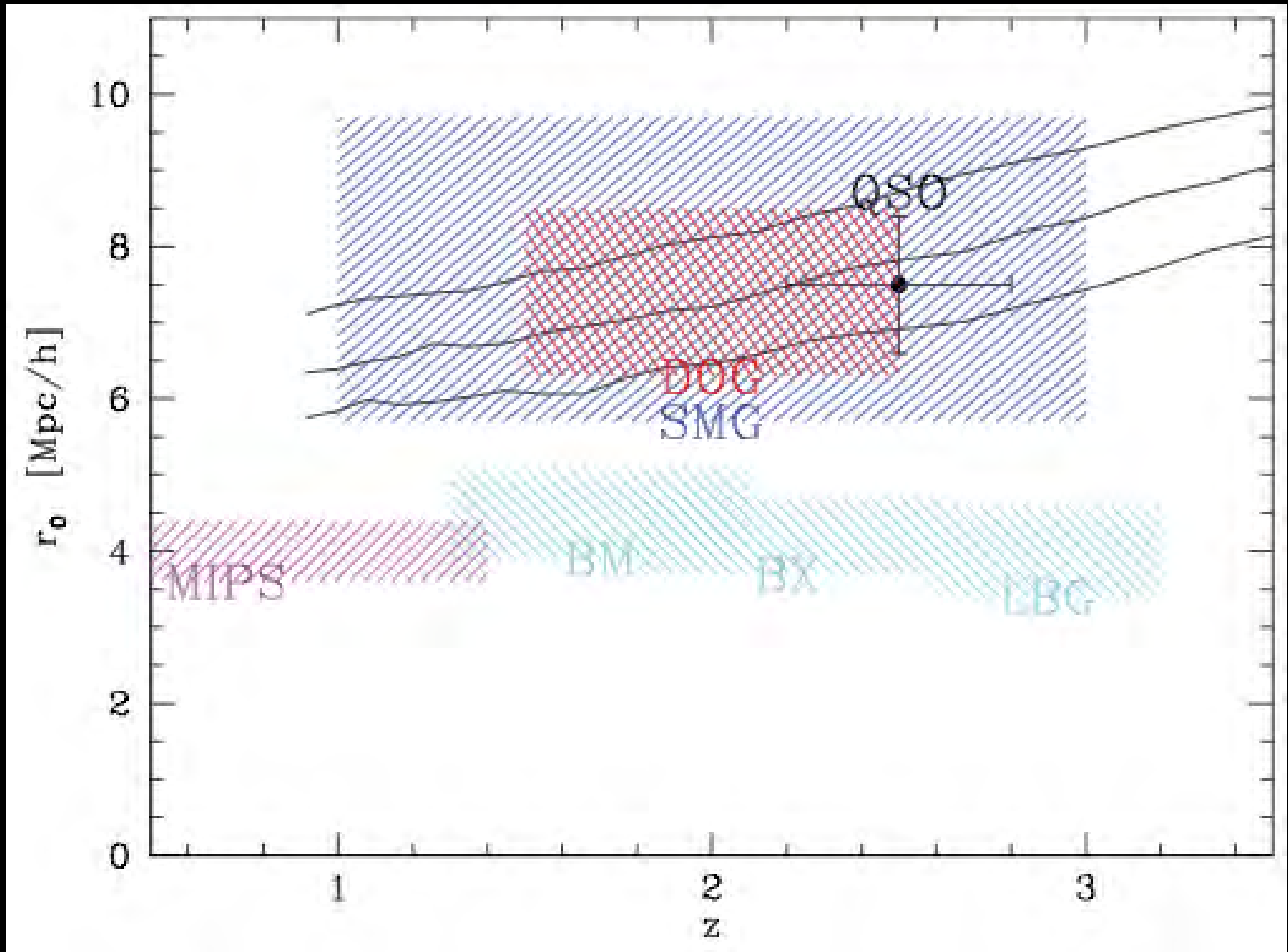
# What 'Quenched' these Galaxies?

Radio Galaxy 3C353  
VLA 3.6cm image



Copyright (c) NRAO/AUI 1999

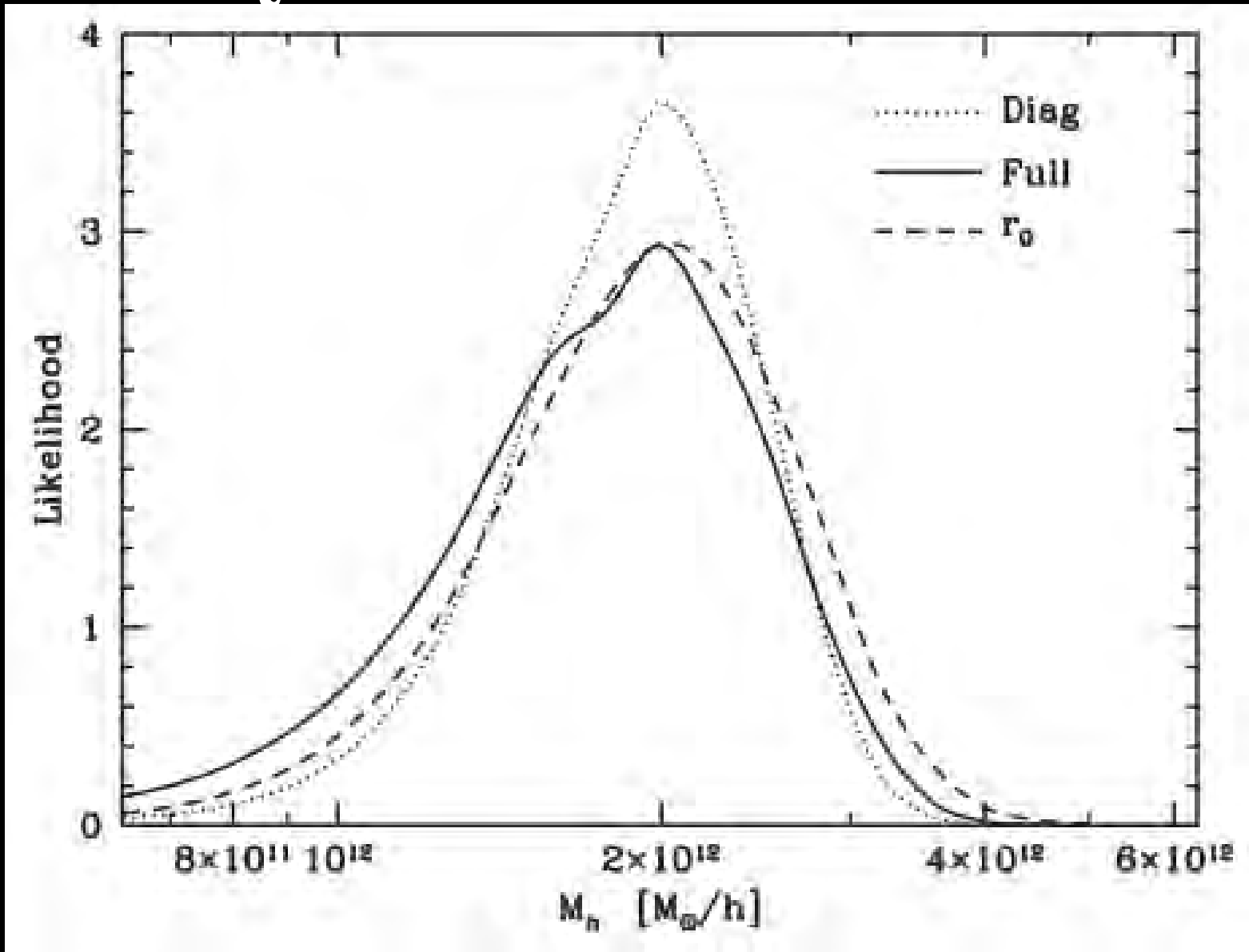
# Quasars 'Tag' Massive Galaxies



White+12

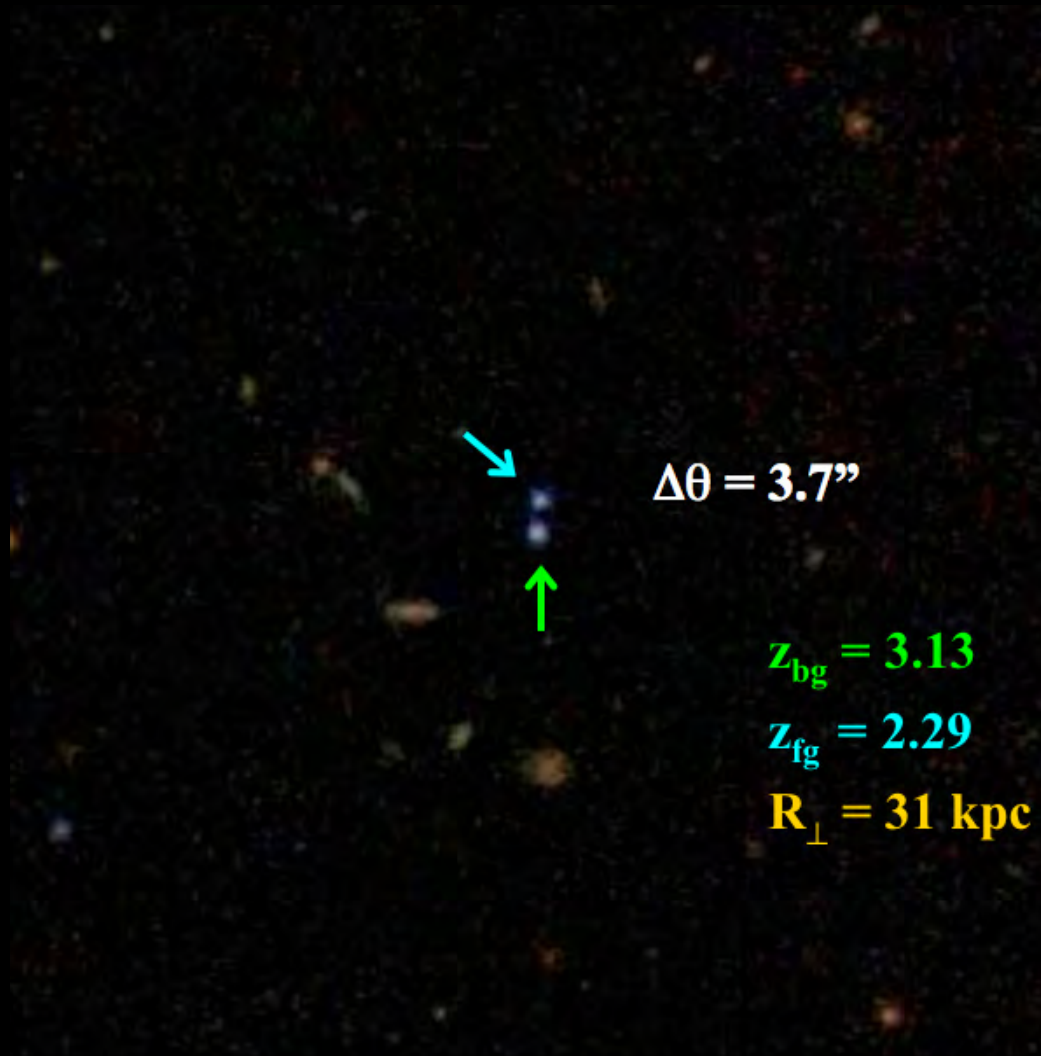


# Quasar Halo Mass



White+12

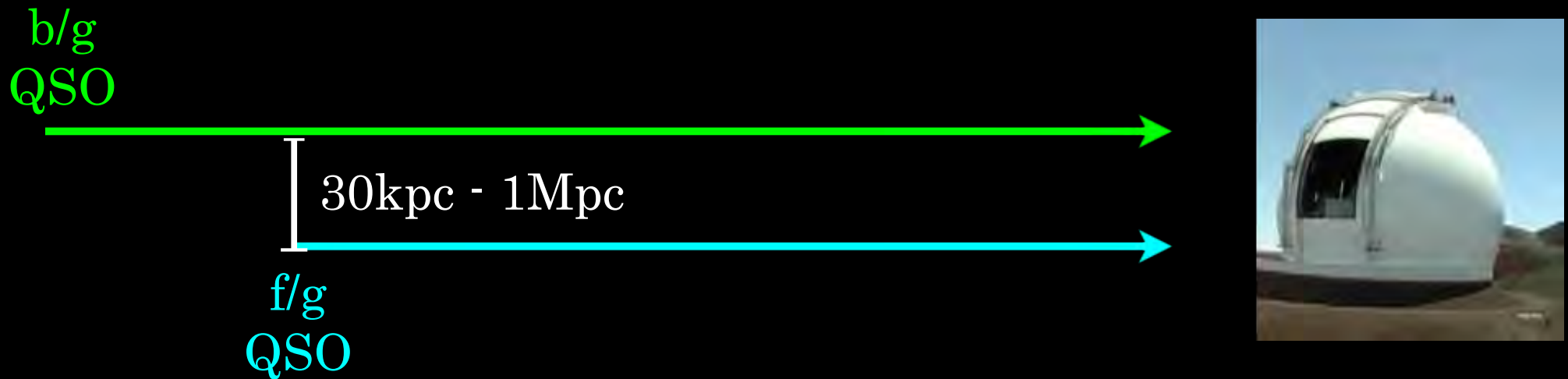
# Quasars Probing Quasars (QPQ)



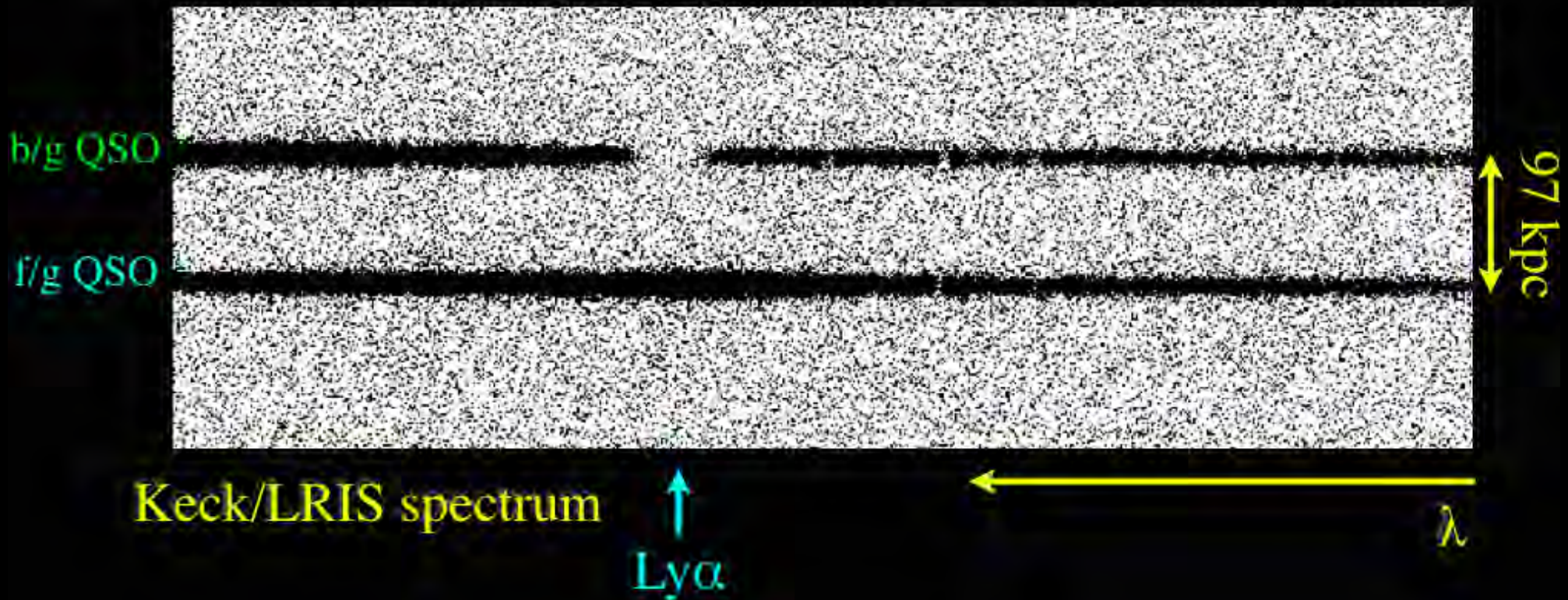
Hennami+05



# Quasars Probing Quasars (QPQ)



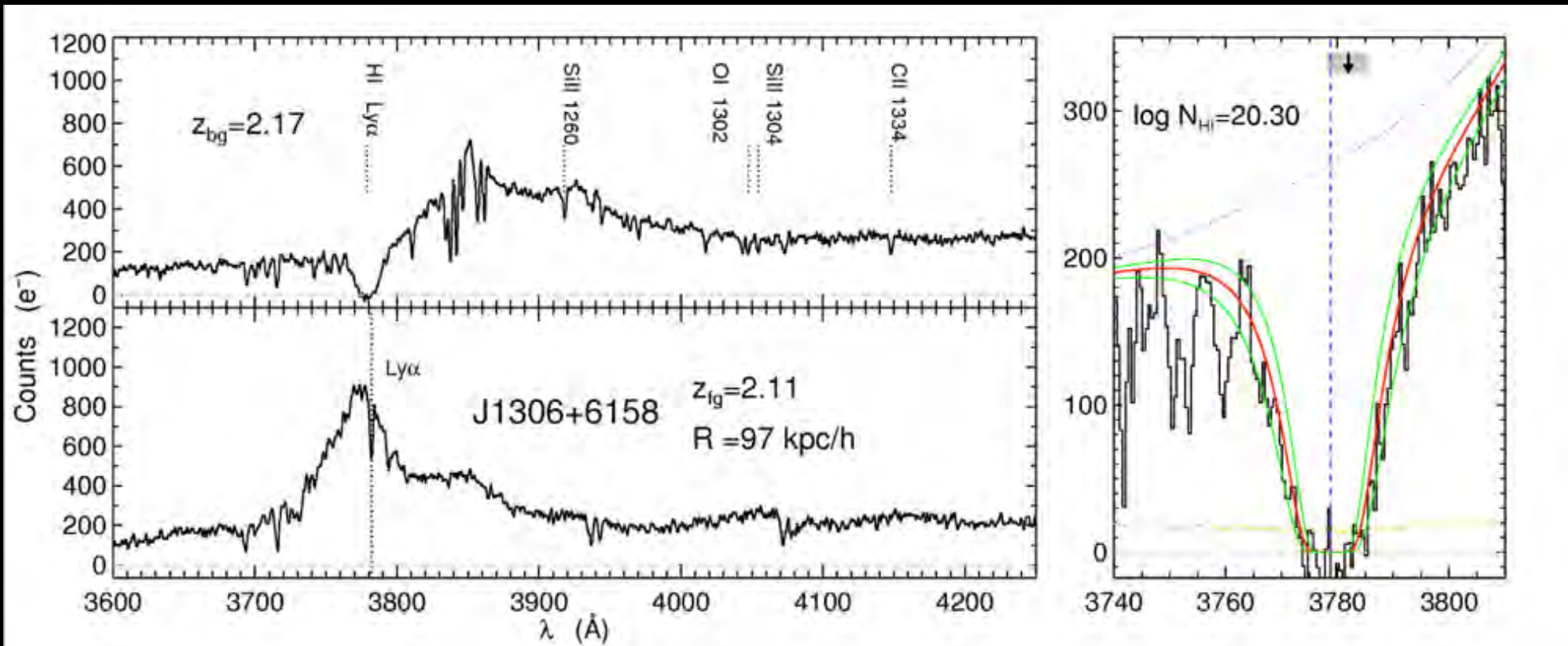
# Quasars Probing Quasars (QPQ)



Strong HI Ly $\alpha$  absorption from gas at the f/g quasar.



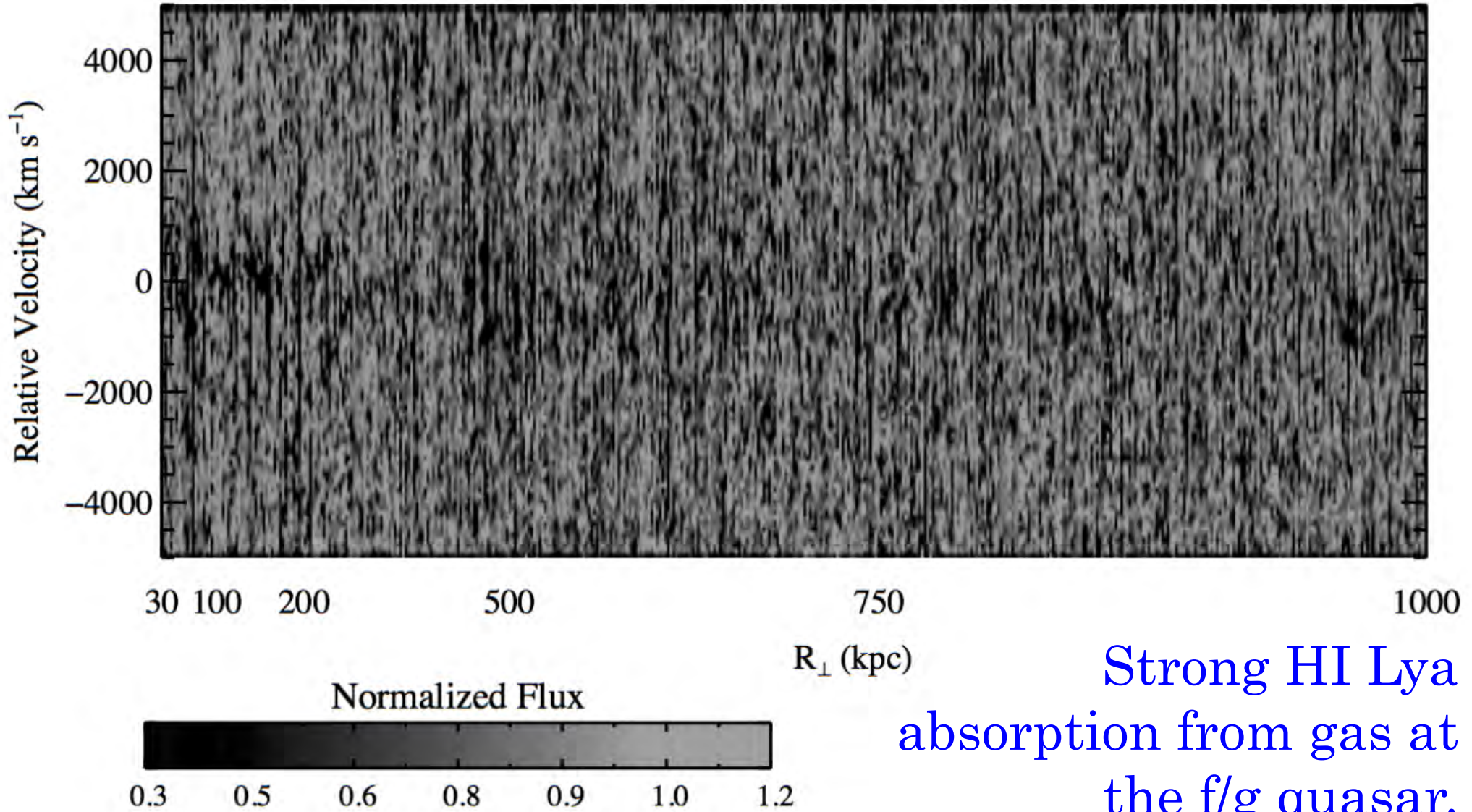
# Quasars Probing Quasars (QPQ)



Strong HI Ly $\alpha$  absorption from gas at the f/g quasar.

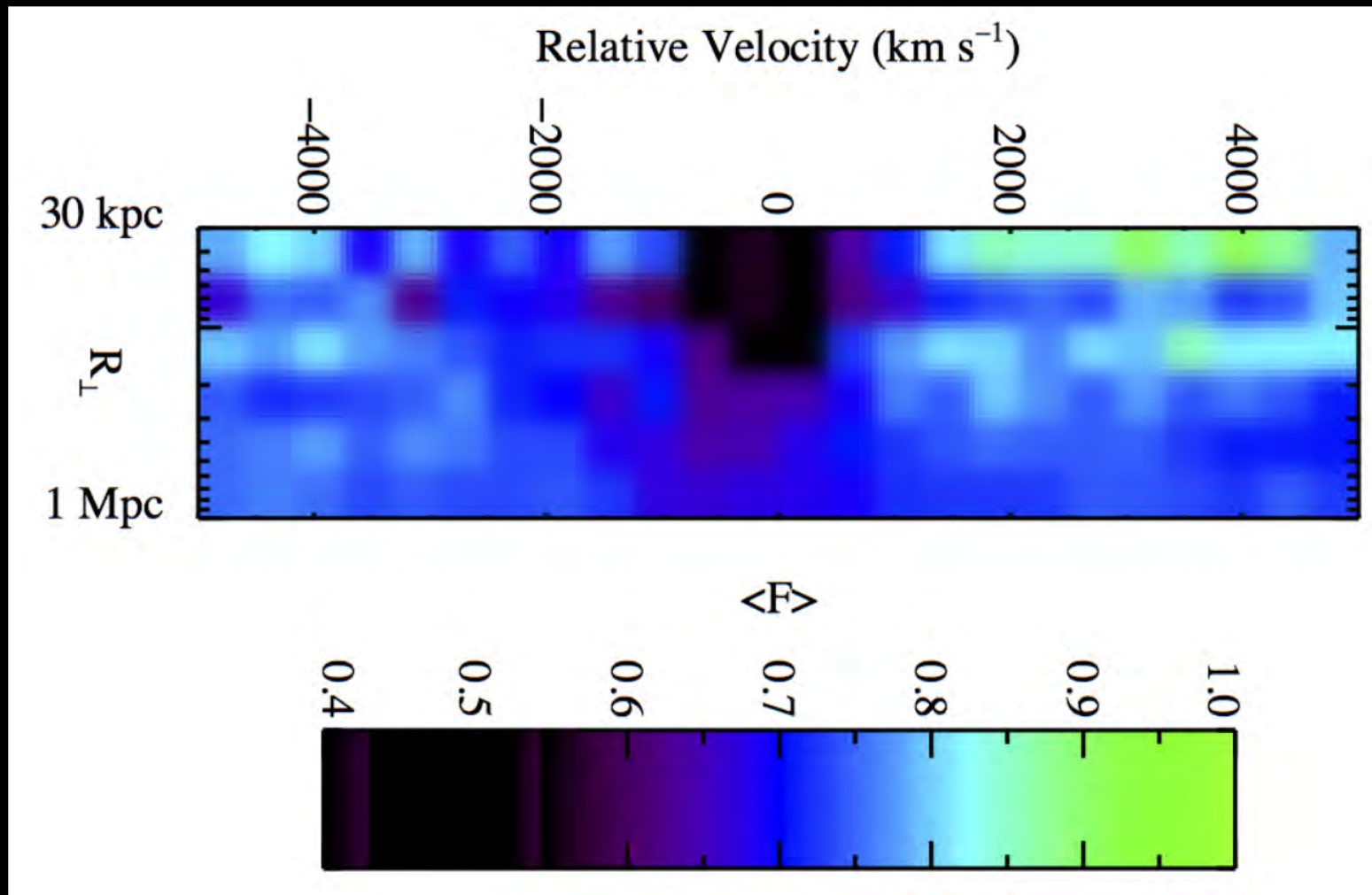
Hennami  
Prochaska

# Quasars Probing Quasars (QPQ)





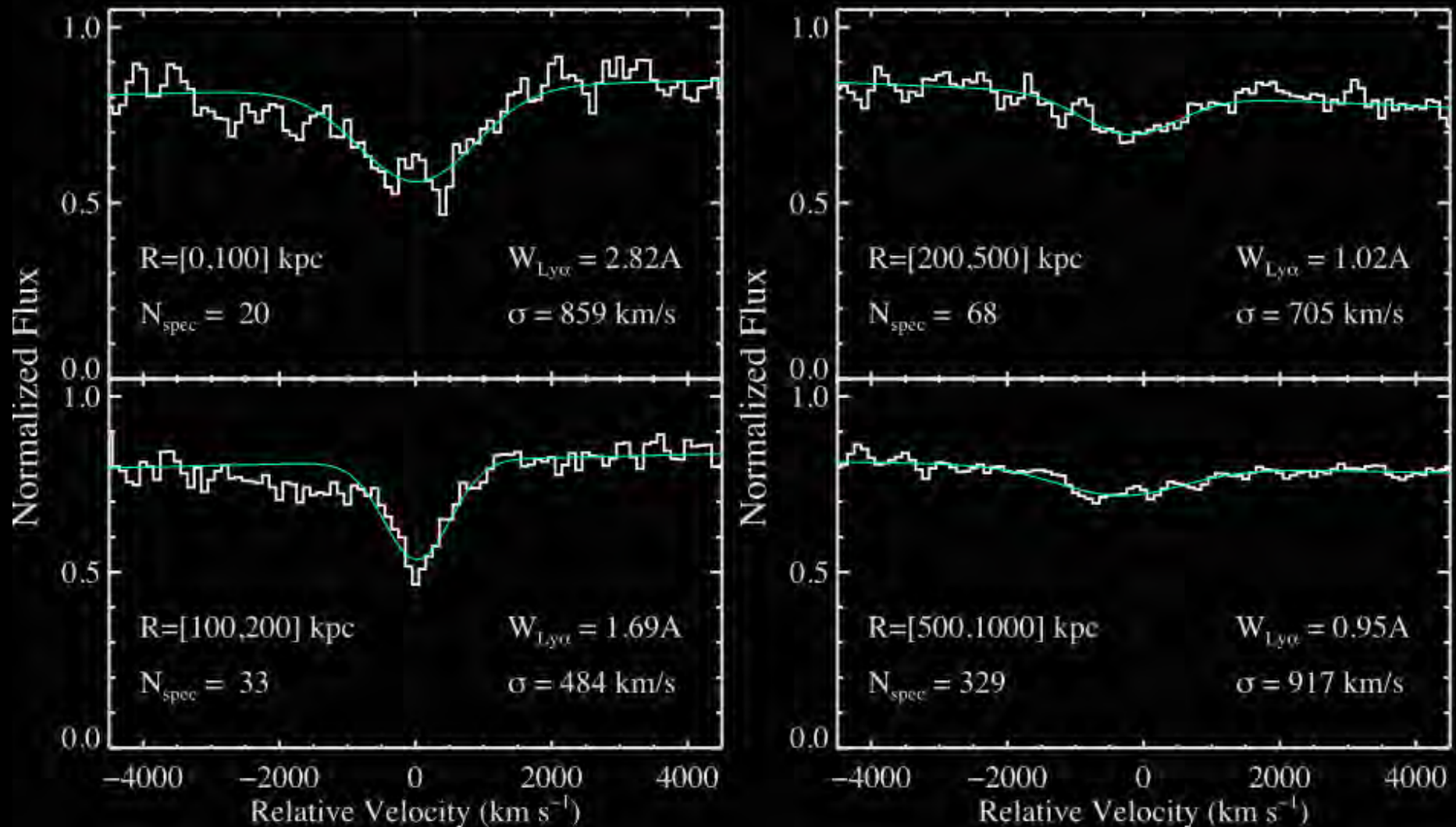
# Quasars Probing Quasars (QPQ)



Strong HI Ly $\alpha$  absorption from gas at the f/g quasar.

Hennami  
Prochaska

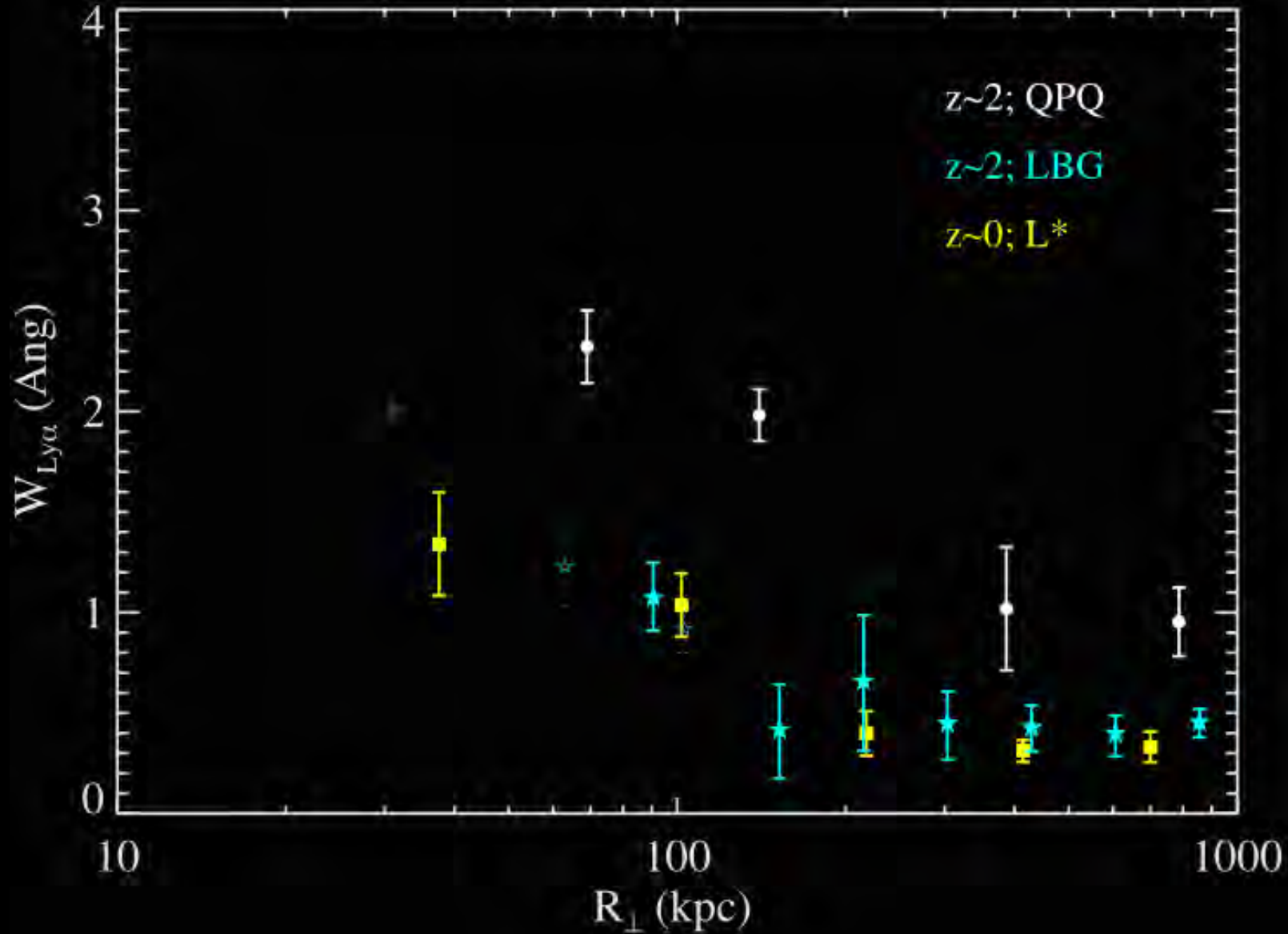
# Quasars Probing Quasars (QPQ)



Strong HI Ly $\alpha$  absorption from gas at the f/g quasar.

Hennami  
Prochaska

# Quasars Probing Quasars (QPQ)

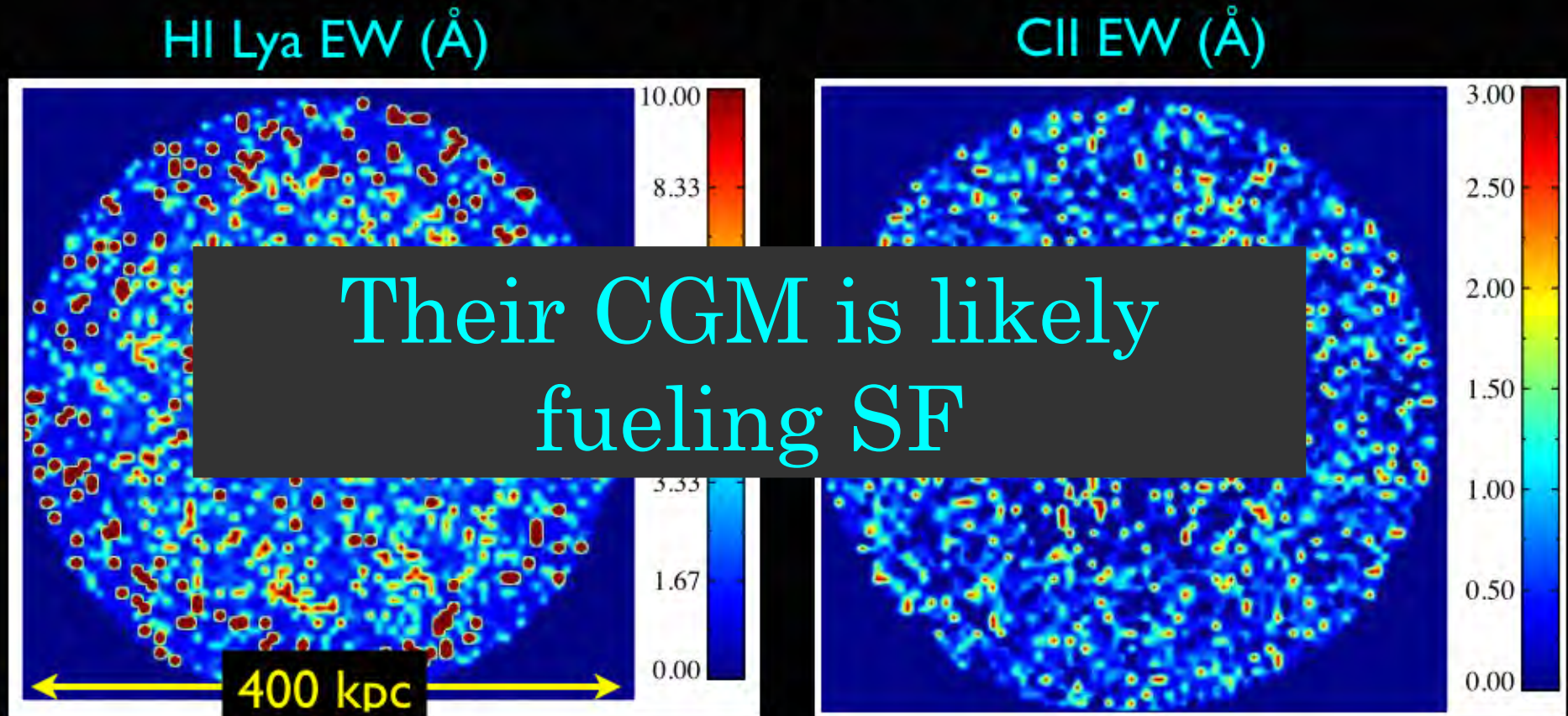


Hennami  
Prochaska



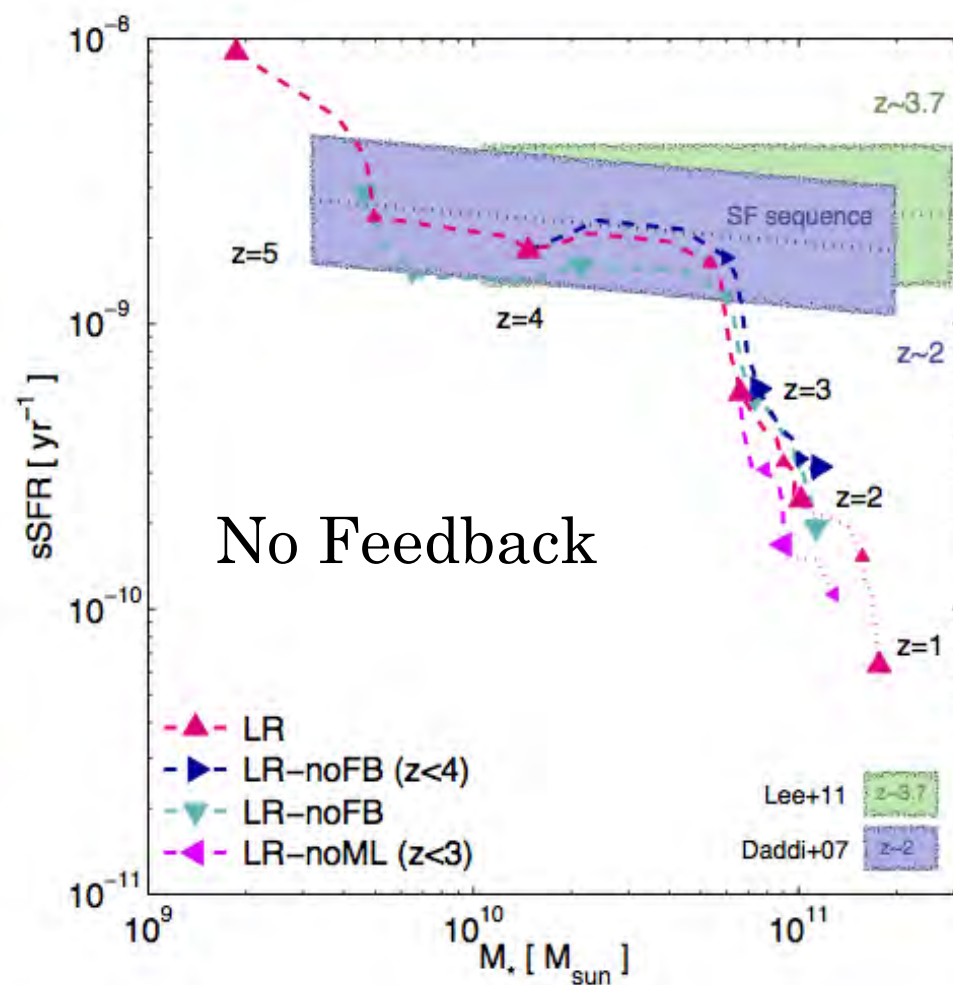
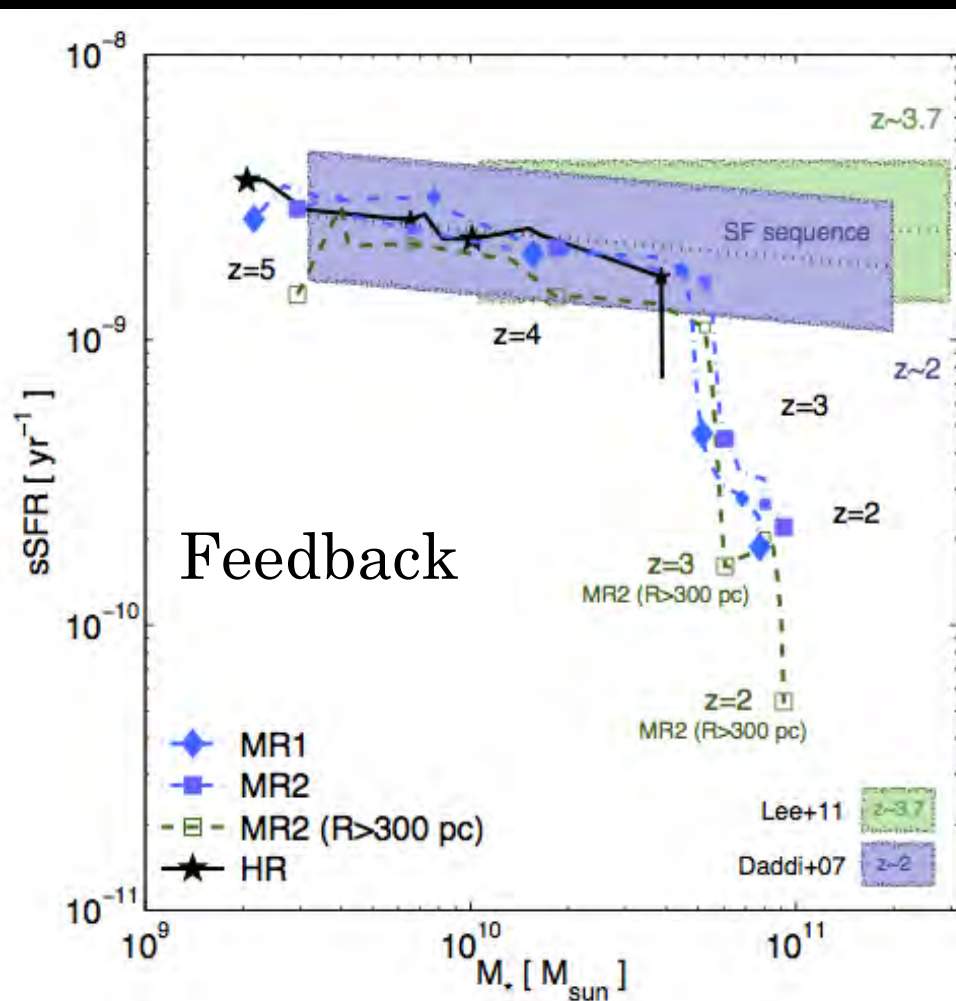
# Massive Galaxy: Gaseous Env.

## QPQ Empirical Summary



Massive galaxies ( $\sim 10^{12.5} M_{\text{Sun}}$ ) tagged by QSOs at  $z \sim 2$  are enveloped in a massive reservoir of cool, enriched gas.

# So what 'Quenched' these Galaxies?

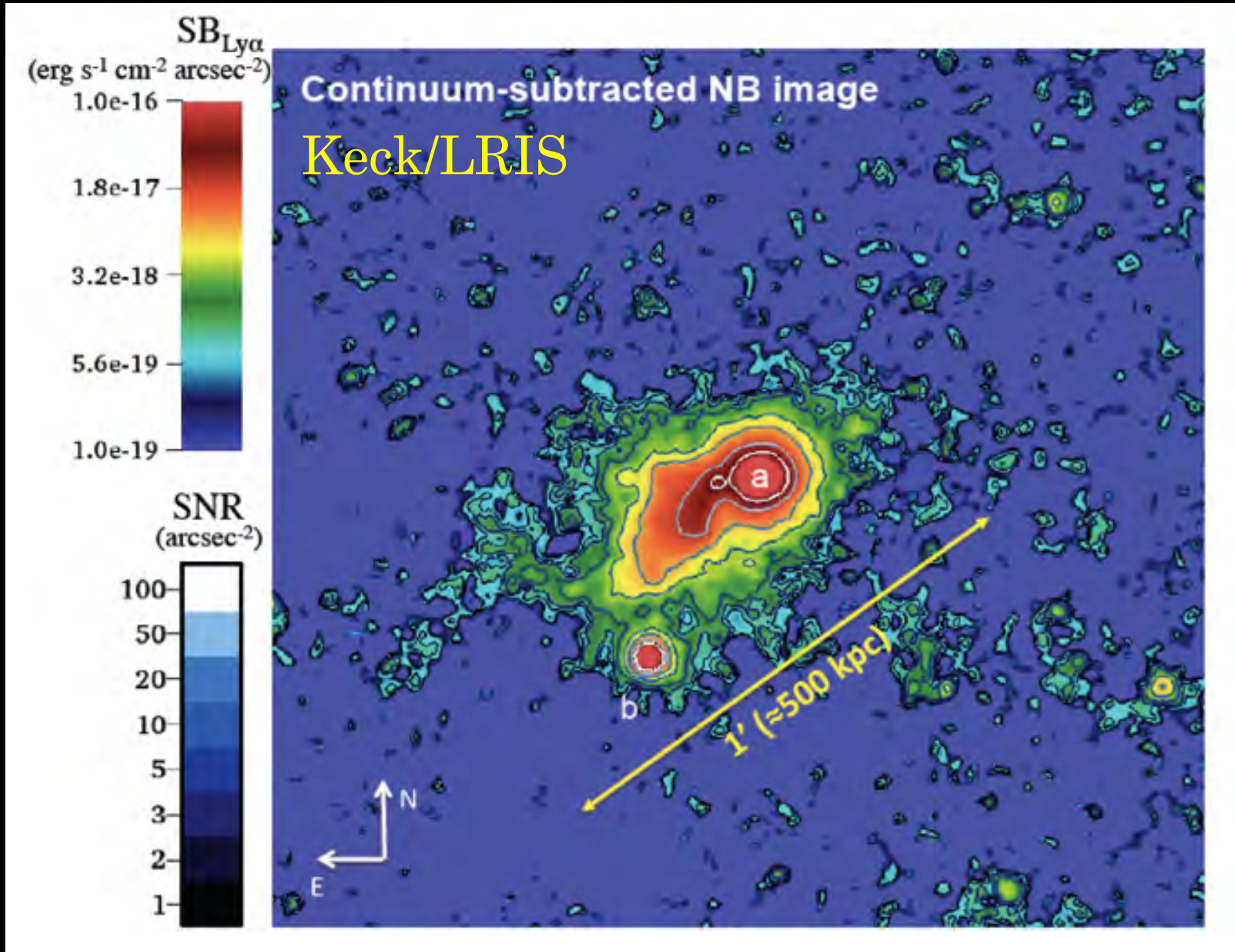


Feldmann+15



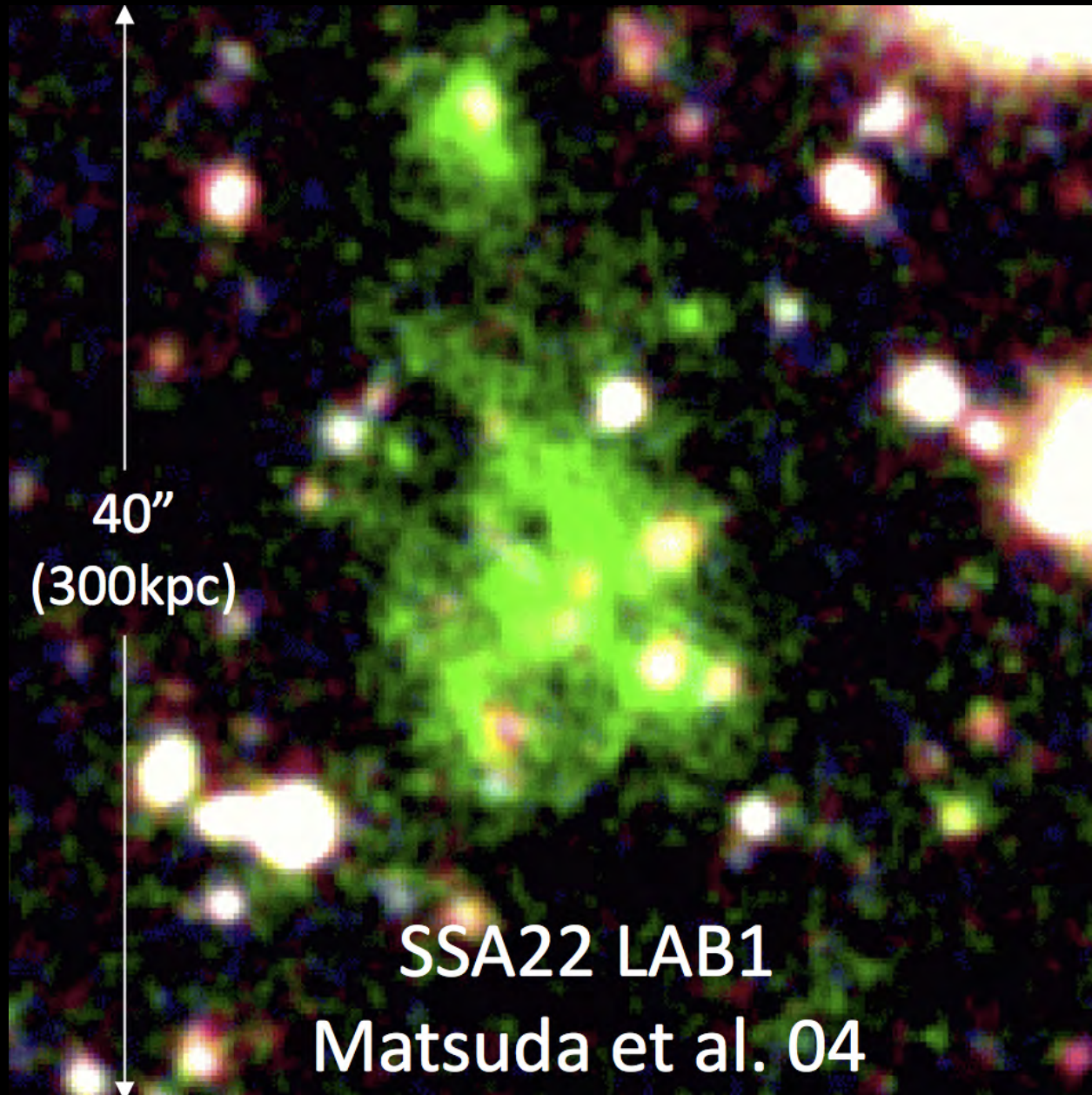
# Slug Nebula

Cantalupo+14



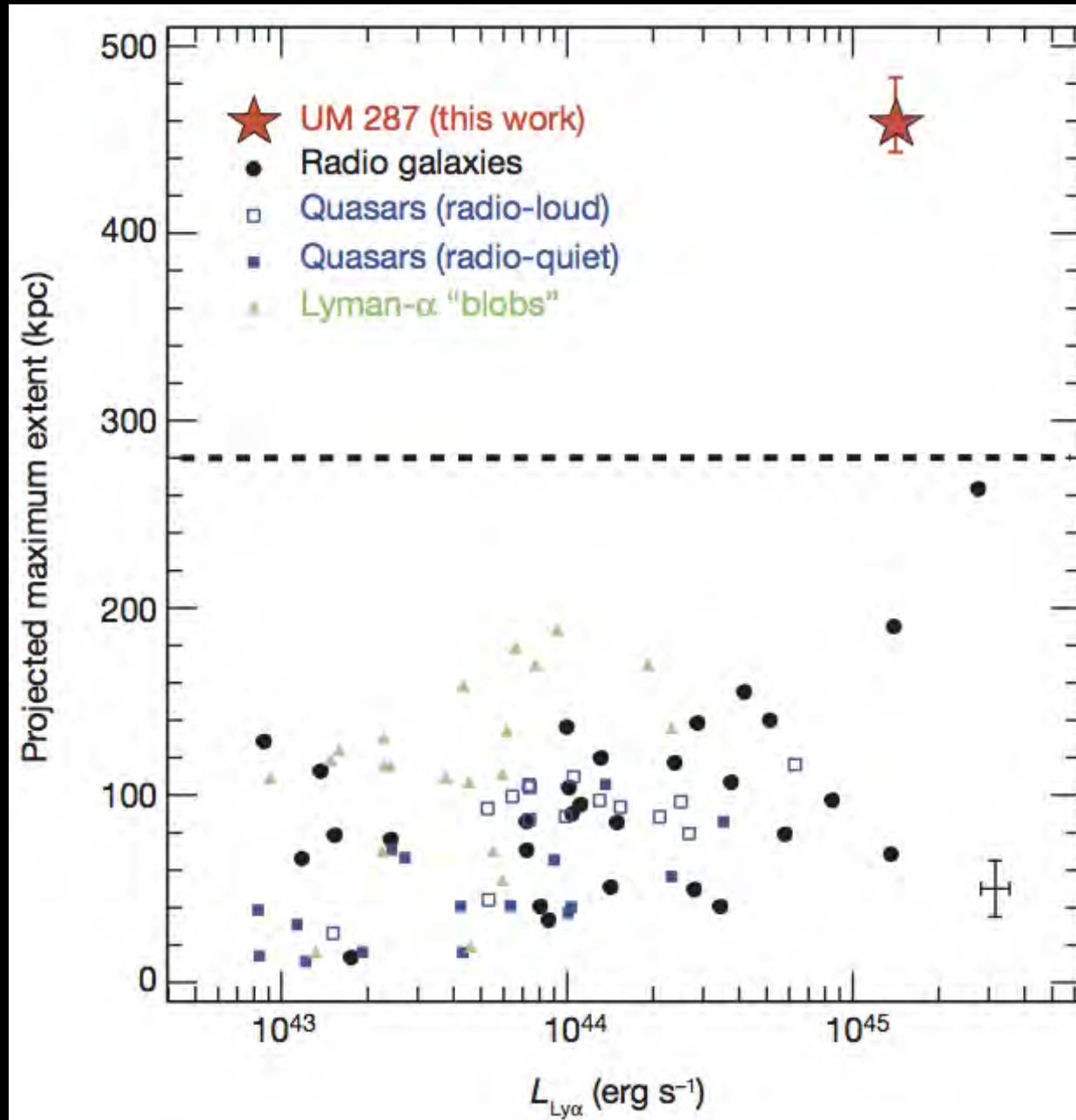


# Lya Blobs



# Enormous Ly $\alpha$ Nebula (ELAN)

Cantalupo+14





# Enormous Lya Nebula (ELAN)





# Science with ELAN



## Internal:

How common are ELAN, i.e. what is their role in galaxy formation?

What astrophysics dominates the emission?

**elan**

WWW.ELANSKIS.COM

# Science with ELAN



## External (CGM/IGM):

What are the CGM kinematics?

What is the CGM metallicity?

What governs CGM astrophysics?

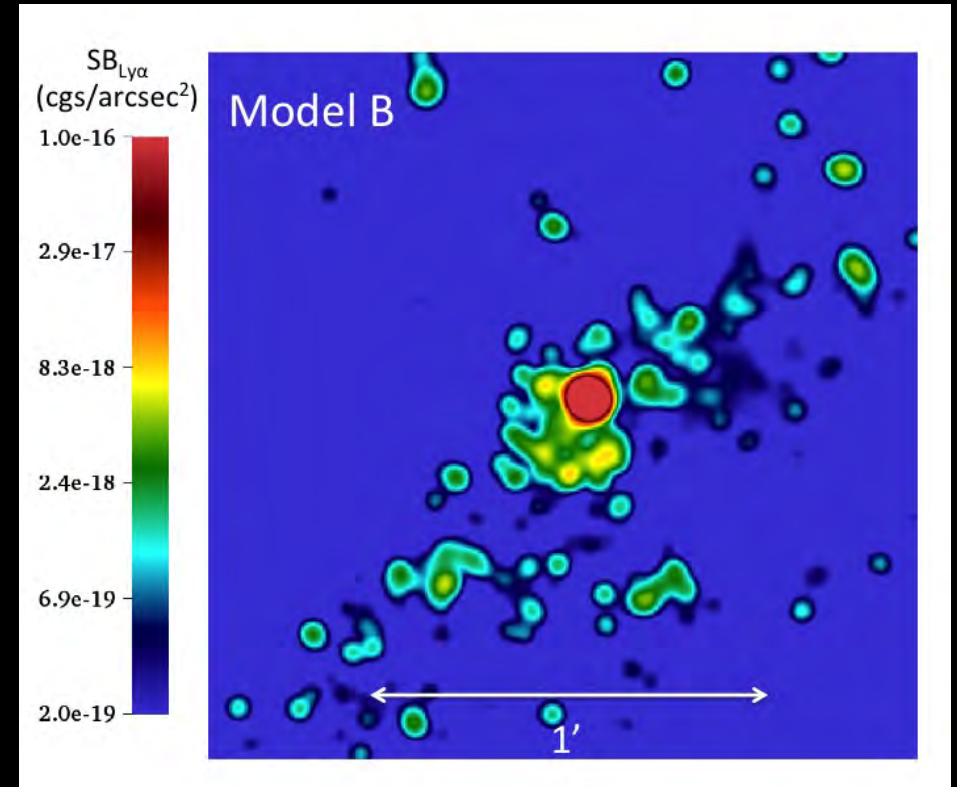
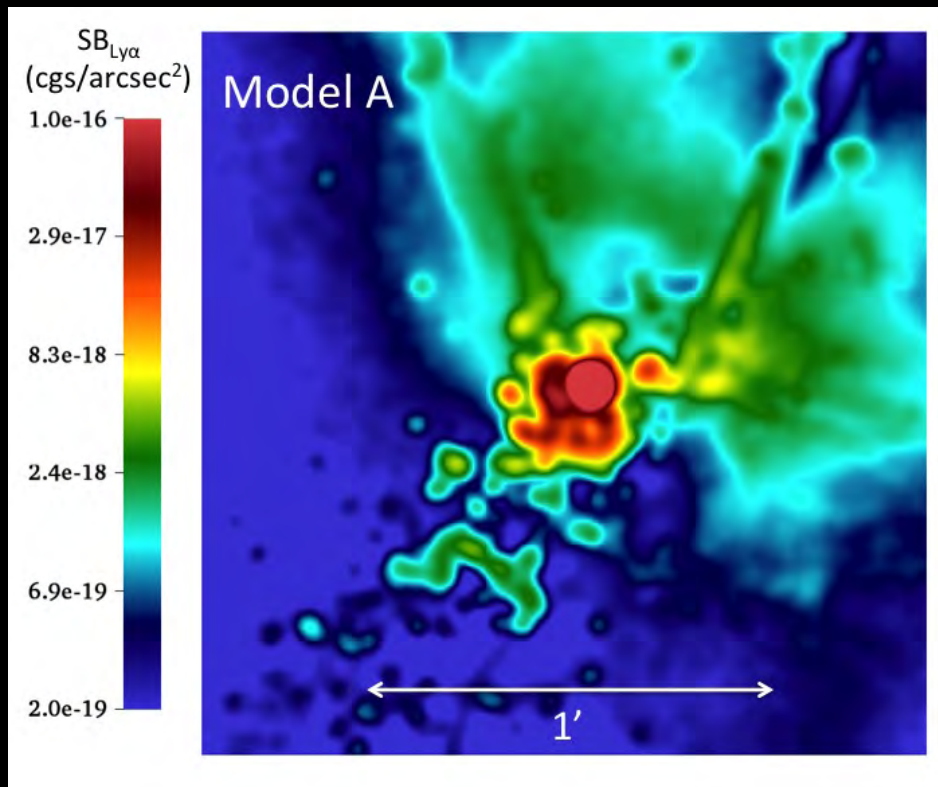
What is the morphology/extent of the CGM?

**elan**

WWW.ELANSKIS.COM

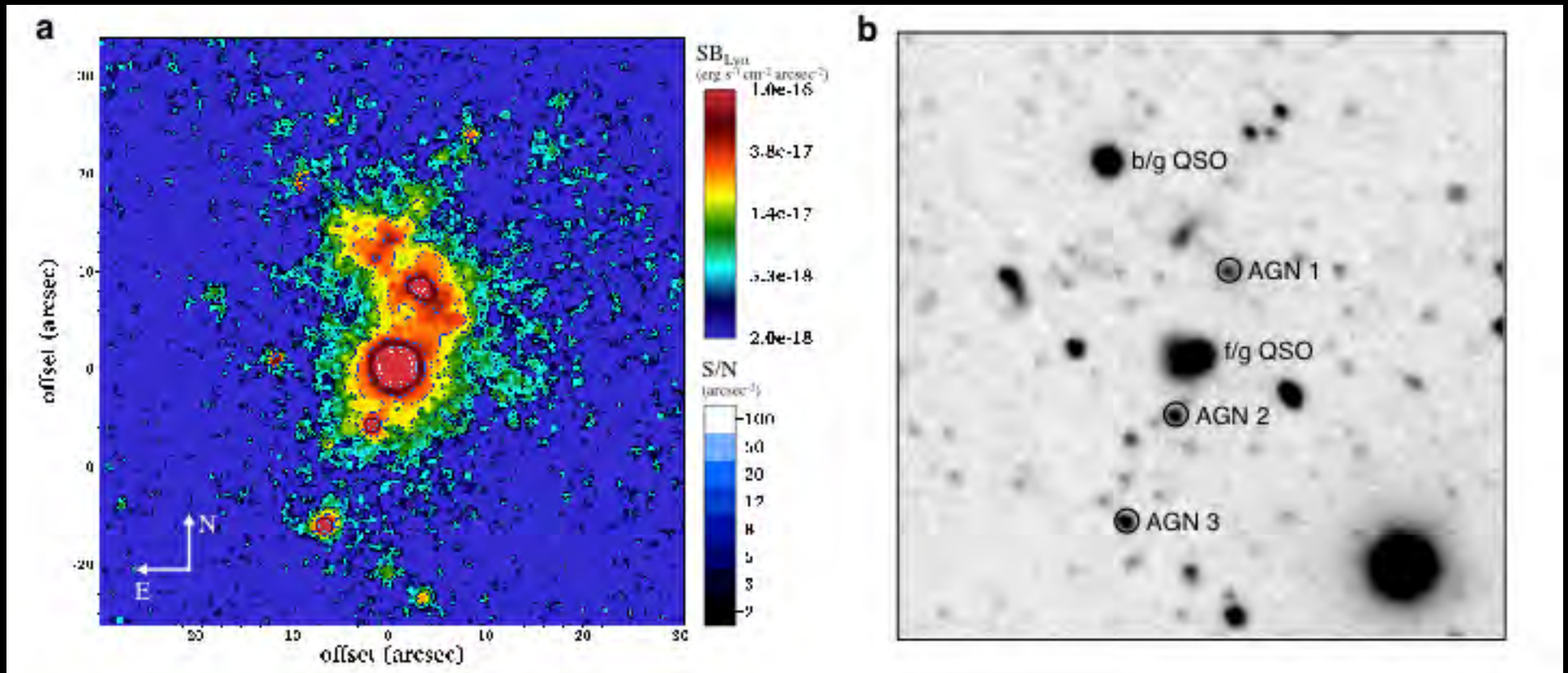


# Slug Nebula – Clumping





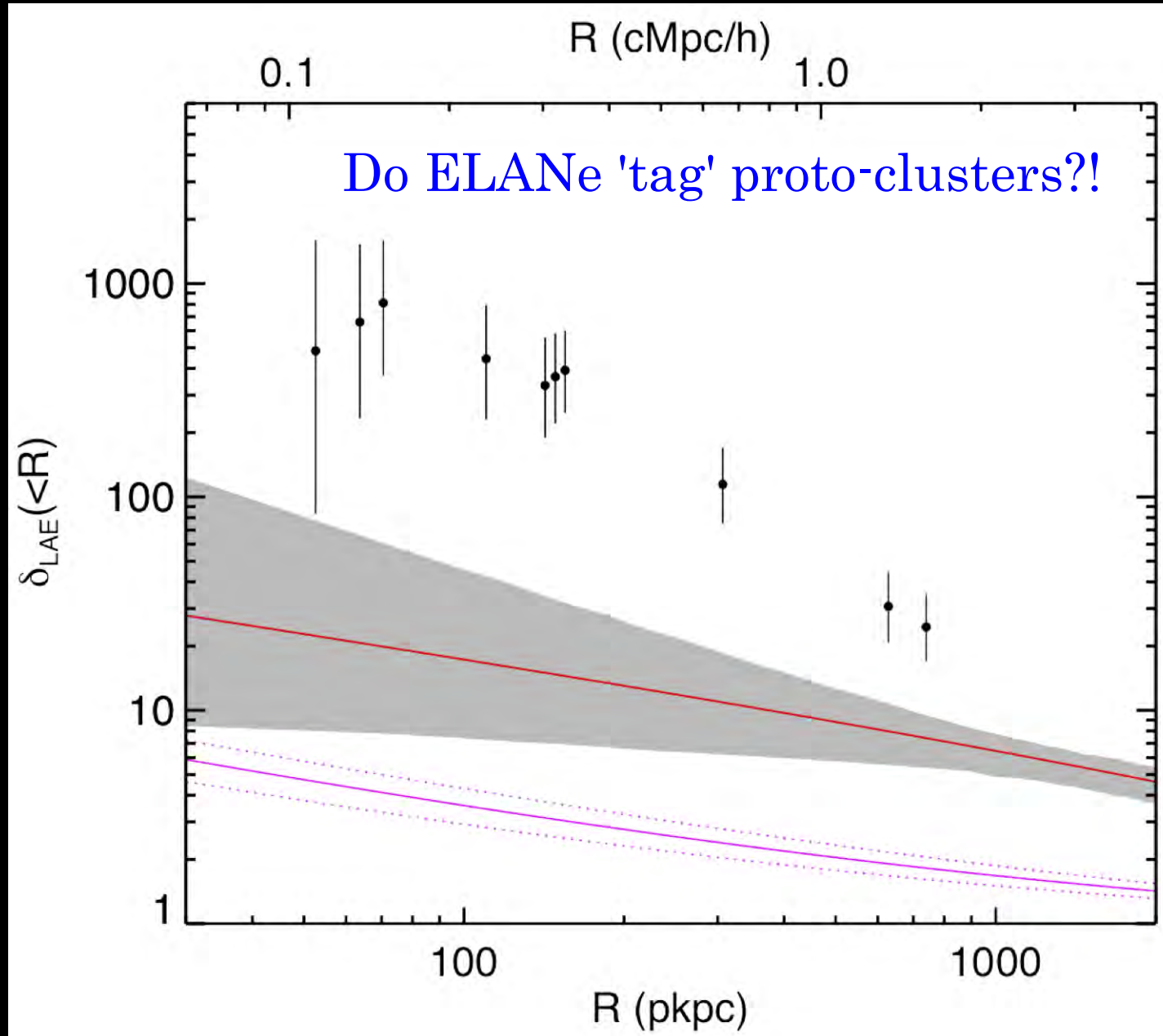
# Jackpot Nebula (ELAN)



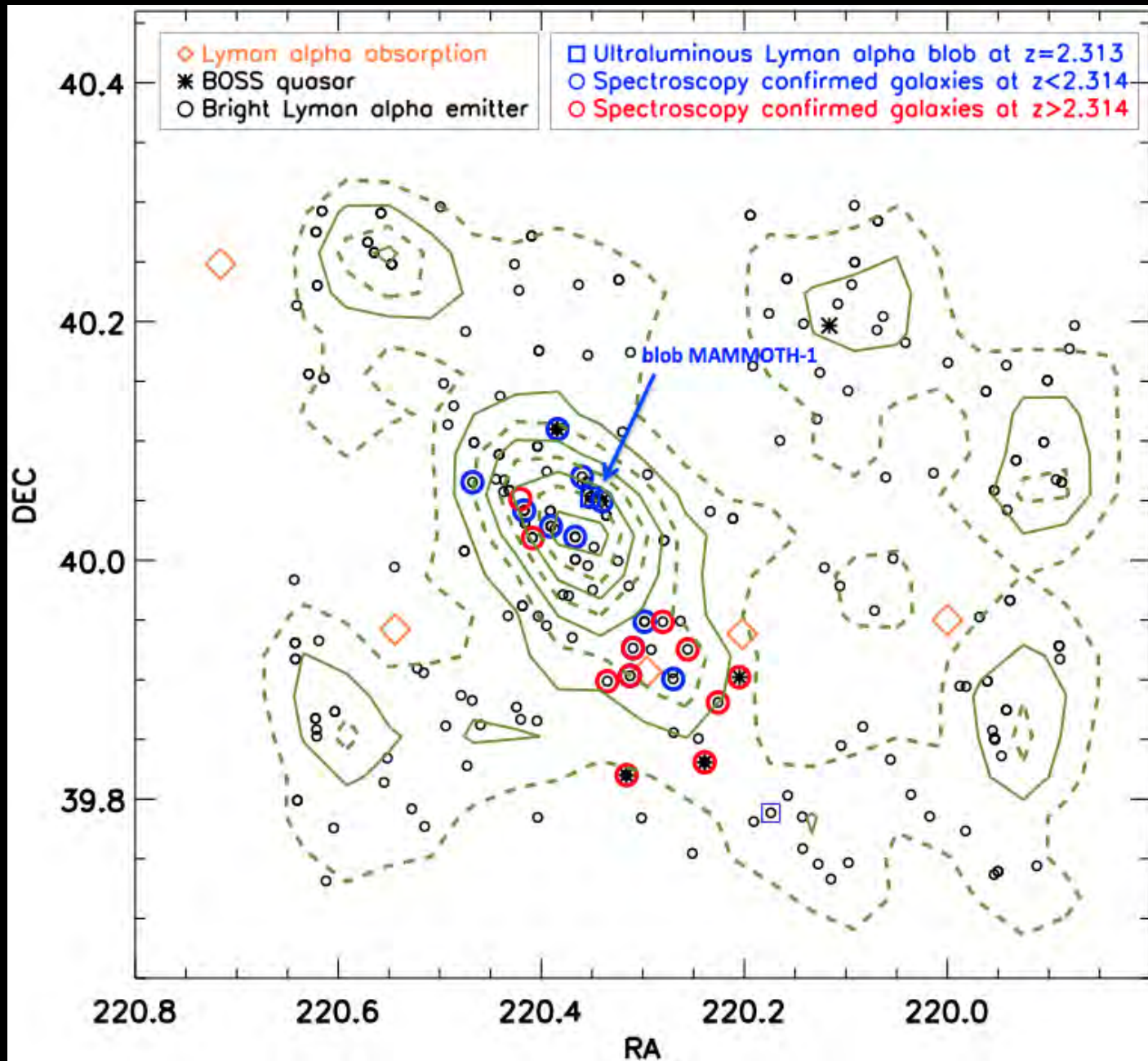
Hennawi+15

# Jackpot Nebula (ELAN)

Hennawi+15



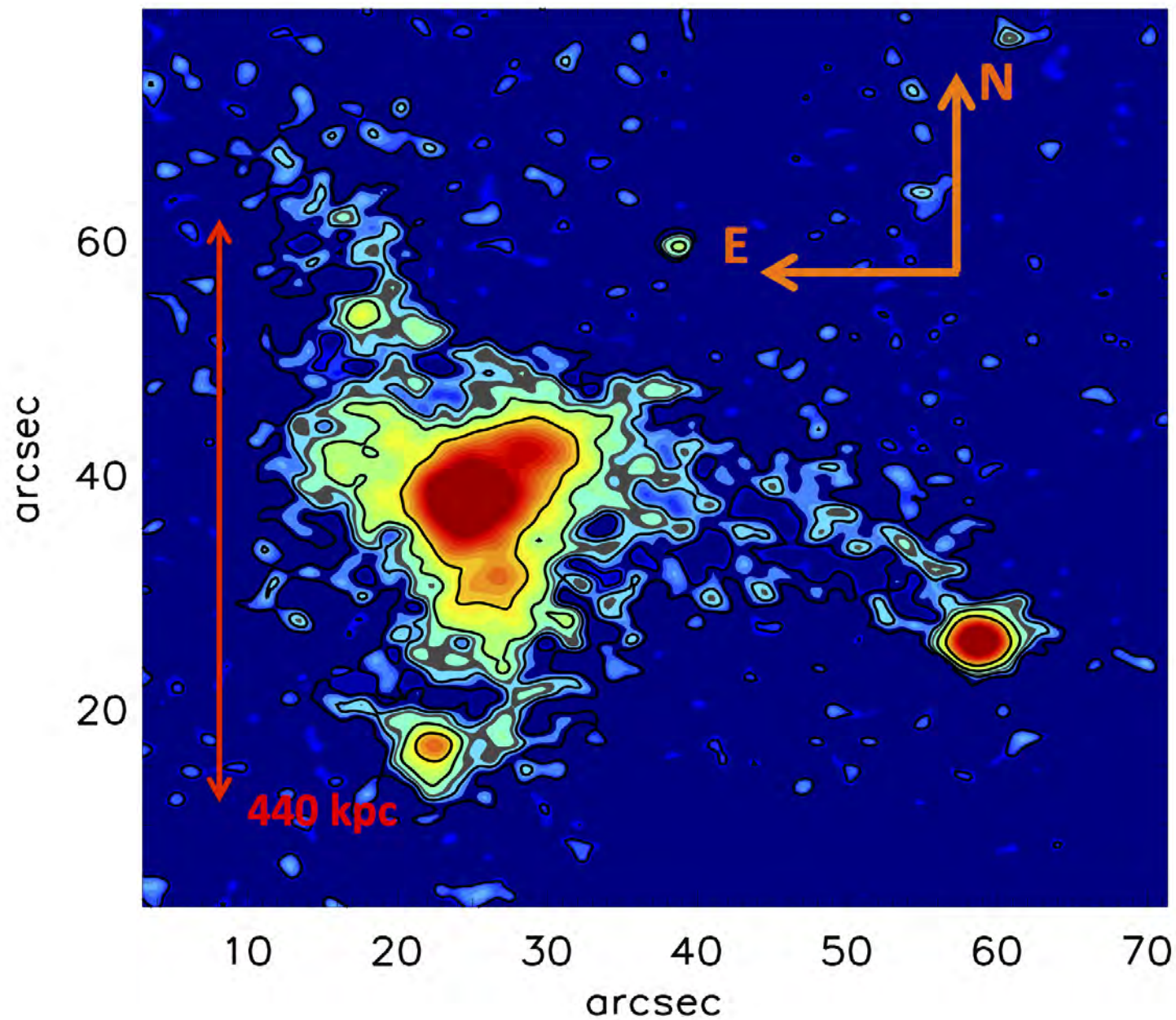
# MAMMOTH-1 ELAN



Cai+16b

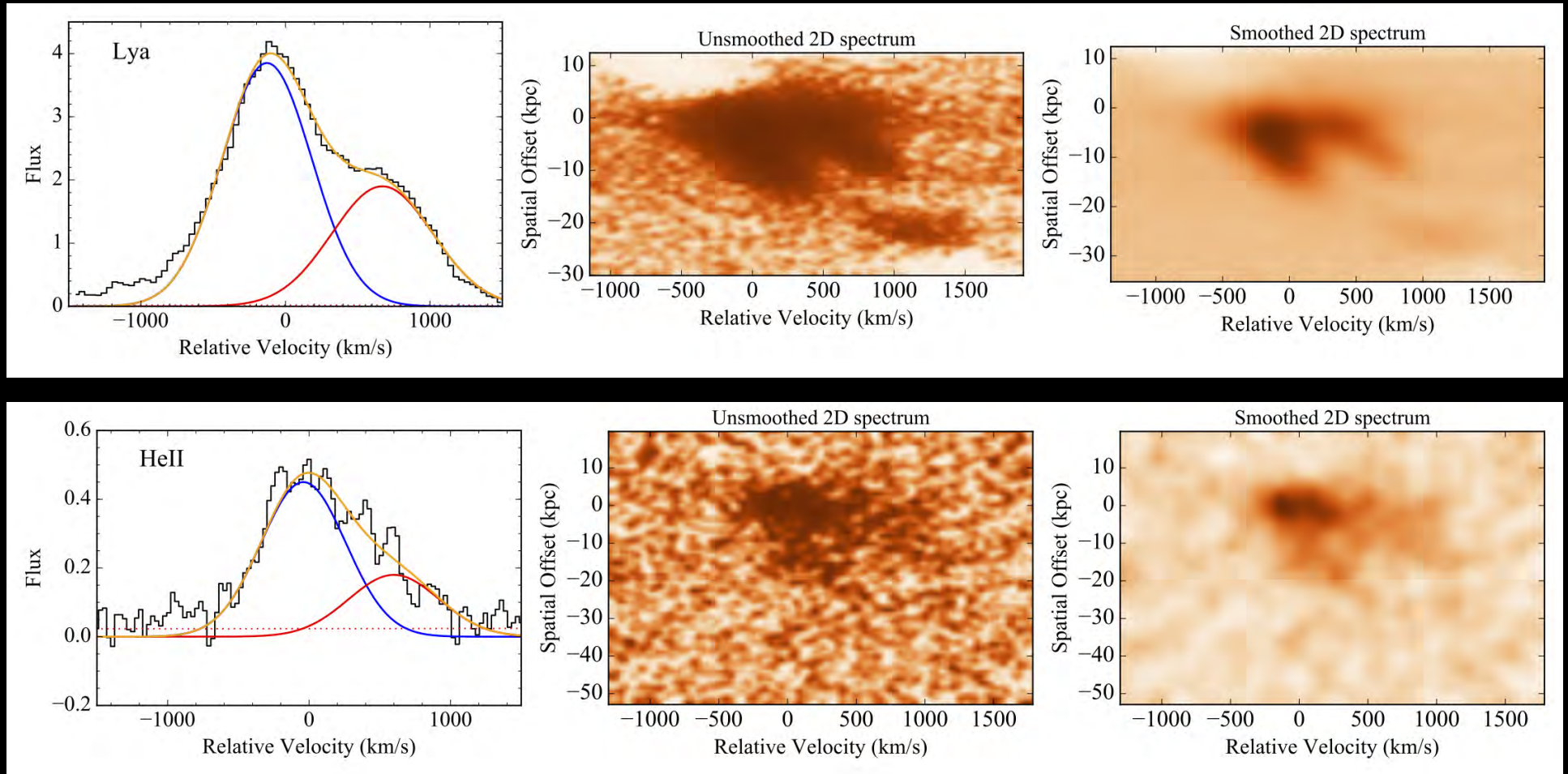


# MAMMOTH-1 ELAN



Cai+16

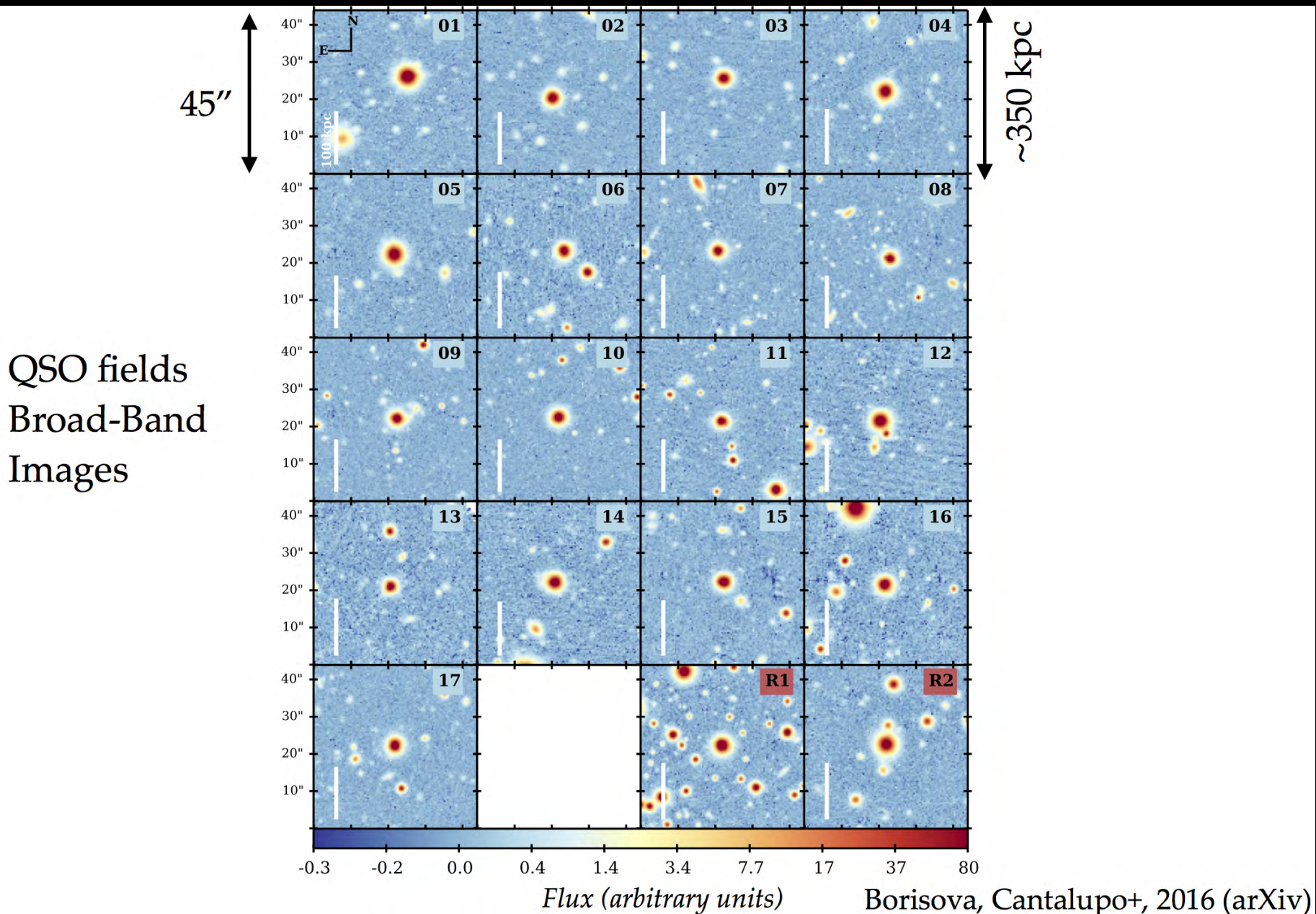
# MAMMOTH-1 ELAN



Cai+16

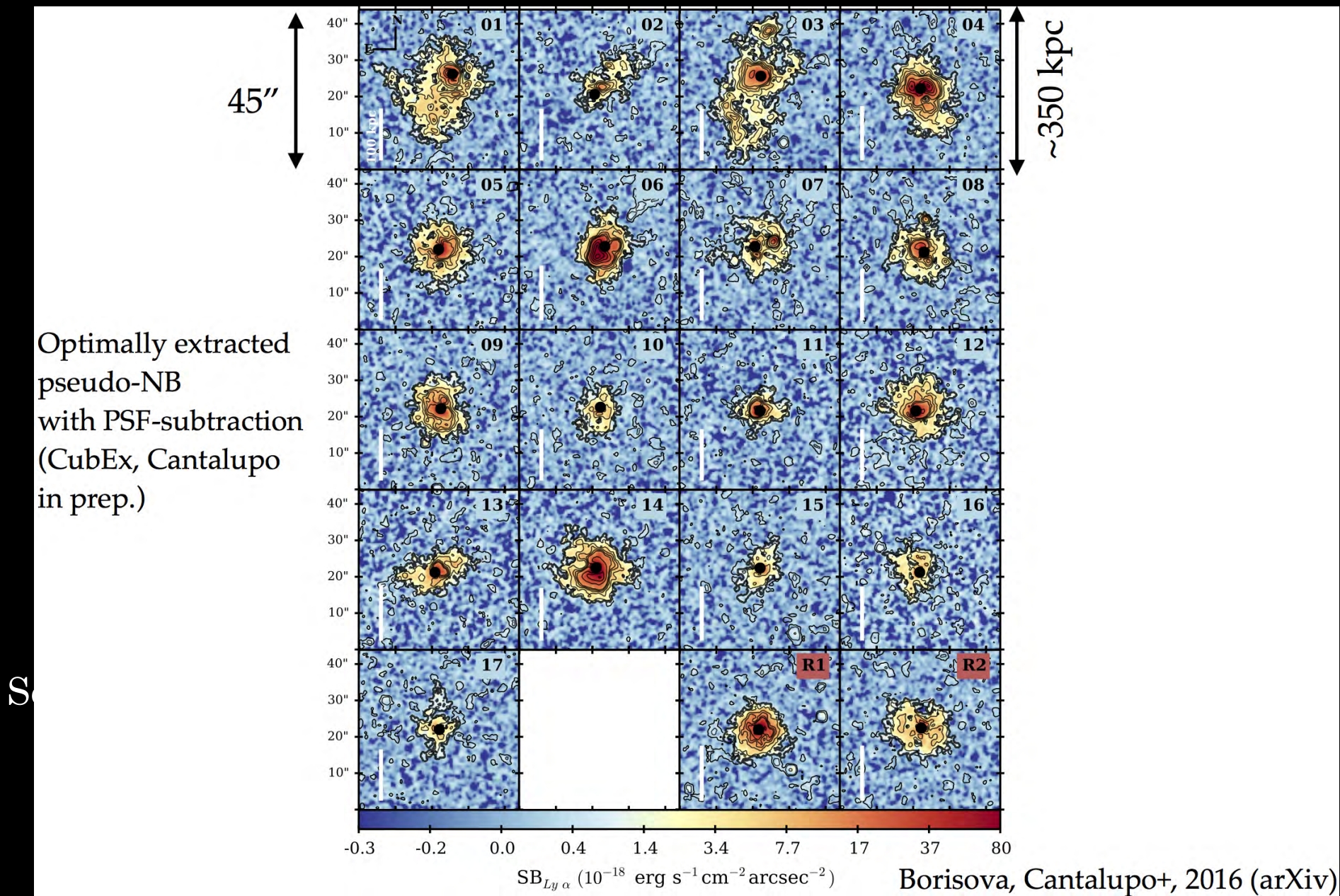


# ELAN at $z > 3$



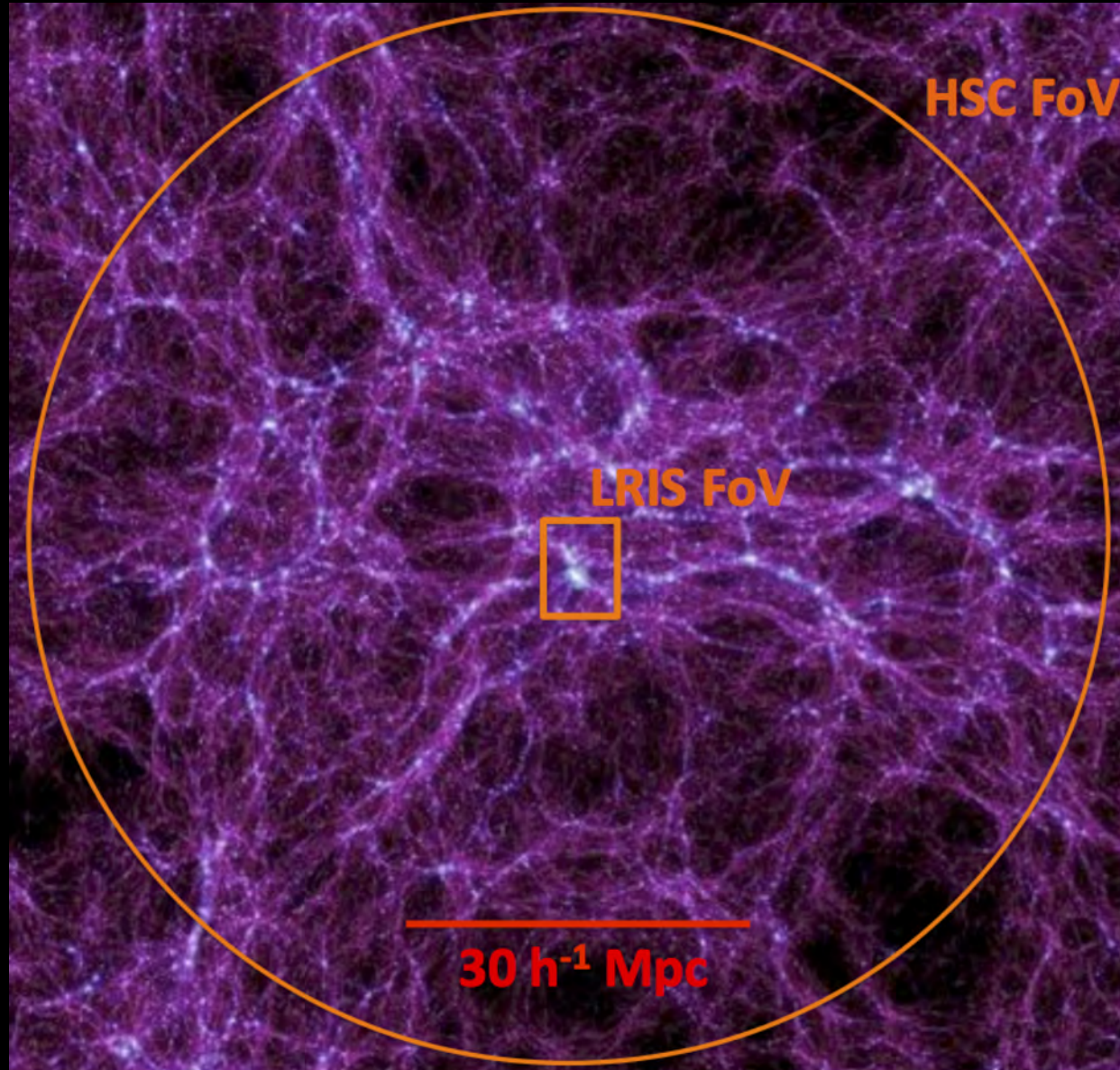


# ELAN at $z > 3$



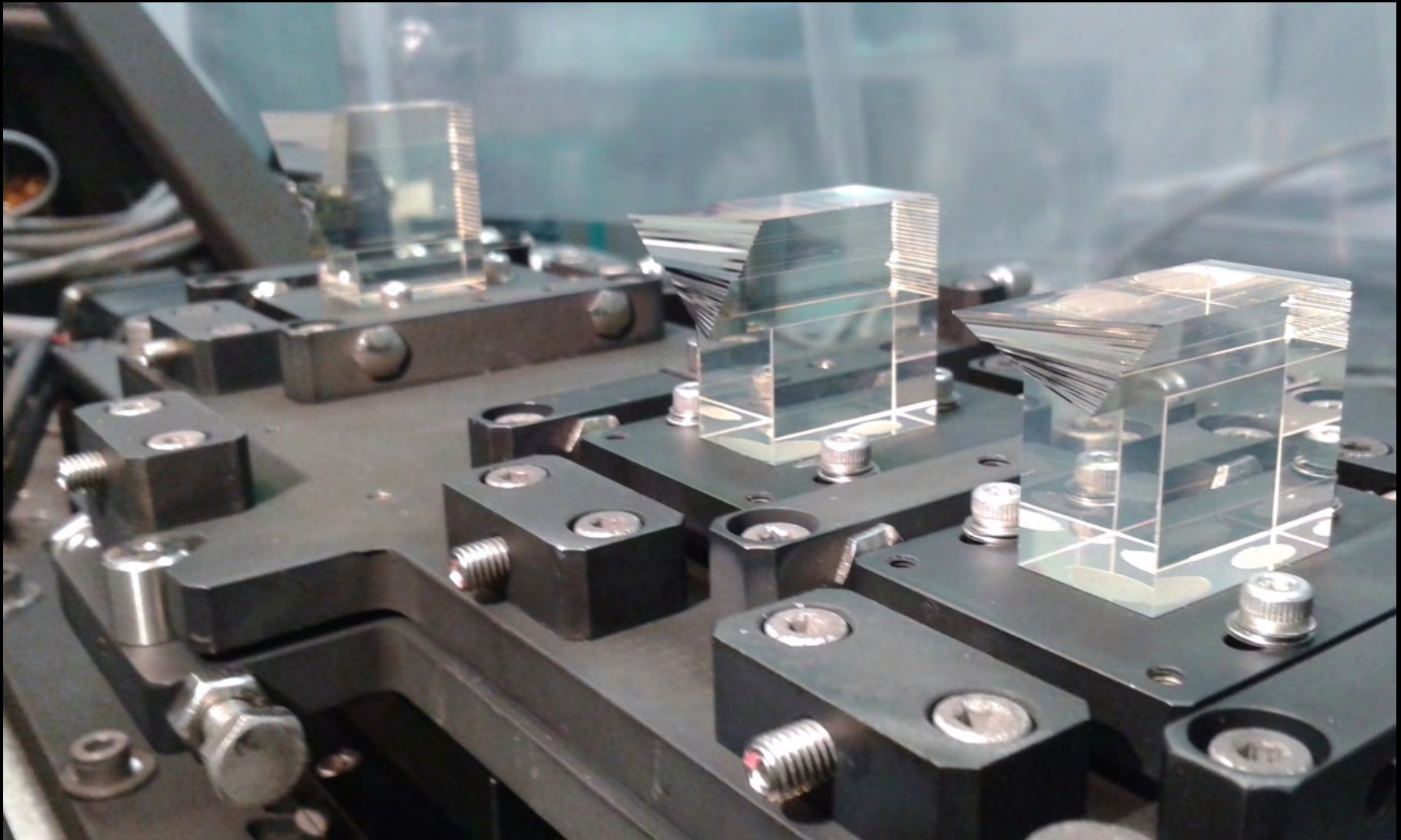


# Future Paths: More Protoclusters



Z. Cai  
(preparing for  
a Hawaiian  
hurricane at  
Subaru)

# Future Paths: KCWI



Martin+  
Shipping in October

IPMU 2016



# Future Paths: Numerical

??+

# Summary

- Massive galaxies hosting quasars exhibit a massive and enriched reservoir of cool gas, *in absorption* (QPQ)
  - $10^{11}$  Msun,  $\sim 1/3$  solar
  - Fuel for future SF
  - Highly improbable that quasars quench galaxies
- Massive galaxies hosting quasars exhibit a massive and enriched reservoir of cool gas, *in emission* (ELAN)
  - Illuminating the CGM and nearby IGM ( $d > 300$  kpc)
  - Kinematic characteristic of dark matter halo potential (FWHM  $\sim 500$  km/s)
  - Ly $\alpha$  Luminosity and absence of HeII imply clumpy, dense ( $> 10^2$  cm $^{-3}$ ) gas not currently captured by hydro simulations