Connecting Gas & Stars: Insights from Abundances and Kinematics

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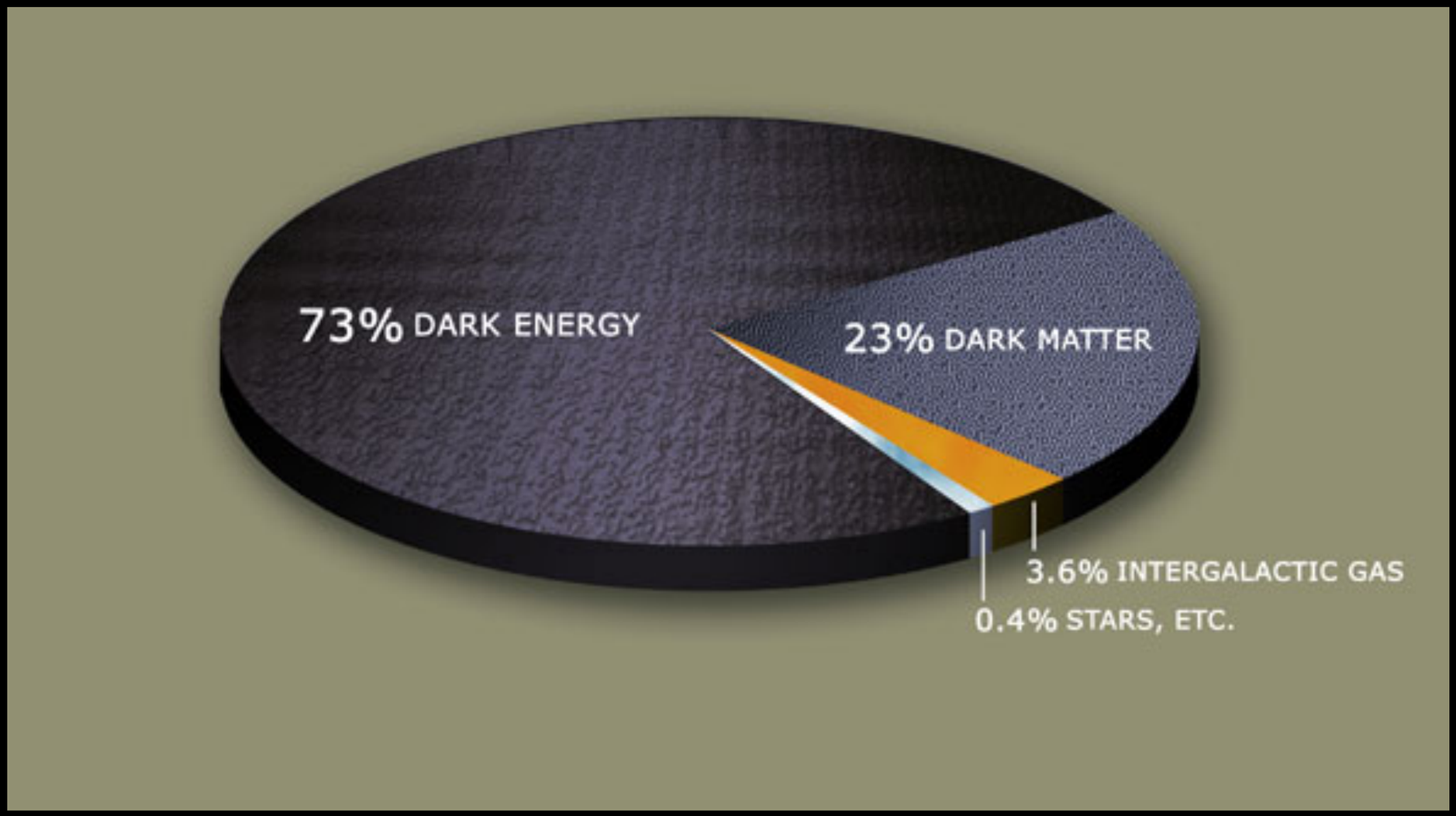
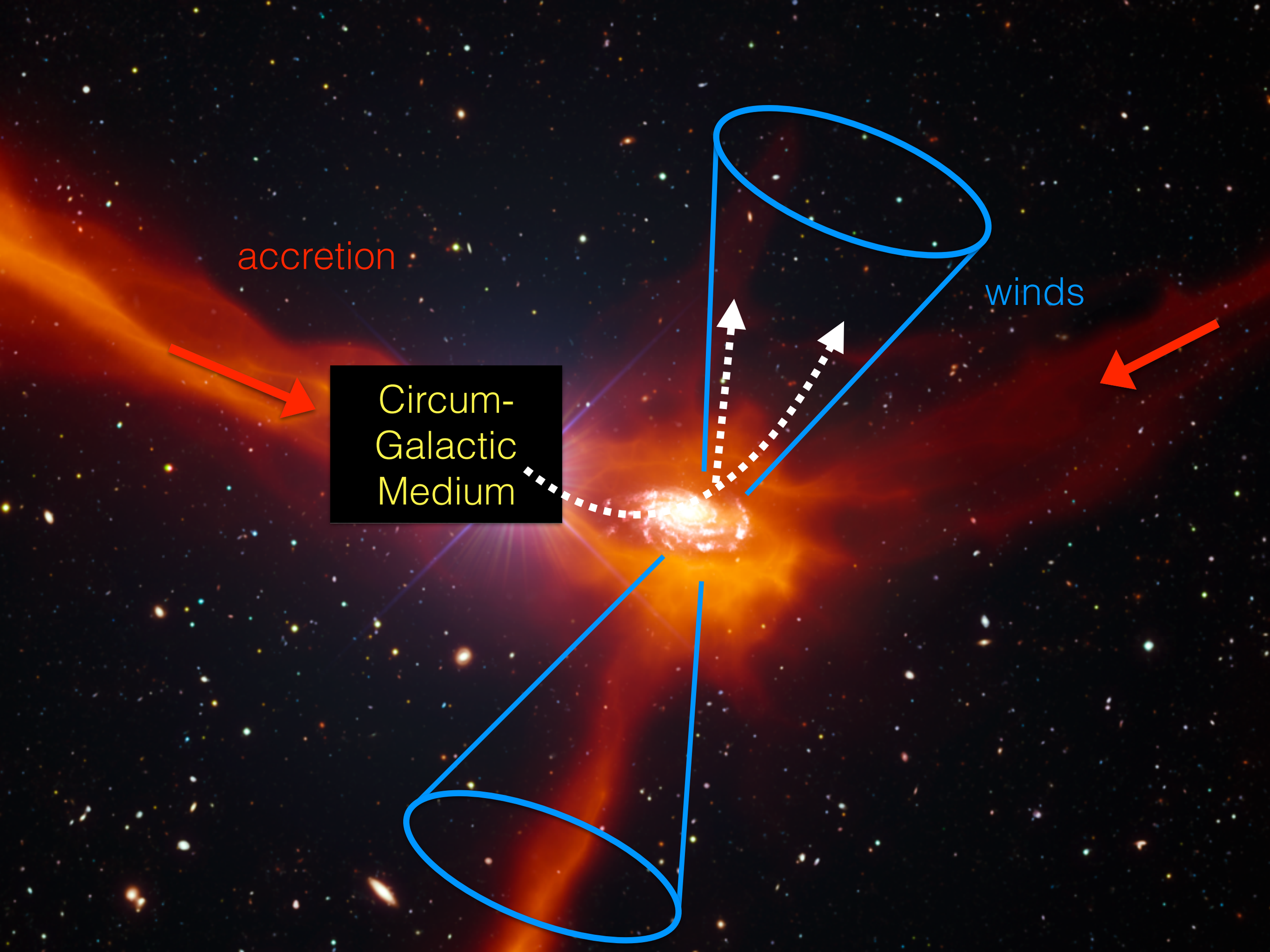
Max Pettini, Varsha Kulkarni, Don York

90% of baryons in gas

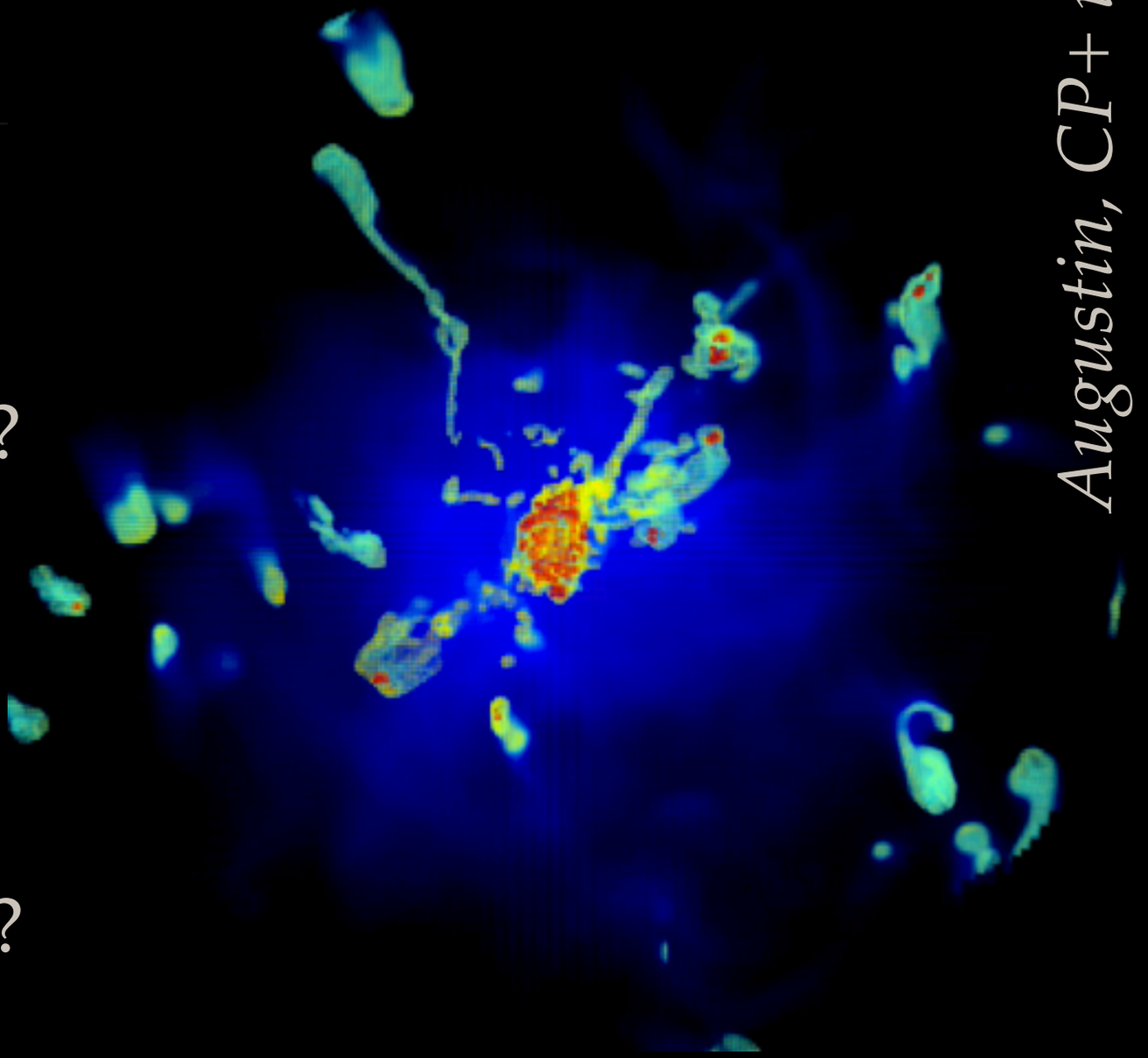



accretion
Circum-
Galactic
Medium
winds

Questions to Address

- What are the physical properties of the circumgalactic medium?
- How do galaxies accrete gas?
- How much mass do winds carry?
- Can we get a census of the different phases of the CGM?

Dave+17



Augustin, CP+ in prep

RAMSES AMR zoom simulations
Lyα, z=0.7, spatial resolution 380pc/h

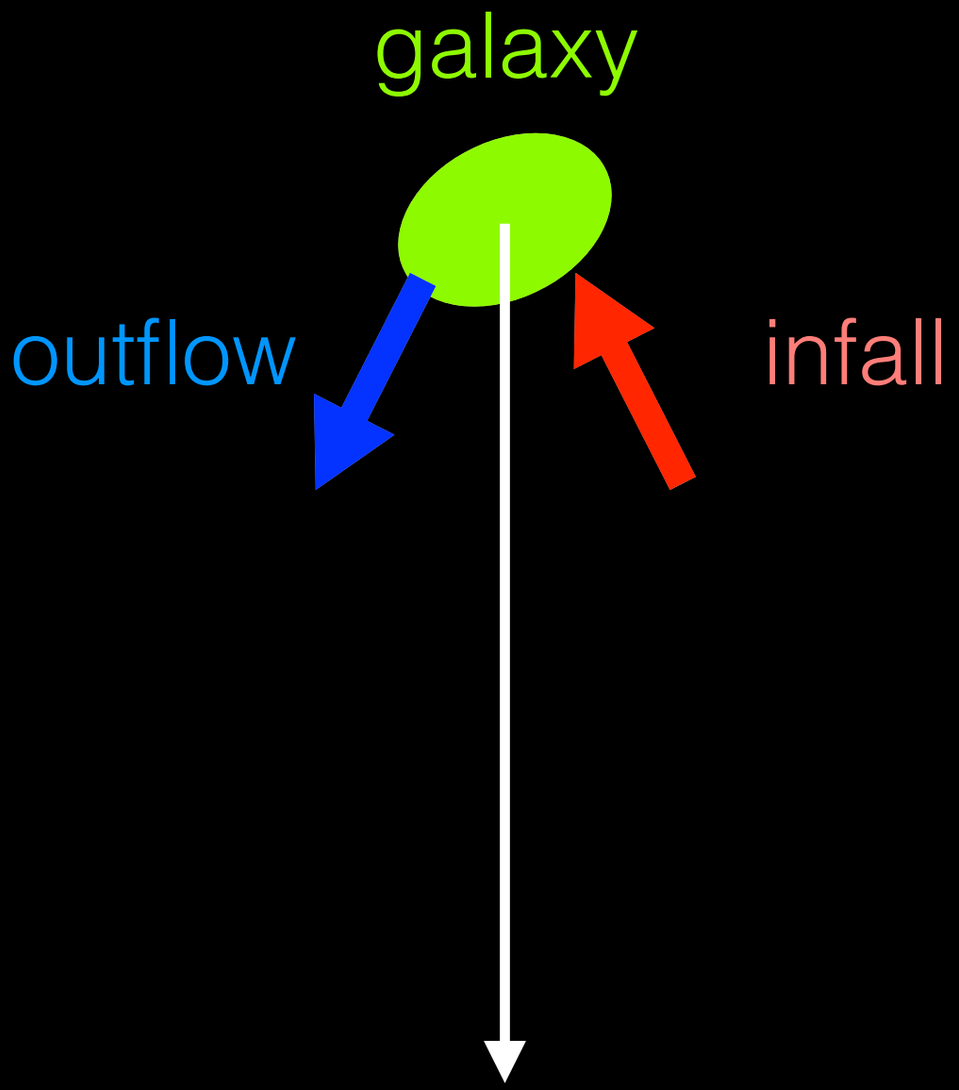
quasar

accretion

winds

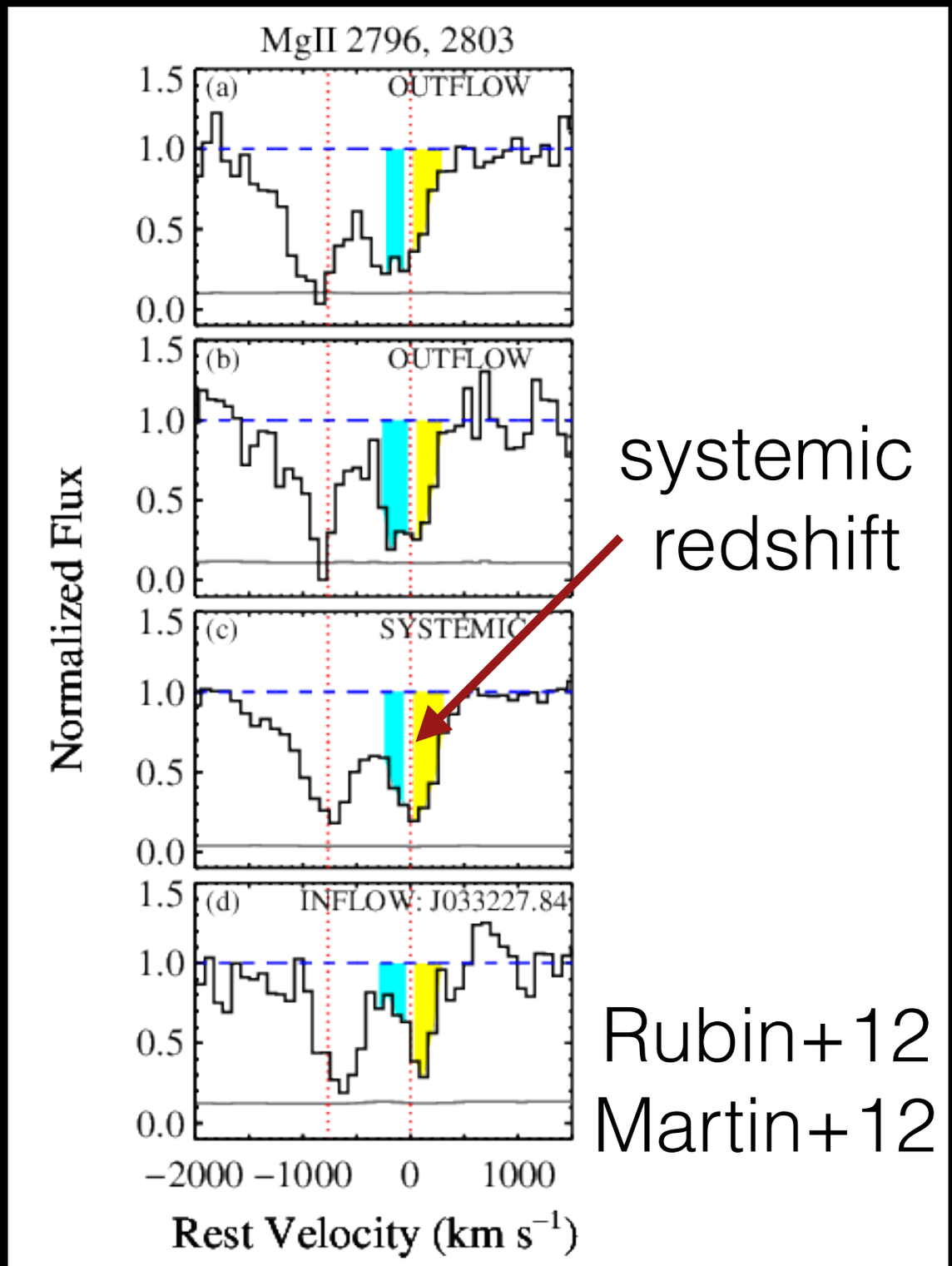
Circum-
Galactic
Medium

Observational Evidences for Accretion are scarce



Sanchez Almeida +14

no information on distance



Combining Emission & Absorption

galaxy

outflow

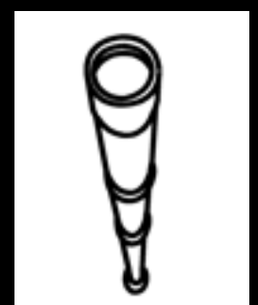
infall

no information
on distance

quasar

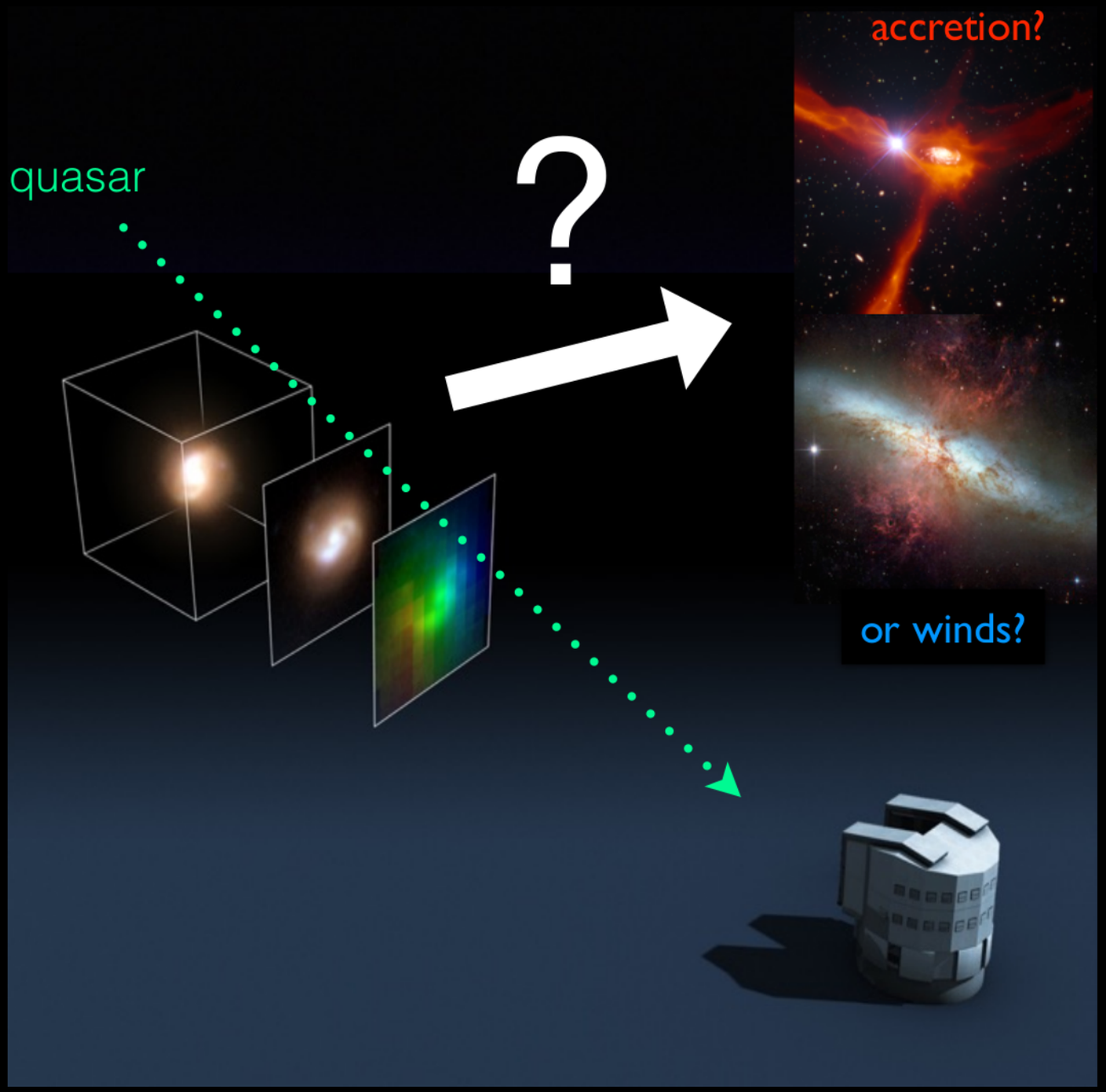
infall behind
or
outflow in front

outflow behind
or
infall in front



distance
known

3D spectroscopy:
a powerful tool to connect gas & stars

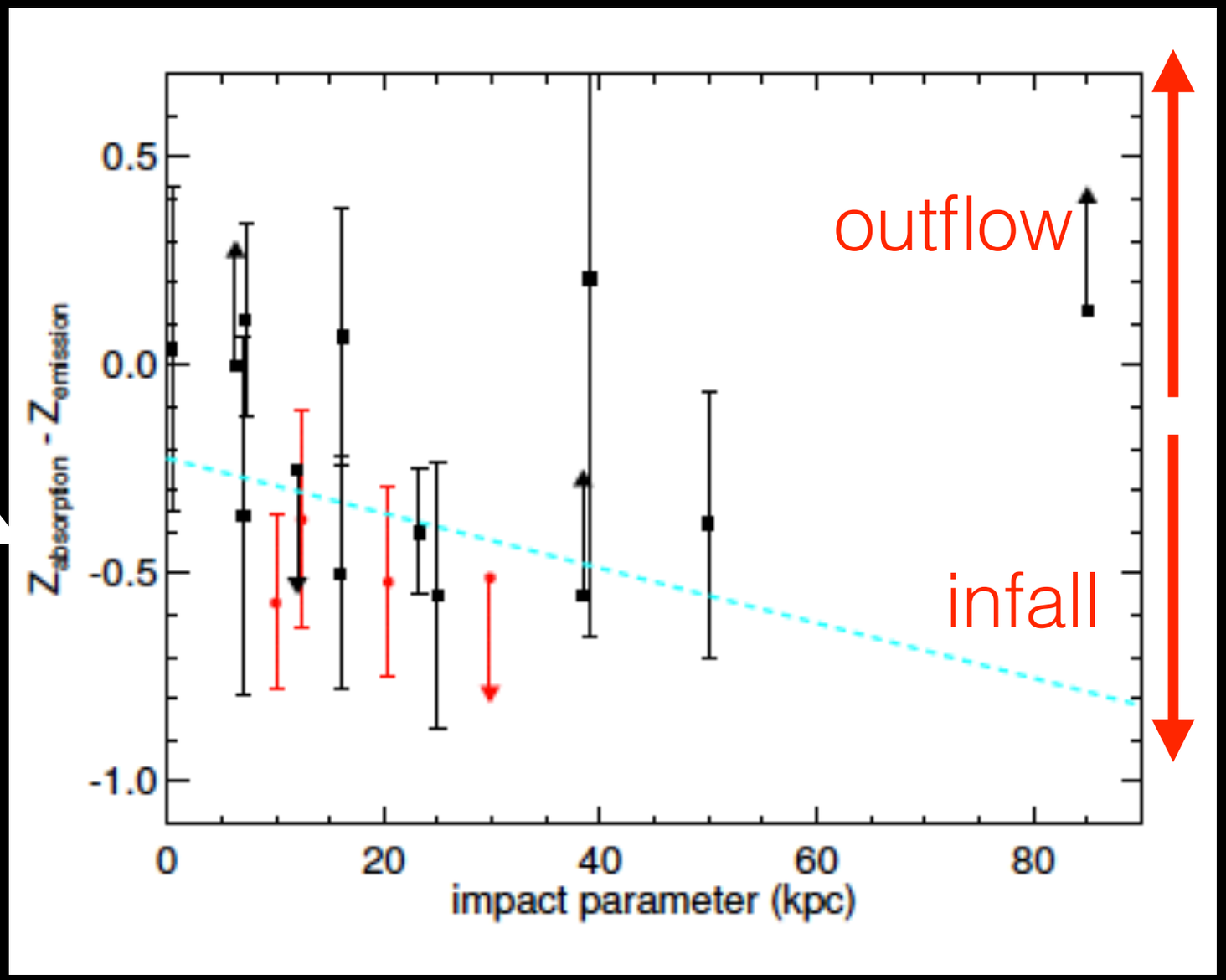


VLT/MUSE

- optical = 480-930 nm, OIII @ z<0.8
- 24 IFU, R=1770-3590
- FoV=1’x1’, 0.2” / pixel
- now AO-enhanced

HI Gas & HII Regions Metallicities: tracer of gas flows

gas to galaxy metallicity difference

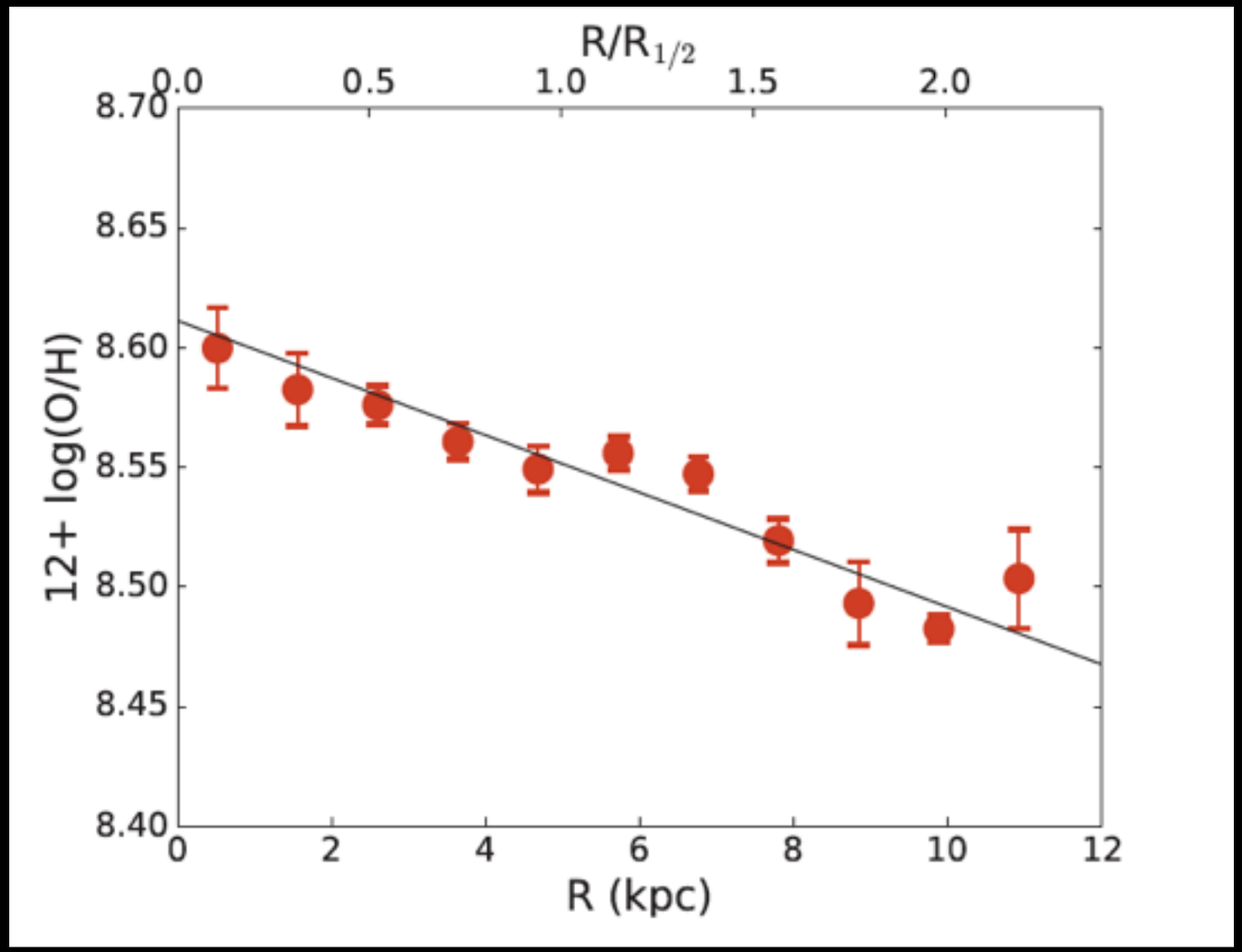


Rahmani, CP+ 16

Hadi Rahmani

Metallicity Gradients

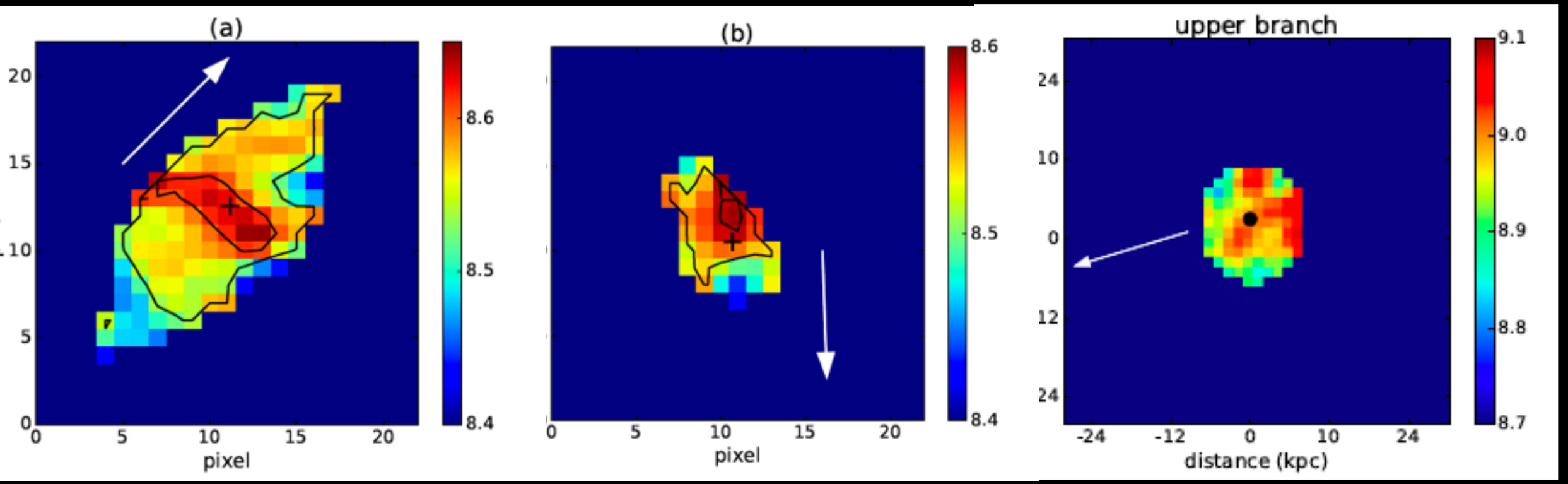
- shallow gradients



Rahmani, CP+ sub

Mannucci+

Beyond Metallicity Gradients: resolved metallicity map

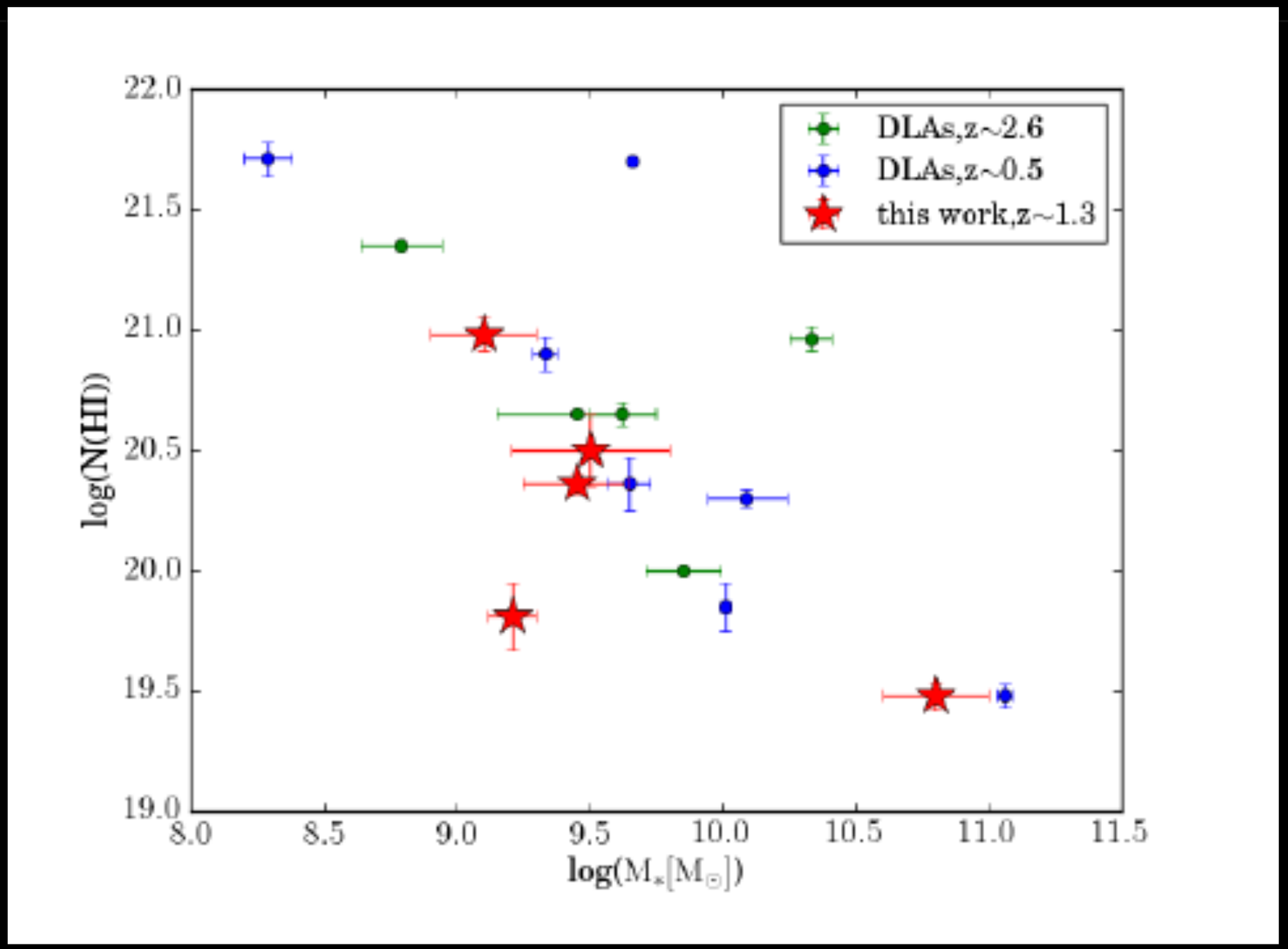


- Metallicity distribution is inhomogeneous

Cresci+10, Troncoso+14

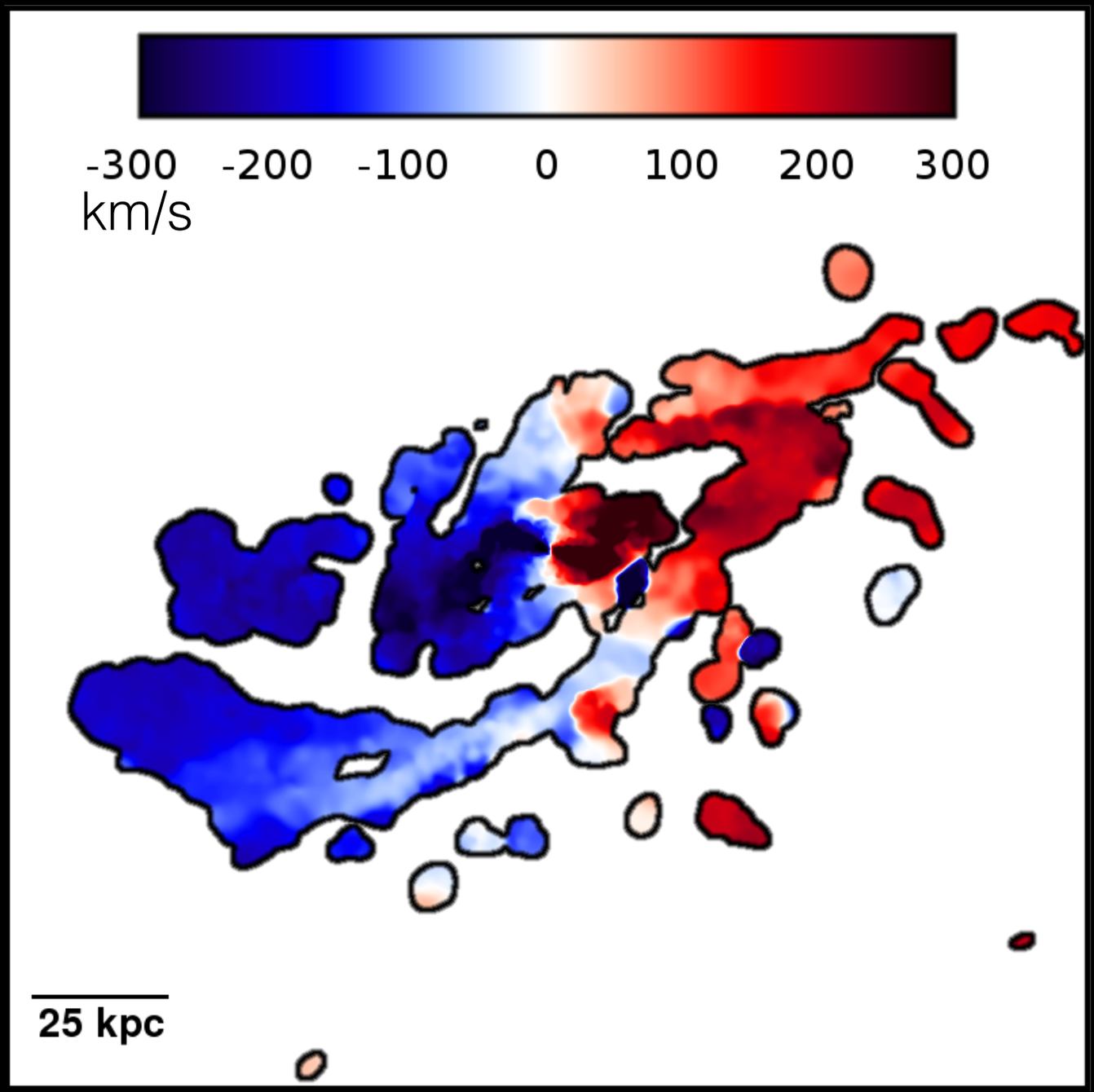
Stellar Masses

Ramona Augustin



Augustin, CP+ in prep

Accretion is co-rotating with disk

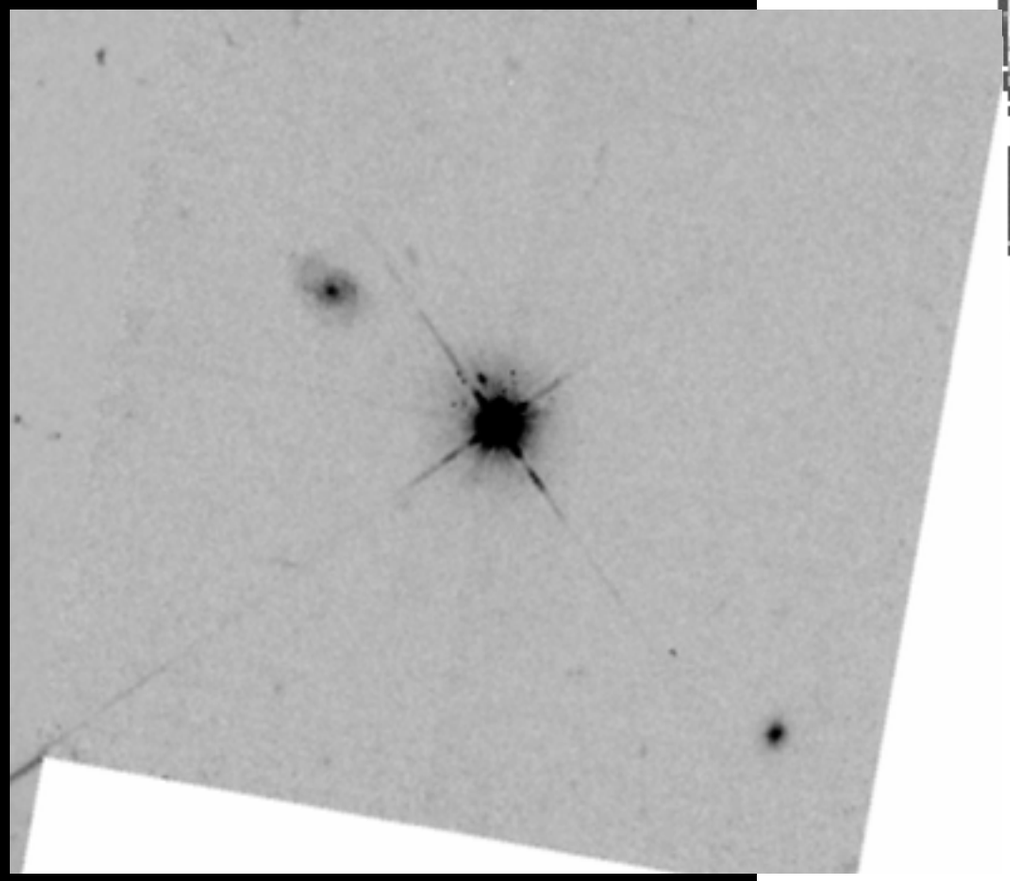


Keres+09, Stewart+11

- accretion has higher angular momentum than disc

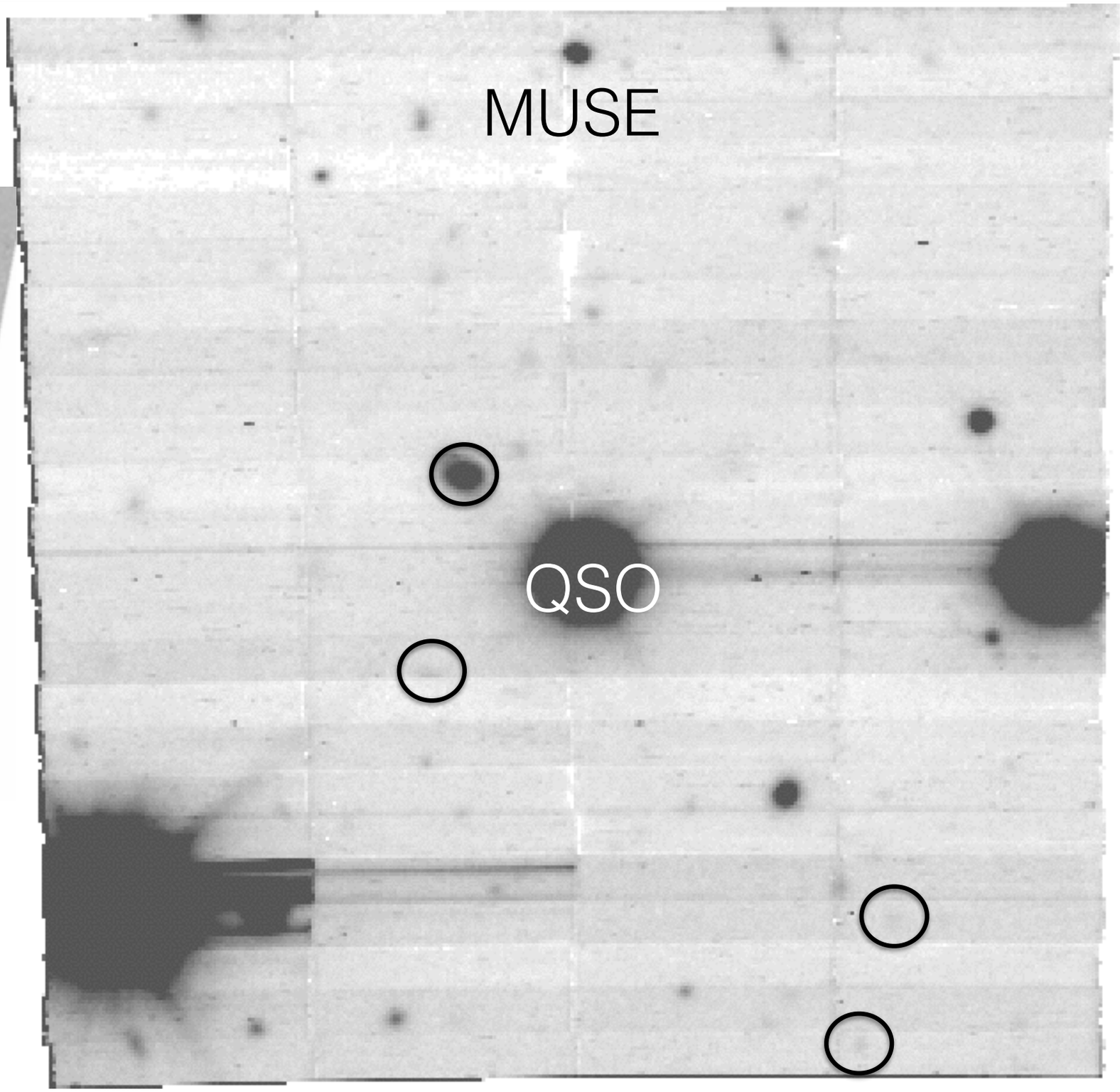
Relating Stars and Gas

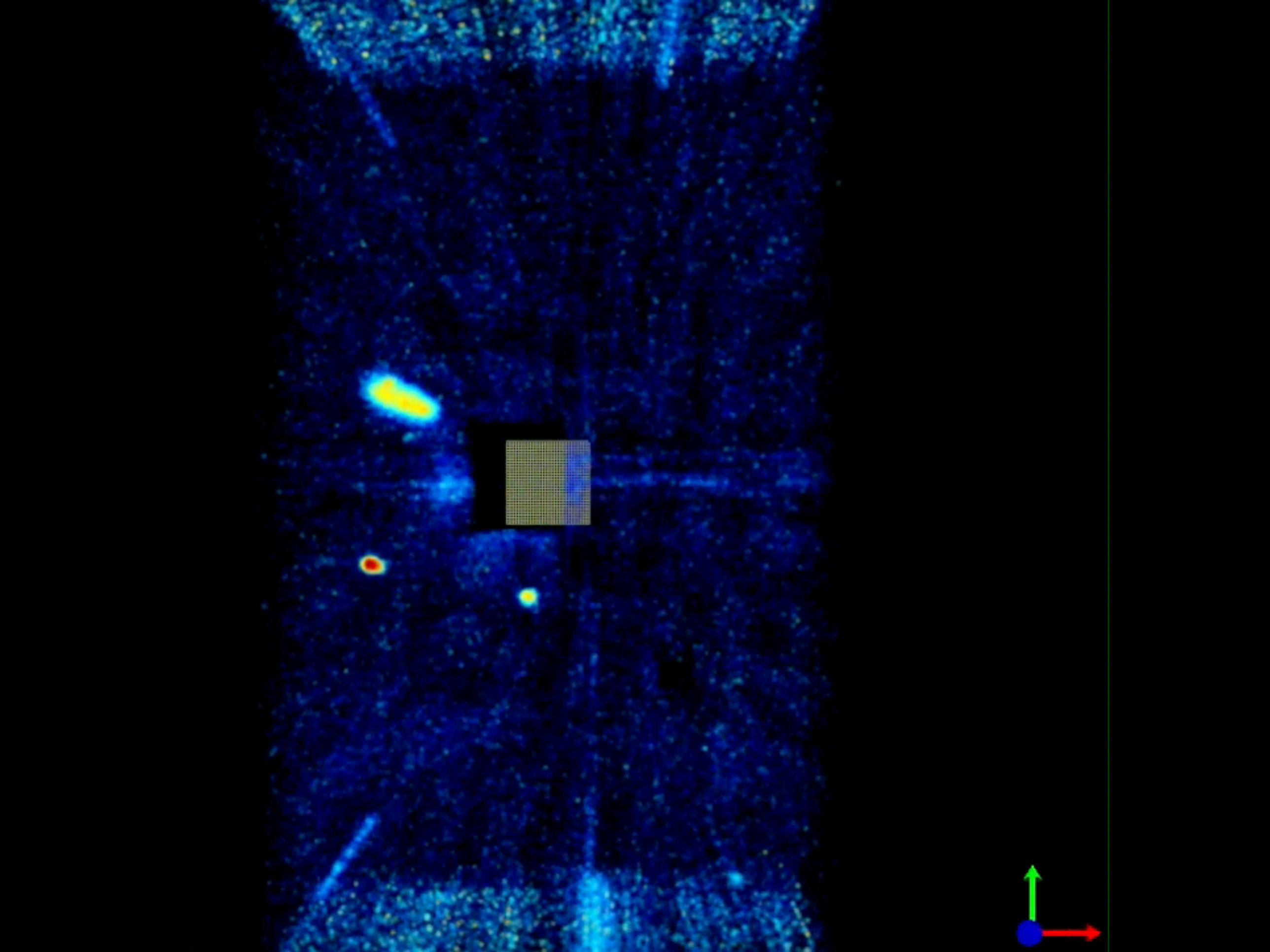
HST



z=0.43
N(HI)=19.5
$Z_{abs}=1/3Z_{\odot}$

MUSE





[OIII] 5008 Obs Flux

2.5

1.5

1.0×10^{-19} erg/s/cm^2

Obs Velocity

150

-150 km/s

Vel Dispersion

90

60

40 km/s

QSO

2”

Galaxy “a”

N

E

Model Velocity

150

-150 km/s

Residuals

15

-15 sigma

[OIII] 5008 Obs Flux

2.5

1.5

Obs Velocity

150

Vel Dispersion

90

60

40 km/s

QSO

- azimuthal angle=12+/-1 deg
- $M_{dyn}=7x10^{10}M_{sun}$, $M_{halo}=3x10^{12}M_{sun}$

Galaxy "a"

N

E

als

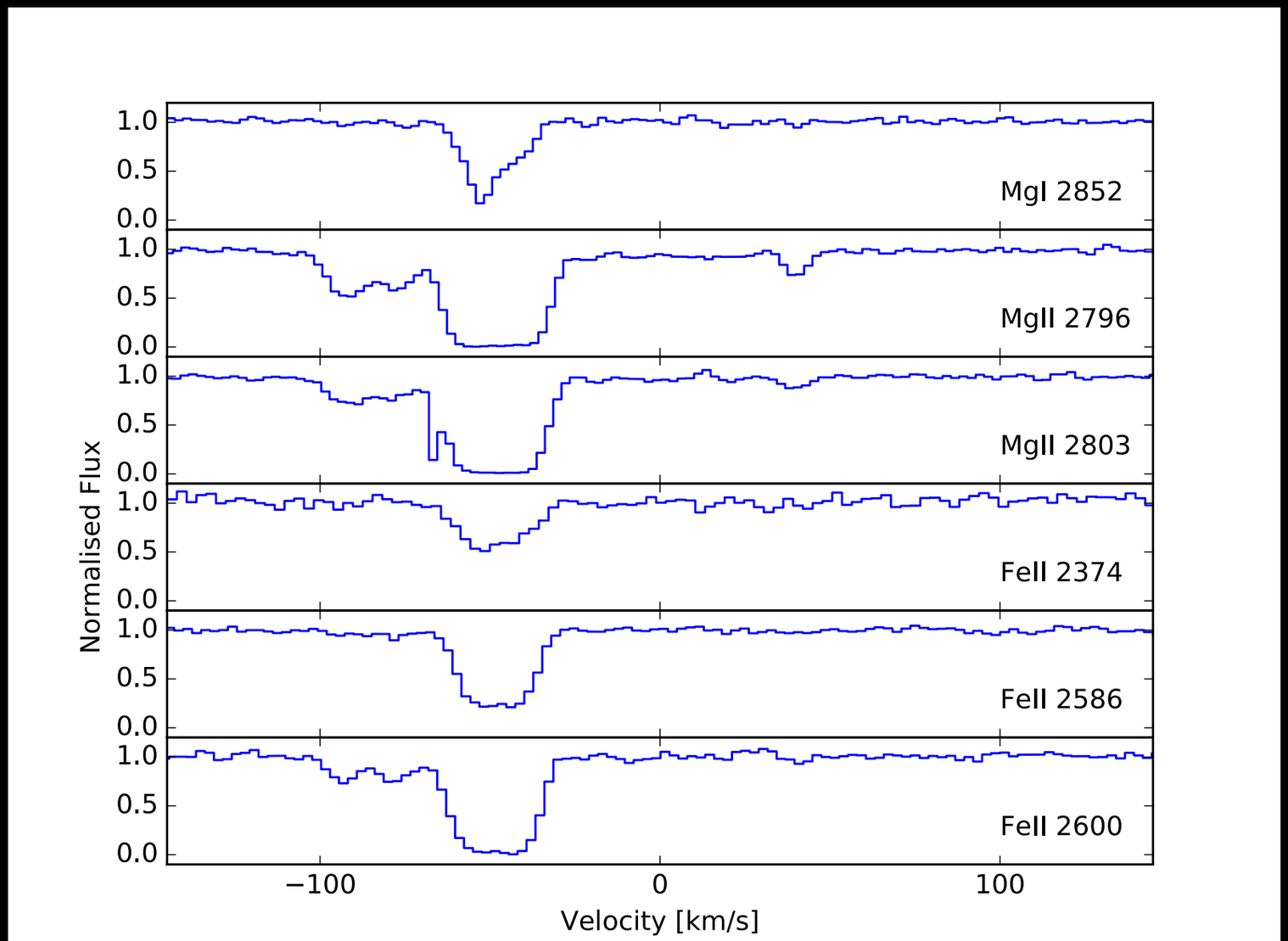
15

-150 km/s

-15

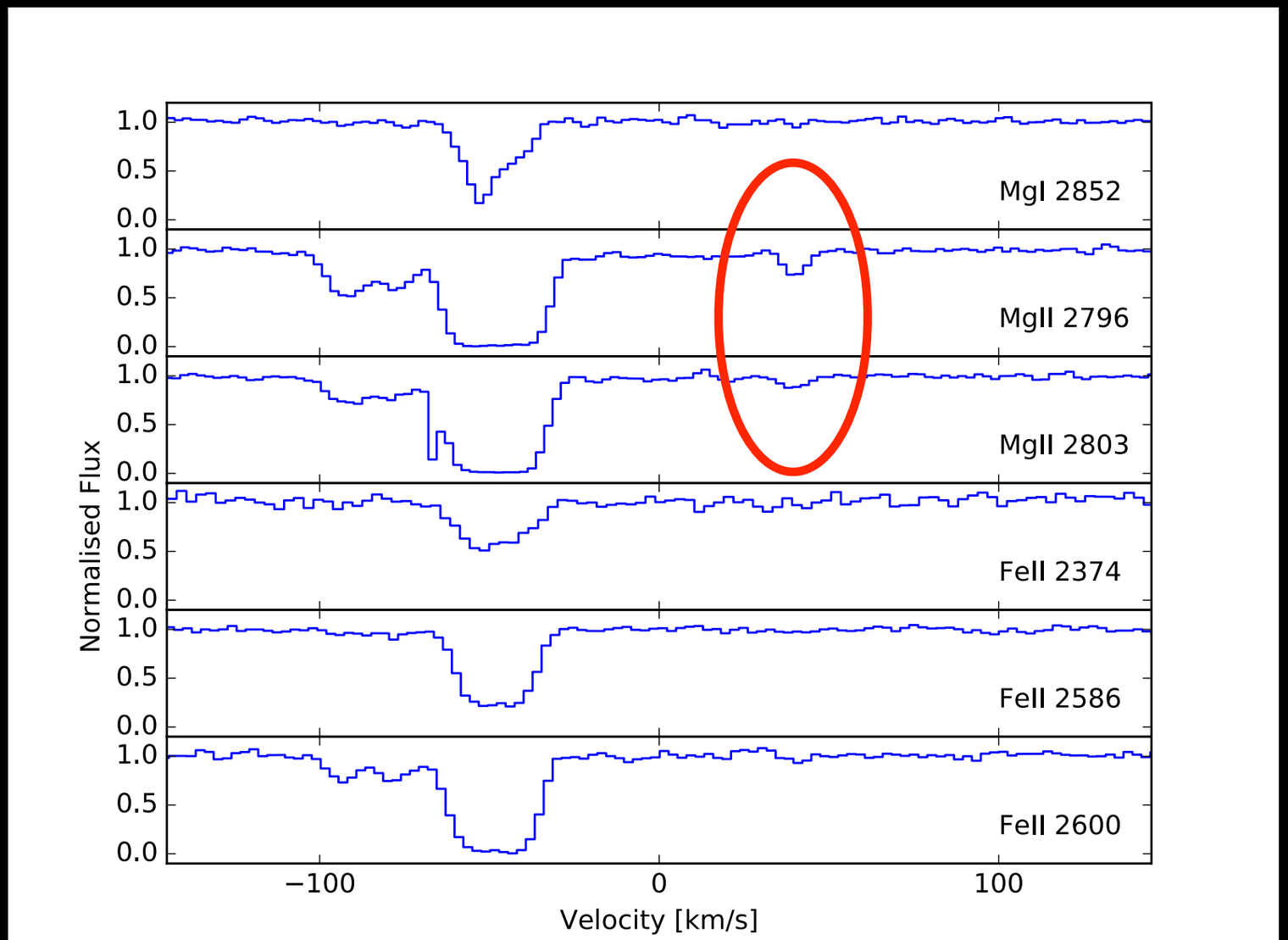
sigma

What is this Gas?



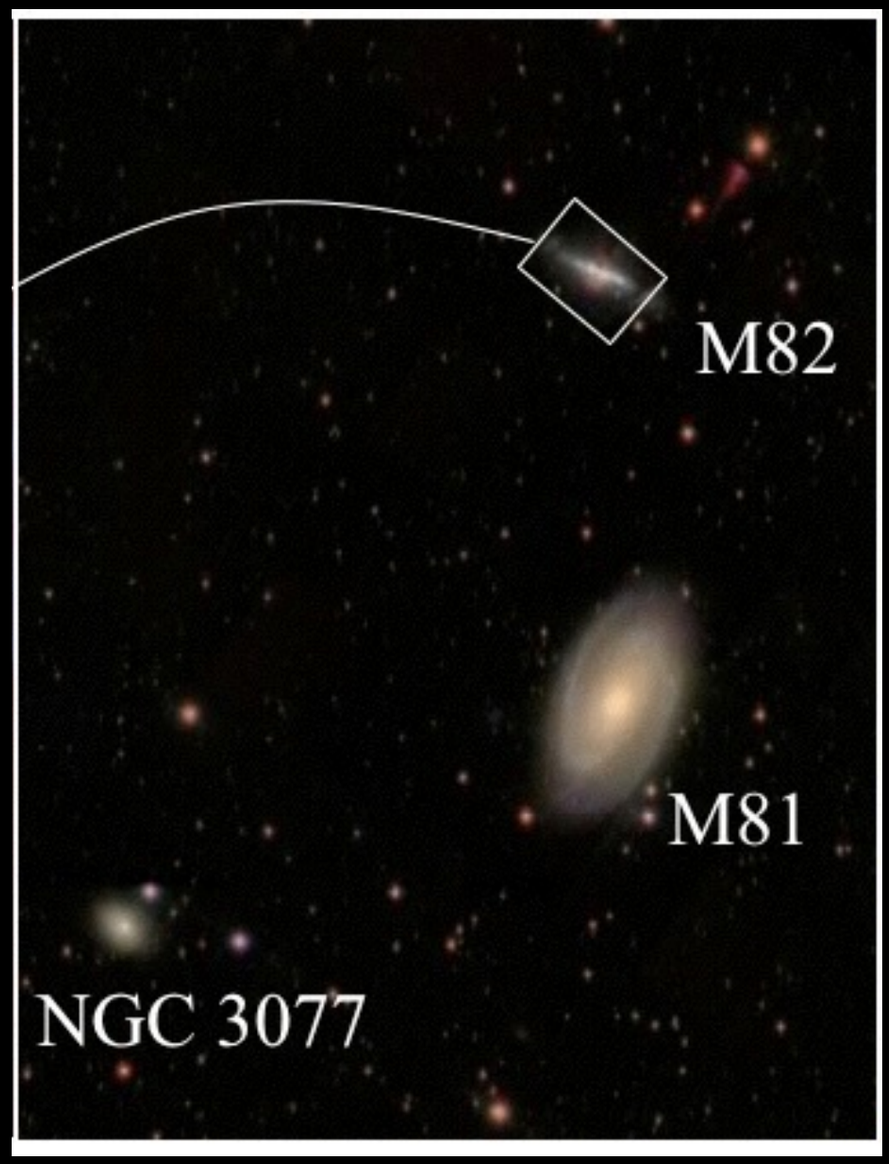
CP+17

What is this Gas?



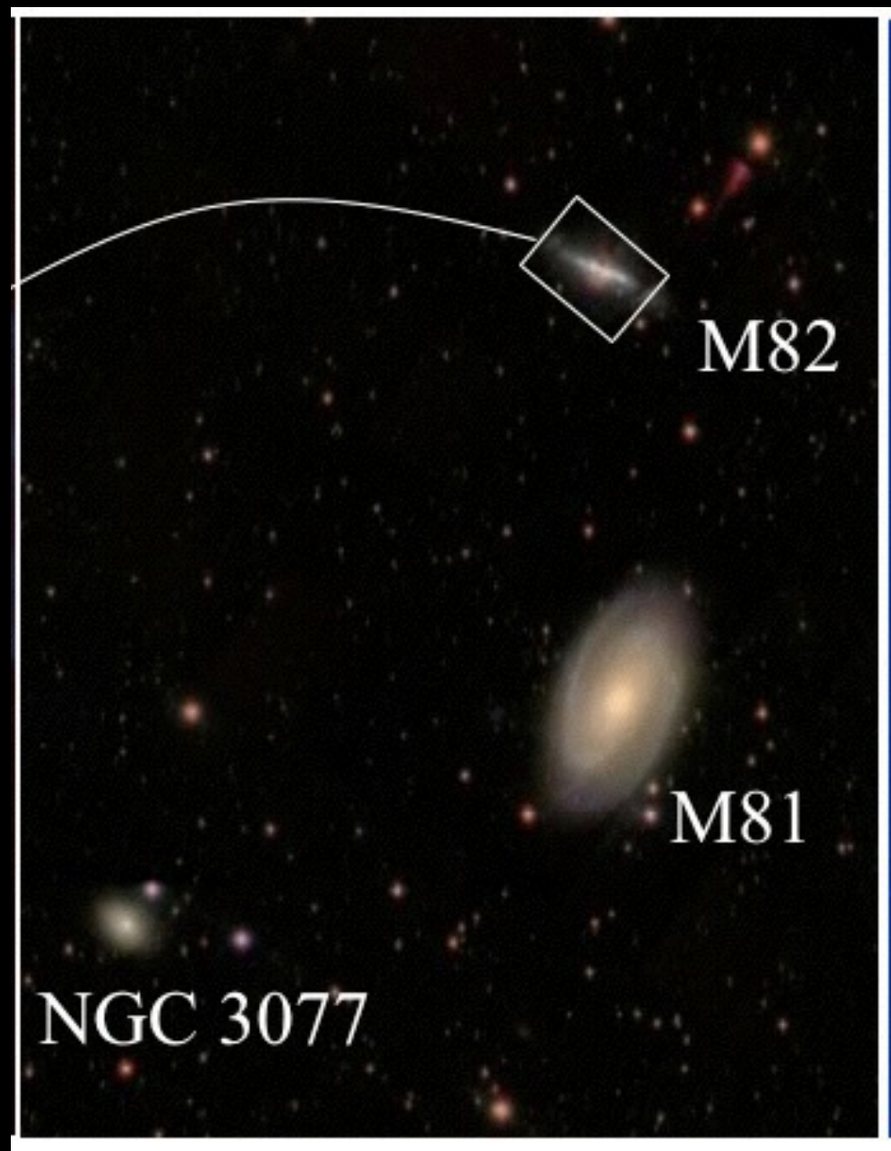
CP+17

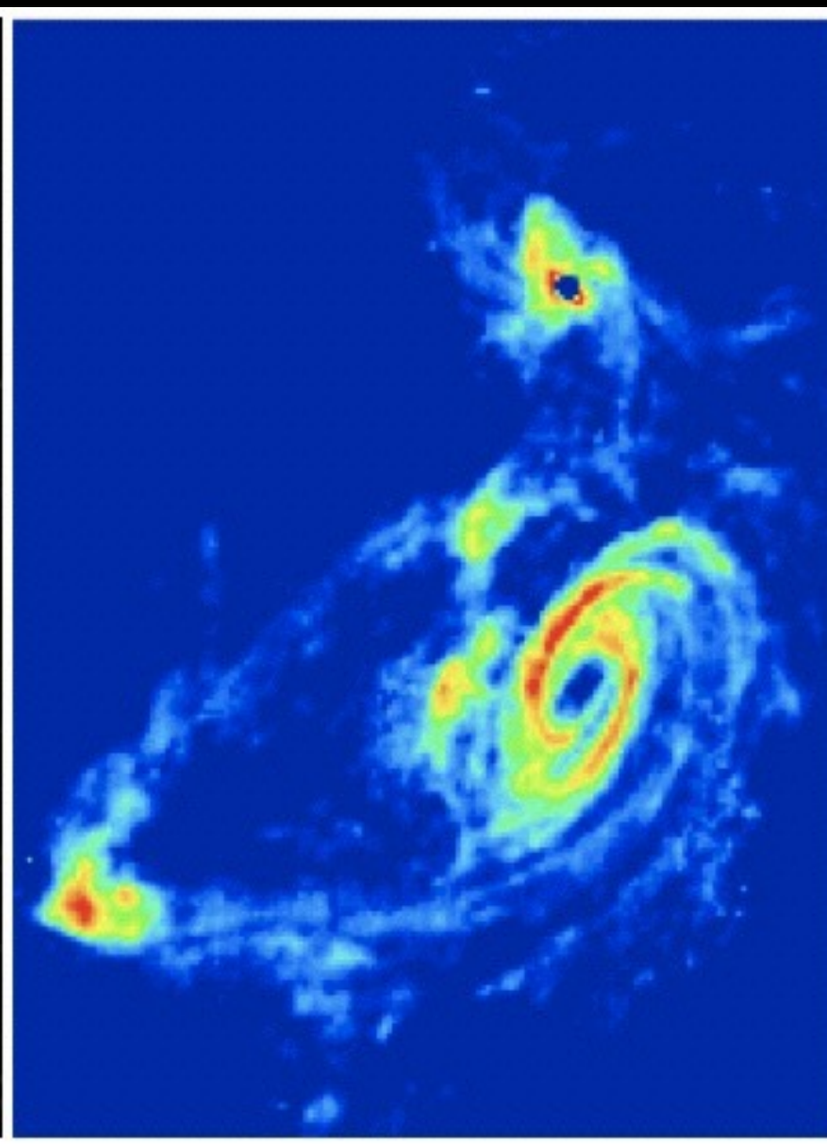
Low-redshift Analog



Starlight
(optical)

Low-redshift Analog

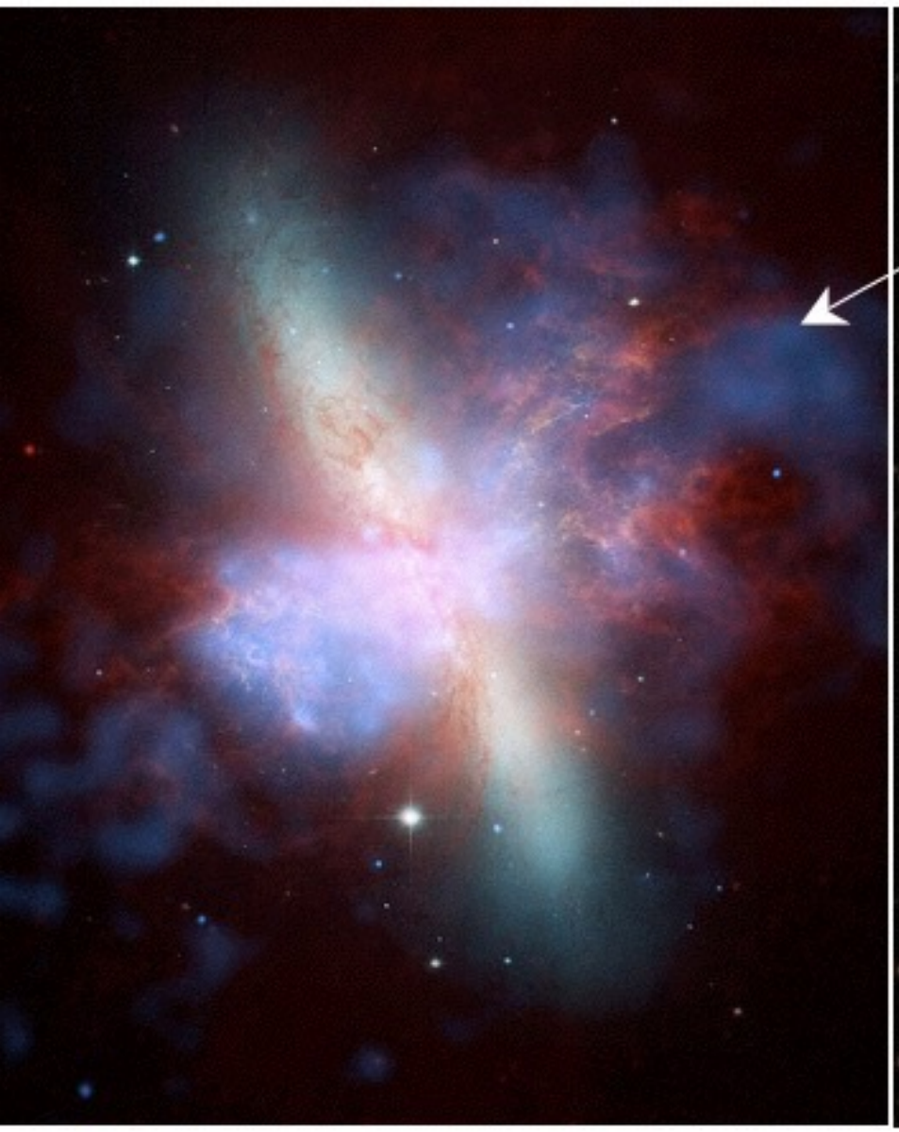


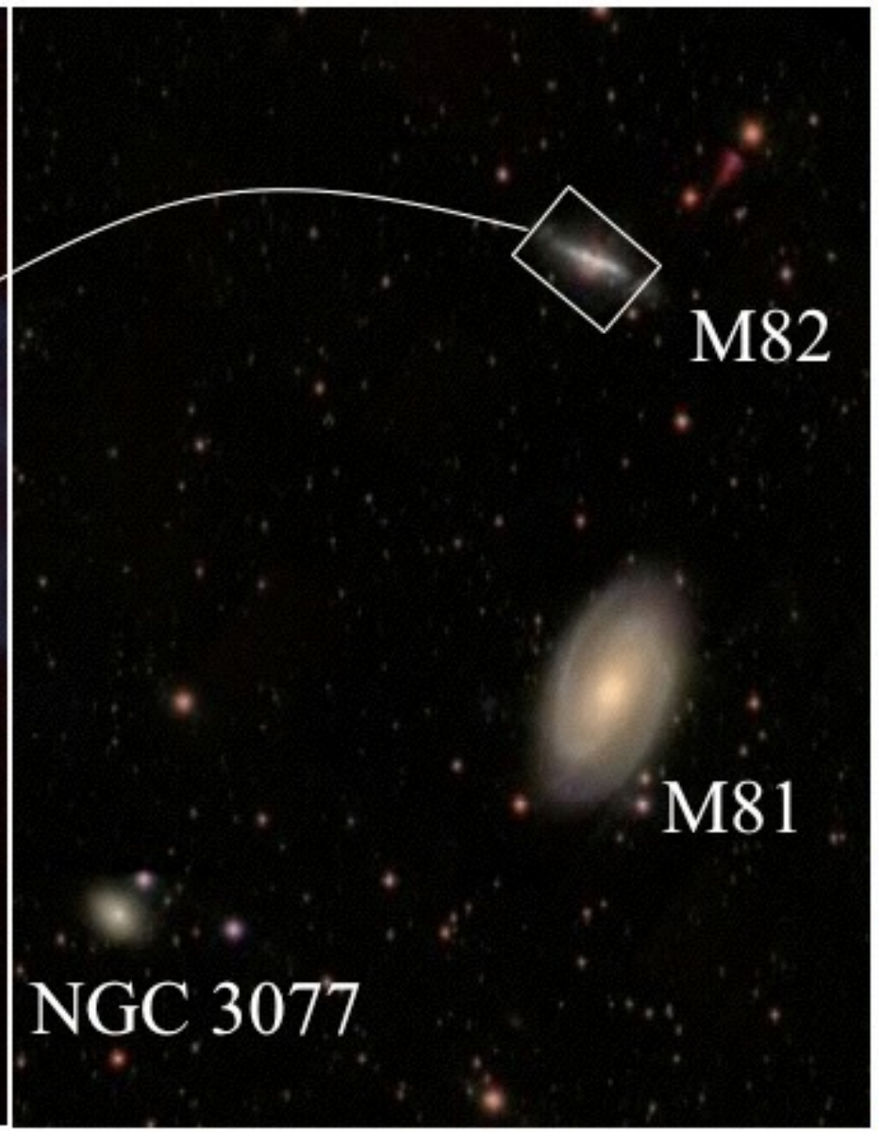


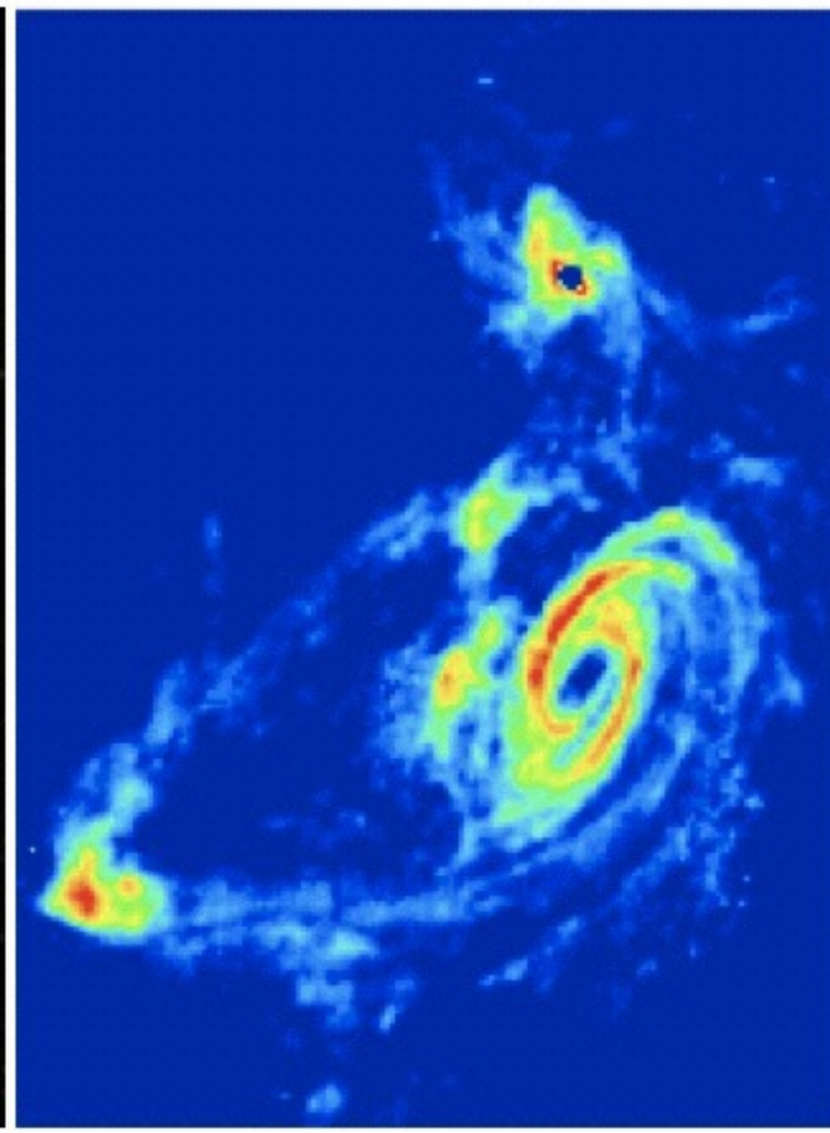
Starlight
(optical)

HI Gas
(radio)

Low-redshift Analog







Galactic Wind
(M82)

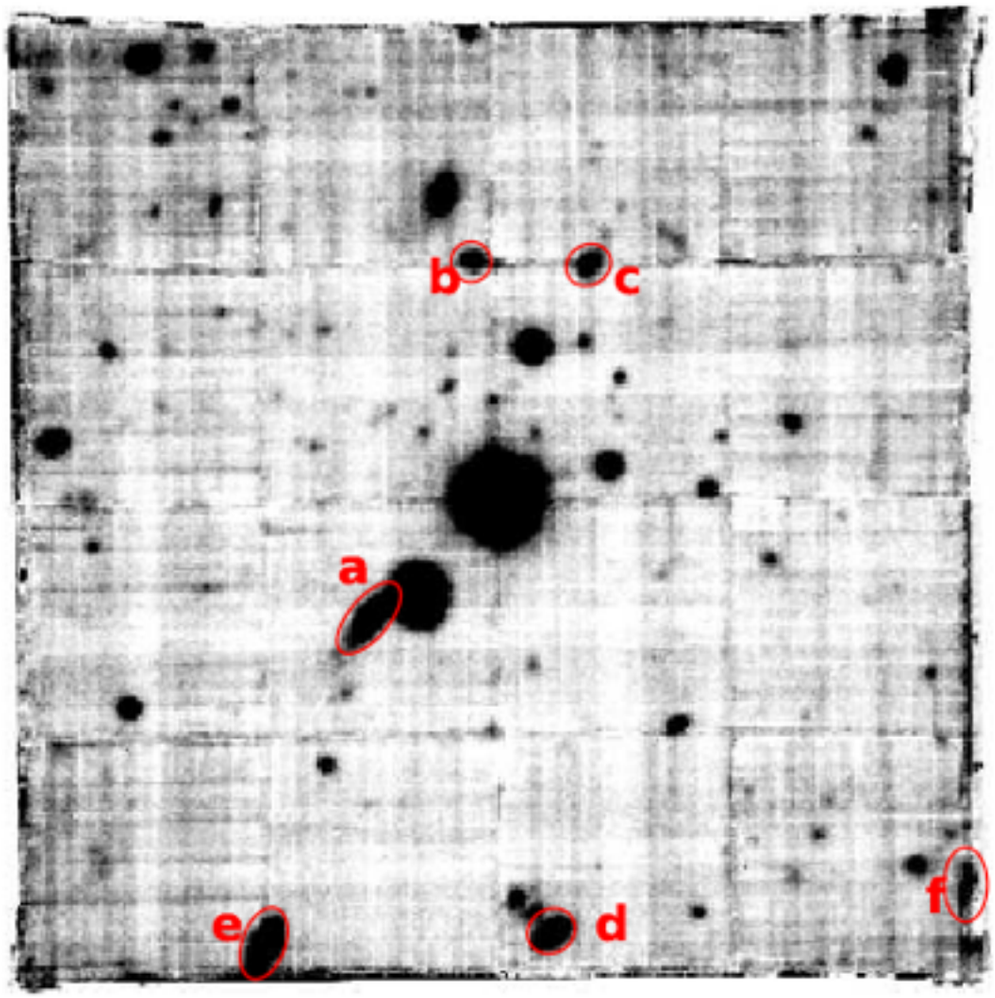
Starlight
(optical)

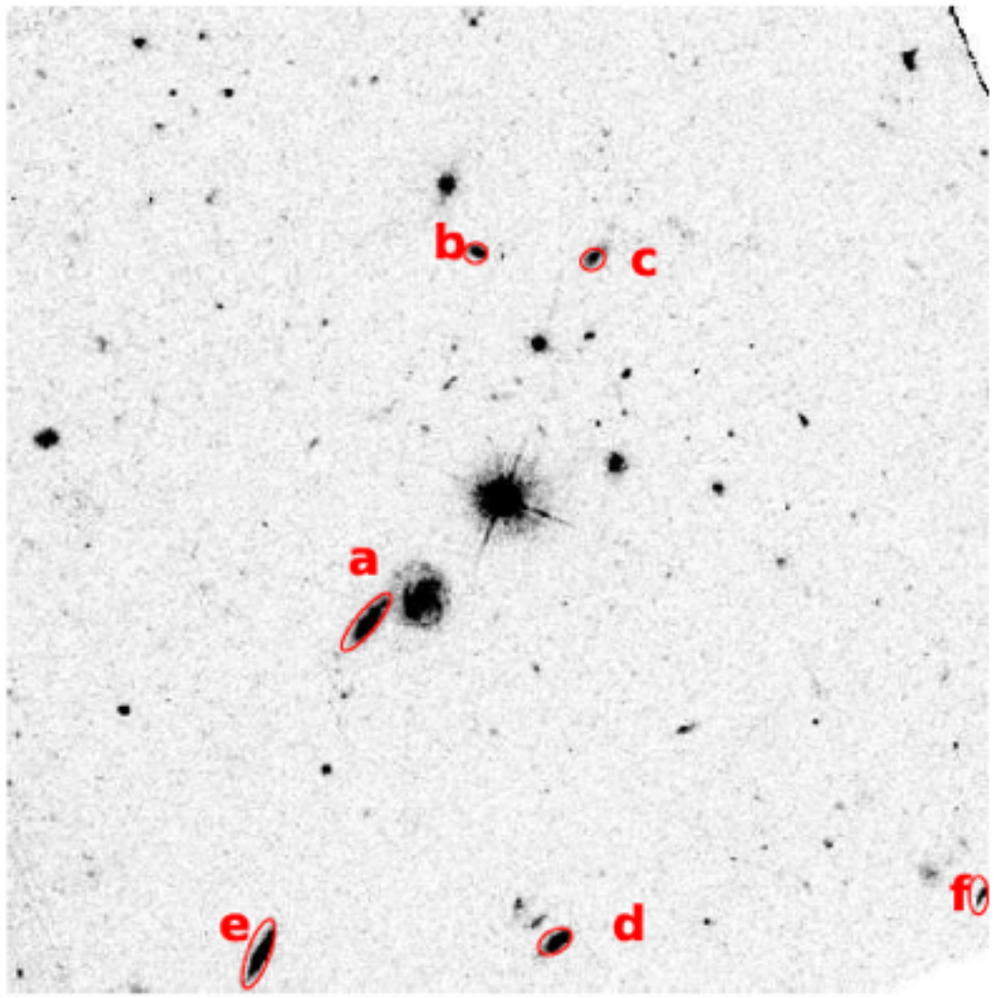
HI Gas
(radio)

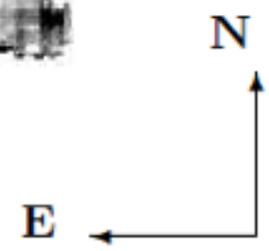
Evidence for Accretion

MUSE

HST

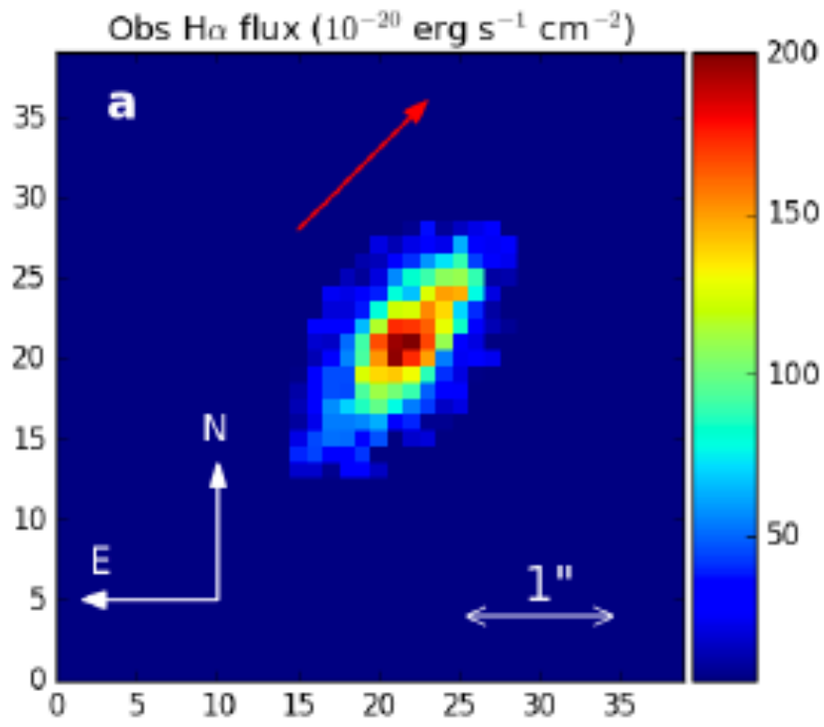


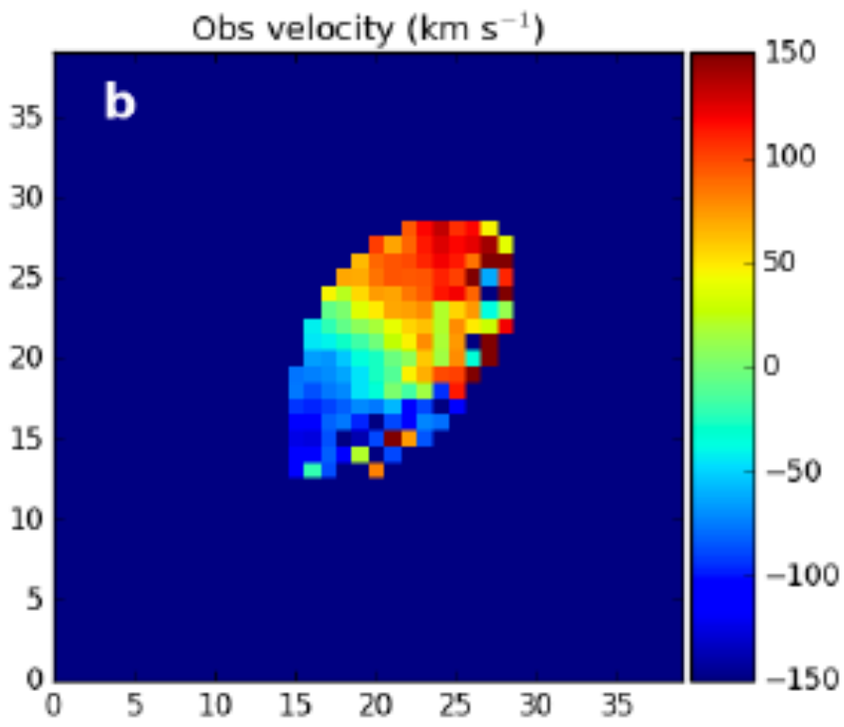


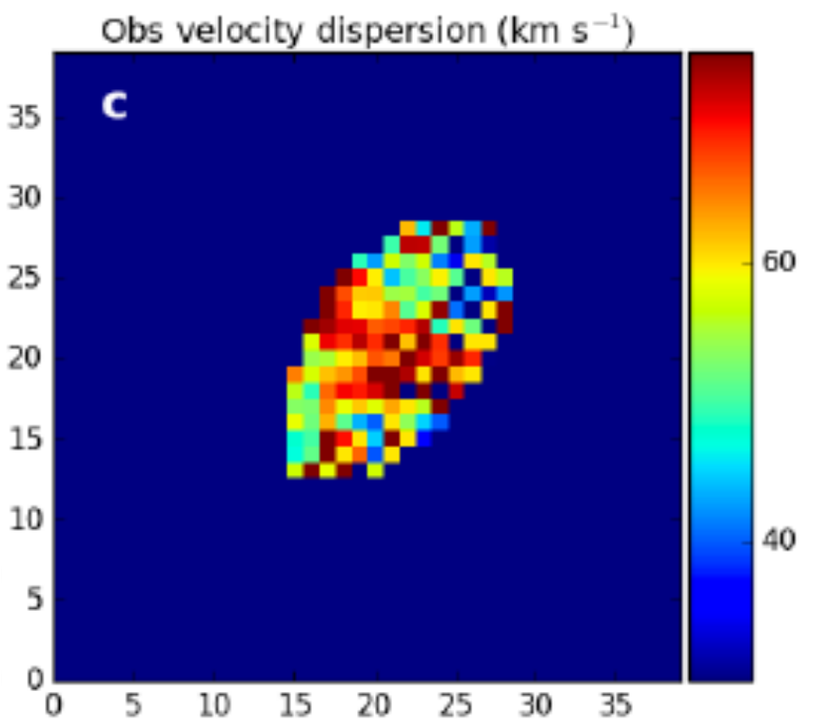


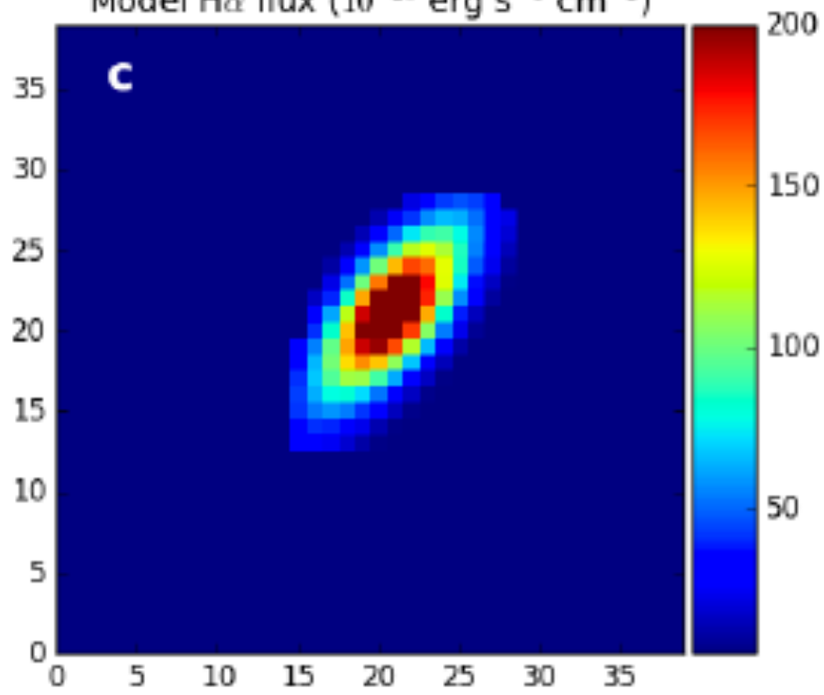
z=0.38, N(HI)=18.7, Z_{abs}=1/10$Z_{\odot}$

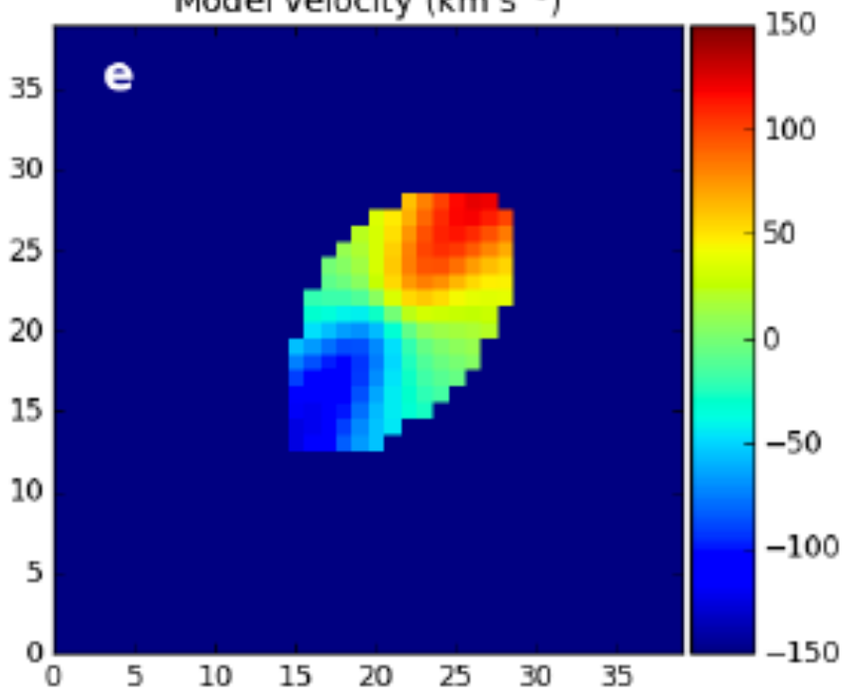
Sanchez Almeida+,Jones+

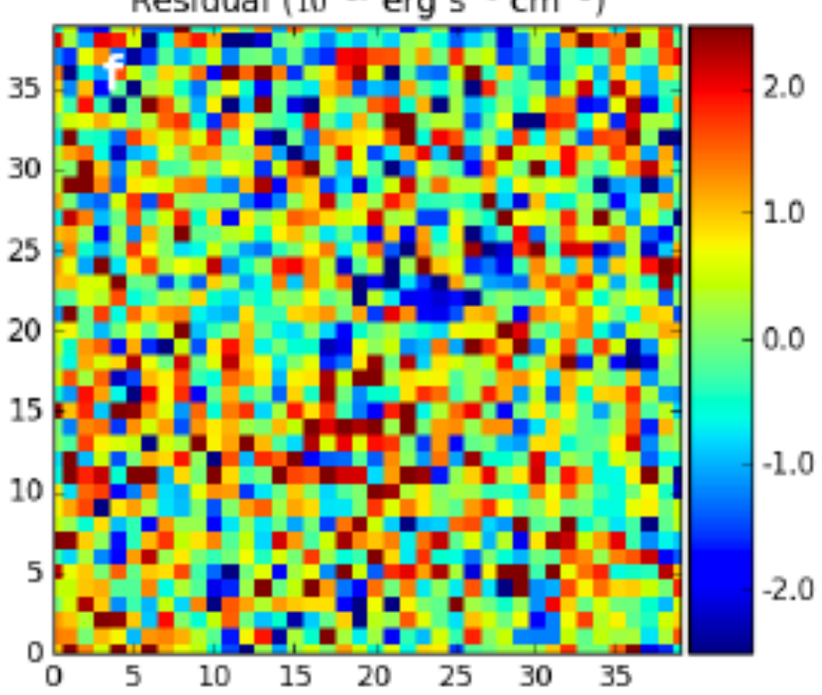

Obs Hα flux (10^{-20} erg s^{-1} cm^{-2})
a
N
E
1"
200
150
100
50

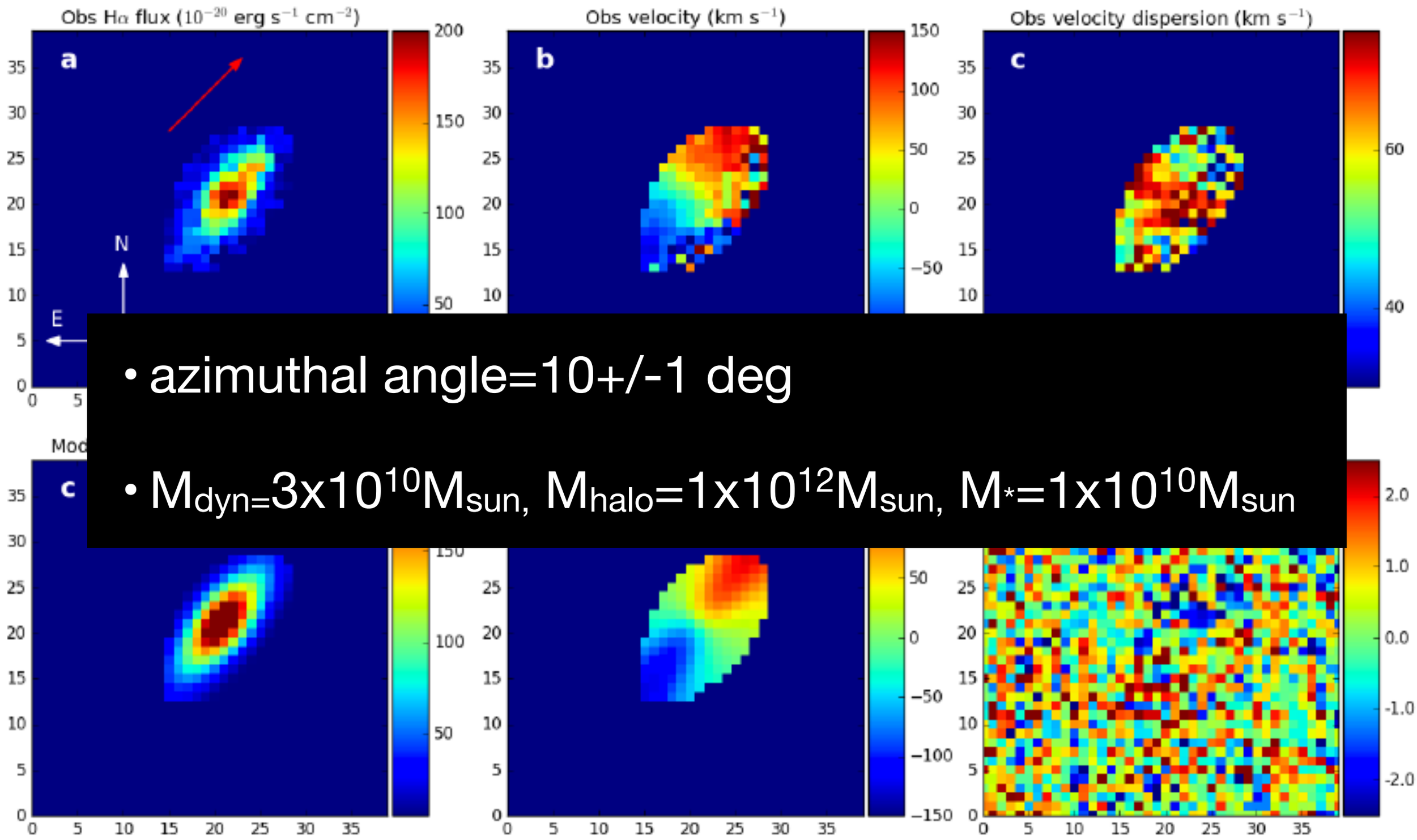

Obs velocity (km s^{-1})
b
150
100
50
0
−50
−100
−150


Obs velocity dispersion (km s^{-1})
c
60
40


Model Hα flux (10^{-20} erg s^{-1} cm^{-2})
c
200
150
100
50

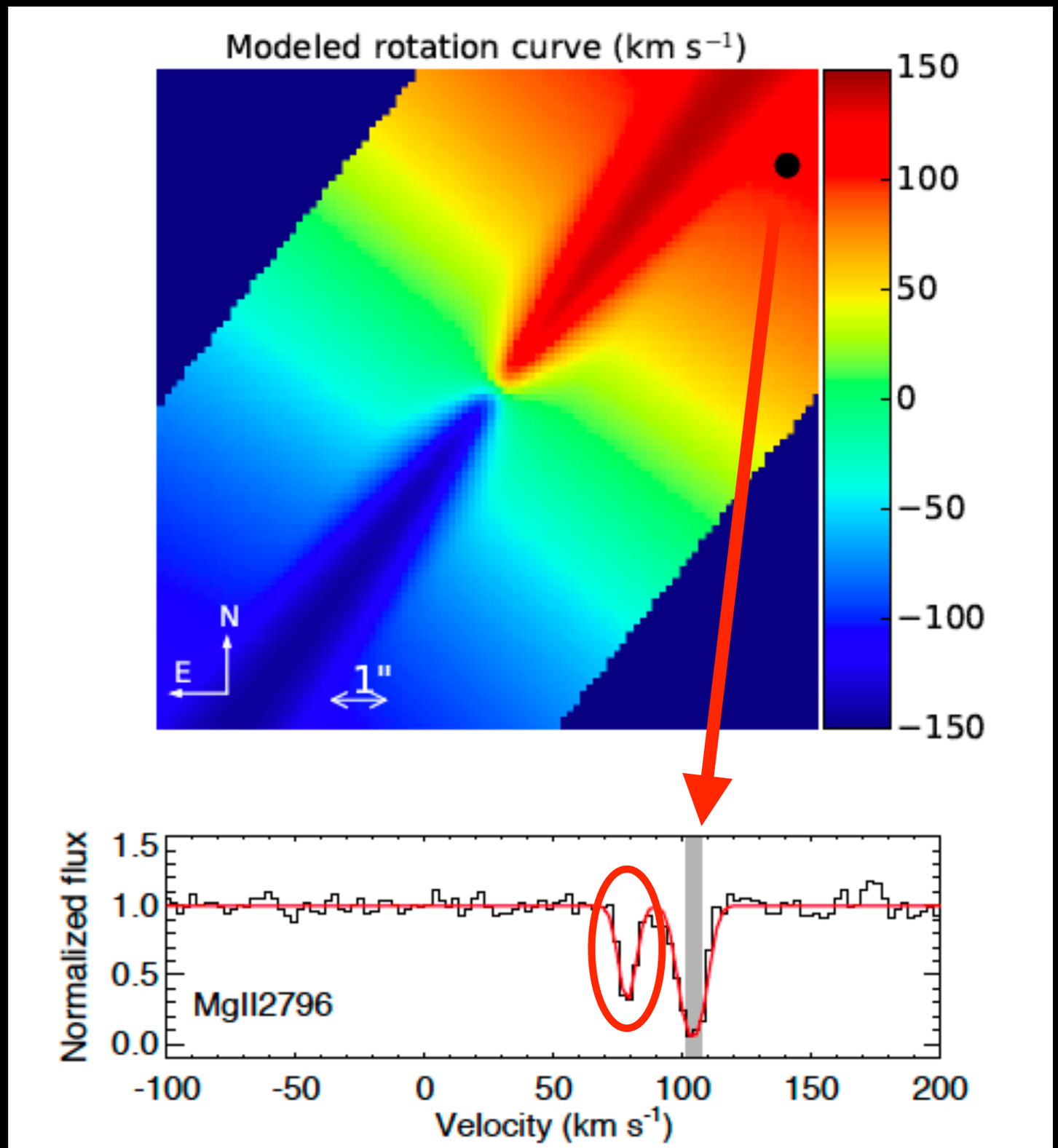

Model velocity (km s^{-1})
e
150
100
50
0
−50
−100
−150


Residual (10^{-20} erg s^{-1} cm^{-2})
f
2.0
1.0
0.0
-1.0
-2.0



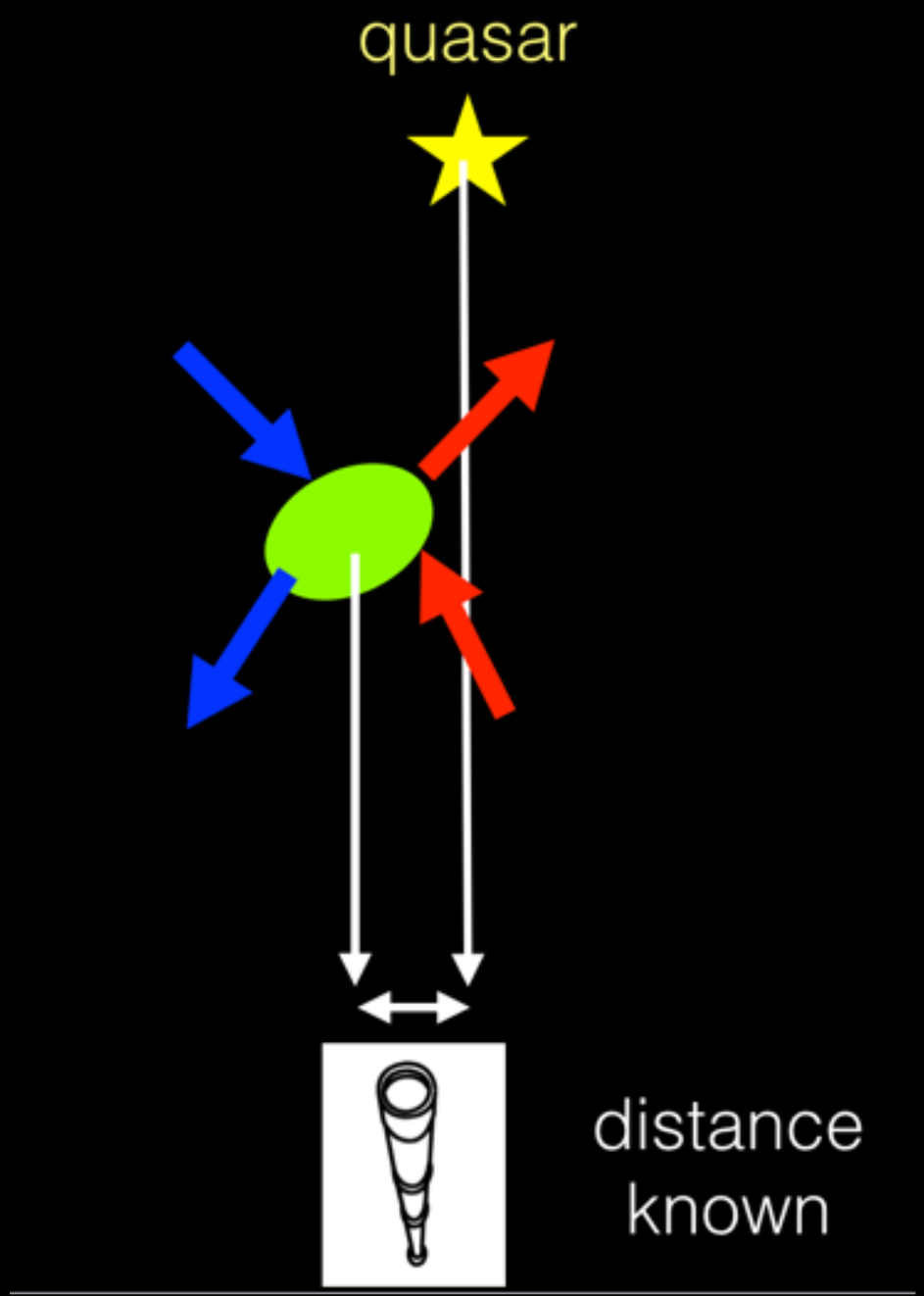
- azimuthal angle=10+/-1 deg
- $M_{dyn}=3x10^{10}M_{sun}$, $M_{halo}=1x10^{12}M_{sun}$, $M_*=1x10^{10}M_{sun}$

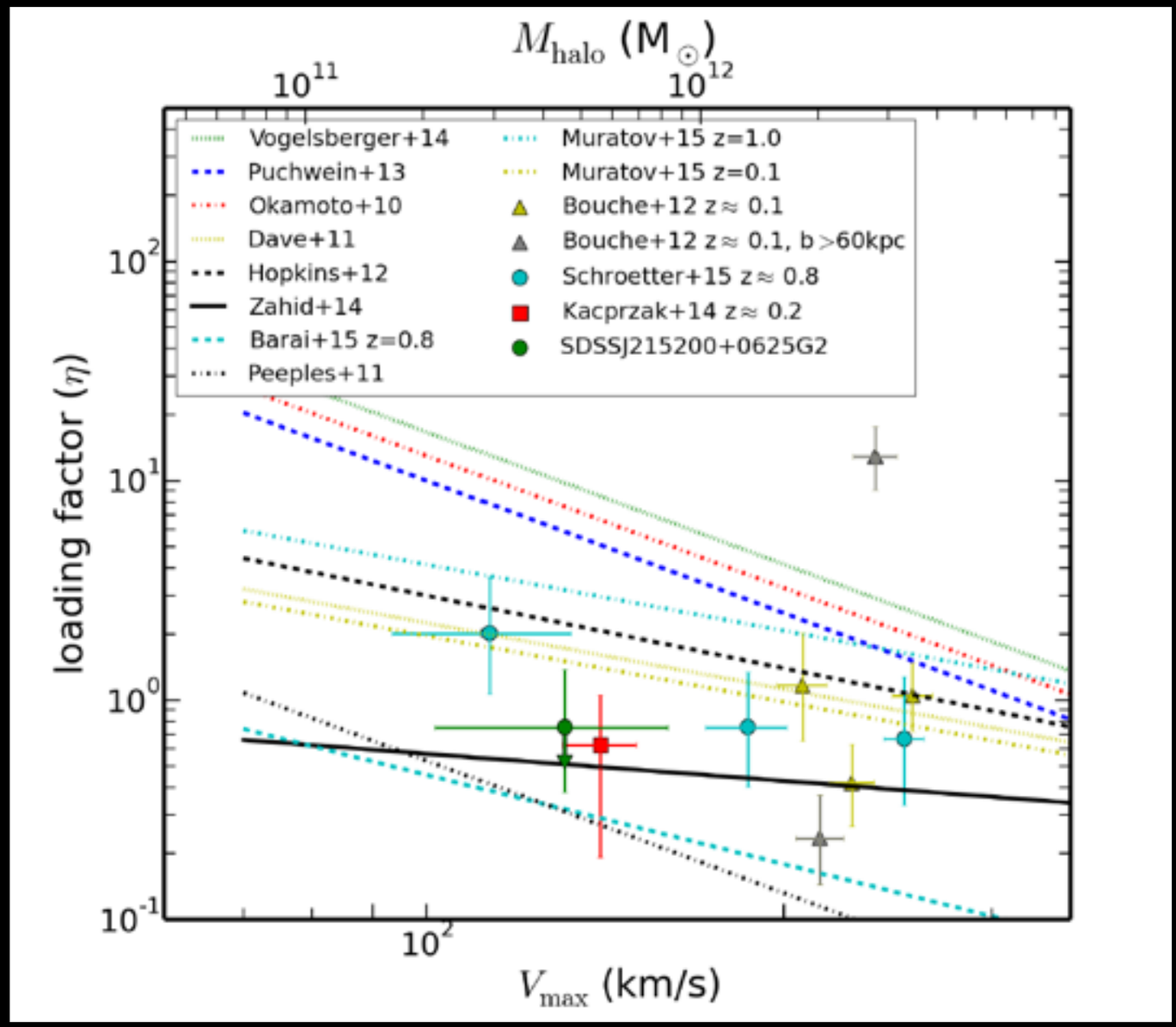
Cold Flow Accretion



Rahmani, CP+sub

Mass Loading Factor



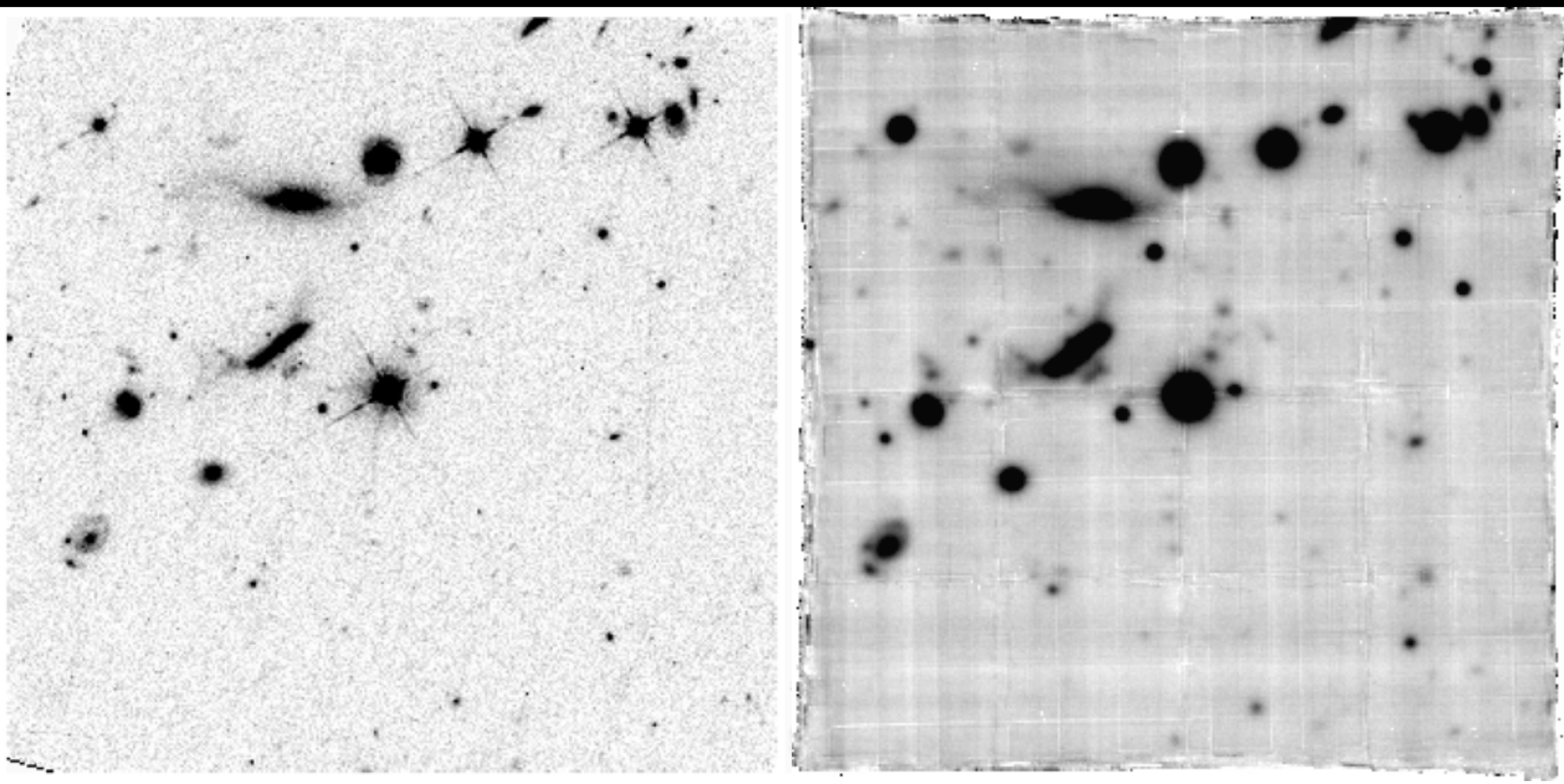


Schroetter.CP+15,Schroetter+16

Is the CGM Multi-Phase?

HST

MUSE



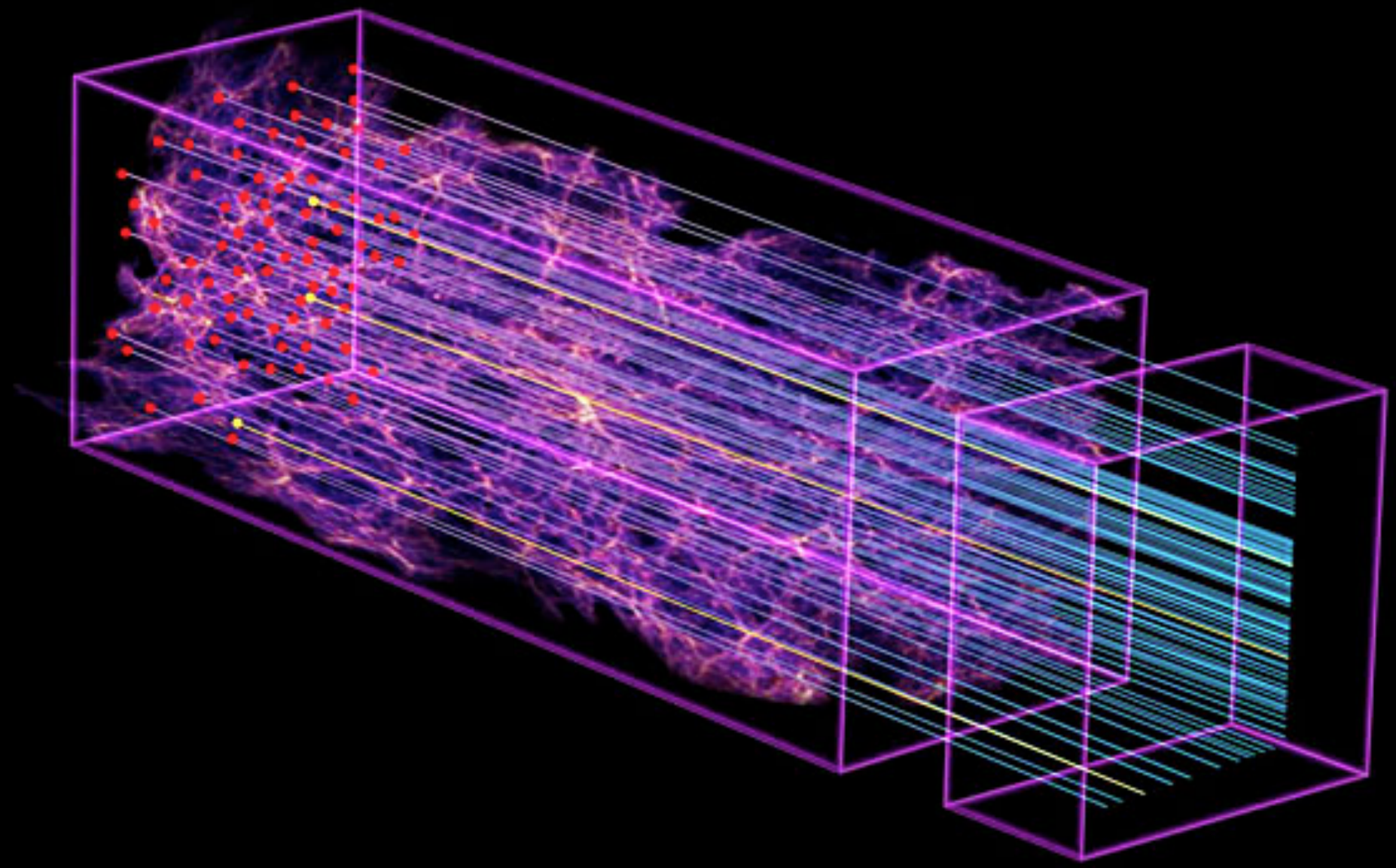
z=0.31, N(HI)=21.7, Z_{abs}=1/10$Z_{\odot}$

MUSE

ALMA

CO+in prep

Beyond Galaxy-Absorber Association: cosmic web reconstruction

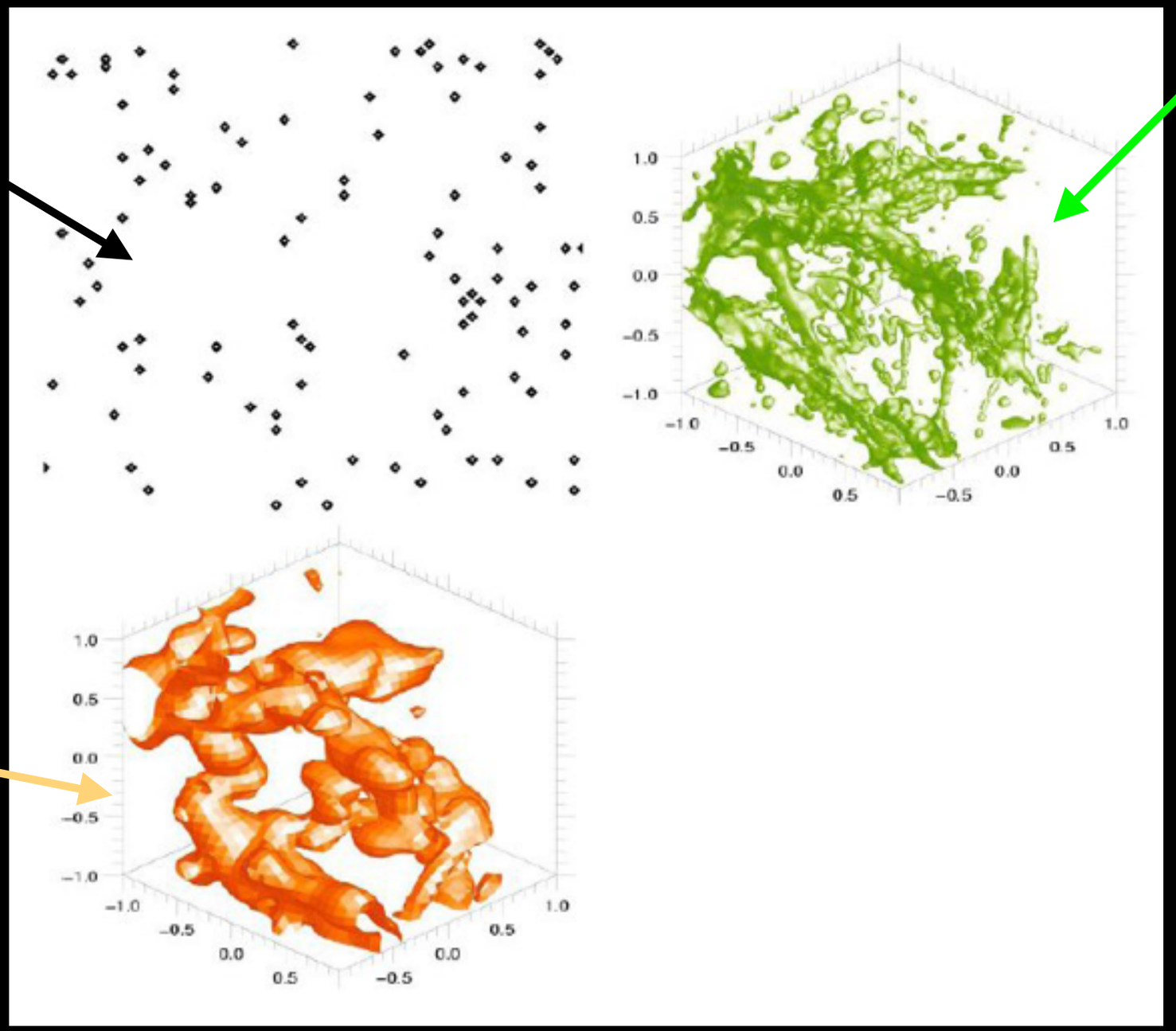


- densely paved background sources

Cosmic Web Reconstruction: method

100 random lines-of-sight

simulated density field

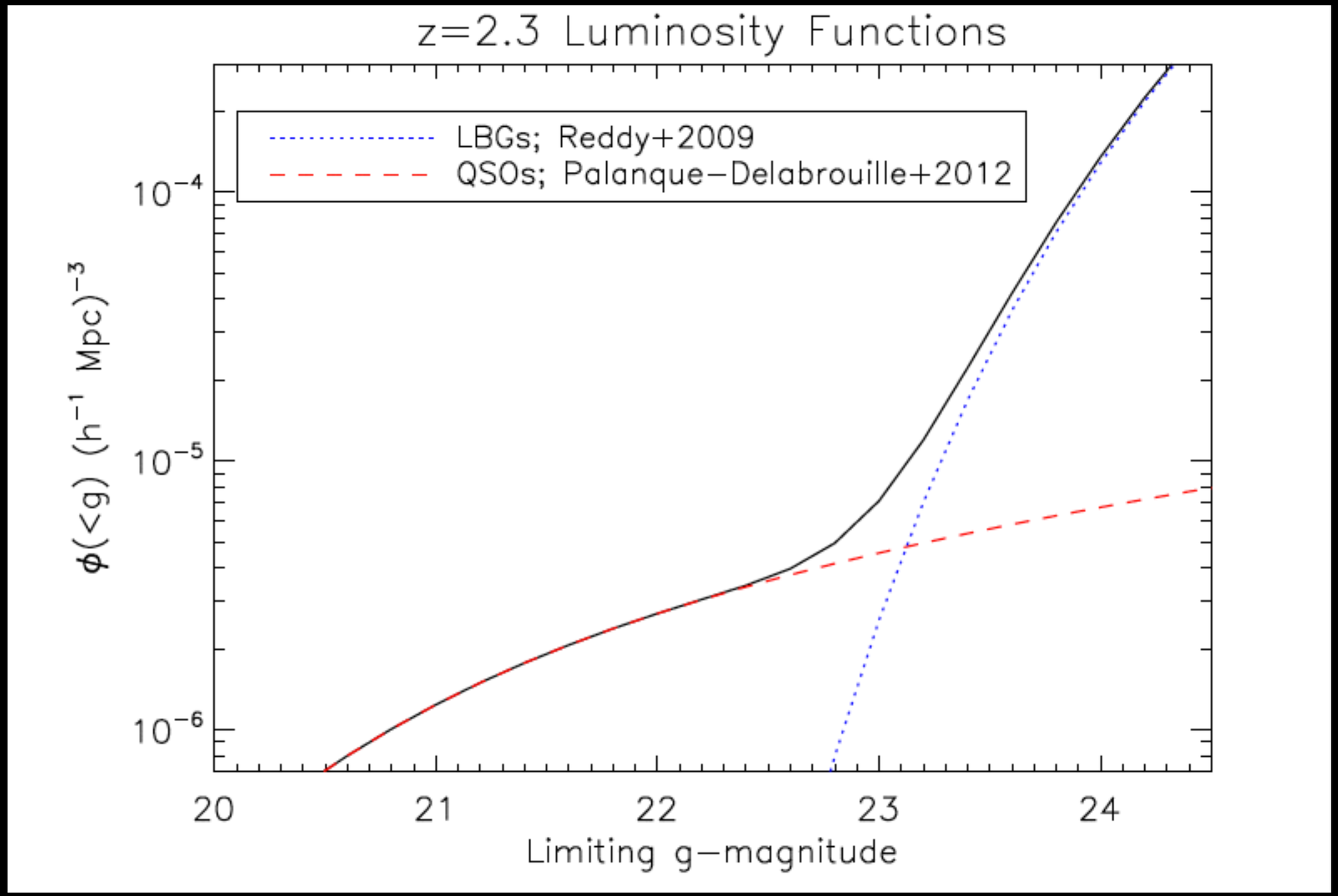


reconstructed density field

Pichon+01, Caucci+08

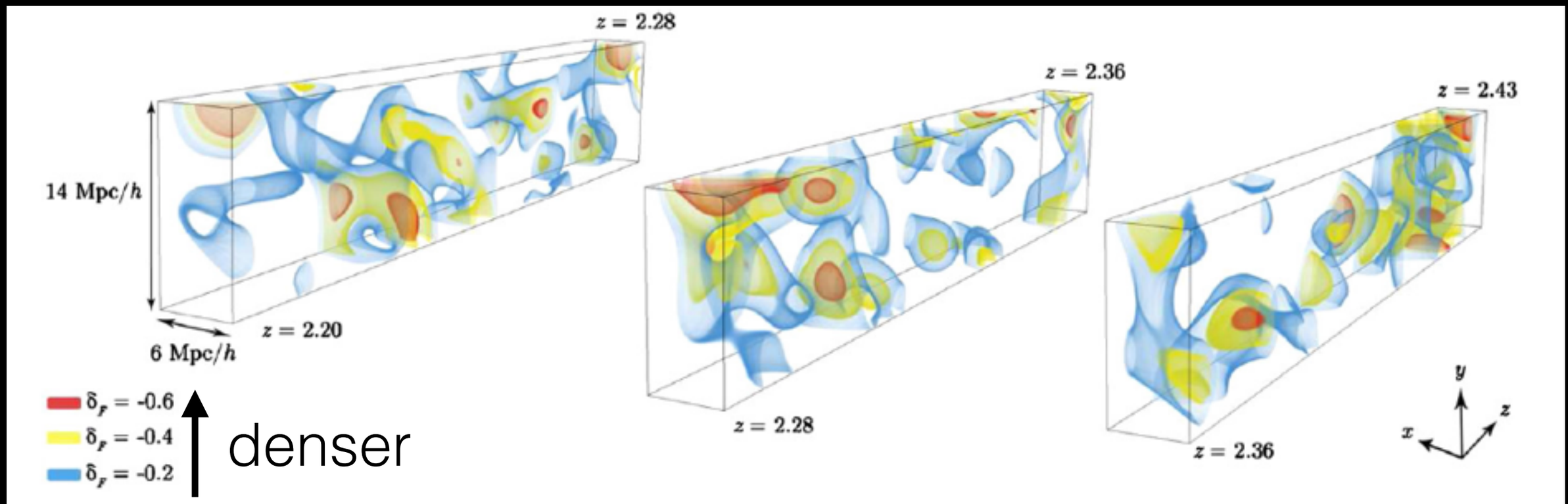
50x50x50 Mpc

Which background source?



Lee+14a

Cosmic Web Reconstruction: 1st results

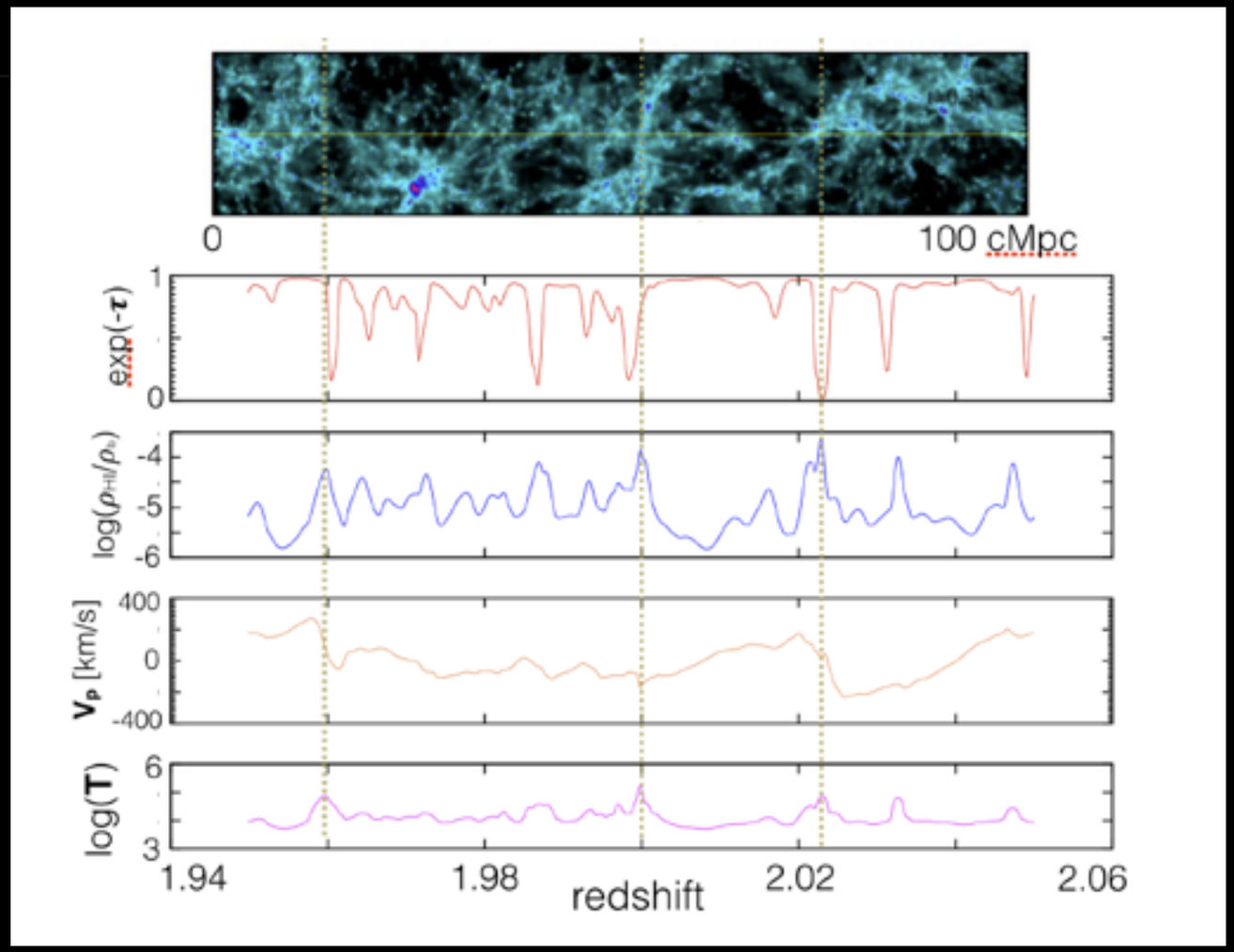


Lee+14b

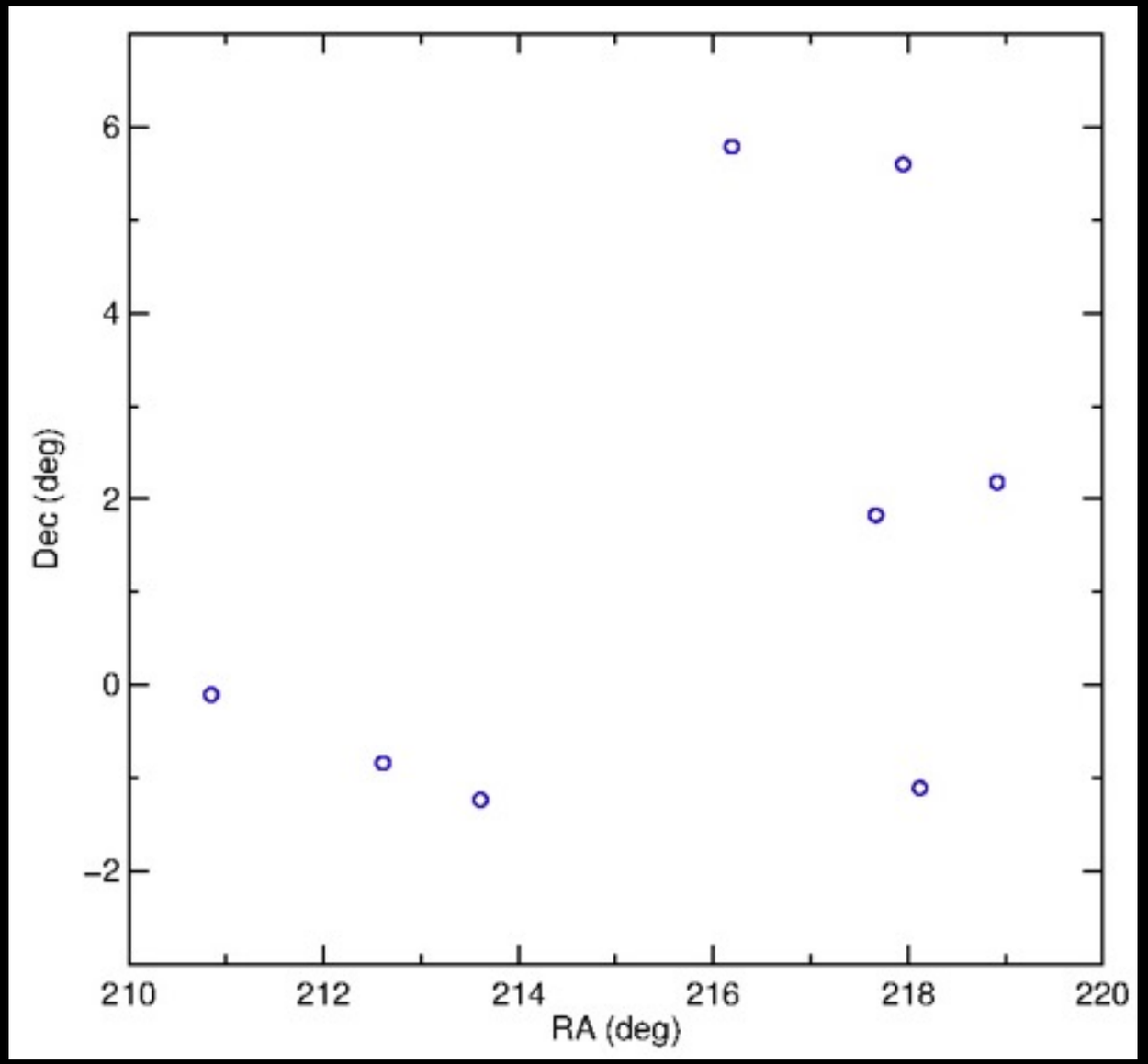
- star forming gal in COSMOS field with Keck/LRIS

Looking Forward: MOS Surveys

- WEAVE and 4MOST
- PFS: 24k z>2 LBGs:
  - 3D HI map with 3 cMpc resolution
  - cross-correlation between gas (HI, metals) and galaxies



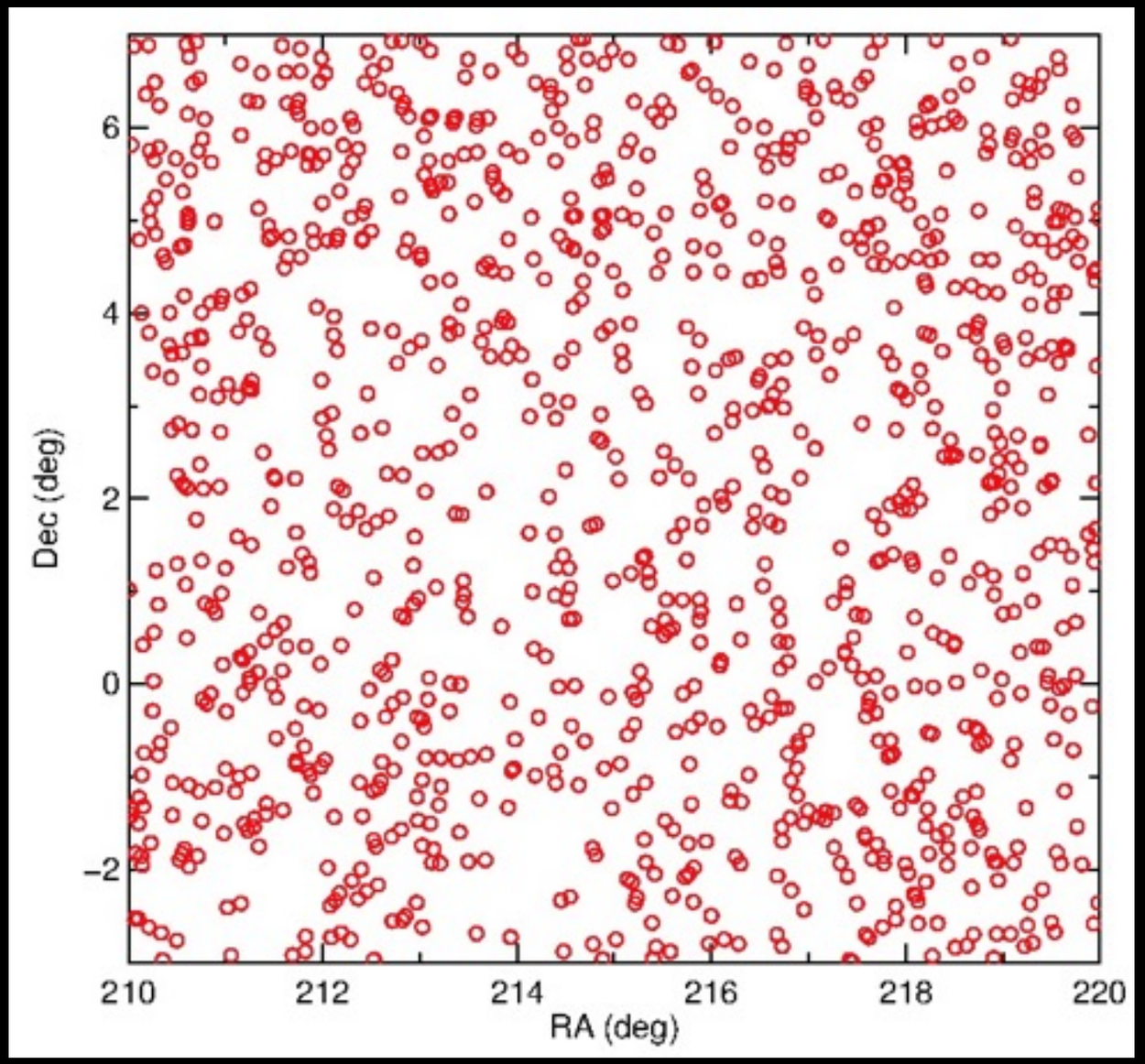
8-m Class Telescope



Beckers+15

m_r<18

30-m Class Telescope



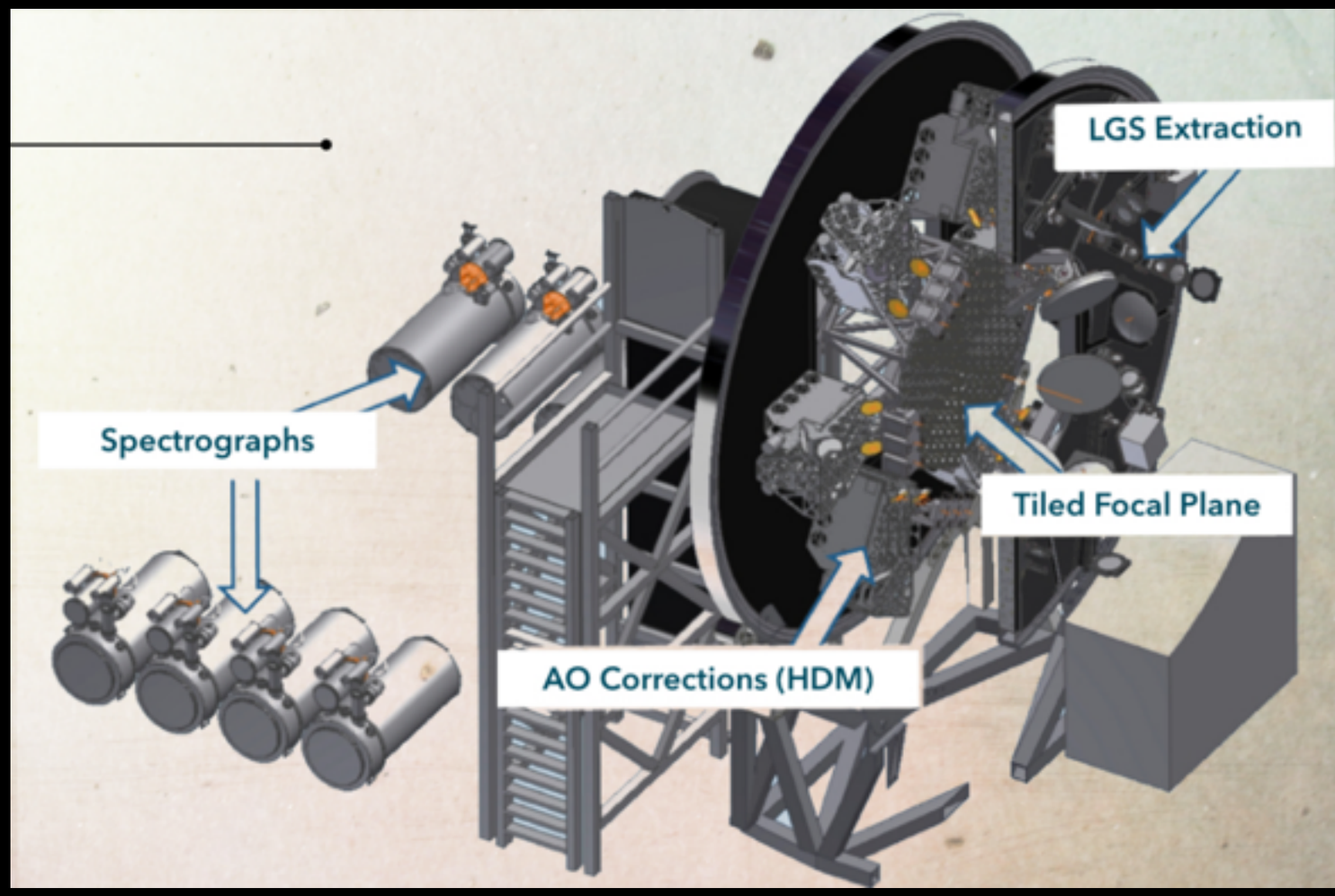
Becker+15

m_r<21

ELTs/MOS: the ultimate tool for cosmic web reconstruction

ELT/MOSAIC:

- blue coverage
- IFU capability
- survey
- synergy with HIRES



Take Home Messages

- Connecting gas and star of the same galaxies
- Report observational evidences of accretion
- Measure loading factors in galactic winds
- CGM is multi-phase