Probing Gas Flows around z~1 Galaxies with SINFONI

Project REGAL: what REgulates the growth of GALaxies? The missing piece to understand galaxy evolution
OCEVU-funded since 2014

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PLAN

- Where are the baryons?
- Detecting absorbing-galaxies
- Kinematics
- Gas Flows

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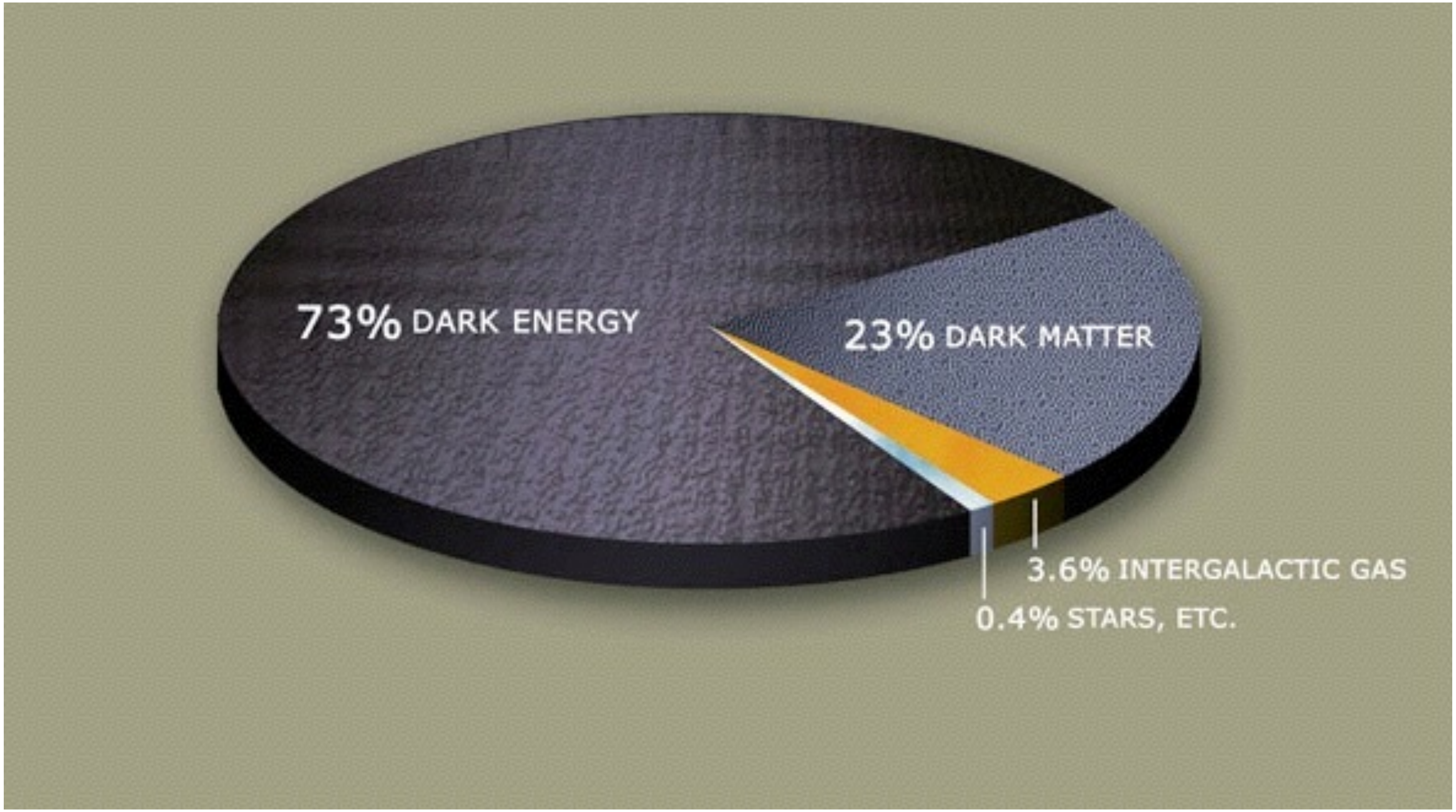
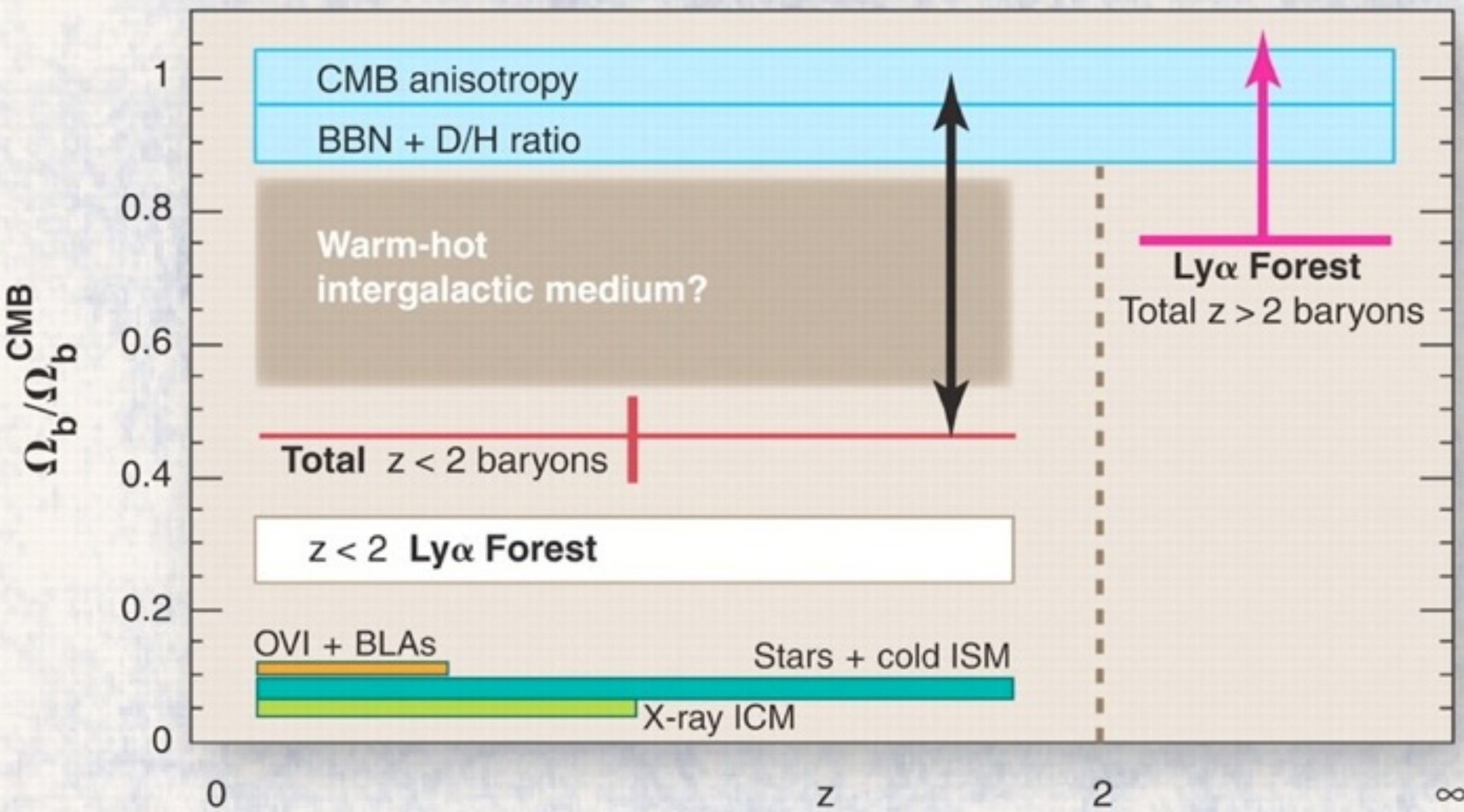
The Universe Constituents



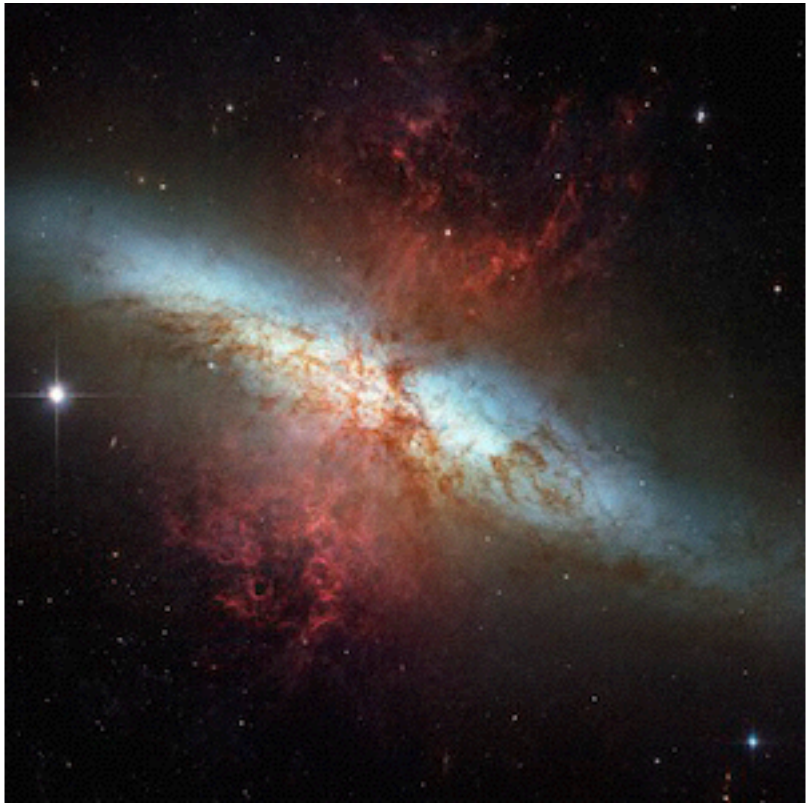
Baryon Census

(Nicastro, Mathur & Elvis 2009, Science)



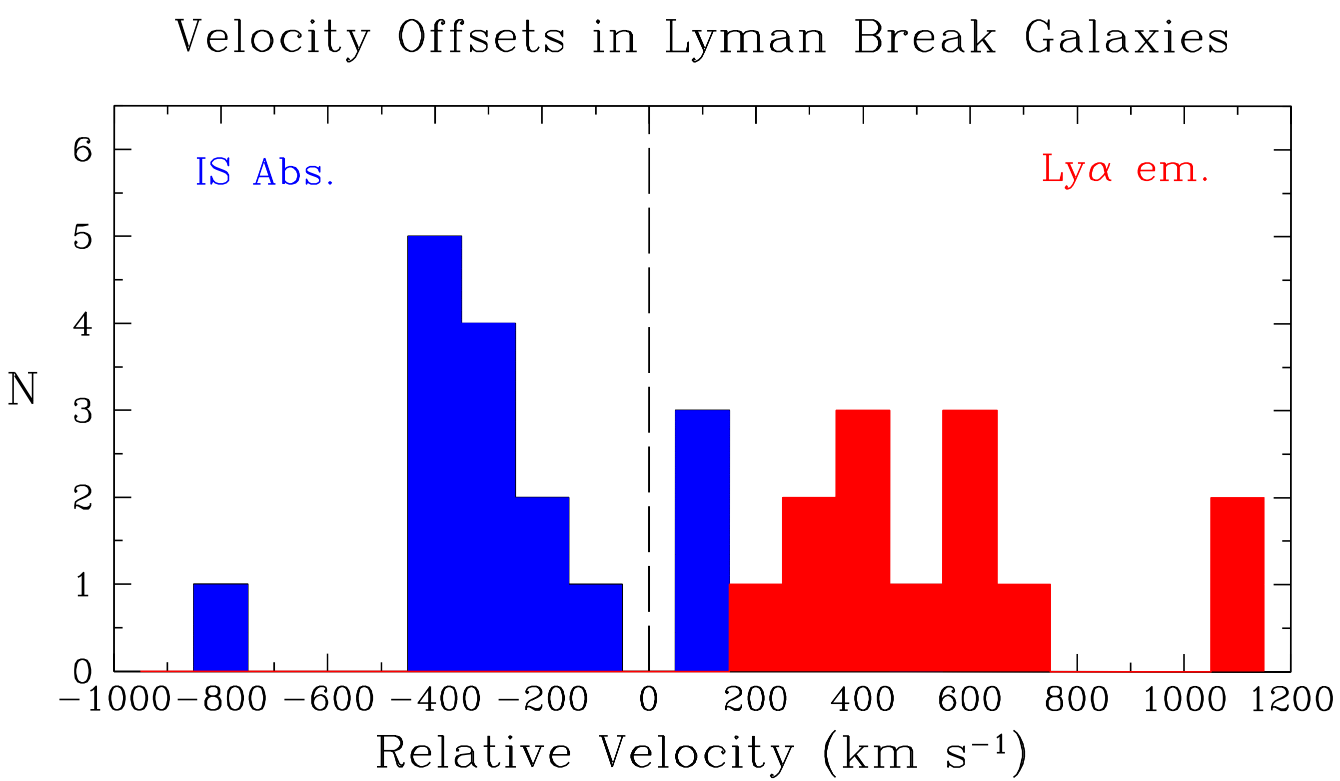
Low-z Observational Evidence for Winds

- NaID in local ULIRGS (Crystal Martin et al.)
- MgII in high-z galaxies
- UV-bright galaxies (Heckman et al.)



Evidence for Winds

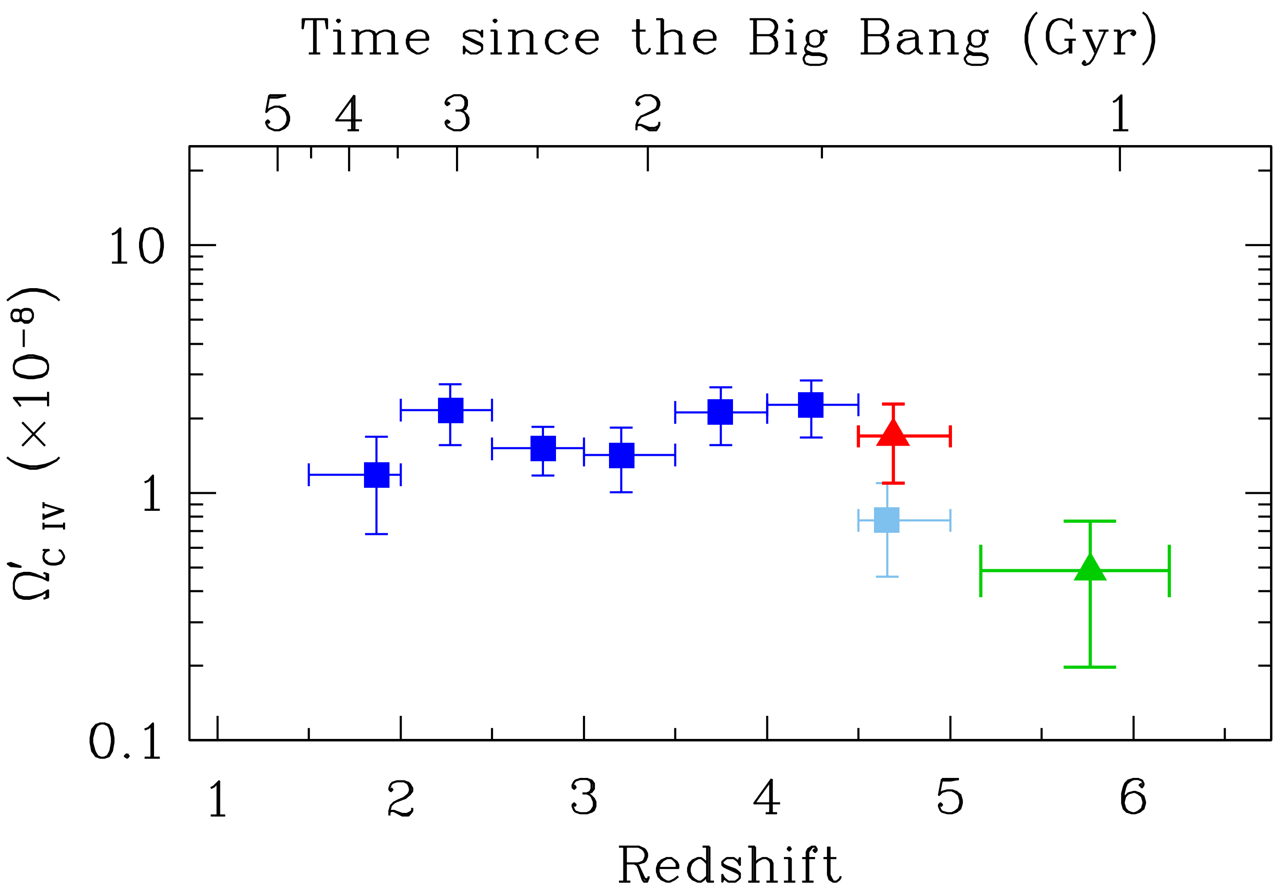
- outflows



(Pettini 2003)

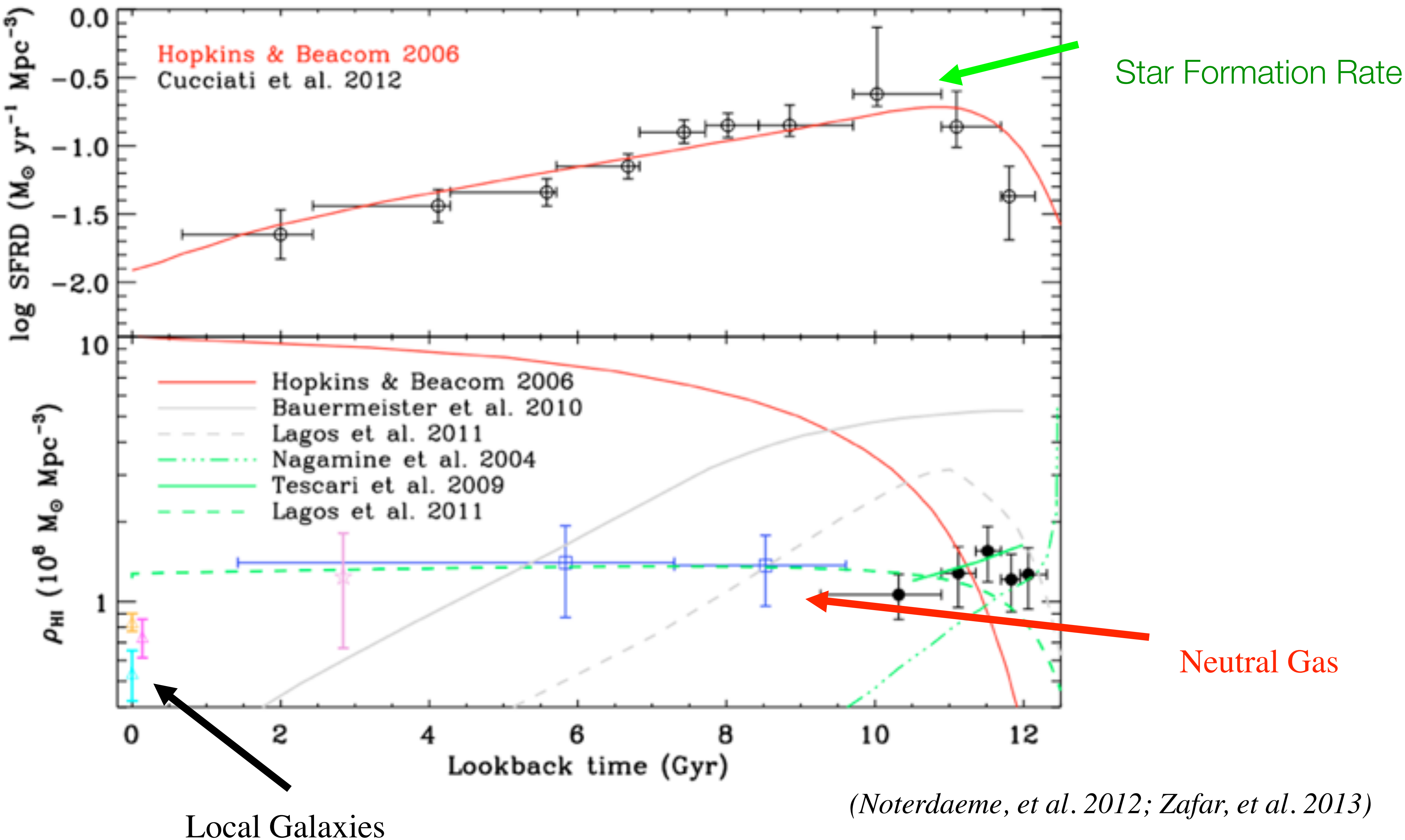
Metal Pollution

- Carbon IV evolution in the IGM



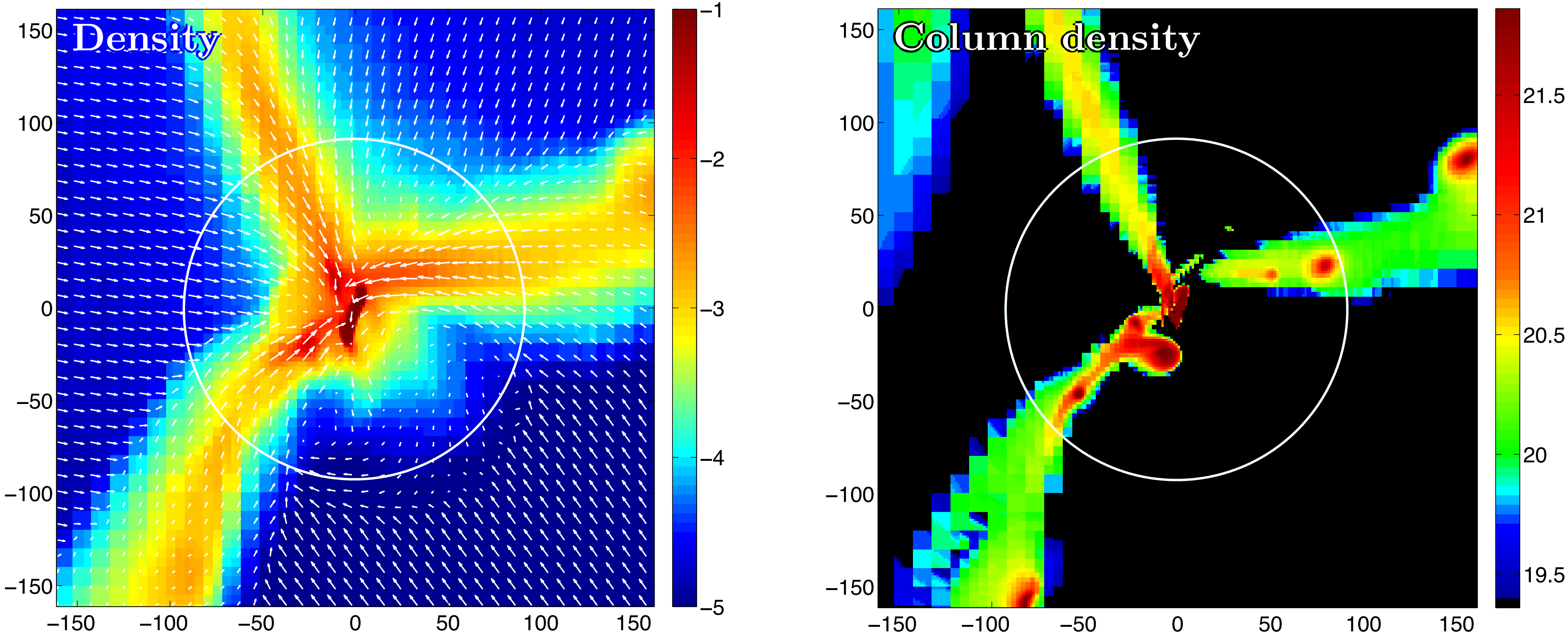
(Ryan-Weber, Pettini, Madau & Zych 2009)

Evidence for Accretion



(Noterdaeme, et al. 2012; Zafar, et al. 2013)

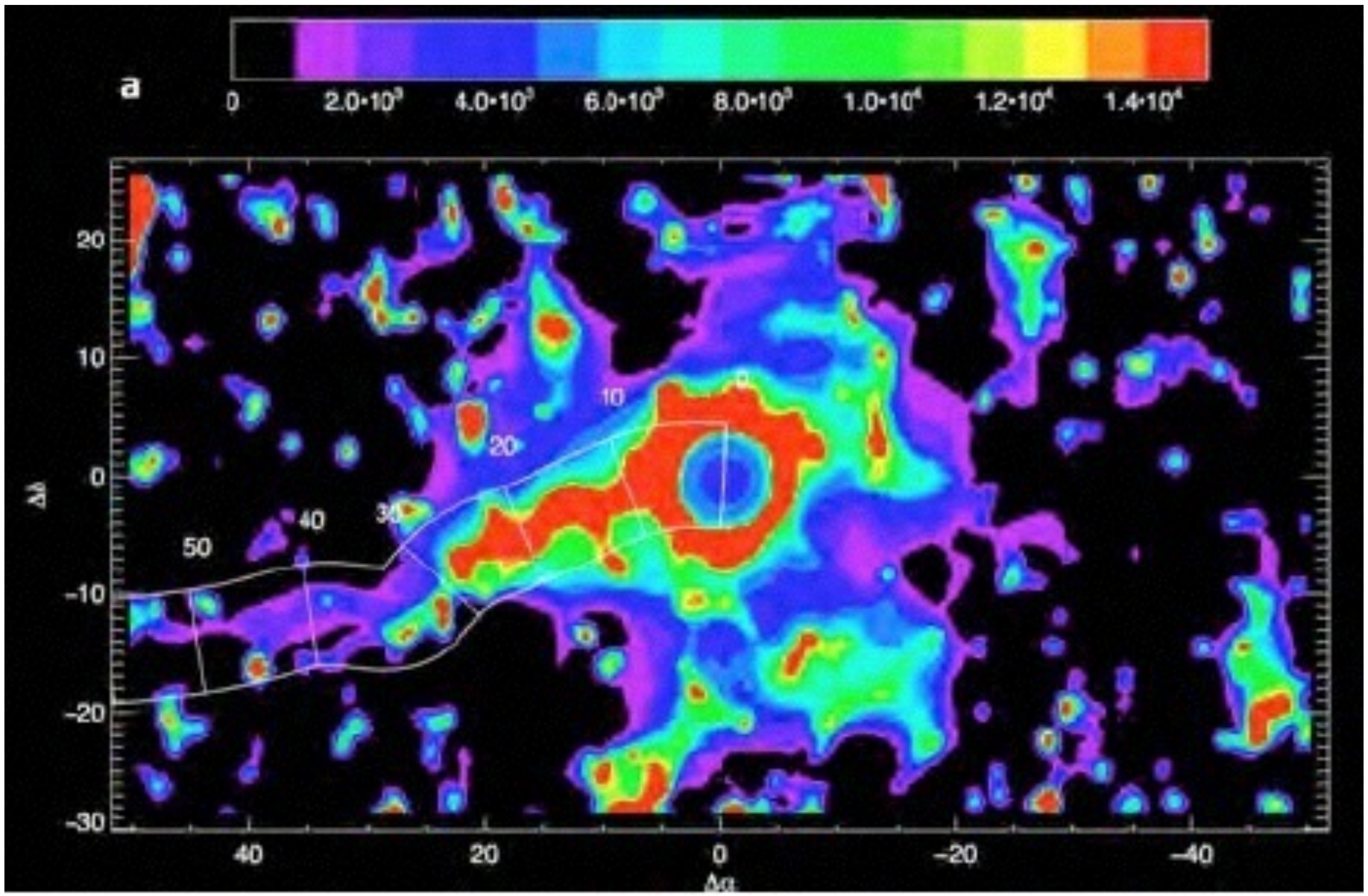
Accretion along Filaments



(Dekel et al. 2008)

Galaxies/IGM co-Evolution

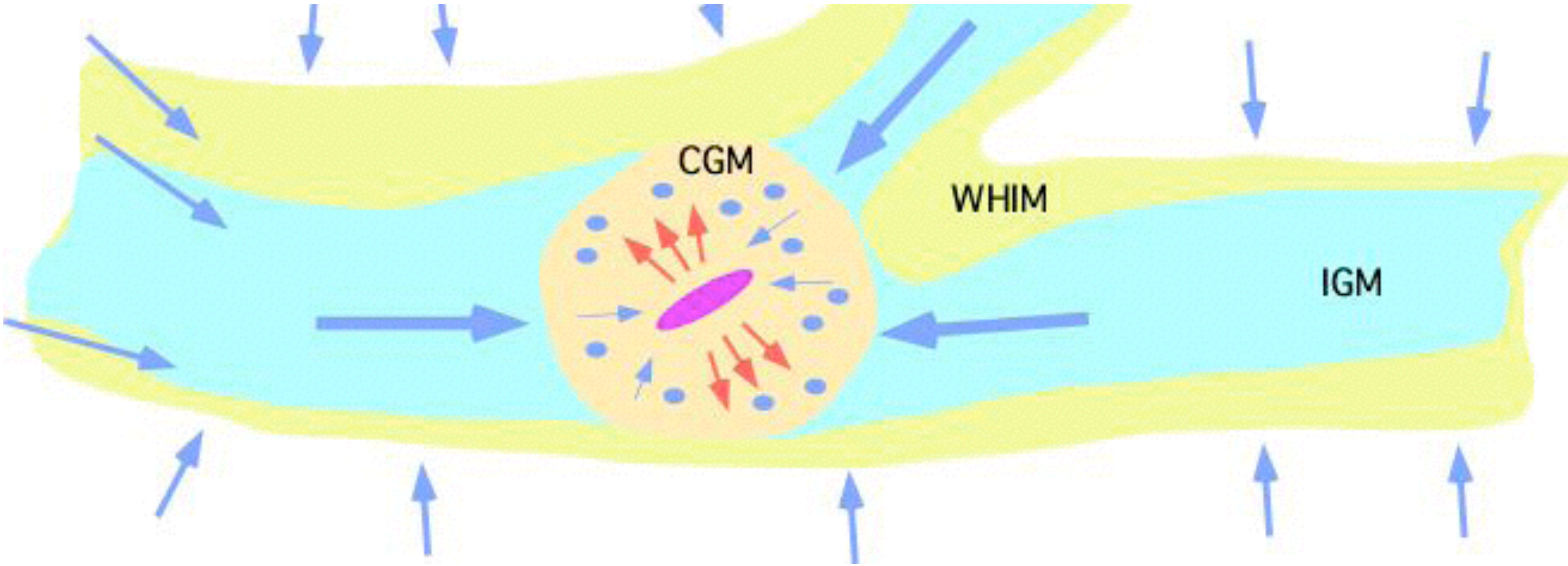
- filaments around a quasar (CWI at Palomar)



(Martin et al. 2014)

Galaxies/IGM co-Evolution

- CGM = Circum-Galactic Medium



Why do we care about baryons?

Matter power spectrum depends on baryonic effects so will impact i.e. Euclid cosmology results.

(van Daalen et al. 2011; Sawala et al. 2013)

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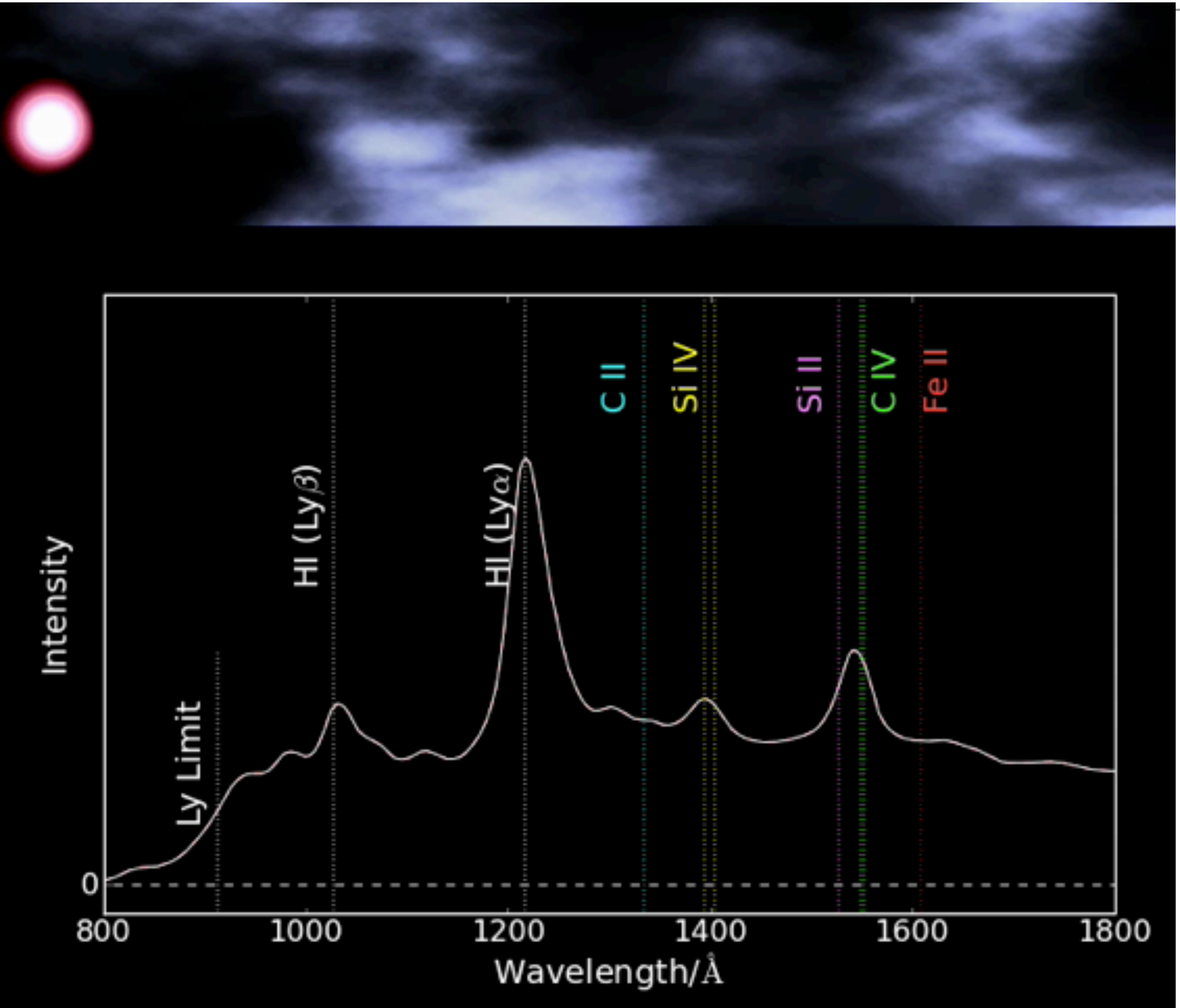
In Practice, Observation in Absorption



- Quasar Absorbers

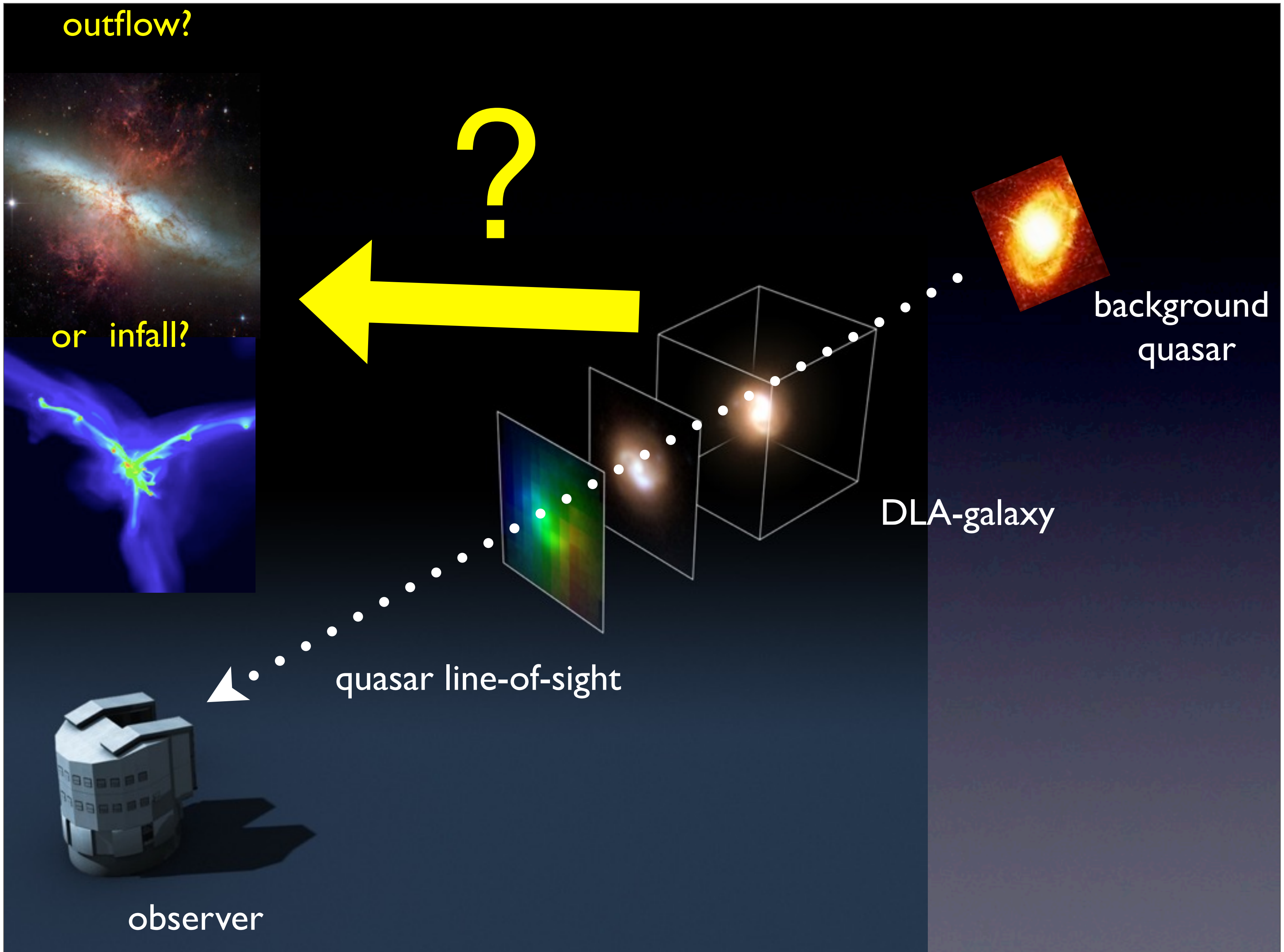
(Pontzen et al. 2008)

Quasar Absorbers

- Selected on the basis of the cross-section of the neutral hydrogen gas
- Selected regardless of luminosity, morphology, etc.
- Observed at all redshifts
- Physical properties (like HI, metallicity, etc.) are well constrained
- Connect gas and stars in galaxies

Neutral HI → Molecular H_2 → star formation

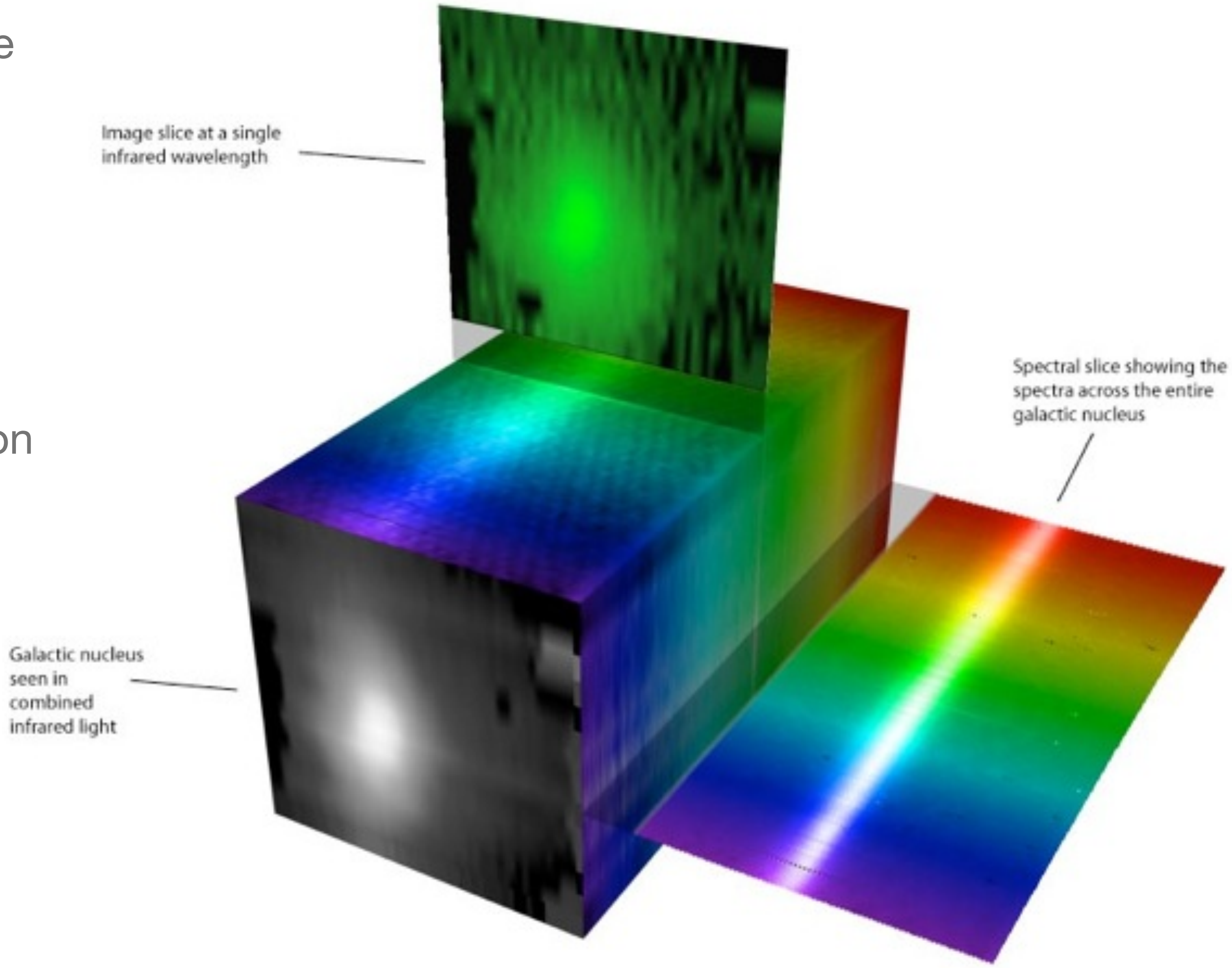
Connecting Gas & Star Formation



The IFU Approach

- quasar emission line is de-coupled from absorber-galaxy emission line
=> probe small impact parameters

- secured identification thanks to the absorber-galaxy spectrum
=> can study the properties of the galaxy



The Sample

- => aim at detecting redshifted H-alpha
- select 22 intervening absorbers
- known N(HI) (DLAs + sub-DLAs)
- known metallicity from high-resolution observations
- $0.7 < z_{abs} < 2.6$; 10 @ z~1 + 12 @ z~2
- free from OH line contamination

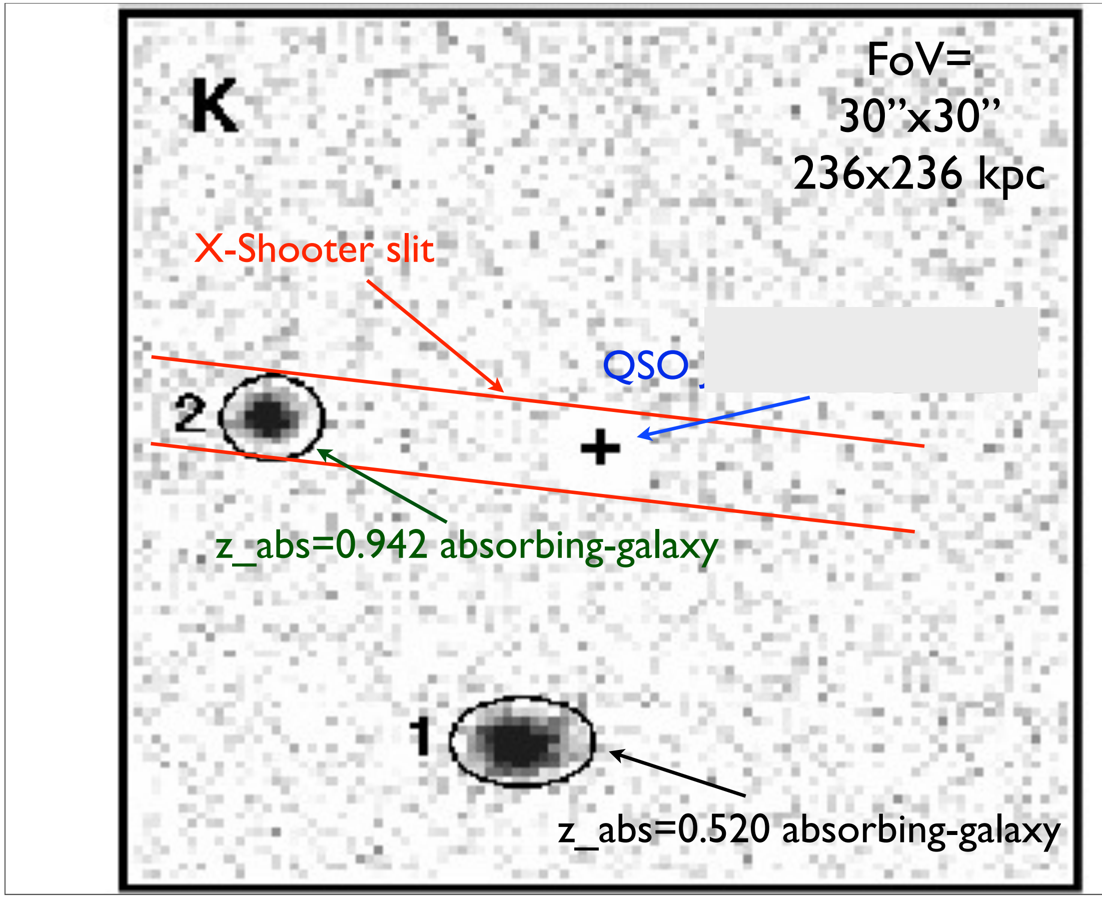
The Observations

VLT/SINFONI

- mosaic around the quasar for sky subtraction and larger radius search
- 0.10-0.25" pixel, seeing= 0.4-1.1”
- use quasar for NGS/AO

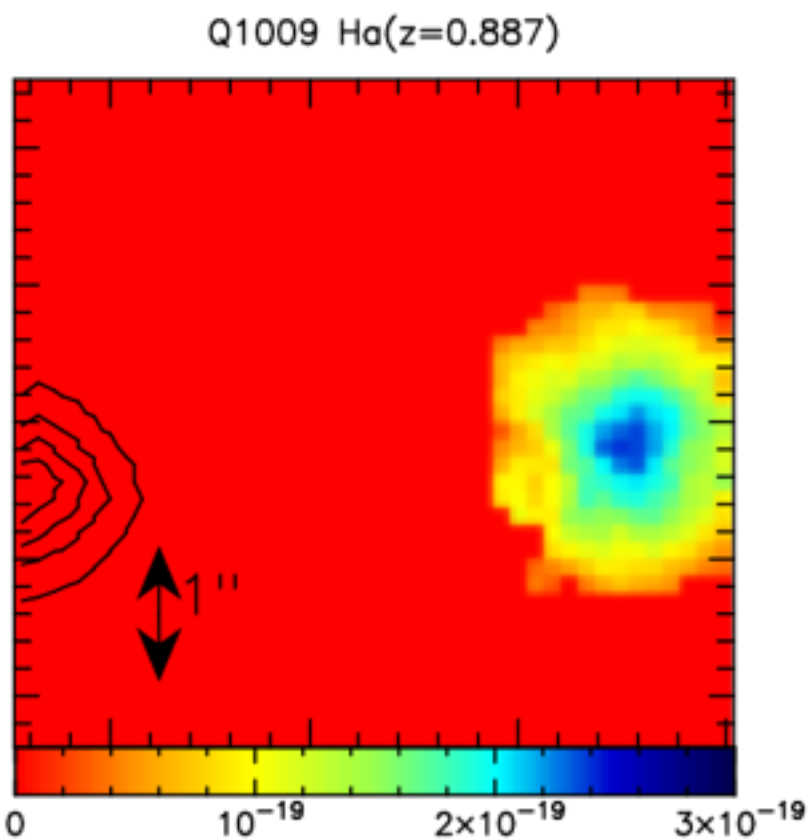
VLT/X-Shooter

- slit aligned to include both quasar and absorbing-galaxy
- R=30-60 km/s depending on arm

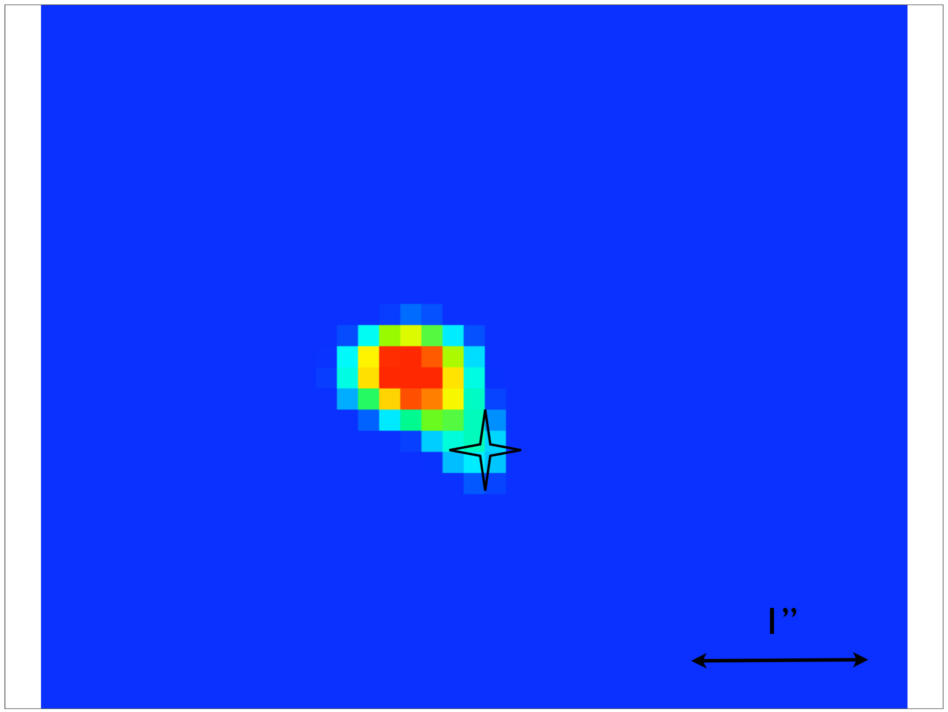


H-alpha Detections

- Looking in emission for absorbing gas with SINFONI



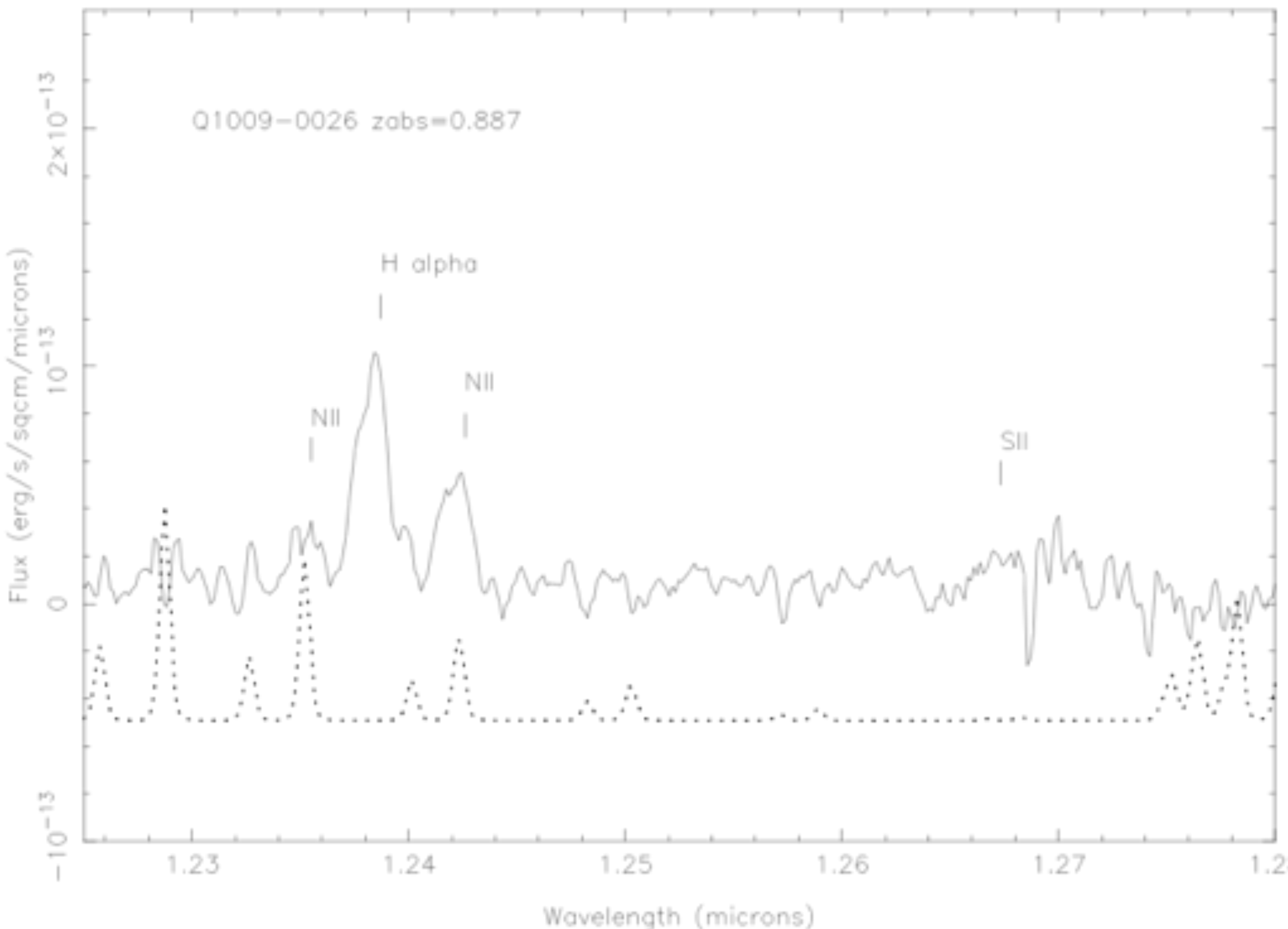
z~2



(Peroux et al. 2011a, 2012)

Typical Physical Properties

- F(H-a)=few 10^{-17} erg/s/cm^2
- L(H-a)=few 10^{41} erg/s
- SFR ~ few M_{sun}/yr at z~1
  ~20 M_{sun}/yr at z~2
- [O/H] metallicity from N2 indicator ~ solar
- [Zn/H]>-1.0 = 1/10 solar
- b = 10-40 kpc



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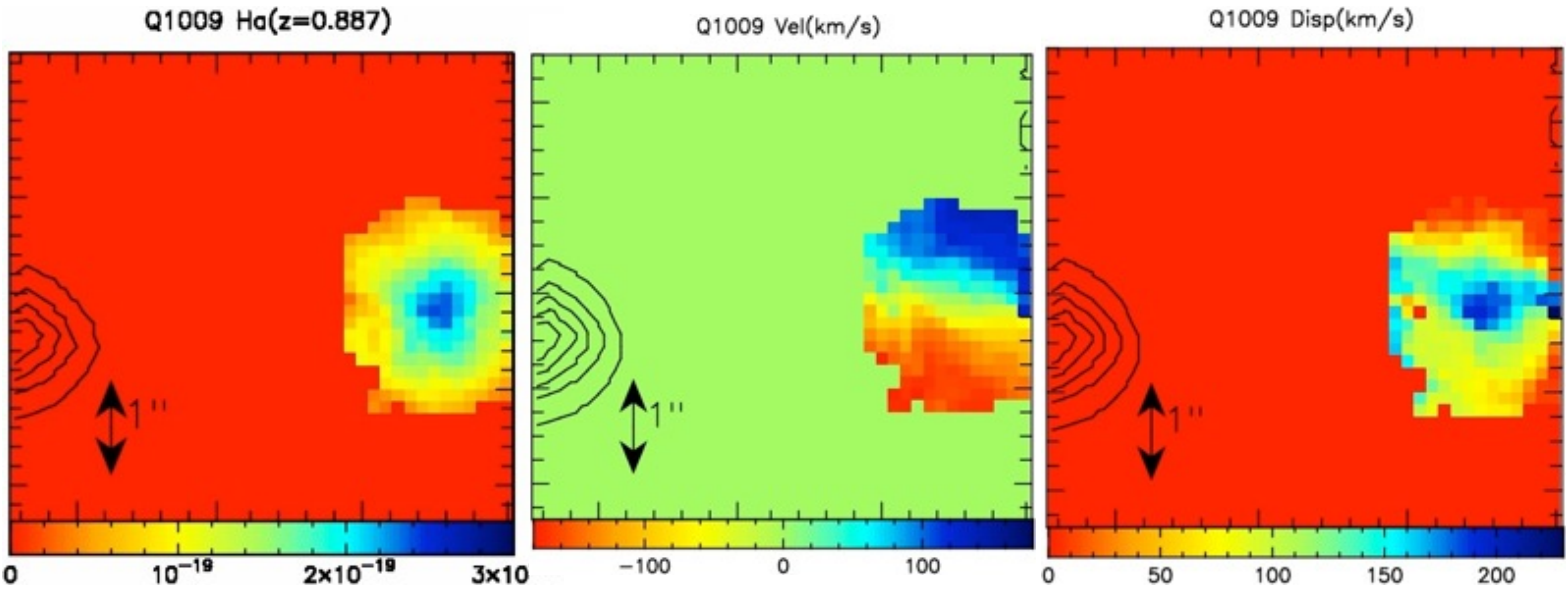
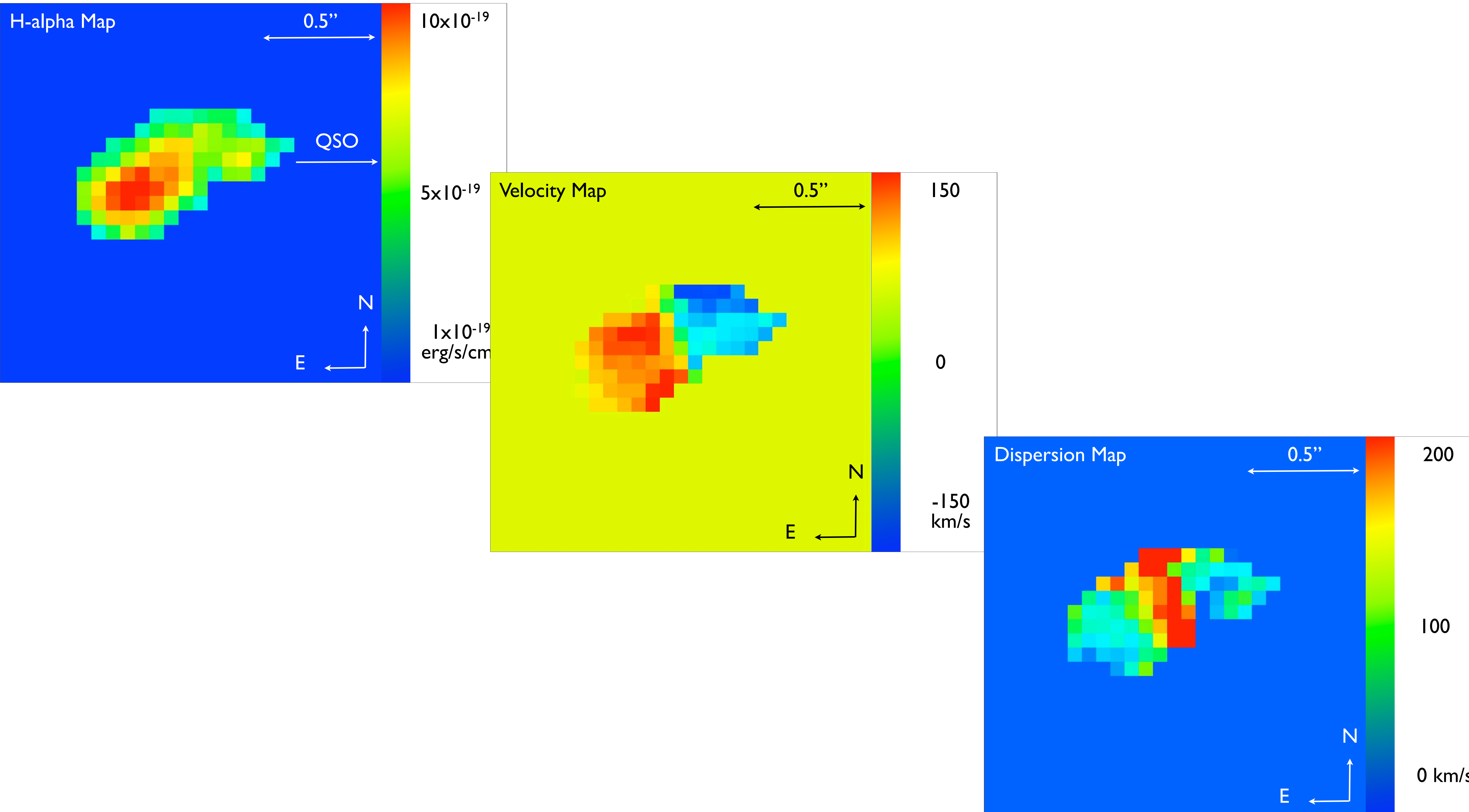
Kinematics



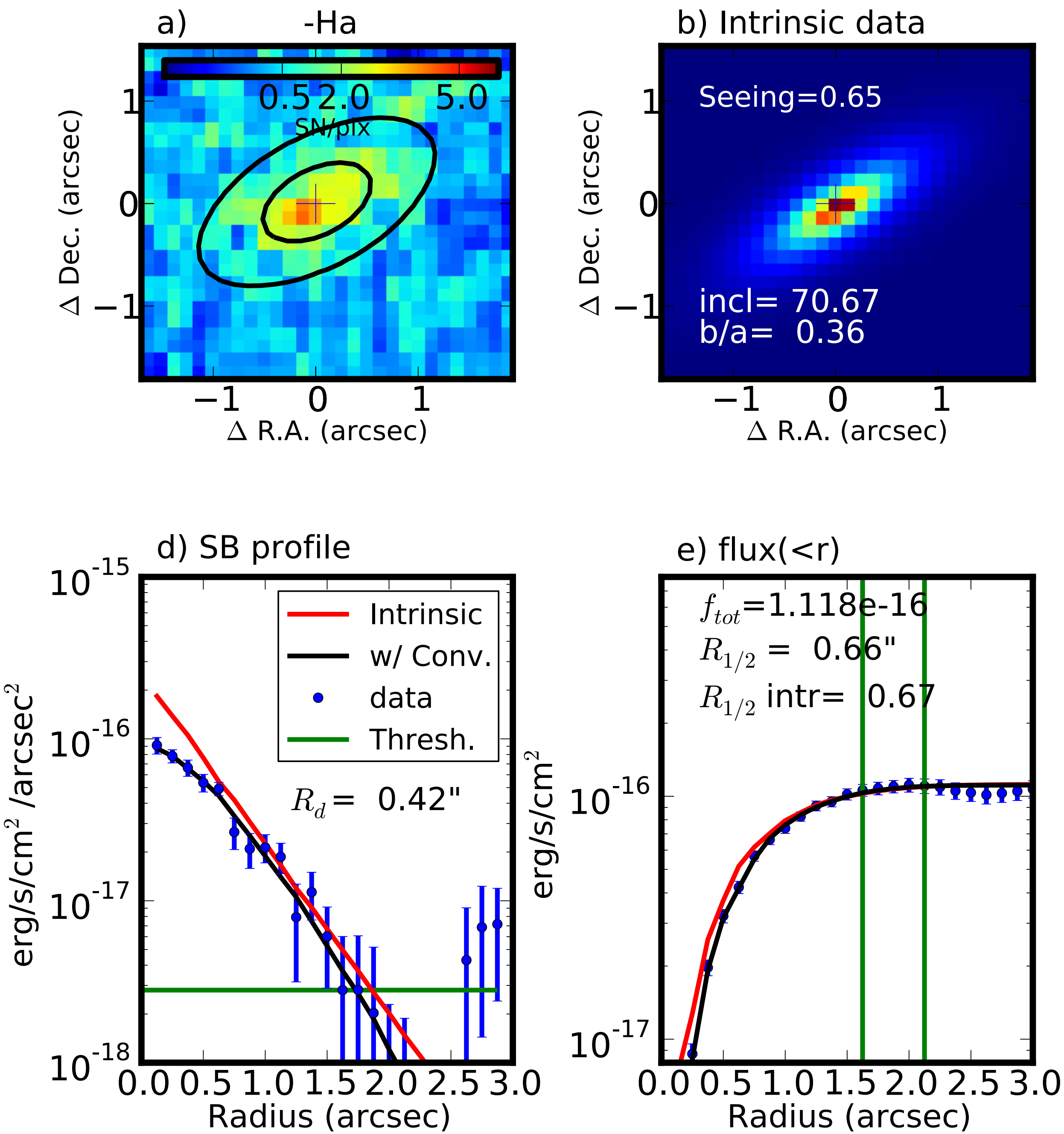
- inclination: sin i, velocity and dispersion: v/sigma

(Peroux et al. 2011b)

Kinematics


H-alpha Map
0.5"
QSO
N
E
10x10-19
5x10-19
1x10-19
erg/s/cm
Velocity Map
0.5"
N
E
150
0
-150
km/s
Dispersion Map
0.5"
N
E
200
100
0 km/s

Mass Estimates



- 3-D fit with 9 parameters [Bouche et al. 2013]

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Independent Indicators to Constrain Gas Flows

- interaction and merging
- star formation rate per unit area
- EW(MgII)
- comparison of emission/absorption kinematics
- inclination/orientation to quasar line-of-sight
- internal metallicity gradient

Independent Indicators to Constrain Gas Flows

- interaction and merging:

2 out of 5 => tidal streams/merging?

Independent Indicators to Constrain Gas Flows

- star formation rate per unit area:

  $\Sigma_{SFR}>0.1\ M_{sun}/yr/kpc^2$ => outflows? [Heckman et al. 2003]

Independent Indicators to Constrain Gas Flows

- EW(MgII):

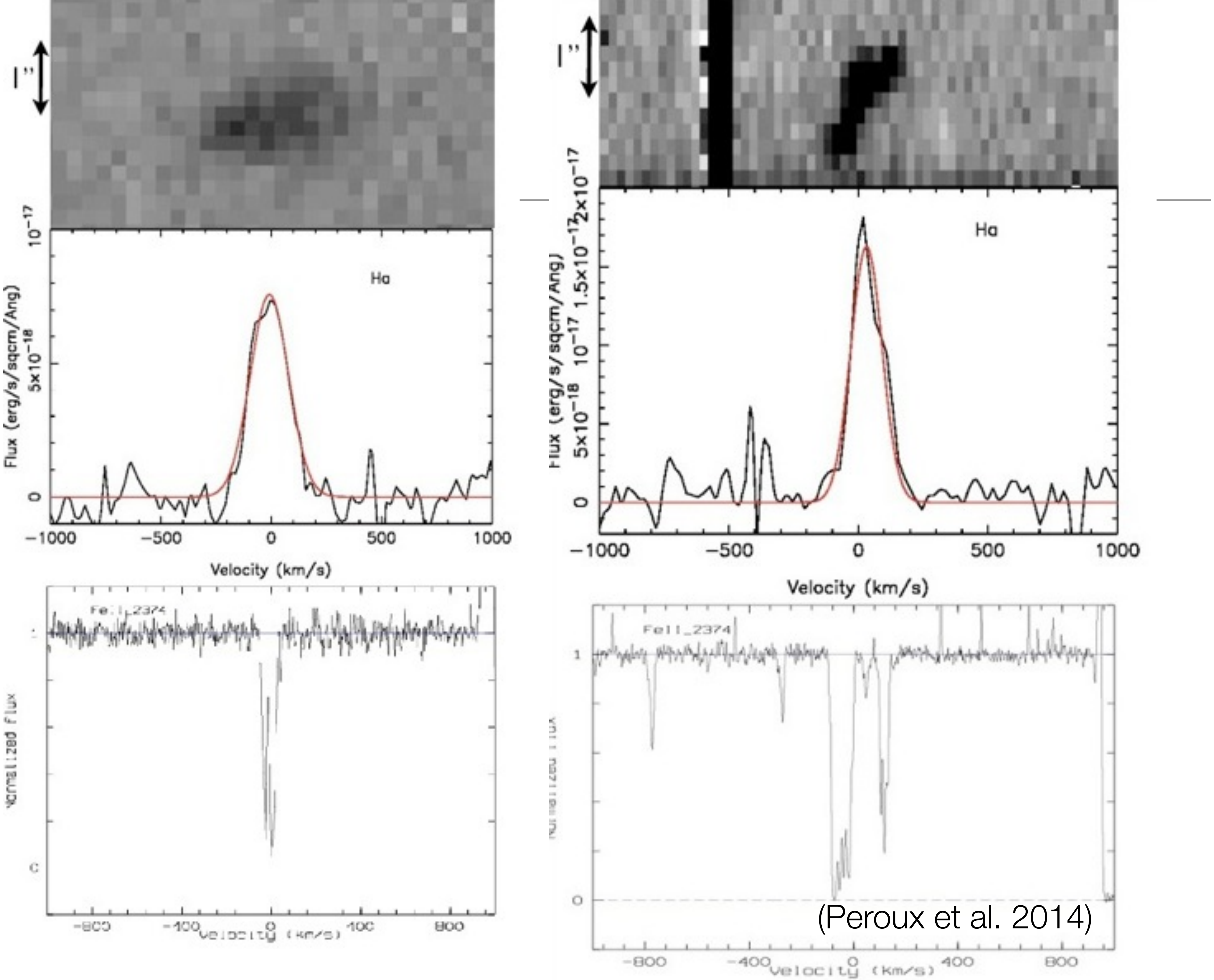
>0.1Ang in all cases => winds?

Independent Indicators to Constrain Gas Flows

- comparison of emission/absorption kinematics:

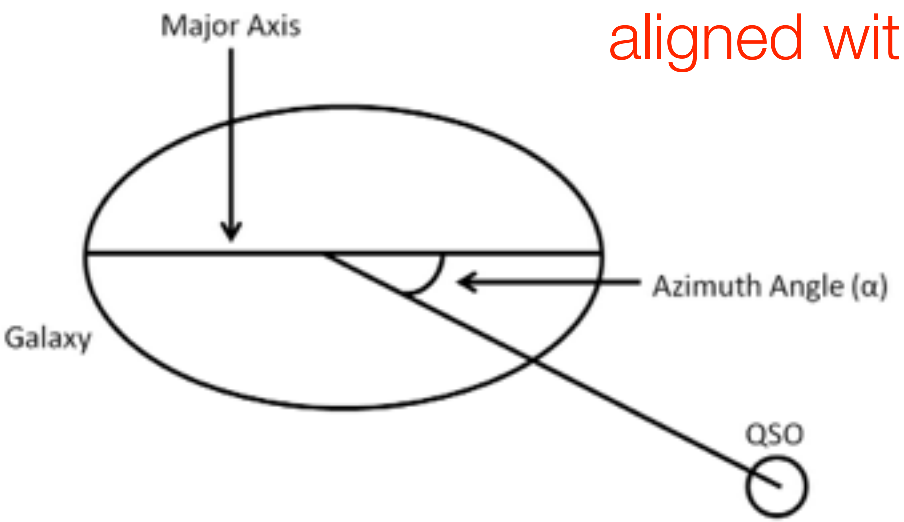
compare V_{max} and Δ_v

=> in 2 cases gas could be co-rotating with the halo



(Peroux et al. 2014)

Inclination/Orientation

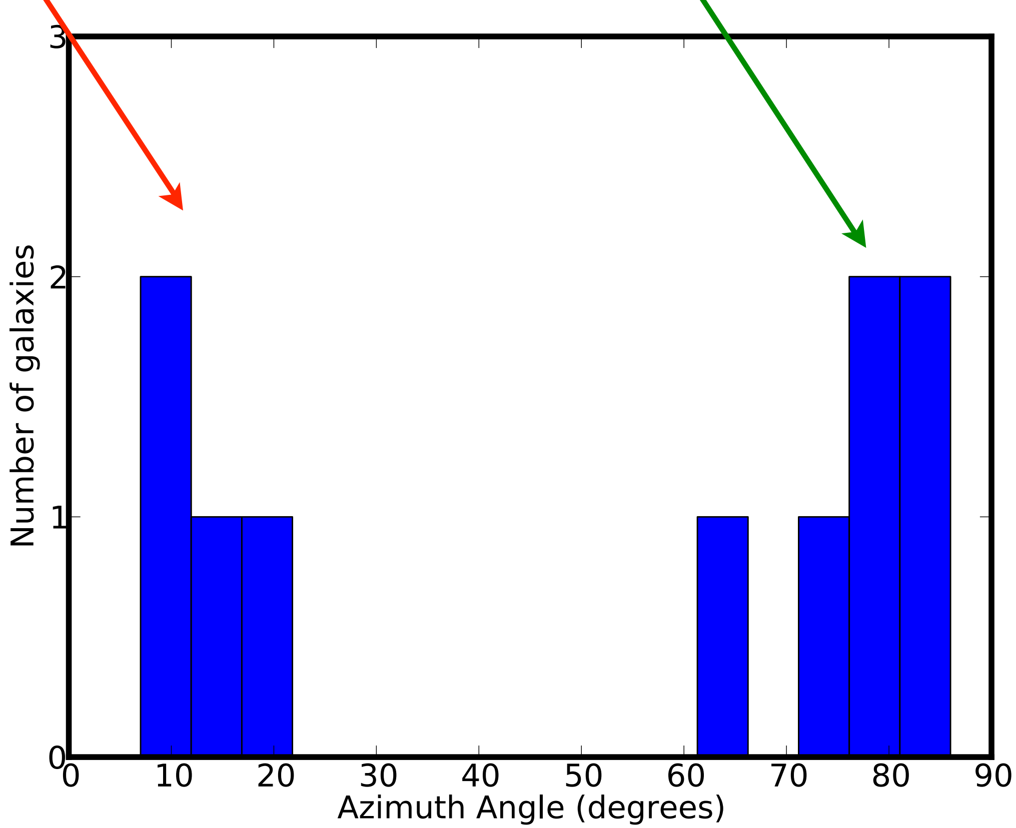


- 2 aligned with minor axis
- 2 aligned with major axis
- 1 unconstrained

Bordoloi et al. 2011;
Bouche et al. 2012

aligned with major axis

align with minor axis:
outflow



Independent Indicators to Constrain Gas Flows

- internal metallicity gradient:

  uniform in all 3 cases => no indication of accretion

Putting it altogether

Quasar	Galaxy Orientation	b [kpc]	Direction to quasar line-of-sight aligned with	V_{max} [km/s]	Δv [km/s]	Absorption Profile	Conclusion
Q0302−223	edge-on	25	minor axis	11	120	doubled-peaked	⇒co-rotating/outflow?
Q0452−1640	face-on?	16	major axis	100	230	either-side of z_{gal}	⇒merger/outflow?
Q1009−0026	edge-on	39	minor axis?	250	334	asymmetrical	⇒outflow
Q2222−0946	edge-on	6	n/a†	20	200	centred and complex	⇒outflow
Q2352−0028	edge-on	12	major axis	140	220	centred and complex	⇒co-rotating/outflow?

†: in the case of Q2222−0946, the major axis is undefined because of the compact nature of the galaxy.

- => in 2 cases, we have strong indications of outflows

Conclusions

- Detect with SINFONI:
  - detect 5/22 (mostly z~1)
  - allows to probe low impact parameters
  - provides a way to securely confirm the galaxy redshift right away

- SFR of quasar absorbers ~ few M_{sun}/yr, b<40kpc in a couple of hours

- 3 systems consistent with outflows while 2 indicate strong evidences for outflows

- new sample of quasar/absorbing-galaxies observed with both SINFONI and X-Shooter (50hrs of VLT time in P92) => post-doc Hadi Rahmani from Nov 2014