Probing Gas Flows around Galaxies with SINFONI and X-Shooter

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PLAN

- Detecting absorbing-galaxies
- Kinematics
- Metallicity
- Gas Flows

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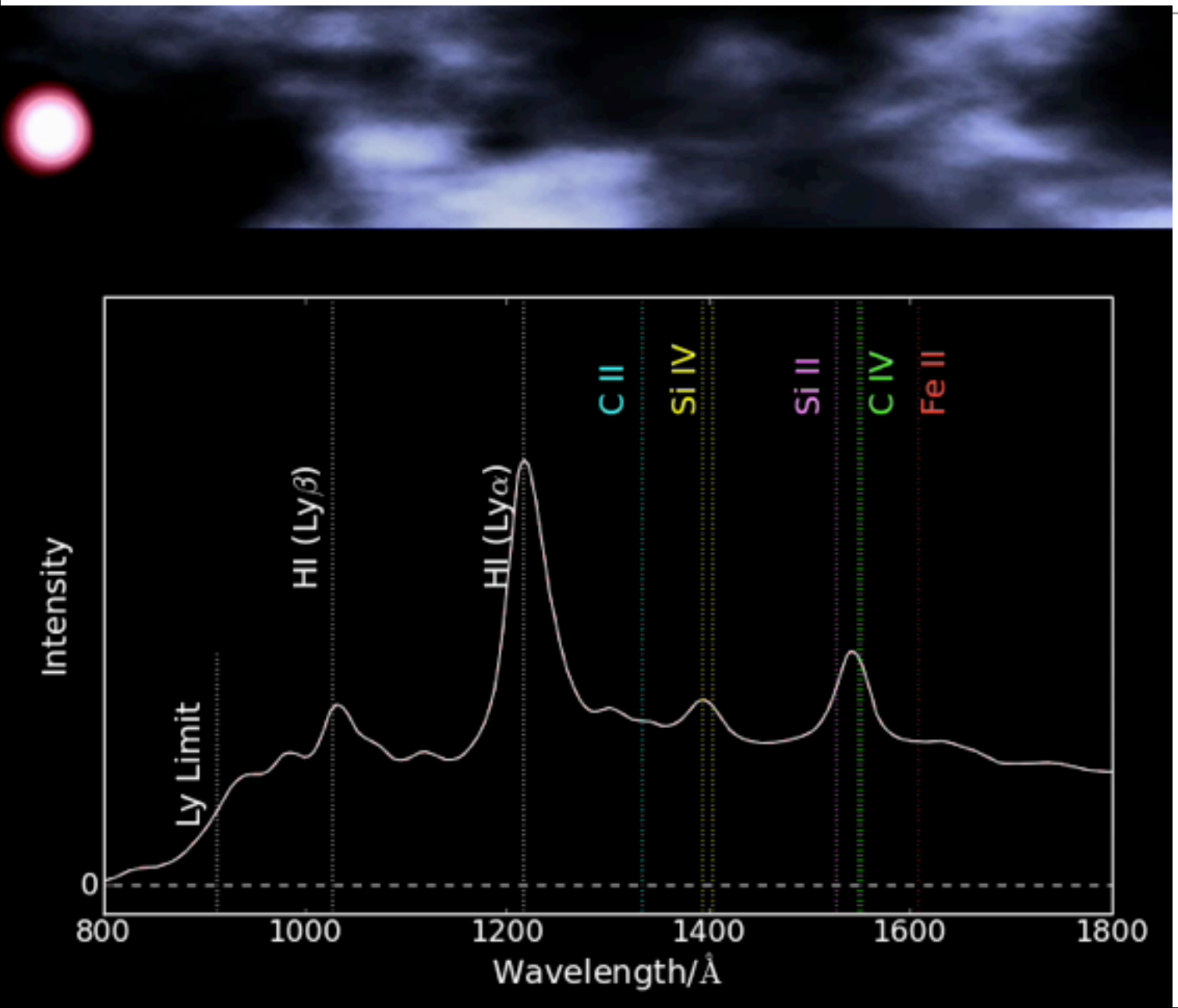
Observation in Absorption



- Quasar Absorbers

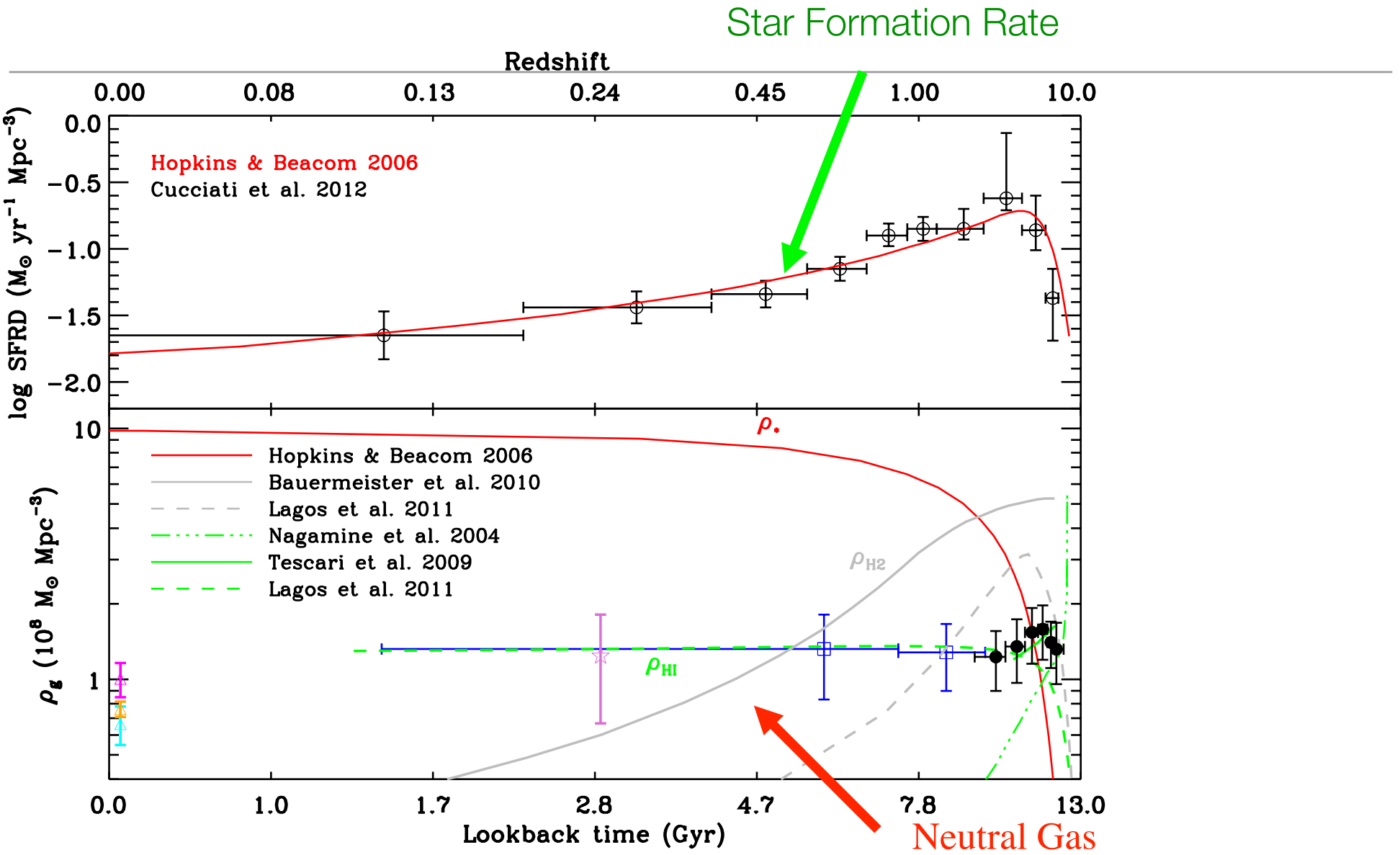
(Pontzen et al. 2008)

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

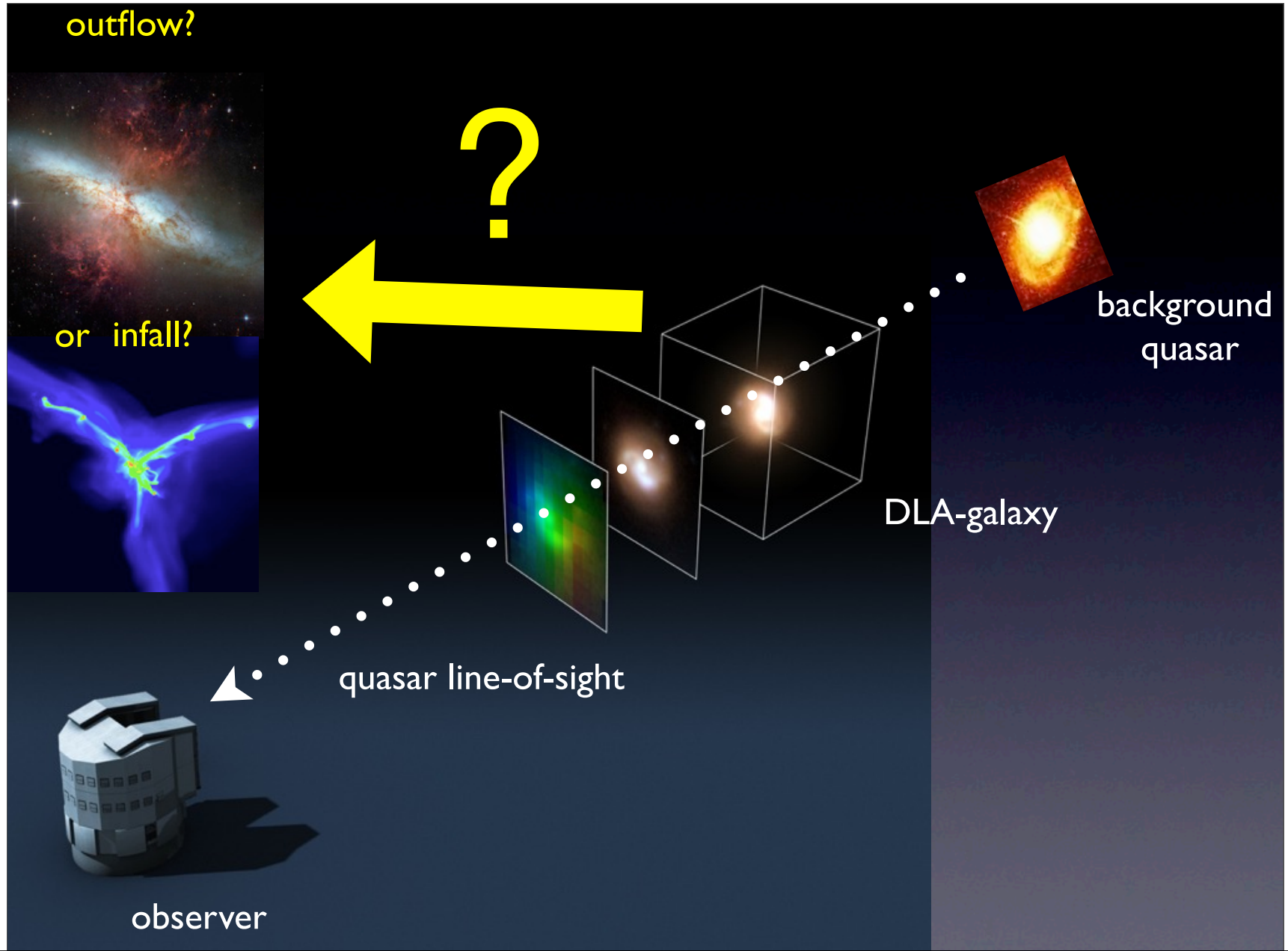
Cosmological Evolution of Neutral Gas Mass



=> z<2: for SKA to explore

(Zafar et al., 2013b)

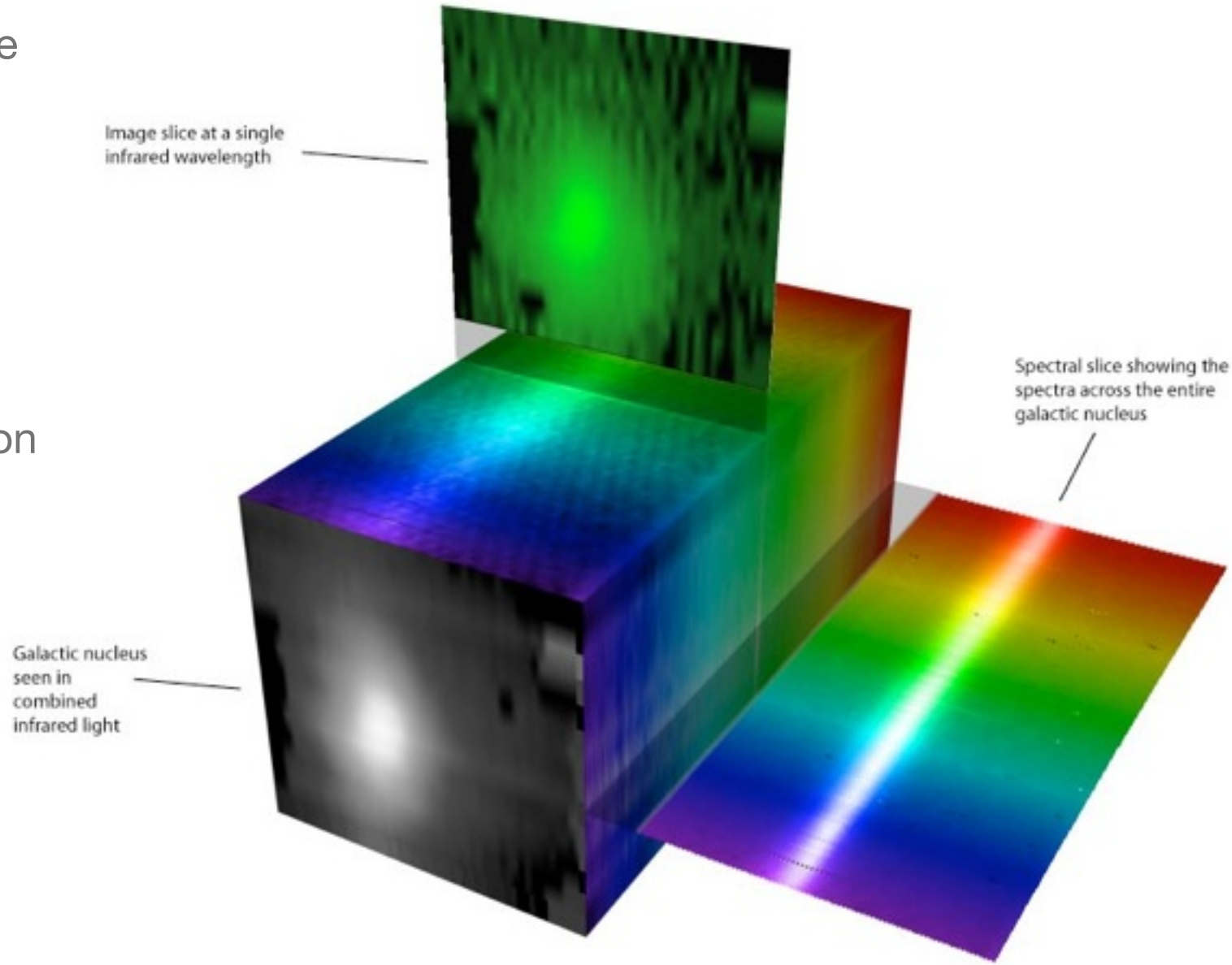
Connecting Gas & Star Formation



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

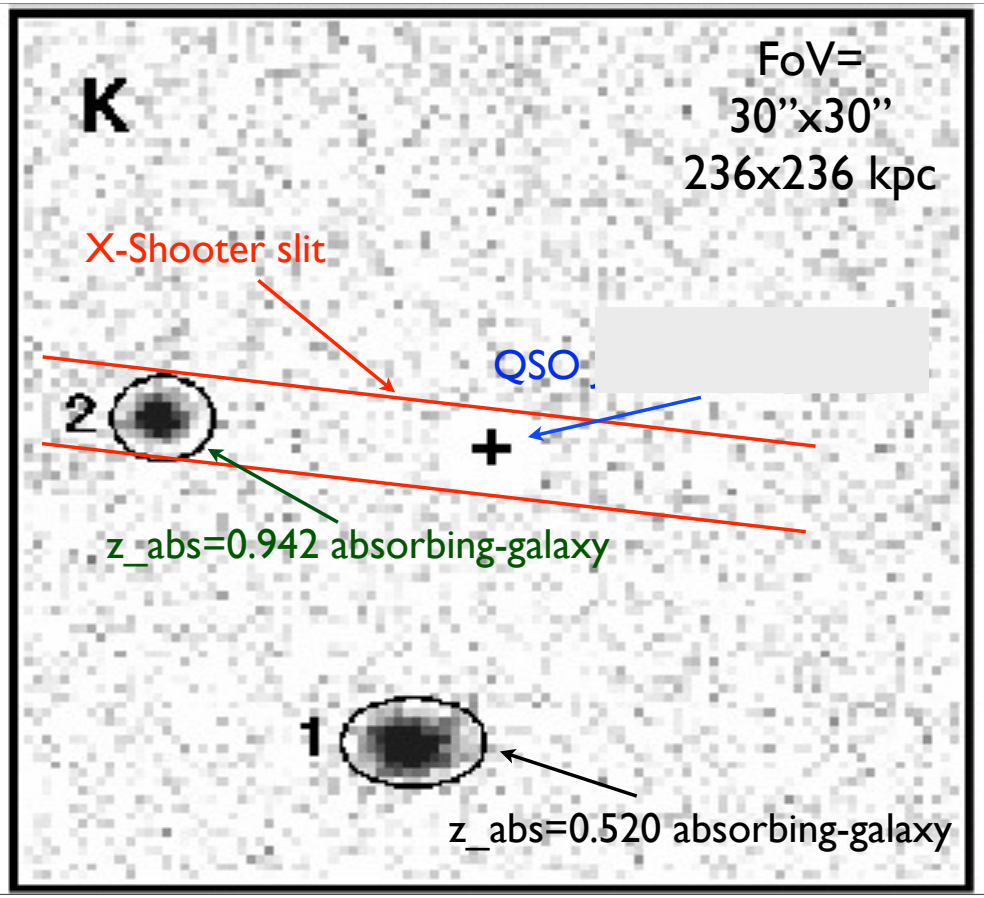
The Observations

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

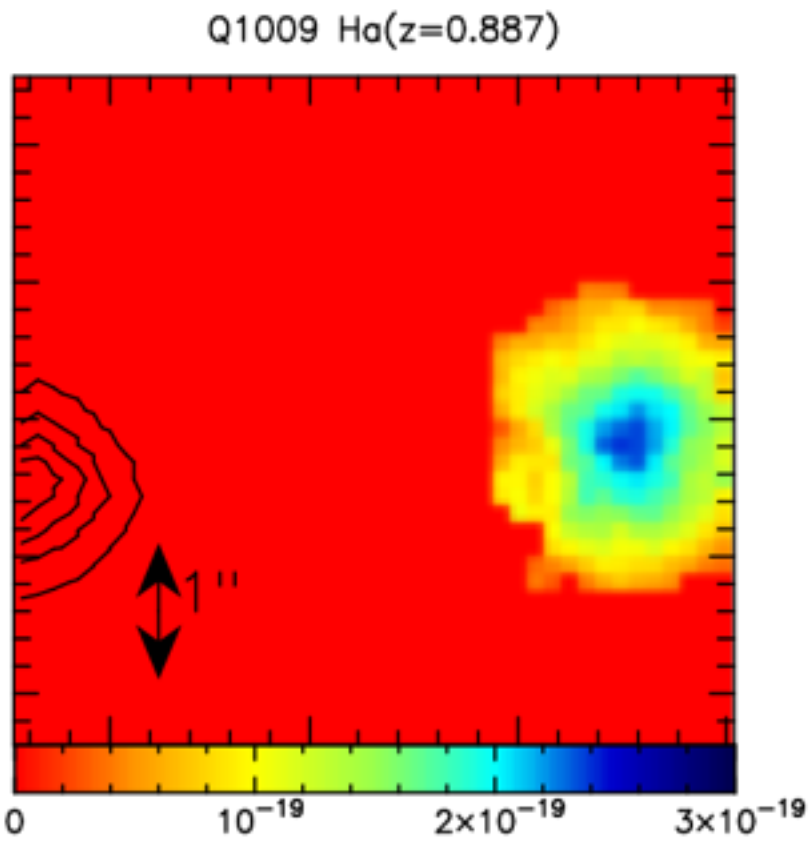
VLT/X-Shooter

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

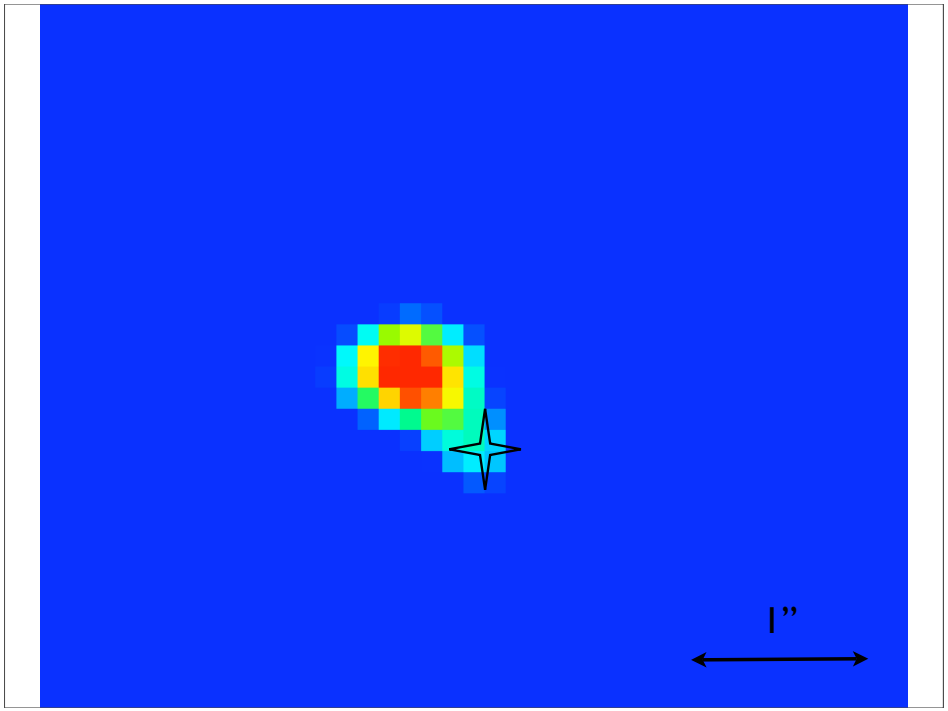


H-alpha Detections

- Looking in emission for absorbing gas with SINFONI



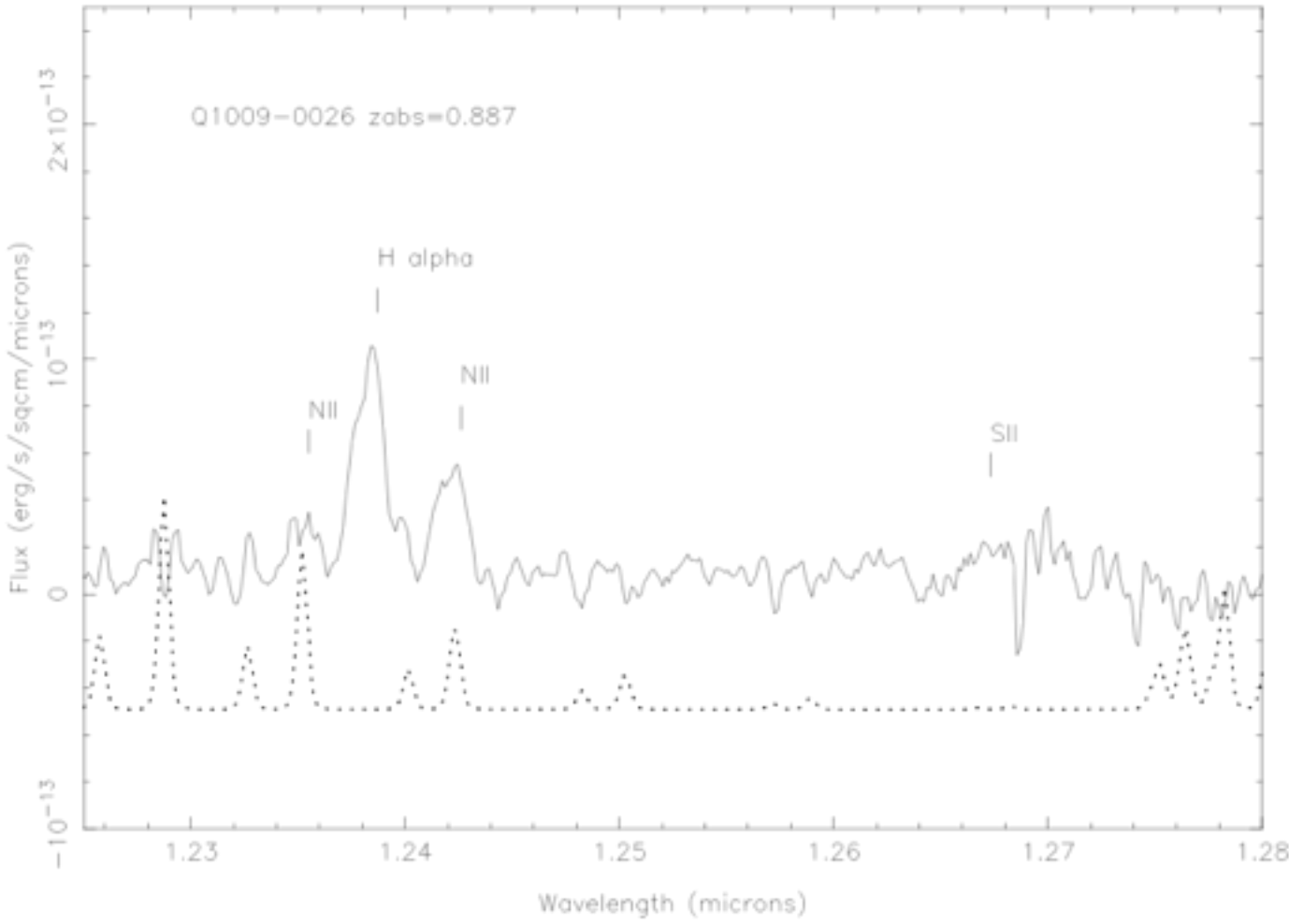
z~2



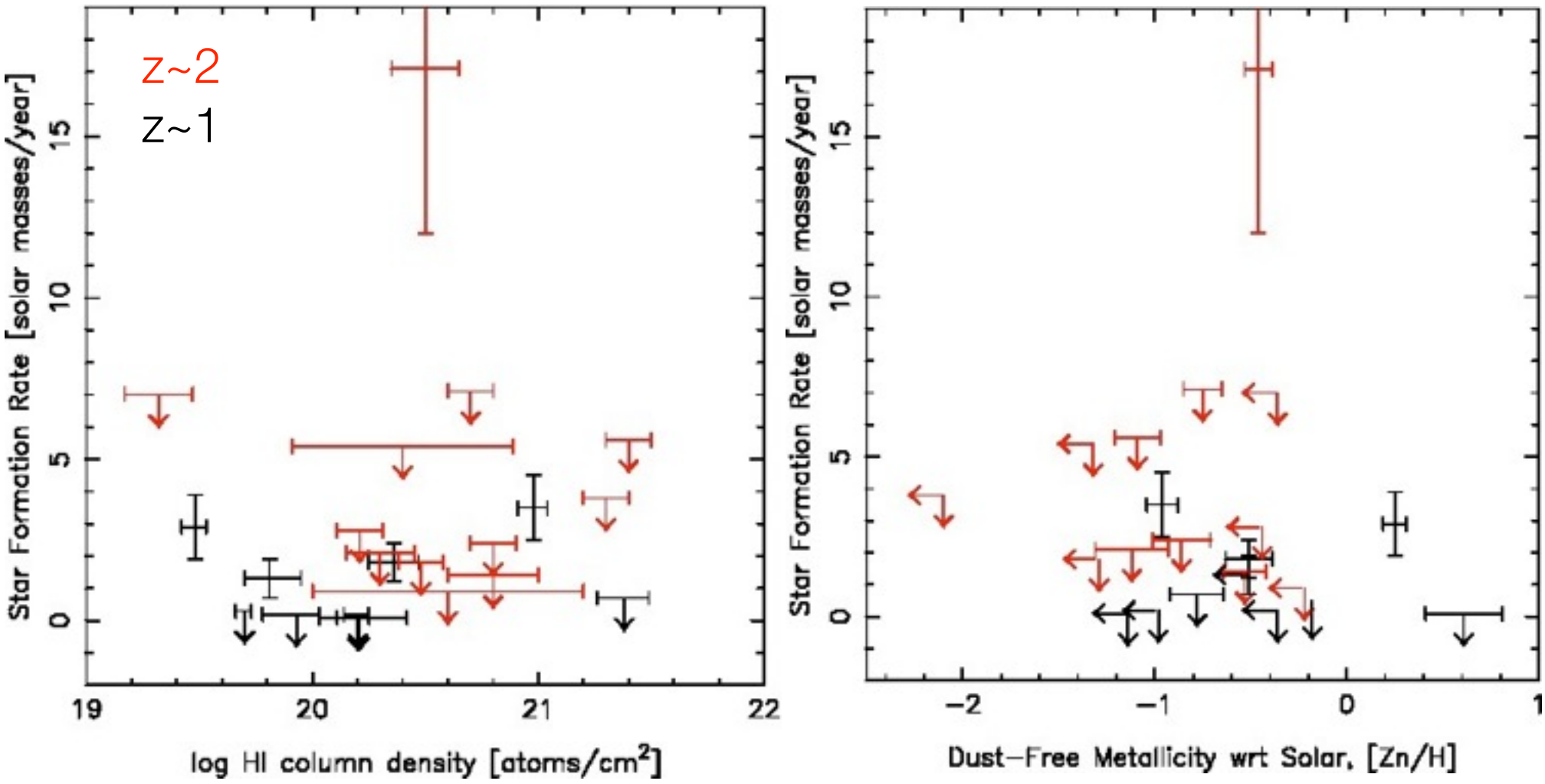
(Peroux et al. 2011a, 2012)

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

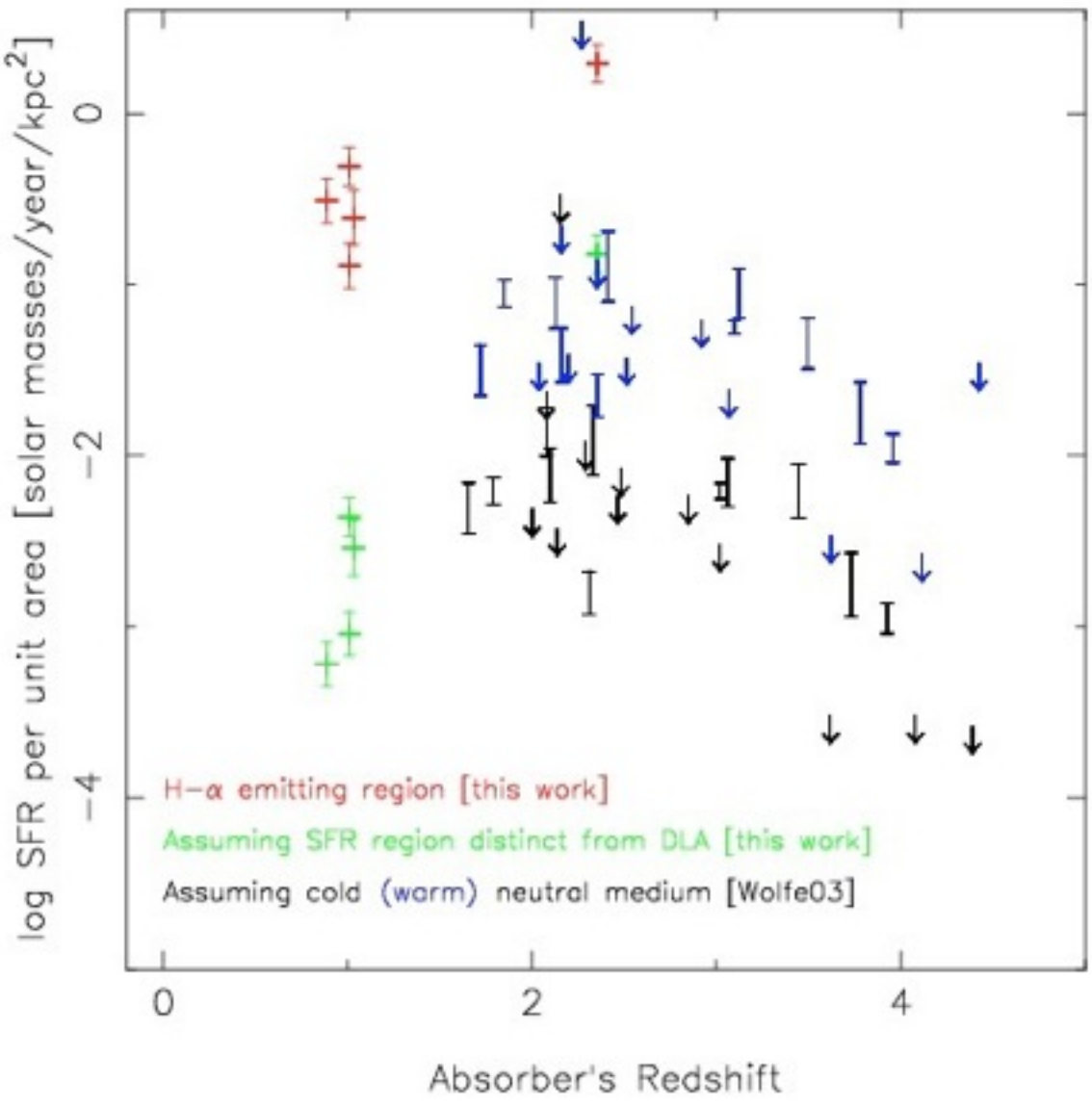


Star Formation Rates



=> detections among most metal-rich systems

Star Formation Rates per Unit Area



PLAN

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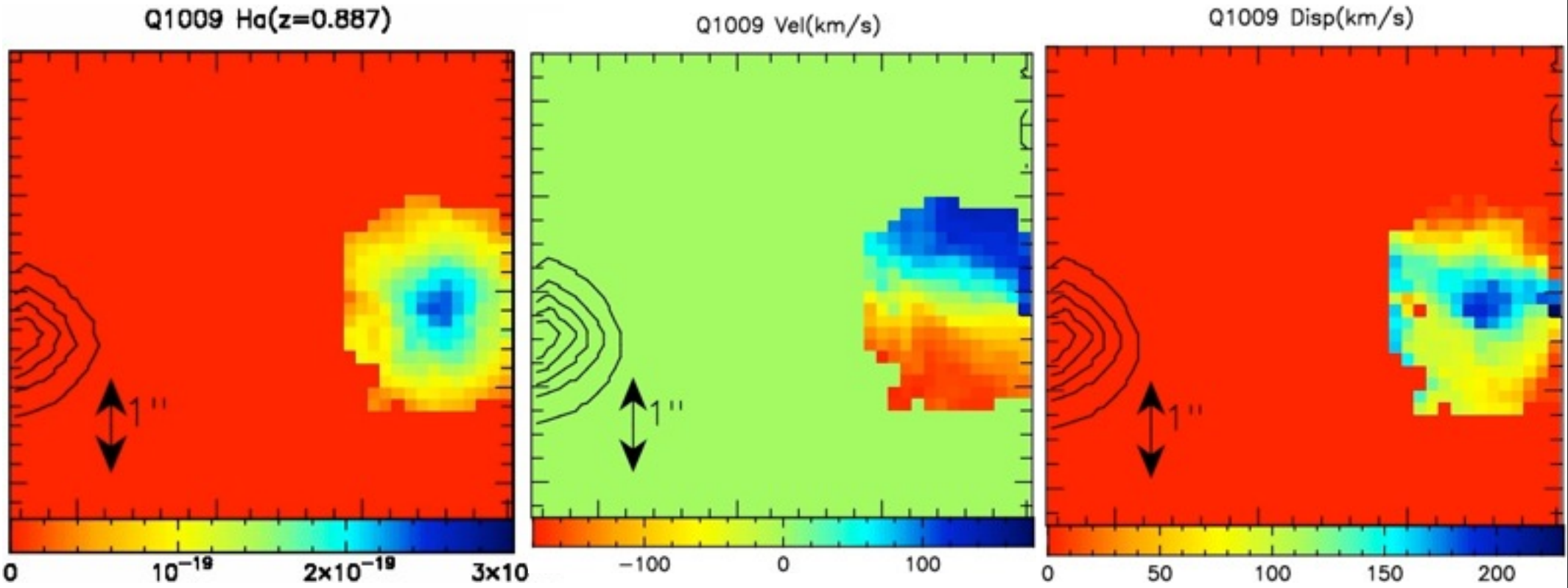
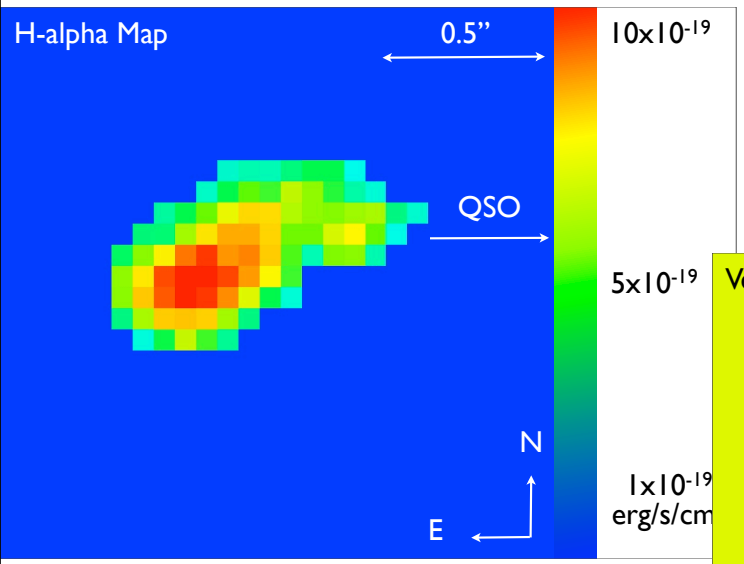
Kinematics

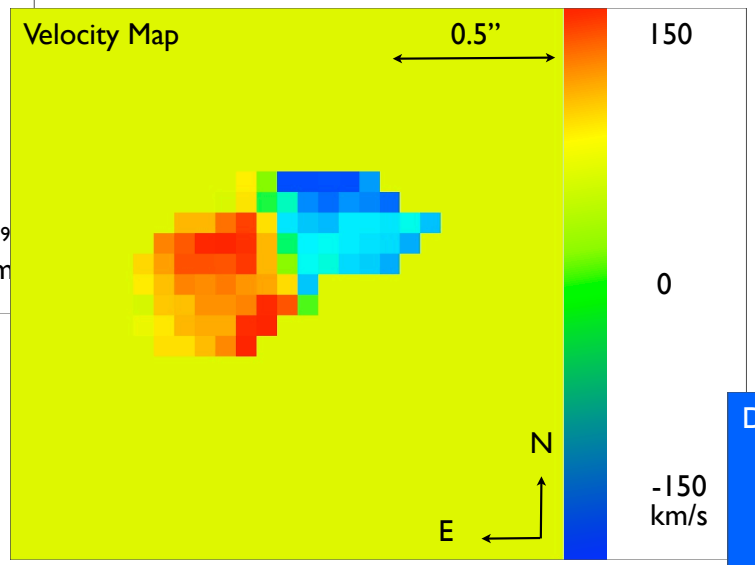


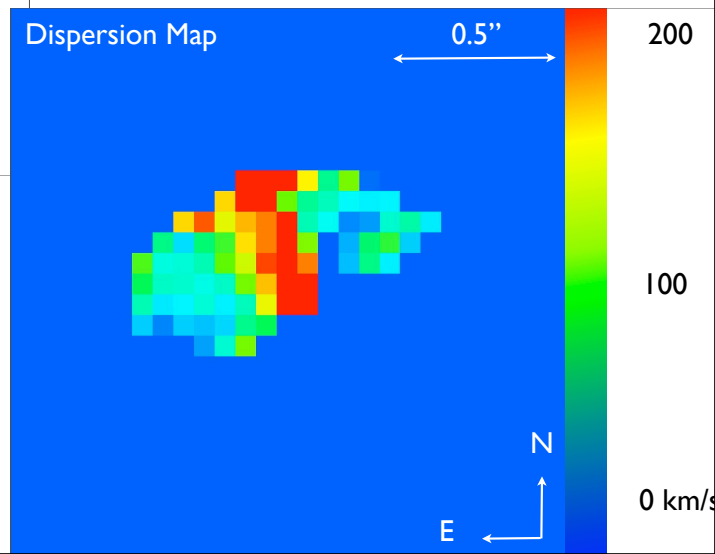
- inclination: sin i, velocity and dispersion: v/sigma

(Peroux et al. 2011b)

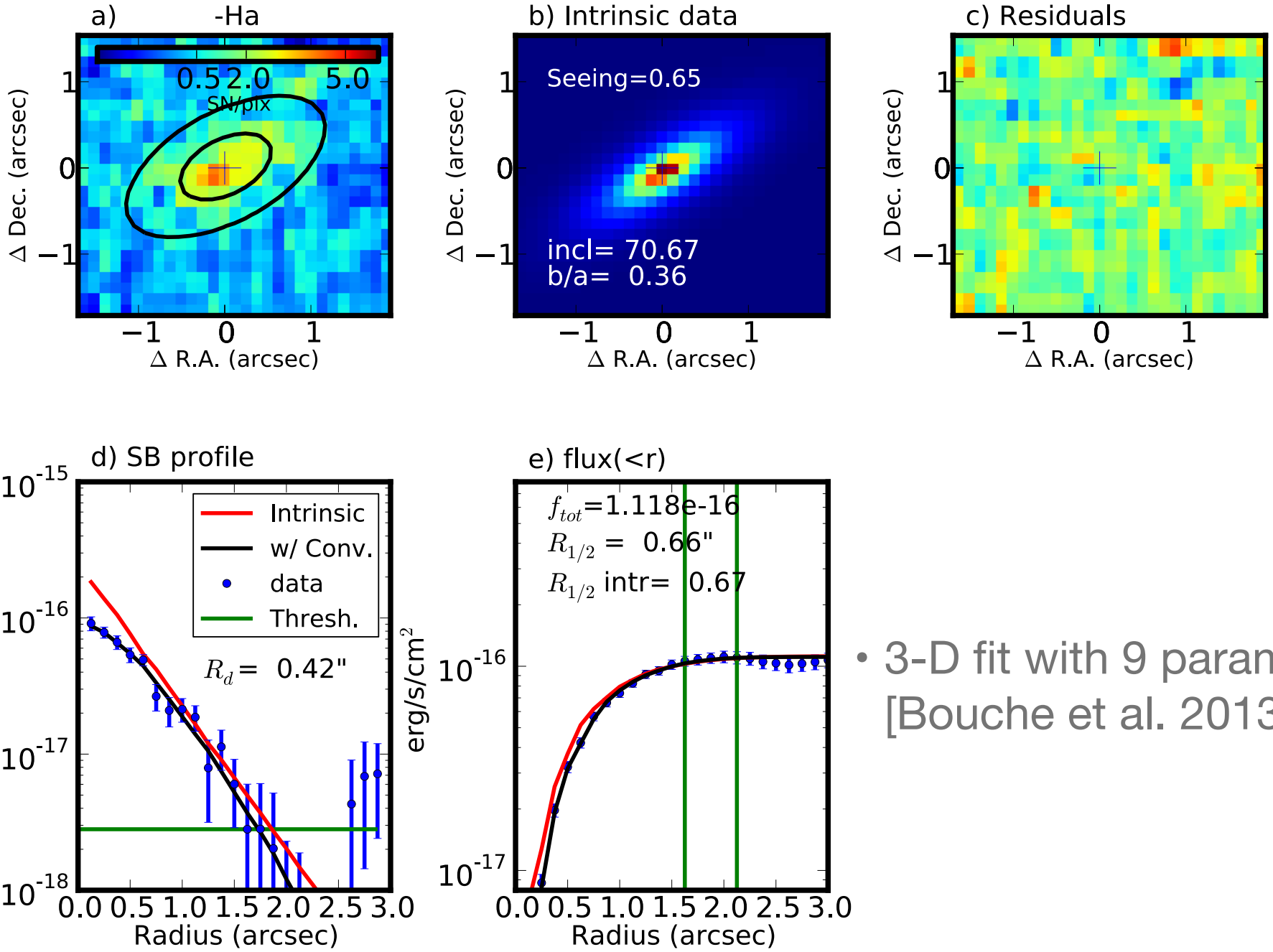
Kinematics


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]

Mass Estimates

- $M_{dyn} \sim 10^{10\text{-}11}\ M_{sun}$
- $M_{gas} \sim 10^{9\text{-}10}\ M_{sun}$
- $M_{star} \sim 10^{9\text{-}10}\ M_{sun}$ => follows mass-metallicity relation
- $M_{halo} \sim 10^{12\text{-}13}\ M_{sun}$ => 1 order of mag > predicted by Pontzen et al. 2008

(Peroux et al. 2013)

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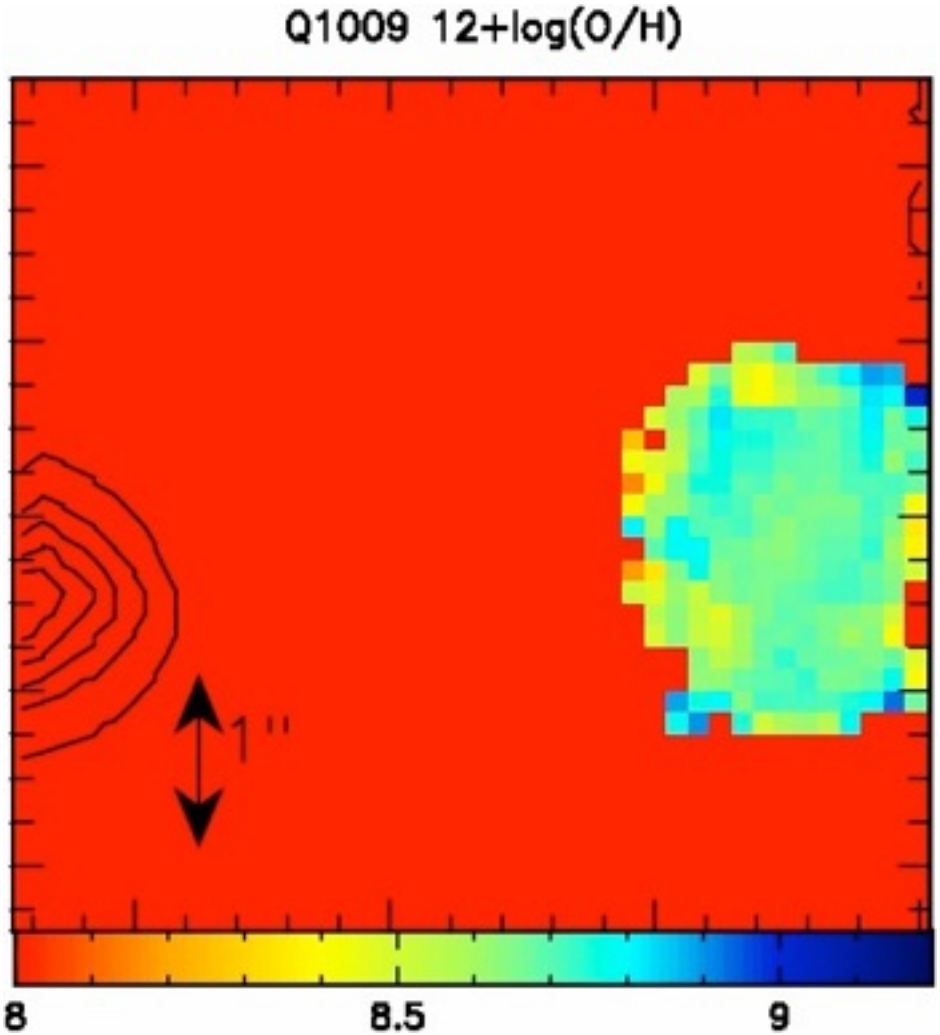
2D SINFONI Metallicity Maps

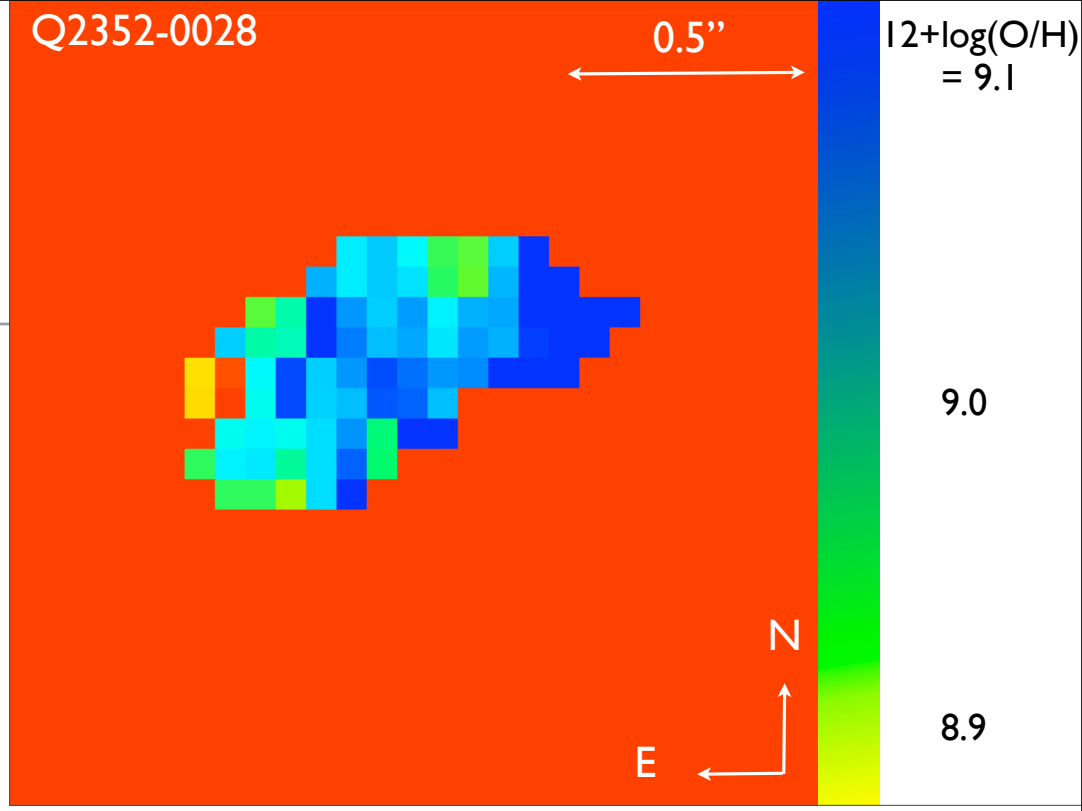
- N2 parameter [Pettini & Page 2004]
- collapsed [NII]/H-alpha ratio map
- metallicity rather uniform gradients: -0.11+/-0.17 (Q0452), <0.10 (Q1009) and -0.07+/-0.35 (Q2352) dex/kpc

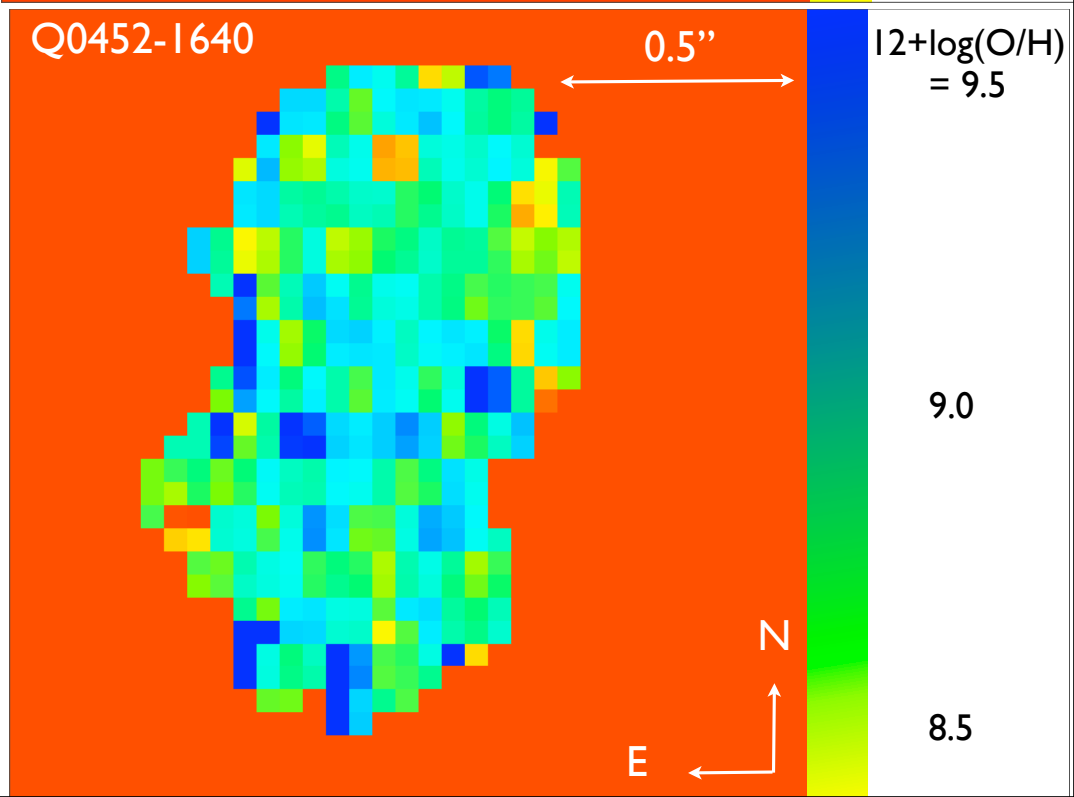
  => no indication of accretion

[Queyrel, et al. 2012,
Troncoso et al. 2013]

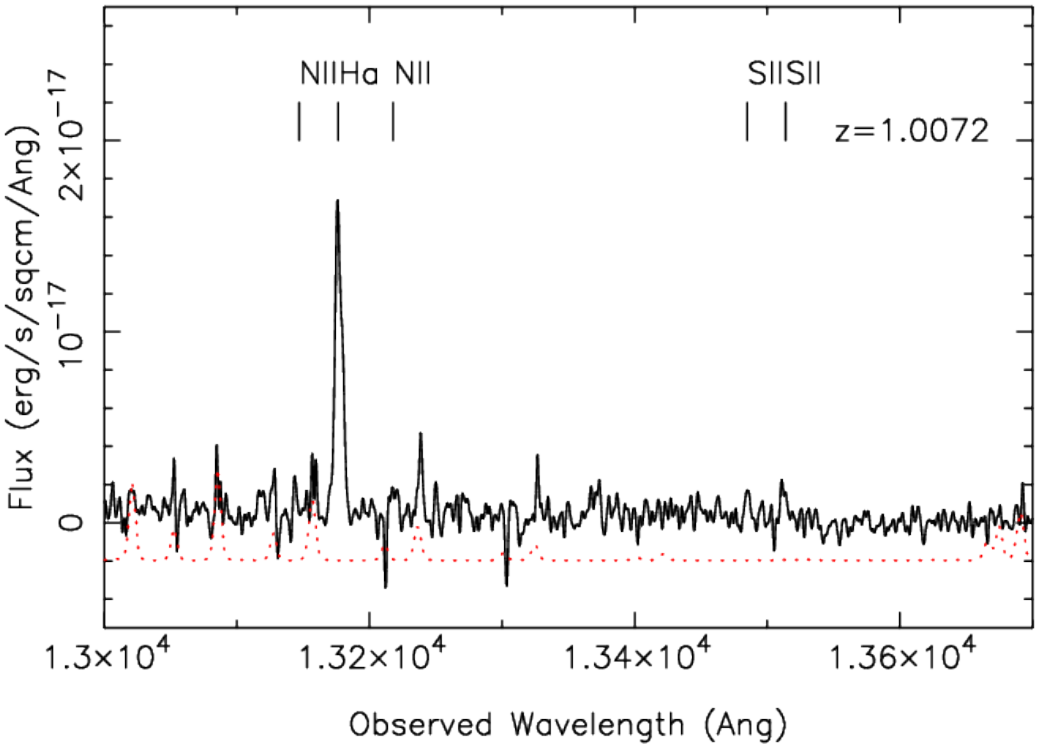
Metallicity Maps



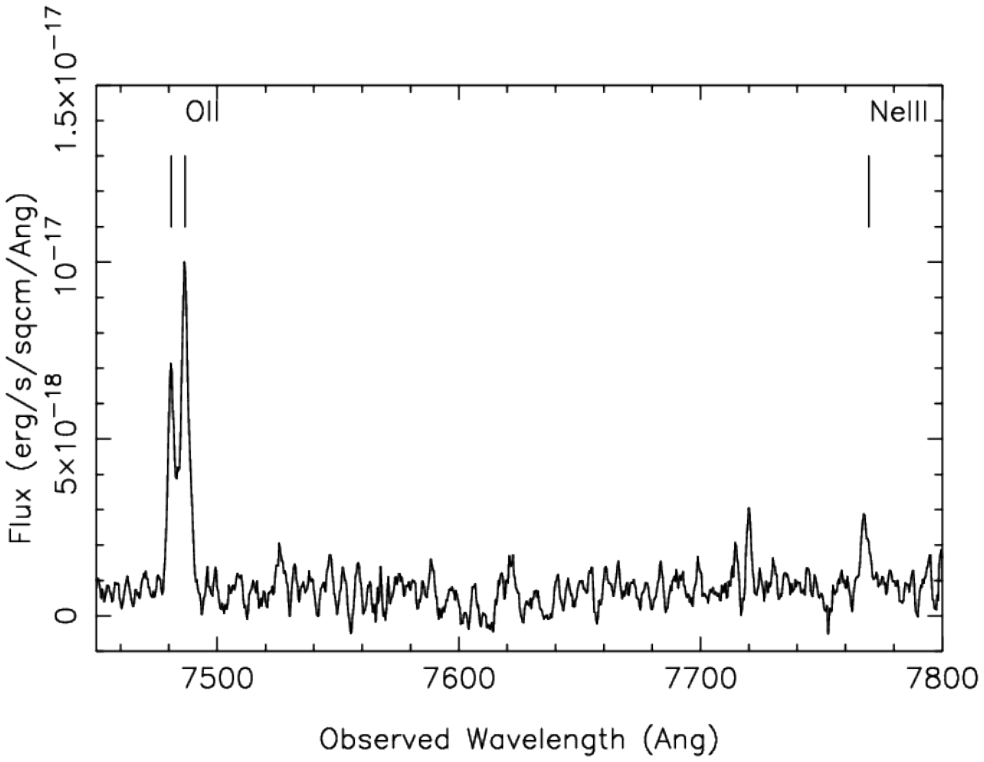




X-Shooter Absorbing-Galaxy Spectra



- detect Ha, Hb, Hg, Hd, OII, OIII, NII, SII
- OII doublet resolved



- use several indicators: N2, O3N2, R23
- HII metallicities ~ 12+log[O/H]=8.2-8.7

HI vs HII Metallicities

HII metallicity in emission

Table 4. Metallicity with respect to solar measured in absorption at given impact parameter and in emission.

Quasar	phys dist [kpc]	Absorption Abundance [X/H]	Ion X	Emission Metallicity[a] 12+log(O/H)	Gradients [dex/kpc]	Reference
HS1543+5921	0.4	−0.41±0.06	S	−0.54±0.20	+0.32±0.21	Bowen et al. 2005
Q1009−0026	39	+0.25±0.06	Zn	+0.04±0.80	+0.01±0.80	This work
AO0235+164	7	−1.80±0.40	Fe	−0.24±0.15	−0.22±0.43	Chen et al. 2005
Q0302−223	25	−0.51±0.12	Zn	< −0.06	> −0.02	This work
PKS0439−433	7	−0.72±0.12	Fe	+0.45±0.15	−0.17±0.19	Chen et al. 2005
Q0827+243	36	−1.01±0.11	Fe	> +0.06	< −0.03	Chen et al. 2005
Q0452−1640	16	−0.96±0.08	Zn	−0.26±0.01	−0.04±0.08	This work
Q2222−0946	6	−0.46±0.07	Zn	< −0.46	> −0.00	This work
Q2352−0028	12	< −0.51	Zn	−0.26±0.03	< −0.02	This work

[a]: The emission metallicities are derived from R_{23} (Pagel et al. 1979) except for objects studied in this work where we used N2 (Pettini & Pagel 2004)

HI metallicity in absorption

HI vs HII Metallicities

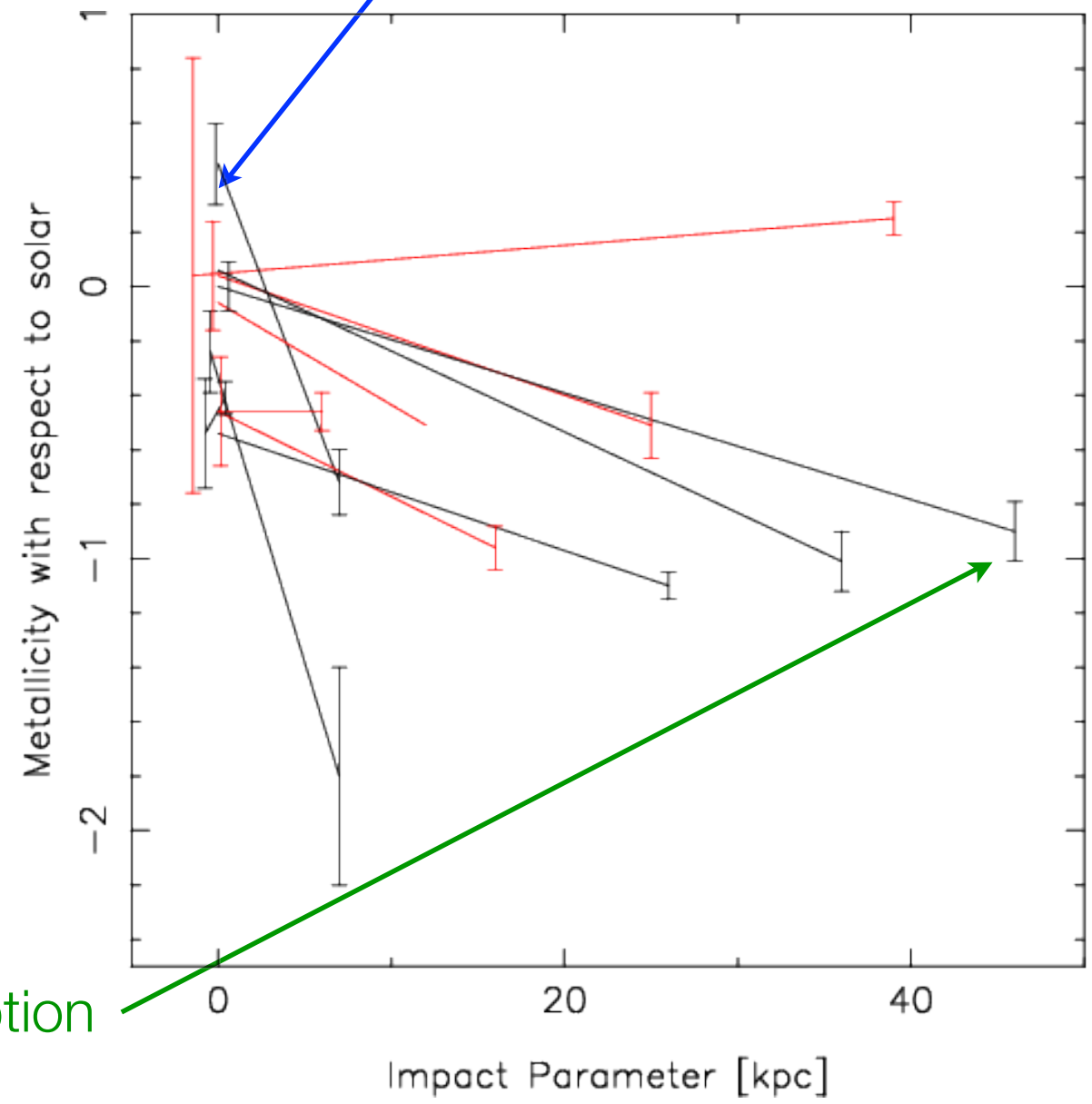
HII metallicity in emission

- this survey more than double number of systems for which such measures are possible
- gradients: -0.22 to +0.32 dex/ kpc
- difference neutral/ionised gas

[James et al. 2013]

(updated figure with latest measurements)

HI metallicity in absorption



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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:

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

Independent Indicators to Constrain Gas Flows

- EW(MgII):

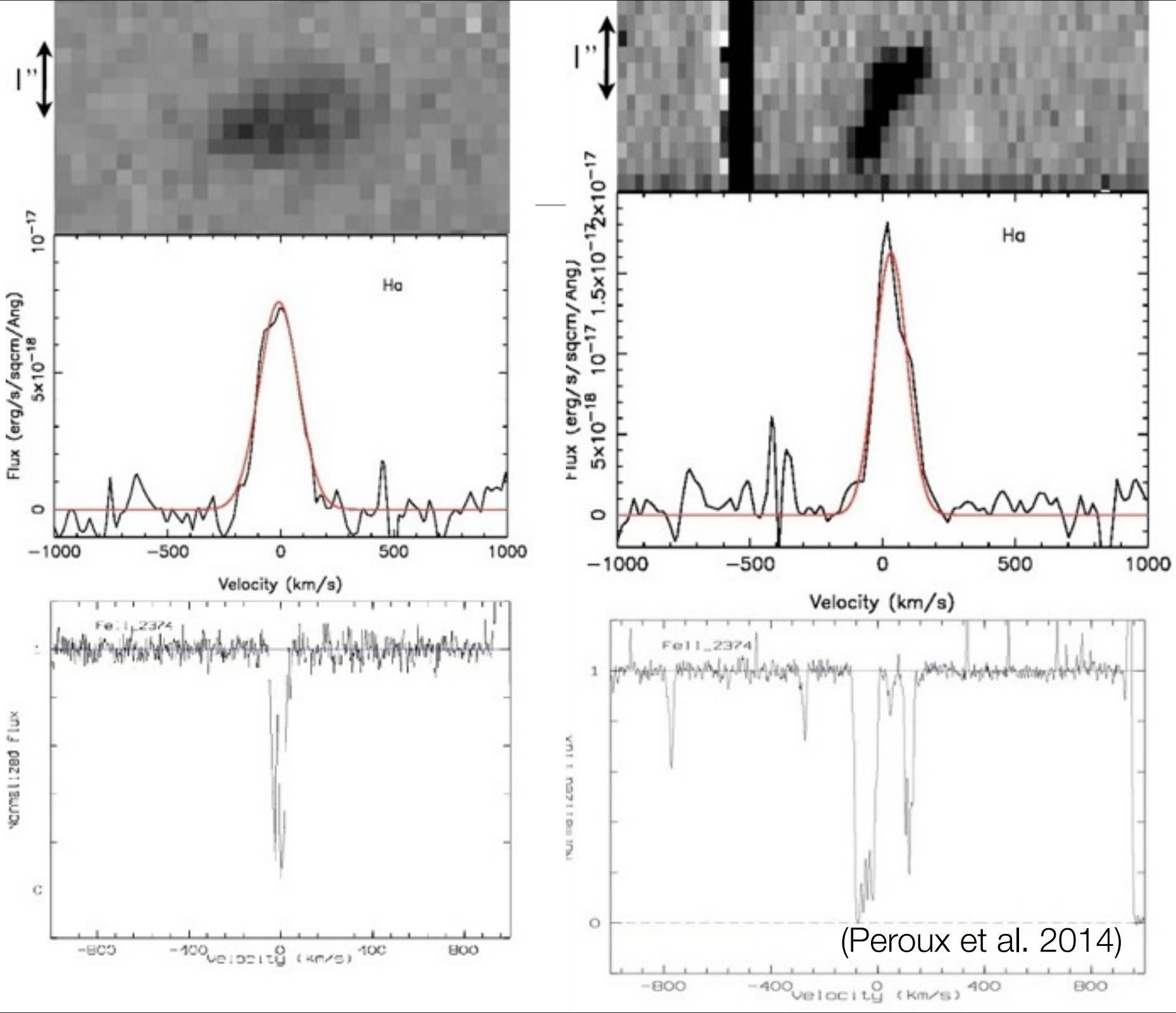
>0.1Ang in all cases => winds?

Independent Indicators to Constrain Gas Flows

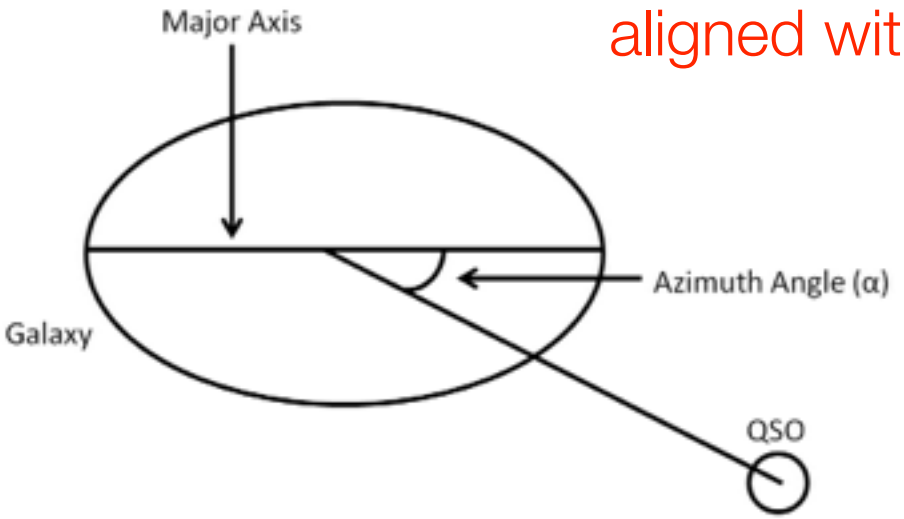
- comparison of emission/absorption kinematics:

compare V_{max} and Δ_v

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

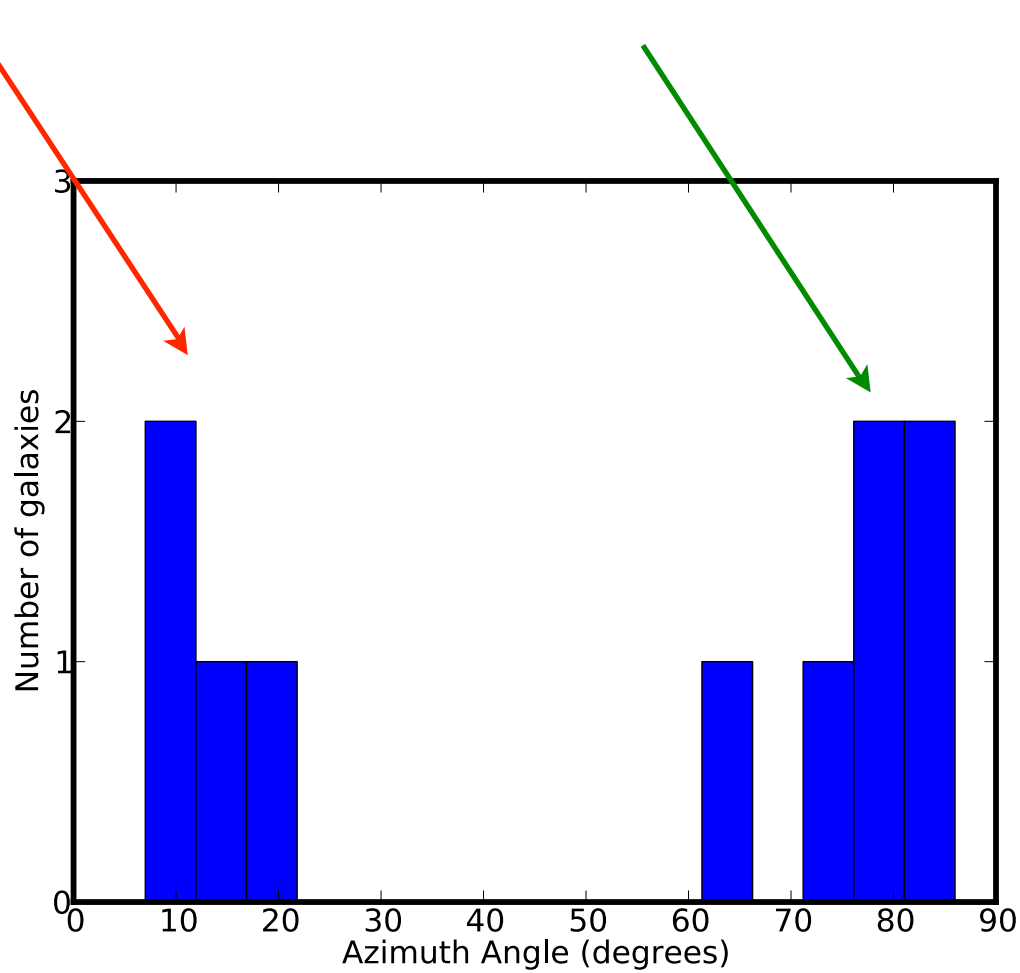

1"
Ha
Flux (erg/s/sqcm/Ang)
Velocity (km/s)
FeII_2374
Normalized Flux
(Peroux et al. 2014)

Inclination/Orientation



aligned with major axis

align with minor axis: outflow



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

Bordoloi et al. 2011;
Bouche et al. 2012

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

- Emission dynamical properties: $M_{gas=}10^{9}$-$10^{10}M_{sun}$, $M_{halo}=10^{12}$-$10^{13}M_{sun}$

- Metallicity with SINFONI + X-Shooter:
  - HII metallicity map: internal gradients are rather flat
  - metallicity in absorption and in emission are comparable

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