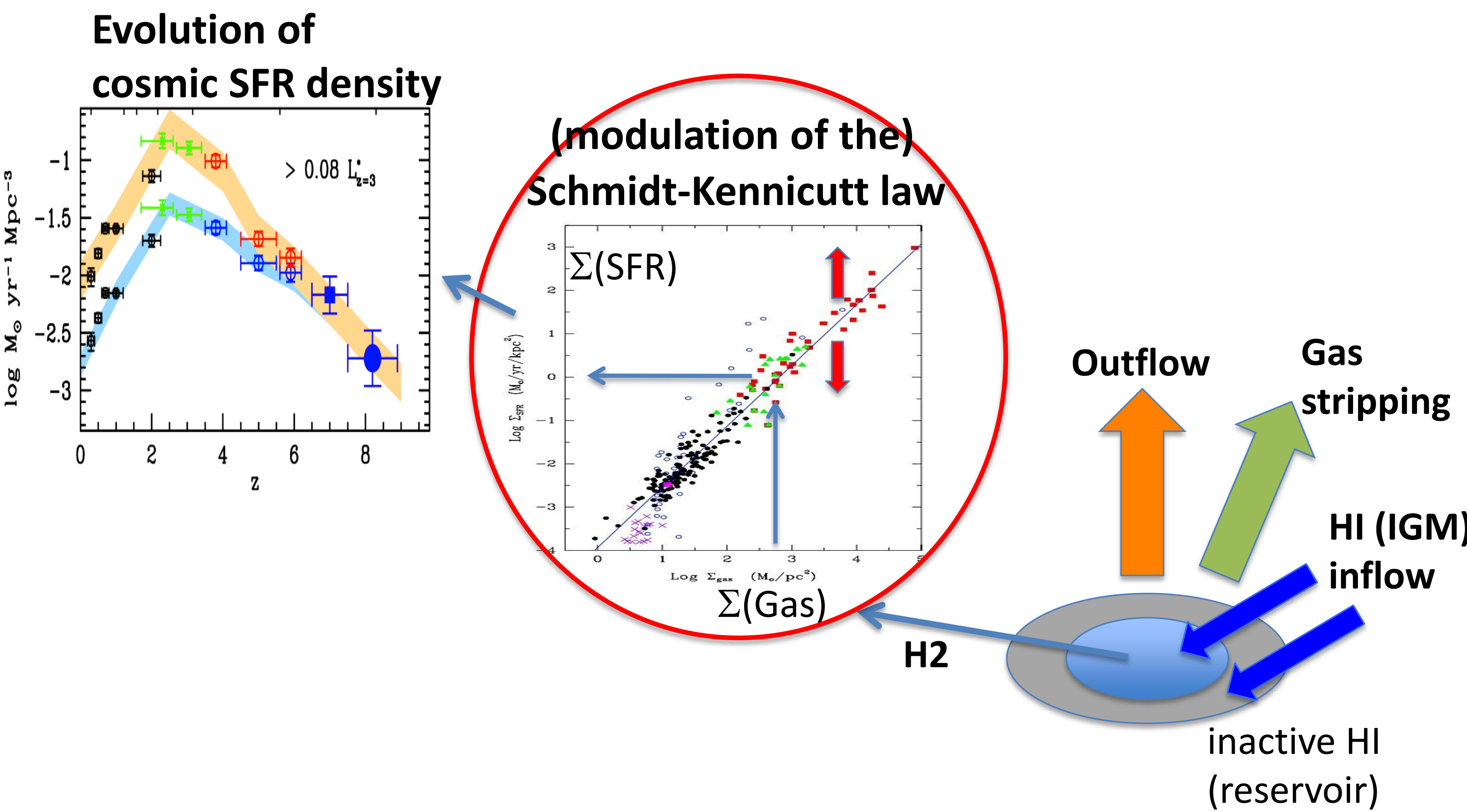
ESO in the 2020's

Gas in galaxies

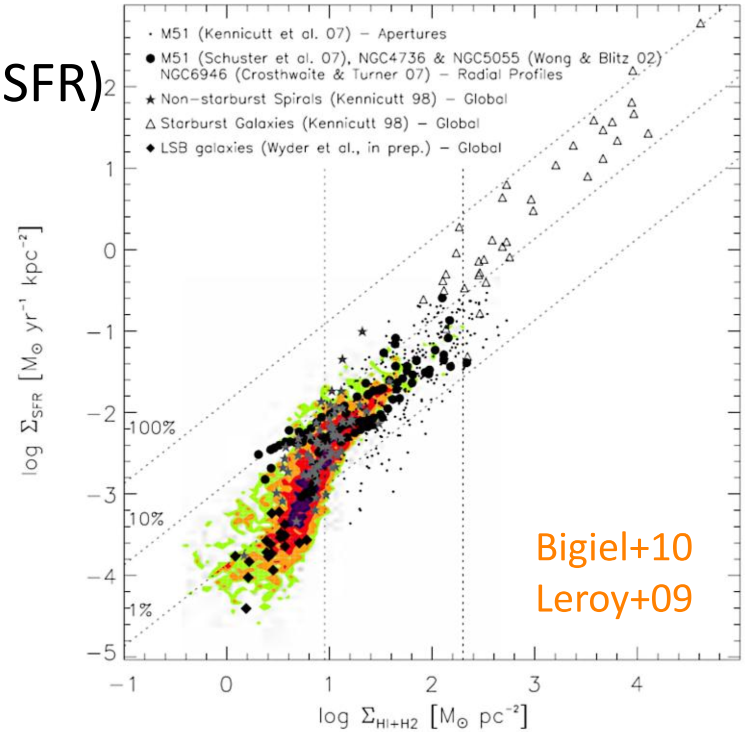
Roberto Maiolino



Evolution of
cosmic SFR density
> 0.08 L*z=3
log M⊙ yr⁻¹ Mpc⁻³
z
(modulation of the)
Schmidt-Kennicutt law
Σ(SFR)
Log Σ_SFR (M⊙/yr/kpc²)
Log Σ_gas (M⊙/pc²)
Σ(Gas)
Outflow
Gas
stripping
HI (IGM)
inflow
H2
inactive HI
(reservoir)

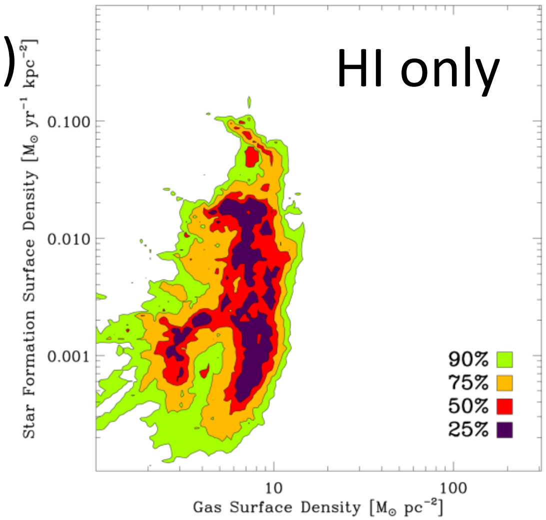
The Schmidt-Kennicutt law(s)

Σ(SFR)



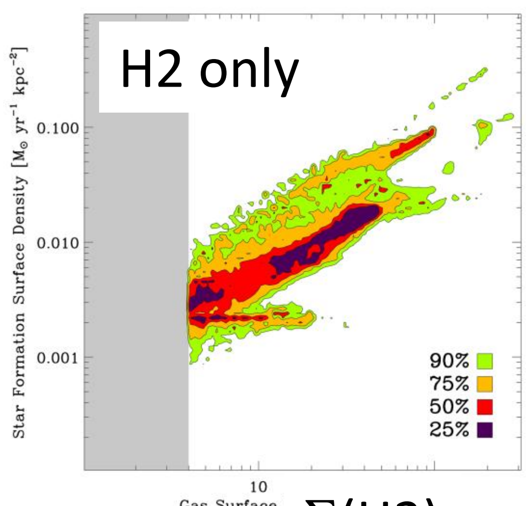
Σ(HI+H2)

Σ(SFR)



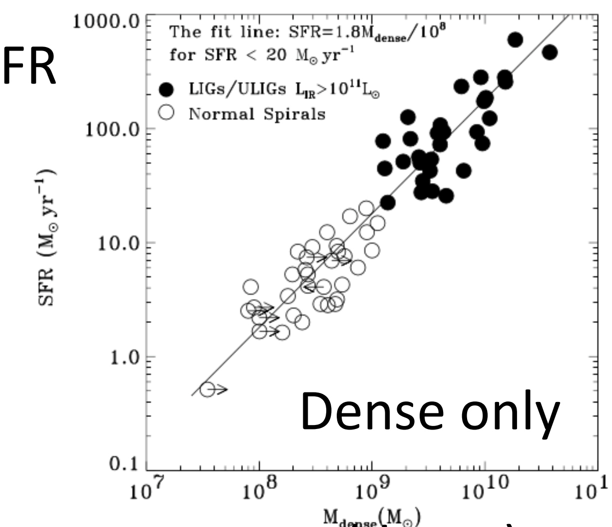
Σ(HI)

Σ(SFR)



Σ(H2)

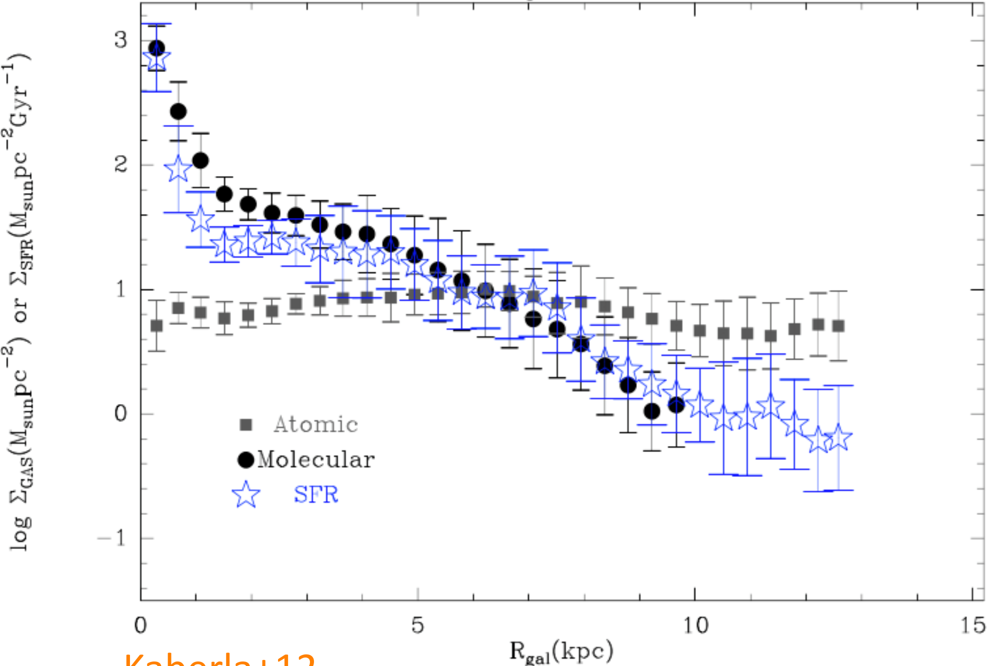
SFR



M(dense)

Molecular dense gas -> linear relation

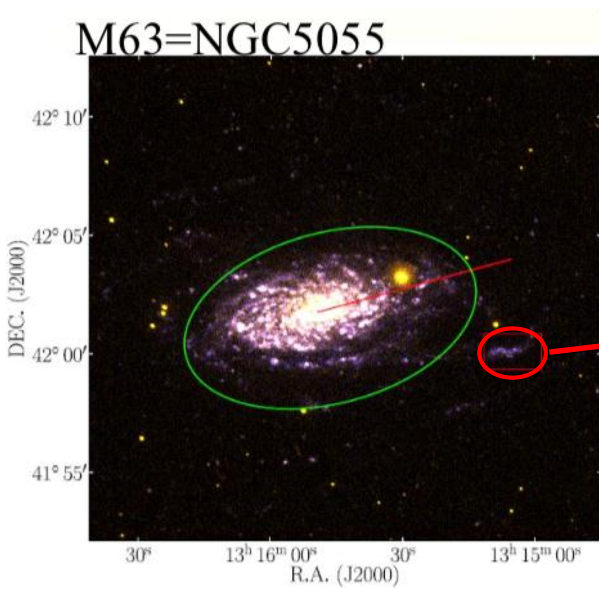
Gao & Solomon'04

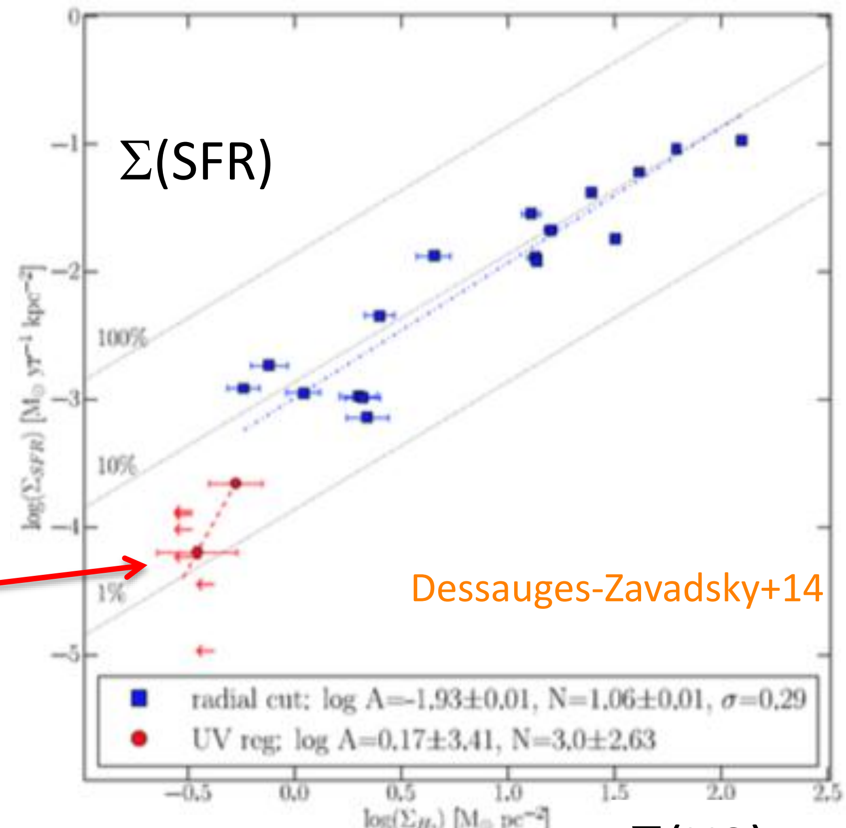


Kaberla+12

Inefficient SF in galaxy outskirts

Not only because mostly HI, but also H2 inefficient





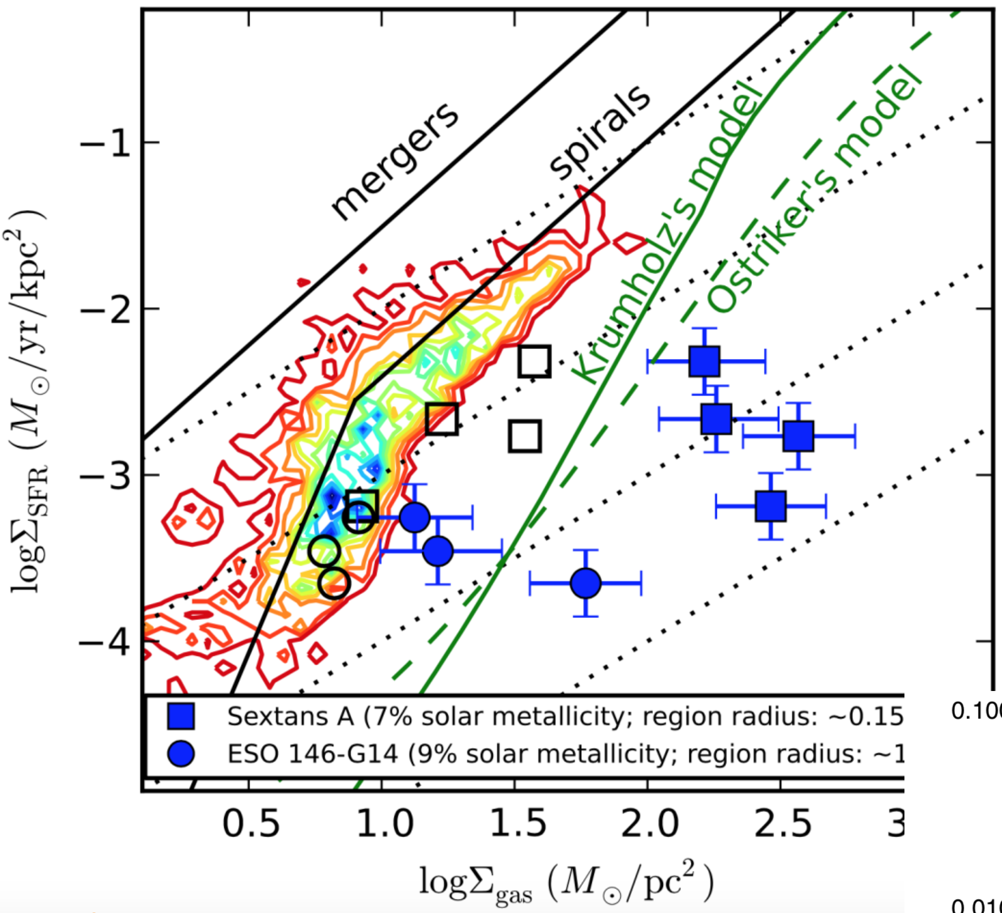
Σ(SFR)

Dessauges-Zavadsky+14

Σ(H2)

=> Reservoir of gas -> inflow on long timescales

-> but accelerated by any interaction or dynamical disturbance

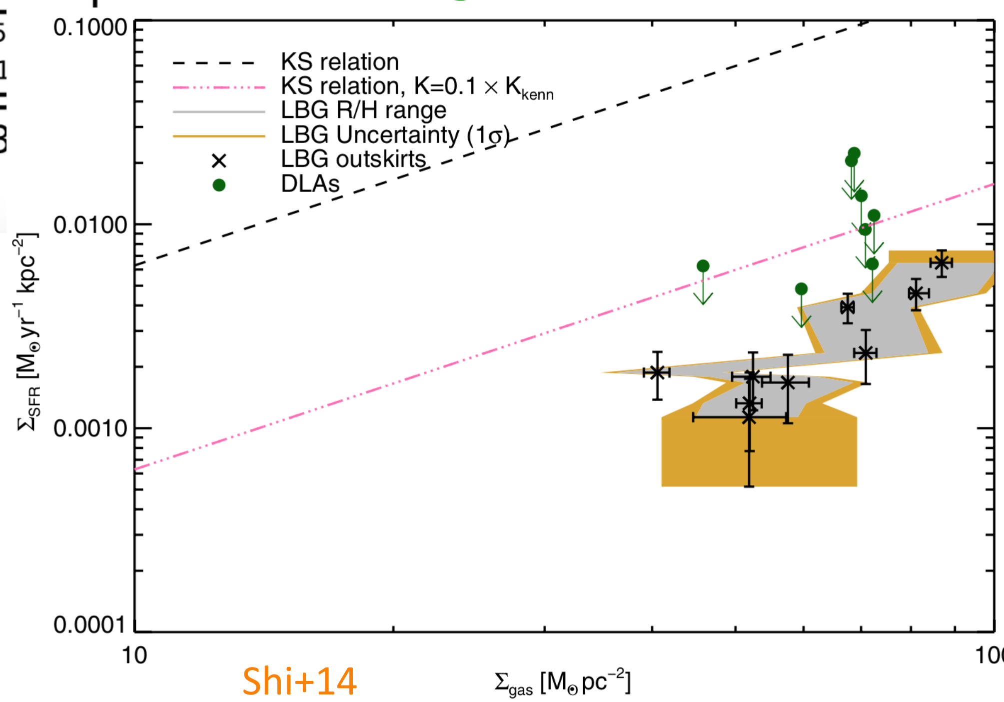


Inefficient SF in low metallicity systems?

Metal poor local galaxies

High-z DLA's

Shi+14

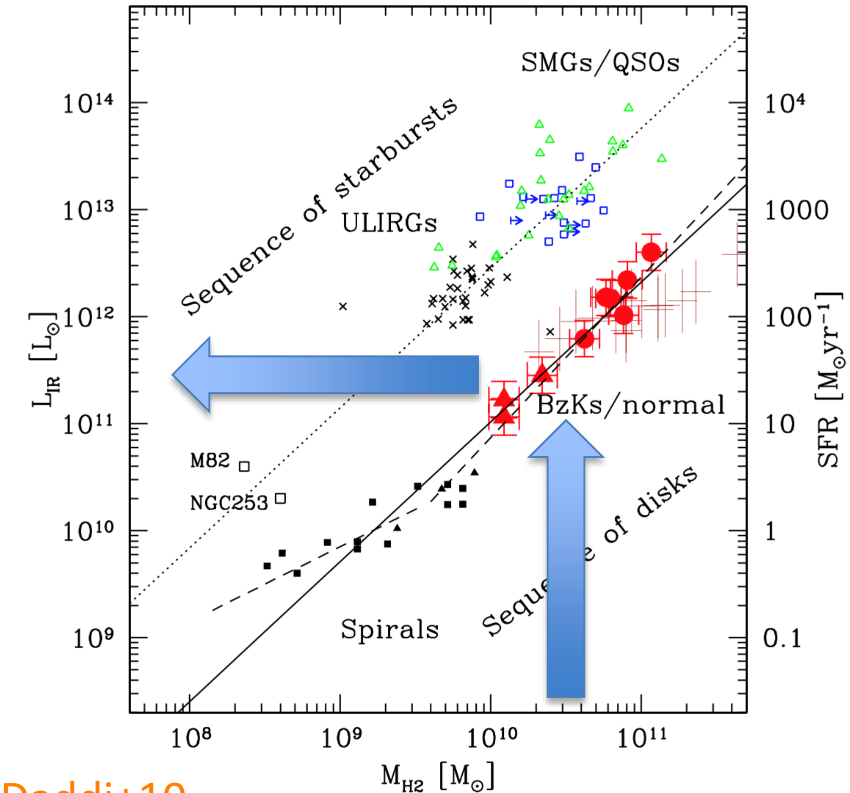


Shi+14

Possibly bulk of the gas is SF-inefficent i.e. "sub-SK"

Modulation of the SK with environment, dynamics and redshift

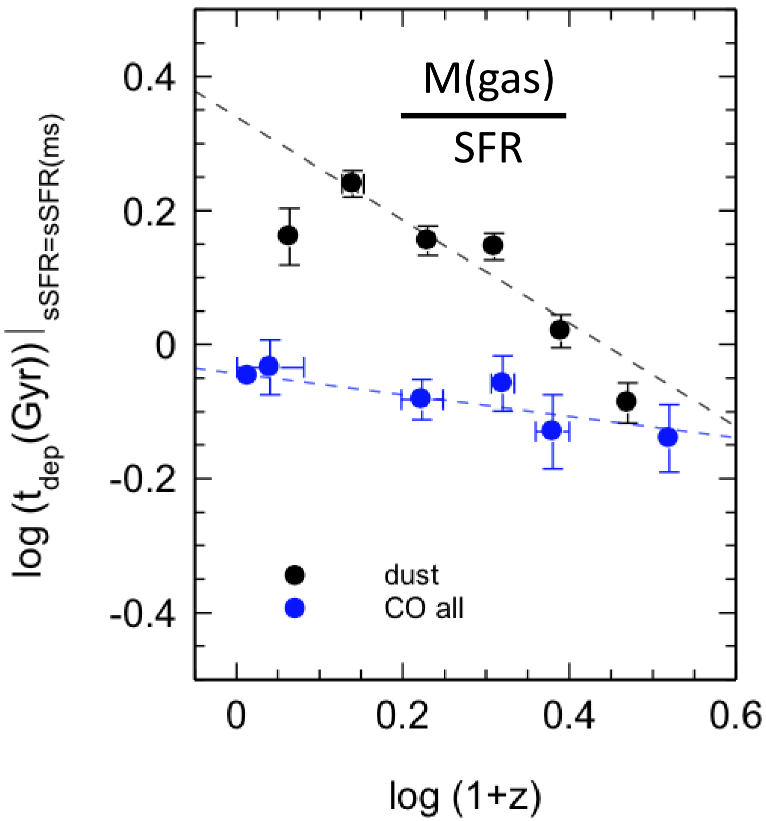
Bimodal S-K



Daddi+10

Genzel+10

Redshift-evolution of the S-K



Genzel+14

Santini+14

Tacconi+13

But debated...

Ivison+11

Santini+14

Papadoupolos+12

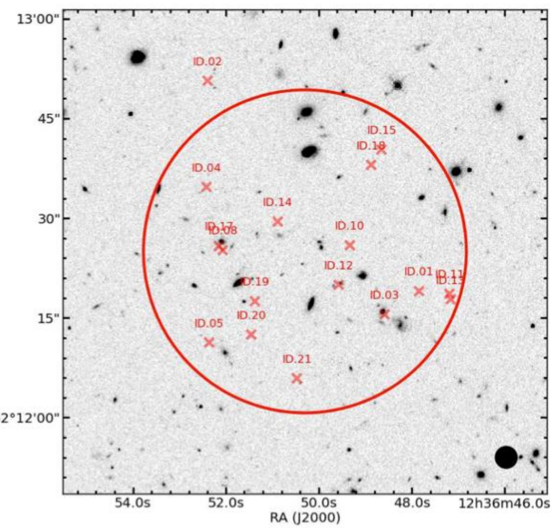
Most of these studies start from galaxies selects by Star Formation...

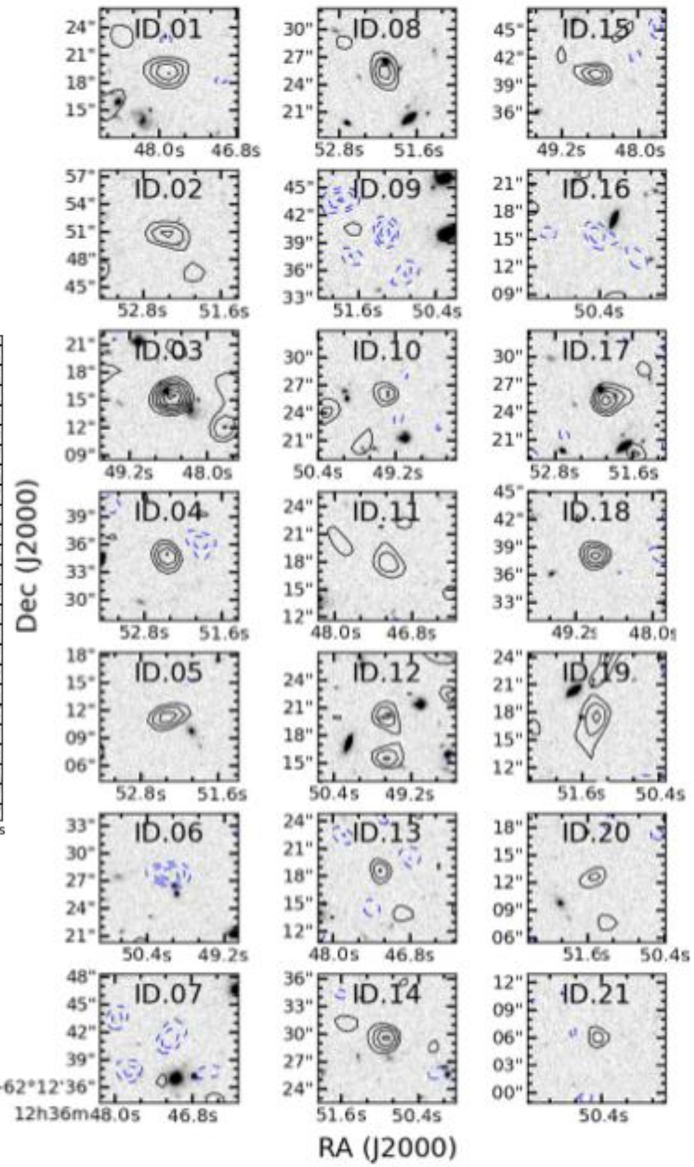
If the key, fundamental quantity is the gas content

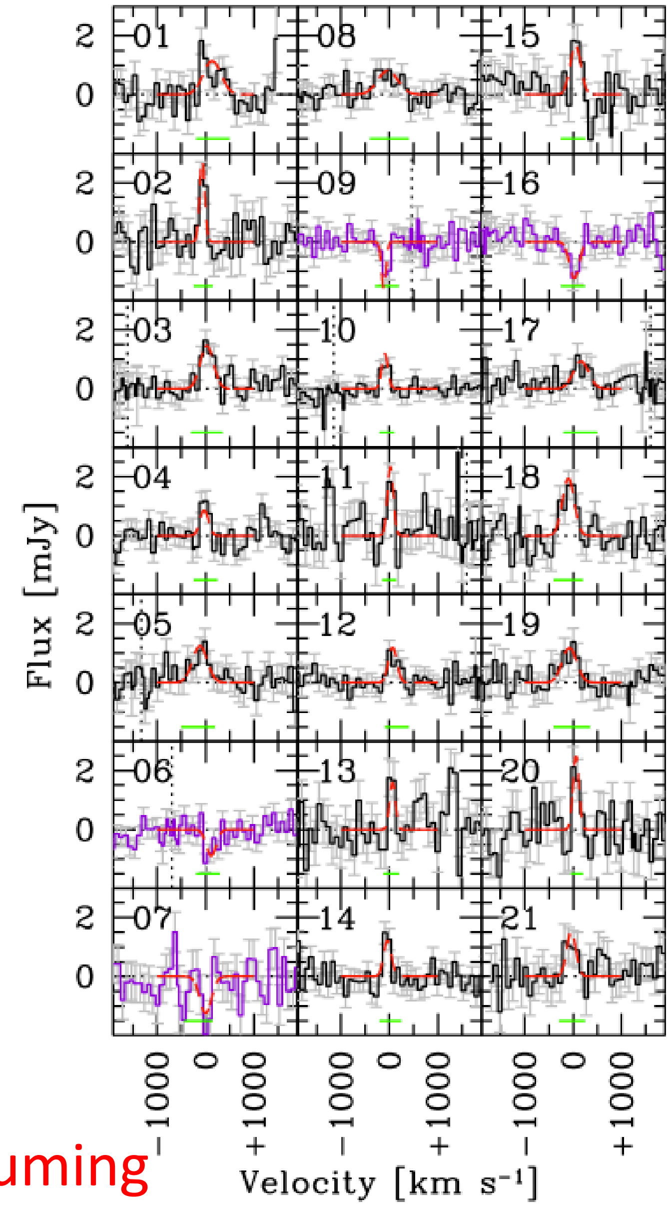
-> cleaner way -> select blindly from gas content

“Blind” CO searches
Tracing the cosmic evolution of Ω_{H2}

HDFN





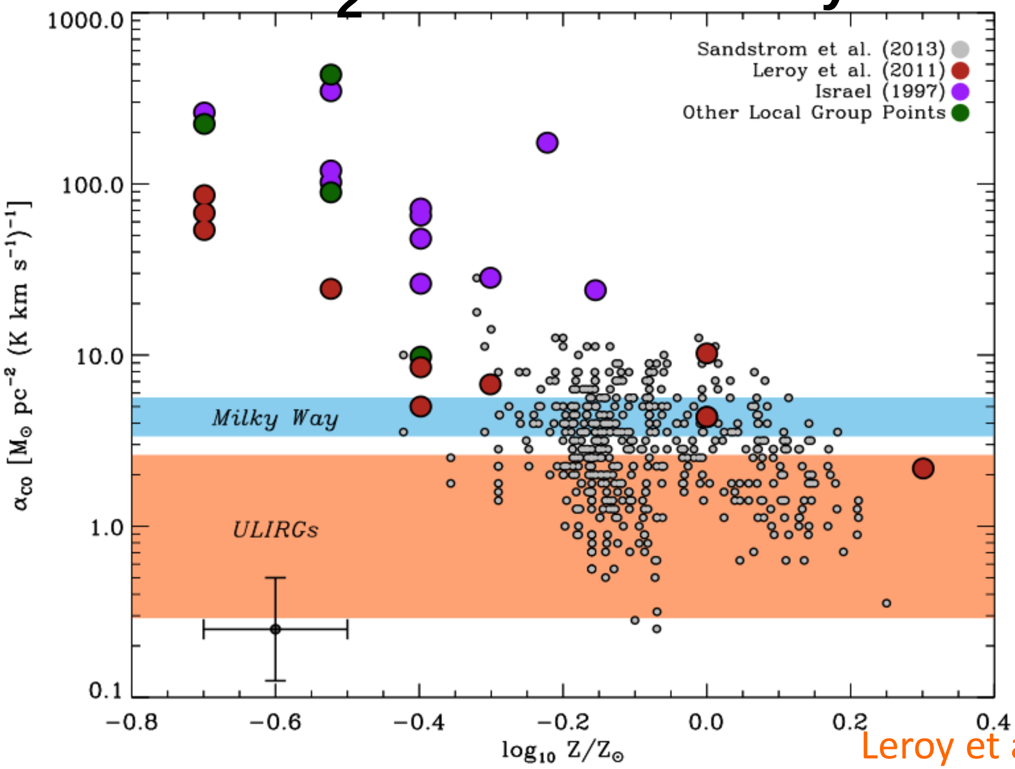


Decarli+14

Very difficult and time consuming

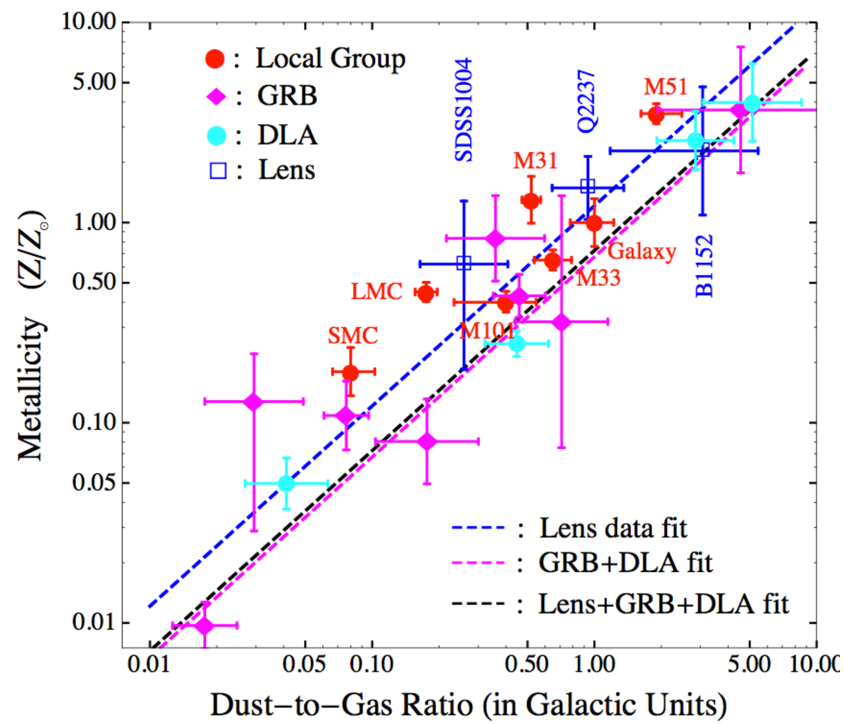
Gas masses from CO and from dust suffer from strong dependence on metallicity (and environment) ...and with large spread

CO-to-H_2 conv $\propto$ metallicity$^{\sim 1.5}$



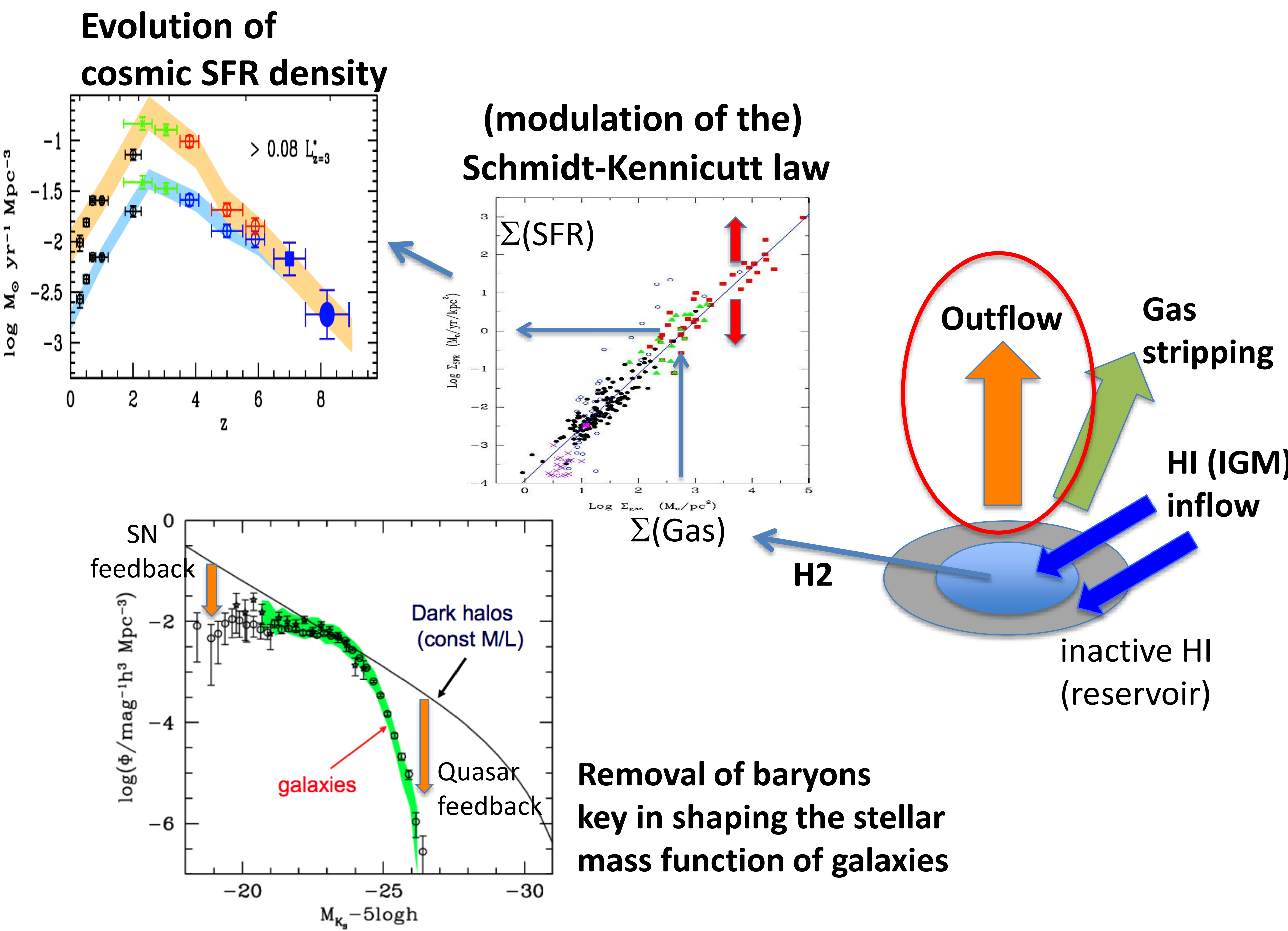
Bolatto+13; Genzel+12
Leroy12; Papadopulos+12
Sandstrom+13

Dust-to-Gas ratio $\propto$ metallicity



Leroy et al. 2011; Smith et al. 2012; Corbelli et al. 2012
Sandstrom et al. 2012, James et al. 2002;
Zafar & Watson 2013; Chen et al. 2013, Remy-Ruyer+14

Serious issue... especially at high redshift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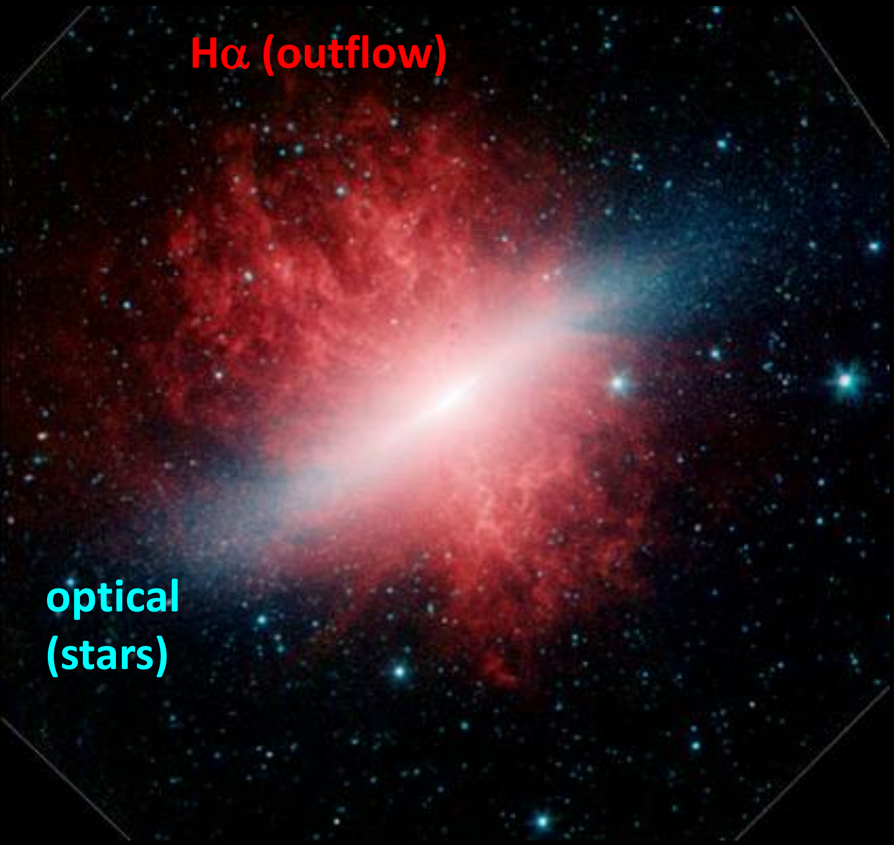
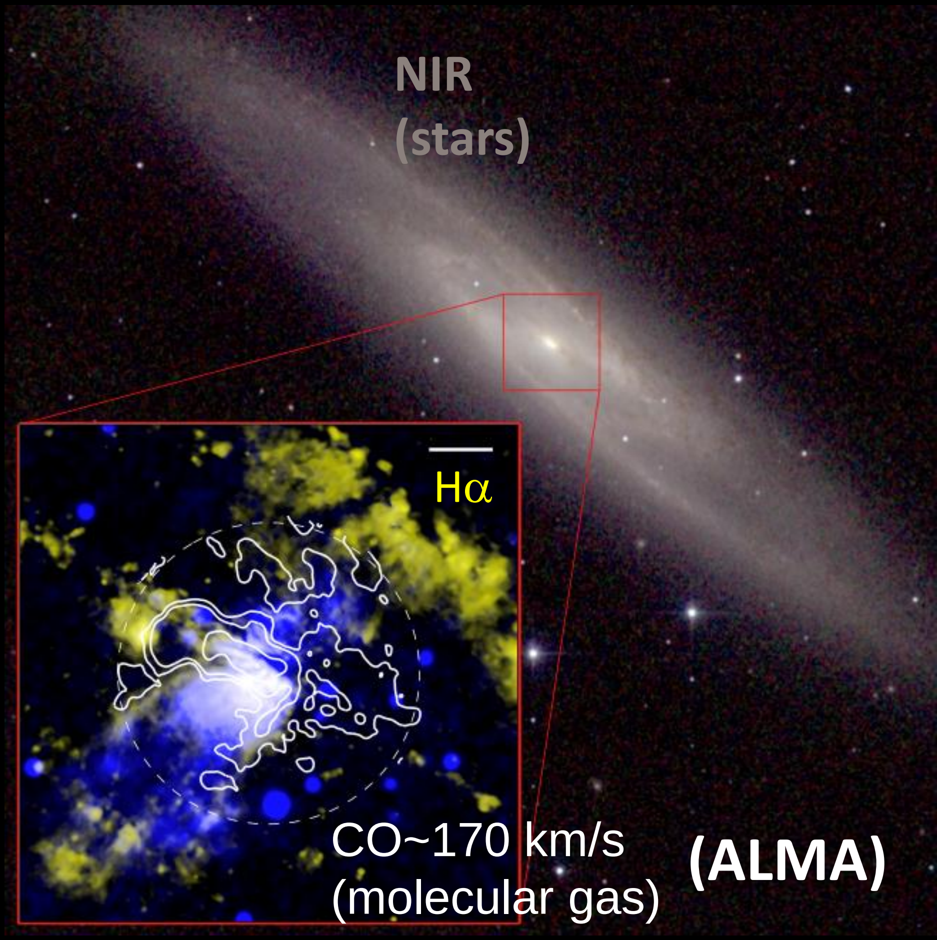
Σ(Gas)
H2
Outflow
Gas
stripping
HI (IGM)
inflow
inactive HI
(reservoir)
SN
feedback
Dark halos
(const M/L)
galaxies
Quasar
feedback
log(Φ/mag⁻¹h³ Mpc⁻³)
M_Ks−5logh
Removal of baryons
key in shaping the stellar
mass function of galaxies

Observationally tracing starburst-driven outflows

SN-driven winds



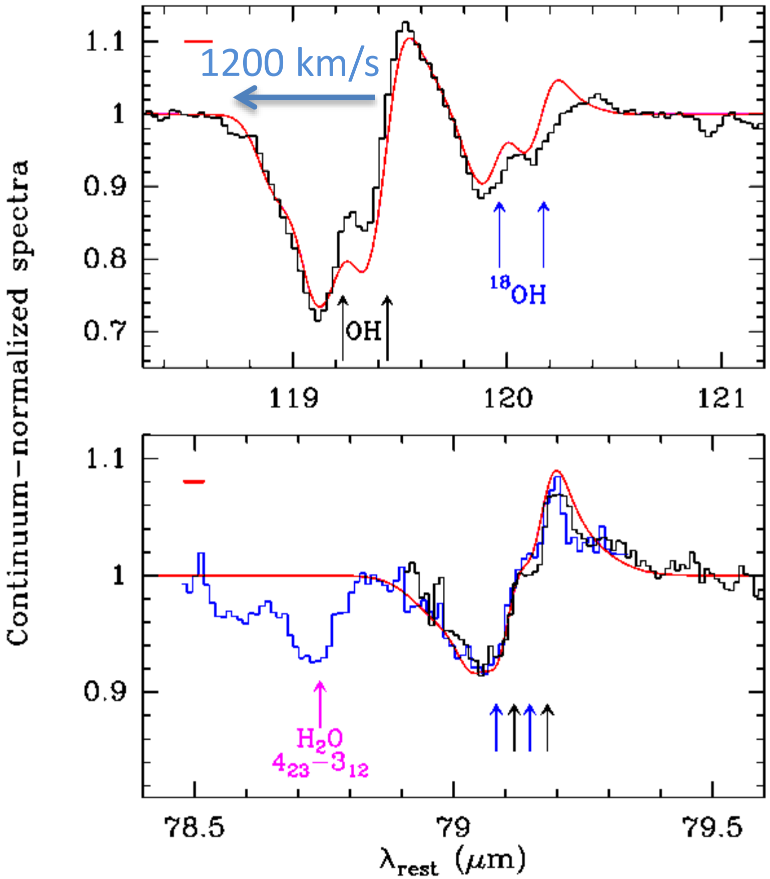


Soft X

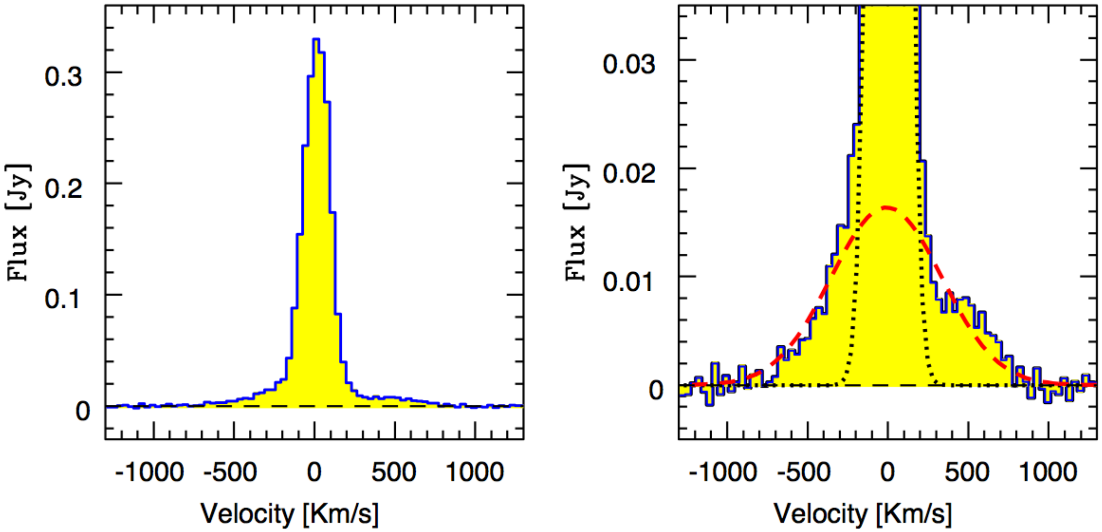
Bolatto+13

First evidence of quasar-driven outflows in local galaxies achieved only recently

OH P-Cygni profiles



CO(1-0) high velocity wings

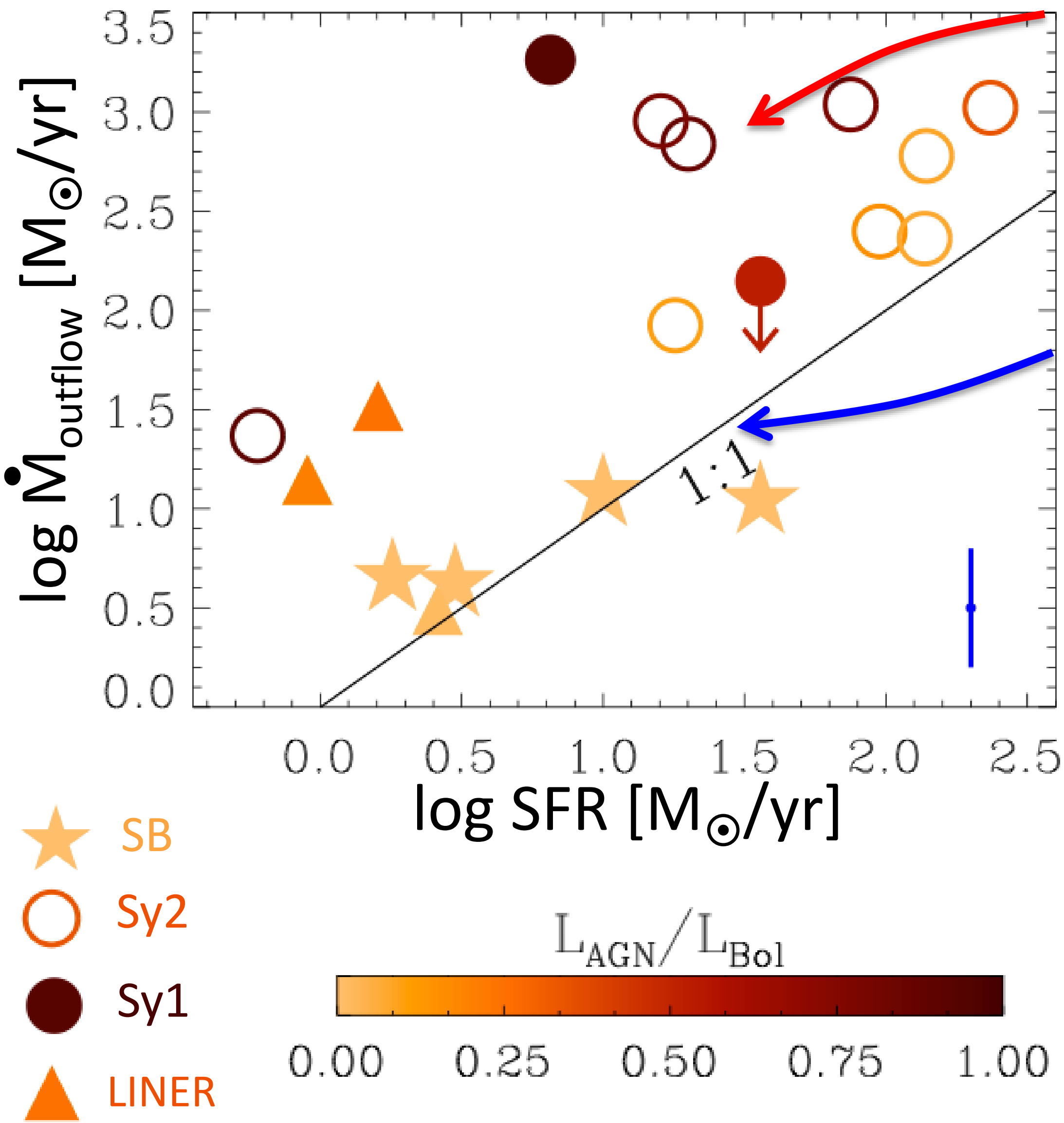


Fischer+10
Sturm+11

Feruglio+10,13

Massive molecular outflows (~1000 $M_\odot$/yr)
Extended on kpc scales

Outflow rate versus SFR in local galaxies



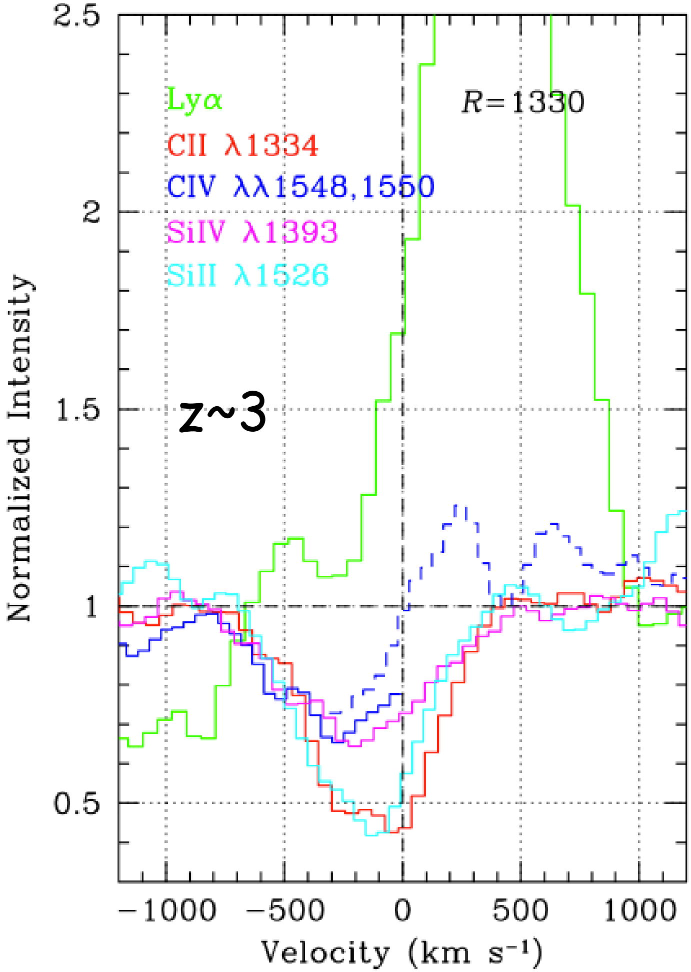
extra outflow-boost in AGN-dominated galaxies

Starburst-driven outflow rate ~ SFR as required by feedback models

Cicone+14

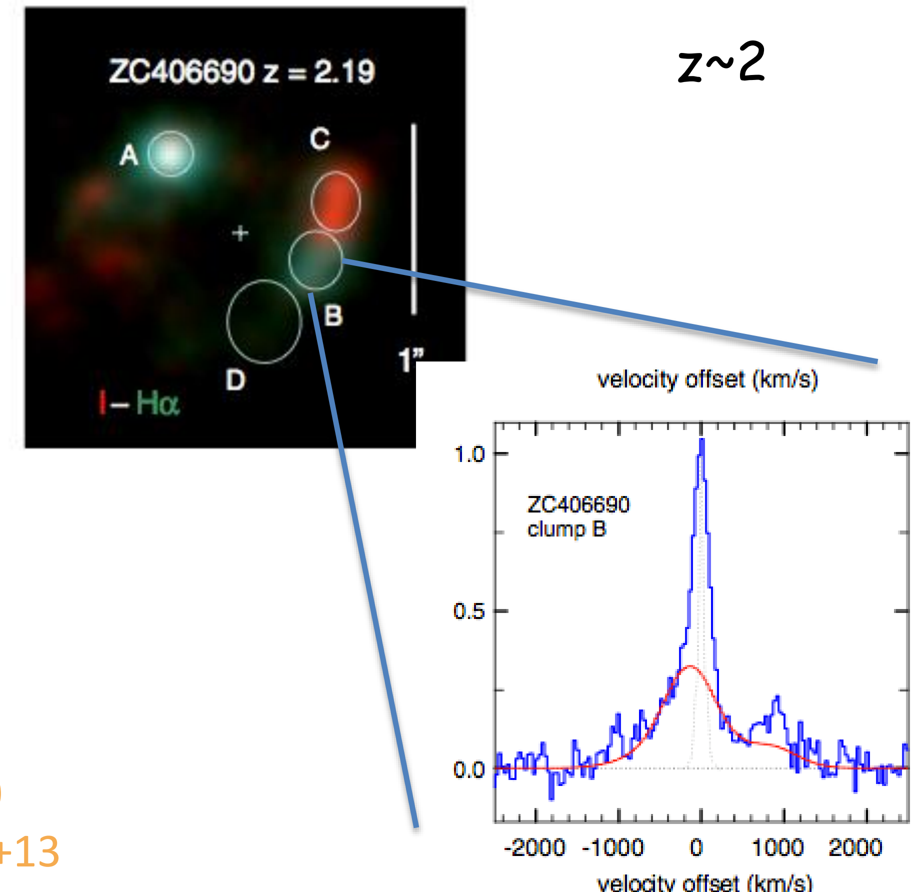
Yet, bulk of the action must occur at high redshift

Absorption spectroscopy
(stacked spectra
-> huge scope for improvement with **E-ELT**)



Steidel+10
Bradshaw+13
Diamond-Stanic+12

3D resolved emission line spectroscopy
(-> large improvement in sensitivity
and resolution with **E-ELT**)

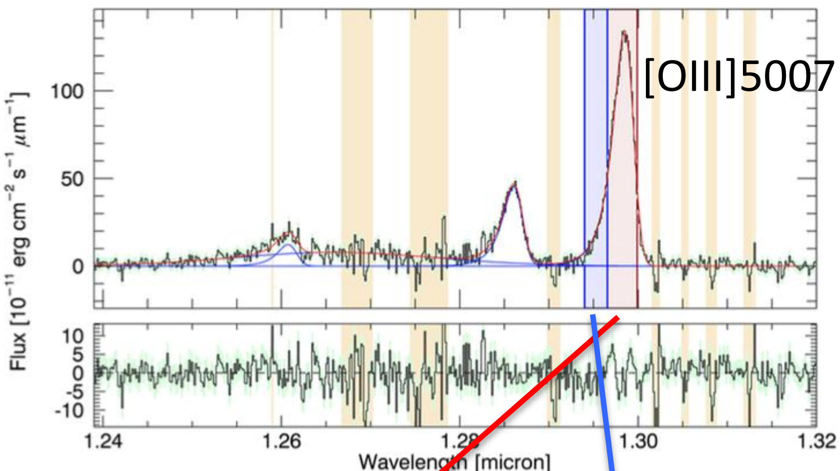


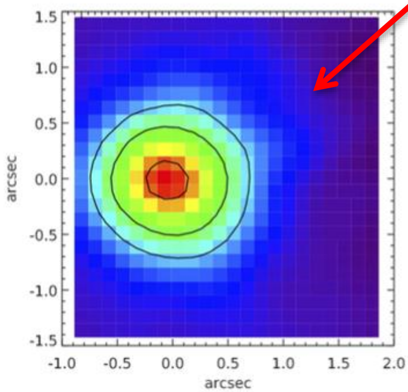
Genzel+12

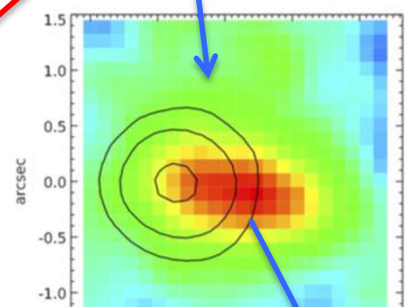
However, these only probe the ionized phase...
the molecular+atomic neutral phases can be much more massive

Quasar/AGN-driven outflows at high-z

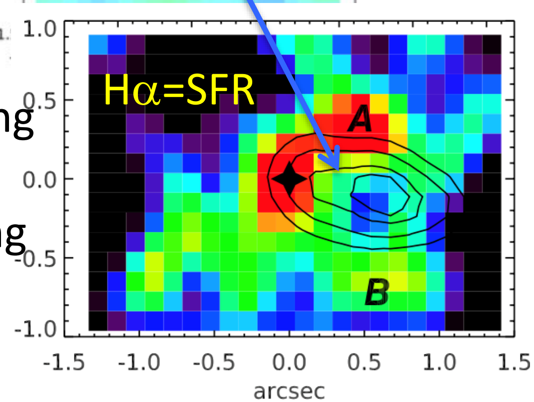
Ionized phase (SINFONI) z~2





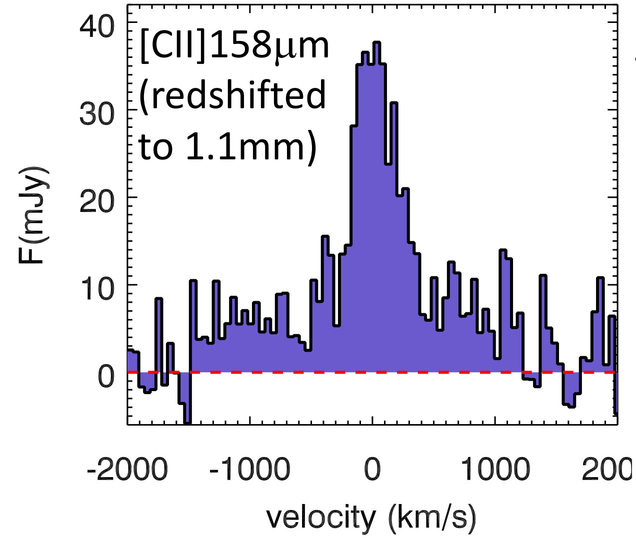


quenching
&
triggering
SF



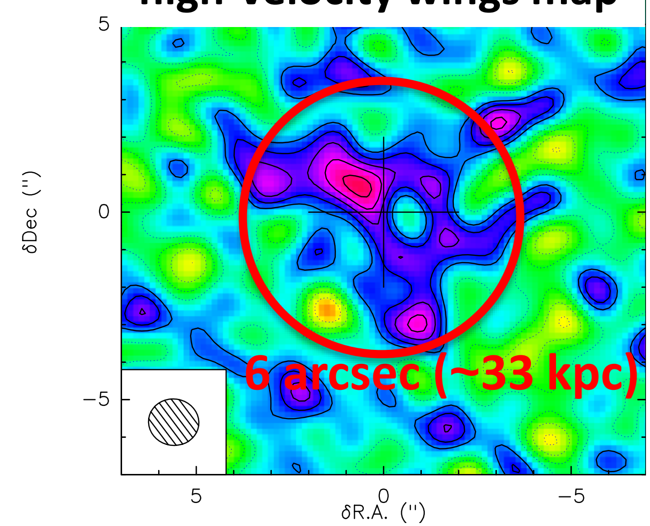
Cresci+14
Genzel+14
Cano-Diaz+12
Alexander+08

Cold phase (IRAM, ALMA)



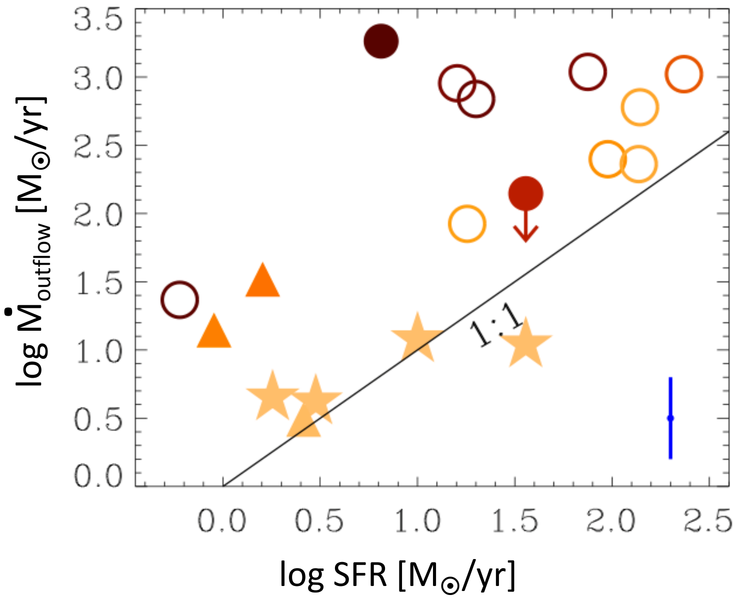
z=6.4

high-velocity wings map



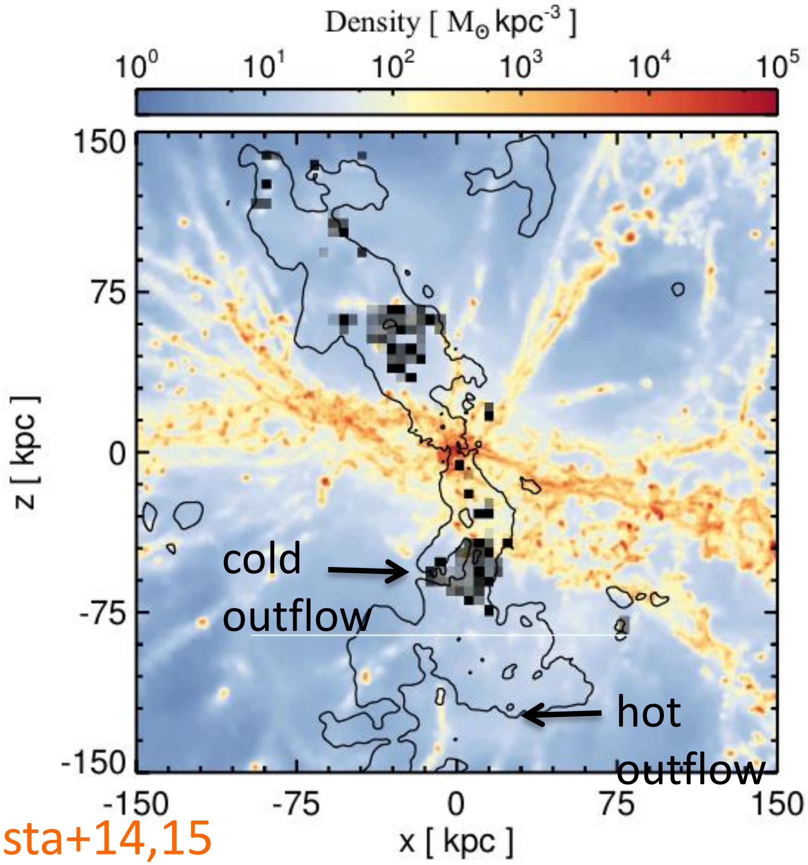
Cicone+14, Maiolino+12, Wagg+13

At high-z we are still far from having the statistics and the information (multi-transitions, multi-phase) available in local outflows...

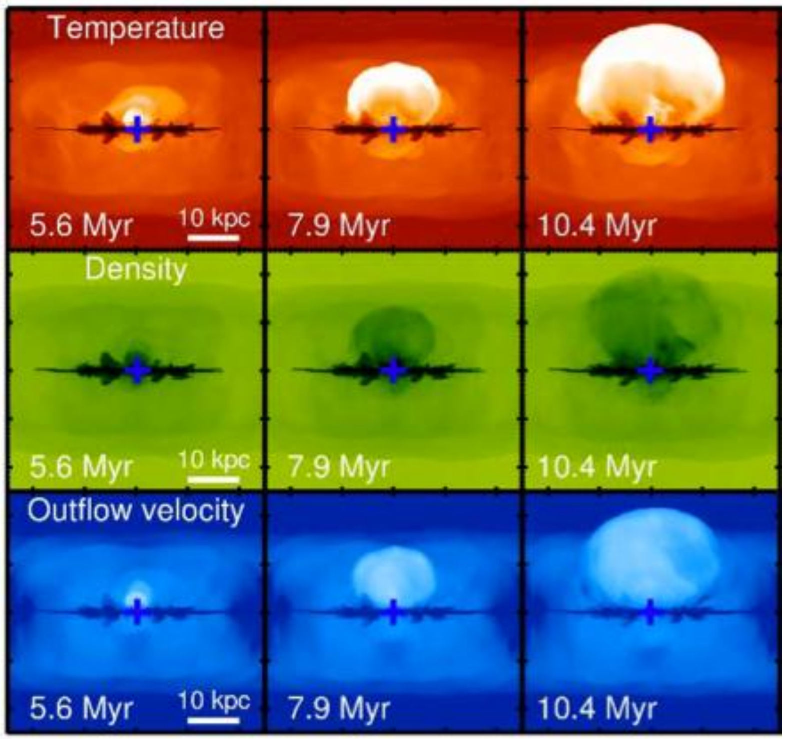


moreover...

Simulations: "effectiveness" of outflows is very low



Costa+14,15



Gabor+14

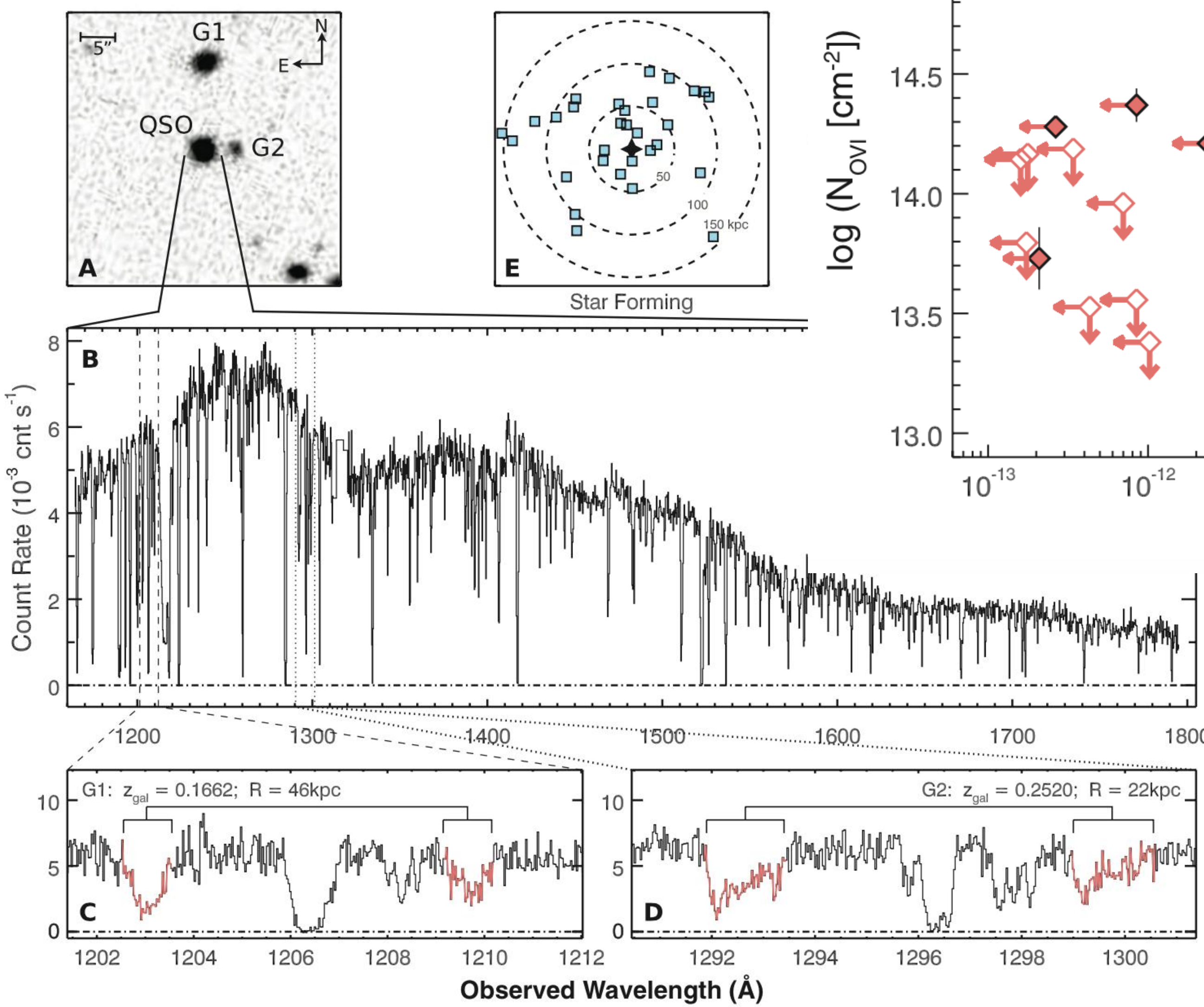
- **Most of the gas escapes through low density, least resistance regions**
- **Does not stop inflow along dense filaments**
- **Most of the gas rains back onto the galaxy**

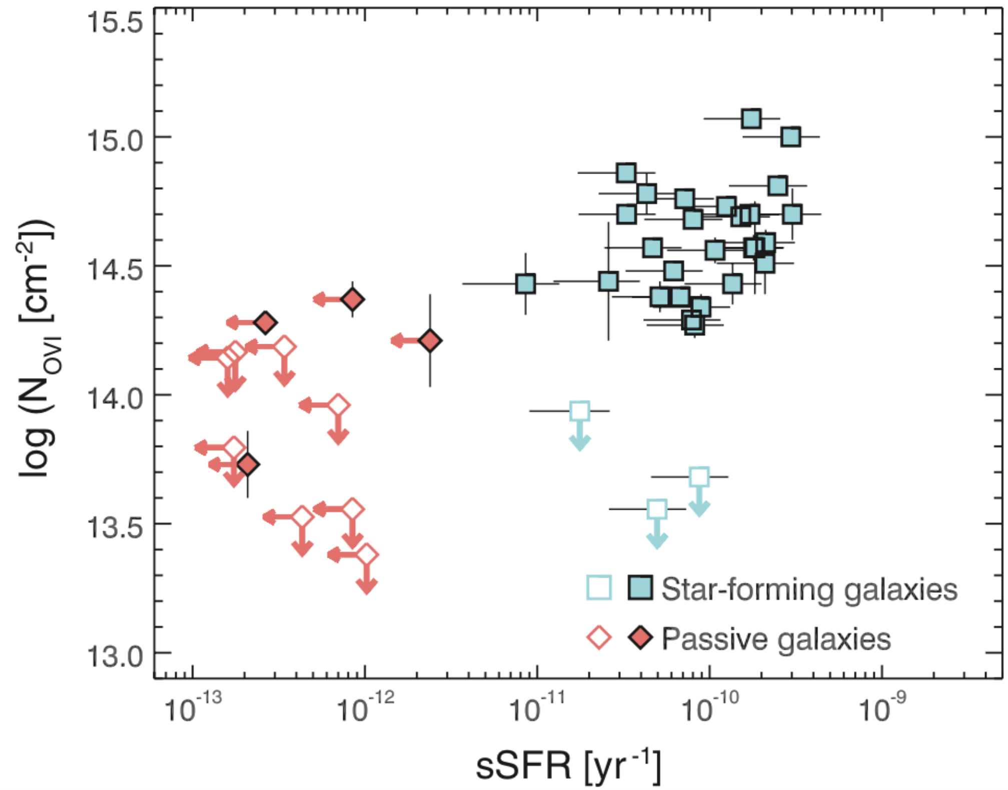
-> Outflows help regulating SF, but may not be capable of really quenching SF...

Need to investigate outflows at very large radii (ALMA+abs. spec.)

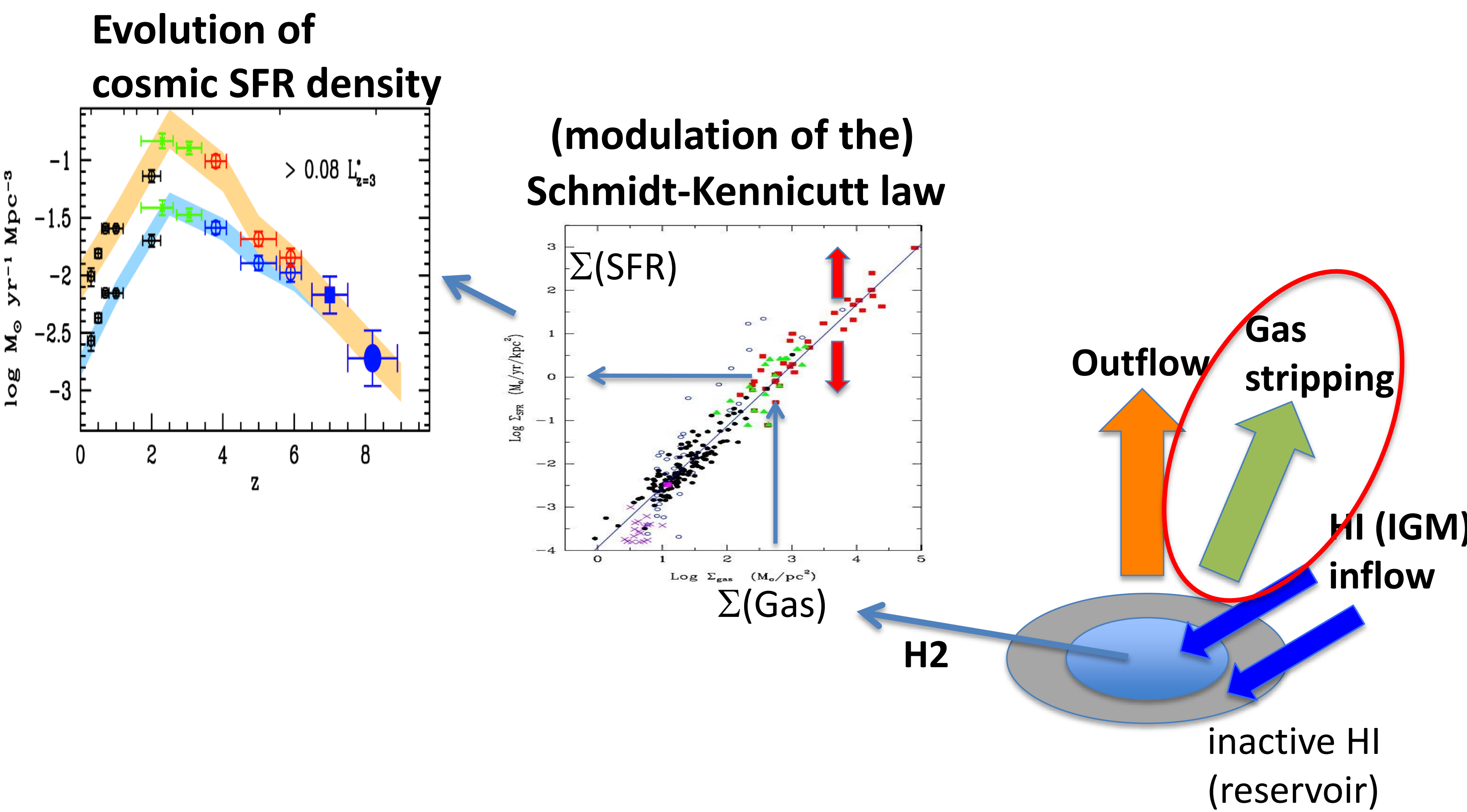
Probing outflow effects at large radii (~150kpc) through absorption spectrosc.

Tumlinson+11
Bouche'+14





With the E-ELT the same test can be performed at high redshift by accessing multiple lines of sights...



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Σ(Gas)
H2
Outflow
Gas
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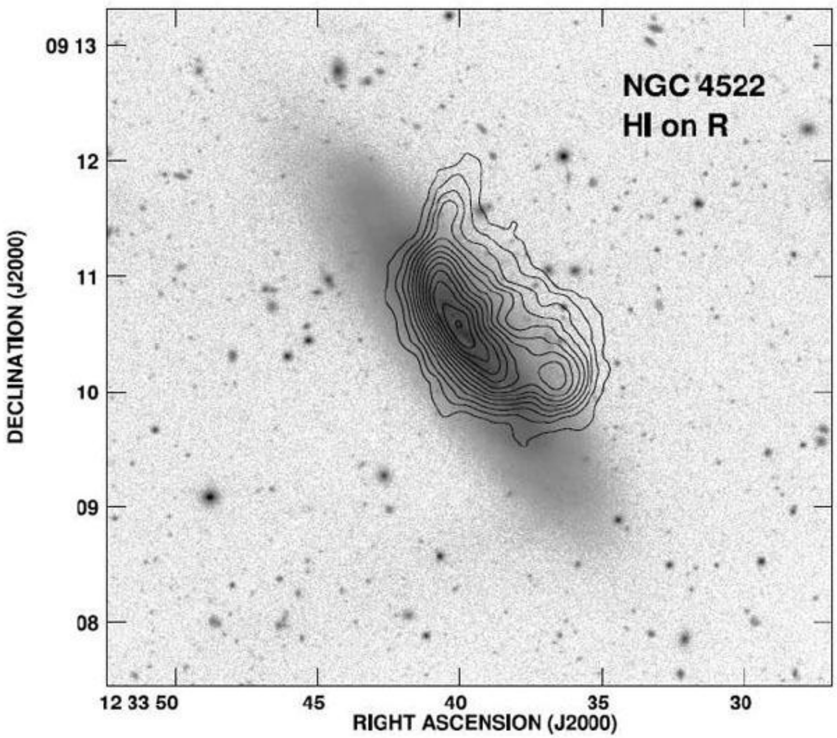
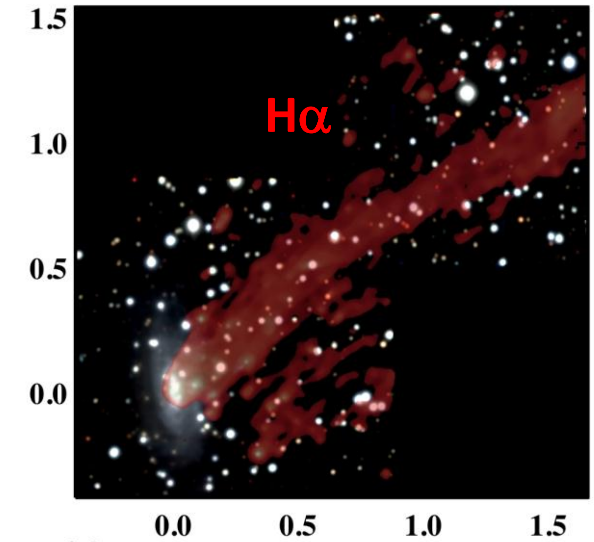
HI (IGM)
inflow
inactive HI
(reservoir)

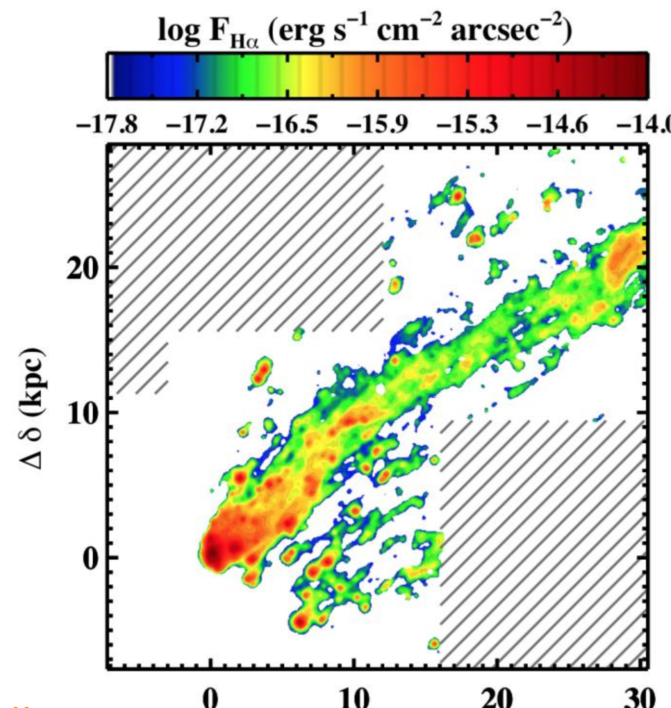
Gas removal by ram pressure: galaxies plunging into hot halos

HI 21 cm



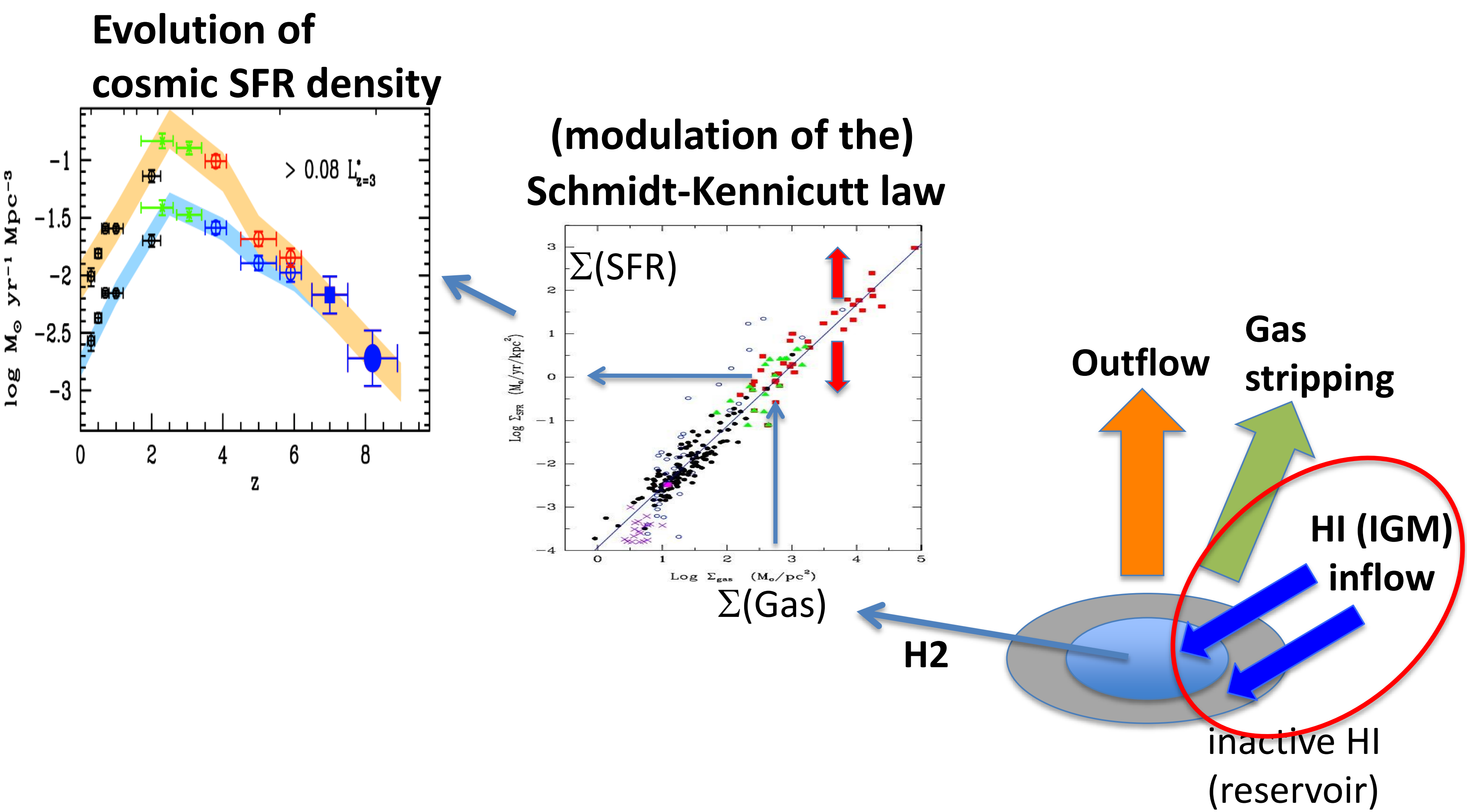
MUSE @ VLT





SKA in phase 2 can probe this out to z~0.5-1 (which is the crucial redshift range for this effect)

Fumagalli+14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Σ(Gas)
H2
Outflow
Gas
stripping
HI (IGM)
inflow
inactive HI
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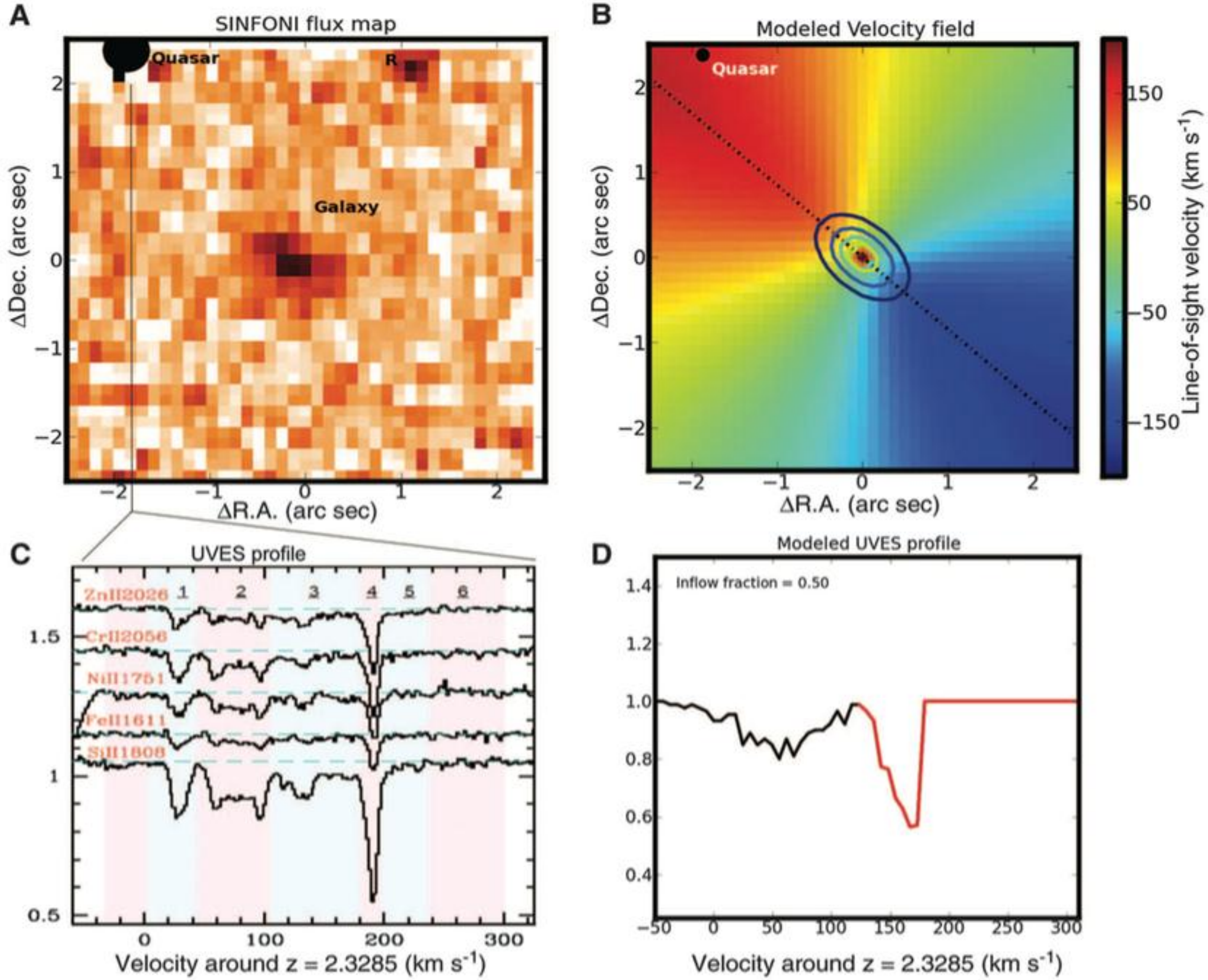
Gas inflows: very difficult to probe observationally

Absorption spectroscopy:

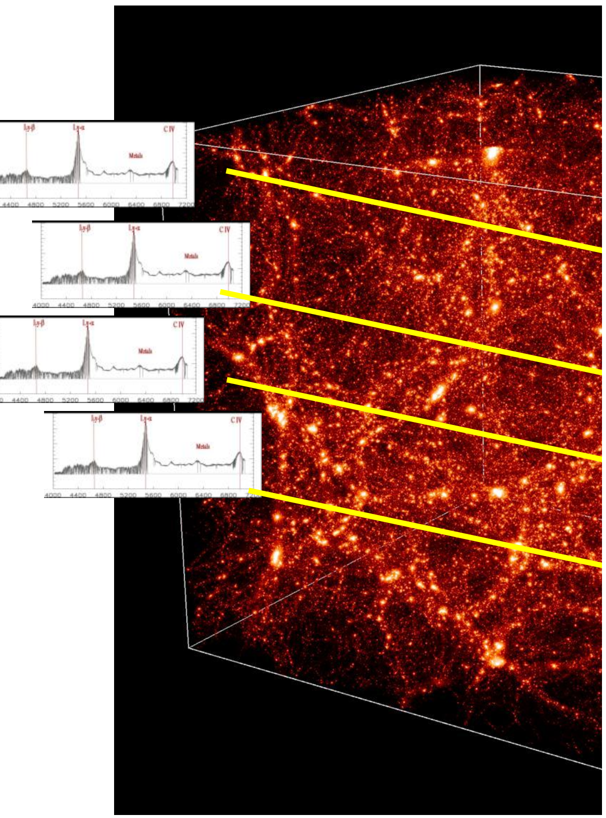
small cross section of accreting medium

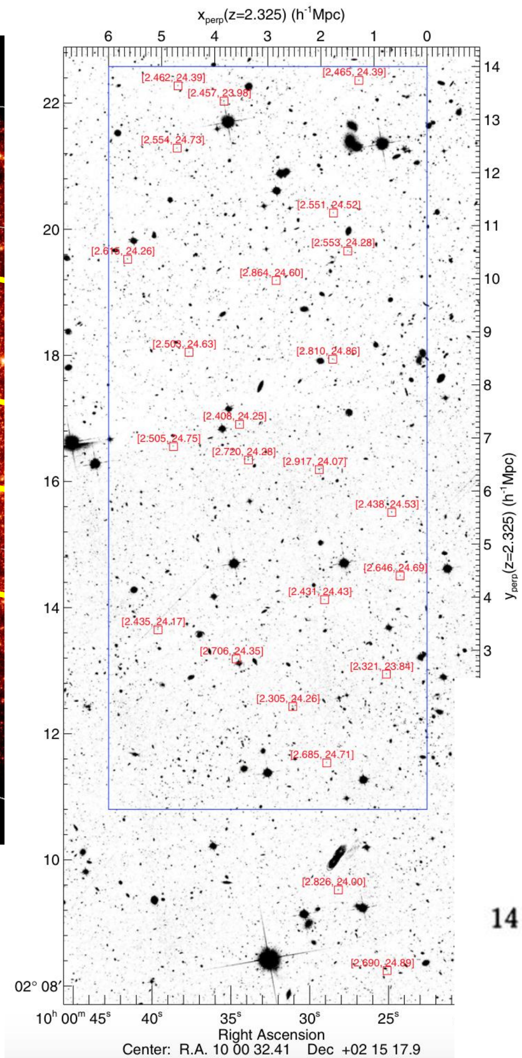


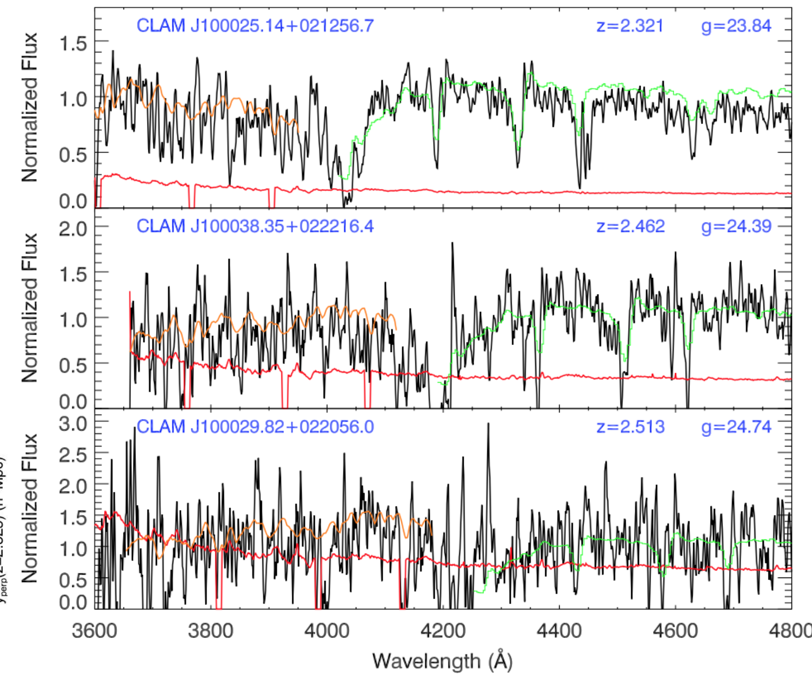
Bouche'+13
Giavalisco+13

IGM tomography: probe Lyα forest through multiple lines of sights by using galaxies as background sources

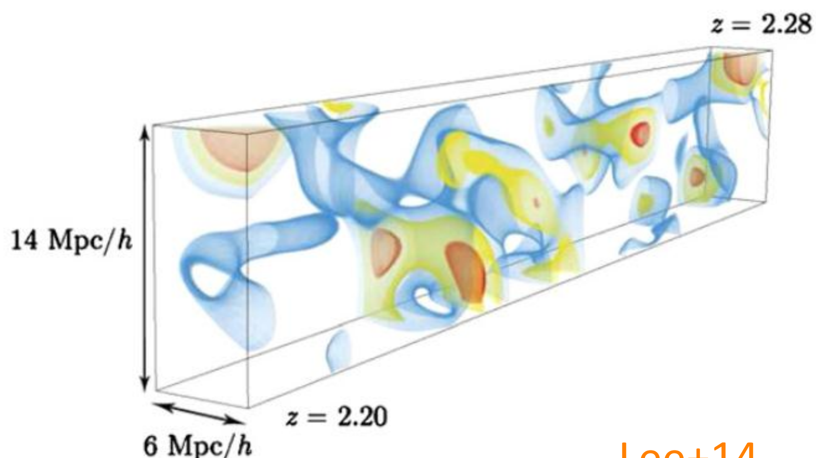
-> mapping baryons in cosmic (accreting) filaments







First results with Keck!



Great expectations for E-ELT MOS!

Lee+14

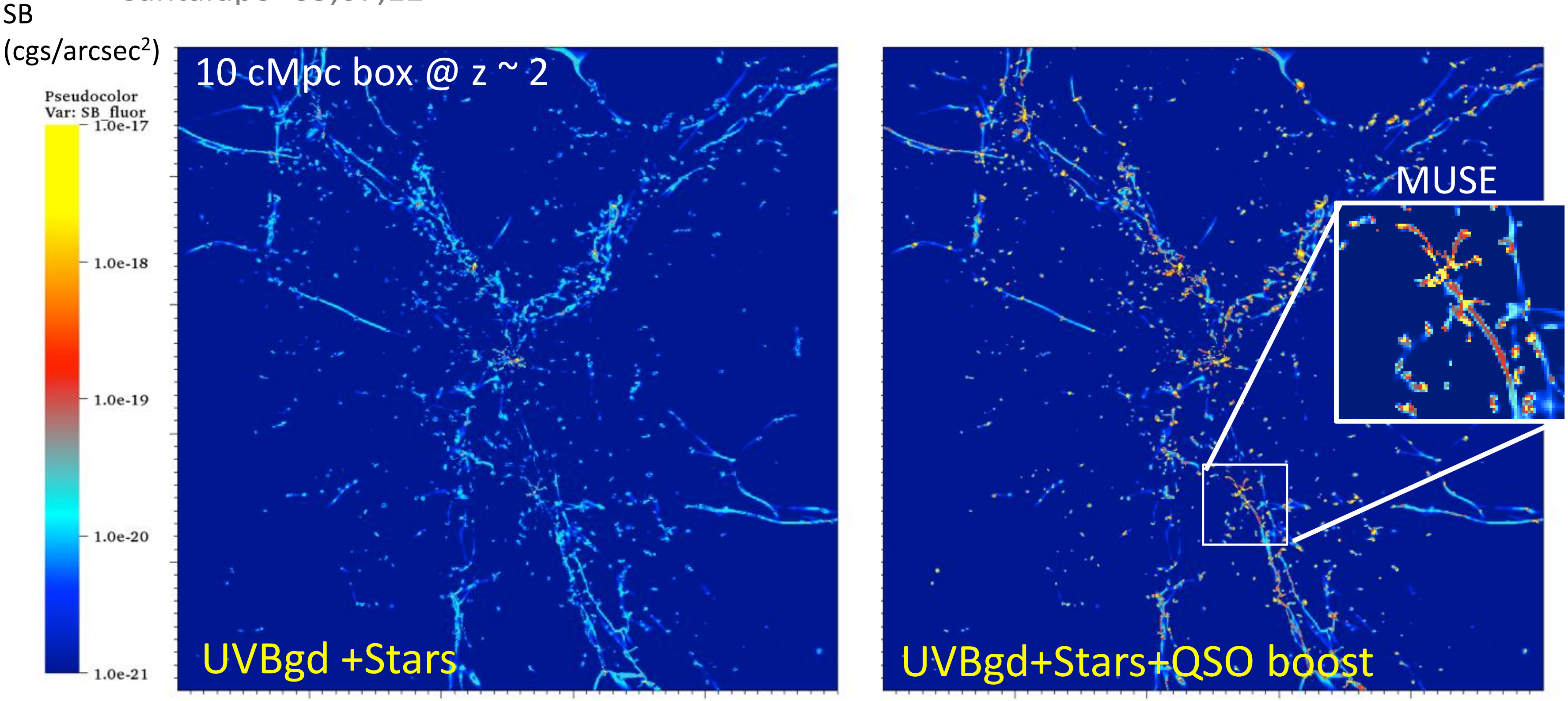
Can we see the cosmic web and feeding filaments in emission?

- Self-shielded neutral gas fluoresces when illuminated by the UV background (in principle every ionizing photon produces ~ 0.6 Lyα photon)

  Hogan & Weymann 1987; Gould & Weinberg 1996; Zheng & Miralda-Escude 2005; Cantalupo+05,07; Kollmeier+08, Cantalupo+12

- Extra illumination by a nearby quasar shrinks self-shielded region but boosts surface brightness over region > 10 Mpc

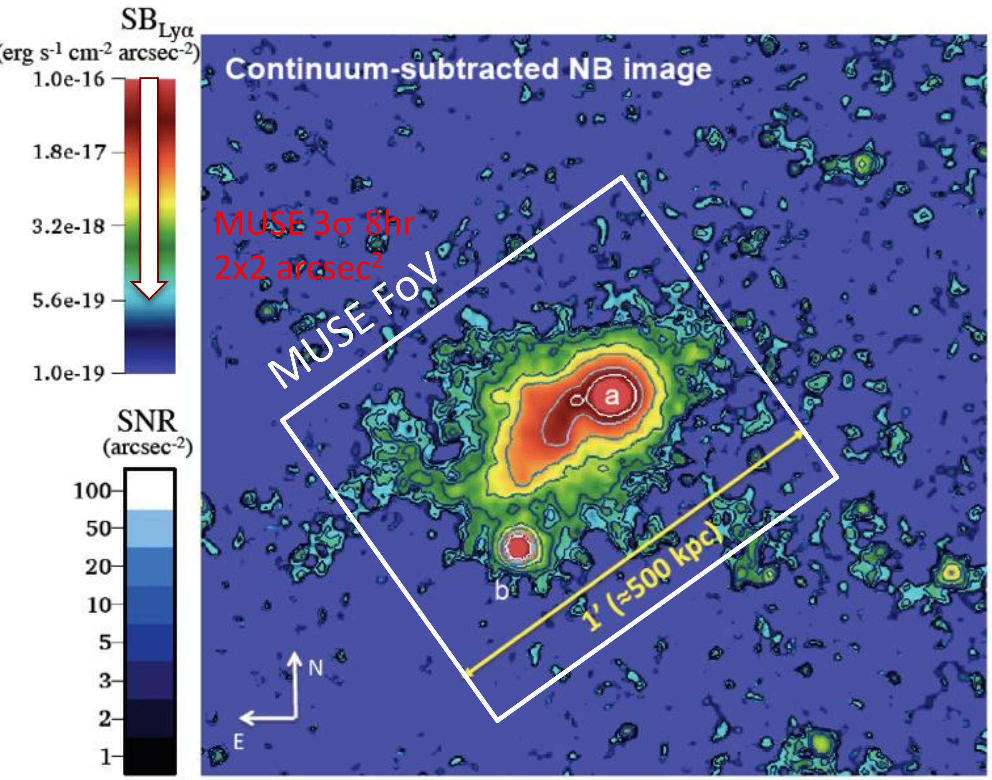
  Cantalupo+05,07,12



from Cantalupo et al 2012

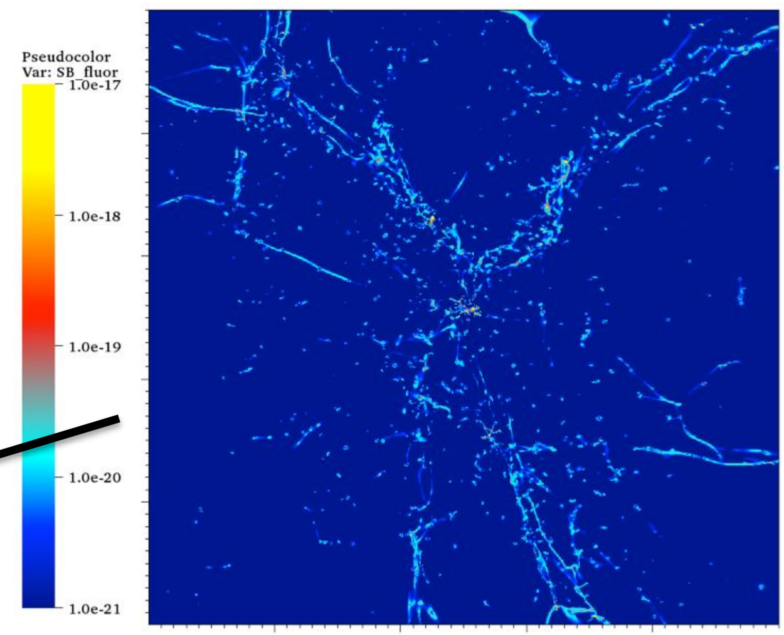
Borrowed from Lilly @ ESO-3D conf.

Detecting Lyα from high-z feeding filaments illuminated by QSO, within reach of MUSE



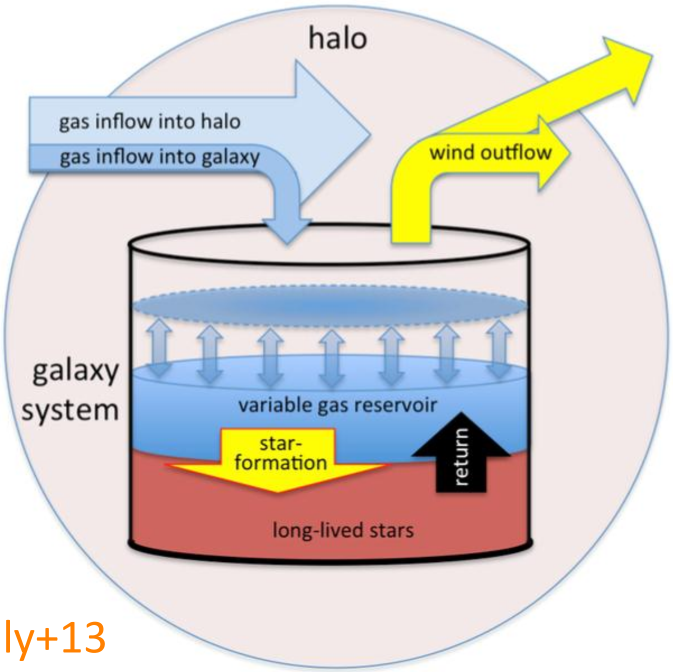
Cantalupo+14

Full mapping of Lyα filaments illuminated by UV-background...
...~unfeasible/at the verge for MUSE



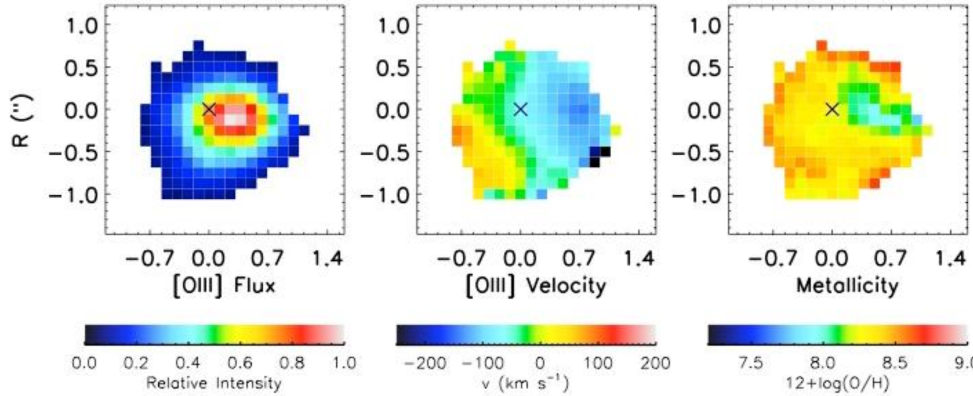
MUSE-like instrument at E-ELT?

Indirect tracers of inflows: metallicity dilution



Lilly+13
Dekel+13
Peng & Maiolino '14

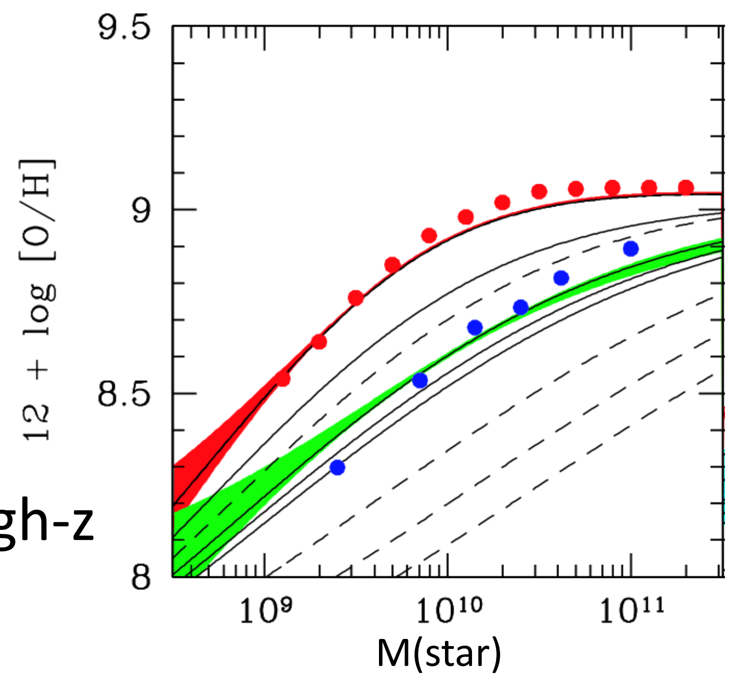
Metallicity gradients at high-z (KMOS)



Cresci+10, Troncoso+14

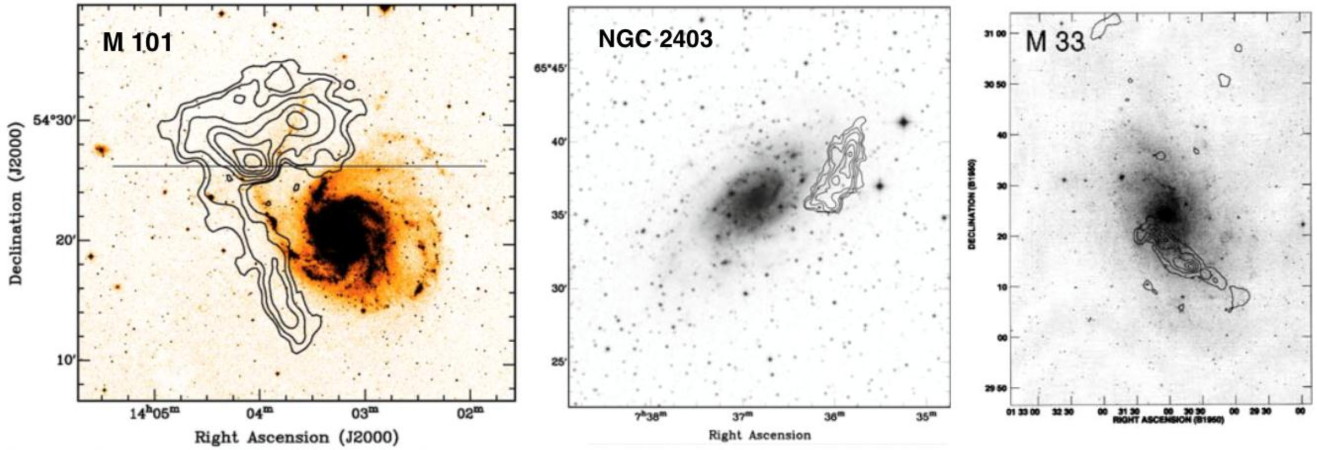
Evolution of the mass-metallicity-SFR scaling relations

SDSS-like survey at high-z
-> MOONS @ VLT



Direct HI imaging of accreting gas

Local Universe



van der Hulst+88, Fraternali+02, Sancisi+08

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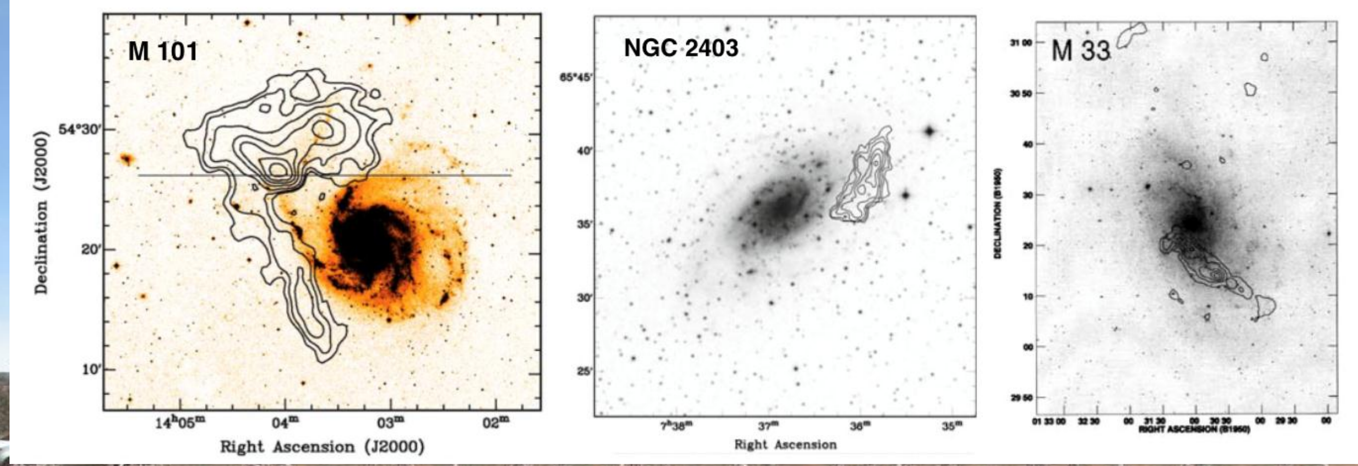
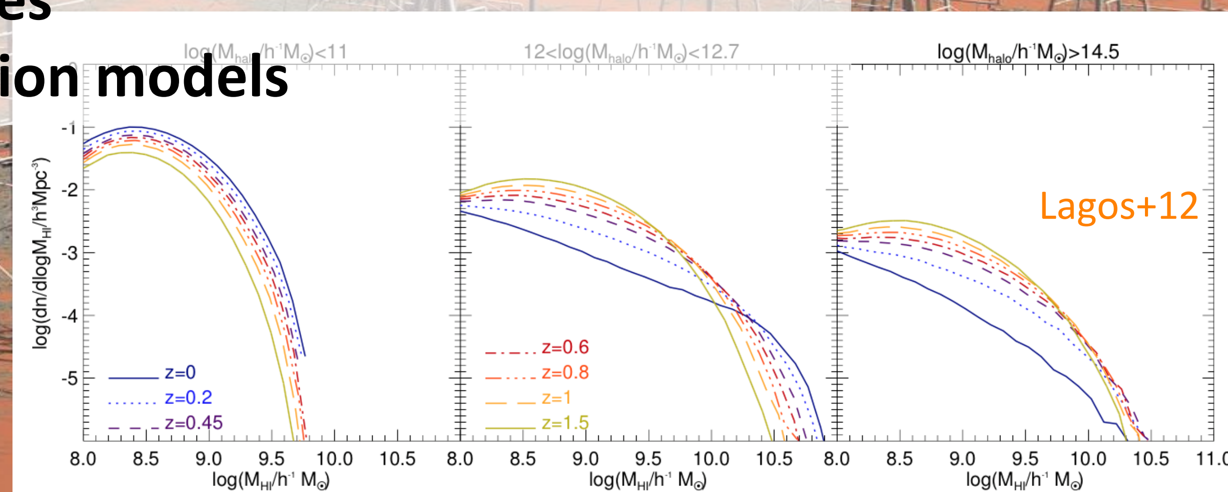
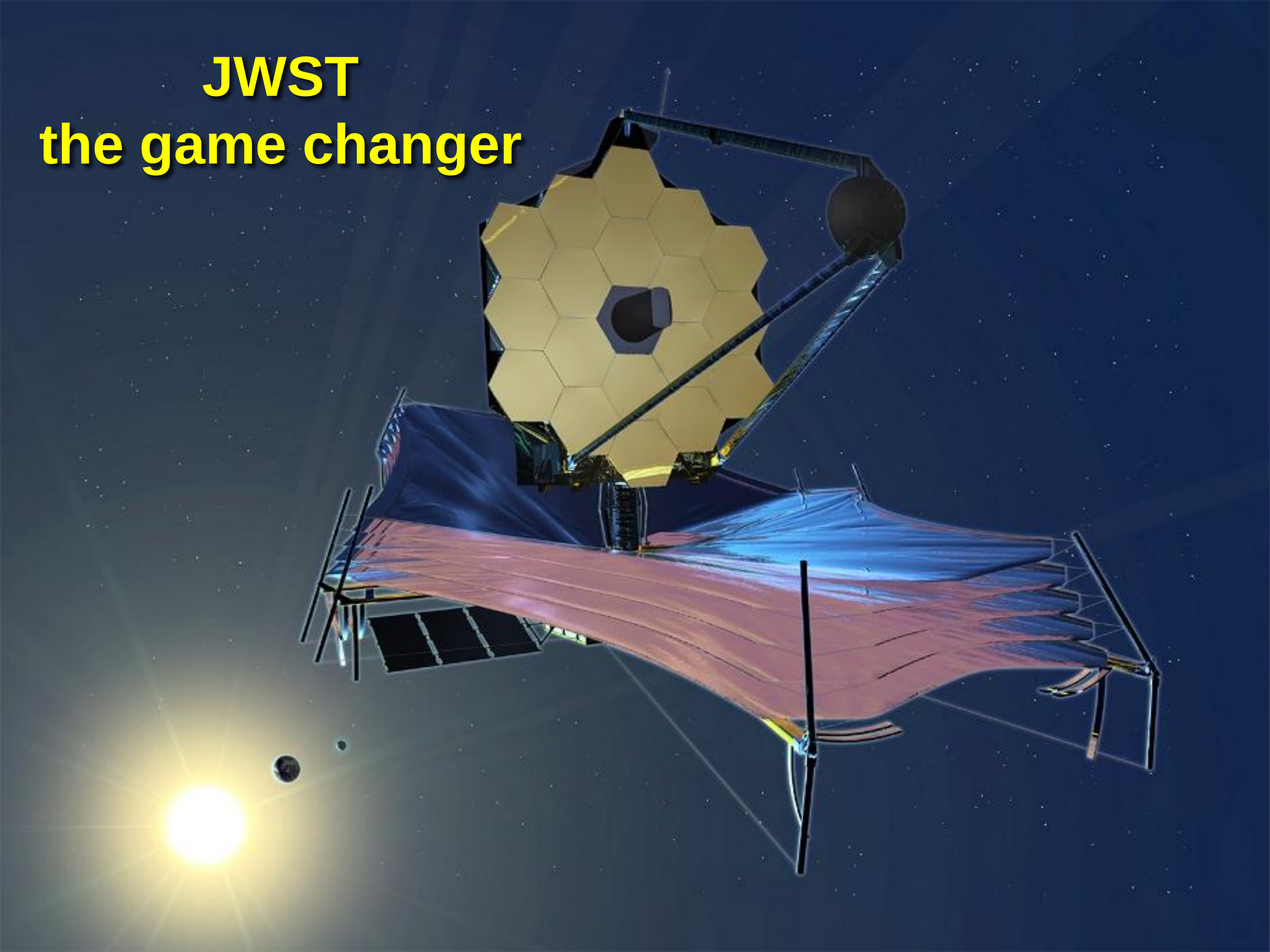


van der Hulst+88, Fraternali+02, Sancisi+08

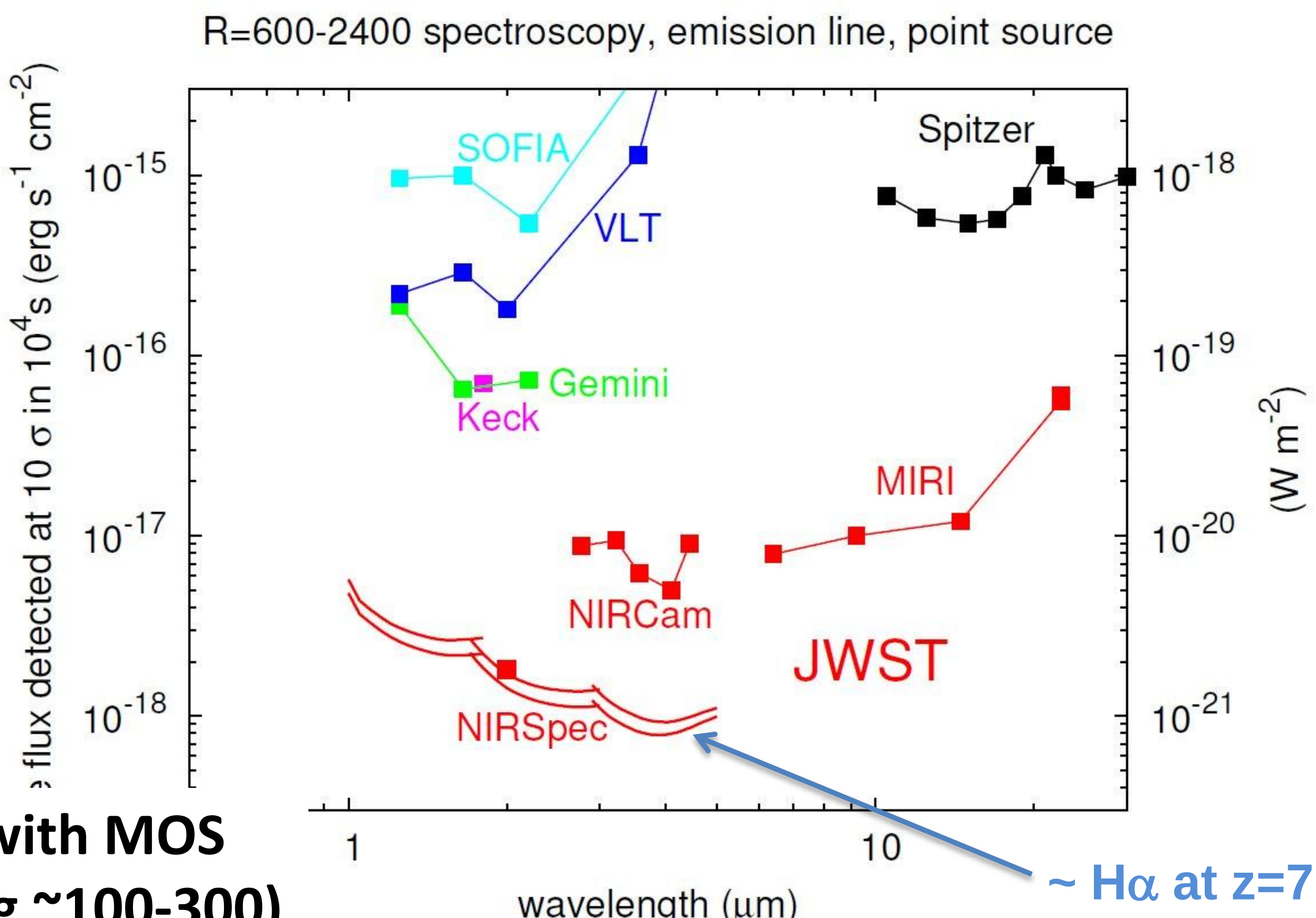
SKA will allow us to directly probe accreting gas at intermediate redshift (z~0.3-0.5)

At higher redshift, z~1-2 SKA will be able to probe the HI content in M_* galaxies
-> crucial test to accretion models




JWST
the game changer

JWST spectroscopy: jump by ~ 2-3 orders of magnitude in em. line sensitivity (!!!)



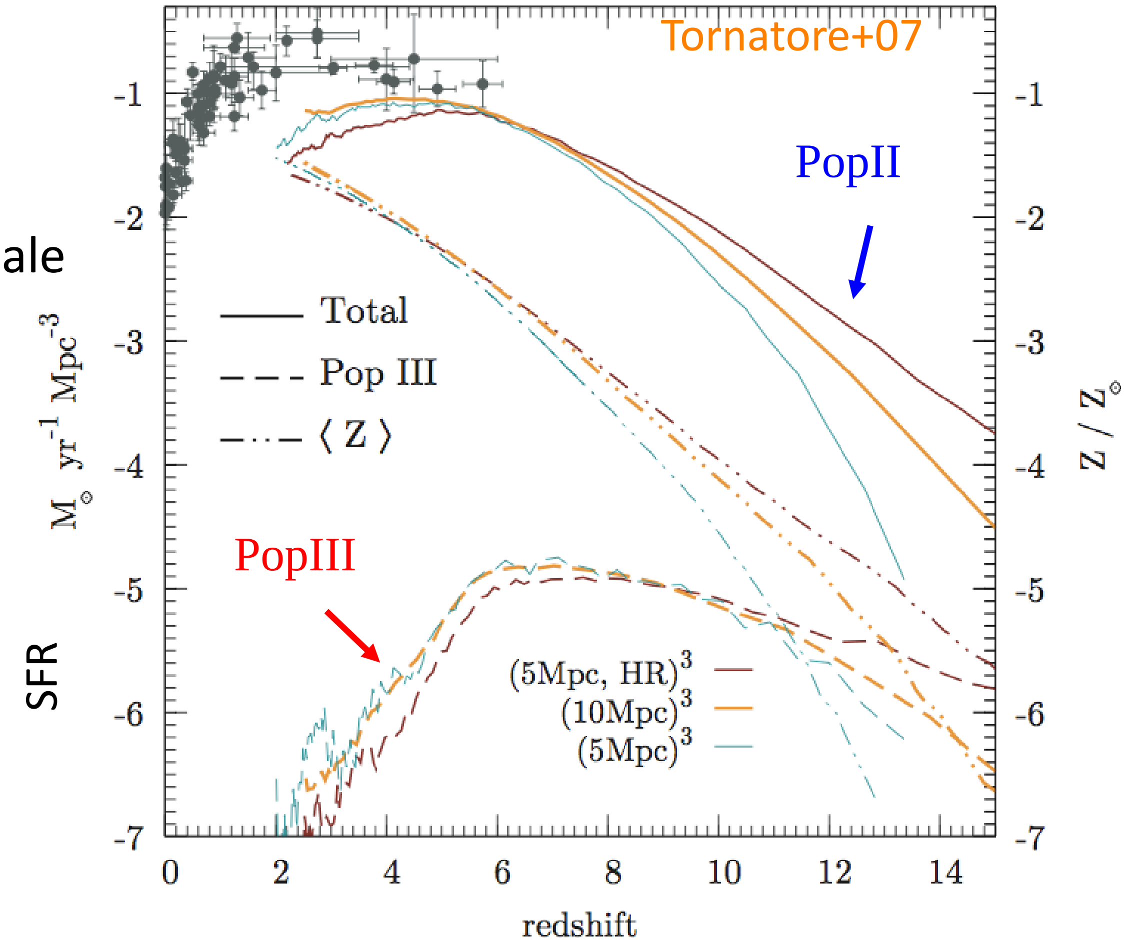
This comes with MOS (multiplexing ~100-300) and IFU capabilities

~ Hα at z=7 with SFR ~ 1 $M_\odot$/yr
(shallow exposure)

Do not even think about "competing"
-> "Exploit" and complement JWST -> go for high angular and high spectral resolution

PopIII identification

JWST will struggle to detect the signatures of PopIII,
because of their very short timescale and very quick ISM pollution



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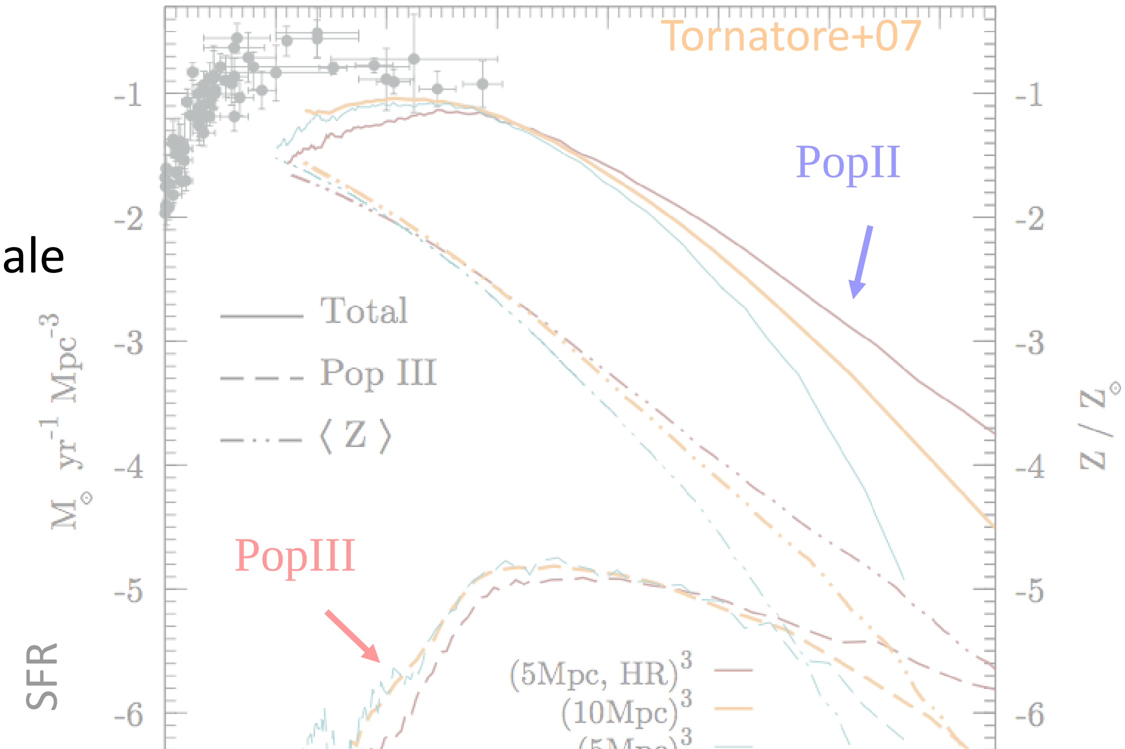
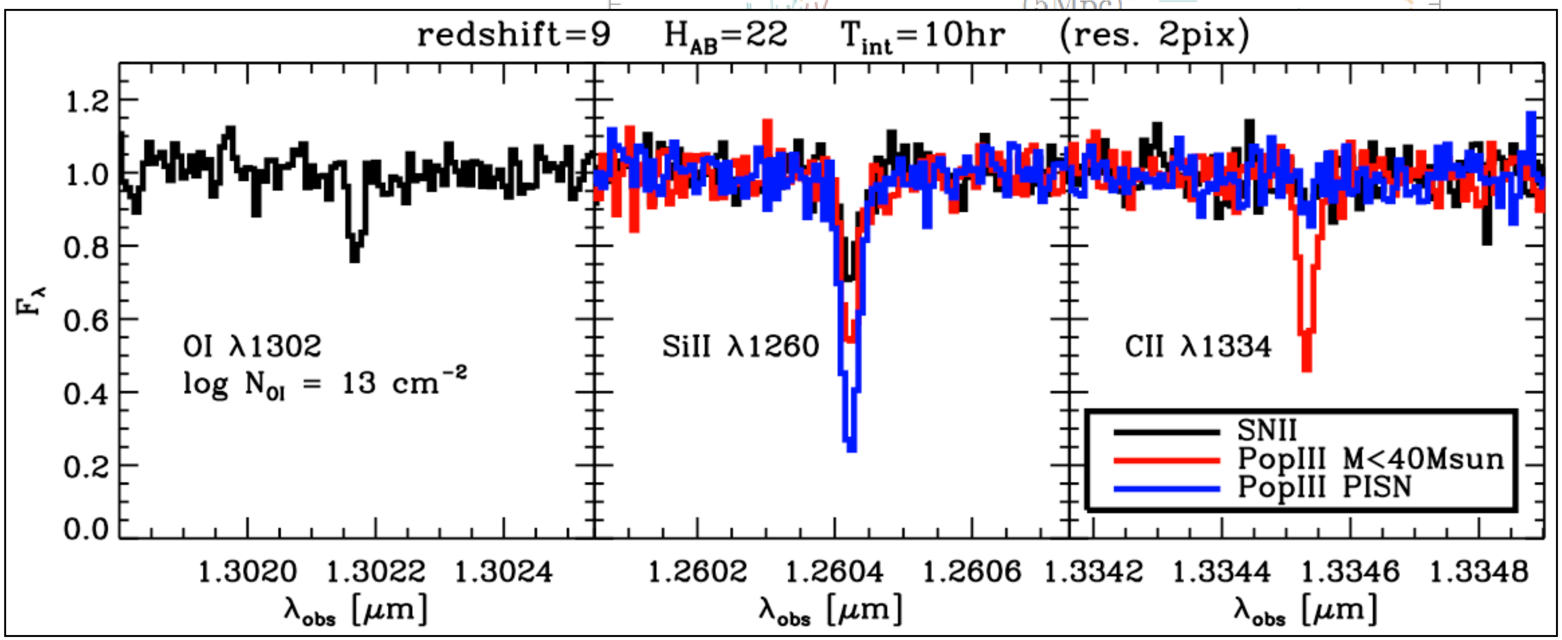


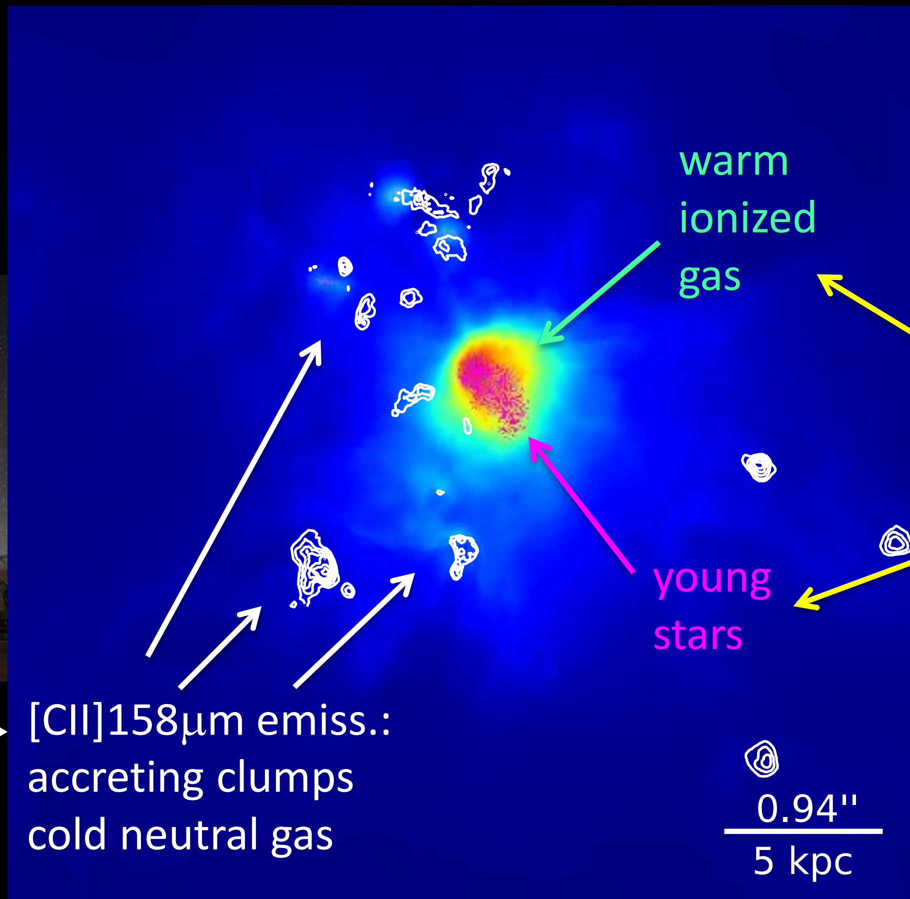
E-ELT + HIRES can detect the signatures of PopIII SNe in the high-z ISM and IGM



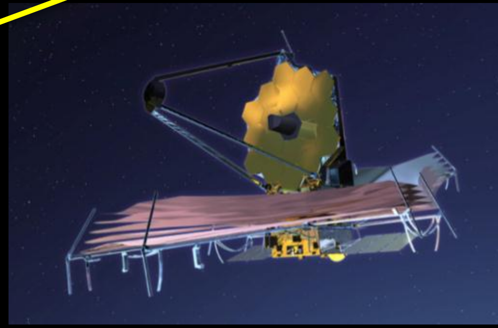
Simulation of a primordial galaxy at z=7

(Vallini et al. 2014)

ALMA →

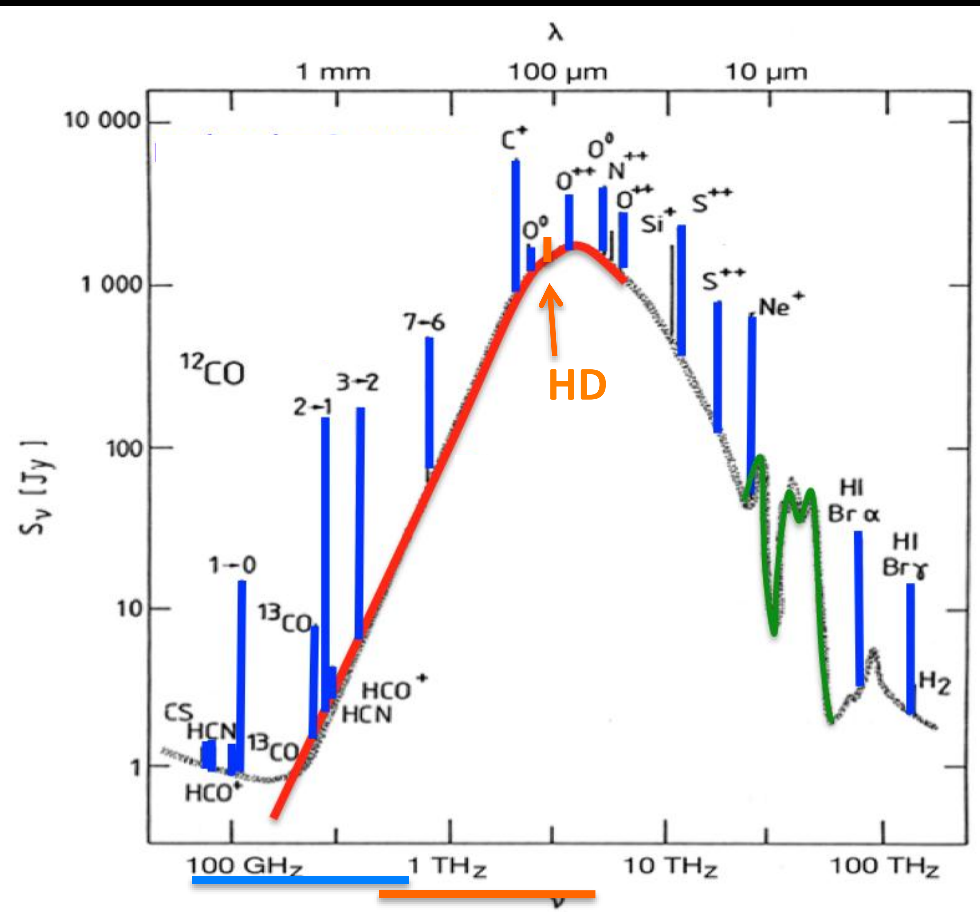


JWST



What about proving molecular gas in these early metal-ppoor systems?

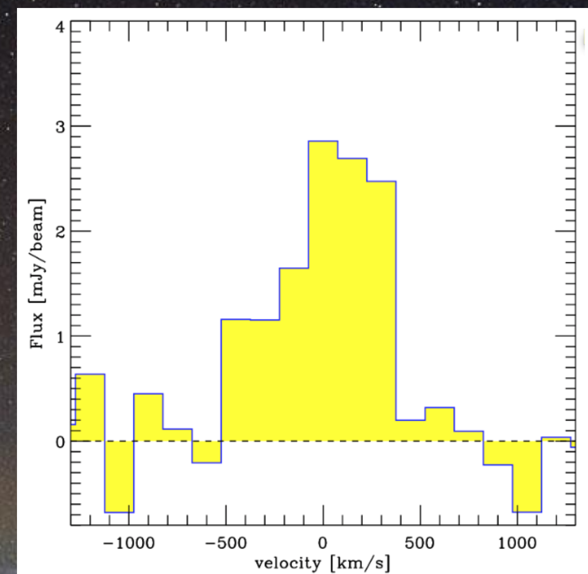
Molecular gas in the early universe in metal poor systems...



ALMA range (local)

ALMA range (z=6)

HD 112μm metallicity-independent tracer of molecular gas



Simulated spectrum SMG @ z=6
ALMA 1h, 35 antennae

Test ongoing in Cycle 2
-> Possible tracer also at low-z (bands 9-10...11)

2020’s, personal (ambitious) wish list (not sorted by priority):

- E-ELT: MOS
- E-ELT: HIRES
- E-ELT: “MUSE”
- ALMA: more antennae (double)
- CCAT? (Only if equipped with large format, broad-band on-chip spectrometer array)
- SKA: phase 2
- A new car

Thank you!