Powerful quasar feedback in local and very distant galaxies

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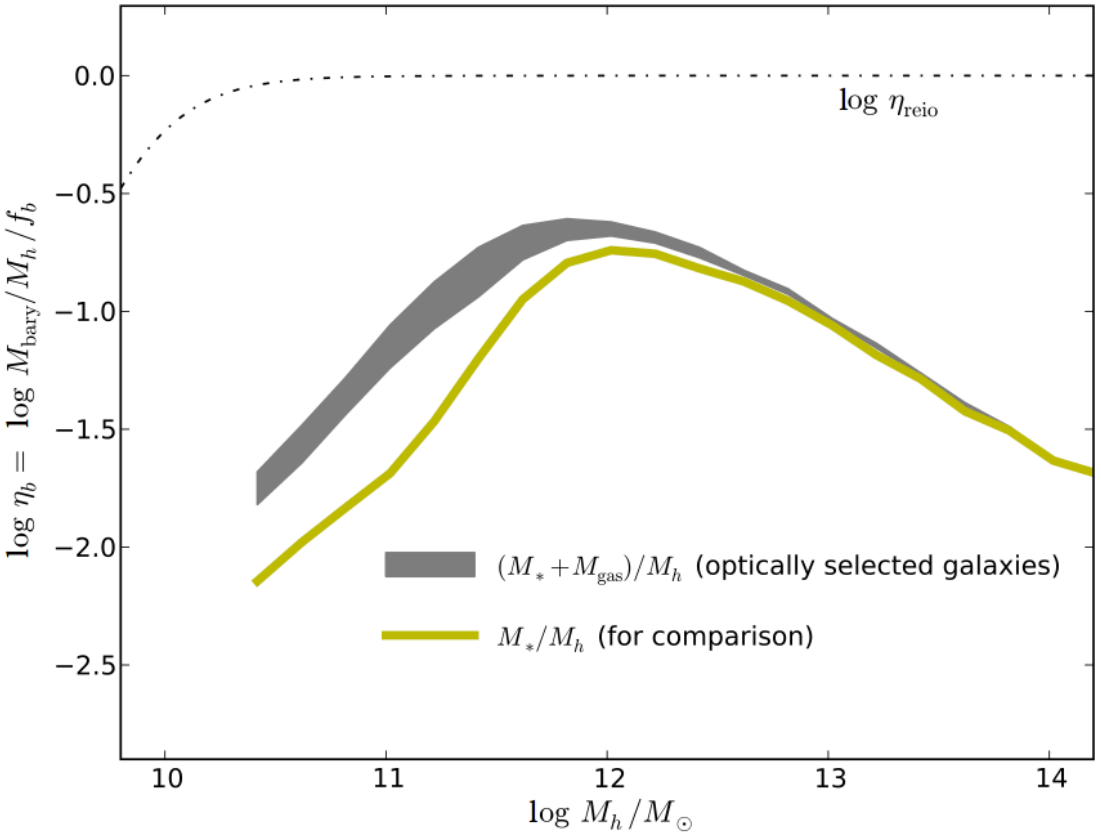
Photo by ESO Photo Ambassador Babak A. Tafreshi, “ALMA’s Solitude”

M_{baryon}-M_{halo} relation



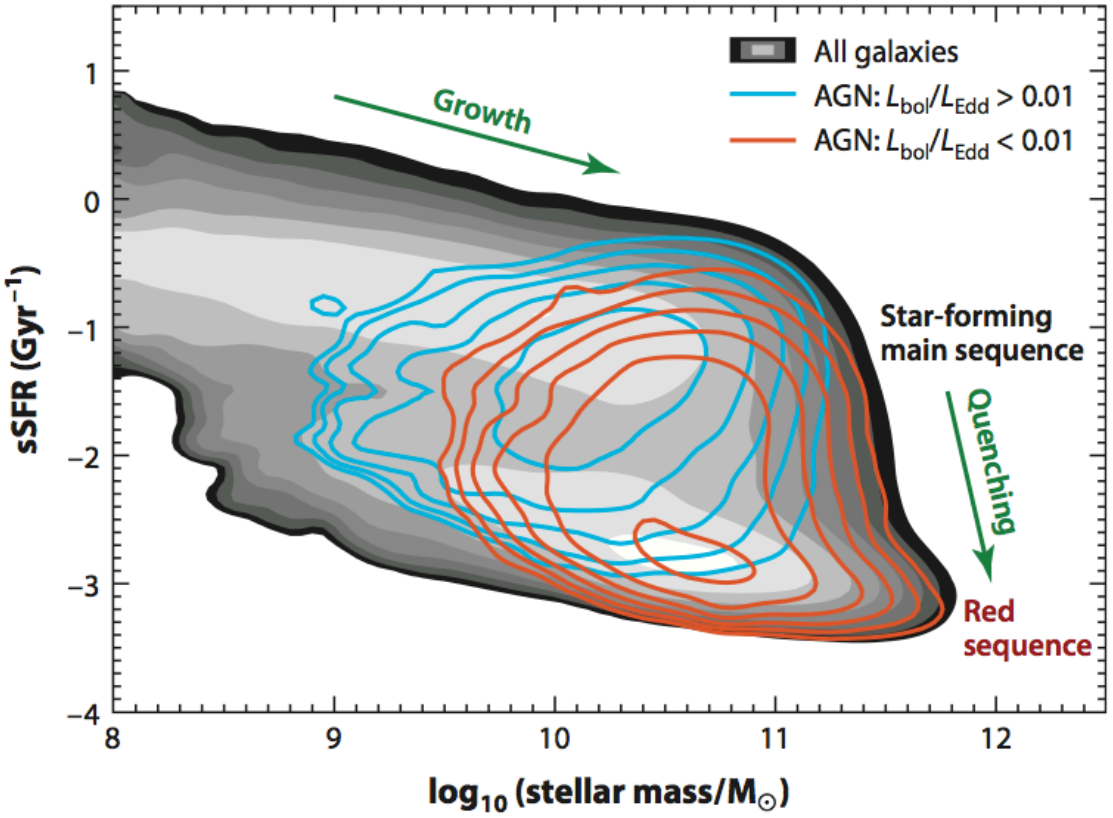
Only small portion of cosmic baryonic budget resides in galaxies

Distribution of baryons depends on (halo) mass in a complex way

Stellar feedback key at low masses, feedback from AGN needed in massive halos

Papastergis+12, Read & Trentham 05

Color bimodality



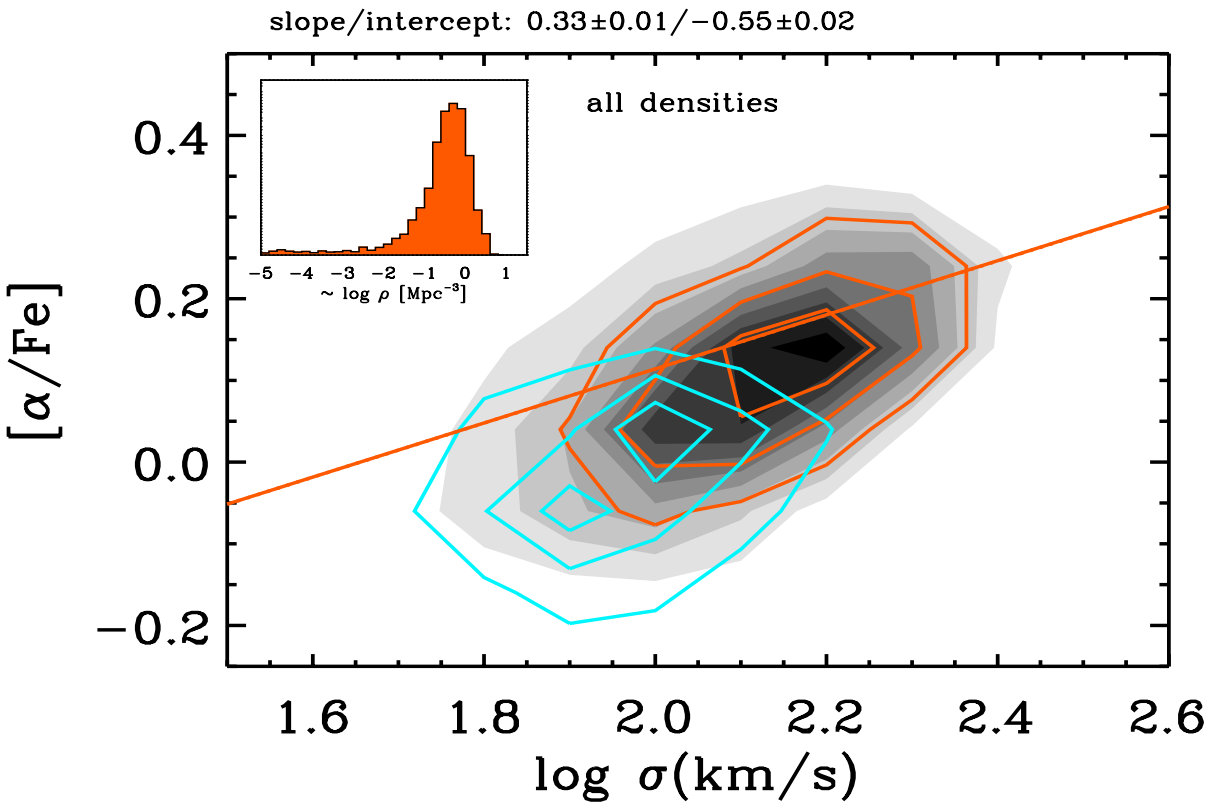
Most local galaxies either actively star forming or passive

What suppresses star formation in (massive) galaxies?

Passive galaxies detected also at z~2 (feedback at work since z~6)

Heckman+Best 2014, Schawinski+14, Wuyts+11, Peng+10, Baldry+04

α-enhancement of massive spheroids



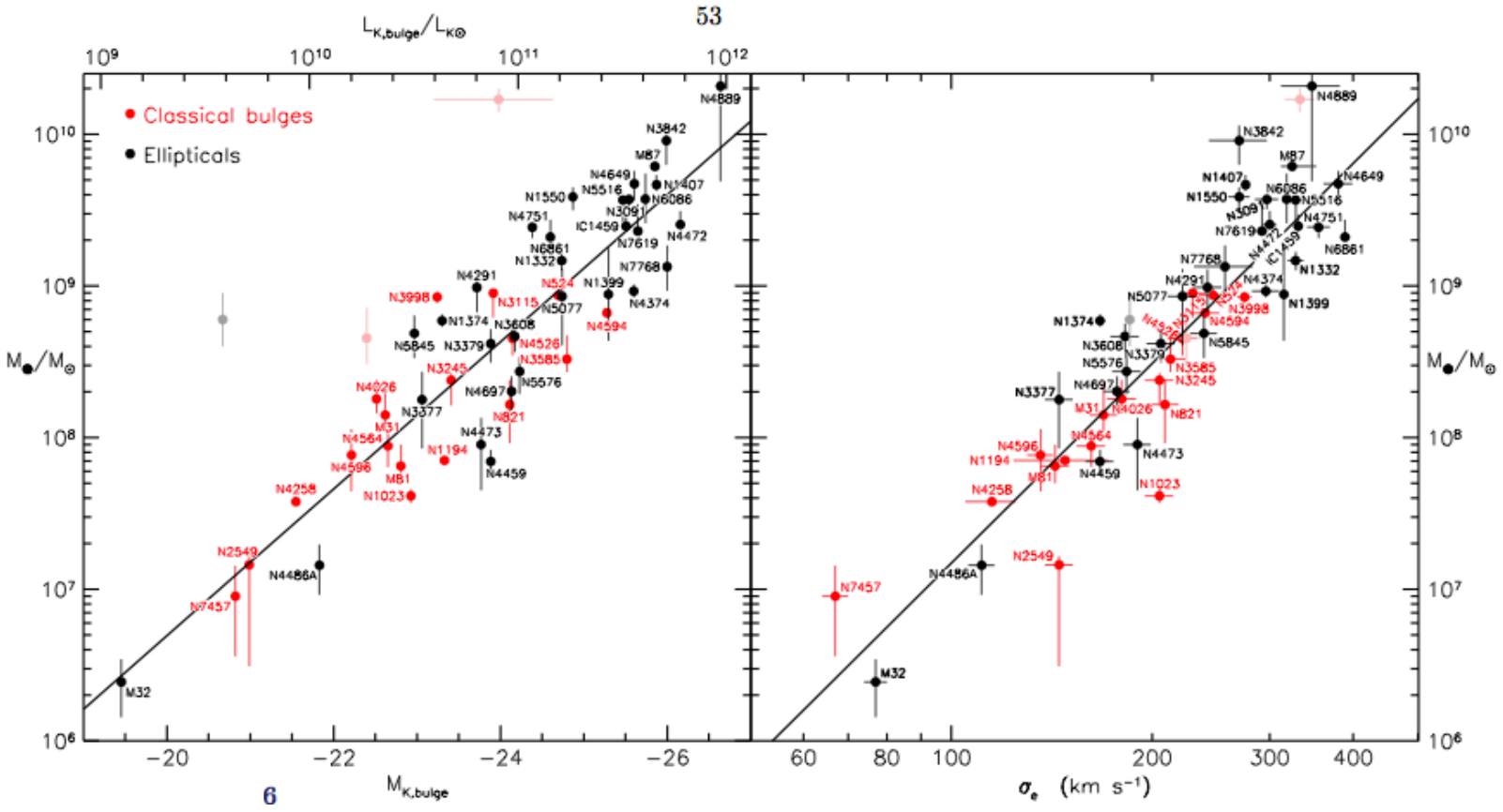
High stellar [α/Fe] in massive ellipticals

Bulk of stars must have formed before Type Ia SNe explosions (<1 Gyr, probably < 3 x 10^8 yr)

Rapid cessation of star formation (explosive feedback) provides a natural explanation

Thomas+10, Fontanot+09, Matteucci 94, Gargiulo+15

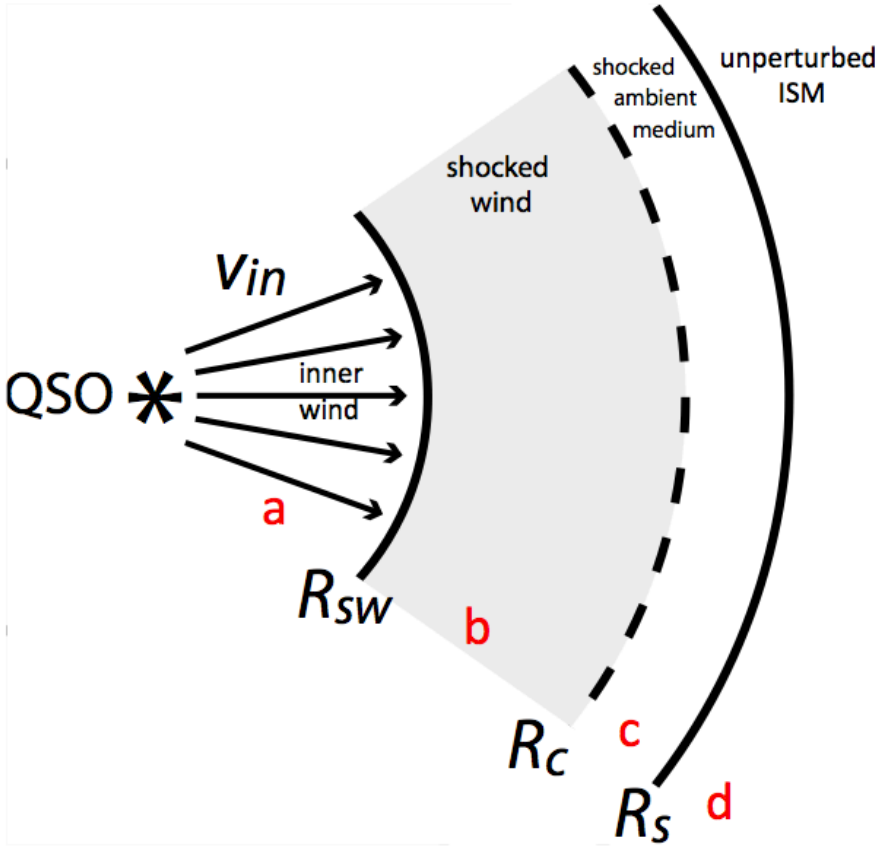
M_{BH}-σ_{stars} relation



Motivates hypothesis of a concomitant growth of AGN and ``classical'' bulges

Kormendy+Ho 2013 & refs therein

Quasar-mode (i.e. ejective) feedback?



Requires coupling of AGN radiation to host galaxy ISM

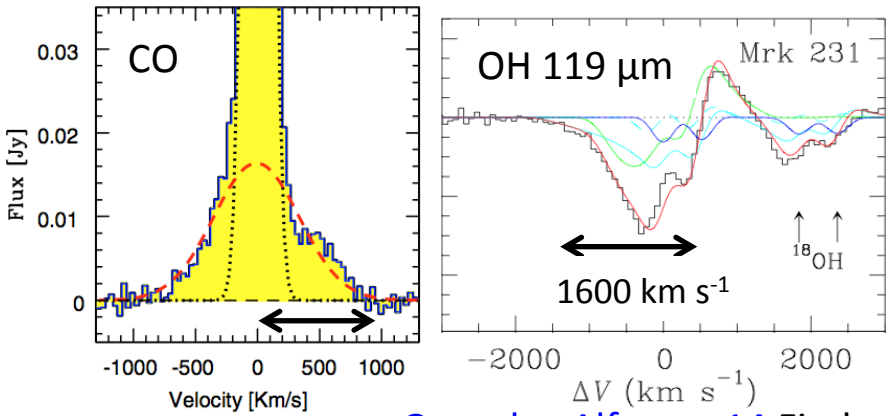
Best candidates are powerful, gas-rich quasars at high-z

Observational challenges:

- Intrinsically elusive nature of the sources (obscured, high-z)
- Physical scales of interest
- Transient phase, statistically rare to observe

Faucher-Giguere+Quataert 2012, Menci+06, King 2010, Zubovas+King12, Costa+14, Hopkins+Elvis 2010, Fabian 2012, Roth+12, Thompson+15

Massive molecular outflows at z~0

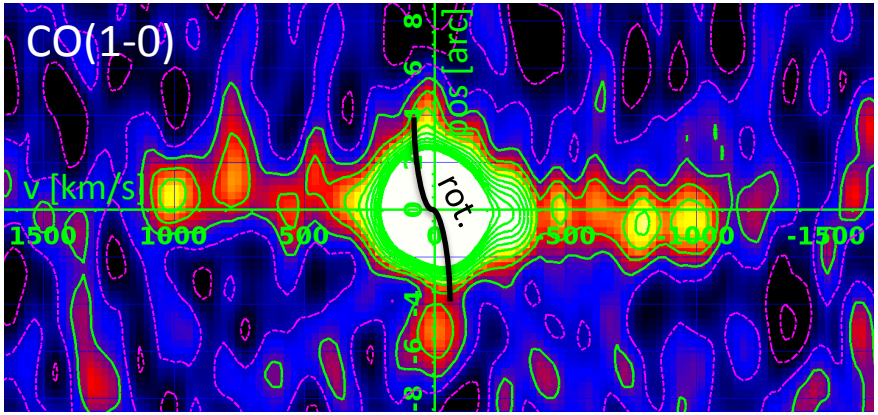


Feruglio+10+15, Cicone+12

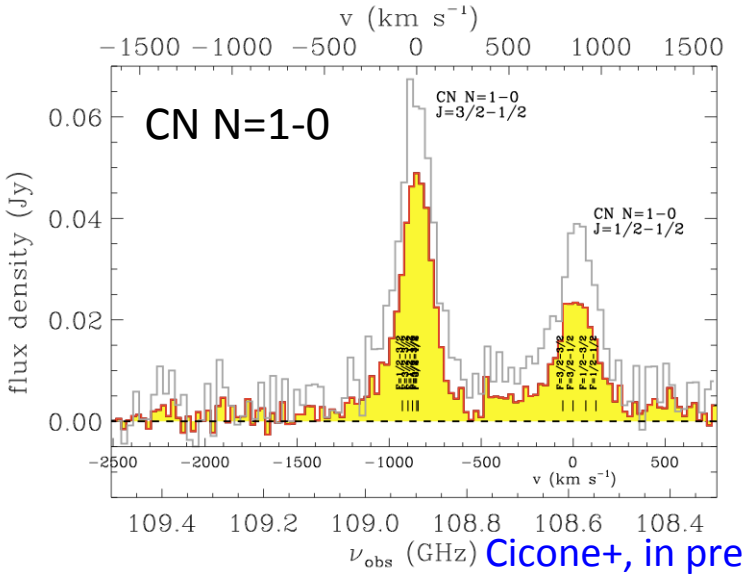
Gonzalez-Alfonso+14,Fischer+10, Sturm+11,Veilleux+13,Spoon+13

Cold (and dense!) H_2 gas in outflow at v ~ 10^2-10^3 km/s in SBs and AGNs

Any mechanism affecting cold H_2 (on kpc-scales) can affect the galaxy's capability of forming new stars



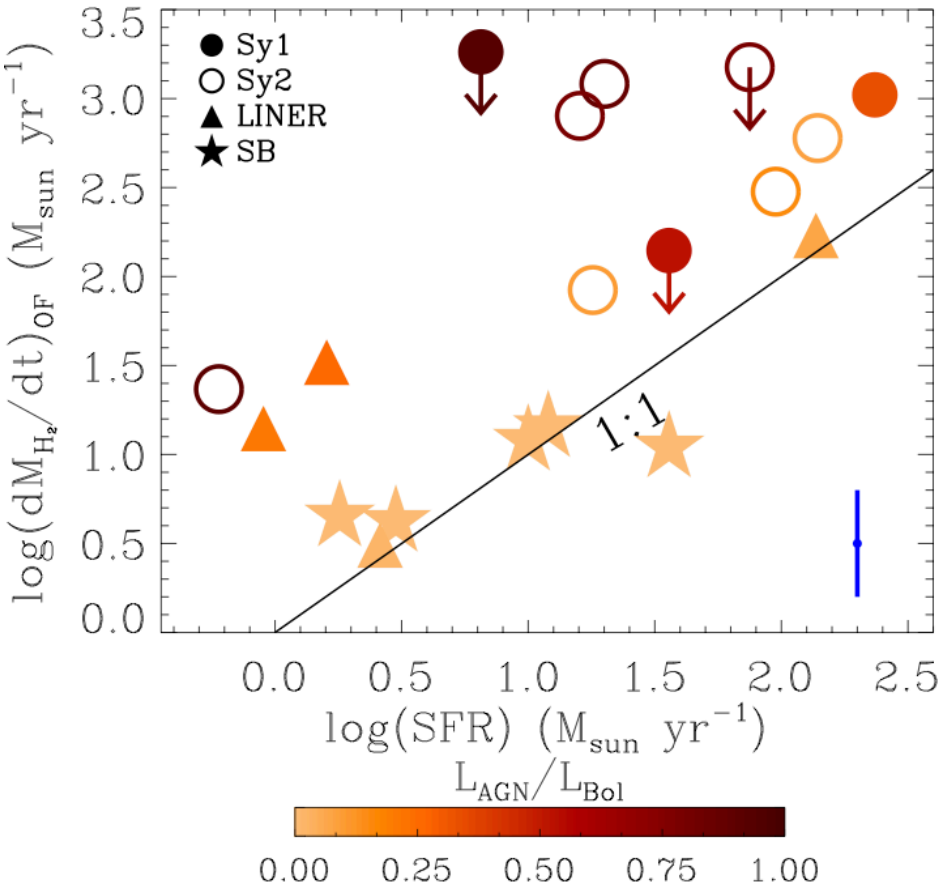
Cicone+14



Cicone+, in prep

Rapidly expanding field: Feruglio+13a,b,Aalto+12,+15,Alatalo+11,+15,Bolatto+13, Garcia-Burillo+14, Combes+13, Dasyra+12,+14,Morganti+13,Sun+14,Sakamoto+14,Tunnard+15

Outflow mass-loss rate vs SFR

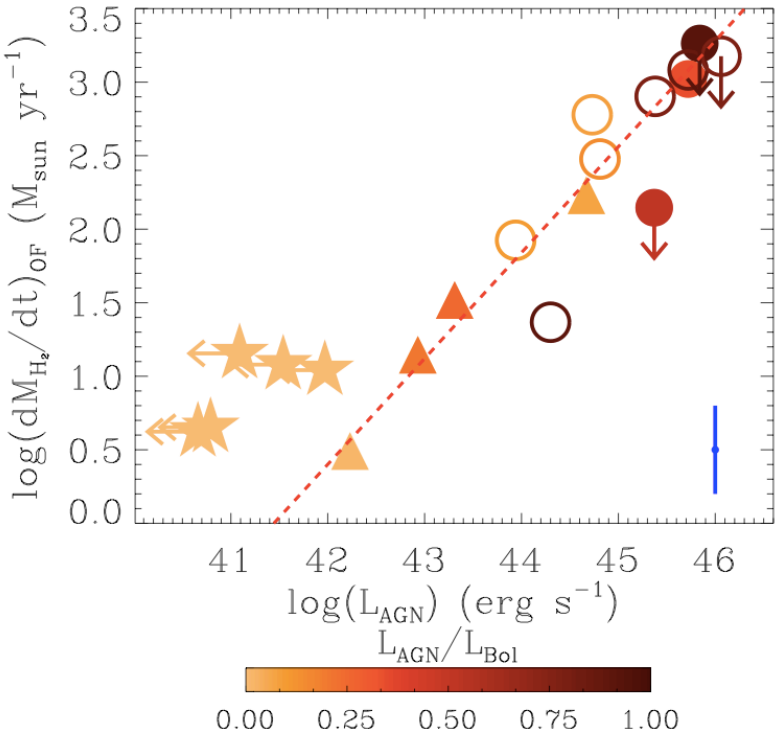


Starburst-dominated galaxies: outflow rate and SFR comparable (mass load η~1)

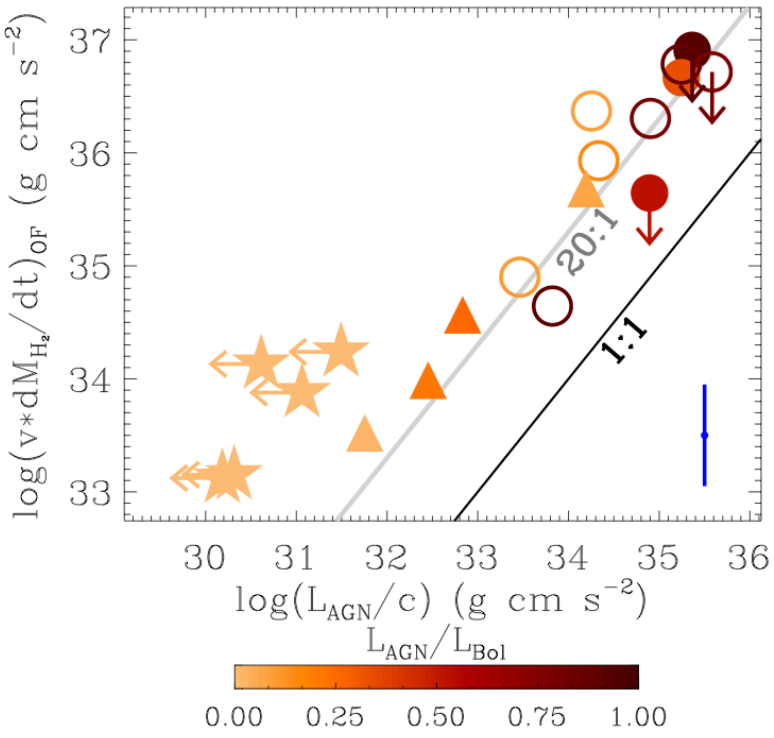
Outflow rates strongly **boosted** by the presence of an AGN (outflow boost increases with L_{AGN}/L_{bol} up to factor of ~100)

Cicone+14

Quasar-mode feedback at z~0?



Outflow rate correlates with L_{AGN} in AGN host galaxies



Outflow momentum rates vs L_{AGN}/c show momentum boosts of ~20

Cicone+14

Quasar-mode feedback at high-z

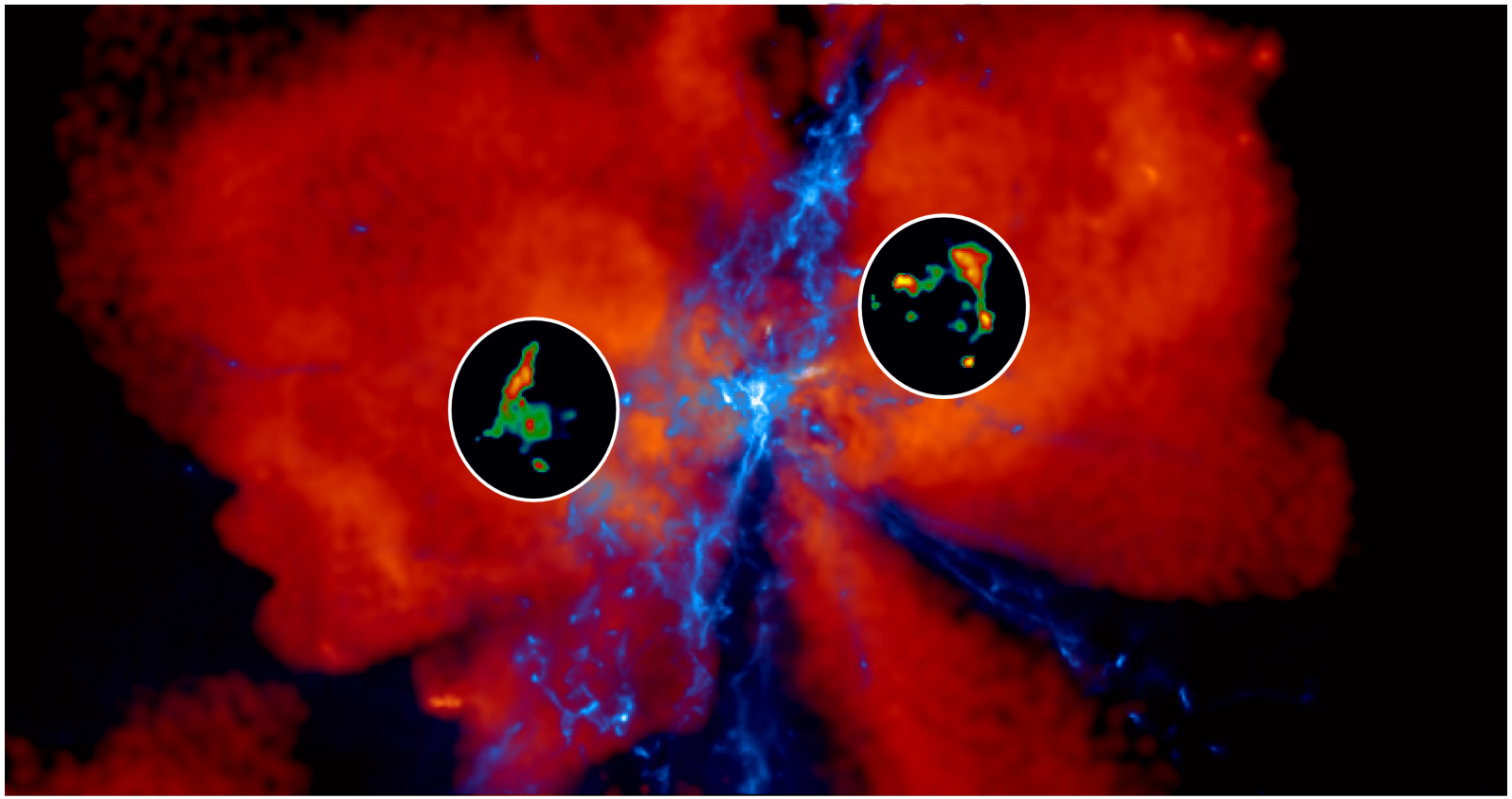


Image & simulations by T. Costa, D. Sijacki & M. Haehnelt 2015

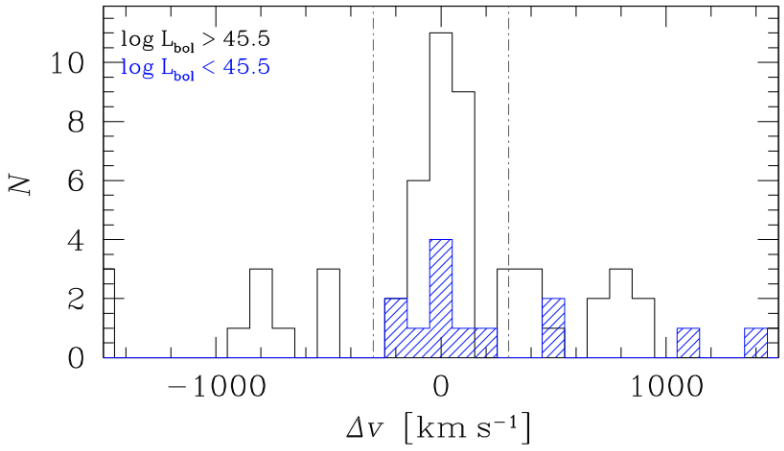
High-z quasars: fast and *synchronous* growth of SMBHs and their host galaxies. Feedback mechanisms expected to be important!

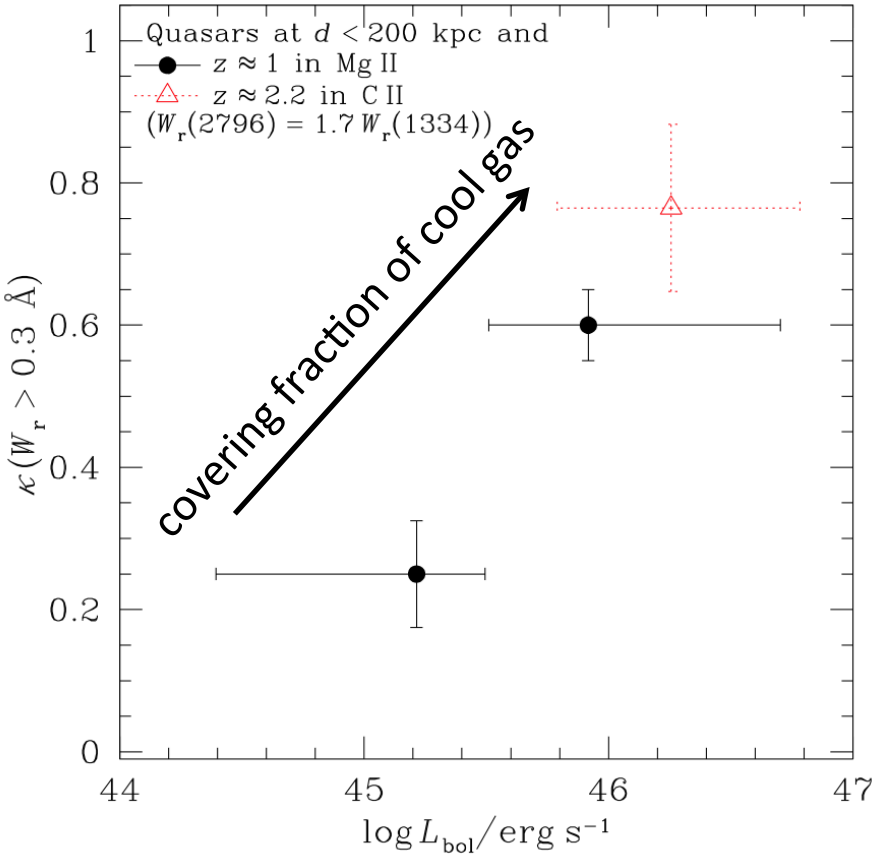
Excess of cool gas in quasar halos

Excess of cool metal-enriched gas in luminous quasar halos at z~1-2 compared to inactive galaxies

High incidence (40%) of high velocity gas |v|>300 km/s

Suggest link with quasar feedback



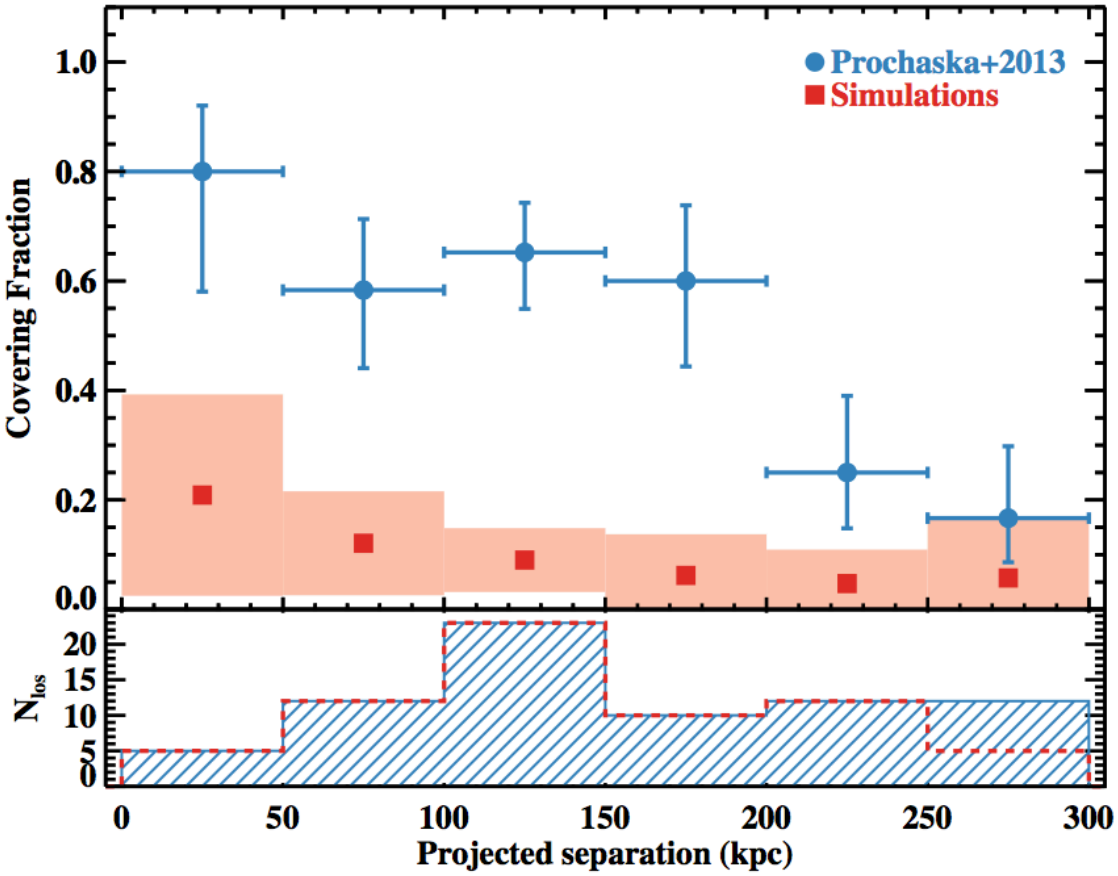


Johnson+15, Prochaska+14

Simulations cannot explain the excess

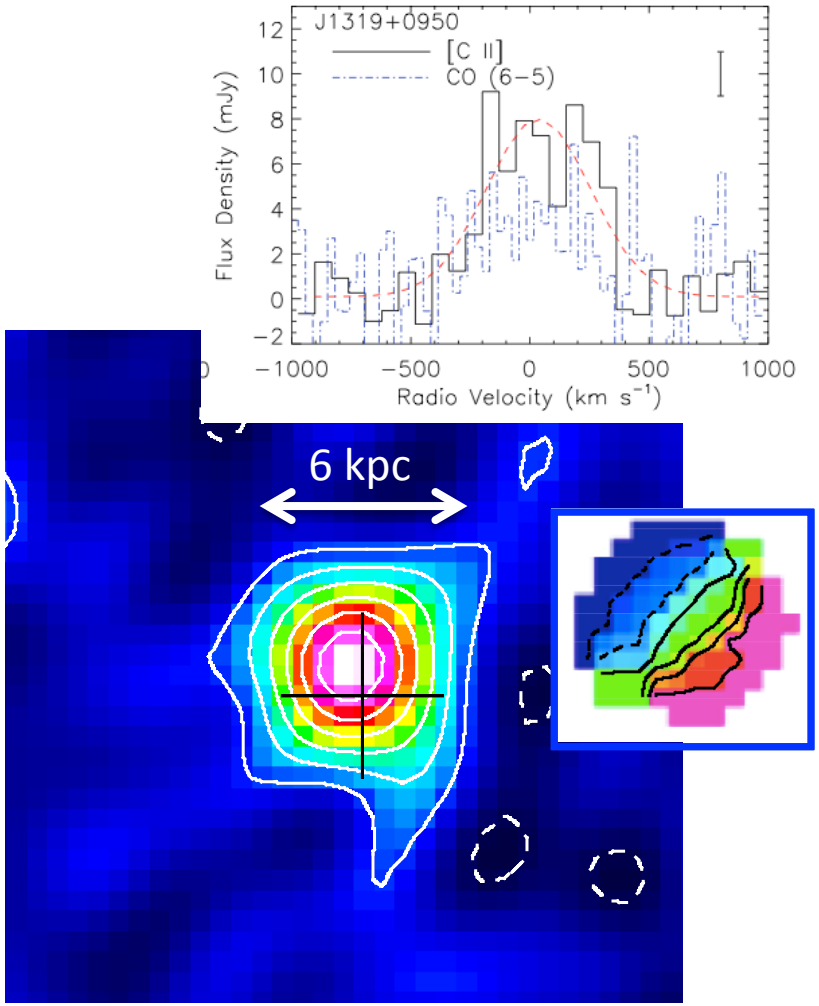
Simulations including *only stellar feedback* cannot reproduce the large HI covering fractions observed around high-z quasars

Large reservoir of cool gas in high-z quasar halos linked to quasar feedback?



Fumagalli+14, Faucher-Giguere+15, Rahmati+15

What about emission line studies?



ALMA Cycle 0, Wang+13

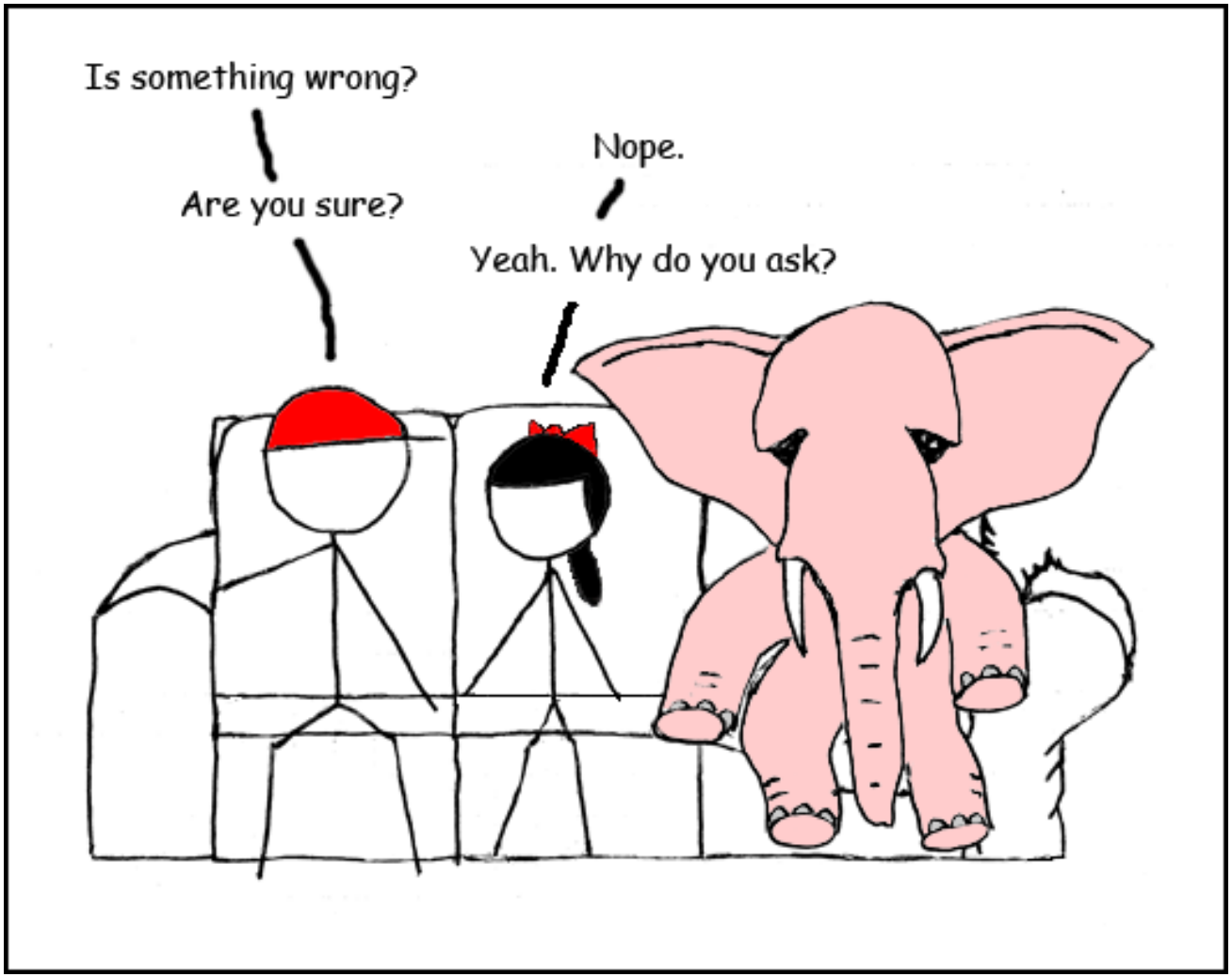
[CII] 157.7µm is the most promising tracer of cool gas at high redshifts

Previous [CII] observations targeting the most extreme high-z quasars show regularly rotating disks, no extended emission, *no signs of feedback*.

What is going on? Conspiracy of:

- Low sensitivity (before ALMA)
- Narrow bandwidth (even with ALMA!)
- Low sensitivity to large-scales (can be an issue with any interferometer)

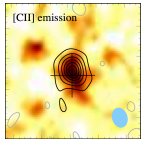
Are we missing the elephant in the room?



[CII] map of SDSS J1148+5251 at z=6.4

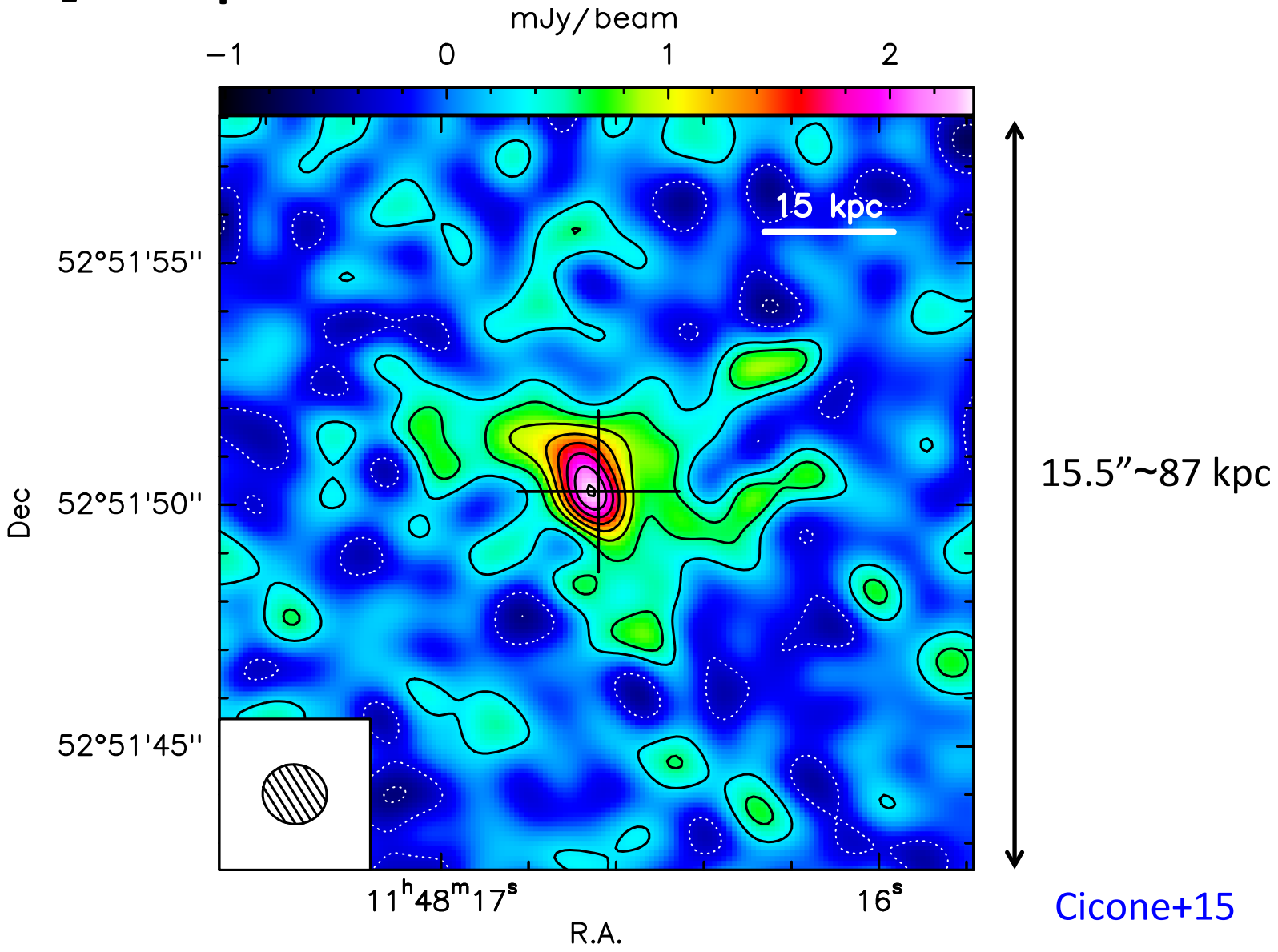
PdBI, A- conf observations by Walter+09

"Here we report a spatially resolved image of [CII] emission of the host galaxy of J114816.64+525150.3 that demonstrates that its star-forming gas is distributed over a radius of about 750 pc around the centre "



2.2" ~ 12 kpc

[CII] map of SDSS J1148+5251 at z=6.4



Cicone+15

[CII] map of SDSS J1148+5251 at z=6.4

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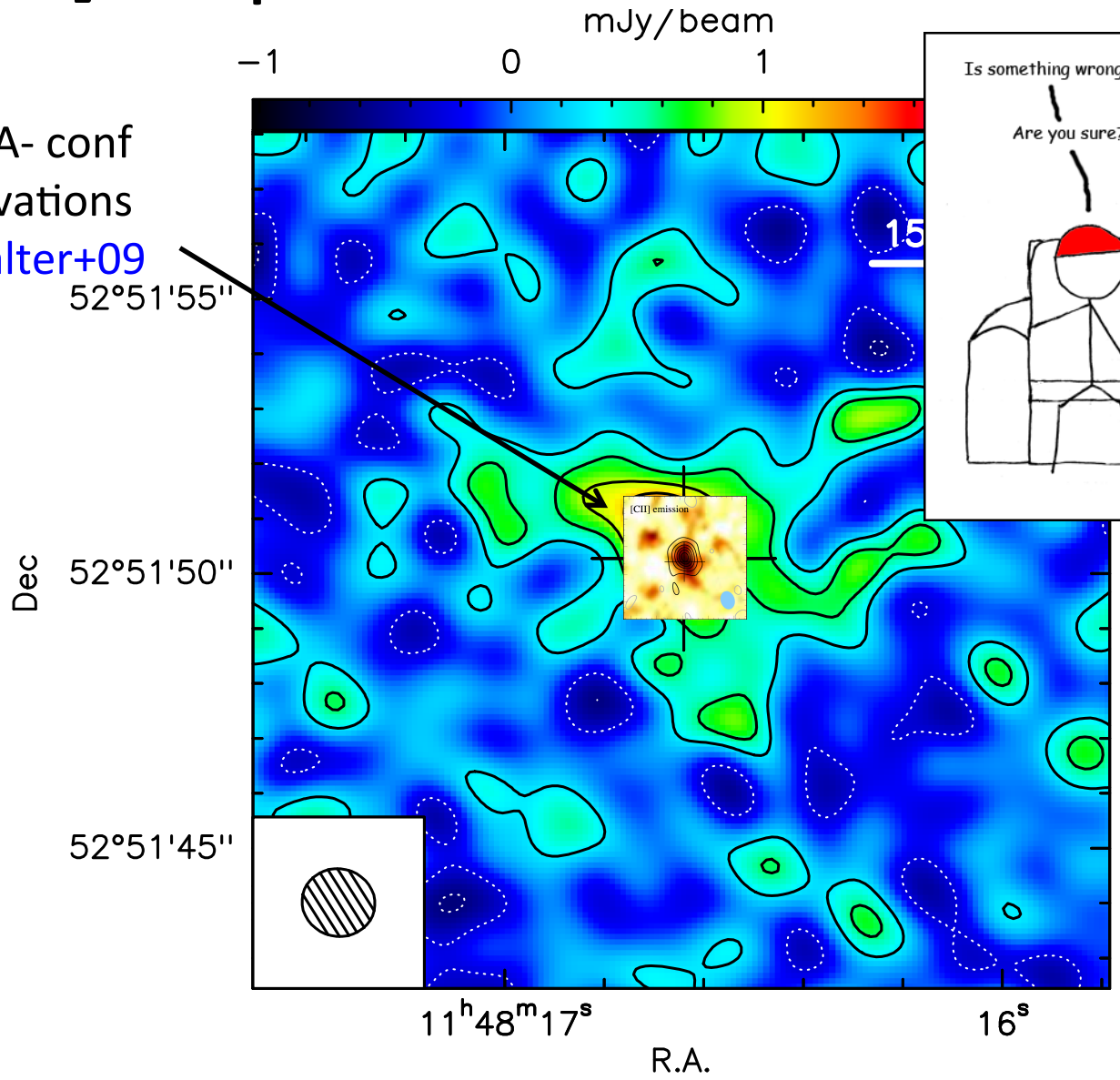
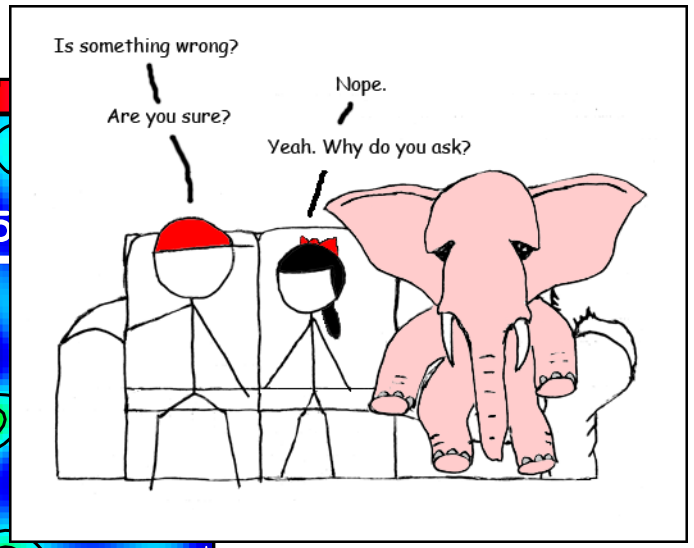
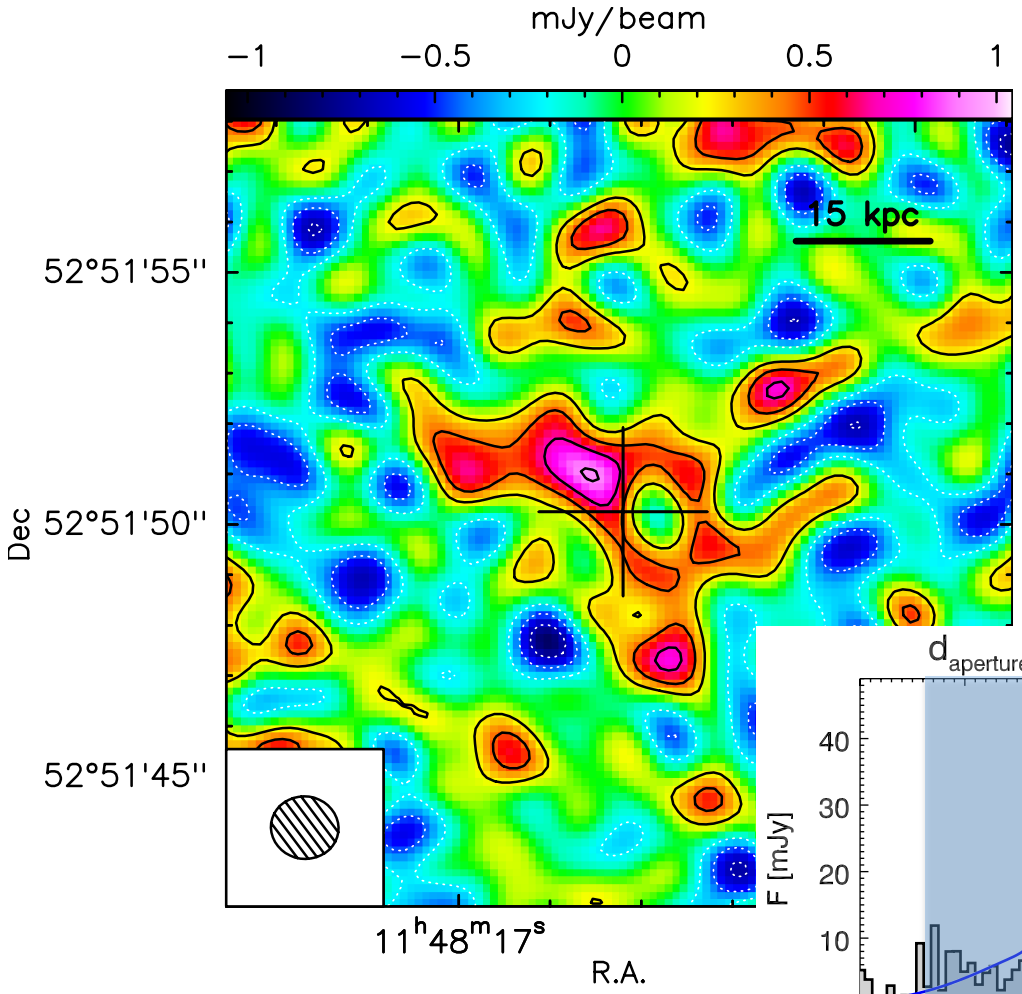
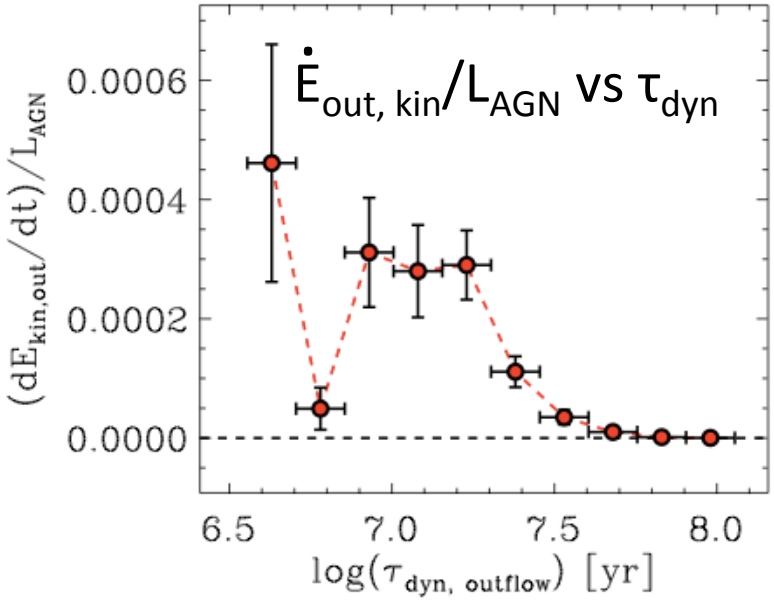


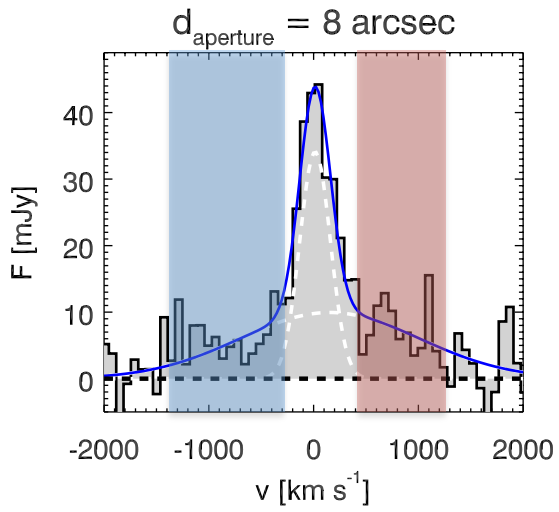


Cicone+15

A giant (r~30 kpc) outflow of cold gas





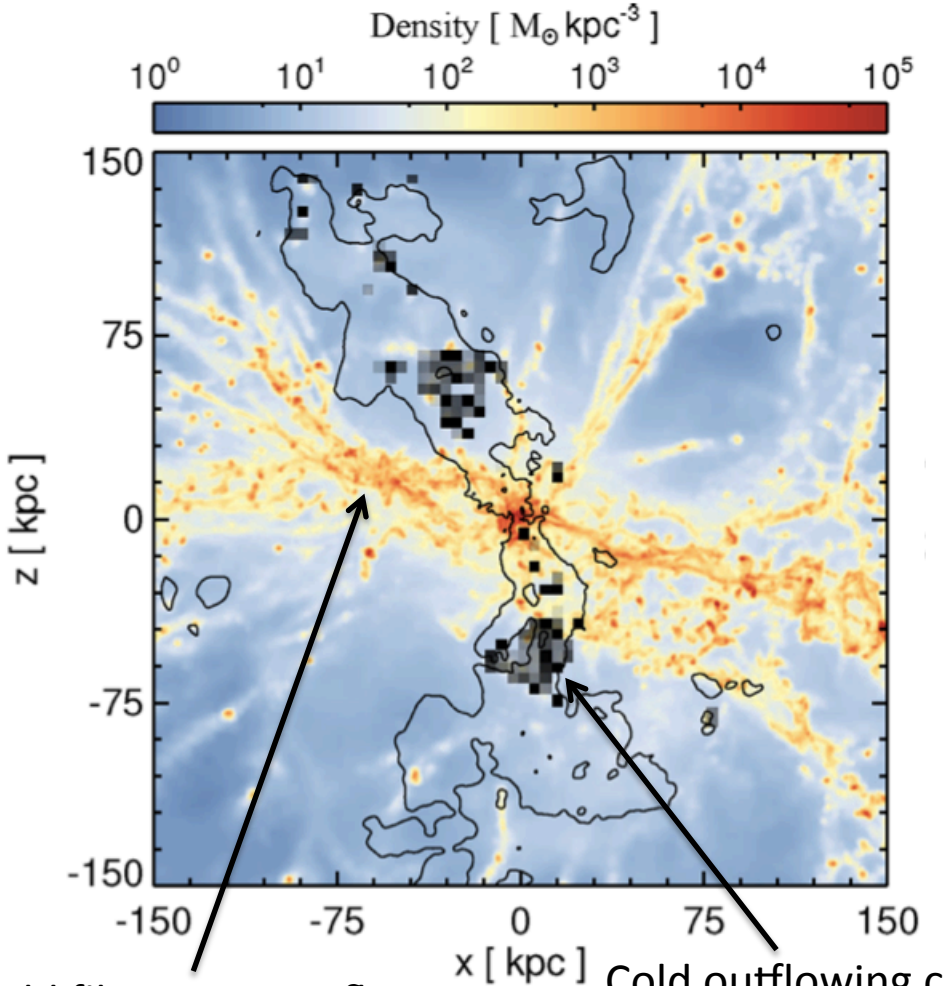


Outflow may have been in place for 100 Myr

Kinetic power and momentum rate modest compared to L_{AGN}

Cicone+15, Maiolino+12

Observations consistent with quasar + SN feedback



Cold filamentary inflows

Cold outflowing clumps (within hot outflow)

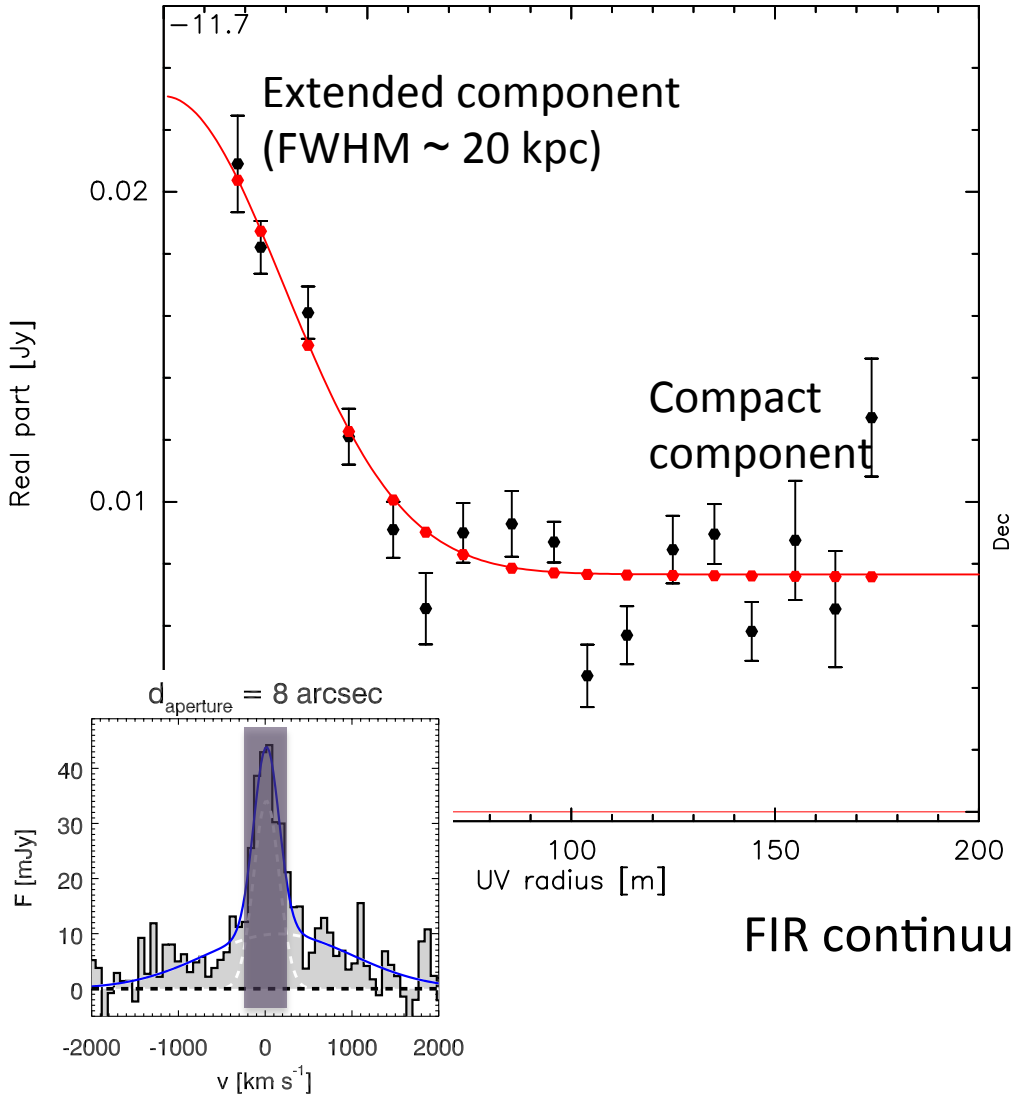
Extended high-velocity gas signature of ***both powerful quasar and supernova feedback***

SNe pre-enrich IGM with metals and fill it with high density clumps

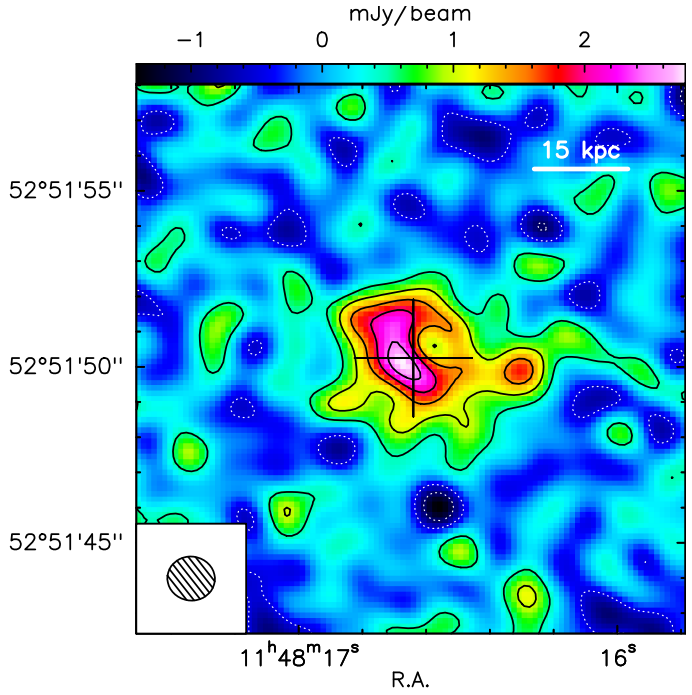
SN feedback allows quasar energy-driven outflow to cool radiatively in short timescales

Costa+15

Halo rich of quiescent (cool) gas



UV-plane modeling: 70% of quiescent [CII] is extended (~20 kpc)



FIR continuum extends up to at least r~ 10 kpc

Cicone+15

Conclusions

- Observational signature of quasar-mode feedback both locally and at high-z
- Local Universe: high level of detail, we can learn a lot
- Early Universe is mind-blowing! Still to explore
- We are lucky: we have ALMA. The early Universe has never been more accessible than now!