UNIVERSITÀ DEGLI STUDI FIRENZE

Fast outflows quenching star formation in quasar host galaxies

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B. Balmaverde, S. Carniani, G. Cresci, M. Brusa,
E. Lusso, R. Maiolino, F. Mannucci, T. Nagao, H. Netzer, G. Risaliti, M. Salvati, O. Shemmer, F. Fiore, F. La Franca, A. Comastri, M. Cano-Diaz, David J. Axon (1951-2012)

Fraction of condensed baryons

- From baryonic Tully-Fisher relation (M_{star} vs V_c), fraction of baryons condensed into galaxies/stars (e.g. Balogh+2001, Zaritsky+2014):
$M_{baryon}/M_{halo} = 0.07$

- Total fraction of baryons in halo
(Planck year 1, Ade+2013):
$\Omega_b/\Omega_0 = 0.0487/0.315 = 0.15$

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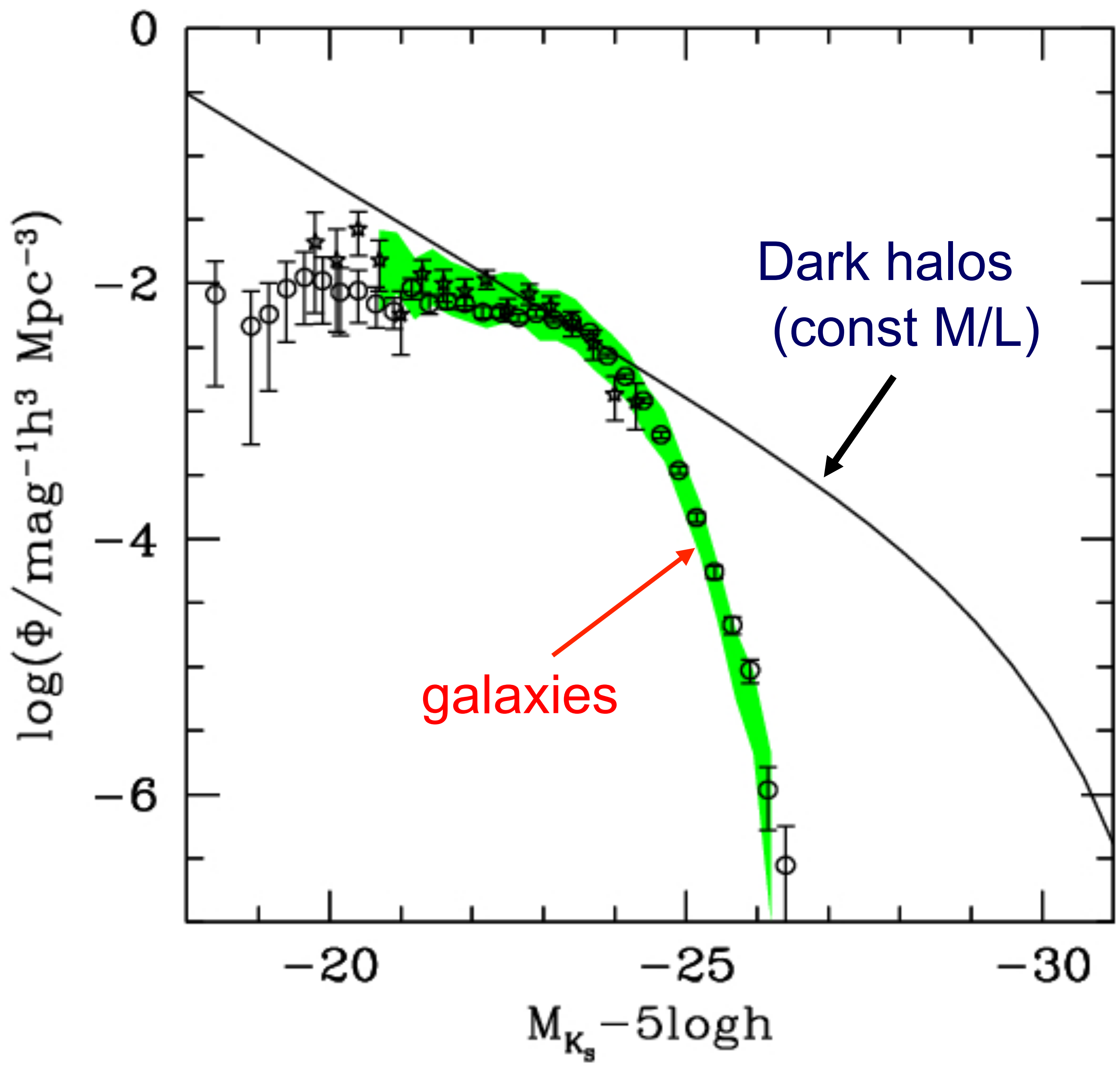
- Observed mass/luminosity function of galaxies is different from mass function of dark haloes rescaled for baryon/dark matter fraction.
- *Why most baryons are not condensed into stars?*



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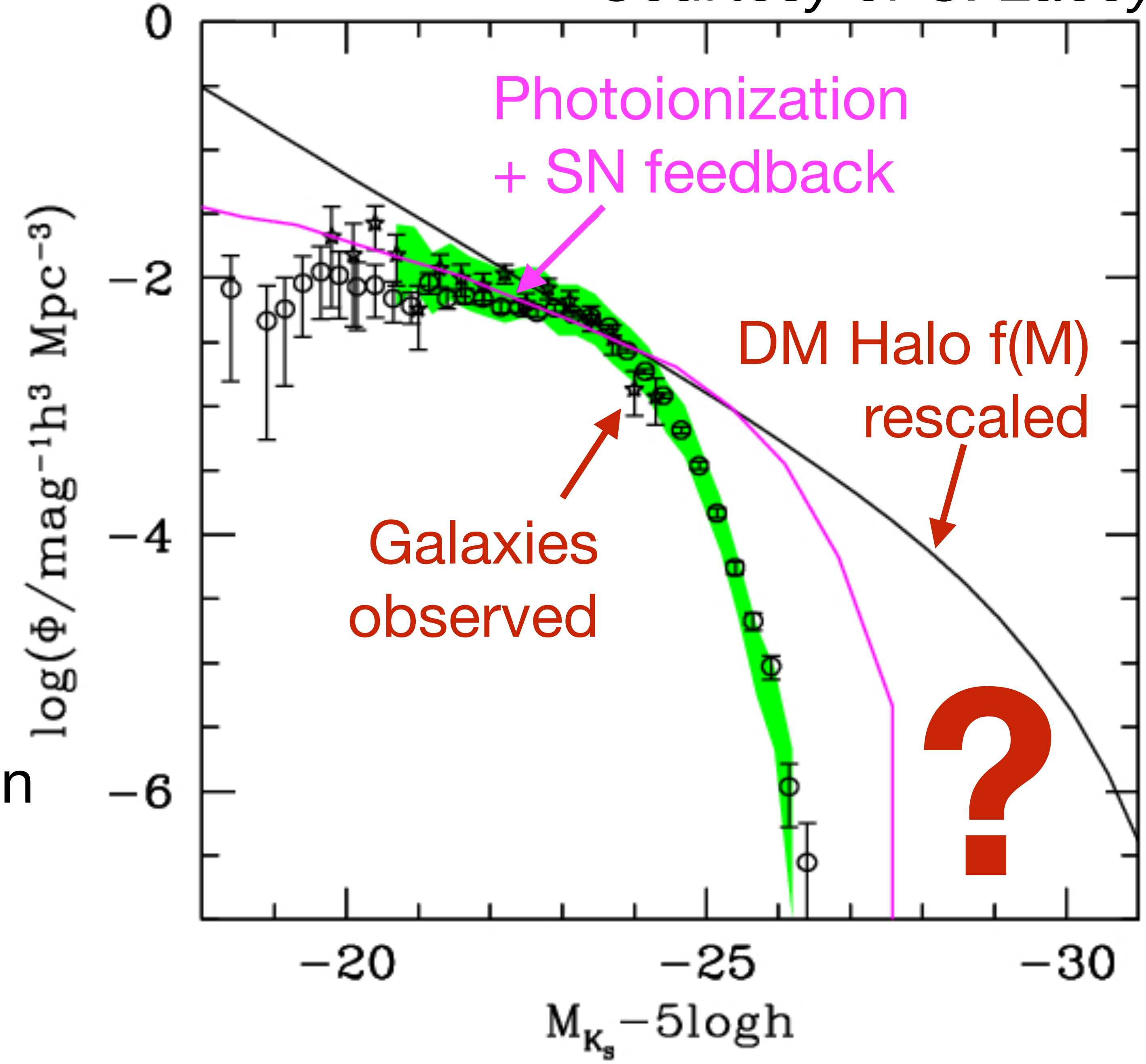
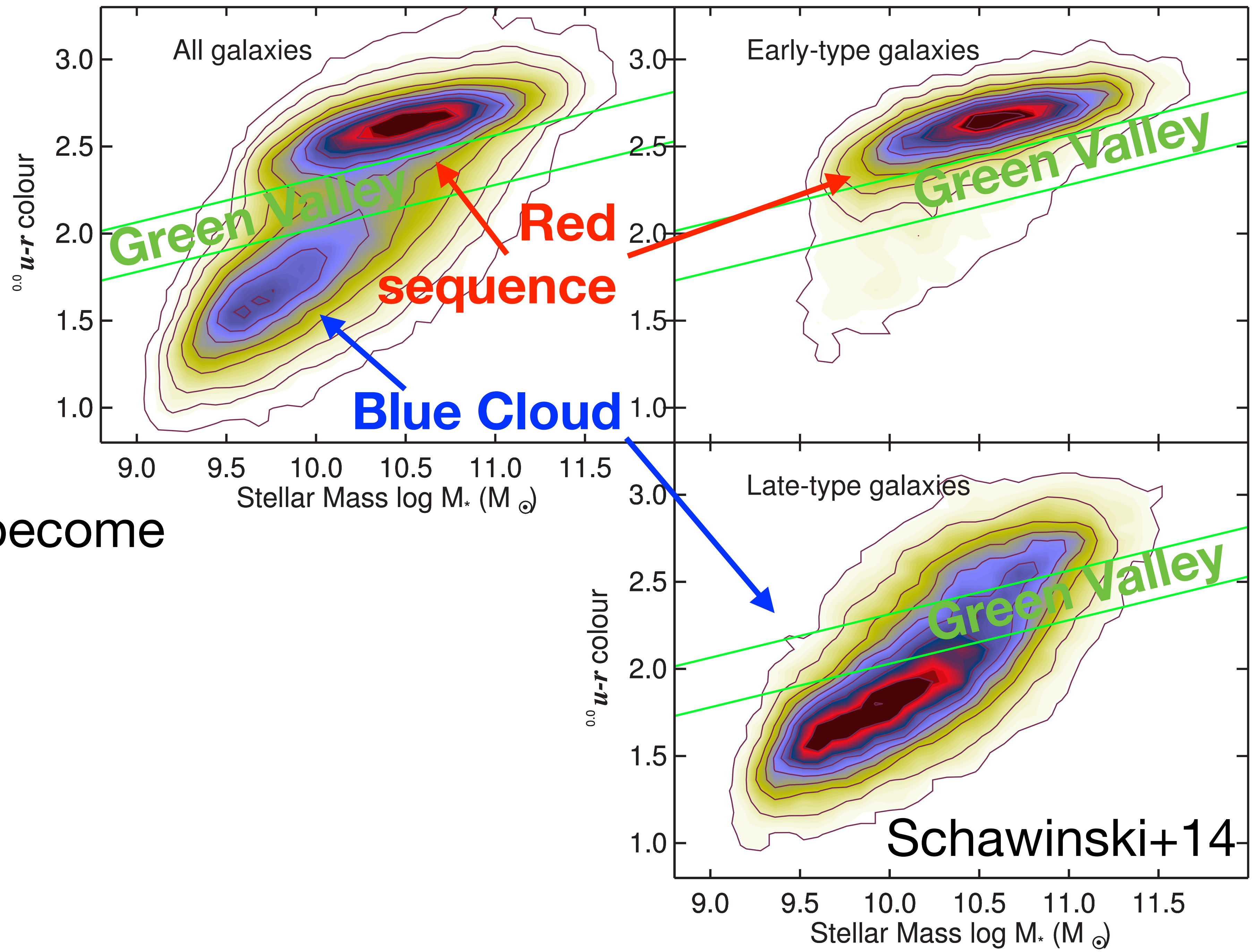
- Observed mass/luminosity function of galaxies is different from mass function of dark haloes rescaled for baryon/dark matter fraction.
- *Why most baryons are not condensed into stars?*
- Stellar feedback cannot explain the missing massive galaxies (e.g. Hopkins+06, Croton+06, Murray+05, Menci+08, …)

Courtesy of C. Lacey



"Red and Dead" galaxies

- Bimodality in color - mag / M_{star} diagram discovered by SDSS (Blanton +2003):
- Red sequence
  Green Valley
  Blue Cloud
- What makes blue cloud galaxies to quickly move to the red sequence and become "red and dead"?



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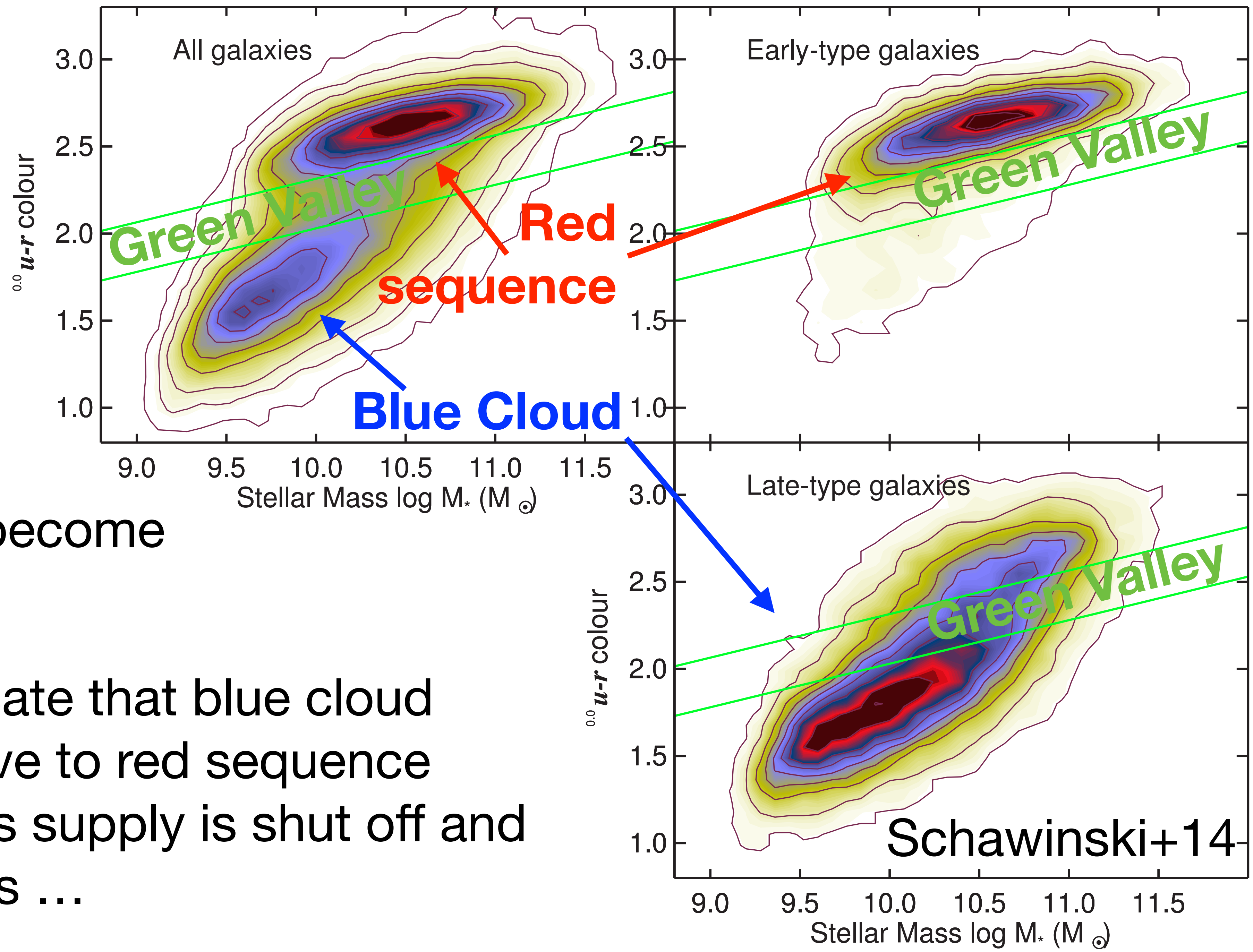

- Red sequence
  Green Valley
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- What makes blue cloud galaxies to quickly move to the red sequence and become "red and dead"?

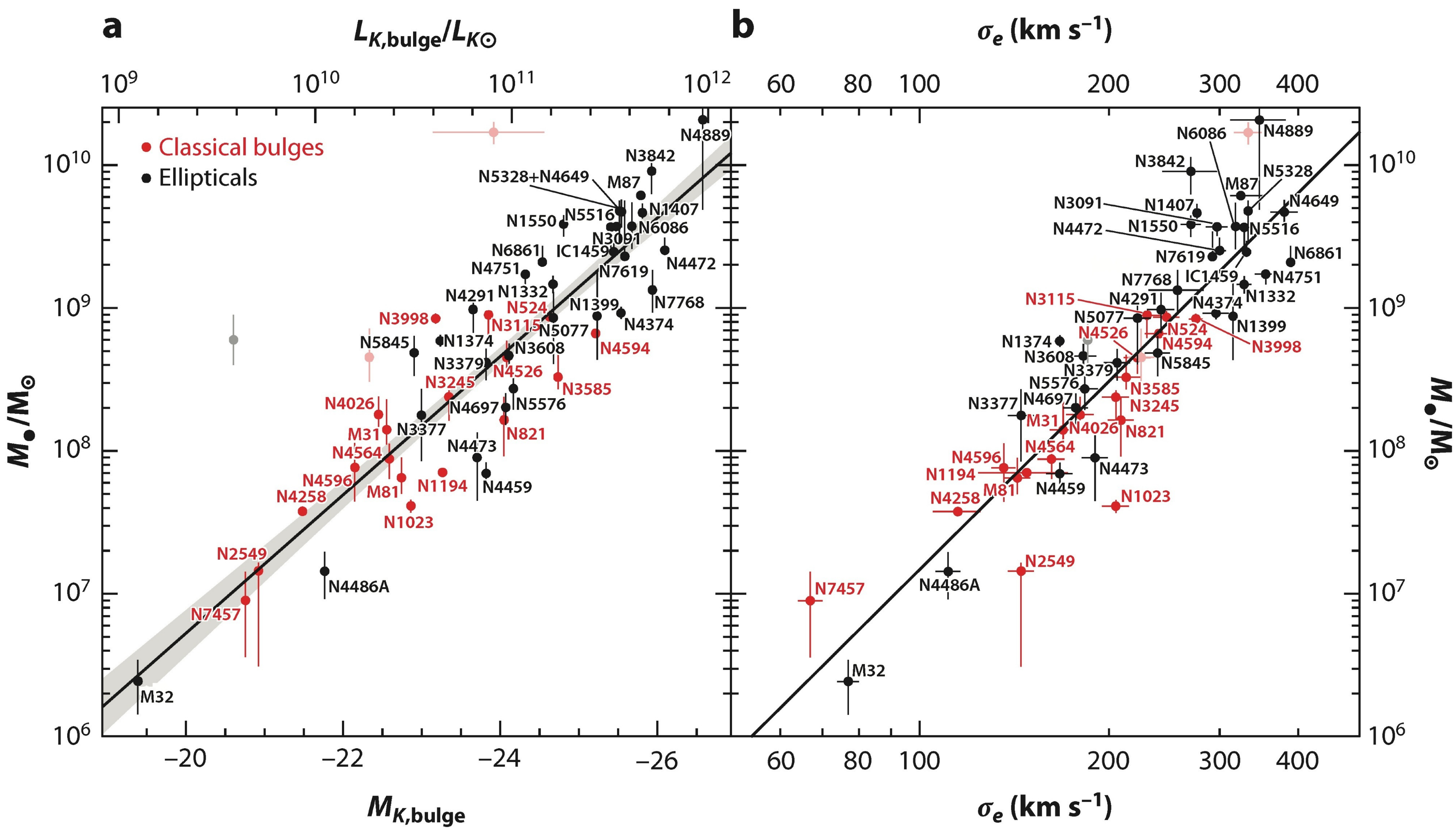
- Recent results indicate that blue cloud galaxies do not move to red sequence but their cosmic gas supply is shut off and SF slowly decreases …

- *… but in red galaxies gas supply and gas reservoir are destroyed virtually instantaneously, with rapid quenching of SF (e.g., Schawinski+14, Silverman+08, Menci+05)*

Supermassive BHs and Galaxies

- Tight relations between supermassive black holes and their host galaxies (eg. Ferrarese & Merritt 2000, Gebhardt+2000 … Marconi & Hunt 2003 … Kormendy & Ho 2013): co-evolution of black holes and host galaxies

- How can BH know about host galaxy and vice versa?



Kormendy & Ho 2013

AGN Feedback

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- During BH growth AGN can release significant amount of energy compared to galaxy gravitational binding energy;
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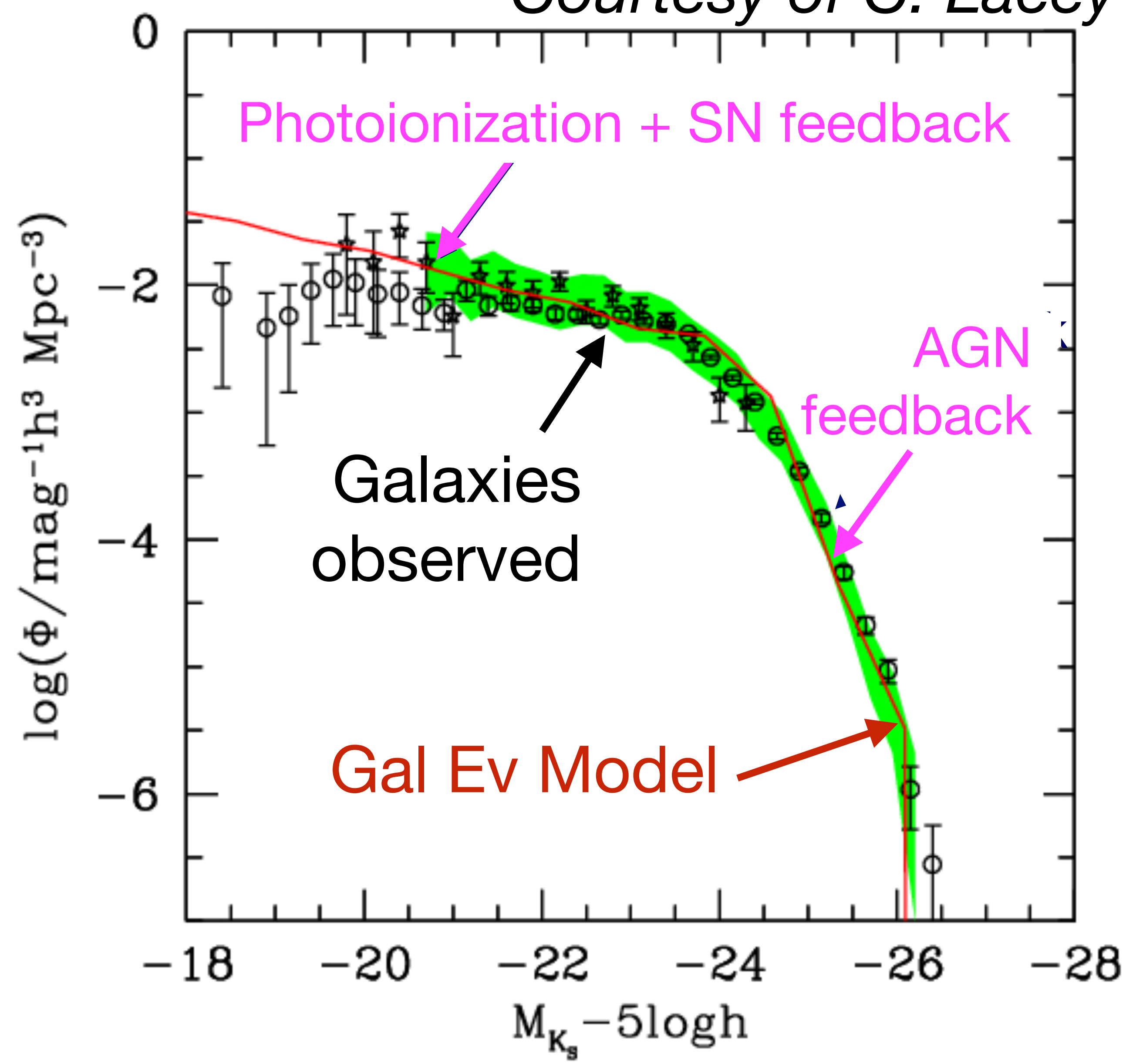

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- Two modes of feedback:
  Quasar mode: high L/L_{Edd}, radiative feedback, short time scale
  Radio mode (maintenance): low L/L_{Edd}, kinetic feedback (jets), long time scale

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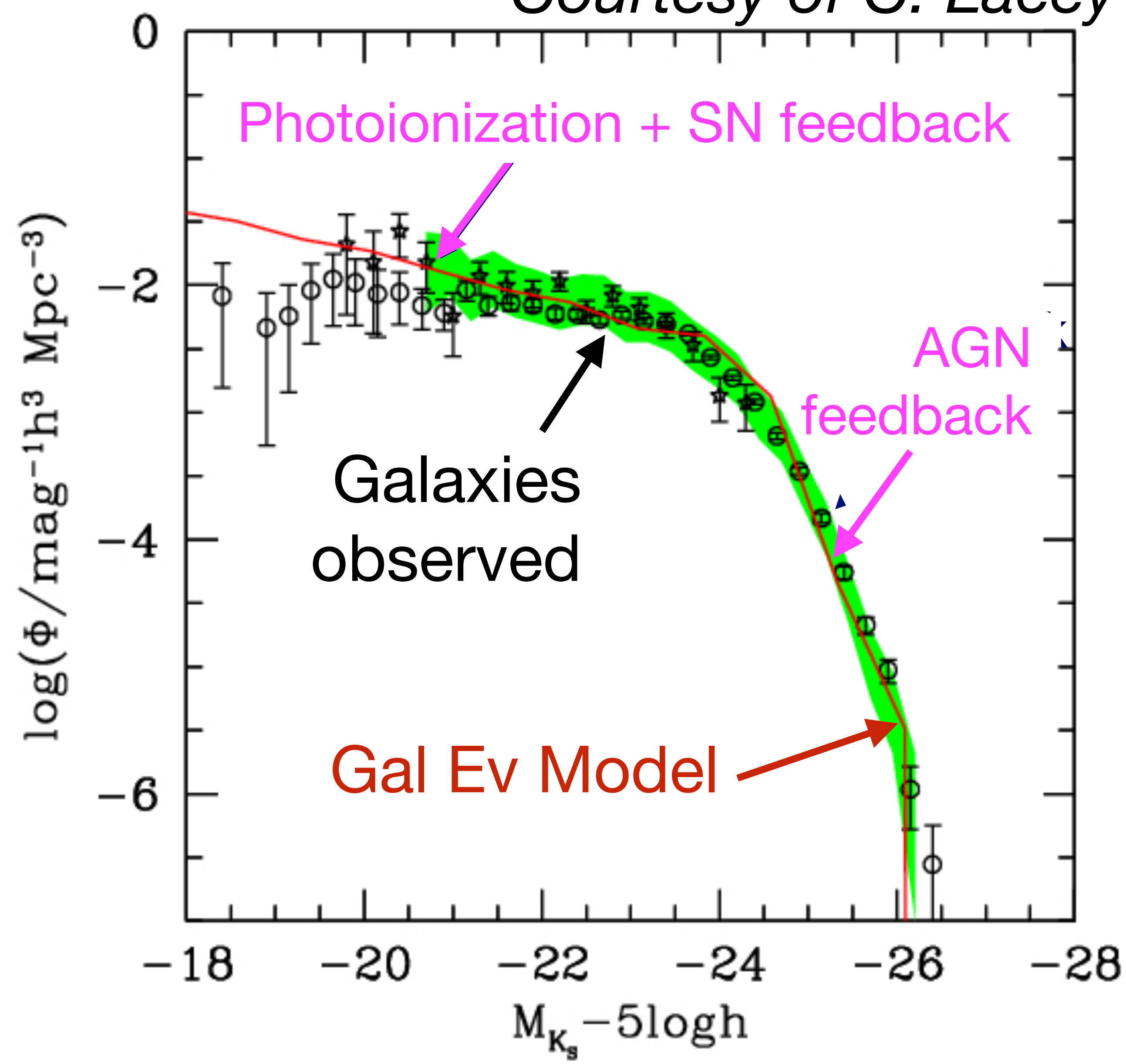

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- Recently: **positive feedback !** Radiation pressure and winds from AGN can trigger star formation, up to ~100 $M_\odot$/yr (Ishibashi & Fabian+14, Silk +13, Zubovas+13, Zubovas & King+14)

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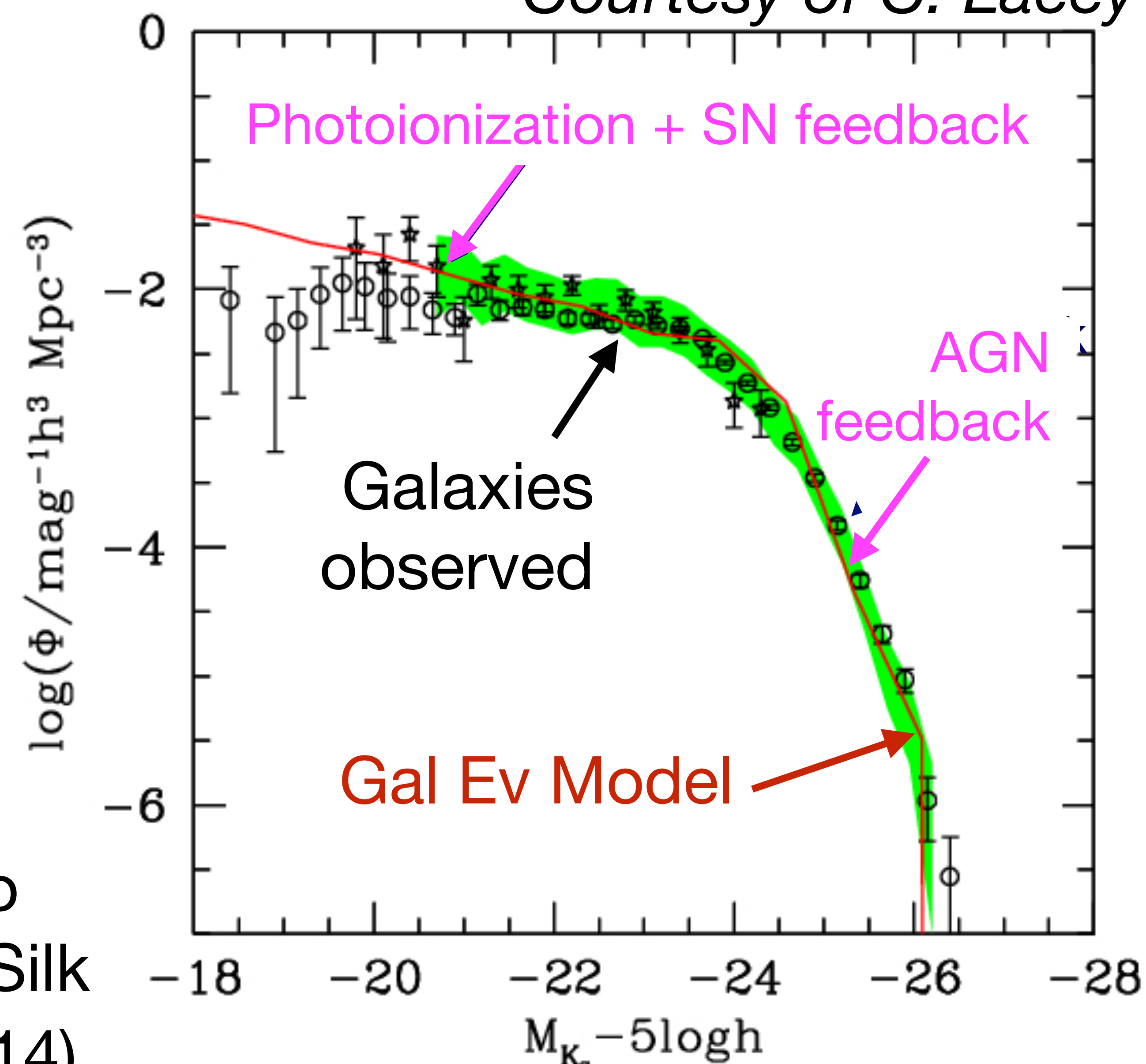
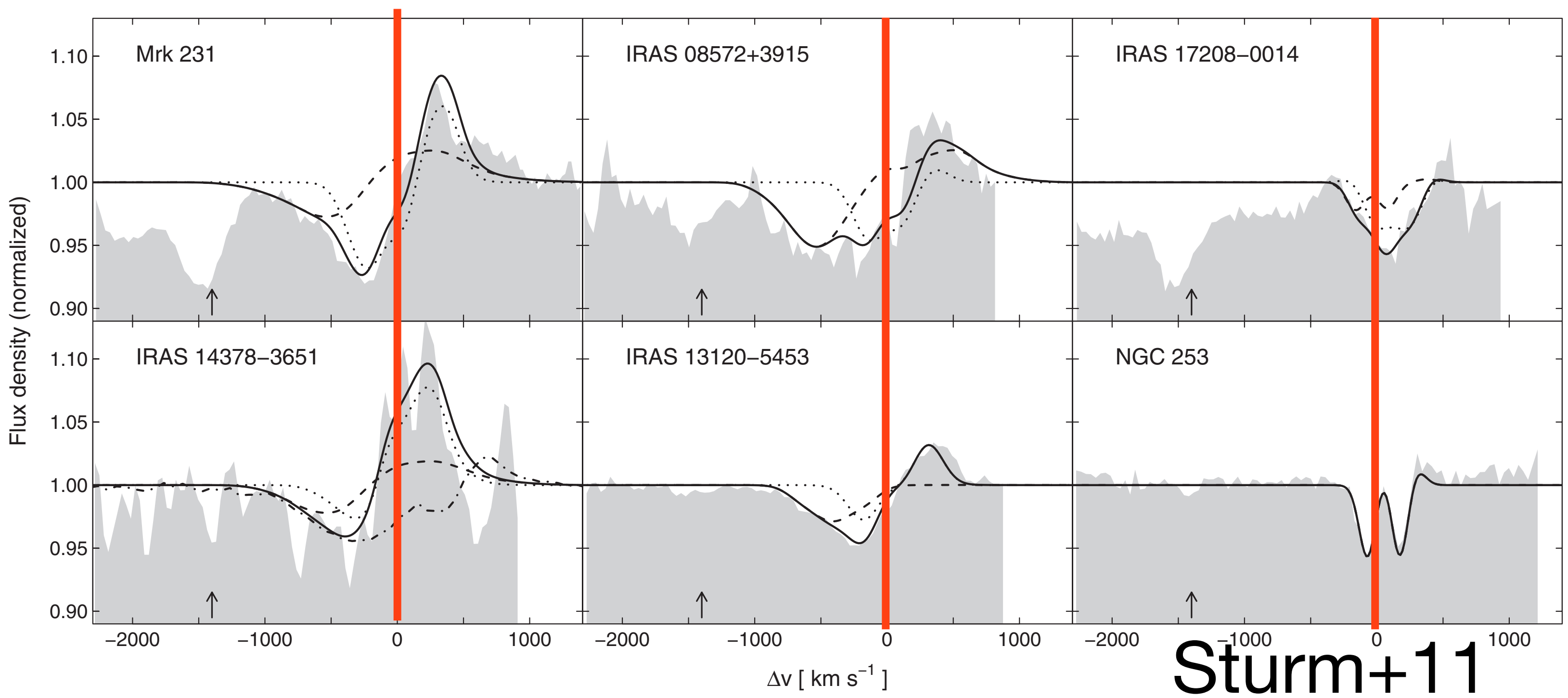


Is feedback really needed?

- Recently, the need for AGN feedback has been questioned …
- M_{BH}-galaxy relations might also come from hierarchical assembly of BH and stellar mass through galaxy merging without any causal origin (Peng 2007, Jahnke & Macciò 2011, Cen 2011, Fanidakis et al 2011)
- But the small (?) scatter in M_{BH}-galaxy relations would not be explained by a non-causal connection: it should result from self regulated BH growth and not BH quenching star formation in the host galaxy (Hopkins, Murray & Thomson 2009)
- Stellar feedback (radiation pressure + supernovae) might be as effective as BH feedback (Hopkins, Quataert & Murray 2012)
- Indeed stellar feedback can work except in most massive objects ($M_{halo} \gg 10^{12}\ M_{\odot}$) where AGN feedback could be needed (Hopkins+14)
- AGN-driven outflows can remove gas on the long-term but impact of AGN feedback on SF is marginal (Roos+14)

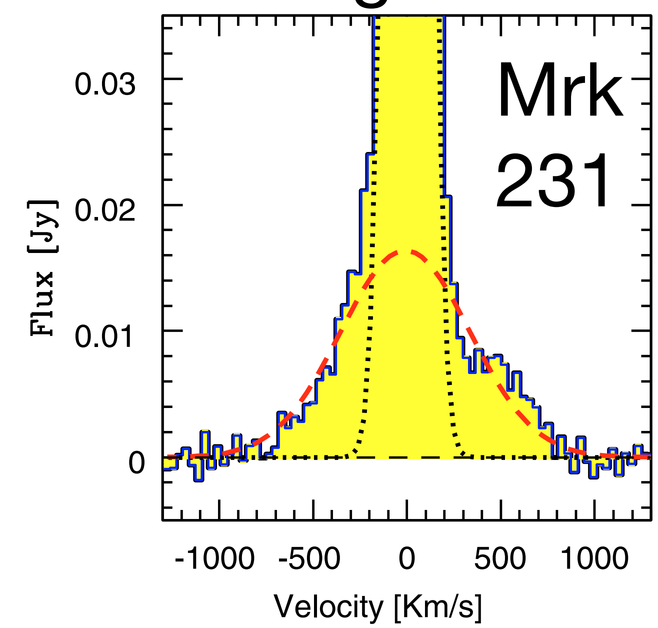
Evidences for AGN feedback?

- Scarce direct evidence (suppression of Star Formation) but almost ubiquitous fast winds in ionised and, especially, molecular gas
- Large outflow rates for SFRs and gas masses (up to ~100-1000 $M_\odot$/yr, several ×SFR) ➙ short depletion time scale (~10^7 - 10^8 yr)

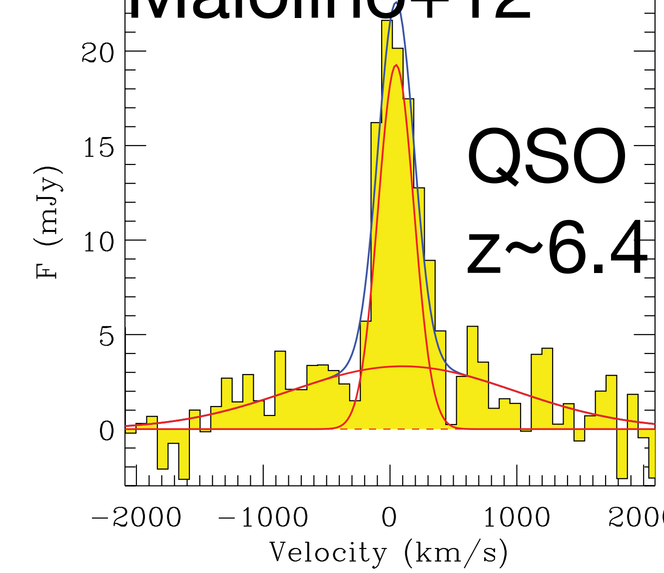


Sturm+11

Feruglio+11

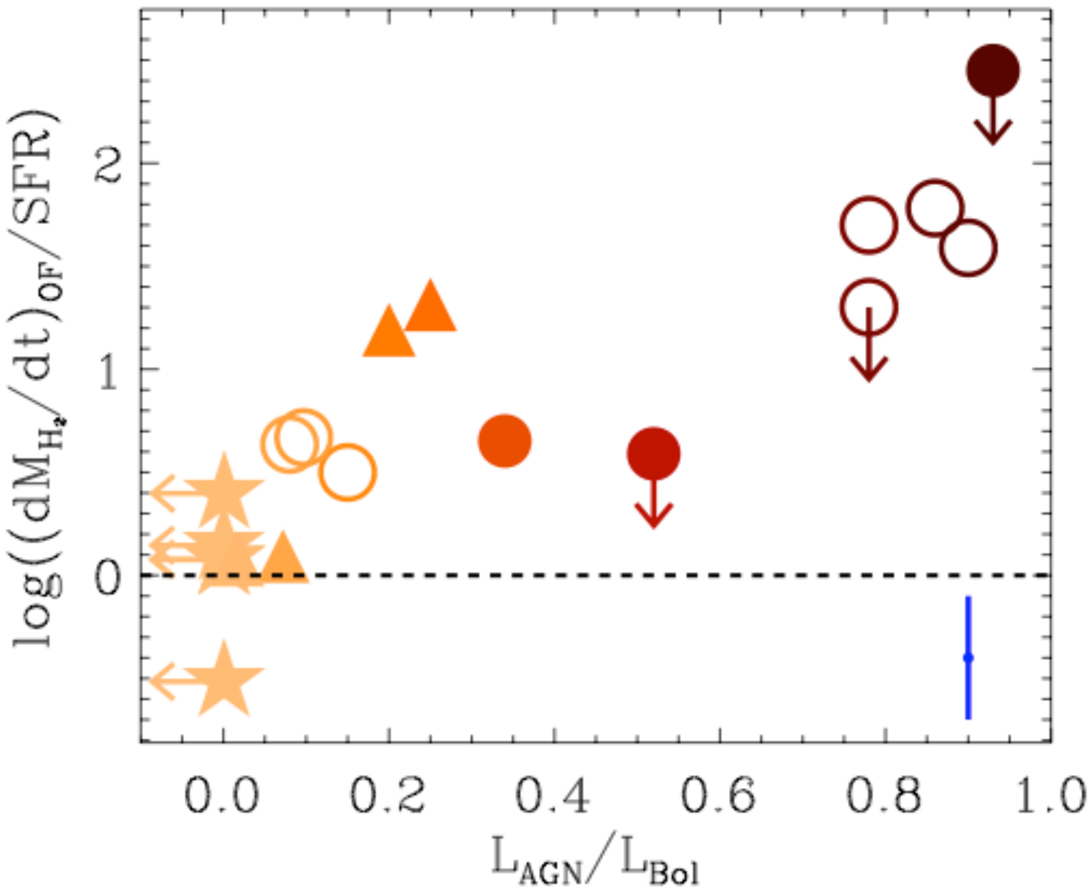


Maiolino+12



- see also Nesvadba+08,+11, Alexander+09, Harrison+12, Cicone+13,14, Greene+11,+14, Liu+14, Mullaney+13, Harrison+14, Brusa+14 …
- *If outflows are the source of AGN feedback there should be a connection between outflows and quenching of star formation*

Mol. Outflows

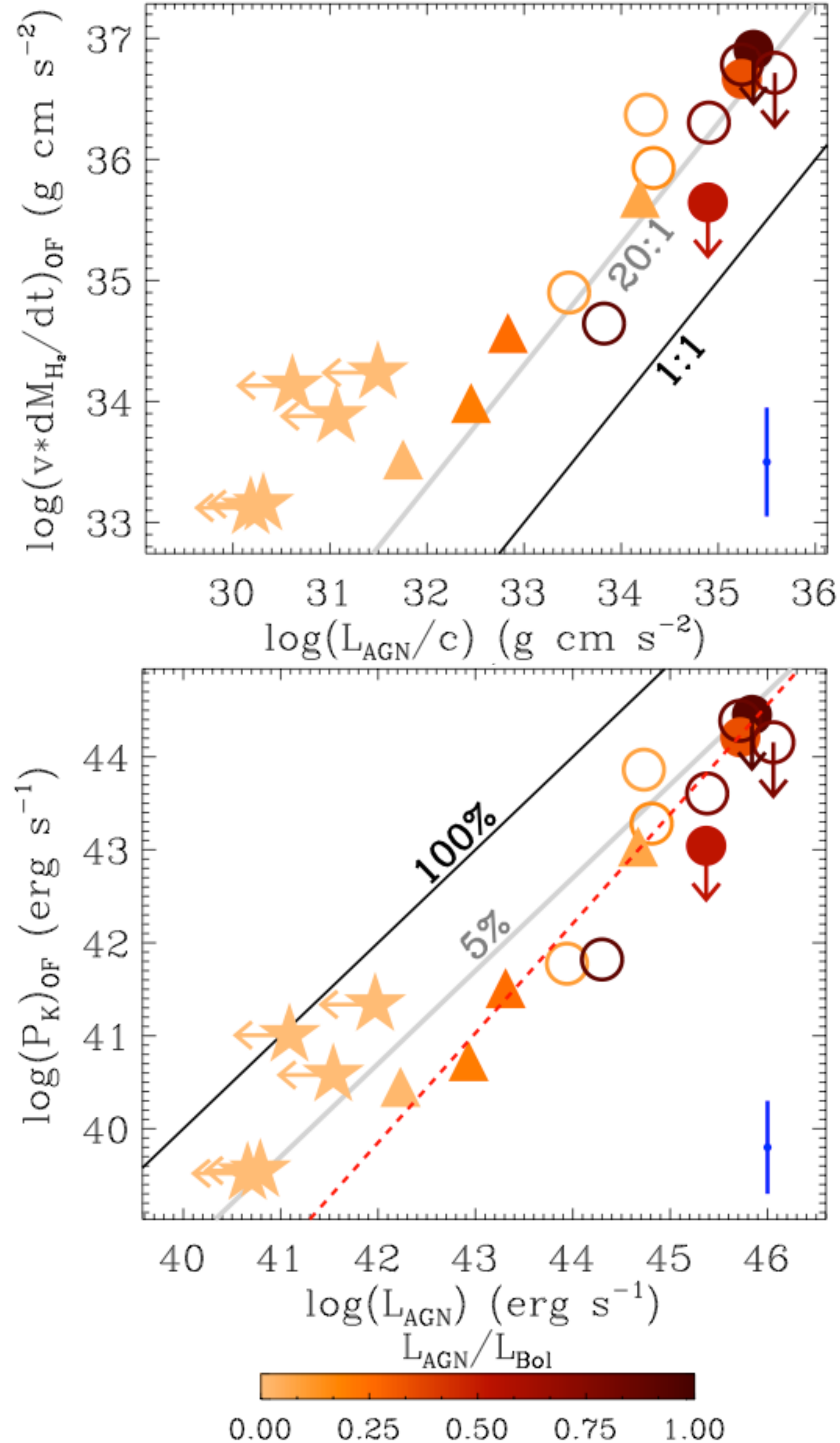


Compare with predictions from fast wind model by King & Pounds 2003

$L_{kin} \sim 1/2\ Mdot\ v^2 \sim 0.05\ L_{Edd}$

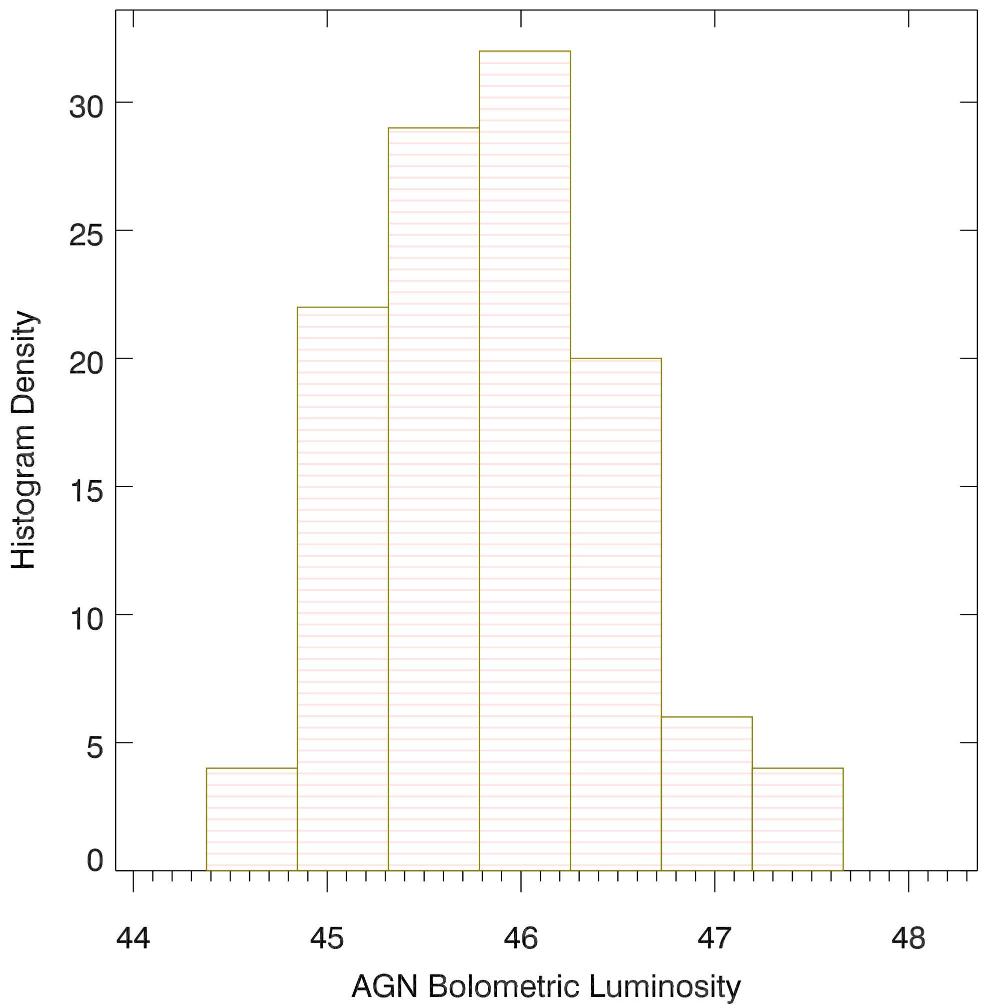
$Q_{kin} \sim Mdot\ v \sim 20\ L_{Edd}/c$

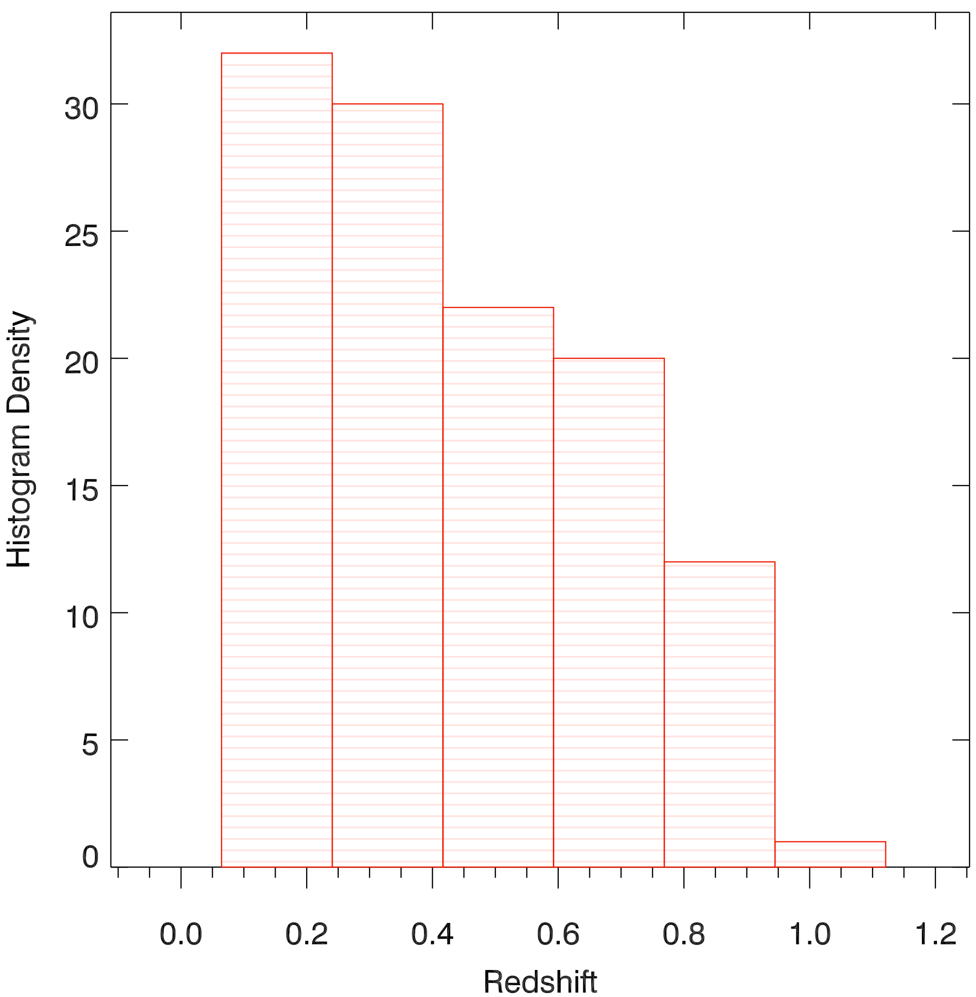
Cicone+14



Ionized outflows and SF in local quasars

- Quasars host galaxies are precursors of local massive galaxies; feedback is needed here!
- Quasar phase is the one where “quasar mode” feedback should be operating
- Sample: ~100 luminous unobscured quasars from SDSS DR7 and DR 10 with z < 1 observed by Herschel





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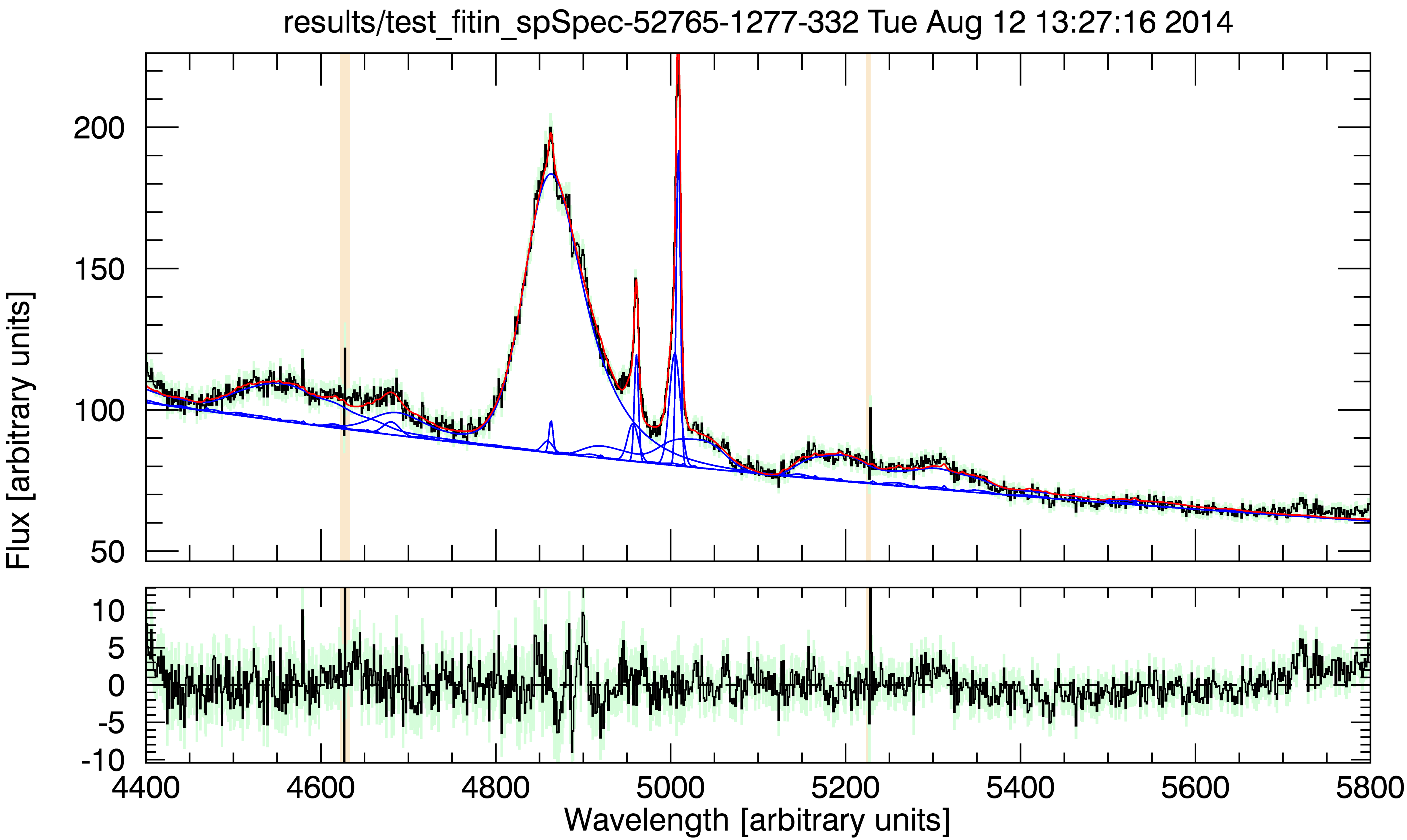

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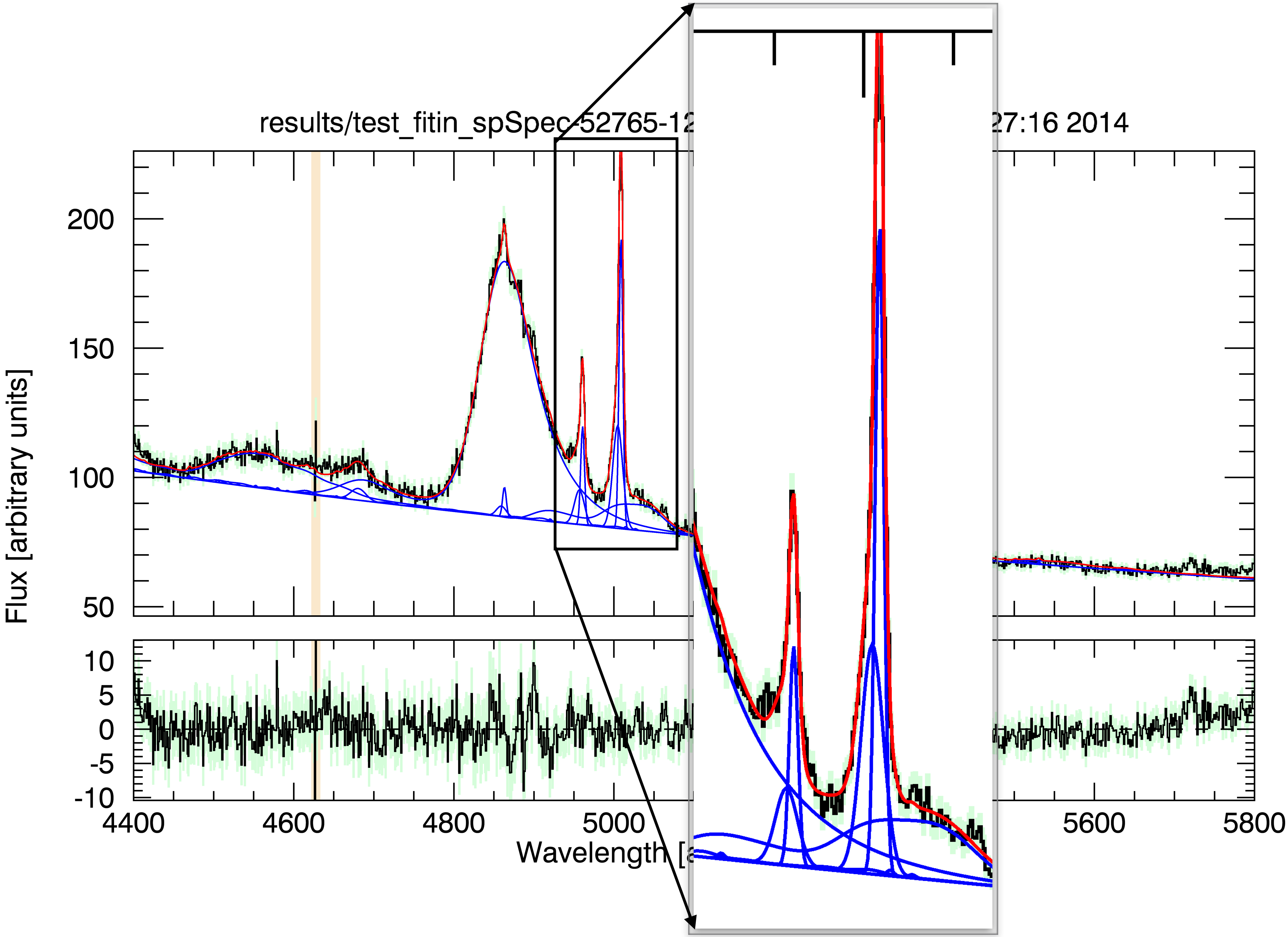

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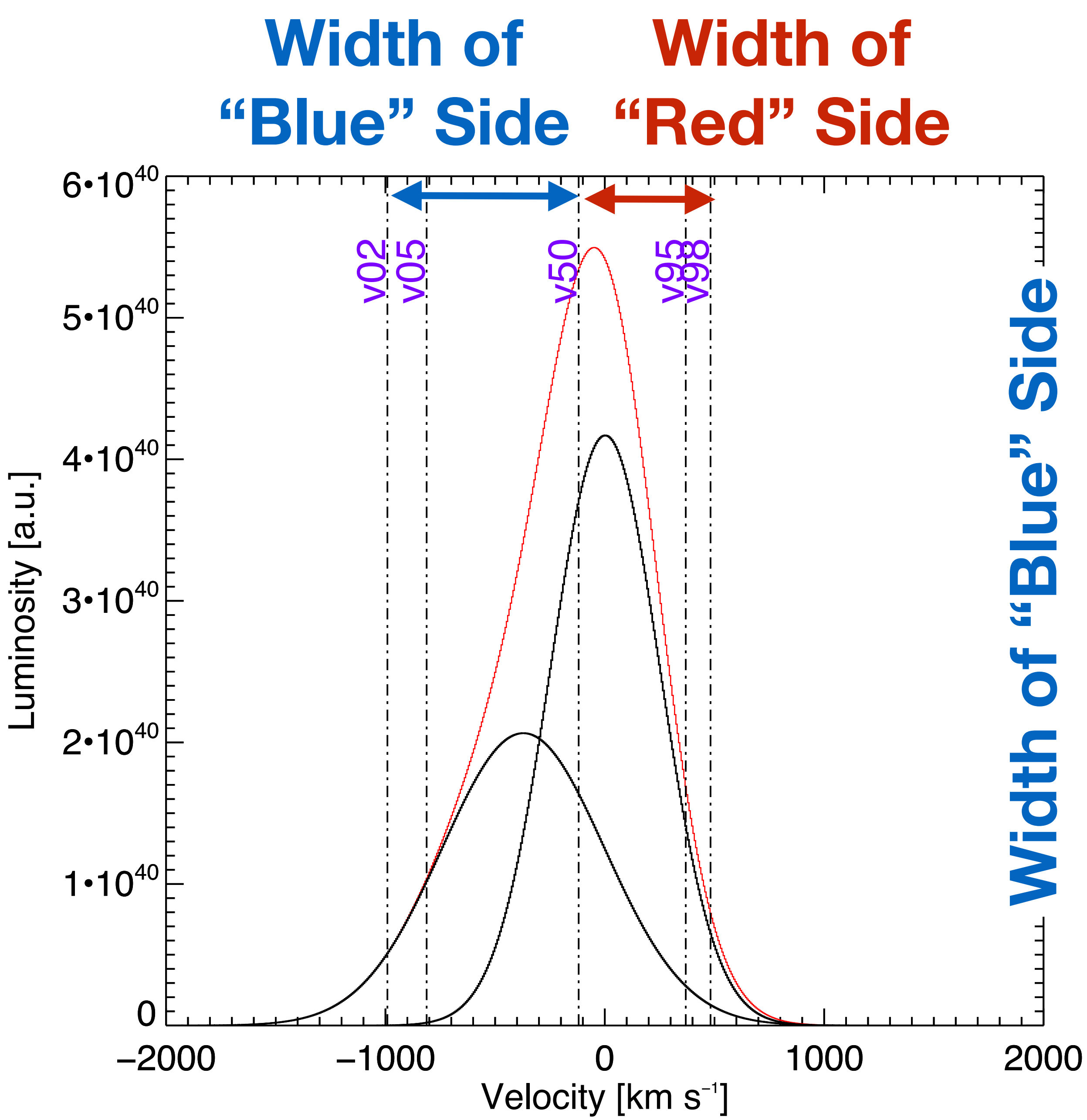
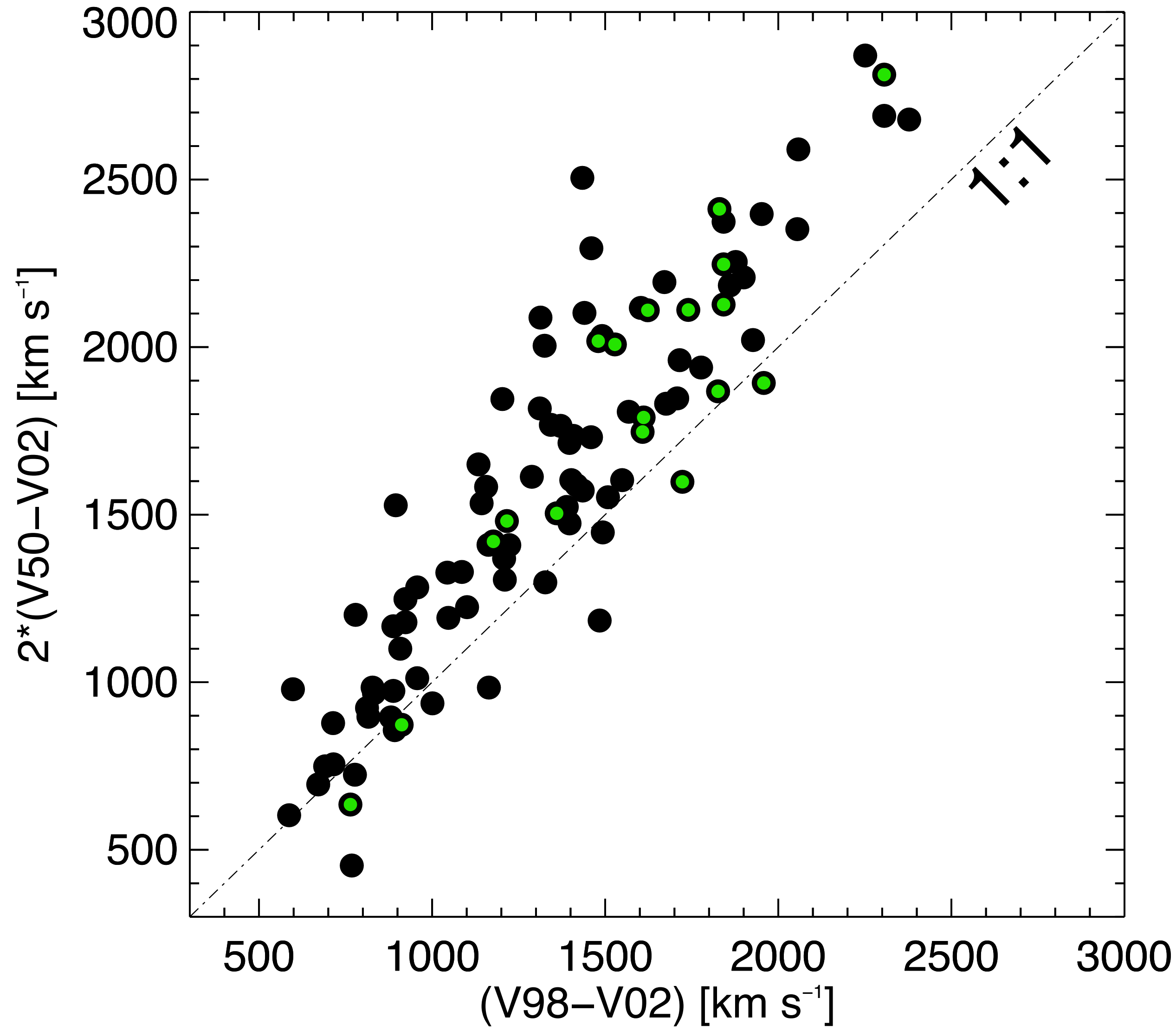
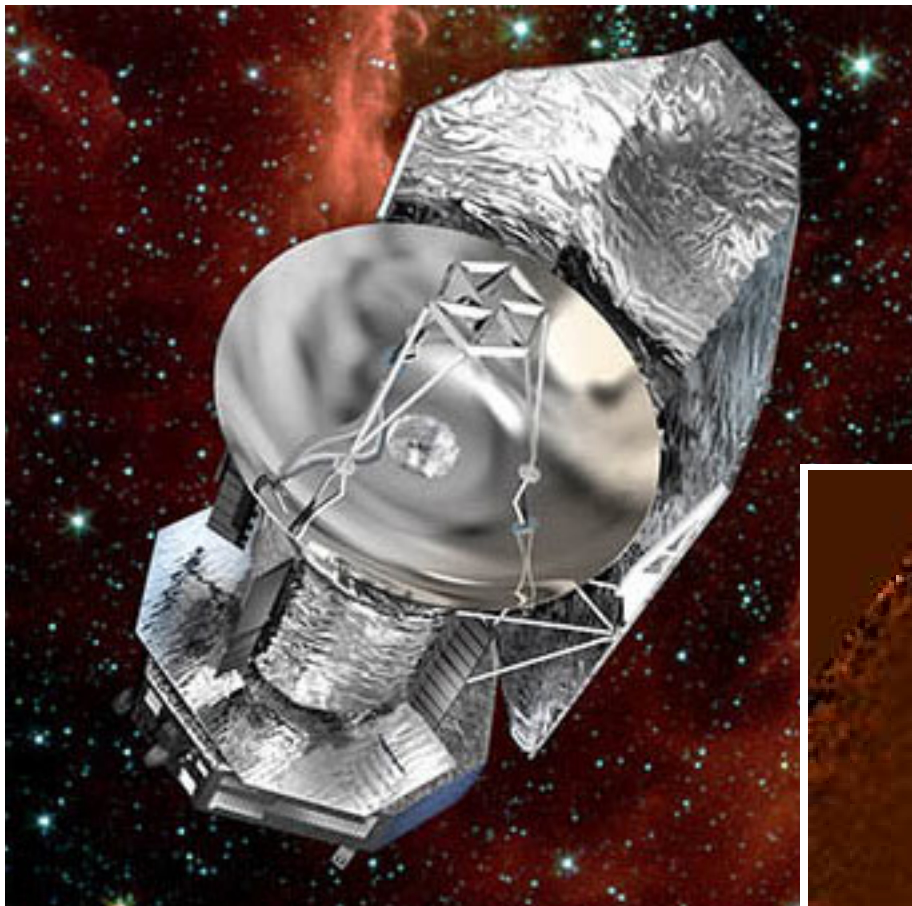
⭐ Fast ionised outflows …

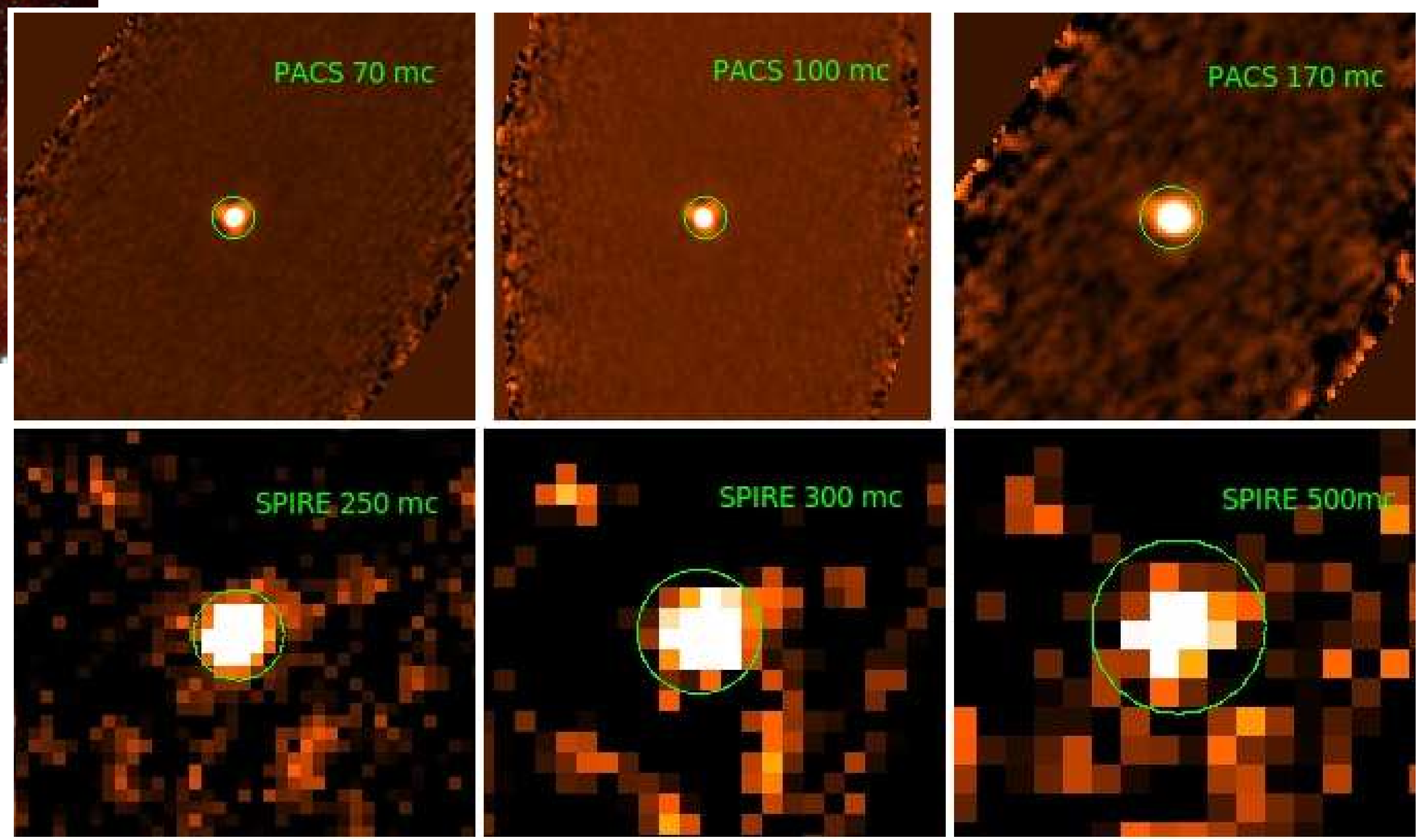




Ionized outflows and SF in local quasars

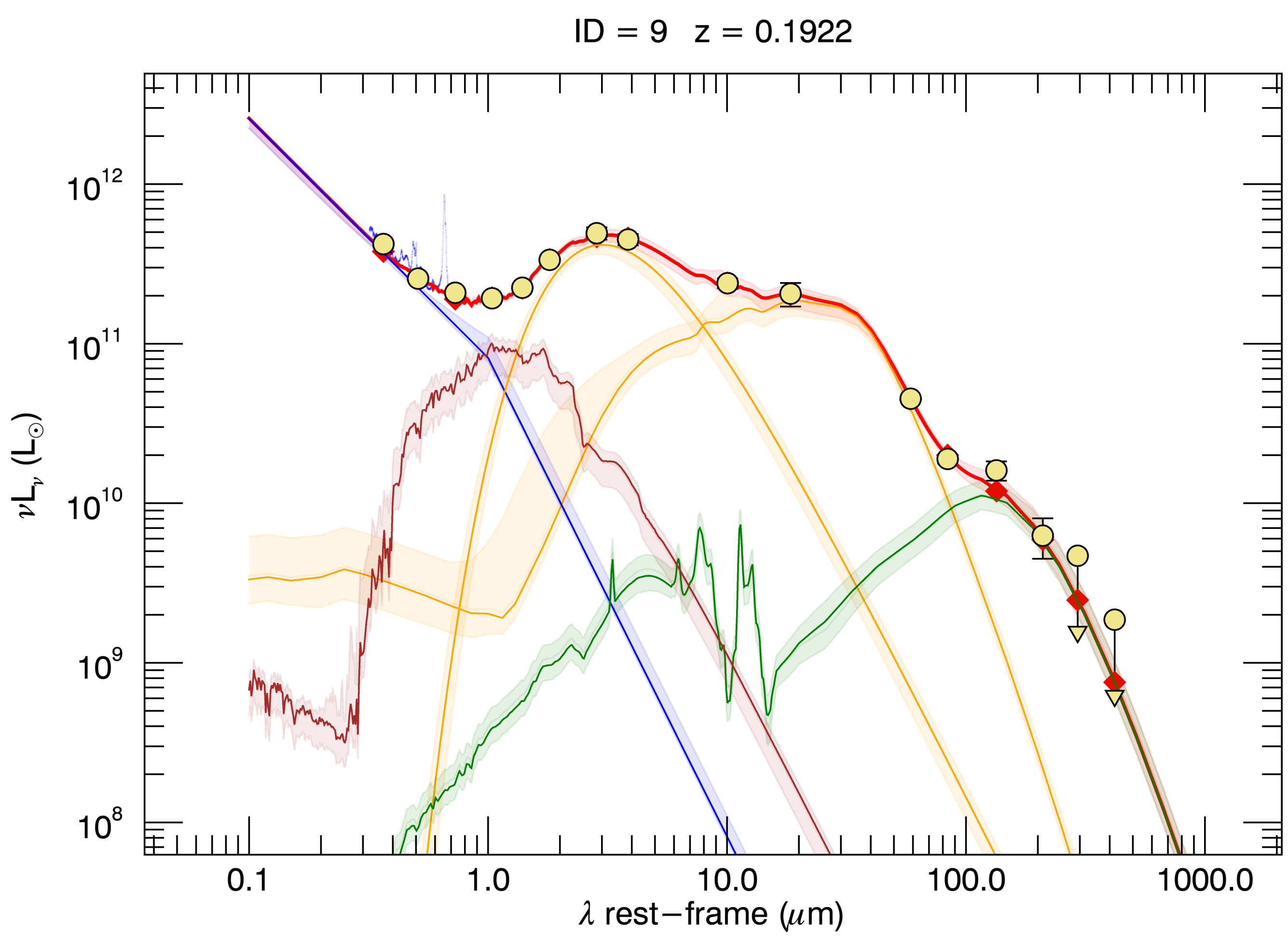
- Herschel observations at ~100 μm to measure the emission of “cold” dust heated by young stars

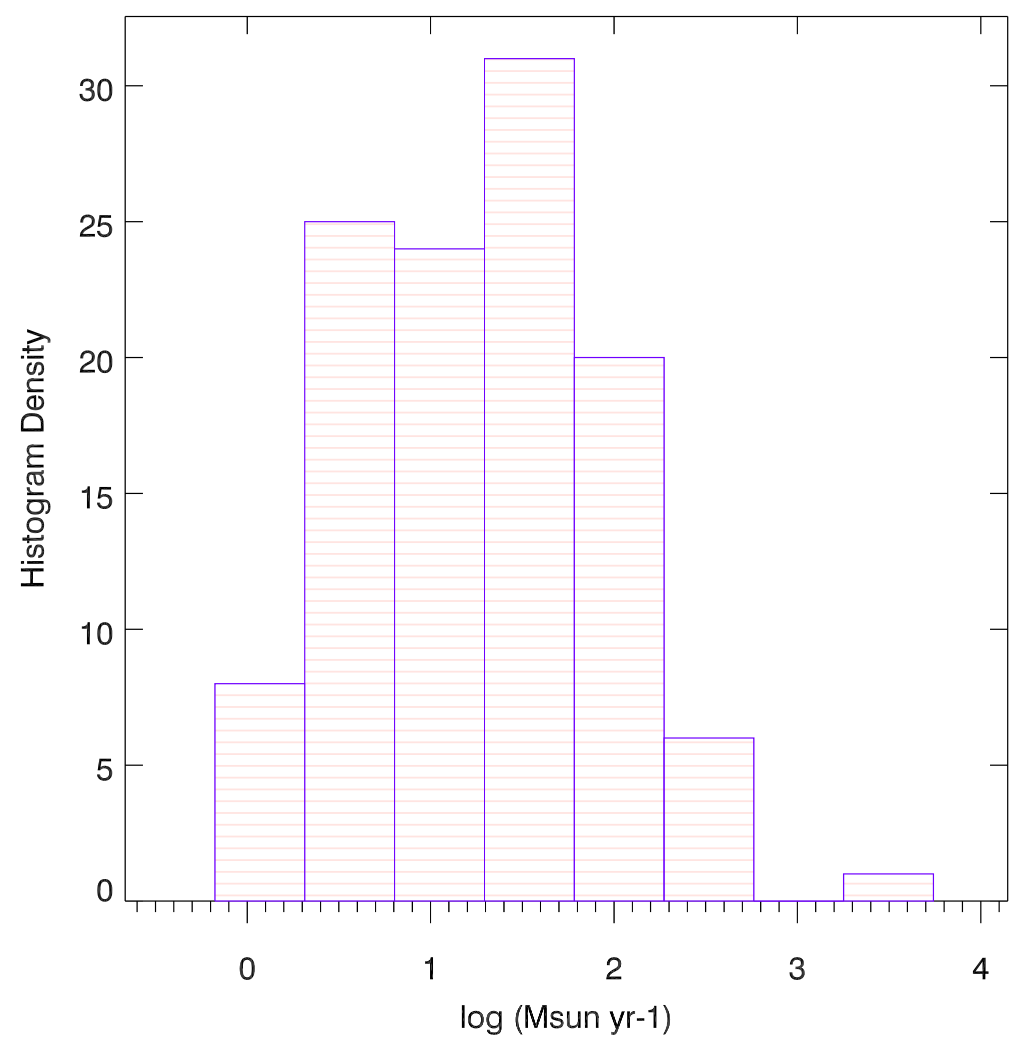




Ionized outflows and SF in local quasars

- SED combining Herschel + WISE + 2MASS + SDSS measurements
- SED fitting to estimate AGN IR luminosity and SF (Clumpy torus models by Nenkova & Elitzur, Starburst templates by Chary & Elbaz, Starr by Bruzual & Charlot 2003)
- From Kennicutt+98 $$SFR = 4.5\left(\frac{L_{FIR}}{10^{44}\,\mathrm{erg\,s^{-1}}}\right)\,\mathrm{M_\odot\,yr^{-1}}$$





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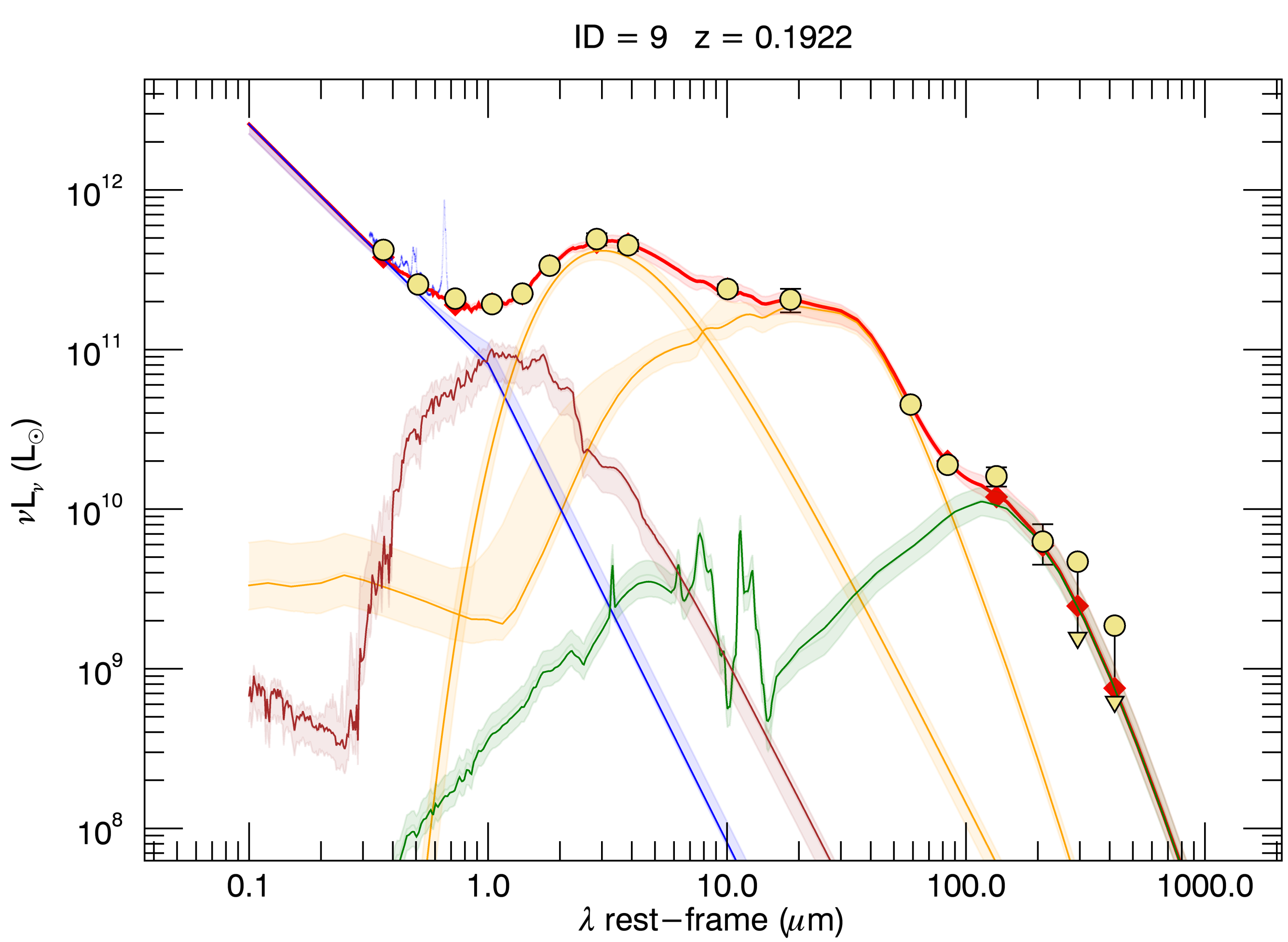
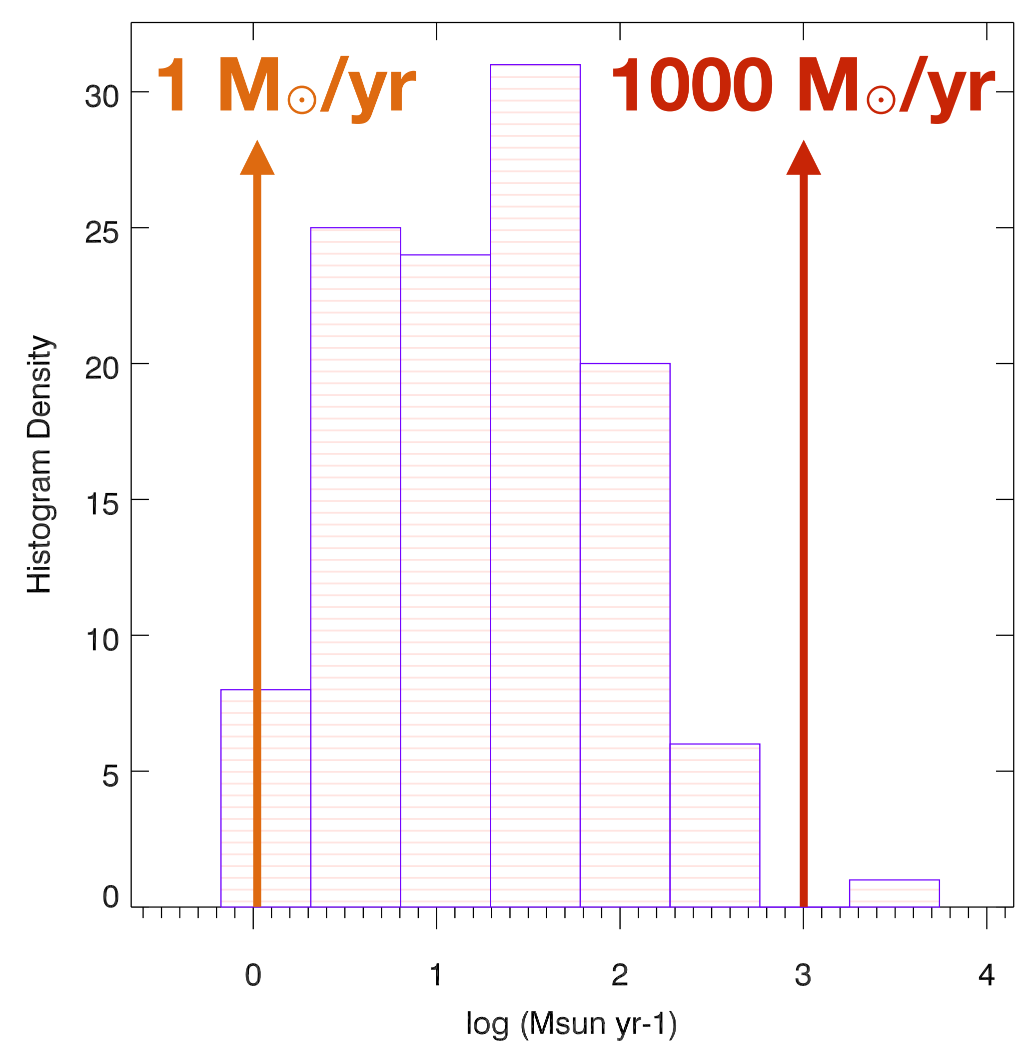
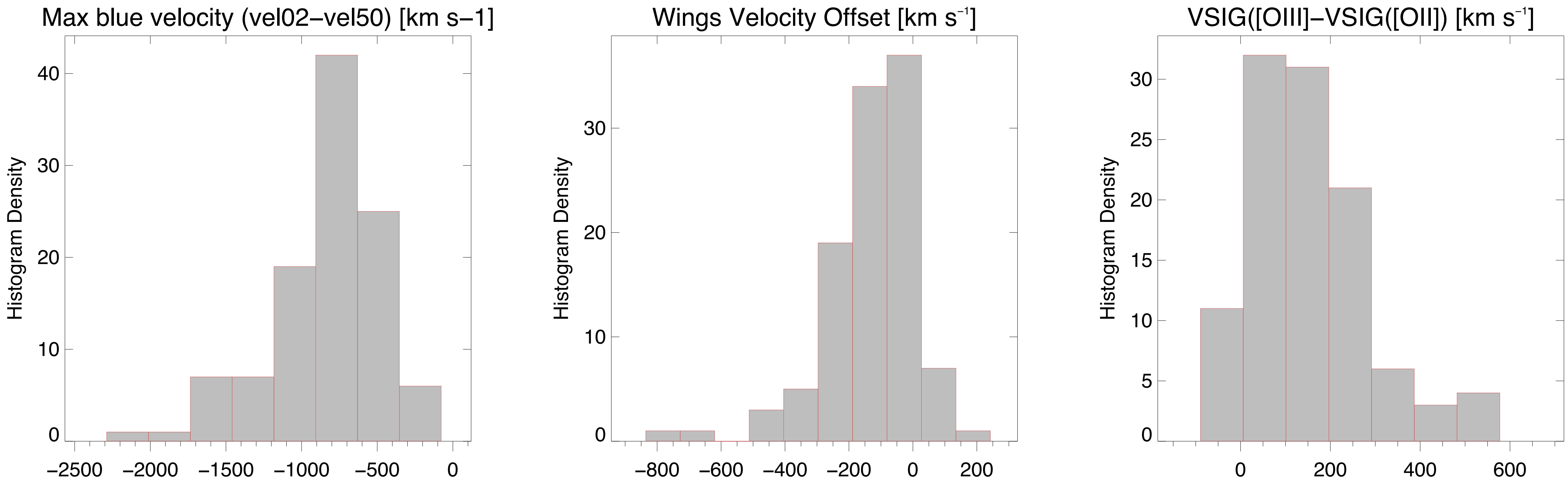




Ionized outflows and SF in local quasars

- High-redshift galaxies have SFRs higher than in the local Universe.
- Mean SFR in four z bins: outflow-dominated and unperturbed galaxies.
- Results are clearly in contrast with the negative AGN model



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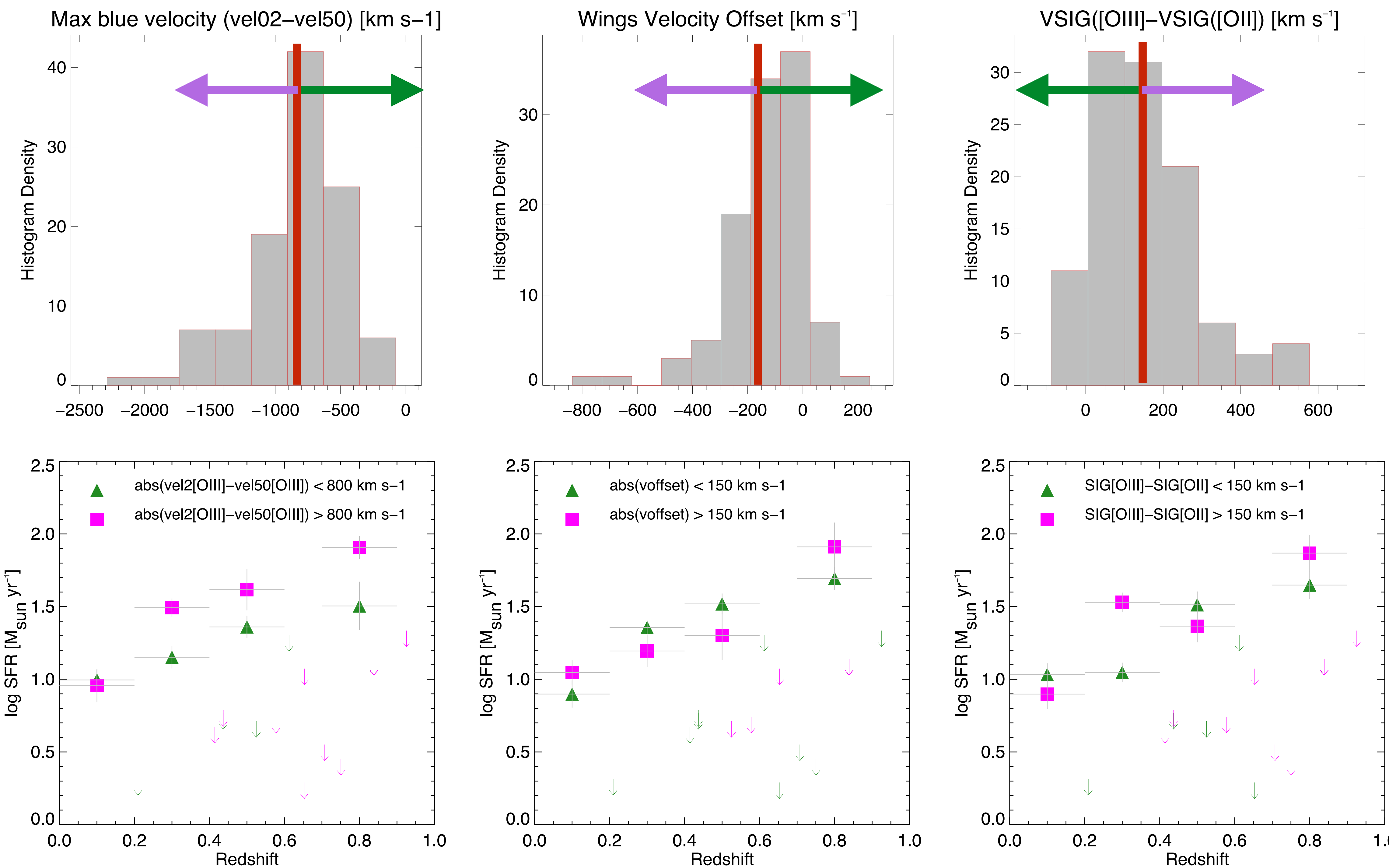

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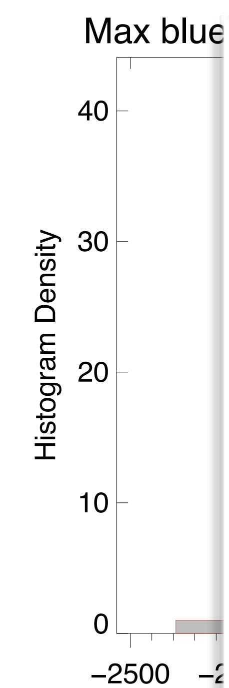
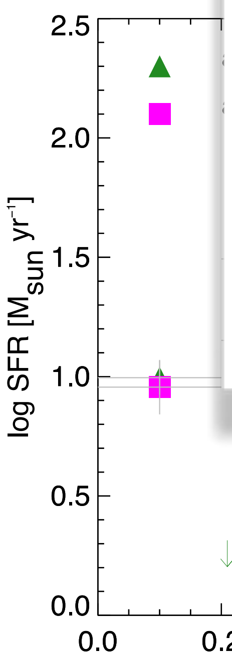
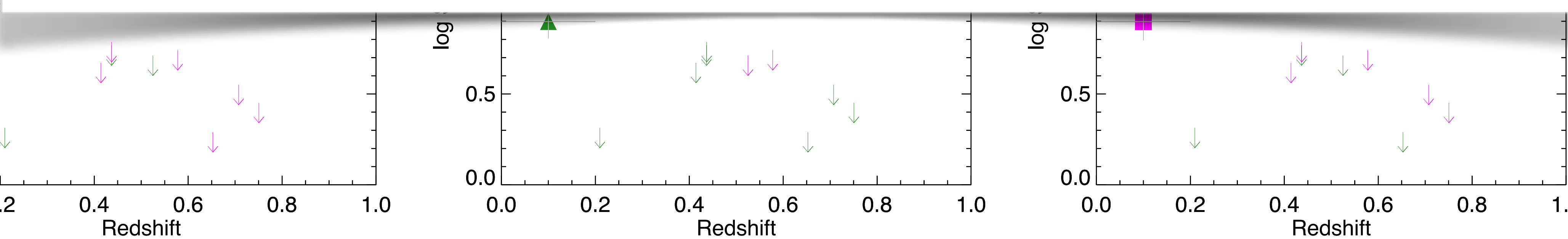


No relation between ionised outflows and star formation in luminous quasars. Why?

- AGN feedback only affects central regions of galaxy (BH growth self regulated, galaxy wide feedback made by stars)
- Mixture of positive and negative feedback which washes away any correlation
- QSO lifetime much shorter than timescale needed for feedback effects to manifest

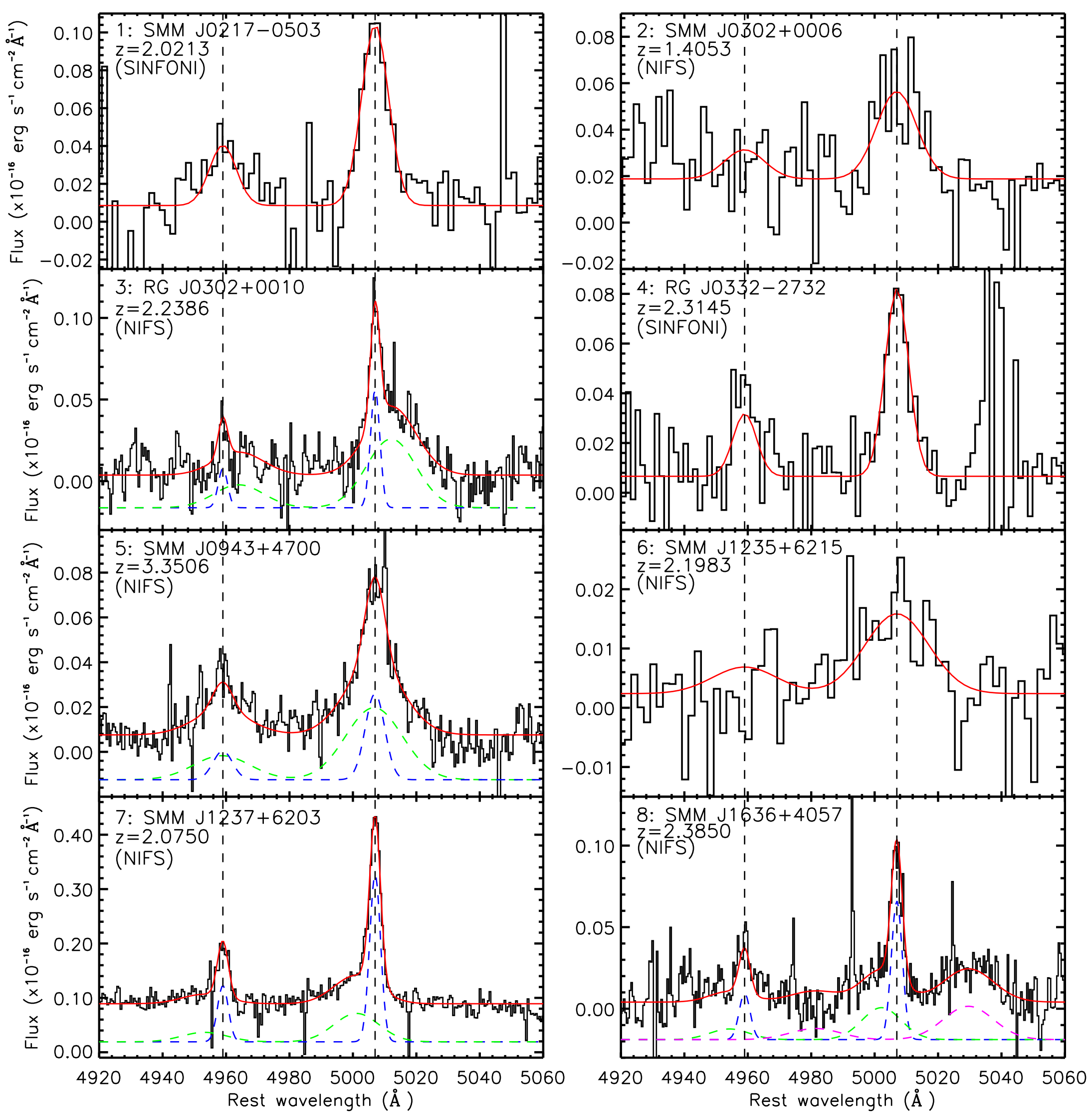


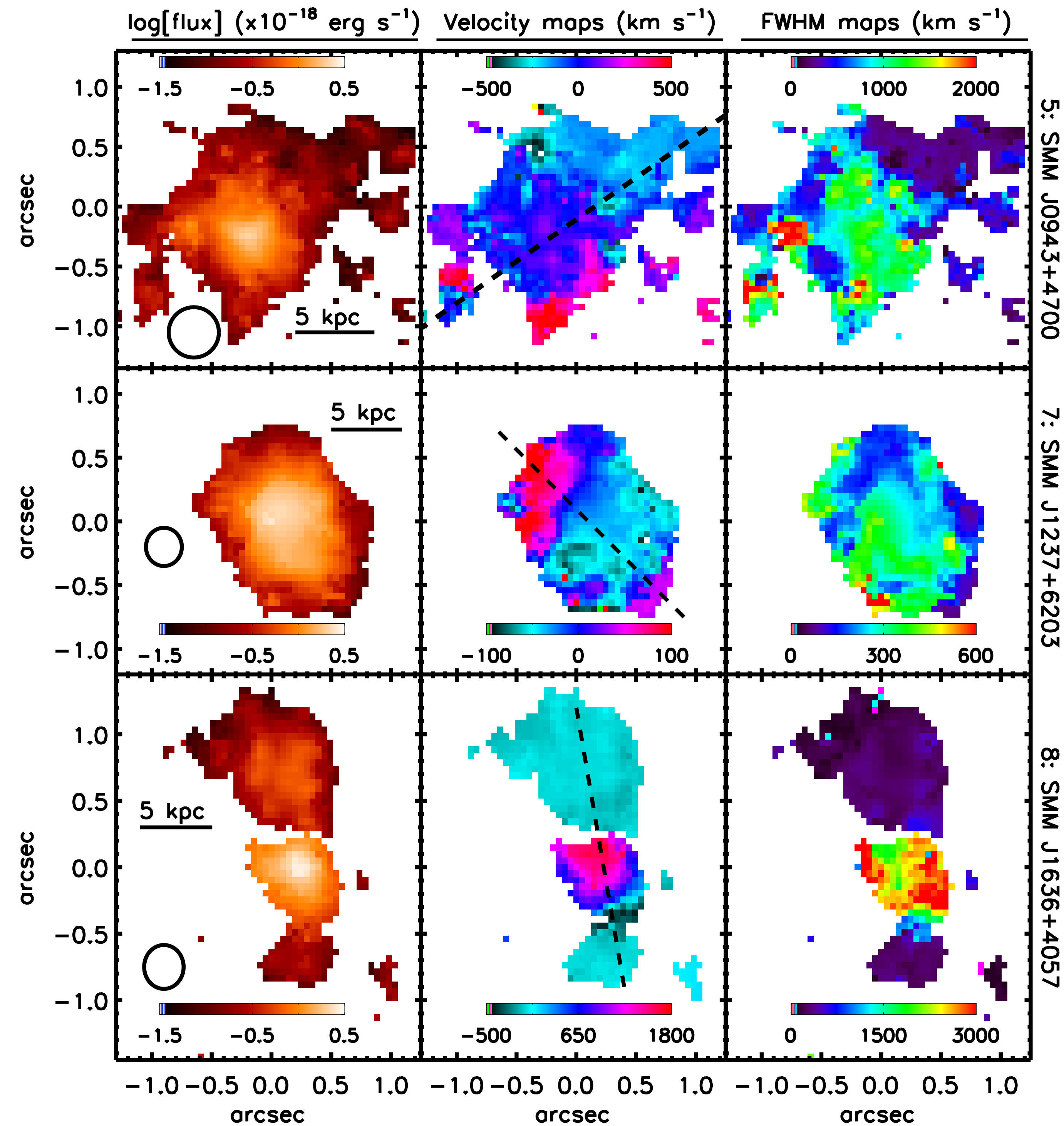


Ionized Outflows (see Marcella's talk)

Outflows at z~1.5-3.5 in ULIRGs (also SMGs) with radio quiet AGN

- traced by [OIII]λλ5007,4959
- L([OIII])~ 1-4 ×10^{43} erg s^{-1}
- FWHM([OIII]) ~700-1400 km/s
- v_{out} ~ 300-900 km/s
- extended over 4-15 kpc
- P_{kin} ~ 10^{43}-10^{45} erg/s

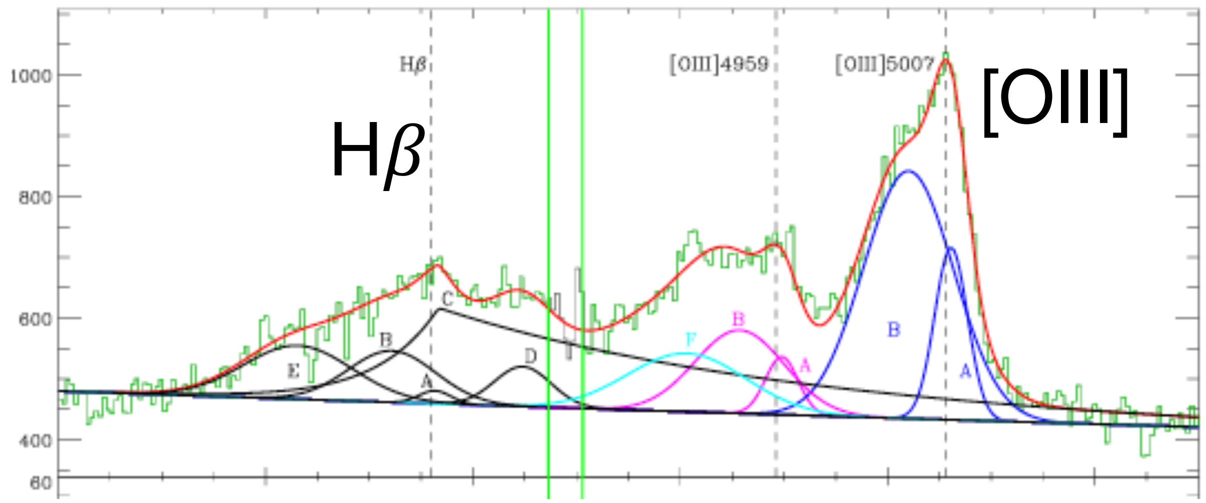




Alexander et al. 2010, Harrison et al. 2012

Ionized outflows in luminous quasars

- The prequel: luminous “normal” quasar at z~2.4 VLT/SINFONI H band



Very “broad” [OIII] FWHM ~1500 km/s

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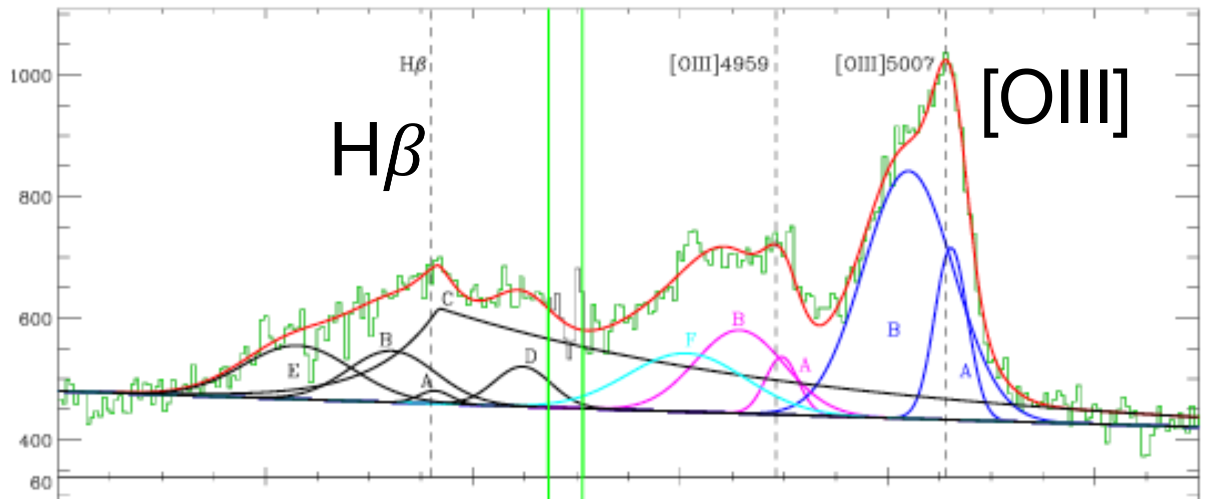

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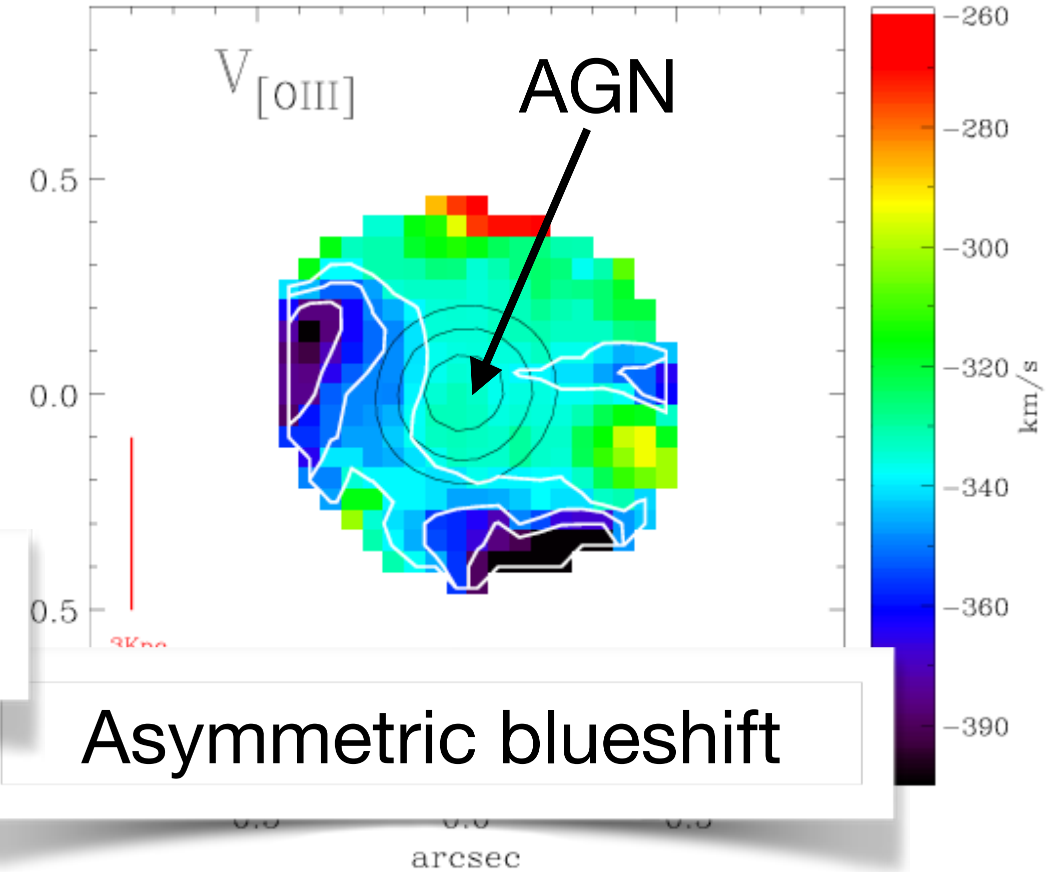

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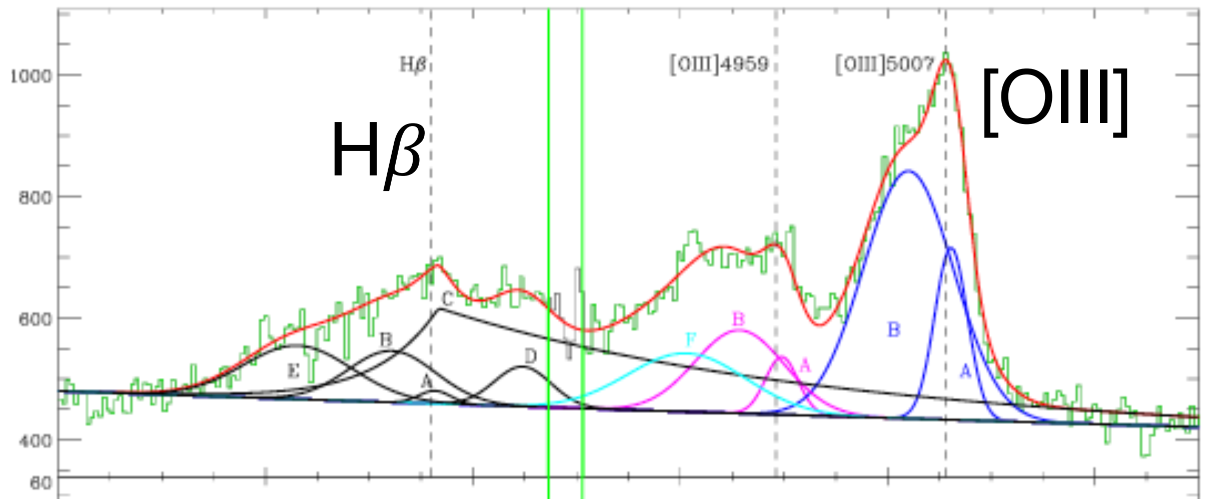

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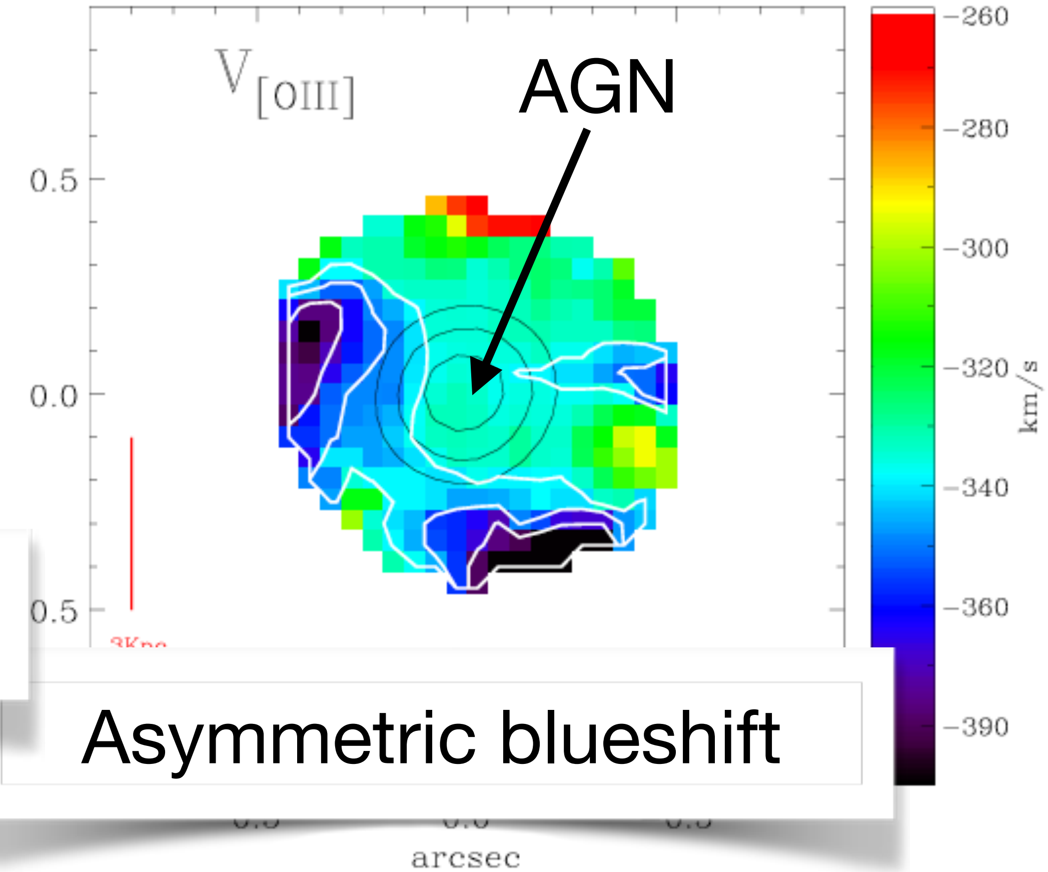

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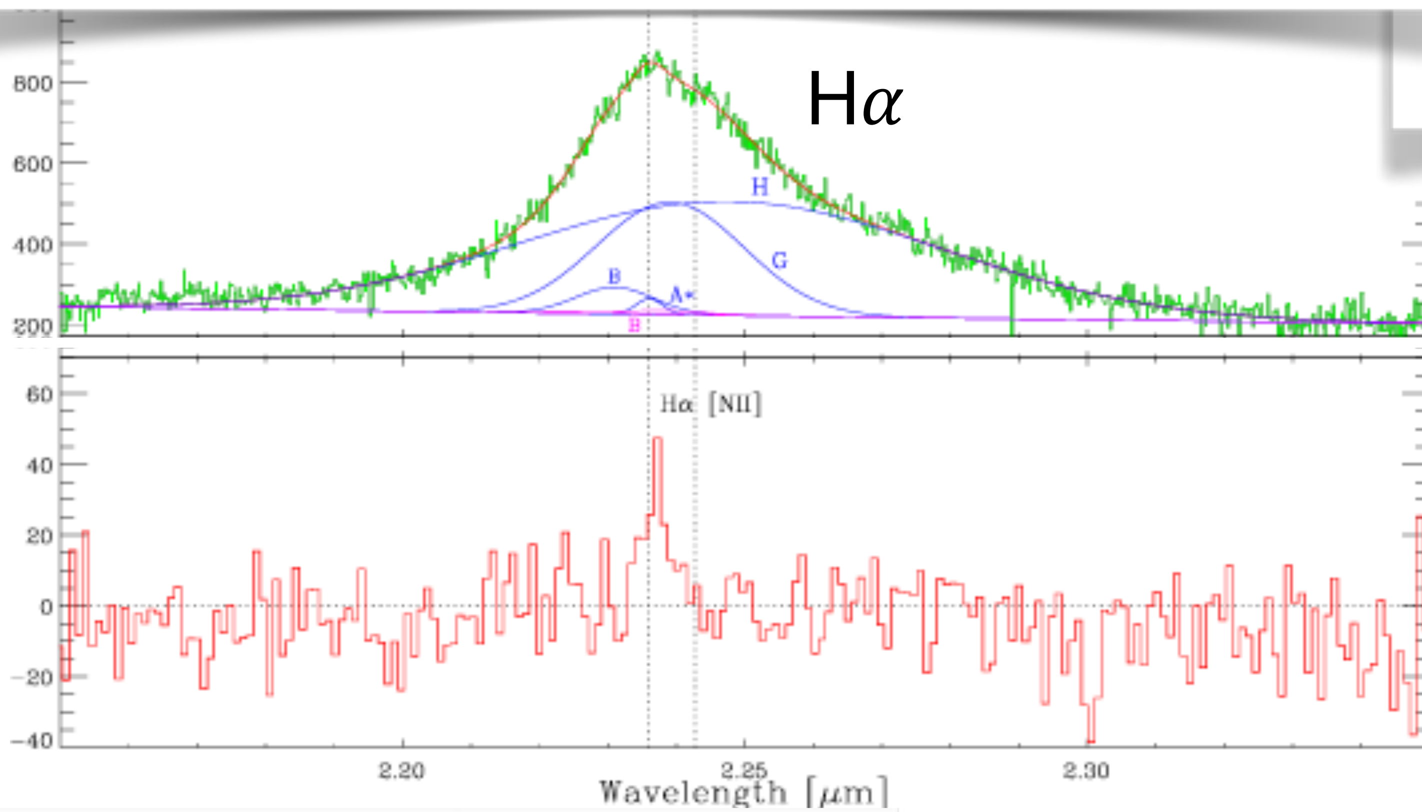

Narrow Hα from SF

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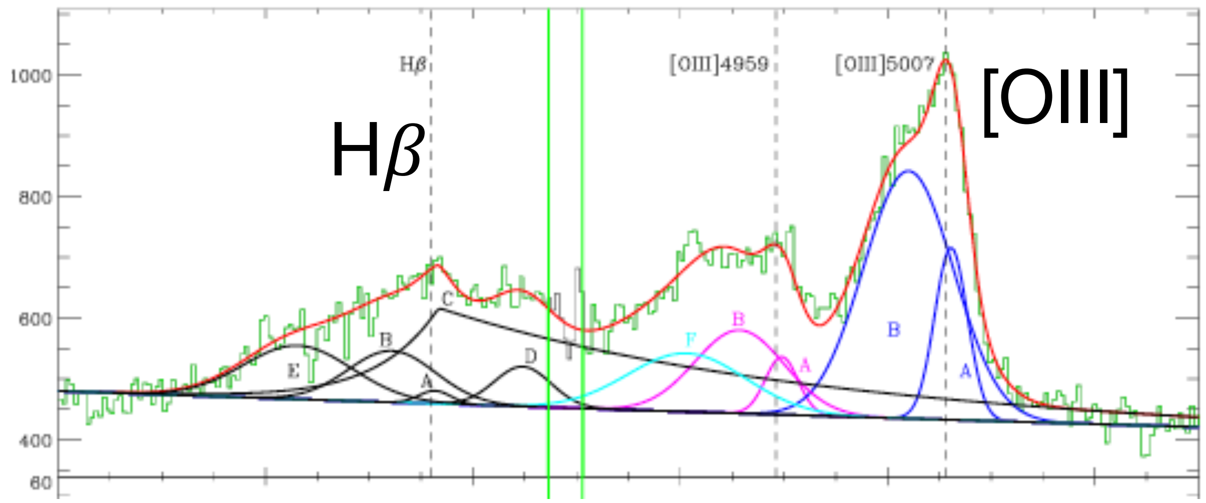

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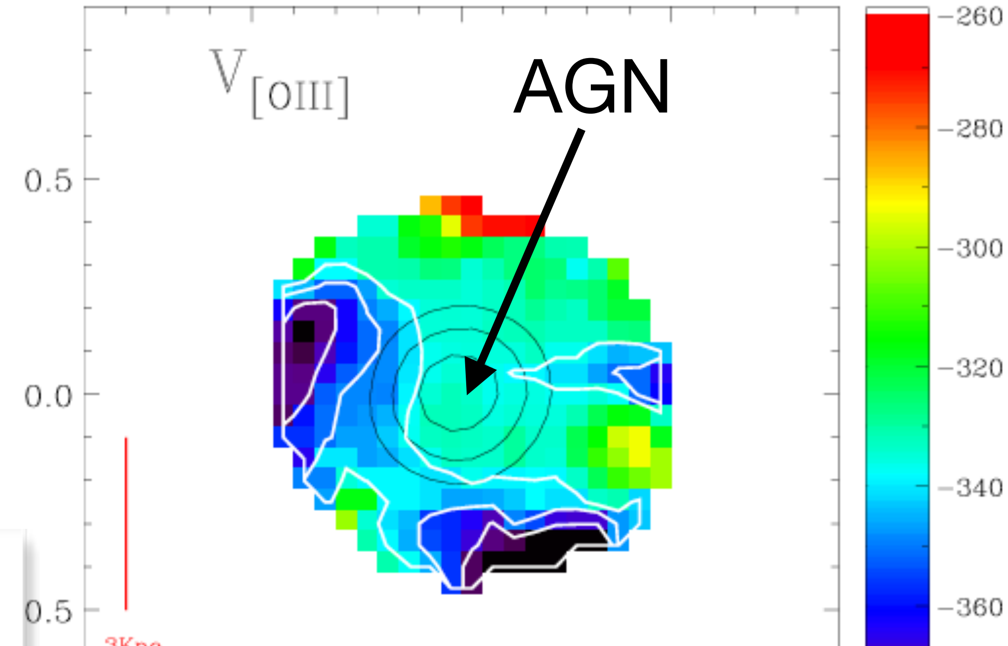
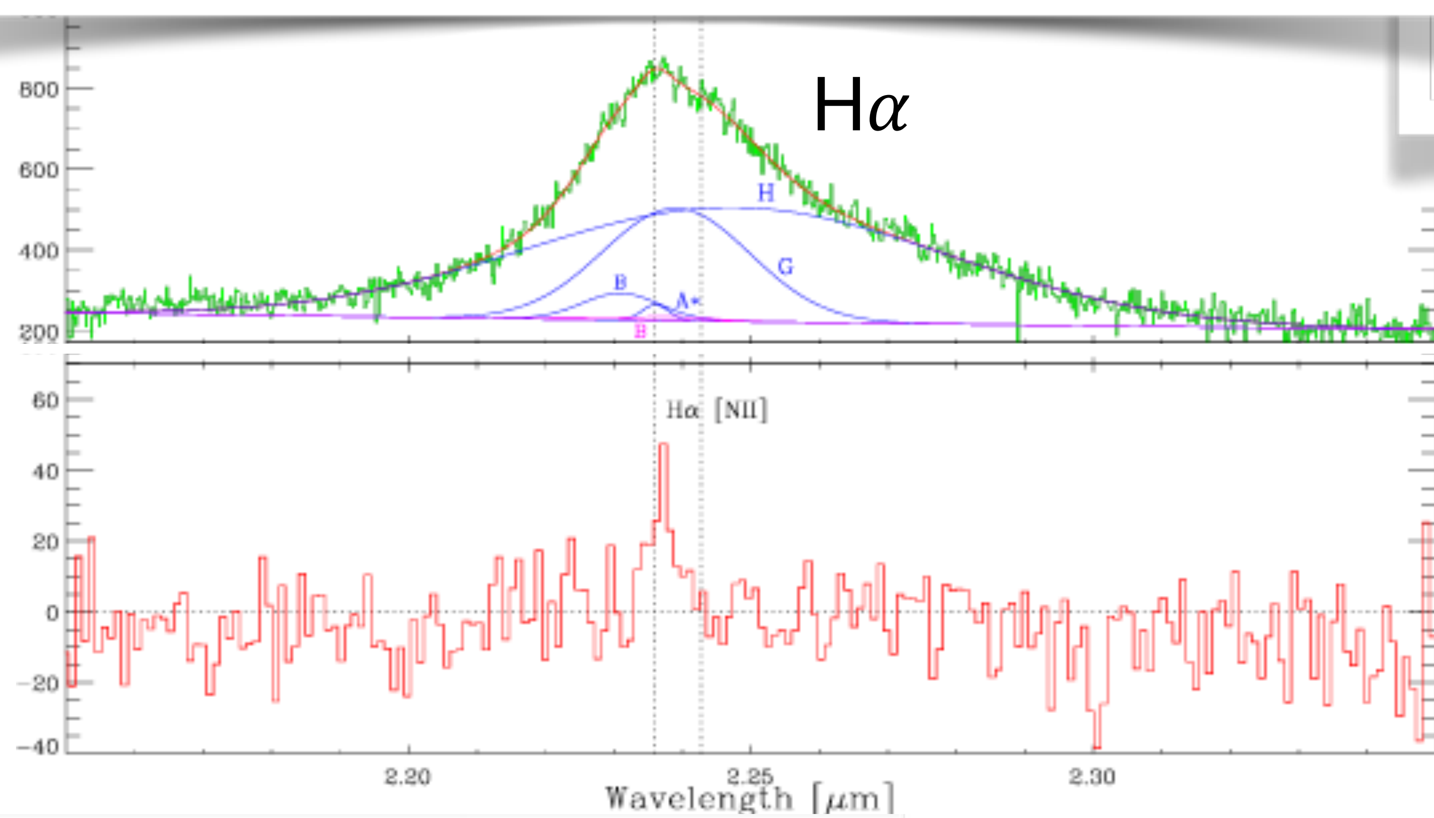


Asymmetric blueshift

No SF with fast outflow!



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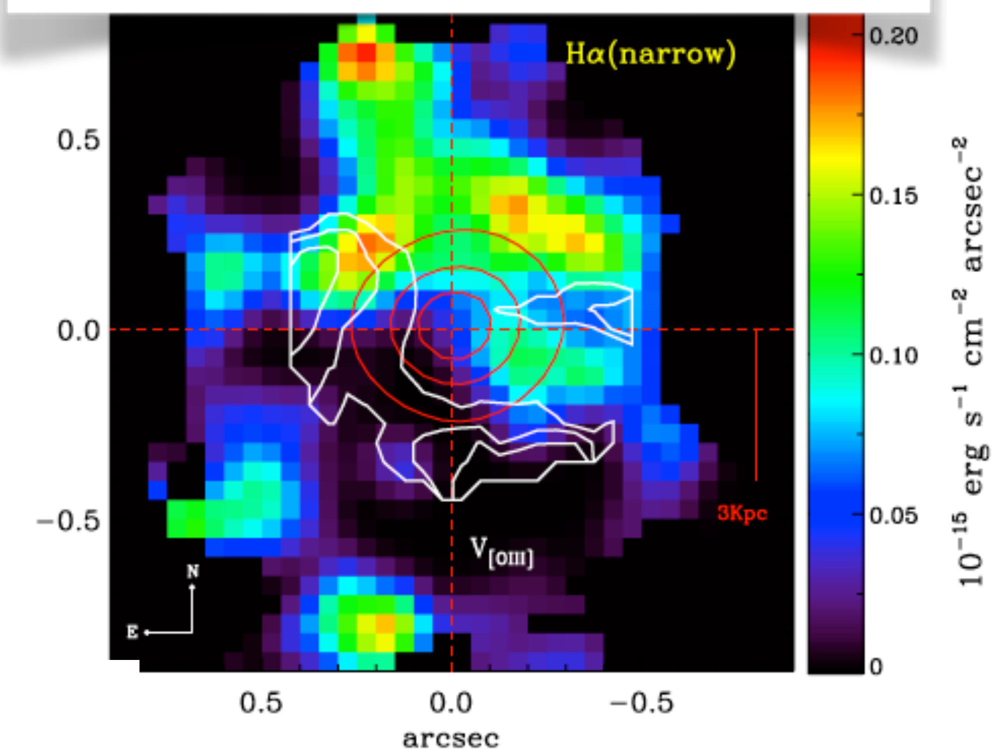
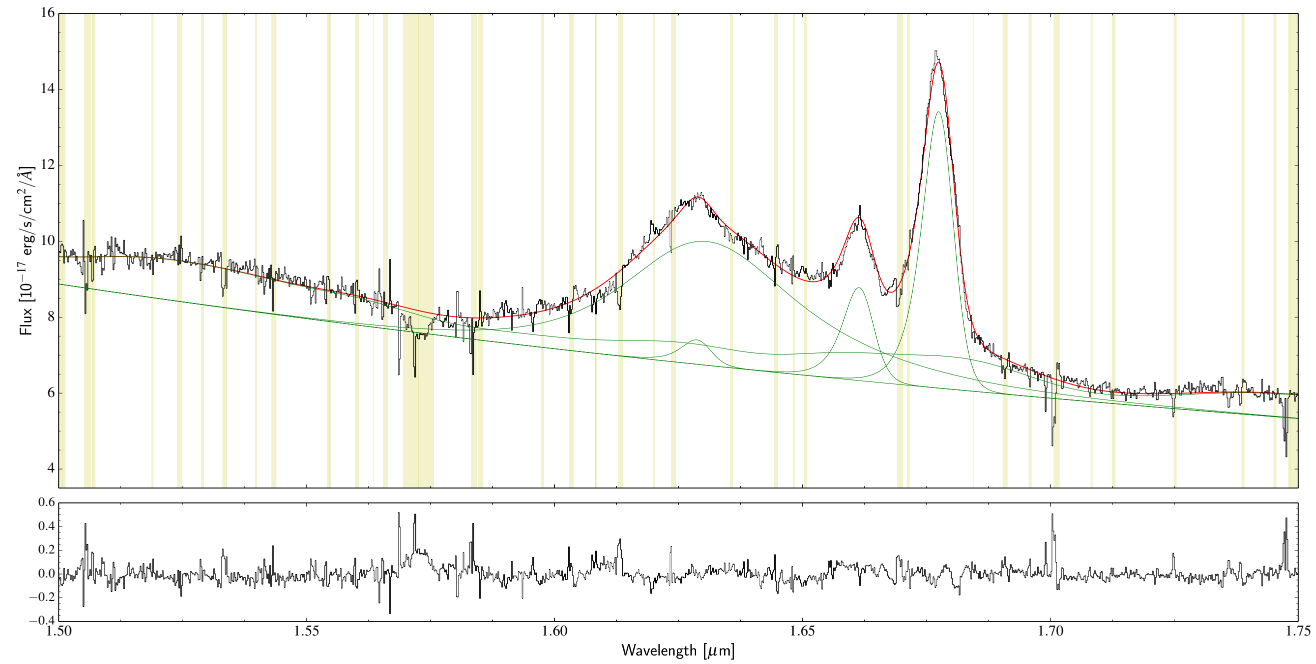
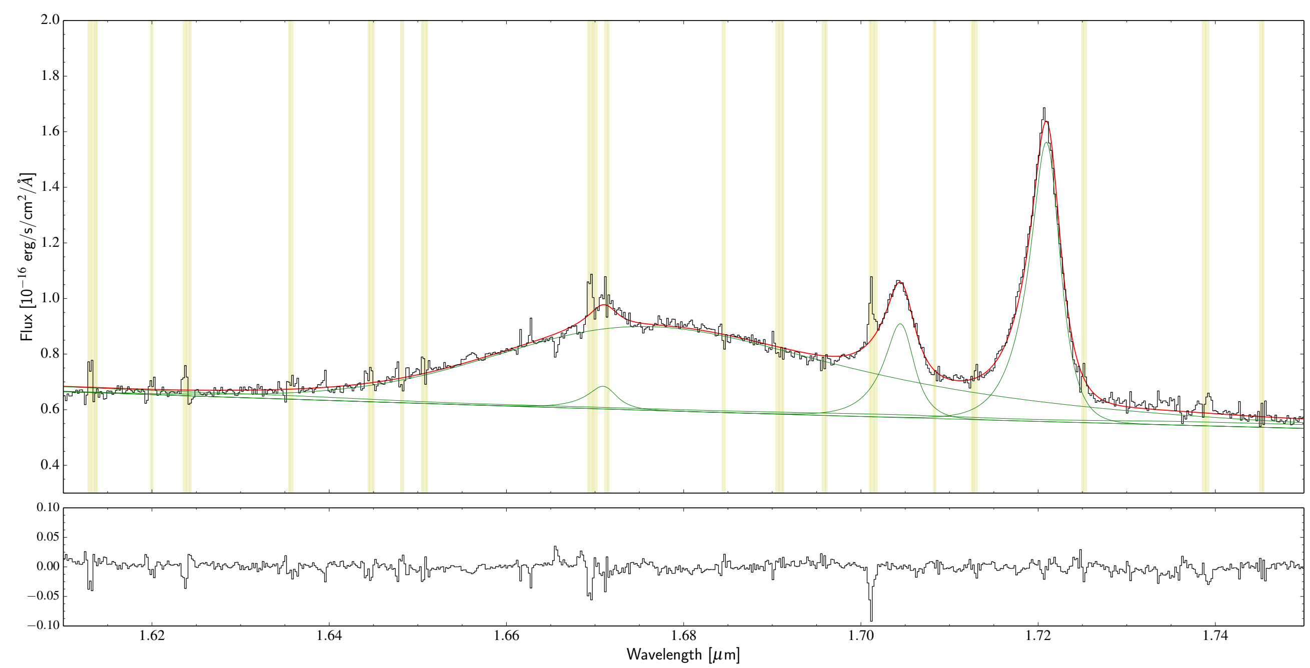


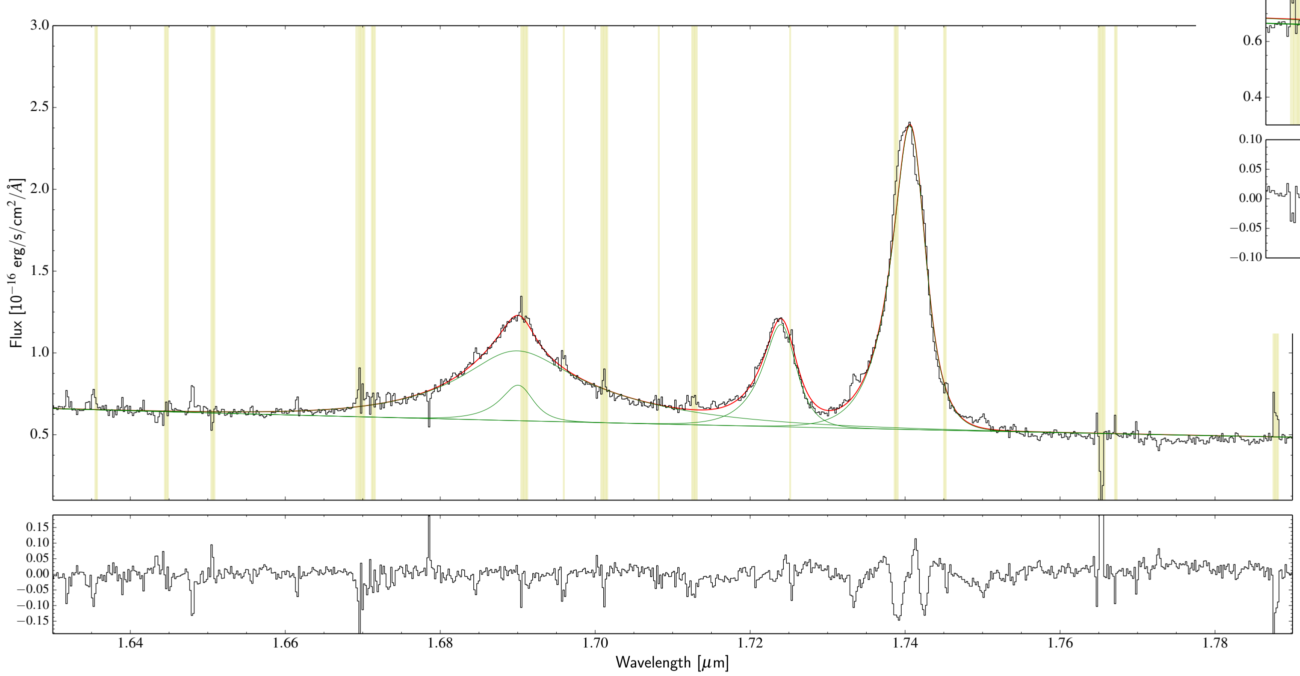
Cano-Diaz+12

Ionized outflows in luminous quasars

- The sequel: sample of 6 luminous “normal” quasars at z~2.3-2.5
- L_{bol}~ 10^{47} - 10^{48} erg sec^{-1}
- SINFONI@VLT spectroscopy in H band
- seeing limited resolution (~0.5” → ~4 kpc @ z=2.4)
- broad [OIII], FWHM ~ 1000-2000 km/s







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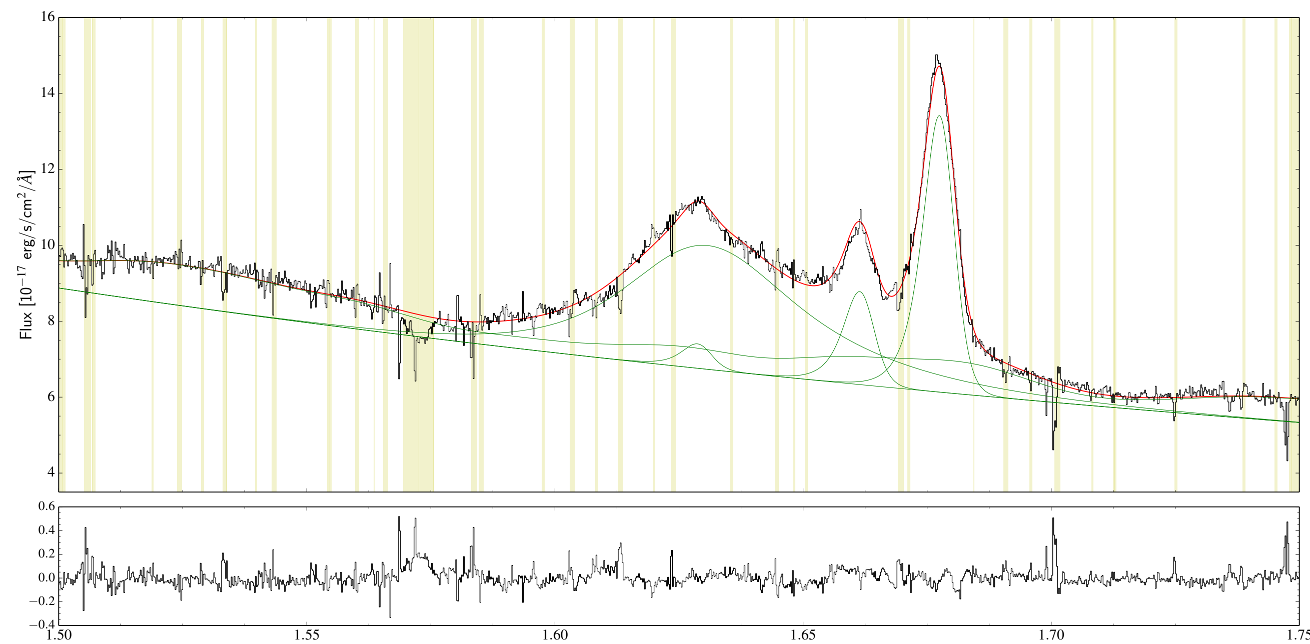
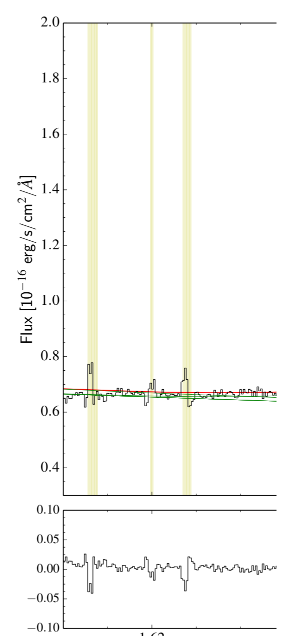
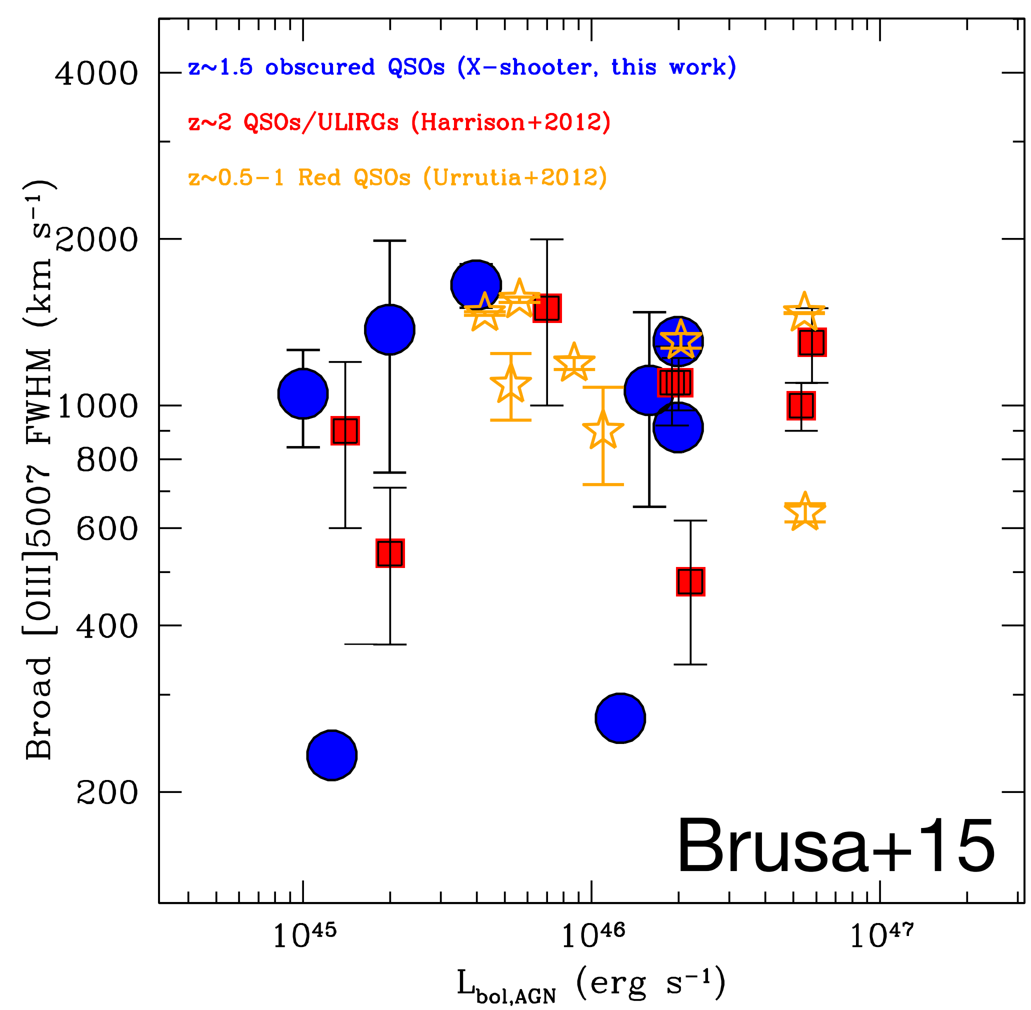
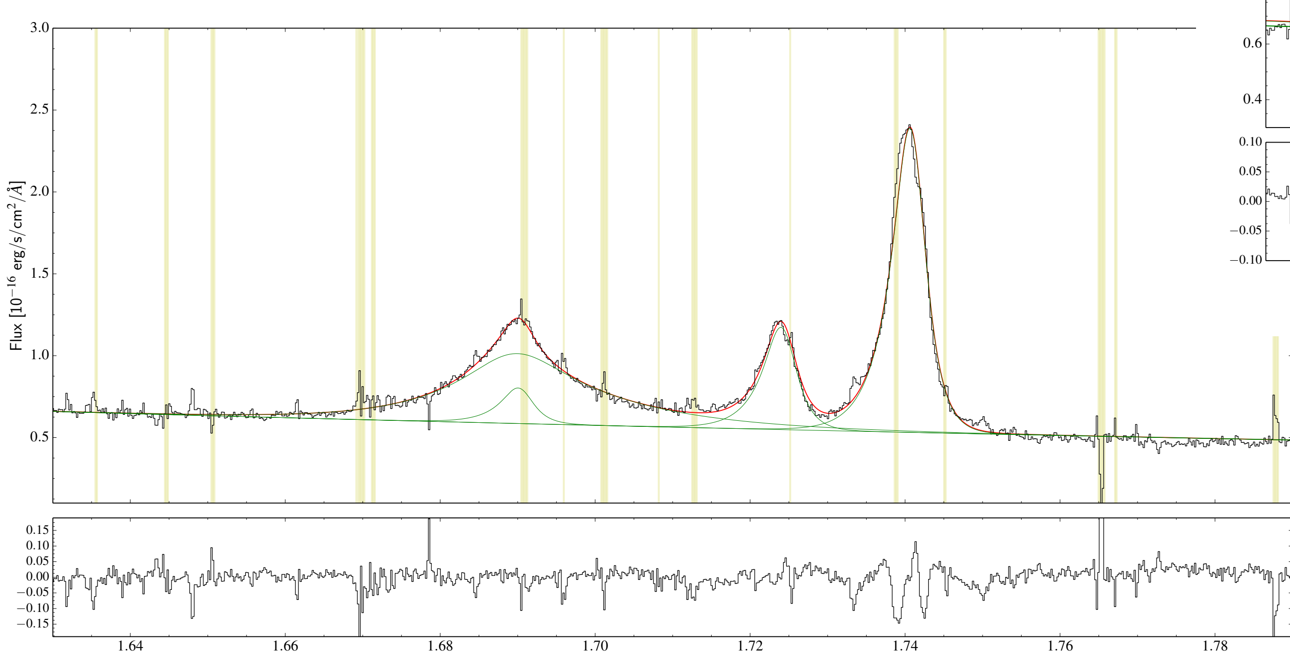


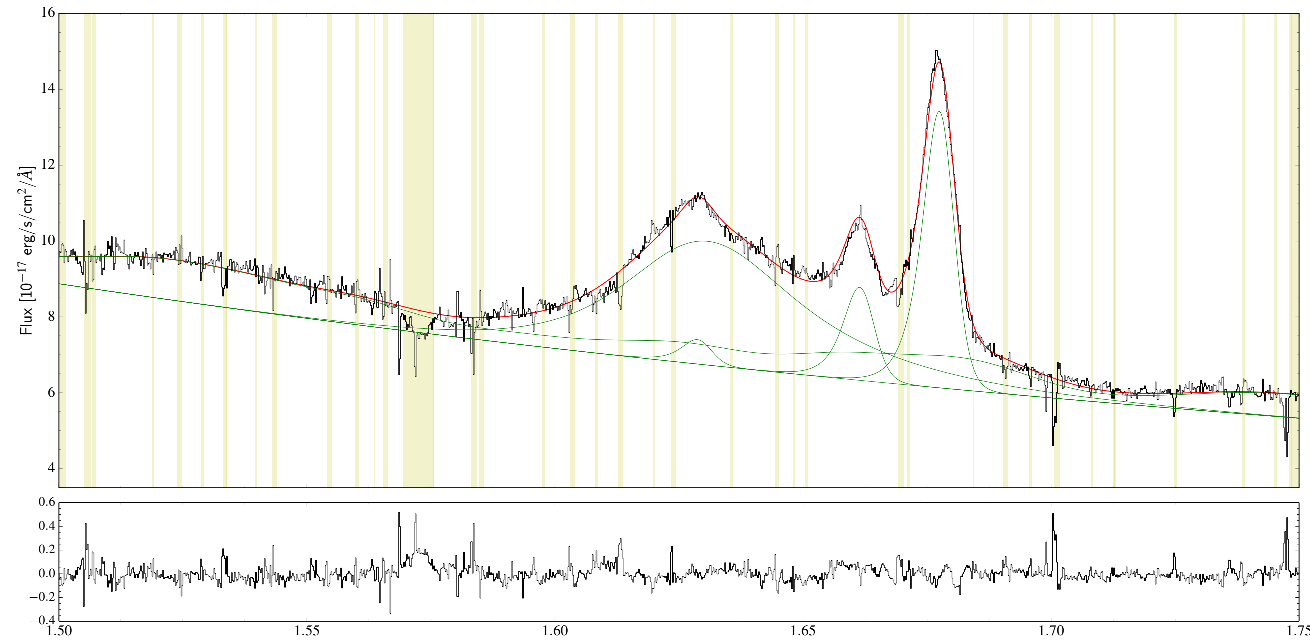


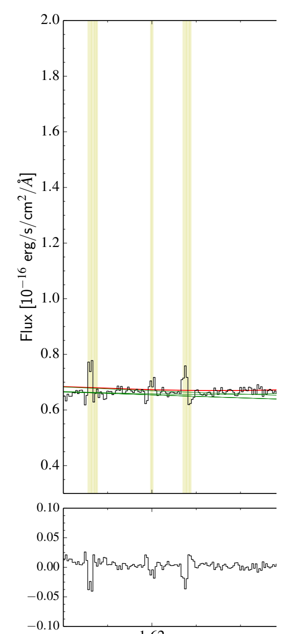


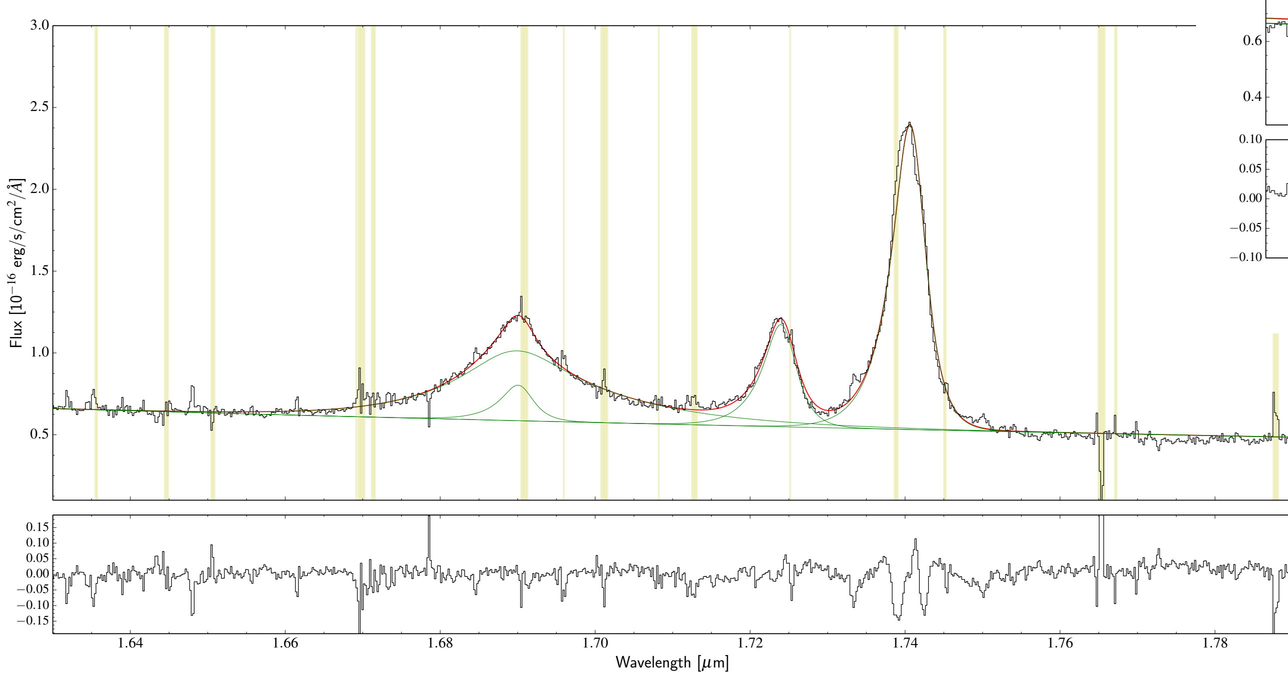


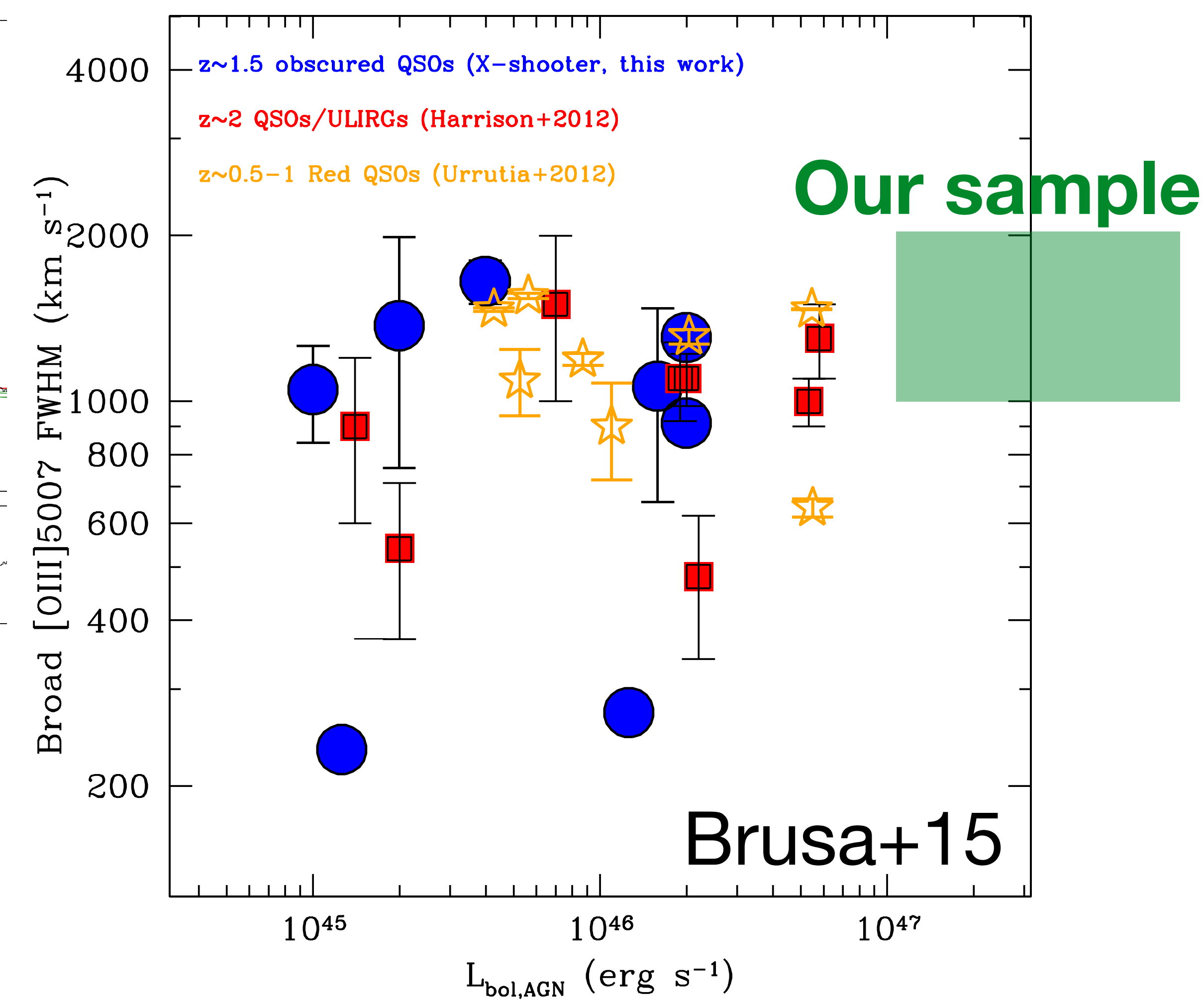
Ionized outflows in luminous quasars

- The sequel: sample of 6 luminous “normal” quasars at z~2.3-2.5
- L_{bol}~ 10^{47} - 10^{48} erg sec^{-1}
- SINFONI@VLT spectroscopy in H band
- seeing limited resolution (~0.5” → ~4 kpc @ z=2.4)
- broad [OIII], FWHM ~ 1000-2000 km/s



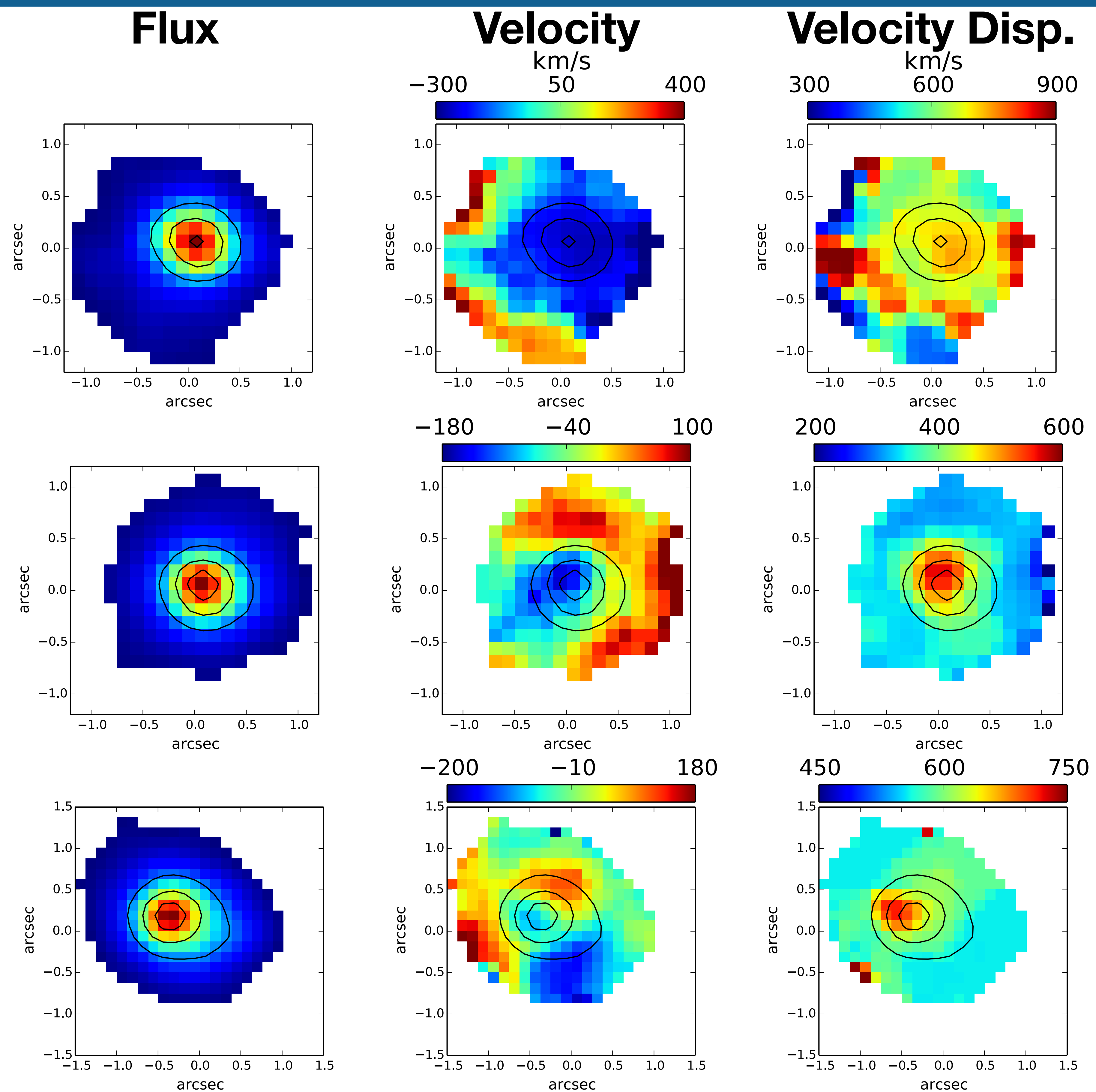






Ionized outflows in luminous quasars

- Get PSF from broad Hβ flux map
- *Spatially resolved [OIII] kinematical maps in 5/6 objects*
- *Outflow velocities of ~300-600 km/s*
- *Velocity dispersions up to ~800 km/s*



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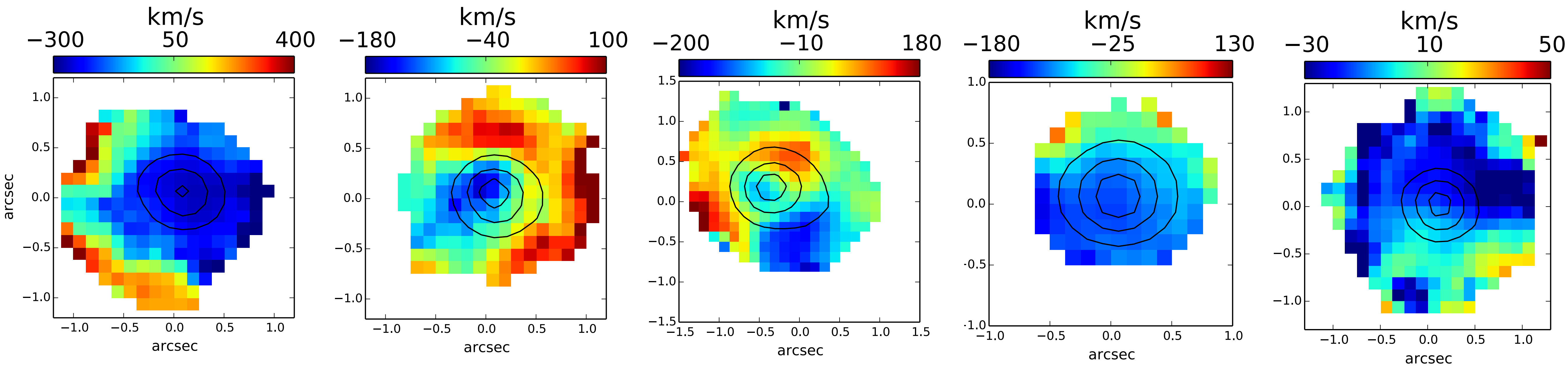
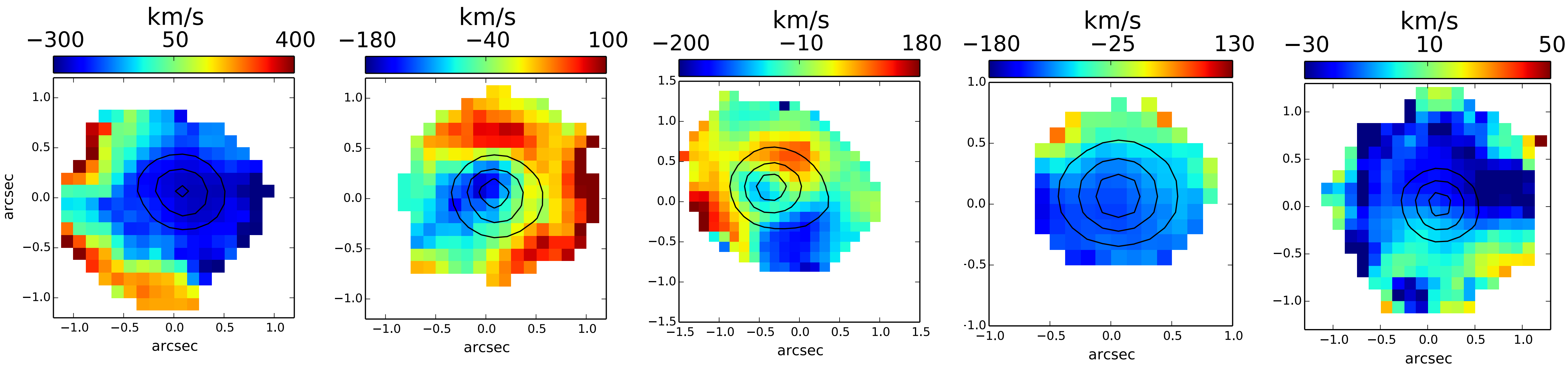
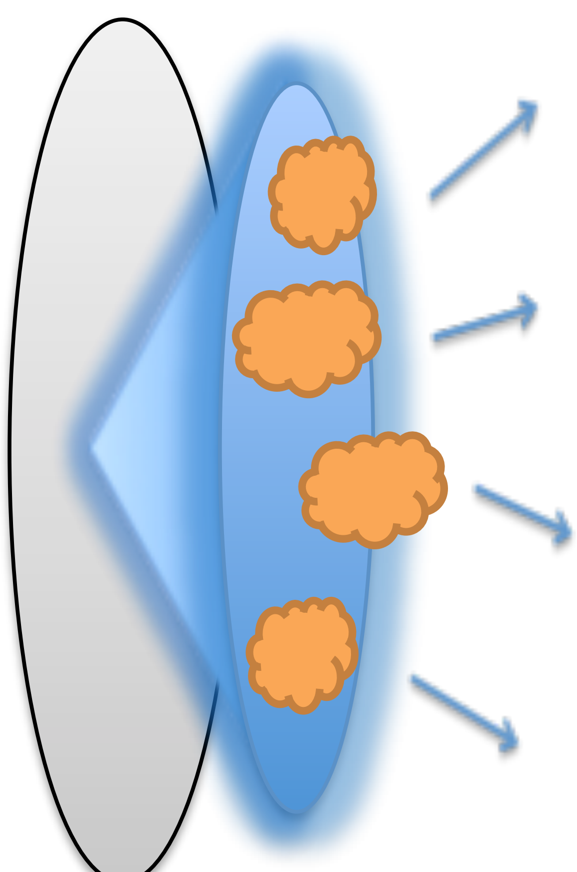


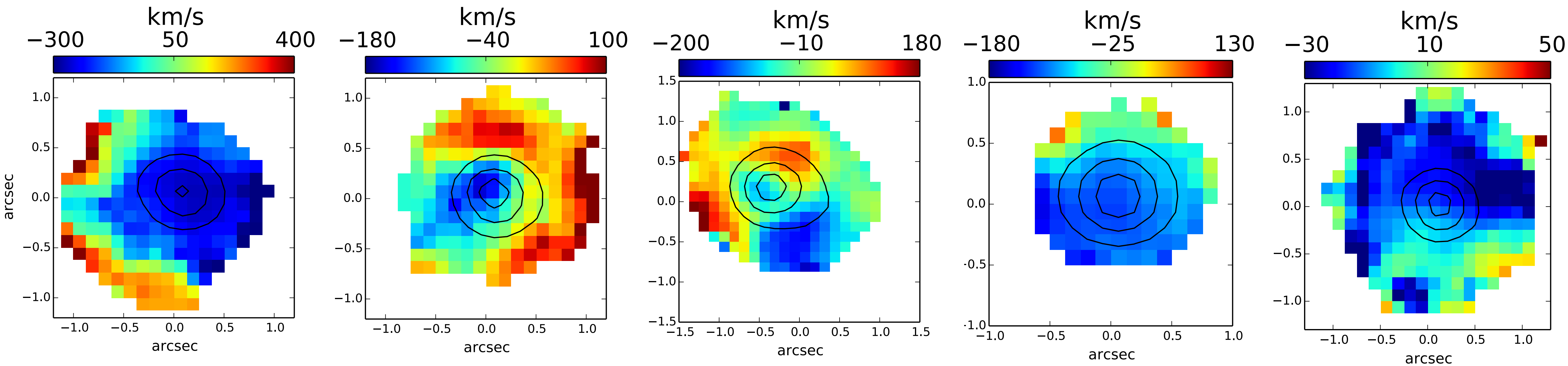
Ionized outflows in luminous quasars



Simple kinematical model:
disk + conical outflow



Ionized outflows in luminous quasars



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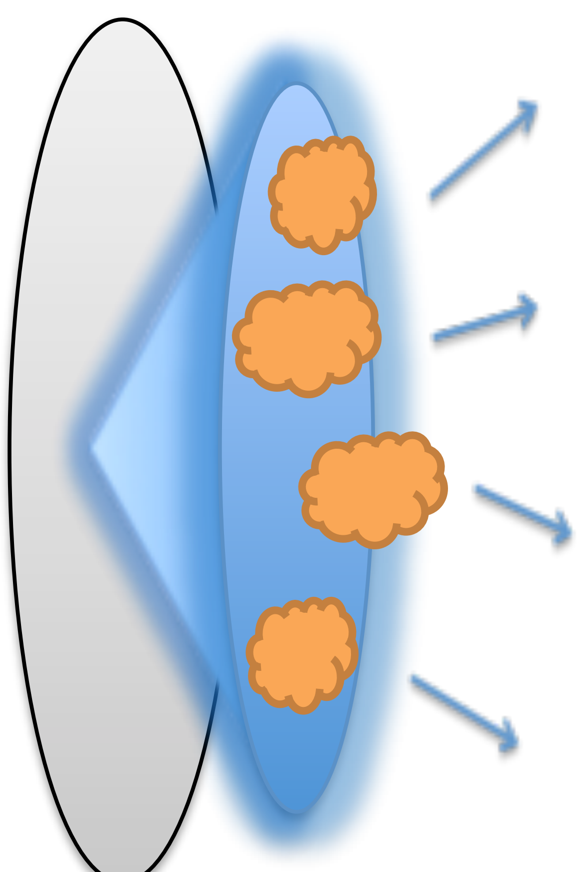
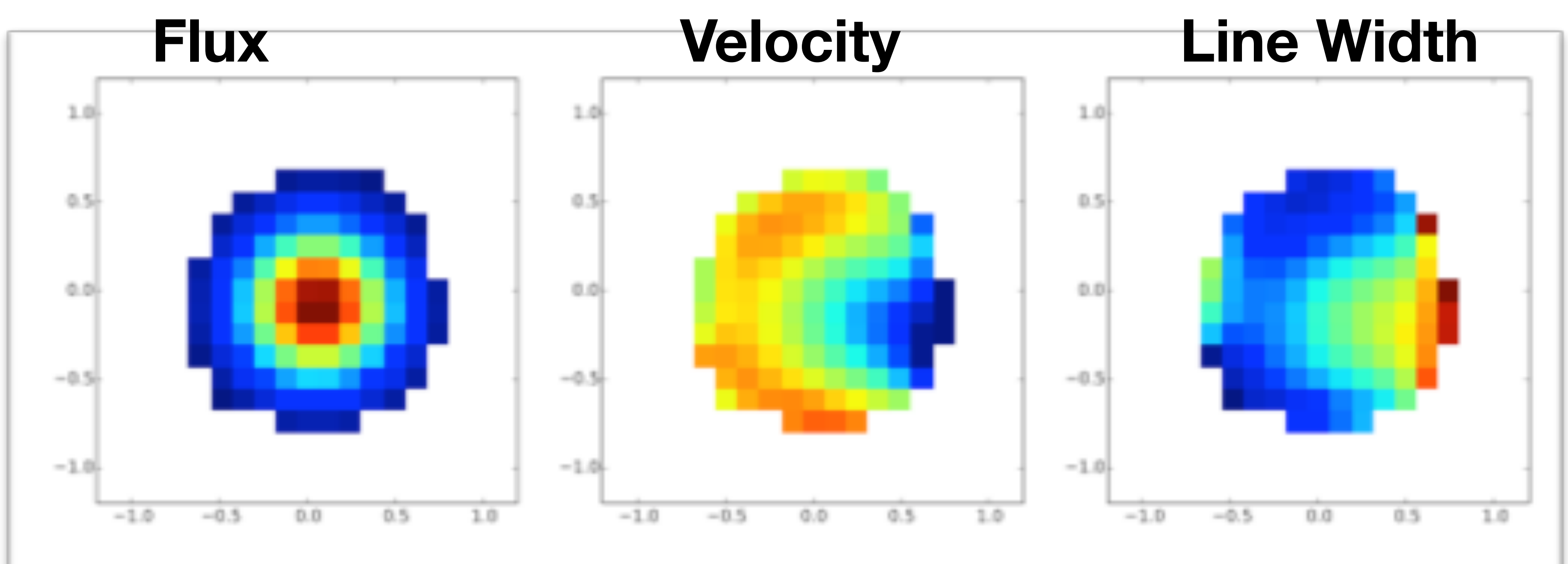


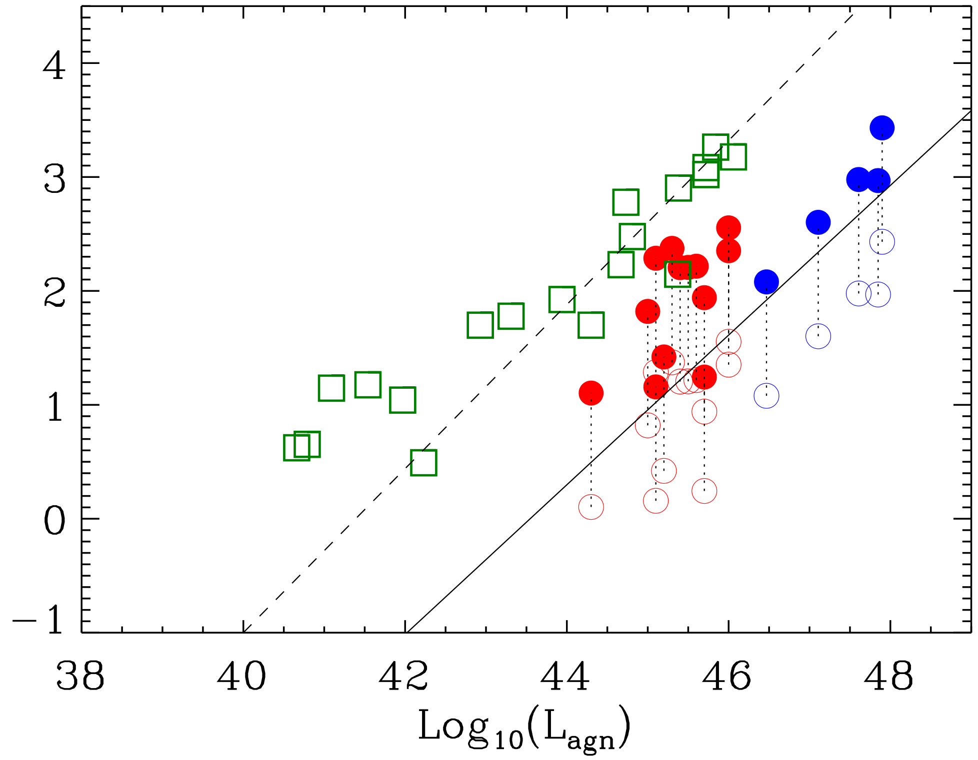
Observed velocity maps provide evidence for conical outflows



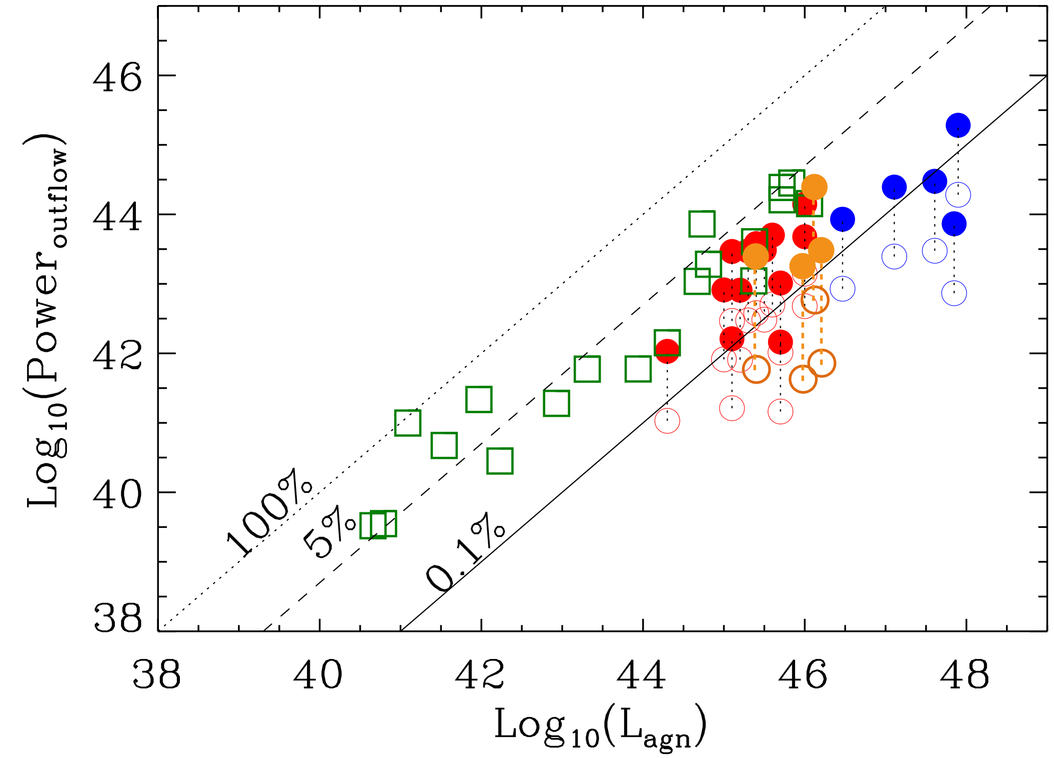
Ionized outflows in luminous quasars

Physical properties of ionised outflows: uncertainty on outflow mass, only ionised gas is traced !

Outflow rate

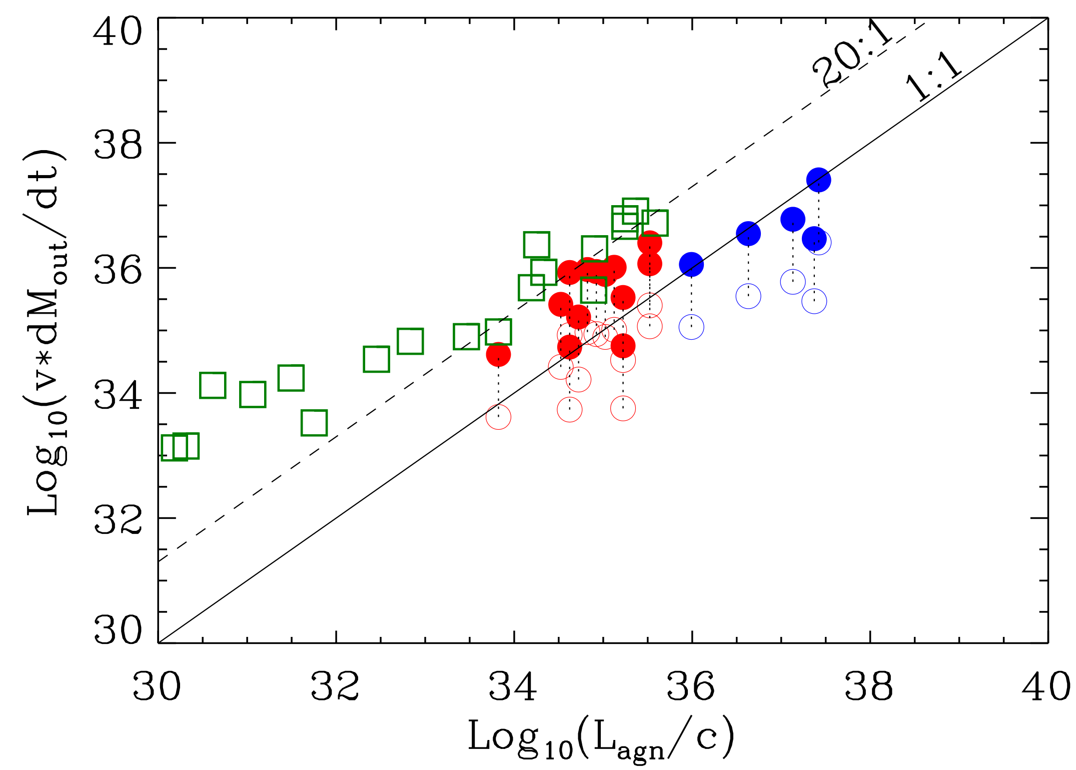


Kinetic power



- Molecular outflows in local AGN (Cicone+2014)
- [OIII] outflows in Type 2 local AGN (Harrison+2014)
- [OIII] outflows in X-ray obscured AGN (Brusa+2014)
- [OIII] outflows in z~2.5 quasars (Carniani+, in prep.)

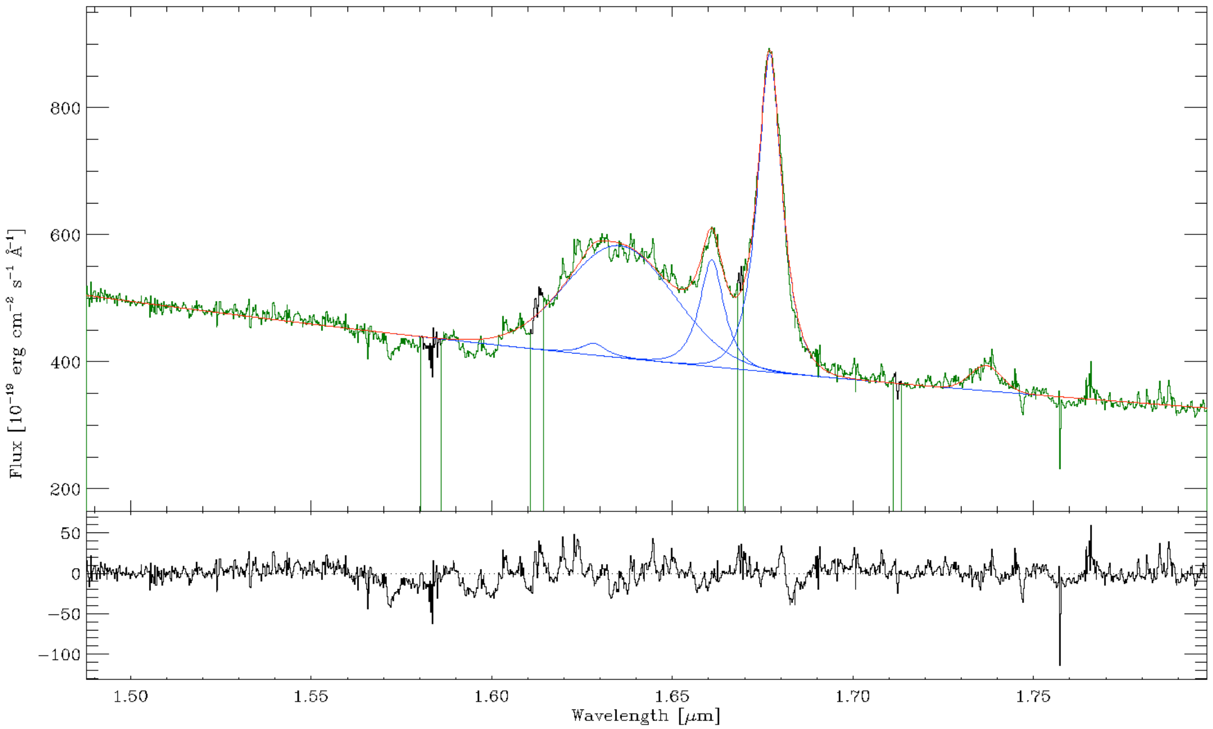
Momentum

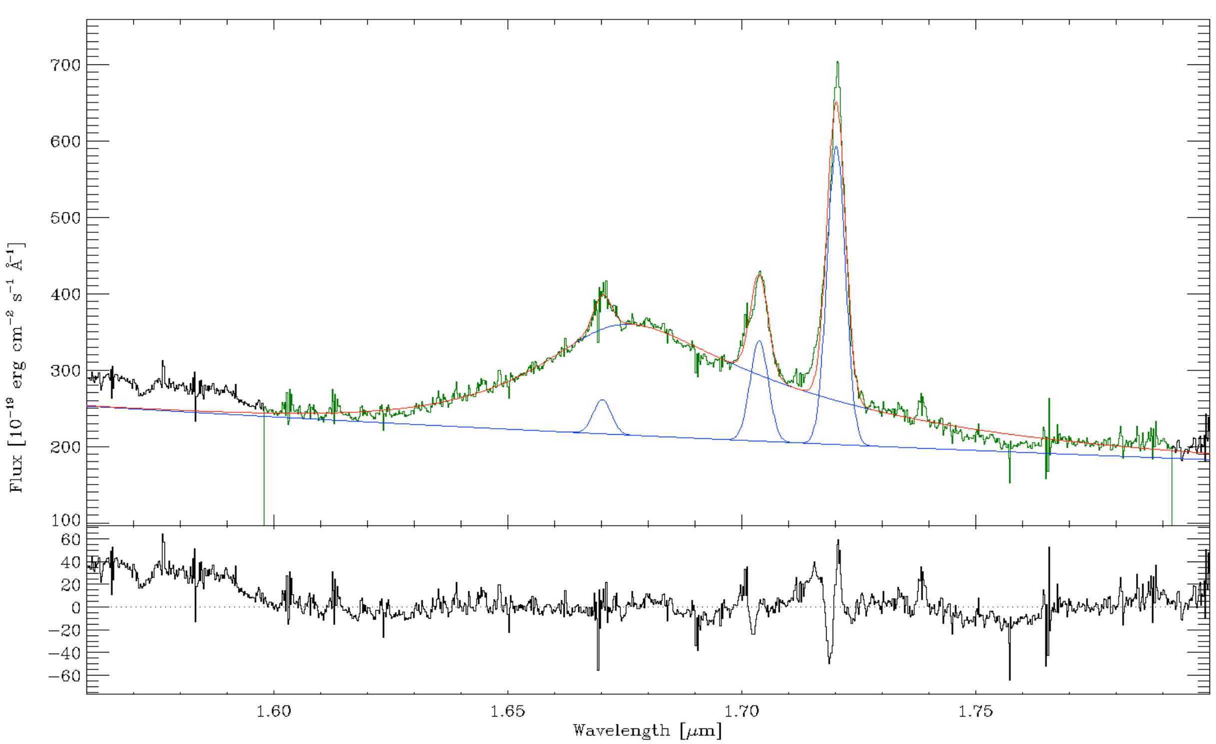


Carniani, AM+, in prep.

Ionized outflows in luminous quasars

Subtract “broad” (~1000-1500 km/s) [OIII] ➙ outflow





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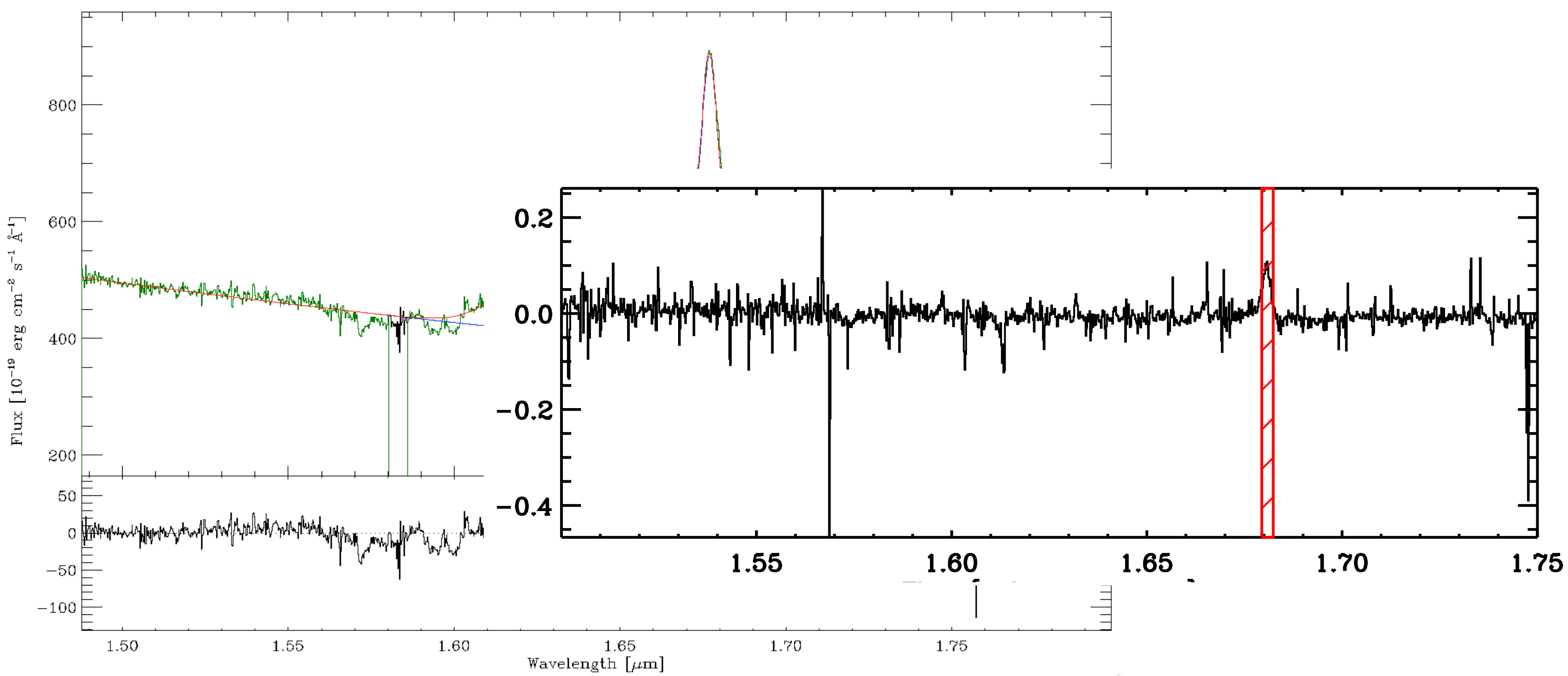
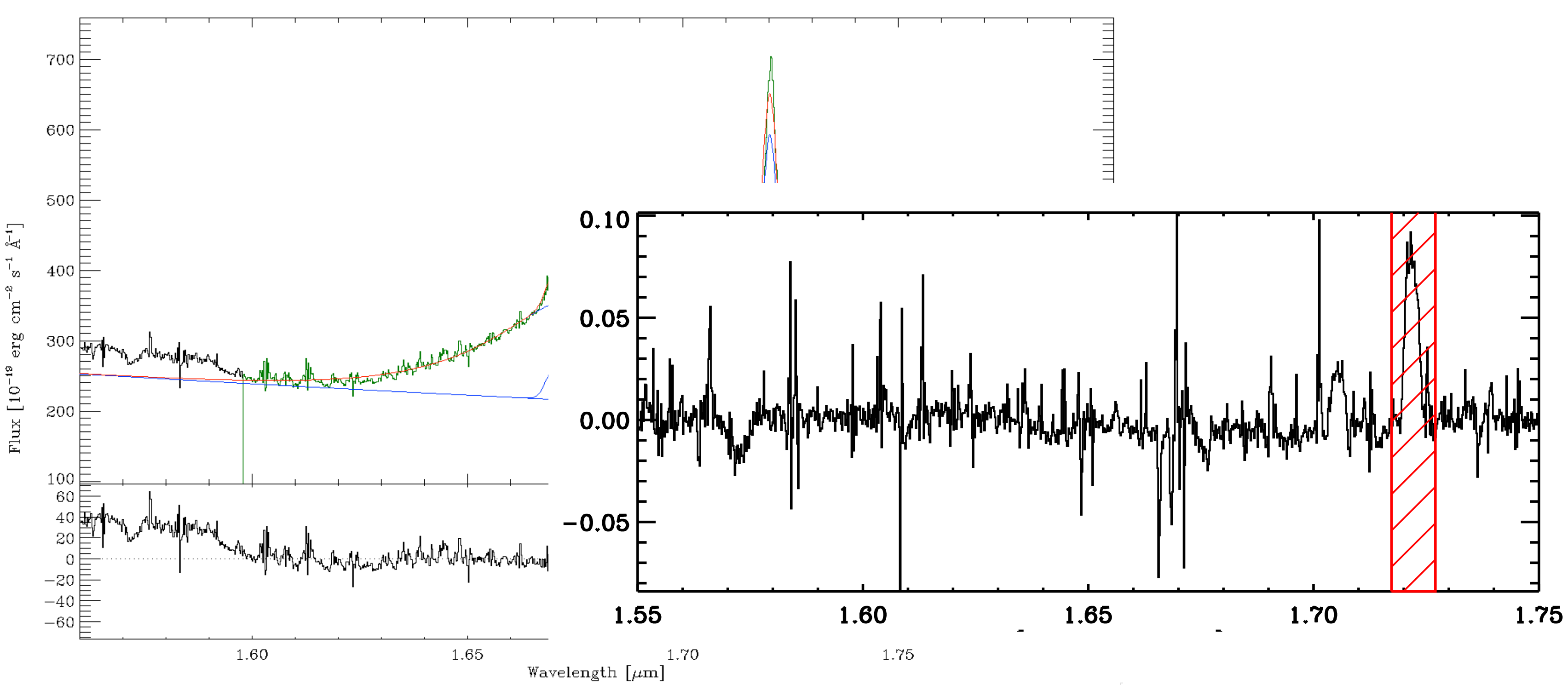
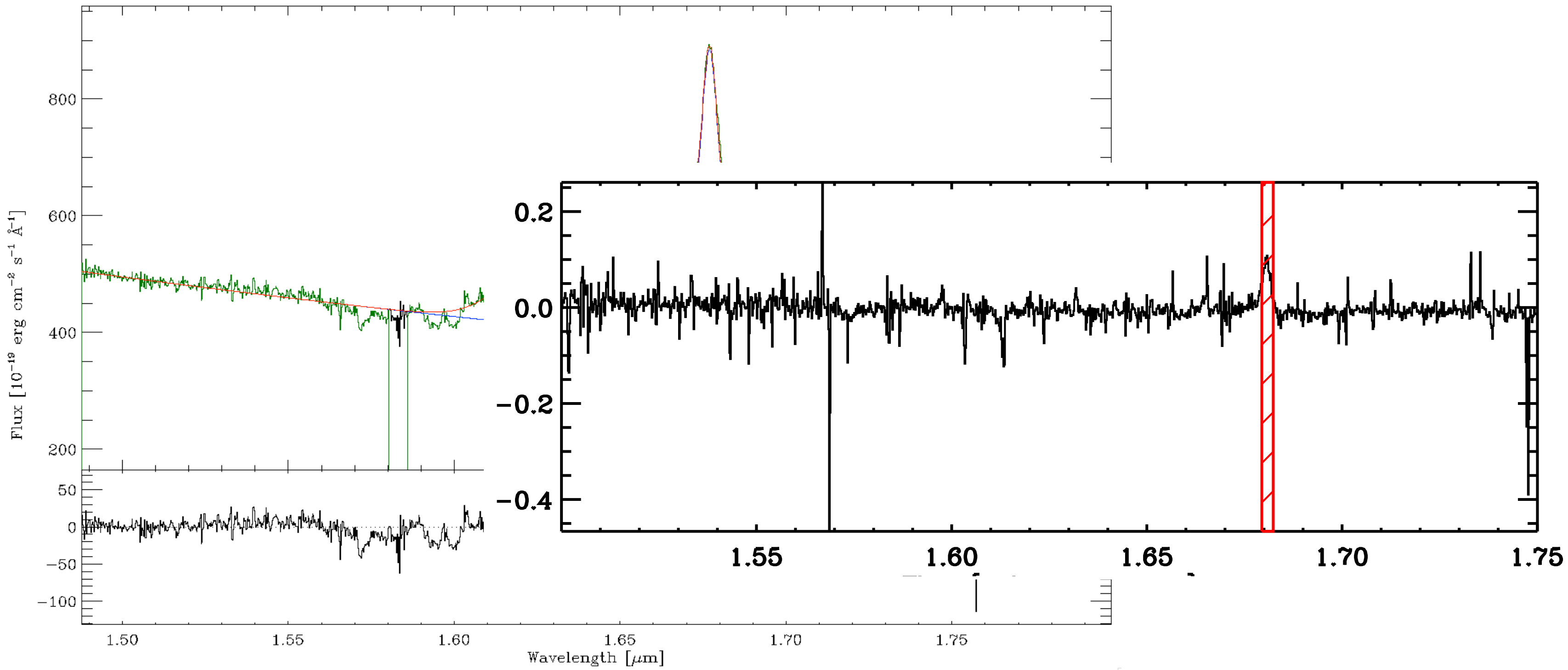


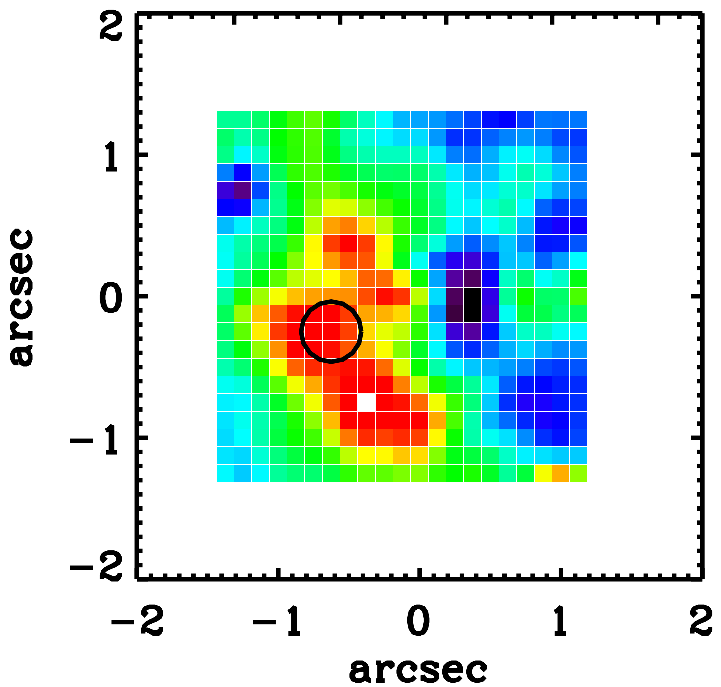


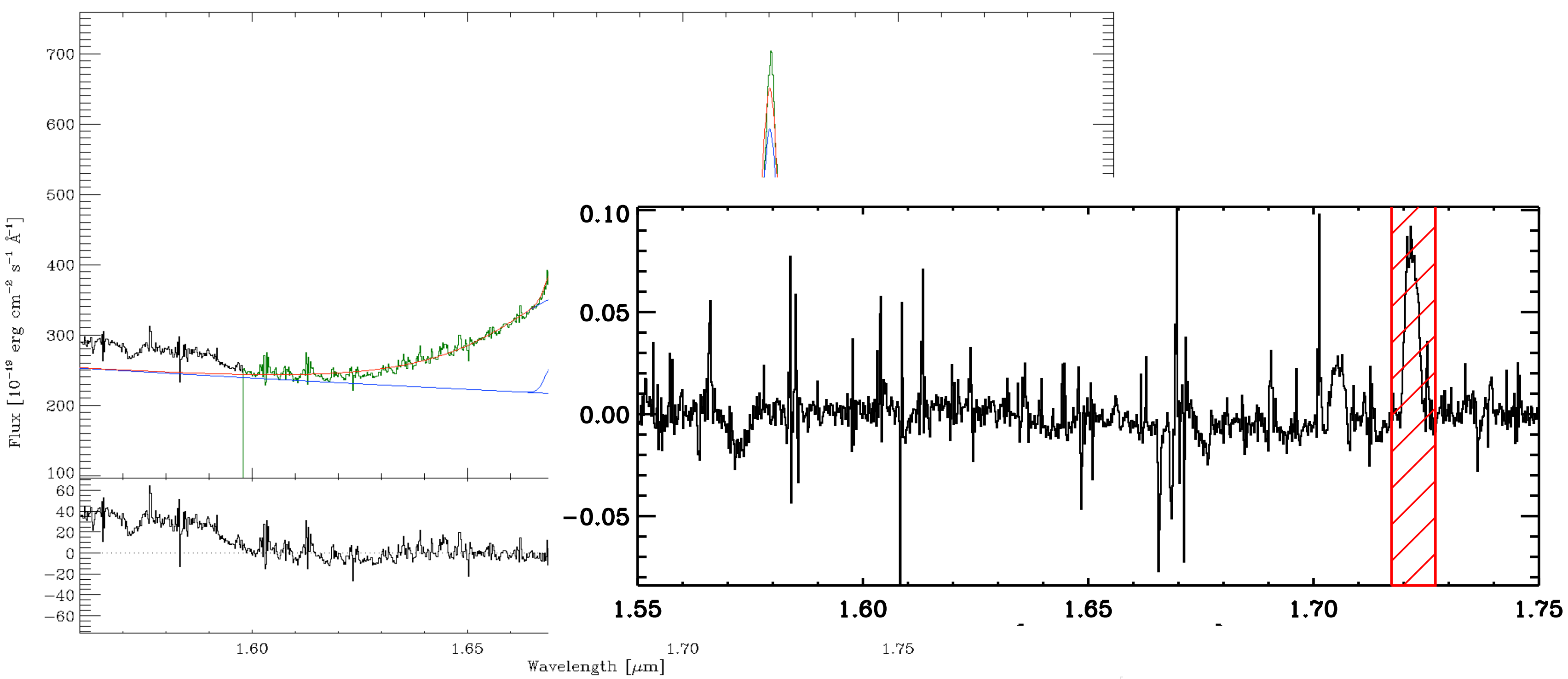
Ionized outflows in luminous quasars

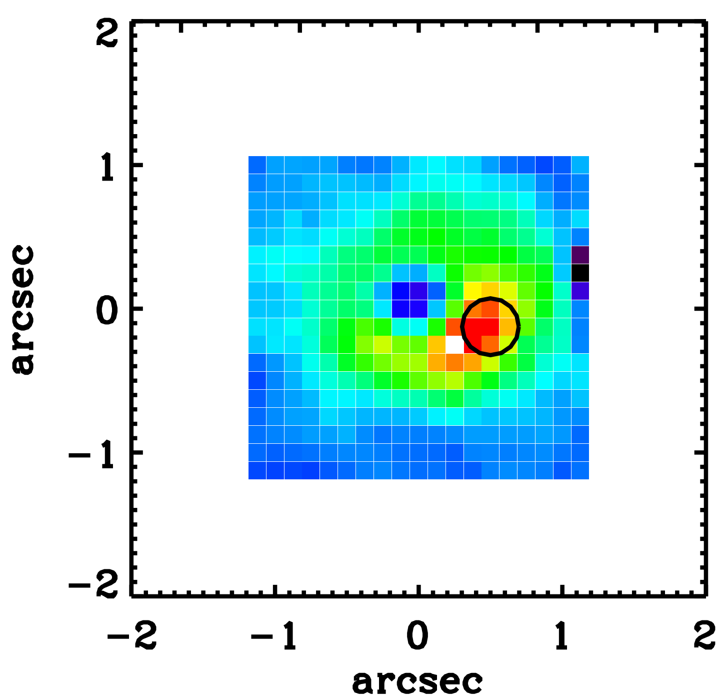
Subtract “broad” (~1000-1500 km/s) [OIII] ➙ outflow

Residual faint “narrow” (~100-200 km/s) [OIII] ➙ host galaxy, star formation?









Ionized outflows in luminous quasars

Origin of “narrow” [OIII] emission? AGN or Star Formation excited?

K band observations targeting *Hα … subtract broad Hα and outflow component … narrow Hα residual*

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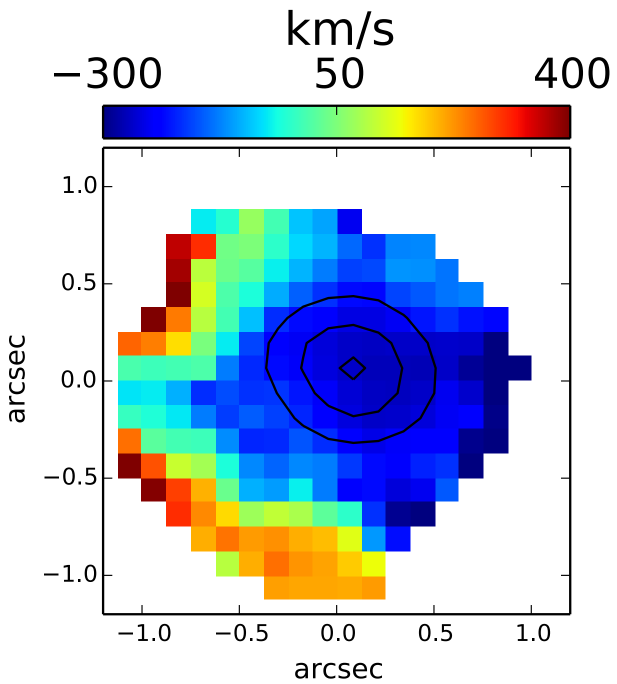
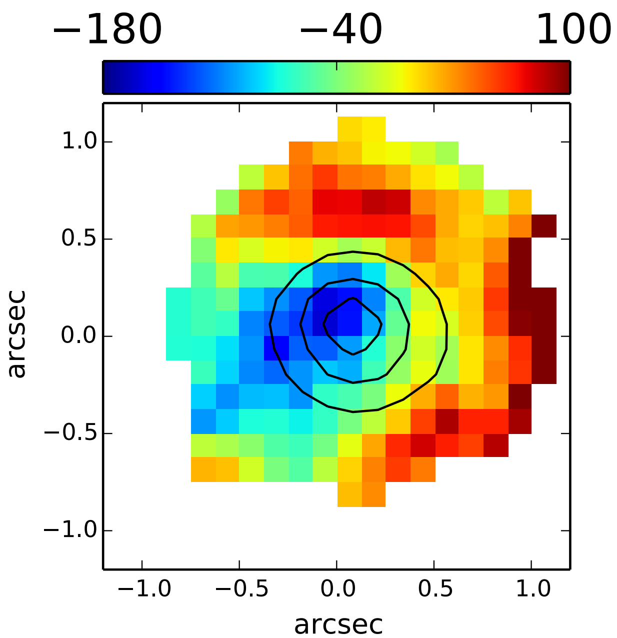
[OIII] velocity





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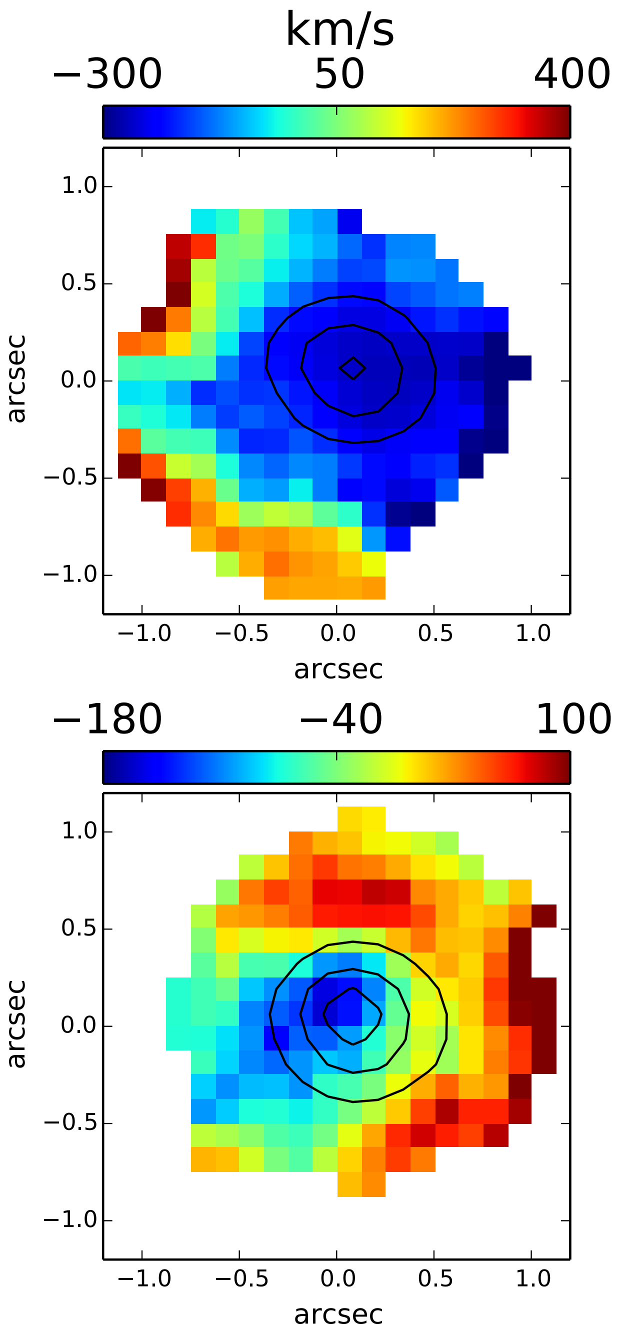
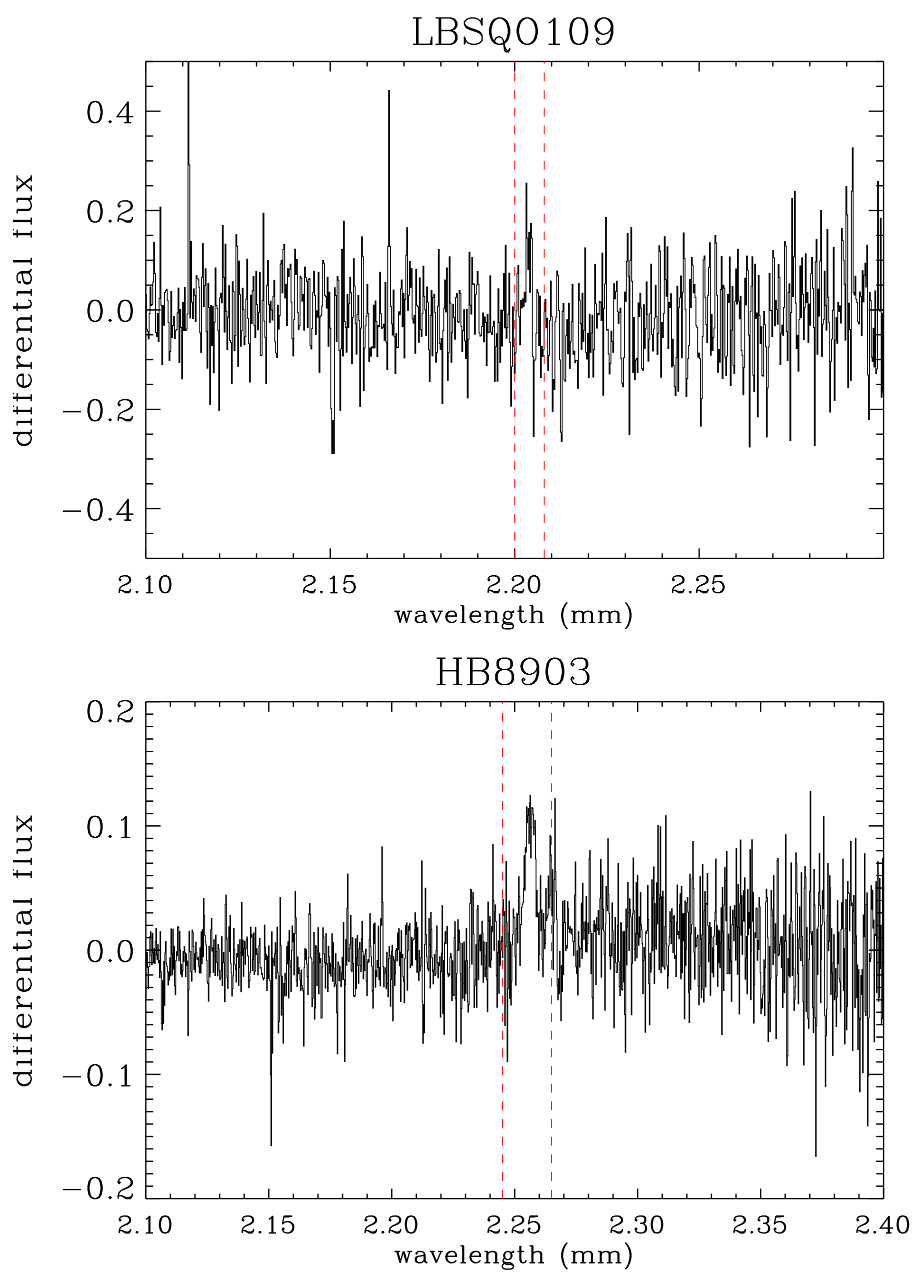


K band: broad Hα subtracted



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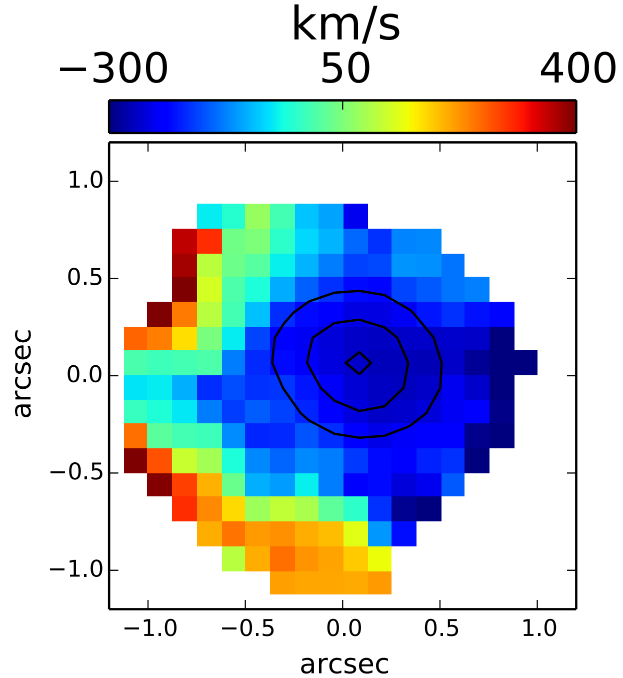

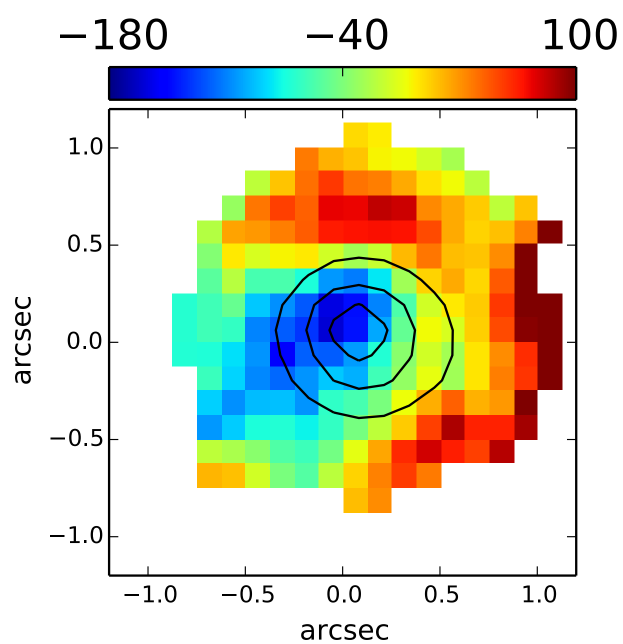

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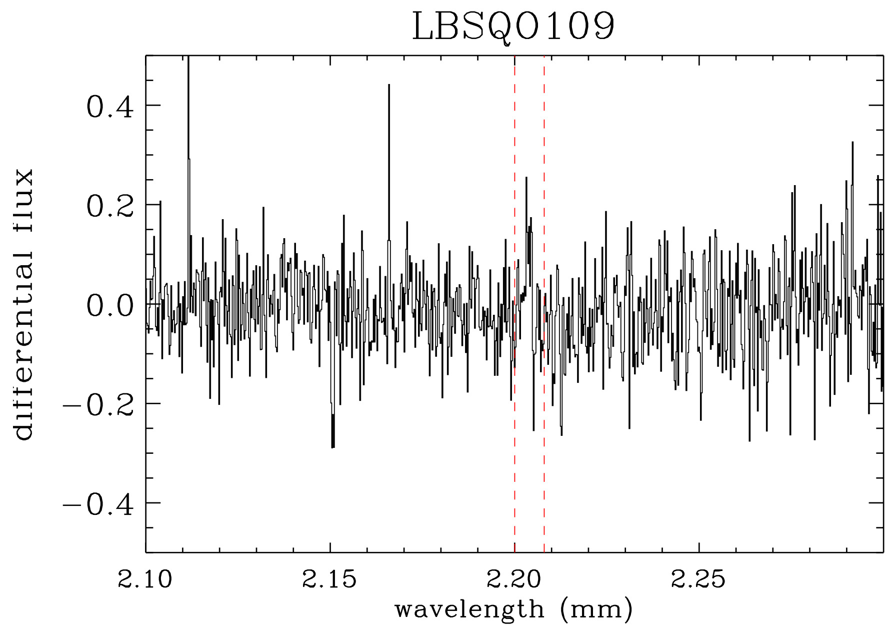

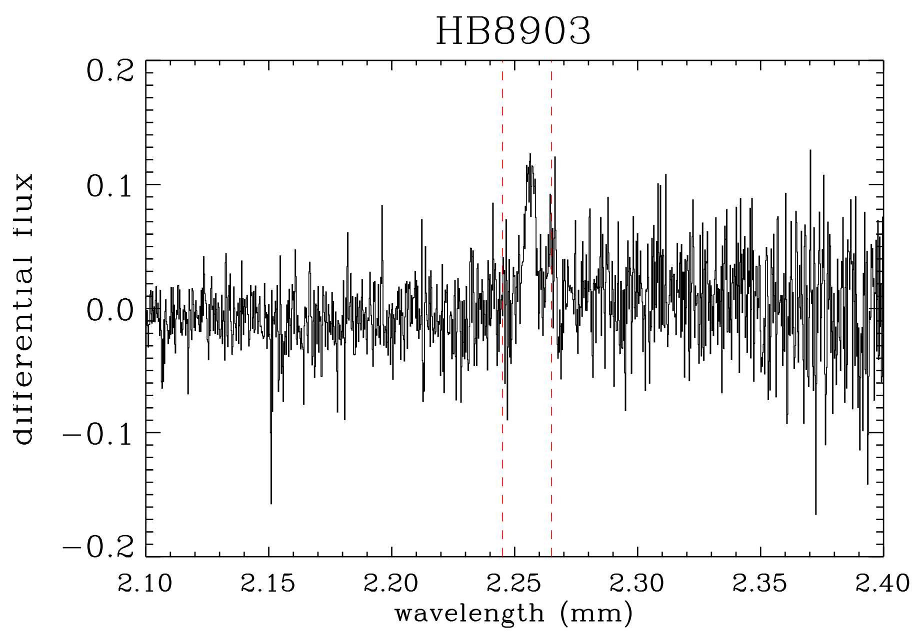

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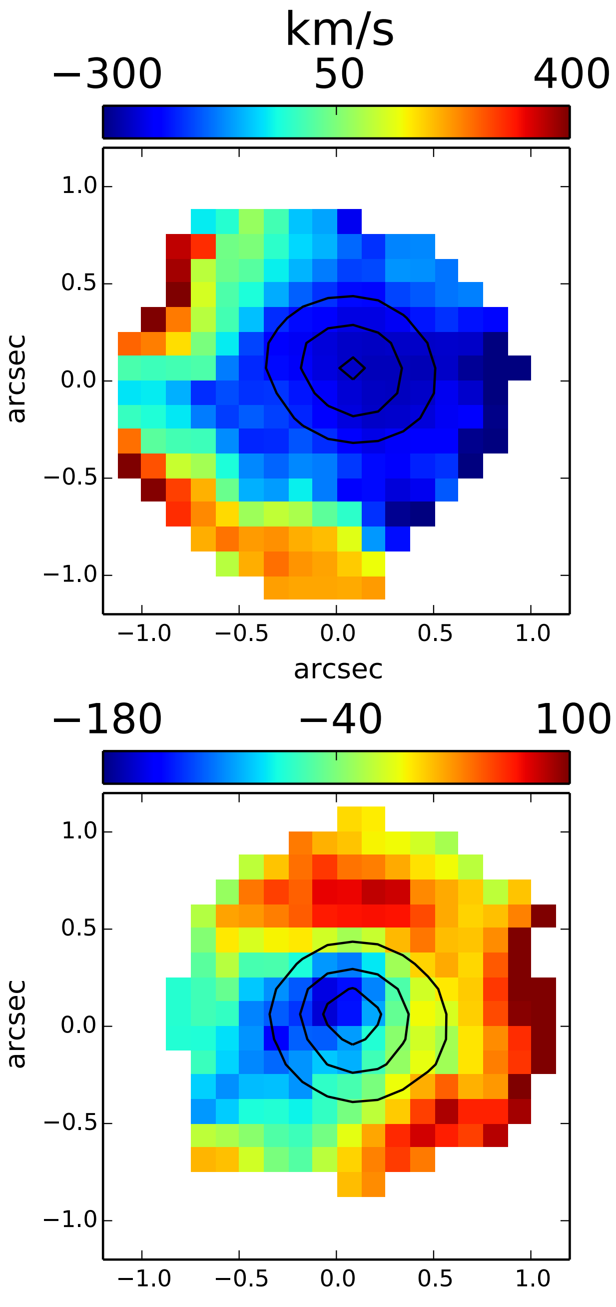

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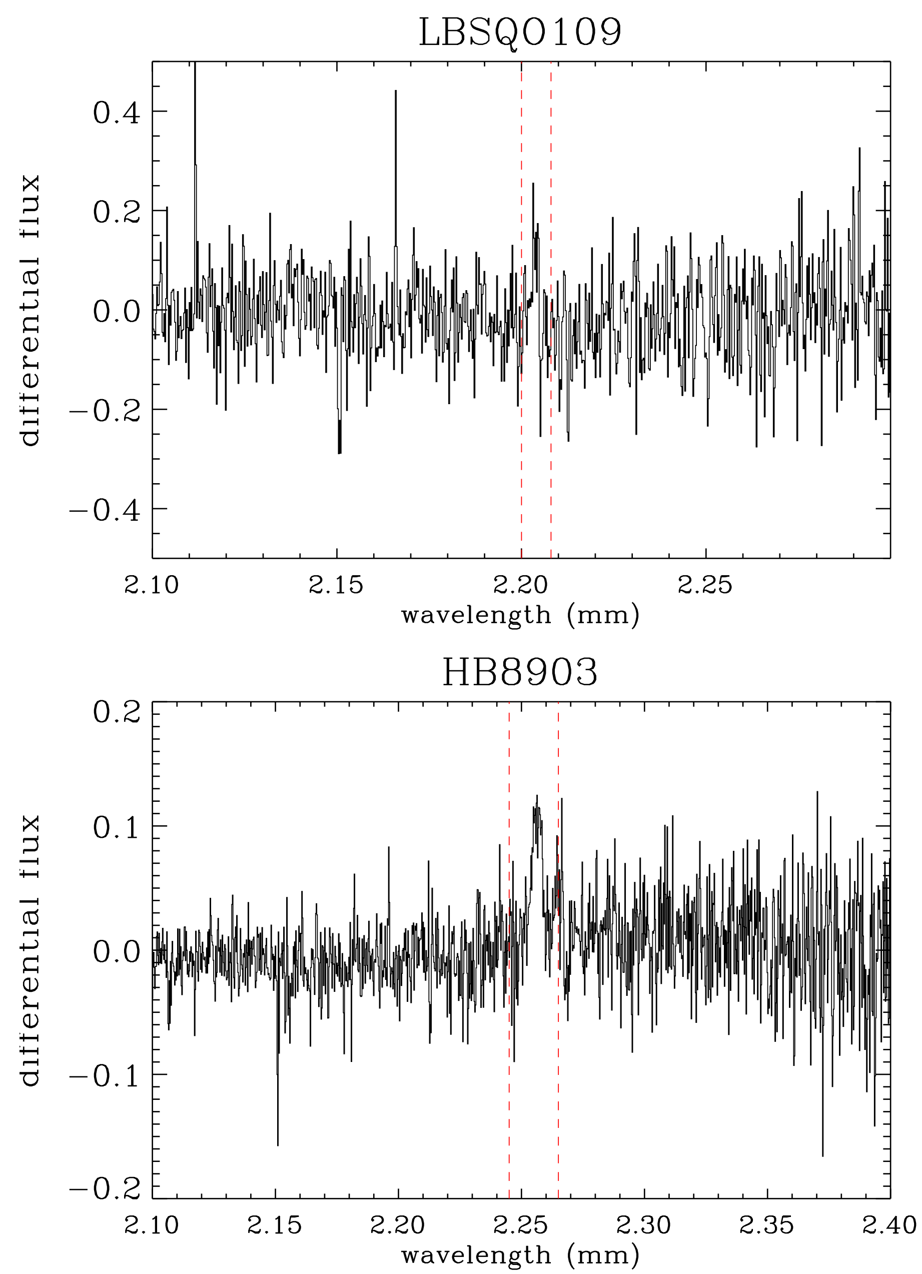
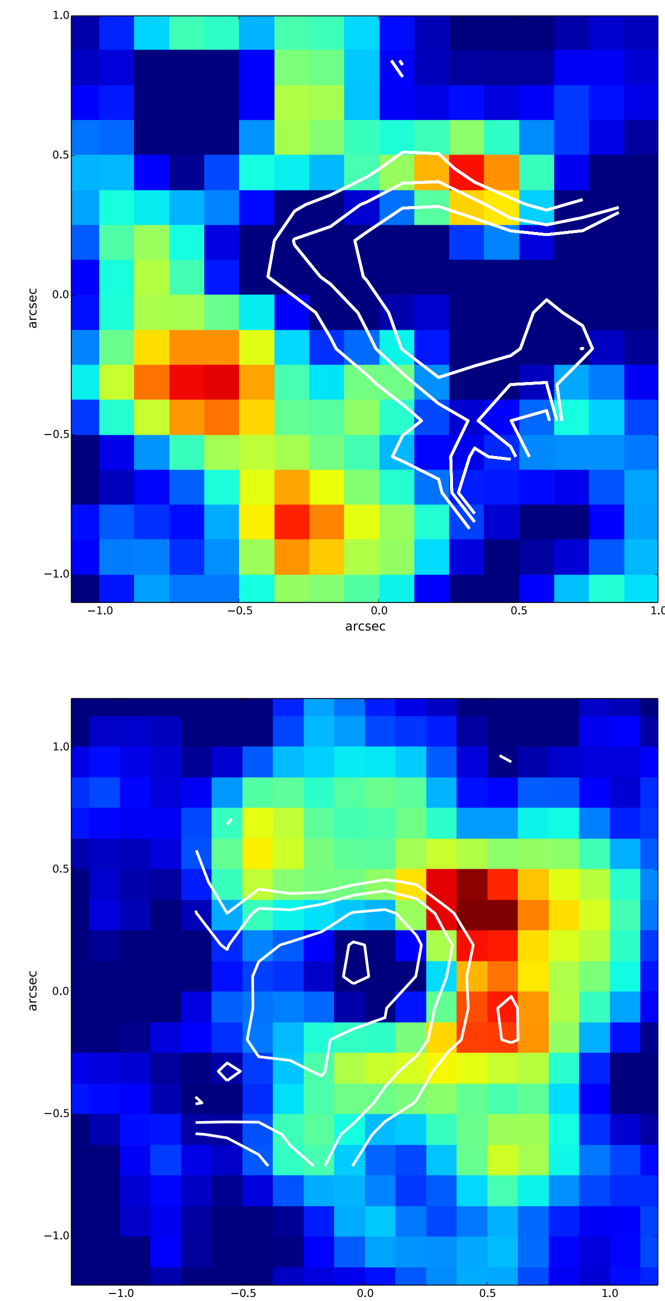


Narrow Hα flux



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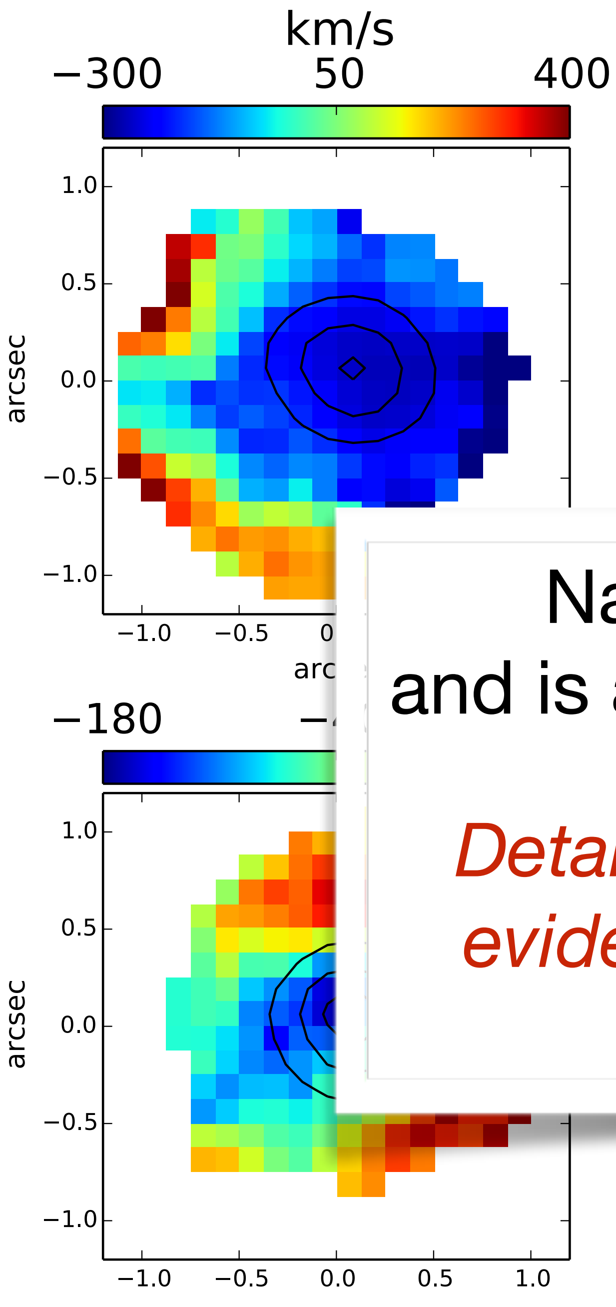
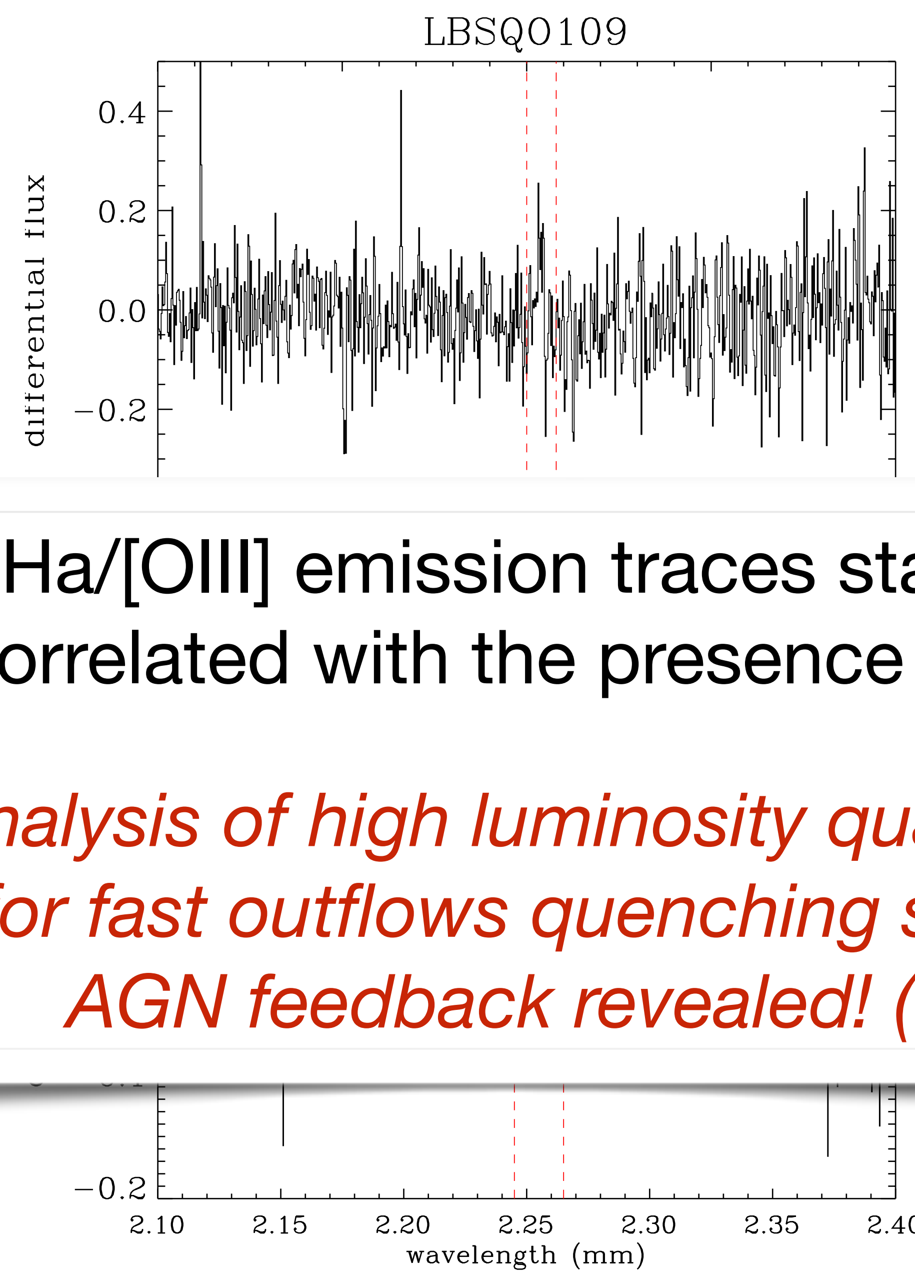
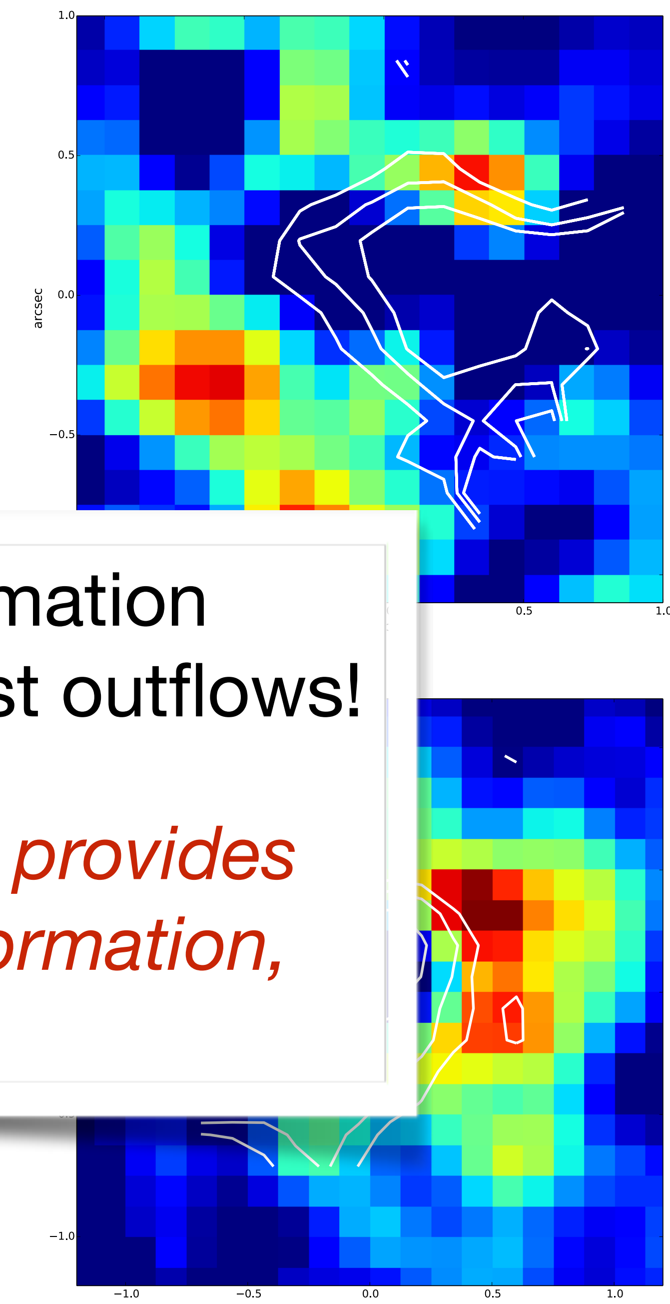


K band: broad H*α* subtracted



Narrow H*α* flux



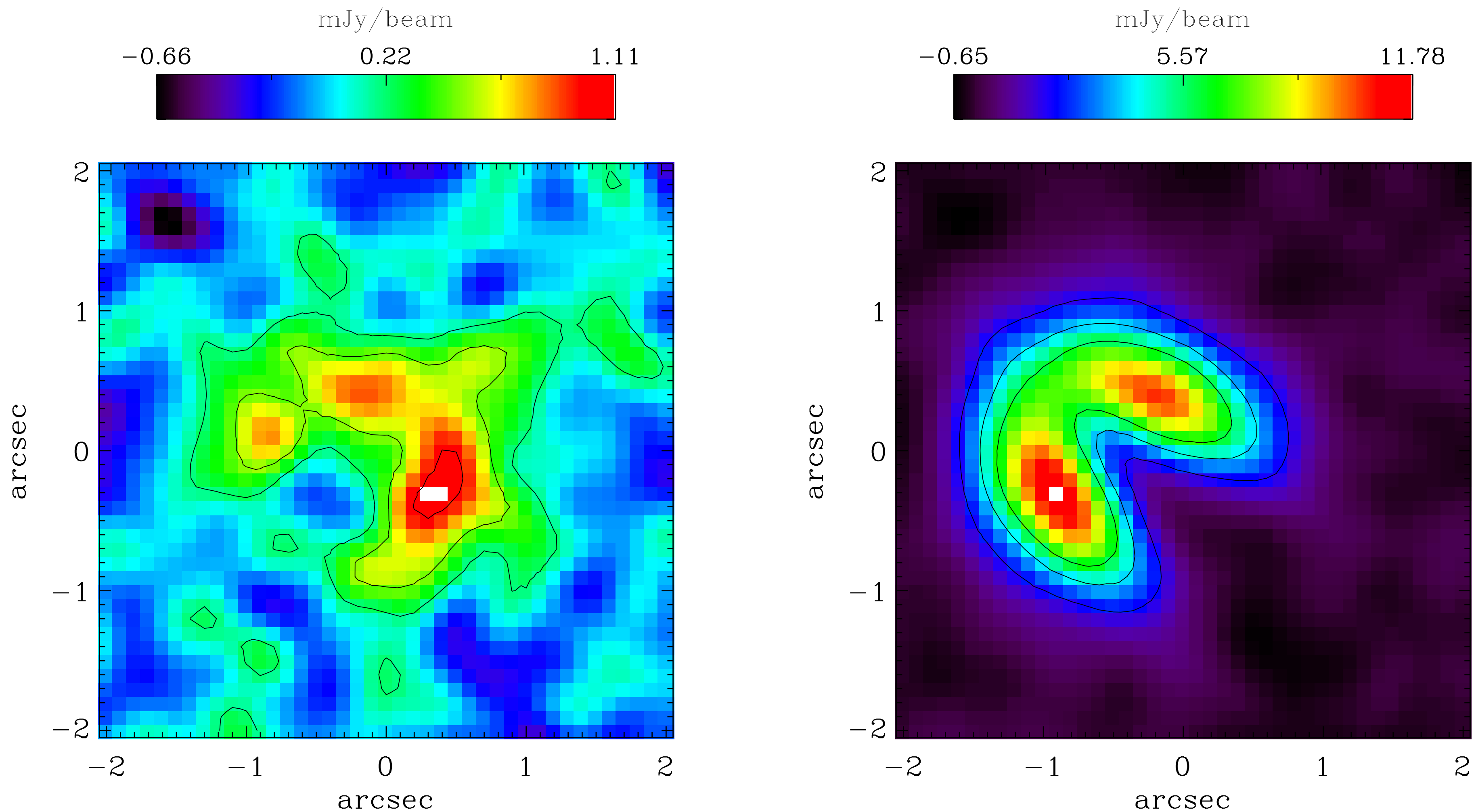
Narrow Ha/[OIII] emission traces star formation and is anti-correlated with the presence of fast outflows!

Detailed analysis of high luminosity quasars provides evidence for fast outflows quenching star formation, AGN feedback revealed! (?)

Next Steps

- Compare molecular and ionized outflow using future ALMA observations (project approved, priority B)

- Improve outflow model to compare with observations



Simulations of observations with ALMA of CO(3-2) emission for the two approved sources (assuming outflows remove molecular gas)

Conclusions

- From sample of local quasars at z < 1:
  the presence of ionized outflows does not appear to significantly affect star formation (problem of time scales?)
- From a small sample of obscured AGN at 1.5 and quasars at z~2.5 with detailed Integral Field Spectroscopy **(see also talk by Marcella Brusa)**
  ionized gas outflows (partially) sweep away gas in quasar host galaxies and prevent star formation

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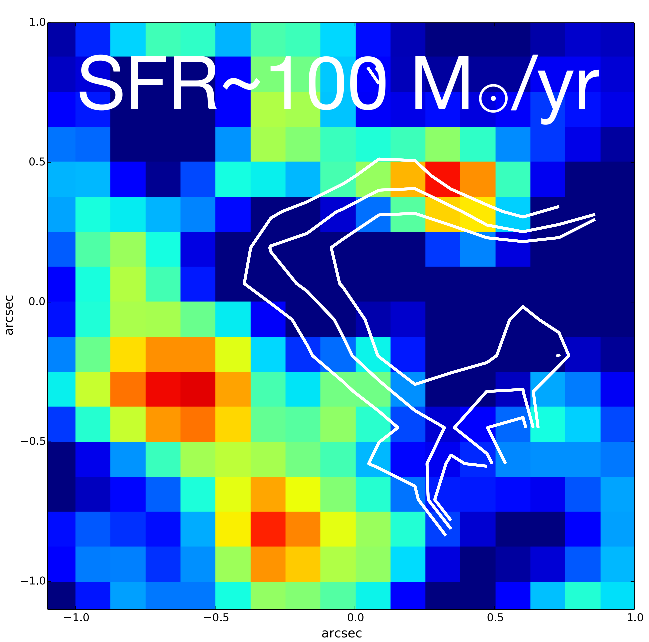

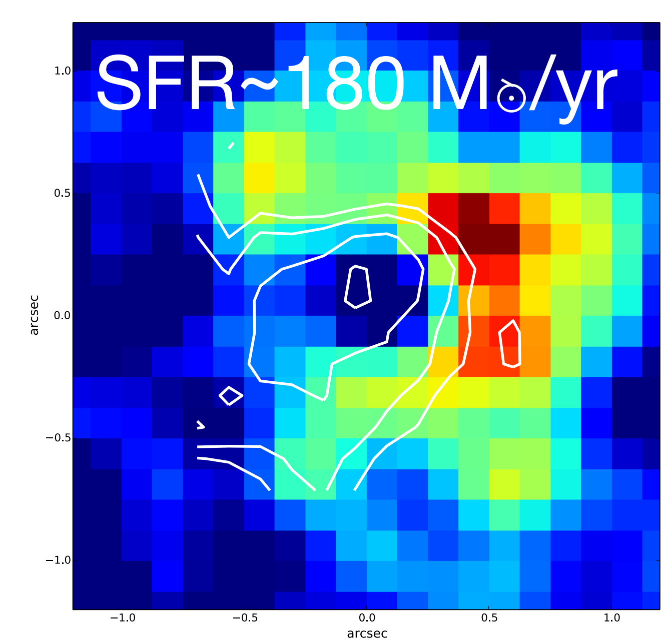

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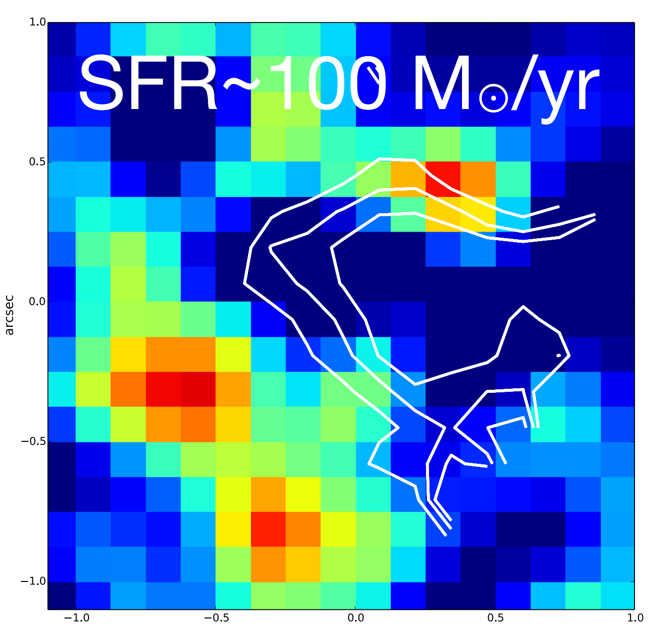

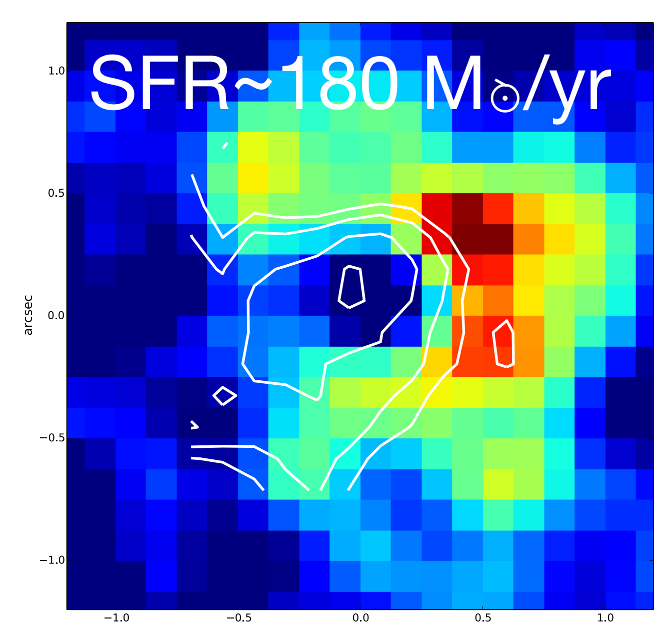

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- ALMA observations planned
- Stay tuned for more !
  Brusa+15, arXiv:1409.1615,
  Perna+15, arXiv:1410.5468
  Cresci+15, arxiv.org:1411.4208
  Balmaverde+, 2015a, 2015b
  Carniani+, 2015