AGN feedback

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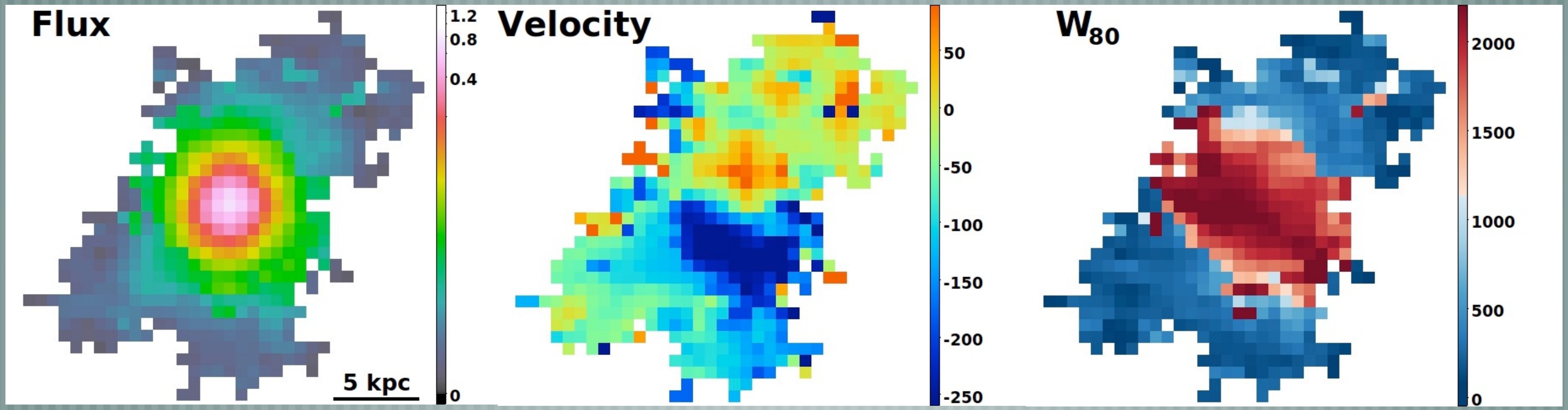
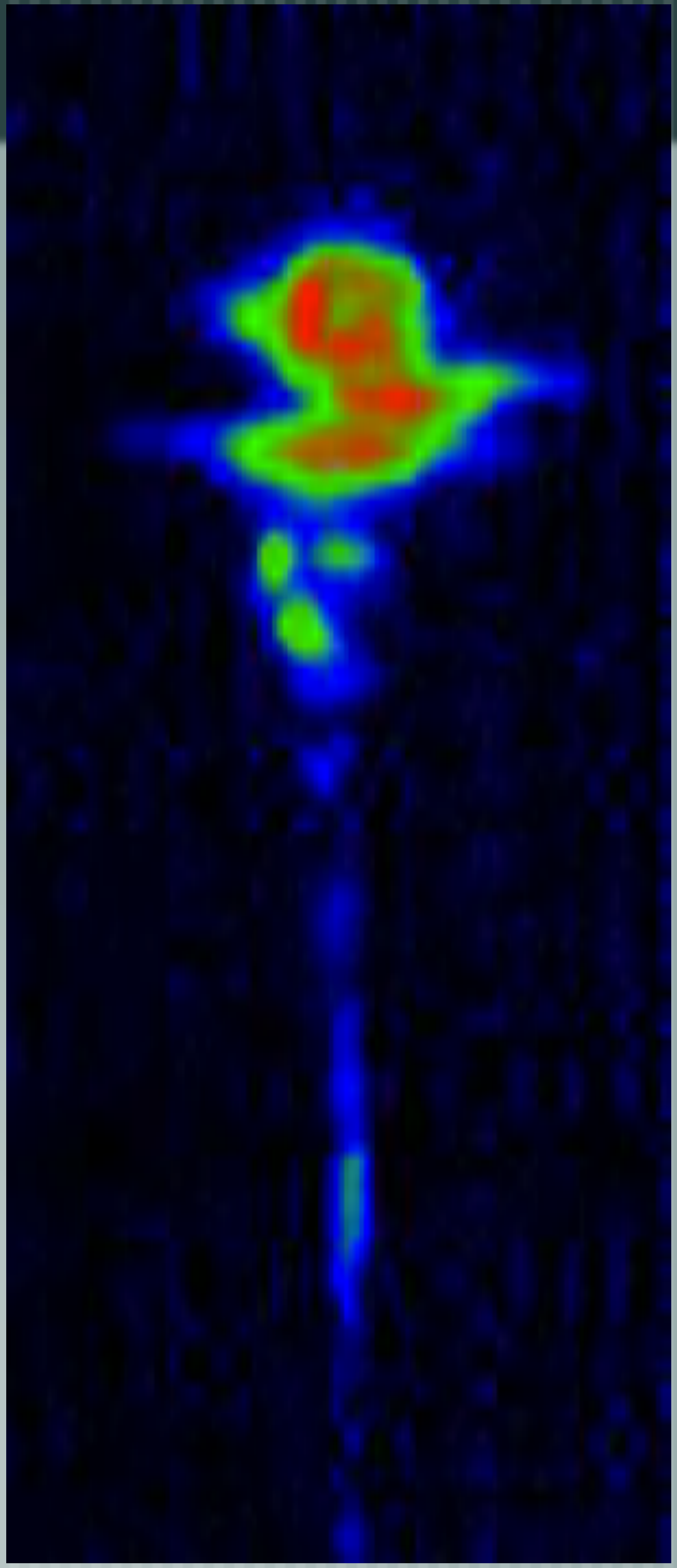
Johns Hopkins University



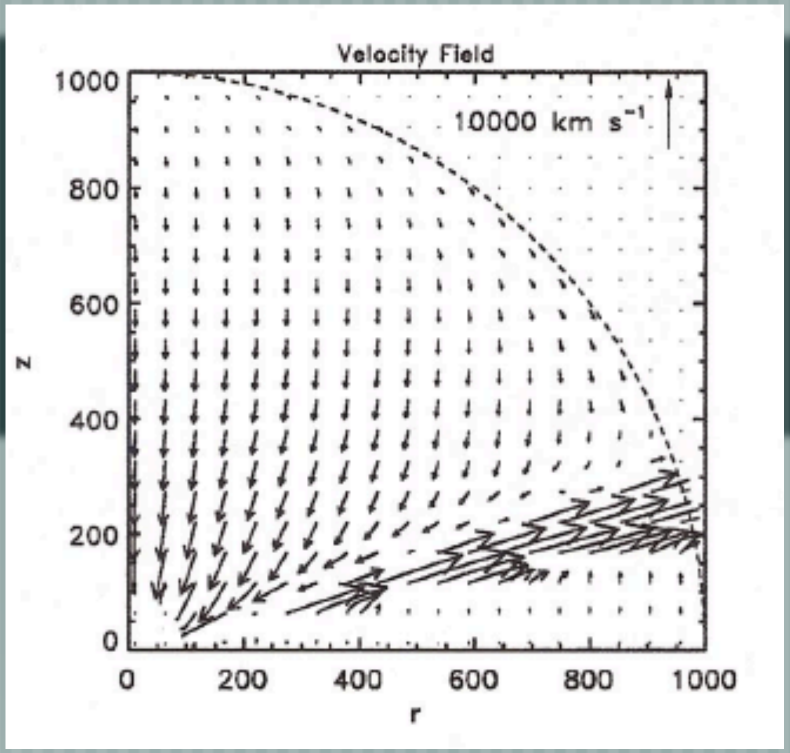
AGN feedback



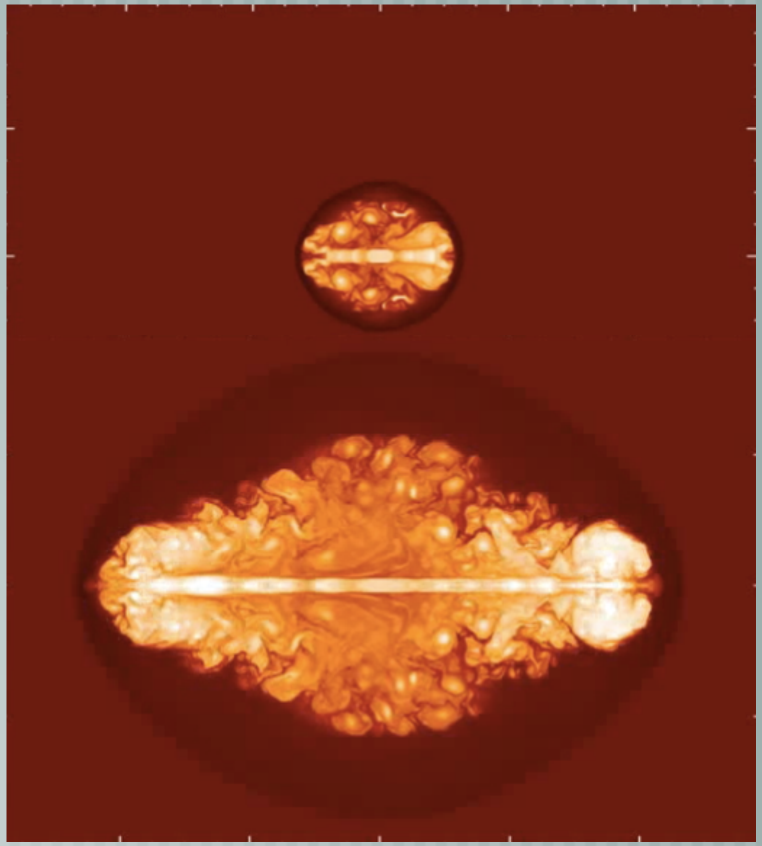
- Mechanism of AGN feedback
- Ionized gas
- Extreme ionized gas outflows at high z
- Sunyaev-Zeldovich effect
- Quasar winds and radio emission

1. Mechanism of AGN feedback

- On small scales: radiation pressure winds, jets
- Slams into surrounding gas
- Drive shocks, outflows into interstellar medium
- Morphology of wind critically depends on ISM structure, not on input morphology!
- Produces outflows ~1000 km/sec
- Quasar needs to be luminous enough to push gas out of galaxy (>3e45 erg/sec, Veilleux et al. 2013, Zakamska & Greene 2014, King)



Murray et al. 1995, Proga et al. 2000
Equatorial disk winds



Gaibler et al., Begelman & Cioffi
growth of jet cocoon

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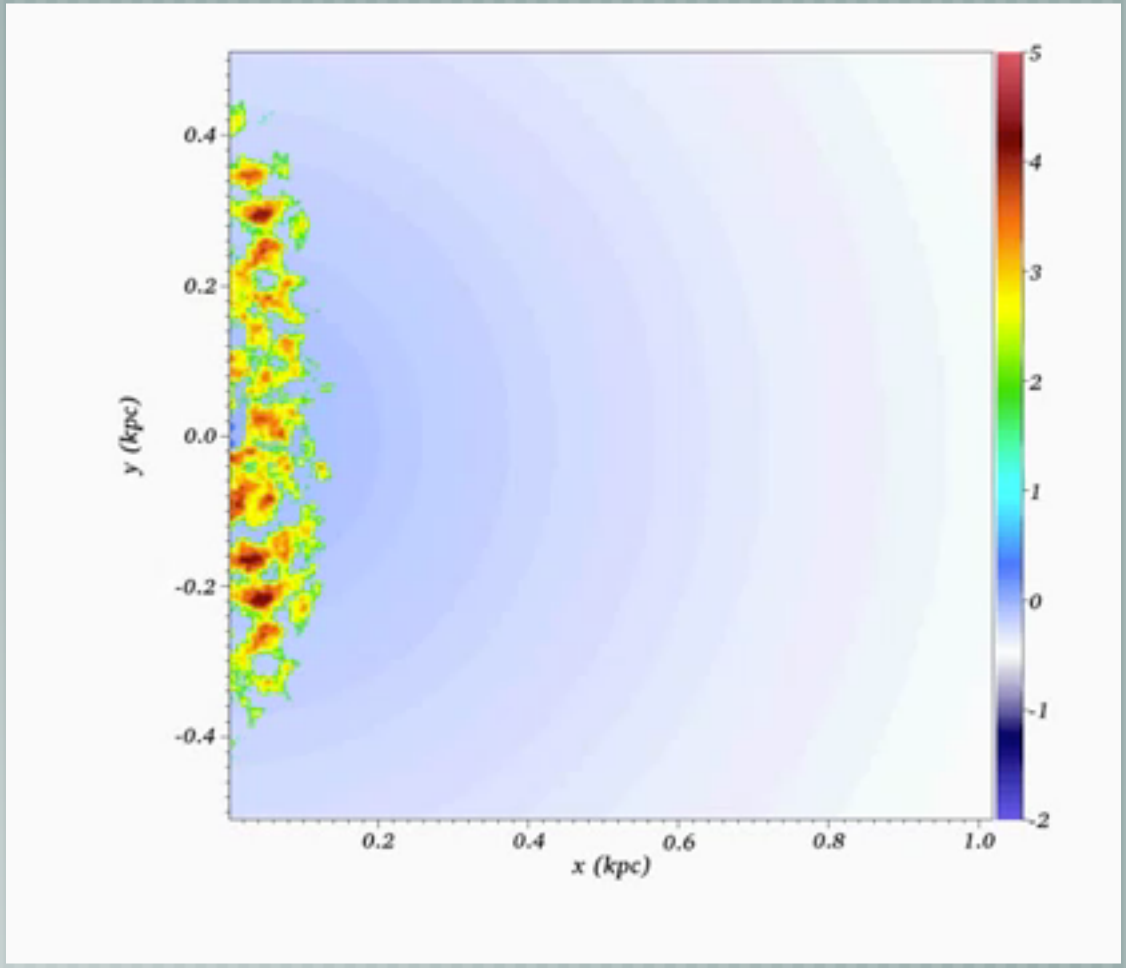
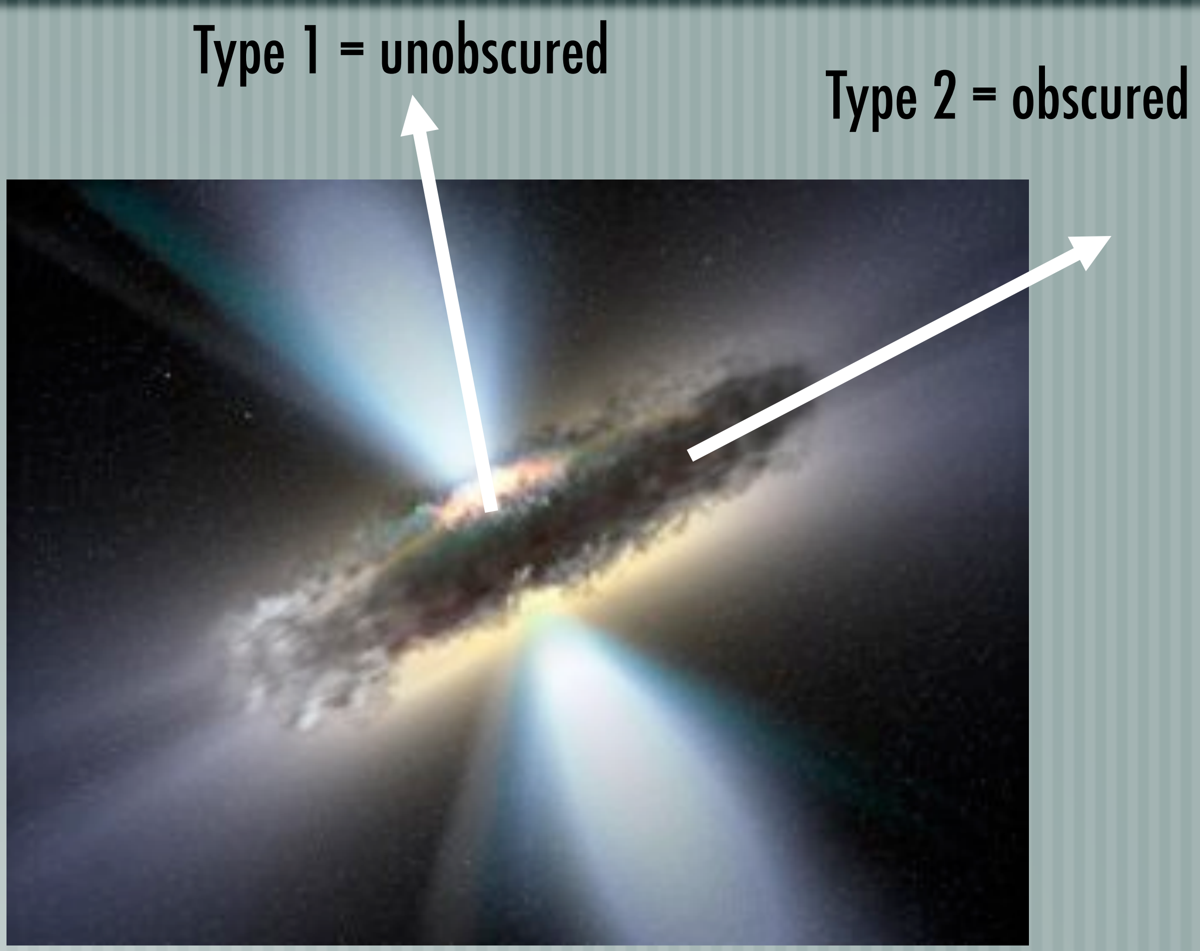


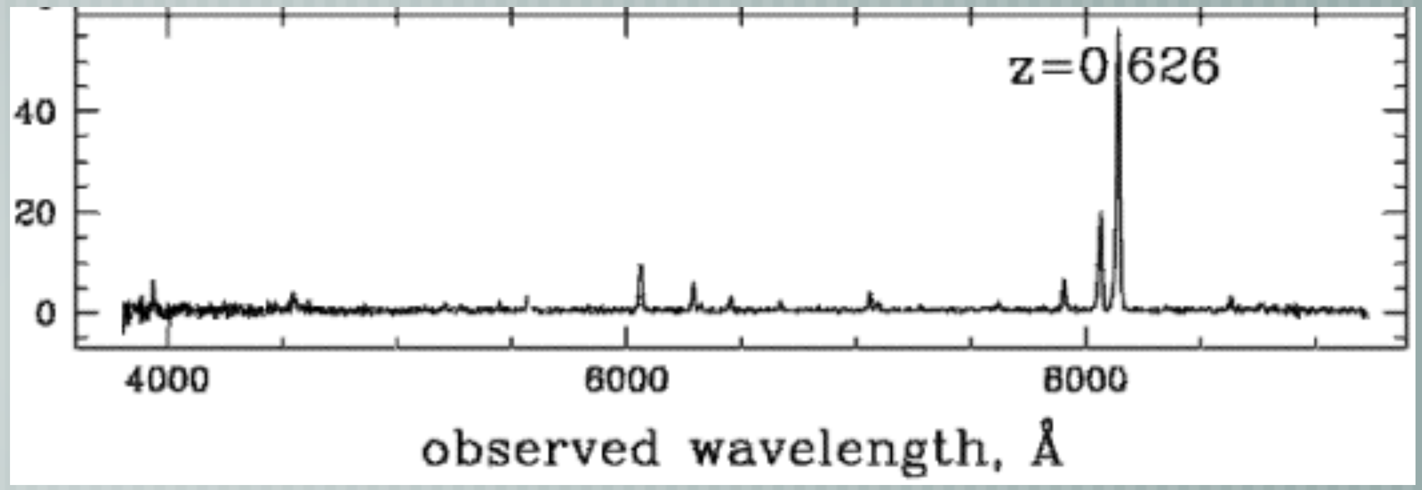
Wagner et al. 2013
Spherically symmetric models: King, Faucher-Giguere & Quataert:
typical velocities at large scales of 1000 km/sec.

2. Observations: ionized gas

- Gas at several kpc from the nucleus, ionized by the quasar should be observable
- Focusing on radio-quiet type 2 quasars (no jets)
- Liu, Zakamska, et al. 2013ab, 2014 based on Gemini IFU data, $L_{bol}>10^{46}$ erg/sec
- Large widths, large asymmetries, on galaxy-wide scales
- If quasi-spherical outflow, then v~800 km/sec



"Geometric unification model"



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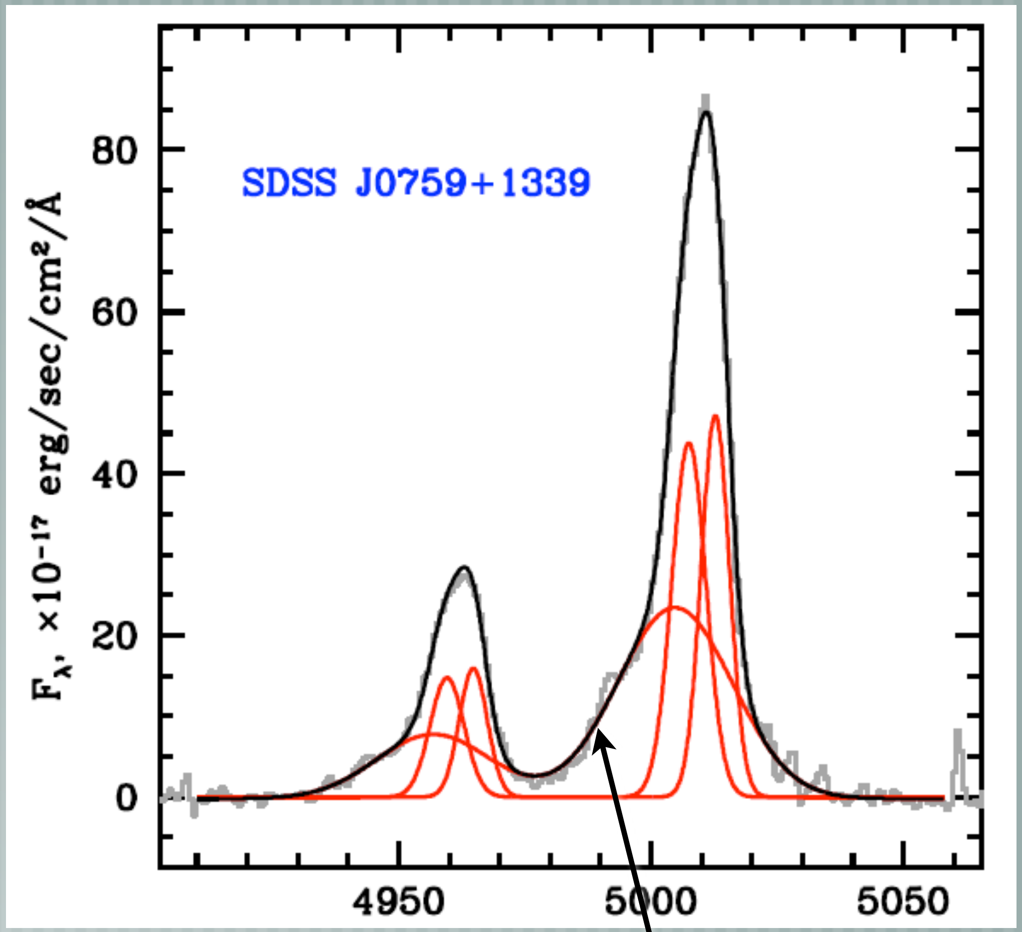

FWHM=1800 km/sec

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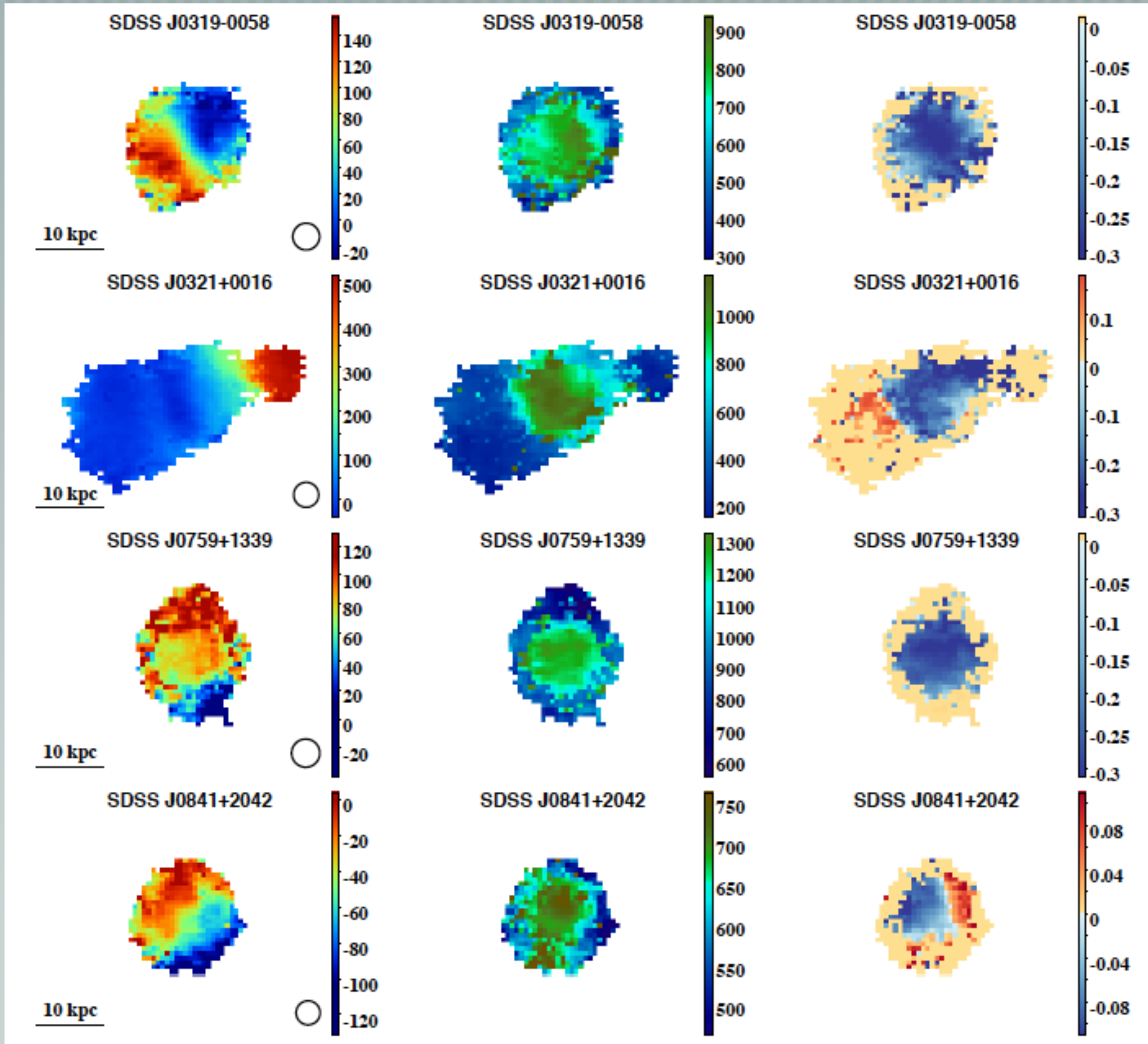
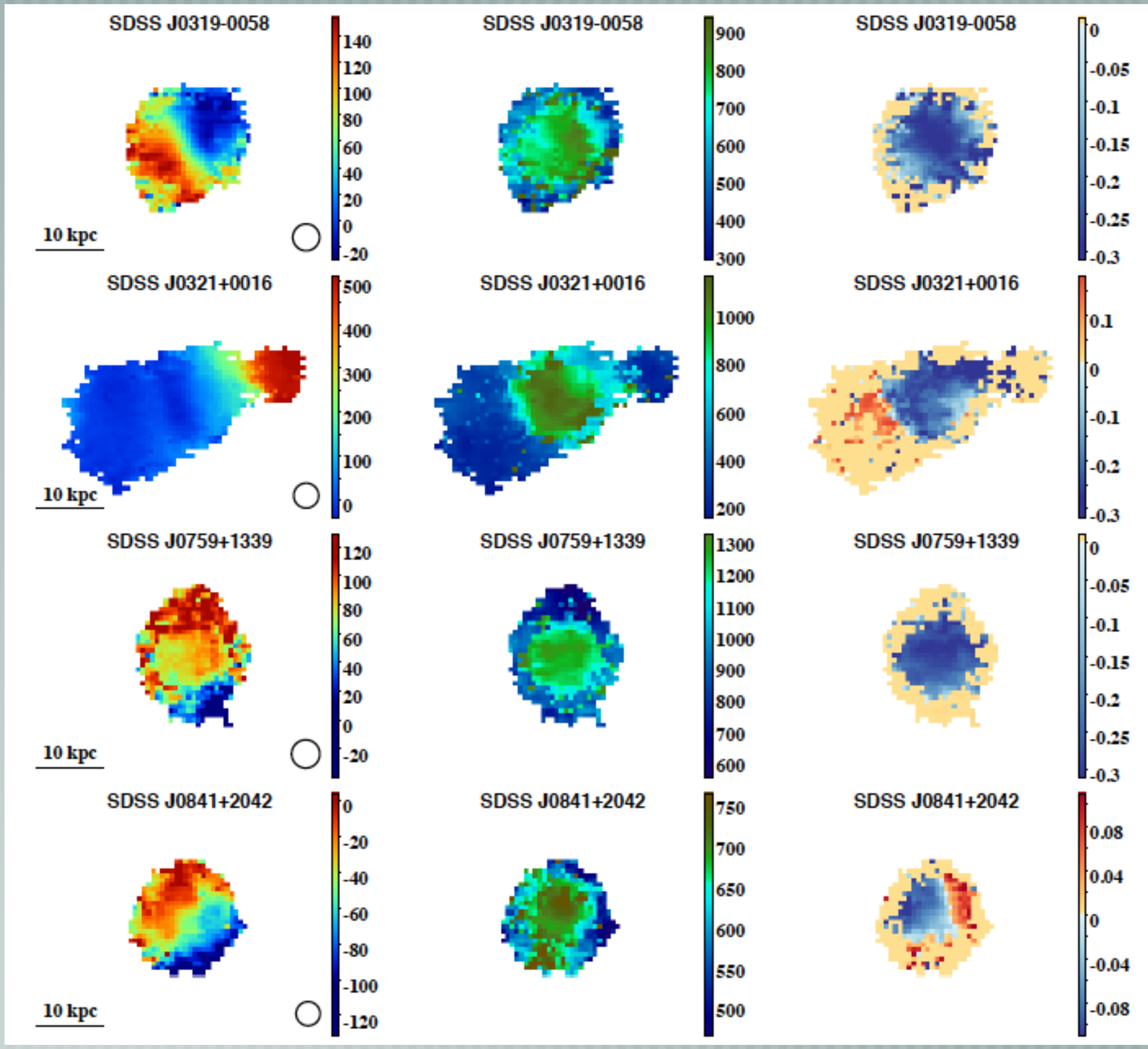


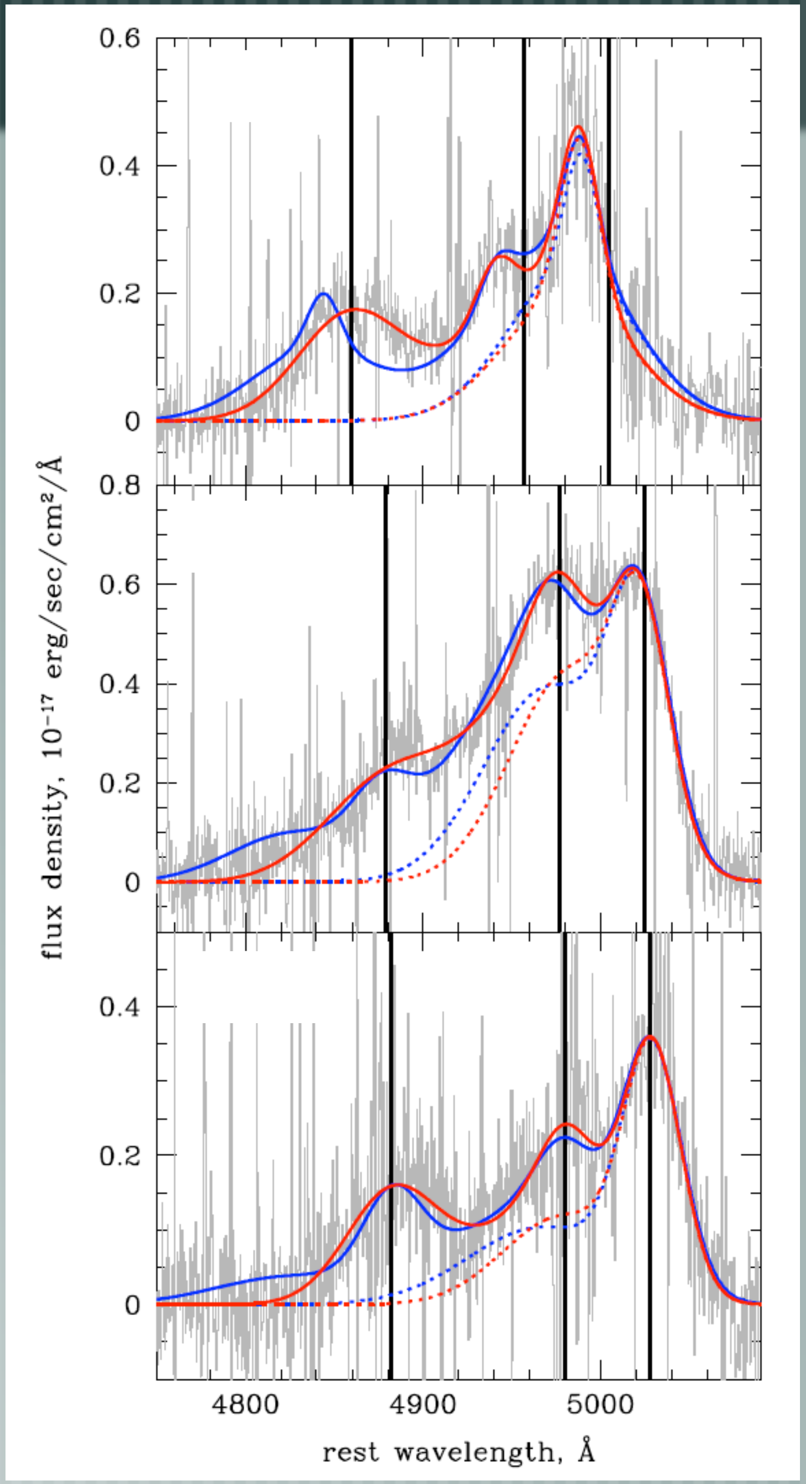
2. Observations: ionized gas

- Now seen by several groups in type 1 and type 2 quasars (e.g., Harrison et al., Rupke & Veilleux, Husemann et al., Villar-Martin et al., Hainline et al., Alexander et al., Cano-Diaz et al., Carniani et al., Perna et al., etc.)



3. Extreme outflows at high z

- z>2: the peak galaxy formation epoch, perhaps key point in evolution of massive galaxies
- Population of red quasars at z=2.5 with unusual optical properties (Ross et al. 2015)
- NIR / rest-frame optical spectra
- Extreme broadening of emission lines
- Physical velocities of >3000 km/sec.
- Nothing like this seen at low z, perhaps a luminosity effect?



Zakamska, Hamann, Paris, et al. 2016

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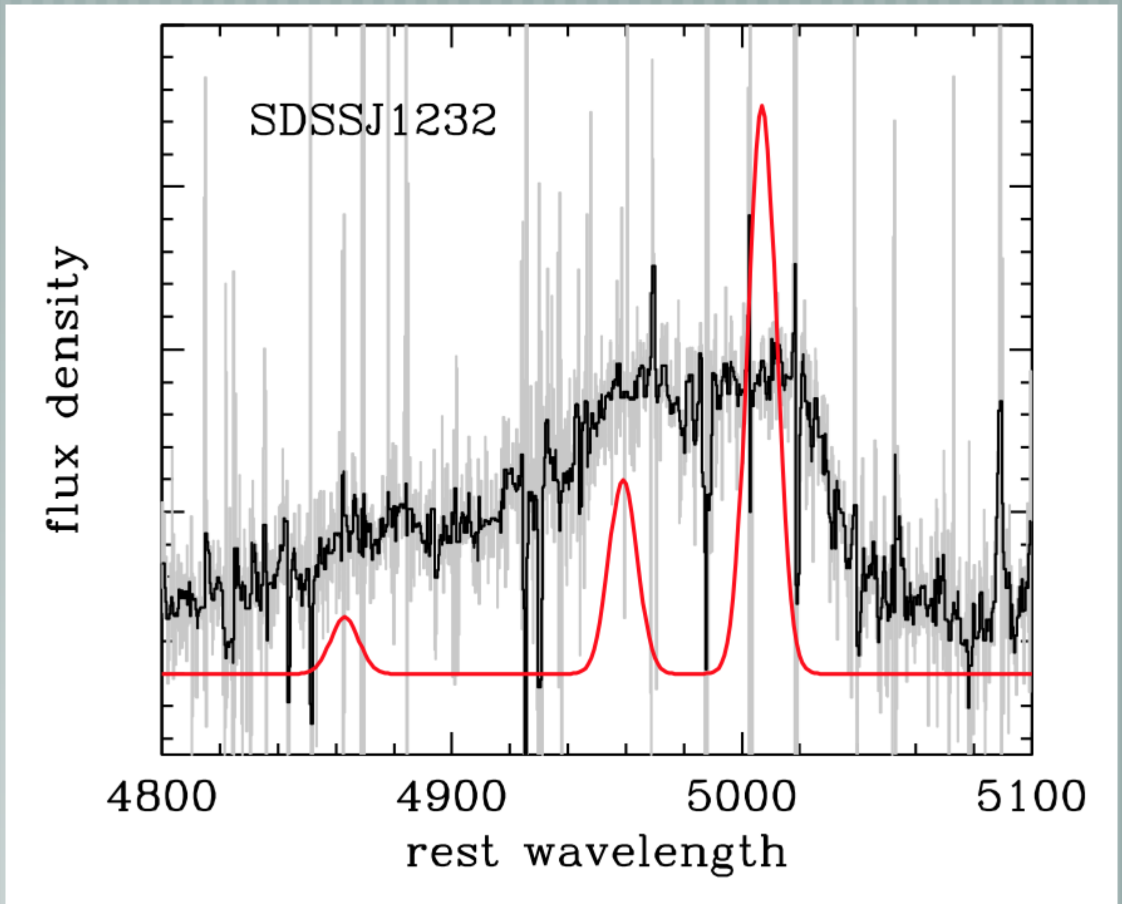
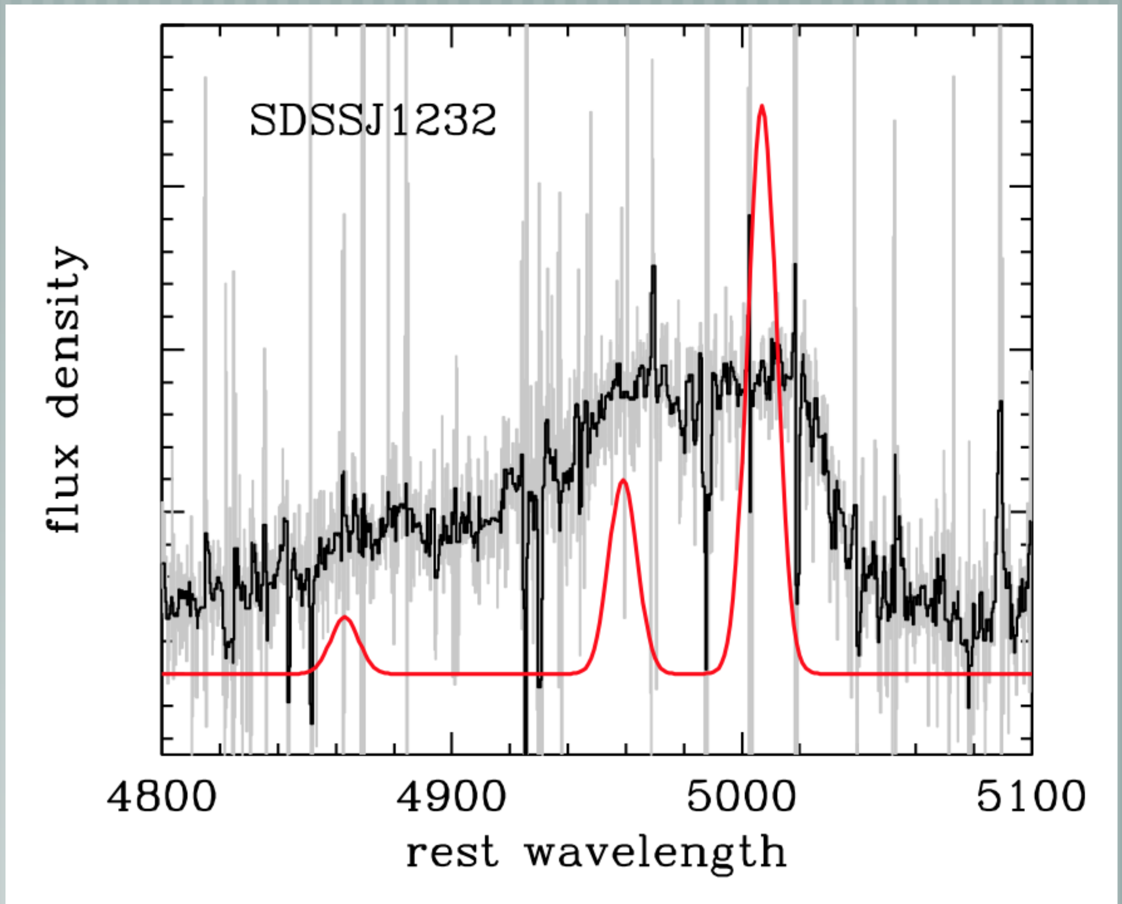


Zakamska, Hamann, Paris, et al. 2016

3. Extreme outflows at high z

- Probing geometry of these outflows with spectropolarimetry observations
- Poster by Rachael Alexandroff



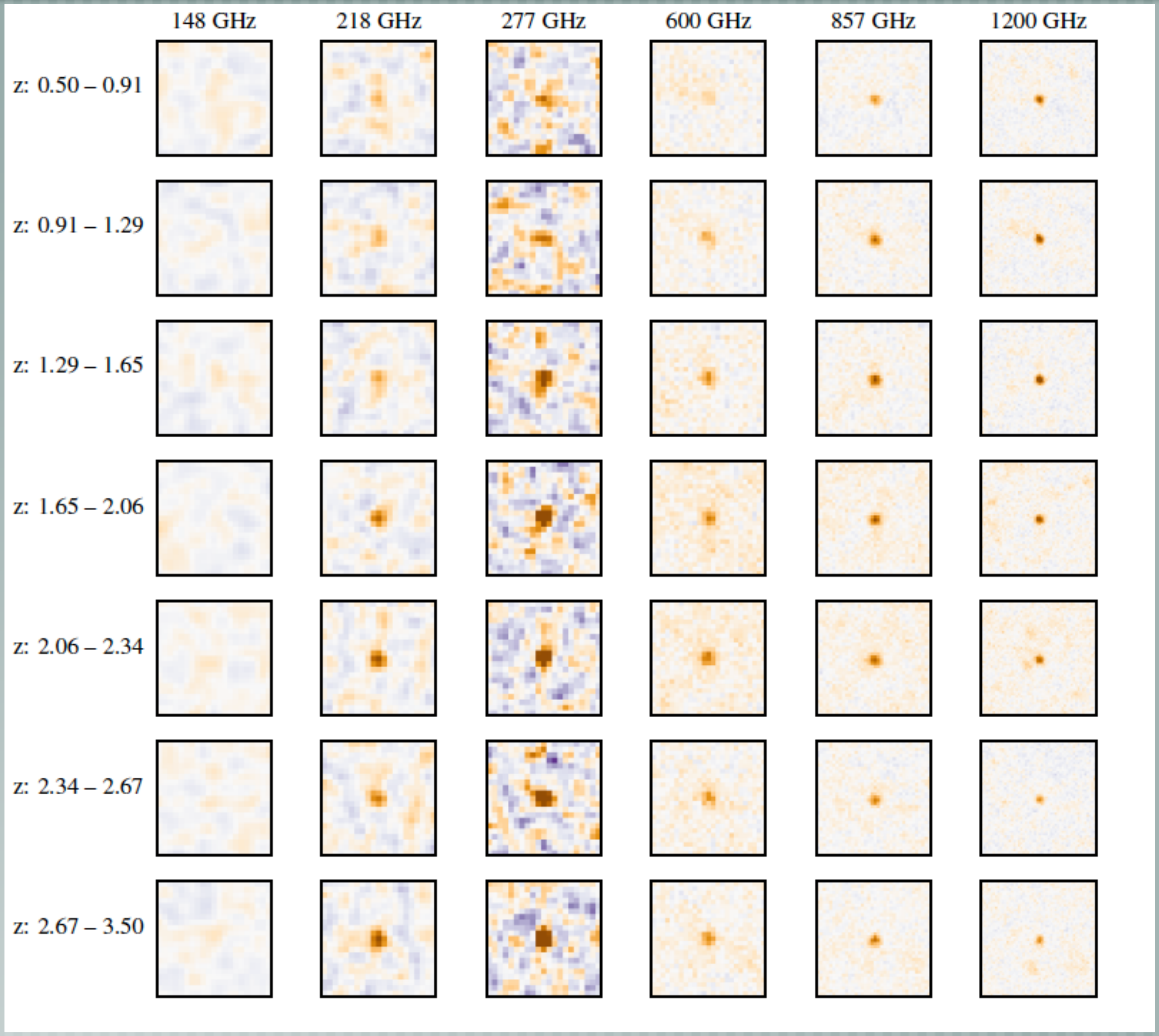
Zakamska, Hamann, Paris, et al. 2016

4. Sunyaev-Zeldovich effect from quasar feedback

- Models predict invisible, low-density, extremely hot component
- Overpressured bubble
- Use ACT and Herschel data to construct stacked SEDs of 20,000 quasars
- Look for Sunyaev-Zeldovich effect
- We have a detection!

$$\int P \mathrm{d}V = f L_{\mathrm{bol}} \tau$$

- f=15% (tau=10^8 years).



Crichton et al. 2016

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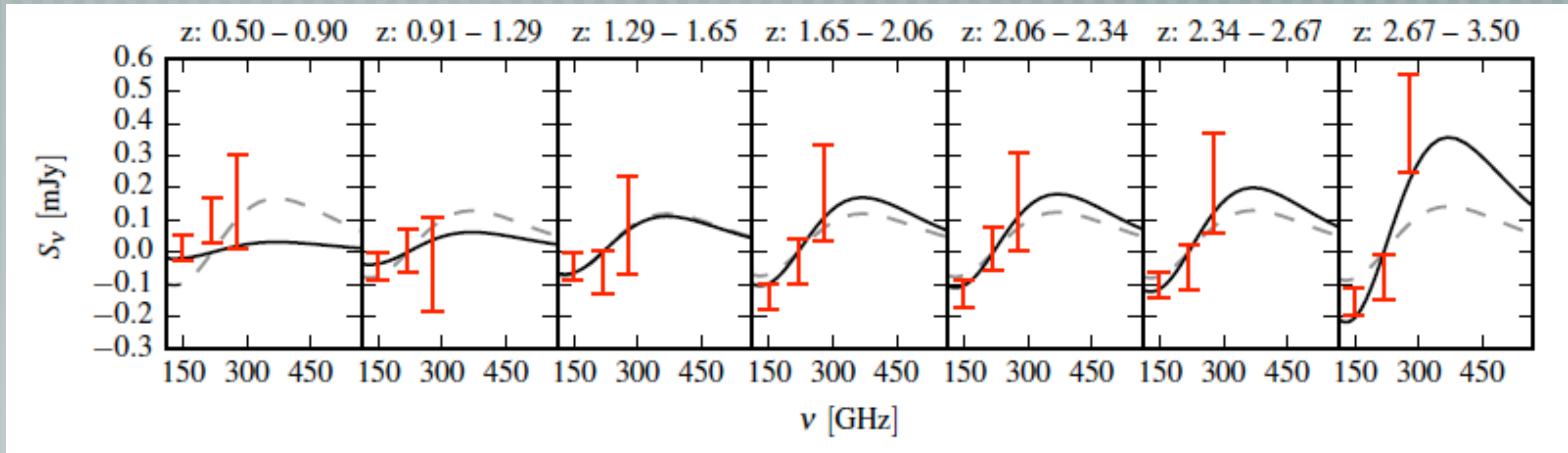
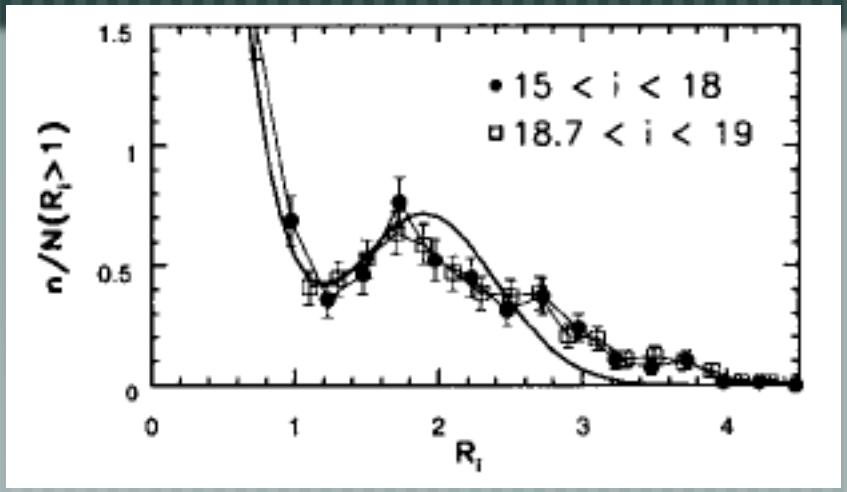


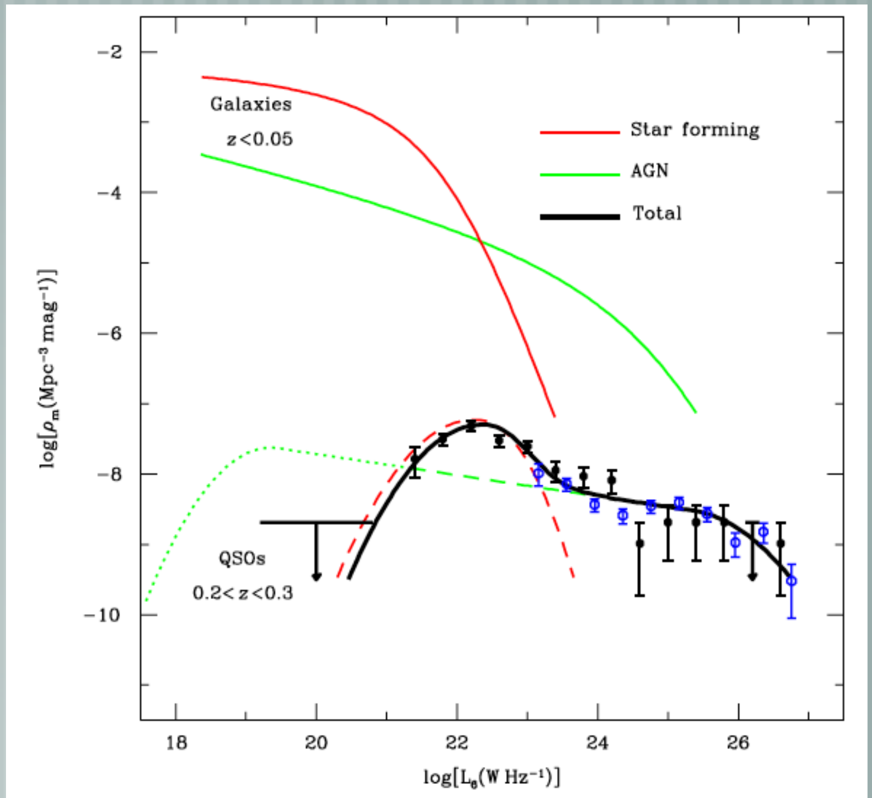
Crichton et al. 2016

5. The nature of the radio emission in RQ quasars

- Distribution of radio power is very broad
- many (>5) orders of magnitude (faint end hard to probe)
- Is it a smooth or a bi-modal function?
- Is the mechanism of production of radio emission the same (just scaled up and down) or different?
- Why do we care? – Is every black hole capable of producing a jet? Or are jet-producing BH special?



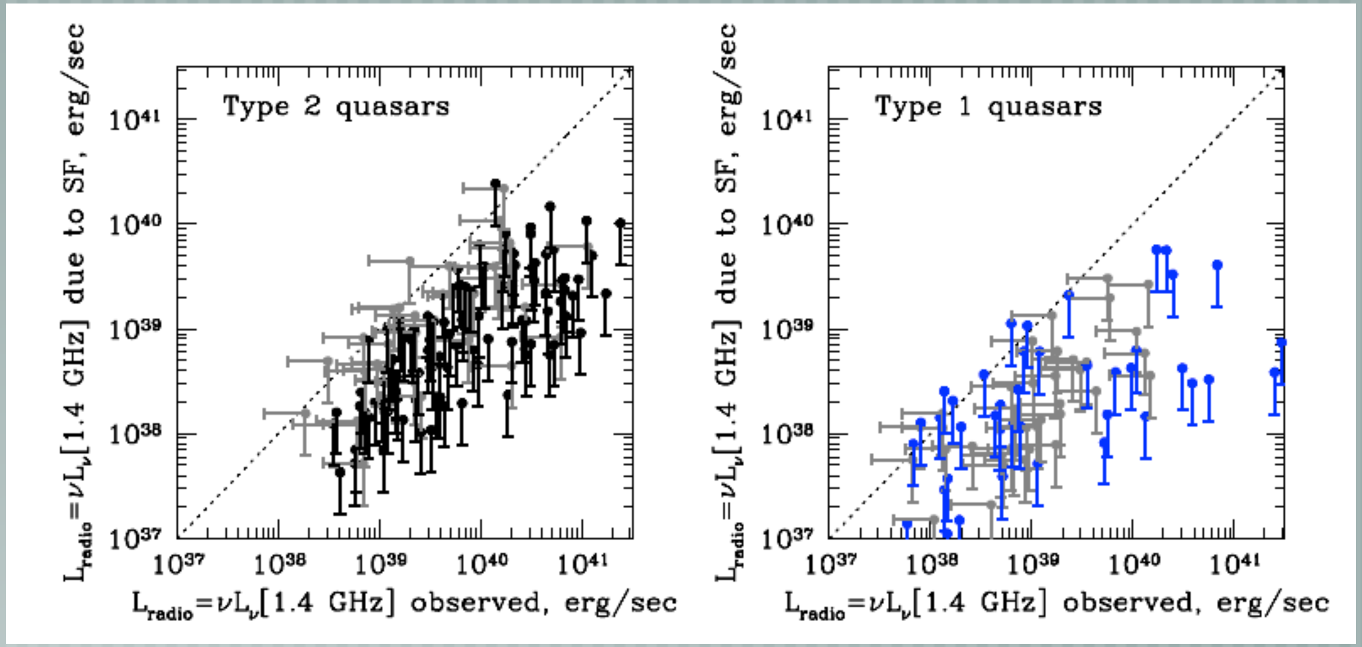
Ivezic et al. 2002
distribution of radio-to-optical ratios



Kimball et al. 2011

5. The nature of the radio emission in RQ quasars

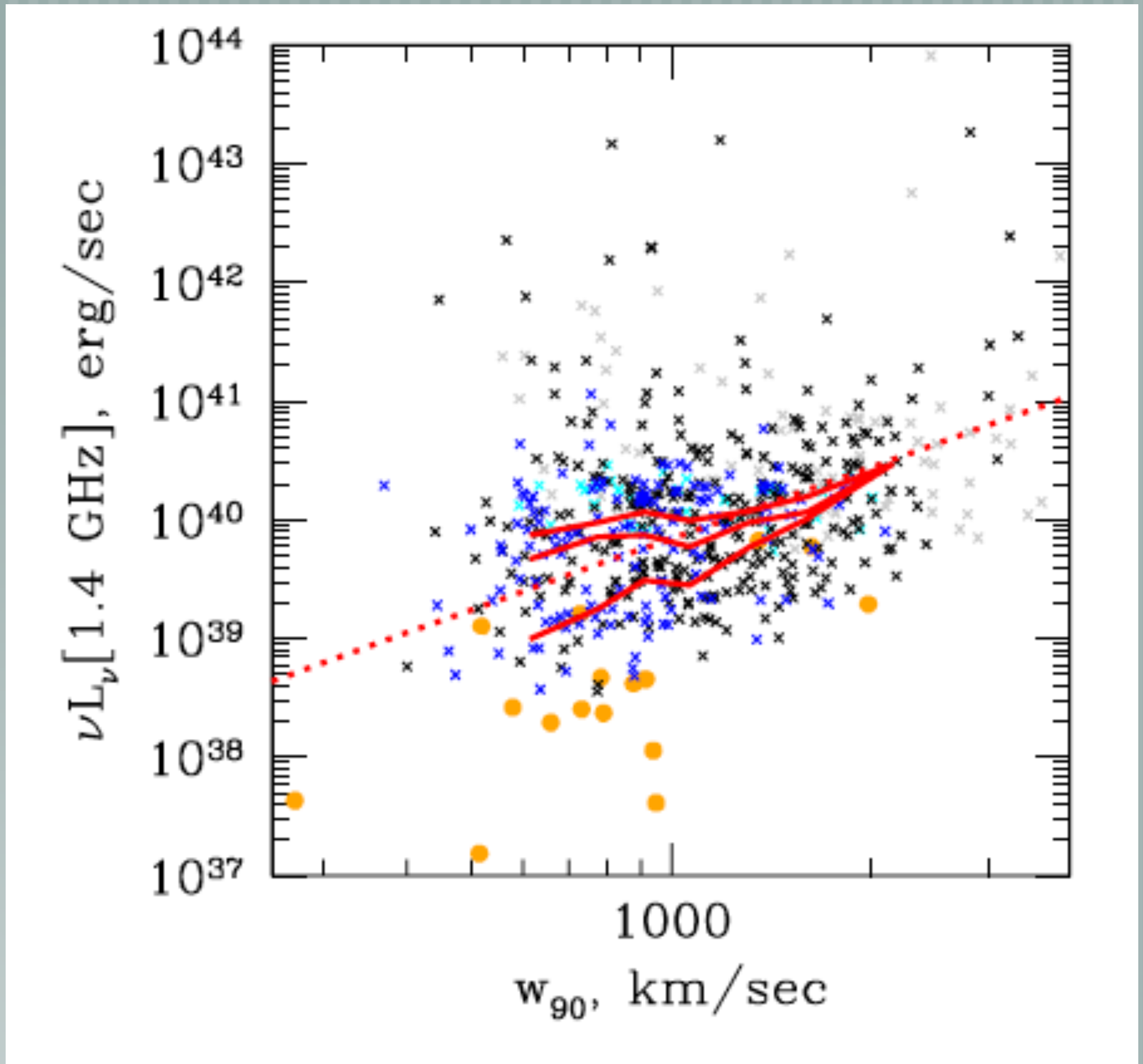
- What is the origin of the radio emission in RQ quasars?
- Star formation insufficient by a factor of 10.



Zakamska et al. 2016

5. The nature of the radio emission in RQ quasars

- New evidence: Correlation between line width (=outflow velocity) and radio luminosity
- These are “the 90%”: faint point sources
- Quasar-driven shocks accelerate particles, produce radio emission
- Zubovas & King, Faucher-Giguere & Quataert, Jiang et al, also Stocke et al. 1992
- Different from jets accelerating gas



Zakamska & Greene 2014

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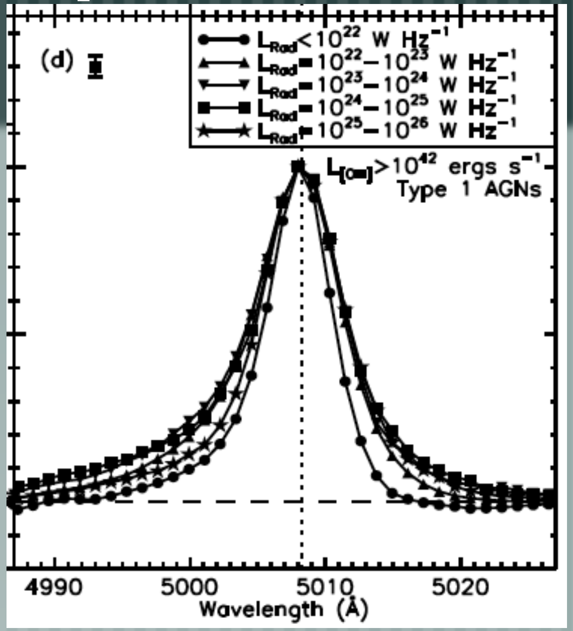
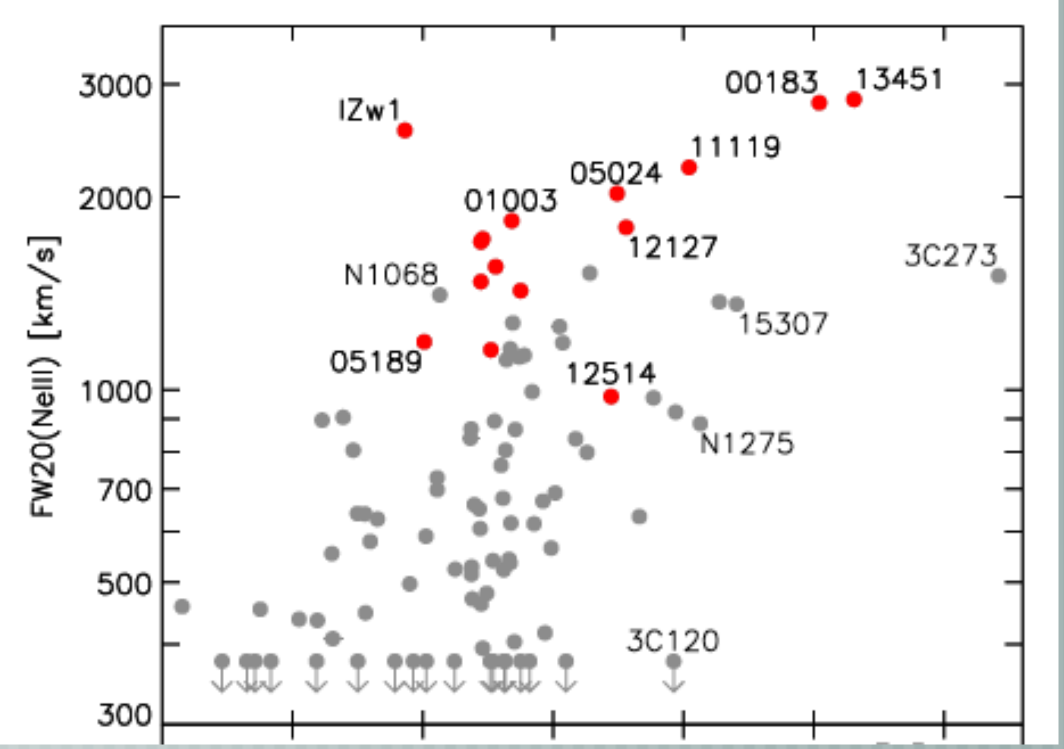


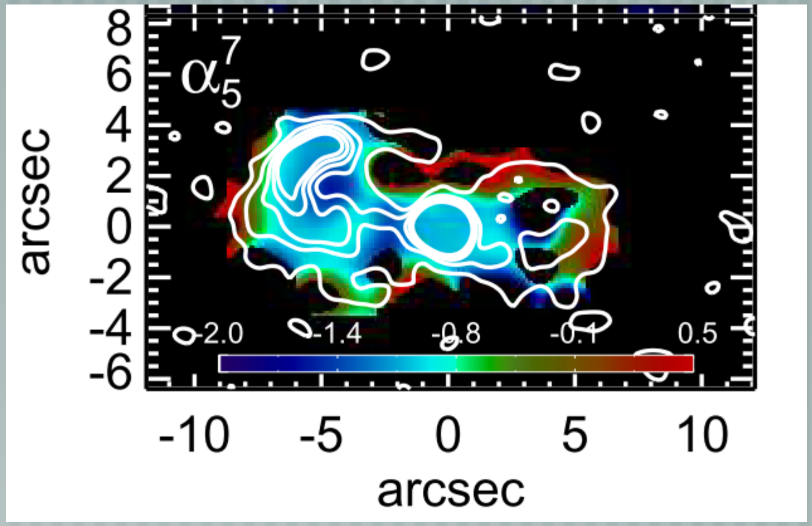
Mullaney et al. 2013



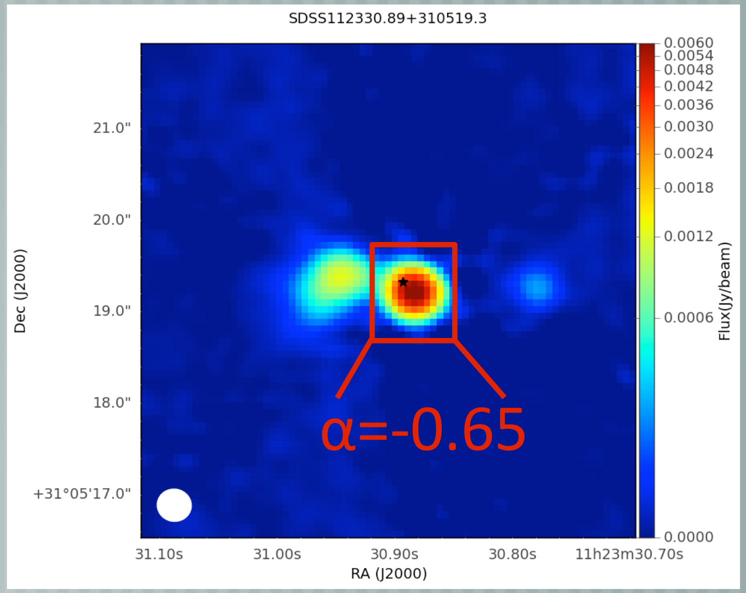
Spoon & Holt 2009

5. The nature of the radio emission in RQ quasars

- Distinguish between compact jets and quasar winds?
- Combination of radio luminosity, morphology and spectral index can help
- Steep spectrum, unresolved radio core and radio lobes imply
    - compact jets with episodes on scales of ~10^7 years
    - synchrotron emission from quasar winds



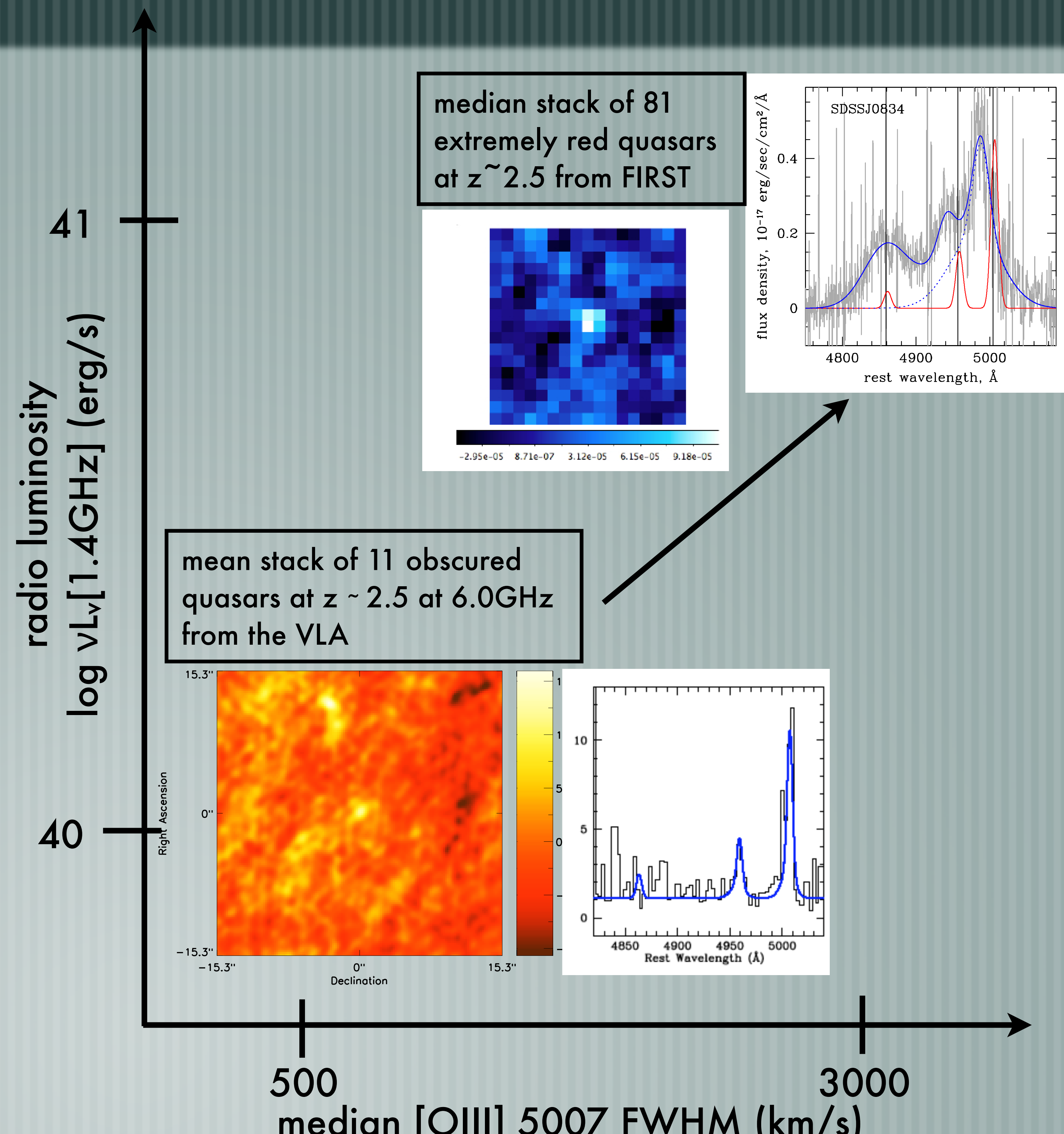
"Teacup AGN"
Harrison et al. 2015
z = 0.085



Alexandroff et al. 2016
z = 0.3

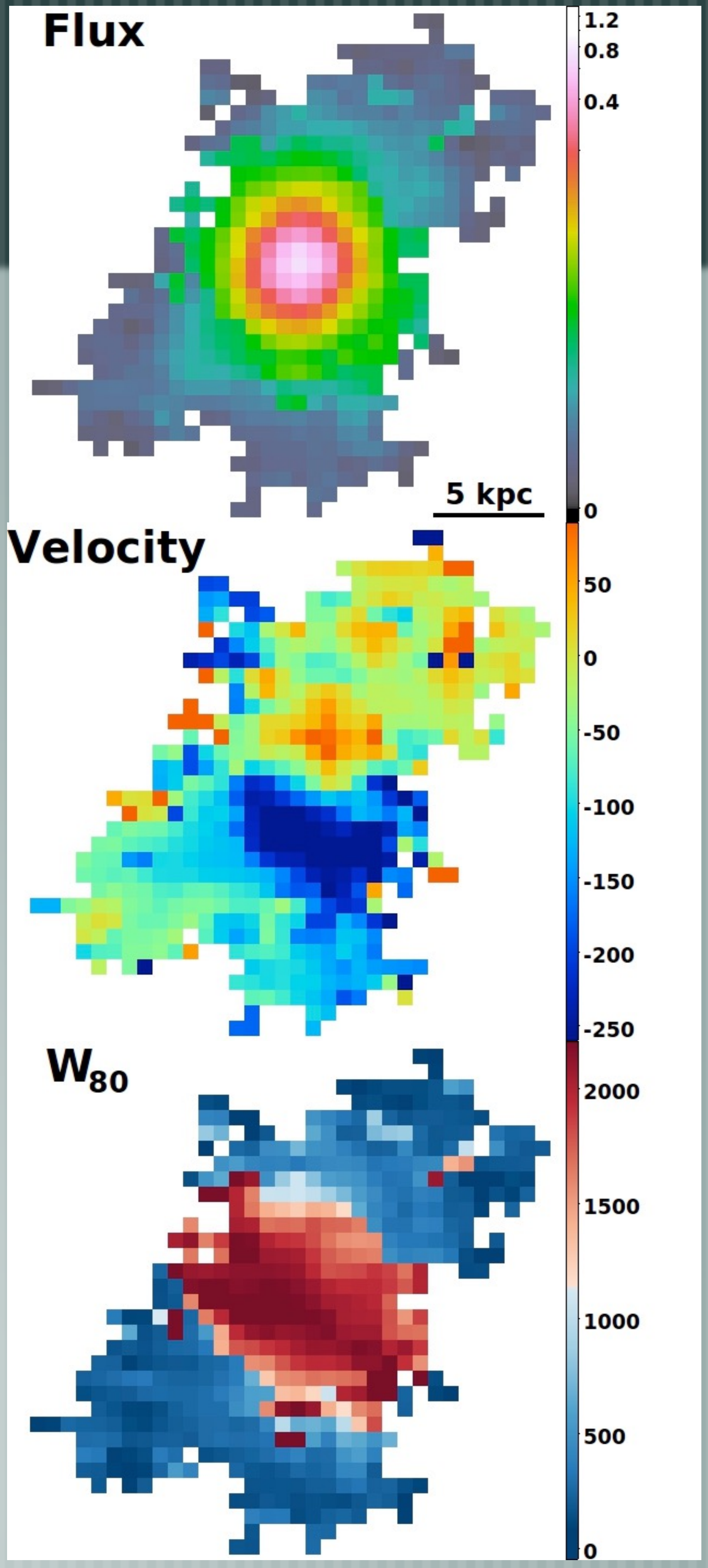
5. The nature of the radio emission in RQ quasars

- Hints of extension in the correlation between outflow velocity and radio luminosity to high redshift (z~2.5)
- If you want to learn more come by poster 14!



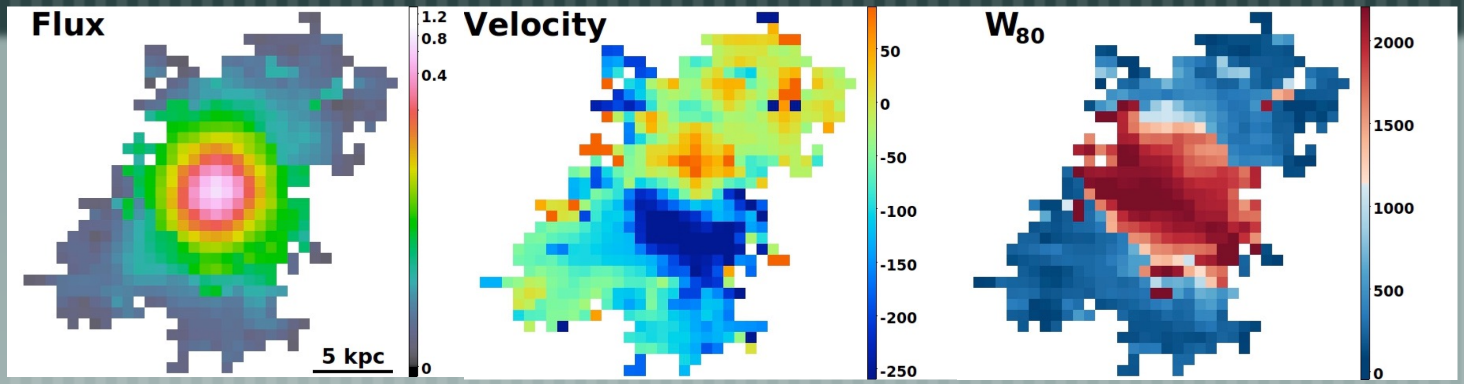
Conclusions

- Growing observational evidence for powerful, galaxy-wide quasar-driven winds
- Radio-quiet objects (no powerful jets)
- Ionized gas (including extreme kinematics, many x 1000 km/sec), molecular gas, bubbles, evidence for the volume-filling component!
- We propose that radio emission in RQ quasars = bi-product of shocked winds
- Effect of quasar feedback on star formation: talk by Dominika Wylezalek this afternoon

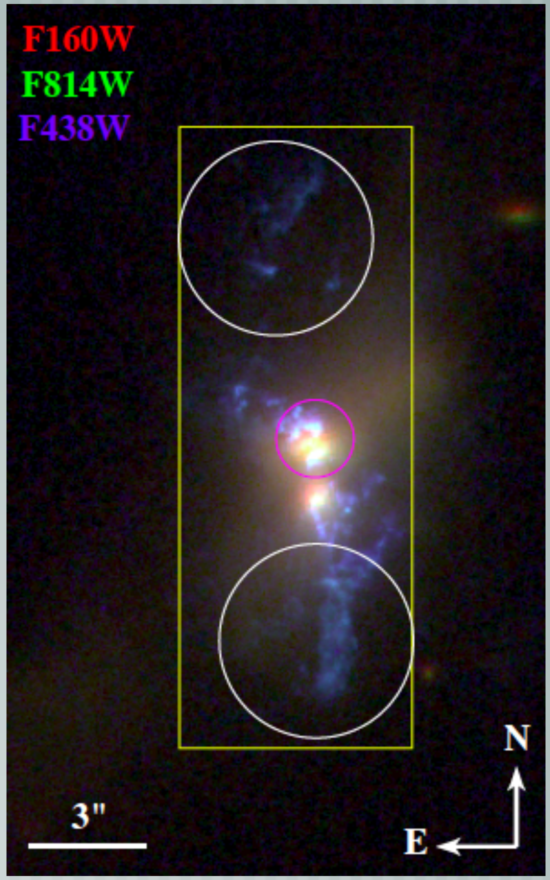


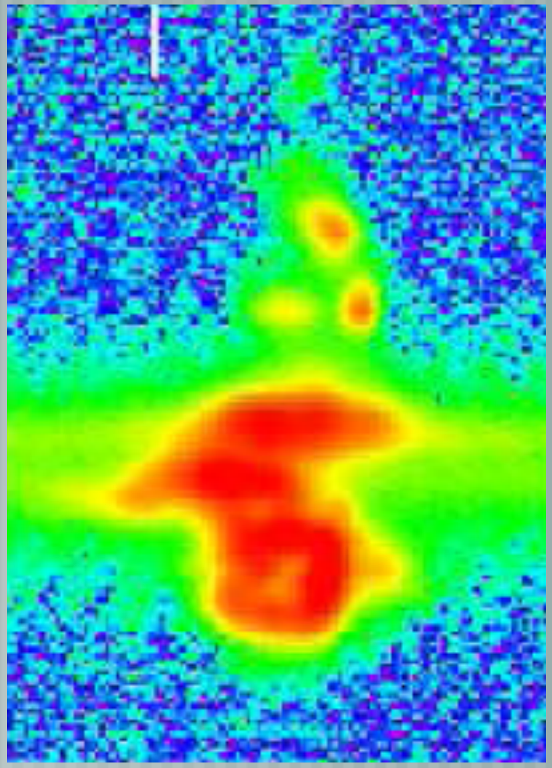
2. Observations: ionized gas bubbles

- Winds look for the path of least resistance
- In disk galaxies, expect them to "break out" perpendicular to galaxy plane
- Have several candidates
- Energy estimates using completely different methods: a few per cent (large uncertainty) of L_{bol}



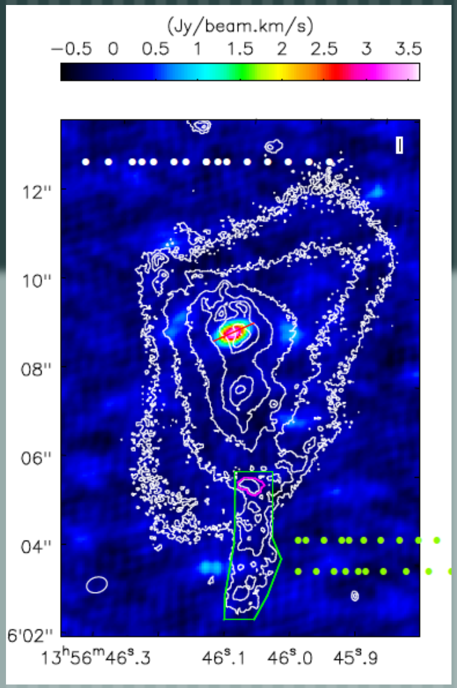
Liu, Zakamska, et al. 2013b



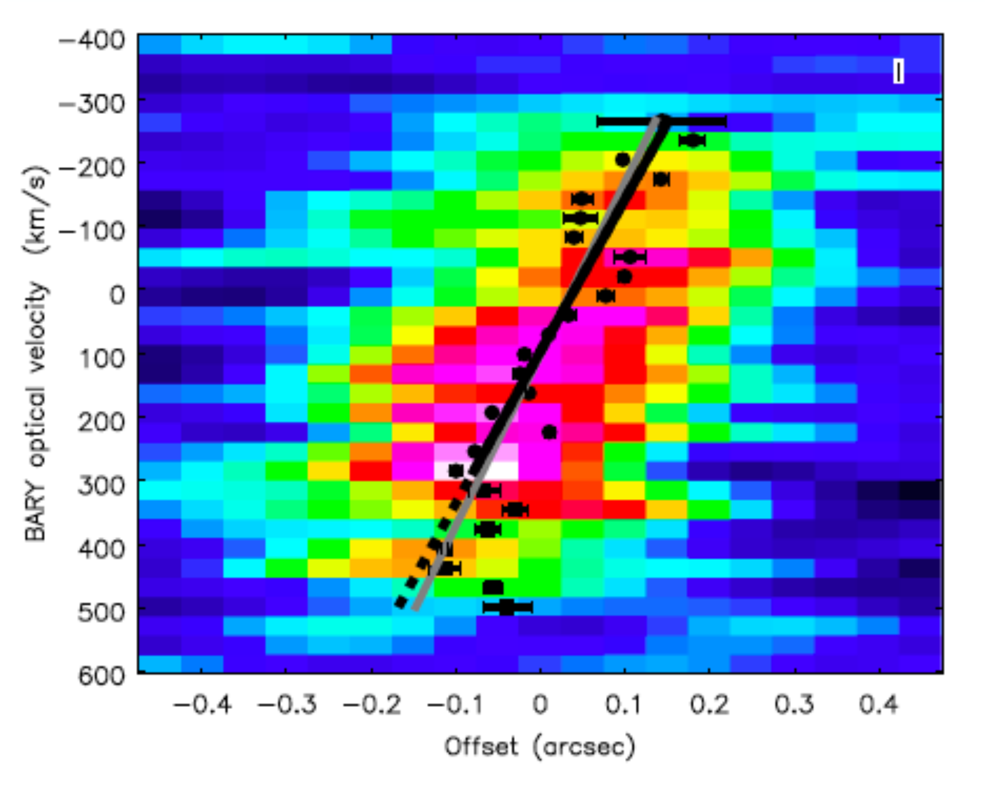


Greene, Zakamska, Smith 2012,
Greene, Pooley, Zakamska, et al. 2014

2. Observations: ionized gas bubbles



- Multi-phase winds:
- hot, volume filling, invisible component
- cooler denser clumps (ionized, neutral, molecular)
- Ionized – emission lines
- Molecular – ALMA!
- 350 Msun/year, will deplete in 10^6 years



Sun, Greene, Zakamska, Nesvadba 2014