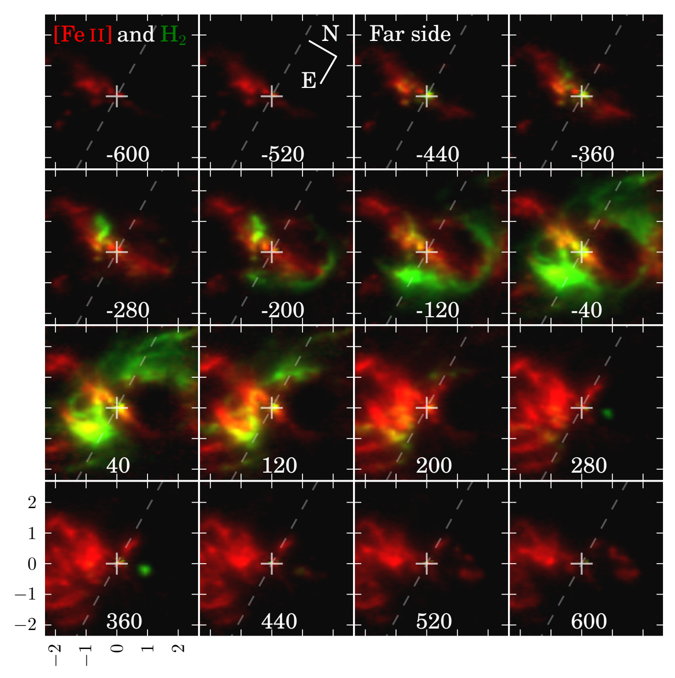

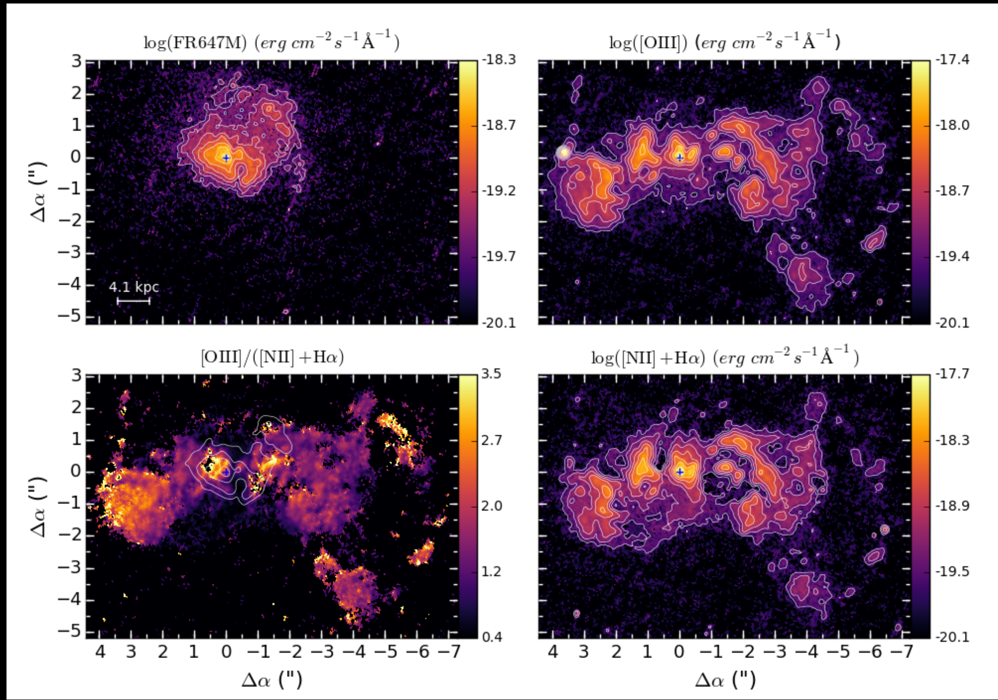

Observational constraints on outflows from Active Galactic Nuclei

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AGNIFS (AGN Integral Field Spectroscopy) collaboration

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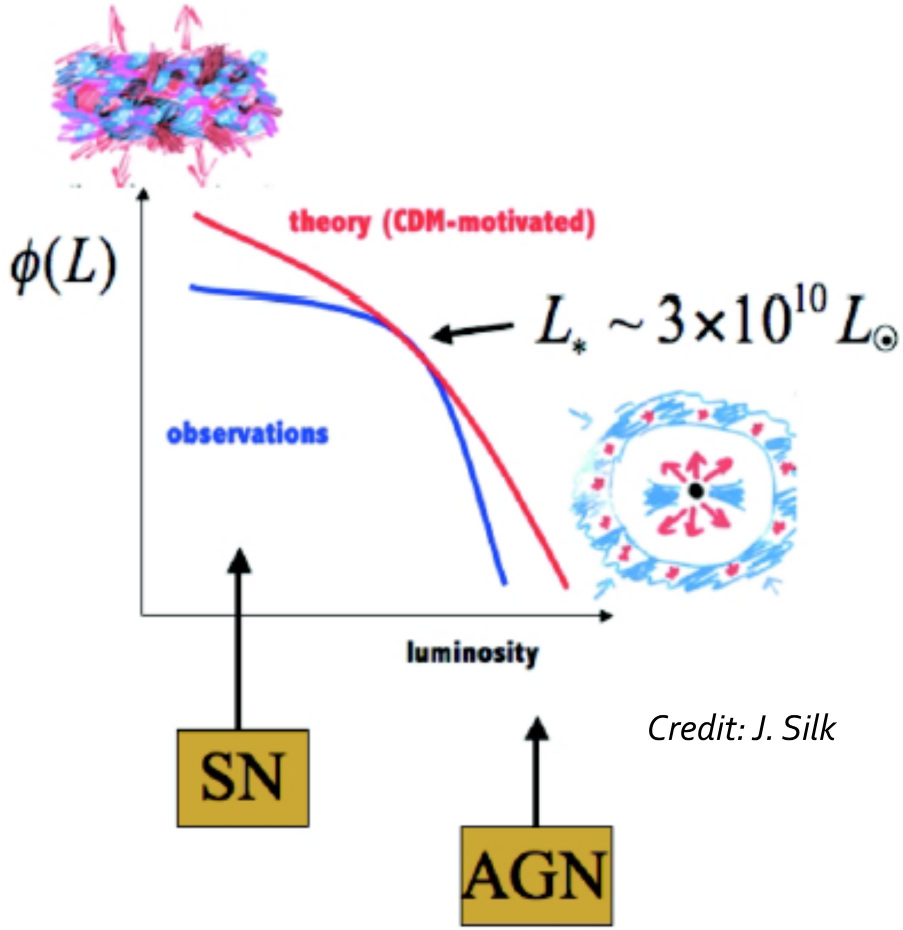
Henrique R. Schmitt
Travis Fisher
Mike Crenshaw
Steven Kraemer

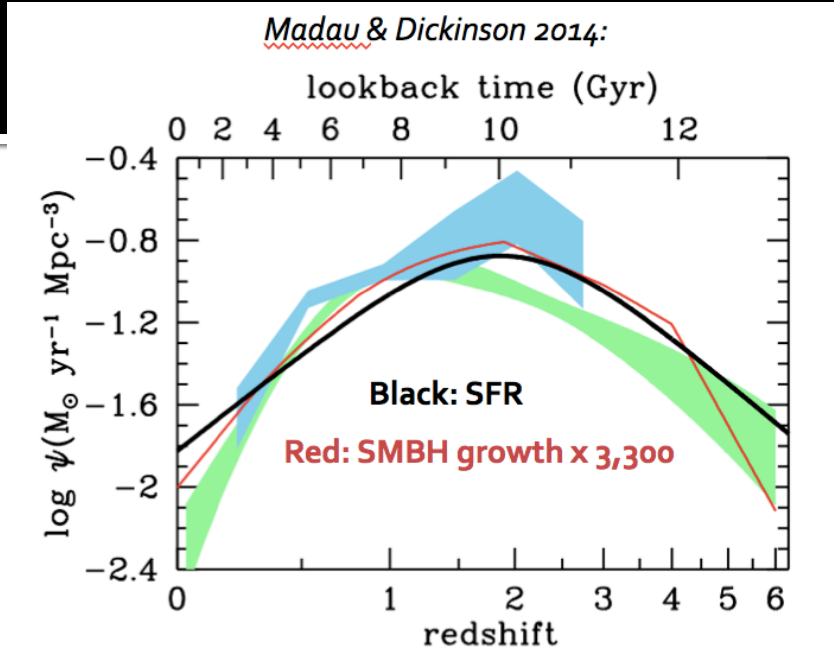
Importance of feedback in AGN

- Cosmological models without feedback do not reproduce galaxy luminosity function
- Low L end: feedback from supernovae
- High L end: feedback from Active Galactic Nuclei (Bower et al. 2012)



Credit: J. Silk

Feedback



- More important in the past:

- But geometry constraints are better at z~0

- Quasar mode (radiative) and radio mode feedback

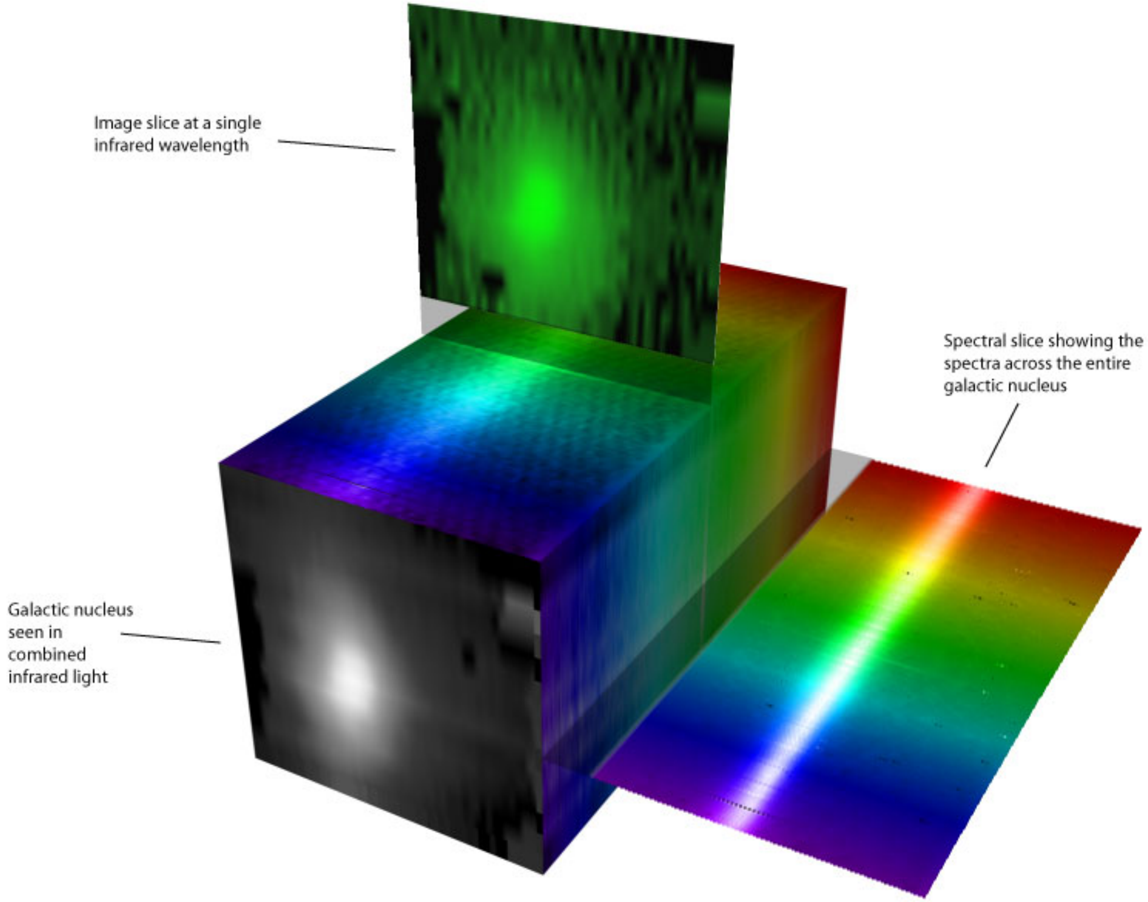
Kinematics: Data cubes (e.g. Gemini IFUs)

Near-IR: NIFS + ALTAIR (adaptative optics)

- FOV: 3″ x 3″
- Sampling: 0.04″×0.1″
- PSF ~ 0.1″
- R~5500, Z, J, H, K

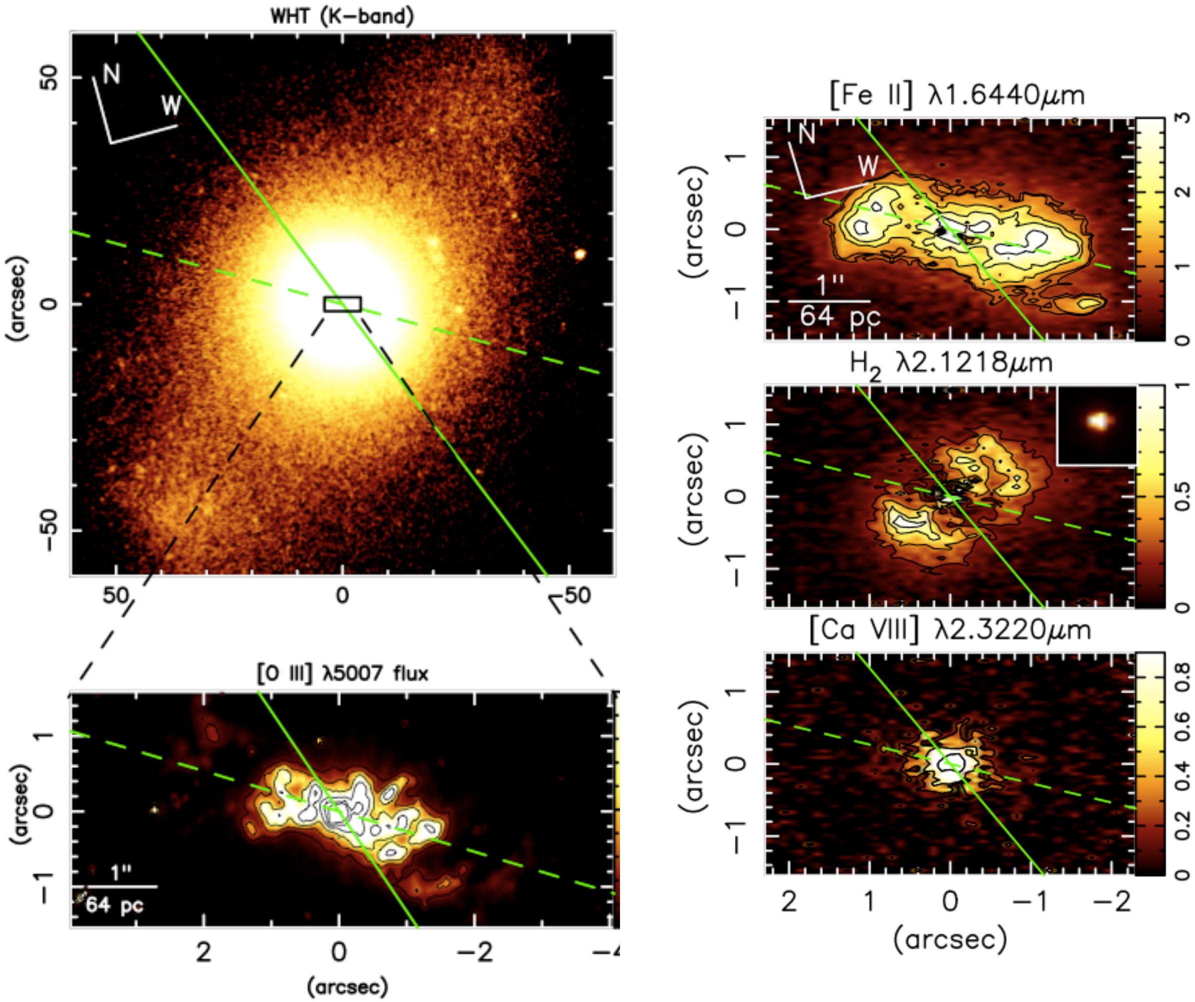
Optical: GMOS IFU

- FOV: 3.5″x5″ or 5″x7″
- Sampling 0.2″
- PSF ~ 0.6″
- R~2500



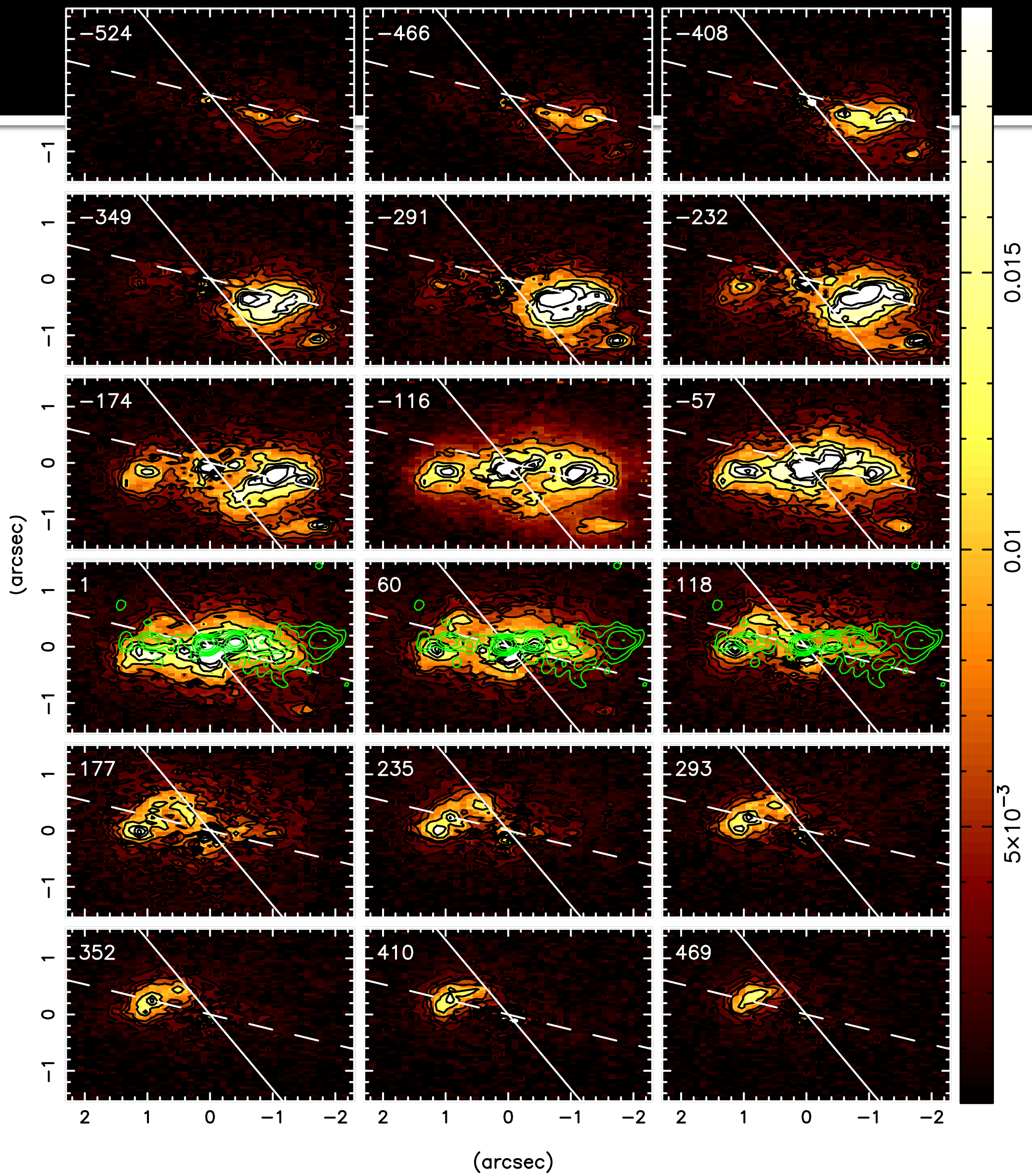
Outflows in NGC4151 (log L[OIII]= 42.2)

(NIFS, Storchi-Bergmann+09,10)



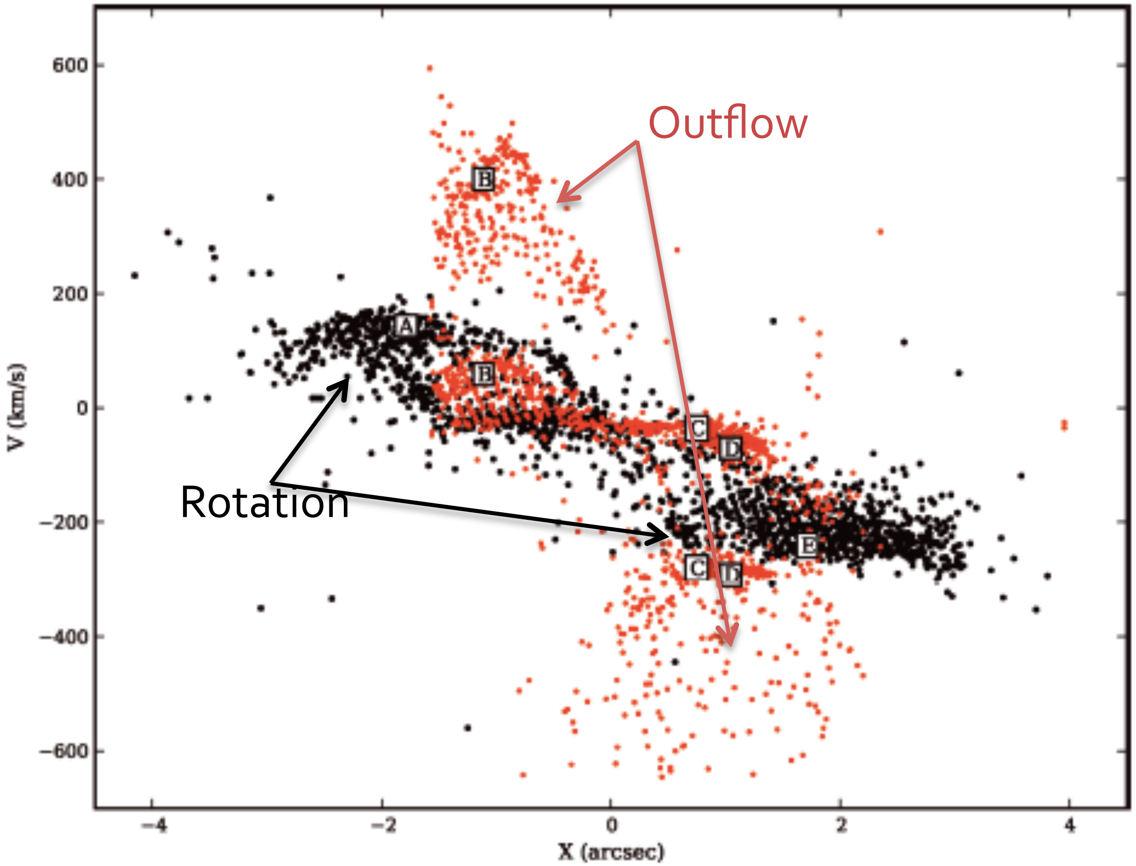
- SABab, Sy 1.5
- 1”: 64 pc
- [FeII] : ioniz. cone, ~ 100 pc
- H_2 : along bar; 50 pc, avoids cone
- Coronal lines: barely resolved

NGC4151 [Fe II] channel maps: outflows



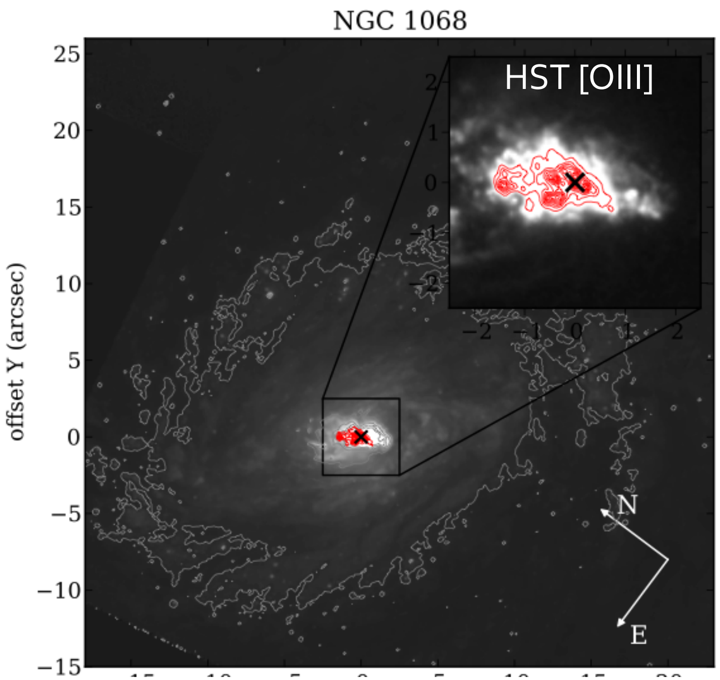
- -600 km s^{-1} < v < + 600 km s^{-1}
- Mass outflow rate ~ 2 $M_{\odot}$ yr^{-1}
- Kinetic power of outflow: 0.3% L_{bol}
- ~ required by models to explain M_{BH} vs. σ relation
- In 10^7 yr : push 10^8 $M_{\odot}$ of gas away from galaxy

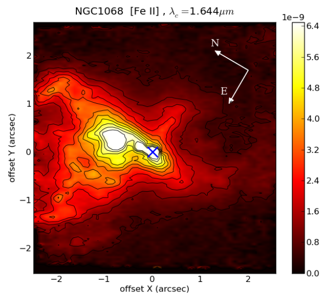
Outflows in NGC4151

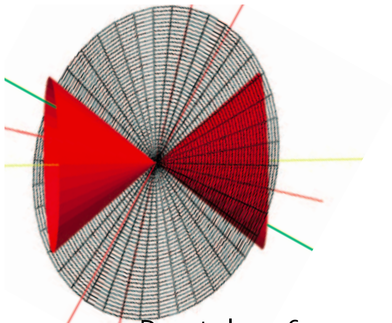


- Outflow restricted to inner 2″: 130 pc
- Outwards: rotation
- -> Lower resolution data could be interpreted as the outflow being more extended

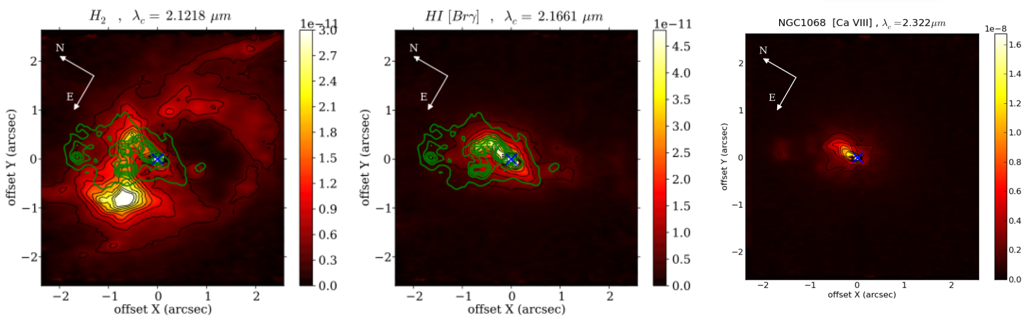
Outflows in NGC 1068 (log L[OIII]= 41.5)
(NIFS, Barbosa +14)





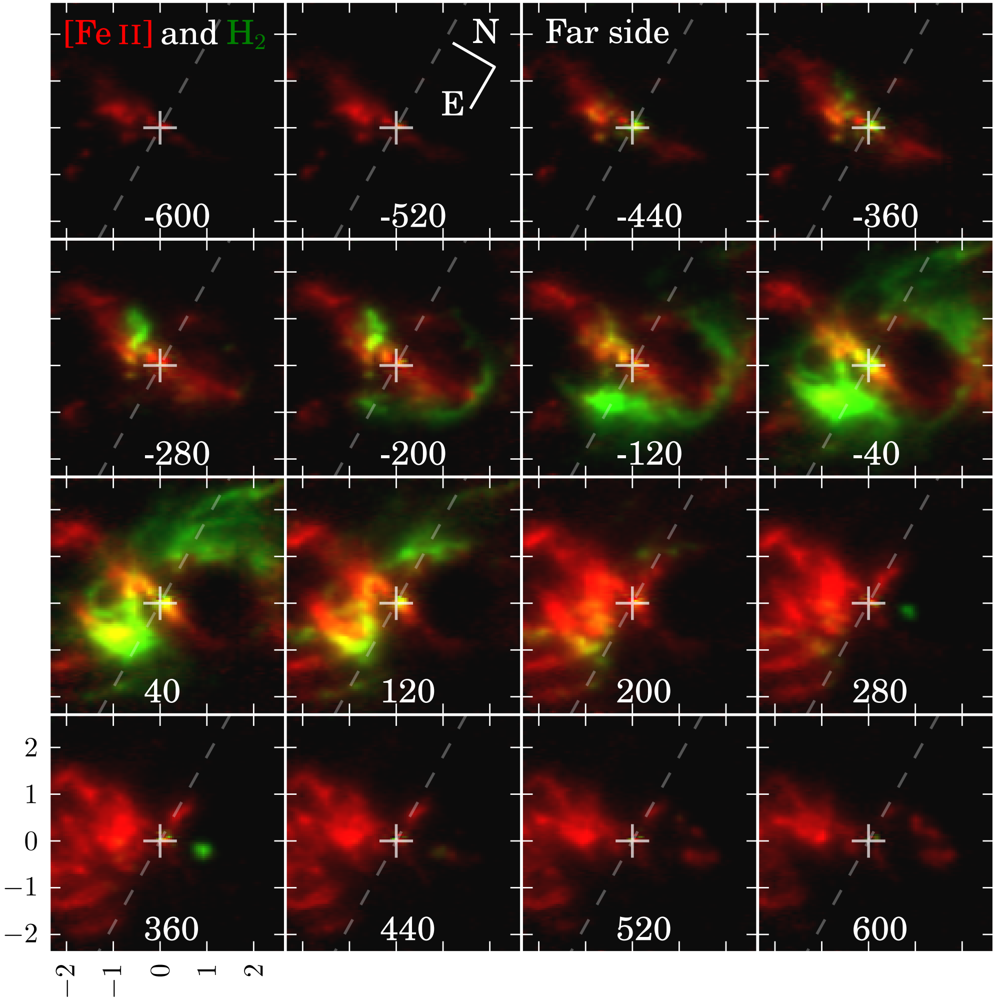


Das et al. 2006



- Sb, Seyfert 2
- 500 pc x 500 pc
- 1"= 64 pc
- [FeII]: bipolar "hourglass"
- H_2: 100 pc (radius) off-centered ring

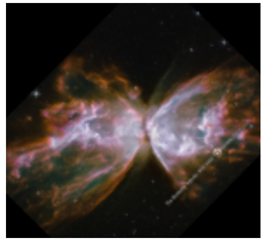
NGC1068 channel maps: [FeII] and H2
(NIFS, Barbosa +14)



[Fe II]: outflows

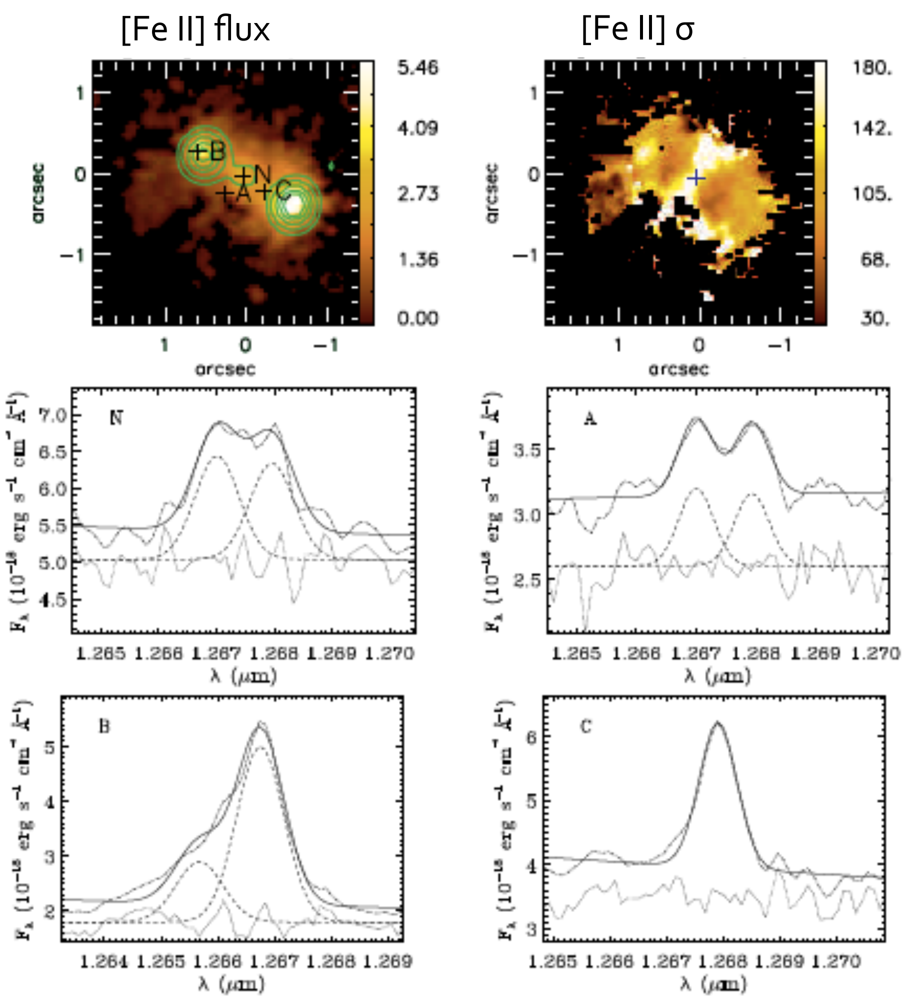
- Velocities up to 800 km/s
- Mass outflow rate: 4± 1 $M_\odot$ yr^{-1}

Hourglass shape as PN NGC6302



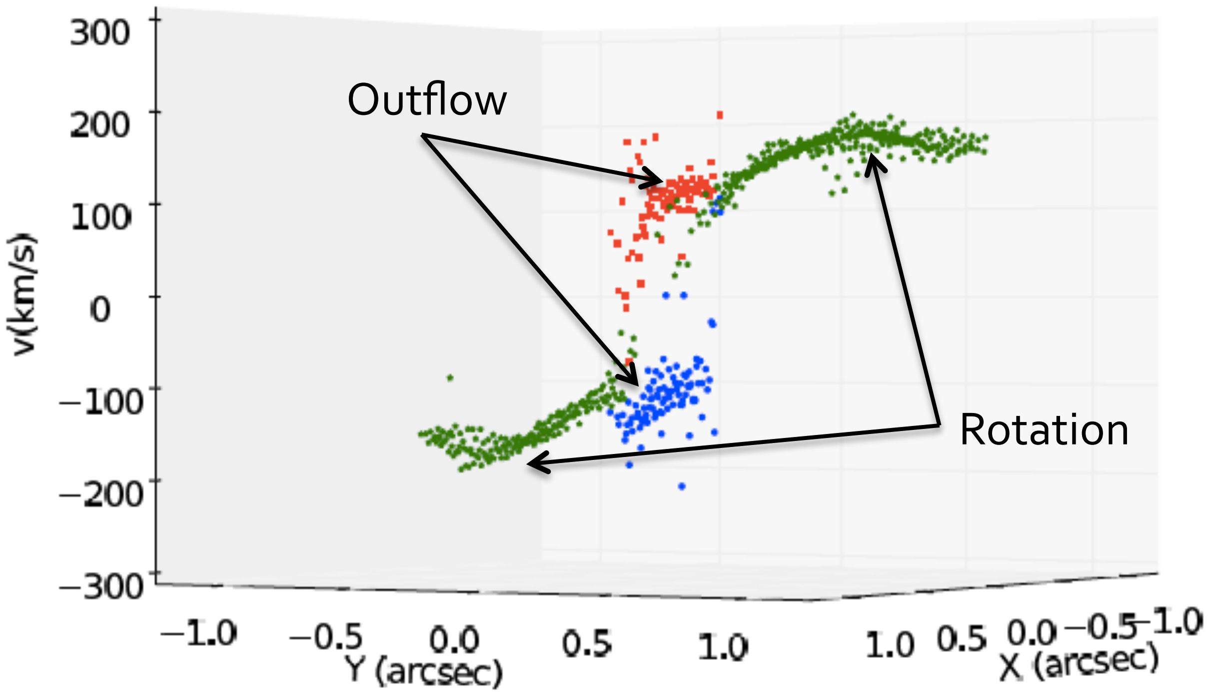
- Power of the outflow: ~ 0.1% L_{bol}
- Weak effect in the galaxy
- Extent of the outflow: 200 pc

Outflow in NGC5929 (log L[OIII]= 40.5) (NIFS, Riffel +13,+15);



- Sab pec, Sy 2, 2 radio blobs
- 1"= 175 pc
- High σ perp. ioniz./radio axis: double lines
- -> equatorial outflow: strip 50 pc x 250 pc

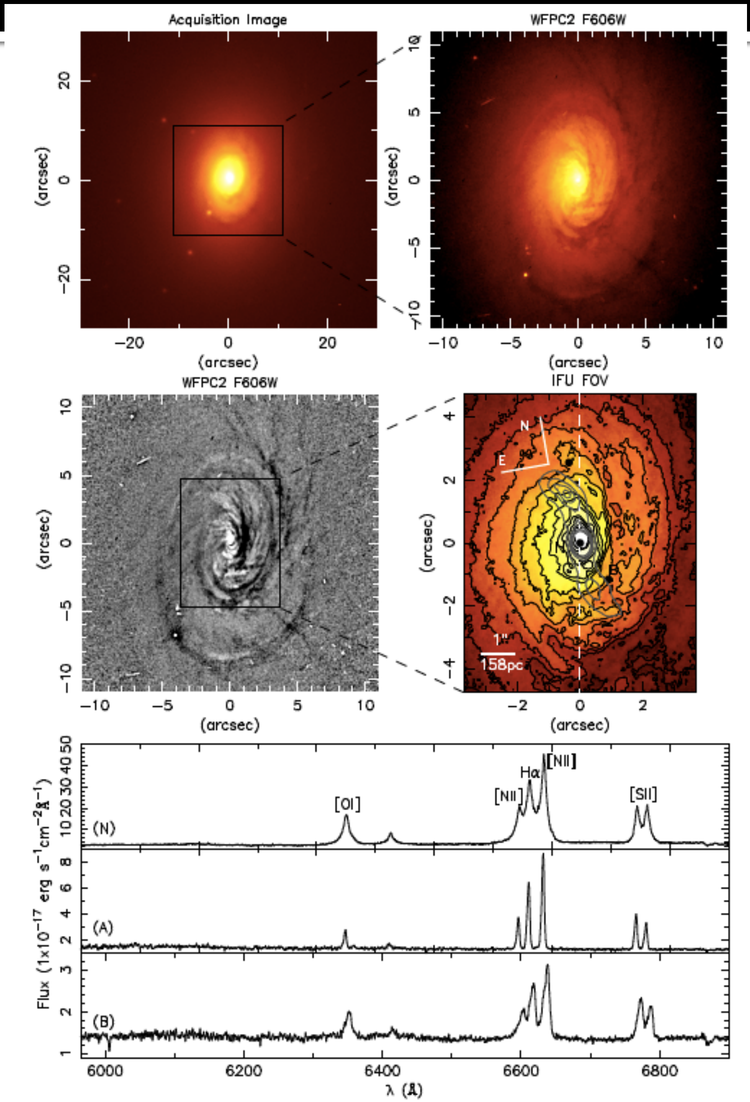
Outflow in NGC5929 (log L[OIII]= 40.5) (NIFS, Riffel +13,+15)



- Rotation
- Equatorial outflow
- Expansion of torus? (Elitzur+12;Hönig+13)
- Lateral expansion due to radio jet?
- Mass outflow rate:
- ~ 0.4 $M_{\odot}$ yr^{-1}

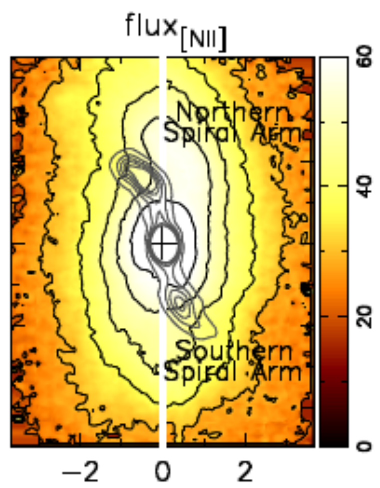
Outflow in NGC2110 (log L[OIII]= 40.6)

(GMOS-IFU, Schnorr Müller +14)

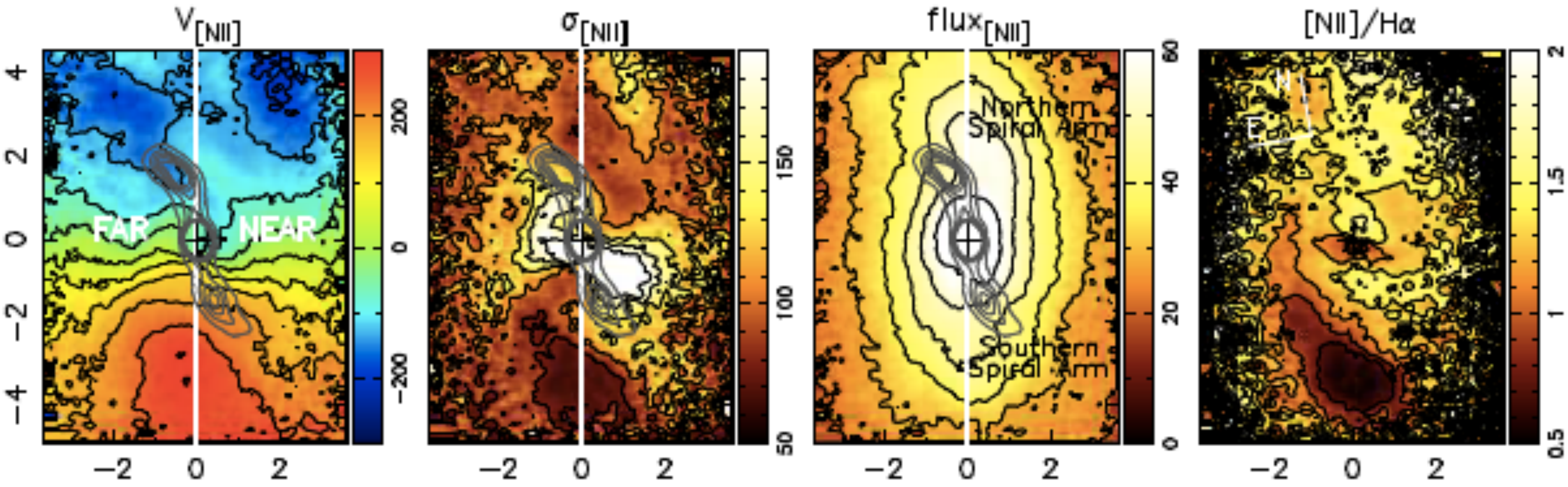


- SO galaxy
- 1"= 160 pc
- Radio jet extending by ~4" (~600pc)

Line emission over whole FOV (800 pc)



Outflow in NGC2110 (log L[OIII]= 40.6)
(GMOS-IFU, Schnorr Müller +14)

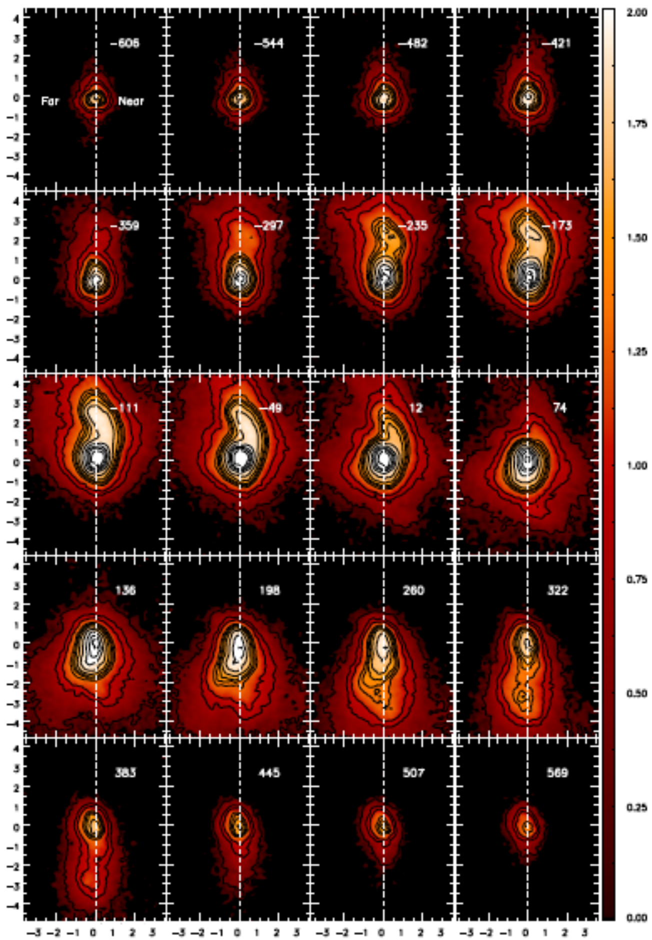


- Velocity field: dominated by rotation, although disturbed
- High σ approx. perpendicular to the ionization axis

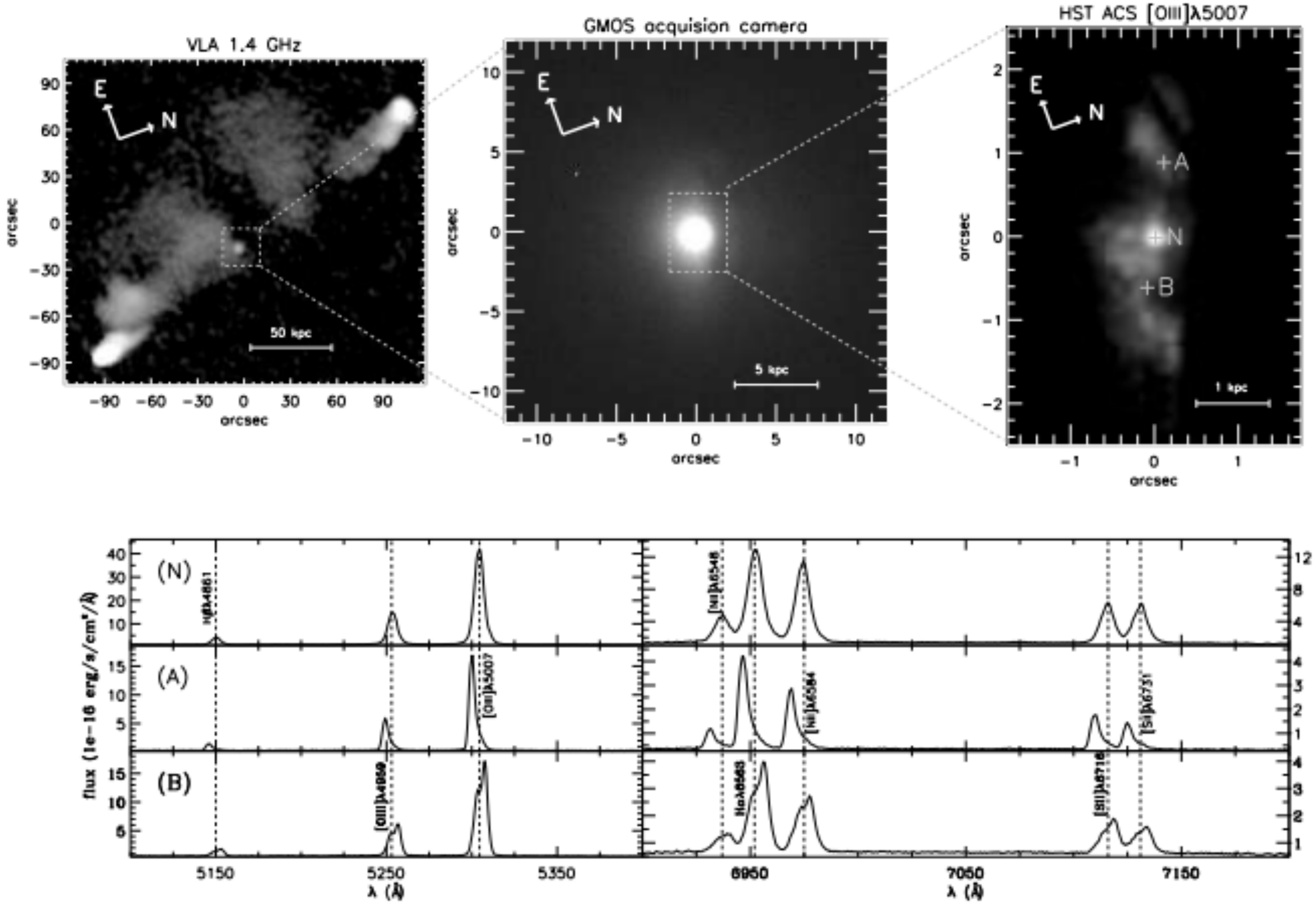
Kinematics: Compact Outflow

Main components:

- Extended emission: gas rotating in the plane out to > 800 pc
- Outflow in inner ~200 pc (high σ)
- Mass of ionized gas: $10^8 M_\odot$
- Mass outflow rate: ~0.9 $M_\odot\ yr^{-1}$
- Power of the outflow: 0.3% L_{Bol}

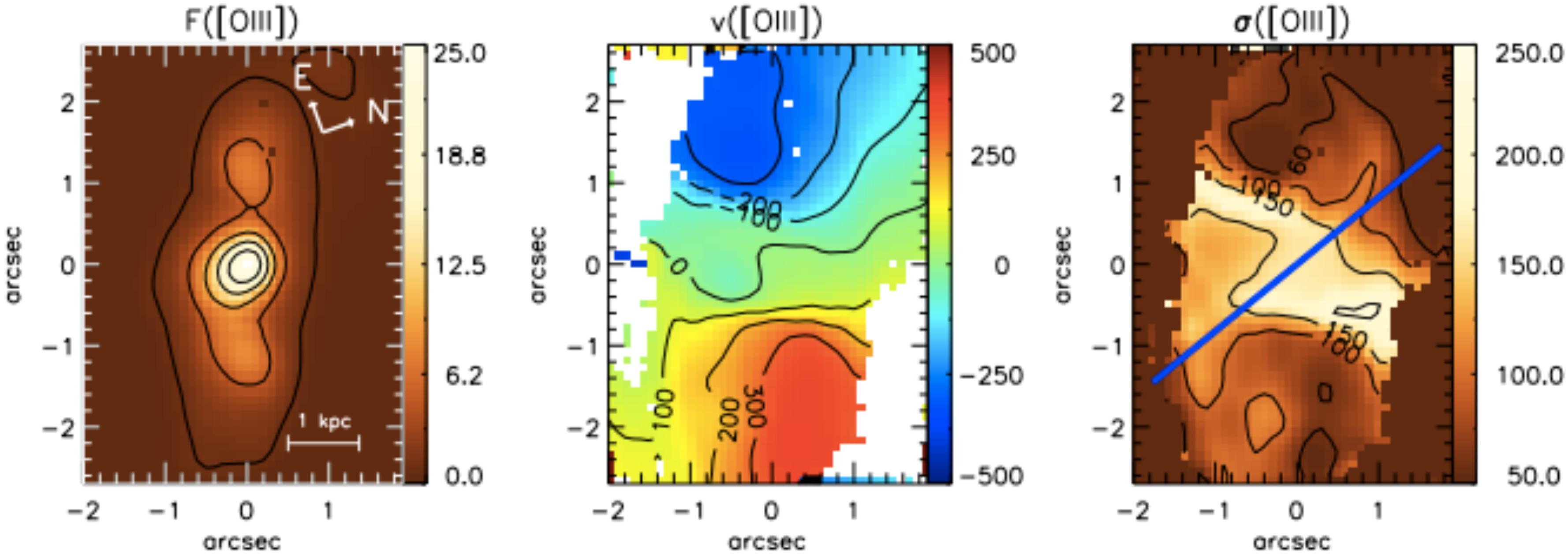


Outflow in radio galaxy 3C33
(log L[OIII]= 42.8) (GMOS, Couto+17)



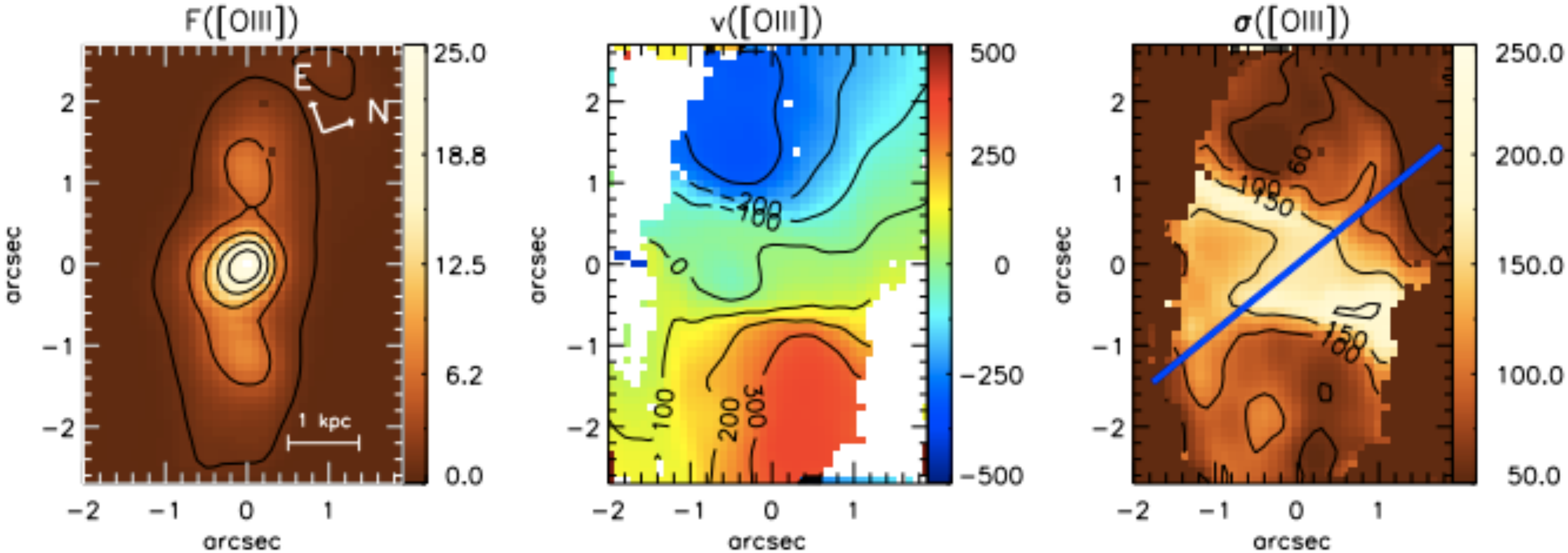
- Radio gal.
- FRII
- 1″=1.15 kpc

Outflow in radio galaxy 3C33
(log L[OIII]= 42.8) (GMOS, Couto+17)



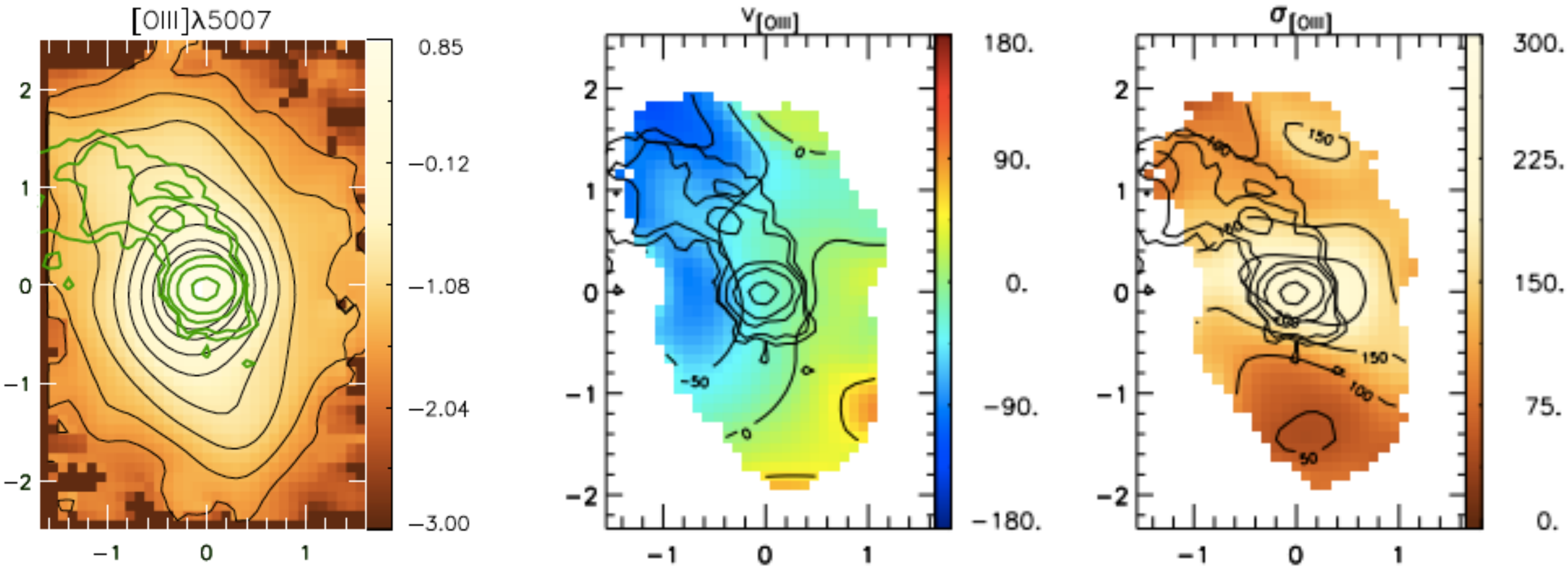
- Dominant kinematics: rotation, distorted in strip ~perp. to ioniz. axis/radio jet
- Strip show high σ

Outflow in radio galaxy 3C33
(log L[OIII]= 42.8) (GMOS, Couto+17)



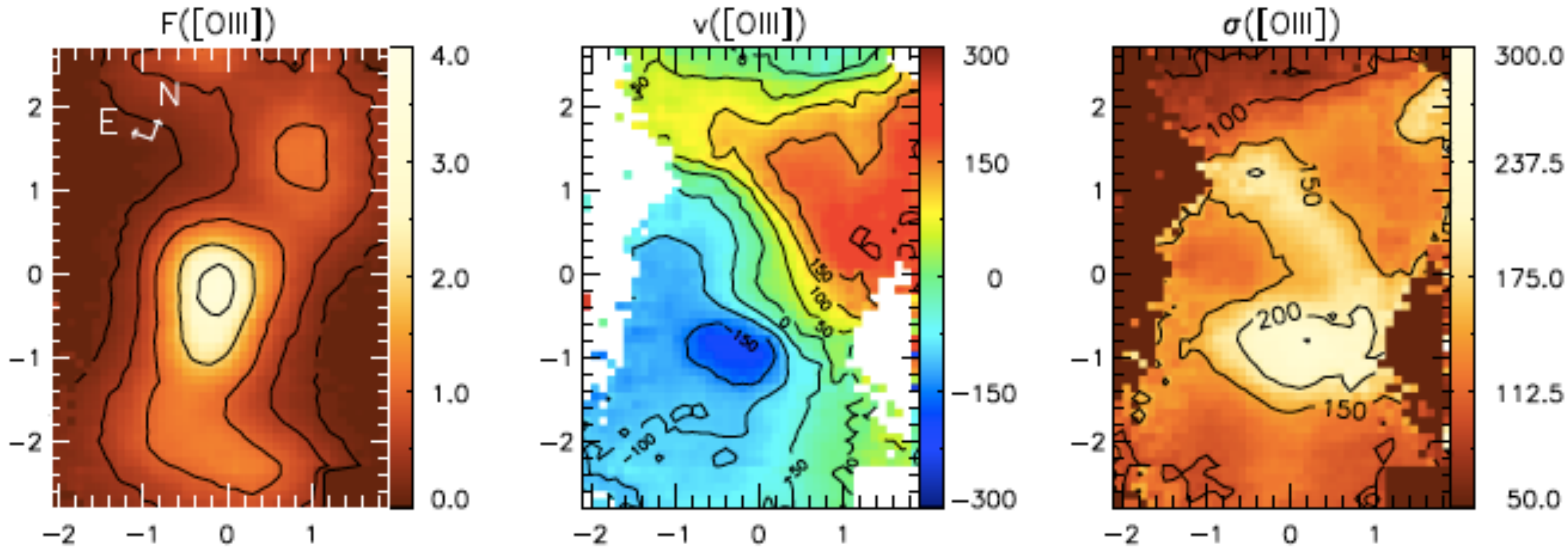
- High σ: lateral expansion by passage of jet?
- Mass outflow rate: ~ 0.2 $M_{\odot}$ yr^{-1}; outflow power ~ 0.3% L_{bol} (jet feedback)
- Effect may be larger in intergalactic medium

Outflow in radio galaxy Arp102B
(log L[OIII]= 42) (GMOS, Couto+13)



- -> Larger σ perp. ioniz. axis/jet
- Mass outflow rate: ~ 0.3 $M_{\odot}$ yr^{-1}; outflow power ~ 0.3% L_{bol} (jet feedback)
- Small effect in the galaxy (maybe large in intergalactic medium)

Outflow in radio galaxy 3C+49.30
(GMOS, Couto, in prep.)



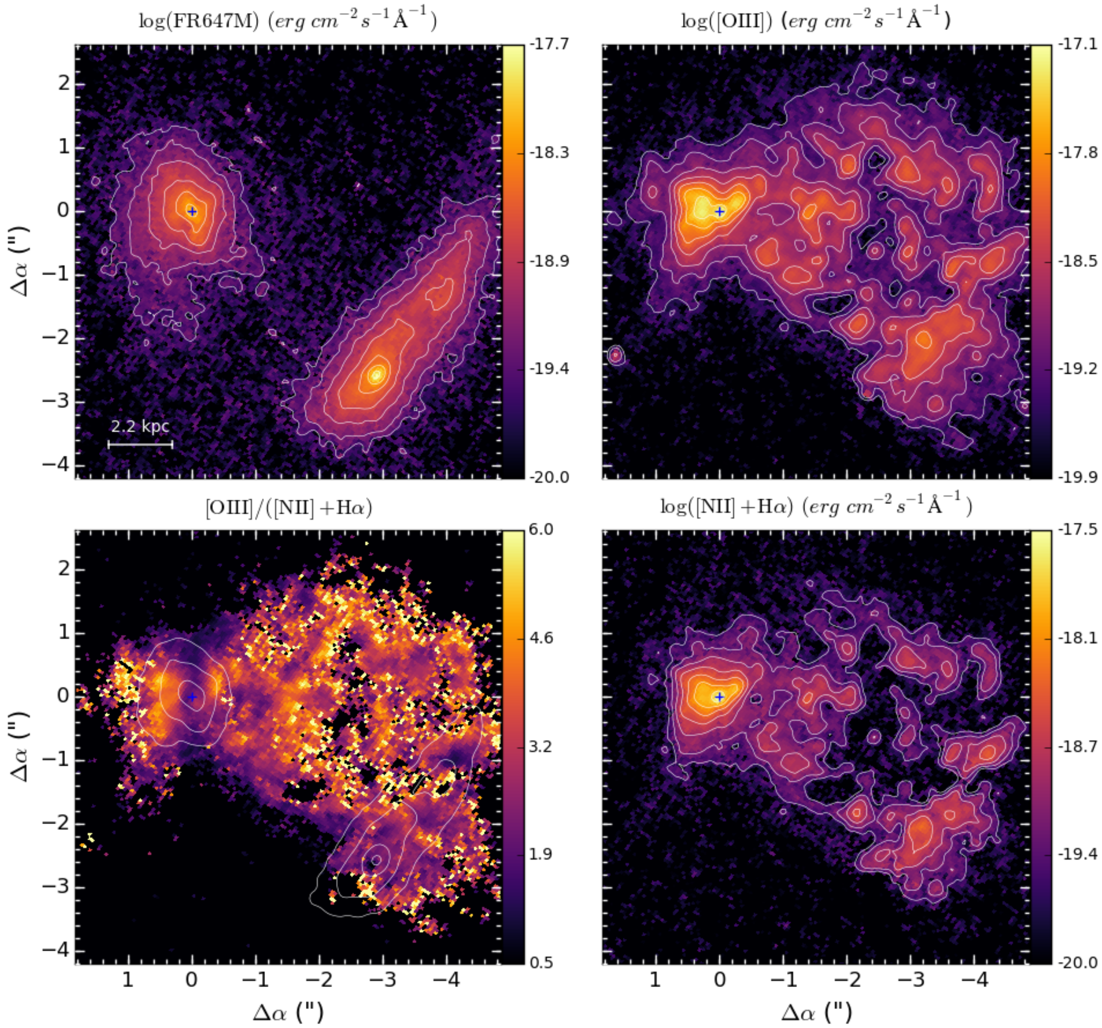
- Strong signature of recent merger, but, again….
- -> Larger σ perp. ioniz. axis/jet: jet feedback?

Quest for more luminous outflows

- Sample selection: from SDSS QSOs 2 catalog of Reyes+08, with Log L[OIII]>42.3
- Fisher+17: 13 QSOs 2, z< 0.12, HST [OIII] images + STIS
- Storchi-Bergmann+17: 9 QSOs 2, 0.1<z<0.5, [OIII] and Hα+[NII] images
- Scale: better than 500 pc/0.1"

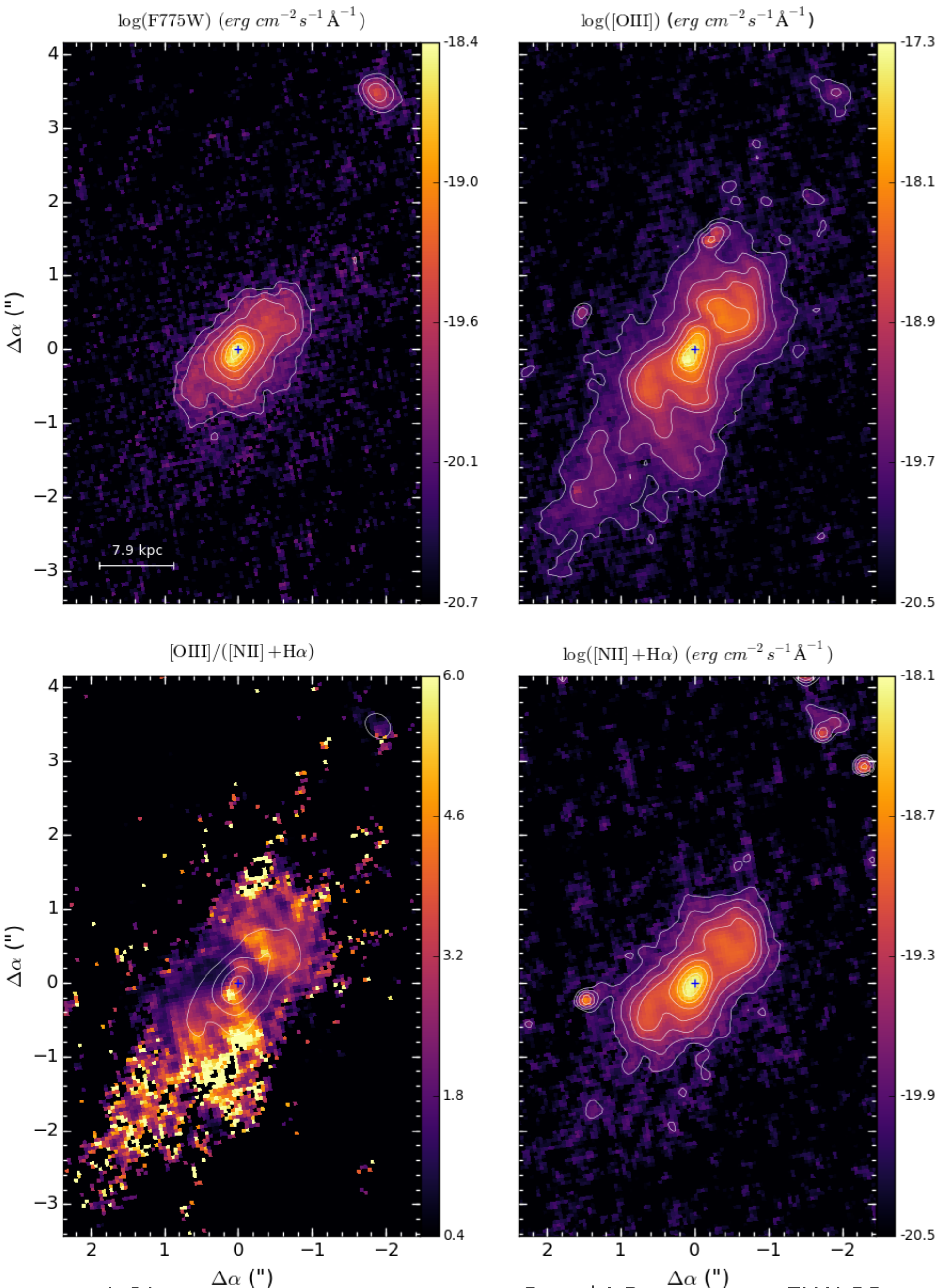
Ionization cones at 0.1<z<0.5

(HST-ACS, Storchi-Bergmann+17)



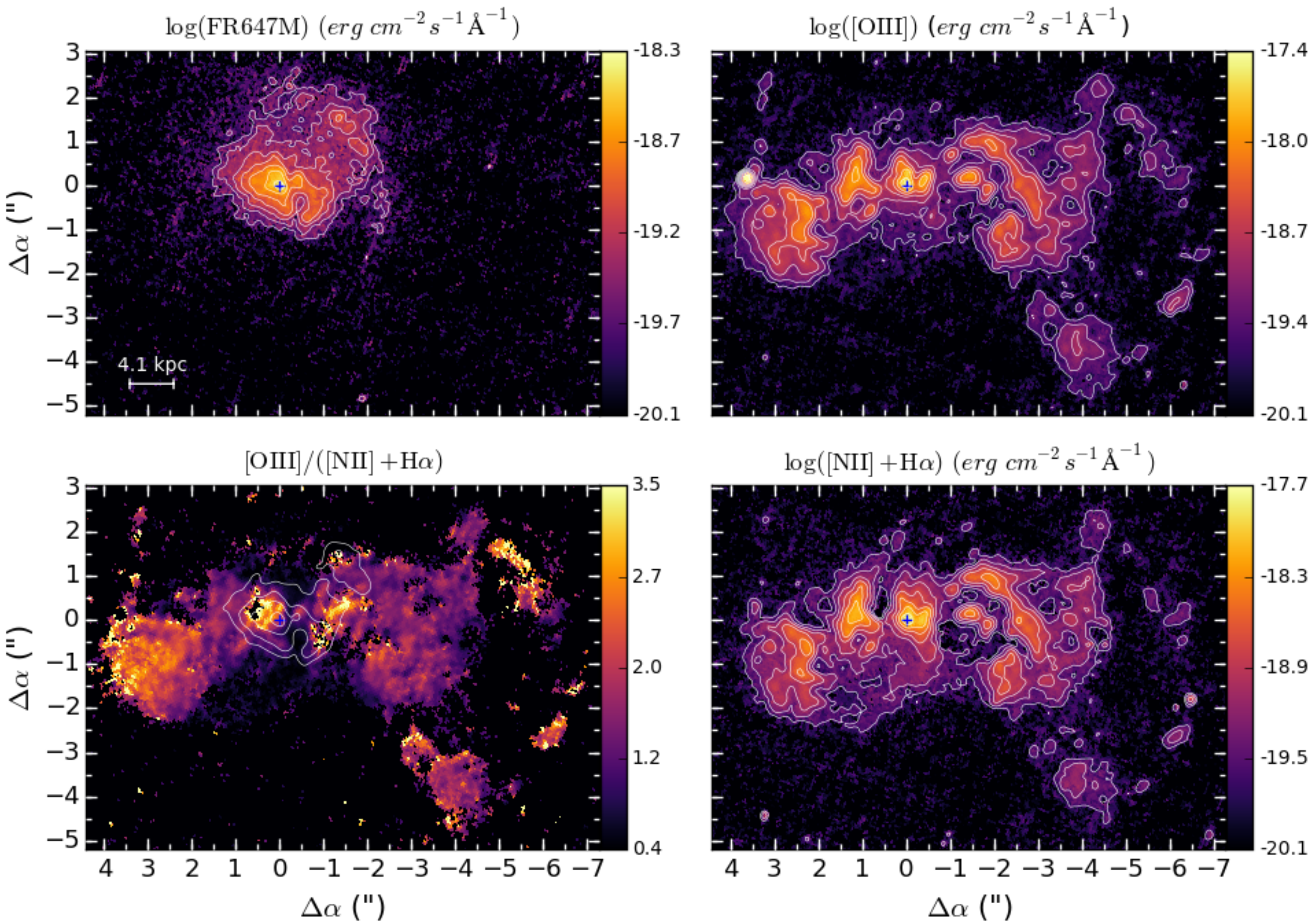
Ionized gas extent:
~ 7 kpc

Ionization cones at 0.1<z<0.5



Ionized gas extent: 19 kpc!

Ionization cones at 0.1<z<0.5
(Storchi-Bergmann+17)

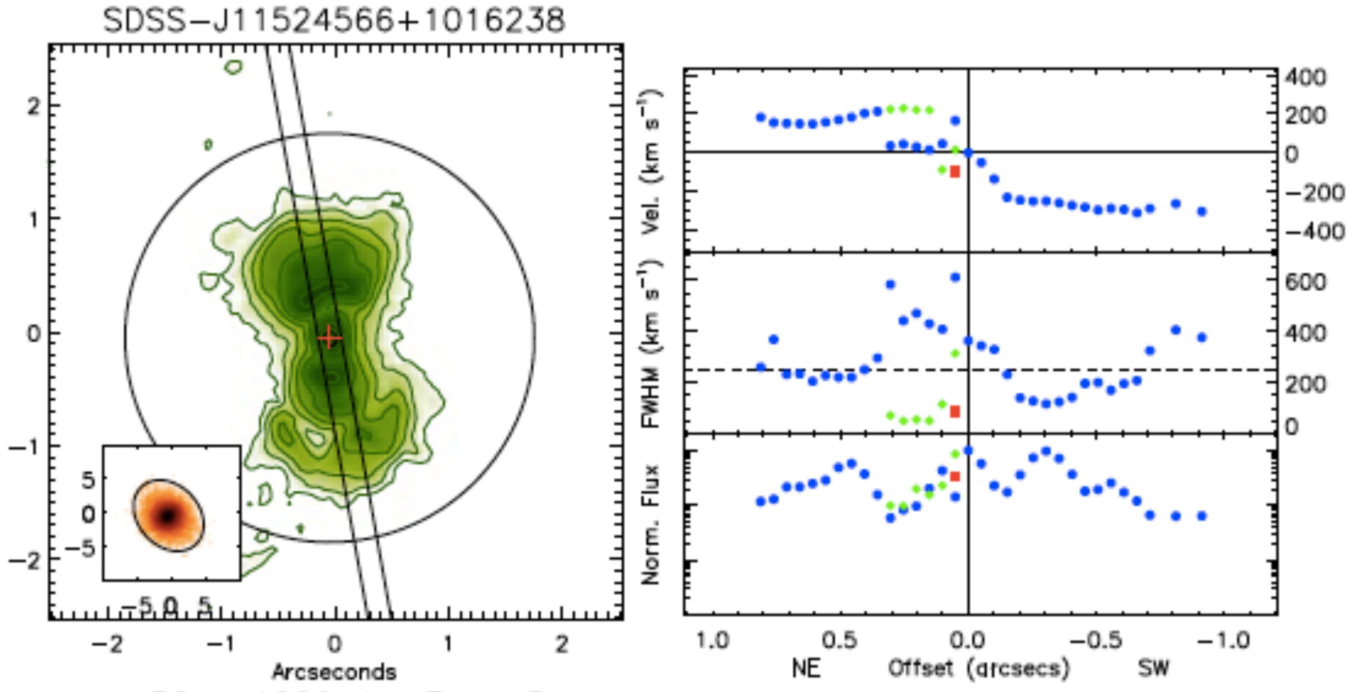


Ionized gas extent: 22 kpc!

Is this gas outflowing? Fischer+17

- STIS spectra of closer sample along ionization axis
- Preliminary results: outflow kinematics much more compact than [OIII] emission

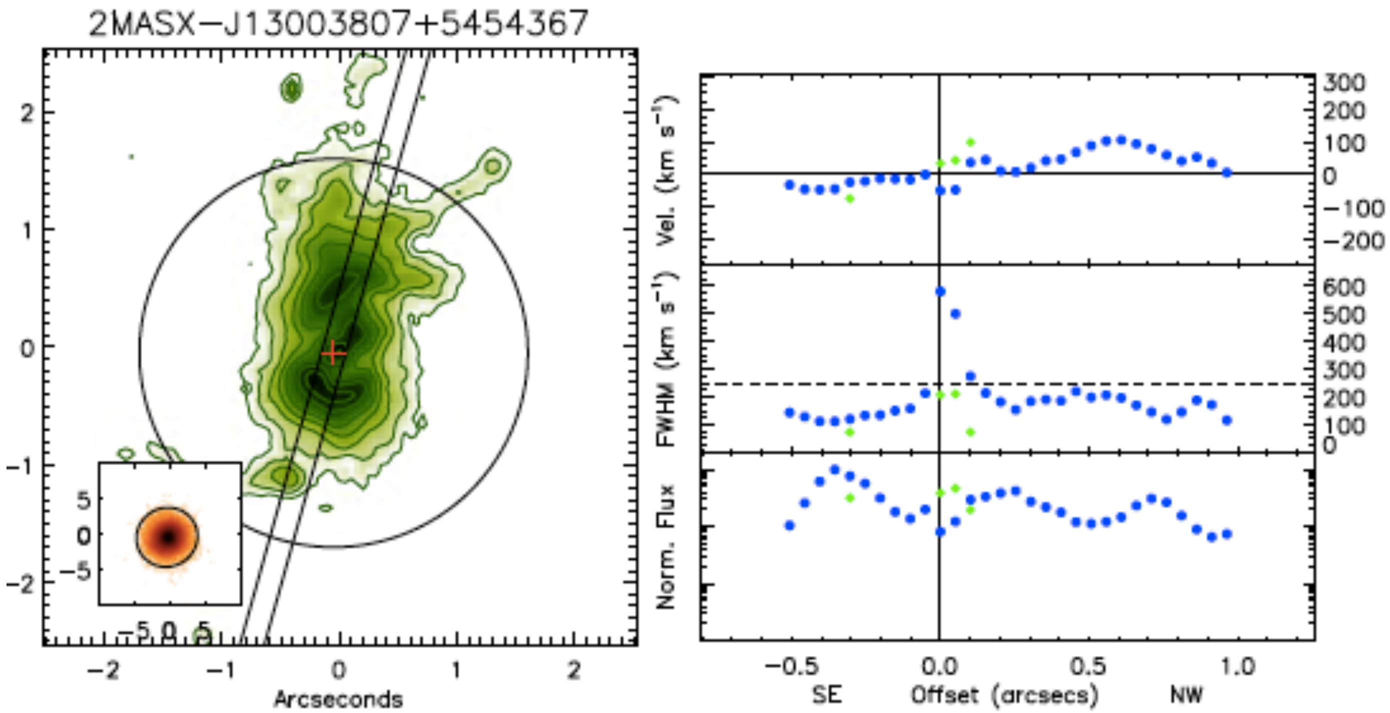
Fischer+17: ACS + STIS



Disturbed (outflow) kinematics within 0.4”: 520 pc (total [OIII]= 2.1 kpc)

Kinematics dominated by rotation

Fischer+17: ACS + STIS



Disturbed (outflow) kinematics within 0.2”: 320 pc (total [OIII]= 4 kpc)

Kinematics dominated by (low) rotation

Summary and Conclusions

- So far ~25 Swift-BAT nearest AGN + more luminous QSO 2 sample of 13 (+9 – only imaging so far)
- Dominating gas kinematics: rotation (disturbed by outflows and inflows)
- Outflow velocities: 200 – 800 km s^{-1}
- Mass outflow rates; few tenths to few $M_\odot$ yr^{-1}
- Extents: 100-500 pc (even though emission extends up to several kpc)
- Geometry:

(1) Hollow conical/hourglass (Fisher+13: ~ 1/3 of AGN)
(2) Compact or unresolved
(3) Equatorial: lateral expansion due to appearance/passage of radio jet?

Summary and Conclusions

- Scenario: most extended emission: gas rotating in the galaxy disk; only inner part is outflowing
- -> overestimation of mass outflow rate if assumed that all gas excited by AGN is outflowing (it has been done!)
- Power of the outflow: ≤ 0.3% L_{bol} in the near Universe
- Filling factors, gas densities, velocity and geometries are fundamental in the calculation of mass outflow rate and power-> discrepancies of 1-2 orders of magnitude