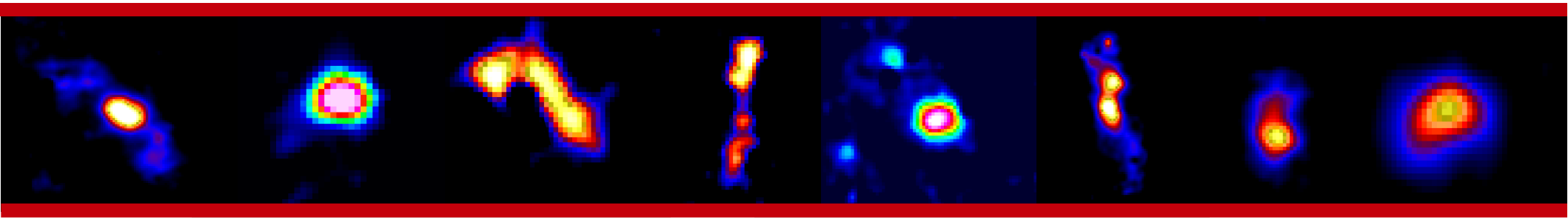
Winds and turbulence in powerful radio-loud obscured quasars at high-z



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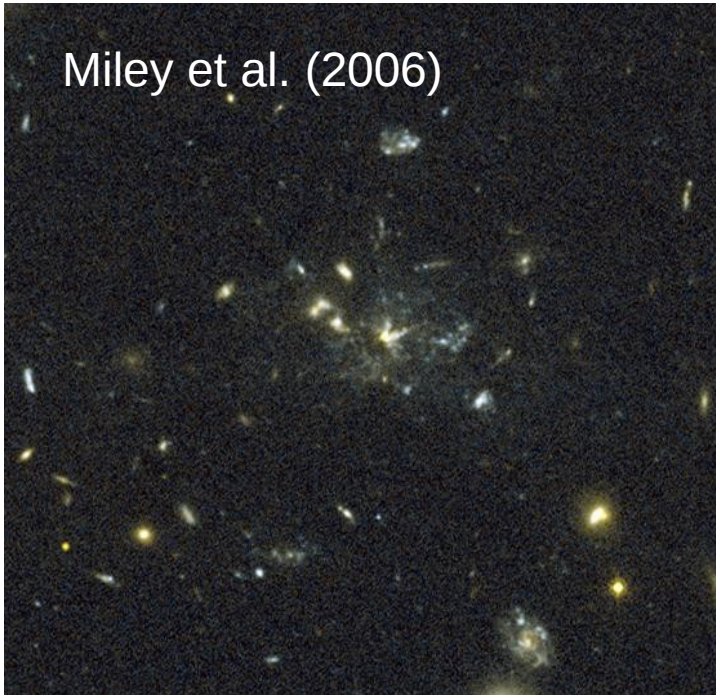
In collaboration with
C. Collet, M. Lehnert, G. Bicknell, F. Boulanger, C. De Breuck, P. Best, P. Guillard, J. Bryant, D. Hunstead, H. Johnston, D. Mukherjee, A. Wagner

High-redshift ~~radio galaxies~~

radio-loud type-2 AGN



- **Most powerful radio sources in the Universe**
  → L_{rad} ~ few x 10^{13-14} L_s
  (e.g., Willott et al. 2000)

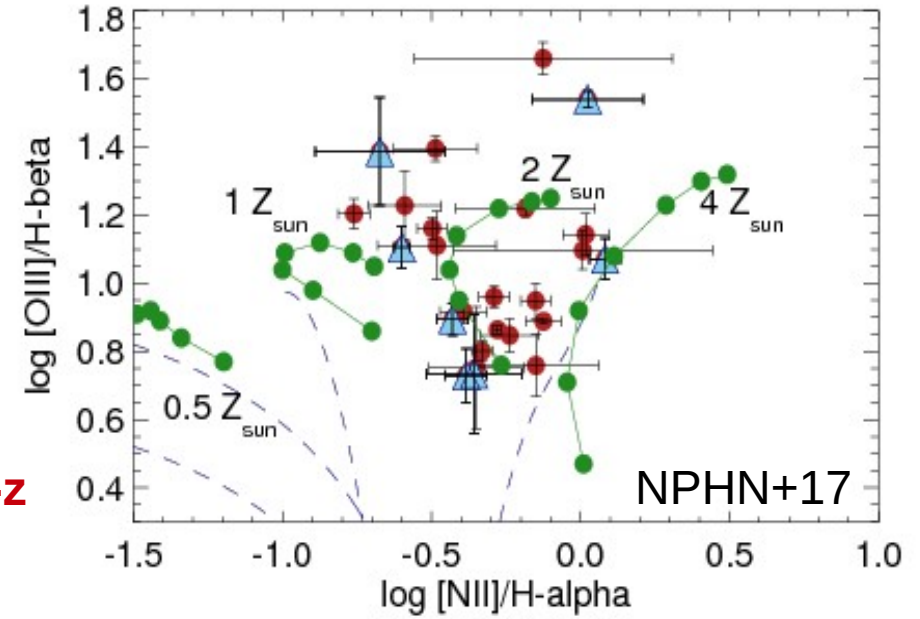
- **Luminous obscured AGN: L_{bol} ~ few 10^{12} – 10^{13} L_{sun}**
  Seymour et al. (2012), Drouart et al. (2014)

- **Intense star formation in 30%: up to 1000 M_{sun} yr^{-1}**
  Seymour et al. (2012), Drouart et al. (2014)

- **Very massive SMBH: up to few 10^{10} M_s**
  Nesvadba et al. (2011), A&A, 525, 43

- **Most massive galaxies at high-z: ~5x10^{11} M_s**
  $M_{stellar}$: Seymour et al. (2007), De Breuck et al. (2010)
  M_{dyn}: Nesvadba et al. (2007), Collet et al. (2014)

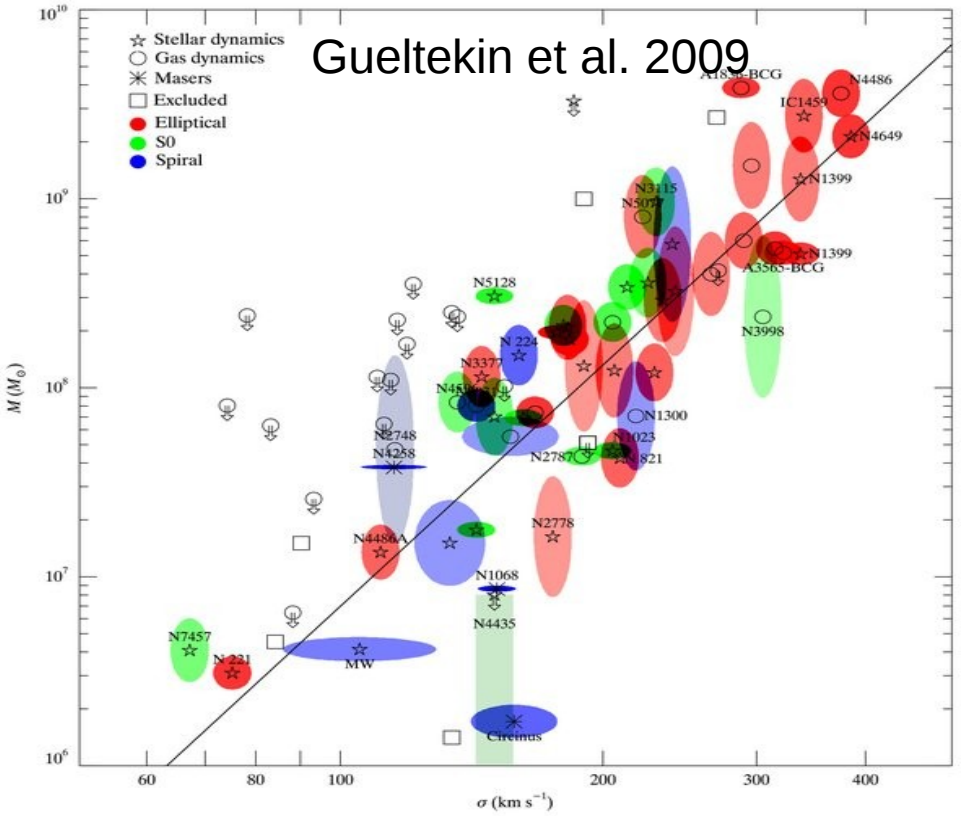
- **Gas-phase metallicity ~ stellar metallicity in low-z massive early-type galaxies**
  Nesvadba et al. (2017a), A&A 599, 123

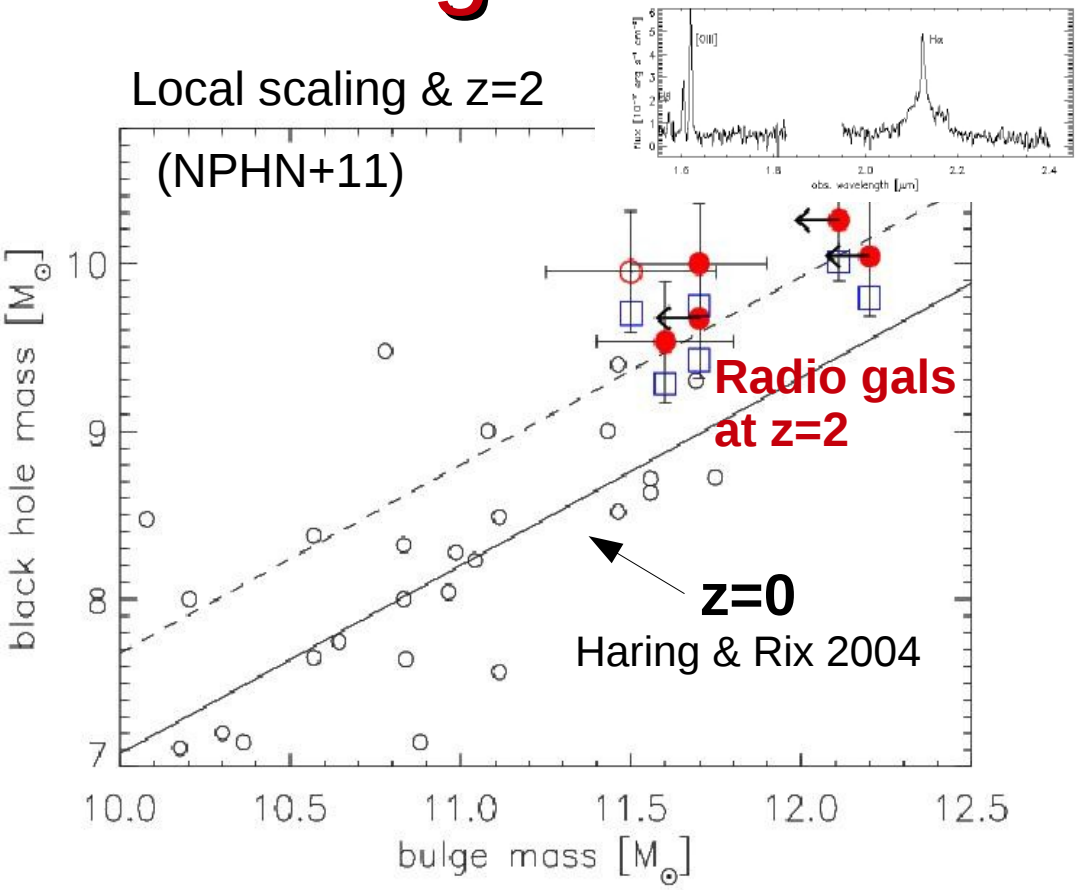


→ Very massive high-z galaxies at the end of their active growth phase

Winds and turbulence … AGN feedback

Black-hole bulge mass scalings





Scalings between SMBH mass and bulge: σ , mass, dark-matter halo, concent. para, …
(Ferrarese et al. 2000, Gebhardt et al. 2000, Mogorrian et al. 1998, Younger et al. 2008, Booth & Schaye 2009, Greene et al. 2006, Nesvadba et al. 2011, ...)

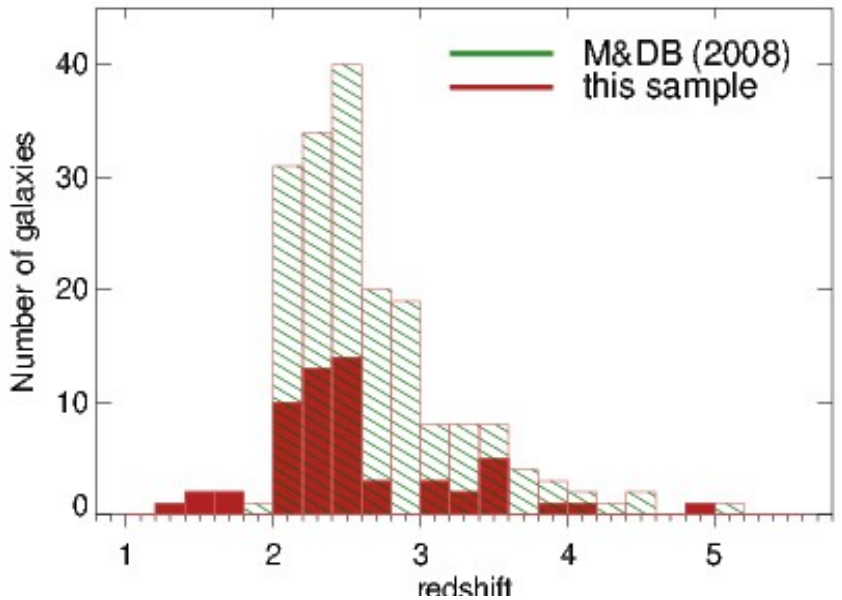
Black hole and bulge fall near the local relationship, offsets are within typical uncertainties at high-mass end

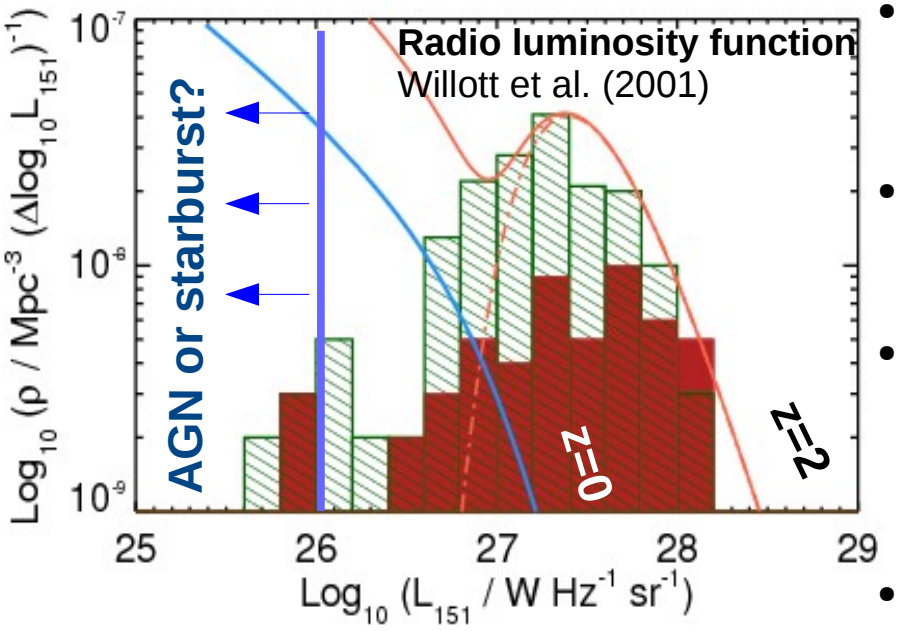
Massive, "mature" galaxies and central black holes

Winds and turbulence … AGN feedback

Nesvadba et al (2017a), A&A 599, 123

The SINFONI survey of powerful radio galaxies during the "Quasar Era"



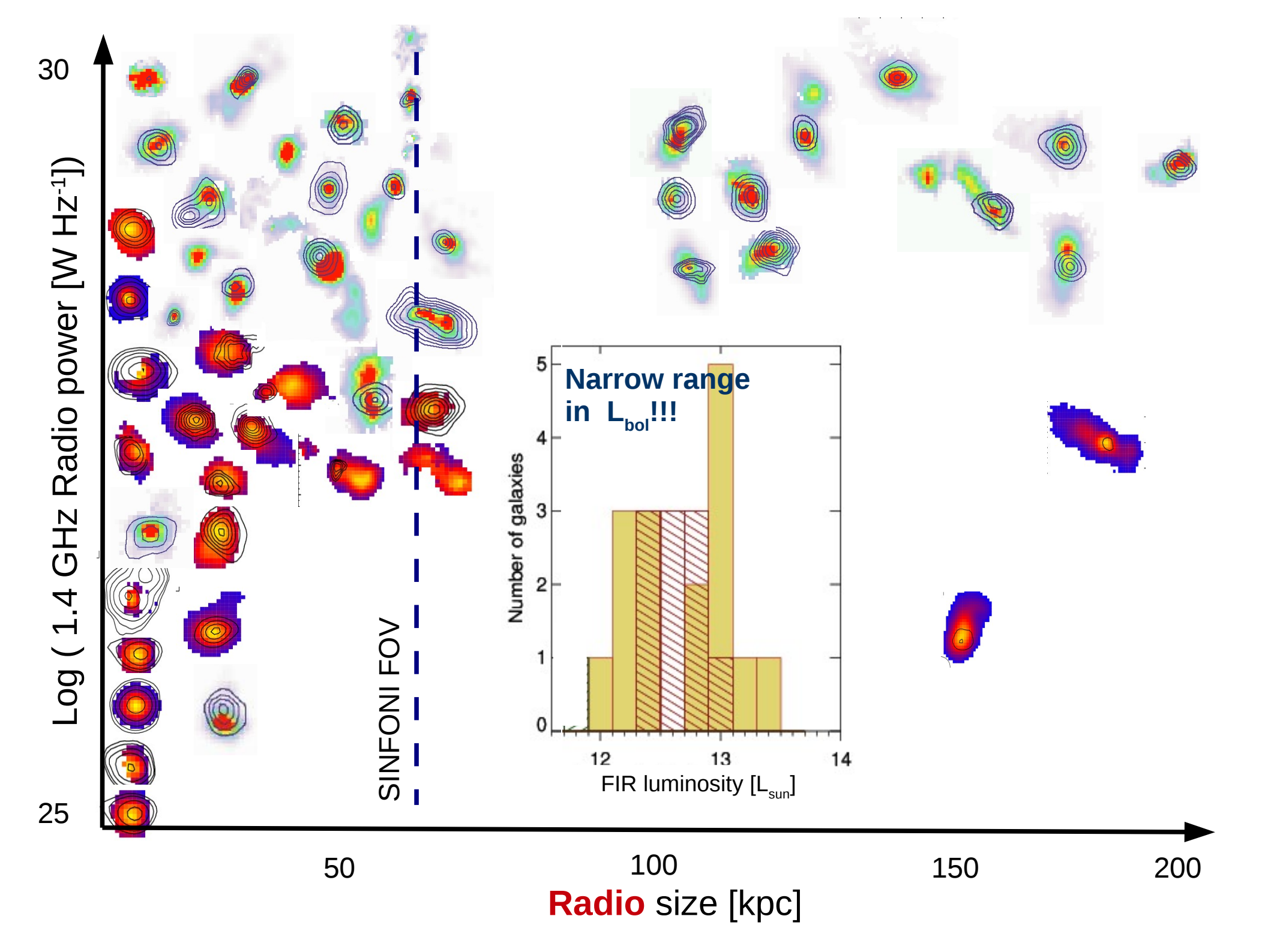


- 49 HzRGs w/ [OIII] & Hβ, [OII] (z~2-2.6) **or** [OIII], Hα, Hβ, [NII], [SII] (z~3-3.6)
- about 200 sources known at z≥2 (Miley & De Breuck 2008)
- systematic analysis ranging from the brightest, very rare radio sources to common, low-power objects
- unique distinction jet / starburst

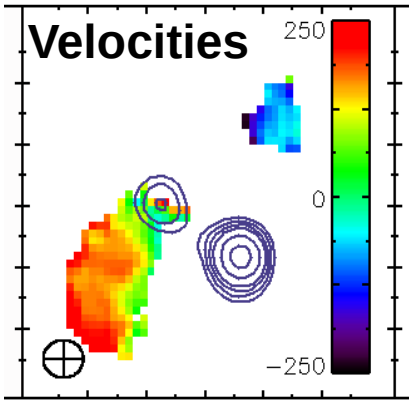
Spitzer/Herschel photometry for 24

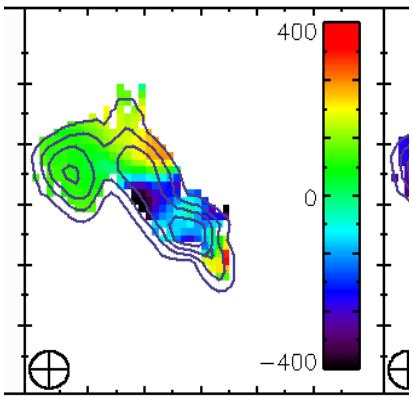
Winds and turbulence … AGN feedback

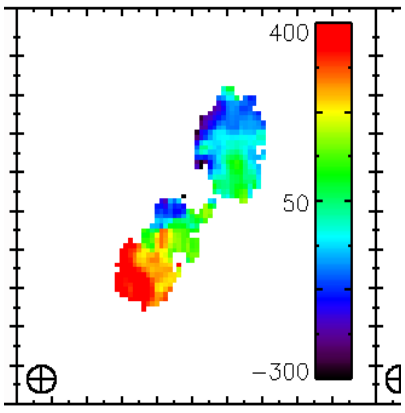
Drouart et al. (2014)


30
25
Log (1.4 GHz Radio power [W Hz-1])
SINFONI FOV
50
100
150
200
Radio size [kpc]
Narrow range
in Lbol!!!
Number of galaxies
0
1
2
3
4
5
12
13
14
FIR luminosity [Lsun]

Gas kinematics and kinetic energy







Velocities

Consistent w/ back-to-back outflows

Δv up to 1500 km s^{-1}

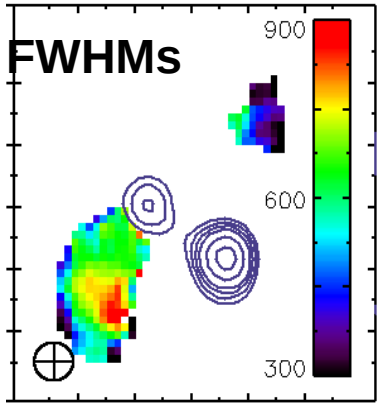
Kinetic energy

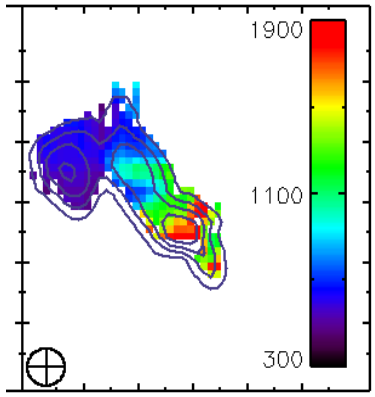
$E_{kin,mech} = ½ \Sigma m_i v_i^2 t_{dyn}$
= few 10^{58} erg

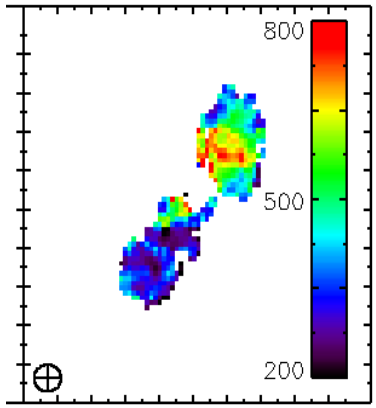
$E_{kin.blast} = 1.5x10^{46} r^2_{10}$, v^3_{1000} $n_{0.5}$ t_{dyn} erg s^{-1}
= few 10^{59} erg

Dynamical timescale

t_{dyn} = size / (½ Δv)
= few 10^7 yrs







FWHMs

Consistent w/ high turbulence

FWHM up to 1500 km s^{-1} (typically 500-1000 km s^{-1})

$E_{kin,turb} = 3/2 \Sigma m_i \sigma_i^2$
= few 10^{58} erg

- **σ / v ~ 1**
- **$v > v_{escape}$ for $P(500) \geq 10^{28}$ W Hz^{-1}**
- **$E_{kin} \sim 10^{-2} M_{BH}$**

Expected signatures of AGN-driven winds

Winds and turbulence … AGN feedback

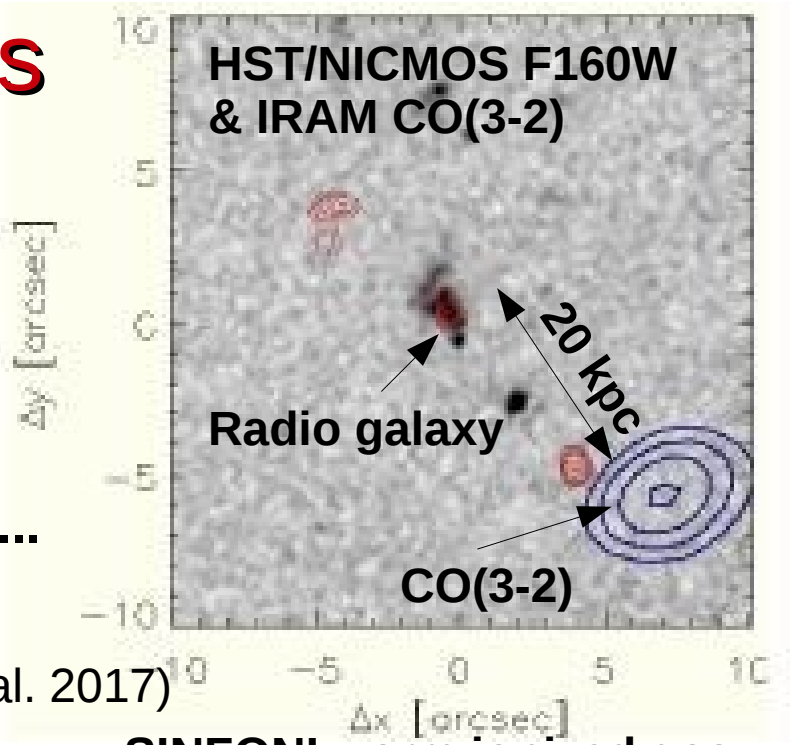
Warm ionized vs. molecular gas

NPHN+17a

Large relative amounts of warm ionized gas:

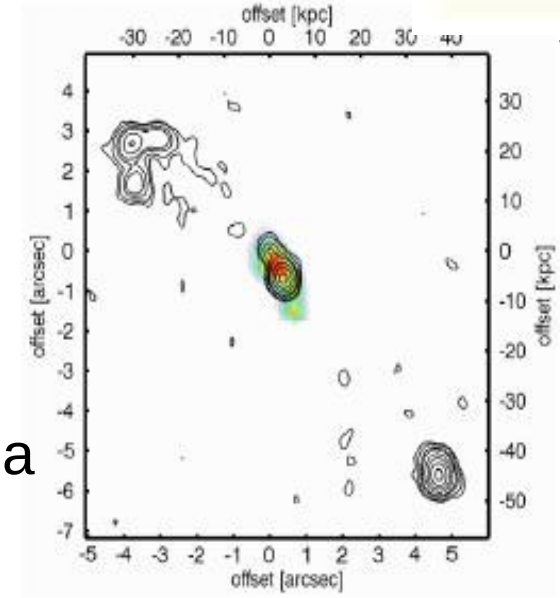
$$M_{WIM} \sim 0.2 - \text{few} \times M_{mol}$$

10^{-3} – 10^{-4} would be normal...

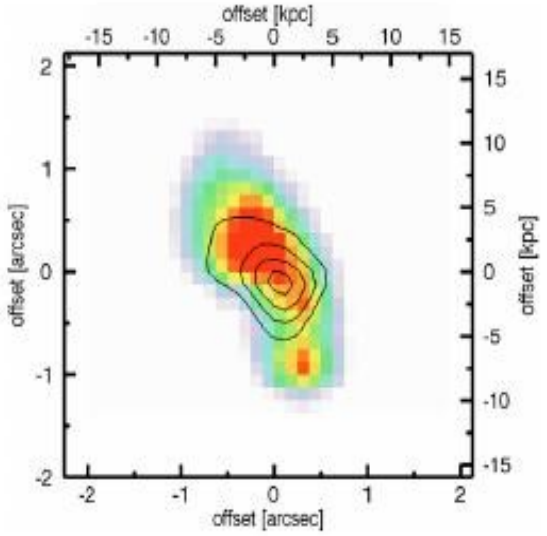


CO, if detected, is often in the halo!!
(NPHN+09, 17, see also, e.g., Ivison et al 2008, Emonts et al. 2017)

- **So far no clear evidence of molecular winds.**
- **"Ionization feedback"**
  Exceptional M_{WIM}/M_{mol} fractions a consequence of turbulence?
  (Hopkins & Elvis 2010)



SINFONI warm ionized gas

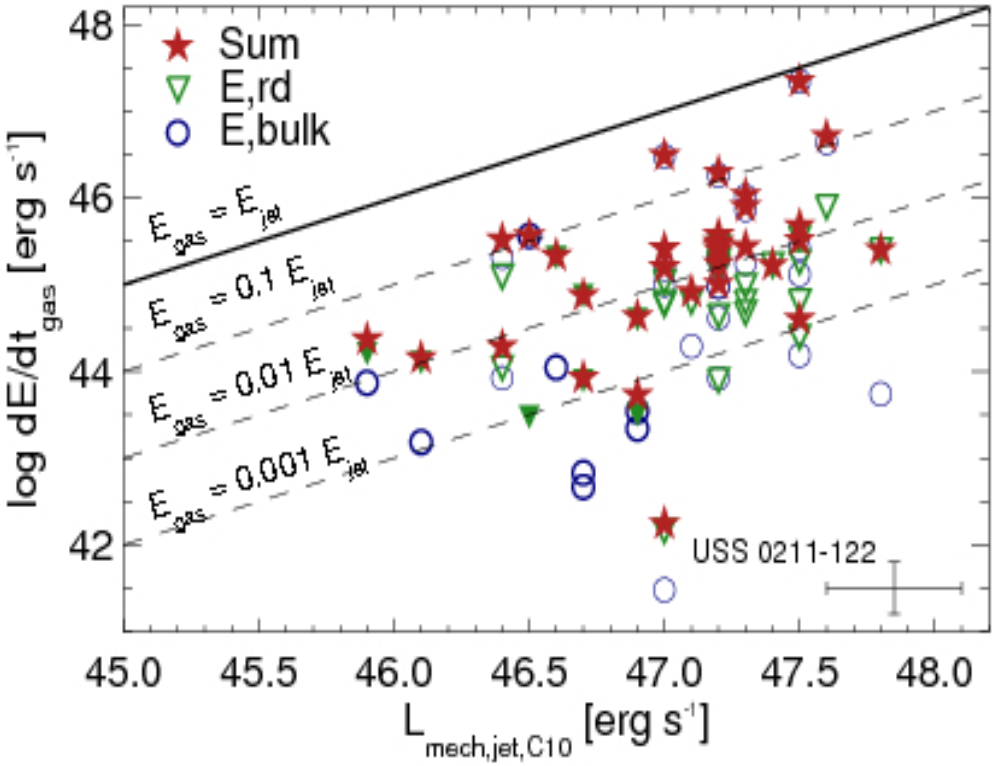


TXS0828+193, z=2.57

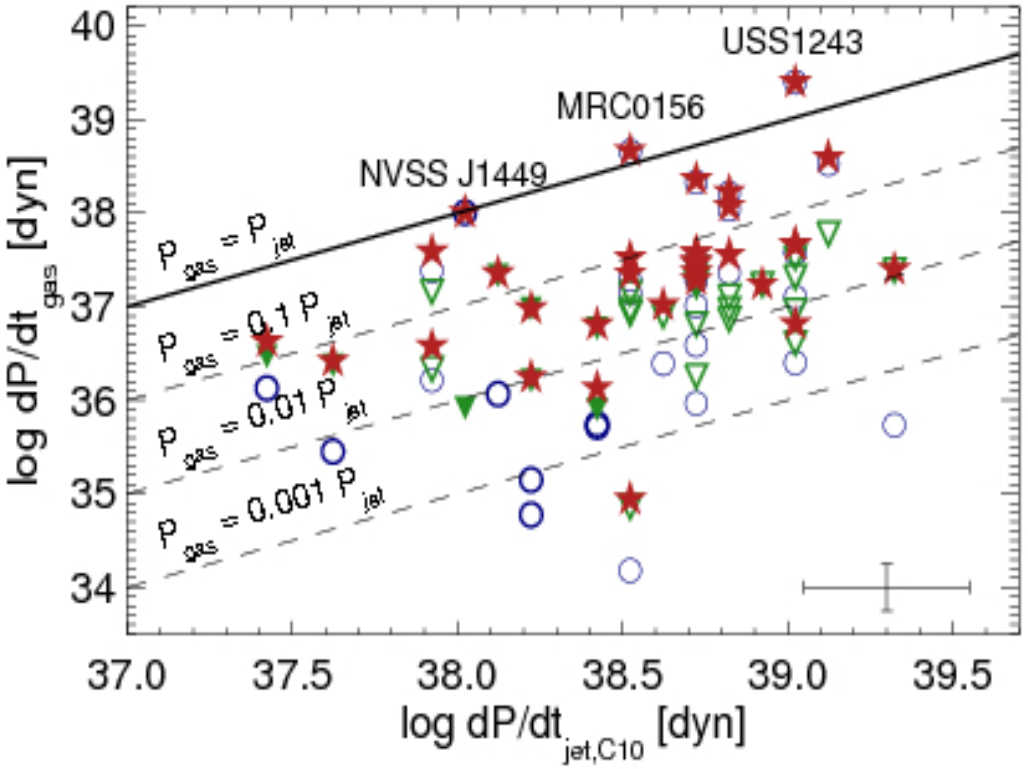
Energy and momentum injection rates

Relativistic particles in jet give rise to synchrotron emission & carry kinetic energy and momentum. ($L_{kin,jet} \sim 10 - 100x\ L_{synch,jet}$)

Gas vs. jet kinetic luminosity



Gas vs. jet momentum



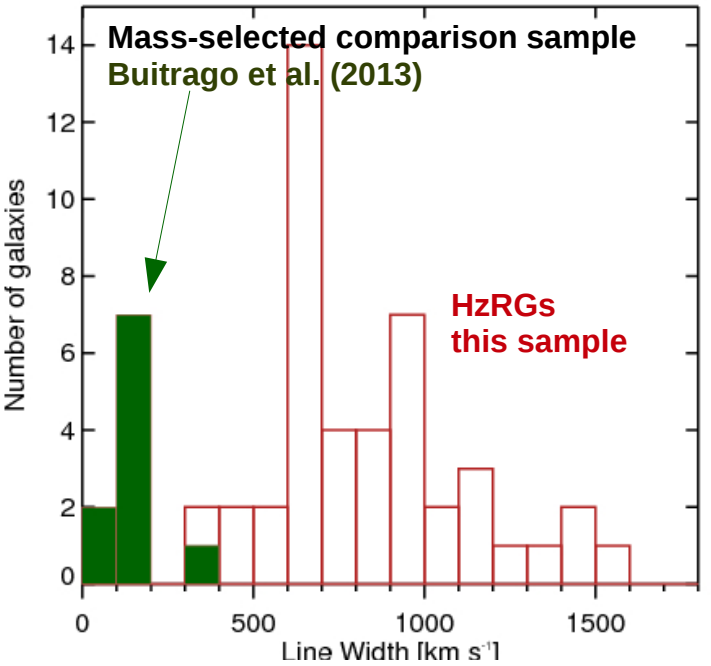
NPHN (2006, 08, 11, 17a,b), Collet et al. (2015, 2016)

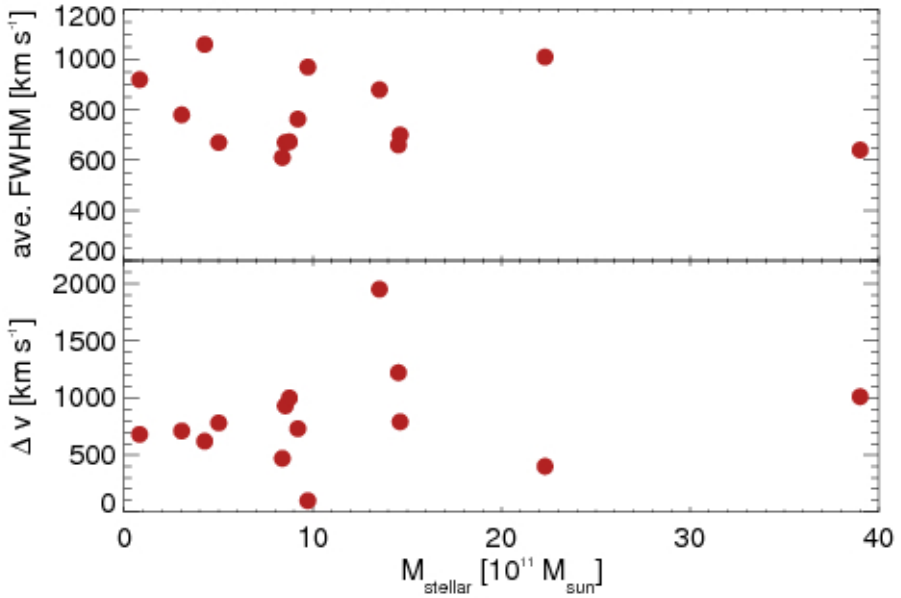
Winds and turbulence … AGN feedback

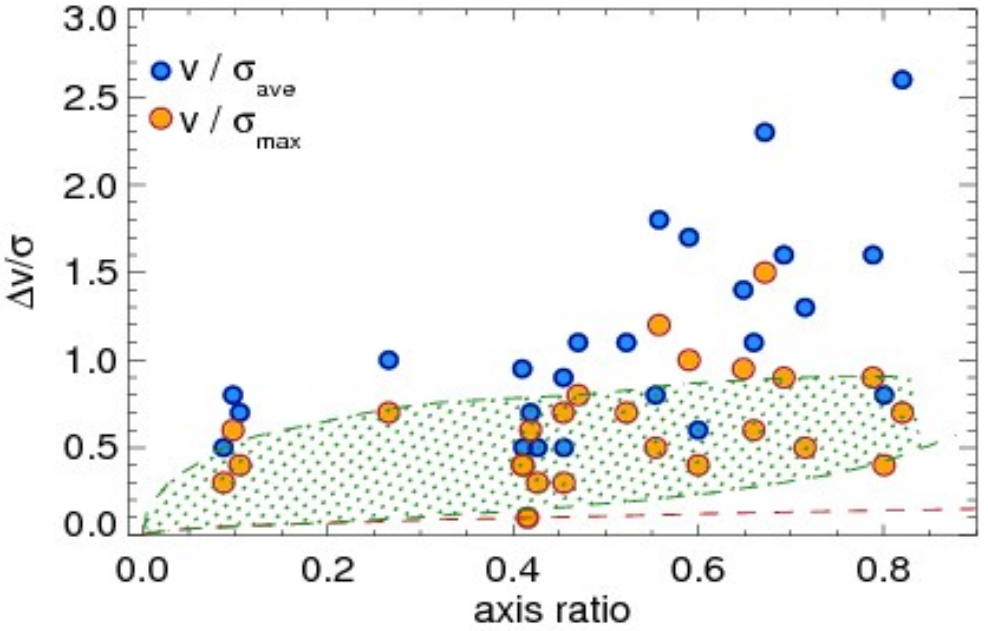
Gravitational motion??

- line widths ≫ than in mass-selected samples of high-z galaxies with $M_{stellar}$ = few 10^{11} M_{sun}
- no trends between kinematics and mass
- higher ratio of bulk / random motion than in pressure-supported (early-type) galaxies

→ **No evidence of rotationally dominated kinematics**







Nesvadba et al. (2017b), A&A 600, 121

Winds and turbulence … AGN feedback

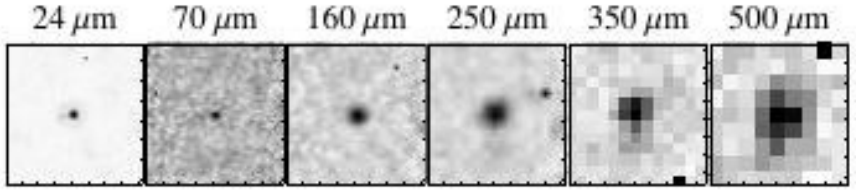
Impact of QSO and star formation? Hergé & SINFONI:

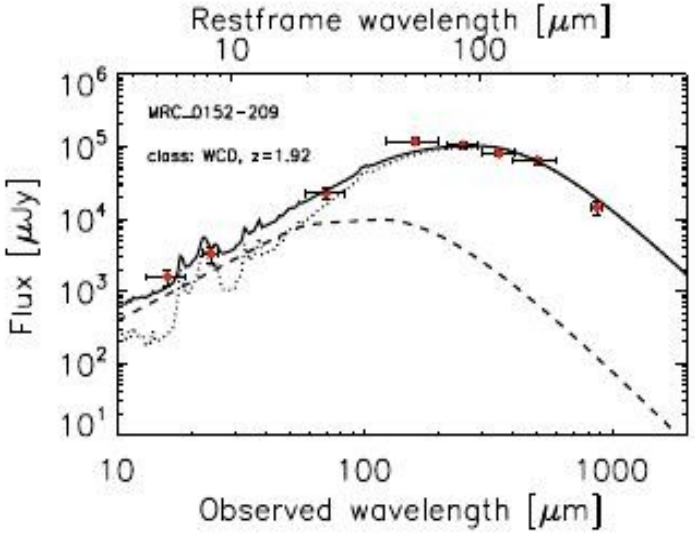
Compare energy and momentum input

Hergé survey: Spitzer / Herschel

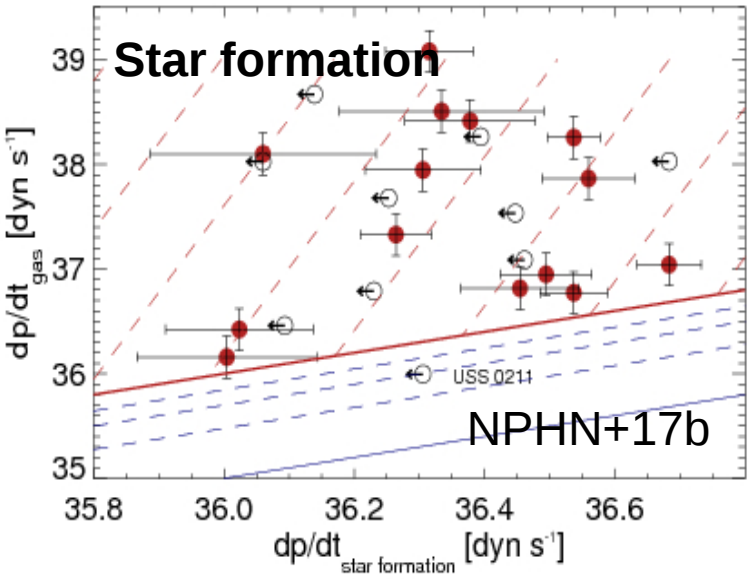
Drouart et al. (2014)

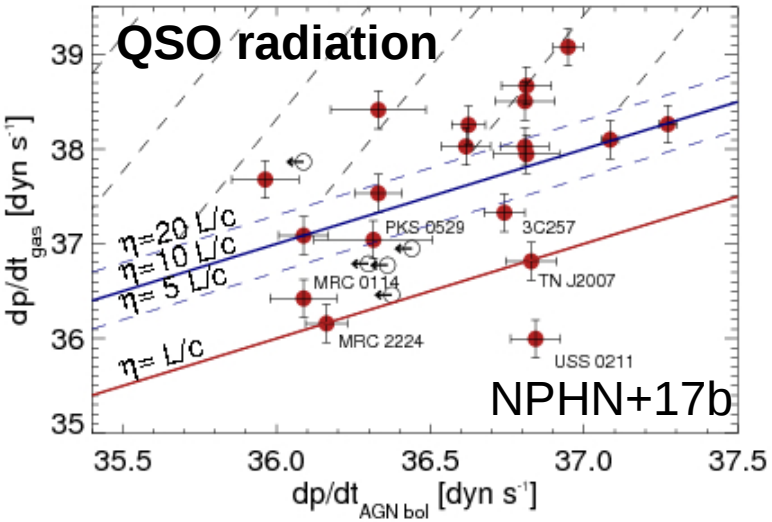
24 sources in common





Decomposition in AGN & starburst





Similar results for kinetic energy.

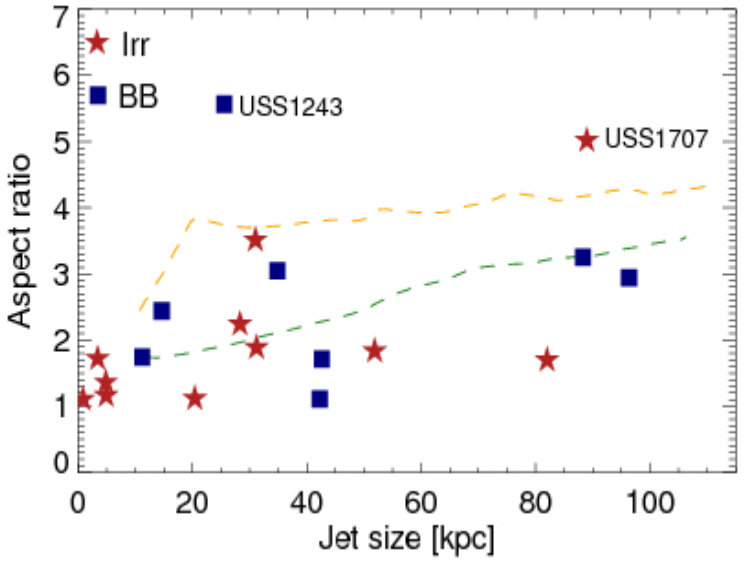
$E_{kin,jet} / E_{kin,QSO} \sim 0.3 - 10$

$P_{jet} / P_{QSO} \sim 3 - 100$

Winds and turbulence … AGN fee

Tests of hydrodynamic models

NPHN+17a



(1) Bubble aspect ratios:

Measure the mechanical advance

Suggest 'light jets' with high density contrast

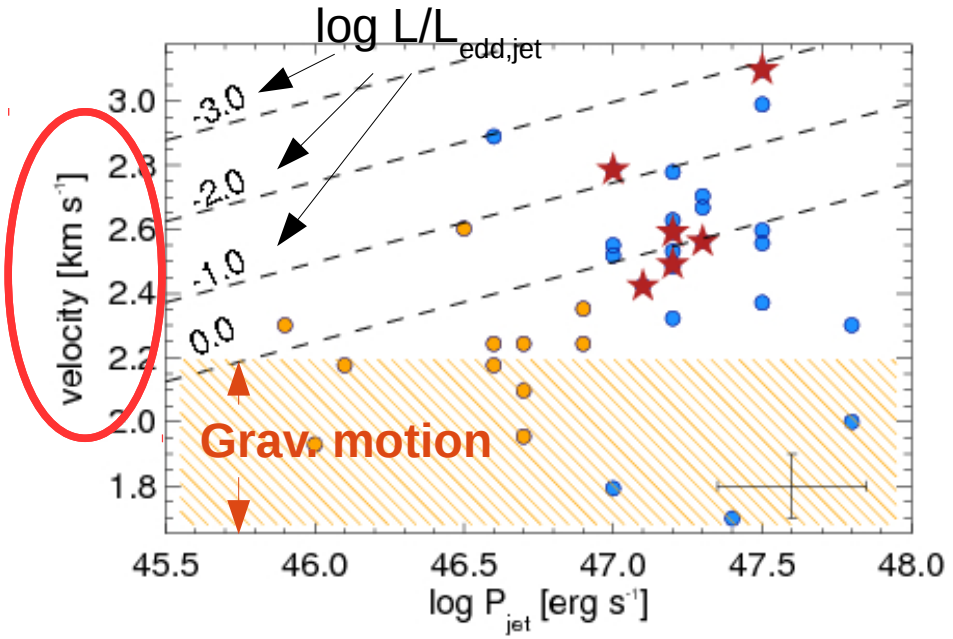
(Models by Gaibler et al. 2009)

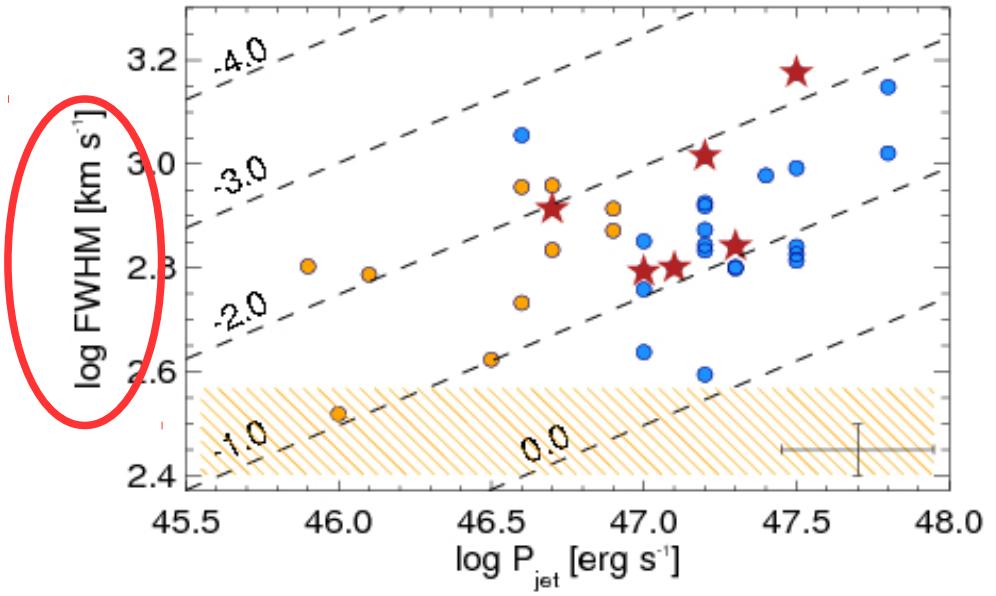
(2) Kinematic constrains: Δv & local FWHM

Bulk (wind) motion & turbulence:

Globally correct, but relative amount of E_{bulk}, E_{turb}?

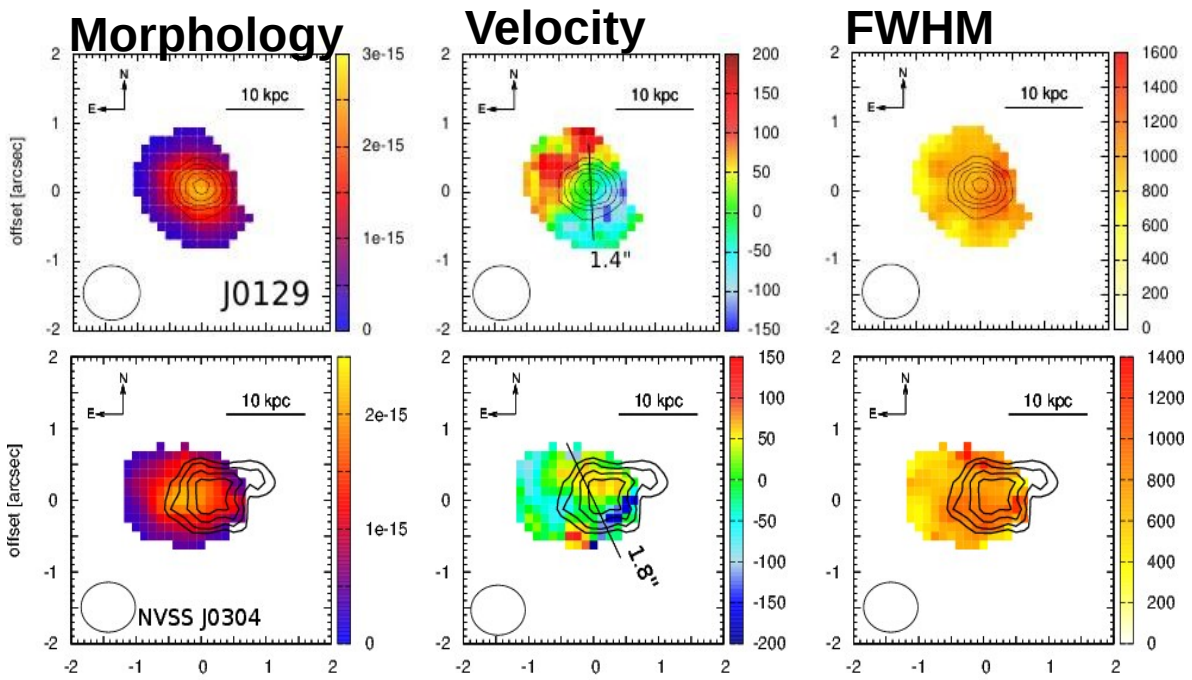
(Models from Wagner et al. 2012)

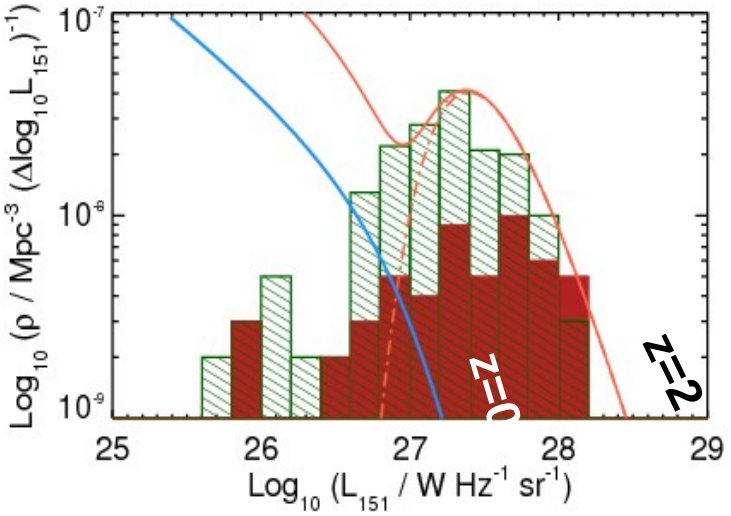




Winds and turbulence … AGN feedback

Low(er)-luminosity radio sources





Smaller velocity gradients
Δv ~ 200-300 km s^{-1}
→ M_{dyn}~10^{11} M_s → disks?

But: well aligned with jet axis

- often irregular velocity fields/FWHM
- large line widths: **800 km s^{-1}**
- less WIM (~few 10^8 M_s) ~ quasars

Disks, winds, or both?

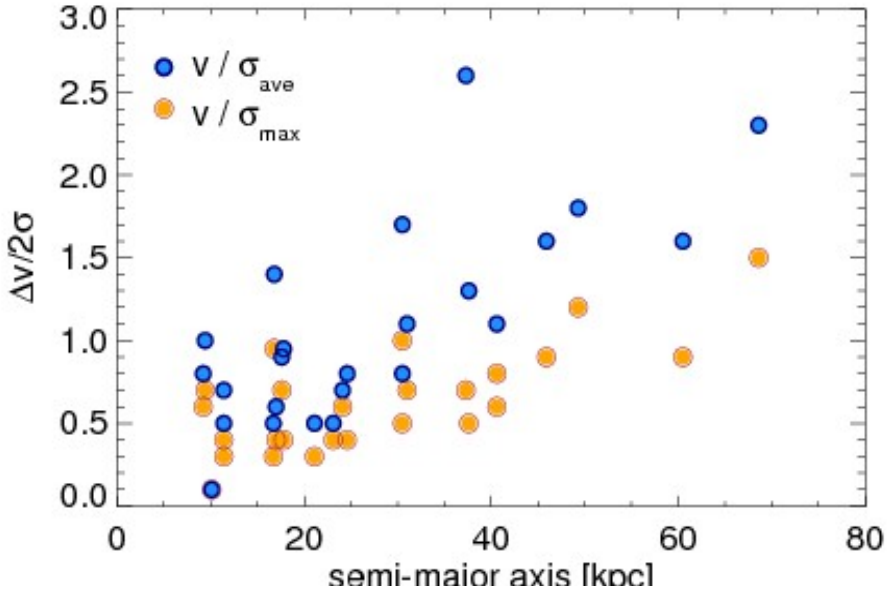
Localized outflows (jet-cloud interactions)? High turbulence?
→ Bulk of the gas unlikely to escape

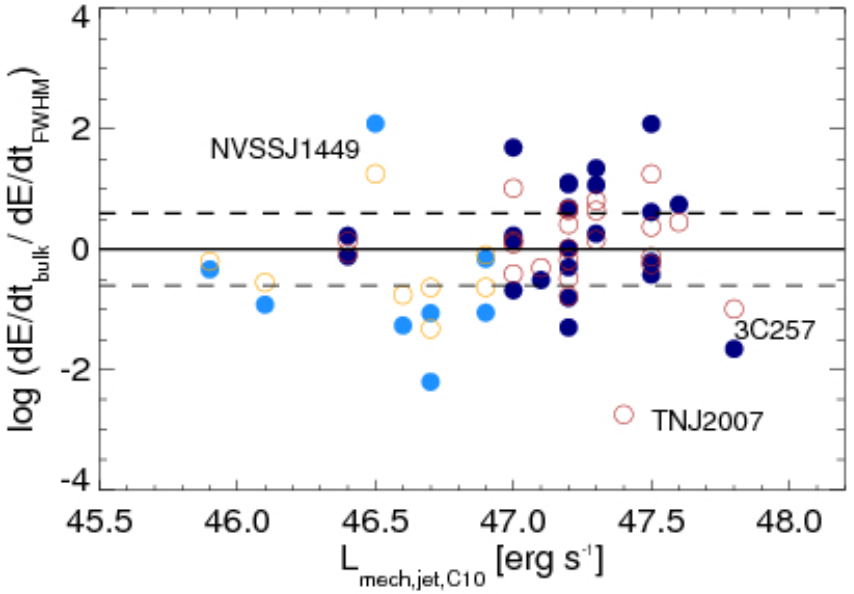
Collet et al. (2015), A&A 579, 89 &
Collet et al. (2016), A&A 586, 152)

Winds and turbulence … AGN feedback

Winds vs. turbulence in HzRGs

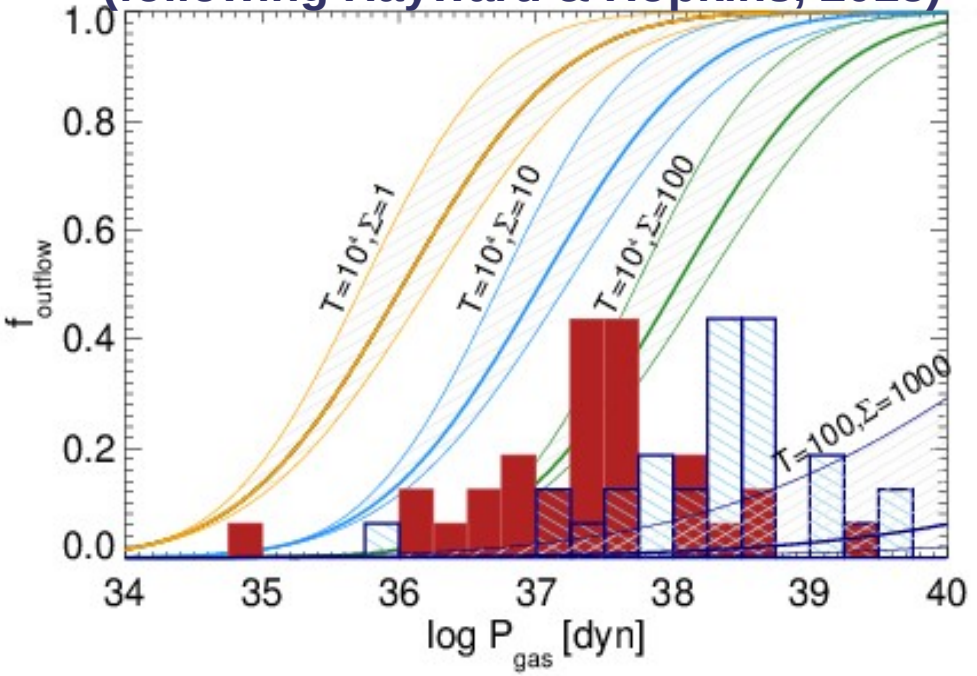
NPHN+17a





- Bulk motion becomes relatively more important for more extended gas and for more powerful radio sources.
- 'Disk bursting' when energy injection overcomes energy loss through, e.g., dissipation?
- Close analogy with recent analytic models

(following Hayward & Hopkins, 2015)



Winds and turbulence … AGN feedback

Concluding remarks

- **Systematic survey of 49 powerful, radio-loud AGN at z~2-4**
  - **High-z 'radio galaxies' are not (yet) old, red, and dead!**
  - **Extreme kinematics, FWHM~800 km s^{-1}, Δv up to 1500 km s^{-1}**
- **WIM is a major gas component, comparable to H_2**
  - **Massive outflows of warm ionized gas, but little evidence (so far) for similar molecular outflows**
- **Good general agreement with models,**
  - **… but discrepancies in role of bulk & turbulent energy, momentum.**
- **Role of turbulence vs. winds, in particular in low-power AGN?**
  - **Impact of turbulence on feedback & star formation?**
  - **Are winds facilitated / a side-effect of turbulence?**