The gentle monster PDS456 seen by ALMA

the galaxy scale molecular outflow and its implications for AGN feedback

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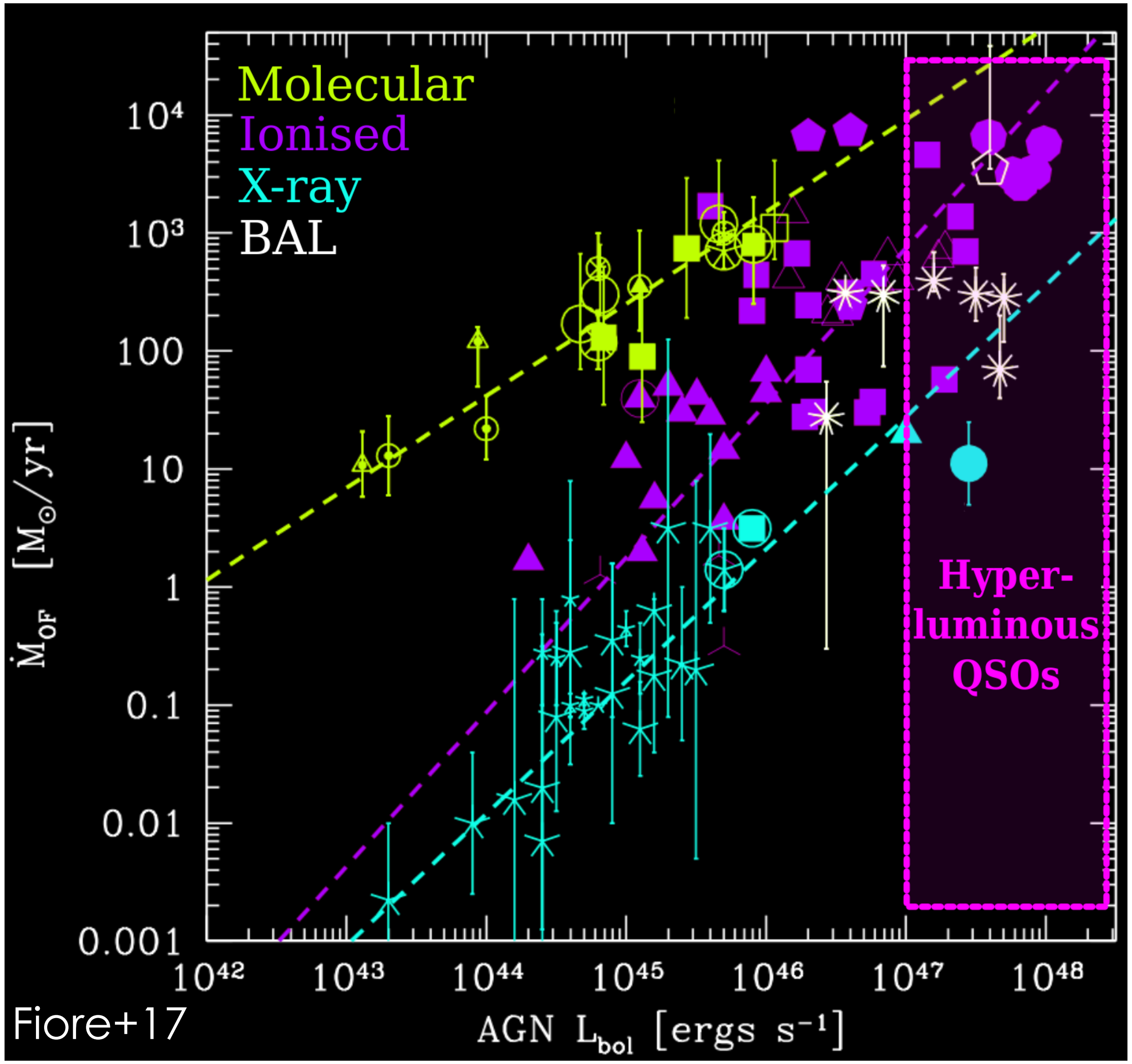
Investigating the maximum impact of AGN feedback

Theory + Observations: the most luminous QSOs are ideal targets to probe the maximum impact of AGN feedback (huge radiative output, powerful outflows)

(Faucher-Giguère+12, Zubovas & King+12, Cicone+14, Fiore+17)



The mass outflow rate correlates with L_{Bol}

- **Ionised phase**
  Hyper-luminous QSOs up to z~3 studied at INAF OAR (The WISSH QSOs project, Bischetti+17, Vietri+18, Travascio+19 in prep.)

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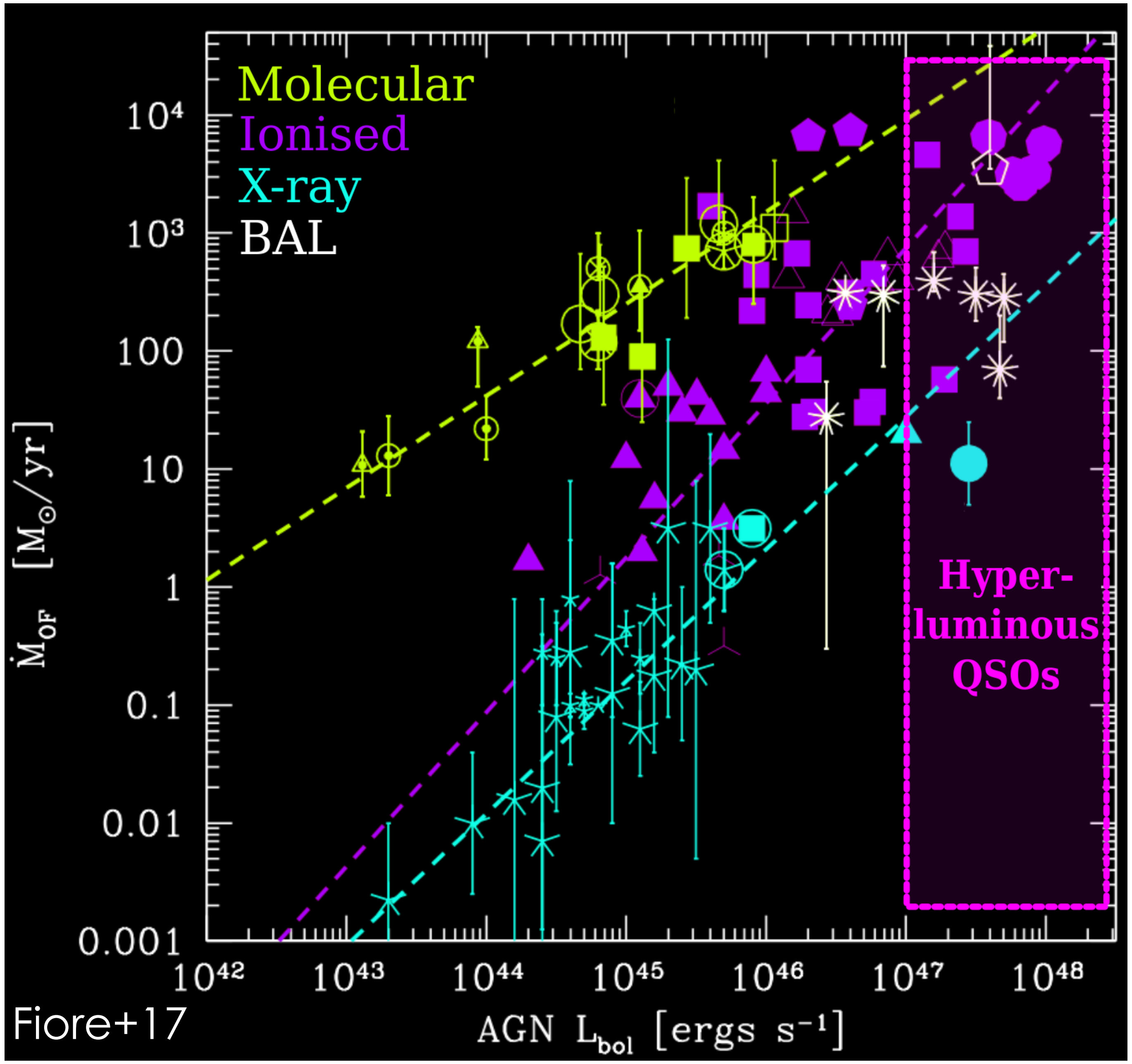


The mass outflow rate correlates with L_{Bol}

- **Ionised phase**
  Hyper-luminous QSOs up to z~4 studied at INAF OAR (The WISSH QSOs project, Bischetti+17, Vietri+18, Travascio+19 in prep.)

- **Molecular gas phase: direct fuel for SF**
  Mostly limited to low-moderate luminosity, local AGN

UFOs as driving mechanism of galaxy-scale AGN outflows

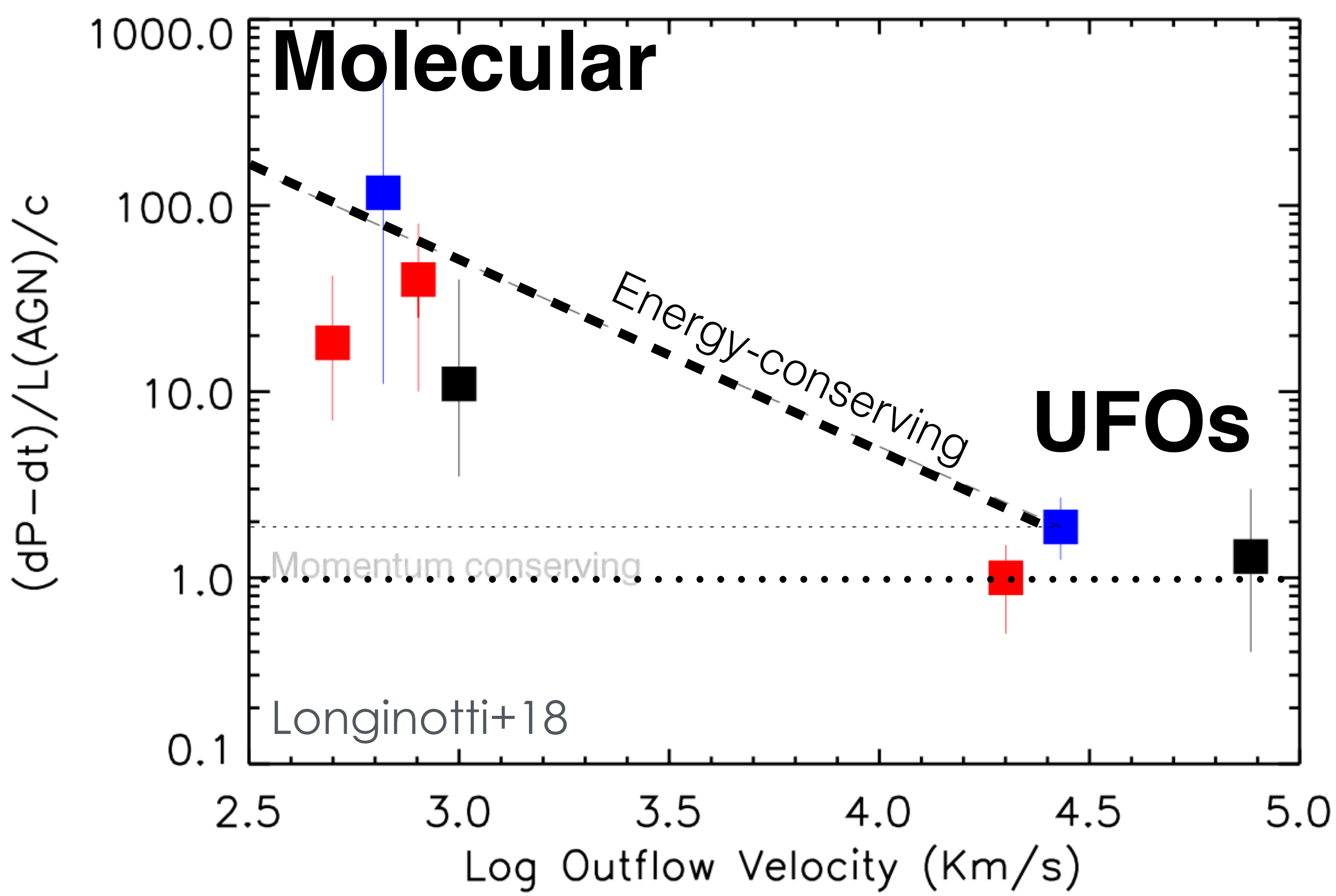
- **Two-phase mechanism for the outflow expansion on galactic scale based on the cooling of an expanding UFO which shocks into the surrounding ISM**

Weak cooling → energy-conserving → momentum flux boost >> Lbol/c

(King+03, Faucher-Giguère & Quataert +12, Zubovas & King 12 , Menci +19)

Molecular outflows:
$\dot{P}_{mol}$ / $\dot{P}_{rad}$ ~ 5 - 50
($\dot{P}_{rad}$ = L_{AGN}/c = radiative momentum flux)
(Feruglio+10, Sturm+11, Cicone+14)

UFO vs. Molecular outflows: consistent with an energy-conserving expansion!
(Tombesi+15, Feruglio+15, Longinotti +18 but see also Veilleux+18)



PDS 456: the most luminous QSO of the local Universe

Pointed out from the brazilian Pico dos Dias Survey (PDS) for young stellar objects

- Located at galactic coordinates close to the galactic bulge (A_V = 1.5 mag)
- B=12.6 & radio quiet (S_{5GHz}<42 mJy) ⟶ radio-quiet analog of 3C273

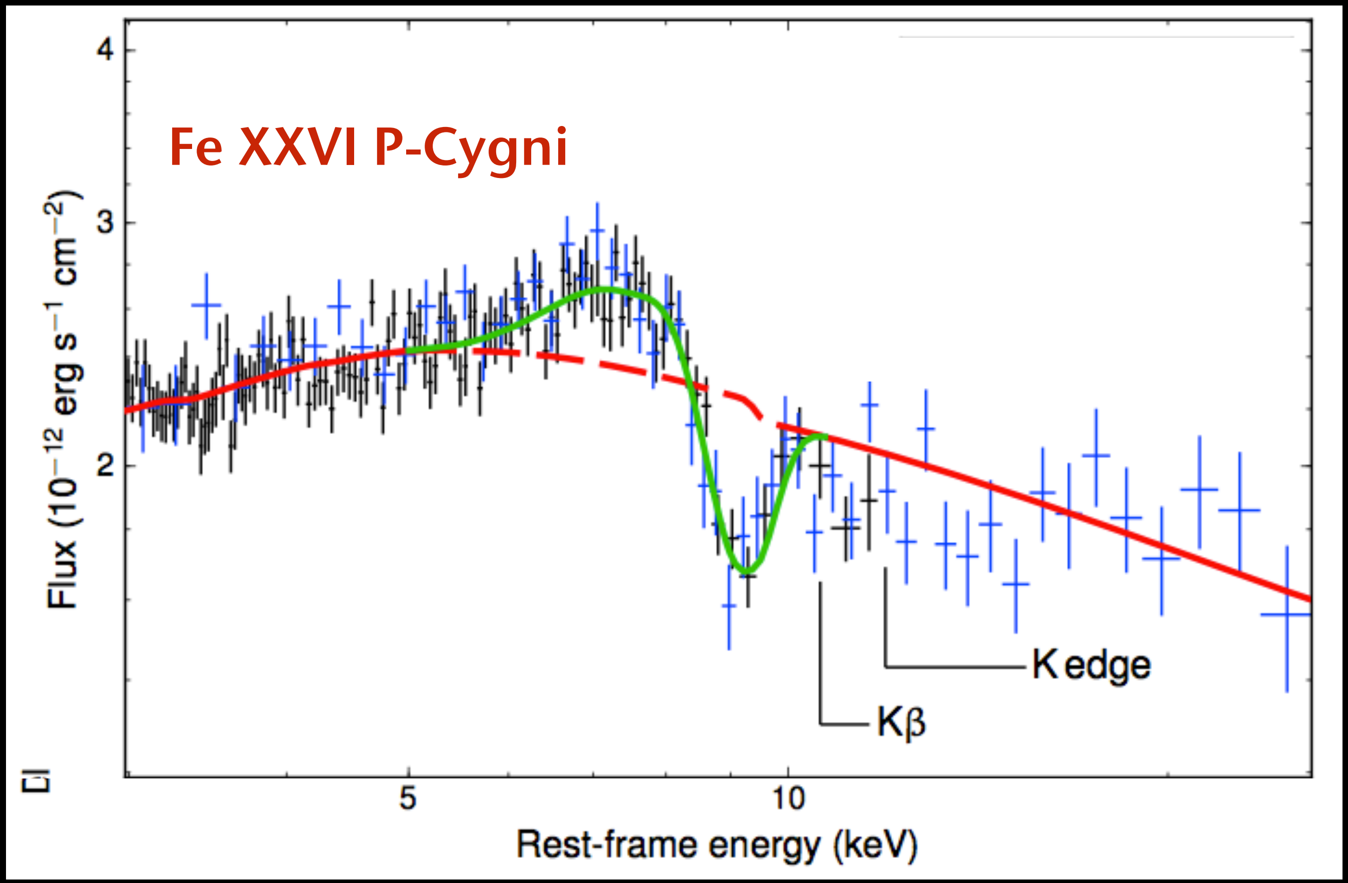
(Torres+97, Simpson+99, Yun+04)

z	0,185
L	10
M	2 x 10
L	~1
Accretion rate	~20 M

A local analogue of the hyper-luminous QSOs dominating the SMBH growth at Cosmic noon (z~2-4)

PDS 456: widespread presence of AGN winds in X-ray and UV

- Highly-blueshifted FeXXV-XXVI absorptions
  (Reeves+00; Reeves+03; Reeves+09; Gofford+09)



The prototype of massive and persistent UFO

Nardini+15 (XMM+Nustar):
P-Cygni profile tracing a quasi-spherical, UFO with v~0.25 c

Kinetic power ~ 20% of L_{Bol}

- Balmer lines with very broad wings (up to ~30000 km/s)
- Very broad CIV emission line blue-shifted by 5200 km/s
- Broad Lyα absorption blue-shifted by ~20000 km/s

(O'Brien+15)

… and several others!

The ALMA view of PDS 456

Investigating the molecular gas properties in the hyper-luminous QSO with the most powerful nuclear wind

!!Very compelling science case!!

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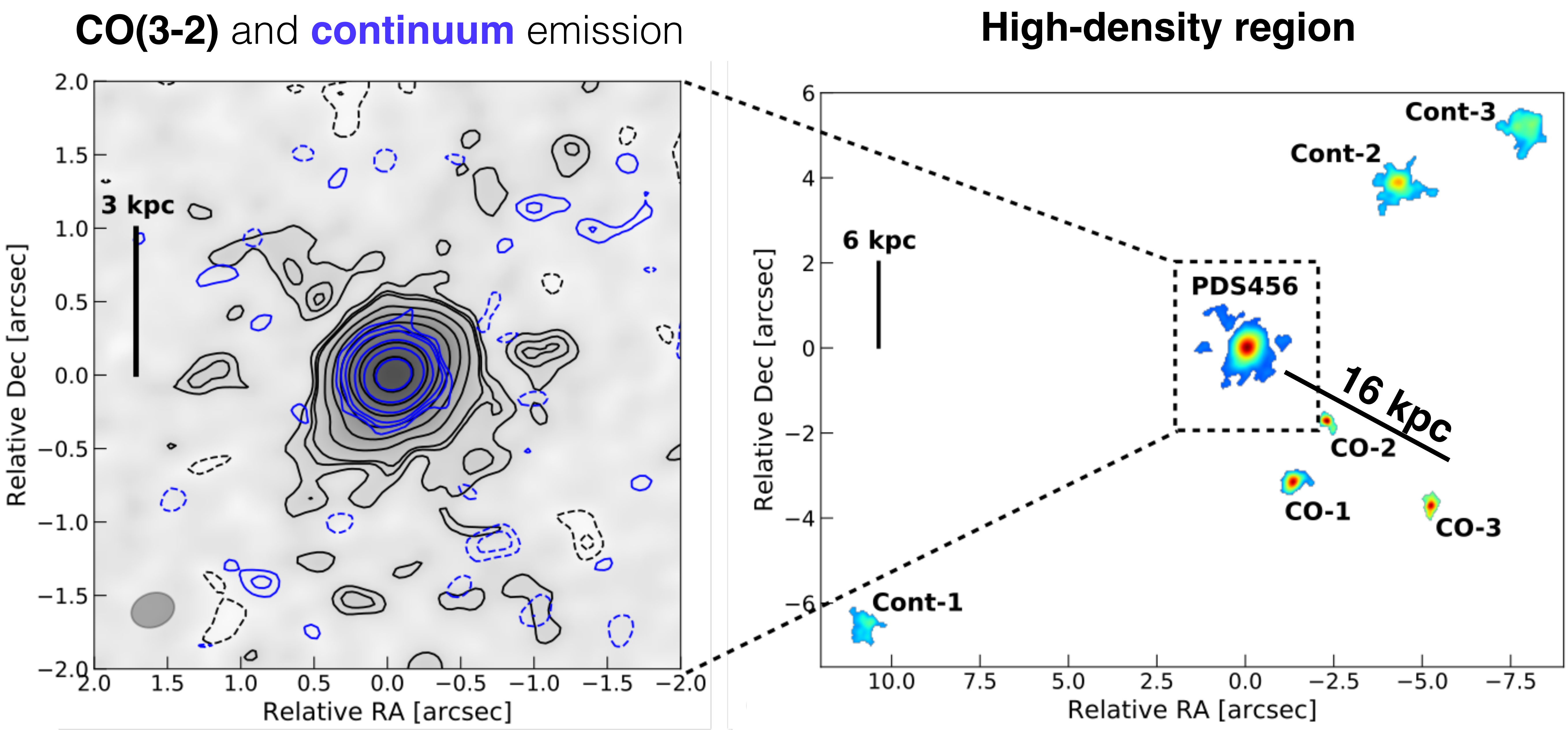
Exposure: 4h on-source - ALMA Band 7
CO(3-2) with angular resolution of 0.25 arcsec (~700 pc!)

The highest resolution map ever taken of the molecular gas in a hyper-luminous QSO to:

- Measure the molecular gas reservoir and constrain the CO kinematics
- Reveal a kpc-scale AGN-driven molecular outflow

The ALMA view of PDS 456



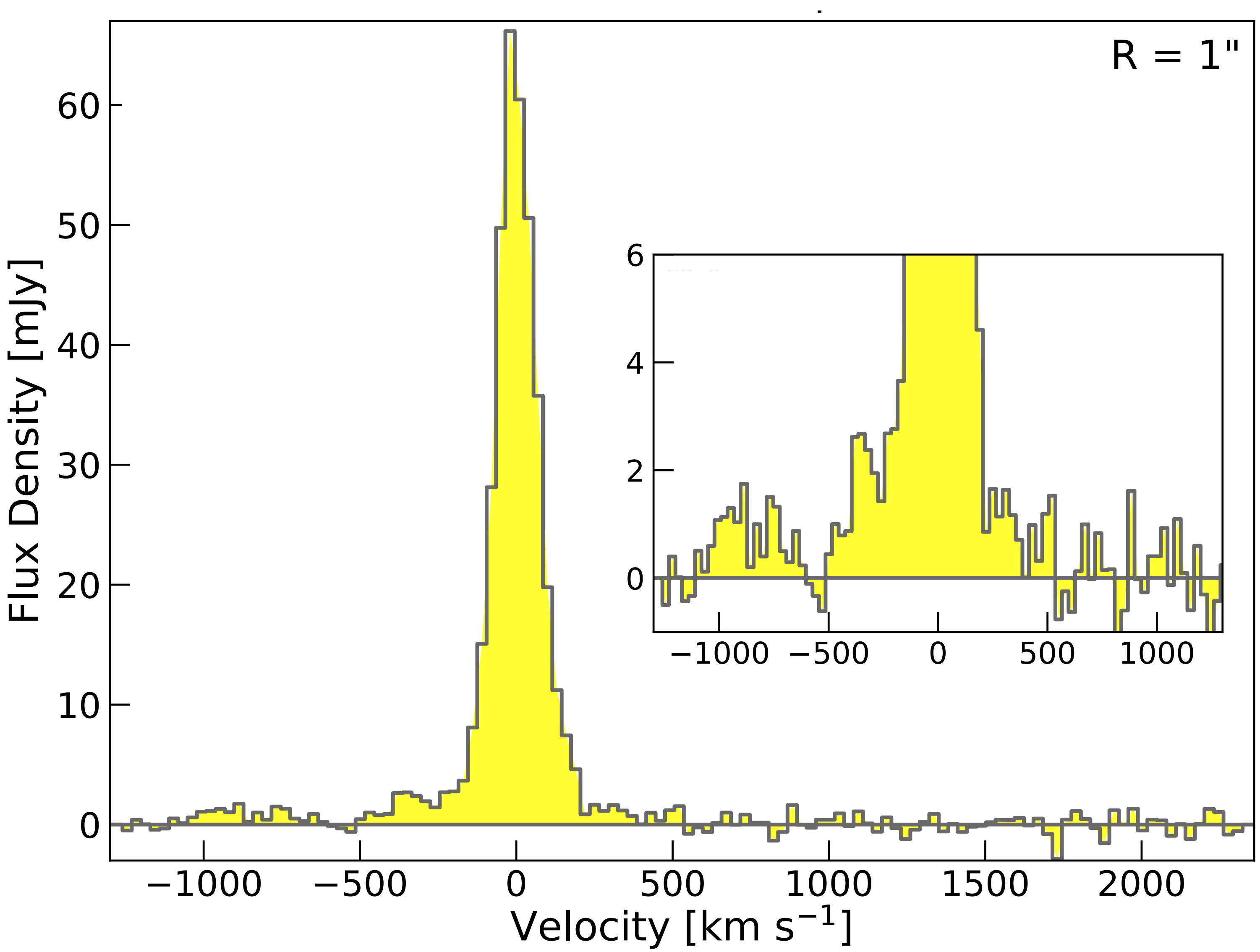
- **Merger-driven scenario for hyper-luminous QSOs**
- **Fundamental role of high-resolution studies to probe host-galaxy properties**

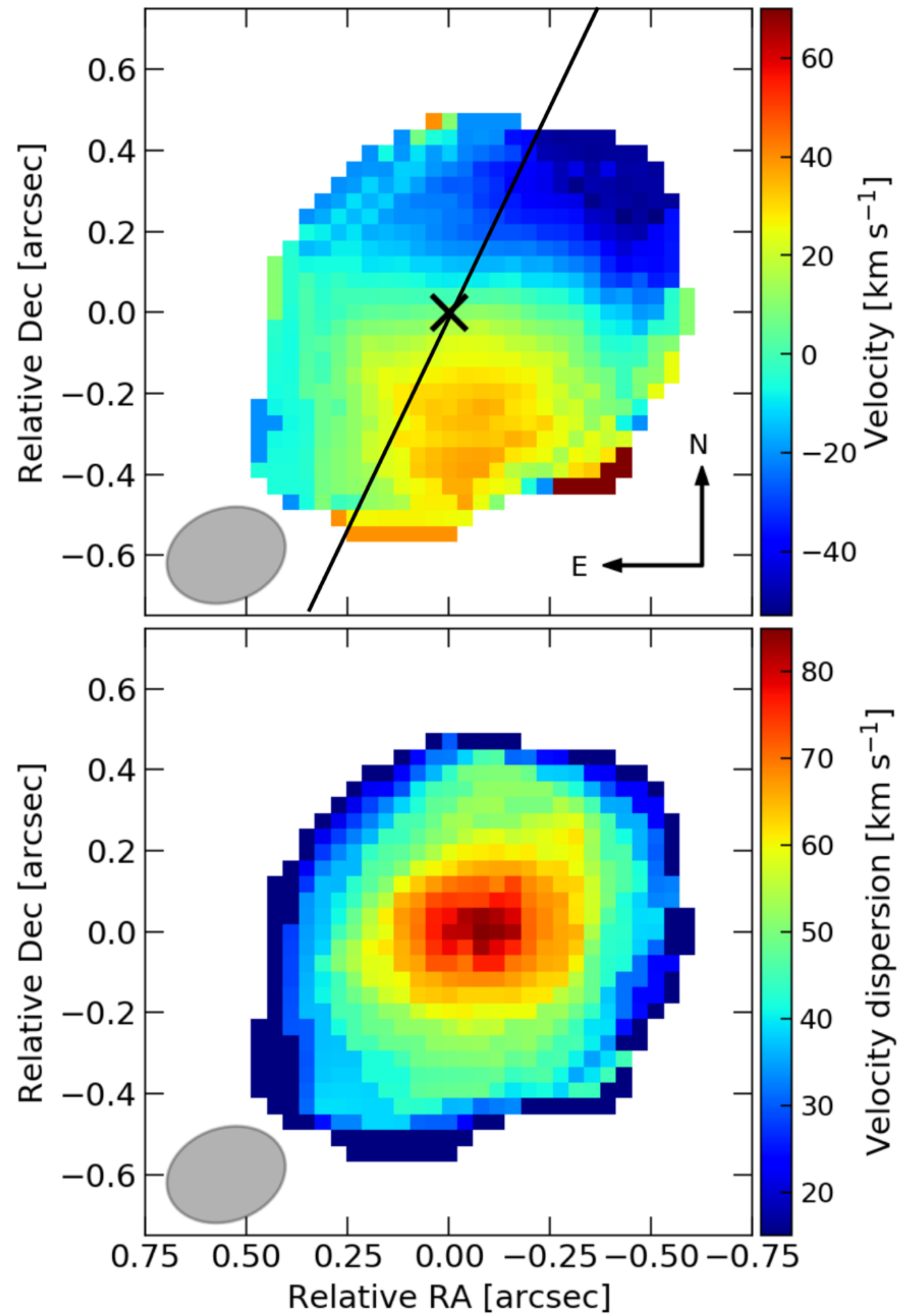
  850 μm continuum flux ratio PDS456/Total ~ 0.3 ⟶ IR luminosity of PDS456 needs revision!

  Newly estimated SFR ~30-80 $M_{\odot}$/yr (Vignali et al. in prep.)

Kinematics of CO(3-2) emission in PDS 456

- The molecular gas reservoir is located in a compact (D ~ 1.3 kpc), rotating (v_{rot}~ 280 km/s) disk seen close to face-on (*i* = 25 deg)





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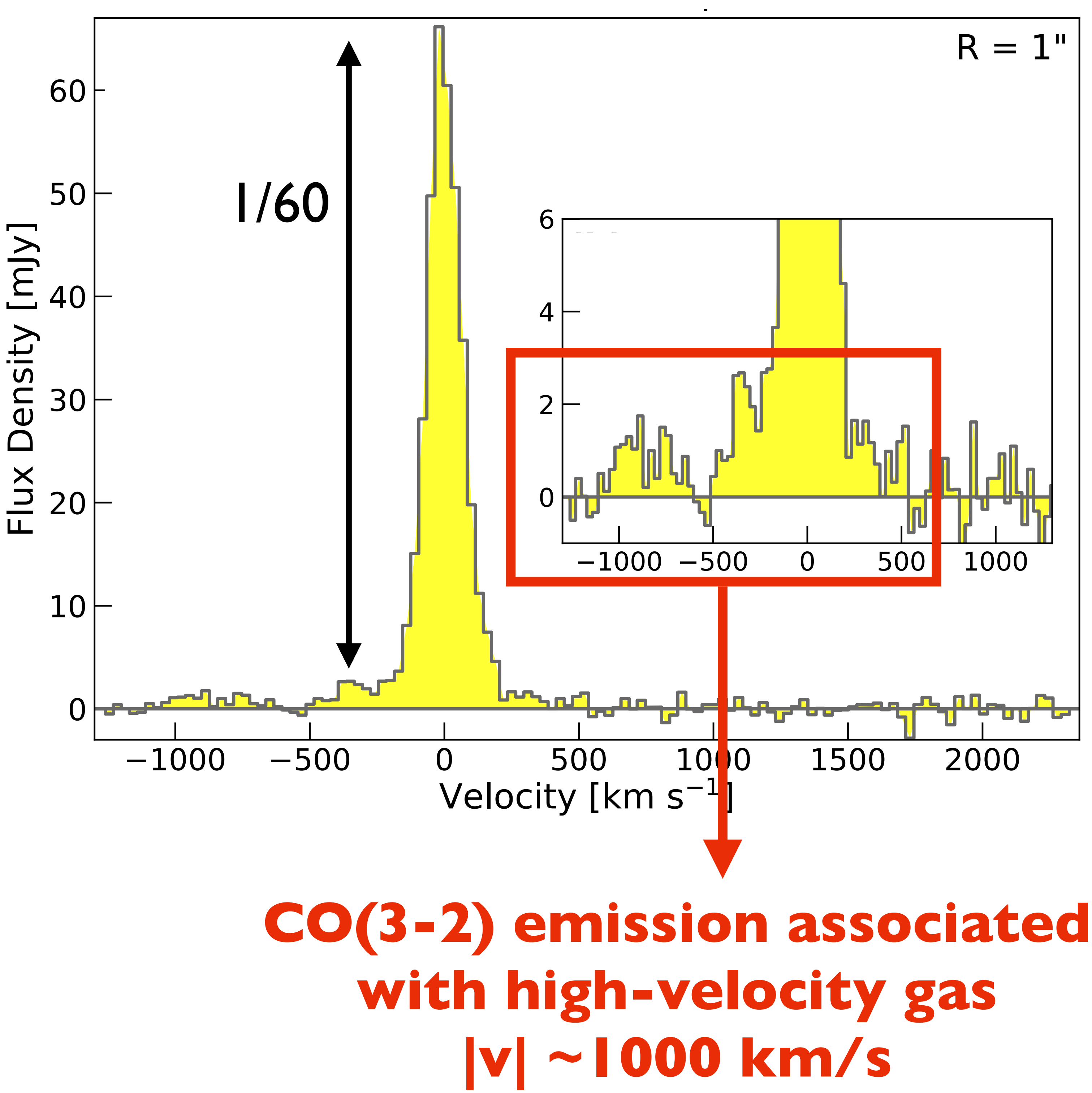
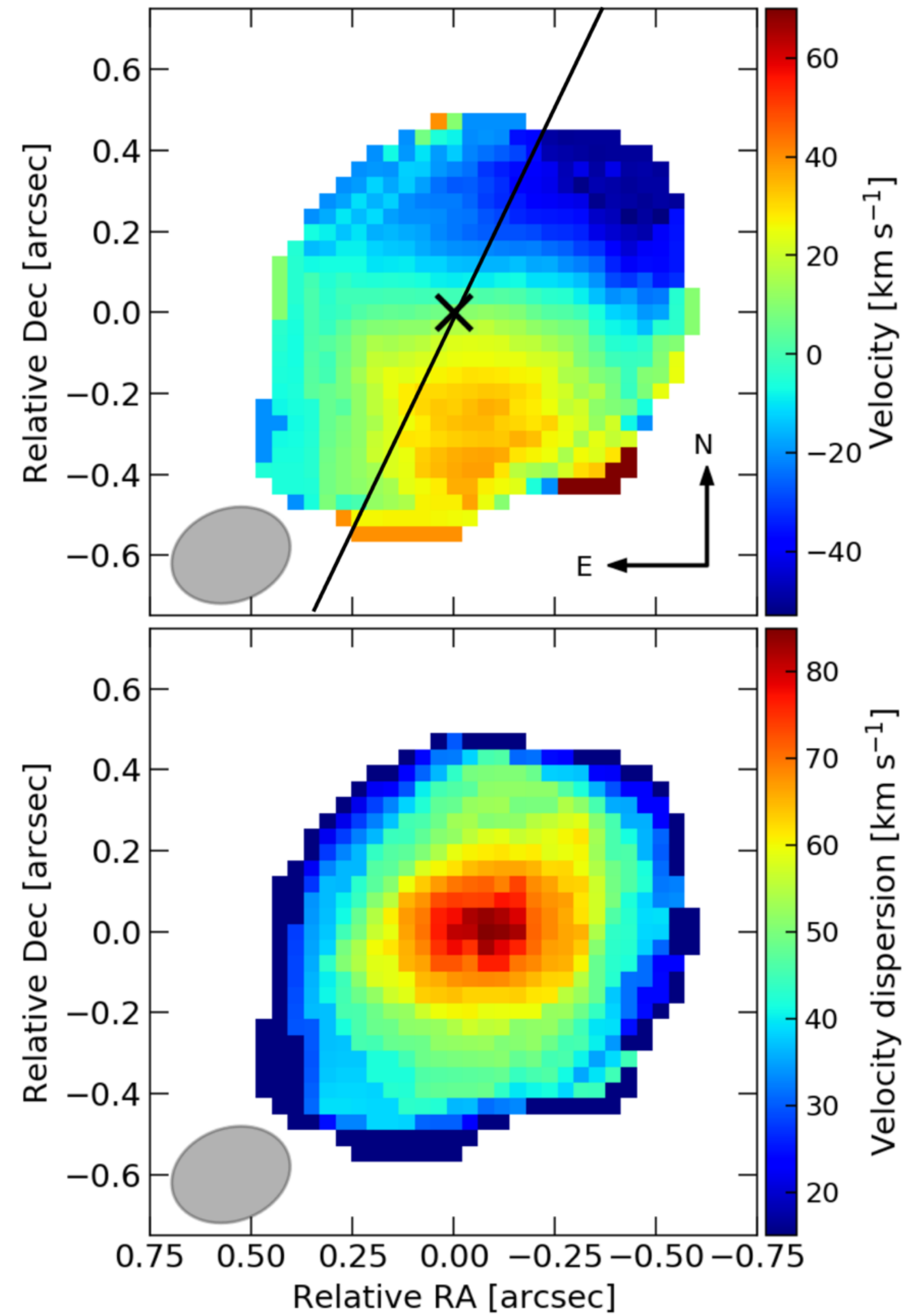
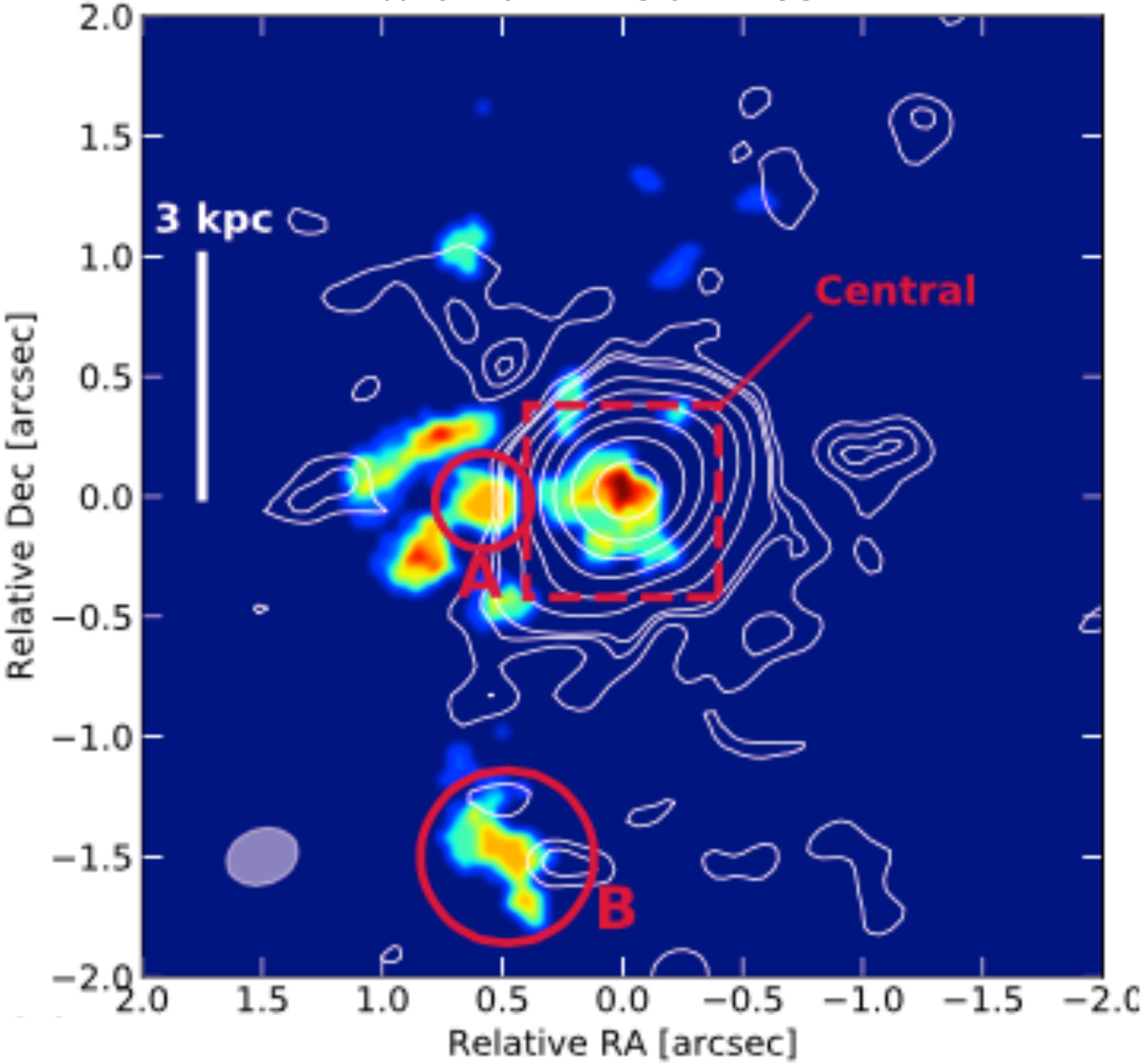


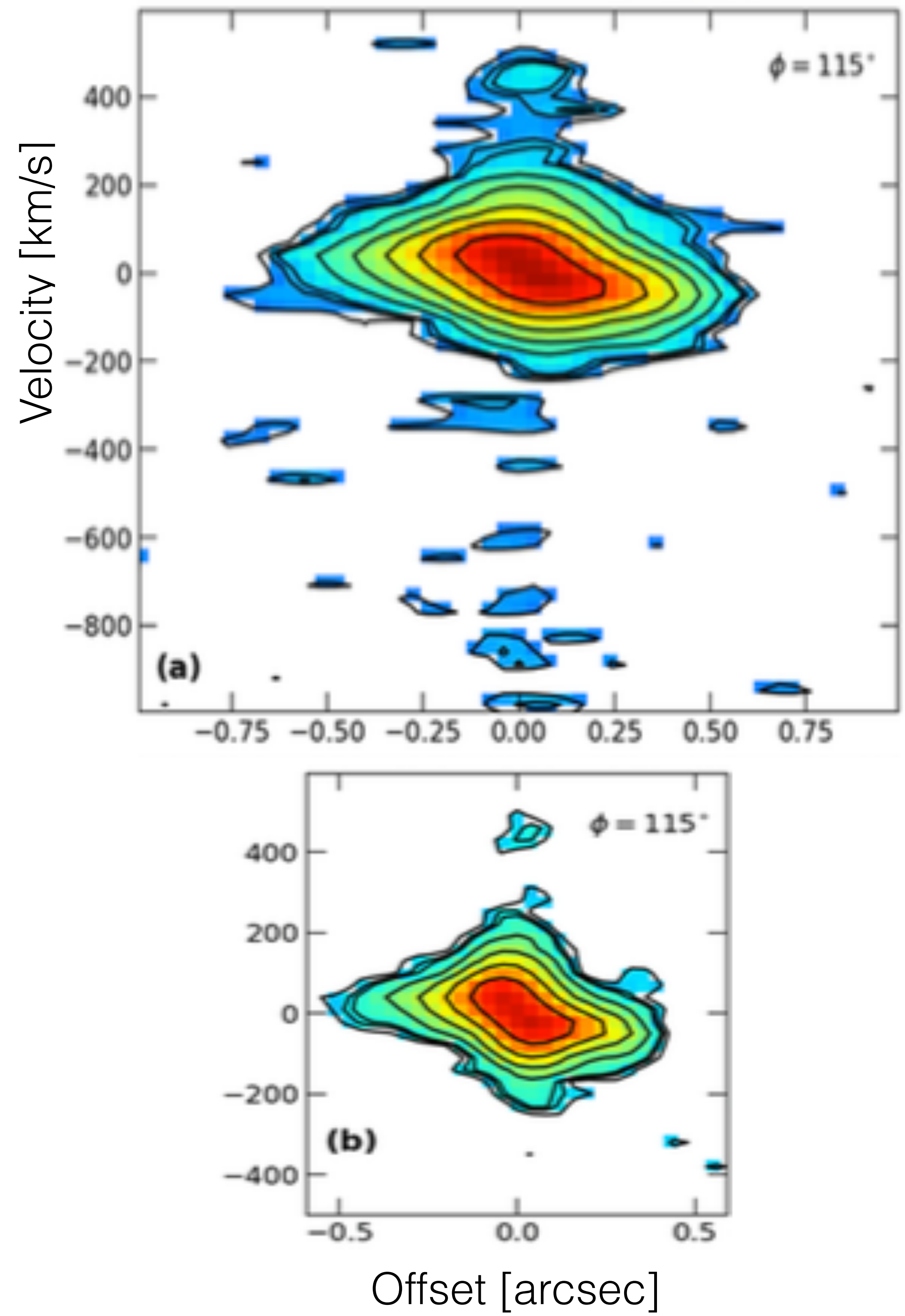


Discovery of a kpc-scale molecular outflow

Integrated map of CO emission
with v < -250 km/s



Central component R < 1 kpc



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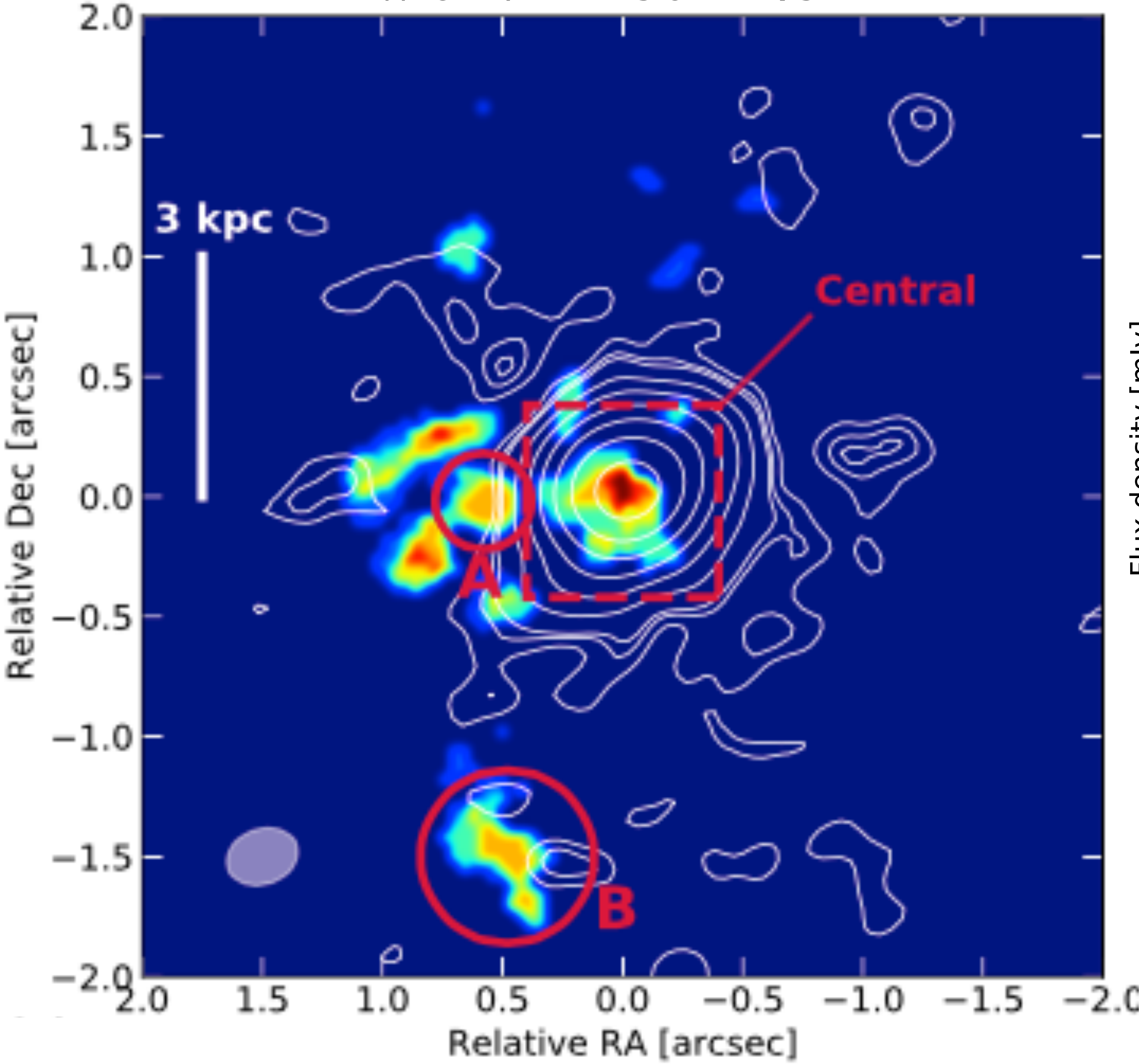
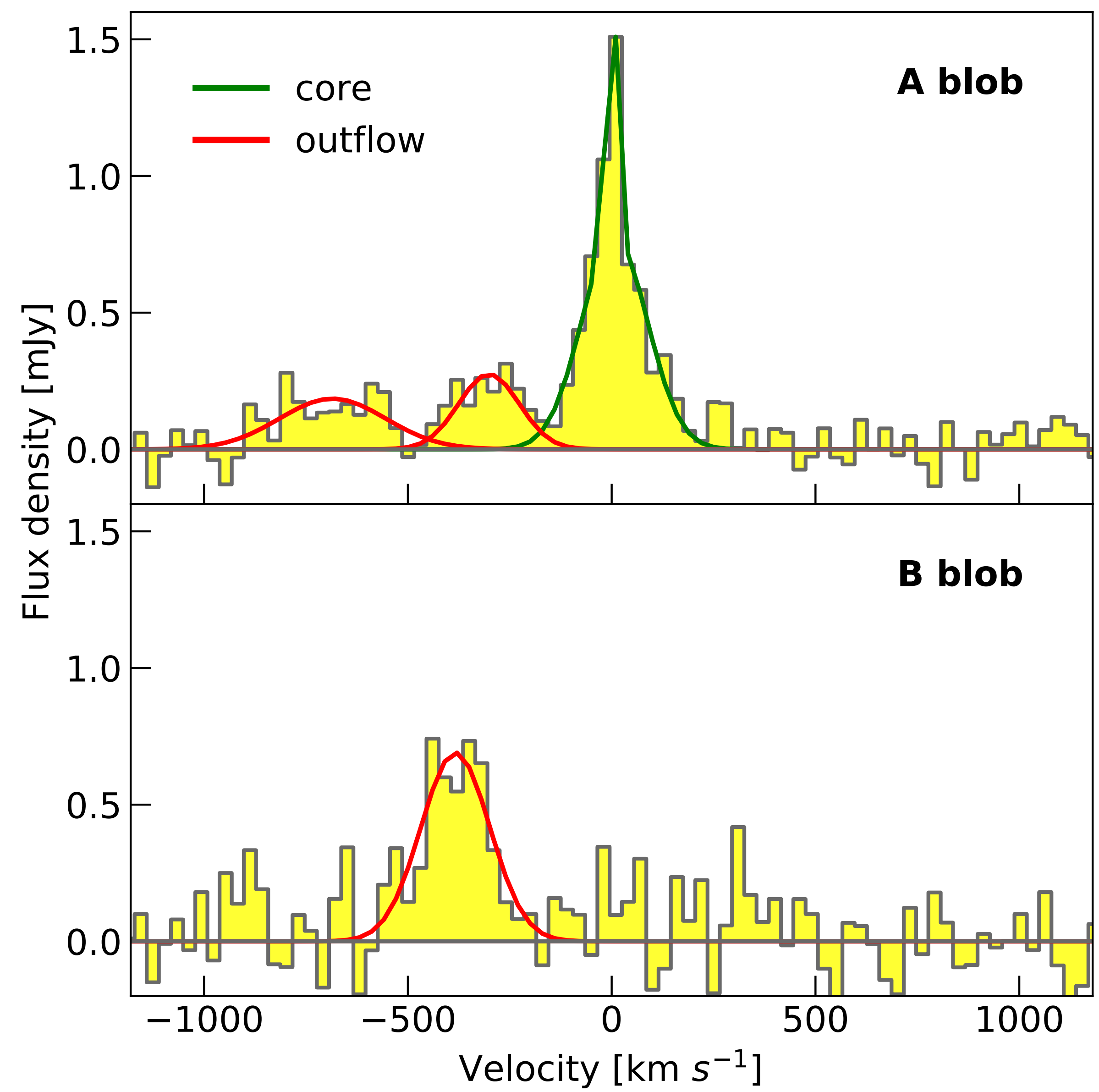


Extended component
1.5 kpc < R < 5 kpc



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AGN feedback in action

$$\dot{M}_{\rm mol} \sim 300\ M_\odot/{\rm yr}$$

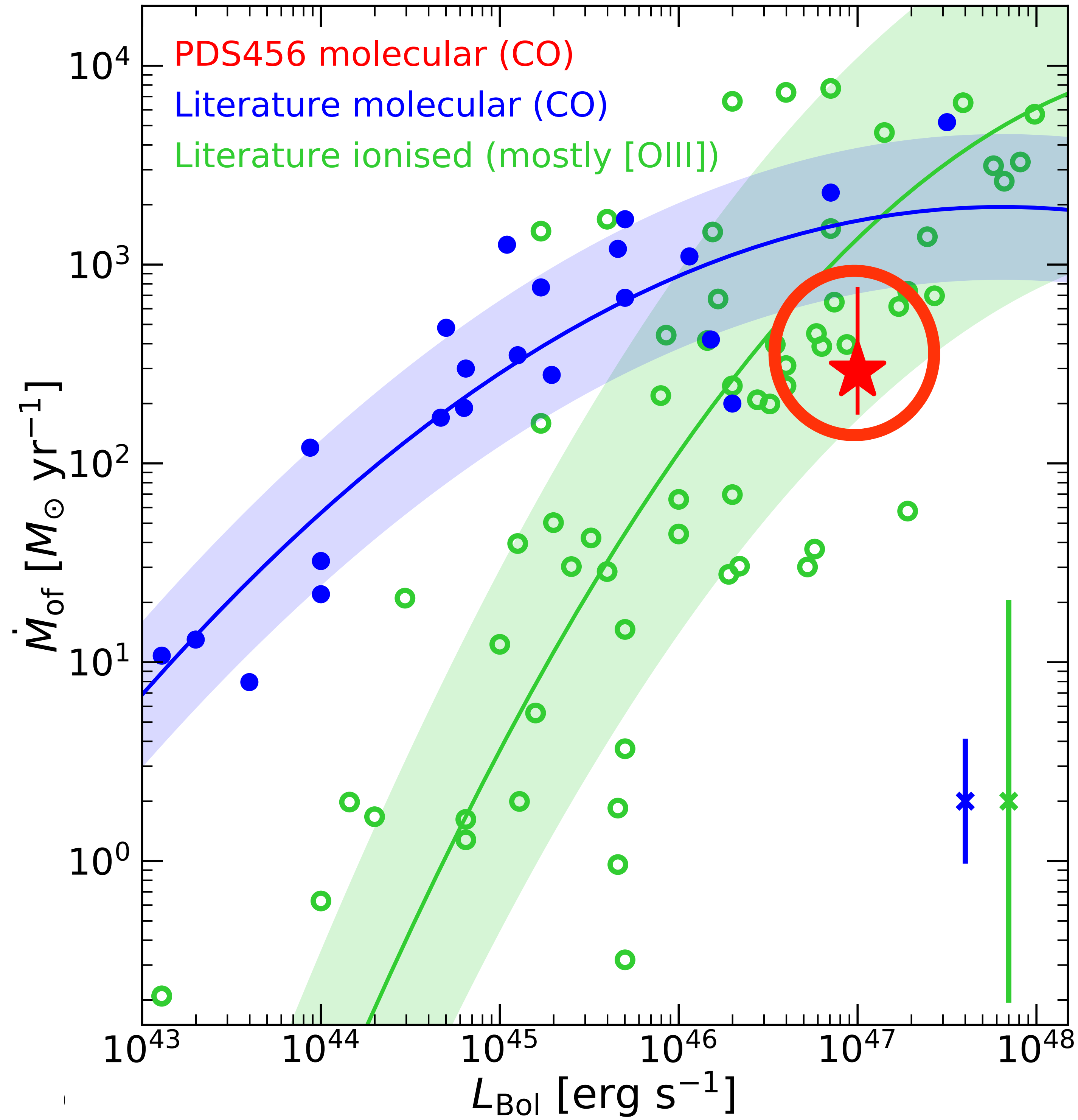
$$\tau_{\rm dep} = M/\dot{M}_{\rm mol} \sim 8\ {\rm Myr}$$

Very short depletion timescale

$$\dot{M}_{\rm mol}/SFR \sim 4 - 10$$

Molecular gas removed before it forms stars

Most updated collection of AGN-driven outflows



The QSO is able to affect the evolution of its host-galaxy!

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Challenging the energy-conserving scenario

$$\dot{M}_{\rm mol} \sim 300\ M_{\odot}/{\rm yr}$$

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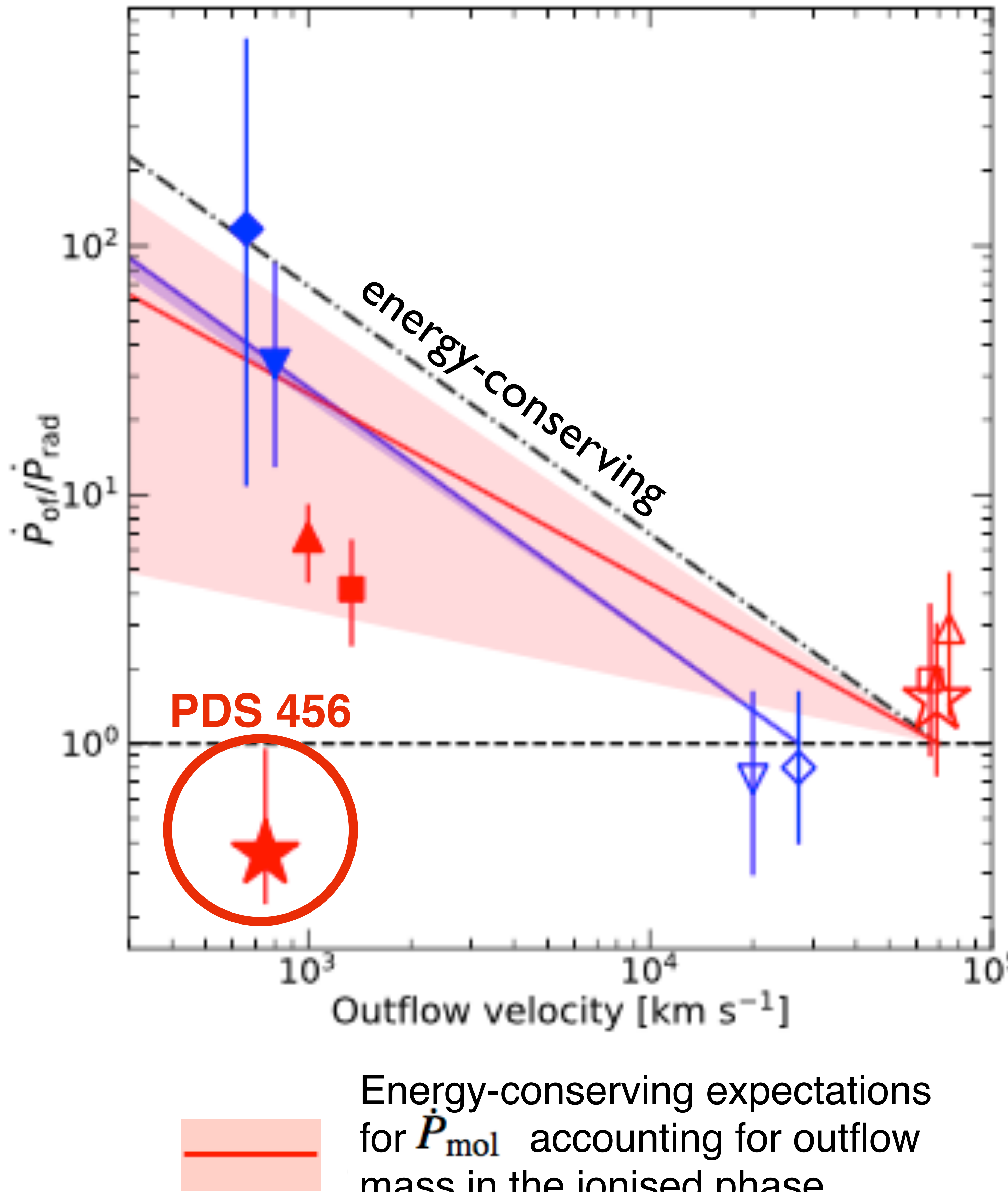
Very short depletion timescale

but…

$$\dot{P}_{\rm mol}/\dot{P}_{\rm rad} \sim 0.4$$

≠

energy conserving expectations ($\dot{P}_{mol}/\dot{P}_{rad}$ >> 1)



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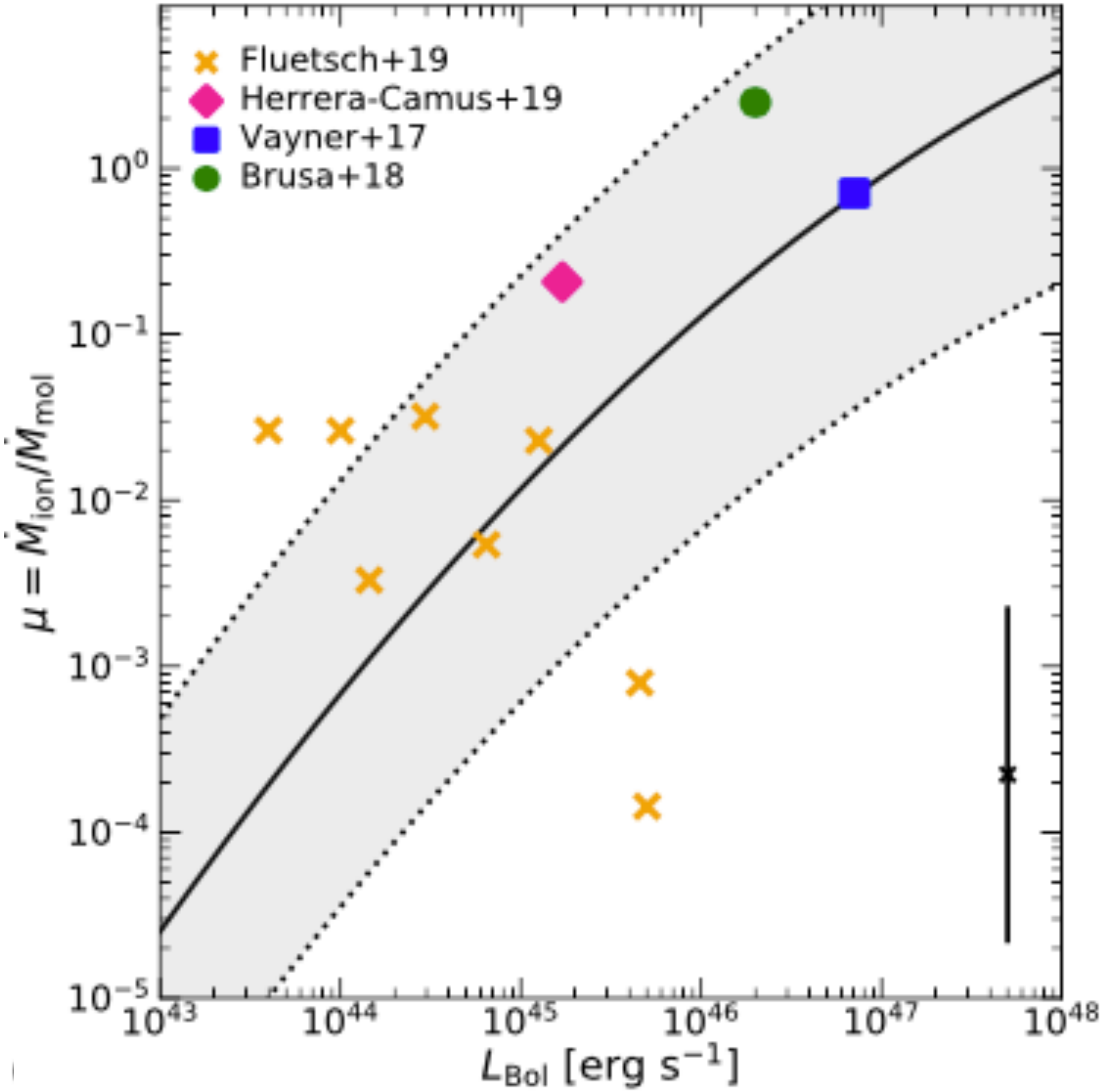

Unless at high-luminosities (L_{Bol}~10^{47} erg/s) the ionised outflow becomes important

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Challenging the energy-conserving scenario

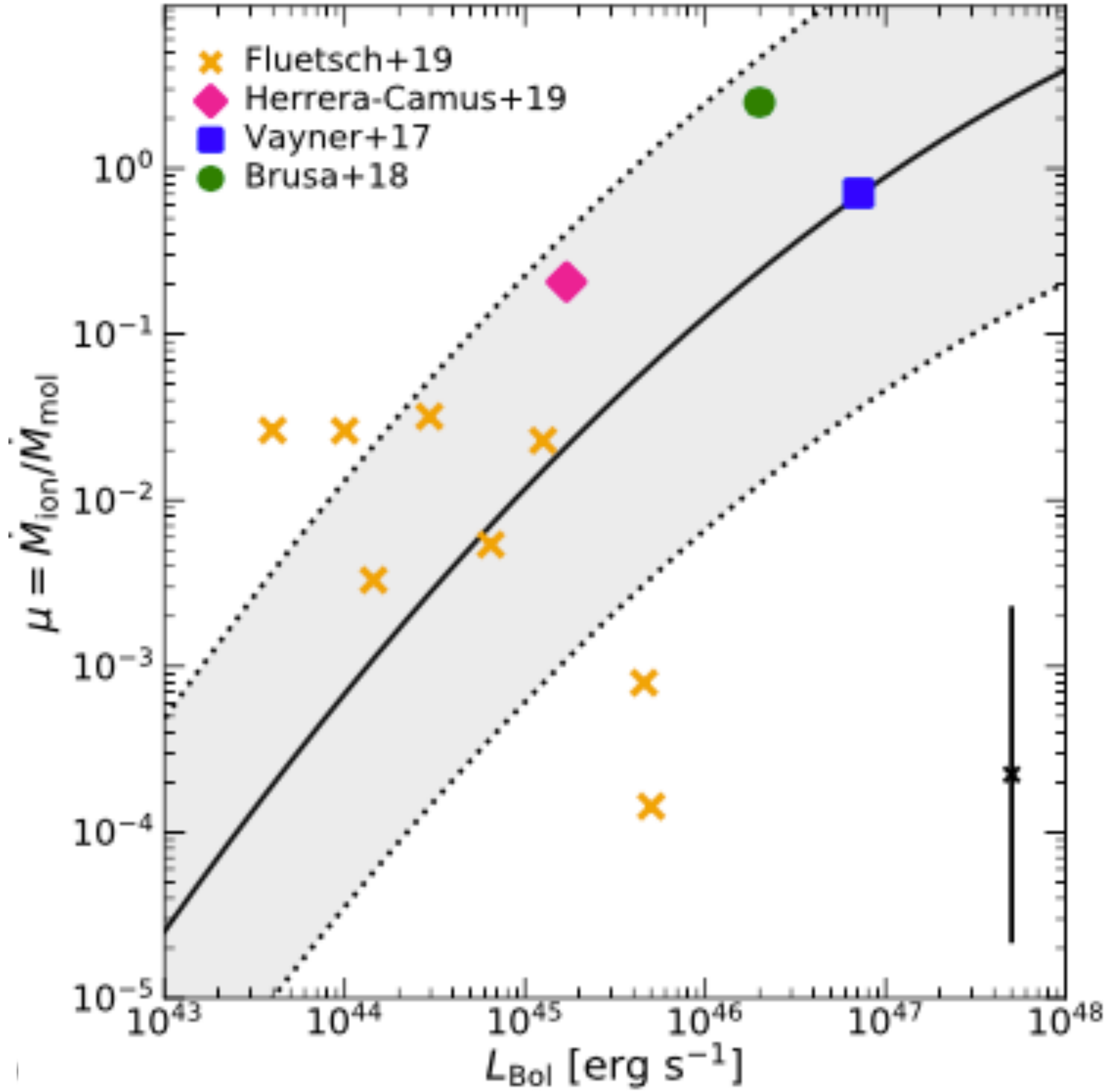
Recently performed MUSE (PI E. Piconcelli)

narrow field mode (<100 pc resolution)

+

wide field mode (~kpc resolution)

will allow us to test this hypothesis in PDS456!



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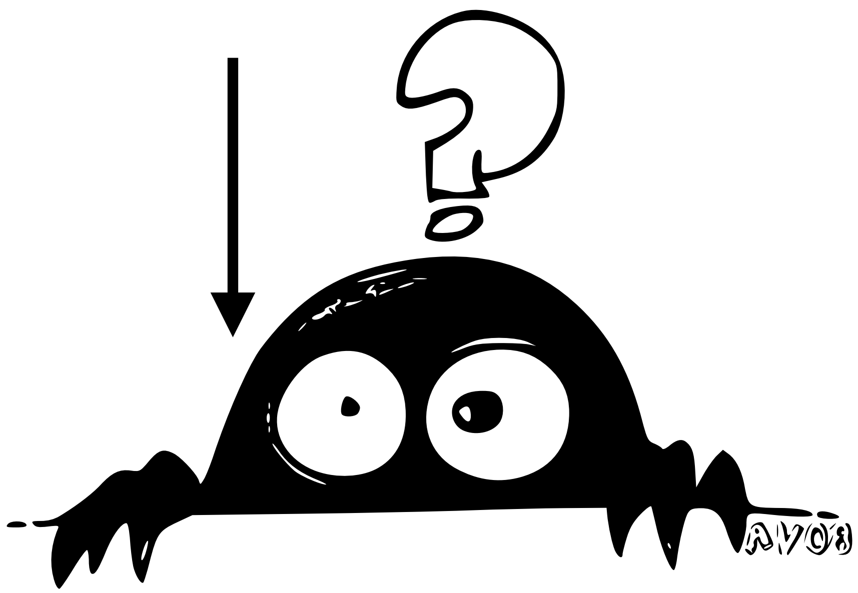
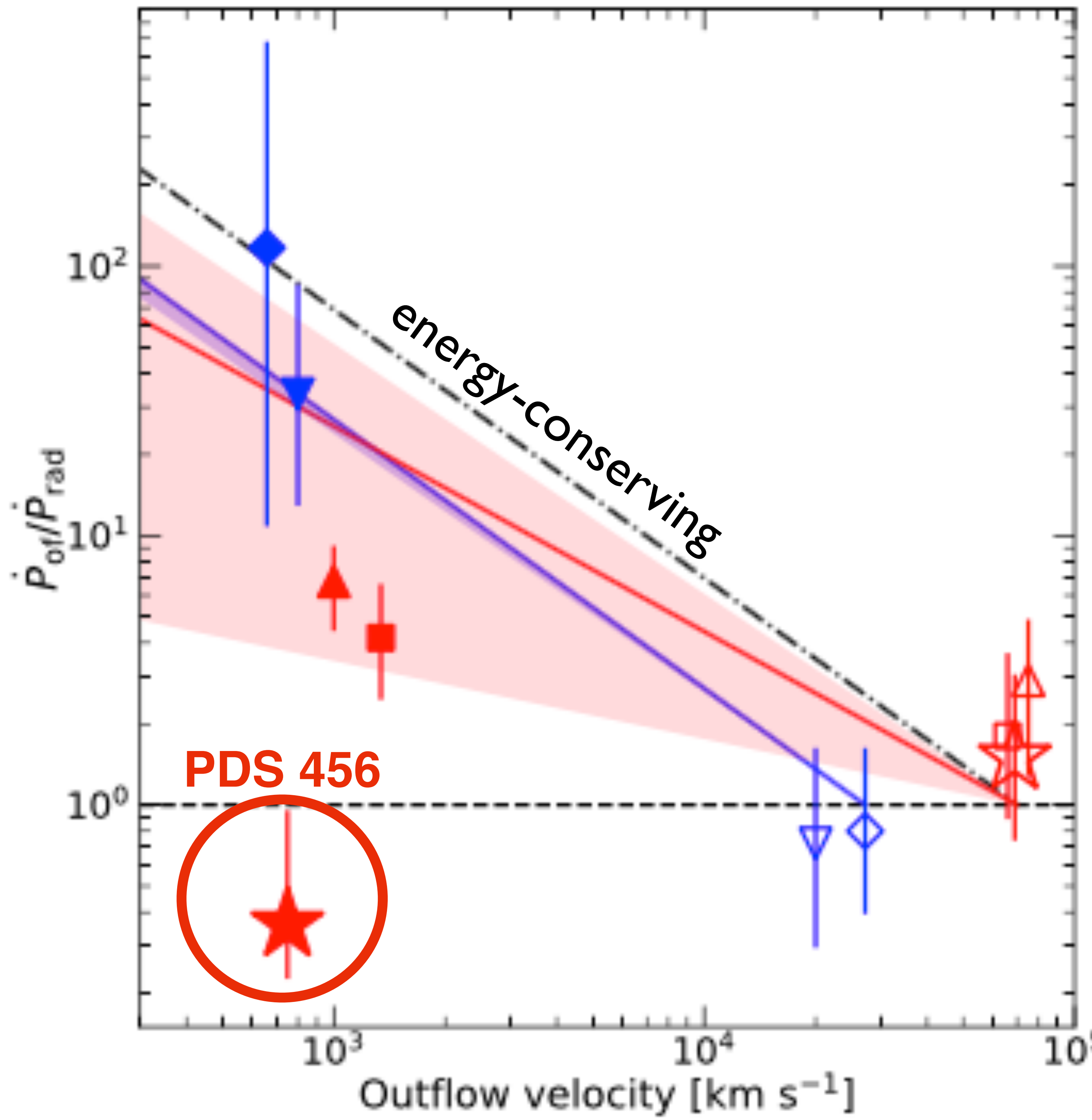
Challenging the energy-conserving scenario

Bust still a discrepancy for a $\dot{M}_{ion}$ as high as 10^4 $M_\odot$ in PDS456!!



Is the two-phase energy-conserving scenario really working…or NOT?



Energy-conserving expectations for $\dot{P}_{mol}$ accounting for outflow mass in the ionised phase

Challenging the energy-conserving scenario

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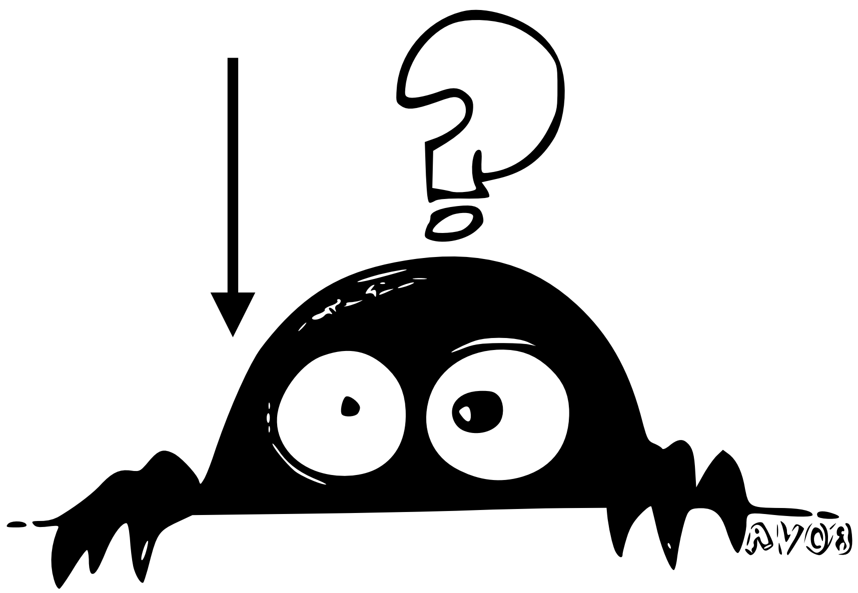

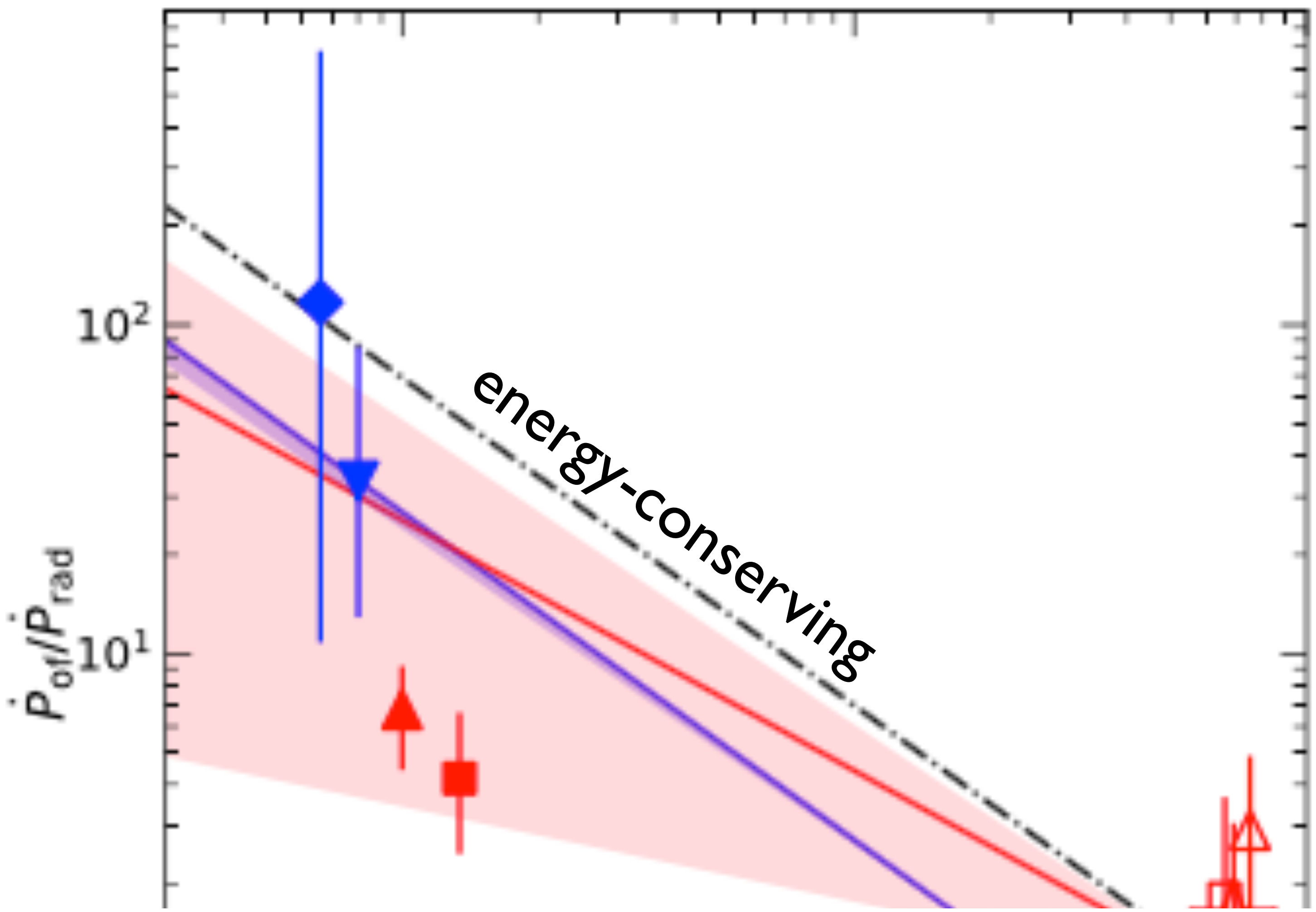

These observations require new models/driving mechanisms to be explained

Alternative scenarios:

- Energy-conserving, two-phase expansion if the outflow is highly inclined with respect to the disk plane (Menci+19)
- Huge radiative power of the QSO leads to radiation-pressure driven winds

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Summary & Conclusions

- The ALMA observation of PDS 456 is the first sub-kpc mapping of the molecular gas in a hyper-luminous QSO
- PDS 456 is located in a galaxy over-density (at least 3 companions)
- Molecular gas reservoir located in a compact (1.3 kpc) rotating disk
- Molecular outflow is there! Complex morphology:
  Extended (~5 kpc) clumps + central compact component
- Molecular mass outflow rate ~ 300 $M_\odot$ /yr
  Able to deplete the molecular gas in ~ 8 Myr before it forms stars
- Momentum flux MUCH lower than what expected from L_{Bol} and UFO power

↓

Feedback in action in the host-galaxy of PDS456

The discovered molecular outflow challenges the energy-conserving scenario: new models/driving mechanisms required