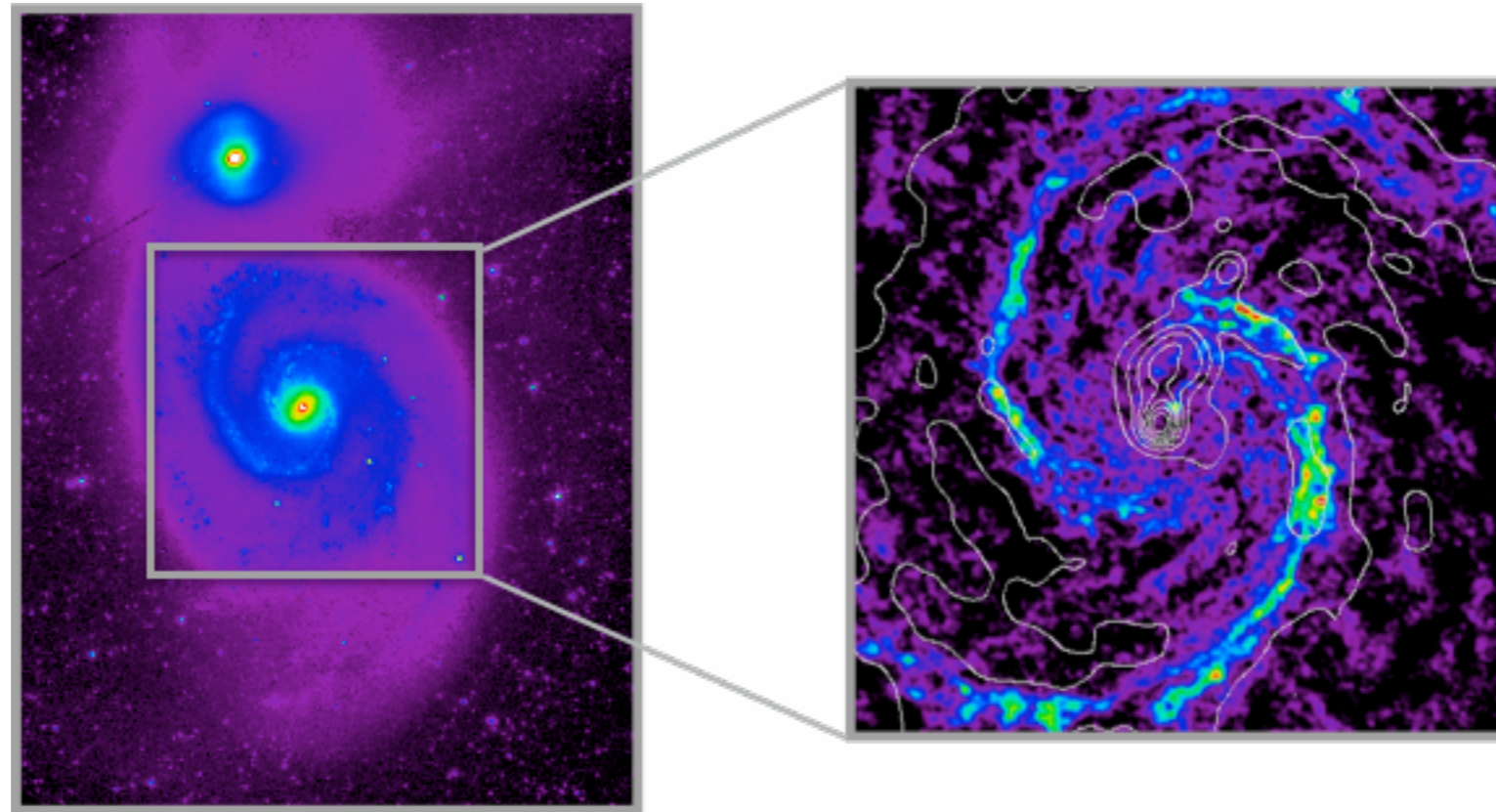


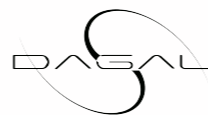
A detailed look at the AGN in M51: molecular inflow and outflow



Miguel Querejeta

Max Planck Institute for Astronomy

Eva Schinnerer, Sharon Meidt, Santiago García-Burillo, Jérôme Pety, and PAWS

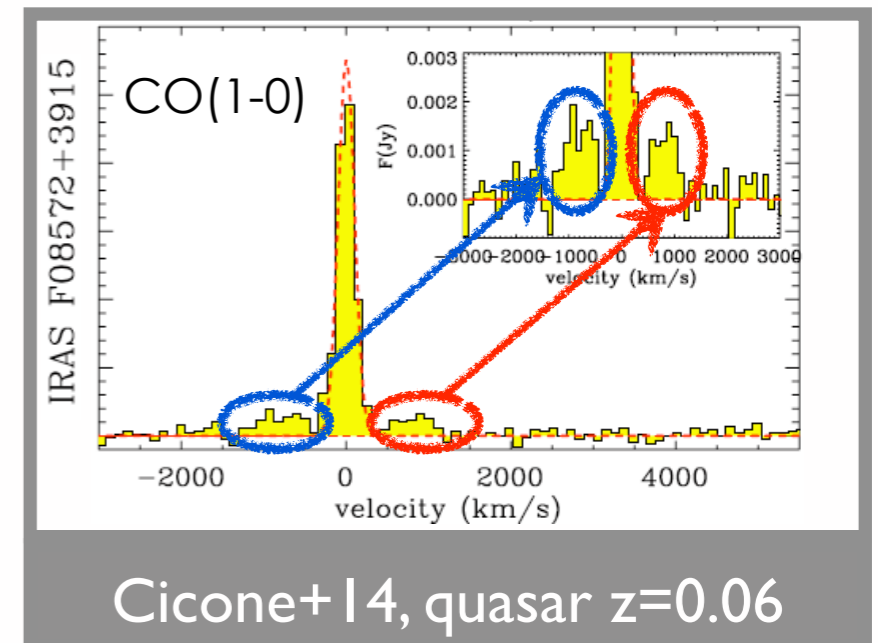


DETAILED
ANATOMY OF
GALAXIES



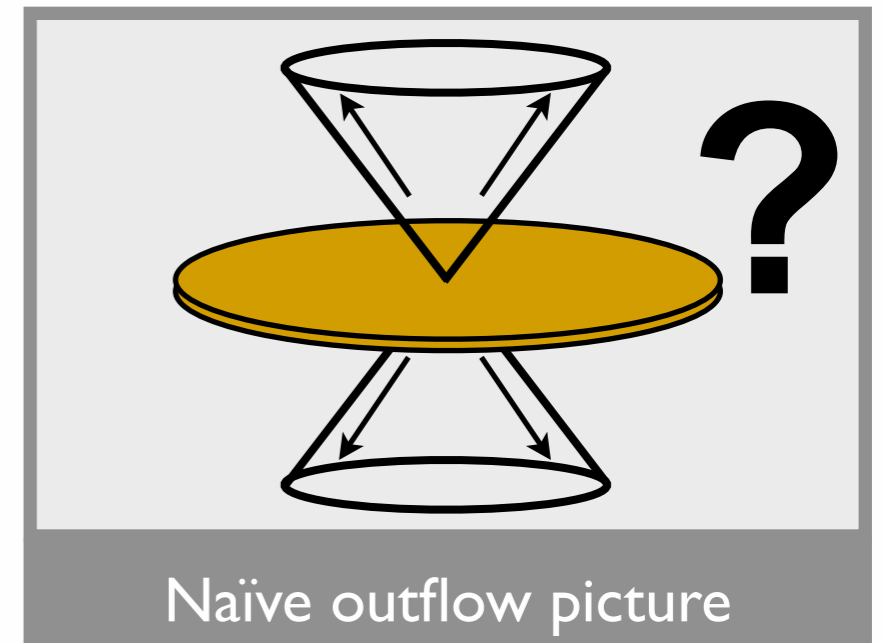
AGN Feedback in the ALMA/NOEMA Era

- Feedback: regulate star formation, matching simulations with observations
e.g. Alexander&Hickox12, Fabian+14
- Associated with (molecular) *outflows*: fuel of star formation removed from disc
- Numerous detections at high-z; details still unclear
e.g. Feruglio+10; Maiolino+12; Cicone+12,14,15



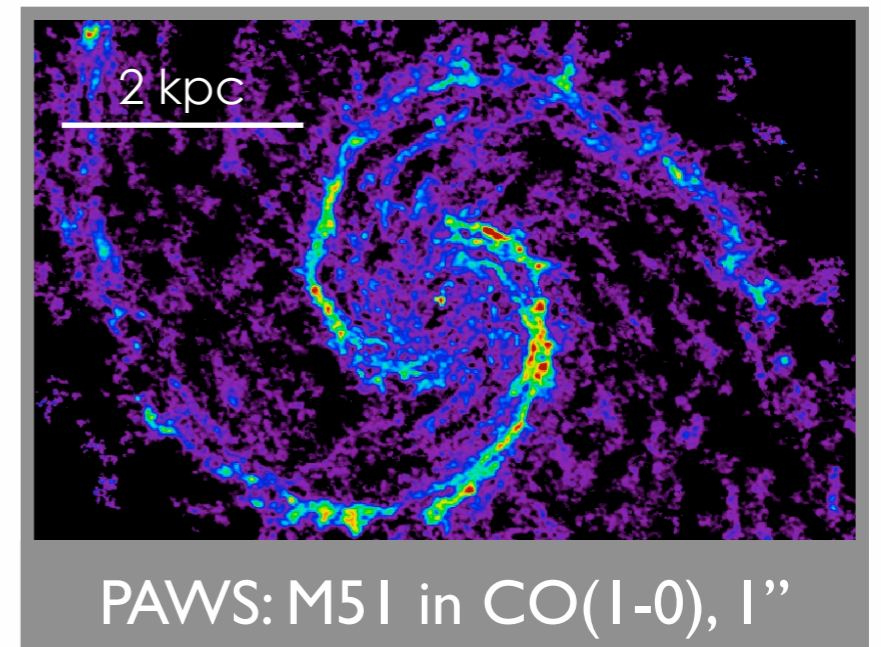
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AGN Feedback in the ALMA/NOEMA Era

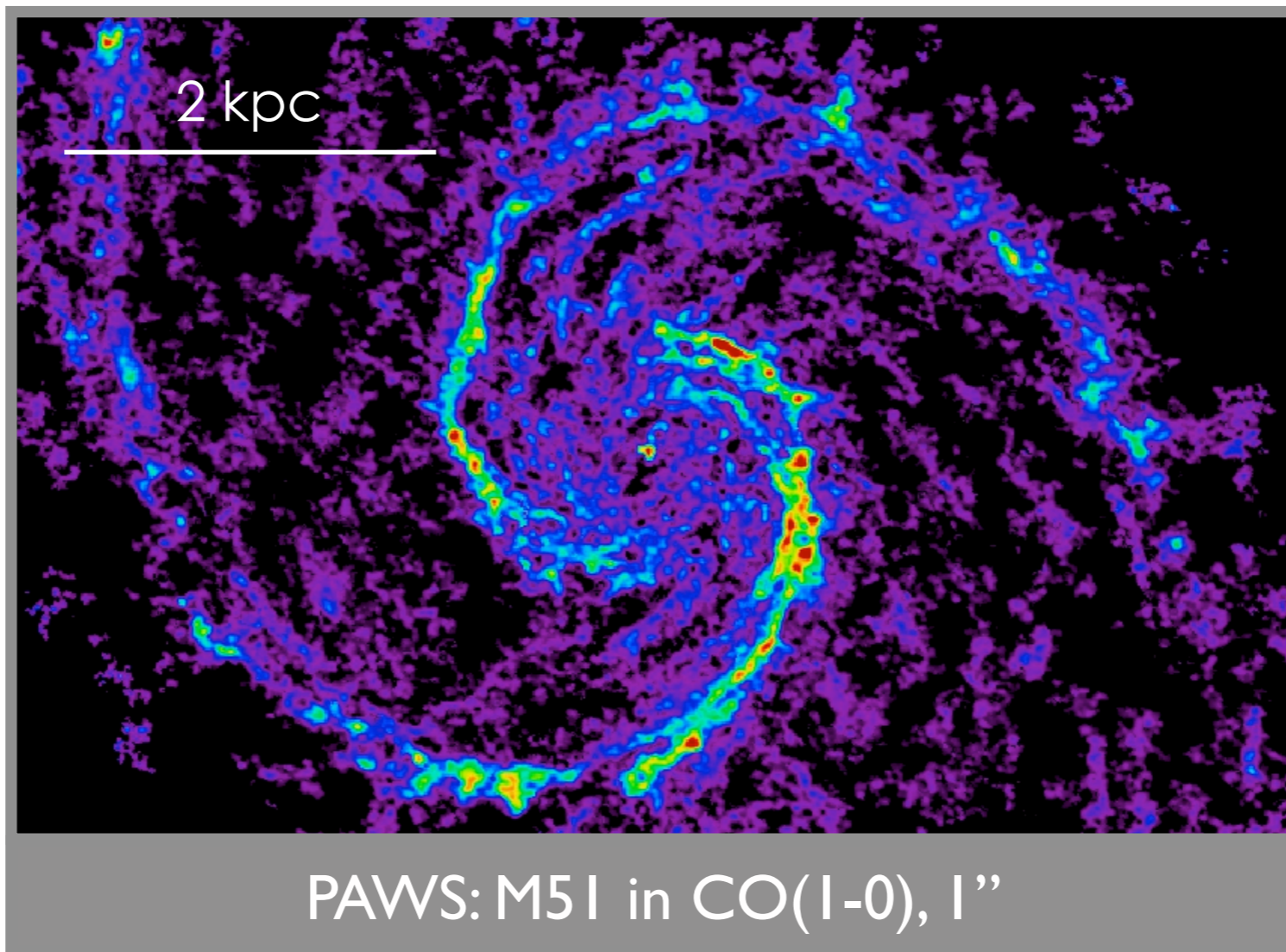
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- ALMA/NOEMA: hope to reveal mechanisms at play
- M51 with PAWS: pilot study of what will become routine with ALMA/NOEMA



The PAWS Picture: high-resolution CO map of M51

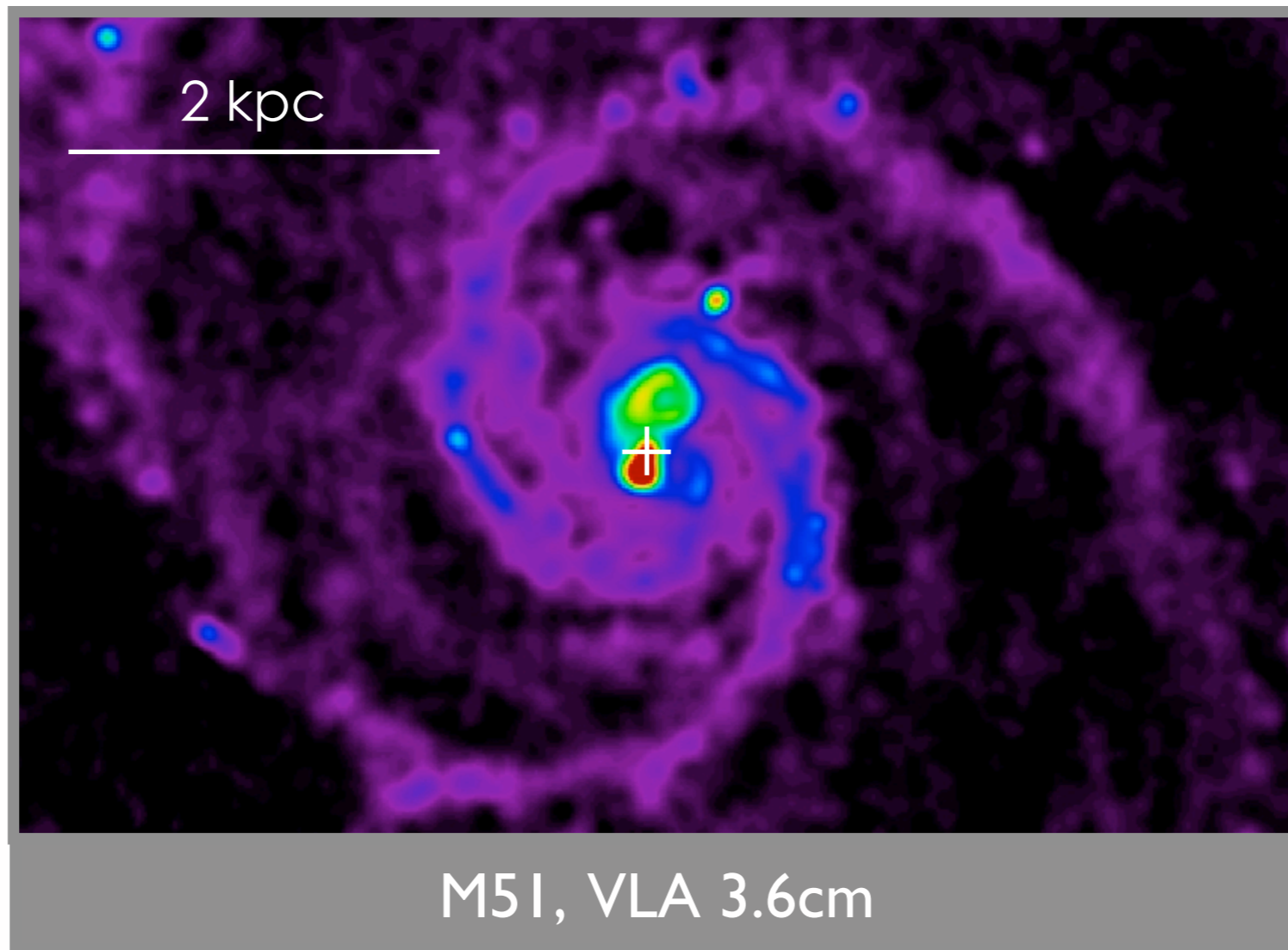
- Plateau de Bure Whirlpool Survey (PAWS): pioneering studies of GMCs properties in external galaxies. 1'' (36 pc), 5 km/s resolution

Schinnerer+13; Pety+13; Hughes+13; Meidt+13; Colombo+14a,b; Meidt+15



The PAWS Picture: high-resolution CO map of M51

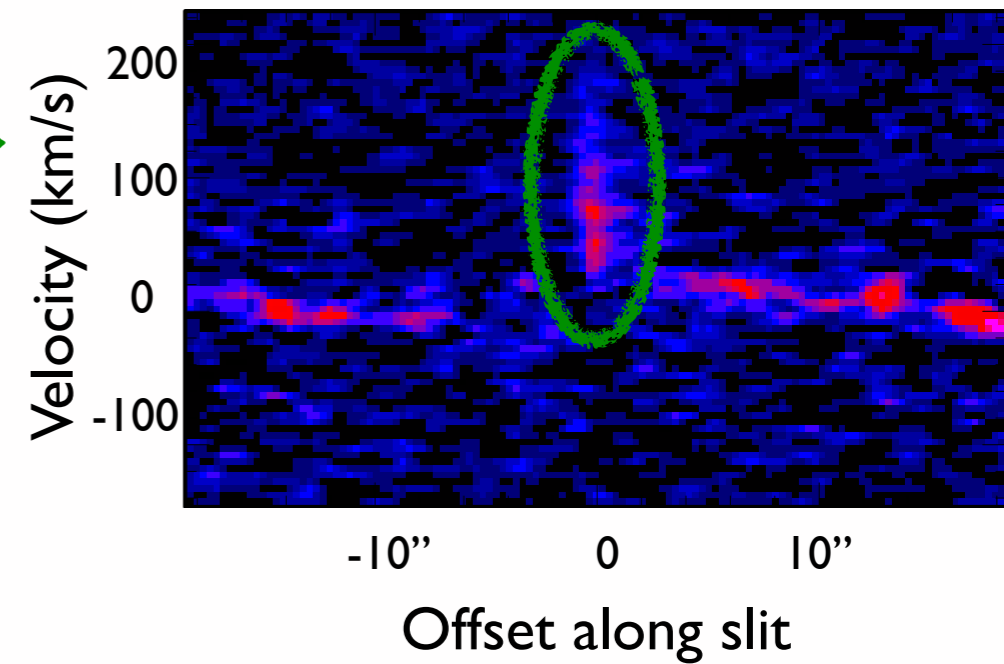
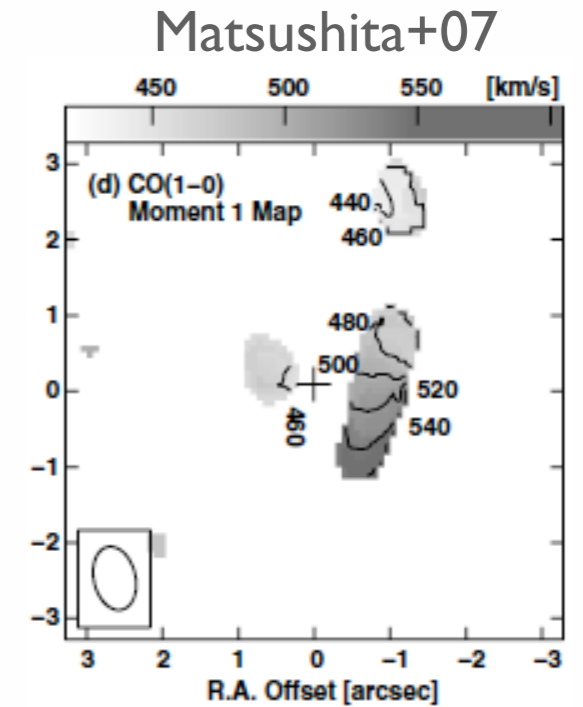
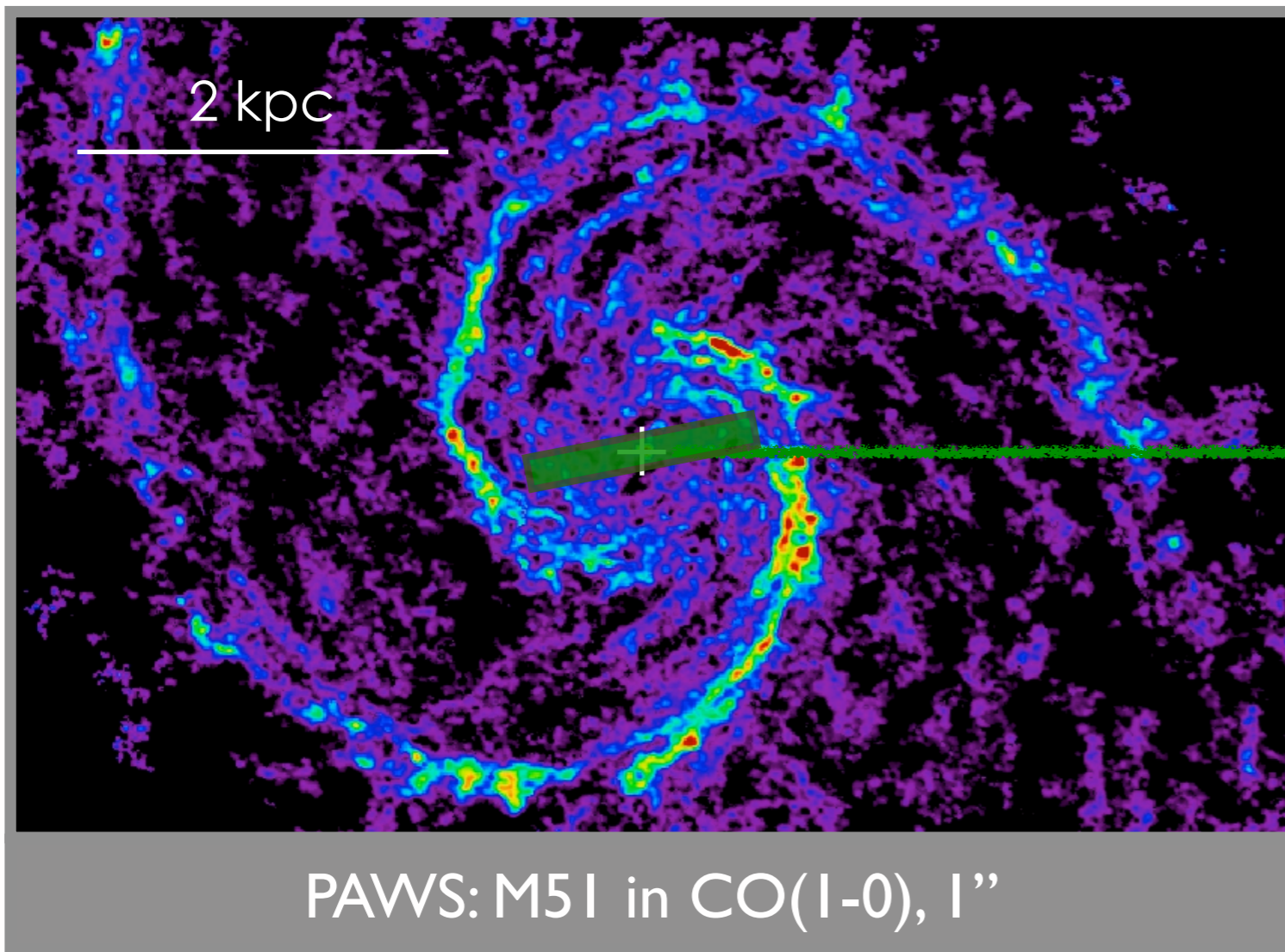
- Seyfert 2 nucleus, with two radio lobes



The PAWS Picture: high-resolution CO map of M51

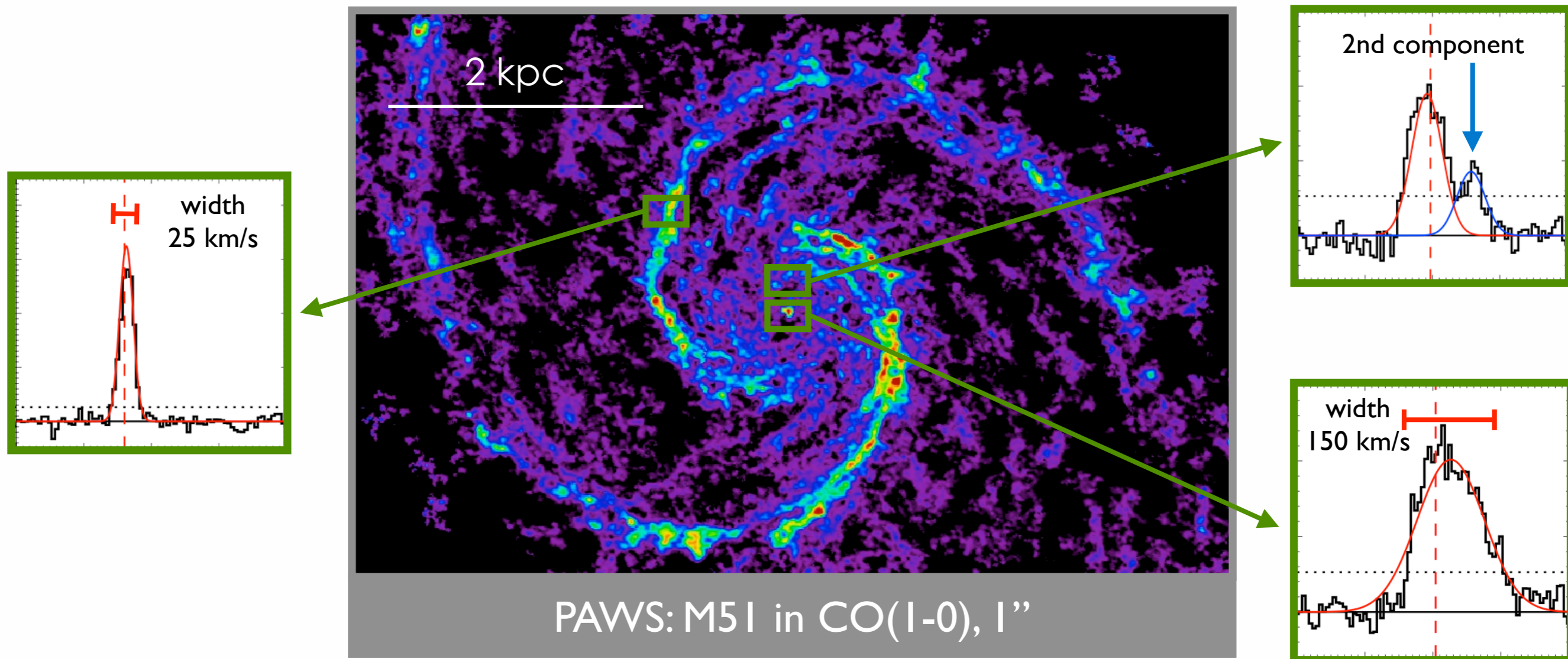
- Unusual nuclear molecular gas kinematics

e.g. Scoville+98, 01; Matsushita+04, 07, 14



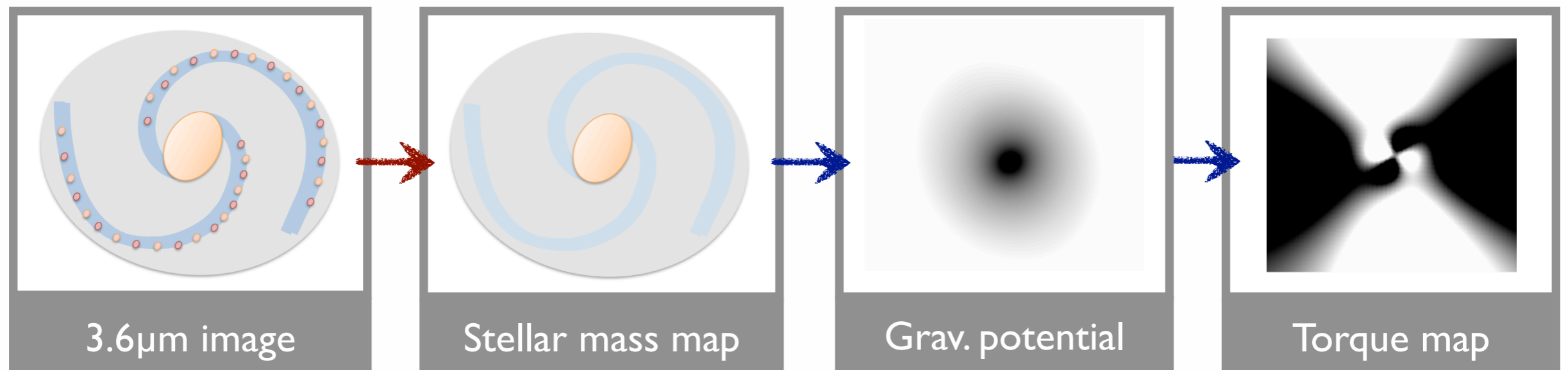
The PAWS Picture: high-resolution CO map of M51

- Evidence for complex CO line profiles near nucleus



Feeding the Nucleus: Gravitational Torques Acting on Gas

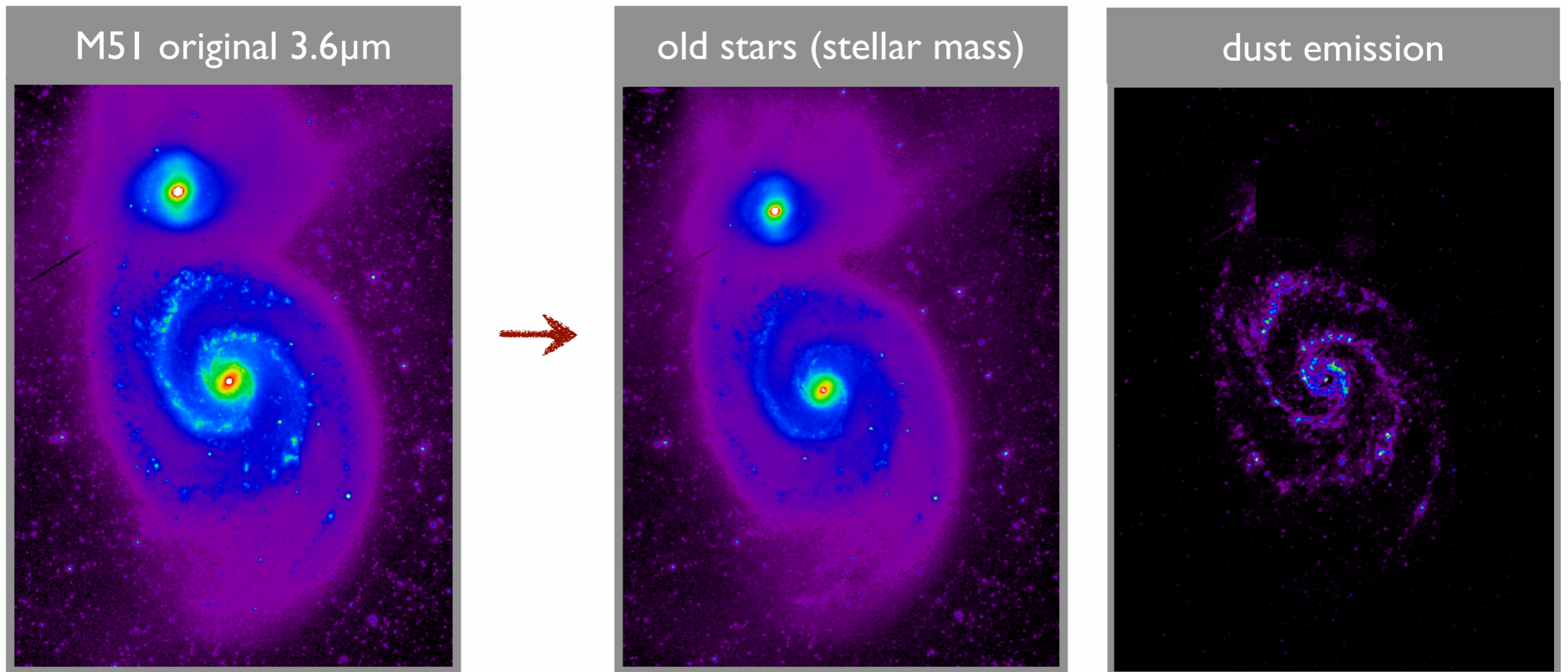
- Gravitational torques increase/remove angular momentum from gas → *radial flows*



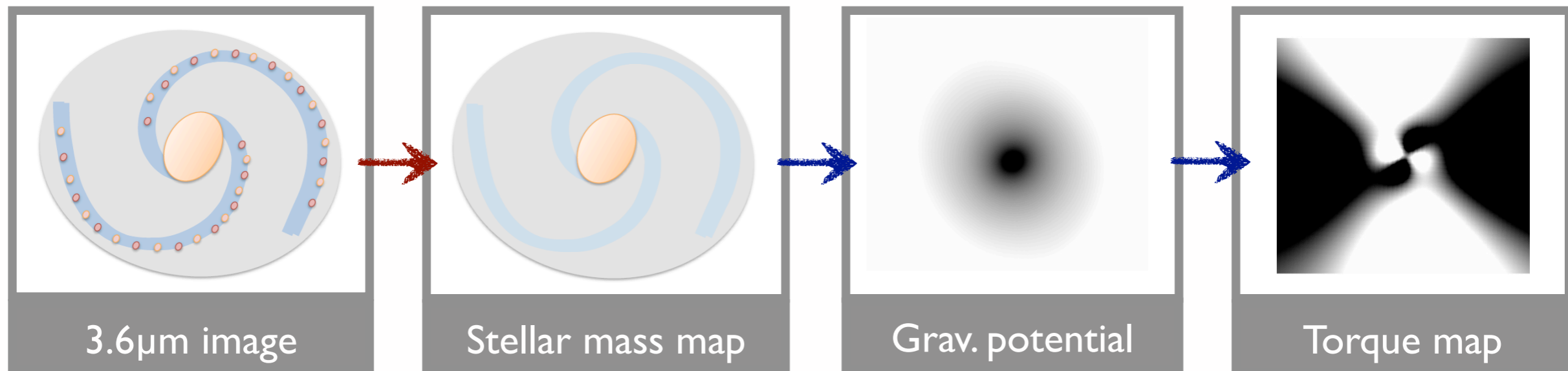
- 3.6 μ m dominated by old stars (tracing stellar mass), but dust emission also present
- Independent Component Analysis (ICA): separate stars from dust using 3.6 and 4.5 μ m
e.g. Pahre+04, Willner+04, Peletier+12, Meidt+14, Querejeta+14:
old stars \Rightarrow [3.6]-[4.5]<0
dust \Rightarrow [3.6]-[4.5]>0
- S⁴G pipeline 5: mass maps for >1500 nearby galaxies (*public on IRSA!* Querejeta+14)

Feeding the Nucleus: Gravitational Torques Acting on Gas

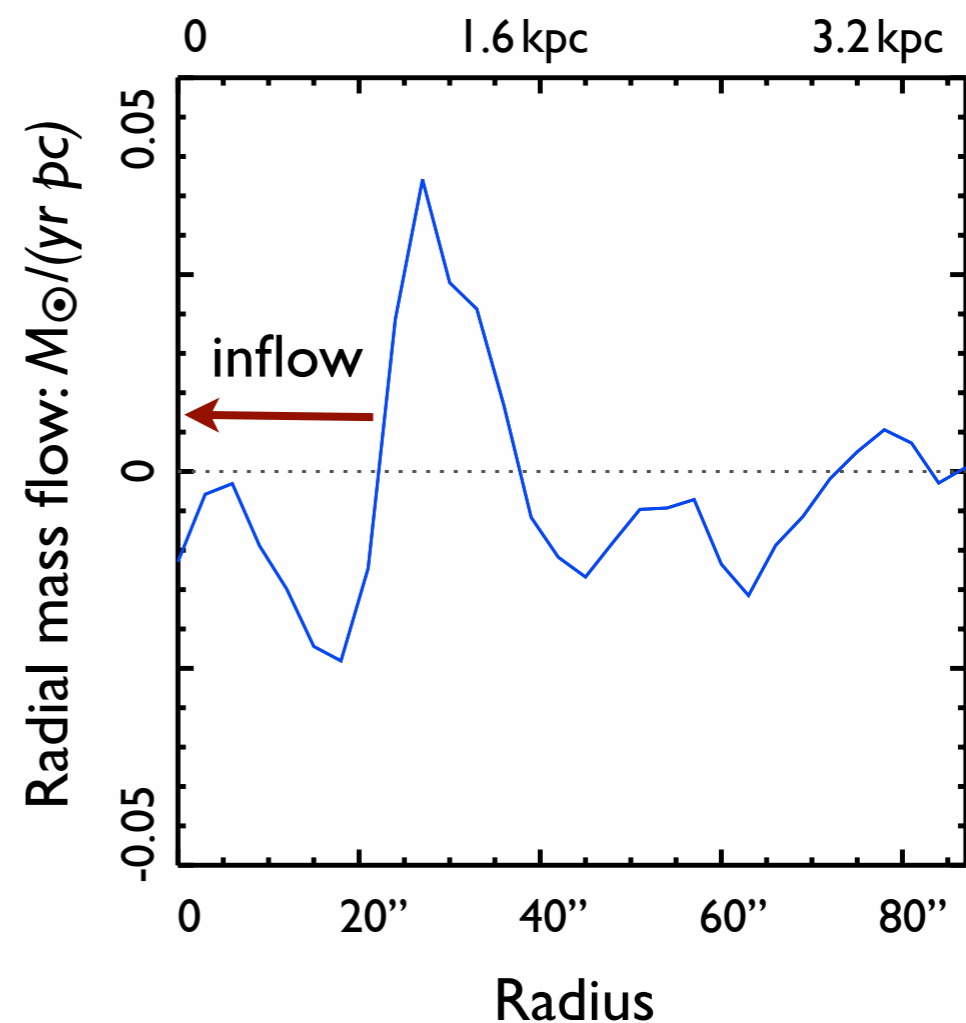
- Correct 3.6 μm image for dust emission: retrieve 2D stellar mass distribution



Feeding the Nucleus: Gravitational Torques Acting on Gas

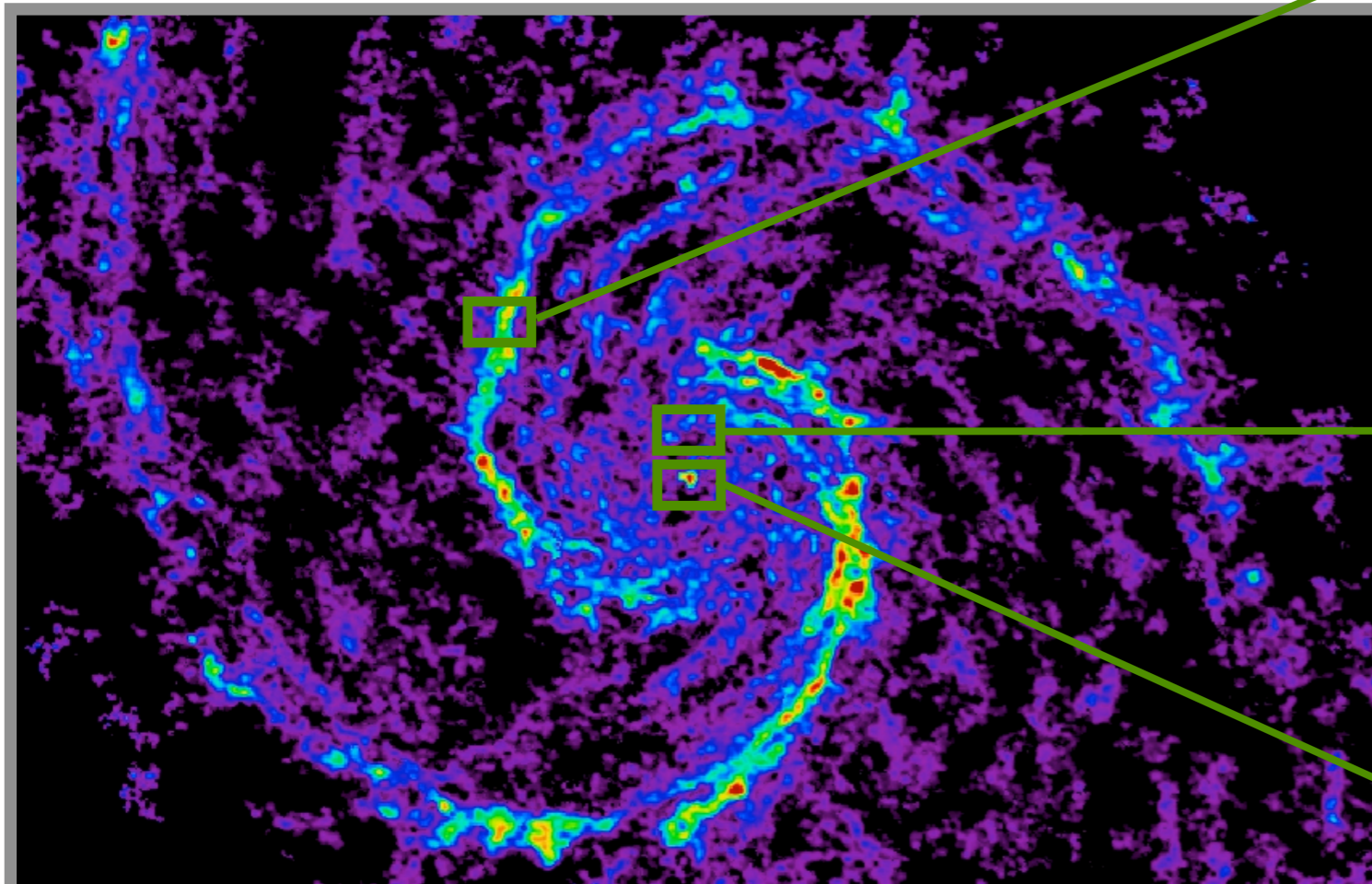


- Azimuthal average of the torques (weighted by the molecular gas):
García-Burillo+05, Haan+09
- Molecular gas (radial) inflow: $\sim 1 M_{\odot}/\text{yr}$
- Evidence for AGN feeding at present

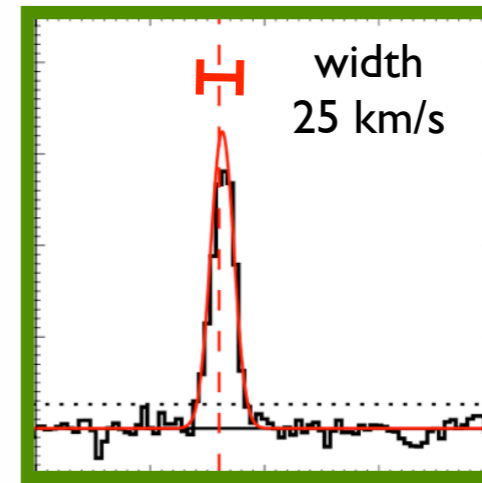


AGN impact on molecular gas

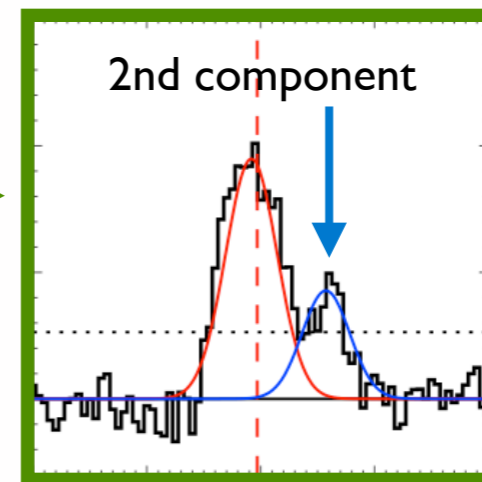
- Broad and multiple CO lines near nucleus



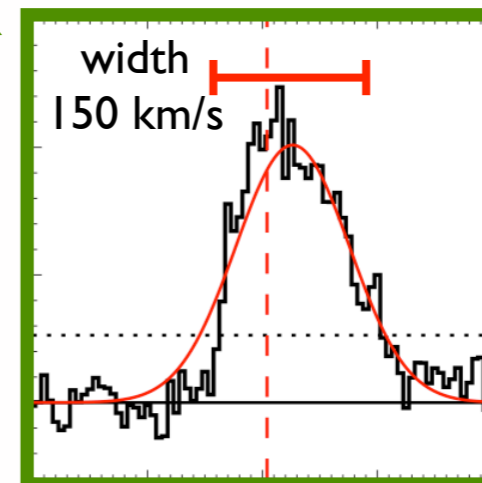
PAWS: M51 in CO(1-0), 1''



Typical disc line



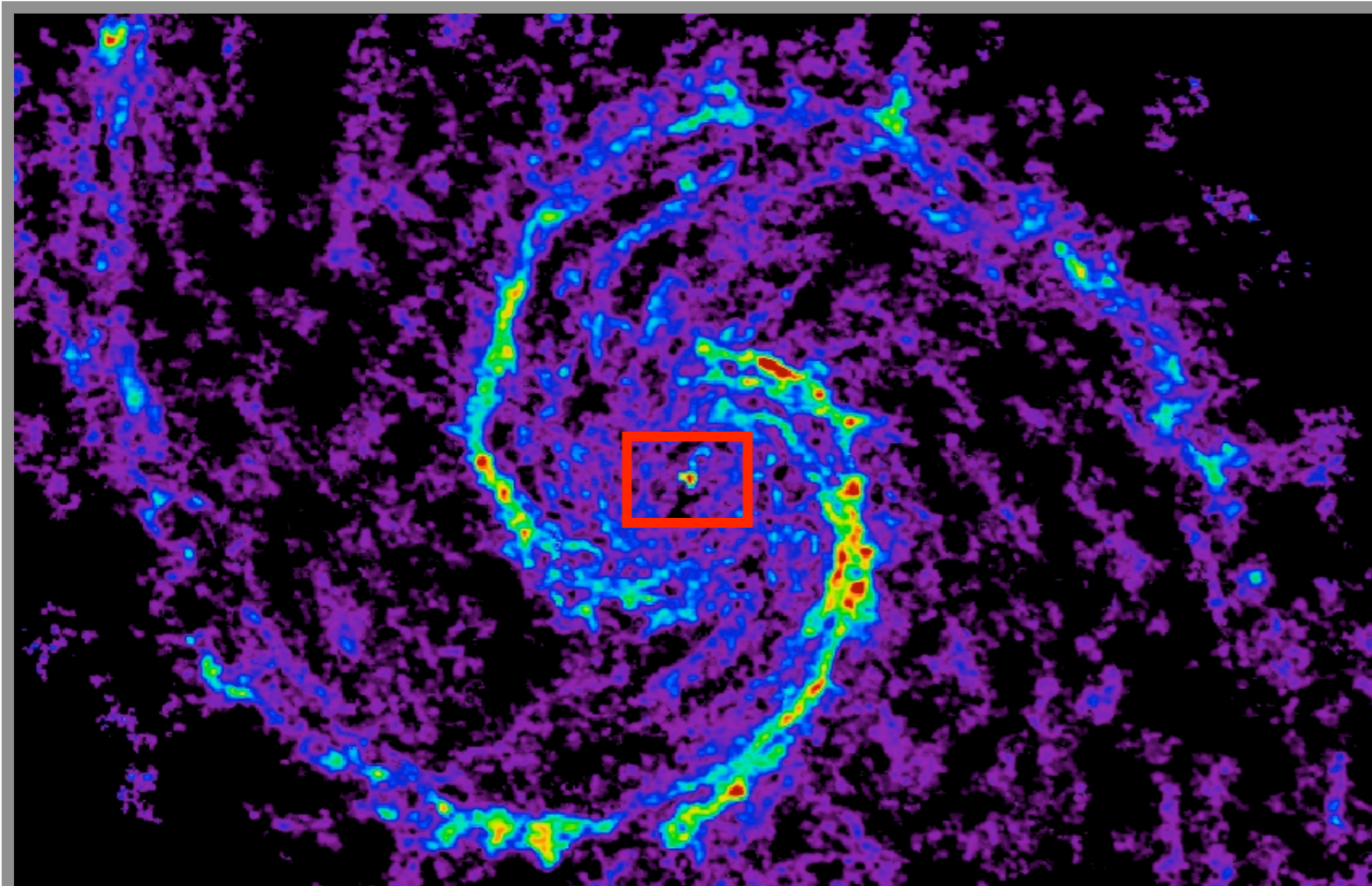
2nd component north of nucleus



Broad line at nucleus

AGN impact on molecular gas

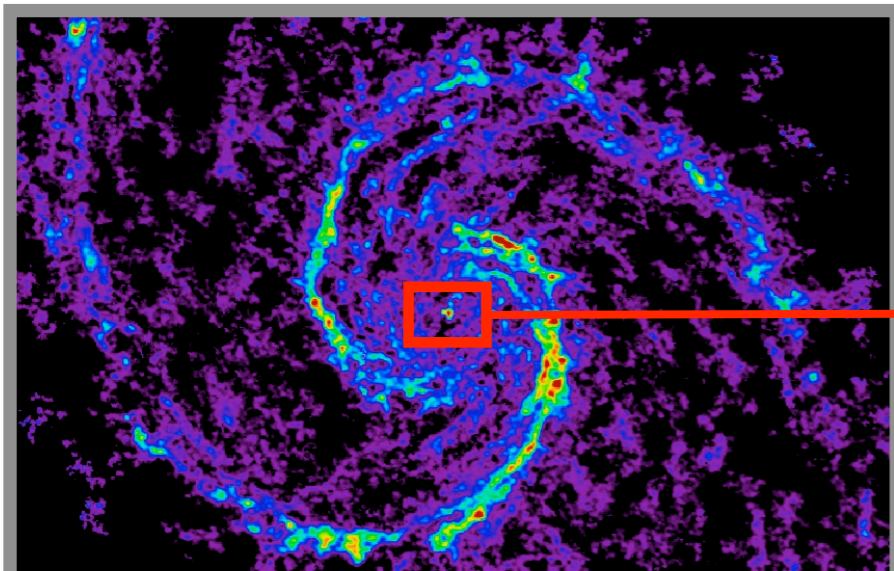
- Zoom on the nuclear M51 area



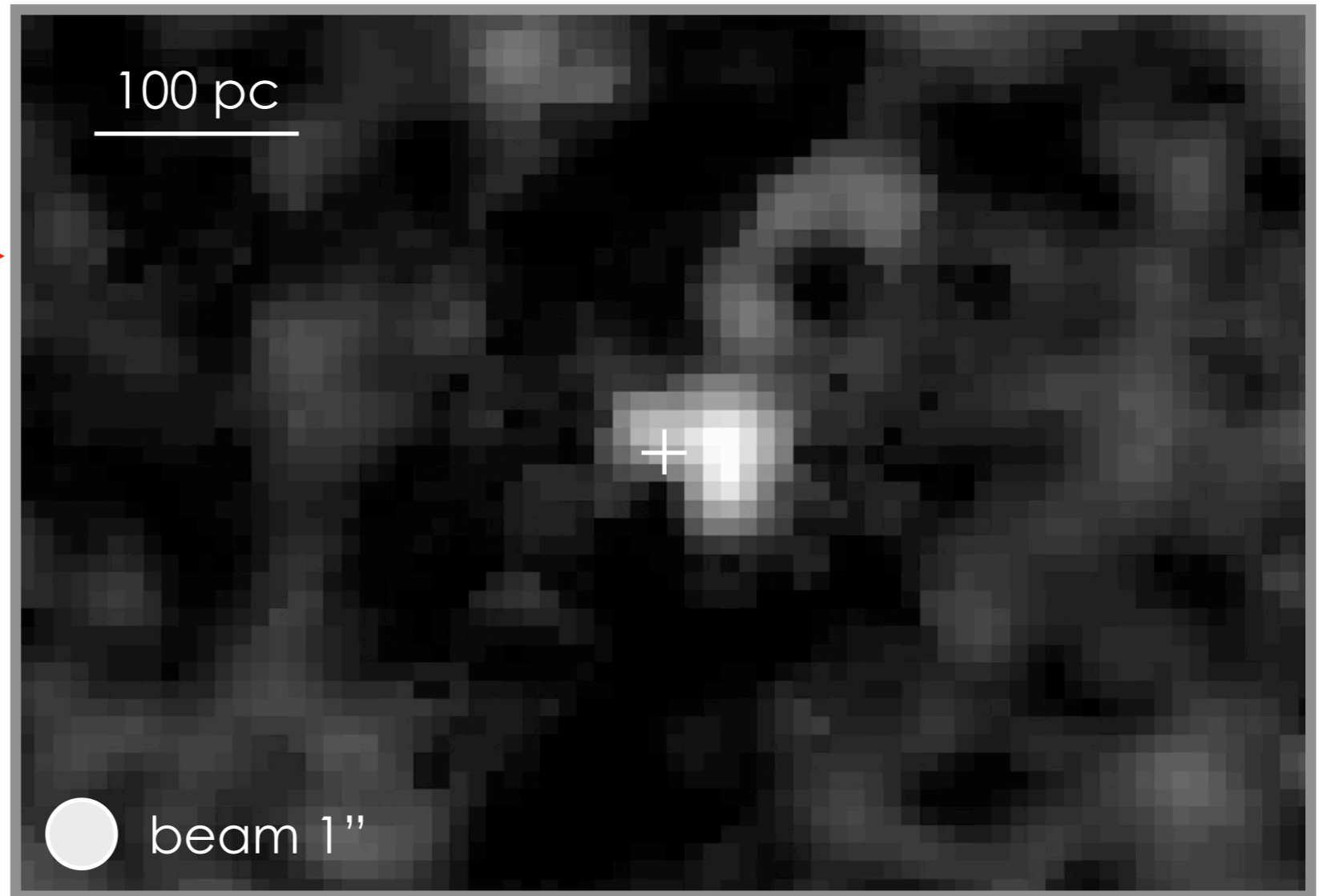
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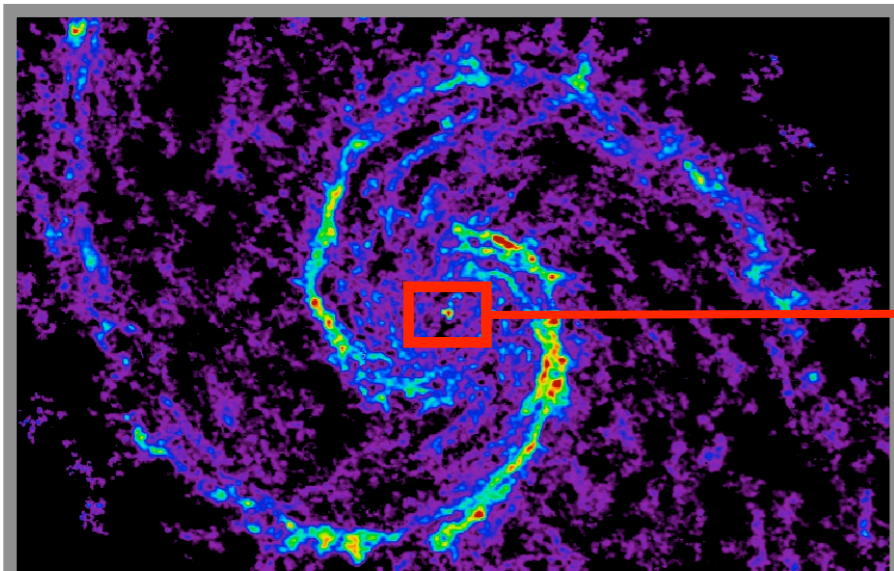


100 pc

beam 1''

AGN impact on molecular gas

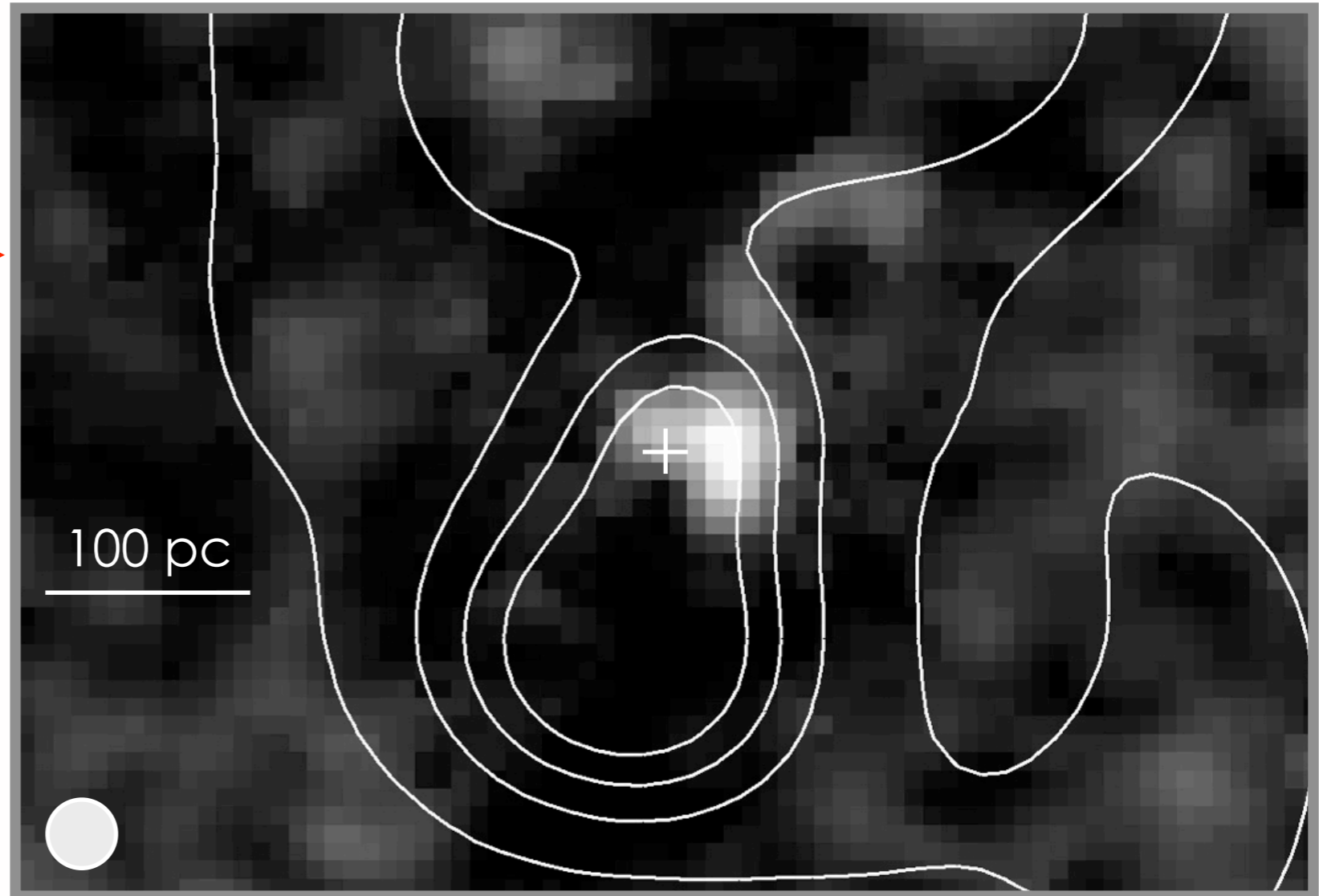
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PAWS: M51 in CO(1-0), 1''

Contours:

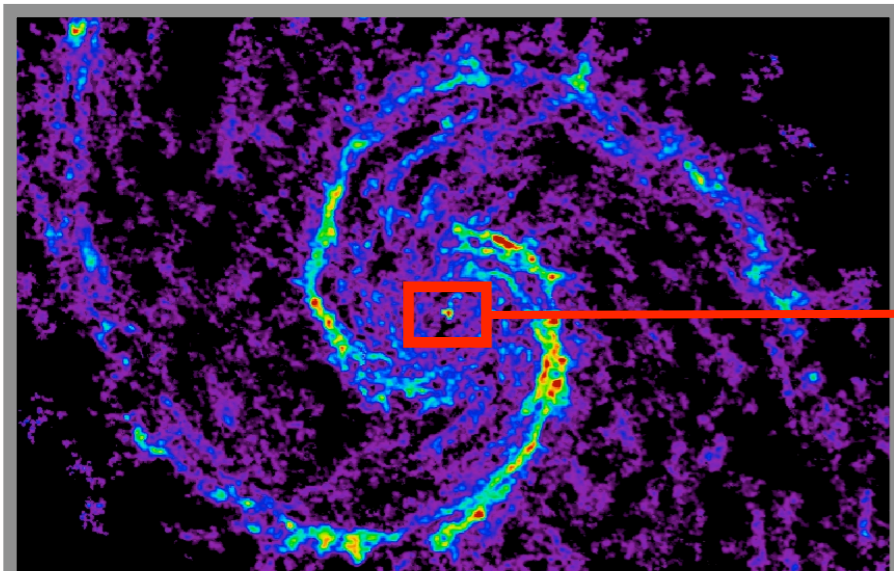
- *white*: VLA 3.6cm



Dumas+11

AGN impact on molecular gas

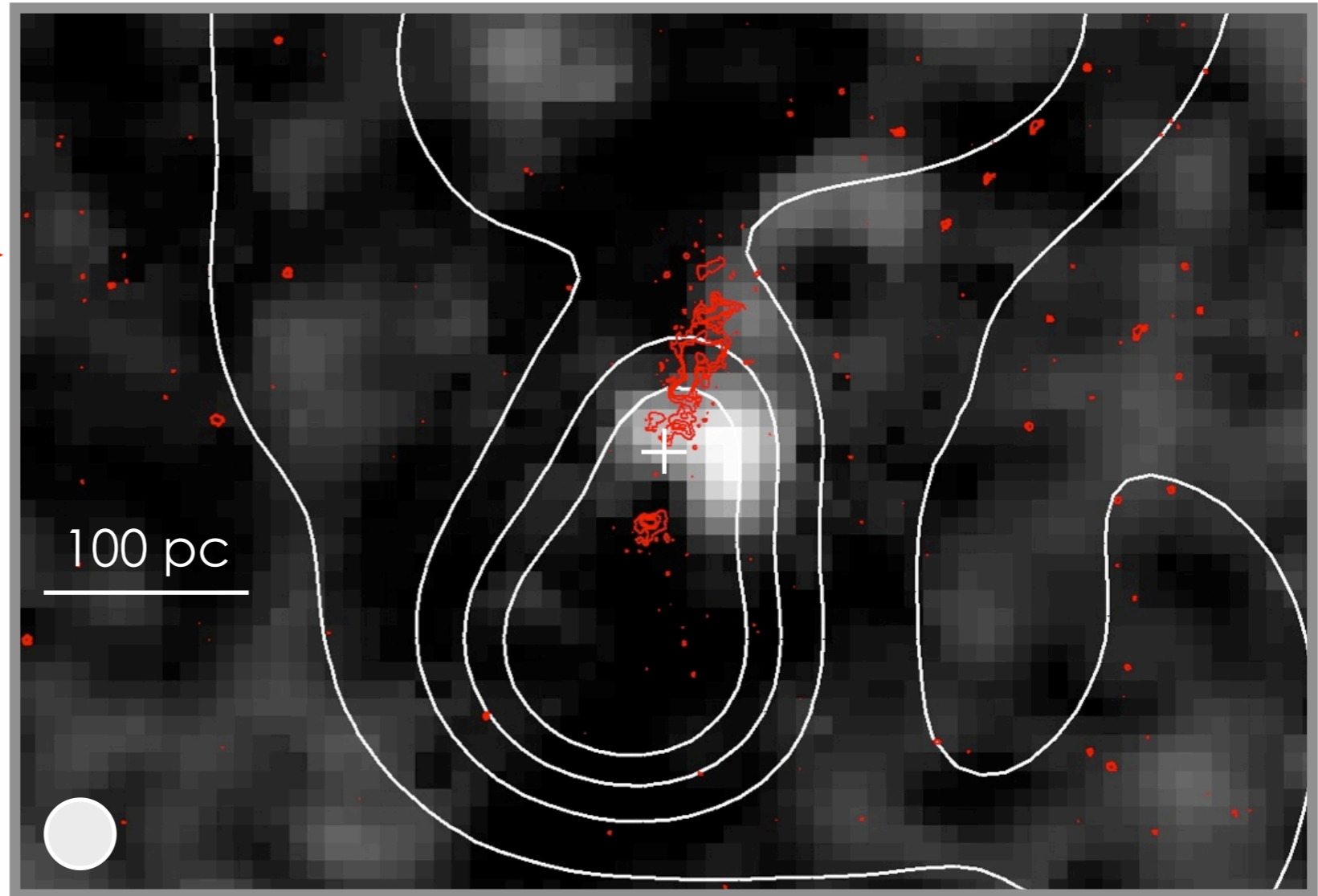
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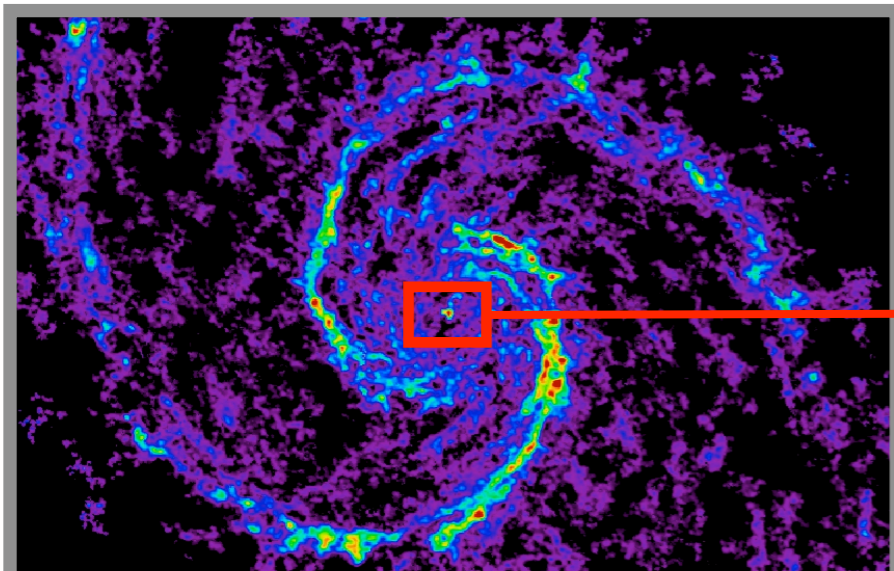
- *white*: VLA 3.6cm
- *red*: [OIII], HST/WFPC2 F502N



Dumas+ I I, Bradley+04

AGN impact on molecular gas

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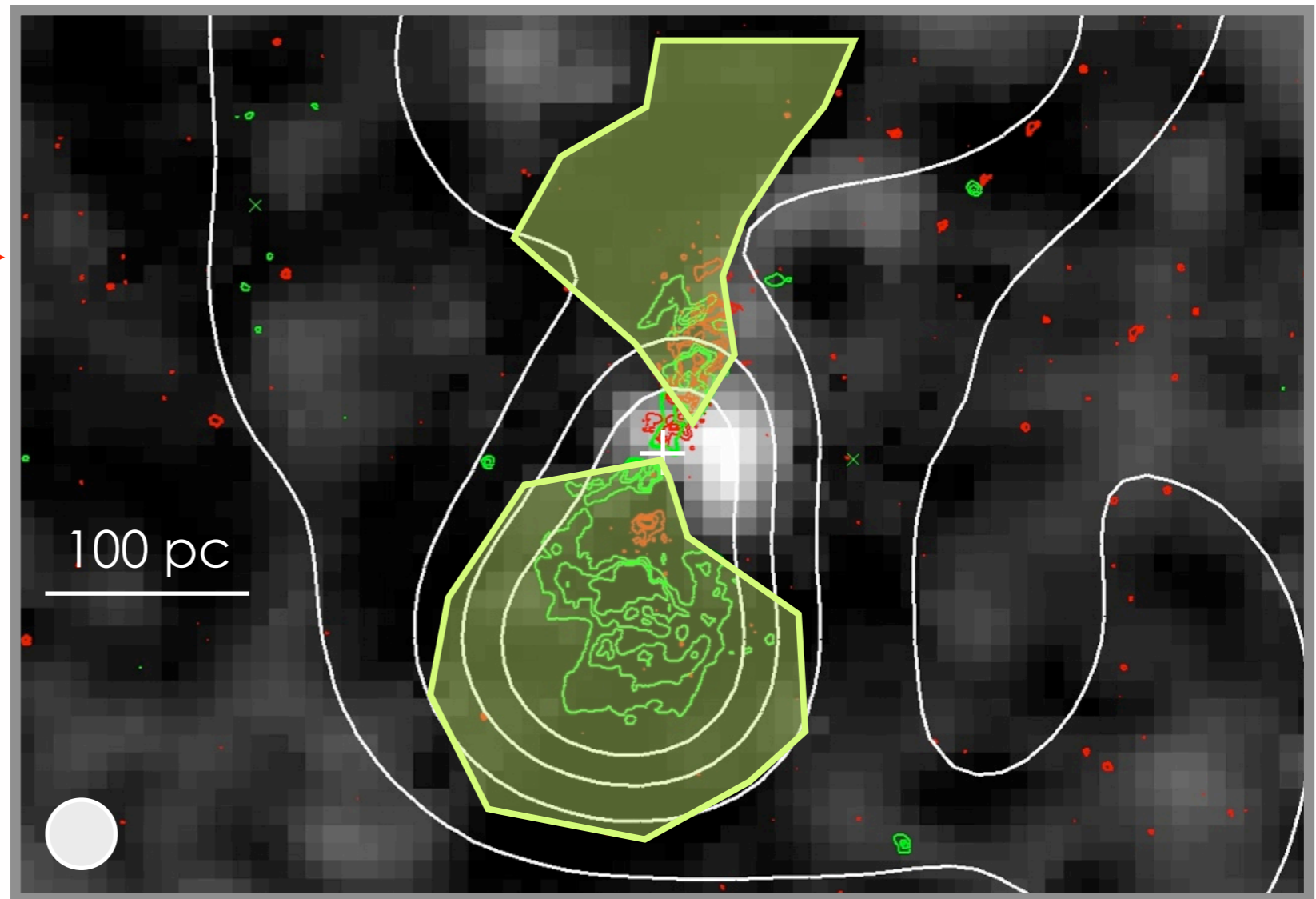


PAWS: M51 in CO(1-0), 1''

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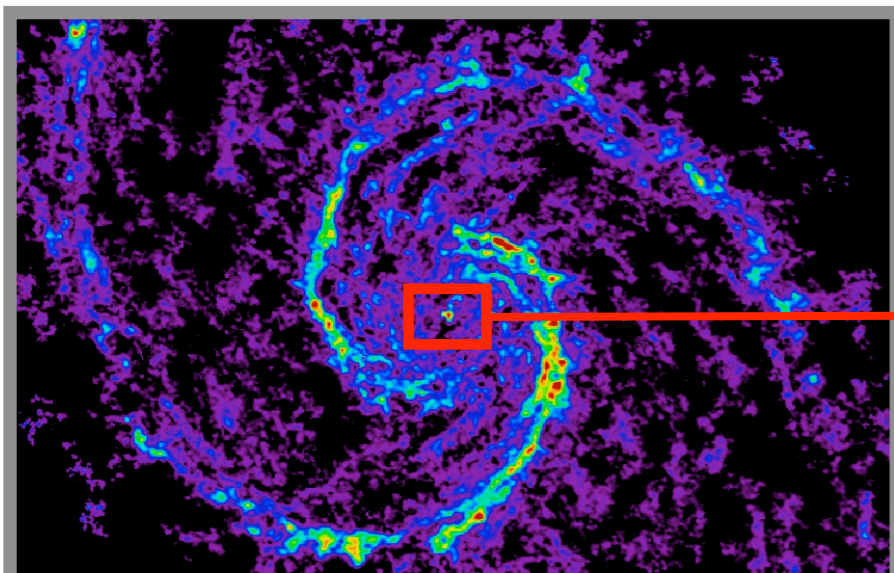
- *white*: VLA 3.6cm
- *red*: [OIII], HST/WFPC2 F502N
- *green*: H α , HST/WFPC2 F656N

Dumas+11, Bradley+04

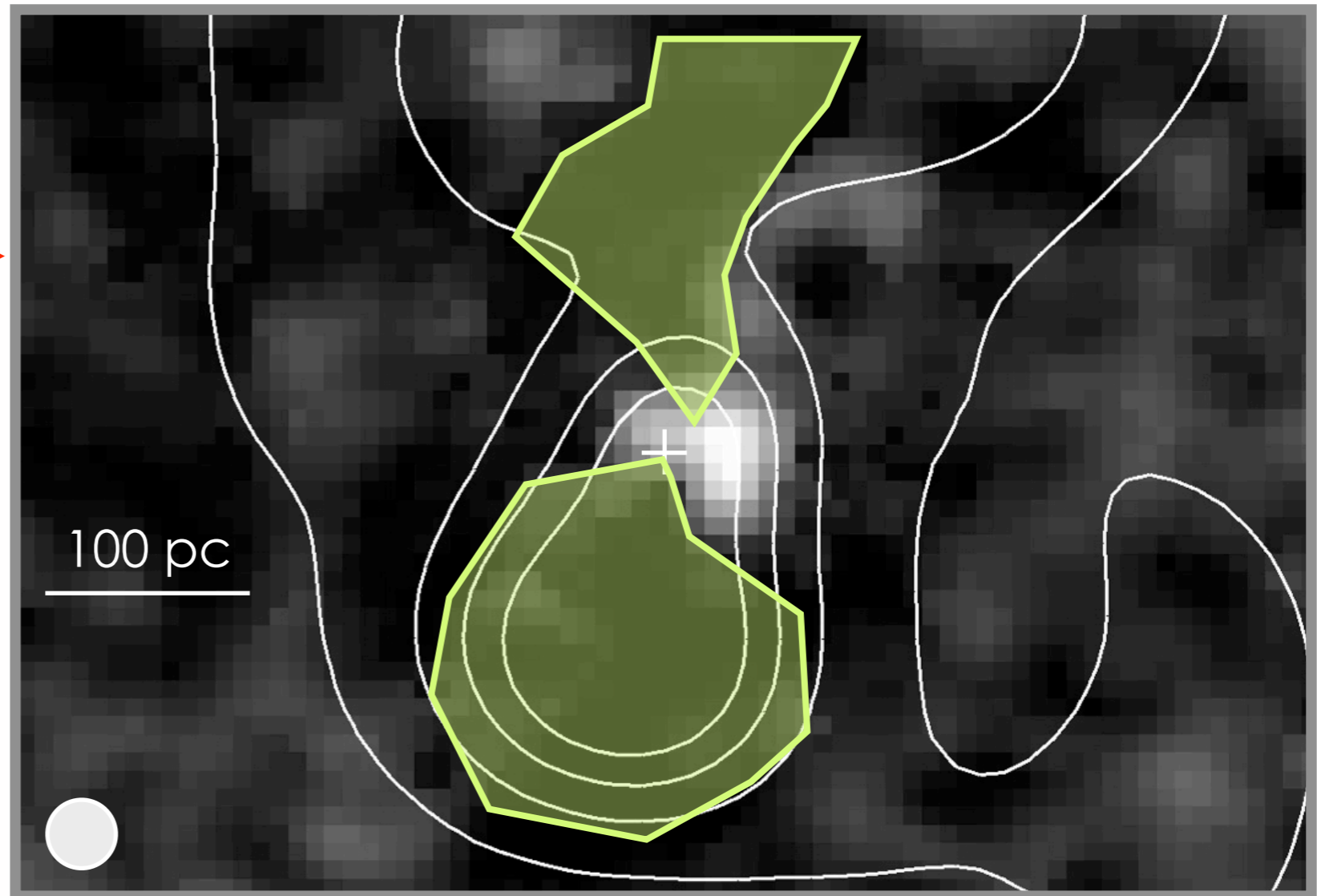


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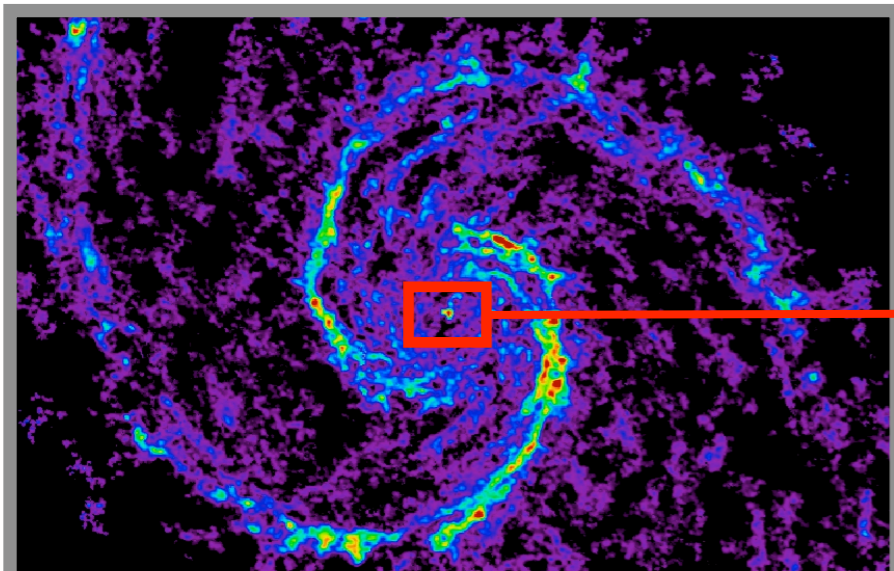


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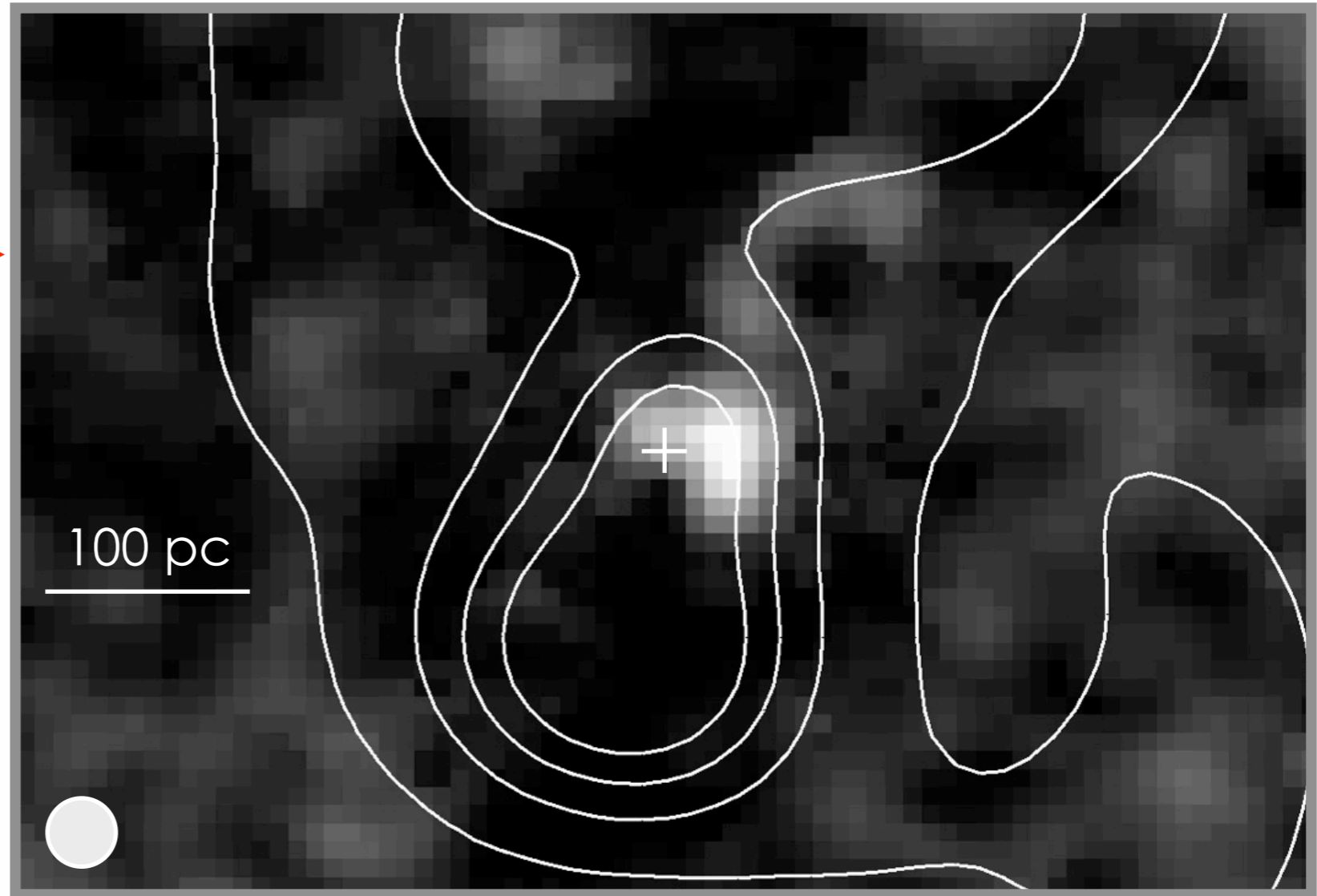


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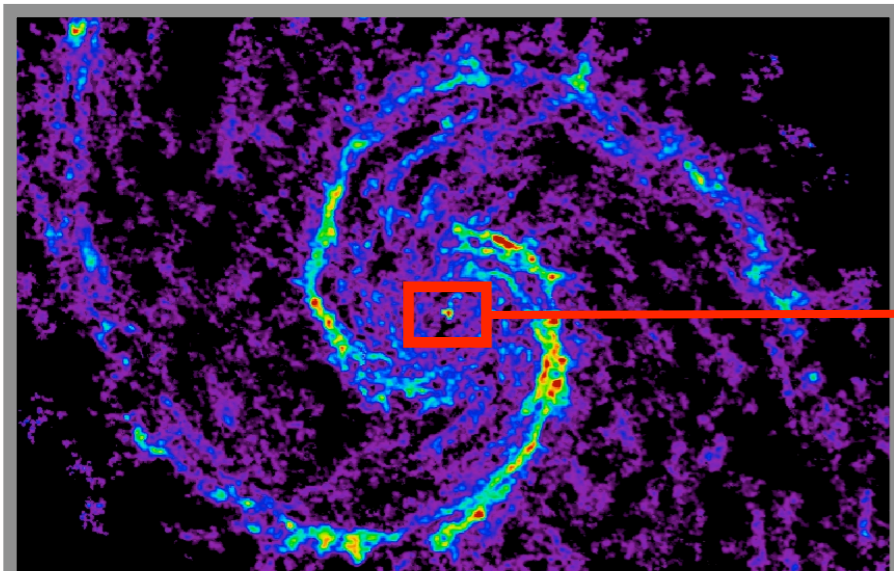


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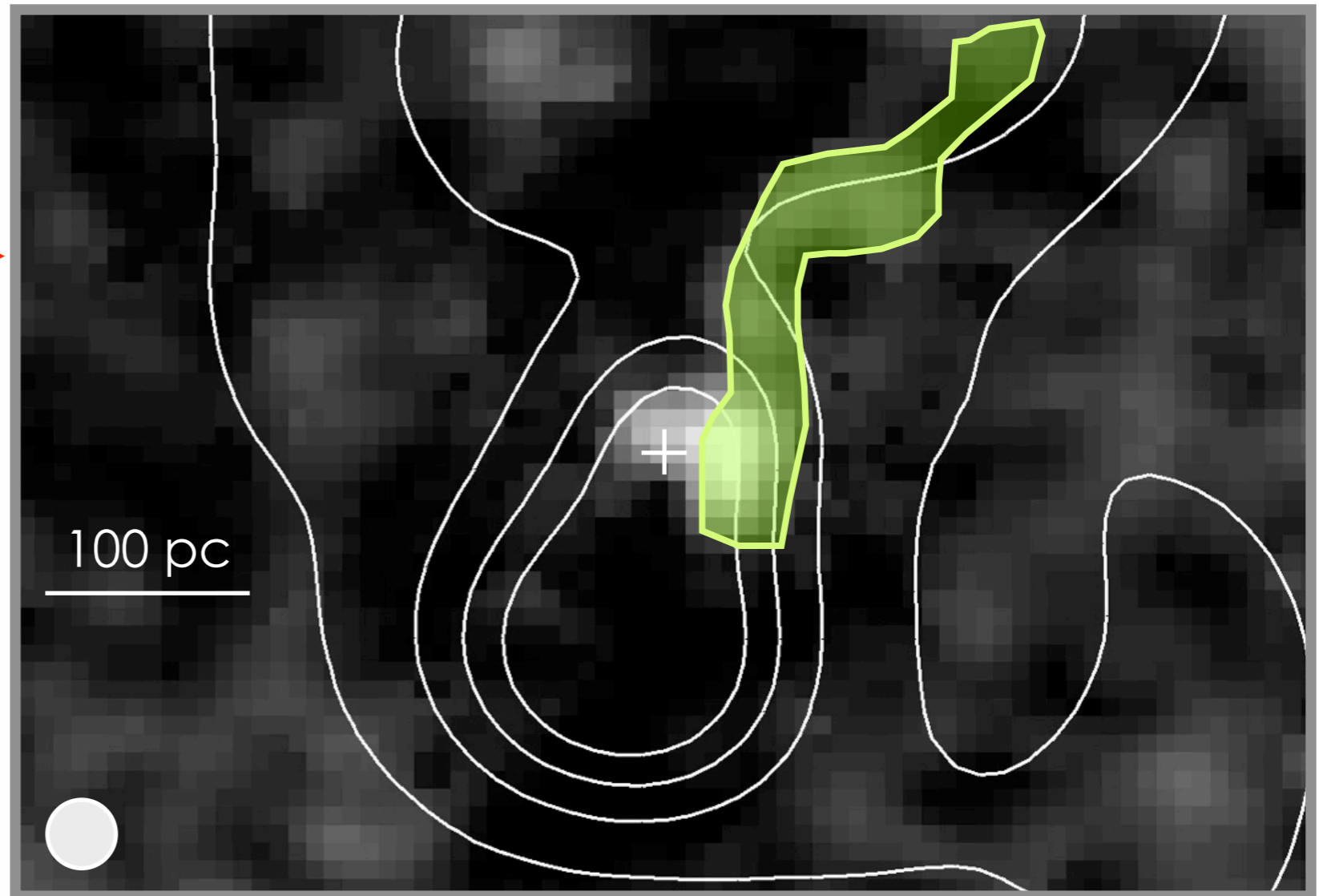


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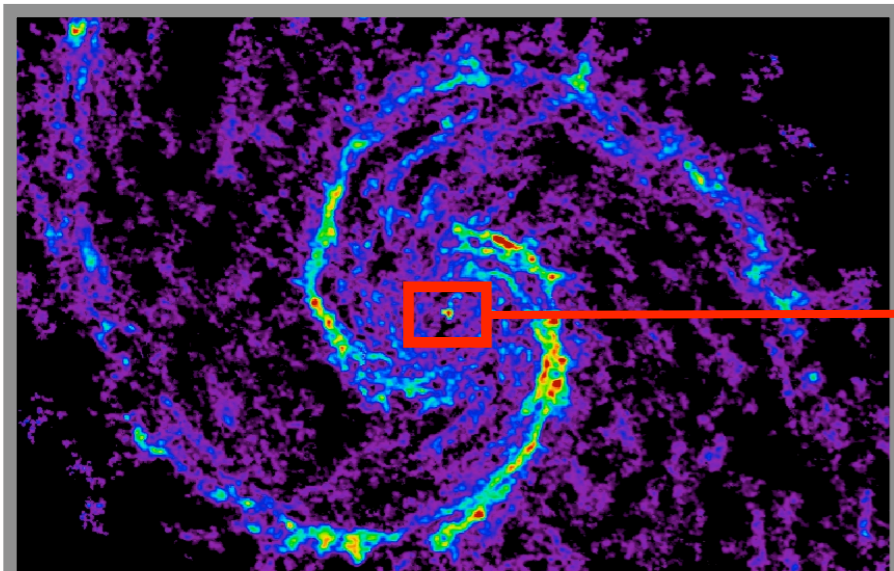


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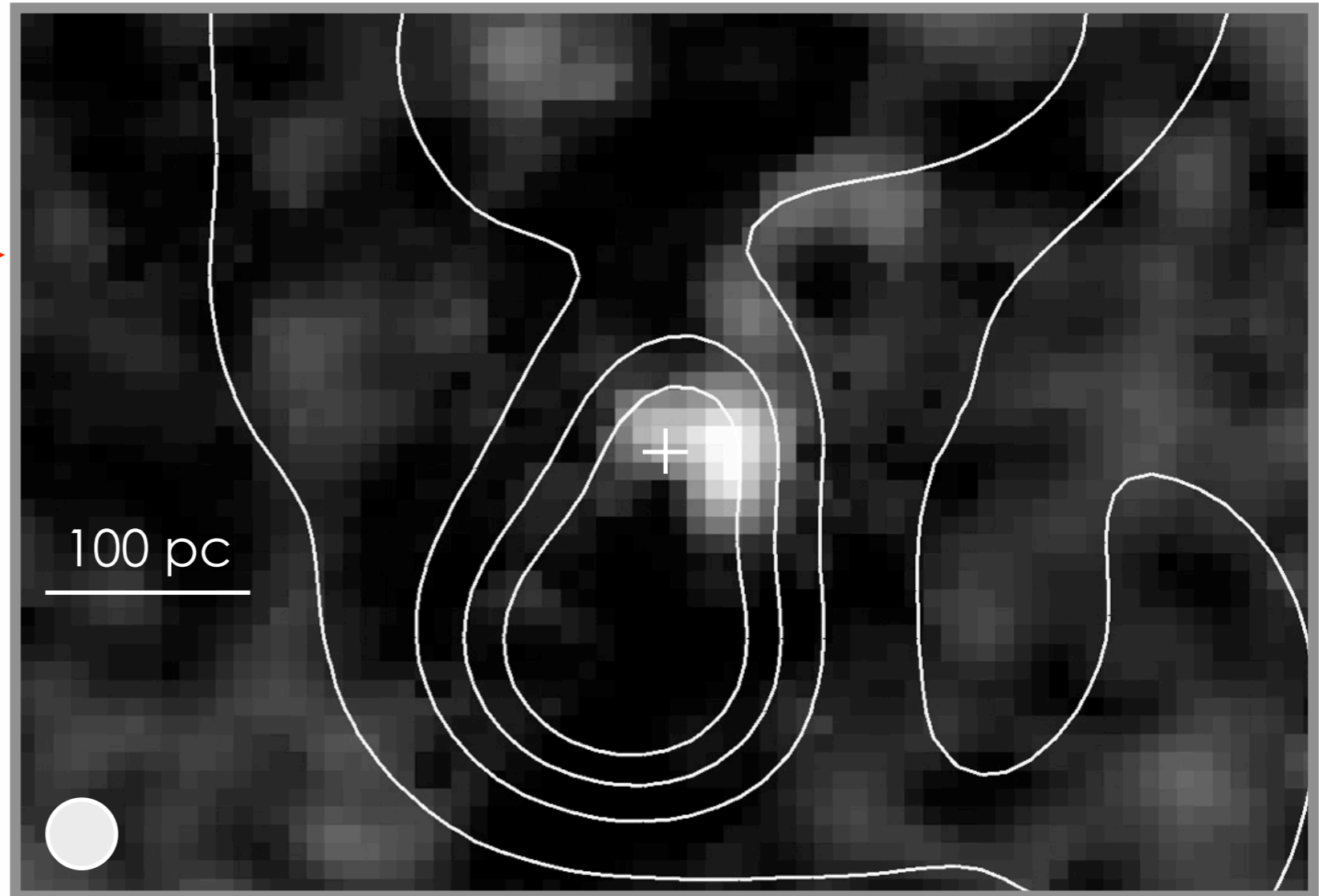


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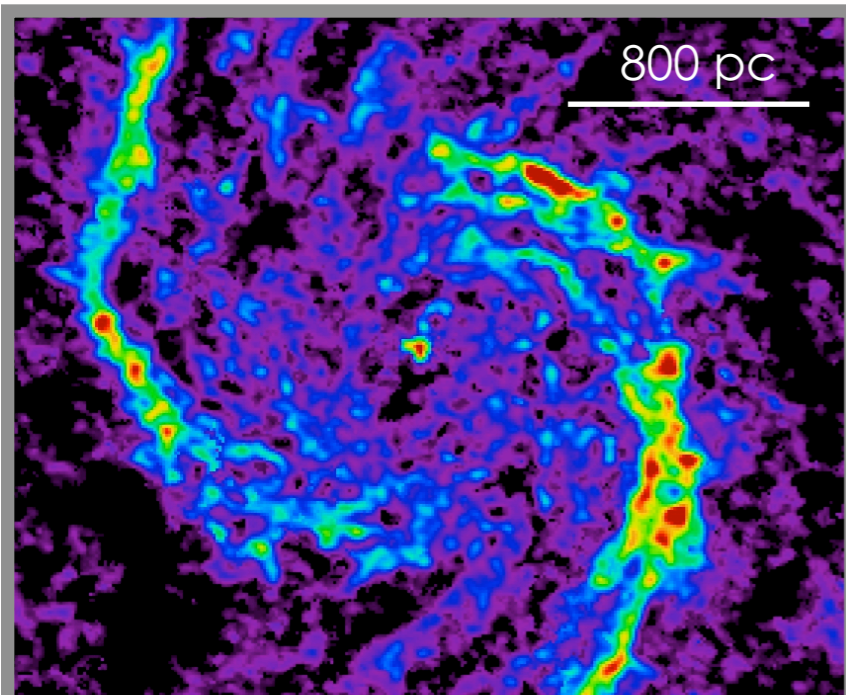


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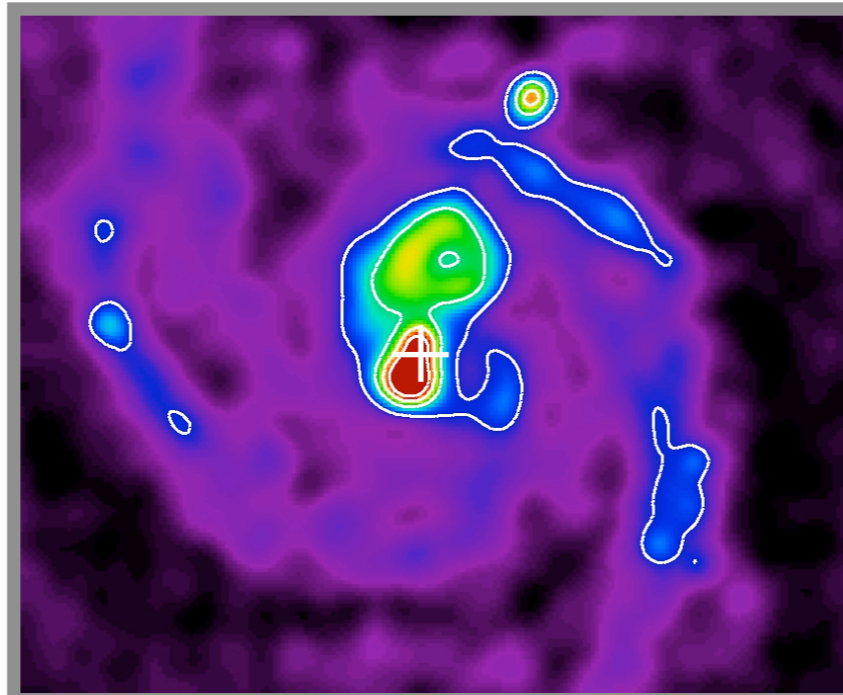


New observations of M51 with dense gas tracers

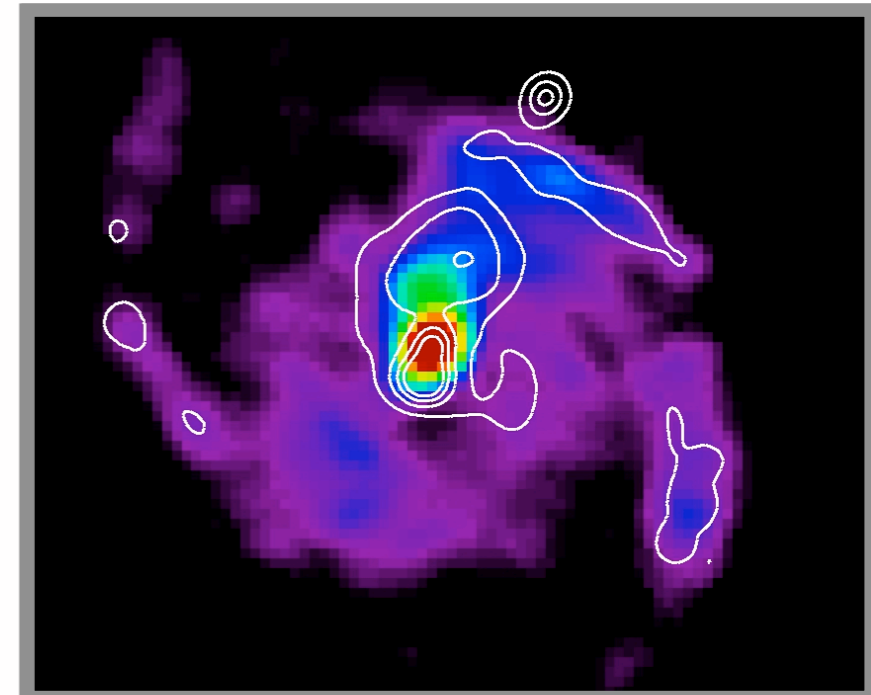
- New observations of central $R=1$ kpc with dense gas tracers
- Plateau de Bure Interferometer + 30m (short spacings); 4'' resolution (natural)



PAWS: M51 in CO(1-0), 1''



M51, VLA 3.6cm

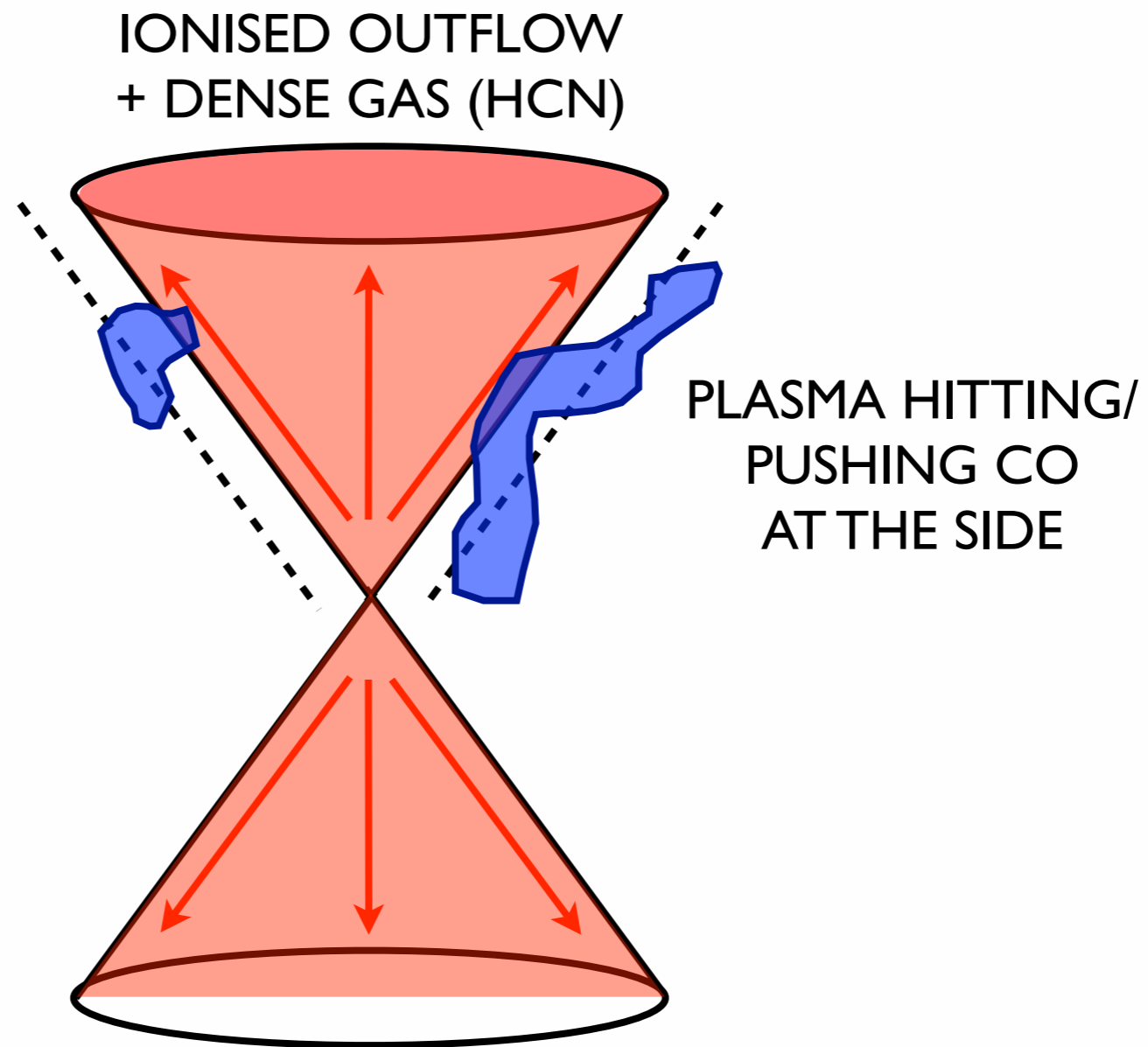


HCN, PdBI+30m, 4''

- Dense molecular gas closely follows 3.6cm distribution
- Line ratios (CO, HCN, HNC, HCO⁺) will provide some constraints on chemistry

Geometry: working hypothesis

- Ionisation cone rather depleted of CO, but plenty of HCN emission: *stratification*



Conclusions

- 1) Gas inflow in the central kpc of M51
- 2) Biconical CO outflow not applicable to M51
- 3) Dense gas emission closely related to radio continuum
- 4) Radio plasma driving stratified molecular outflow, not radiation pressure