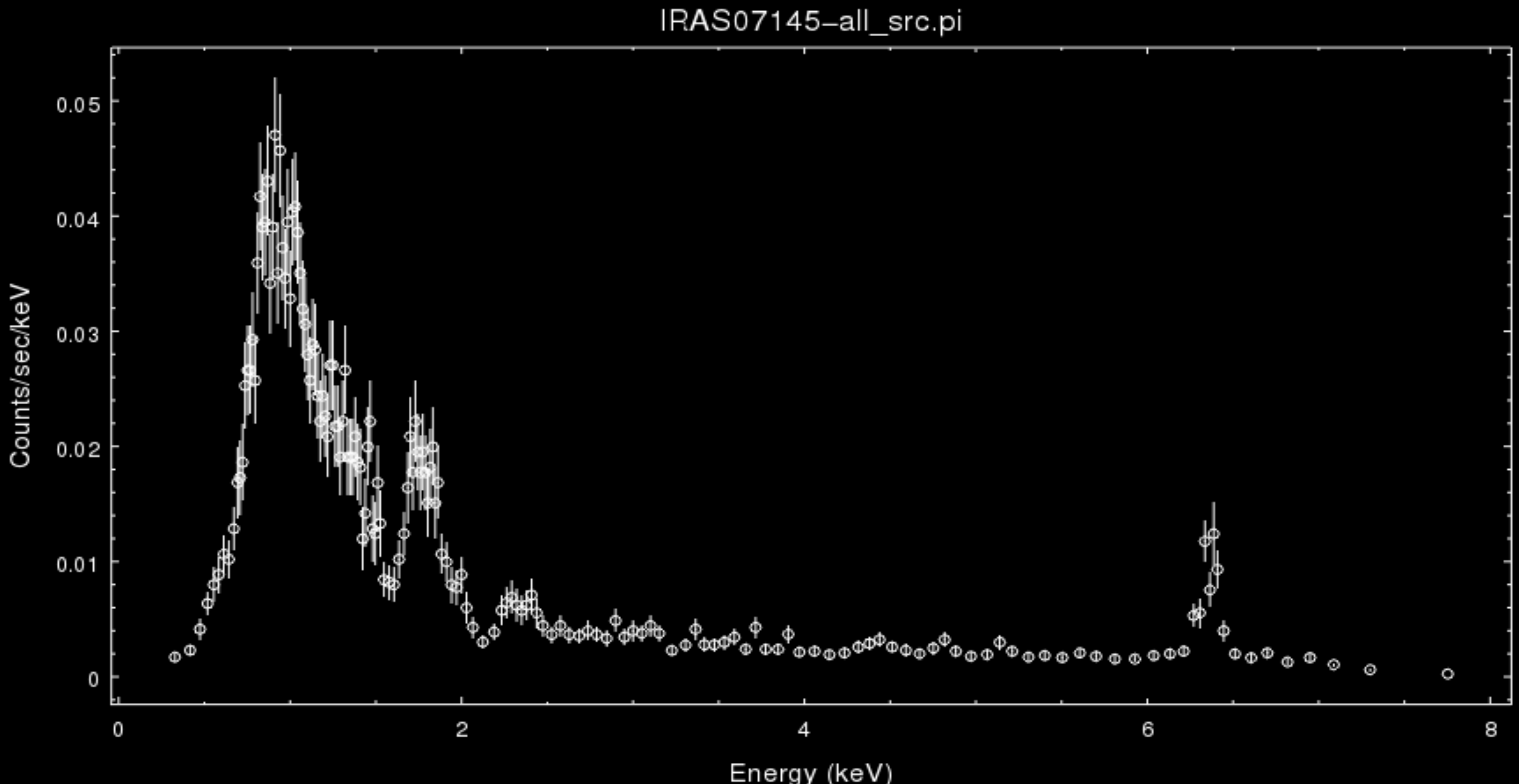
3D feeding & feedback in obscured AGN

Joining Chandra - ALMA - SINFONI & MUSE/VLT to understand kinematics, inflows/outflows, obscuration, from kpc-scale down to the nucleus

C. Feruglio
thanks to:
Pepi Fabbiano - Manuela Bischetti - Martin Elvis - Alessandro Marconi - FF, EP, et al.

Chandra ACIS X-ray spectrum of CT AGN ESO428-G14



Soft line emission
OVII, OVIII, NeIX,
MgXI, SiXIII, etc.

Hard continuum

Fe K lines
Neutral and Fe XXV

Courtesy P. Fabbiano

Fabbiano et al 2017, 2018a, 2018b, ApJ

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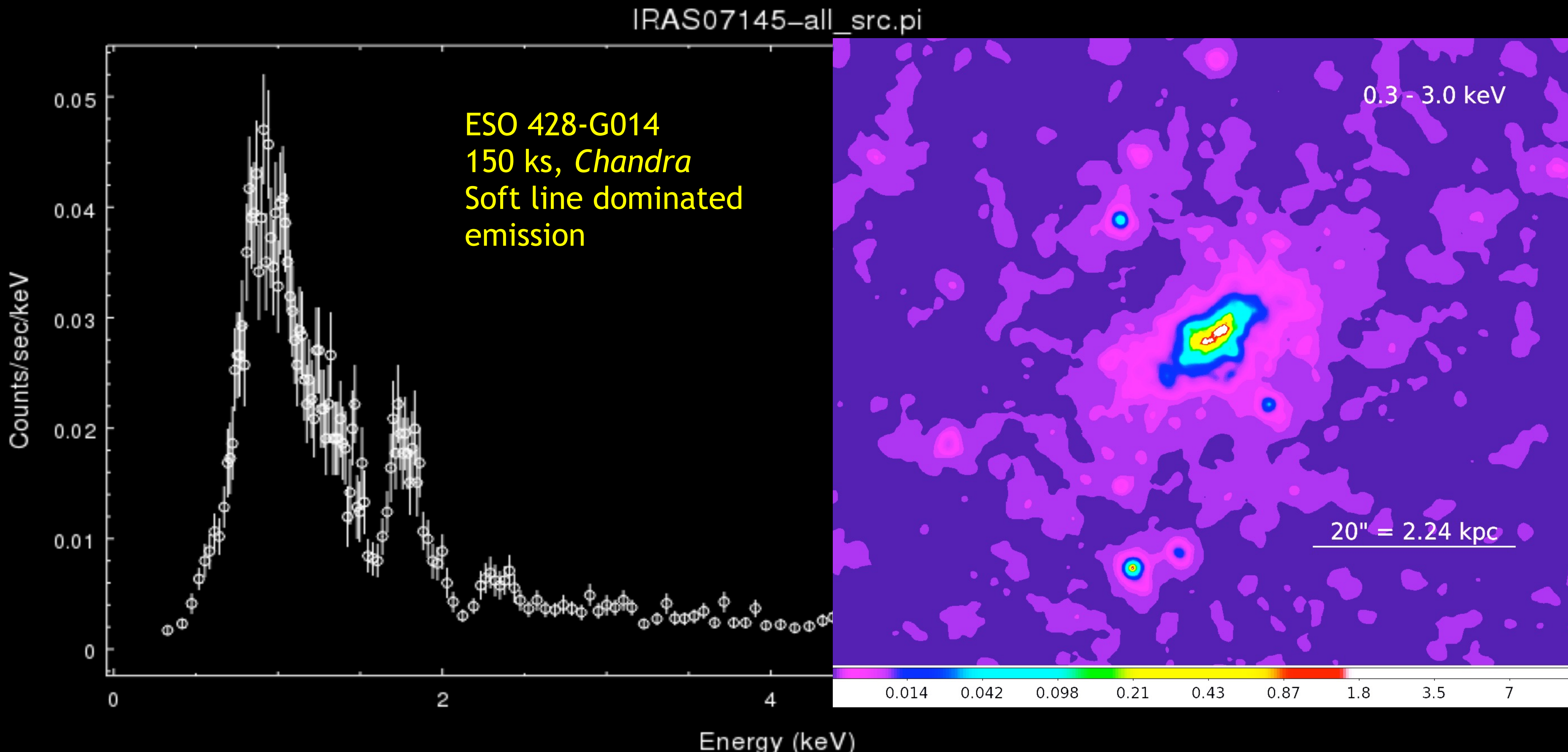

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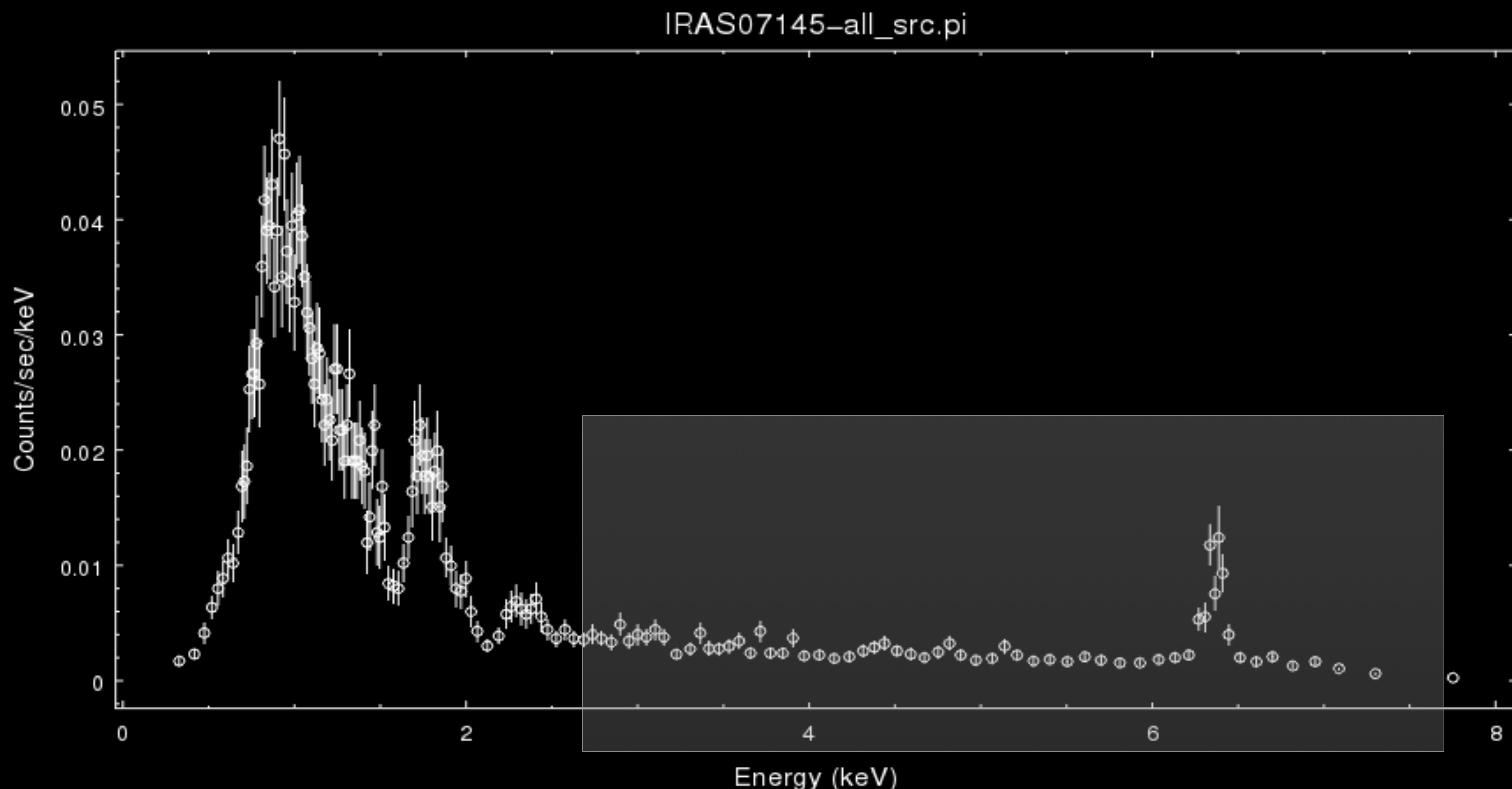

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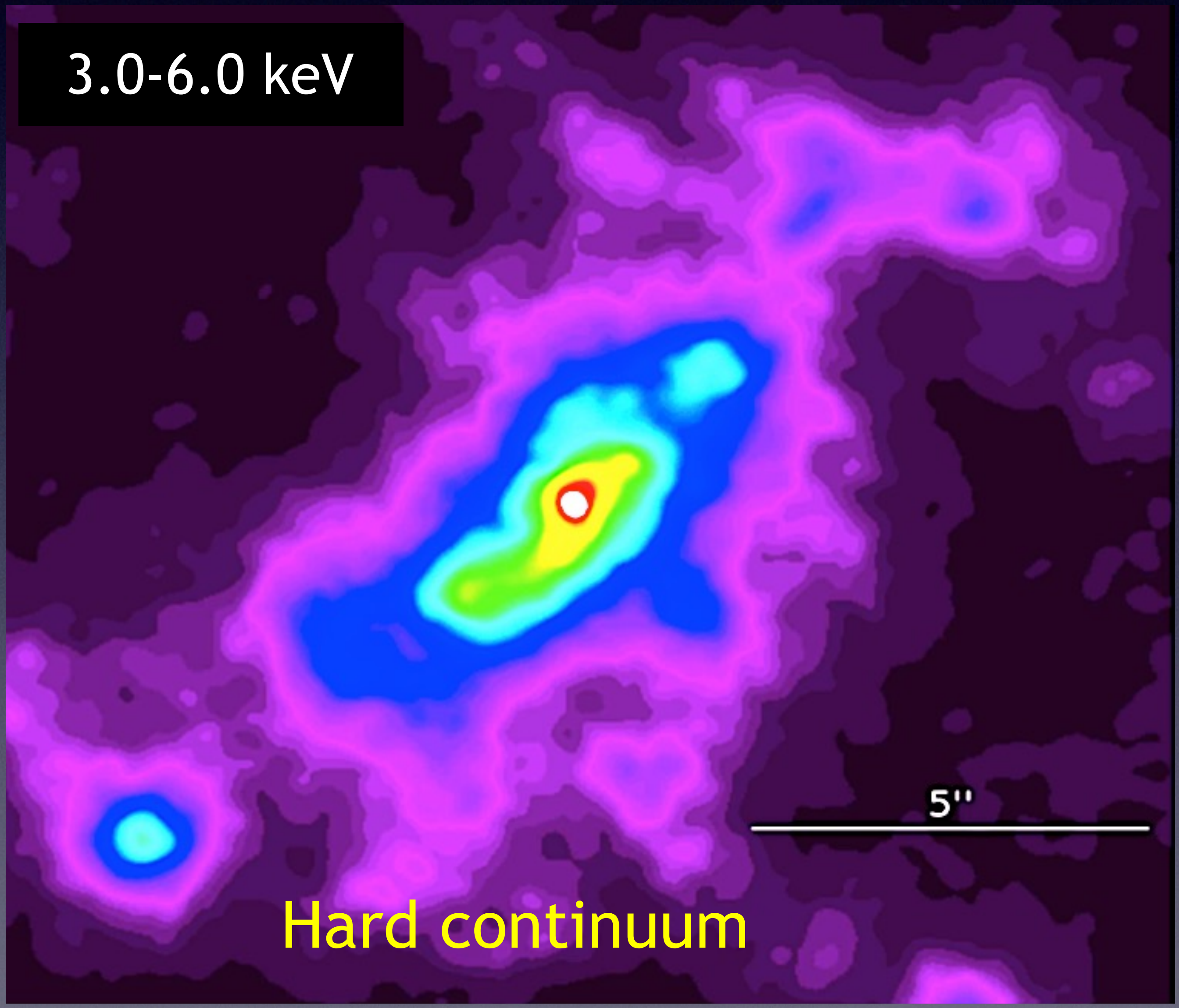
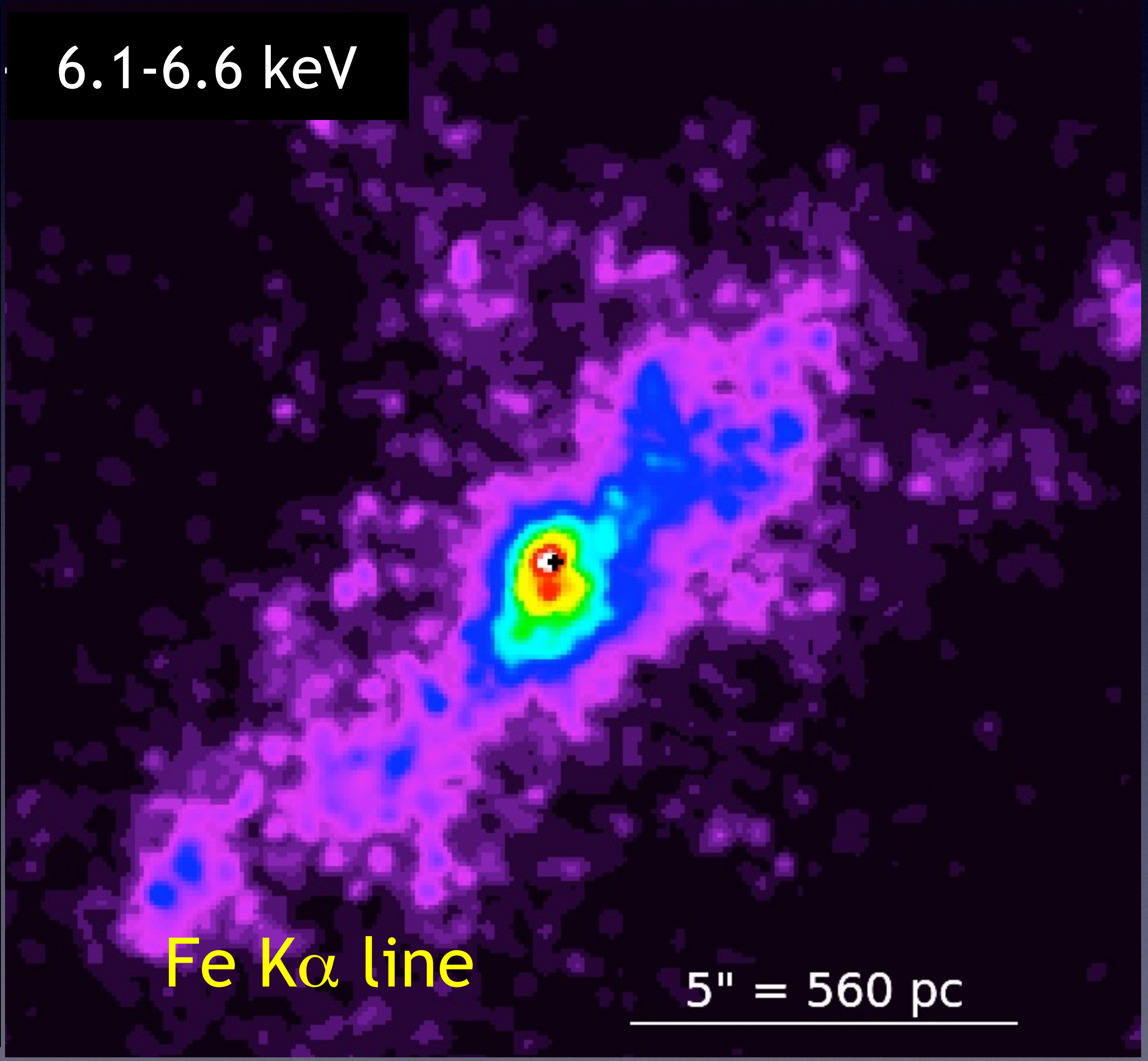
ESO 428-G014

Chandra ACIS S
T_{exp} ~154 ks

>2 kpc-scale hard continuum and ~ 1 kpc Fe Kα line emission

Counts in extended component (1".5 – 8" annulus) are 30 % of counts in r < 1".5 (Fabbiano et al 2017, 2018a, b)





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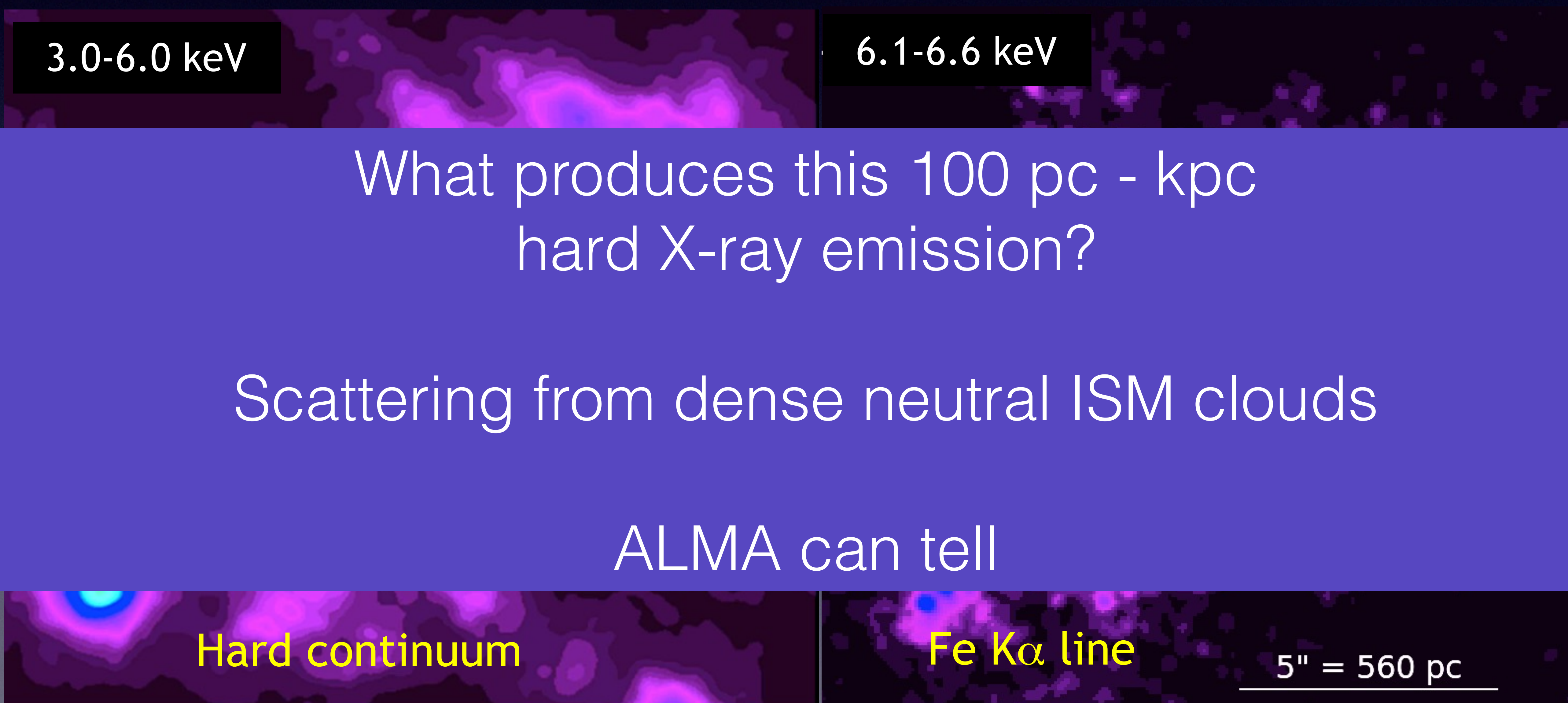


What produces this 100 pc - kpc hard X-ray emission?

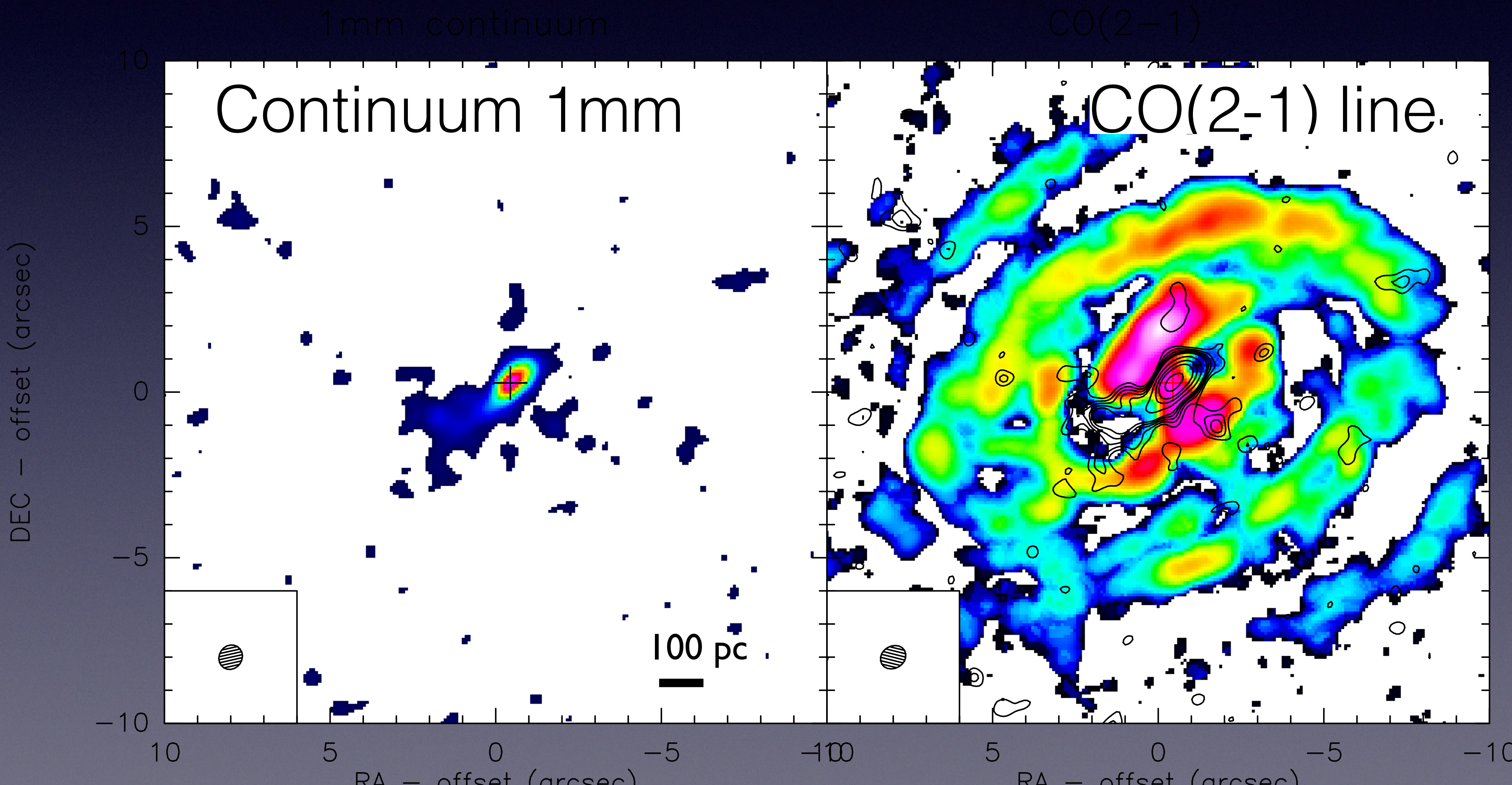
Scattering from dense neutral ISM clouds

ALMA can tell

Courtesy P. Fabbiano

ALMA maps with ~80 pc resolution

Feruglio, Fabbiano+2019, arxiv1904.01483



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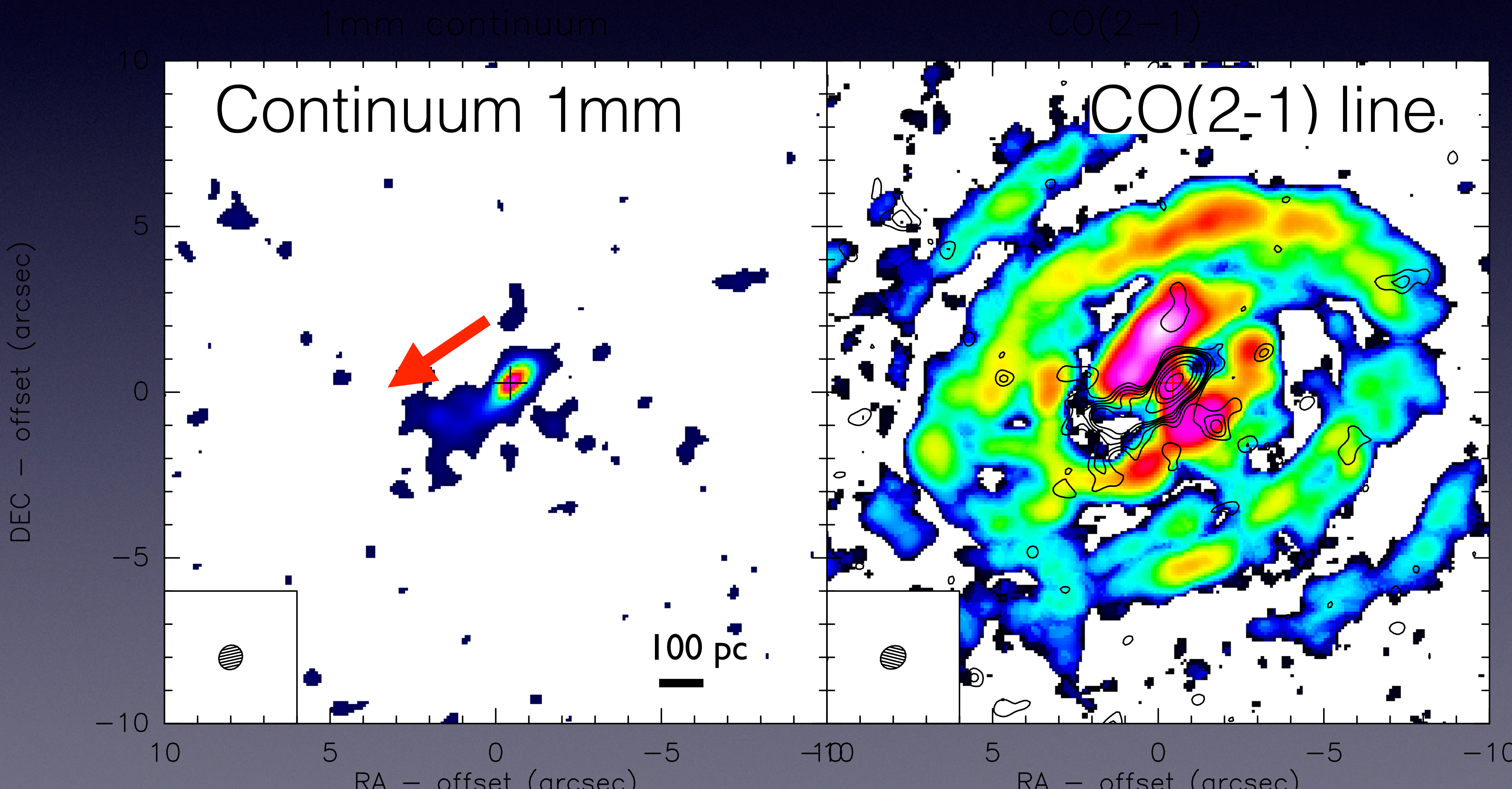
- compact continuum
- extended continuum



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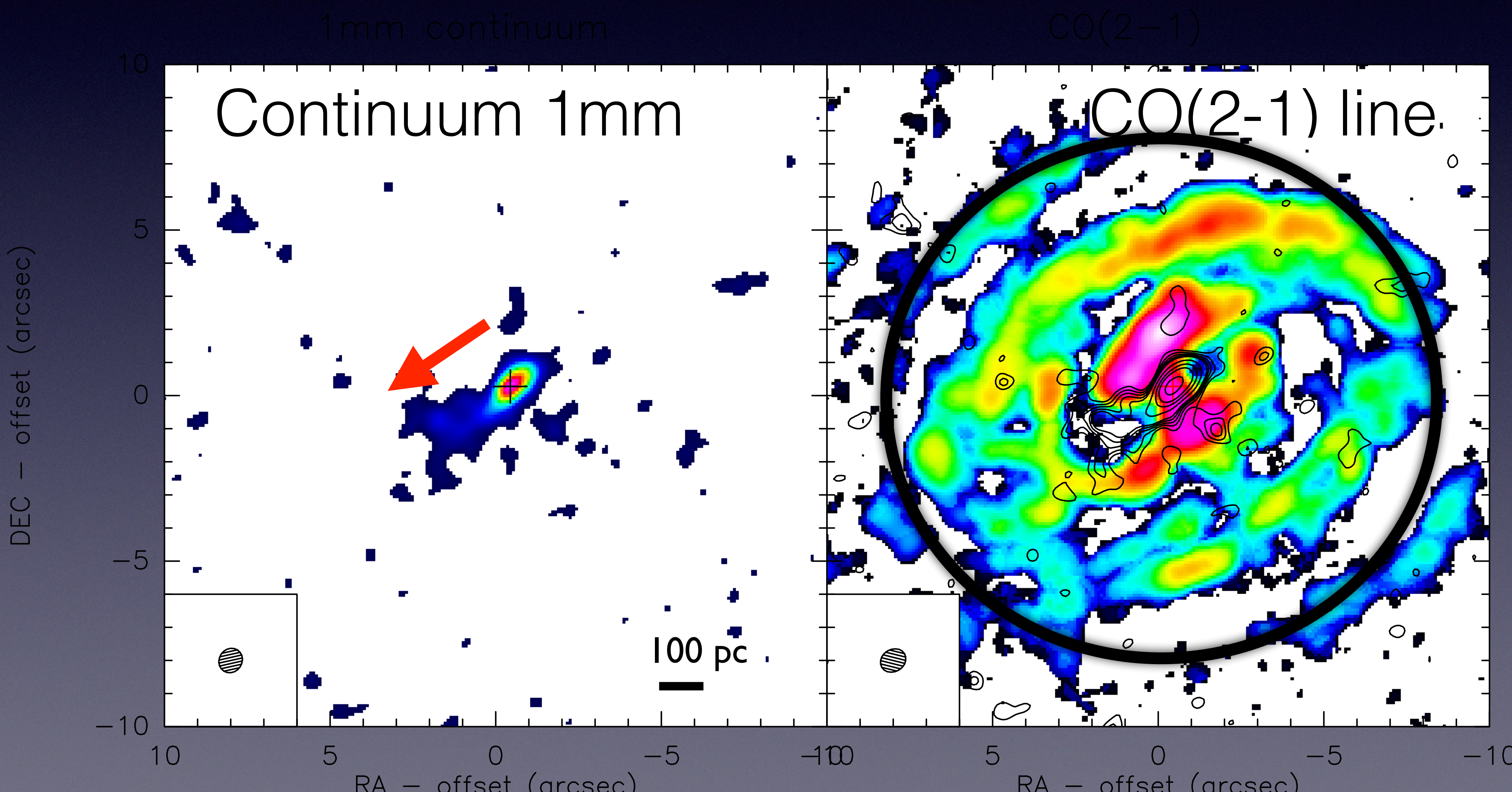
- clumpy disk

- compact continuum
- extended continuum



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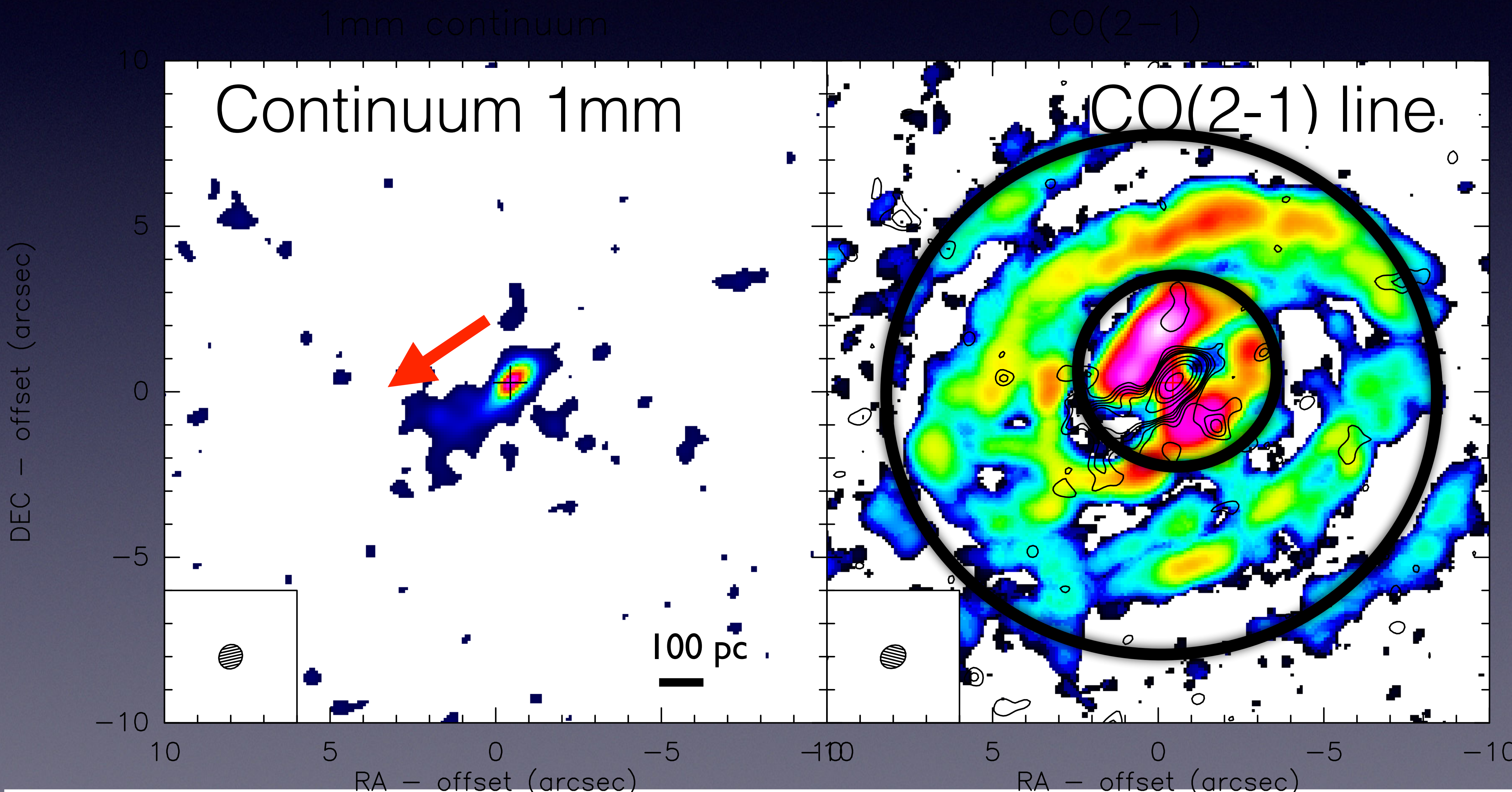
- 200 pc lopsided circum nuclear ring (CNR) - inner Lindblad resonance



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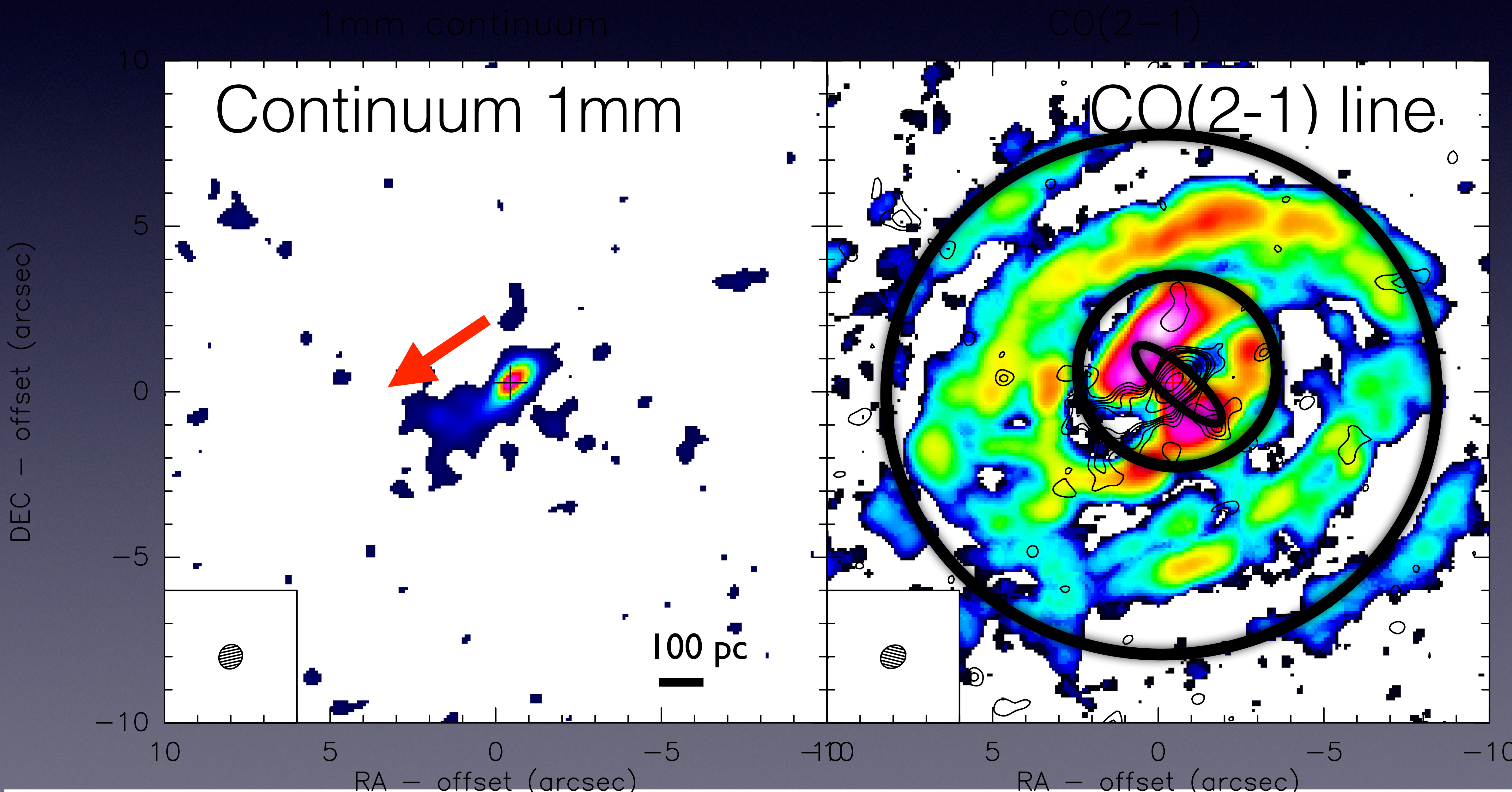

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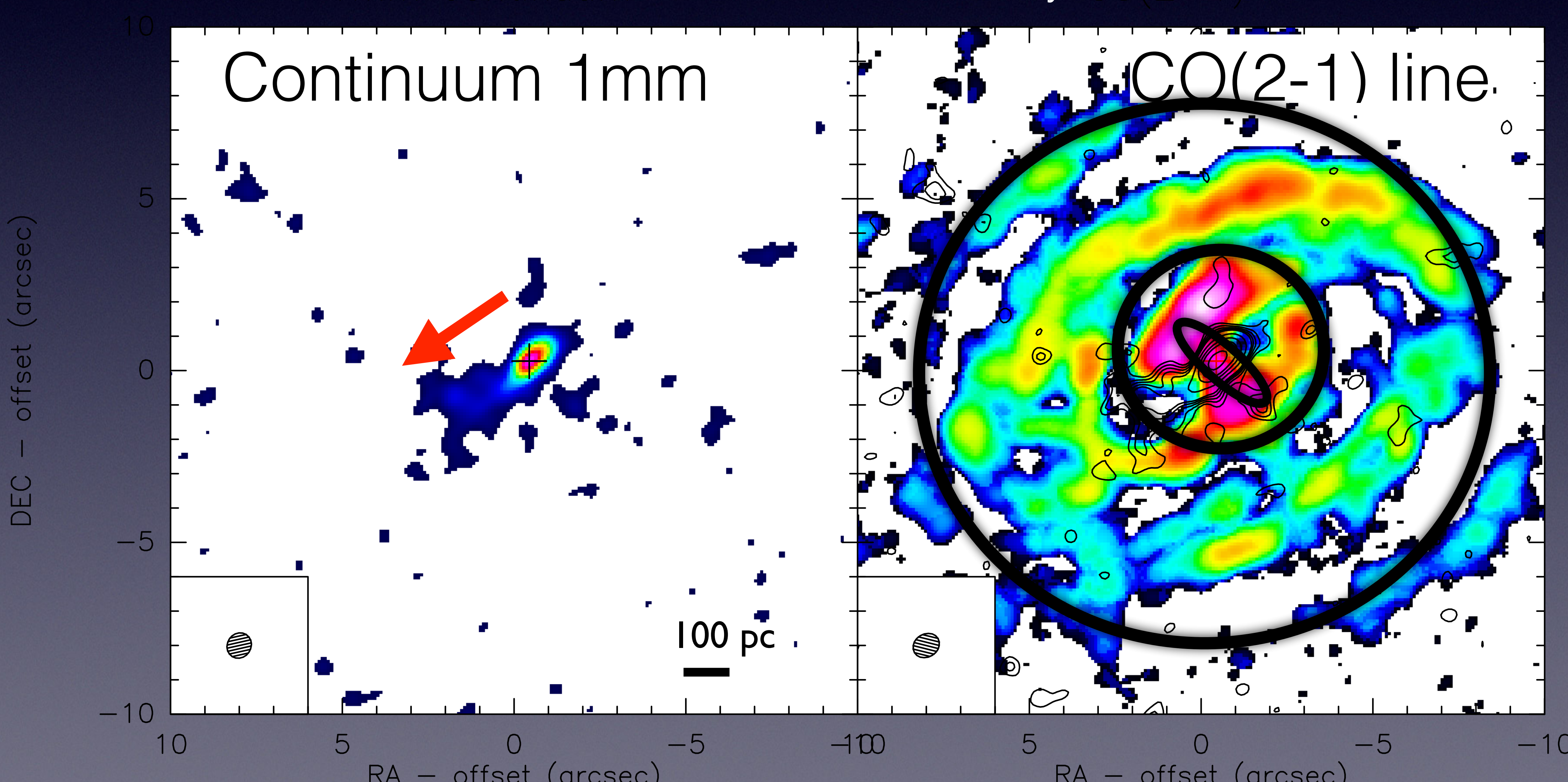
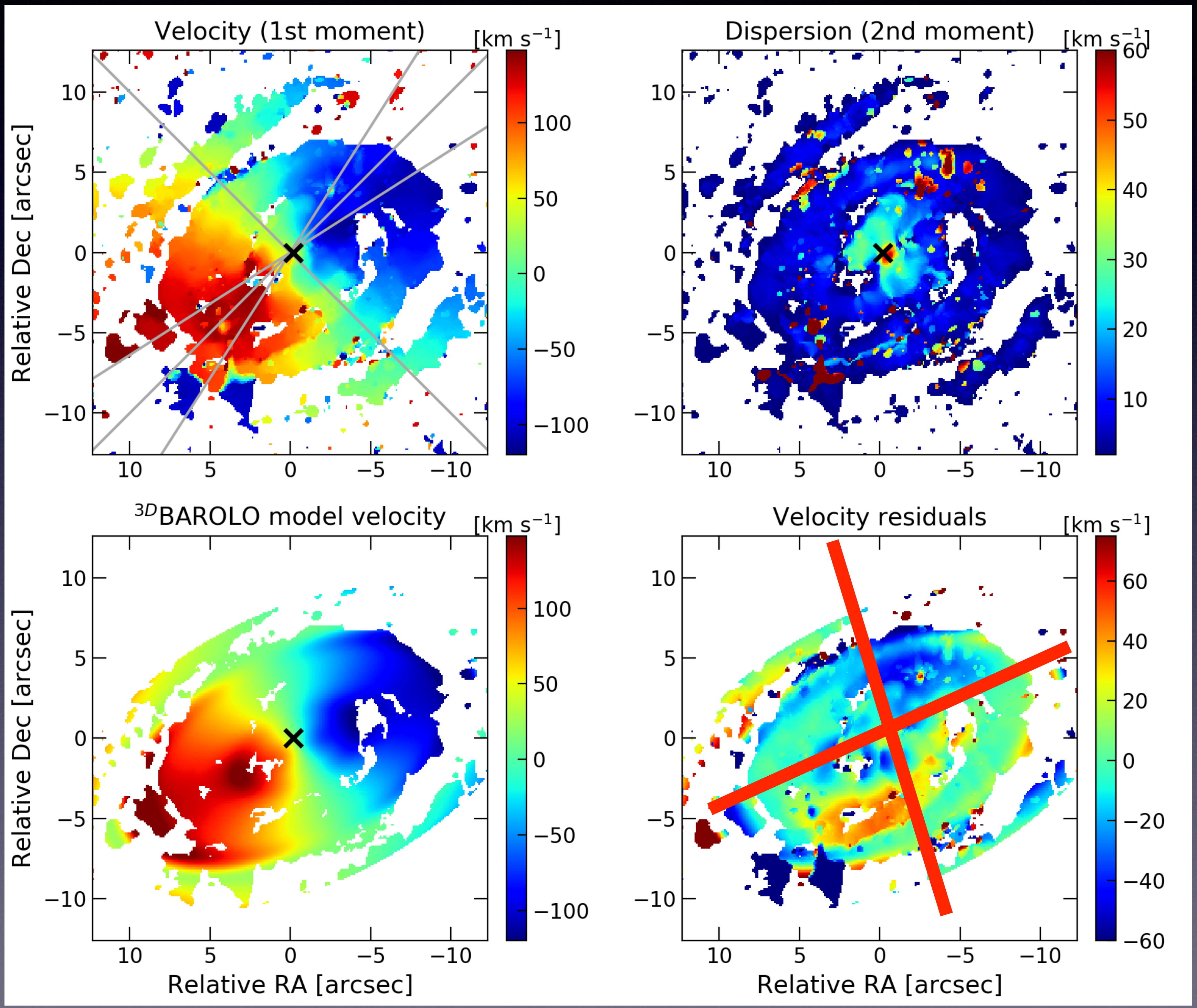
- <100 pc **nuclear bar** coming in from CNR towards AGN
- CO-cavity filled with continuum em.



Molecular gas kinematics: from galaxy scale to nucleus

Feruglio, Fabbiano+2019, arxiv1904.01483



- large scale velocity gradient
- deviations from smooth velo gradient in bi-conical structure

3DBAROLO model

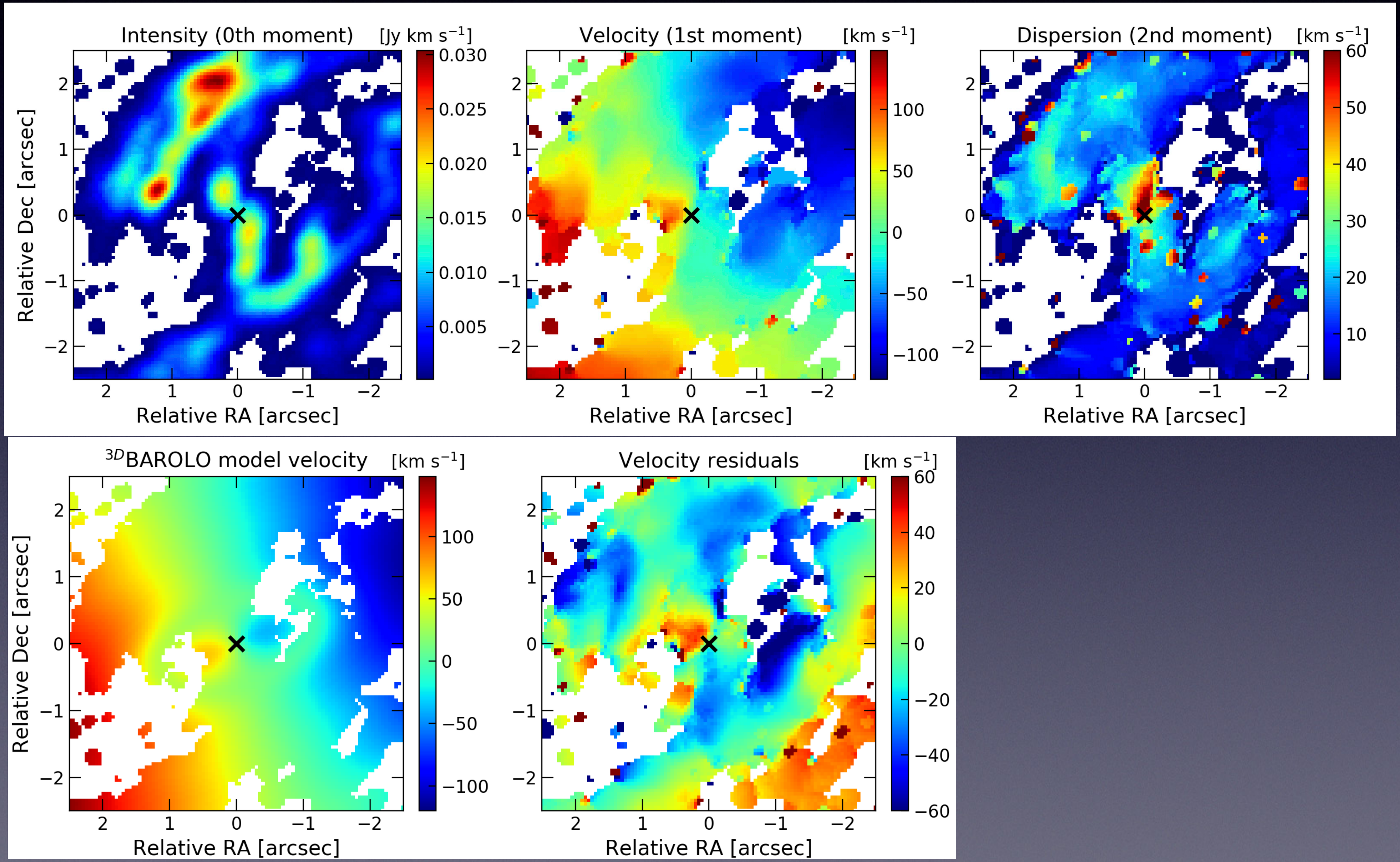
- disk rotation +
- bi-coninical wide angle molecular outflow along ionisation cones

$$\dot{M}_{OF} = 0.8(\alpha_{CO}/0.8)\ M_{\odot}/yr$$
$$R_{OF} \sim 700\ pc$$

- increased vel dispersion at CNR and nucleus

Feeding the AGN

Super-resolution CO maps
to trace gas kinematics at nucleus



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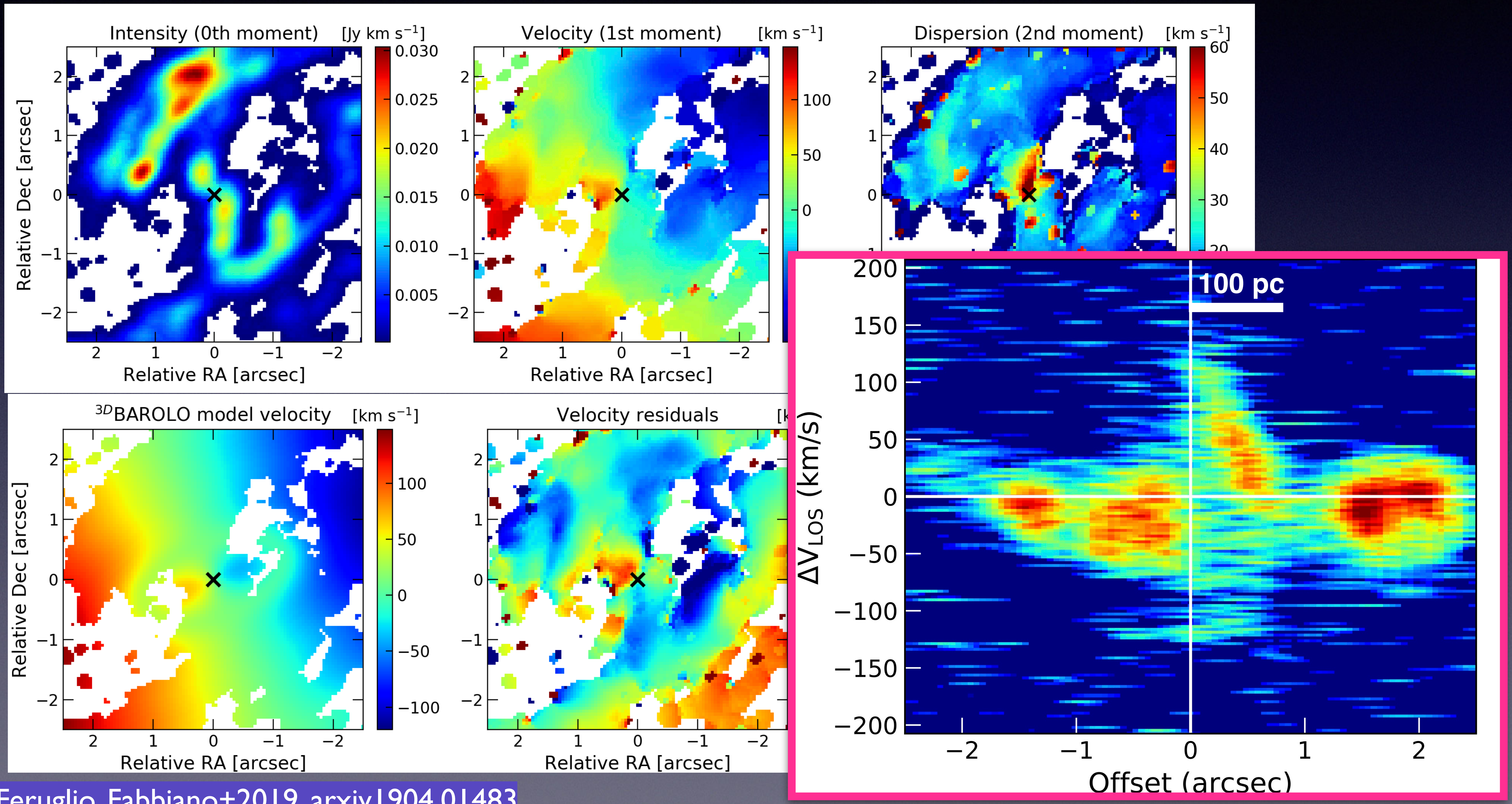
Non rotational motion in inner 80 pc
velocity increases toward nucleus



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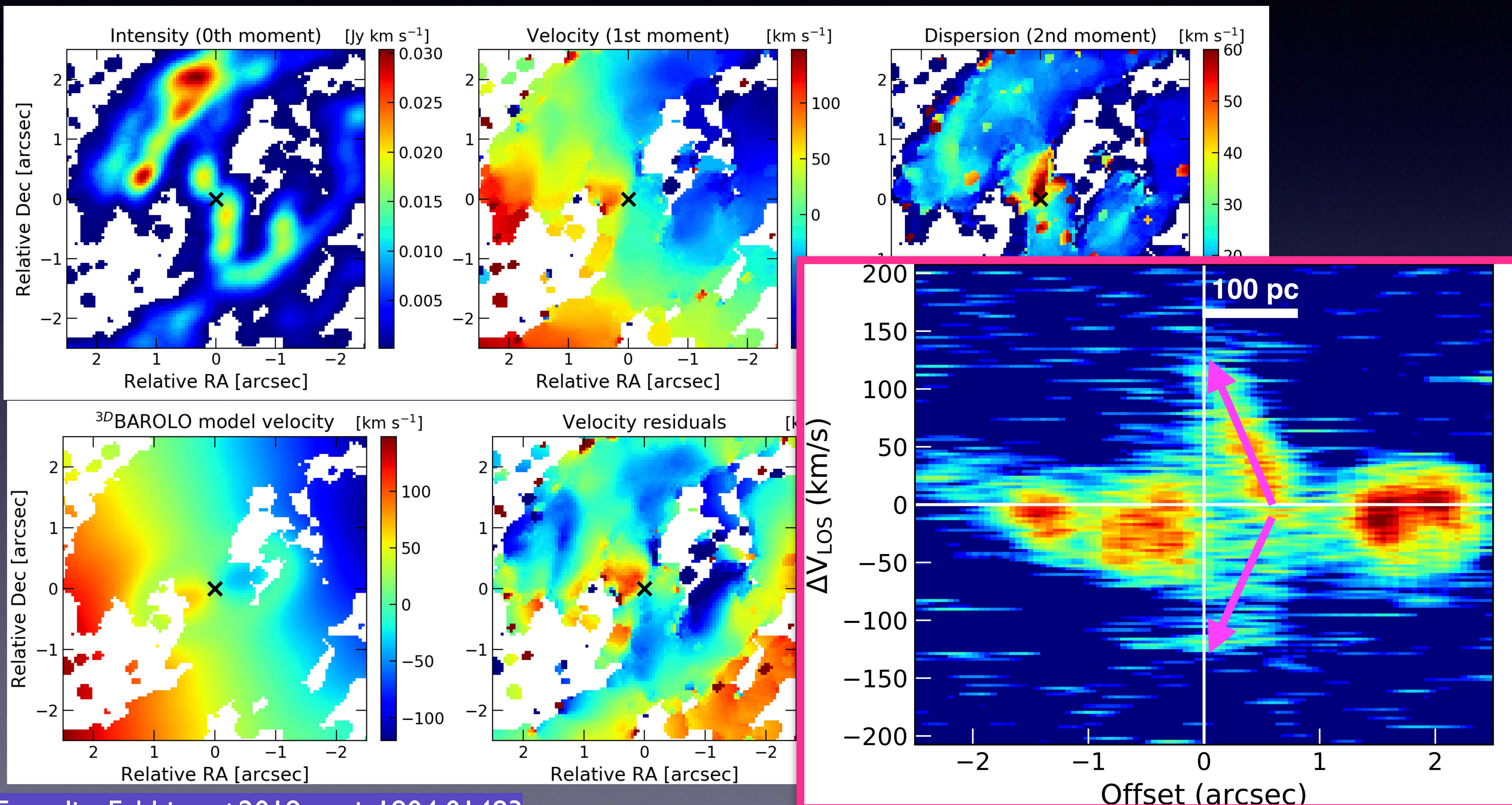

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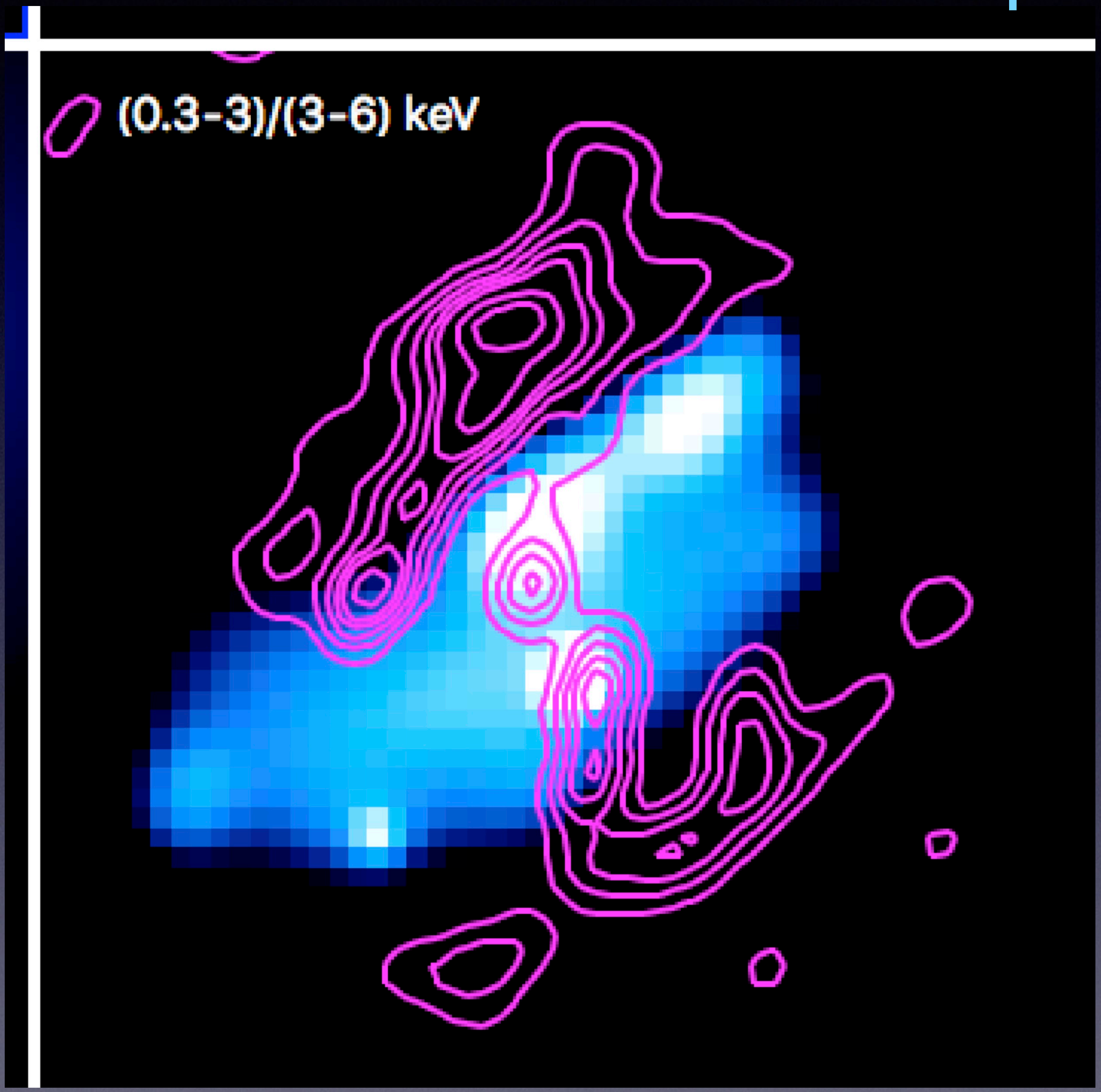
Chandra+ALMA
Obscuration & feeding @nucleus

Chandra Hardness ratio map



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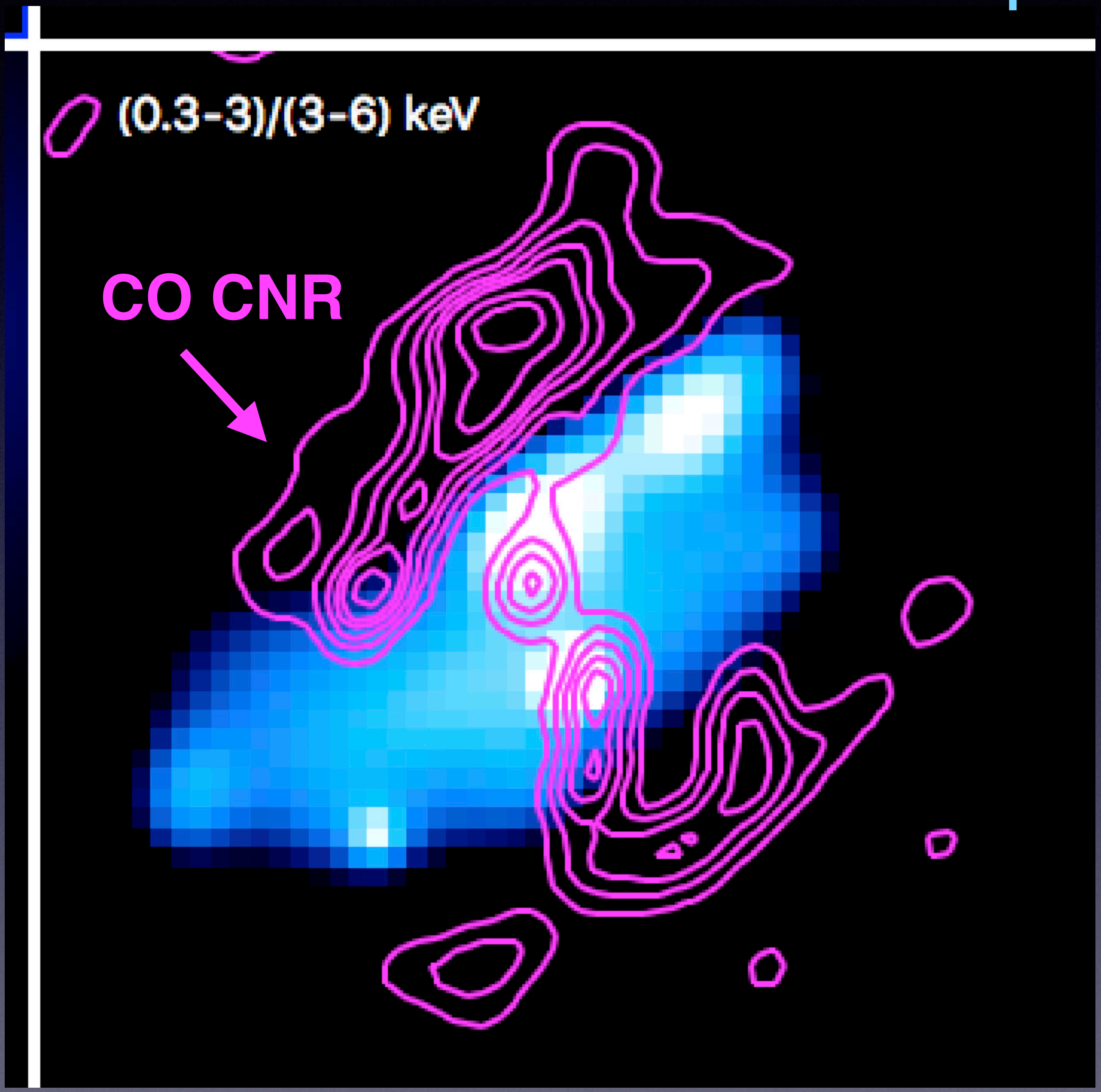

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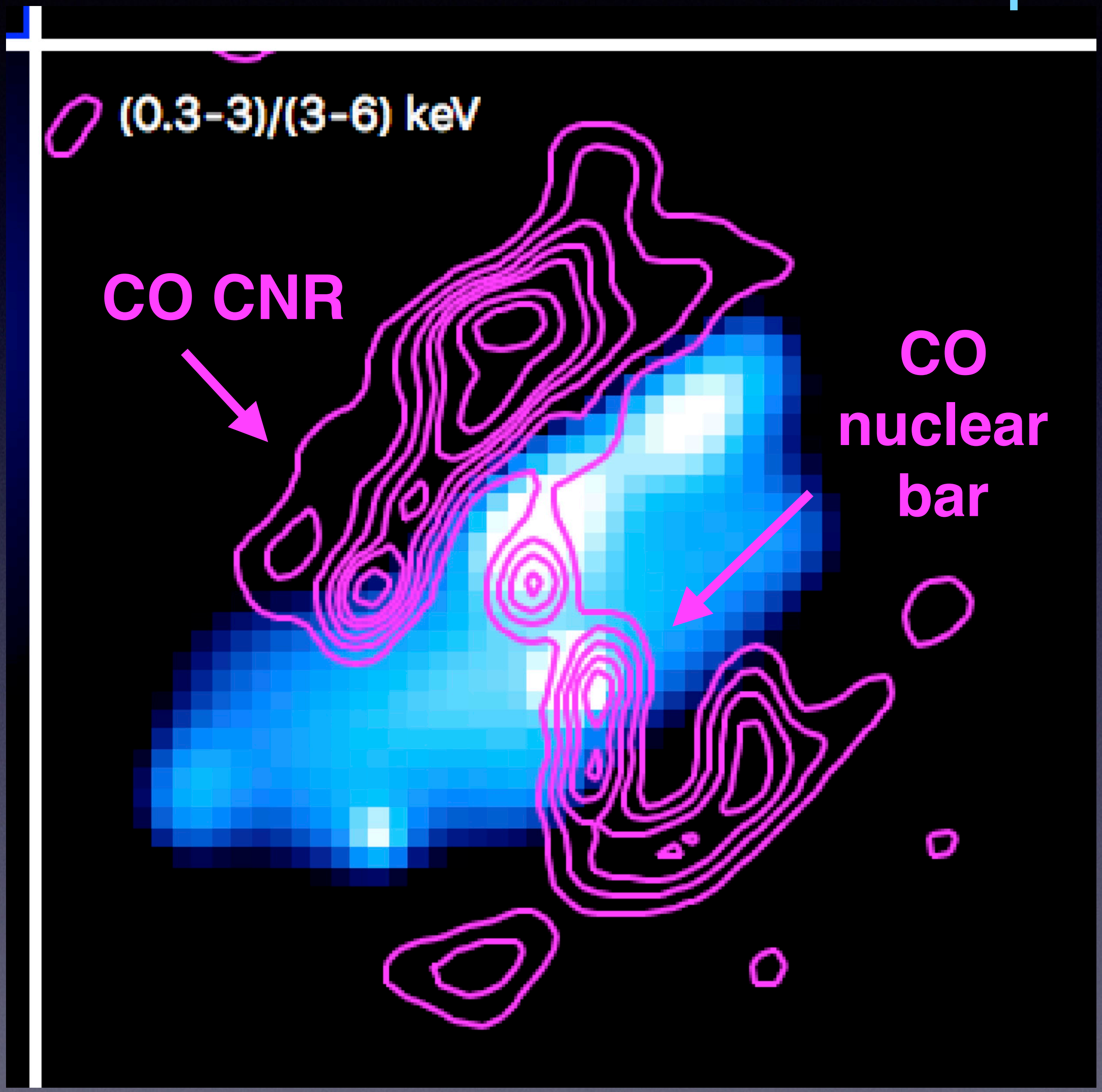

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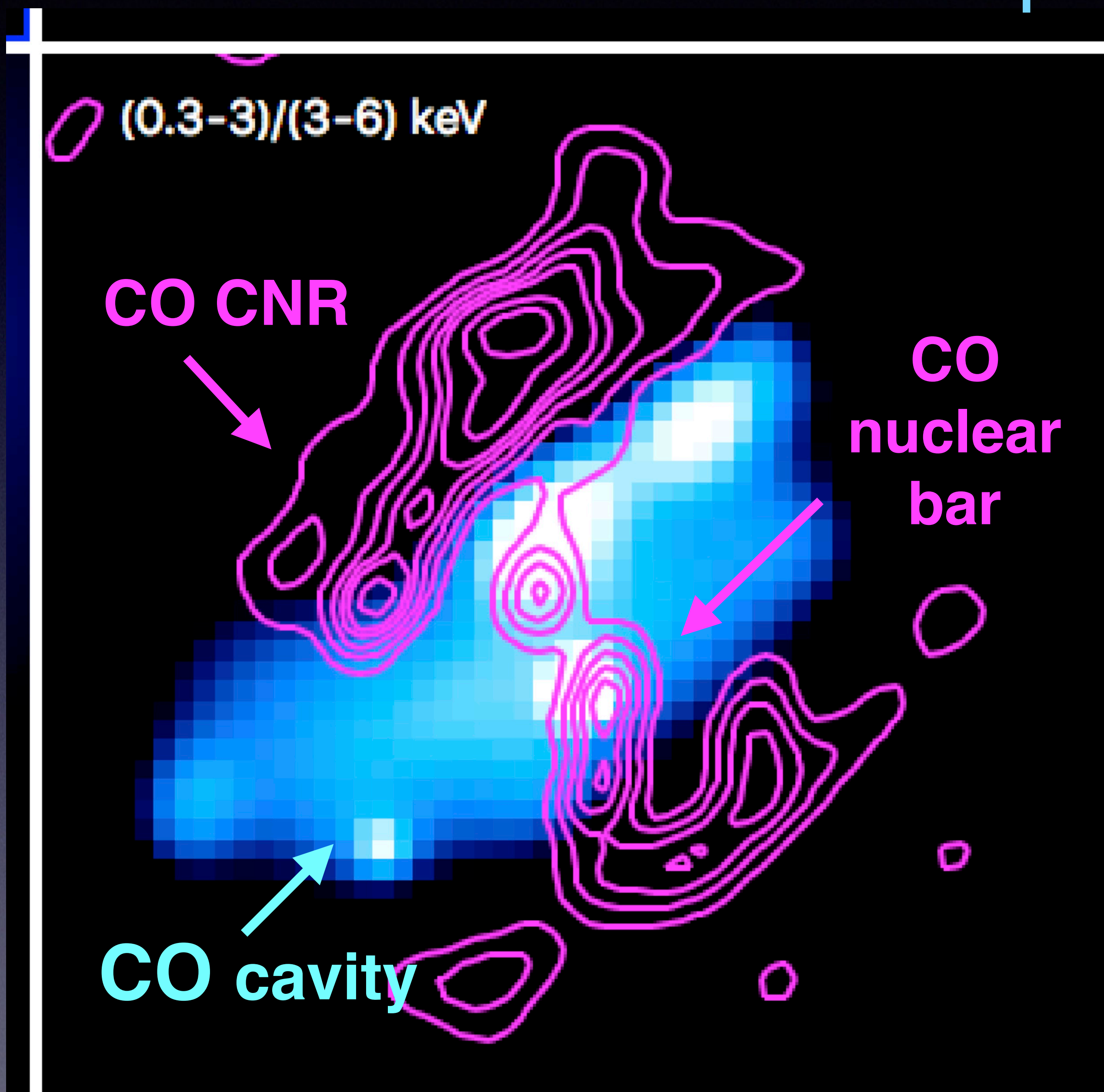

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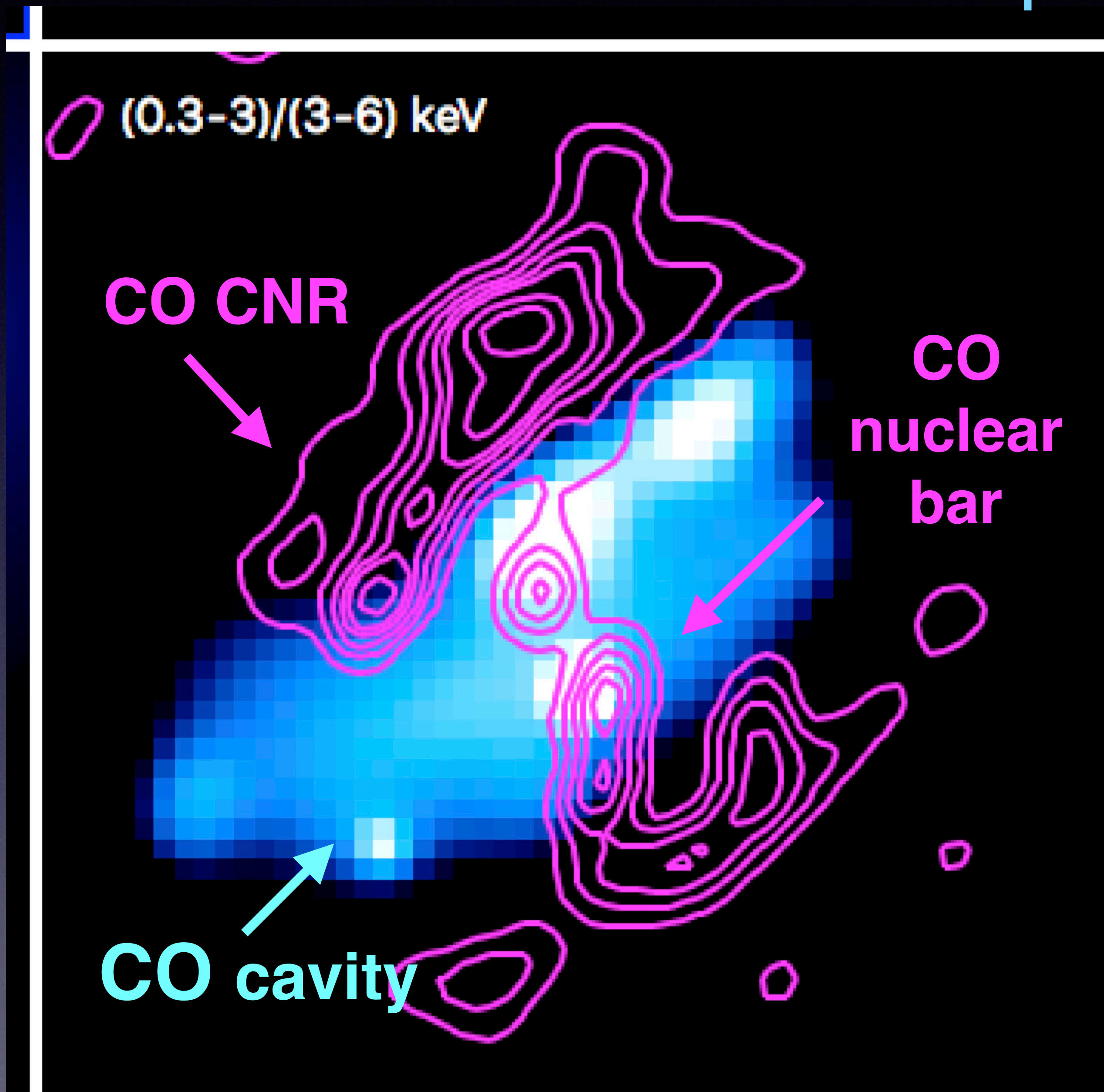

Nuclear CO-bar

- overlaps with most CT region
  (Fabbiano+18) $N(H_2) \sim 2\ 10^{23}\ cm^{-2}$

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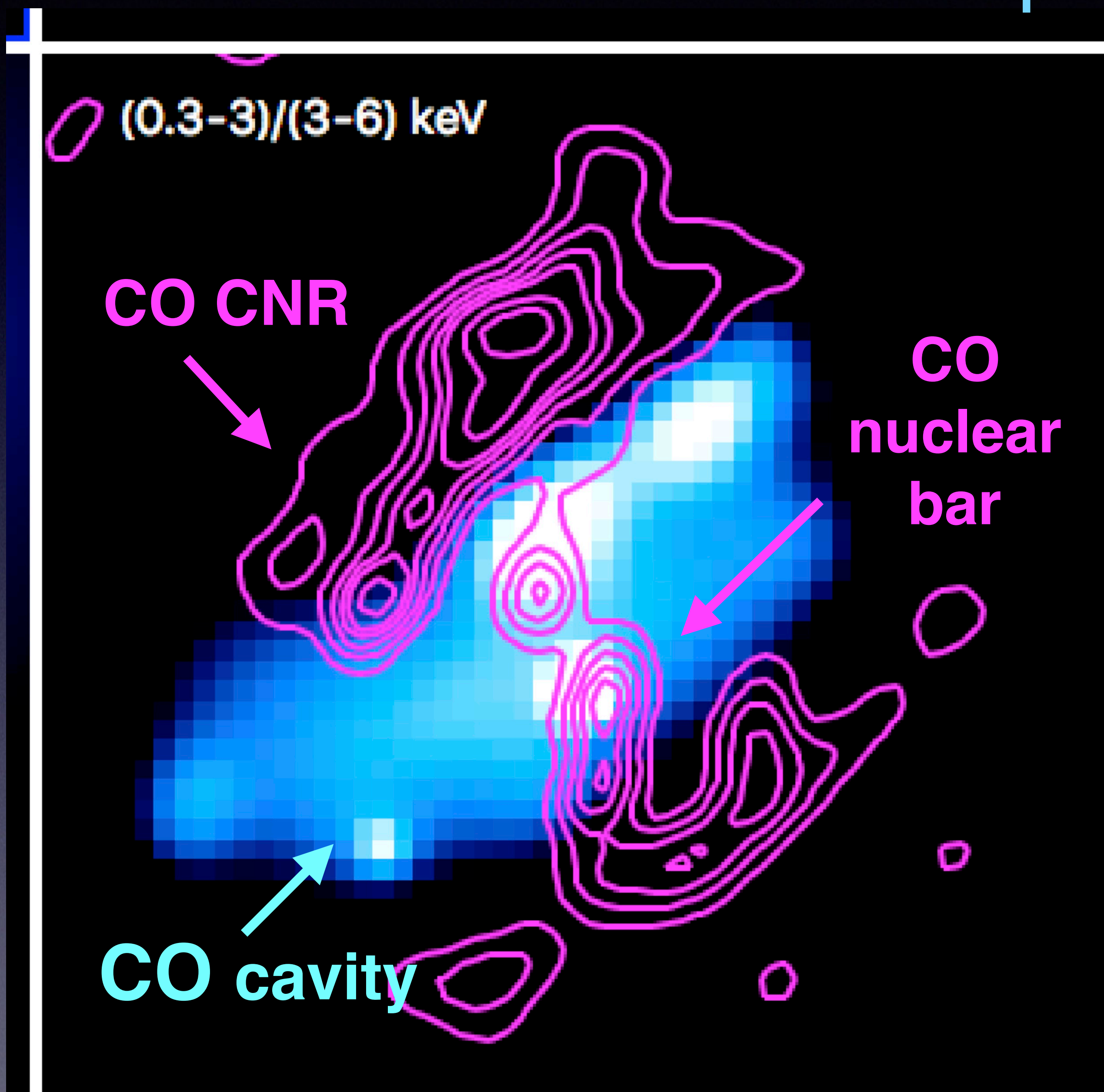

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- Drives inflow at rate

$$\dot{M}_{in} = v_{max,R_{in}} \times M(H_2)/R_{in} \sim 2\ M_\odot/yr$$

$$R_{in} = 100pc\ ;\ v_{max,R_{in}} = 50km/s$$

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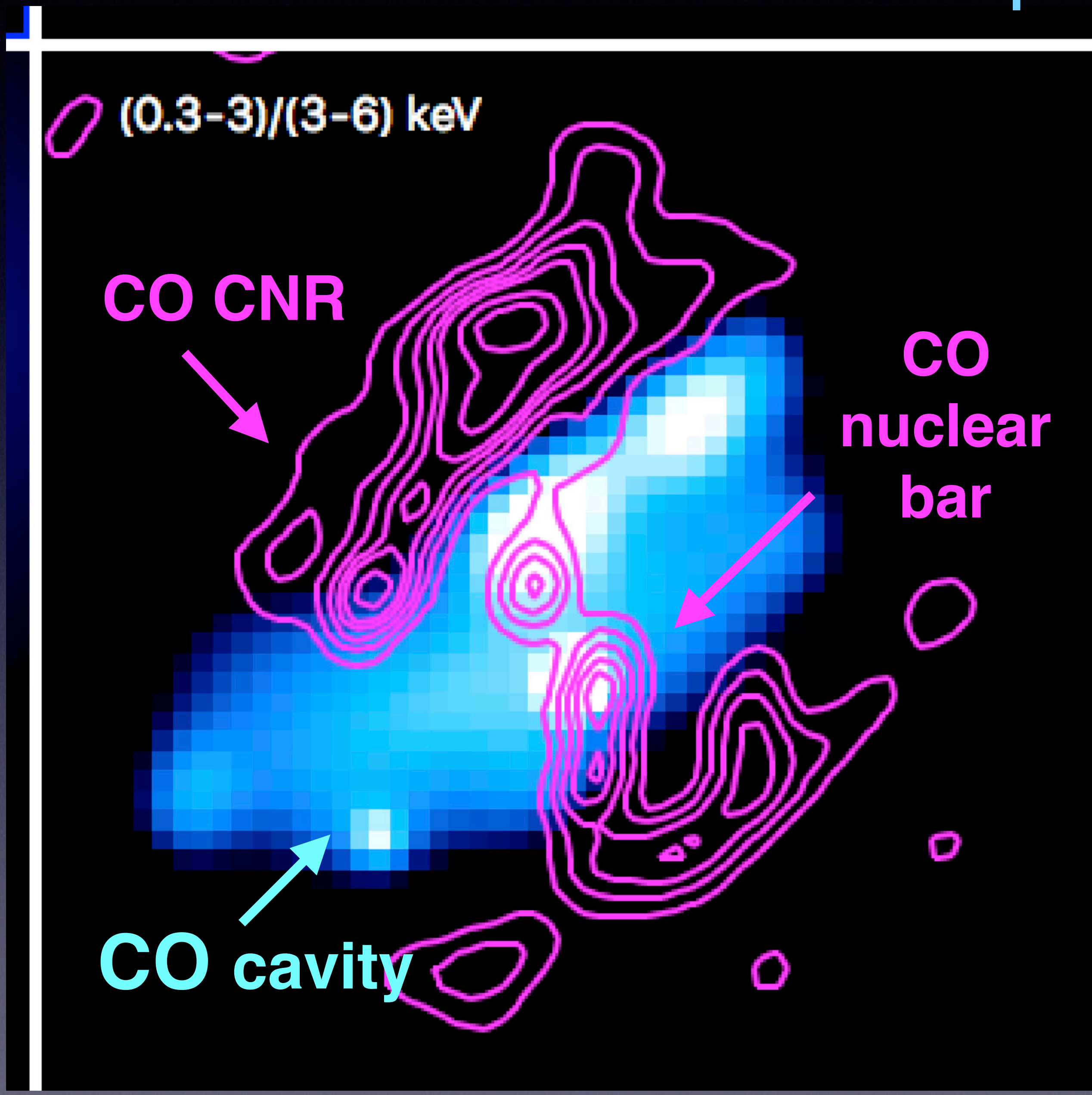

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$r_B \sim 1pc << \text{inner bar}$

Fragmentation & SF before reaching AGN?

No because $t_{dyn} << t_{dep}$

$$t_{dep} = M_{gas}/SFR \sim 30\ Myr$$

$$t_{dyn} = R/v(R) \sim 2\ Myr$$

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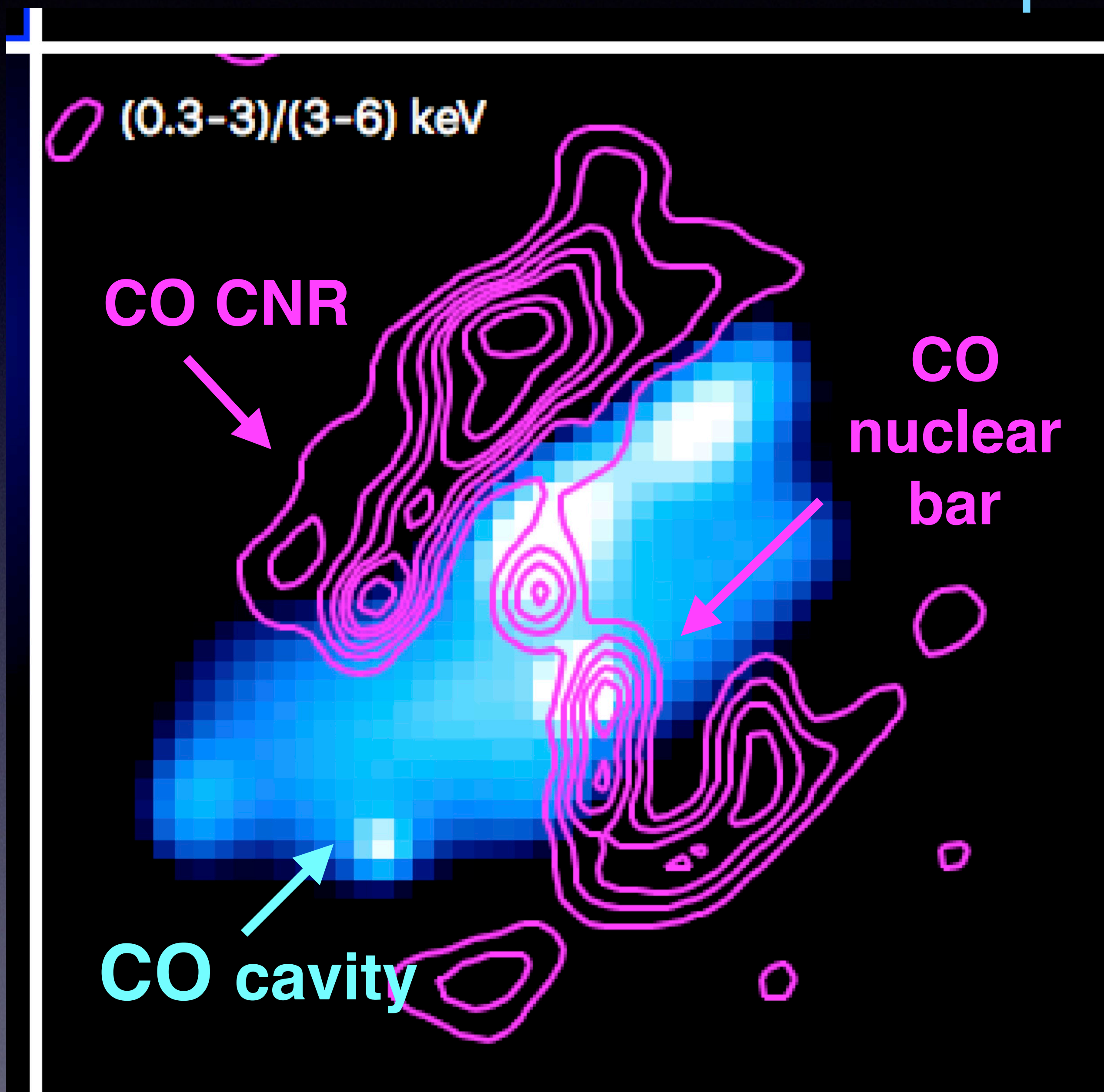

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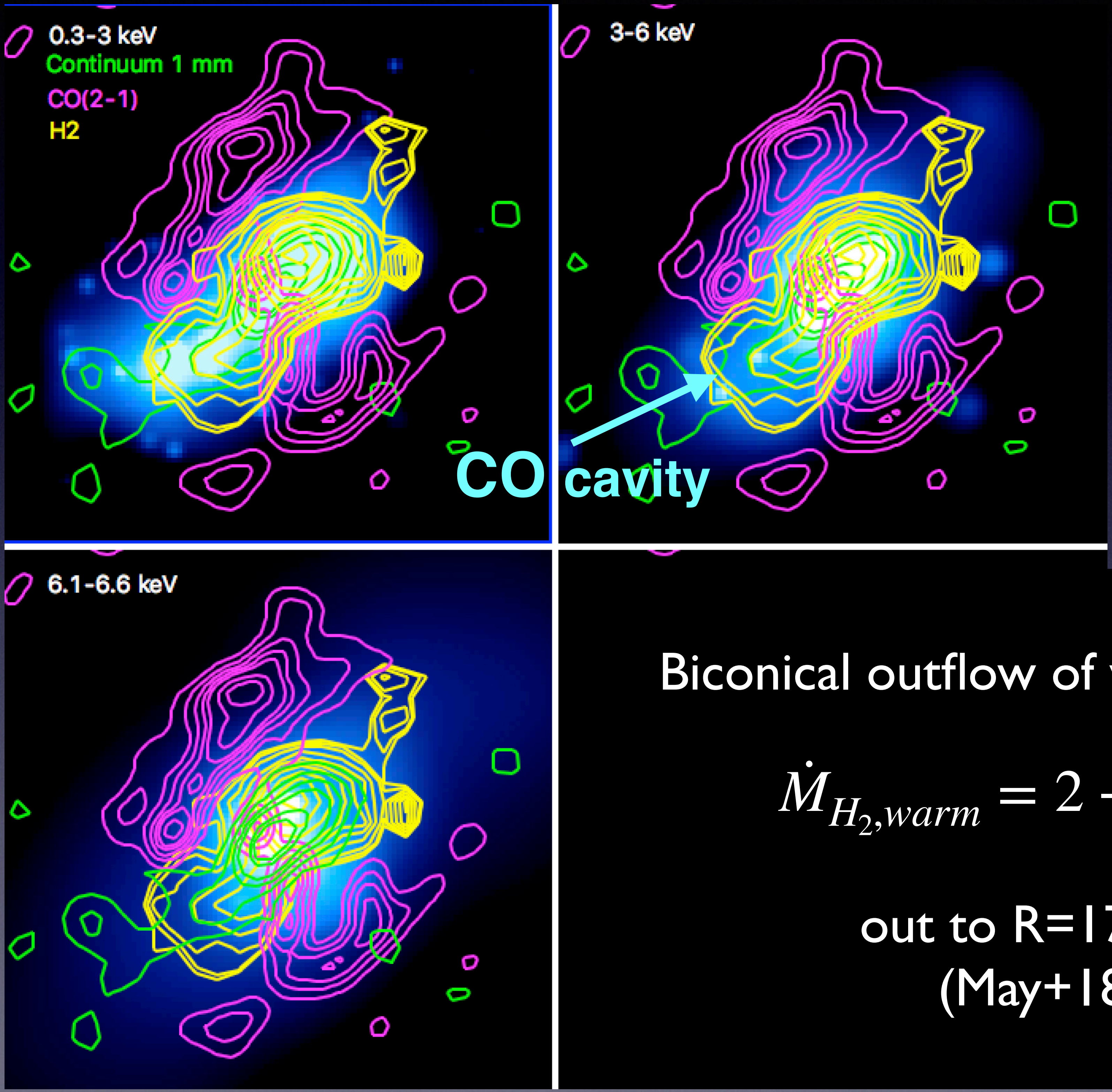
$$\dot{M}_{BH} = L_{bol}/\epsilon c^2 = 0.007\ M_{\odot}/yr\ for\ \epsilon = 0.1$$

$$0.07\ M_{\odot}/yr\ for\ \epsilon = 0.01$$

Large fraction of gas lost in outflow (Sadowski2016)

Chandra+ALMA+SINFONI
Feedback @nucleus



CO cavity filled with H2 warm gas - scattering material

CO(2-1) suppressed by AGN irradiation/shocks

Biconical outflow of warm H2 with

$$\dot{M}_{H_2,warm} = 2 - 8\ M_{\odot}/yr$$

out to R=170 pc
(May+18)

Feruglio, Fabbiano+2019, arxiv1904.01483

Chandra+ALMA+SINFONI
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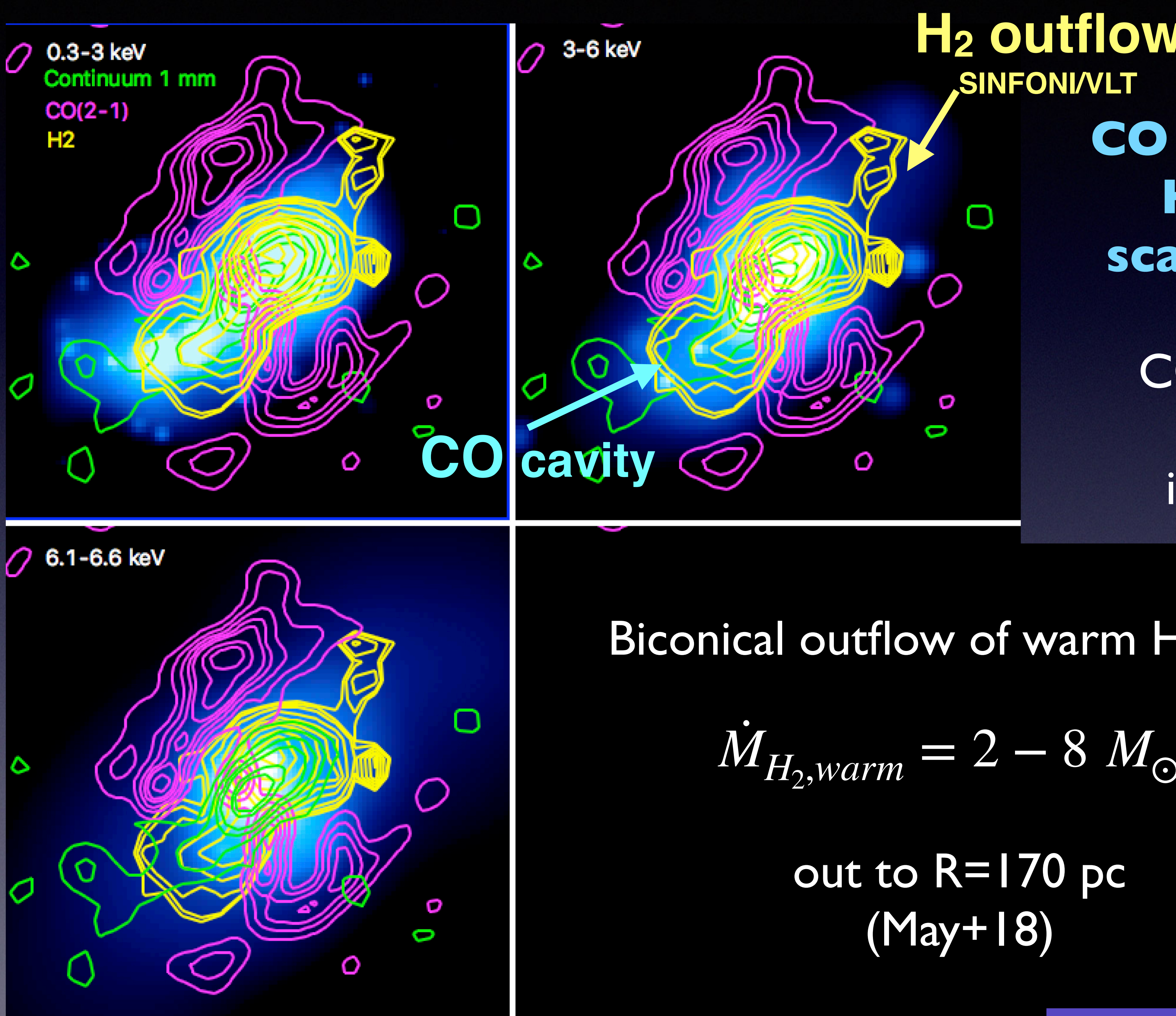

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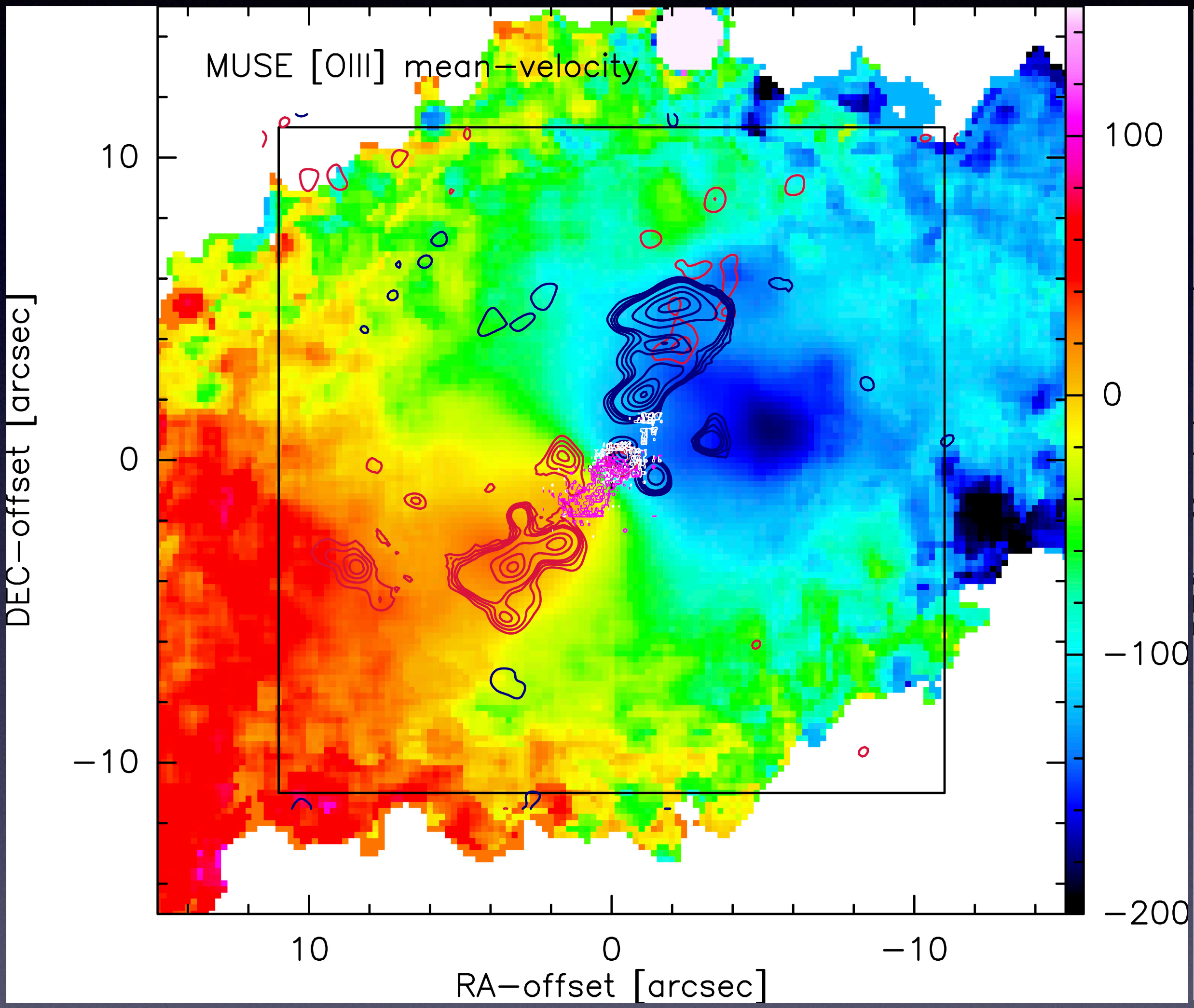
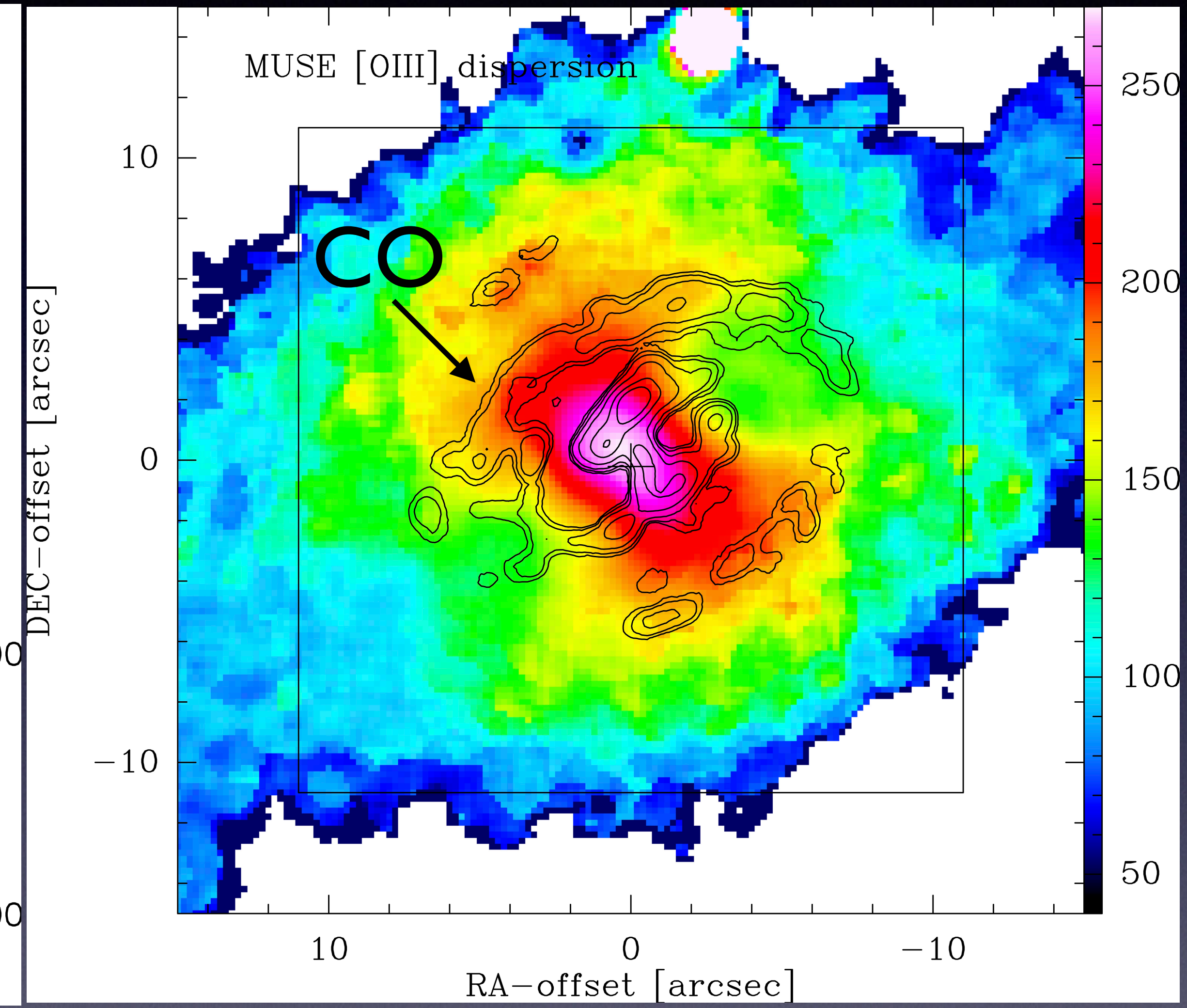
MUSE+ ALMA+ SINFONI

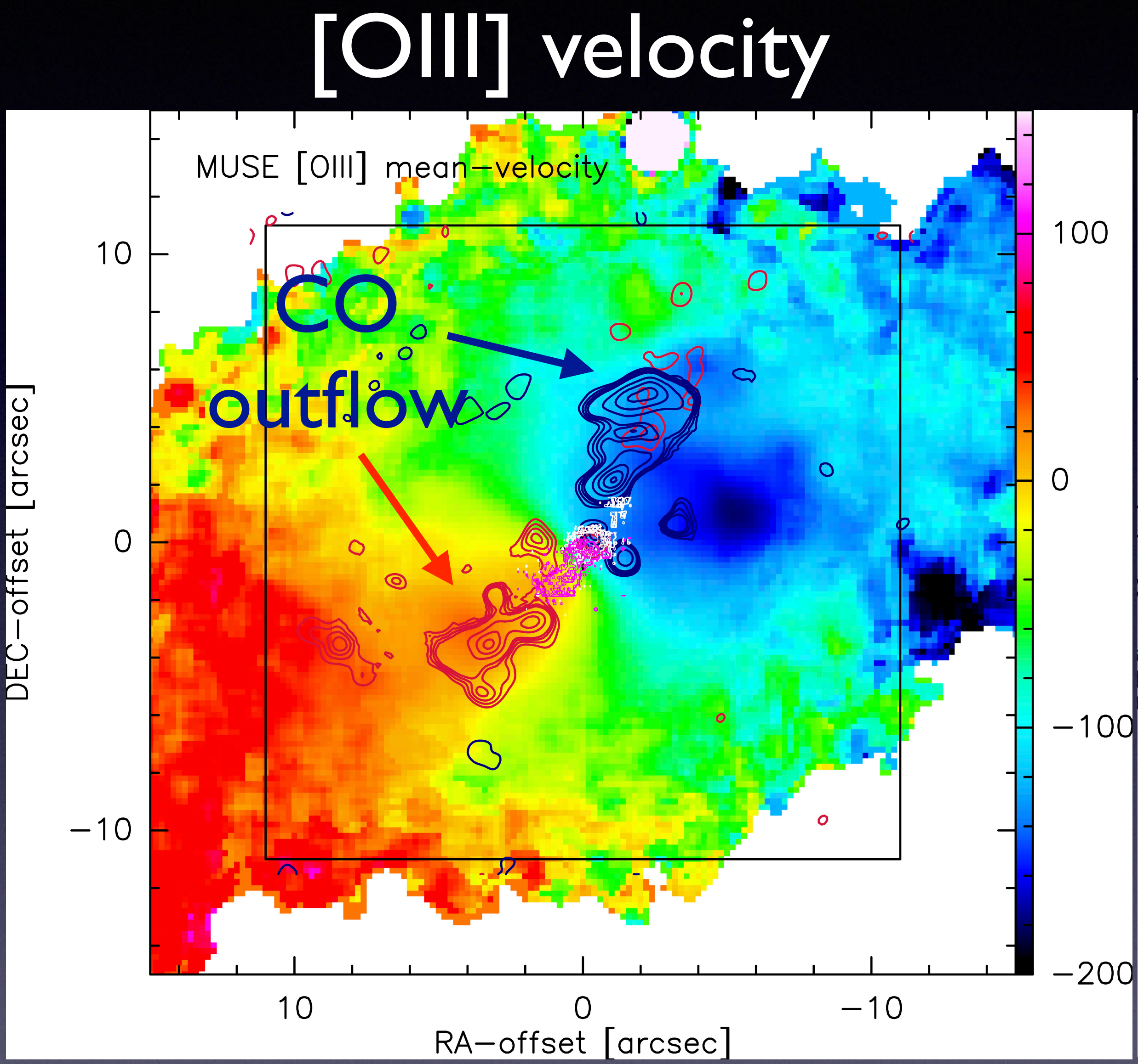
[OIII] velocity

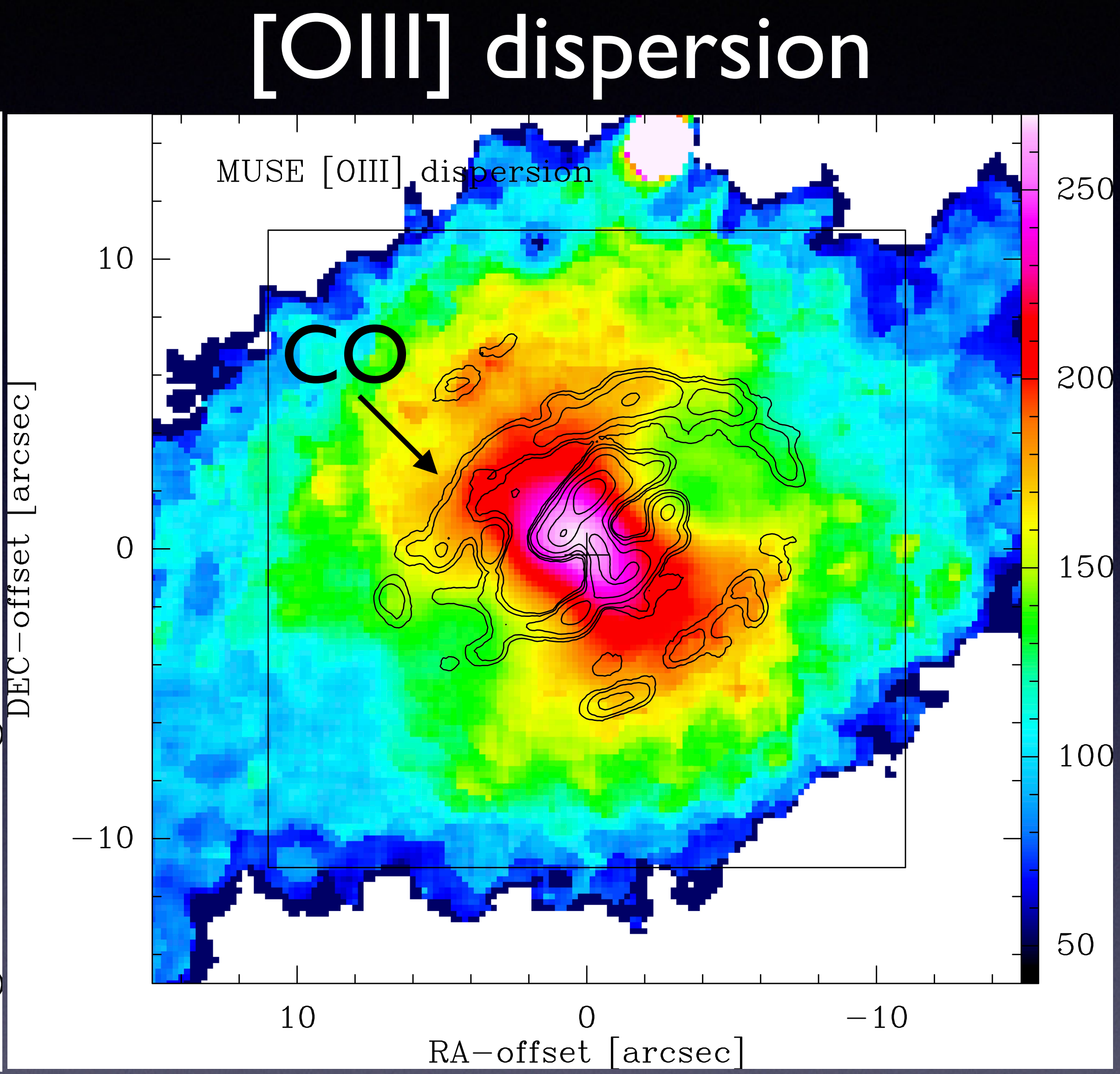


[OIII] dispersion



MUSE+ ALMA+ SINFONI





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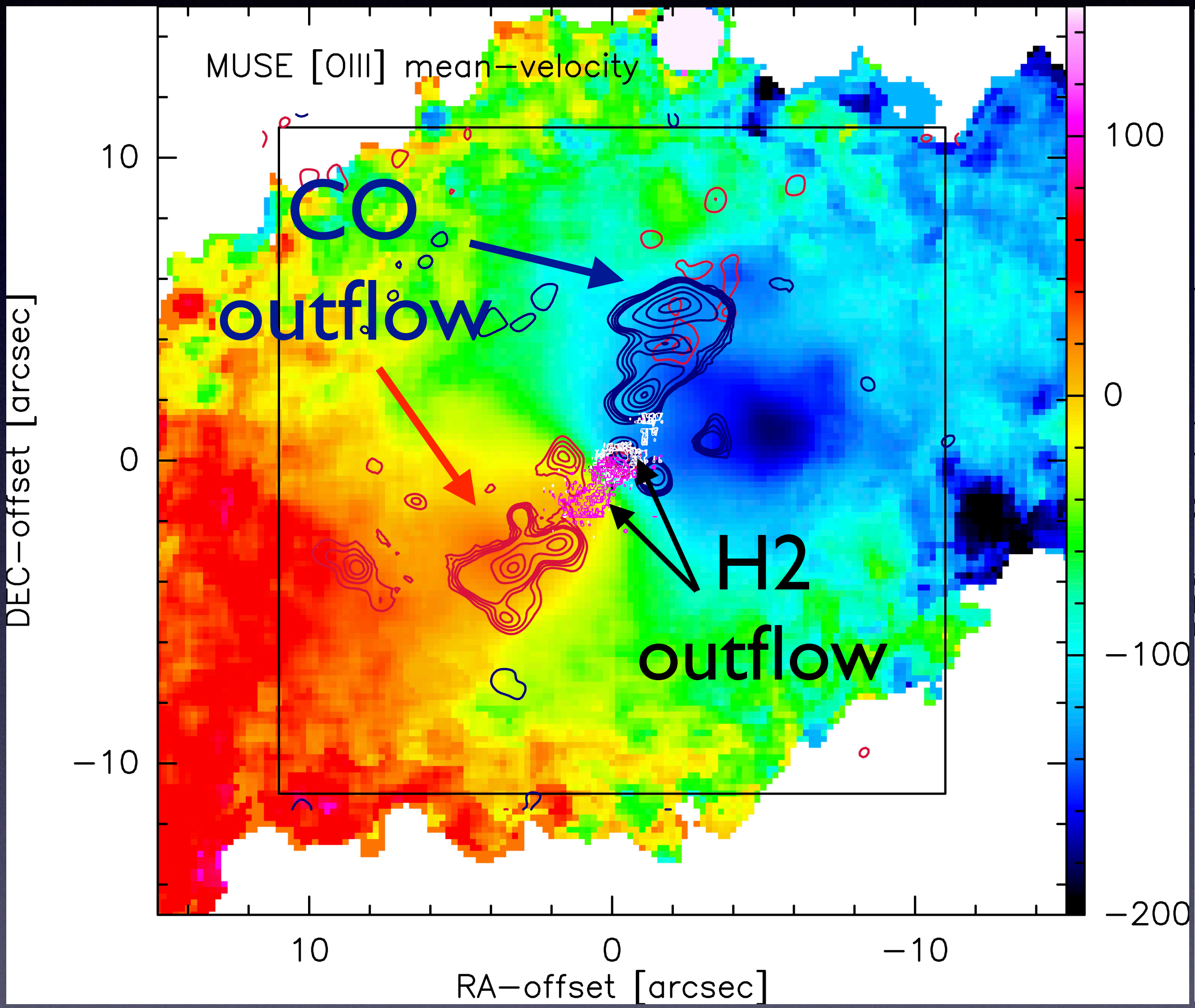

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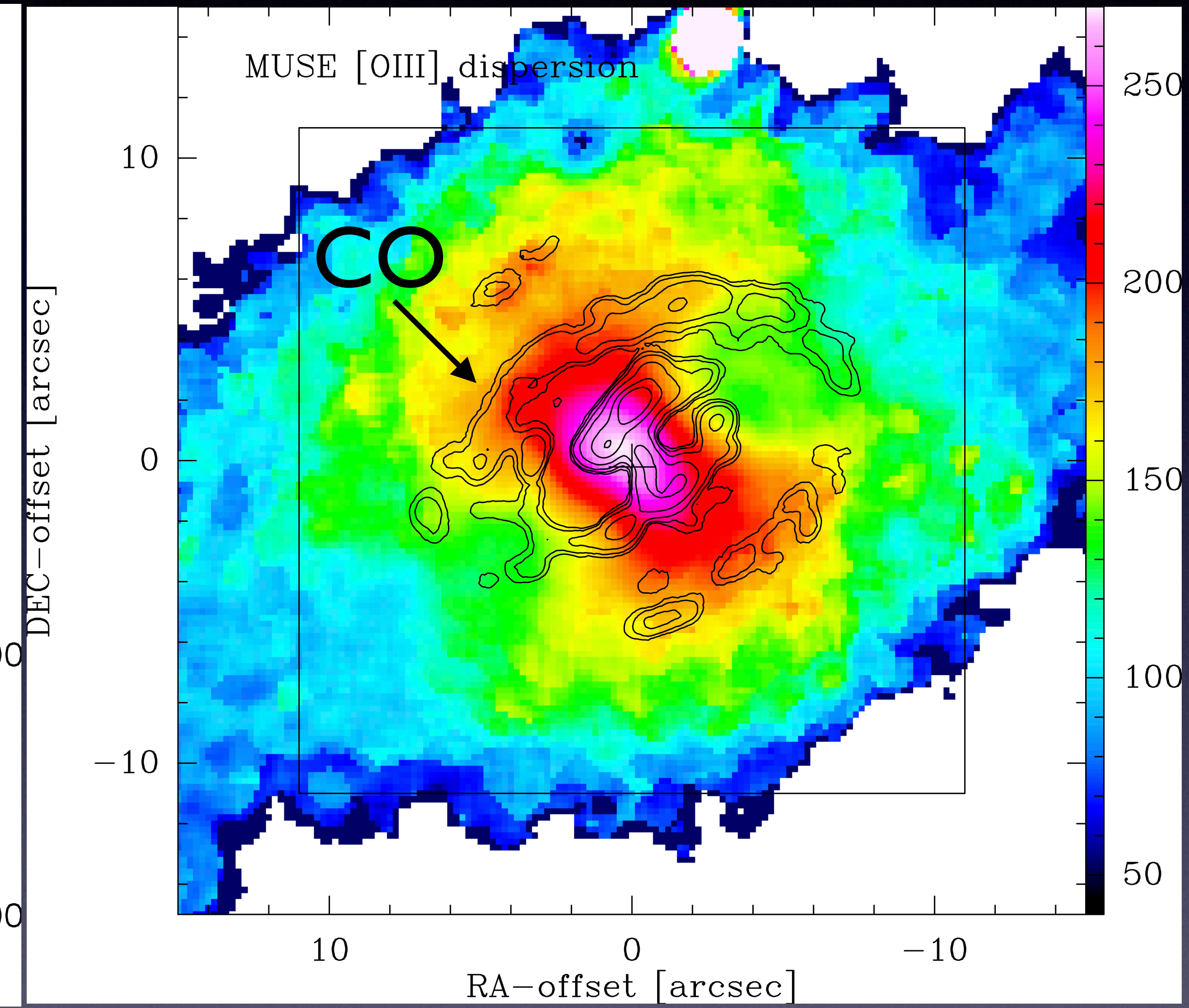

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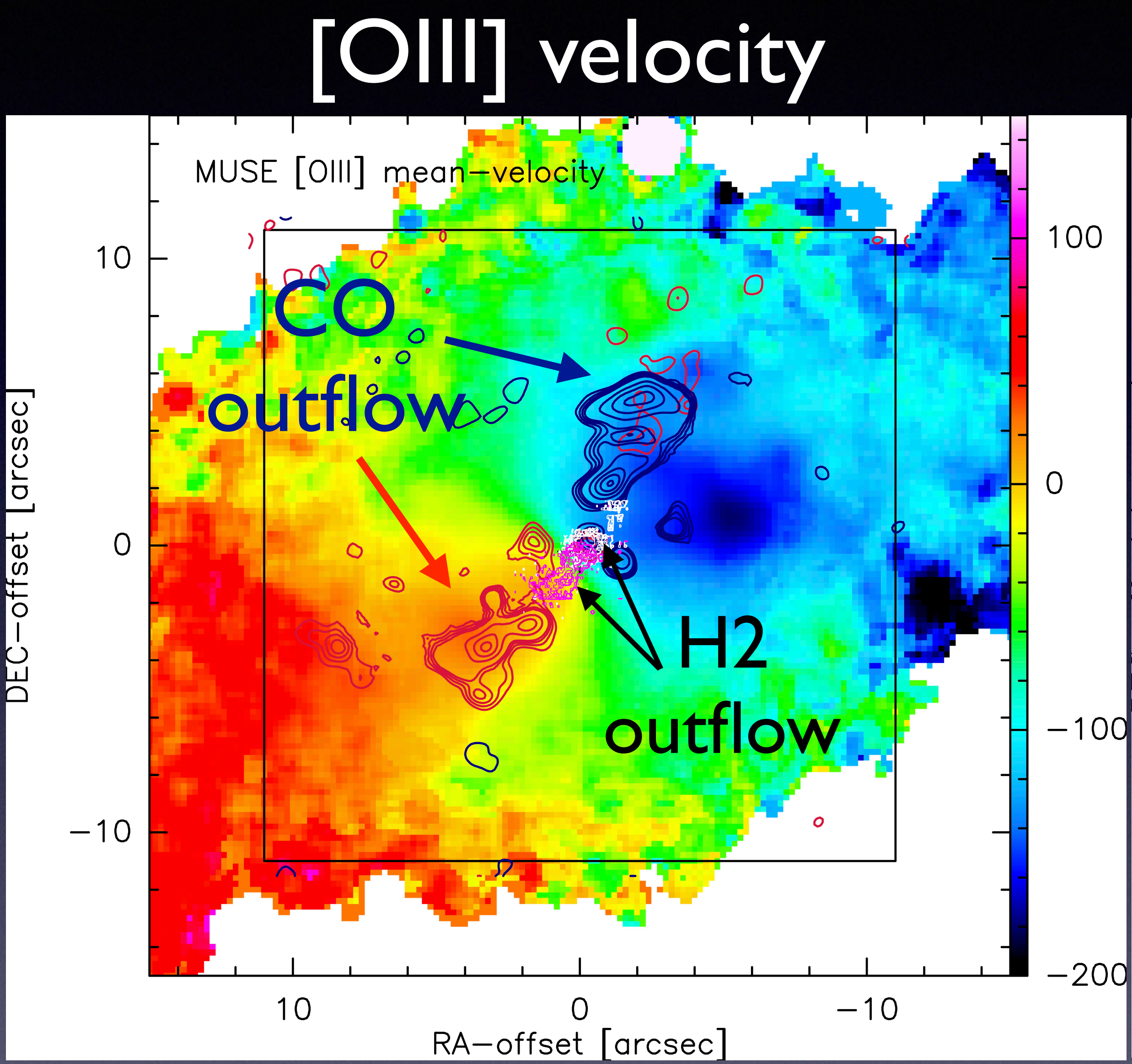

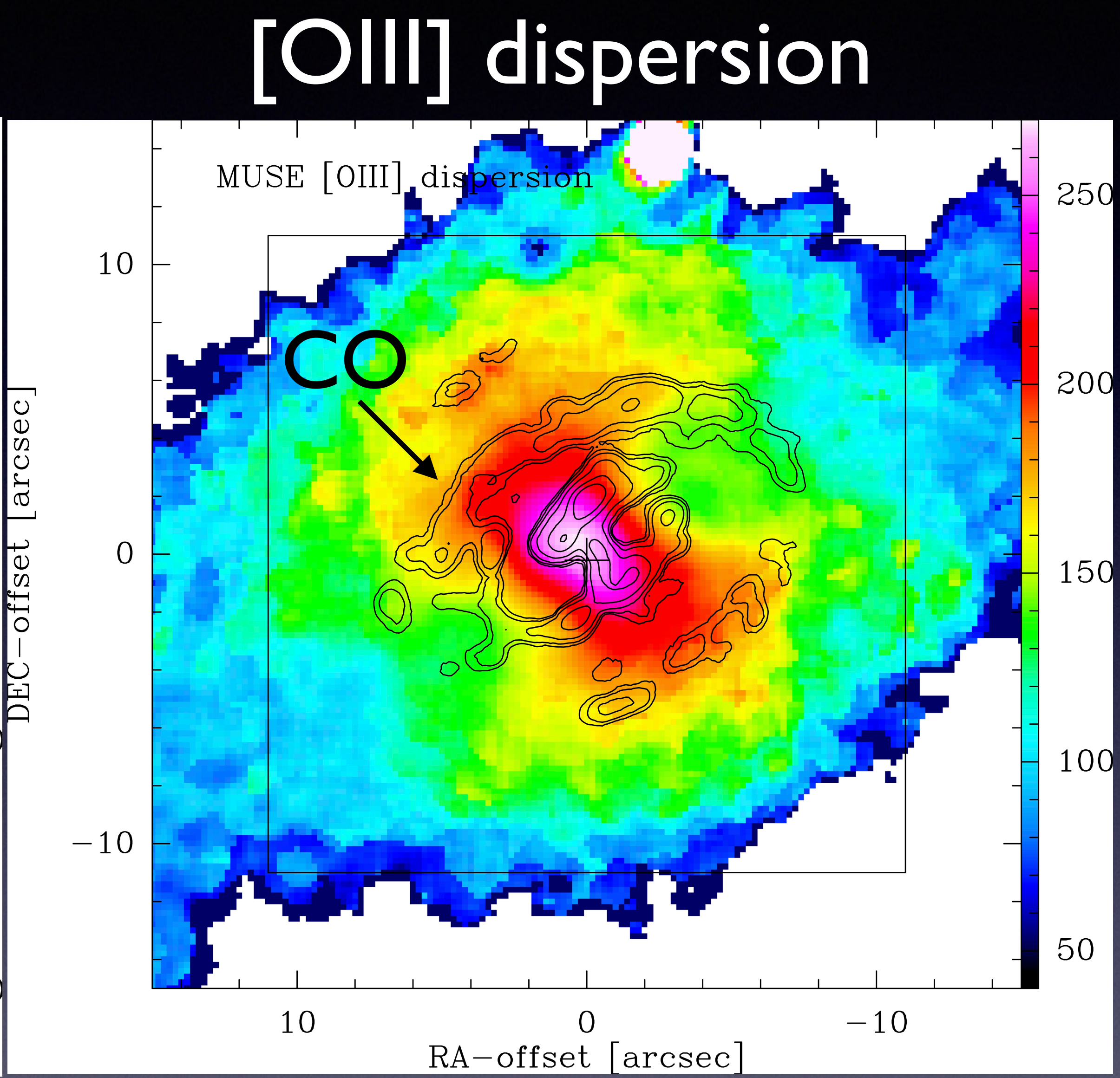

Biconical outflow

$H_{2,warm}$ out to 170 pc

CO out to 700 pc

Gas cooling while leaving AGN

Conclusions

1. kpc cold (CO) molecular outflow ~ ionized outflow
2. Joins smooty with warm molecular outflow on hundreds pc scale
3. Nuclear CO inflow (<80pc) >> MdotBH
4. CO nuclear bar coincident with Chandra HR peak emission
5. Chandra HR extended emission coincident with warm molecular gas outflow (no CO).
6. Extended hard X-ray emission probably scattering from both cold and warm molecular gas.

Other similar cases:
NGC5643 Fabbiano+2018 & Alonso-Herrero+2018
NGC2110 Rosario+2019
Circinus Kawamuro's talk
and more