Using the Ultimate Resolution of Chandra to Image AGN Feedback: **Winds, Jets, or Radiation?**

Martin Elvis, G. Fabbiano

Center for Astrophysics | Harvard & Smithsonian

See review: Fabbiano & Elvis, 2022, arXiv:2202.13803

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Yes!

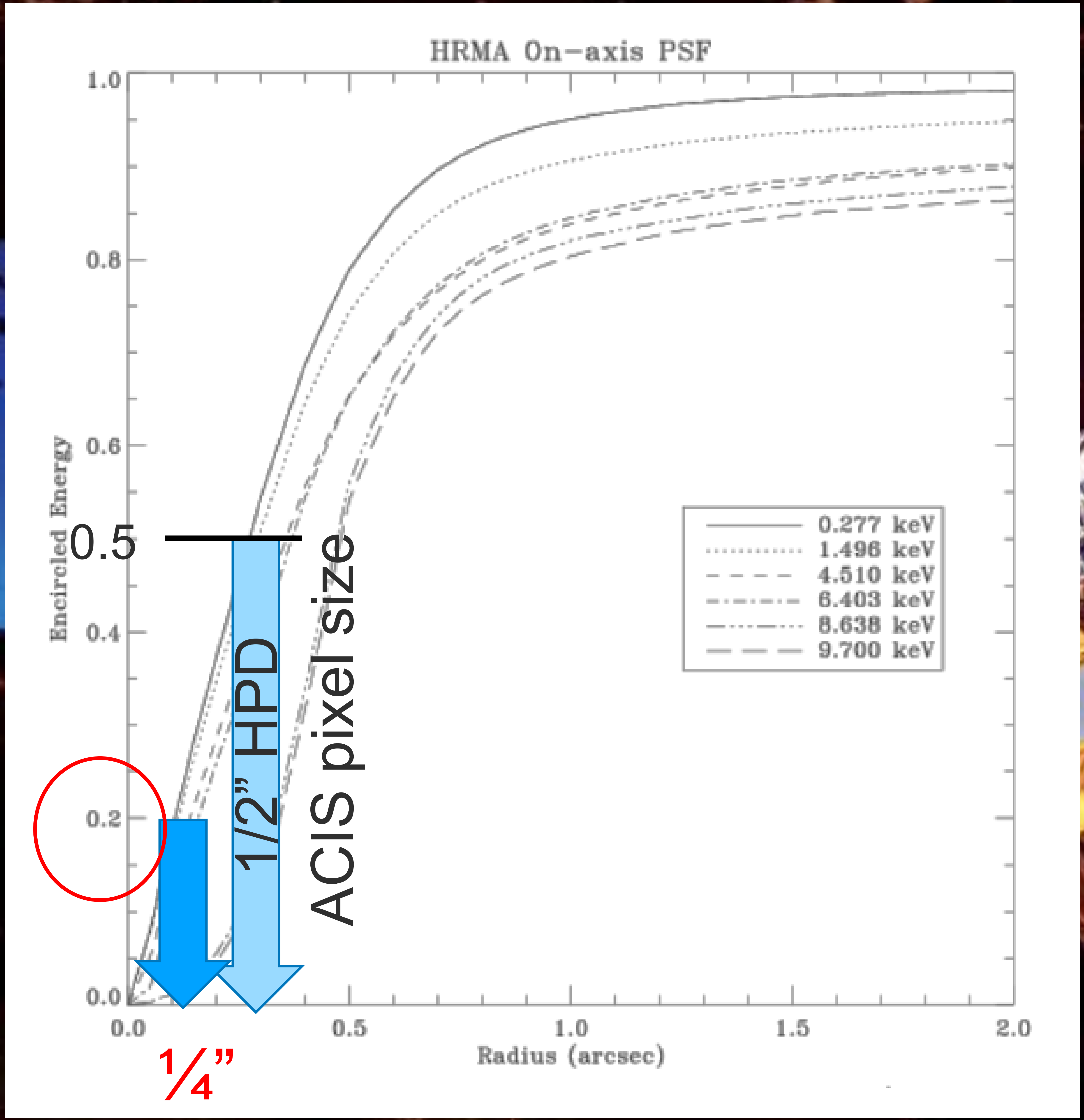
with sub-pixel imaging

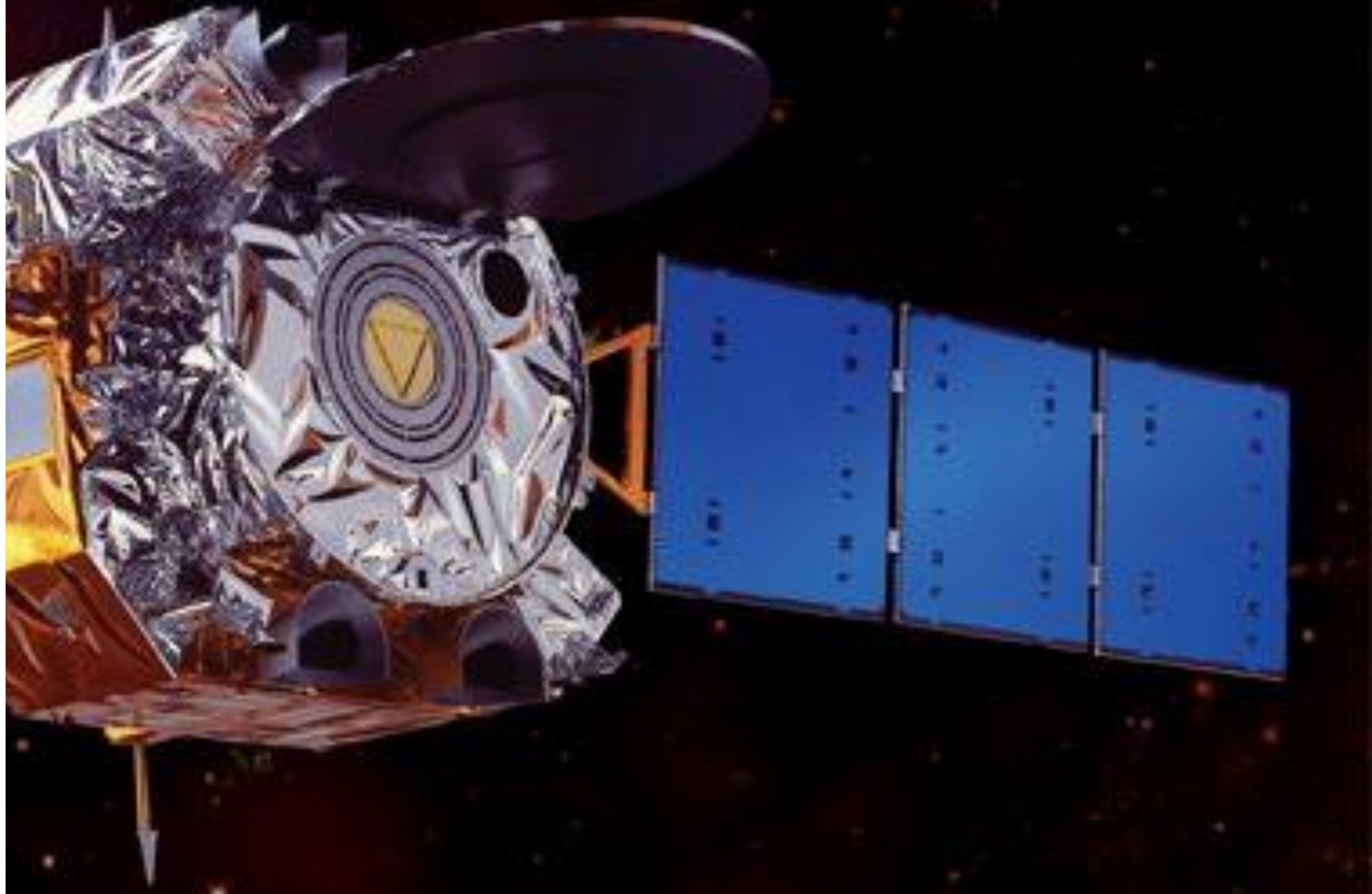
→ ~30pc – 100 pc

(D<70 Mpc)

See review: Fabbiano & Elvis, 2022, arXiv:2202.13803

Chandra is a ¼" Imager





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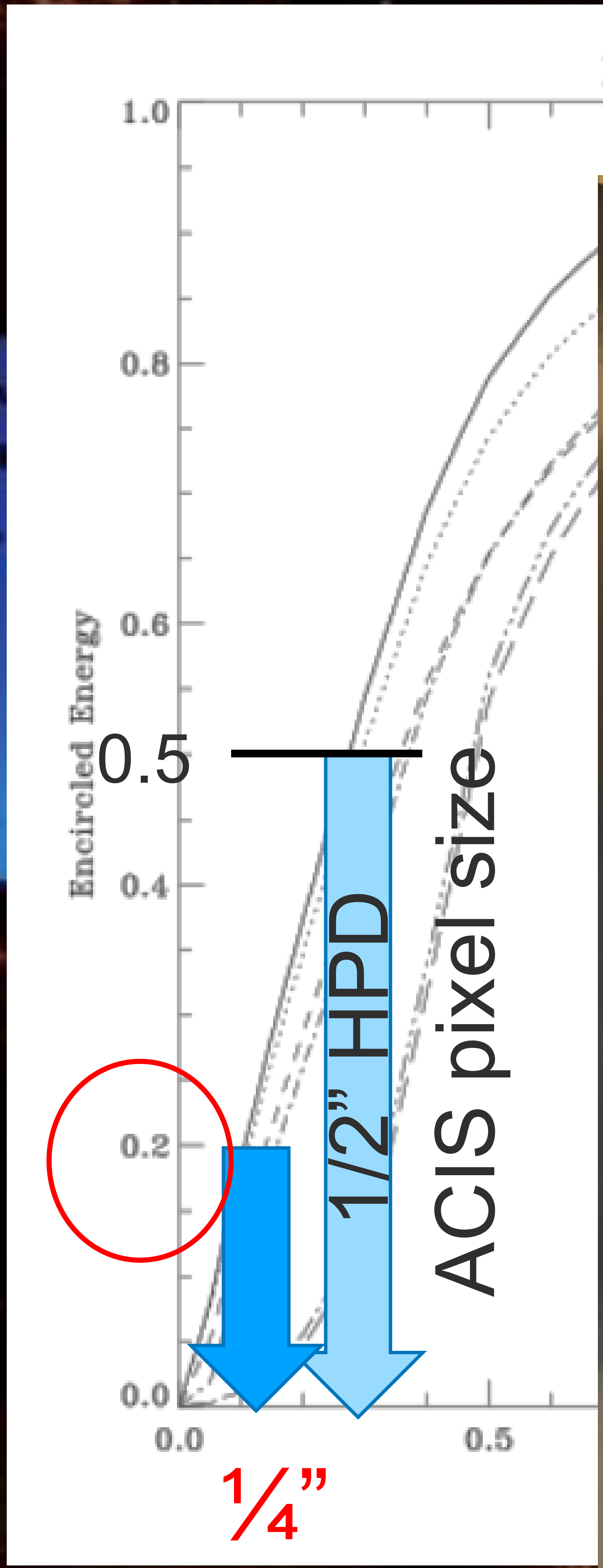
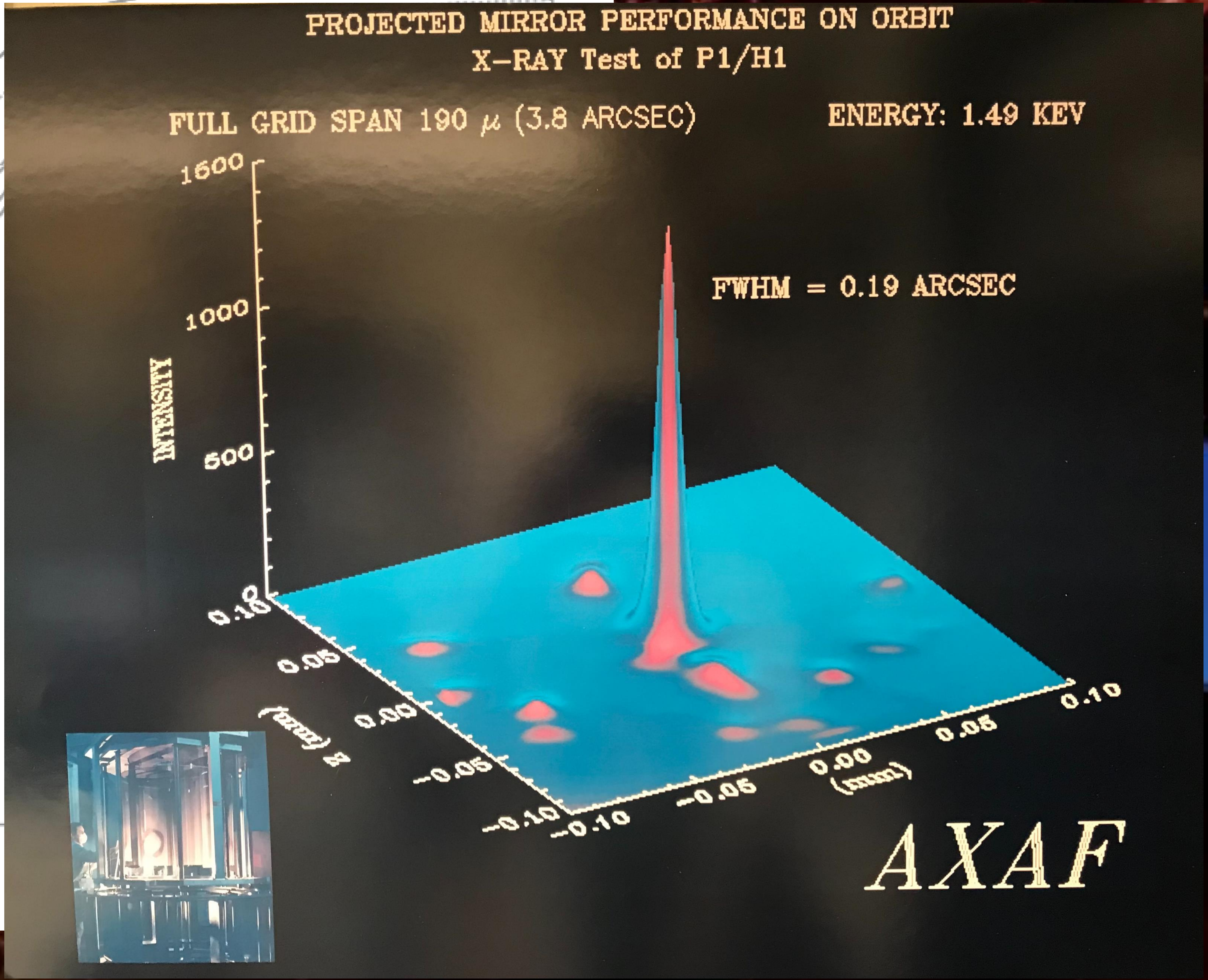


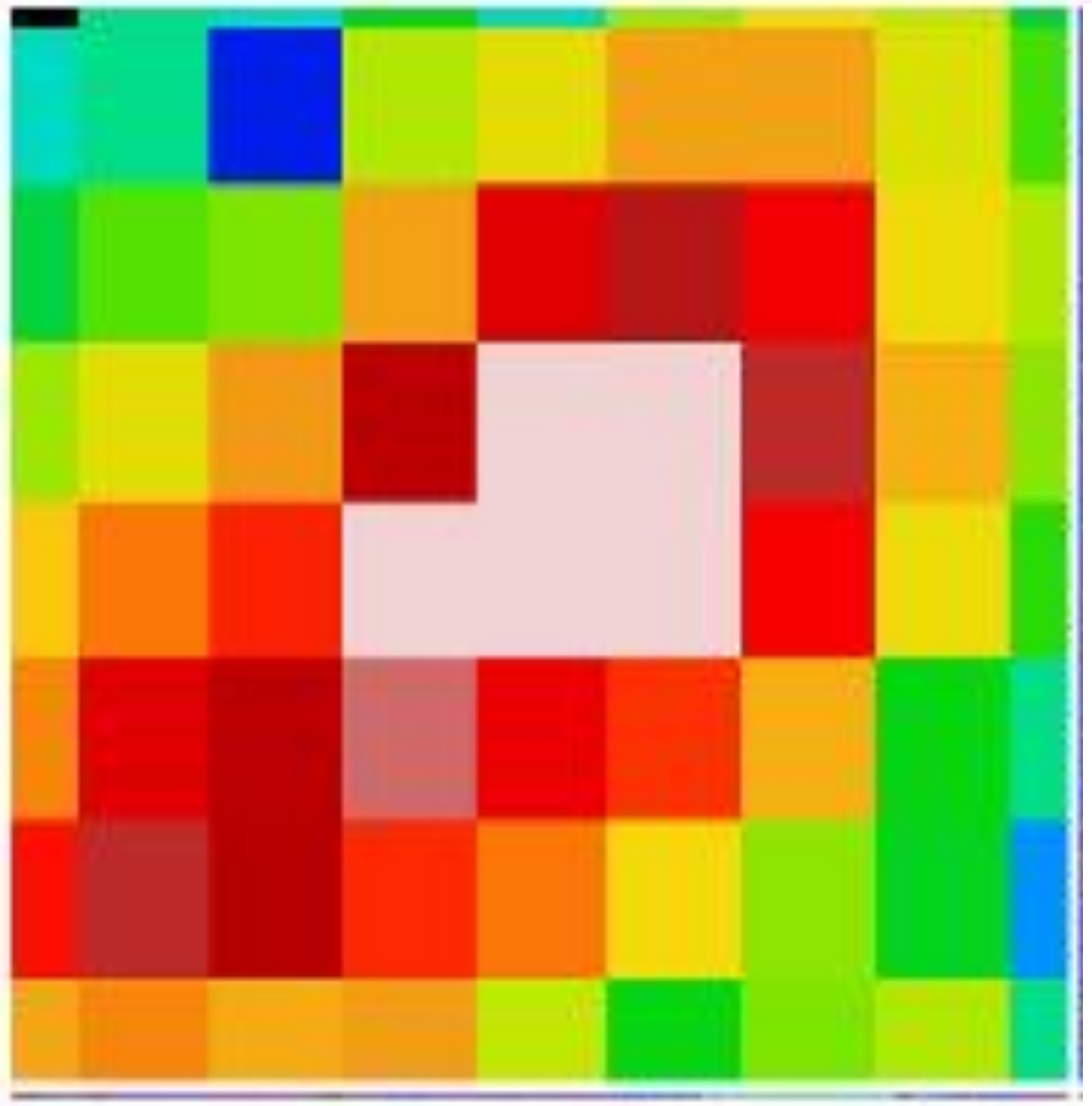


AGNs with Sub-Pixel Binning – Comparison with HST Images

Fabbiano et al. 2018

ESO 428 – G014

ACIS – 0.495 pixel	ACIS – 1/16 pixel	ACIS 1/16 – PSF Deconvolved	with HST Hα contours



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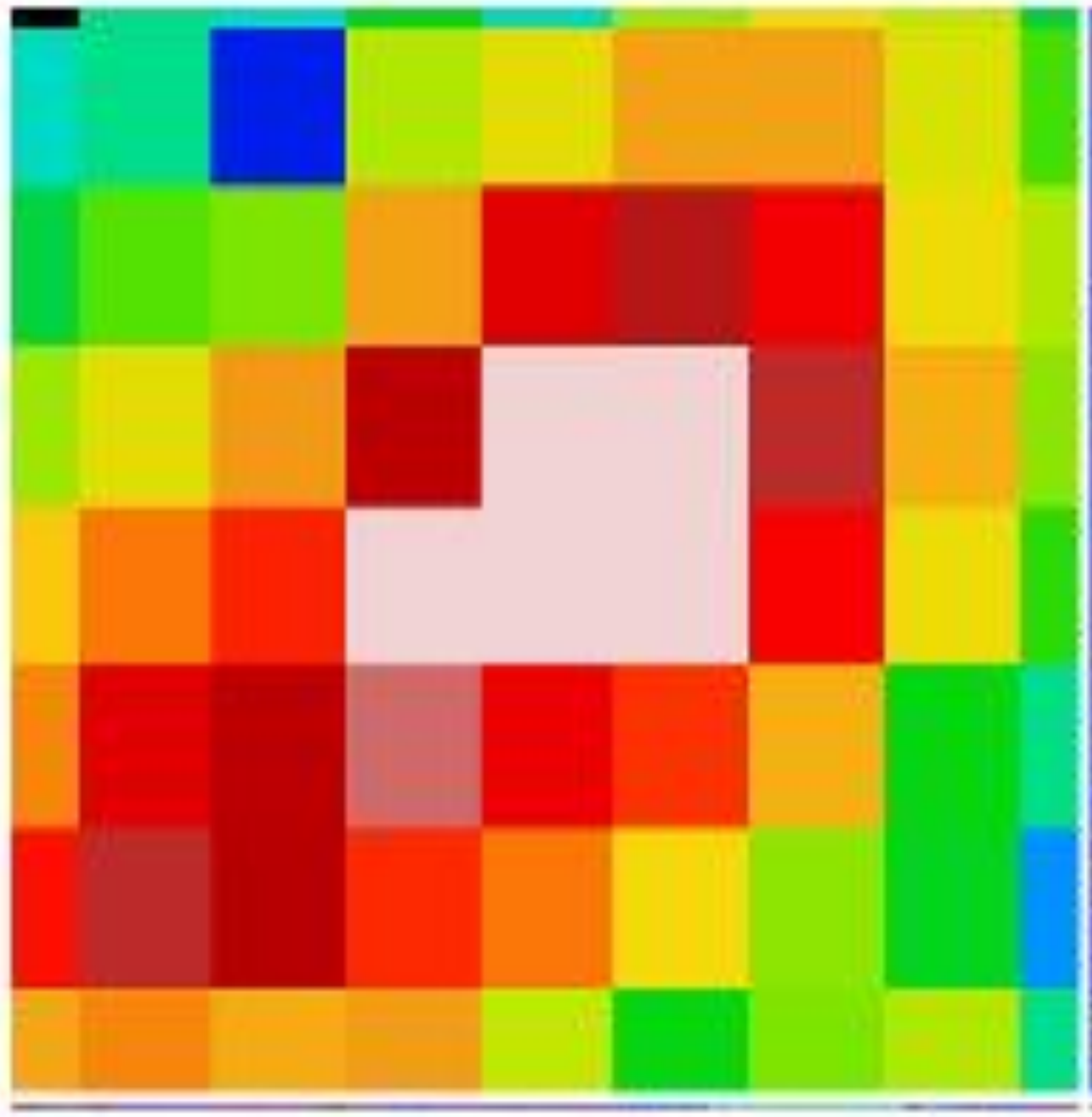

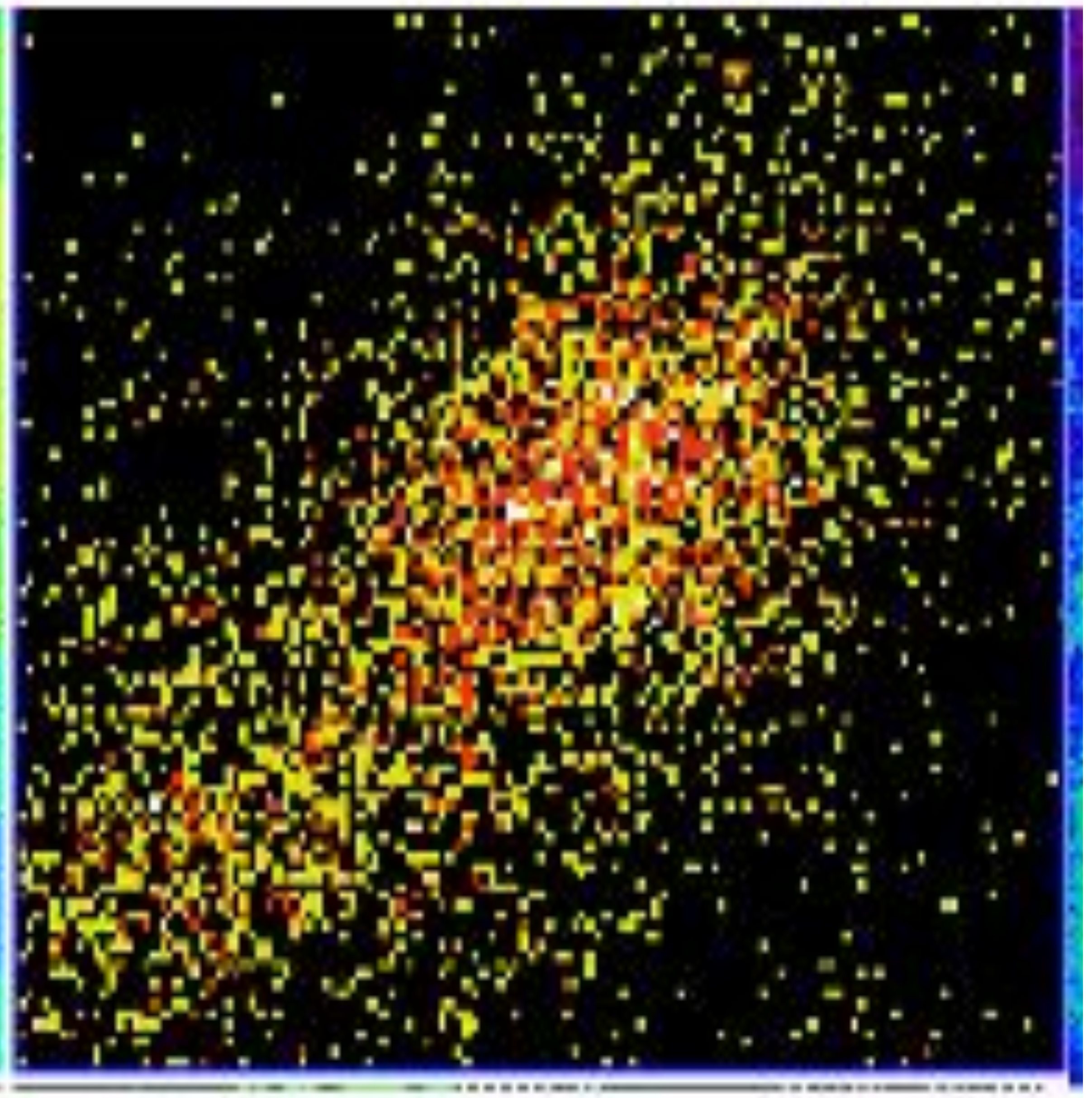

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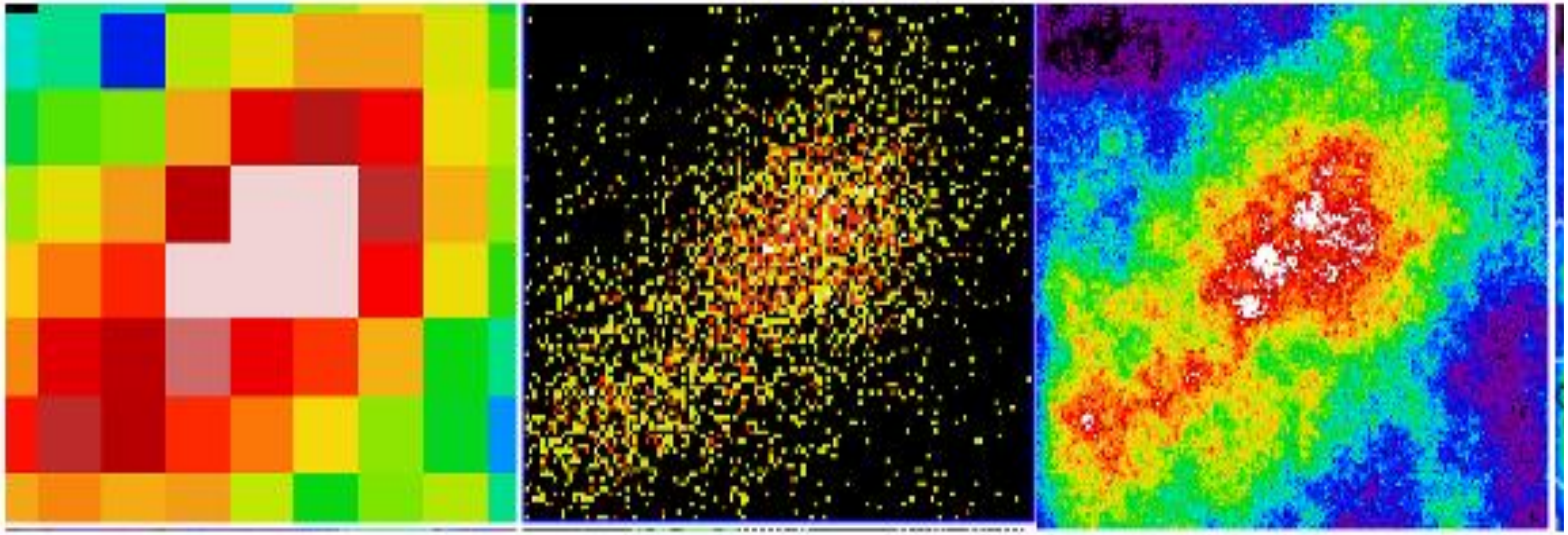

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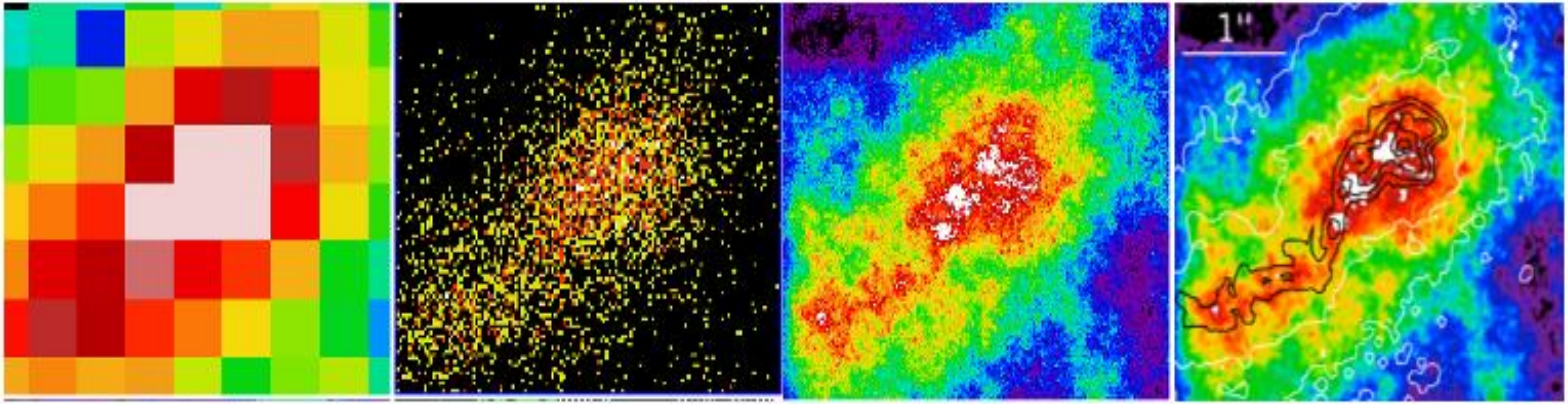
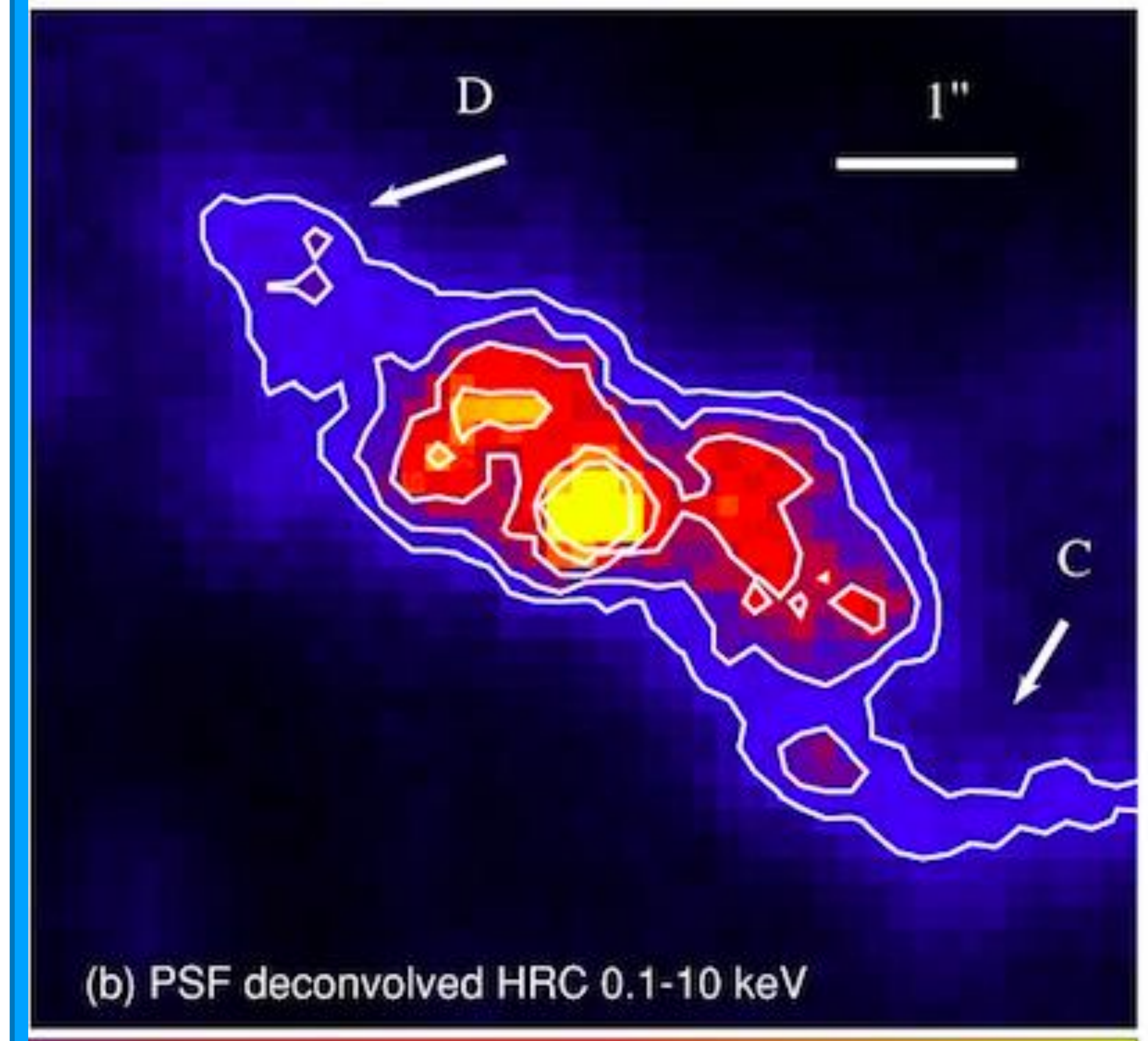


AGNs with Sub-Pixel Binning – Comparison with HRC images

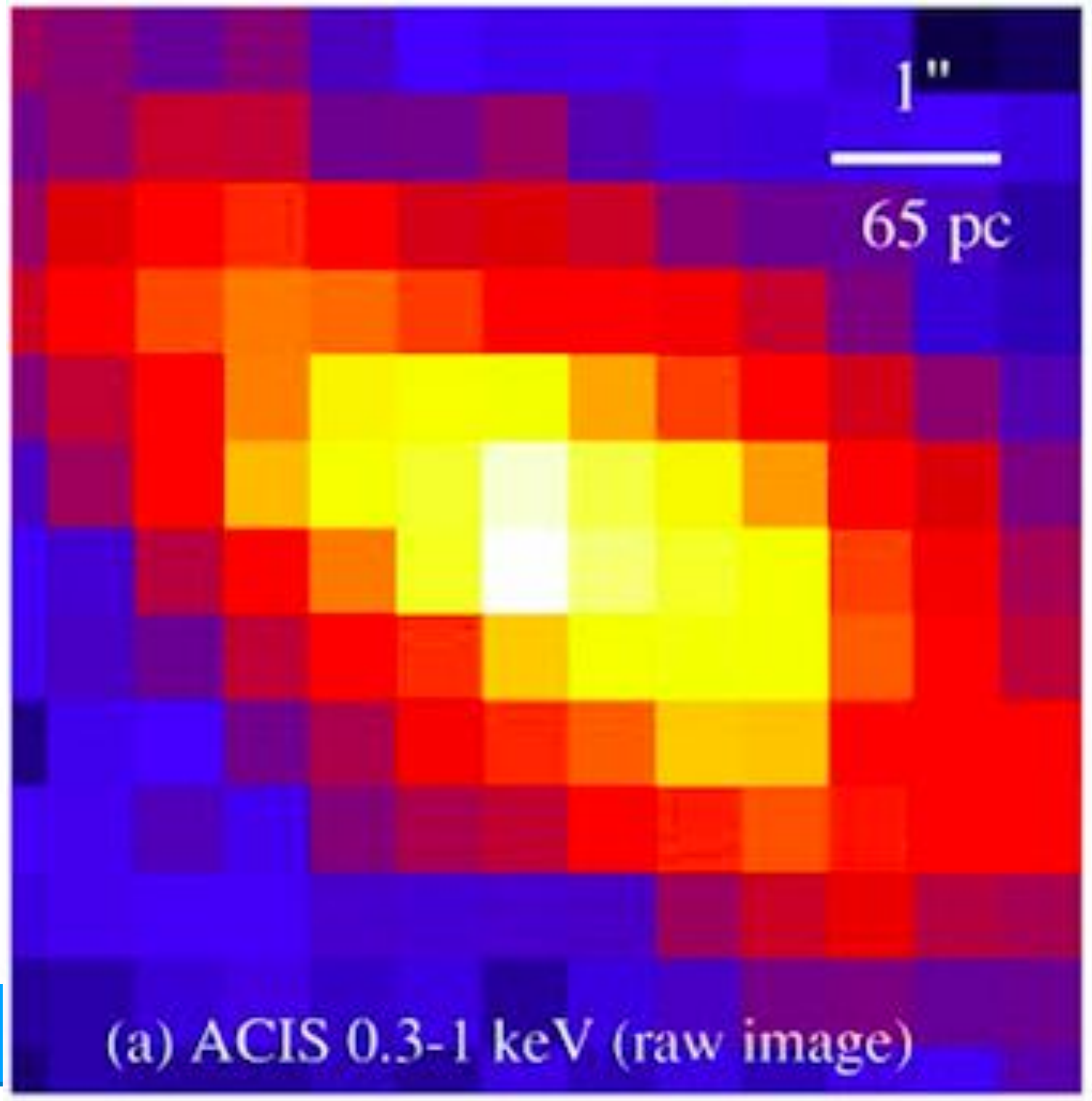
NGC 4151

Wang, Junfeng et al. 2011

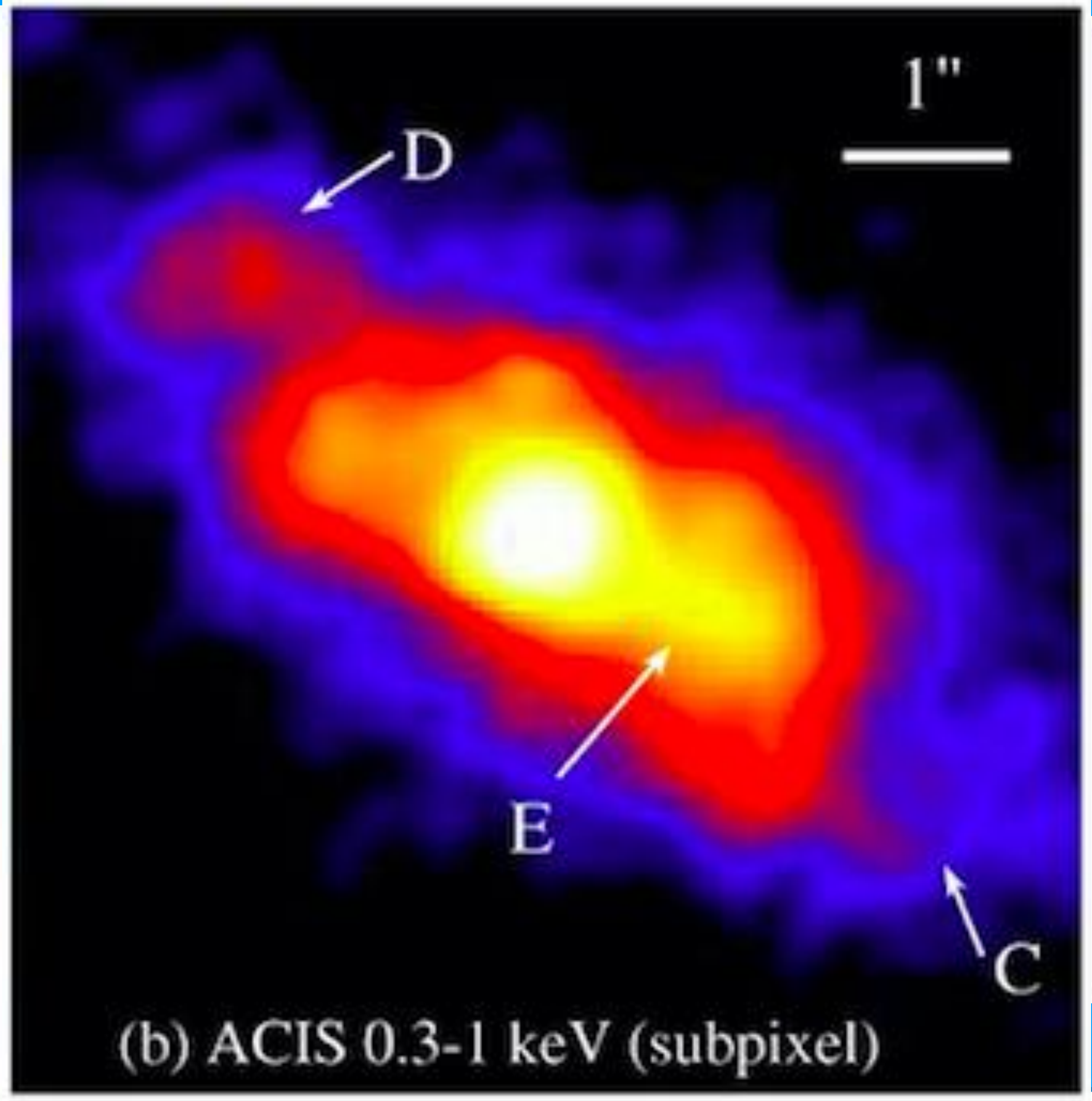
HRC – PSF Deconvolved



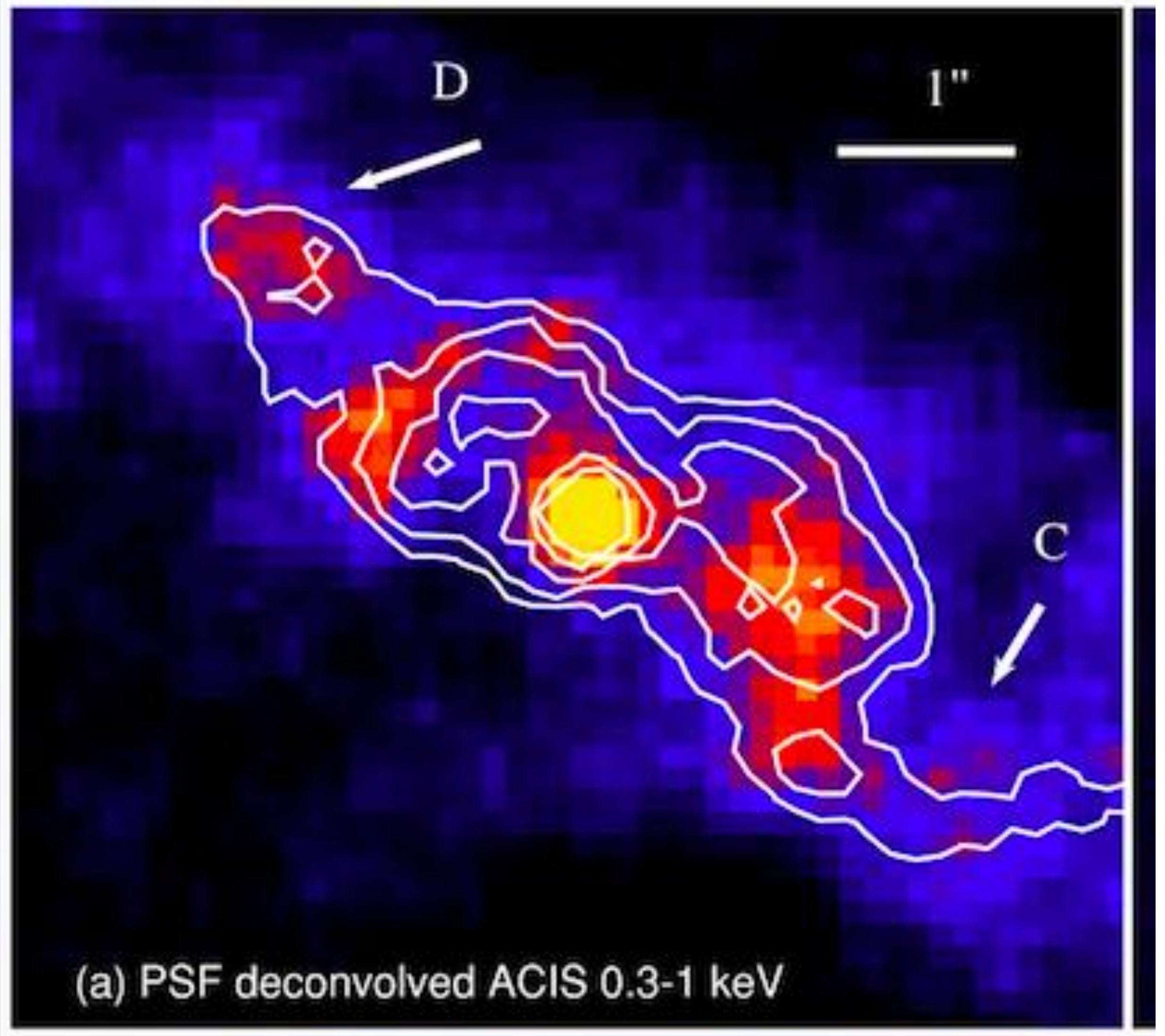
ACIS – 0.495 pixel



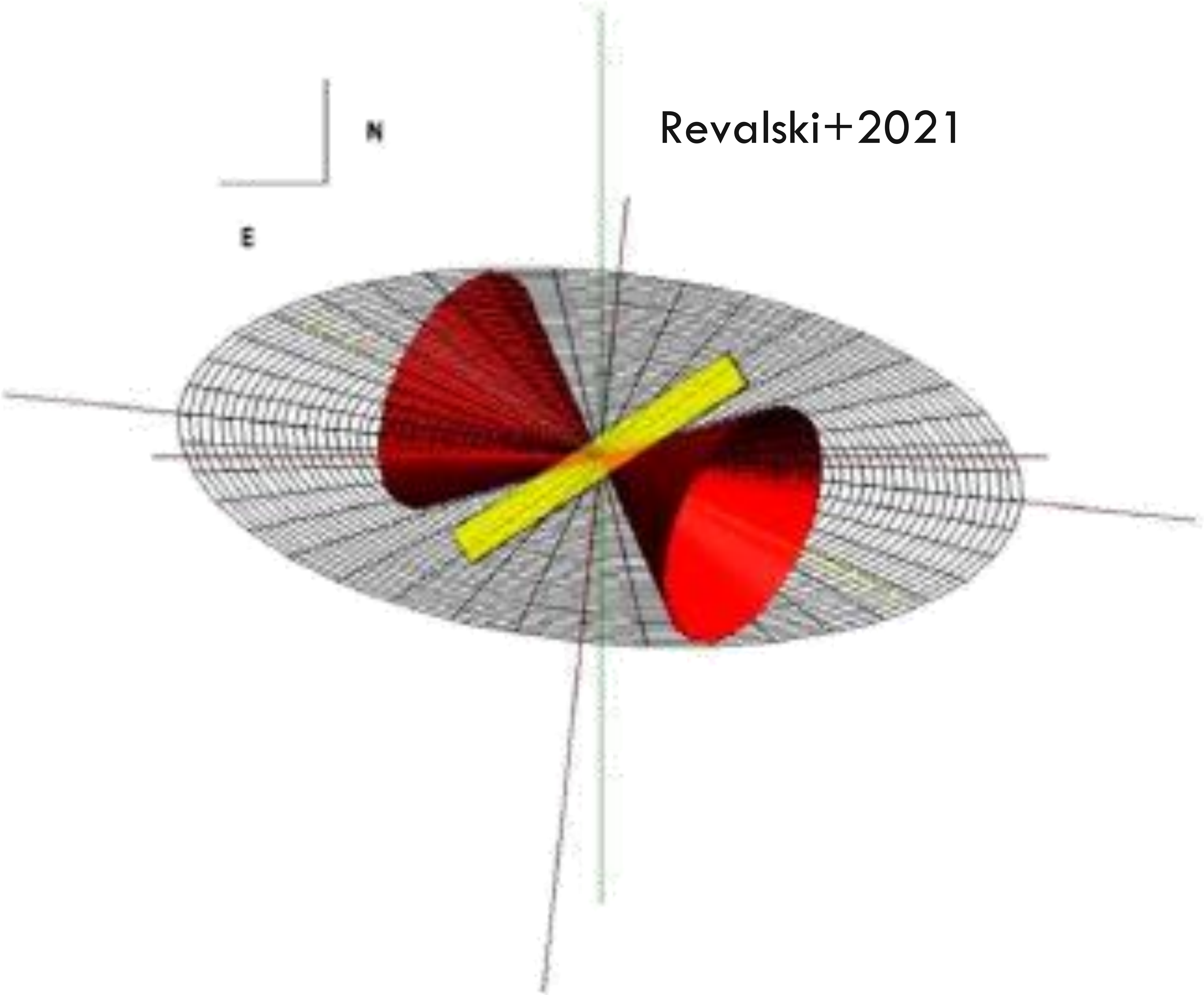
ACIS – 1/8 pixel



ACIS 1/8 – PSF Deconvolved +HRC contours



1. Winds MRK 78

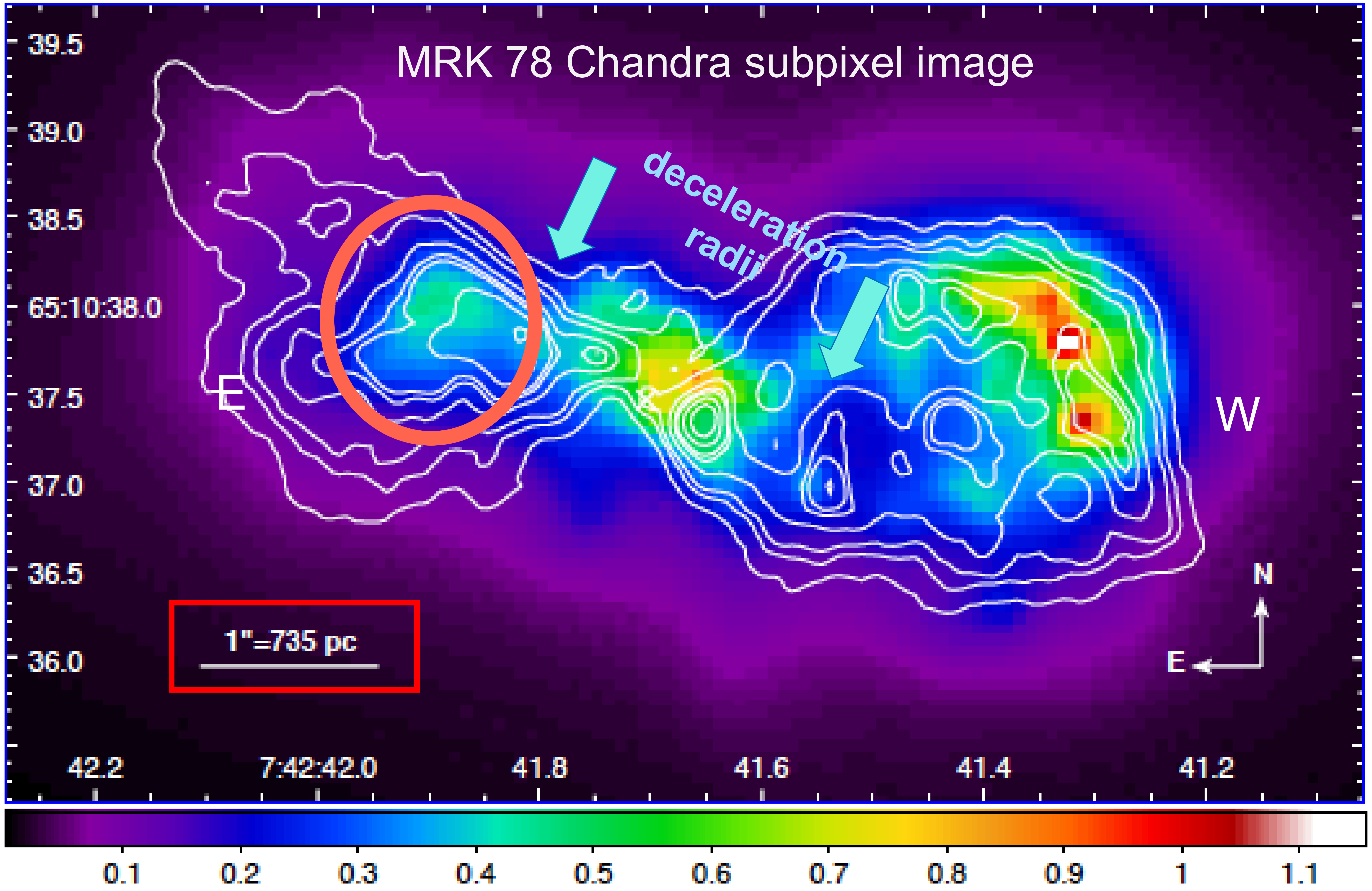


Revalski+2021

- Biconical ~1000 km s^{-1} [OIII] outflows
- acceleration for ~few 100 pc
- ***deceleration in <100 pc***

  Fischer+2011, Revalski+2021
- KE loss ~$10^{42.5}$ erg s^{-1}
- shock kT ~ 1.3 keV *X-rays*
- Do we see these X-rays?

1. Winds MRK 78



Fornasini+2022

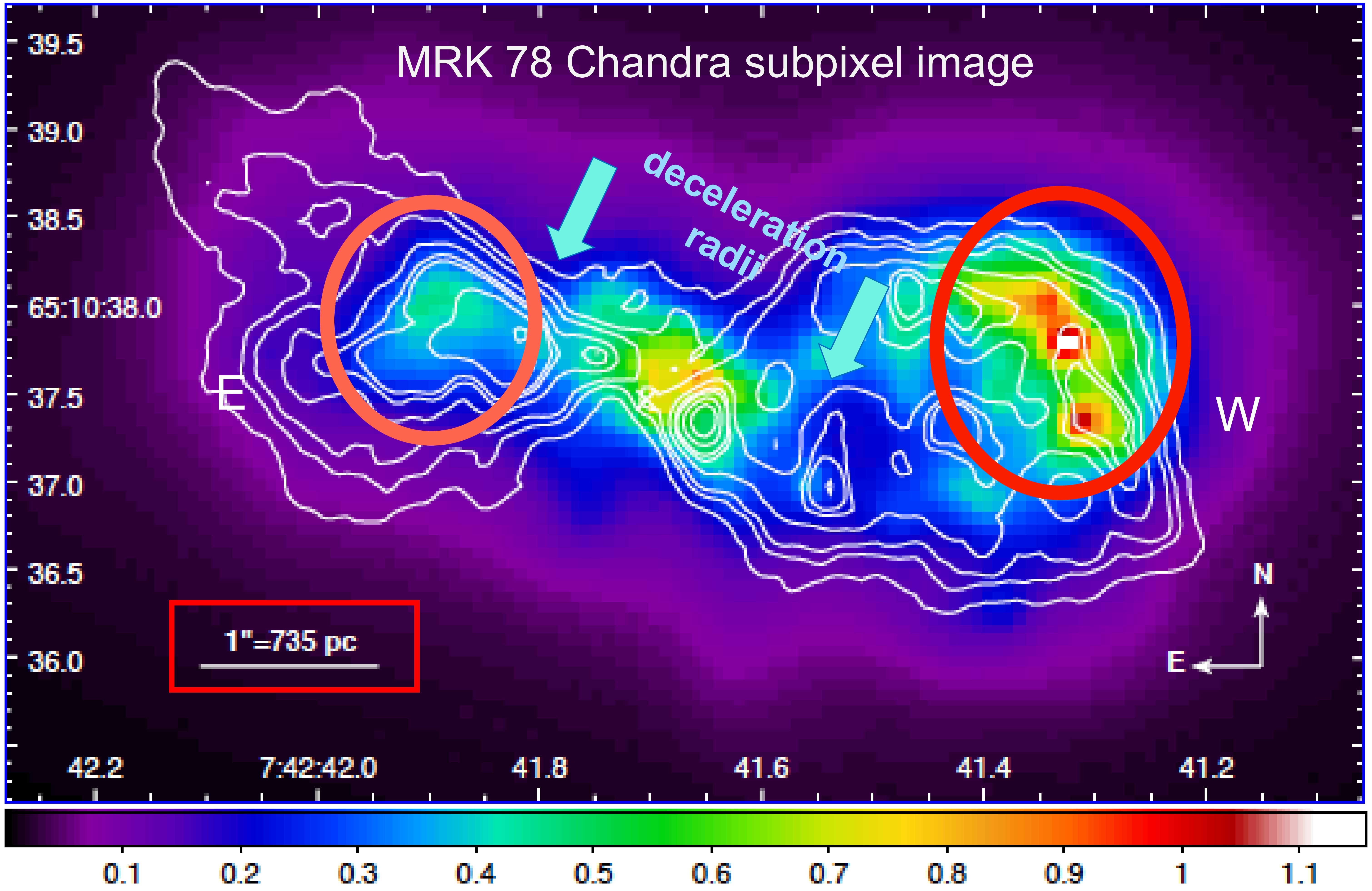
East deceleration radius ✓

(~900 pc Revalski+2021)

West deceleration radius ✗

where does the power go ?

1. Winds MRK 78



Fornasini+2022

East deceleration radius ✓

(~900 pc Revalski+2021)

West deceleration radius X

where does the power go ?

Seen ~1 kpc "downstream" !

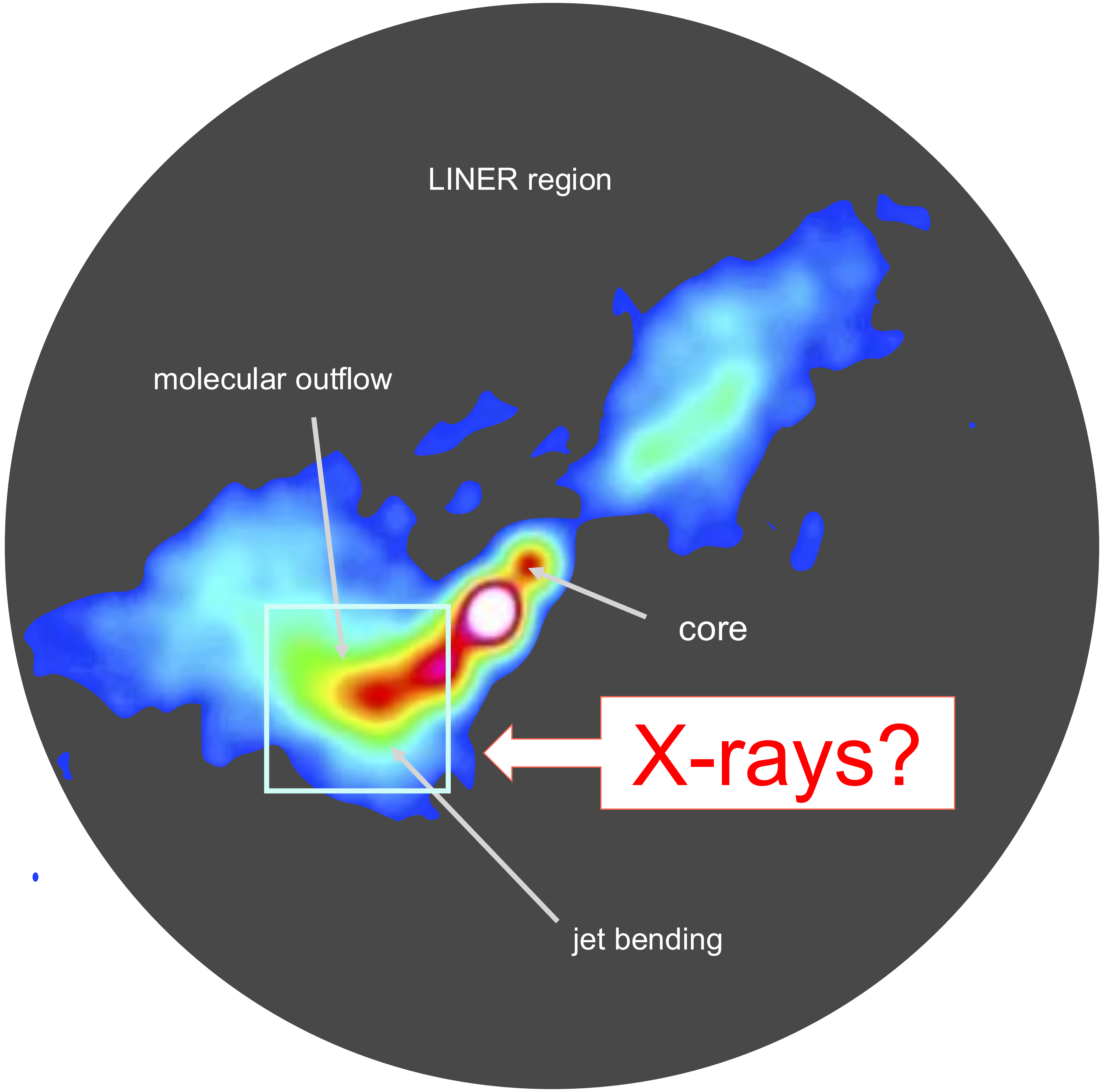
Too hot to radiate efficiently

(c.f. H-Haro objects, Heathcote+98)

Cooling time -> 1 kpc

2. Jets NGC 1167/B2 0258+35

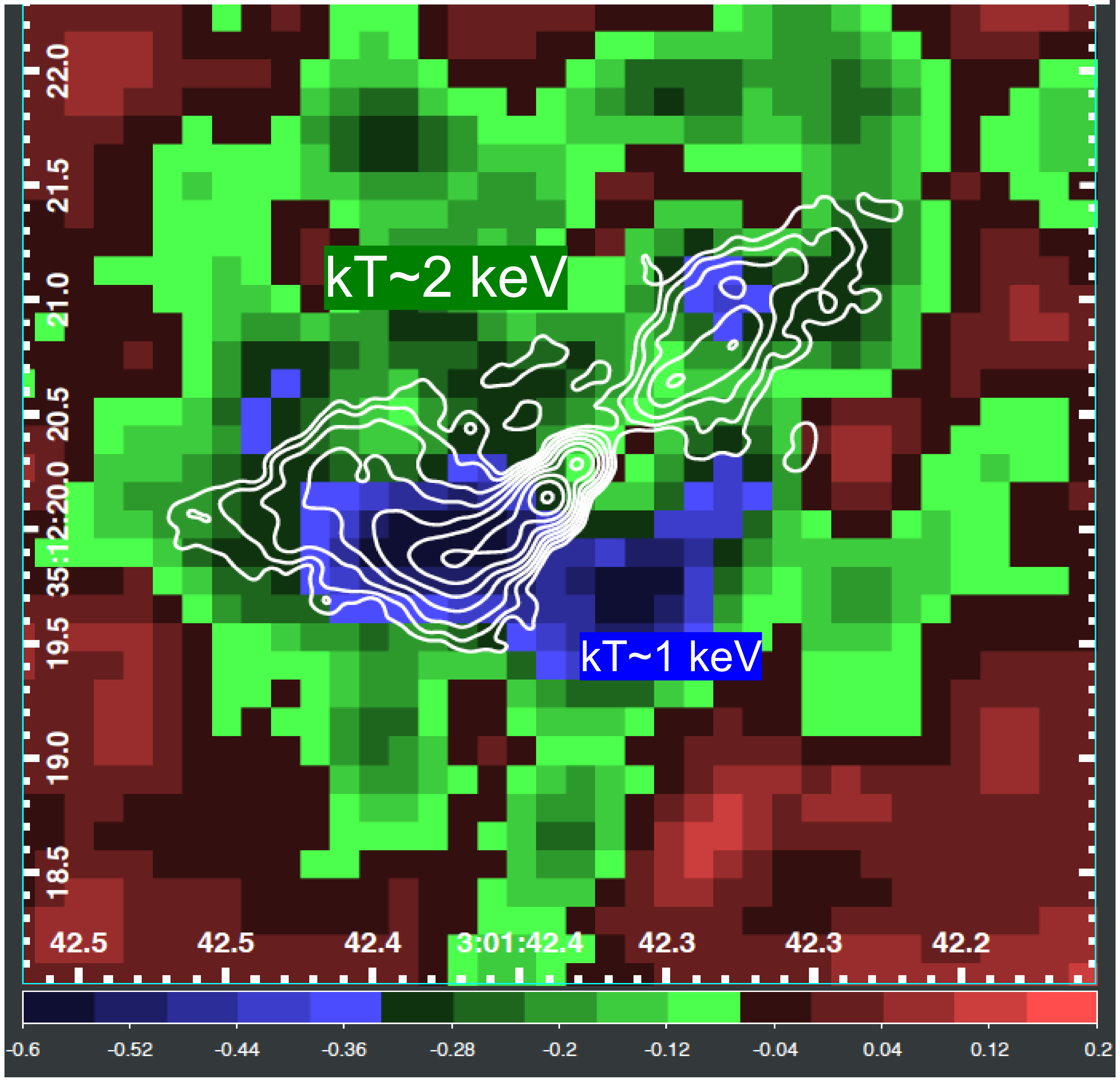
Fabbiano+2022



- L(radio,1.4GHz)~10X NGC 4151
- jet slowed, diverted by ISM (CO)

  Murthy+2022
- Young radio source (~0.4×10^6 yr)
- v_{out} ~ few 1000 km s^{-1} → X-rays

Chandra X-ray Temperature Map



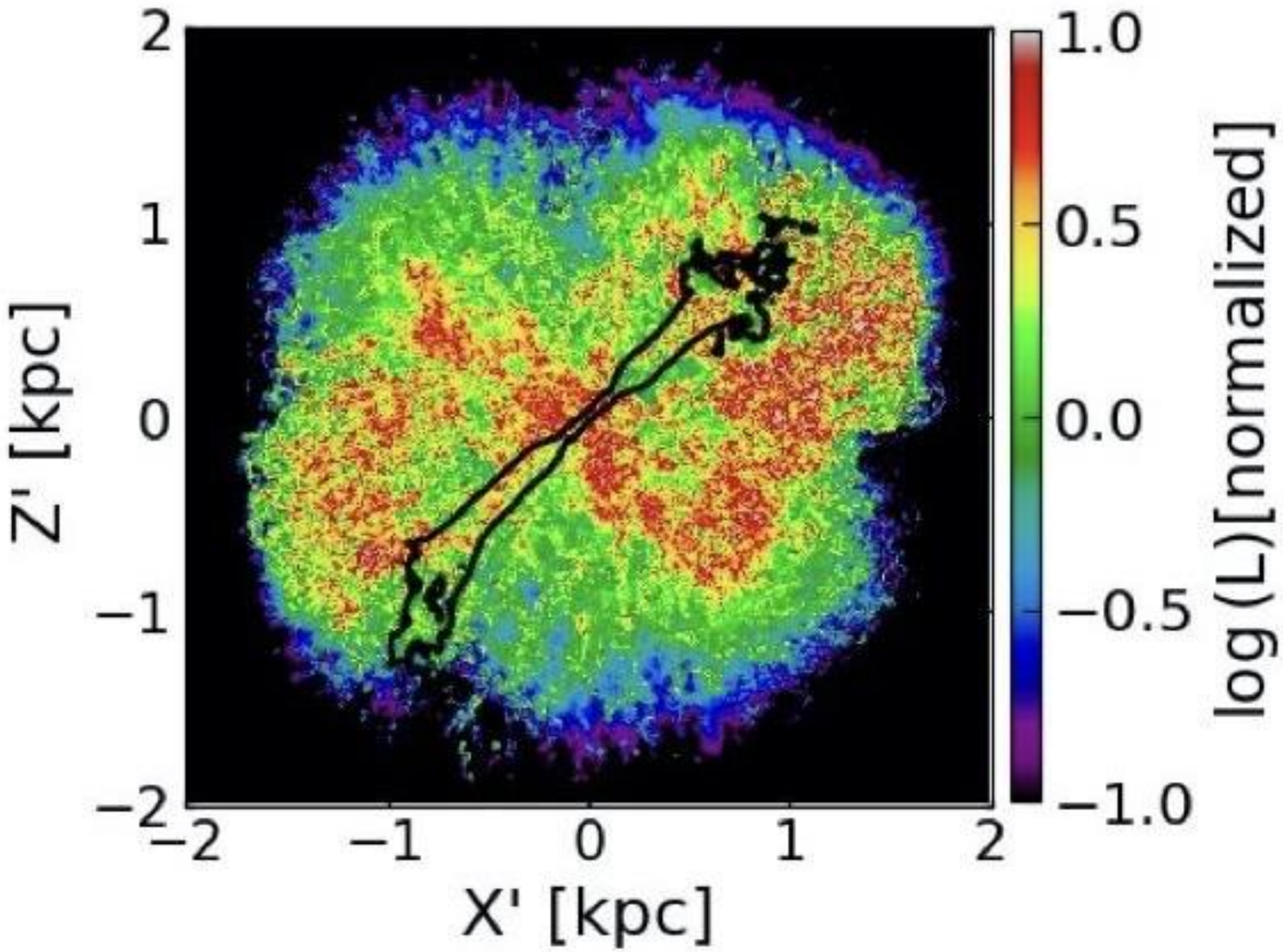
2. *Jets* NGC 1167/B2 0258+35

Fabbiano+2022

- X-rays where jet bends
- Low kT~1 keV (<1000 km s^{-1})
- Compressed ISM → rapid cooling?
- Cool to S (jet motion? CO outflow?)
- ALSO: X-rays extended *cross-jet*
- too hot to be a bound galaxy halo

2. *Jets* NGC 1167/B2 0258+35

Fabbiano+2022



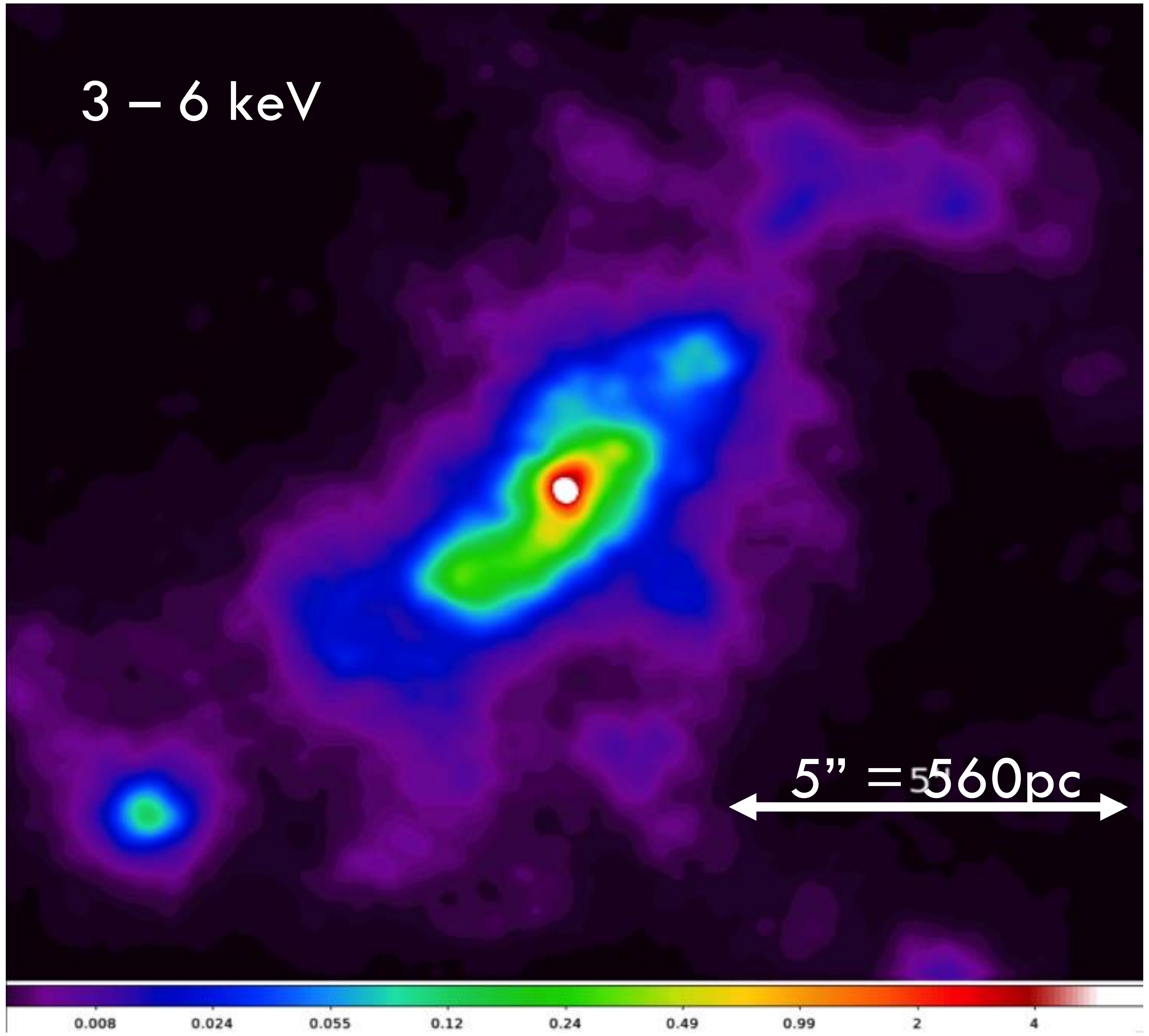
- Hot ISM predicted in simulations (Mukherji+)
- for *clumpy* ISM
- drive shocks to ~10 kpc

  → galaxy-wide negative feedback

Low power jets are common

3. Radiation ESO428-G014

Fabbiano+2017, 2018, 2019



- Extended hard X-ray, Fe-K

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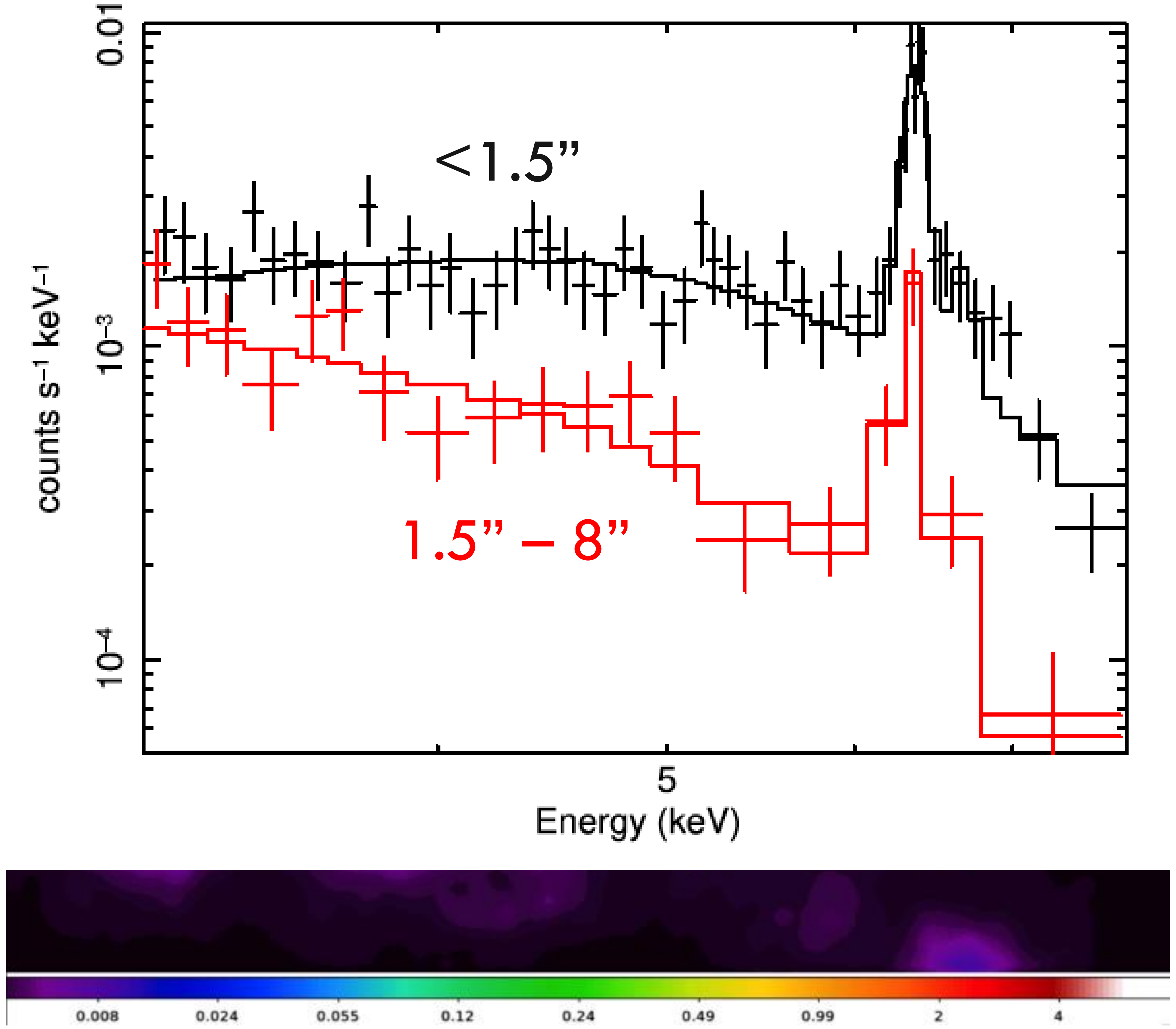
Fabbiano+2017, 2018, 2019



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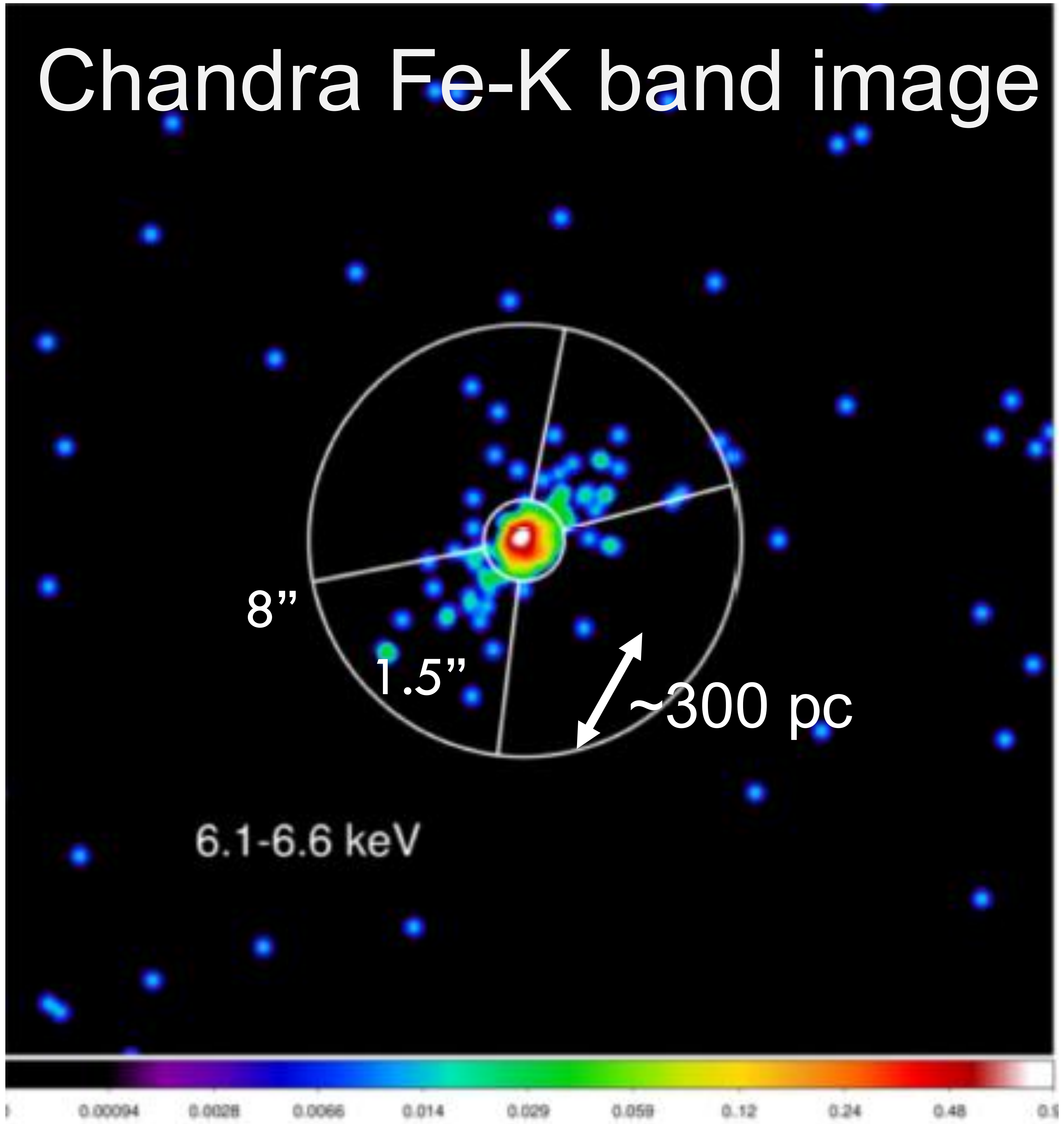
Fabbiano+2017, 2018, 2019



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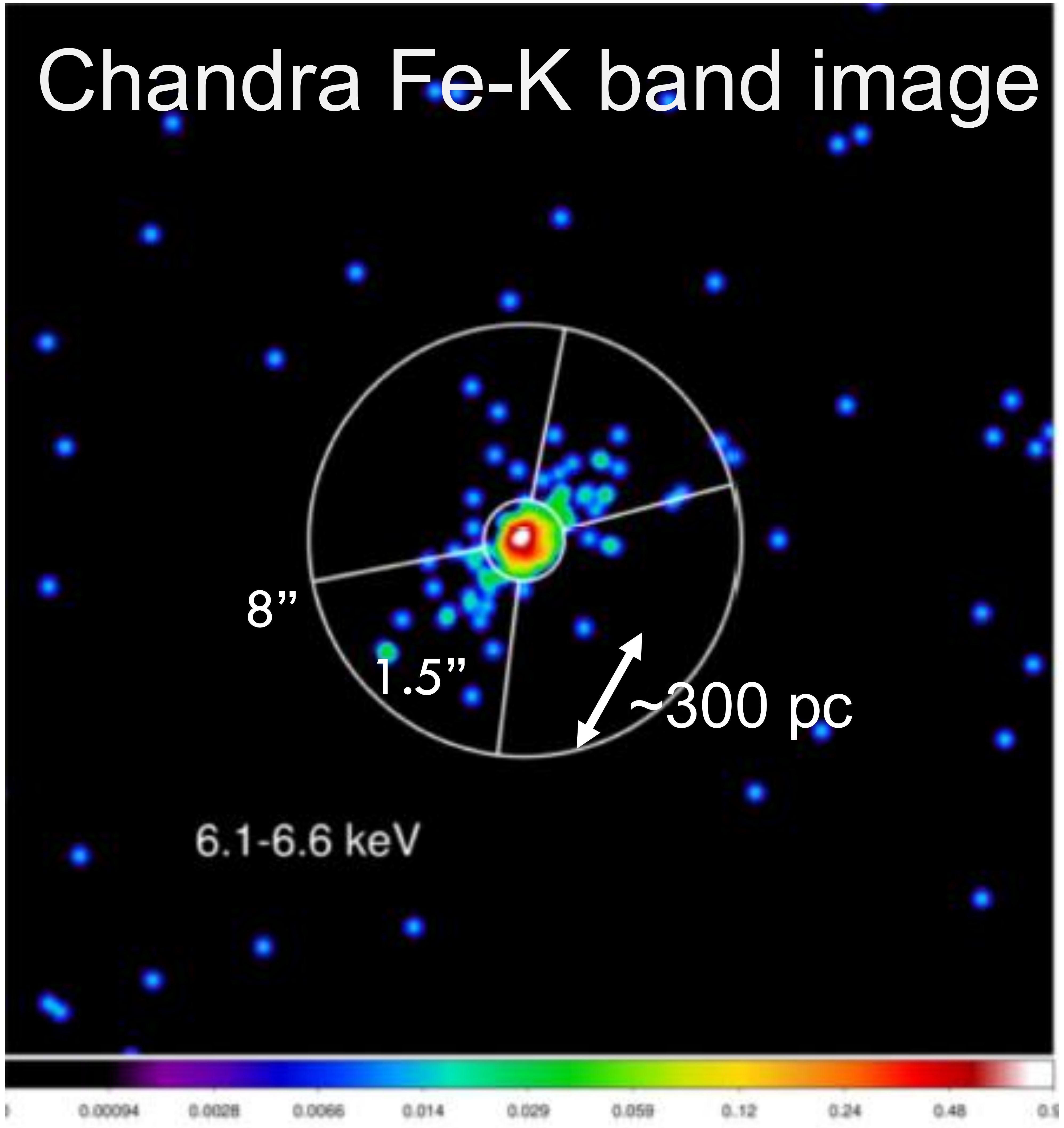


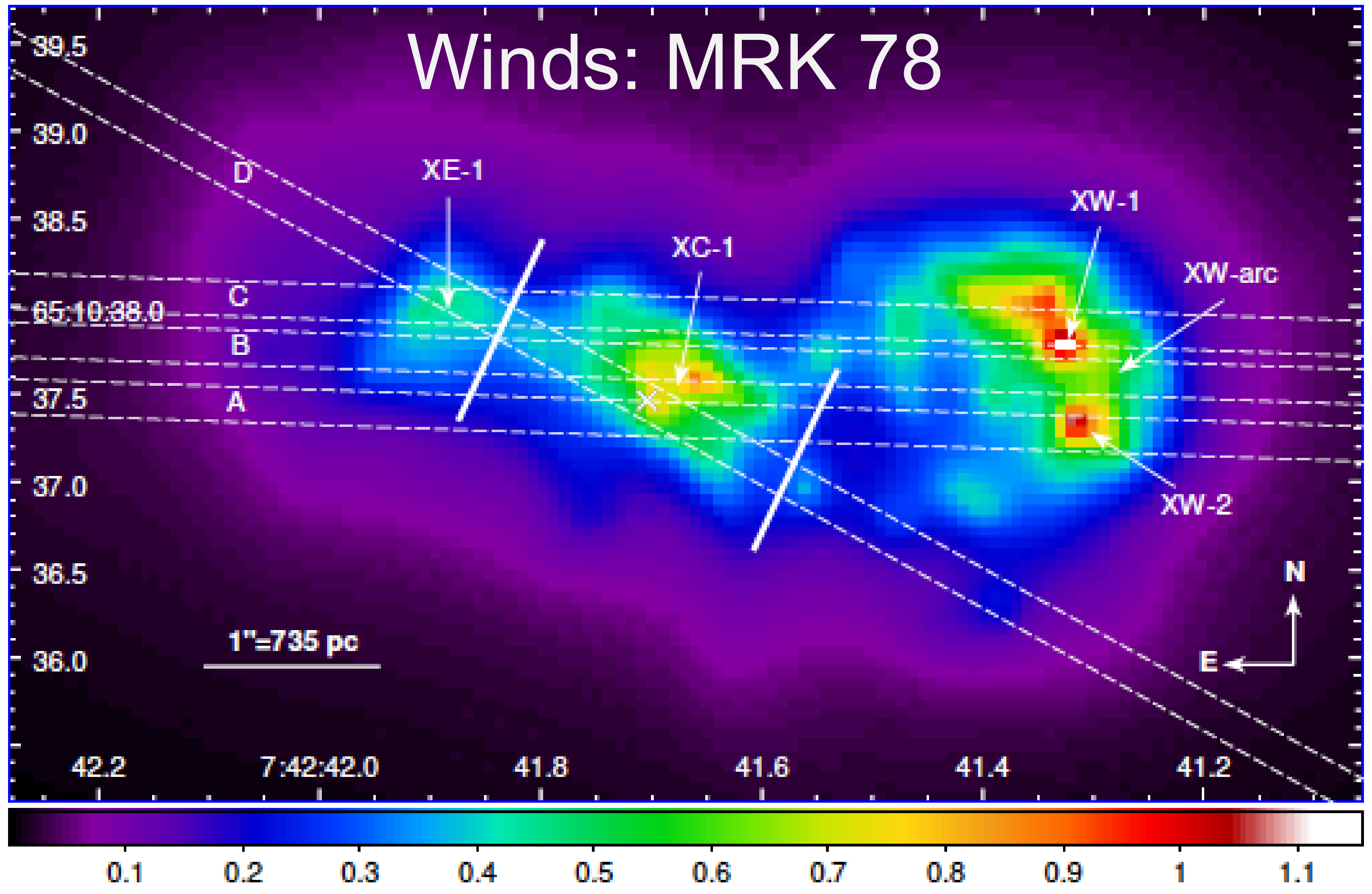
- Extended hard X-ray, Fe-K

→Compton thick cold reflectors: $N_H \sim 10^{24}$ cm^{-2}

- ~300 pc from nucleus
- Normal ISM (1cm^{-3}) over 1 kpc ~$N_H \sim 10^{21.5}$ cm^{-2}

→**Molecular clouds in host disk**

- Will irradiation destroy the clouds?



Winds, Jets, and Radiation

Fabbiano & Elvis, 2022,

arXiv:2202.13803

- Yes!

Winds, Jets, and Radiation

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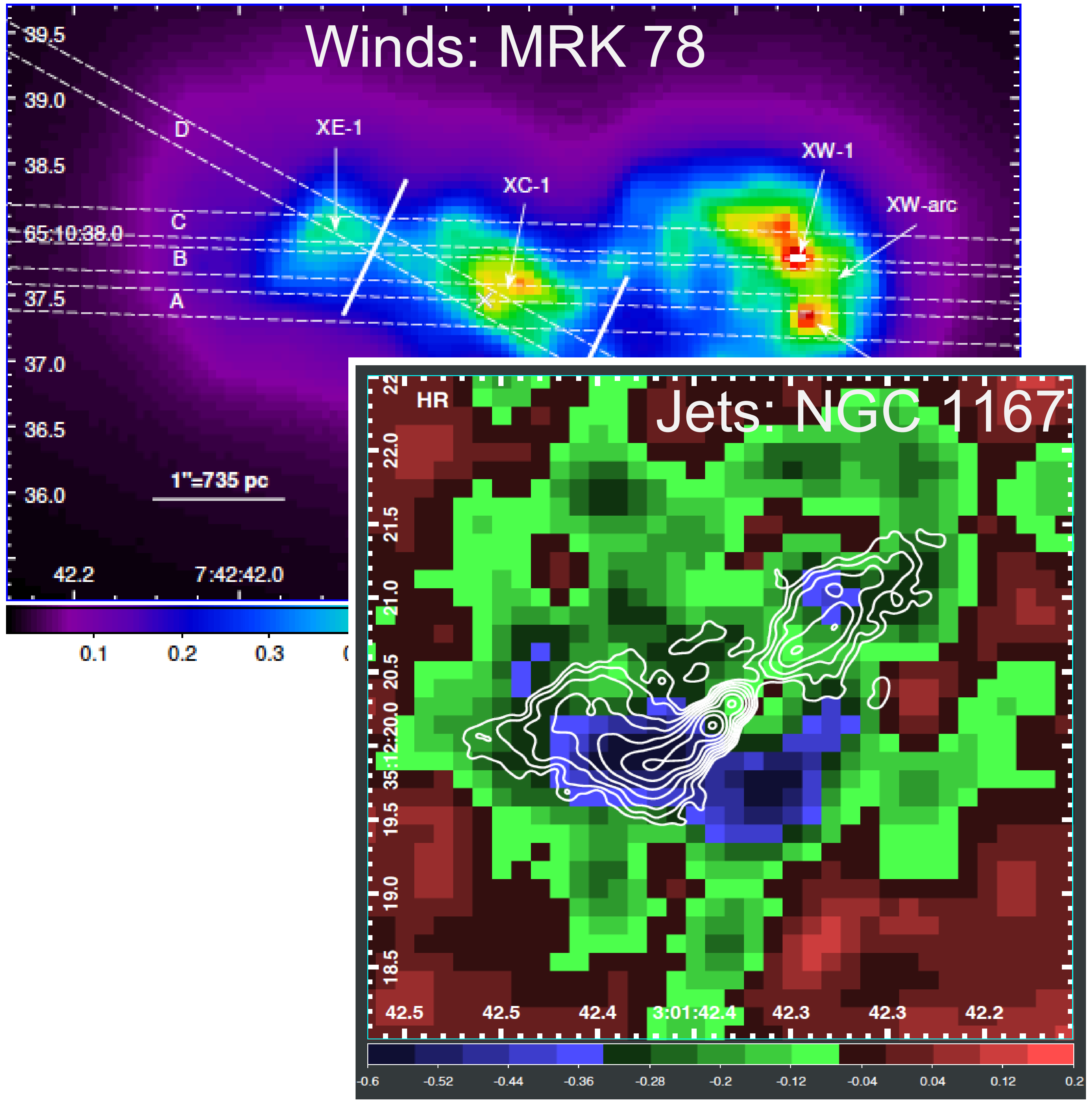

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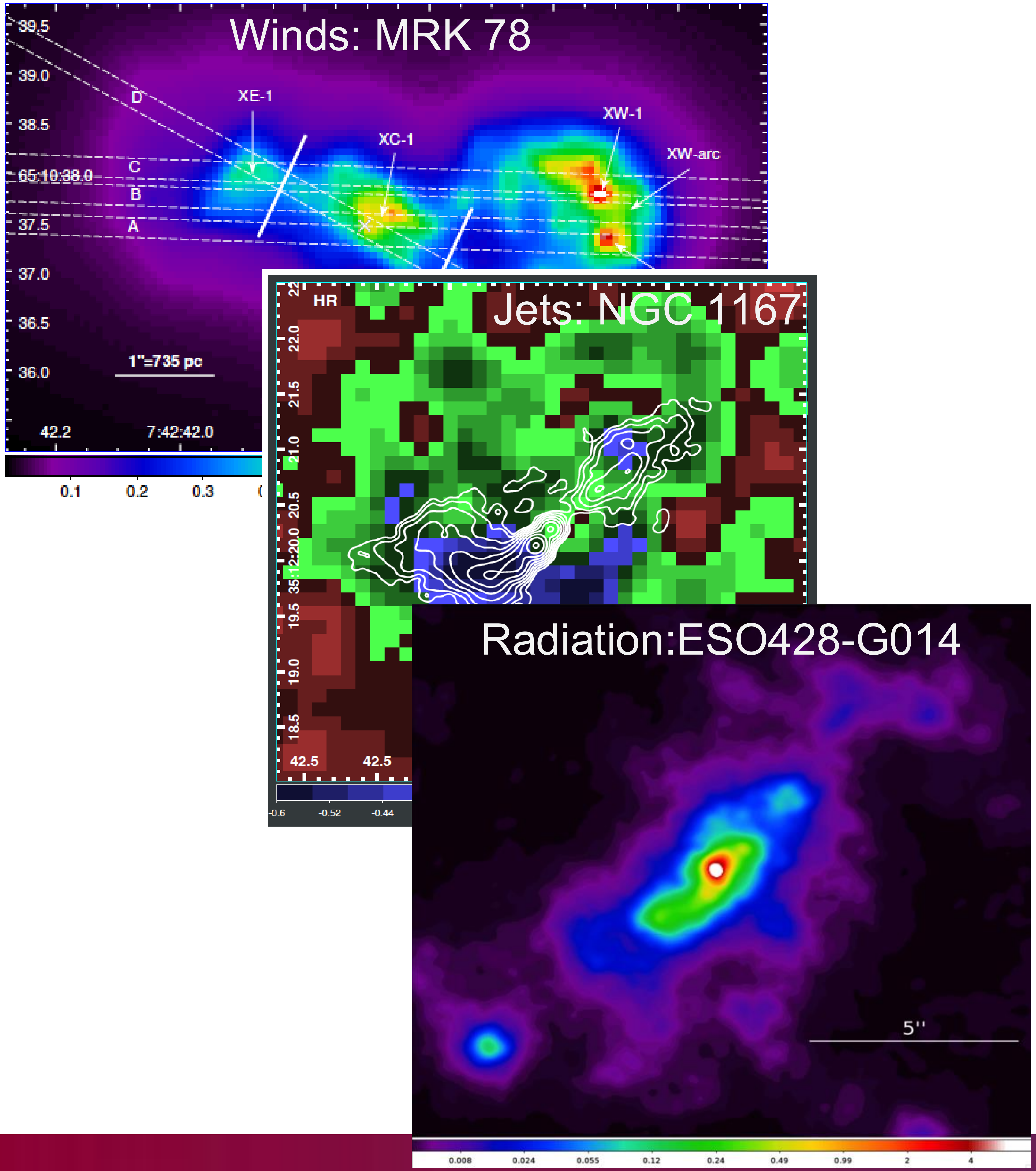


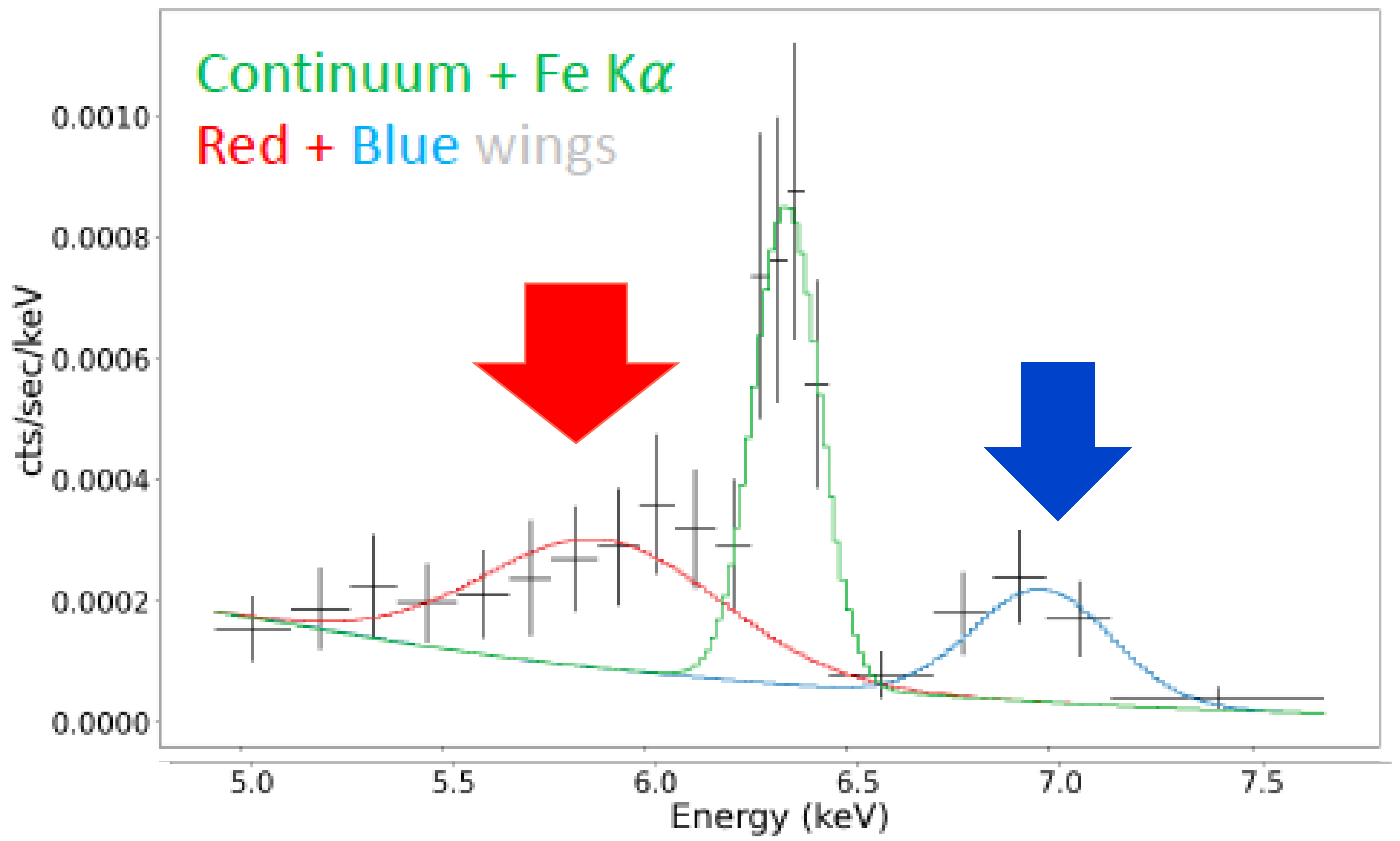
- Yes!
- All 3 mechanisms ***seen at work***

→ demonstrates

The Uniqueness of Sub-arcsecond Resolution in X-ray Astronomy

4. *New* Fast Outflows

Maksym et al., 2023, arXiv2209.14326M
Trindade Falcão et al., 2023,



- UFOs, BALs ~0.1c close to nucleus
- **Chandra sees them 100s pc out ?**

MRK 34 Maskym+2023

NGC 5728 Trindade Falcão+2023

- **v ~ 0.1 c**

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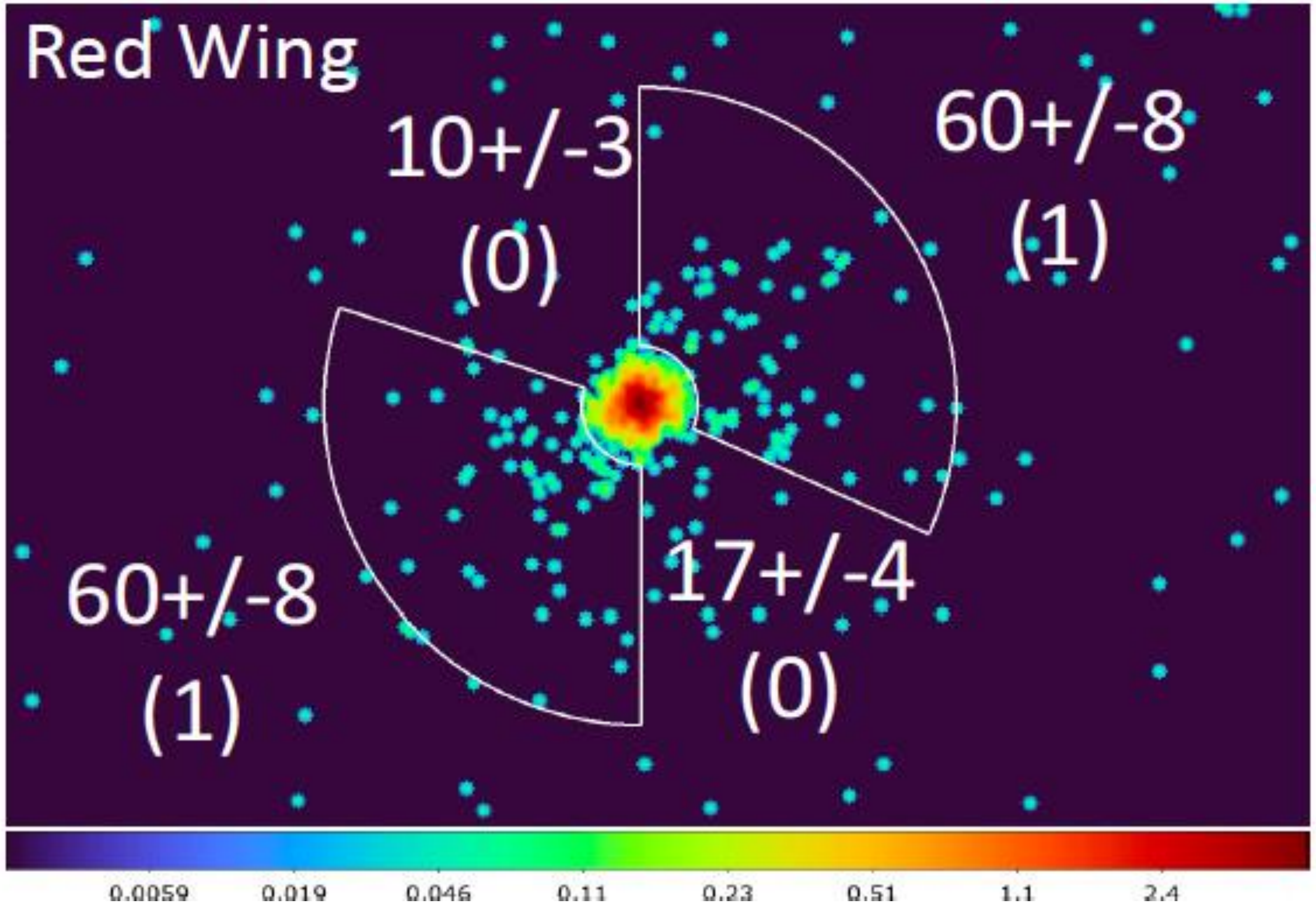

- UFOs, BALs ~0.1c close to nucleus
- **Chandra sees them 100s pc out ?**
  - MRK 34 Maskym+2023
  - NGC 5728 Trindade Falcão+2023
  - **v ~ 0.1 c**
- BAL/UFO in emission?
- Co-exists with WA-like slow outflow
- $L_{KE} \sim v^3$
- Far larger L_{KE} @ 1kpc

How to get X-ray velocities

- Now have to ***assume*** $v_{X\text{-ray}} = v_{[OIII]}$
- Astro2020: fly a Lynx-like flagship
- <1/2" HPD mirror; large area
- imaging microcalorimeter as on XRISM
- >2045 in Astro2020

→ a long wait.

Accelerating Astro2020?

Elvis, Lawrence, & Seager,

Physics Today, February 2023

- SpaceX Starship could cut the wait
- Huge mass, volume @ same launch cost
- Greatly simplifies design, lowers cost.
- UVONIR: single primary mirror Douglas+2024
- Lynx: at least 3 "massive mirror" ideas
- Slash cost? Accelerate by a decade?

Using the Ultimate Resolution of Chandra to Image AGN Feedback: Winds, Jets, Radiation & Fast Outflows

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Thank you

Fabbiano & Elvis, 2022, arXiv:2202.13803

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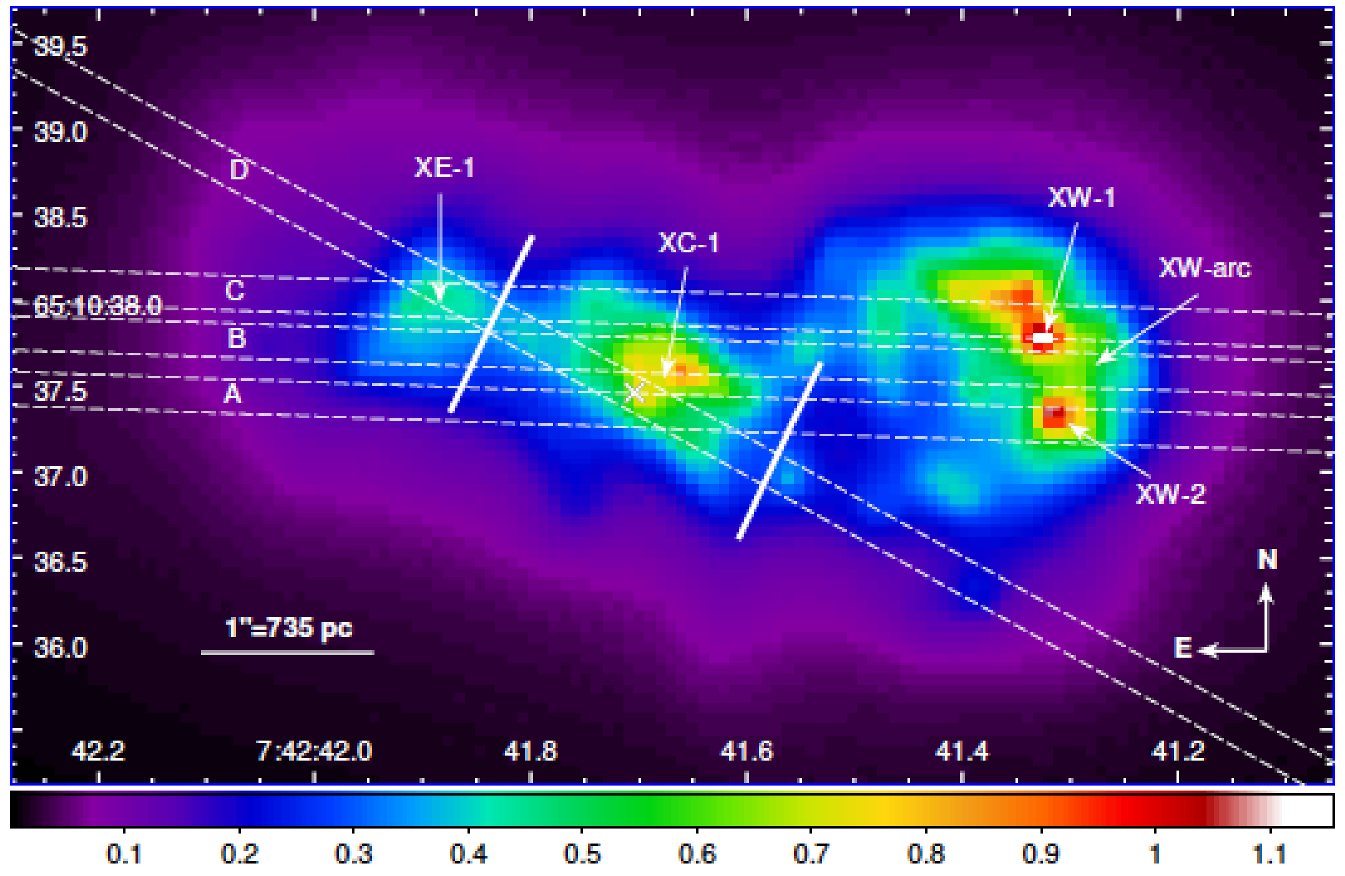
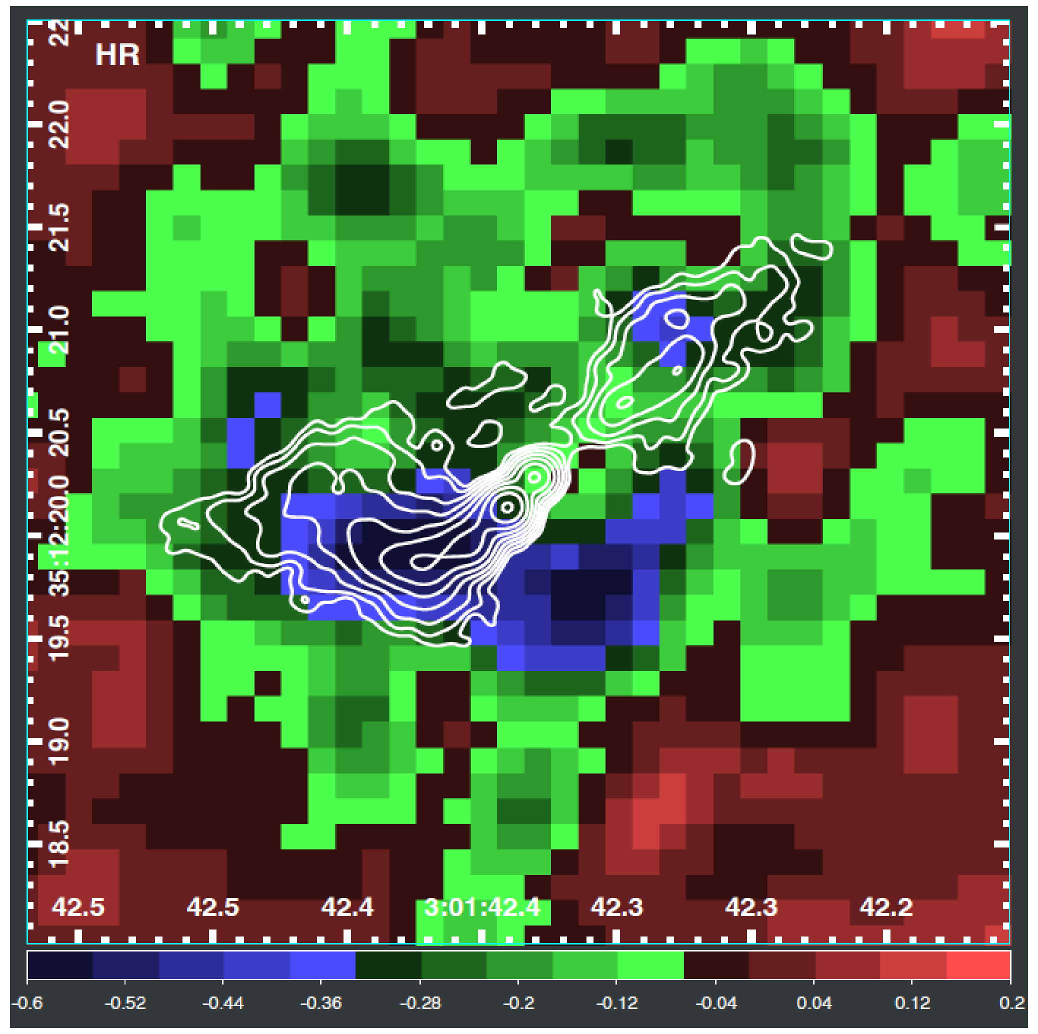
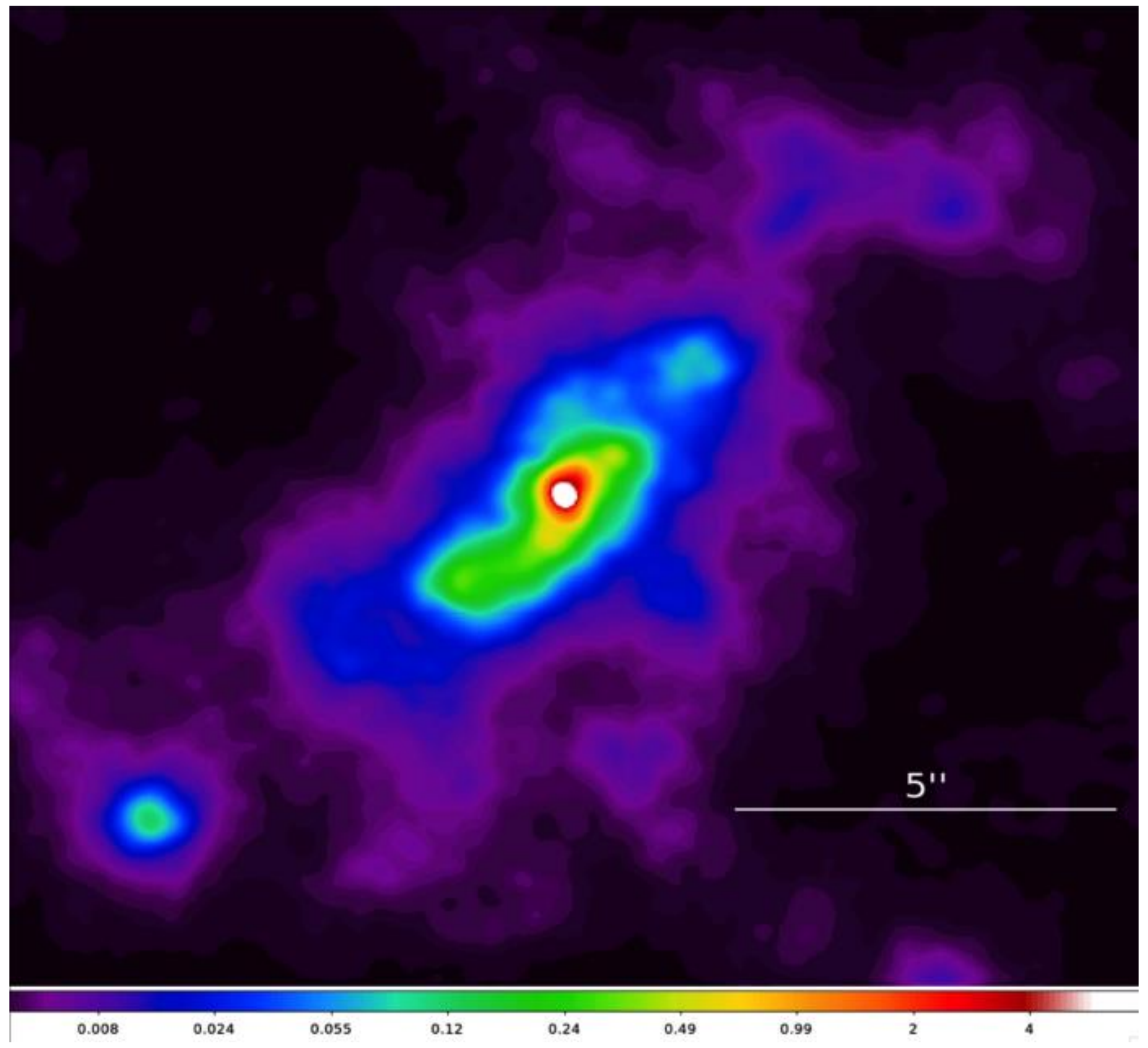


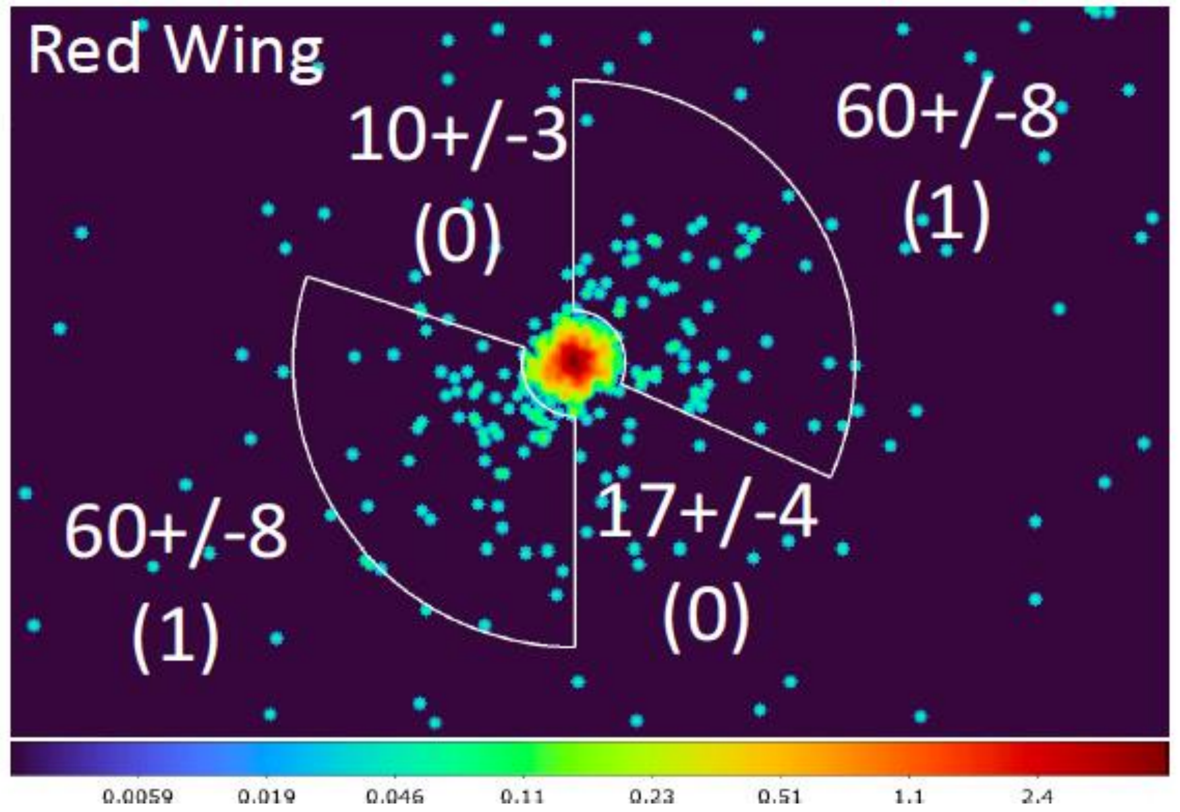
Jets: NGC 1167



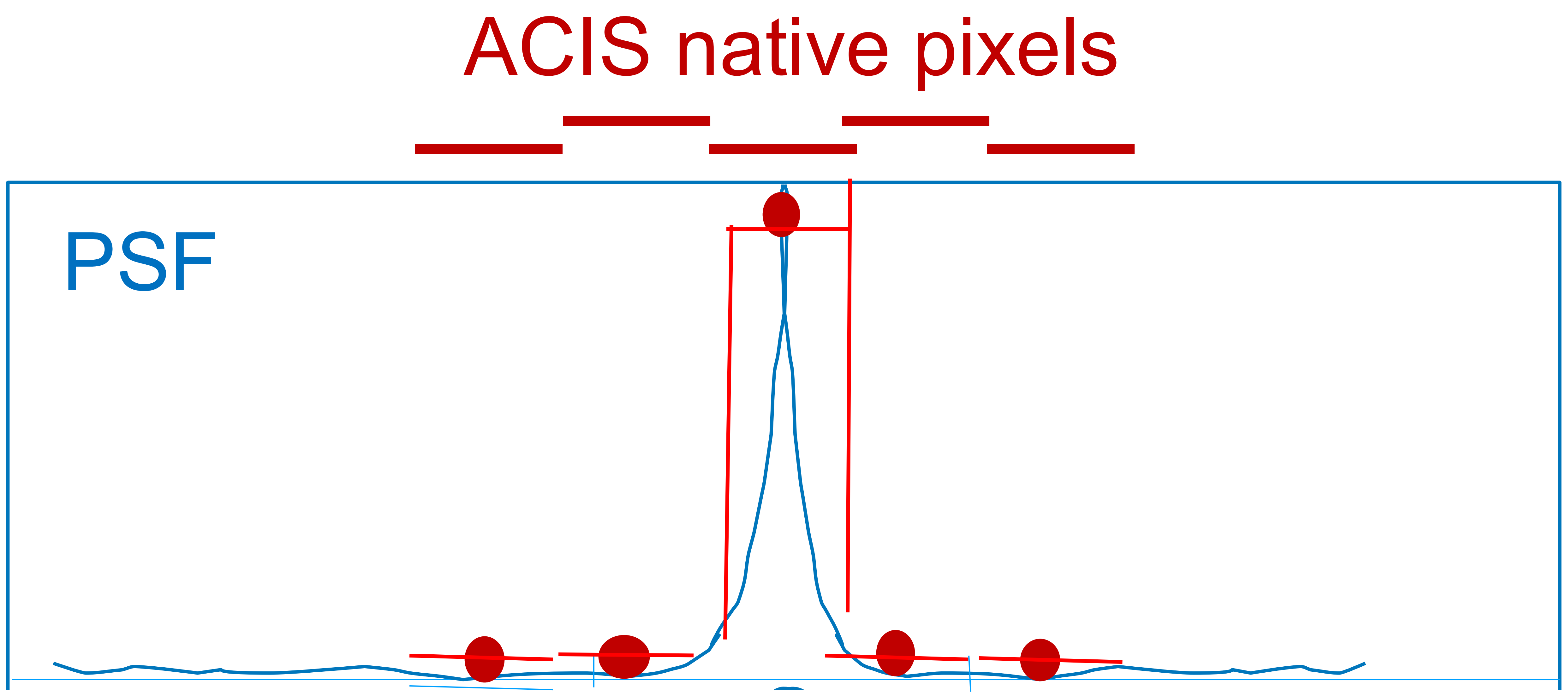
Radiation: ESO428-G014



Fast outflows: NGC 5728



Chandra sub-pixel imaging



dither oversamples PSF

well-established in opt/IR

Fabbiano & Elvis 2023
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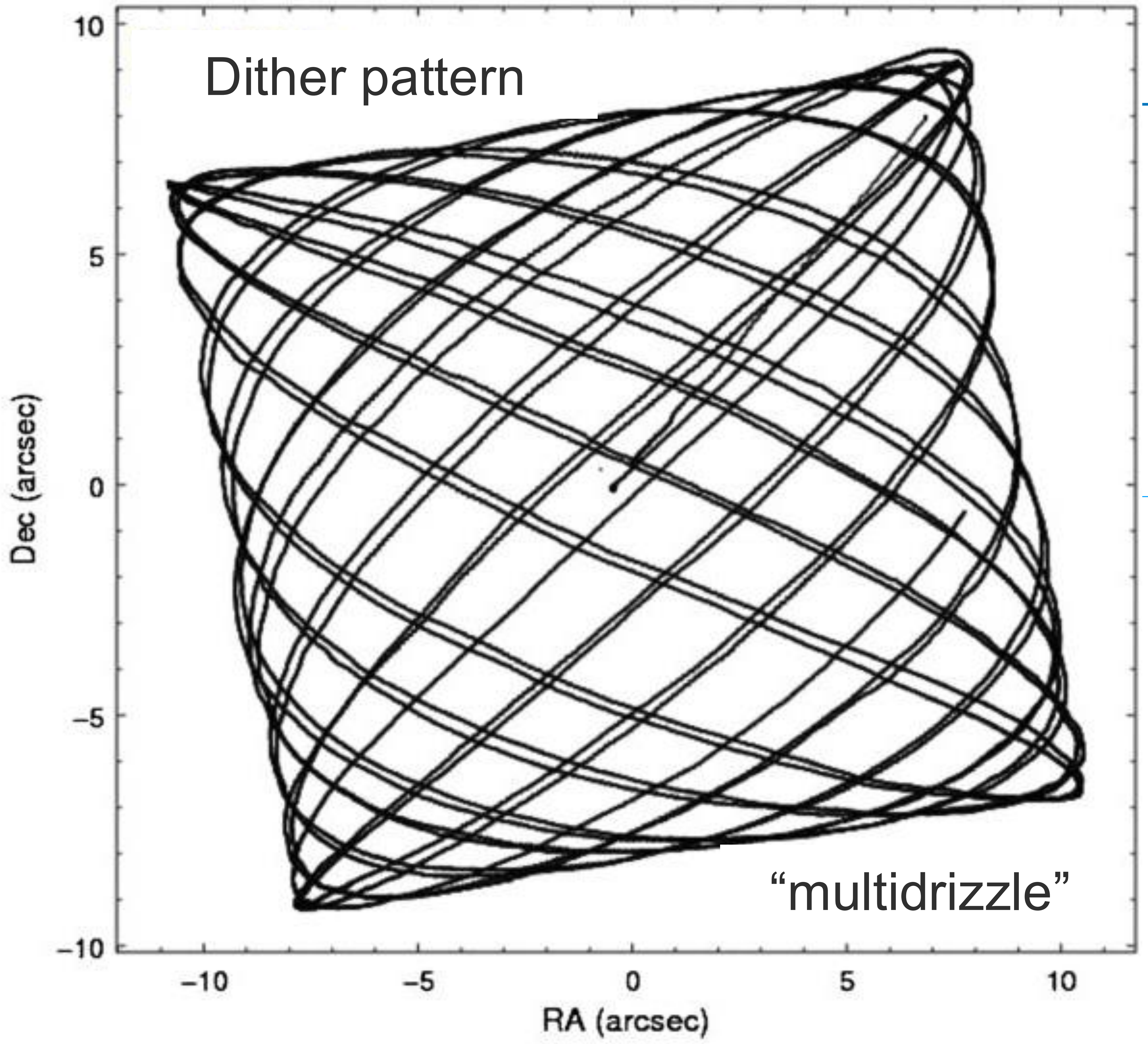

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Eg STScI: Astrodrizzle, Multidrizzle

https://hst-docs.stsci.edu/drizzpac/chapter-2-observational-dithering-options-for-drizzling-data/2-1-dithering-strategies

Fabbiano & Elvis 2023

arXiv:2202.13803

Martin Elvis melvis@cfa.Harvard.edu Chandra PSF for High Resolution Imaging, Bologna 10 May 2023

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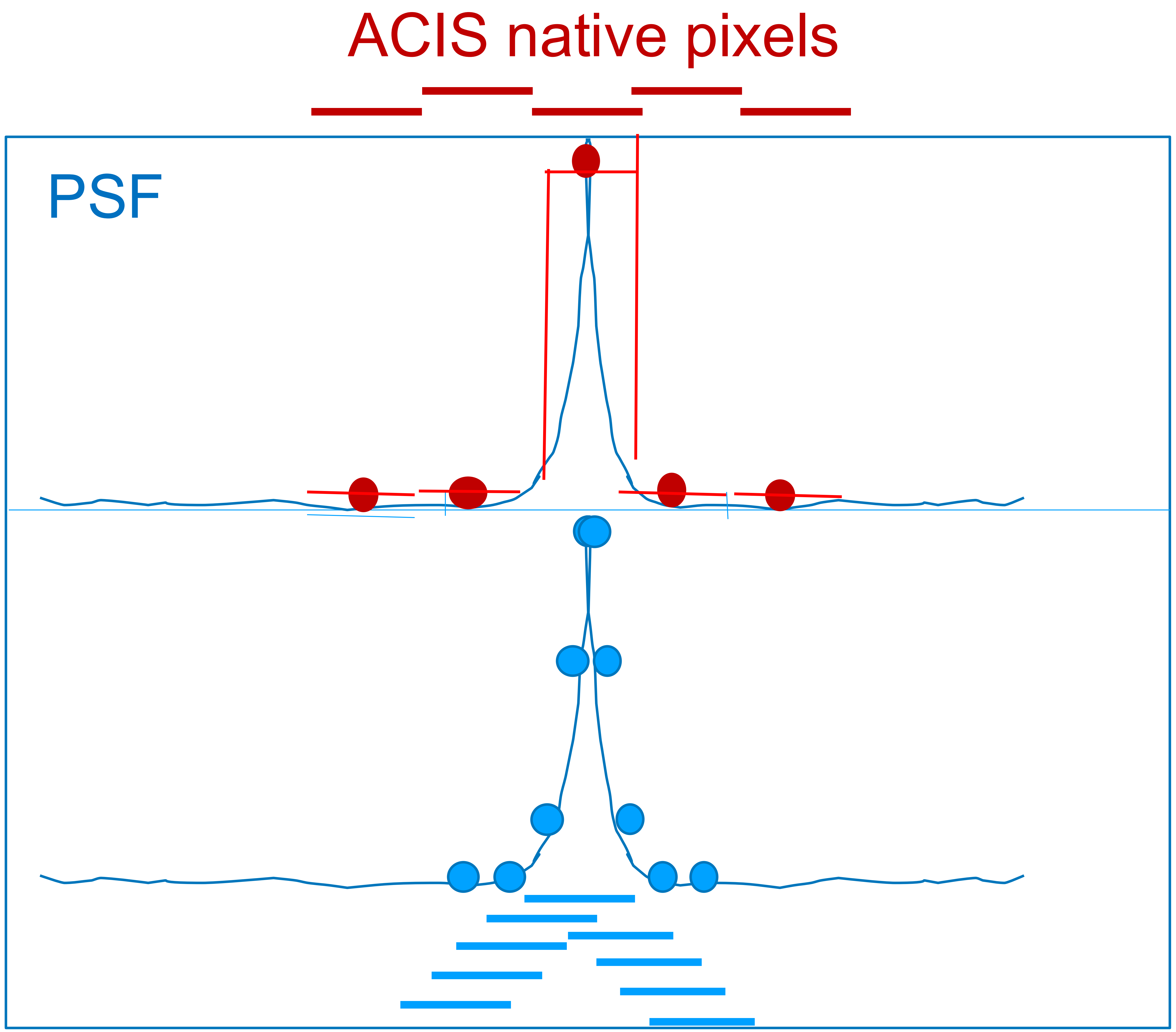

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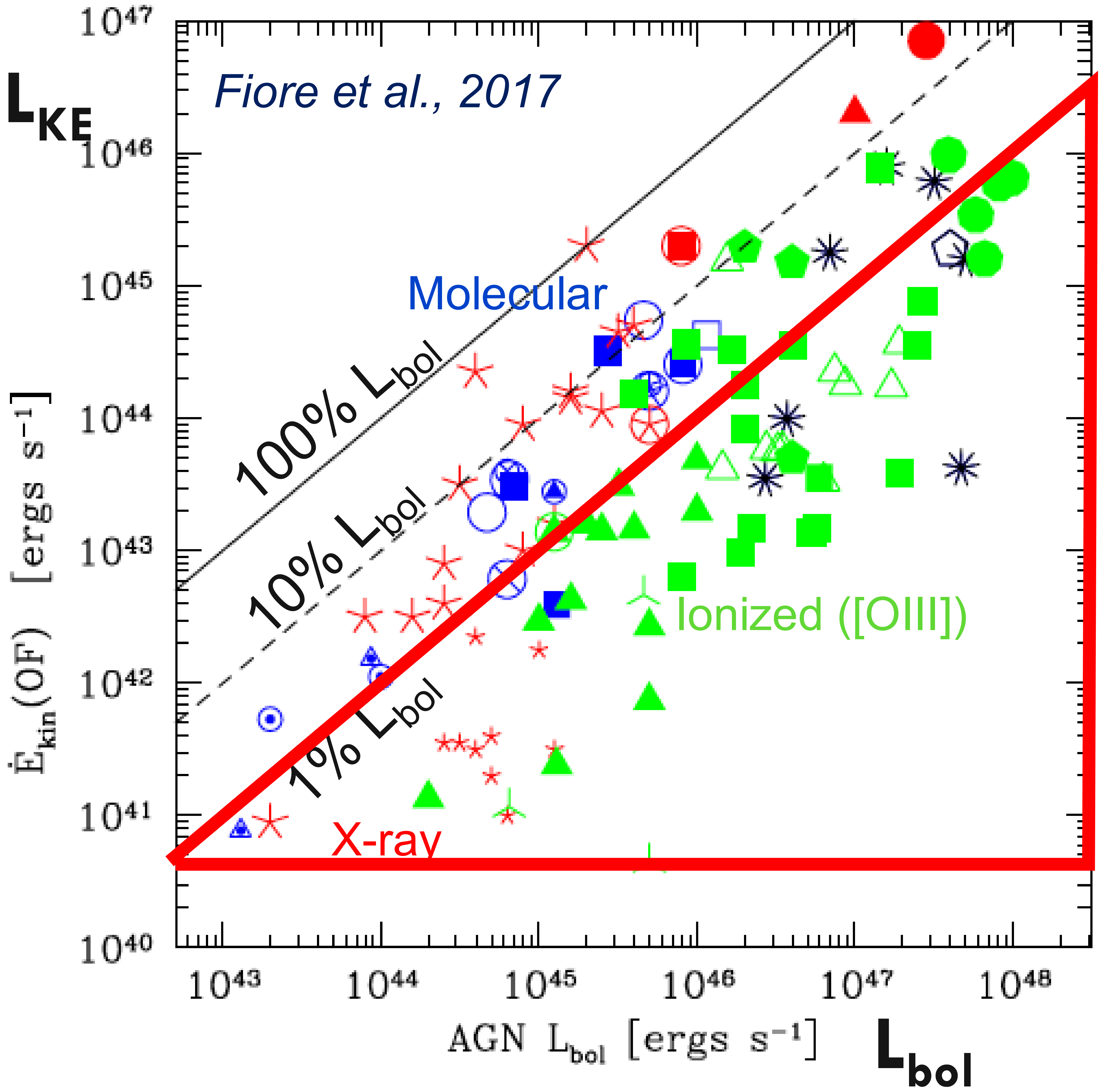
https://hst-docs.stsci.edu/drizzpac/chapter-2-observational-dithering-options-for-drizzling-data/2-1-dithering-strategies

X-rays give the limiting case:

continuous vs discrete

Fabbiano & Elvis 2023
arXiv:2202.13803

The AGN Feedback Failure Problem



- need $L_{feedback}$ >0.5% - 5% L_{bol}

  Hopkins & Elvis 2010, DiMatteo+2005

- $L_{fb} = \varepsilon\ L_{KE}$
- $L_{KE} < 1\%\ L_{bol}$ Fiore+2017
- does Feedback not work??
- ***X-rays measure feedback in action***

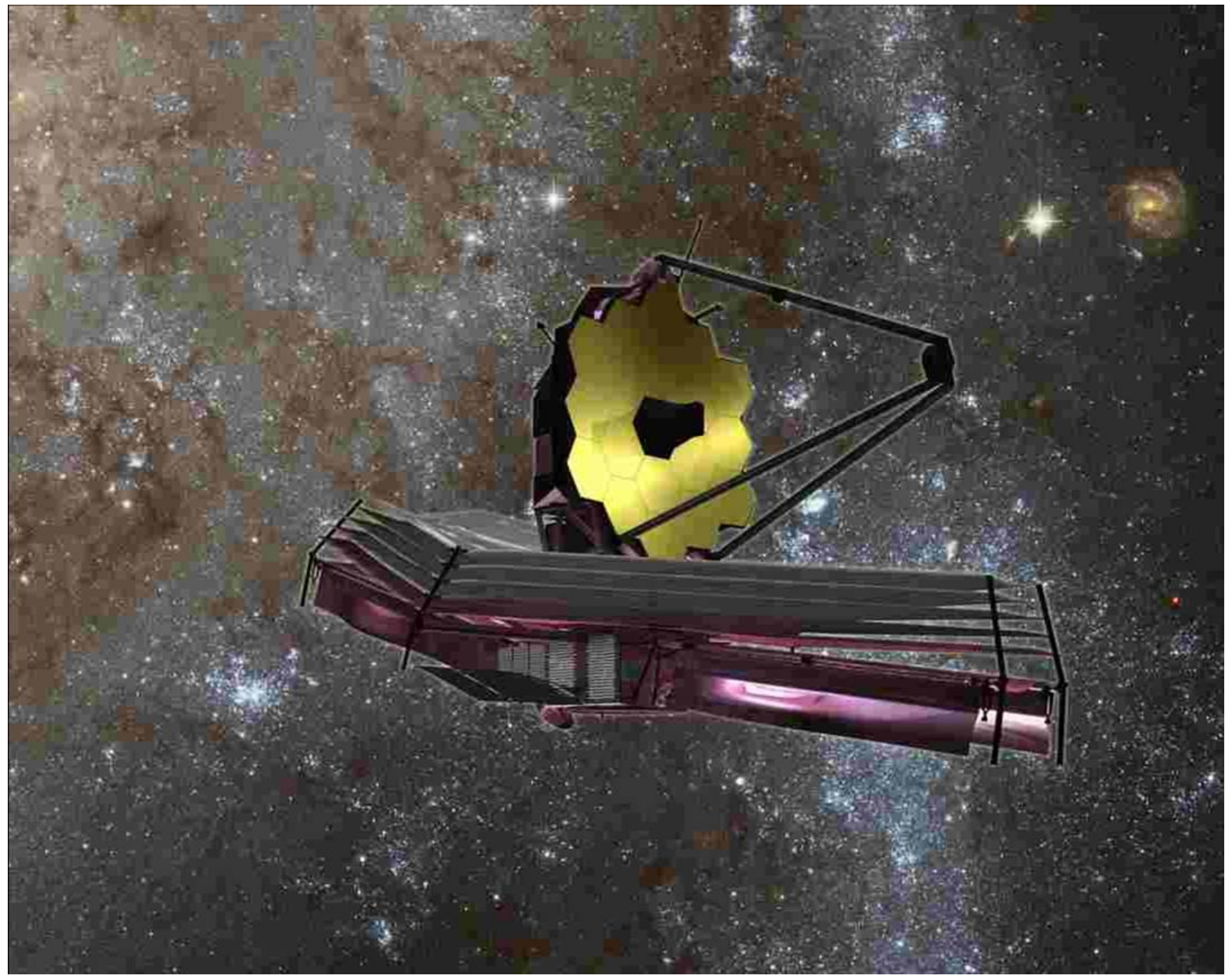
AGN Feedback Imaged by Chandra

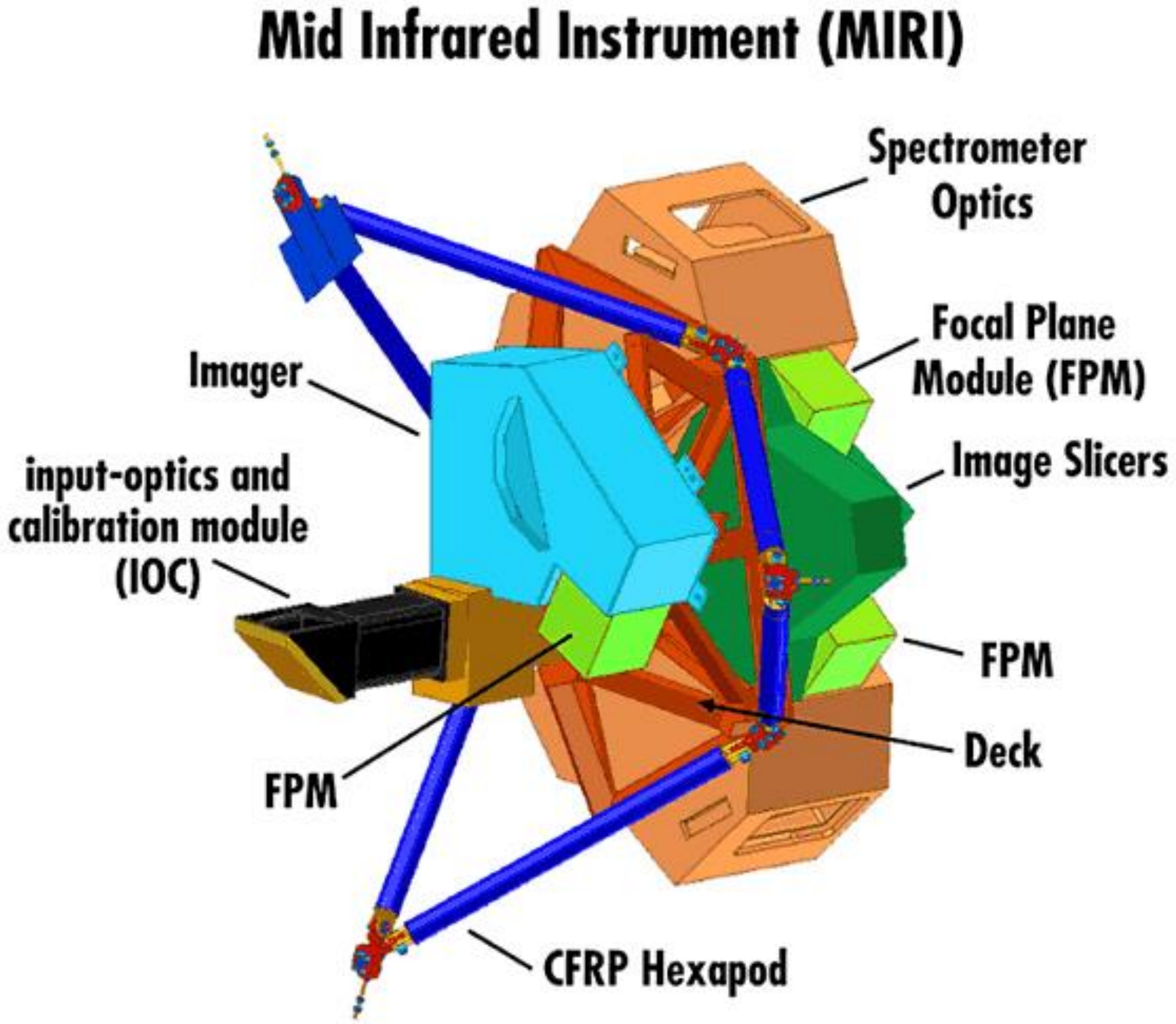
100s pc – few kpc

Fabbiano & Elvis, 2022, arXiv:2202.13803

FIR Proxies with JWST

Armus +2022





- JWST/MIRI coronal lines
- E.g. NGC7469; Seyfert 1.5
- extended nuclear region has
- [OIV], [NeV], [NeVI], [Si IV], [FeVII]
- IP ~100 eV
- Blue wings only in high IP lines
- ~500-1000 km s^{-1}

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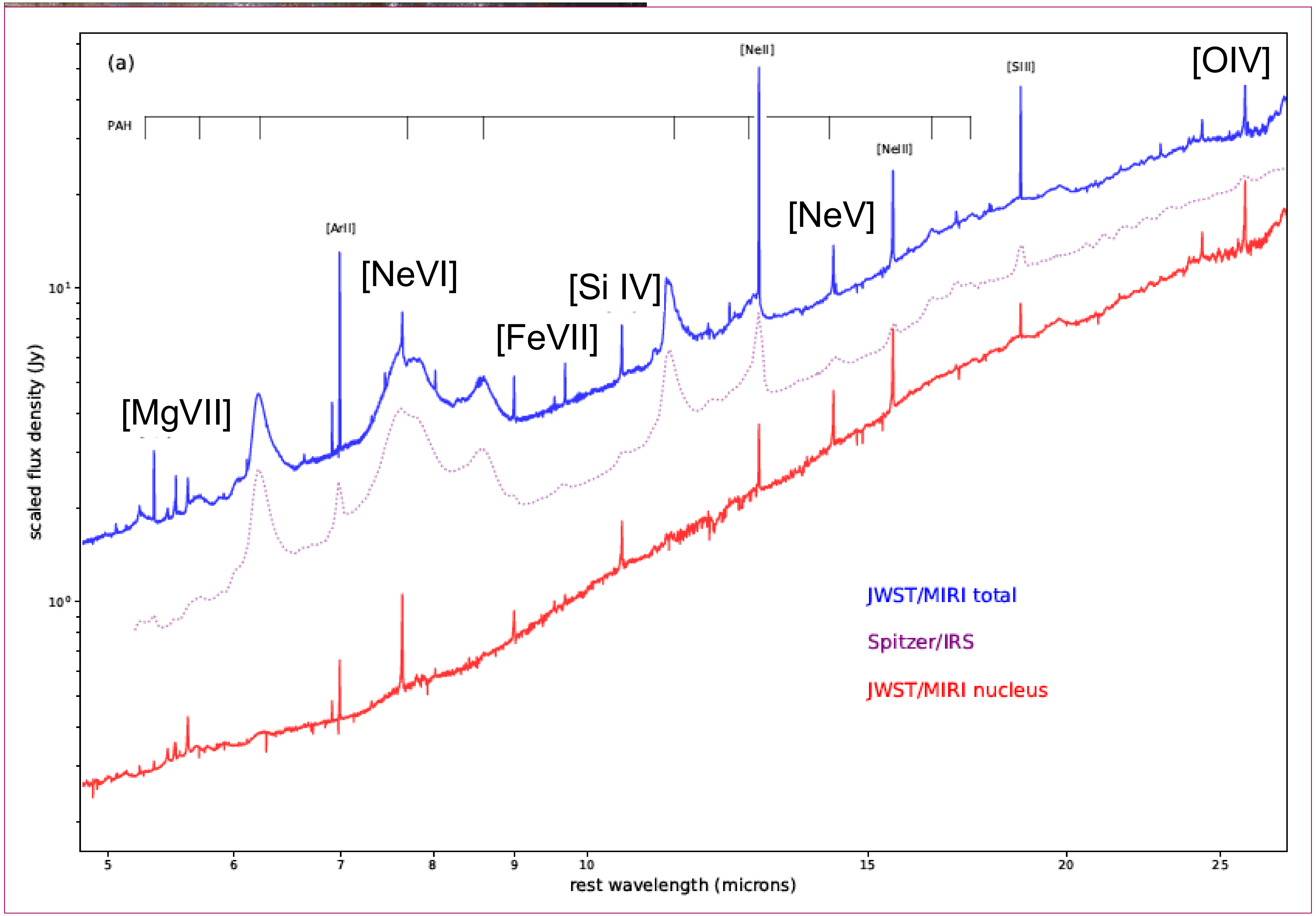

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