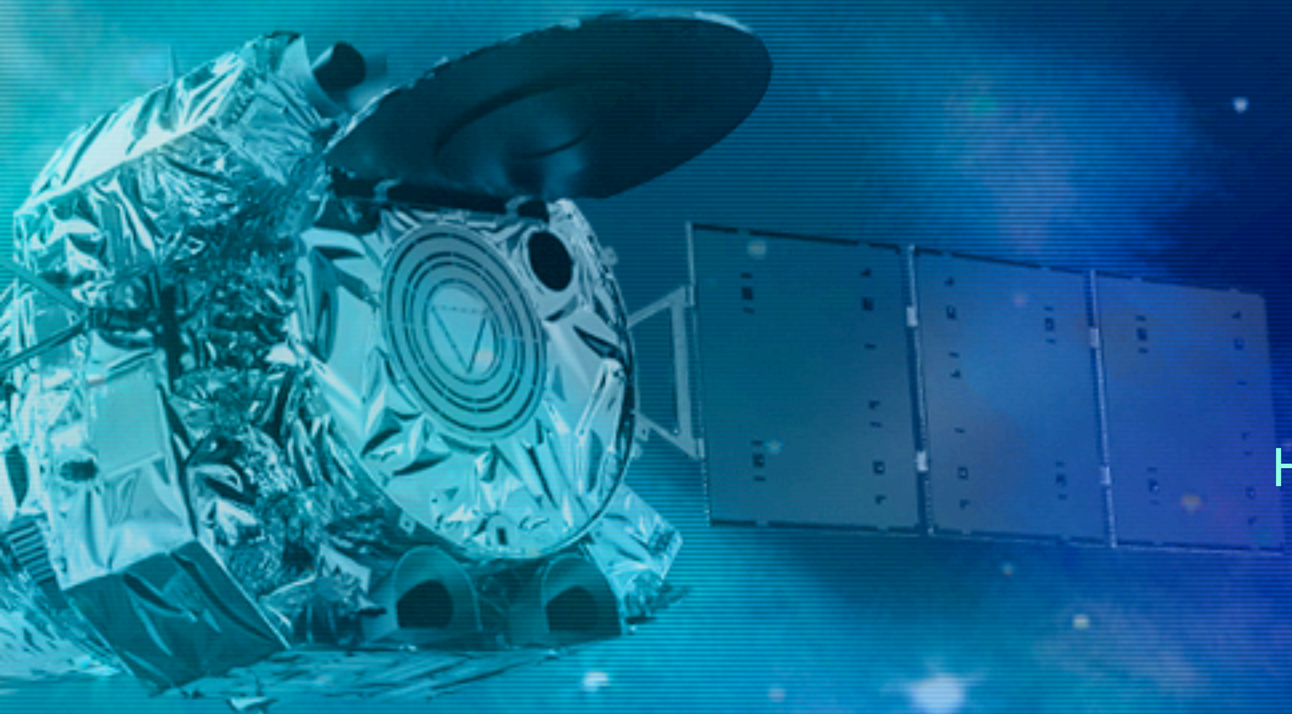
Chandra X-ray Observatory



G. Fabbiano
Harvard-Smithsonian CfA
August 2011 - CfA

Chandra Observations of Galaxies

AGN – host interaction

Main Contributors – XRBs, Hot ISM, Nuclei

X-RAY EMISSION – XRB POPULATIONS

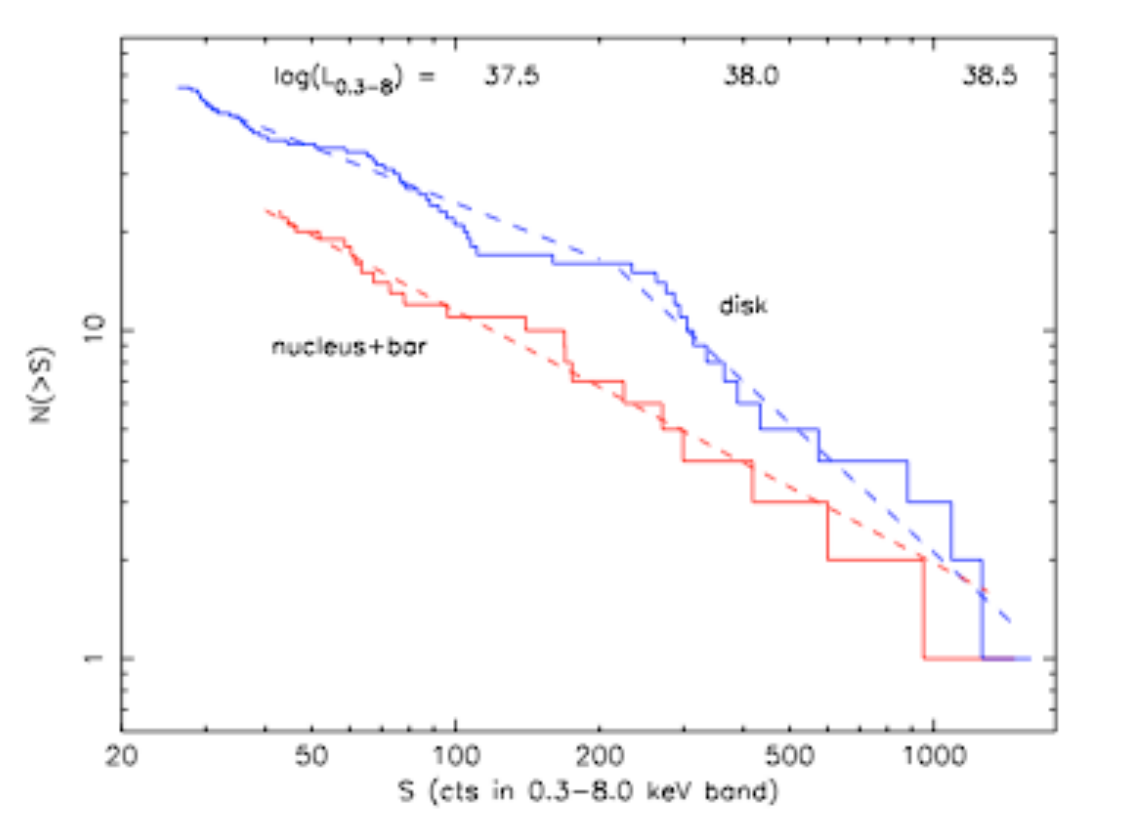
- NS and BH
  - XRBs are individually detected
    - » Markers of parent stellar population
  - Luminosity functions
  - Population studies

M83 – Soria & Wu 2003

ESO VLT

Chandra ACIS

AGE EFFECT ON XLF – M83

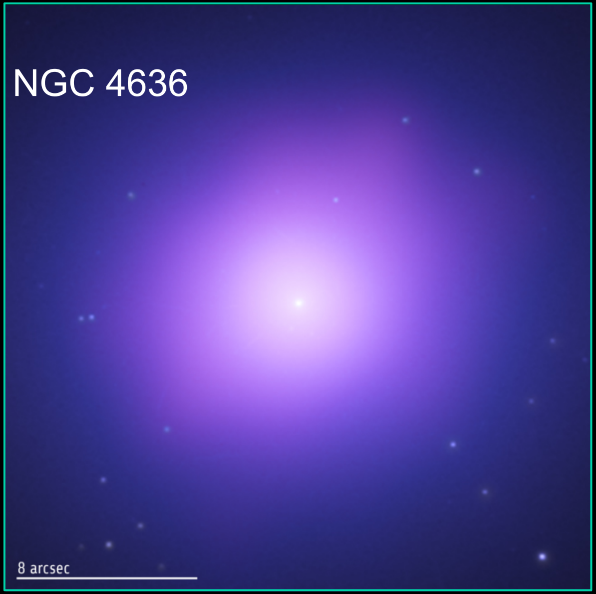


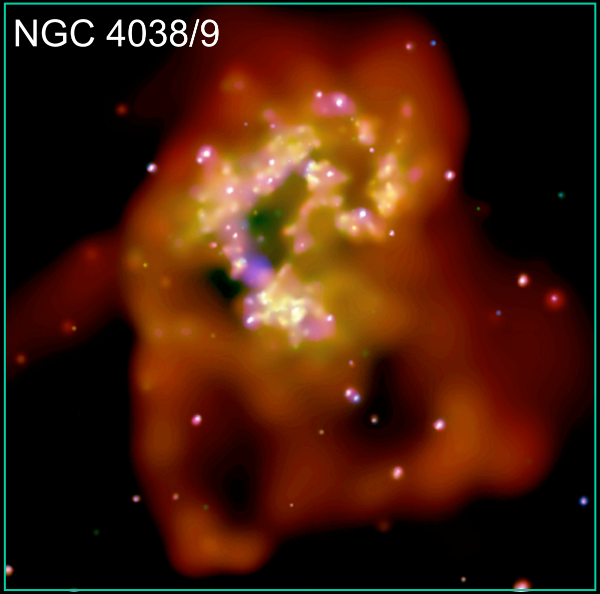
Soria & Wu 2003

- Flat power-law XLF in starburst nucleus
- Broken power-law in older disk
  - Aging = depletion of most luminous HMXB

X-RAY EMISSION – HOT ISM

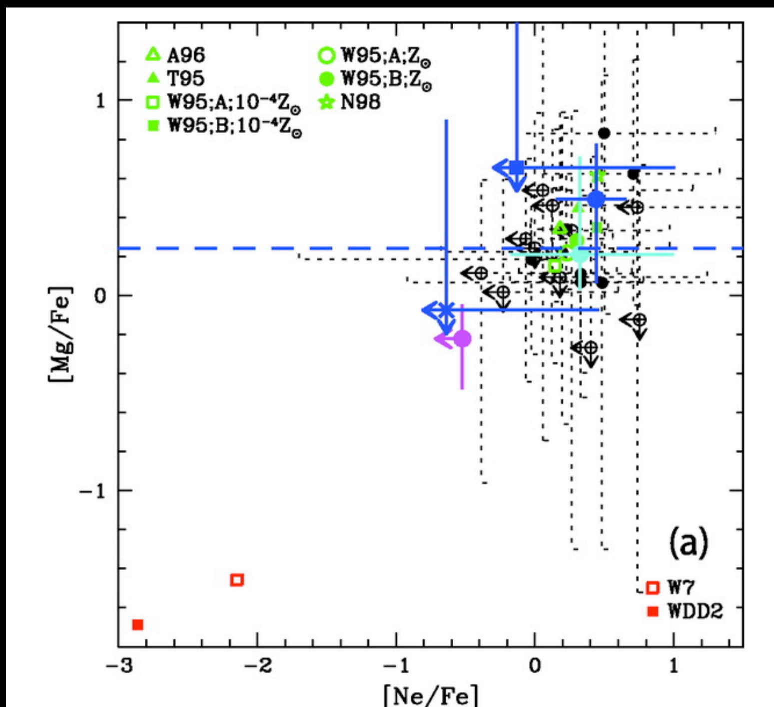
- Halo evolution in E & S0
  - energy input vs Dark Matter
- Metal enrichment
  - SNII, SNIa

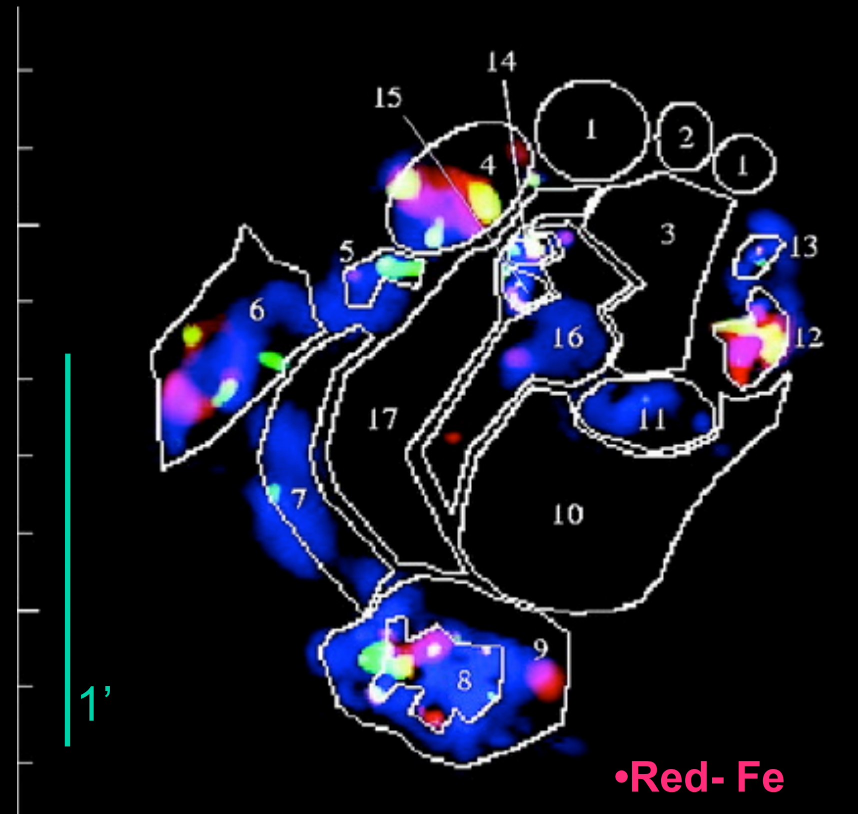




Hot ISM of the Antennae – Metal Abundances

Yields consistent with SNII enrichment





•Red- Fe

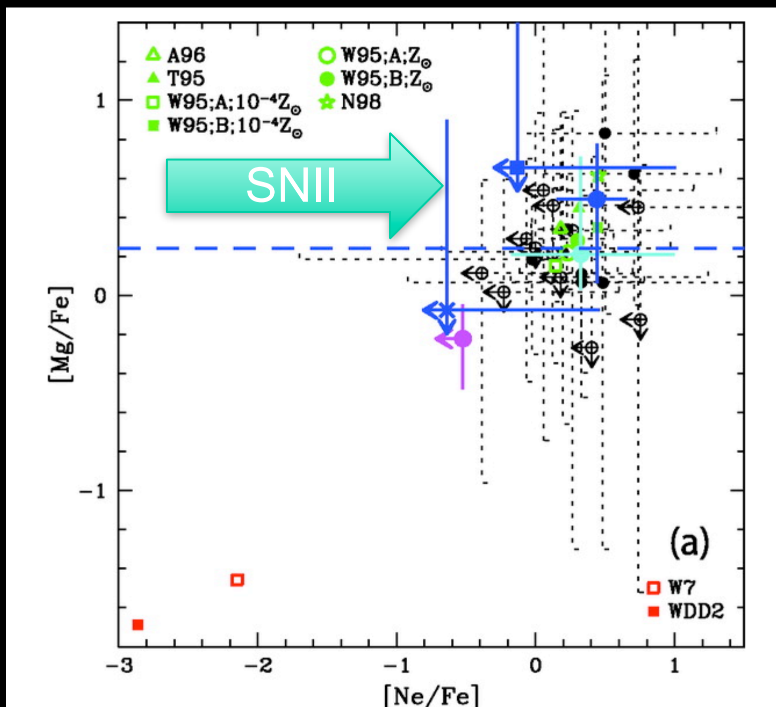
•Green – Mg

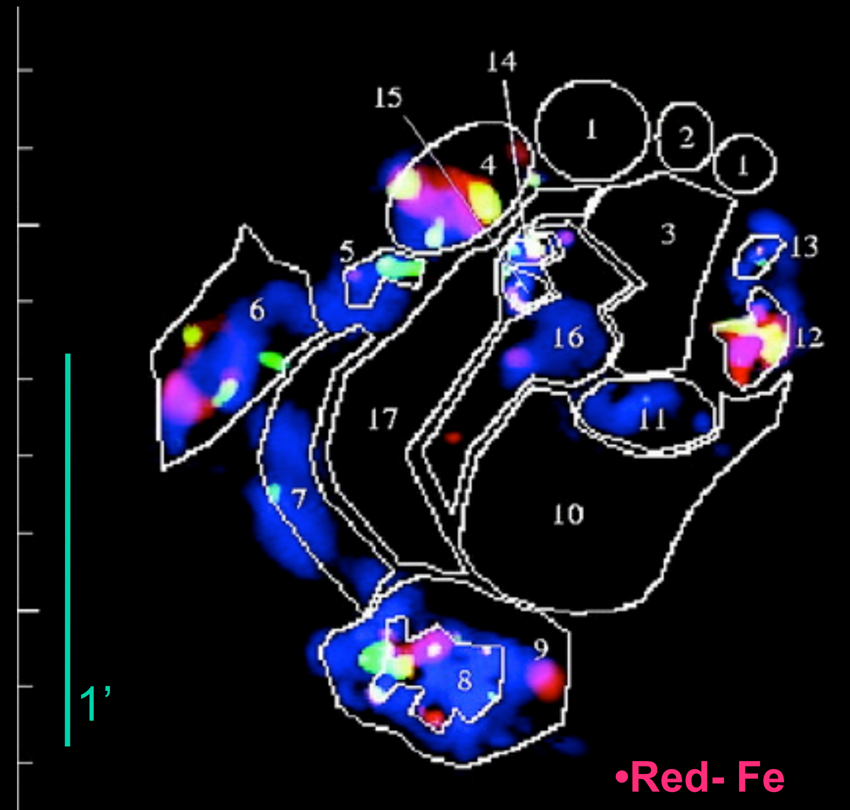
•Blue - Si

Baldi et al 2006a, b

HOT ISM OF THE ANTENNAE – METAL ABUNDANCES

Yields consistent with SNII enrichment





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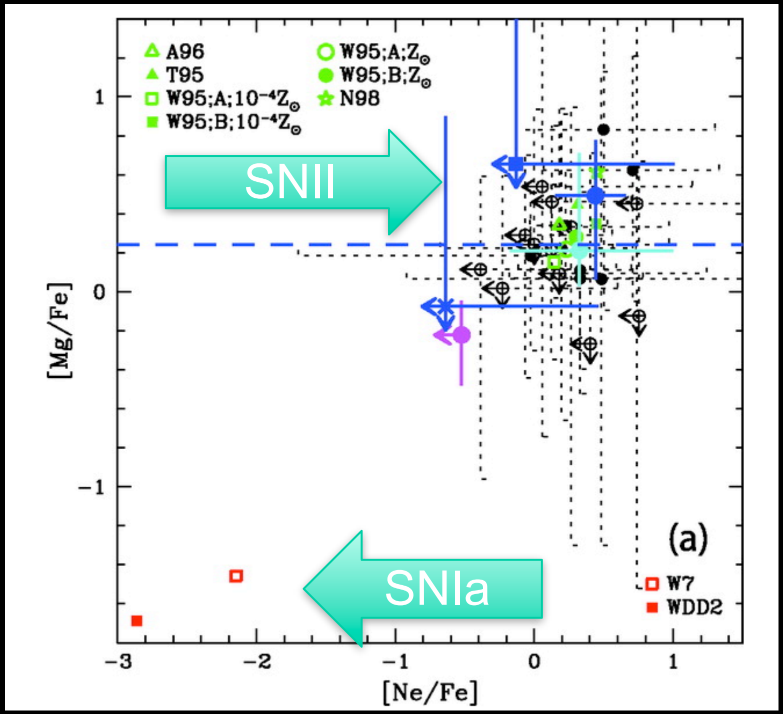

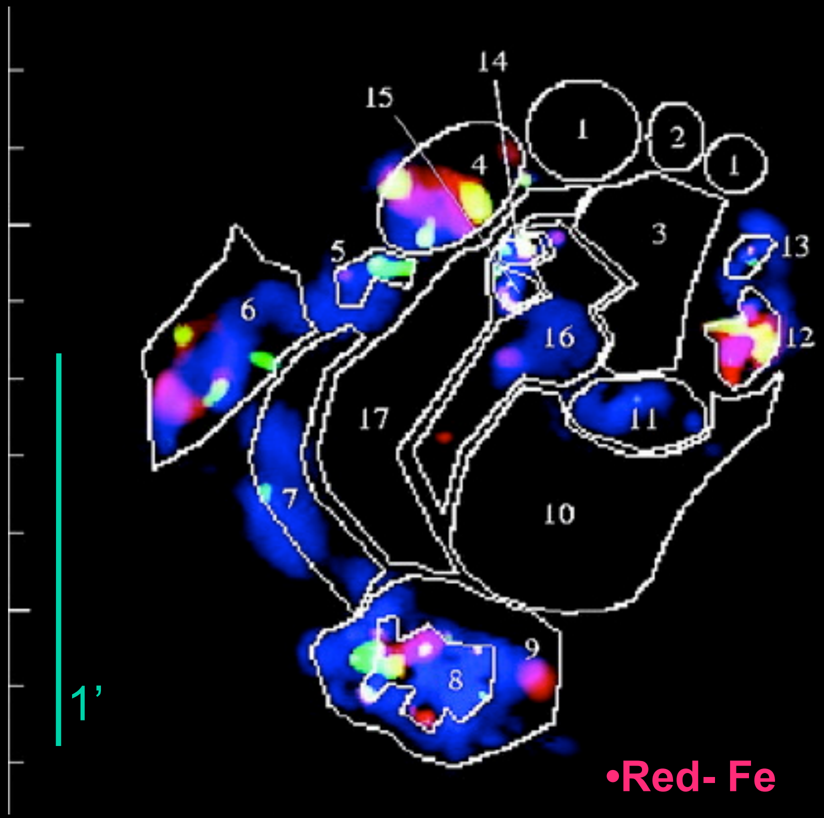

Baldi et al 2006a, b

Circum-nuclear Regions

- Direct imaging/spectra of circum-nuclear regions
- Accretion and feedback

Alessandro Paggi

Junfeng Wang

Martin Elvis

Guido Risaliti

CIRCUM-NUCLEAR REGIONS

- Direct imaging/spectra of circum-nuclear regions
- Accretion and feedback

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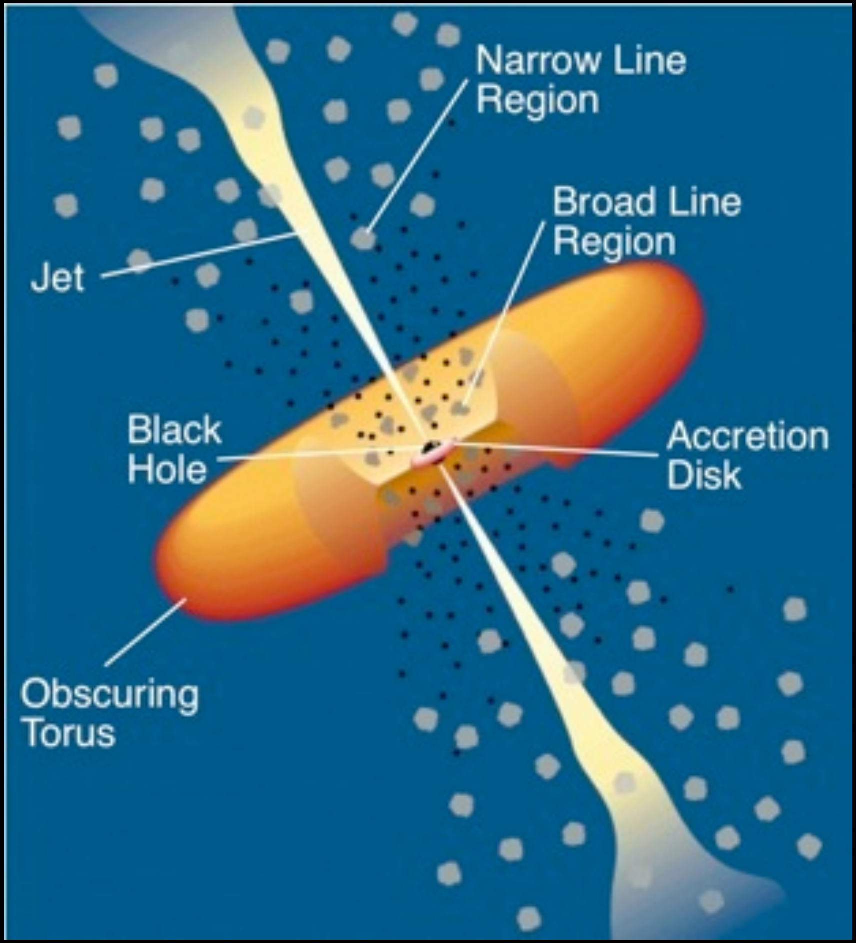
THE AGN PARADIGM

- Accretion-fed BH
    - Obscuring torus
- Photoionization
- Ionization cone



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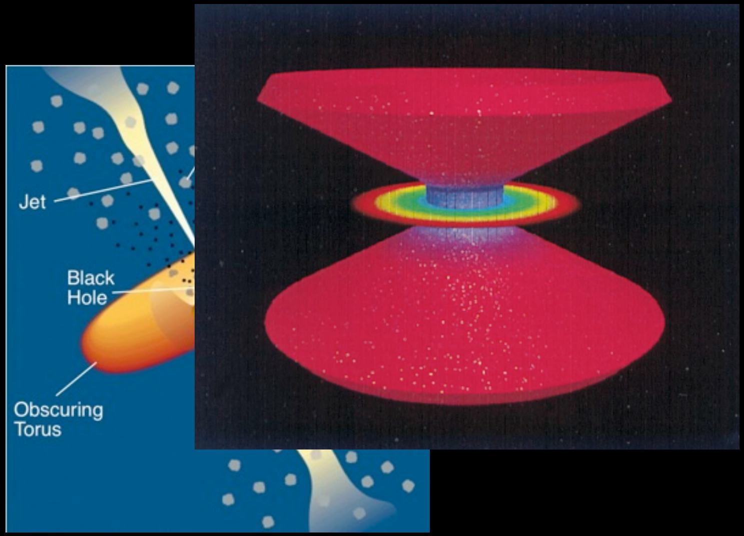

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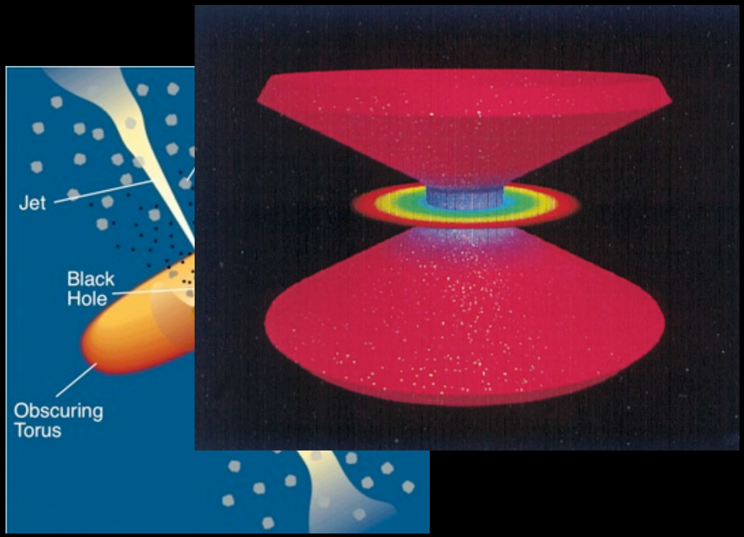

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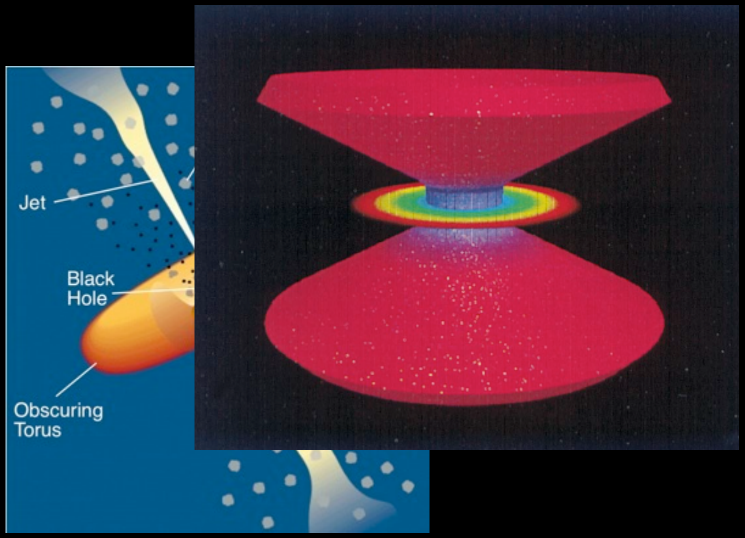

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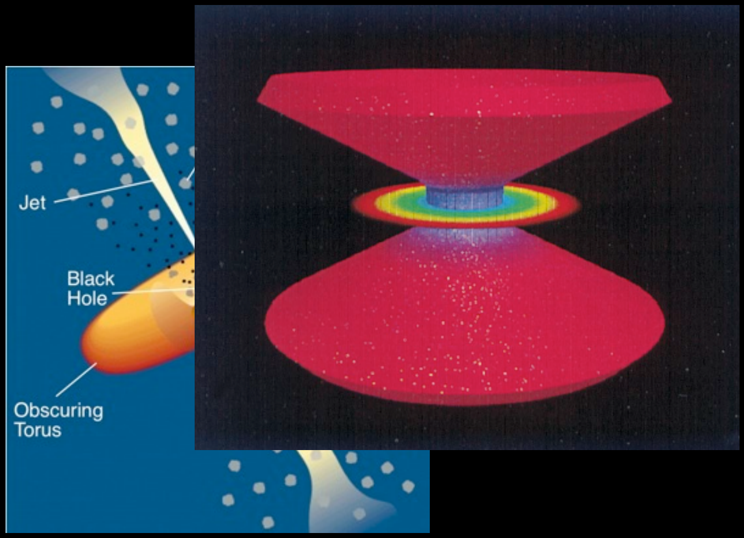

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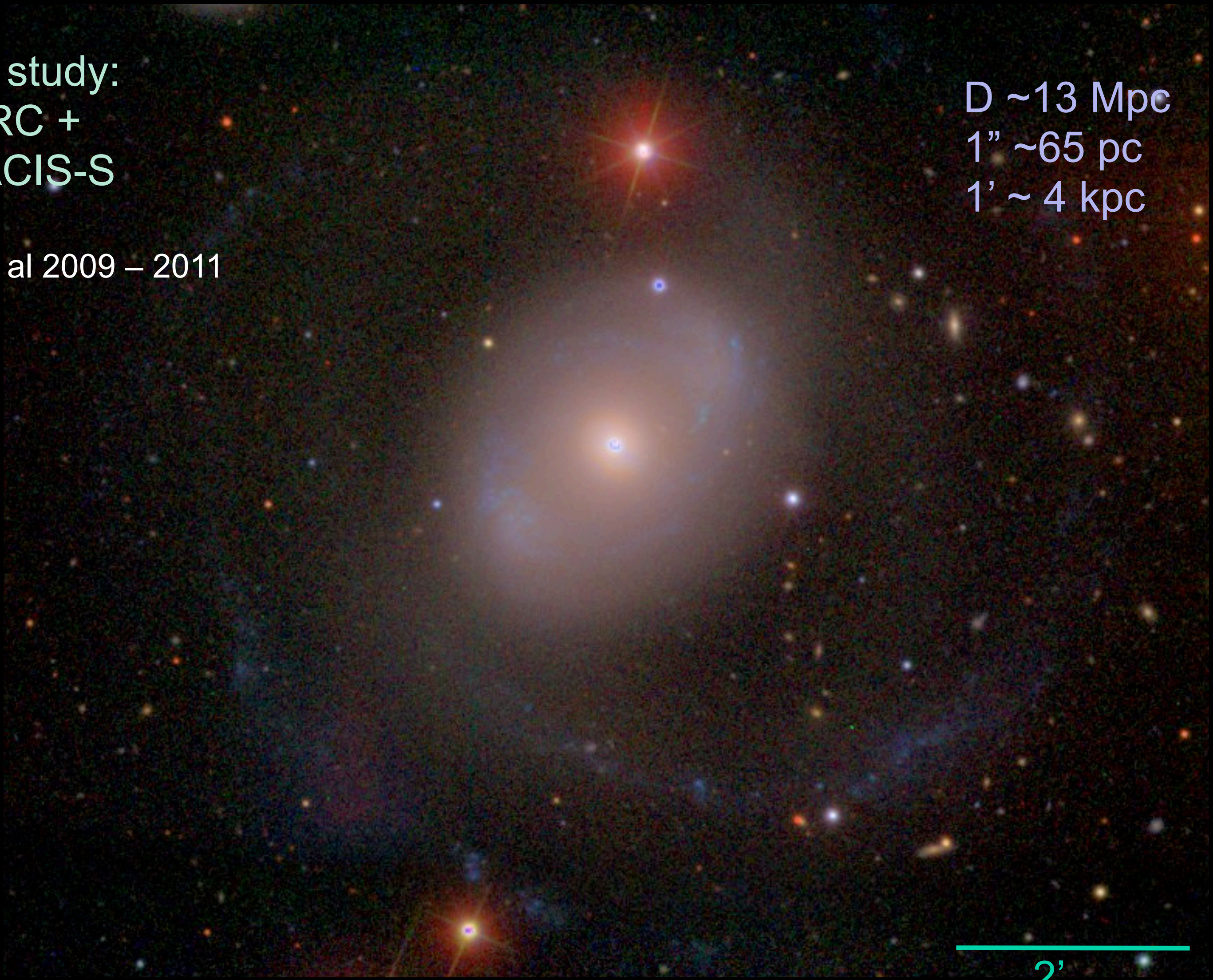
- AGN feedback?
- Case studies: NGC 1365; NGC 4151; Mkn 573, …..

NGC 4151 – AGN / Galaxy Interaction

Chandra study:
50 Ks HRC +
200 Ks ACIS-S

Wang, J. et al 2009 – 2011
6 papers

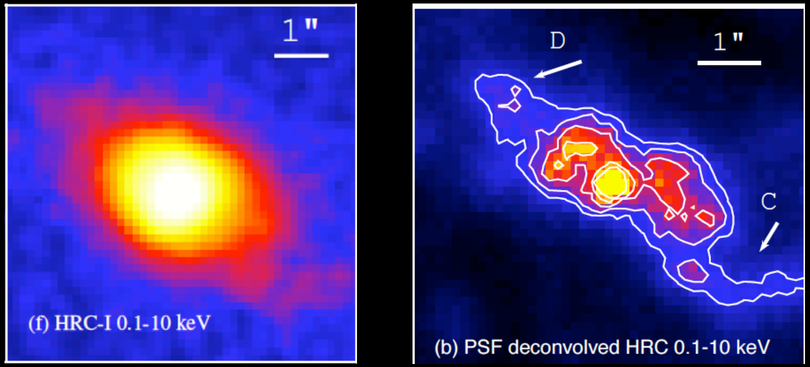


NGC 4151 – The Central 150 pc–A Technical Preamble

Wang et al 2009, 2011

Chandra – HRC

- − No energy resolution
- + Pixel (.13”) < than PSF
- + PSF very well-calibrated



EMC2 deconvolution

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- Energy resolution
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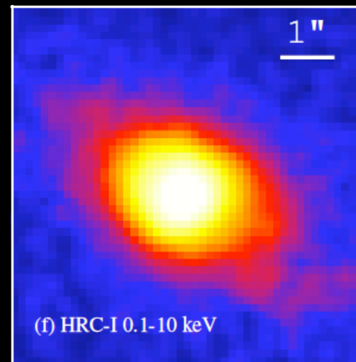

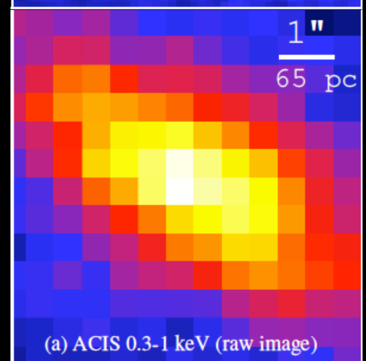

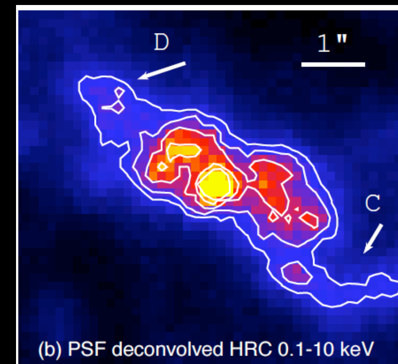

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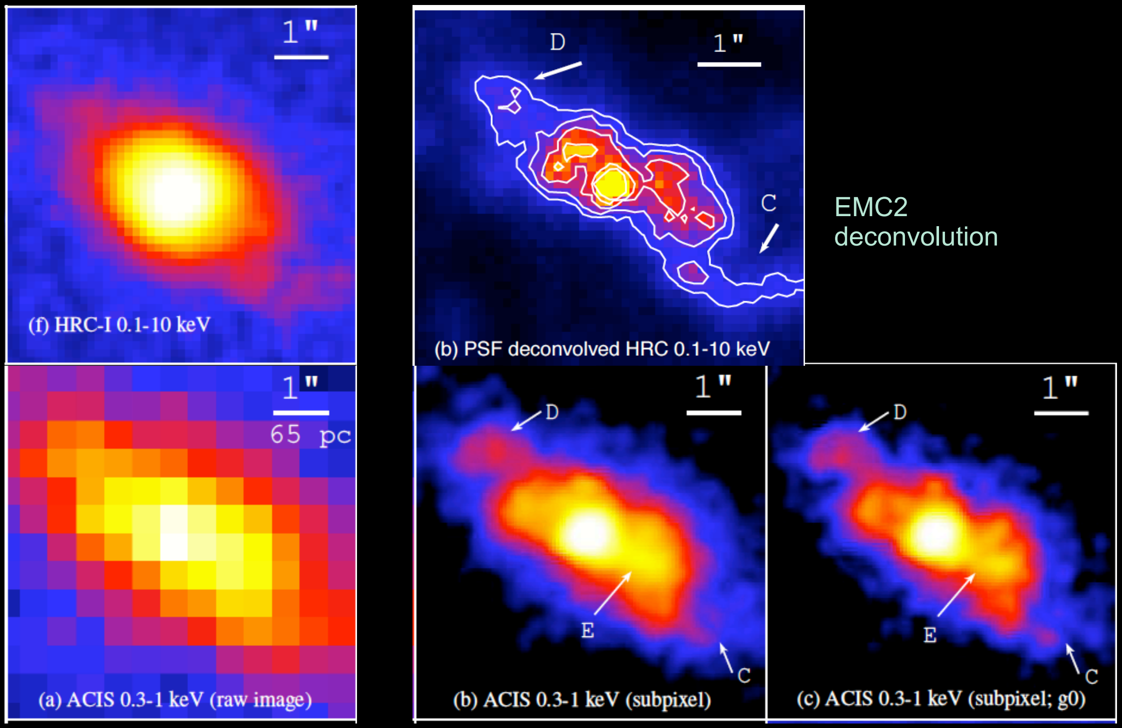
➔ Subpixel imaging



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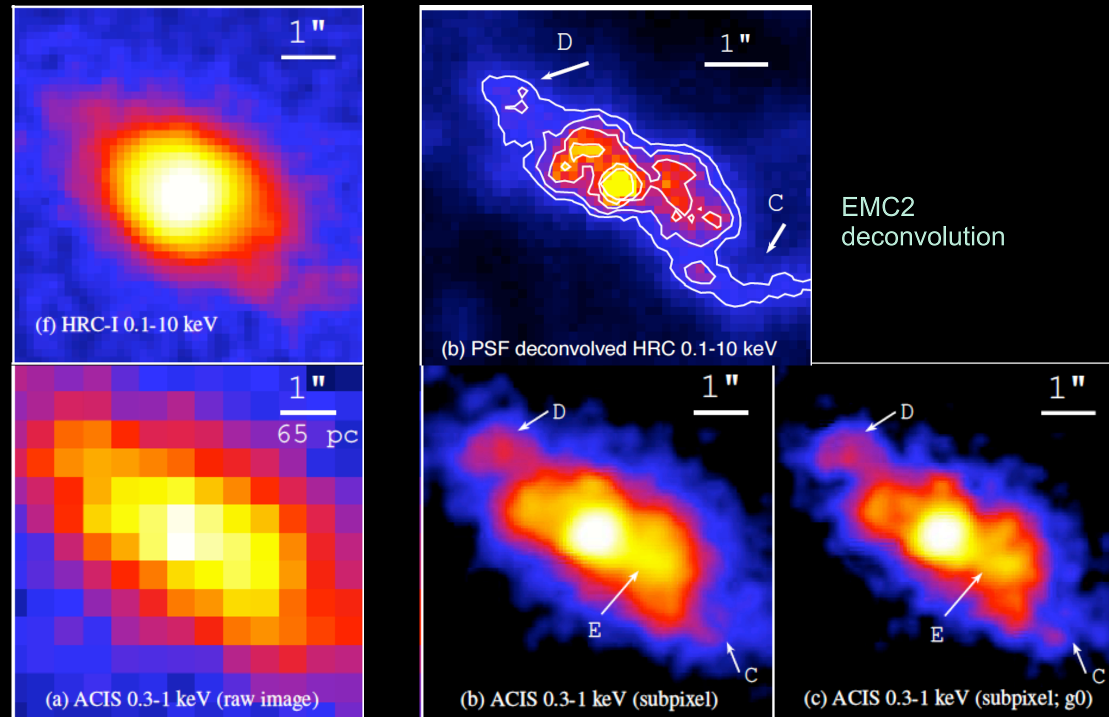

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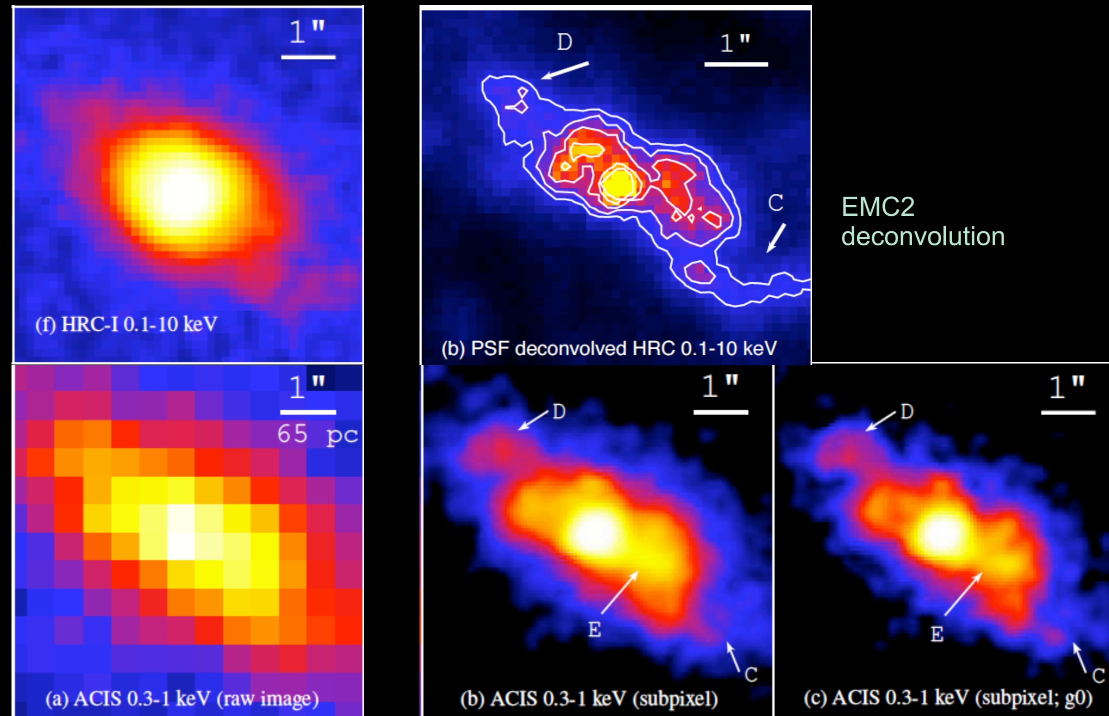

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→ Requires care

→ We have established that it does not affect the extended features

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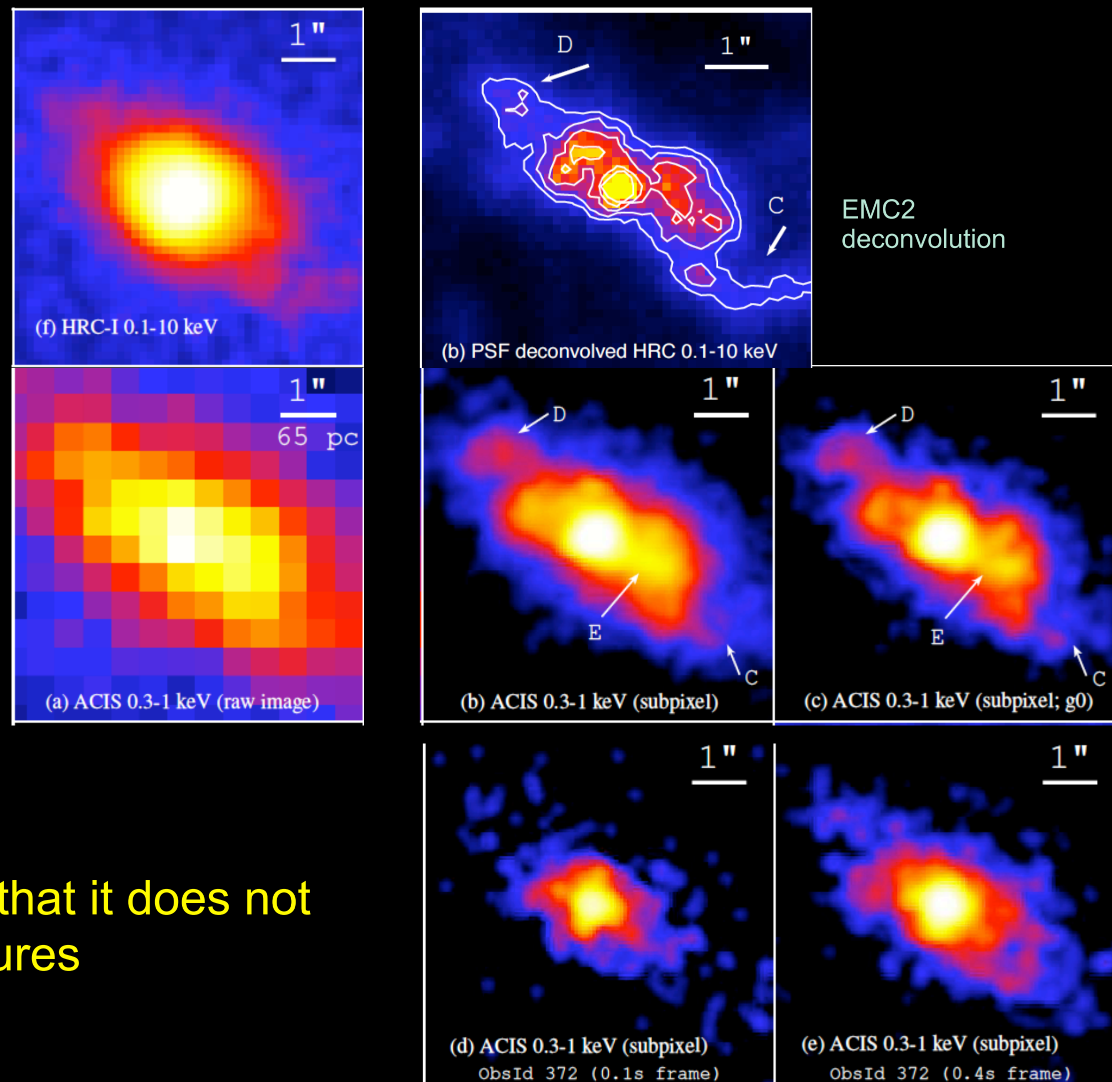
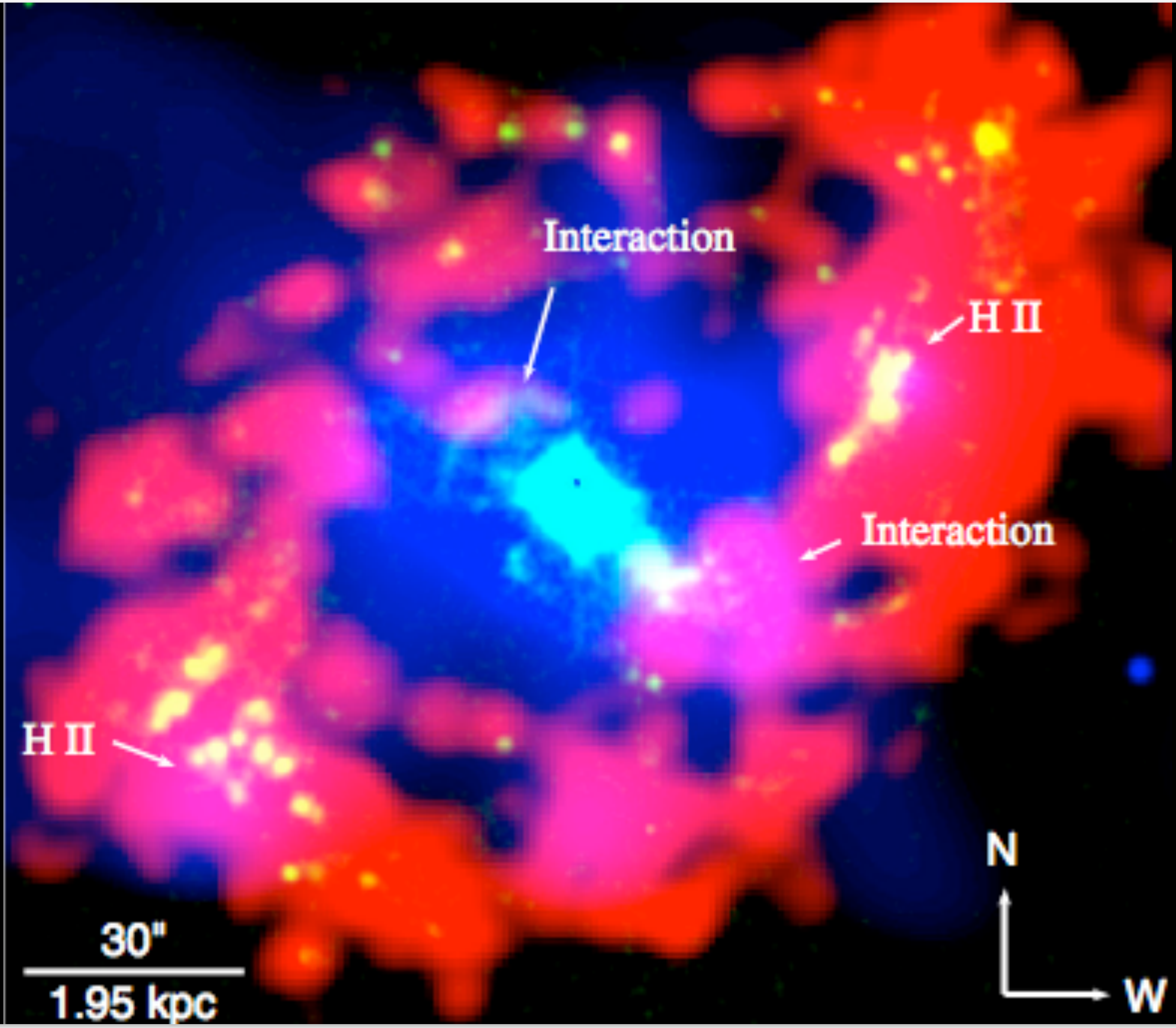


NGC 4151 – THE 4 KPC X-RAY FILLED CAVITY

Wang et al 2010

NGC 4151 – The 4 Kpc X-ray Filled Cavity

Wang et al 2010



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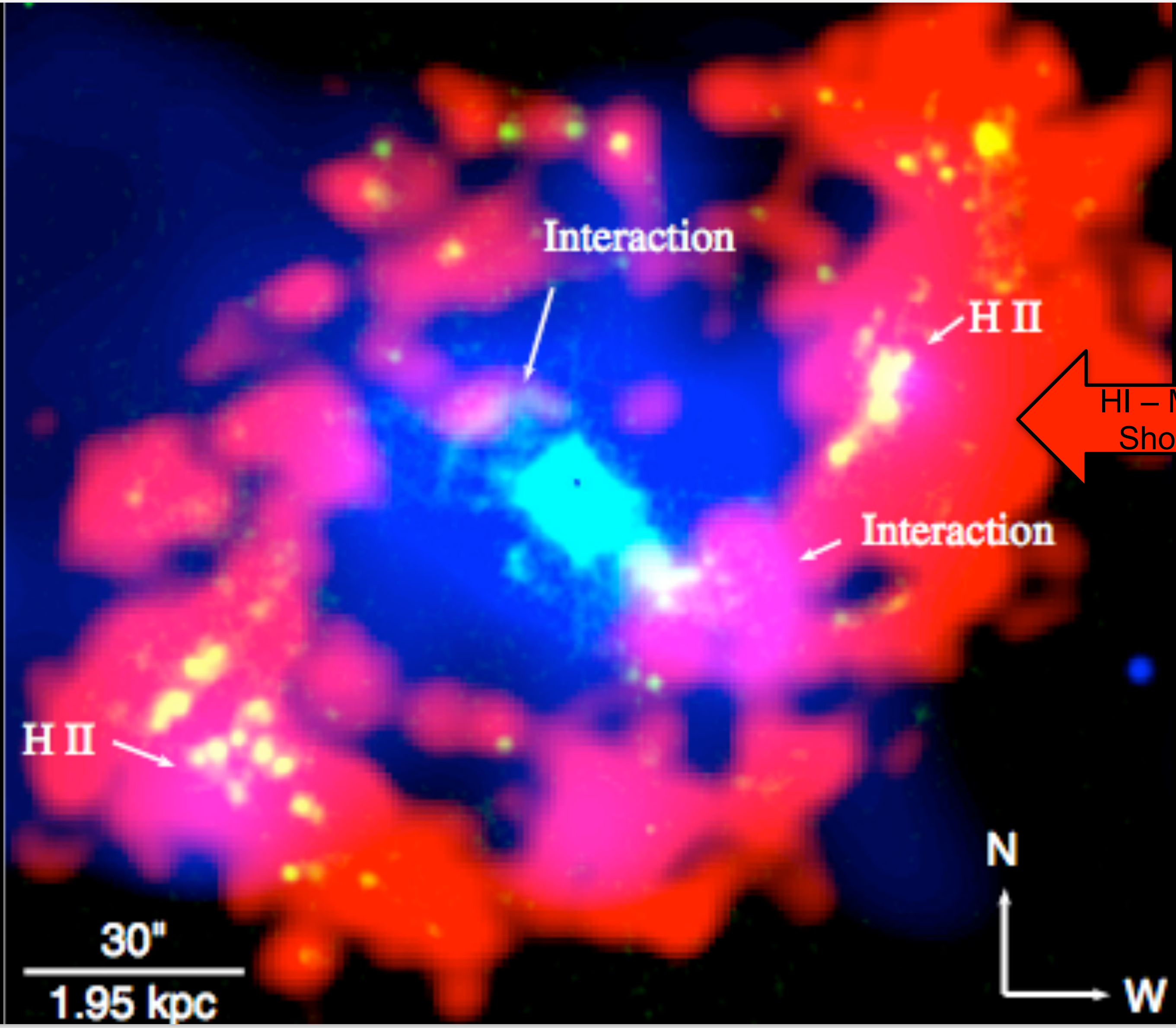
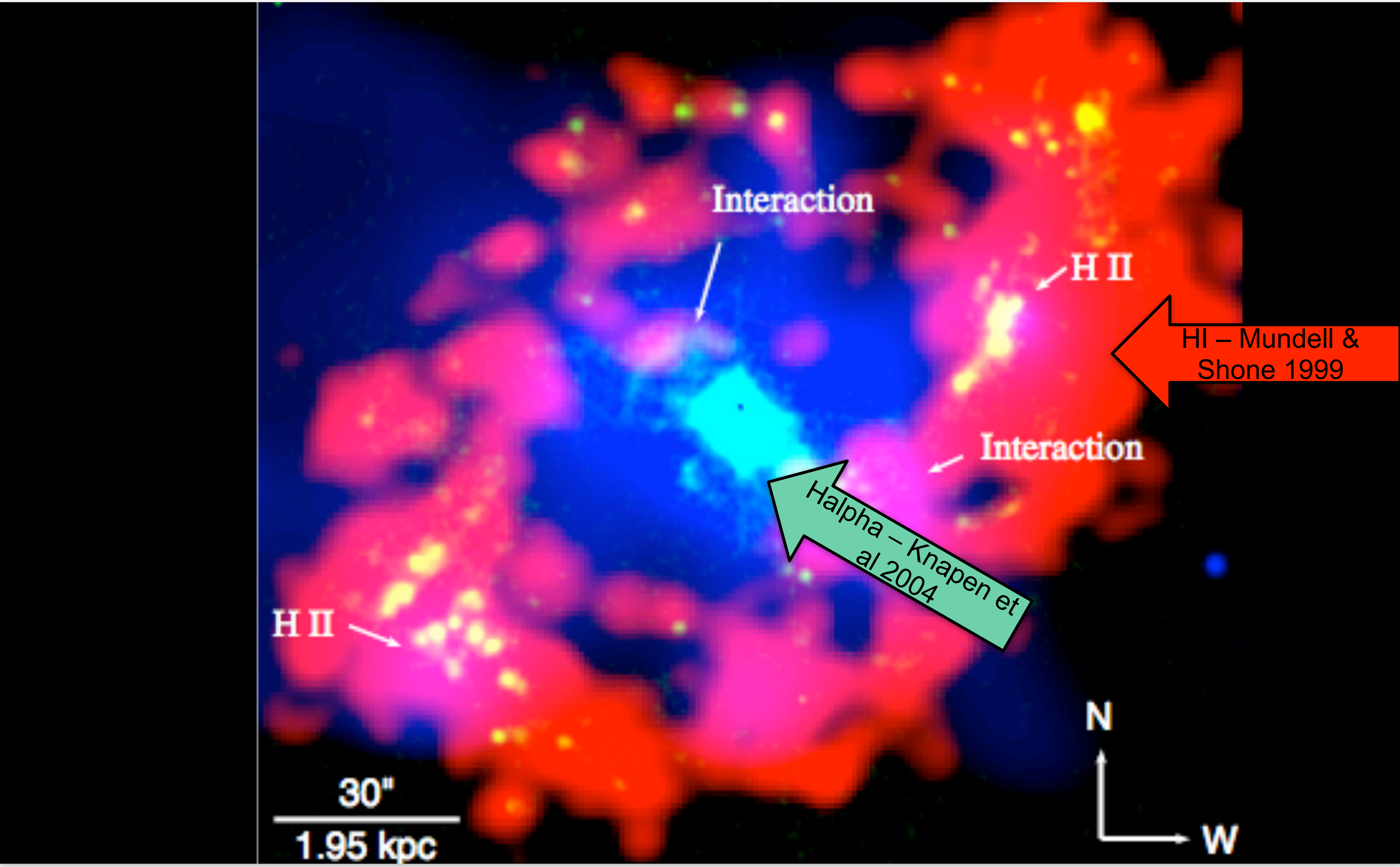


HI – Mundell & Shone 1999

NGC 4151 – THE 4 KPC X-RAY FILLED CAVITY

Wang et al 2010



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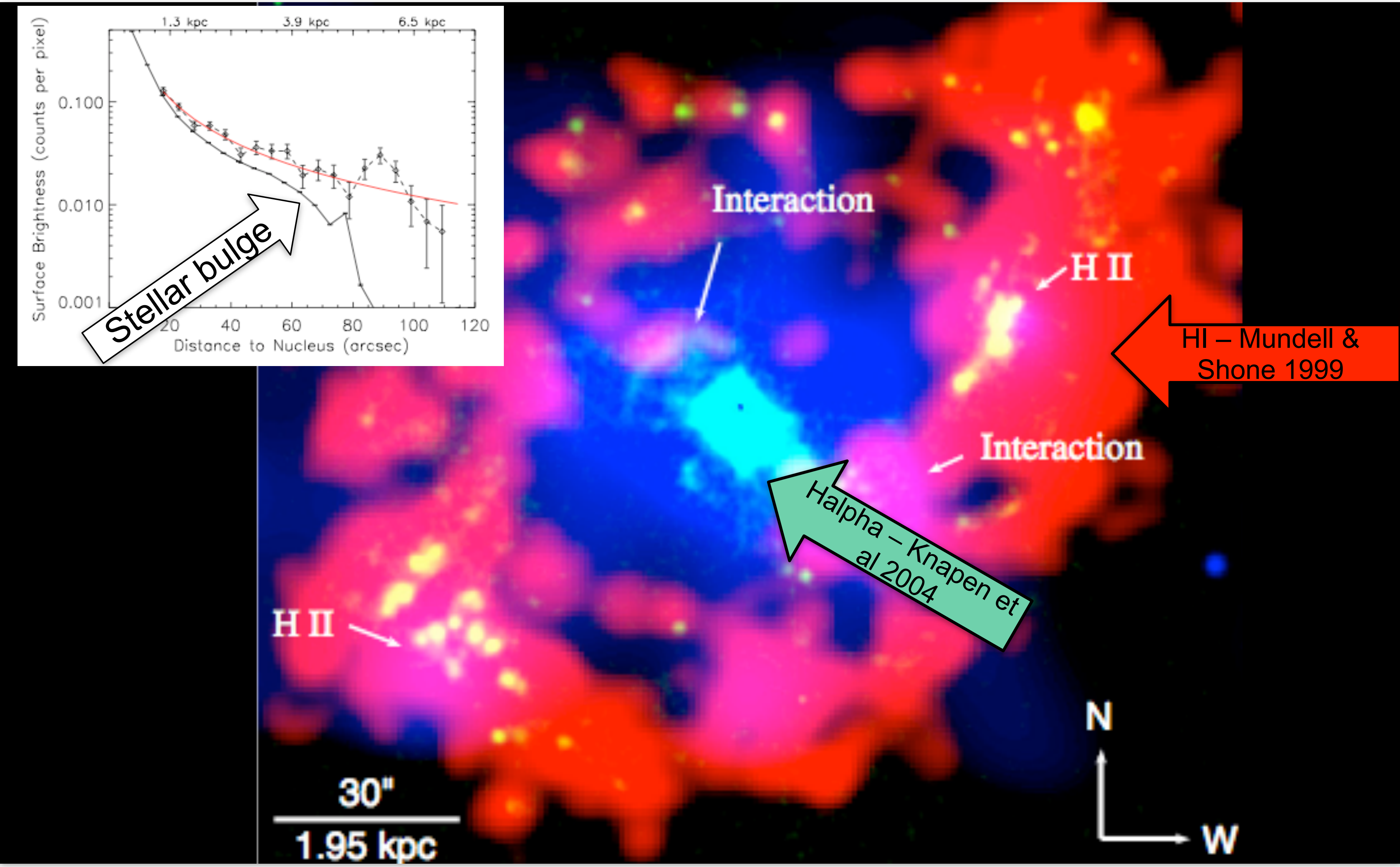

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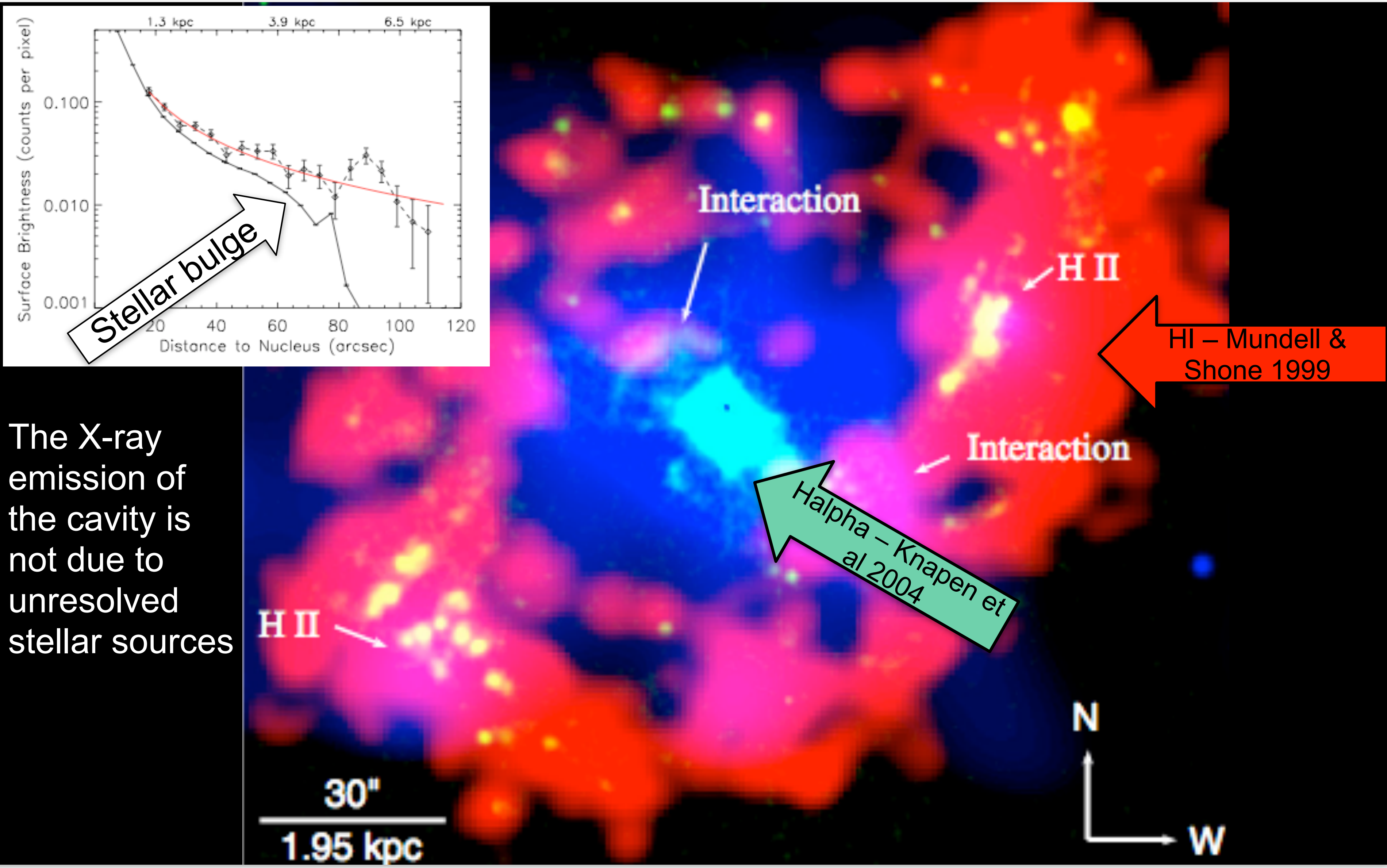
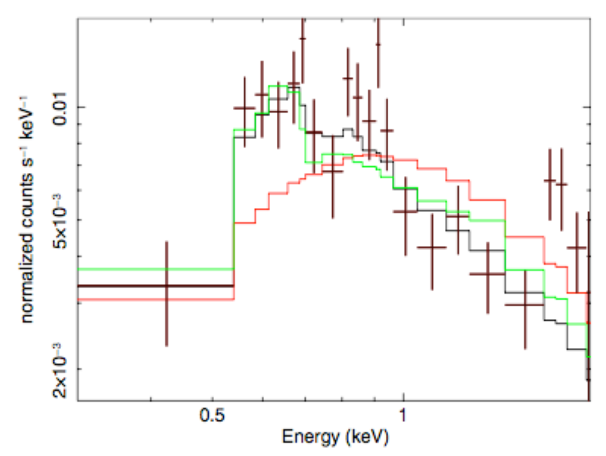
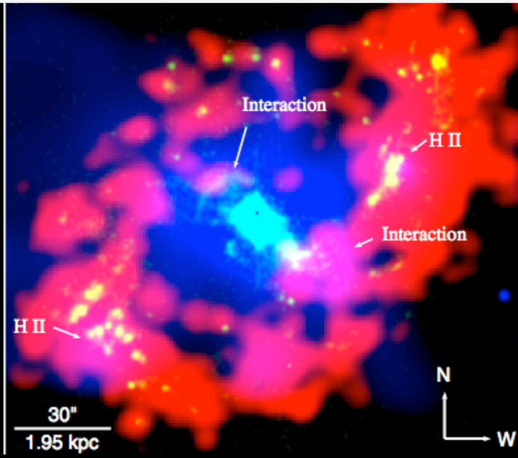


The X-ray emission of the cavity is not due to unresolved stellar sources

NGC 4151 – The 4 Kpc X-ray Filled Cavity

Wang et al 2010





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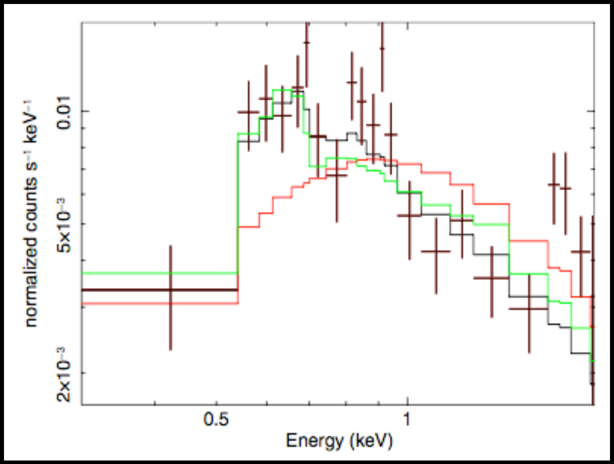
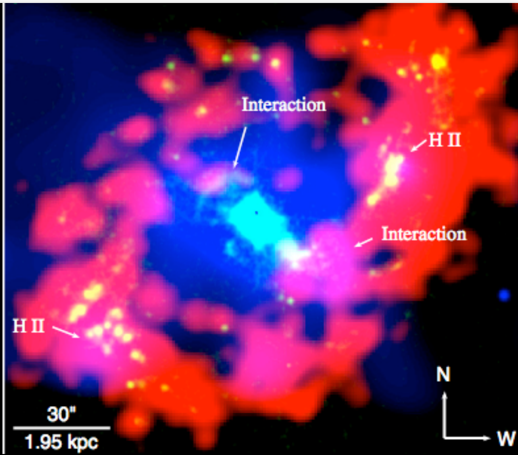


X-ray spectrum fit requires nuclear power-law (PSF wings + stellar)
+ additional component, either
Photoionized logξ = 1.7±0.2
ionization param. $\xi = L/nR^2$
or
Thermal kT = 0.25±0.4 keV



<u>Photo-ionization</u>

Given ξ, n=2 cm^{-3} (HI), R=3kpc

➔L ~ 6×10^{45} erg s^{-1} ~L_E

➔Time ~10^4 yrs

(either recombination or light travel)

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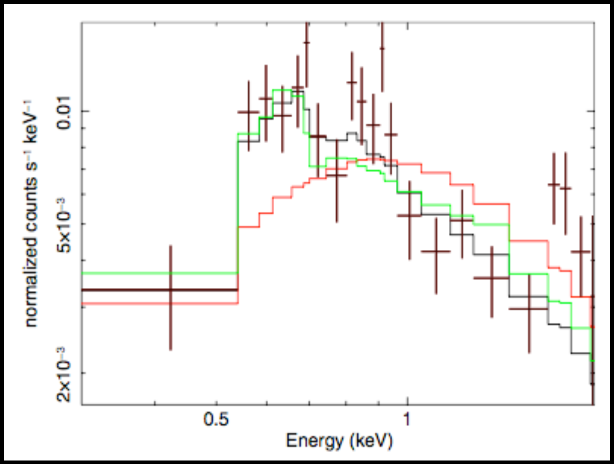

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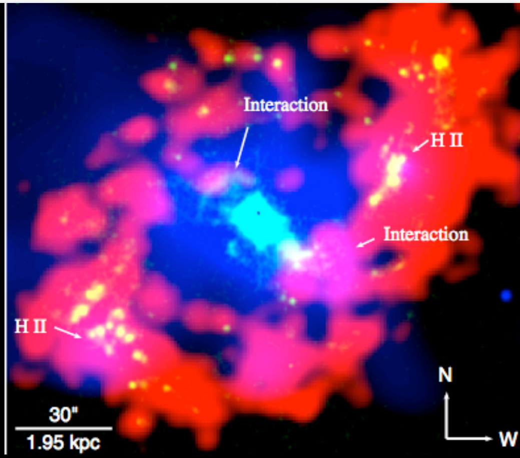

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Burst scenario

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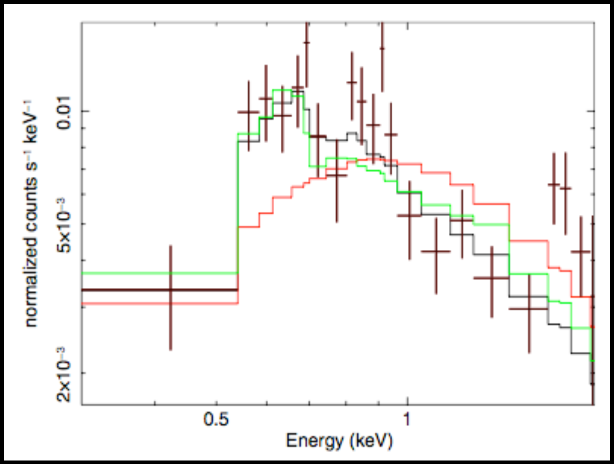

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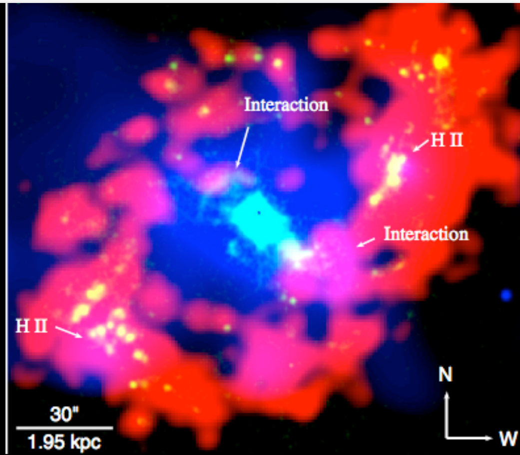

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Hot gas in pressure balance with HI

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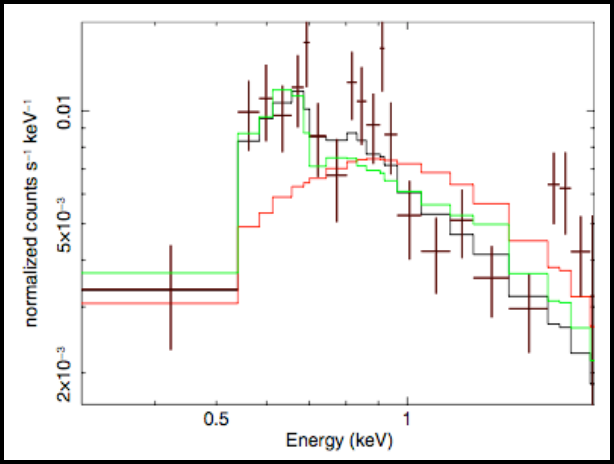

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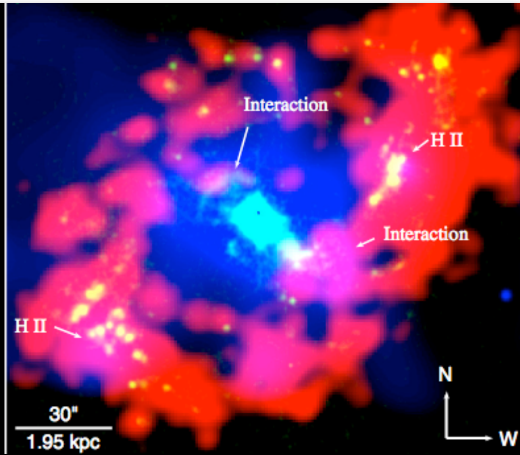

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Hot gas in pressure balance with HI

Given present L$_{bol}$ ~ 7×10^{43} erg s^{-1}

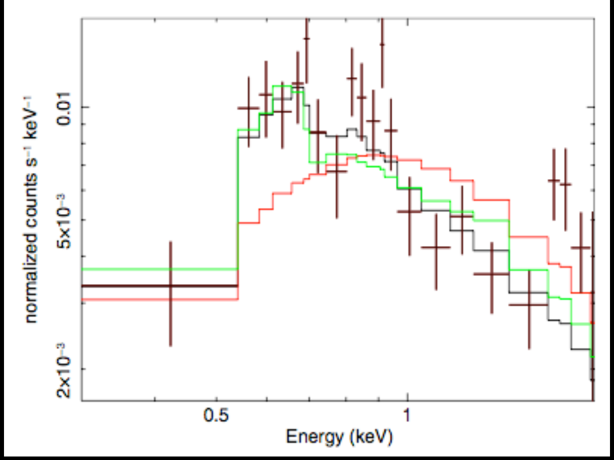
If 5% goes into cavity (Hopkins et al 2005)

→Time ~4×10^4 yrs of AGN heating to create Eth

→Also expansion time off disk ~10^5 yrs

NGC 4151 – THE 4 KPC X-RAY FILLED CAVITY

Wang et al 2010



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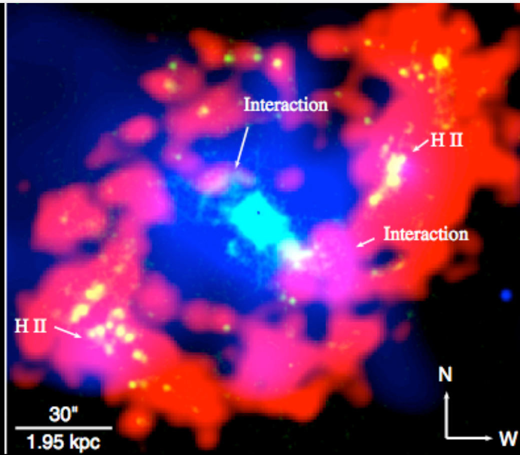

This could be steady-state

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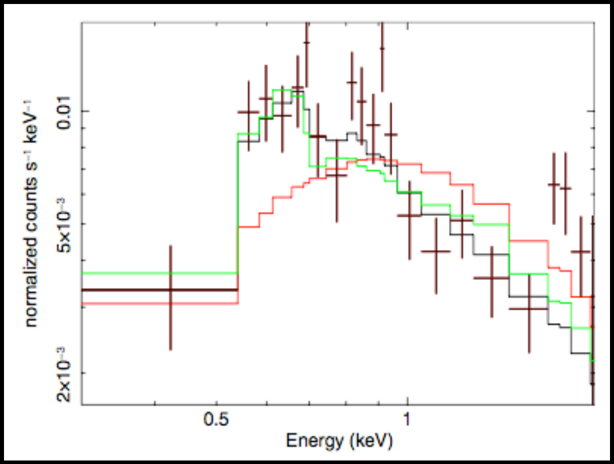

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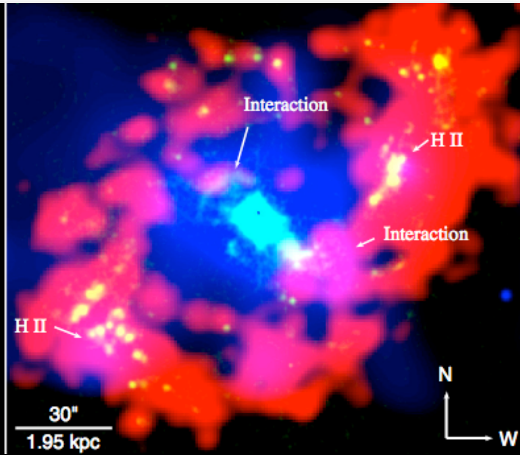

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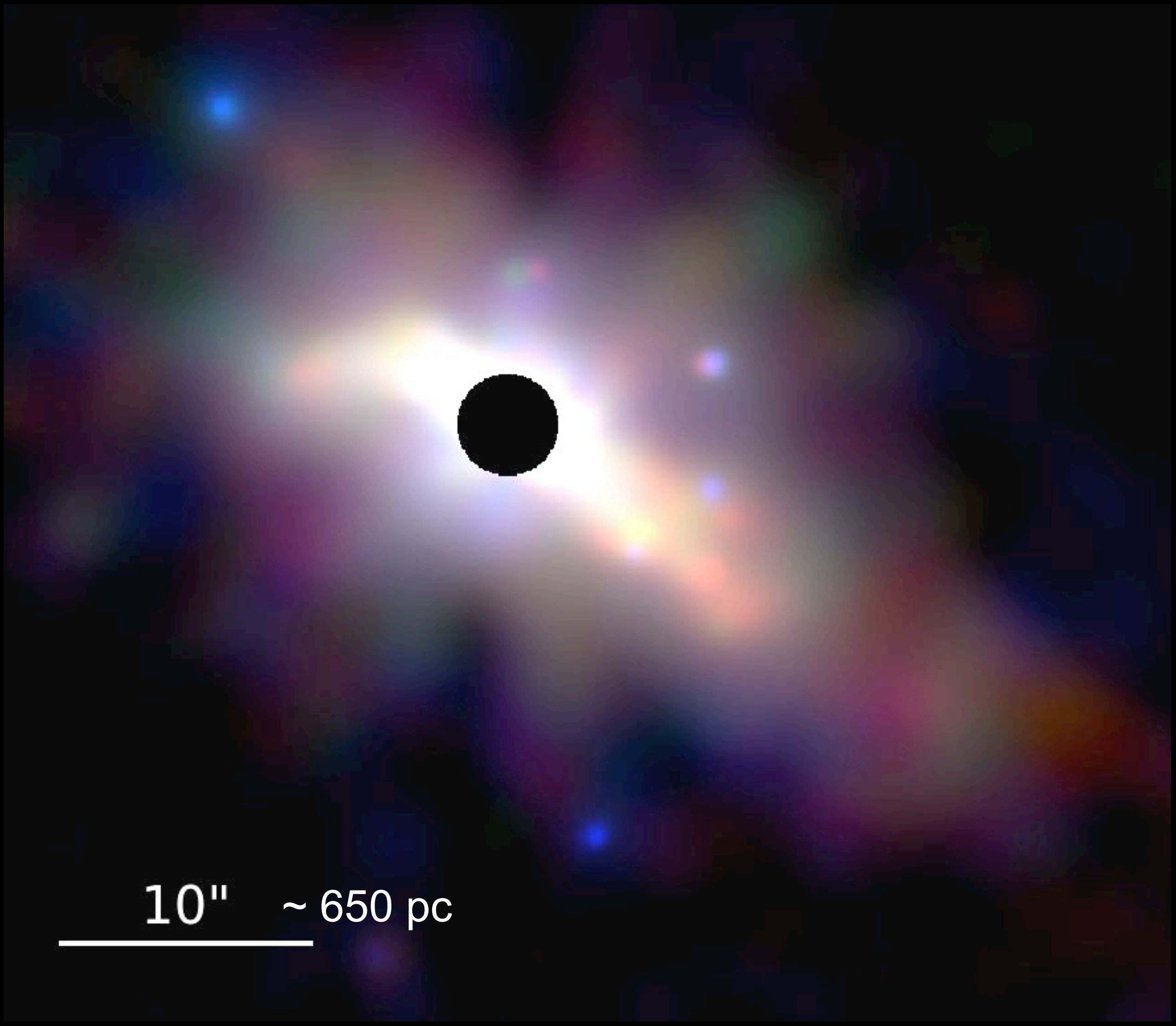
➔How much of this outflow is powered by SN heating? (see M31, Bogdan & Gilfanov 2008)

Circum-Nuclear X-ray Emission of NGC 4151



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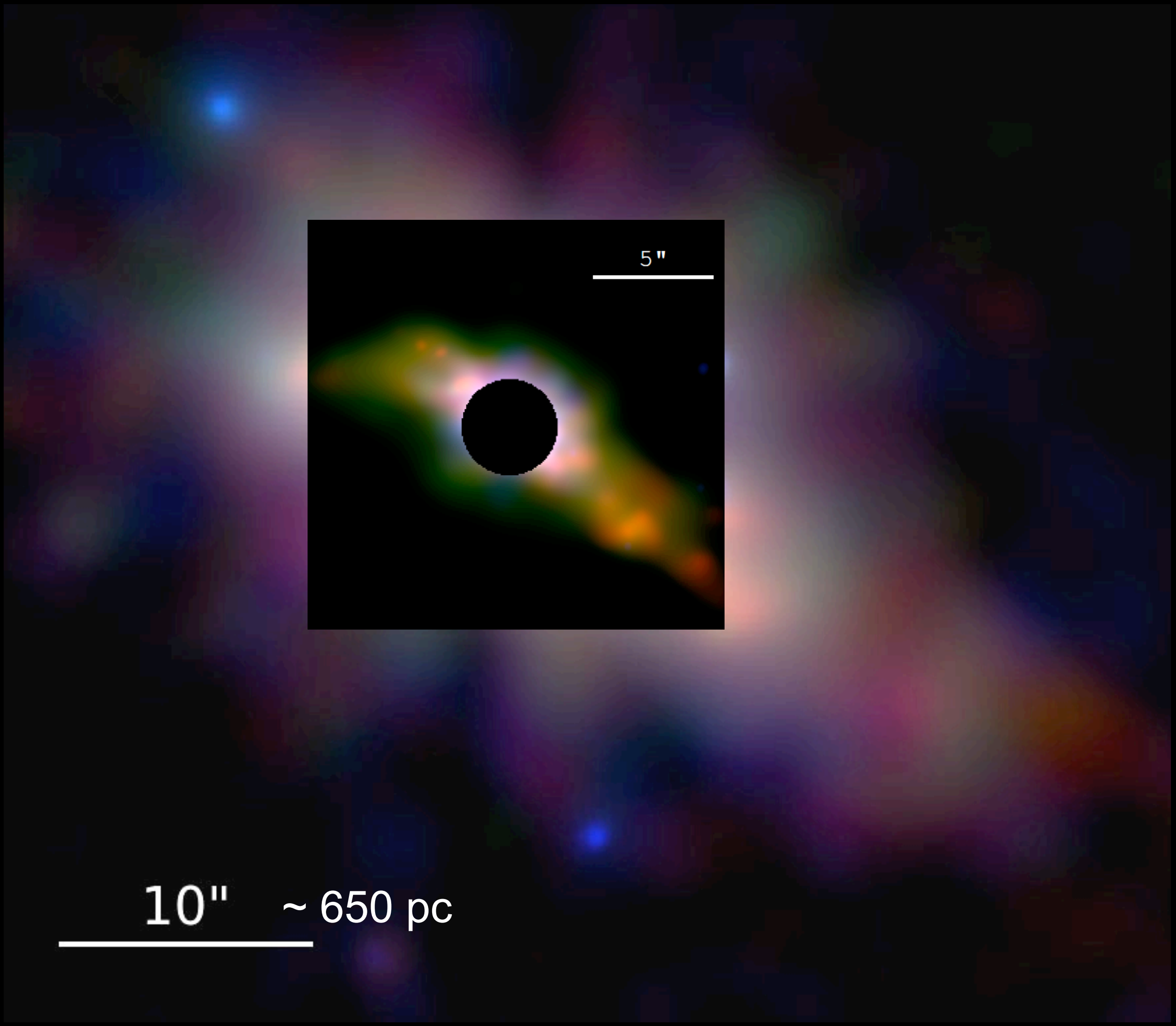

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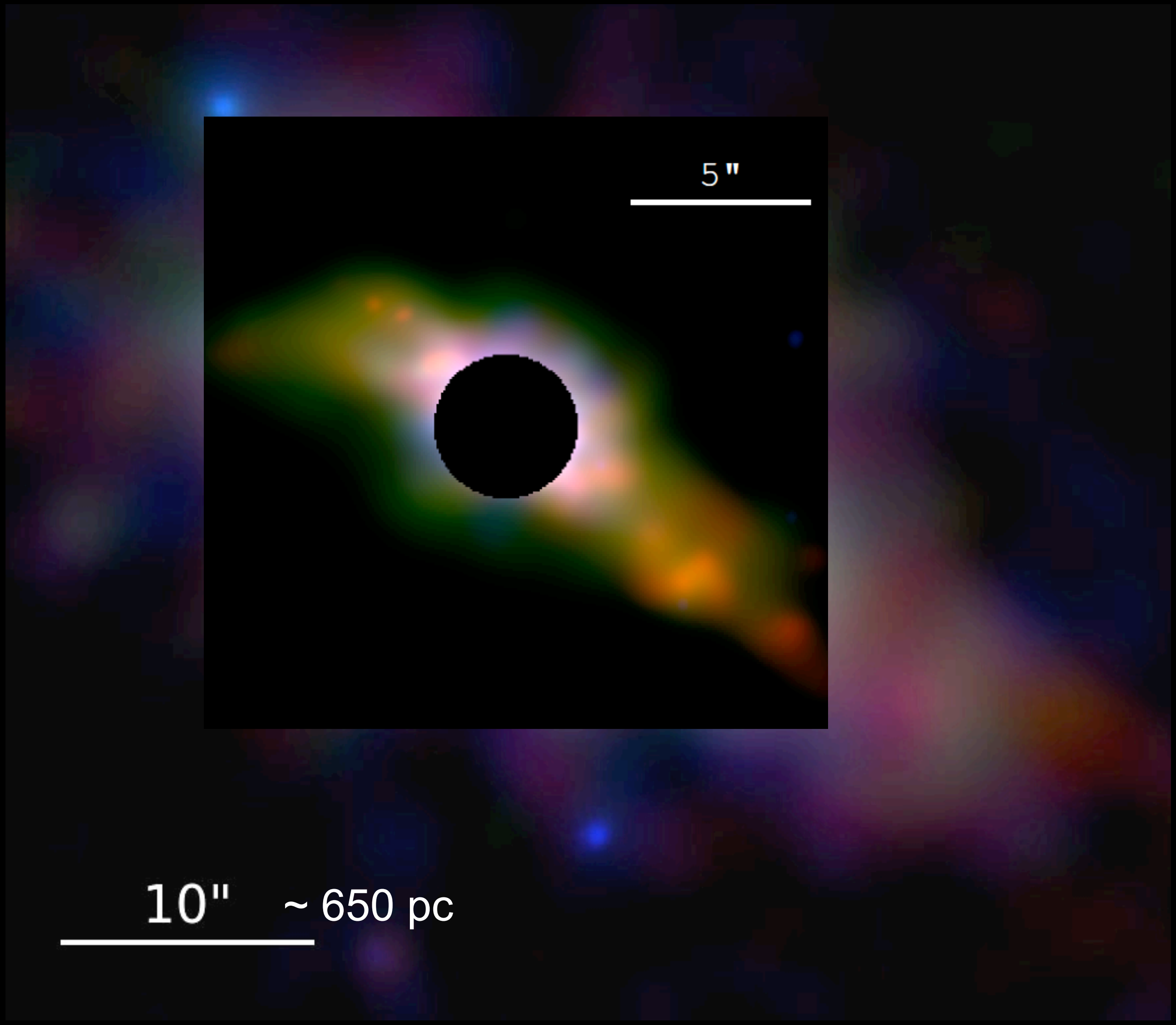
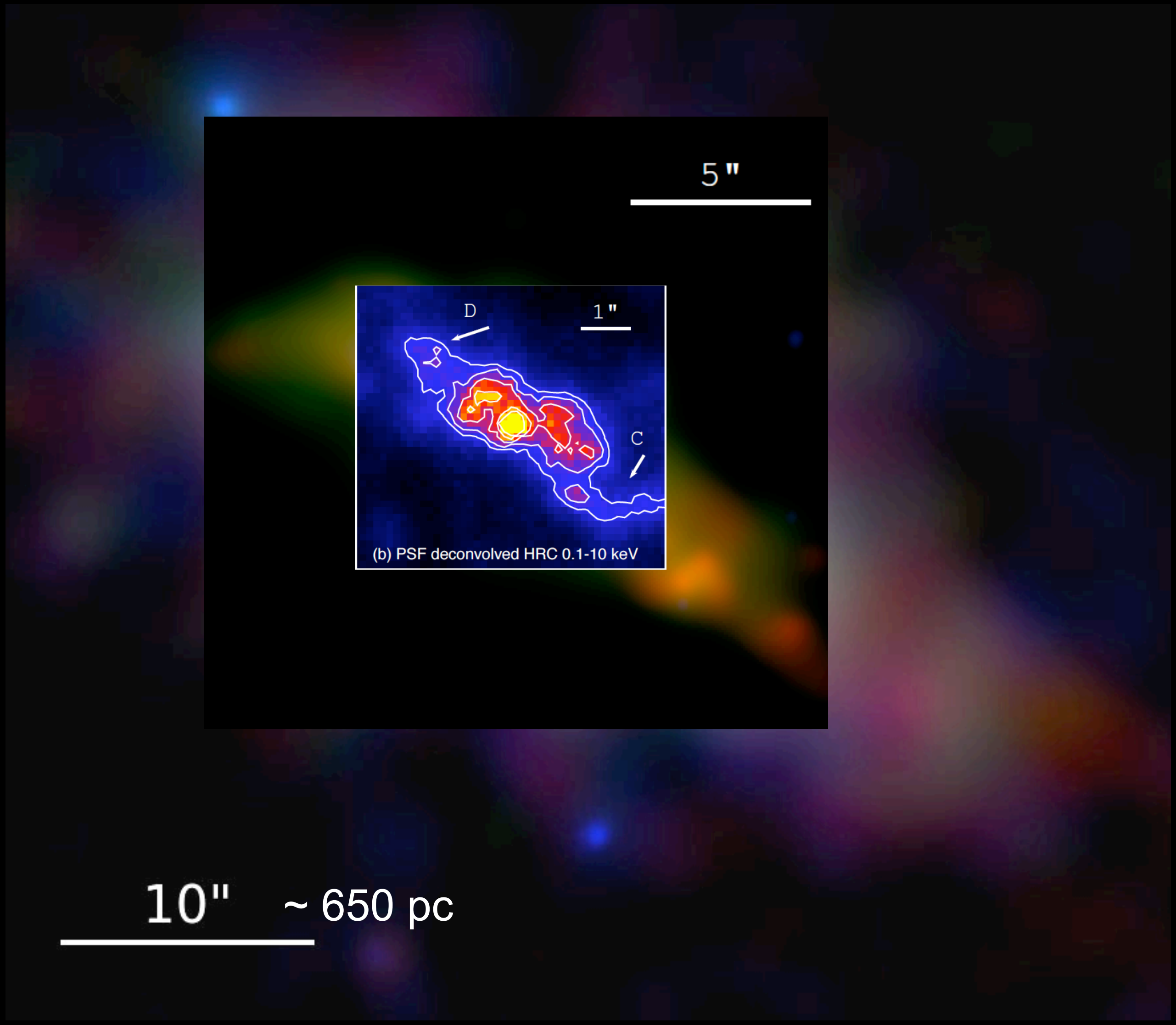
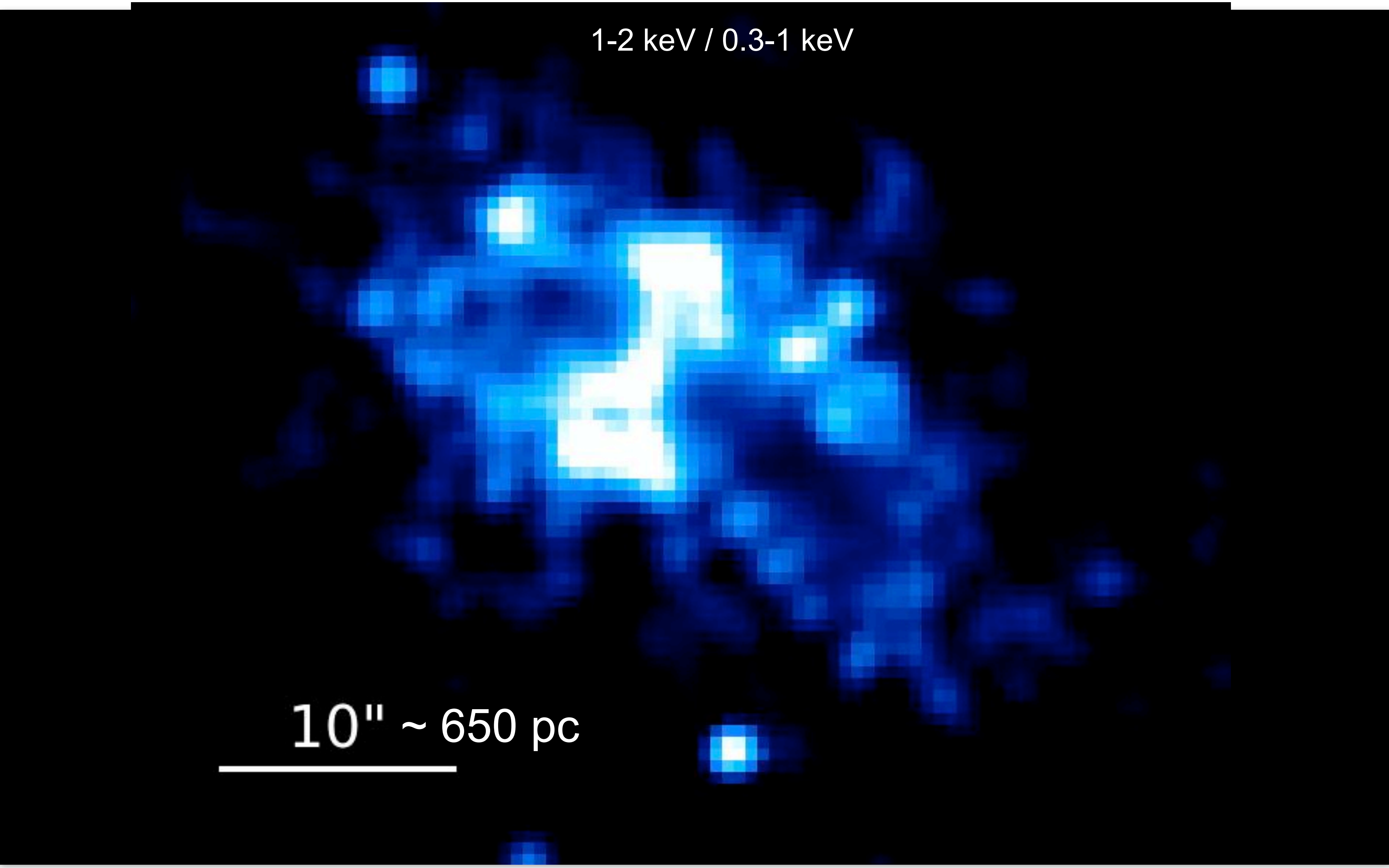


CIRCUM-NUCLEAR X-RAY EMISSION OF NGC 4151



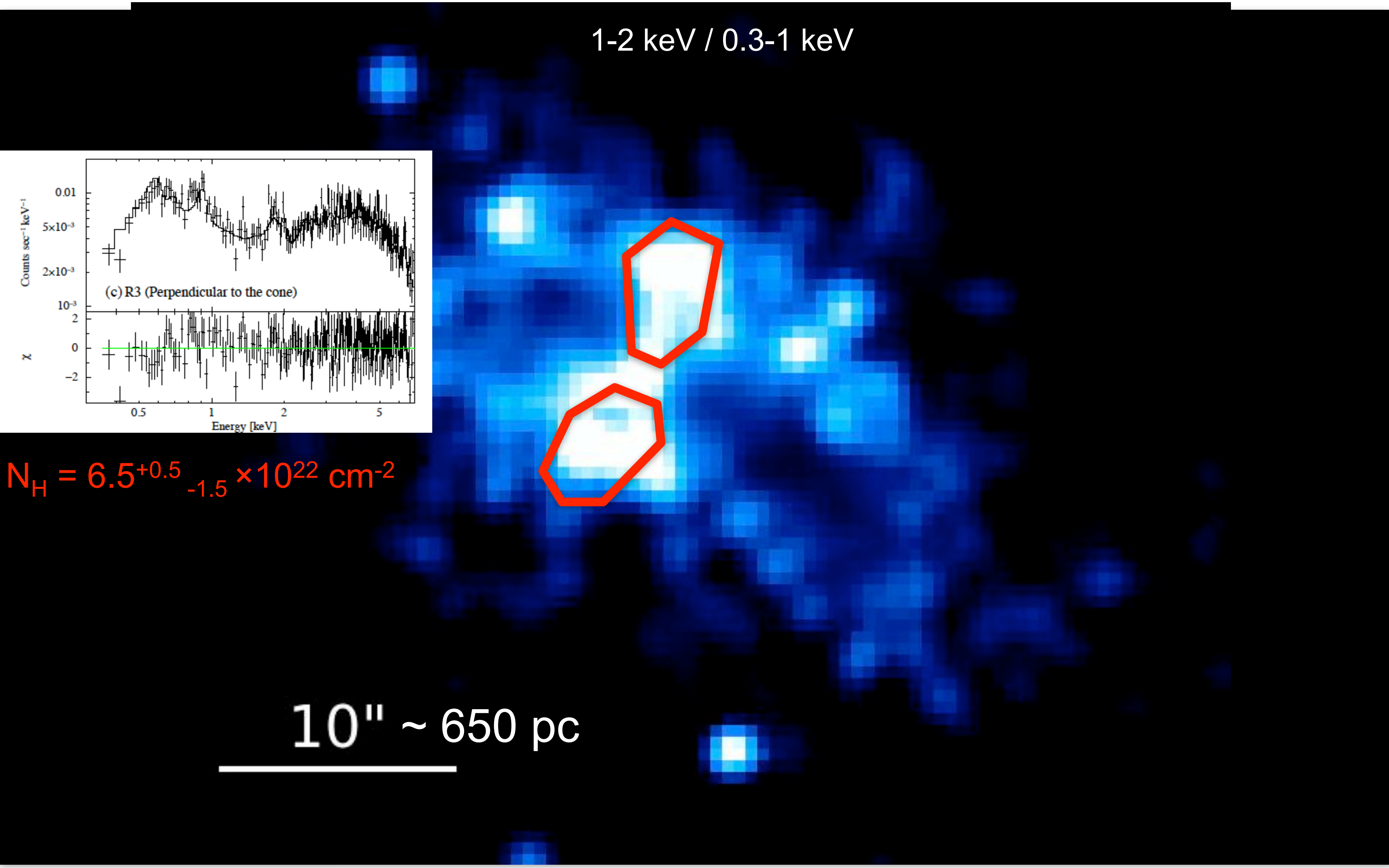
NGC 4151 – X-RAY ABSORPTION MAP

Wang et al 2011a



NGC 4151 – X-RAY ABSORPTION MAP

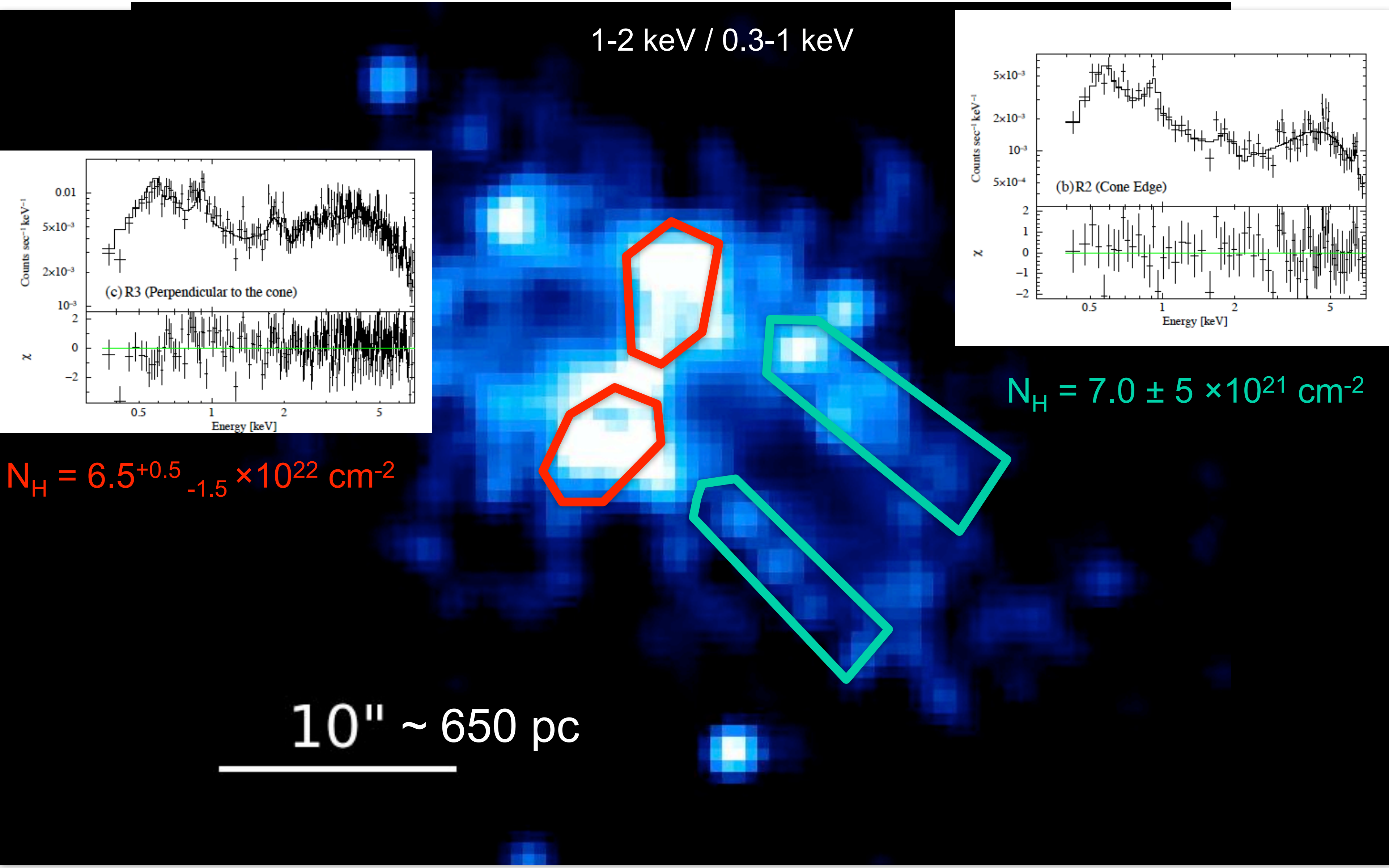
Wang et al 2011a



$N_H = 6.5^{+0.5}_{-1.5} \times 10^{22}$ cm^{-2}

NGC 4151 – X-RAY ABSORPTION MAP

Wang et al 2011a



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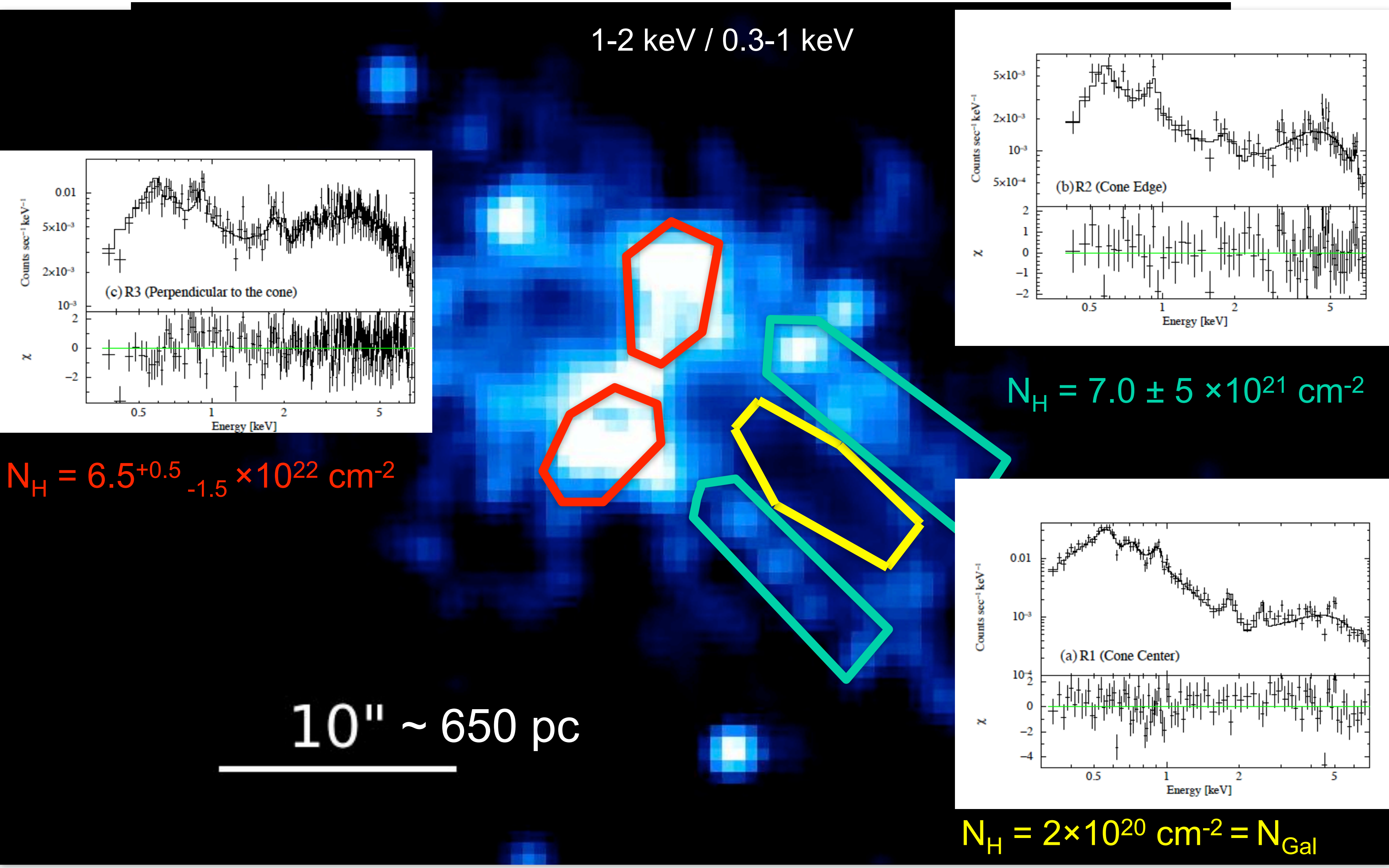
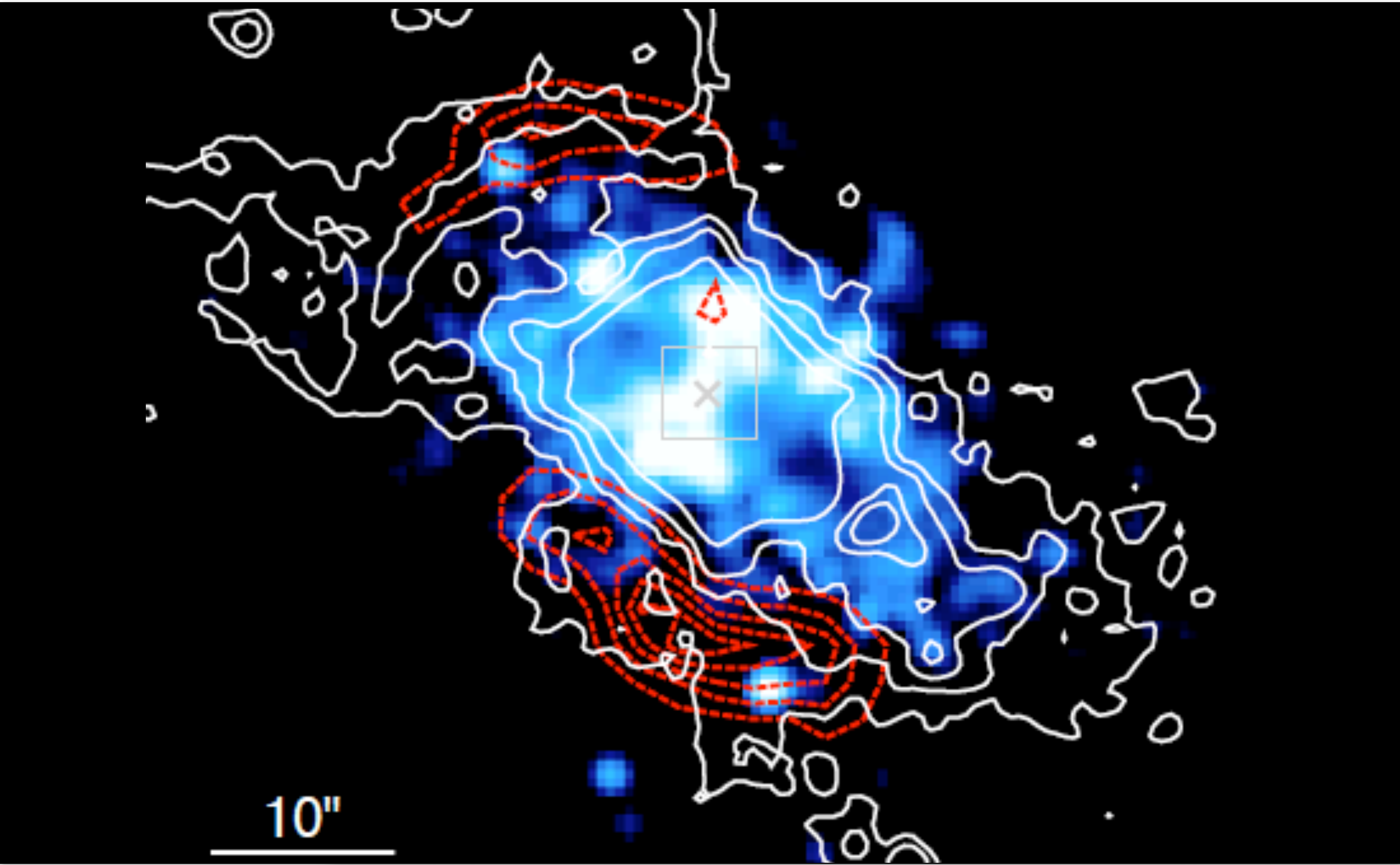
Wang et al 2011a



NGC 4151 – X-ray Emission and Obscuring Clouds

Wang et al 2011a

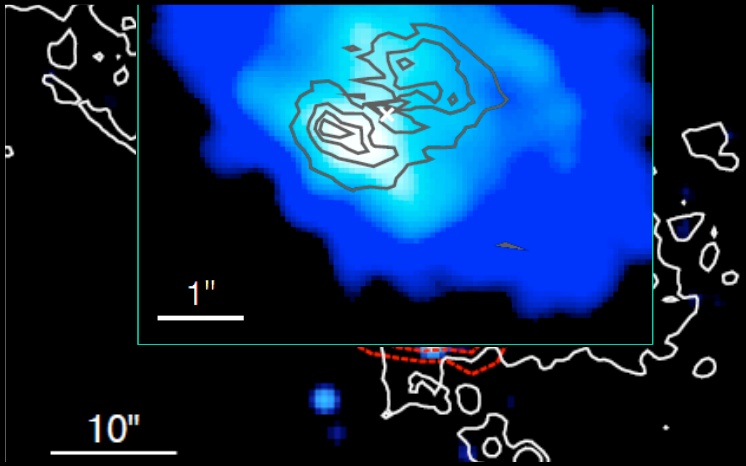


NGC 4151 – X-RAY EMISSION AND OBSCURING CLOUDS

Wang et al 2011a

•Assuming no HI, H_2 mass from N_H ~$2\times10^7 M_\odot$
Mass from H_2 emission ~10^7 -10^9 $M_\odot$
(Storchi-Bergmann et al 2009)

•H2 could be photo-excited from AGN
➔Not blocked by molecular torus
➔Low CO abundances in nucleus because of X-rays (XDR)



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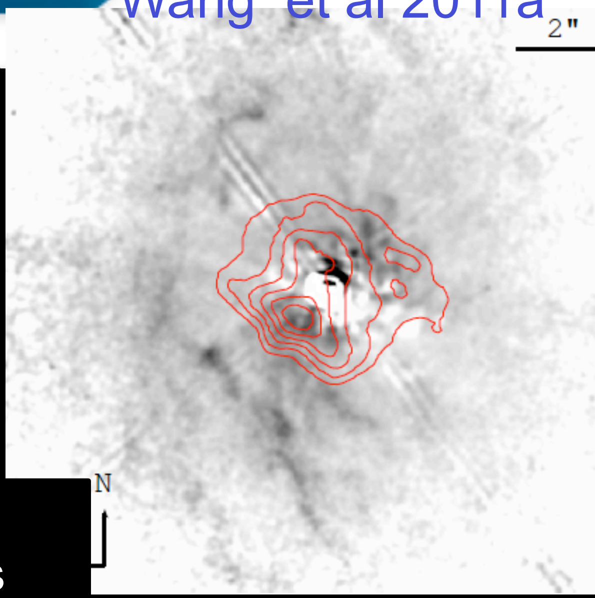
Wang et al 2011a



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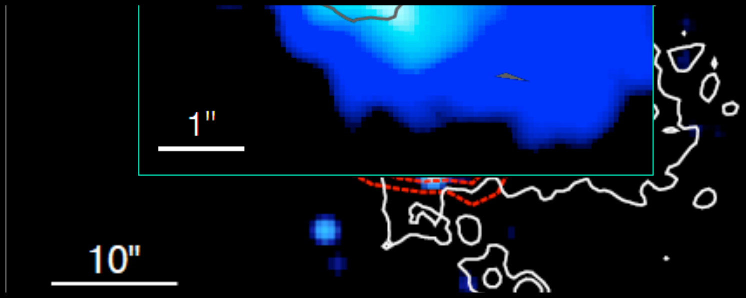
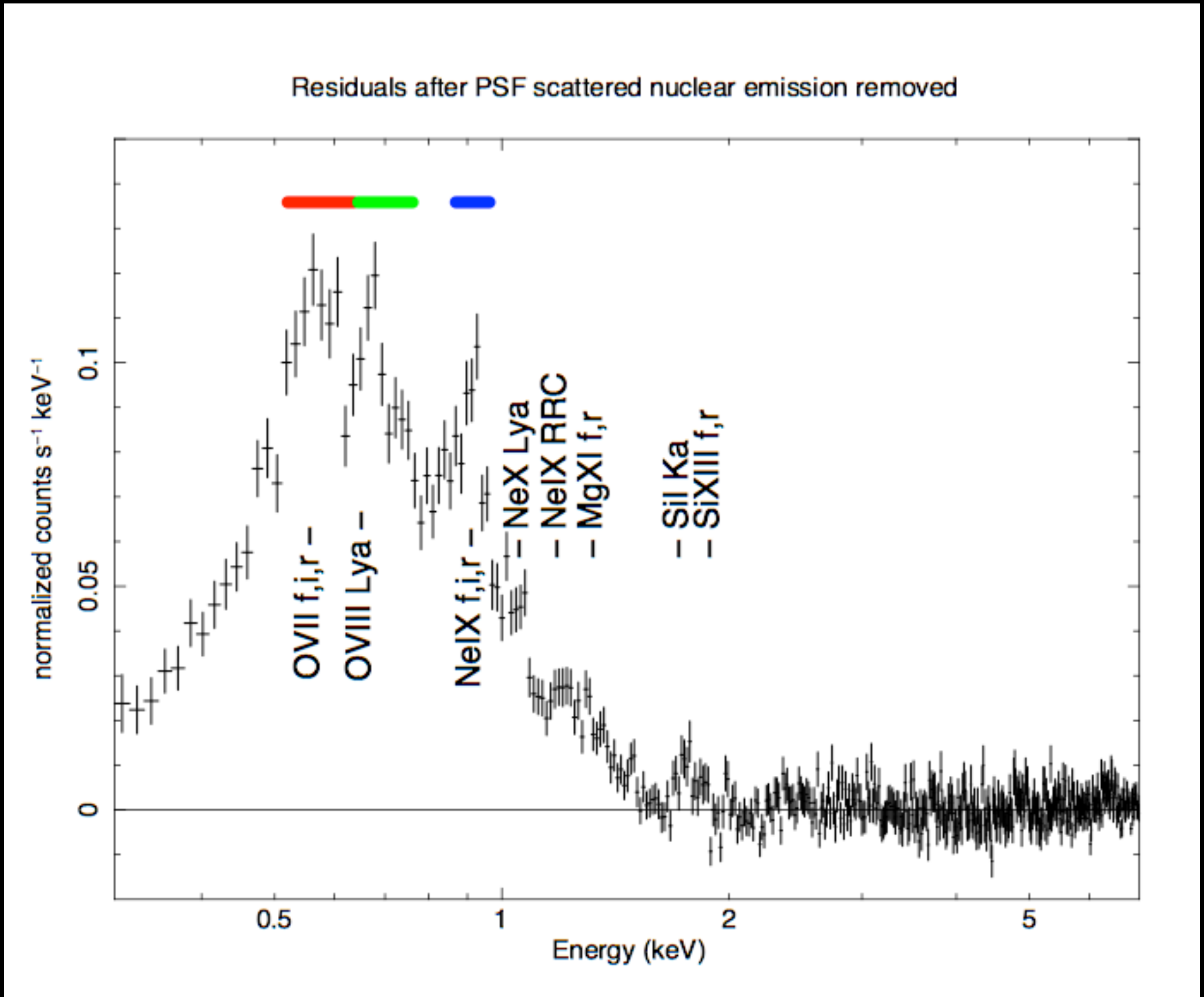
•H2 could be photo-excited from AGN
➔Not blocked by molecular torus
➔Low CO abundances in nucleus because of X-rays (XDR)

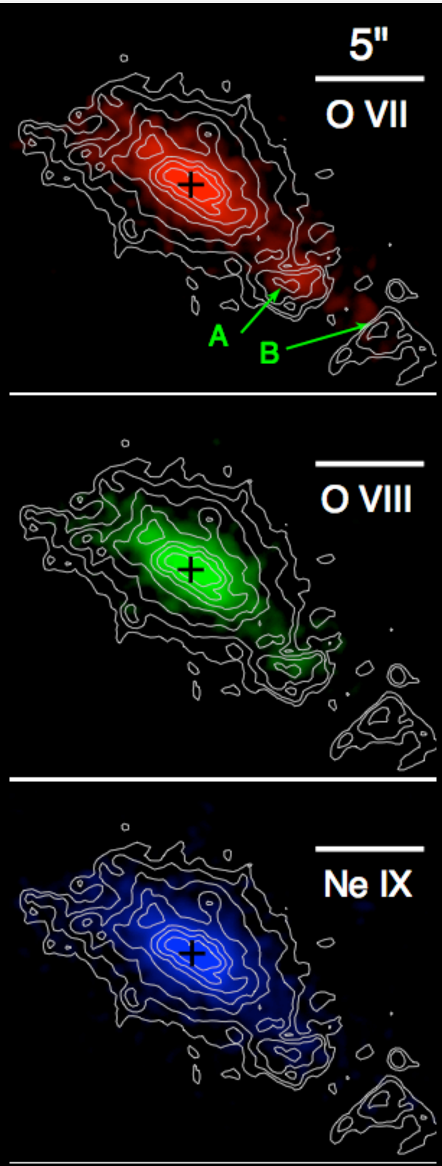
•CO (Dumas et al 2010) and V-H map suggest 'spiral' features accreting to the nucleus



NGC 4151 – DIFFUSE EMISSION SPECTRUM

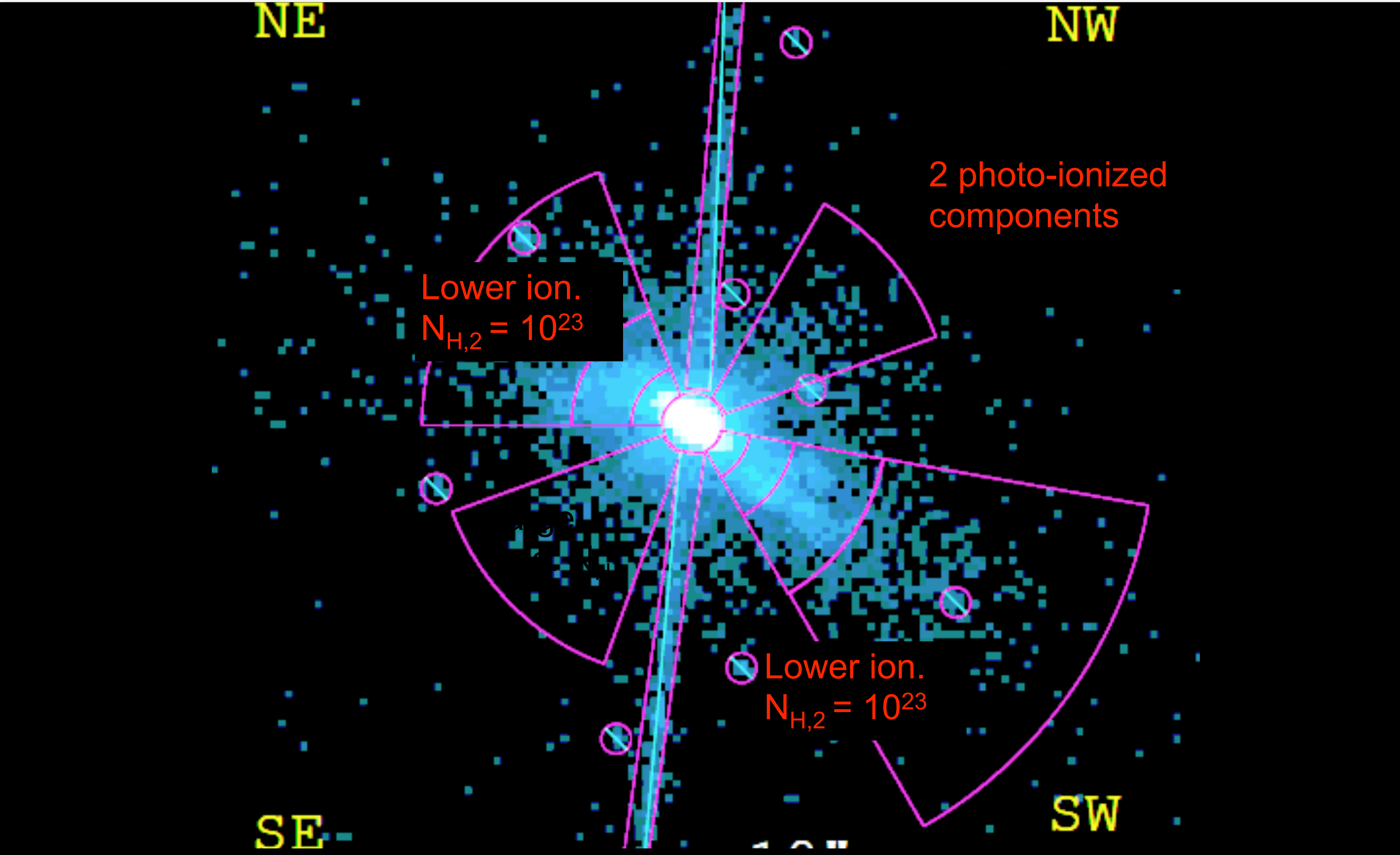
Wang et al 2011c





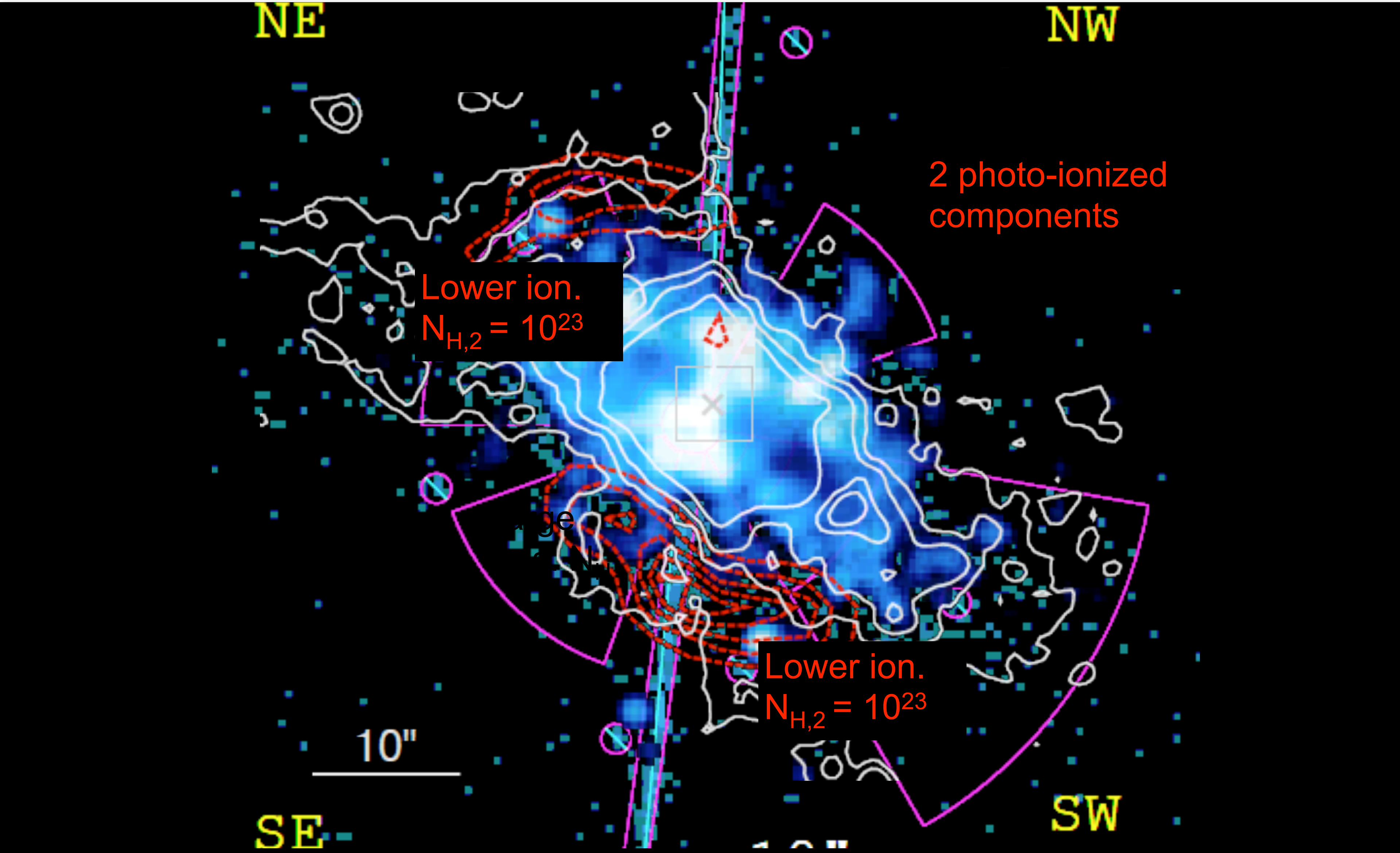
SPECTRAL ANALYSIS – PHOTO-IONIZATION

Wang et al 2011c



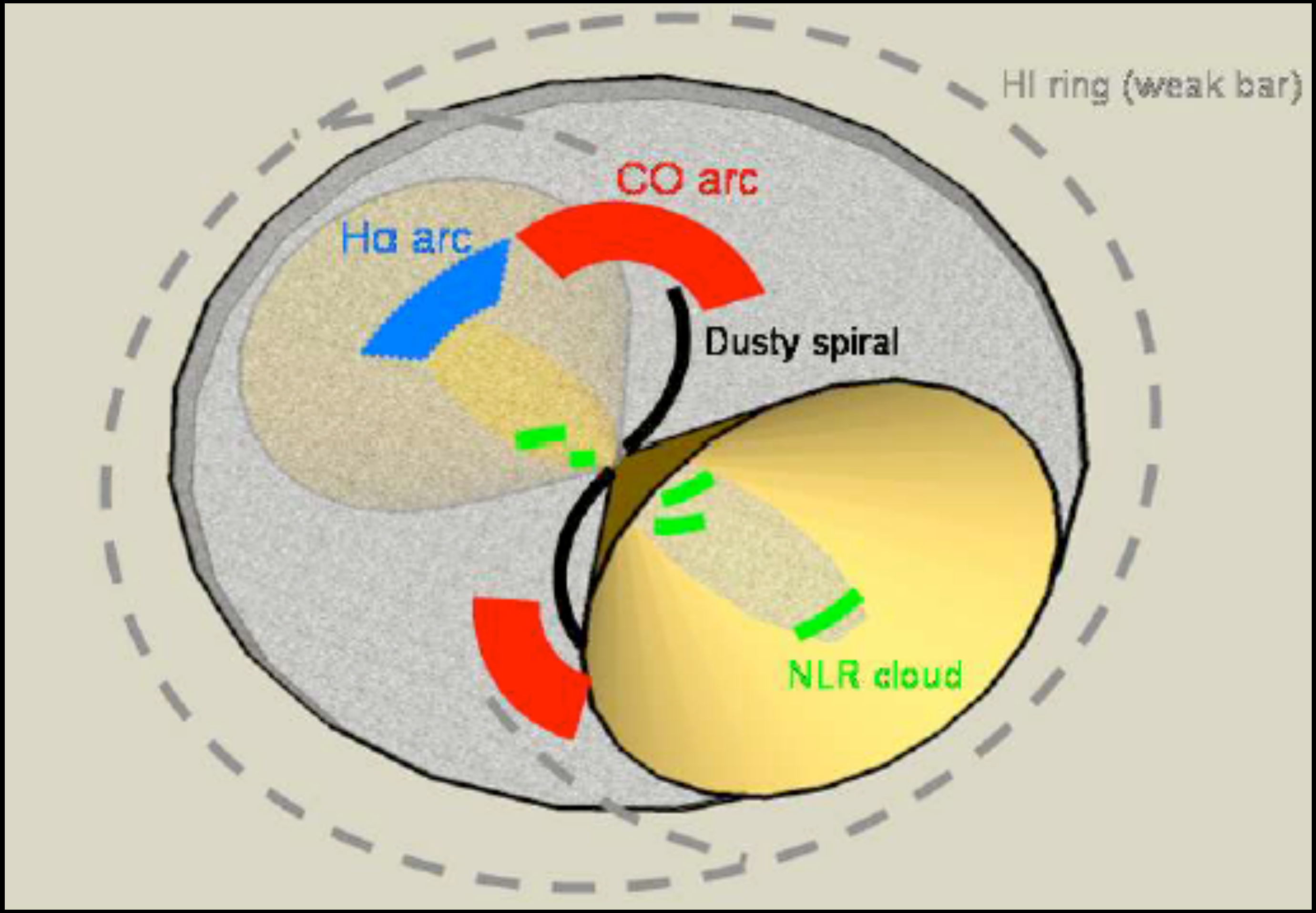
Spectral Analysis – Photo-ionization

Wang et al 2011c



The Central ~4 kpc of NGC 4151 – A Cartoon

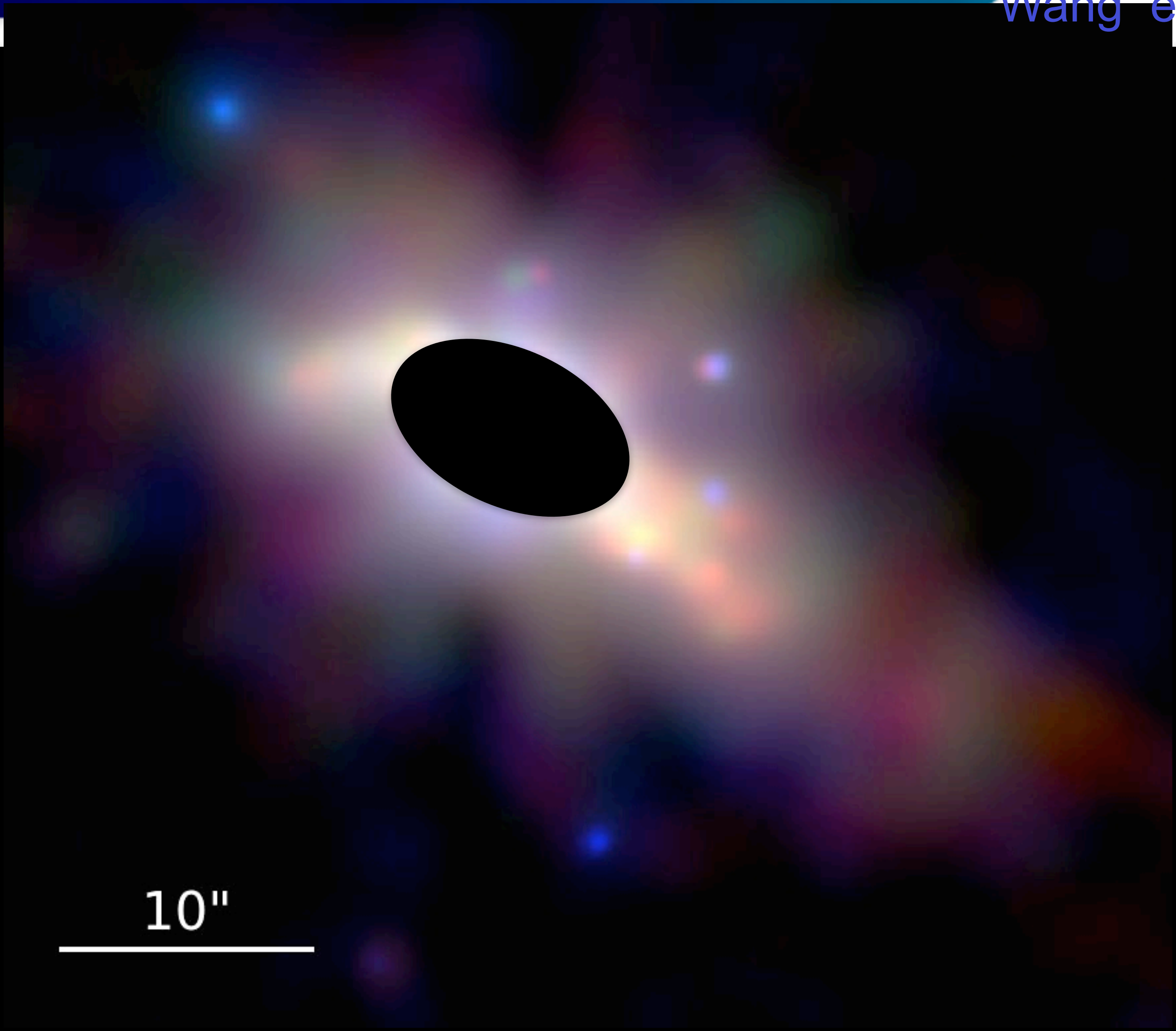
Wang et al 2011c



Soft X-ray Emission of NGC 4151 Circum-Nuclear Region

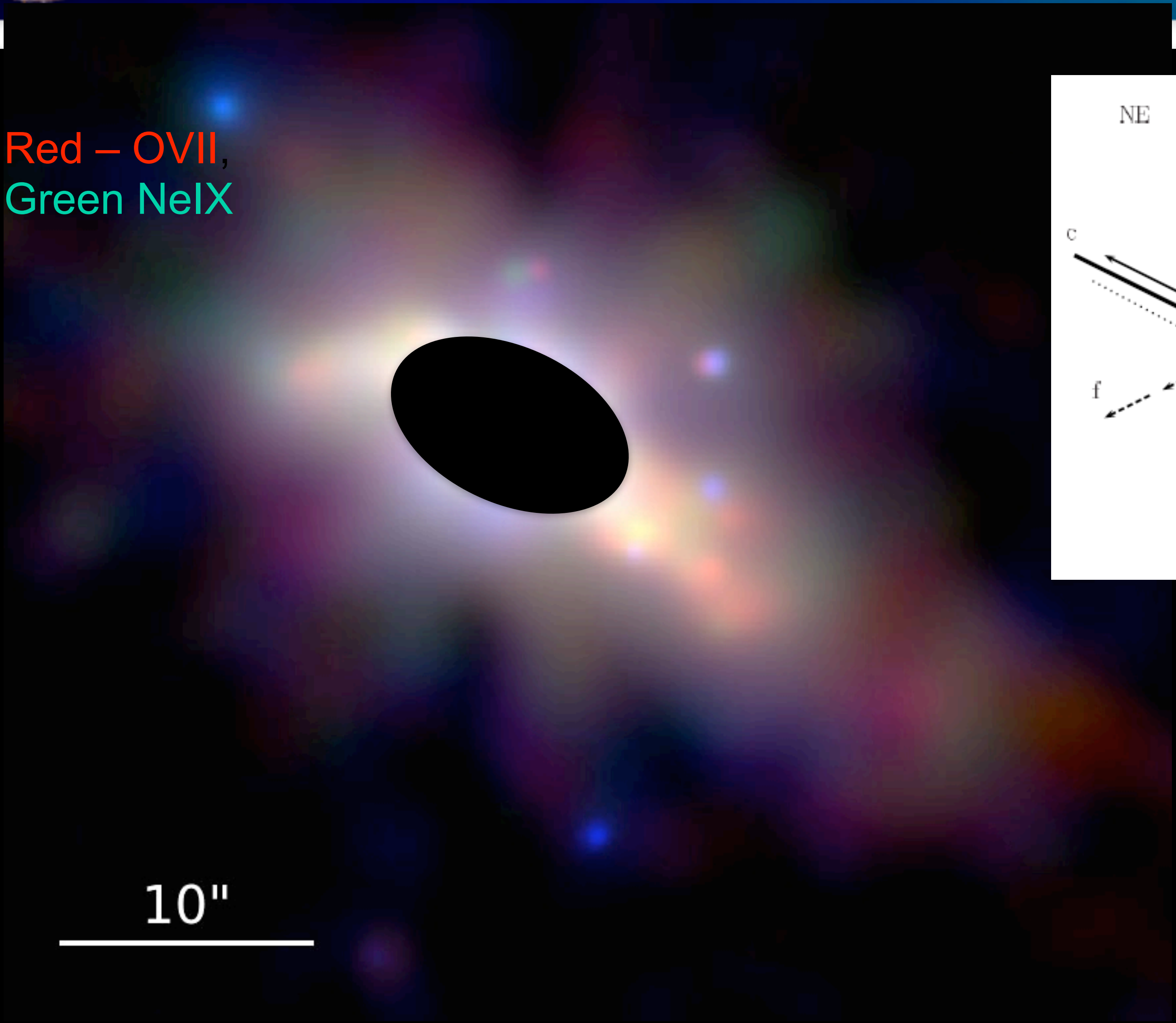
Wang et al 2011c

Red – OVII
Green NeIX

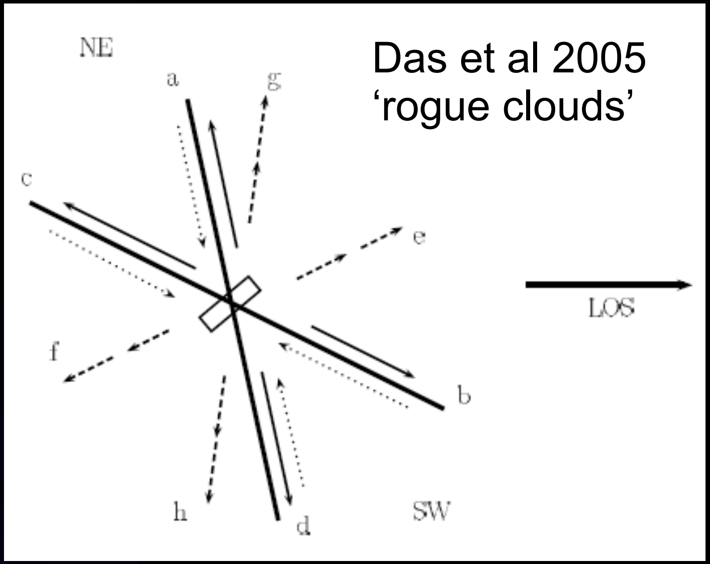


SOFT X-RAY EMISSION OF NGC 4151 CIRCUM-NUCLEAR REGION

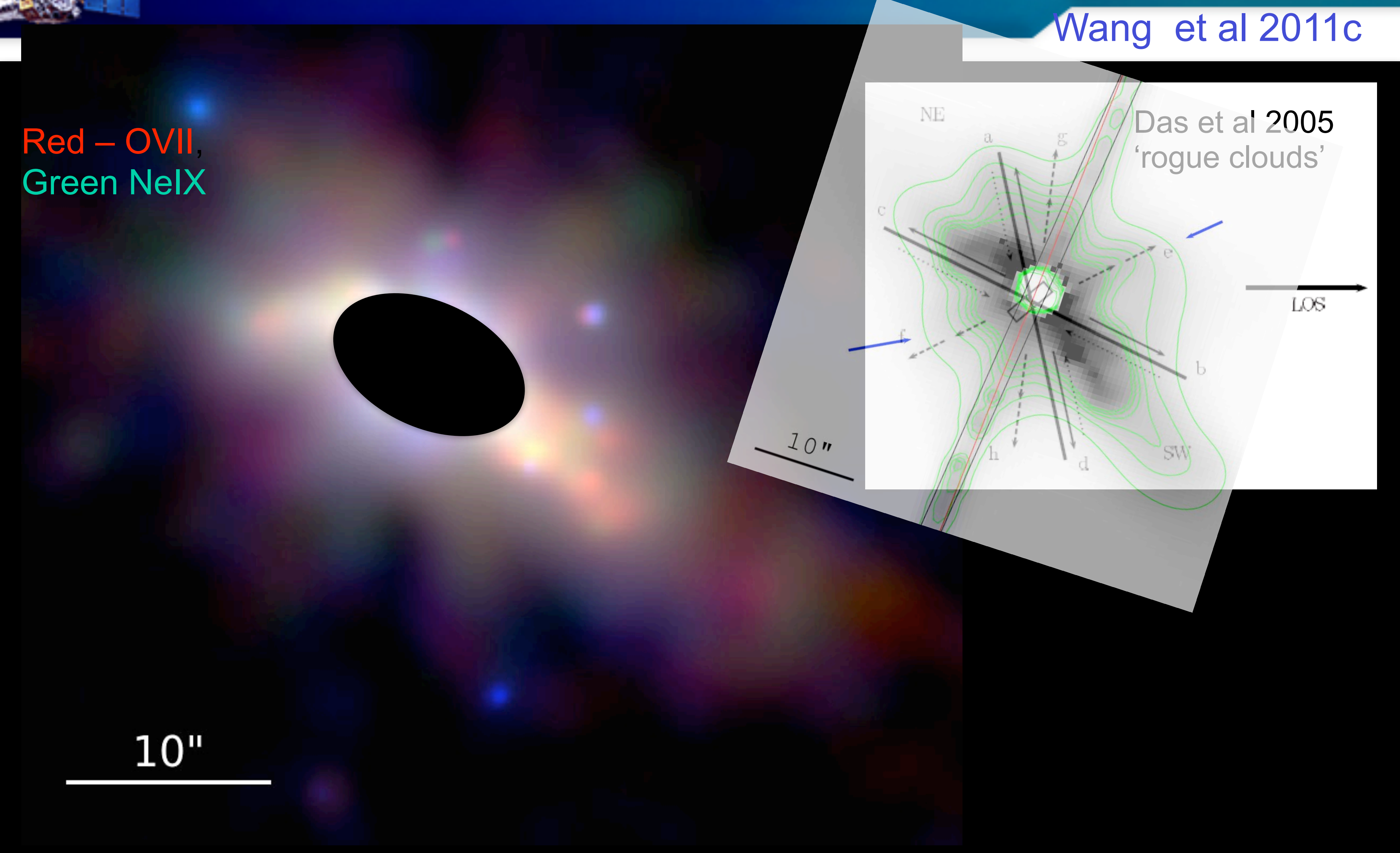
Wang et al 2011c



Das et al 2005
‘rogue clouds’

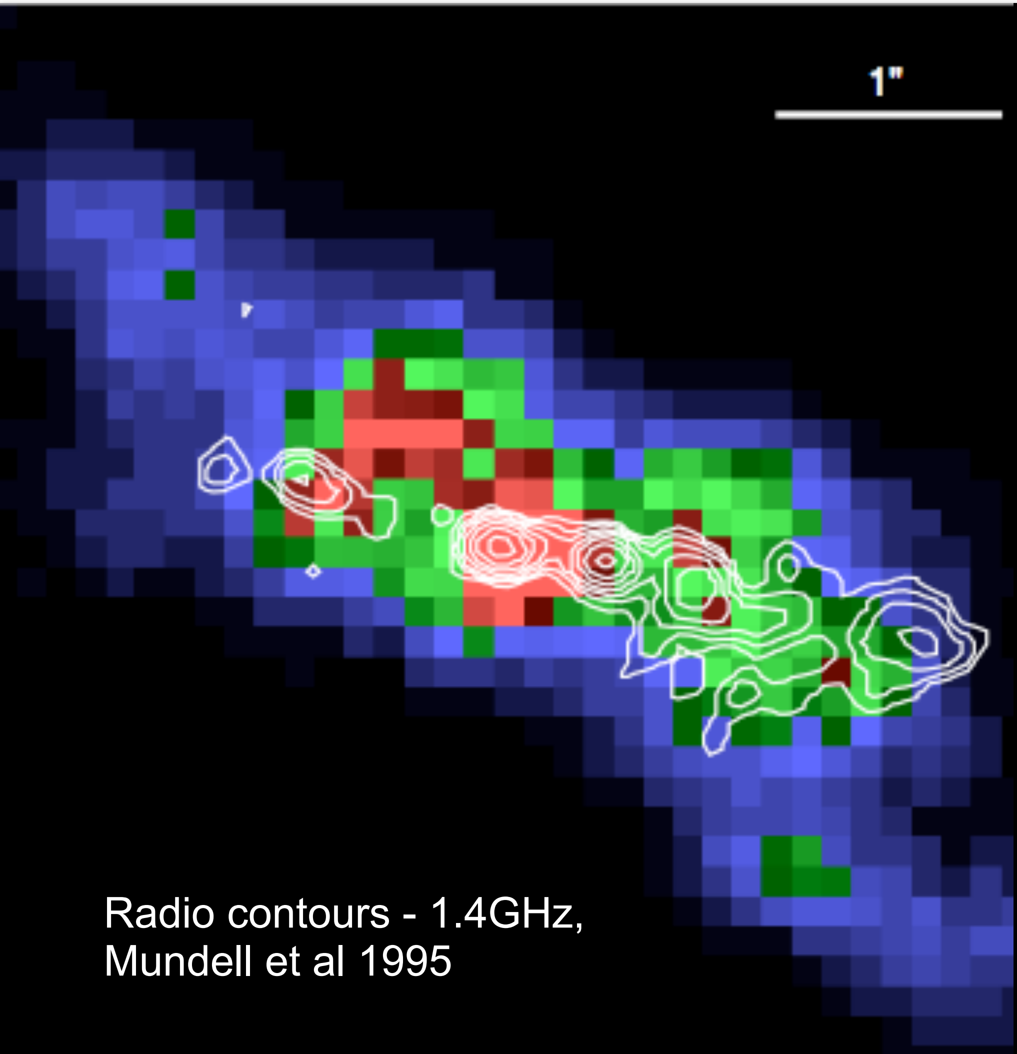


SOFT X-RAY EMISSION OF NGC 4151 CIRCUM-NUCLEAR REGION

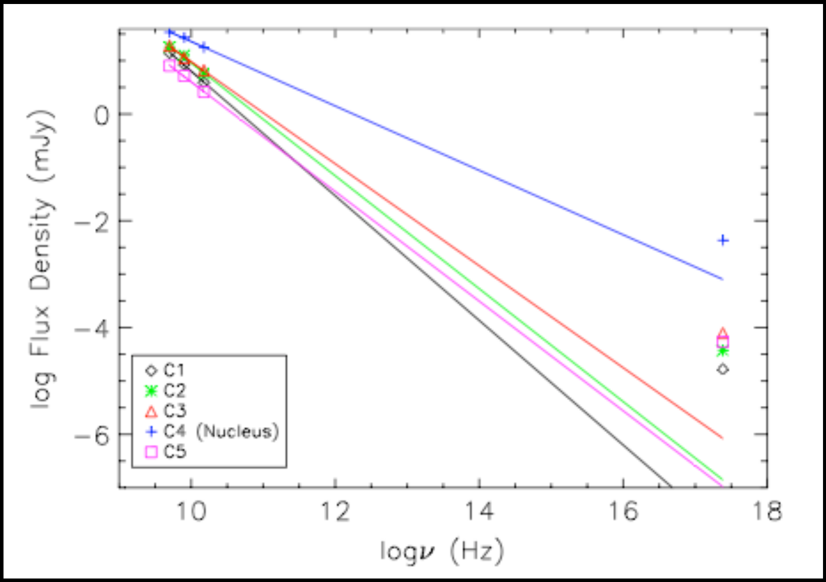


X-RAY EMISSION AND RADIO JET

Wang et al 2009



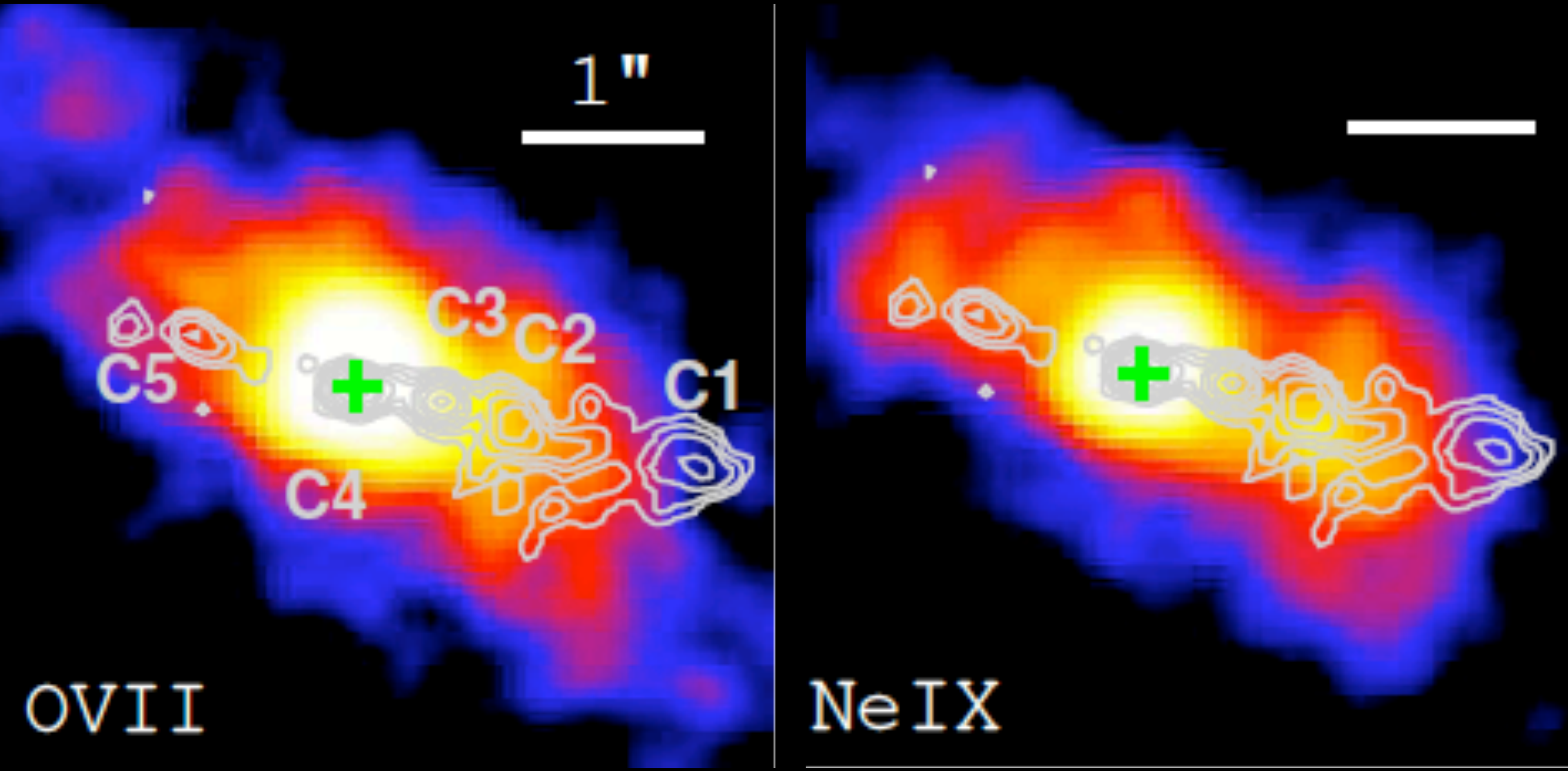
Radio contours - 1.4GHz,
Mundell et al 1995



- X-ray emission of radio knots, way in excess of Synchrotron extrapolation (and IC of the CMB)
- Thermal emission from cloud interaction?

X-RAY LINE EMISSION AND RADIO JET – CLOUD INTERACTION

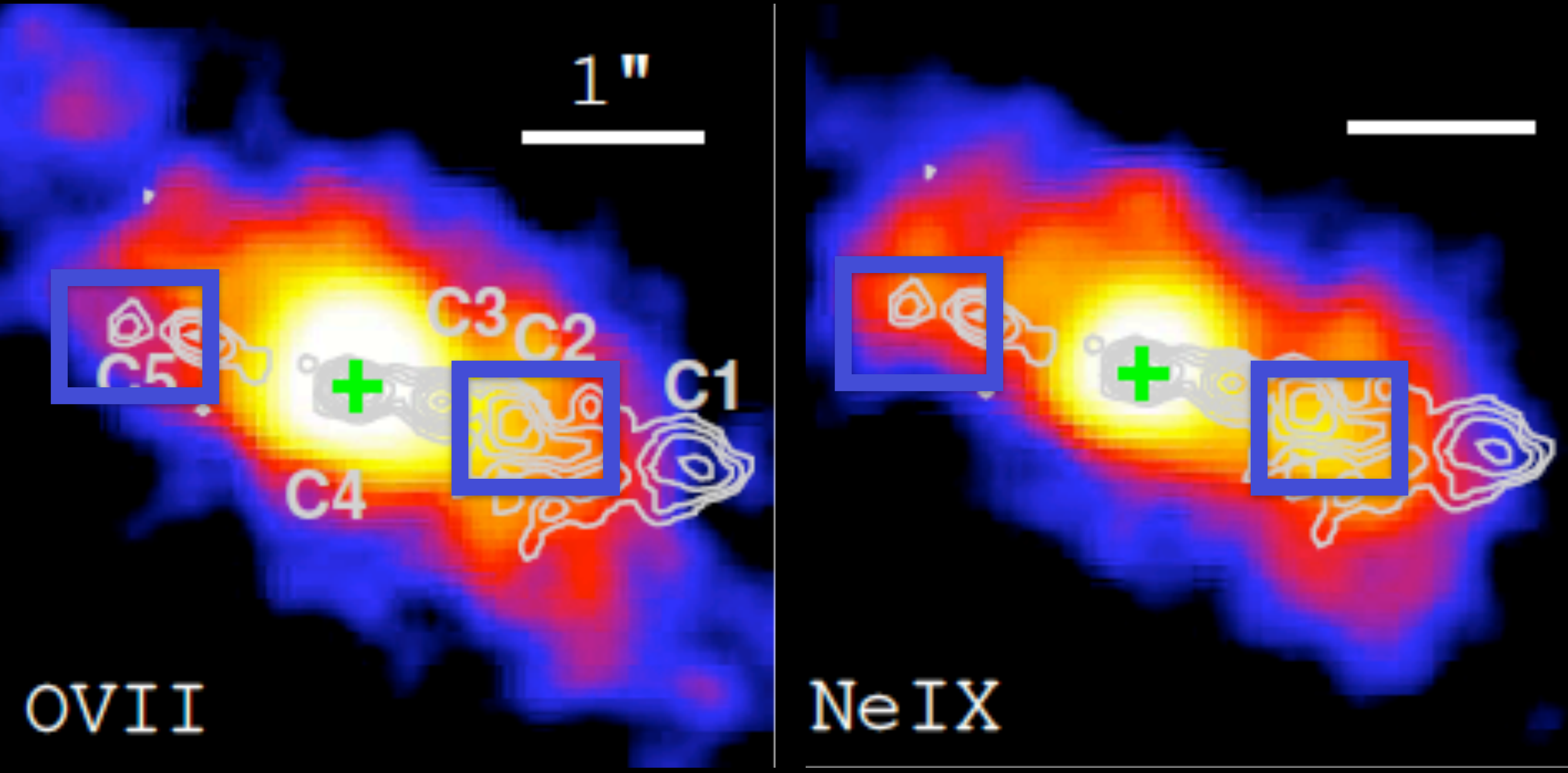
Wang et al 2011b



Chandra ACIS-S

X-RAY LINE EMISSION AND RADIO JET – CLOUD INTERACTION

Wang et al 2011b



Chandra ACIS-S

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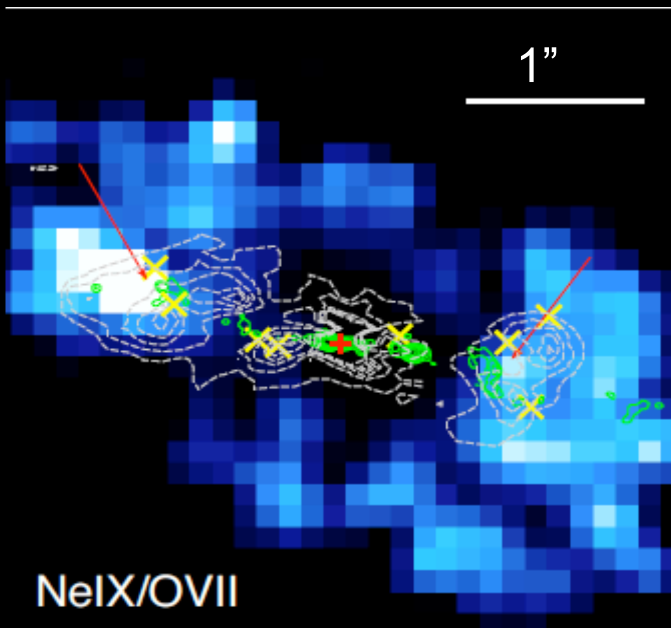
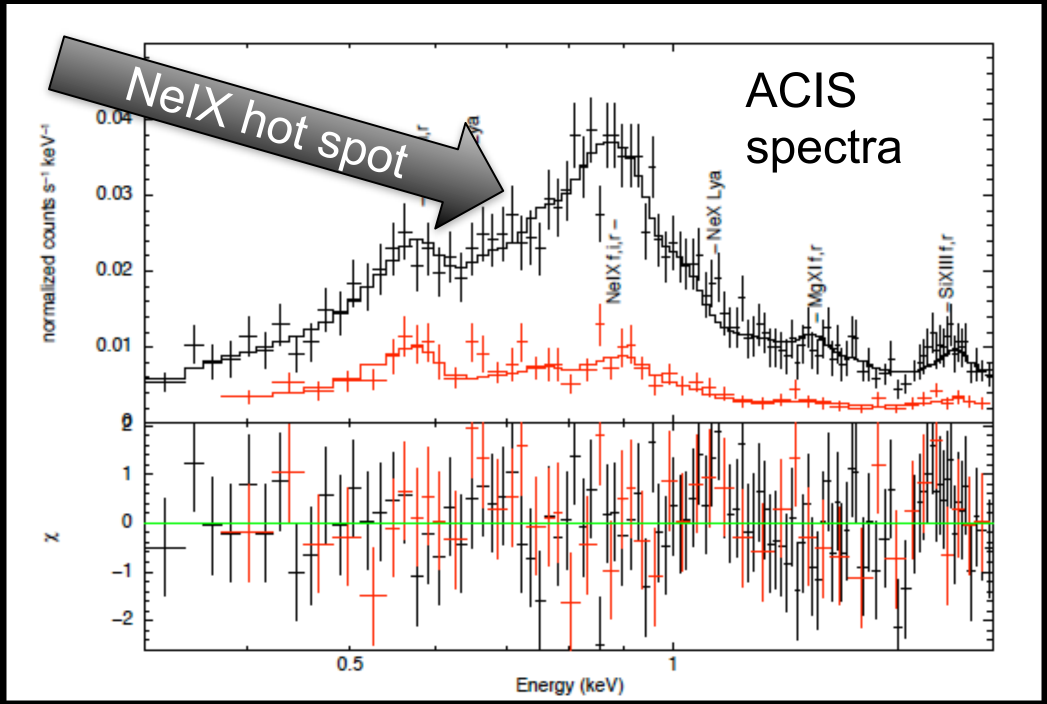
Wang et al 2011b





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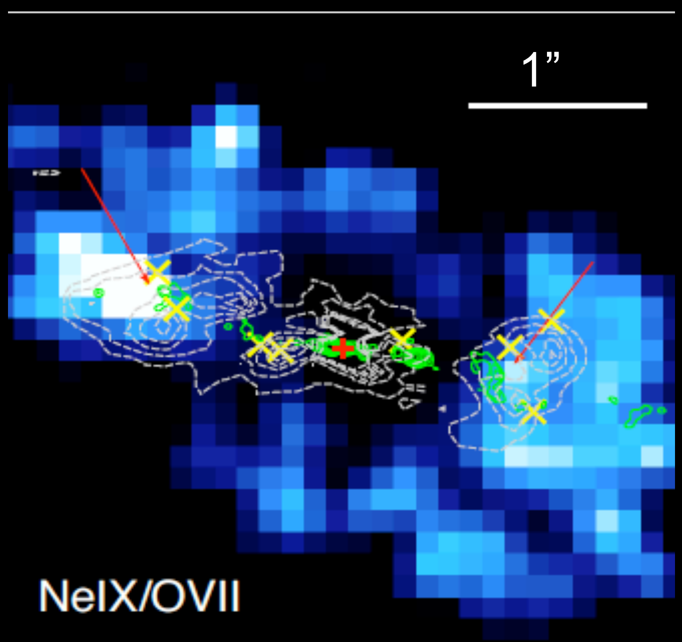
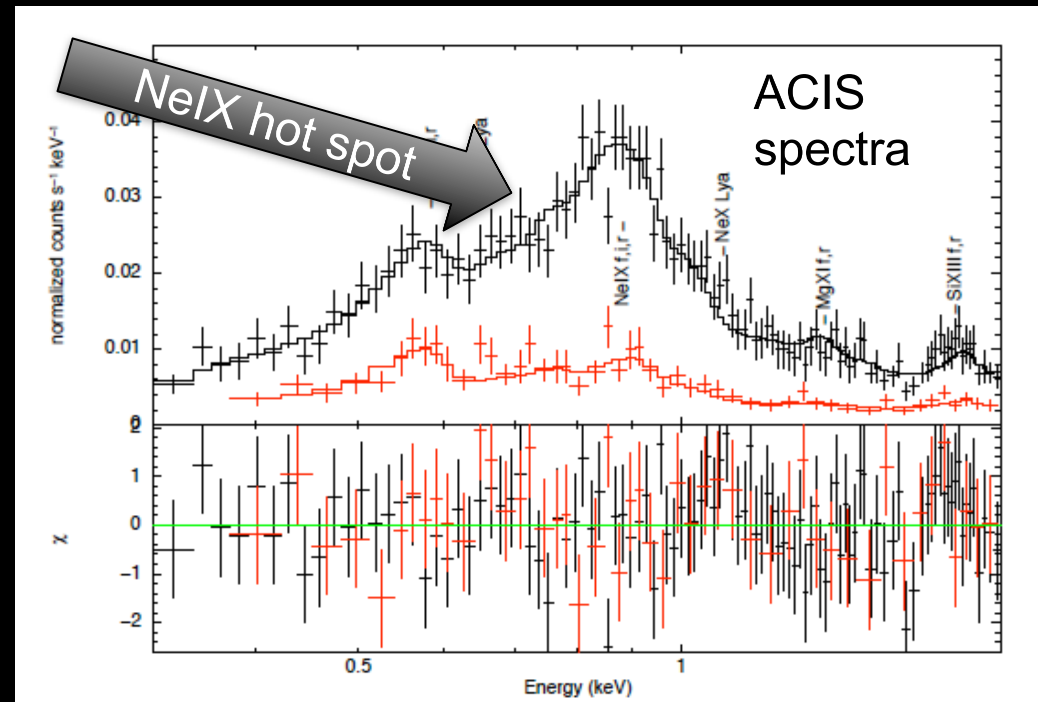
Wang et al 2011b



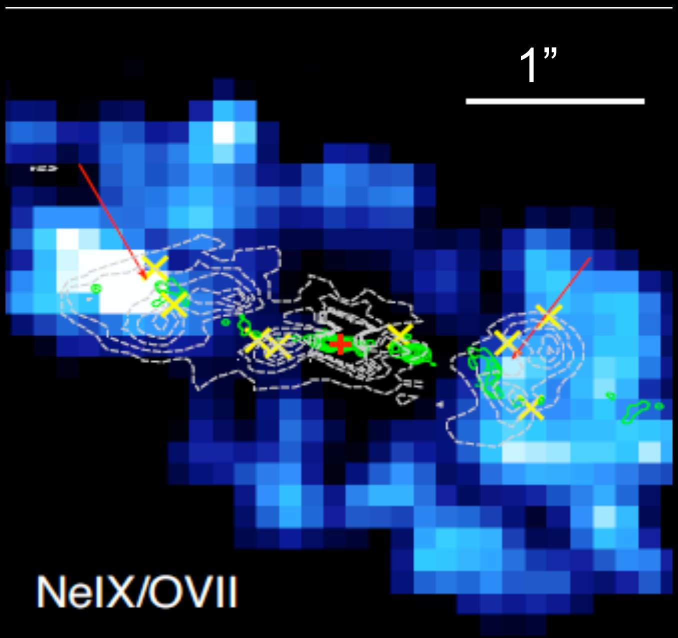


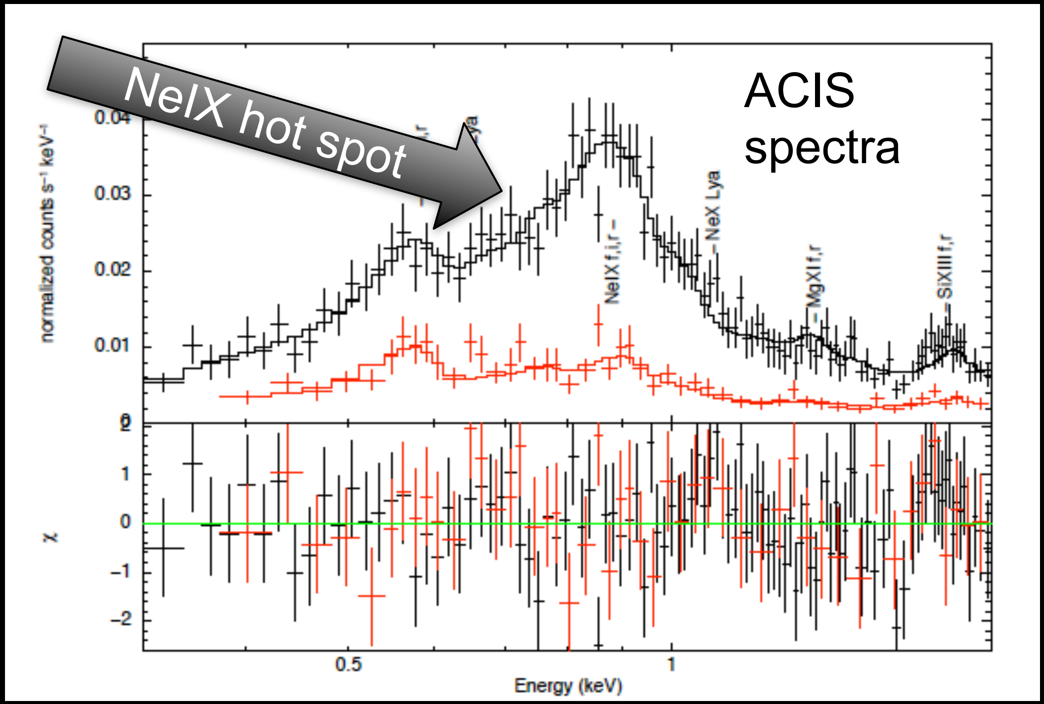
- Model fit requires thermal kT~0.6 keV component in addition to photoionization

➔Pressure equilibrium between collisionally and photo-ionized gas

X-RAY LINE EMISSION AND RADIO JET – CLOUD INTERACTION

Wang et al 2011b





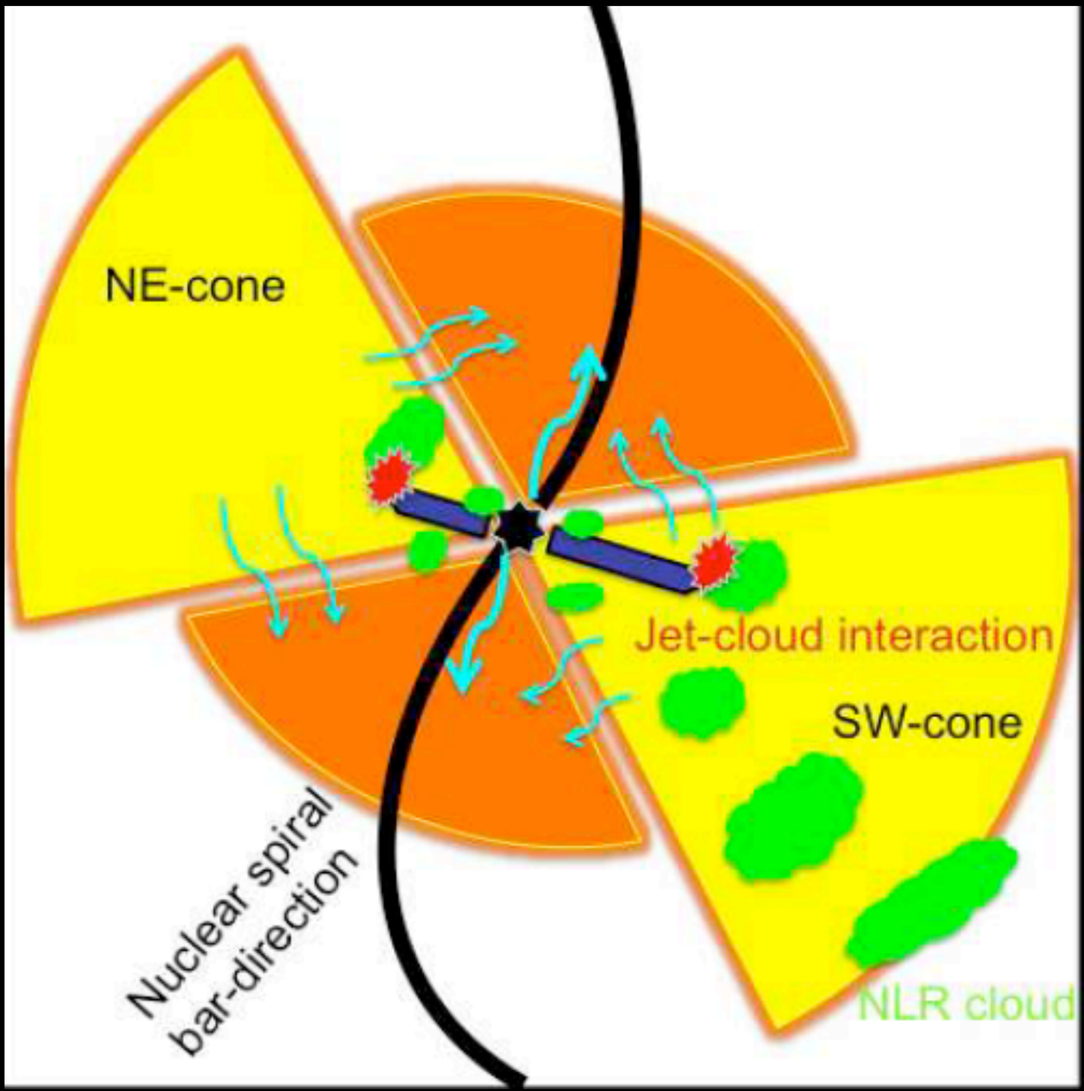
•Model fit requires thermal kT~0.6 keV component in addition to photoionization

➔Pressure equilibrium between collisionally and photo-ionized gas

➔0.1% of jet power is deposited into the ISM (~1×10^{39} erg/s ; p_{jet}~10^{42} erg/s)

THE CENTRAL ~ 600 PC OF NGC 4151 – A CARTOON

Wang et al 2011c



Is NGC 4151 an oddity?

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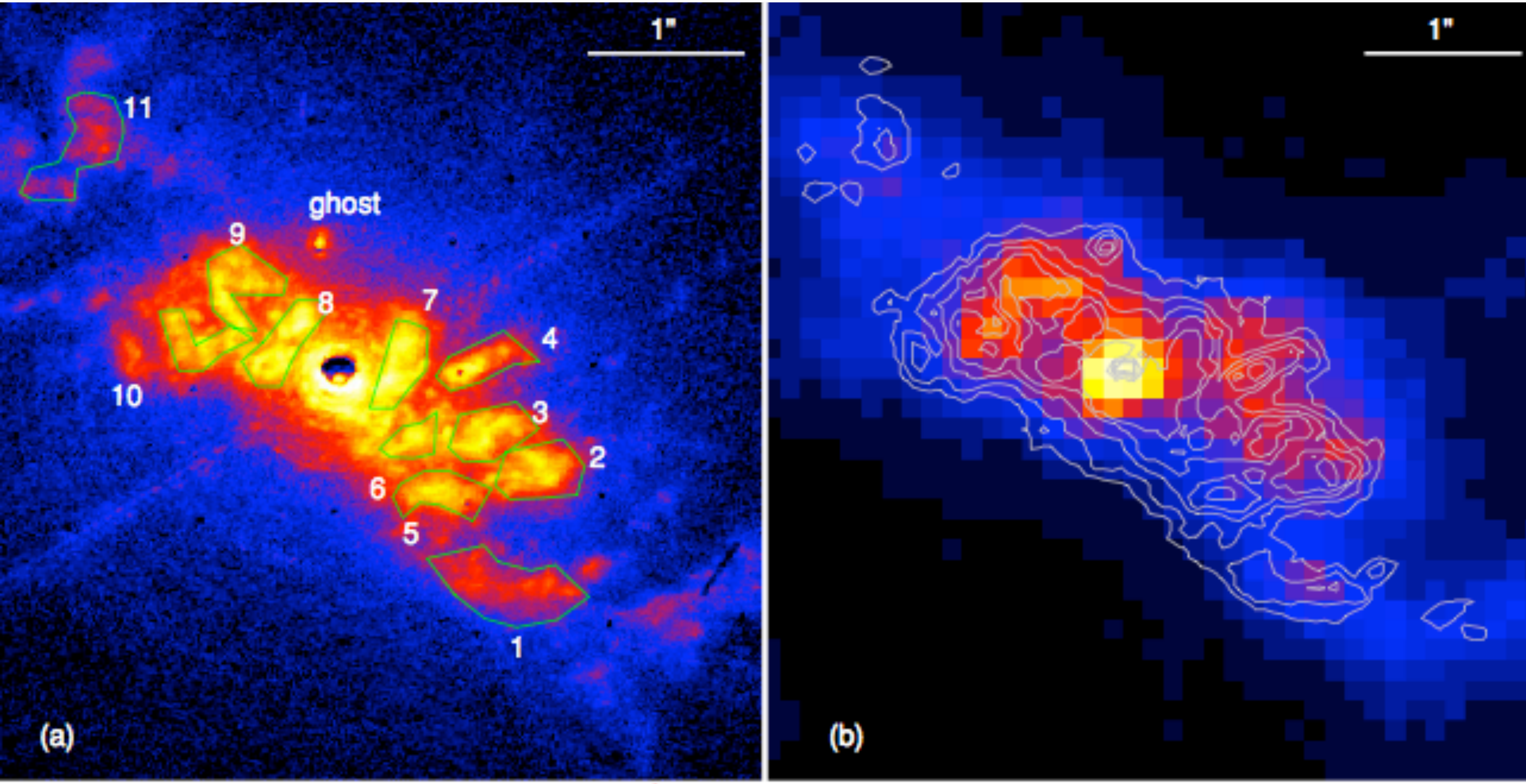
Similar features seen in Mkn 573
(Paggi et al in preparation)

THE NUCLEAR WIND

NGC 4151 – Central 150 pc, X-ray and [OIII] Clouds

Wang et al 2009

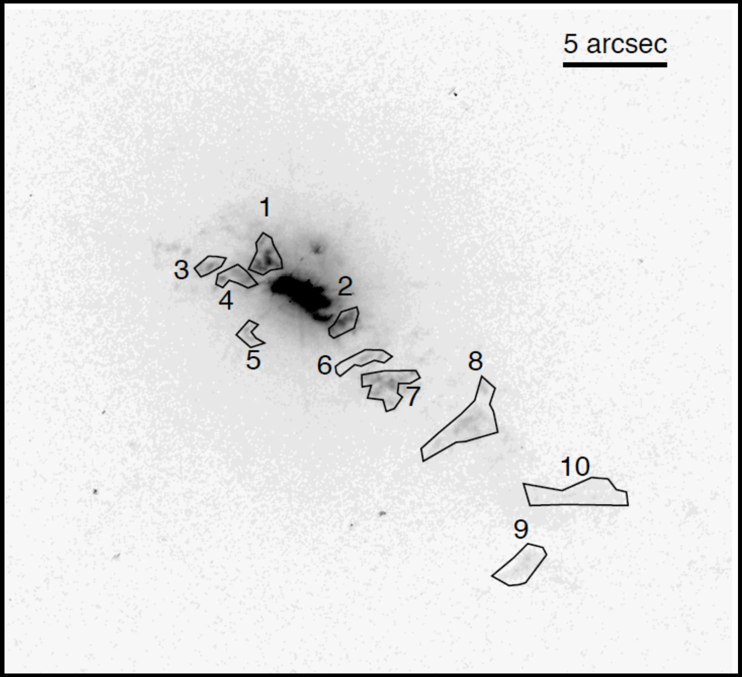


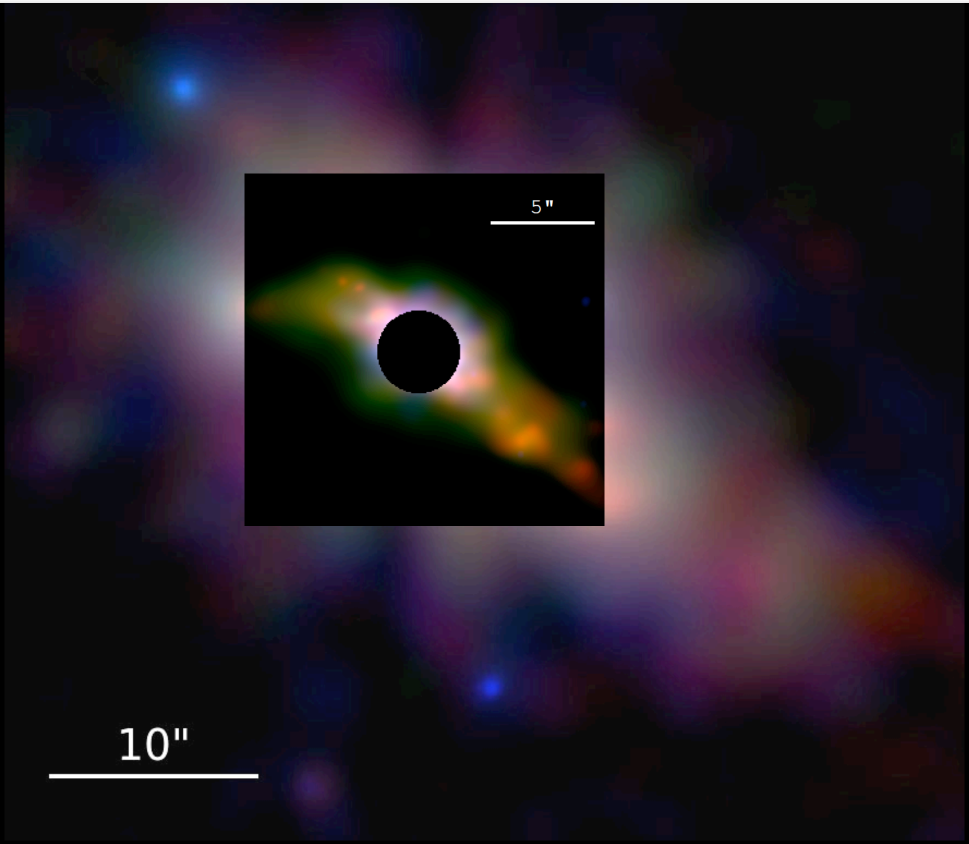
HST/FOC F502N [OIII], Winge et al 1997

Chandra HRC, Wang et al 2009

NGC 4151 –[OIII] / X COMPARISON AT LARGER RADII

Wang et al 2011c



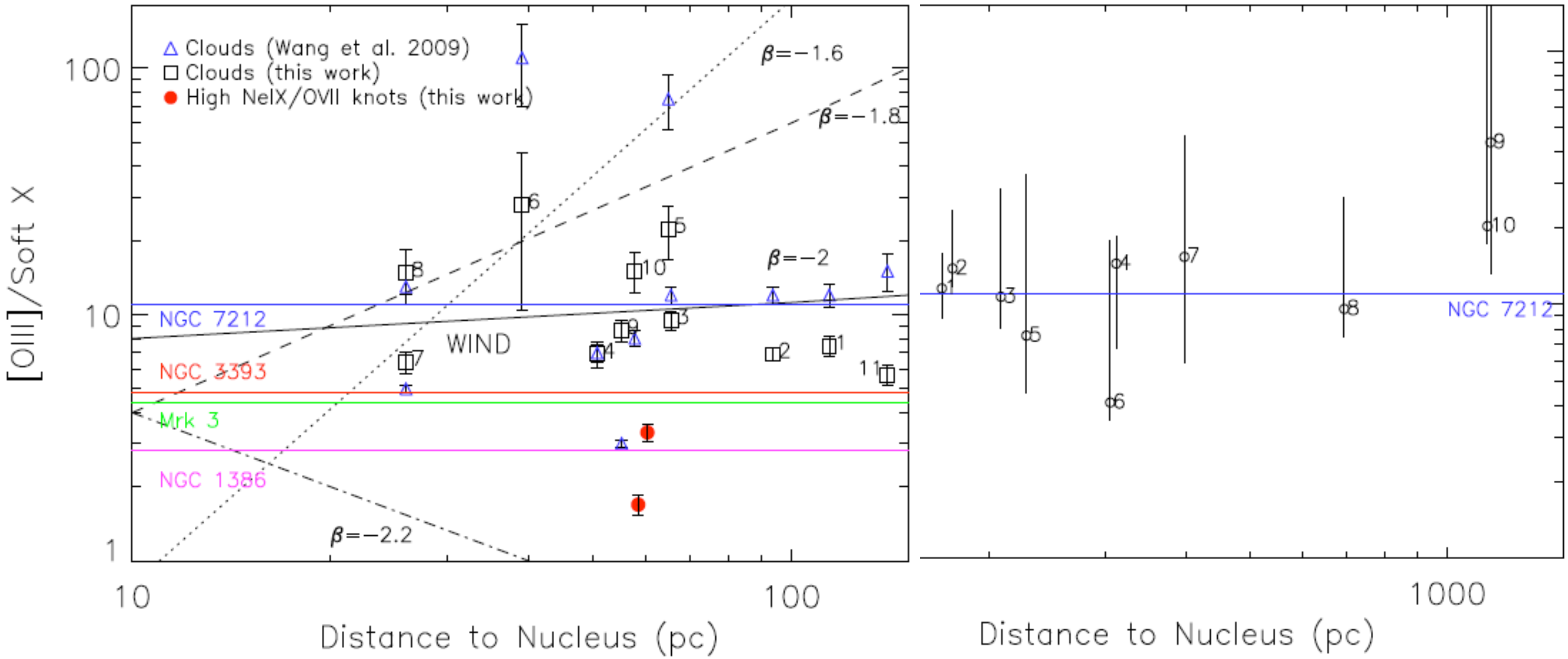


HST – [OIII]

Chandra ACIS

NGC 4151 – Constant [OIII] / X Ratio from ~20 to 1000 pc

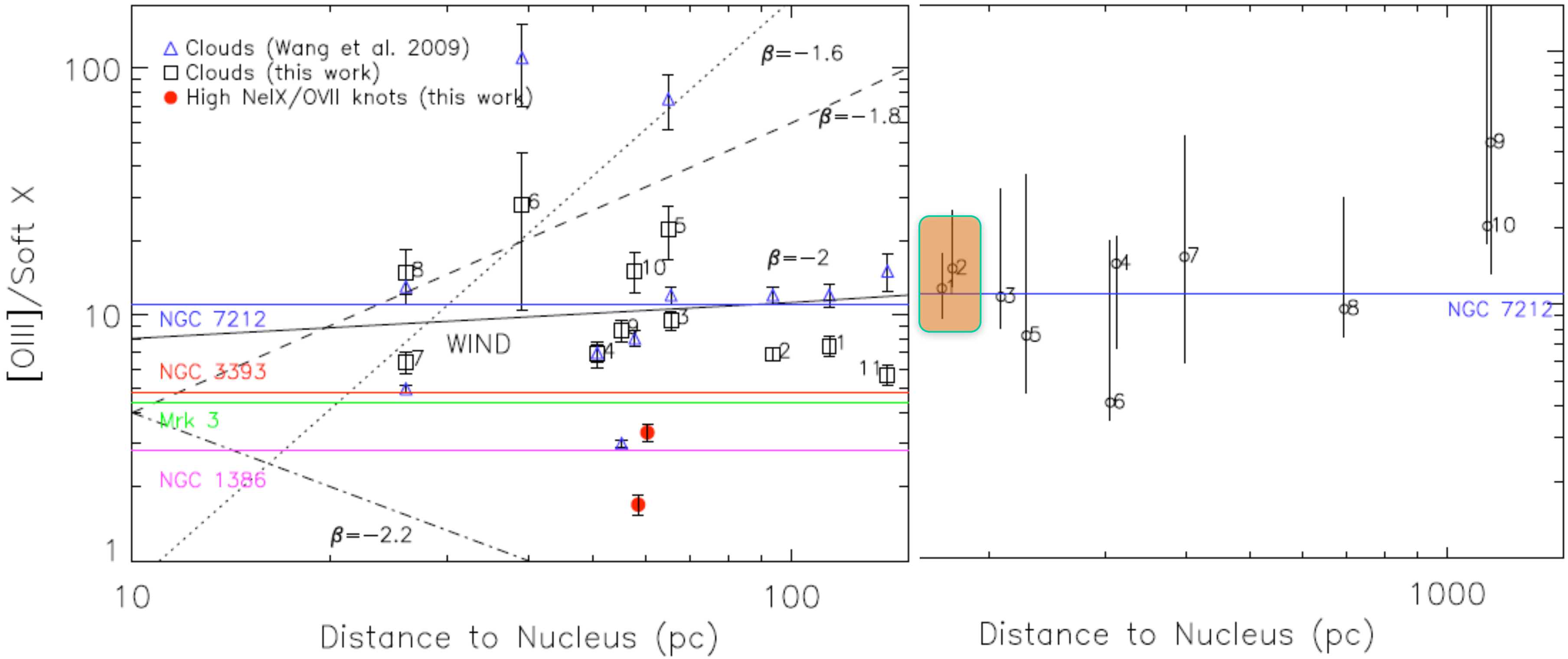
Wang et al 2011c



Constant Ionization Parameter → $n \sim r^{-2}$ – nuclear wind

NGC 4151 – Constant [OIII] / X Ratio from ~20 to 1000 pc

Wang et al 2011c



Constant Ionization Parameter ➔ $n \sim r^{-2}$ – nuclear wind

Implications for AGN Feedback

Wang et al 2011c

From Cloudy modeling of clouds 1 and 2

→ $dM/dt = n_H m_p v_r C_g A \sim 2.1\ M_\odot yr^{-1}$ comparable with NIR (Storchi-Bergmann et al 2010)

→ $L_{outflow} = ½\ dM/dt\ v^2 = 1.7\times10^{41}$ erg s^{-1} ~ 0.2% of accretion power

<< than most feedback models but consistent with 2 stage feedback model (Hopkins & Elvis 2010)

Implications for AGN Feedback

Wang et al 2011c

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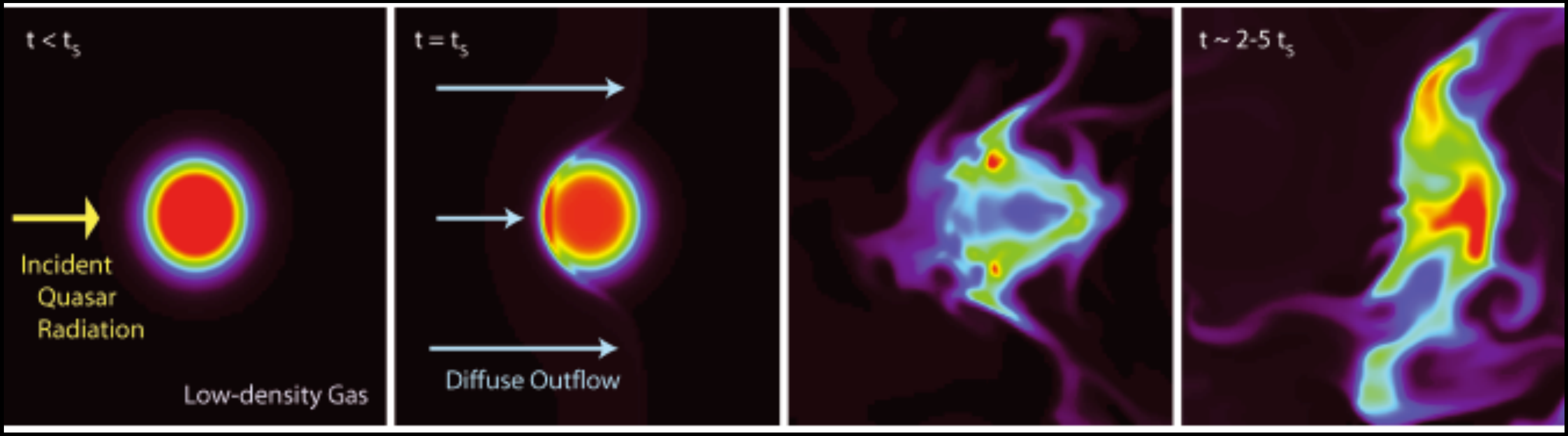
→ $dM/dt = n_H m_p v_r C_g A \sim 2.1\ M_{\odot} yr^{-1}$ comparable with NIR (Storchi-Bergmann et al 2010)

→ $L_{outflow} = \frac{1}{2}\ dM/dt\ v^2 = 1.7\times10^{41}$ erg s^{-1} ~ 0.2% of accretion power

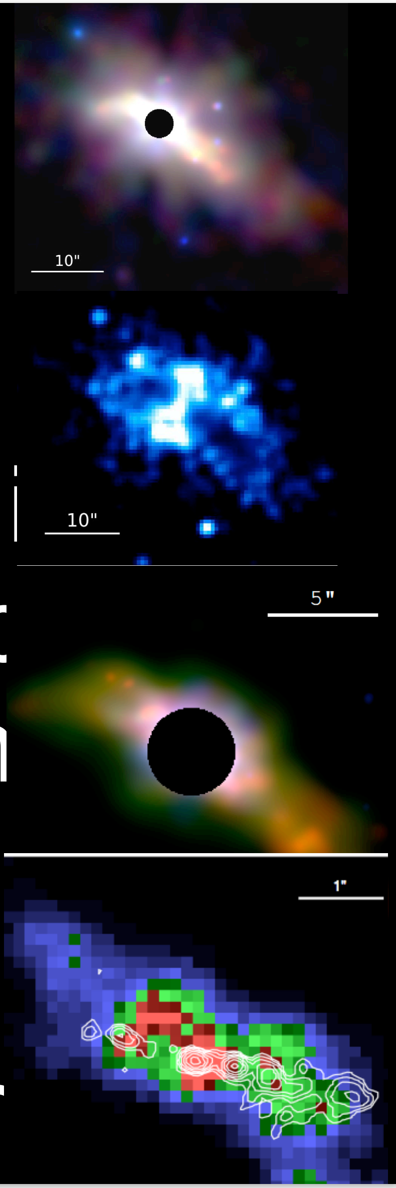
<< than most feedback models but consistent with 2 stage feedback model (Hopkins & Elvis 2010)



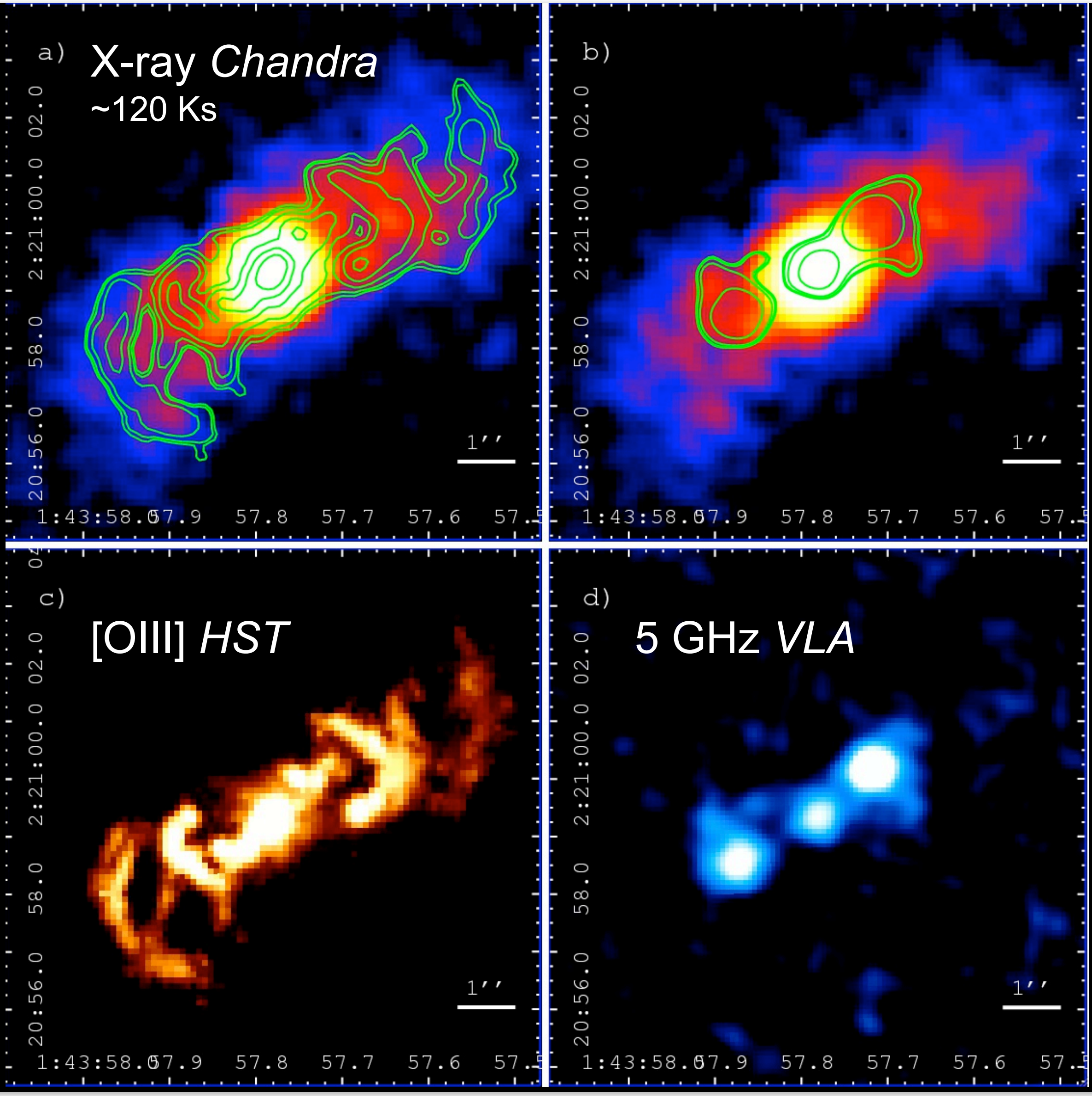
DIRECT VIEW OF AGN / GALAXY FEEDBACK

NGC 4151 & Mkn573

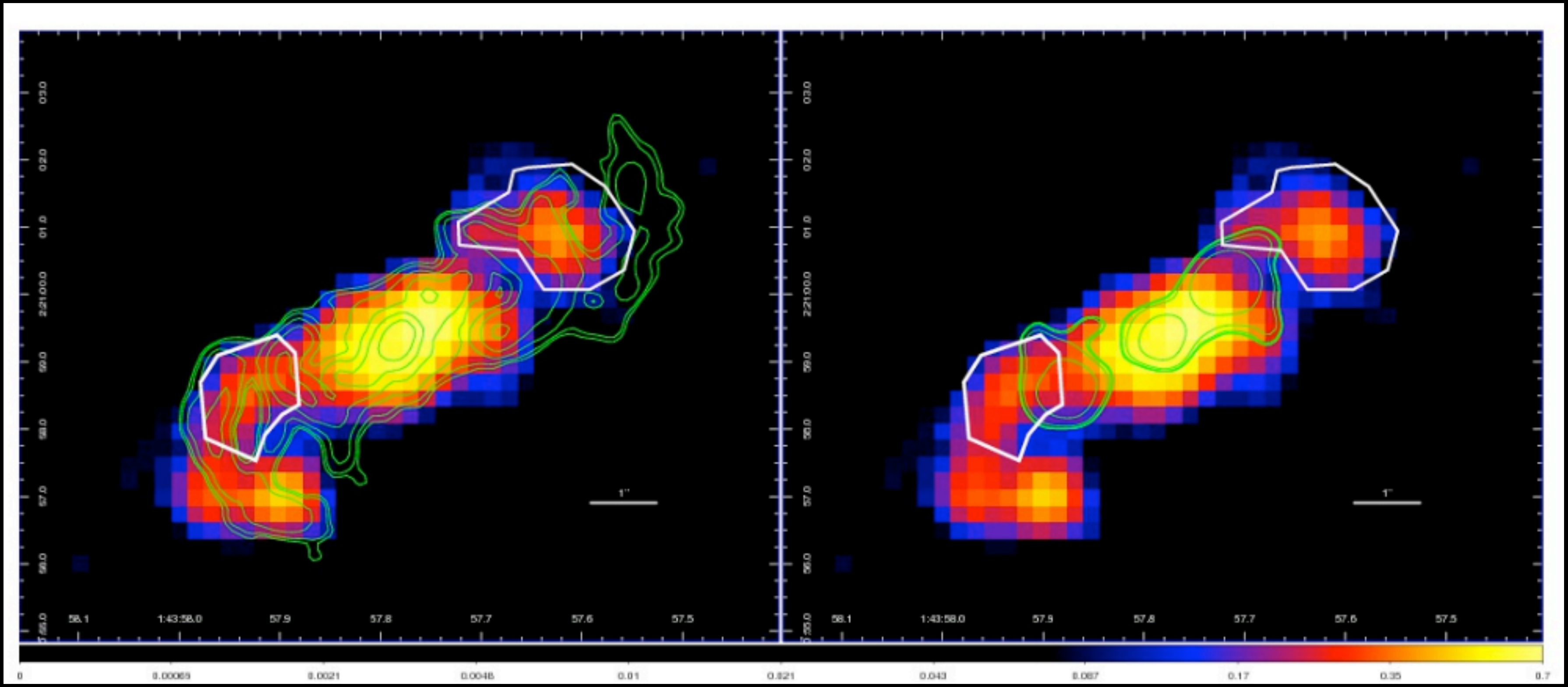
- → NGC 4151 cavity: photoioni and/or heating out to ~2kp
- → Mkn 573: 10 kpc radius ion cone
- → Both: Radio jet /cloud inter



MKN573 (D~70 MPC)– THE CENTRAL R~12" = 4 KPC



MKN573 – OVIII / OVII – PHOTO VS. COLLISIONAL IONIZATION



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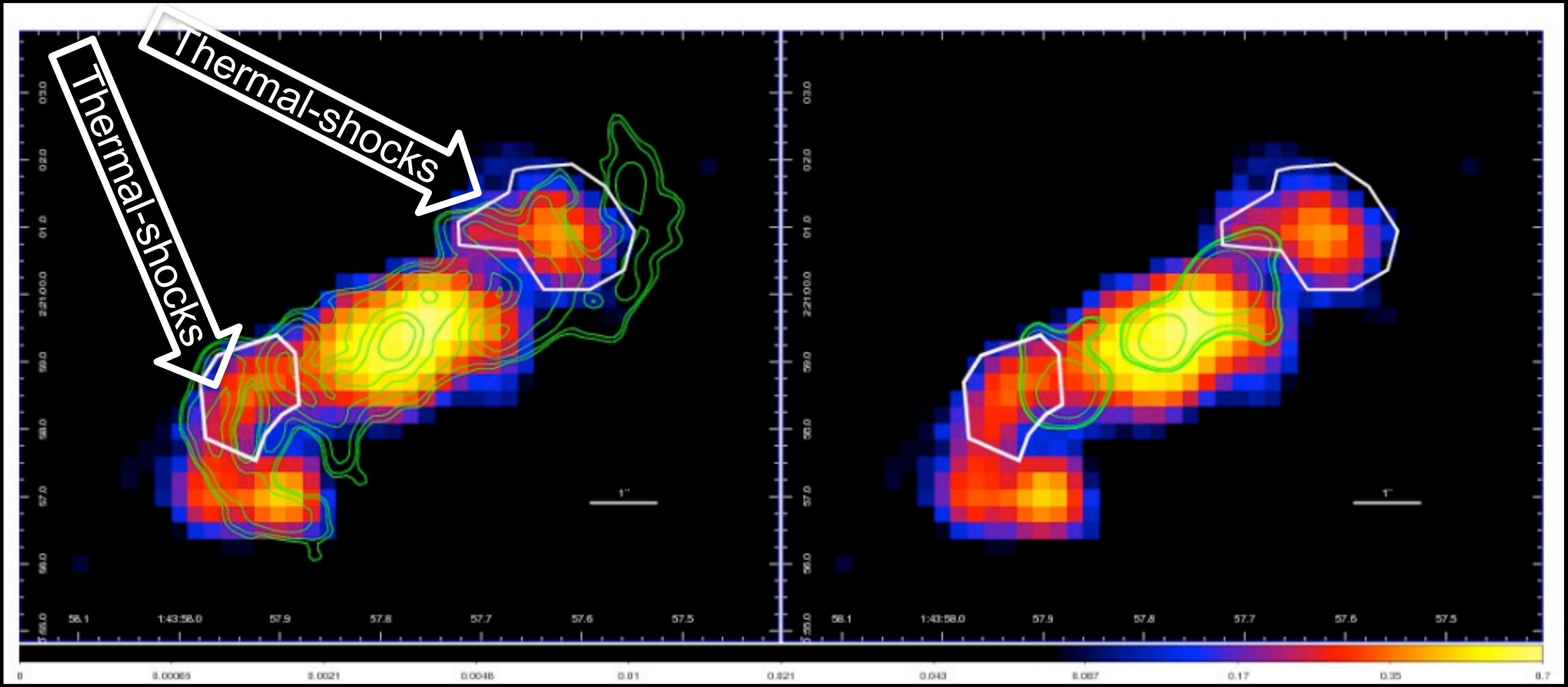
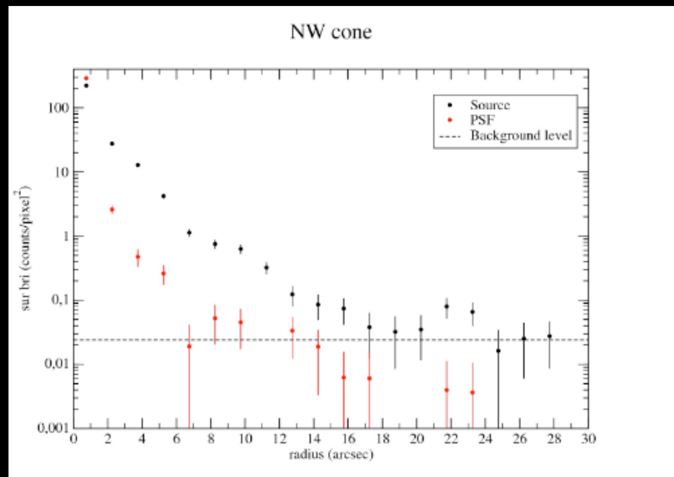
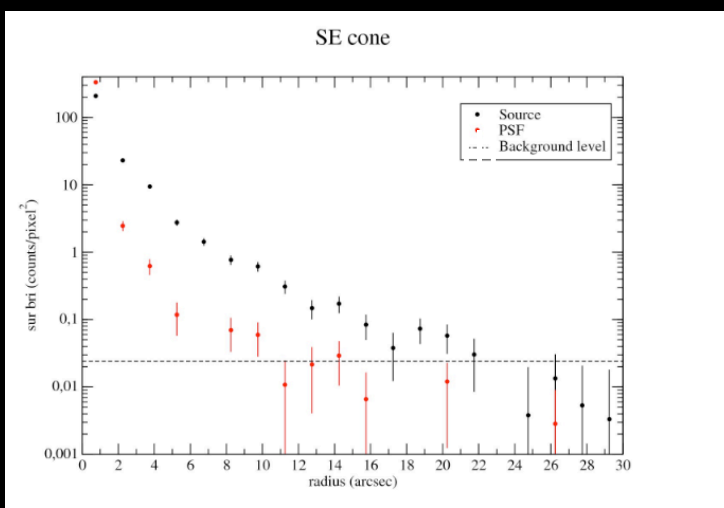
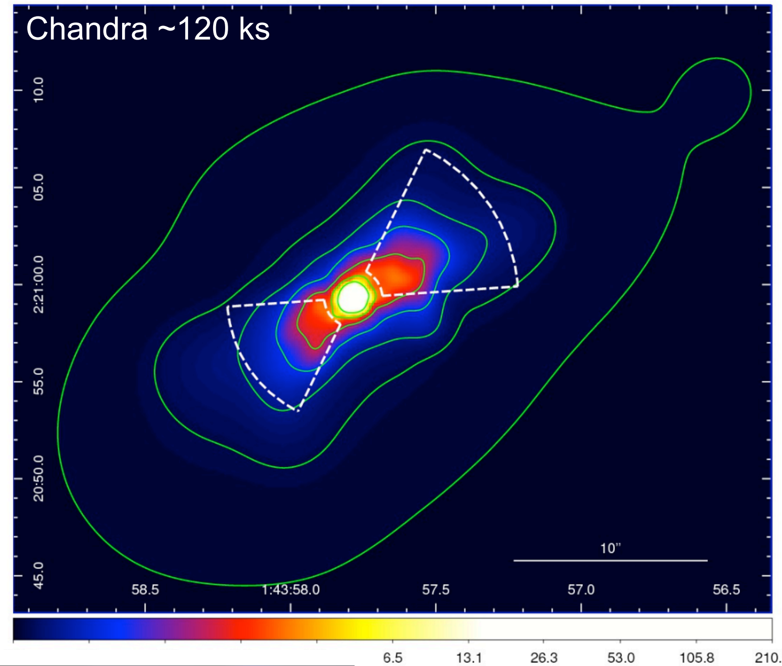
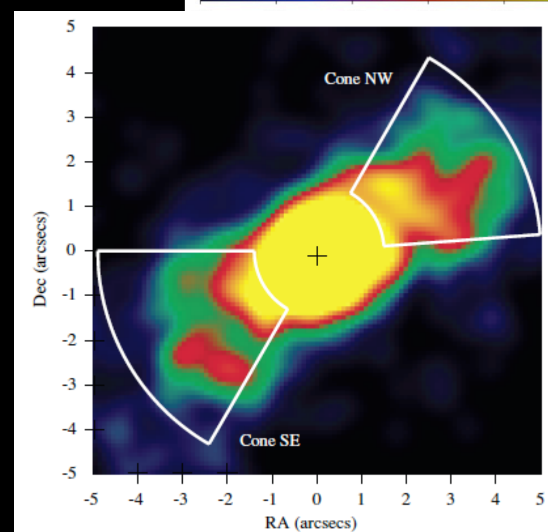


MKN573 – A VERY EXTENDED IONIZATION REGION – R~10KPC



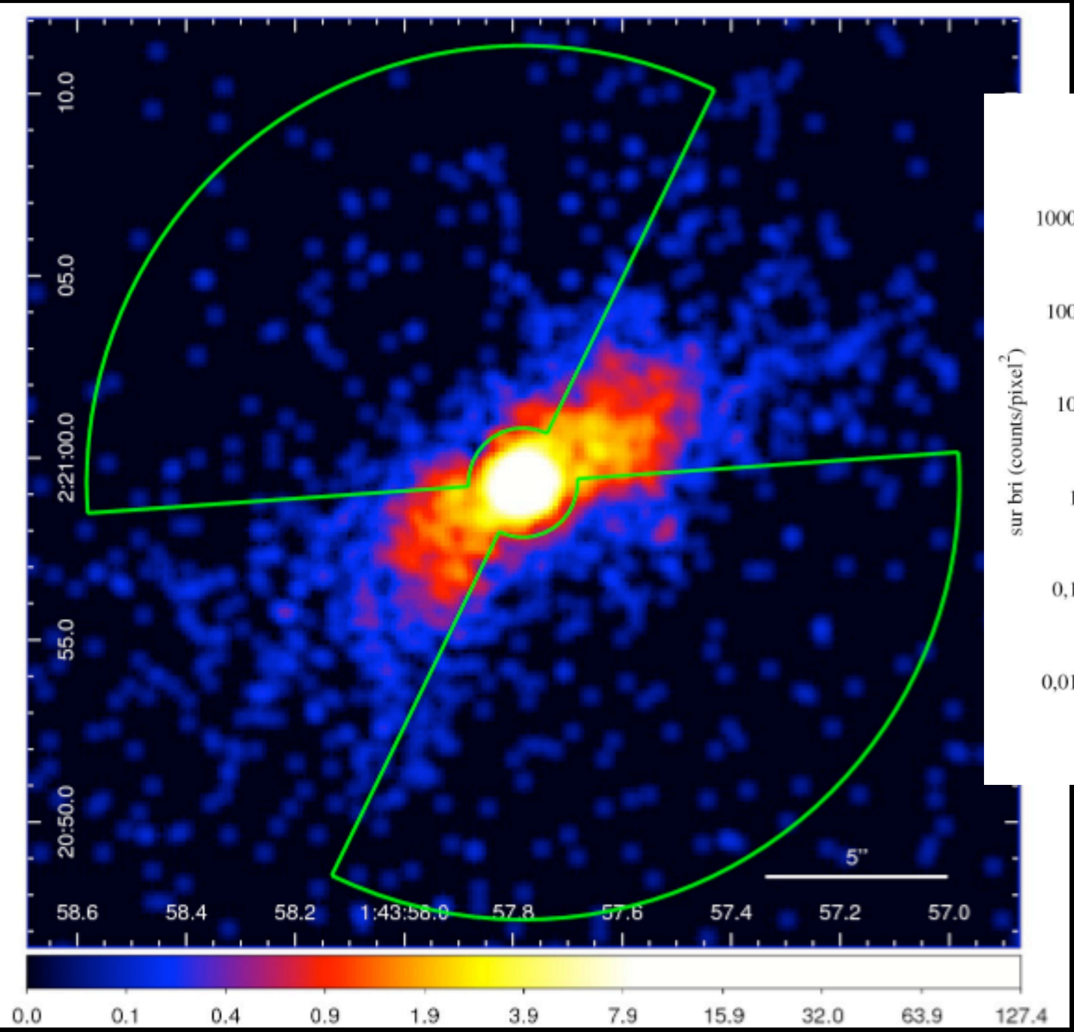


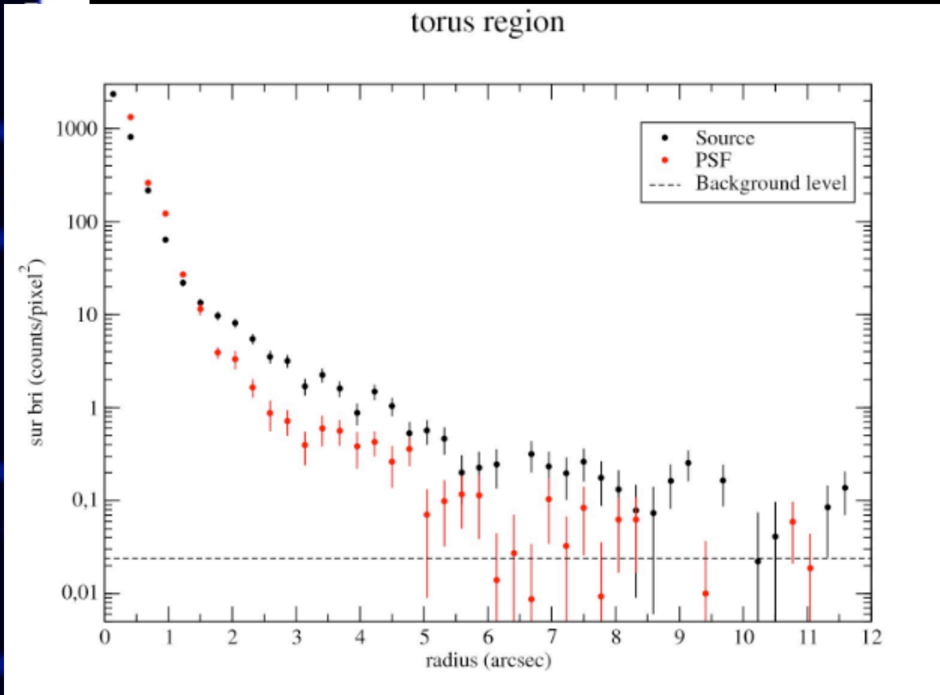




Gonzales – Martin
et al 2010
Chandra 35 ks

MKN573 – ANOTHER 'LEAKY TORUS'



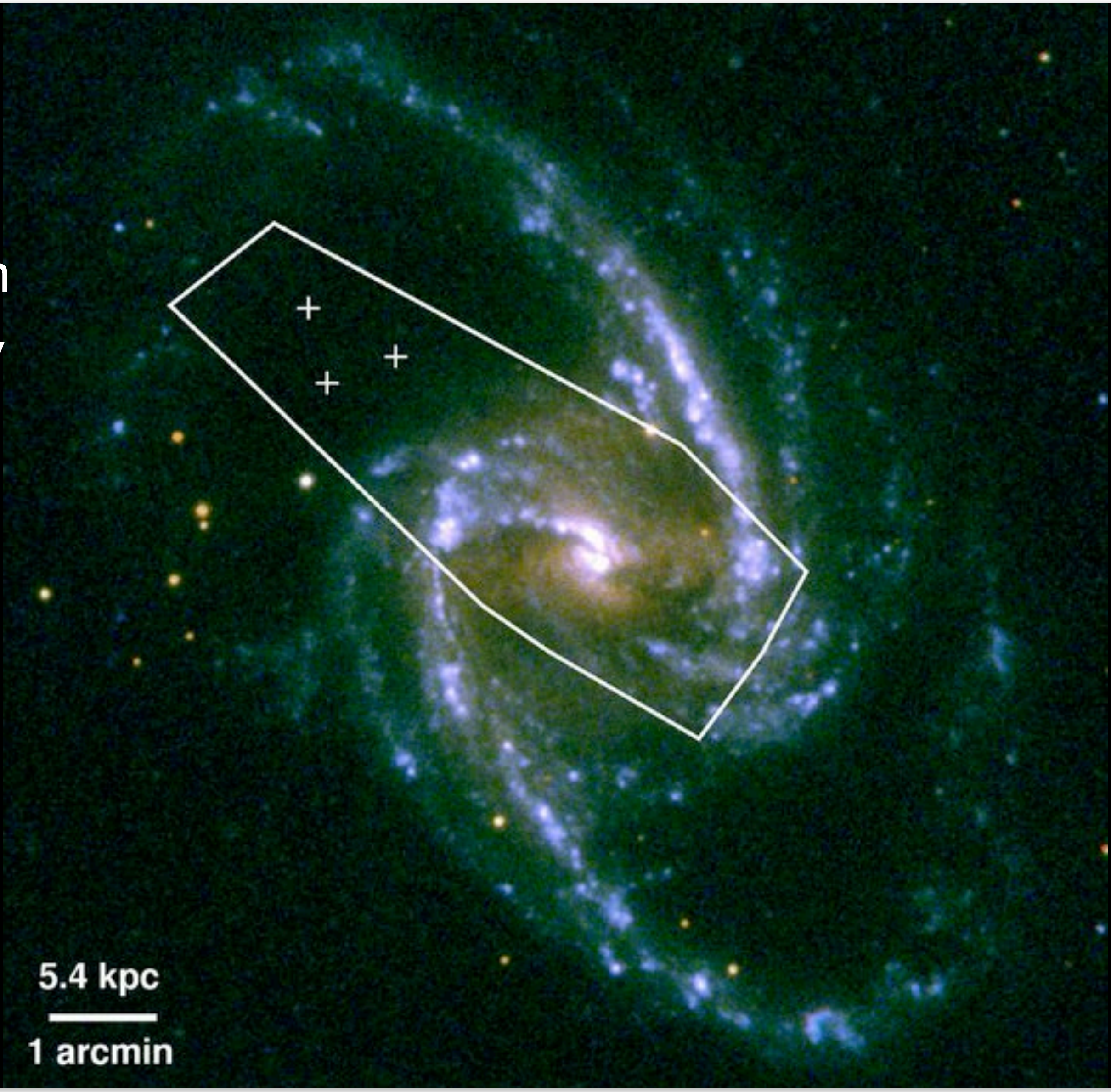


NGC 1365: PHOTO-IONIZATION CONES OR STARBURST WINDS?

Wang et al 2009

- NGC 1365
- D ~19 Mpc
- Lots of star formation
- Compton thick highly variable AGN

~100 ks
Chandra ACIS



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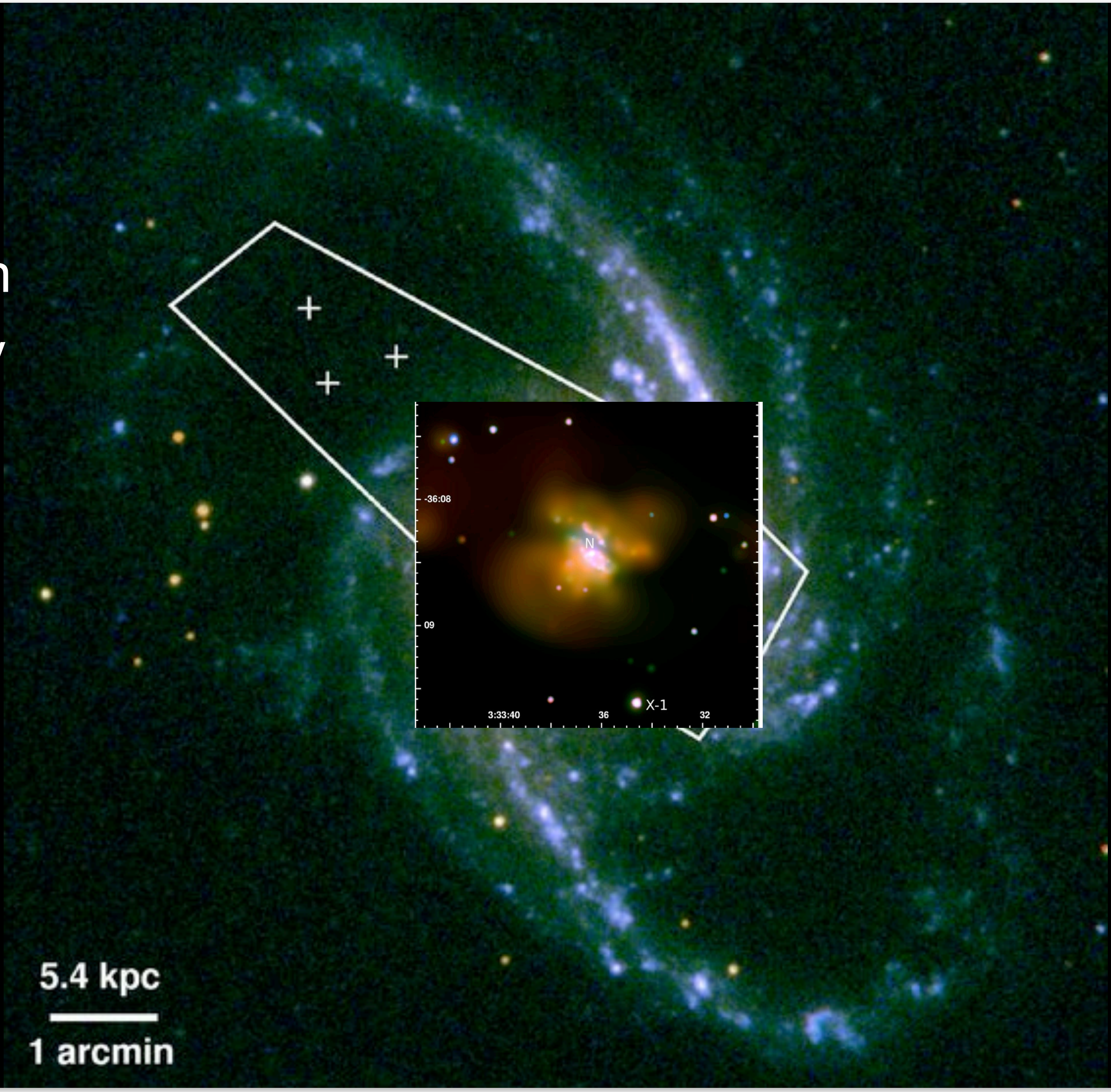

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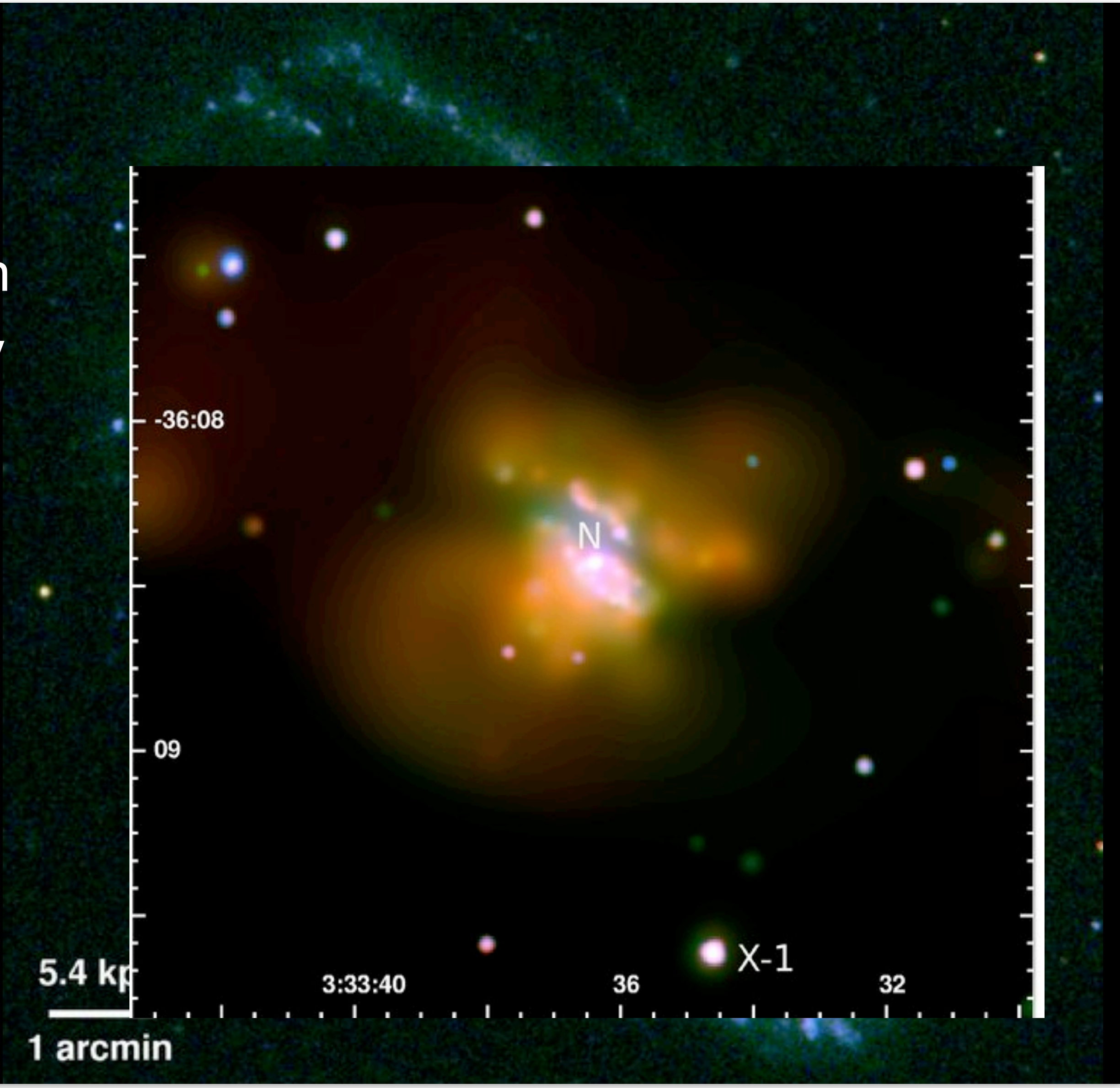

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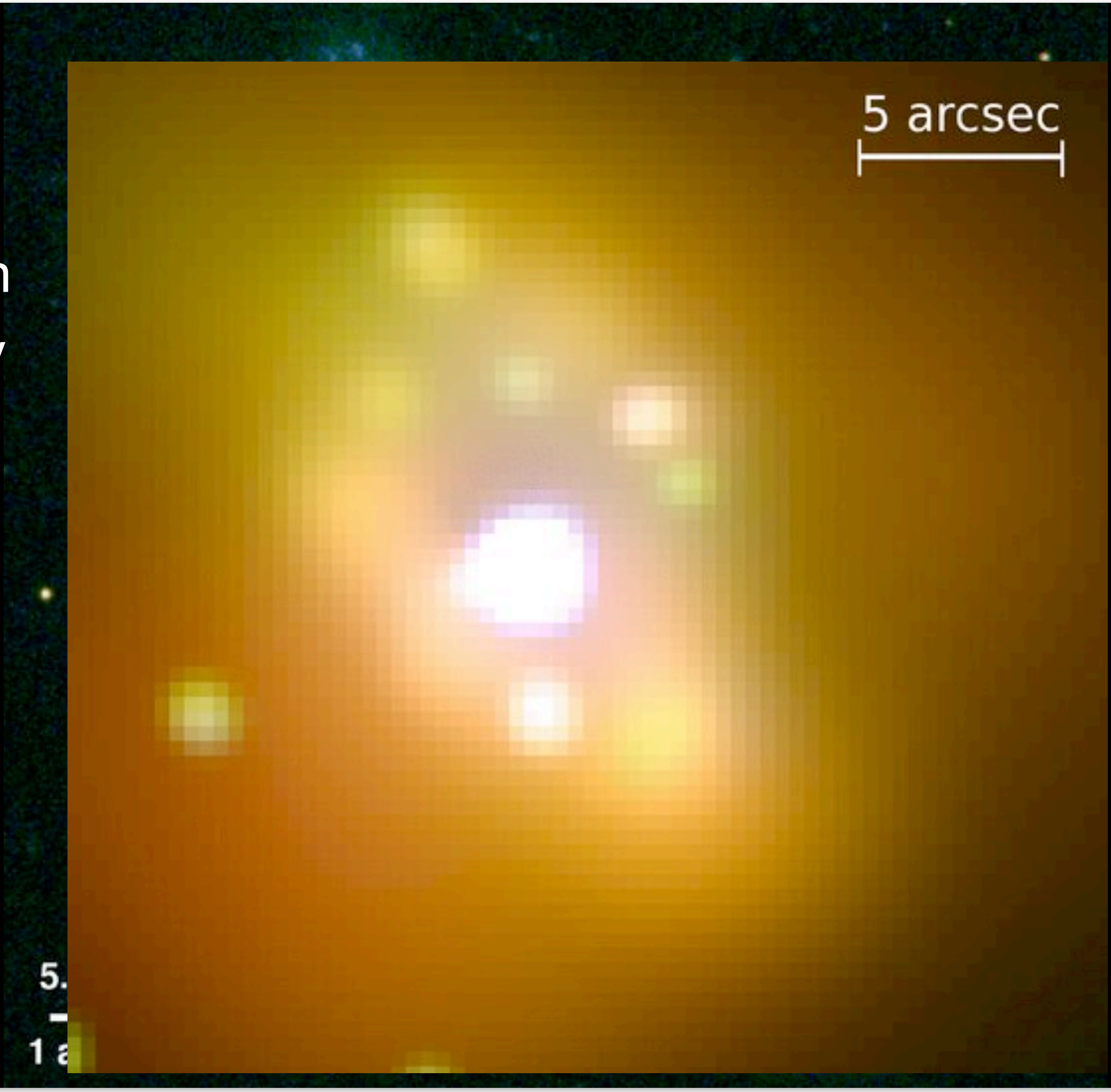
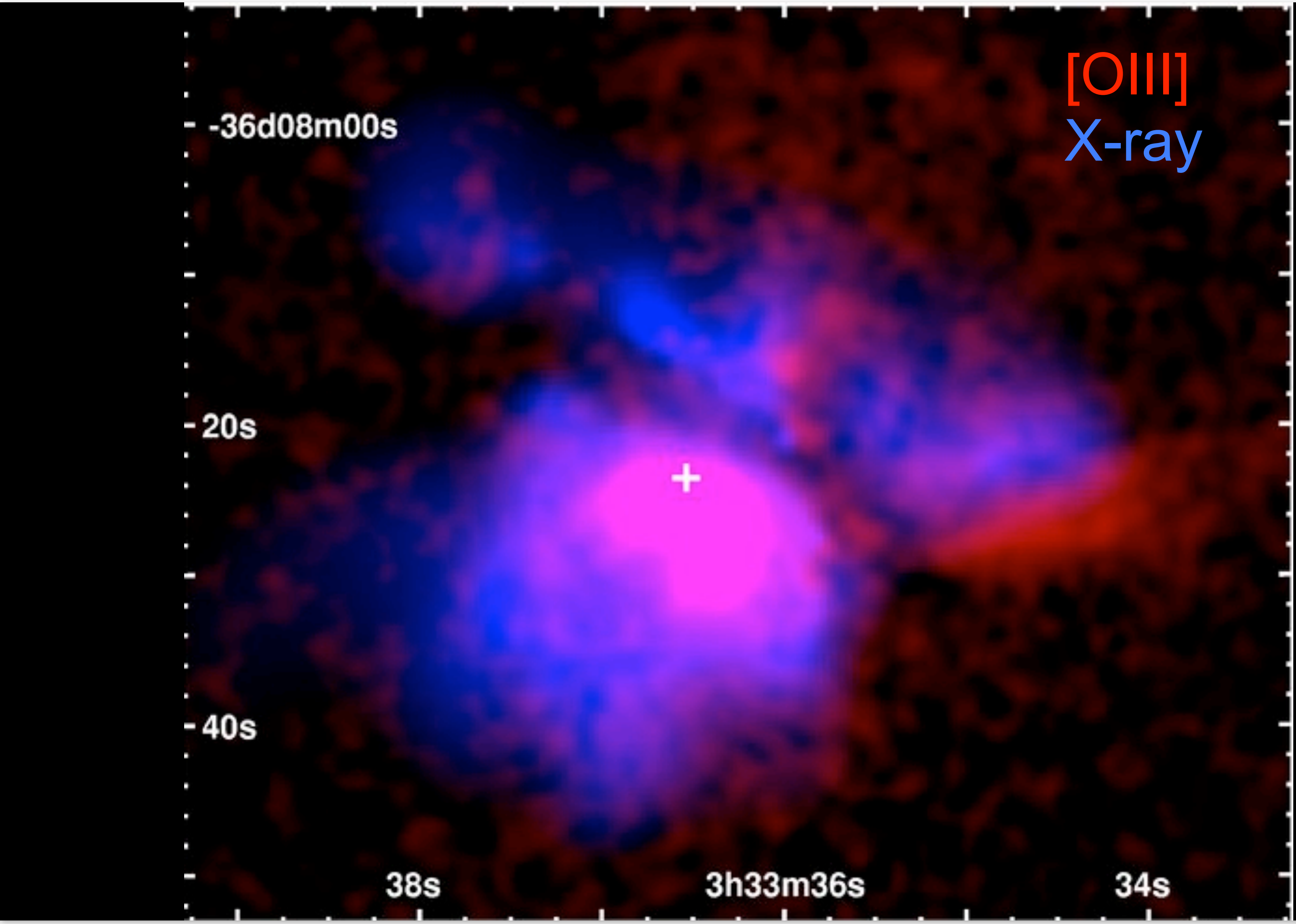
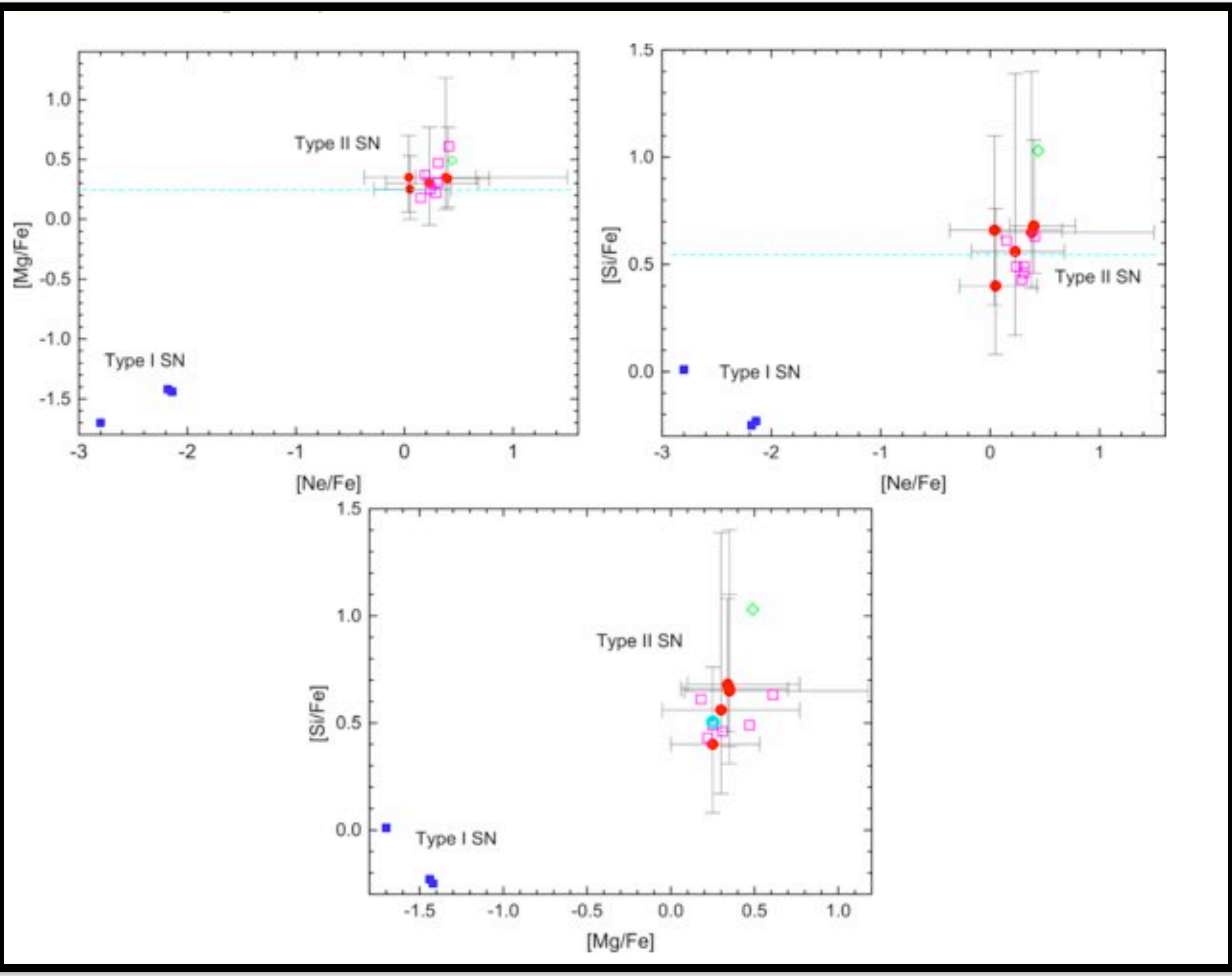


NGC 1365 – [OIII] – X-RAY MORPHOLOGY



NGC 1365 – SN II Enriched hot ISM



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