Disentangling AGN-Host Galaxy Interactions From An X-ray Perspective

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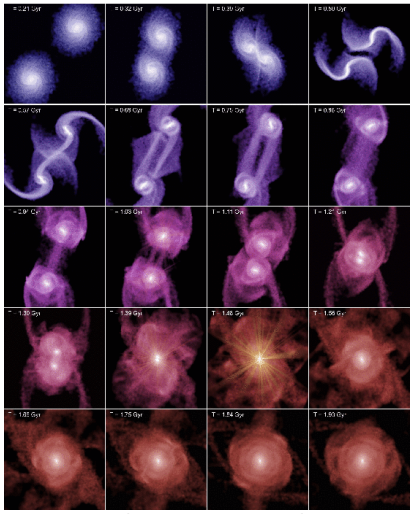
HST+Chandra image
NGC 6240 Nardini, Wang+2013 ApJ, 765,141; Wang et al. 2014 ApJ, 781,55

AGN Feedback — How does it work?

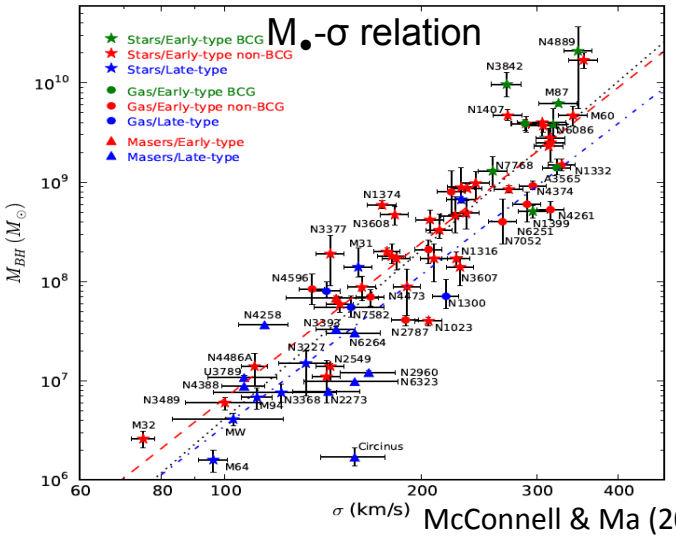
Fabian (2012), Kormandy & Ho (2013) ARA&A

Simulations



Springel 2005; Hopkins et al.(2006)

Observables



McConnell & Ma (2013)

$$E_{\rm gal} \approx M_{\rm gal}\sigma^2$$

$$E_{\rm BH} \approx 0.1 M_{\rm BH} c^2$$

$$M_{\rm BH} \approx 1.4 \times 10^{-3} M_{\rm gal}$$

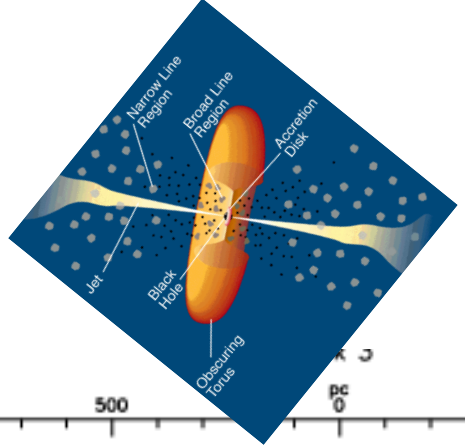
$$E_{\rm BH}/E_{\rm gal} \sim 100$$

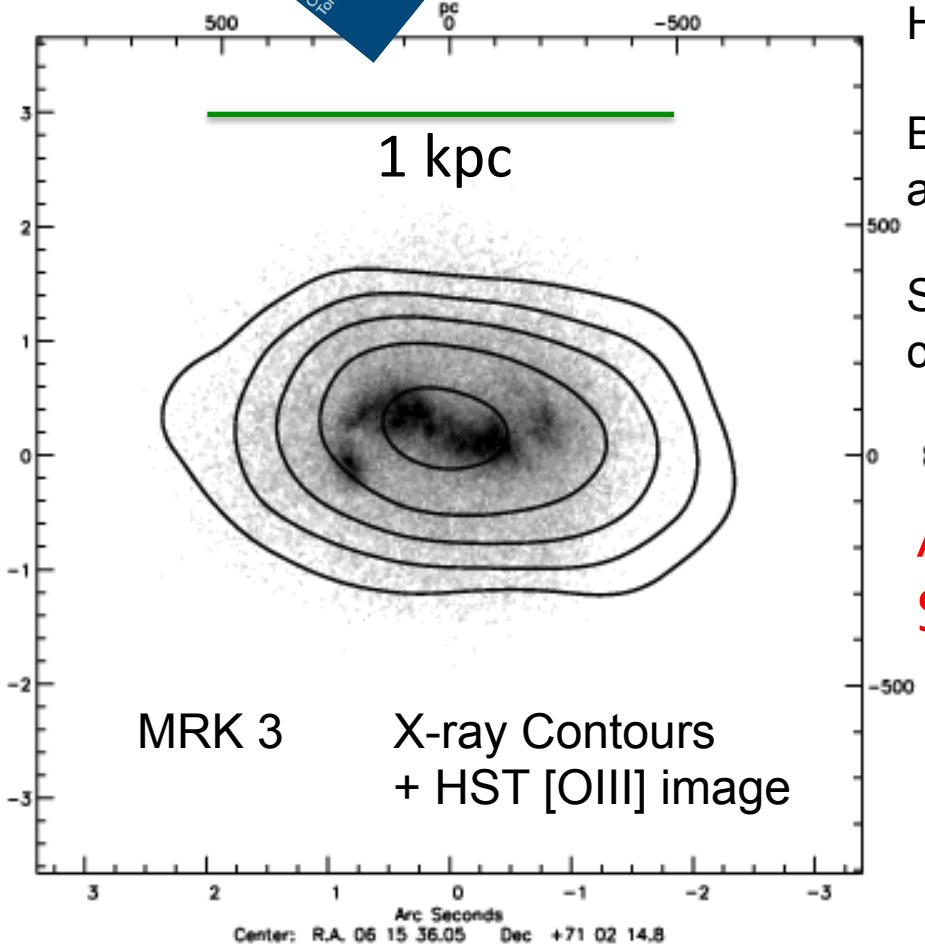
Energy injection efficiency ~5% L_{bol} often assumed
(Silk & Rees 1998, Di Matteo et al. 2005, Hopkins et al. 2008)

Need observational determination !

- Ultrafast Outflows in absorption (e.g., Tombesi et al. 2011)
- Outflow in Mrk 231
  Rupke & Veilleux (2011); González-Alfonso et al. (2014)
- Type 2 quasars with broad wings in narrow lines
Greene & Zakamska (2011)

Direct Visible Sign of AGN—Host Galaxy Interaction in Nearby Seyfert Galaxies





kpc–scale extended narrow line regions
HST [OIII] snapshot survey Schmitt et al. (2003)

Biconical outflows of ionized gas (Crenshaw et al. 2000; Kraemer et al. 2001)

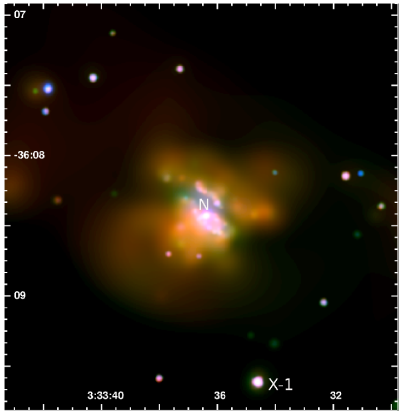
Soft X-ray morphologies show spatial correspondence with [OIII]

AGN photoionization vs.
Shock heating (starburst wind, jets)

Spatially Resolved Spectroscopy Needed !

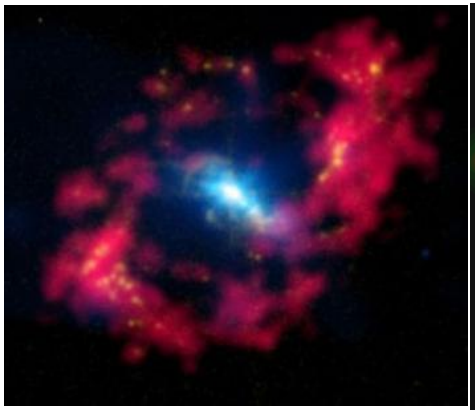
Bianchi et al. (2006)
Guainazzi et al.(2007); Evans et al. (2006, 2010); Bianchi et al. (2010)

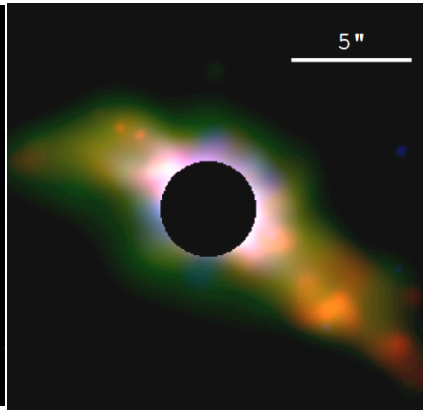
Spatially Resolved Chandra Imaging of the Hot-phase ISM



NGC 1365
Wang+09ApJ

NGC 3393
Fabbiano, Wang+11
Nature

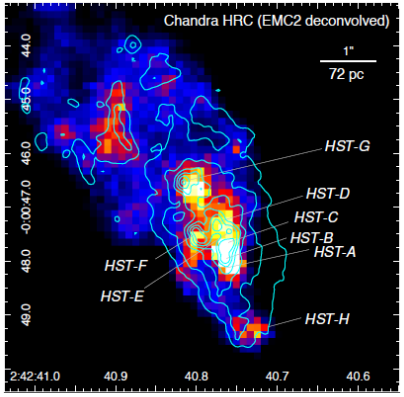




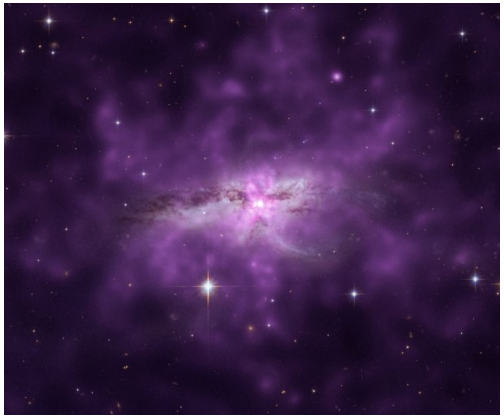
NGC 4151
Wang+10ApJL; Wang+11a,b,c ApJ

Mrk 573
Paggi, Wang+12
ApJ

NGC 4507
Marinucci,
Risaliti, Wang+13
MNRAS



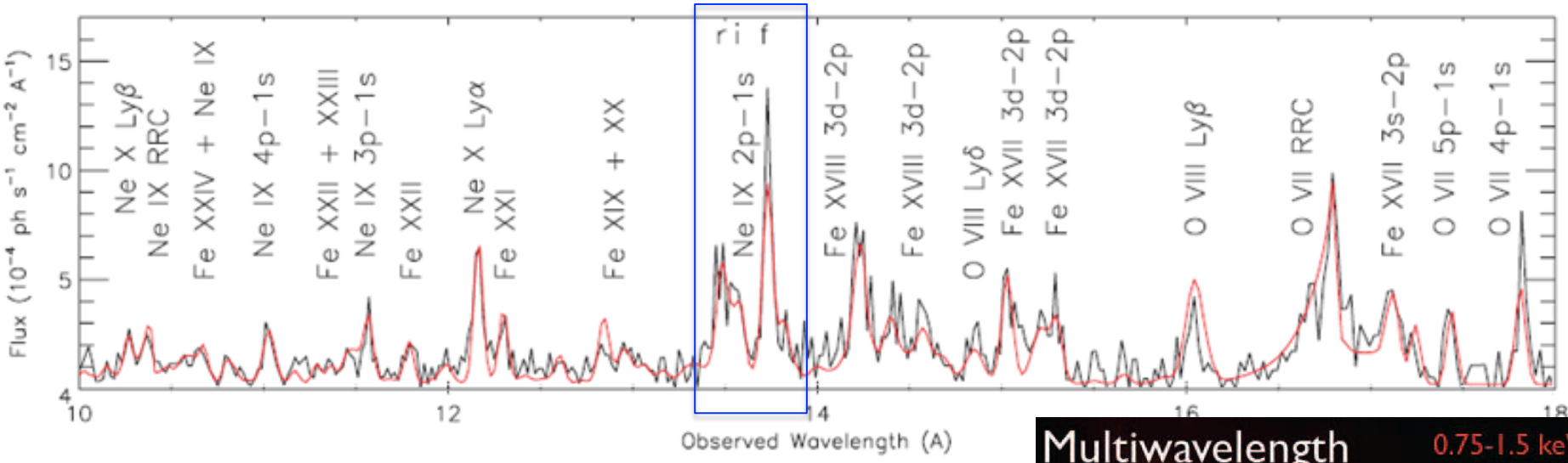
NGC 1068
Wang+12
ApJ,756,180



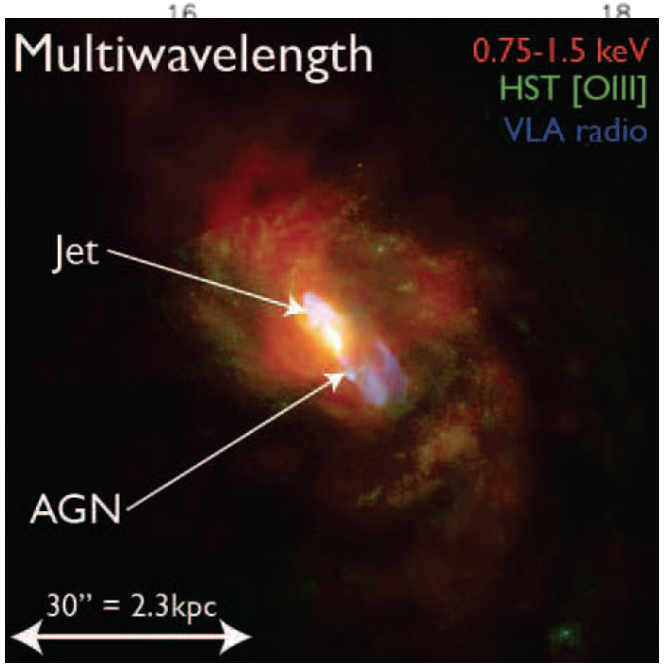
NGC 6240
Wang+14 ApJ 781,55
Nardini,Wang+13, ApJ,
765,141

X-ray Emission Line Diagnostics
The Prototypical Example – NGC 1068 Grating Observations

(Kinkhabwala et al. 2002; Brinkman et al. 2002; Ogle et al. 2003; Evans et al. 2010; Kallman et al. 2013)

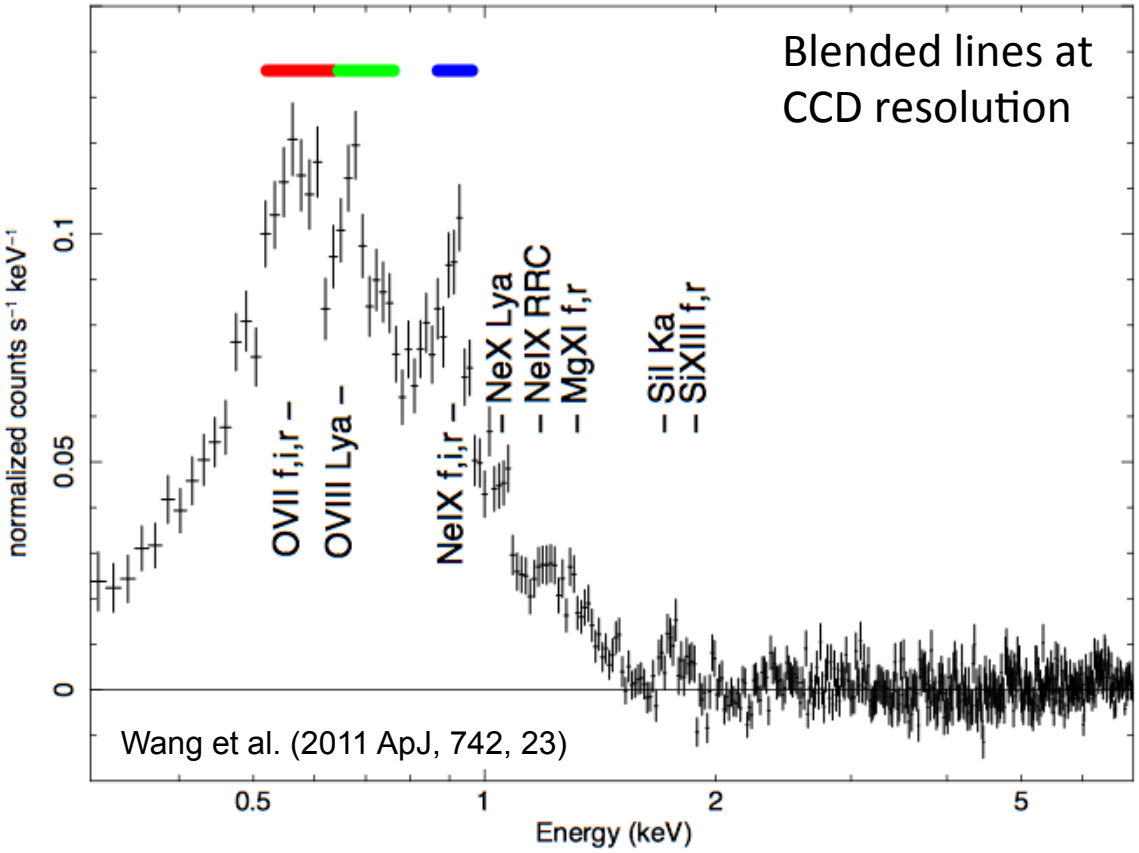


- H-like and He-like N, O, Ne, Mg, Al, Si, S, narrow RRCs indicate photoionization
- HETG spectrum of off-nuclear gas consistent with photoionization



Chandra/ACIS: An X-ray "Wide Field IFU"

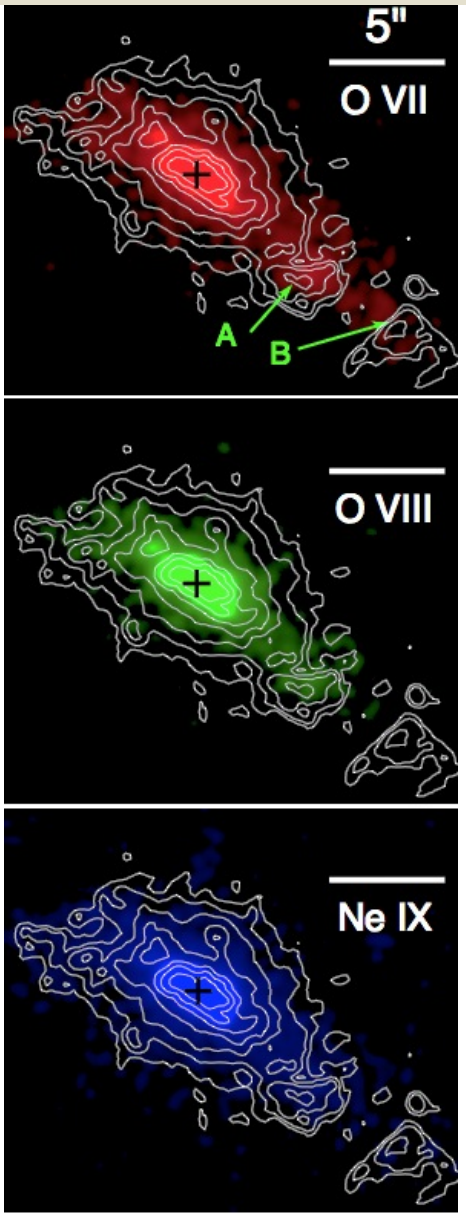
Example: X-ray imaging spectroscopy of Seyfert 1 galaxy NGC 4151 (photoionized outflow)



photoionization modeling of brightest clouds

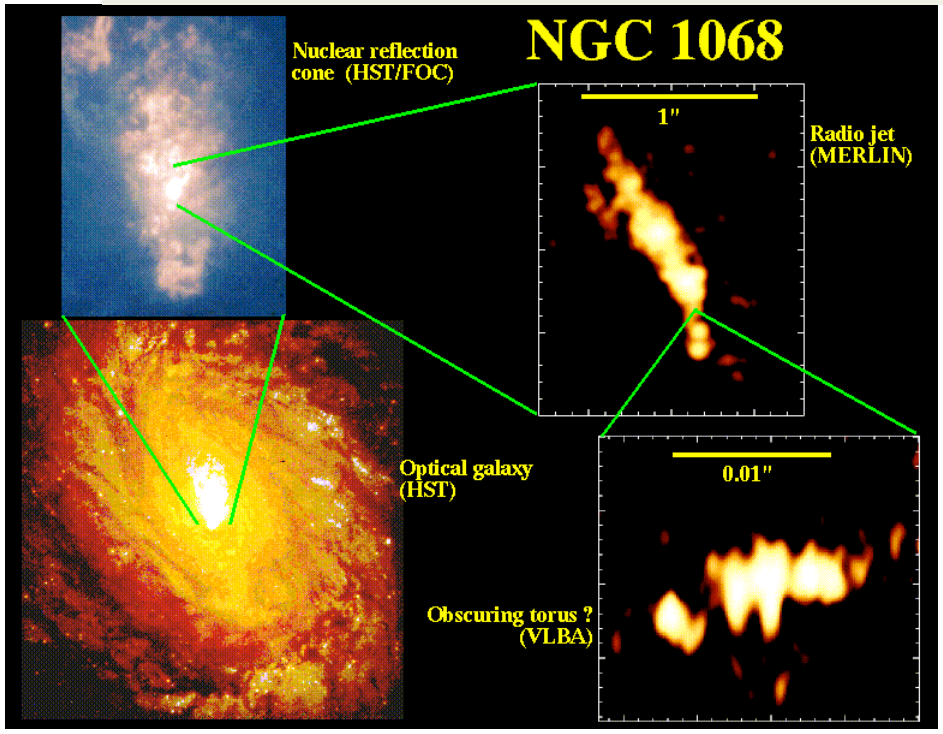
➔ dM/dt ~ 2 $M_\odot yr^{-1}$

➔ $L_{outflow}$ = ½ dM/dt v^2 = 1.7×10^{41} erg s^{-1} ~ 0.3% of Lbol

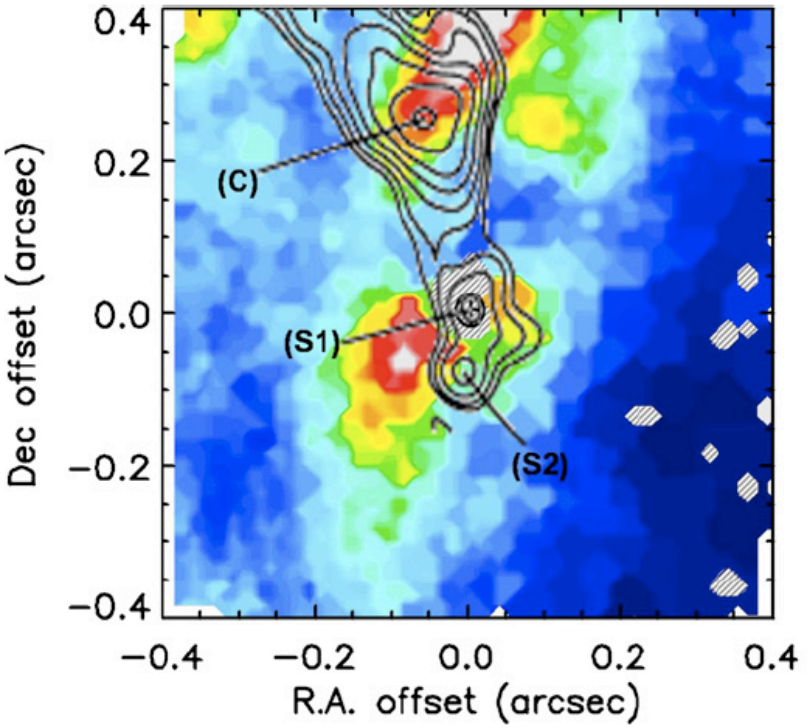


Contours [OIII]

Chandra Imaging of an Archetypal Seyfert 2 NGC 1068



Montage courtesy of B.Keel

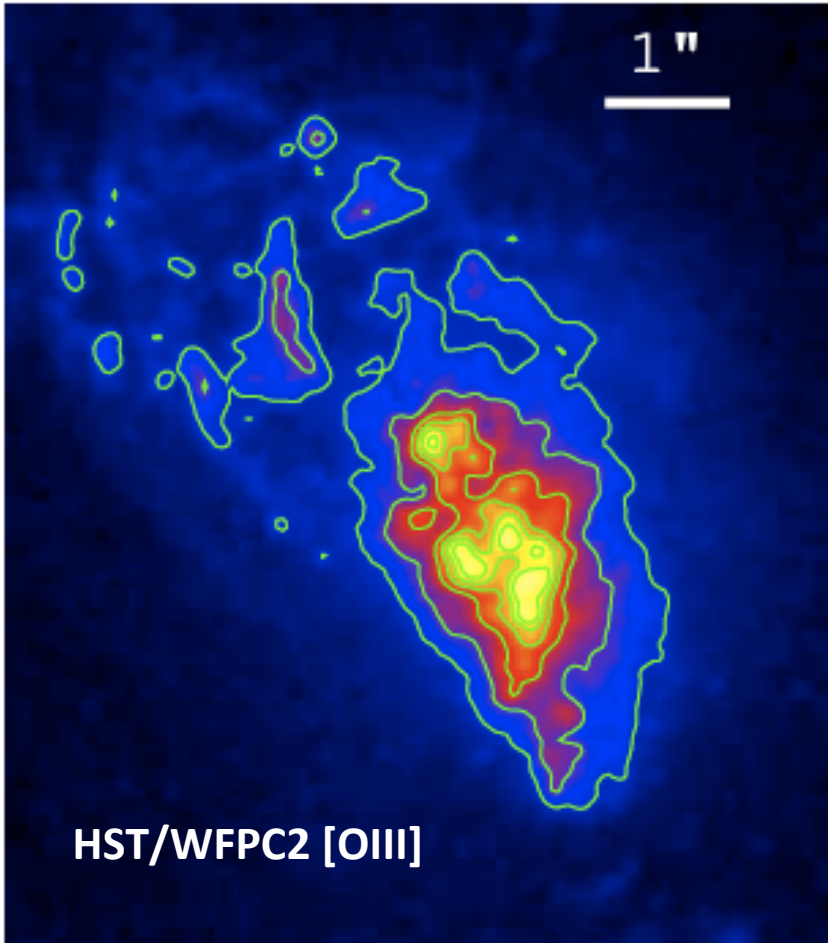


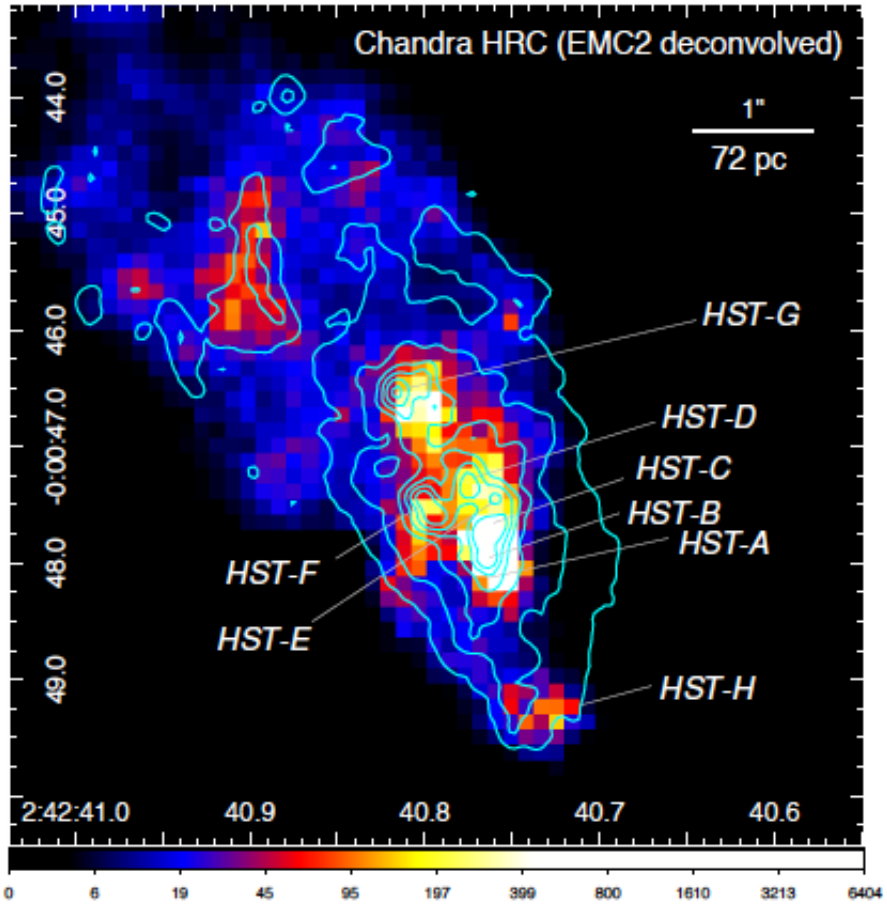
VLT/SINFONI H_2
Müller Sánchez, et al. (2009)

- One of the nearest and brightest Seyfert 2 galaxies containing a rapidly growing SMBH (M_{BH}~10^7 $M_\odot$; Greenhill+96)
- L_{bol}=6.4E+44 erg s^{-1}
- N_H>10^{25} cm^{-2} (Compton-thick)
- Anticorrelation between radio and optical emission

Jet clearing a channel?

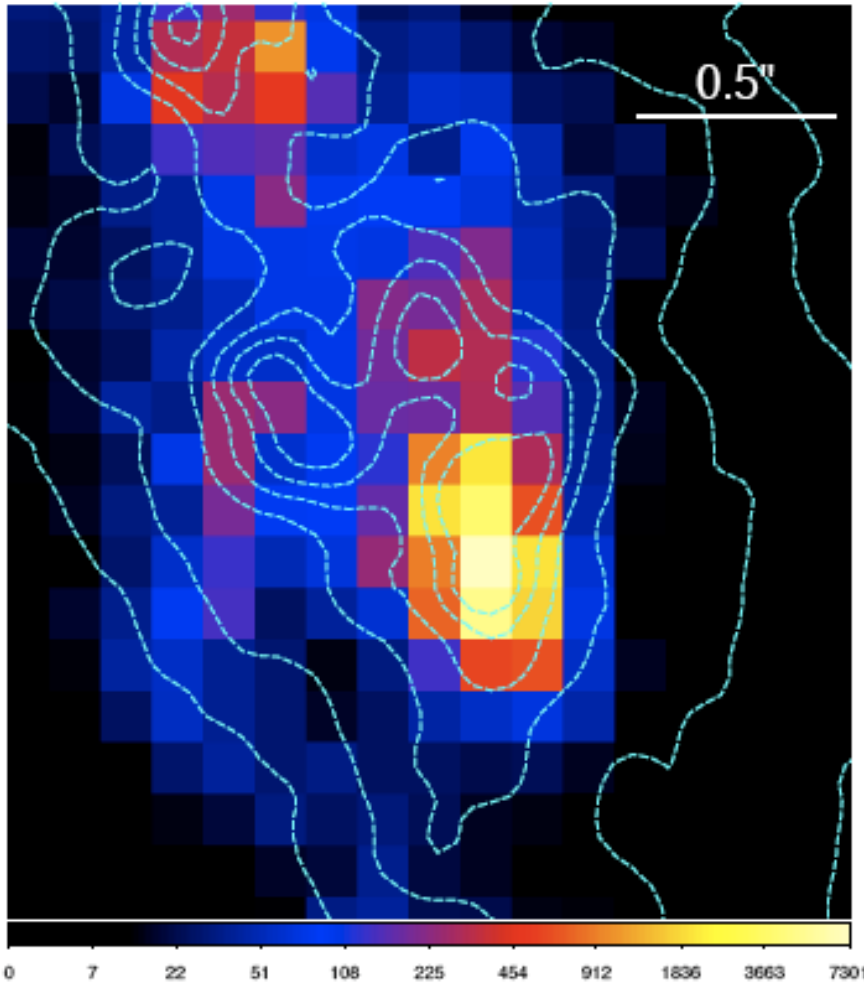
X-ray View of NGC 1068 Nuclear Region



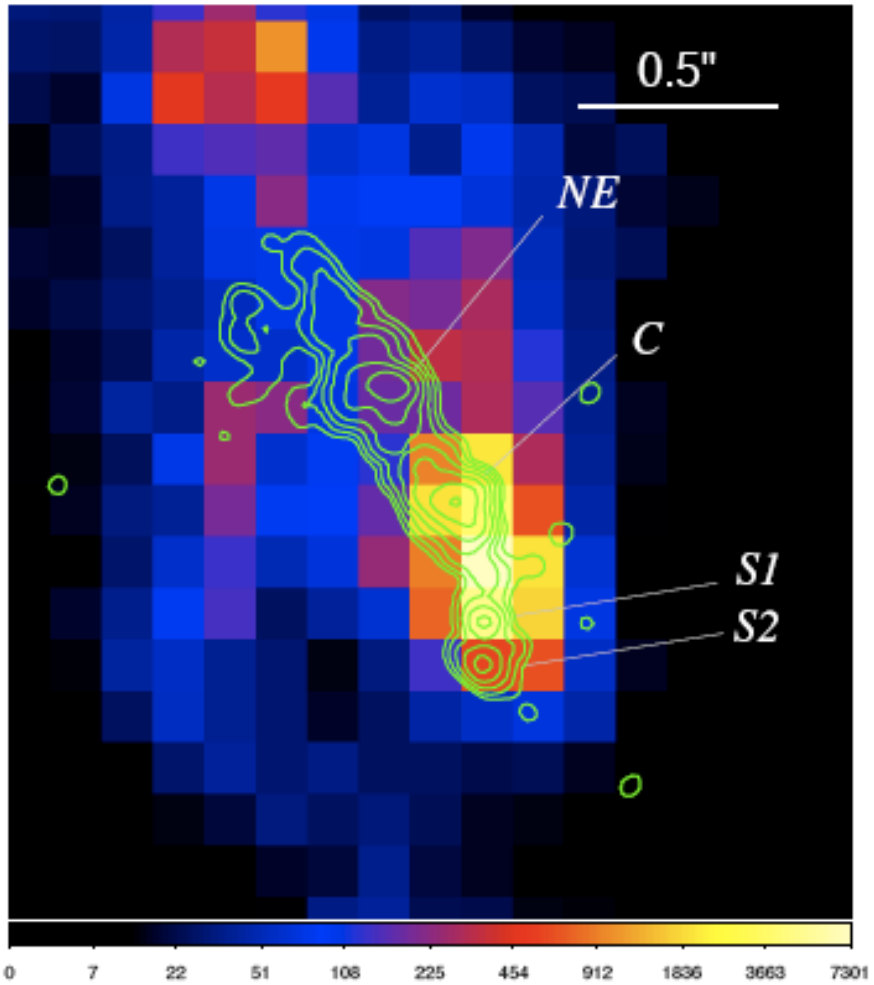


Chandra/HRC+HST [OIII] contours

Inner-most 100 pc

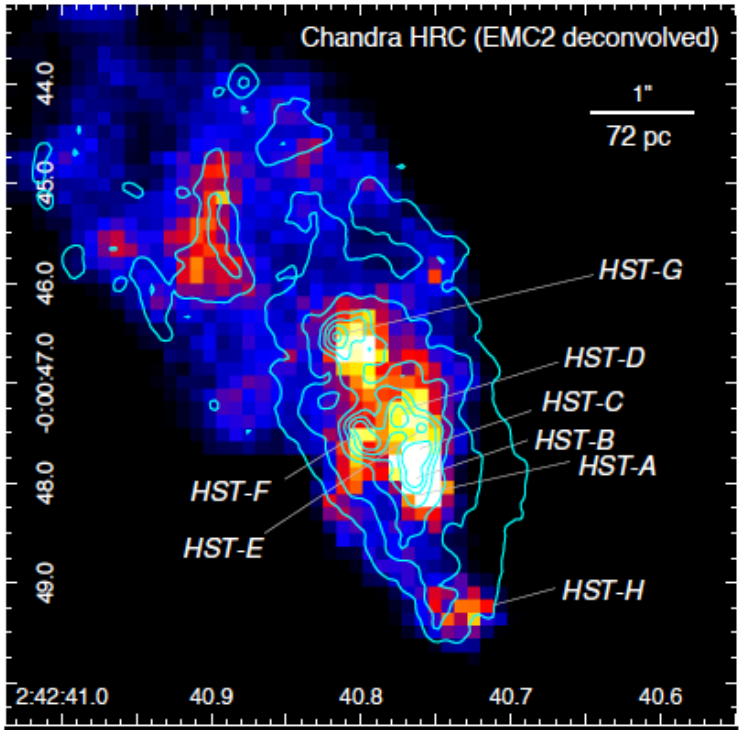


HRC+HST [OIII]

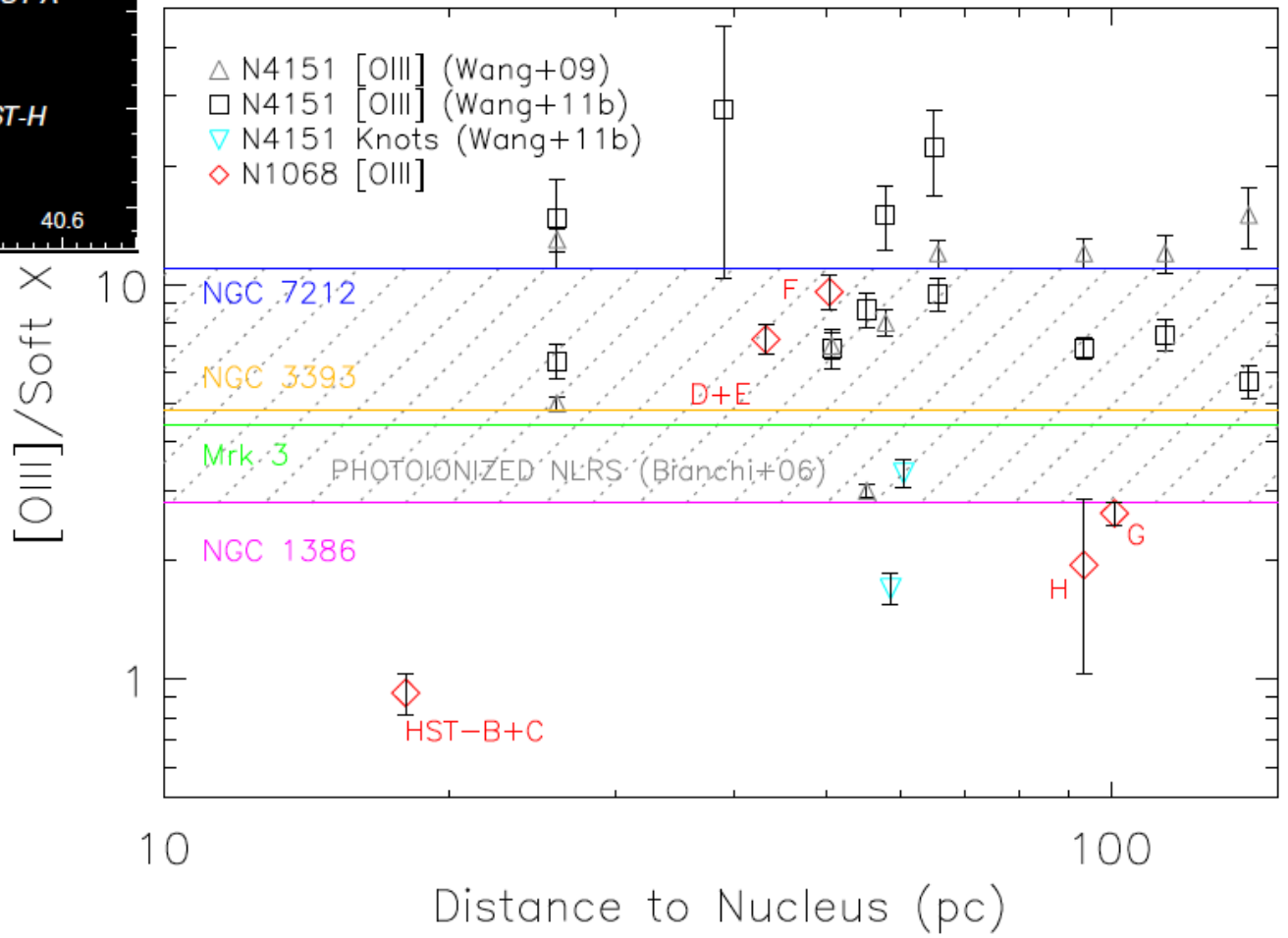


HRC+MERLIN 1.4 GHZ

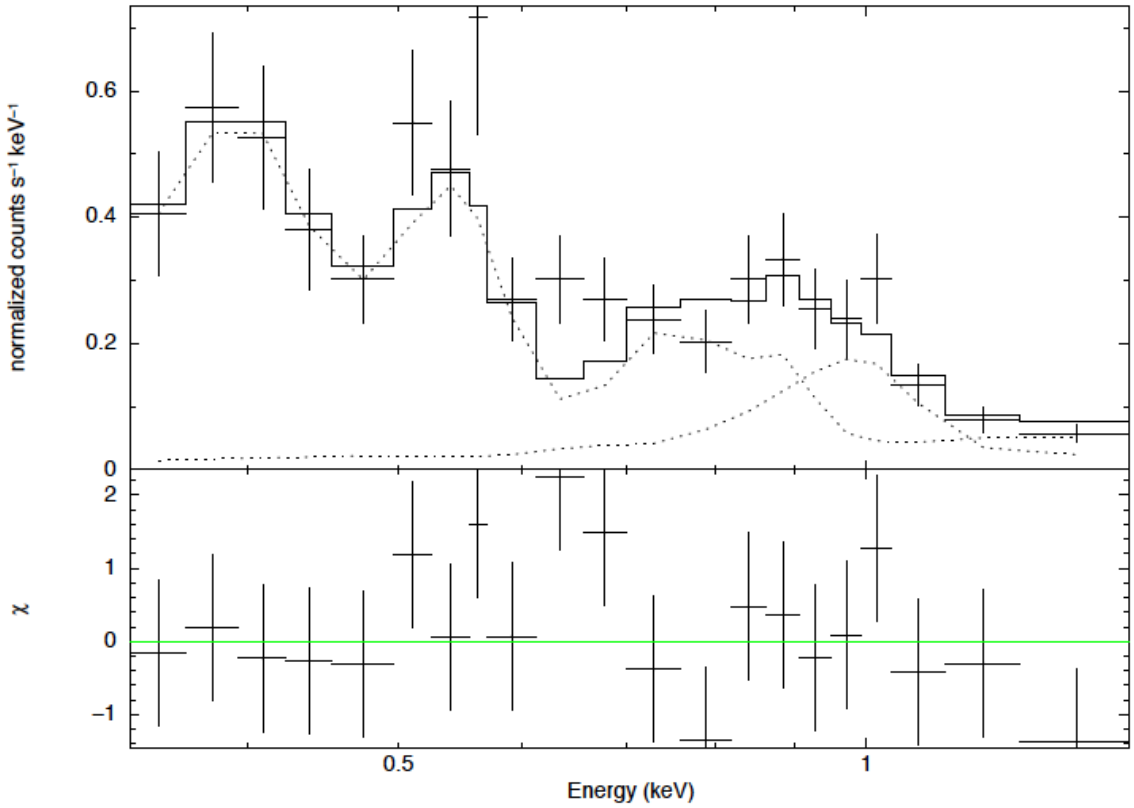
Identifying the Soft X-ray Excess due to Shock Heating



Three locations show evidence for jet-cloud collision

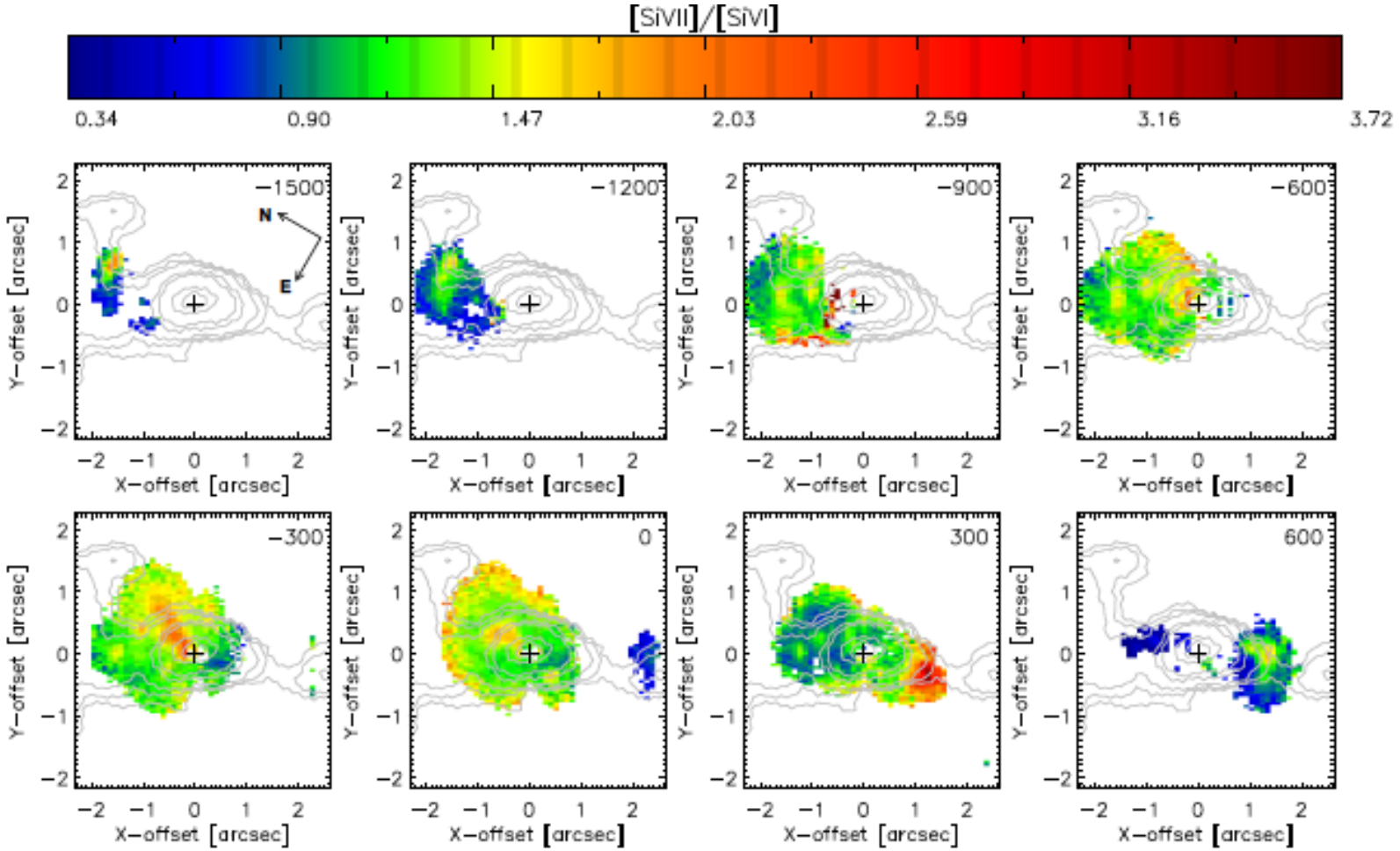


X-ray Spectral Modeling of HST Cloud-G



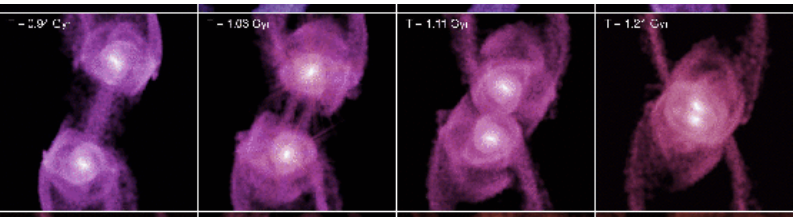
- logU= -1.7, N_H=21.7 (photoionization model CLOUDY)
- A thermal component with kT=1.08±0.11 keV required
- Lx=4.5x10^{39} erg s^{-1}
- Kinetic luminosity due to shocks $L_{K.E.}$=6x10^{38} erg s^{-1}
- ~10^{-4} of the jet power

The X-ray Identified Shock Locations (HST G and H) Confirmed to Show Higher **[Si** vii**] /[Si** vi**]** Line Ratios



Gemini NIFS coronal line emission study of NGC 1068

by Mazzalay et al. (2013) supports that radio jet plays an important role in the kinematics as well as structure of NGC1068



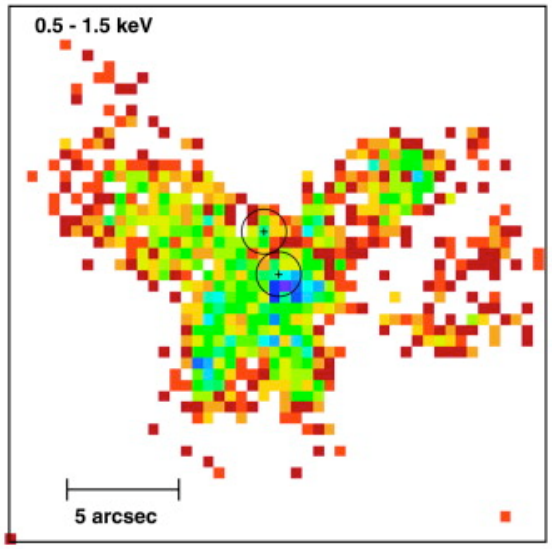
X-ray View of the Galaxy Merger NGC 6240: Resolving the Starburst and the AGN

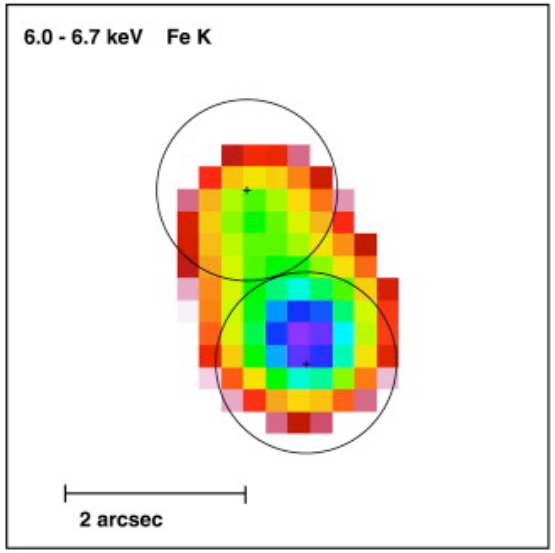
Ultraluminous Infrared Galaxies (ULIRG)

$L_{IR}=7x10^{11}\ L_{\odot}$

Merging galaxy with dual AGN

z=0.0245; D=106 Mpc



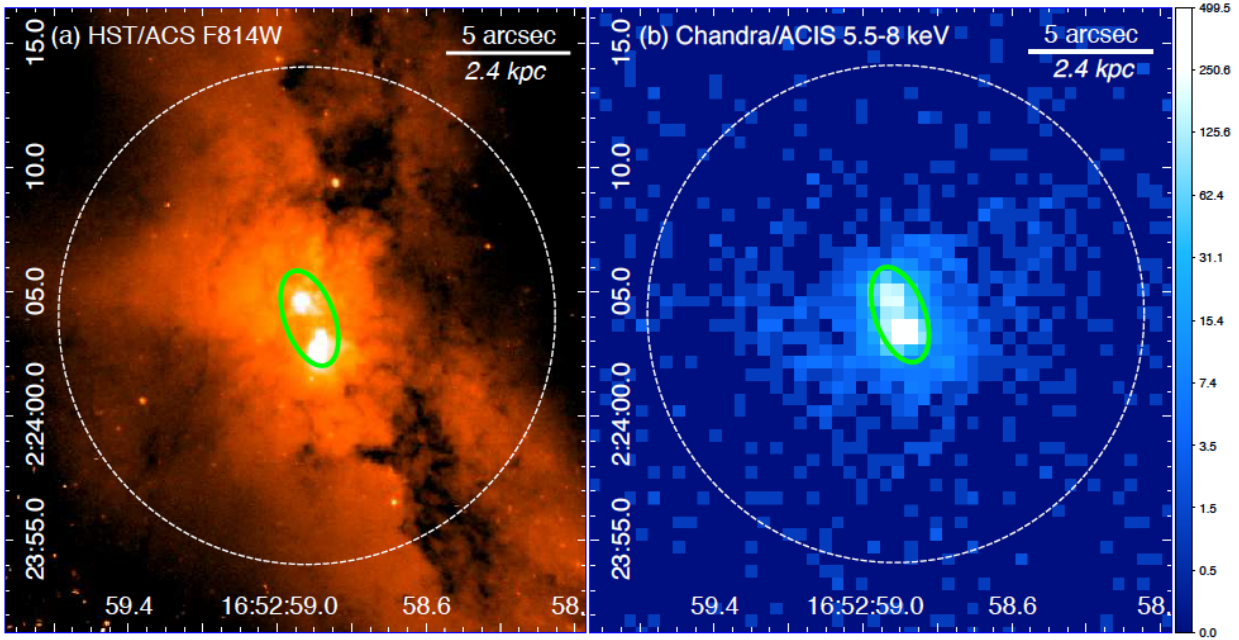


Komossa et al. (2003)

HST/ACS

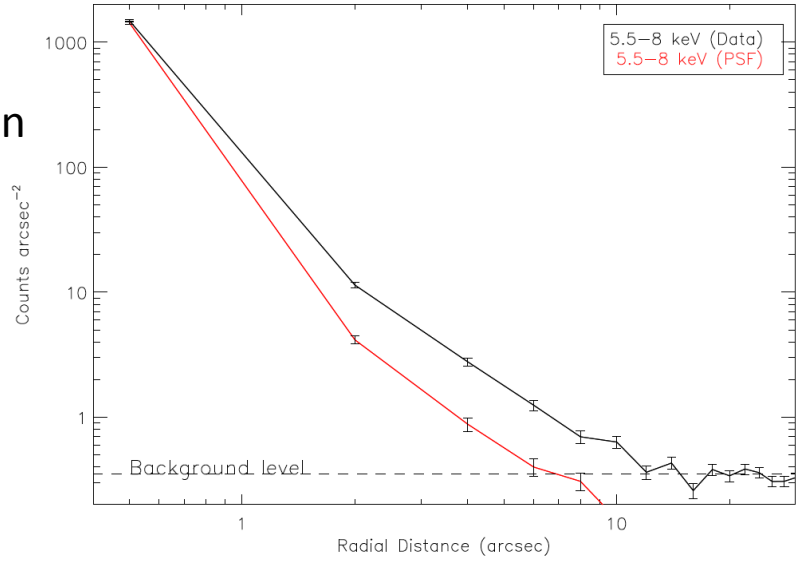
A Deep Chandra View of the ULIRG NGC 6240: Resolving the Starburst and the AGN

PI: Fabbiano



Detection of Extended Hard X-ray Emission

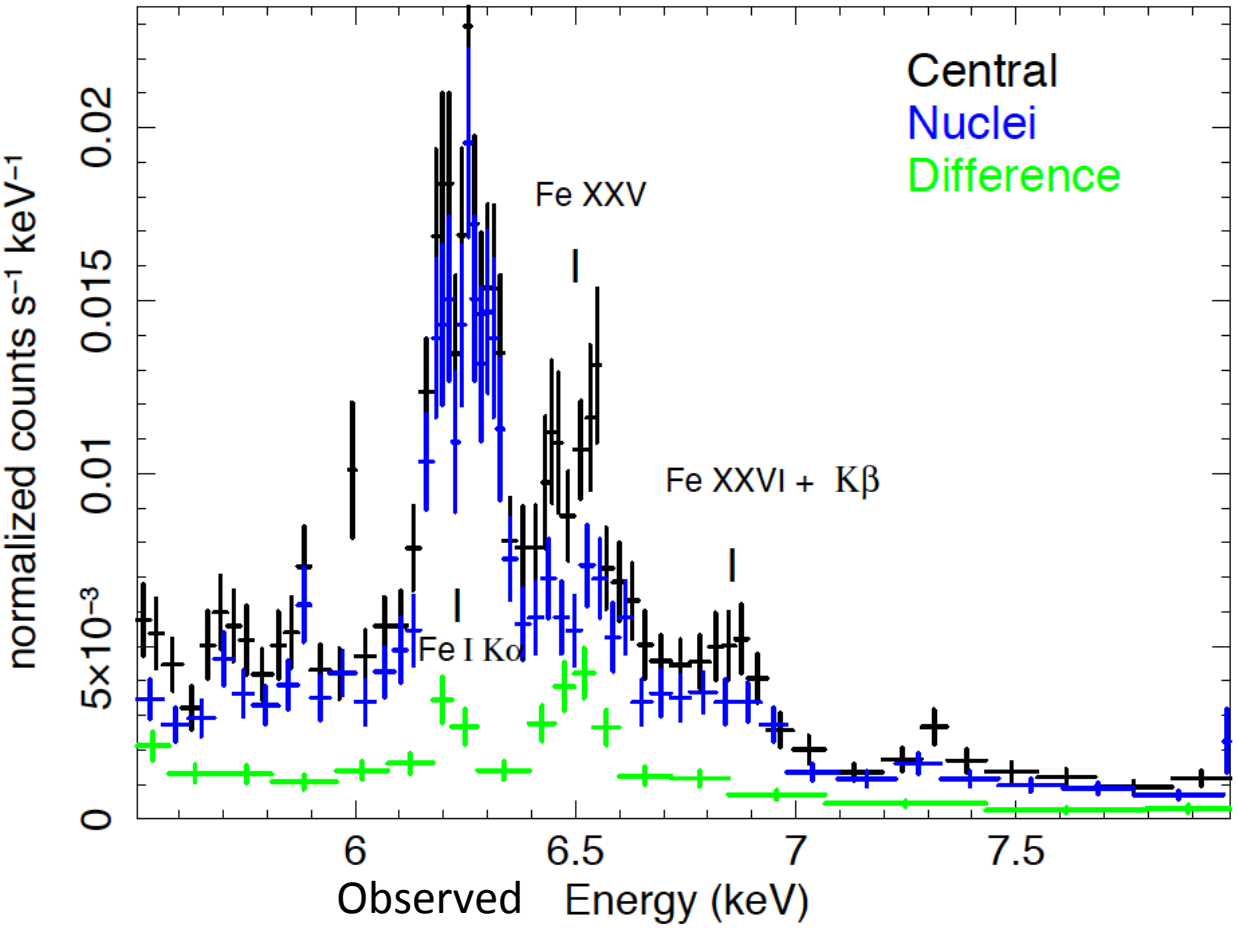
Significant excess over PSF



Detection of Extended Hard X-ray Emission

- Marginal detection in Komossa et al. (2003)
- Hot gas emitting Fe XXV line (highly ionized iron)

Extended to 10 arcsec ~5 kpc



Origin of the Extended Hard X-ray Emission?

Physical Parameters of the Hot Gas

- kT=6.1±0.3 keV (70 Million K)
- Lx=5.5E+42 erg s^{-1} (~100 times more luminous than the hot gas in M82)
- Estimated V_{sh}~2000 km s^{-1} (unlikely from direct collision of the galaxies)

The Case for Superwind

- ✓ SFR=25 Msun yr^{-1} (Engel et al. 2010)
- ✓ FWZI ~ 1600 km s^{-1} seen in H_2 and Ha line
- ✓ Initially very hot gas (10^8 K; P/k~10^7 K cm^{-3}) needed to drive the superwind (Heckman et al.2000), matching the observed.
- ✓ Ejected M_{Fe}=3.4E+6 $M_\odot$ vs. $M_{Fe,X\text{-}ray}$ > 4E+5 $M_\odot$
- ✓ Energetics: R_{SN}=2 yr^{-1} provides E=4E+57 ergs over 20 Myr of starburst, vs. E_{th}=6.5E+57 in the 70MK gas

Origin of the Extended Hard X-ray Emission?

Role of AGN Outflow

- If filling factor of the hot gas ~100% (Strickland & Stevens 2000), E_{th} exceed the available SN output by order of magnitude
- Multiphase gas bulk motion: Feruglio et al. (2013) resolved CO outflow with kinetic energy

  $E_{K.E.}$=3.8E+57 ergs

→ Additional heating from AGN outflow

Summary

- Chandra (plus multi-λ) imaging spectroscopic observations are powerful probes of ionized environments in AGN - Host galaxy interaction

- Seyfert galaxy NGC 1068 results suggest that AGN photoionization dominates, but radio jet-environment interaction is also present.

- Starburst powered 70 MK gas in ULIRG merging galaxy NGC 6240, but energy injection from AGN outflow likely

Thanks!