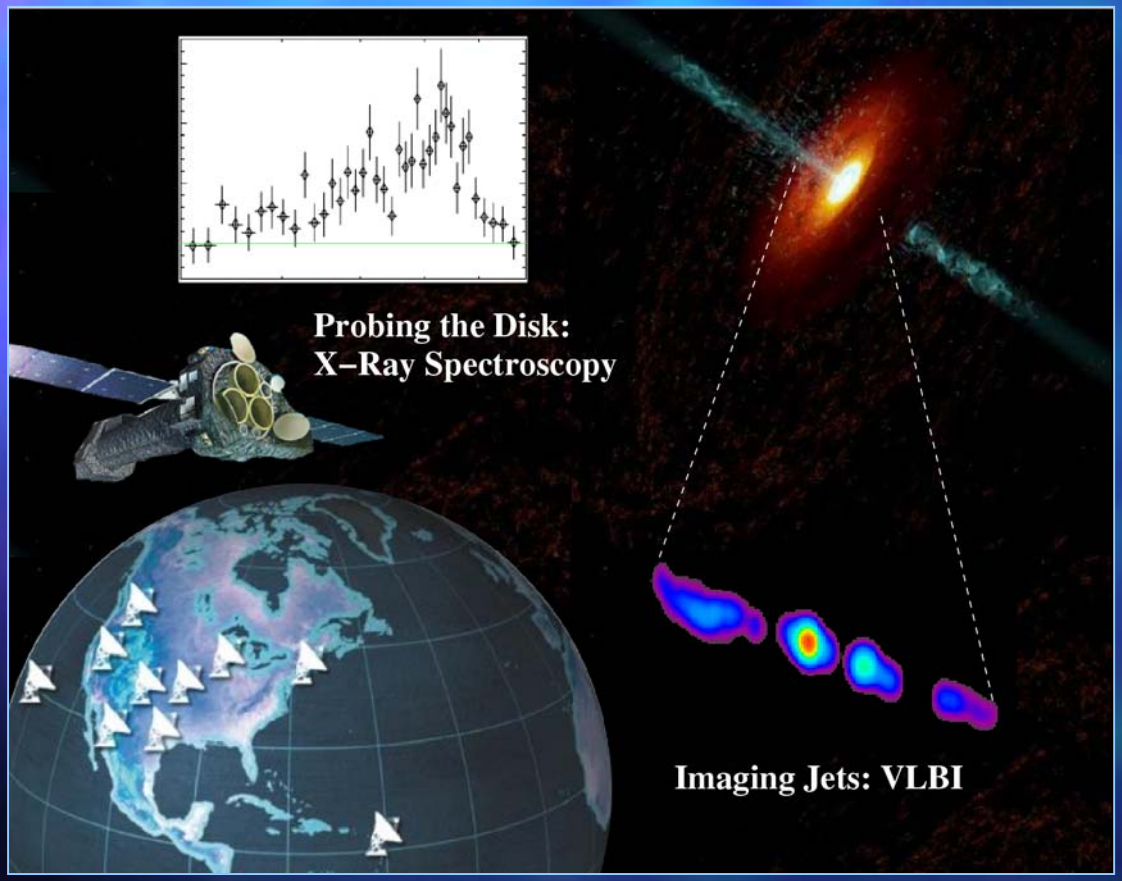
Combined VLBI- and X-ray Observations of Active Galactic Nuclei

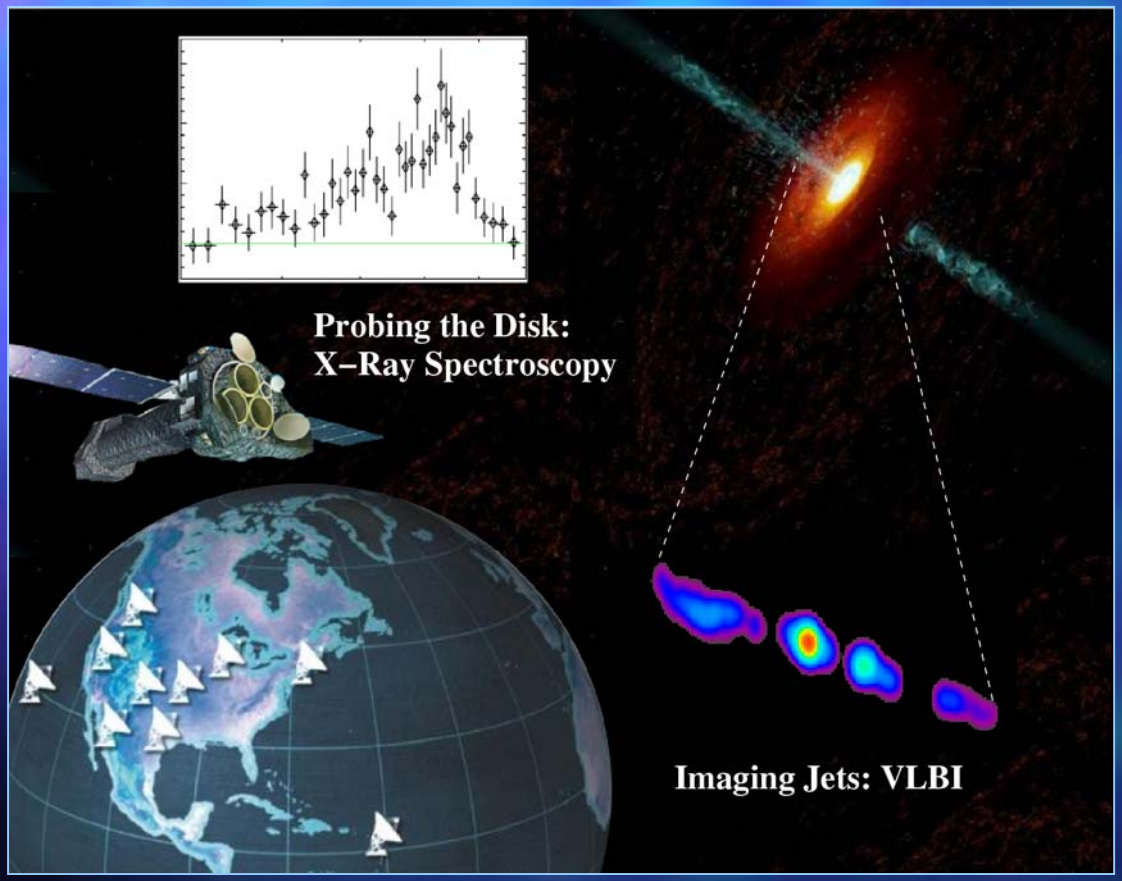


Matthias Kadler
(Max-Planck-Institut für Radioastronomie)
and
E. Ros[1], J. Kerp[2], Y.Y. Kovalev[3], J.A. Zensus[1]

[1]MPIfR, [2]RAIUB, [3]NRAO

Toledo, (Oct. 12th,2004)

Combined VLBI- and X-ray Observations of Active Galactic Nuclei



In Collaboration with:

K.A. Weaver

(GSFC)

&

The 2cmSurvey Team

(www.nrao.edu/2cmsurvey)

Differences Between Radio-Loud and Quiet AGNs at X-Rays

Both show power-law spectra

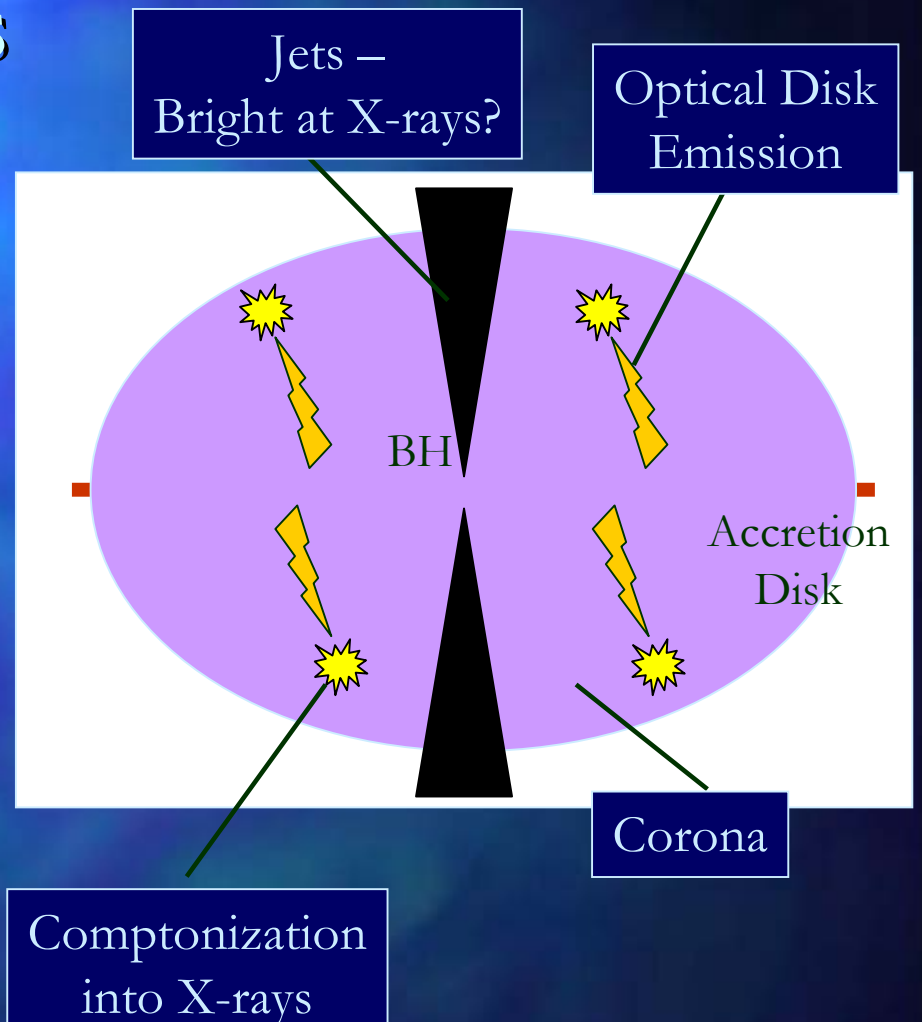
Radio-Quiet AGNs:

- Typical photon index ~ 1.7-2.0
  (P_E [Photons/keV] ~ $n^{-\Gamma} \Rightarrow \Gamma - 1 = \alpha$)
- Optical emission from disk
- Comptonization in Disk-Corona

  (see, e.g., Fabian et al. 2000, PASP, 112, 1145)

Radio-Loud AGNs:

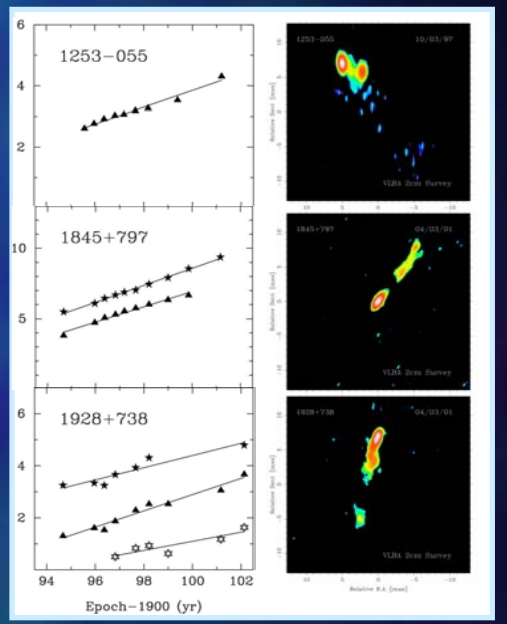
- Flatter photon indices ~ 1.5-1.7
- Which role plays the jet in the production of the nuclear X-rays?
- Do the X-rays tell us anything new about the jets?



An X-Ray Spectral Survey of Core-Dominated Radio-Loud AGNs

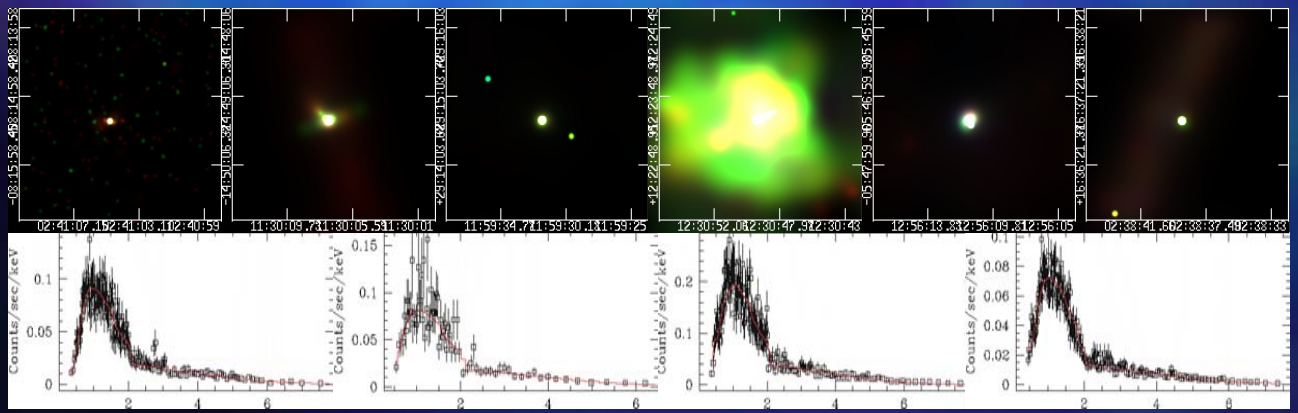
- Systematic survey of the X-ray properties of radio-loud core-dominated AGNs
- X-ray sample of 54 sources (the **2cm-X-Sample**)
- Based on radio-core properties rather than extended stuff, e.g., radio lobes, etc.

VLBA 2cmSurvey



www.nrao.edu/2cmsurvey

Kellermann et al. (1998),
Zensus et al. (2002),

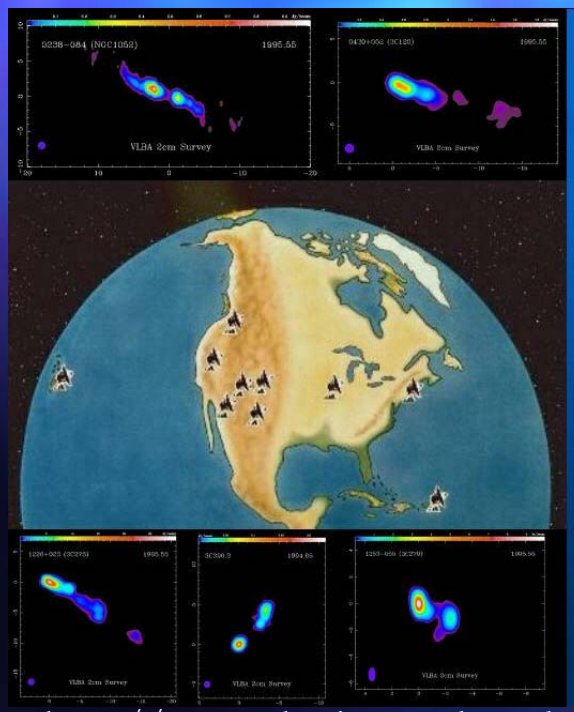


Archival *CHANDRA*, *XMM-Newton*, *ASCA*, and *Beppo*Sax data

The 2cm-X-Sample

- Representative of the MOJAVE sample (the 133 radio-brightest compact AGN in the northern sky)
- See 2cmSurvey Paper 3 & 4

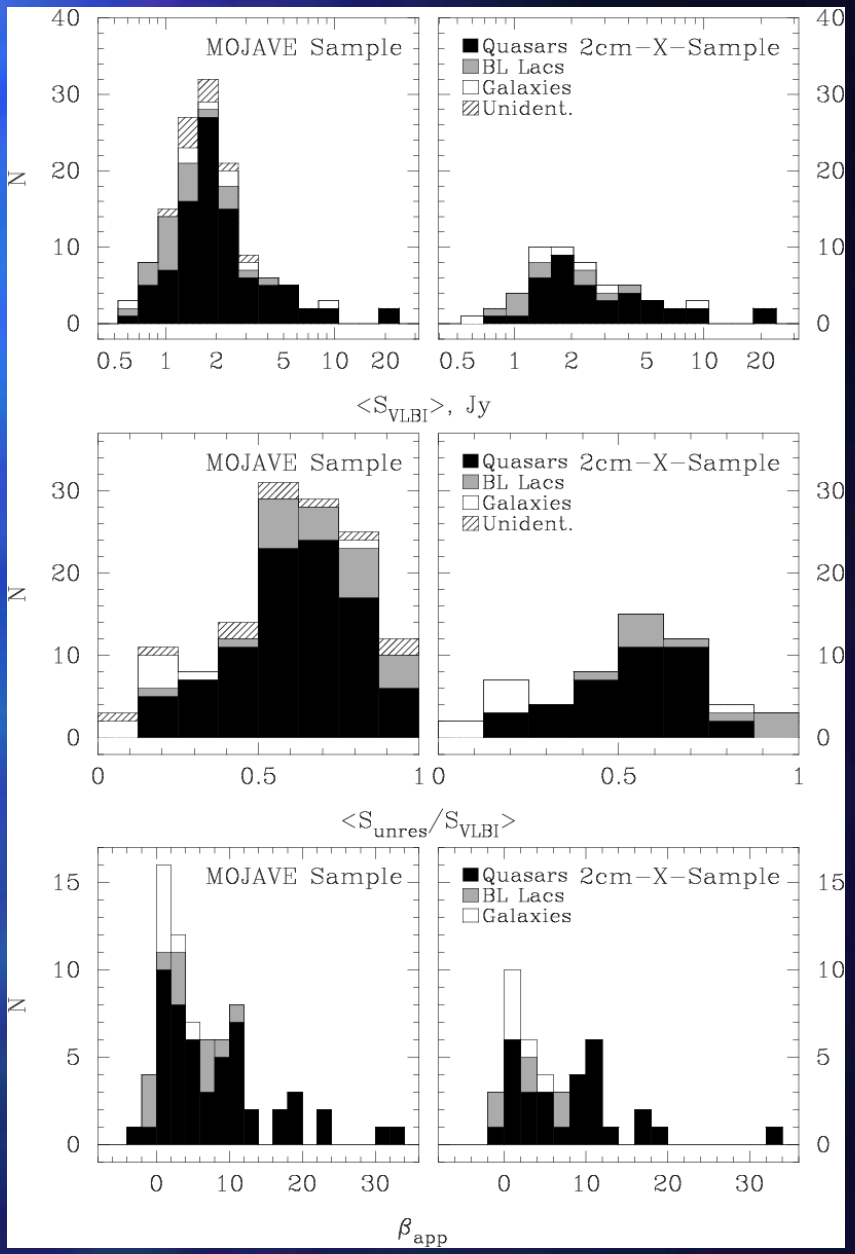
(Kellermann et al. 2004; Kovalev et al., in prep.)



Monitoring
Of
Jets in
Active galaxies with
VLBA
Experiments

http://www.physics.purdue.edu/astro/MOJAVE/

Kadler et al. (2004, astro-ph/0409300)



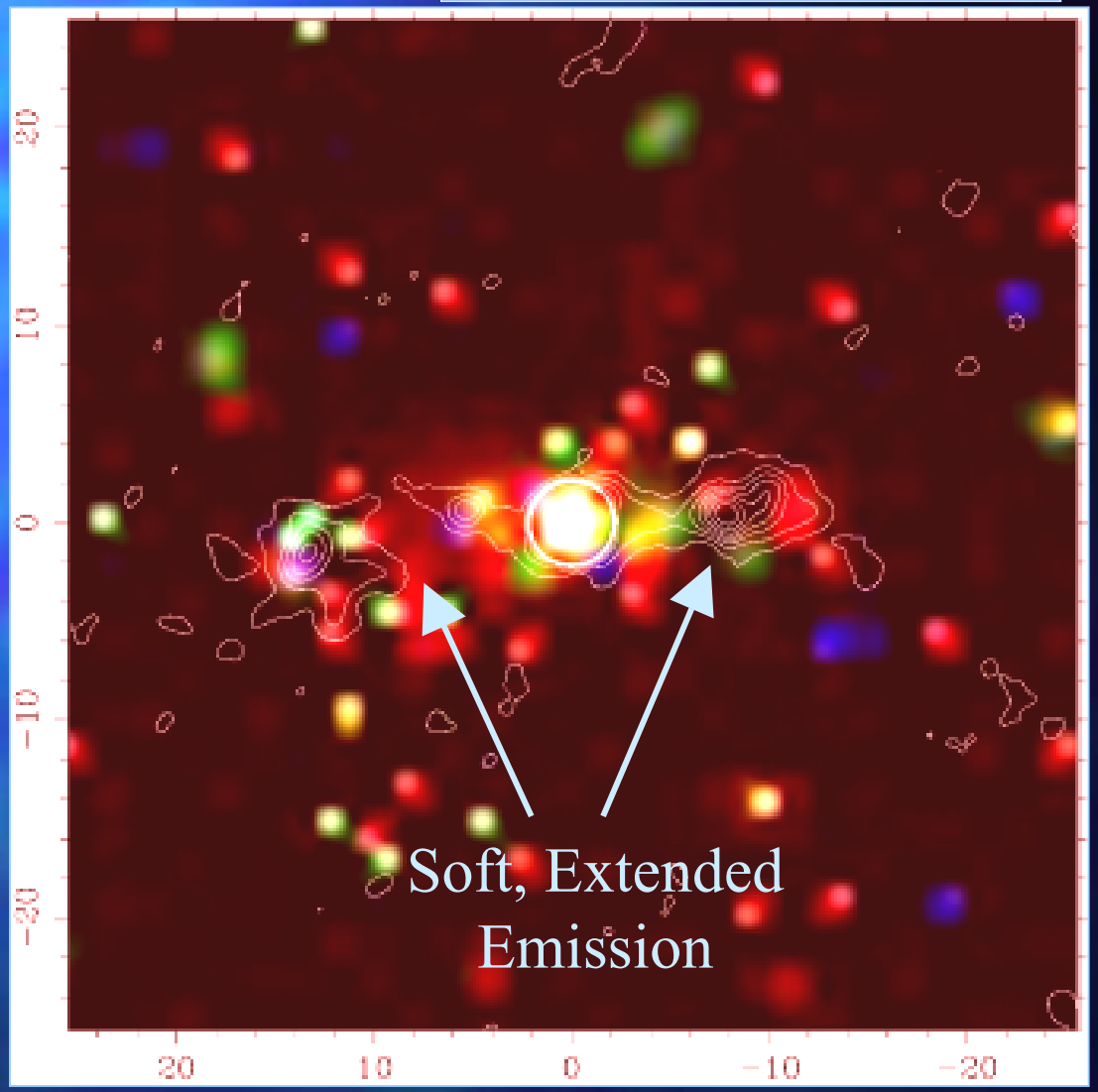
Source:	*Alt. Name*:	*CHANDRA*-Data:	*XMM*-Data	*ASCA*-Data	*Beppo*Sax-Data	Source:	*Alt. Name*:	*CHANDRA*-Data:	*XMM*-Data	*ASCA*-Data	*Beppo*Sax-Data
0007+106	III Zw 2		√	√	√	1228+126	M 87	√	√	√	√
0048-097	OB –080				√	1253-055	3C 279	√		√	√
0234+285	CTD 20				√	1308+326	OP +313		√	√	
0235+164	OD +160	√	√	√	√	1334-127	OP-158.3		√		
0238-084	NGC 1052	√	√	√	√	1413+135	OQ +122			√	
0316+413	3C 84	√	√	√	√	1458+718	3C 309.1	√			
0333+321	NRAO 140			√	√	1502+106	4C 10.39		√		
0415+379	3C 111		√	√	√	1510-089	OR -017	√		√	√
0420-014	OA +129			√	√	1611+343	DA 406				√
0430+052	3C 120	√	√	√	√	1633+382	4C38.41			√	
0458-020	DA 157	√				1641+399	3C 345	√			√
0528+134	OG +147			√	√	1655+077	OS +092	√			
0605-085	OH -010	√				1741-038	OT -068				√
0716+714			√	√	√	1749+096	4C 09.57			√	
0735+178	DA 237			√		1803+784					√
0736+017				√	√	1823+568	4C 56.27				√
0738+313	OI +363	√	√			1828+487	3C 380	√			
0827+243		√				1928+738	4C 73.18	√		√	√
0836+710	4C 71.07	√	√	√	√	1936-155					√
0851+202	OJ +287			√	√	1957+405	Cyg A	√		√	√
0923+392	4C 39.25	√		√		2134+004	DA 553				√
1038+064	4C 06.41		√	√		2145+067				√	
1055+018	4C 01.28	√				2200+420	BL Lac	√		√	√
1127-145	OM -146	√	√		√	2223-052	3C 446			√	√
1156+295	4C 29.45	√				2230+114	CTA 102			√	√
1222+216		√		√		2243-123	OY -176				√
1226+023	3C 273	√	√	√	√	2251+158	3C 454.3	√			√

The X-Ray View of NGC1052

Kadler et al., 2004, A&A, 420, 467

Extended emission:
- (Anti-)Correlated with the radio jet
- Thermal spectrum (0.5keV)

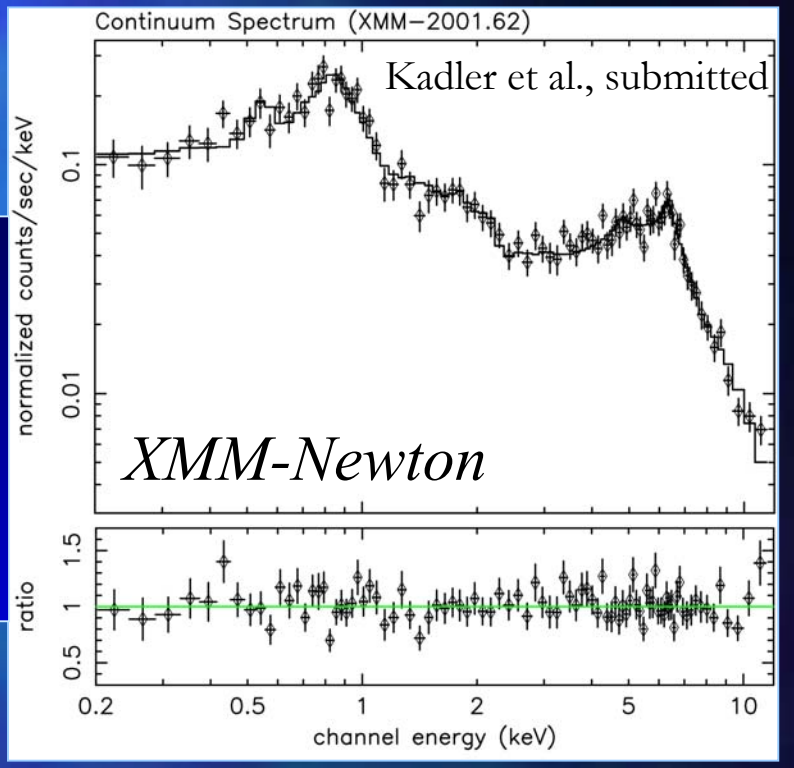
Nuclear emission:
- Extremely flat
- Heavily absorbed ($N_H \sim 10^{22}$-10^{23} cm^{-2} consistent with VLBI)



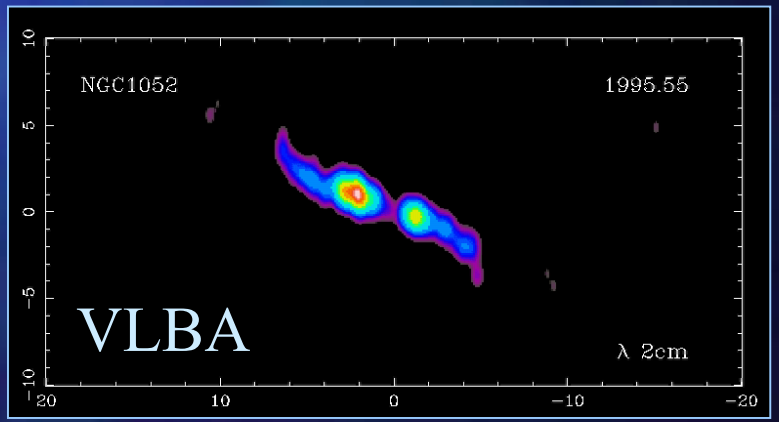
CHANDRA Image (0.1-3 keV)

VLBI- and X-Ray Observations of NGC1052

- The First Highly Relativistic, Broad Iron Line in a Radio-Loud AGN
- Line Profile Discloses Disk Properties:
  - Emission from $6R_G$ – $60R_G$
  - Disk Inclination: ≈ 80°



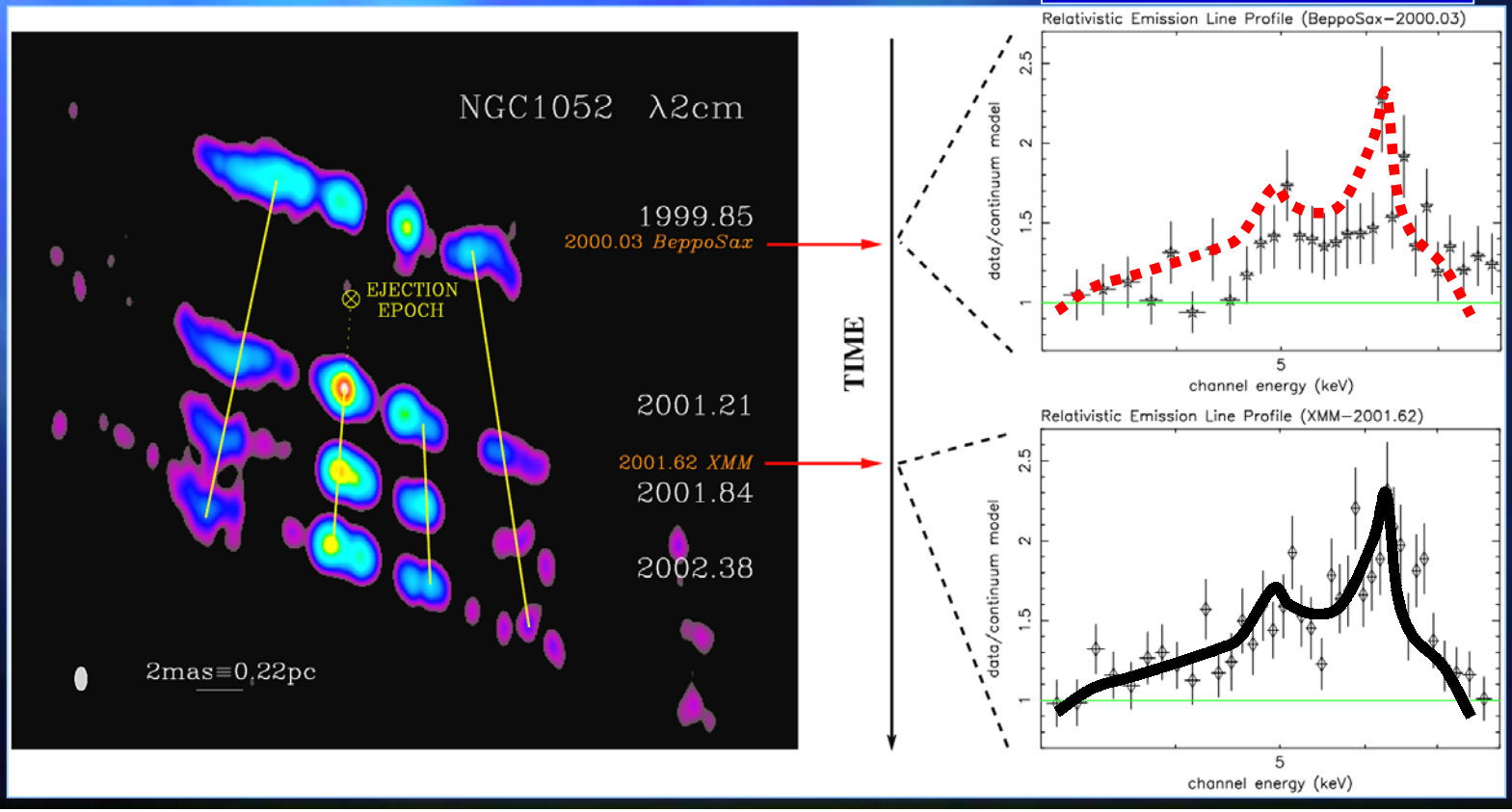
- VLBI Results (e.g., Kadler et al. 2004, A&A, in press; Vermeulen et al. 2003, A&A, 401,113) :
  - Obscuring Torus
  - Jet Inclination: 60°-80°



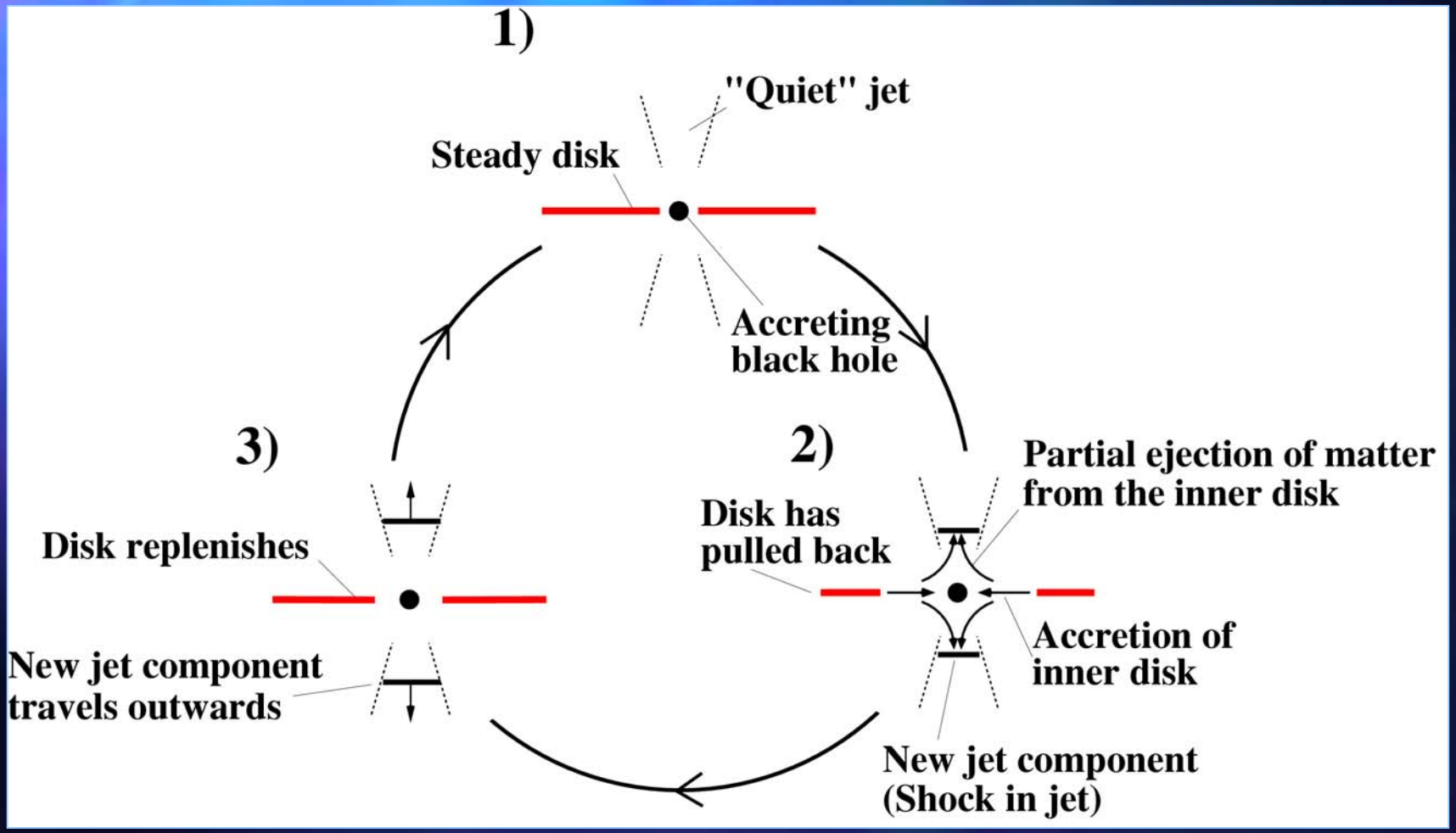
Caught in the Act: An Accretion-Ejection Event in NGC1052

- Violent Plasma Ejection in 1999/2000
- Variability of the Broad Iron Line

Kadler et al., submitted
Ros et al. in prep.



NGC1052 from 1999 to 2001:
A Simple Model



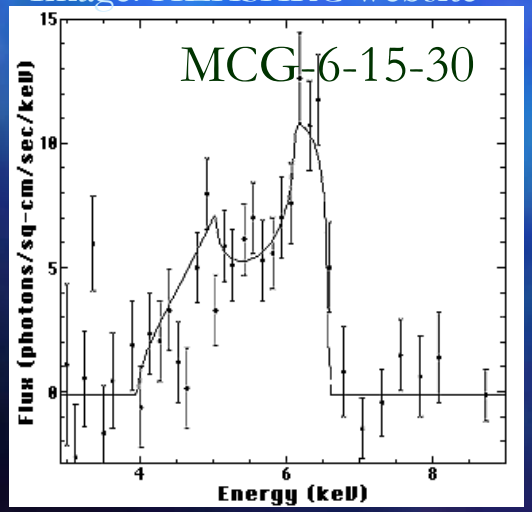
What Makes an AGN Radio-Loud?

- NGC1052 might tell us the answer, finally!
- A parsec-scale jet- plus iron-line monitoring can show us what triggers the production of jets!
- Occurrence of "dips" in the X-ray light curve? (like in 3C120; Marscher et al. 2002)

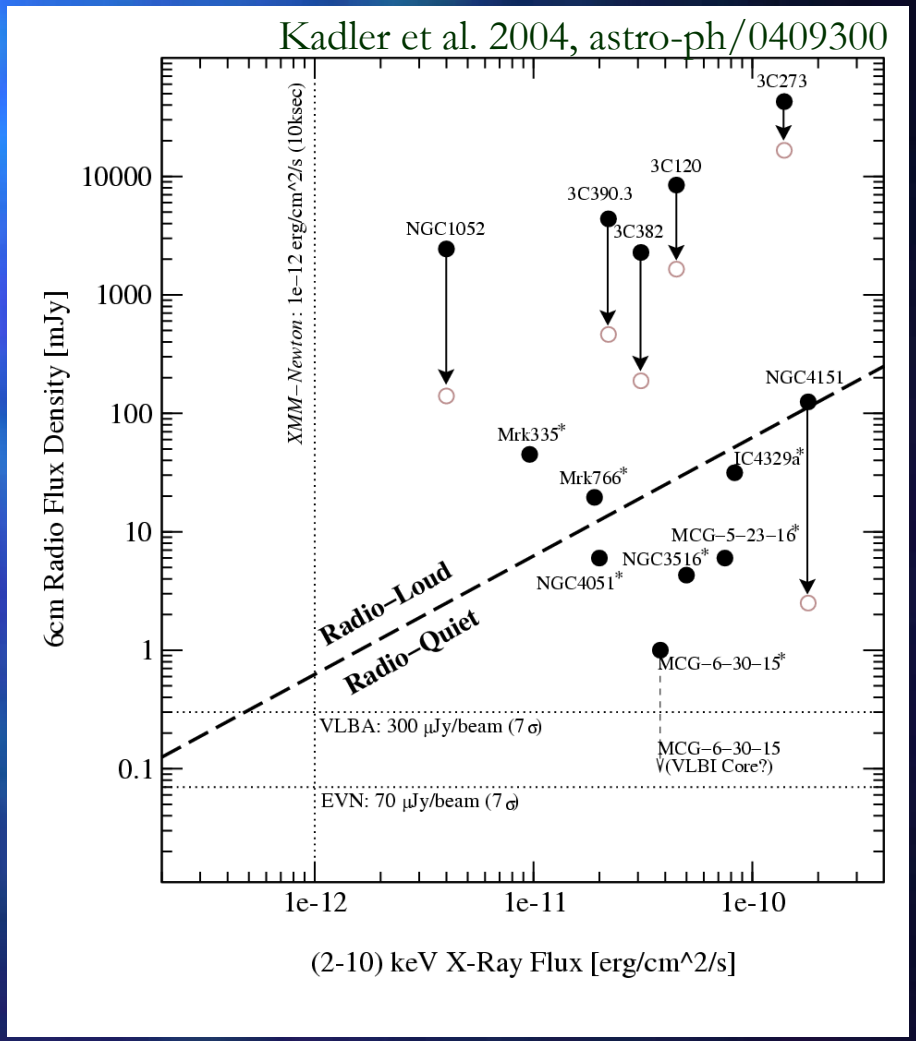
Radio-Quiet AGN – Not so Quiet After All

- Prominent broad iron lines seen in a sample of Seyfert galaxies
- Attractive targets for highly sensitive VLBI observations

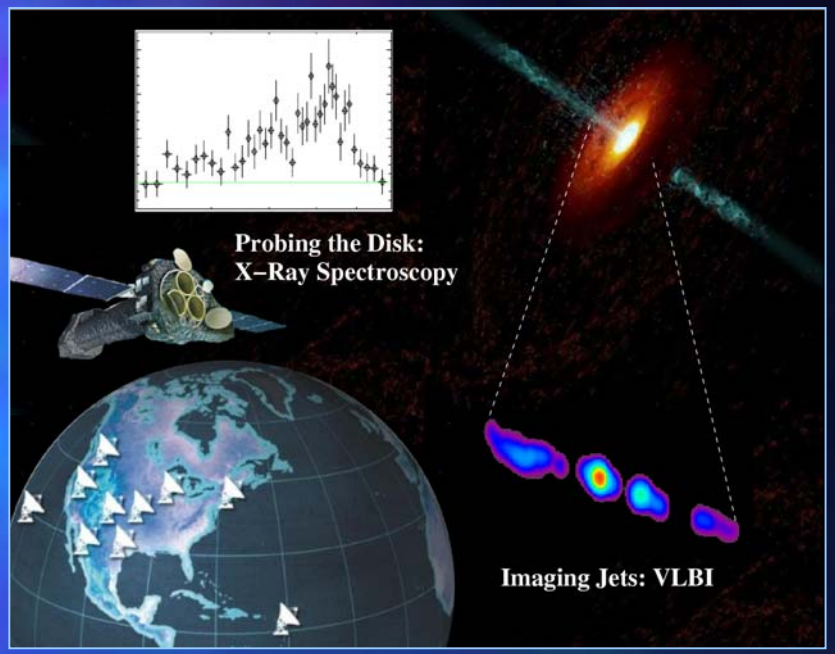
Image: HEASARC website



Kadler et al. 2004, astro-ph/0409300



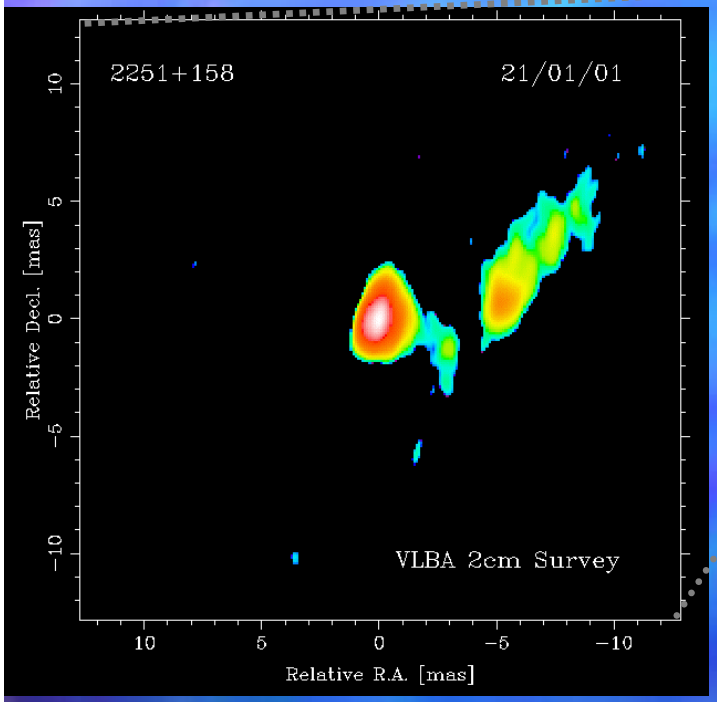
Summary

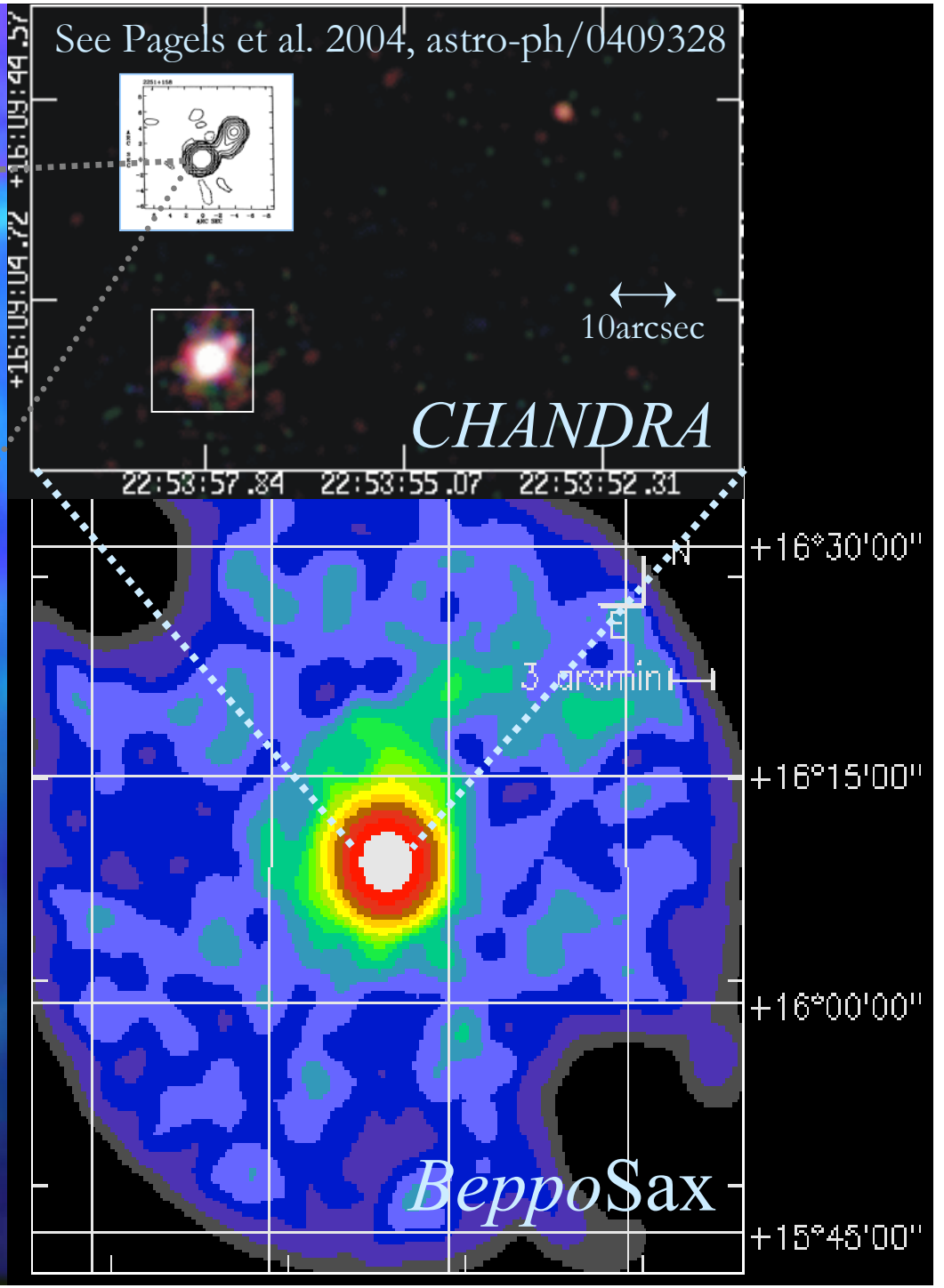


- VLBI and X-ray spectroscopy are combined in a systematic radio X-ray spectral survey of compact AGN

- Combined VLBI and X-ray observations revealed
  - A highly relativistic, broad iron line in a radio-loud AGN: NGC1052
  - Association between line variability and jet production
  - Ultimately, NGC1052 might tell us what makes an AGN radio-loud

3C454.3

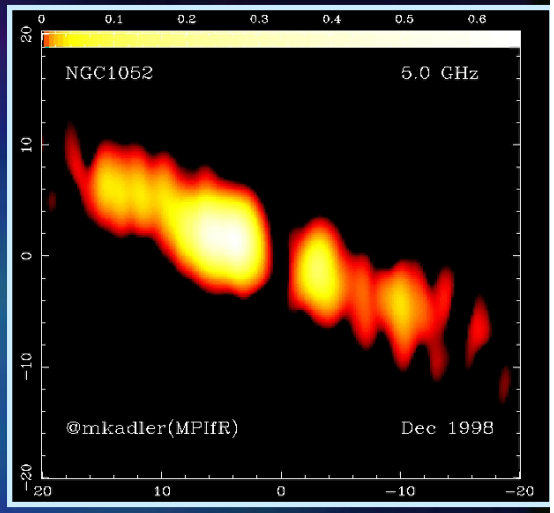




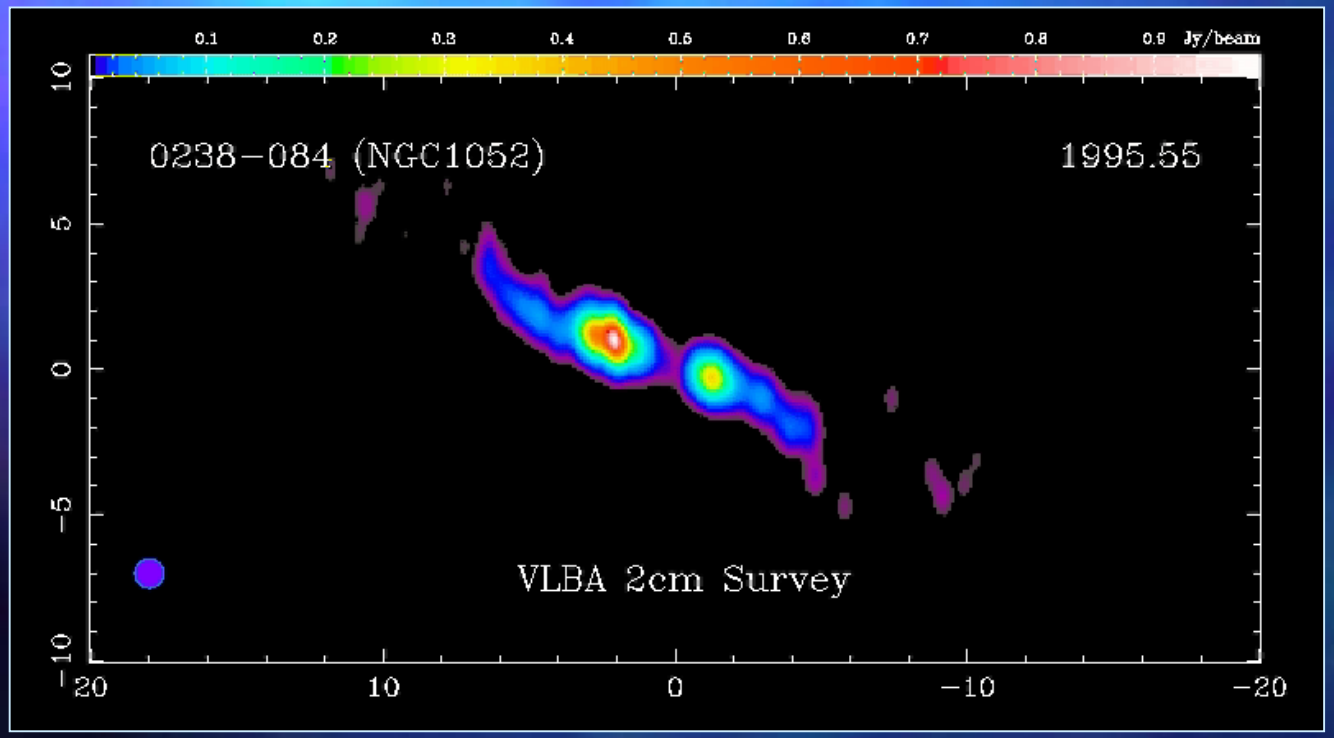
Higher angular resolution reveals the jet contribution on arcsecond-scales! What about the parsec-scale jet?

VLBA Observations of NGC1052

Obscuring Torus
(see Kadler et al. 2004, A&A, in press)



Multi-ν Observations



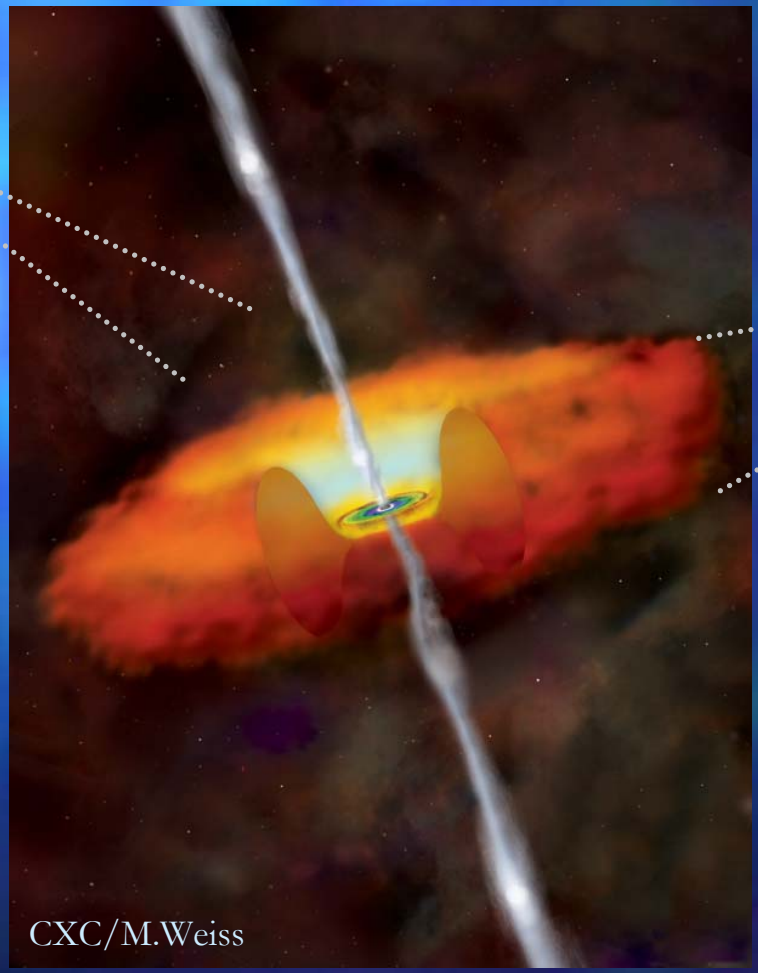
Multi-Epoch Observations

Jet Kinematics
(see Vermeulen et al. 2003, A&A, 401,113)

The Standard Model of AGN-Activity

Type 1:

One-Sided Jets;
Broad and Narrow Line Region;
No absorption of soft X-Rays

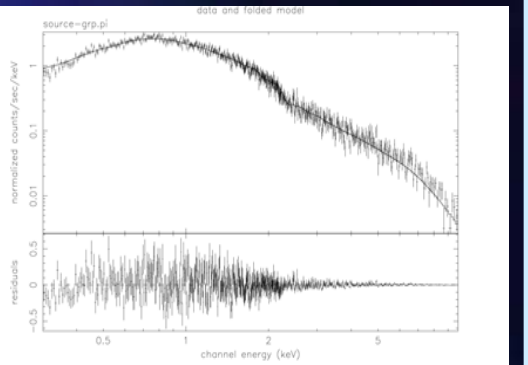


Type 2:

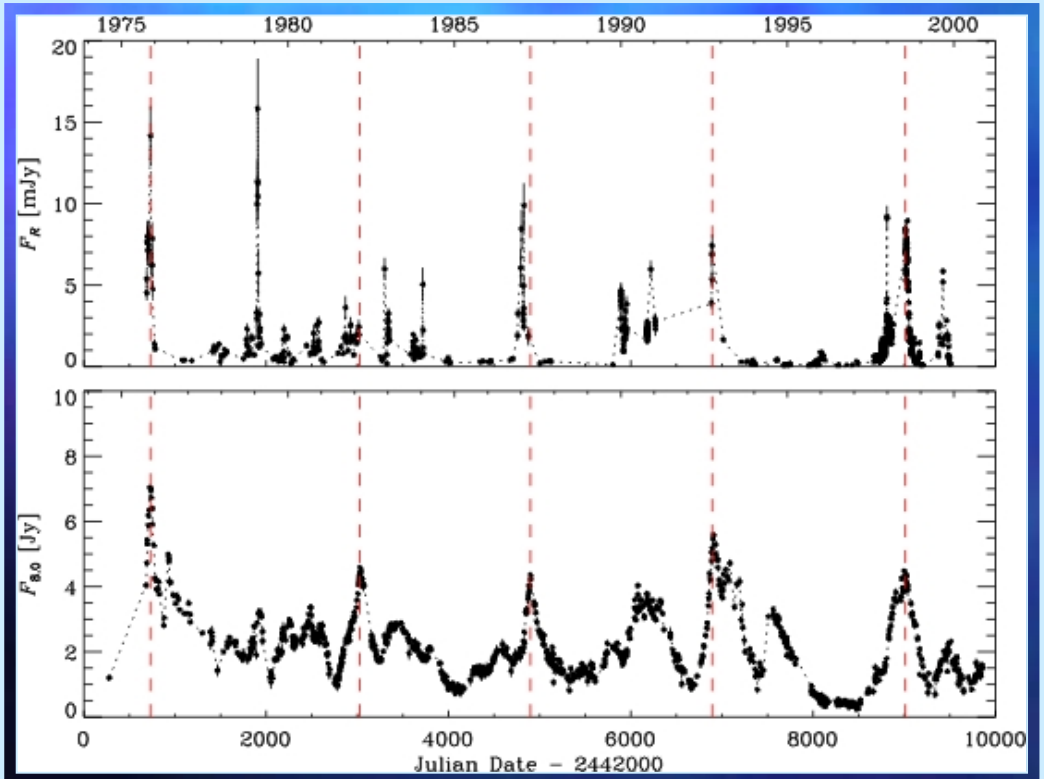
Two-Sided Jets;
Free-Free Absorption;
Narrow Line Region;
Strong Absorption of soft X-Rays

AO 0235+164 – a WEBT Campaign

XMM

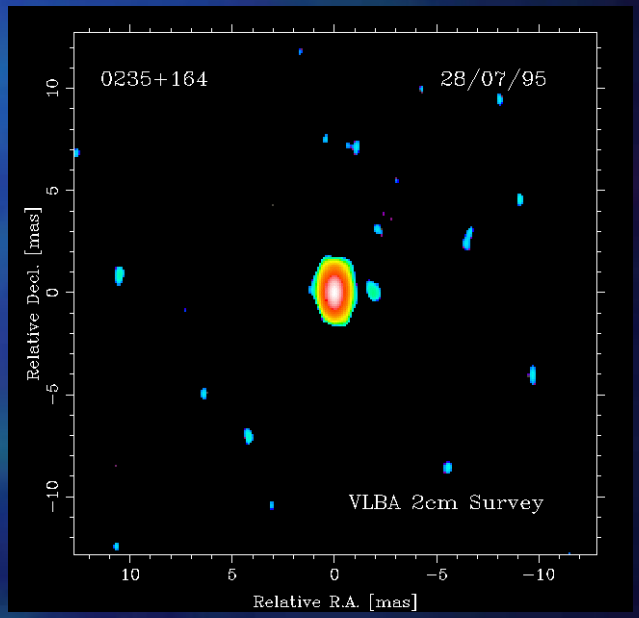


Raiteri et al. 2001

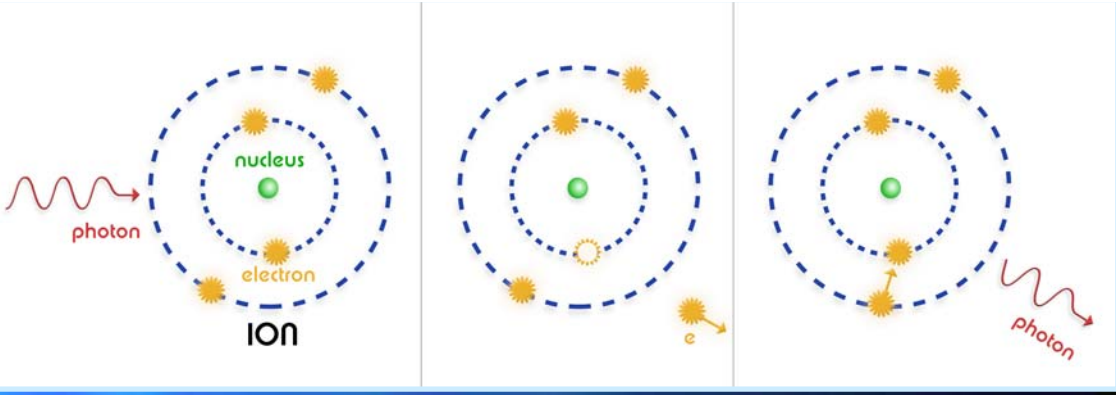


Radio and Optical Flux Monitoring

VLBI



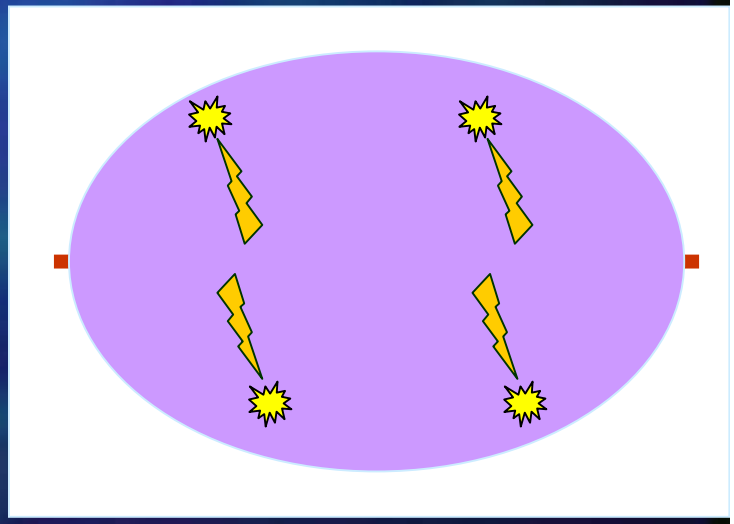
Broad Fe-Lines in AGNs



Line Production:

- X-ray continuum illuminates the accretion disk
- Incident photon can be Compton scattered by free or bound electrons ⇒ Reflection Component
- Photoelectric absorption can take place followed by fluorescent line emission or Auger de-excitation
- Fe Kα is the strongest fluorescent line (high cross-section for absorption; most abundant metal)

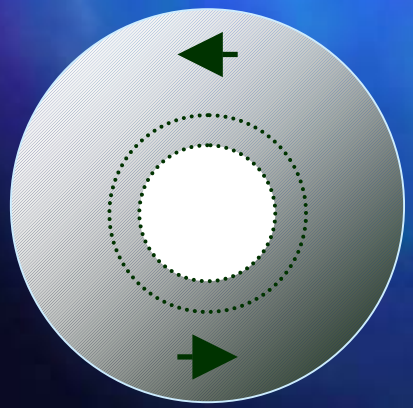
1. Optical emission from disk
2. Comptonization in Disk-Corona
3. Disk-Reflection

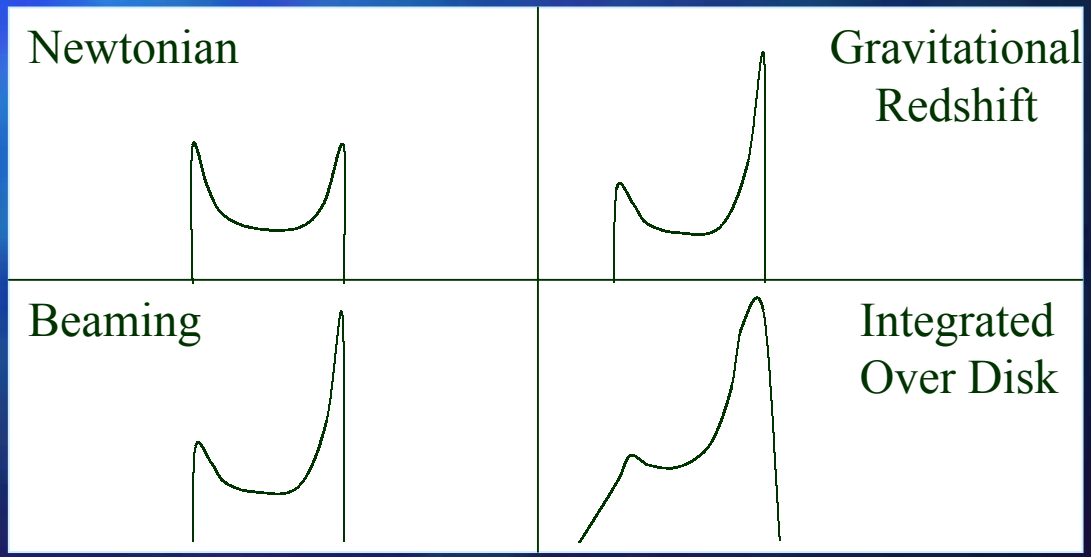


Broad Fe-Lines in AGNs II

Line Profile:

- Fe Kα line is intrinsically narrow.
- Broadening can be attributed to the disk dynamics (Doppler shifts) and gravitational redshifting. ⇒ Characteristic broad, skewed line
- "Blue" End: Inclination angle – "Red" End: Inner Radius

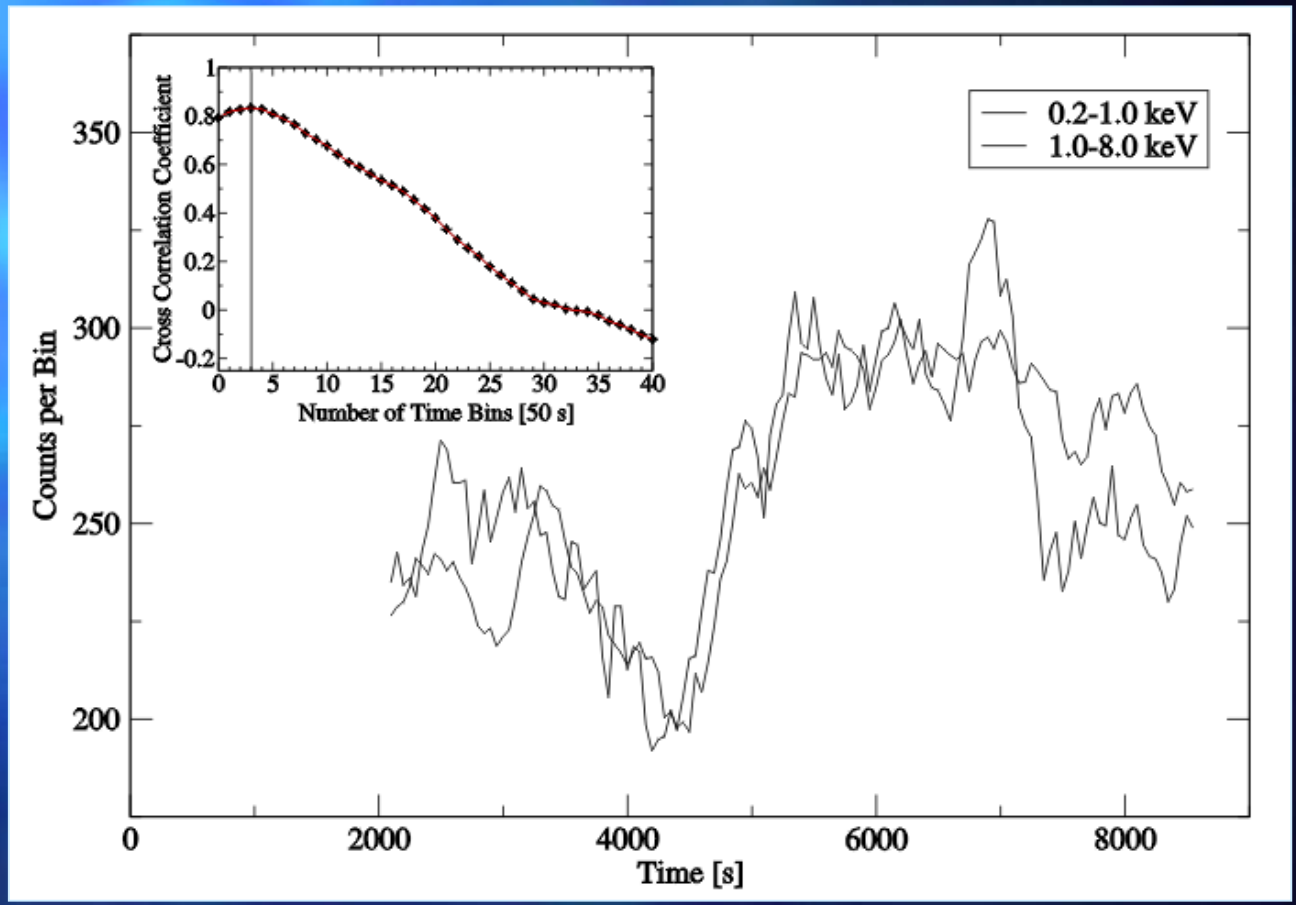




0716+714

- Pronounced short term variability in March 2002
- Soft Lag of ~150s

⇒ Cooling

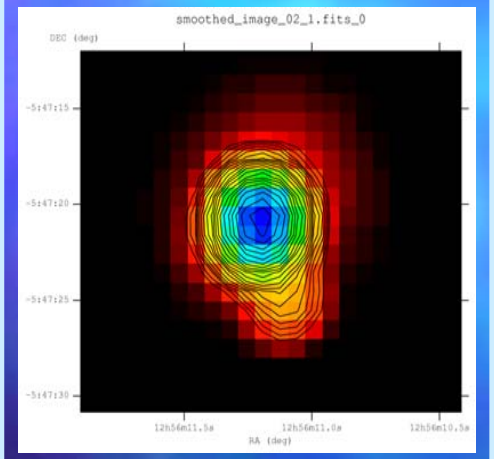


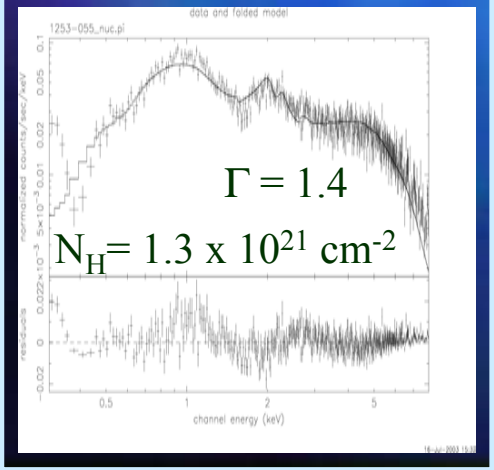
Kadler et al. 2003, A&A, submitted

Another Type 1 Object: 1253-055 (3C279)

Homan et al. (2003)

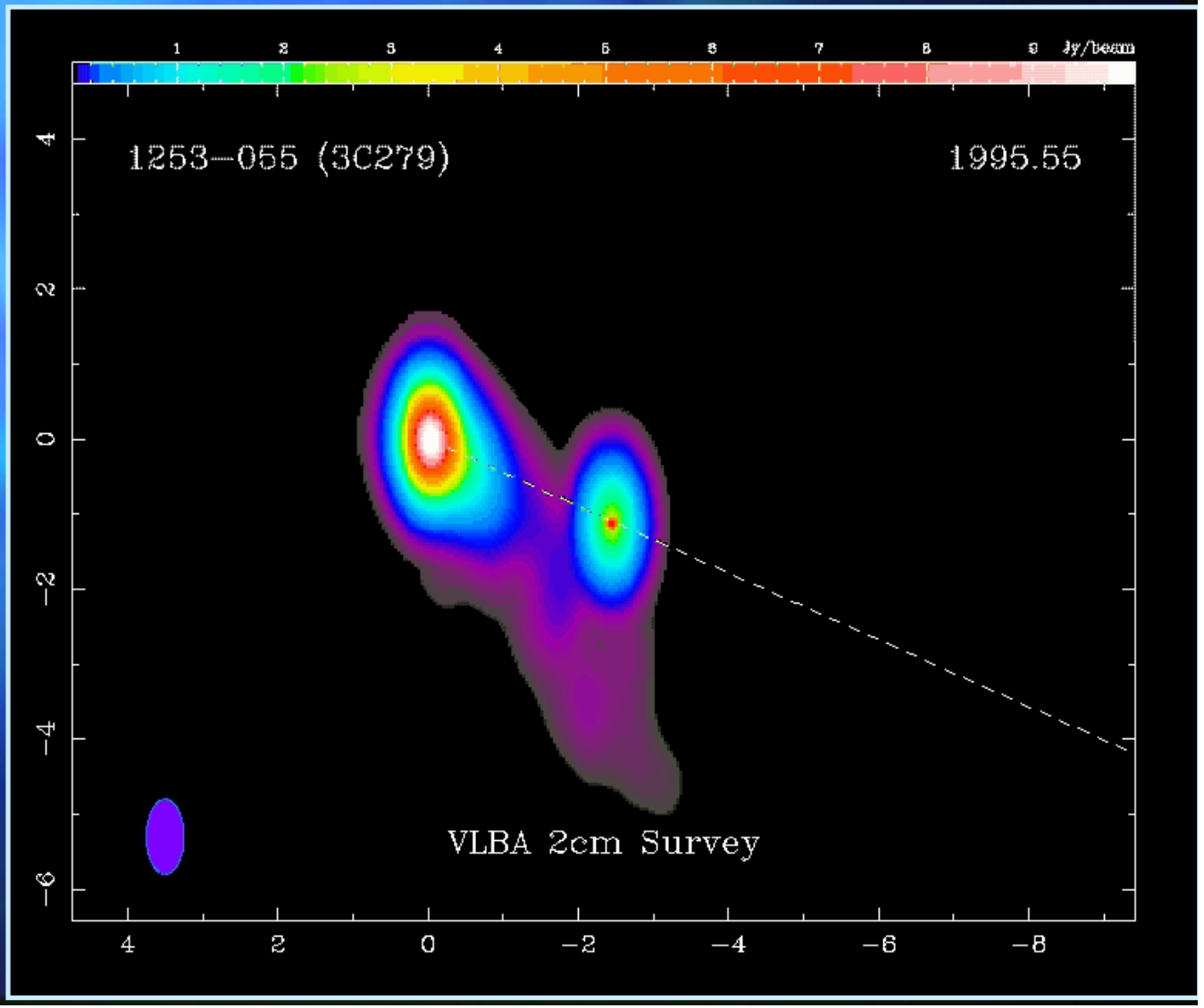
CHANDRA

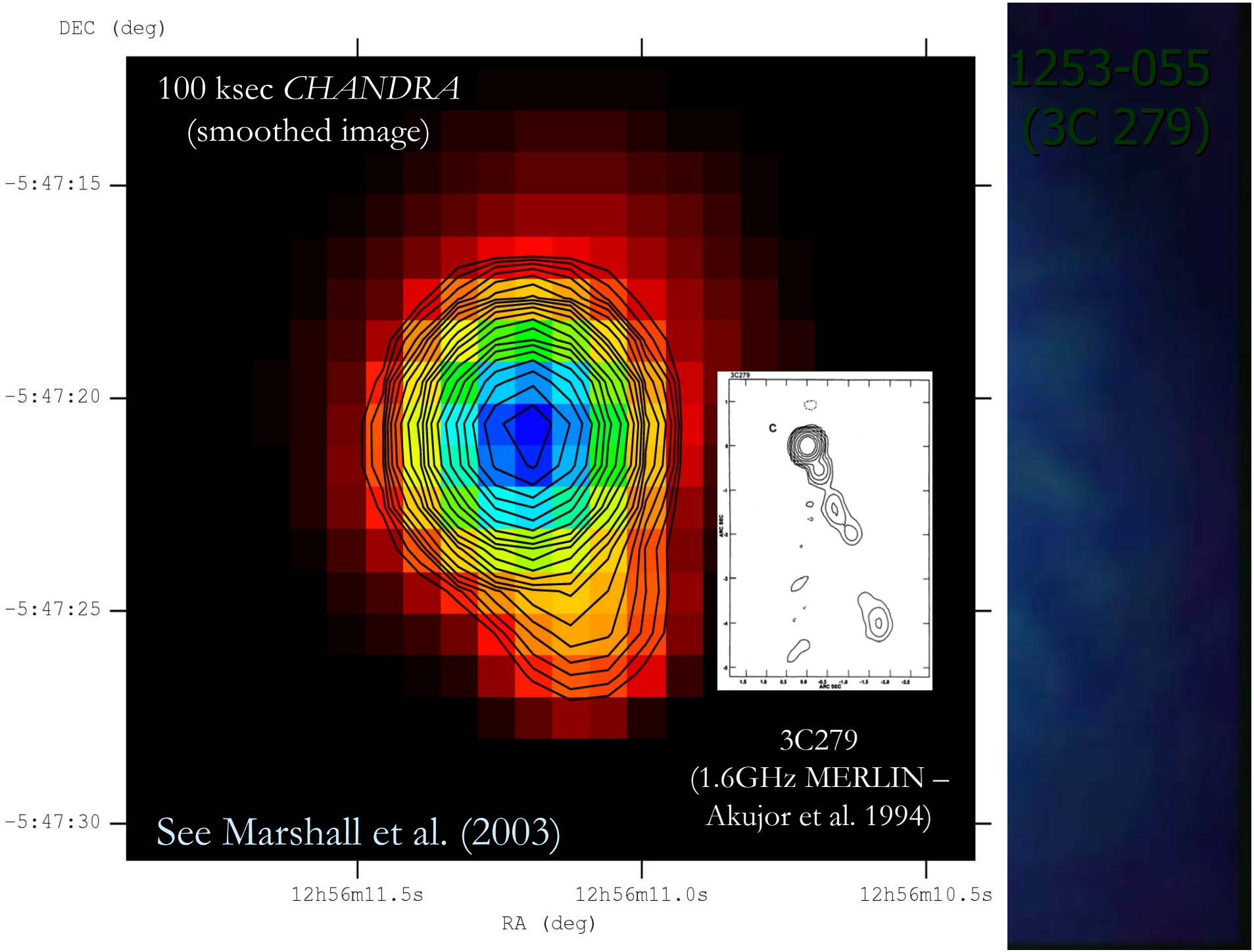




$\Gamma = 1.4$

$N_H = 1.3 \times 10^{21}$ cm^{-2}

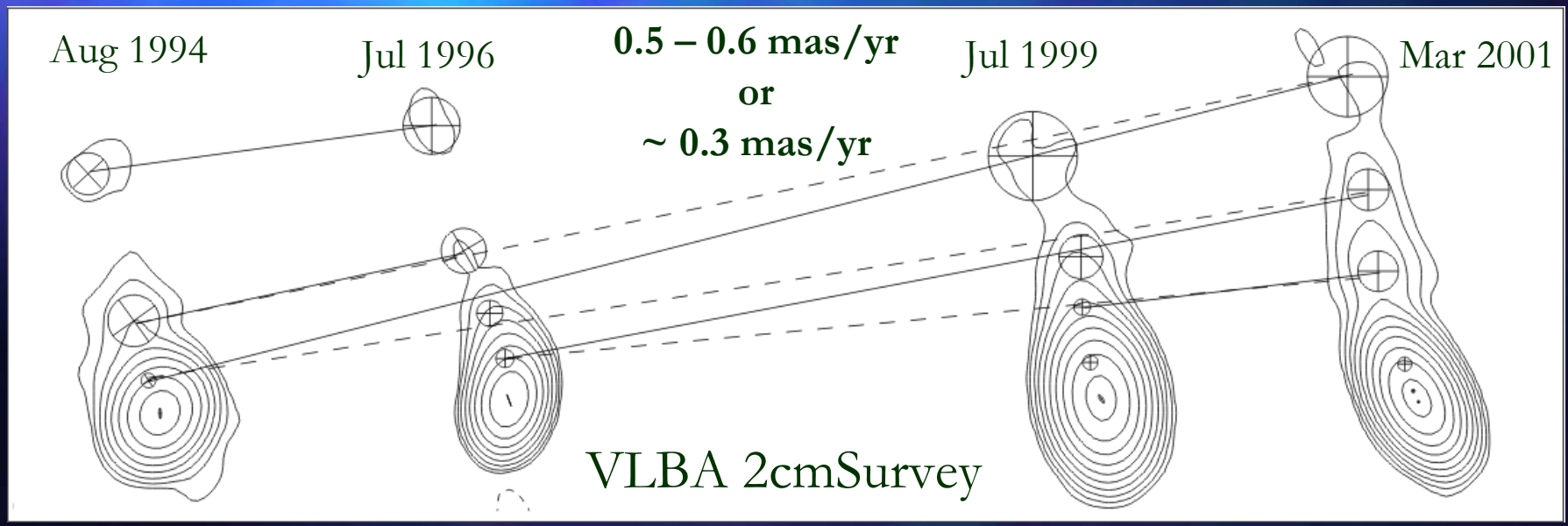



DEC (deg)
-5:47:15
-5:47:20
-5:47:25
-5:47:30
12h56m11.5s
12h56m11.0s
12h56m10.5s
RA (deg)
100 ksec CHANDRA
(smoothed image)
3C279
(1.6GHz MERLIN –
Akujor et al. 1994)
See Marshall et al. (2003)
1253-055
(3C 279)

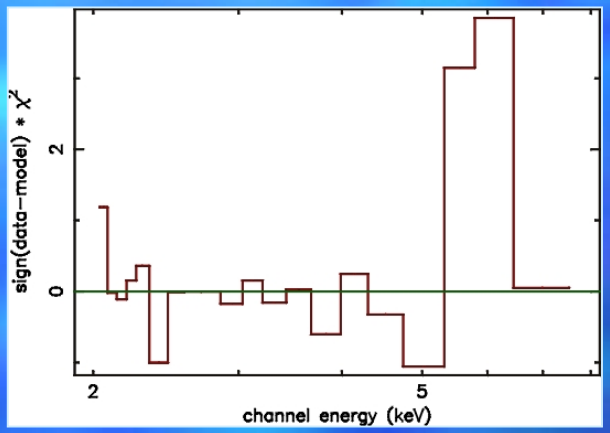
0716+714 – A Hard Nut to Crack

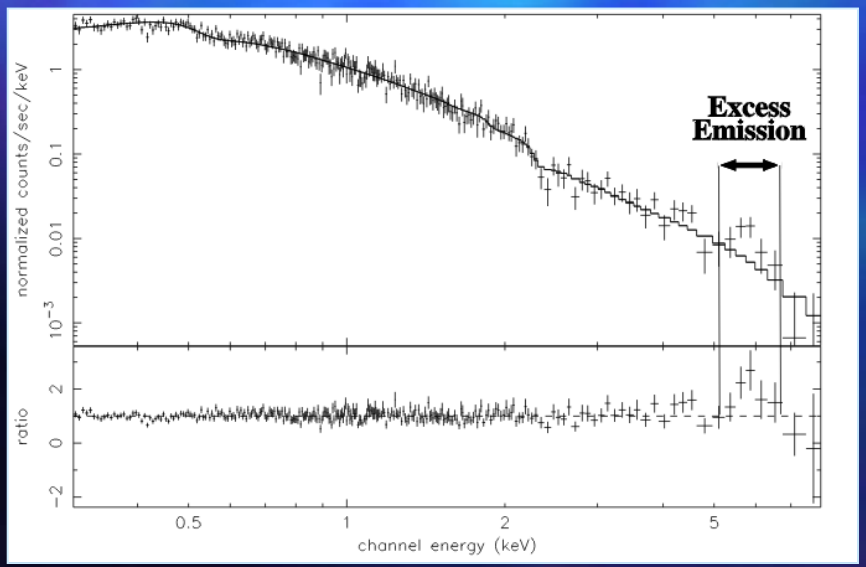
Unclear kinematics:

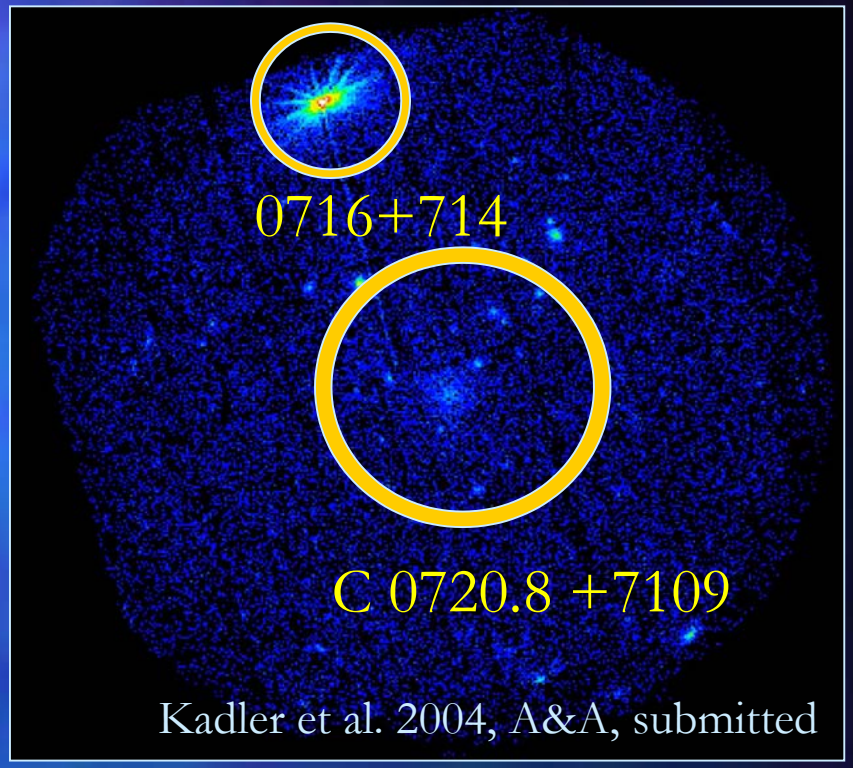
Witzel et al. (1988), Gabuzda et al. (1998):	Subluminal source
Jorstad et al. (2001):	0.9-1.2 mas/yr
Bach et al. (2003):	0.3-0.9 mas/yr



0716+714







Kadler et al. 2004, A&A, submitted

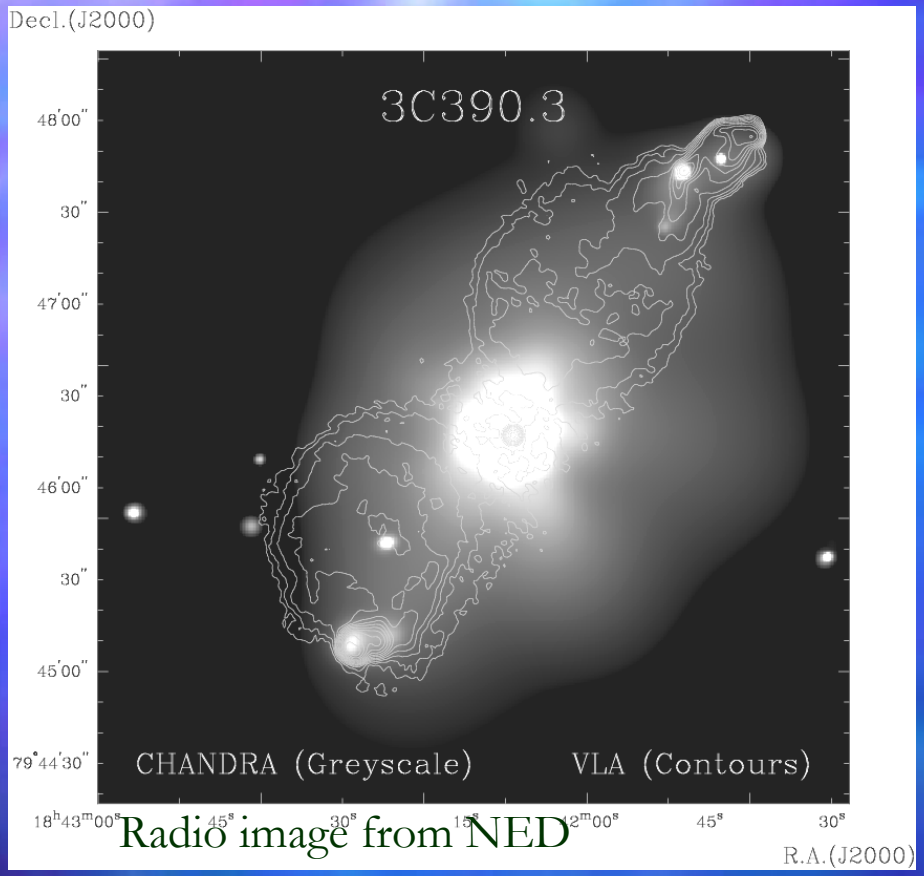
- 3 *XMM* epochs:
- Two distinct spectral components (synchrotron, IC)
- First direct distance measurement using the iron line: z = 0.1 ?

  (Wagner et al. 1996 estimated z > 0.3)

Outline of the Talk

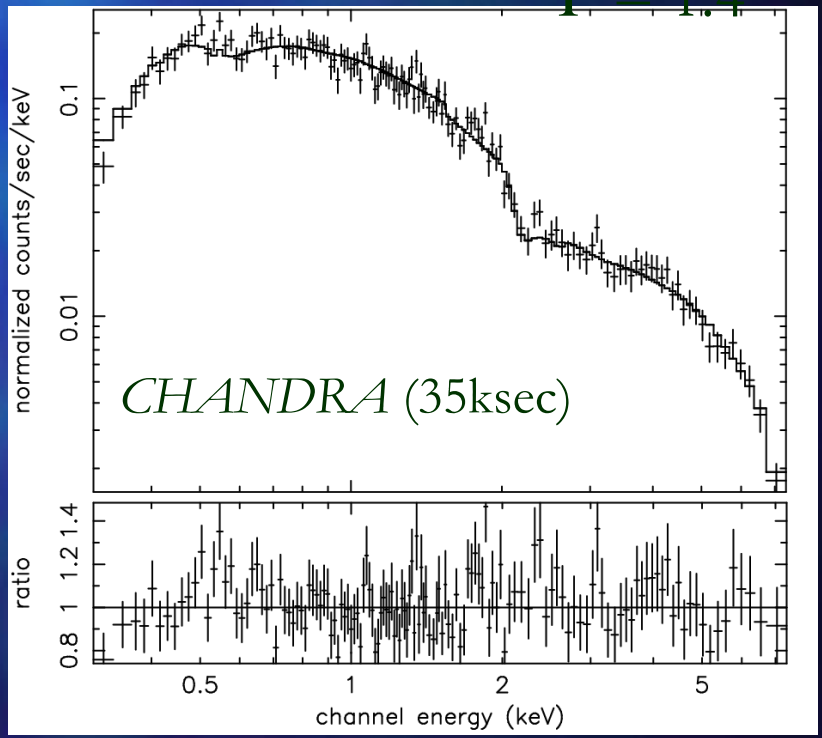
- Combined VLBI and X-Ray Observations of AGN:
  - ✓ An X-Ray Spectral Survey of Core-Dominated Radio-Loud AGNs
  - ✓ The 2cm-X-Sample
- NGC1052: Jet-Disk Coupling in an Active Galaxy
  - ✓ Radio observations
  - ✓ X-ray observations
  - ✓ Combining VLBI and X-ray spectroscopy
  - ✓ Implications

Another radio-loud candidate: 3C390.3



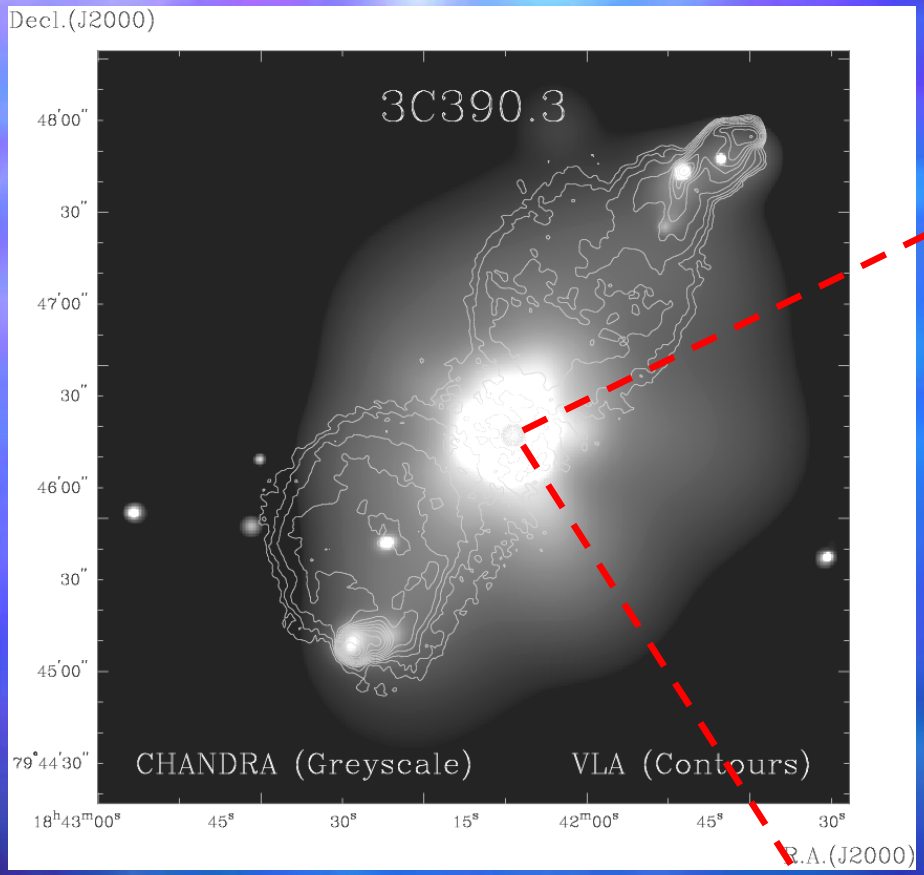
Radio image from NED

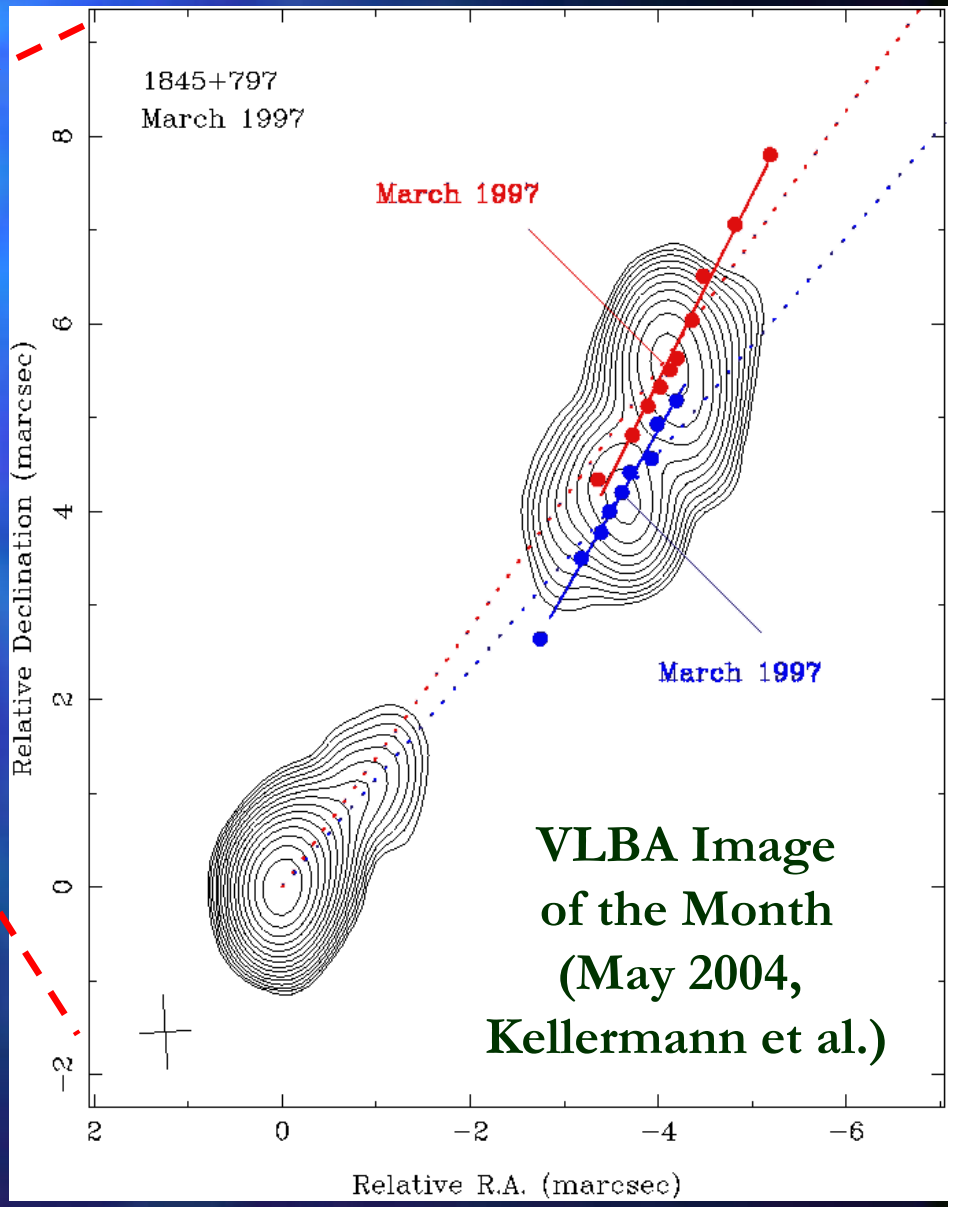
- Broad line radio galaxy at $z = 0.057$
- Sambruna et al. (1999) report a broad iron line



- No broad iron line visible with *CHANDRA*
- Complex extended structure discloses different emission mechanisms at work

3C390.3





VLBA Image of the Month (May 2004, Kellermann et al.)

- Non-ballistic motions on milliarcsecond scales seen in the 2cmSurvey monitoring