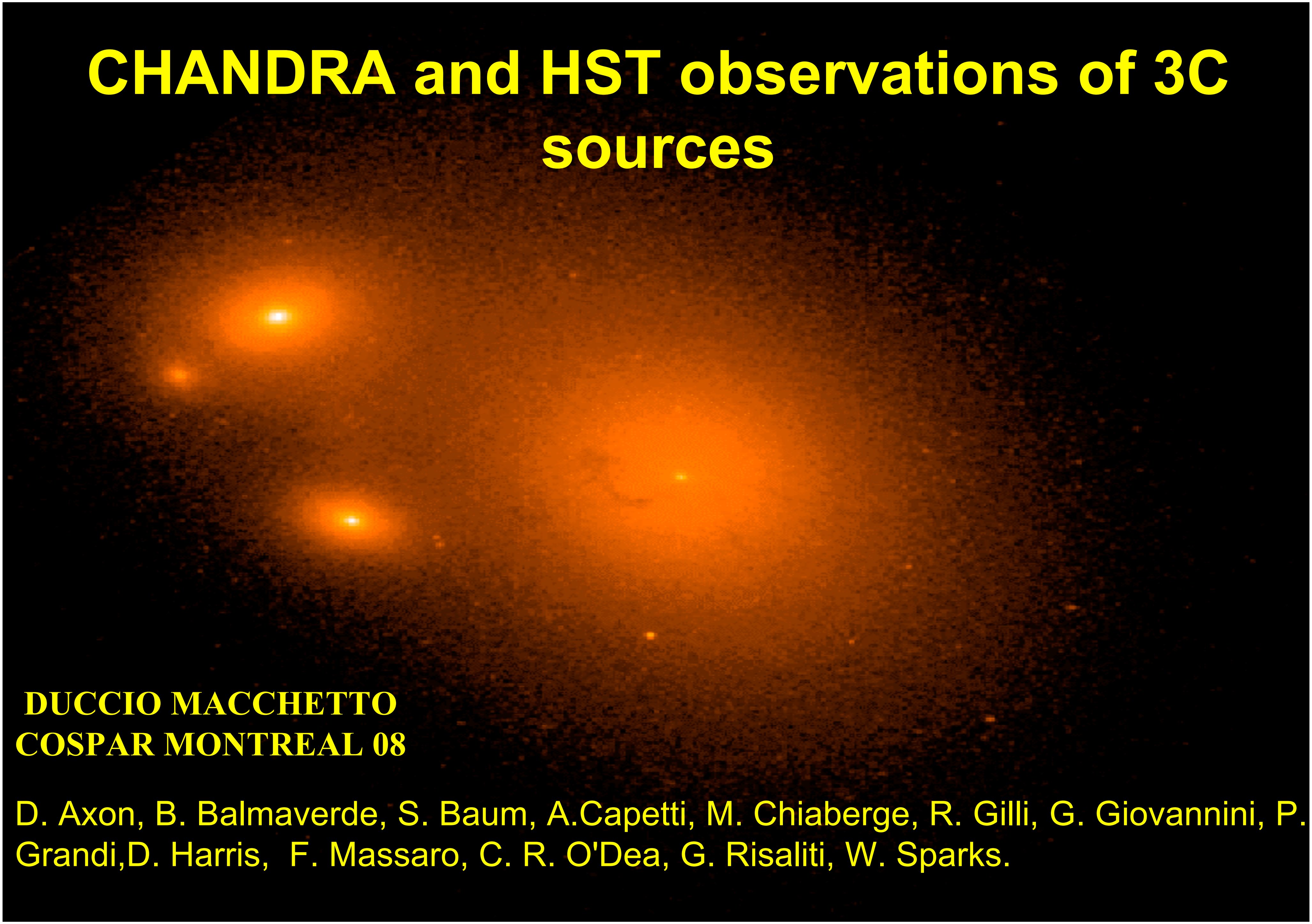
CHANDRA and HST observations of 3C sources

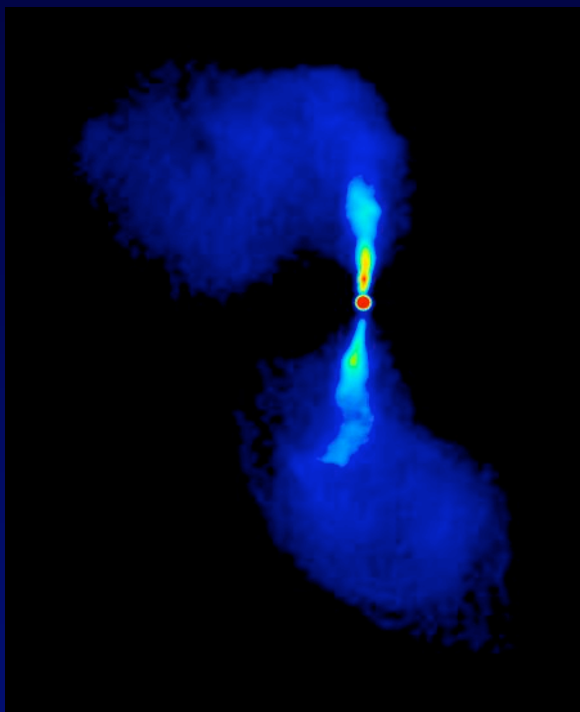


DUCCIO MACCHETTO
COSPAR MONTREAL 08

D. Axon, B. Balmaverde, S. Baum, A.Capetti, M. Chiaberge, R. Gilli, G. Giovannini, P. Grandi,D. Harris, F. Massaro, C. R. O'Dea, G. Risaliti, W. Sparks.

MORPHOLOGICAL CLASSIFICATION OF RADIO GALAXIES

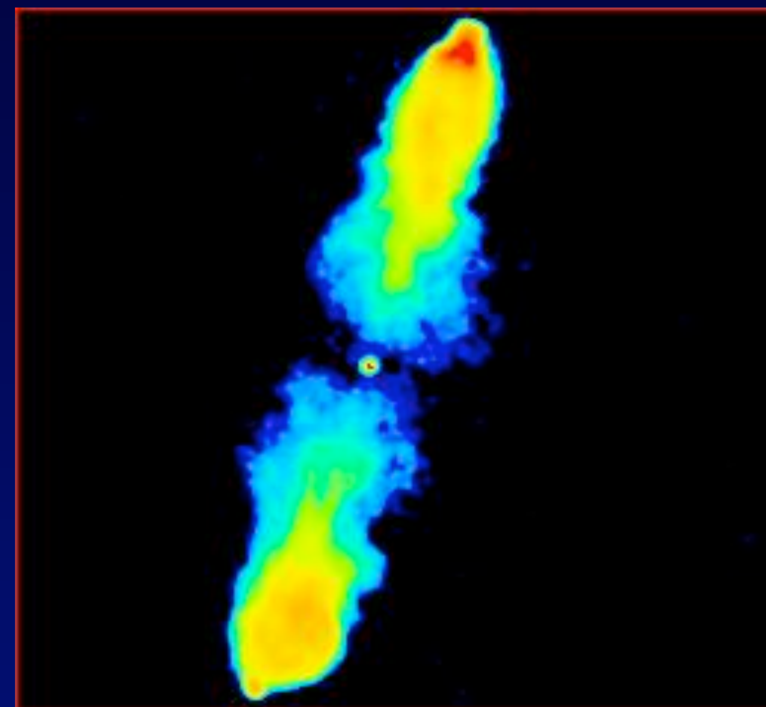
FR I



LOW POWER

$L_{178} \sim< 2 \times 10^{26}$ W Hz^{-1}

FR II



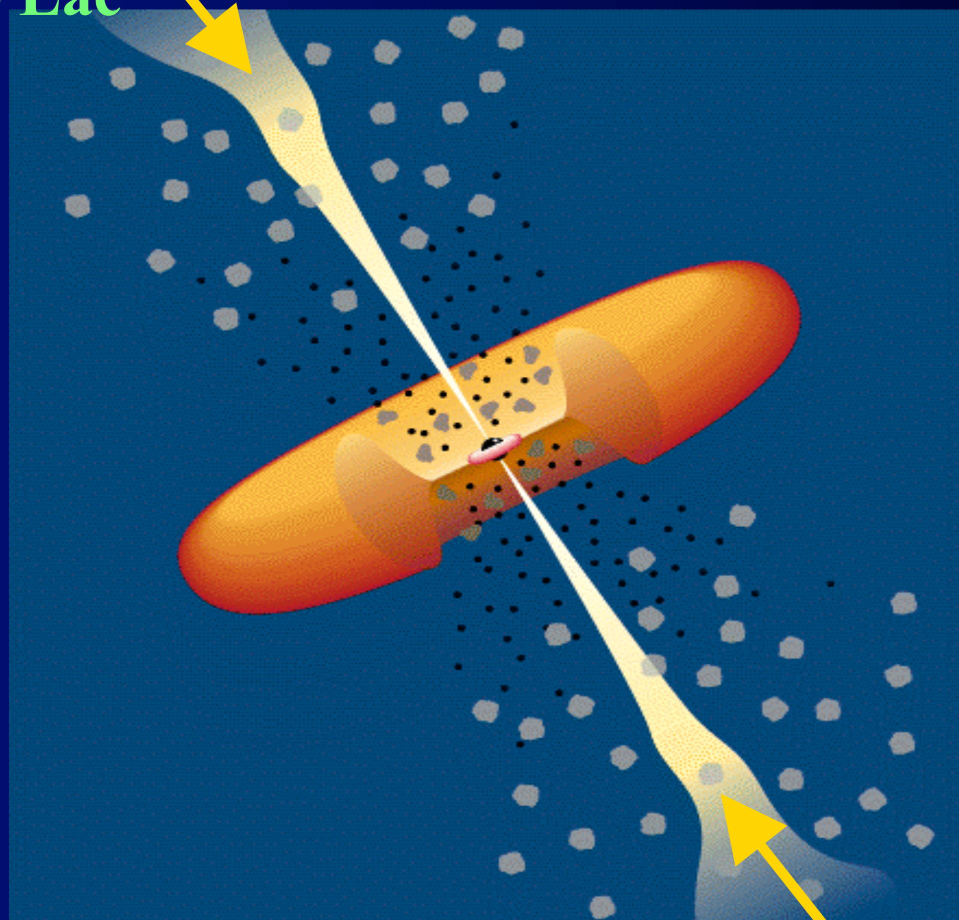
HIGH POWER

$L_{178} >\sim 2 \times 10^{26}$ W Hz^{-1}

Fanaroff & Riley 1974

The radio-loud AGN unification model

BL Lac



FR I

FR II

NLRG

LEG

HEG

BLRG & SSRQ

FSRQ

LOW POWER

$L_{178} \sim< 2 \times 10^{26}$ W Hz $^{-1}$

HIGH POWER

$L_{178} >\sim 2 \times 10^{26}$ W Hz $^{-1}$

Urry & Padovani 1995

KEY QUESTIONS

- What are the properties of the central engines of radio galaxies?
- Are **FR I** and **FR II** intrinsically different?
- What is the relationship between their X-ray, optical and radio properties?
- What is the accretion rate around the central BH?
- What is the role of the different "flavours" of radio galaxies in the framework of **AGN** unification schemes?

3CR catalog as a basis for HST and Chandra studies

- Best studied sample of radio of radio-loud galaxies in existence of radio-loud galaxies in existence
- Its selection criteria are unbiased for optical or X-ray observations
- It spans a wide range in redshift and radio power
- There is a vast suite of ground and spaced based observations for comparison at all accessible wavelengths and we are adding to it!

3CR catalog as a basis for HST and Chandra studies

- During the last few years we have carried-out snapshot surveys of (almost!) the complete sample of 3CR sources using HST in red, blue and ultraviolet continuum, emission-line imaging and optical spectroscopy.

- We are currently completing an additional survey in the near infrared (H-band) with HST/NICMOS

3CR catalog as a basis for HST and Chandra studies

- We have also obtained
  - deep ground based infrared K-band imaging
  - VLA radio imaging and optical spectroscopy of the small fraction of the sample for which high quality data are not yet available and
  - VLBA data for all the objects with z < 0:1

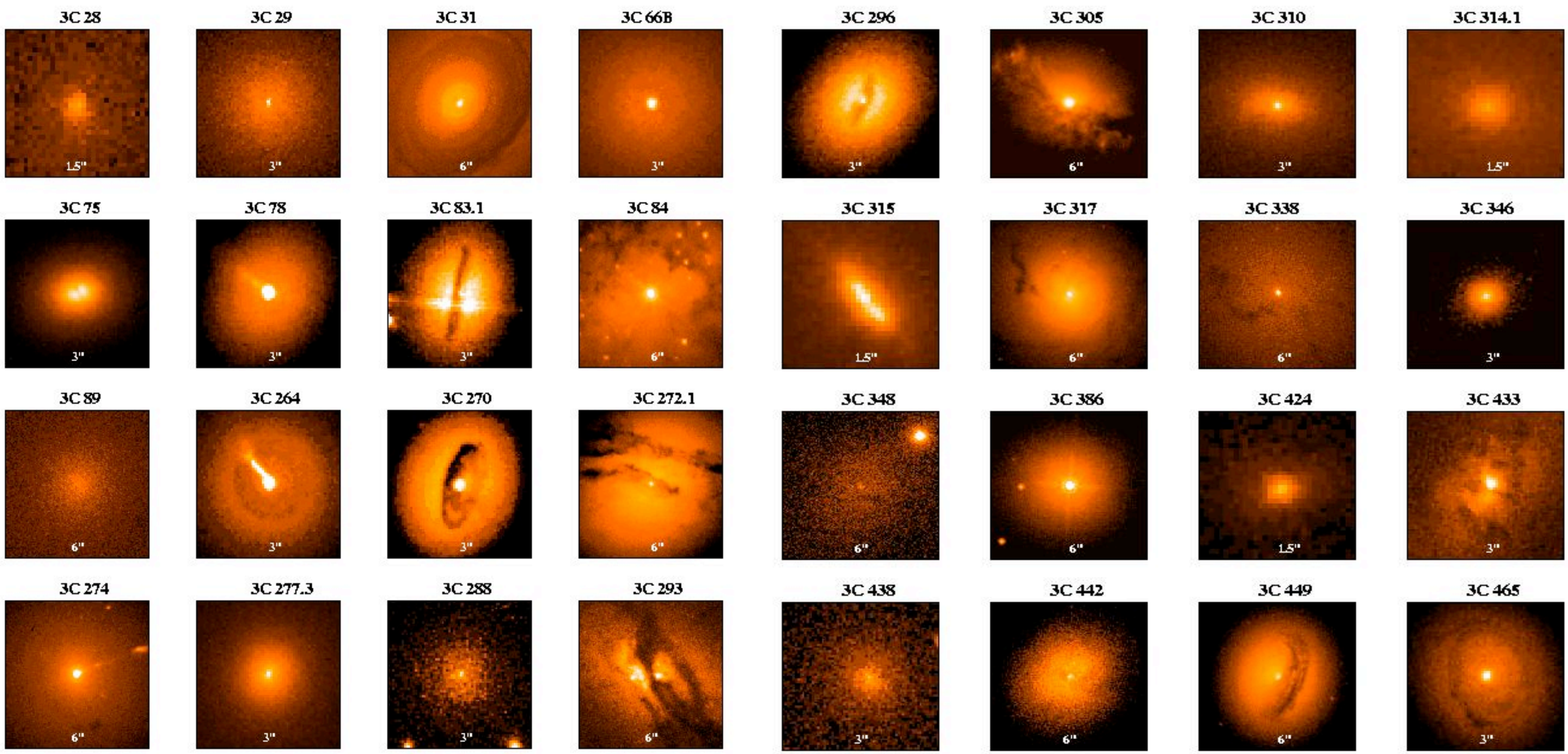
NEED FOR HST DATA

- To study the nuclei of radio galaxies in the optical at the highest possible resolution
- To disentangle the nuclear source from the host galaxy stellar component
- To correlate the optical and radio properties
- **To test the radio loud AGN unification scheme**

FRI OF THE 3CR CATALOG

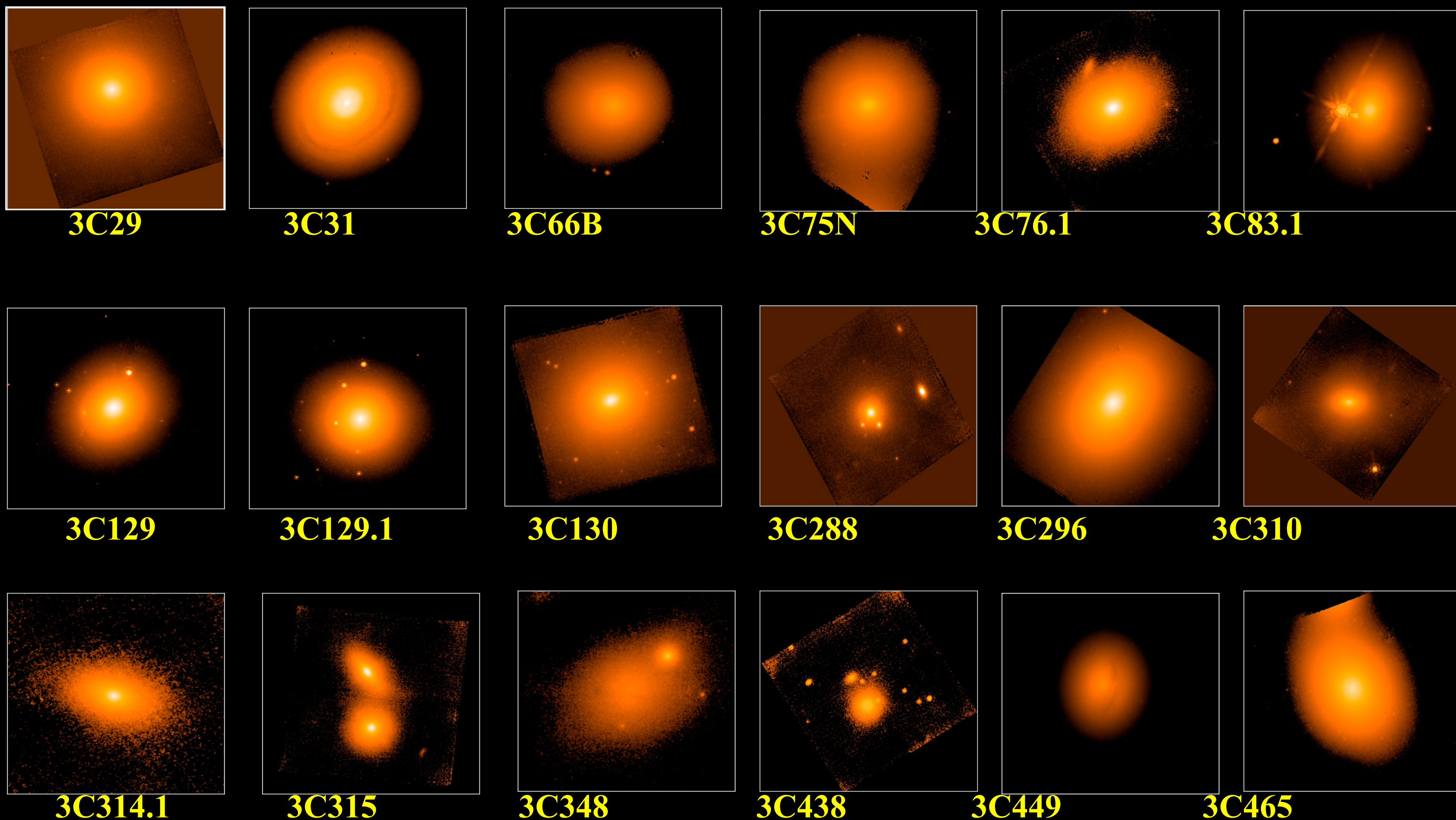
The HST/WFPC2 snapshot survey of 3CR radio sources (Sparks et al)

Complete sample: all of the FRI of the 3CR catalogue
33 objects, 32 with HST R-band observations



Chiaberge, Capetti & Celotti

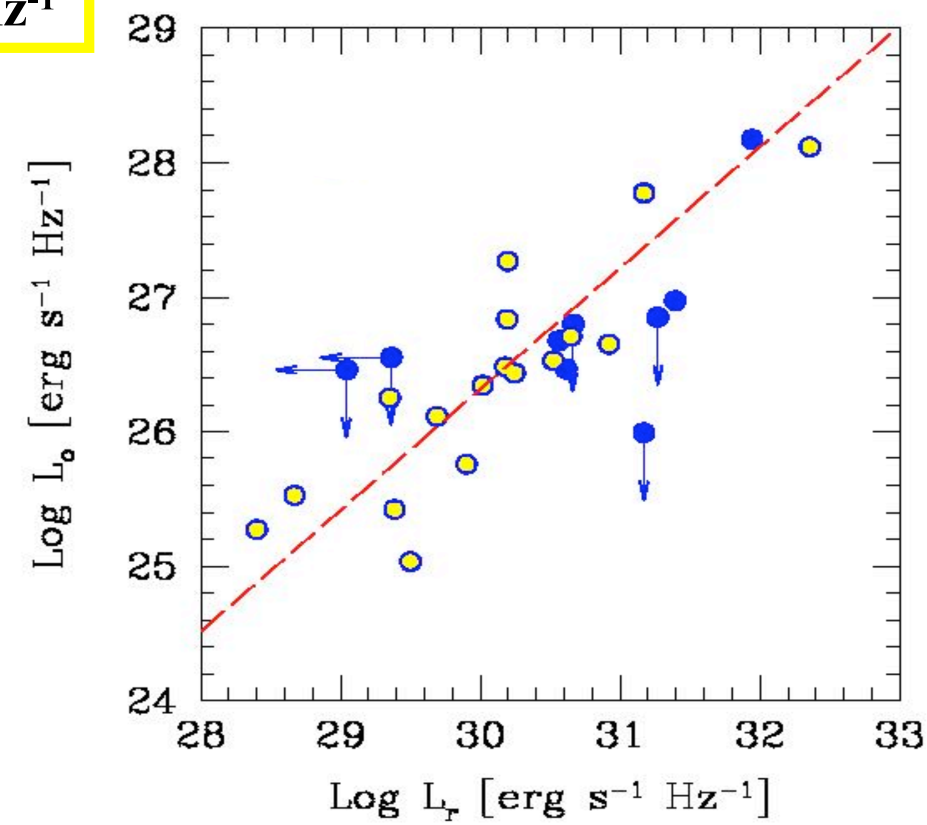
HST/NICMOS Snapshots of 3CR Radio Galaxies
FR-I



THE OPTICAL - RADIO CORE CORRELATION

$L_{178} < 2 \times 10^{26}$ W Hz^{-1}

$z < 0.1$



$L_{178} > 2 \times 10^{26}$ W Hz^{-1}

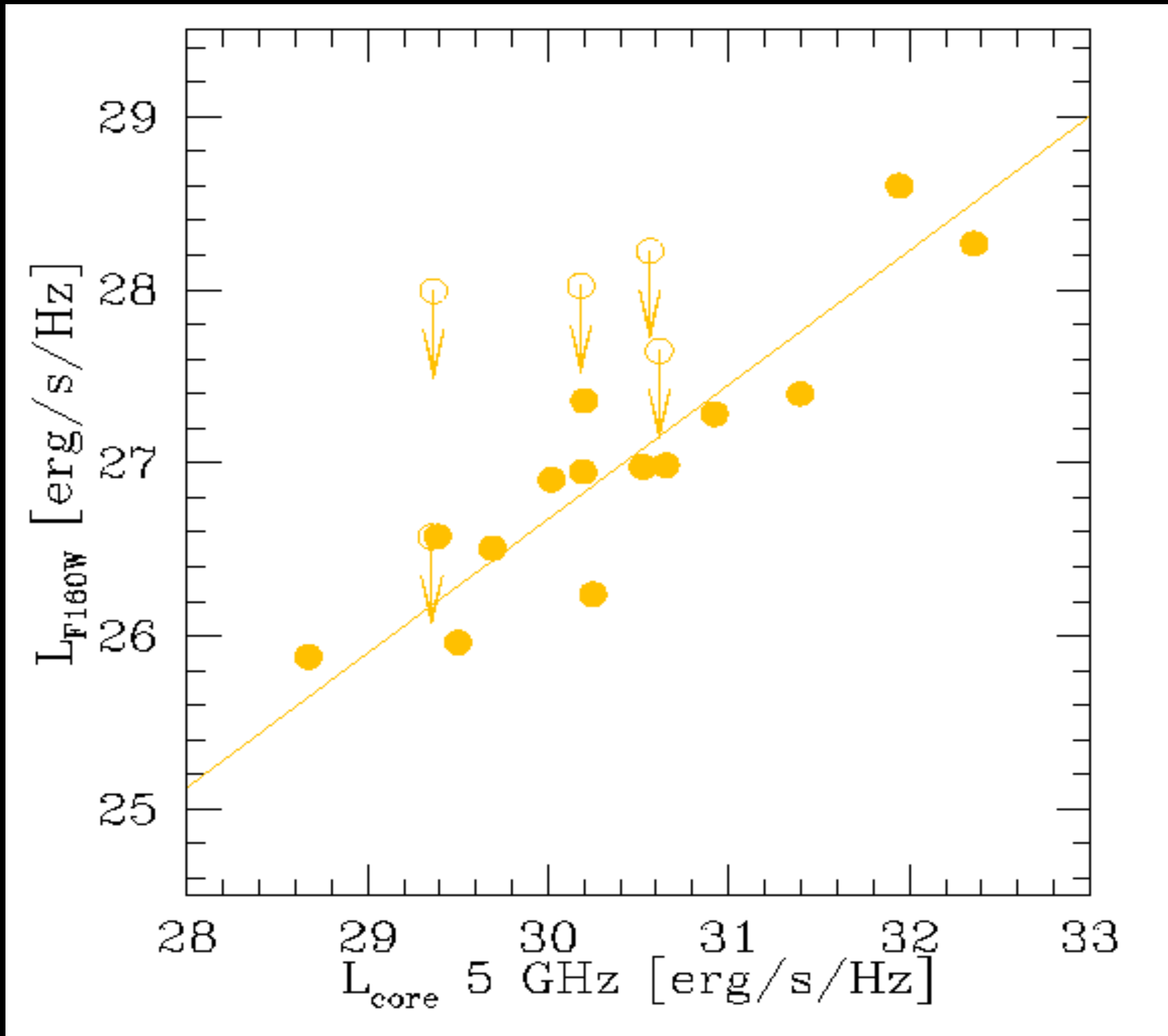
$0.1 < z < 0.3$

THE CORRELATION IS LINEAR

Chiaberge, Capetti & Celotti 1999

$\alpha_{r-o} = 0.6 - 0.9$

NIR - RADIO CORE CORRELATION



Baldi et al. in prep.

No IR (thermal) excess

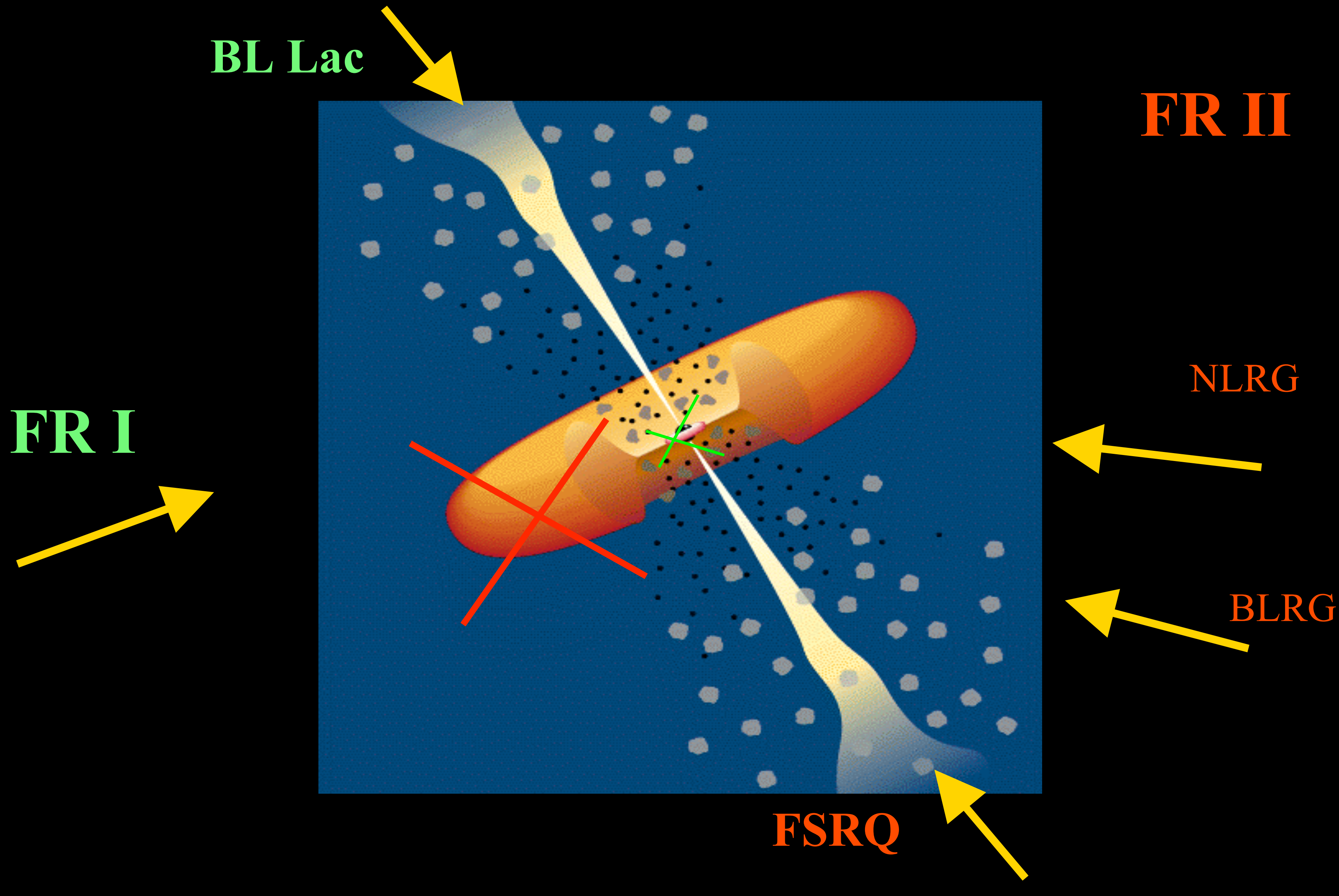
FR I results

- High core emission detection rate: 85%
- NO thick TORI in FRI $h/r < 0.15$
- NO obscuration
- NO BLR
- Optical emission is synchrotron emission from the inner jet
- The optical cores are the optical counterparts of radio cores
- CCC are upper limits to any thermal component
  - $L_{CCC} < 10^{-4}-10^{-7}\ L_{Edd}$ ($M_{BH} = 10^{8}\ M_{sun}$)

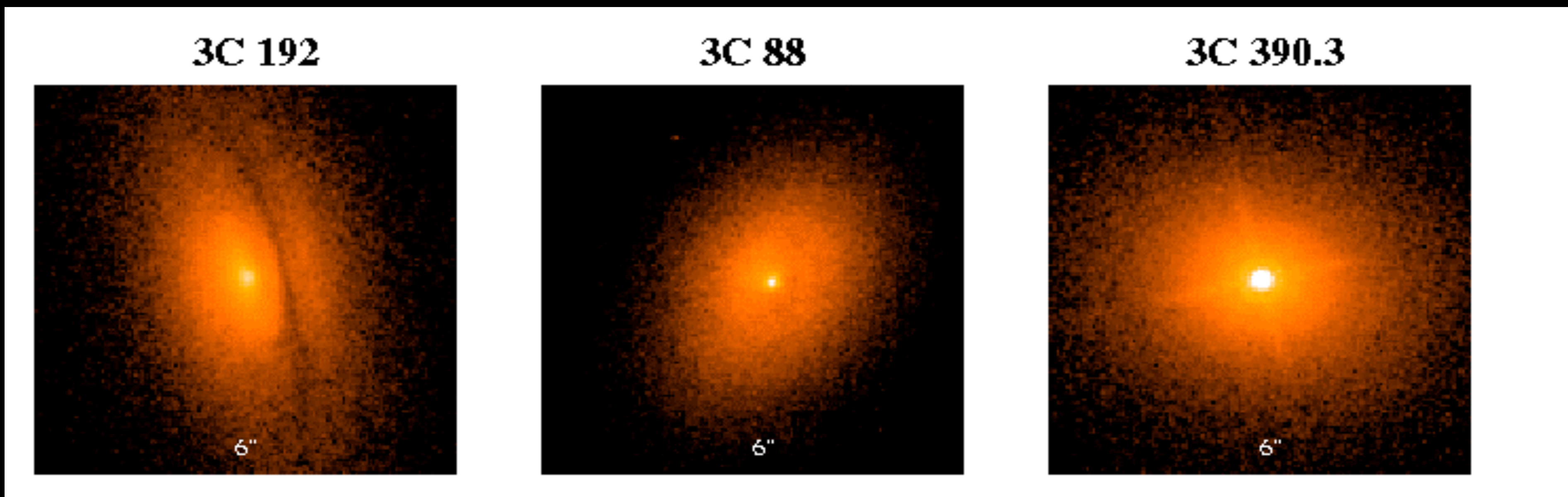
- ***Optical/radio correlation implies that most FRI's nuclei are jet dominated !***

The radio-loud AGN unification model

What do we expect to observe in FR II ?

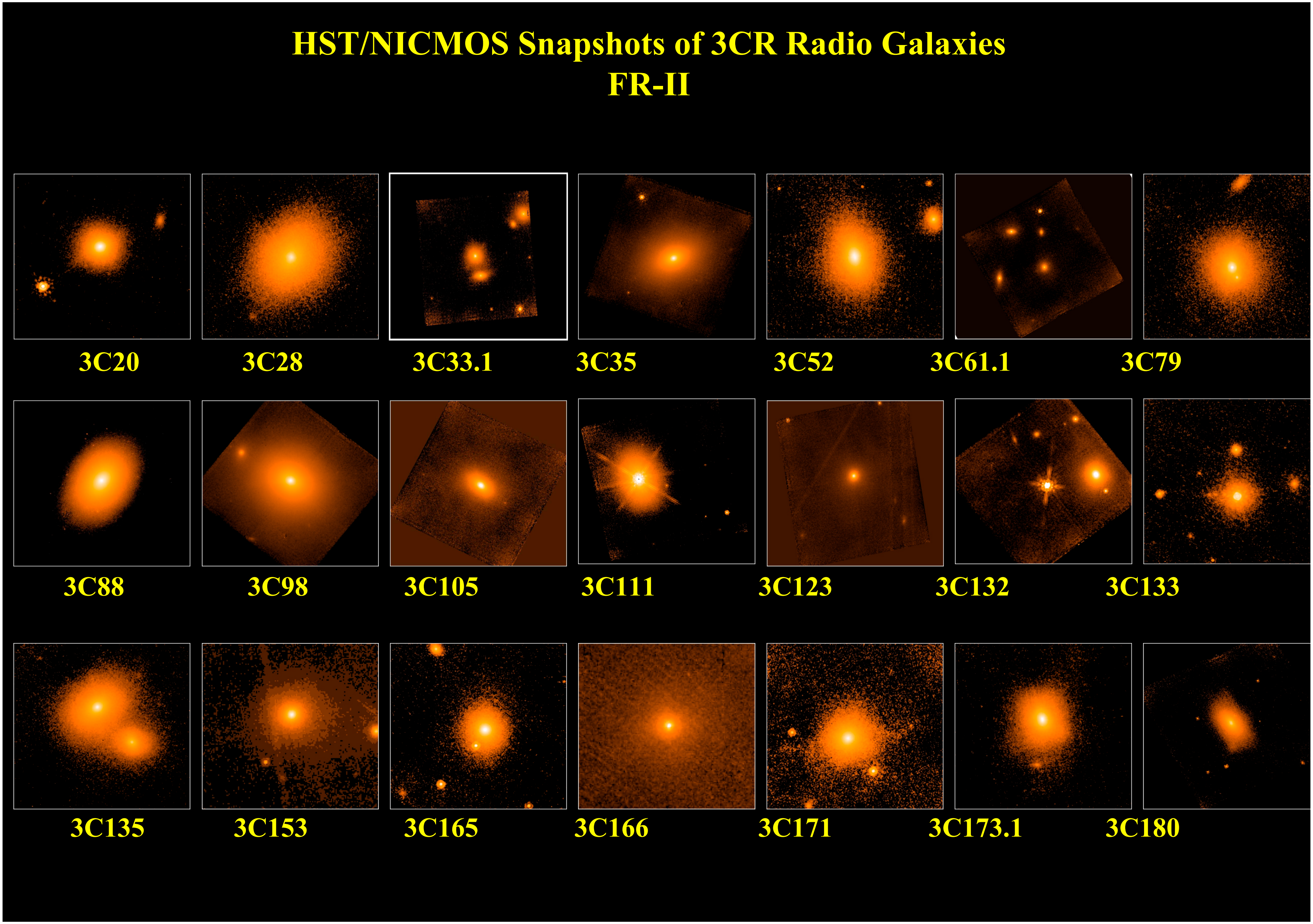


HST OBSERVATIONS OF FR II NUCLEI



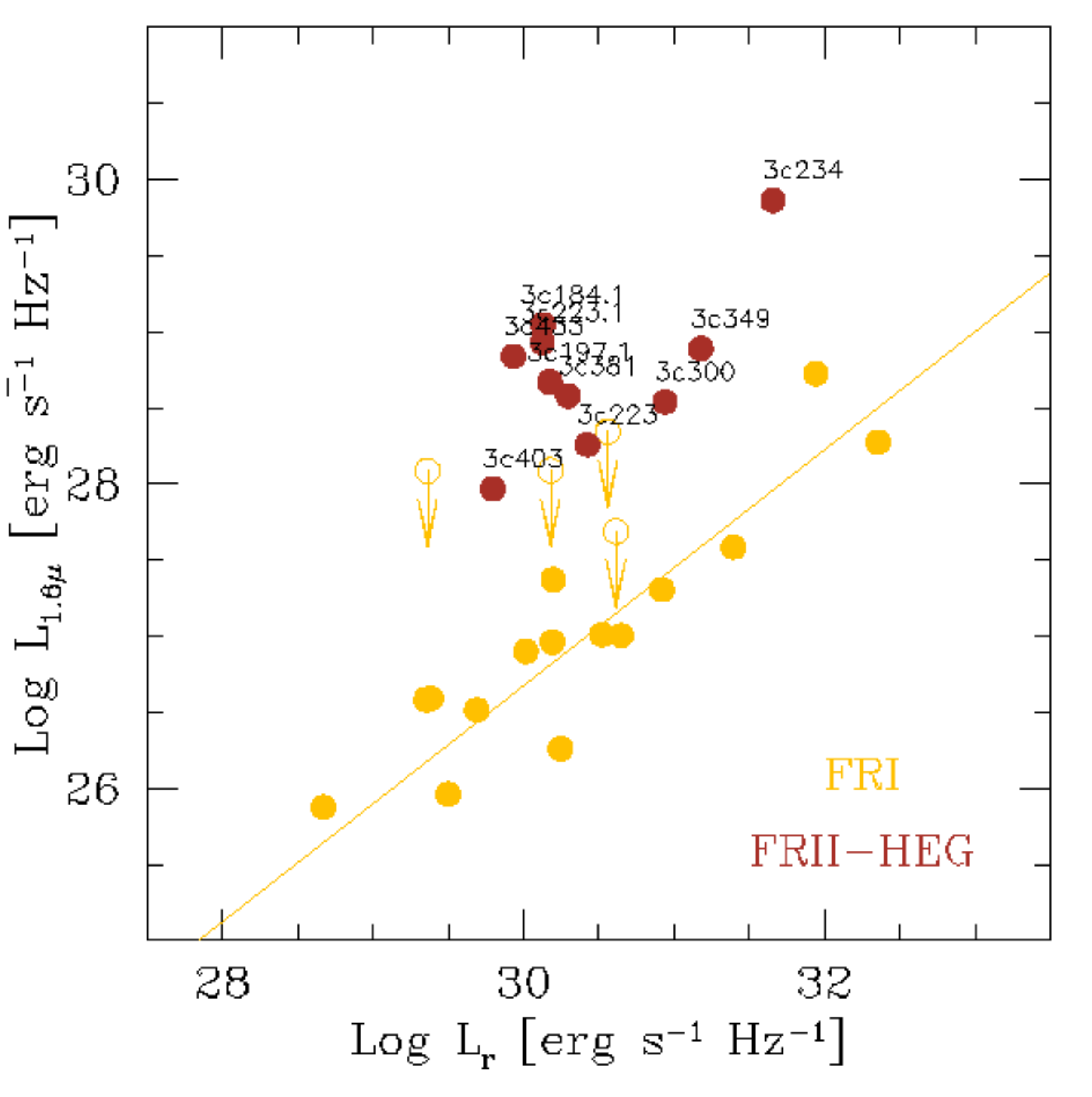
NLRG BLRG

OBSCURED FAINT BRIGHT


HST/NICMOS Snapshots of 3CR Radio Galaxies
FR-II
3C20
3C28
3C33.1
3C35
3C52
3C61.1
3C79
3C88
3C98
3C105
3C111
3C123
3C132
3C133
3C135
3C153
3C165
3C166
3C171
3C173.1
3C180

THE NIR - RADIO CORE CORRELATION

FRII SHOW IR EXCESS
-THERMAL CONTRIBUTION???



Baldi et al. in prep.

NEED FOR CHANDRA DATA

- The completeness of X-ray data lags behind
- Only < 25% of the complete sample had been observed by modern X-ray satellites such as Chandra or XMM
- We are observing the complete sample of the 3CR sources, out to a limiting redshift of $z < 0.3$
- The redshift limit is imposed to take advantage of the highest spatial resolution Chandra

KEY QUESTIONS

- What is the relation between fueling, accretion disk structure and the launching of jets?
- With radio and optical data, we found two very different manifestations of nuclear emission
- Radiatively efficient accretion disk co-exist with sources in which non-thermal radiation processes constitute the bulk of the radiative losses (Chiaberge et al. 1999, A&A 349, 77; Chiaberge et al. 2002, ApJ 571, 247).
- Are there two fundamentally different launching mechanisms at work? NEED X-ray data!

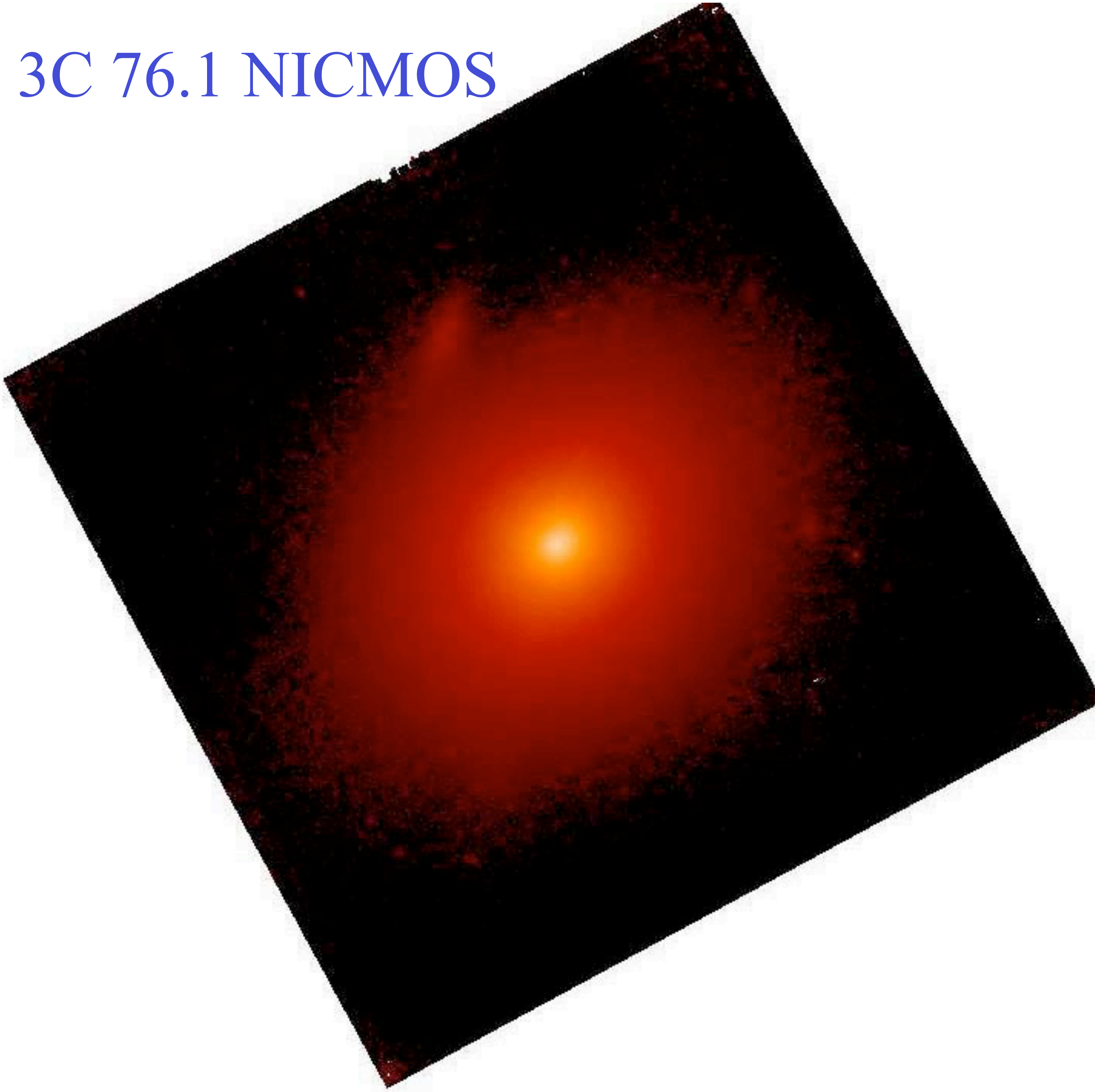
PRELIMINARY RESULTS

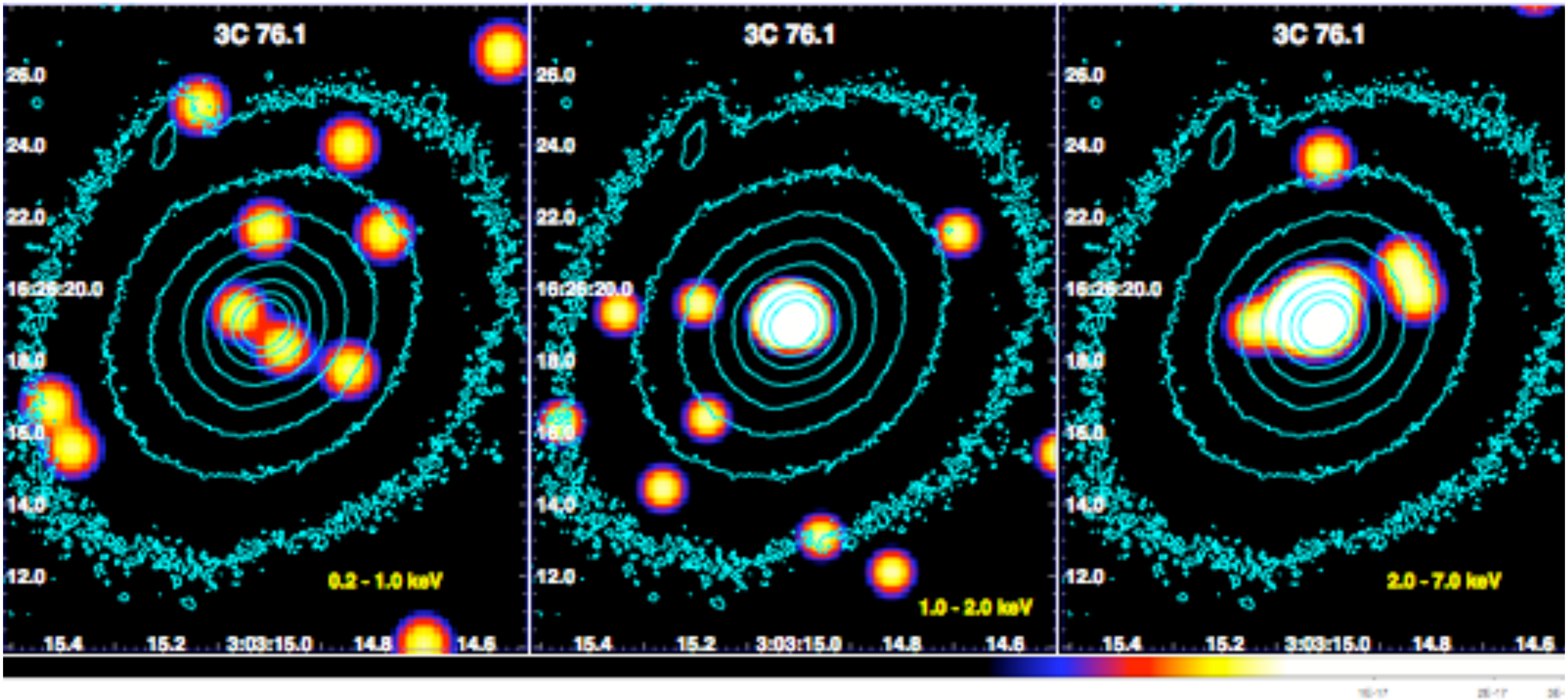
- Observed 28 of 30 sources so far
- Detected X ray emission in most sources; except 3C135 and 3C 315
- Examples of all types of sources:
  - nuclear emission,
  - extra-nuclear emission from jets, hot-spots
  - extended features and diffuse emission

PRELIMINARY RESULTS: NUCLEI

- Nuclear emission detected in most cases, except 3C 135 and 3C 315
- X-ray nuclear emission provides a unique view of the processes of accretion at work in these sources
- We can derive the SED of the nuclei.
- We will test the correlations between X-ray nuclei and other properties of our radio sources

3C 76.1 NICMOS

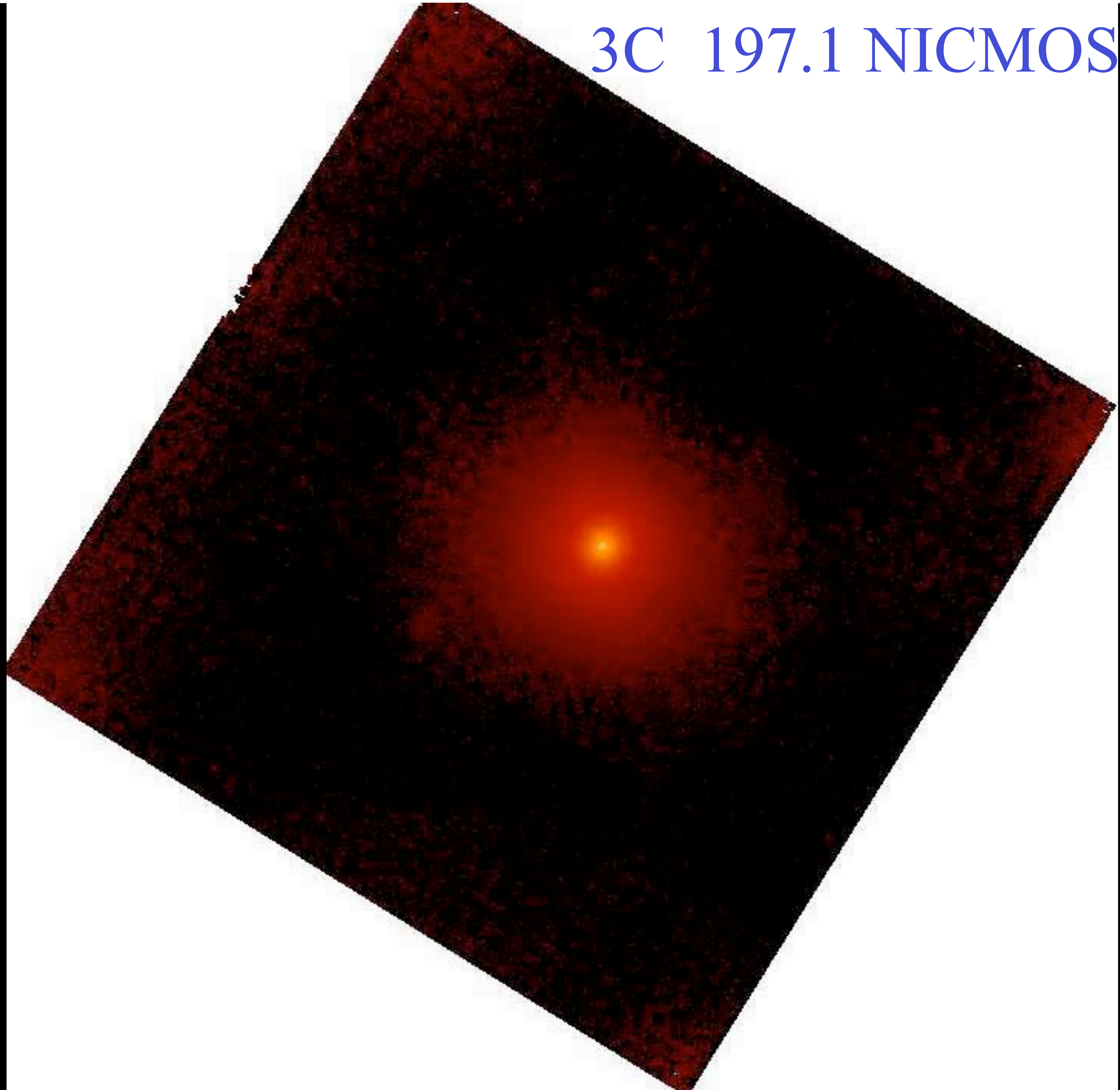


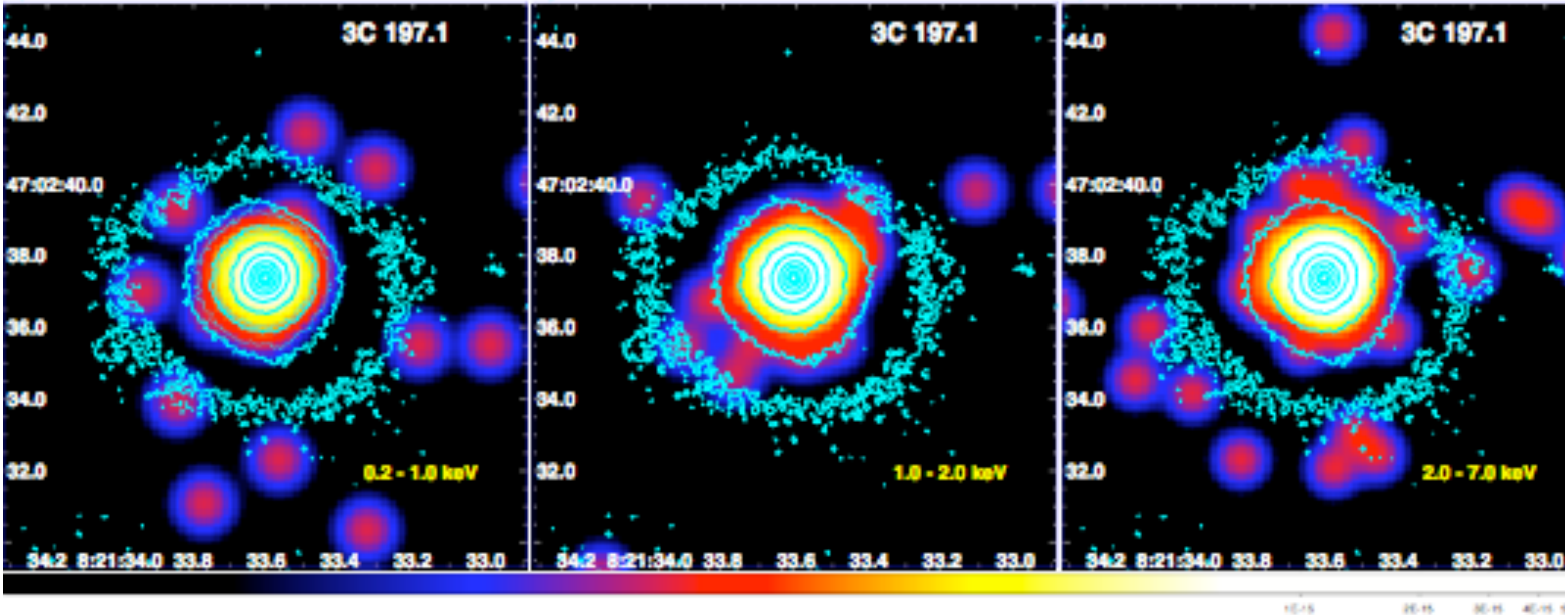


3C 76.1 in three different bands:
soft (0.2-1.0 keV) (left panel), medium (1.0-2.0 keV) (middle panel) and hard (2.0 -7.0 keV) (right panel). HST IR contours are shown in cyan.
No detection of nuclear emission in the soft band,clearly detected in the medium and hard bands; ***intrinsic absorption? or intrinsic hard spectrum????***

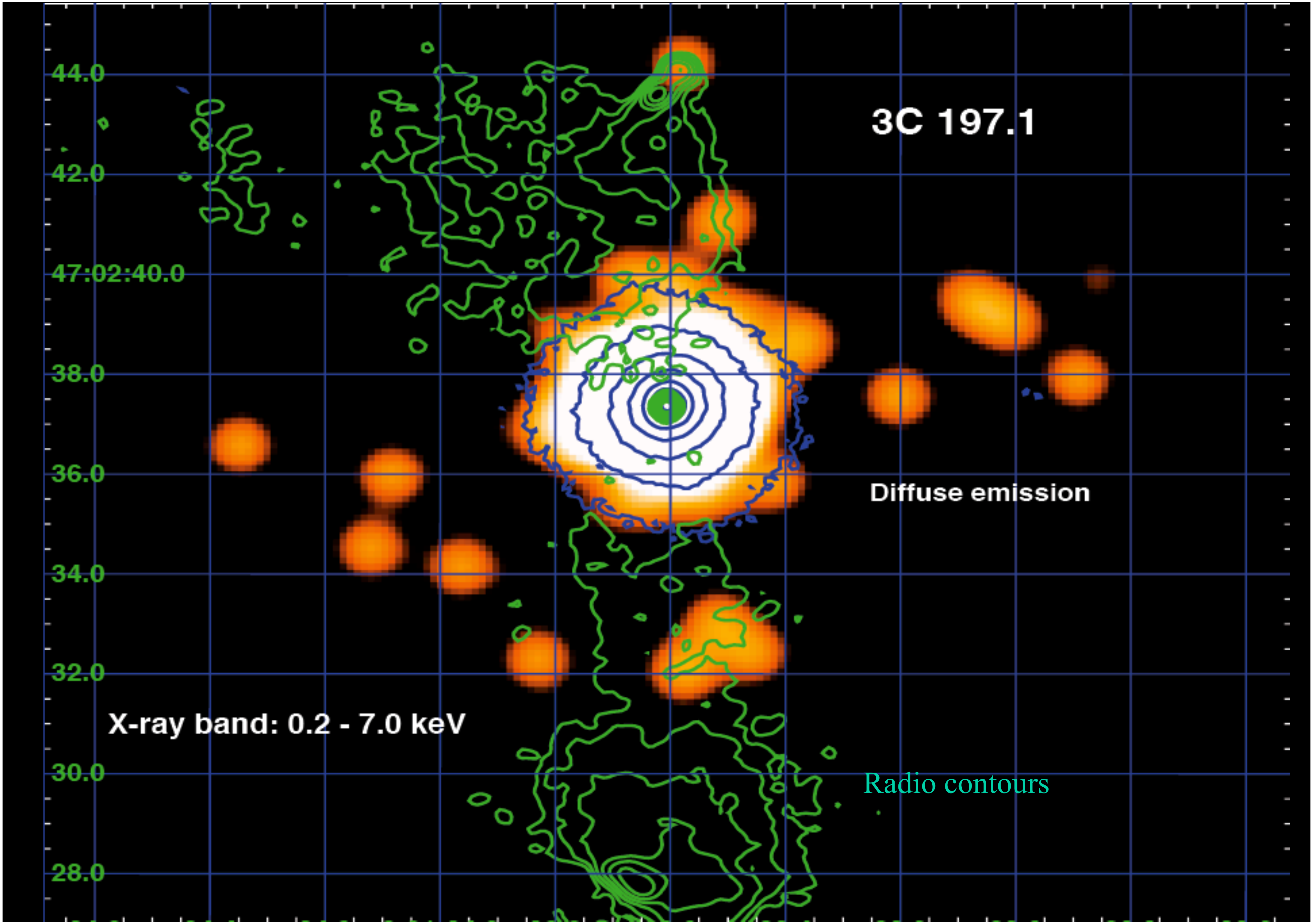
PRELIMINARY RESULTS: DIFFUSE EMISSION

- 3C 197.1
- Compact radio core radius ≤ 0.3" (0.67 kpc)
- X-ray diffuse emission, around this region, extends to about 1.75" (3.9 kpc), similar to the IR radiation shown by the HST data


3C 197.1 NICMOS



3C 197.1 in three different bands:
soft (0.2 -1.0 keV) (left panel), medium (1.0 - 2.0 keV) (middle panel) and hard (2.0- 7.0 keV) (right panel).
HST IR contours are shown in cyan.
The nuclear emission is detectable in all bands.


3C 197.1
44.0
42.0
47:02:40.0
38.0
36.0
34.0
32.0
30.0
28.0
Diffuse emission
X-ray band: 0.2 - 7.0 keV
Radio contours

JETS

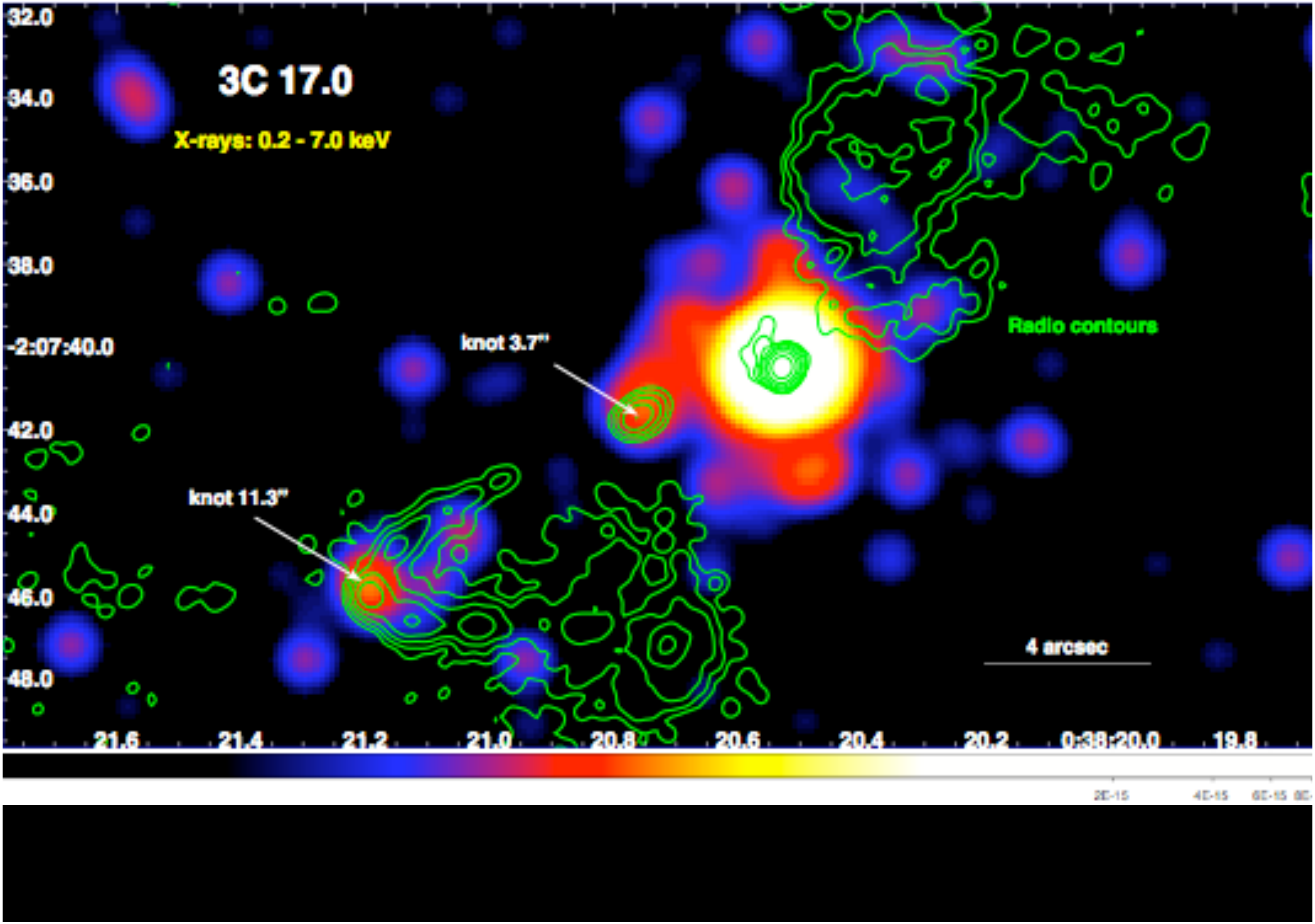
Why and how are jets formed?

- Through the optical emission we can infer the properties of the accretion mechanism
- Through the radio core and extended emission we study the jets properties.

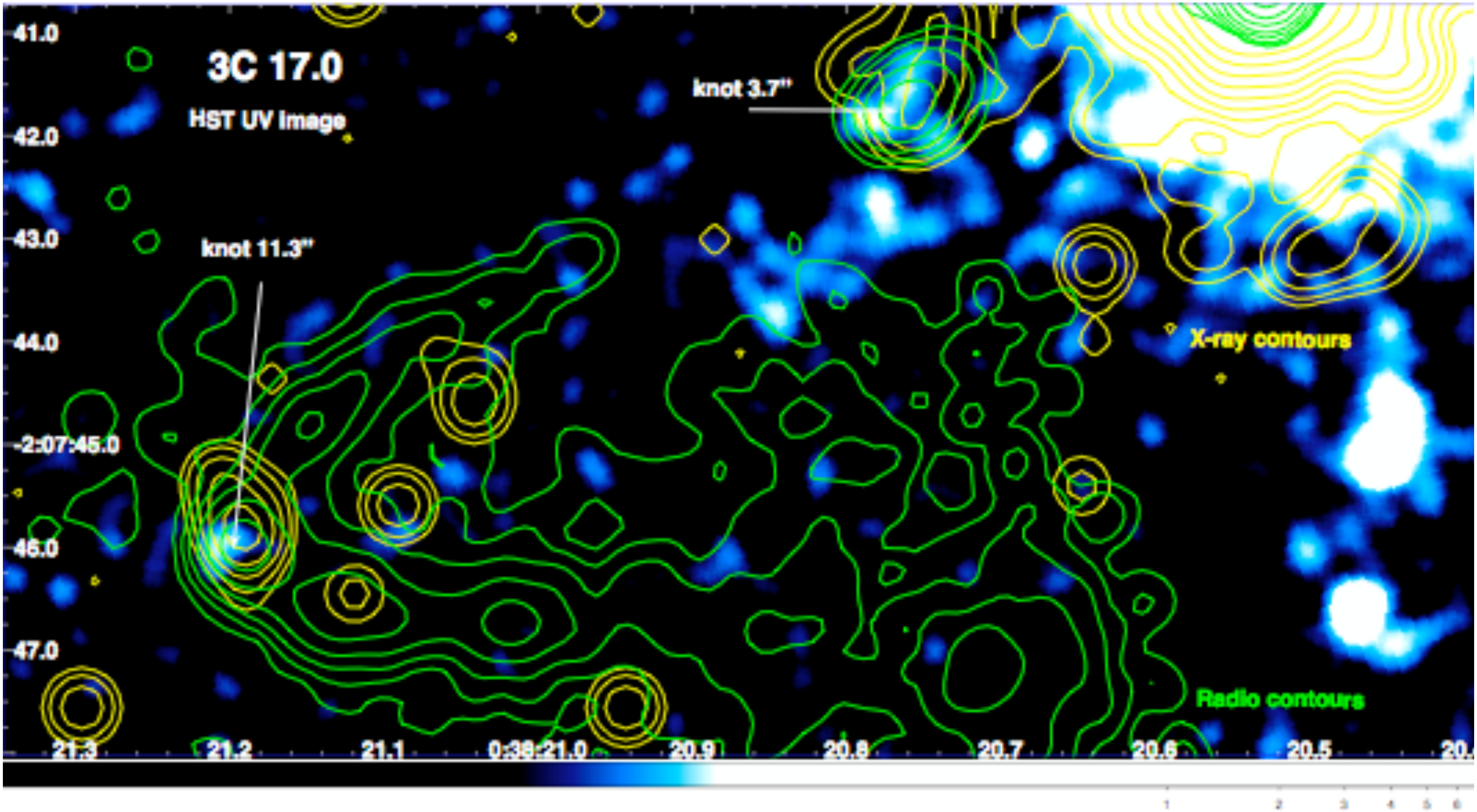
- **Are accretion properties and jets formation related processes or are they independent?**

PRELIMINARY RESULTS: JETS

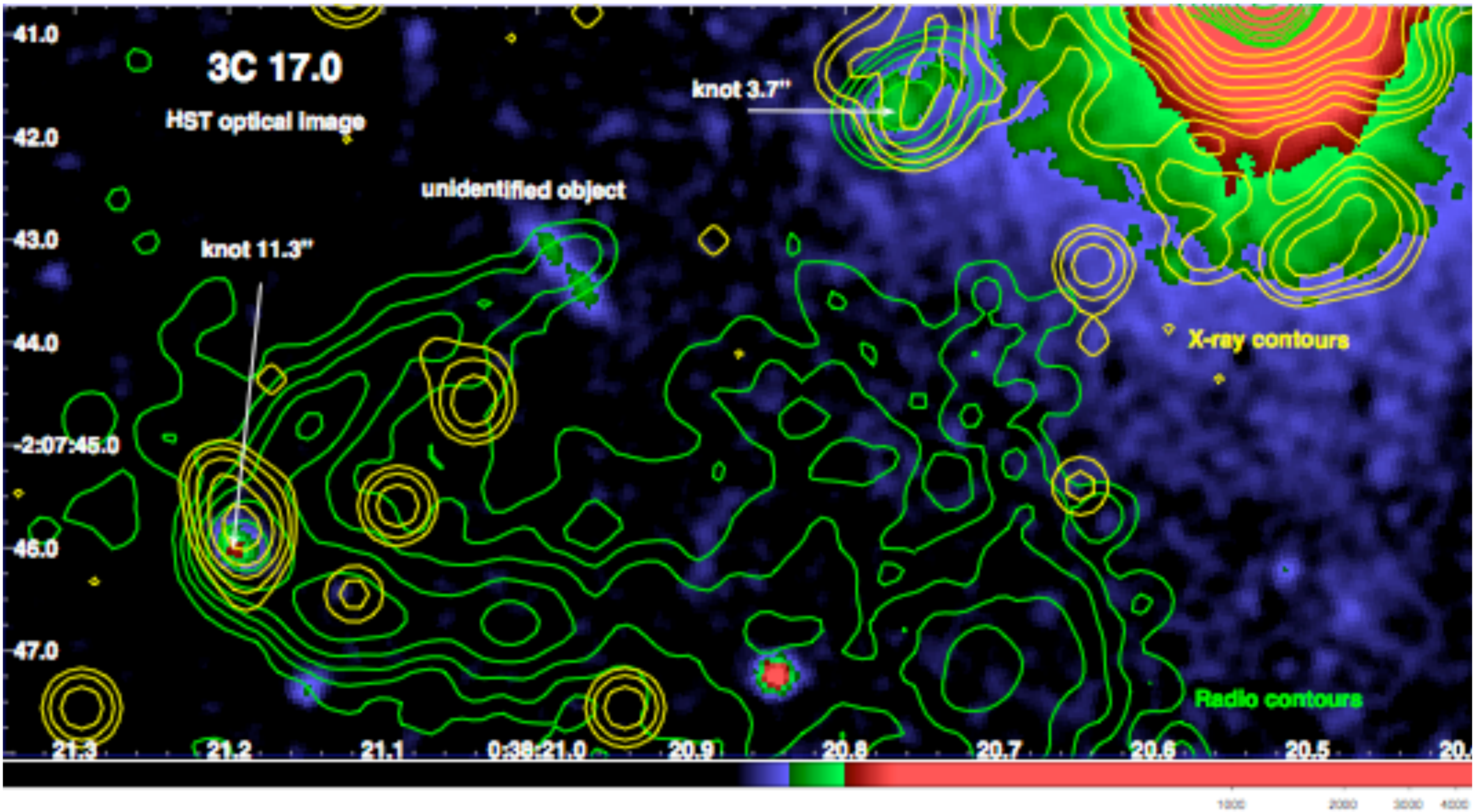
- 3C 17.0
- VLA radio map shows a bent jet (Morganti et al. 1999) in the southeast region
- We found the X-ray counterparts of two radio knots.
  - The first knot ~ 3.7" (12.8 kpc) from the nucleus
  - Second knot ~ 11.4" (39.5 kpc) away

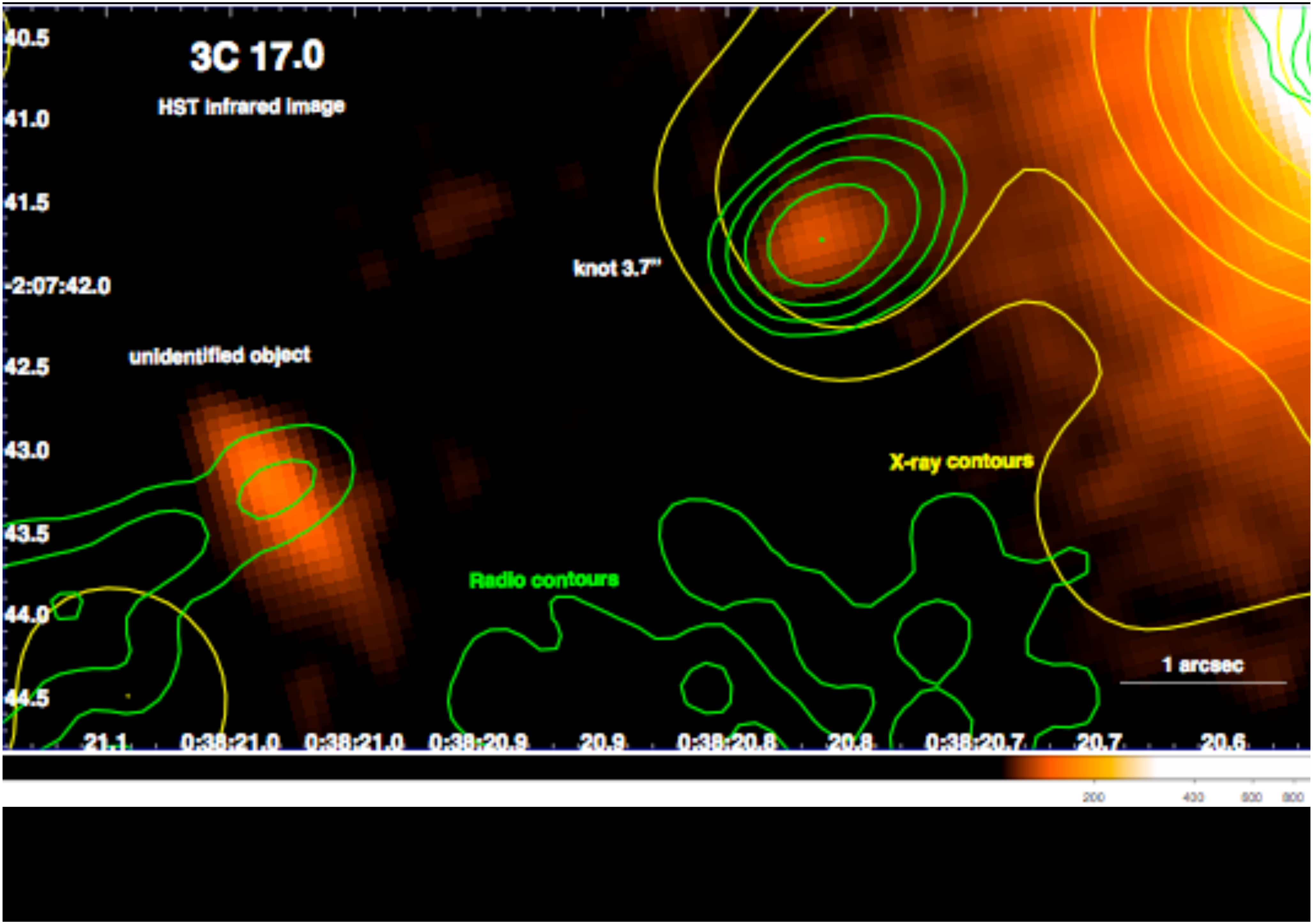


3C 17.0
X-rays: 0.2 - 7.0 keV
Radio contours
knot 3.7"
knot 11.3"
4 arcsec
32.0
34.0
36.0
38.0
-2:07:40.0
42.0
44.0
46.0
48.0
21.6
21.4
21.2
21.0
20.8
20.6
20.4
20.2
0:38:20.0
19.8

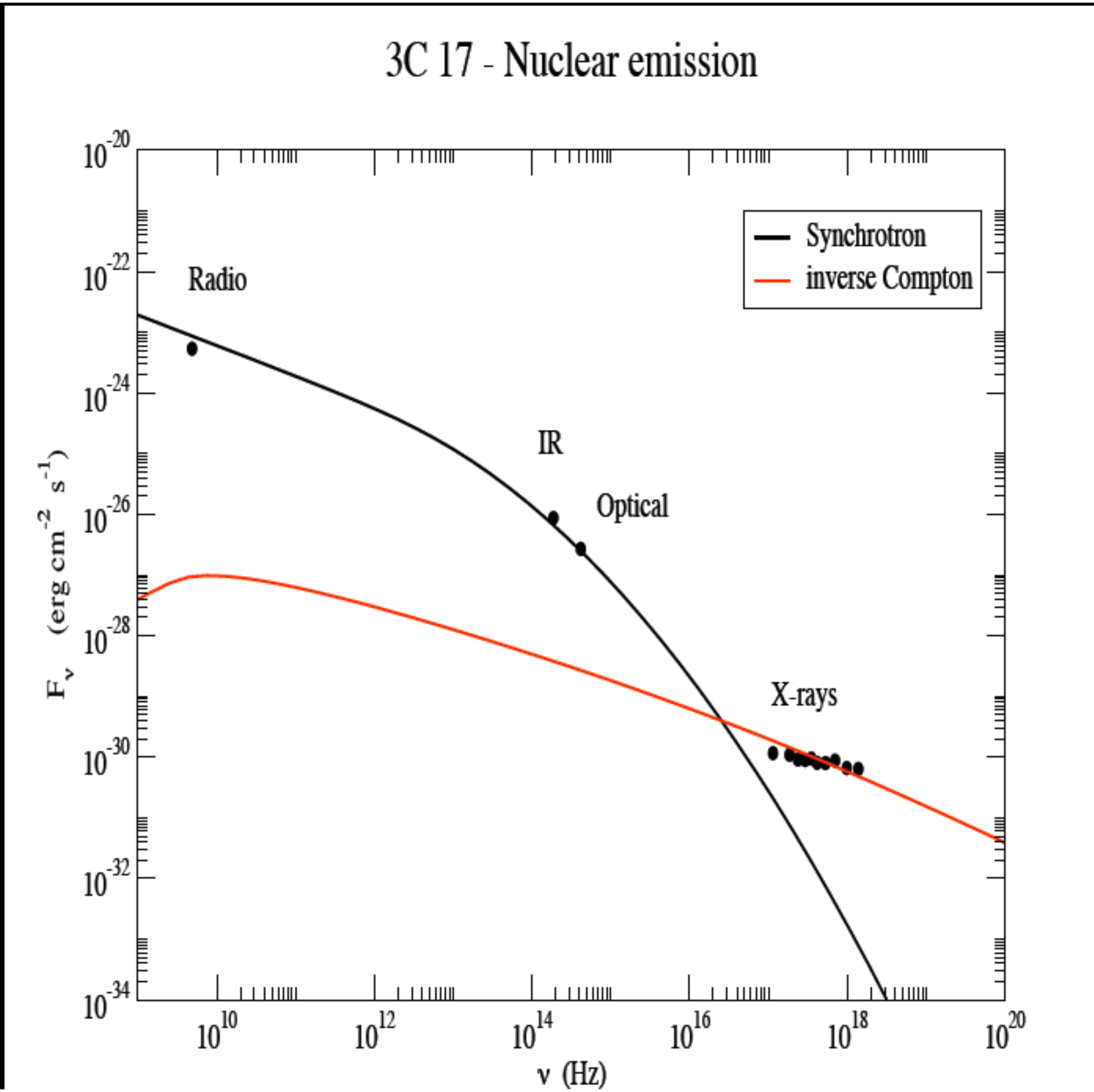


3C 17.0
HST UV Image
knot 3.7"
knot 11.3"
X-ray contours
Radio contours
41.0
42.0
43.0
44.0
-2:07:45.0
46.0
47.0
21.3
21.2
21.1
0:38:21.0
20.9
20.8
20.7
20.6
20.5


3C 17.0
HST optical image
knot 3.7"
unidentified object
knot 11.3"
X-ray contours
Radio contours
41.0
42.0
43.0
44.0
-2:07:45.0
46.0
47.0
21.3
21.2
21.1
0:38:21.0
20.9
20.8
20.7
20.6
20.5
1000
2000
3000
4000



3C 17.0
HST infrared image
knot 3.7"
unidentified object
X-ray contours
Radio contours
1 arcsec
40.5
41.0
41.5
-2:07:42.0
42.5
43.0
43.5
44.0
44.5
21.1
0:38:21.0
0:38:21.0
0:38:20.9
20.9
0:38:20.8
20.8
0:38:20.7
20.7
20.6
200
400
600
800

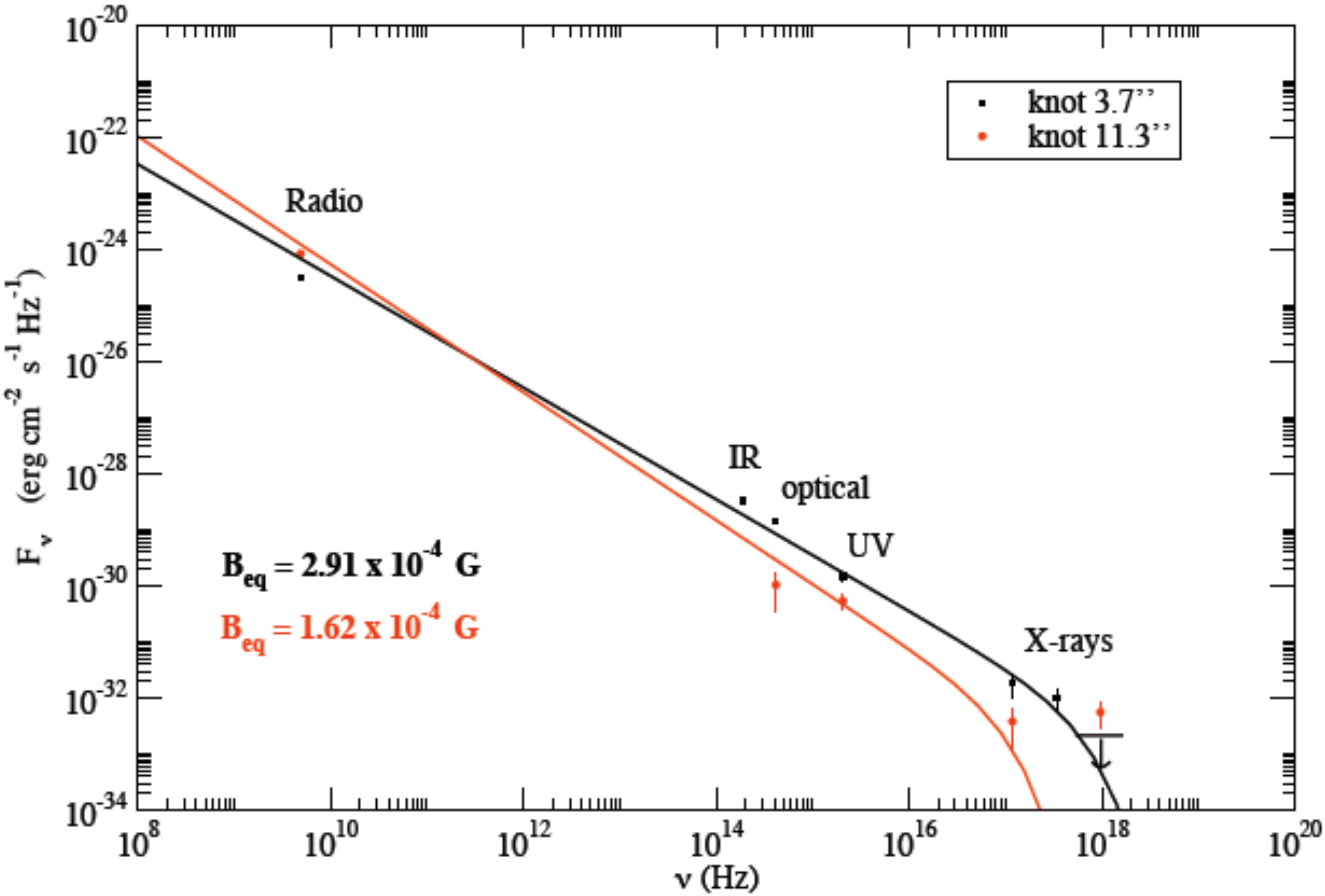


3C 17 - Nuclear emission
Synchrotron
inverse Compton
Radio
IR
Optical
X-rays
F_ν (erg cm^-2 s^-1)
ν (Hz)
10^-20
10^-22
10^-24
10^-26
10^-28
10^-30
10^-32
10^-34
10^10
10^12
10^14
10^16
10^18
10^20

3C 17 JET EMISSION

- We assumed
  - the distribution of emitting electrons is a power-law
  - the volume of the accelerating region is the same as the emitting region, and correspond to that measured with the radio data
  - the magnetic field is in equipartition with electrons.
- Best fit is synchrotron

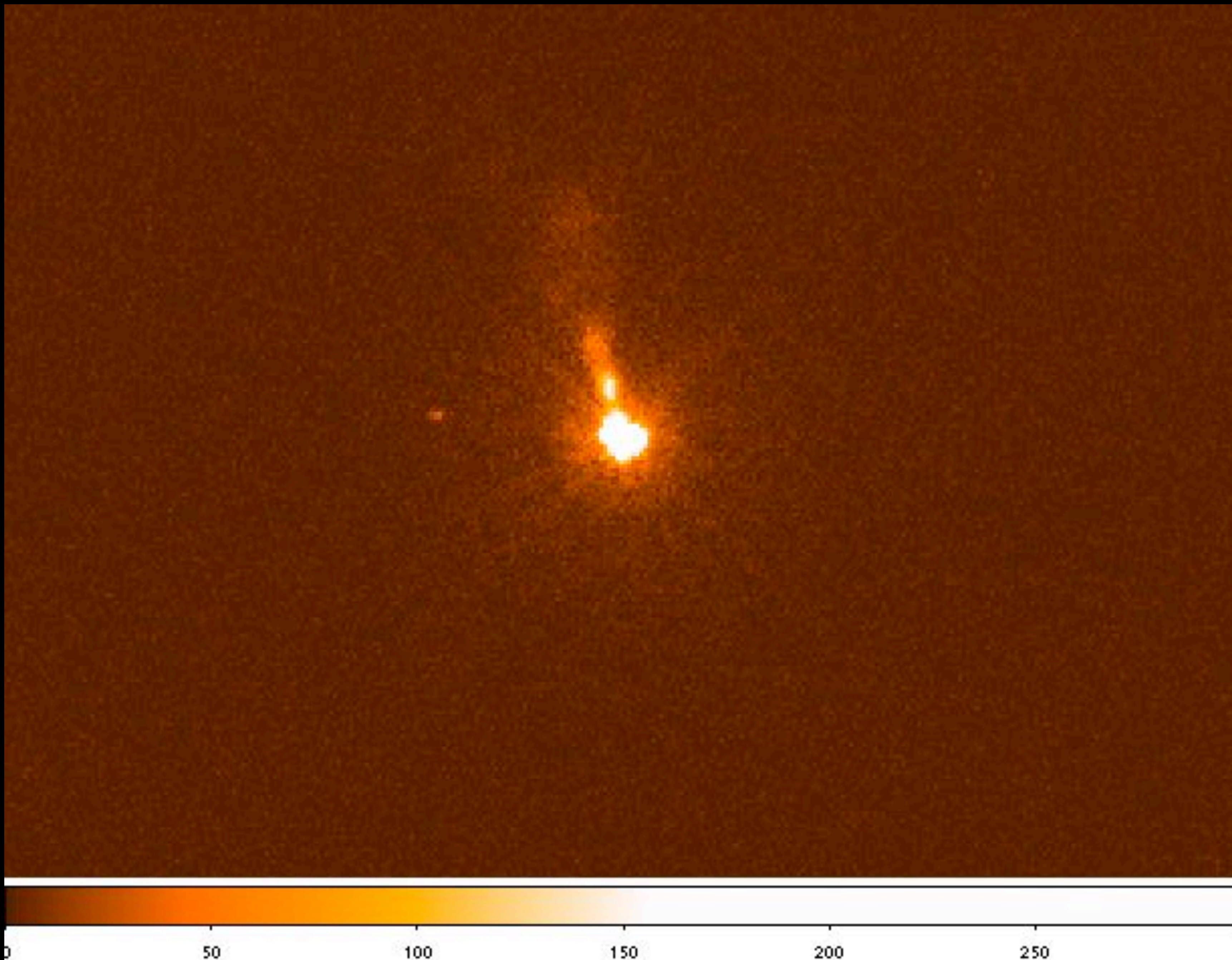
3C 17.0 knot spectra

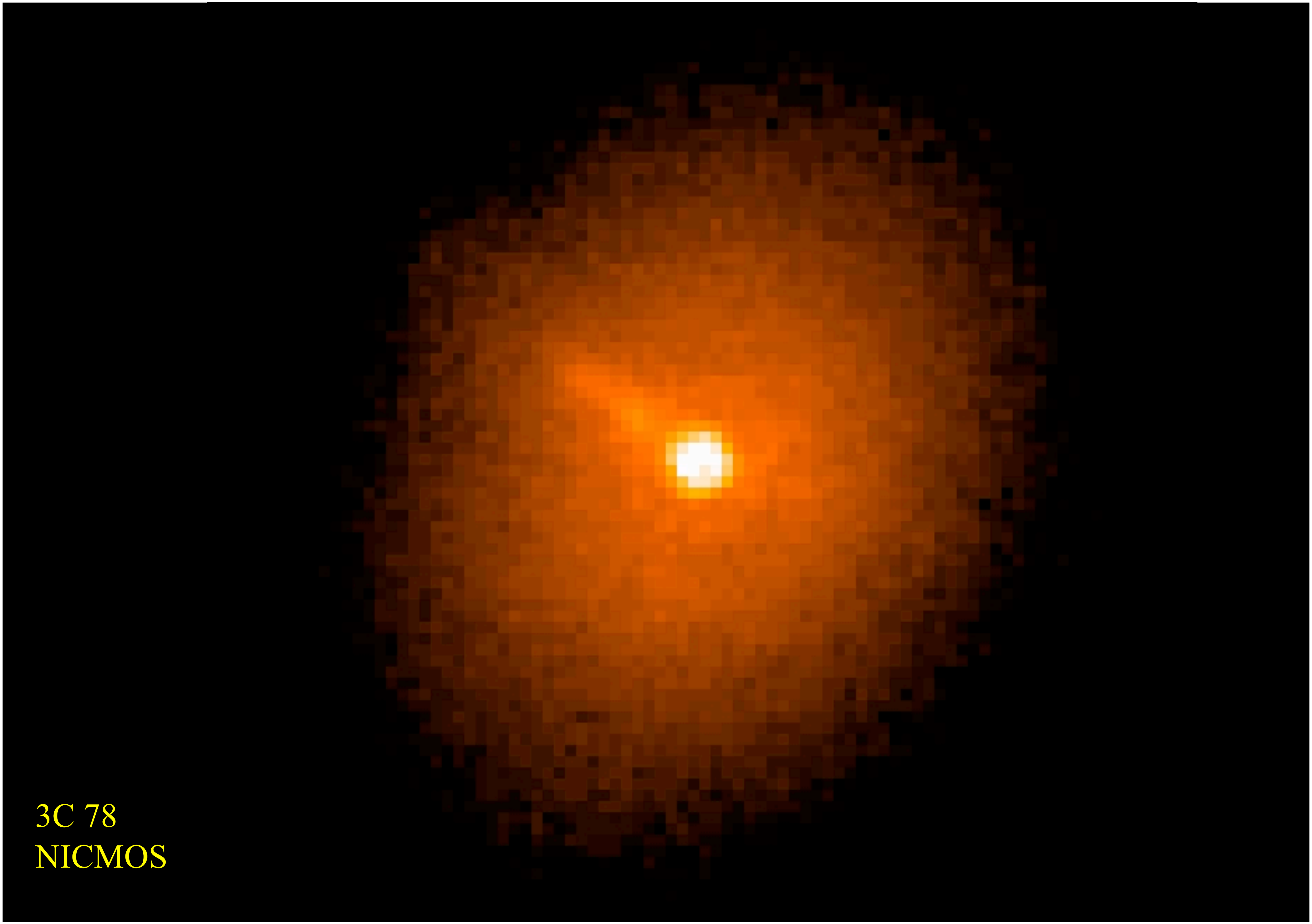


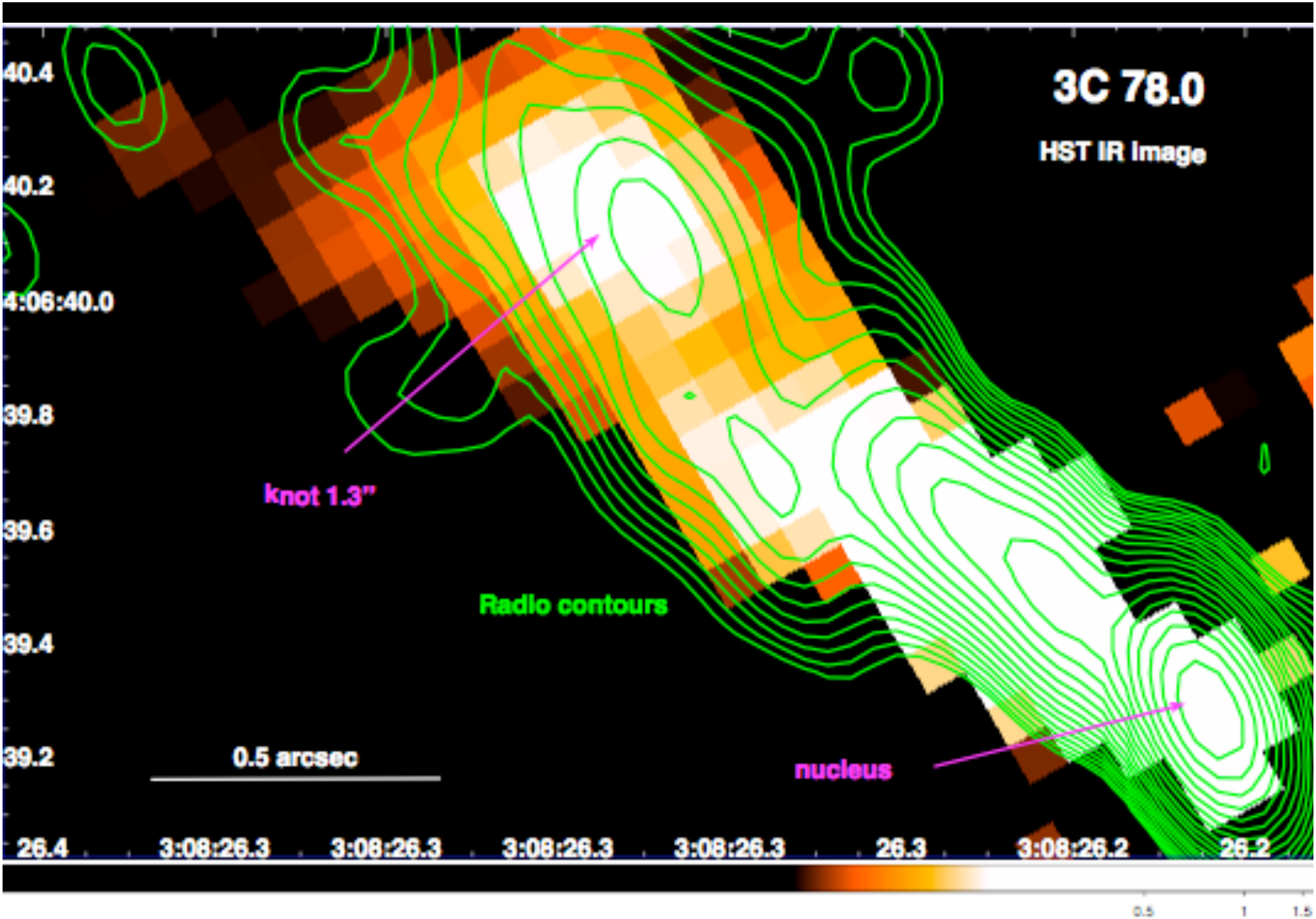
3C 78

- 3C 78 (NGC 1218) is a nearby ($z \leq 0.03$) S0 galaxy (Schmidt et al. 1965) with a prominent optical synchrotron jet detected with the WFPC2.
- It is associated with the radio emission detected by Unger et al. (1984) in the MERLIN observation and by Morganti et al. (1993) with the VLA
- The X-ray emission detected for the knot 1.3" (0.73 kpc) is 6.69×10^{14} erg cm^2 s-^{1} in the 0.2 - 7.0 keV band

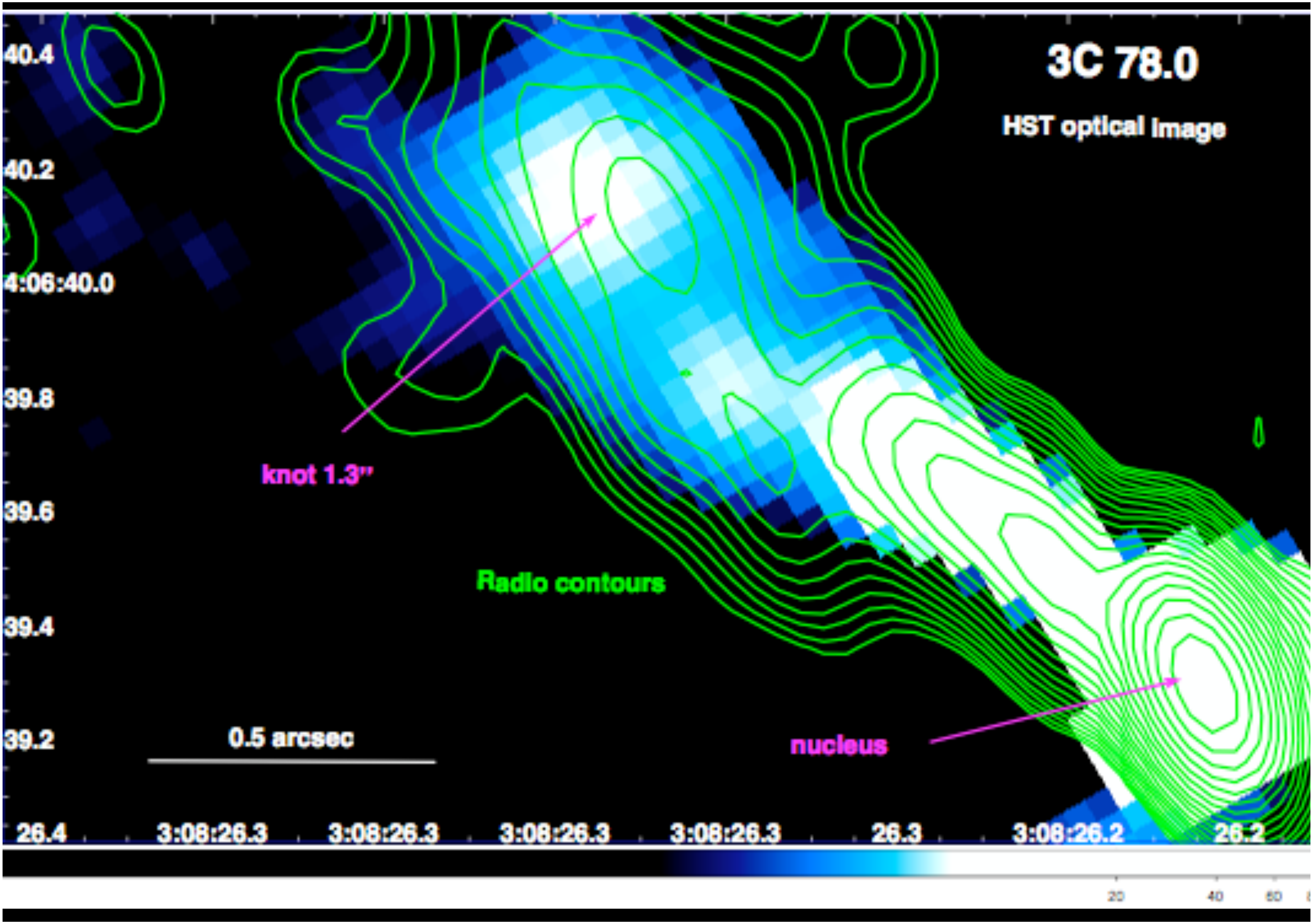
3C 78 UV




3C 78
NICMOS



3C 78.0
HST IR Image
knot 1.3"
Radio contours
nucleus
0.5 arcsec
40.4
40.2
4:06:40.0
39.8
39.6
39.4
39.2
26.4
3:08:26.3
3:08:26.3
3:08:26.3
3:08:26.3
26.3
3:08:26.2
26.2
0.5
1
1.5



3C 78.0
HST optical image
knot 1.3"
Radio contours
nucleus
0.5 arcsec
40.4
40.2
4:06:40.0
39.8
39.6
39.4
39.2
26.4
3:08:26.3
3:08:26.3
3:08:26.3
3:08:26.3
26.3
3:08:26.2
26.2

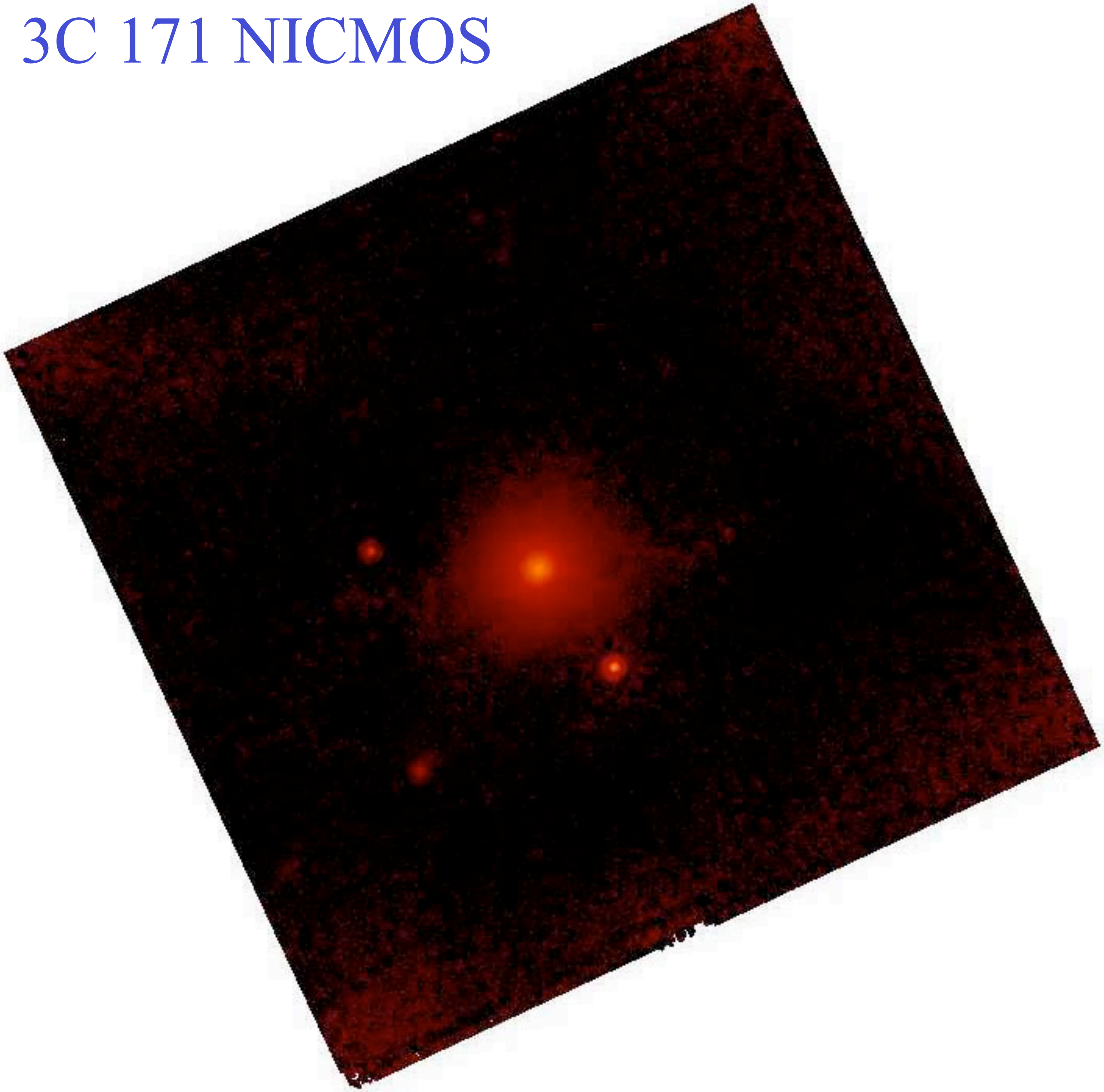
KEY QUESTIONS: HOT SPOTS

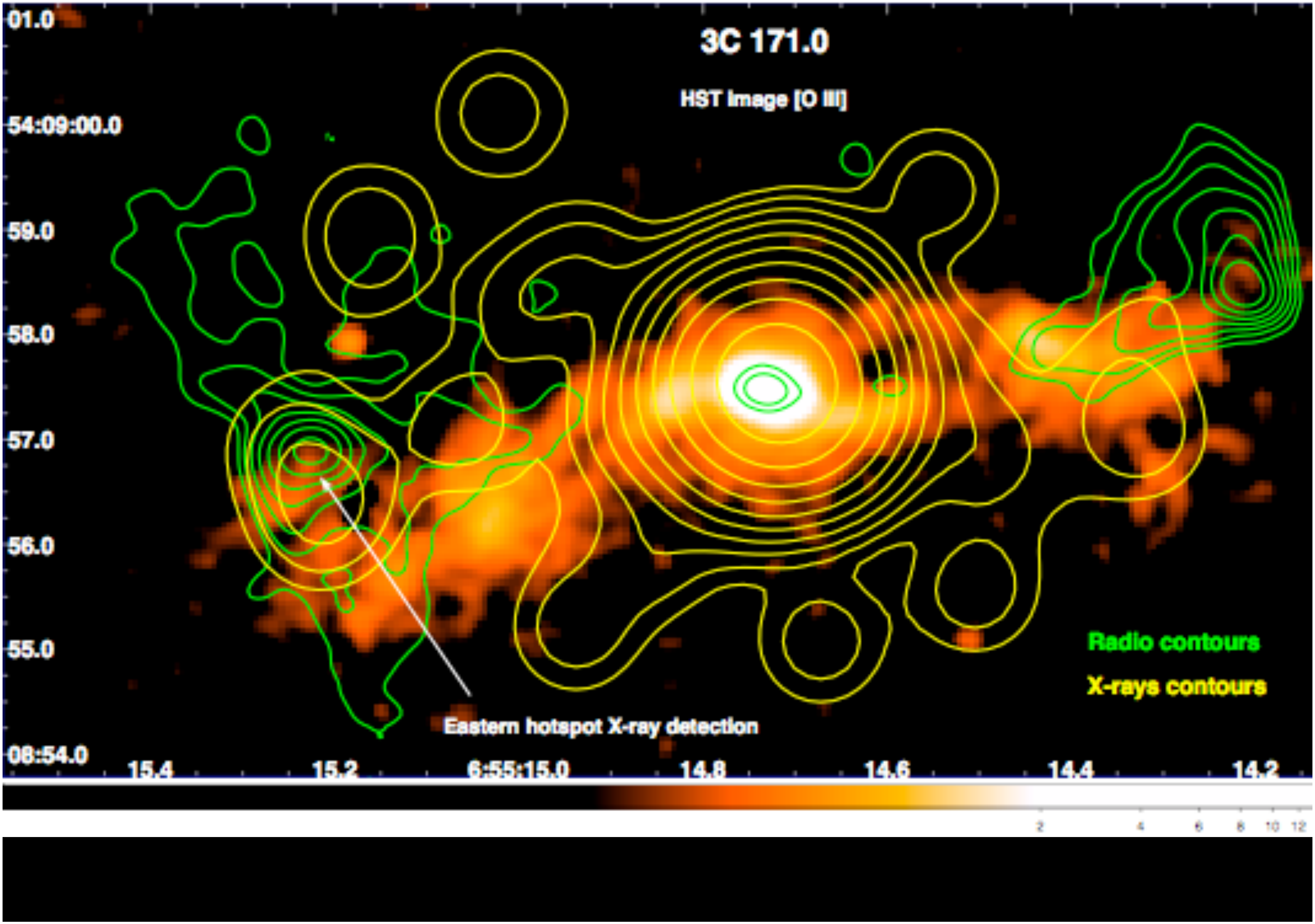
- How common are hot-spots in X-rays?
- And what is the emission mechanism?
- Synchrotron and synchrotron-self Compton are the most plausible scenarios.
- The broad-band spectral index of hot spots is often steep and the X-ray emission can be well explained as due to SSC radiation
- However, several hot spots are best modeled with synchrotron radiation (emitted by a single population of relativistic electrons) from the radio to the X-rays

PRELIMINARY RESULTS: HOT SPOTS

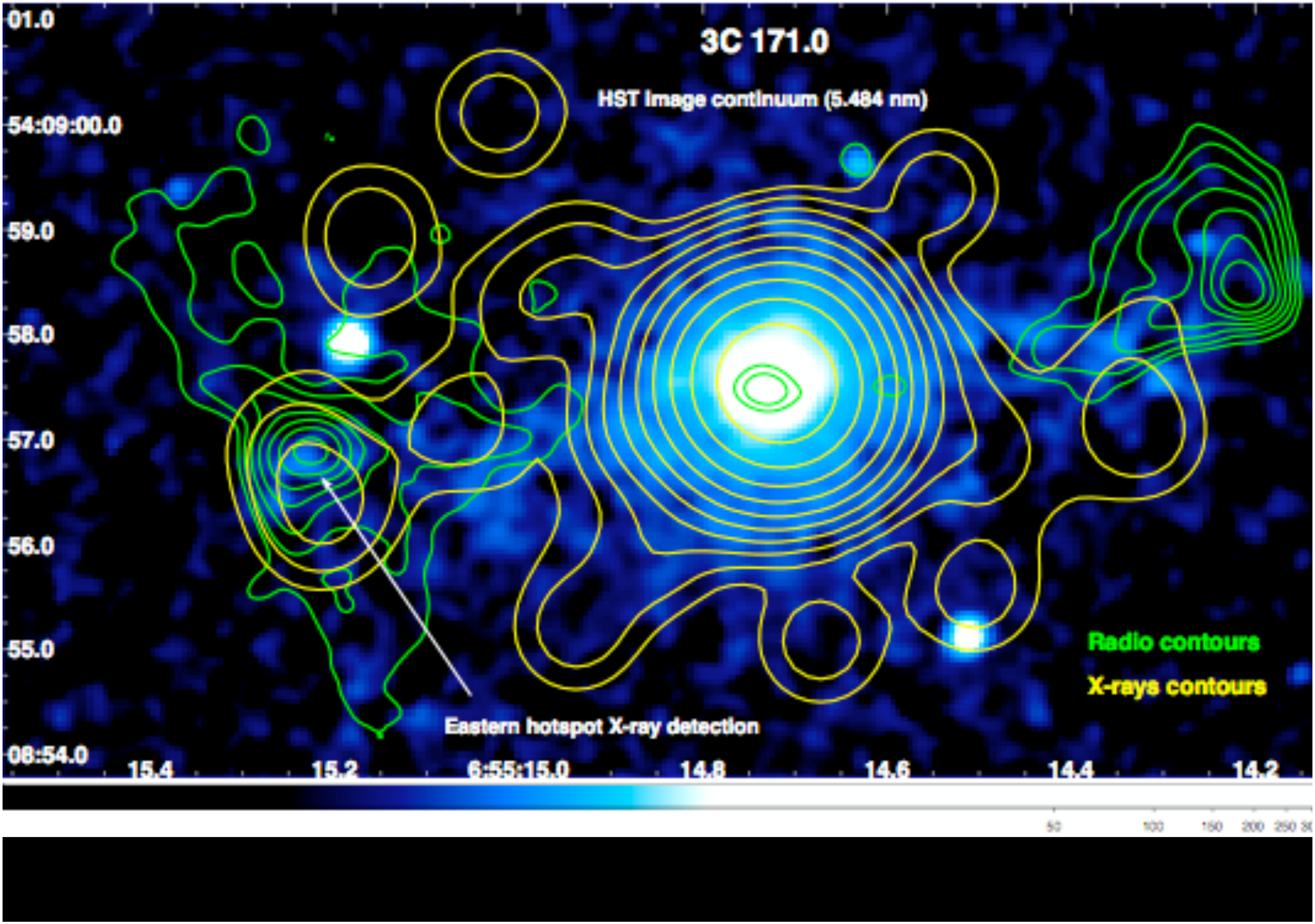
- 3C 171
- Detected emission associated with the East hotspot of 3C 171
- Interesting correspondence with O III emission
- Recalls similar correlation we found with HST in nearby Seyferts, Markarian galaxies and other 3C sources
  - (3C 236 O'Dea et al ApJ 01, 3C 244.1Feinstein et al ApJ 02)

3C 171 NICMOS

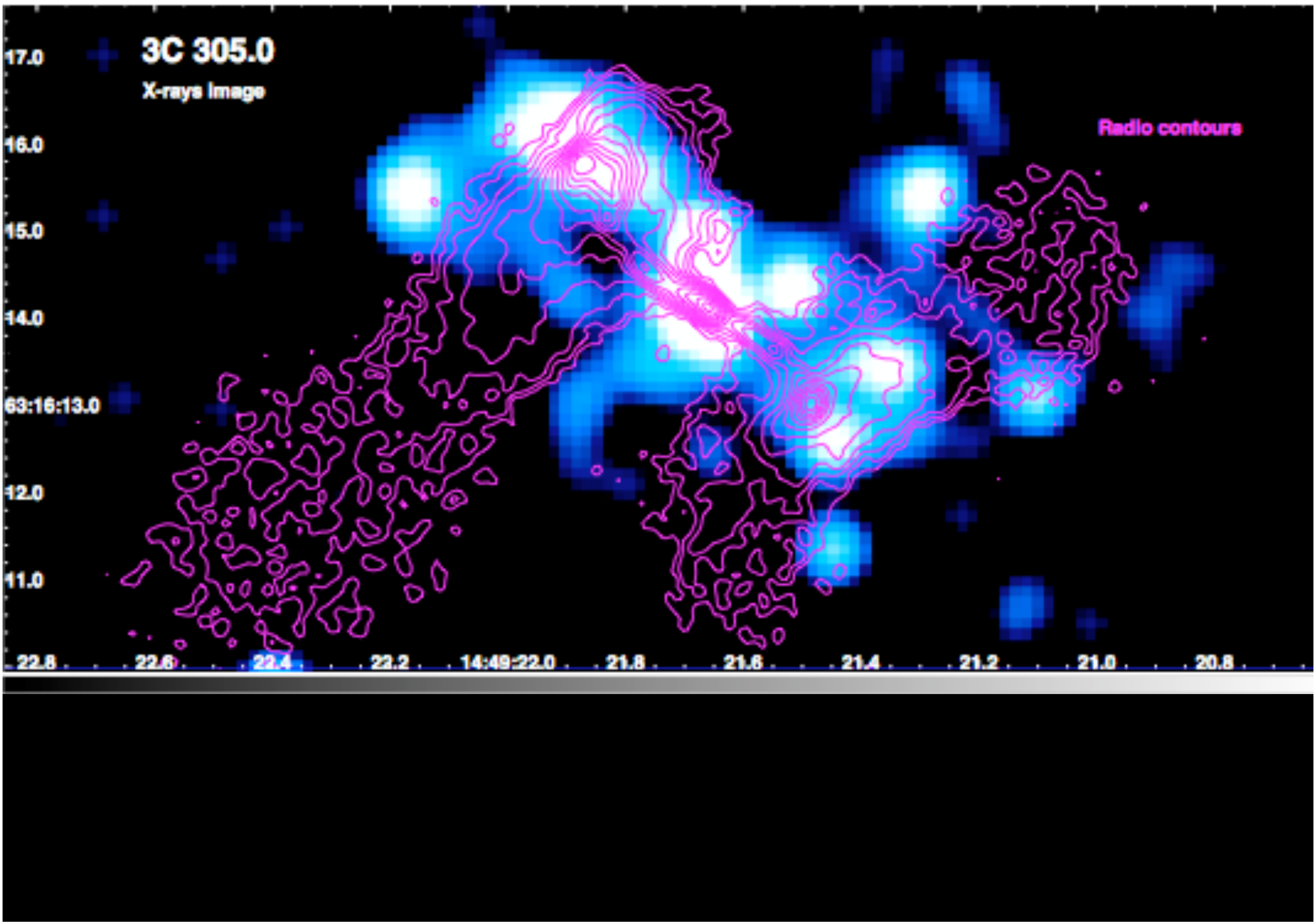


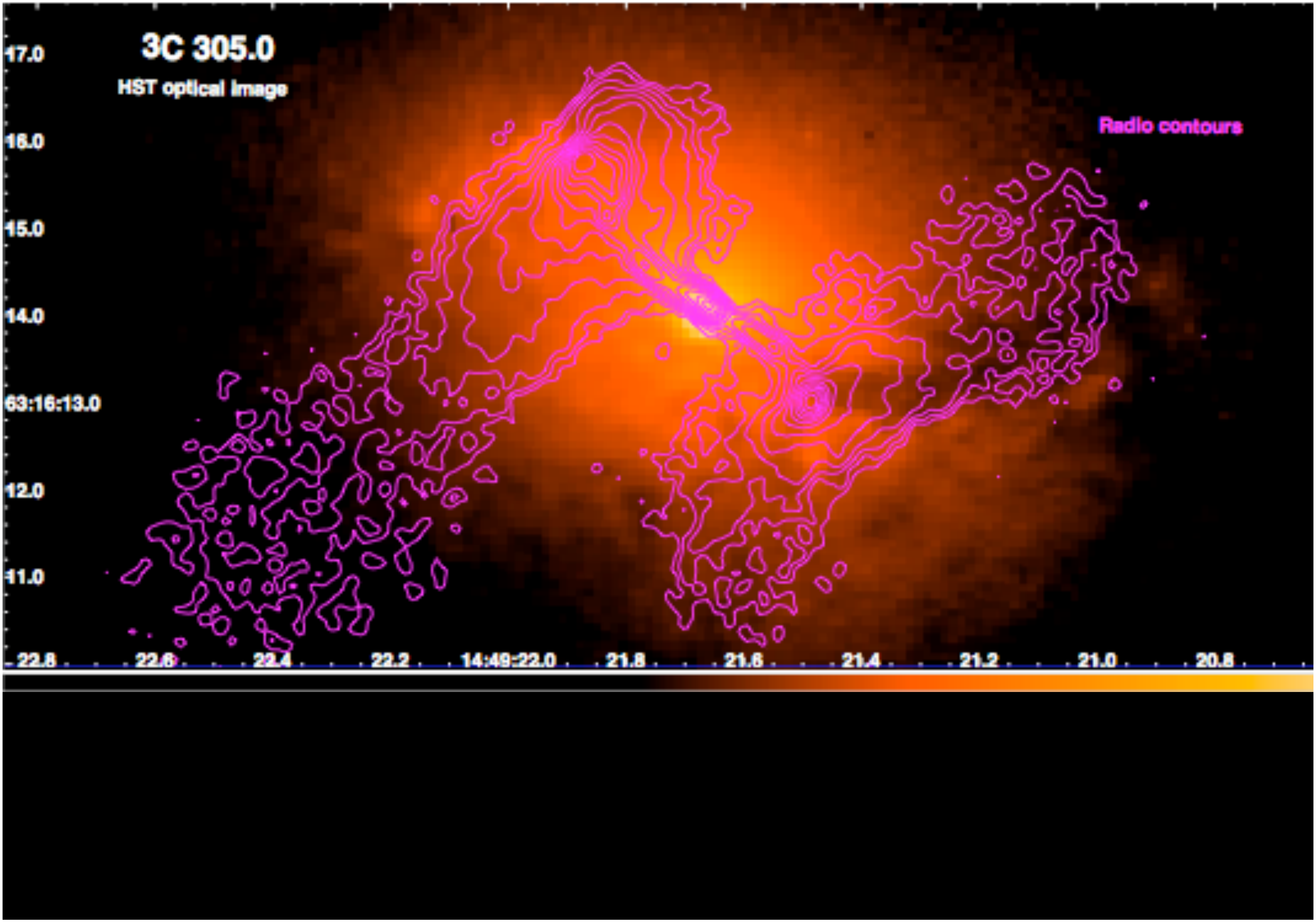


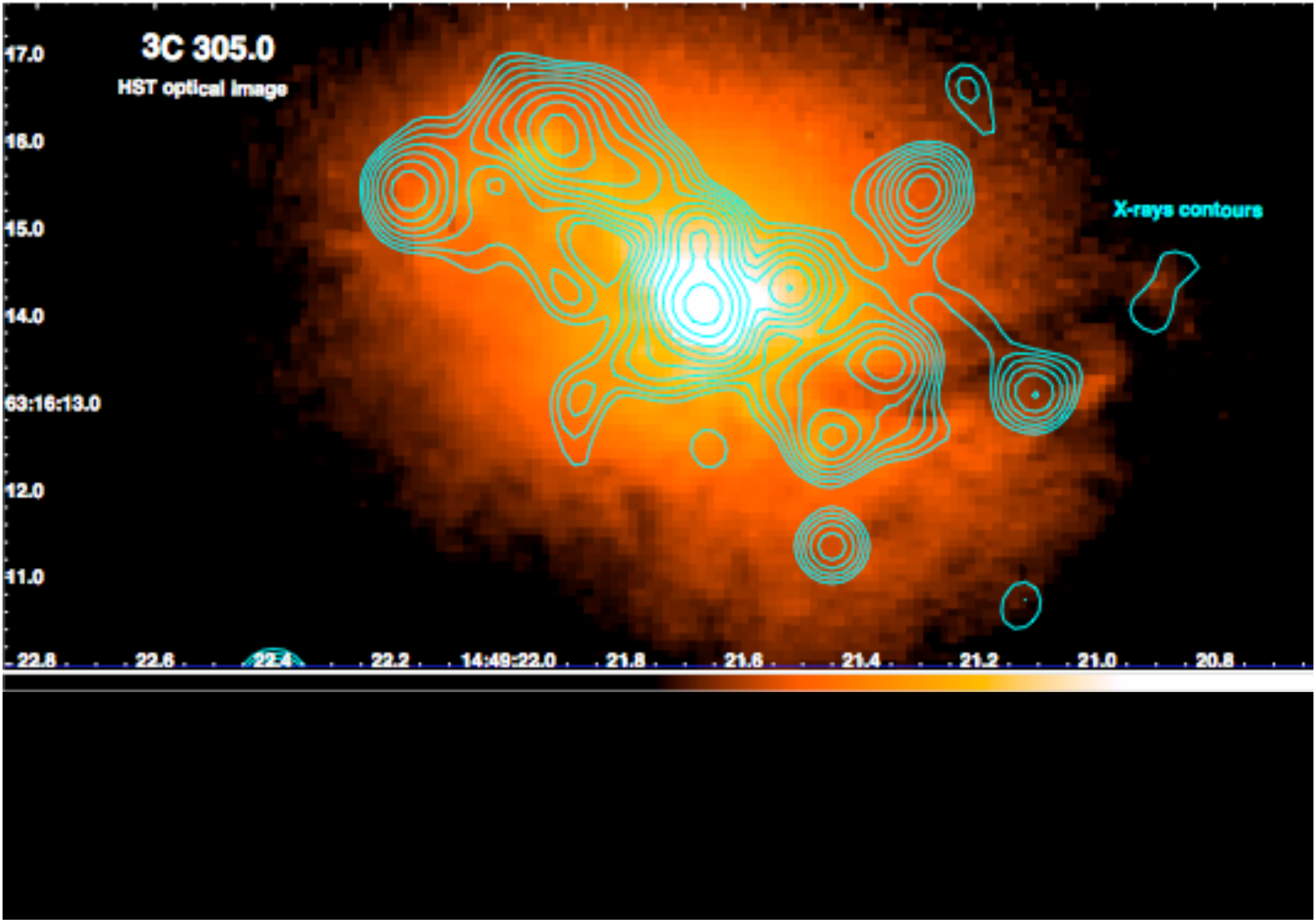
3C 171.0
HST Image [O III]
Radio contours
X-rays contours
Eastern hotspot X-ray detection
01.0
54:09:00.0
59.0
58.0
57.0
56.0
55.0
08:54.0
15.4
15.2
6:55:15.0
14.8
14.6
14.4
14.2
2
4
6
8
10
12

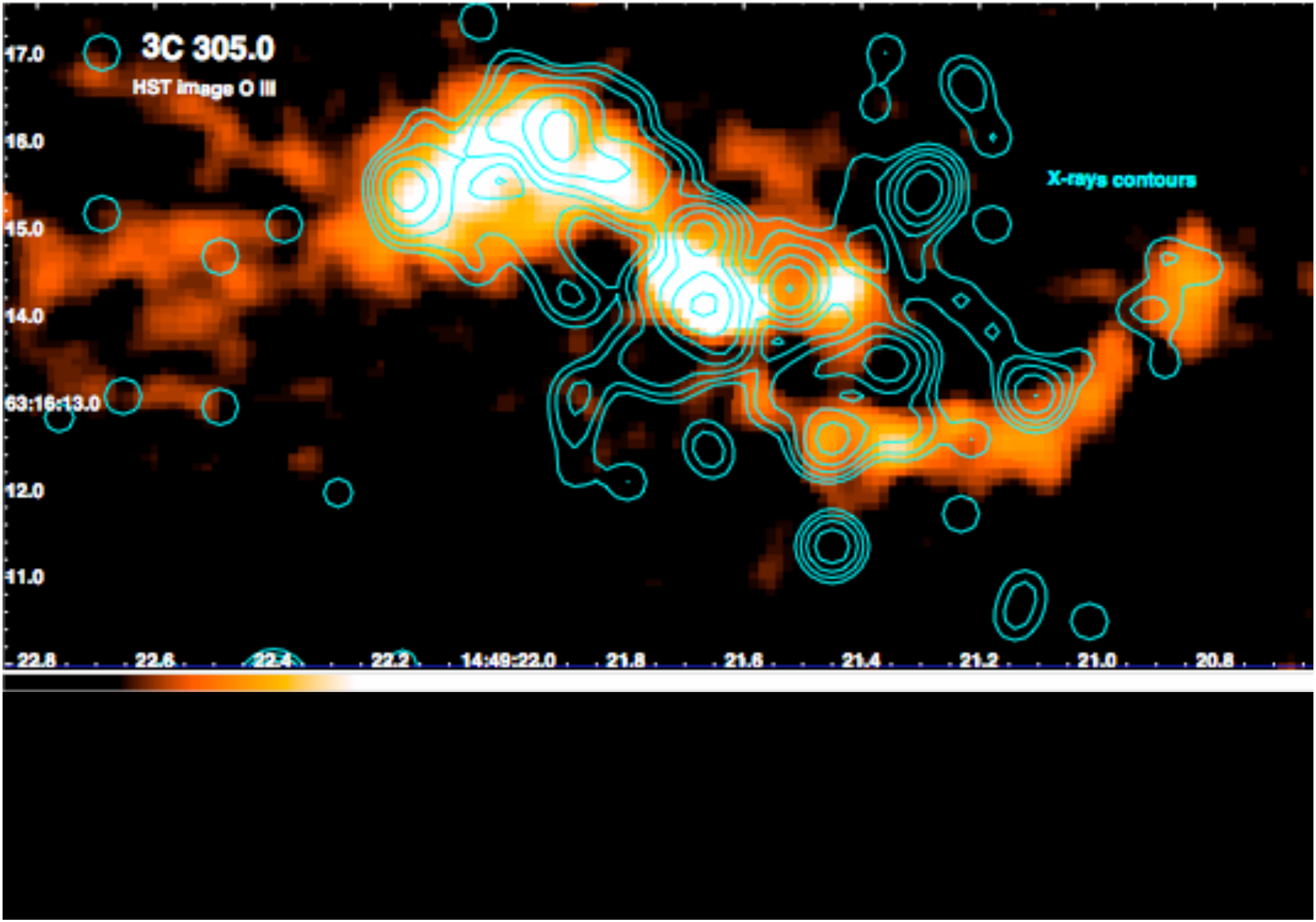


3C 171.0
HST image continuum (5.484 nm)
Radio contours
X-rays contours
Eastern hotspot X-ray detection
01.0
54:09:00.0
59.0
58.0
57.0
56.0
55.0
08:54.0
15.4
15.2
6:55:15.0
14.8
14.6
14.4
14.2
50
100
150
200
250


3C 305.0
X-rays image
Radio contours
17.0
16.0
15.0
14.0
63:16:13.0
12.0
11.0
22.8
22.6
22.4
22.2
14:49:22.0
21.8
21.6
21.4
21.2
21.0
20.8


3C 305.0
HST optical image
Radio contours
17.0
16.0
15.0
14.0
63:16:13.0
12.0
11.0
22.8
22.6
22.4
22.2
14:49:22.0
21.8
21.6
21.4
21.2
21.0
20.8


3C 305.0
HST optical image
X-rays contours
17.0
16.0
15.0
14.0
63:16:13.0
12.0
11.0
22.8
22.6
22.4
22.2
14:49:22.0
21.8
21.6
21.4
21.2
21.0
20.8



3C 305.0
HST image O III
X-rays contours
17.0
16.0
15.0
14.0
63:16:13.0
12.0
11.0
22.8
22.6
22.4
22.2
14:49:22.0
21.8
21.6
21.4
21.2
21.0
20.8

3C 305

- Soft X-Ray/OIII connection similar to what has been found in Seyfert 2 sources (Bianchi et al A&A, 2006)
- The soft X-ray emission is produced by gas photoionized by the nuclear source.
- The same source accounts for the OIII emission

CONCLUSIONS FOR FR I

- LOW LUMINOSITY RADIO GALAXIES DO NOT HAVE THREE OF THE MOST CHARACTERISTIC SIGNATURES OF THE AGN ACTIVITY :
  - A RADIATIVELY EFFICIENT ACCRETION DISK
  - A BROAD LINE REGION
  - A GEOMETRICALLY THICK OBSCURING TORUS
- *THEY ARE THE MANIFESTATION OF A FUNDAMENTALLY DIFFERENT STRUCTURE OF THE CENTRAL ENGINE*
- *Optical/radio correlation implies that most FRI's nuclei are jet dominated !*

CONCLUSIONS FOR FR II

- BLO HAVE UNOBSCURED NUCLEI AND AN OPTICAL EXCESS
  - IS THERE A TRESHOLD AT WHICH THE ACCRETION REGIME CHANGES?
  - ARE WE OBSERVING THE ACCRETION DISK?
- LEG ARE FRI - LIKE
  - SYNCHROTRON DOMINATED NUCLEI - NO HIDDEN QUASAR
  - THEY MUST BE UNIFIED WITH BL LACS AND NOT WITH QSO
- HEG ARE OBSCURED QUASARS
  - THEIR NUCLEI ARE VISIBLE IN THE IR