ULX bubbles

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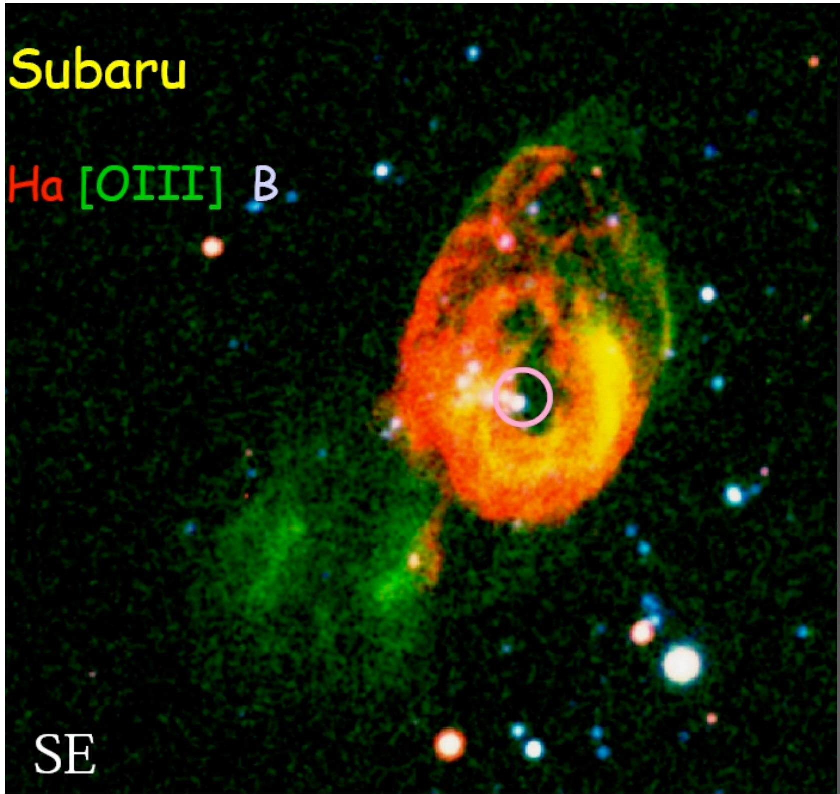
Outline

- Old(ish) and new examples of ionized ULX bubbles
  NGC 7793 S26: a triple system (X-ray core + lobes)

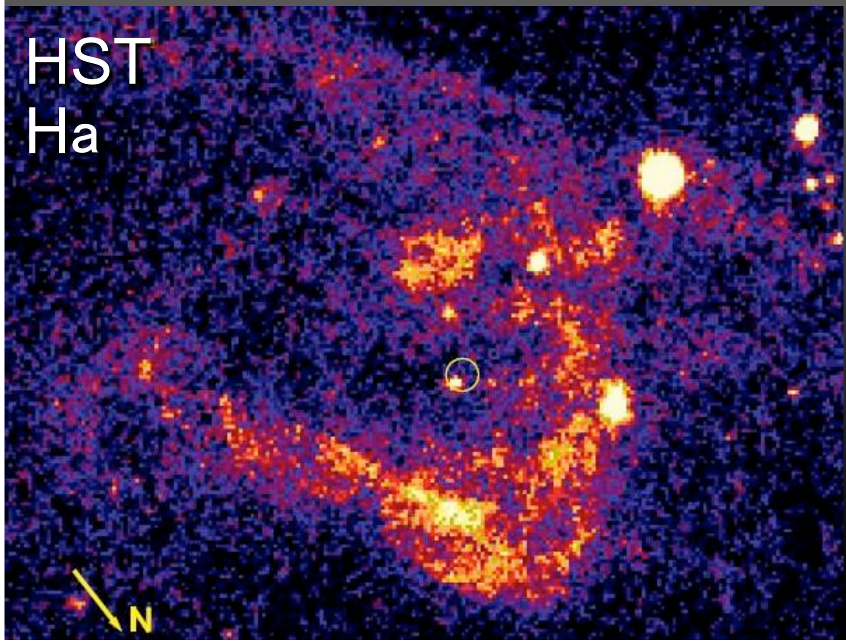
- Interpretation: SNRs or jet/wind - inflated bubbles?
  More likely inflated by BH outflows

- General problem of radiative vs mechanical power
  ULX accretion states different from Galactic BHs?



Holmberg IX X1

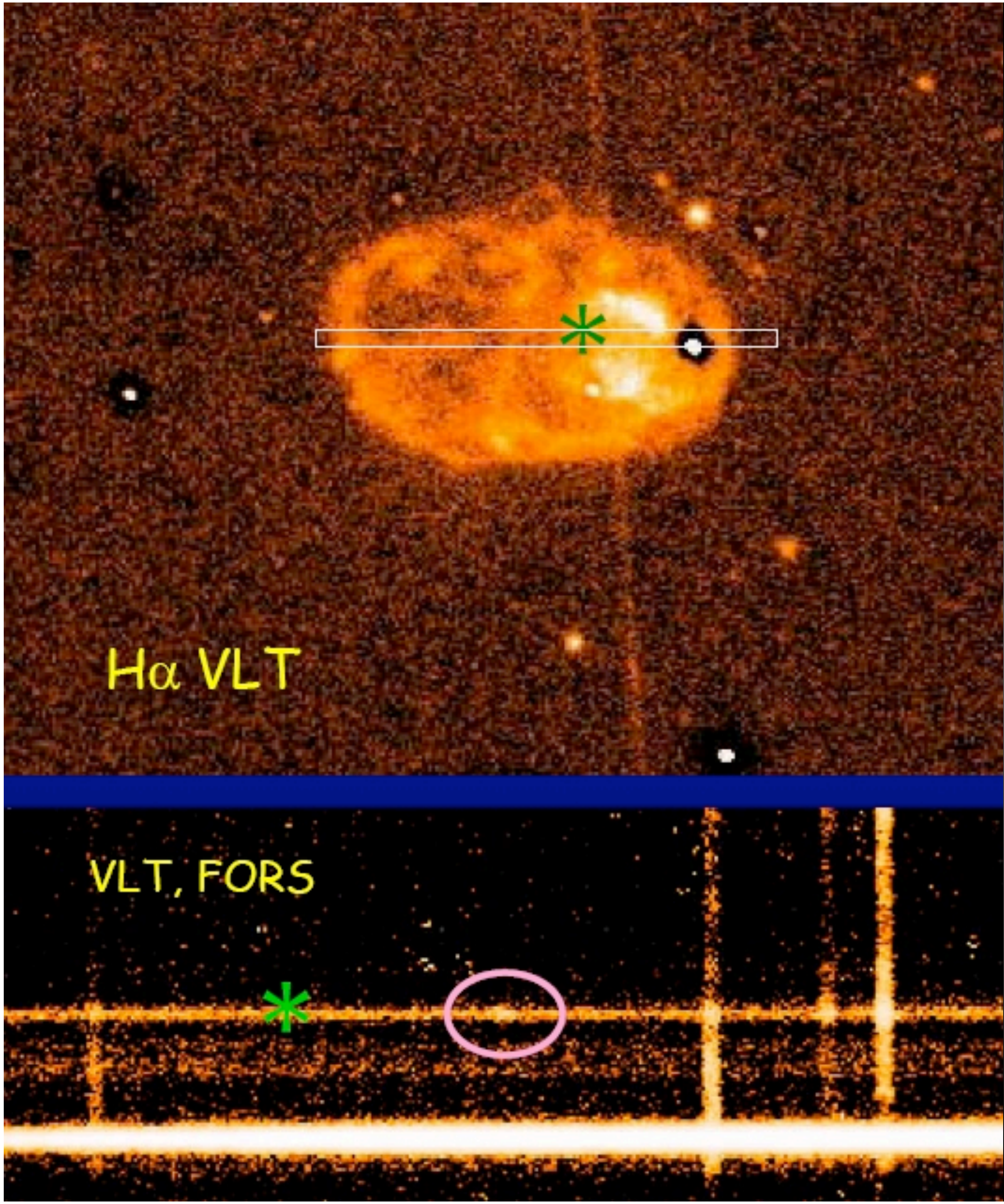
Pakull & Mirioni 2002
Grise’ et al 2008



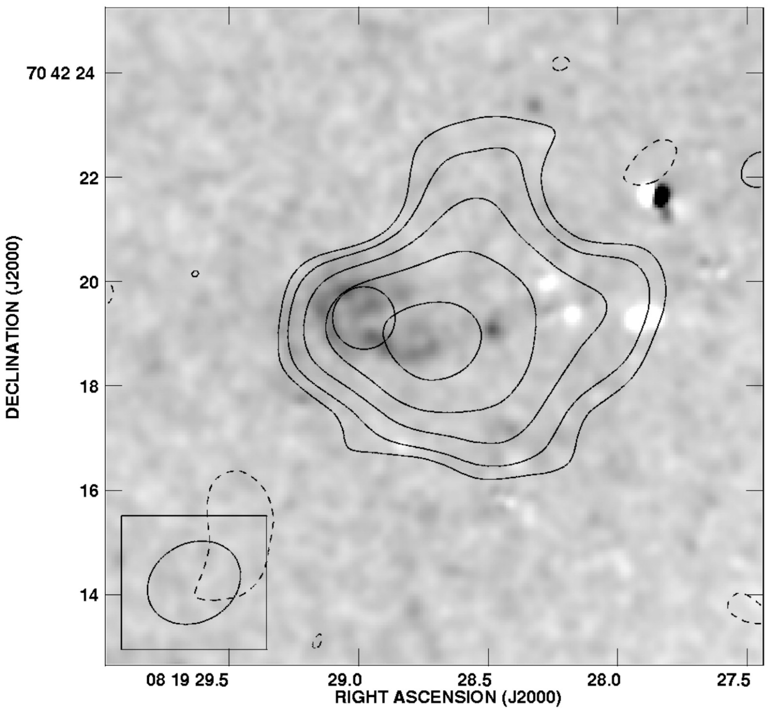
IC342 X1 (“foot nebula”)

Pakull & Mirioni 2002
Feng & Kaaret 2008

NGC1313 X2



Grise' et al 2008
Grise' et al 2010 in prep

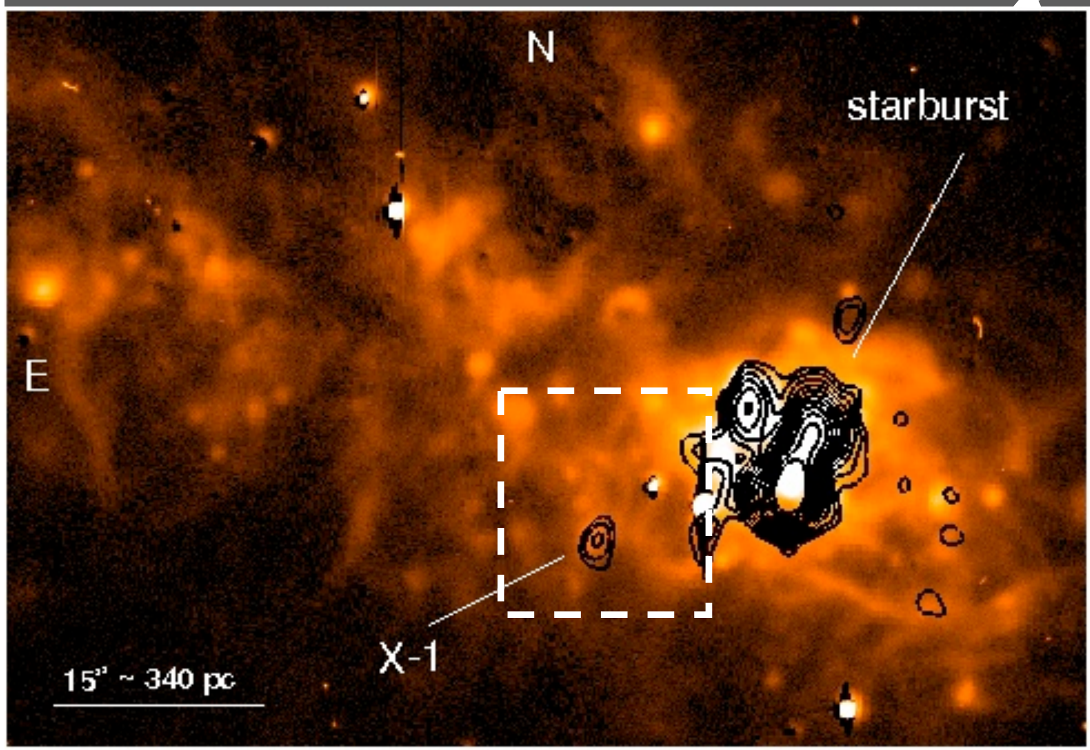


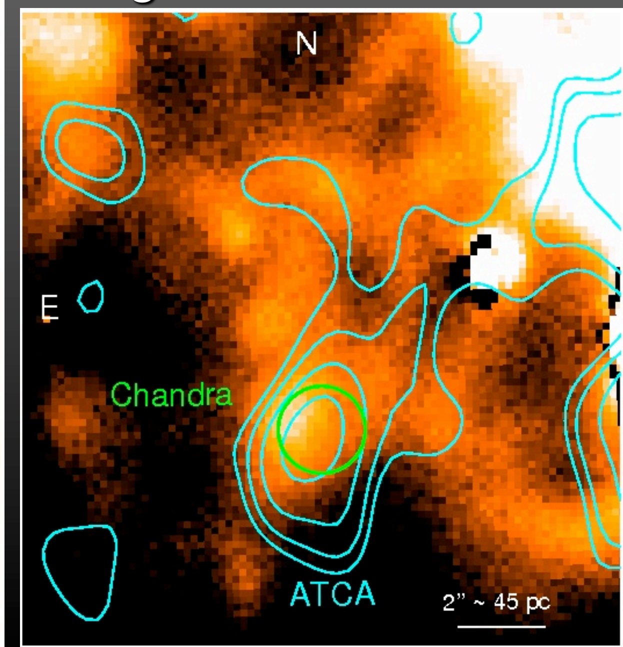
Holmberg II X1

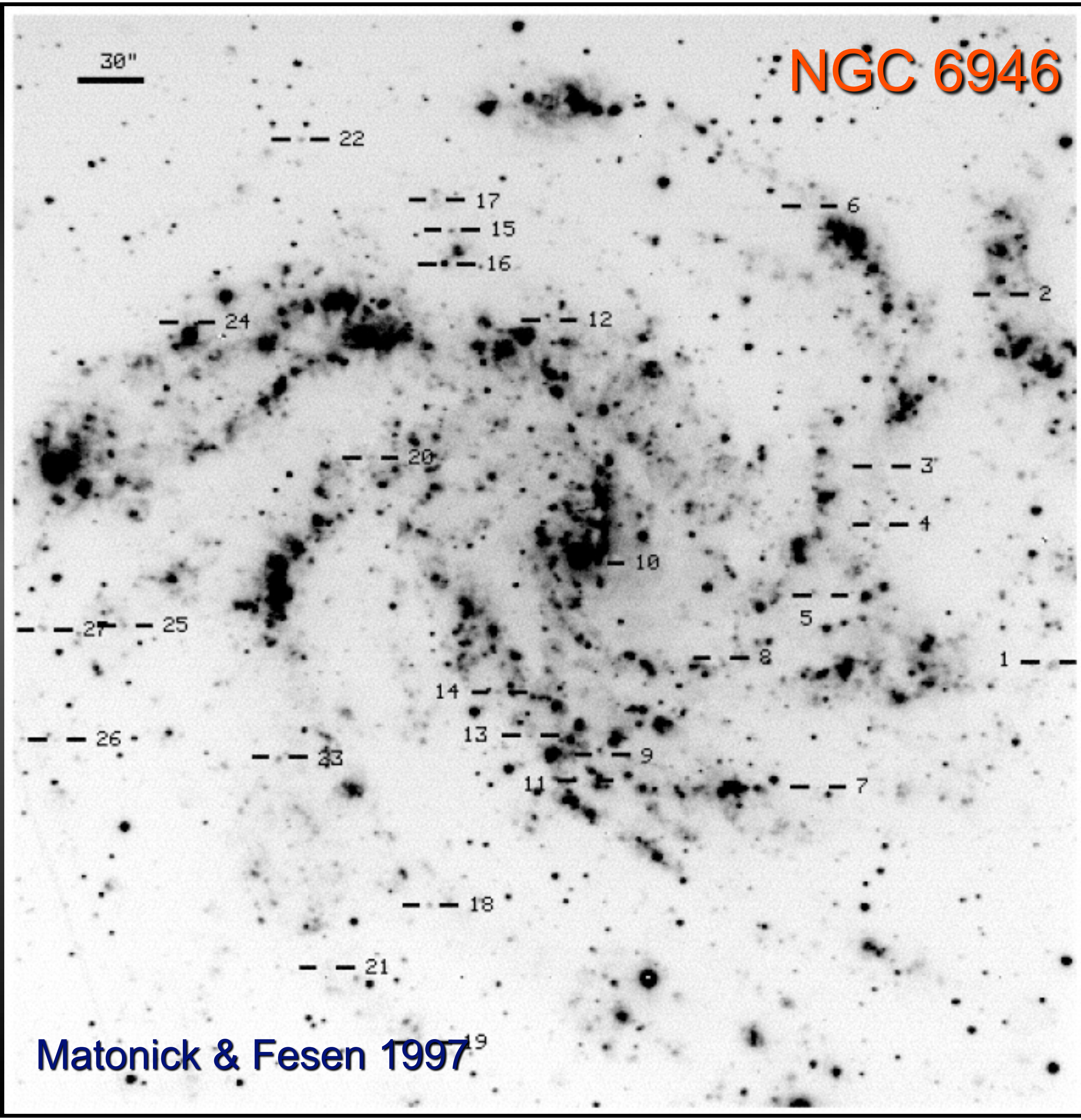
Miller, Mushotzky & Neff 2005

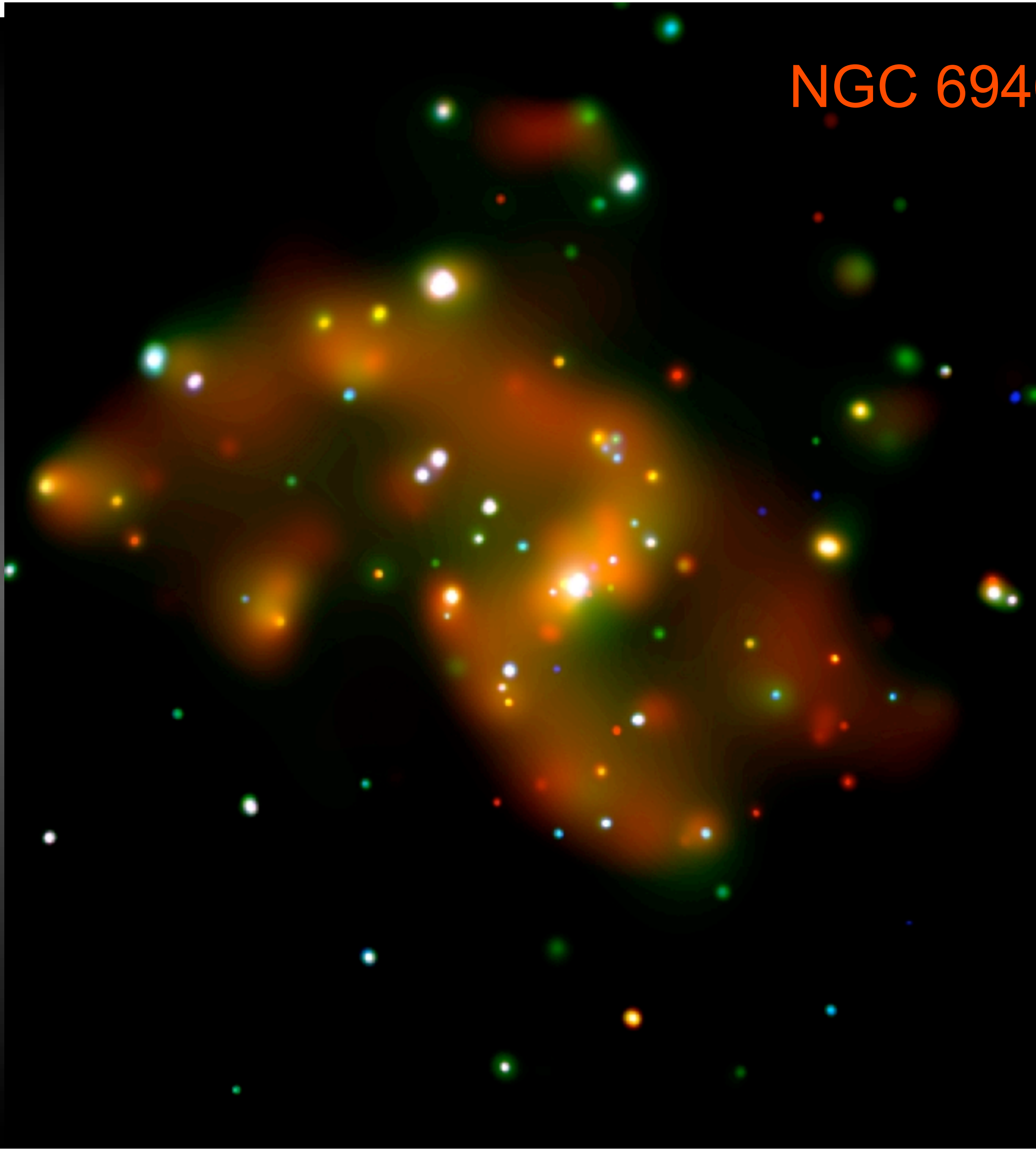
NGC5408 X1

Kaaret et al 2003
Soria et al 2006
Lang et al 2007

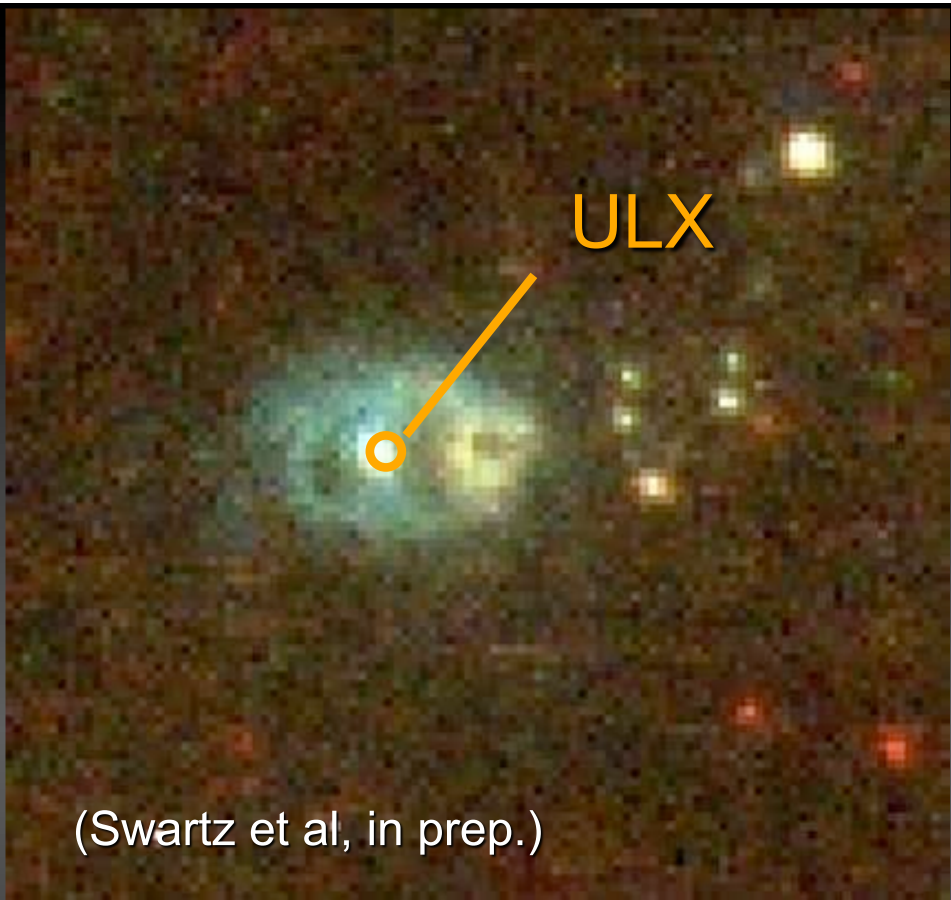





NGC 6946
30"
22
17
15
16
6
2
24
12
20
3
4
10
5
27
25
8
1
14
26
13
23
9
11
7
18
21
19
Matonick & Fesen 1997


NGC 6946

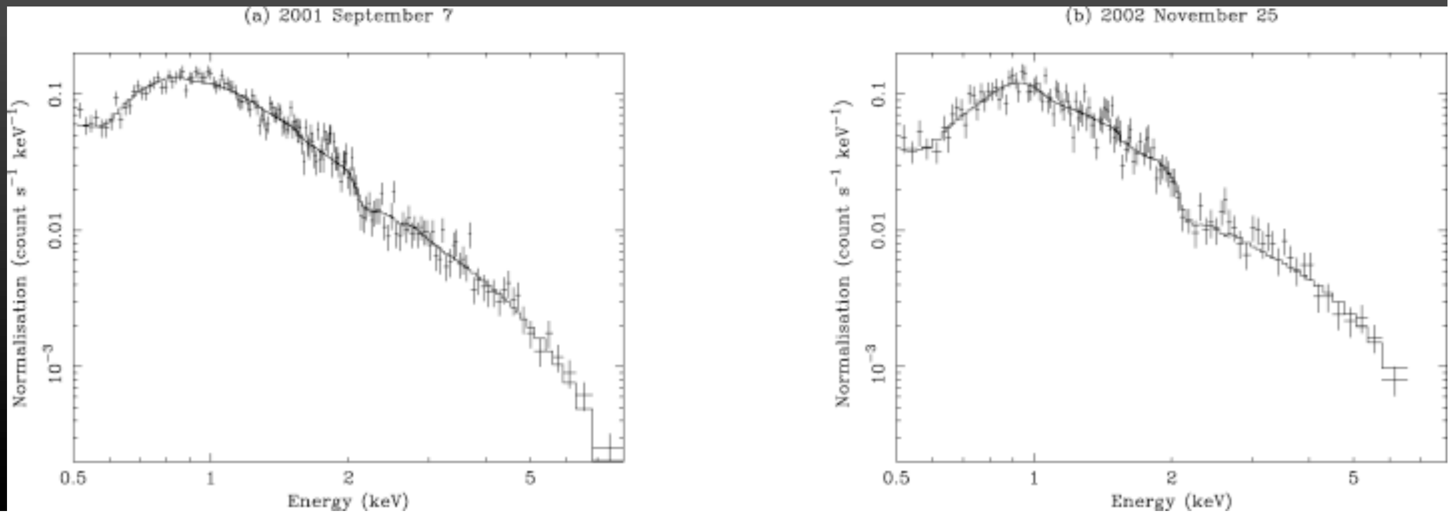
MF16 in NGC 6946

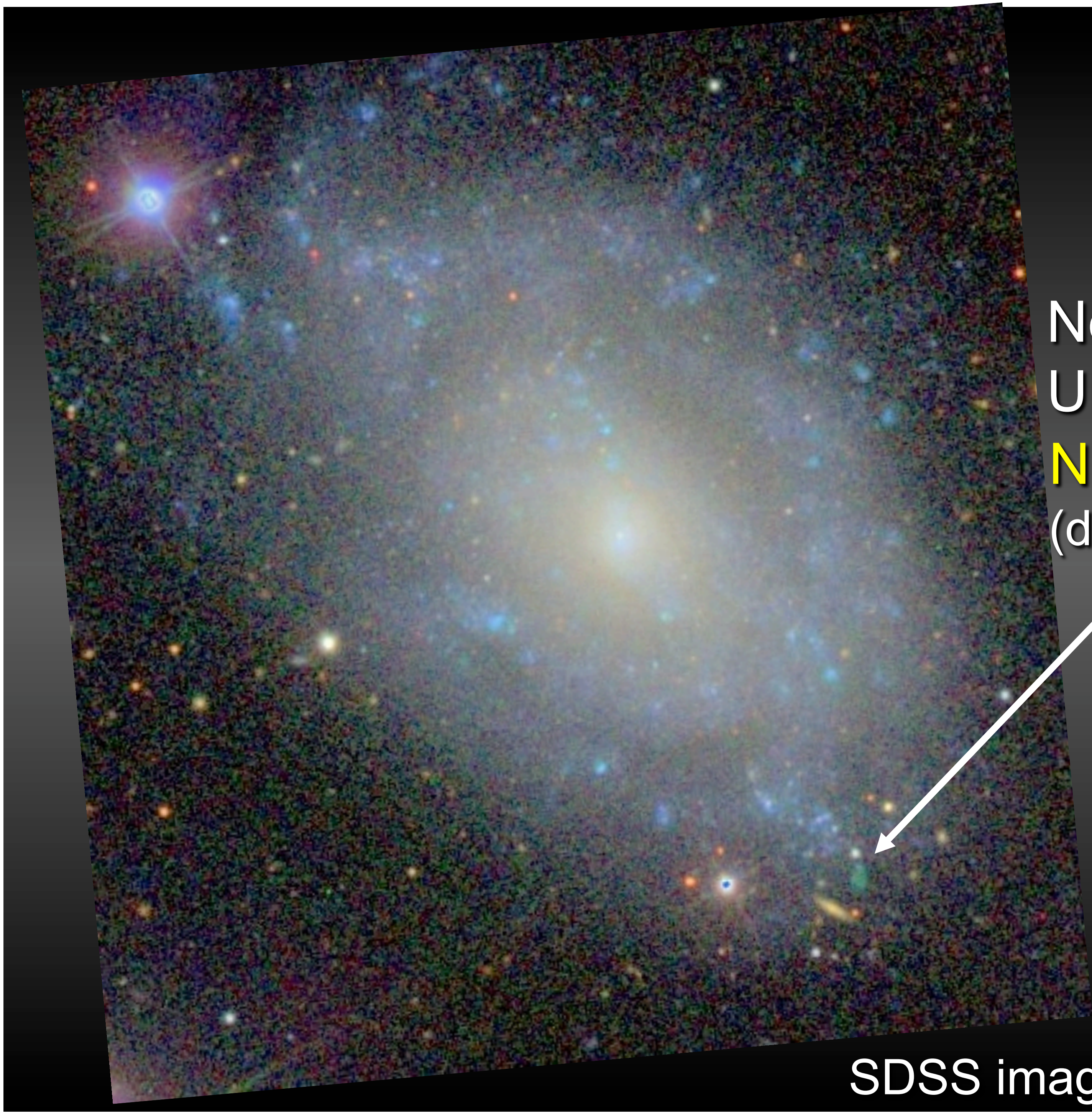


Radio source
steep synchrotron
L_R ~ 4 x Cas A

(Van Dyk et al 1994)

Chandra X-ray spectrum
(Roberts & Colbert 2003)

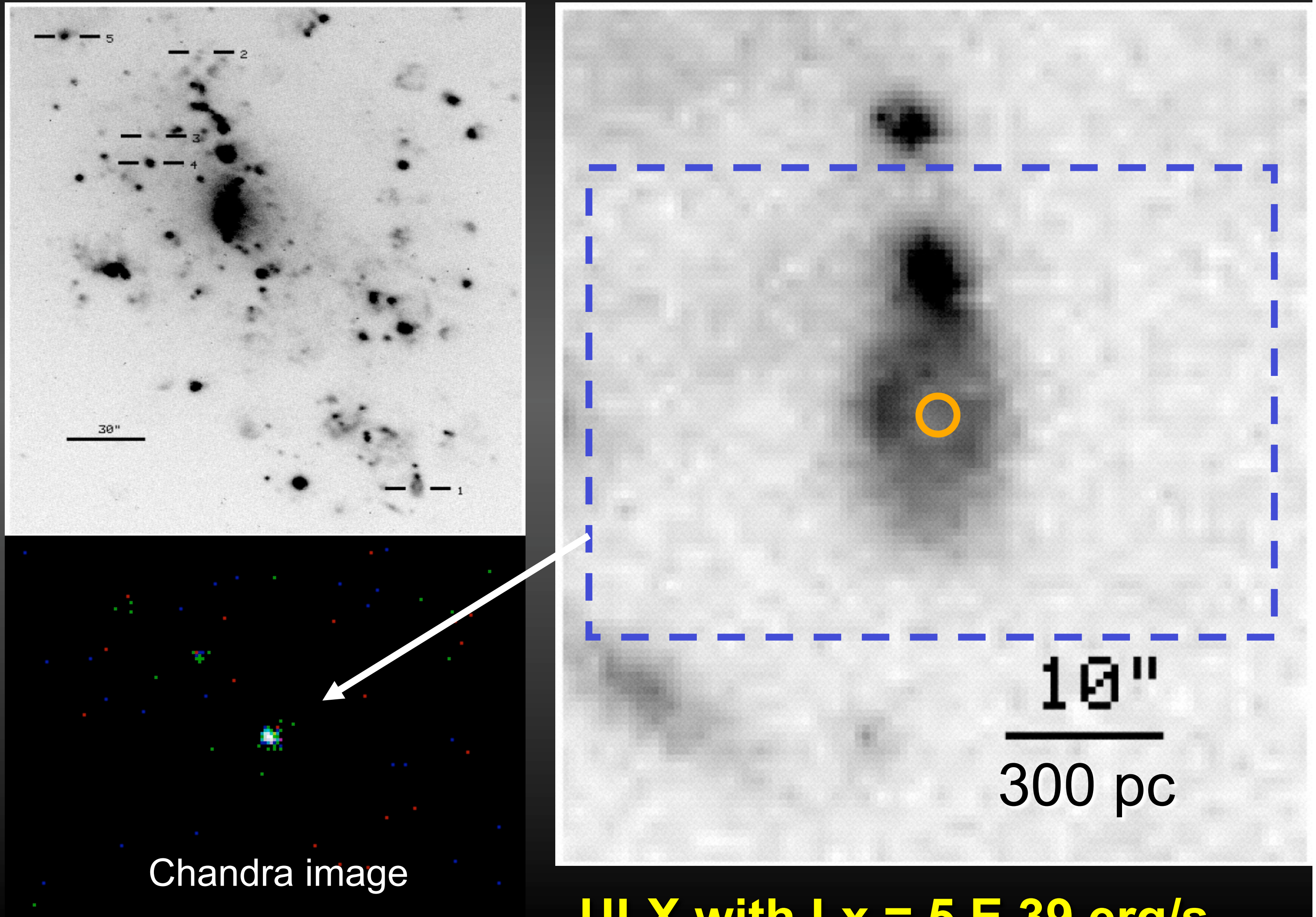




New discovery:
ULX & bubble in
NGC 5585
(d ~ 7 Mpc)

SDSS image

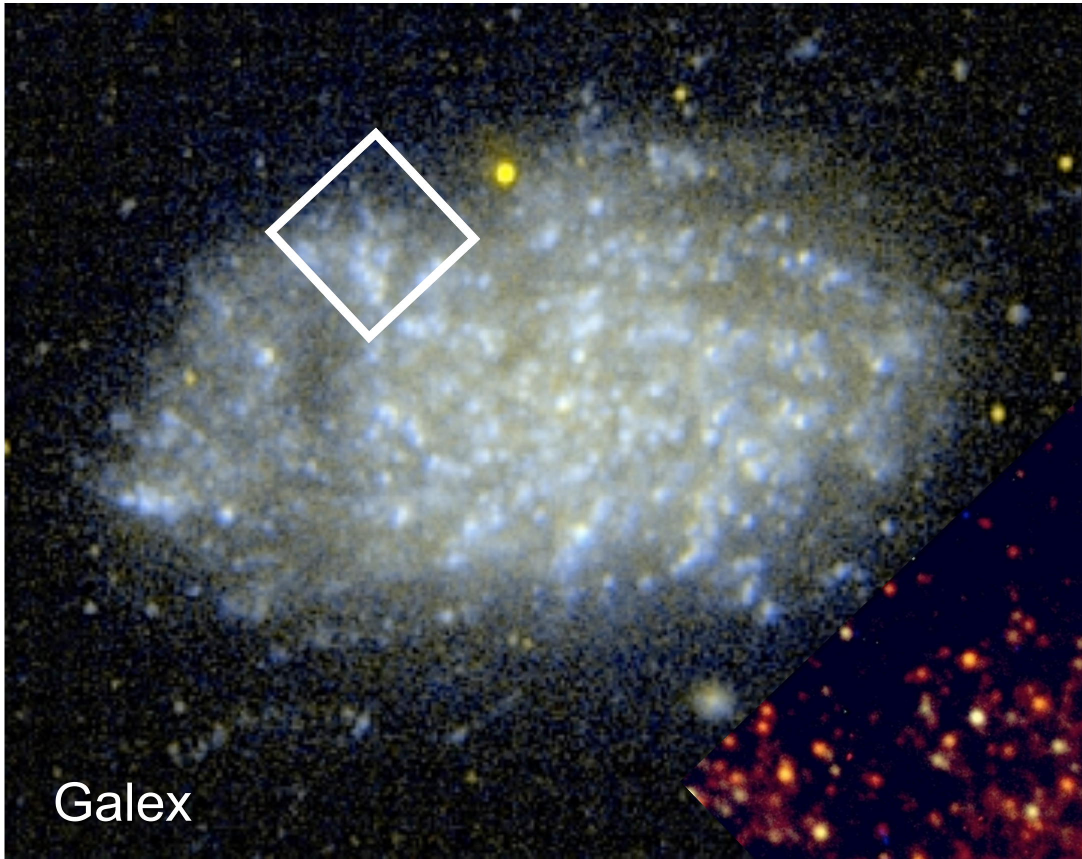
Check with Matonick & Fesen's Hα survey

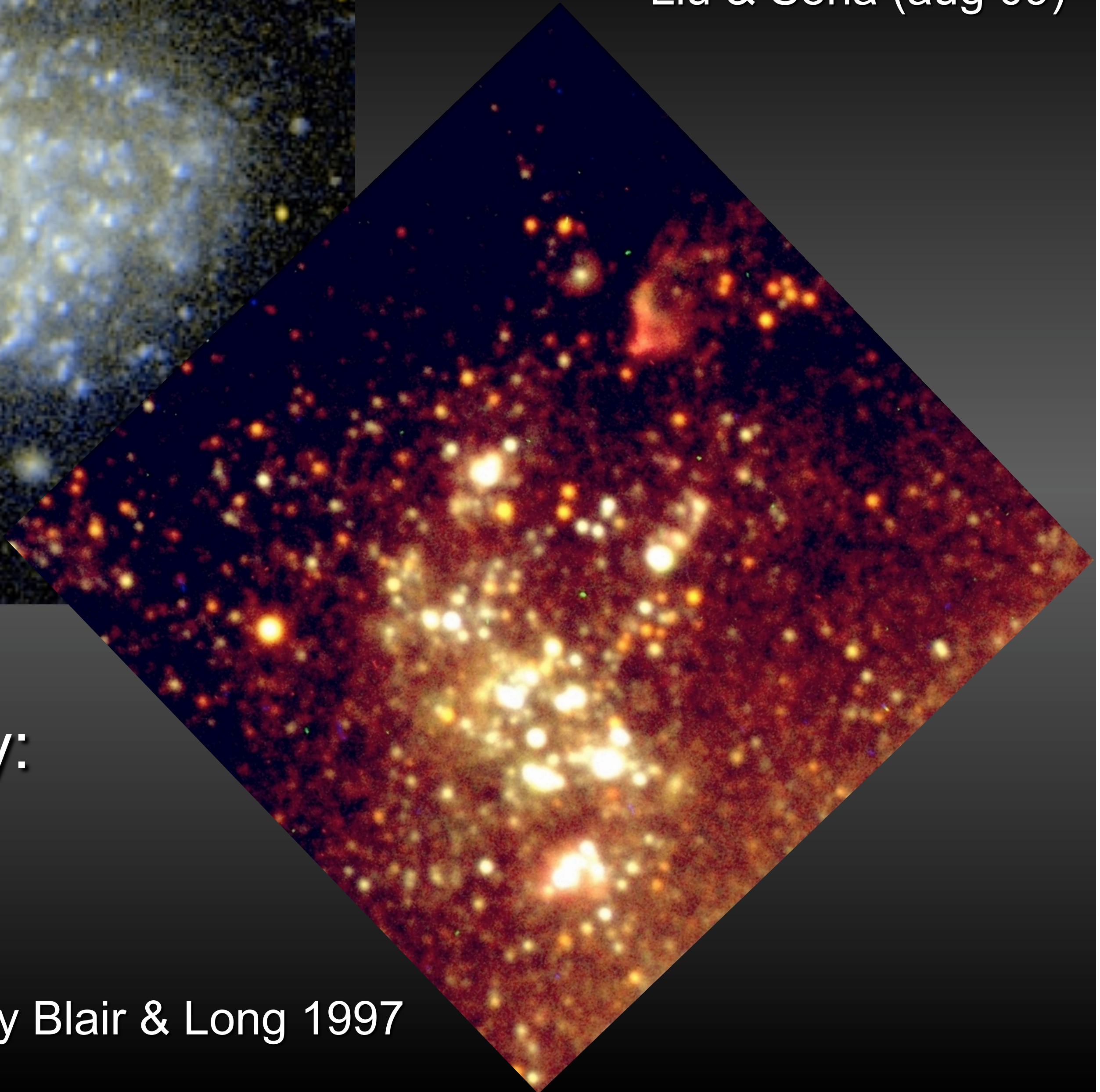


ULX with Lx = 5 E 39 erg/s

VLT image (BVR)

Liu & Soria (aug 09)





Another new entry:

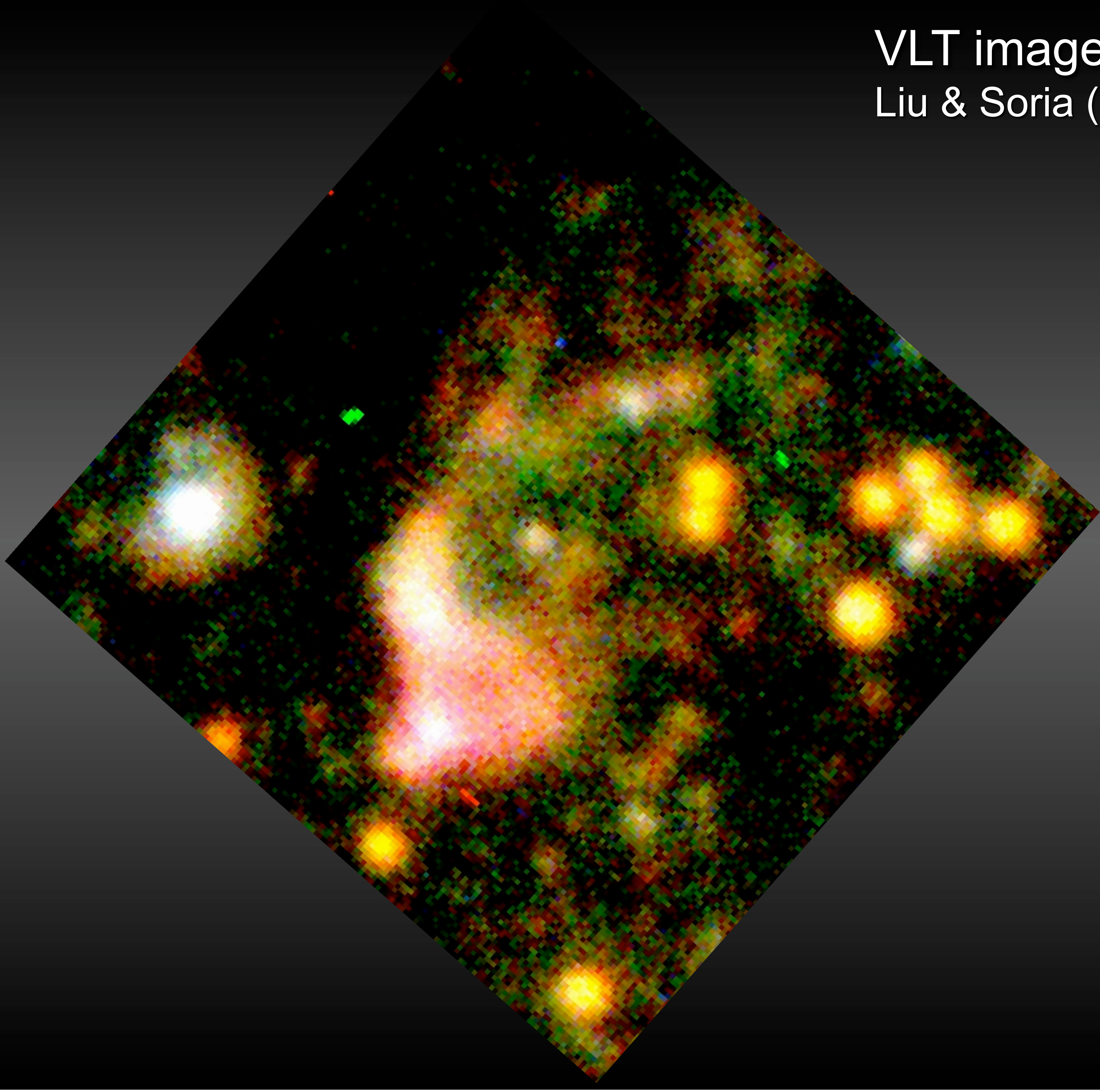
NGC 7793 S26

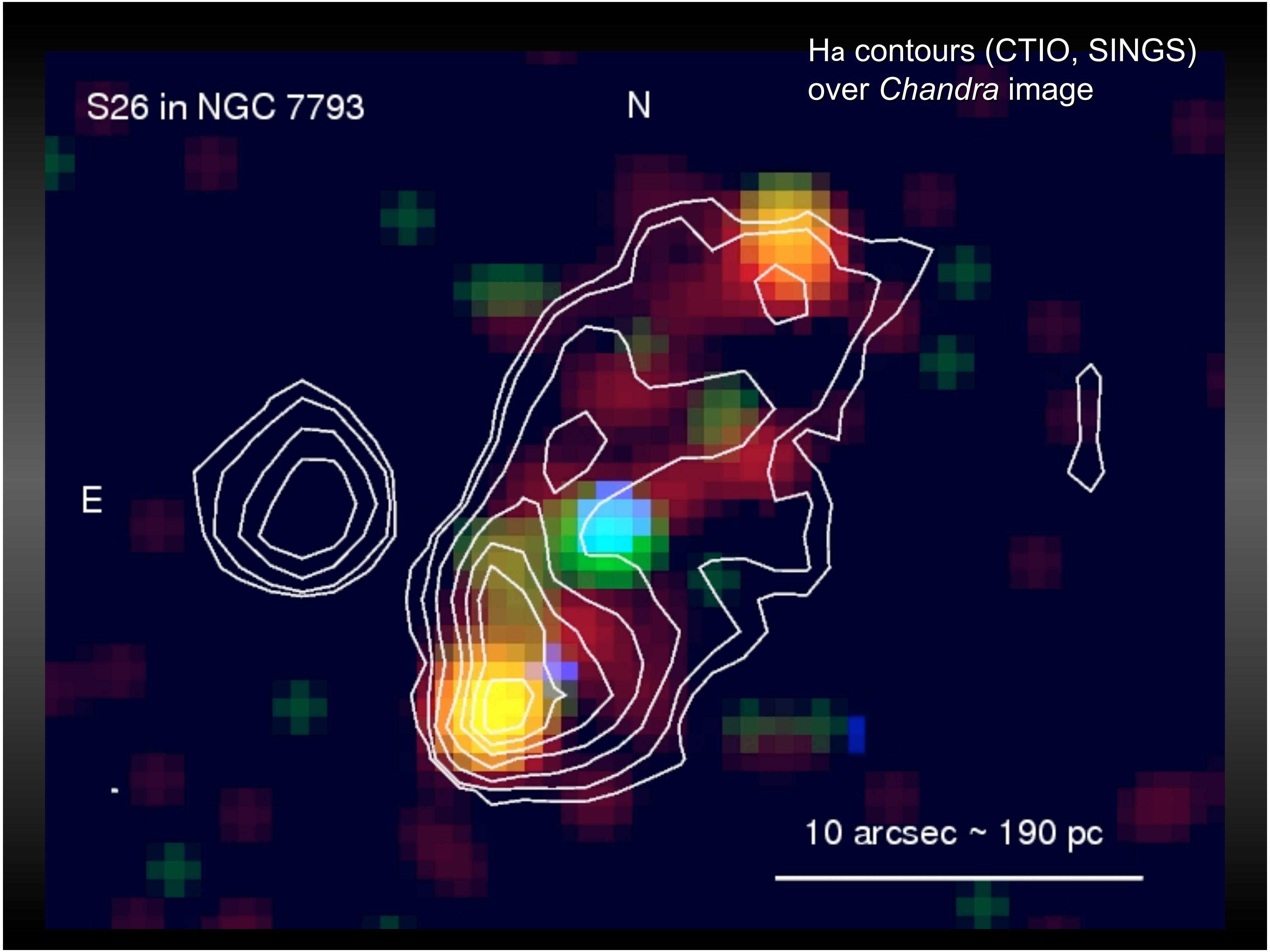
(d ~ 3.9 Mpc)

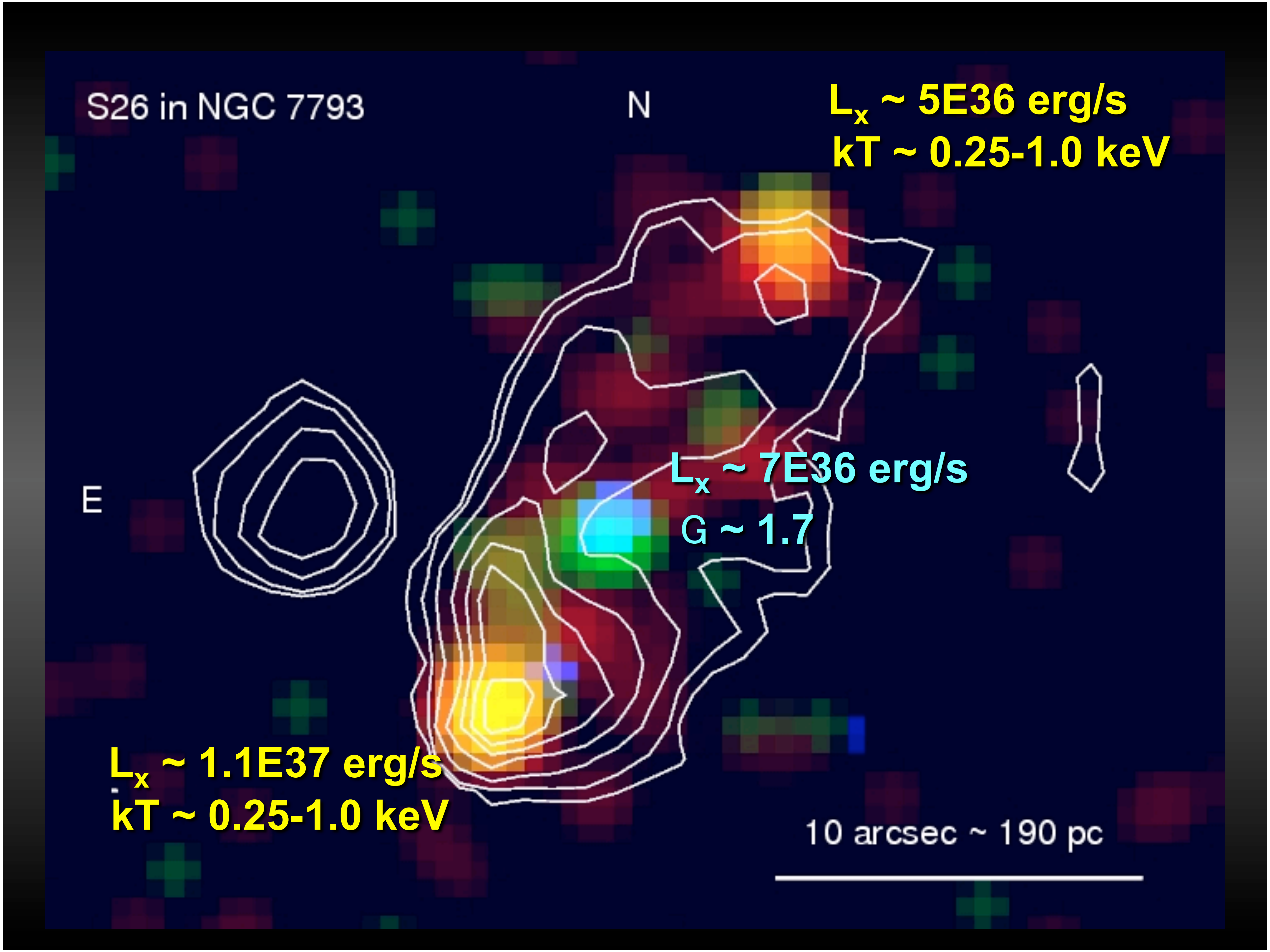
S26 nebula discovered by Blair & Long 1997

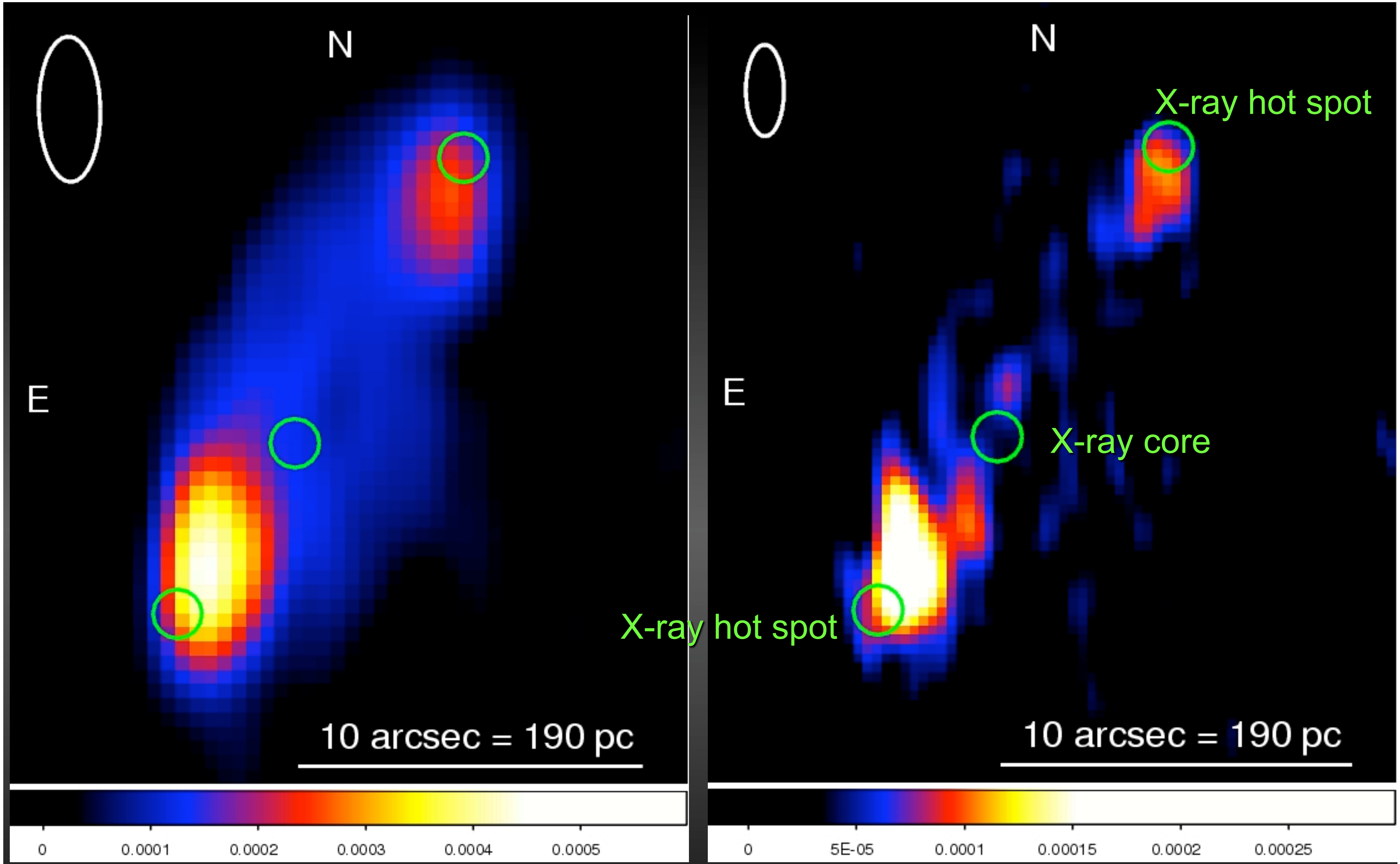
VLT image (BVR)

Liu & Soria (aug 09)




Hα contours (CTIO, SINGS)
over *Chandra* image
S26 in NGC 7793
N
E
10 arcsec ~ 190 pc


S26 in NGC 7793
N
E
L_x ~ 5E36 erg/s
kT ~ 0.25-1.0 keV
L_x ~ 7E36 erg/s
G ~ 1.7
L_x ~ 1.1E37 erg/s
kT ~ 0.25-1.0 keV
10 arcsec ~ 190 pc

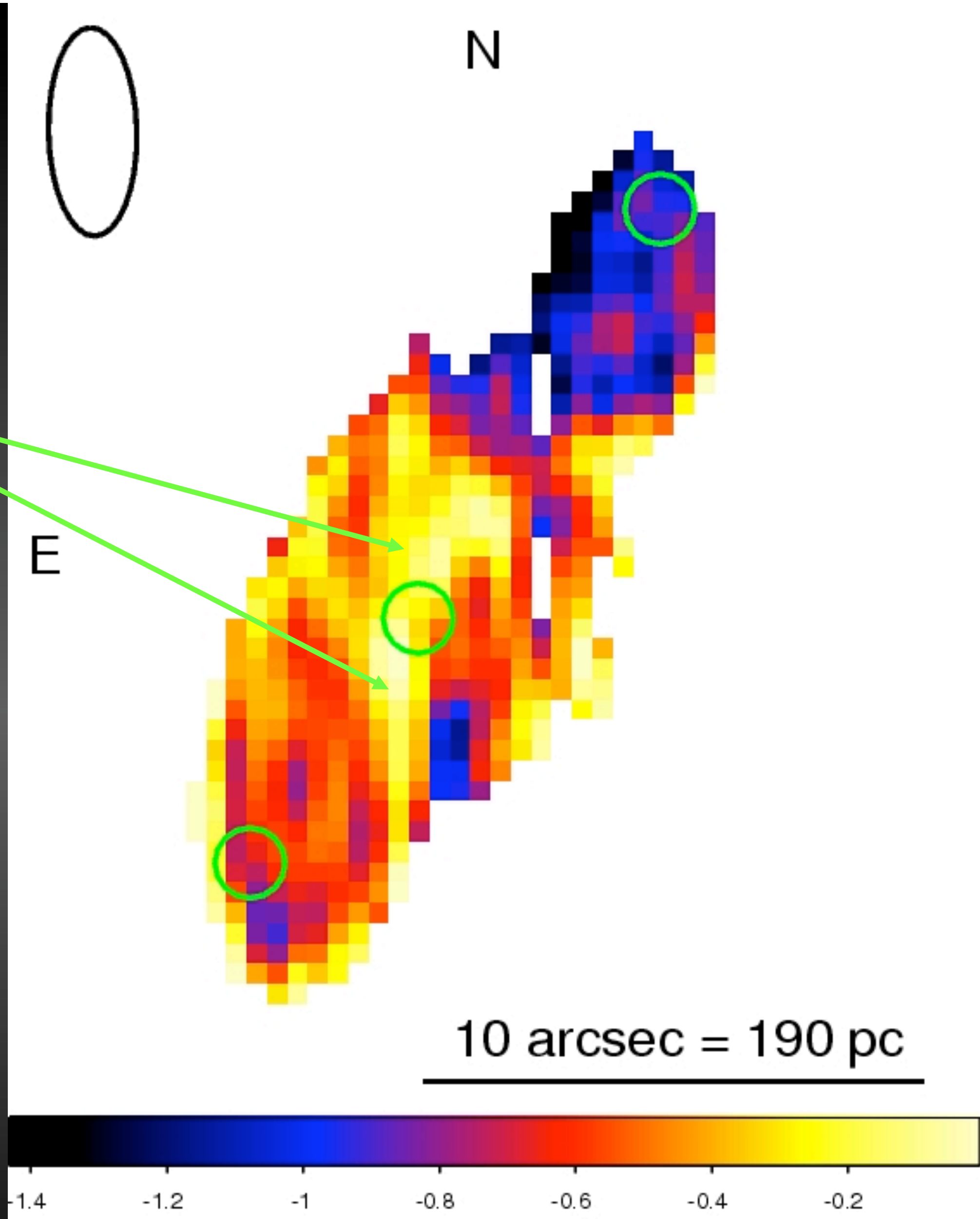


ATCA maps at 5.5 GHz (left) and 9 GHz (right)

(Soria et al 2009, arXiv:0912.2732)

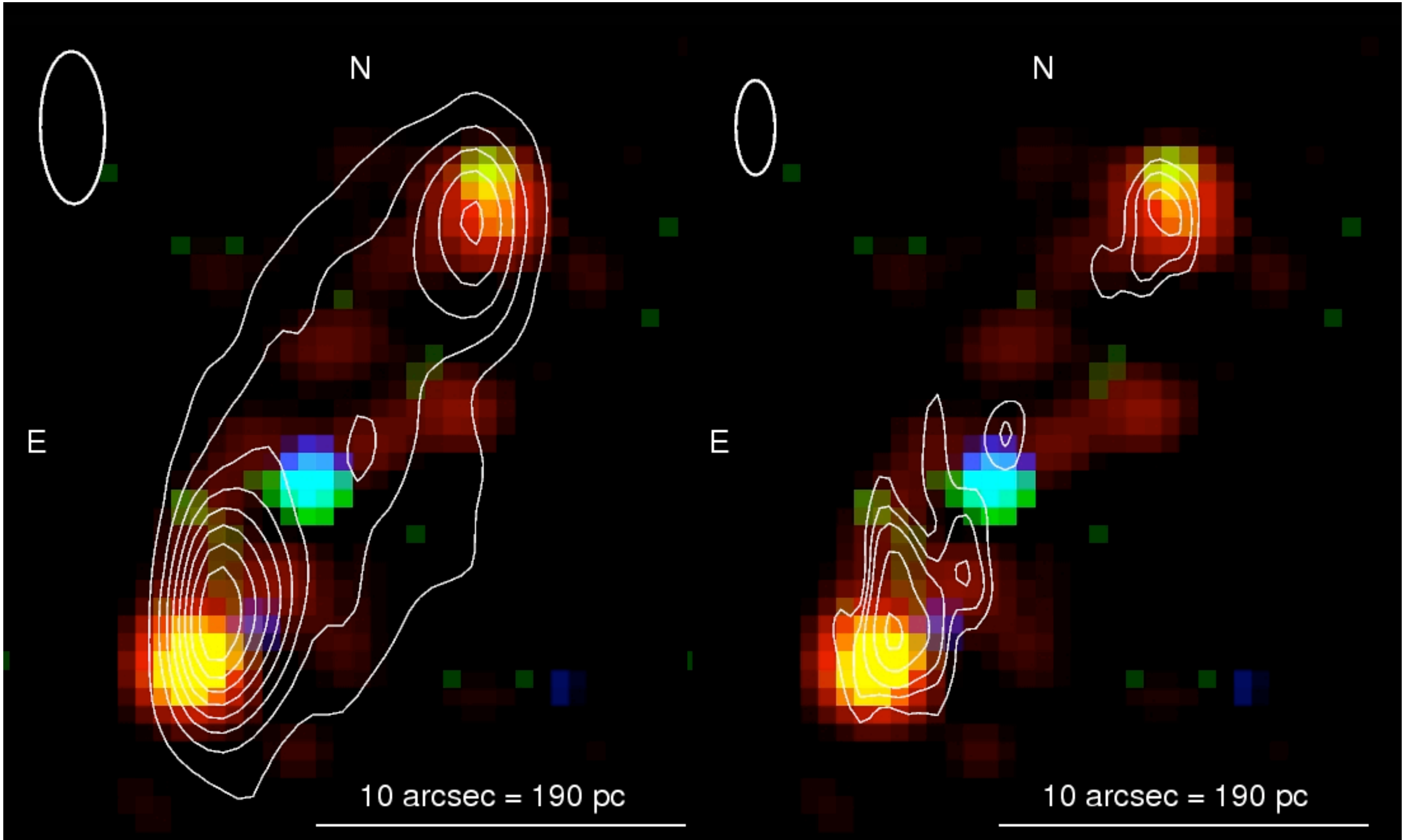
Inner jet has a flat spectrum
(recent ejections?)

Lobes have a steep spectrum



Spectral index map, from our 2009 ATCA data

(Soria et al 2009, arXiv:0912.2732)



ATCA contours (5.5 & 9 GHz) superposed over *Chandra* image

(Soria et al 2009, arXiv:0912.2732)

Energetics of ULX bubbles

Size 2R ~ 250 x 150 pc (typical sizes ~ 50 – 300 pc)

v_s ~ 300-400 km/s? (from T ~ 0.5 keV at shock front and Hα line width).

v ~ 80-100 km/s in other sources

$$n \sim 0.6\, I_{\alpha,-6}\, v_{100}^{-2.4}\ \mathrm{cm}^{-3}$$

Hα intensity for fully radiative shock (Dopita & Sutherland 1996)

→ $n \sim 0.1 – 1\ \mathrm{cm}^{-3}$

Two alternatives: SNR or jet-inflated (Pakull et al 2006)

$$E_{SNR} \sim 1.9 \times 10^{52}\, R_{100}^{3}\, v_{100}^{2}\, n\ \mathrm{erg}$$

$$P_J \sim 3.8 \times 10^{39}\, R_{100}^{2}\, v_{100}^{3}\, n\ \mathrm{erg/s}$$

Energetics of ULX bubbles

$$E_{SNR} \sim \text{few}\, 10^{52} \ \text{erg}$$

$$P_J \sim 5\times 10^{39} \ \text{erg/s}$$ over an age

$$\tau \approx (3/5)(R/v) \sim 2\times 10^5 - 1\times 10^6 \ \text{yrs}$$

Arguments AGAINST SNR scenario

Too energetic
SNR don’t survive that long
No O stars available to explode 1 Myr ago
(ULXs surrounded by B stars with ages ~ 10-20 Myr)

Energetics of ULX bubbles

ULX bubbles inflated by jets and winds

$$P_J \sim 5\times 10^{39}\ \text{erg/s}$$ over an age

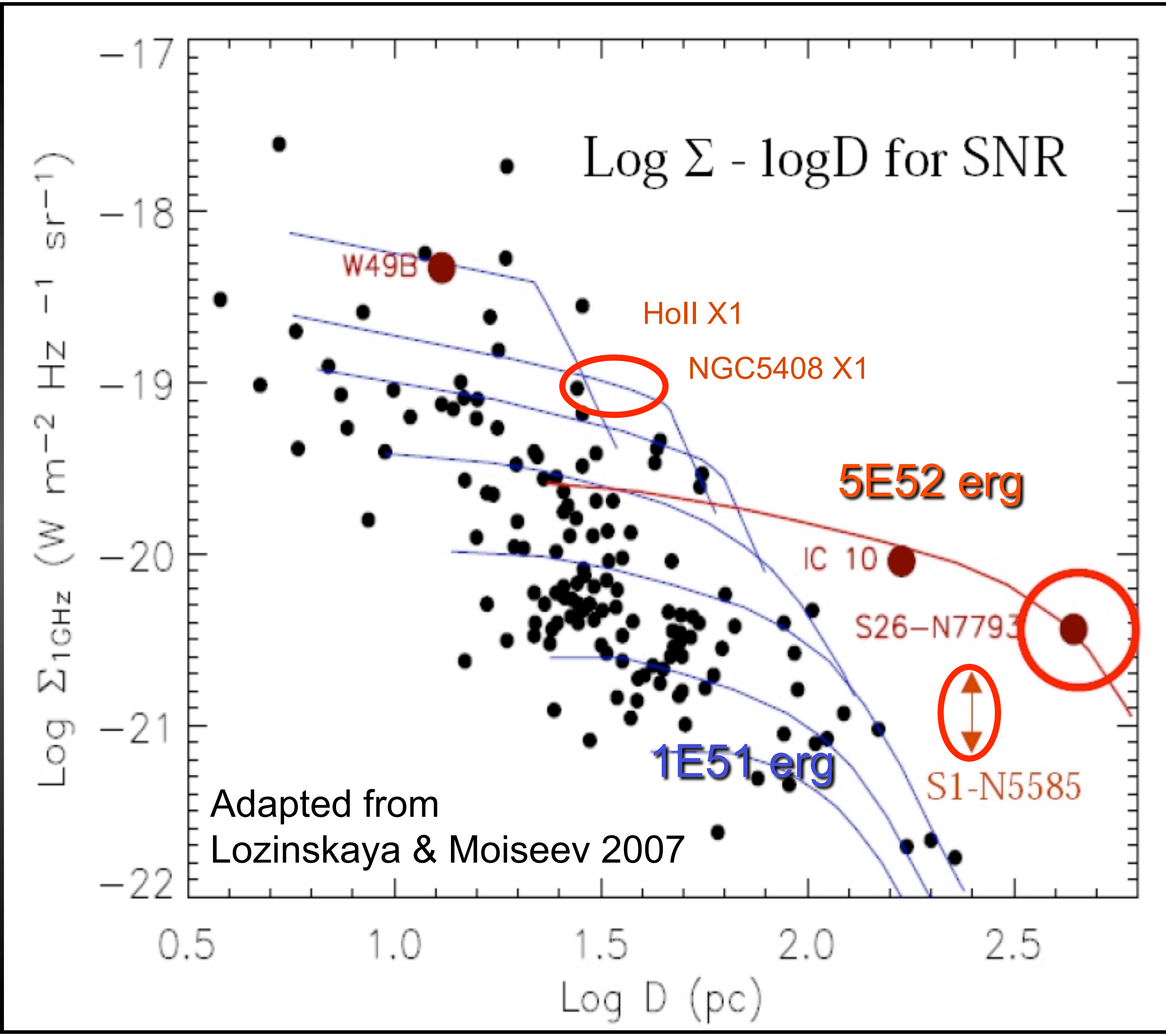
$$\tau \approx (3/5)(R/v) \sim 2\times 10^5 - 1\times 10^6\ \text{yrs}$$

Age of the active phase of mass transfer

Energy consistent with E inferred from resolved radio-synchrotron ULX nebulae (flux + slope)

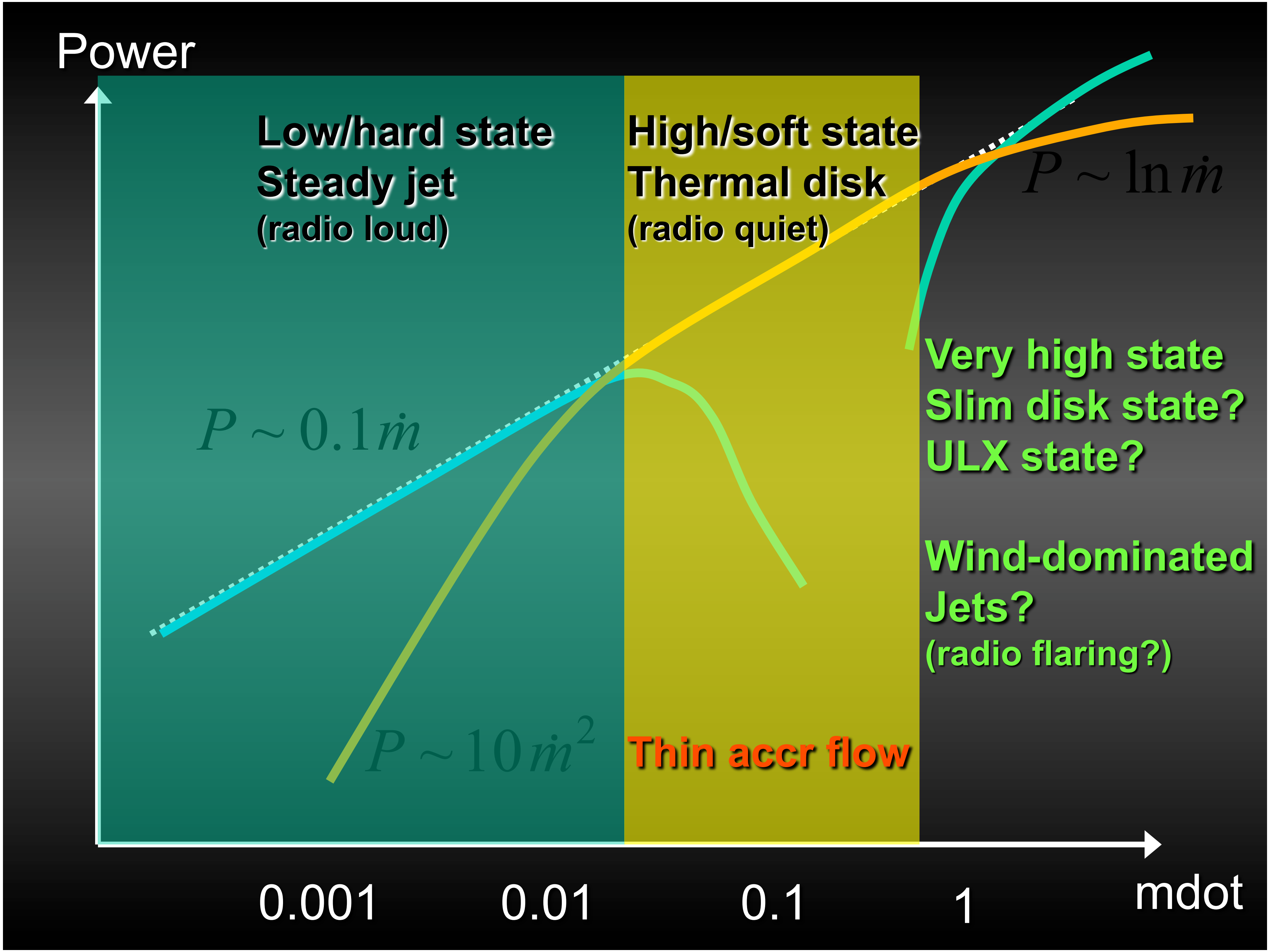
Age consistent with nuclear timescale of B donor evolving off the main sequence (filling the RL)

(stellar evolution models by Rappaport, Podsiadlowski et al)


Log Σ - logD for SNR
W49B
HoII X1
NGC5408 X1
5E52 erg
IC 10
S26–N7793
S1-N5585
1E51 erg
Adapted from
Lozinskaya & Moiseev 2007
Log D (pc)
Log Σ1GHz (W m−2 Hz −1 sr−1)
−17
−18
−19
−20
−21
−22
0.5
1.0
1.5
2.0
2.5

Fundamental problem:

radiative versus mechanical power in accreting BHs


Power
Low/hard state
Steady jet
(radio loud)
High/soft state
Thermal disk
(radio quiet)
$P \sim \ln \dot{m}$
Very high state
Slim disk state?
ULX state?
$P \sim 0.1\dot{m}$
Wind-dominated
Jets?
(radio flaring?)
$P \sim 10\dot{m}^2$
Thin accr flow
0.001
0.01
0.1
1
mdot

In Galactic BHs:

steady jet power <~ 1/100 Eddington power

P_{jet} <~ few E37 erg/s for 10-M_{sun} BHs

At least some ULX bubbles inflated by jets

Long-term-avg jet power required >~ few E39 erg/s

Does this imply BH masses ~ 1000 M_{sun} in ULXs?

Personal opinion: No, not enough evidence of IMBH

(recall Tim Roberts' arguments against IMBHs)

Two poorly understood properties of ULXs

Average jet power may be >~ few E 39 erg/s

X-ray spectrum often dominated
by hard power-law even at L_x ~ 1E40 erg/s

(To be discussed at Ferrara workshop)

Speculation:

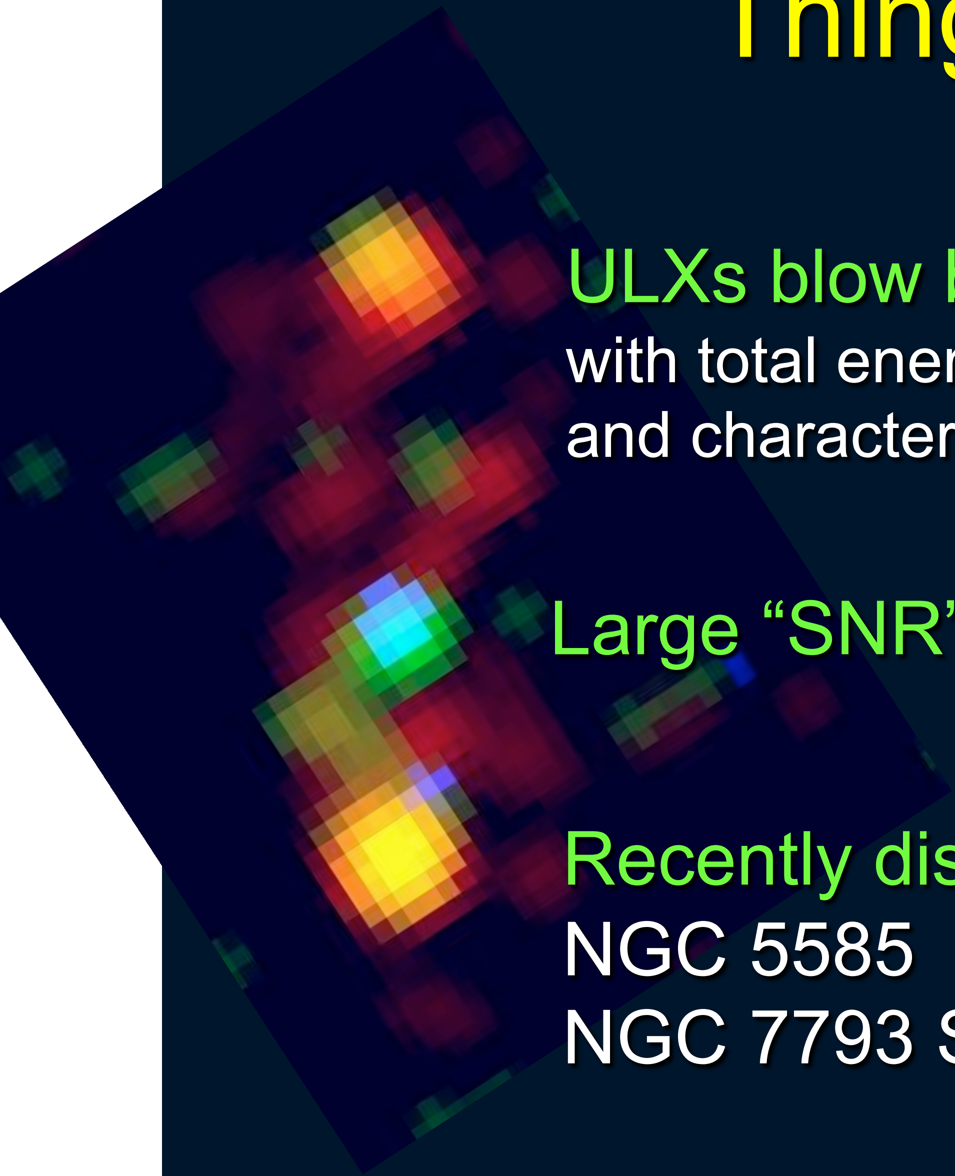
Many ULXs never switch to thermal-dominant state

Never collapse the flow to a thin standard disk

Never suppress the jet, even at mdot → 1

(low/hard ←→ high/hard states)

Things we know



ULXs blow bubbles

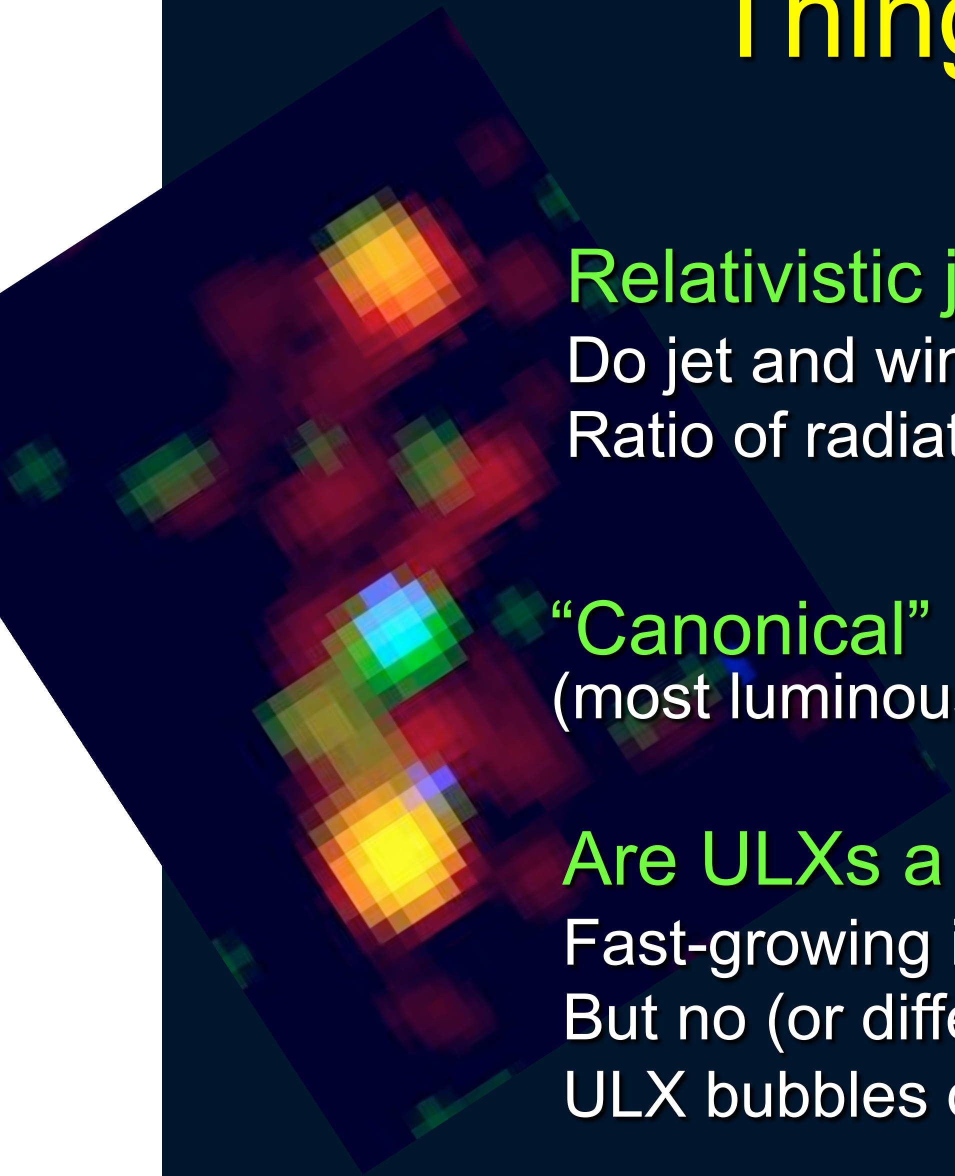
with total energy >~ 1E52 erg
and characteristic age ~ 0.2 - 1 MYr

Large "SNR" are more likely ULX bubbles

Recently discovered bubbles:

NGC 5585 X1: contains active ULX
NGC 7793 S26: contains X-ray triple:
two (jet) hot spots and
a central BH in low/hard state

Things we don’t know



Relativistic jets or massive winds in ULXs?

Do jet and winds coexist when mdot >~ 1 ?
Ratio of radiative/mechanical power at mdot >~ 1 ?

“Canonical” ULX accretion states?

(most luminous ULXs have hard power-law spectrum)

Are ULXs a good analogy for quasars?

Fast-growing in the early universe with mdot > 1
But no (or different) feedback in ULXs:
ULX bubbles do not shut off BH accretion from star