How ULXs heat the surrounding gas

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Department of the Premier and Cabinet
Office of Science

Overview

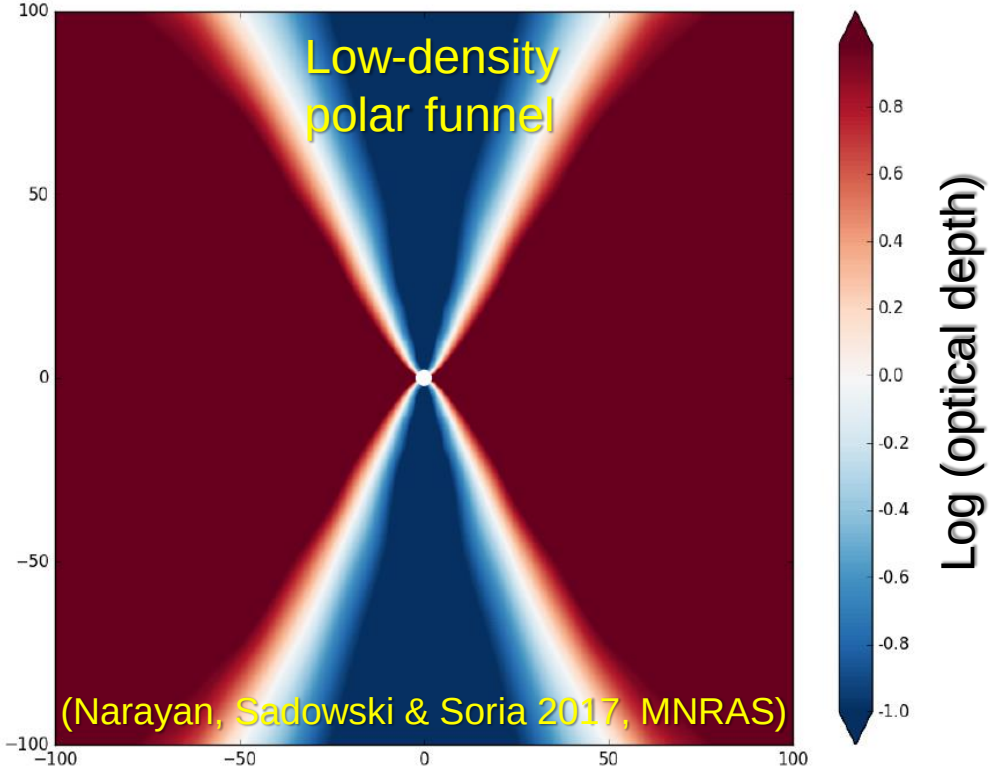
1. Collimated jets (radio synchrotron emission)

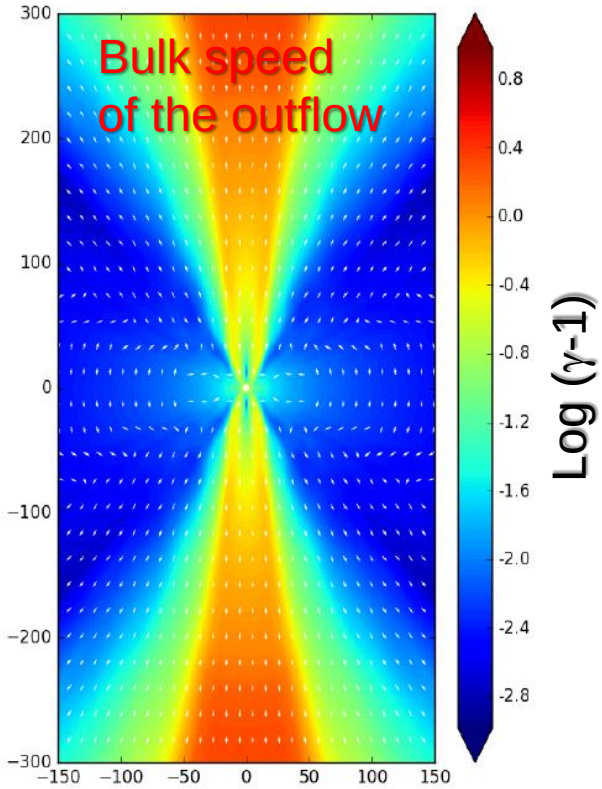
2. ULX bubbles (photo-ionized and shock-ionized)

3. Massive outflows (supersoft spectra)

Jets in the super-Eddington regime

Theoretical models always predict jets





Observations still inconclusive

Evidence of jets in some sources but not in others

Often difficult to prove super-Edd accretion

Radio emission from ULXs

Possible origin of synchrotron radio emission

i) steady jet *[unresolved, flat spectrum]*

ii) flaring jet, discrete ejecta *[size <~ 0.1", steep spectrum]*

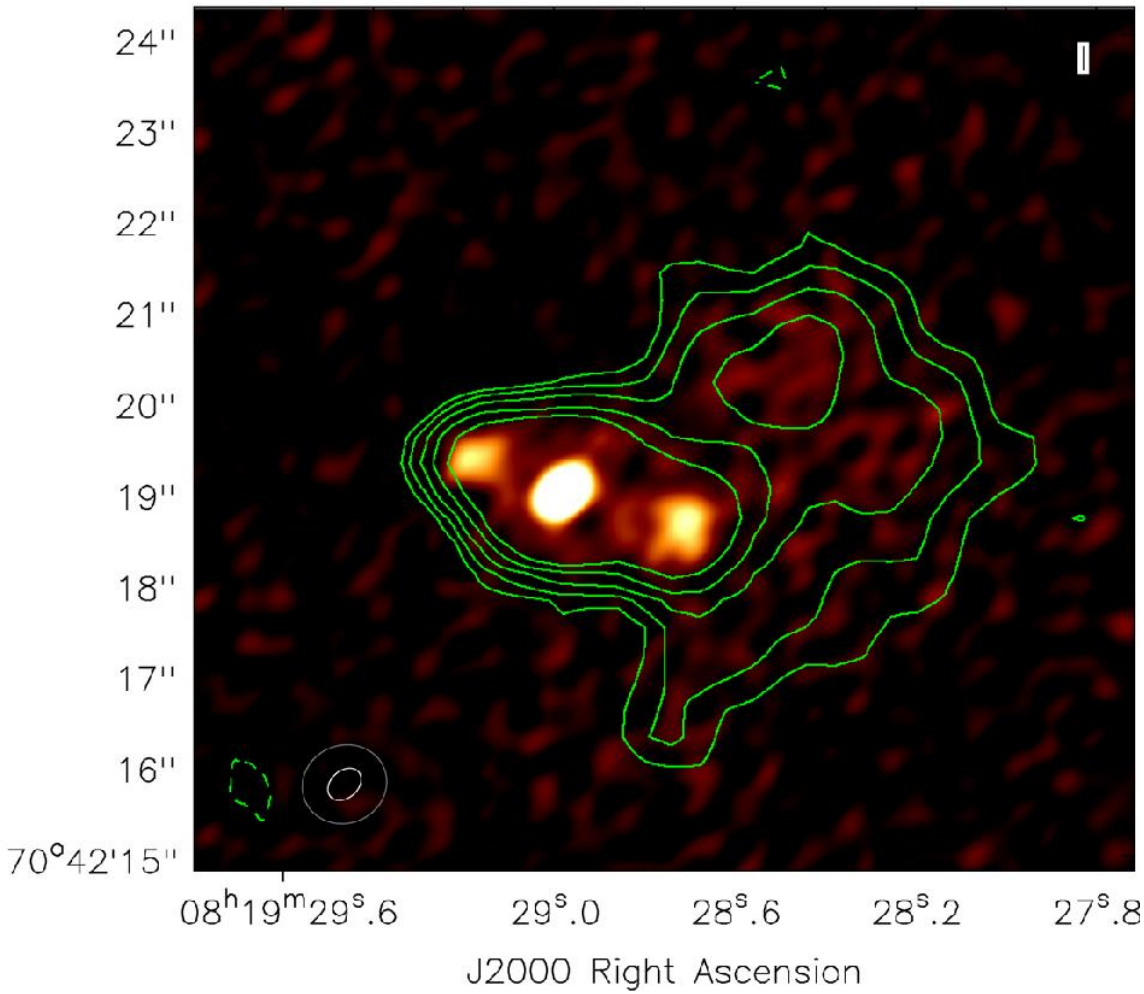
iii) internal shocks (re-acceleration) *[size ~ 1"—10", steep sp.]*

iv) hot spots, lobes, bubble = jet/ISM interaction
[size ~ 1"—10" , steep spectrum]

Three main unknown quantities:

L_R / L_X, L_R / P_J, $P_J / (\dot{m} c^2)$

Radio emission from flaring ULX jets



$L_R \sim 1 \times 10^{34}$ erg/s

$P_J \sim 2 \times 10^{39}$ erg/s

$L_X \sim 4 \times 10^{39}$ erg/s

Steep radio spectrum

Flaring jet in Holmberg II X-1 (Cseh et al 2014,2015)

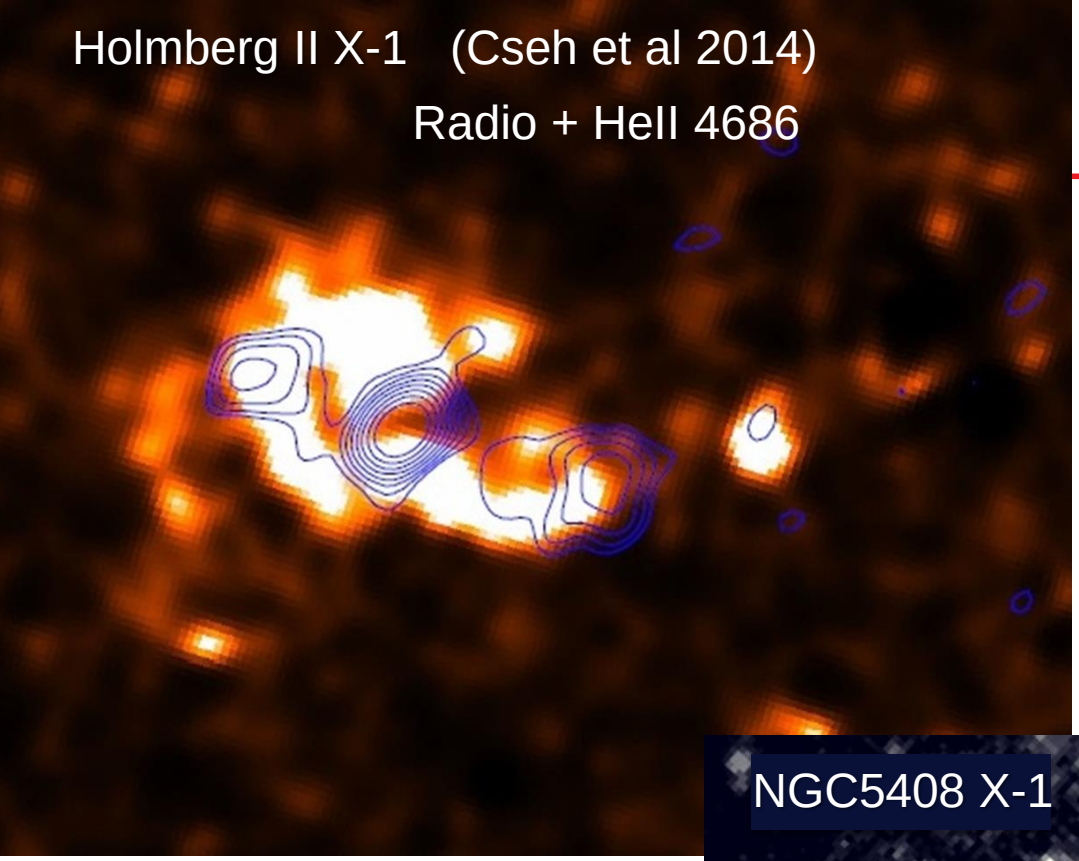


Photo-ionized bubbles

Optical lines:

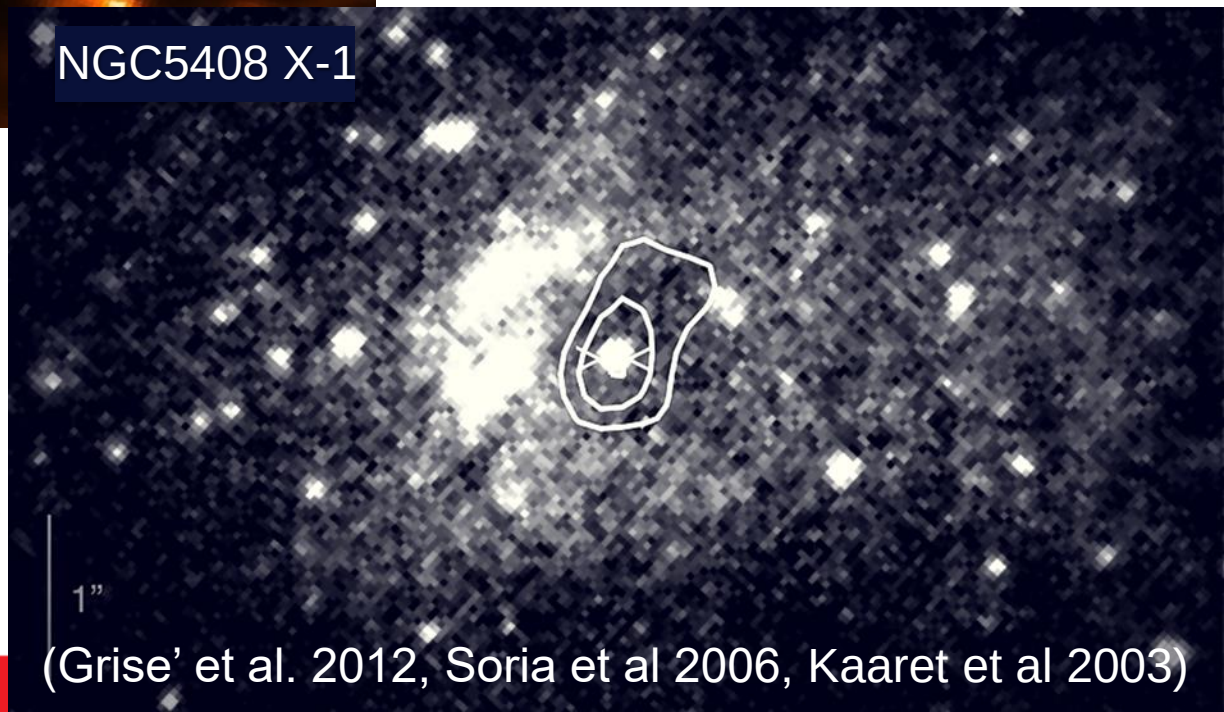
HeII 4686, [O III], [O I], Hα

Radio emission = jets

(optically-thin synchrotron)

P_{jet} ~ a few 10^{39} erg/s

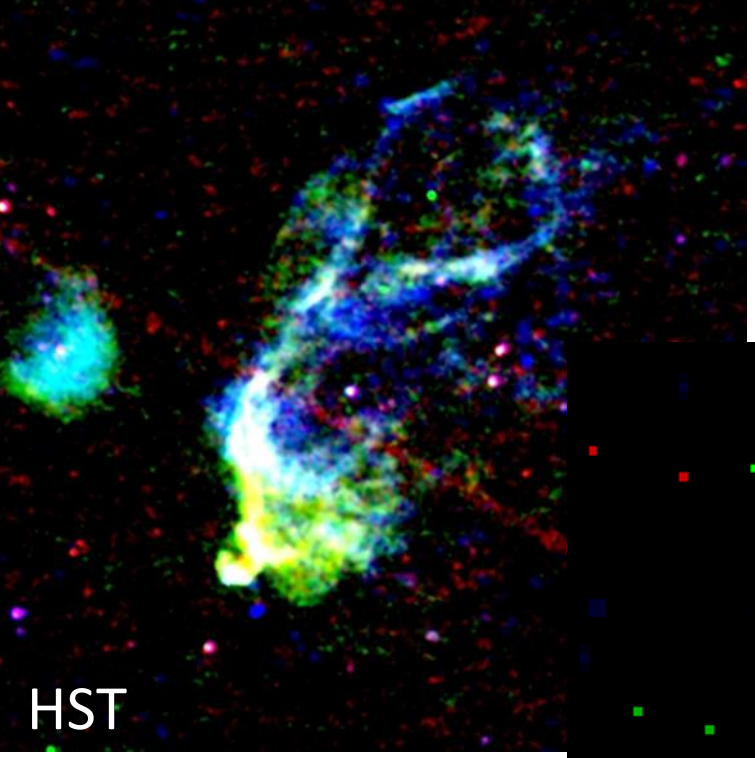
inferred from the radio emission

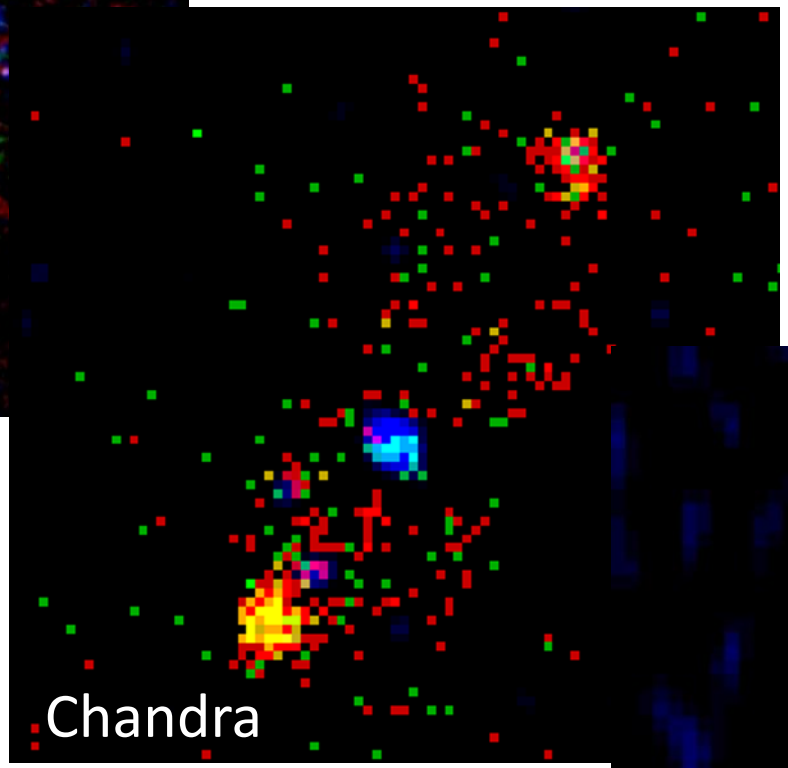


(Grise’ et al. 2012, Soria et al 2006, Kaaret et al 2003)

Jet-inflated bubble

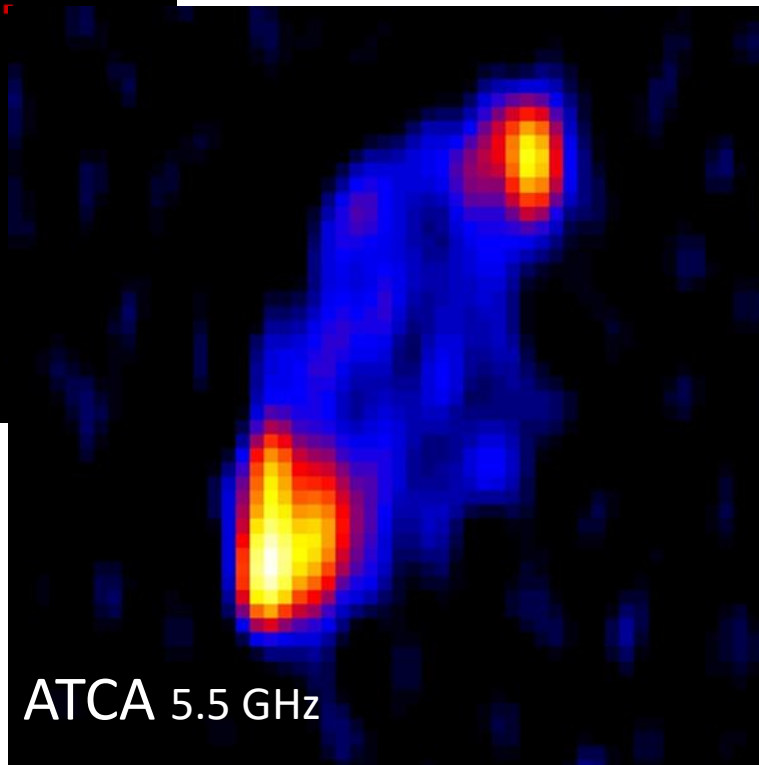
S26 microquasar in NGC7793





Pakull, Soria & Motch (2010)
Soria et al (2010)

diameter ~ 270 pc



X-ray & radio hot spots

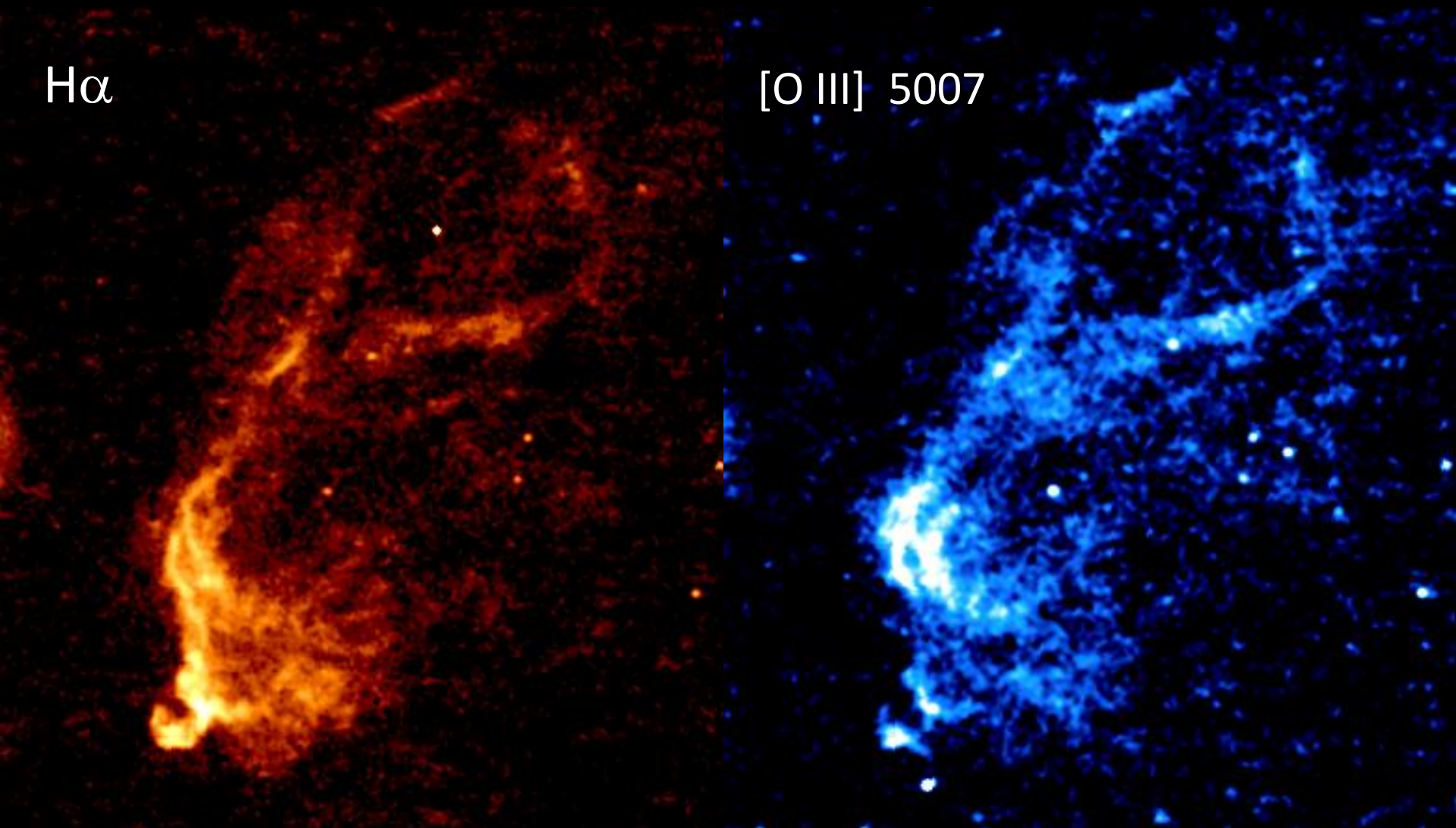
$P_J \sim 10^{40}$ erg/s > (apparent) L_X

L_{5GHz} (bubble) ~ 10^{35} erg/s

S26 microquasar in NGC7793

Shock-ionized bubble

Age ~ 300,000 yrs, v ~ 270 km/s



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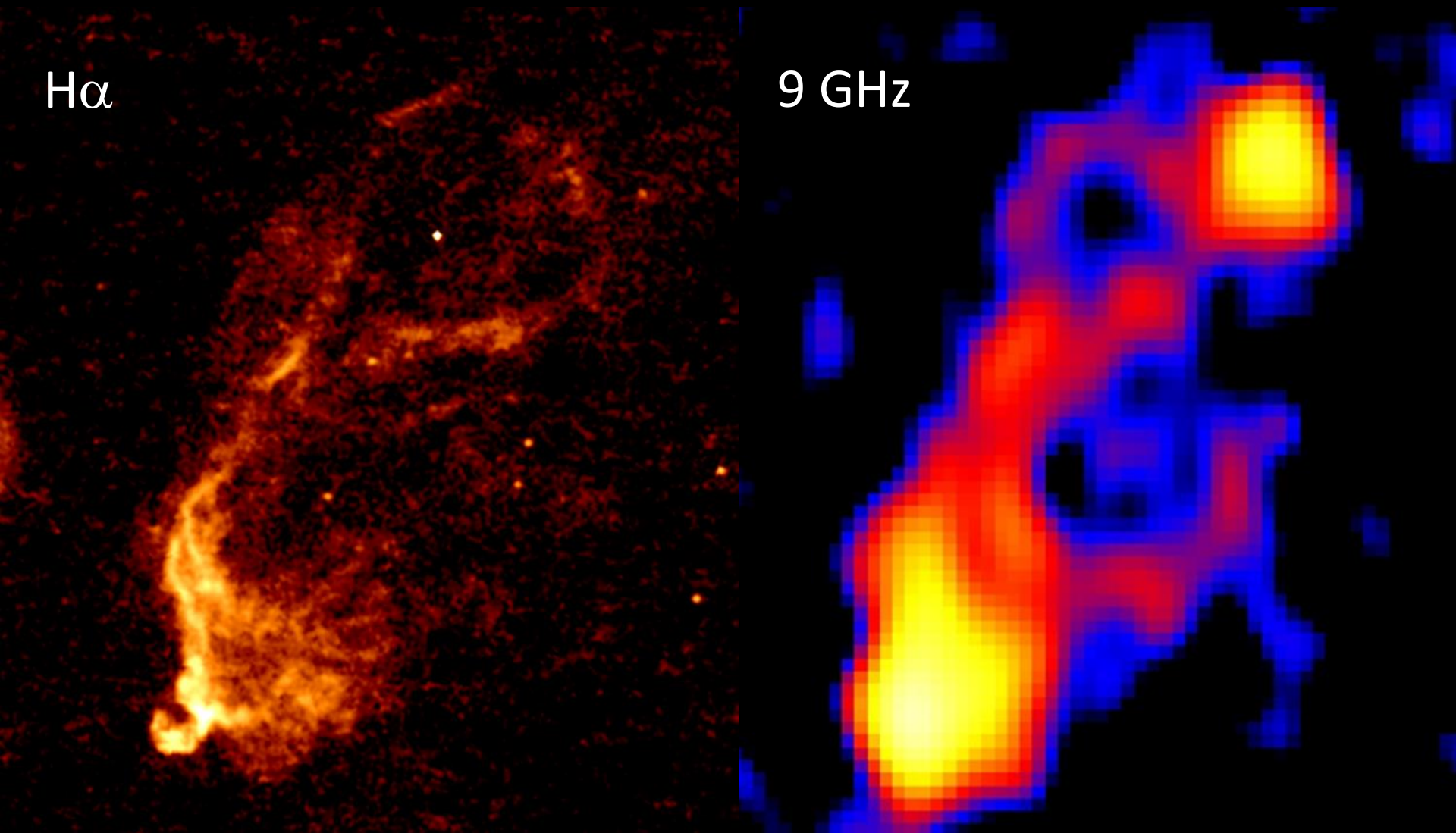
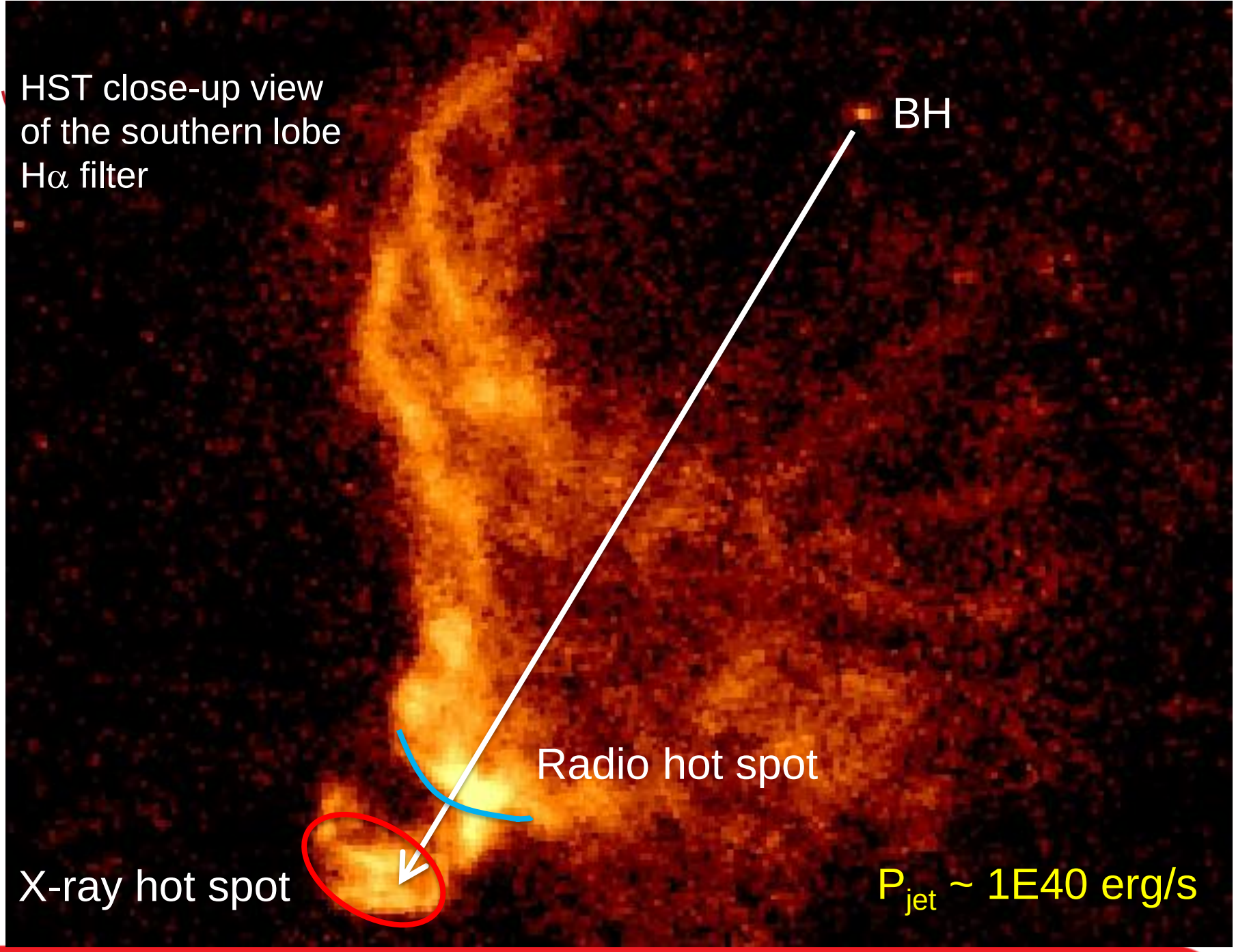
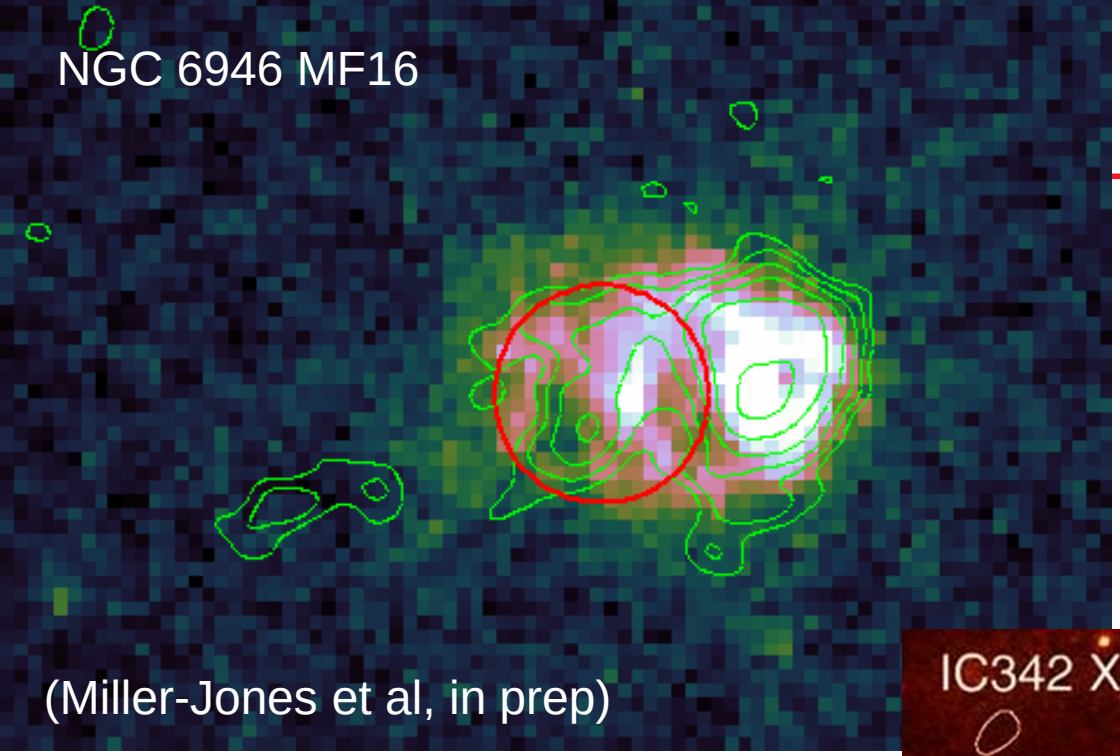



HST close-up view
of the southern lobe
Hα filter
BH
Radio hot spot
X-ray hot spot
P_{jet} ~ 1E40 erg/s

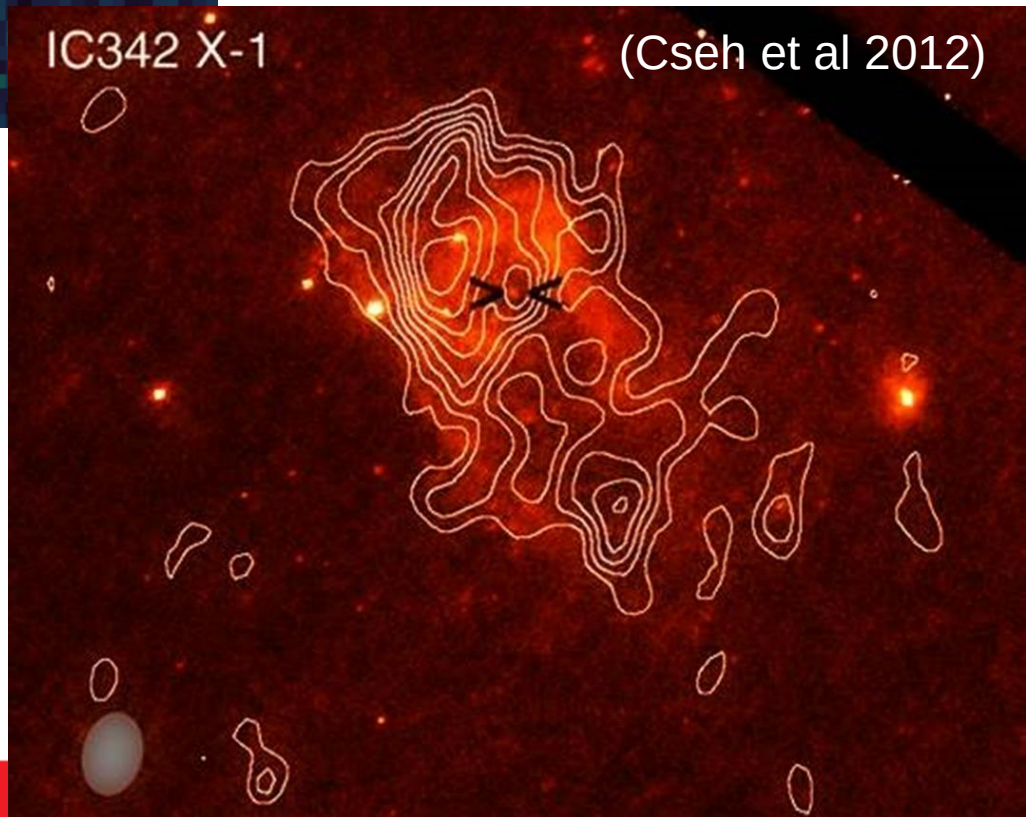
Jet-inflated bubbles

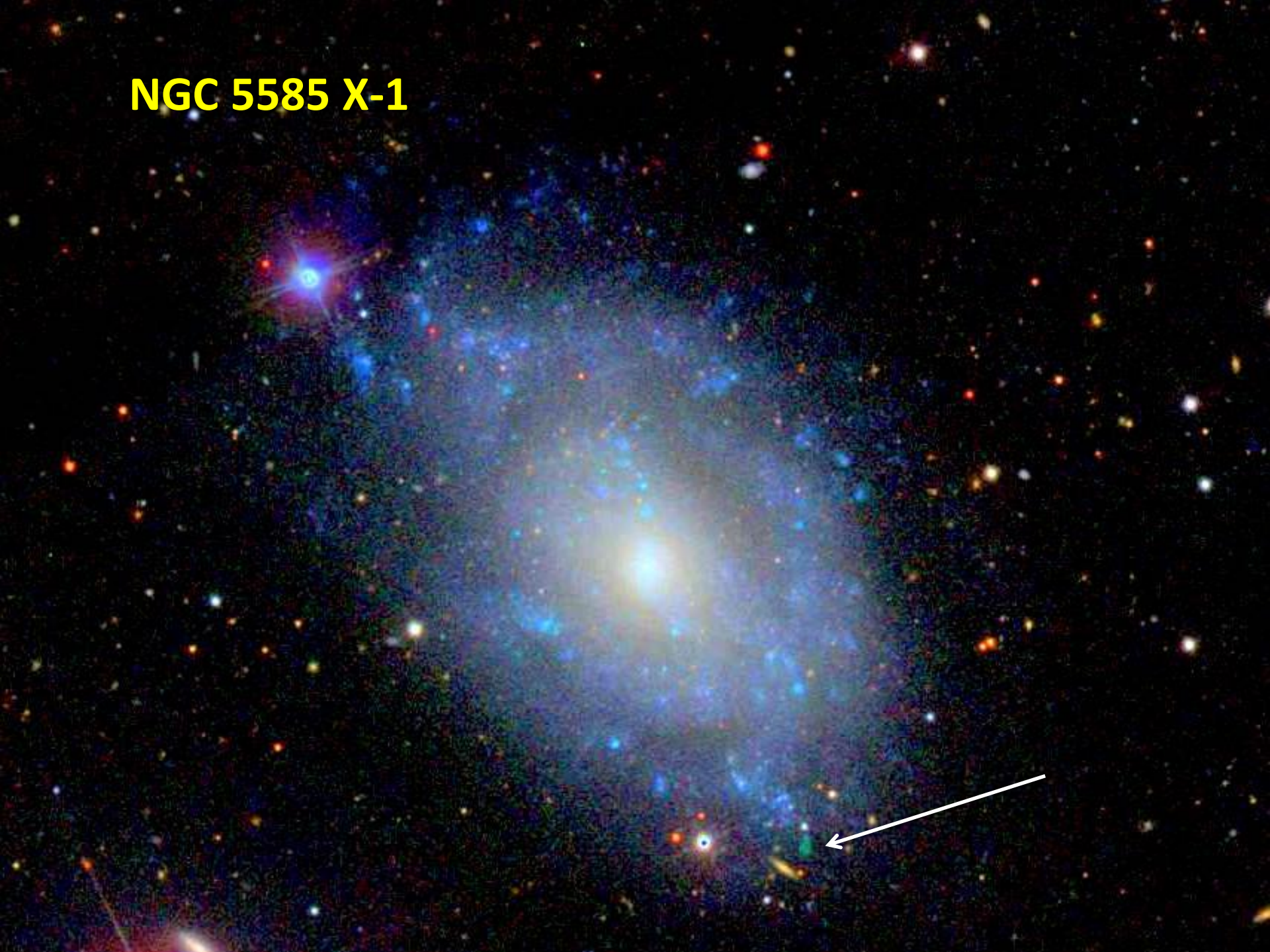


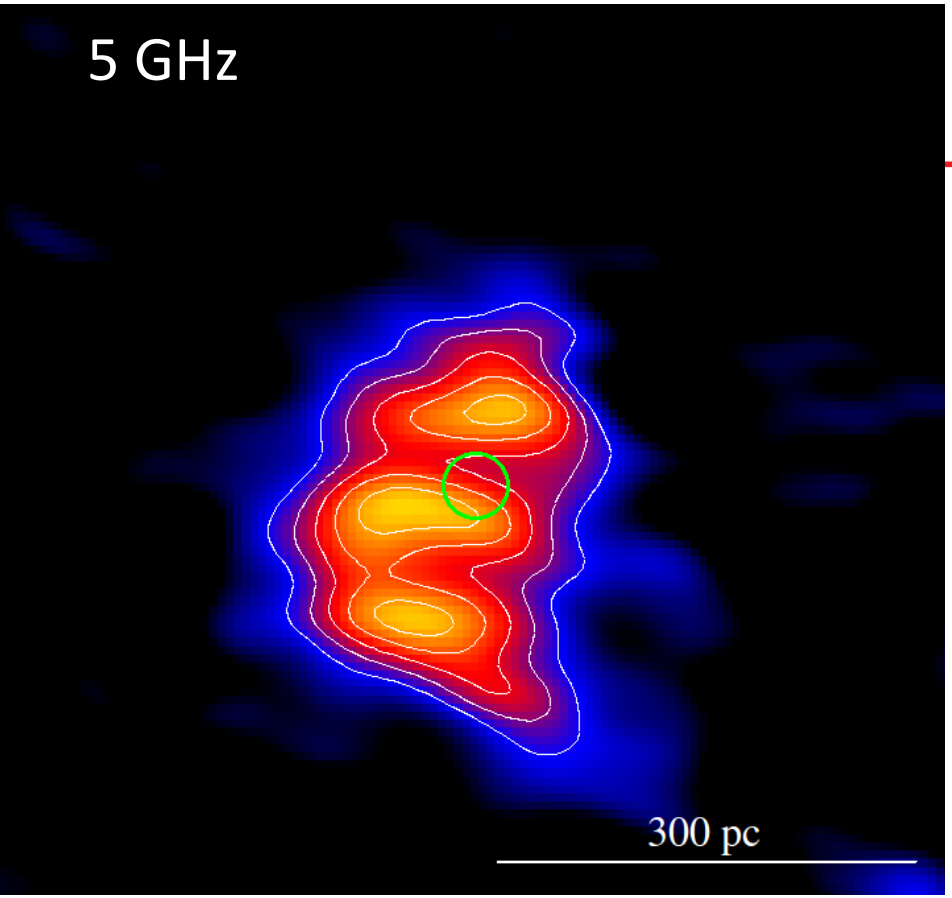
Optical images
+ radio contours

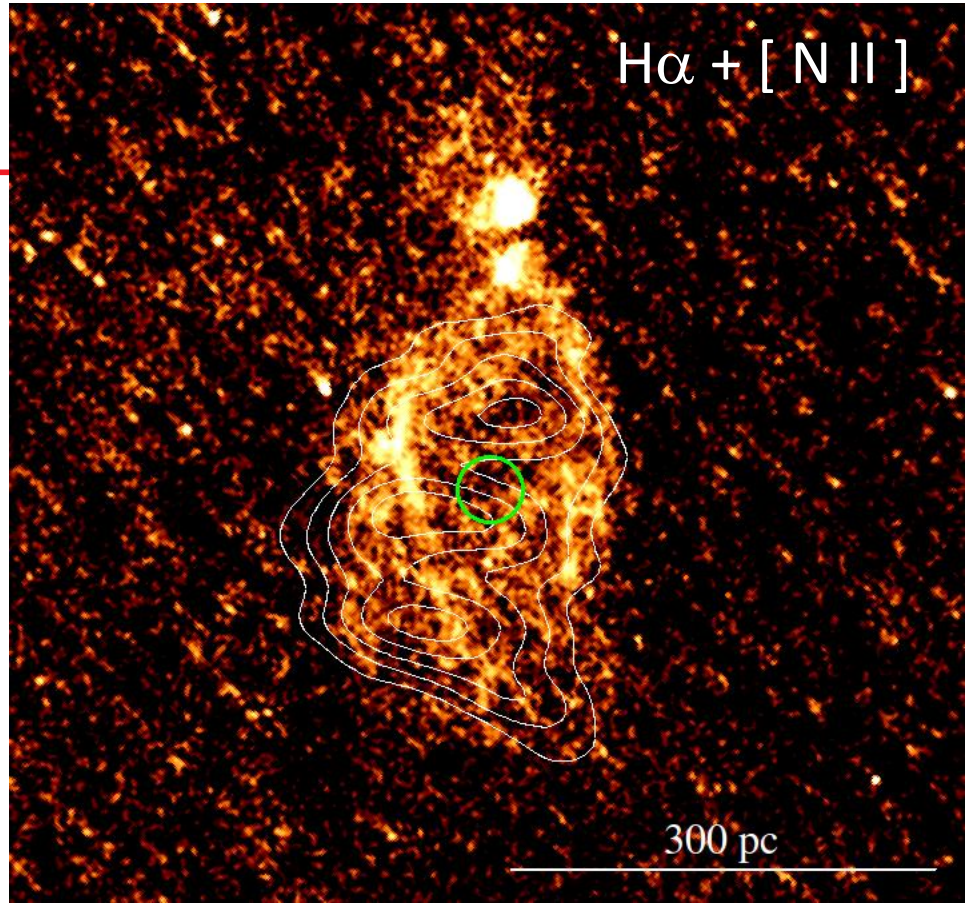
P_J ~ a few 10^{39} erg/s

L_{5GHz} (bubble) ~ 10^{35} erg/s




NGC 5585 X-1



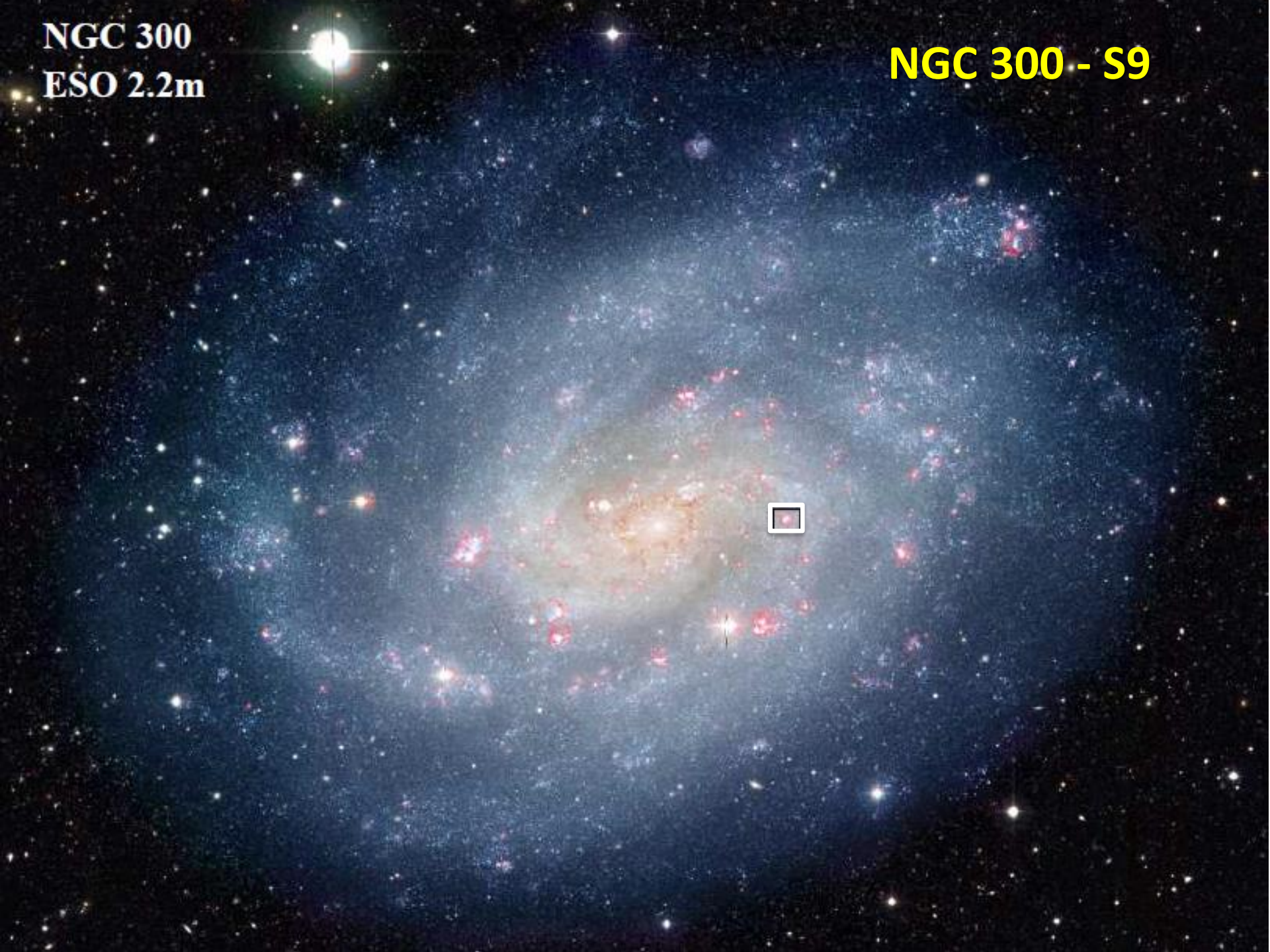


NGC 5585 X-1

ULX + shock-ionized optical bubble + radio synchrotron bubble

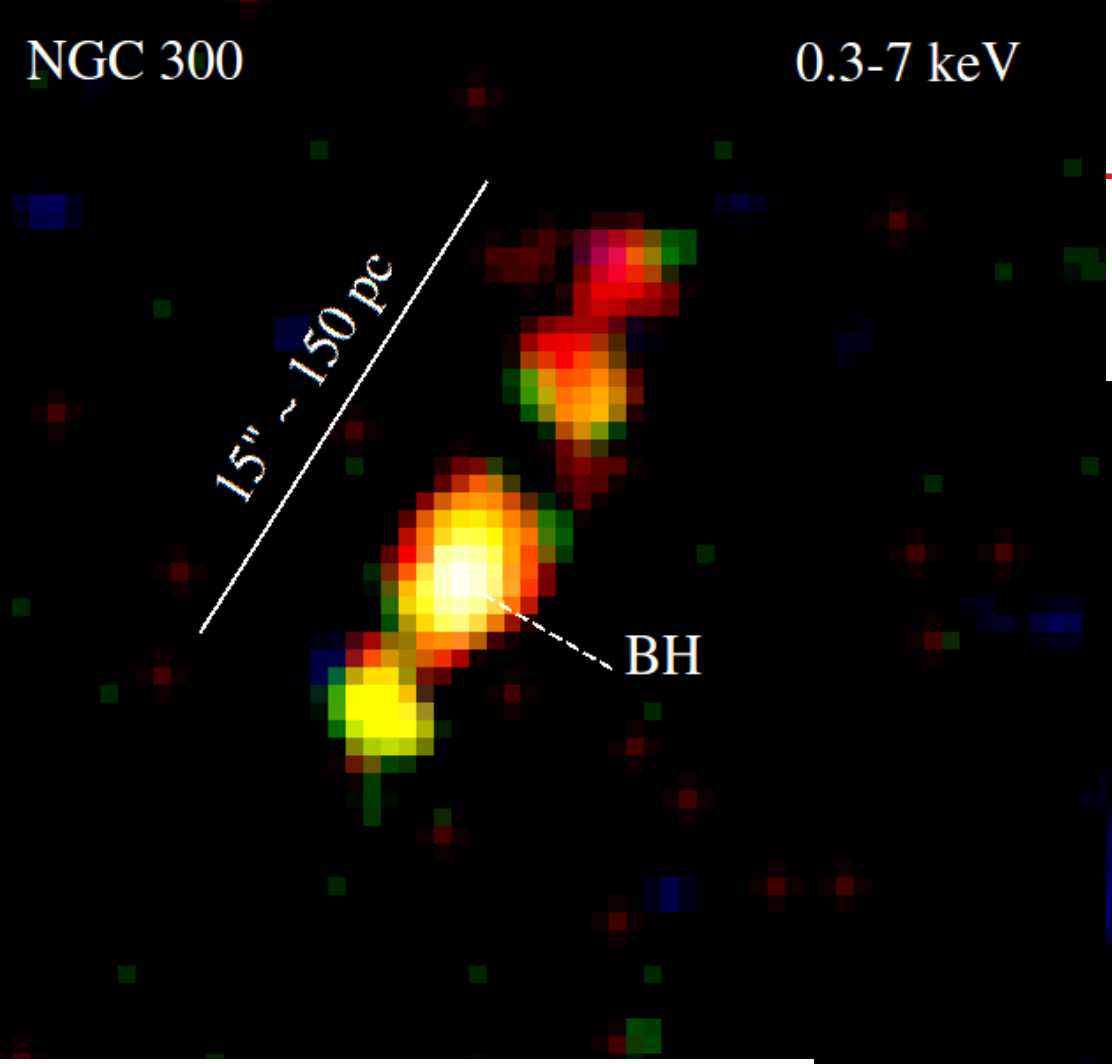
L_{5GHz} (bubble) ~ 10^{35} erg/s

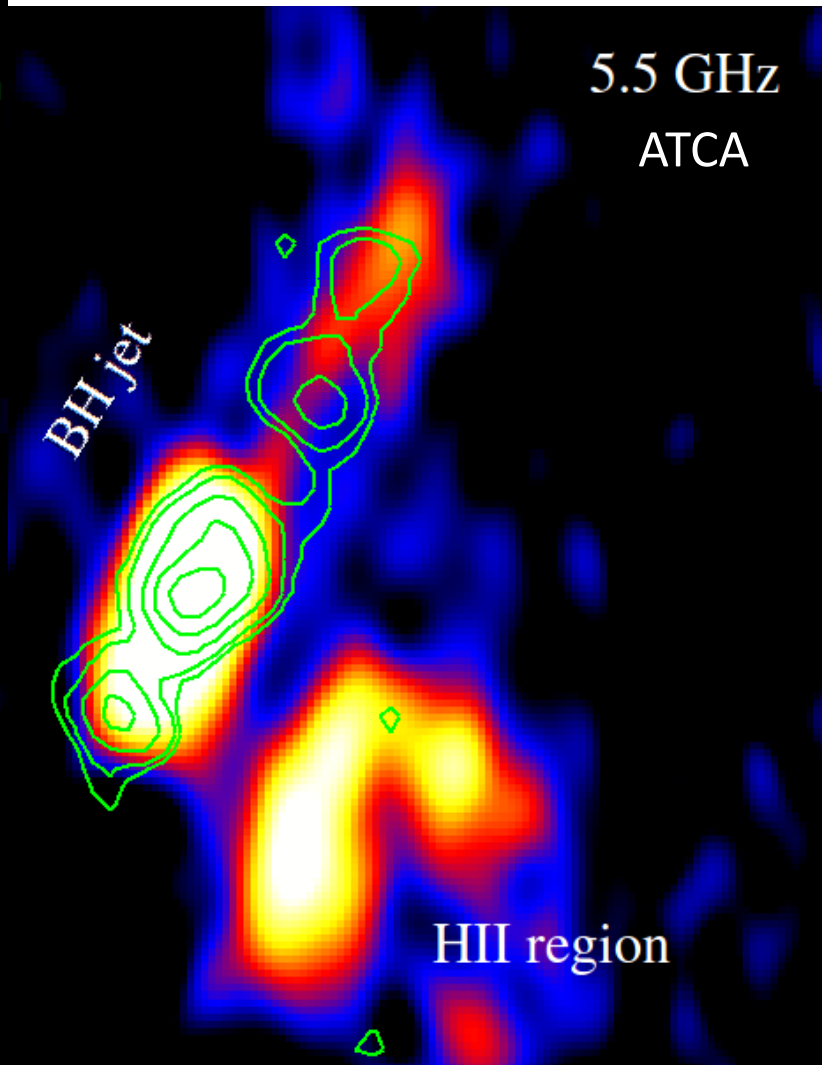
(Soria, Miller-Jones, Ryan, et al., in prep.)


NGC 300
ESO 2.2m
NGC 300 - S9

NGC 300 - S9

Jet with multiple
X-ray knots





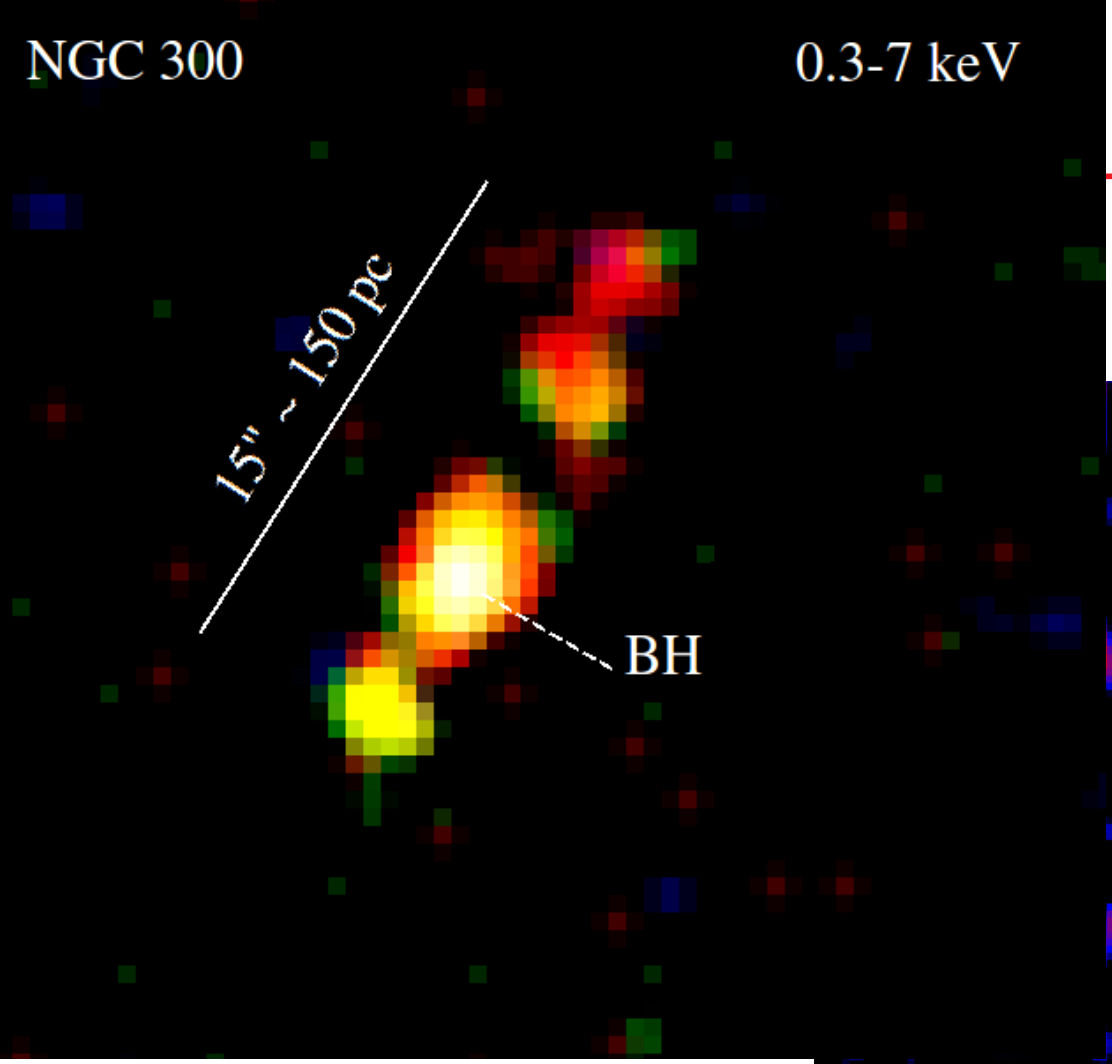
X-ray, Hα
and radio detection

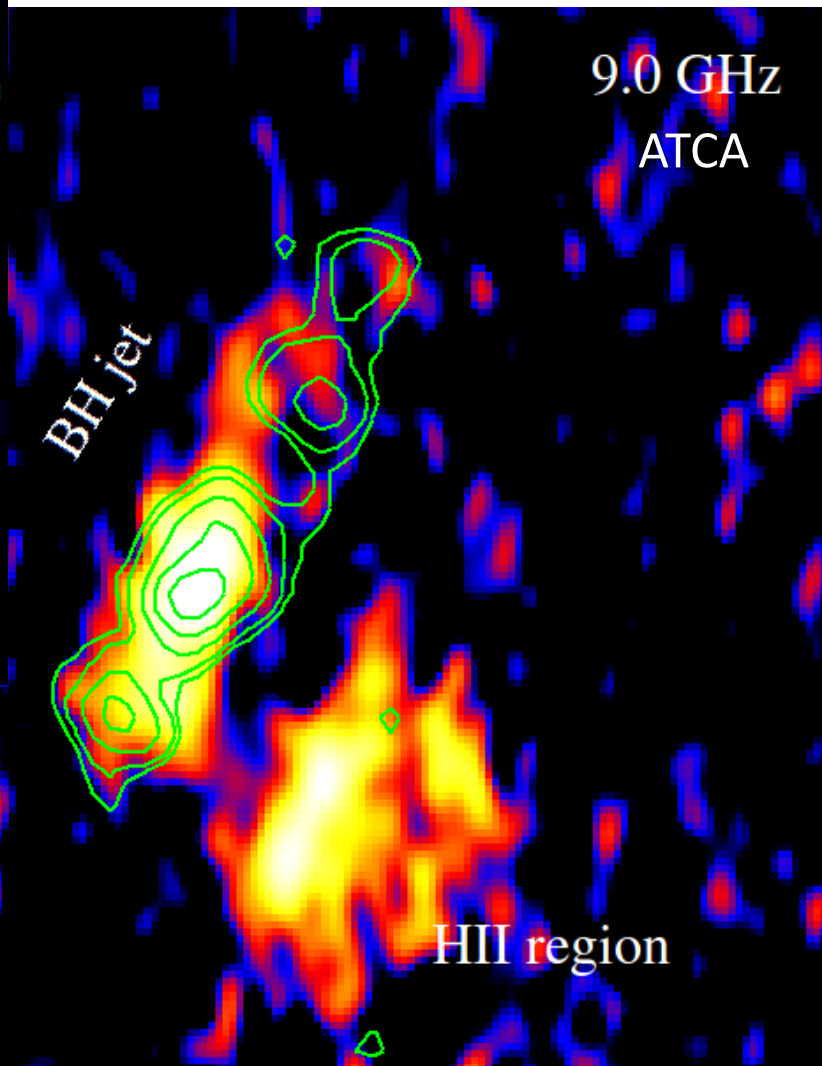
L_{5GHz} (jet) ~ 10^{34} erg/s

(Urquhart, Soria, et al 2017 in prep)

NGC 300 - S9

Jet with multiple
X-ray knots





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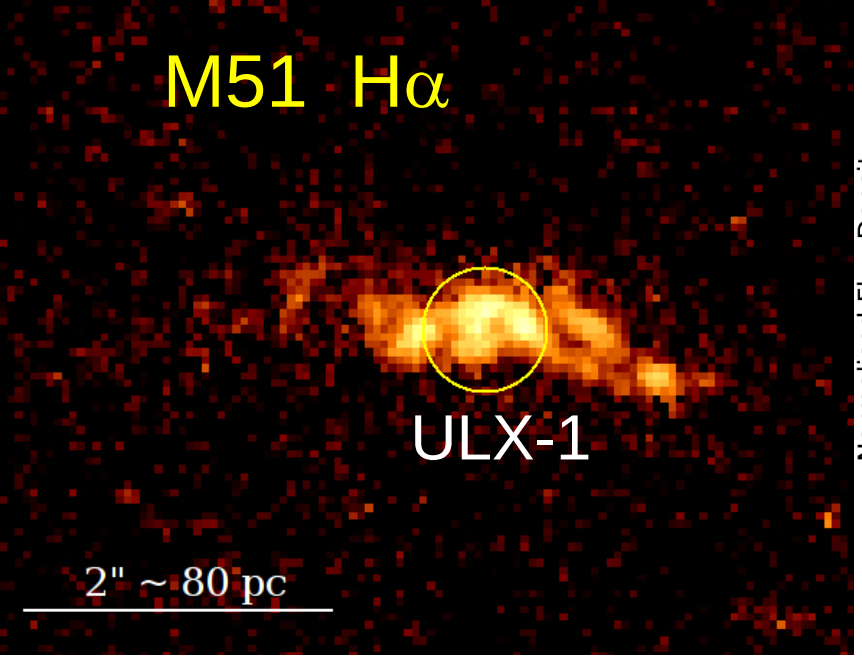
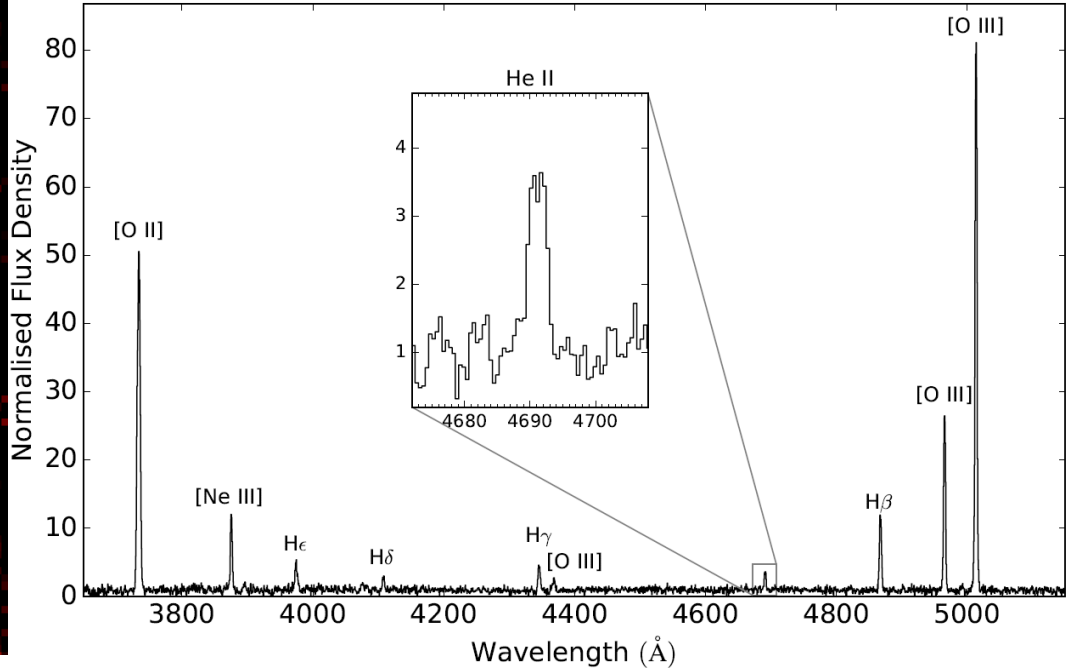
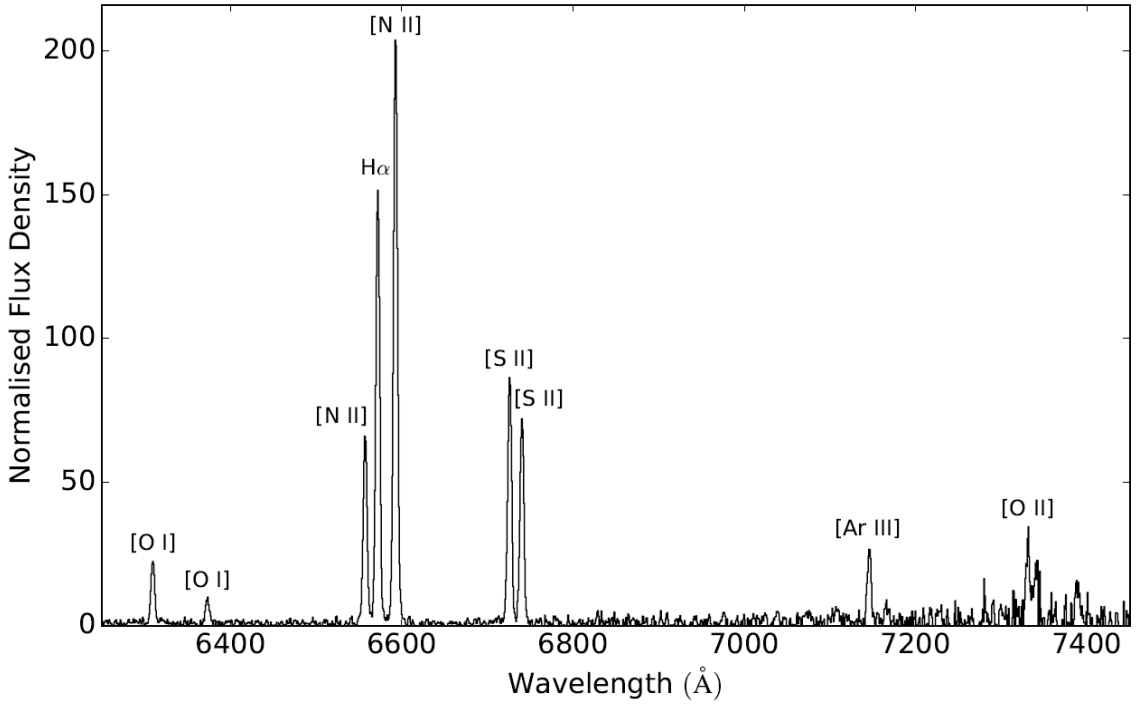






Jet-inflated bubble in M51

(Urquhart, Soria, et al, submitted)

$P_J \sim 2 \times 10^{39}$ erg/s

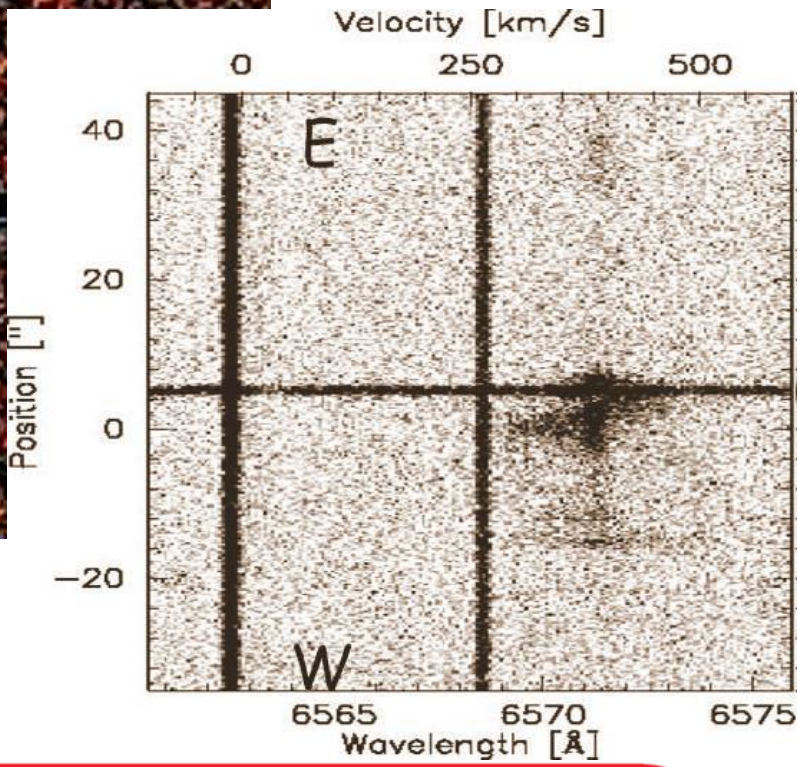
$L_{5GHz} \sim 2 \times 10^{34}$ erg/s

NGC1313 X-2

size ~ 300 x 200 pc

Hα VLT

(Grise' et al 2008
Ramsey et al 2006)



Shock-ionized bubble. Winds.

No radio. No evidence of jets.

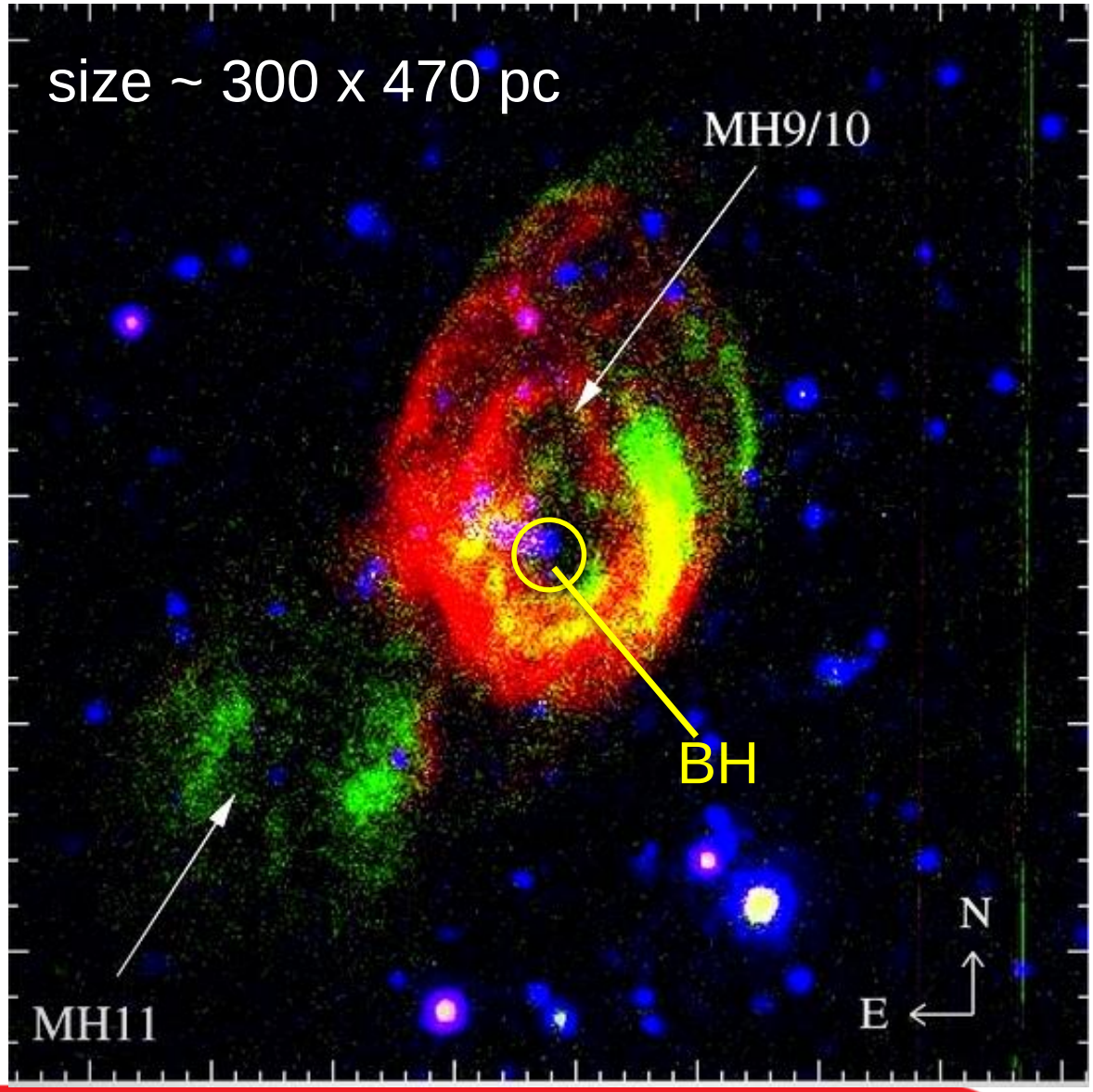
Holmberg IX X-1

Subaru image: [OIII]=green, Ha=red, V-band = blue

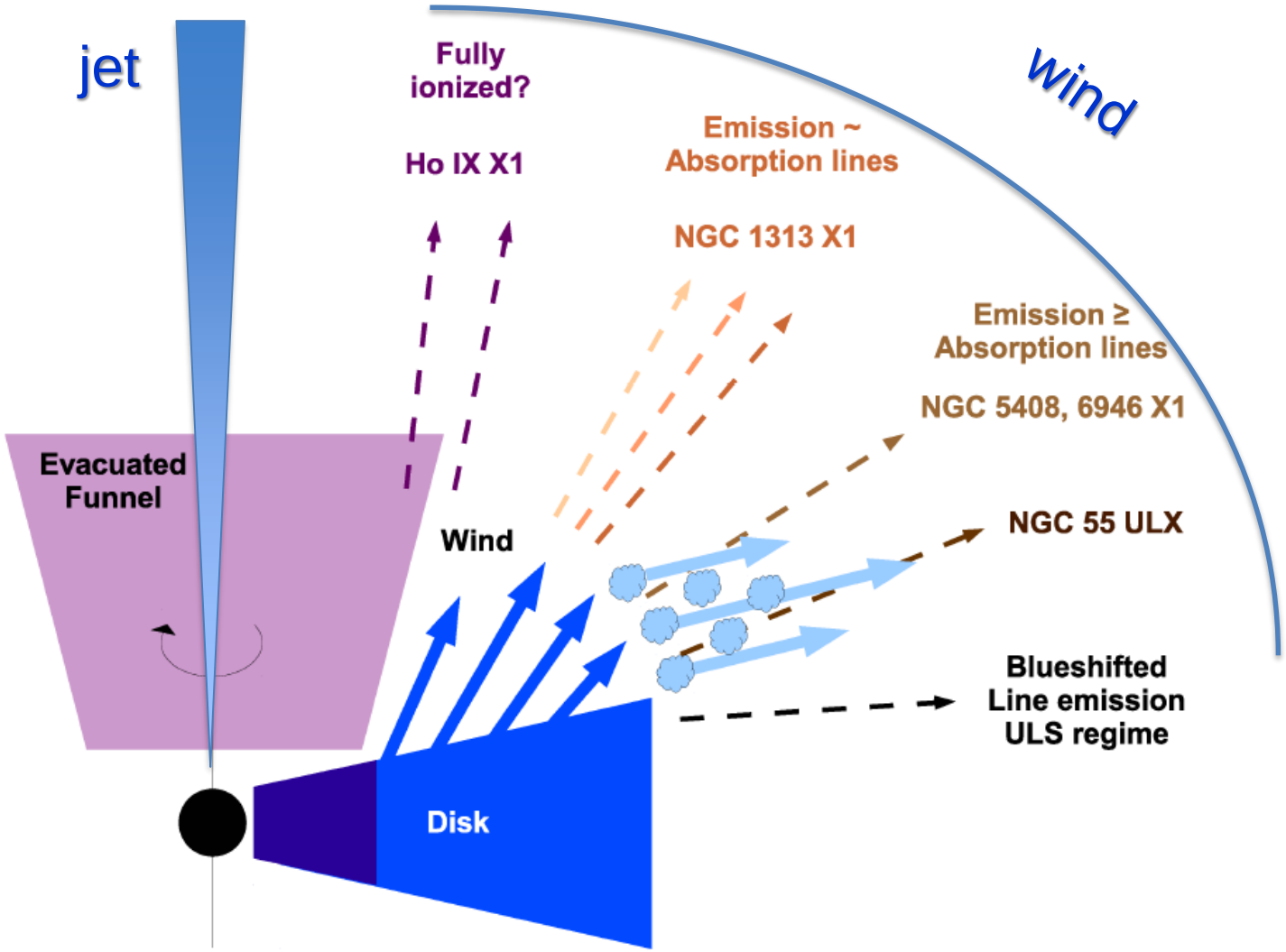
Shock-ionized bubble

No radio bubble
No evidence of jets

(Grise' et al 2011)



X-ray signatures of winds from ULXs

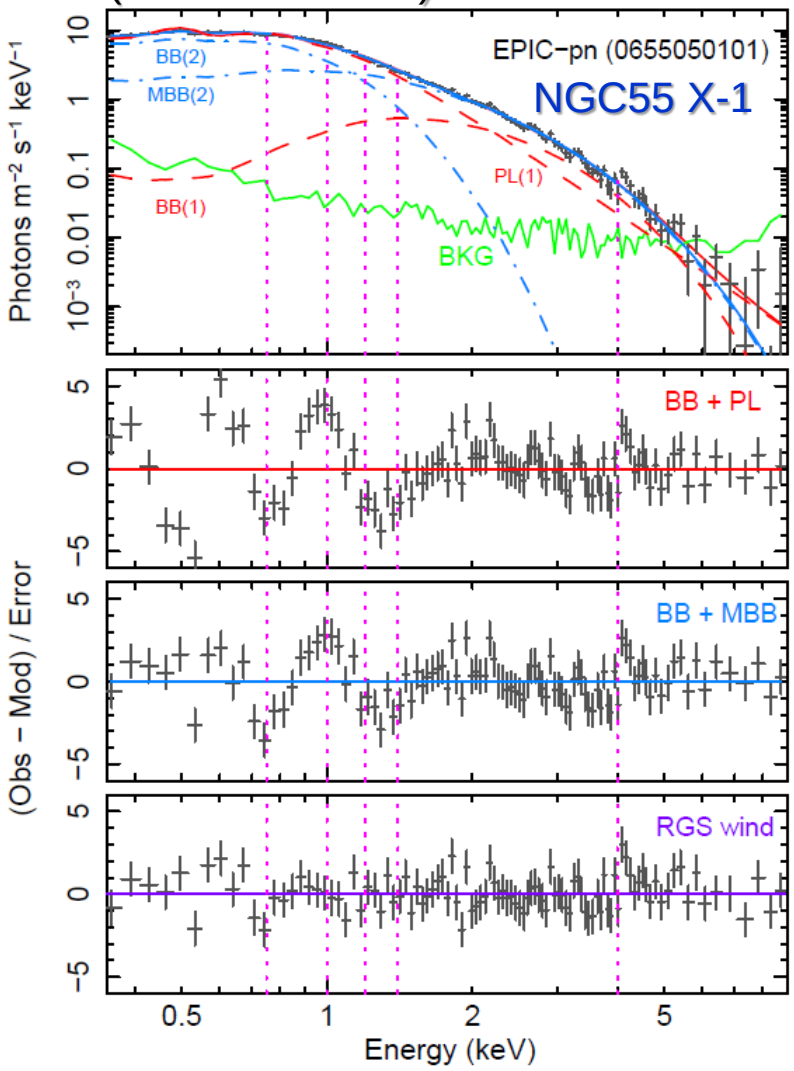


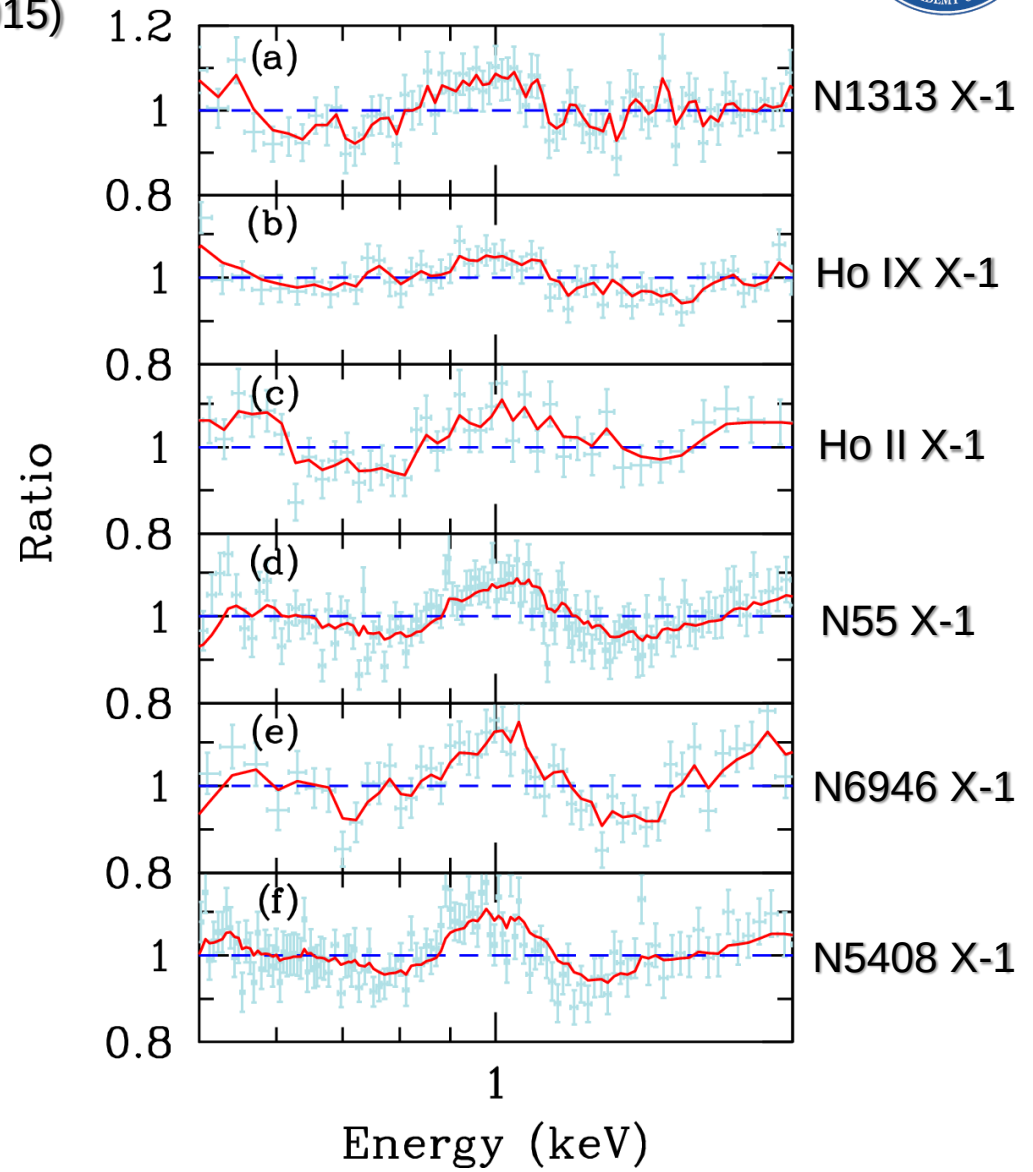
(adapted from Pinto et al 2017)

X-ray signatures of winds from ULXs

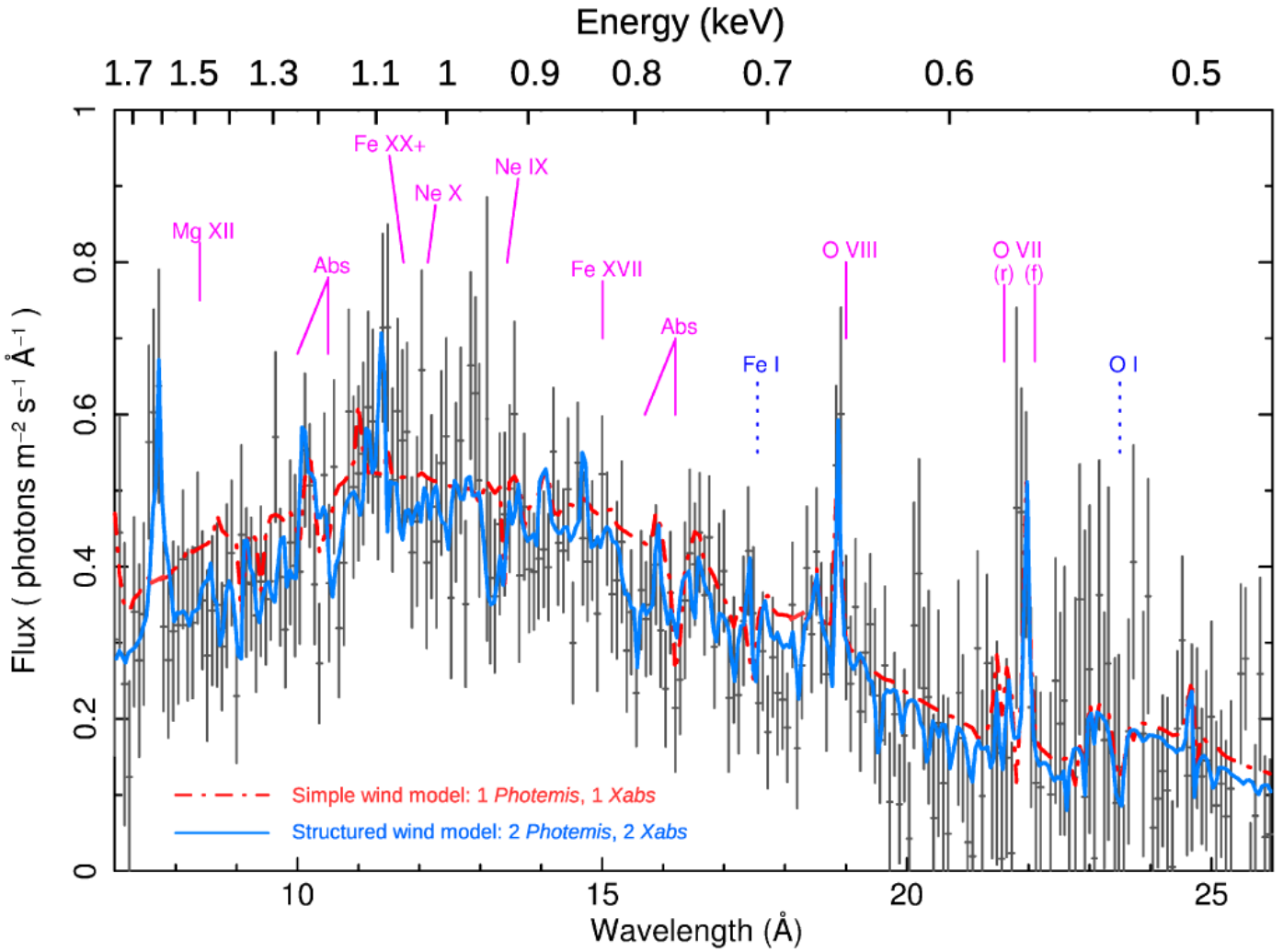
(Middleton et al 2015)

(Pinto et al 2017)





X-ray signatures of winds from ULXs



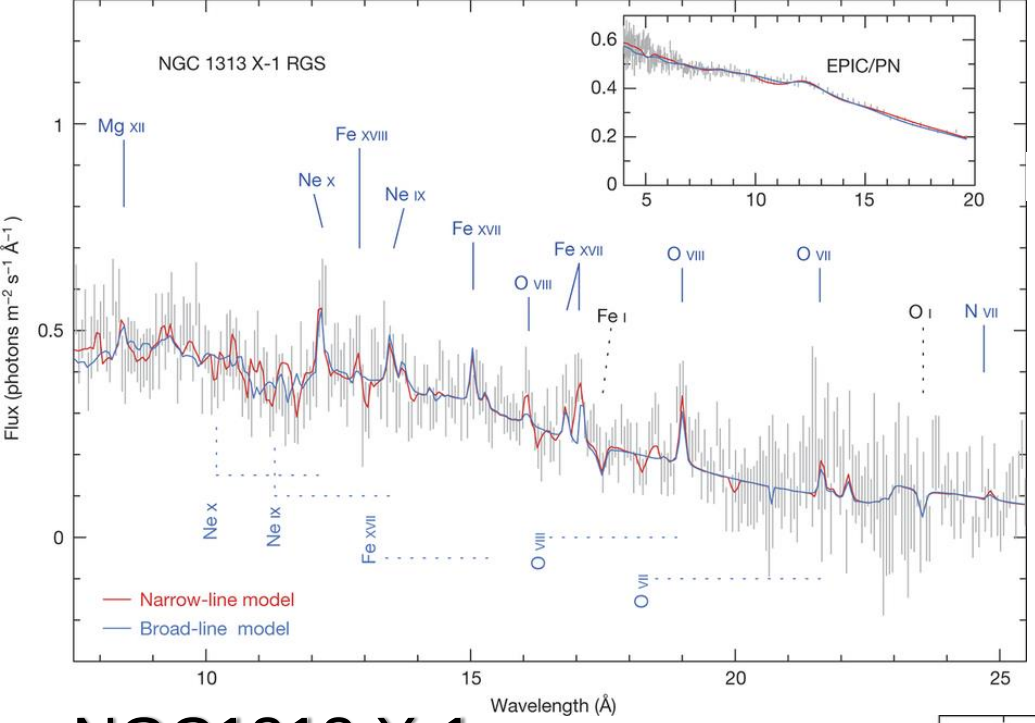
120-ks *XMM-Newton*/RGS spectrum of the ULX in NGC 55

(Pinto et al 2017)

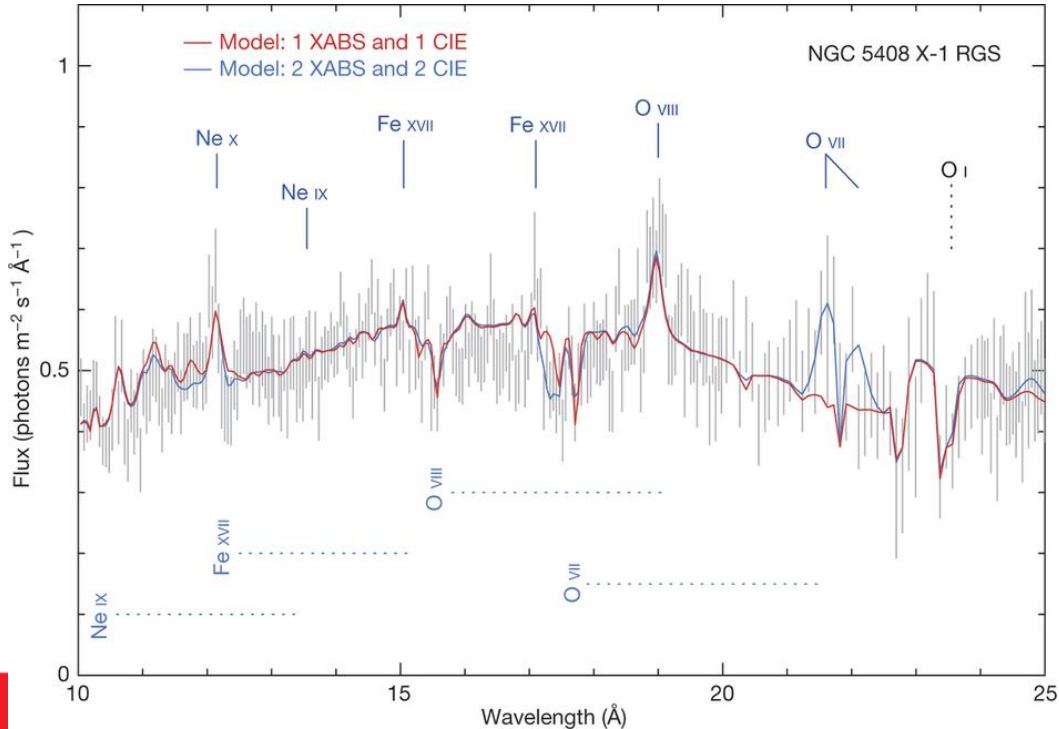
X-ray signatures of winds from ULXs

Emission lines
from slow-moving gas
v ~ 0.01—0.1 c

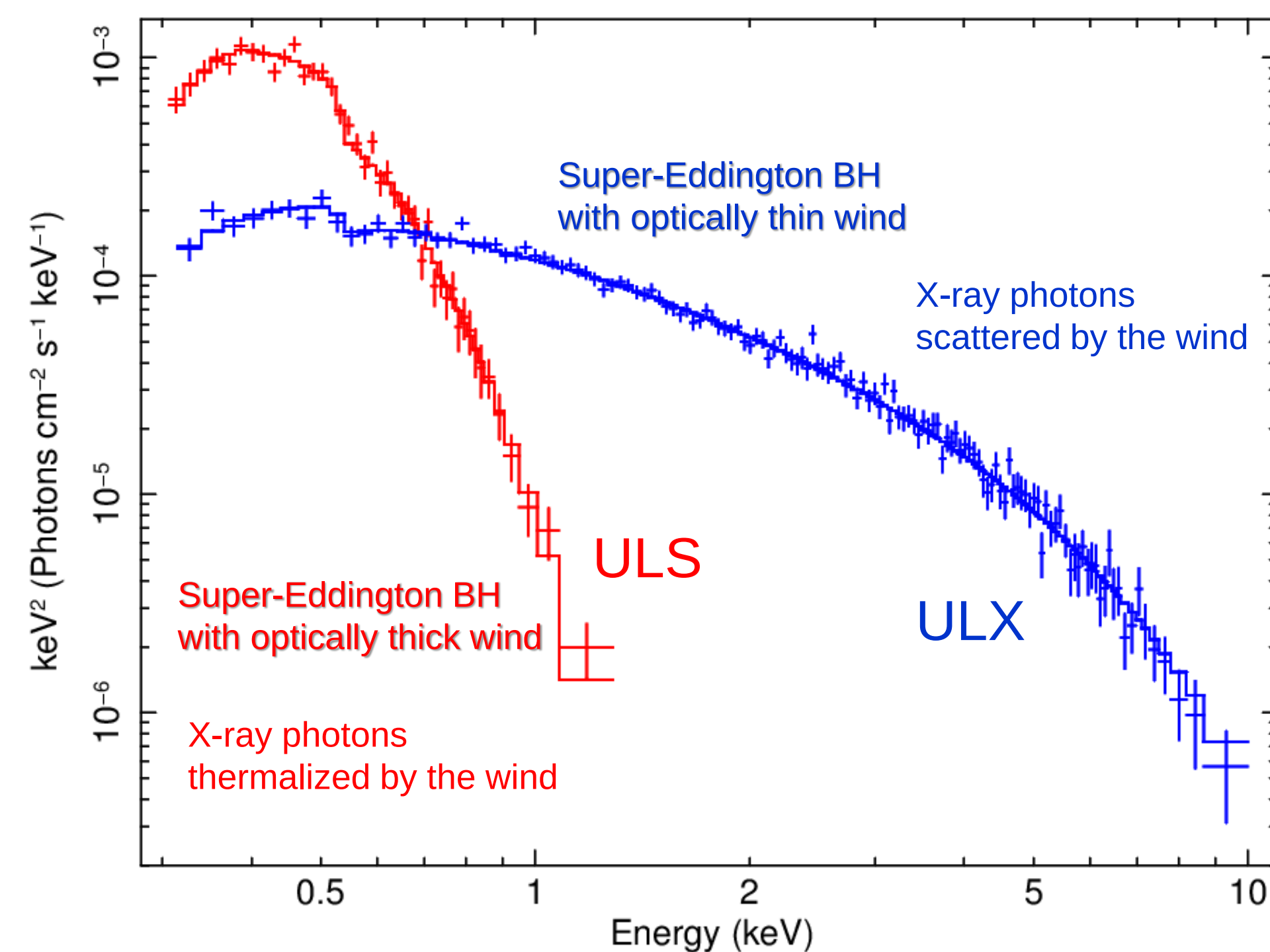
Absorption lines
from fast-moving gas
v ~ 0.1—0.2 c

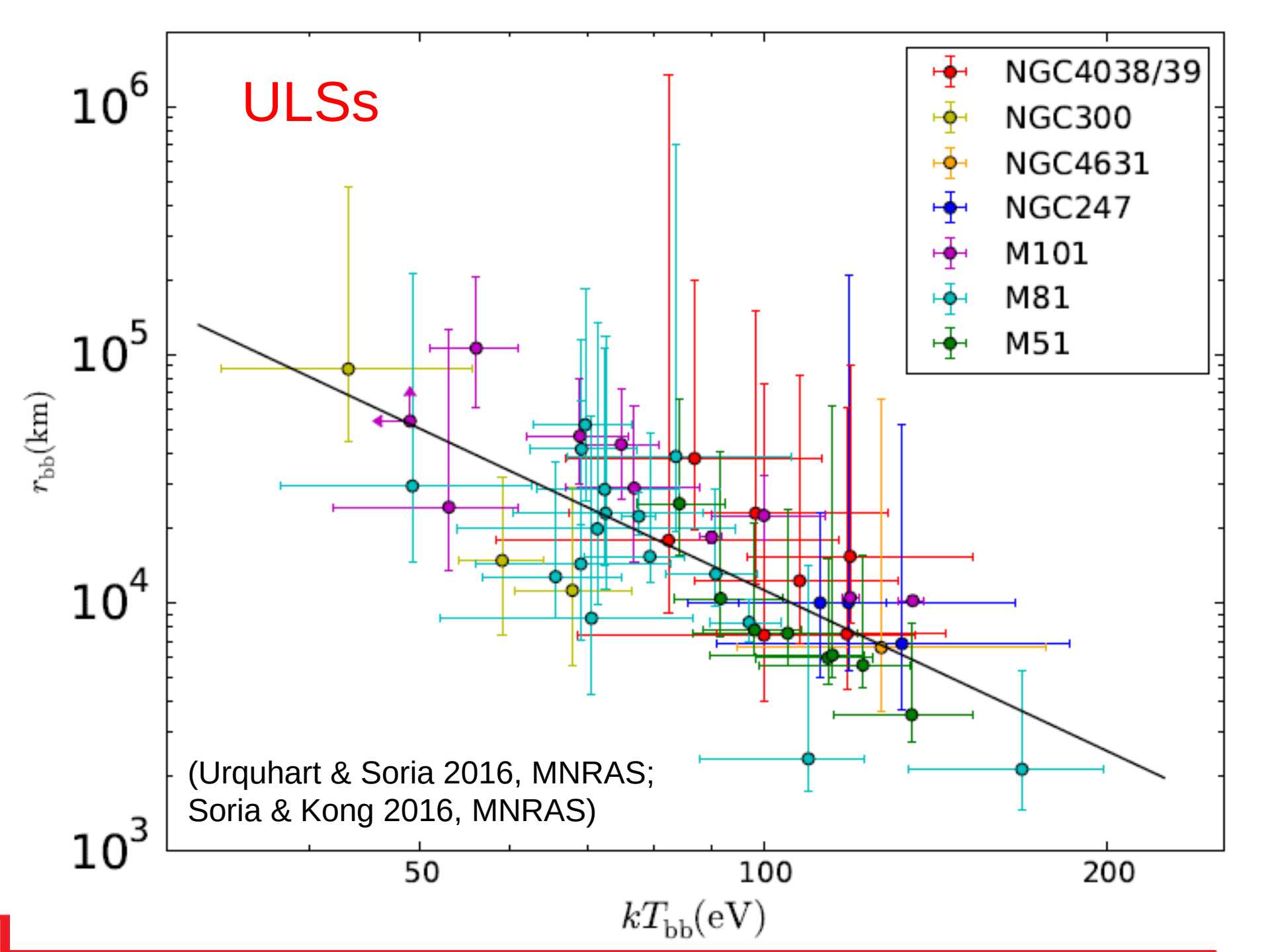


NGC1313 X-1
350-ks RGS spectrum
(Pinto et al 2016)



NGC5408 X-1
650-ks RGS spectrum
(Pinto et al 2016)


Super-Eddington BH
with optically thin wind
X-ray photons
scattered by the wind
ULS
ULX
Super-Eddington BH
with optically thick wind
X-ray photons
thermalized by the wind
keV² (Photons cm⁻² s⁻¹ keV⁻¹)
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
0.5
1
2
5
10
Energy (keV)


ULSs
NGC4038/39
NGC300
NGC4631
NGC247
M101
M81
M51
10^6
10^5
10^4
10^3
$r_{\rm bb}$(km)
50
100
200
$kT_{\rm bb}$(eV)
(Urquhart & Soria 2016, MNRAS;
Soria & Kong 2016, MNRAS)

Conclusions

ULXs heat the surrounding gas with radiation, jets and winds

Jet power inferred from ULX bubbles

$P_{jet} \sim 1^{E}39—1^{E}40$ erg/s

Wind properties inferred from X-ray spectra

Softer spectra = denser wind

ULXs = ideal test for super-critical accretion and BH feedback

Significant contribution to cosmic re-ionization?