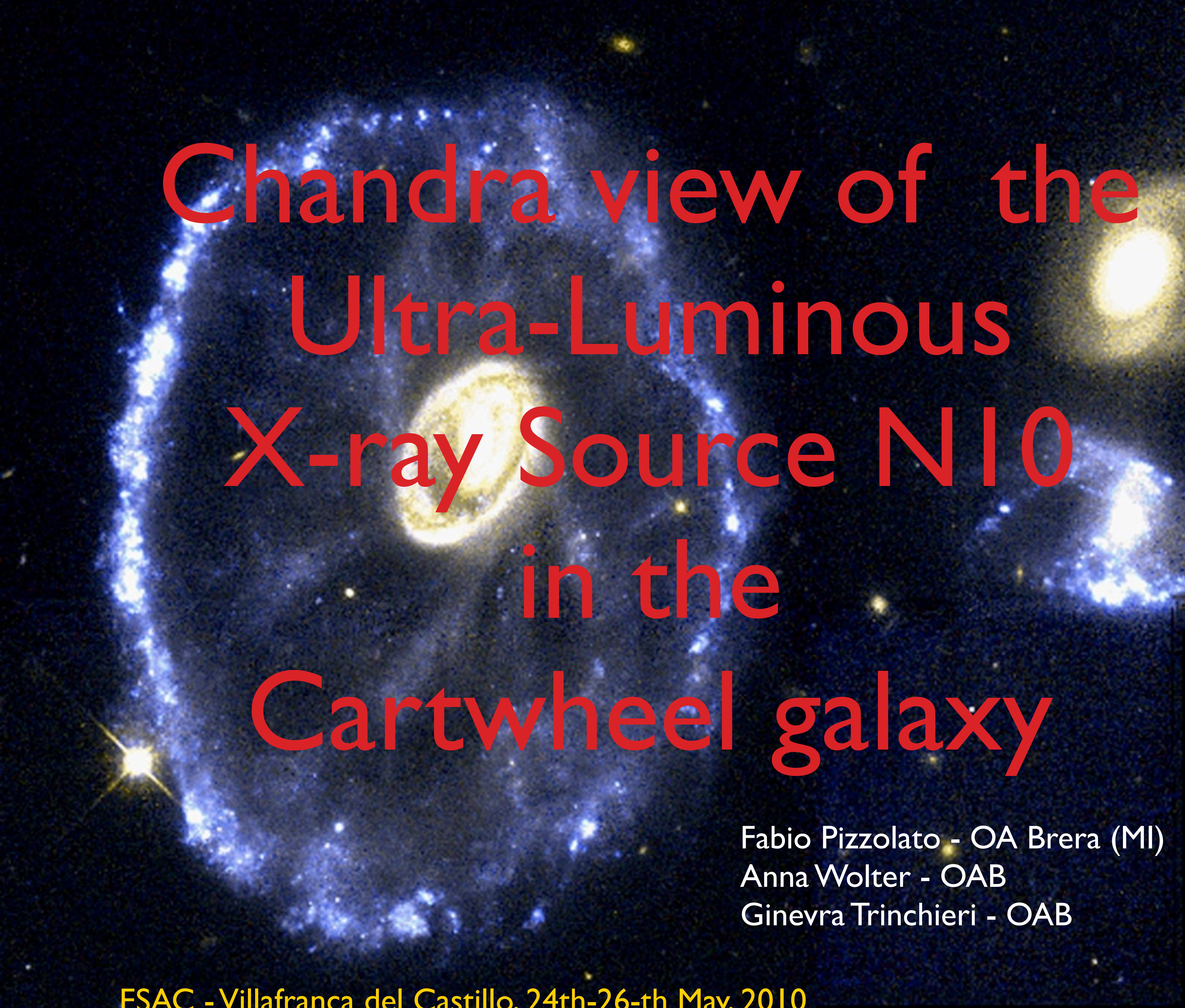

Chandra view of the Ultra-Luminous X-ray Source N10 in the Cartwheel galaxy

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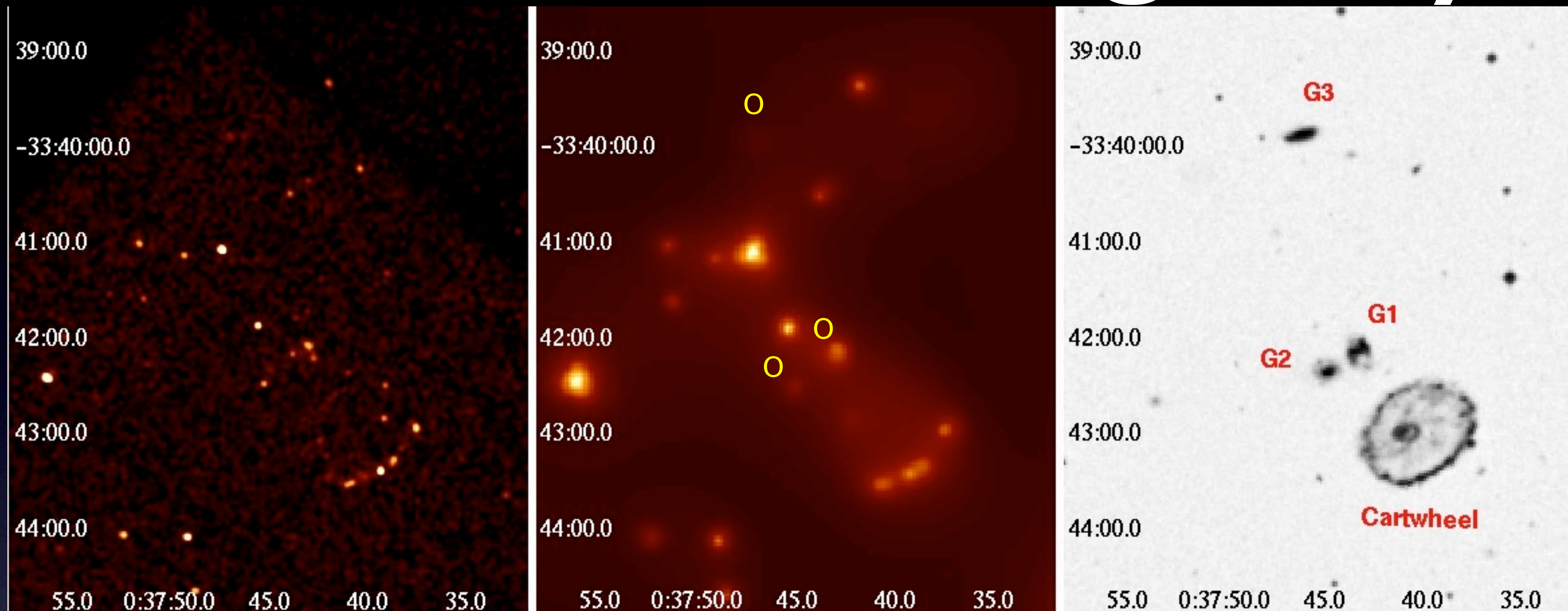
ESAC - Villafranca del Castillo, 24th-26-th May, 2010

Outline

- Why the Cartwheel?
- The Chandra observations of N10
- Derive the properties of some spectral ULX models for the source N10
- Models: accretion disc (several flavours), supernova

The Cartwheel galaxy



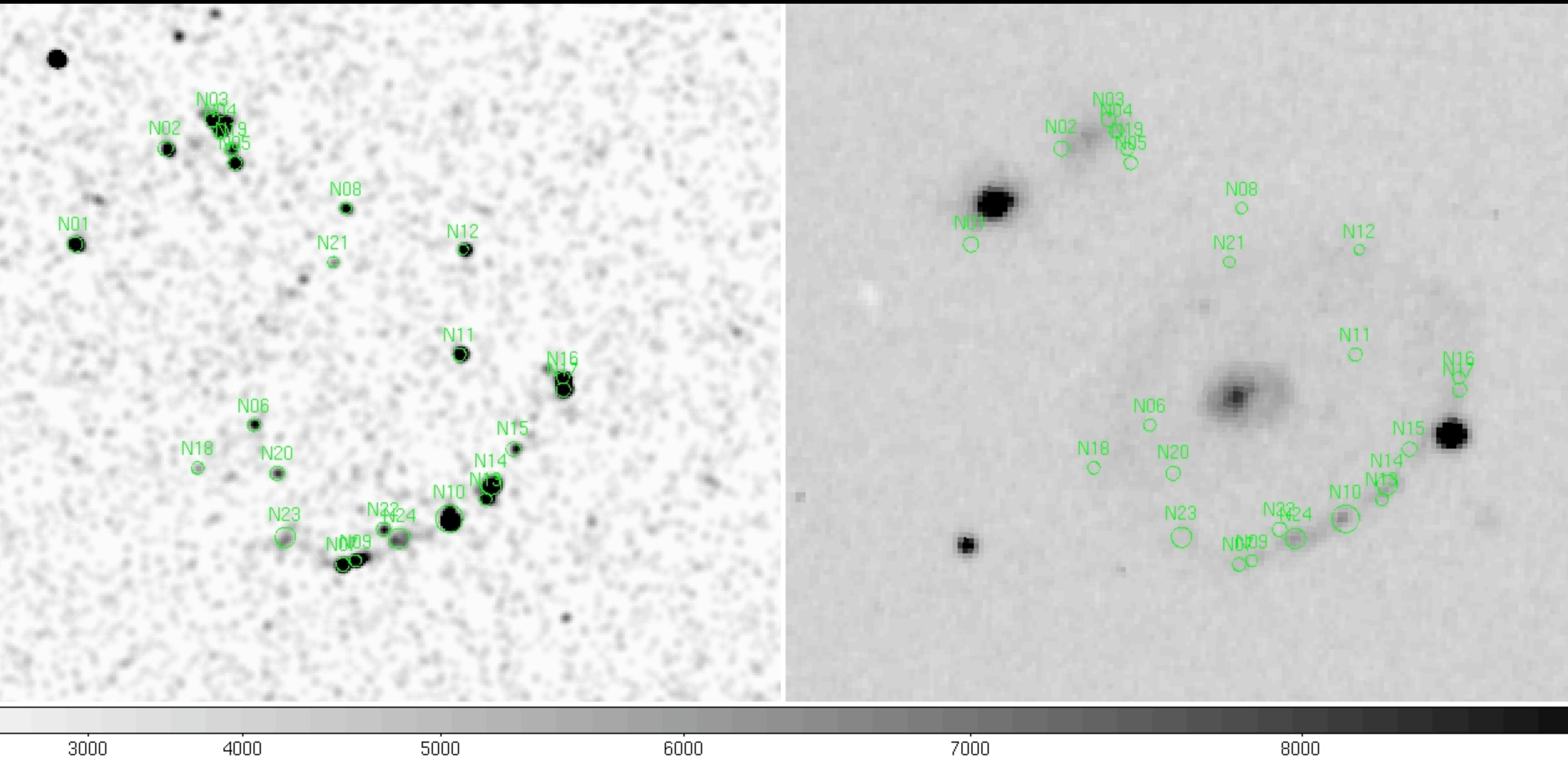
ACIS-S data smoothed with a 3″ Gaussian

Sum of 2 pn datasets smoothed with a 3″ Gaussian

Cartwheel group as defined by Higdon (1995)

- D = 122 Mpc (quite far!)
- The Cartwheel owes its odd shape a major collision (with the galaxy G3) happened ~100 Myr ago (Higdon et al., 1986, Mapelli et al., 2008): strong burst of star formation (SFR=15-25 $M_\odot$/yr: Wolter & Trinchieri, 2004)
- Bright X-ray emission from the diffuse gas (6 x 10^{40} erg/s, Wolter & Tricheri, 2004)
- Extremely metal poor environment (Fosbury & Hawarden, 1977)
- 10-15 ULXs in the ring: L_X~10^{39}-10^{41} erg/s, many of them variable

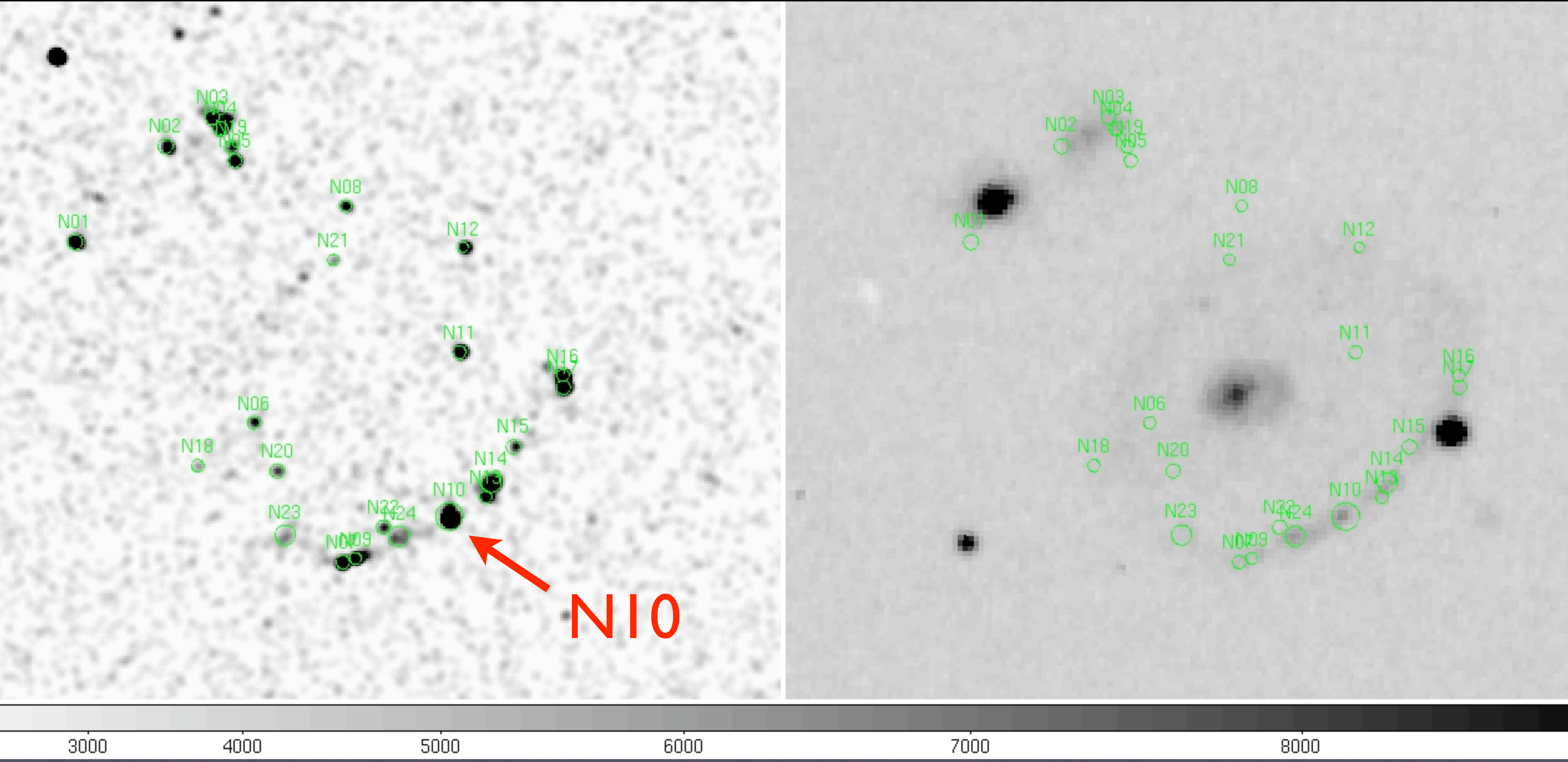
X-ray Compact Sources in the Cartwheel Galaxy



X-ray sources

Optical

X-ray Compact Sources in the Cartwheel Galaxy

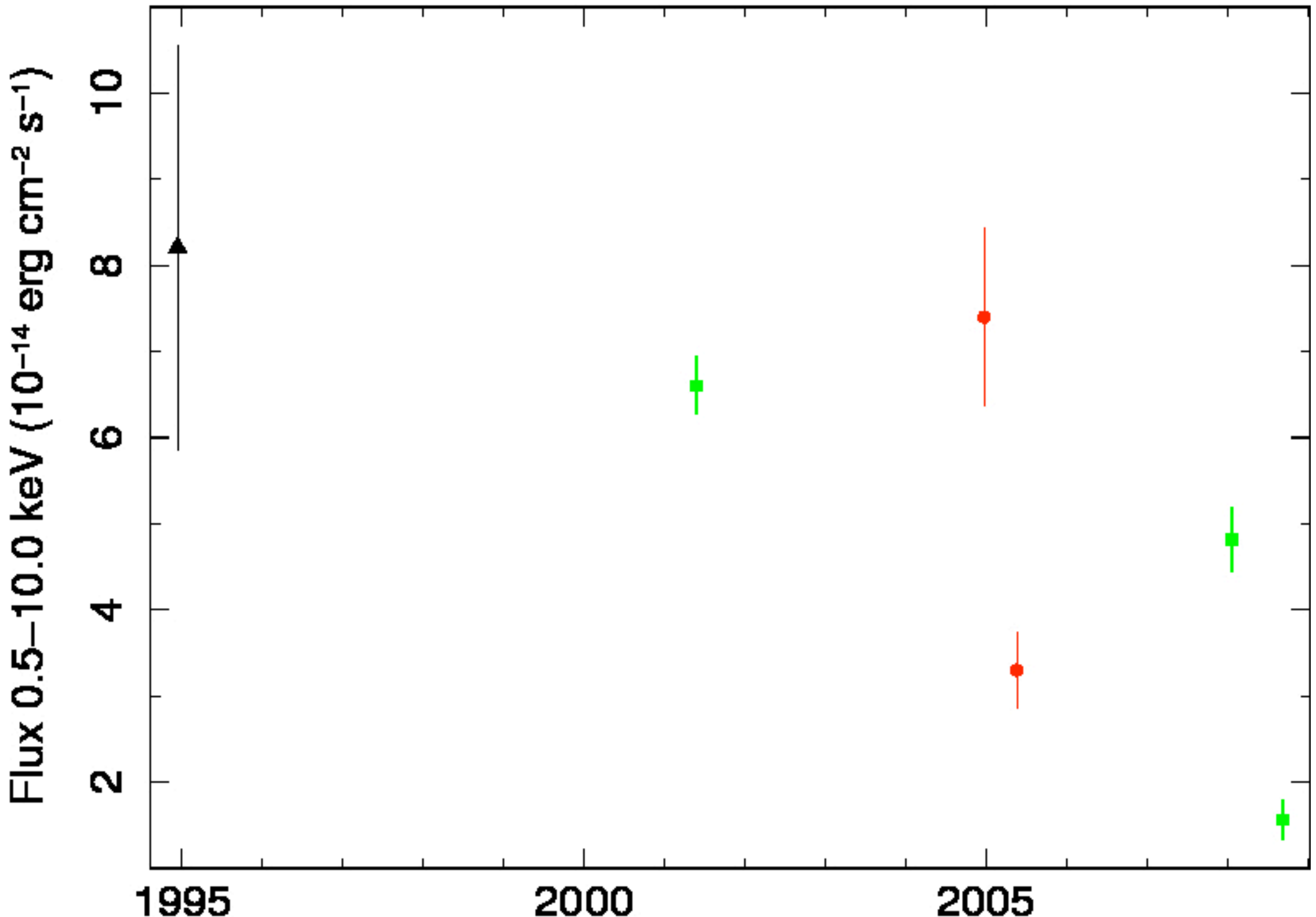


X-ray sources

Optical

Chandra observation log of N10

Obs id.	Date	Exposure after cleaning (ks)	Count rate (10^{-3} cts/s)	Counts
2019	26/05/2001	76.1	5.3	400
9531	21/01/2008	48.0	3.6	173
9807	09/09/2008	49.5	1.2	59



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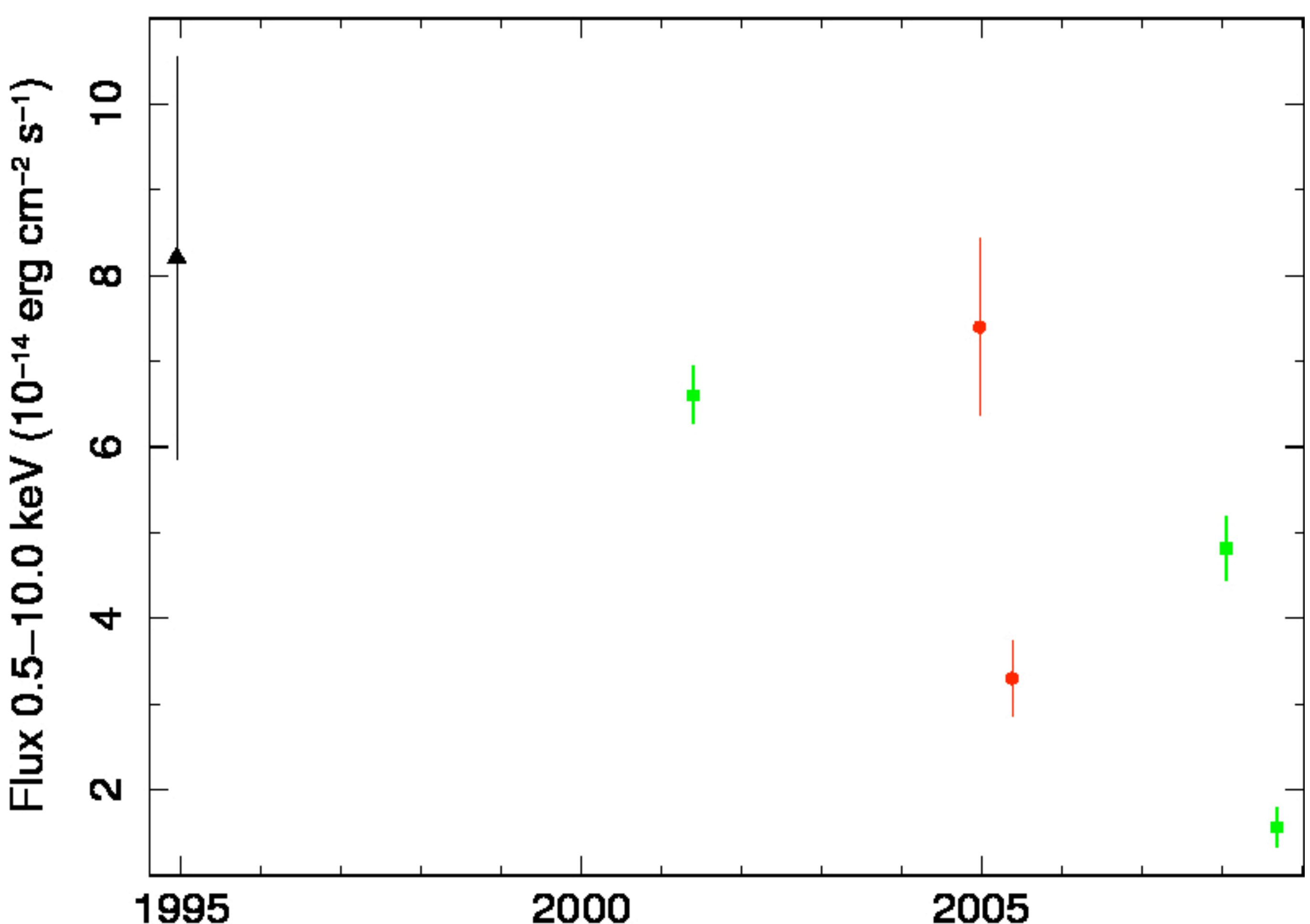


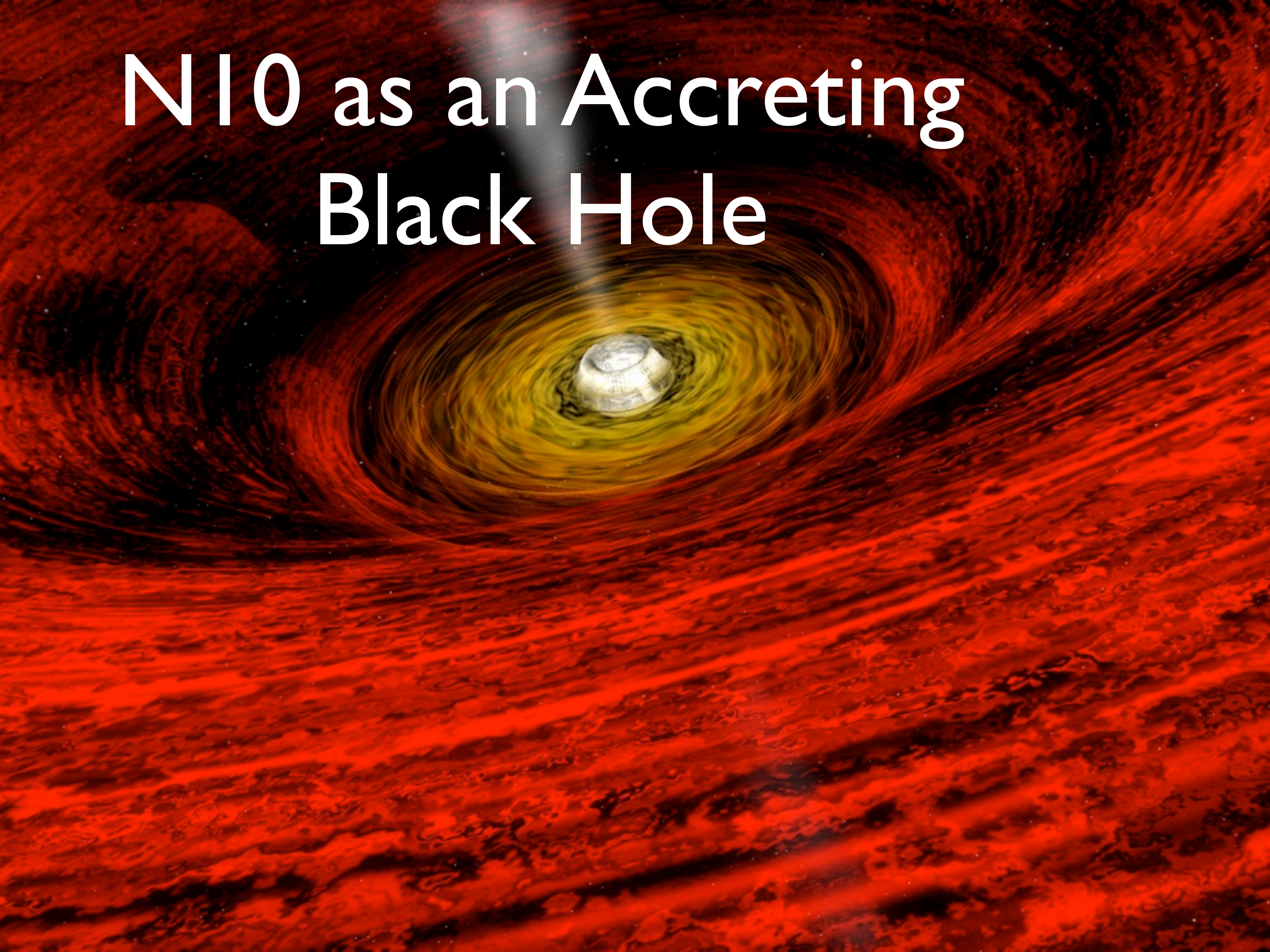
$L_X \sim 10^{40}$-10^{41} erg/s

Fading source!

Spectral modelling with Chandra

- The good news: little gas/instrumental bkg contamination (tiny PSF)
- The bad news: few photons: all the spectral models return similar χ^2 (or C-stat). It is impossible to discriminate them on purely statistical grounds: we have to resort to the self-consistency of the interpretation

N10 as an Accreting Black Hole



N10 as an Accreting Black Hole

- Standard multicolour disc (MCD) around a Schwarzschild BH
- Kerr disc (around a fast-spinning BH)
- Slim disc (super-Eddington, radiatively inefficient)

MCD discs

- Locally radiate as black bodies
- Appropriate for accretion regimes below Eddington
- Temperature profile $T(R) \sim R^{-3/4}$
- Opacity due to electron scattering
- Compton hardening: parameter $f = T_{col}/T_{eff} \sim 1.7-2$ for accretion rates 0.1-1 L_{Edd} (Shimura & Takahara 1995); $f \sim 2.3-6.5$ for strongly super-Eddington regimes (Kawaguchi 2003)

Estimating the BH mass

$$R_D = \xi \left(\frac{L_D}{4\,\pi\,\sigma_{SB}} \right)^{1/2} \left(\frac{T_{\rm in}}{f} \right)^{-2}$$

- Hypothesis: the disc extends all the way down to the last stable orbit: $R_D = R_{LSO}$
- T_{in} from the shape of the spectrum
- L_D from the count rate
- R_D: normalisation

$$R_D = \frac{6\,G\,M_\bullet}{c^2}$$

MCD results/1 (of 2)

- Simple models (MCD only) yield relatively high temperatures (1.33, 1.21 and 0.89 keV)
- $M_{BH} \sim 61_{-12}^{+18}\ (f/2.0)^2\ M_{\odot}$, (face-on disc)
- $L \lesssim 5\ L_{Edd}$, and the hardening parameter f=2 is consistent with such a (relatively low) accretion regime

MCD results/2 (of 2)

- Adding a hard spectral component (e.g. a Compton corona) lowers the best-fitting temperatures (0.53, 0.36 and 0.09 keV), and raises M_{BH} to ~140_{-42}^{+78} $(f/1.7)^2$ $M_\odot$
- The hole accretes close to the Eddington limit (or ~2×10^{-6} $M_\odot$/yr)
- $\tau \sim 1$

Slim discs

- Refinement of MCDs, appropriate for high (super-Eddington) mass accretion rates
- Disc heat content dragged inside the horizon before it can be radiated
- Radiative inefficiency $L \sim T_{in}^2$ (Watarai et al., 2001)
- $T(R) \sim R^{-1/2}$

Slim disc models: results

- BH mass consistent with anything above 80 $M_\odot$
- Accretion rates 5 to 40 times the Eddington rate ($=L_{Edd}/c^2$)
- Caveat: we find: $T \sim R^{-3/4}$, (diskpbb spectral model)
- Other ULXs successfully modelled with slim discs give the T(R) expected from slim discs (e.g. Watarai et al., 2000; Ohsuga et al. 2003)

The (extreme) Kerr disc

- Same conclusions as before, MBH is consistently around 90 $M_{\odot}$ with no extra hard component
- Caveat: the hole's mass is inferred from the observed luminosity, and it depends on the inclination angle. An almost edge-on disc yelds $M_{BH} \approx 10^3 M_{\odot}$

Summary of the accretion model(s)

- Slim discs models not fully supported (T-R)
- Self-consistent accretion models return a ~100 $M_{\odot}$ black hole accreting close to L_{Edd} or ~$2x10^{-6}$ $M_{\odot}$/yr
- Higher BH mass are possible, if the disc is almost edge-on

Comments

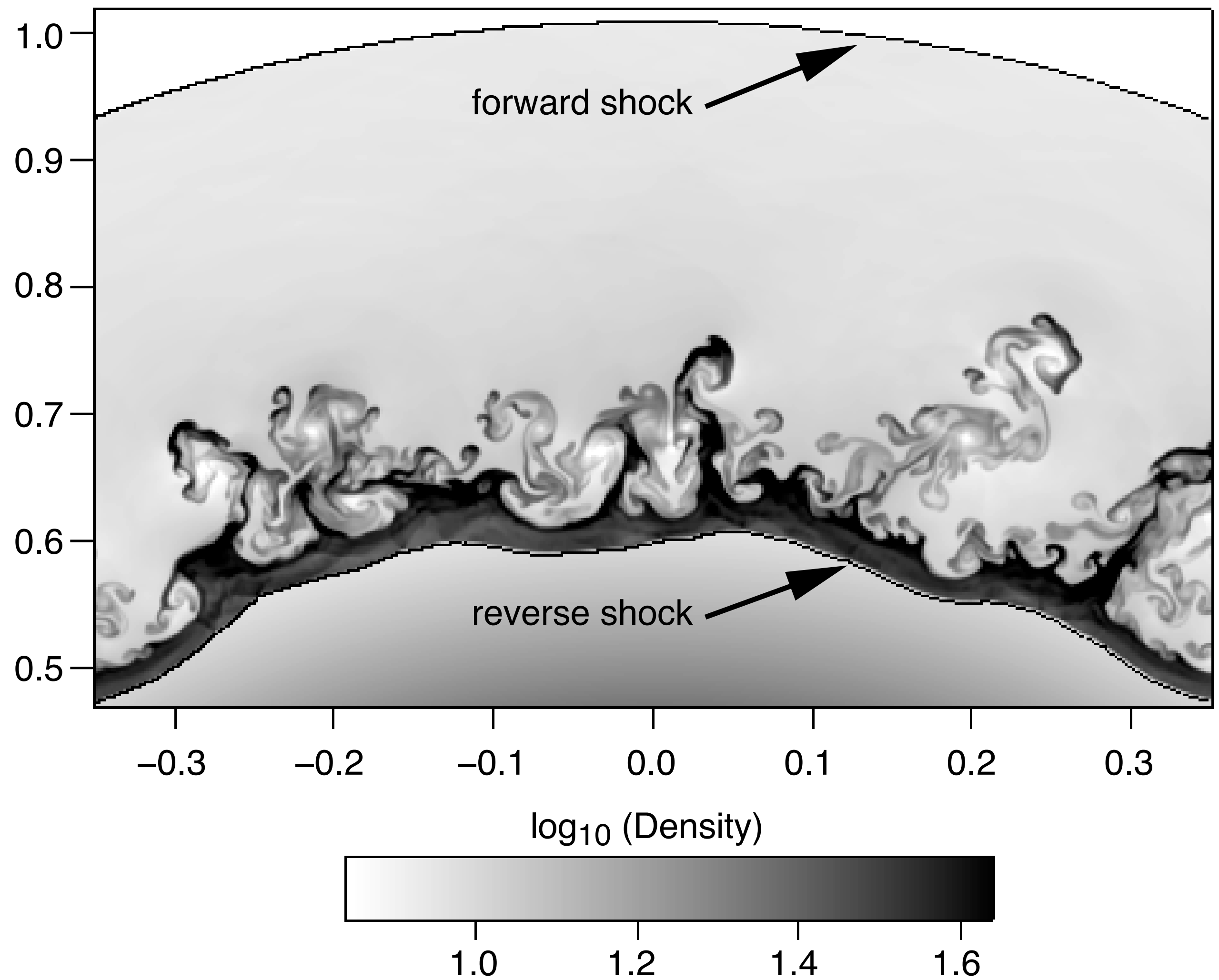
- A 100 $M_\odot$ BH is a borderline case of the end product of the evolution of a massive star (HMXB)
- The mass accretion rate is consistent with a disc accretion from a massive donor on a thermal time scale
- In a metal-poor environment (Cartwheel), massive stars are more likely to form (Yungelson et al., 2008, Ohkubo et al, 2008)
- Stars > 40 $M_\odot$ do not explode as SNe but directly collapse into BHs (Fryer, 1999; Fryer & Kalogera, 2001), retaining their initial mass

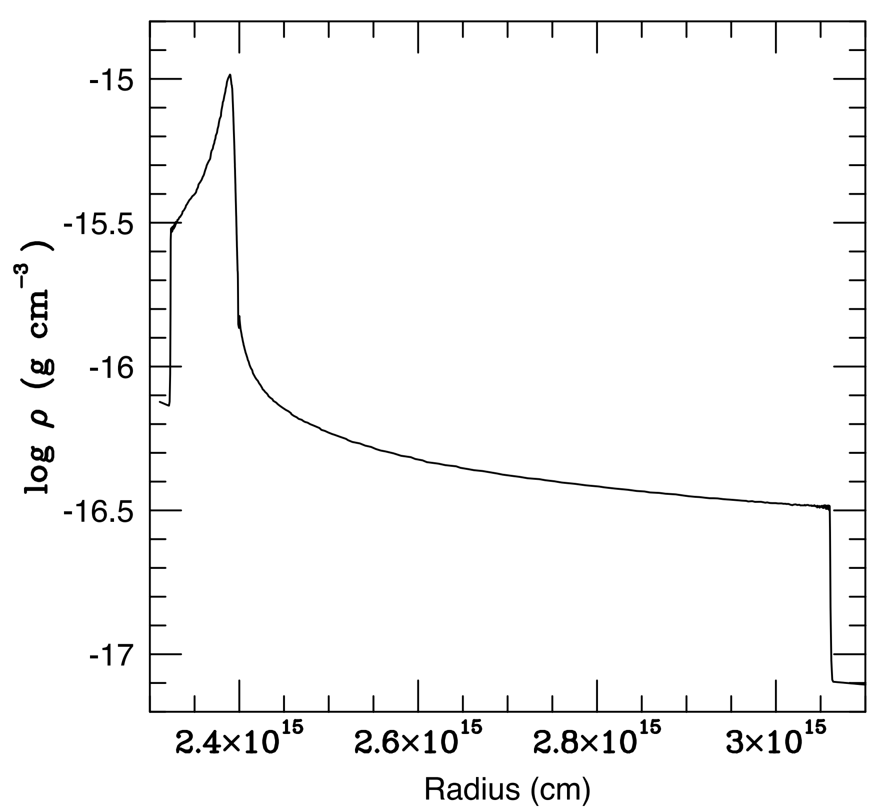
N10 as a Supernova

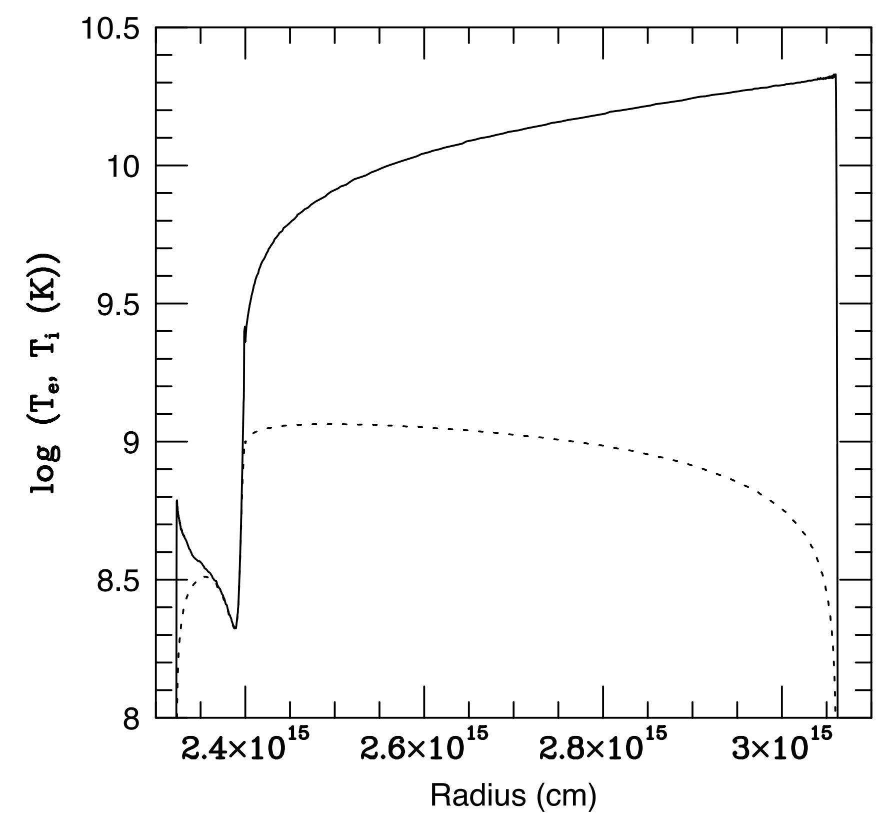
N10 as a Supernova

- SNe suggested as an explanation for some ULXs, as alternatives to accreting BHs
- ~25% of the ULXs are estimated to be young SNe (Swartz et al., 2004)
- Few X-ray SNe known (15, as of 2003; review by Immler and Lewin 2003)
- $L_X = 10^{37}-10^{41}$ erg/s
- Powered by the interaction btw the ejecta and the circumstellar medium

SN interaction with the CSM







Chevalier and Fransson (2001)

X-rays from a SN Reverse Shock?

- Well modelled with a thermal model (APEC/NEI) with C/ndf=95.9/100
- $T=5.1_{-1.6}^{+3.1}$ keV, and metallicity <0.2 solar; OK with the low metallicity measured by Fosbury & Hawarden, 1977
- Normalisation consistent with size (~10^{15} cm) and density (10^{-15}-10^{-16} g cm^{-3}) of a young SN

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CONCLUSION:

the data are consistent with a SN (IIn)

Summary

- N10 is the brightest ULX in the Cartwheel $L_X \sim 10^{40}$-10^{41} erg/s
- Accretion models: N10 is a BH of ~100 $M_\odot$ accreting close to the Eddington limit ~2×10^{-6} $M_\odot$/yr
- Higher masses (~1000 $M_\odot$) are still possible, if the disc is seen almost edge-on
- Alternatively, N10 may still be a young, fading SN, most likely of type IIn
- .... so we need more Chandra time to discriminate the models