Diffuse X-ray emission around an ultra-luminous X-ray pulsar

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outline

- Introduction - NGC 5907 ULX1
- Observation - an extended feature
- Interpretation - a ULX bubble

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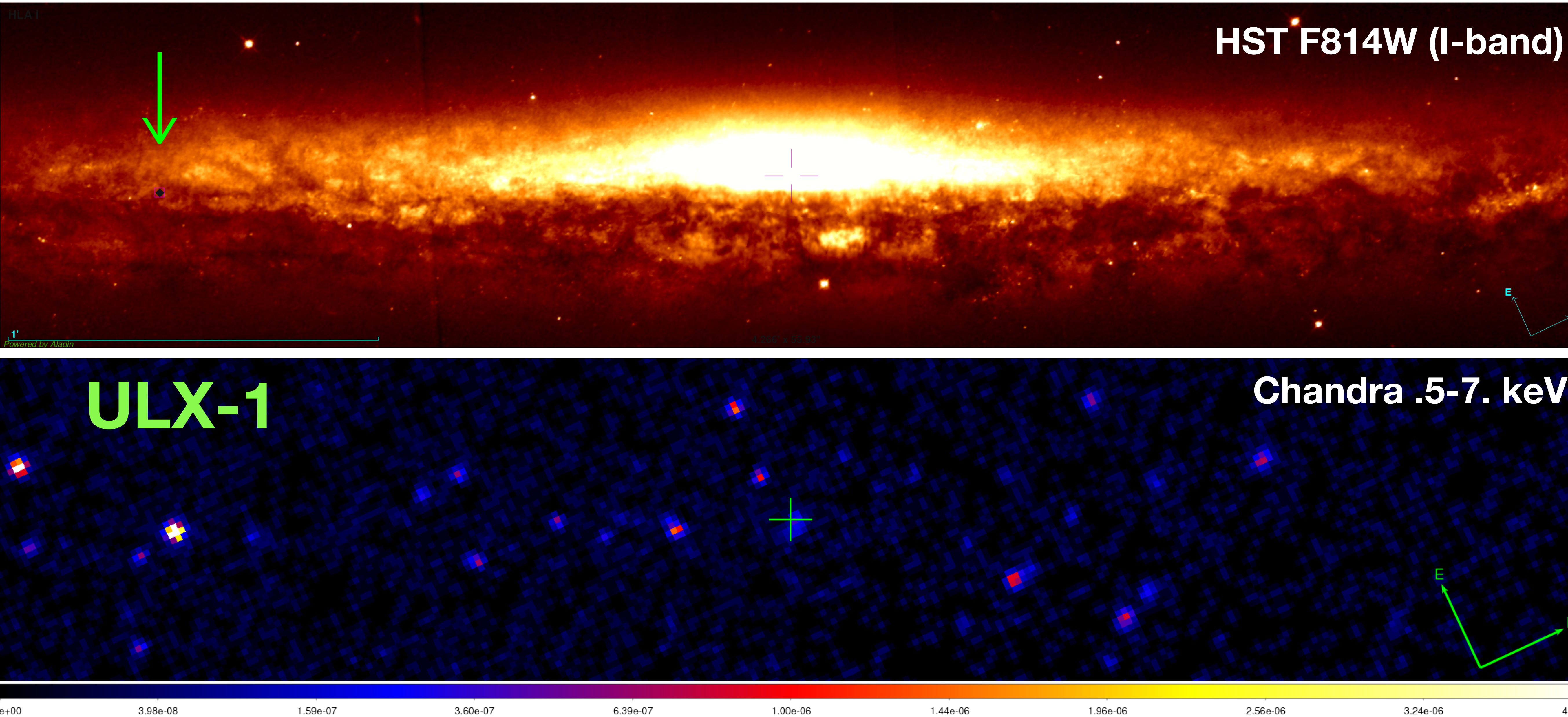
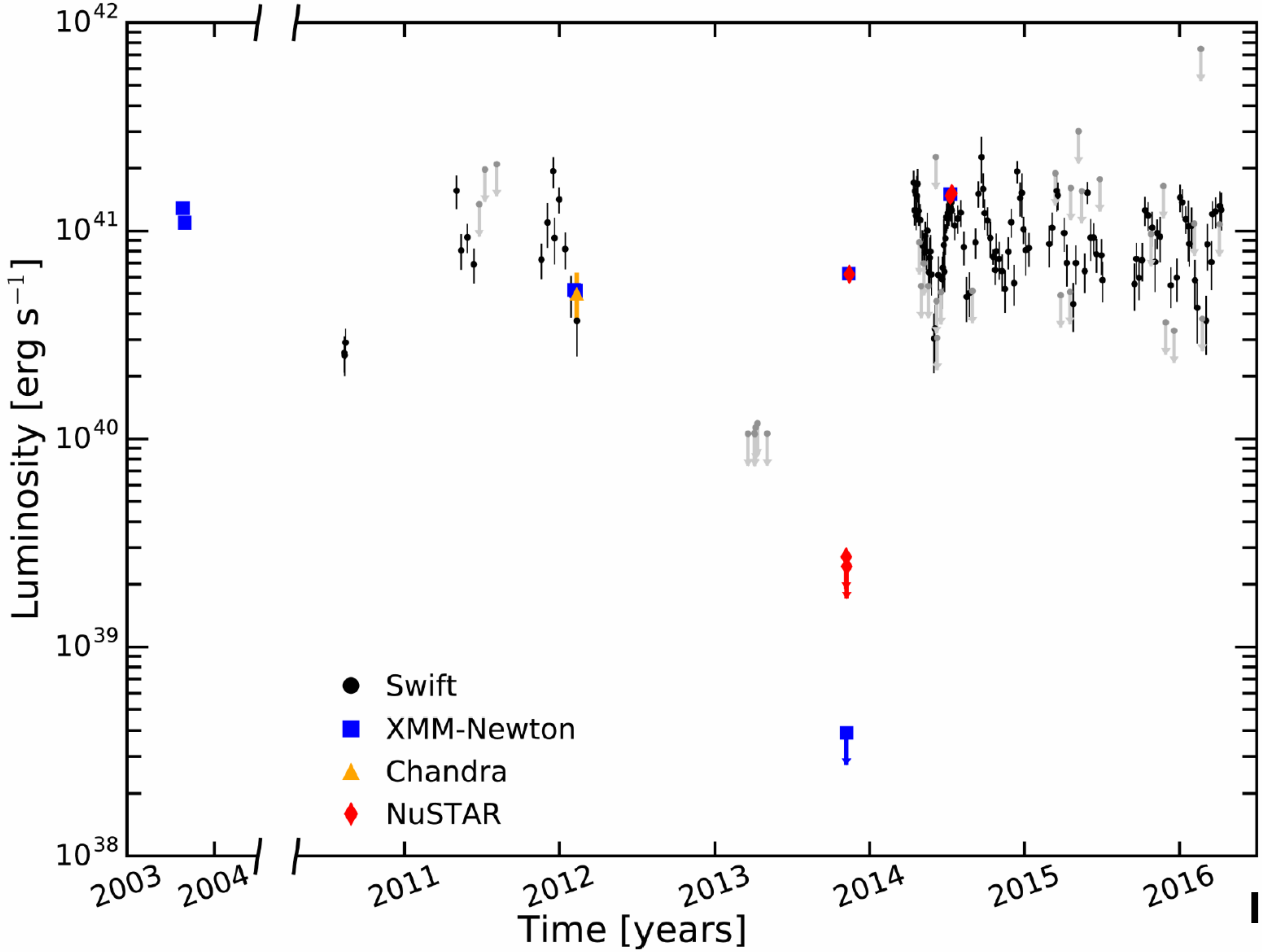
NGC 5907

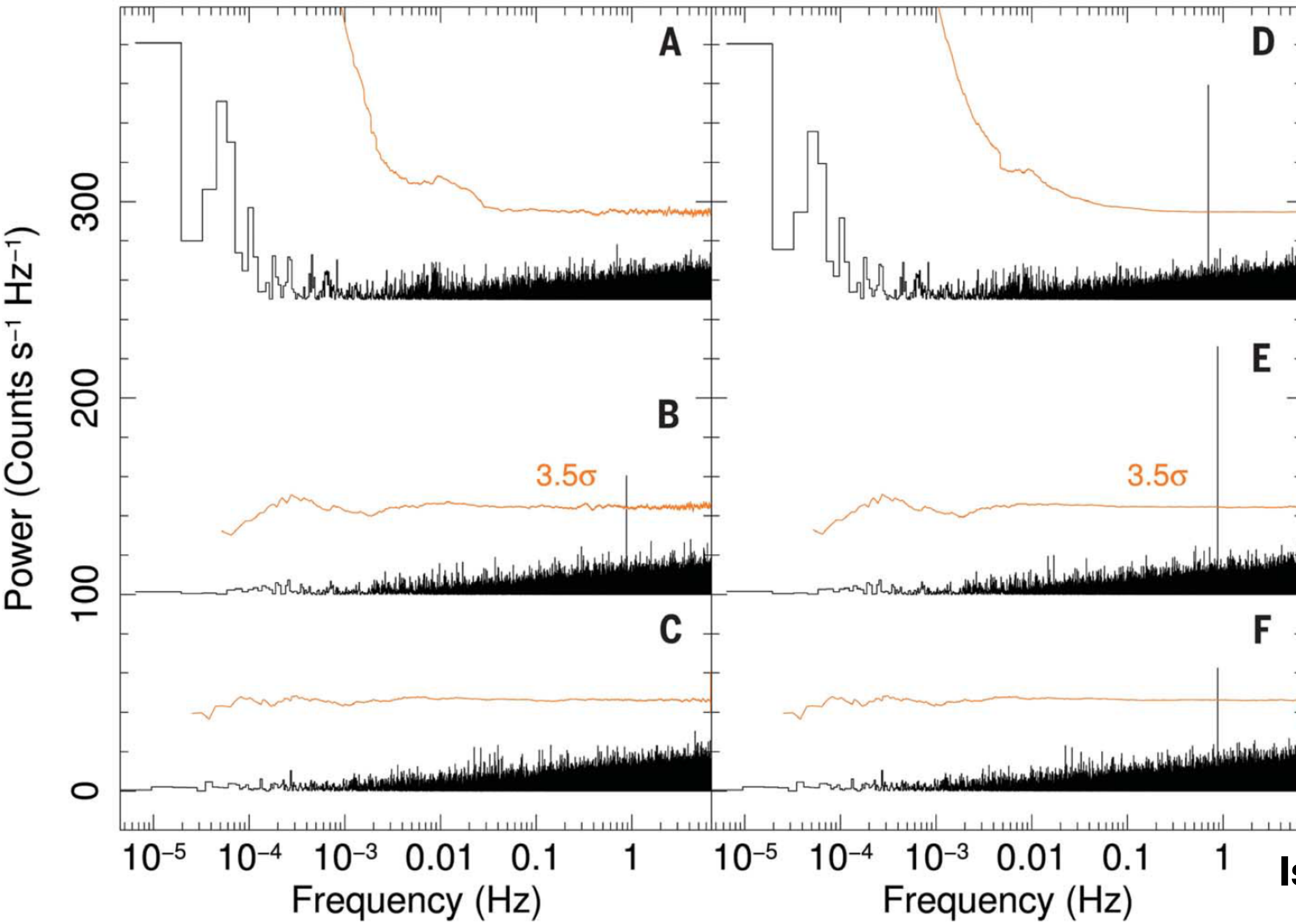


- spiral galaxy type=Sbc (Ann et al 2015 - SDSS)
- distance d=17.1+/-.1 Mpc (Tully et al 2013 - TRGB)
- inclination i=87.2+/-.2 deg (Xilouris et al 1999)



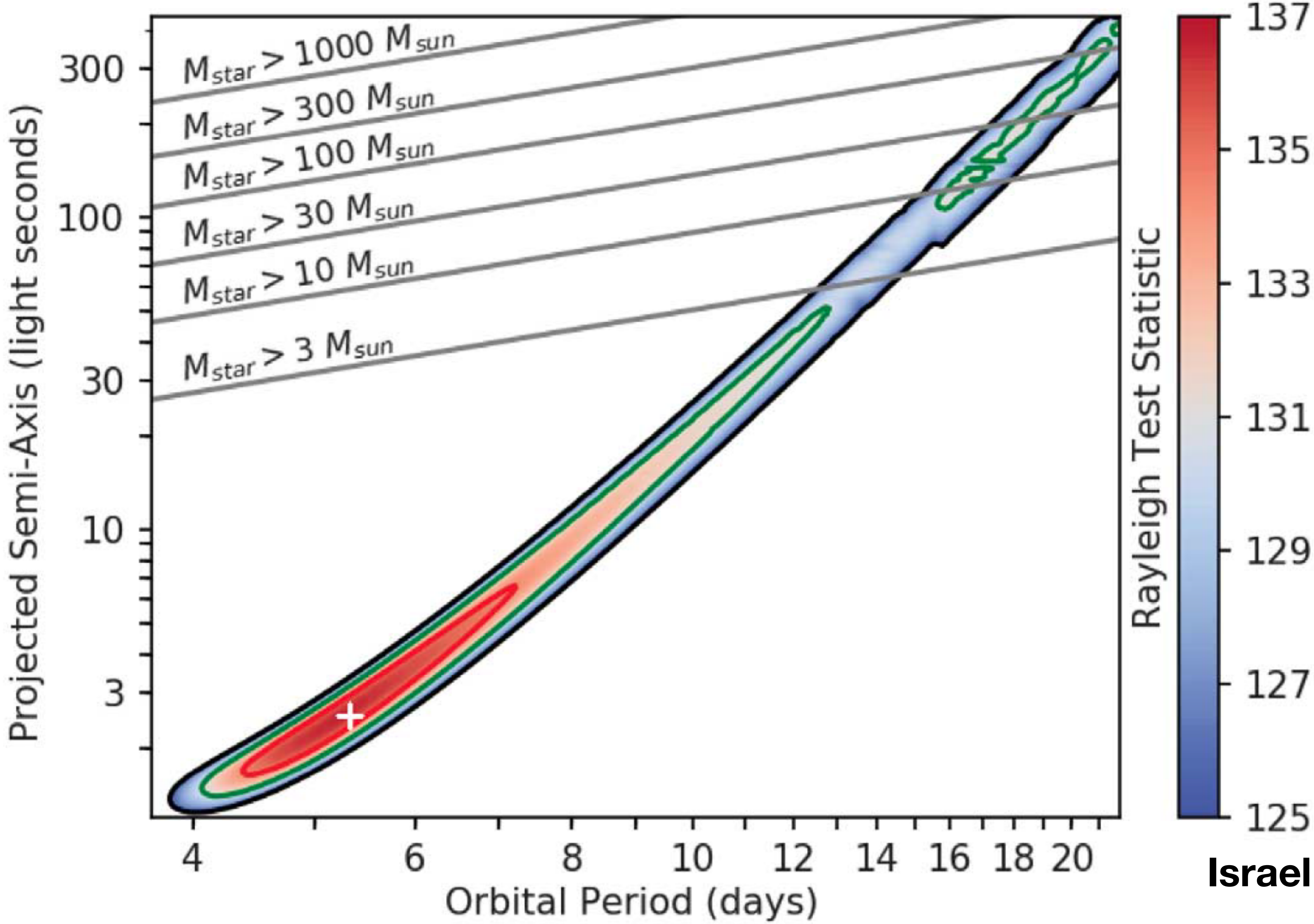
Israel et al 2017

- NGC 5907 ULX (ULX1) peaks at $L_X > 10^{41}$erg/s
- Quasi periodic modulation 78.1+/-.5d (Walton et al 2016)
- Off state with abrupt switch-on <4d (Walton et al 2015)



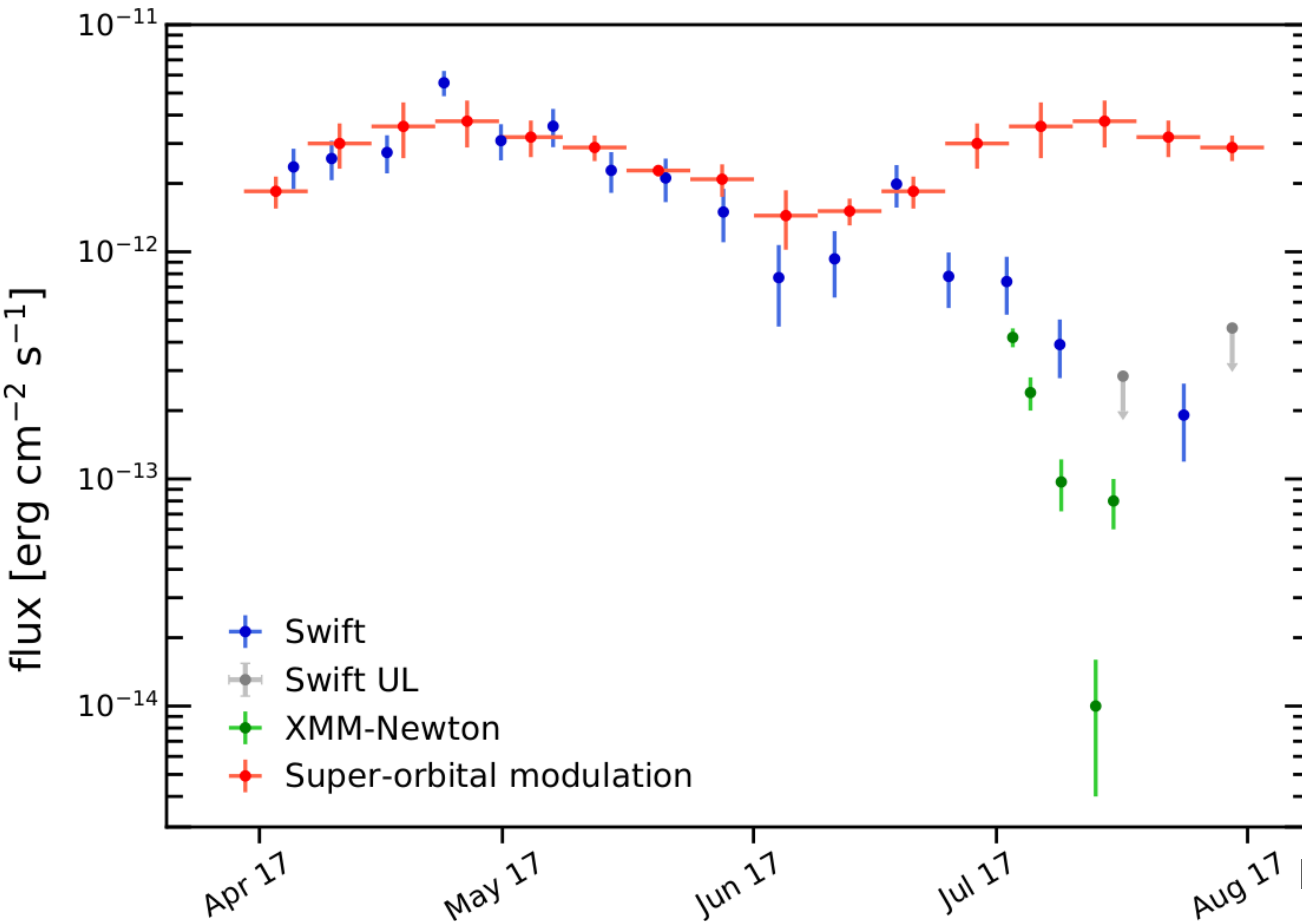
Israel et al 2017

- EXTraS: discovery of pulsation => accreting neutron star
- mass < 2.8 M_{sun} => L_{Edd}<3.4x10^{38}erg/s => L_X>~500 L_{Edd}
- P(2003)=1.43s P(2014)=1.13s => t_{spinup}<40 yr



Israel et al 2017

- weak constraints on the orbital parameters from timing
- recent XMM observations confirm the 1σ estimate
- we run a campaign Swift+XMM+NuSTAR to get the orbit



Belfiore et al in prep

- Swift monitoring resumed in Apr 2017
- XMM/NuSTAR LP to refine the orbit observed a switch-off
- Chandra TOO to probe the lowest state in Nov 2017

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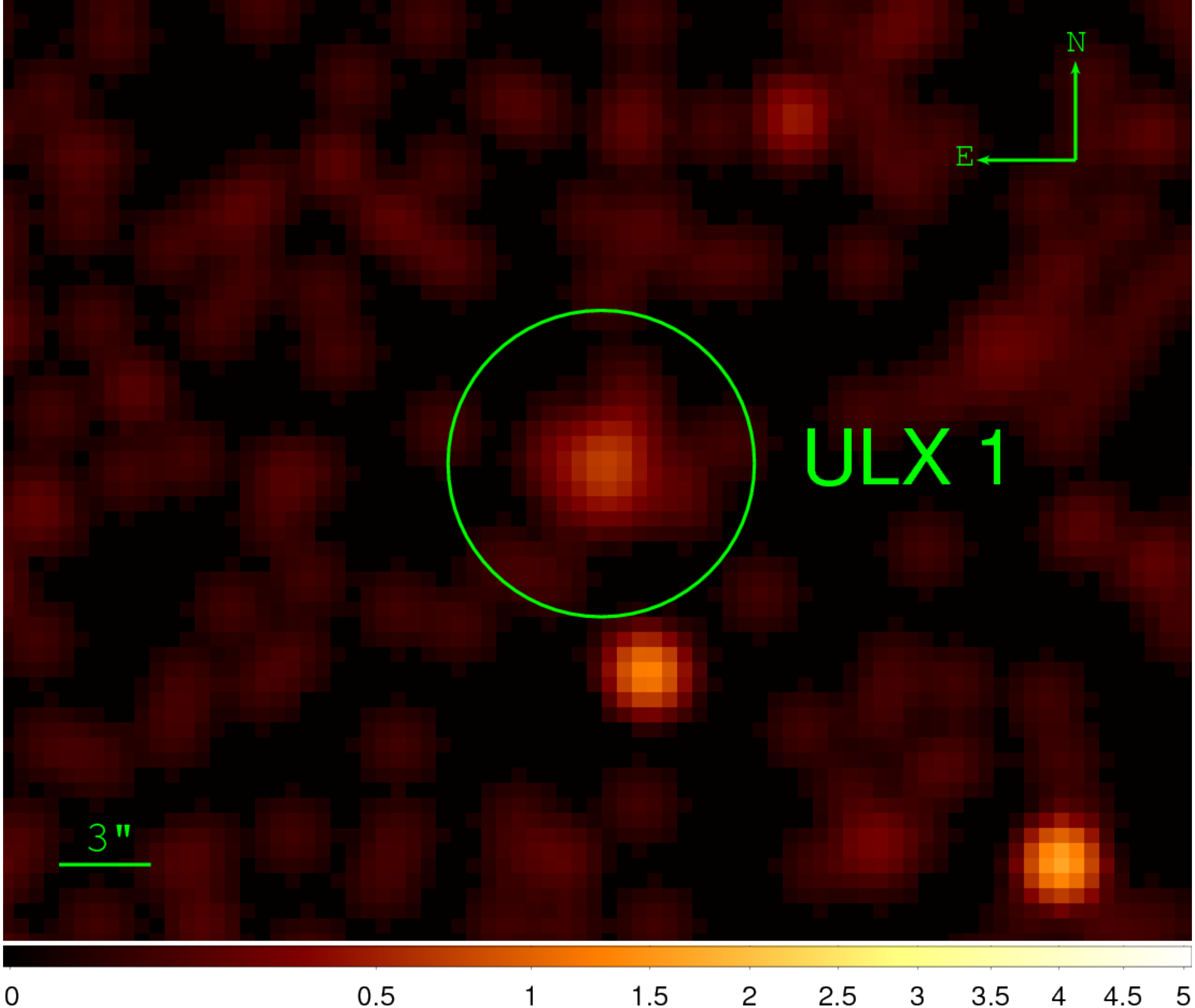
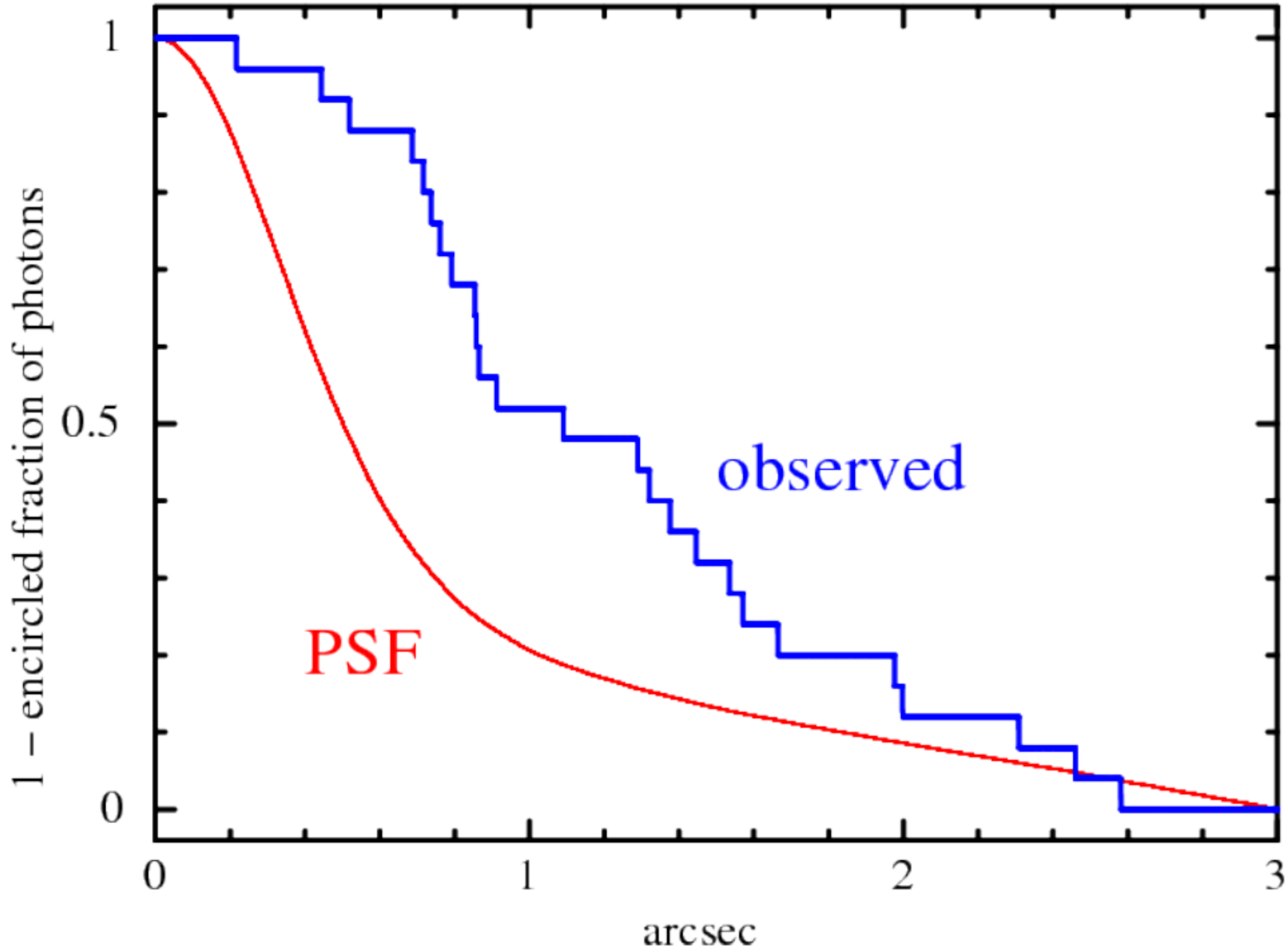
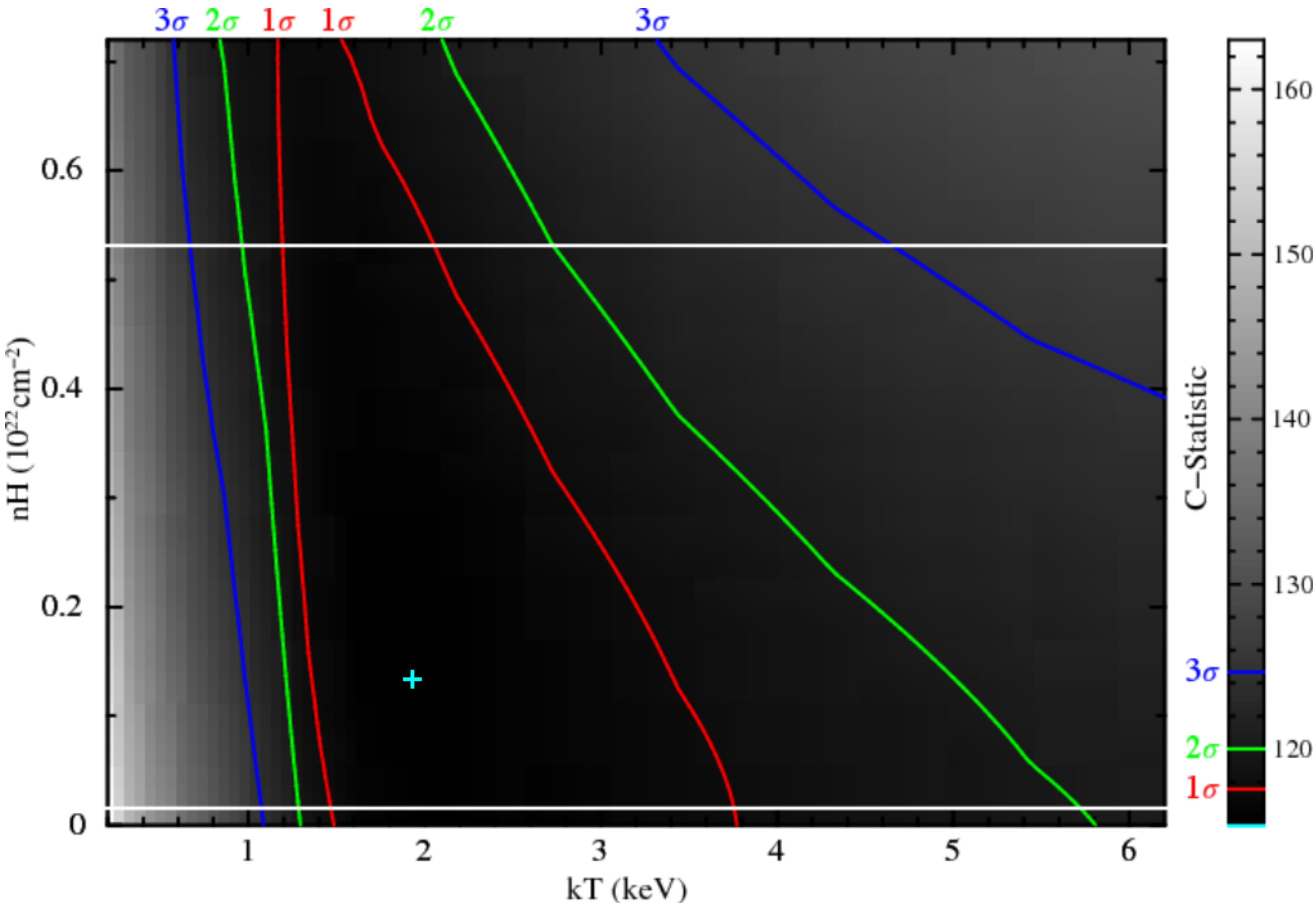


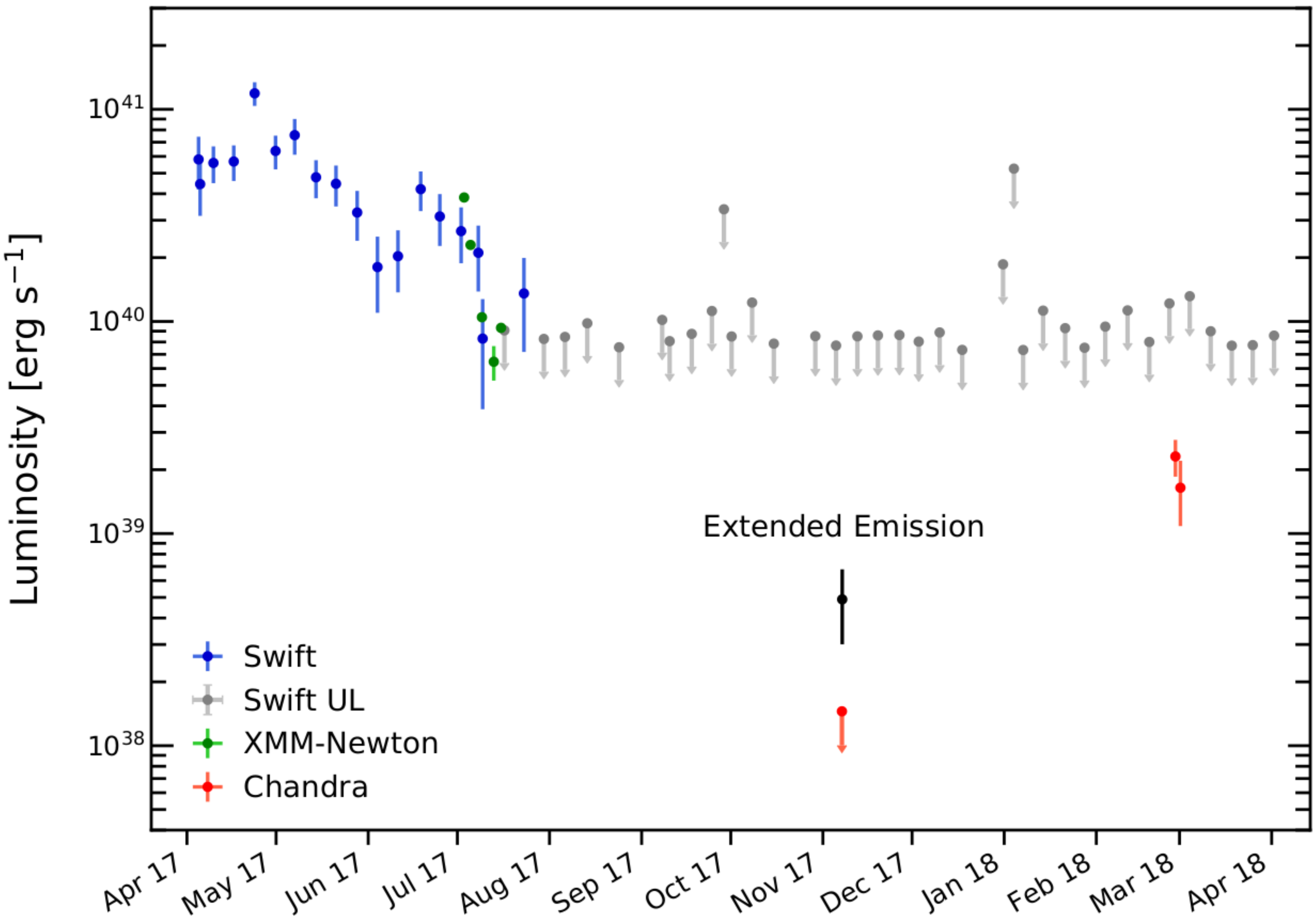
- 50ks ACIS obs on Nov 7 2017



- Strong source detection (7.3σ)
- Perfectly aligned with NGC 5907 ULX1 (<.1 arcsec)
- Evidence for extension (5.0σ) (verified with Montecarlo)



- absorbed APEC model in XSPEC weakly constrained
- no photons below 0.8 keV + external constraints on nH
- 1.1 keV<kT<4.2 keV => 1.2×10^{38} erg/s<L_X<4.2×10^{38} erg/s



- Deep upper limit on the point source ($L_X<L_{Edd}$)
- Follow-up Chandra TOO caught ULX1 in intermediate state too bright to detect and study the nebula

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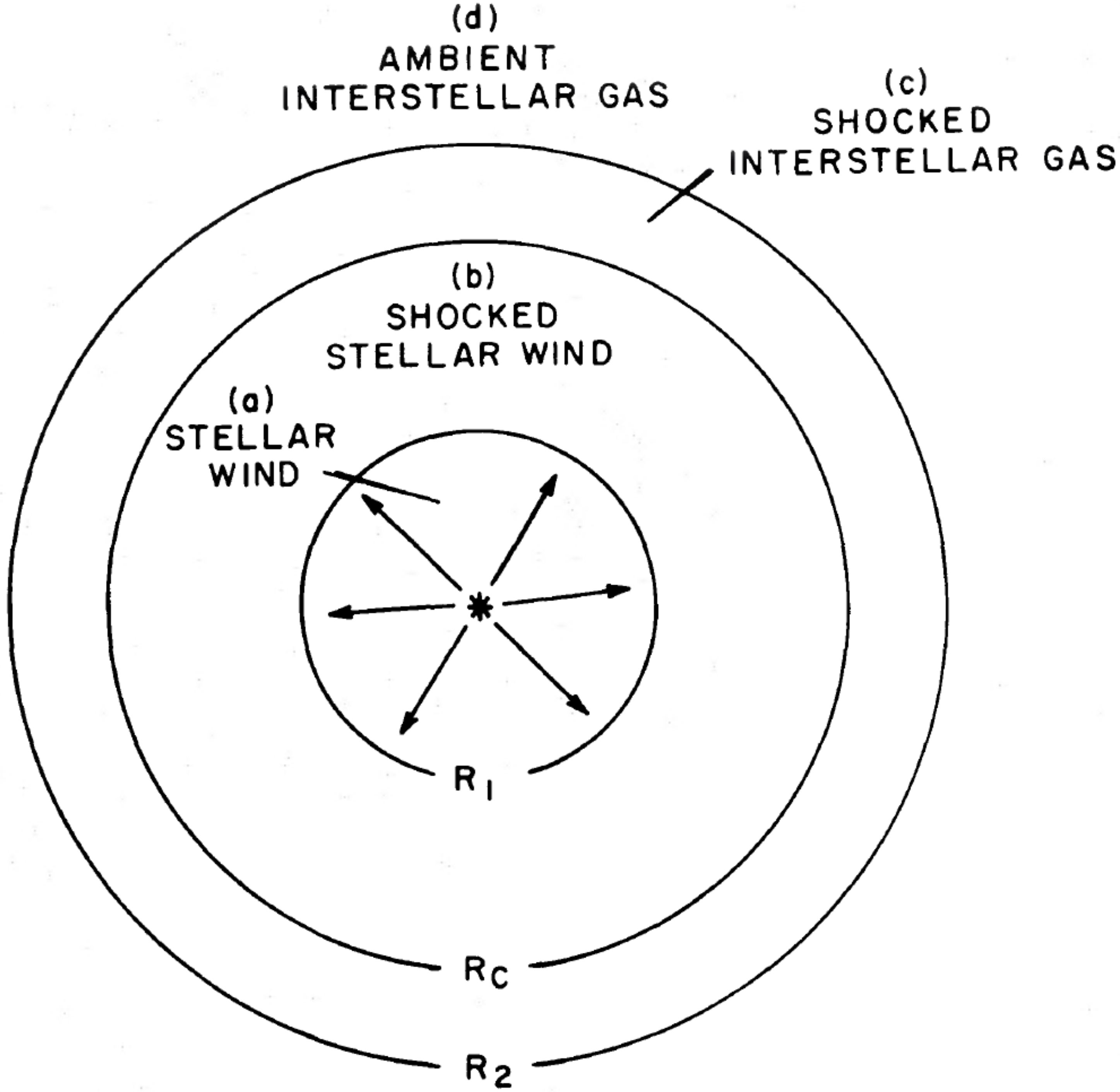
how do we interpret this feature?

- Local scattering - inconsistent with nH (too low)
- Local diffuse emission - very hot and bright
- Dust scattering within NGC 5907 - requires fine tuning
- A hypernova remnant - hard to get a NS in ULX1
- A ULX bubble - never observed in X-rays before

- We try and go after this last interpretation



Weaver et al 1977

- standard expansion phases: free - adiabatic - radiative
- mild MWL constraints (radio Halpha) => adiabatic phase
- internal shell has low X-ray efficiency (Siwek et al 2017)

- @17.1 Mpc the radius of the bubble is 112+/-42 pc
- RH conditions map kT into a shock speed:

$$v_{\rm sh}^{(0)} = \sqrt{\frac{16}{3}\frac{kT}{m_{\rm p}}} = \left(3.3^{+1.6}_{-0.8}\right) \times 10^{-3} c = \left(9.9^{+4.8}_{-2.4}\right) \times 10^{2}\,{\rm km\,s^{-1}}$$

- we allow for a non ideal shock speed: $v_{\rm sh} = v_{\rm sh}^{(0)} \times \xi$
- bubble theory predicts in this phase a radial evolution:

$$R_2(t) = \alpha \left(\frac{L_{\rm w} t^3}{n_{\rm ISM} m_{\rm p}}\right)^{1/5}$$

- therefore we can estimate the age of the bubble as:

$$\tau = \frac{3}{5}\frac{R_2}{v_{\rm sh}} = \left(6.7^{+3.1}_{-2.8}\right) \times 10^{4}\,{\rm yr} \times \xi^{-1}$$

- this is fully consistent with the adiabatic hypothesis

- we derive n_{ISM} from R and the spectral normalisation
- we allow also for a non-ideal compression factor W>4
- the expansion law leads to an estimate of the wind power:

$$L_{\mathrm{w}} = \frac{m_{\mathrm{p}} n_{\mathrm{ISM}} R_2^5}{\alpha^5 \tau^3} = \left(1.3^{+9.8}_{-1.0}\right) \times 10^{41}\,\mathrm{erg\,s^{-1}} \times \xi^3 \times \left(\frac{W}{4}\right)^{-\frac{1}{2}}$$

- as this is fixed by the model, the bubble stores an energy:

$$E = L_{\mathrm{w}} \tau = \left(2.8^{+18}_{-2.2}\right) \times 10^{53}\,\mathrm{erg} \times \xi^2 \times \left(\tfrac{W}{4}\right)^{-\frac{1}{2}}$$

- which is split between bulk motion and thermal energy

- as the ultimate source of energy is accretion, for a NS:

$$M_{\rm accr} = \frac{E}{\eta c^2} \simeq \left(1.8^{+12}_{-1.5}\right) \times 10^{33}\,{\rm g} = 0.9^{+5.9}_{-0.7}\,M_\odot$$

- high: could induce a collapse into a BH, but still plausible

- as the energy is carried by the wind, if we limit its mass, its speed must be mildly relativistic (Pinto et al 2016)

- as $t_{\rm spinup} << \tau$ a very efficient mechanism for dissipating the NS angular momentum must exist (propeller?)

- as the energy stored in a single bubble is huge, their feedback on the host galaxy could be non-negligible

summary

- NGC 5907 ULX1: extreme super-Eddington X-ray pulsar
- It shows a complex variability behaviour
- In a low state we detected an extended feature
- We can interpret it as a bubble powered by the ULX wind
- This implies extreme energetics and an age ~70kyr
- Still a lot to do to confirm this result, constrain the model, find similar cases in other ULXs, probe their population, understand their evolution and impact on host galaxies

thank you for your attention
that’s all!

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Belfiore et al. in press