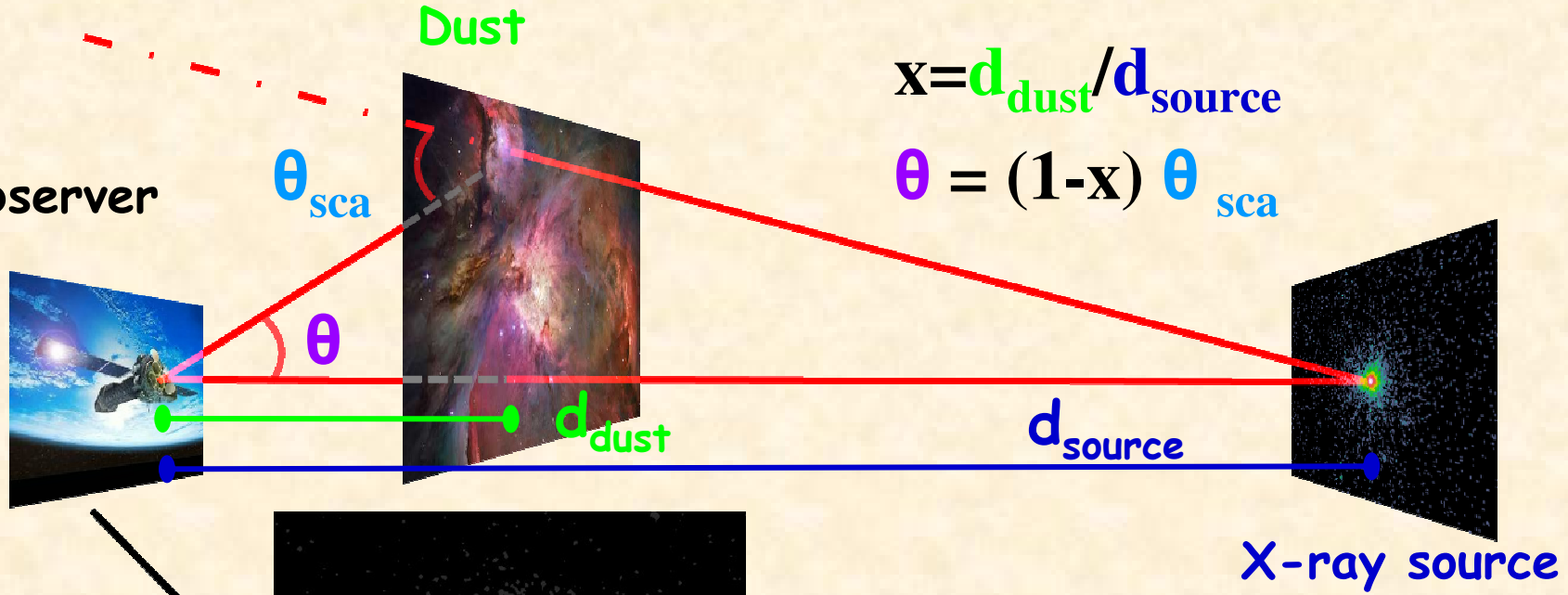
Bologna, 2009 September 8

The spectacular X-ray echo of a magnetar burst

Andrea Tiengo
INAF, IASF-Milano

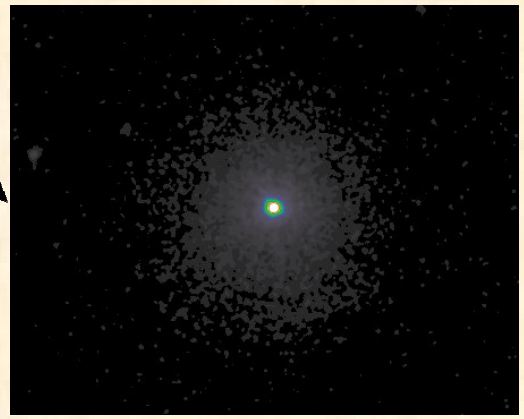
G. Vianello, P. Esposito, S.Mereghetti, G.L. Israel, L. Stella,
R. Turolla, S. Zane, N. Rea, D. Götz, F. Bernardini, A. Moretti,
P. Romano, N. Gehrels, N. Schartel

Dust-scattering geometry



$x = d_{dust}/d_{source}$

$\theta = (1-x)\,\theta_{sca}$

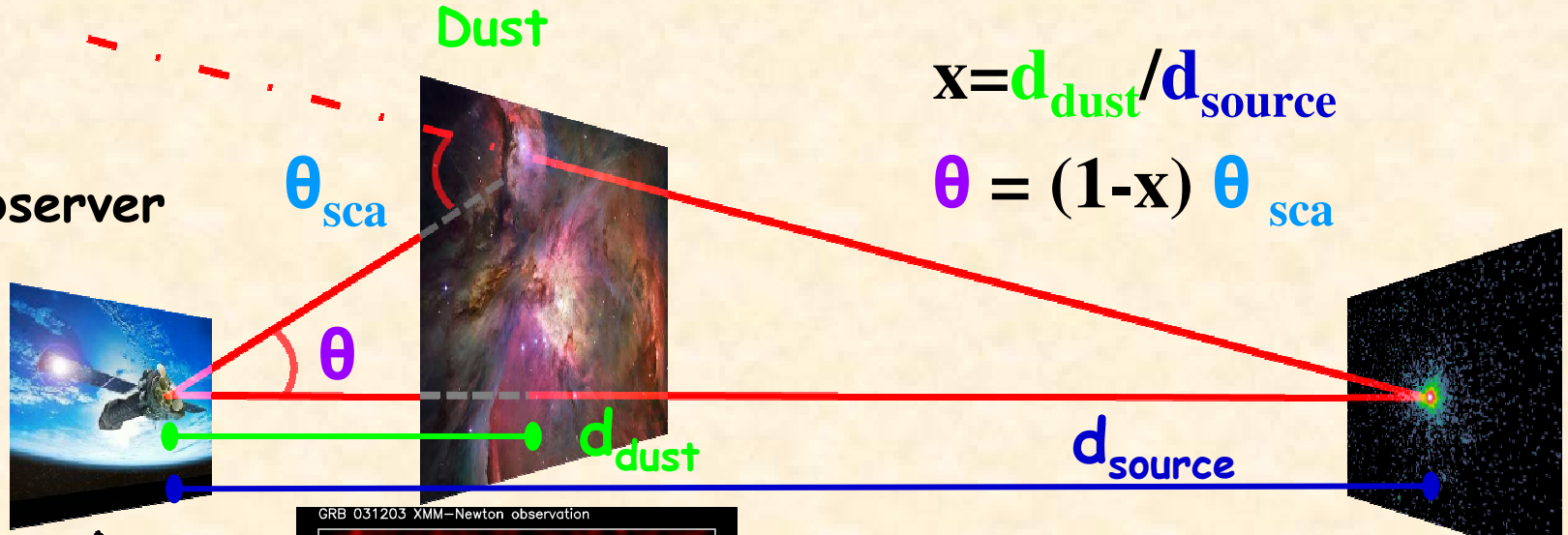


Dust-scattered X-rays are detected at off-axis angle θ and with a time delay $(t - t_0)$

$$(t - t_0) = \frac{x}{1-x}\,\frac{d_{source}\,\theta^2}{2c} \Rightarrow \theta(t) = \sqrt{\frac{1-x}{x}\,\frac{2c(t - t_0)}{d_{source}}}$$

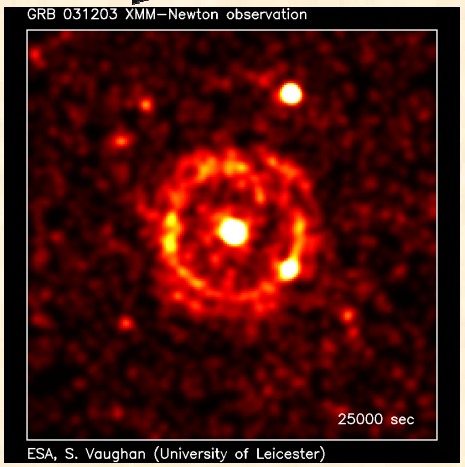
Diffuse dust and/or persistent X-ray source ⇒ X-ray halo

Dust-scattering geometry



$x = d_{dust}/d_{source}$

$\theta = (1-x)\,\theta_{sca}$



Dust-scattered X-rays are detected at off-axis angle θ and with a time delay $(t - t_0)$

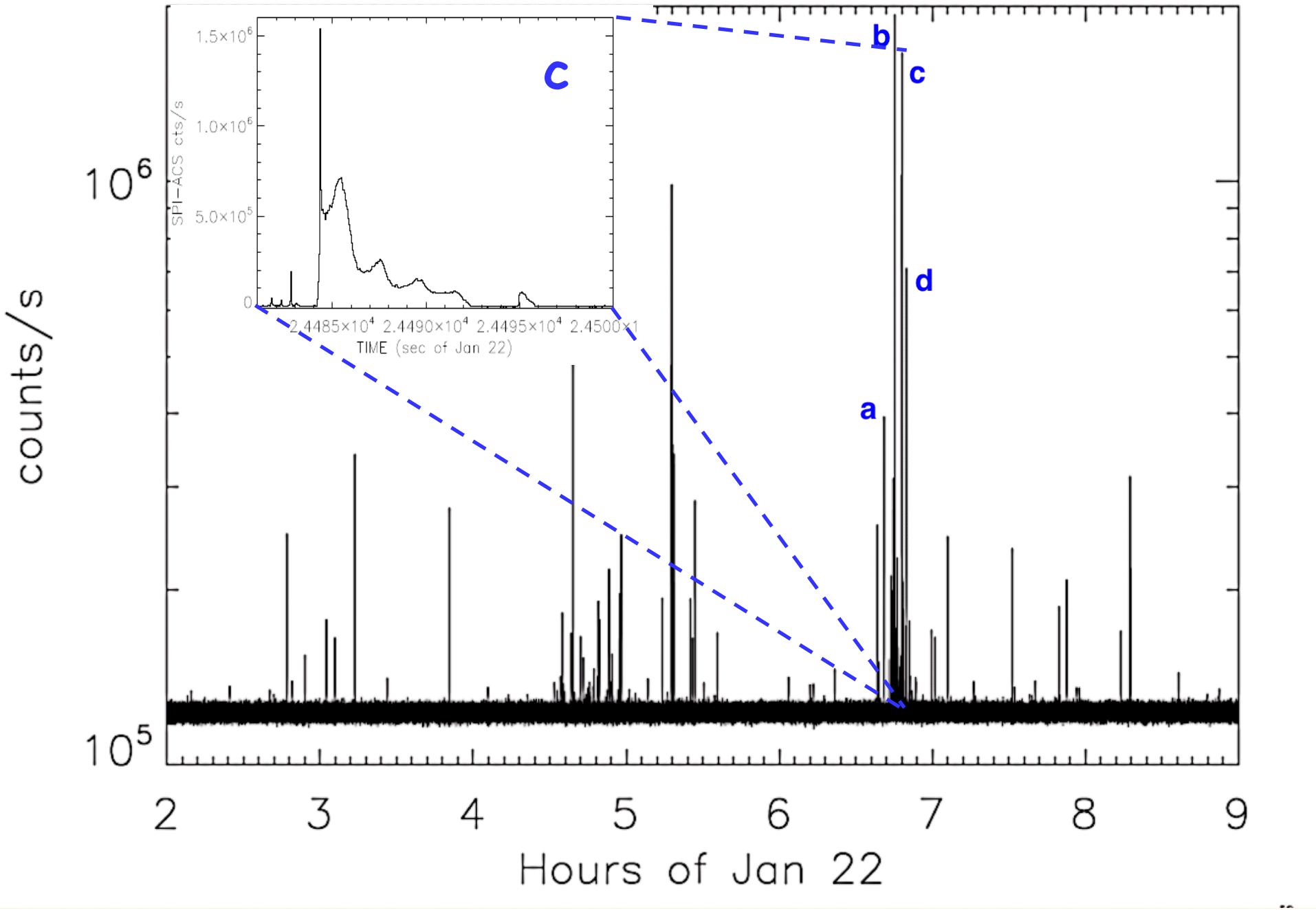
$$(t - t_0) = \frac{x}{1-x}\,\frac{d_{source}\,\theta^2}{2c} \Rightarrow \theta(t) = \sqrt{\frac{1-x}{x}\,\frac{2c(t - t_0)}{d_{source}}}$$

Thin dust layer AND X-ray impulse ⇒ X-ray expanding rings

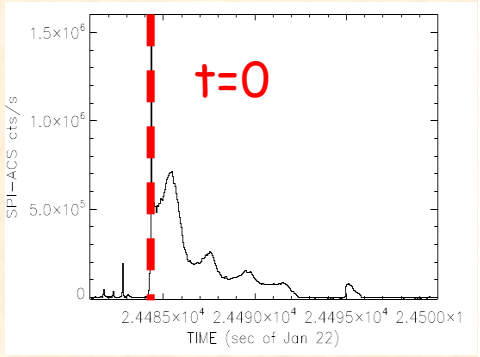
The magnetar 1E 1547.0-5408

- **Gelfand & Gaensler *(2007, ApJ 667, 1111):*** proposed 1E1547 to be a ***magnetar,*** based on X-ray spectrum, lack of stellar companion and location in SNR
- **Camilo et al. *(2007, ApJ 666, L93):*** discovery of radio pulsations $\Rightarrow$ becomes 2nd magnetar showing radio pulsations and the fastest spinning magnetar (period = 2 s)
- **Halpern et al. *(2008, ApJ 676, 1178):*** X-ray flux increase and detection of X-ray pulsations
- **2008 Oct:** first SGR-like bursts detected and large flux increase ***(Israel et al., in prep)***
- **2009 Jan:** many bright bursts, huge flux increase and X-ray rings ***(Tiengo et al., in prep)***

INTEGRAL SPI anti-coincidence (E>80 keV) *(Mereghetti et al., ApJ 696, 2009)*

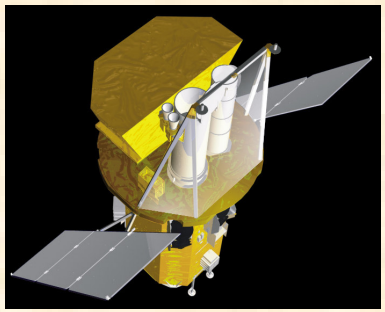


X-ray observations



*Fixing **t=0** at the time of the burst with pulsating tail:*

- **t<1 d:** 1-2 ks Swift/XRT observations in Windowed Timing (WT) mode
  ⇒ each column collapsed in one pixel
  ⇒ ***no 2D imaging***

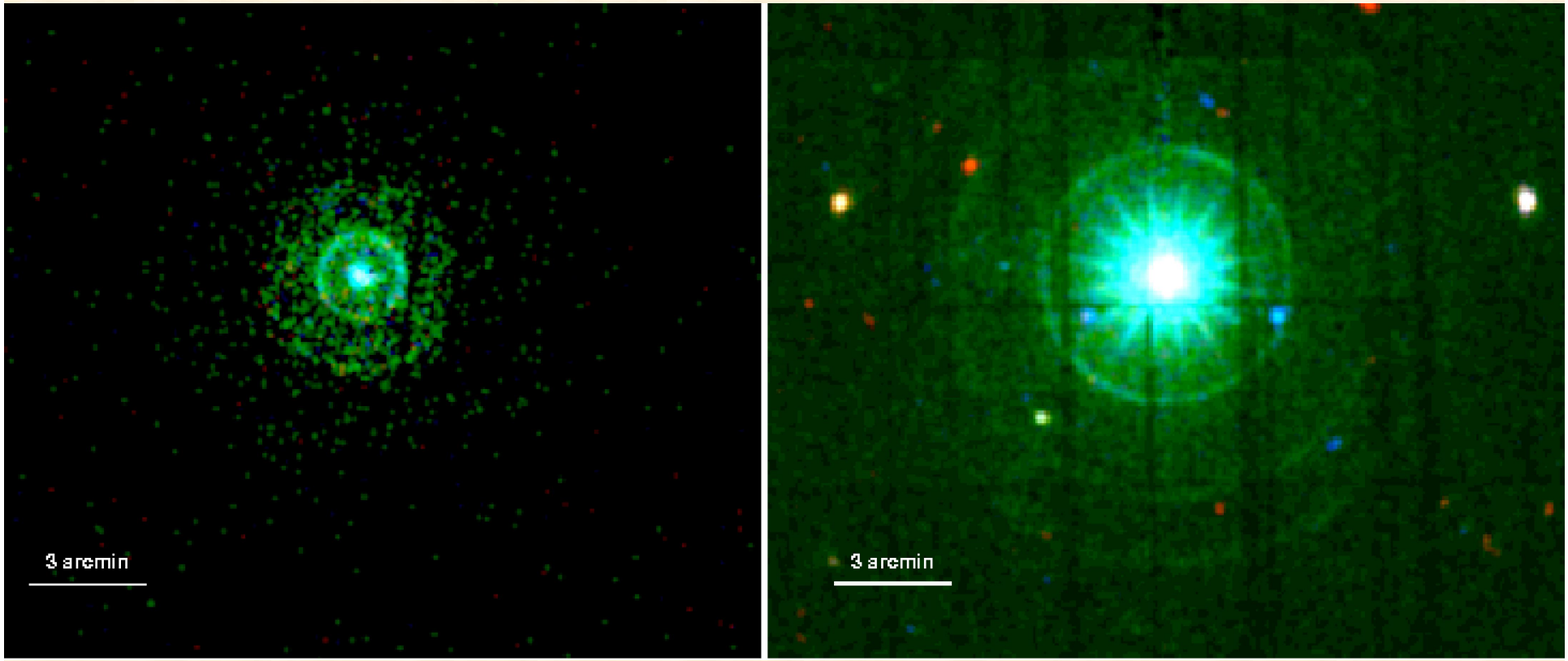


- **t>1d:** 2-6 ks Swift/XRT observations in Photon Counting (PC) mode

- **t=13 d:** 50 ks *XMM-Newton*/EPIC ToO observation in Full Frame mode

Swift/XRT: t=1.37 d

XMM/EPIC: t=12.3 d

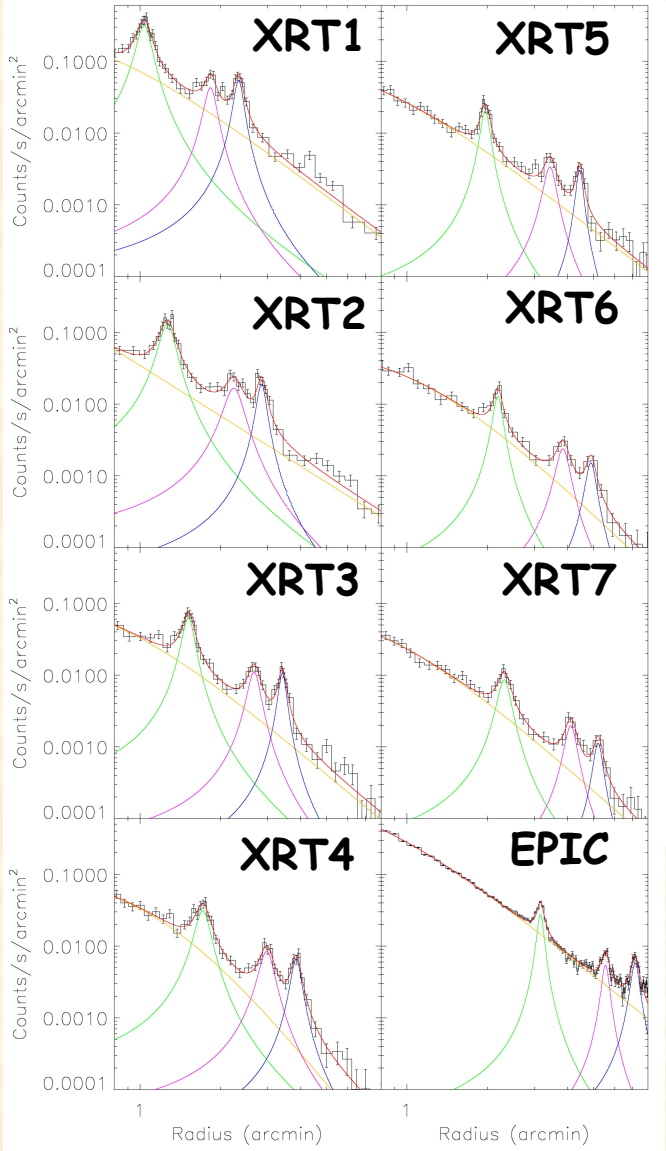


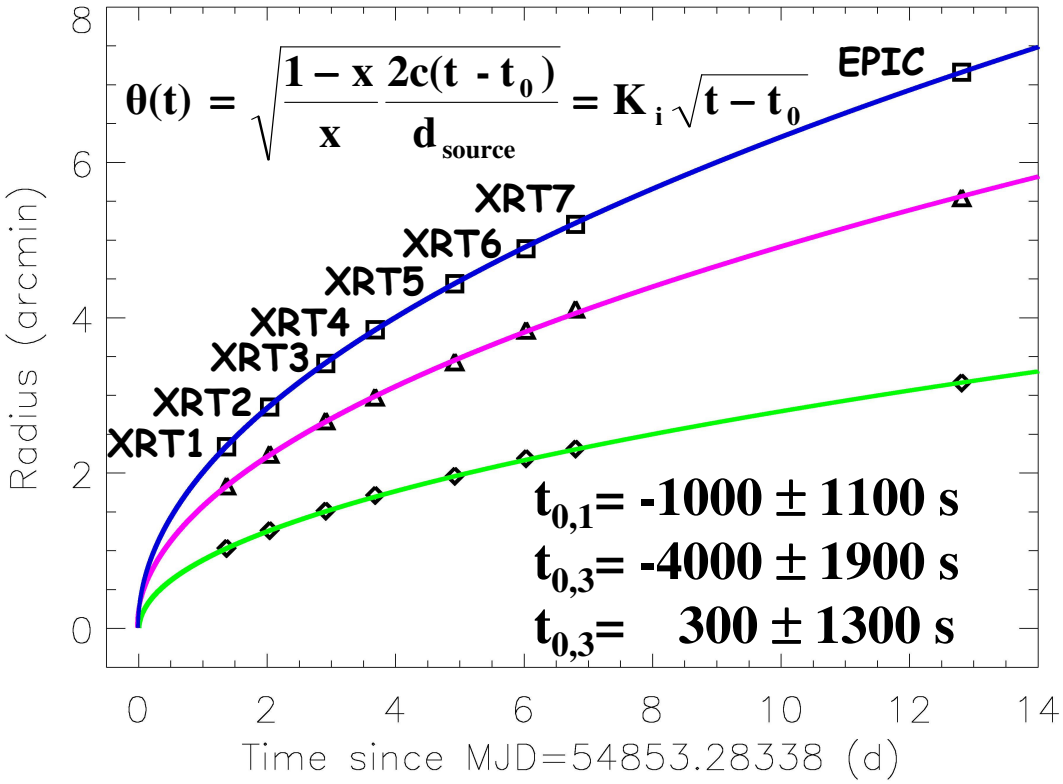
<u>3 rings:</u> 1 burst (which one?) and 3 dust layers?

OR

3 bursts (which ones?) and 1 dust layer?

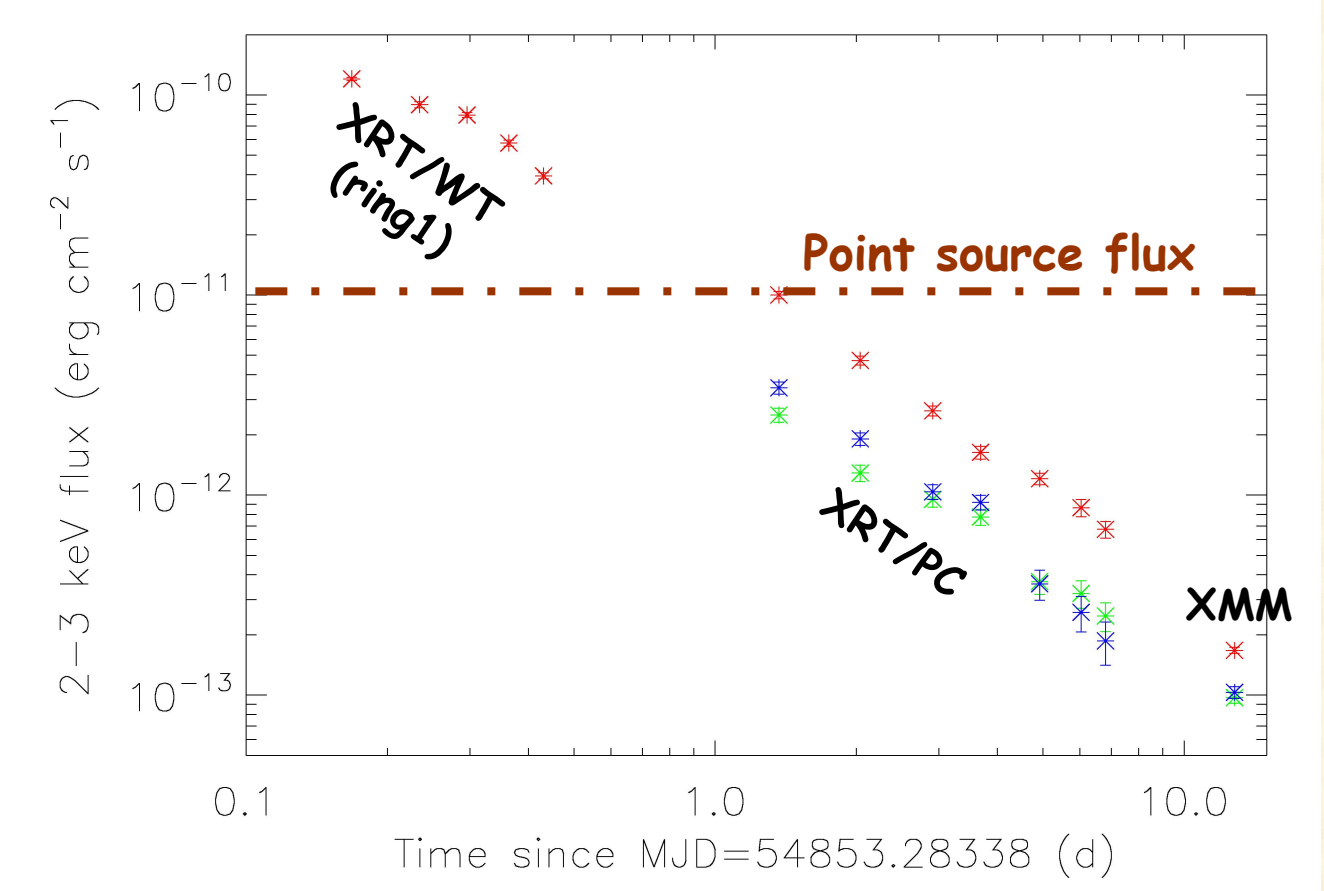
Radial profiles and rings expansion





t_0 consistent with t=0, but also with bright (saturated) burst emitted ~3 minutes earlier

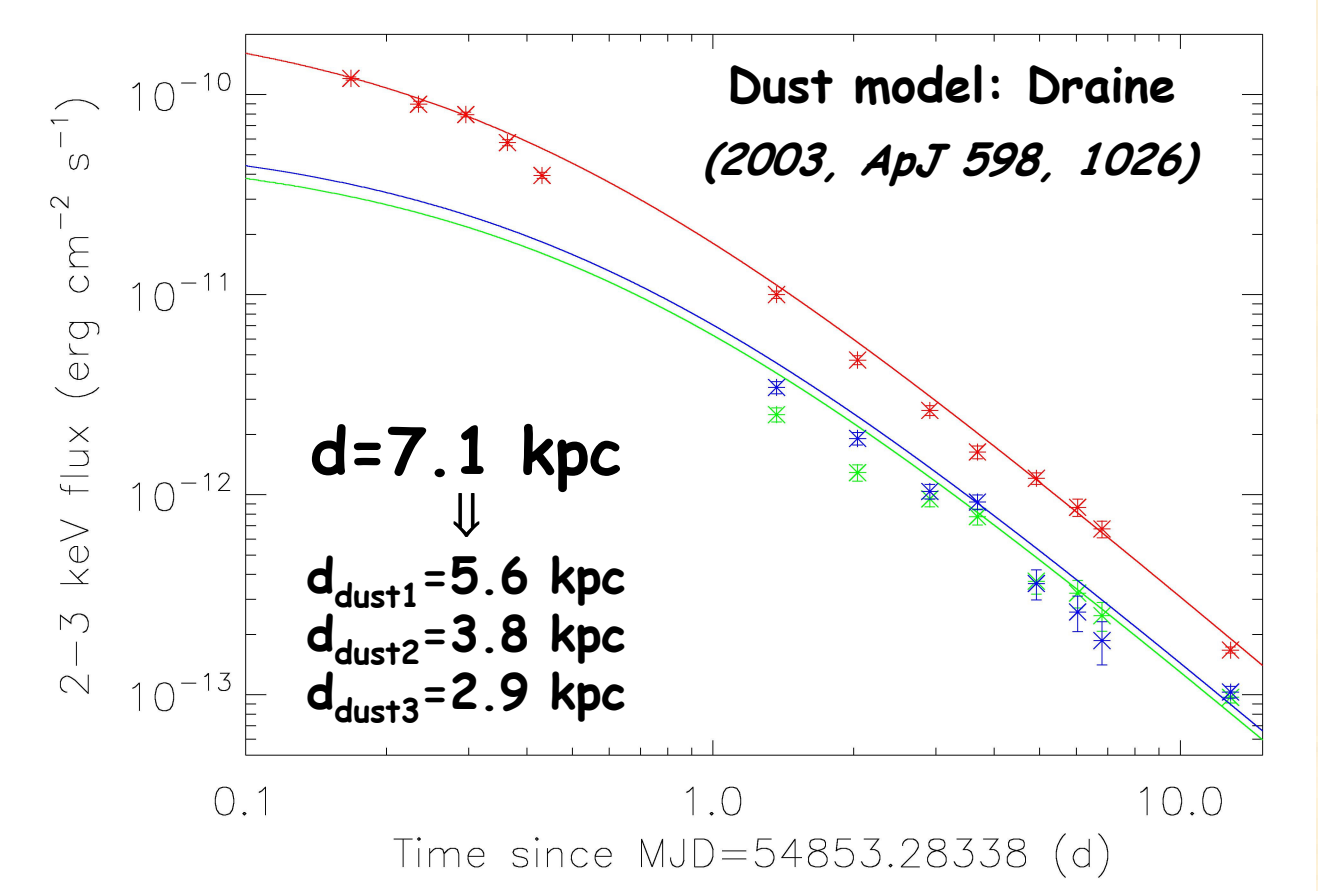
Rings lightcurve



For ~1 day the flux of the innermost ring was brighter than the persistent X-ray emission of the magnetar

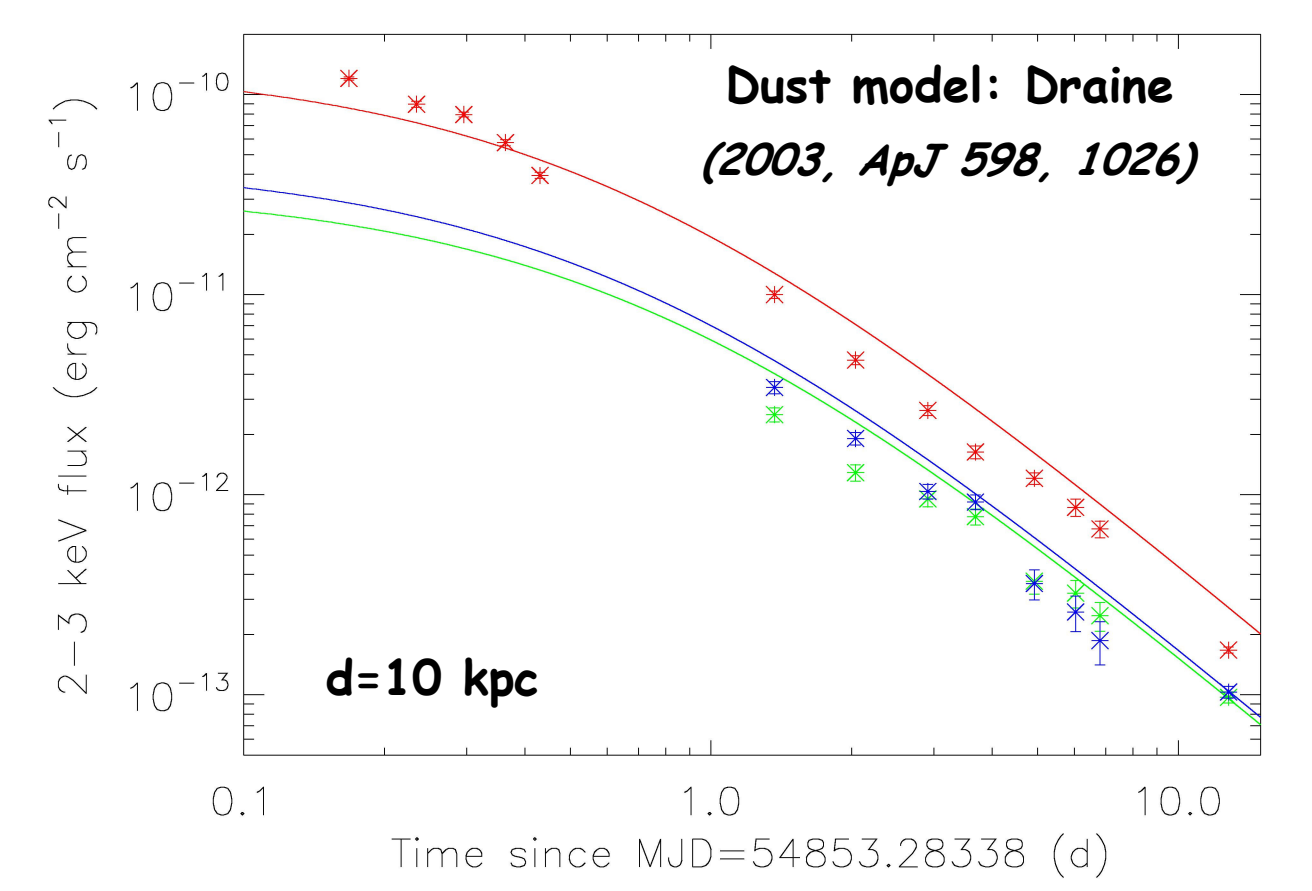
⇒ WT data are dominated by dust-scattered emission

Rings lightcurve = halo profile



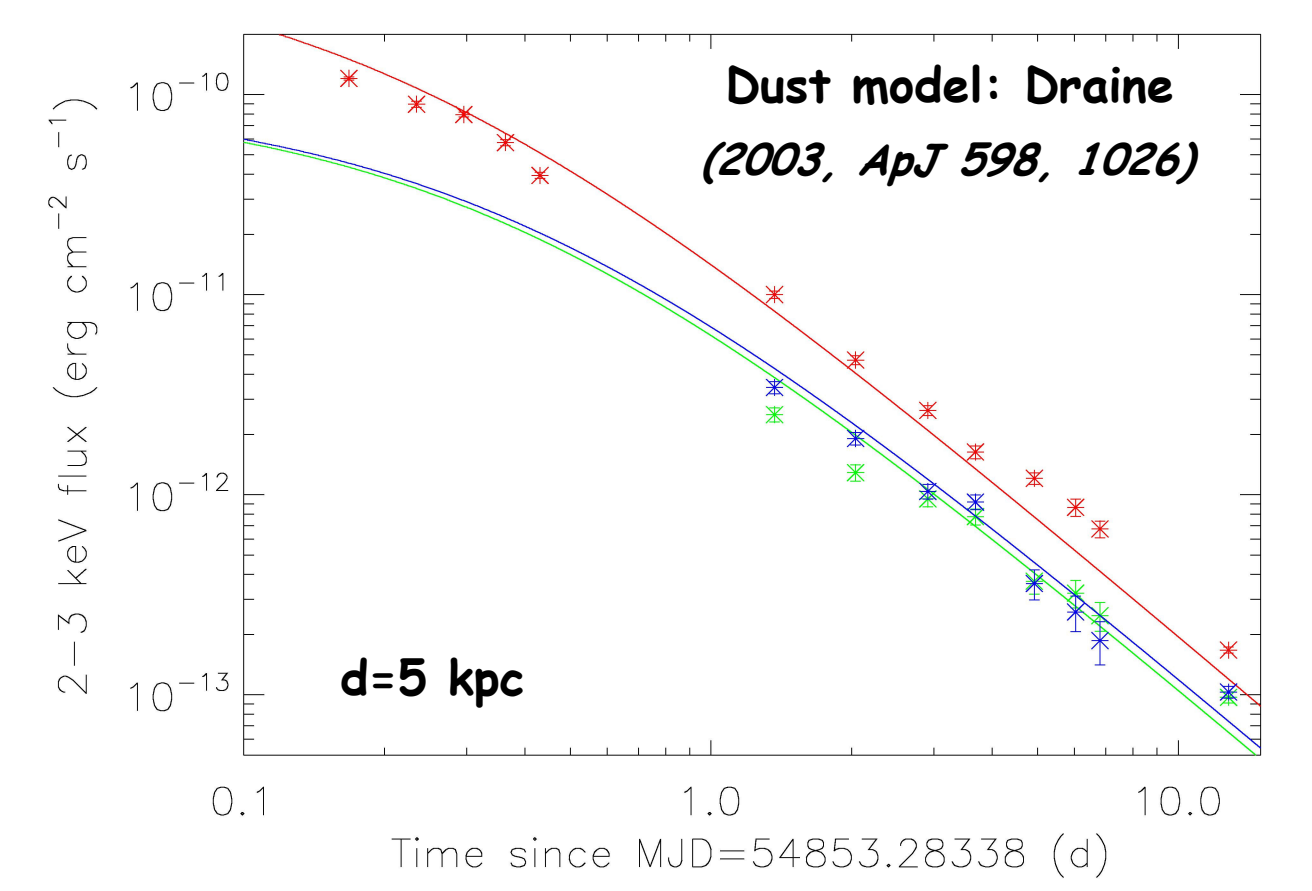
Assuming the dust composition and grain size distribution, simultaneous fit of all spectra for each ring provides source distance and burst spectrum (and the burst fluence assuming A_V of dust layer)

Rings lightcurve = halo profile



Assuming the dust composition and grain size distribution, simultaneous fit of all spectra for each ring provides source distance and burst spectrum (and the burst fluence assuming A_V of dust layer)

Rings lightcurve = halo profile



Assuming the dust composition and grain size distribution, simultaneous fit of all spectra for each ring provides source distance and burst spectrum (and the burst fluence assuming A_V of dust layer)

What have we learnt from this spectacular event?

- **The distance of the magnetar (and of the dust layers):** systematic uncertainties in dust models and non-standard data analysis *(work in progress)*

- **These data are a severe test for dust models:** although the burst X-ray spectrum was not measured (but a future bright burst might be directly observed), we have 3 independent measures of distance and burst spectrum

- **The dust echo of a bright magnetar burst can dominate over its persistent X-ray emission:** X-ray afterglows of other magnetar bursts might also be contaminated by dust scattering