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The spectacular X-ray echo of a magnetar burst

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Dust-scattering geometry

Diffuse dust and/or persistent X-ray source \( \Rightarrow \) X-ray halo

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

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

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

\( x = \frac{d_{\text{dust}}}{d_{\text{source}}} \)
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Thin dust layer AND X-ray impulse $\Rightarrow$ X-ray expanding rings

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$\theta = (1 - x) \theta_{\text{sca}}$
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 ⇒ becomes 2nd magnetar showing radio pulsations and the fastest spinning magnetar (period = 2 s).


- **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).
X-ray observations

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

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

- $t>1\text{ d}$: 2-6 ks Swift/XRT observations in Photon Counting (PC) mode

- $t=13\text{ d}$: 50 ks XMM-Newton/EPIC ToO observation in Full Frame mode
Swift/XRT: $t=1.37\text{ d}$  
XMM/EPIC: $t=12.3\text{ d}$

3 rings: 1 burst (which one?) and 3 dust layers?  
OR  
3 bursts (which ones?) and 1 dust layer?
Radial profiles and rings expansion

\[ \theta(t) = \sqrt{1 - \frac{2c(t - t_0)}{x d_{\text{source}}}} = K_i \sqrt{t - t_0} \]

\[ t_{0,1} = -1000 \pm 1100 \text{ s} \]
\[ t_{0,3} = -4000 \pm 1900 \text{ s} \]
\[ t_{0,3} = 300 \pm 1300 \text{ s} \]

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

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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