Swift Observations of Stellar Flares

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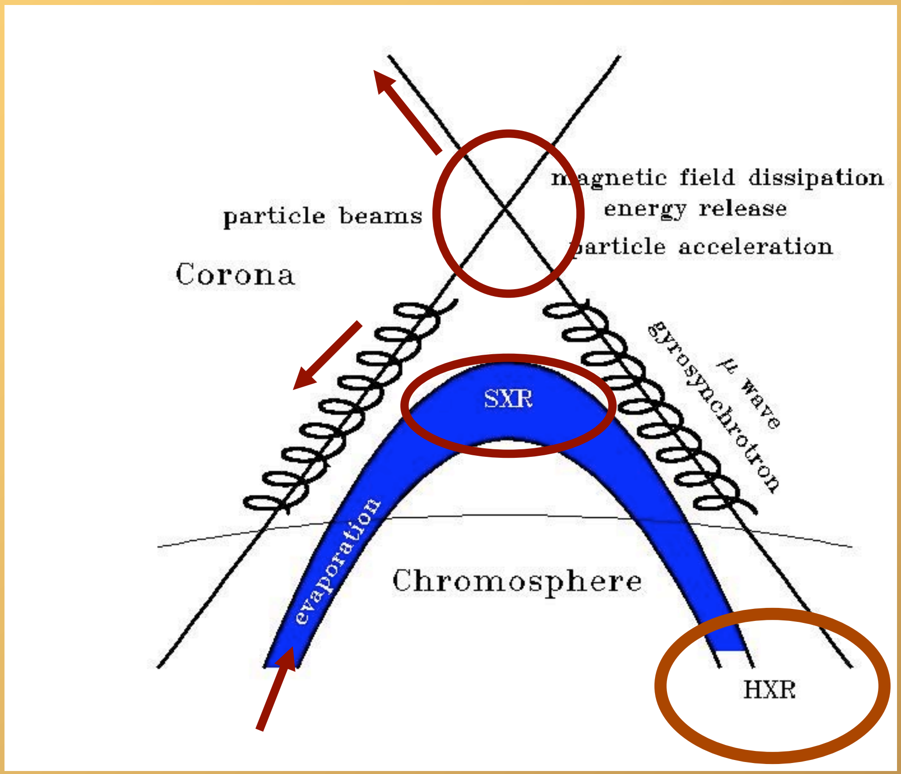
Outline

- *Science of stellar flares*
- *Recap of II Peg flare event: importance, what we learned about stellar flares*
- *HR 1099 flare(s): why we need the lowered threshold*
- *Multi-wavelength coordination*
- *Expected flare rates*

Basic Flare Scenario



Interrelation of thermal / nonthermal processes constrains underlying heating, dynamics, energetics

Neupert Effect = Observational temporal relationship between (incoherent) signatures of accelerated particles and plasma heating

$SXR(t) = {}_{t0}\int^{t} HXR(t')dt'$

or MW(t')

Impact on stellar atmosphere, environment

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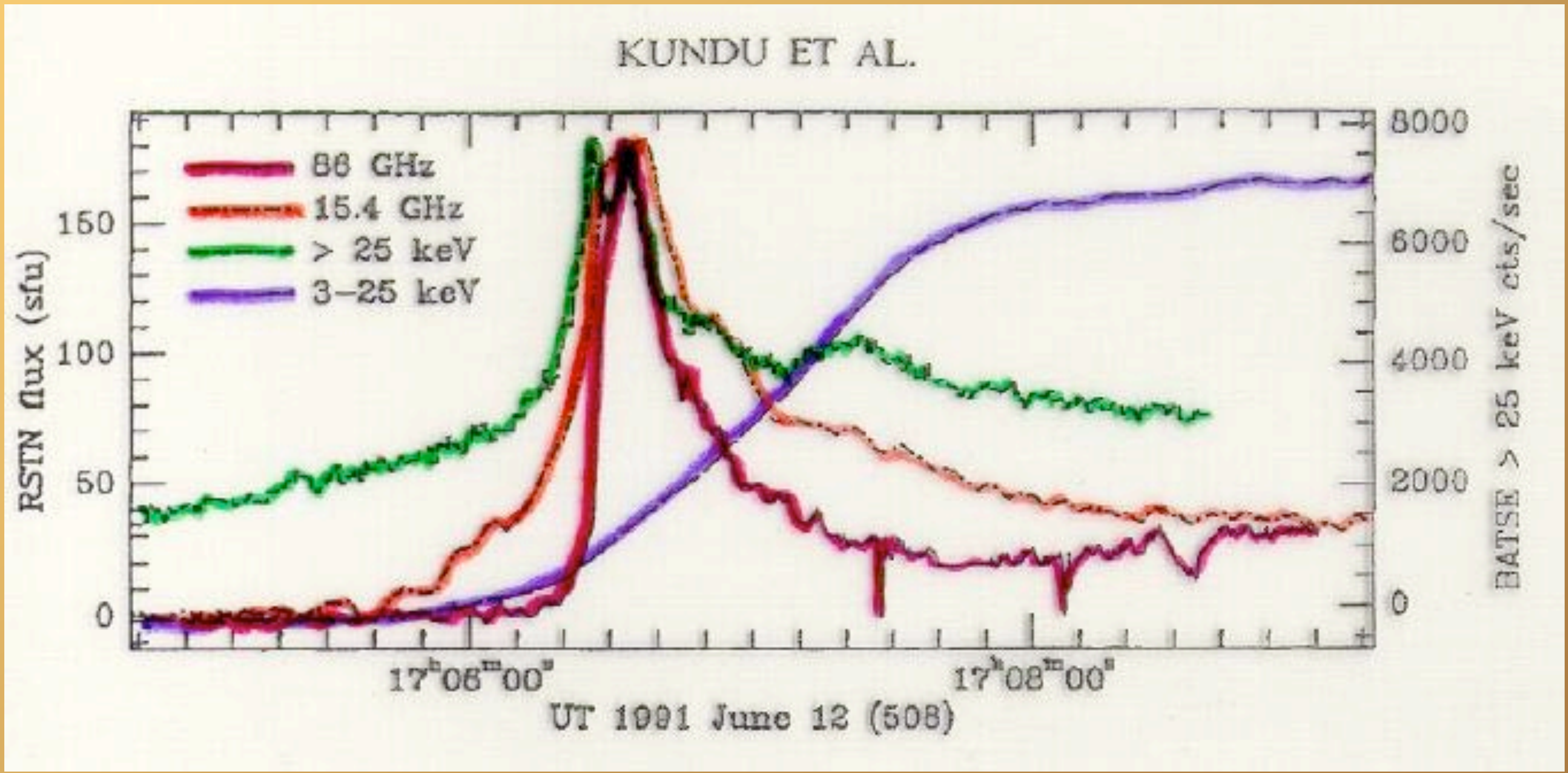
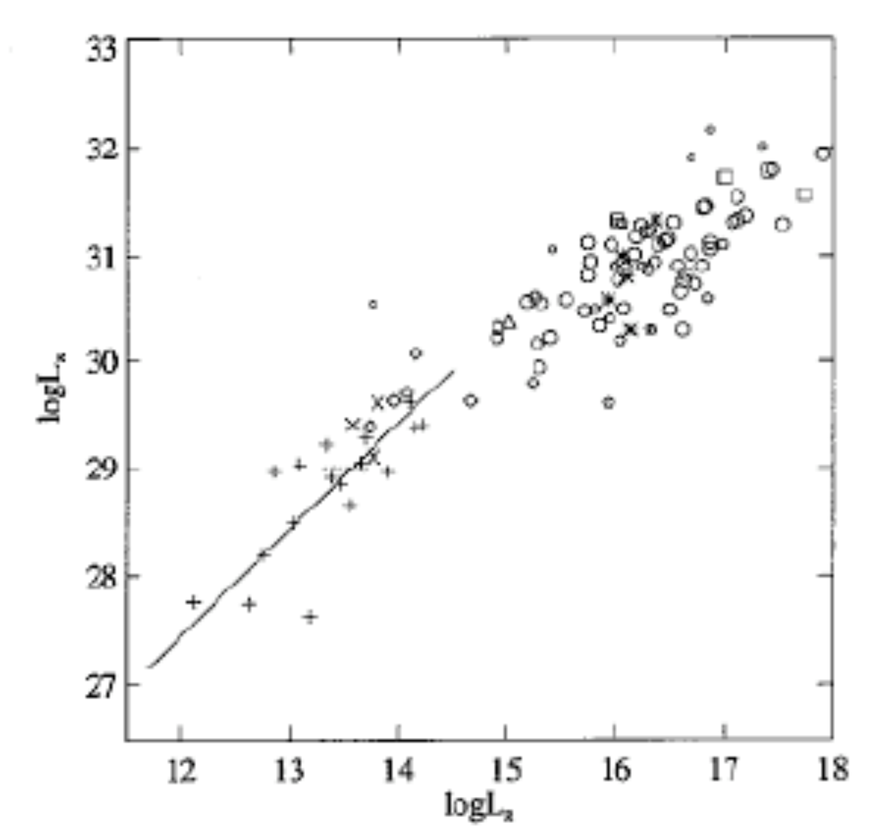


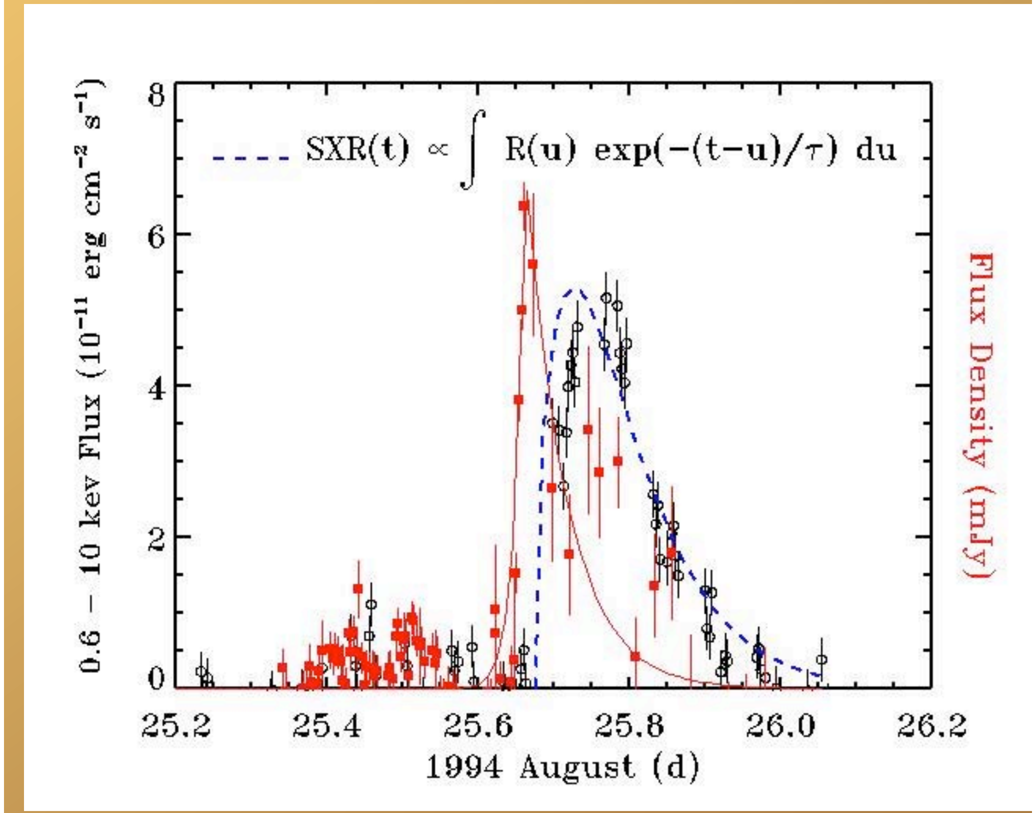
"Normal" Flares

- *Solar flares: T_{max}~20-30 MK*
- *NTHXR emission lasts ~ minutes, accompanied by impulsive radio gyrosynchrotron emission*
- *Flare rate fn of flare energy: α=-1.8*

- *Stellar flares: T_{max} 'usually' 50—80 MK*
- *SXR flares can be accompanied by radio gyrosynchrotron, impulsive*
- *Flare rate fn of flare energy: α=-1.7 RS CVns, >-2 dMe?*

Multi-Wavelength Correlations



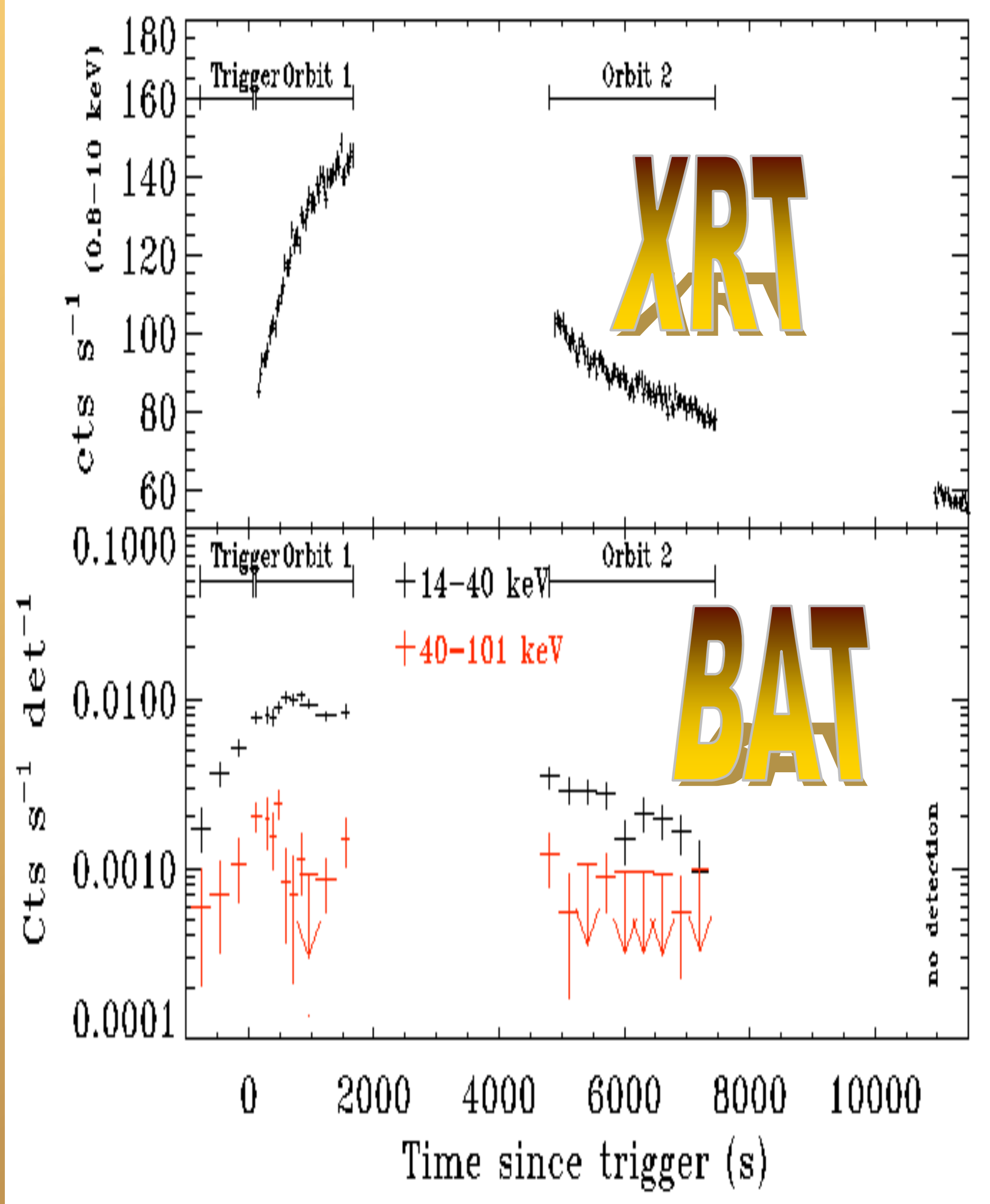


Time-averaged L_X, L_r
(Güdel & Benz 1993)

Time-dependent flare L_X, L_r
Osten et al. (2004)

Triggered HXR observations of a stellar superflare on II Peg ($K2IV+dM$, $P_{orb}=6.7d$): 12/16/05

- *NT HXR emission out to 200 keV*
- *Fe Kα emission 6.4 keV*
- *Thermal plasma > 120 MK*
- *L_x/L_{bol} (0.8-200 keV) at peak ~38%*
- *$L_x \sim 10^{33}$ erg/s (0.8—10 keV)*
- *$E_{rad} \sim 10^{37}$ erg*
- *$E_{tot,therm} \sim 10^{40}$ erg $\sim E_{NT}$*
- *NT emission in flare decay*



Osten et al. 2007

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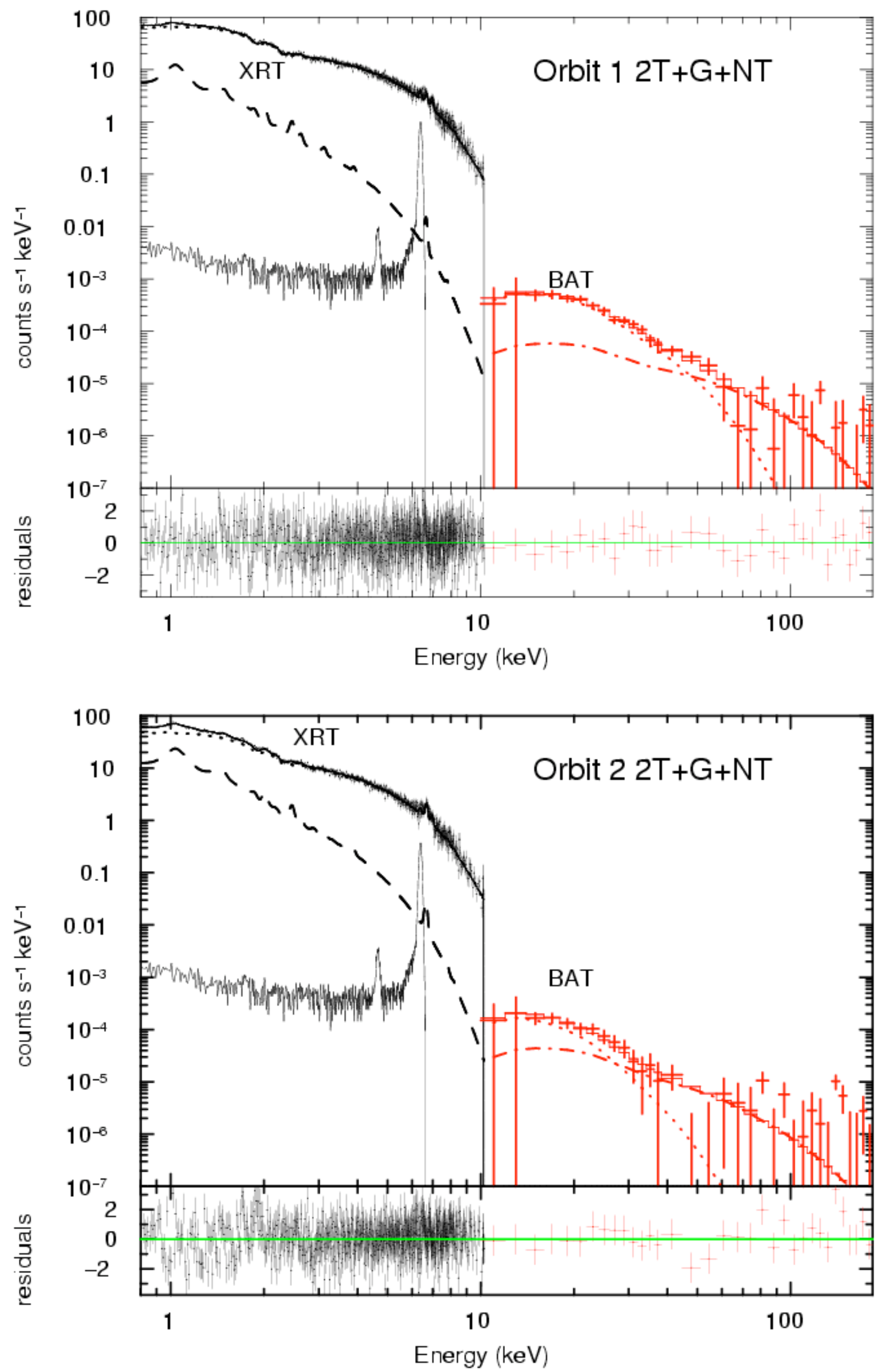


Old Star Unleashes Monster Flare

On December 16, 2005, Rachel Osten (University of Maryland) and six colleagues had the good fortune to observe one of the most powerful stellar flares ever. Energetic X-rays from the active binary star II Pegasi (HD 224085) triggered sensors on NASA's Swift satellite.

Located about 135 light-years from Earth, II Peg is at least a billion years older than our Sun and has only about 80% of its mass. These characteristics would normally suggest a quiescent star. But tidal forces exerted by the nearby companion cause the star to rotate quickly (once every seven days), generating a dynamo capable of igniting powerful flares. The December 2005 outburst released 100 million times more energy than a typical solar flare — a similar event from our Sun would extinguish much of life on Earth. The "superflare" gives scientists insight into the physics of stellar flares that they cannot obtain from the Sun alone.

Thanks to the flare's strength, Osten's team identified direct evidence of charged particles being accelerated along the star's magnetic-field lines — an early stage of a stellar flare. While a full-blown flare releases a burst of radiation across a wide swath of the spectrum, the particle-acceleration signatures are fainter and isolated to just a few spectral regions, including high-energy X-rays. According to Osten, "Previous generations of X-ray telescopes haven't had the sensitivity or the energy coverage to collect enough photons" to reveal the spectroscopic signature of particle acceleration.

NASA's TRACE satellite captured this solar flare at X-ray wavelengths in 2005. Such events can cause power blackouts and satellite failures at Earth. Now imagine scaling this up 100 million times; such was the power of II Pegasi's flare.

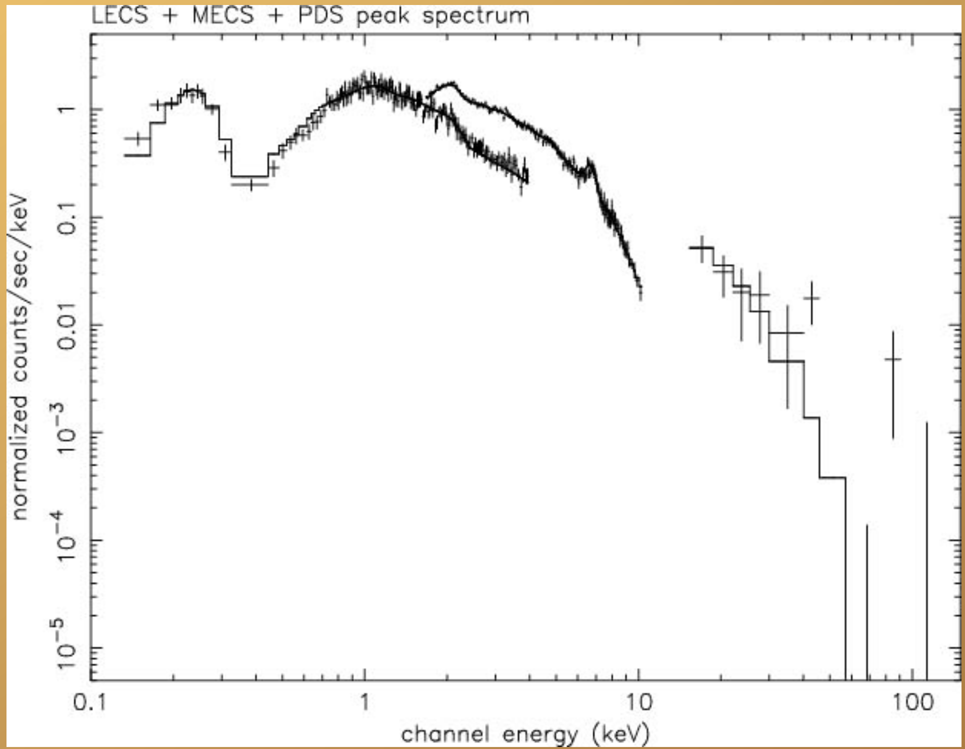
Many flares, like a record-setting burst from the red dwarf Gliese 3685A in 2004 (*S&T*: September 2005, page 17), had been observed in visible or ultraviolet light. But such emission "is only the tip of the iceberg of flare energetics," says Eric Feigelson (Penn State University). With the detection of high-energy X-rays, says Feigelson, Osten and her team "found the iceberg."

Osten's group reports its results in the January 1st *Astrophysical Journal*.

— Kate Becker

Swift Flare on II Peg: First Detection of Nonthermal Hard X-ray Emission from a Stellar Flare

- *Previous detections inconclusive as to presence of nonthermal emission*
- *HXR spectra could be explained by thermal tail of superthermal plasma*
- *Fe Kα emission only seen in young stars w/disks*



Franciosini et al. (2001): large long-duration flare on UX Ari (G5V+K0IV; P=6.44 d) seen by BeppoSAX

HR 1099 (K1IV+G5IV, P_{orb}=2.8d) event 11/29/06

- 3 detections in ~4 min., SNR~7 (15-50 keV)
- Intensity ~400 mCrab, ~1/2 peak flux of II Peg event, L_x~2e32 erg/s
- XRT TOO took place 40 hrs later
- Also detected in March '06 at ~8 times lower intensity
- This event would have resulted in a trigger using new, lower threshhold
- Superhot thermal plasma only or nonthermal emission as well? Iron Kα emission? Radio response?

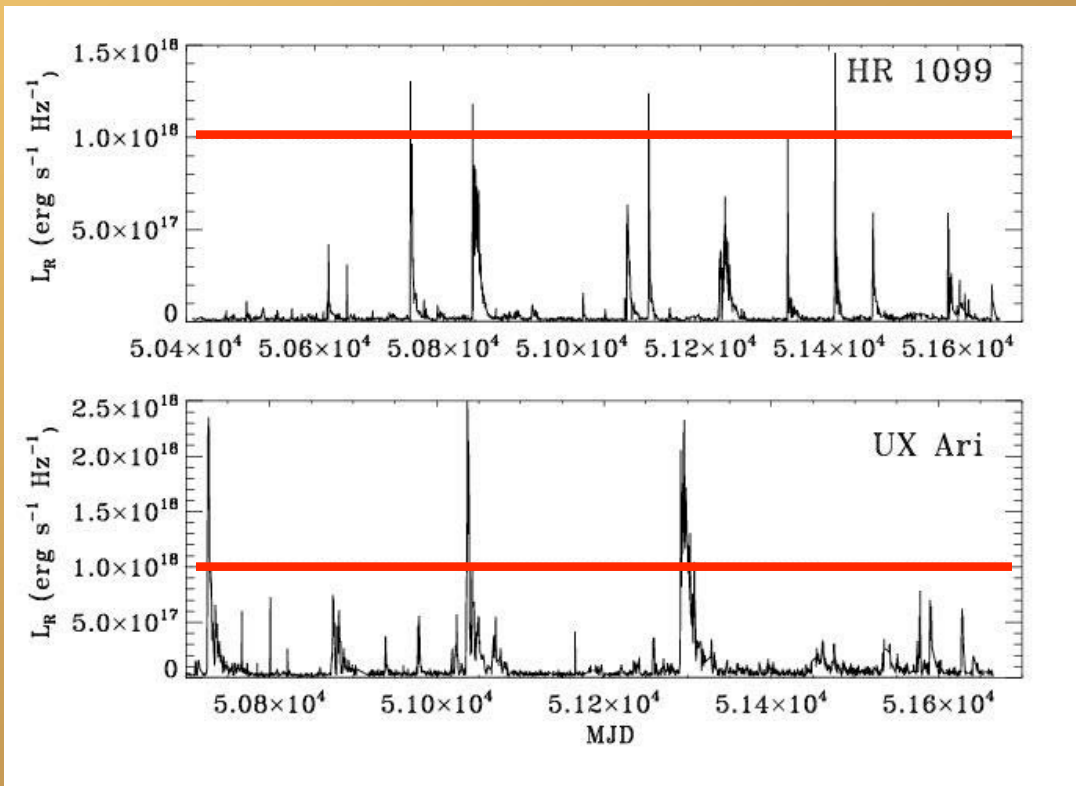
Multi-wavelength coordination

- Catalog of ~60 sources: "usual suspects" mix of active binaries, dMe flare stars, other active stars
  - Active binaries too bright for UVOT grism
  - dMe flare stars V>9 mag. UVOT UV grism?
- VLA TOO proposal for subsequent flares
  - Triggers off GCN notice, on source within 0.5 hour, multi-frequency observations
- Importance of XRT+BAT+other wavelengths
  - Incidence of XR flares with superhot plasma + NT emission
  - Fe Kα emission, formation mechanism
  - Radio/NT HXR emission correlation
  - UV response – max. continuum enhancement for dMe flares

Expected Superflare Rates for Active Binary Systems

GBI light curves

- Radio surveys
  - HR 1099: 2.4/yr
  - UX Ari: 12/yr (10^{18}erg/s/Hz≈ $100^{*}L_{R,Q}$ 10^{33}—10^{34} erg/s using GB L_X-L_R)
- Flare frequency distributions from EUVE (Osten & Brown 1999)
  - 0.08 flares/yr/star above 100x min. flare EUV lum., or ~10^{31} erg/s HXR
  - II Peg-level flares 0.003/yr/star
- X-ray surveys: Ariel V (Schwartz et al. 1981) 11/yr >6x10^{-10} erg/cm^2/s II Peg (10^{32} erg/s), Pye & McHardy (1983) all-sky: 23/yr above 4e-10, 2.3/yr above 4e-9



Additional possibilities

- Superflares on ordinary, solar-like stars (Schaefer et al. 2000)
  - Rare events, use distance-limited sample of GK stars?
- Superflares in young stars (Eric's talk)