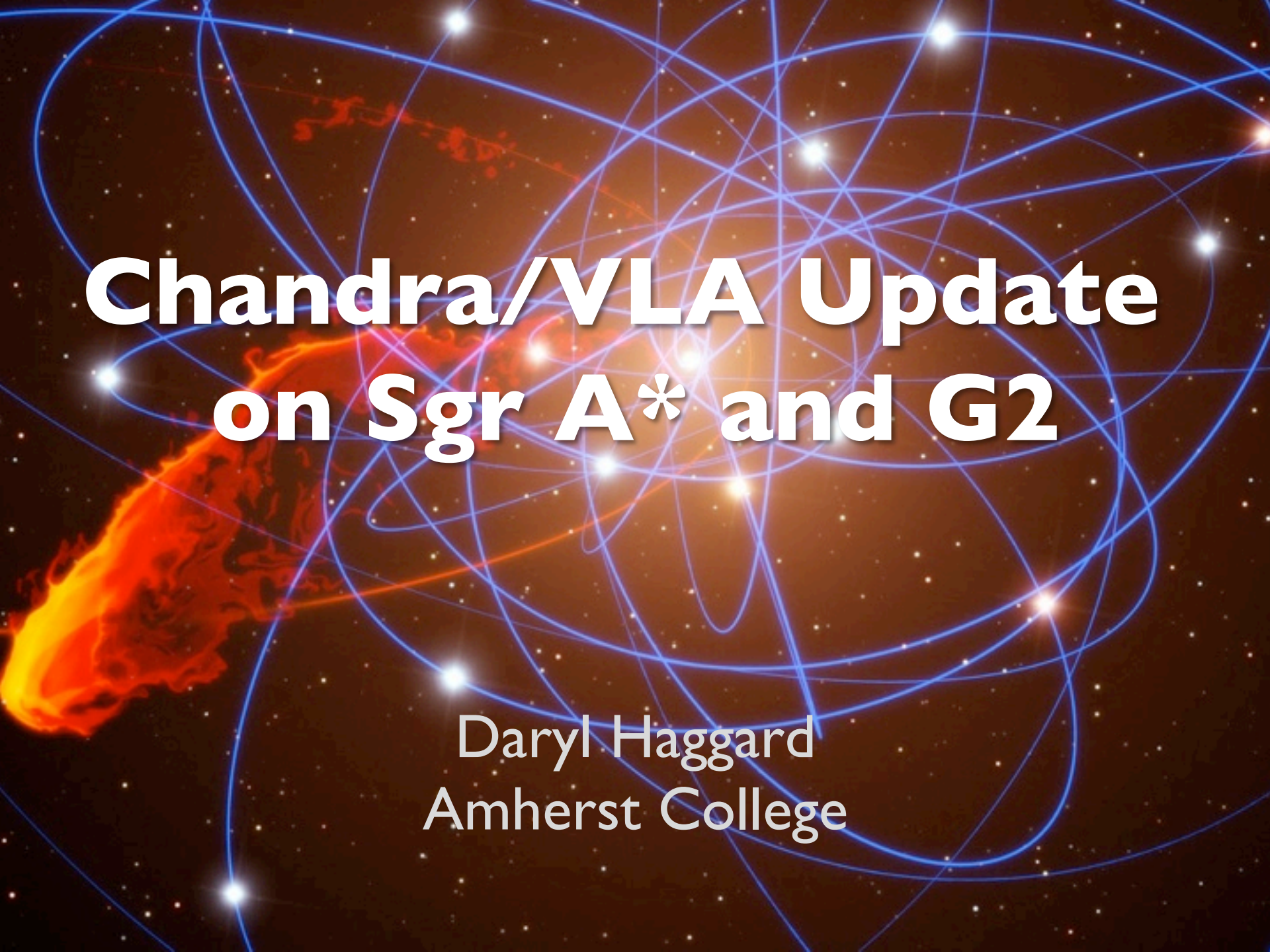


Chandra/VLA Update on Sgr A* and G2

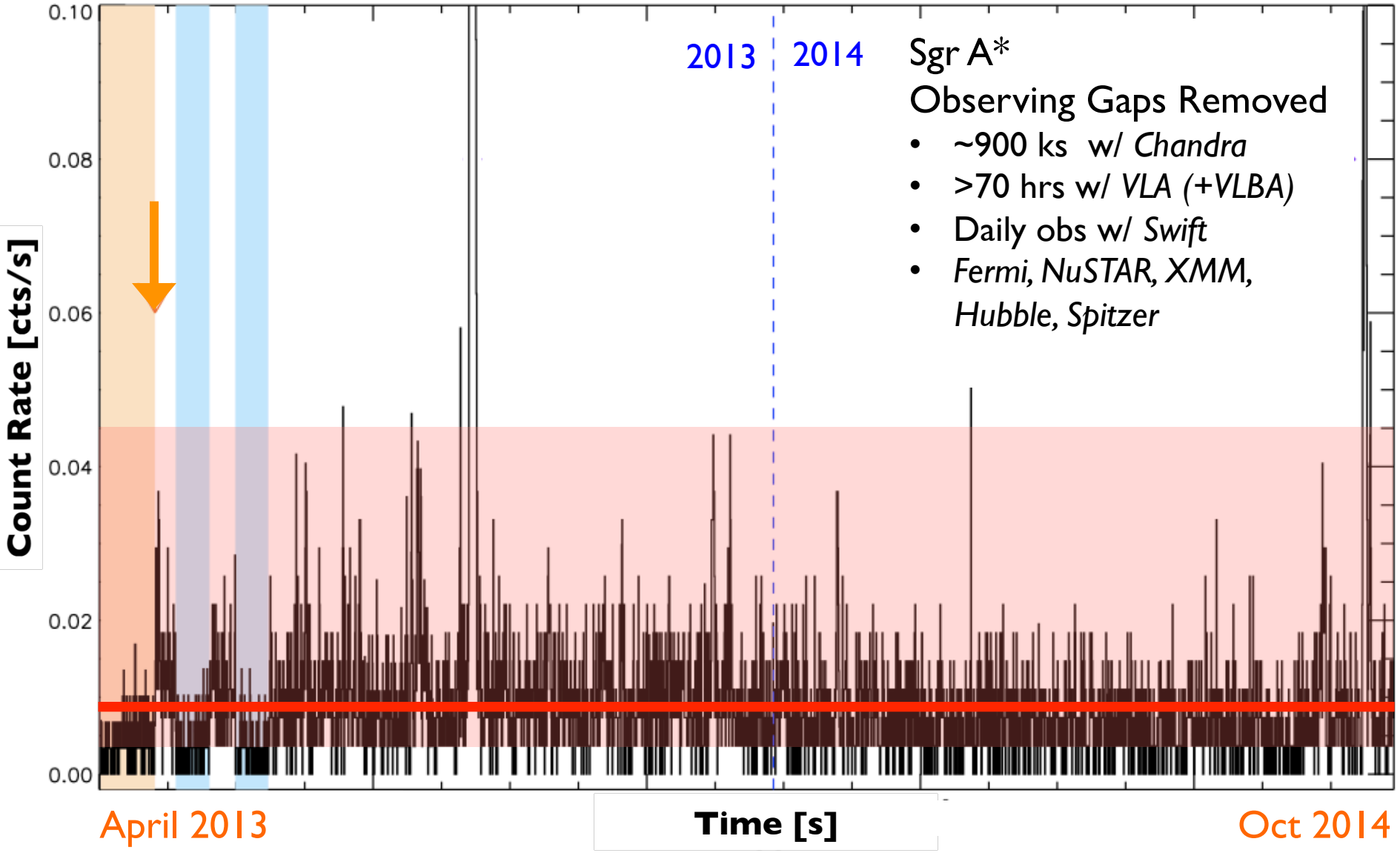
Daryl Haggard
Amherst College

Collaborators

Baganoff, Frederick
Bower, Geoffrey
Brinkerink, Christaan
Bushouse, Howard
Corales, Lia
Coti-Zelati, Francesco
Degenaar, Nathalie
Dexter, Jason
Dibi, Salome
Falcke, Heino
Fragile, P. Chris
Ghez, Andrea
Gillessen, Stefan
Grosso, Nicolas
Heinke, Craig
Kosack, Karl
Law, Casey
Markoff, Sera
Morris, Mark
Neilsen, Joey
Nowak, Michael
Ponti, Gabriele
Porquet, Delphine
Rea, Nanda
Roberts, Douglas
Wang, Q. Daniel
Willner, Steven
Yusef-Zadeh, Farhad

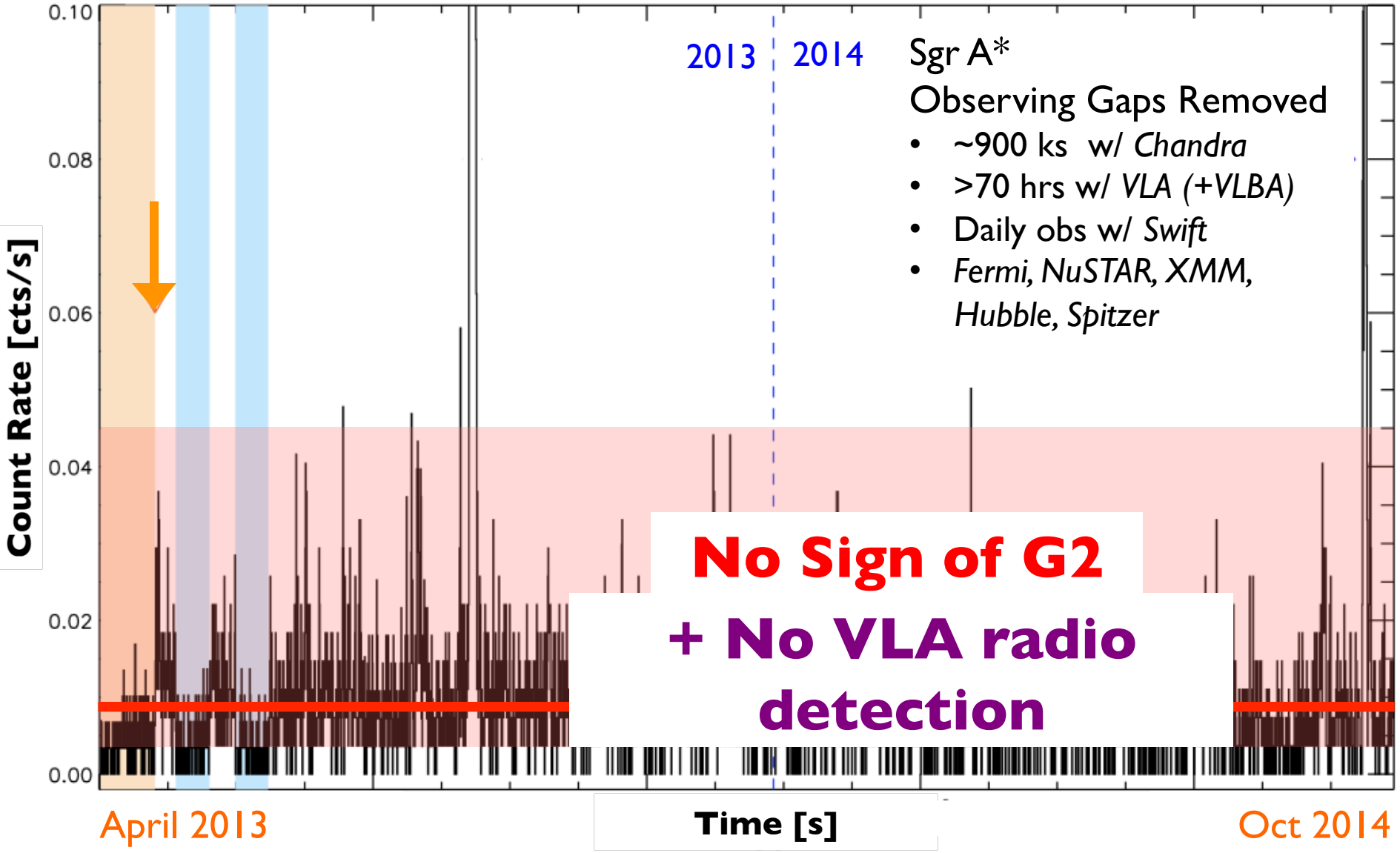
Sgr A* X-ray Light Curve

[**Haggard** et al, Atel #6242; **Haggard**, et al. *in prep*]



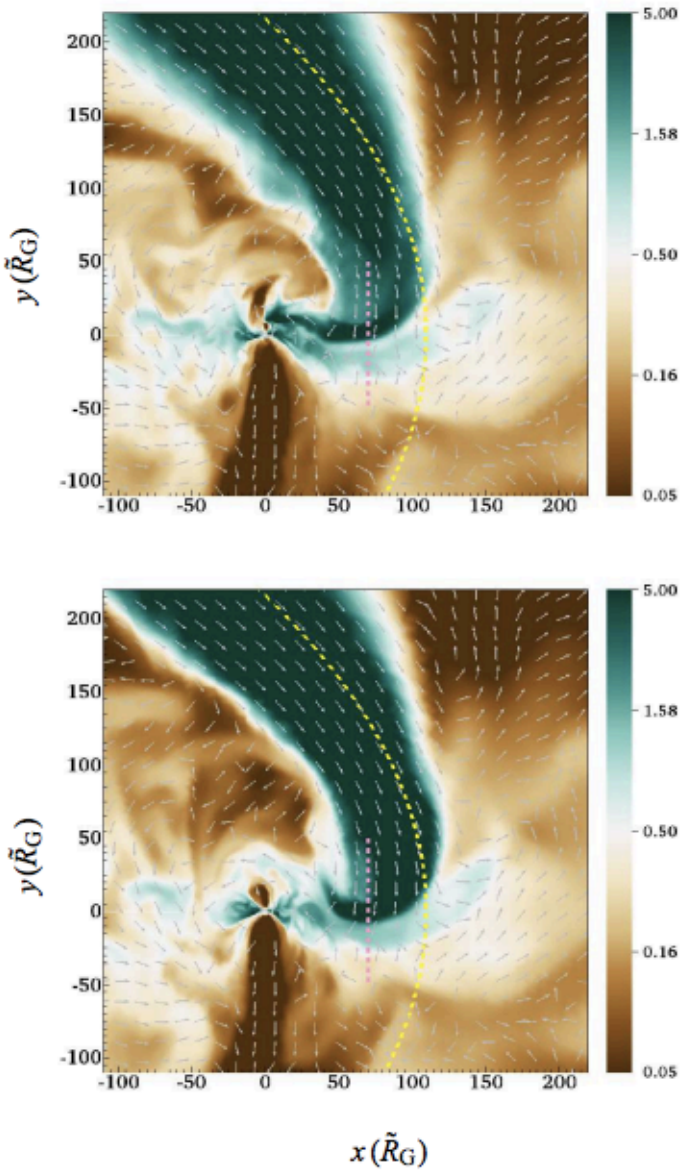
Sgr A* X-ray Light Curve

[**Haggard** et al, Atel #6242; **Haggard**, et al. *in prep*]



No X-ray or Radio Signature

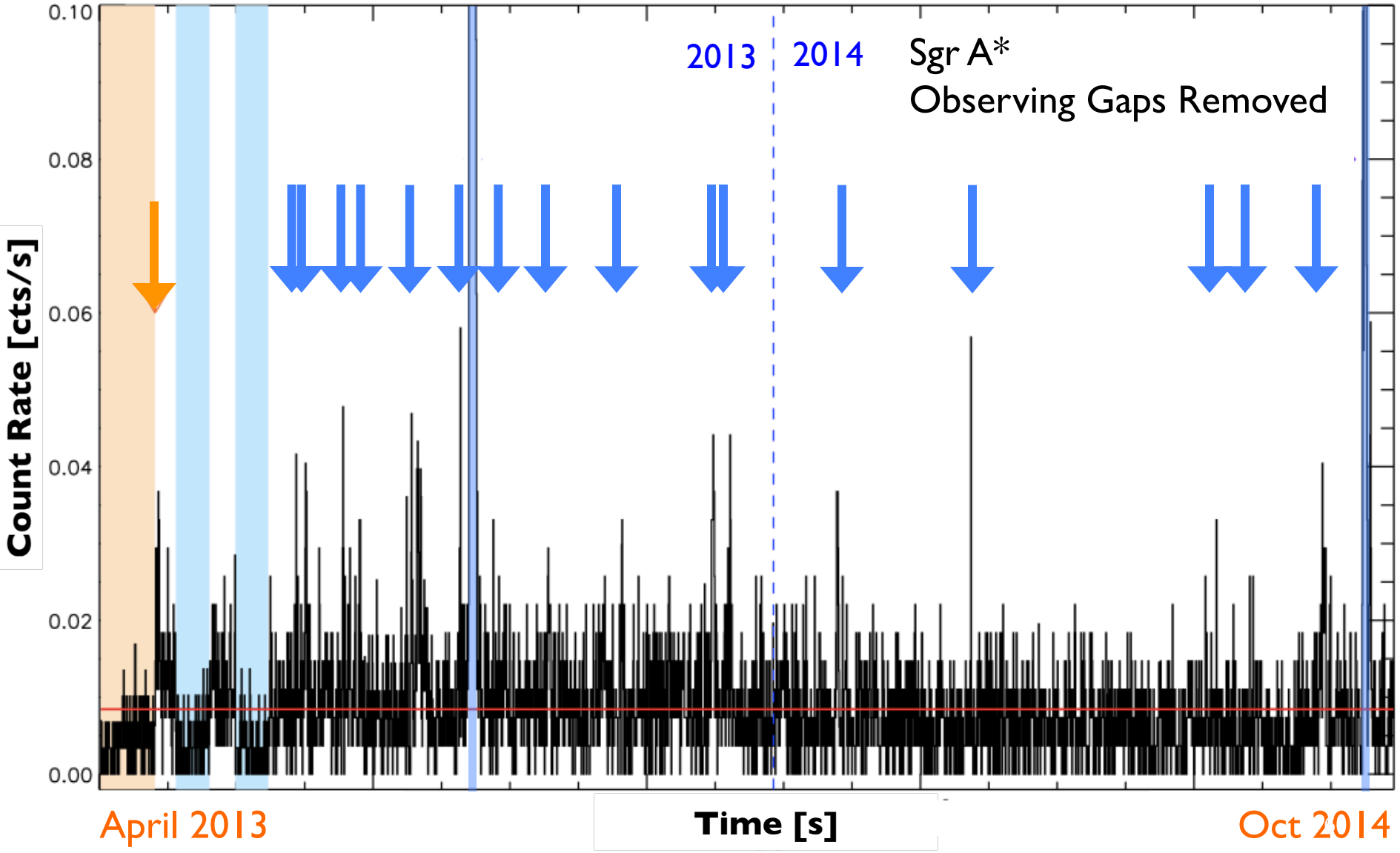
- No shock front
  - G2 is clumpy and/or the accretion flow is clumpy (G2 fell through a "void")
  - G1 already cleared the path
  - Accretion flow is lower density than expected
  - Non-detection may be constraining
- Uncertain viscosity and accretion timescale
  - Years vs. months
  - Continued monitoring may tell…



[Sadowski et al, 2013]

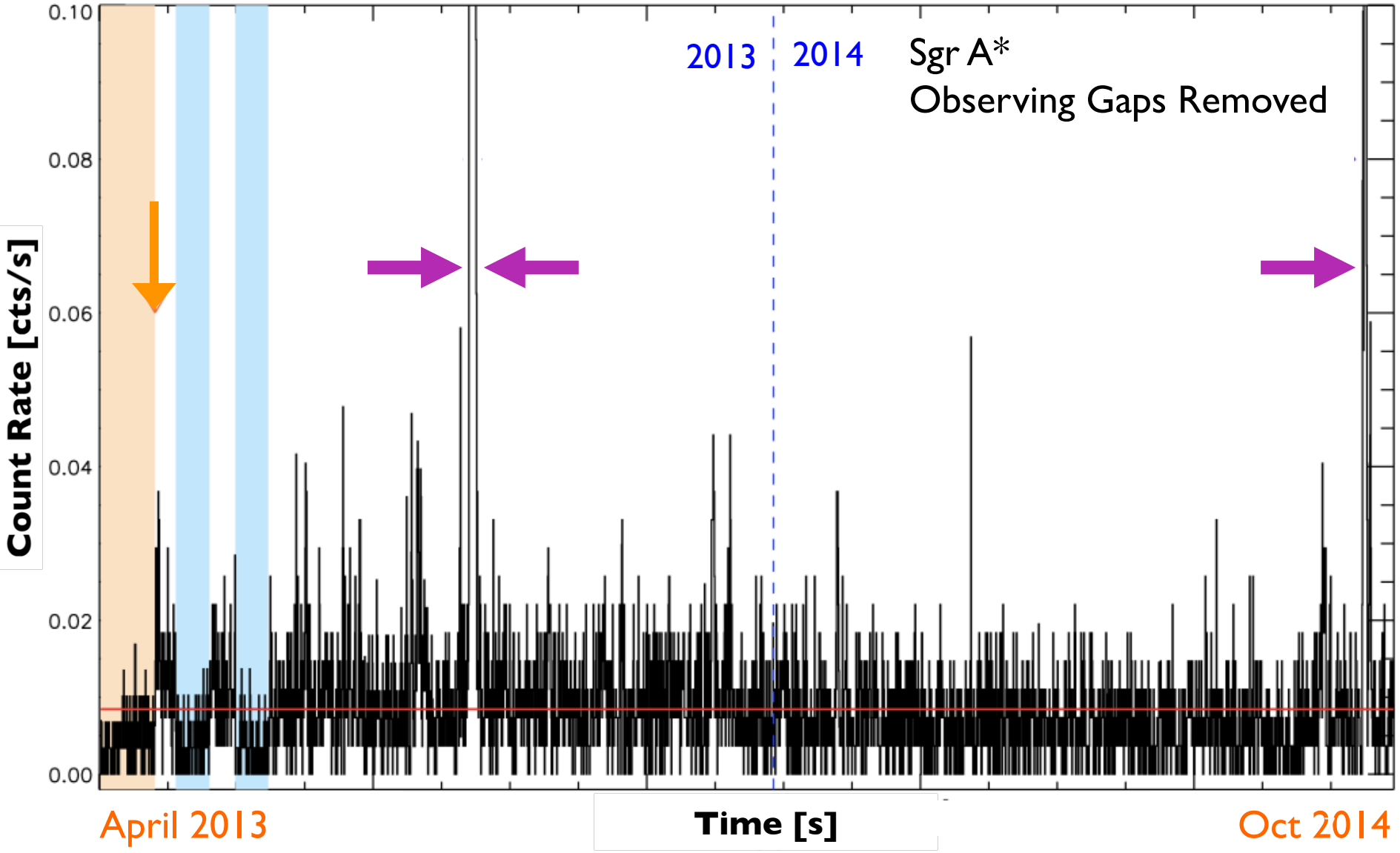
Sgr A* X-ray Light Curve

[**Haggard** et al, Atel #6242; **Haggard**, et al. *in prep*]



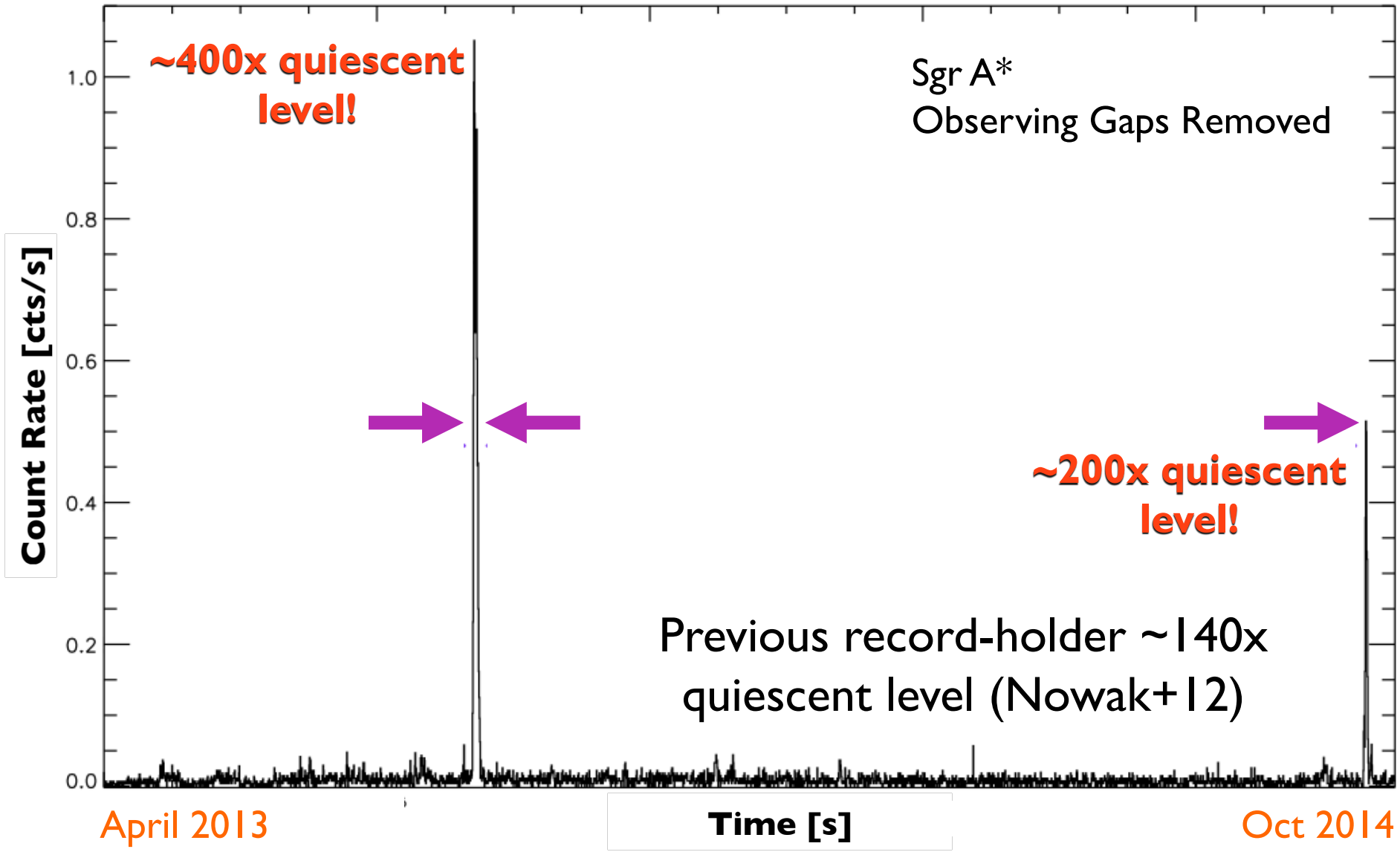
Sgr A* X-ray Light Curve

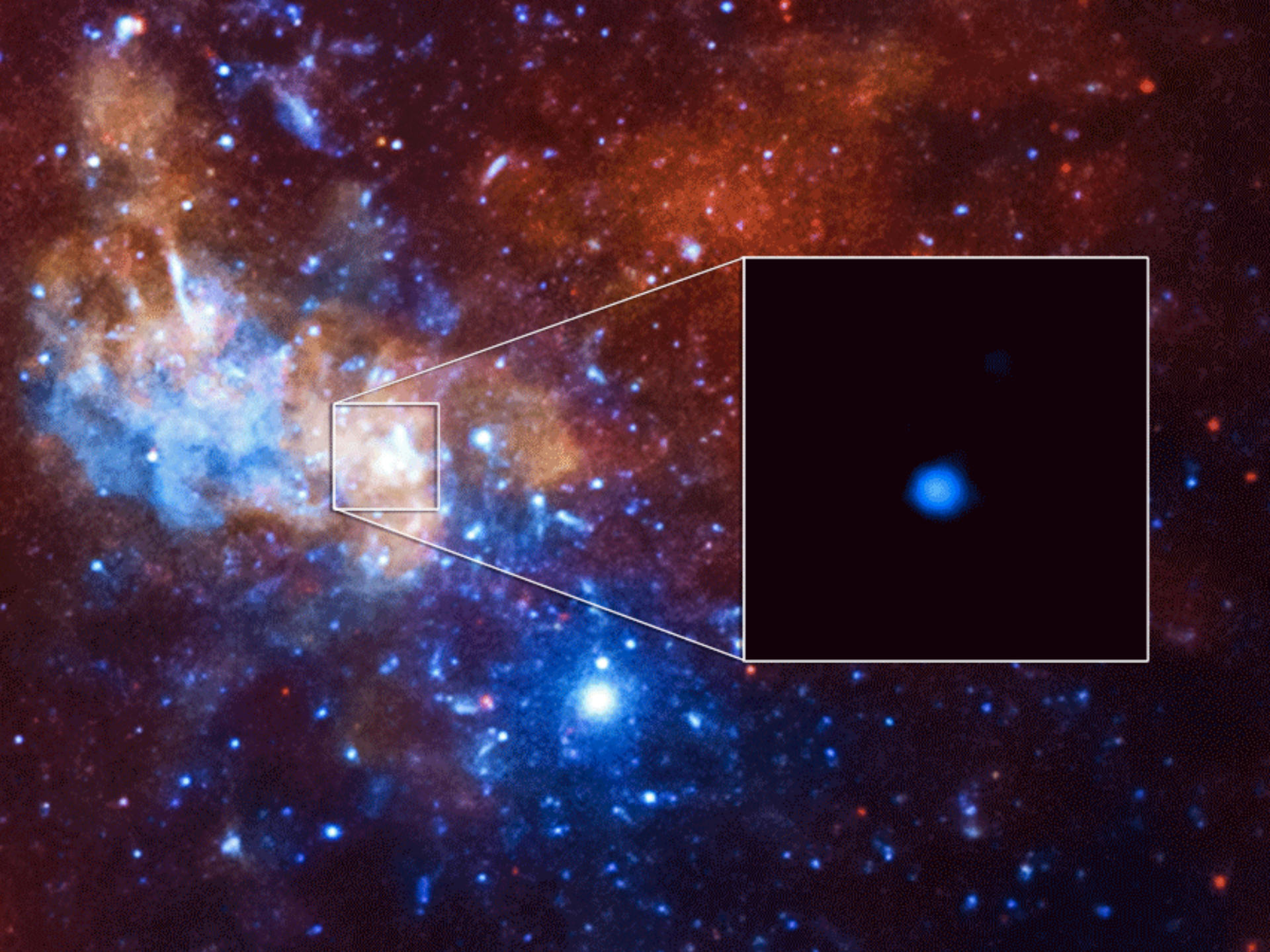
[**Haggard** et al, Atel #6242; **Haggard**, et al. *in prep*]



Sgr A* Bright (!) Flares

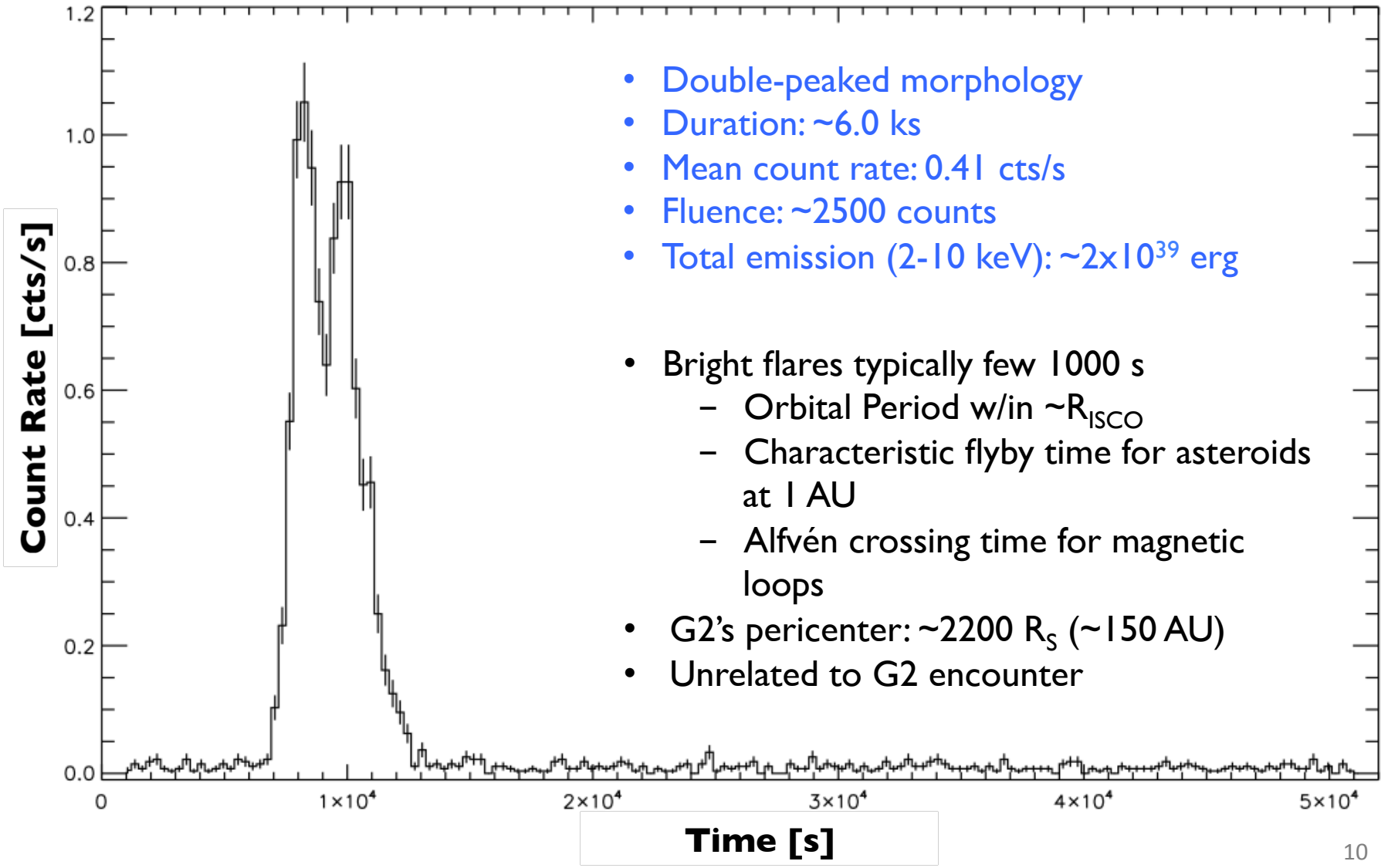
[**Haggard** et al, Atel #6242; **Haggard**, et al. *in prep*]





2013 Bright Flare

[**Haggard**, et al. *in prep*]

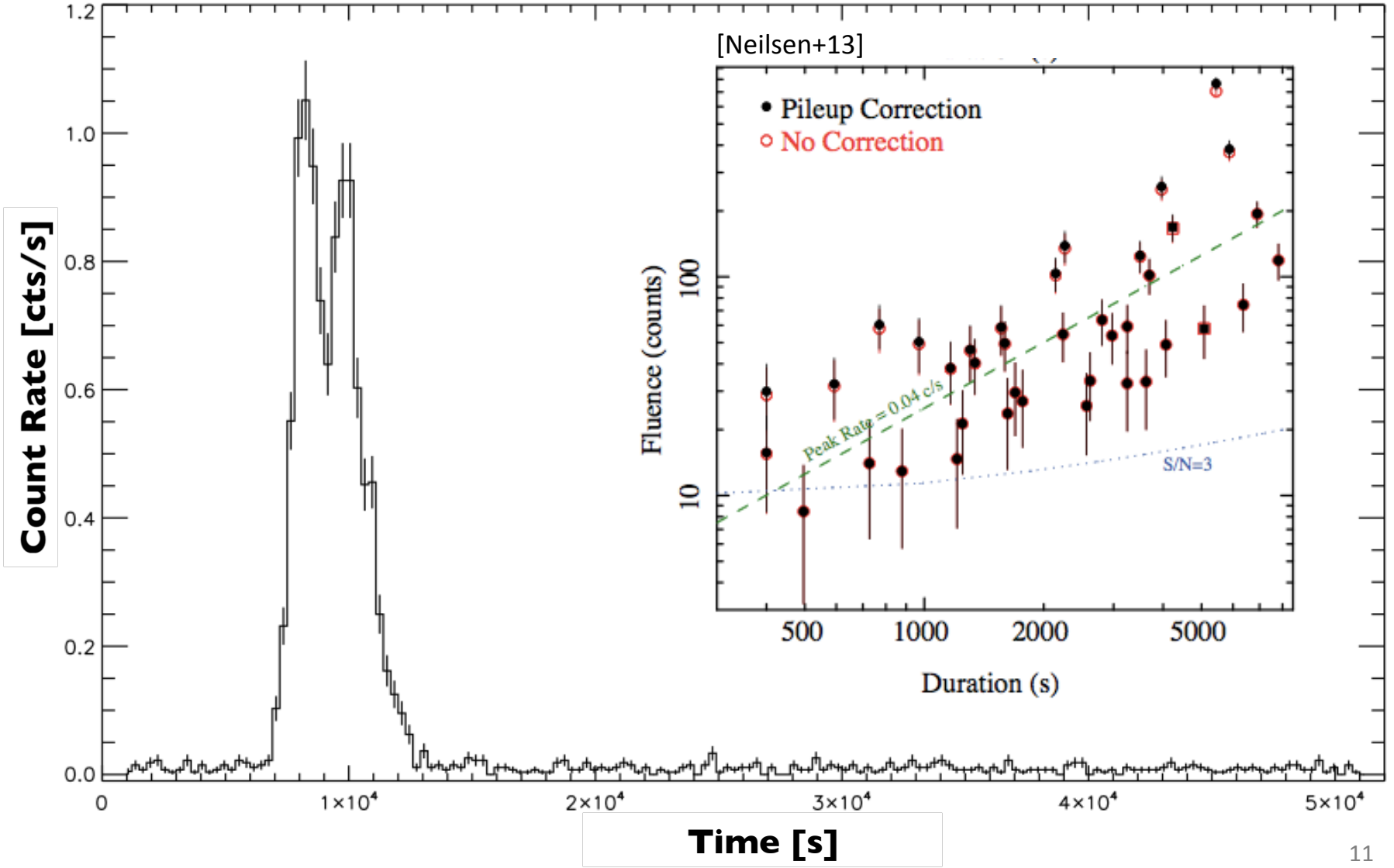


- Double-peaked morphology
- Duration: ~6.0 ks
- Mean count rate: 0.41 cts/s
- Fluence: ~2500 counts
- Total emission (2-10 keV): ~2×10^{39} erg

- Bright flares typically few 1000 s
  - Orbital Period w/in ~R_{ISCO}
  - Characteristic flyby time for asteroids at 1 AU
  - Alfvén crossing time for magnetic loops
- G2's pericenter: ~2200 R_S (~150 AU)
- Unrelated to G2 encounter

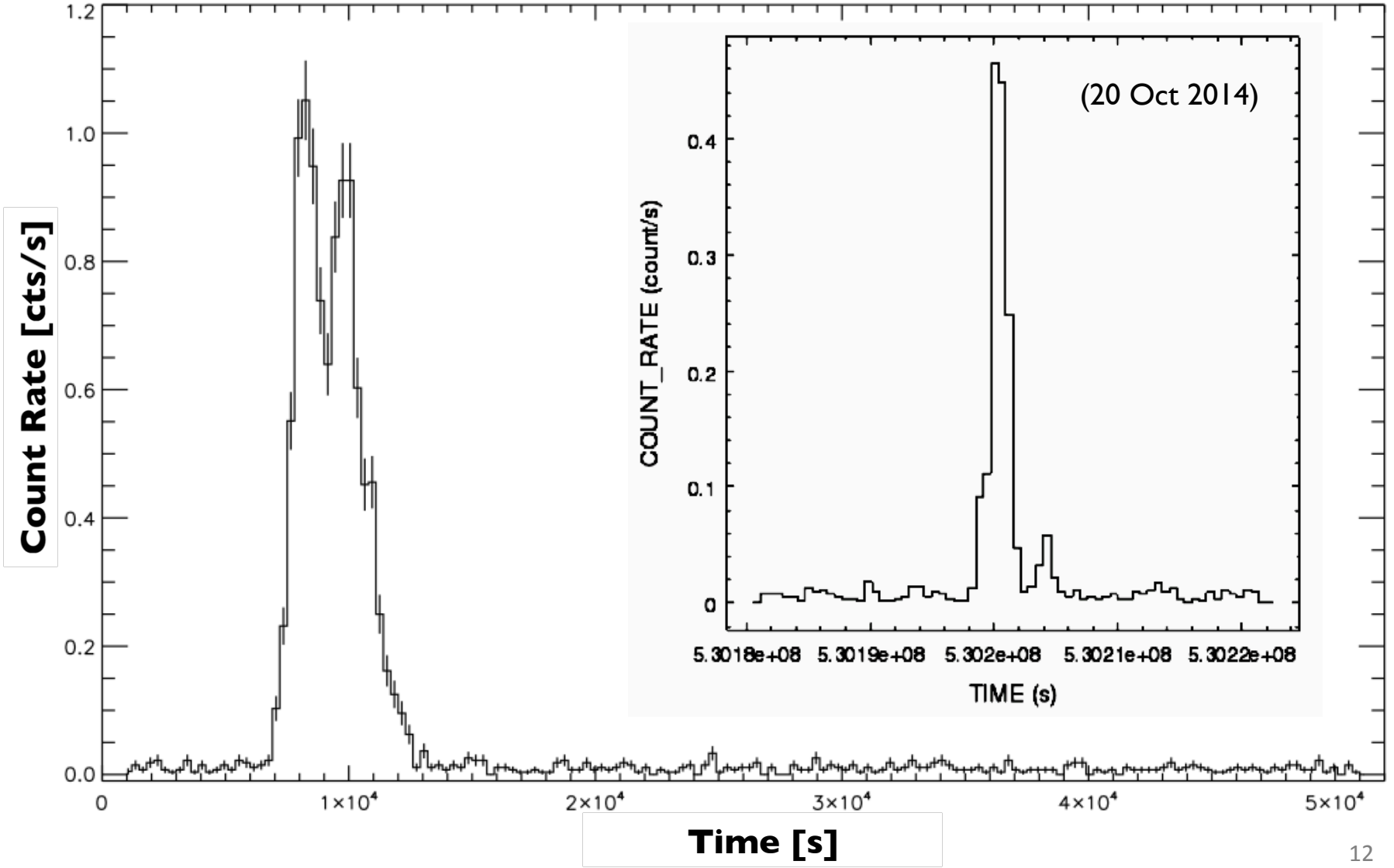
2013 Bright Flare

[**Haggard**, et al. *in prep*]

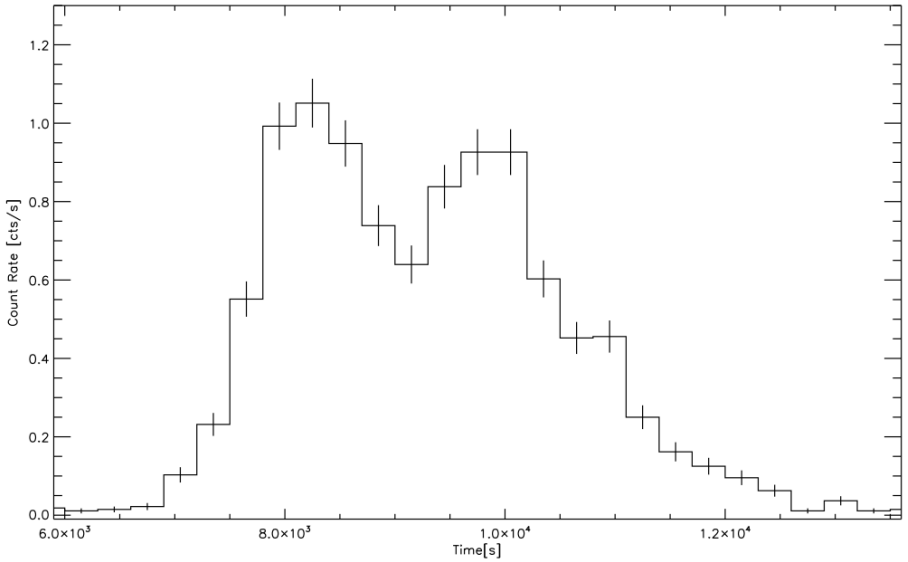


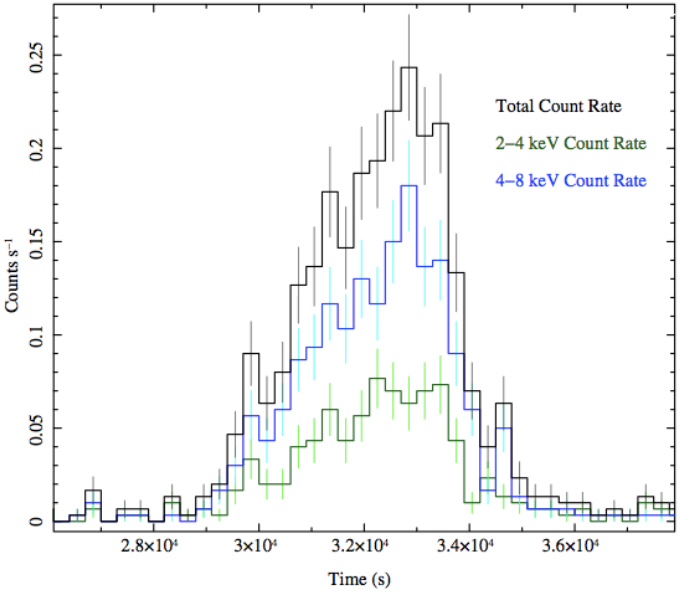
2013 Bright Flare

[**Haggard**, et al. *in prep*]



Bright Flare Comparison

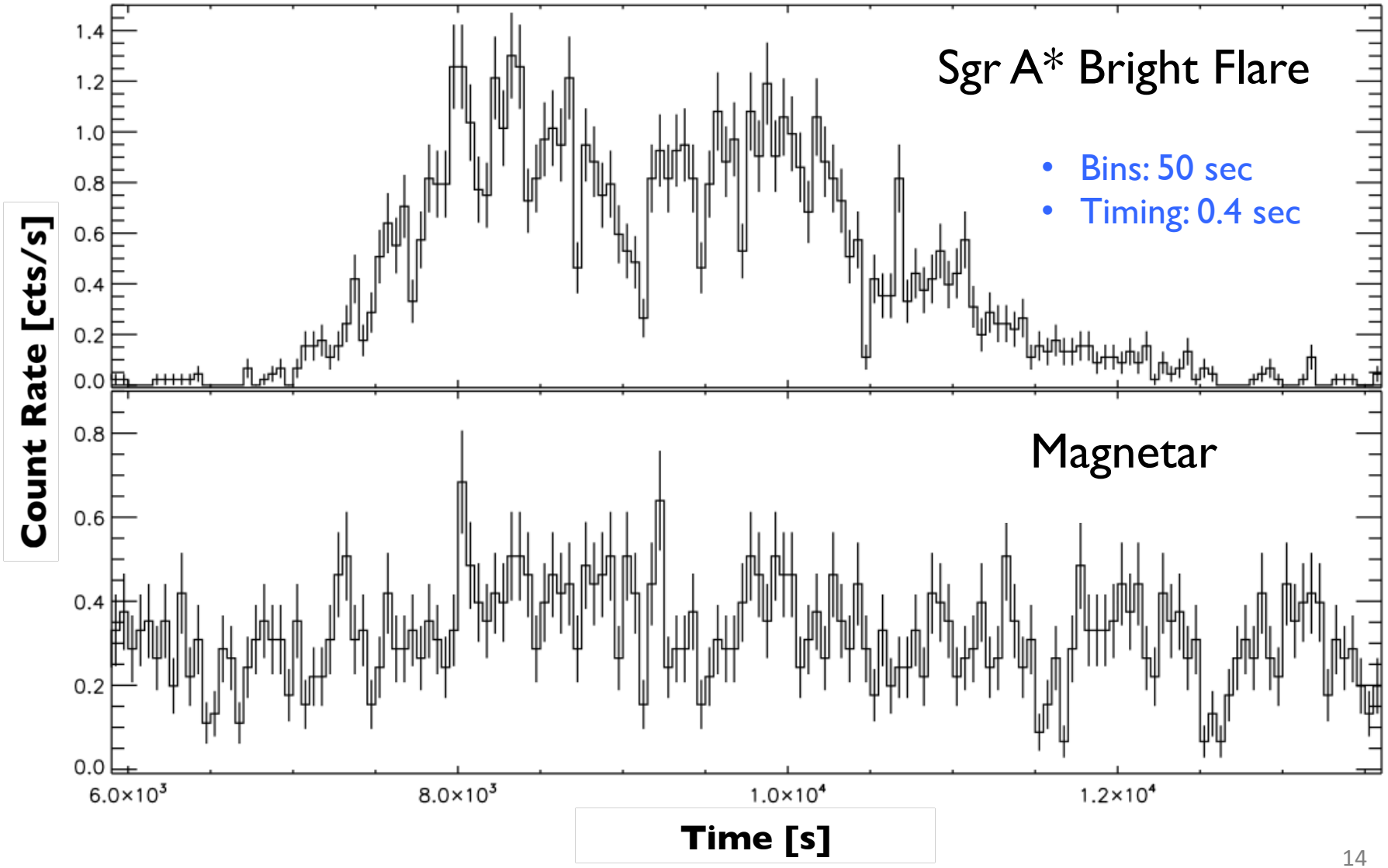




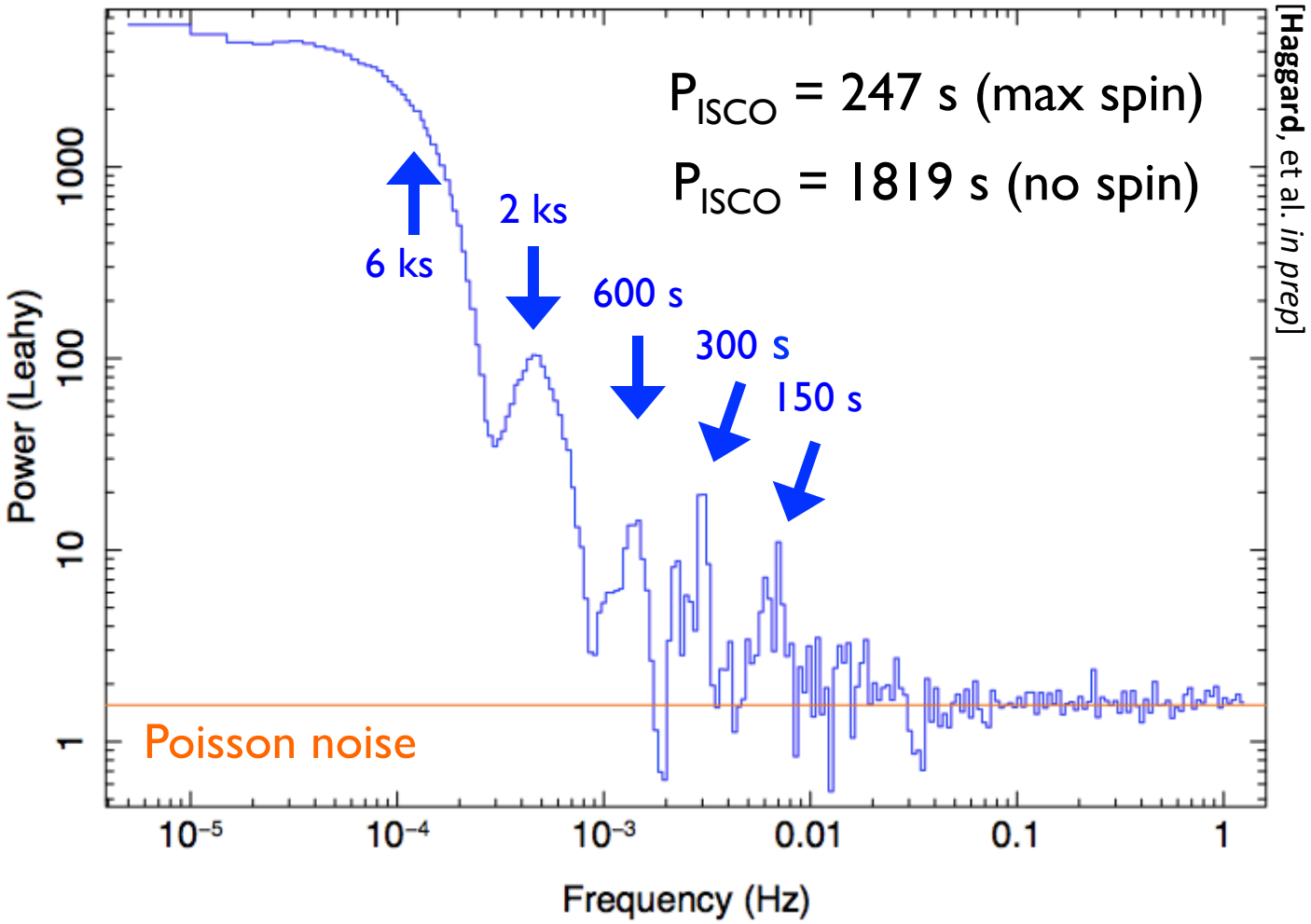
Flare	**NH [10^{23} cm^{-2}]**	**Γ**	**fx (2-8 keV, abs) [erg/cm^2/s]**	**Duration [ks]**	**Fluence [erg/cm^{-2}]**	**Energy (2-10keV) [erg]**
Haggard+	$1.43_{-1.5}^{+0.69}$	$2.1_{-0.3}^{+0.1}$	$2.1_{-0.3}^{+0.4} \times 10^{-11}$	6.6	$1.4\pm0.3 \times 10^{-7}$	1.7×10^{-39}
Nowak+12	$1.43_{-3.6}^{+4.4}$	$2.0_{-0.6}^{+0.7}$	$8.5\pm0.9 \times 10^{-12}$	5.6	$4.7\pm0.5 \times 10^{-8}$	1.0×10^{-39}
Porquet+08 (Nowak+12)	$1.63_{-2.6}^{+3.0}$	$2.4_{-0.3}^{+0.4}$	$4.8_{-0.3}^{+0.2} \times 10^{-12}$	2.9	$1.4\pm0.1 \times 10^{-8}$	3.5×10^{-38}
Porquet+03 (Nowak+12)	$1.61_{-2.2}^{+1.9}$	2.3±0.3	$7.7\pm0.3 \times 10^{-12}$	2.8	$2.2\pm0.1 \times 10^{-8}$	5.3×10^{-38}

Morphology & Timing

[**Haggard**, et al. *in prep*]

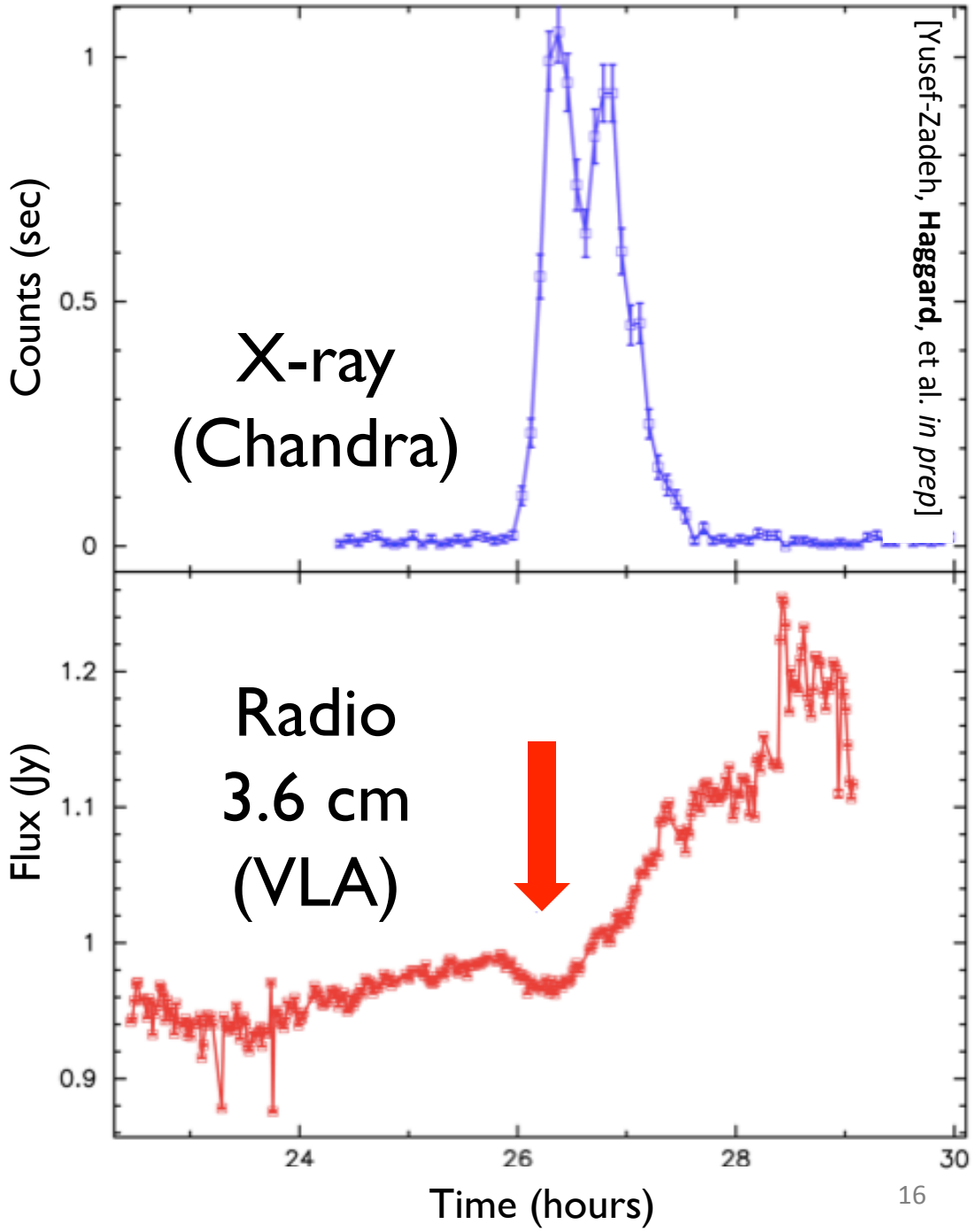


Power Spectral Distribution



Radio View

- Continuous coverage
- Radio (3.6 cm) flux increase of 25%
- Cross correlation peak >130 min
- Consistent with previous time delay estimates
- Anti-correlation radio-X-ray peak



What's Causing the Flares?

Magnetic Reconnection

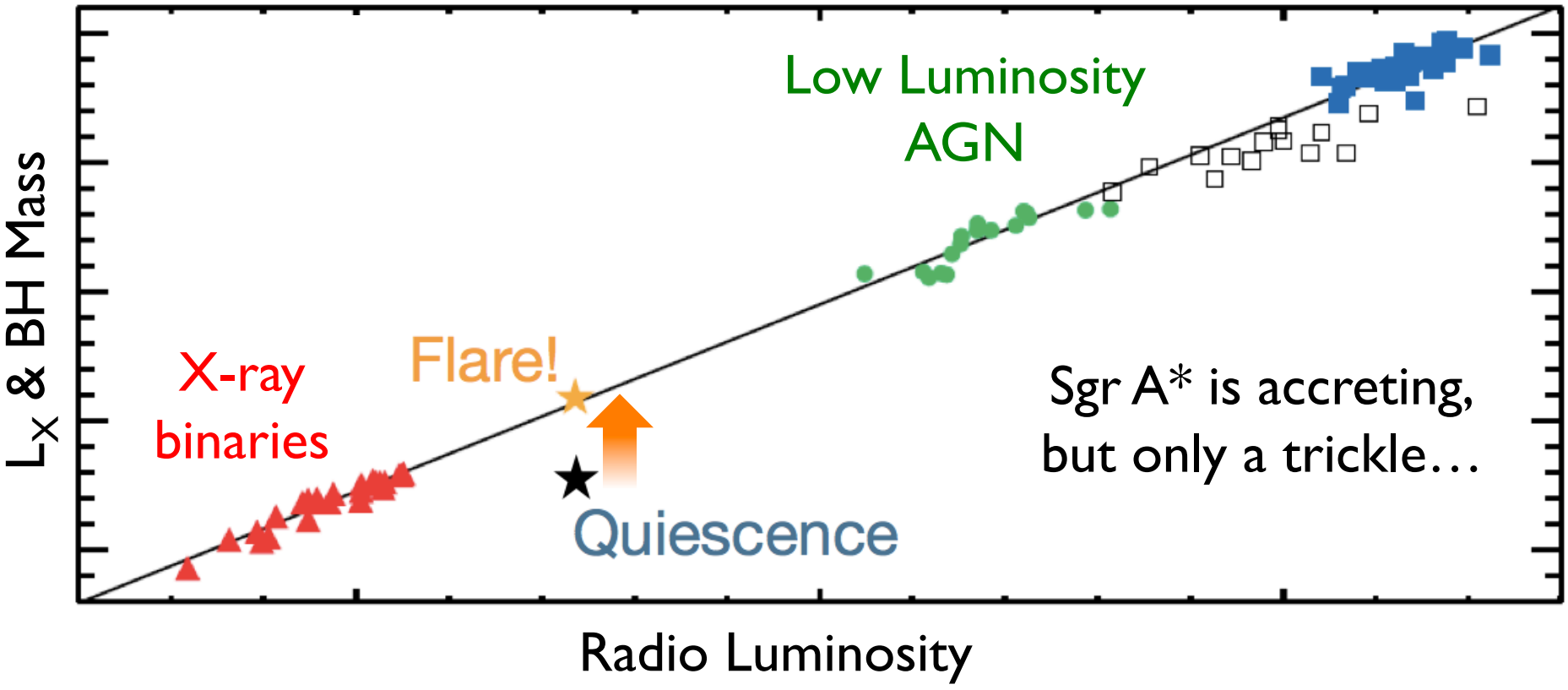
Asteroid Disruption

This is an *unsolved* mystery…

Markoff et al. 2001; Liu & Melia 2002; Liu et al. 2004; Yuan et al. 2003, 2004; Eckart et al. 2004, 2006; Marrone et al. 2008; Cadez et al. 2008; Kostic et al. 2009; Dodds-Eden et al. 2009; Yuan et al. 2009a; Zubovas et al. 2012; Witzel et al. 2012; Yusef-Zadeh et al. 2012; Nowak et al. 2012; Neilsen et al. 2013

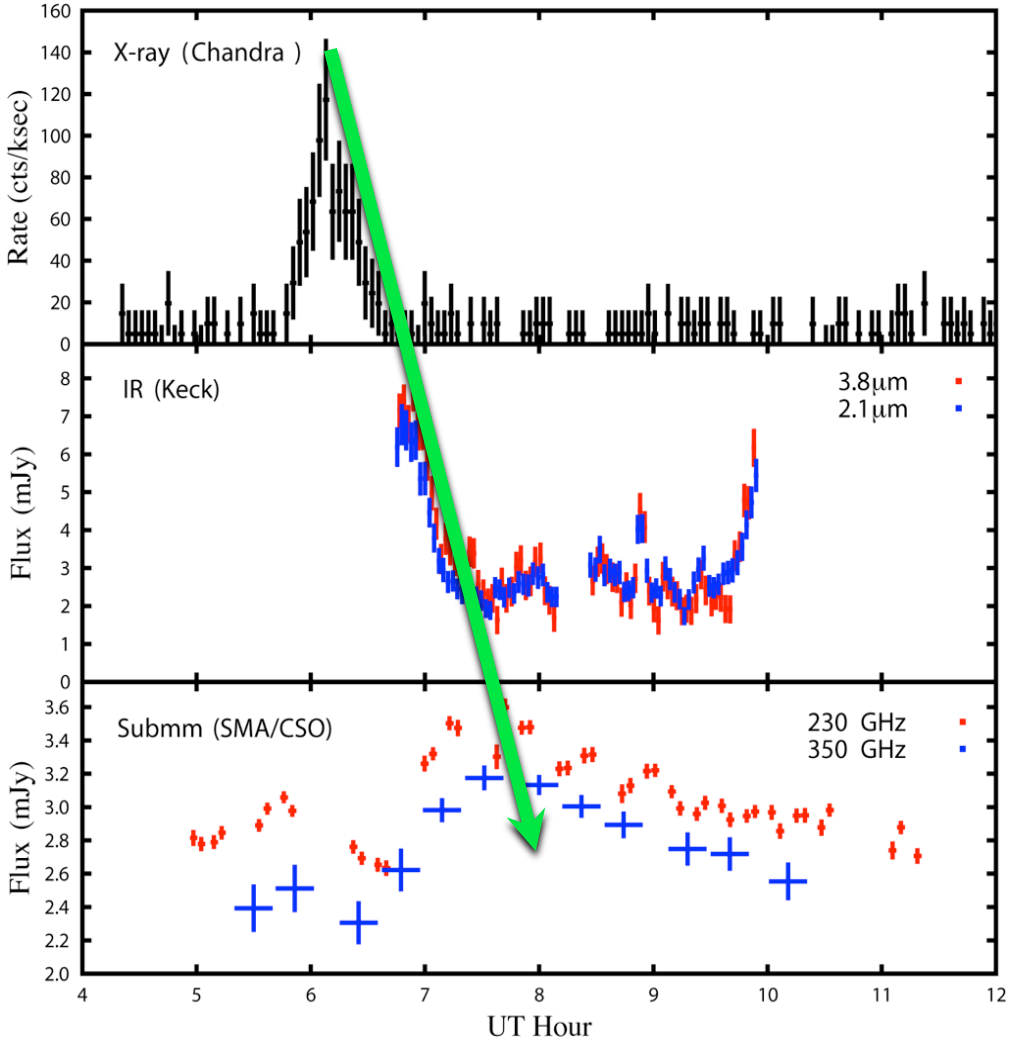
Black Hole "Fundamental Plane"

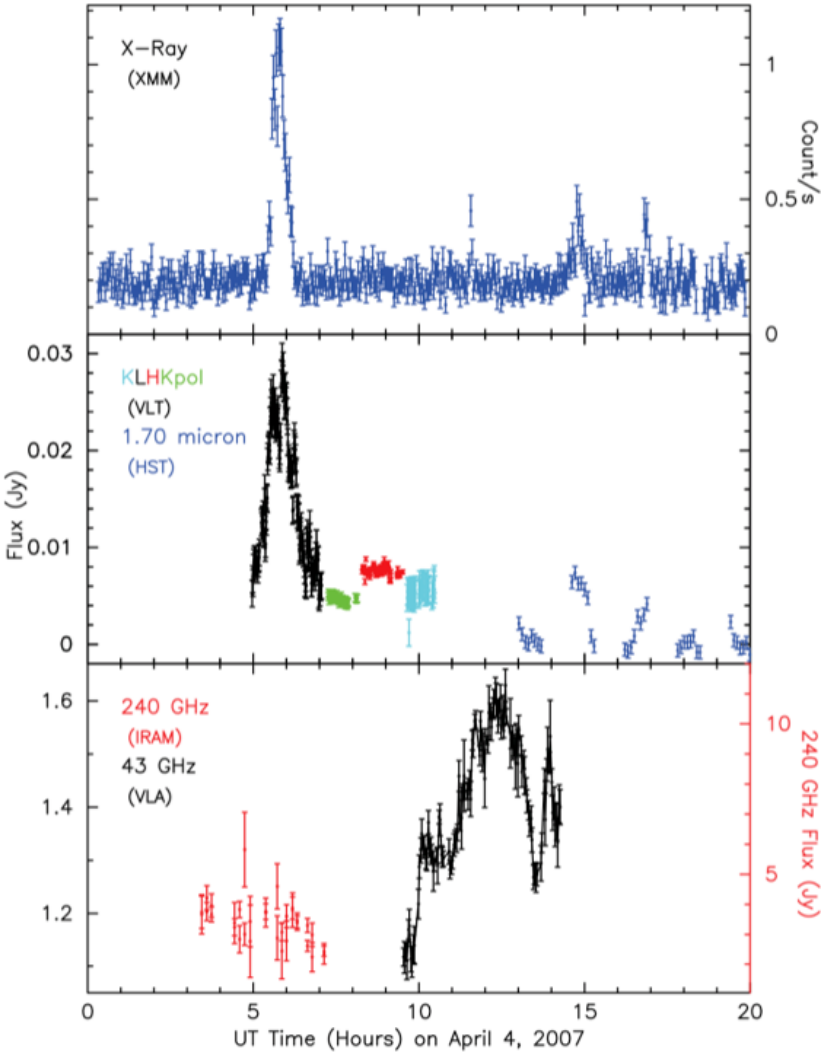
[Plotkin, et al. 2012]



Does Sgr A* reside on the BH fundamental plane?

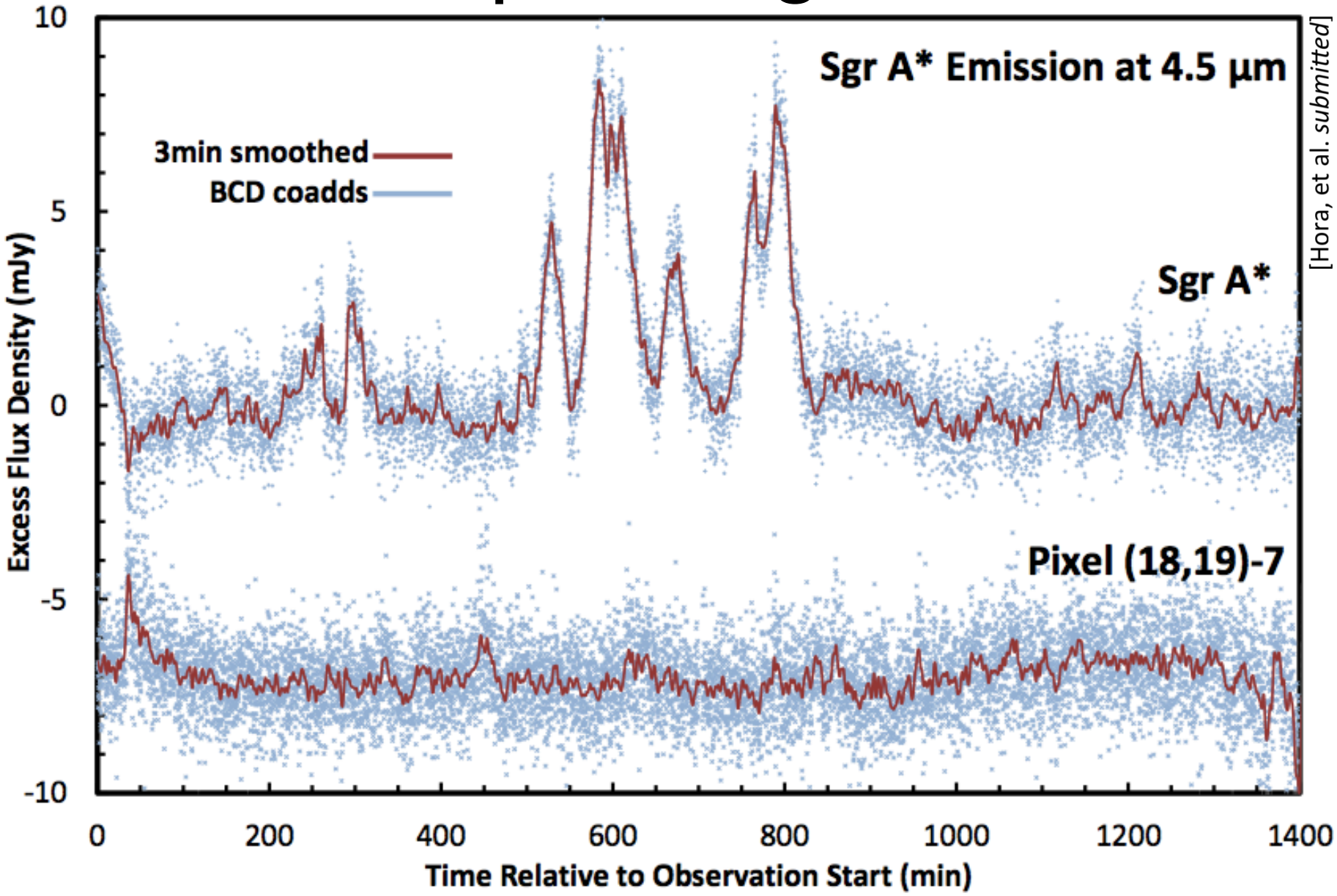
We need more *simultaneous* radio/submm/IR/X-ray flares!!!



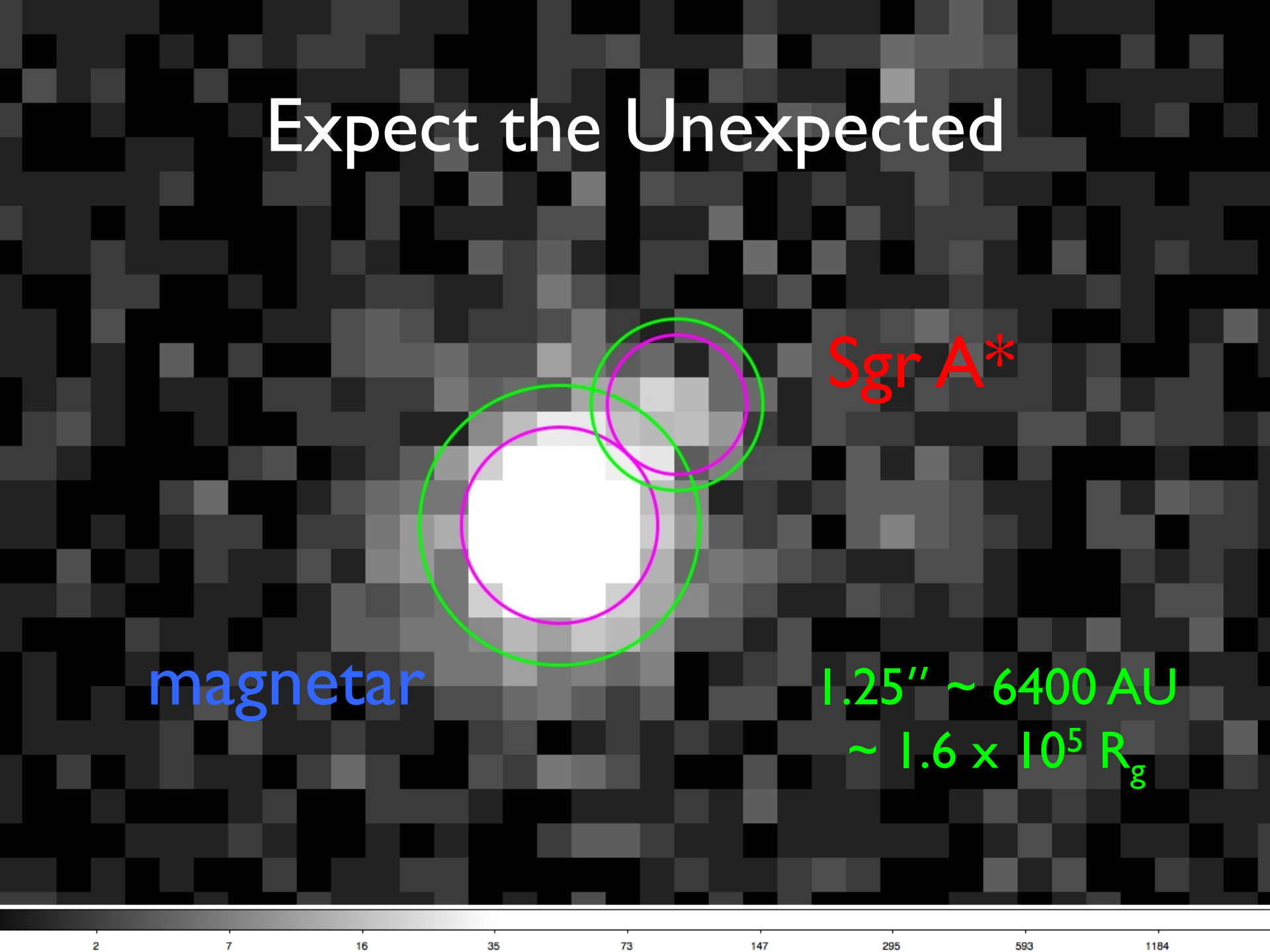


[Marrone, et al. 2008, Yusef-Zadeh et al. 2009]

New Spitzer Lightcurve



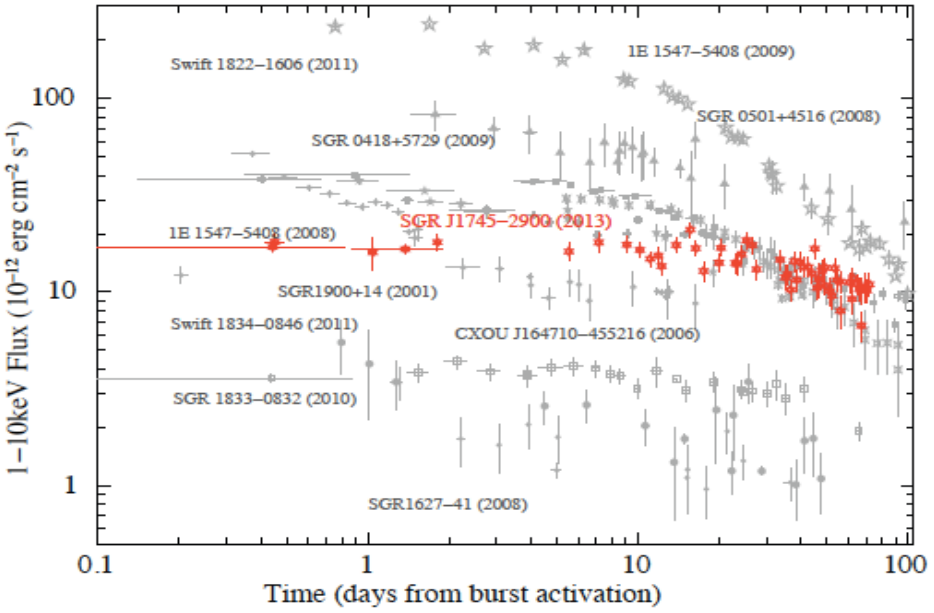
Expect the Unexpected



Magnetar SGR J1745

- 2.4”±0.3” from Sgr A*
- Slow decay relative to other known magnetars
- 90% prob. of being bound to Sgr A* w/ orbital period 500 yr to several kyr
- Previous outburst from this or other magnetars may contribute to Fe K fluorescence/echos

[Rea, et al. 2013]



P = 3.7635537 s
Pdot =6.61x10^{-12} s/s
B_{dip} =1.6x10^{14} G
Edot = 5x10^{33} erg/s
tau_c = 9 kyr

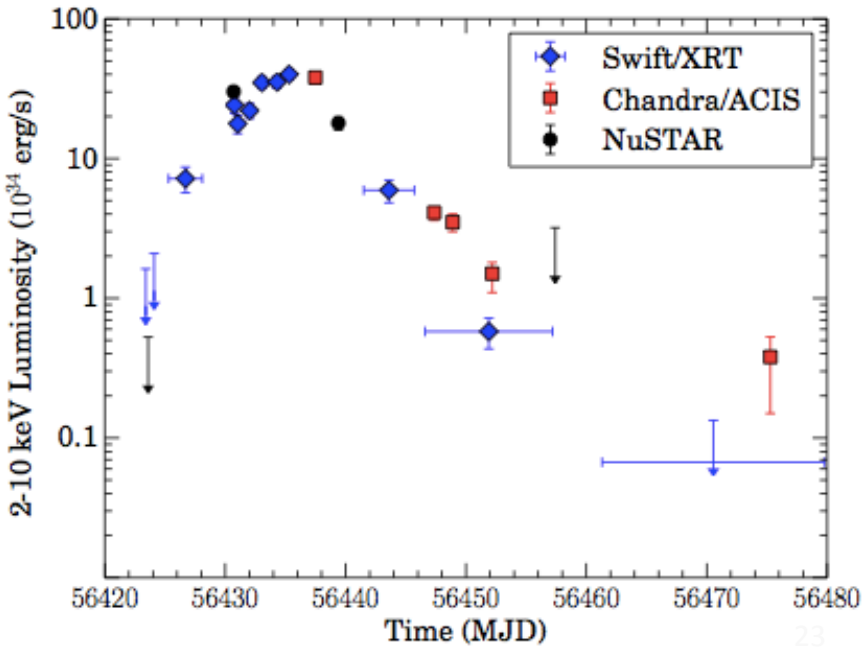
Thermal spectrum
kT = 0.99keV
Nh = 0.98 x 10^{23} cm^{-2}

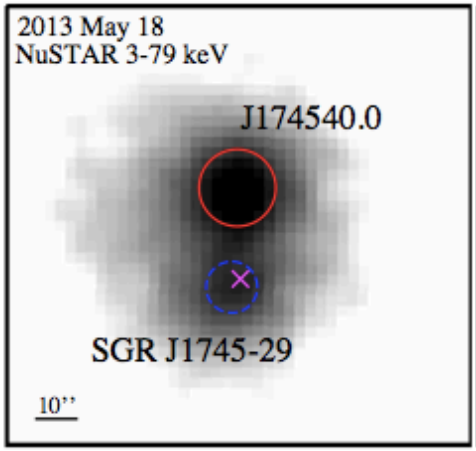
[Swift (Kennea+13), NuSTAR (Mori+13, Kaspi+14), Chandra (Rea+13, Coti Zelati+*in prep*) + radio (Eatough+13, Bower+13, Spitler+13, Shannon+13)]

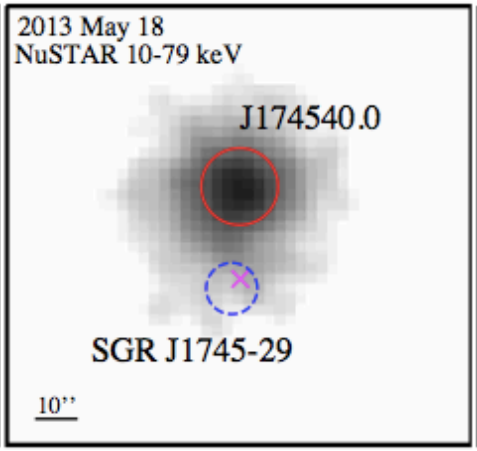
CXO J1745-2900

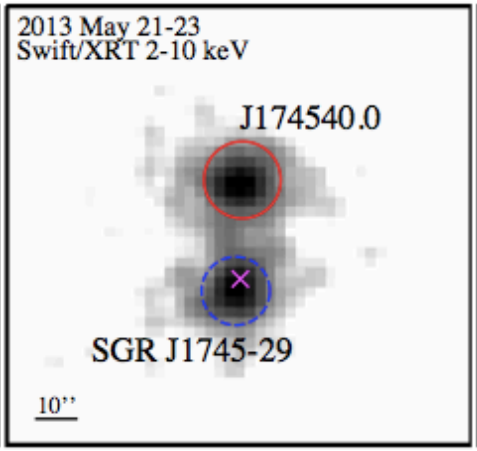
- Best-studied outburst from a very faint X-ray transient (VFXT)/LMXB (Lx < 10^{36} erg/s)
- Chandra, Swift, and NuSTAR data above 10^{34} erg/s fit by PL with $\Gamma \sim 1.7$ (from 2 to 70 keV)
- Chandra obs at 4×10^{33} ergs/s substantially softer; suggests a thermal blackbody-like component

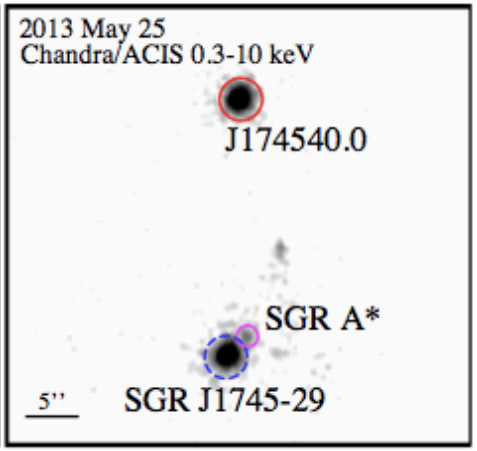
[Koch, et al. 2014]







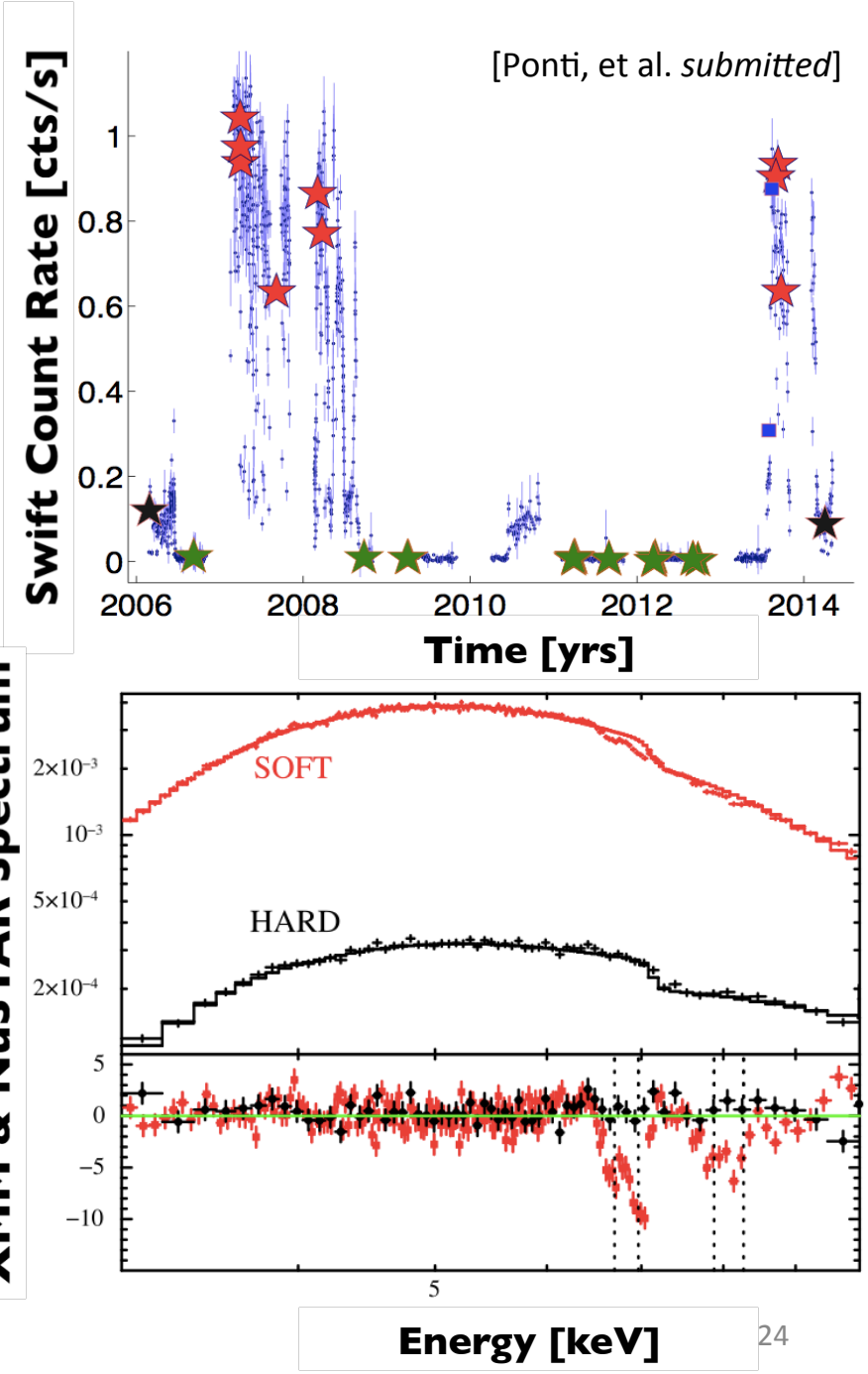




AX J1745.6-2901

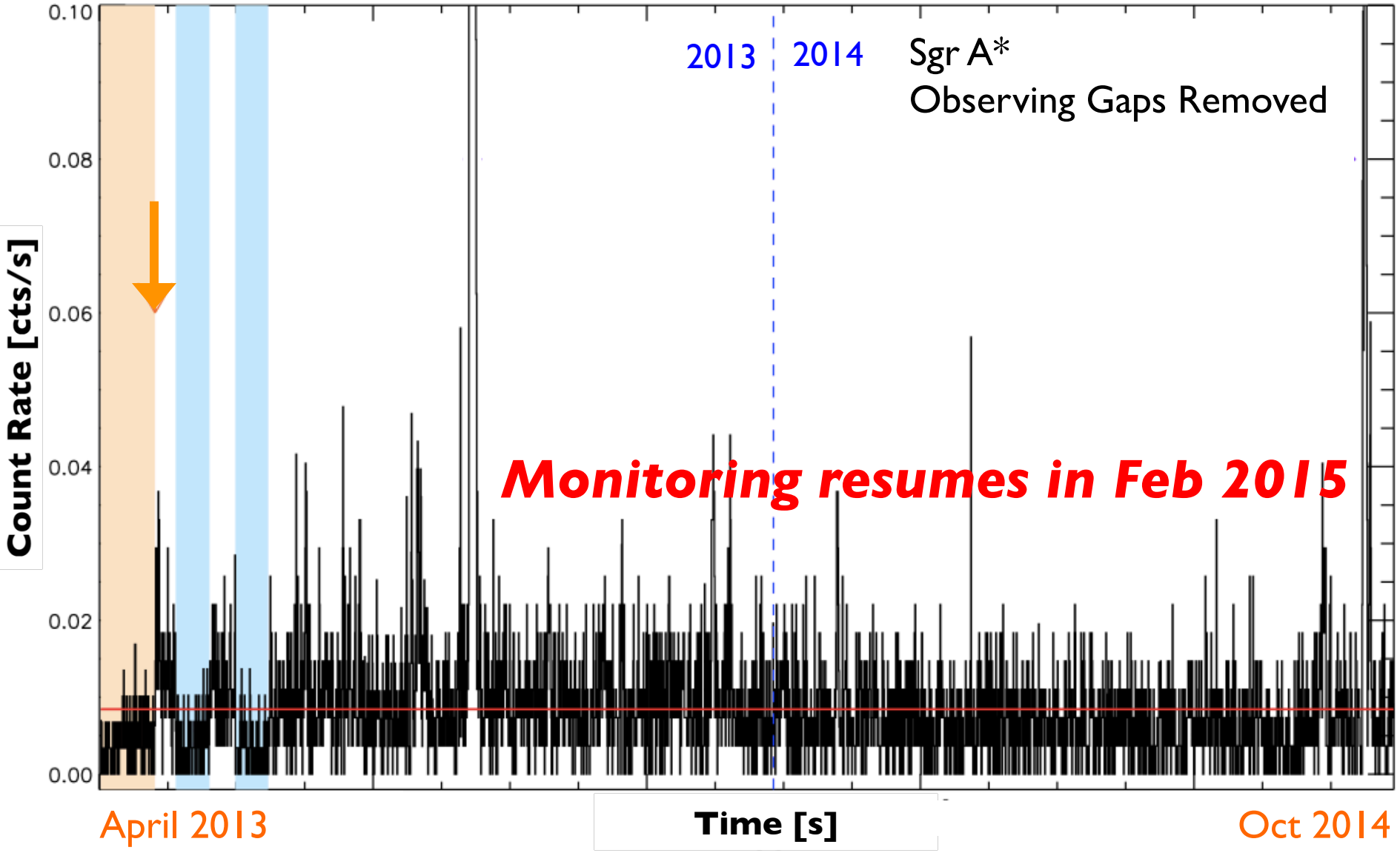
- High-inclination (eclipsing) neutron star Low Mass X-ray Binary (LMXB)
- Less than ~1.5 arcmin from Sgr A*
- >8 years of *Swift*, *XMM-Newton* and *NuSTAR* obs; 40 *XMM* obs, 12 in outburst
- Fe K absorption clearly seen in the soft-state, but disappears during the hard state
- Evidence for connection between the wind-Fe K absorber and the accretion state of the binary

[Ponti, et al. *submitted*]



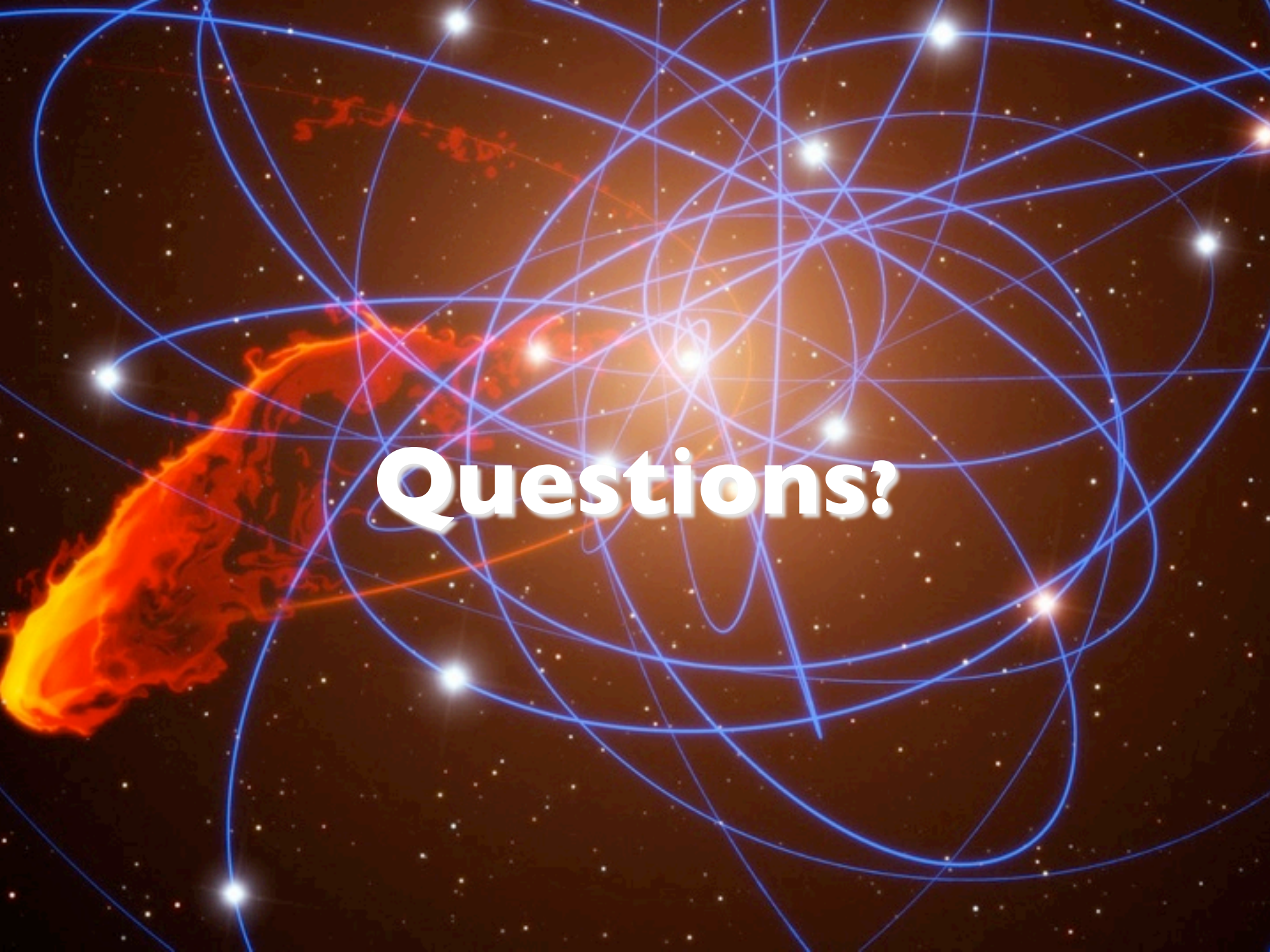
Sgr A* X-ray Light Curve

[**Haggard** et al, Atel #6242; **Haggard**, et al. *in prep*]



Sgr A*/G2++ Summary

- No X-ray or radio G2 sighting … yet?
- Monitoring will distinguish G2's origin and fate
- Sgr A* flares detected by *Chandra*
  - Faint and one ***very*** bright flare
  - Bright flare: spectrum comparable to other bright flares, double-peaked morphology, detailed timing, radio lag
  - Flare rate: TBD, but not enormously enhanced
- Other Excellent X-ray + Multiwavelength Science
  - XMM & Swift: lightcurves, spectroscopy
  - VLA/VLBA: lightcurves, astrometry, polarization
  - Absorption measure along Sgr A* line of sight
  - X-ray transients: Magnetar, CXO J1745, AX J1745.6


Questions?