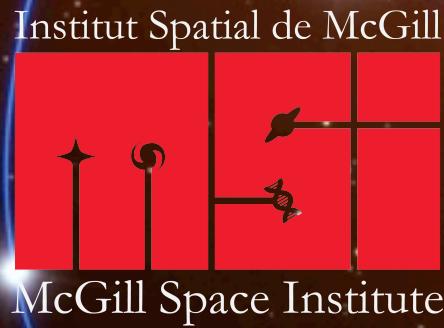


Interpreting Sgr A*'s Most Luminous X-ray Flares



Institut Spatial de McGill

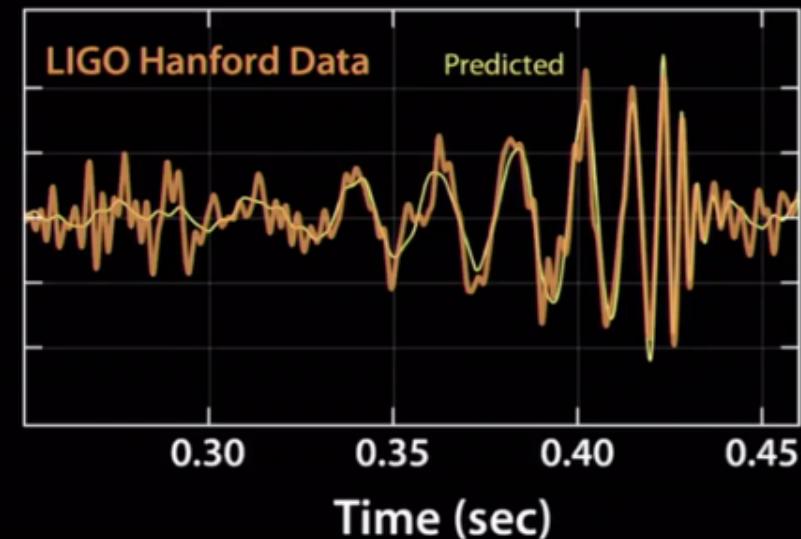
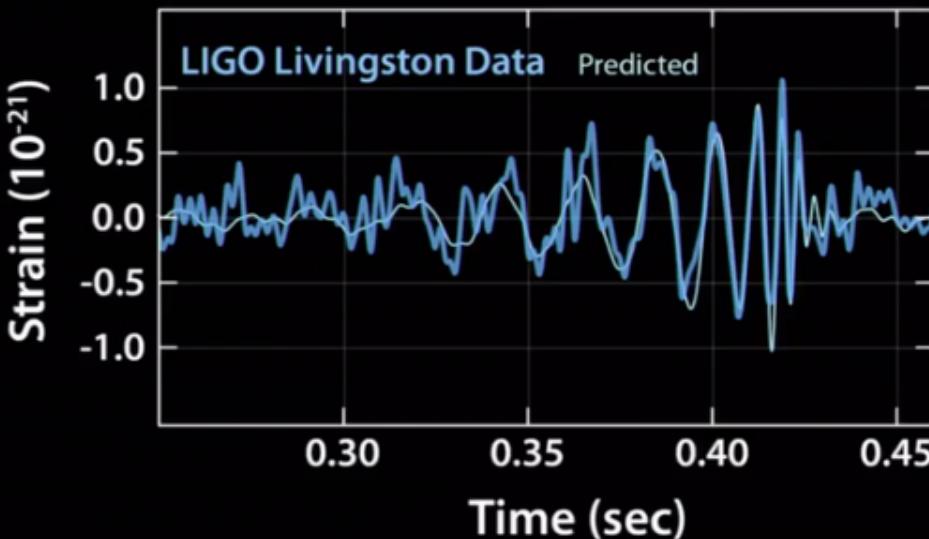
McGill Space Institute

Daryl Haggard
McGill University

What a wonderful day - and in our (my) lifetime. The wave revealed from a spectacular collision, spectacularly long gone. A new way to examine the universe!

Exciting for your field and for you who dedicated yourself to it.
Congratulations.

Gravitational Waves!!!



Collaborators

Baganoff, Frederick

Bower, Geoffrey

Brinkerink, Christaan

Bushouse, Howard

Corales, Lia

Coti-Zelati, Francesco

Degenaar, Nathalie

Dexter, Jason

Falcke, Heino

Fazzio, Giovanni

Fragile, P. Chris

Ghez, Andrea

Gillessen, Stefan

Heinke, Craig

Hora, Joseph

Kosack, Karl

Law, Casey

Markoff, Sera

Marrone, Dan

Morris, Mark

Neilsen, Joey

Nowak, Michael

Ponti, Gabriele

Rea, Nanda

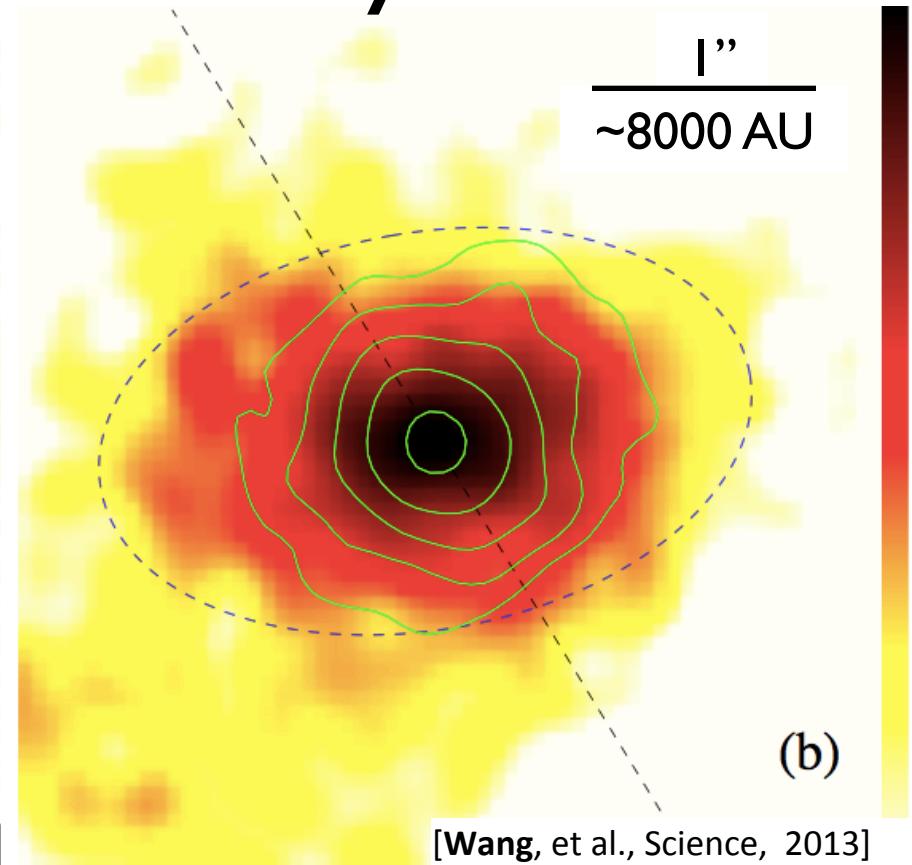
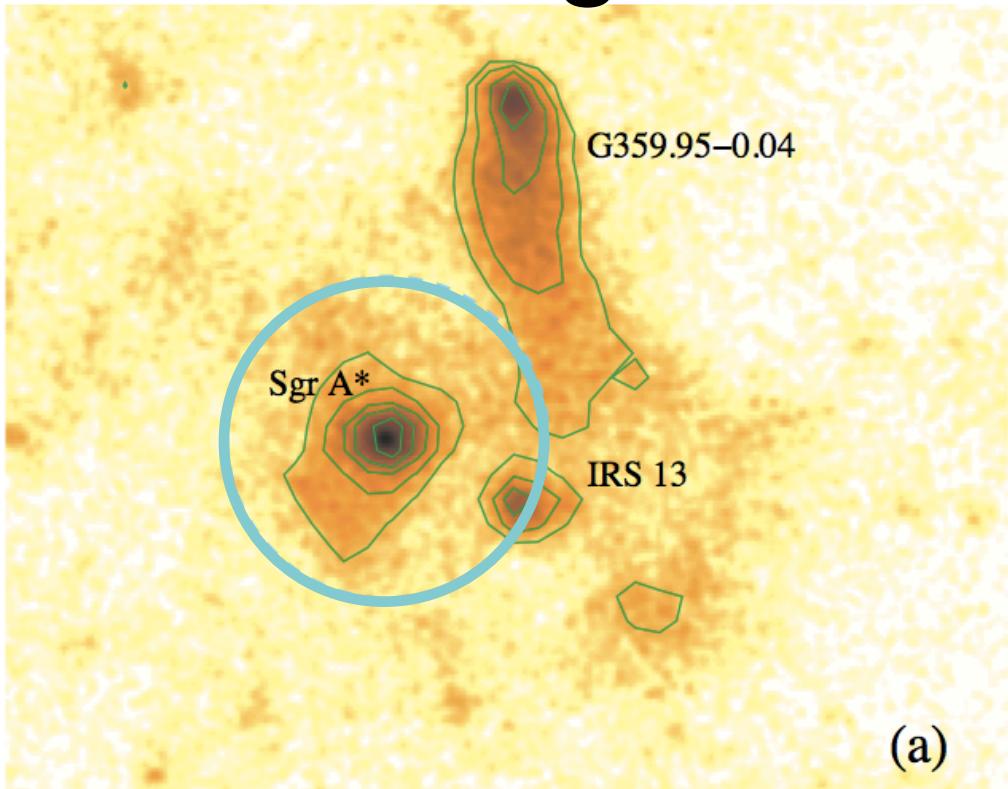
Roberts, Douglas

Wang, Q. Daniel

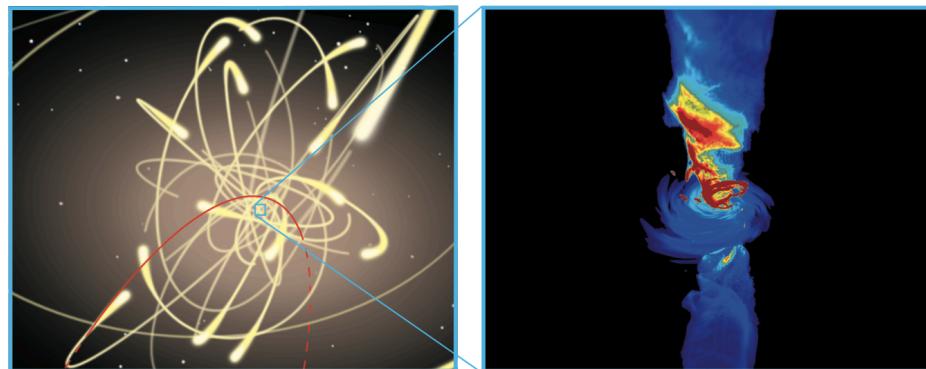
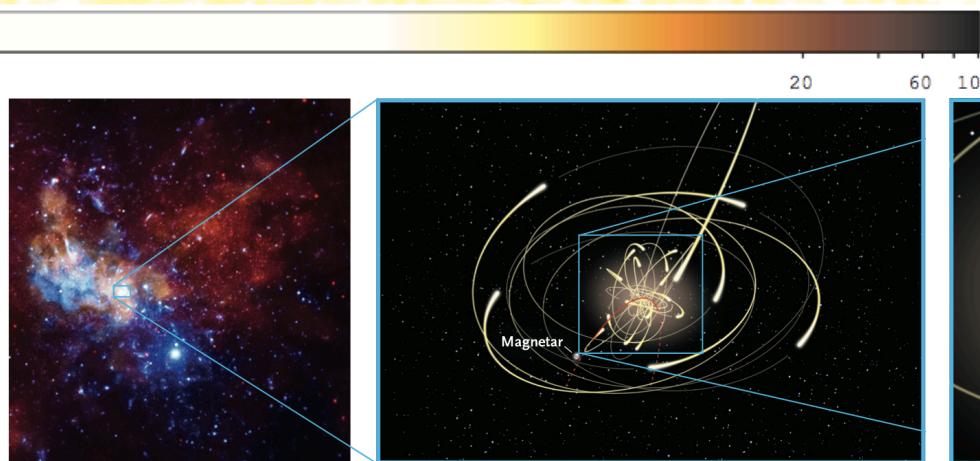
Willner, Steven

Yusef-Zadeh, Farhad

Sgr A* in the X-ray

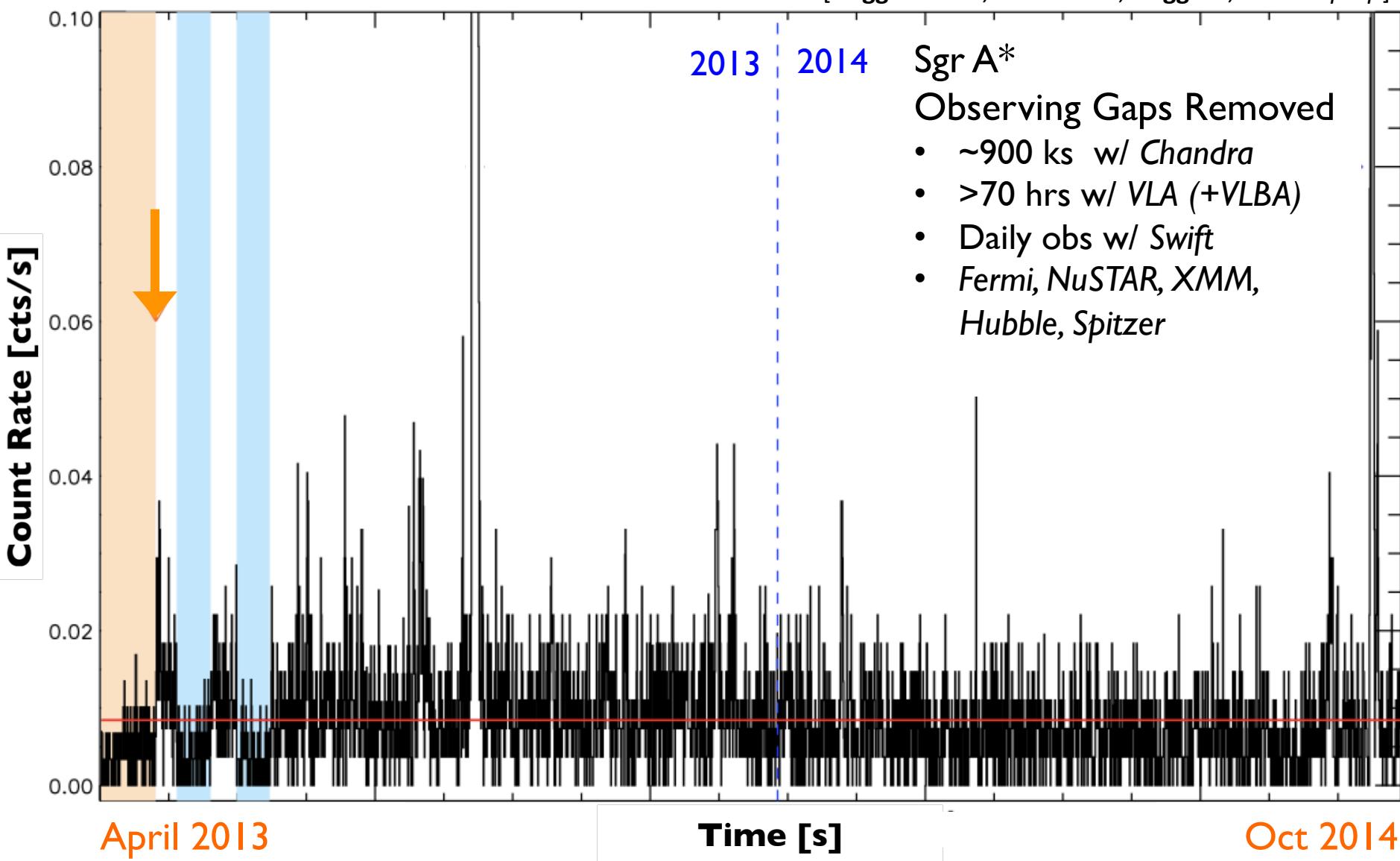


[Wang, et al., Science, 2013]



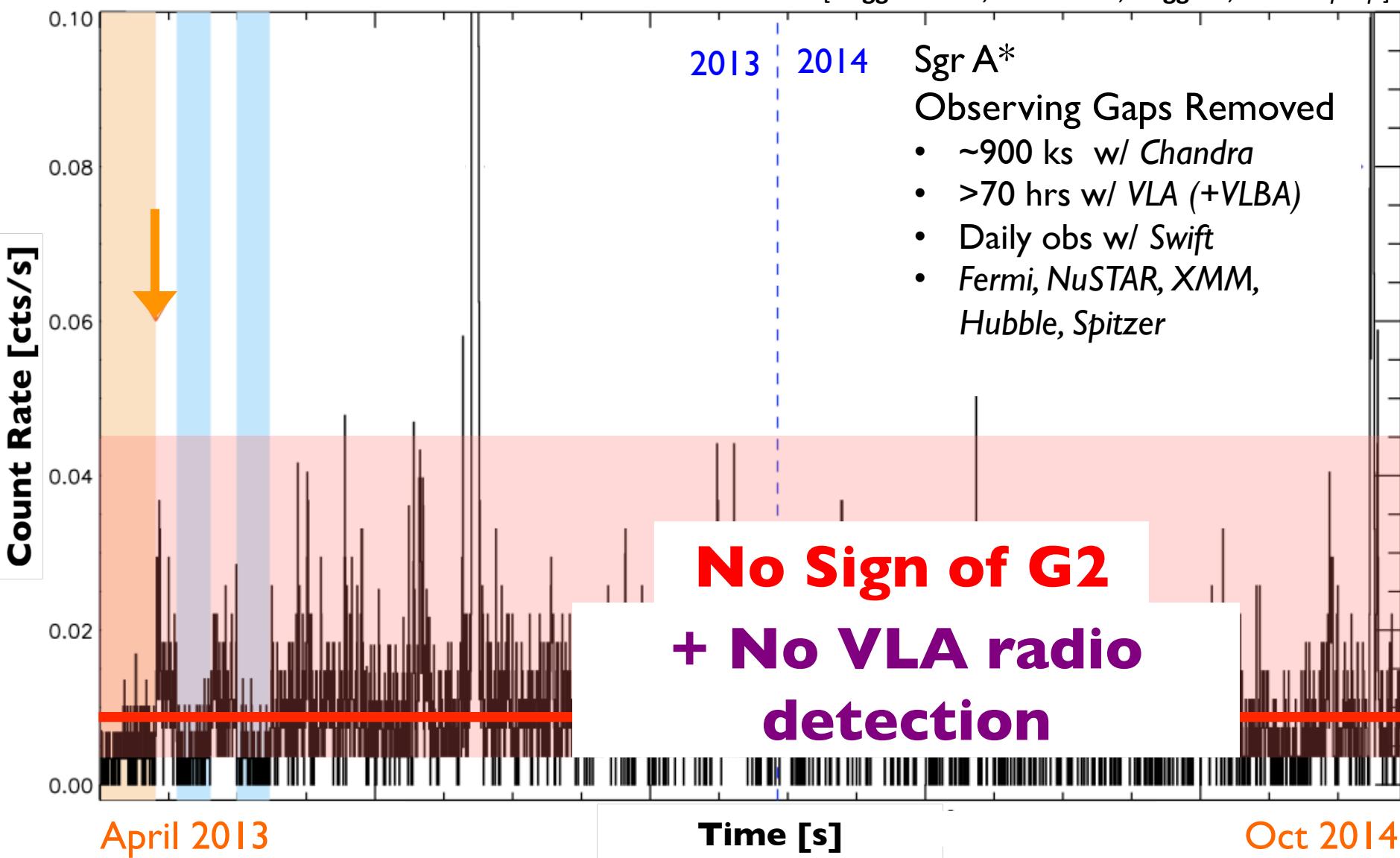
Sgr A* X-ray Light Curve

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

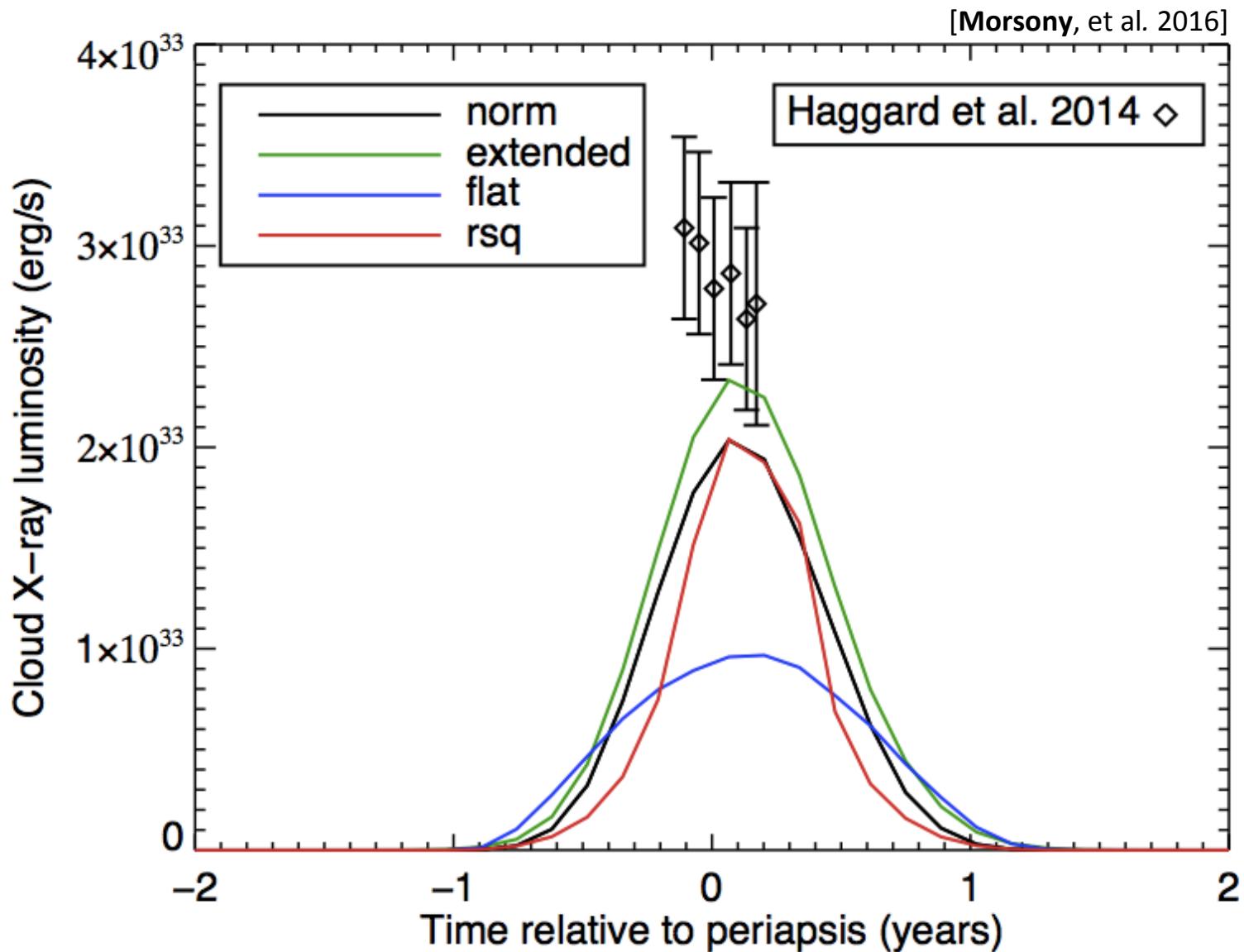


Sgr A* X-ray Light Curve

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

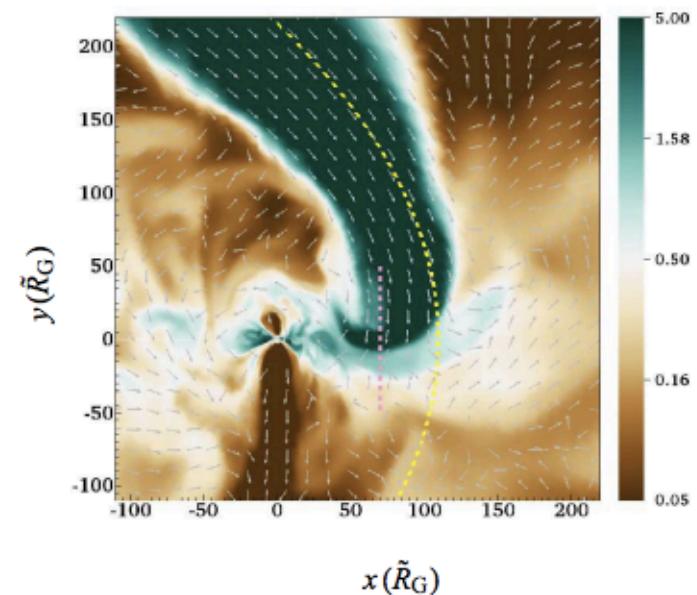
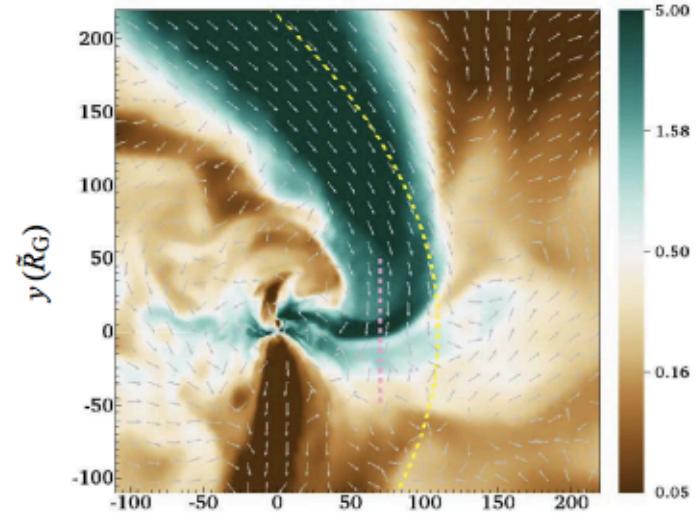


X-rays from G2 Encounter?



No X-ray or Radio Signature

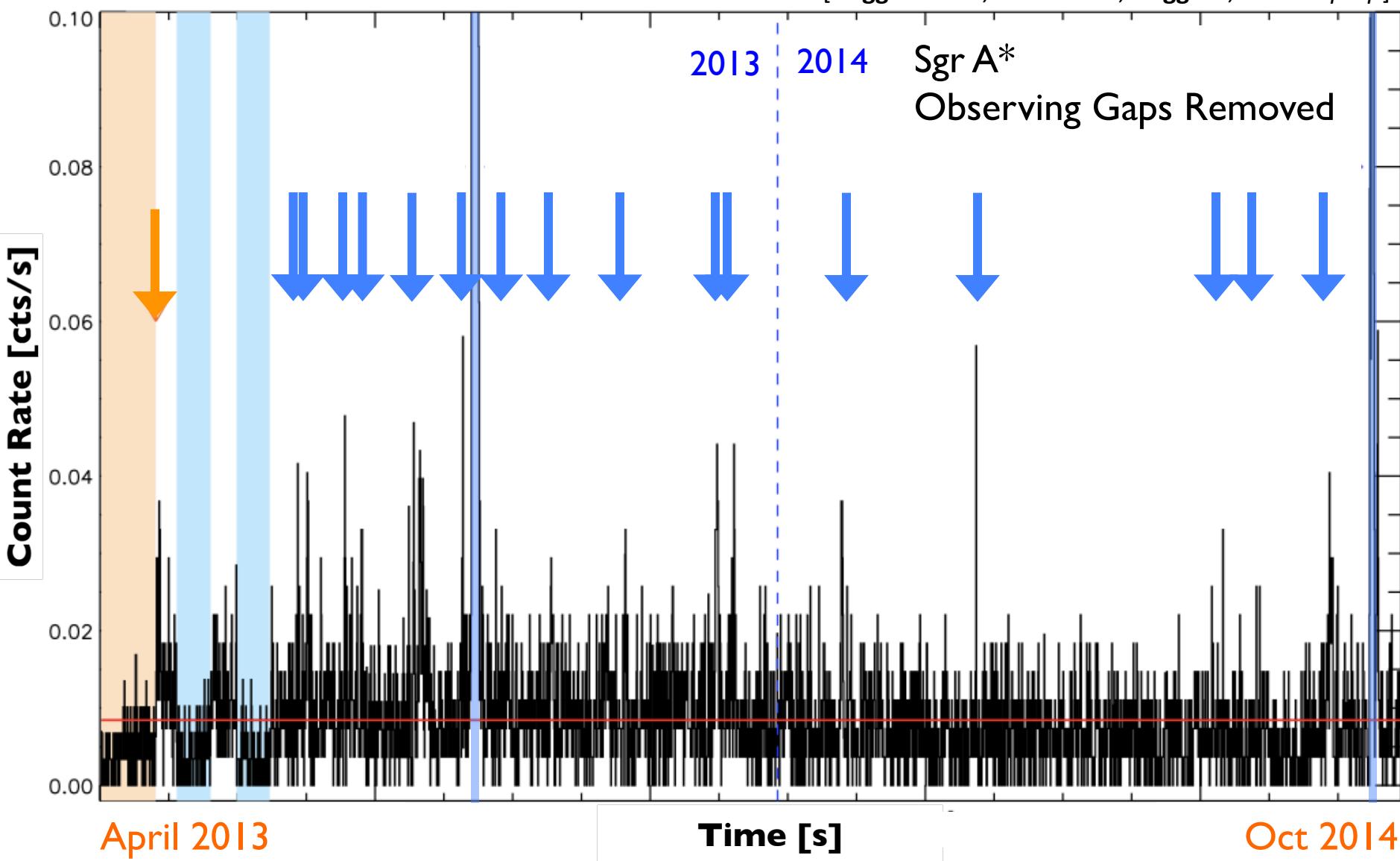
- No shock front
 - G2 is clumpy and/or the accretion flow is clumpy (G2 fell through a “void”)
 - GI already cleared the path
 - Accretion flow is lower density than expected
 - Non-detection may be constraining
- Uncertain viscosity and accretion timescale
 - Years vs. months
 - Continued monitoring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



[Sadowski et al, 2013]

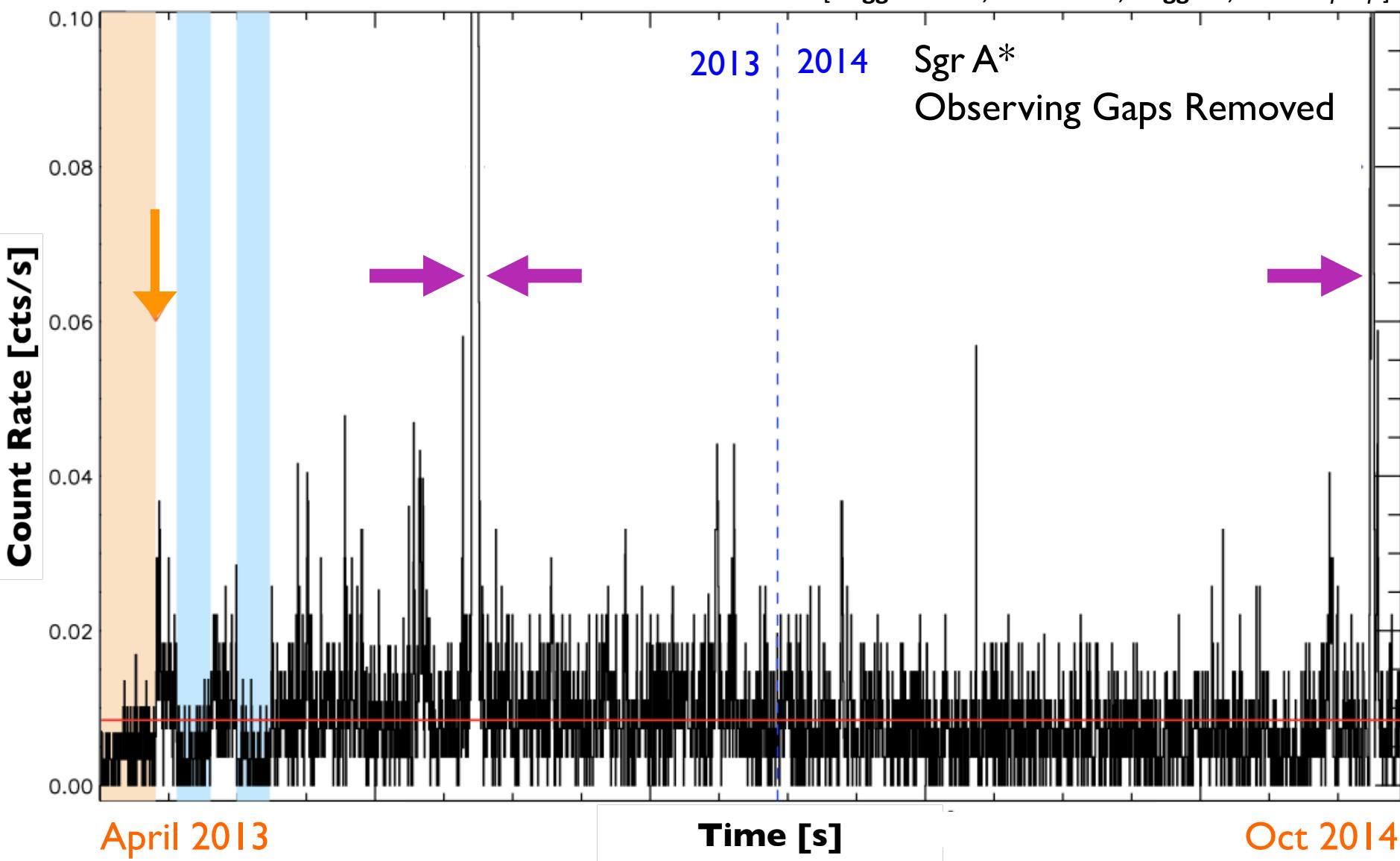
Sgr A* X-ray Light Curve

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



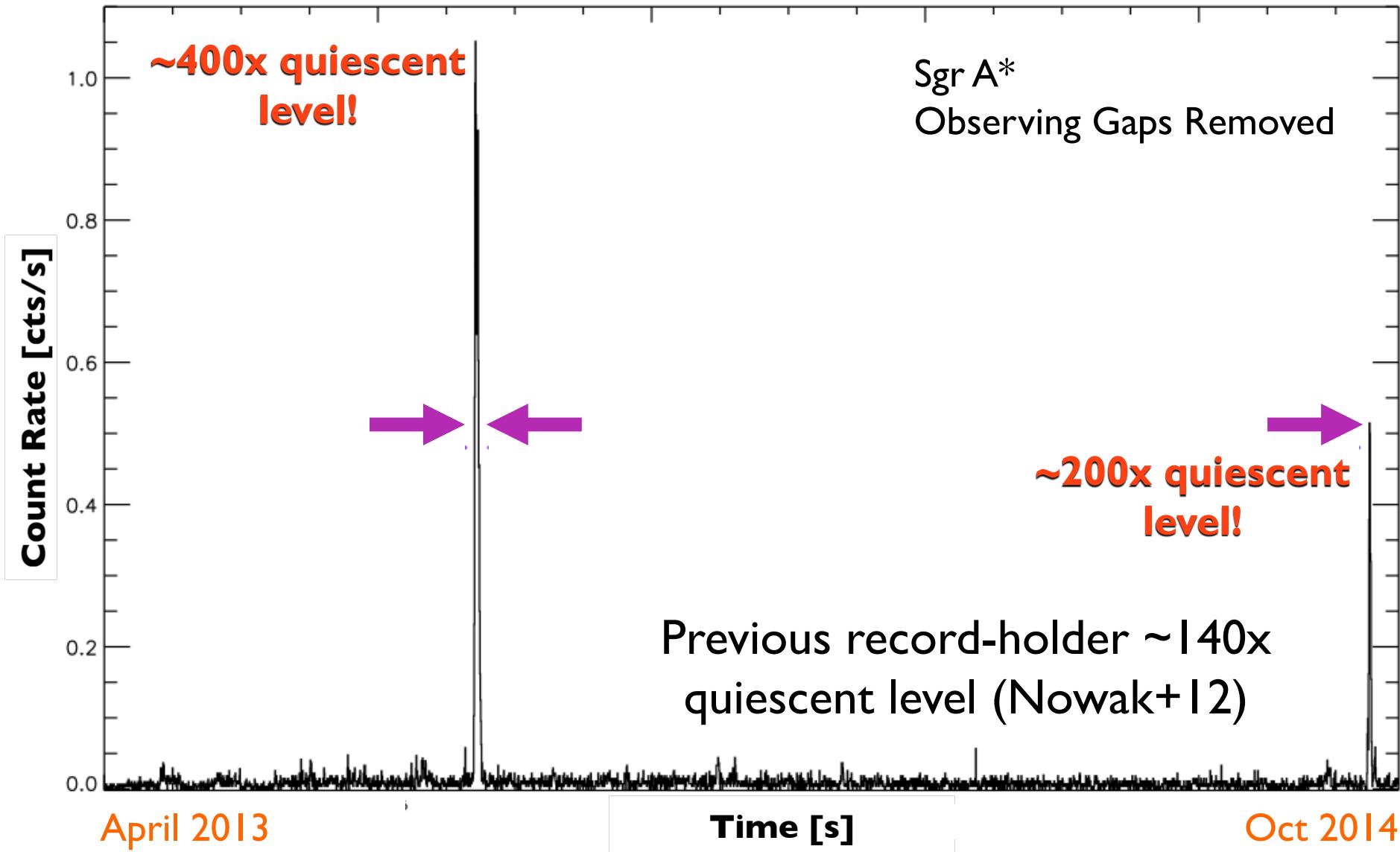
Sgr A* X-ray Light Curve

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



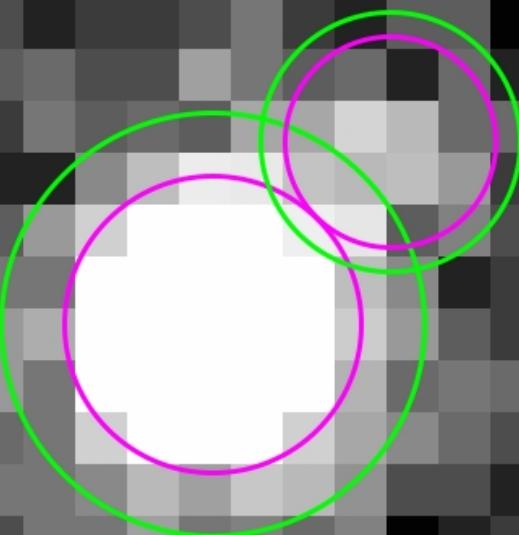
Sgr A* Bright (!) Flares

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



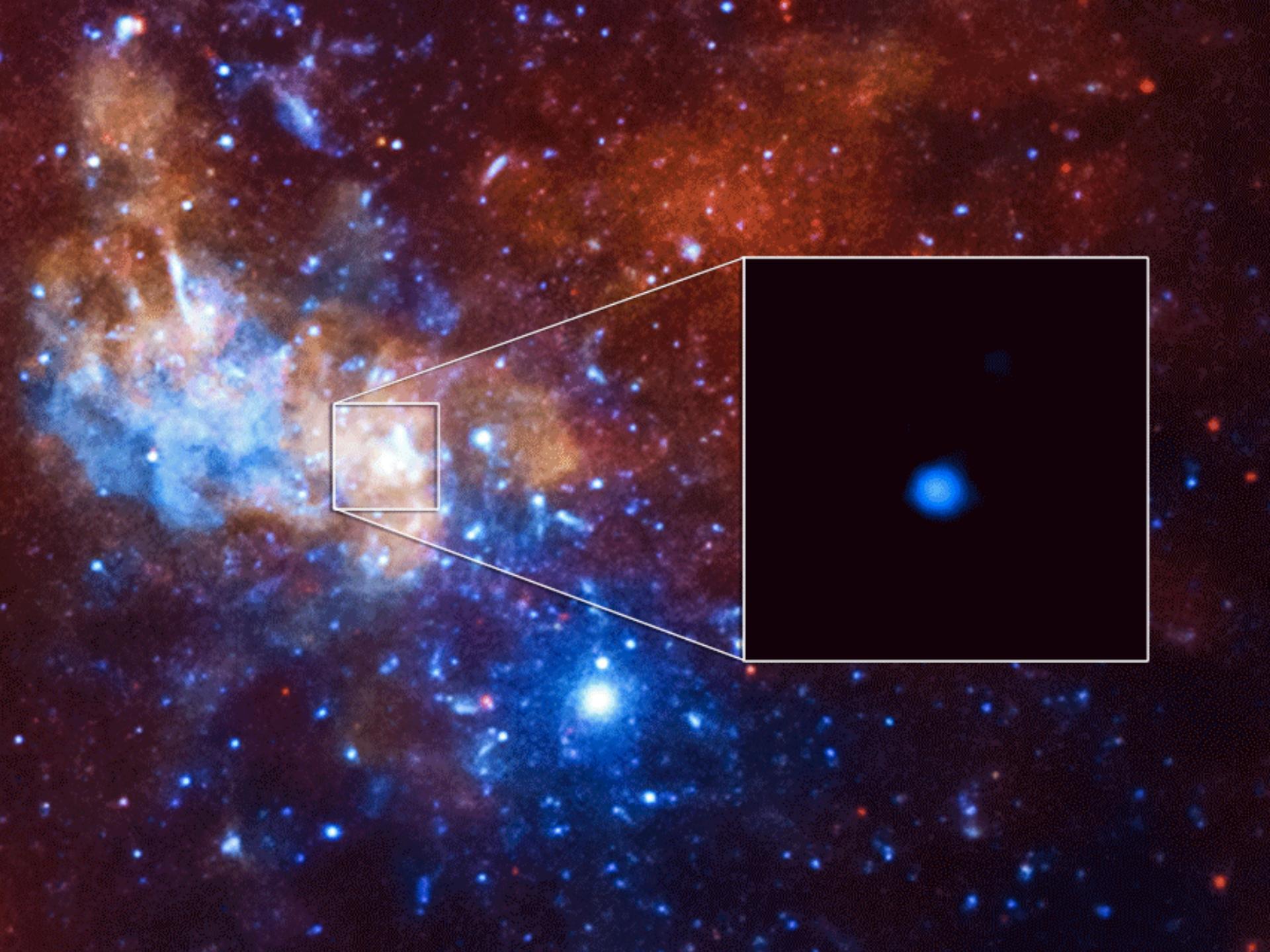
Magnetar “Contamination”

magnetar

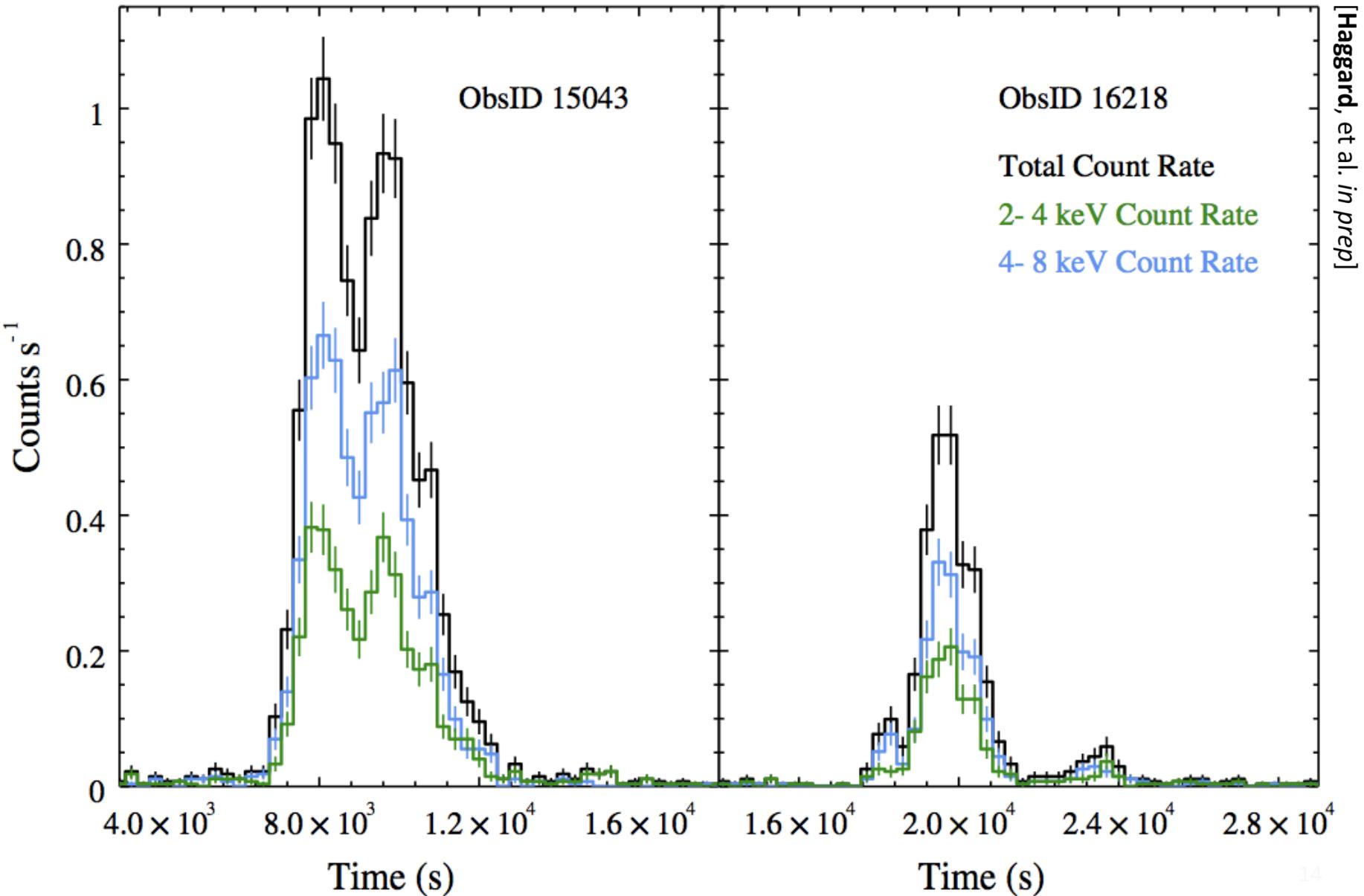


Sgr A*

1.25'' \sim 10,000 AU
 $\sim 1.25 \times 10^5 R_s$

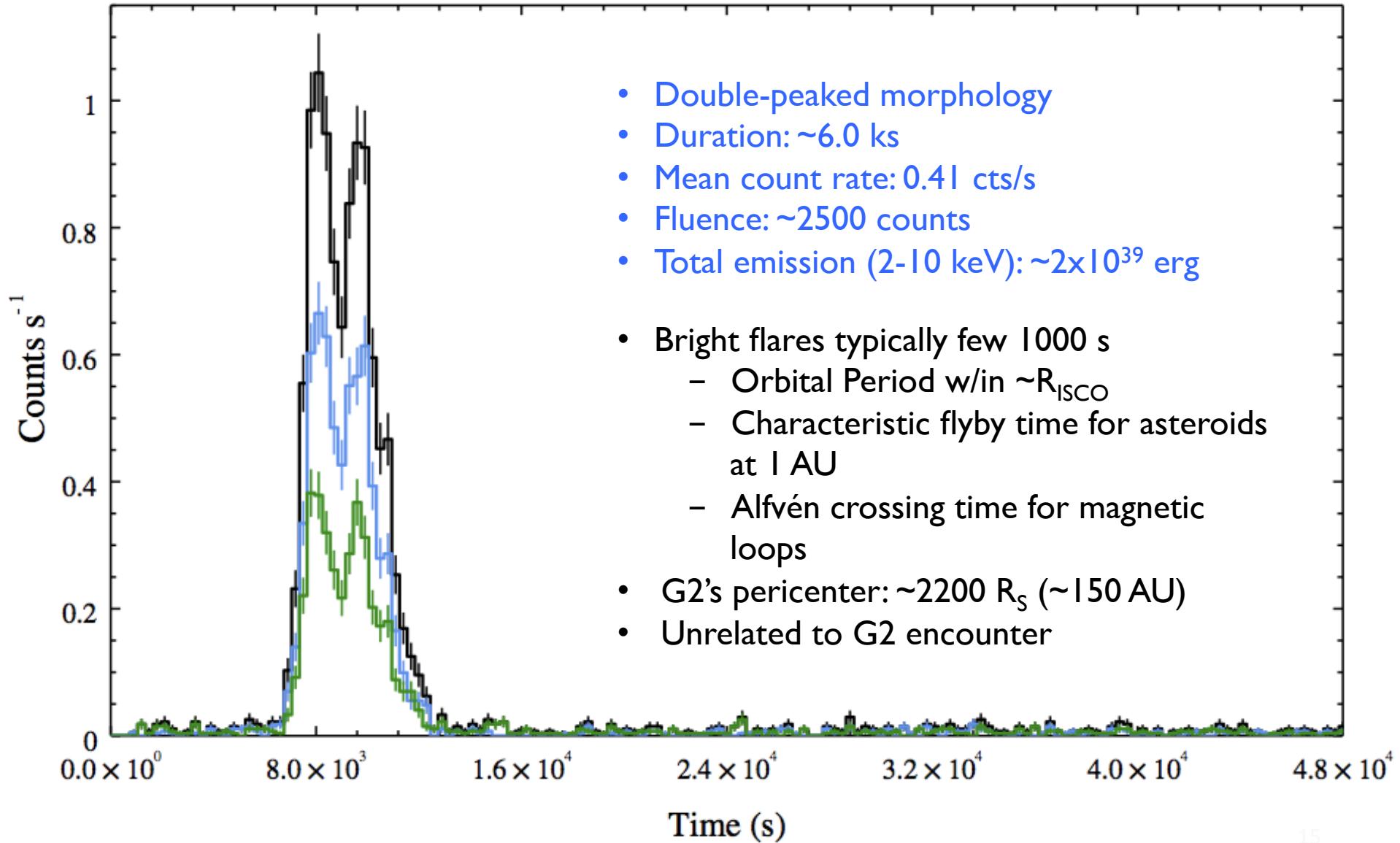


Sgr A* Two Brightest Flares



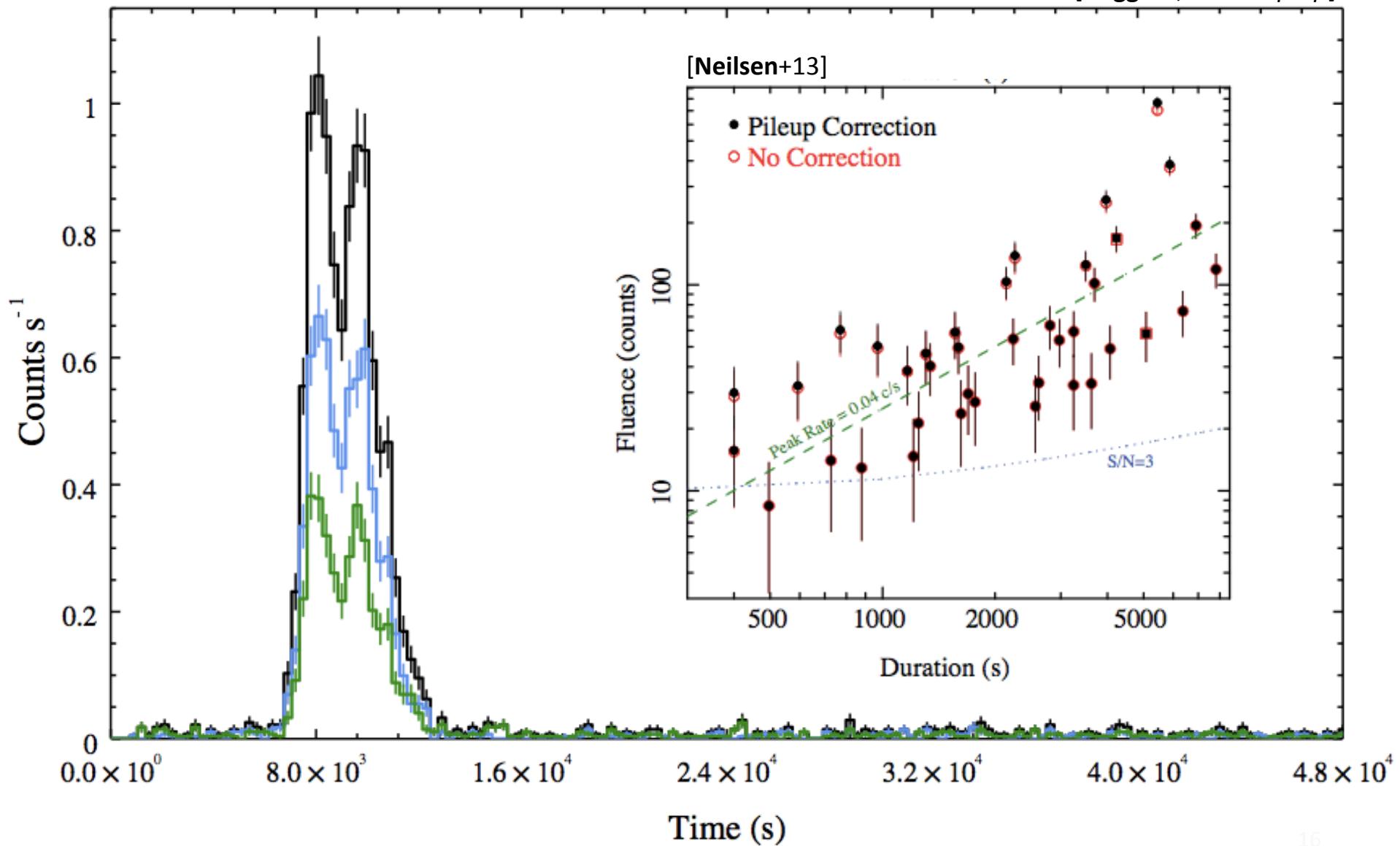
2013 Bright Flare

[Haggard, et al. *in prep*]

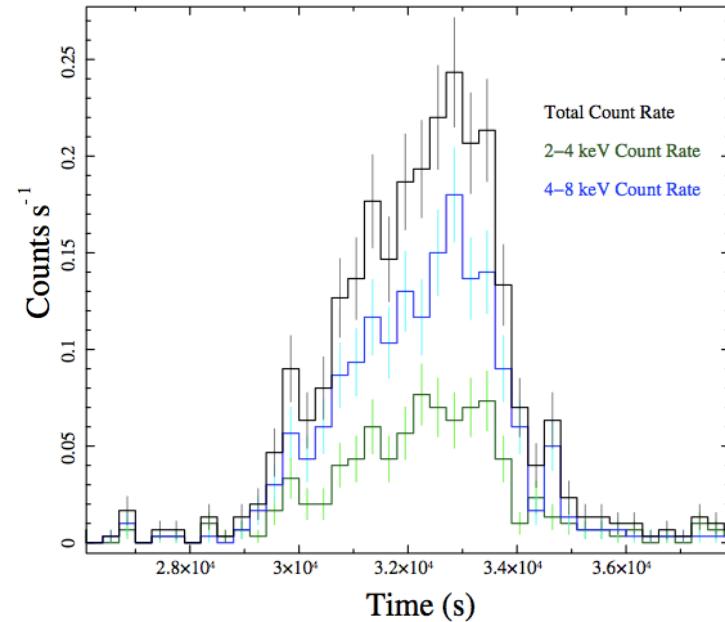
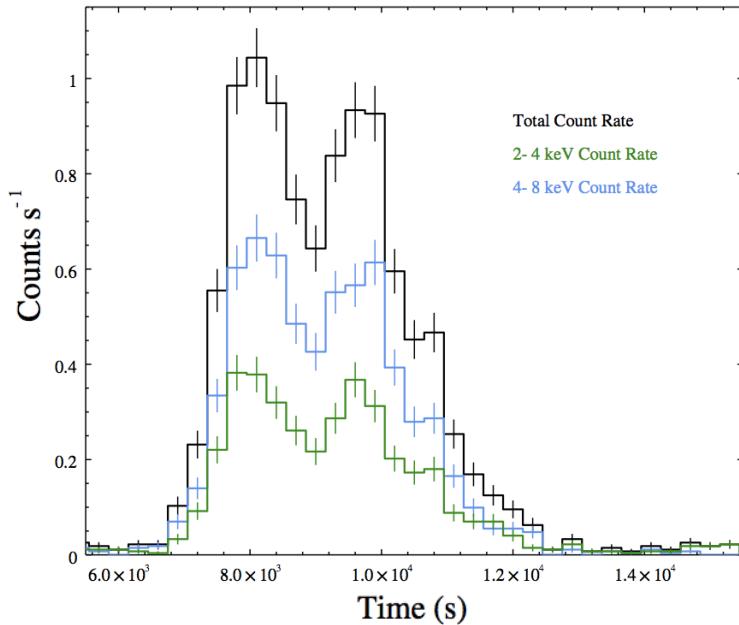


2013 Bright Flare

[Haggard, et al. *in prep*]



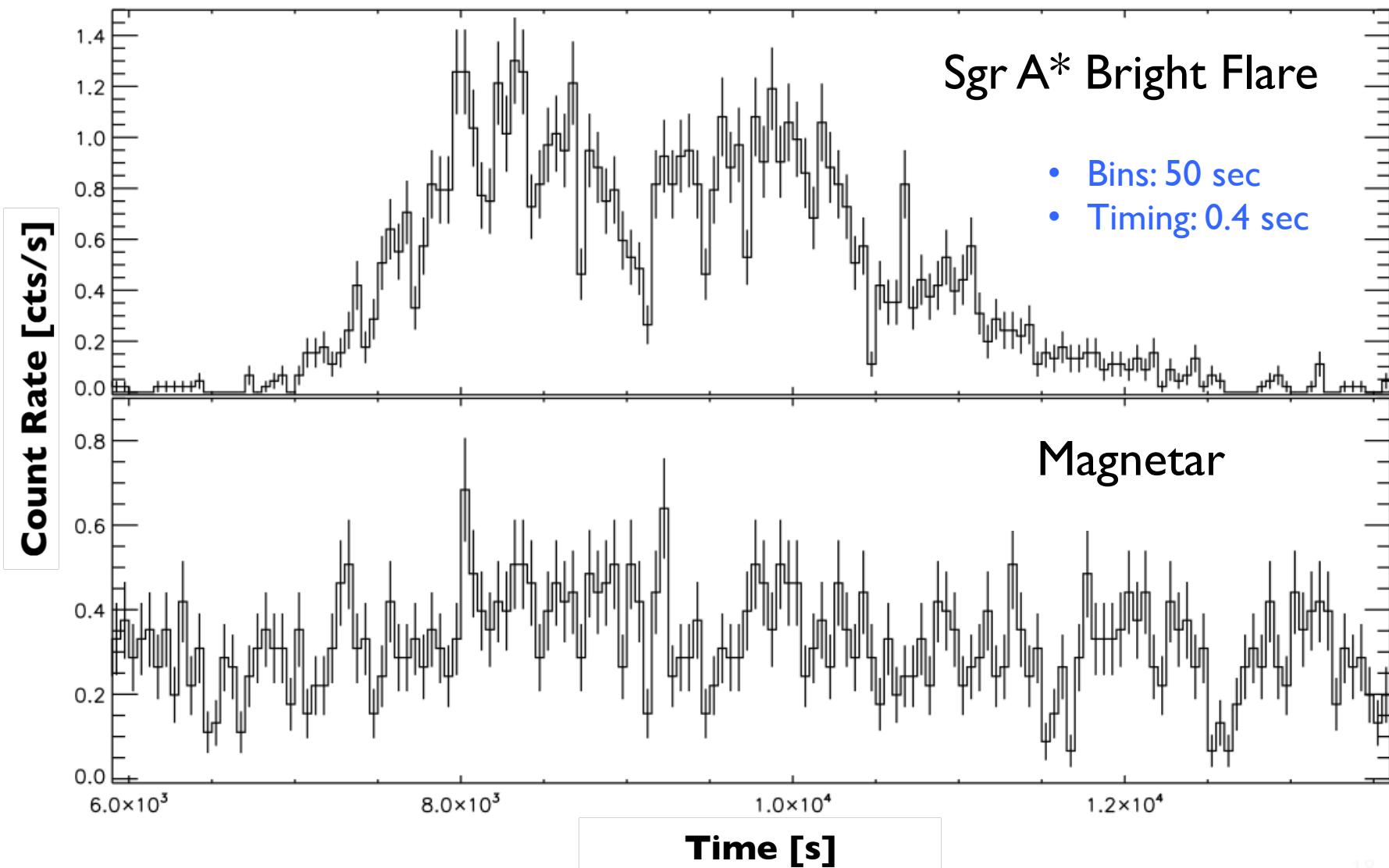
Spectroscopy



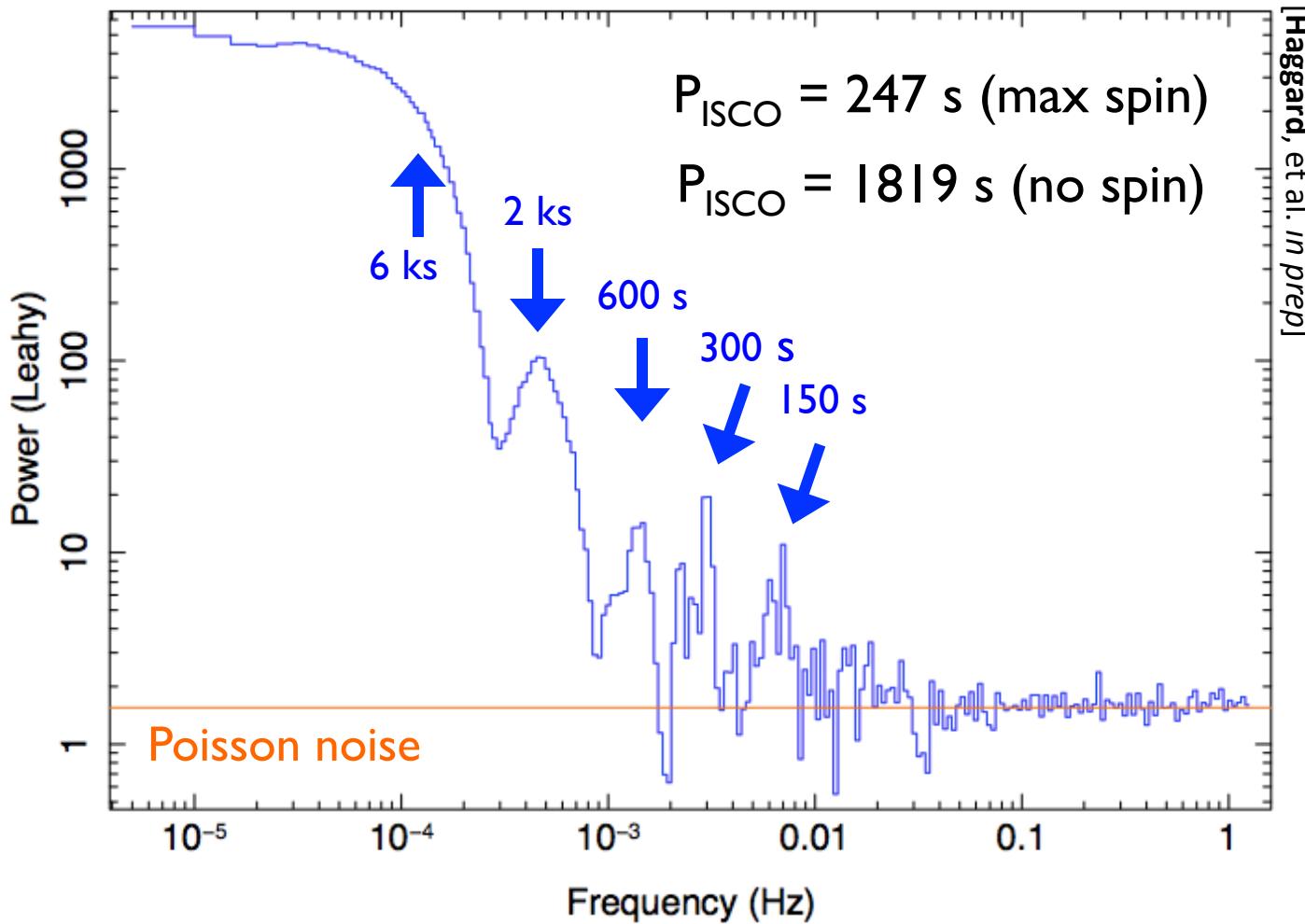
Flare	NH [10^{23} cm^{-2}]	Γ	$f\chi$ (2-8 keV, abs) [$\text{erg/cm}^2/\text{s}$]	Duration [ks]	Fluence [erg/cm^{-2}]	Energy (2-10keV) [erg]
Haggard+	$1.43_{-1.5}^{+0.69}$	$2.1_{-0.3}^{+0.1}$	$2.1_{-0.3}^{+0.4} \times 10^{-11}$	6.6	$1.4 \pm 0.3 \times 10^{-7}$	1.7×10^{-39}
Nowak+12	$1.43_{-3.6}^{+4.4}$	$2.0_{-0.6}^{+0.7}$	$8.5 \pm 0.9 \times 10^{-12}$	5.6	$4.7 \pm 0.5 \times 10^{-8}$	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	$1.4 \pm 0.1 \times 10^{-8}$	3.5×10^{-38}
Porquet+03 (Nowak+12)	$1.61_{-2.2}^{+1.9}$	2.3 ± 0.3	$7.7 \pm 0.3 \times 10^{-12}$	2.8	$2.2 \pm 0.1 \times 10^{-8}$	5.3×10^{-38}

Morphology & Timing

[Haggard, et al. *in prep*]

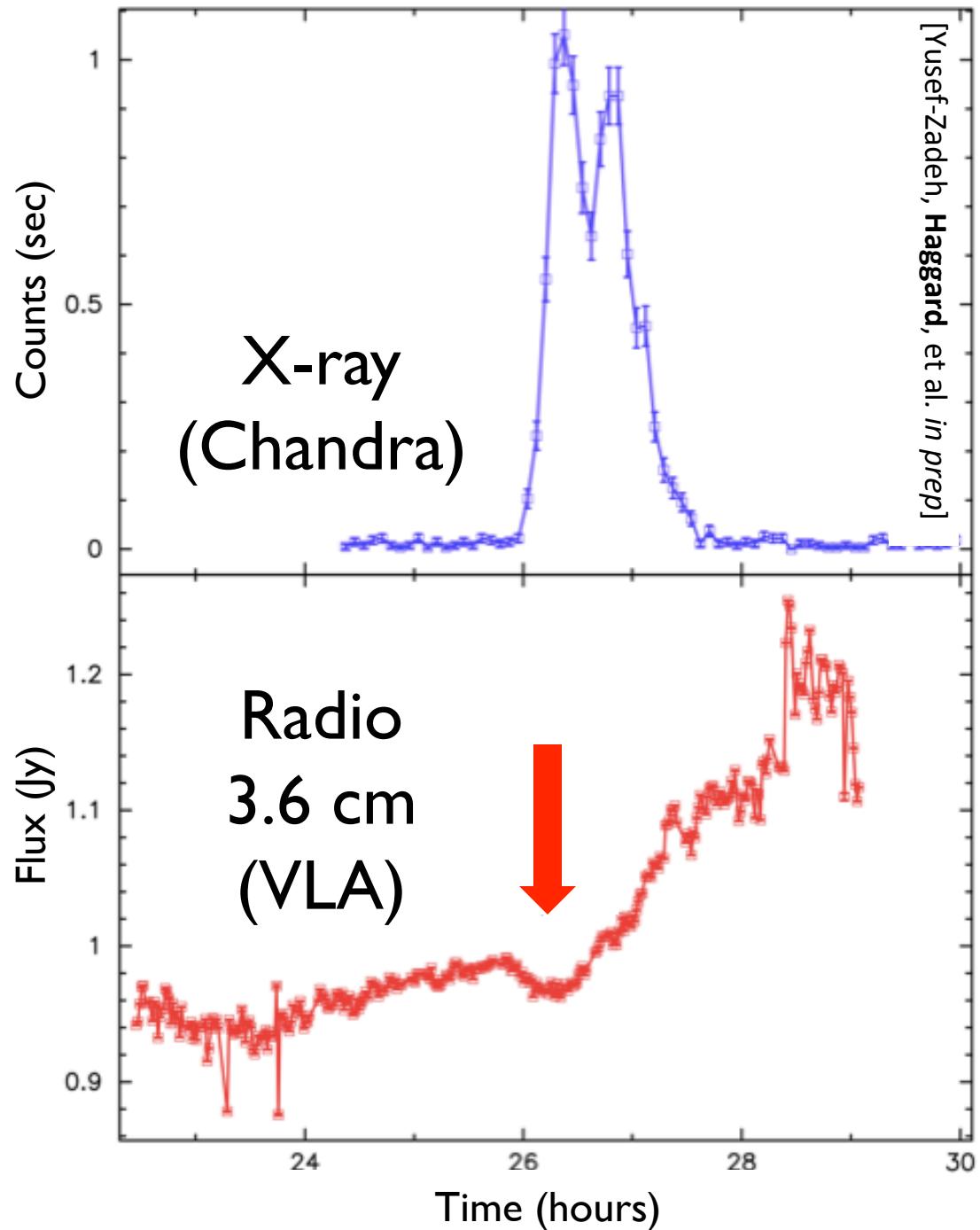


Power Spectral Distribution

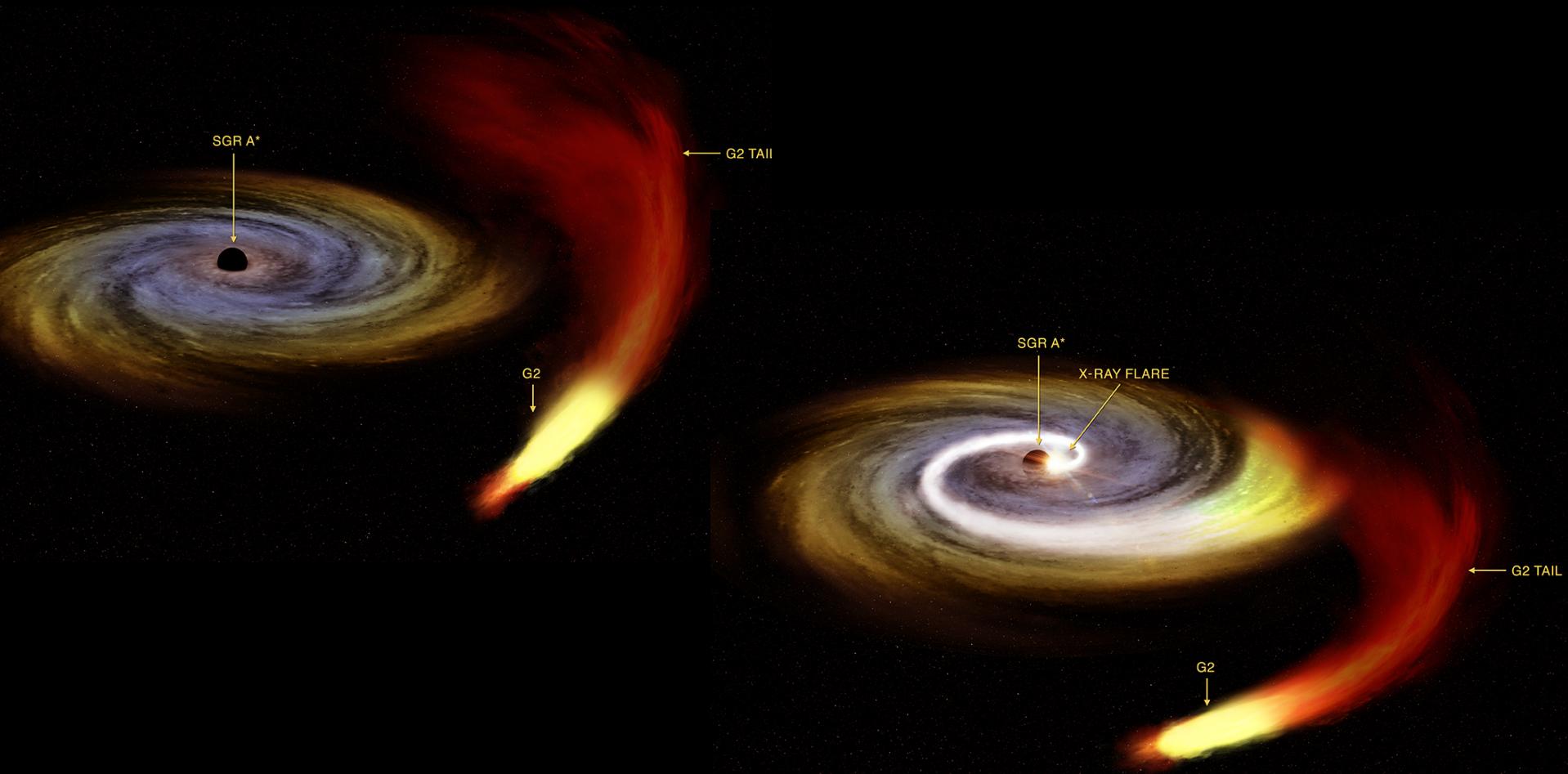


Radio View

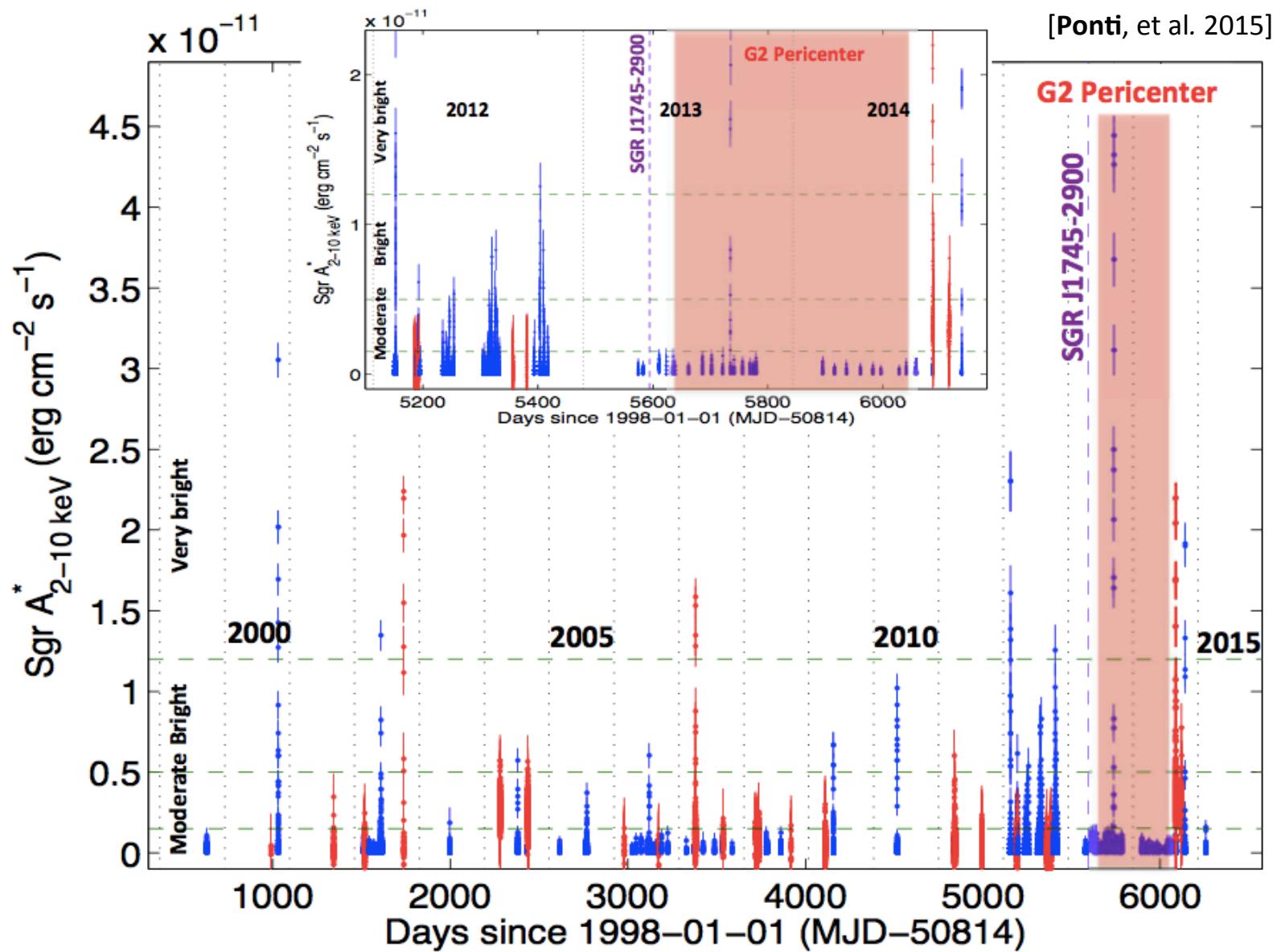
- Continuous coverage
- Radio (3.6 cm) flux increase of 25%
- Cross correlation peak > 130 min
- Consistent with previous time delay estimates
- Anti-correlation radio-X-ray peak



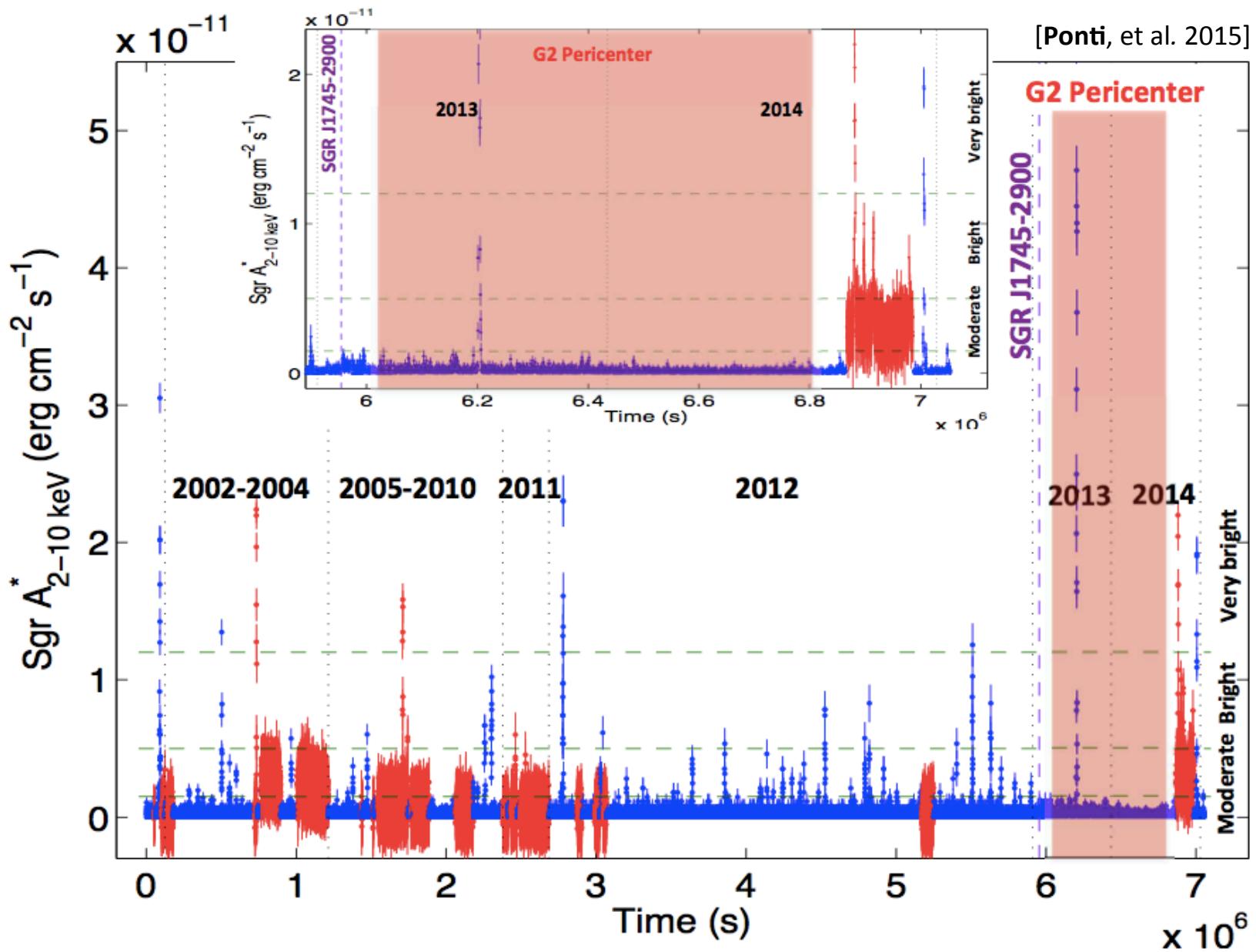
Increased Flare Rate?



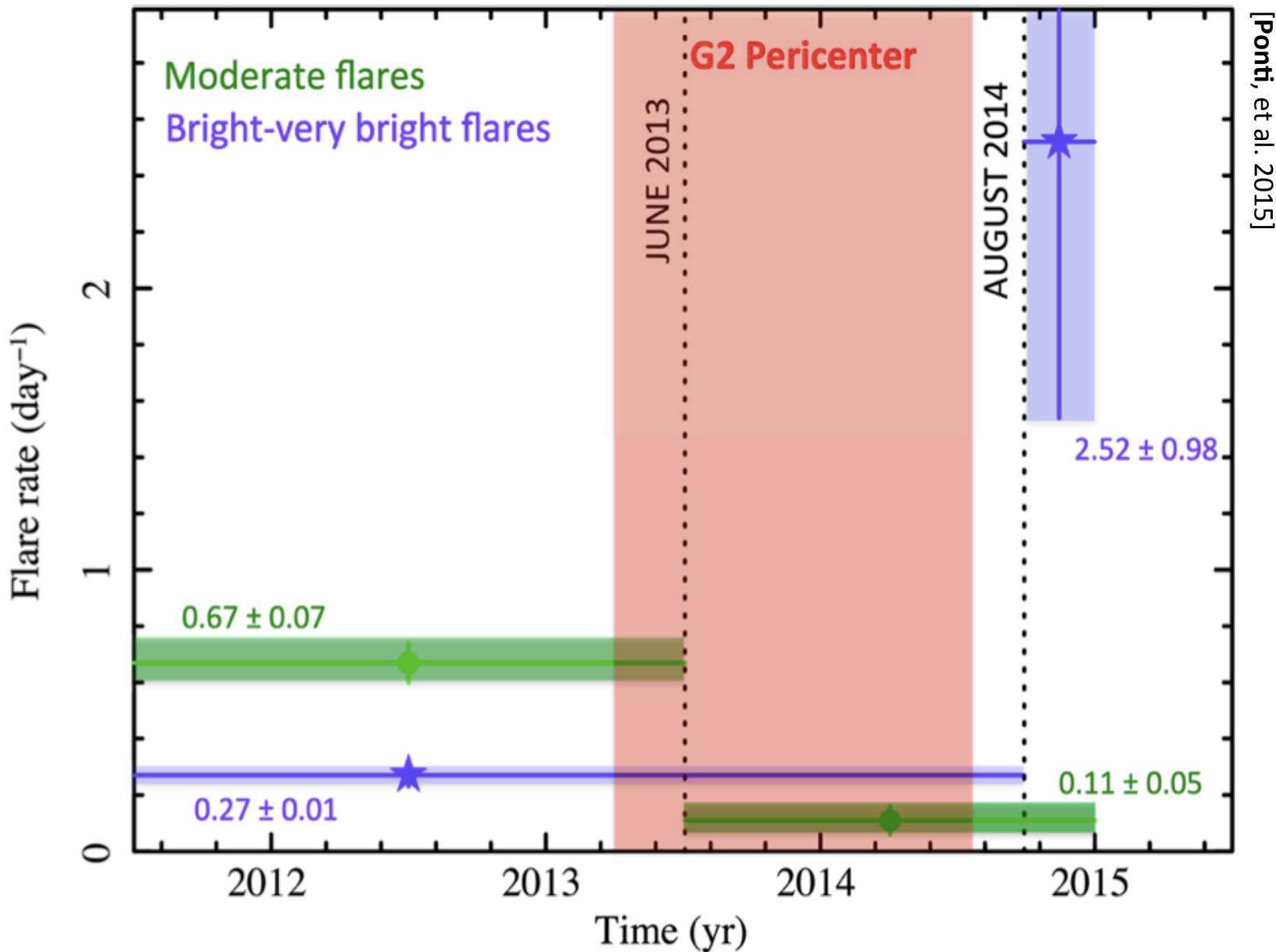
Flare Rates: Chandra, XMM, Swift



Flare Rates: Chandra, XMM, Swift



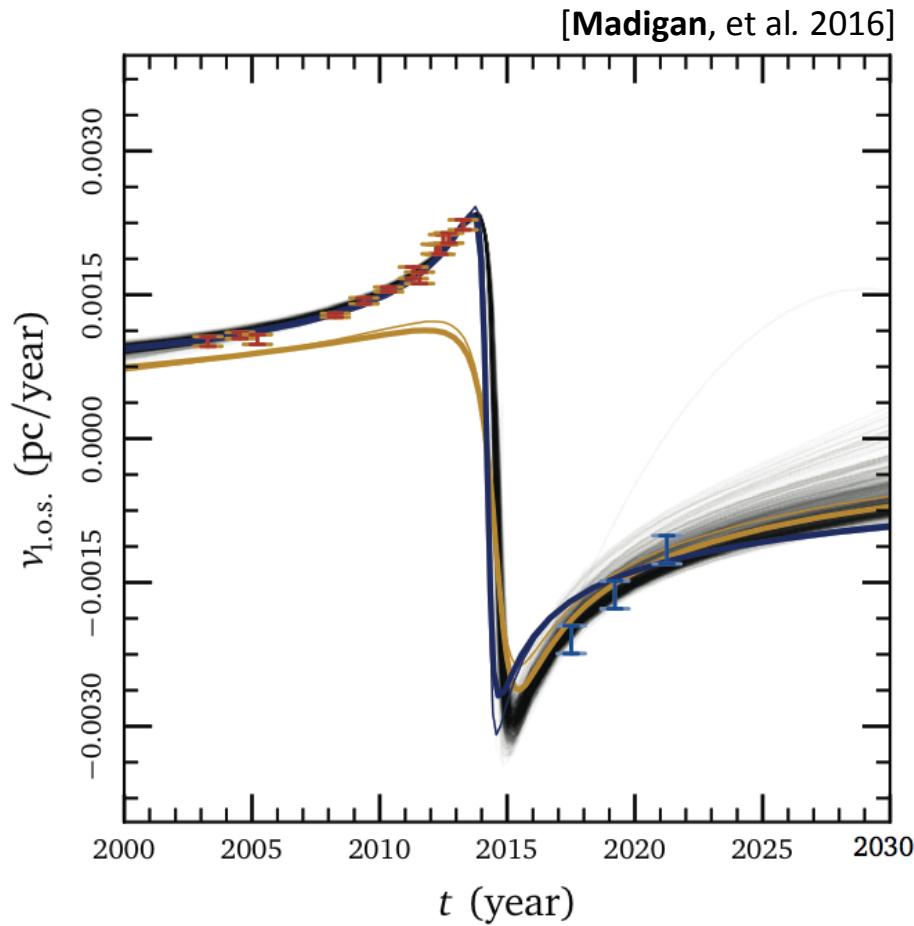
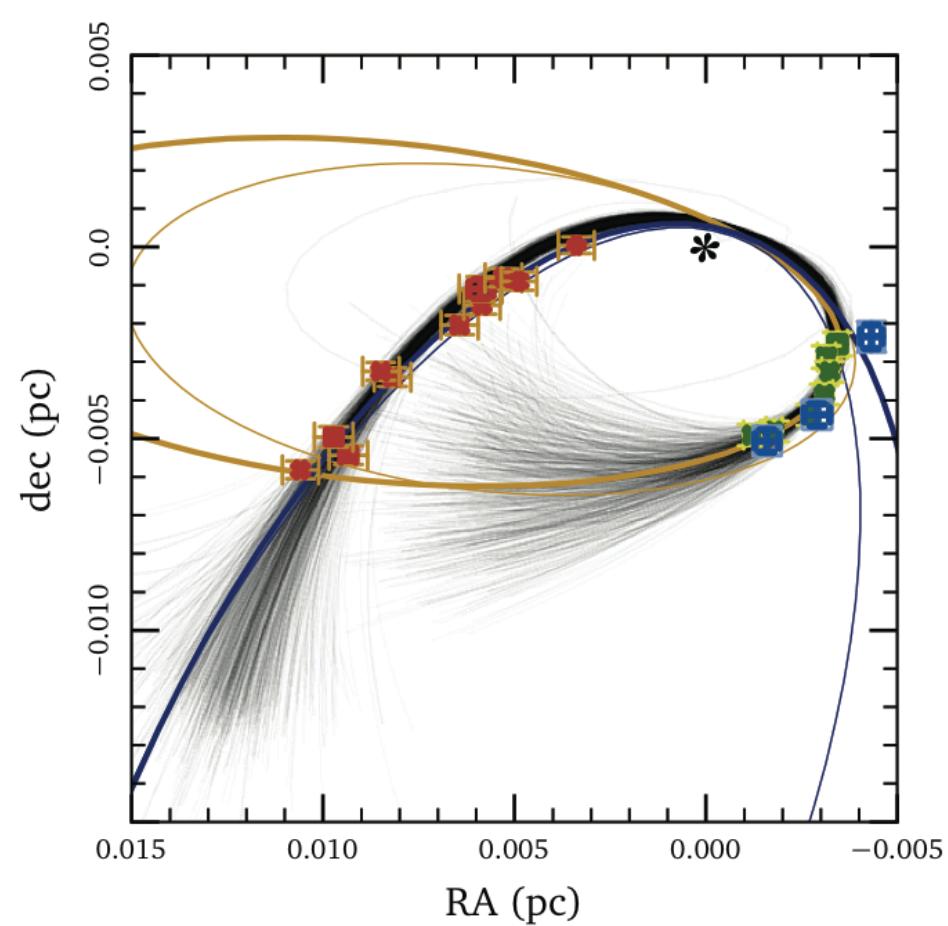
Increase in Bright Flares?



Increase in Bright Flares?

- Observed increase may be connected to G2, but may instead arise from flare clustering
- Faint flares cluster on timescales of \sim 20-70 ks in *Chandra* data from 1999-2012 (Yuan & Wang 2015)
- Analysis of the faint flares in the 2013-2015 data is ongoing (Swift and XMM Newton cannot weigh in due to magnetar contamination)
- Could indicate that the flare clustering has a luminosity dependence; correlation between flare fluence and duration already established
- No increase in the rate connected to S2's last passage in \sim 2002; next close passage in 2018!

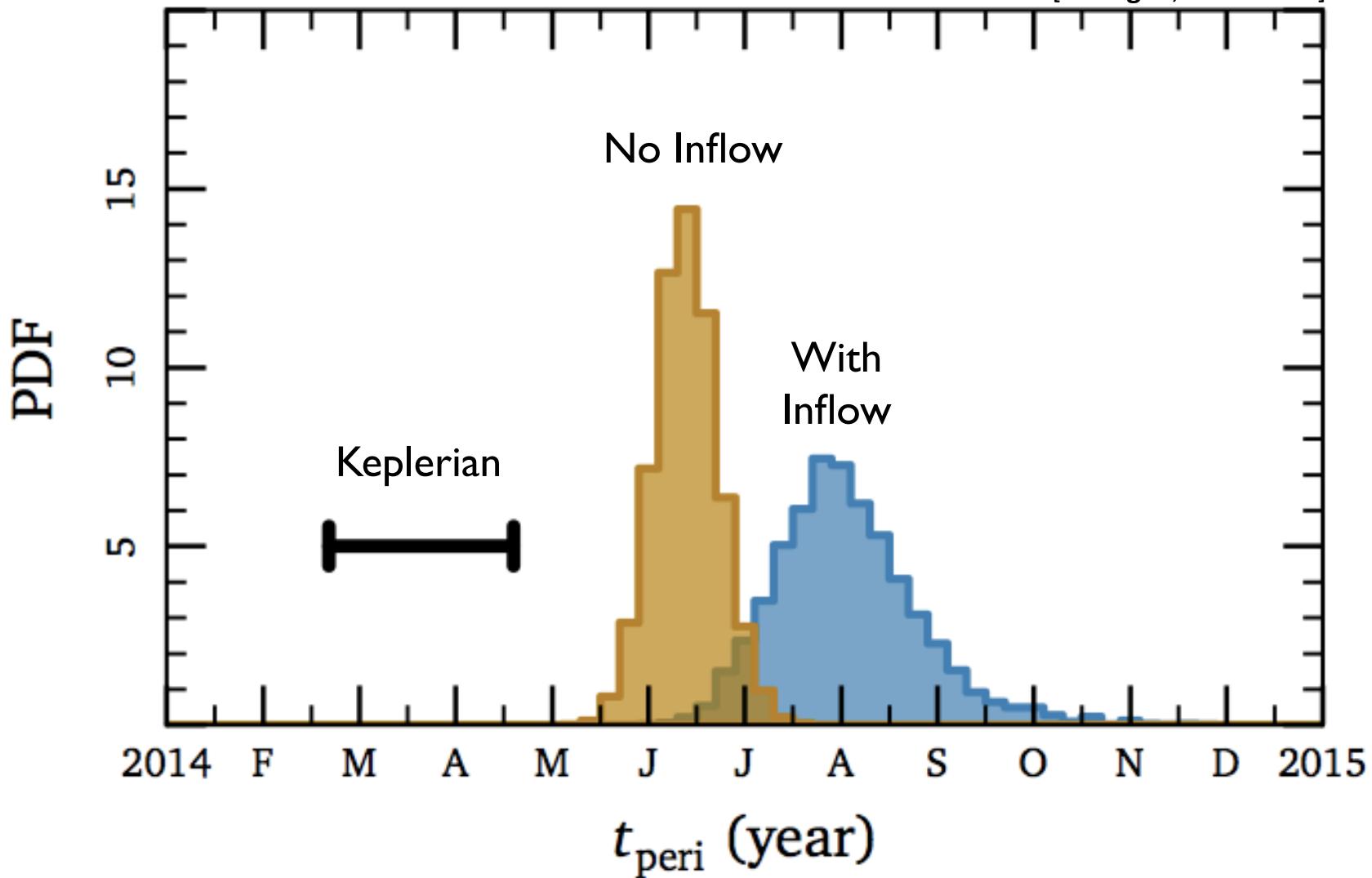
GI/G2 Modeled Orbits



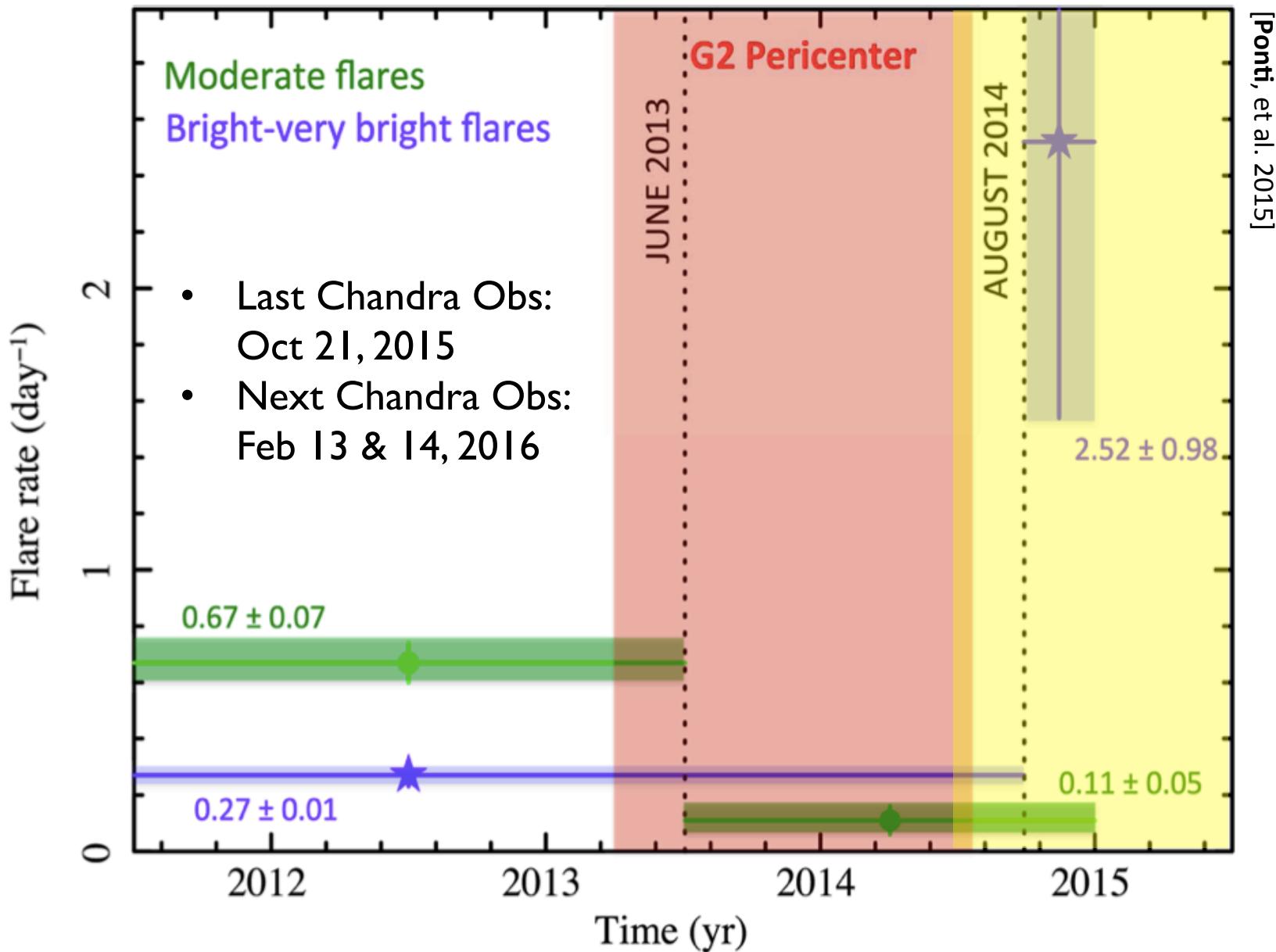
[Madigan, et al. 2016]

GI/G2 Modeled Orbits

[Madigan, et al. 2016]

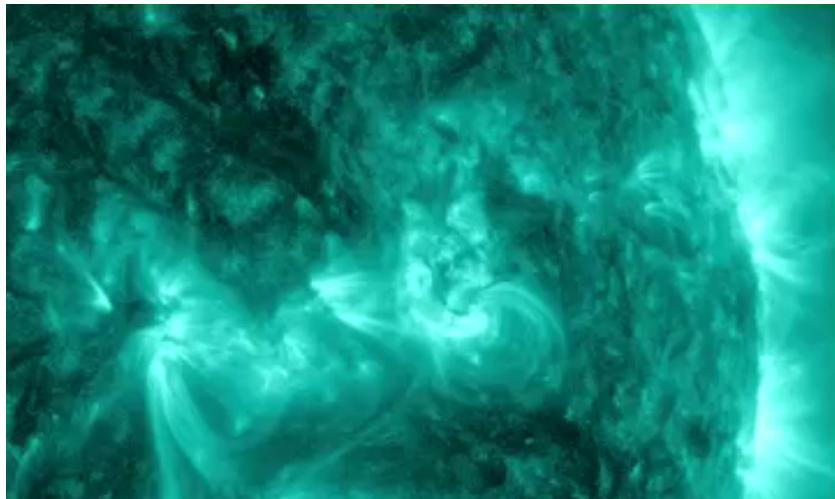


Increase in Bright Flares?



What's Causing the Flares?

Magnetic
Reconnection



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; Chan et al. 2015

AIA 131 - 2014/08/25 - 13:29:44Z

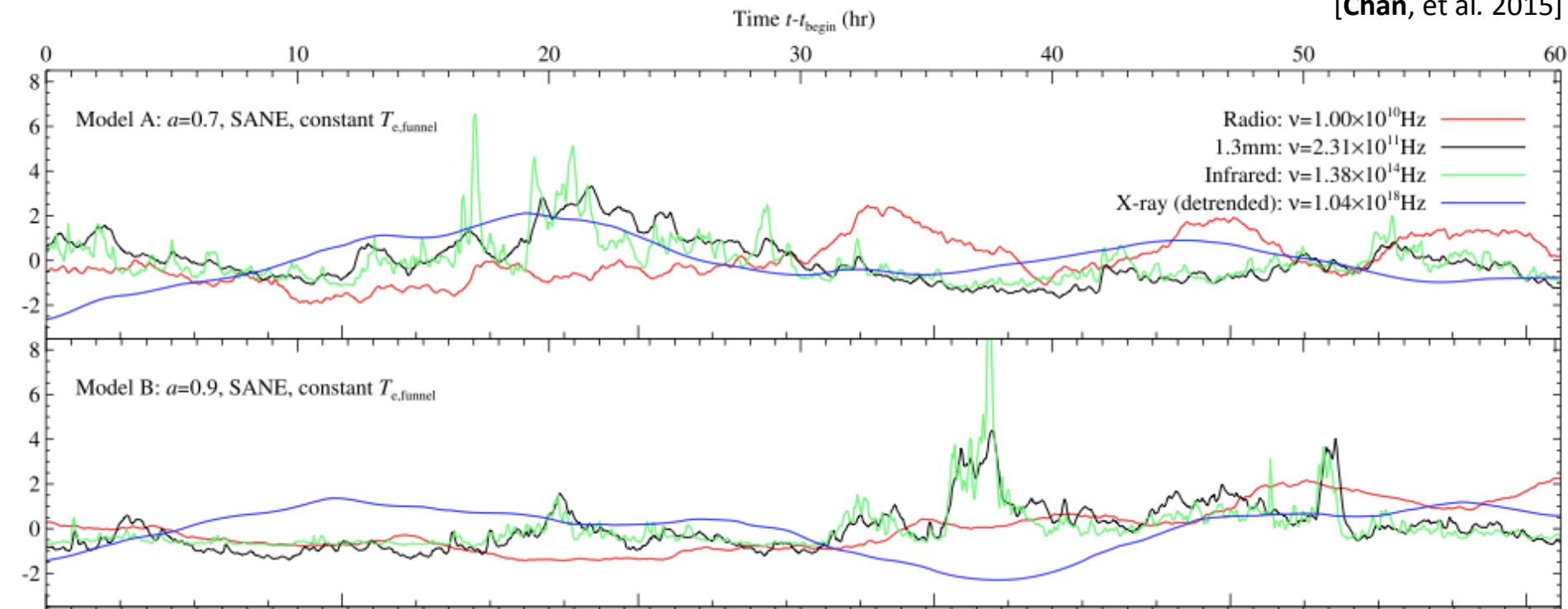
Asteroid
Disruption



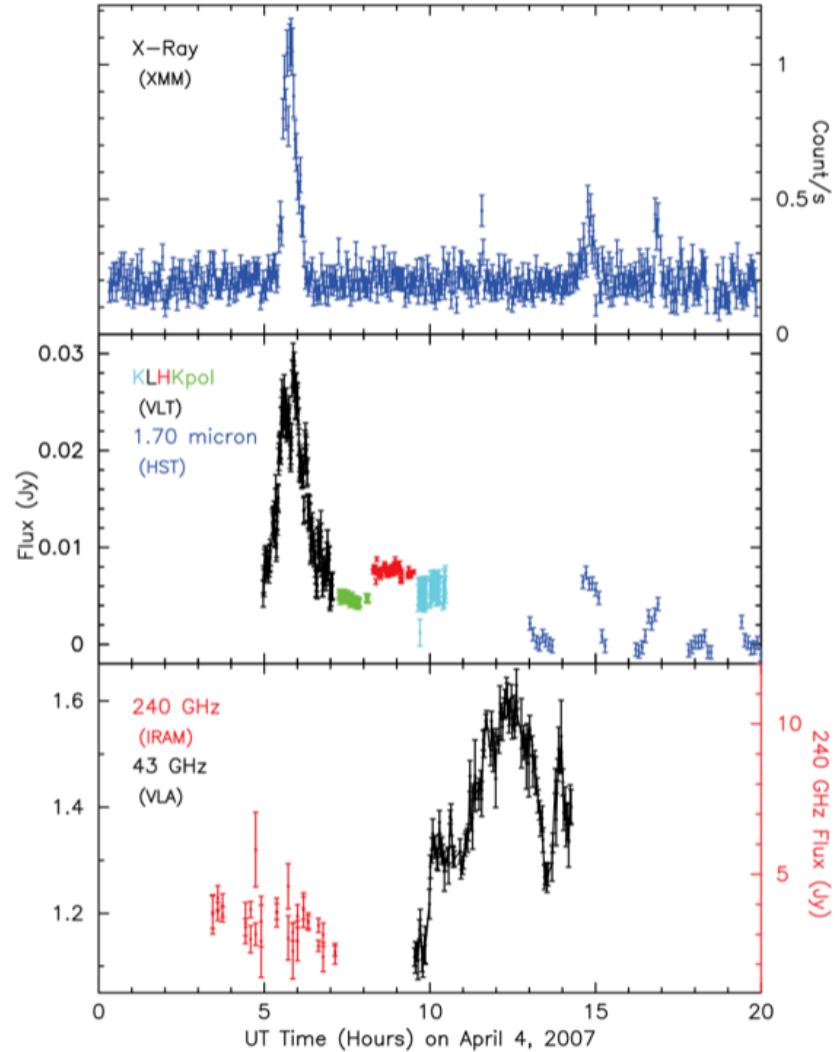
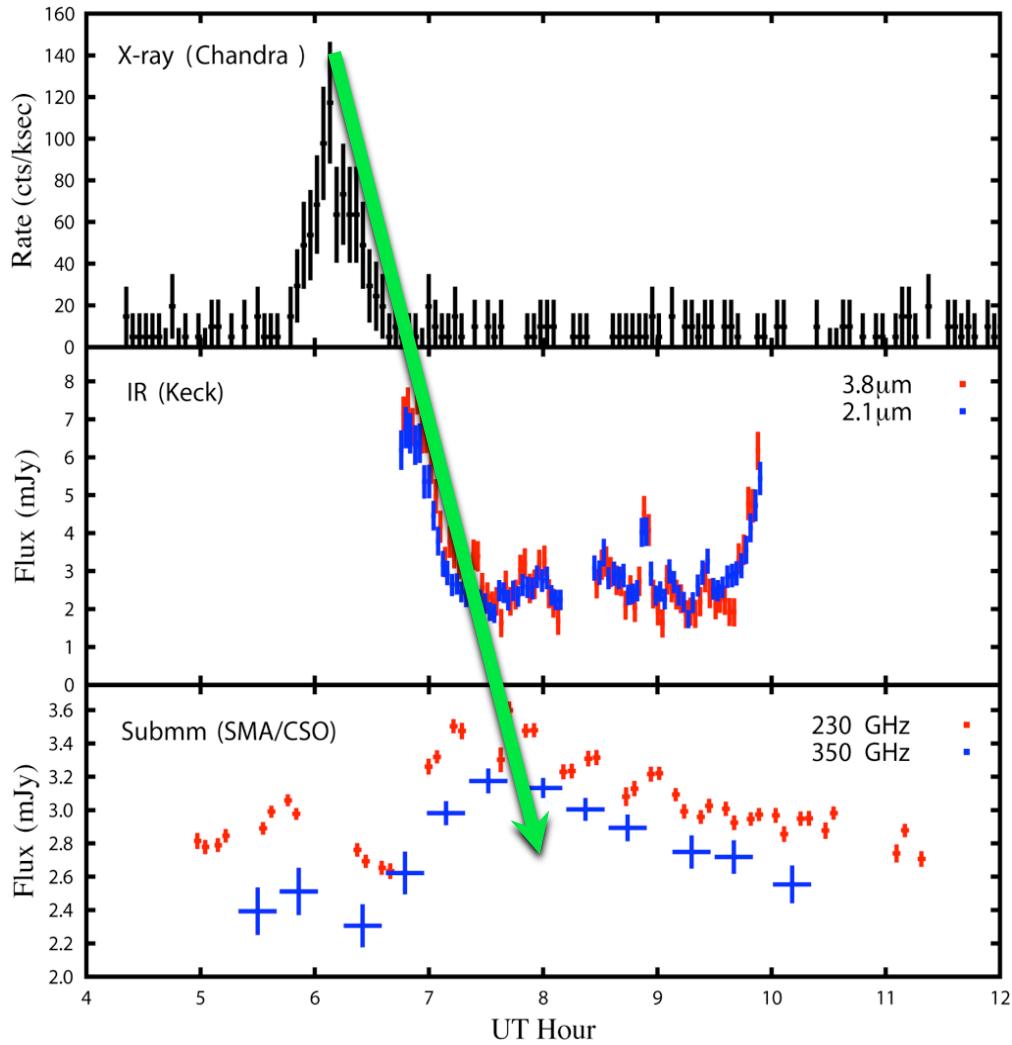
GRMHD Modeling

- General relativistic magnetohydrodynamic simulations
- Variability and time lags from short-lived B-flux tubes and strong-field gravitational lensing near the horizon
- No X-ray flares ... yet?

[Chan, et al. 2015]

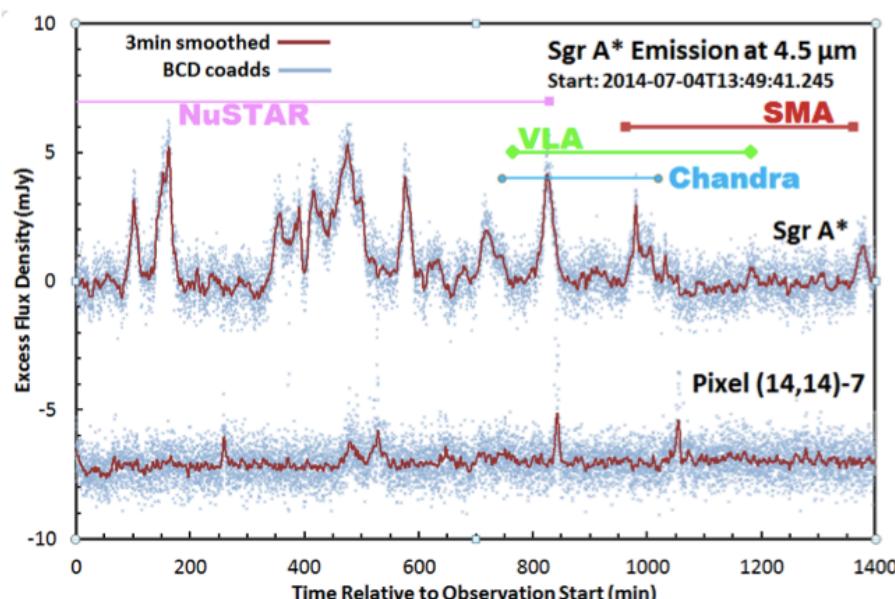
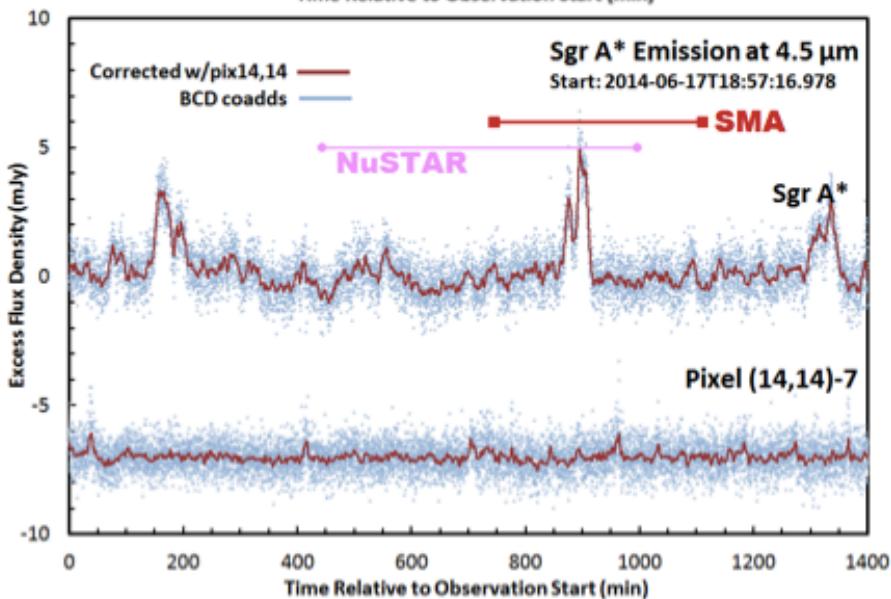
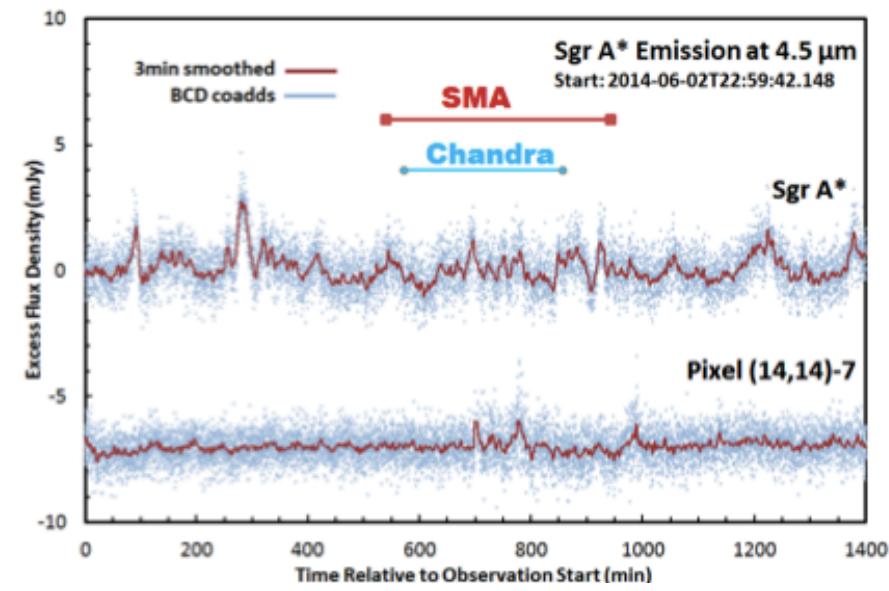
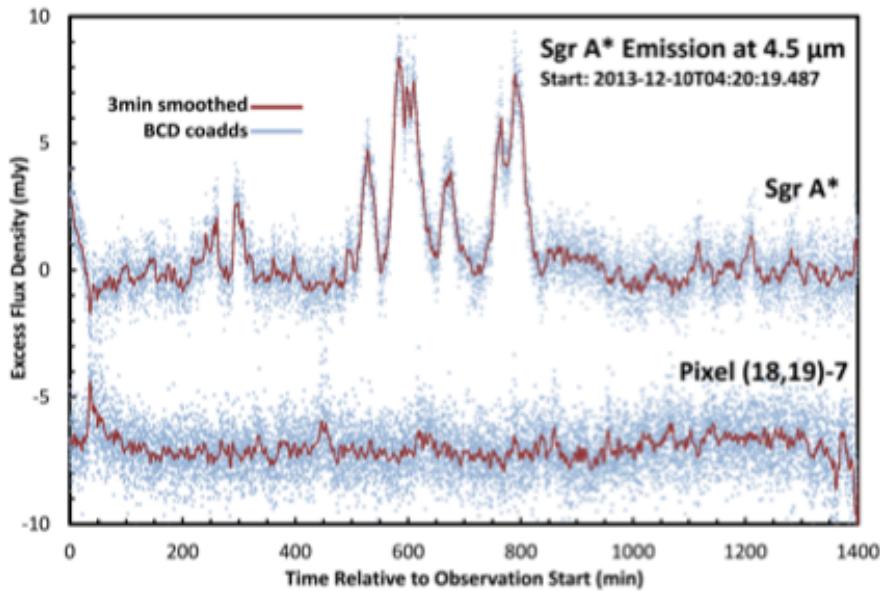


We need more simultaneous radio/submm/IR/X-ray flares!!!

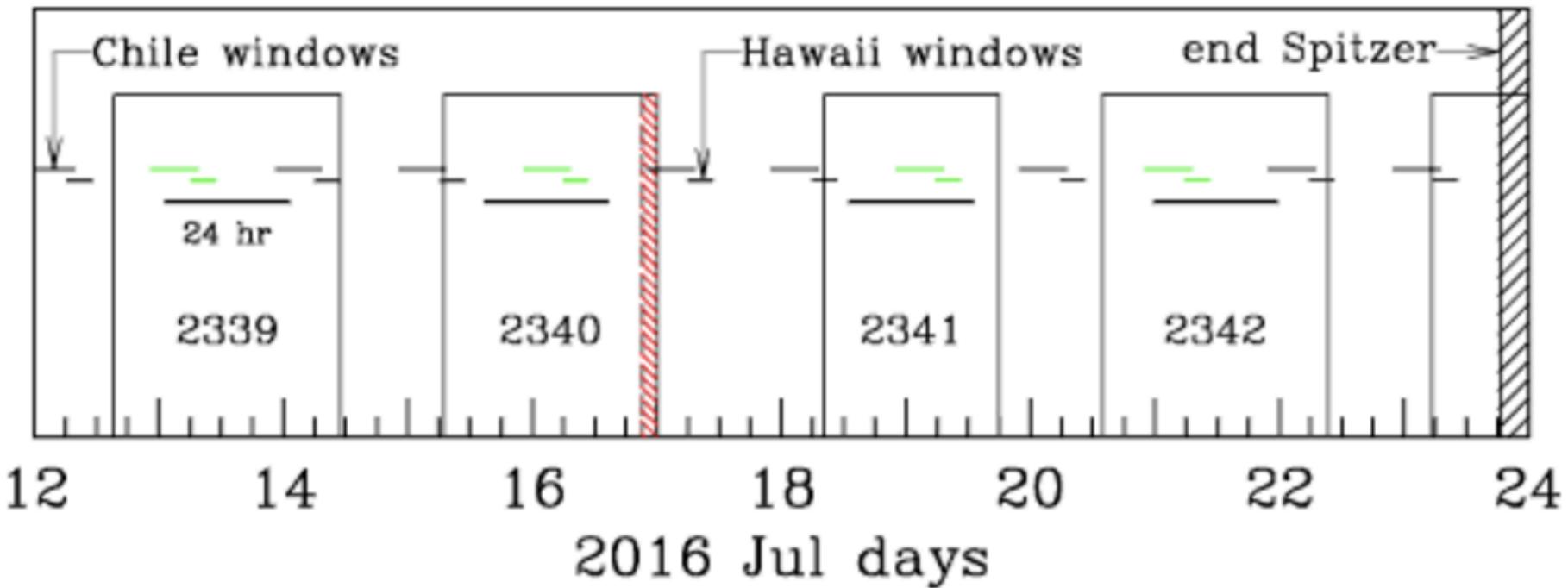


[**Marrone**, et al. 2008, **Yusef-Zadeh** et al. 2009]

Coordinated Spitzer Obs



Joint *Spitzer/Chandra* Monitoring for bright flares in 2016



Everyone interested in monitoring Sgr A* is encouraged to observe at the same times as *Chandra* and *Spitzer* if possible.

<https://www.cfa.harvard.edu/irac/gc/>

Summary

- No X-ray or radio G2 sighting; continued monitoring may distinguish G2's origin and fate
- Sgr A* flares detected by *Chandra*
 - Faint and two **very** bright flares
 - Bright flares: spectrum comparable to other bright flares, asymmetric morphologies, detailed timing, radio lag
 - Flare rate: Perhaps some increase or clustering for brightest flares?
 - Flare mechanism still highly debated
- Other Excellent X-ray + Multiwavelength Science
 - XMM & Swift: lightcurves, spectroscopy
 - VLA/VLBA: lightcurves, astrometry, polarization
 - Absorption measure along Sgr A* line of sight