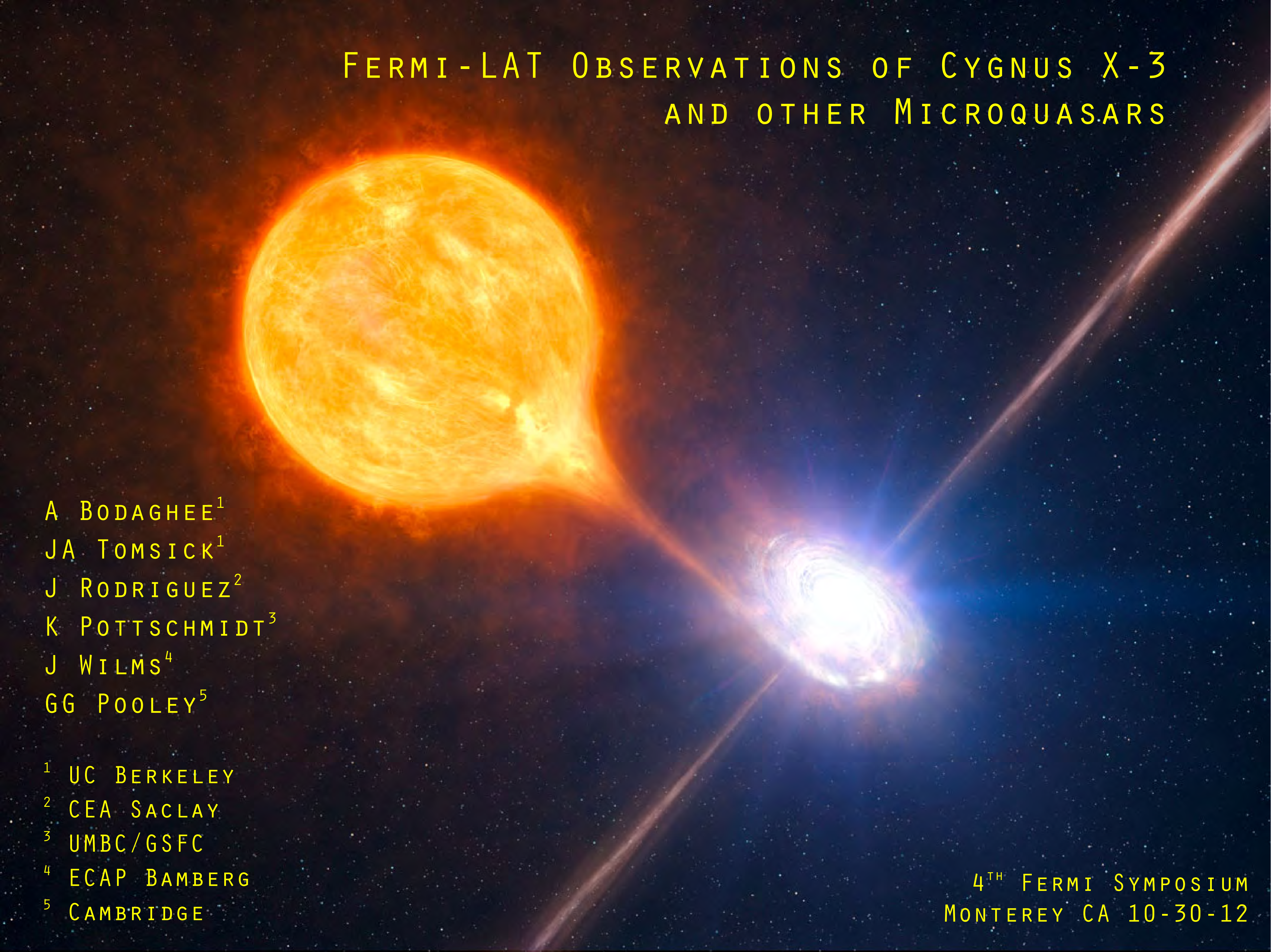
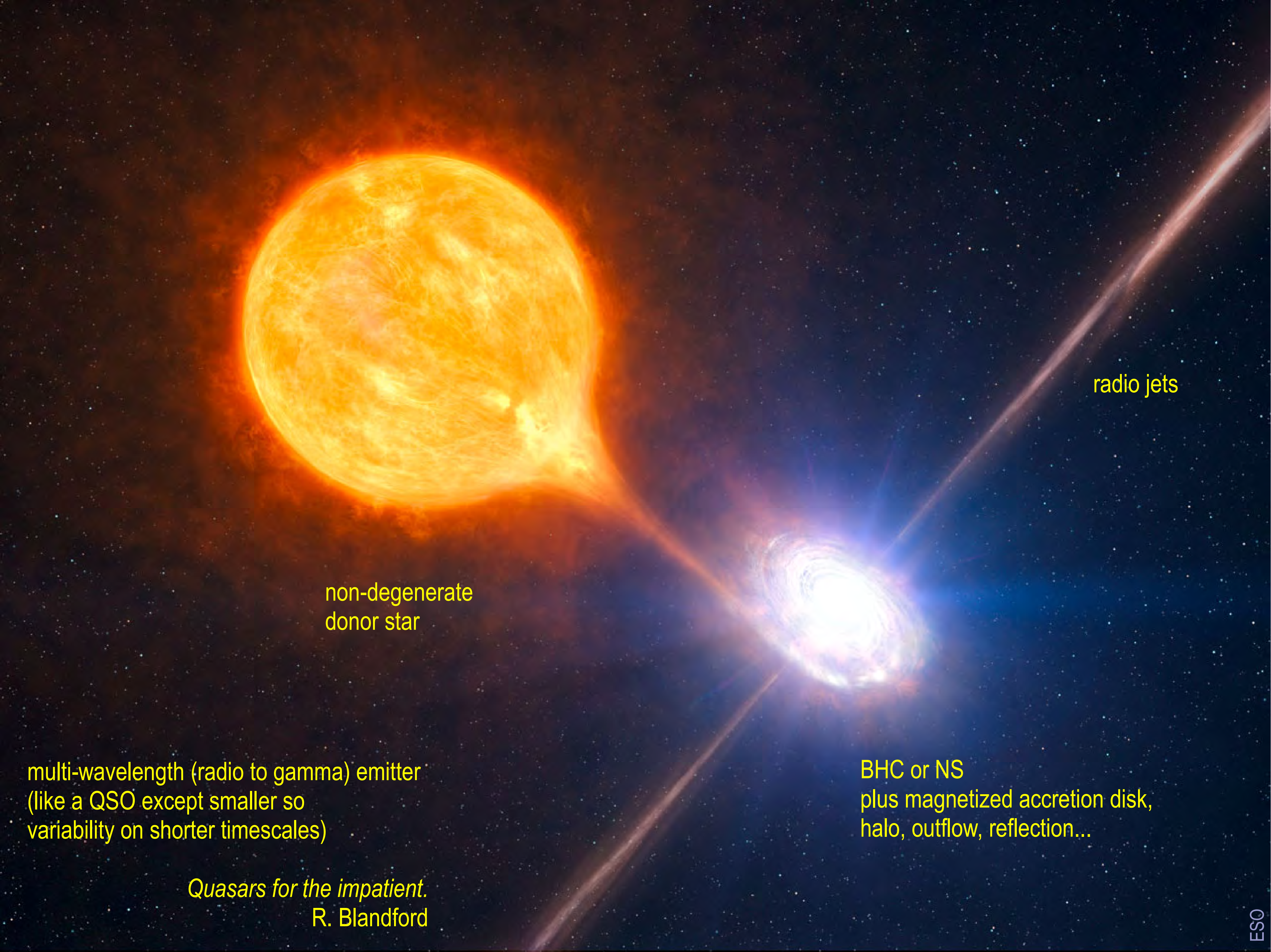


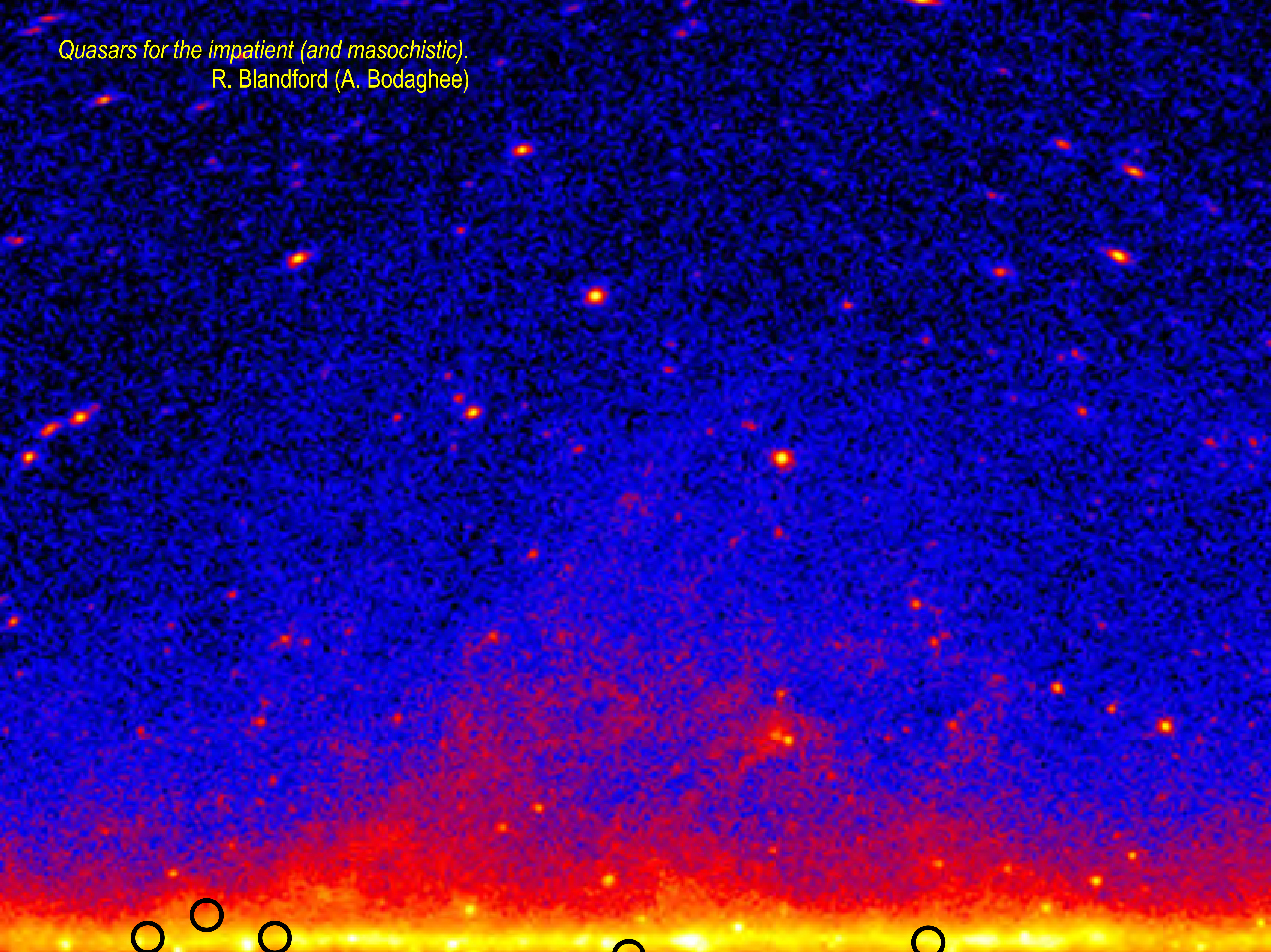
Fermi-LAT Observations of Cygnus X-3 and other Microquasars

A Bodaghee[1]
JA Tomsick[1]
J Rodriguez[2]
K Pottschmidt[3]
J Wilms[4]
GG Pooley[5]

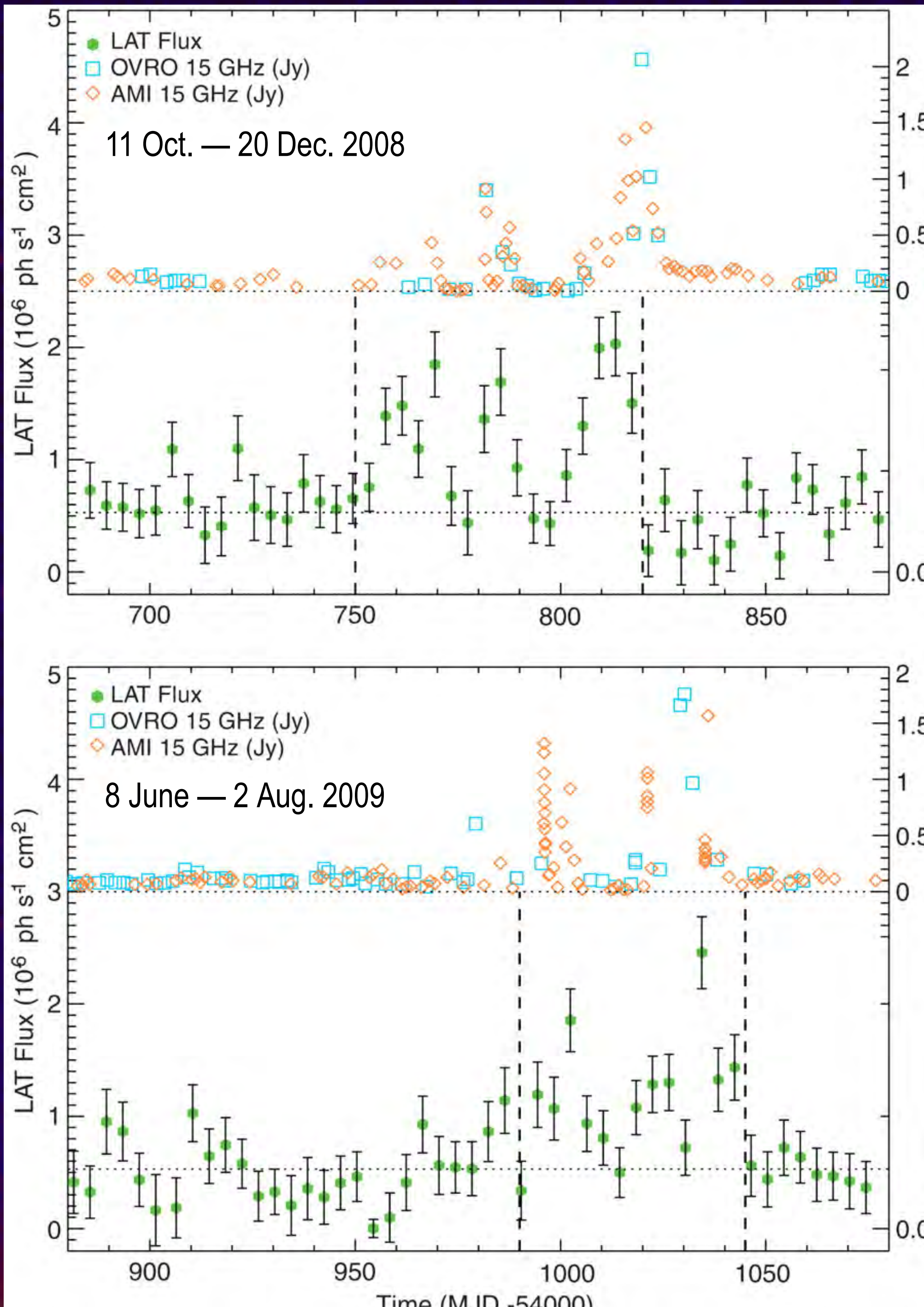
[1] UC Berkeley
[2] CEA Saclay
[3] UMBC/GSFC
[4] ECAP Bamberg
[5] Cambridge

4th Fermi Symposium
Monterey CA 10-30-12


radio jets
non-degenerate
donor star
multi-wavelength (radio to gamma) emitter
(like a QSO except smaller so
variability on shorter timescales)
BHC or NS
plus magnetized accretion disk,
halo, outflow, reflection...
Quasars for the impatient.
R. Blandford
ESO


Quasars for the impatient (and masochistic).
R. Blandford (A. Bodaghee)

Cyg X-3: a microquasar detected in the gamma-rays

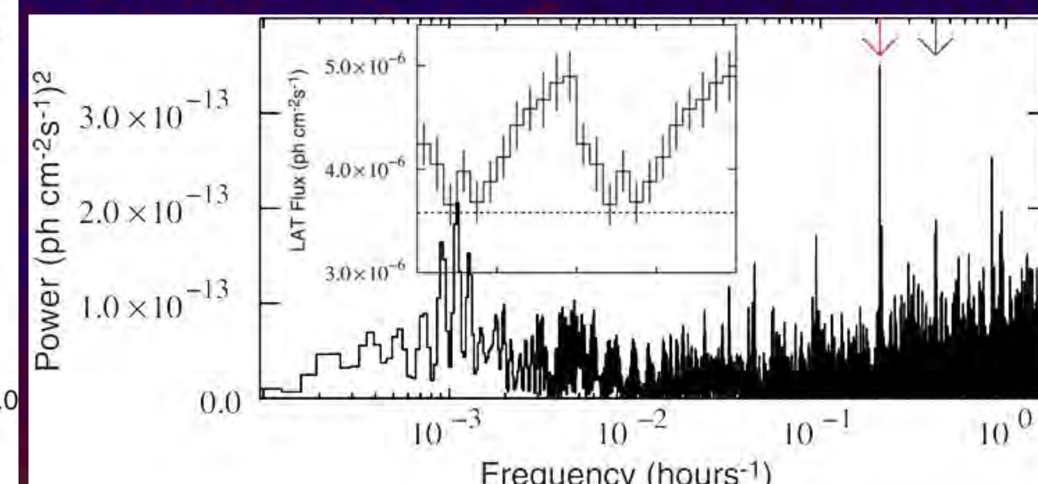


Fermi-LAT collab. (S. Corbel) 2009 Sci. 326 1512

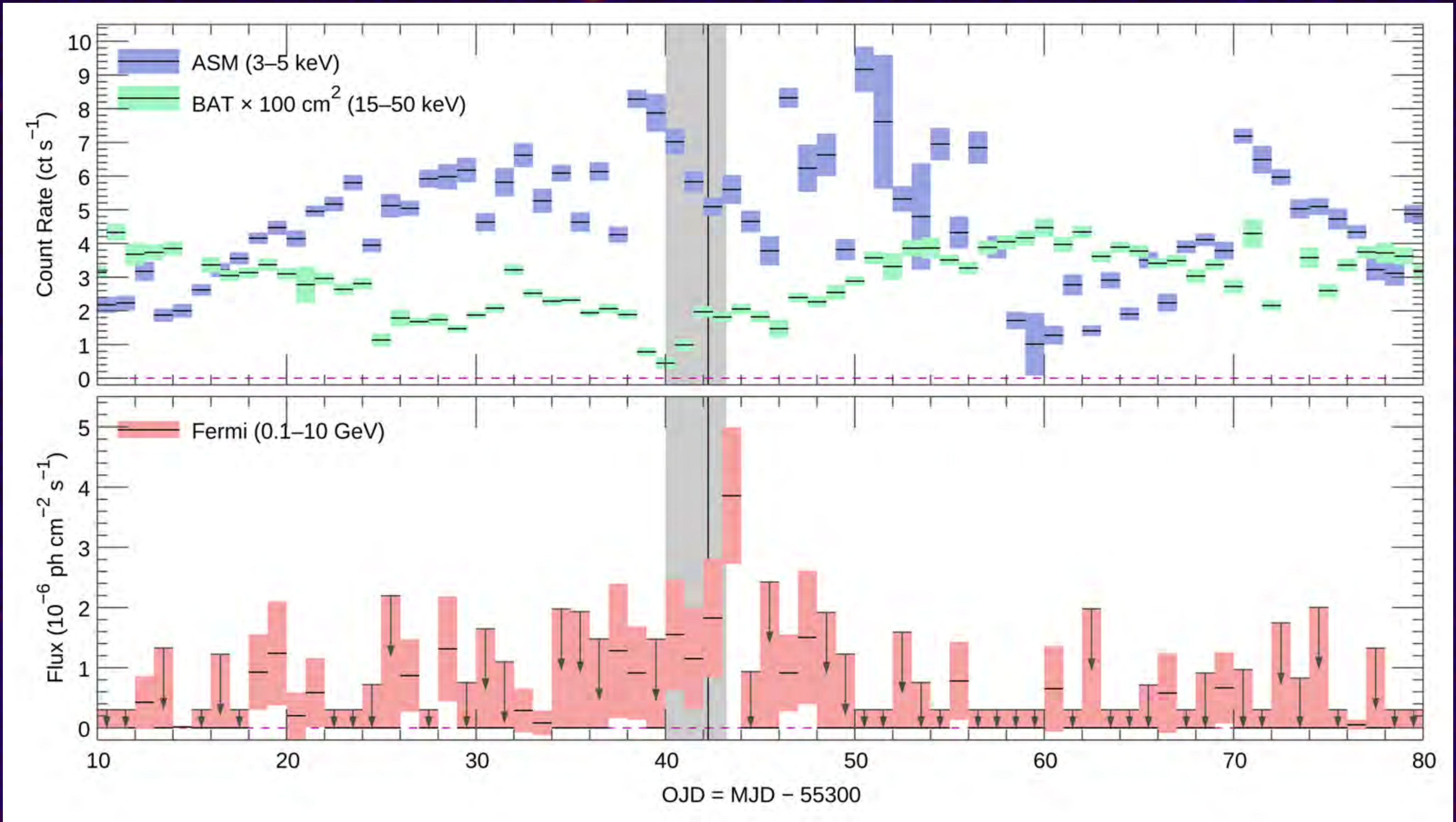
sequence: gamma-rays then radio (lag: 5±7 days)

⇒ probably inverse Compton:
UV photons from WR star upscatter
off of relativistic electrons in the jet

c.f. AGILE: Piano et al. 2012 A&A 545 110
(next talk: including leptonic/hadronic models)



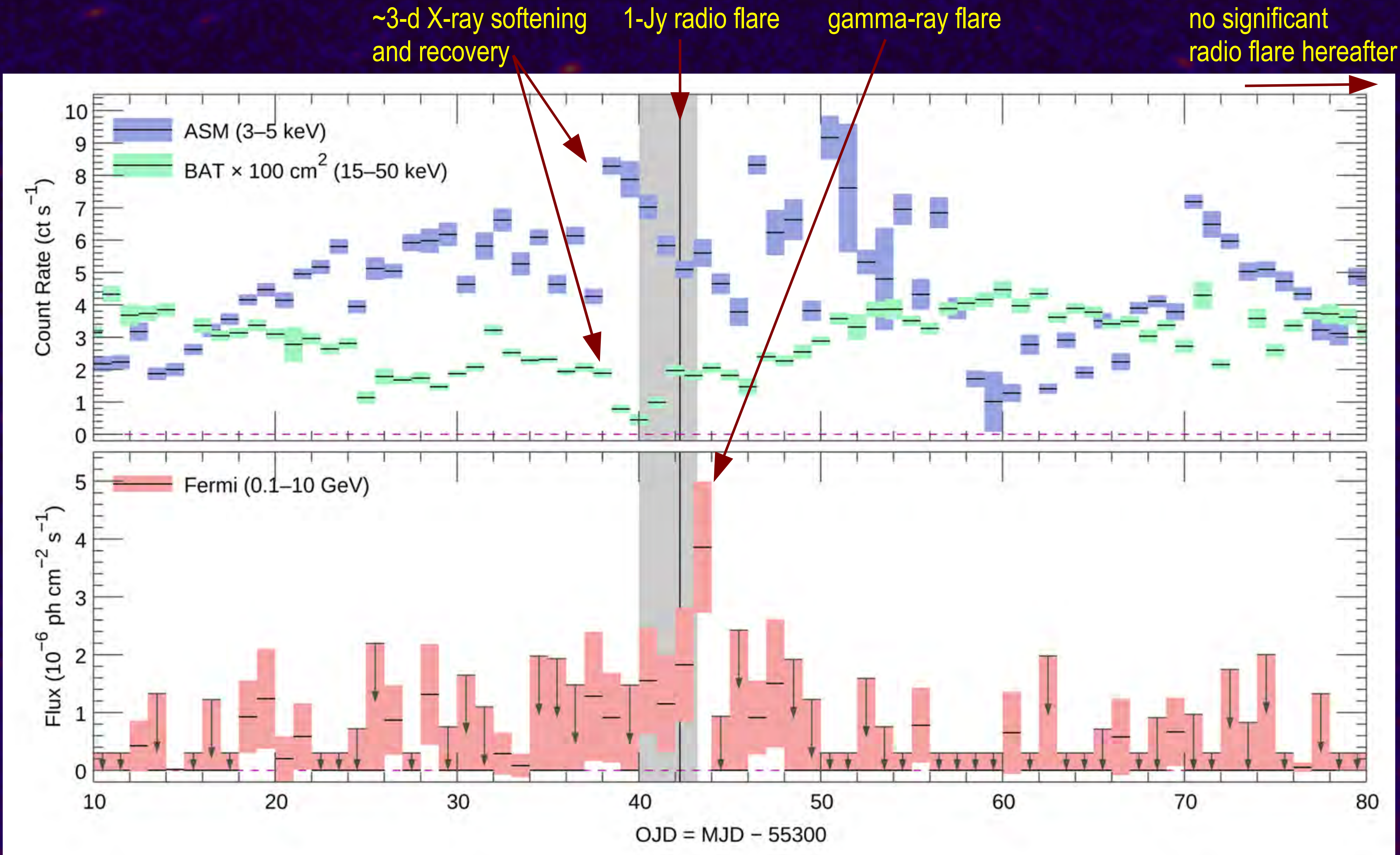
Cyg X-3: gamma-ray flare of May 2010



AGILE: Bulgarelli et al. 2010 ATel 2609, 2645
Fermi: Corbel et al. 2010 ATel 2611, 2646

Williams et al. 2011 ApJL 733 20

Cyg X-3: gamma-ray flare of May 2010

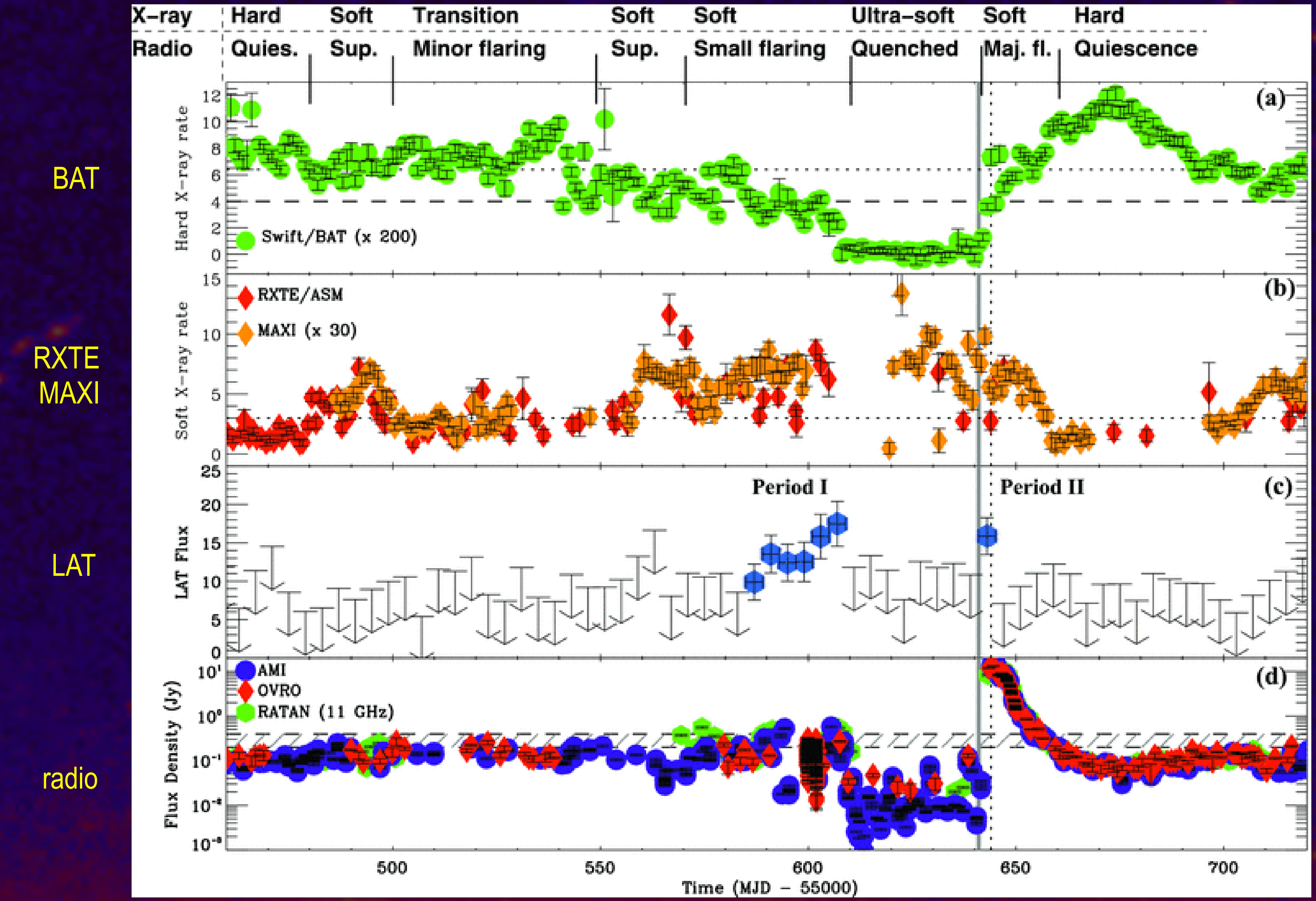


radio flare precedes gamma-ray emission by 1 day: consistent with IC
other possibility: hadronic processes? $p + \gamma \rightarrow \pi^0 + ... \rightarrow 2\gamma$

Williams et al. 2011 ApJL 733 20

Cyg X-3: gamma-ray flare of March 2011

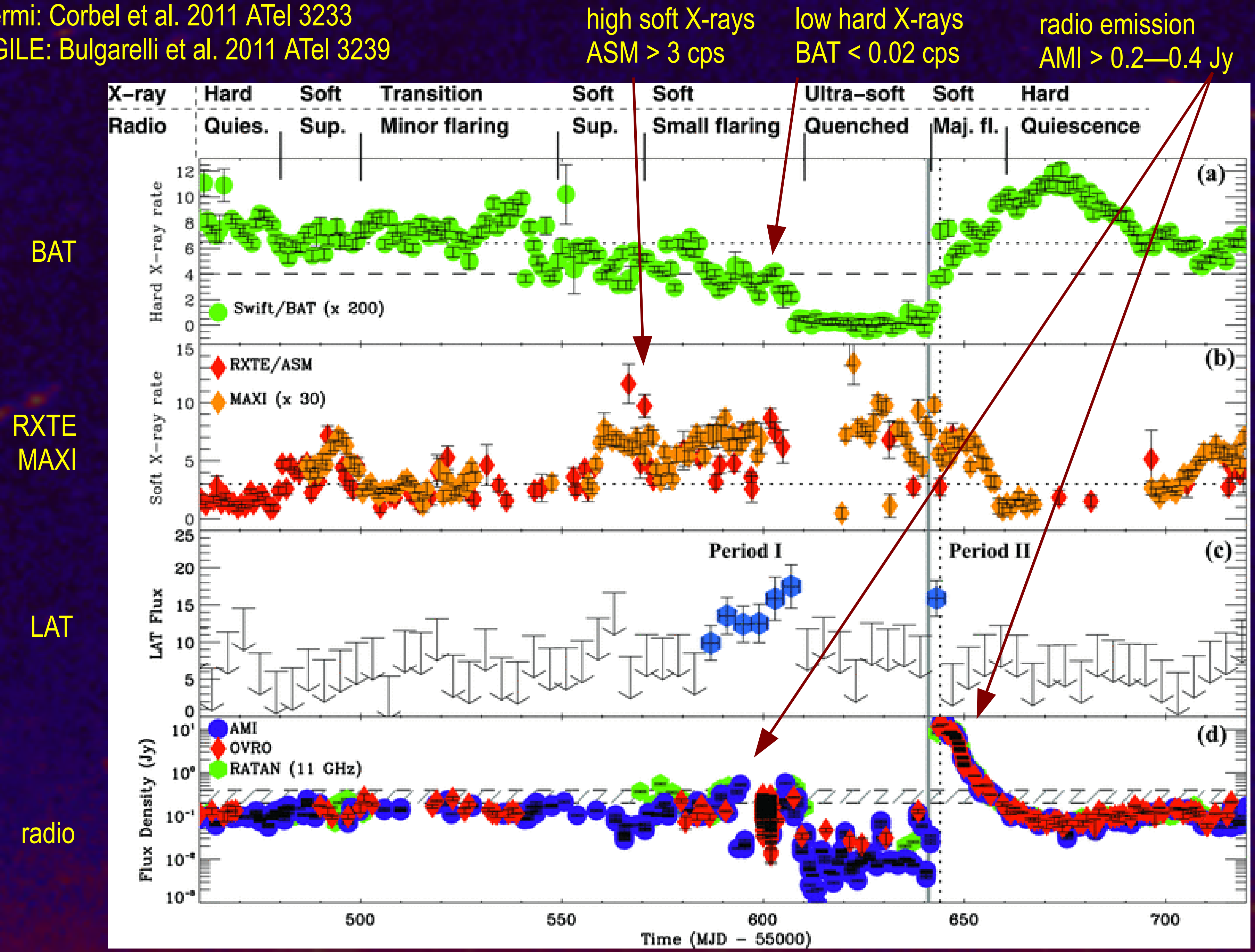
Fermi: Corbel et al. 2011 ATel 3233
AGILE: Bulgarelli et al. 2011 ATel 3239



Corbel et al. 2012 MNRAS 421 2947

Cyg X-3: gamma-ray flare of March 2011

Fermi: Corbel et al. 2011 ATel 3233
AGILE: Bulgarelli et al. 2011 ATel 3239



Corbel et al. 2012 MNRAS 421 2947

Fermi-LAT observations of microquasars

100 MeV – 10 GeV
all data within 20° of each target (p7v9r27)
from aug 2008 until may 2012

timescale: 0.1, 1, and 10 days
spectral model: 2FGL (+diffuse emission) refined with binned likelihood analysis of full data set

1) wide-aperture unbinned likelihood analysis ⟶ Test Statistic (TS)
2) aperture-restricted event weighting ⟶ Probability (P)

name	type	l	b	Po (days)
4U 1630–47	LMXB	336.9	+0.3	---
4U 1957+11	LMXB	51.3	–9.3	0.38823(2)
Cygnus X-1	HMXB	71.3	+3.1	5.6008(7)
Cygnus X-3	HMXB	79.8	+0.7	0.1996907(7)
GRO J1655–40	LMXB	355.0	+2.5	2.621(7)
GRS 1758–258	LMXB	4.5	–1.4	18.973(7)
GRS 1915+105	LMXB	45.4	–0.2	33.5(1.5)
GX 339–4	LMXB	338.9	–4.3	1.7563(3)
LS I+61 303	HMXB	135.6	+1.1	26.496(3)
SAX J1819.3–2525	HMXB	6.8	–4.8	2.8019(2)
SS 433	HMXB	39.7	–2.2	13.080(3)
SWIFT J1753.5–0127	LMXB	24.9	+12.2	---

Fermi-LAT observations of microquasars

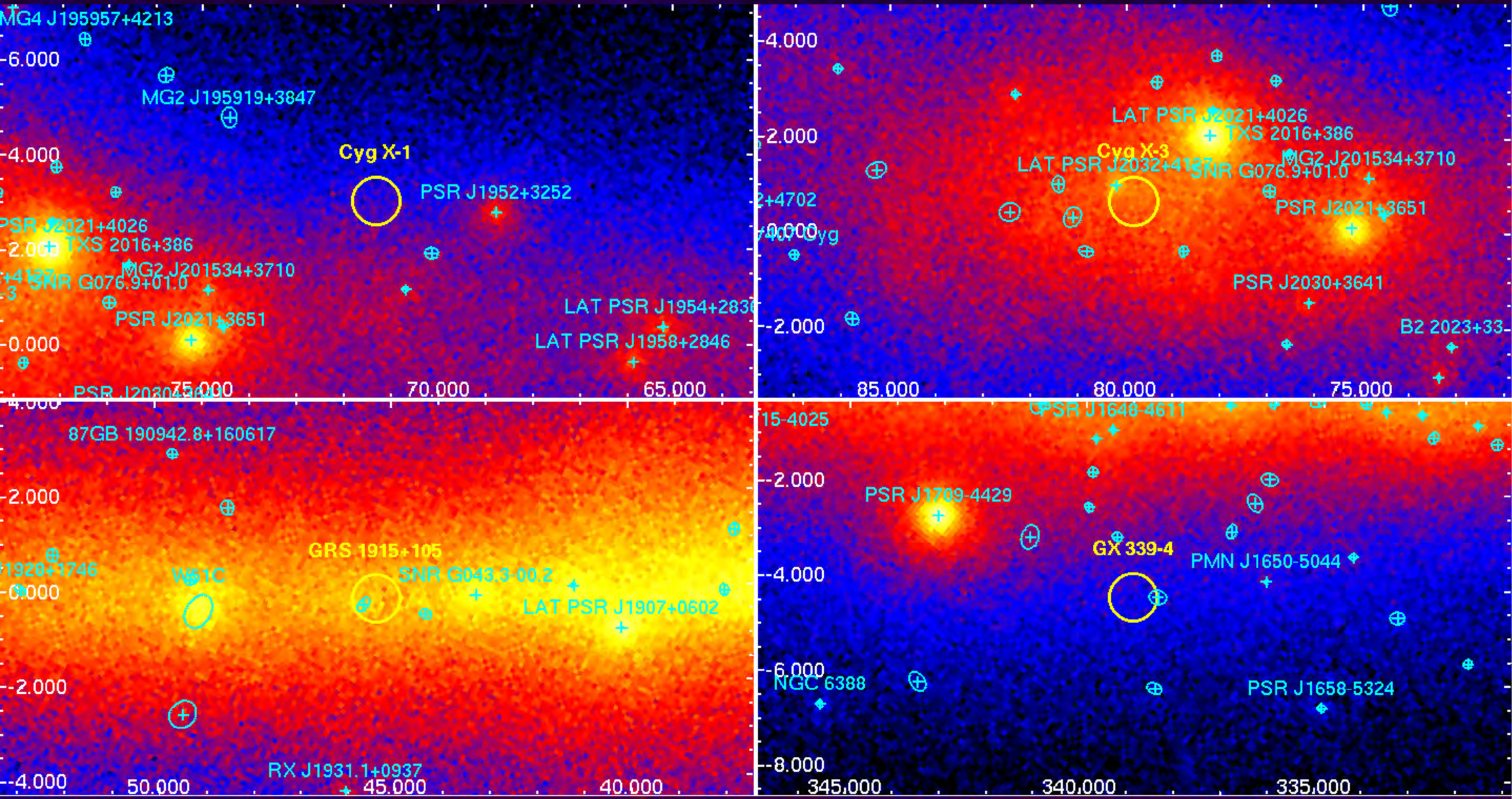
100 MeV – 10 GeV
all data within 20° of each target (p7v9r27)
from aug 2008 until may 2012

timescale: 0.1, 1, and 10 days
spectral model: 2FGL (+diffuse emission) refined with binned likelihood analysis of full data set

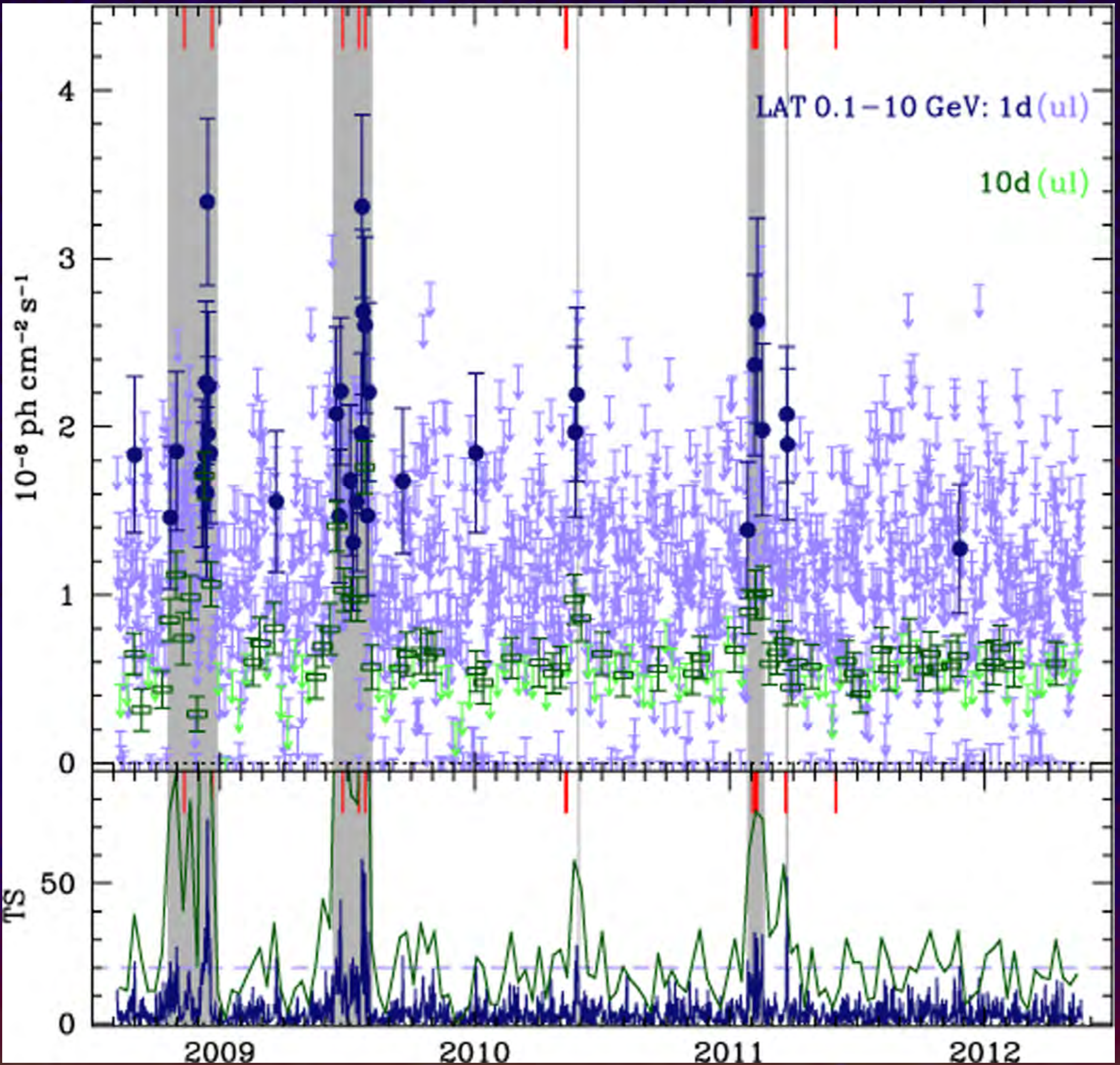
1) wide-aperture unbinned likelihood analysis ⟶ Test Statistic (TS)
2) aperture-restricted event weighting ⟶ Probability (P)

name	type	l	b	Po (days)
4U 1630–47	LMXB	336.9	+0.3	---
4U 1957+11	LMXB	51.3	–9.3	0.38823(2)
Cygnus X-1	HMXB	71.3	+3.1	5.6008(7)
Cygnus X-3	HMXB	79.8	+0.7	0.1996907(7)
GRO J1655–40	LMXB	355.0	+2.5	2.621(7)
GRS 1758–258	LMXB	4.5	–1.4	18.973(7)
GRS 1915+105	LMXB	45.4	–0.2	33.5(1.5)
GX 339–4	LMXB	338.9	–4.3	1.7563(3)
LS I+61 303	HMXB	135.6	+1.1	26.496(3)
SAX J1819.3–2525	HMXB	6.8	–4.8	2.8019(2)
SS 433	HMXB	39.7	–2.2	13.080(3)
SWIFT J1753.5–0127	LMXB	24.9	+12.2	---

Cyg X-1, Cyg X-3, GRS 1915+105, GX 339-4: photon counts maps (0.1–10 GeV)



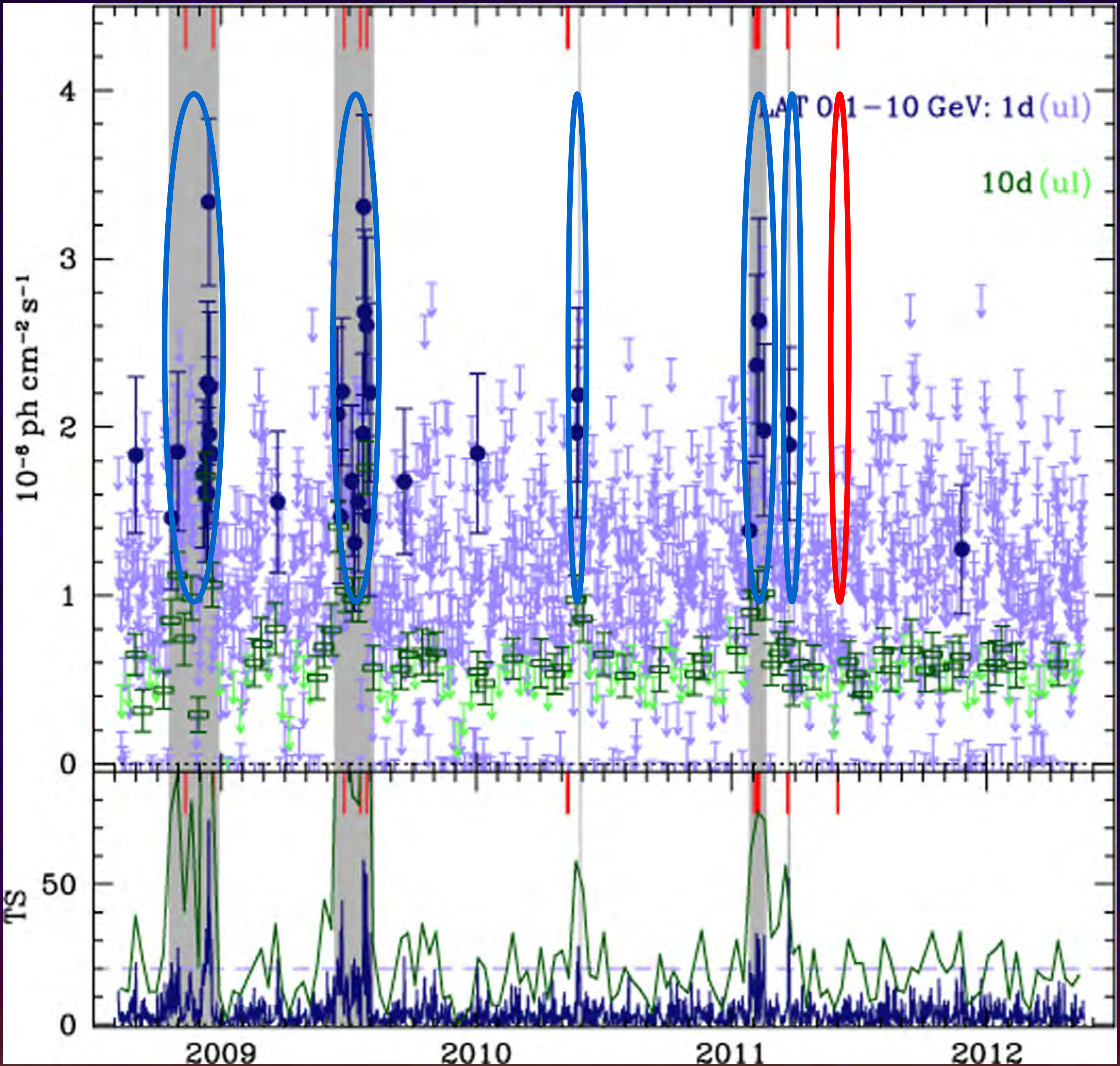
Cyg X-3: gamma-ray light curve



Cyg X-3: gamma-ray light curve

previous gamma-ray detections by LAT or AGILE are reproduced (except the last one)

fluxes and TS consistent with previous results

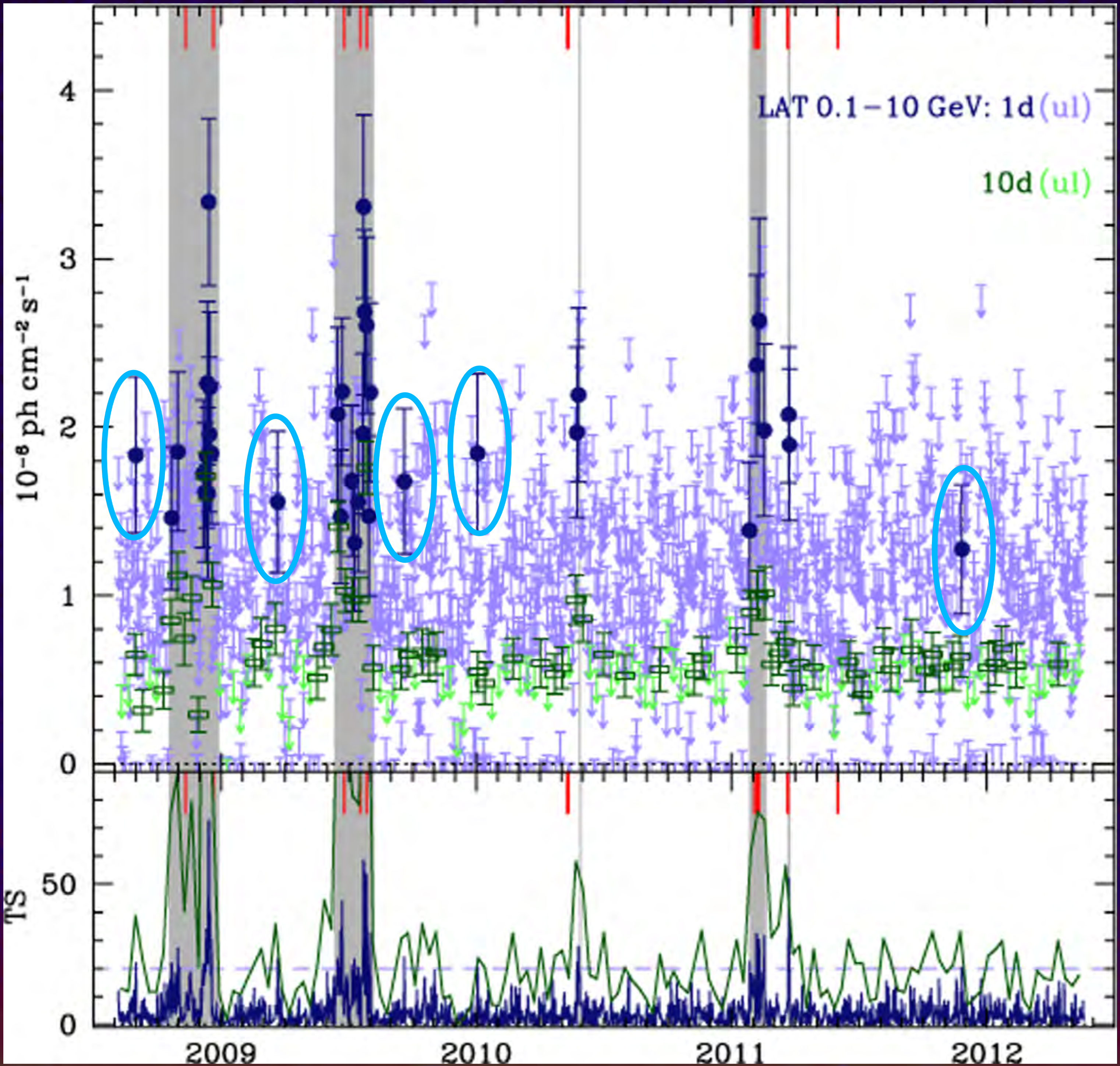


Cyg X-3: gamma-ray light curve

previous gamma-ray detections by LAT or AGILE are reproduced (except the last one)

fluxes and TS consistent with previous results

there are 5 new daily detections not previously reported (TS ~ 20—25; backed up by 10-d)



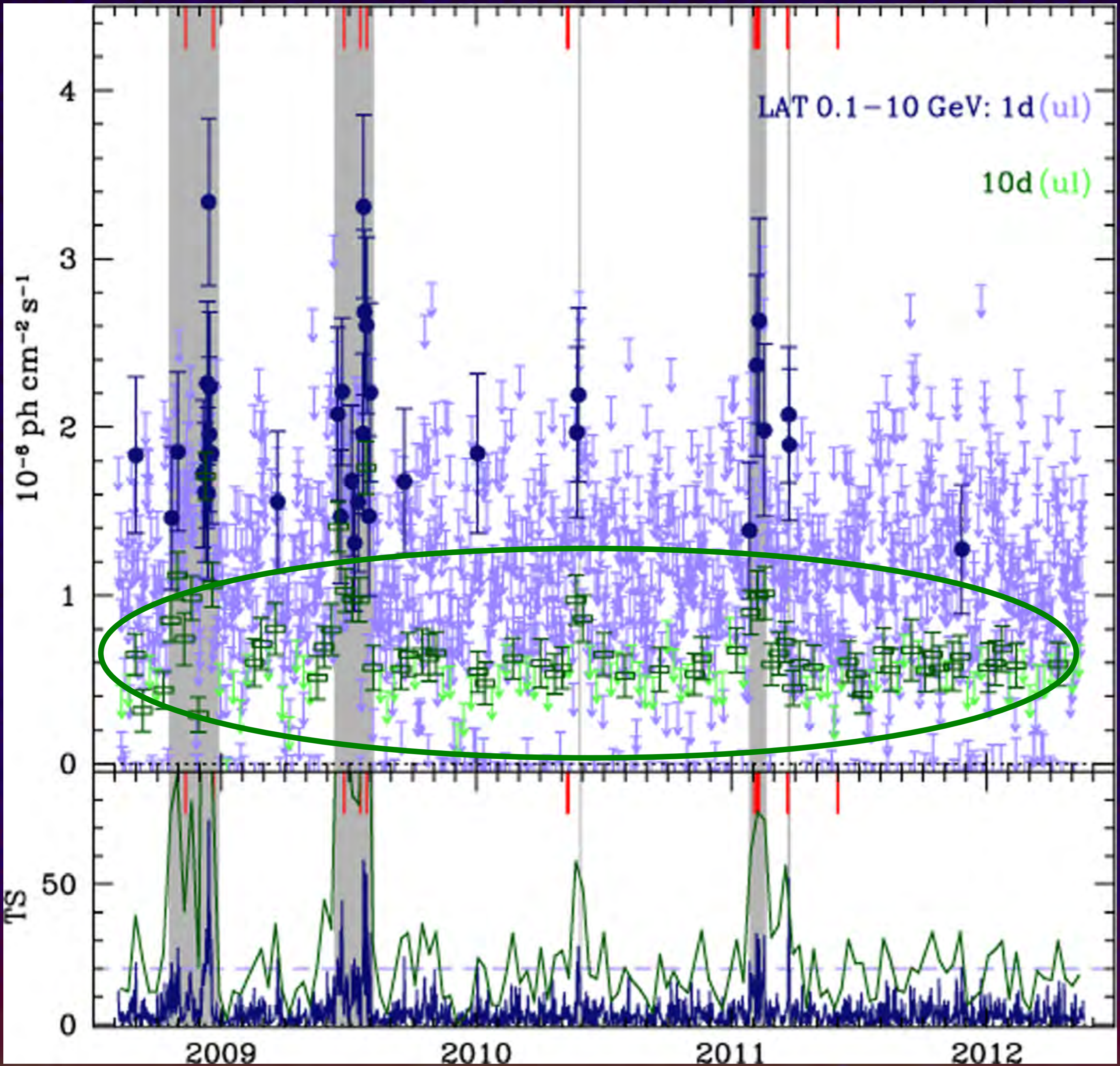
Cyg X-3: gamma-ray light curve

previous gamma-ray detections by LAT or AGILE are reproduced (except the last one)

fluxes and TS consistent with previous results

there are 5 new daily detections not previously reported (TS ~ 20—25; backed up by 10-d)

numerous 10-d detections in and out of flaring epochs: persistent gamma-ray emission?



Cyg X-3: X-ray/gamma-ray light curve

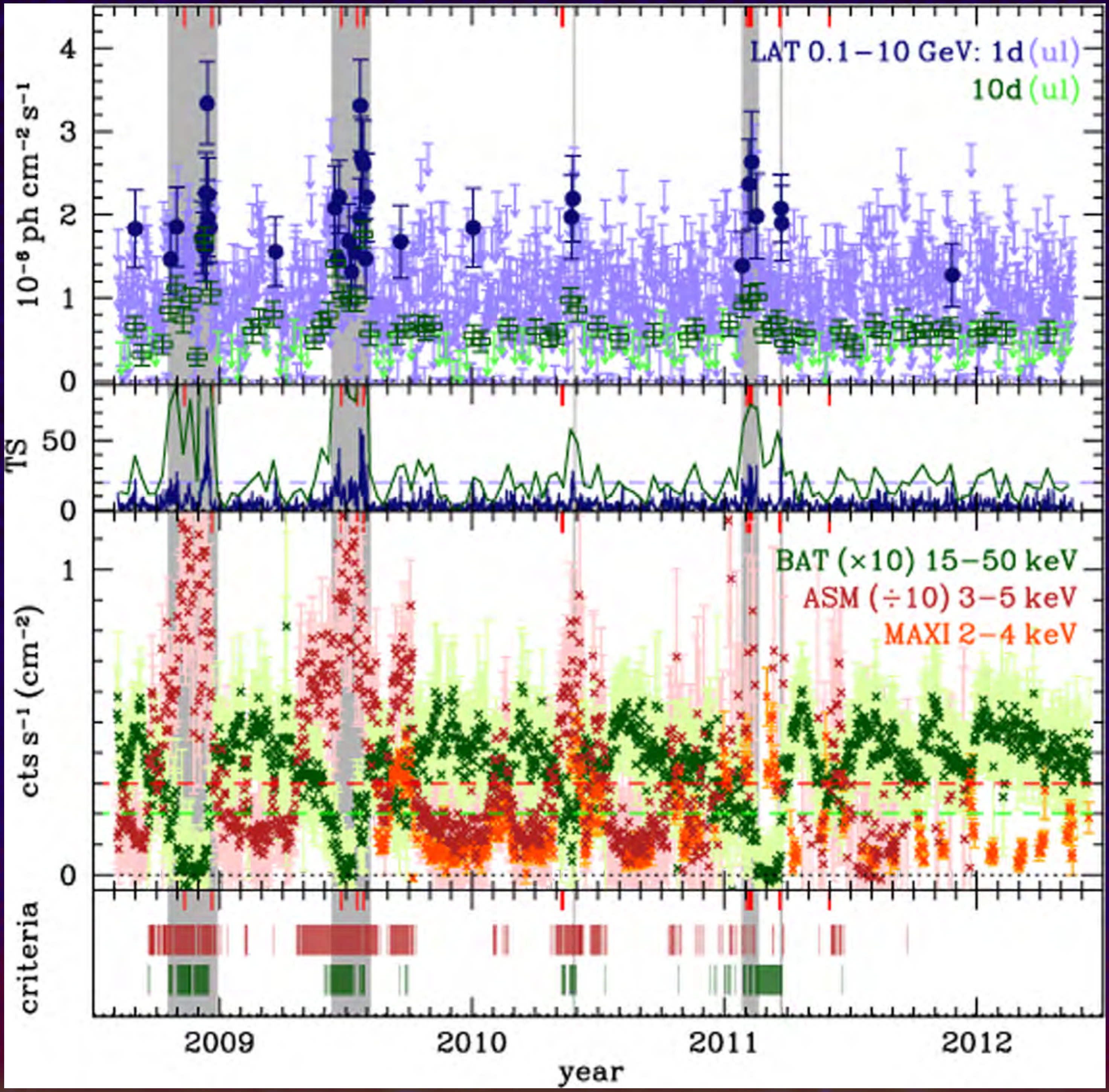
previous gamma-ray detections by LAT or AGILE are reproduced (except the last one)

fluxes and TS consistent with previous results

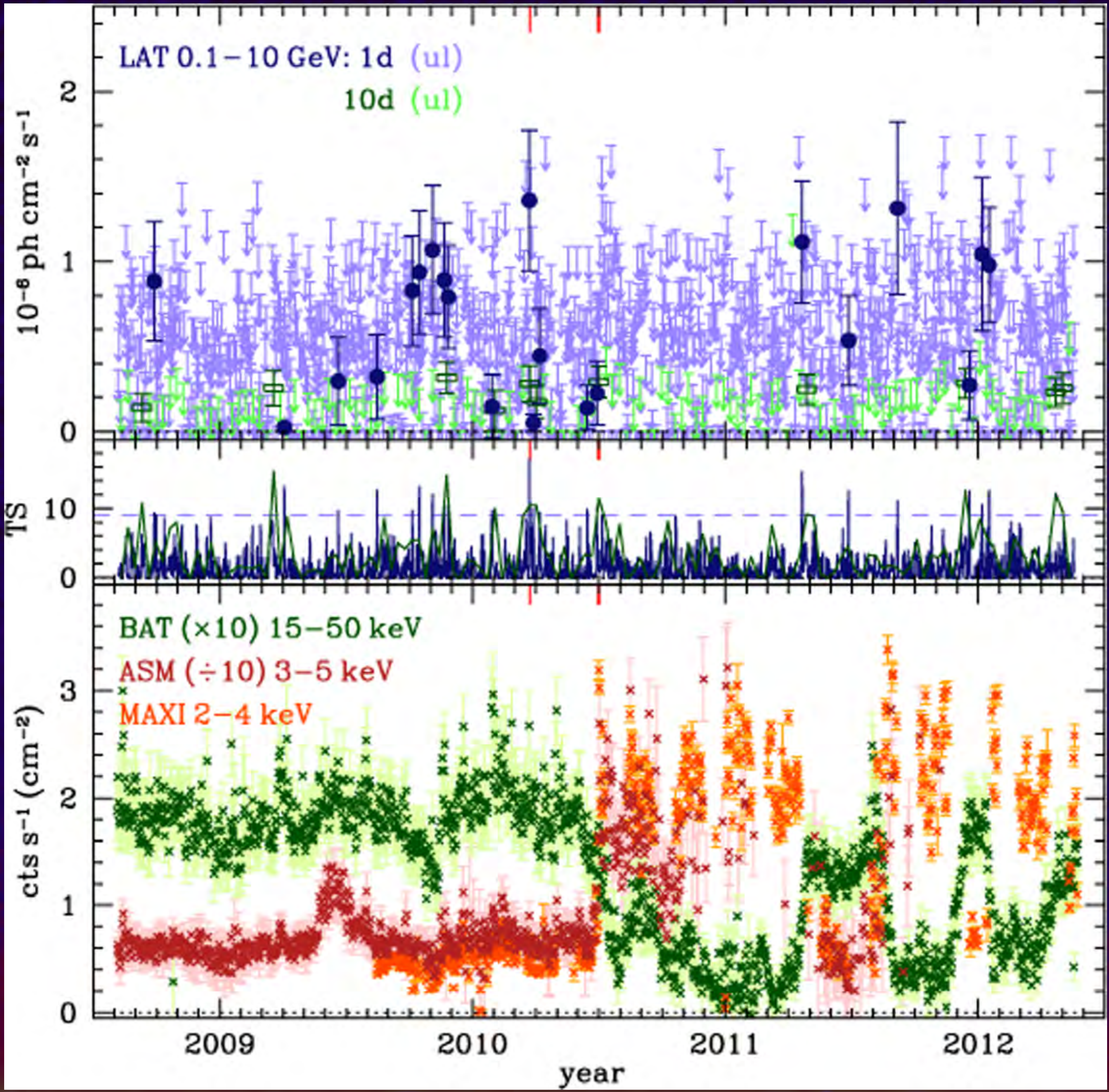
there are 5 new daily detections not previously reported (TS ~ 20—25; backed up by 10-d)

numerous 10-d detections in and out of flaring epochs: persistent gamma-ray emission?

criteria of Corbel et al. (2012) are good predictors of gamma flaring



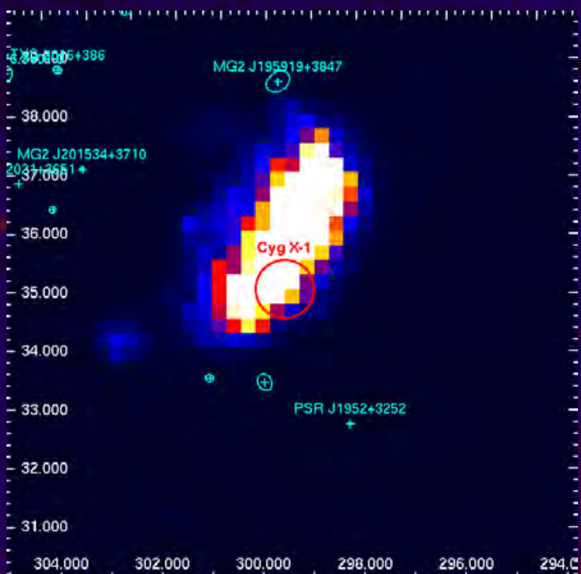
Cyg X-1: gamma-ray light curve



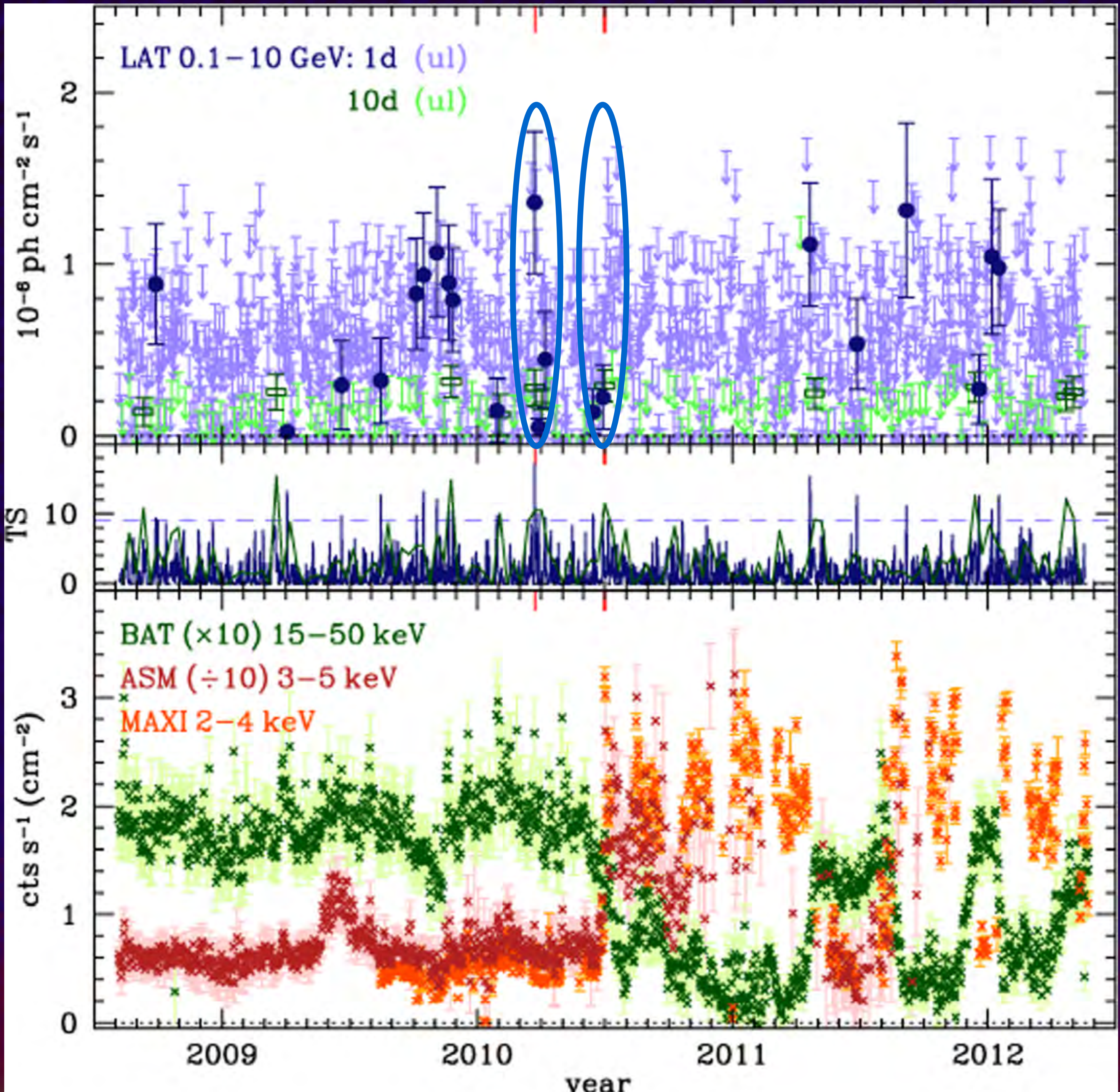
Cyg X-1: gamma-ray light curve

previous gamma-ray detections by AGILE are reproduced for the first time with LAT

fluxes and TS comparable to previous results



TS differential map
(MJD 55277: TS ~ 17)

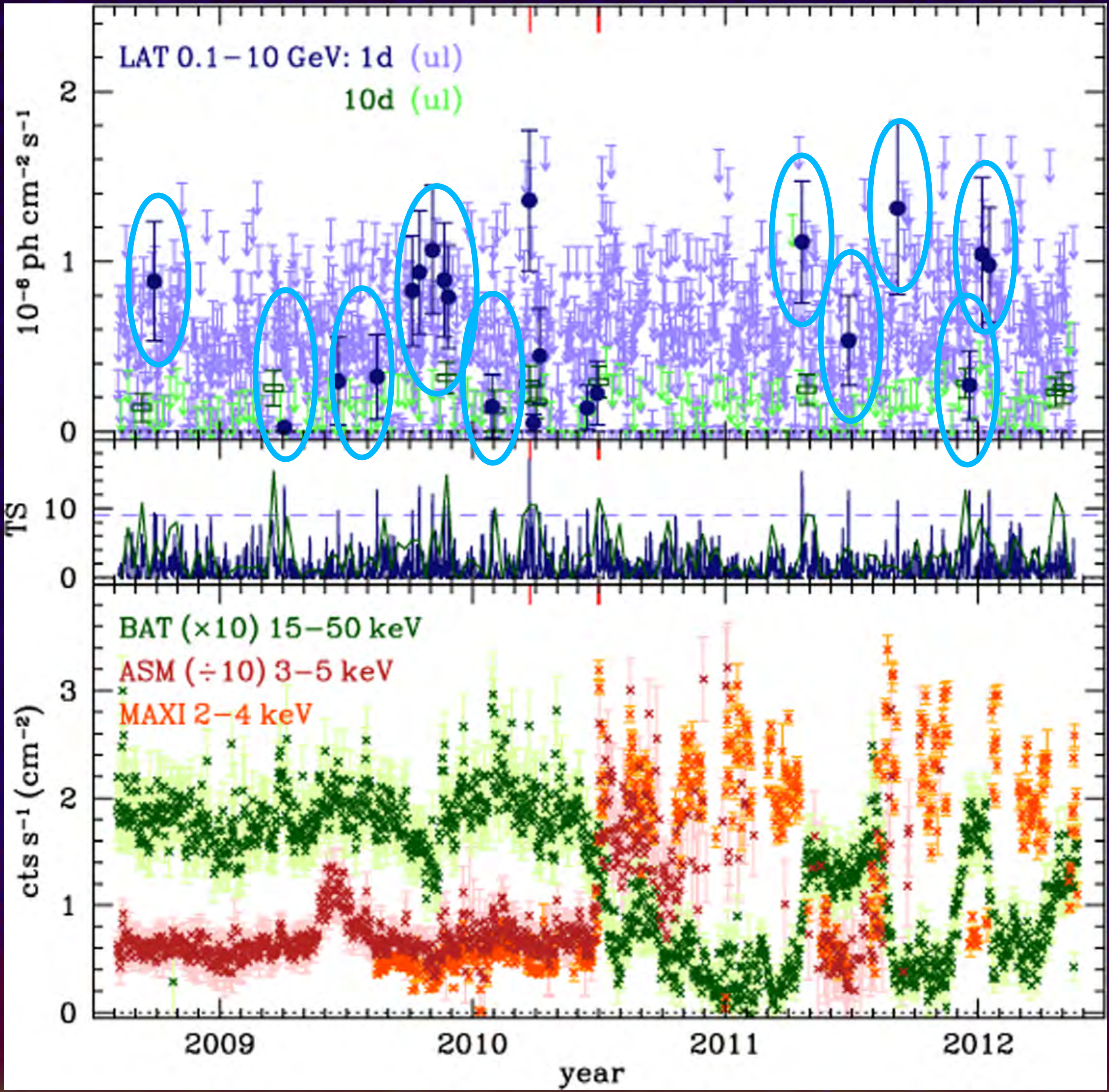


Cyg X-1: gamma-ray light curve

previous gamma-ray detections by AGILE are reproduced for the first time with LAT

fluxes and TS comparable to previous results

there are 16 days with TS ~ 9—16
some are backed by 10-d
(not trial corrected)



Cyg X-1: gamma-ray light curve

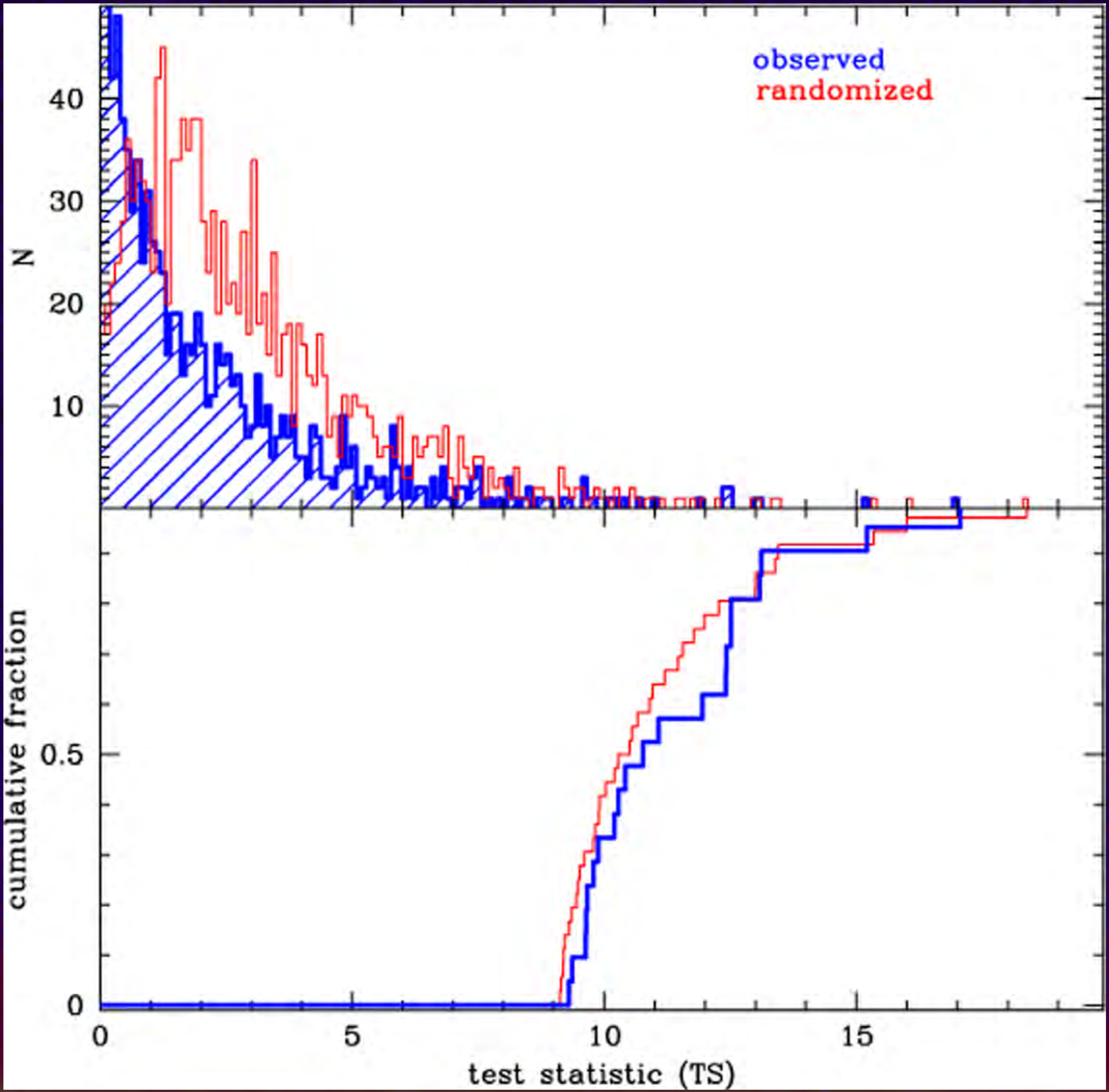
previous gamma-ray detections by AGILE are reproduced for the first time with LAT

fluxes and TS comparable to previous results

there are 16 days with TS ~ 9—16 some are backed by 10-d (not trial corrected)

comparison with TS distribution of spurious EGRET source yields 55% KS-test prob. of match

⇒ "detections" outside of AGILE epochs are probably spurious



Cyg X-1: gamma-ray light curve

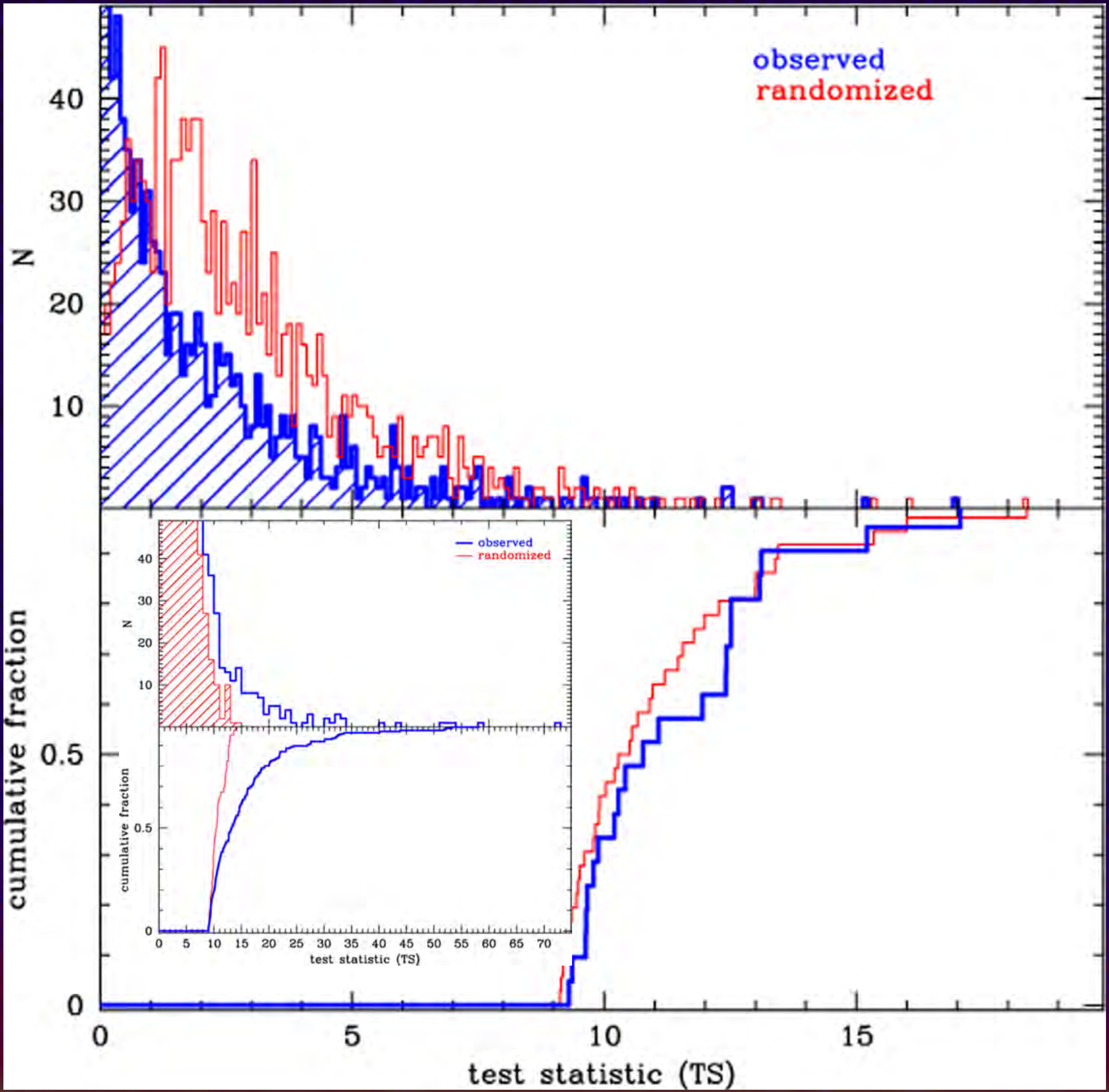
previous gamma-ray detections by AGILE are reproduced for the first time with LAT

fluxes and TS comparable to previous results

there are 16 days with TS ~ 9—16 some are backed by 10-d (not trial corrected)

comparison with TS distribution of spurious EGRET source yields 55% KS-test prob. of match

⇒ “detections” outside of AGILE epochs are probably spurious



GRS 1915+105   GX 339–4

no prior gamma-ray detections by AGILE or LAT

few low-significance 1-d (TS ~ 9—15; few 10-d)

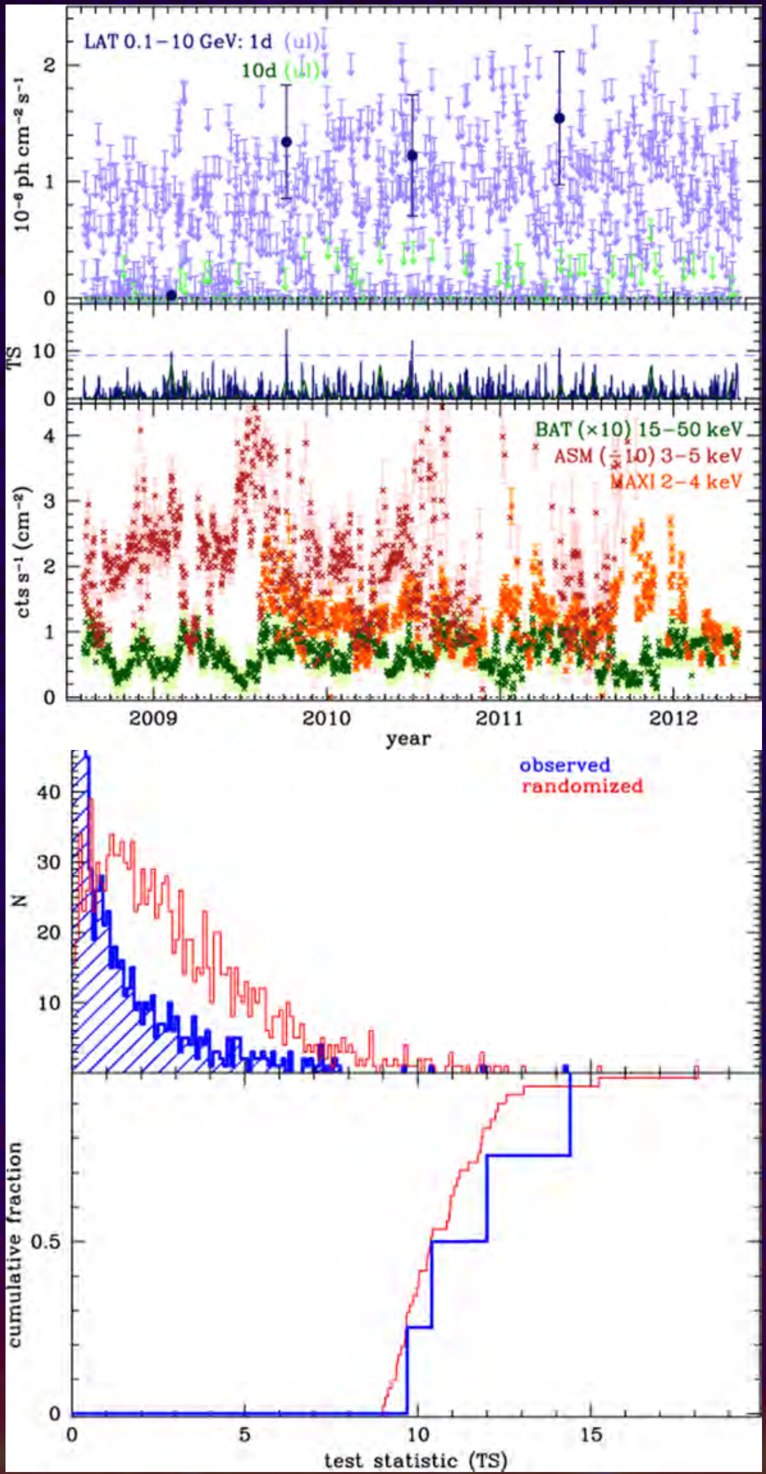
comparison with TS distribution of spurious EGRET source yields >70% KS-test prob. of match

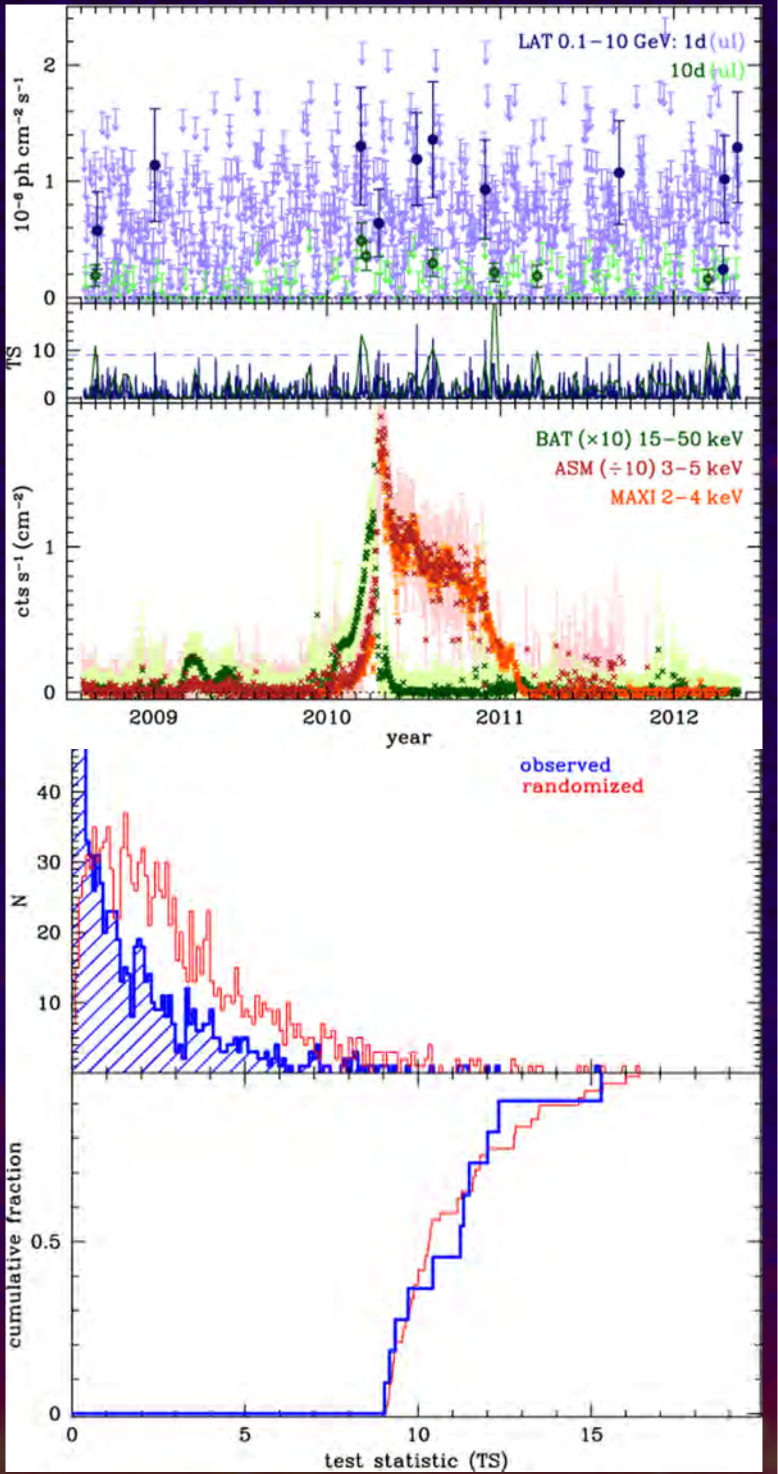
⇒ “detections” are probably spurious

3σ upper limits of:

GRS1915+105: 3.9×10^{-6} ph/cm^2/s

GX 339–4: 4.2×10^{-6} ph/cm^2/s



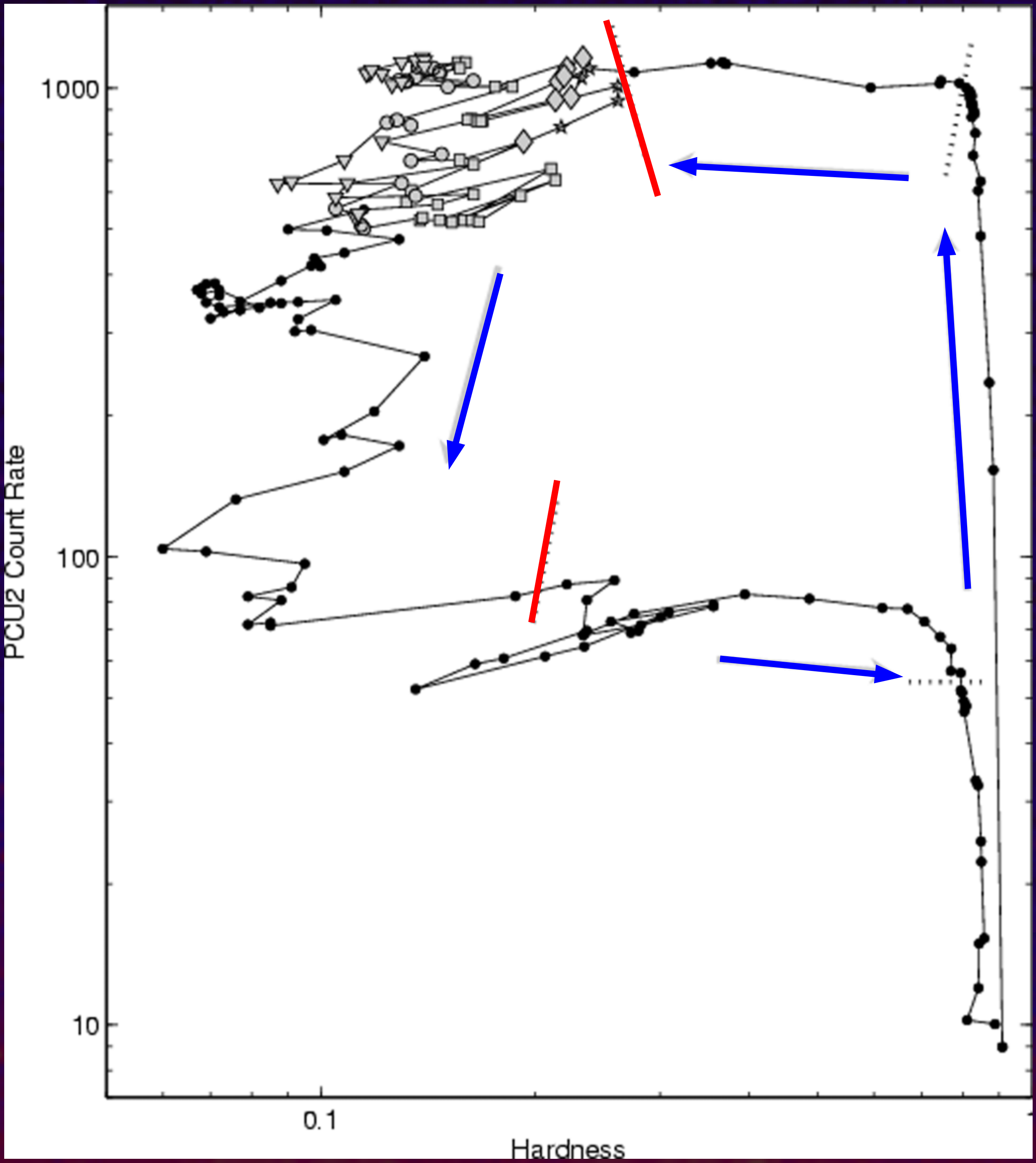


GX 339-4: X-RAY STATES

are there specific states in which gamma-rays could be emitted?

→ when radio jets are present

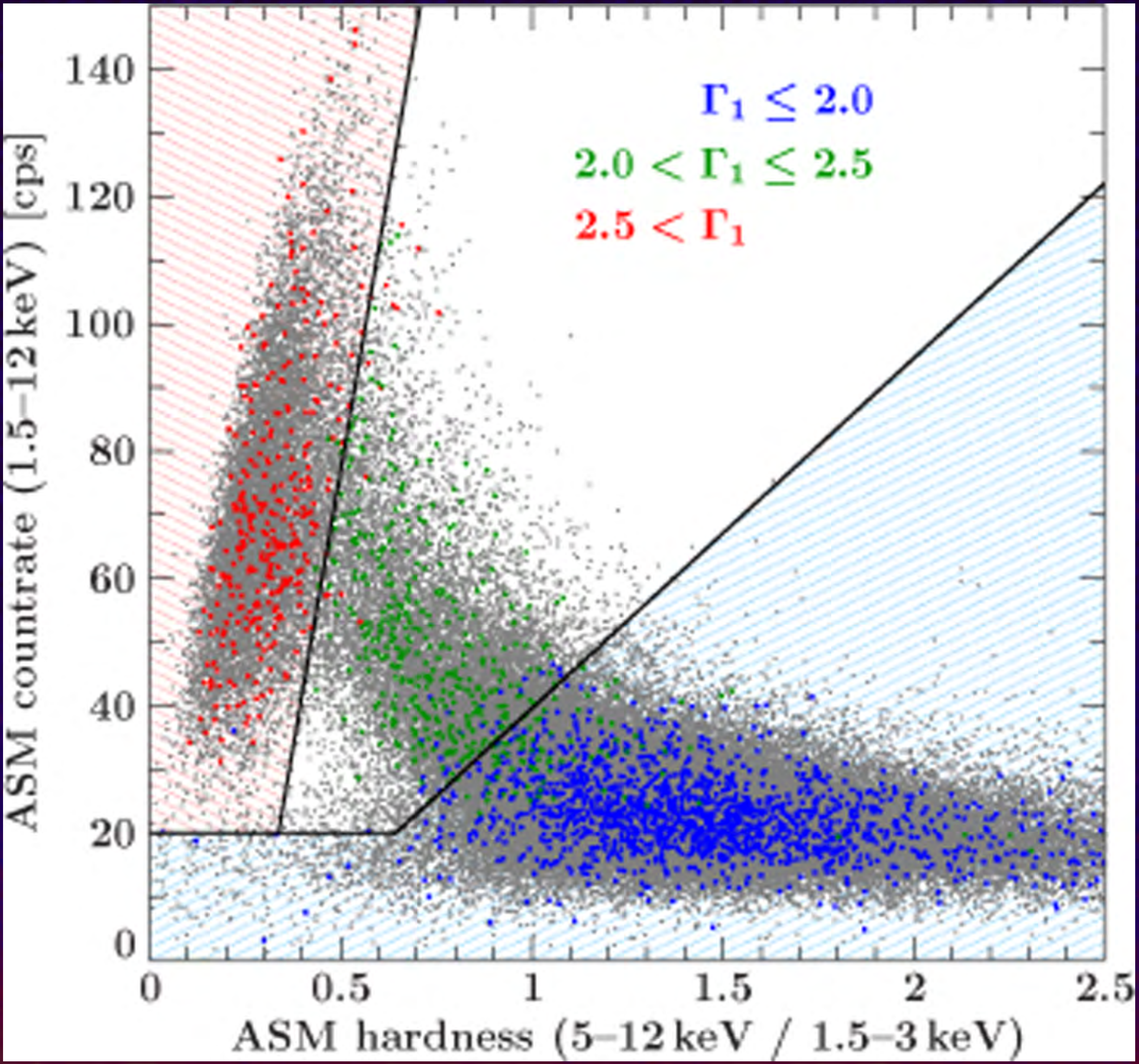
(but radio data not always available)



Belloni et al. 2004 (and ref. therein)

Cyg X-1: X-ray states

are there specific states in which gamma-rays could be emitted?



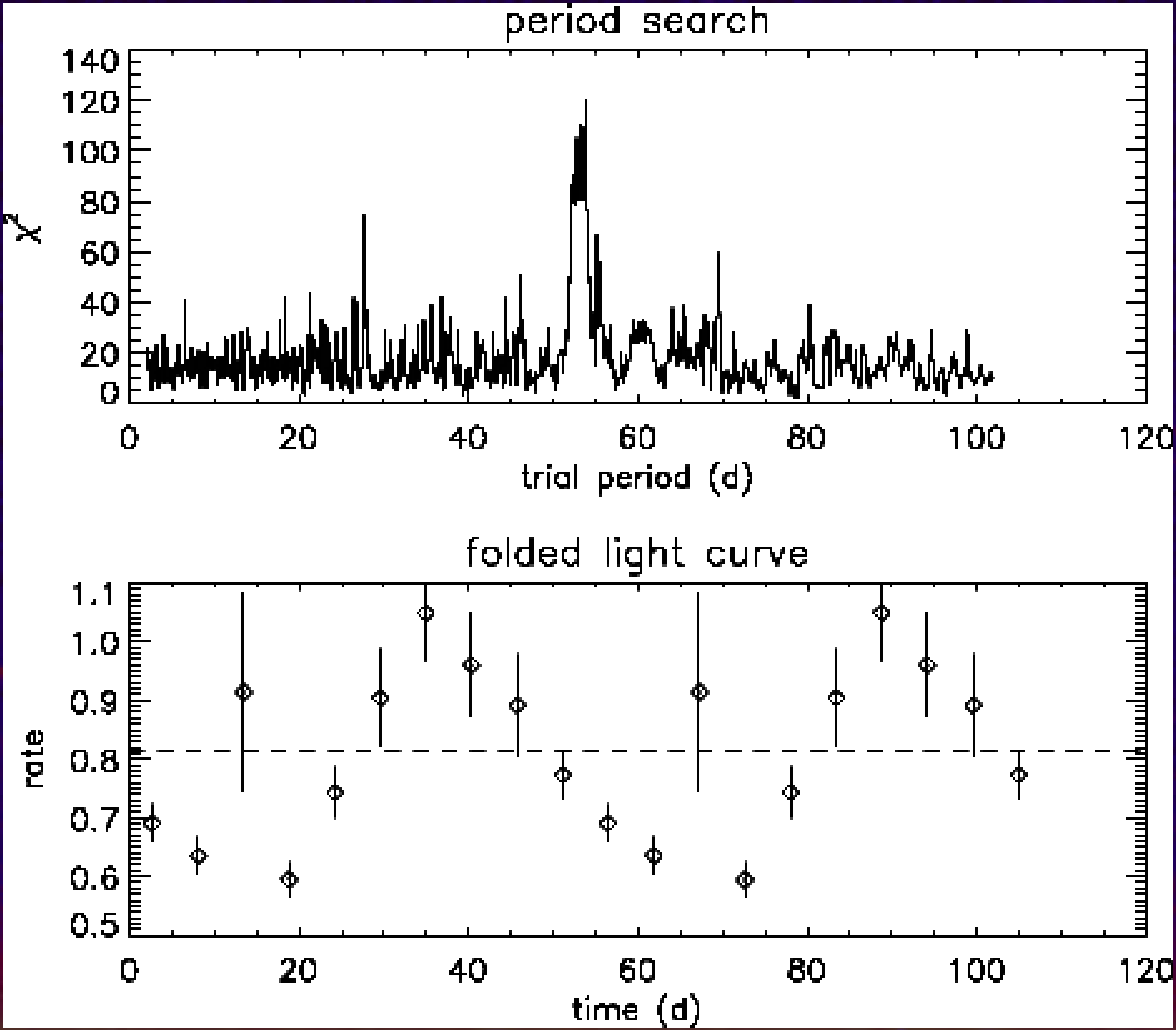
Grinberg et al. 2012 in prep.

GRS 1915+105: ORBITAL SEARCH

known 33-d period not seen

55-d period detected

some initial excitement ...

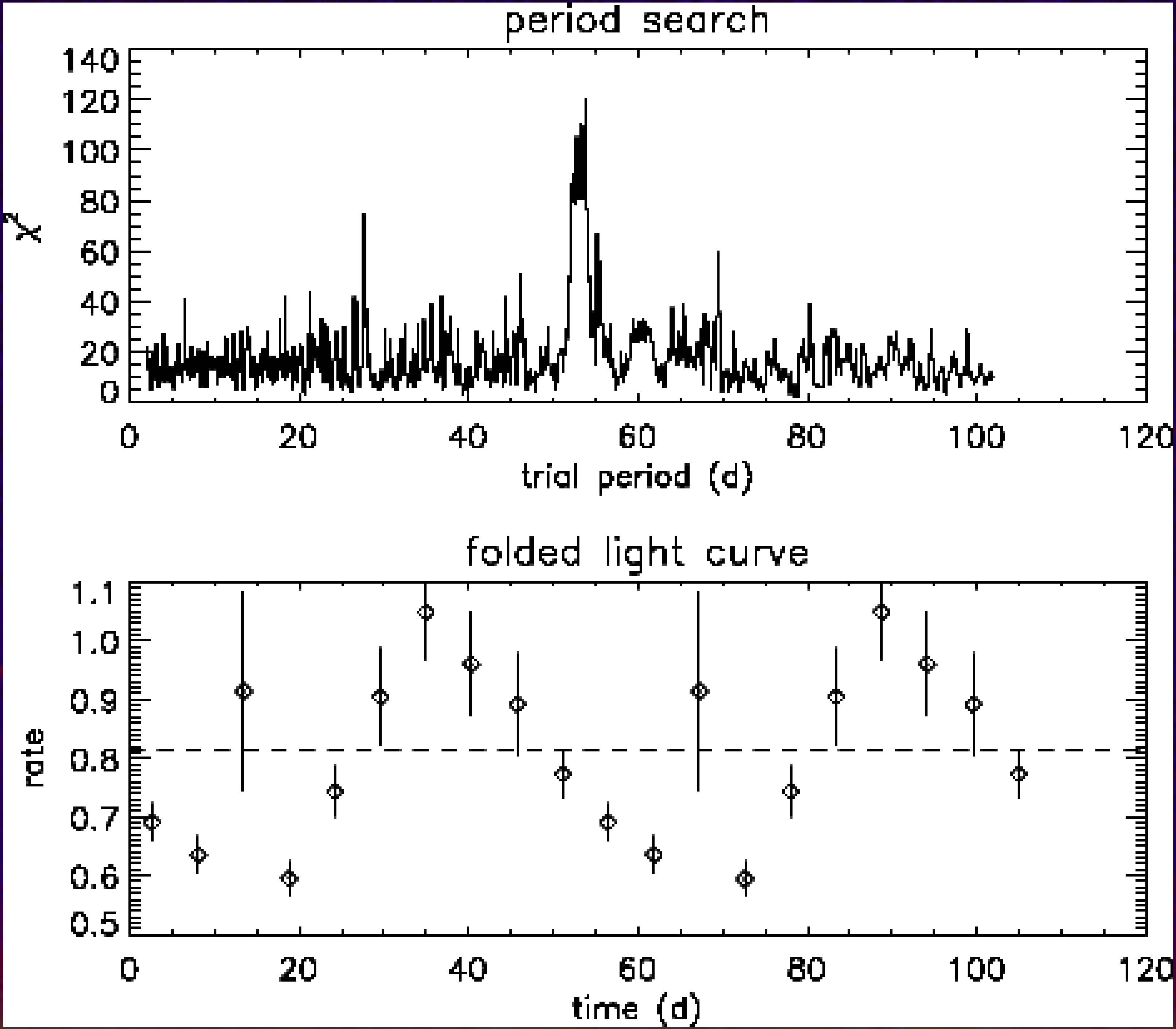


GRS 1915+105: ORBITAL SEARCH

known 33-d period not seen

55-d period detected

some initial excitement ...
then realized we detected
Fermi's precession period



Summary & Conclusions

Cyg X-3:

- confirmed all reported gamma-ray detections (except 1)
- five additional unreported gamma-ray flares
- evidence of persistent emission

Summary & Conclusions

Cyg X-3:

- confirmed all reported gamma-ray detections (except 1)
- five additional unreported gamma-ray flares
- evidence of persistent emission

Cyg X-1:

- prior gamma-ray detections by AGILE possibly confirmed with LAT
- other low-TS gamma-ray flares likely spurious

Summary & Conclusions

Cyg X-3:

- confirmed all reported gamma-ray detections (except 1)
- five additional unreported gamma-ray flares
- evidence of persistent emission

Cyg X-1:

- prior gamma-ray detections by AGILE possibly confirmed with LAT
- other low-TS gamma-ray flares likely spurious

GRS 1915+105 and GX 339–4:

- no prior gamma-ray detection with which to compare so trial correction necessary
- low-TS gamma-ray flares likely spurious

Summary & Conclusions

Cyg X-3:

- confirmed all reported gamma-ray detections (except 1)
- five additional unreported gamma-ray flares
- evidence of persistent emission

Cyg X-1:

- prior gamma-ray detections by AGILE possibly confirmed with LAT
- other low-TS gamma-ray flares likely spurious

GRS 1915+105 and GX 339–4:

- no prior gamma-ray detection with which to compare so trial correction necessary
- low-TS gamma-ray flares likely spurious

ongoing:

- X-ray state selected gamma-ray light curves
- orbital-folded light curves based on event weighting
- create SED to constrain leptonic/hadronic models

Summary & Conclusions

Cyg X-3:

- confirmed all reported gamma-ray detections (except 1)
- five additional unreported gamma-ray flares
- evidence of persistent emission

Cyg X-1:

- prior gamma-ray detections by AGILE possibly confirmed with LAT
- other low-TS gamma-ray flares likely spurious

GRS 1915+105 and GX 339–4:

- no prior gamma-ray detection with which to compare so trial correction necessary
- low-TS gamma-ray flares likely spurious

ongoing:

- X-ray state selected gamma-ray light curves
- orbital-folded light curves based on event weighting
- create SED to constrain leptonic/hadronic models

Fermi observations of microquasars can shed light on the role of relativistic jets in producing gamma-ray emission around accreting compact objects.

Bodaghee et al. 2012d in prep.

thank you