Gamma-ray science for binaries and Update on the Compton Spectrometer and Imager

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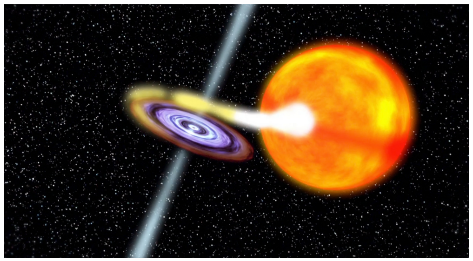


COSI
Formerly NCT

Overview

- Gamma-ray emission from binaries
  - Partly from discussions with Colleen Wilson-Hodge, David Smith, and Eric Grove for the GammaSIG roadmap
  - Black hole: polarization and the broadband spectrum
  - Black hole: positrons and the bigger picture
  - Neutron stars: pulsar wind interactions
  - Neutron stars: neutron capture

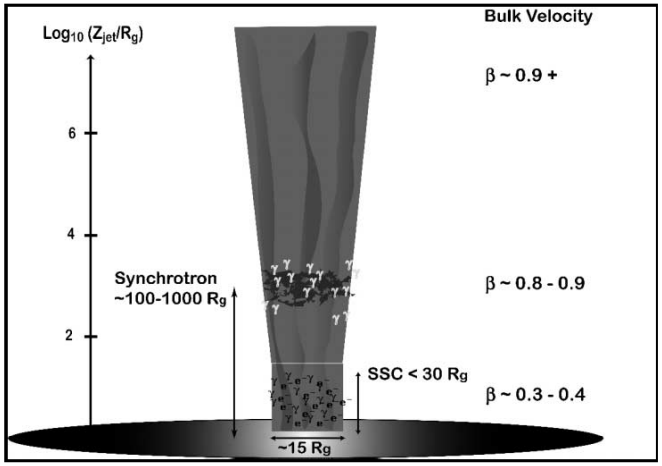
- Compton Spectrometer and Imager (COSI)
  - Update: balloon flight from New Zealand
  - Compton telescopes and binaries

List of binaries that are known emitters at >1 MeV

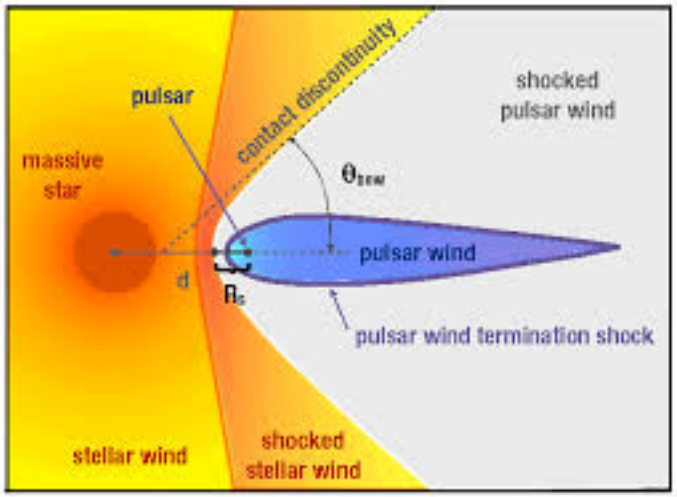
- Accreting Black Holes
  - Cyg X-1, Cyg X-3
- Gamma-ray binaries
  - PSR B1259+63, LS 5039, LS I +61 303, HESSJ0632+057, 1FGL J1018.6-5856
- Transitional millisecond pulsars
  - PSR J1023+0038, IGRJ18245-2452, XSS J12270-4859
  - Tentative detection of one well-known neutron star X-ray binary: SAX J1808.4-3658 (de Ona Wilhelmi et al. 2015)
- Classical novae
  - V407 Cyg, V1324 Sco, V959 Mon, V339 Del

Possible origins of the >MeV emission

- Jets
  - synchrotron, SSC, or IC
  - seed photons from jet, disk, or companion star
- Shocks
  - pulsar wind/stellar wind collisions
  - pulsar wind/disk collisions
  - ejecta from novae/stellar wind collisions

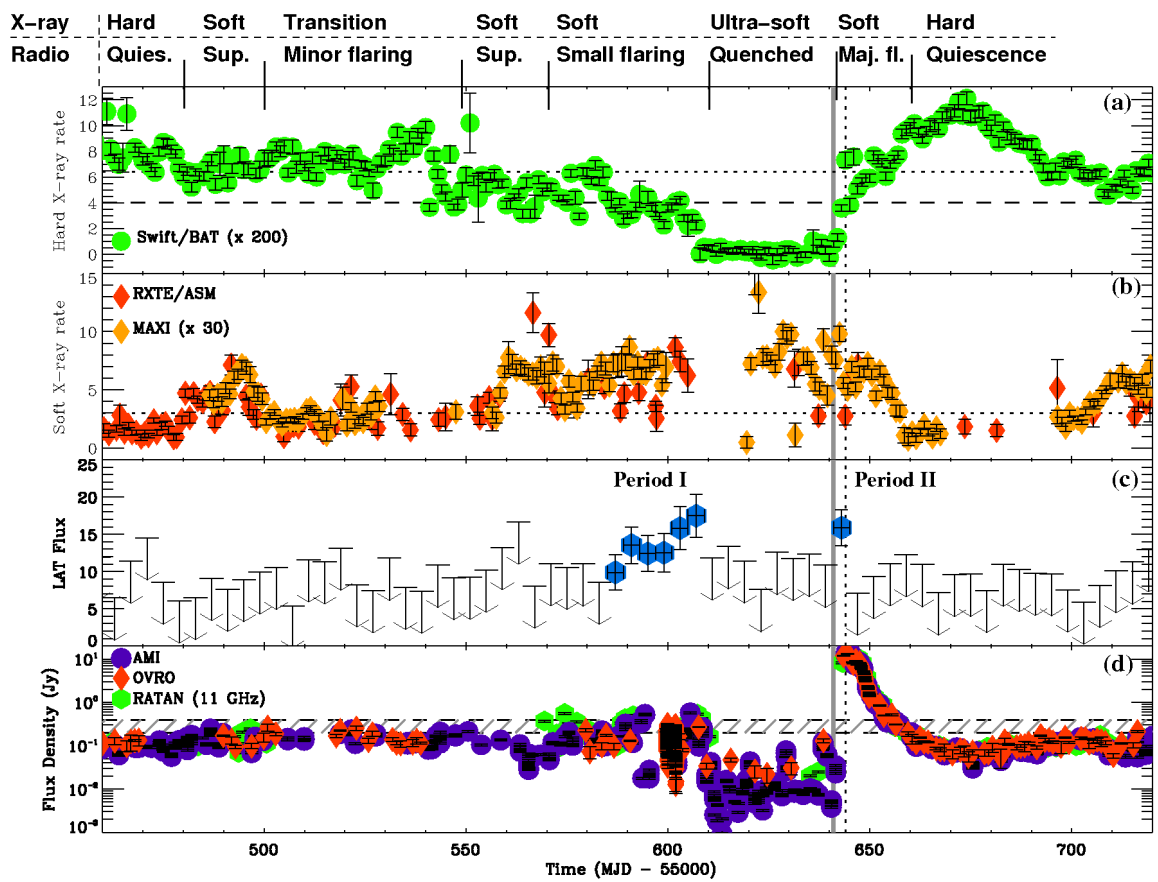


Markoff et al. 2005



Cyg X-3

- Original detections by AGILE (Tavani et al. 2009) and Fermi (Adbo et al. 2009) were period II flares
- Period I flares may be related to steady jets

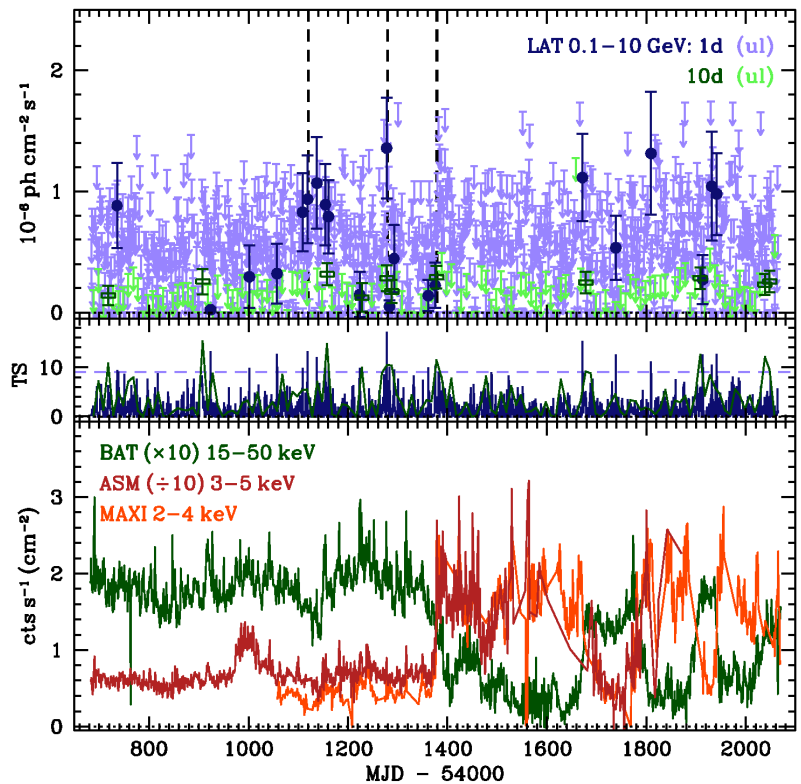


Corbel et al. 2012; see also Williams et al. 2011

Cyg X-1

- Since COMPTEL, there has been no doubt that the emission extends to at least a few MeV (McConnell et al. 2000)

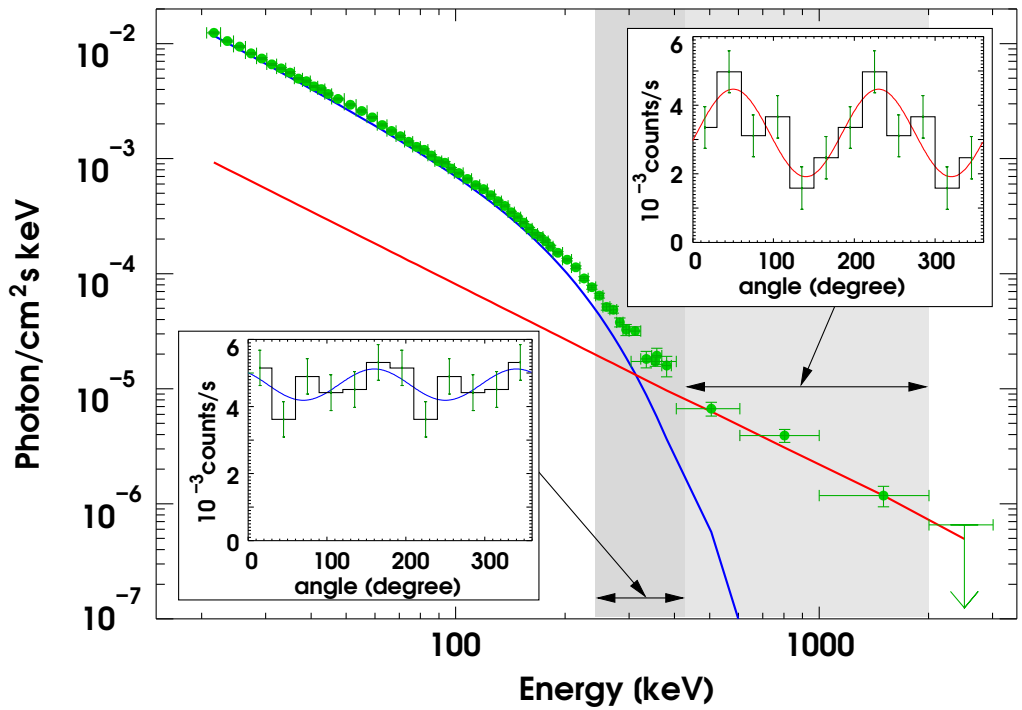
- Some significant Fermi/LAT and AGILE detections at >100 MeV



Bodaghee et al. 2013; see also Sabatini et al. 2013; Malyshev et al. 2013

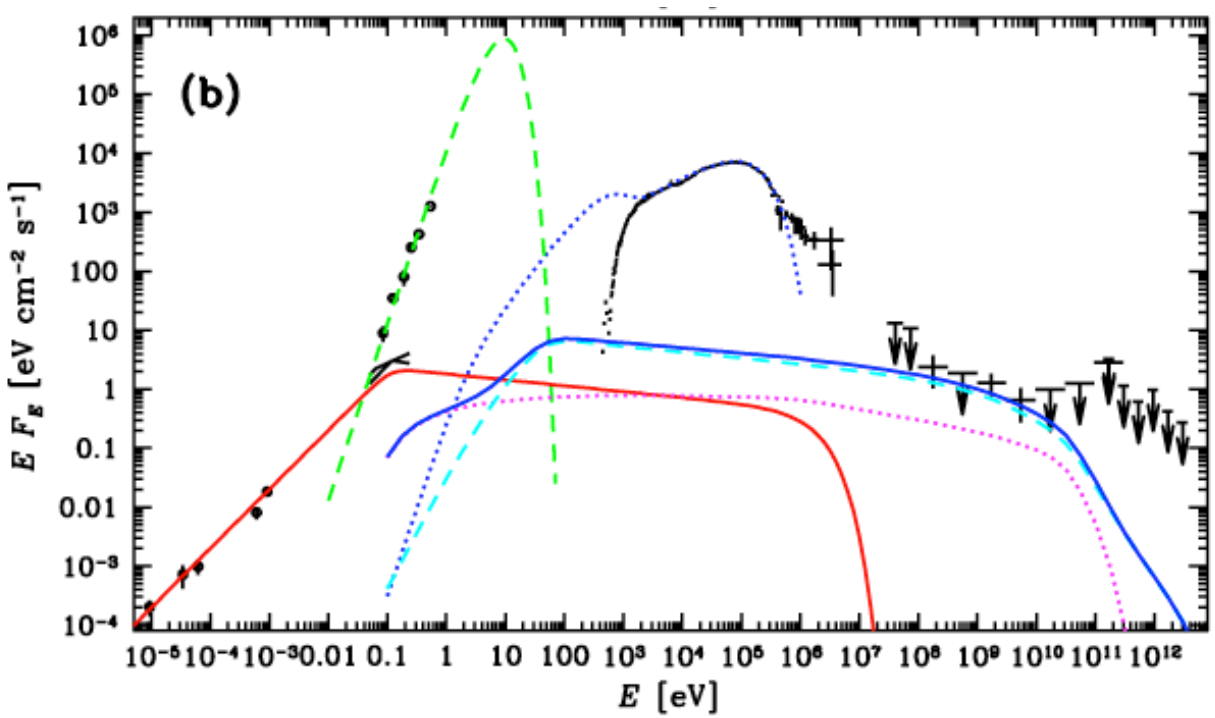
The MeV component from Cyg X-1

- Polarization measurements by INTEGRAL
  - IBIS (Laurent et al. 2011)
    - <20% (0.25-0.4 MeV)
    - 67±30% (0.4-2 MeV)
  - SPI (Jourdain et al. 2012)
    - <20% (0.13-0.23 MeV)
    - >75% (0.37-0.85 MeV)
- Interpretation
  - Unpolarized thermal Comptonization component plus polarized non-thermal component, possibly from the jet



Cyg X-1 spectrum and modulation curves (from ESA press release)

Jet model for Cyg X-1

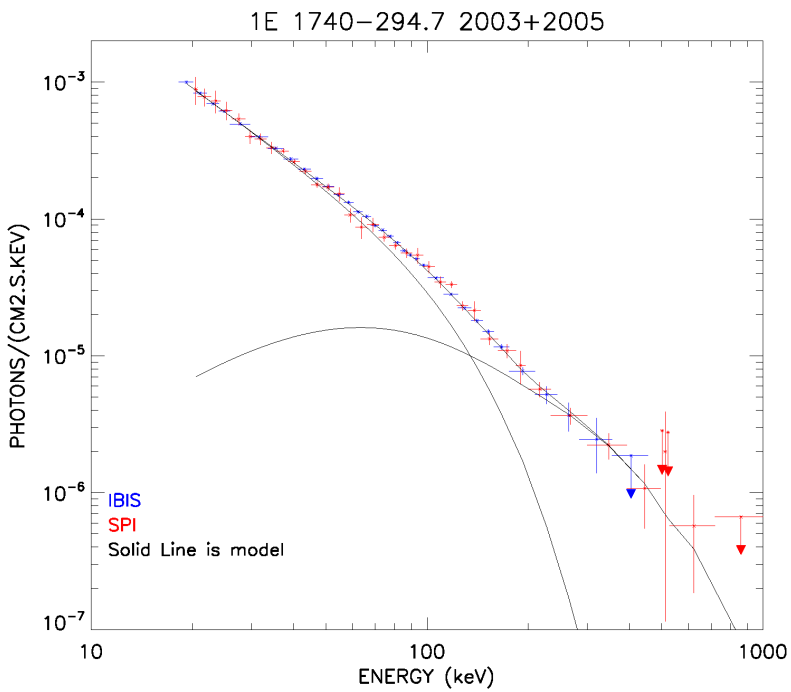


- Blazar-like model with synchrotron (red) and inverse Compton (blue)
- See Malyshev et al. 2013 and Zdziarski et al. 2014

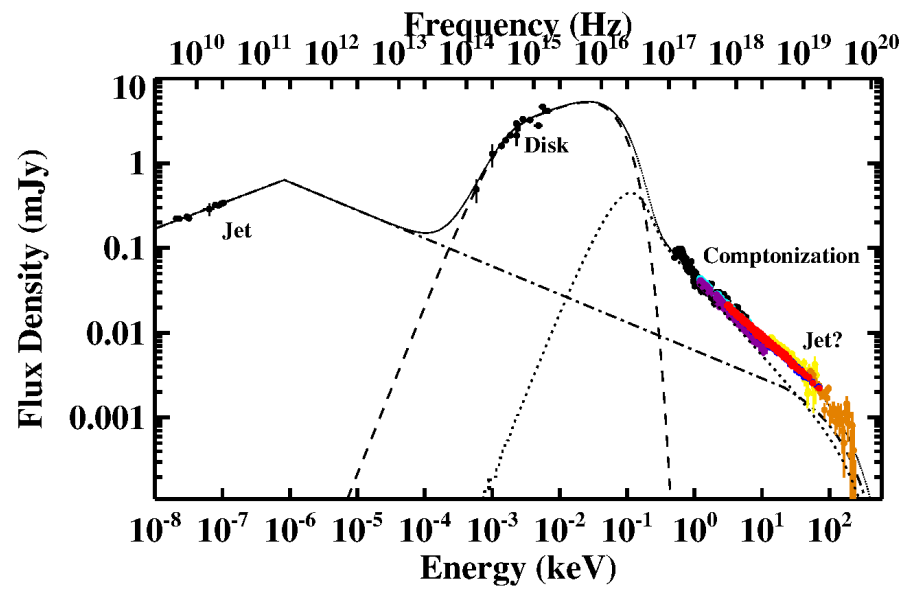
List of BH sources with multiple high-energy components

- Cyg X-1 (McConnell et al. 2000; Laurent et al. 2011; Jourdain et al. 2012) – only one with a polarization measurement
- GX 339-4 (Joinet et al. 2007; Droulans et al. 2010)
- GRS 1915+105 (Rodriguez et al. 2008)
- 1E 1740.7-2942 (Bouchet et al. 2009)
- XTE J1550-564 (Russell et al. 2010)
- V404 Cyg (Rodriguez et al. 2015; Roques et al. 2016)
- Swift J1753.5-0127 (Tomsick et al. 2015)

Multiple component examples



INTEGRAL measurement
by Bouchet et al. 2009

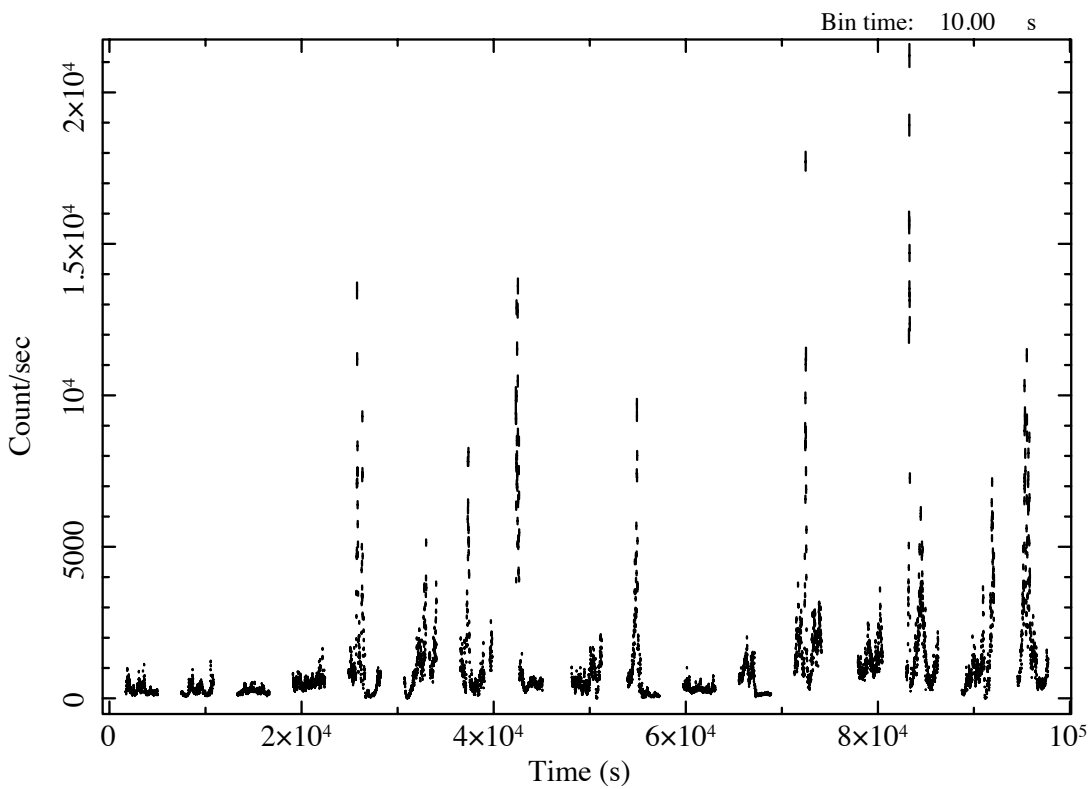


Swift J1753.5-0127

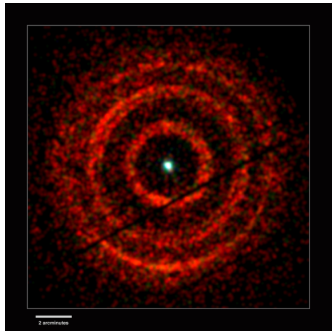
- Radio, near-IR, optical, Swift, NuSTAR, Suzaku
- Tomsick et al. 2015

- 0.1-1 MeV polarization measurements to separate components
- 0.1-10 MeV continuum measurements of spectral cutoffs or to look for additional components

V404 Cyg: first outburst since 1989



- *NuSTAR* 3-79 keV light curve from 2015 June 24-26
- 60+ ATELs during the 2015 June outburst

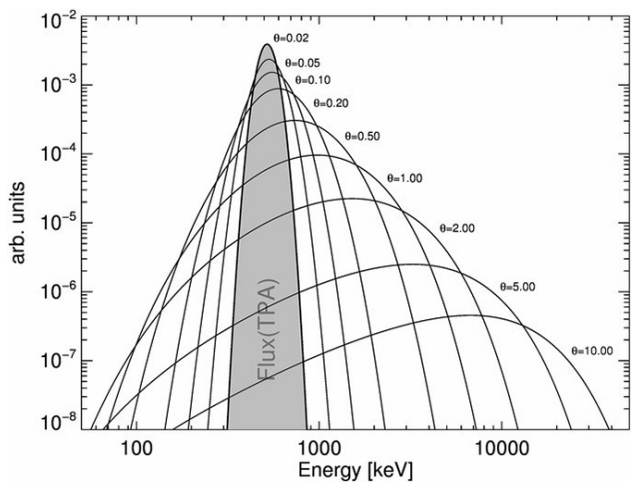


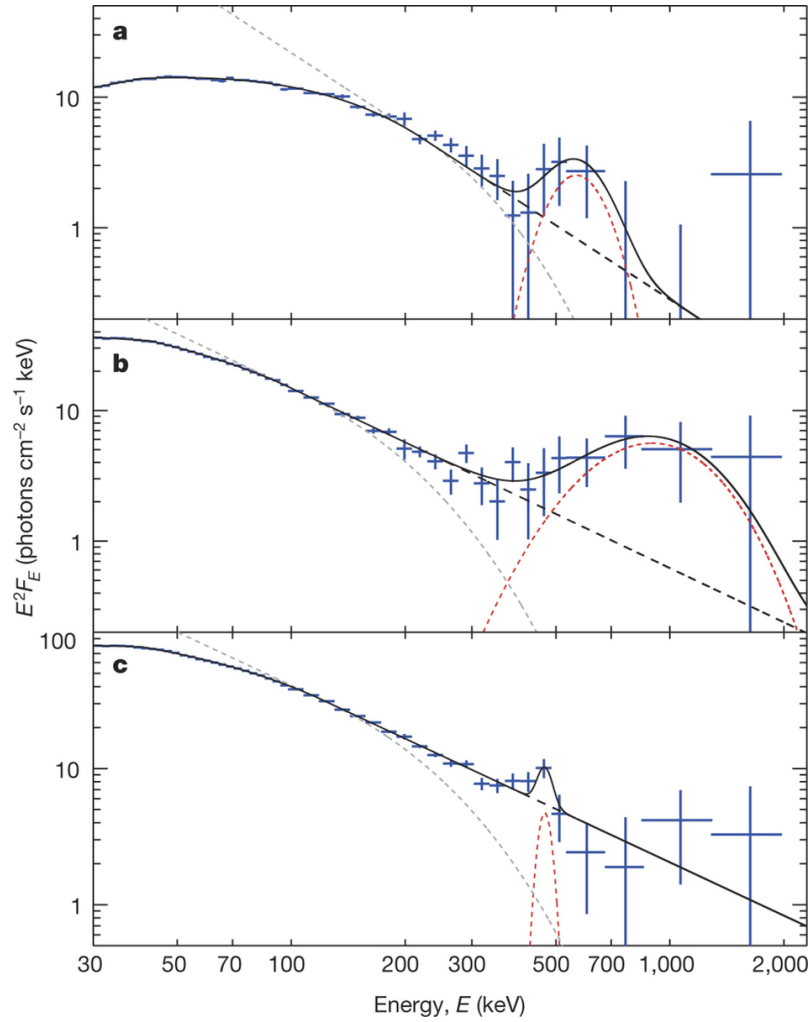
Beardmore et al. 2015; Vasilopoulos & Petropoulou 2015

- Nearby with parallax distance (2.39±0.14 kpc)
- Flares approach L_{Edd} for a 9 M_{sun} black hole

Positron annihilation signatures

- INTEGRAL observed V404 Cyg for almost 2 weeks
- Detected excess in the 0.4-2 MeV range consistent with positron annihilation
- Width due to coronal temperatures of 30 keV (a) and 170 keV (b)
- Cause of redshift in (c) unclear





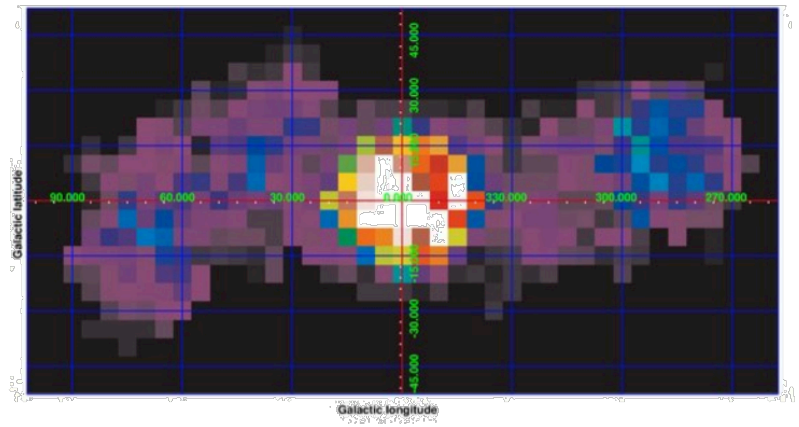
Siegert et al. 2016, Nature

Positron annihilation at 511 keV

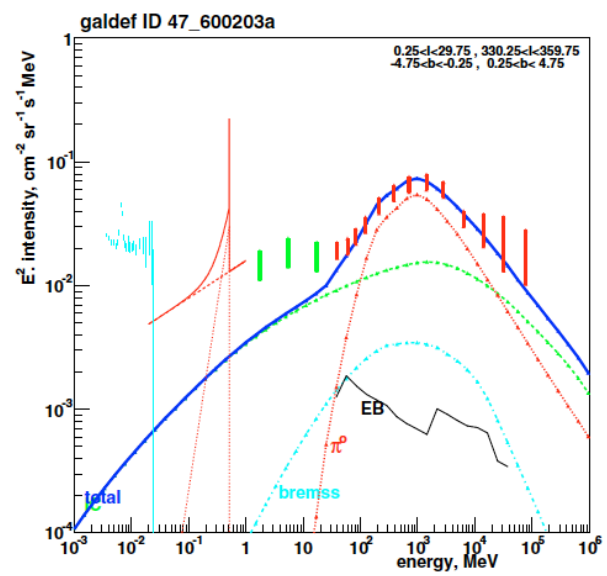
- For accreting BHs, this topic has a bit of a checkered history
  - e.g., 1E 1740.7-2942 is not "the great annihilator," but is there some 511 keV emission?
  - transients
    - e.g., Nova Muscae 1991 (GS 1124-68), but questionable whether this is a true detection
- The main point is that the known sources of positrons cannot explain the 511 keV emission from the bulge. Finding even one new production site would go a long way toward understanding where the excess comes from.

Implications
(bigger picture for positron result)

- Need (1-2)x10^{43} e^+e^-/s to explain the bulge excess
- For V404 Cyg, Siegert et al. (2016) calculate:
  - dN/dt = 10^{42} e^+e^-/s
- With a duty cycle of 10^{-3}, need 10,000 V404Cyg's
- Need to be able to constrain positron production for more BH sources
- May also be able to explain the continuum MeV excess (discussed in Regina Caputo's Dark Matter talk yesterday)



INTEGRAL/SPI Galactic center map of the positron annihilation radiation (511 keV) *(Bouchet et al. 2010)*

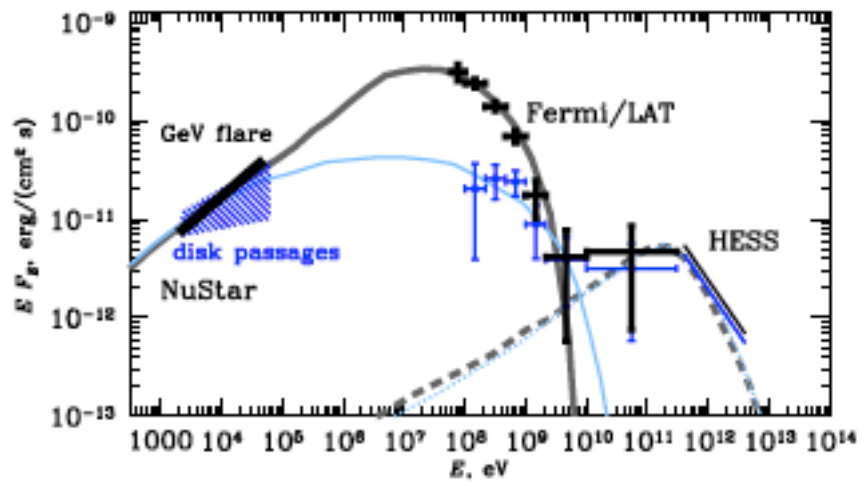


Strong et al. (2005)

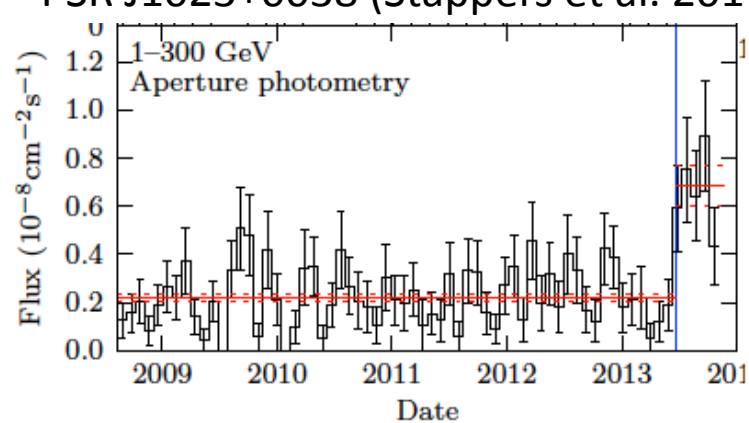
Gamma-ray binaries and transitional millisecond pulsars

- Gamma-ray binaries
  - PSR B1259-63
    - Be star/pulsar in a 3.4 yr eccentric orbit
    - Gamma-ray flares at periastron passage
    - Theory is that gamma-rays are produced when the pulsar interacts with the Be star's circumstellar disk
- tMSPs
  - PSR J1023+0038
    - Radio pulsations turn off when accretion begins
    - Gamma-ray flare at the same time
    - Possibly a similar pulsar/ disk interaction

PSR B1259-63 (Chernyakova et al. 2015)



PSR J1023+0038 (Stappers et al. 2014)



Neutron capture lines

- In accreting neutron stars, a 2.2 MeV line might be produced by radiative capture of free neutrons by hydrogen nuclei
- Boggs & Smith (2006) report non-detections, but the theoretical predictions suggest that the fluxes might be just below the INTEGRAL detection limits
- Gravitational redshift at the NS surface
  - NS equation of state

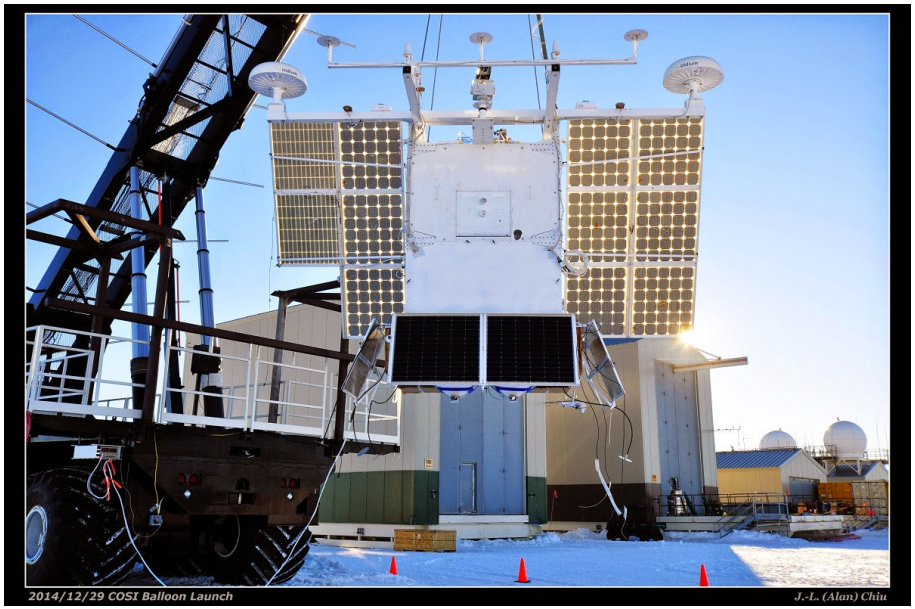
The COSI Collaboration:

- S.E. Boggs (PI), C. Kierans, A. Lowell, C. Sleator, J. Tomsick, A. Zoglauer *(UCB/SSL)*
- M. Amman *(LBL)*
- P. Jean, P. von Ballmoos *(IRAP, France)*
- *H.-K. Chang, J.-L. Chiu, C.-Y. Yang, J.-R. Shang, C.-H. Tseng (NTHU, Taiwan),*
- *C.-H. Lin (AS, Taiwan), Y.-H. Chang , Y. Chou (NCU, Taiwan)*

Also, ASIC development at NRL (Eric Wulf, Eric Grove, Bernard Phlips, Neil Johnson)

COSI US is supported through grants by NASA

http://cosi.ssl.berkeley.edu/

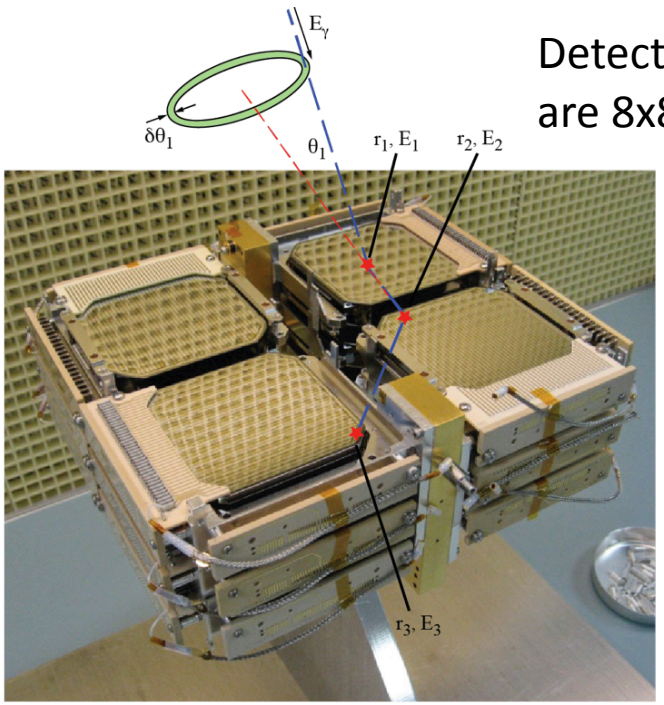


Pictures from Antarctica 2014 December

Overview: Instrument & Campaigns

Instrument:

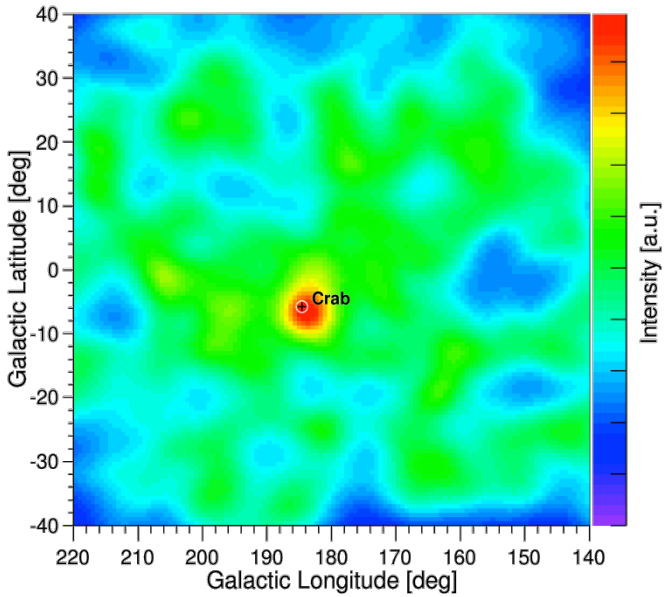
- Balloon-borne Compton telescope
- Energy range: 0.2-several MeV
- 12 Ge detectors (GeD), 2 mm strip pitch
- Energy resolution: 1.5-3.0 keV FWHM
- Large field-of-view: almost 1/4 of sky
- Angular resolution: ~4° FWHM



Detectors are 8x8 cm^2

Balloon campaigns:

- NCT: 2 GeD prototype flew from Ft. Sumner, New Mexico in 2005
- NCT: 10 GeD instrument flew from Ft. Sumner, New Mexico in 2009
- NCT: Failed launch from Alice Springs, Australia in 2010
- COSI: 2014 Antarctica campaign
- ***COSI: 2016 New Zealand campaign***



Bandstra et al. 2011

Current New Zealand Campaign

Flight type:
- Superpressure ULDB
- Up to 100 days – multiple times around the world

Anticipated launch date:
- 2016 April!

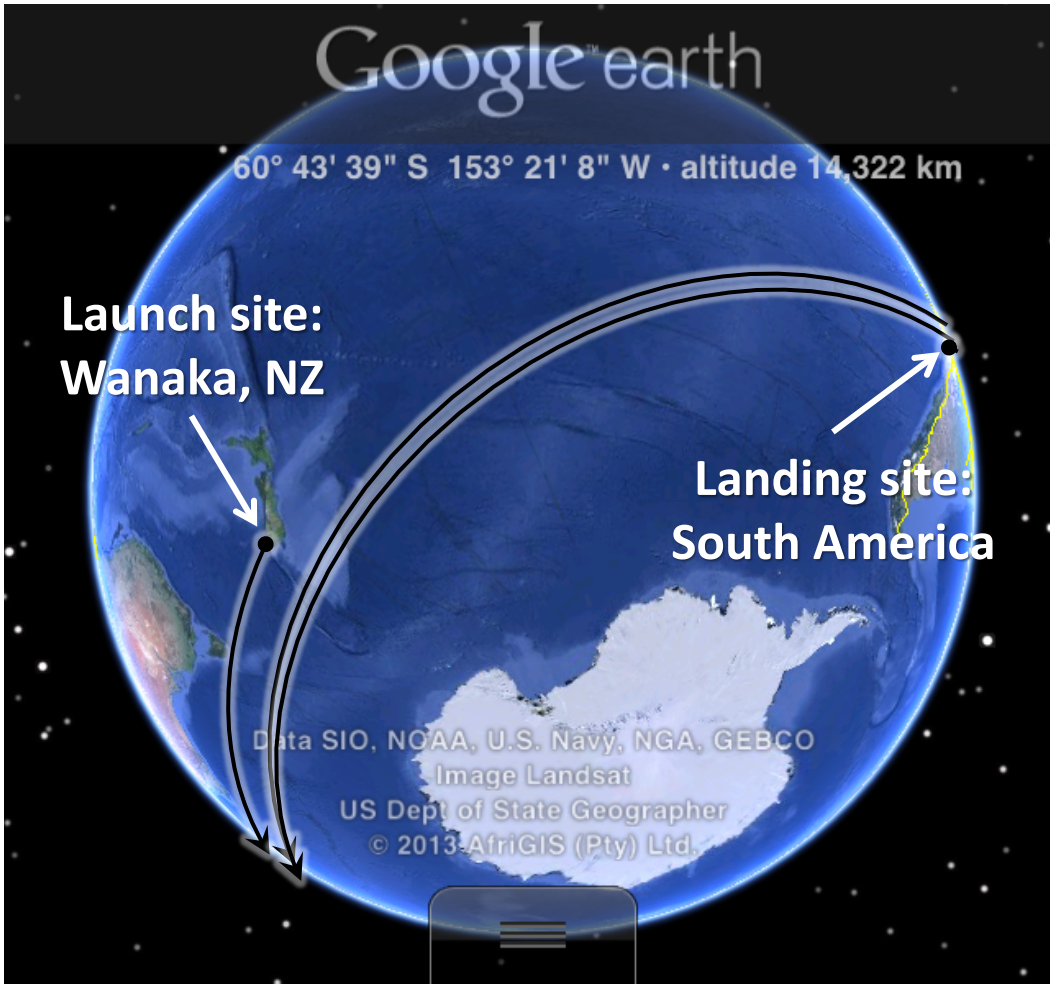
Upgrades (since 2010):
- Mechanical cooler
- New CsI shielding

Science goals:

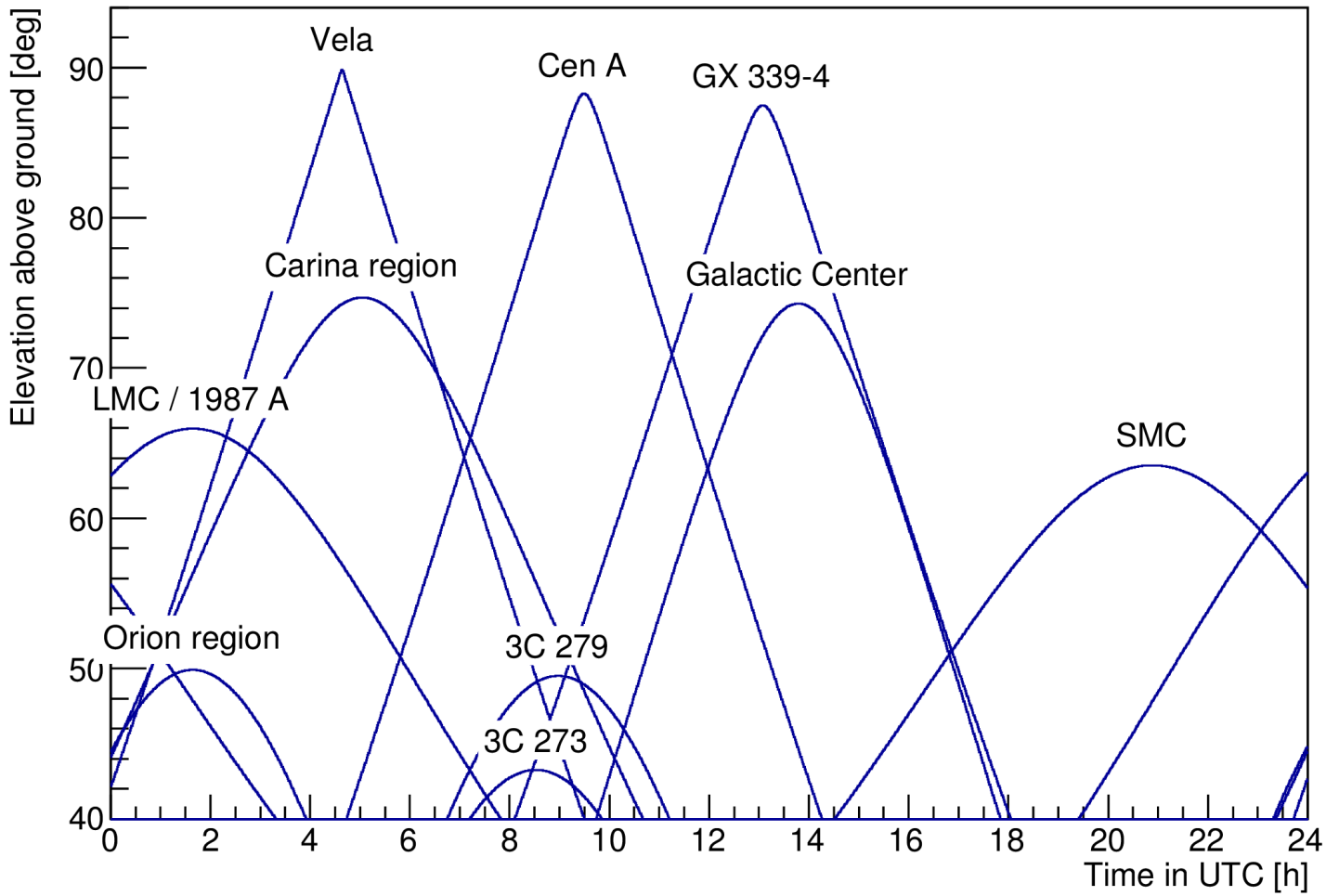
- Polarimetry of GRBs, pulsars, binaries, and AGN

- 511 keV measurements in the Galactic Center region

- Nuclear lines over much of the Galactic Plane



Observable Sources New Zealand Campaign

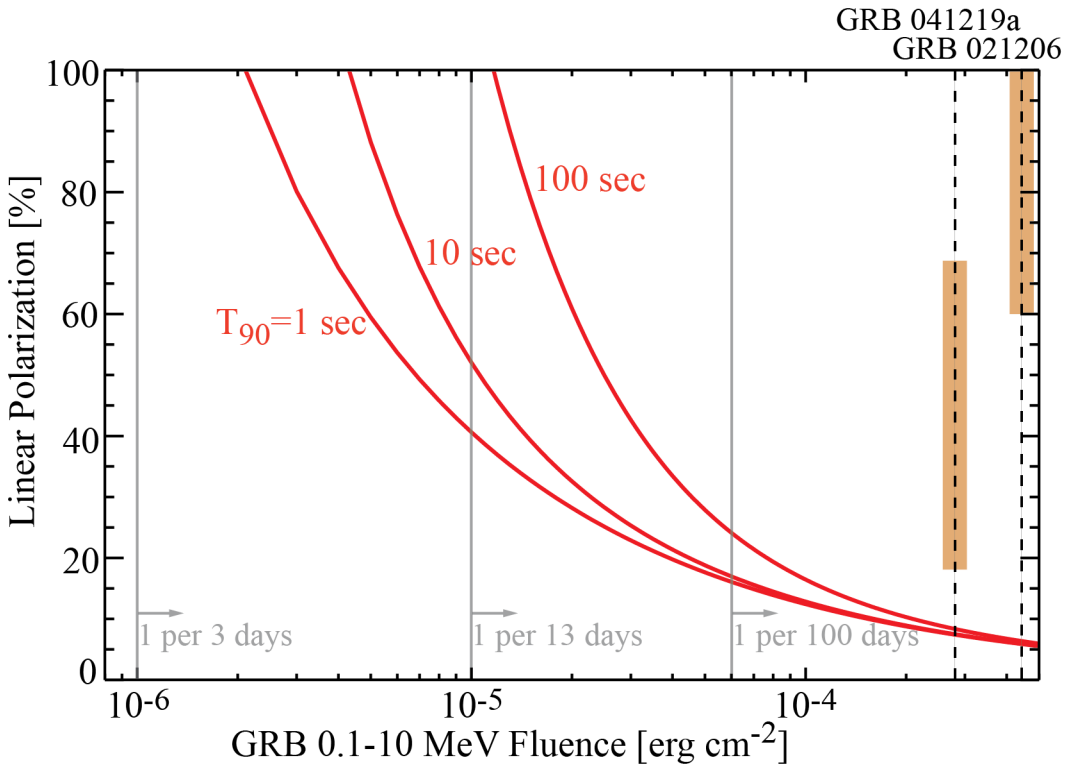


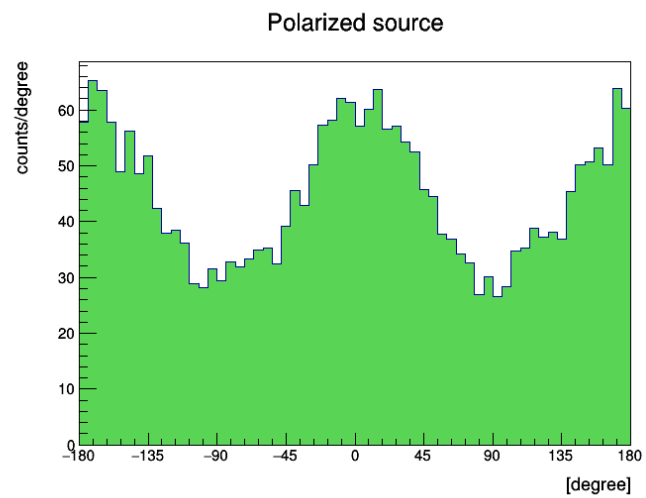
Notes:

- Carina/Vela/Orion for nuclear lines (see Dieter's talk from yesterday)
- Check for extended emission from Cen A (Justin Finke's talk)

Gamma-ray Burst Predictions

3-sigma minimum detectable polarization as a function of fluence and burst duration





- COSI modulation curve from 2016 March 18-19 taken as part of the ongoing calibration leading up to launch

- For a 100 day flight, we estimate that COSI will detect 30 GRBs, including 7-8 bright enough for polarization constraints!

Compton telescopes and binaries

- COSI is optimized for large FOV
- Possible re-designs for binaries or other point source applications
  - Hitomi/Astro-H Soft Gamma-ray Detector
    - collimated and shielded Si/CdTe Compton telescope
    - 40-600 keV spectroscopy; 50-200 keV polarimetry
  - Compton detector with focusing optics or a concentrator
    - multilayer mirrors
    - Laue lens to even higher energies

Summary

- Accreting Black Holes
  - Polarization to isolate jet emission
  - Positron science
- Neutron stars
  - Probing pulsar wind/disk interactions in Gamma-ray binaries and tMSPs
  - 2.2 MeV neutron capture line and EOS
- Follow the progress of COSI in New Zealand
  - http://cosi.ssl.berkeley.edu/
- Optimizing for point source science