Simultaneous Bayesian Location and Spectral Analysis of GRBs

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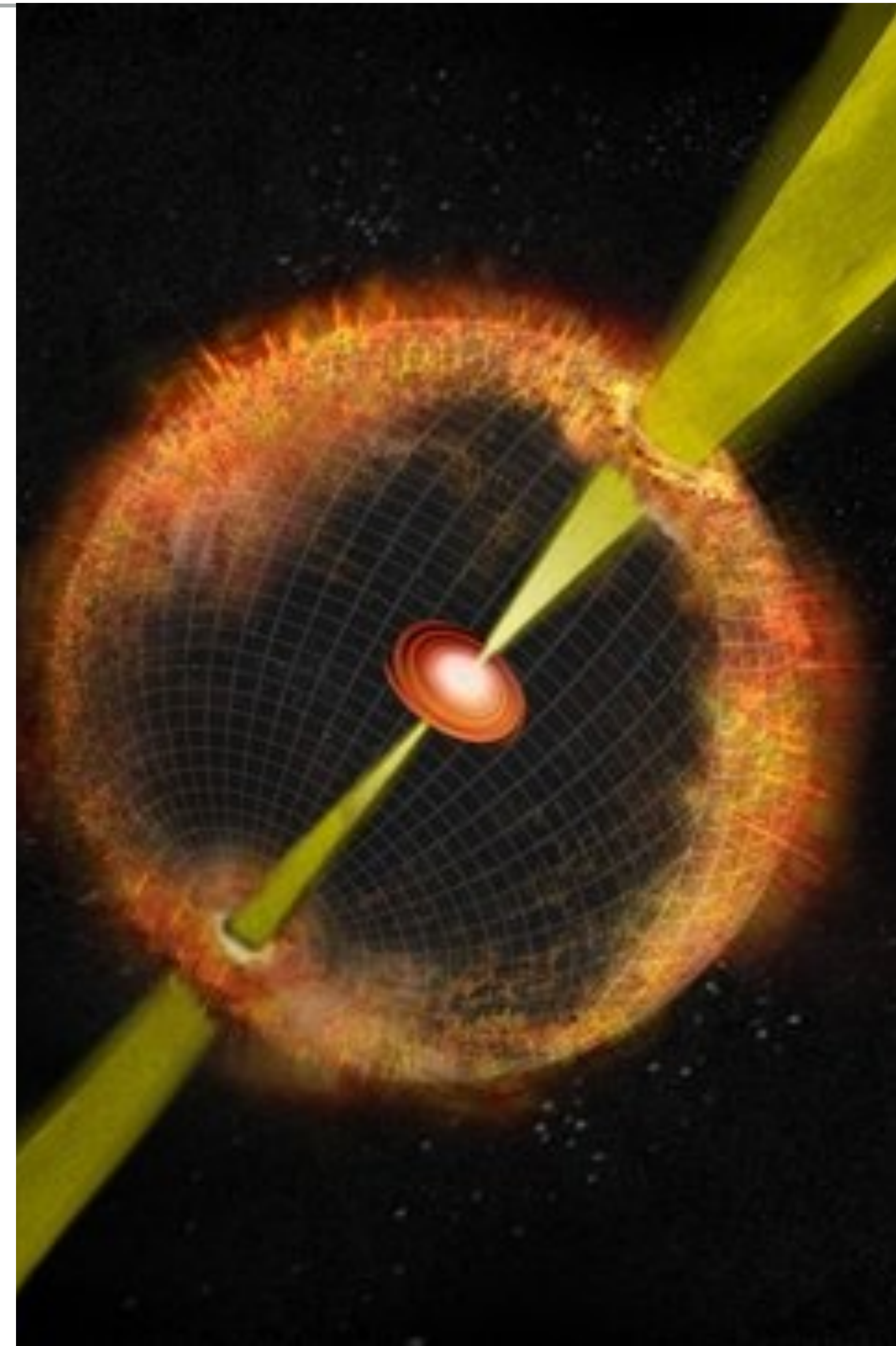
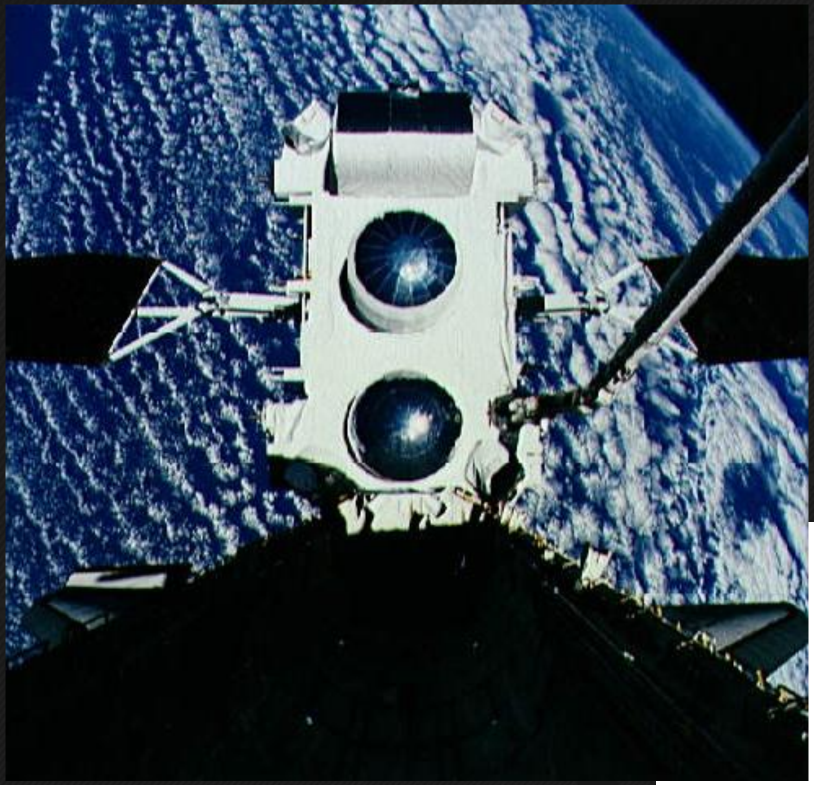
Bayes Forum - 18.11.2016

GAMMA-RAY BURSTS (GRBS)

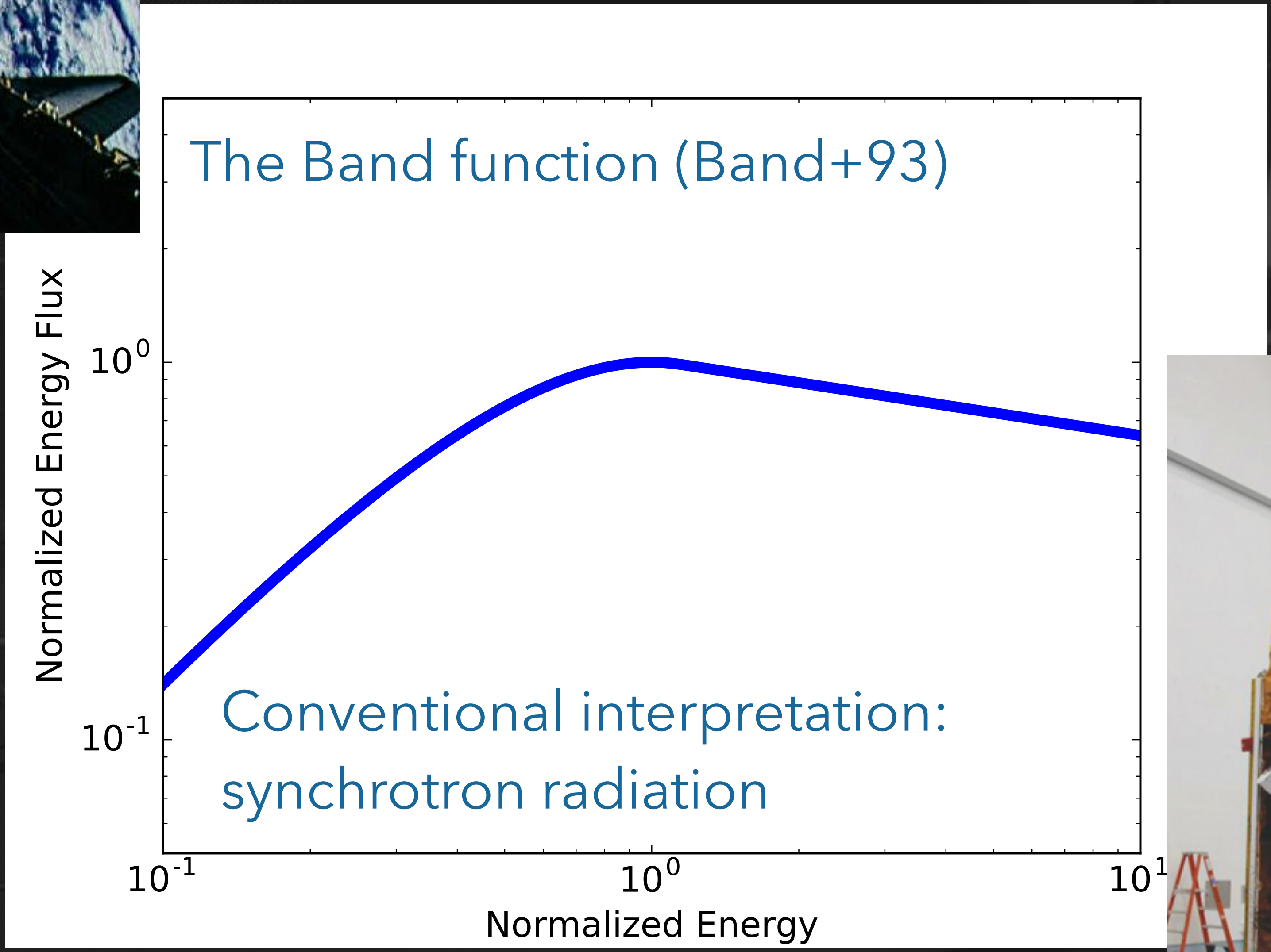
- Discovered by accident in the 1960s
- The most energetic events in the Universe: ~$10^{51\text{-}55}$ erg/s
- 0.5 events per day (over 3000 observed)
- Most likely the death cry of Pop III stars or binary neutron star mergers.
- Hyper-relativistic outflows (the compactness problem)
- Cosmological (z = 0.1 - >~ 9.0)
- No agreed upon the so-called prompt emission mechanism



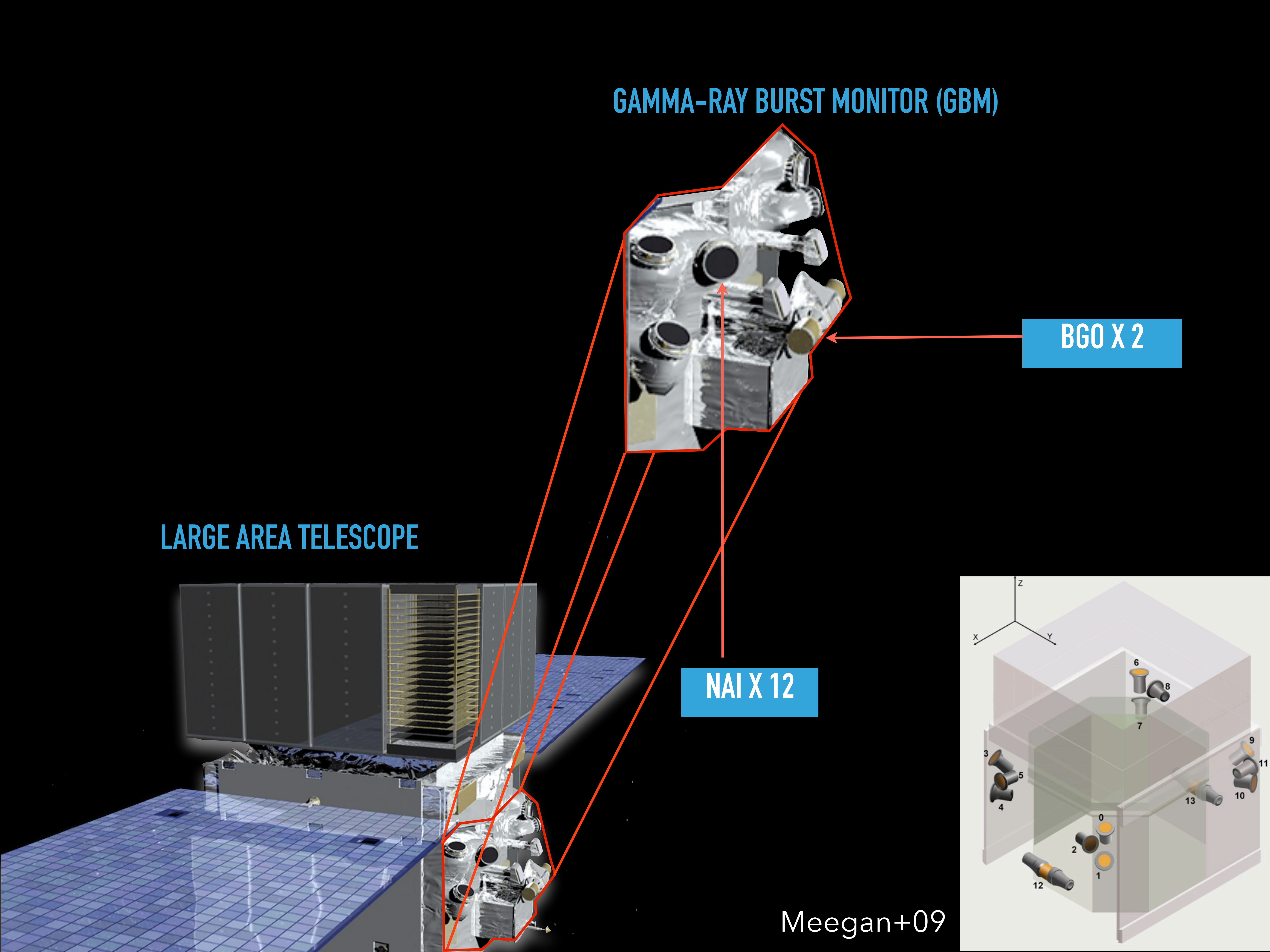
Compton Gamma Ray Observatory & BATSE
1991 - 2000

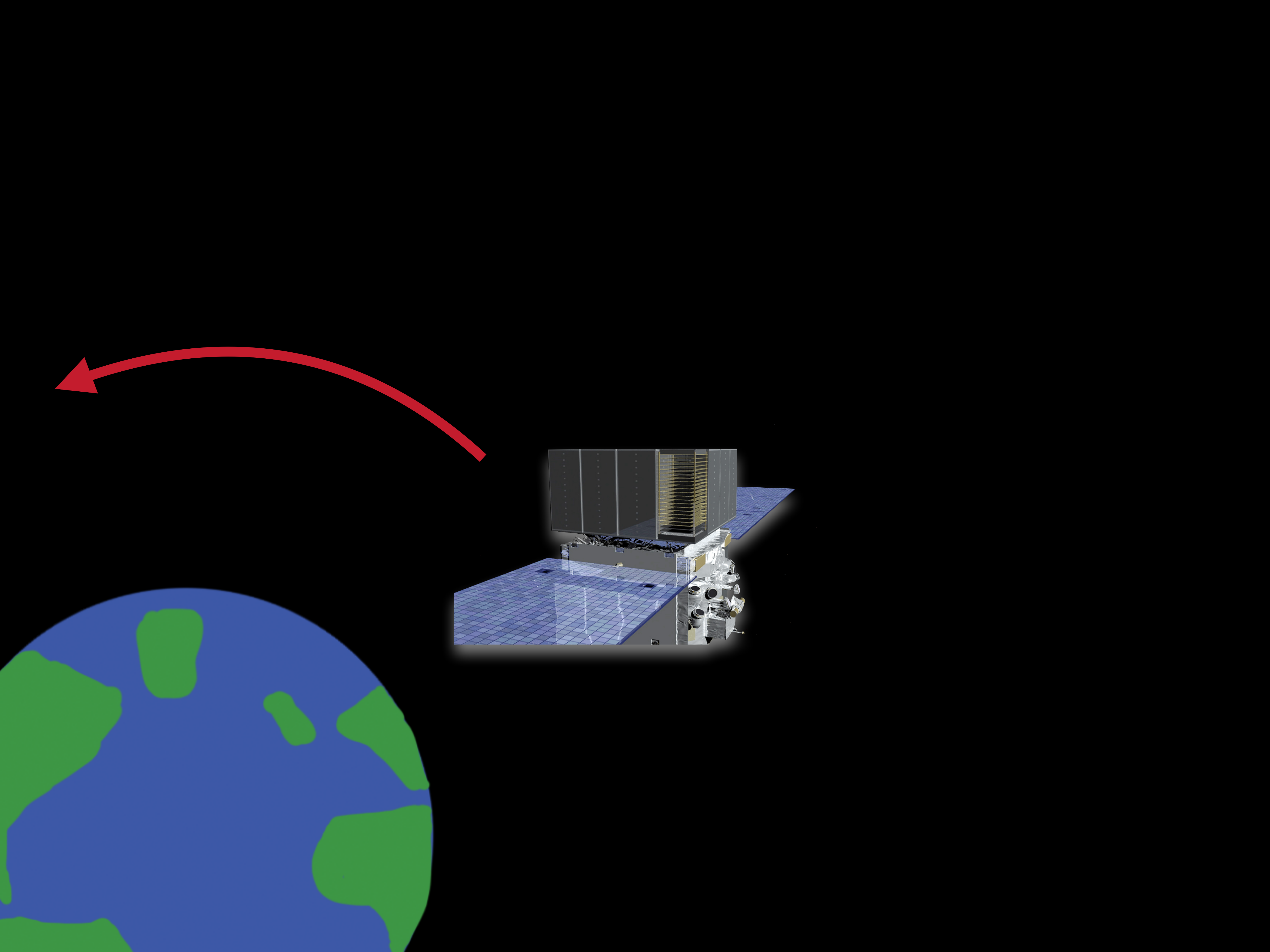


Typical GRB prompt spectrum



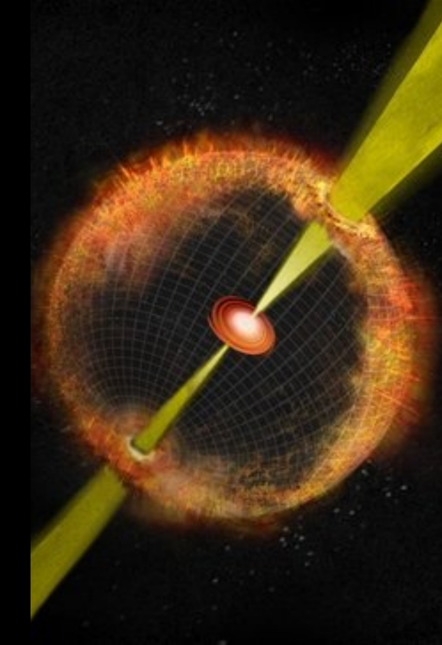
Fermi Gamma-ray Space Telescope & GBM
2008 - present

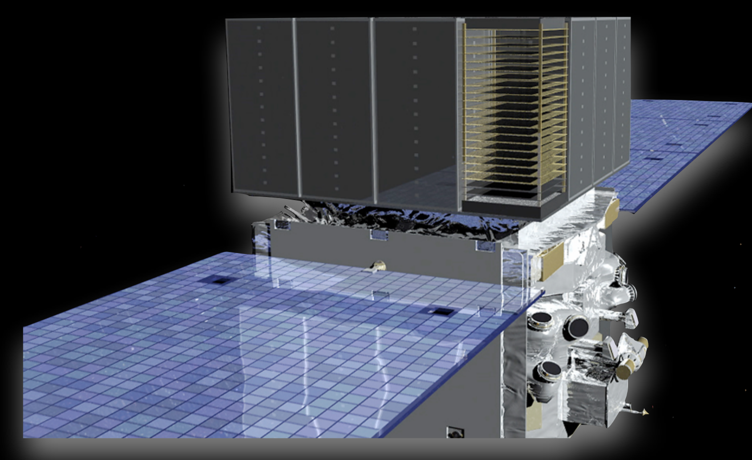

GAMMA-RAY BURST MONITOR (GBM)
BGO X 2
LARGE AREA TELESCOPE
NAI X 12
Meegan+09

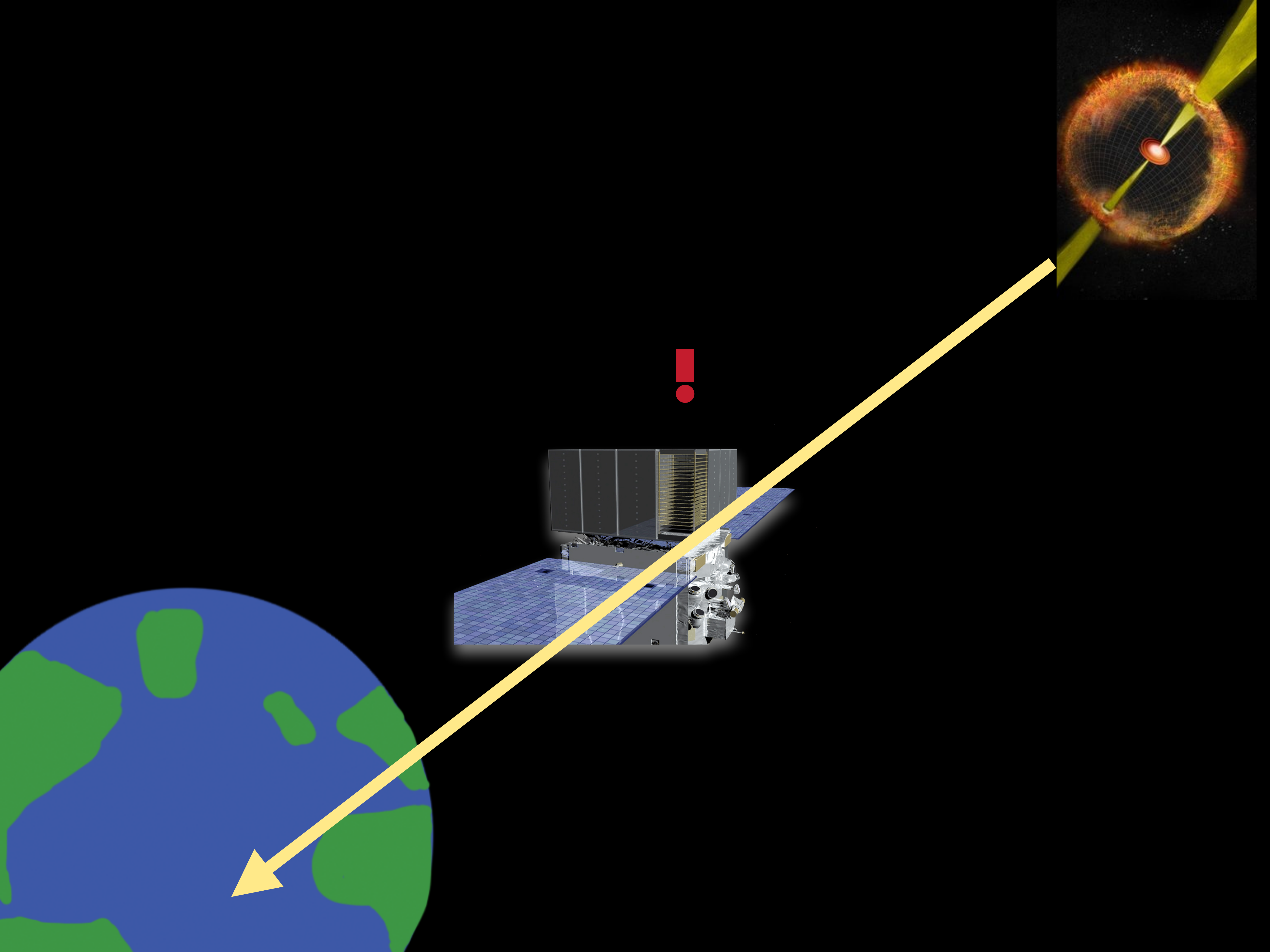


bomb!

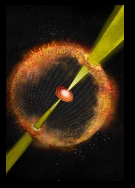
(no sound in space btw)

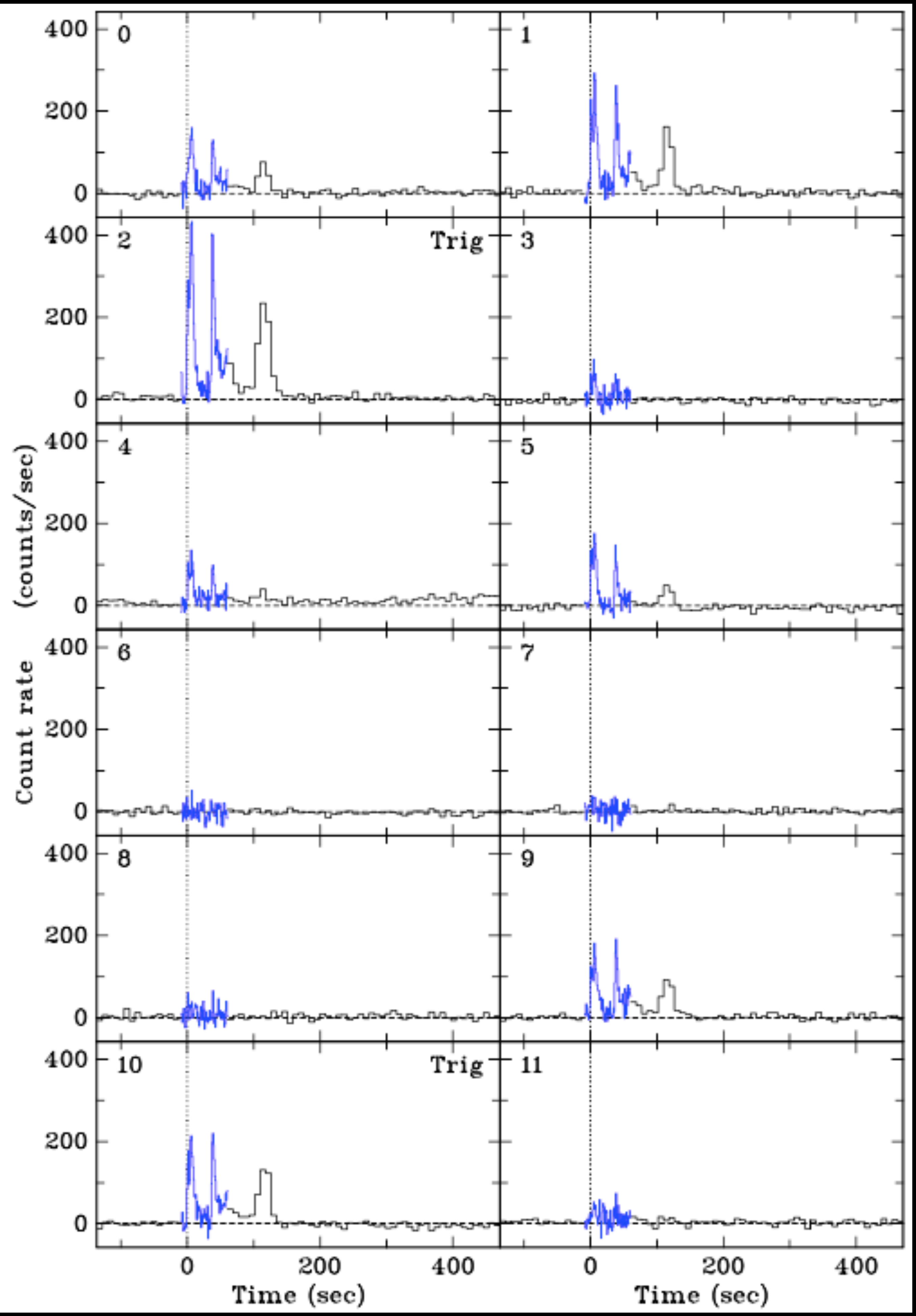


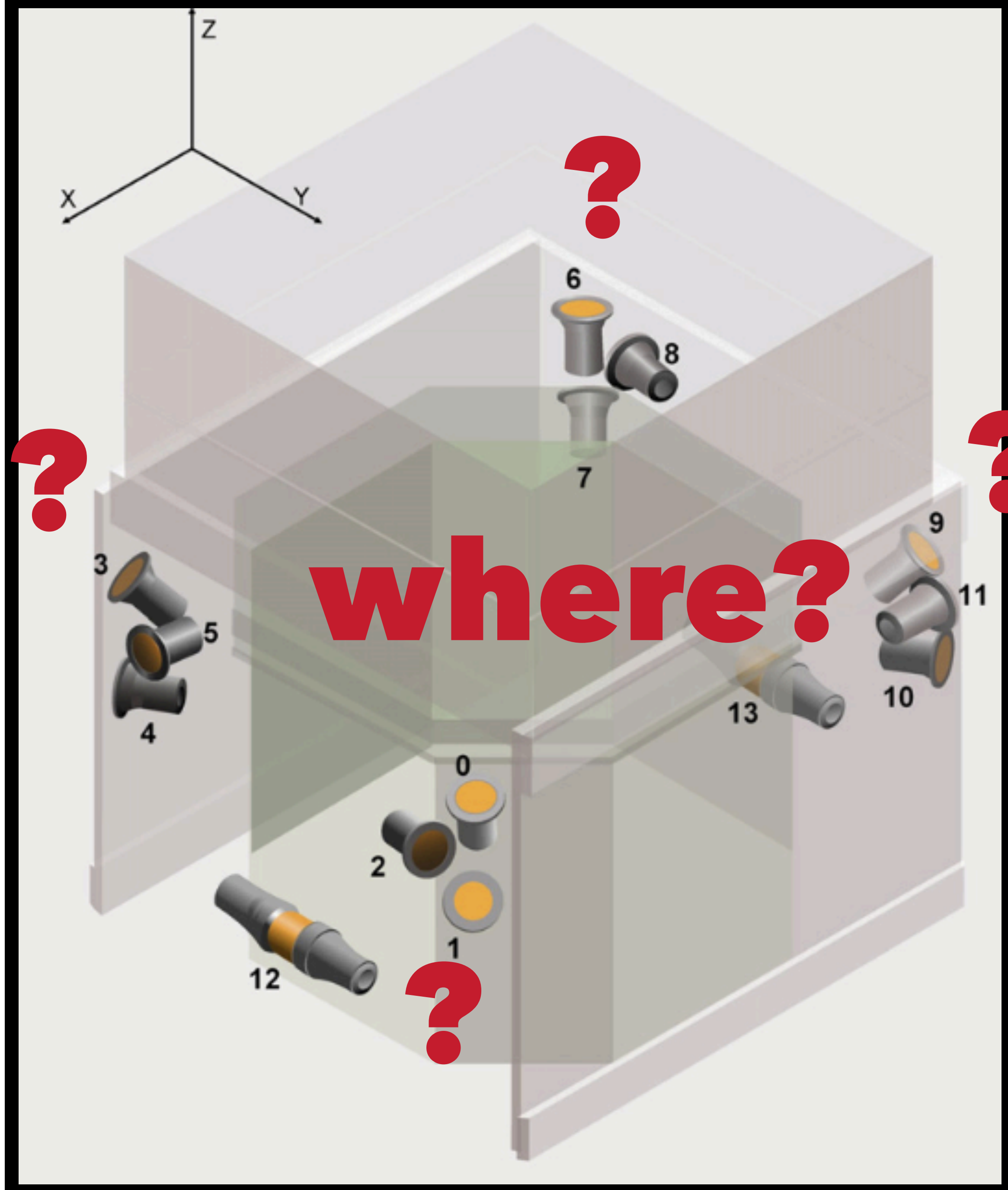




here





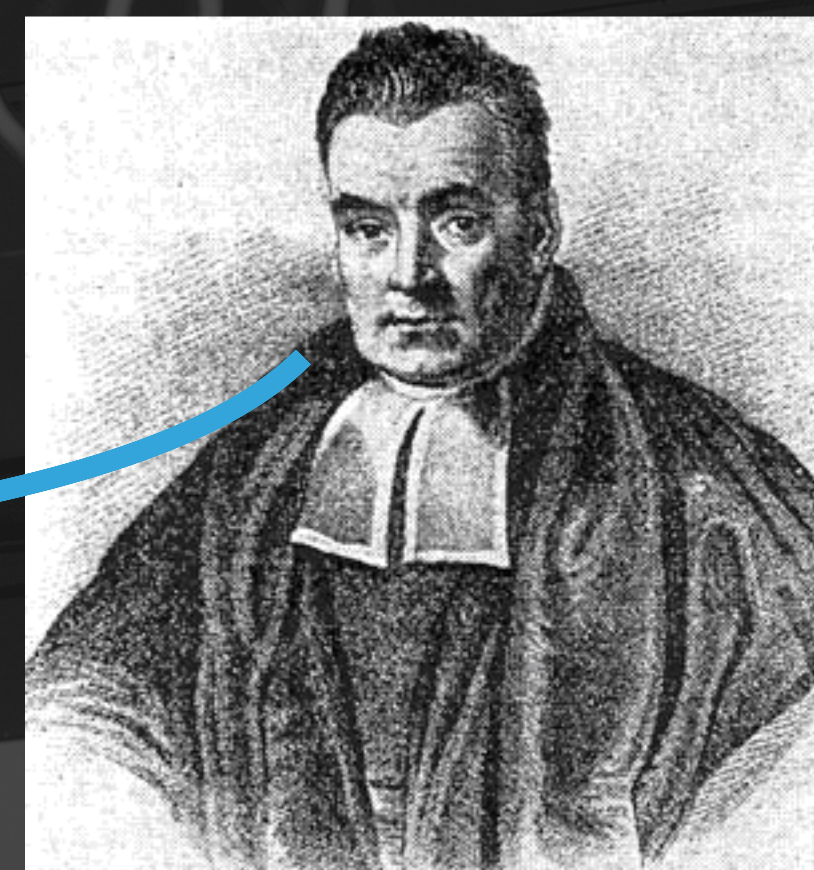


Bayes' Theorem

Posterior — Likelihood — Prior

P(model | data) = P(data | model) * P(model) / P(data)

Thou shall Bayesian.



A photon has an intrinsic energy E from a direction ψ

The detector registers its arrival time and observed energy ε

effective area

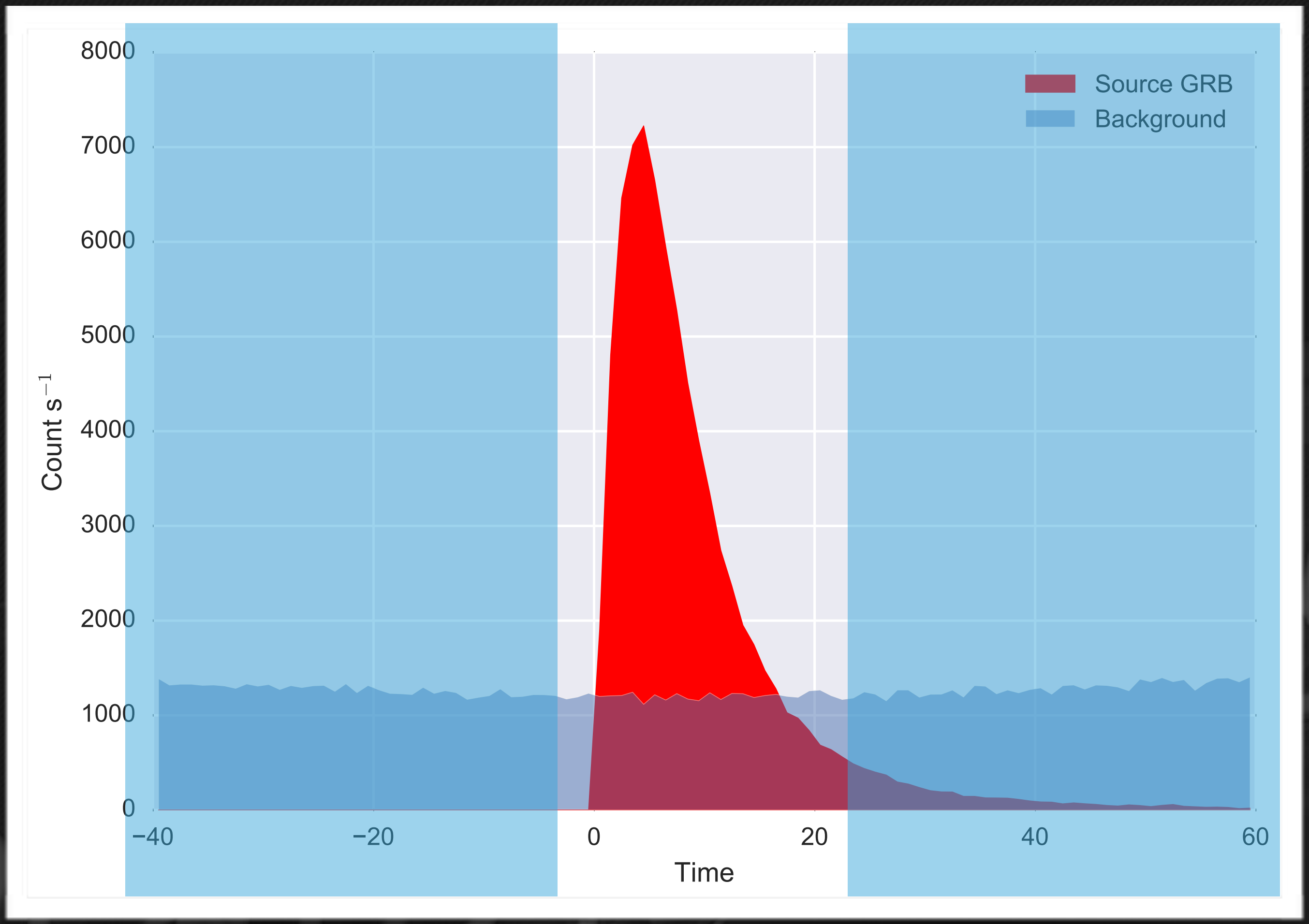
$$R_d(\varepsilon, E, \psi) = A_d(E, \psi)\,\mathrm{Pr}(\varepsilon | E, \psi, d, \text{detected})$$

detector response matrices (DRMs)

energy dispersion

Data reduction means to invert the detection process in order to obtain the intrinsic energies of a spectrum of photons at the same arrival time

First, we need to estimate the GBM BACKGROUND



- Associated errors on parameters are assumed Gaussian to allow for error propagation
- Error propagation assumes parabolic surface for profile of parameter and then Taylor expands assuming small errors
- This of course fails if any of these assumptions is false!

MODEL BACKGROUND AS POLYNOMIAL

$$P(t;\theta_0^j,\theta_1^j\ldots\theta_n^j) = \theta_0^j + \theta_1^j t + \ldots + \theta_n^j t^n$$

APPLY POISSON MLE

$$-2\log L = 2\sum_{i=1}^{N} M_i - S_i + S_i(\log S_i - \log M_i)$$

the posterior of the fit background is propagated into the on source time interval

Then, we need to define the SOURCE function

$$S_{d,c} = \int_{E_{\min,c}}^{E_{\max,c}} \mathrm{d}\varepsilon \int_0^{\infty} \mathrm{d}E \int \mathrm{d}\Omega \, n(E,\psi) \, R_d(\varepsilon, E, \psi)$$

assuming GRBs are point sources at cosmological distances

$$n(E,\psi) = f(E, \boldsymbol{\phi}_{\mathrm{S}}) \, \delta_{\mathrm{D}}(\psi, \psi_{\mathrm{S}})$$

$$S_{d,c}(\psi_{\mathrm{S}}, \boldsymbol{\phi}_{\mathrm{S}}) = \int_0^{\infty} \mathrm{d}E \, f(E, \boldsymbol{\phi}_{\mathrm{S}}) \int_{E_{\min,c}}^{E_{\max,c}} \mathrm{d}\varepsilon \, R_d(\varepsilon, E, \psi_{\mathrm{S}})$$

Φ_s are the GRB spectral energy distribution (SED) parameters

Bayes' Theorem

Posterior Likelihood Prior

P(model | data) = P(data | model) * P(model) / P(data)

$$\Pr(\{N_{d,c}\}|\psi_\mathrm{s},\boldsymbol{\phi}_\mathrm{s}) = \prod_{d=1}^{N_\mathrm{d}} \prod_{c=1}^{N_\mathrm{c}} \Pr\left[N_{d,c}|S_{d,c}(\psi_\mathrm{s},\boldsymbol{\phi}_\mathrm{s})\right]$$

for a single channel:

$$\Pr(N|S,B) = \frac{[(S+B)\,T]^N\, e^{-(S+B)\,T}}{N!}$$

Bayes' Theorem

Posterior | Likelihood | Prior

P(model | data) = P(data | model) * P(model) / P(data)

$$\Pr(\psi_\mathrm{S}, \phi_\mathrm{S} | \mathrm{GRB}) = \Pr(\psi_\mathrm{S} | \mathrm{GRB}) \Pr(\phi_\mathrm{S} | \mathrm{GRB})$$

ψ_s $\Pr(\psi_\mathrm{S} | \mathrm{GRB}) = 1/(4\pi)$

Φ_s uniform with appropriate bounds

Bayes' Theorem

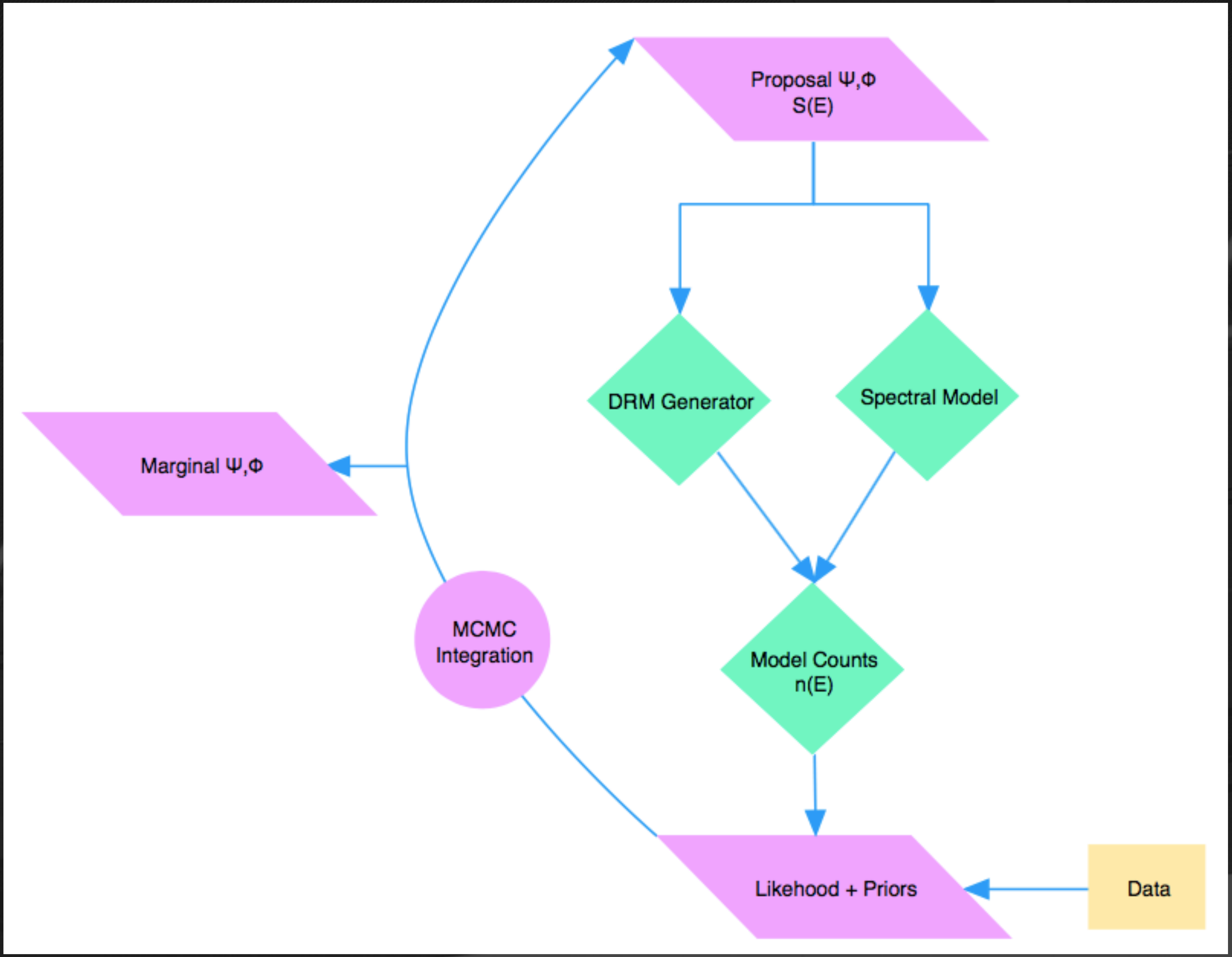
Posterior Likelihood Prior

P(model | data) = P(data | model) * P(model) / P(data)

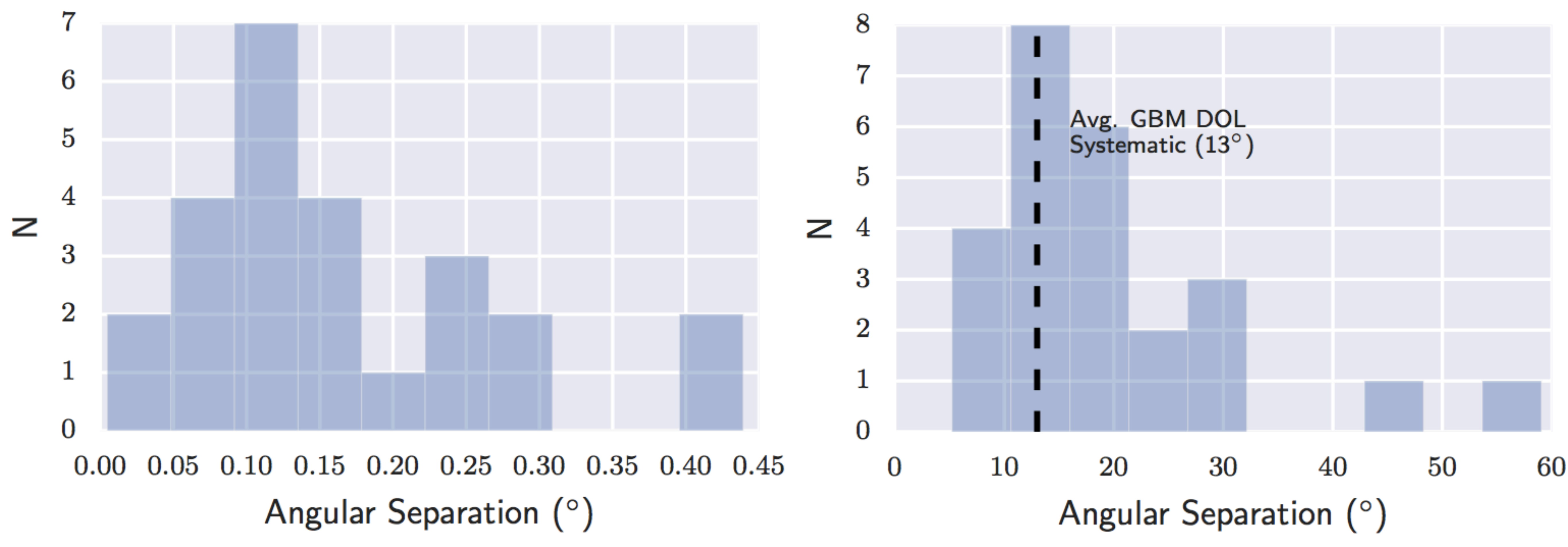
$$\Pr(\psi_{\mathrm{S}}, \boldsymbol{\phi}_{\mathrm{S}} | \{N_{d,c}\}, \mathrm{GRB}) \propto \Pr(\psi_{\mathrm{S}}, \boldsymbol{\phi}_{\mathrm{S}} | \mathrm{GRB}) \Pr(\{N_{d,c}\} | \psi_{\mathrm{S}}, \boldsymbol{\phi}_{\mathrm{S}})$$

BALROG (BAyesian Location Reconstruction Of Gamma-ray bursts)

BALROG scheme



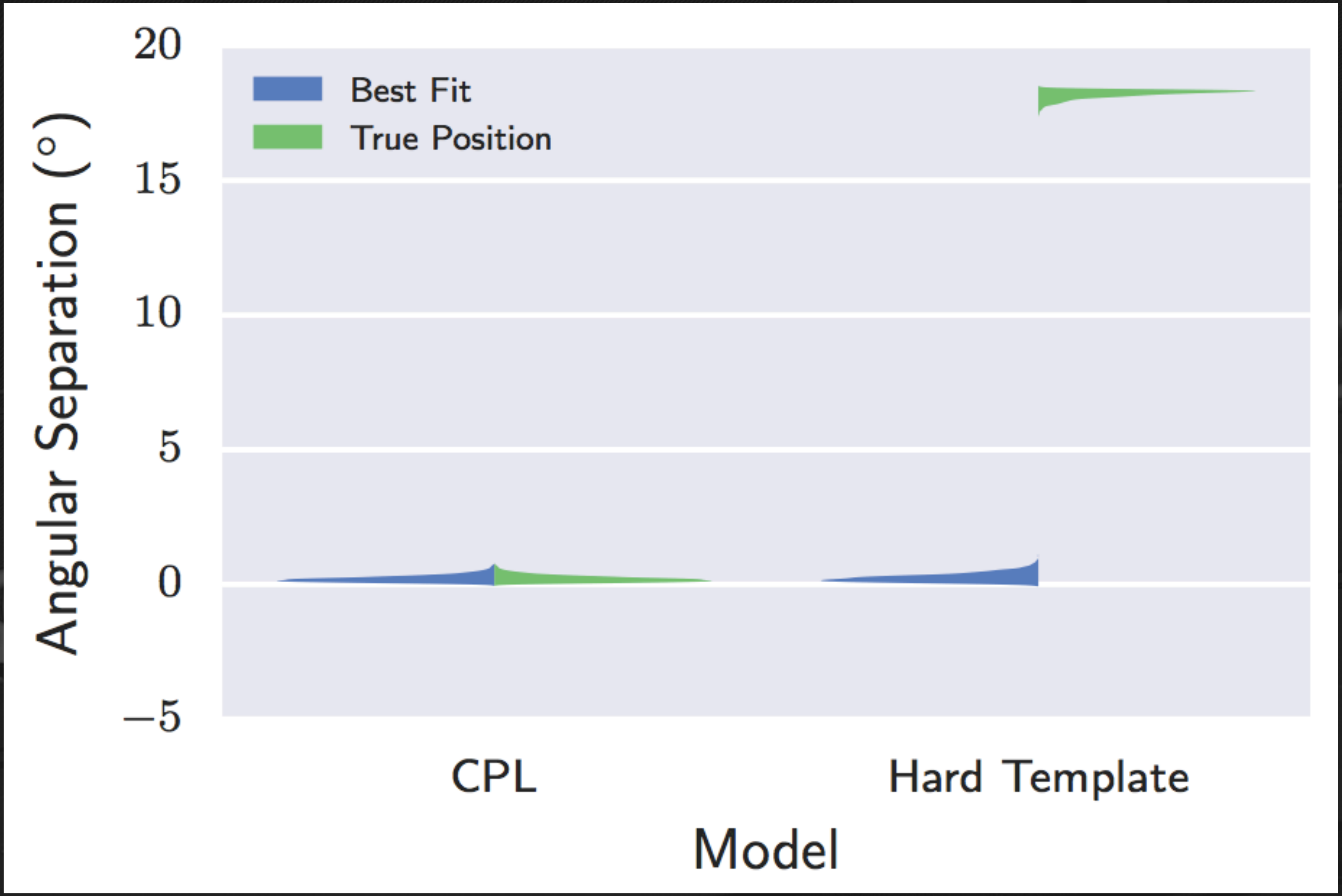
Checking BALROG with simulated bursts



CPL

standard "hard' template (Connaughton+15)

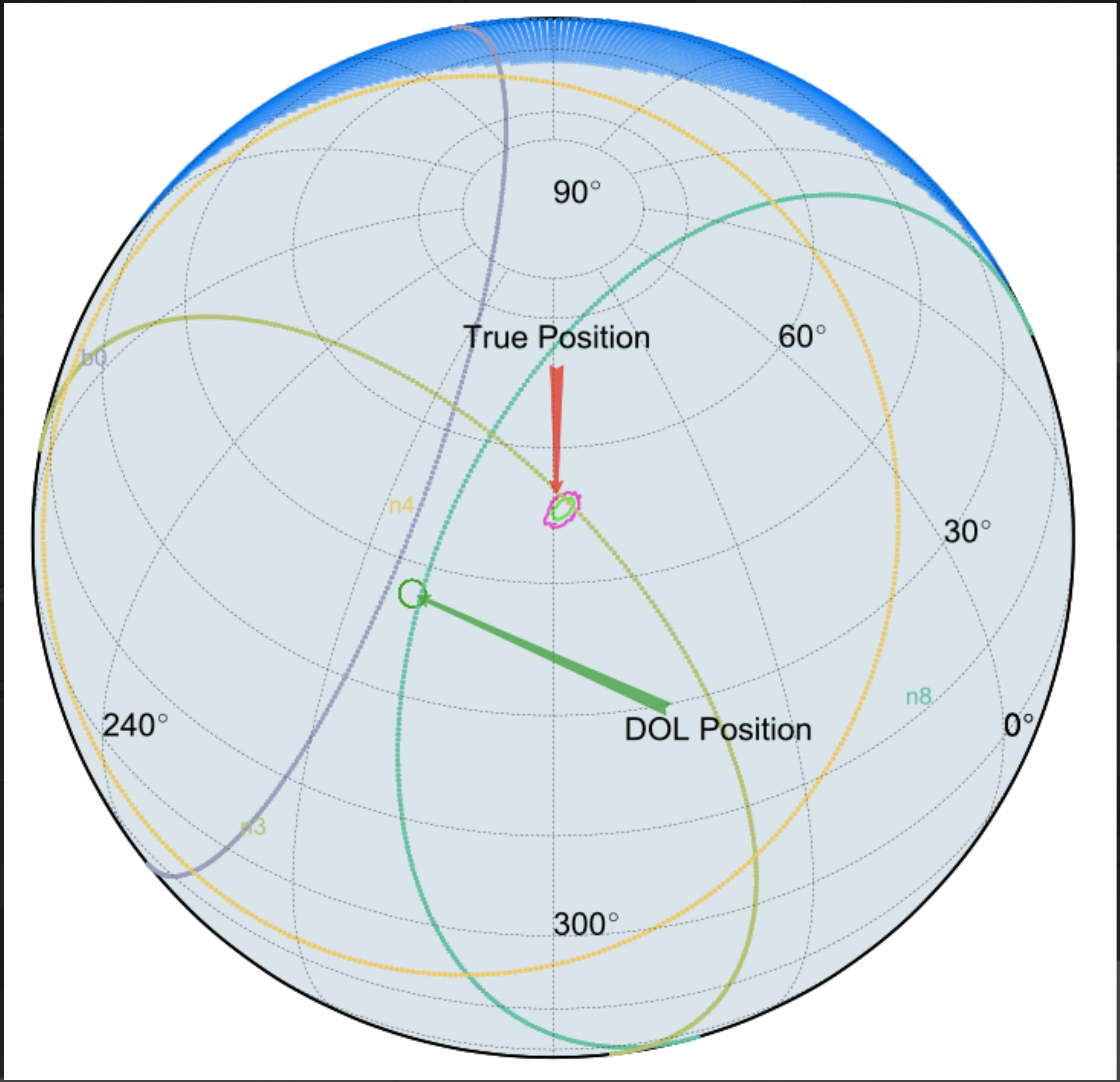
Checking BALROG with simulated bursts



angular separation of the location posterior and the best fit location (blue) and true location (green)

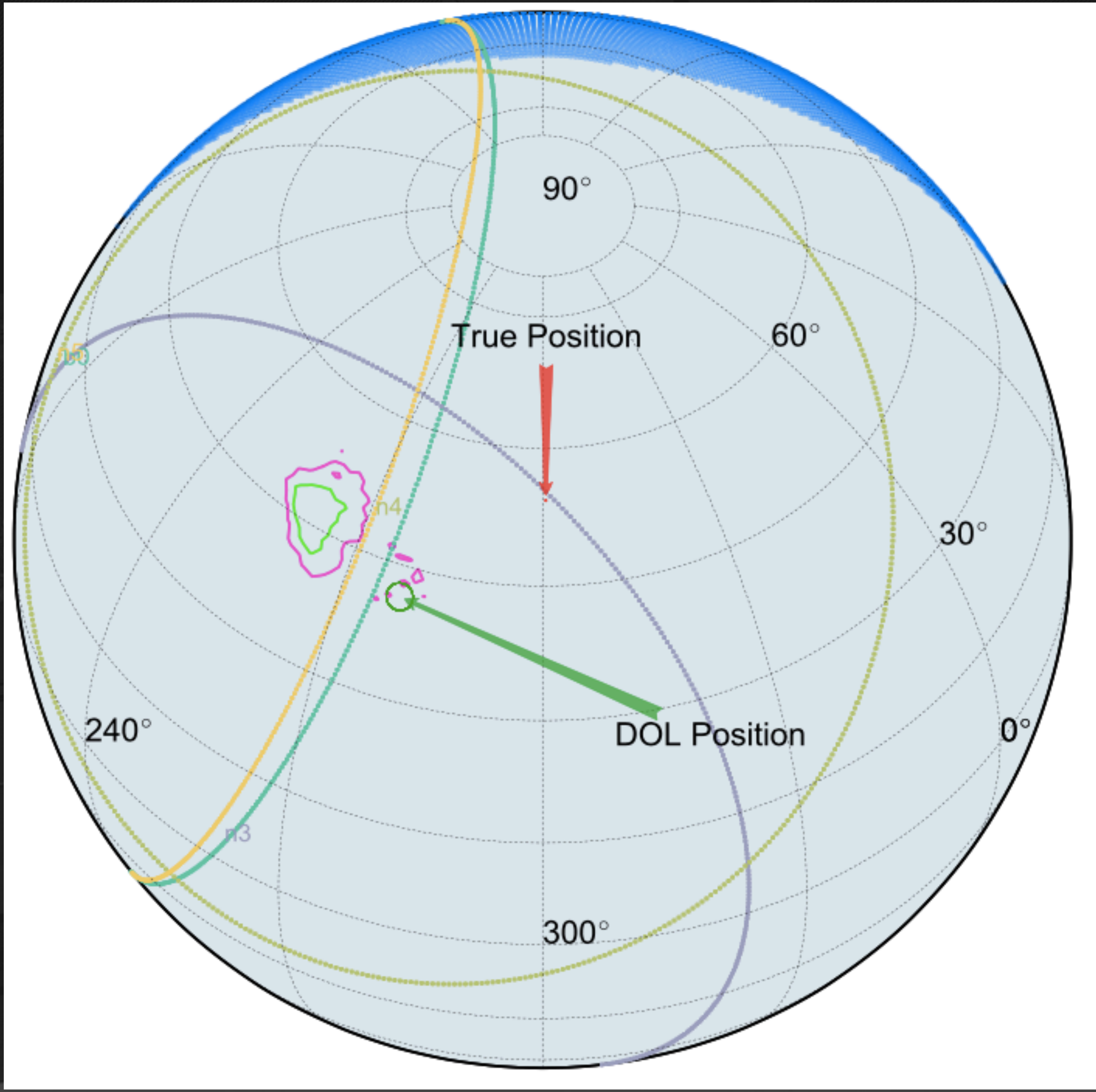
BALROG result for GRB 121128212

CPL + subset of detectors



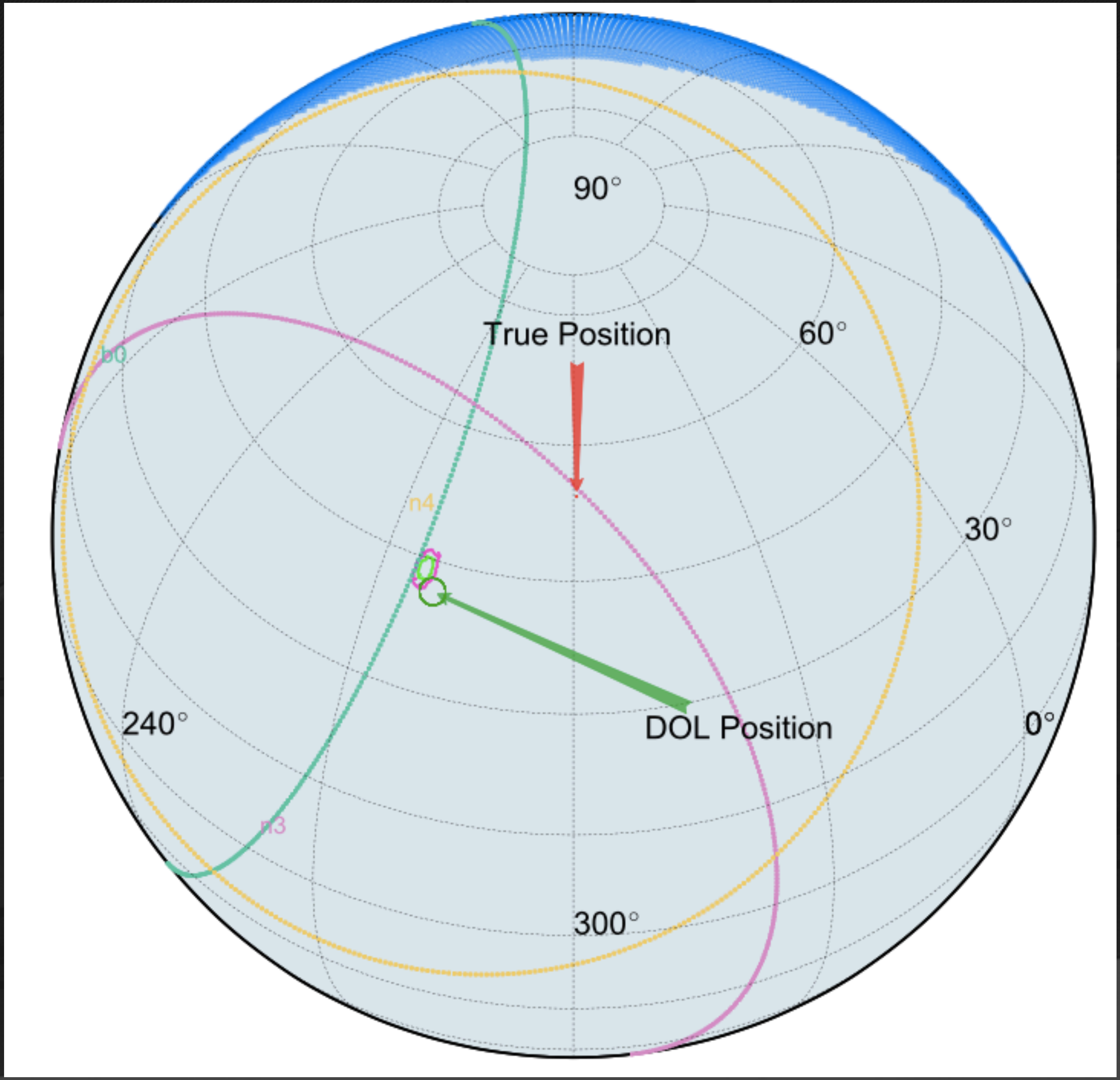
BALROG result for GRB 121128212

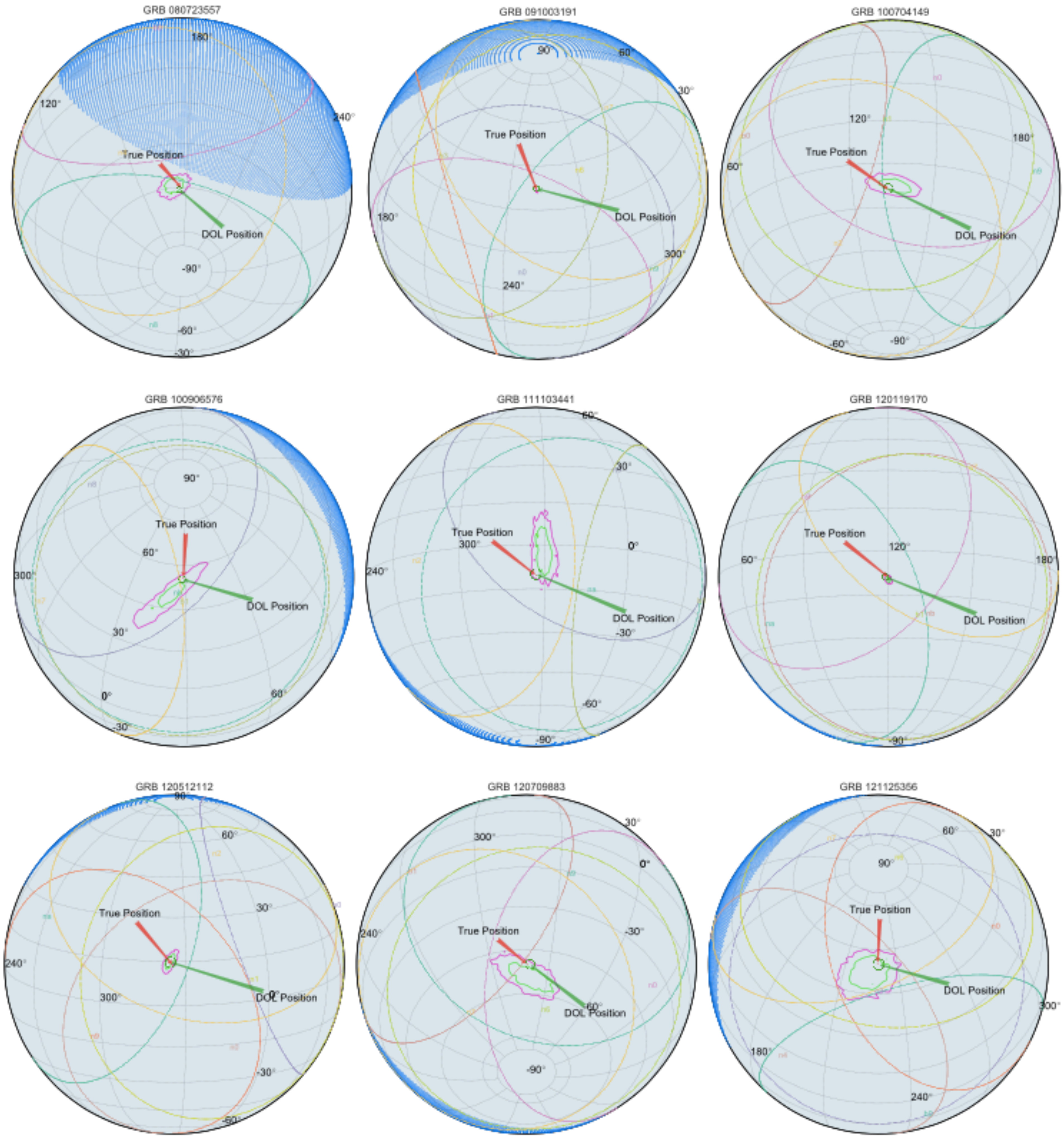
"hard" template + subset of detectors

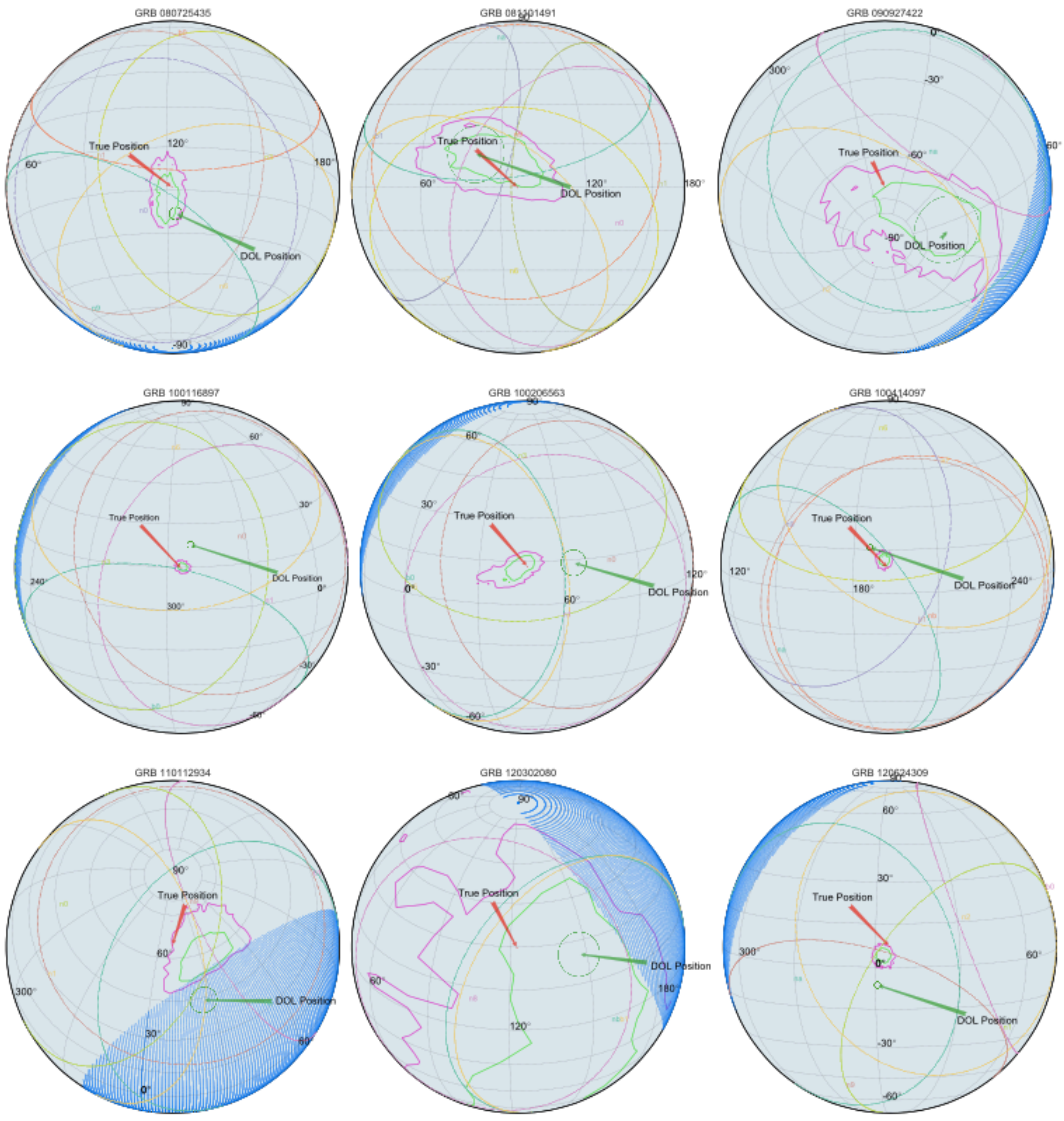


BALROG result for GRB 121128212

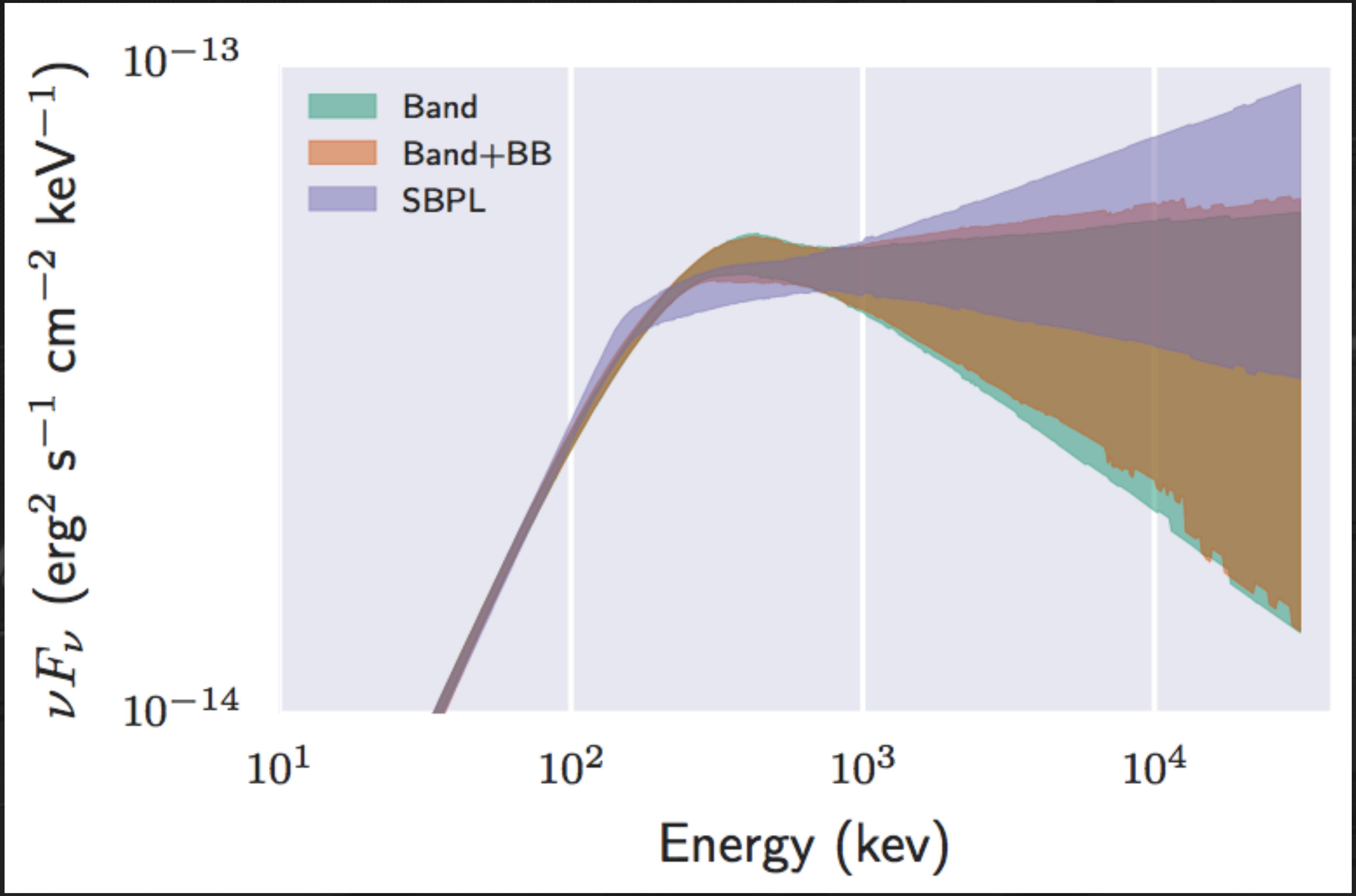
CPL + all detectors




GRB 080723557
True Position
DOL Position
GRB 091003191
True Position
DOL Position
GRB 100704149
True Position
DOL Position
GRB 100906576
True Position
DOL Position
GRB 111103441
True Position
DOL Position
GRB 120119170
True Position
DOL Position
GRB 120512112
True Position
DOL Position
GRB 120709883
True Position
DOL Position
GRB 121125356
True Position
DOL Position

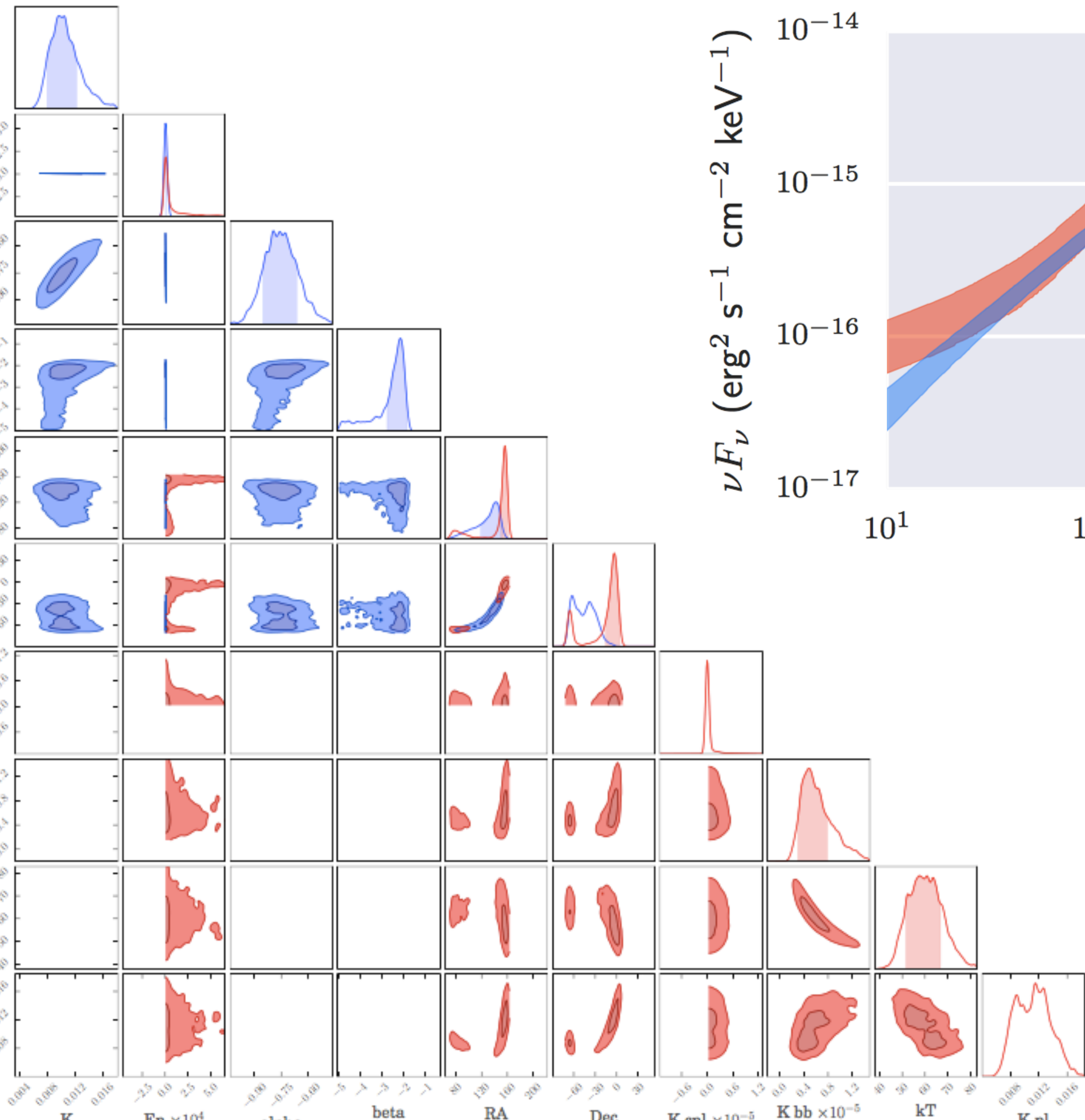

GRB 080725435
True Position
DOL Position
GRB 081101491
True Position
DOL Position
GRB 090927422
True Position
DOL Position
GRB 100116897
True Position
DOL Position
GRB 100206563
True Position
DOL Position
GRB 100414097
True Position
DOL Position
GRB 110112934
True Position
DOL Position
GRB 120302080
True Position
DOL Position
GRB 120624309
True Position
DOL Position

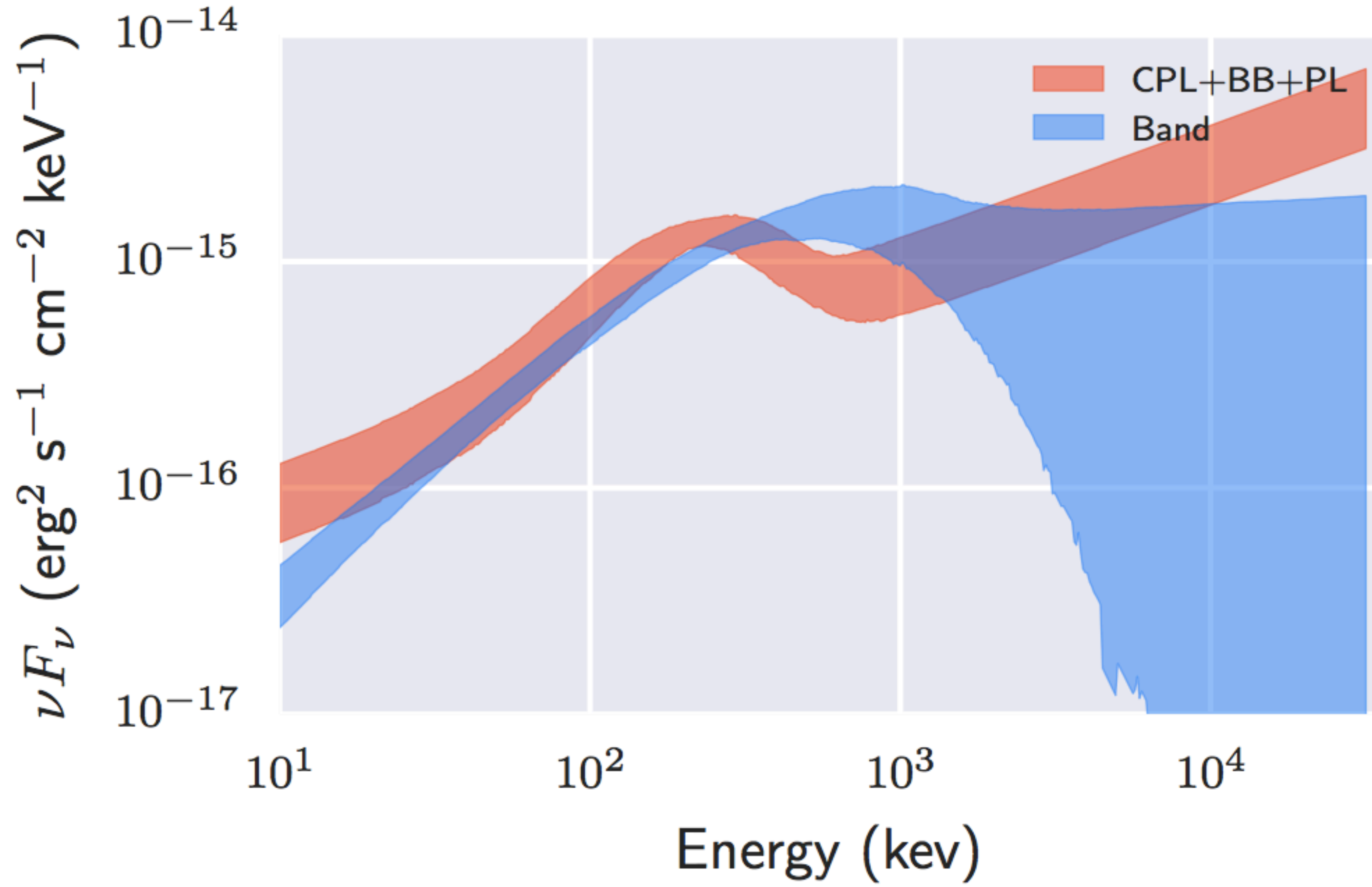
BALROG result for GRB 080916C



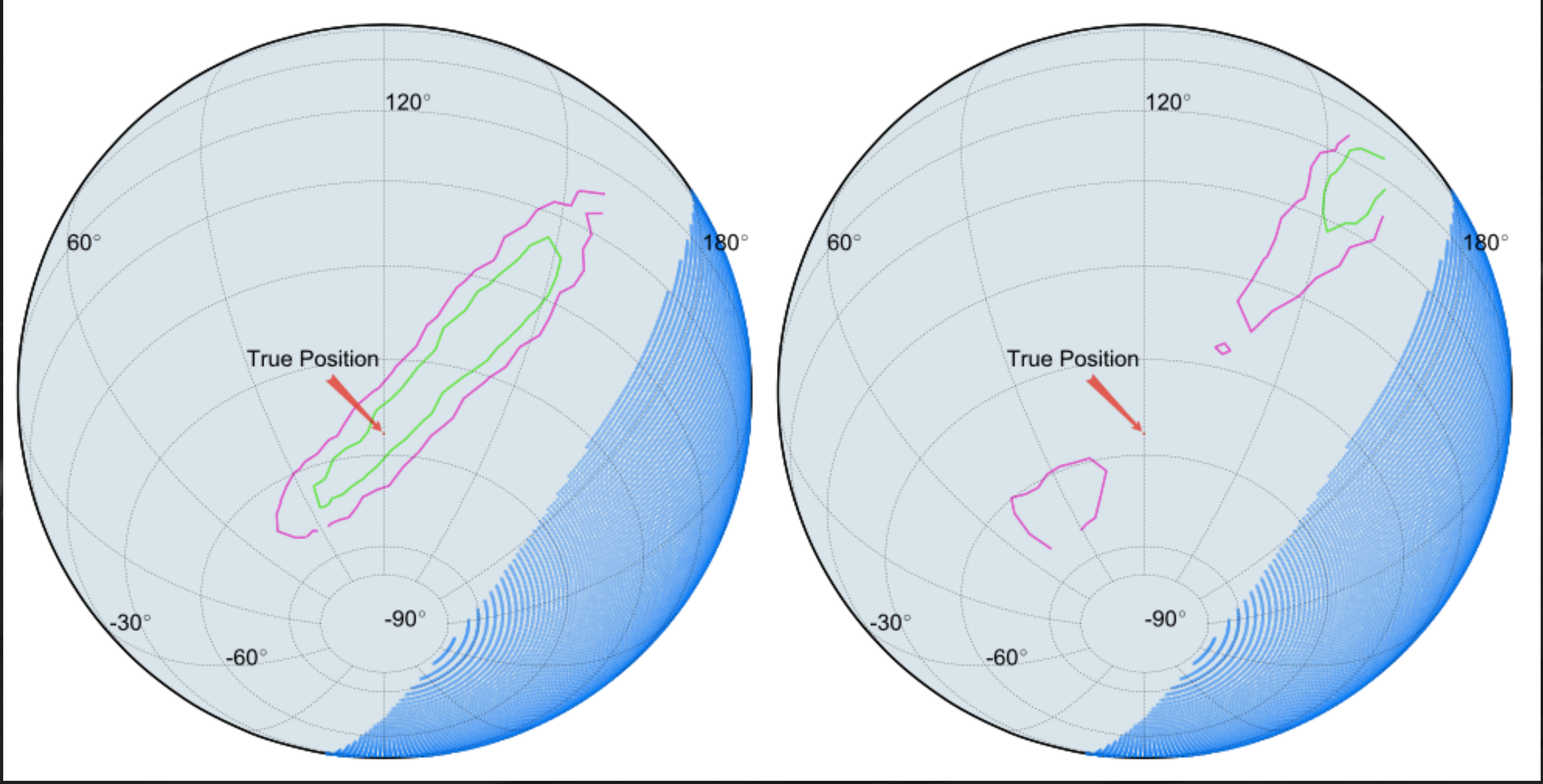
BALROG prefers Band function only

BALROG result for GRB 080916C





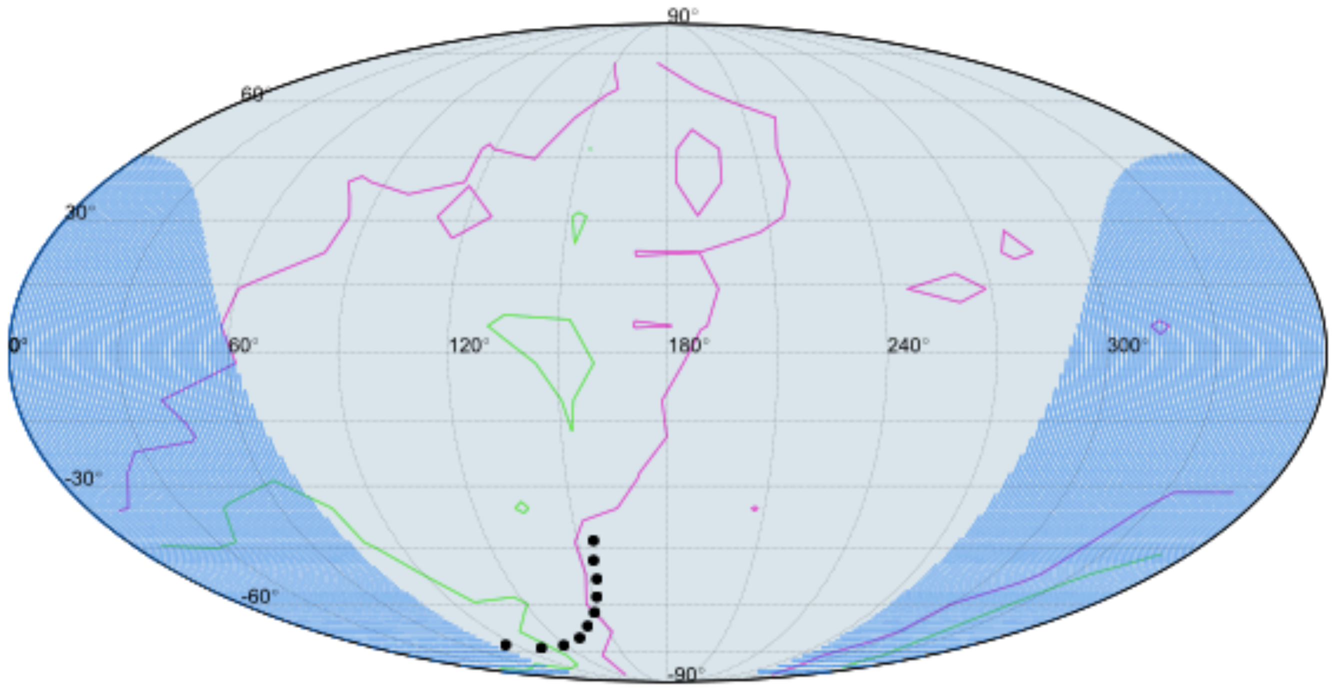
BALROG result for GRB 080916C

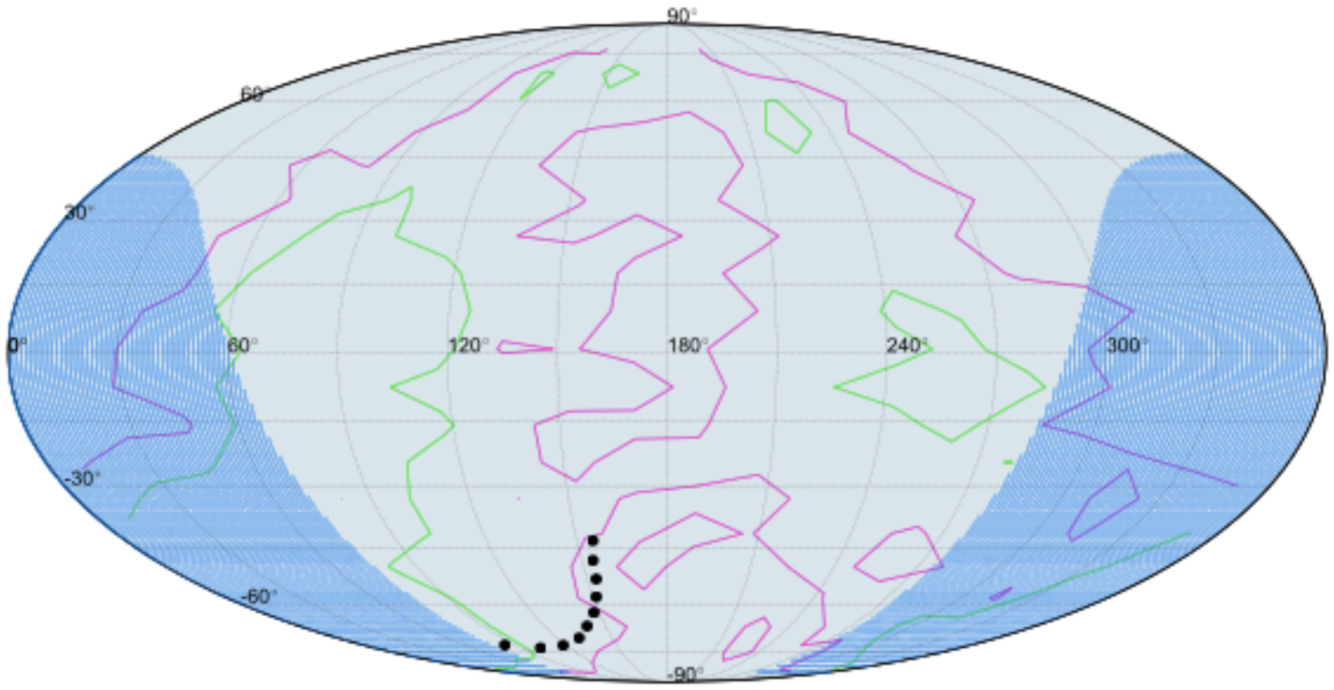


BALROG result for the claimed GBM signal of GW 150914

PL

CPL

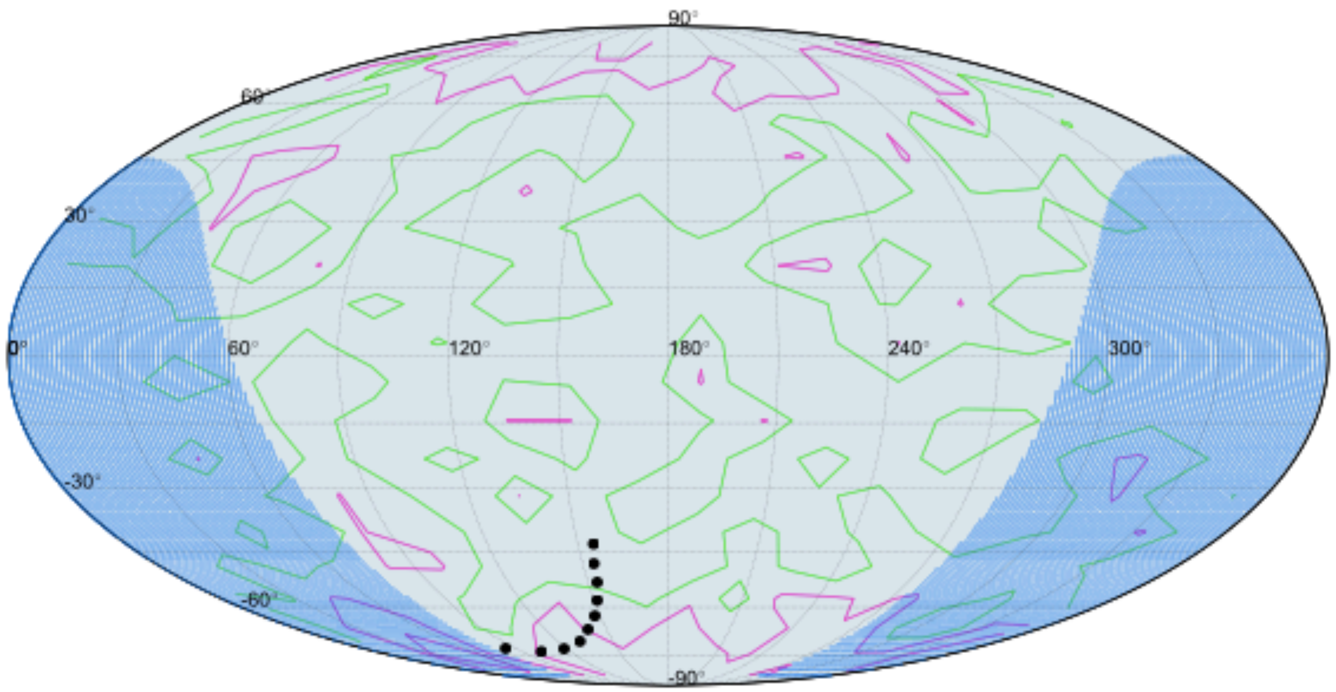




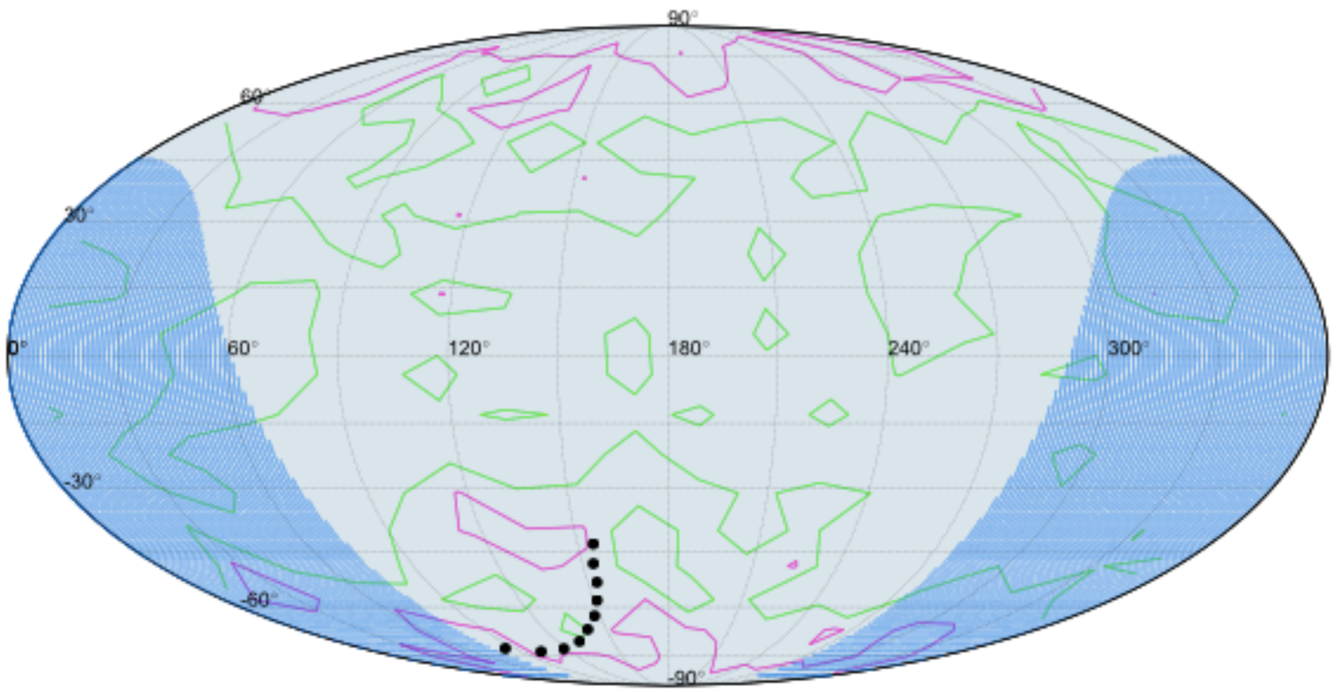
all detectors, as in Connaughton+16

BALROG result for the claimed GBM signal of GW 150914

PL

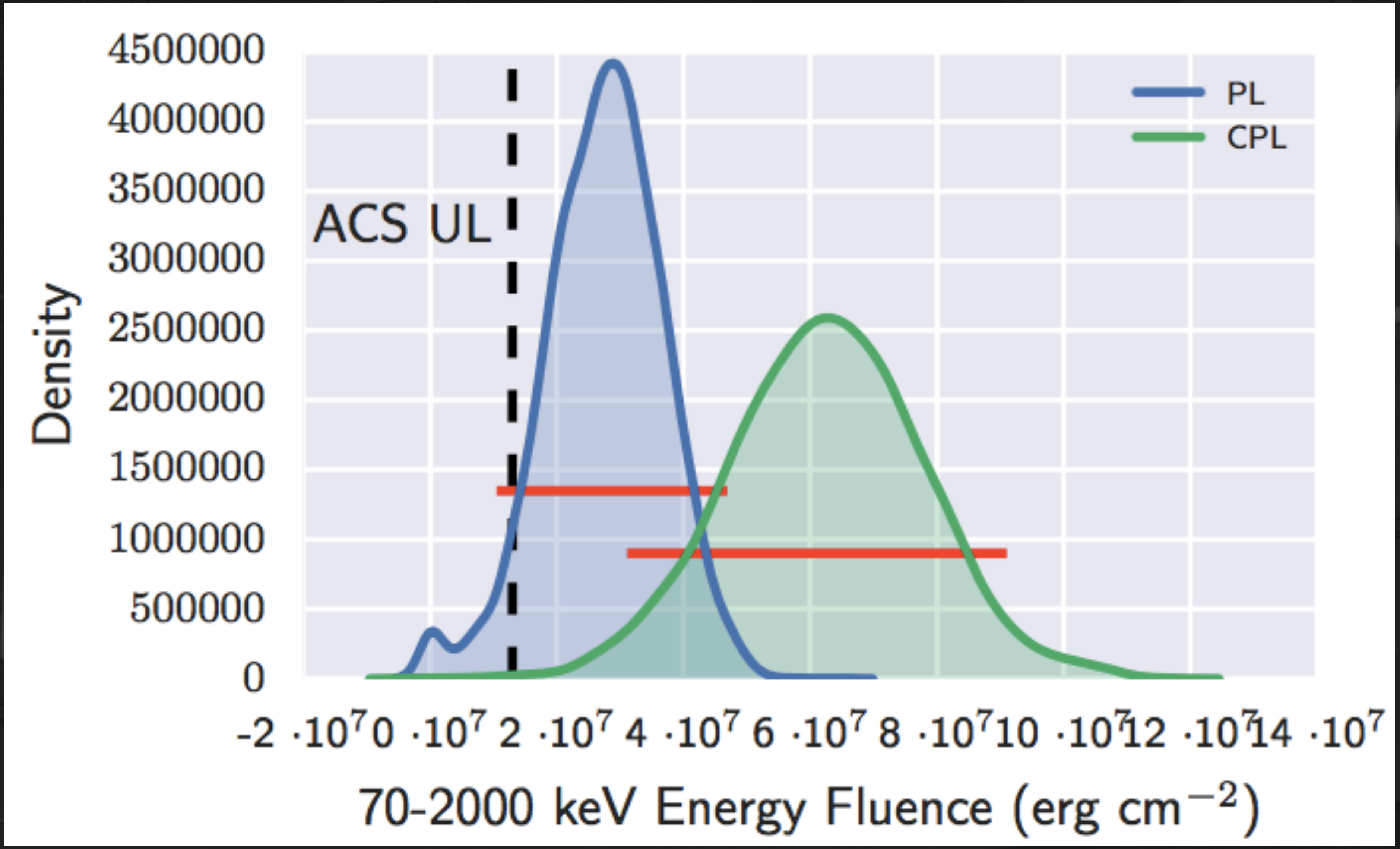


CPL



only n5 and b0, as in Greiner+16

BALROG result for the claimed GBM signal of GW 150914



see Greiner+16 and Savchenko+16 for more details!

BALROG on arXiv:1610.07385

MNRAS 000, 1–20 (2016) Preprint 7 November 2016 Compiled using MNRAS LaTeX style file v3.0

Awakening the BALROG (BAyesian Location Reconstruction Of GRBs): A new paradigm in spectral and location analysis of gamma ray bursts

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Accepted XXXX December XX. Received XXXX December XX; in original form 2016 October XX