Rapid follow up of high energy transients

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Partially based on LIGO-G1701190

Rapid follow up of high energy transients

Gamma ray bursts
EM counterparts to GW sources

EM signatures

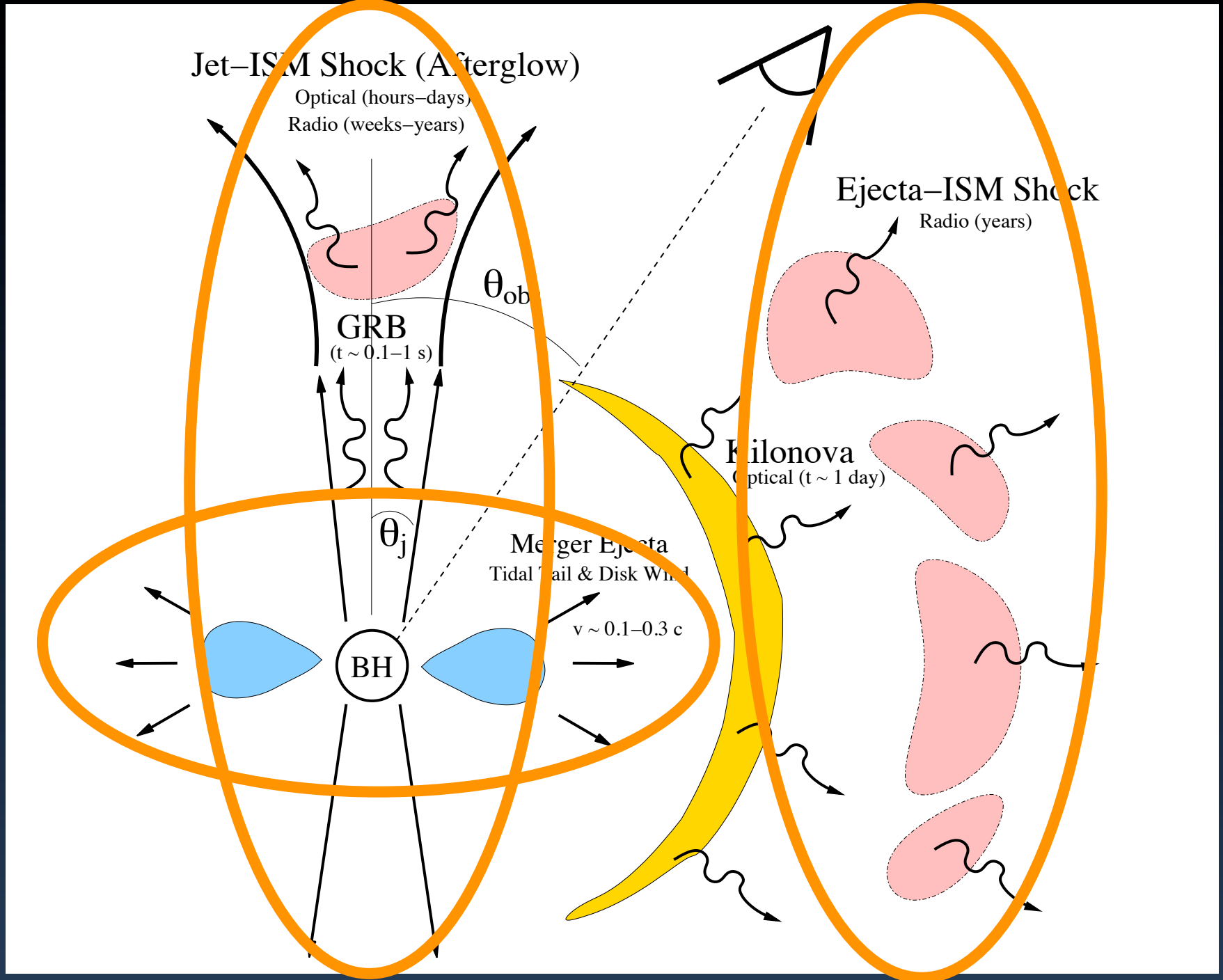


Figure from Metzger & Berger, 2012, ApJ, 746, 48

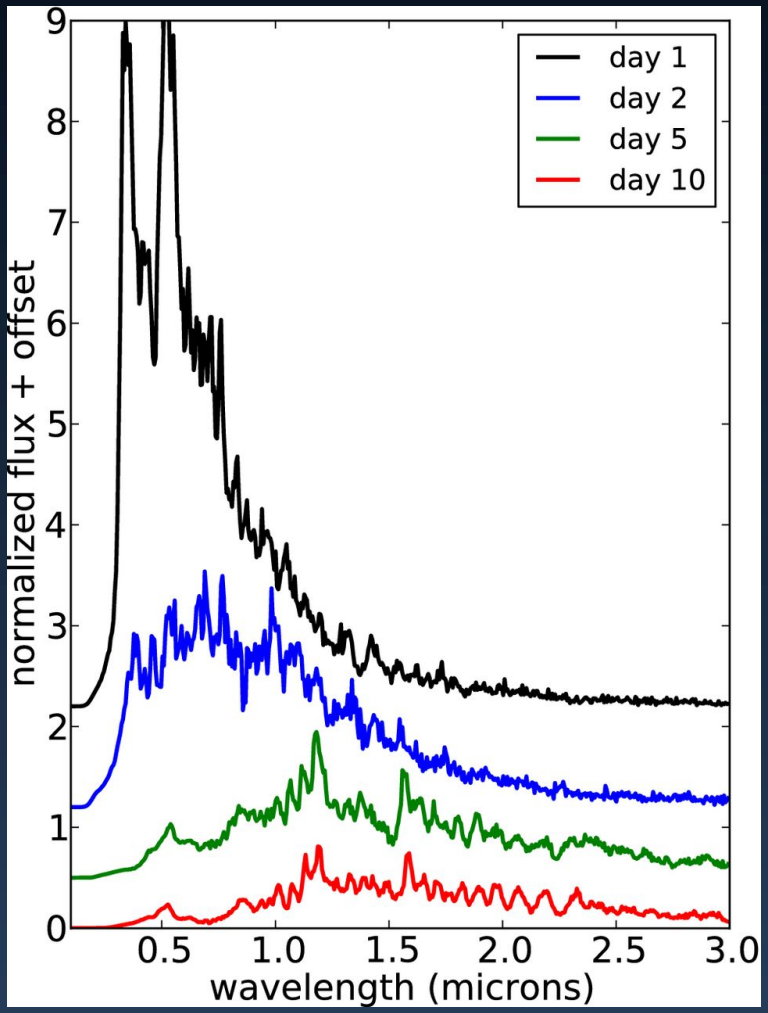
X-ray signatures

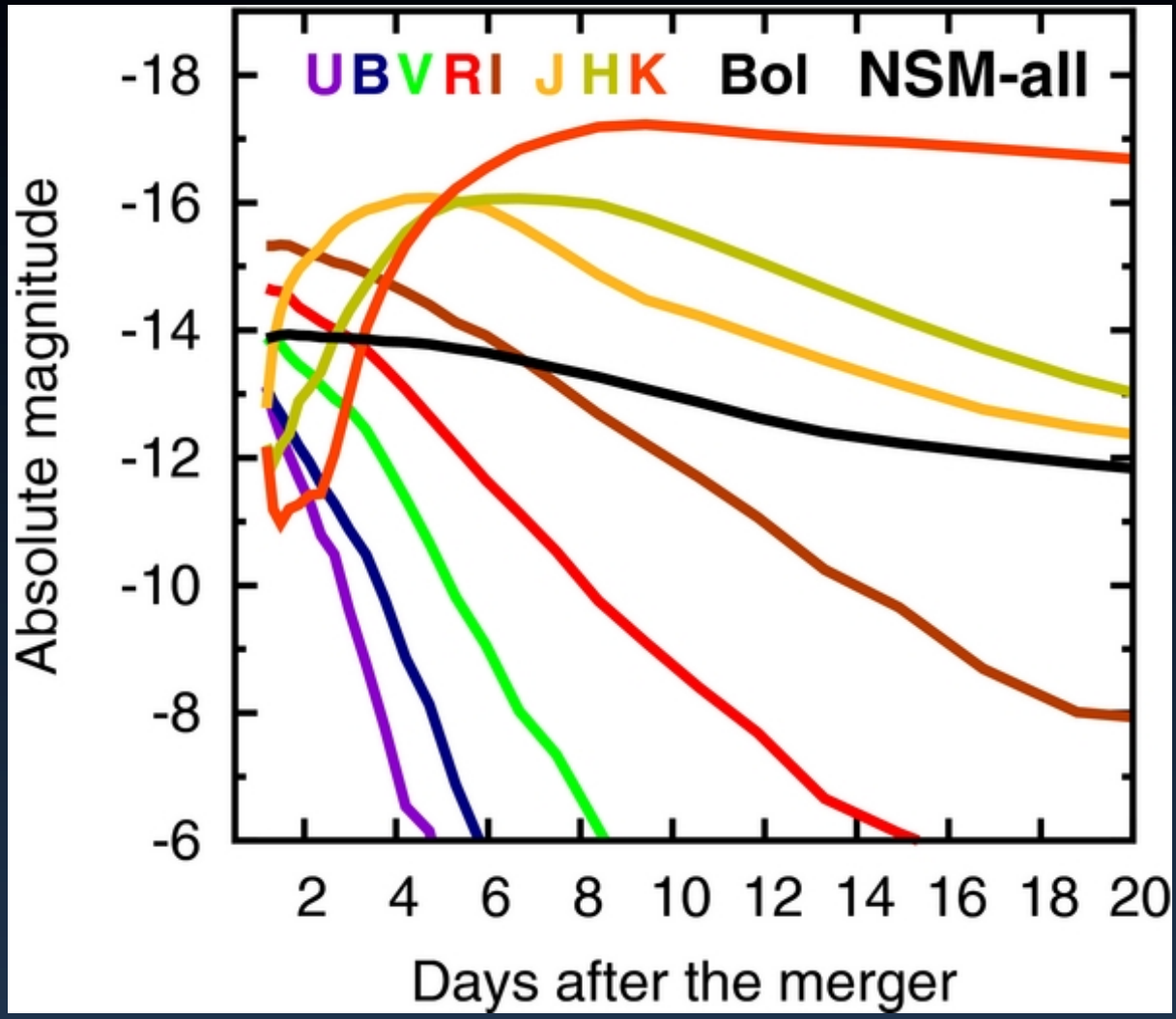
- Gamma Ray Burst!
  - » The final proof associating Short Hard GRBs to merger of two neutron stars

- Only if nearly face-on system
  - » May have some near-isotropic emission component

Optical/IR

- GRB afterglows
- Kilonovae





Theoretical kilonova lightcurves: Takana & Hotokezaka 2013

← Simulated kilonova spectra, Kasen, Metzger 7 Berger 2015

Rapid follow up of high energy transients

Wavebands
Timescales

Rapid followup

- Gamma-ray / X-rays
  - » Seconds – minutes
- Optical
  - » Minutes – hours
- Radio
  - » Months – years

Follow-up challenges

The follow-up challenge

Right place,

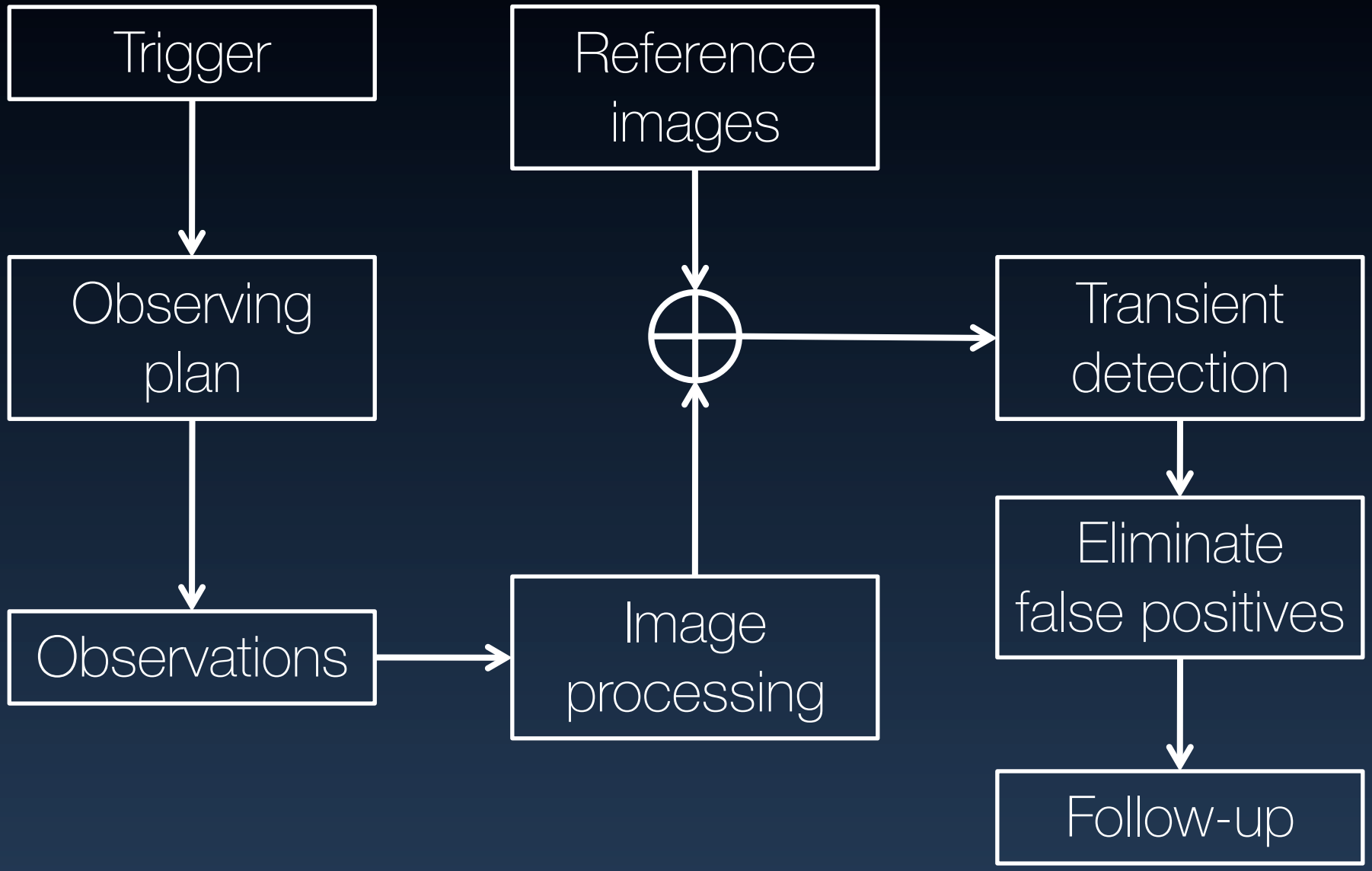
Right time,

Right equipment

Overcoming the challenge

- Hardware:
  - » Rapid slew capabilities
  - » Constant connectivity
- Software:
  - » Automated responses (GCNs)
  - » Decision and priority algorithms
- Logistical:
  - » Remove humans from loop
  - » Add redundancy

Finding transients



Needle in the 100 deg2 haystack

Singer et al, 2015, ApJ, 806, 52

The Astrophysical Journal, 806:52 (22pp), 2015 June 10 doi:10.1088/0004-637X/806/1/52

THE NEEDLE IN THE 100 deg^2 HAYSTACK: UNCOVERING AFTERGLOWS OF *FERMI* GRBs WITH THE PALOMAR TRANSIENT FACTORY

Leo P. Singer[1,2,32], Mansi M. Kasliwal[3], S. Bradley Cenko[2,4], Daniel A. Perley[5,33], Gemma E. Anderson[6,7], G. C. Anupama[8], Iair Arcavi[9,10], Varun Bhalerao[11], Brian D. Bue[12], Yi Cao[5], Valerie Connaughton[13], Alessandra Corsi[14], Antonino Cucchiara[2,32], Rob P. Fender[6,7], Derek B. Fox[15], Neil Gehrels[2], Adam Goldstein[16,32], J. Gorosabel[17,18,19], Assaf Horesh[20], Kevin Hurley[21], Joel Johansson[22], D. A. Kann[23,24], Chryssa Kouveliotou[16], Kuiyun Huang[25], S. R. Kulkarni[5], Frank Masci[26], Peter Nugent[27,28], Arne Rau[24], Umaa D. Rebbapragada[12], Tim D. Staley[6,7], Dmitry Svinkin[29], C. C. Thöne[17], A. de Ugarte Postigo[17,30], Yuji Urata[31], and Alan Weinstein[1]

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Received 2015 January 2; accepted 2015 February 28; published 2015 June 8

ABSTRACT

The *Fermi* Gamma-ray Space Telescope has greatly expanded the number and energy window of observations of gamma-ray bursts (GRBs). However, the coarse localizations of tens to a hundred square degrees provided by the *Fermi* GRB Monitor instrument have posed a formidable obstacle to locating the bursts' host galaxies, measuring their redshifts, and tracking their panchromatic afterglows. We have built a target-of-opportunity mode for the intermediate Palomar Transient Factory in order to perform targeted searches for *Fermi* afterglows. Here, we present the results of one year of this program: 8 afterglow discoveries out of 35 searches. Two of the bursts with detected afterglows (GRBs 130702A and 140606B) were at low redshift ($z = 0.145$ and 0.384, respectively) and had spectroscopically confirmed broad-line Type Ic supernovae. We present our broadband follow-up including spectroscopy as well as X-ray, UV, optical, millimeter, and radio observations. We study possible selection effects in the context of the total *Fermi* and *Swift* GRB samples. We identify one new outlier on the Amati relation. We find that two bursts are consistent with a mildly relativistic shock breaking out from the progenitor star rather than the ultra-relativistic internal shock mechanism that powers standard cosmological bursts. Finally, in the context of the Zwicky Transient Facility, we discuss how we will continue to expand this effort to find optical counterparts of binary neutron star mergers that may soon be detected by Advanced LIGO and Virgo.

Key words: gamma-ray burst: individual (GRB 130702A, GRB 140606B) – gravitational waves – methods: observational – supernovae: general – surveys

Supporting material: figure set, machine-readable tables

[32] NASA Postdoctoral Fellow.
[33] Hubble Fellow.

iPTF TOO Marshal - Mozilla Firefox

iPTF TOO Marshal

yupana.caltech.edu/marshals/too/event/Fer

Back | Fermi439459520 | Log out

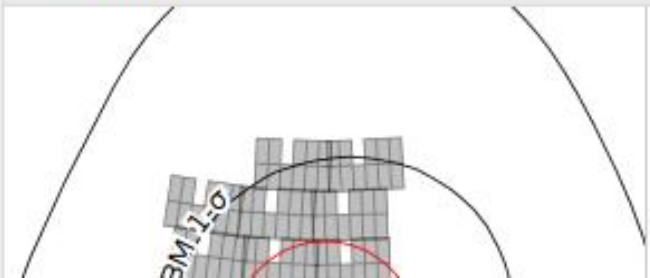
Trigger information

Name	Fermi439459520 GCN notice GRB 141205A
iPTF name	none edit...
Date	2014-12-05T08:05:17.490 (≈ 6 days ago)
RA, Dec	$06^h\ 14^m\ 48^s$ (93.700°) +51° 48′ 36″ (+51.810°)
Radius	4.37°
Gal. lat.	15.71°

Observability

Palomar **RIGHT NOW**,
≈ 6 days after the trigger,
from 05:57 to 13:41 and 02:26 to 05:56 (UT)
from 21:57 to 05:41 and 18:26 to 21:56 (Pacific)

Sky map



iPTF TOO Marshal - Mozilla Firefox

iPTF TOO Marshal

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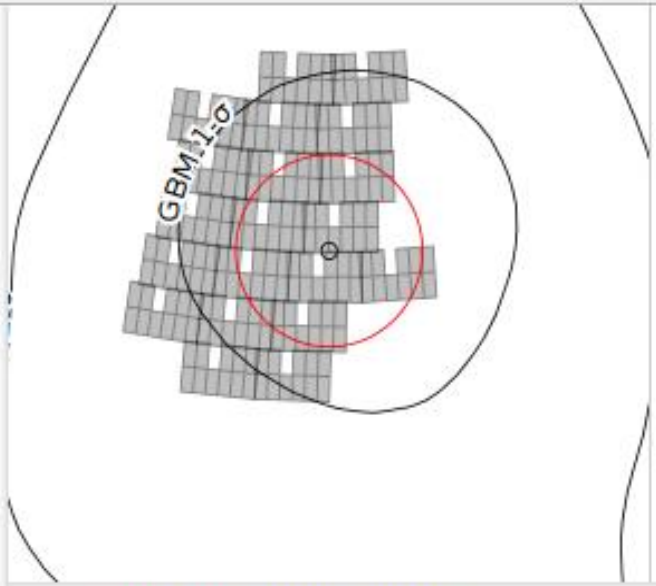
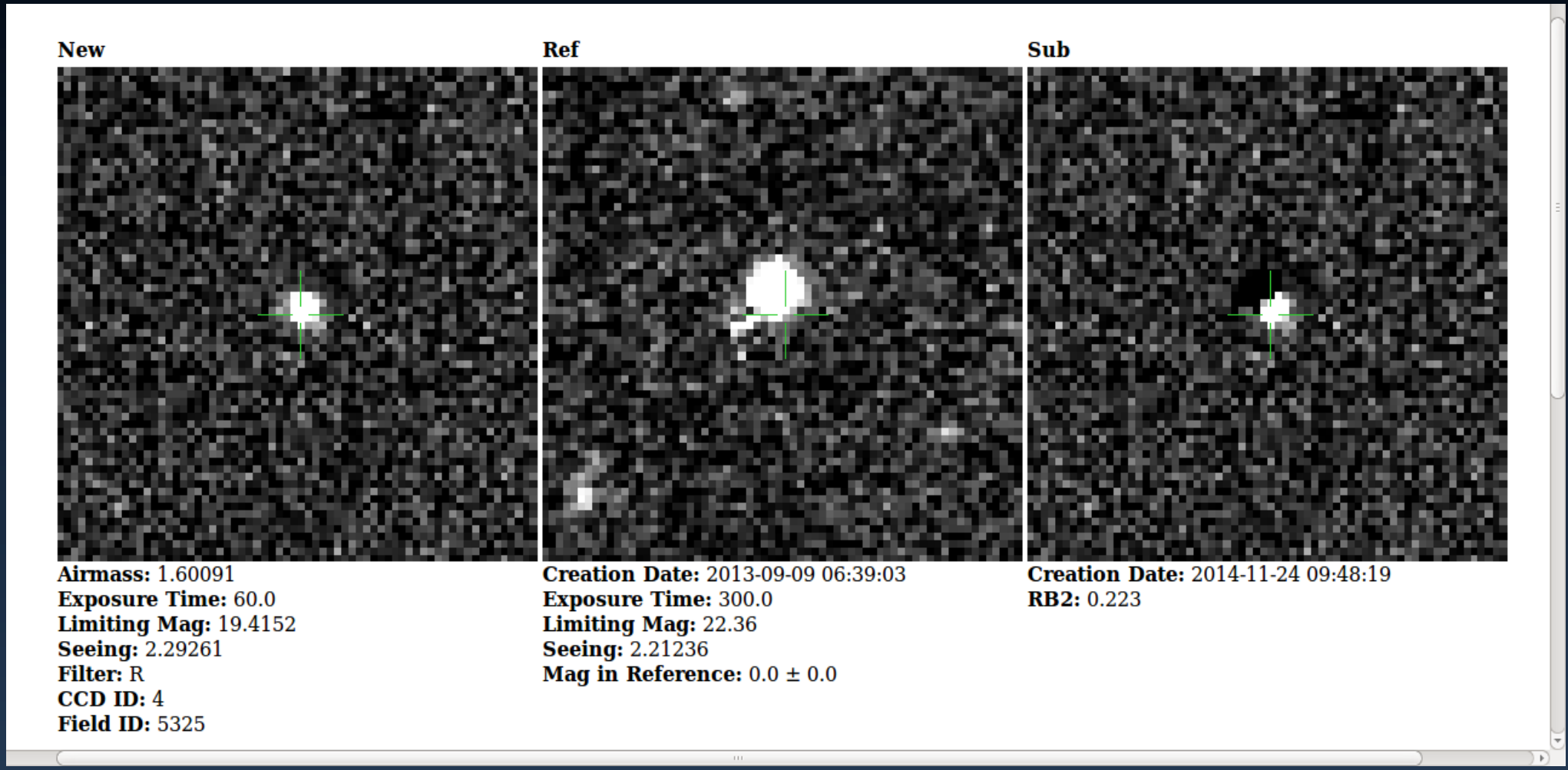


Schedule more P48 observations

Fields	+
Airmass	2.5
Cadence (s)	18(
Moon distance	15
Epochs	1 2 3 4
Filter	R g Ha656 Ha663

cancel | go

Bad subtractions



Lots of statistically significant residuals!

False positives

- Instrumental:
  - » PSF mismatch
  - » CCD defects
  - » Diffraction spikes

- Astrophysical:
  - » Asteroids
  - » Satellites
  - » Cosmic rays

Detection is contextual!

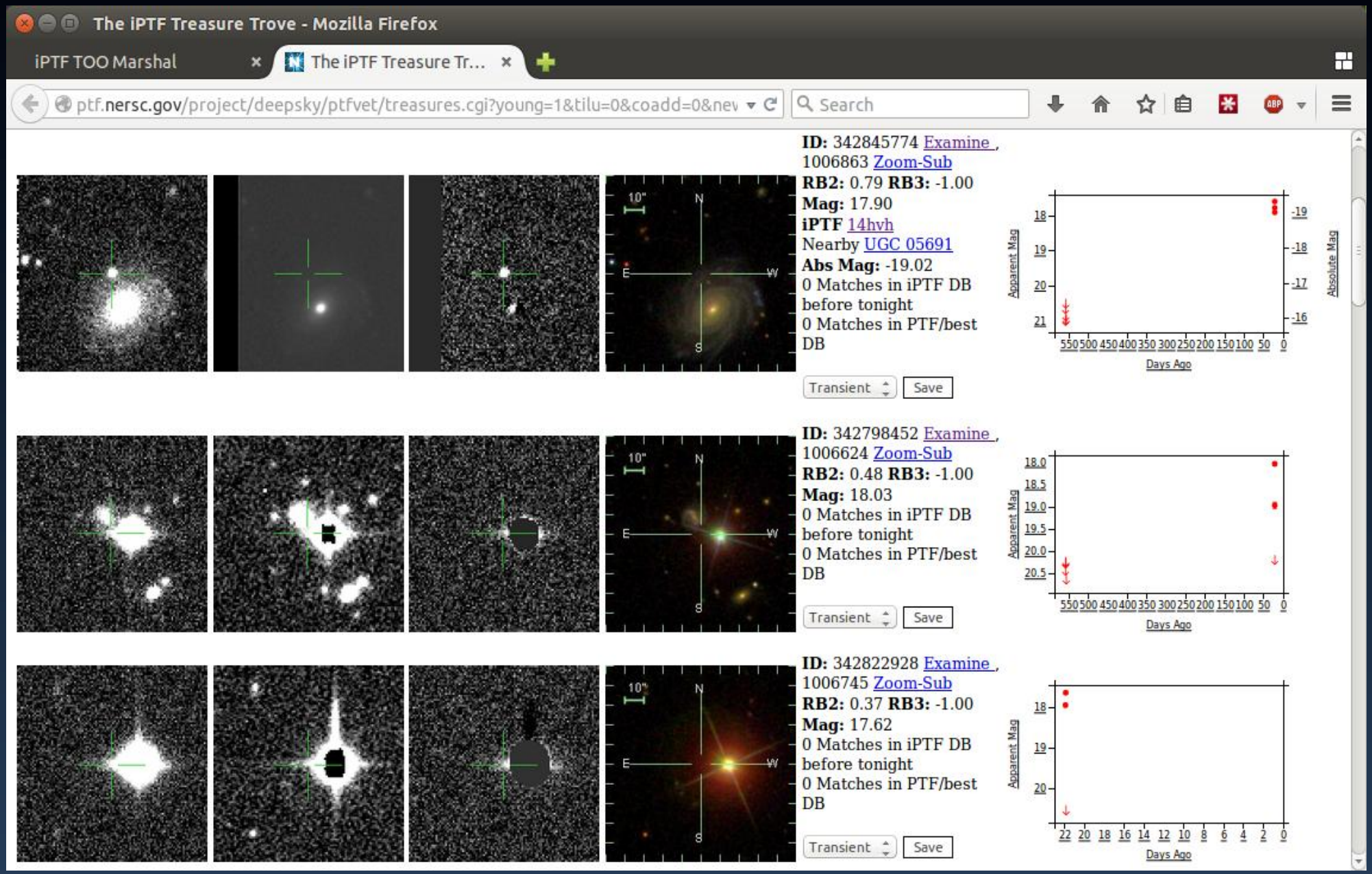
- Run-of-the-mill transients are contaminants
  - » Flare stars, variables

- Utilize expected source properties
  - » GRB: expect fading
  - » Use multiple exposures
  - » Also eliminates asteroids (move tens of arcsec per hour)

Filtering steps

	Survivors
• SNR > 5	
• “RealBogus2” score	36%
• Not known star	17%
• Not known asteroid	16%
• Detect at least twice	1%
• Human inspection	0.1%

Human “vetting”



Good days, Bad days

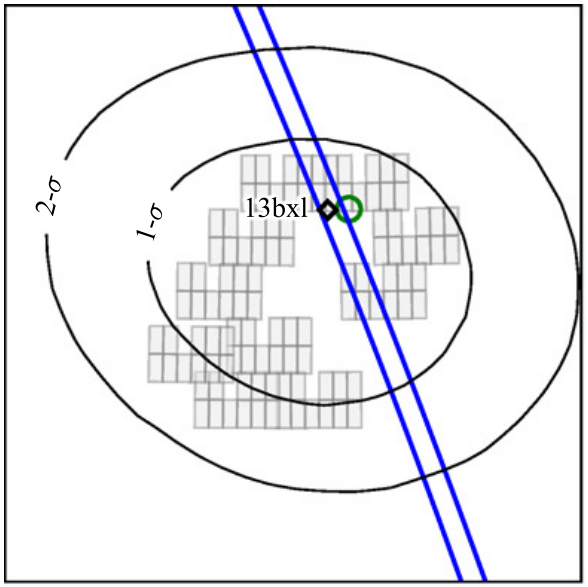
GRB 140808A

- 19,853 detections > 5σ
- 4,804 with RB2 > 0.1
- 2,349 not stellar
- 2,349 not asteroids
- 127 detected twice
- 12 saved for follow-up

GRB 140620A

- 152,224 detections > 5σ
- 50,930 with RB2 > 0.1
- 17,872 not stellar
- 17,872 not asteroids
- 34 saved for follow-up

GRB 130702A / iPTF13bxl



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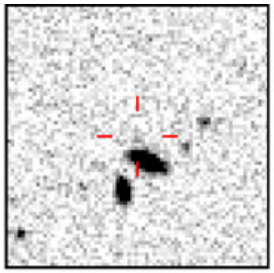

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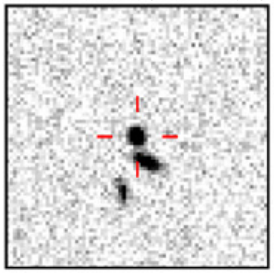

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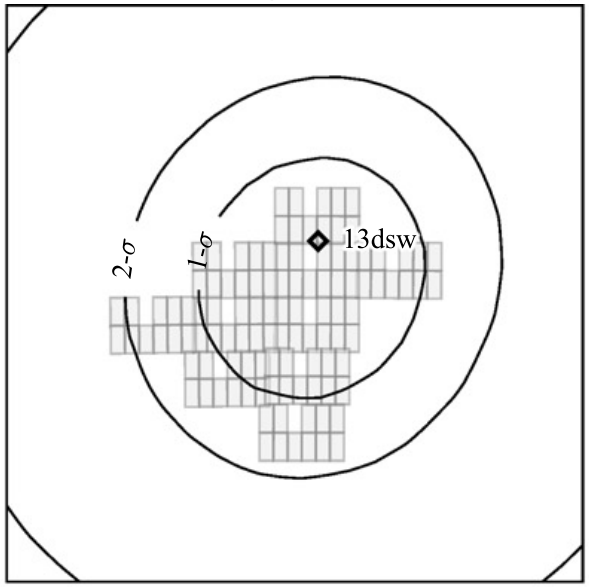

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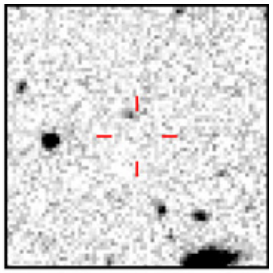

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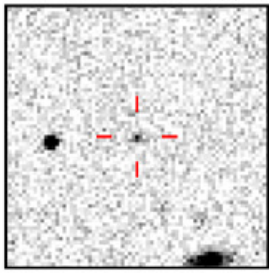

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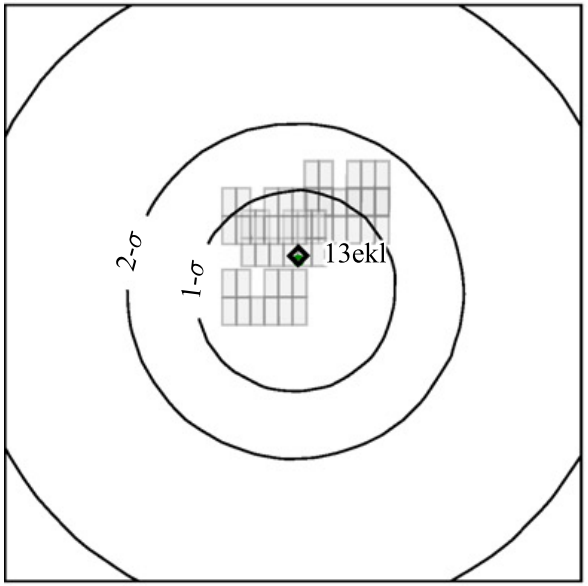

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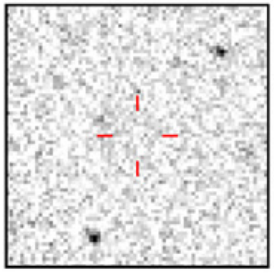

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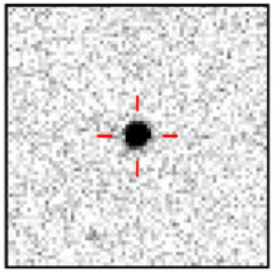

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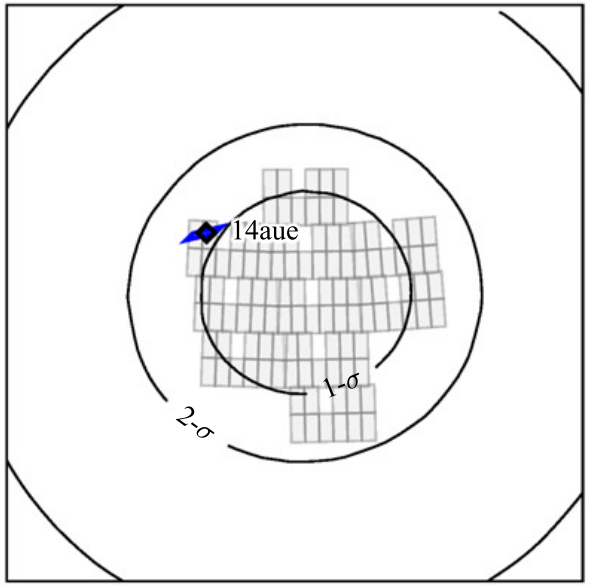

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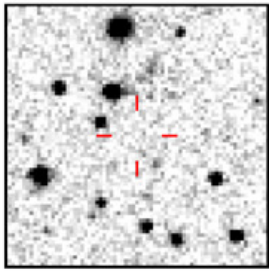

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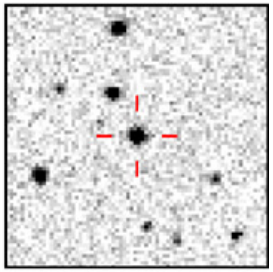

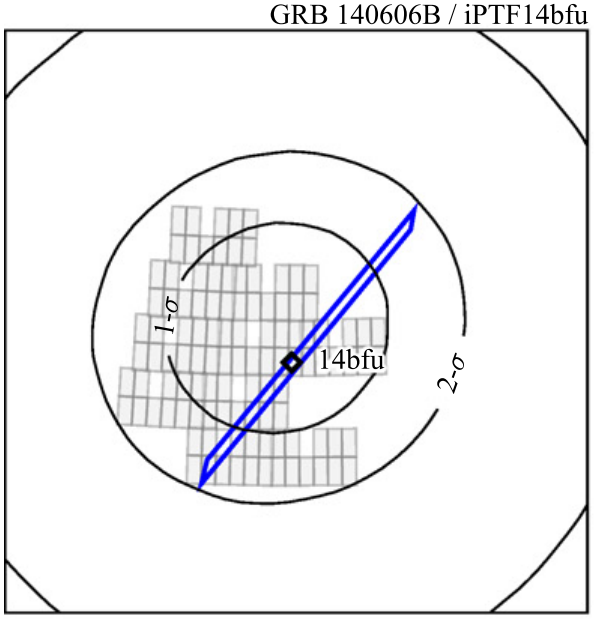
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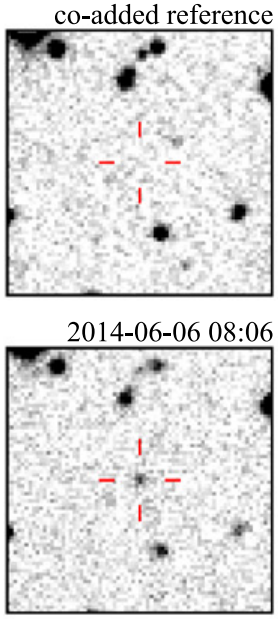
1-σ
2-σ
14bfu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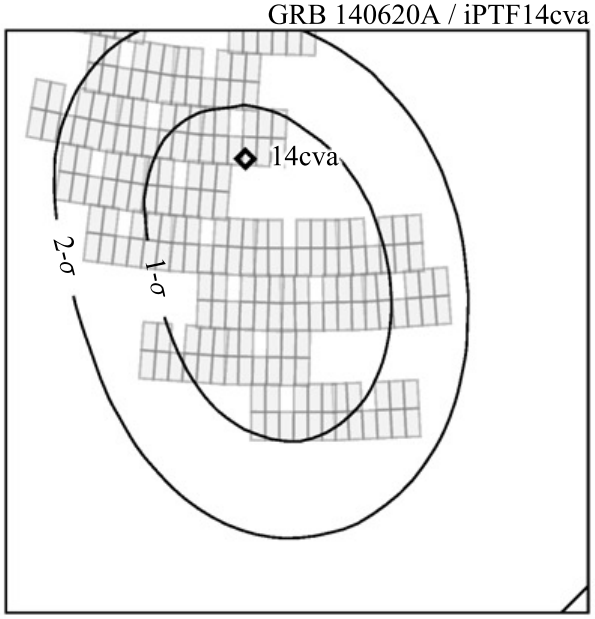
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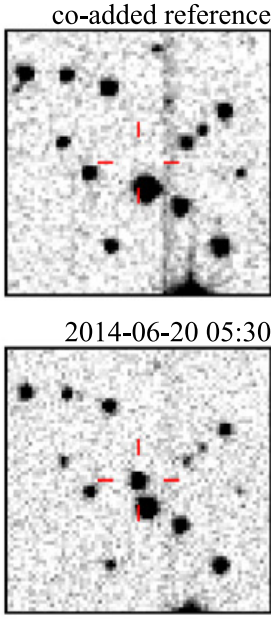
14cva
2-σ
1-σ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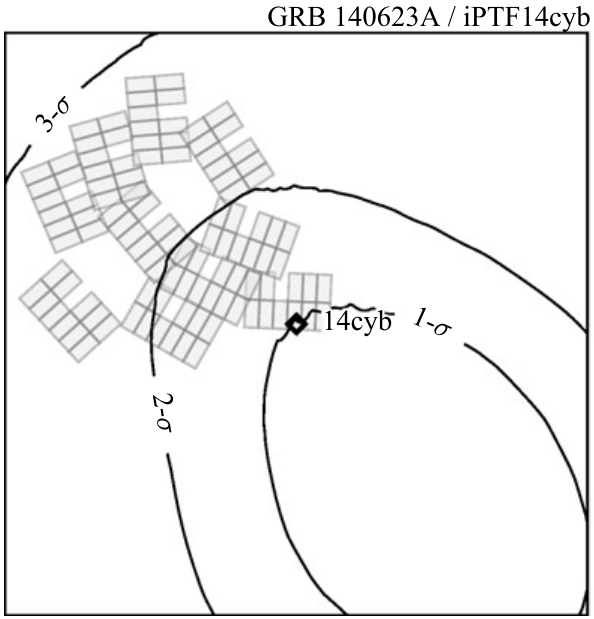
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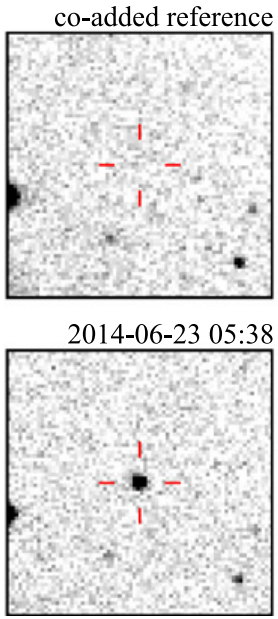
3-σ
14cyb
1-σ
2-σ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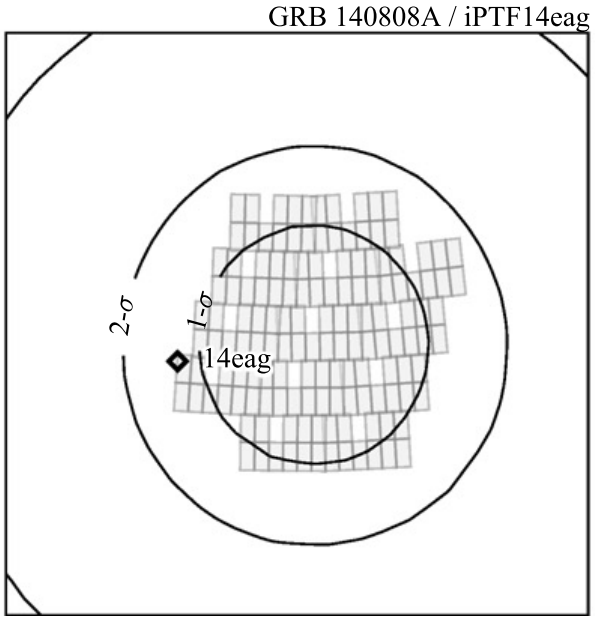
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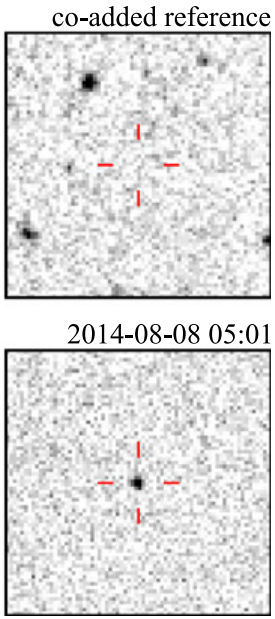
2-σ
1-σ
14eag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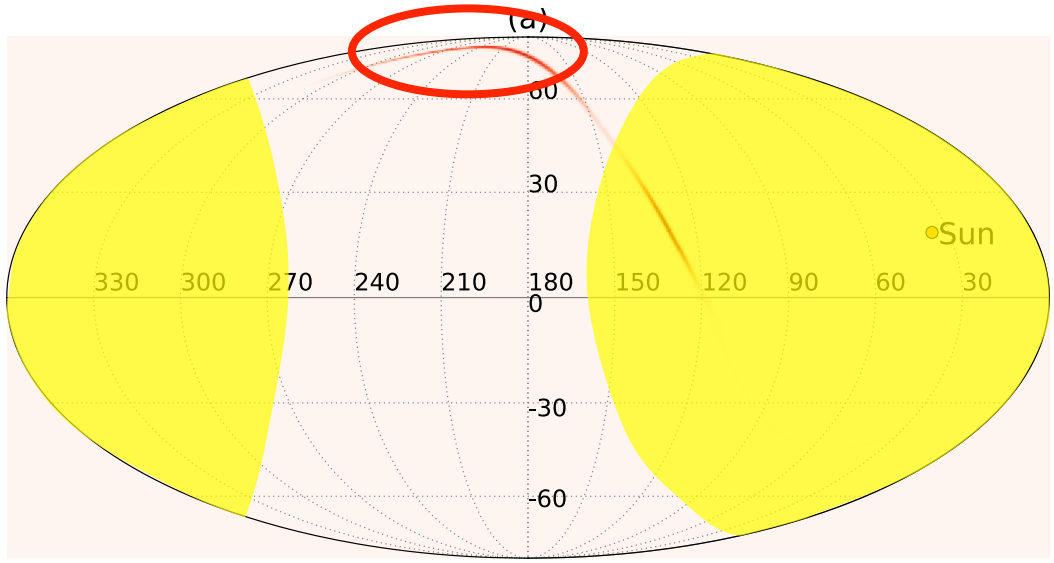
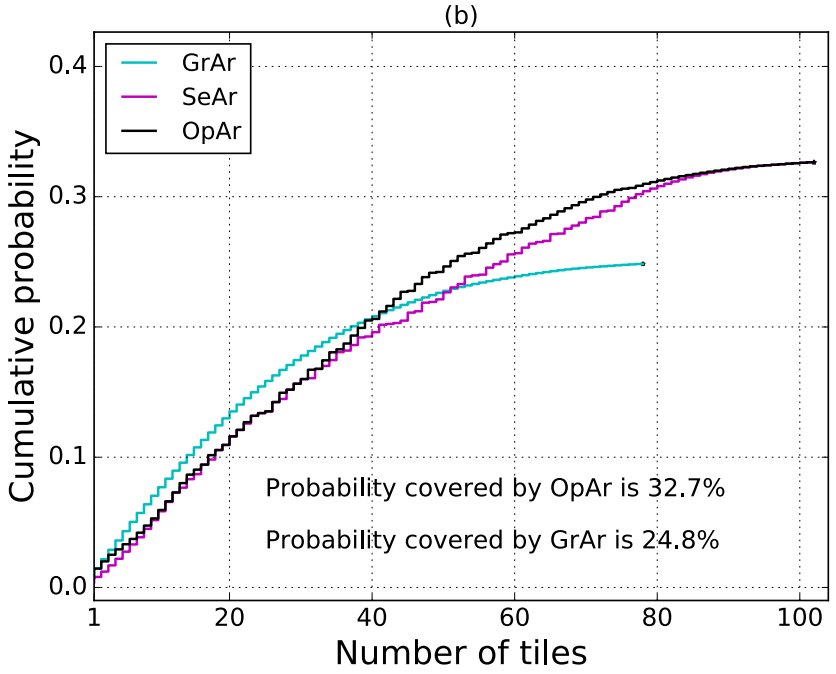
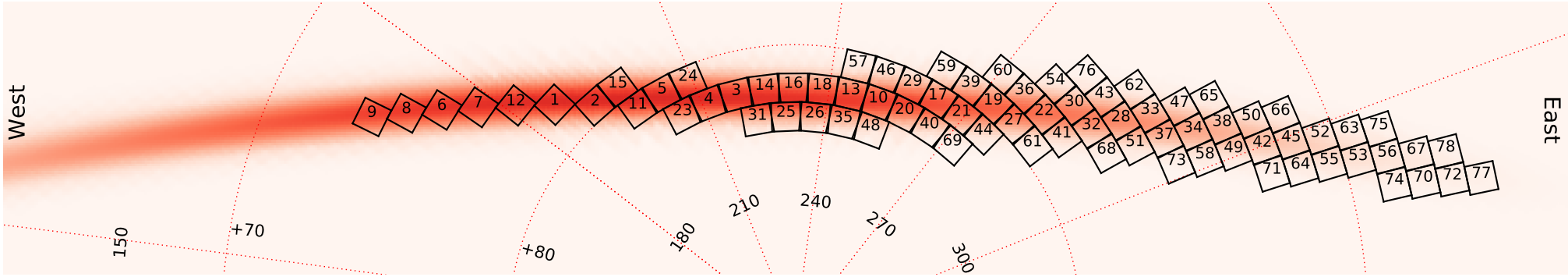
Scheduling and coordination

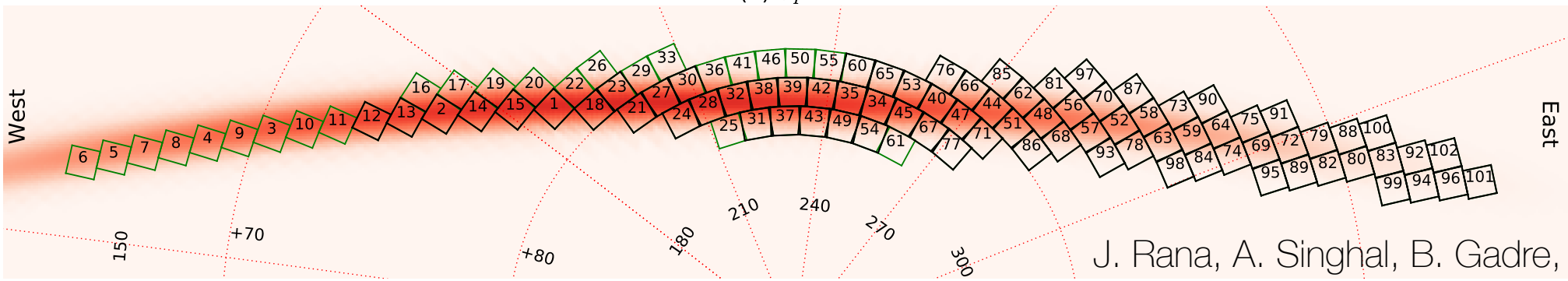




(c) *GrAr*



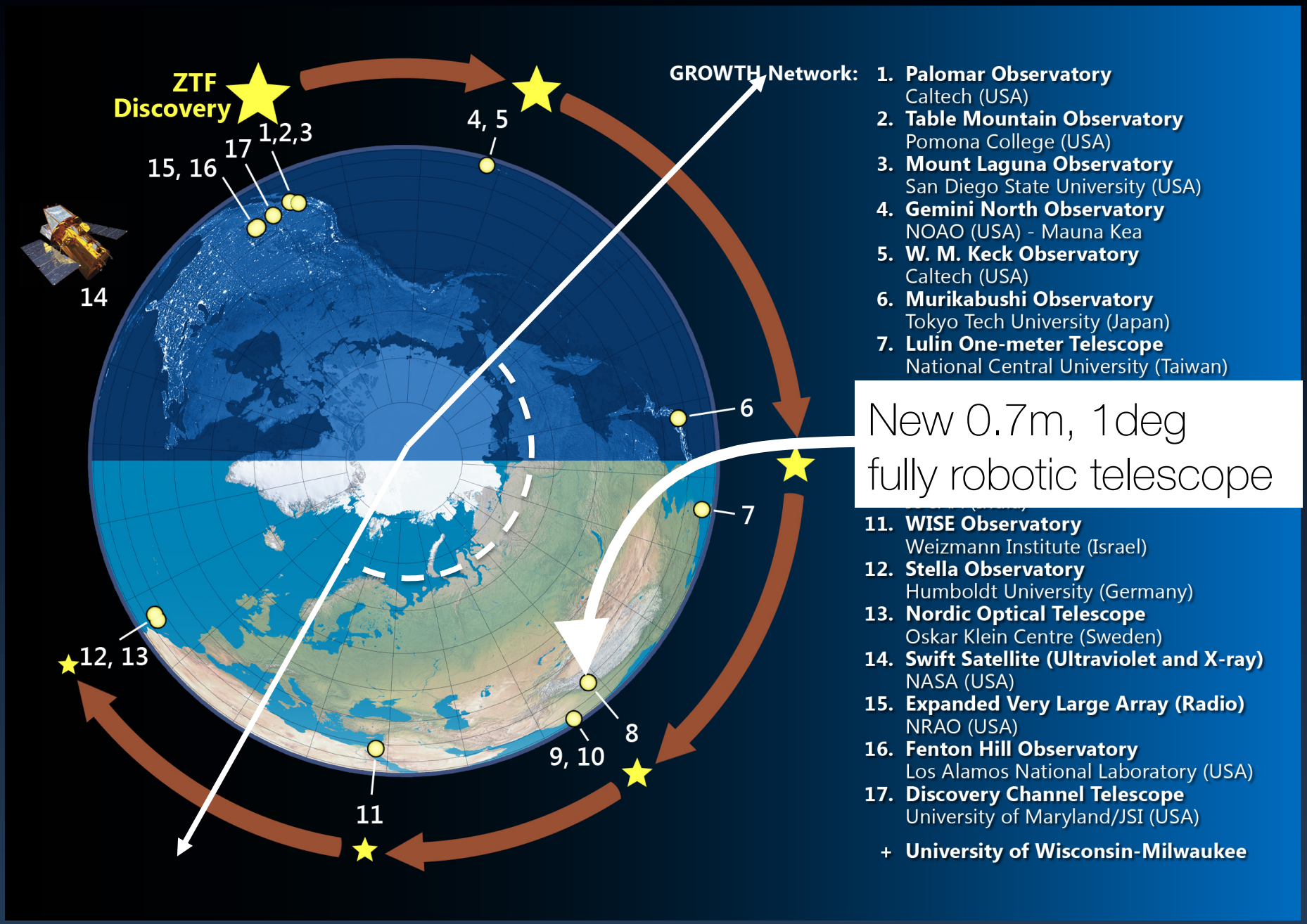
(d) *OpAr*



J. Rana, A. Singhal, B. Gadre,
V. Bhalerao, S. Bose, arXiv:1603.01689

Global Relay of Observatories

Watching Transients Happen



GROWTH Network:

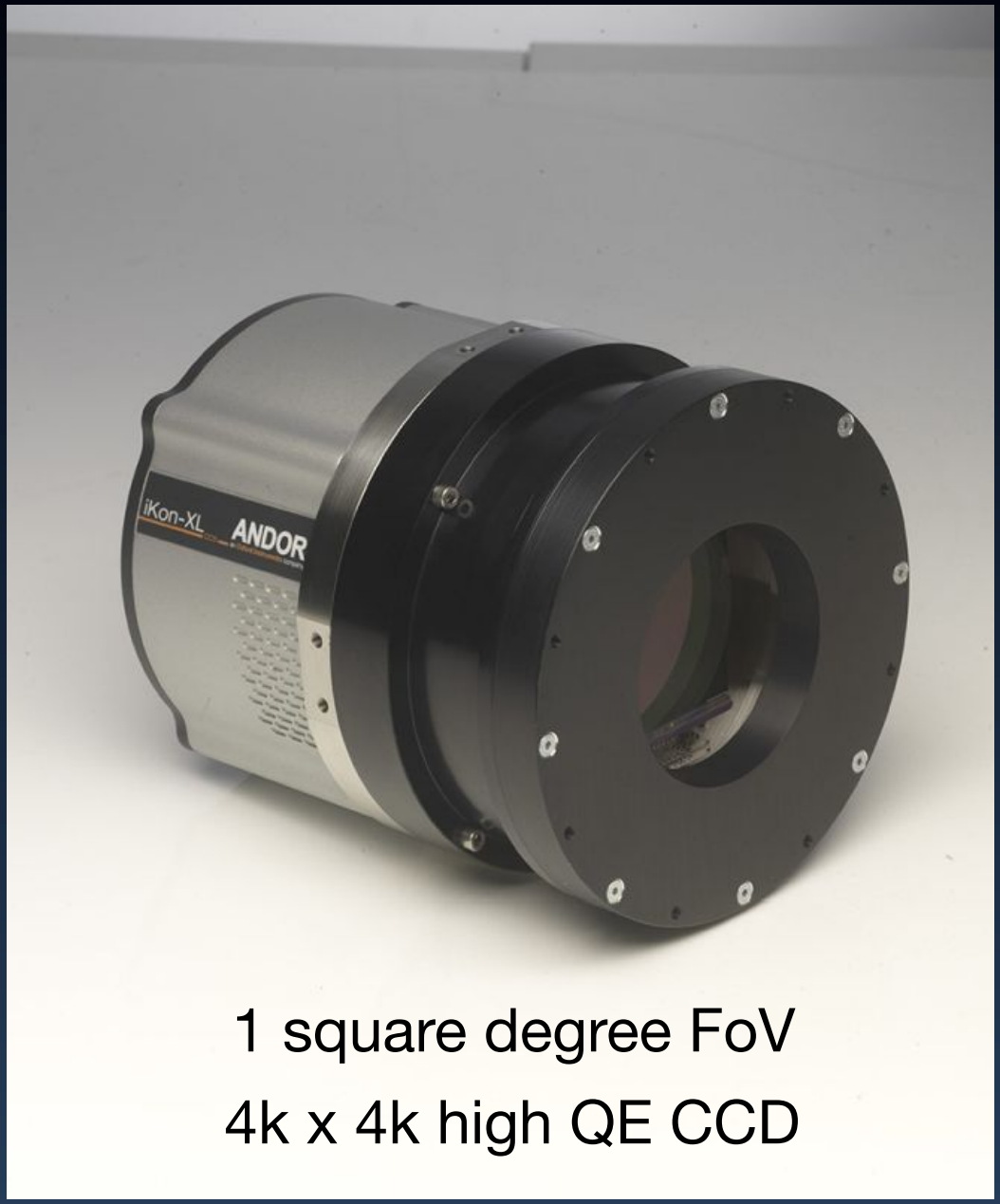
1. **Palomar Observatory**
   Caltech (USA)
2. **Table Mountain Observatory**
   Pomona College (USA)
3. **Mount Laguna Observatory**
   San Diego State University (USA)
4. **Gemini North Observatory**
   NOAO (USA) - Mauna Kea
5. **W. M. Keck Observatory**
   Caltech (USA)
6. **Murikabushi Observatory**
   Tokyo Tech University (Japan)
7. **Lulin One-meter Telescope**
   National Central University (Taiwan)

New 0.7m, 1deg
fully robotic telescope

11. **WISE Observatory**
    Weizmann Institute (Israel)
12. **Stella Observatory**
    Humboldt University (Germany)
13. **Nordic Optical Telescope**
    Oskar Klein Centre (Sweden)
14. **Swift Satellite (Ultraviolet and X-ray)**
    NASA (USA)
15. **Expanded Very Large Array (Radio)**
    NRAO (USA)
16. **Fenton Hill Observatory**
    Los Alamos National Laboratory (USA)
17. **Discovery Channel Telescope**
    University of Maryland/JSI (USA)

\+ **University of Wisconsin-Milwaukee**

GROWTH-India: Robotic telescope

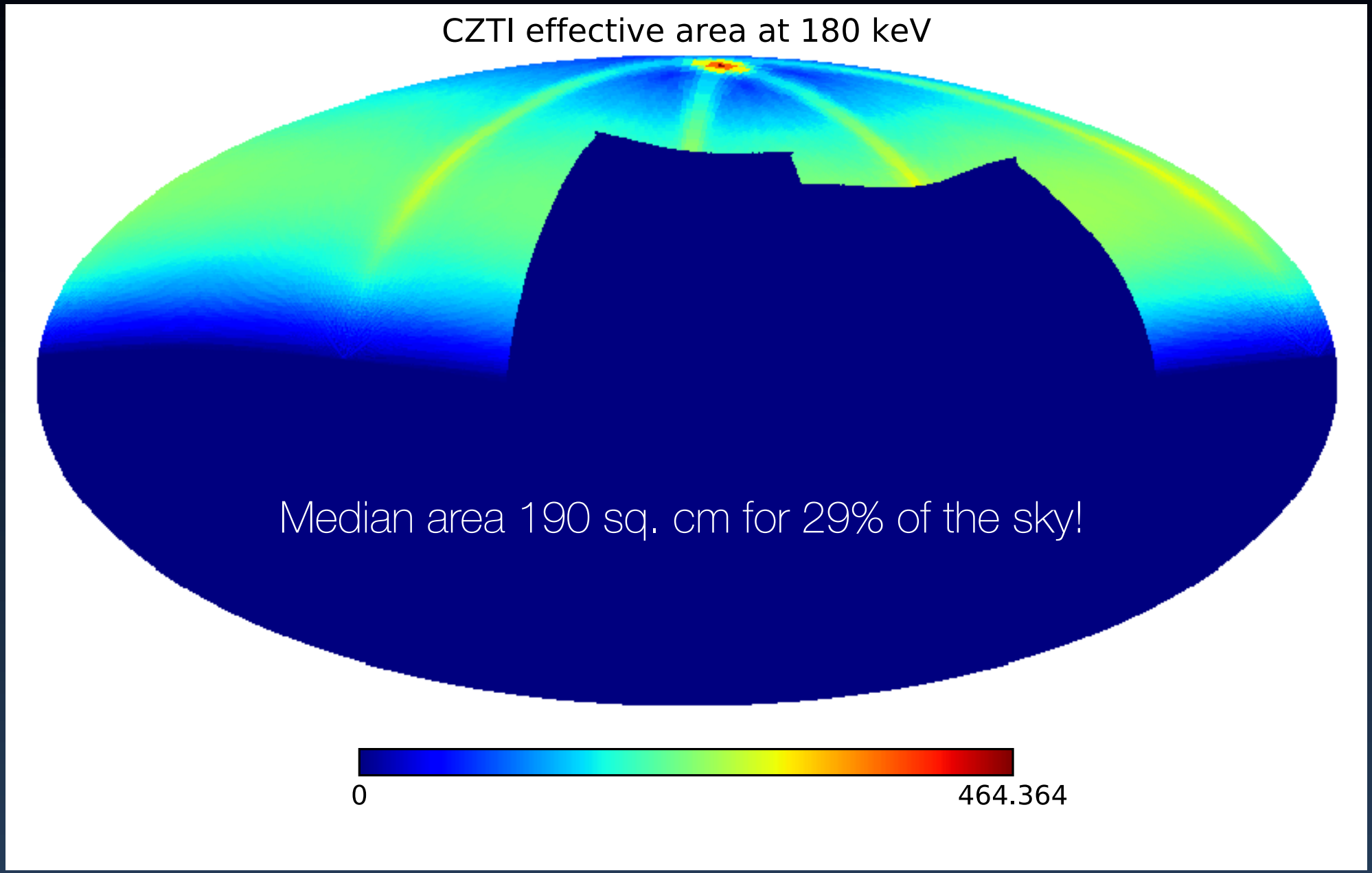


1 square degree FoV

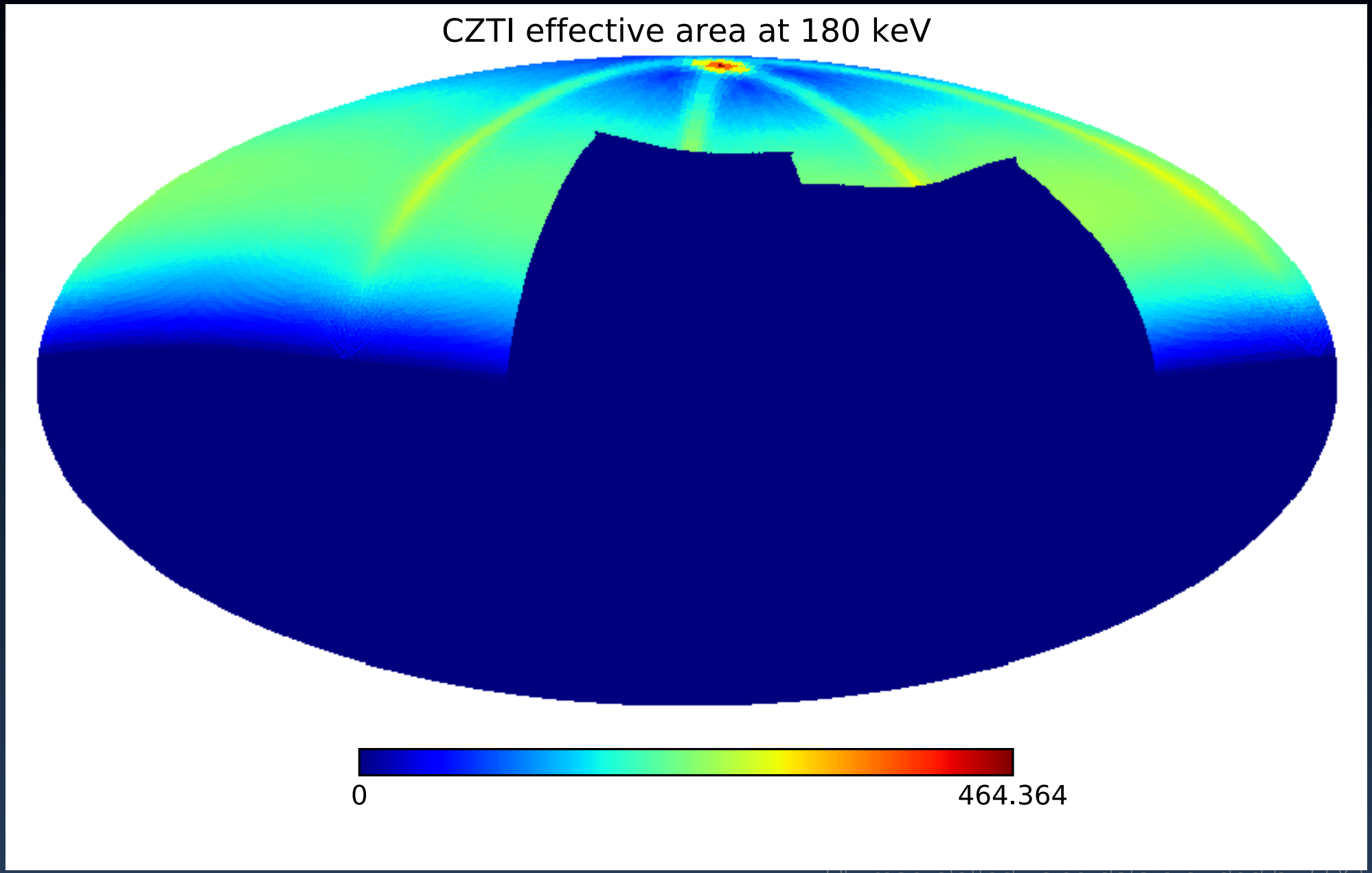
4k x 4k high QE CCD

GRBs with CZTI

CZTI as a wide angle monitor



Coverage for GW151226



Skymap plotted using data provided by LSC.

A tale of two transients

The start…

- 3:42 pm: LIGO picks up a signal, named G268556
- 10:28 pm: LSC goes through basic checks and informs astronomers
- 11:18 pm: I get a text message about a LIGO trigger
- Next 40 minutes: chaos !

… but nothing happens …

- AstroSat observed large part of the LIGO region, saw nothing
- Hanle clouded out – no Indian ground-based data

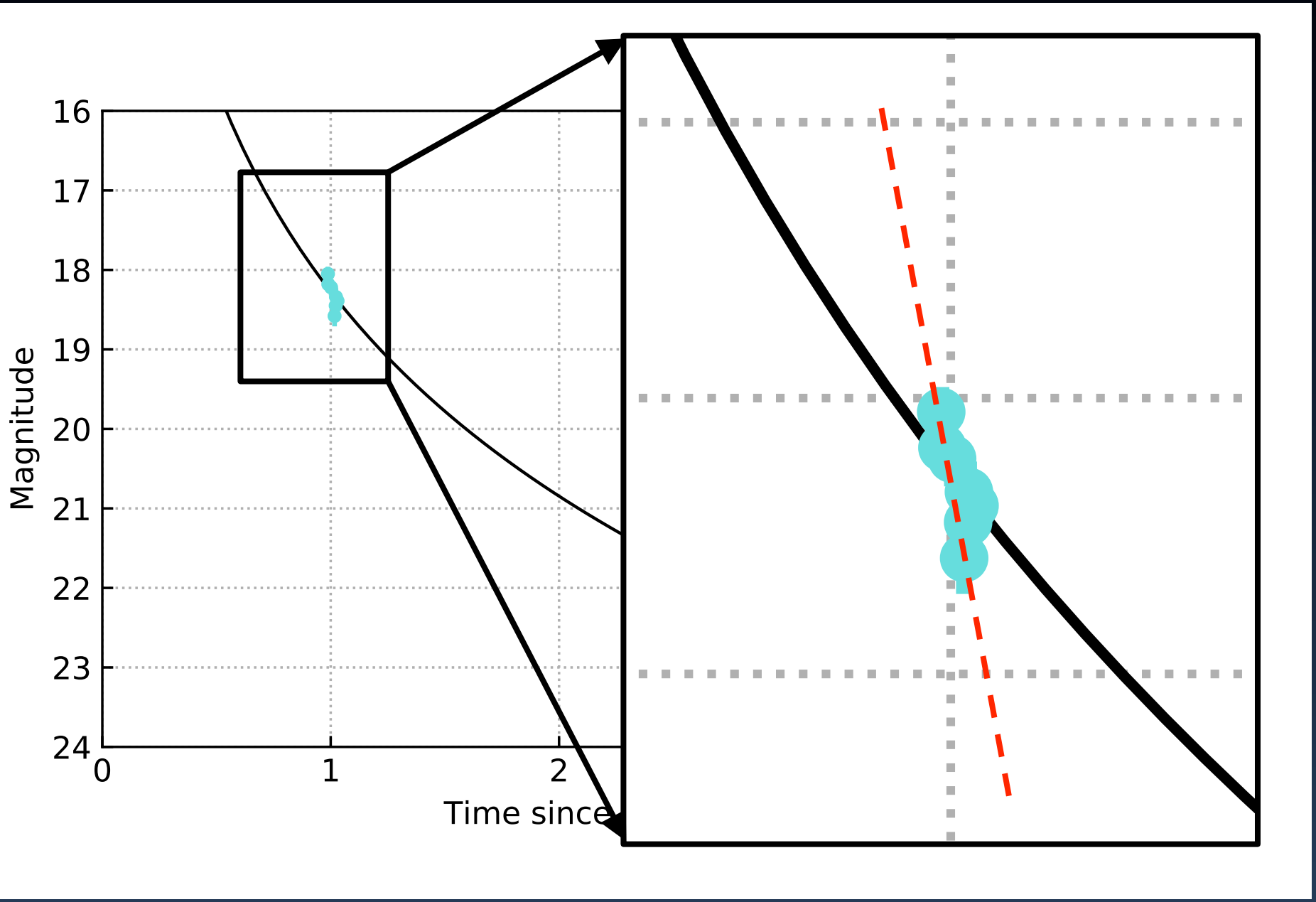
- iPTF ready to observe, but Palomar clouded out

At last, ATLAS17eau

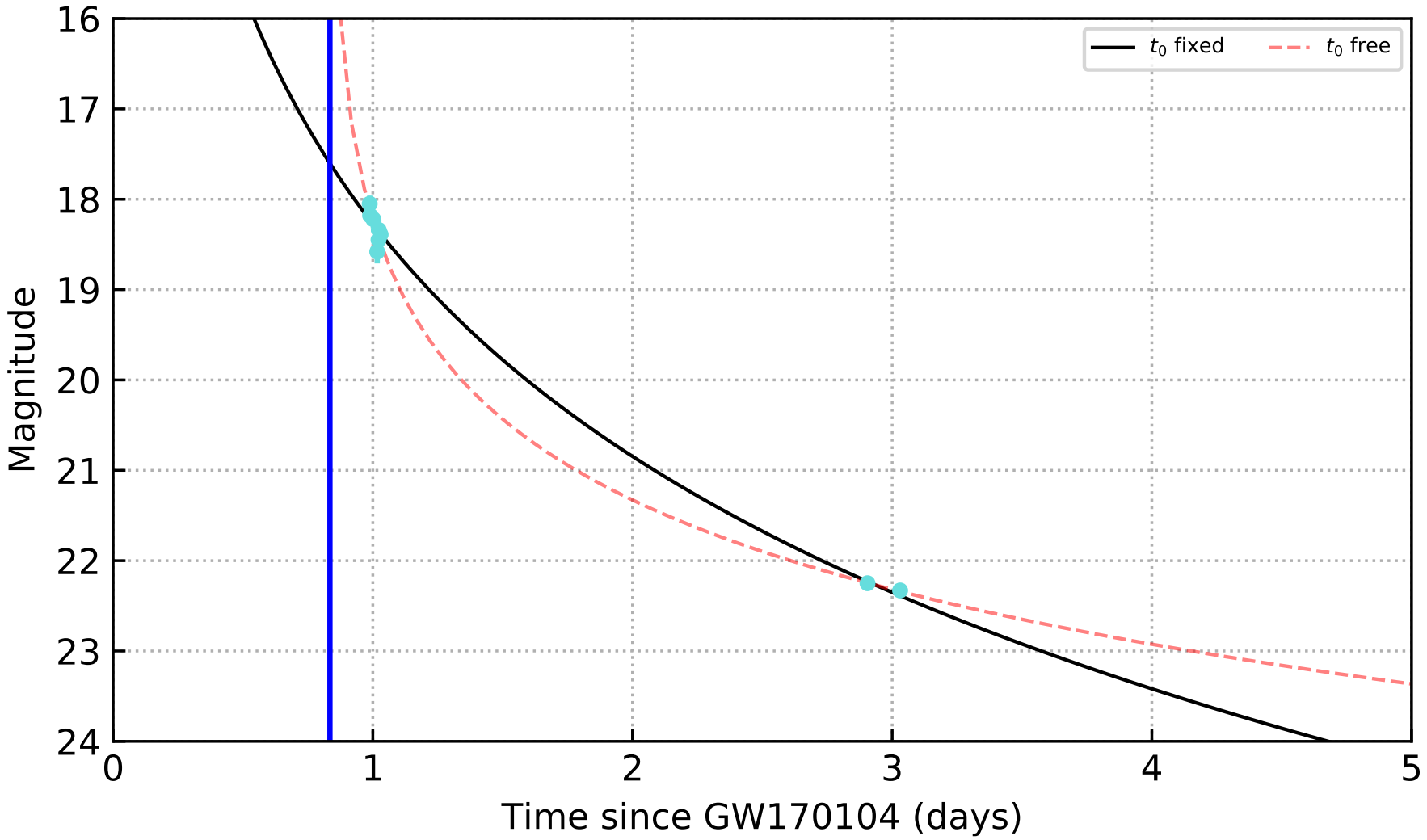
- 00:49 am, 7 Jan :
  - » ATLAS reports a fast fading source
- Run! Run! Get Hanle data!
  - » but clouds again
- Get data from Lulin 1-m telescope
  - » Nope, spectrograph mounted, target too faint

- Wait for 12 hours for it to get dark at Palomar

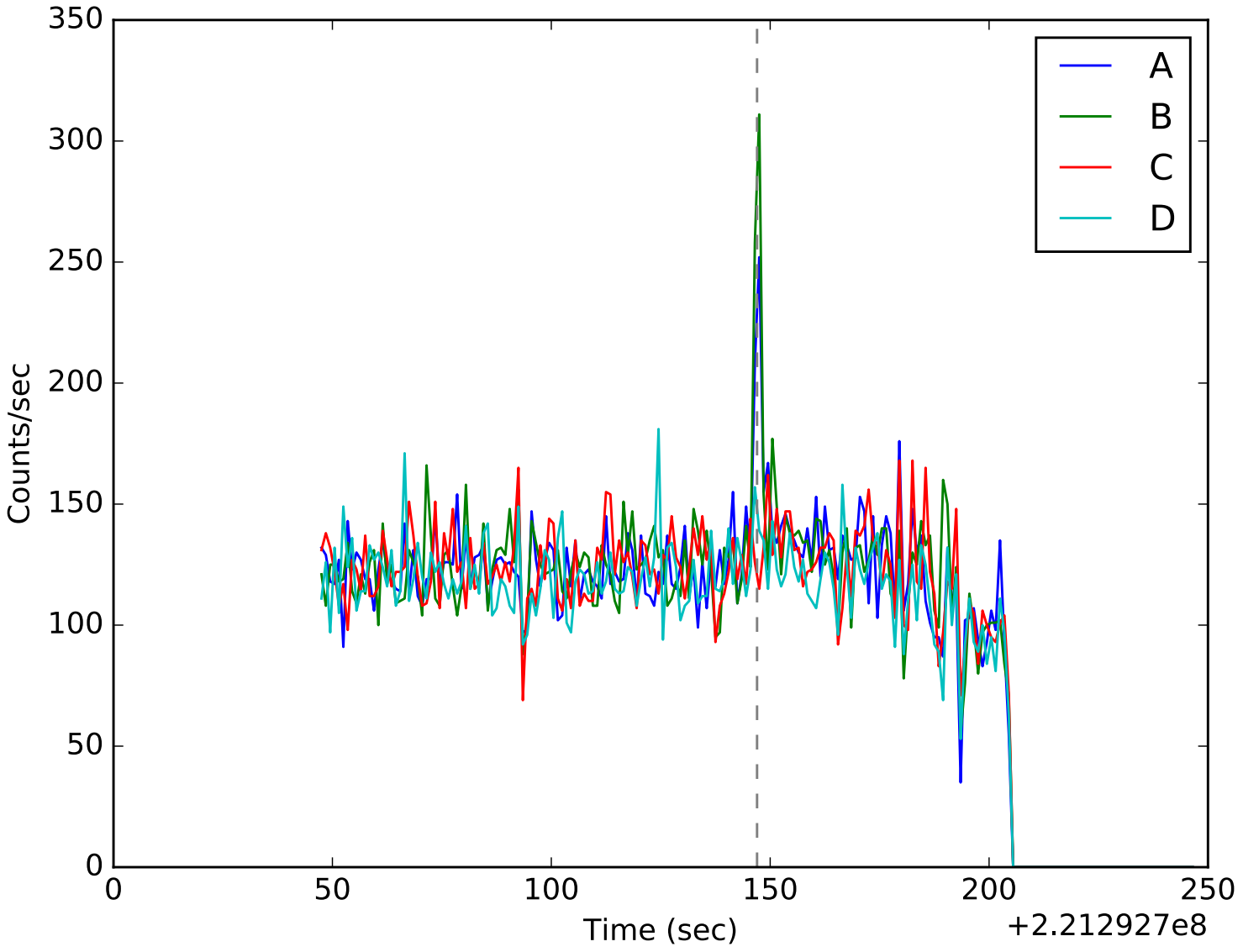
So, what is this thing?



An imposter!

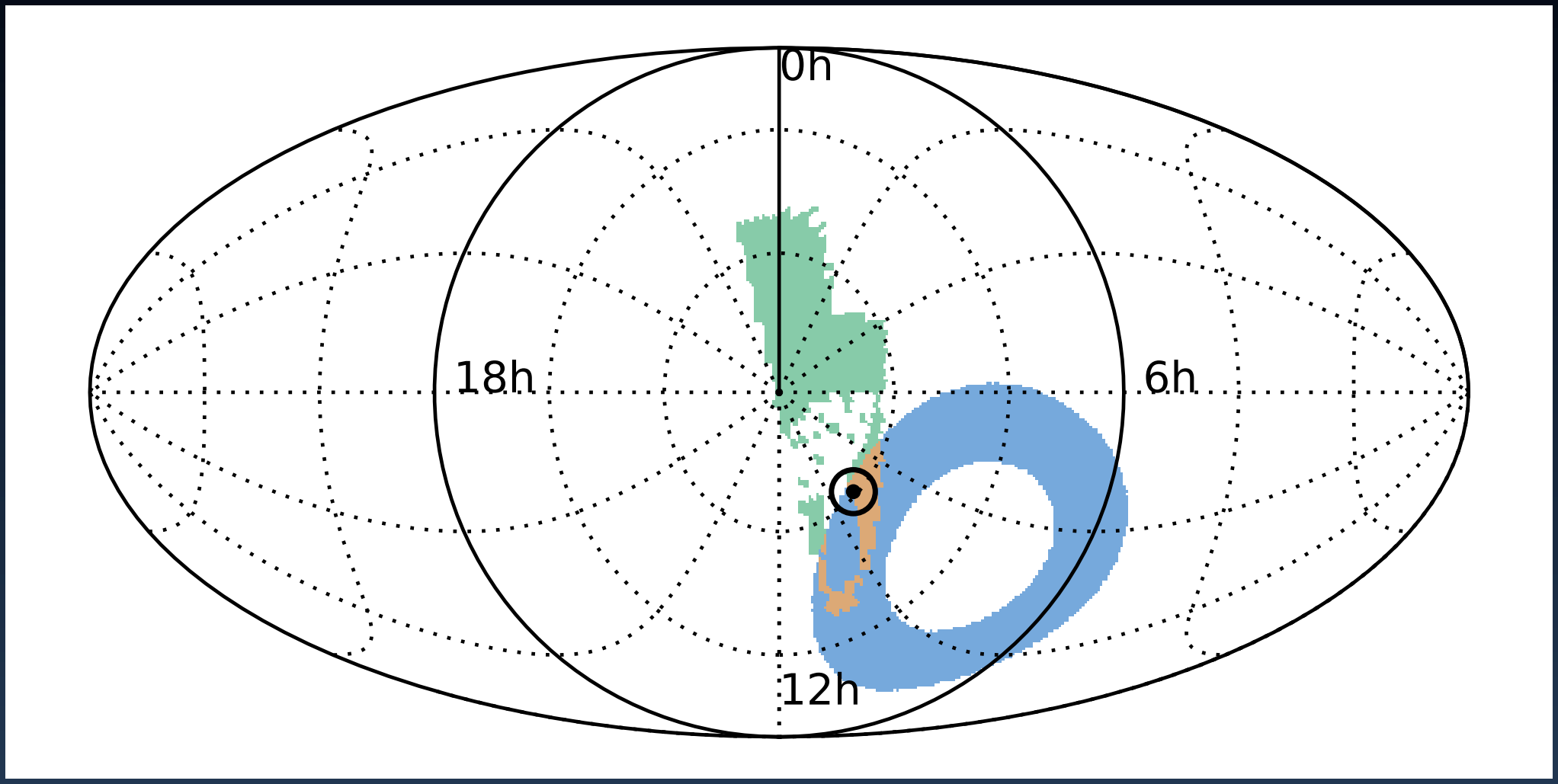

t_0 fixed
t_0 free
Magnitude
Time since GW170104 (days)
16
17
18
19
20
21
22
23
24
0
1
2
3
4
5

GRB170105A


350
300
250
200
150
100
50
0
Counts/sec
0
50
100
150
200
250
Time (sec)
+2.212927e8
A
B
C
D

CZTI localisation

Astrosat Localisation – 1148 deg^2



Common – 192 deg^2

IPN Localisation – 2600 deg^2

What’s next?

What do we need for GRB studies?

- Upcoming telescopes
  - » OIR: TMT, LSST, ZTF…
  - » Radio: uGMRT, SKA…
  - » X-ray / Gamma Ray: …


Fermi
Swift
?
Energy
Time

Hidden MOTIVE

Monitoring Of Transients Integrating Venus and Earth

Motivation

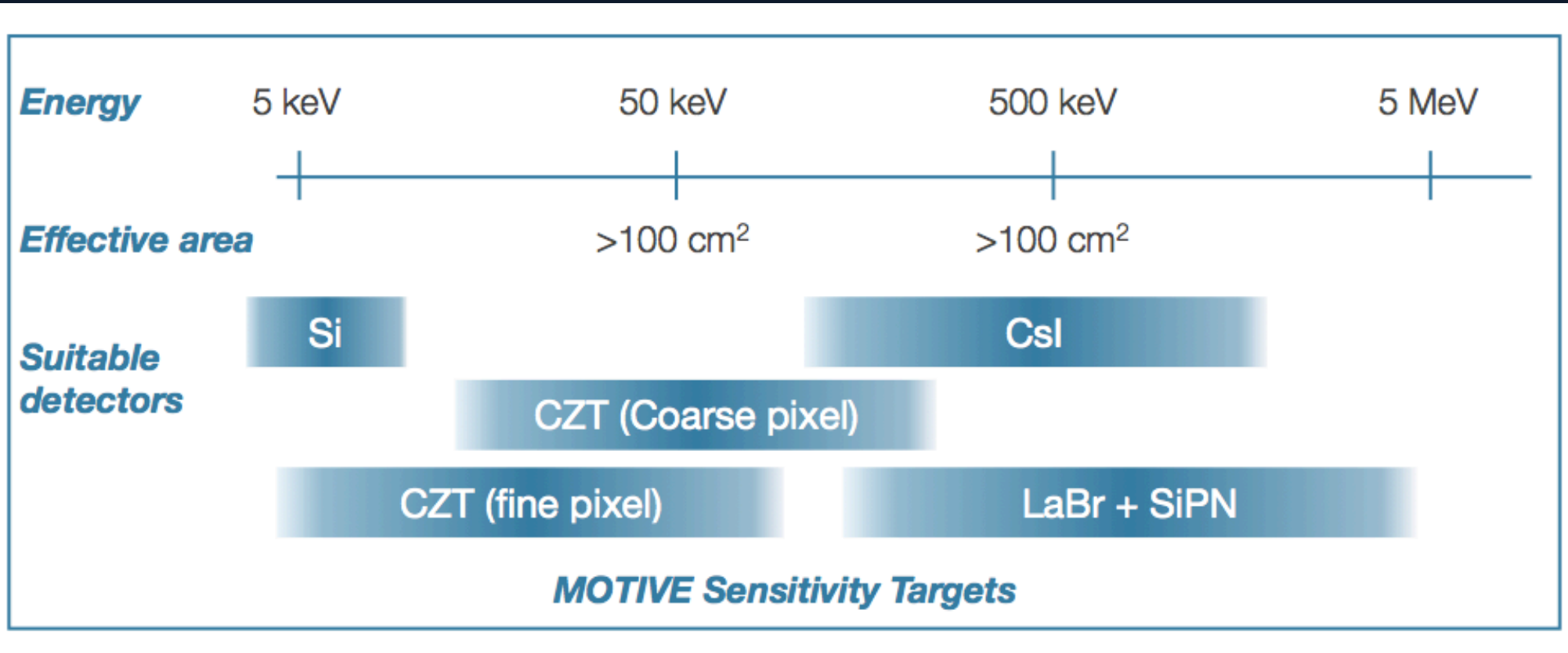
Low, stable background

Large sky visibility

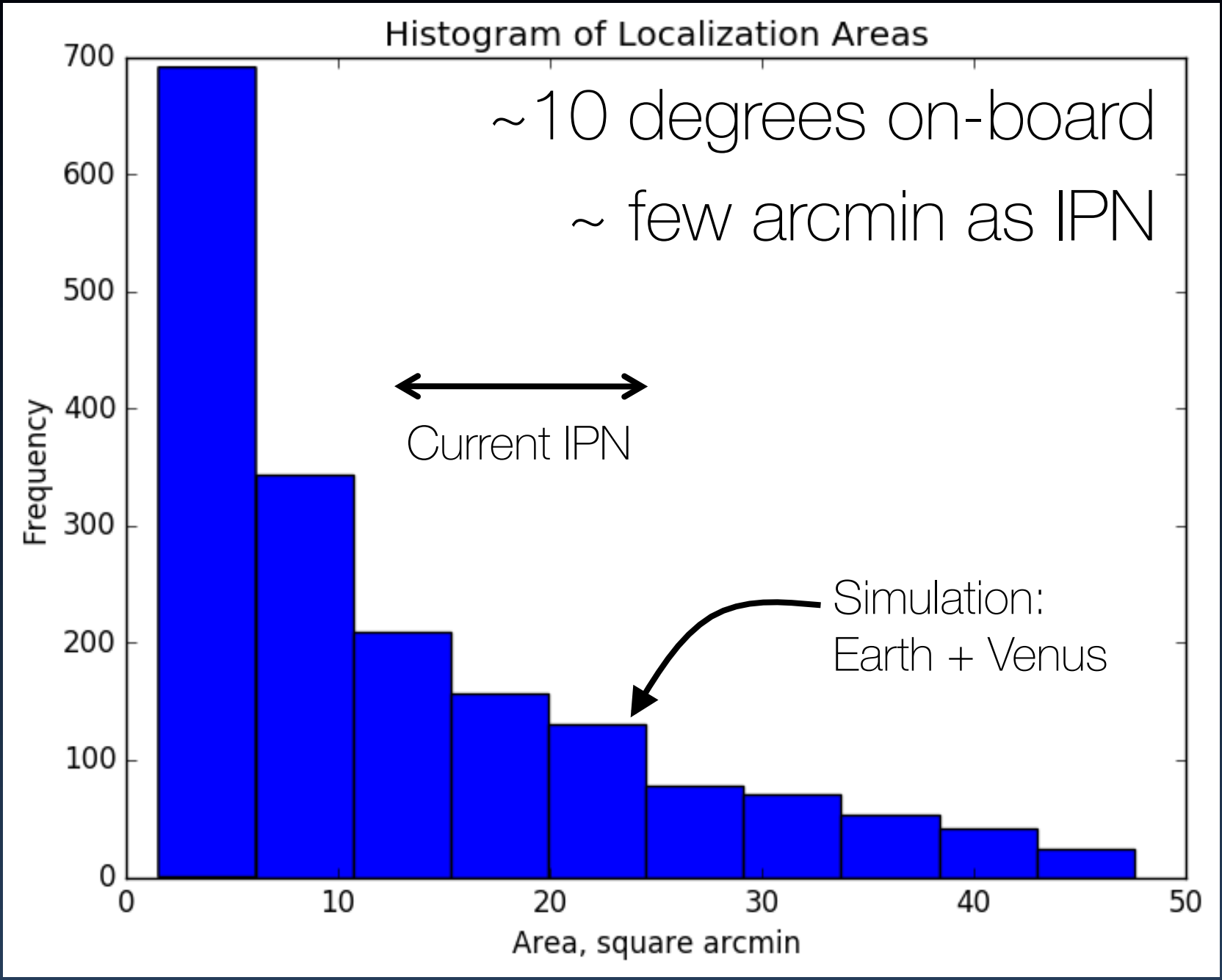
Long baseline

Concept

- Large energy range (few keV – few MeV)
- Large FoV (open detector)
- Large area (> 100 cm^2)



Localisation



Expectations

- 100 GRBs with:
  - » arcmin localisation
  - » Prompt emission spectra
- Electromagnetic Counterparts to GW sources
- Other science:
  - » Venus Gamma ray Flashes
  - » Solar flares