Seeing what we hear: Electromagnetic Counterparts of Gravitational Wave Sources

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GW Sources

EM Counterparts

Followup requirements

Indian Capabilities

Transient Hunt

NS + NS merger

(Resmi's talk)

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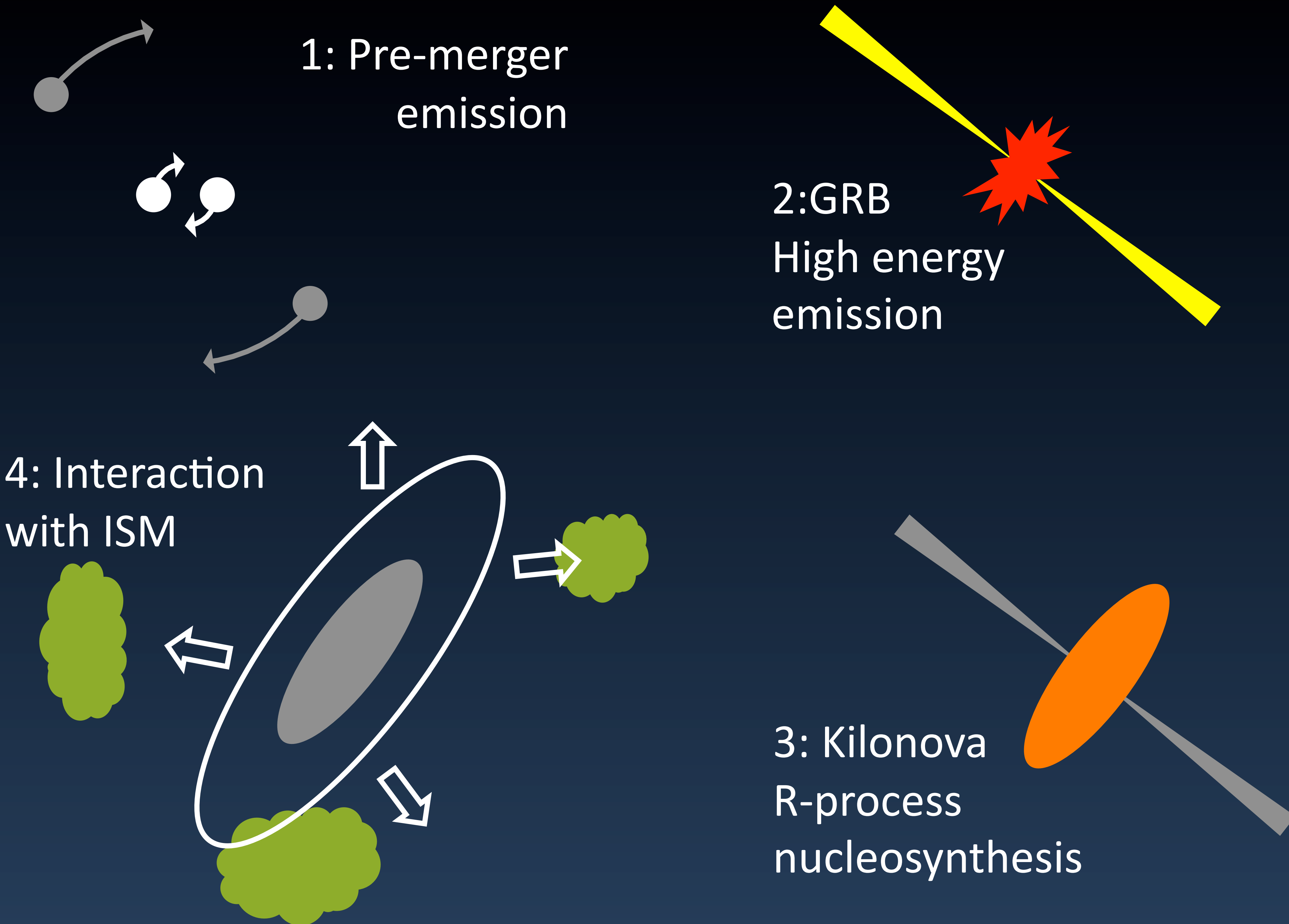
1: Pre-merger emission
2:GRB
High energy emission
3: Kilonova
R-process nucleosynthesis
4: Interaction with ISM

NS + NS inspirals

- Pre-merger emission ???
- Short-Hard Gamma-Ray Bursts – beamed
  - » X-rays, bright detection if on-axis
- "Kilonova" from nucleosynthesis in disk
  - » Optical / IR, faint (22 – 26 mag)
  - » Fast (hours – days)
  - » Rare (One tentative detection so far)
- Radio emission from interaction with surroundings (weeks – months)

Complementary information

GW

- Masses
- Spins
- Geometric properties
  - » Position
  - » Distance
  - » Inclination angle…

EM

- Beaming
- Nucleosynthesis
- Ejecta properties
  - » Mass
  - » Velocity…

Complete astrophysical picture

There are known knowns. These are things we know that we know.
There are known unknowns. That is to say, there are things that we know we don't know.

But there are also unknown unknowns. There are things we don't know we don't know.

Donald Rumsfeld,
US secretary of defense

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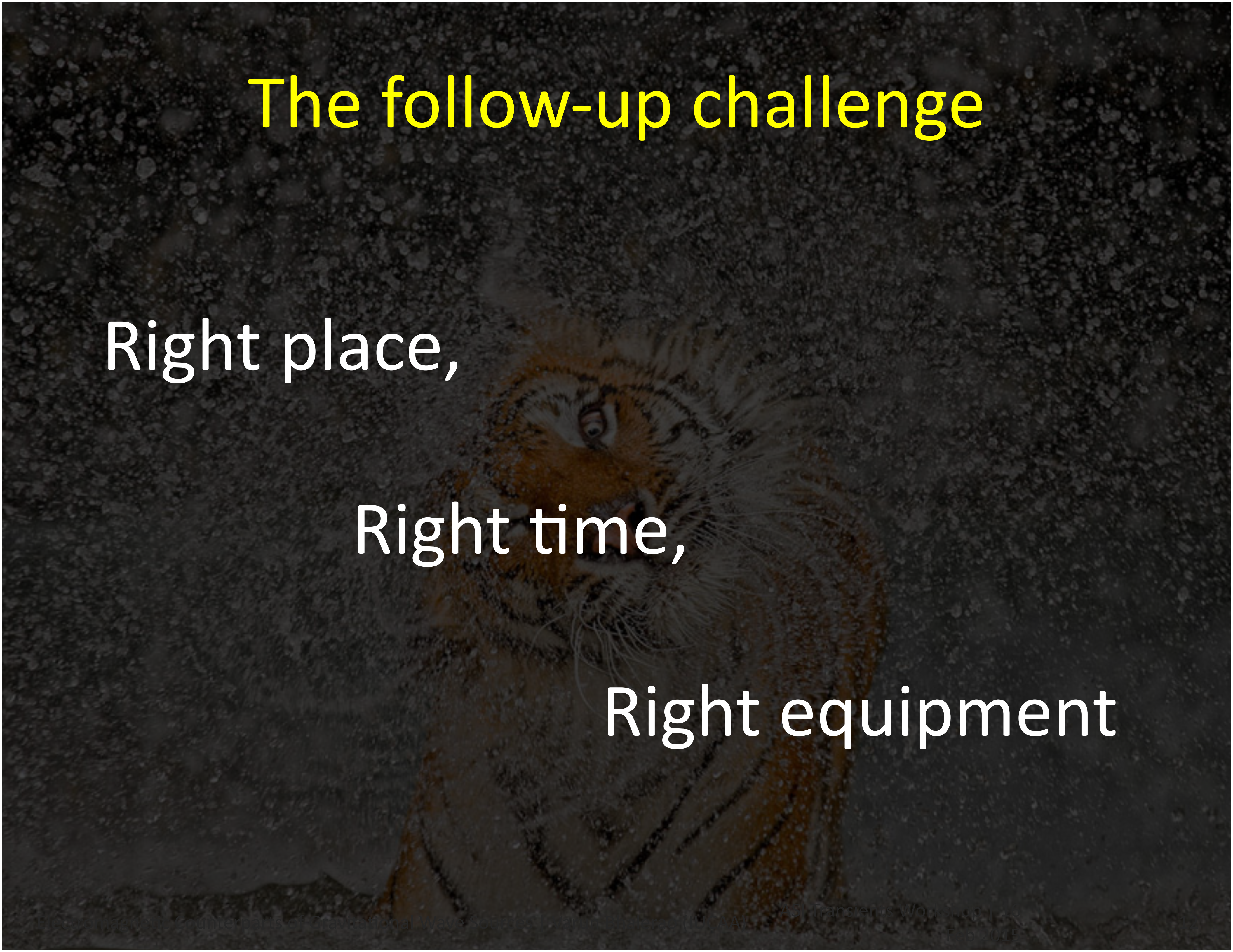
The follow-up challenge



The follow-up challenge

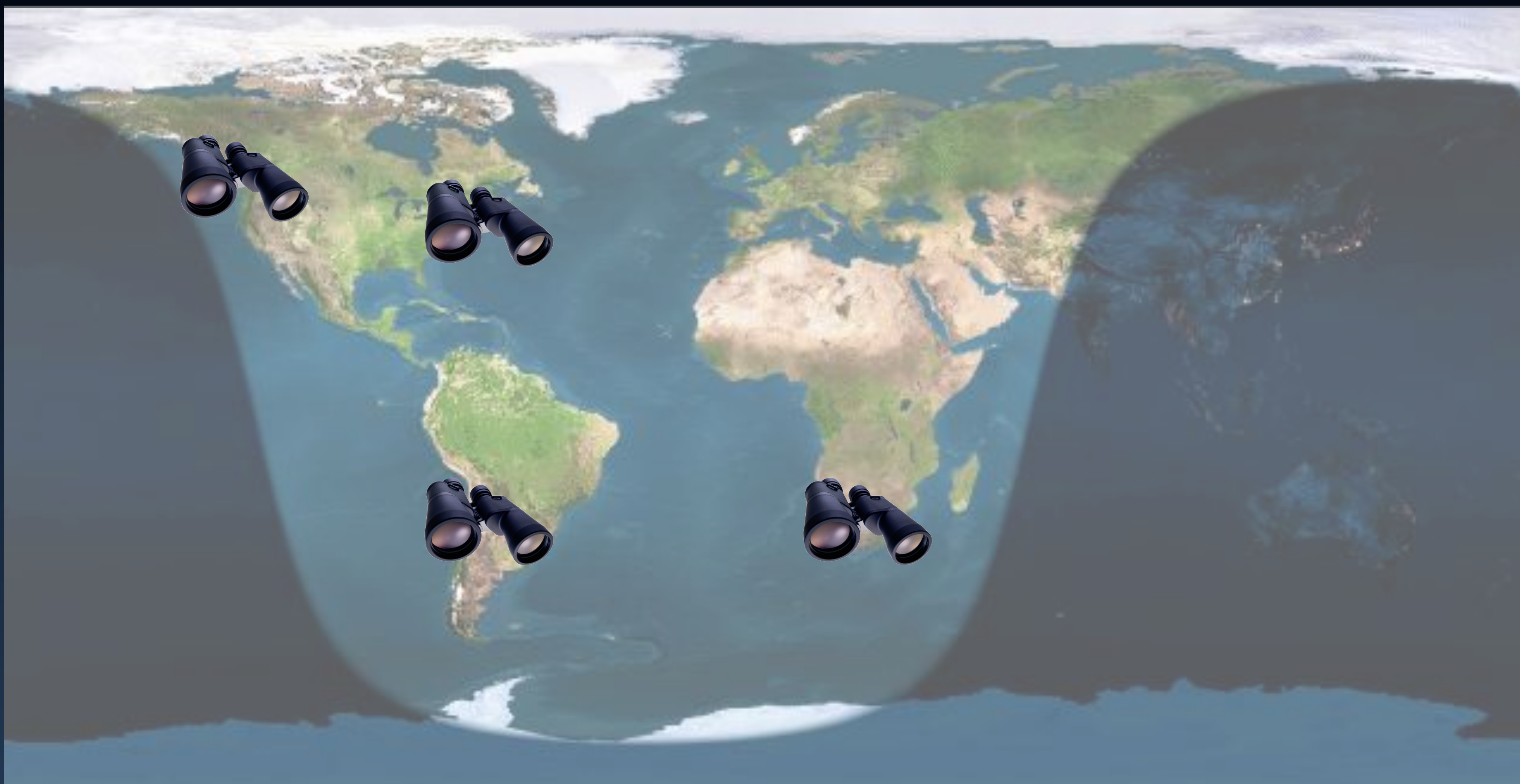
Right place,

Right time,

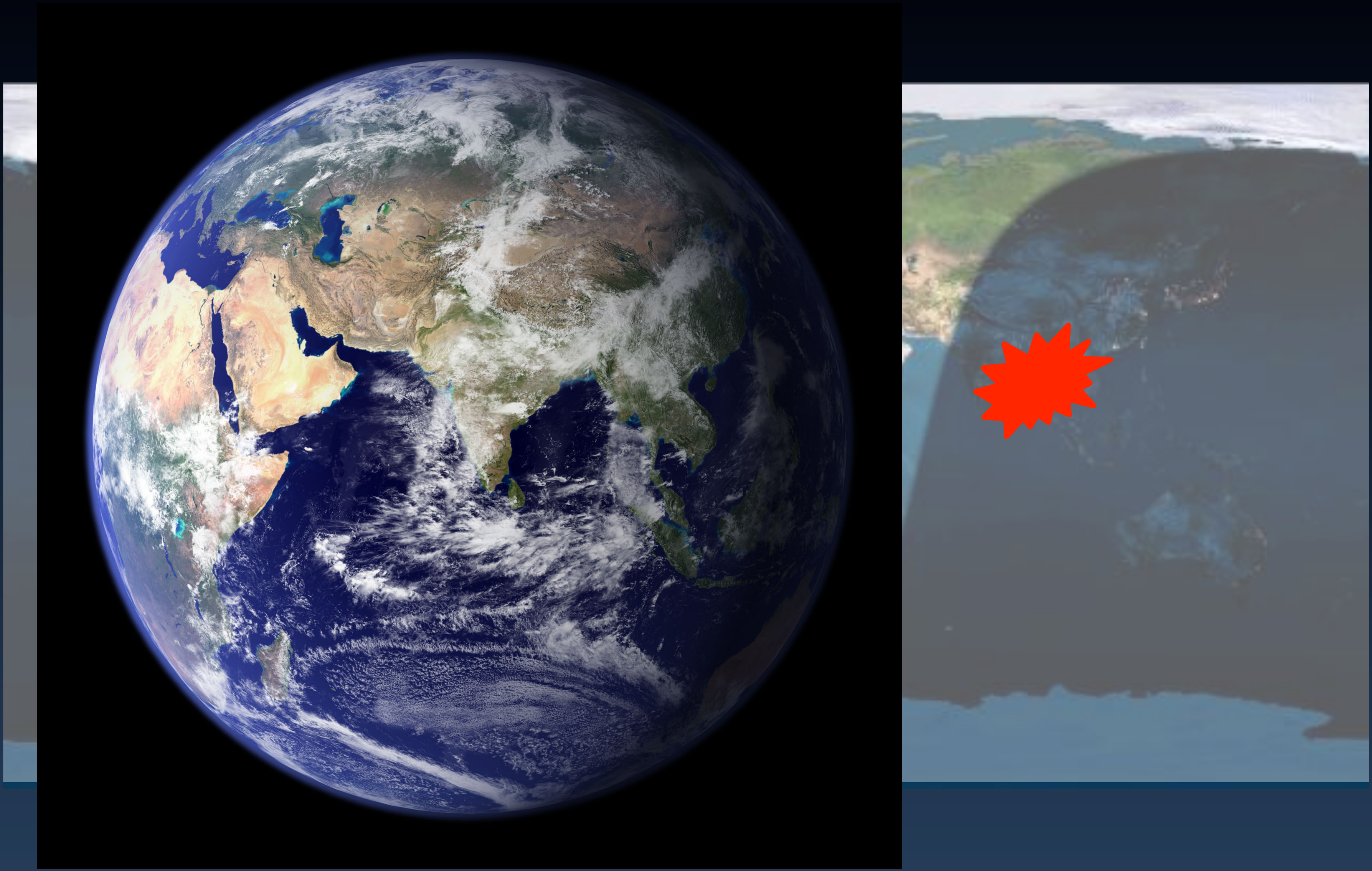
Right equipment

The right place

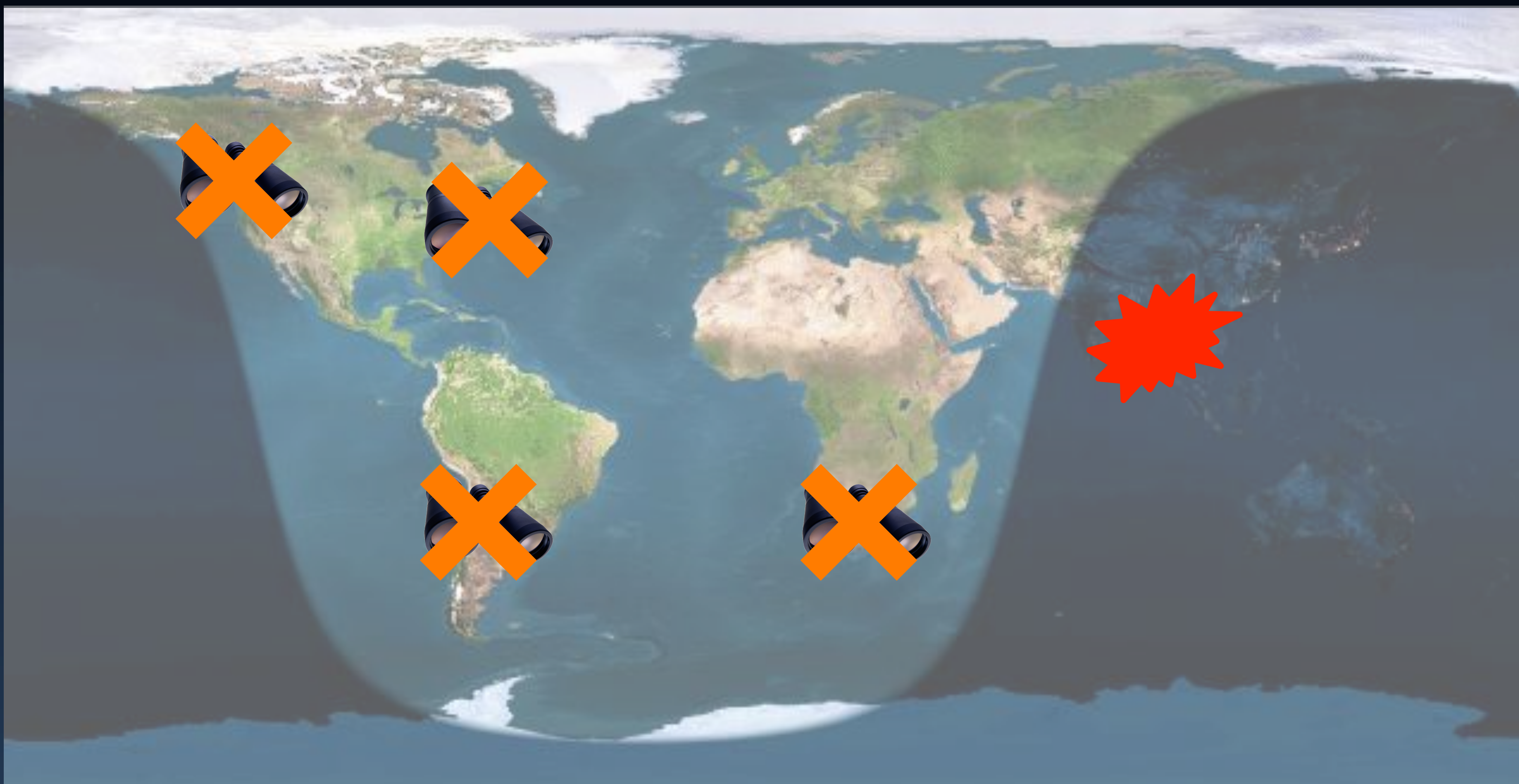
A Global Network



A Global Network

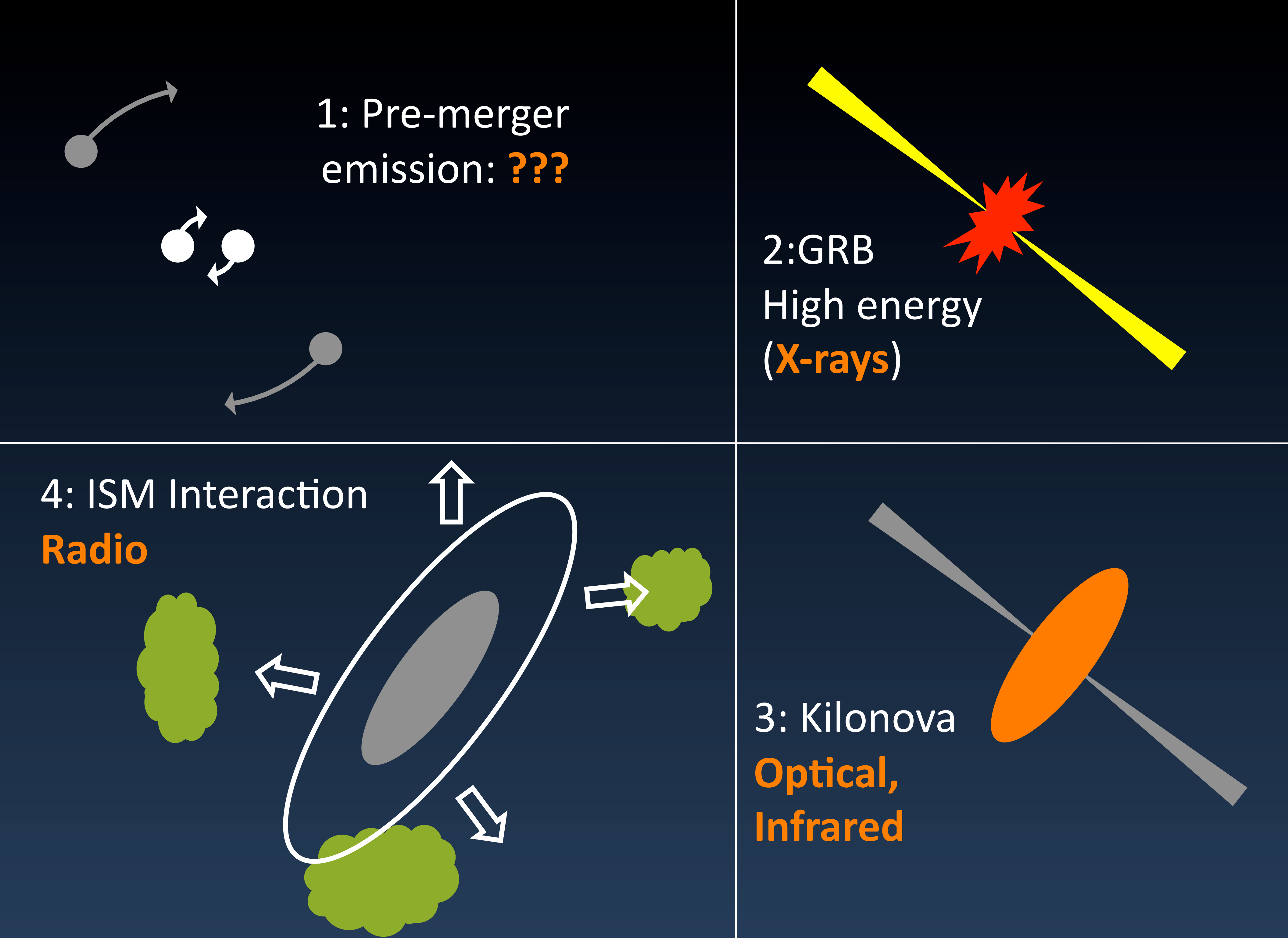


A Global Network



The right time

Day and night!


1: Pre-merger emission: ???
2:GRB
High energy
(X-rays)
4: ISM Interaction
Radio
3: Kilonova
Optical,
Infrared

Response timescales

- Gamma-ray / X-ray : Seconds to Minutes
- Optical / Infrared : Hours
- Radio: Days

The right equipment

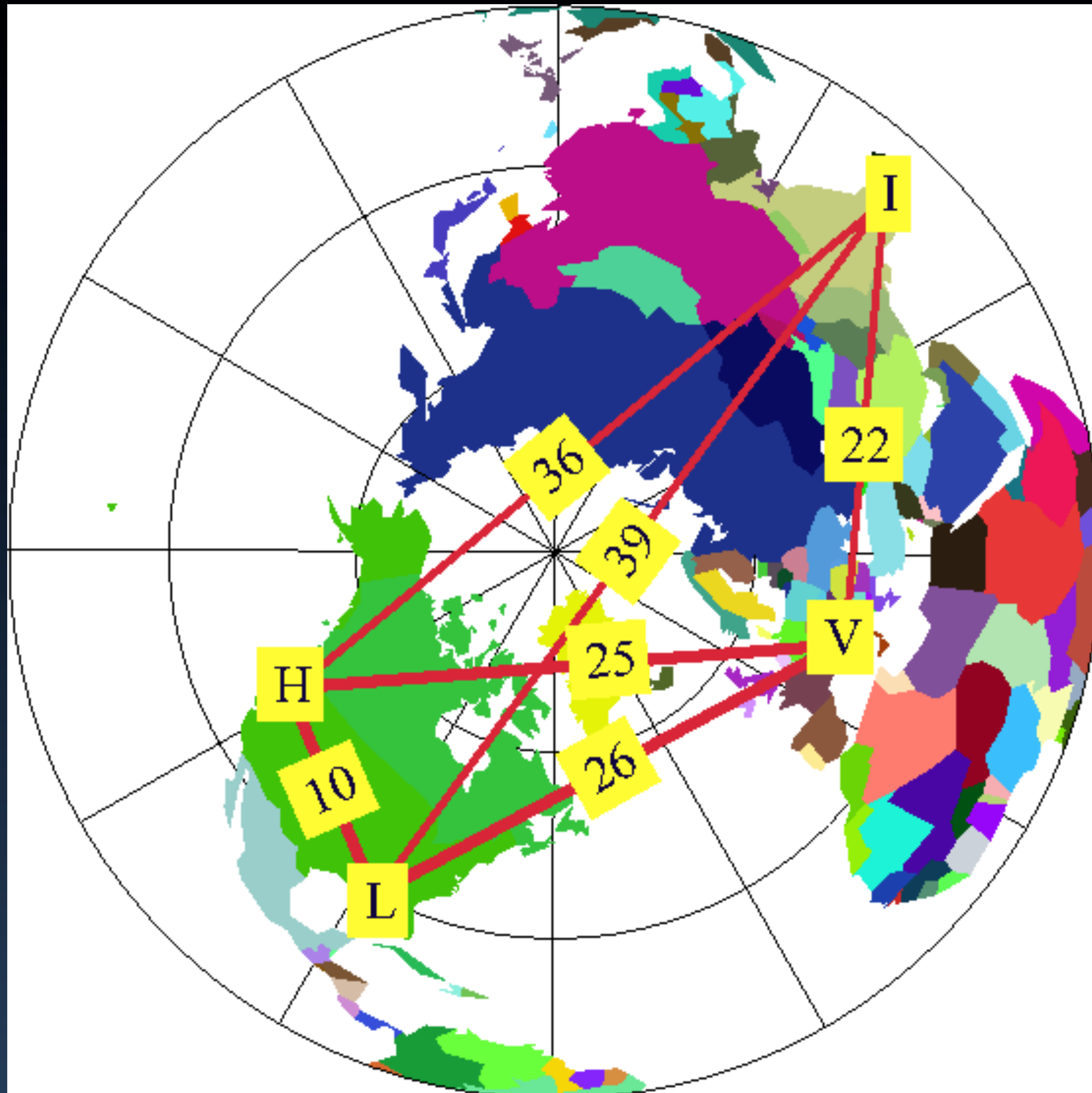
Where/how do we look?

Localization

Triangulate from arrival times

LIGO-India advantage:

- Longer baselines
- Better localization



Source localization

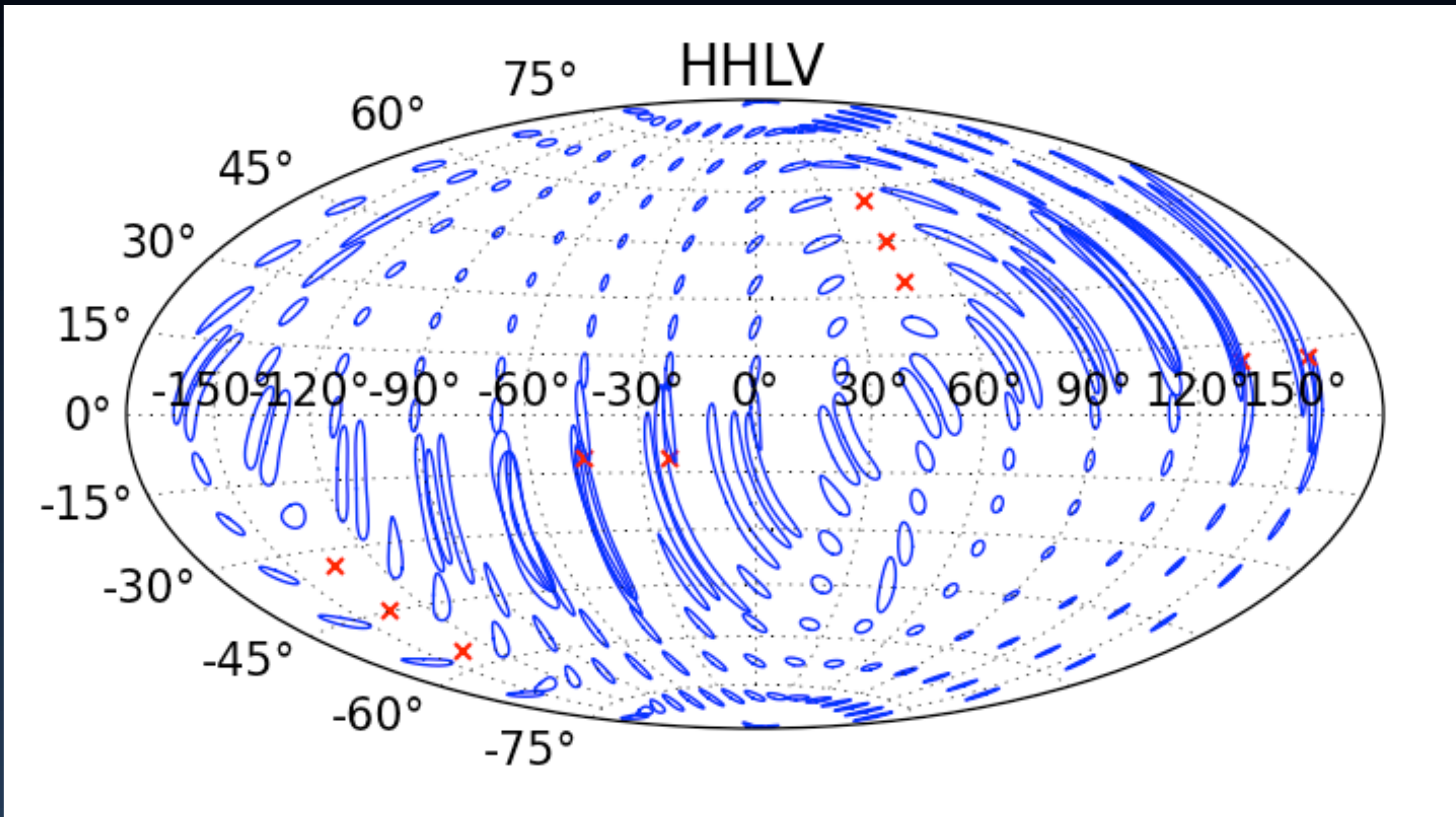


Image: Stephen Fairhurst

LIGO-India: Improved localization

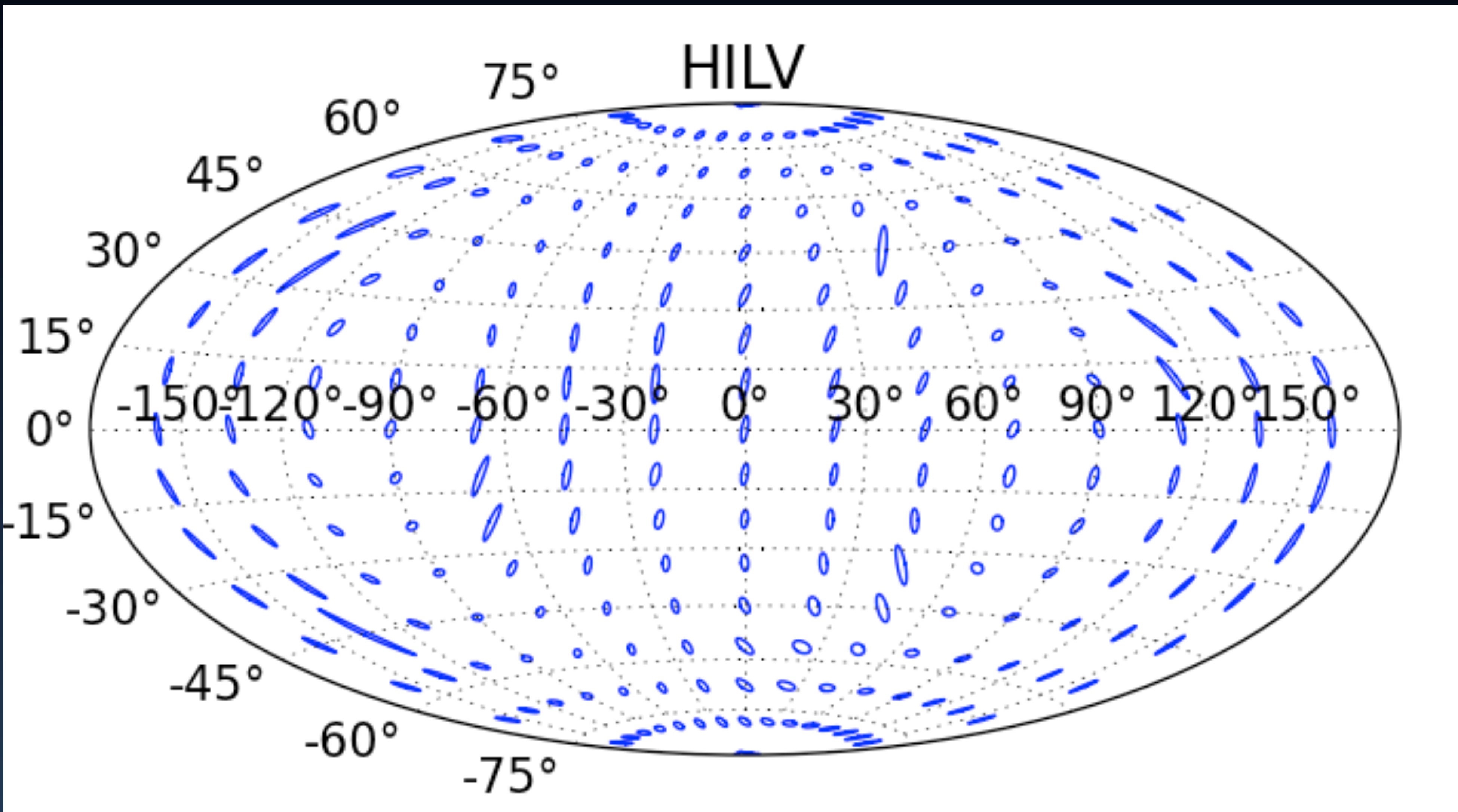
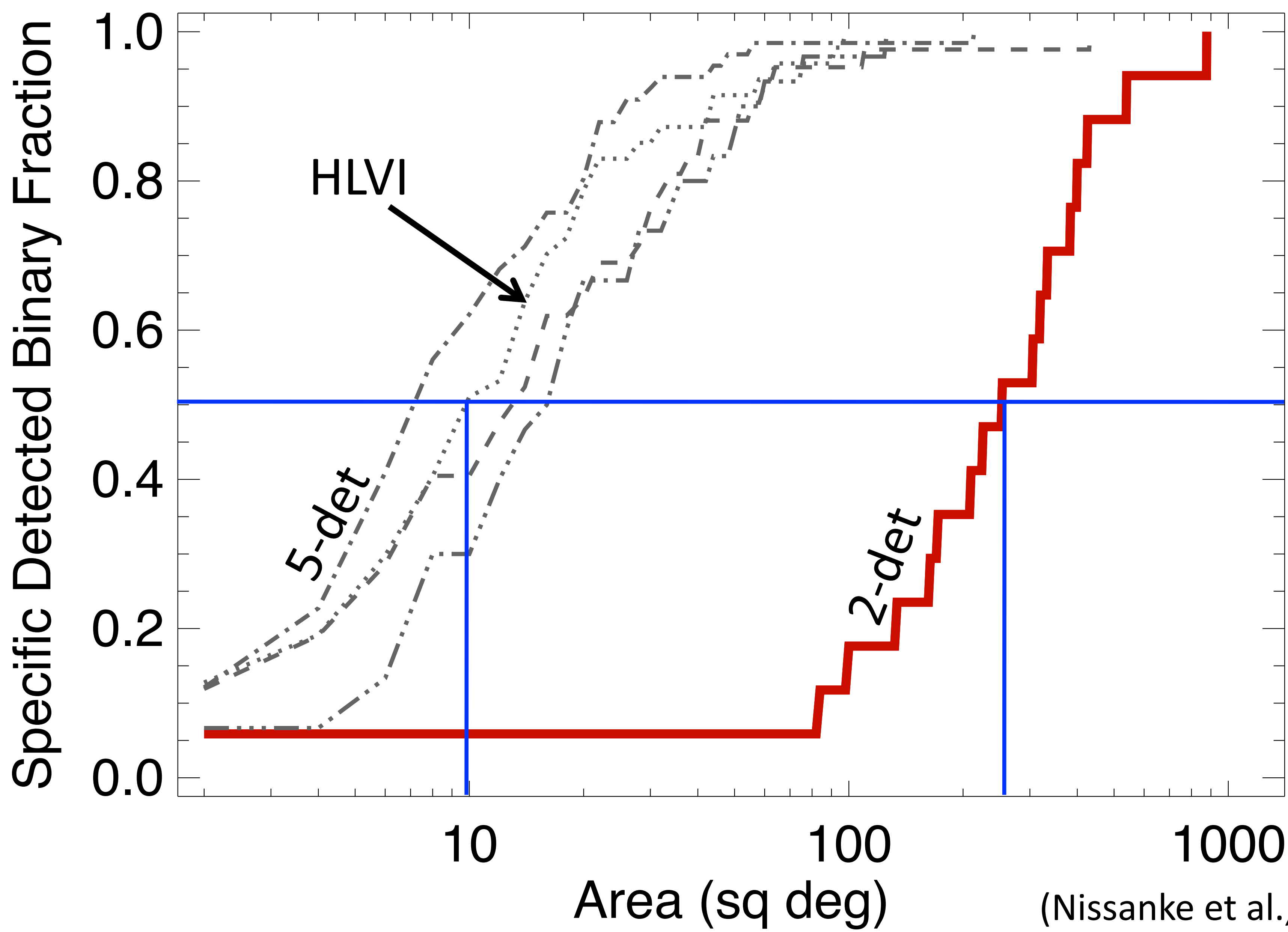


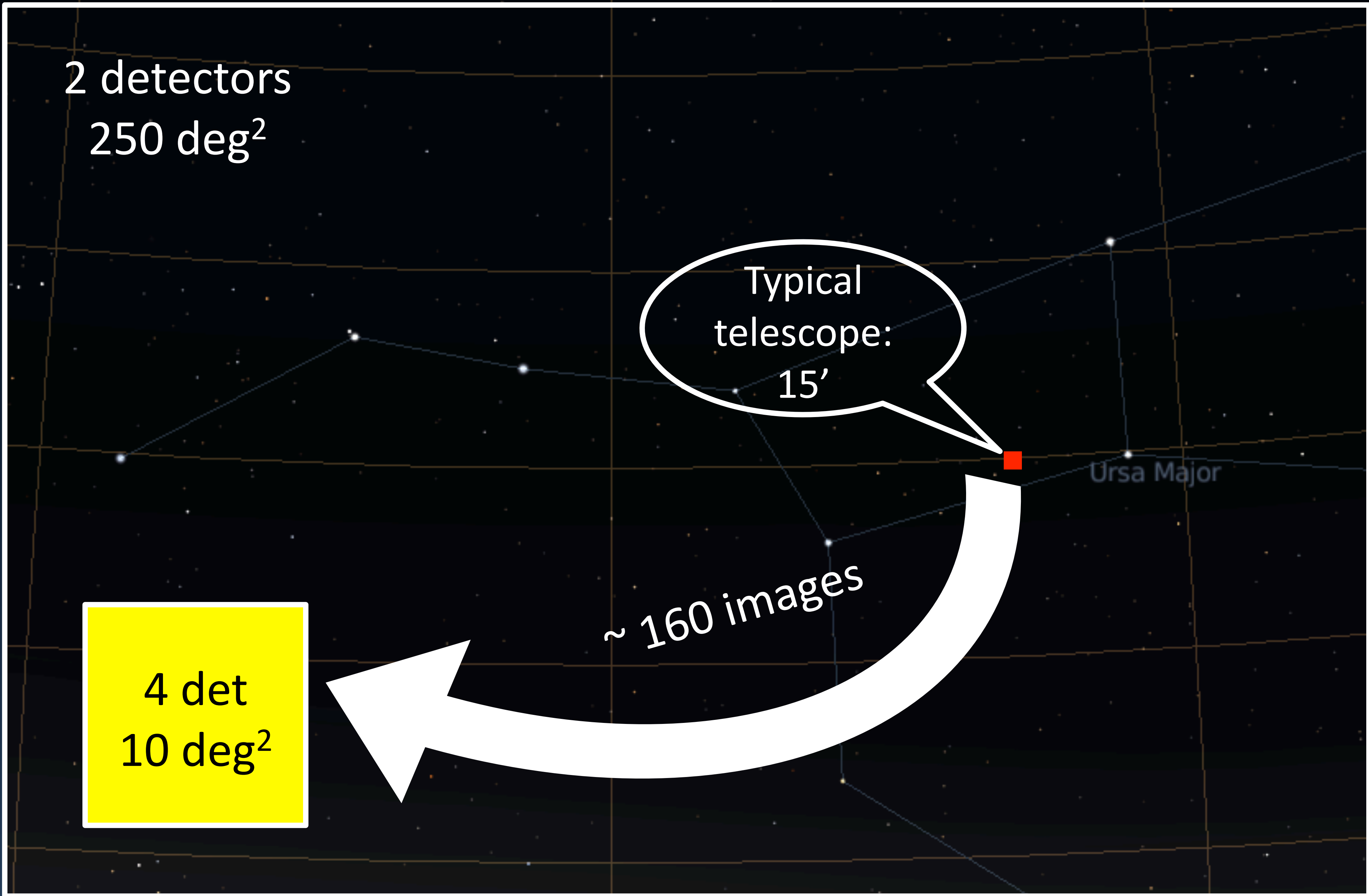
Image: Stephen Fairhurst

How large is the search region?

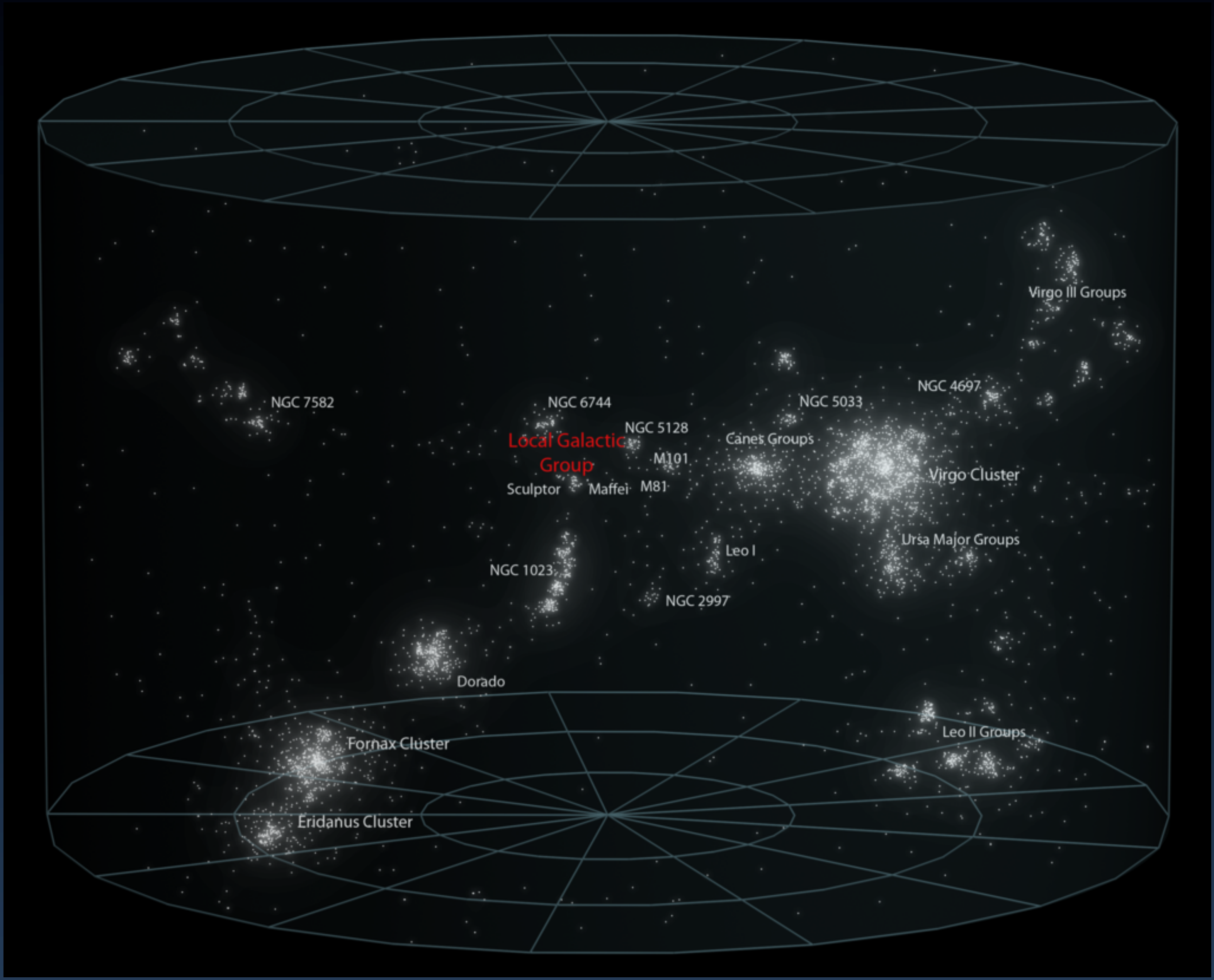


(Nissanke et al., 2012)

Localization

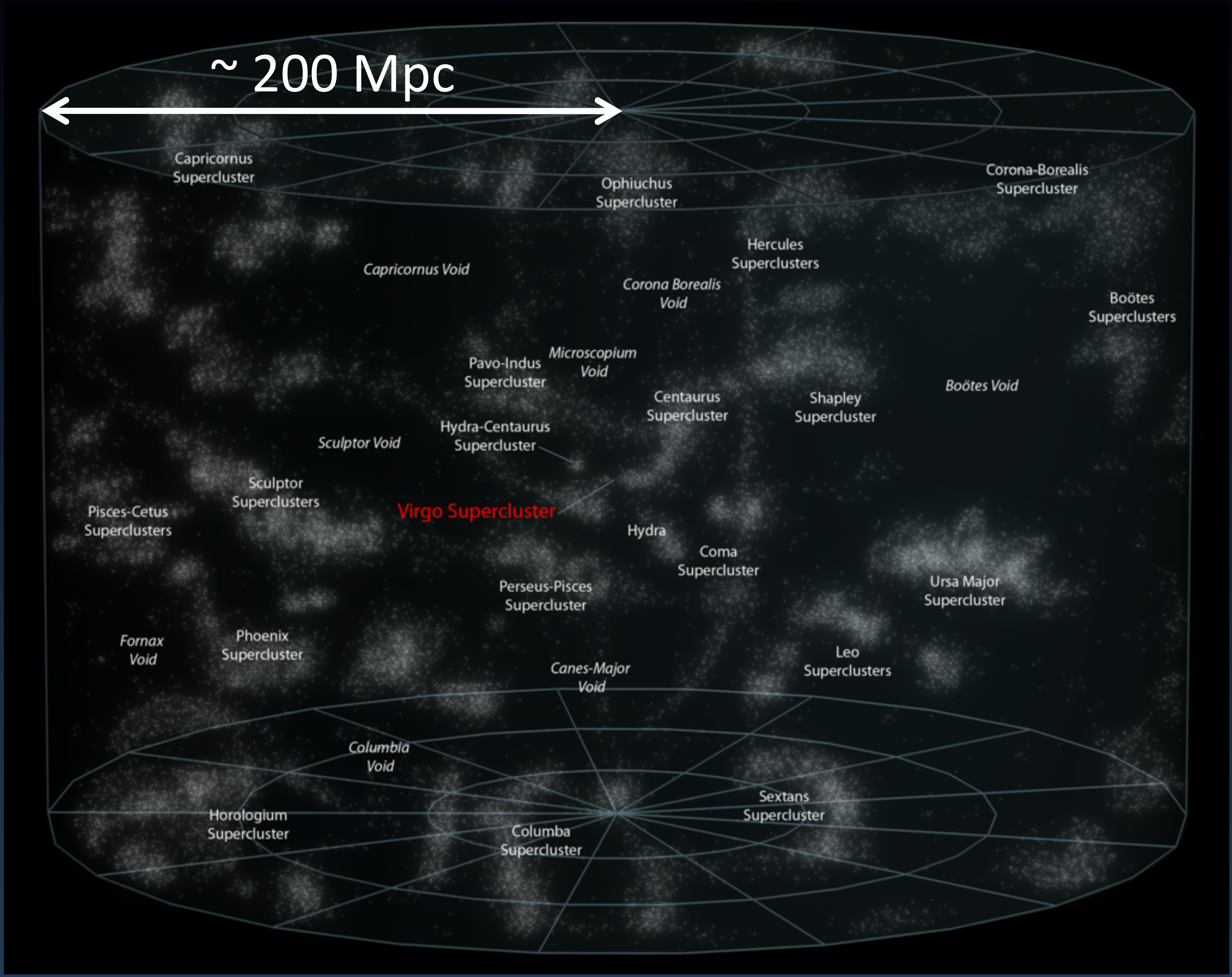


Virgo Supercluster



http://en.wikipedia.org/wiki/File:Earth's_Location_in_the_Universe_(JPEG).jpg

Local Superclusters



http://en.wikipedia.org/wiki/File:Earth's_Location_in_the_Universe_(JPEG).jpg

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GW & India

- LIGO-India awaits cabinet approval
- First detection likely before it is functional

- Can we detect electromagnetic counterparts for triggers from the three other detectors?

Elsewhere in the world

Telescope	Aperture (m)	Field of View (deg^2)	Exposure (sec)	Overhead (Readout)	Sensitivity (5σ mag in R band)
Zwicky Transient Facility	1.2	35	60	15	20.6
La Silla Quest	1.0	9.4 (80%)	60	30	20.5
Catalina Real-Time Transient Survey	0.7	8.0	30	18	19
Palomar Transient Factory	1.2	7.1	60	40	20.6
Pan-STARRS 1	1.8	7.0	60	3	22.0
Skymapper	1.35	5.62	110	20	21.5
CTIO-Dark Energy Camera	4.0	3.0	50	17	23.7
WIYN-One Degree Imager	3.5	1.0	60	30	23
CFHT-Megacam	3.6	0.9	60	40	23
Large Synoptic Survey Telescope	8.4 (6.7)	9.6	15	2	24.5
Subaru-HyperSuprimeCam	8.2	1.77	30	20	24.5

From Nissanke, Kasliwal and Georgiva, 2012, arXiv:1210.6362

Can the small beat the big?

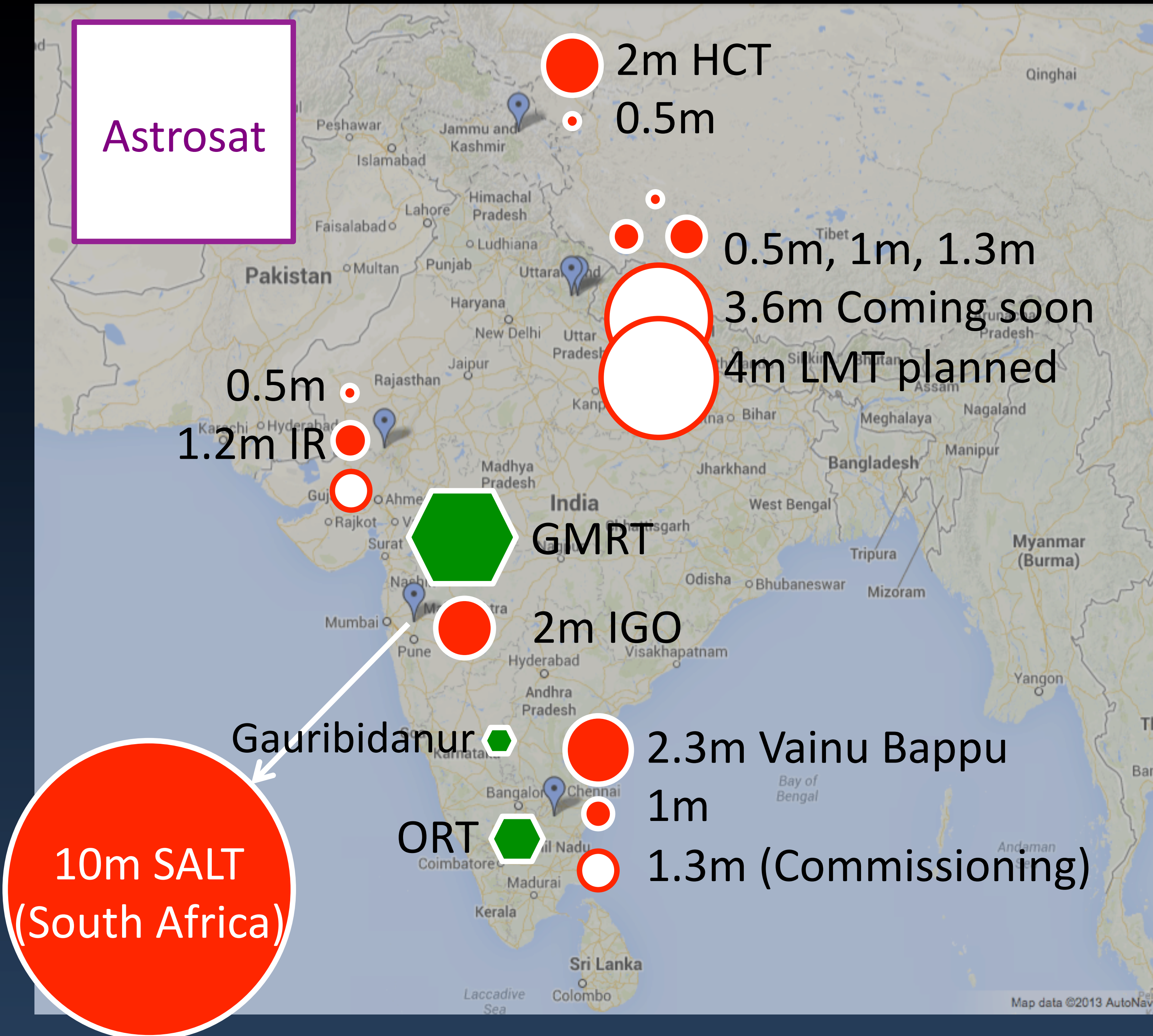
EM observing in India

- Location: Exclusive access to ~ 1/3rd of the sky

EM observing in India

- Location: Exclusive access to ~ 1/3rd of the sky
- Suite of telescopes and instruments

Large Indian Telescopes



ASTROSAT

A Multi-Wavelength Satellite

Astrosat

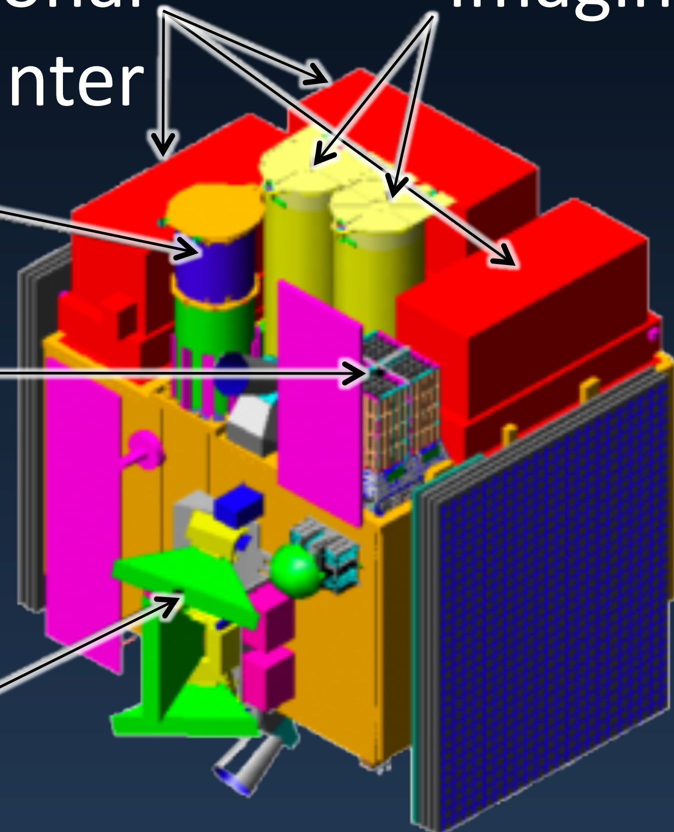
LAXPC: Large Area Xenon Proportional Counter

UVIT: UltraViolet Imaging Telescope

SXT: Soft X-ray Telescope

CZTI: Cadmium Zinc Telluride Imager

SSM: Scanning Sky Monitor



Cadmium Zinc Telluride Imager

- Energy Range:
  - 10-150 keV
- Effective area:
  - ~ 500 cm^2
- Field of view:
  - FOV 5° (FWHM)
  - Resolution 8’
- Timing resolution:
  - 20 μs precision

MOU signed!

http://www.iucaa.ernet.in/~astrosat/czti_specs.html

Giant Meterwave Radio Telescope

Optical / Infrared: Big guns

- 1.3m Devasthal Fast Optical Telescope
- 1.3m Kavalur Telescope

- 2m Himalayan Chandra Telescope
- 2m IUCAA Girawali Telescope
- 1.2m Mt. Abu IR Telescope

- 3.6m ARIES Telescope

Quick specs

Telescope	Aperture	FOV	Info		
DFOT	1.3m	1° × 1°	Img		
HCT	2m	10’ × 10’	Img	Spec	IR
IGO	2m	10’ × 10’	Img	Spec	IR
Mt. Abu IR	1.2m	8’ × 8’		Spec	IR
VBT	2.3m	–		Spec	
Baker Nunn Camera	0.5m	4° × 4°	Img		
Mt. Abu CDK	0.7m	51’ × 51’	Img		

EM observing in India

- Location: Exclusive access to ~ 1/3rd of the sky
- Suite of telescopes and instruments
- Rapid response capabilities
- Readiness: software and manpower

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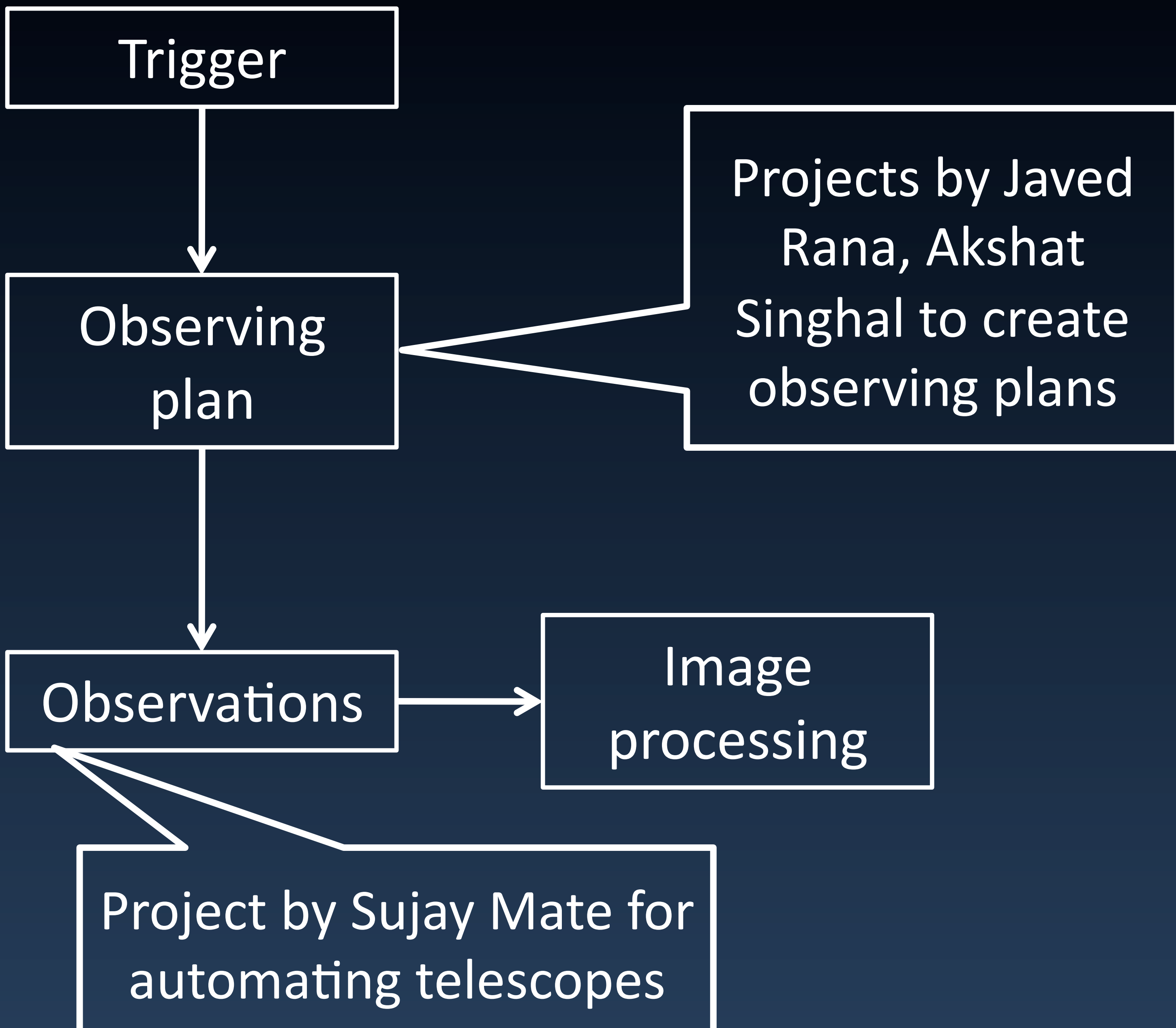
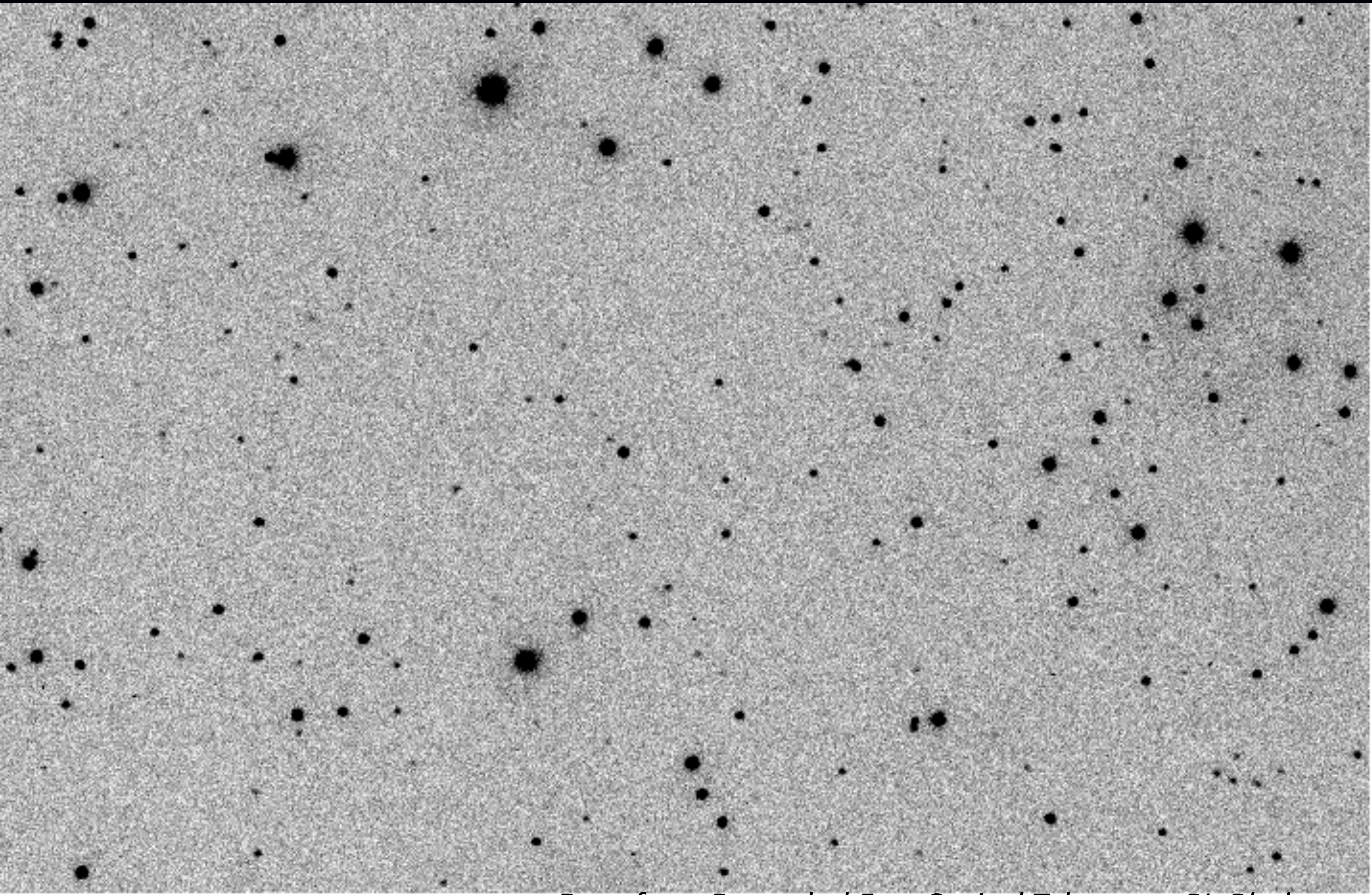
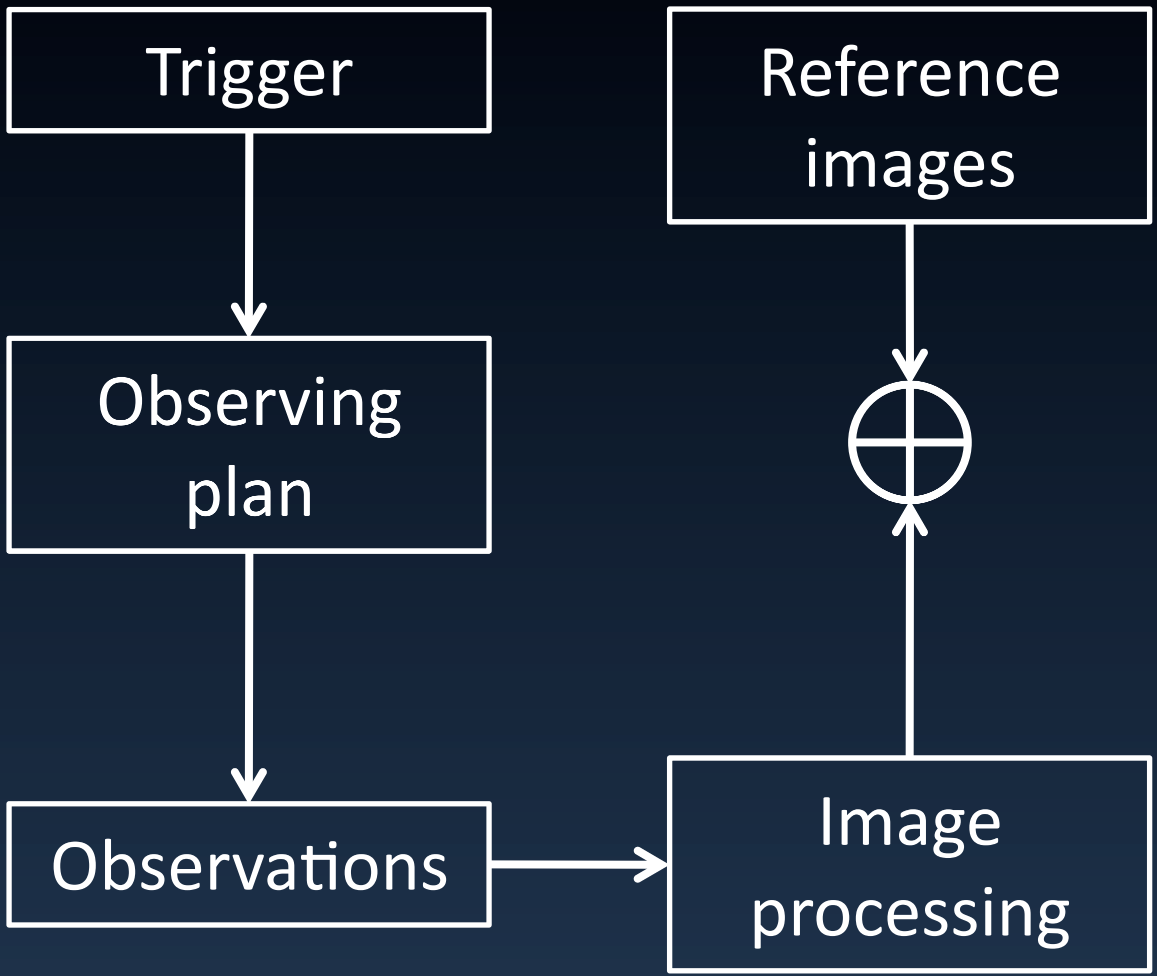
Finding *the* transient





Data from Devasthal Fast Optical Telescope, PI: Bhalerao

Finding *the* transient



Reference images

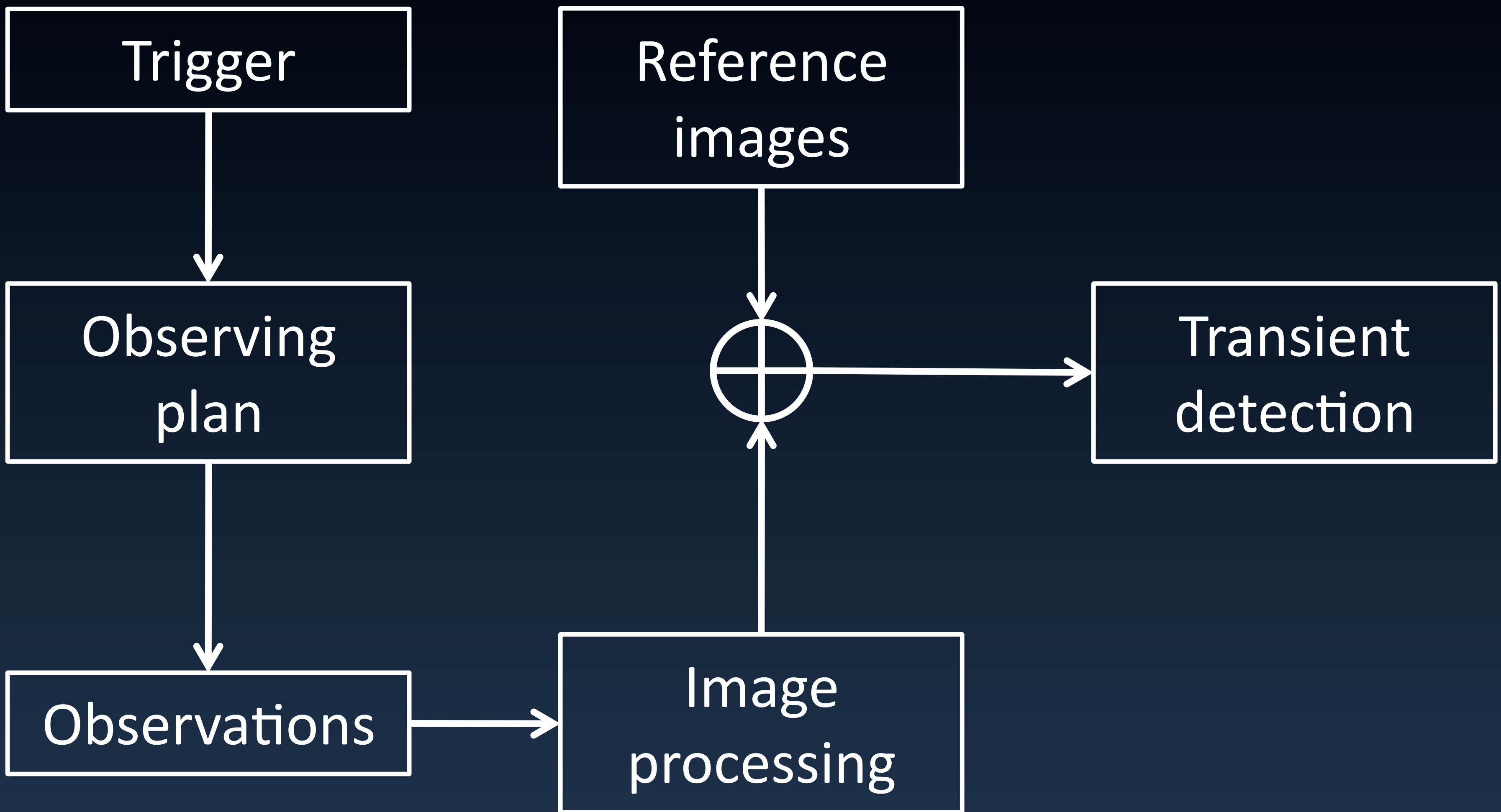
- Better than new data
  - » Deeper
  - » Better seeing
- Example: IGO
  - » Sky visible: $\delta > -40°$ = 36,000 sq deg (88%)
  - » IFOSC FOV = 10'.5 × 10'.5 = 0.03 sq deg
  - » Full sky coverage: 1.2 million images
  - » Few min exp => ~100 per night => ~ 32 years
- ~ 1 year for 1 sq deg FOV

Public reference image data?

- Reference images must be in same band
- SDSS: ~1/3rd sky
- USNO: All sky, lower quality

- CRTS: All sky, unfiltered
  - » Median 100 visits/sky location
  - » Work with CRTS group (Ashish Mahabal et al) to create reference images

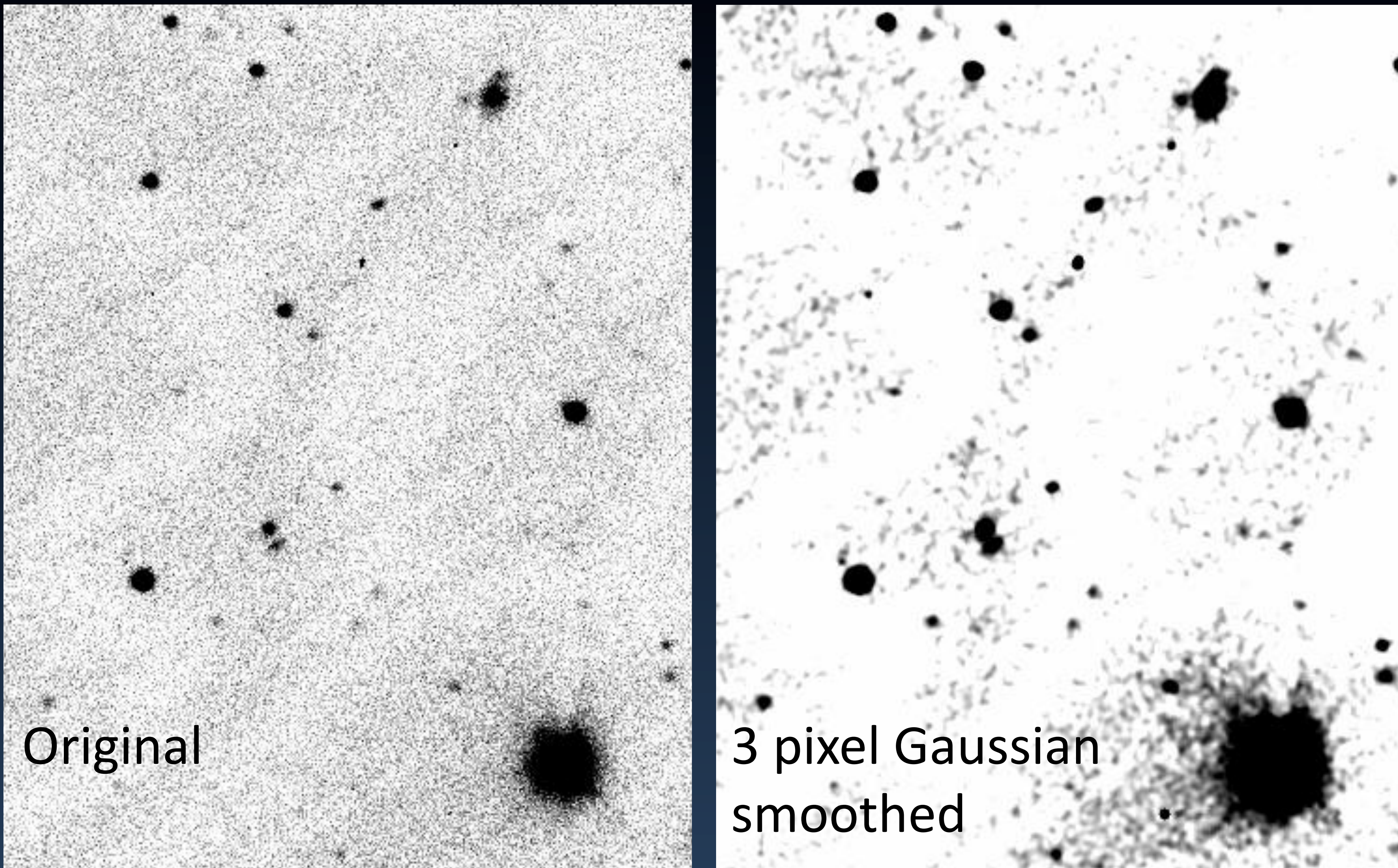
Finding *the* transient



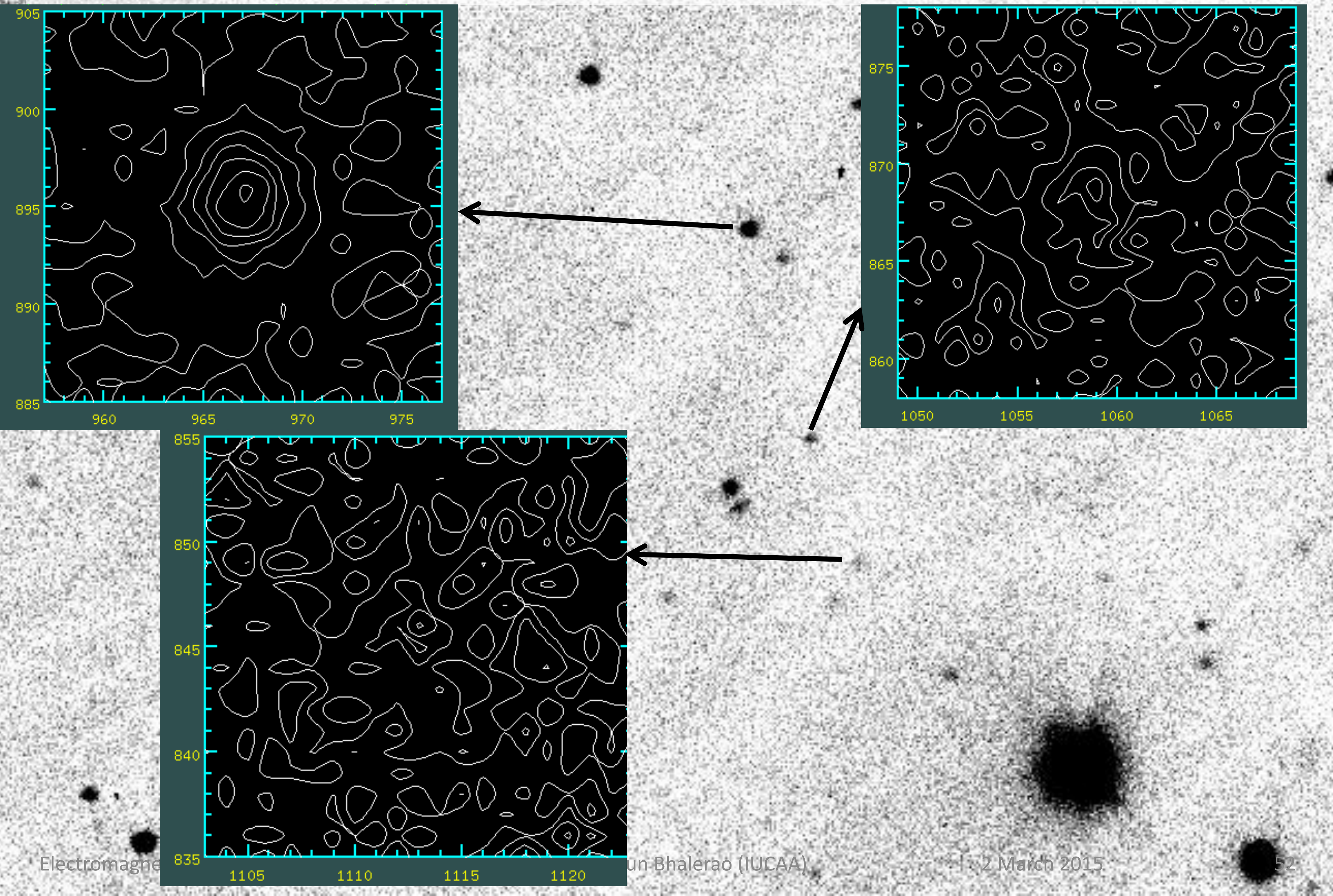
Automatic transient search

- Catalog each source, find new ones
  - » Problem: transients often on galaxies
- Image subtraction
  - » Problem: varying observing conditions
  - » Must match Point Spread Function first

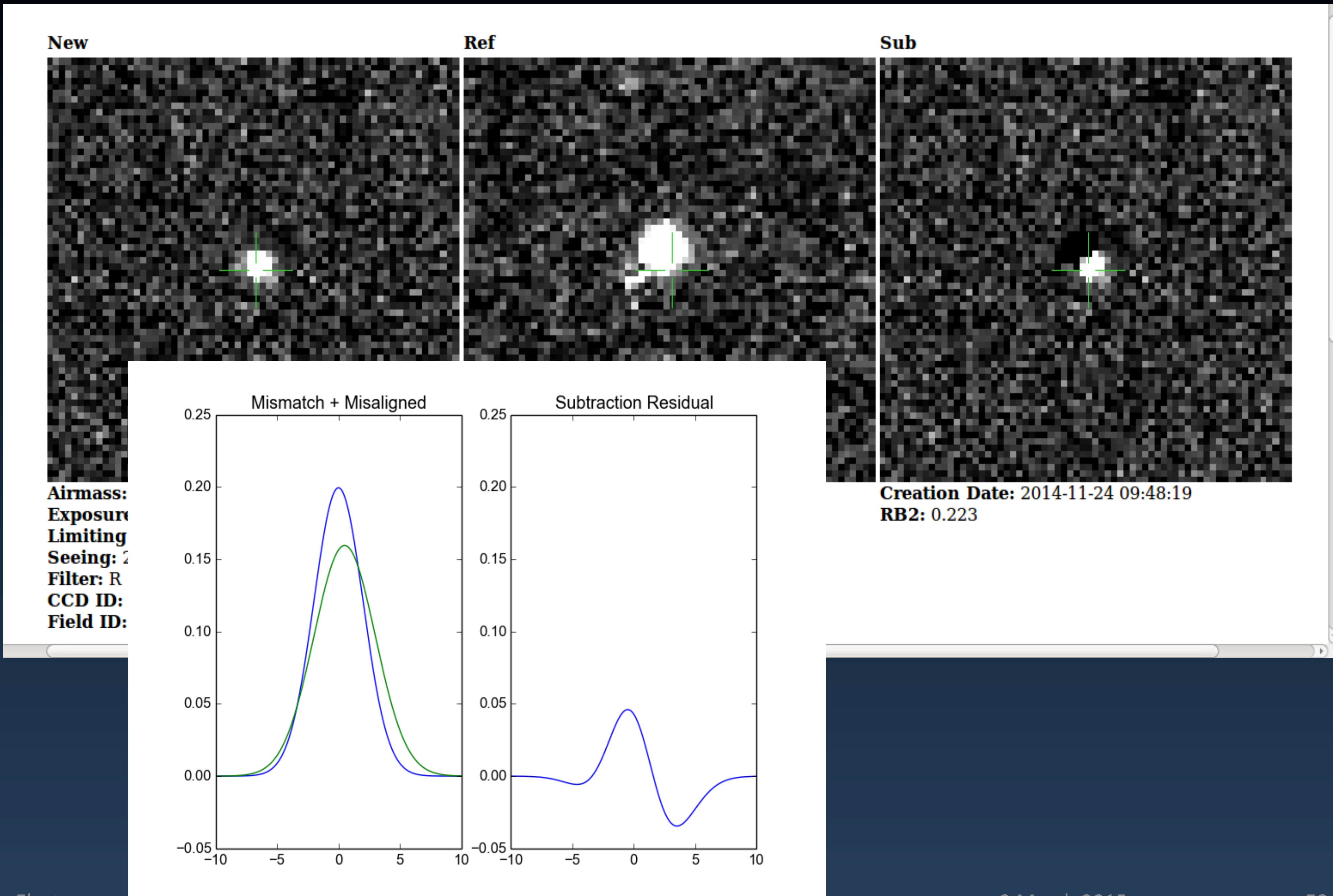
Individual sources: detection easier

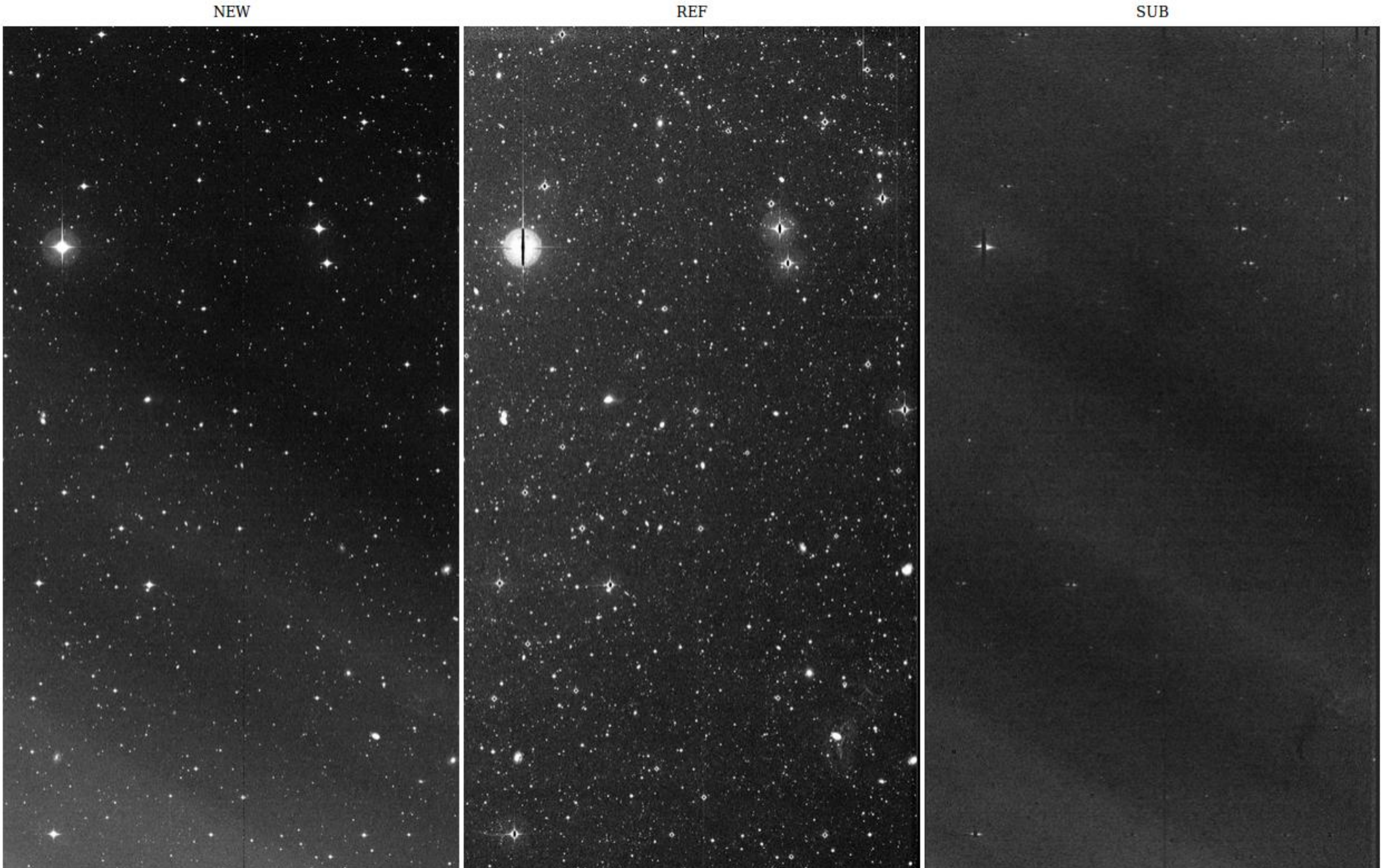


Point Spread Function



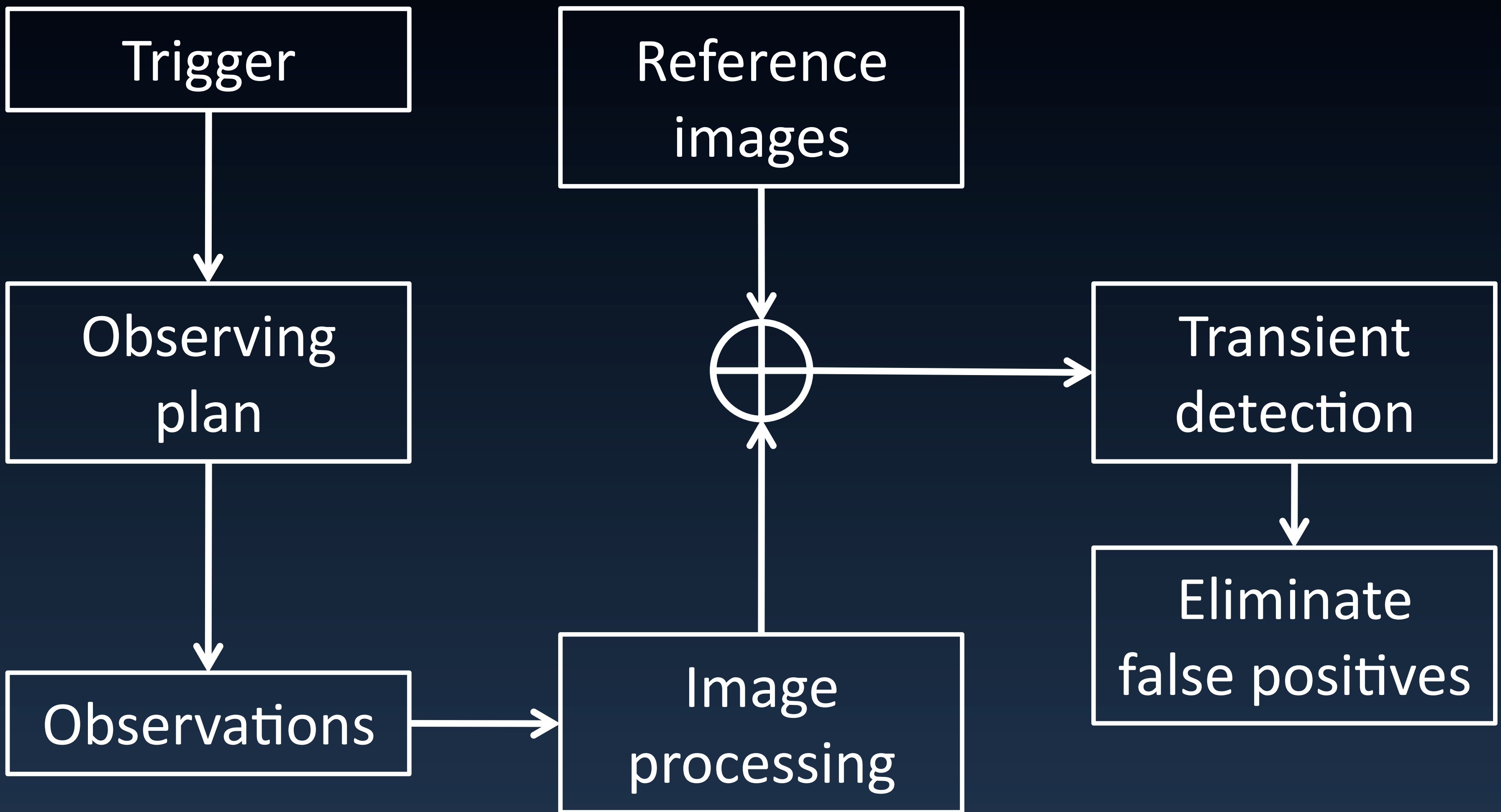
Sample: bad image subtraction





Lots of statistically significant residuals!

Finding *the* transient



False positives

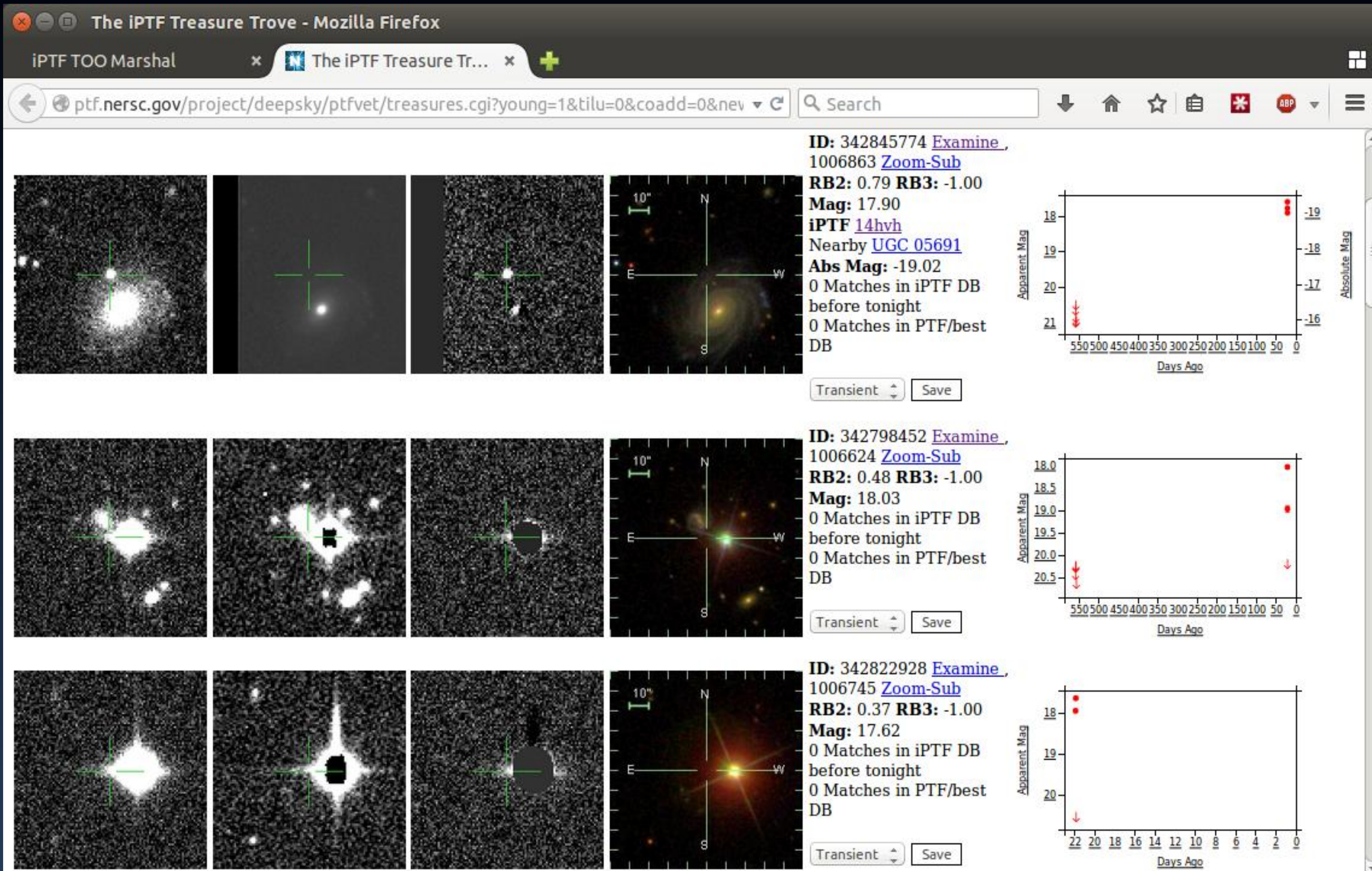
- Instrumental:
  - » PSF mismatch
  - » CCD defects
  - » Diffraction spikes

- 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)

Human “vetting”



Good days, Bad days

GRB 140808A

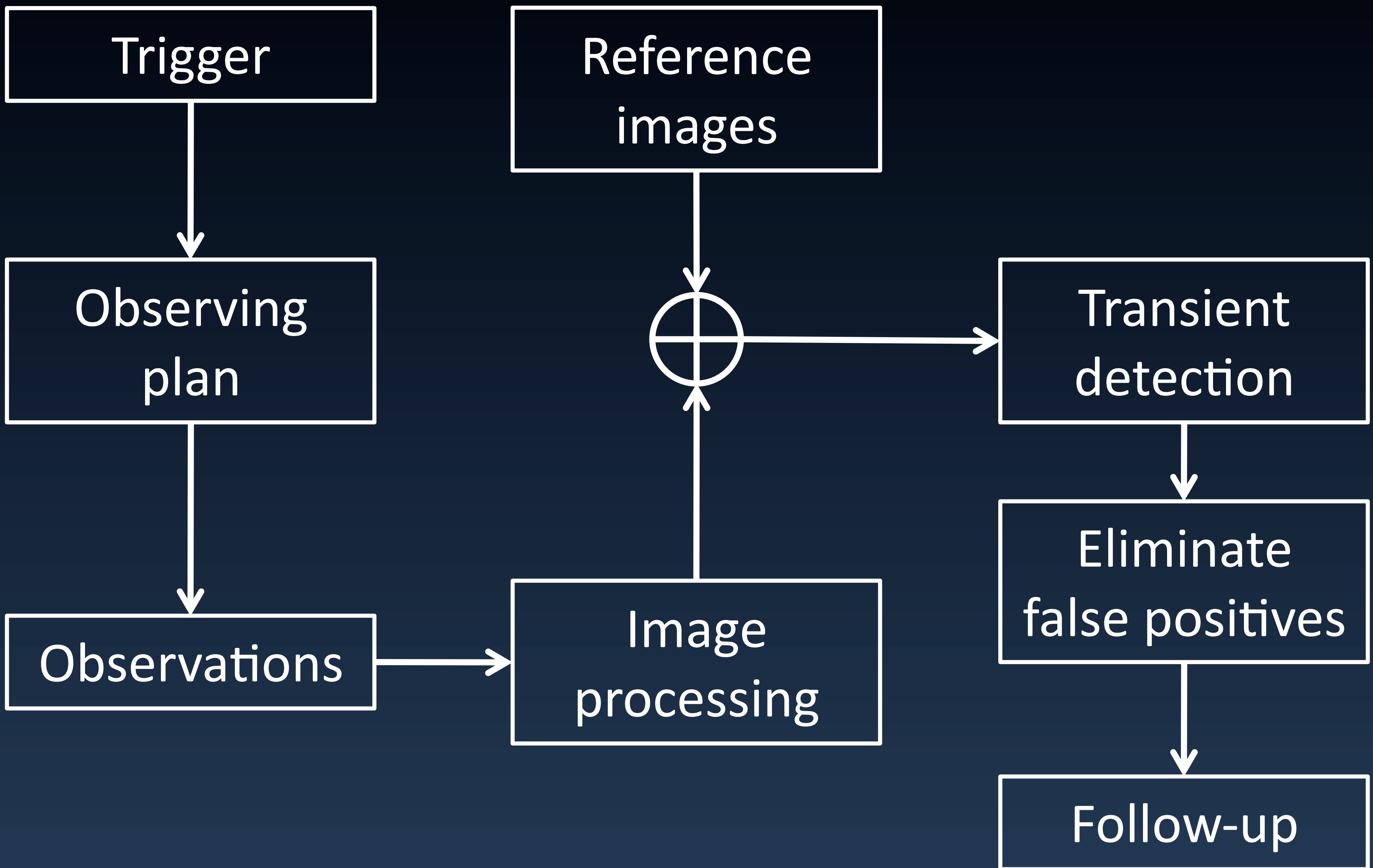
- 19,853 detections > 5σ
- 4,804 with RB2 > 0.1
- 2,349 not stellar
- 2,349 not asteroids
- 127 detected twice
- 12 saved for follow-up

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

Fermi GRB followup project, iPTF collaboration

Finding *the* transient



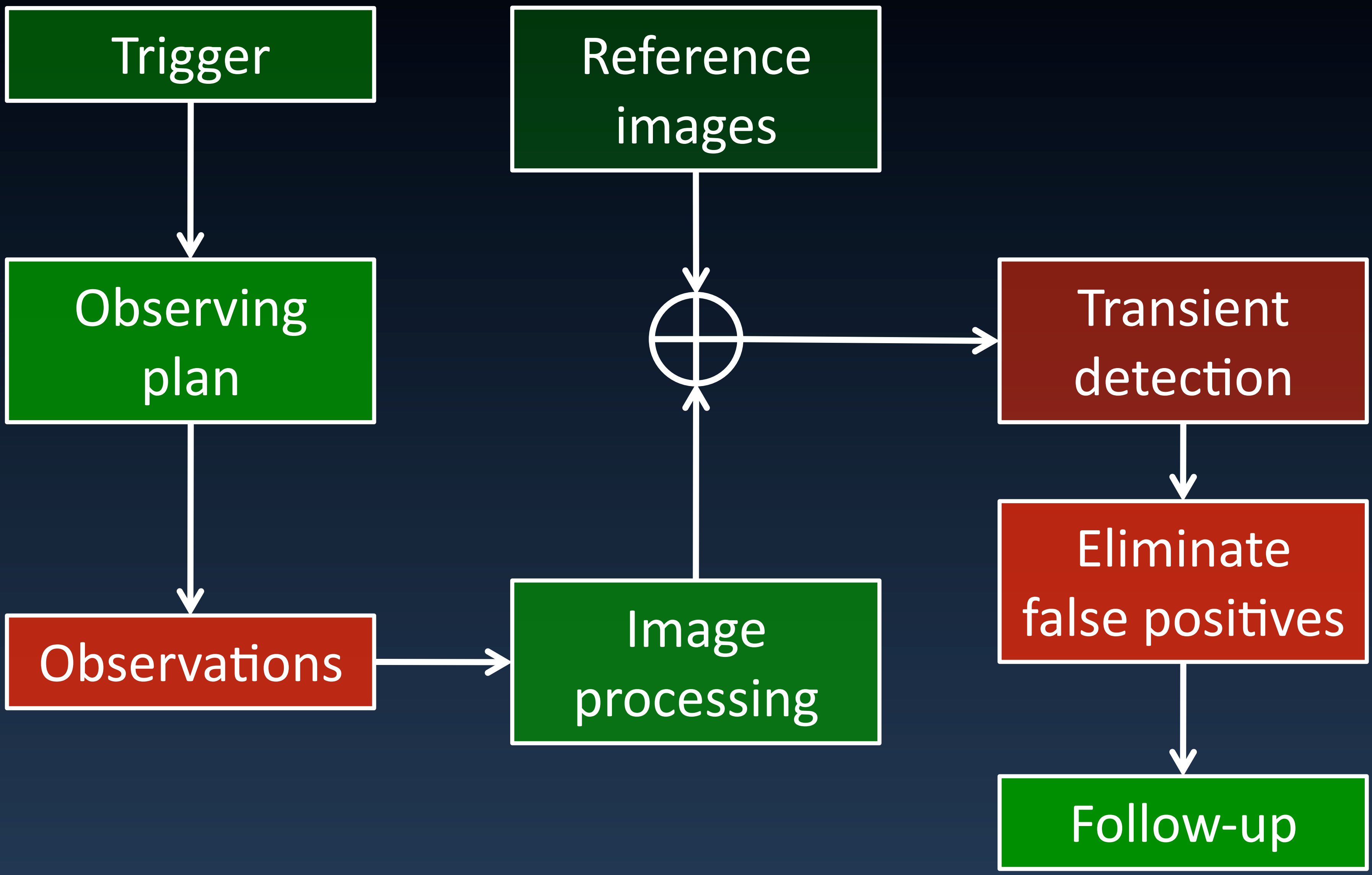
Follow-up

- Multi-wavelength, multi-location
- Optical:
  - » HCT, IGO (multi-band photometry/spectra)
  - » Observe before candidate fades too much
  - » Keck, Palomar, Gemini for next night
- Other wavelengths:
  - » Swift, CARMA

Example: iPTF & Fremi GRBs

- Error boxes for Fermi GBM detections can be 100 – 150 deg^2
- Observe up to 20 tiles, three times each
  - » Helps eliminate new asteroids, spurious events
- Up to 10^5 statistically significant candidates
- 10 – 100 after machine classification
  - » 1000 on bad nights
- 2 – 5 identified as “real” by humans
- Further follow-up identifies afterglow

Summary


Trigger
Reference images
Observing plan
Transient detection
Eliminate false positives
Observations
Image processing
Follow-up

Summary

- Identifying and studying electromagnetic counterparts to gravitational wave sources is crucial for complete astrophysical understanding
- Much remains unknown about possible counterparts
- Search for EM counterparts is an extremely challenging problem…

… and we need to work

very hard to make it possible!