A new approach to observational astronomy to detect the fastest transients and solve the nature of FRBs

Tim Abbott

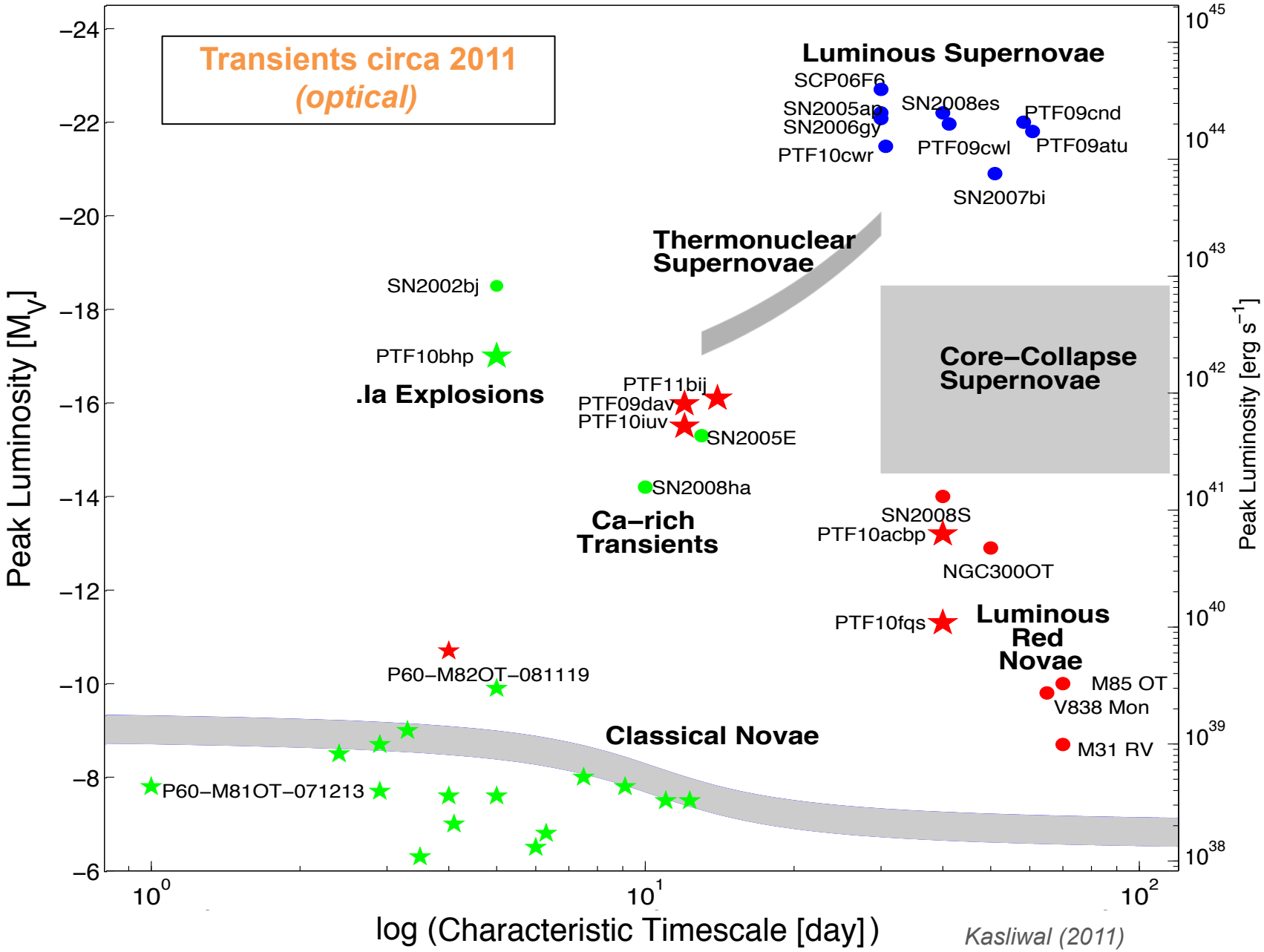
on behalf of Jeff Cooke and the DWF team

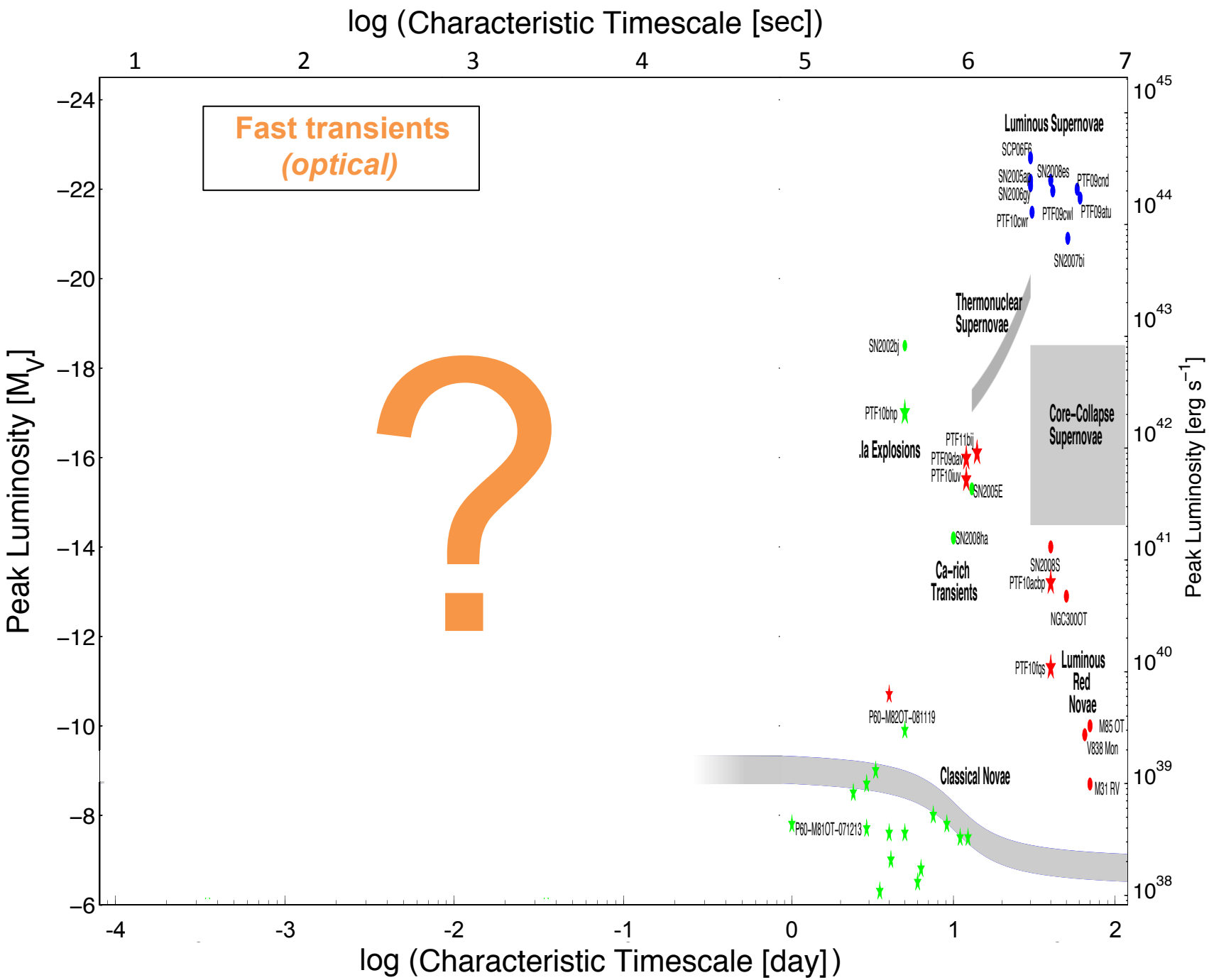
Fast transients

Events with millisecond-to-hours duration

Include very early detections and fast time-sampling of longer duration events

Occur at all wavelengths + particle + gravitational waves


Transients circa 2011
(optical)
Luminous Supernovae
SCP06F6
SN2005ap
SN2006gy
SN2008es
PTF09cnd
PTF09cwl
PTF09atu
PTF10cwr
SN2007bi
Thermonuclear Supernovae
SN2002bj
PTF10bhp
.Ia Explosions
PTF11bij
PTF09dav
PTF10iuv
SN2005E
Core–Collapse Supernovae
SN2008ha
Ca–rich Transients
SN2008S
PTF10acbp
NGC300OT
PTF10fqs
Luminous Red Novae
P60–M82OT–081119
M85 OT
V838 Mon
Classical Novae
M31 RV
P60–M81OT–071213
Peak Luminosity [M_V]
Peak Luminosity [erg s^{-1}]
log (Characteristic Timescale [day])
Kasliwal (2011)


log (Characteristic Timescale [sec])
1
2
3
4
5
6
7
Fast transients
(optical)
?
Luminous Supernovae
SCP06F6
SN2005ap
SN2006gy
SN2008es
PTF09cnd
PTF10cwr
PTF09cwl
PTF09atu
SN2007bi
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−22
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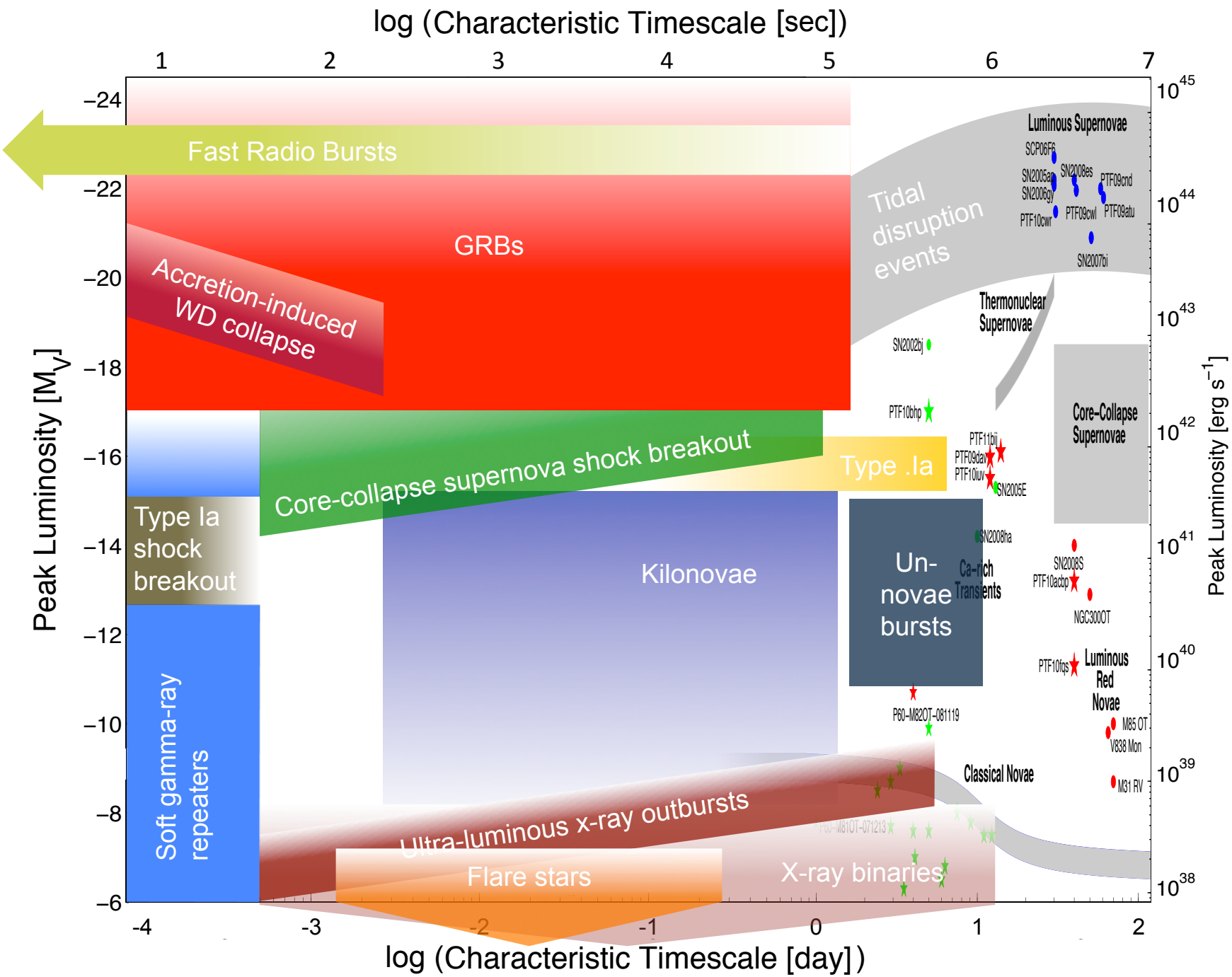
−12
−10
−8
−6
Peak Luminosity [erg s^{-1}]
10^{45}
10^{44}
10^{43}
10^{42}
10^{41}
10^{40}
10^{39}
10^{38}
-4
-3
-2
-1
0
1
2
log (Characteristic Timescale [day])


log (Characteristic Timescale [sec])
1
2
3
4
5
6
7
Peak Luminosity [M_V]
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10^{45}
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10^{43}
10^{42}
10^{41}
10^{40}
10^{39}
10^{38}
Fast Radio Bursts
GRBs
Accretion-induced WD collapse
Tidal disruption events
Luminous Supernovae
SCP06F6
SN2005ap
SN2006gy
SN2008es
PTF09cnd
PTF10cwr
PTF09cwl
PTF09atu
SN2007bi
Thermonuclear Supernovae
SN2002bj
PTF10bhp
Core-Collapse Supernovae
Core-collapse supernova shock breakout
Type .Ia
PTF11bij
PTF09dav
PTF10luv
SN2005E
Type Ia shock breakout
Kilonovae
Un-novae bursts
Ca-rich Transients
SN2008ha
SN2008S
PTF10acbp
NGC300OT
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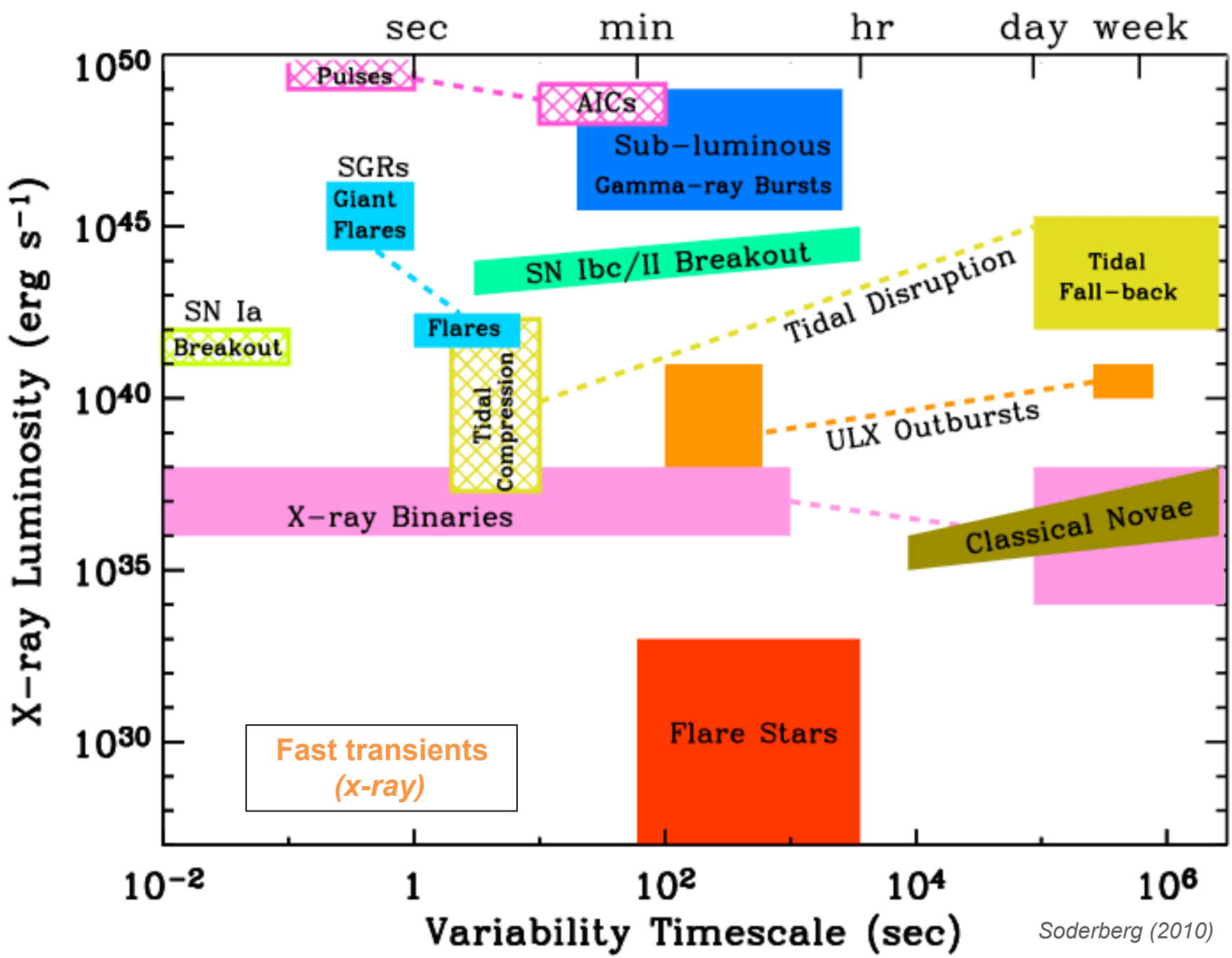
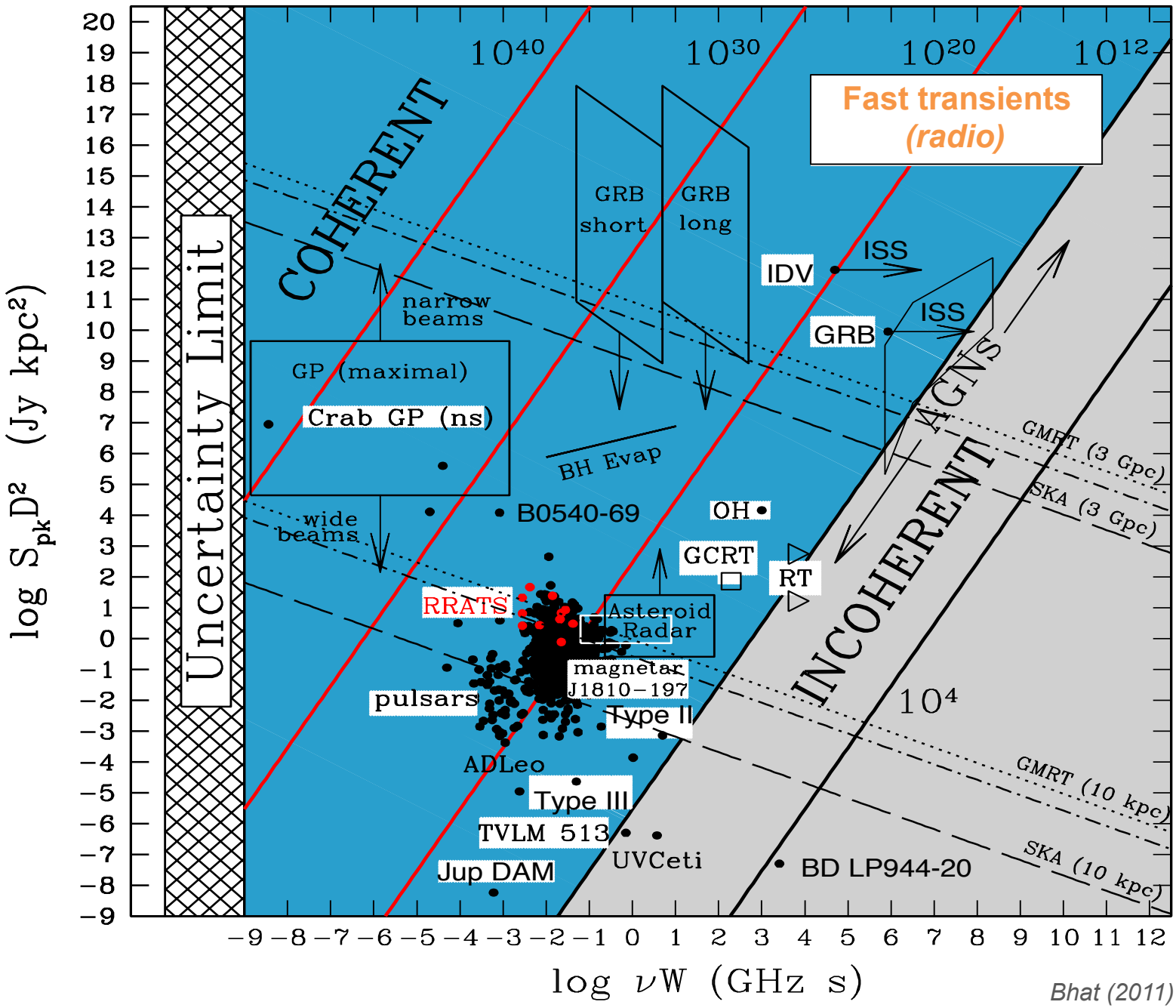
Luminous Red Novae
P60-M82OT-081119
M85 OT
V838 Mon
Classical Novae
M31 RV
Soft gamma-ray repeaters
Ultra-luminous x-ray outbursts
Flare stars
X-ray binaries
-4
-3
-2
-1
0
1
2
log (Characteristic Timescale [day])



Soderberg (2010)


Fast transients
(radio)
COHERENT
INCOHERENT
AGNs
Uncertainty Limit
GRB short
GRB long
IDV
ISS
GRB
ISS
narrow beams
GP (maximal)
Crab GP (ns)
wide beams
BH Evap
B0540-69
OH
GCRT
RT
RRATS
Asteroid Radar
magnetar J1810−197
pulsars
Type II
ADLeo
Type III
TVLM 513
UVCeti
Jup DAM
BD LP944-20
GMRT (3 Gpc)
SKA (3 Gpc)
GMRT (10 kpc)
SKA (10 kpc)
10^{40}
10^{30}
10^{20}
10^{12}
10^{4}
log $S_{pk}D^2$ (Jy kpc^2)
log νW (GHz s)

Bhat (2011)

Short focus on fast radio bursts (FRBs)

Unknown nature so far - as many theories as theorists

Solving the mystery

Need facilities to detect them and, ideally, localise them

Then what?

Programs have triggered **'reactive'** follow up *(hours to days later)*

Nothing so far, perhaps fast and/or faint *(FRBs detected to z ~ 2)*

Host galaxy detections

Doesn't give us the nature of the event

EM emission evolution? Which wavelength? Particles? GW?

Coherent flux? If so, shorter wavelengths arrive Earth before radio

Need to be '**proactive**' - on source ***before***, during, and after the radio detection

Fast transients (in general)

Occur at all wavelengths

- Some only in one wavelength regime
- Others at multiple or all wavelengths
- Some unknown wavelengths *(i.e., FRB counterparts)*
- Some include high-energy particles and gravitational waves

Need to act fast to catch them, work fast to ID them

- Fast exposures needed to sample their evolution
- Simultaneous all-wavelength coverage before they fade
- Need to process and analyse data fast, and identify events fast, for follow up before they fade
- Need deep rapid-response spectroscopy and imaging

All this needs to be done in minutes (or faster) from the moment the light hits the telescopes

What is needed

(1) Coordinated simultaneous detection

(2) Real-time data processing and identification

(3) Rapid-response and conventional ToOs

(4) Longer-term cadenced observations

What we have

(1) Coordinated simultaneous detection

Deep, wide-field, fast-cadenced observations, ~20 of the world's best telescopes. All wavelengths + particles + GWs

(2) Real-time data processing and identification

Fast data transfer, supercomputer processing *(seconds/minutes)*
Software and human identification and confirmation *(in minutes)*

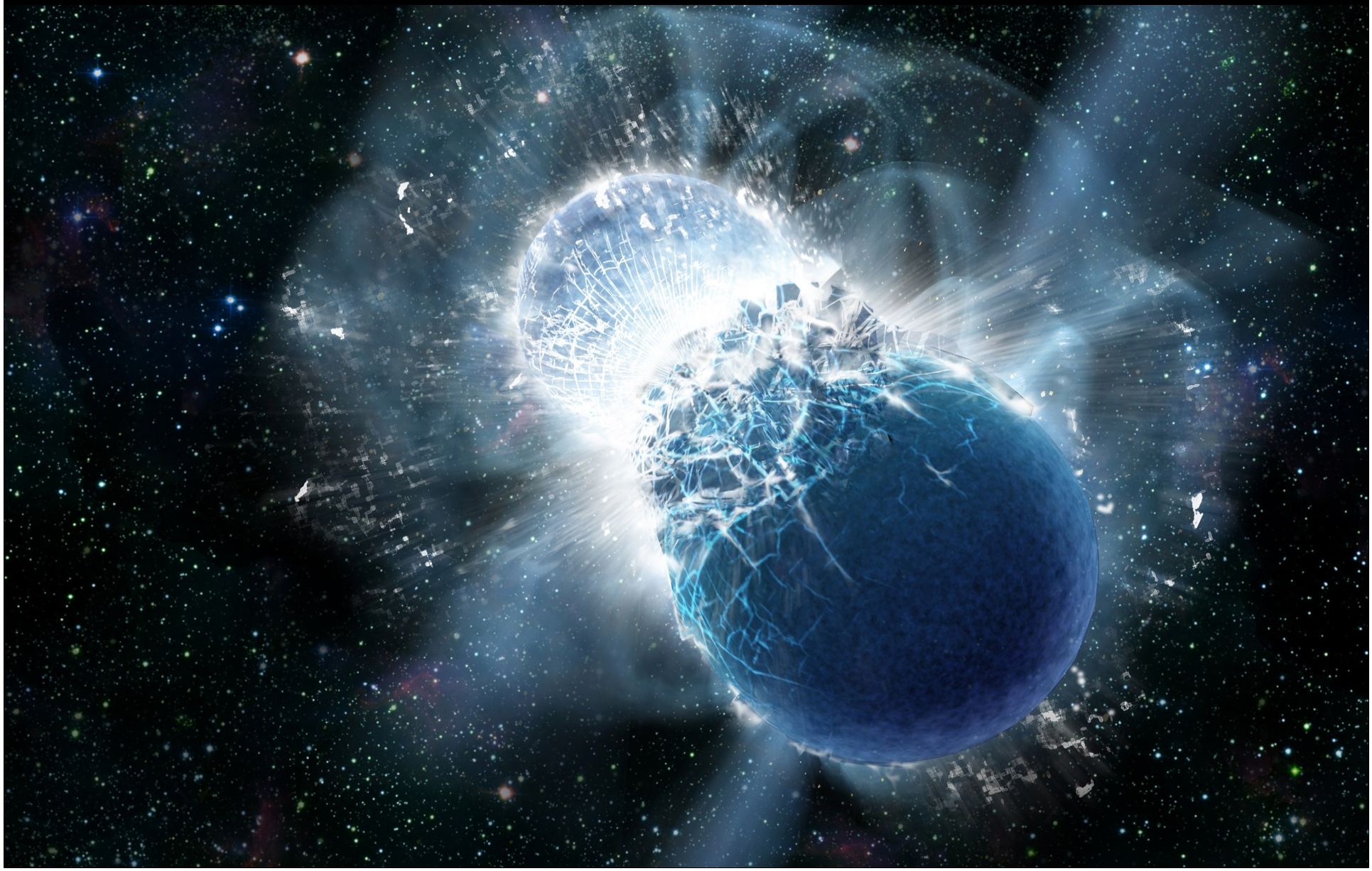
(3) Rapid-response and conventional ToOs

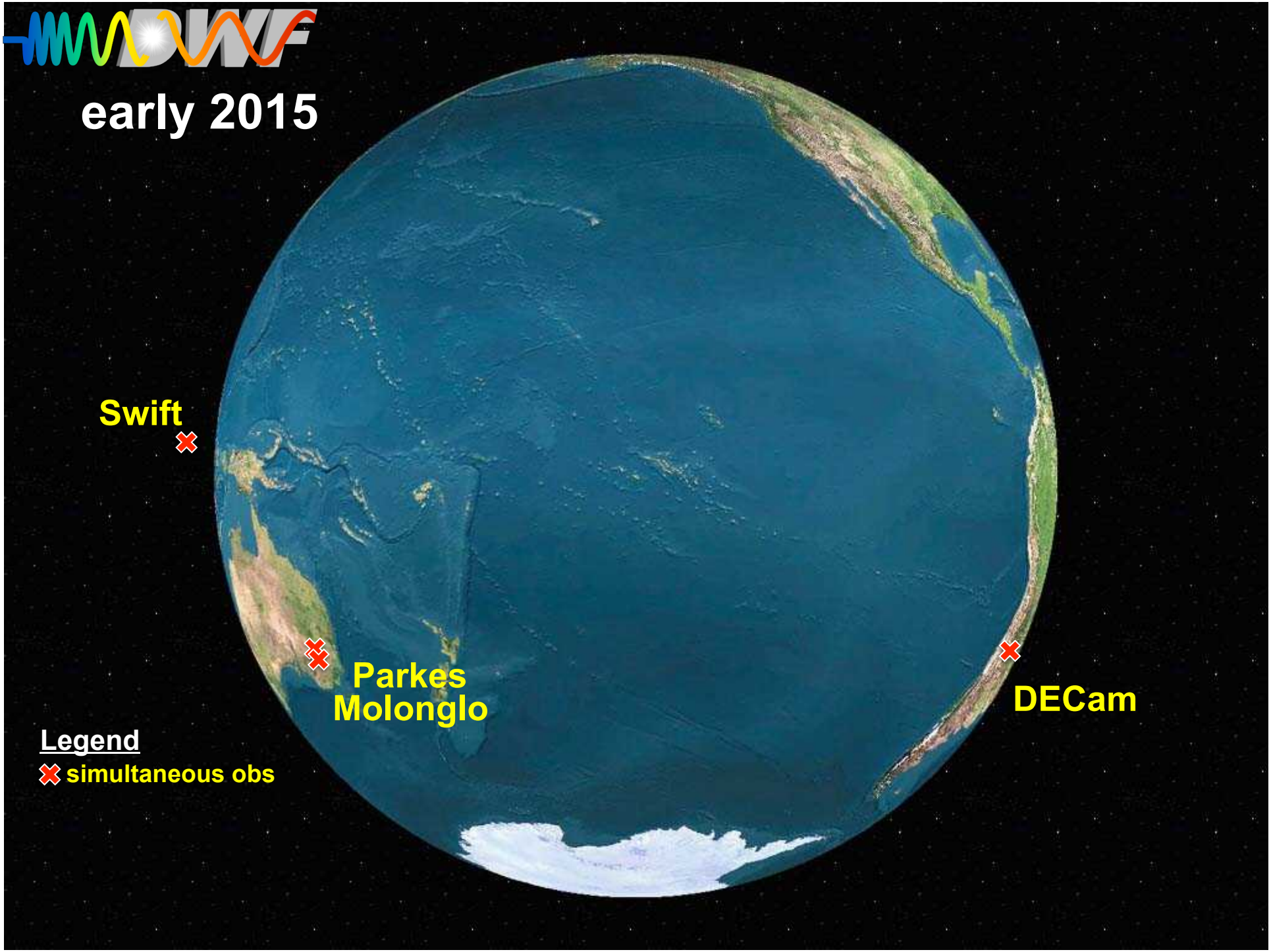
Deep, multi-wavelength RTO/ToO spectroscopy and imaging
~10 space-based and 1-10m class ground-based telescopes

(4) Longer-term cadenced observations

Network of ~30 follow-up telescopes (1-10m class)
Important for confirmation, classification, host galaxies, etc.
(Some fast transients are associated with longer duration events)

Deeper, Wider, Faster program




early 2015
Swift
Parkes
Molonglo
DECam
Legend
simultaneous obs

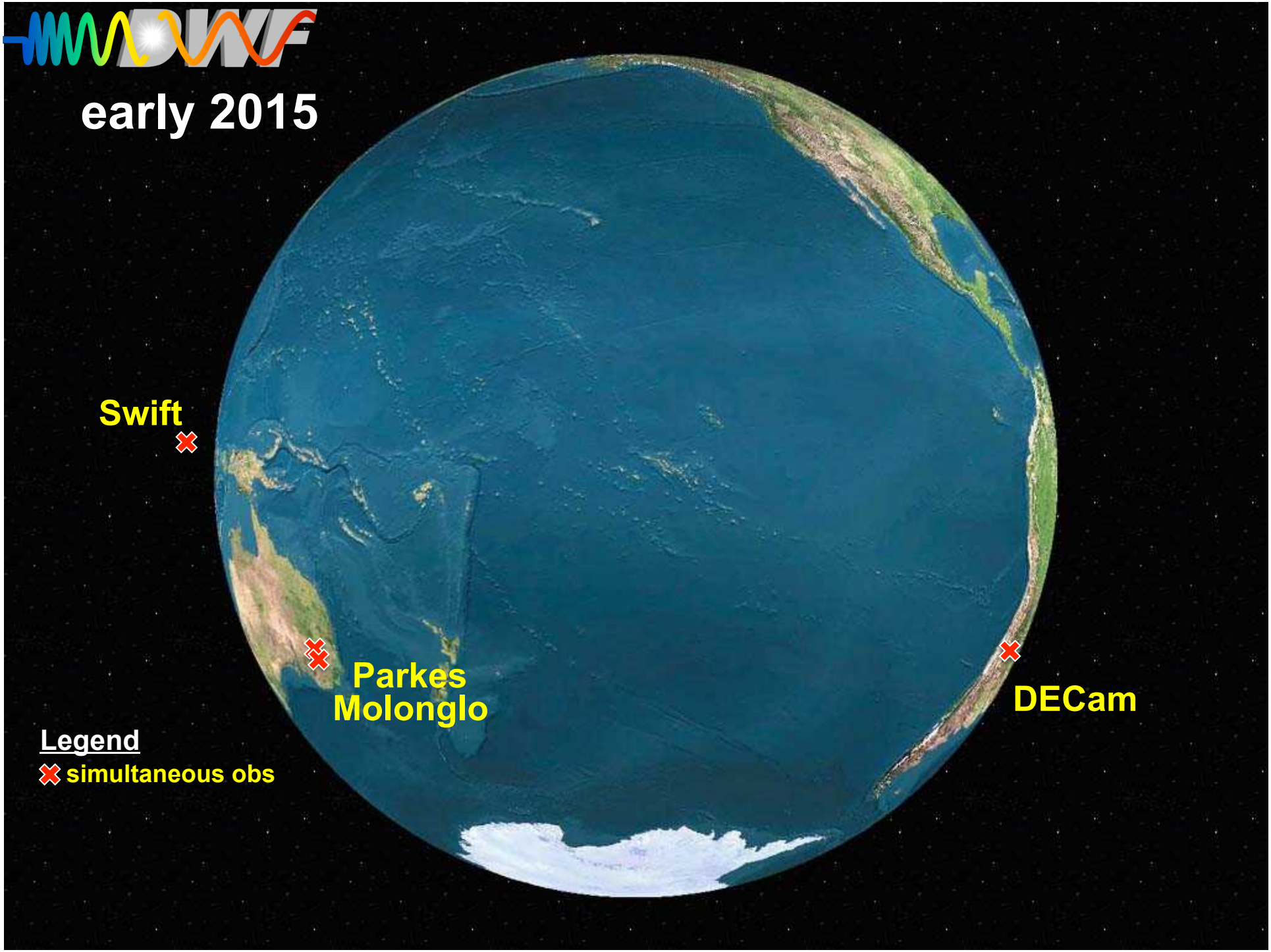
2015 - 2016

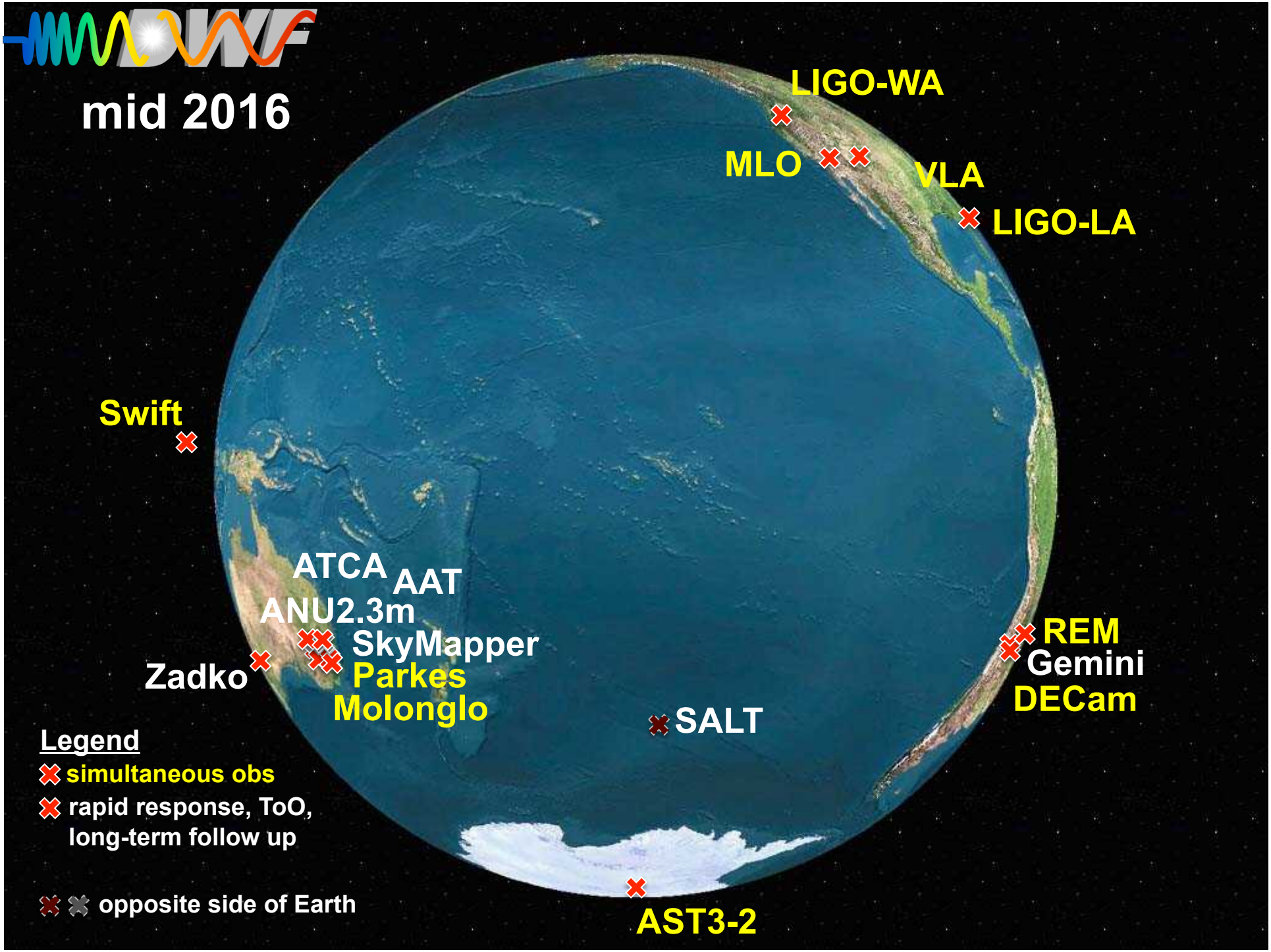
- Successfully coordinated simultaneous Parkes & Molonglo *(radio)*, DECam *(optical)*, and Swift *(UV/x-ray/GR)* observations
- Developed flexible 'lossy' file compression to speed up transfer and maintain >98% success in candidate identification

  Vohl et al., 2017, PASA, 34, 38
- Developed and refined real-time parallel data processing on the Swinburne supercomputer
- Generalised pipeline for transient detection *(here, for use with CTIO DECam and Subaru Hyper Suprime-Cam)*

  Andreoni et al., 2017, PASA, 34, 37
- Progressed real-time data visualisation technology for human transient candidate inspection *(confirmation for triggers)*

  Meade et al., 2017, PASA, 34, 23


early 2015
Swift
Parkes
Molonglo
DECam
Legend
simultaneous obs


mid 2016
LIGO-WA
MLO
VLA
LIGO-LA
Swift
ATCA
AAT
ANU2.3m
SkyMapper
Parkes
Molonglo
Zadko
REM
Gemini
DECam
SALT
AST3-2
Legend
simultaneous obs
rapid response, ToO, long-term follow up
opposite side of Earth

What DWF is

A full *'proactive'* **detection** program and a full **follow up** program

Facilities 2017/2018 *(future/planned facilities in grey)*:

GWs: LIGO-*Hanford*, LIGO-*Livingston*, Virgo, GEO600

Radio: MWA, Molonglo, ASKAP, ATCA, Parkes, VLA, MeerKAT, *Green Bank*

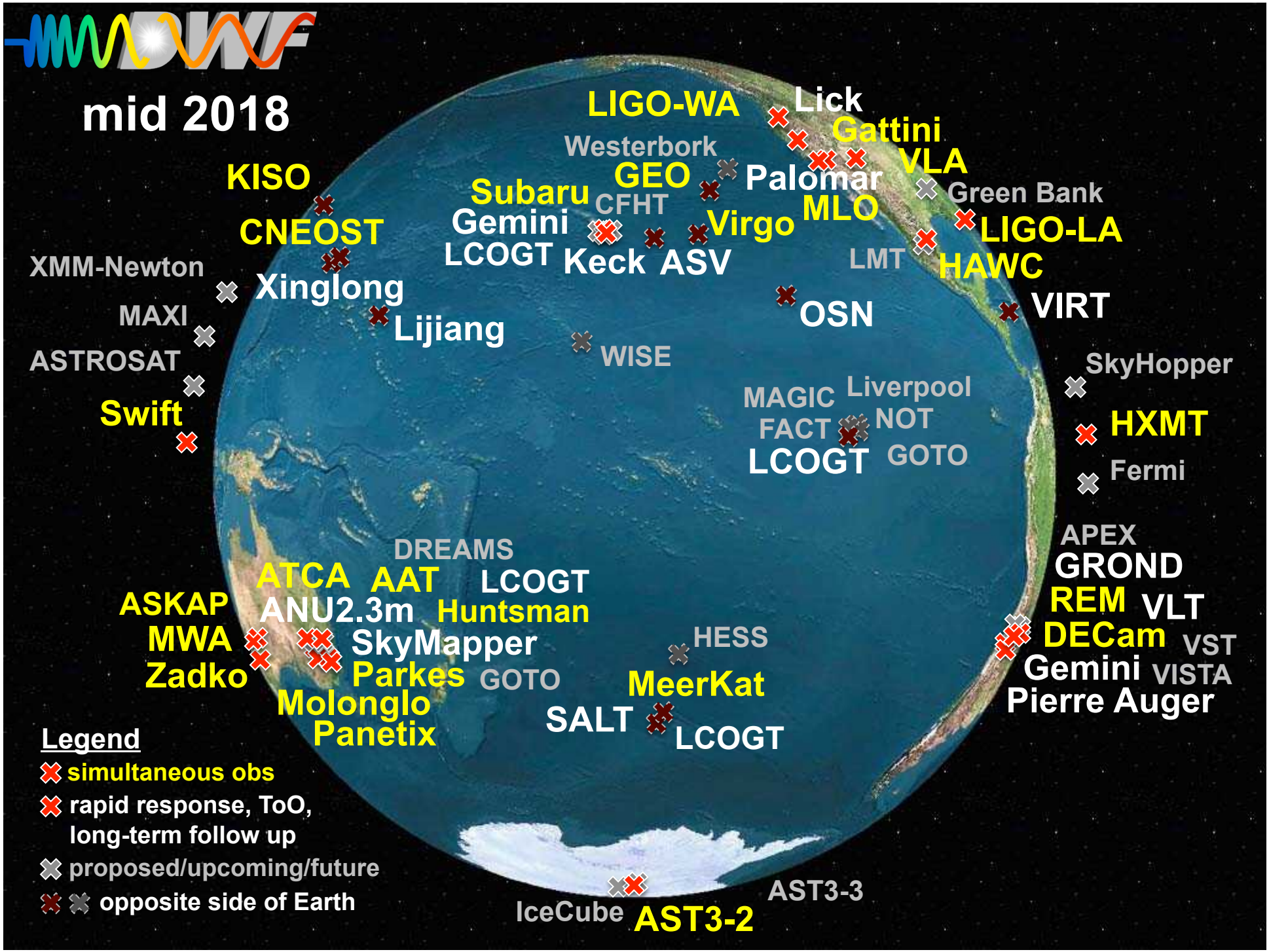
Sub-mm: *LMT, APEX*

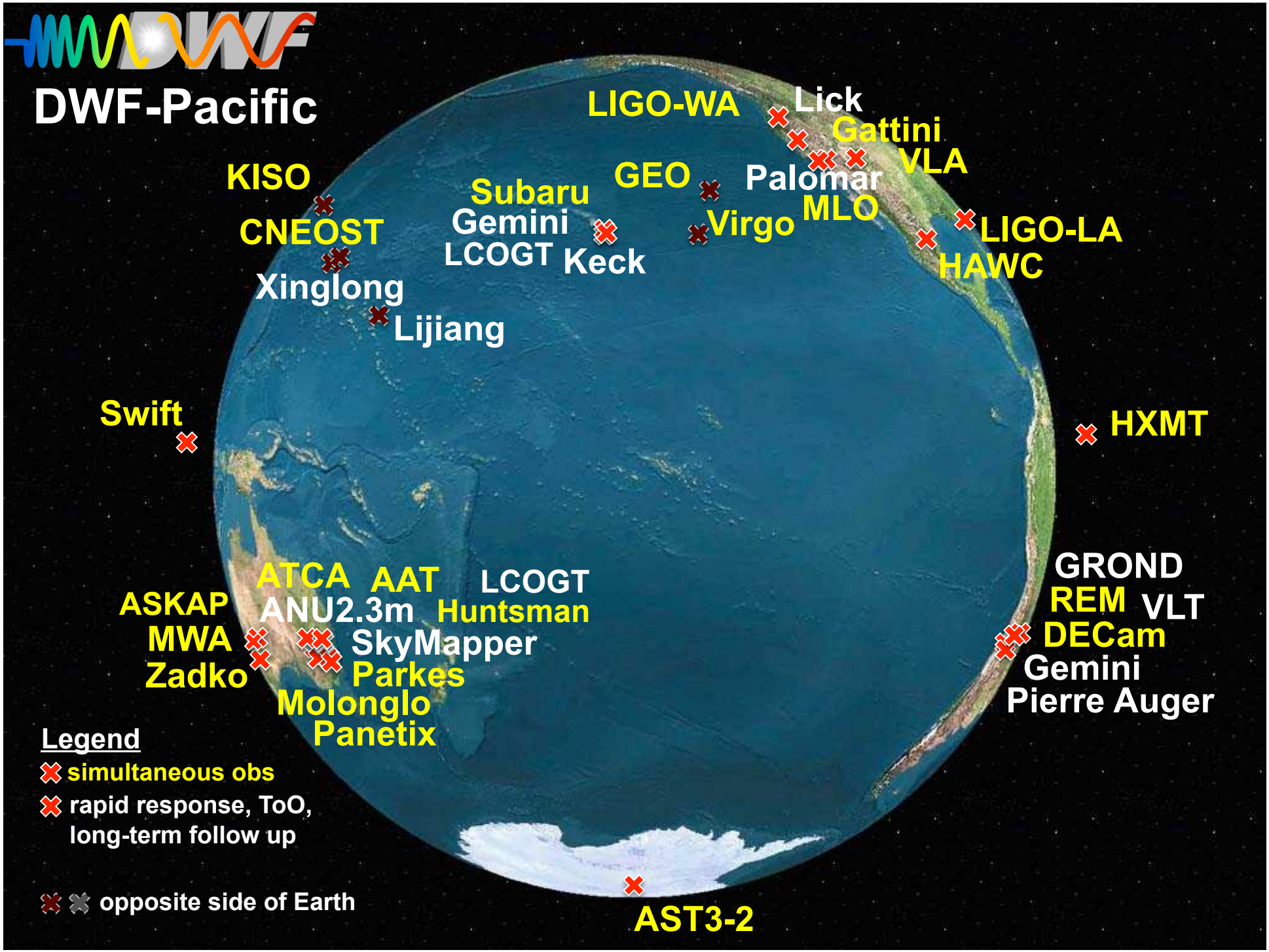
Infrared: GROND, REM, Gattini, *VISTA, DREAMS, AST3-3*

Optical: Keck, SALT, Subaru, VLT, Gemini, Palomar, CTIO Blanco, AAT, Lick, ANU 2.3m, Lijiang, Xinglong, ASV, SkyMapper, LCOGT, KISO, CNEOST, TNTS, MLO, Zadko, AST3-2, VIRT, Panetix, La Hita, Huntsman, *CFHT, Liverpool, VST*

U/X/G: Swift, HXMT, *XMM-Newton, ASTROSAT, MAXI*

High-E: Pierre Auger, HAWC, *HESS, MAGIC, FACT*


mid 2018
LIGO-WA
Lick
Gattini
Westerbork
VLA
KISO
GEO
Palomar
Subaru
CFHT
Green Bank
MLO
Gemini
Virgo
LIGO-LA
CNEOST
LCOGT
Keck
ASV
LMT
HAWC
XMM-Newton
Xinglong
OSN
VIRT
MAXI
Lijiang
WISE
ASTROSAT
SkyHopper
MAGIC
Liverpool
Swift
FACT
NOT
HXMT
LCOGT
GOTO
Fermi
APEX
DREAMS
GROND
ATCA
AAT
LCOGT
REM
VLT
ASKAP
ANU2.3m
Huntsman
DECam
VST
MWA
SkyMapper
HESS
Gemini
VISTA
Zadko
Parkes
GOTO
MeerKat
Pierre Auger
Molonglo
SALT
Panetix
LCOGT
Legend
simultaneous obs
rapid response, ToO, long-term follow up
proposed/upcoming/future
opposite side of Earth
AST3-3
IceCube
AST3-2


DWF-Pacific
LIGO-WA
Lick
Gattini
VLA
Palomar
MLO
GEO
Virgo
Subaru
Gemini
LCOGT
Keck
KISO
CNEOST
Xinglong
Lijiang
LIGO-LA
HAWC
Swift
HXMT
ATCA
AAT
LCOGT
ASKAP
ANU2.3m
Huntsman
MWA
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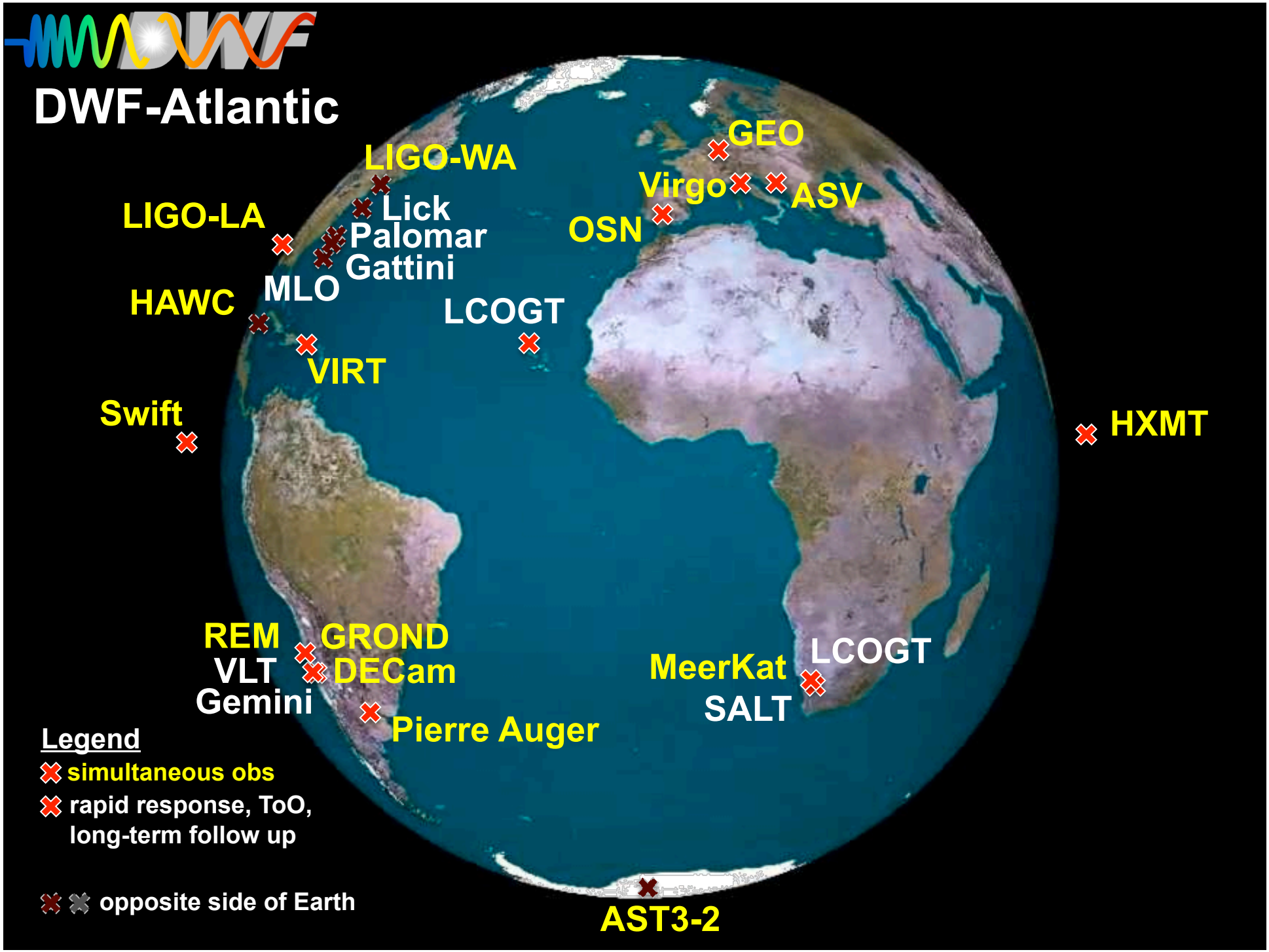
opposite side of Earth

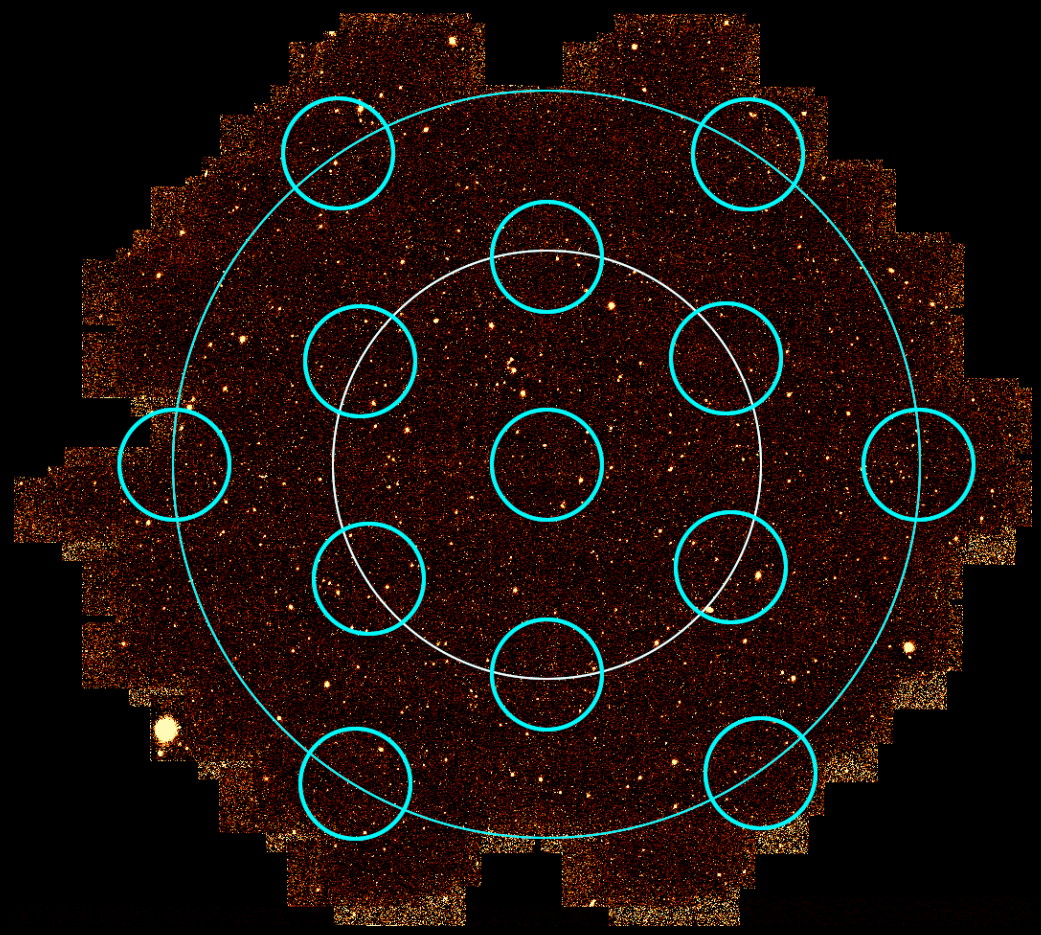

DWF-Atlantic
LIGO-WA
LIGO-LA
Lick
Palomar
Gattini
MLO
HAWC
LCOGT
VIRT
Swift
GEO
Virgo
ASV
OSN
HXMT
REM
GROND
VLT
DECam
Gemini
Pierre Auger
MeerKat
LCOGT
SALT
AST3-2
Legend
simultaneous obs
rapid response, ToO, long-term follow up
opposite side of Earth

(1) Coordinated simultaneous detection

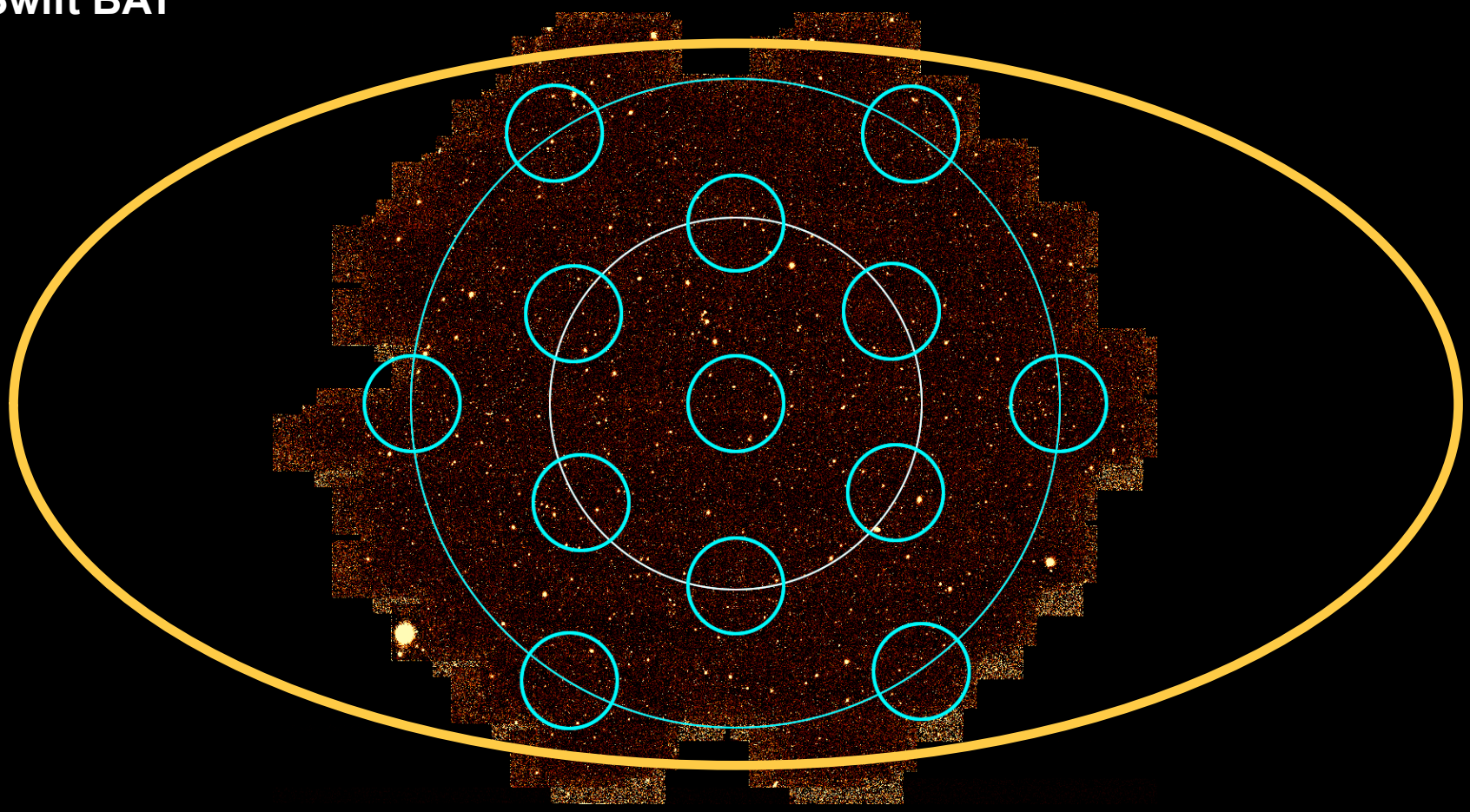
Deep, wide-field, fast-cadenced *observations, ~20 of the world's best telescopes.* All wavelengths + particles + GWs

Fields of view

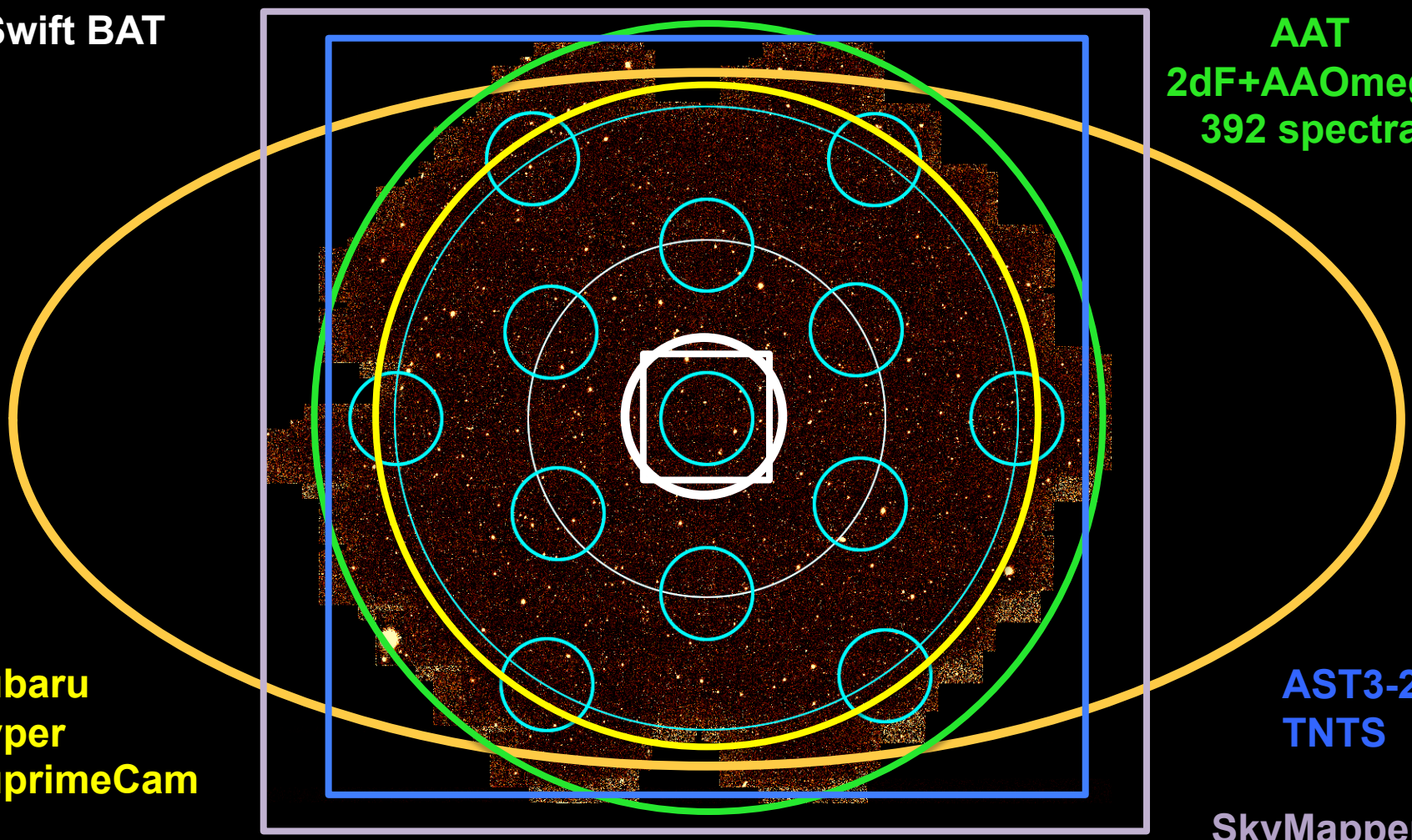
DECam Parkes



Fields of view



Fields of view



(2) Real-time data processing and identification

Fast data transfer, supercomputer processing *(seconds/minutes)*

Software and human identification and confirmation *(in minutes)*

The internet's undersea world

The vast majority of the world's communications are not carried by satellites but an altogether older technology: cables under the earth's oceans. As a ship accidentally wipes out Asia's net access, this map shows how we rely on collections of wires of less than 10cm diameter to link us all together

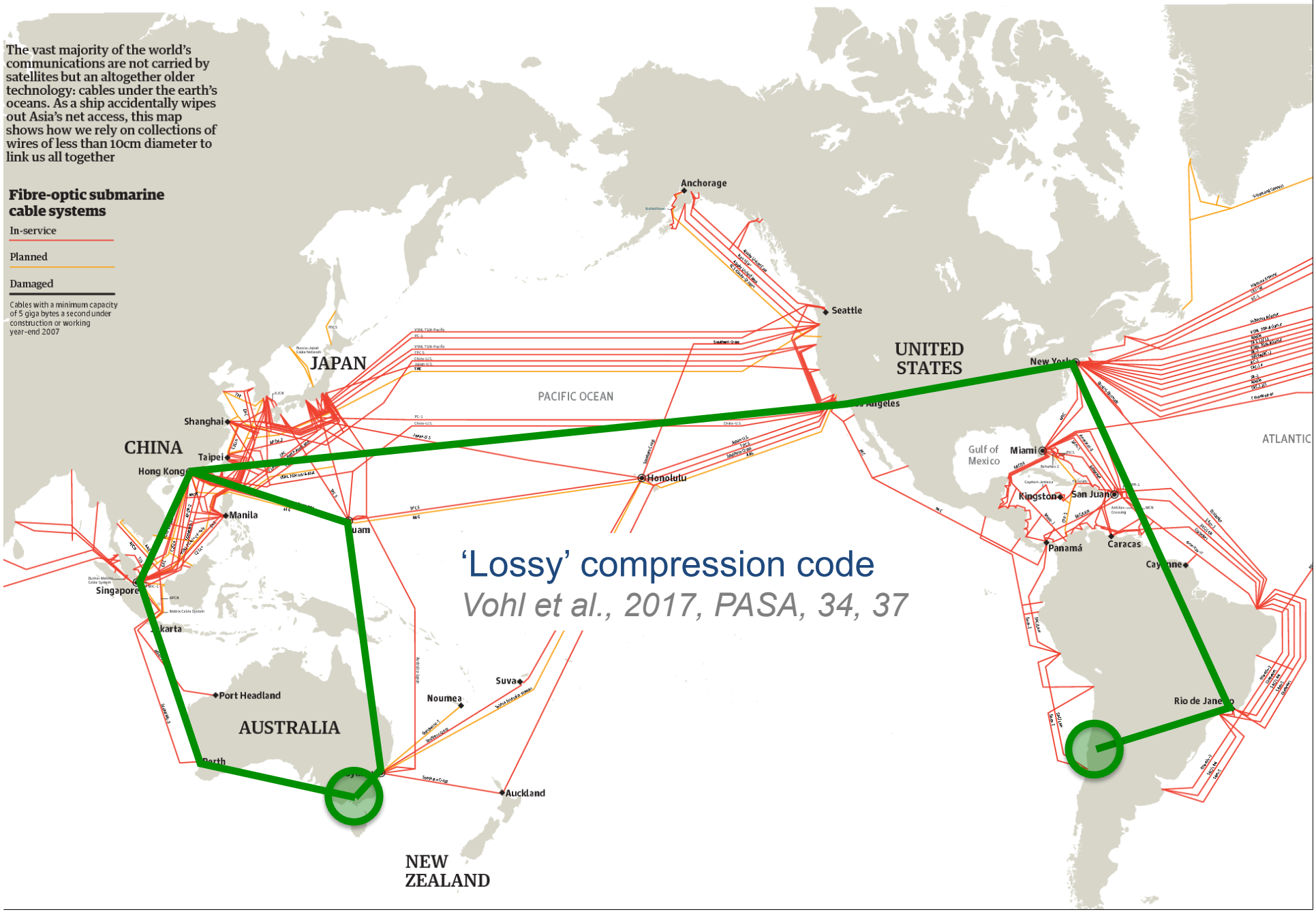
Fibre-optic submarine cable systems

In-service

Planned

Damaged

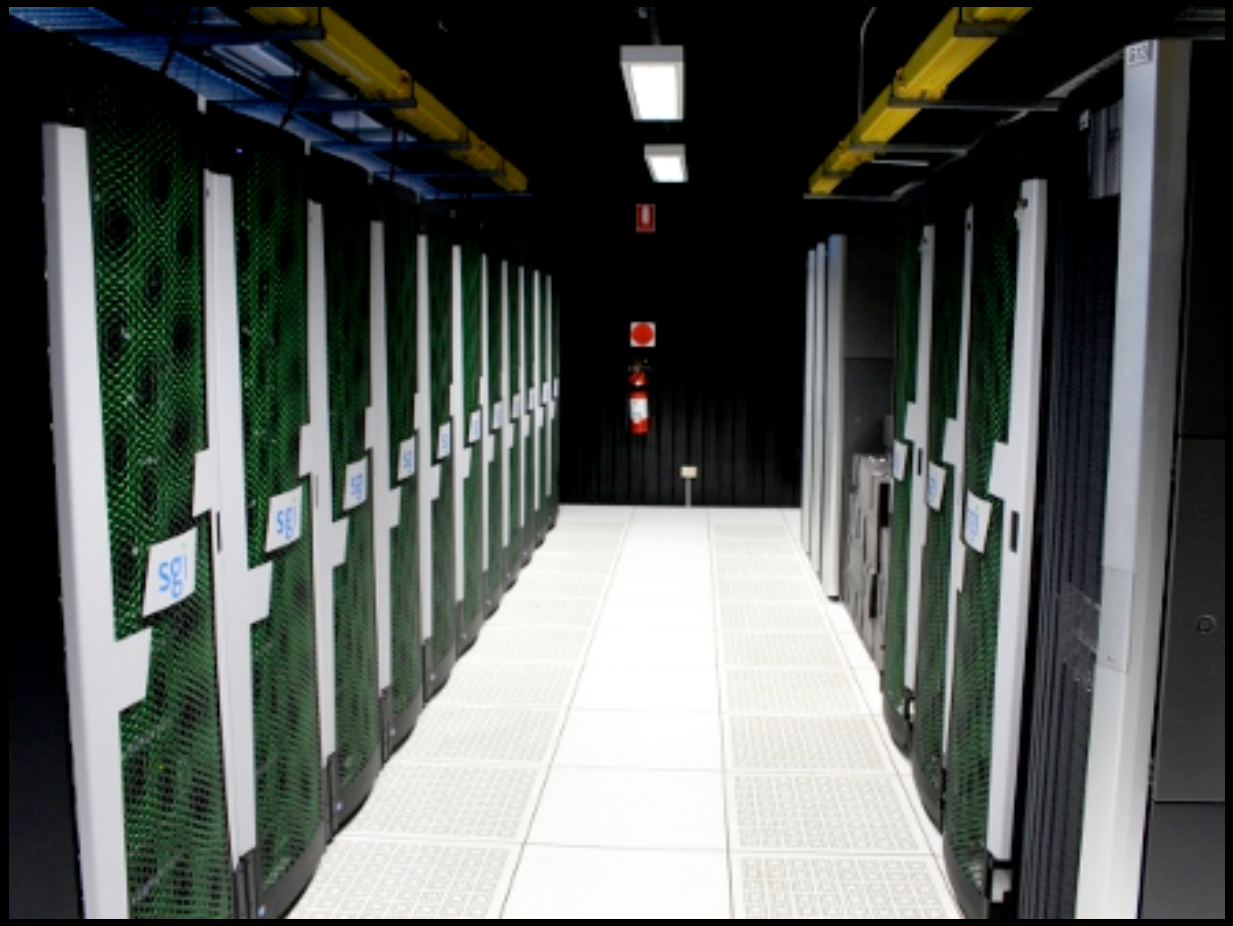
Cables with a minimum capacity of 5 giga bytes a second under construction or working year-end 2007



'Lossy' compression code

Vohl et al., 2017, PASA, 34, 37

Swinburne supercomputer

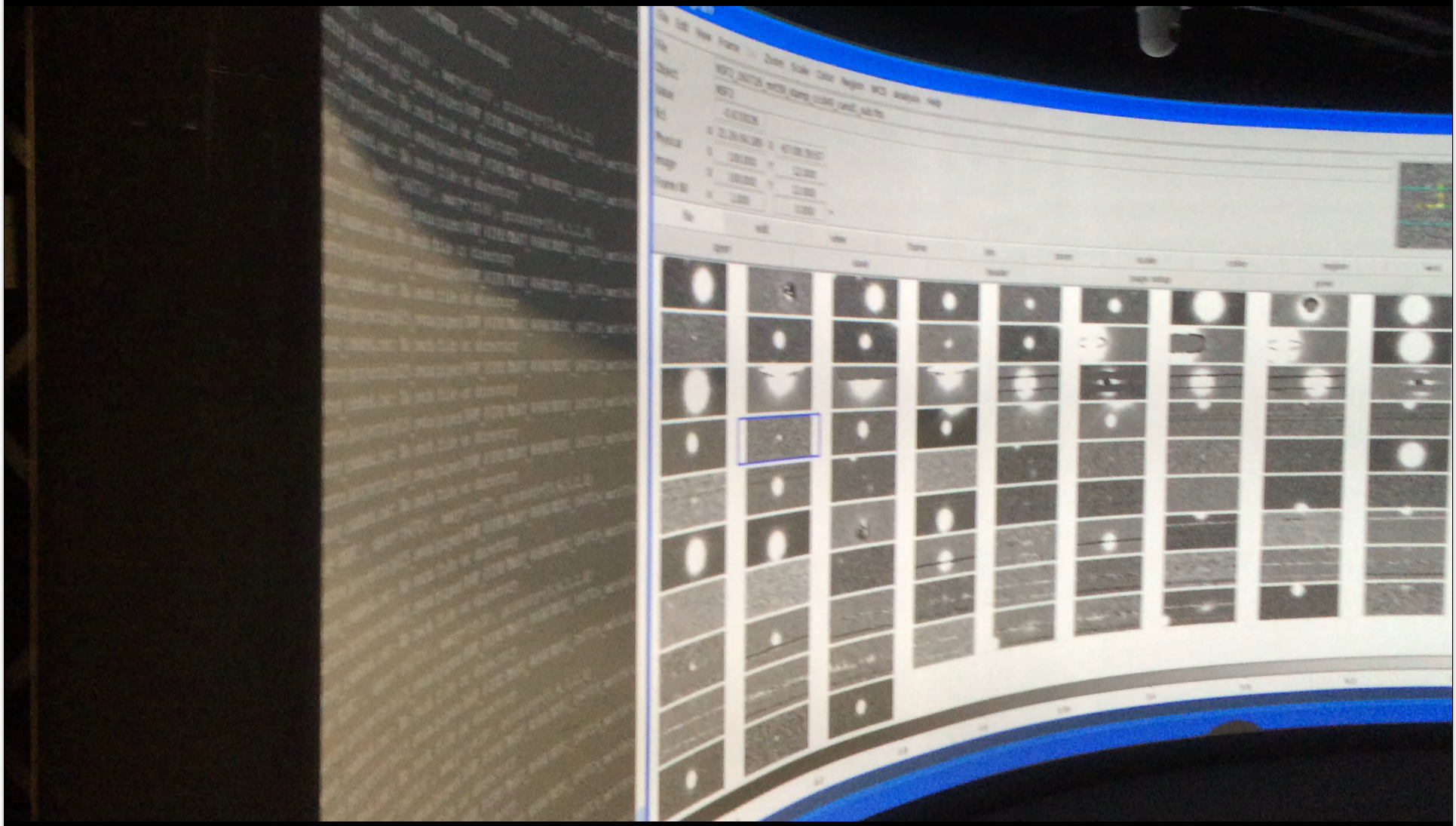


g2

OzSTAR

Supercomputing

Real-time analysis–Dec 2015, Jul/Aug 2016

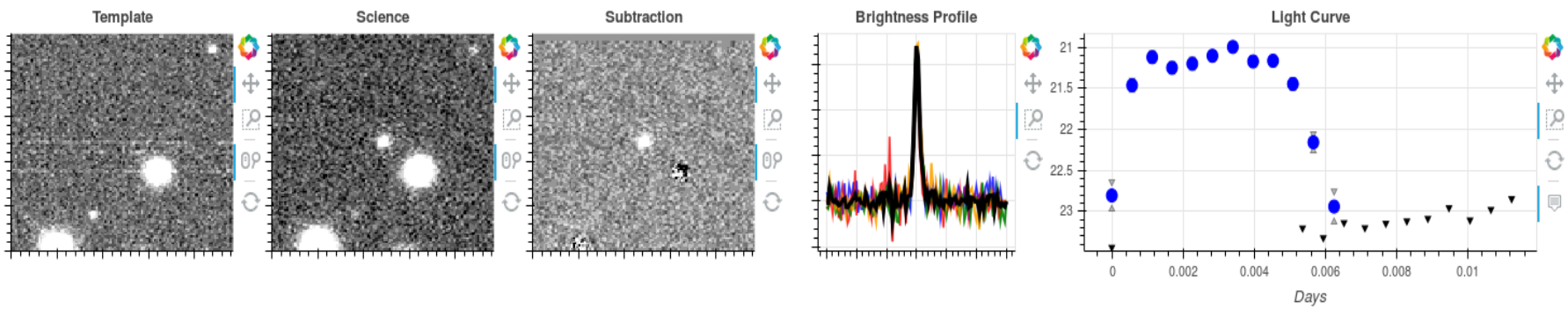


Real-time analysis – Feb 2017

Real-time analysis – Feb 2017

Real-time analysis

Introduction | Query | Candidate Viewer | CCD Viewer | Candidate Summary



Any notes?:

Very interesting! | Possible | Uninteresting | Show on CCD

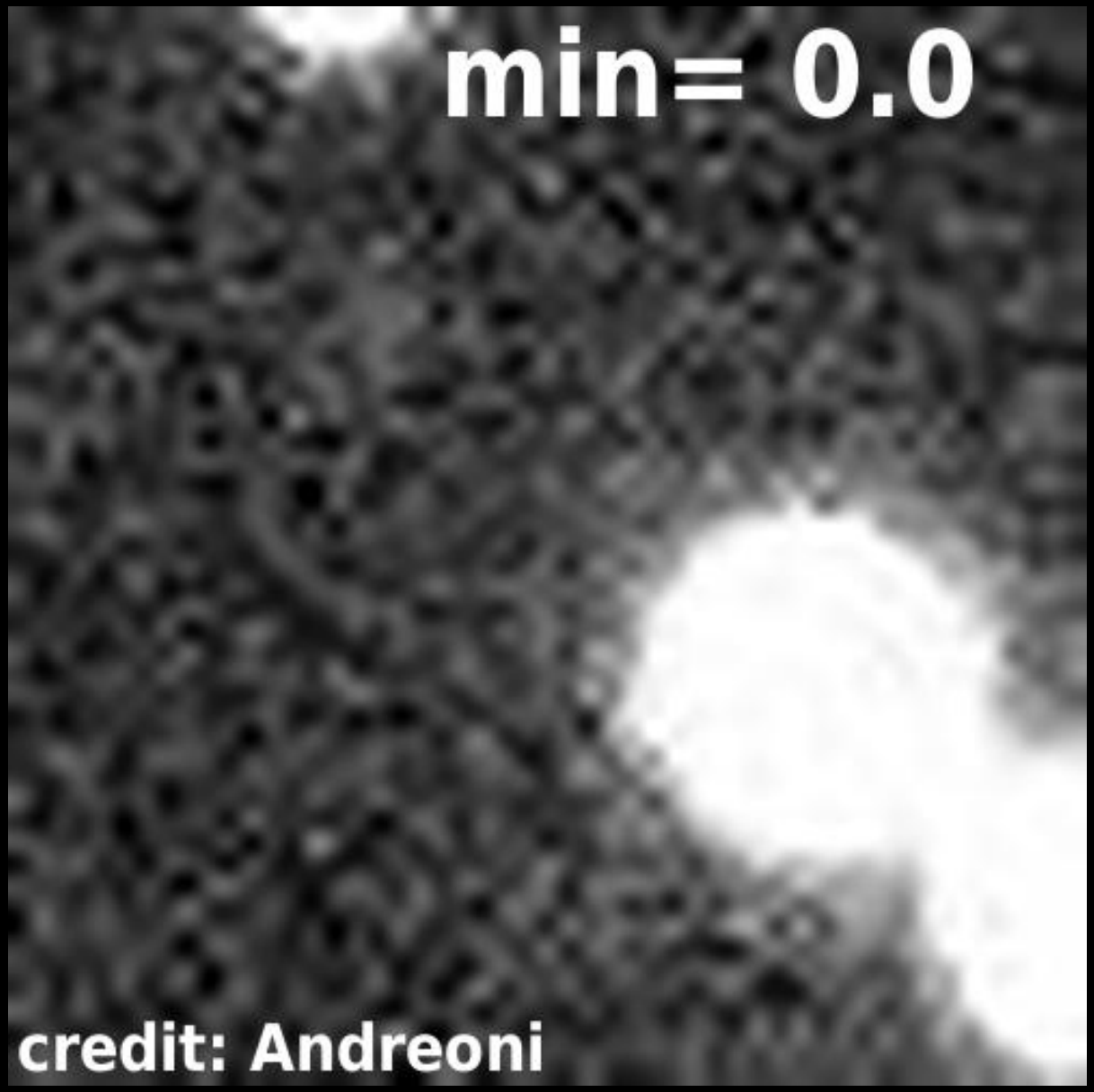
This candidate is ID6136, observed in the 'Antlia' field on 02/02/2017. It is number 5 of 13 you have selected. The auto-ranker has assigned it a ranking 5/5, where 5 is most interesting and 1 is least interesting

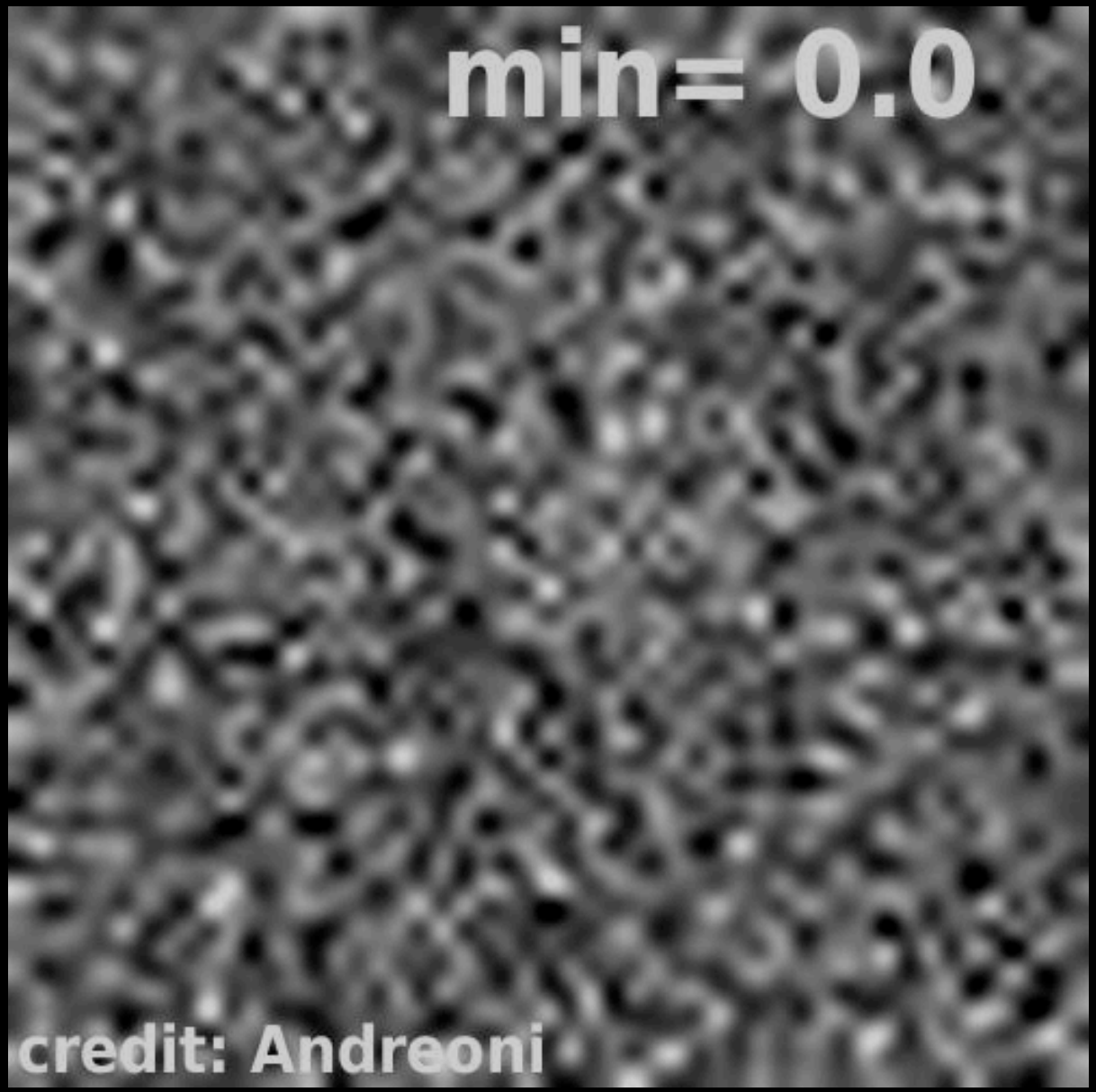
If anyone else has entered notes on this object into the database, they will appear here:

Next candidate

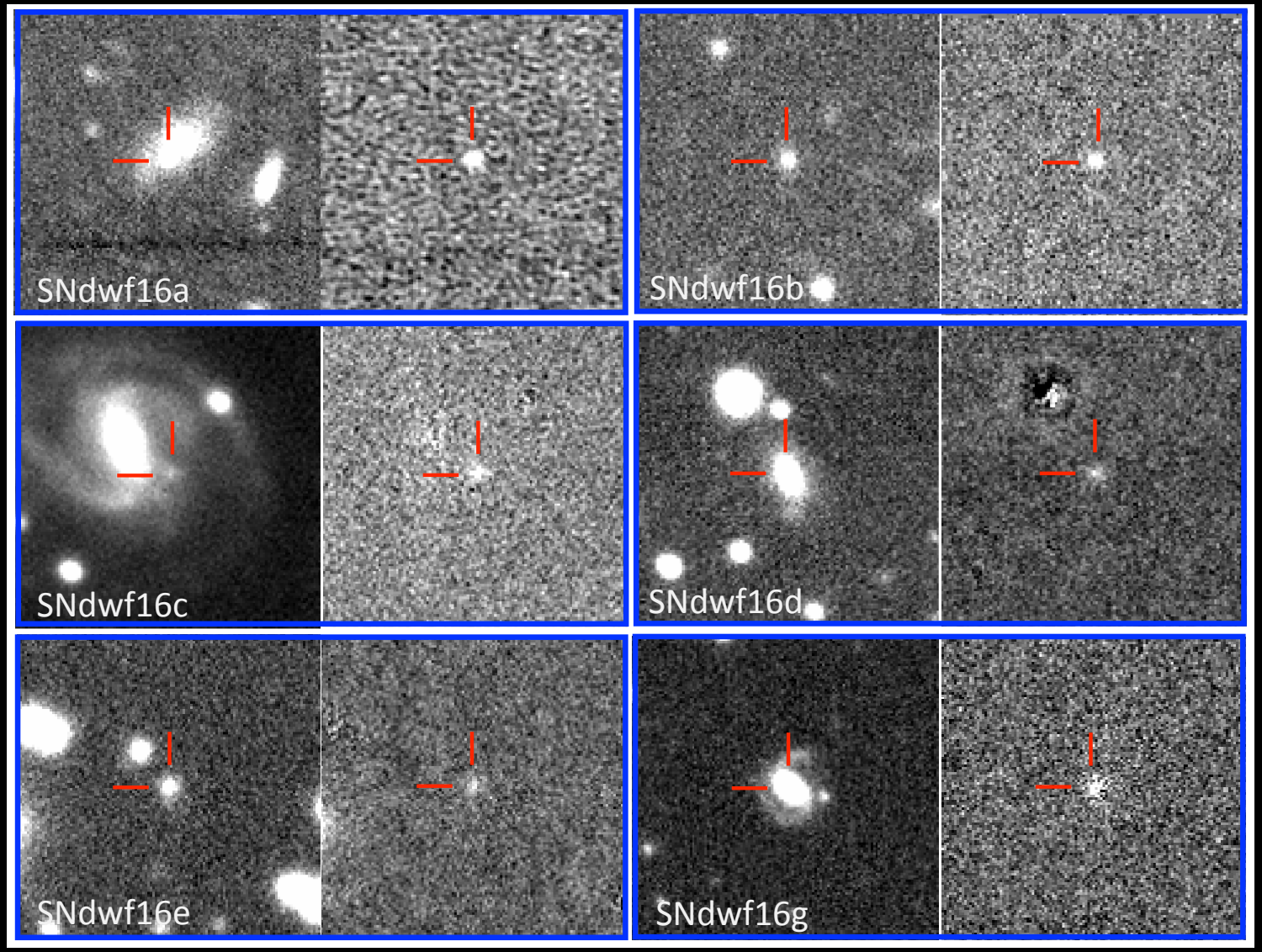
Back

Show CCD

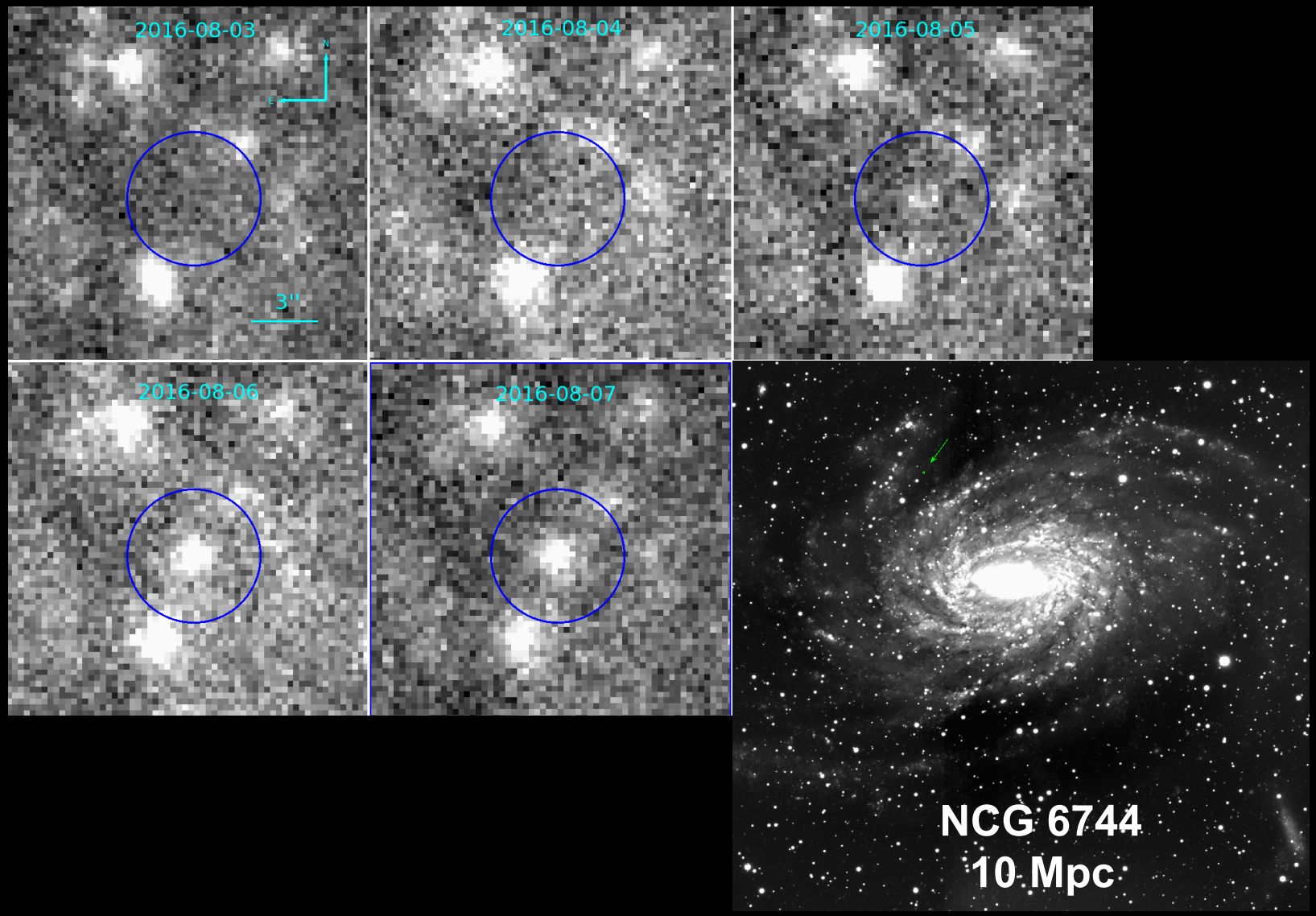

min= 0.0
credit: Andreoni


min= 0.0
credit: Andreoni

Supernovae



Extragalactic novae



(3) Rapid-response and conventional ToOs

Deep, multi-wavelength RTO/ToO spectroscopy and imaging

~10 space-based and 1-10m class ground-based telescopes

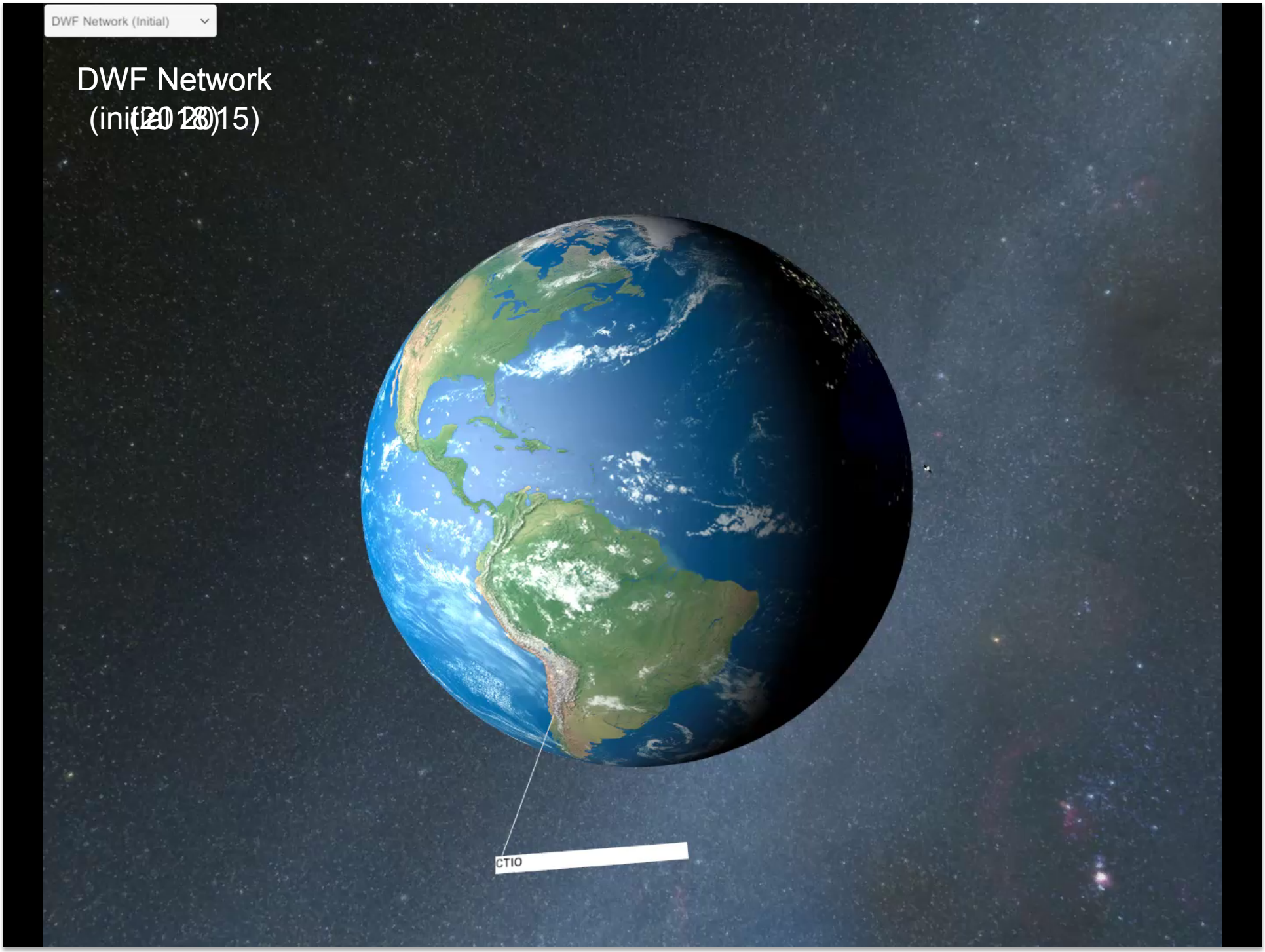

Some of the DWF facilities

(4) Longer-term cadenced observations

Network of ~30 follow-up telescopes (1-10m class)

Important for confirmation, classification, host galaxies, etc.

Some fast transients are associated with longer duration events


DWF Network (Initial)
DWF Network
(initial 2015)
CTIO

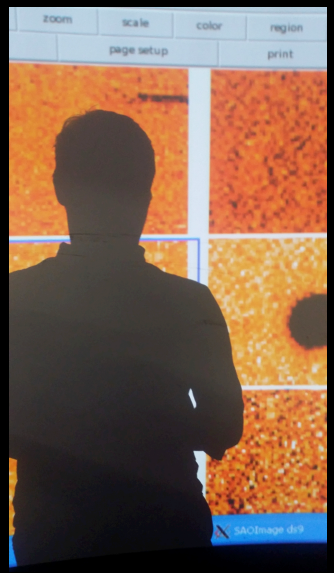
Blanco telescope

Data transfer
(about a minute)

Swinburne Supercomputer

Data processed in about a minute

Visualisation room



High-energy bursts

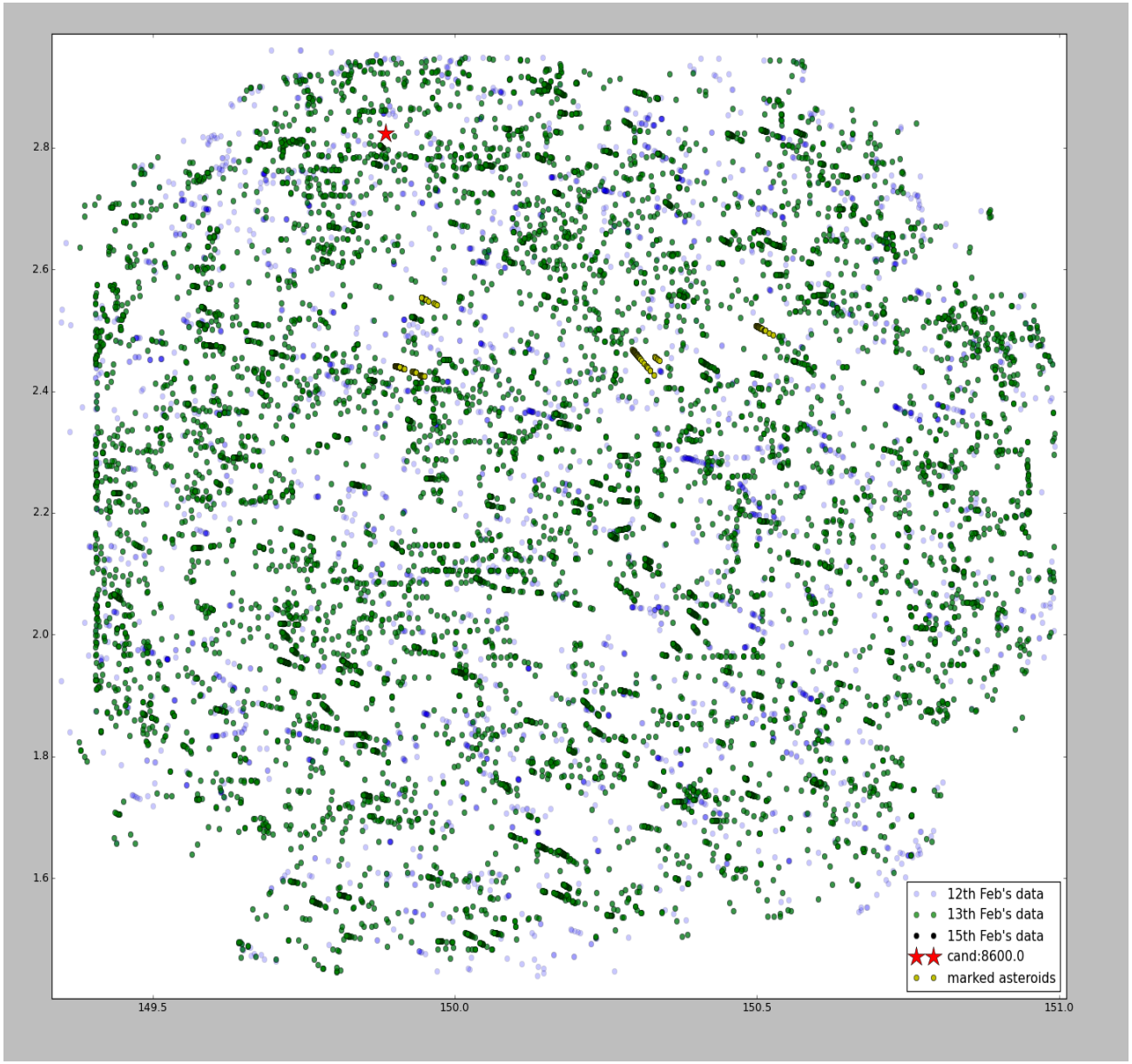
Radio bursts

Identify all bursts within minutes after the light hits the telescopes

Seconds

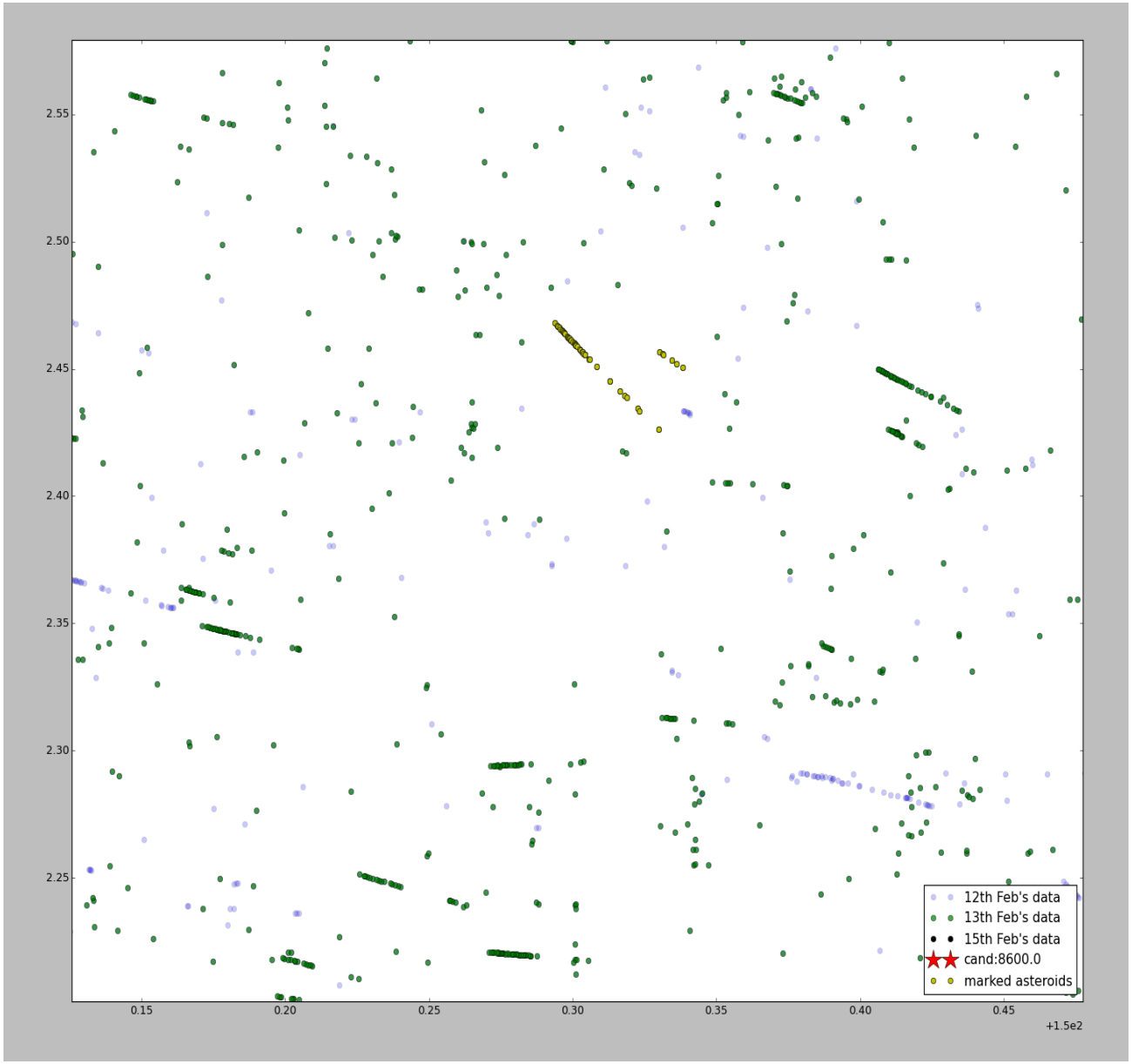
Trigger follow up

Gemini-South



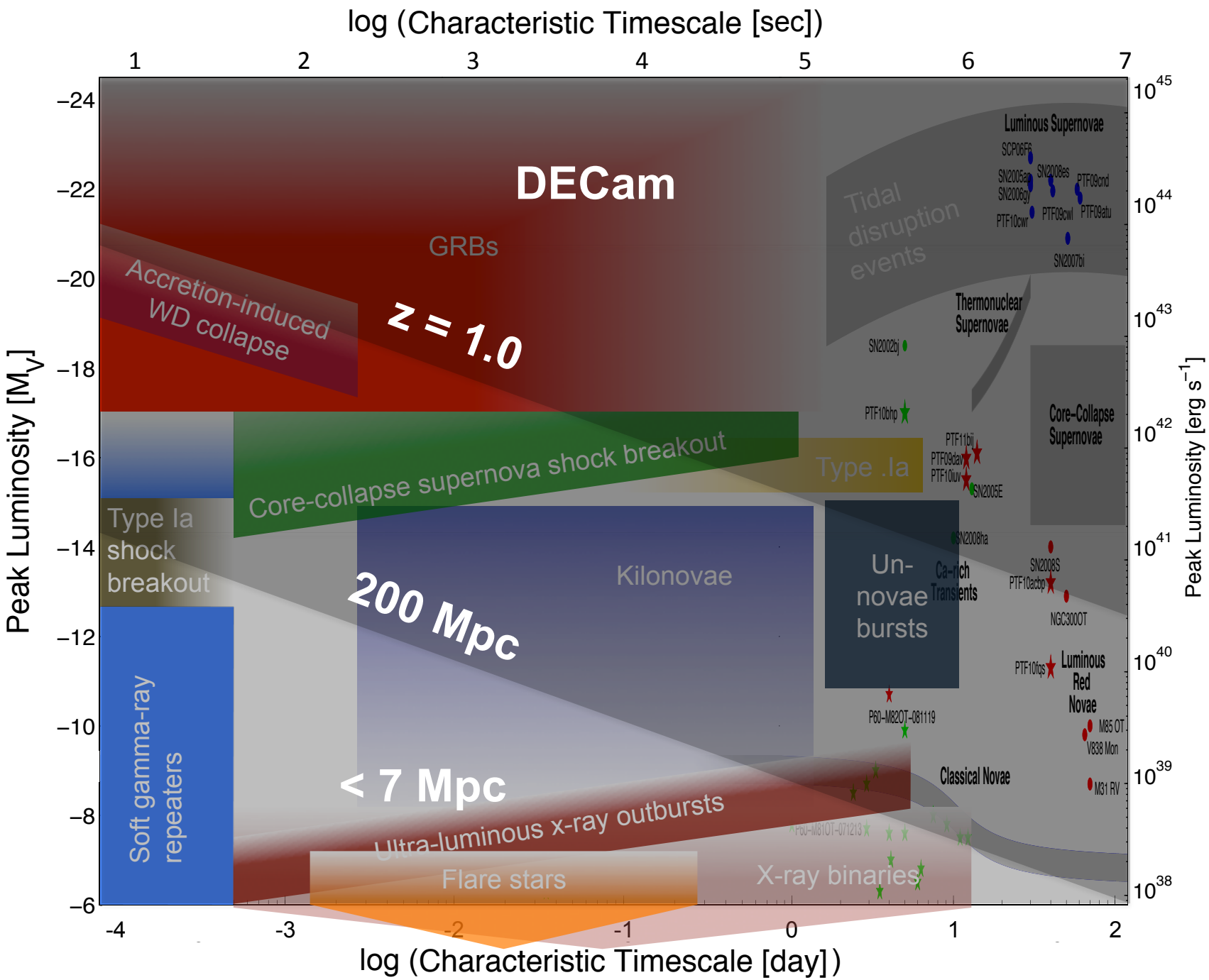
Objects found during
a DWF run

DECam detections to mag
~ 23.5
in 20 seconds



Zoom in of a region

Objects forming lines are asteroids


log (Characteristic Timescale [sec])
1
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6
7
Peak Luminosity [M_V]
−24
−22
−20
−18
−16
−14
−12
−10
−8
−6
Peak Luminosity [erg s^{-1}]
10^{45}
10^{44}
10^{43}
10^{42}
10^{41}
10^{40}
10^{39}
10^{38}
DECam
GRBs
z = 1.0
Accretion-induced WD collapse
Luminous Supernovae
SCP06F6
SN2005ap
SN2006gy
SN2008es
PTF09cnd
PTF10cwr
PTF09cwl
PTF09atu
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Tidal disruption events
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PTF09dav
PTF10iuv
SN2005E
Type .Ia
Core-collapse supernova shock breakout
Type Ia shock breakout
Kilonovae
200 Mpc
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Classical Novae
Soft gamma-ray repeaters
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Ultra-luminous x-ray outbursts
Flare stars
X-ray binaries
-4
-3
-2
-1
0
1
2
log (Characteristic Timescale [day])

Data visualisation

Fast transient candidates require human inspection and confirmation prior to triggering rapid-response and other ToO observations

We use interactive projectors to examine hundreds of candidates every few minutes as the data are continuously processed *(soon VR)*

We use an interactive web-based analysis tool to help identify events in real time – *participants are located worldwide*

We use 4K tiled wall displays to examine the full CCDs, search for artifacts, examine transient environments, cross-talk, etc.

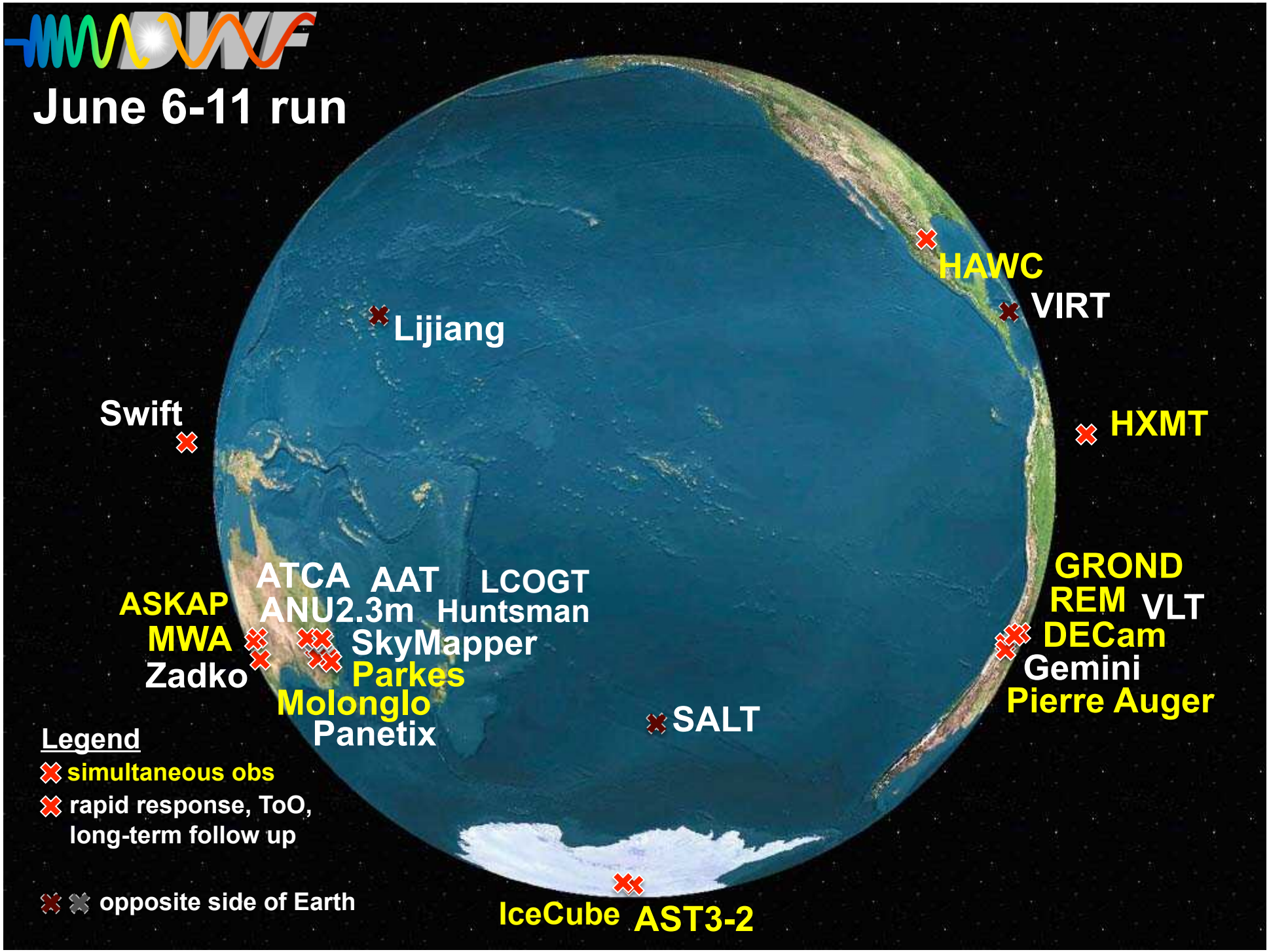
Data sonification

We use pitch, volume, timbre, and stereo *(soon 3-D)* to help enhance and accelerate analysis, leading to more confident identifications

We are exploring higher-order harmonics and “the cocktail party” effect to explore multi-parameter space and low S/N ratio data

Cooke et al., 2018, IAU 339 Conf. Proceedings

June 6-11 run


HAWC
VIRT
Lijiang
Swift
HXMT
ATCA
AAT
LCOGT
ASKAP
ANU2.3m
Huntsman
MWA
SkyMapper
Zadko
Parkes
Molonglo
Panetix
GROND
REM
VLT
DECam
Gemini
Pierre Auger
SALT
IceCube
AST3-2
Legend
simultaneous obs
rapid response, ToO, long-term follow up
opposite side of Earth

DWF summary *(part 1)*

The fast time domain is largely *unexplored territory*

Multi-facility, multi-wavelength global collaborative effort is the only means to capture and study fast transients and to understand the nature of FRBs

DWF is the first program to achieve this aim

- Simultaneous fast-cadenced multi-wavelength detection facility
- Real-time reduction, analysis, and candidate identification
- Rapid-response triggered spectroscopy and imaging
- Long-term monitoring to classify associated slower events, etc.

DWF can resolve the nature of FRBs in a *"single shot"*

DWF summary *(part 2)*

- **A unique and creative use of DECam**
- **Characterising the fast transient Universe**
- **Trailblazing science for LSST**
- **Pioneering a new observational approach**
  - Simultaneous multi-wavelength/multi-messenger observations
  - Real-time data processing
  - Exploring advances in transient rapid identification invoking machine learning and creative techniques
  - Exploring data visualisation and sonification to enhance and accelerate Big Data analysis and transient confirmation
  - Largest global collaboration to acquire simultaneous data and perform rapid-response follow up