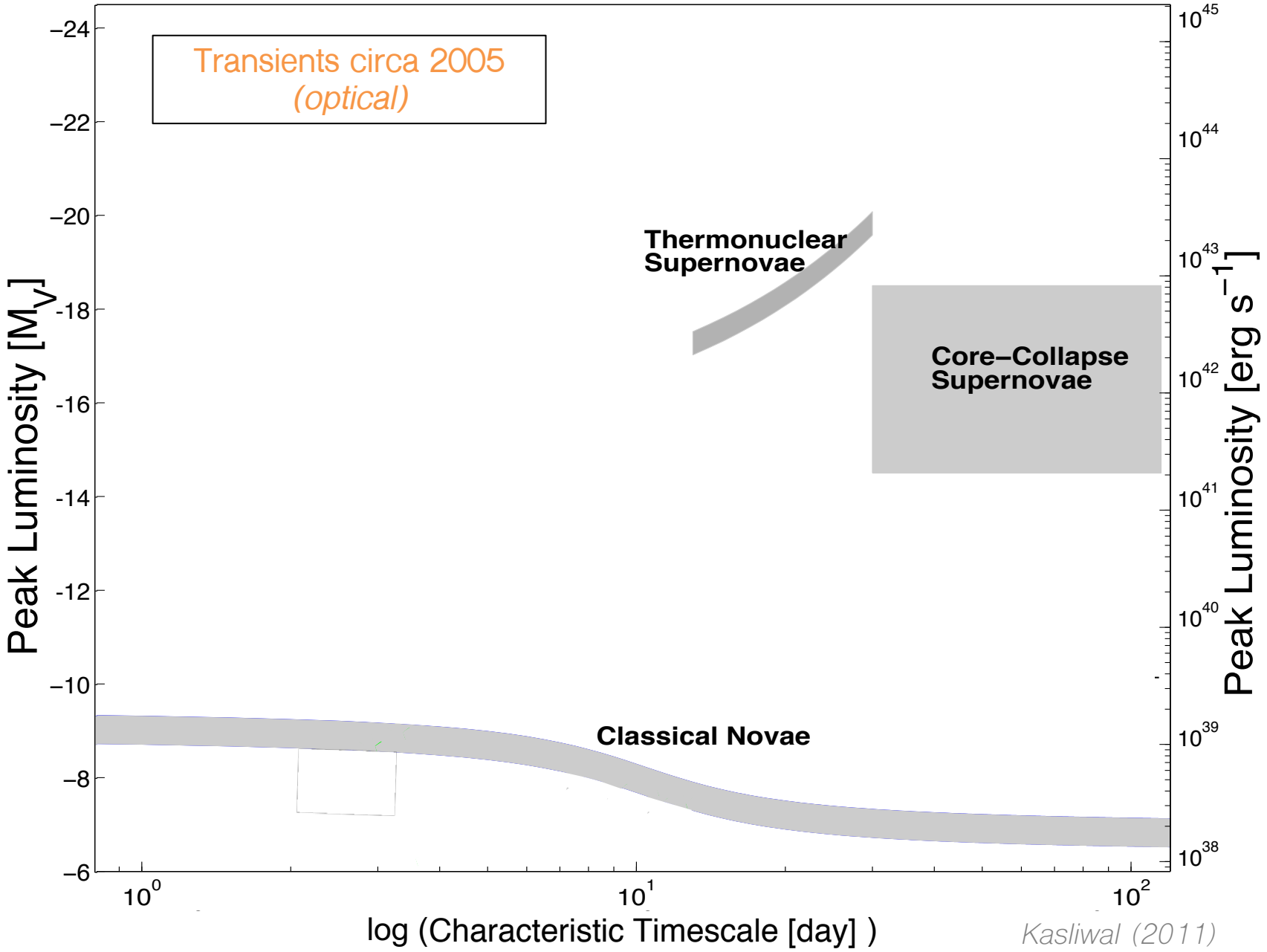
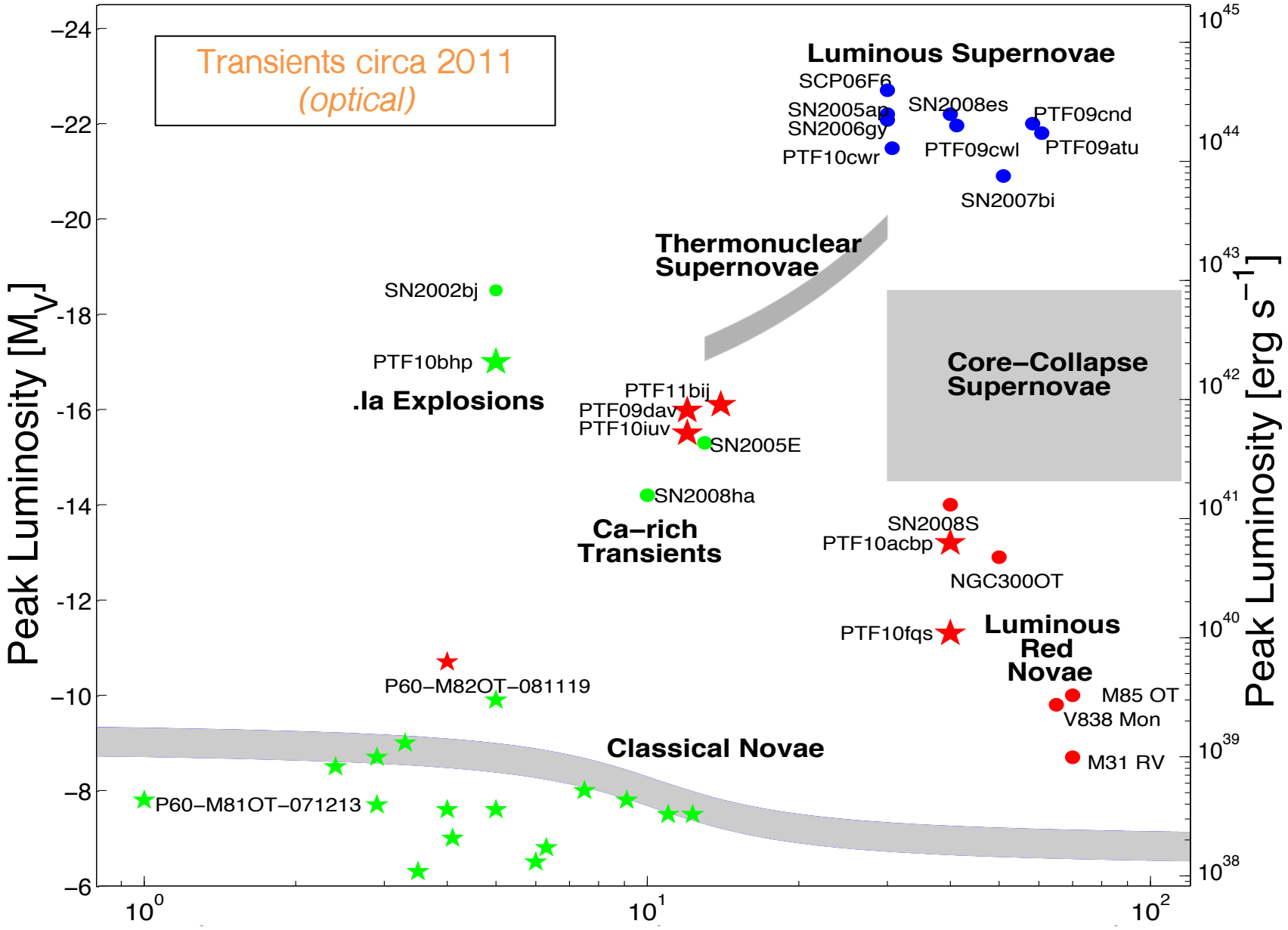
The Deeper, Wider, Faster program

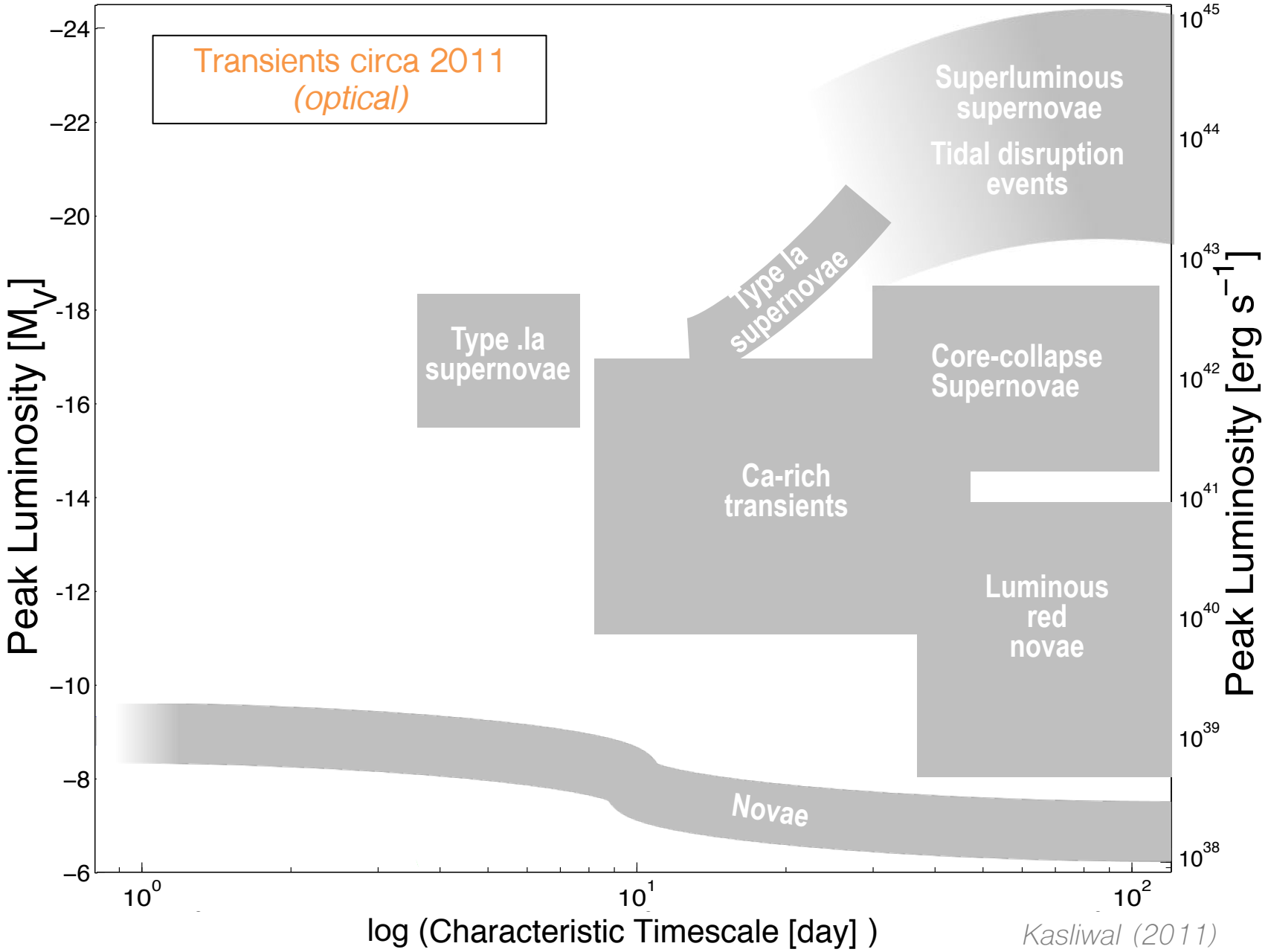
A new approach to observational astronomy to detect the fastest transients and to solve the nature of FRBs

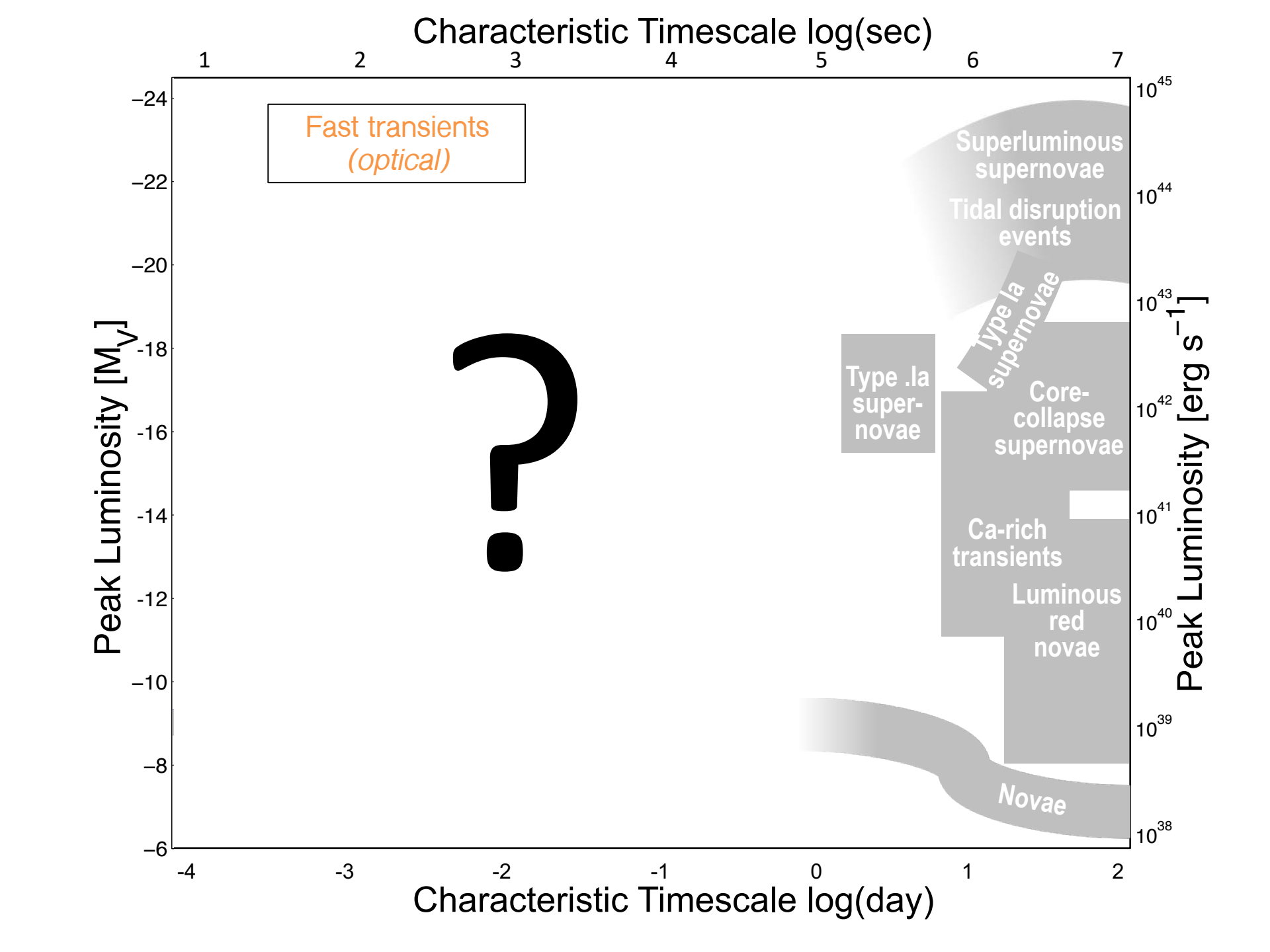
Jeff Cooke
and the DWF team

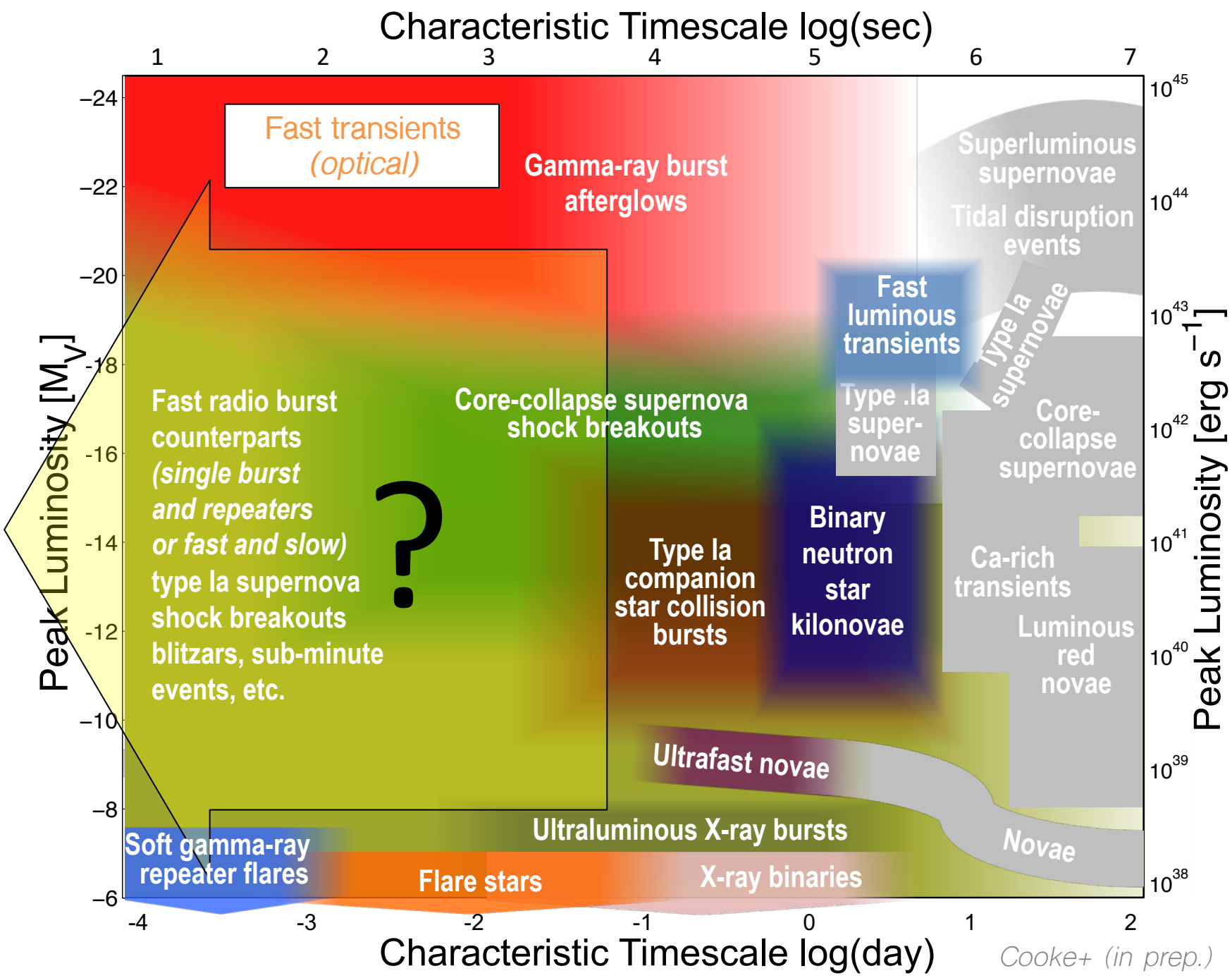


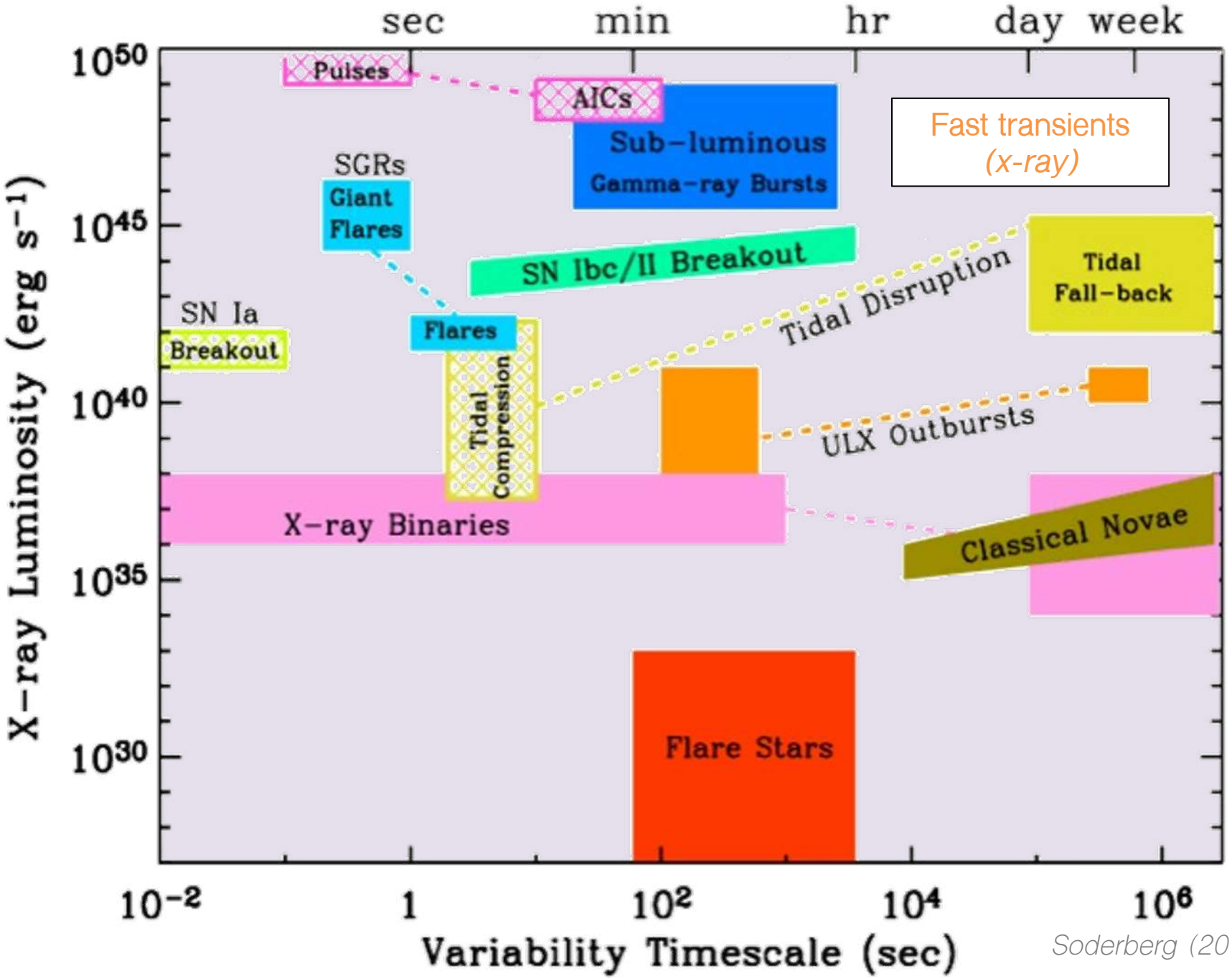
Kasliwal (2011)


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

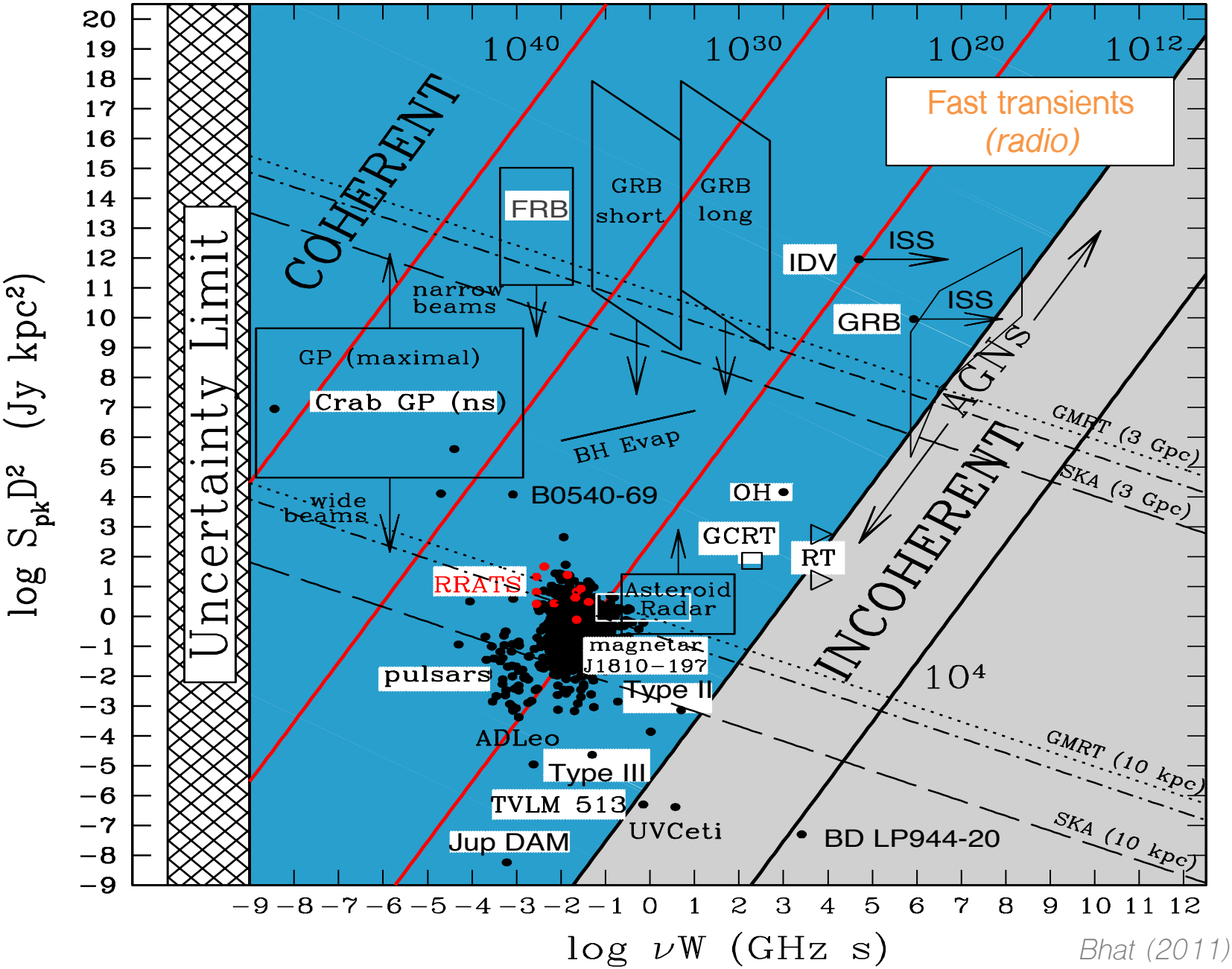

Transients circa 2011
(optical)
Superluminous supernovae
Tidal disruption events
Type Ia supernovae
Type .Ia supernovae
Core-collapse Supernovae
Ca-rich transients
Luminous red novae
Novae
Peak Luminosity [M_V]
Peak Luminosity [erg s^{-1}]
log (Characteristic Timescale [day])
Kasliwal (2011)


Characteristic Timescale log(sec)
1
2
3
4
5
6
7
Fast transients
(optical)
?
Superluminous supernovae
Tidal disruption events
Type Ia supernovae
Type .Ia super-novae
Core-collapse supernovae
Ca-rich transients
Luminous red novae
Novae
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}
-4
-3
-2
-1
0
1
2
Characteristic Timescale log(day)


Characteristic Timescale log(sec)
1
2
3
4
5
6
7
Fast transients
(optical)
Gamma-ray burst
afterglows
Superluminous
supernovae
Tidal disruption
events
Fast
luminous
transients
Type Ia
supernovae
Type .Ia
super-
novae
Core-
collapse
supernovae
Fast radio burst
counterparts
(single burst
and repeaters
or fast and slow)
type Ia supernova
shock breakouts
blitzars, sub-minute
events, etc.
?
Core-collapse supernova
shock breakouts
Type Ia
companion
star collision
bursts
Binary
neutron
star
kilonovae
Ca-rich
transients
Luminous
red
novae
Ultrafast novae
Novae
Ultraluminous X-ray bursts
Soft gamma-ray
repeater flares
Flare stars
X-ray binaries
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
-4
-3
-2
-1
0
1
2
Characteristic Timescale log(day)
Cooke+ (in prep.)

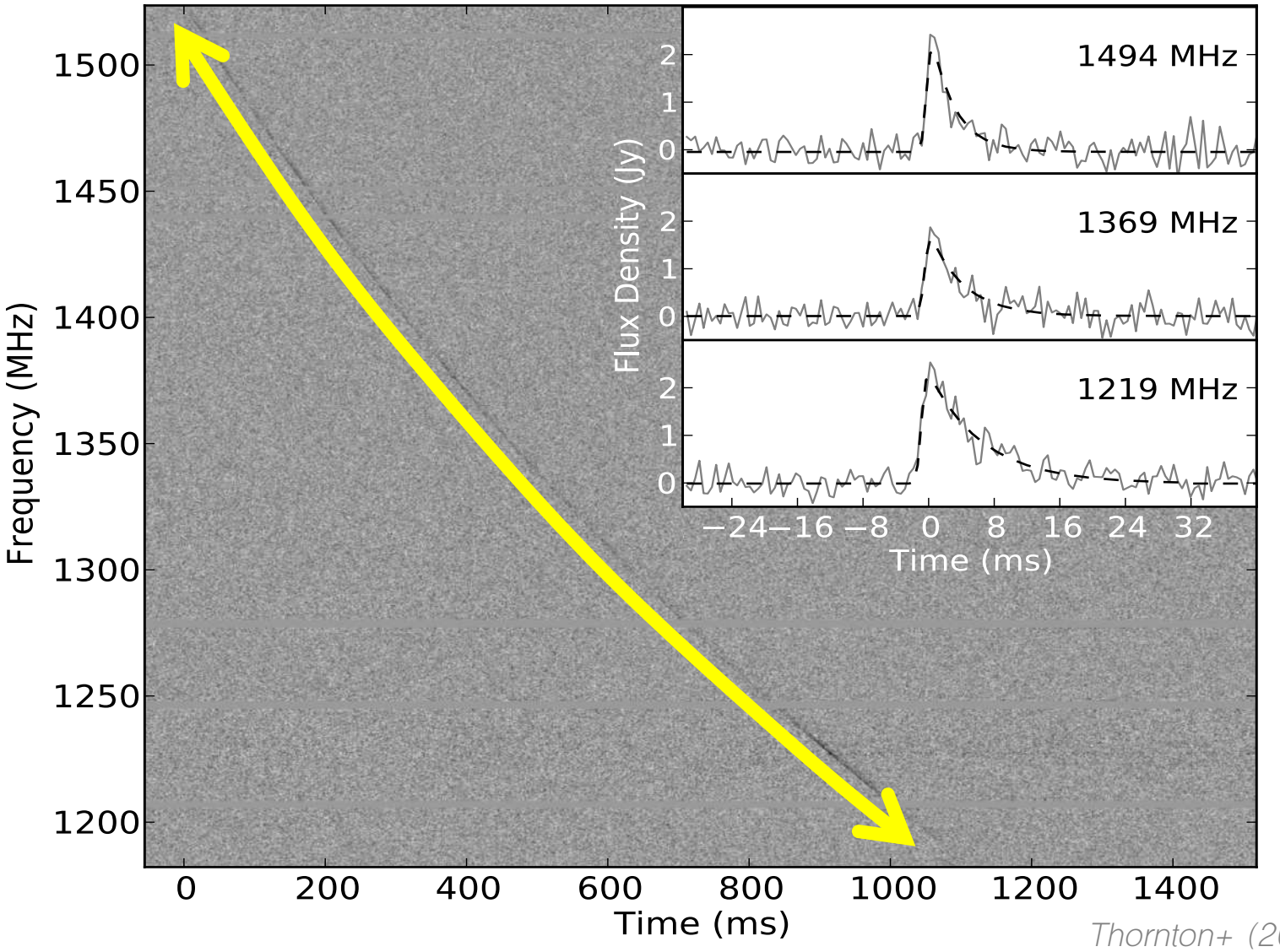


Soderberg (2010)


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

Bhat (2011)

Fast radio bursts



Thornton+ (2013)

Fast transients

Occur at all wavelengths

- Occur in one, multiple, or all wavelength regimes
- Some emit at unknown wavelengths *(e.g., theorized events)*
- Some include high-energy particles and gravitational waves
- Some arrive BEFORE their detection in their discovery wavelength *(e.g., FRB counterparts)*

Need to act fast to catch and identify them

- Fast exposures needed to sample their evolution *(= shallow)*
- Simultaneous all-wavelength coverage to get all possible information for the fastest events before they fade
- Need to process, analyse, and identify events fast to trigger follow up before the 'slower' fast transients 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

How would you design a program to do all this?

Deeper, Wider, Faster program

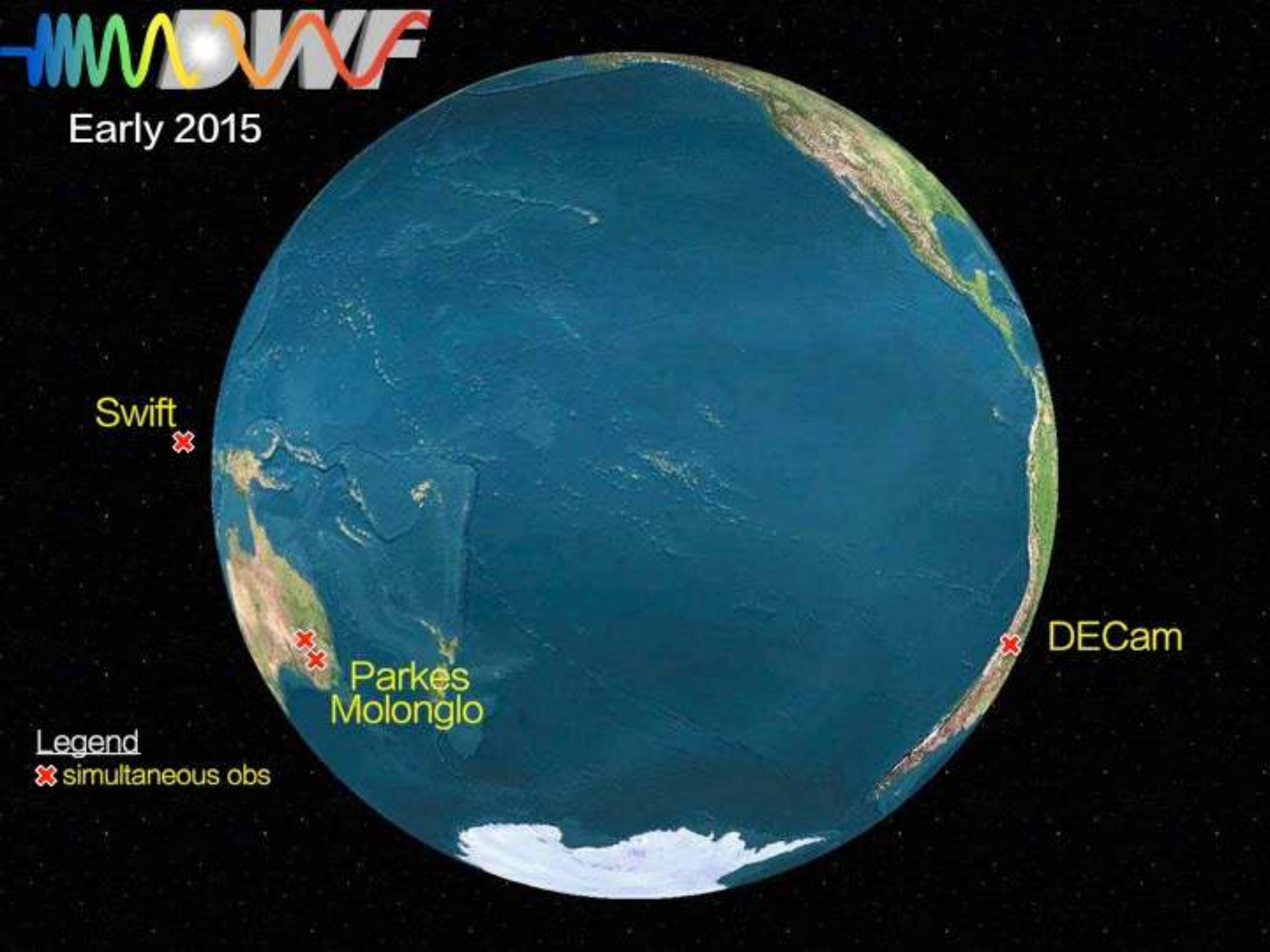
What is needed

(1) Coordinated simultaneous detection, *before, during, and after*

(2) Real-time data processing and identification

(3) Rapid-response and conventional ToOs

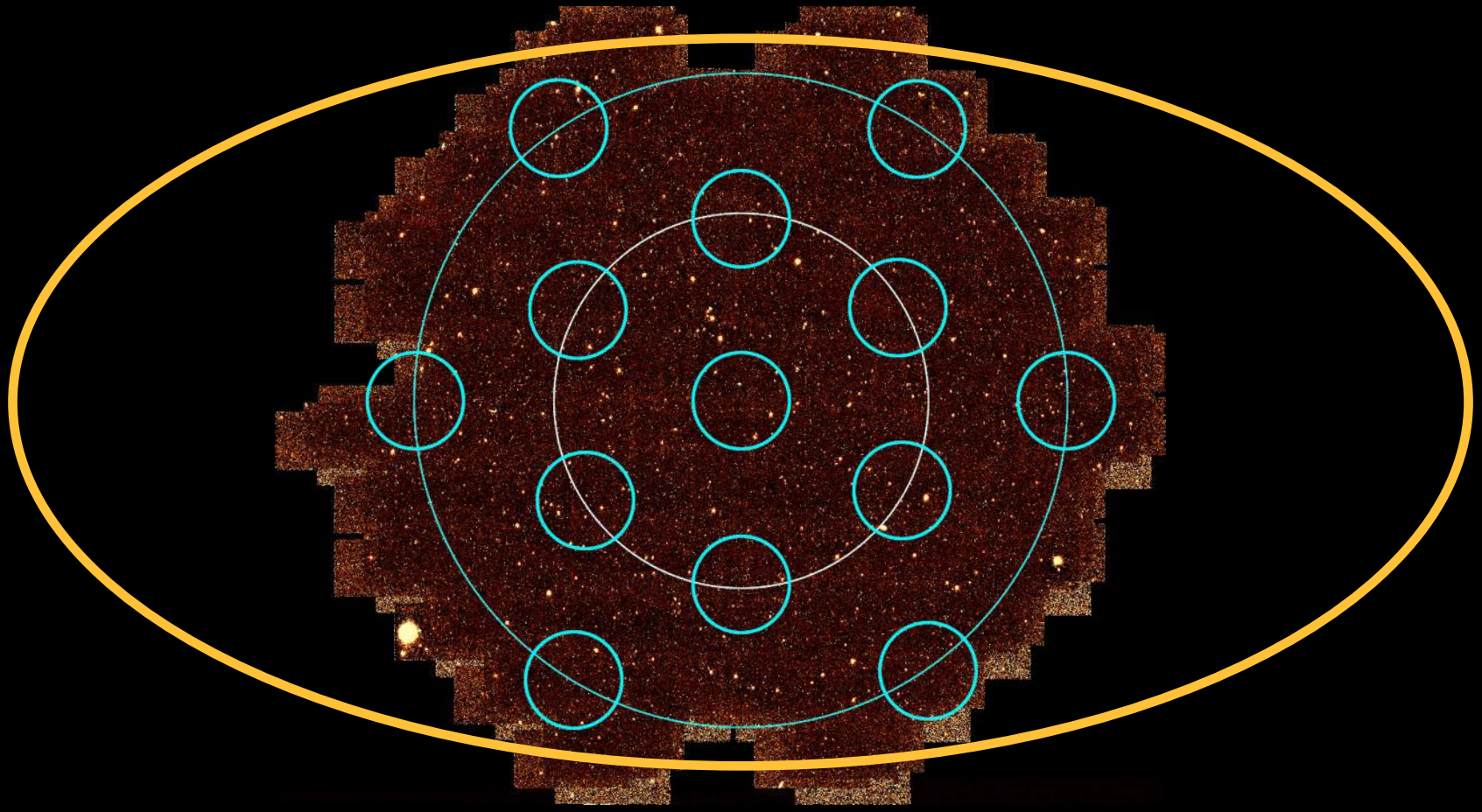
(4) Longer-term cadenced observations


DWF
Early 2015
Swift
Parkes
Molonglo
DECam
Legend
simultaneous obs

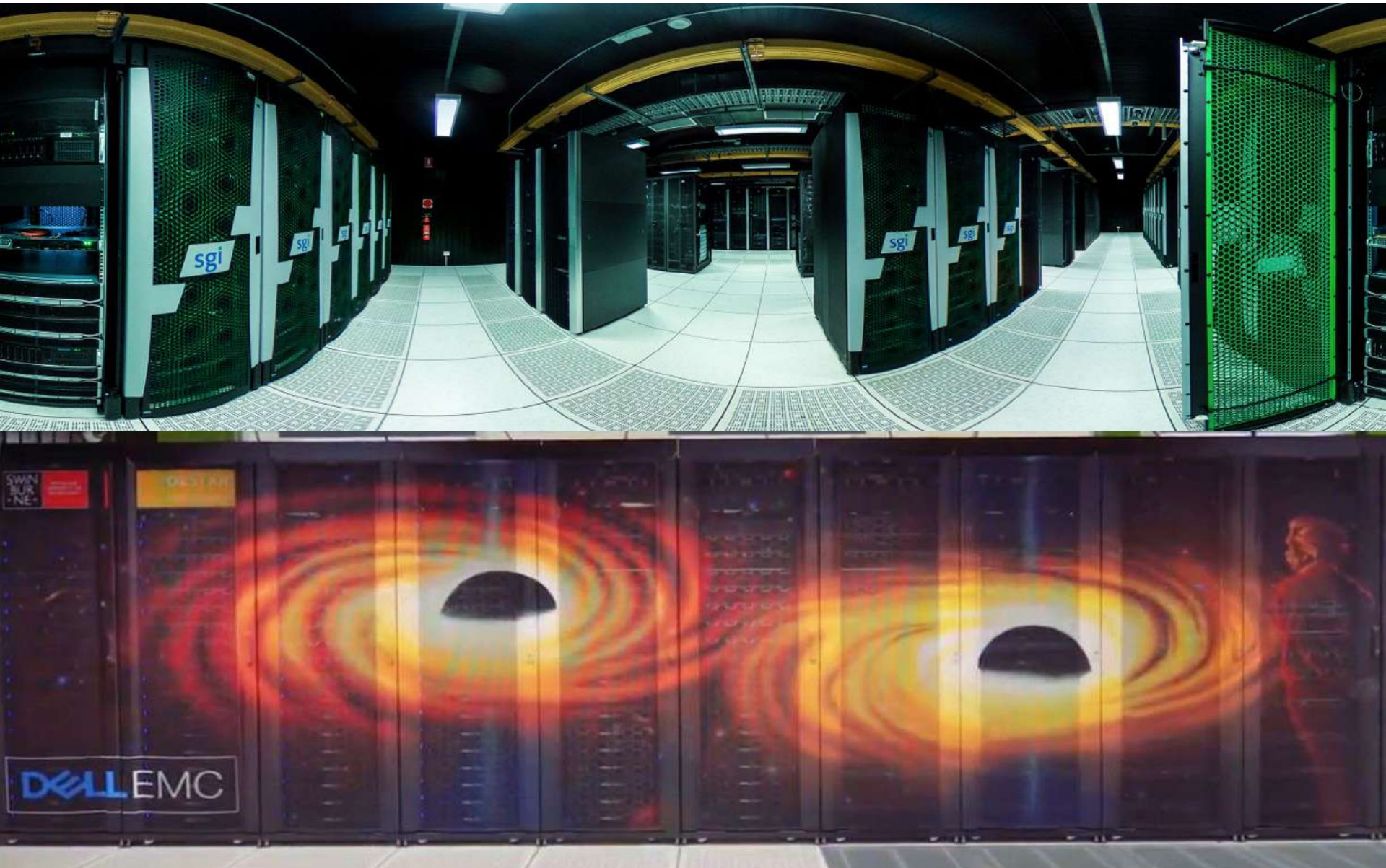
Fields of view

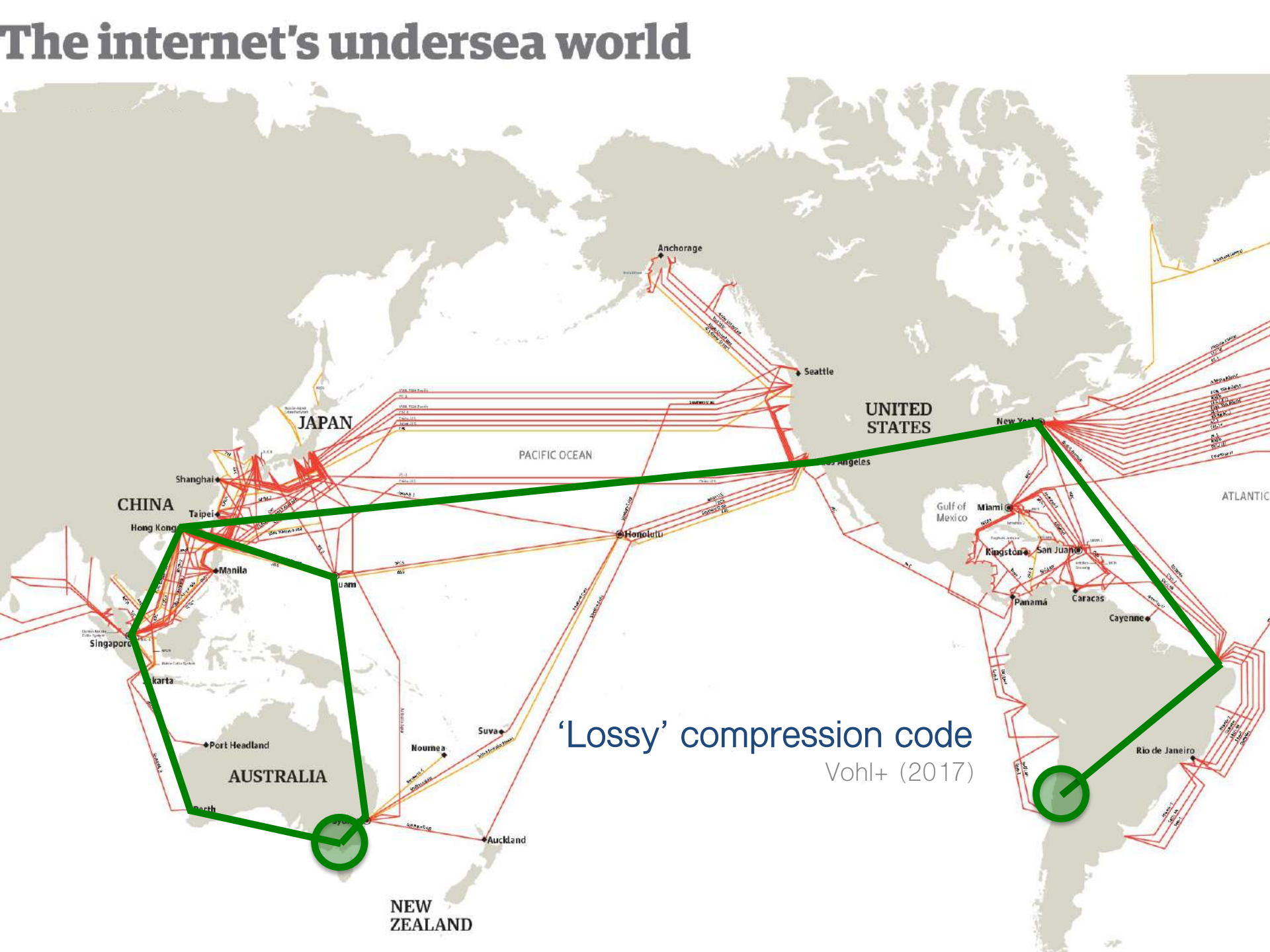
DECam Parkes Molonglo

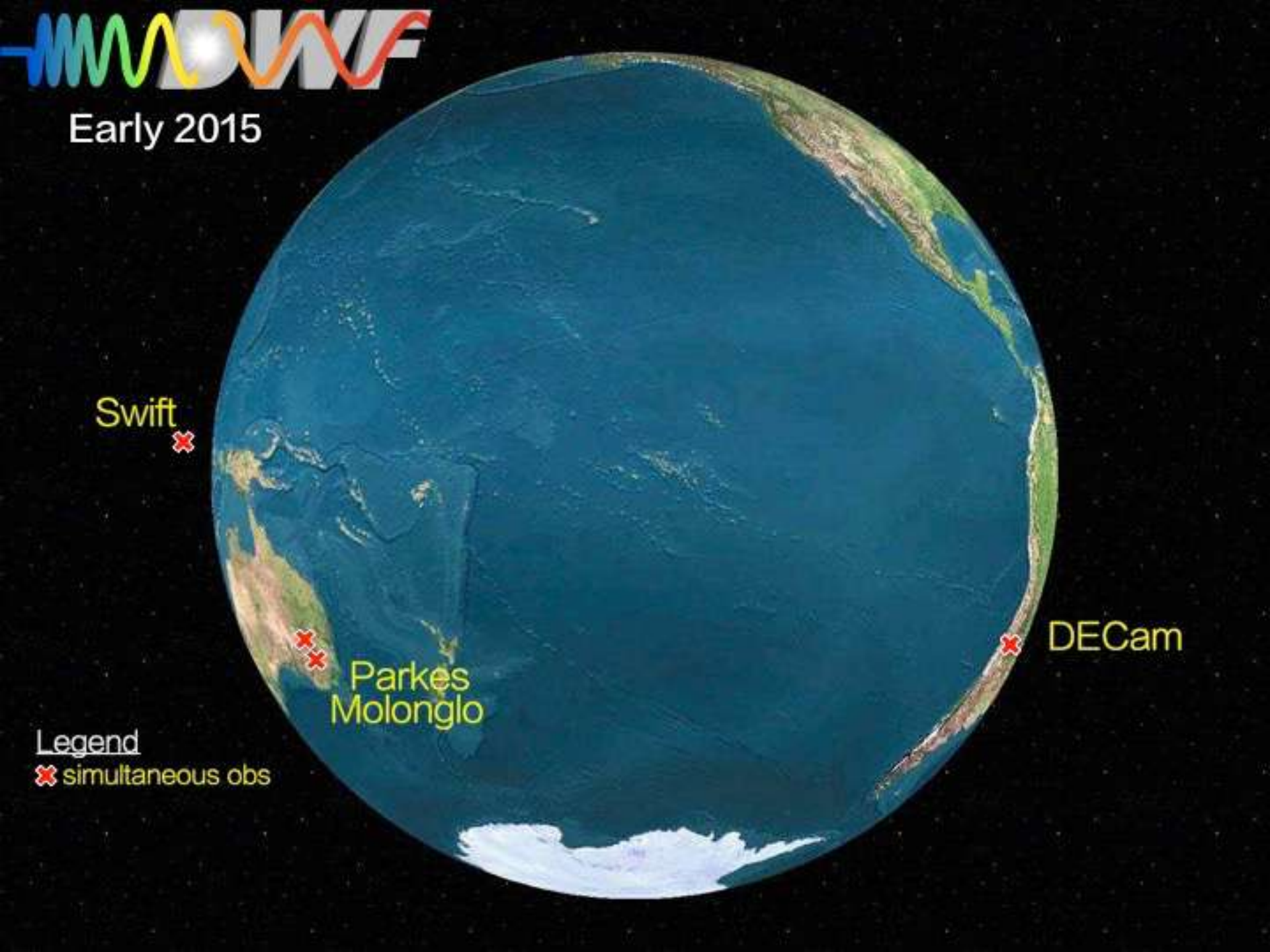
Swift BAT

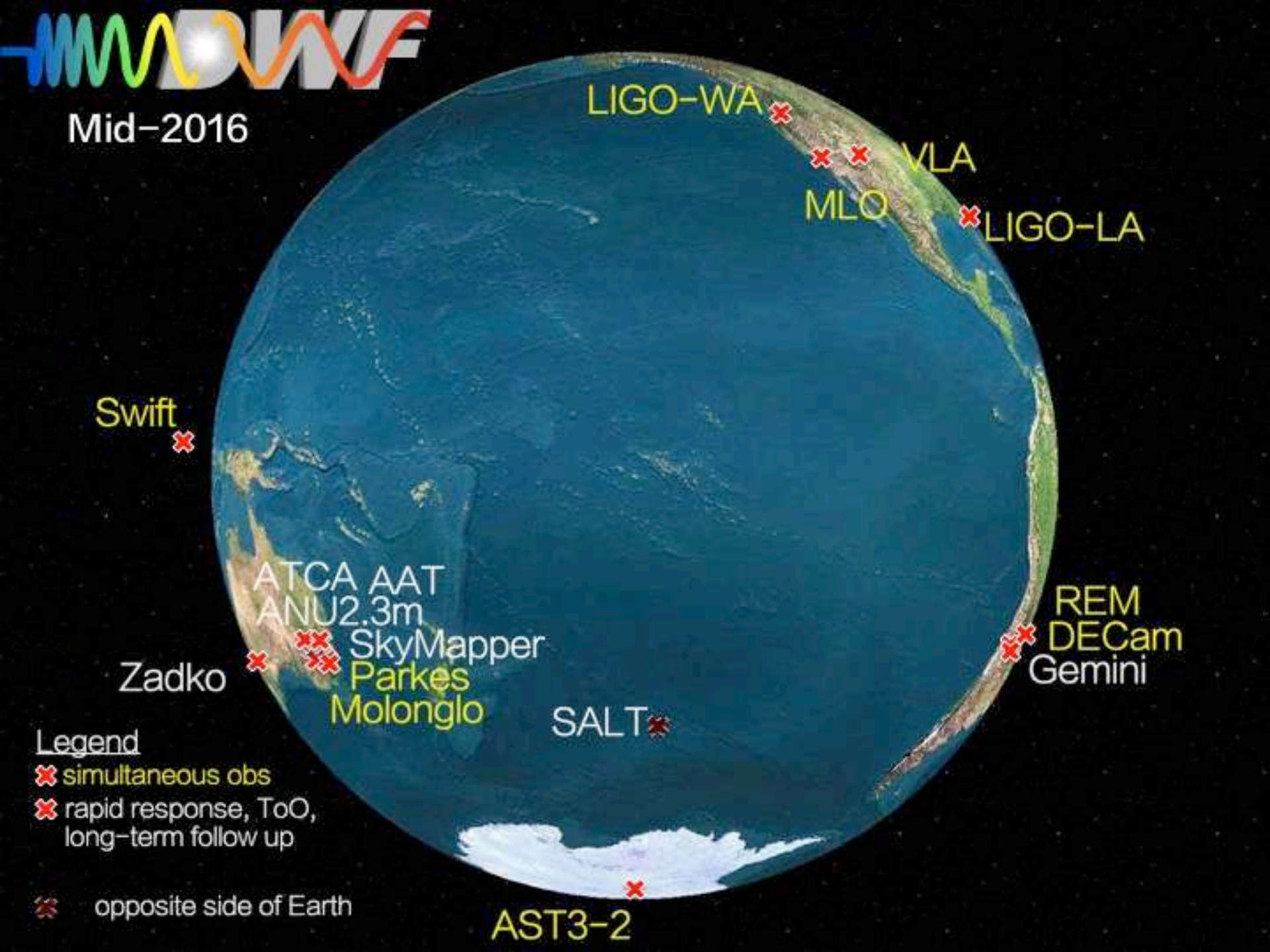


Supercomputer processing/analysis

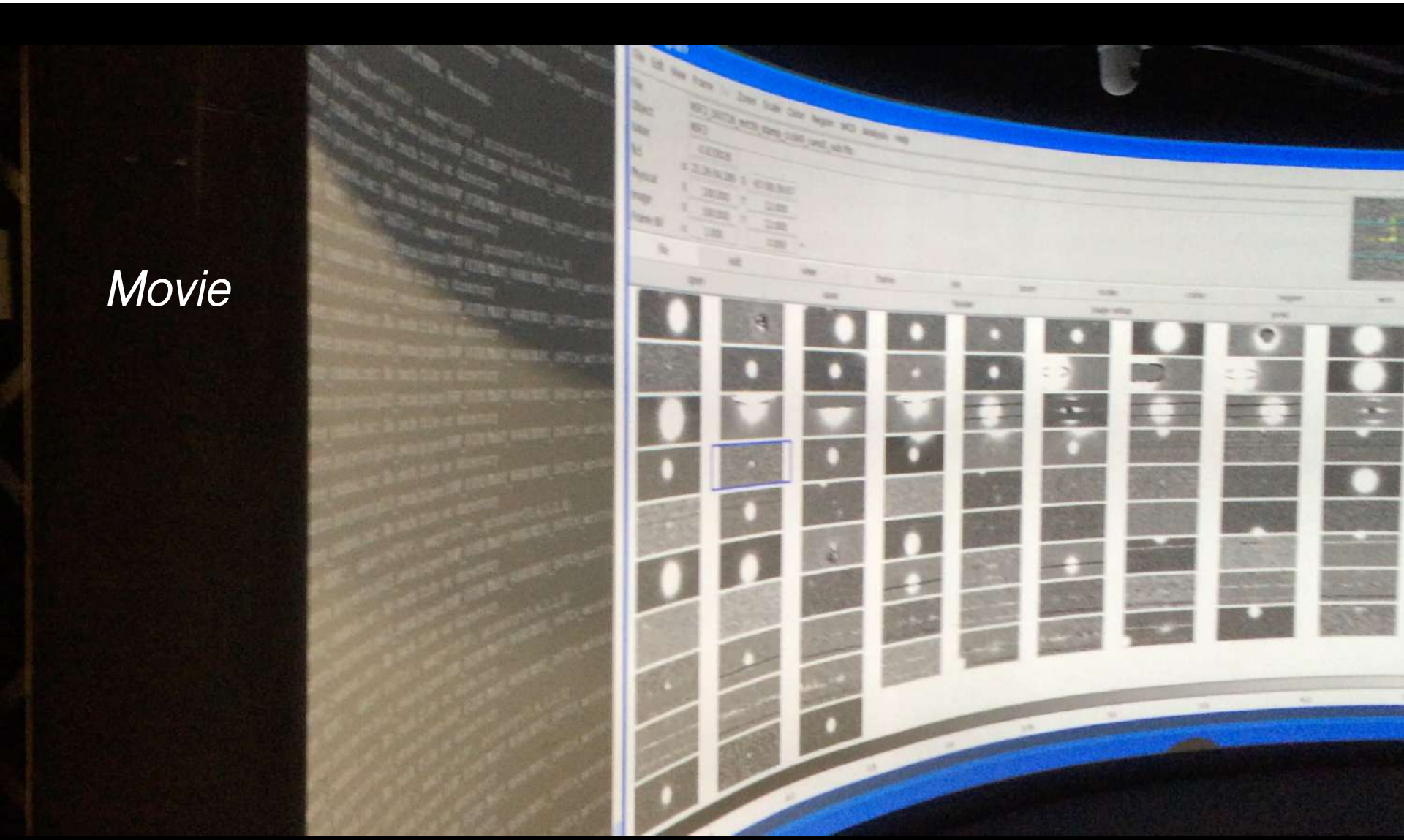


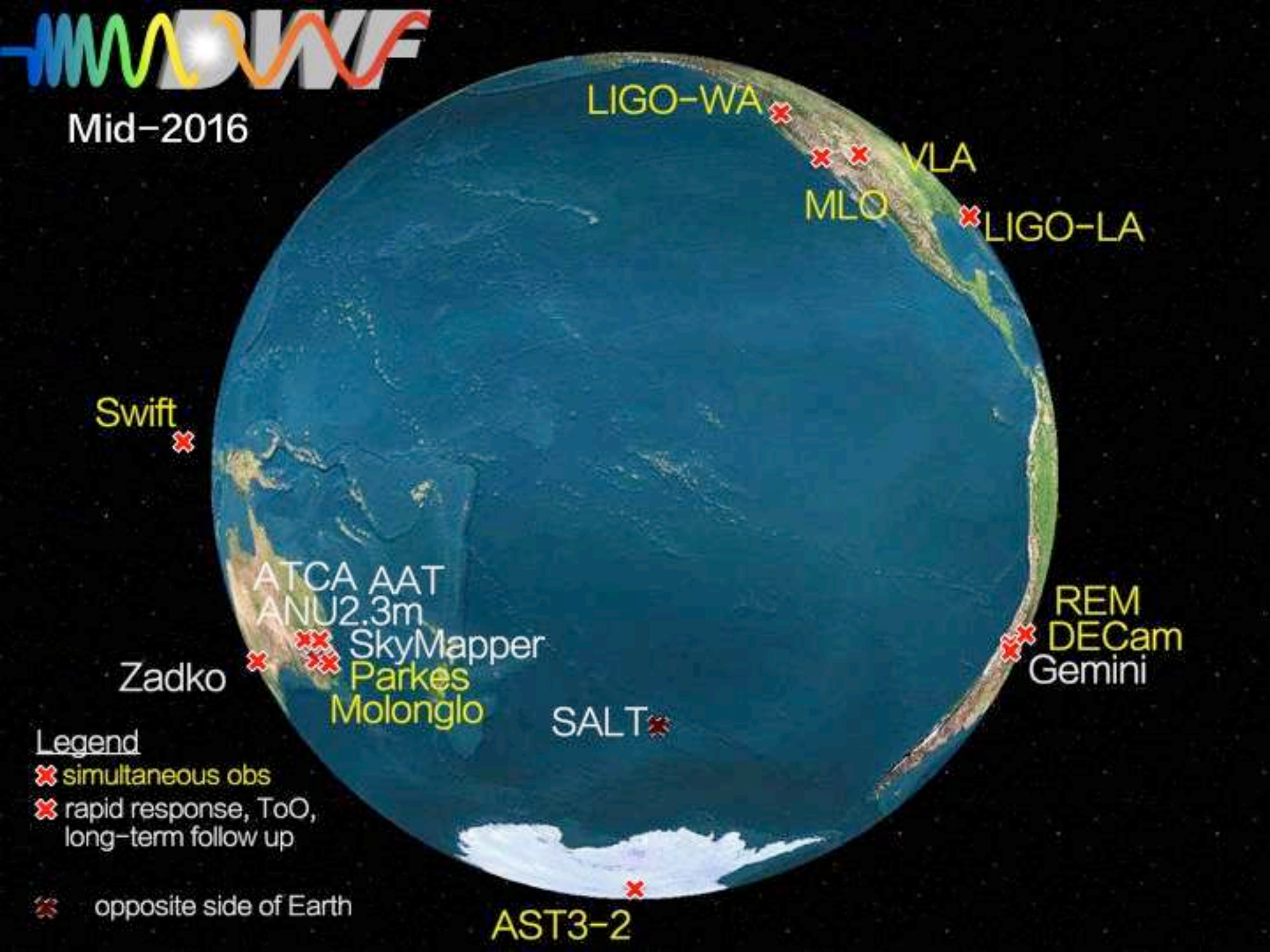

The internet's undersea world
Anchorage
Seattle
JAPAN
PACIFIC OCEAN
UNITED STATES
Shanghai
CHINA
Taipei
Hong Kong
Manila
Honolulu
Guam
Singapore
Jakarta
Port Headland
AUSTRALIA
Suva
Noumea
Auckland
NEW ZEALAND
Gulf of Mexico
Miami
Kingston
San Juan
Panamá
Caracas
Cayenne
Rio de Janeiro
ATLANTIC
'Lossy' compression code
Vohl+ (2017)

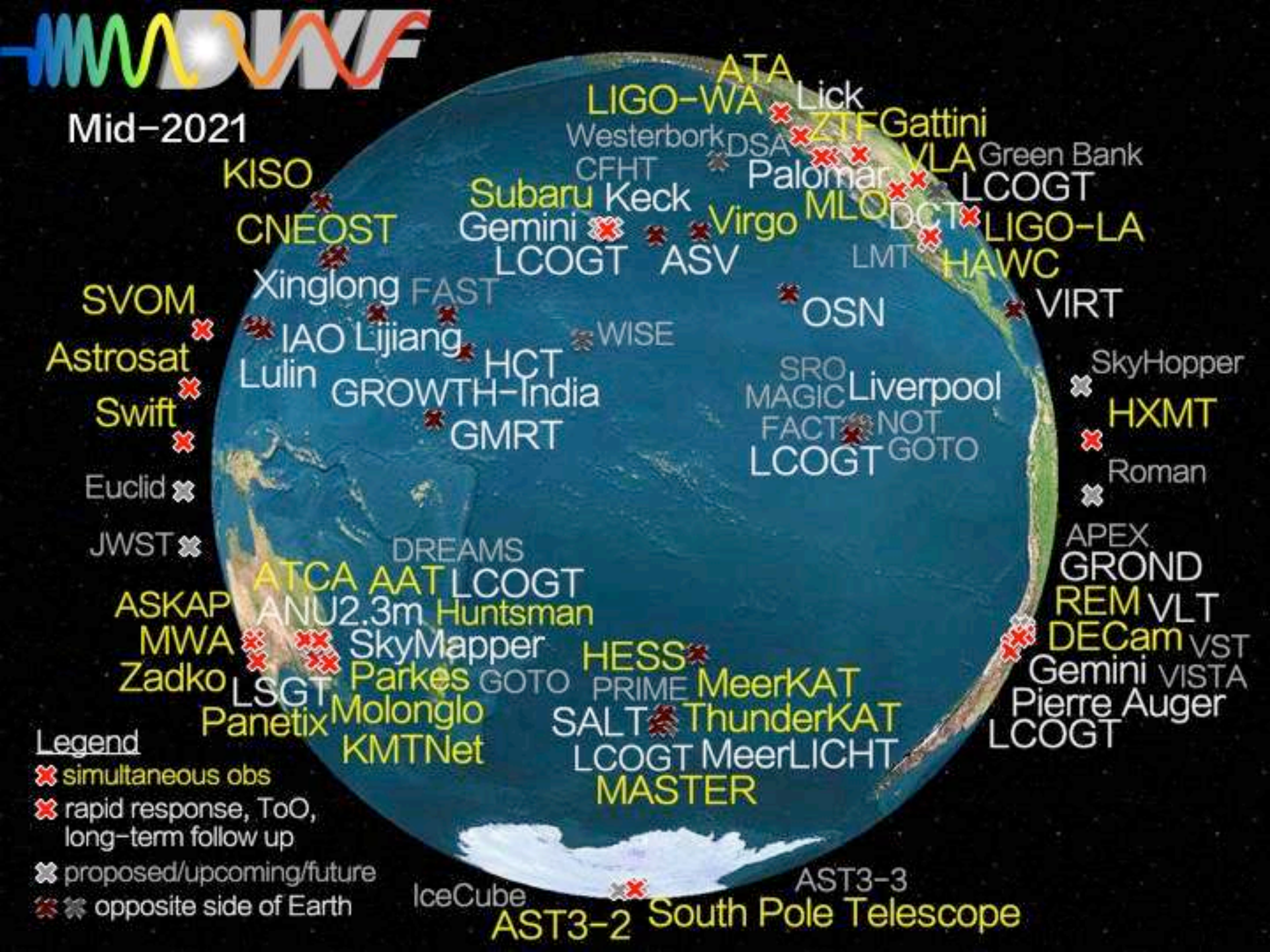

DWF
Early 2015
Swift
Parkes
Molonglo
DECam
Legend
simultaneous obs


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

Real-time analysis — Mission Control room




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


DWF
Mid-2021
ATA
LIGO-WA
Lick
ZTF
Gattini
Westerbork
DSA
VLA
Green Bank
CFHT
Palomar
LCOGT
KISO
Subaru
Keck
MLO
DCT
LIGO-LA
CNEOST
Gemini
Virgo
LCOGT
ASV
LMT
HAWC
Xinglong
FAST
OSN
VIRT
SVOM
IAO
Lijiang
WISE
Astrosat
HCT
SkyHopper
Lulin
SRO
GROWTH-India
MAGIC
Liverpool
Swift
HXMT
GMRT
FACT
NOT
GOTO
LCOGT
Euclid
Roman
JWST
APEX
DREAMS
GROND
ATCA
AAT
LCOGT
REM
VLT
ASKAP
ANU2.3m
Huntsman
DECam
VST
MWA
SkyMapper
HESS
Gemini
VISTA
Zadko
Parkes
GOTO
PRIME
MeerKAT
LSGT
Pierre Auger
Molonglo
SALT
ThunderKAT
Panetix
LCOGT
KMTNet
LCOGT
MeerLICHT
MASTER
AST3-3
IceCube
AST3-2
South Pole Telescope
Legend
simultaneous obs
rapid response, ToO, long-term follow up
proposed/upcoming/future
opposite side of Earth

What is needed *(what we have per run)*

(1) Coordinated simultaneous detection, *before, during, and after*

Wide-field, deep m~22-24 *(m~26 stacked),* fast-cadenced observations, with ~10 of the world's best telescopes. All wavelengths + particles + GWs

(2) Real-time data processing and identification

(3) Rapid-response and conventional ToOs

(4) Longer-term cadenced observations

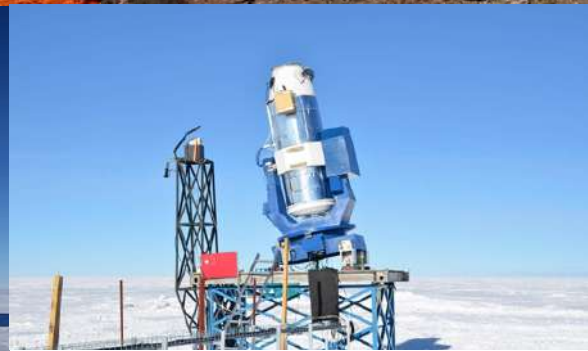
Some simultaneous observing facilities











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(2) Real-time data processing and identification

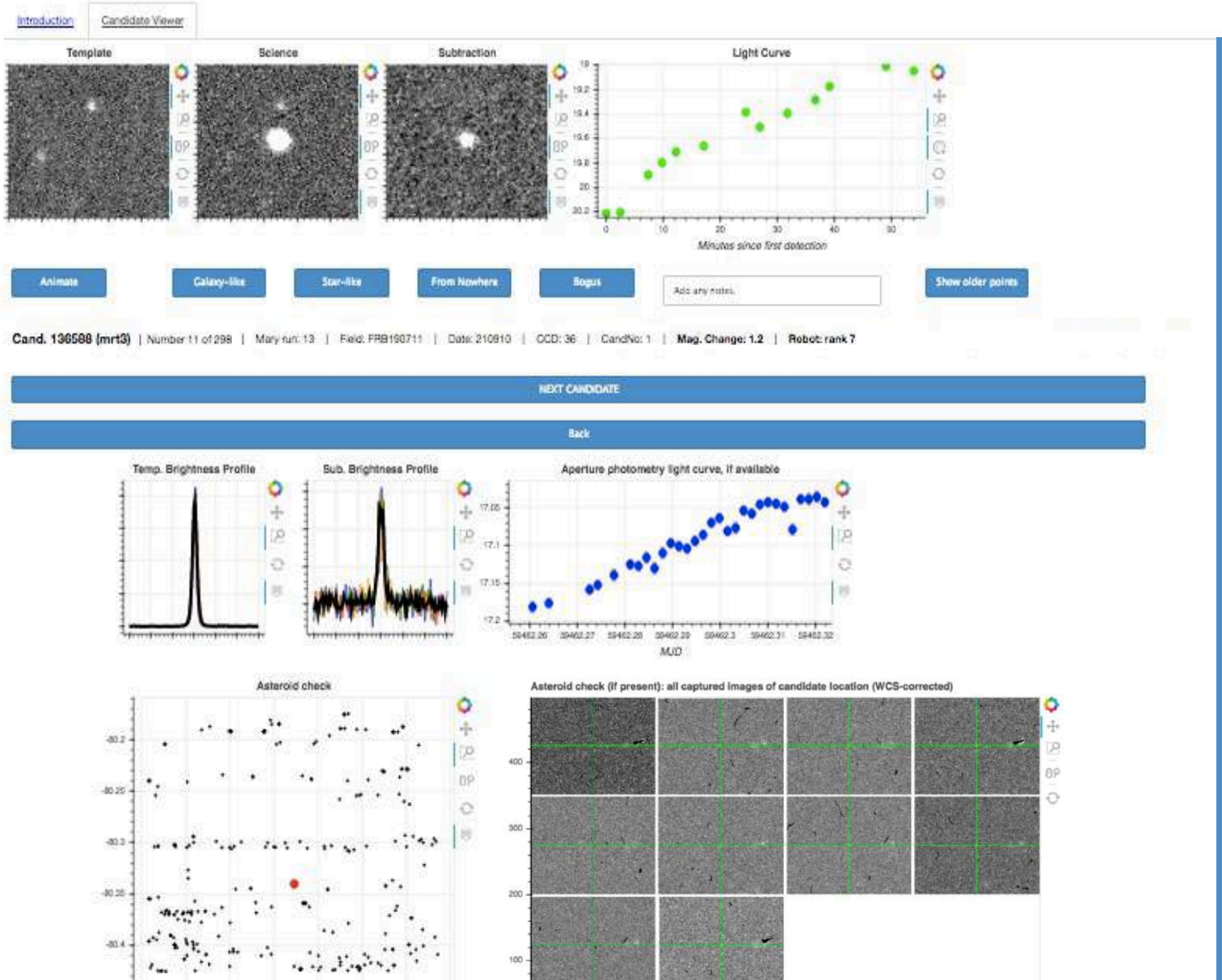
Fast intercontinental data transfer, supercomputer processing *(in seconds)*
ML/software + human identification & confirmation *(in minutes)*

(3) Rapid-response and conventional ToOs

(4) Longer-term cadenced observations

Fast transient identification

Real-time analysis - web tool



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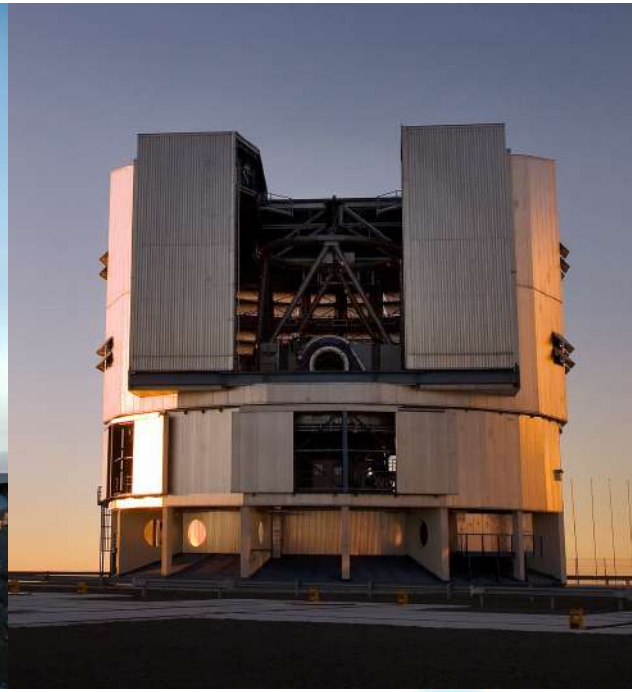
(3) Rapid-response and conventional ToOs

Deep rapid *(in minutes)* and ToO *(hours later)* spectroscopy and imaging with ~10 space-based, radio, and 1-10m ground-based OIR telescopes

(4) Longer-term cadenced observations

Some rapid-response facilities



Some ToO facilities

What is needed *(what we have per run)*

(1) Coordinated simultaneous detection, *before, during, and after*

Wide-field, deep m~22-24 *(m~26 stacked),* fast-cadenced observations, with ~10 of the world's best telescopes. All wavelengths + particles + GWs

(2) Real-time data processing and identification

Fast intercontinental data transfer, supercomputer processing *(in seconds)*
ML/software + human identification & confirmation *(in minutes)*

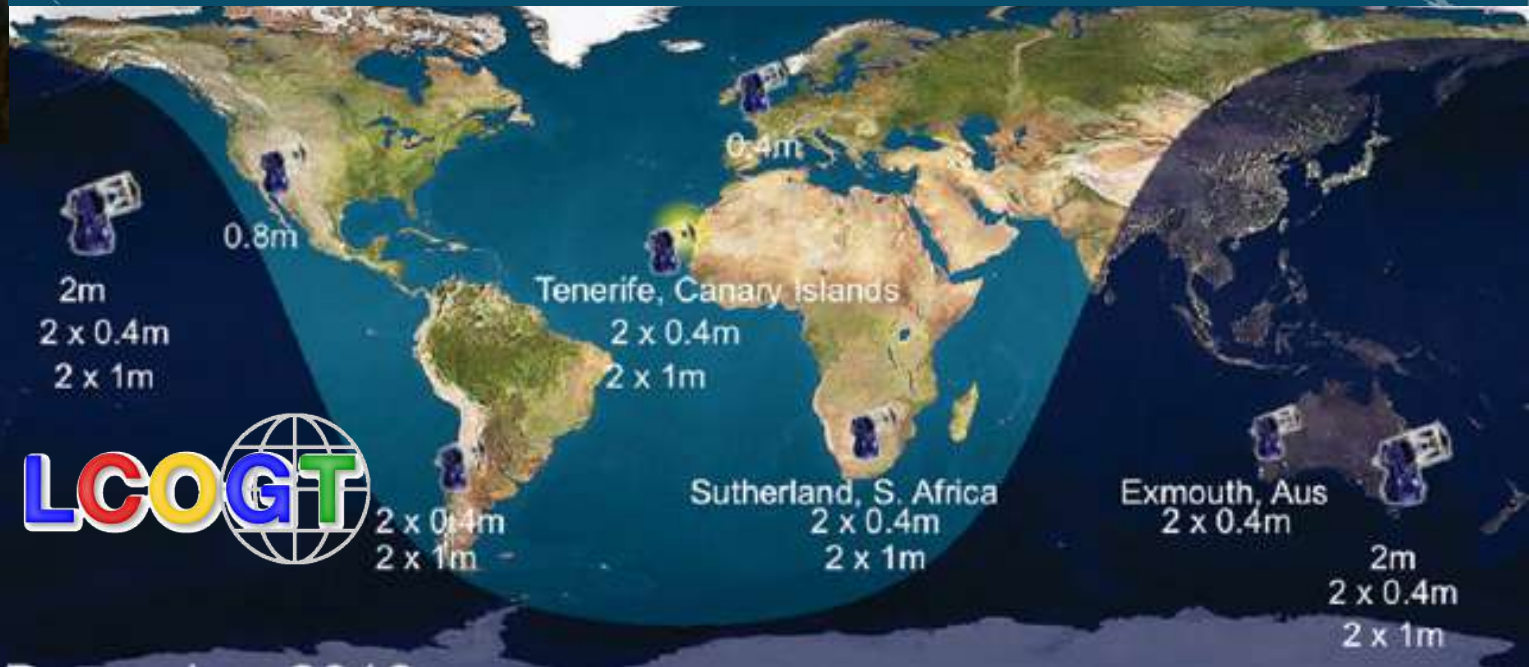
(3) Rapid-response and conventional ToOs

Deep rapid *(in minutes)* and ToO (hours later) spectroscopy and imaging with ~10 space-based, radio, and 1-10m ground-based OIR telescopes

(4) Longer-term cadenced observations

Network of ~20 follow-up telescopes *(1-4m class)*
Important for confirmation, classification, host galaxies, etc., as some fast transients are associated with longer duration events *(e.g., SN SBOs)*

Some late-time monitoring facilities



Blanco telescope

Data transfer
(about a minute)

Data
processed
in about a
minute

Visualisation room

Gemini-South

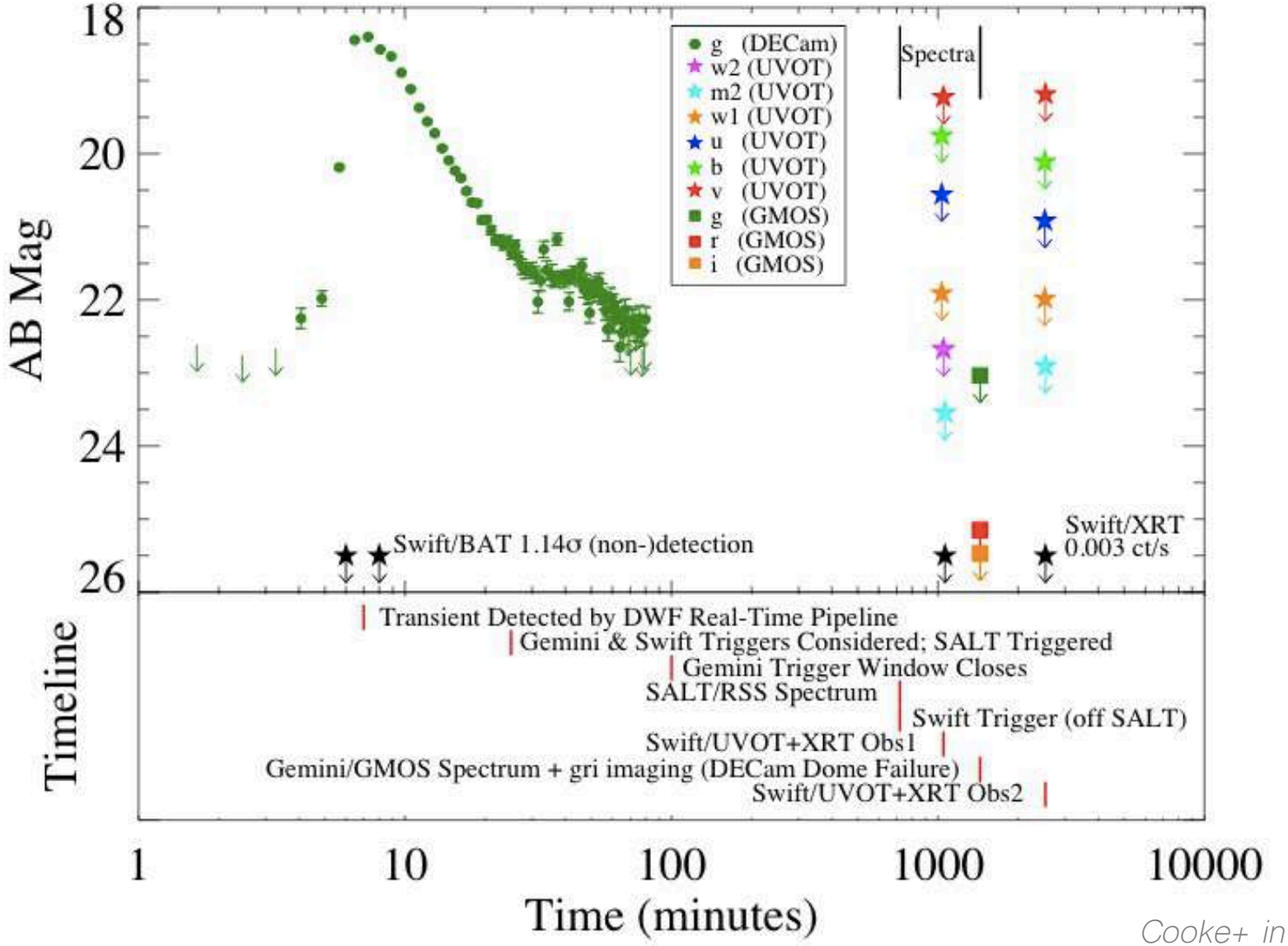
High-energy bursts

Identify bursts within
minutes after the light
hits the telescopes

Radio bursts

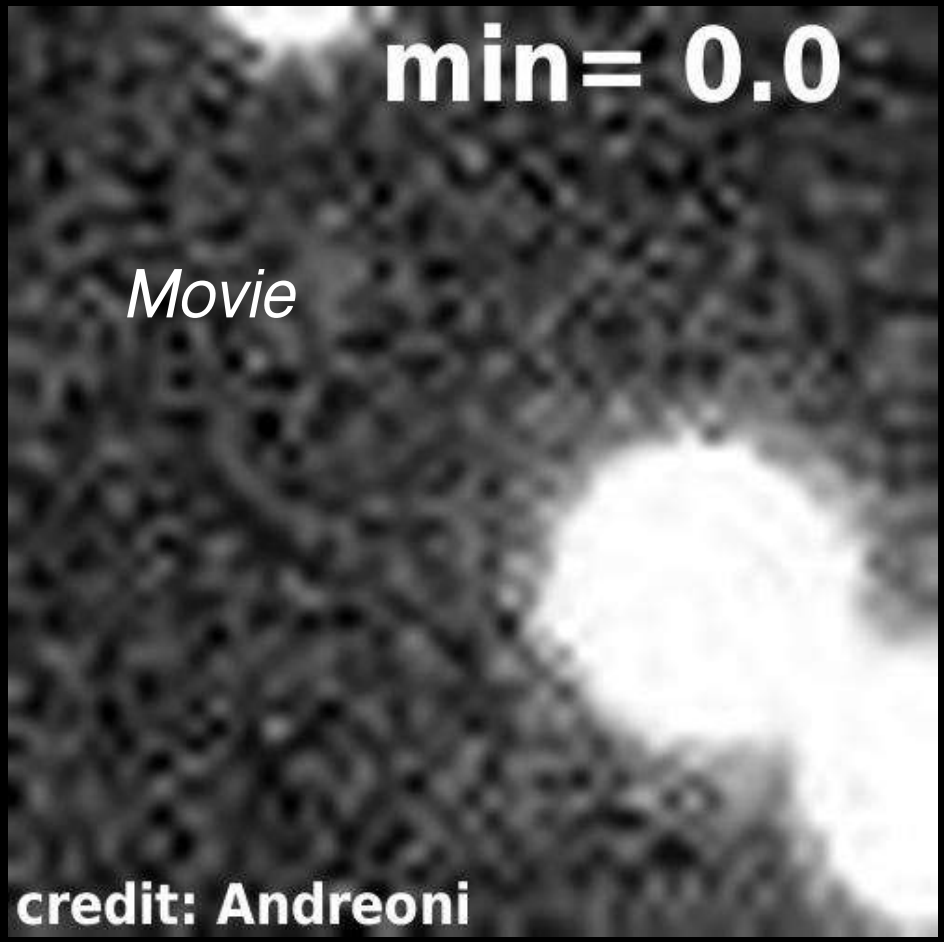
Trigger
follow up

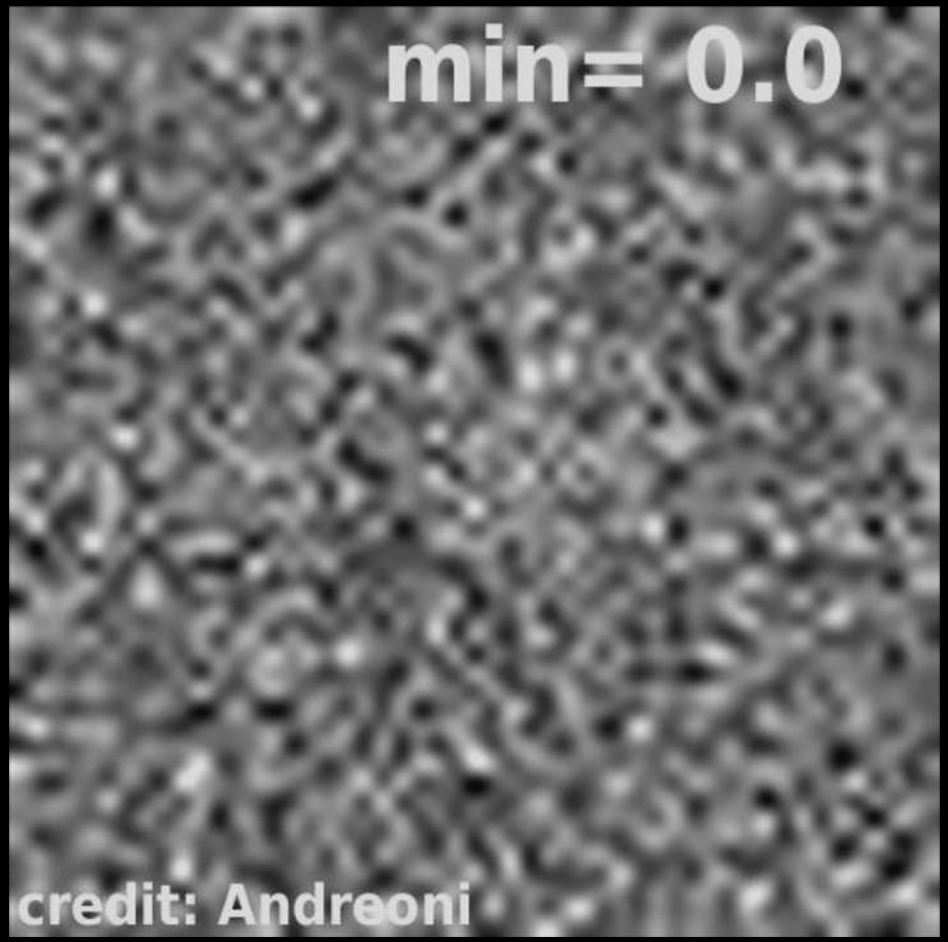
Example event



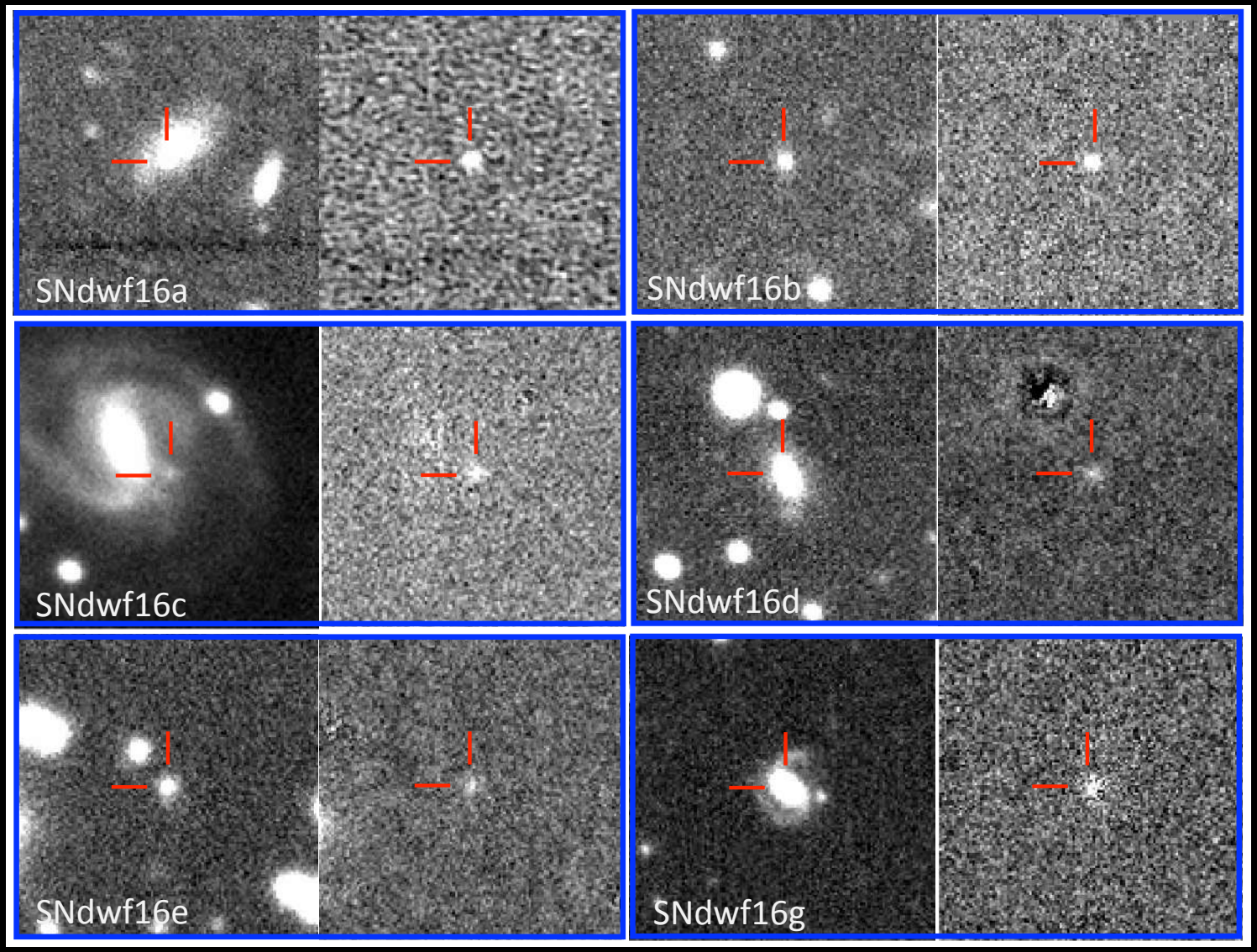
Cooke+ in prep.

Fast transients

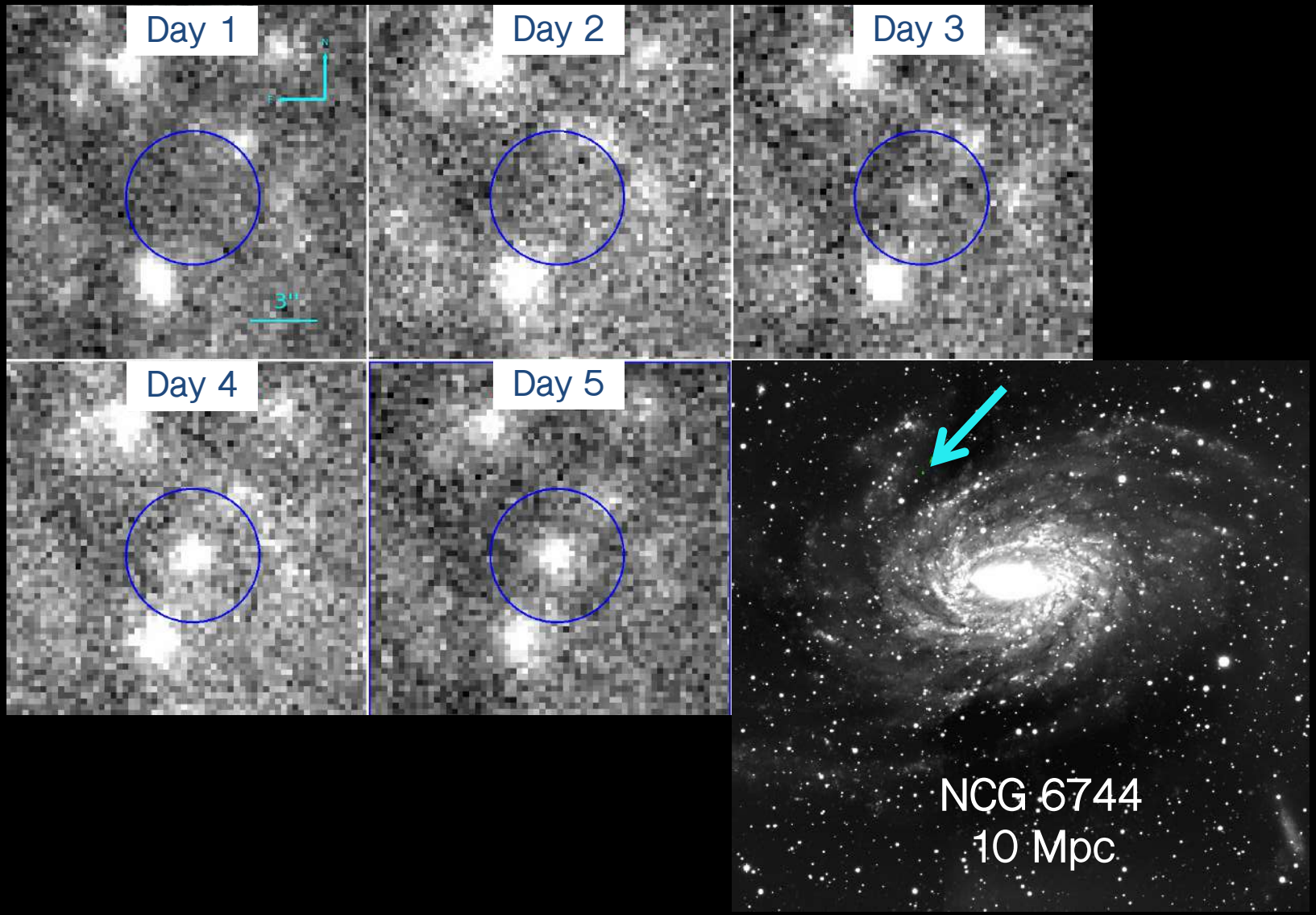




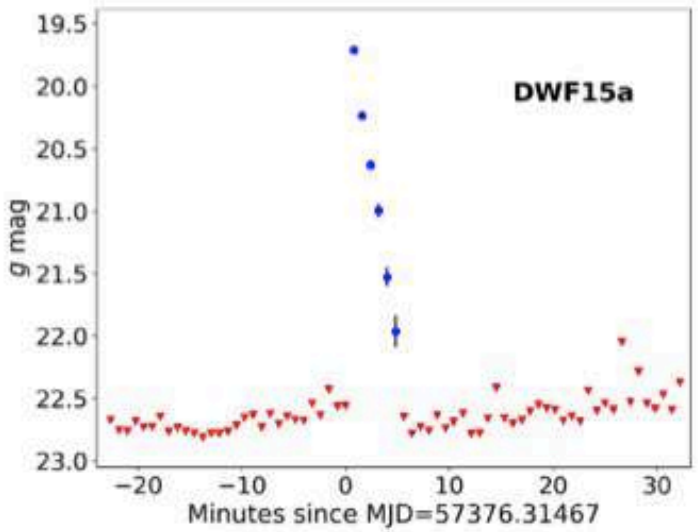
Supernovae

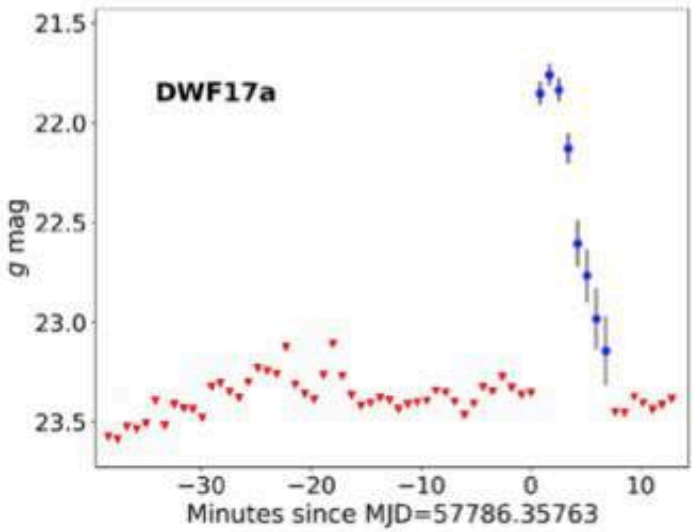


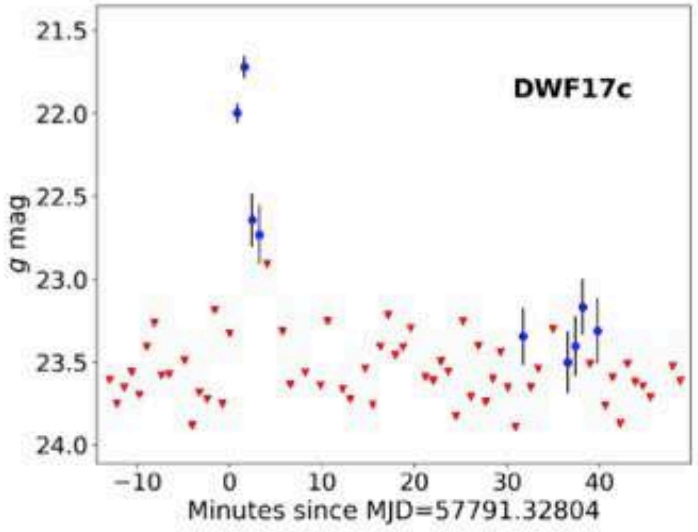
Extragalactic novae

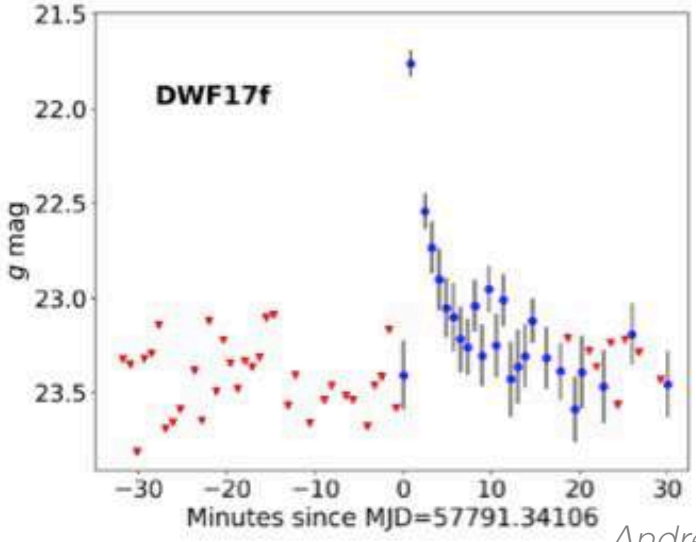


Some discoveries



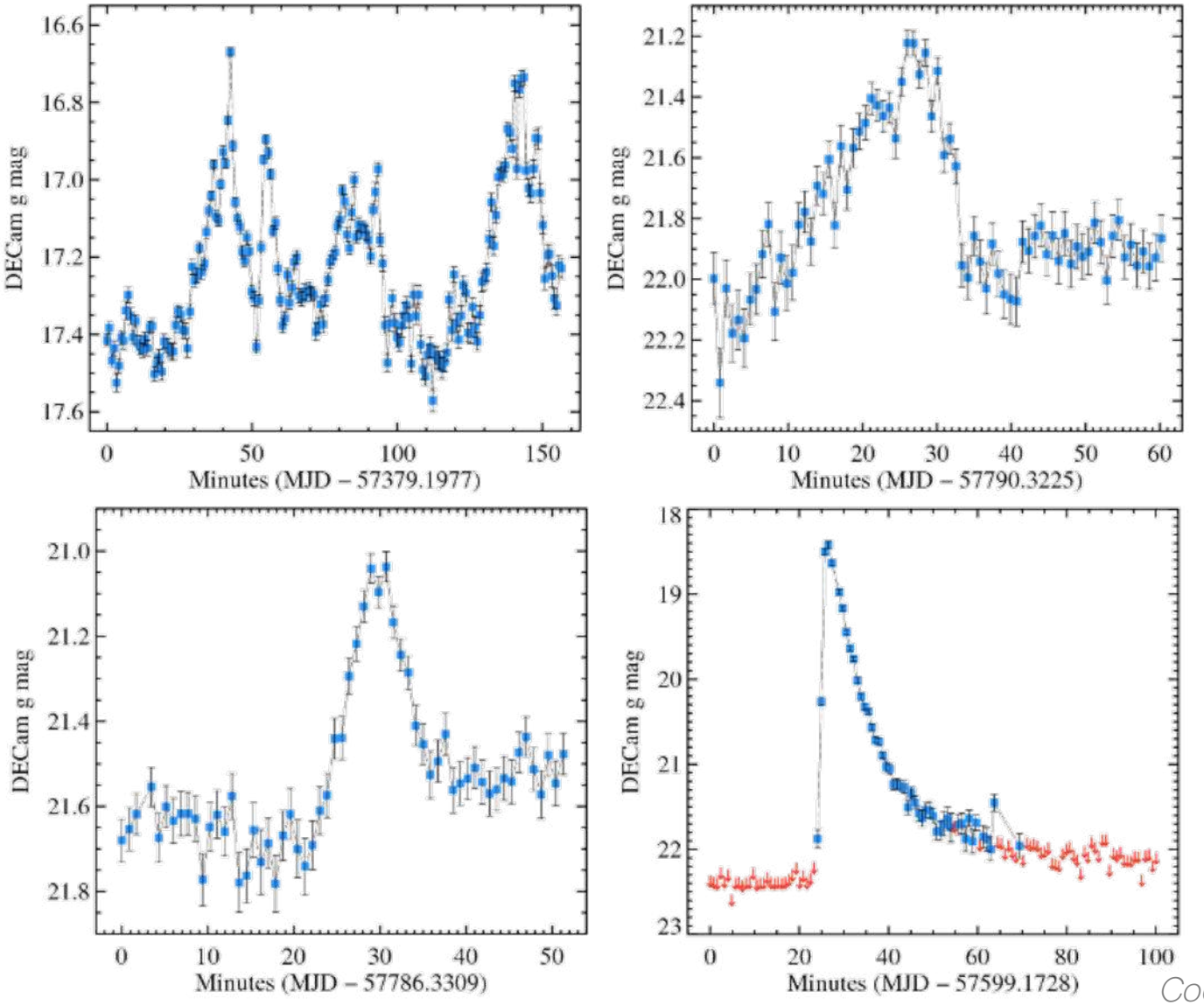






Andreoni+ (2020)

Some discoveries



Cooke+ in prep.

Some discoveries

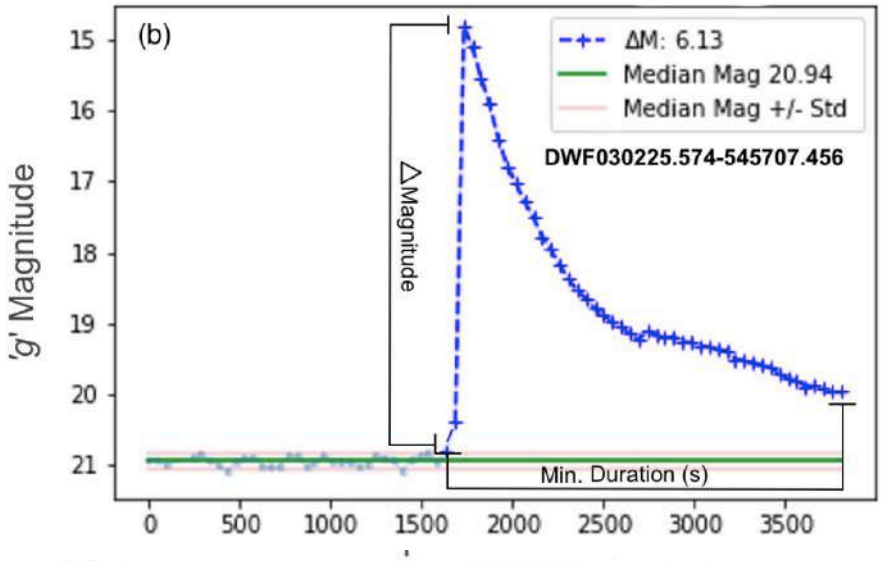
Gravitational wave kilonovae research

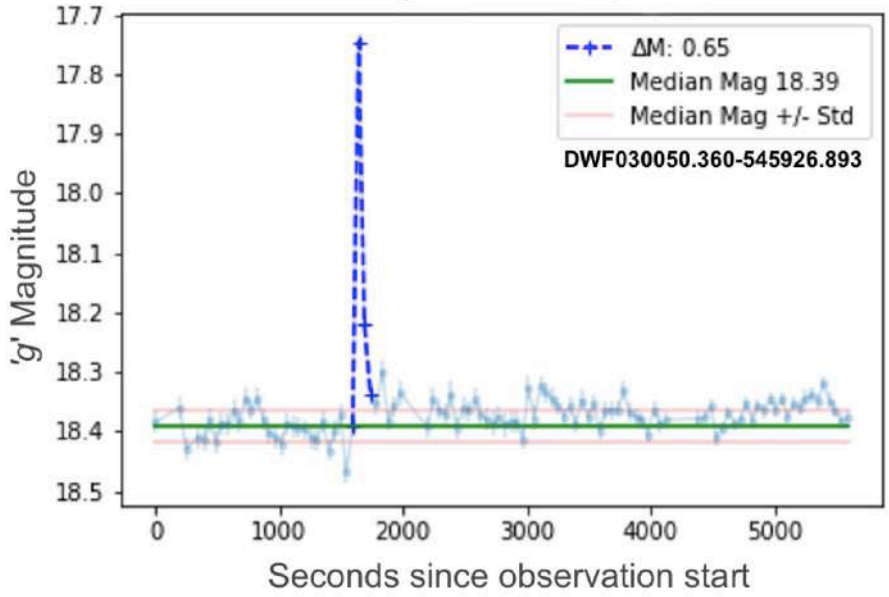
DWF contributed 14 of 70 telescopes for GW170817 search/follow up
- Field set in Australia just before the alert
- Triggered and coordinated optical, infrared, radio observations
- Early wide-field imaging, first optical spectrum, follow up (Australia, Antarctica, Chile, US, US Virgin Islands, South Africa)
- 12 publications on GW search and follow up

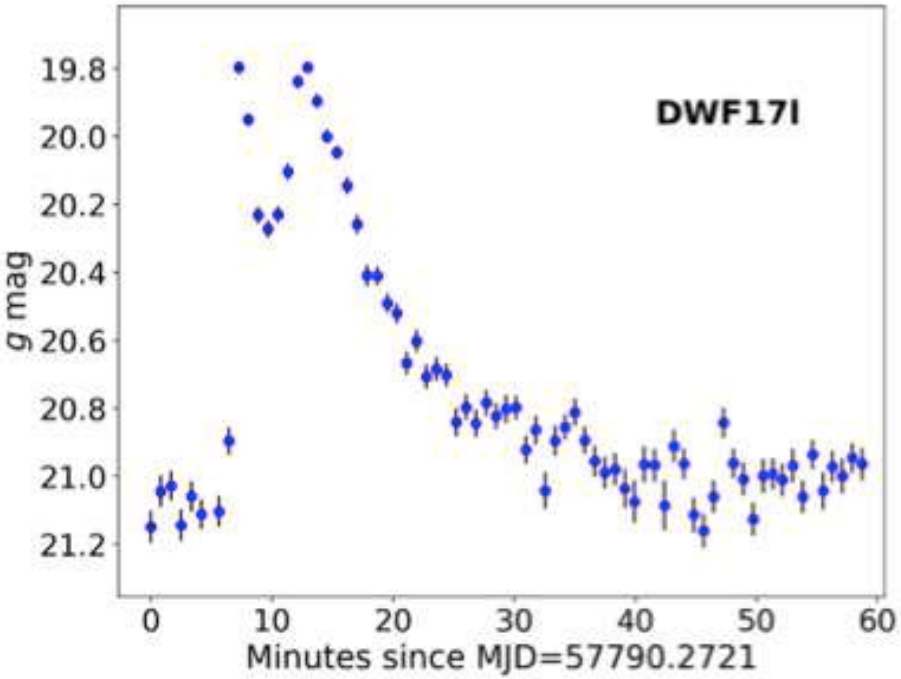
Fast Radio Burst counterpart searches

DWF contributed FRB counterpart search/follow up since 2014
- Early wide-field optical searches (DECam)
- All DWF runs since 2014
- Host galaxy observations
- Mapping of galaxies in the line-of-sight to FRB hosts
- 4 publications on FRB search and follow up *(others in prep)*

Some discoveries

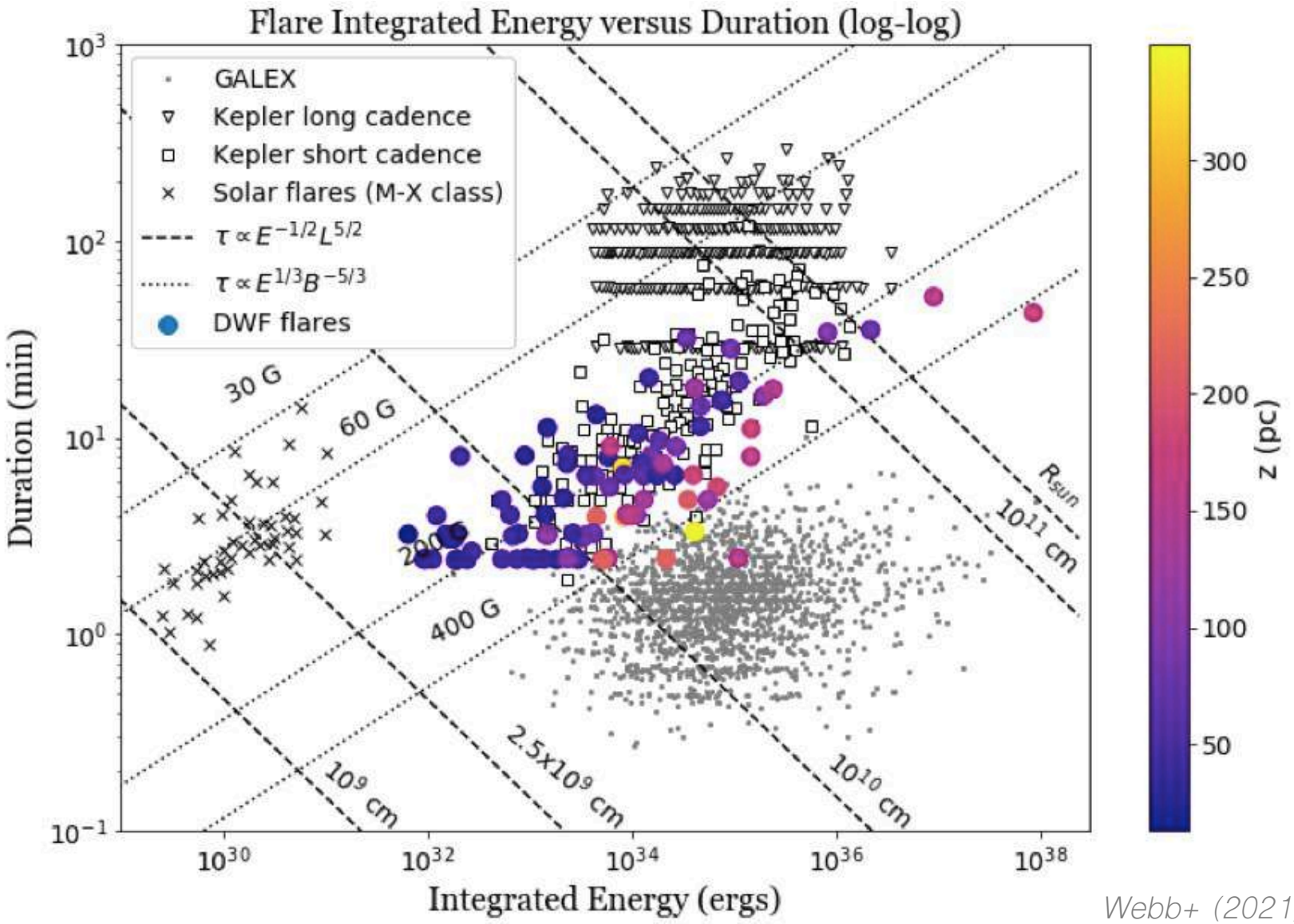






Webb+ (2021), Andreoni+ (2020)

Some discoveries



Webb+ (2021)

September 2020 run

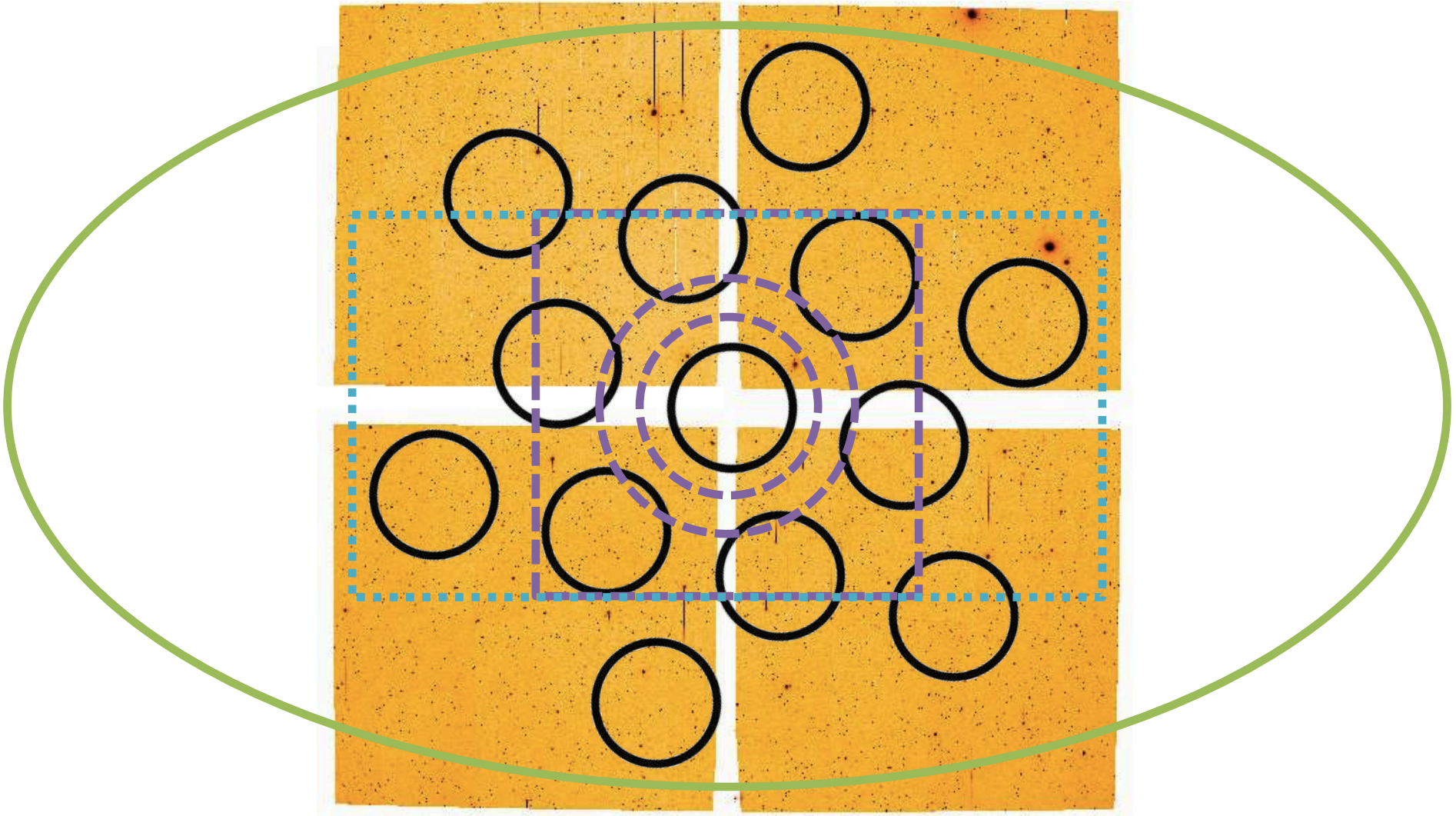
COVID-19!

Coordinated simultaneous facilities – *from our homes!*

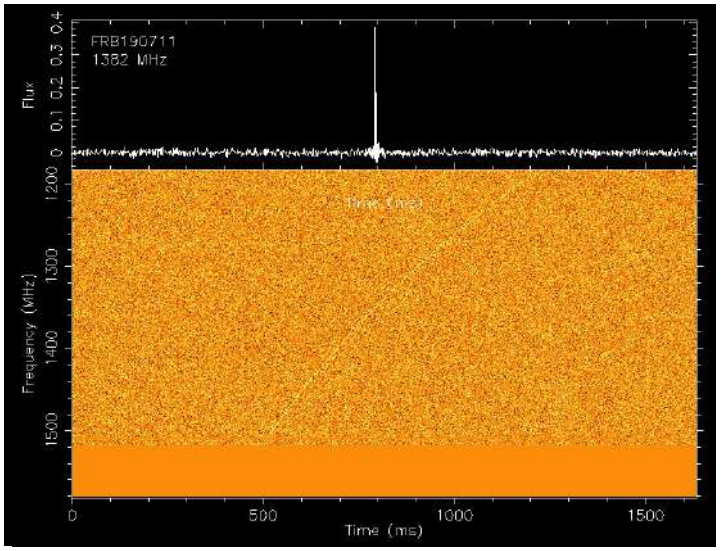
Parkes, Molonglo, KMTNet, Huntsman, Astrosat, HXMT, Swift

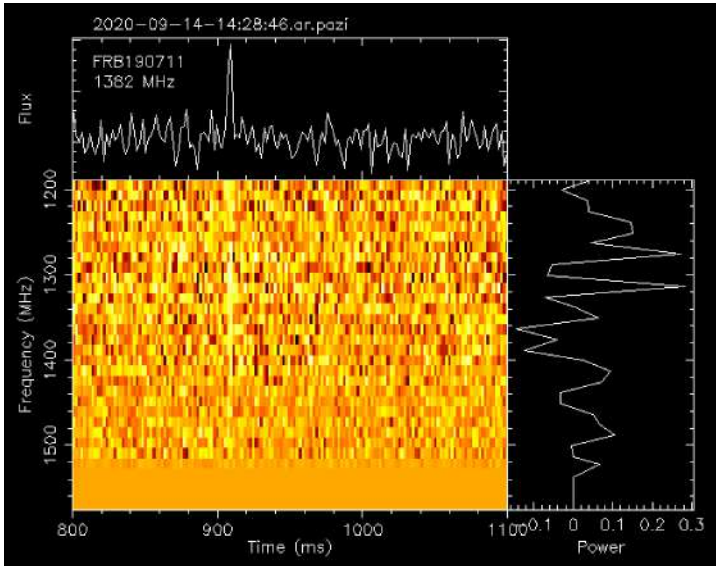
Fields of view

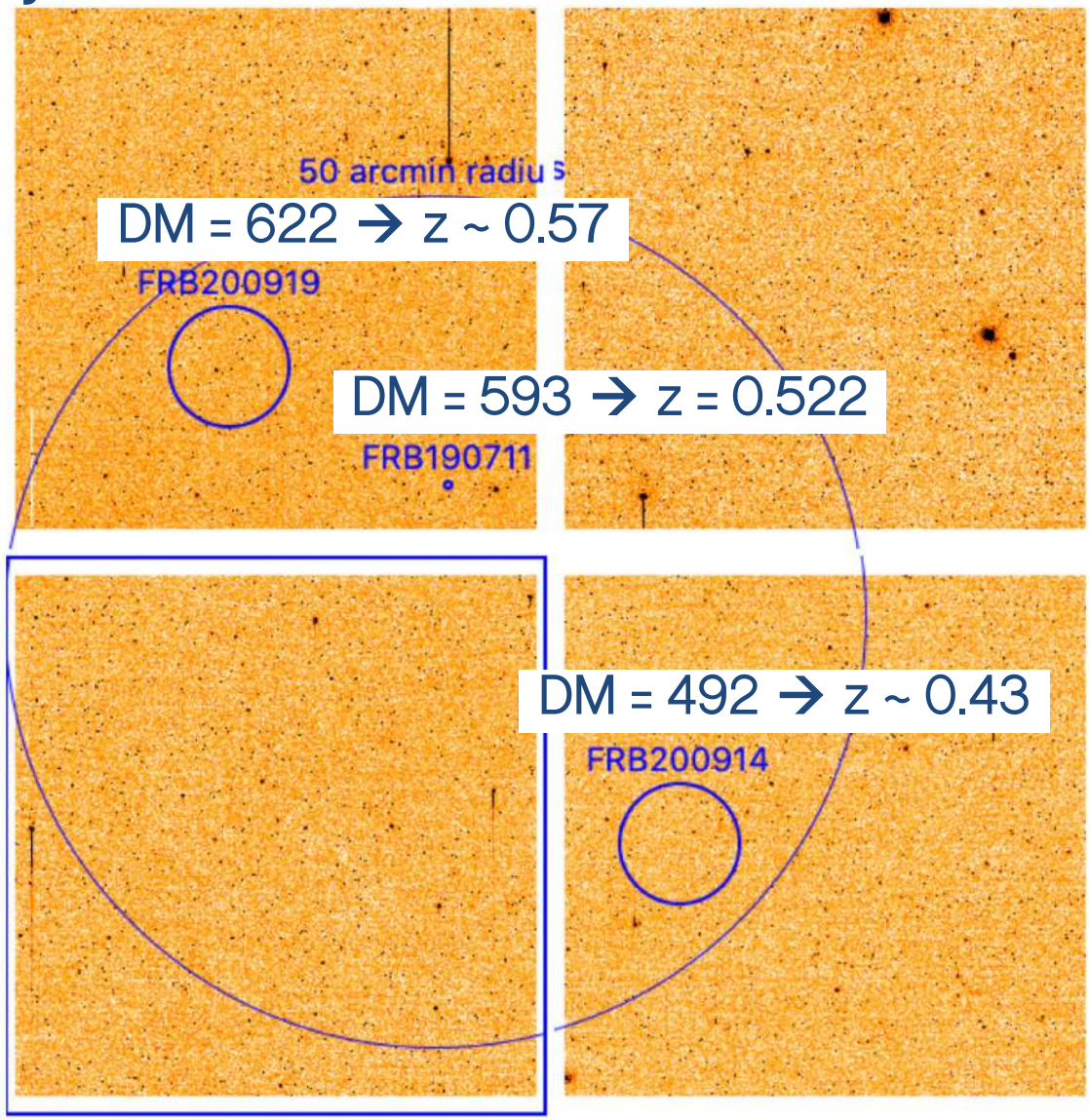
KMTNet (image), Parkes, Molonglo, Astrosat, Huntsman, HXMT (larger than slide)



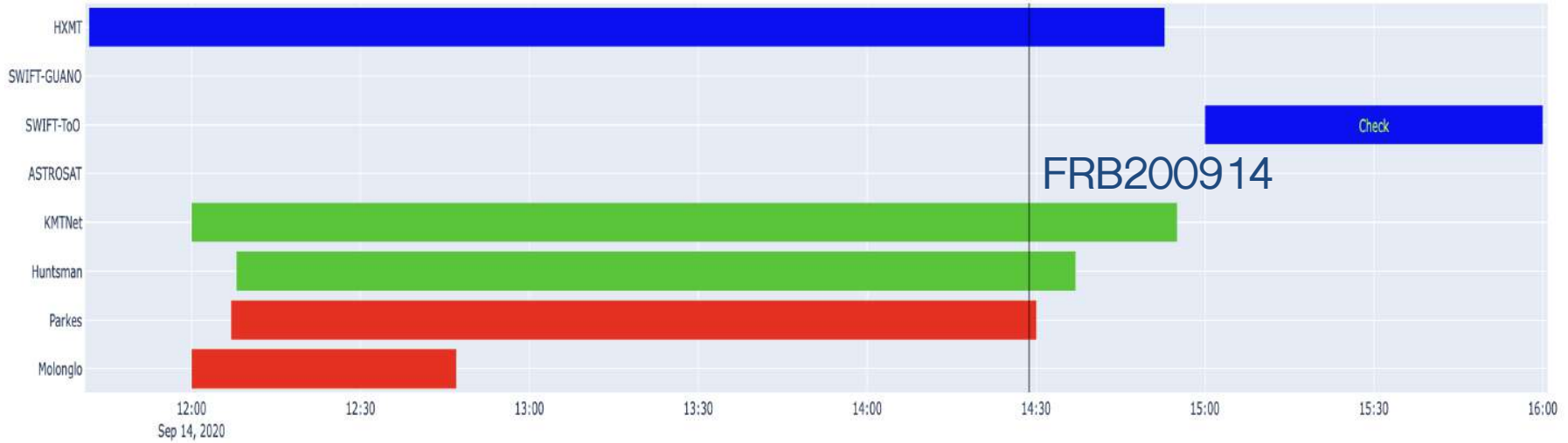
Discovery of two new FRBs!!

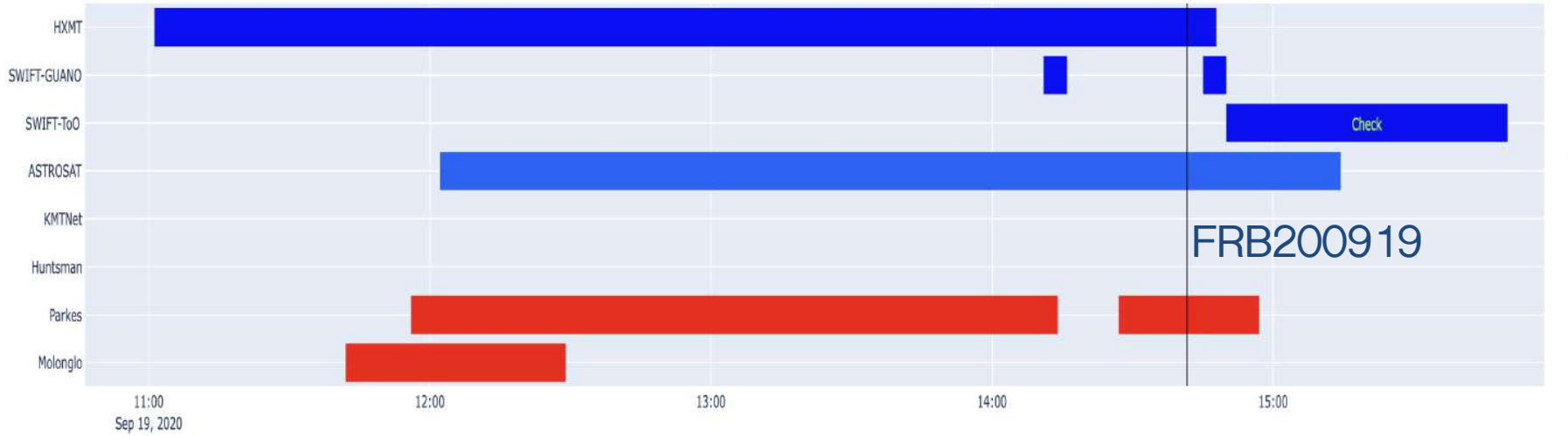




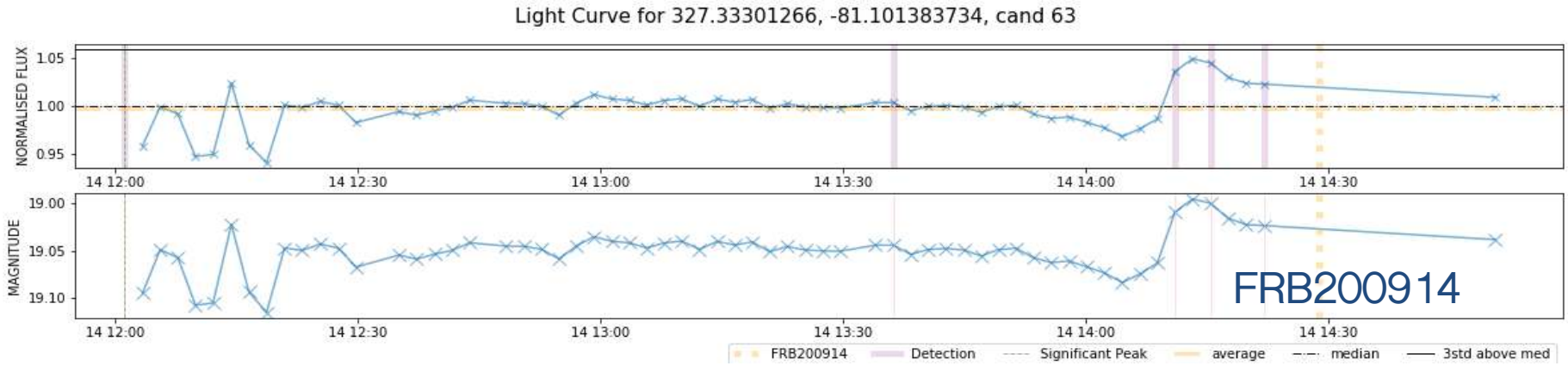


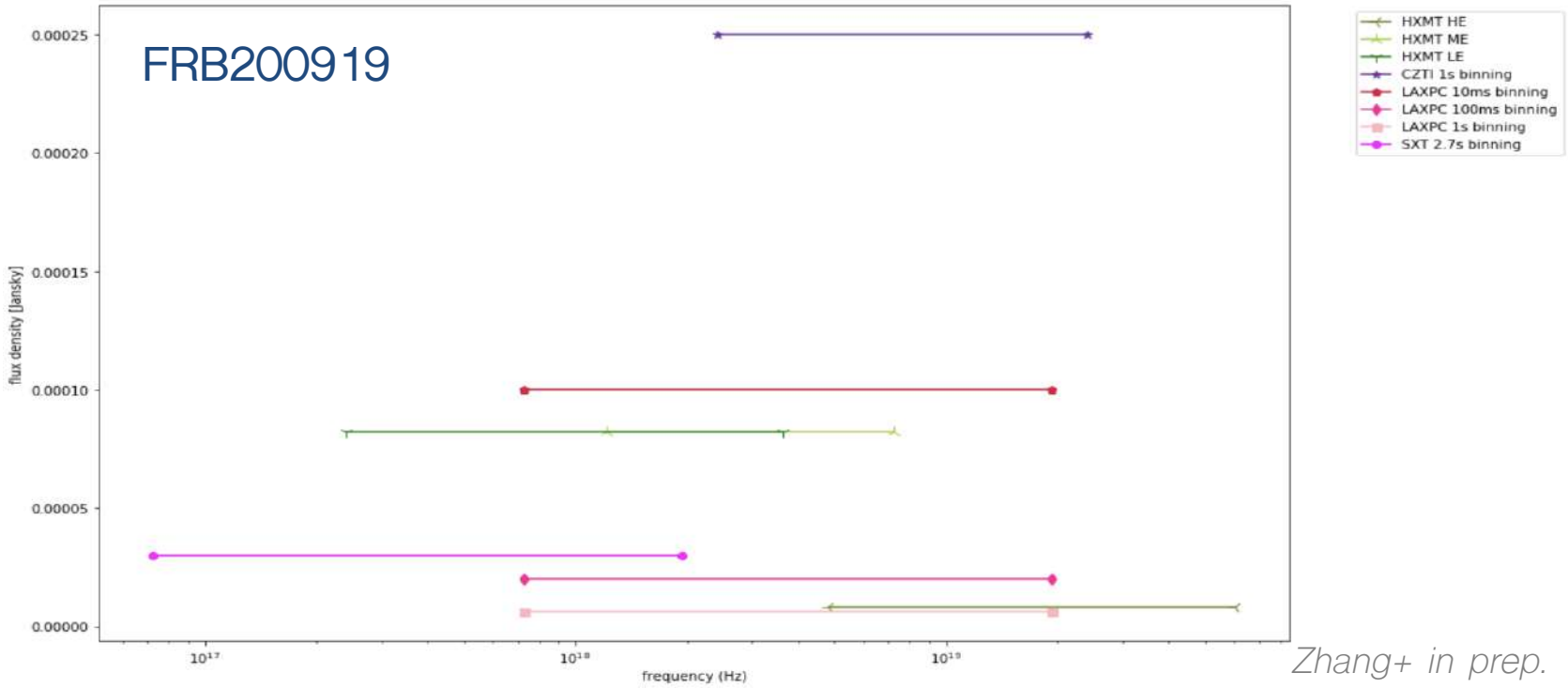
FRB multi-wavelength coverage





Zhang+ in prep.

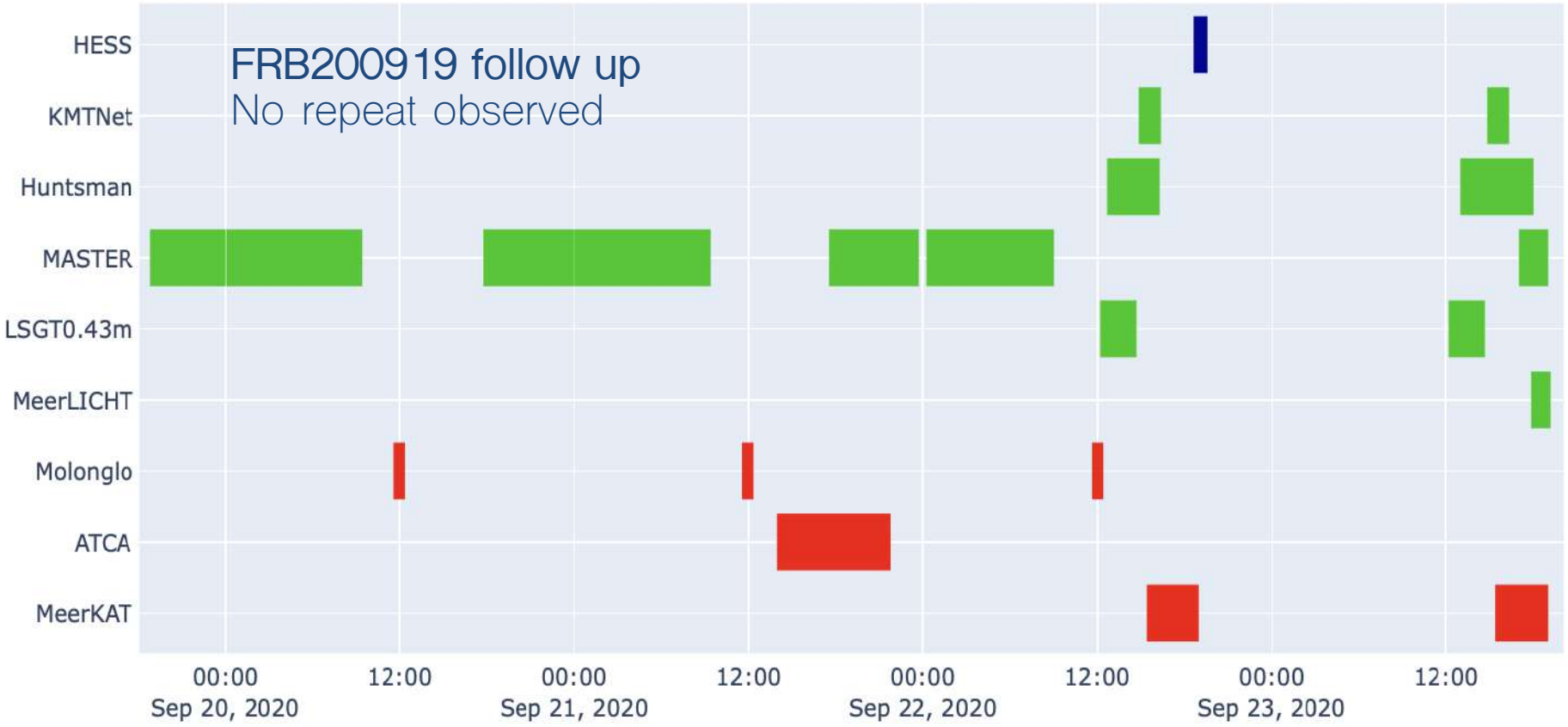




Zhang+ in prep.

Coordinated follow-up facilities – *again, from our homes!*

MeerKAT, ATCA, Molonglo, MeerLICHT, LSGT, MASTER, Huntsman, KMTNet, HESS



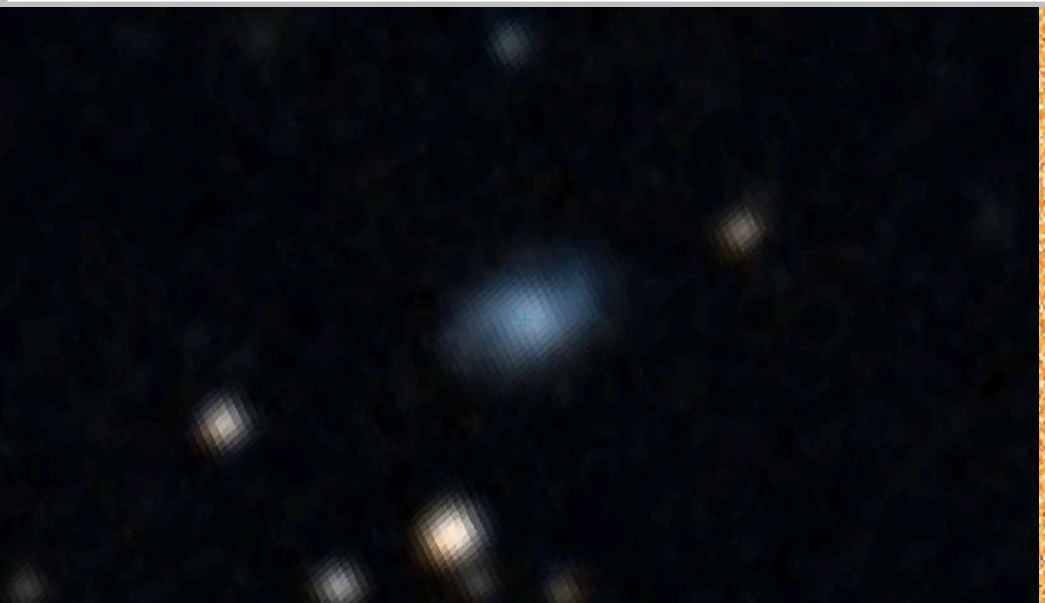
Zhang+ in prep.

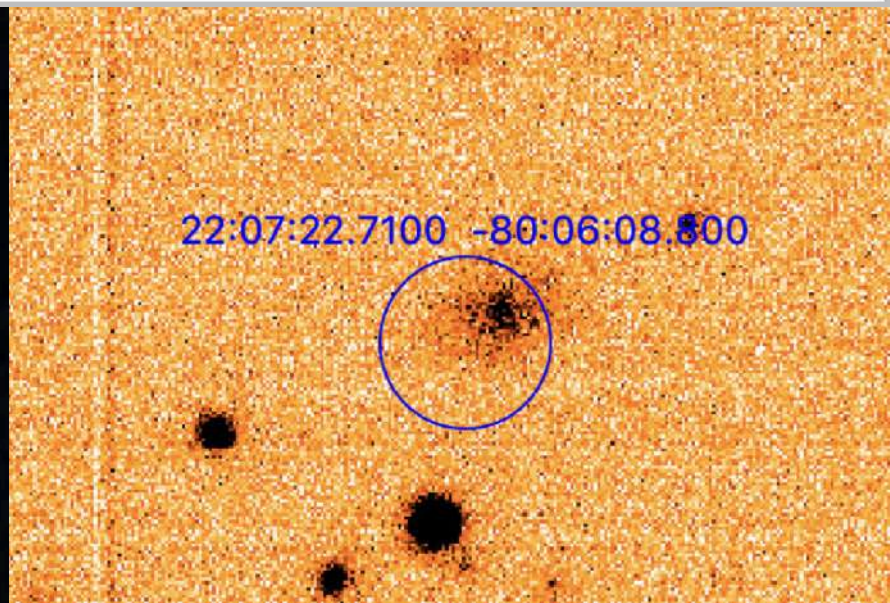
AT2019lbm – MASTER detection, July 13, 2019

Filter	Tel / Inst	Obs-date range	Photometry
Clear-	Other_Other	2017-02-22 01:15:03 - 2019-07-13 07:18:21	3

Photometry

ID	Obs-date	Mag. / Flux	Err	Lim. Mag./Flux	Units	Filter	Tel / Inst	Exp-time	Observer/s	Remarks
78264	2019-07-13 07:18:21	17.4		18.1	VegaMag	Clear-	Other_Other	180	Robot	MASTER-OAFA
78263	2019-07-13 07:14:40	16.7		18	VegaMag	Clear-	Other_Other	180	Robot	MASTER-OAFA
78262	2017-02-22 01:15:03			19.4	VegaMag	Clear-	Other_Other	180	Robot	[Last non detection] MASTER-OAFA





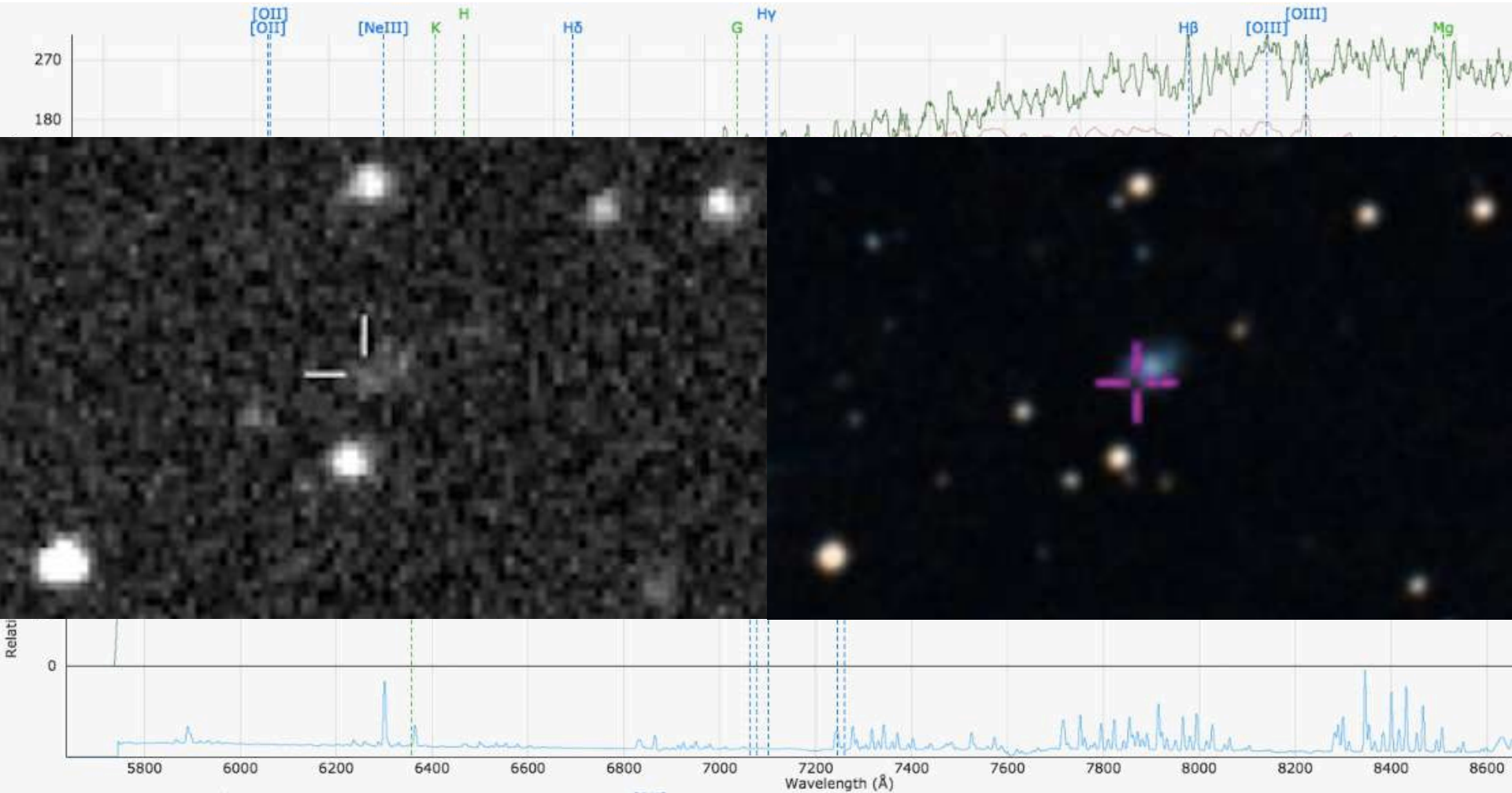
September 2020 run

AAT AAOmega spectroscopy — PI Zhang

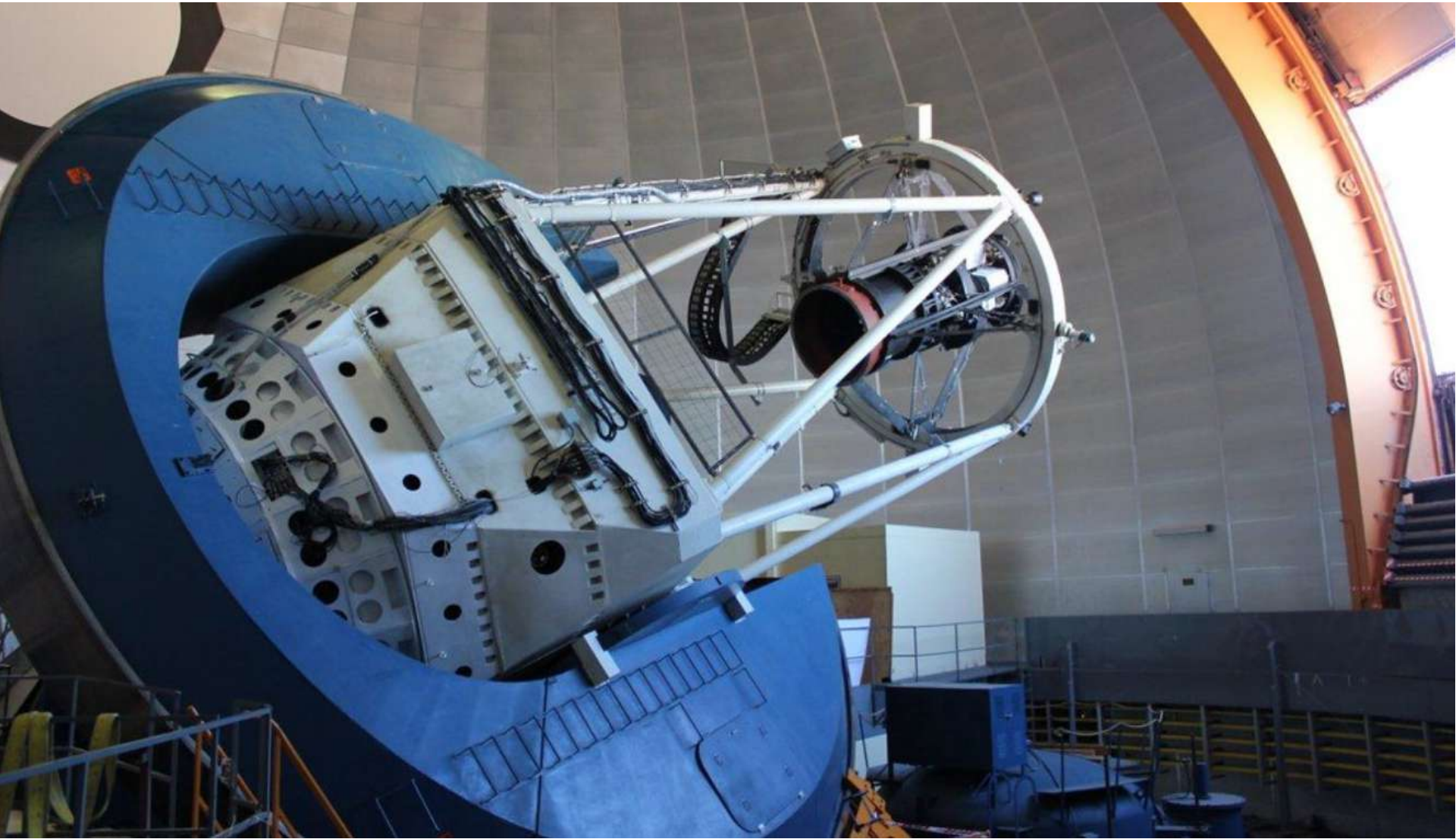
September 2020 run

AAT AAOmega spectroscopy — PI Zhang

z = 0.0785 corresponds to M ~ –20.8, peak(?) Superluminous supernova!



CTIO DECam imaging — PI Lee, z ~ 0.5 galaxy cluster?



AAT AAOmega spectroscopy — PI Lee, z ~ 0.5 galaxy cluster?

The future

DWF – our best chance to uncover the nature of FRBs and characterise the fast transient sky (e.g., for Rubin)

DWF has NOAO long-term status
CTIO DECam for next few runs *(next run March 2022)*
Parkes multi-beam retired – currently UWL, soon PAF
ASKAP CRAFT and MeerKAT will continue to participate

Future September runs?

Advantages and science of FRB190711 field

Redshift z ~ 0.5 cluster? Using colours for AAT spectra

Three FRBs to monitor for repeat bursts, new FRBs
Long visibility (DEC ~ -80), South Pole Telescope
Or second-half nights, South Africa first half nights
PRIME, HESS, SALT, 1-2m follow-up, HXMT, Astrosat

Disadvantage, z ~ 0.5 makes any counterpart faint