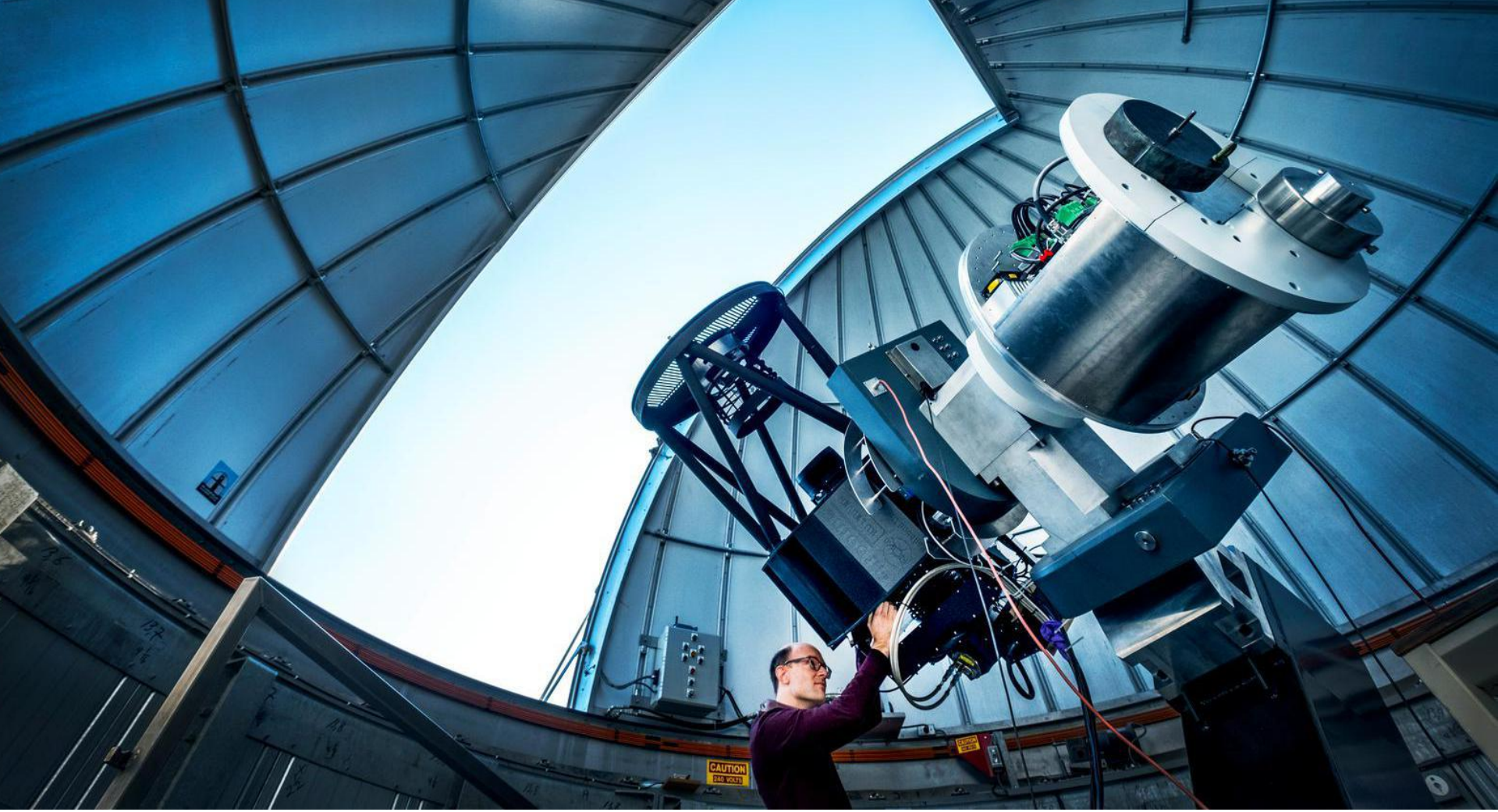
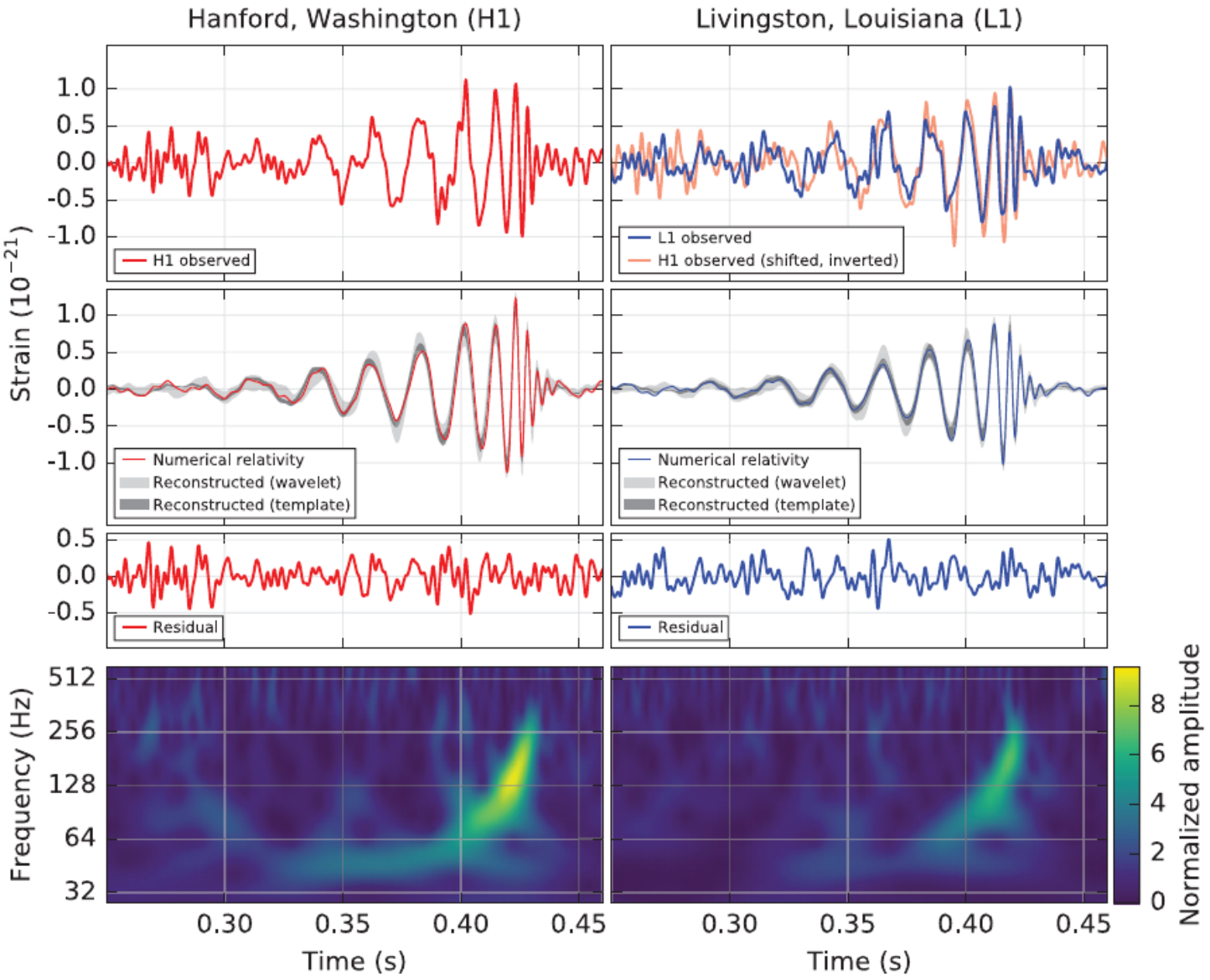


The BlackGEM and MeerLICHT telescopes

Radboud Universiteit Nijmegen

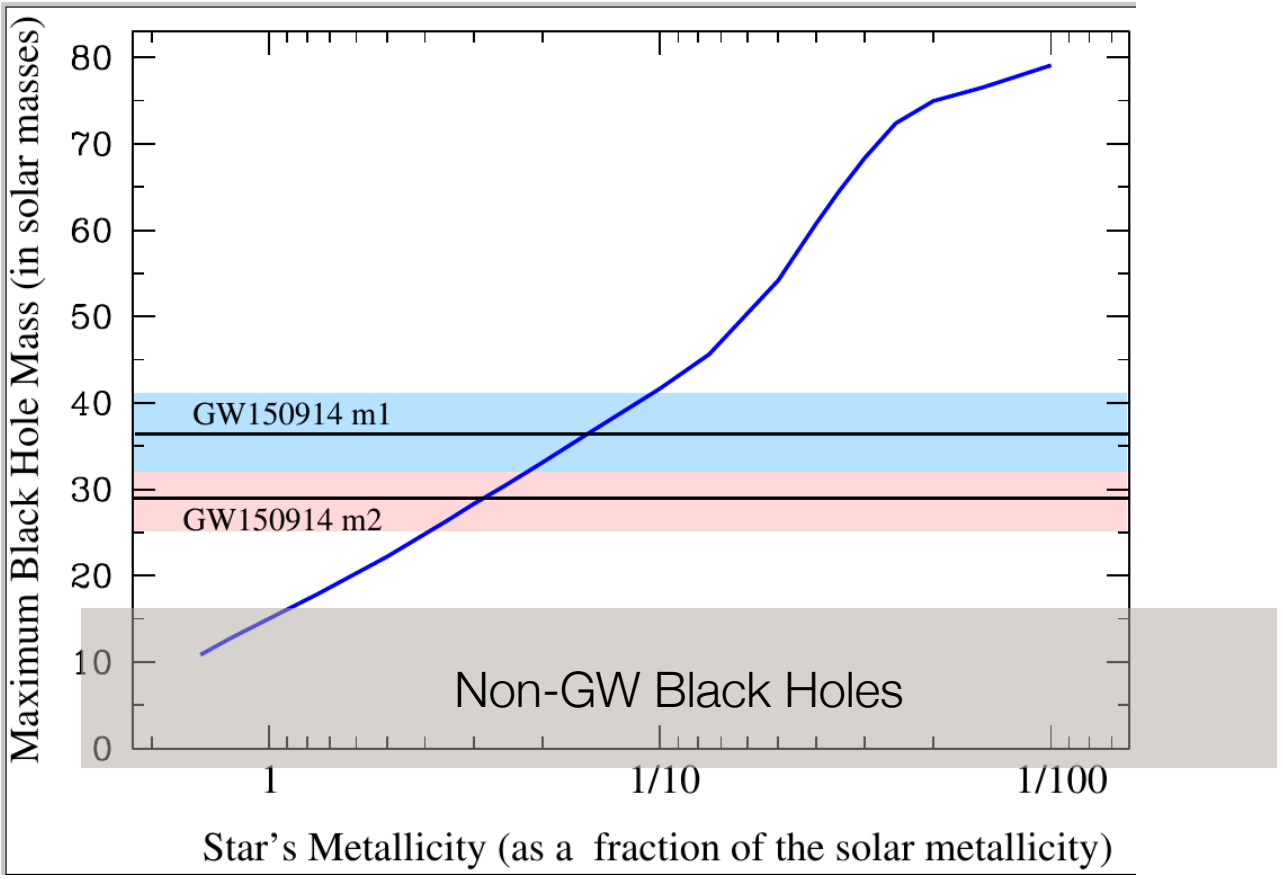
Steven Bloemen
BlackGEM Project Manager
Radboud University, Nijmegen, NL

GW150914

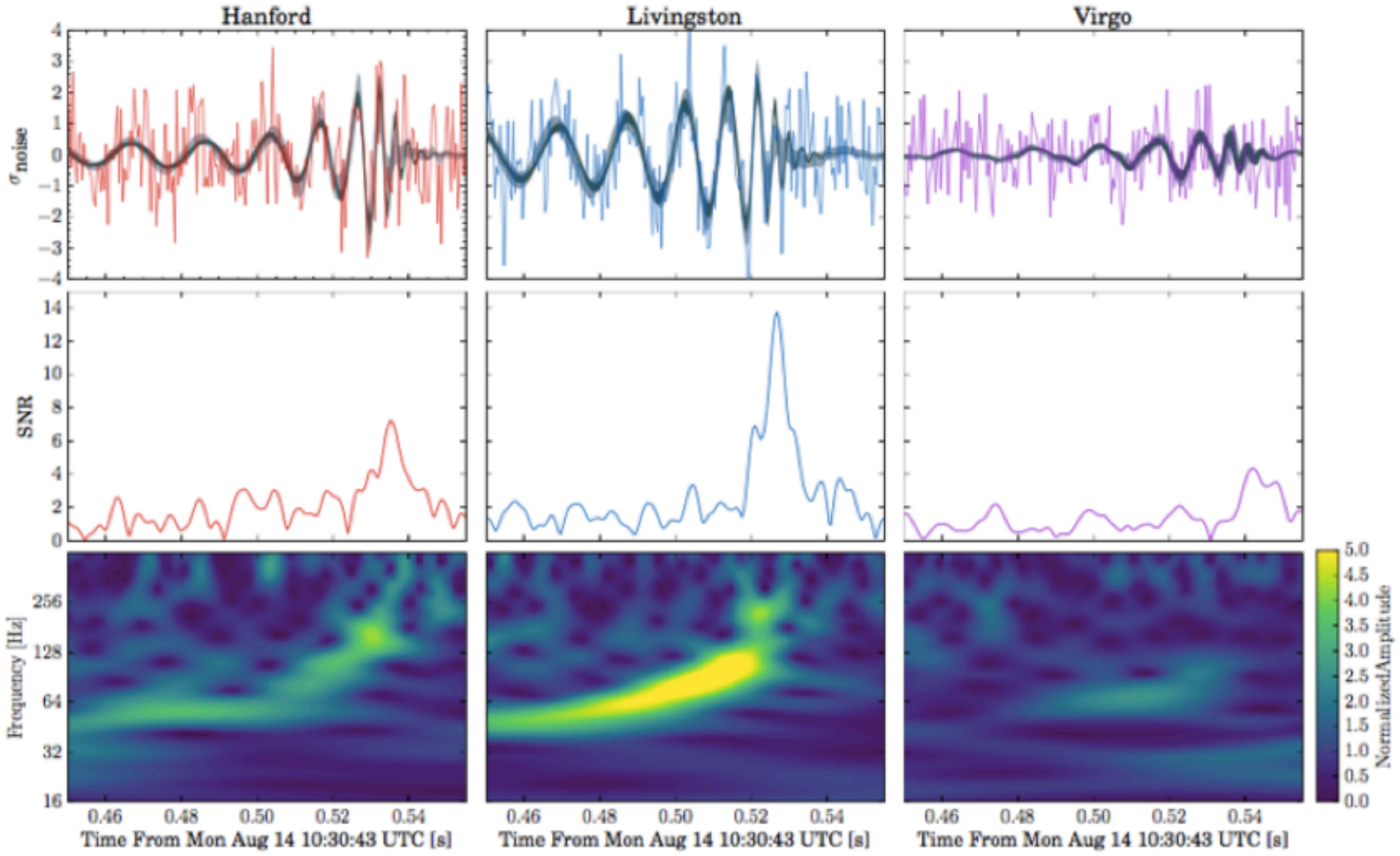

Hanford, Washington (H1)
Livingston, Louisiana (L1)
Strain (10^{-21})
H1 observed
L1 observed
H1 observed (shifted, inverted)
Numerical relativity
Reconstructed (wavelet)
Reconstructed (template)
Residual
Frequency (Hz)
512
256
128
64
32
0.30
0.35
0.40
0.45
Time (s)
Normalized amplitude
0
2
4
6
8

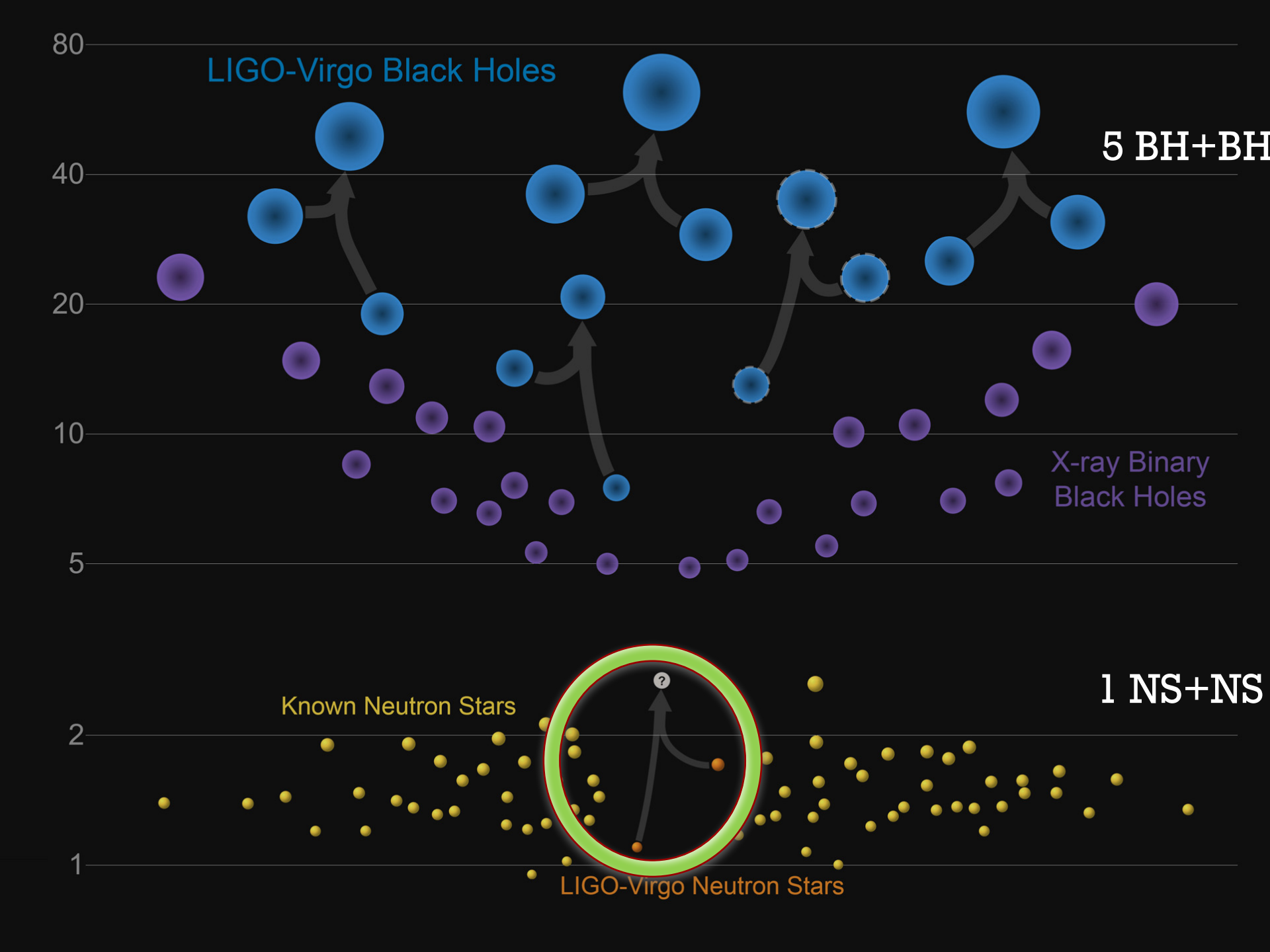
GW150914: Astrophysical implications

- Double black holes exist
- Two BHs can merge into one heavier black hole
- Stellar mass black holes may typically be more massive than expected



14 August 2017: First detection LIGO+Virgo




80
40
20
10
5
2
1
LIGO-Virgo Black Holes
5 BH+BH
X-ray Binary
Black Holes
Known Neutron Stars
1 NS+NS
?
LIGO-Virgo Neutron Stars

The Origin of the Solar System Elements

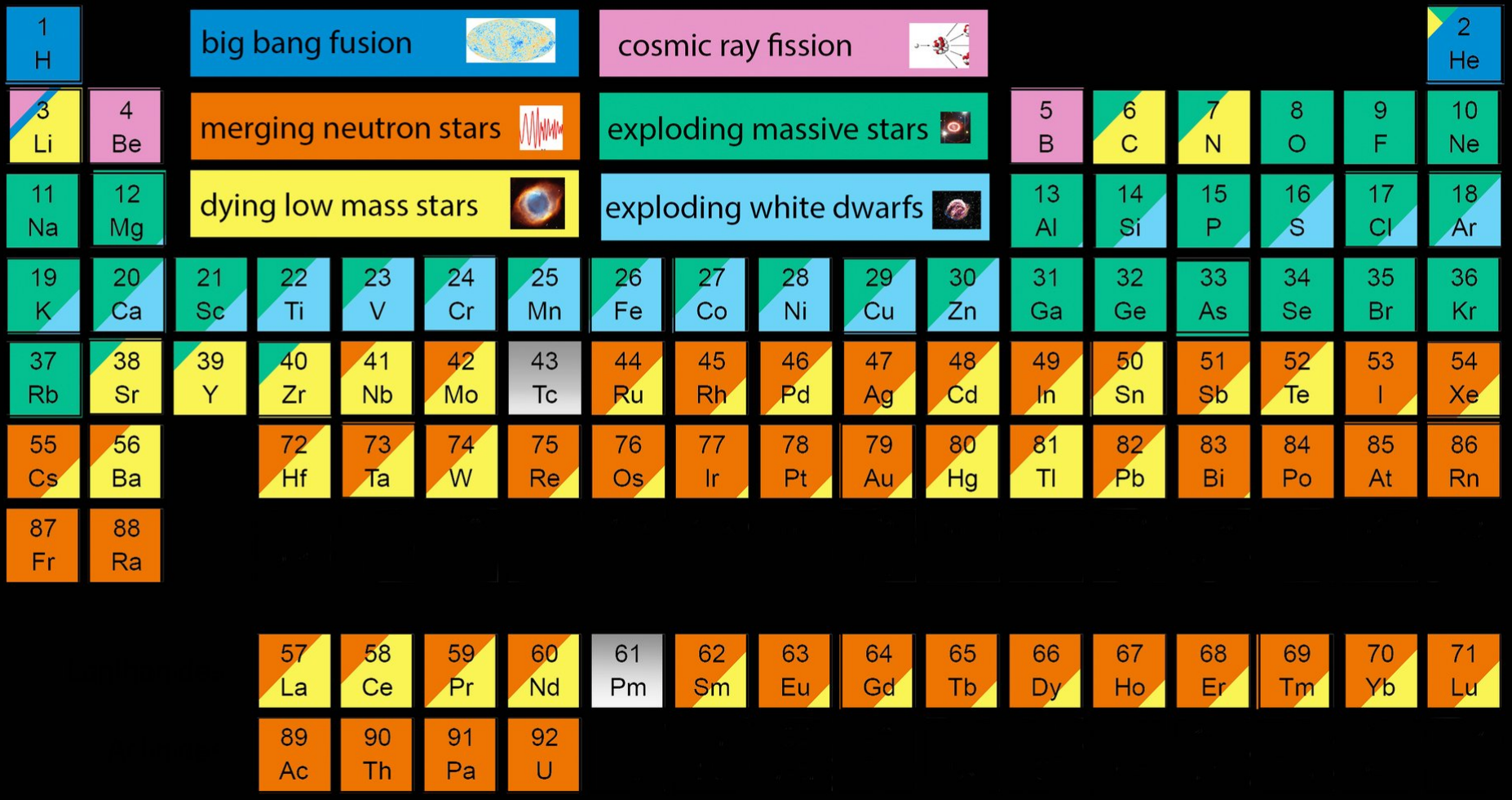
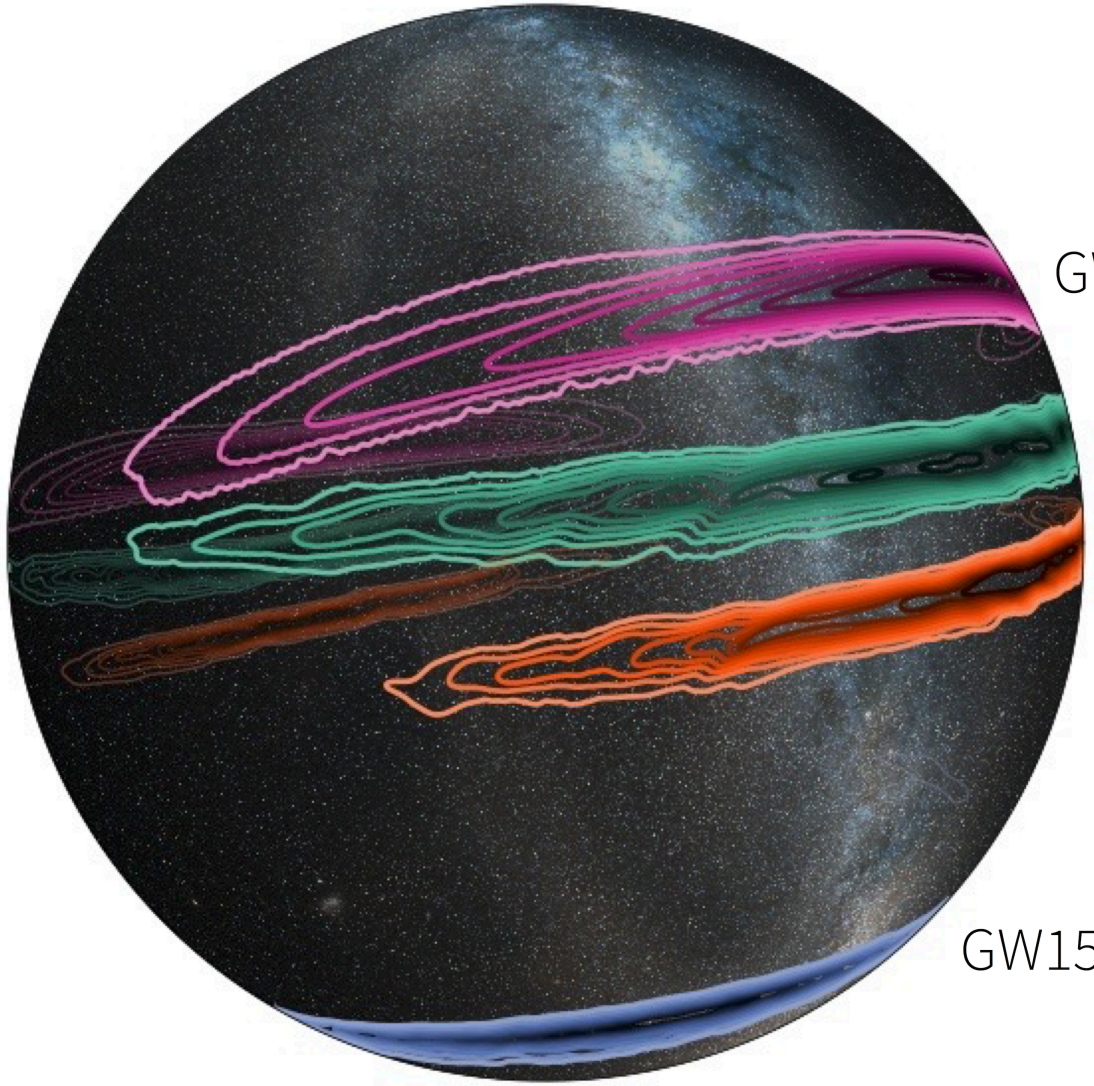


Figure: Jennifer Johnson

Poor sky localization by LIGO+Virgo



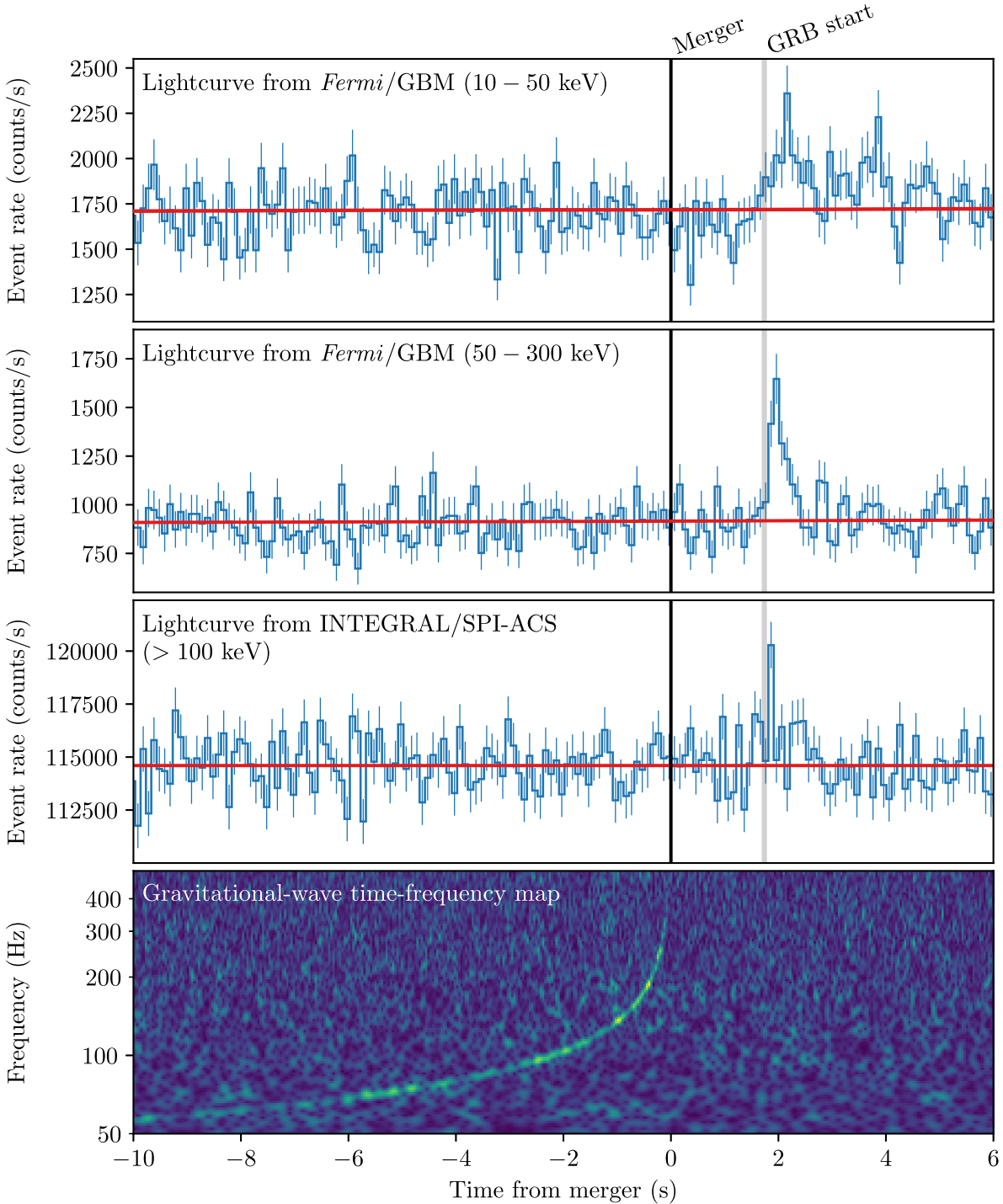
Credit: Leo Singer

GW170817

First NS+NS merger detected in GWs

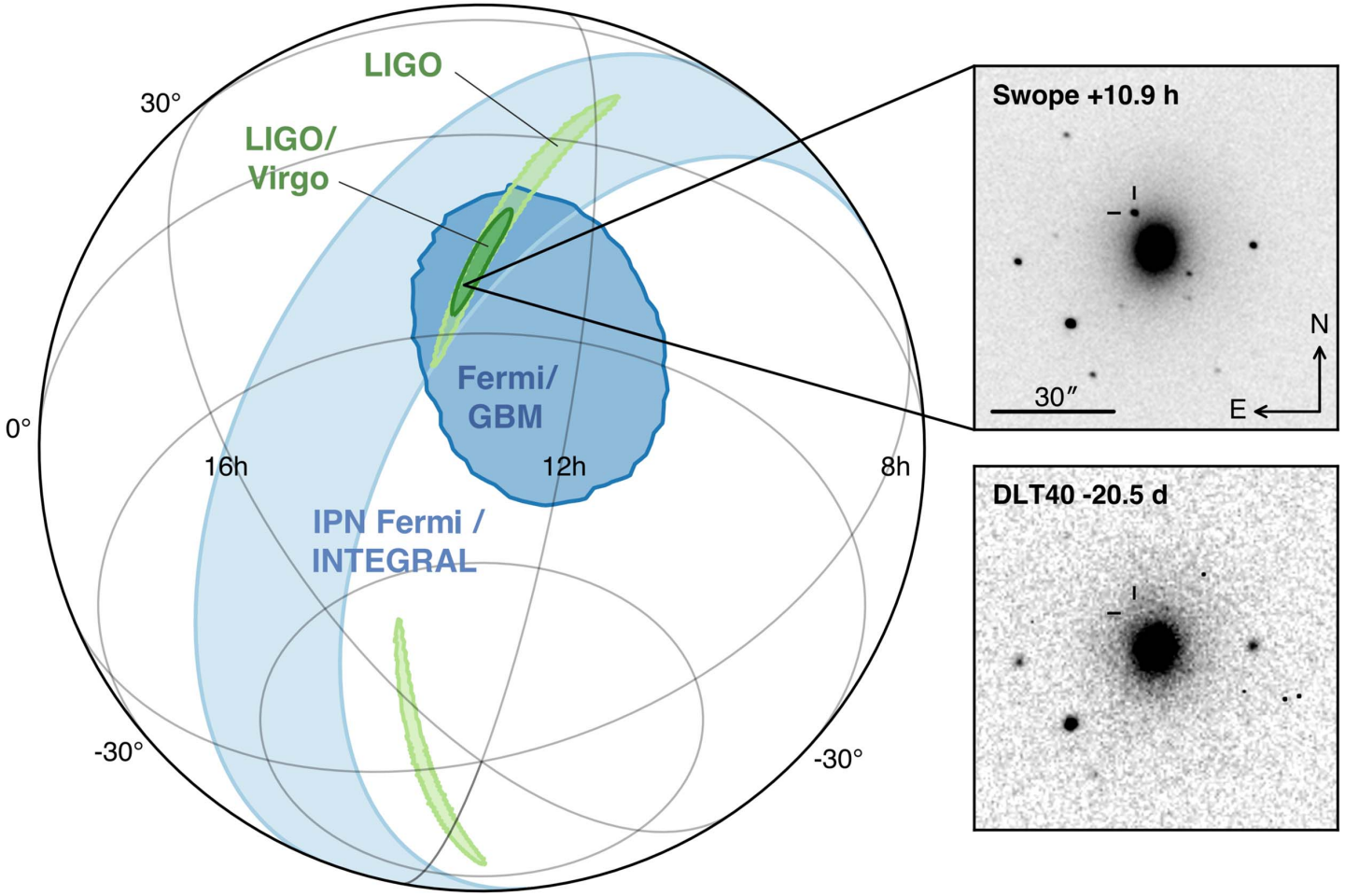
Gamma ray burst!

1.8s between GW and GRB



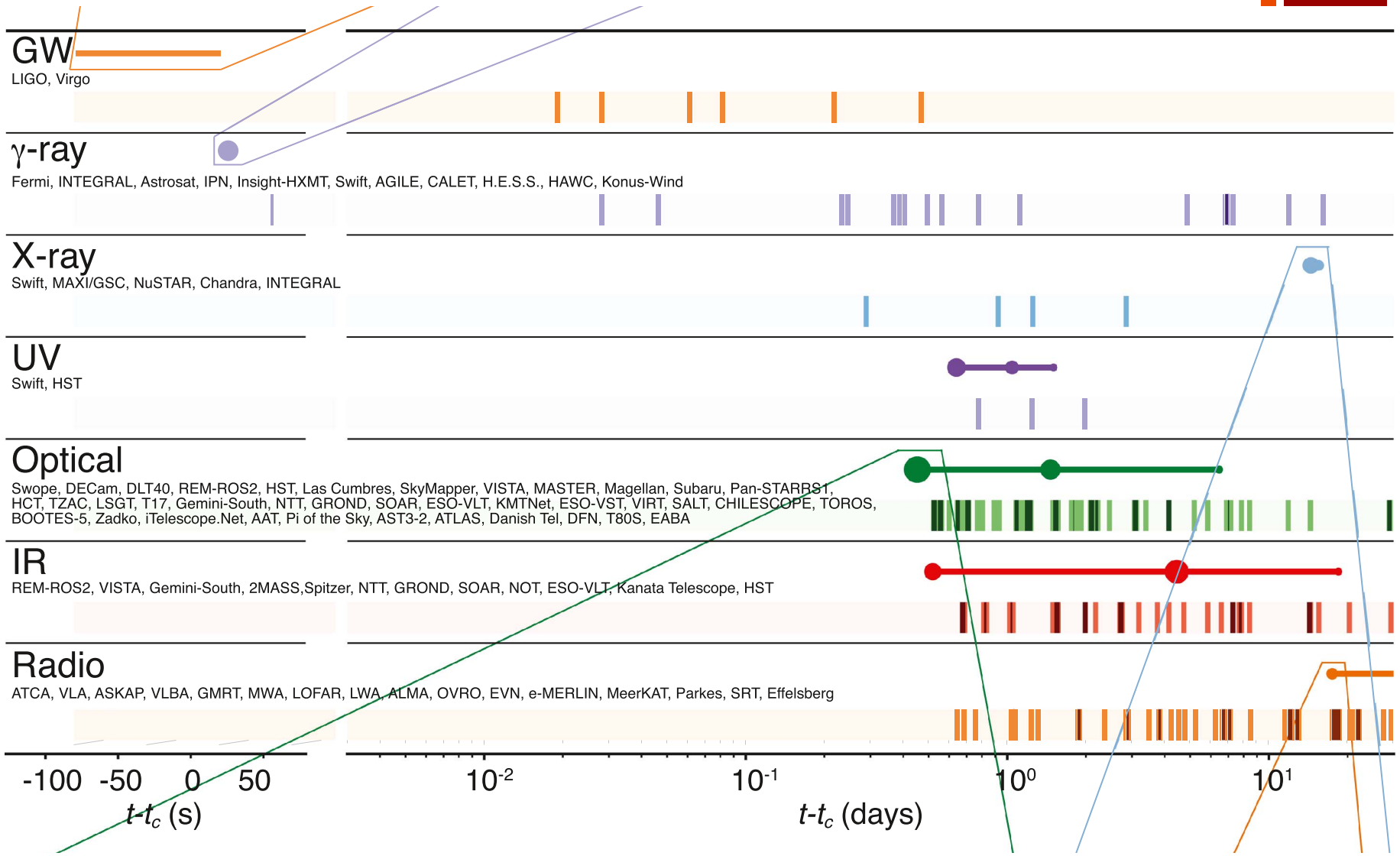
[Abbott et al., ApJL, 2017]

Sky localization confined to ~30 sqdeg



[Abbott et al., ApJL, 2017]

Detected from radio to gamma rays



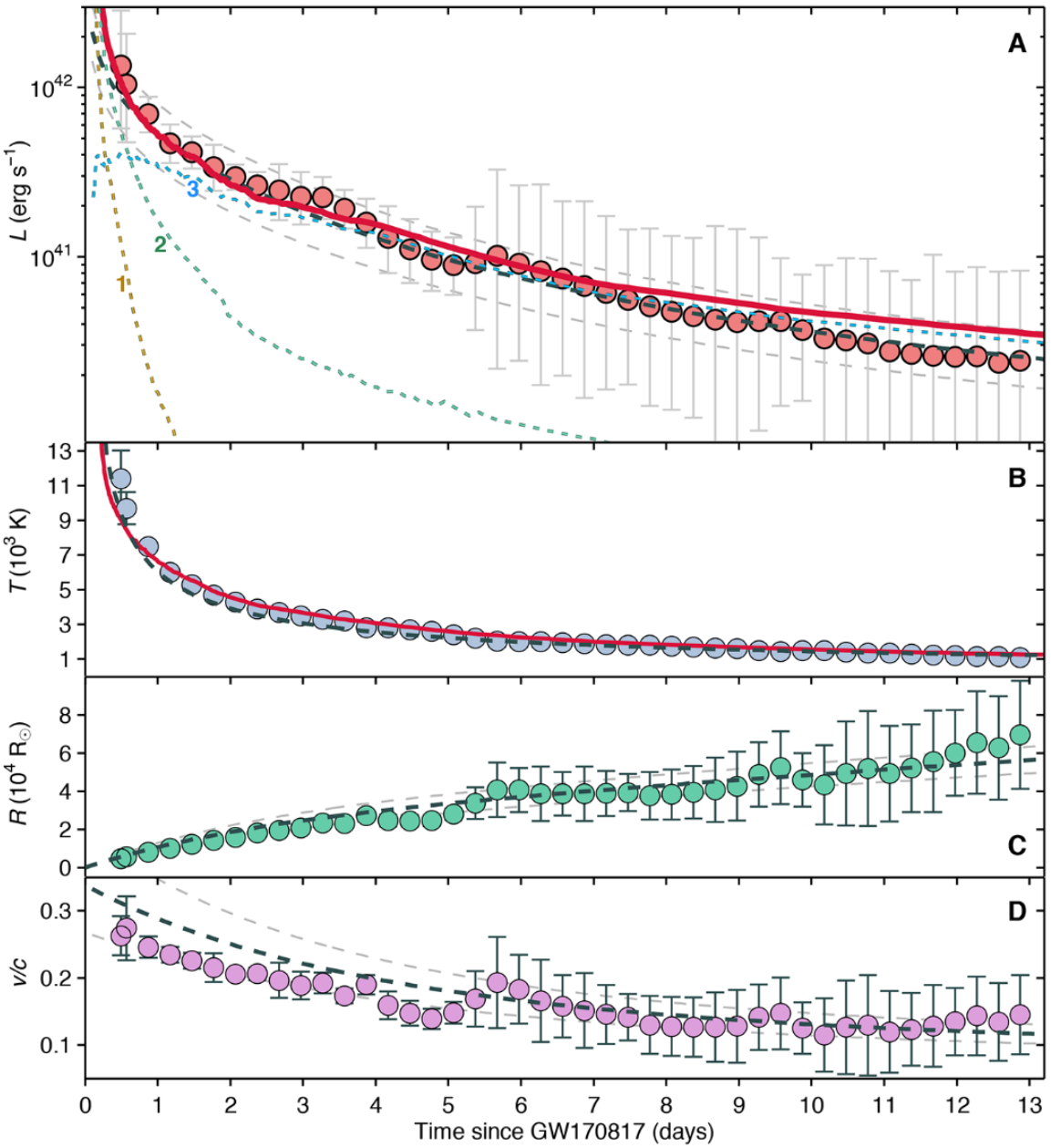
[Abbott et al., ApJL, 2017]

GW170817

0.05 solar mass ejecta
~ 20% speed of light

Based on 1 detection
→ estimate
number/volume/year

Enough to produce all r-process elements



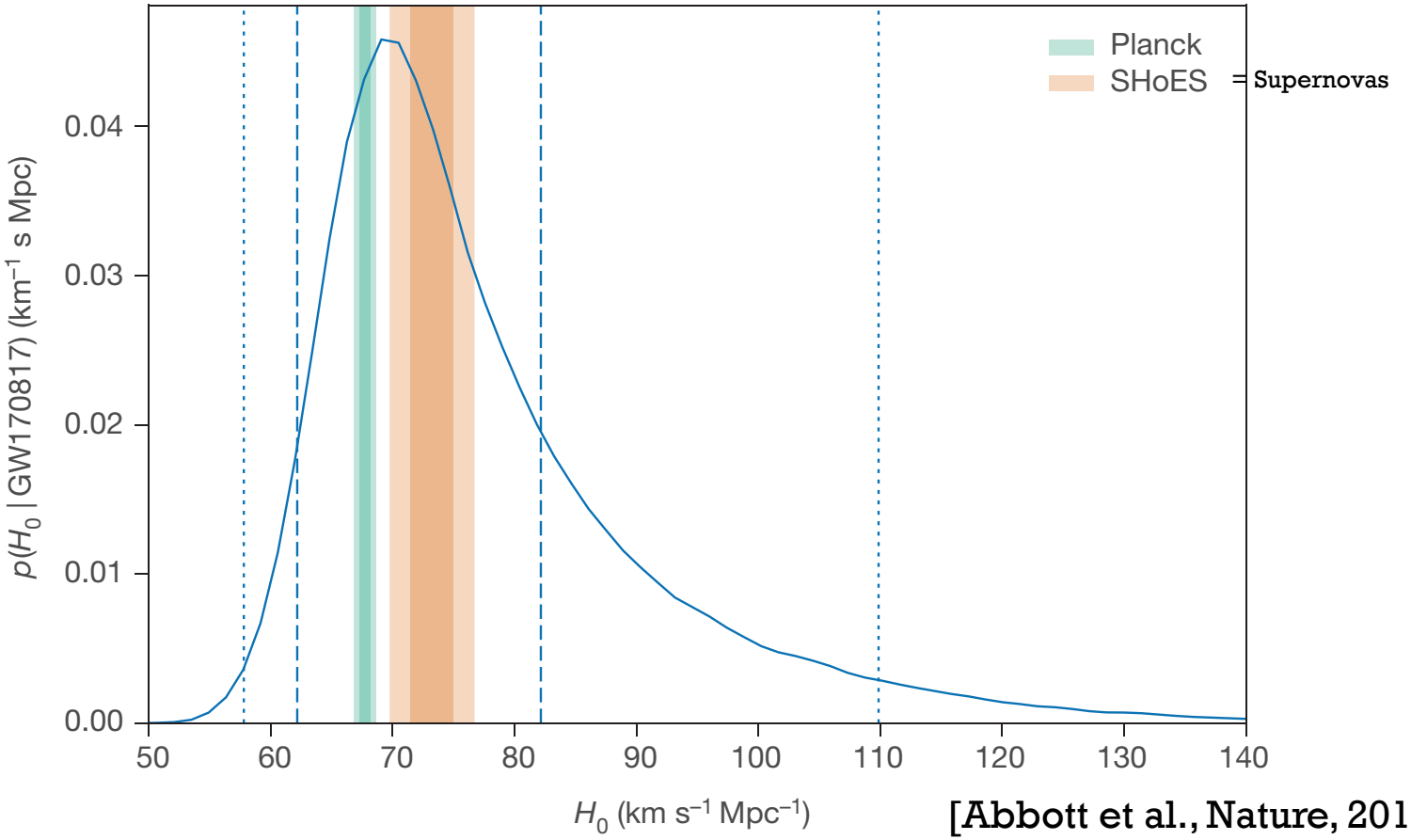
[Kasliwal et al., Science, 2017]

GW170817

Gravitational wave → distance (130 million light years)

Light → Assocation with galaxy → Redshift

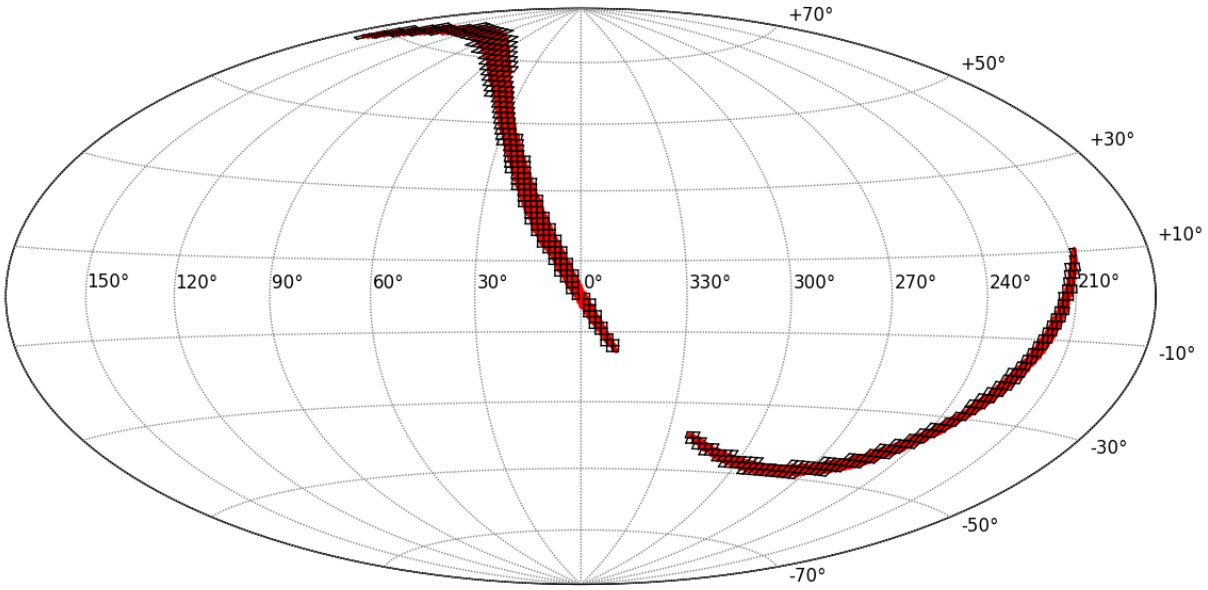
Hubble constant

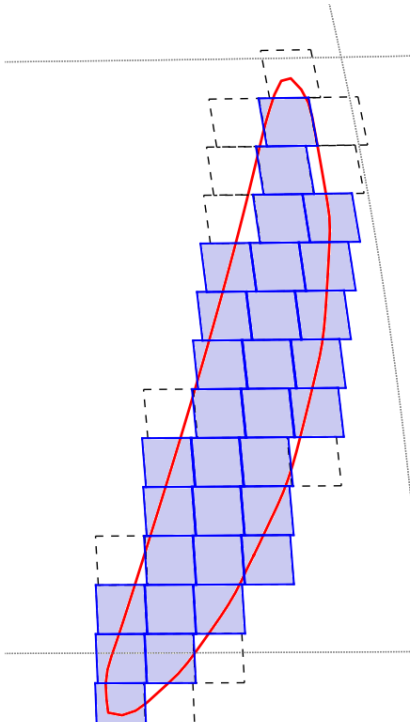


[Abbott et al., Nature, 2017]

Optical counterparts to GW events

- Challenges:
  - Poor sky localization (~100 sqd)
  - Faint (22nd mag at 200 Mpc)
  - False positives
  - Gone in hours/days
- What do we need?
  - Large field of view
  - Sensitivity
  - Colour information
  - Dedicated facility for rates





BlackGEM and MeerLICHT

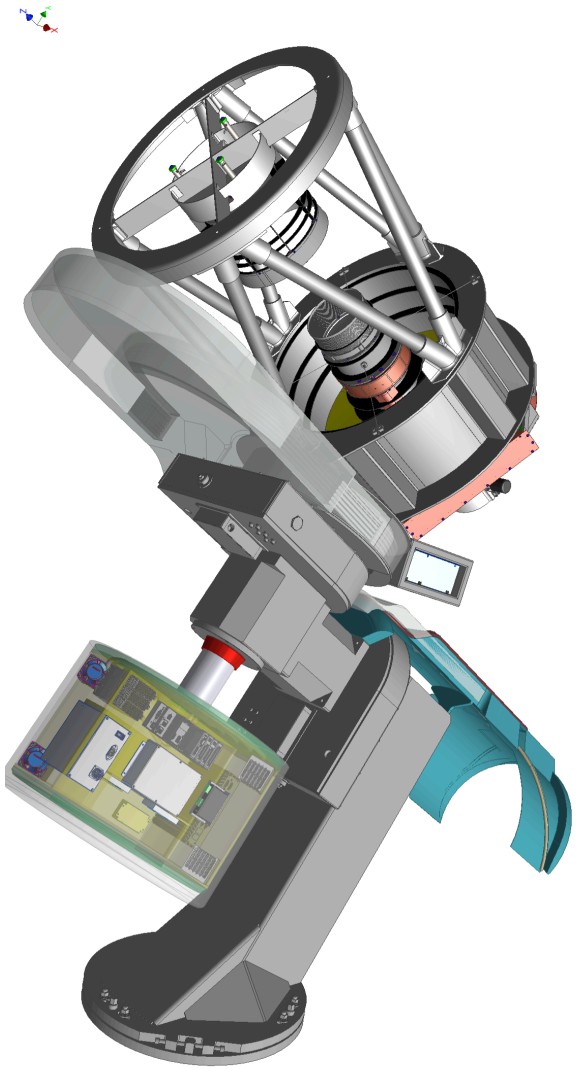
65 cm optical telescope
2.7 sqd FOV @ 0.56 arcsec/pix

MeerLICHT
→ 1 (prototype) telescopes at Sutherland
→ Optical data commensurate with MeerKAT
→ Q3-Q4 2017

BlackGEM
→ 3 telescopes at La Silla
→ GW follow-up
→ Q4 2018

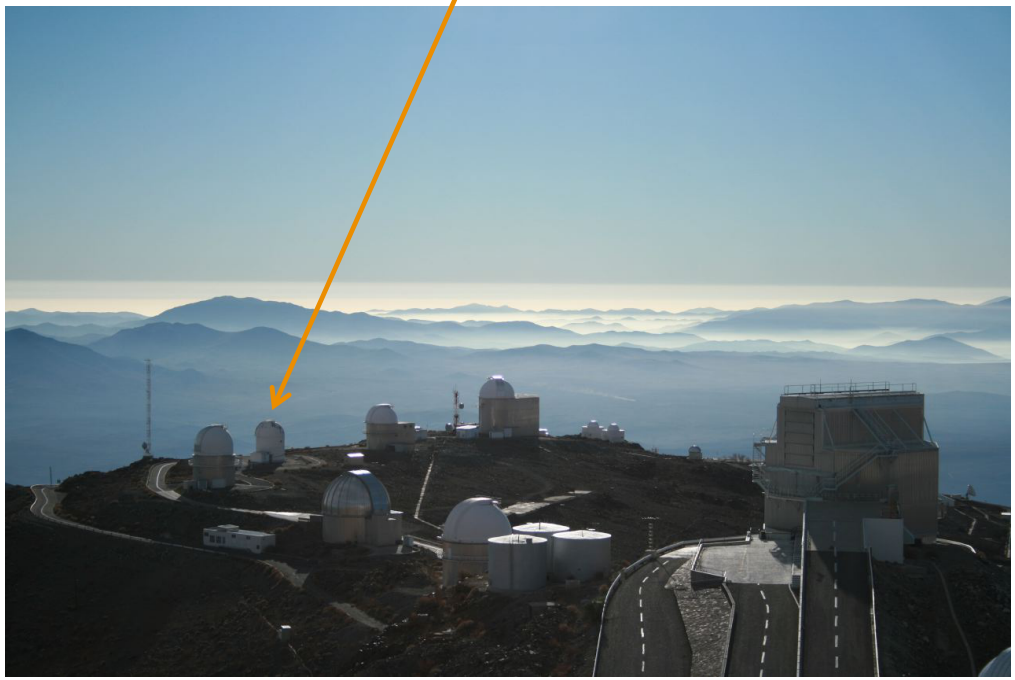
BlackGEM Array

- Phase-I: 3 telescopes
- Southern sky: **La Silla**
  - GW source positions often split
  - Best (EU) follow-up possibilities: VLT/E-ELT, ALMA, SKA, etc.
  - Good seeing allows for smaller mirror
- 2.7 sqd FOV using one 110 Mpix CCD per telescope
- Thanks to good site:
  ~23rd mag in 5 minutes in r'



NOVA · Radboud University · KU LEUVEN · UC University of Canterbury Te Whare Wānanga o Waitaha Christchurch New Zealand · Manchester 1824 The University of Manchester · UC Davis University of California · Tel Aviv University אוניברסיטת תל אביב · Weizmann Institute of Science מכון ויצמן למדע · The Hebrew University of Jerusalem האוניברסיטה העברית בירושלים

BlackGEM site: La Silla



BlackGEM filter set and depth

Typical integration time: 1 min
(background limited in all filters except u)

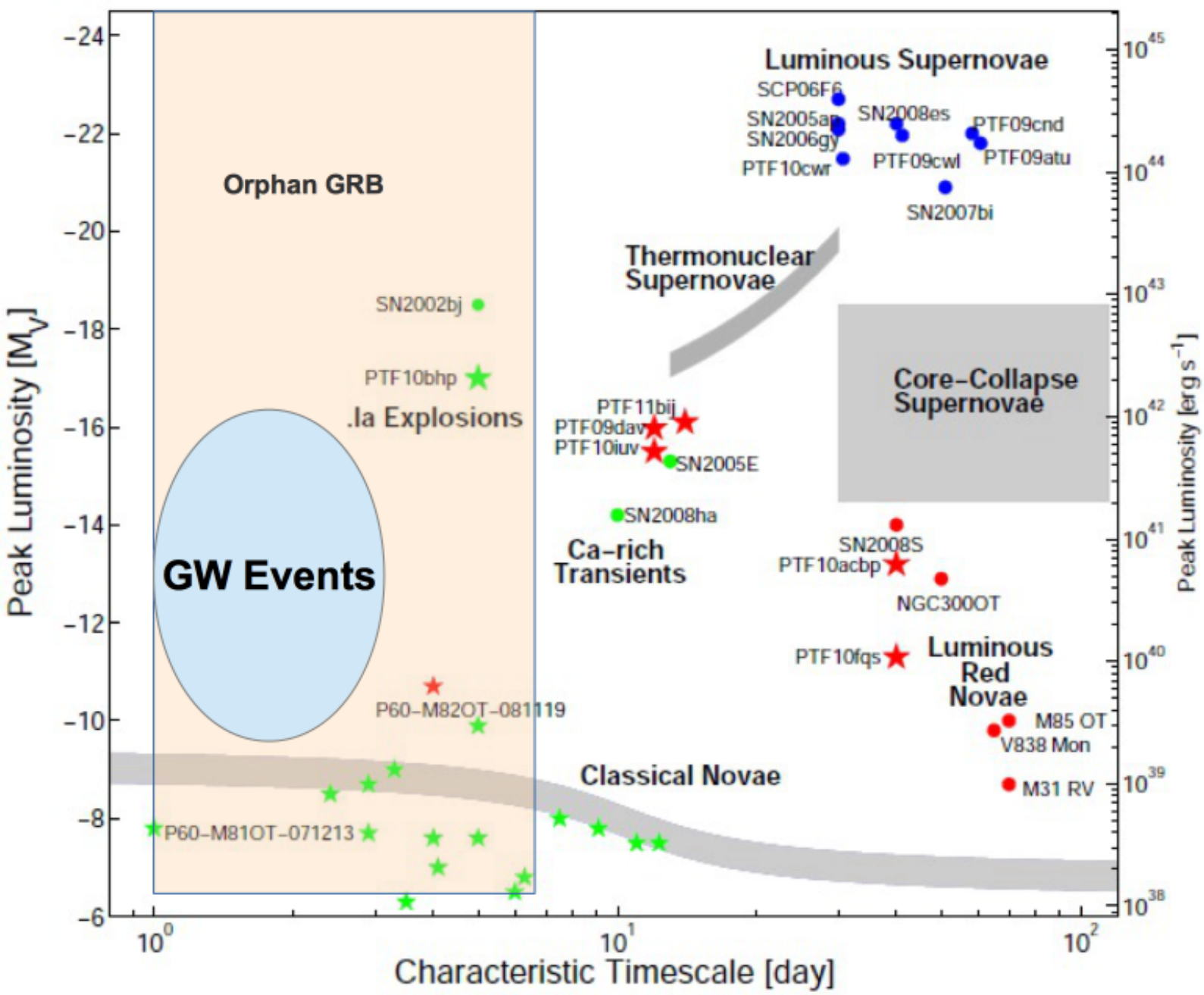
Filter	Wavelength range (nm)	Depth in 1 min ; 5 min (AB mag)
u	350 – 410	19.8 ; 20.9
g	410 – 550	21.9 ; 22.9
r	563 – 690	21.3 ; 22.3
i	690 – 840	20.7 ; 21.7
z	840 – 990	20.4 ; 21.4
vr	440 – 720	22.2 ; 23.2

BlackGEM surveys

- **BlackGEM Southern All Sky Survey**: '***Southern Sloan'***
  → 30 000 sqd down to 22nd mag in u,g,q,r,i,z at 1'' median seeing
- **BlackGEM q-band Scan:** ***'What was there yesterday?'***
  → Visible 10 000 square degrees in q-band every 14 days
- **BlackGEM Fast Synoptic Survey**: ***' What else goes bang?'***
  → 1 min cadence, multi-colour (simultaneous), wide-field, 1-2 weeks
- **BlackGEM Twilight Program:** ***'Local Universe transients'***
  → Every twilight (30 minutes) scan Local Universe galaxies in 2 bands for new transients
- **BlackGEM Trigger Mode**: '***Transients Galore***'
  → GW error box coverage in multiple colours

GW trigger

Outgoing transient triggers


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

Consortium and data access rights

- All-sky data publicly available (ESO)
- *All* survey data available to all consortium partners, for pre-agreed science cases
- Working groups led by PIs and their groups, but can be joined by people from the other institutes
- Aim to make all transient detections public 'immediately'

NOVA
Radboud University
KU LEUVEN
UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND
MANCHESTER 1824 The University of Manchester
UCDAVIS UNIVERSITY OF CALIFORNIA
TEL AVIV UNIVERSITY אוניברסיטת תל אביב
מכון ויצמן למדע WEIZMANN INSTITUTE OF SCIENCE
האוניברסיטה העברית בירושלים THE HEBREW UNIVERSITY OF JERUSALEM

MeerLICHT

First telescope of BlackGEM type

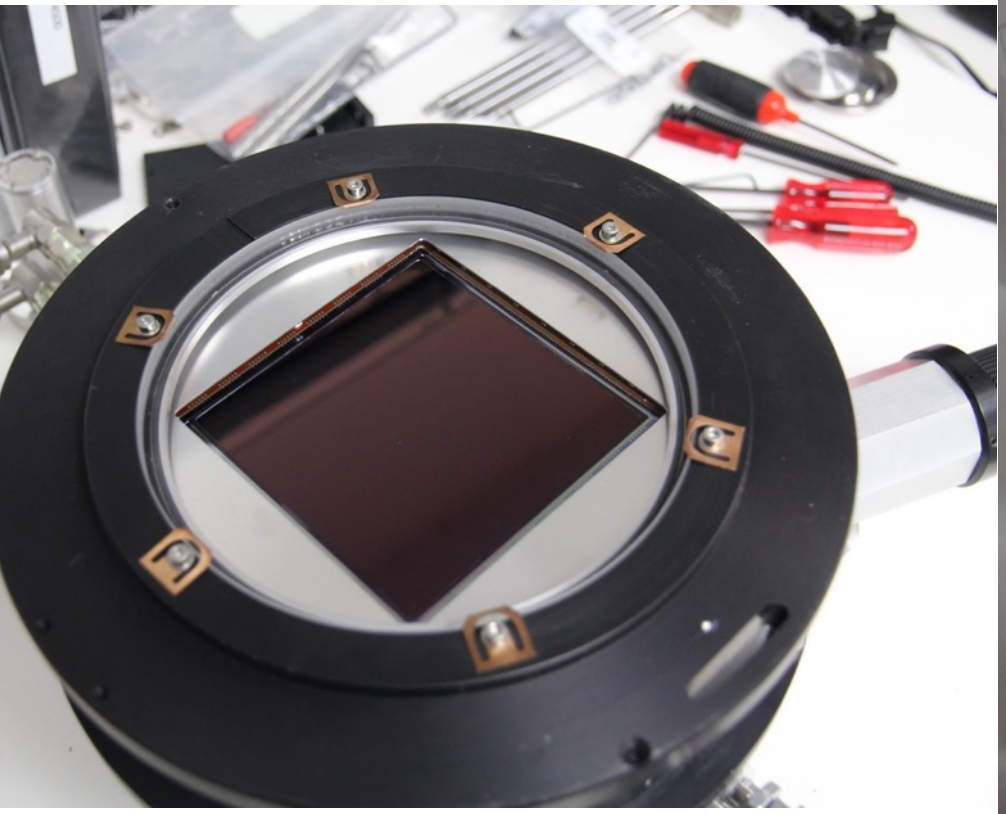
At Sutherland, South Africa

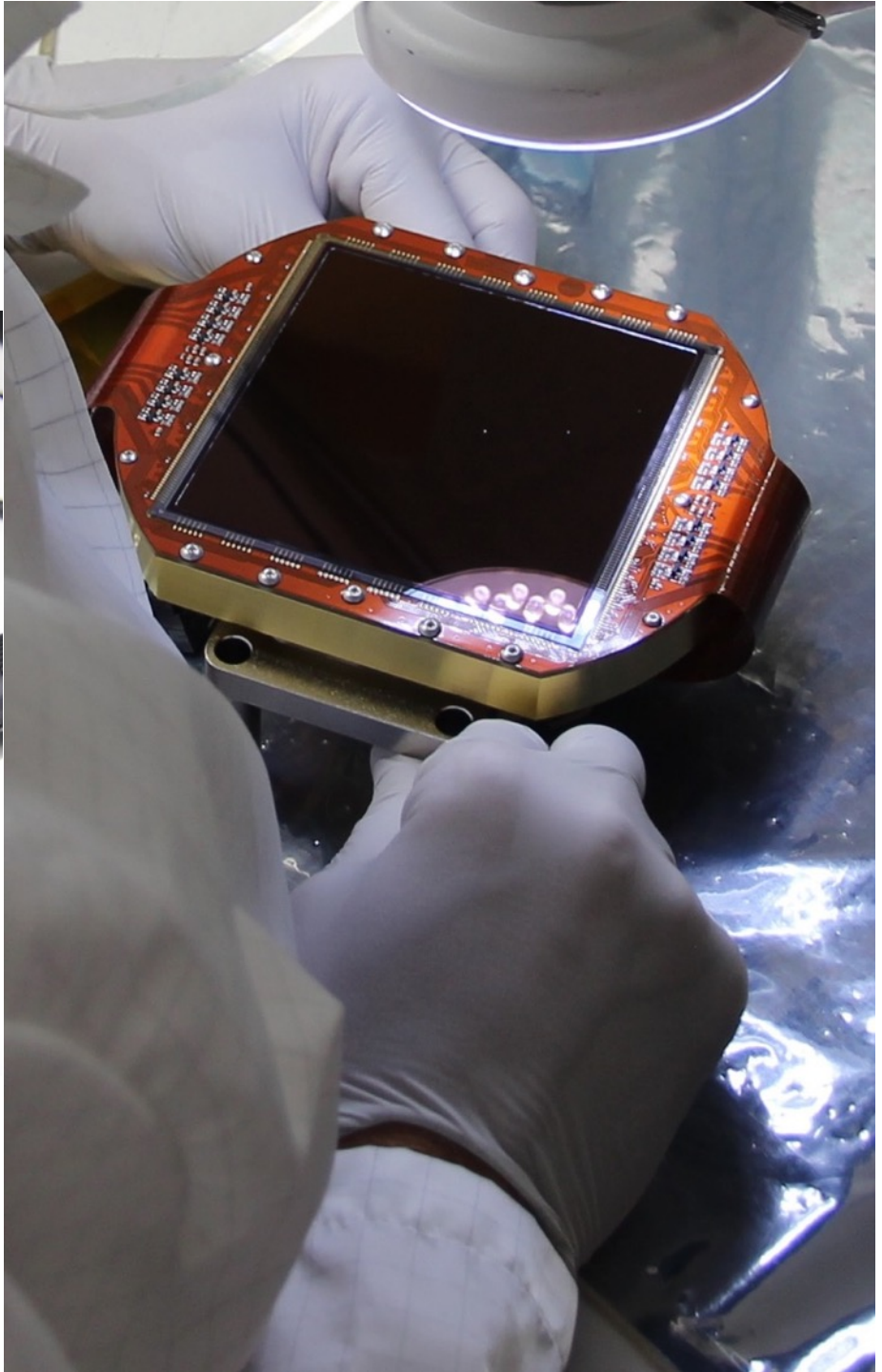
Changing transient science to truly multi-wavelength

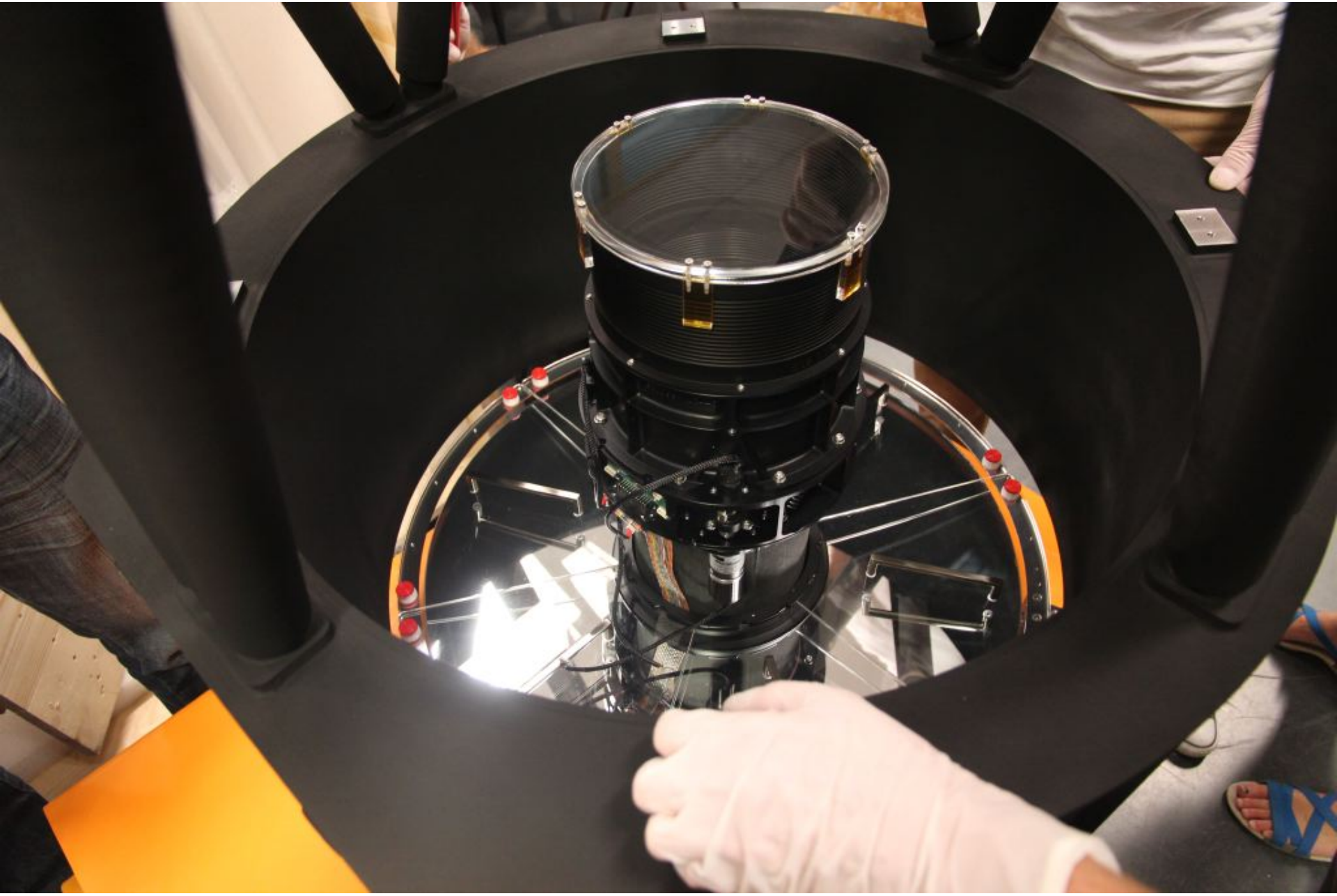
Pointing determined by MeerKAT radio telescope

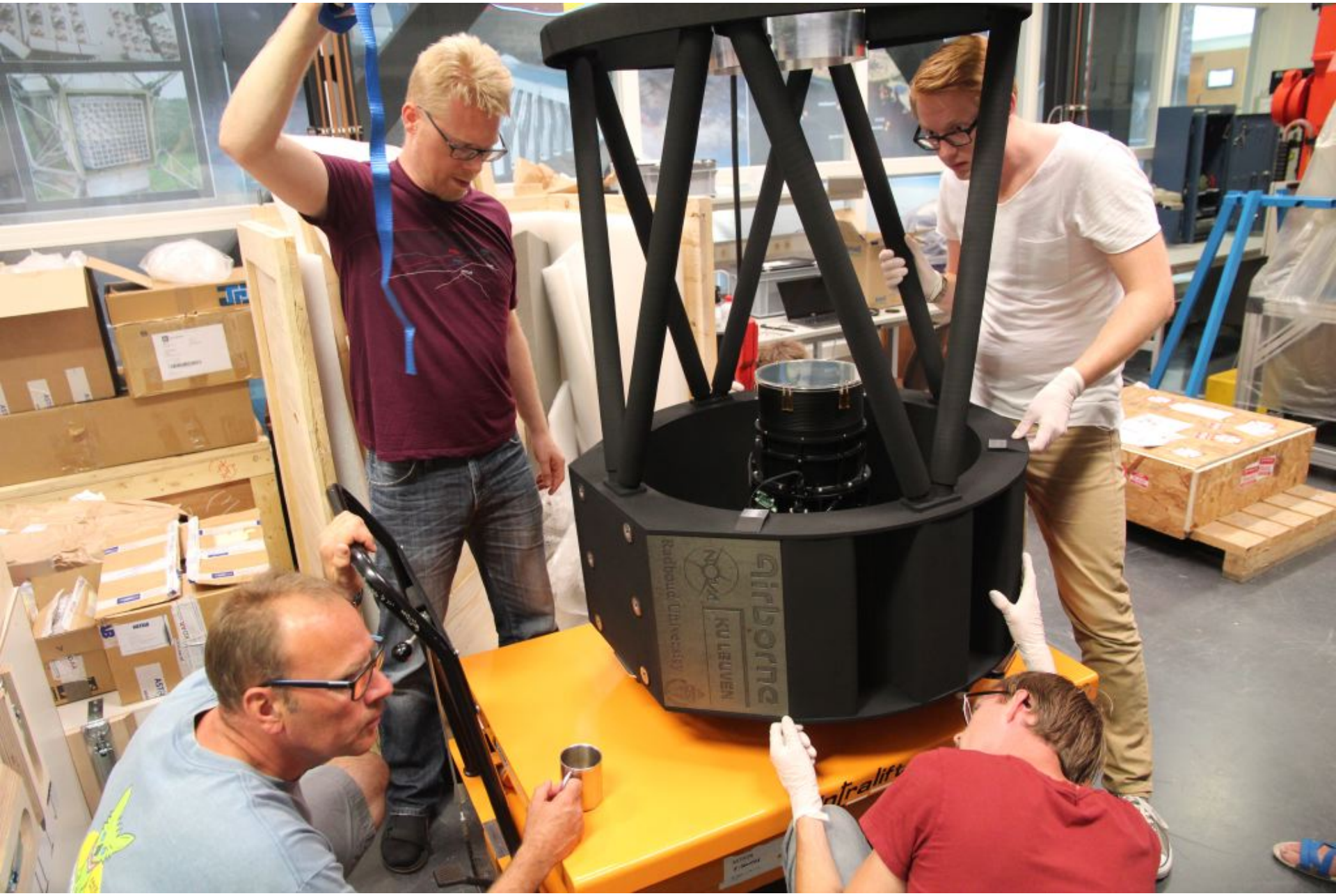
In South Africa: bridge between SALT and SKA/MeerKAT

Partners: Radboud, UvA, NWO (NL); UCT, SAAO (SA); Oxford, Manchester (UK)

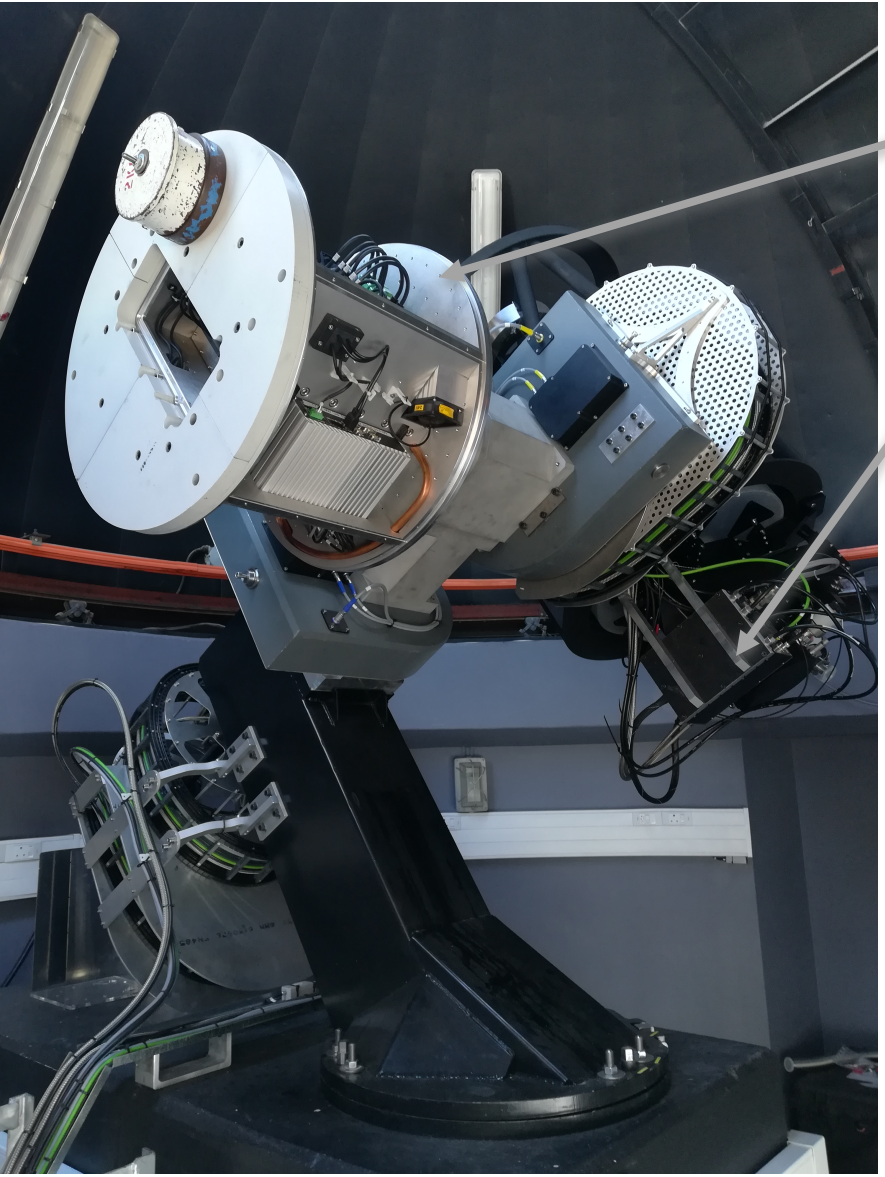







Airborne
KU LEUVEN

Astrodon filters: Sloan'+ wide V+R filter



Water cooled counterweight housing electronics

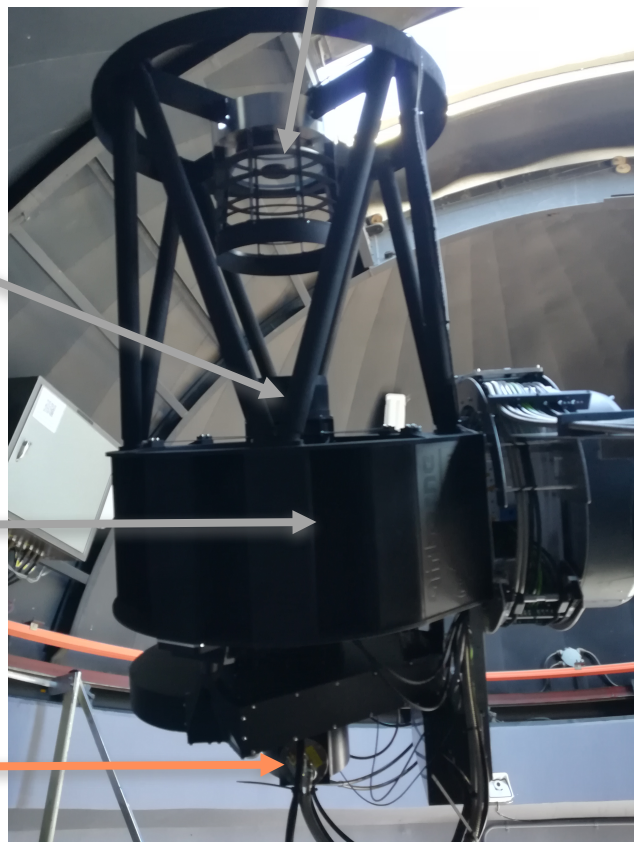
Water cooled Archon (STA) CCD controller

M2 on piezo stage (focus + guiding)

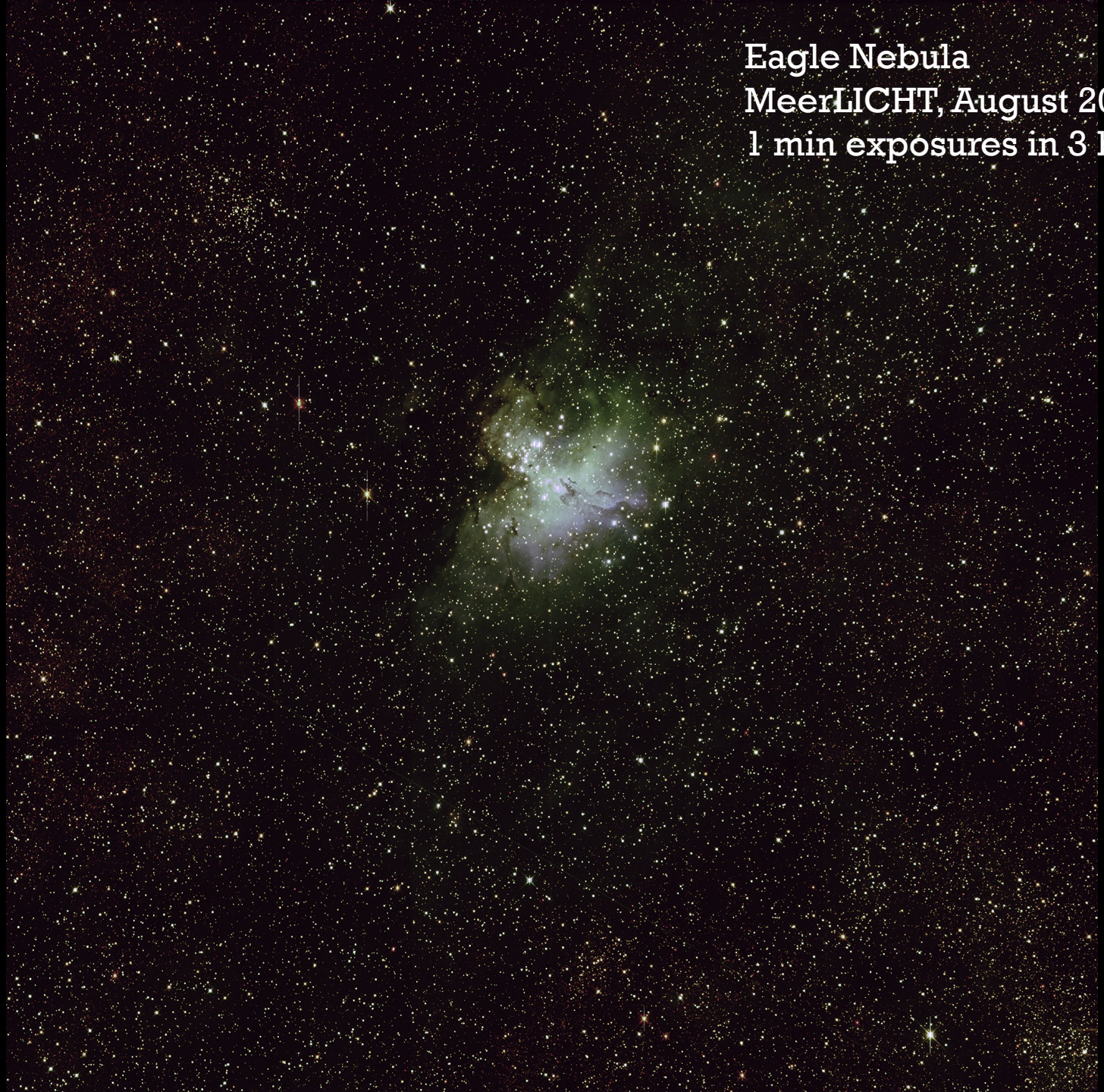
Lens barrel with ADC

Carbon-fibre telescope

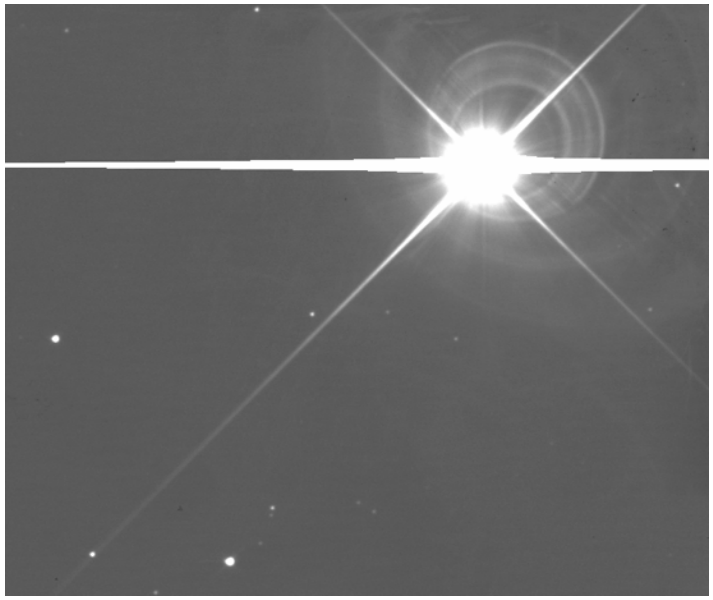
Cryostat (cryotiger cooled) STA1600 CCD (110Mpix)



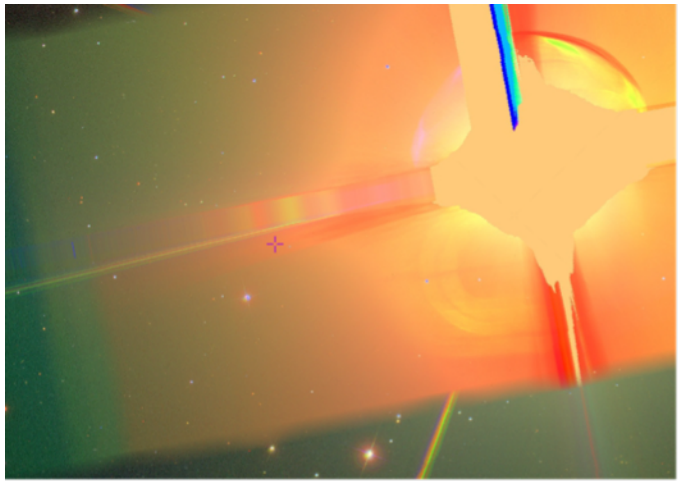

Eagle Nebula
MeerLICHT, August 2017
1 min exposures in 3 bands


Eagle Nebula
MeerLICHT, August 2017
1 min exposures in 3 bands

Ghosting: Arcturus

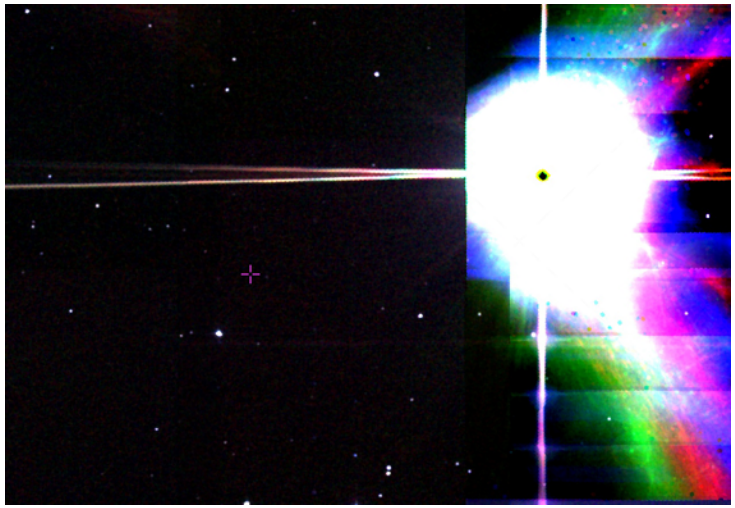


ML@RU

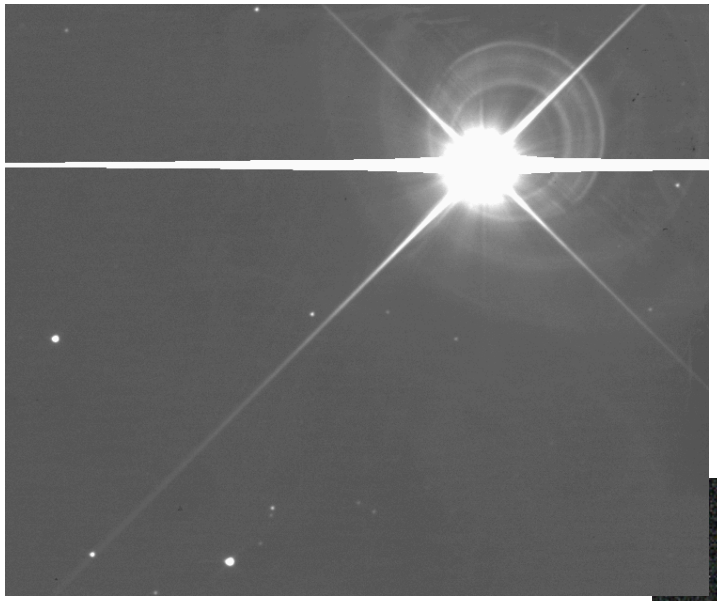


SDSS DR9

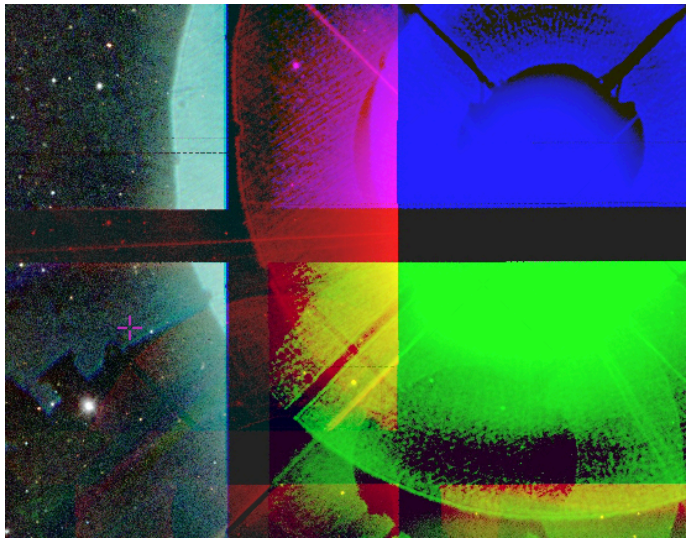
2MASS



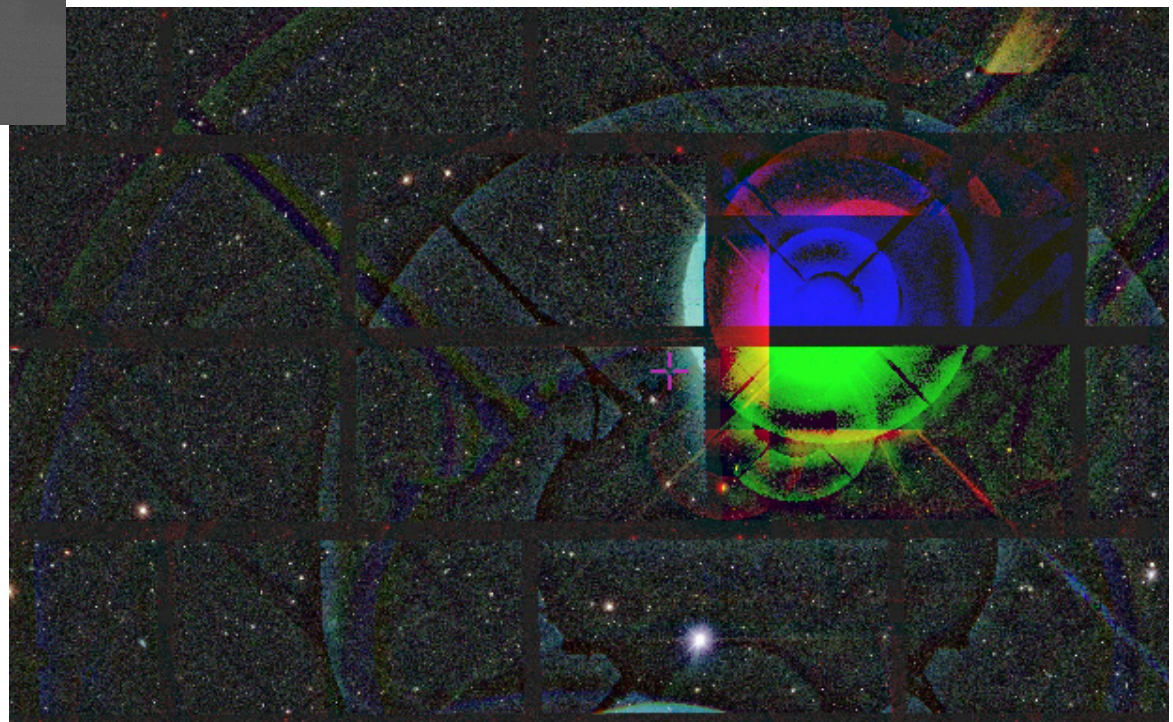
Ghosting: Arcturus



ML@RU

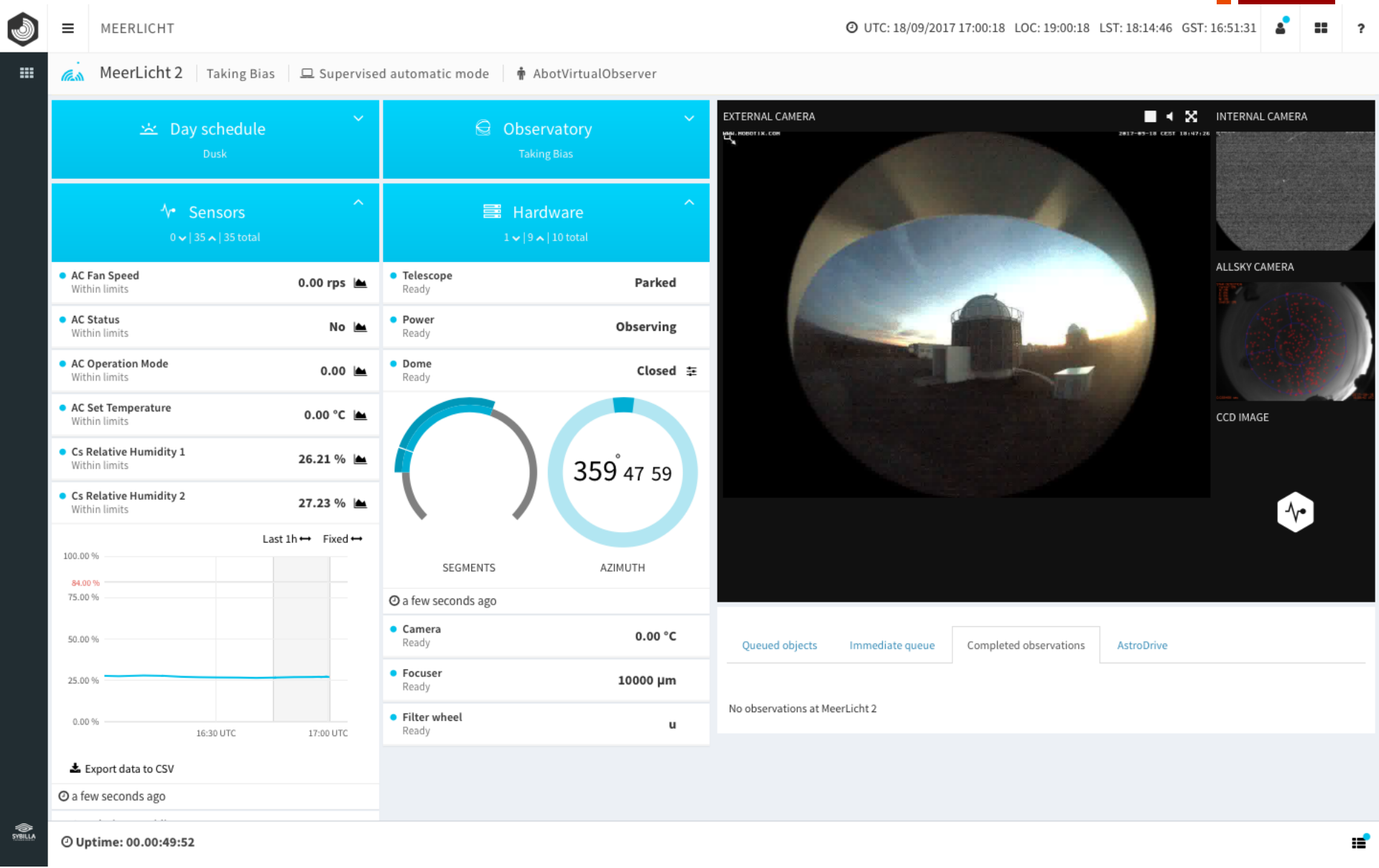


DECaLs/DR3



Robotic operation

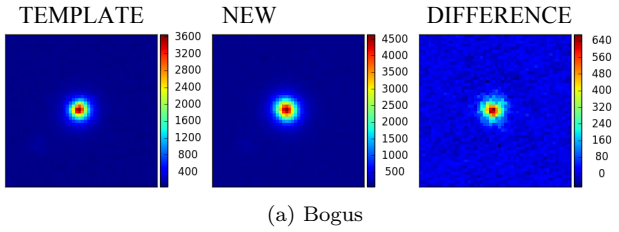
Software by Sybilla Technologies



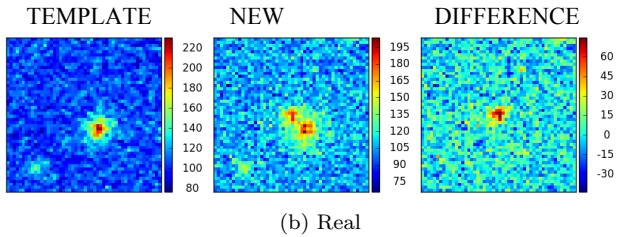
Data challenge

- Real-time transient detection pipeline (<10 mins delay)
  using ZOGY (Zackay+ 2016) image subtraction and

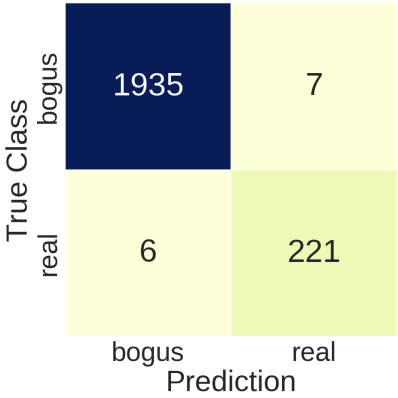
  Deep learning real-bogus vetting (Gieseke, Bloemen + 2017)



(a) Bogus



(b) Real



- 0.5 TB images per night (1 PB after 5 years)
- ~10^5 source detections / minute / telescope
  = ~10^10 / year / telescope
  → 150 TB light curve database
- No fibre to La Silla…

MeerLICHT – Radio/optical transients – South Africa – operational Q1 2018
www.meerlicht.org @MeerLICHT_ZA

BlackGEM – Gravitational wave counterparts – Chile – installation Q4 2018
www.blackgem.org @BlackGEM_Array