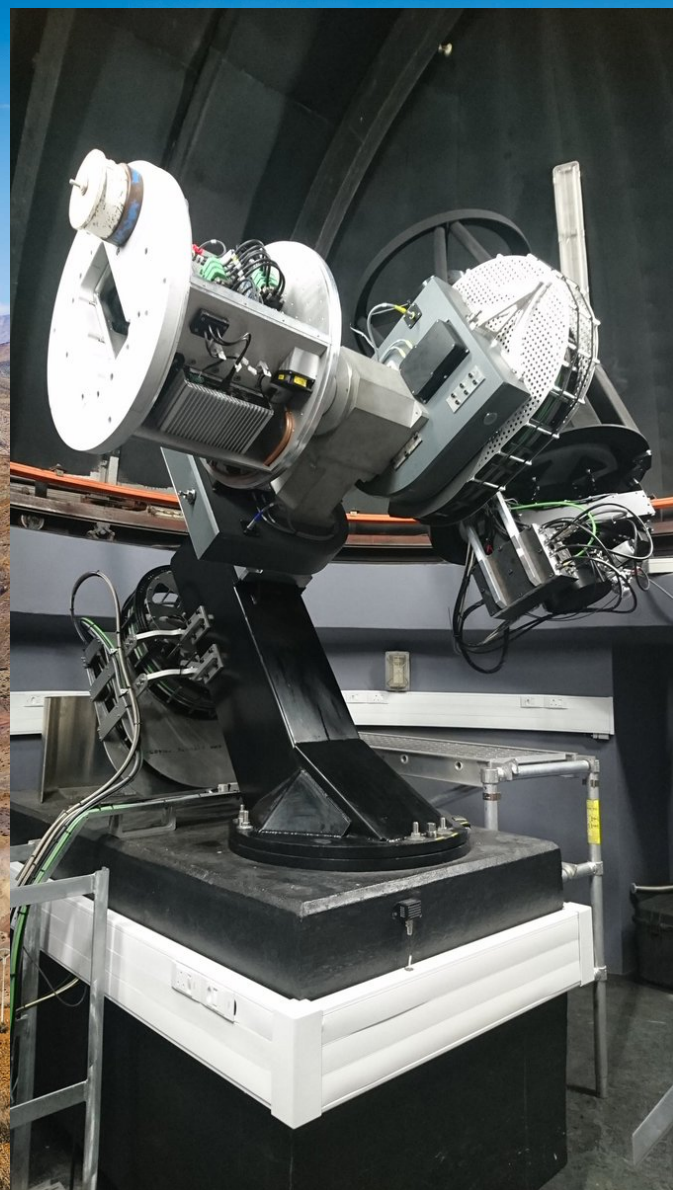




# BlackGEM Telescope array



Prototype system MeerLICHT,  
Installed at SAAO Sutherland

- Gravitational wave counterparts
- Six-band Southern All Sky Survey
- Three-band Synoptic Survey
- Nearby Universe monitoring program

- 
- At ESO La Silla
  - Three telescope array in Phase 1
  - Operational end 2018
  - Expansion to 15 in Phase 2

**PI** Paul Groot  
**PM** Steven Bloemen  
**PS** Peter Jonker





# BlackGEM

## Science:

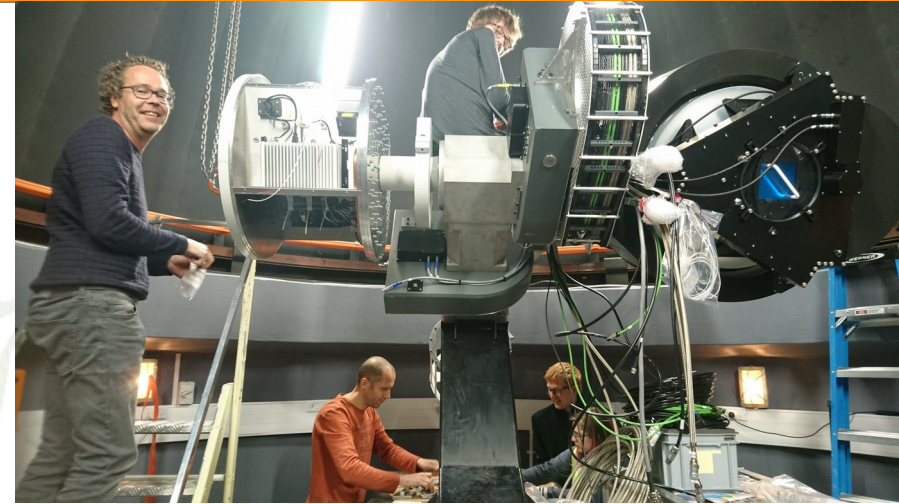
- **Gravitational wave counterparts**
- Southern All Sky Survey
- Fast Transients & Variables
- Nearby Universe Survey

## Phase 1:

- 3 wide field telescopes (8.1 square degr. total)
- Primary mirror: 65cm diameter
- Sensitivity:  $g=23$  in 5 minutes
- Location: ESO La Silla
- Optical quality: seeing limited, 0.9" median
- Camera: 1 CCD/telescope, 10k x 10k, 0.56"/pixel
- Filters:  $u, g, q, r, i, z$  filter set, change in 3s

## Phase 2:

- Expansion to 15 telescopes
- 40 square degrees total field of view (@ 0.56"/pix)
- Location: ESO La Silla; or combi ESO, NZ and SA



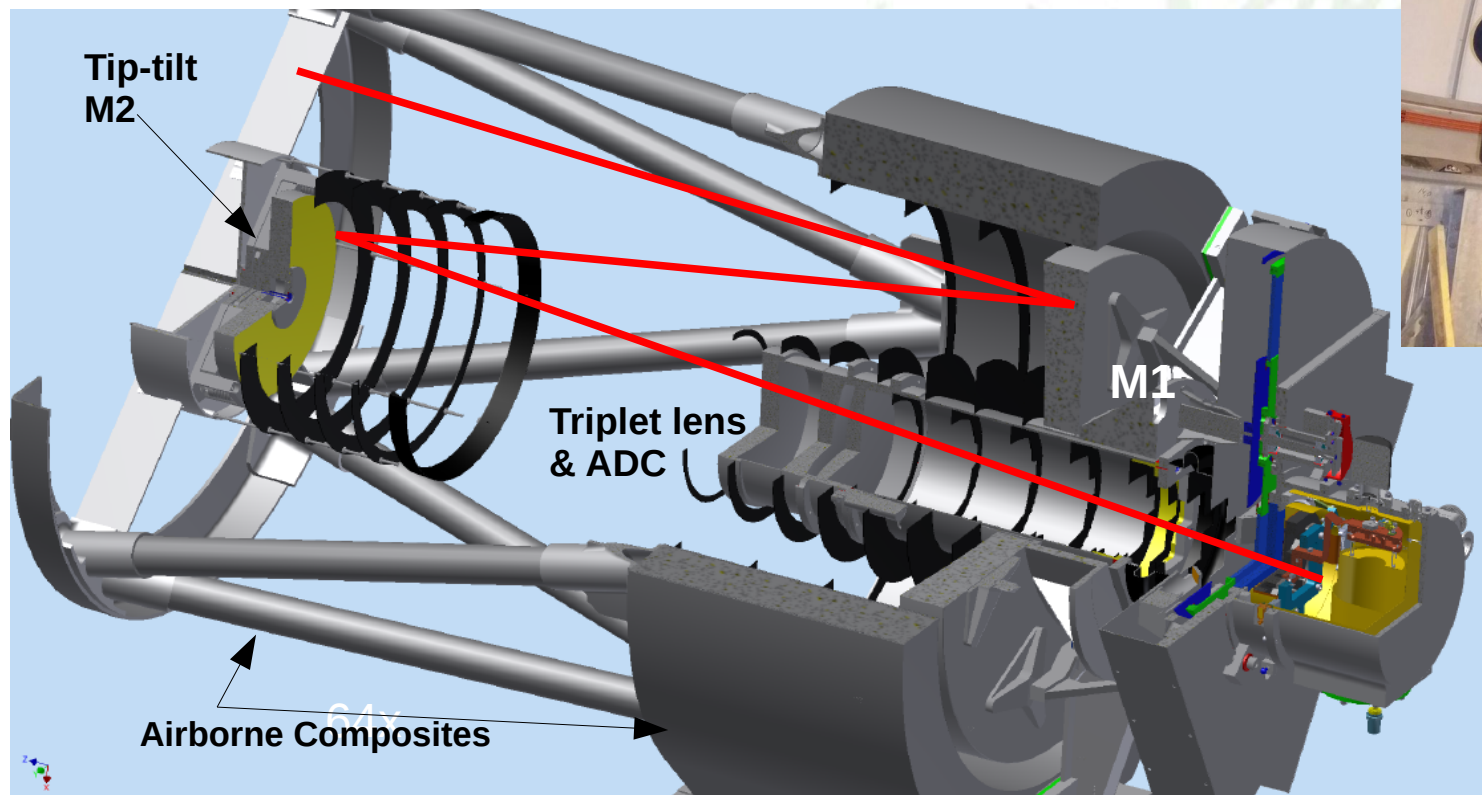


# BlackGEM Unit telescope

- Wynn-Harmer design incl. M2 on tip-tilt piezo stage
- 110 Mpix camera (1 STA 1600 chip)
- 2.7 square degree field-of-view
- 10 second readout + filter change + repointing
- Carbon-fibre structure
- Atmospheric Dispersion Corrector in triplet lens barrel
- Fornax 200 mount
- Fully robotic
- Cooled electronics, in counterweight



*Finished Prototype*



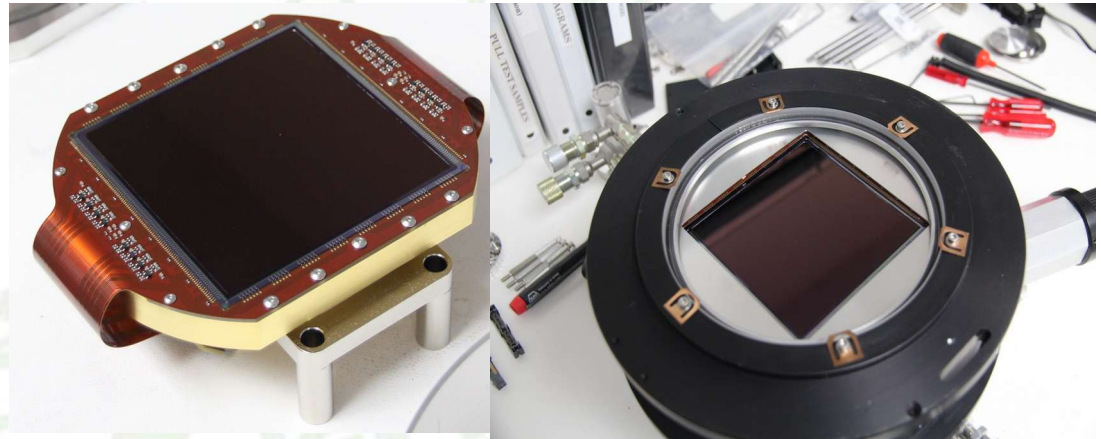
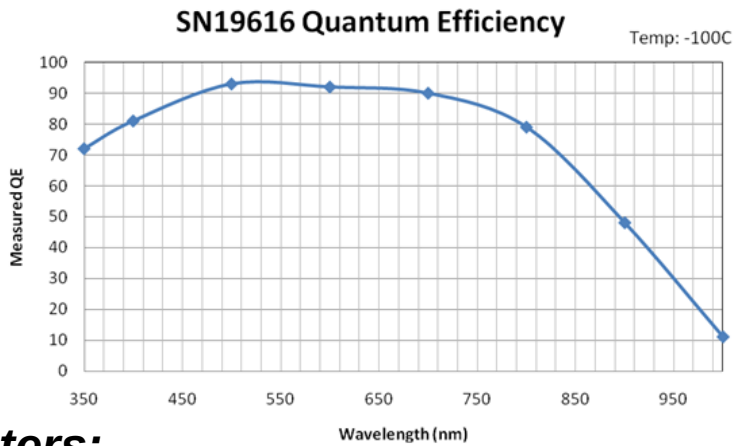
*Design*





# CCD & Filters

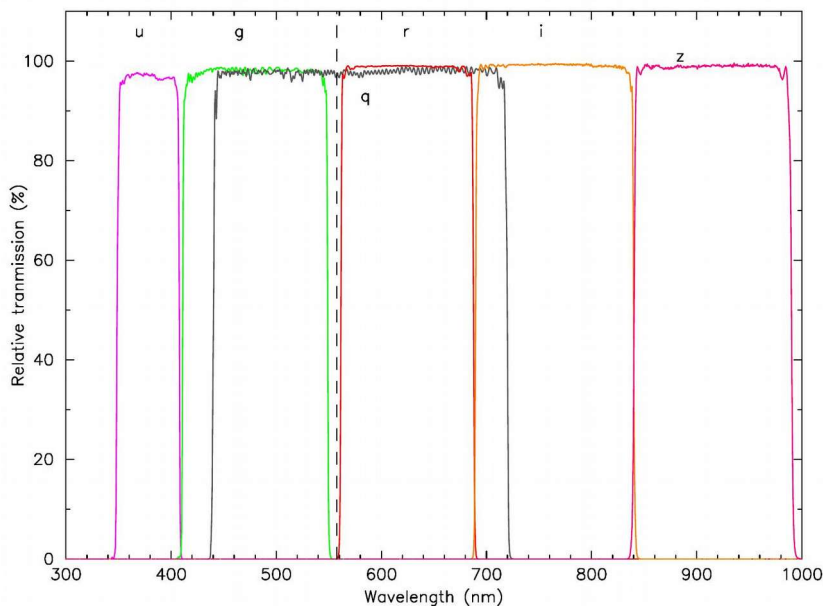
- STA1600, 10.5k x 10.5k CCD, 9  $\mu$  pixel : 110 Mpixel chip
- Scale on sky: 0.562"/pix, total field of view: 2.7 sqd/telescope
- Readout time: 7 seconds (at 1 MHz on 16 ports), RON: 5.5 e<sup>-</sup>



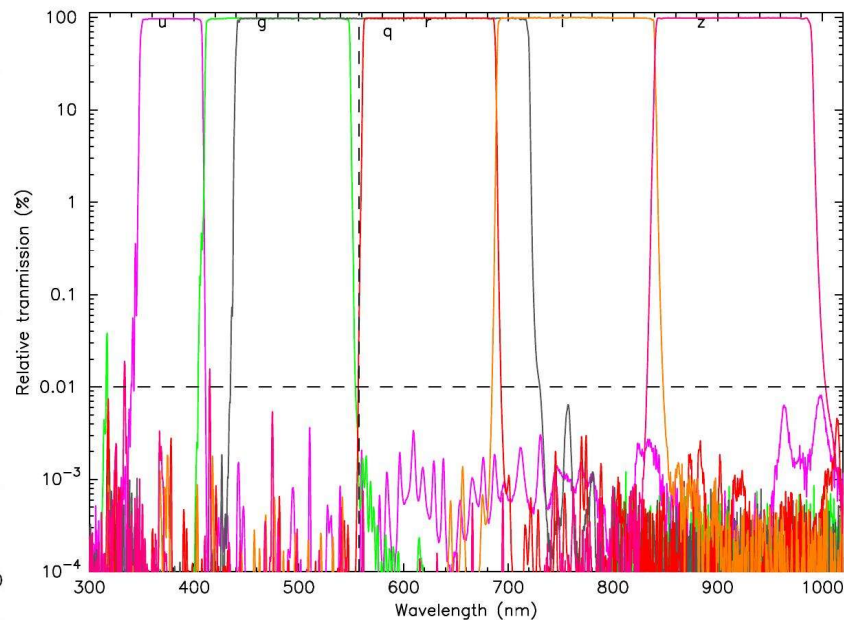
## Filters:

Sloan u,g,r,i,z filters plus broad-band q (440-720nm)

Astrodon BlackGEM set (BG-u,BG-g,BG-r,BG-i,BG-z and BG-vr (=q))



Astrodon BlackGEM set (BG-u,BG-g,BG-r,BG-i,BG-z and BG-vr (=q))







# Dome & Tower

4.5m  
Clam-shell dome

7m high

Raster floor

Outer tube  
holds dome

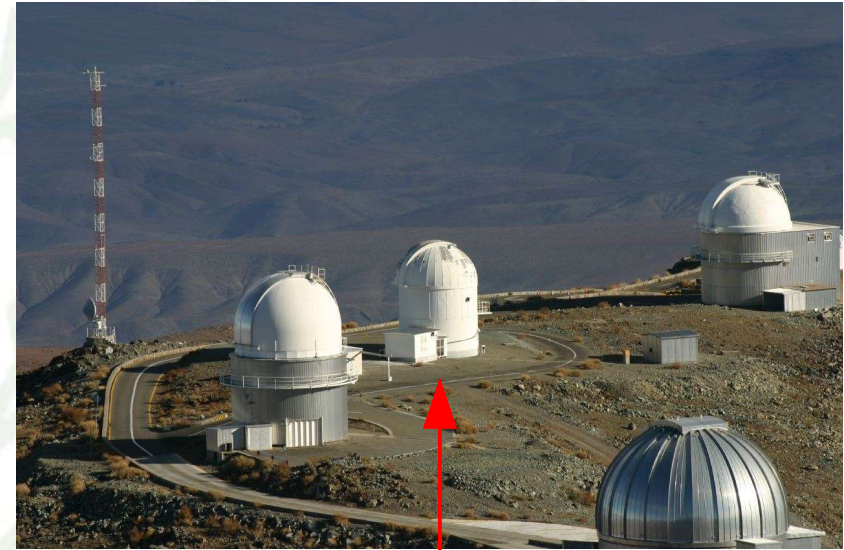
Inner tube holds the  
telescope

Ventilation  
openings

TiO coating on outside  
to prevent daytime heating

Separate  
foundations

Will replace GPO  
Building @ESO La Silla







# BlackGEM Programs

- **BlackGEM Trigger Mode: ' *Transients Galore* '**
  - GW error box coverage in multiple colours
  - 100s of sqd in multiple times over ~week time scale down to  $g=23$   
(TDEs, SN of all types, Dwarf Novae, SN .Ia, SN Iax, etc. )
- **BlackGEM Southern Sky Survey: ' *Southern Sloan* '**
  - 30 000 sqd down to 22<sup>nd</sup> mag in  $u,g,q,r,i,z$  at 1" median seeing
  - By itself a fantastic resource for all kinds of science:  
(galactic streams/structure, dwarf galaxies, stellar populations, 'gems', quasars, weak lensing, high-z galaxies, etc.)
  - ***Includes a 1-minute integration q-band scan of available Southern Sky (10000 sqd) every two weeks, down to  $q\sim 21.5$***
- **BlackGEM Fast Synoptic Survey: ' *Kepler on steroids* '**
  - High cadence (1 min), multi-colour (simultaneous), wide-field
  - Kepler Short Cadence-type sampling on millions of objects
  - Deep drilling fields: thousands of exposures over weeks time-scale
  - Flexibility for experiments: continuous read-out, six filters, etc.  
(fast transients, asteroids, KBOs, early SN, interacting binaries, eclipses etc.)
- **BlackGEM Twilight Program**
  - Every twilight (30 minutes) Local Universe galaxies in 3 bands ( $u,q,z$ ) for new transients (incl. SMC/LMC, Fornax Cluster, Cen A/M83 group, etc.). Fifteen fields (120sqd) per twilight.





# BlackGEM GW counterparts

BlackGEM covers 100 square degrees in 2 hours in 1 filter down to  $g=23$

- Use **ranked tiling** for selection area on sky (see Ghosh, S., et al., 2016)
- No priority-ranking on galaxies. For  $d > 100$  Mpc:  $\Sigma_{\text{gal},100\text{Mpc}} > 1 \text{ sqd}^{-1}$
- Transients announced like normal transients (i.e. public in 15 minutes)
- Will follow the location in the sky of  $\sim 1$  week
- Multi-band observations require **smaller area/lower cadence/shallower/more telescopes**

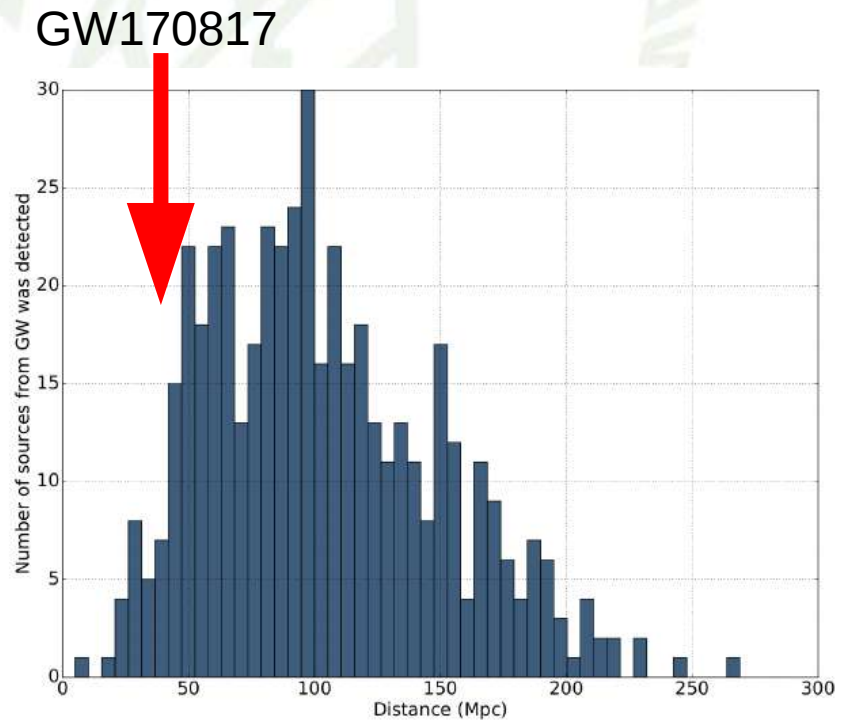
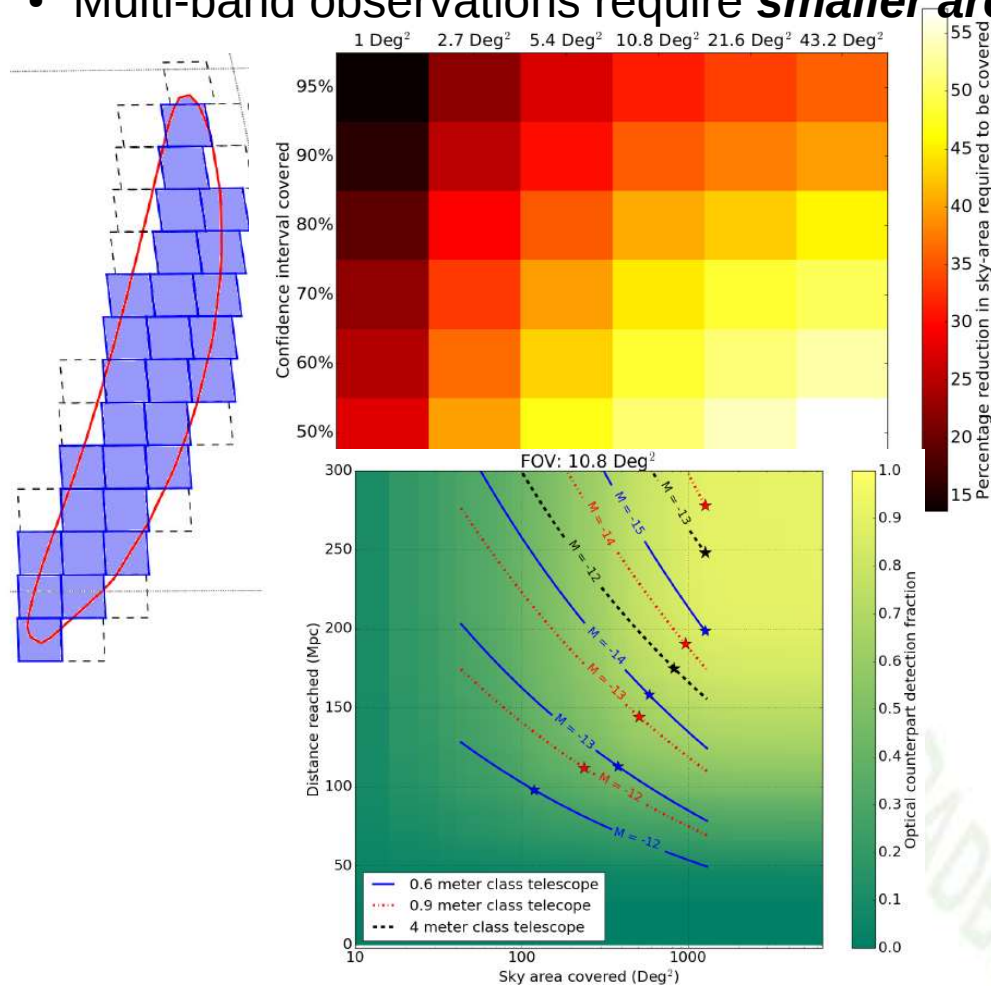


Fig. 9. Simulation of the distance distribution of the detected events from 2016.

Ghosh, S., et al., 2016

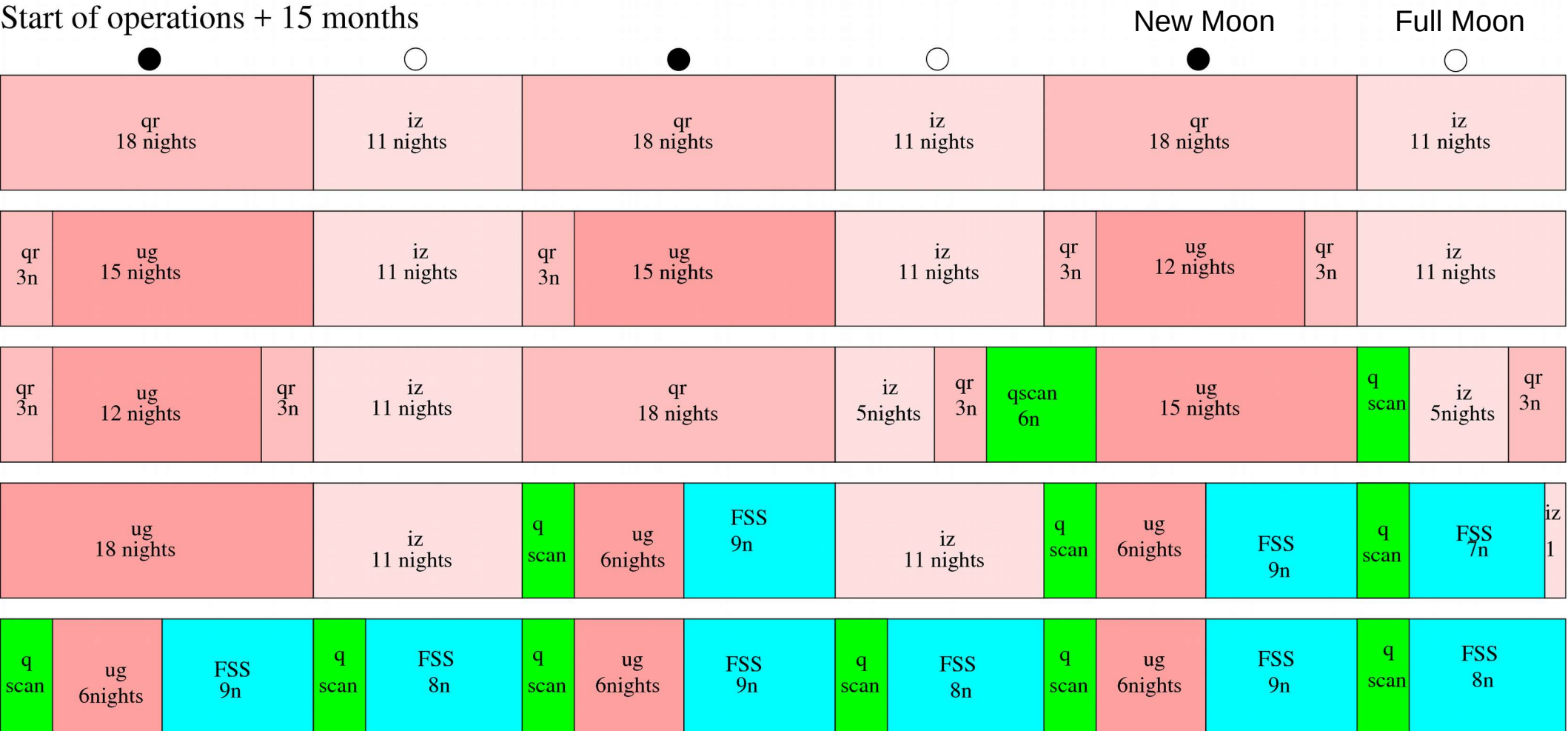




# Southern Sky Survey Planning

BlackGEM Southern All Sky Survey and Fast Synoptic Survey Planning

Start of operations + 15 months



qr: 18n, 18n, 18n, 3n, 3n, 6n, 6n, 18n, 6n

iz+q: 7x11, 5n, 5n, 11n, 11n, 1n

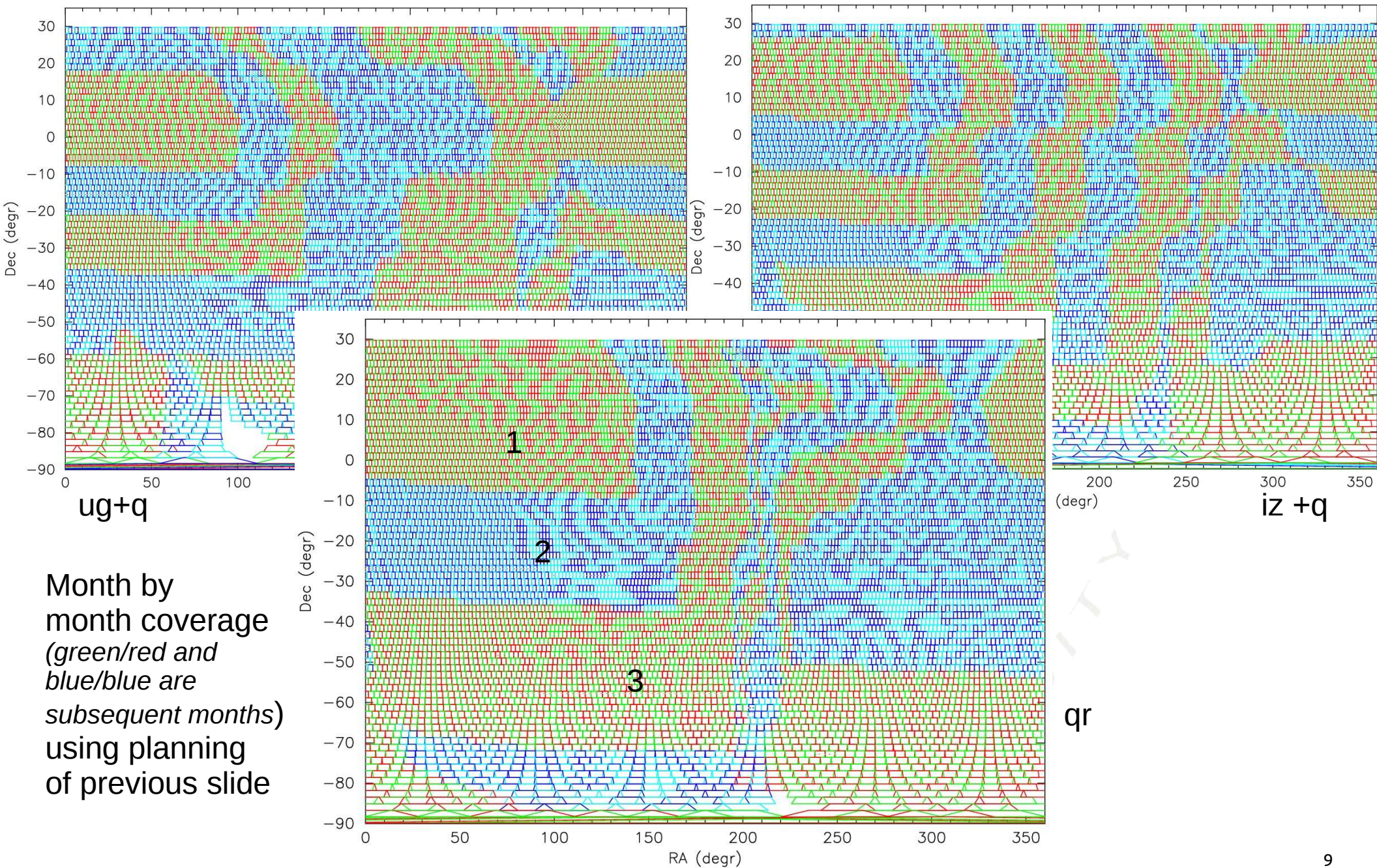
ug+q: 15n, 15n, 12n, 12, 0n, 12n, 18n, 5x6n

Pink = BlackGEM Southern All Sky Survey  
 Green = q-band scan of Southern Sky  
 Blue = Fast Synoptic Survey





# Sky Coverage

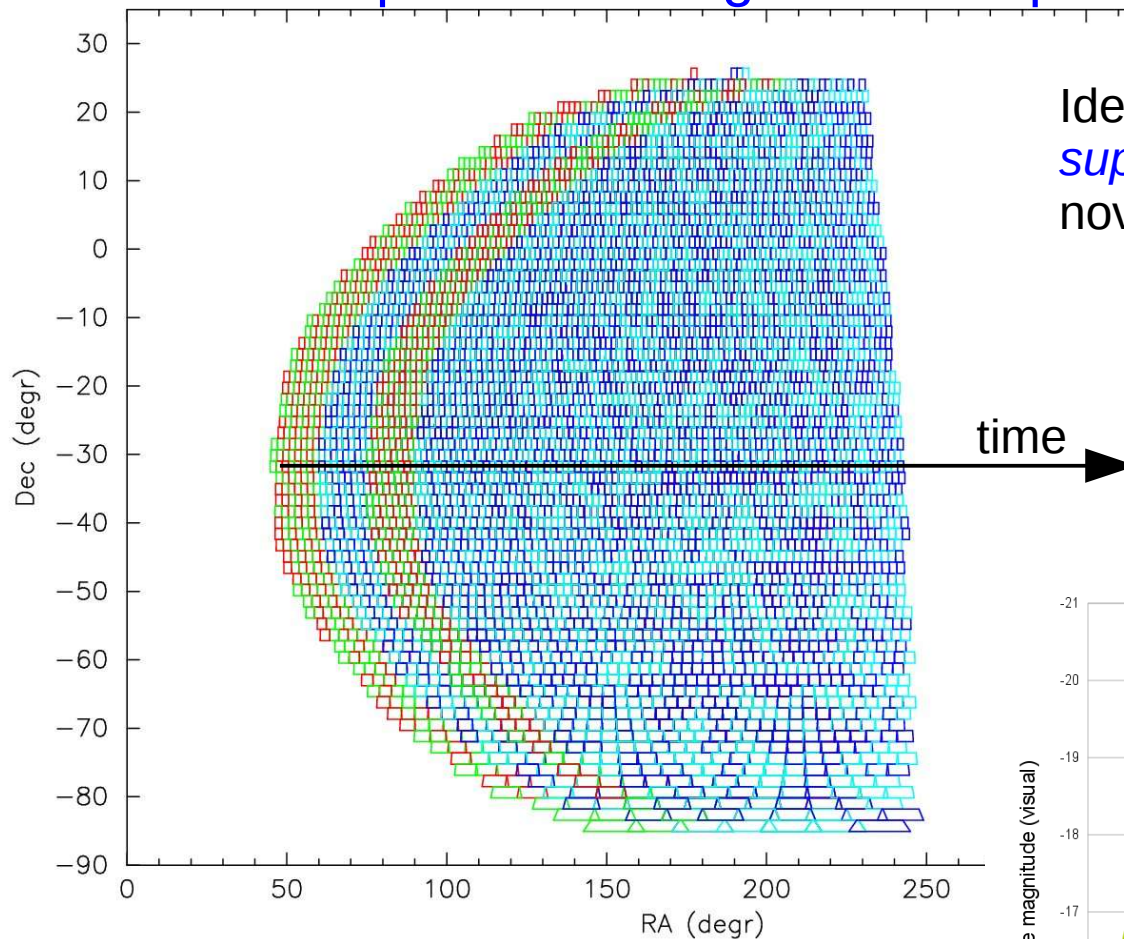




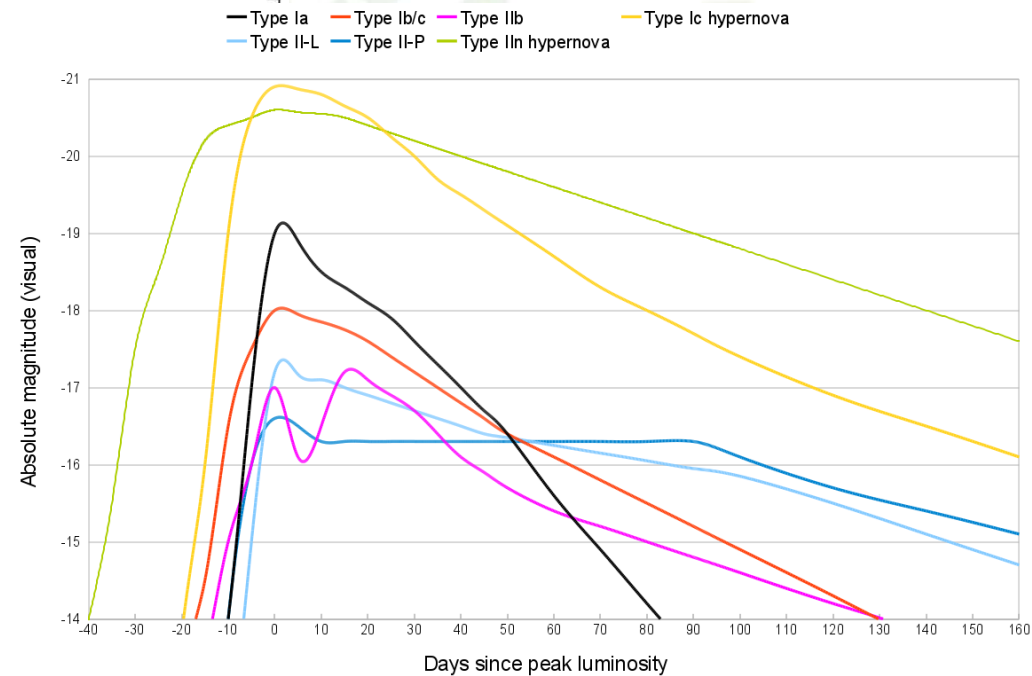


# BlackGEM Bi-Weekly q-scan

Every two weeks 3 nights will be used to scan the available sky:  
10000 sqd. in 60s integrations in q-band



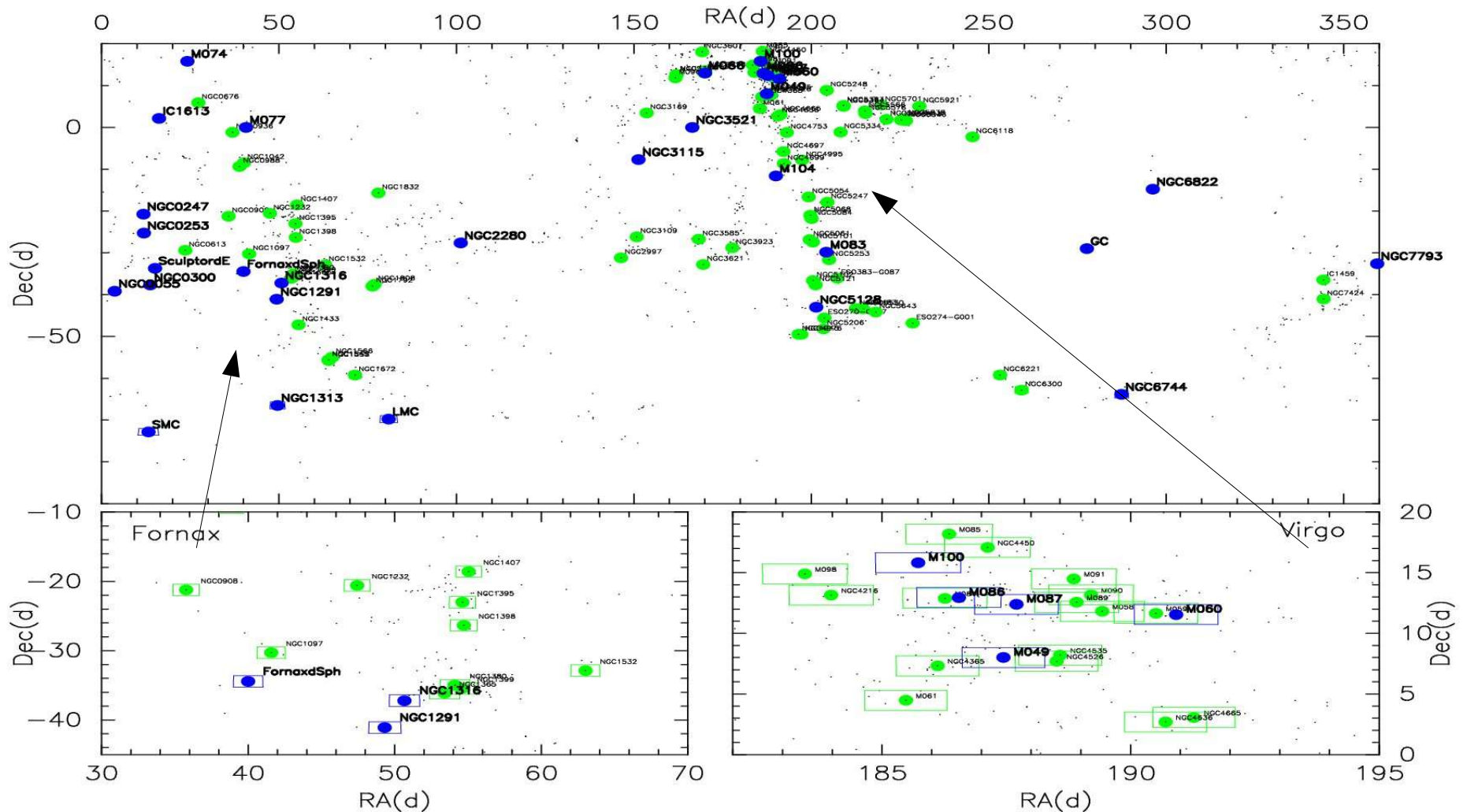
Ideal for slower transients/variables:  
*superluminous supernovae*; TDEs,  
novae, long-period variables, etc





# BlackGEM Twilight Survey

- Every twilight a 30-min window @ end/start twilight calibs and start/stop main data-taking
- In this window: 15x3 fields (2.7 sqd each) in three bands:  $u$ ,  $q$  and  $z/i$
- Nearby *Universe galaxies* with high integrated brightness profiles (incl. Gal.Cen. and  $\Omega$  Cen)



Points:  $d < 30$  Mpc &  $B < 14$  mag; green: 120 brightest, blue 30 brightest

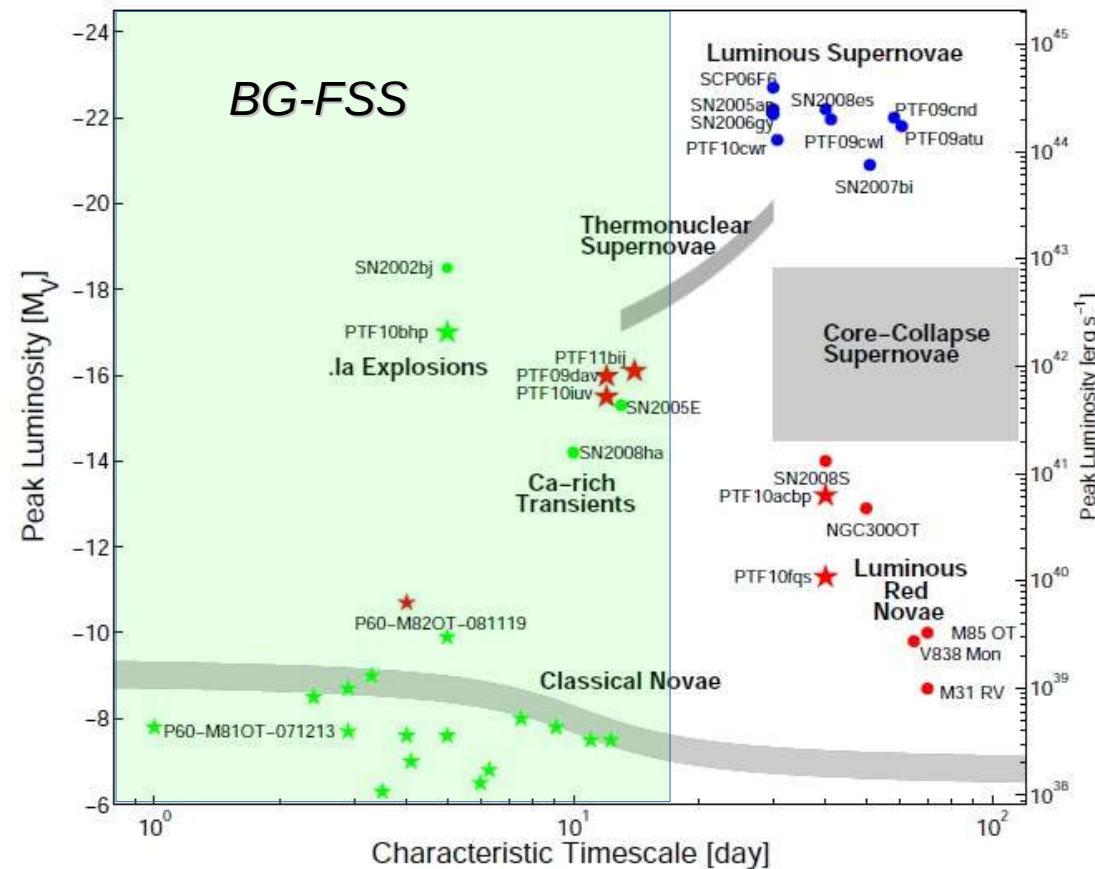




# BlackGEM Fast Synoptic Survey

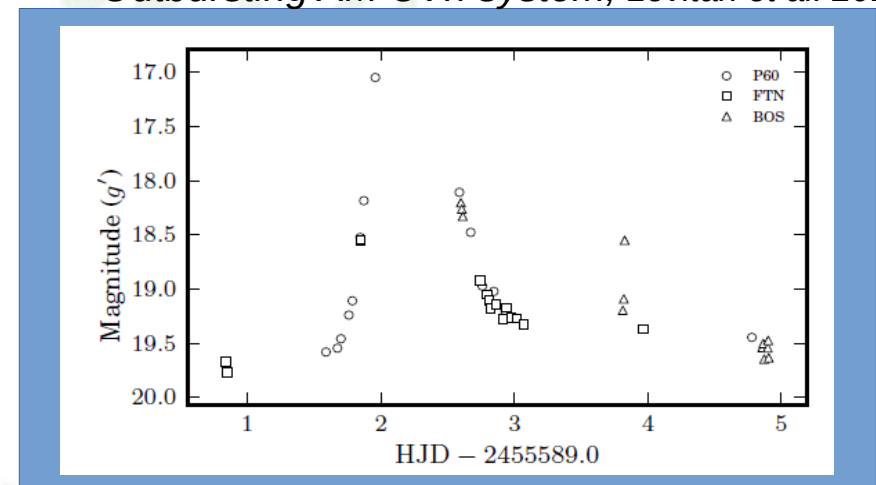
High Cadence survey to characterize fast transient phase space:  
“What goes ‘bang’- ‘bang’ in the night?”

→ 60s integrations, 2 (3?) bands (uqi alternating), continuous for 2 weeks  
i.e. 2800 q-band & 2800 r-band observations, 140s effective cadence



- Fast transients
- Short-period variables
- Fast-moving objects

*Outbursting AM CVn system; Levitan et al. 2012*

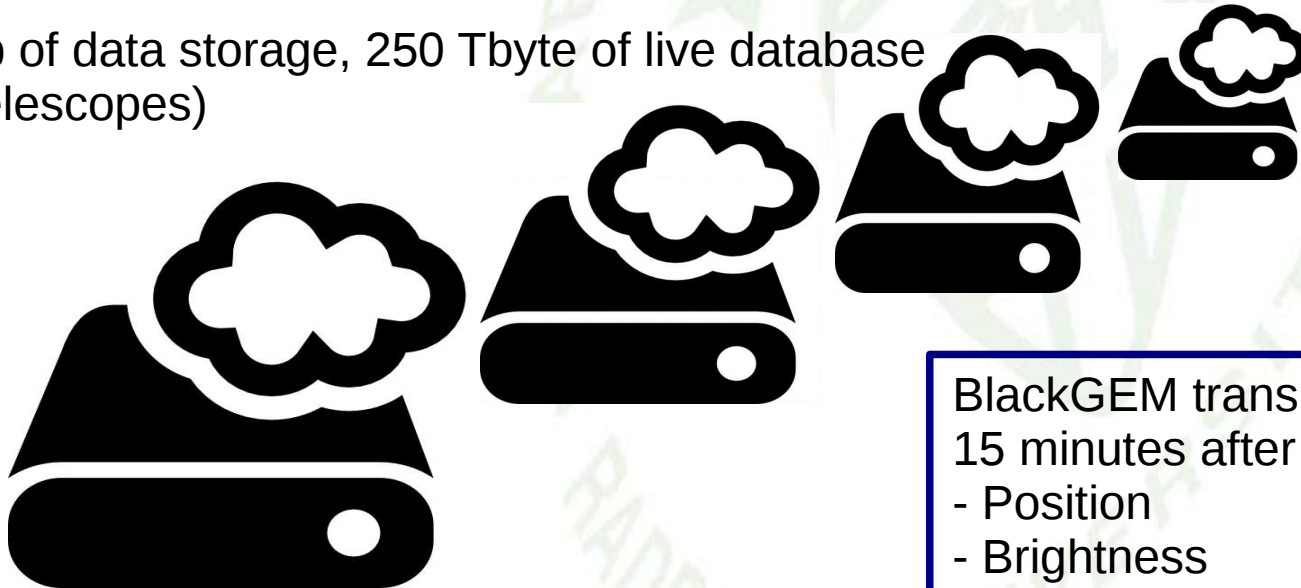




# BlackCloud: A cloud solution



- Data flow pipeline based on *subpipe* data reduction flow SkyMapper
- Aim is to make all BlackGEM data instantly accessible:
  - A live database of any transient is maintained 'on the fly', live processing of 'previous' image during the night, instant alerts (T+15min)
  - All images kept on (spinning) disk for re-reductions and target photometry at any time
  - A live database of all sources, including variability.
- Complete set-up ideal for **cloud solution** on compute, database, storage  
BlackGEM data: the **BlackCloud**.
- 1 Pb of data storage, 250 Tbyte of live database  
(3 telescopes)



BlackGEM transients public,  
15 minutes after data taking:

- Position
- Brightness
- Time





# BlackGEM Team & Consortium

Principal Investigator: Paul Groot (Radboud University)  
Project Scientist: Peter Jonker (SRON/Radboud University)  
Project Manager: Steven Bloemen (Radboud University)

Consortium Institute Partners in Phase 1:



*NOVA = Amsterdam, Leiden, Groningen, Radboud*

**Radboud Universiteit**



**KU Leuven**

Manchester U., Tel Aviv U., U Canterbury, UC Davis, Weizmann, Hebrew U,  
Northwestern committed at PI-level

Possibility for new partners (for 5 year operation):

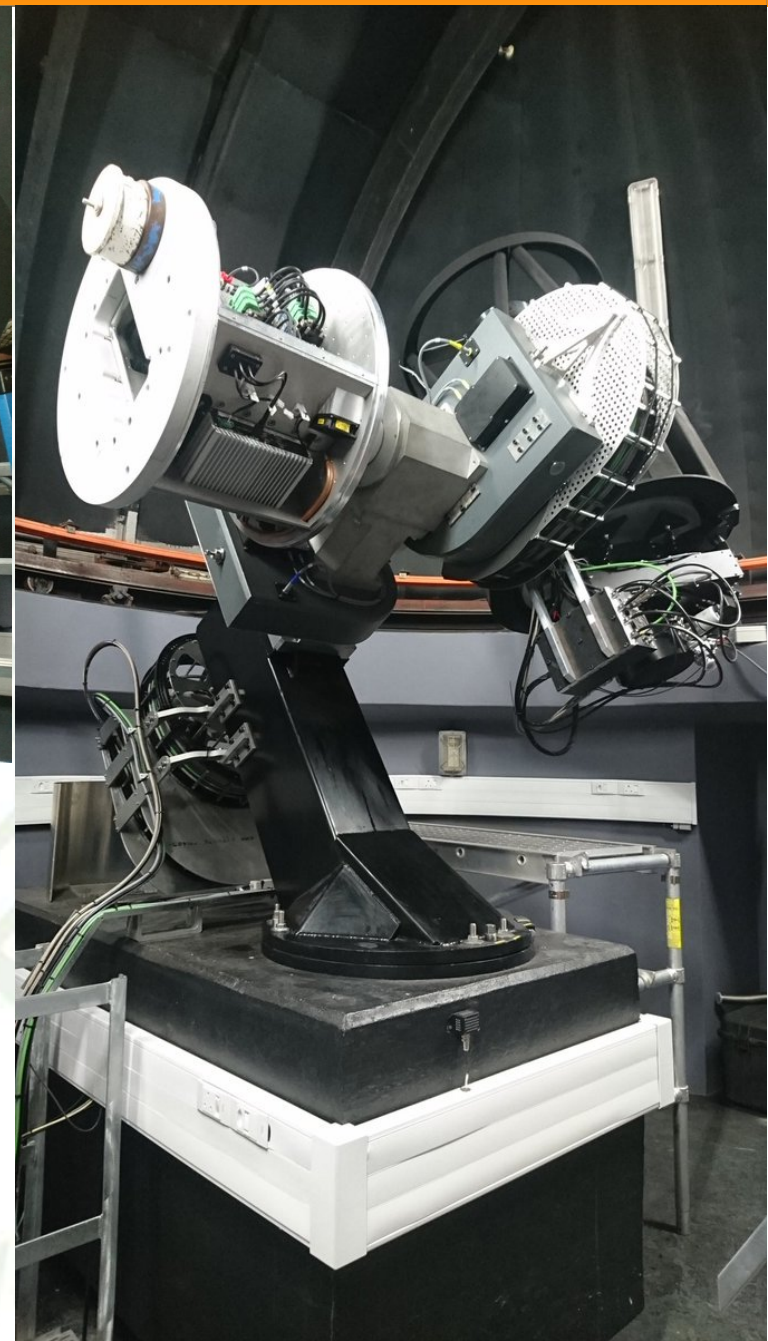
- 150 kEuro to join at PI-level (one faculty member + PDRAs/PhDs)  
(all data, science team, lead science case)
- 1 MEuro to join at Institute level (full institute)  
(all data, science team, lead science case, consortium board)

→ Combinations with in-kind contributions (e.g. follow-up telescope time) possible

[www.blackgem.org](http://www.blackgem.org) ; @BlackGEM\_Array



# MeerLICHT Prototype



Operational at SAAO Sutherland

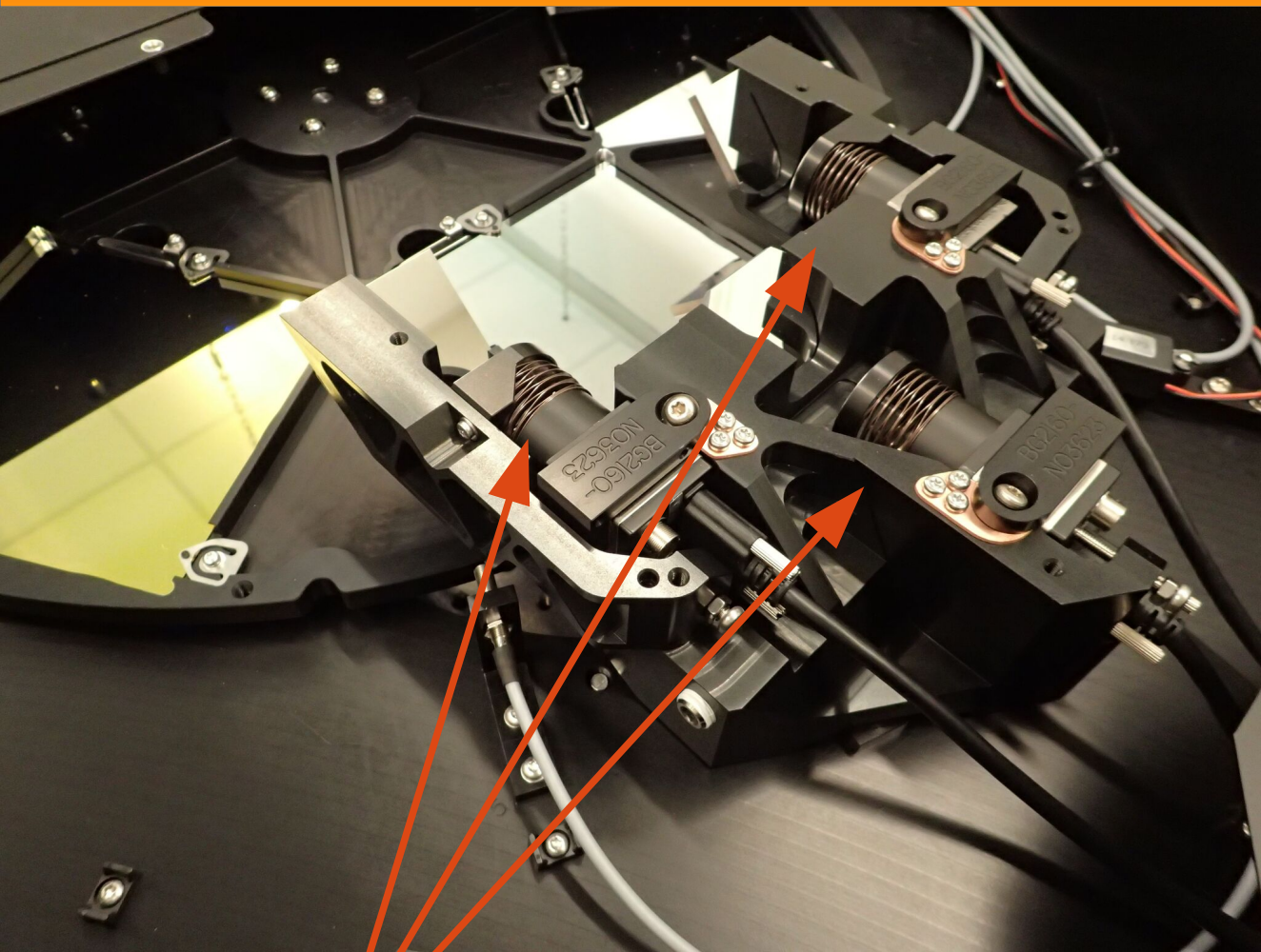
See [@MeerLICHT\\_ZA](https://twitter.com/MeerLICHT_ZA) on Twitter and [www.meerlicht.org](http://www.meerlicht.org) for more pictures







# Guide cameras & Filters



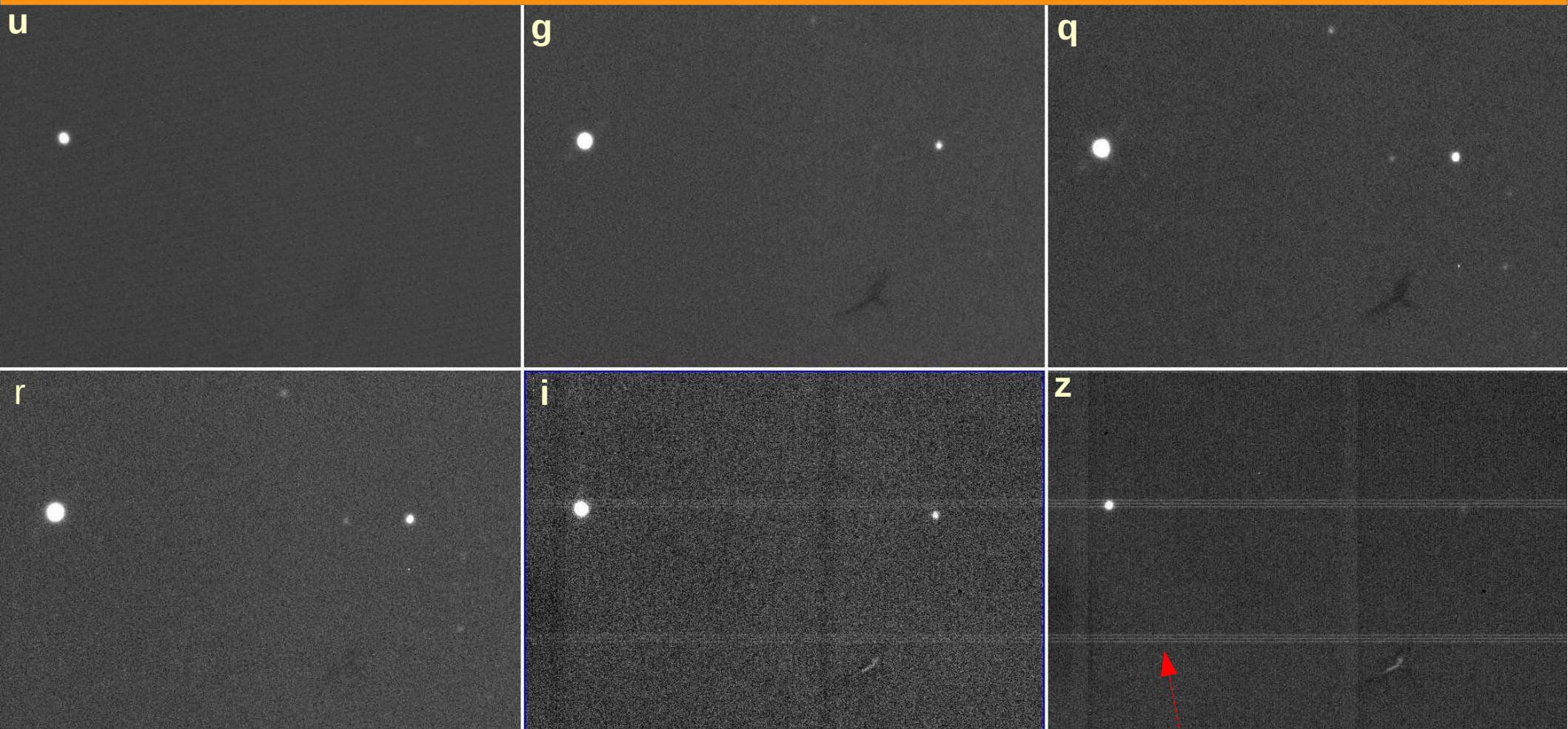
3 Guide cameras

Filter wheel





# Filter performance



All exposures 5 seconds, unguided, on Pole

Reflection on backing structure CCD







# First light on sky

Pole

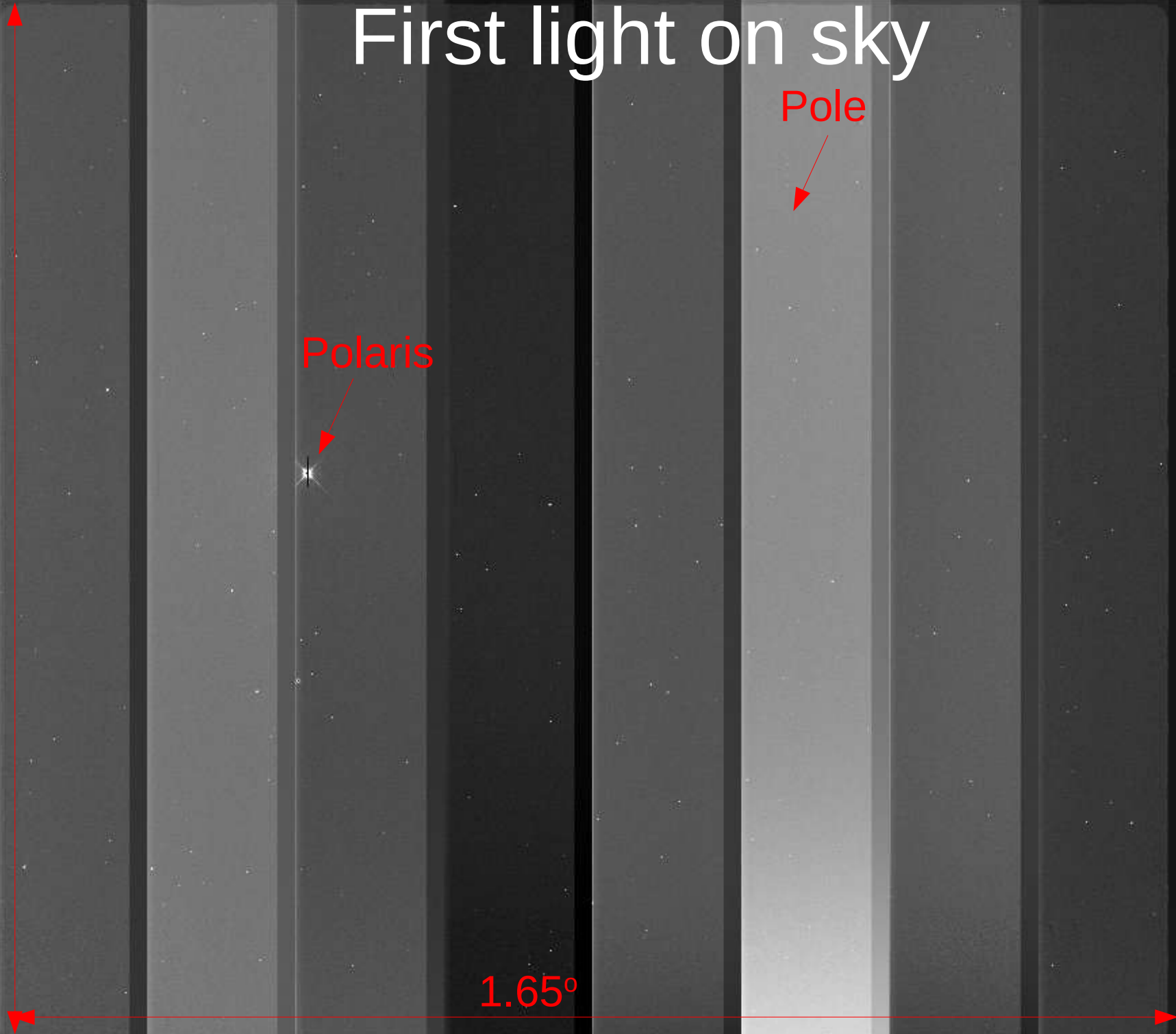


Polaris



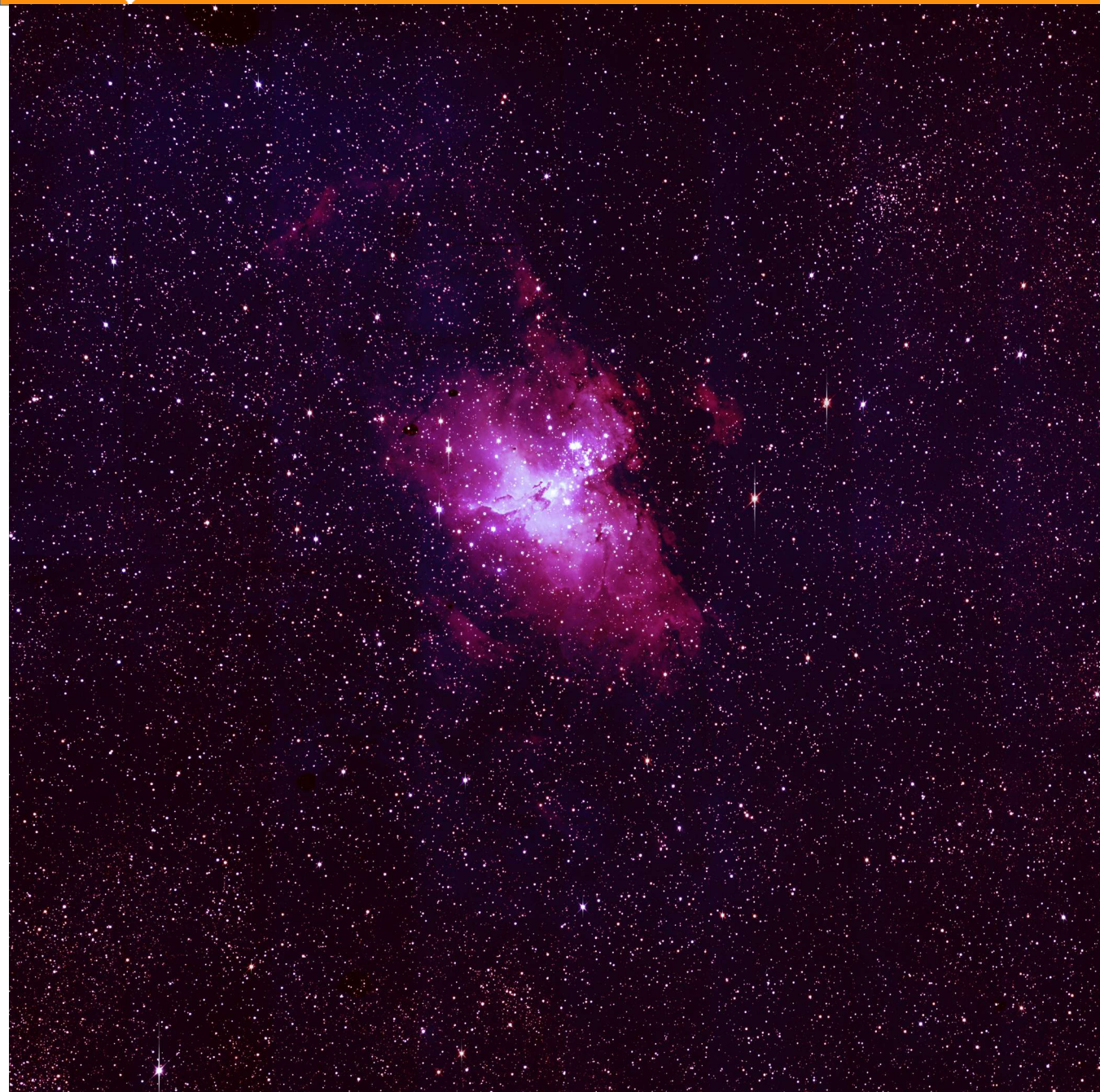
1.65°

1.65°



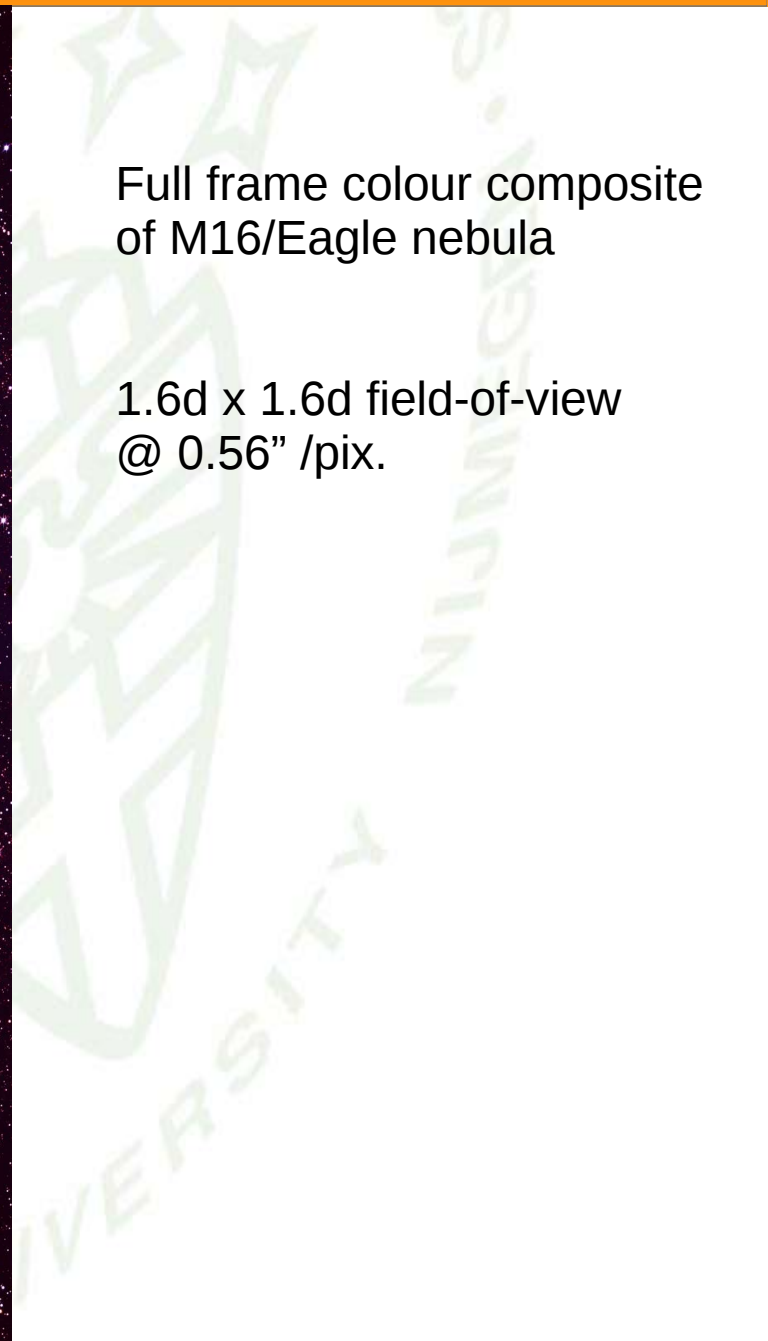


# M16 / Eagle Nebula



Full frame colour composite  
of M16/Eagle nebula

1.6d x 1.6d field-of-view  
@ 0.56" /pix.







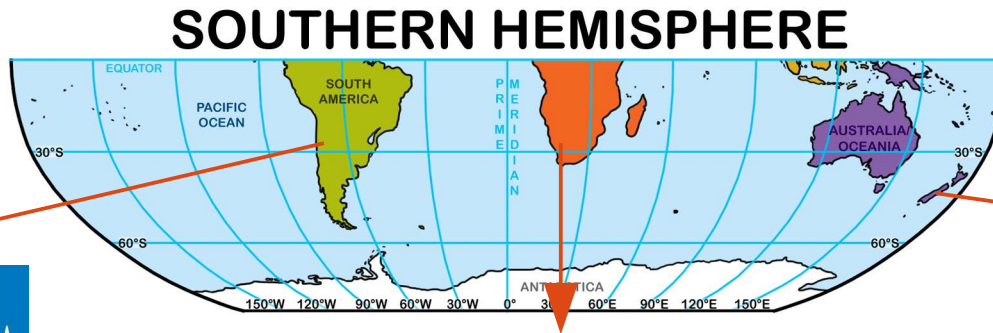
# Schedule BlackGEM

- Prototype testing @Radboud: February 2017
  - Shipment MeerLICHT prototype → ZA June 2017
  - Commissioning MeerLICHT @SAAO August-December 2017
  - Start operations MeerLICHT January 2018
- 
- Final Design Review BlackGEM March 23/24, 2017
  - Manufacturing BlackGEM-Phase1 March 2017 – March 2018
  - Shipment BlackGEM → Chile August 2018
  - Commissioning BlackGEM-Phase1 Sept-Dec 2018
  - Start operations Phase1 January 2019.

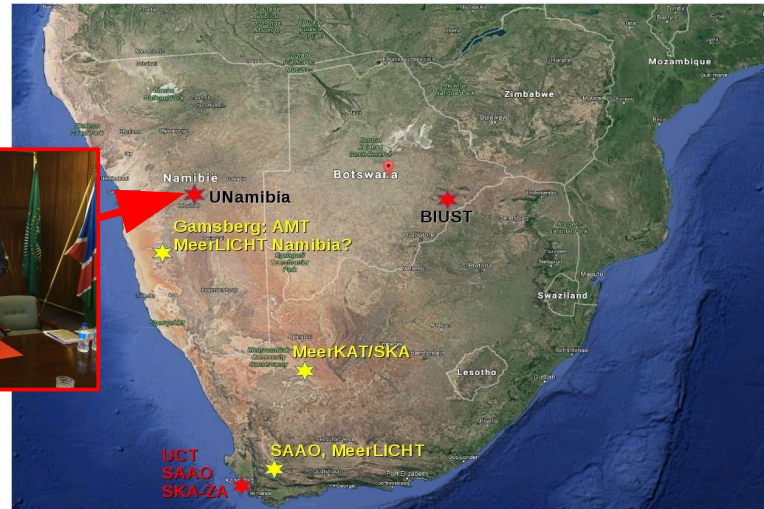
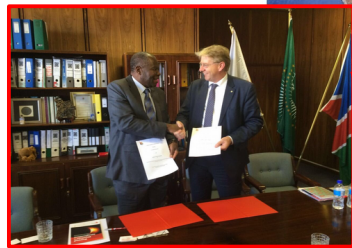


# Future plans

- Expansion of BlackGEM to 15 telescopes (requires additional 15 MEuro)
- Chile, or NZ and/or Southern Africa
- Development/addition of low-cost spectroscopic telescopes



South Africa or Namibia



Mt. John  
U. of Canterbury  
Christchurch

