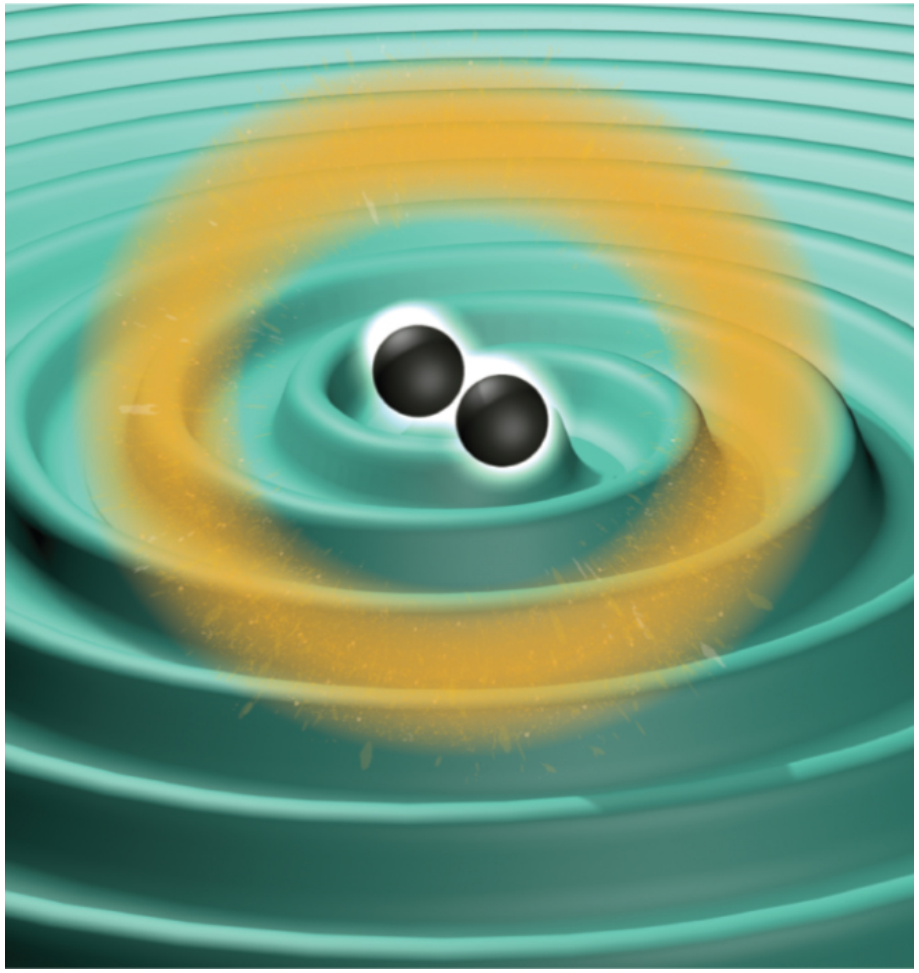
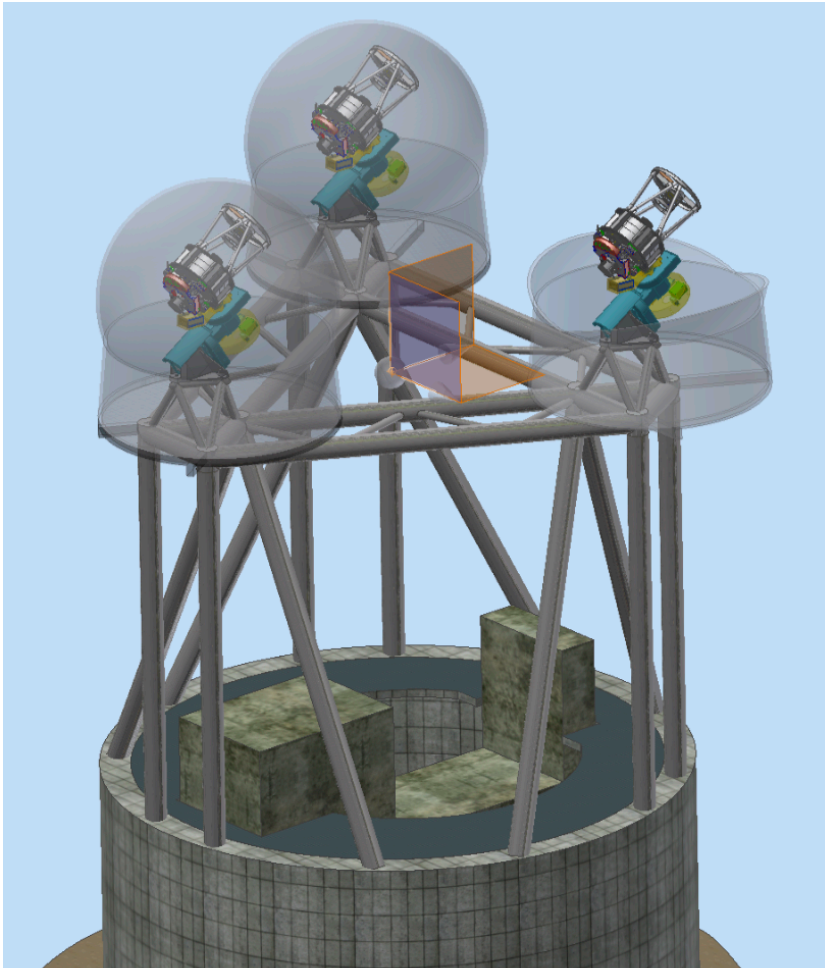




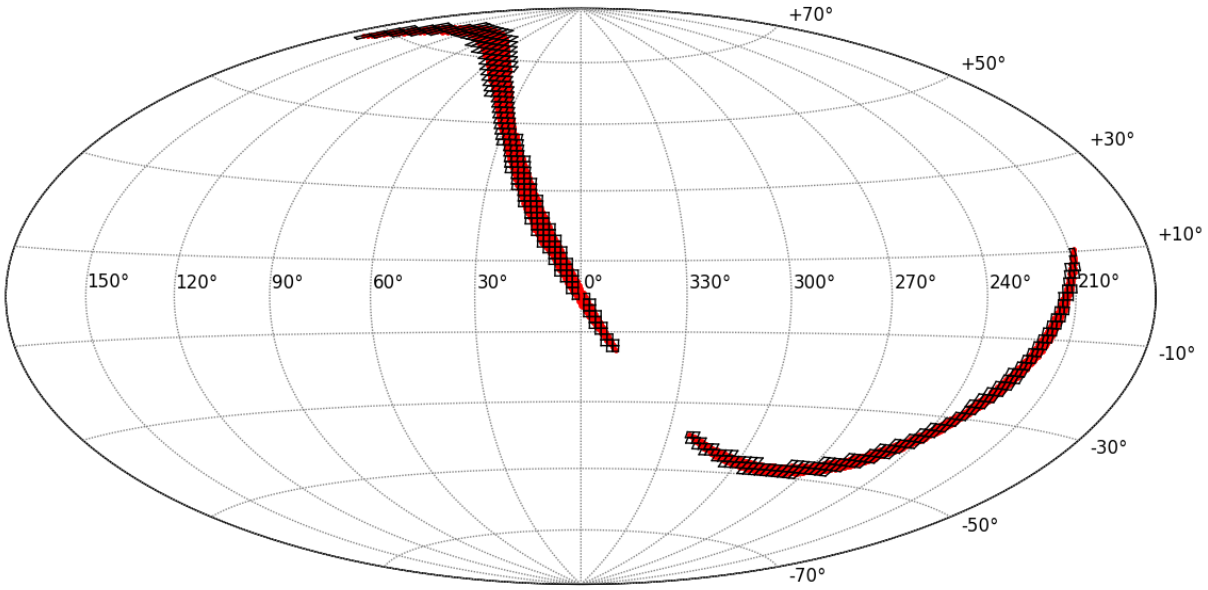
The BlackGEM and MeerLICHT telescopes

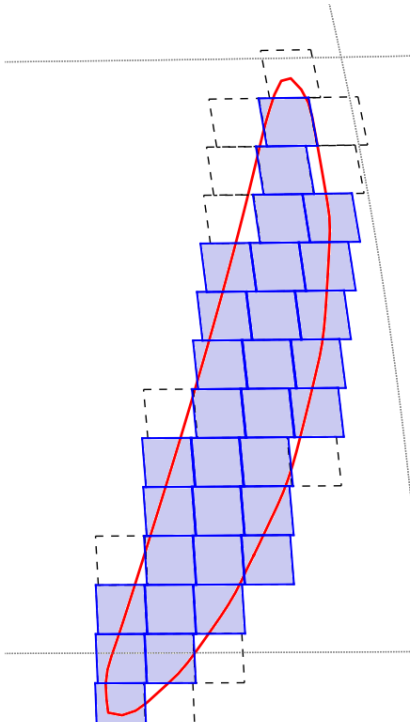
Radboud Universiteit Nijmegen

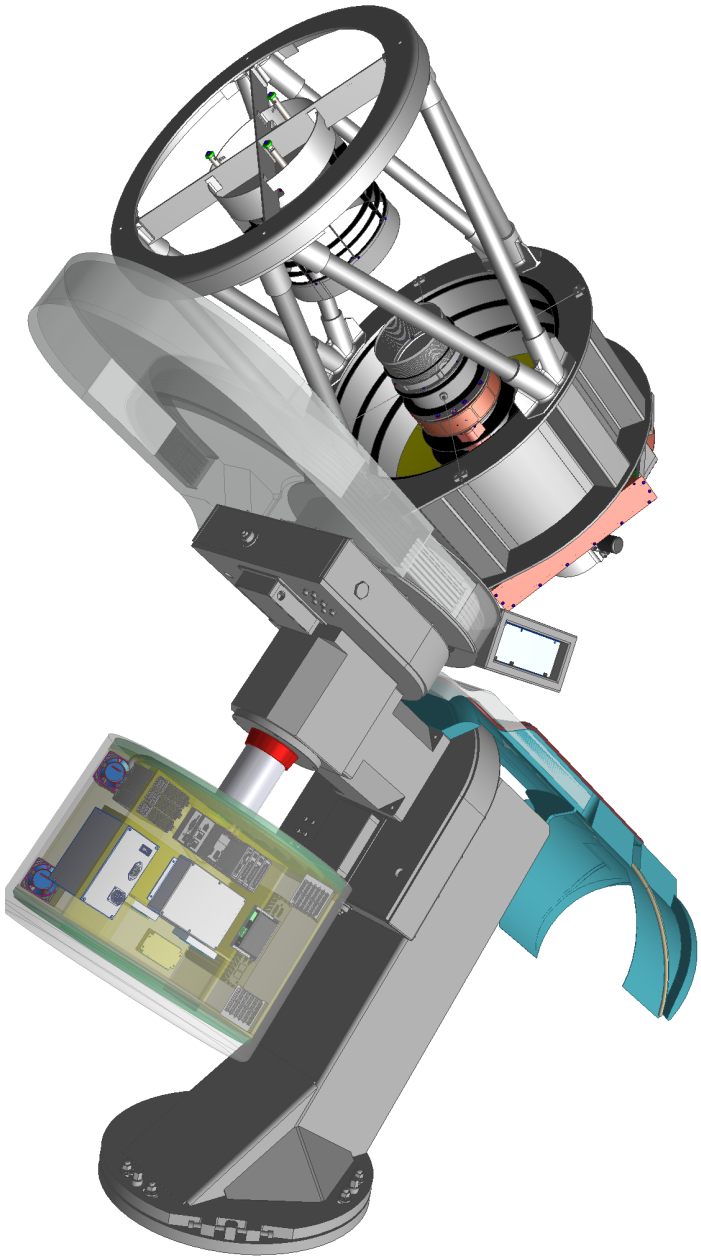
Steven Bloemen
BlackGEM Instrument Scientist
Radboud University, Nijmegen, NL

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
→ Q1 2017

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

BlackGEM Array

- Phase-I: 3 telescopes
  Funded by Netherlands
  (NOVA, RU, FOM) and KU Leuven
- Southern sky: **La Silla**
  - Complementarity to iPTF/ZTF
  - 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 per telescope
- Thanks to good site:
  ~23rd mag in 5 minutes in r'

Q1
2017

MeerLICHT

First telescope of BlackGEM type

Sutherland South Africa

Changing transient science to truly multi-wavelength

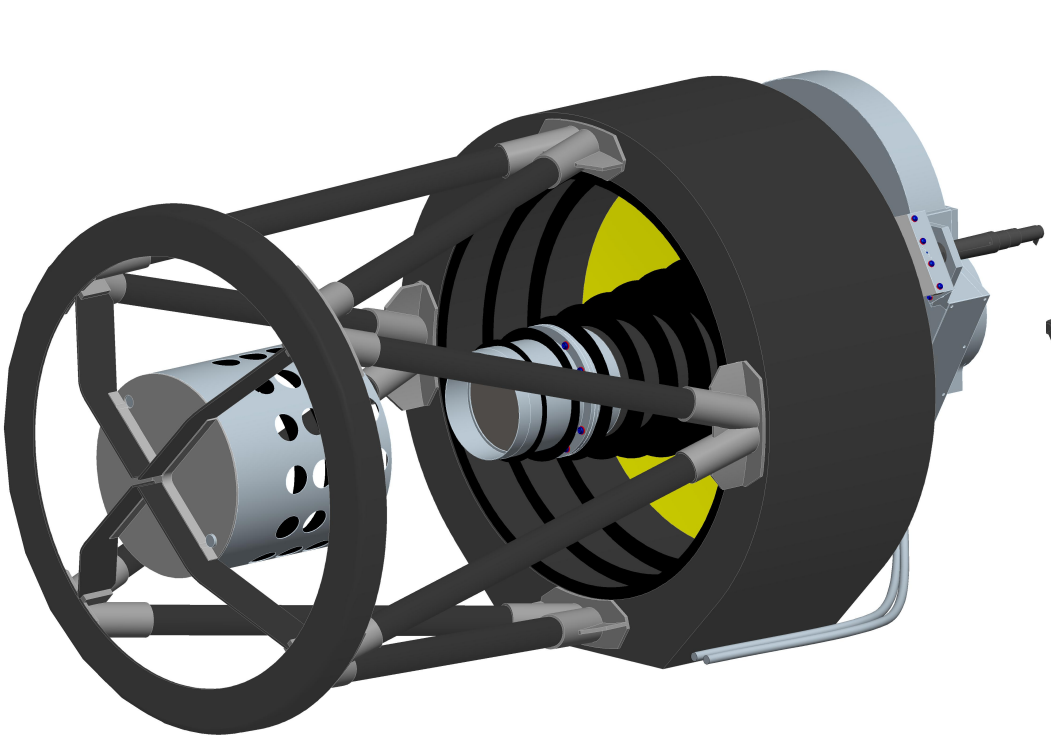
Pointing determined by MeerKAT radio telescope

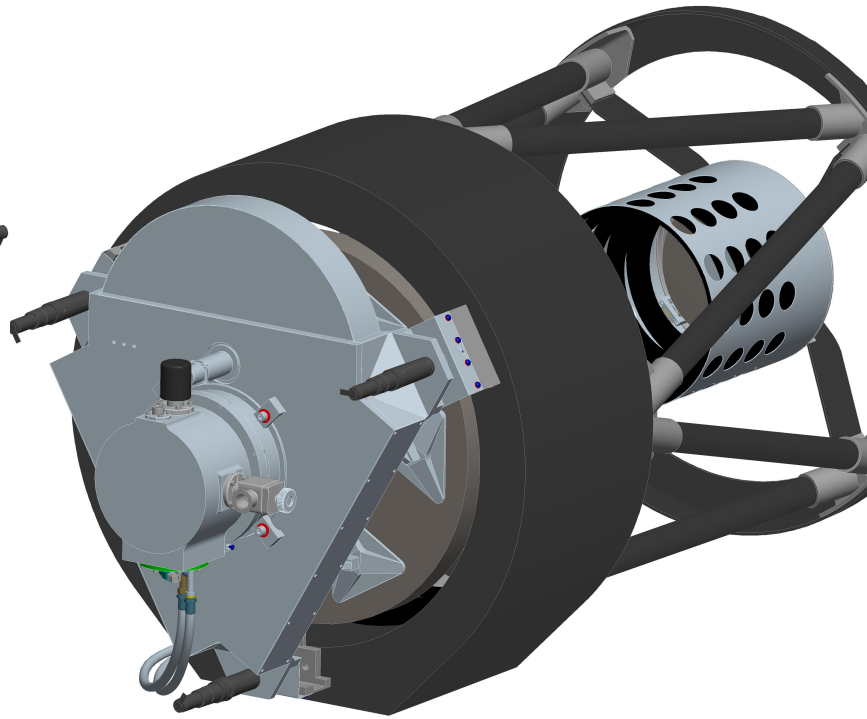
In South Africa: bridge between SALT and SKA/MeerKAT

Radboud, NOVA, NWO (NL);
UCT, SAAO (SA); Oxford (UK)

Custom optical, mechanical design

- Cassegrain camera, u'g'r'i'z' and wide vr filters
- Modified Dall-Kirkham design: 2.7 sqd FOV @ 0.56 arcsec/pix
- Single 10k * 10k CCD per telescope
- ~23rd mag in 5 minutes in g+r wide band
- Nominal cadence of 1 min



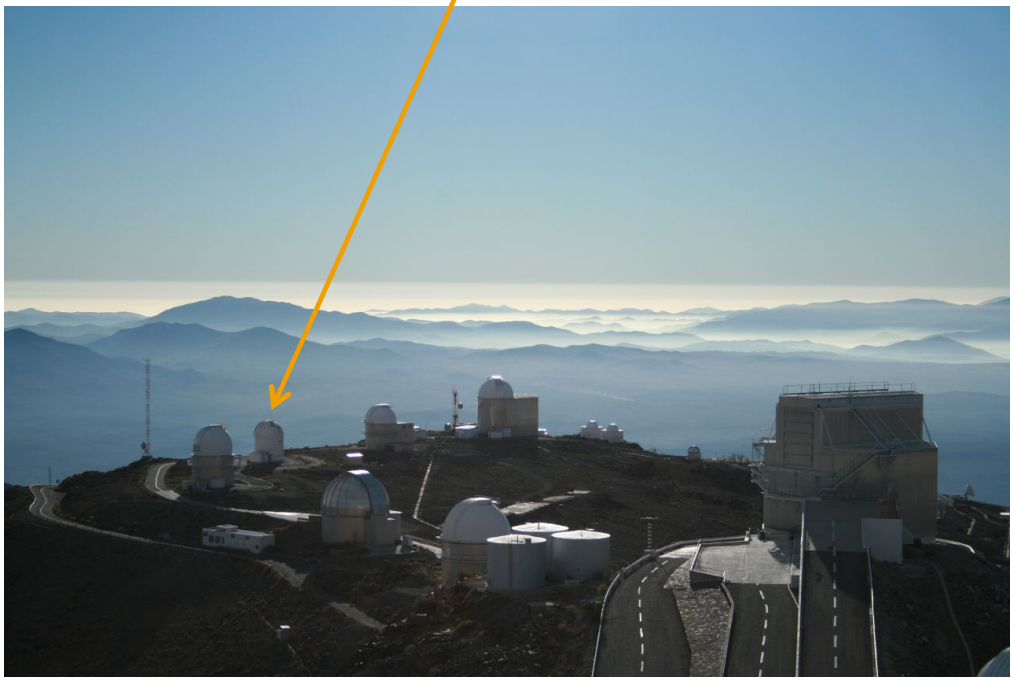


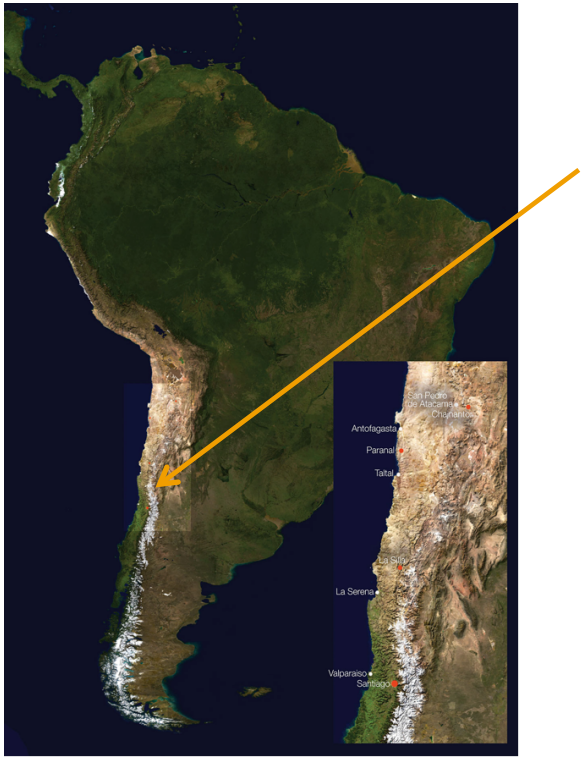
BlackGEM filter set and depth

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 site: La Silla





2018

Three phases in BlackGEM operations

Phase 1: (50% of year 1) **All Sky Survey**

Full Southern Sky in u,g,r,i,z down to ~23nd mag in r'

Phase 2: (50% y1 + when no trigger) **Survey Phase**

Rates of false positives: $N_{candidates}(l,b, \tau, mag, colour)$ $(degr^{-2}\, hr^{-1}\, mag^{-1})$

- Various fields probing different environments/populations
- Cadence: 1 minute, cycling through 3 bands (g+r ,r, i)
- Time per field: 1 to 2 weeks (320 or 160 sqd/year)

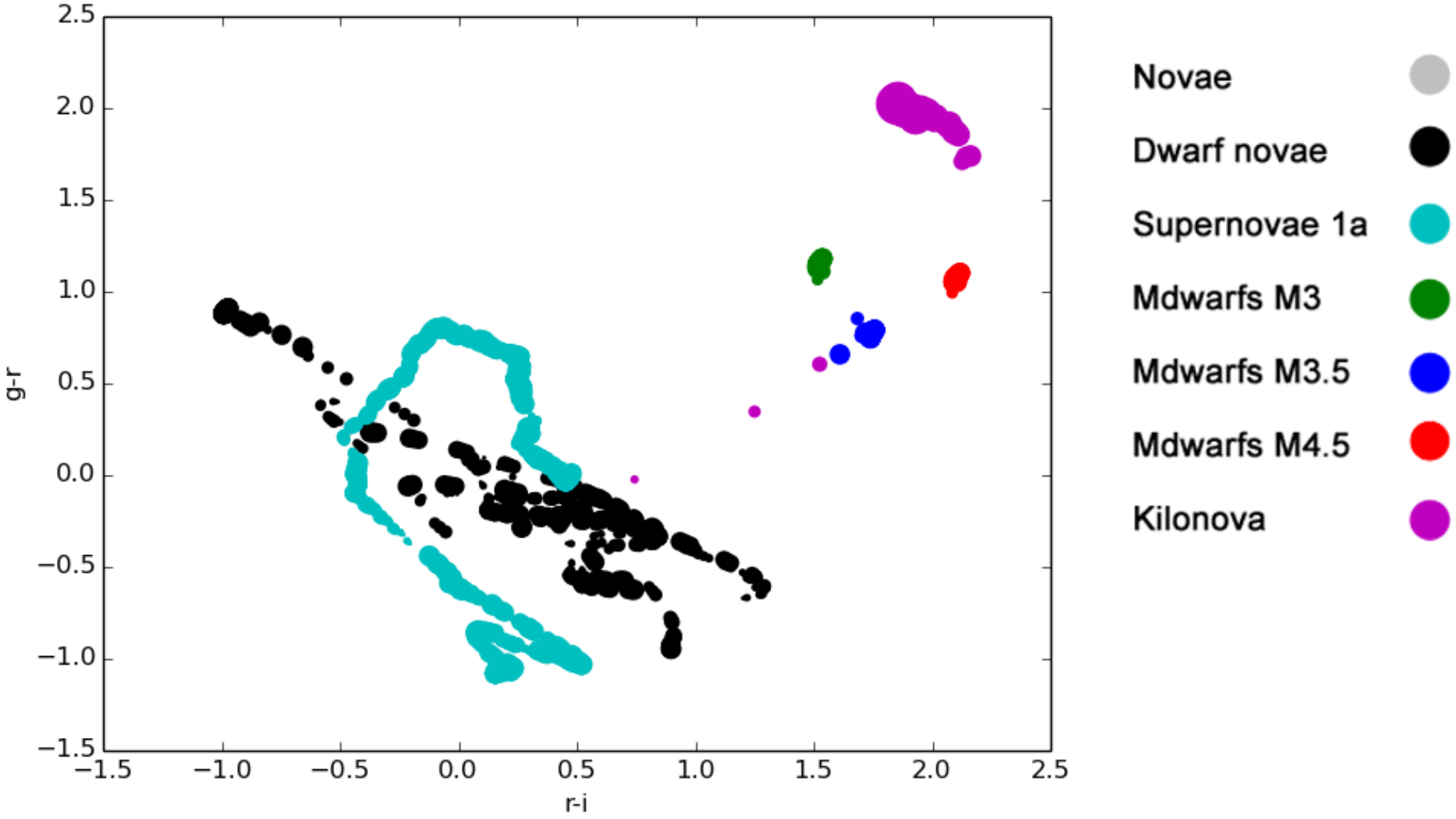
Phase 3: **Trigger Phase**

GW events

- Follow-up of Virgo/LIGO detections
- Cover the error boxes in a tiling pattern

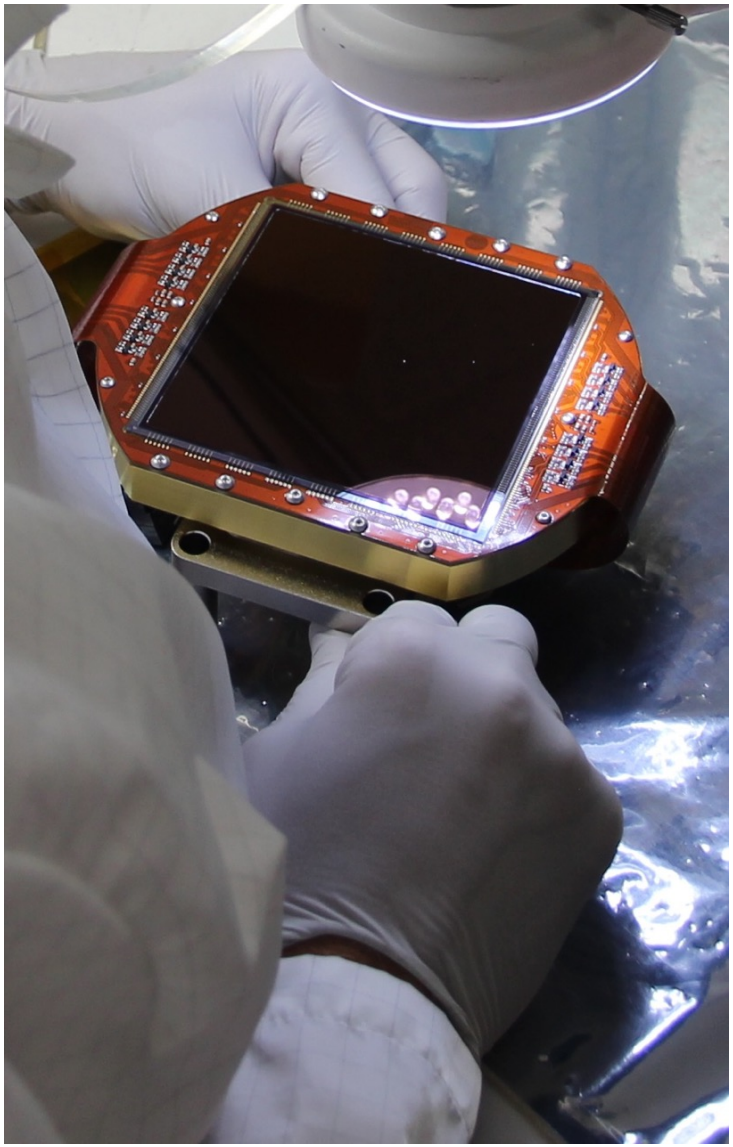
False positives will be the bottleneck

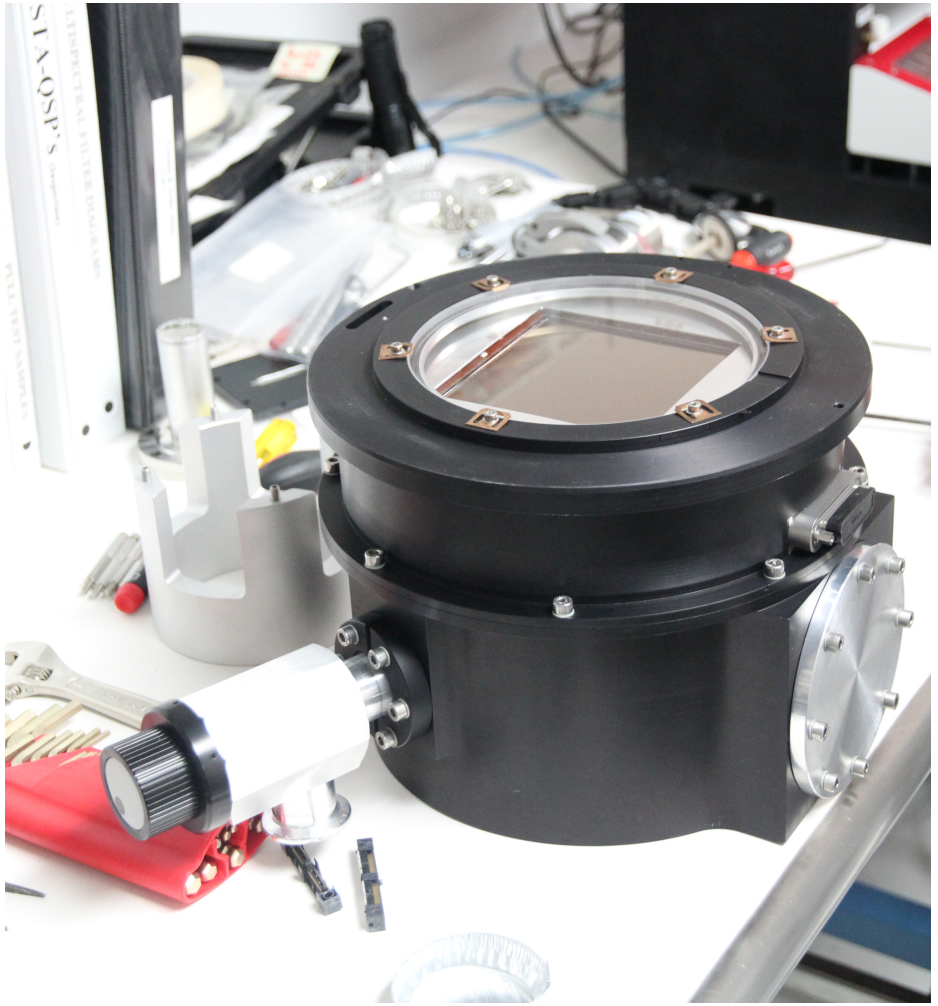
Need colour-info and variability timescale!



Bob Jacobs, BSc student Nijmege

Currently assembling prototype





Data challenge

Sources (non-unique)

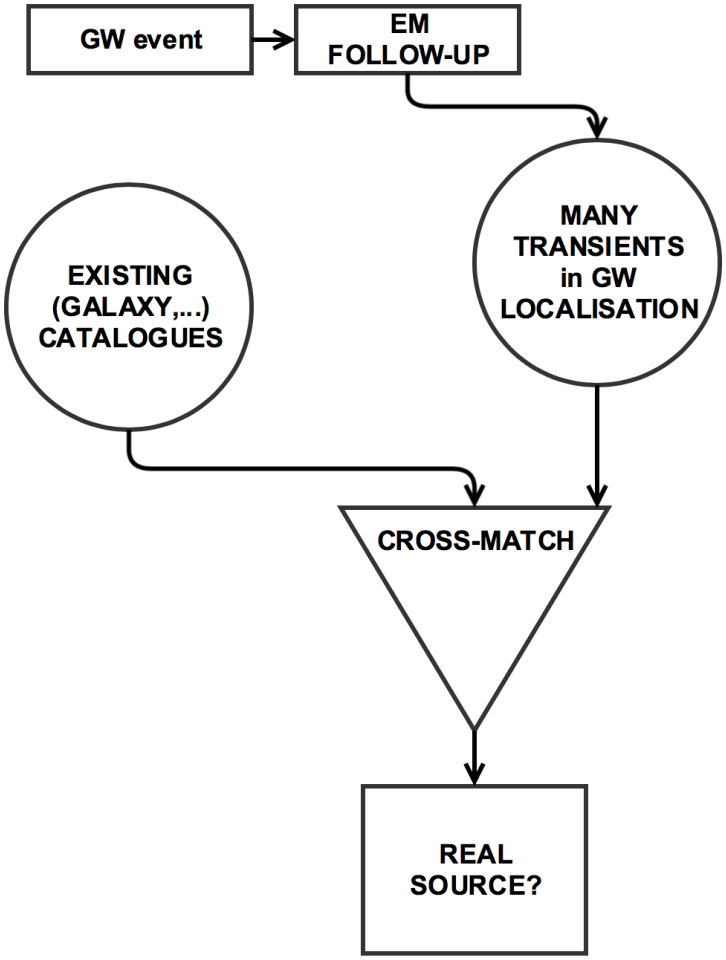
- ~10^5 per 5 minute integration
  * 120 images/night = 12 million / night / telescope
  * 250 days/year = 3 billion / year / telescope

- Many detections are of the same sources
  (database challenge: match 10^5 points with 10^9 catalogue sources in seconds)

Transients & variable sources

- ~10^5 per night after ML vetting and removing known stars

(Potentially) VO-related GW follow-up challenges



- Few GW alerts ('diamonds'); many associated optical alerts ('firehose')

  → One is the 'diamond' you are looking for

- Match with existing catalogues
- Footprint sharing [RA/DEC, colour, depth, time]
- Need to combine data from many instruments:
  - Multi-wavelength
  - Timeseries