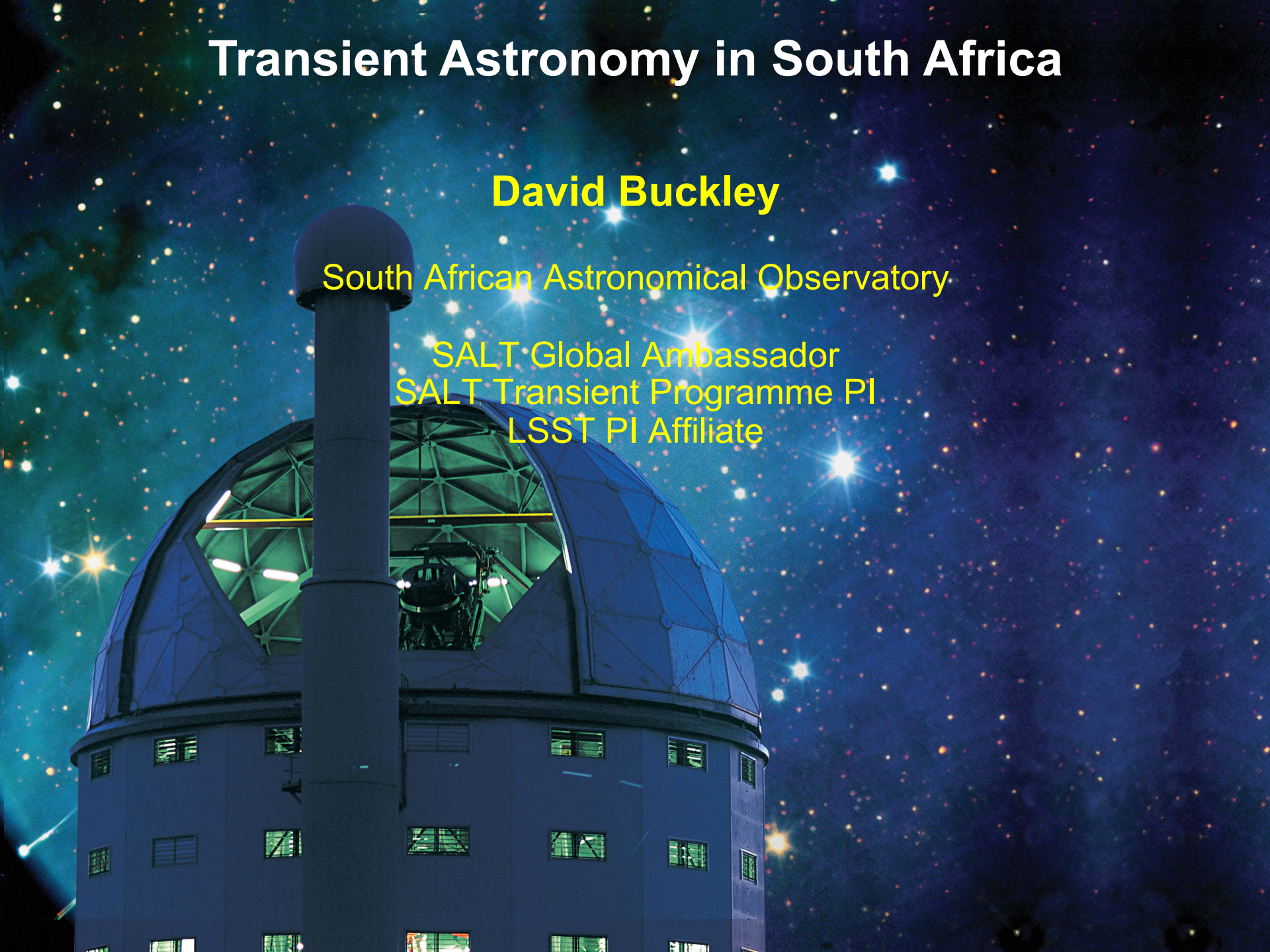
Transient Astronomy in South Africa



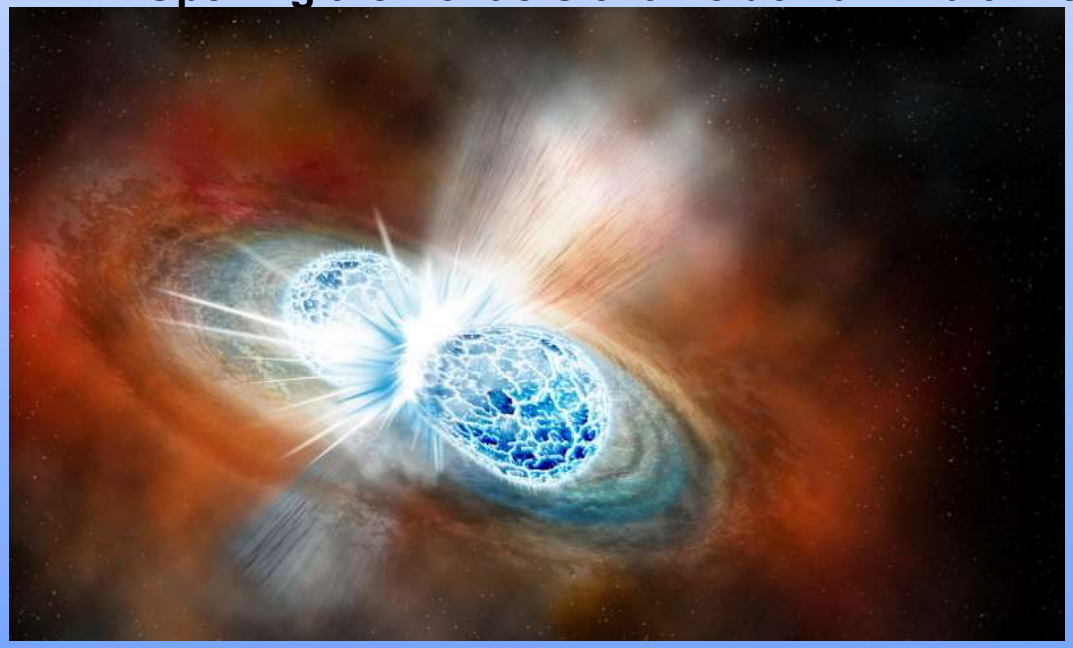
David Buckley

South African Astronomical Observatory

SALT Global Ambassador
SALT Transient Programme PI
LSST PI Affiliate

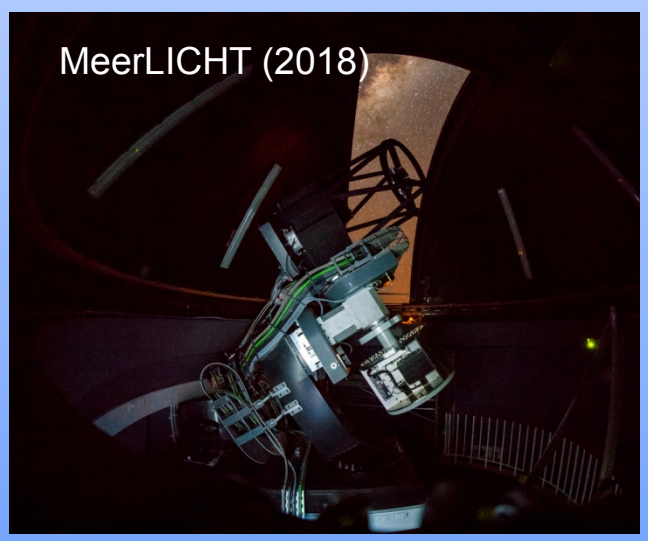
The Transient Universe

- Time domain and transient astronomy is a growing frontier of discovery space
  - "things that go bump in the night"
- Allows studies of variability over timescales of milliseconds to years
- Observations of transient behaviour for a wide range of objects and timescales
  - From the closest (Solar System) to the furthest
  - Some of the most energetic objects in the Universe
  - Opening the frontiers of time domain multi-messenger astronomy

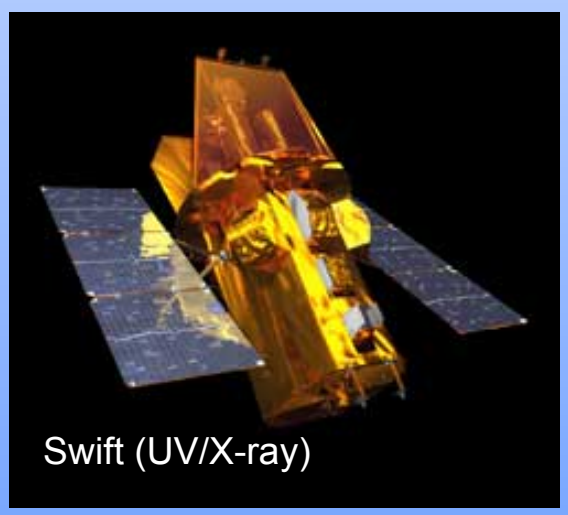


The Transient Universe

- Increasing number of facilities and surveys leading to discoveries of transients of all classes (including new facilities at SAAO)
- Some dedicated to specific classes of objects (e.g. supernovae)
- Others finding many different classes of transients as a by-product of wide-field surveys (e.g. Gaia, OGLE, PanSTARRS, ZTF, TESS)
- Both ground-based and space-based facilities are sources of alerts
- South Africa has developed its own ground-based optical detection facilities
- A SALT large science programme on transients began in 2016
- Paving the way for the next big transient discovery machine: ***the Large Synoptic Survey Telescope (LSST)***
- Need for machine learning tools based on current experiences

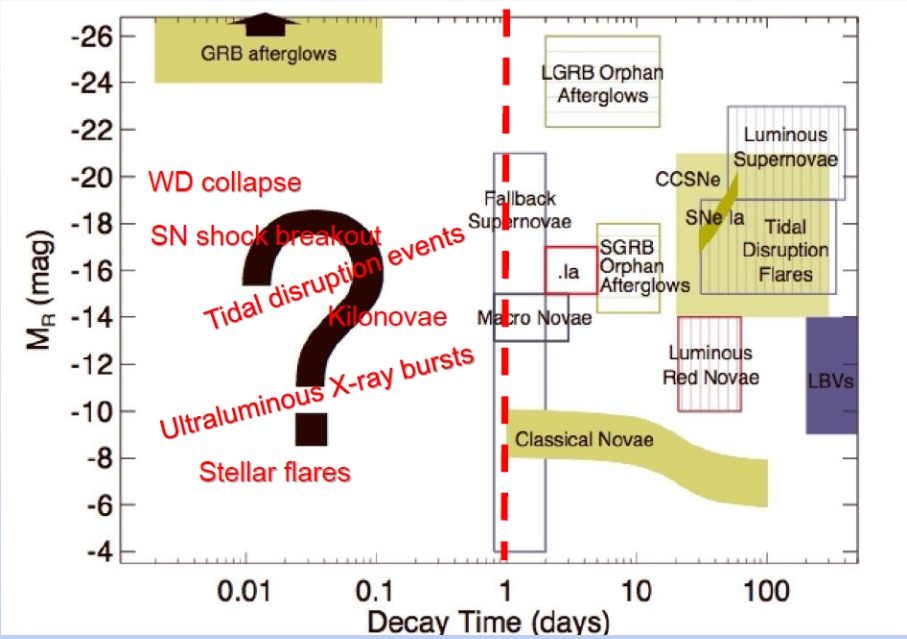

MeerLICHT (2018)

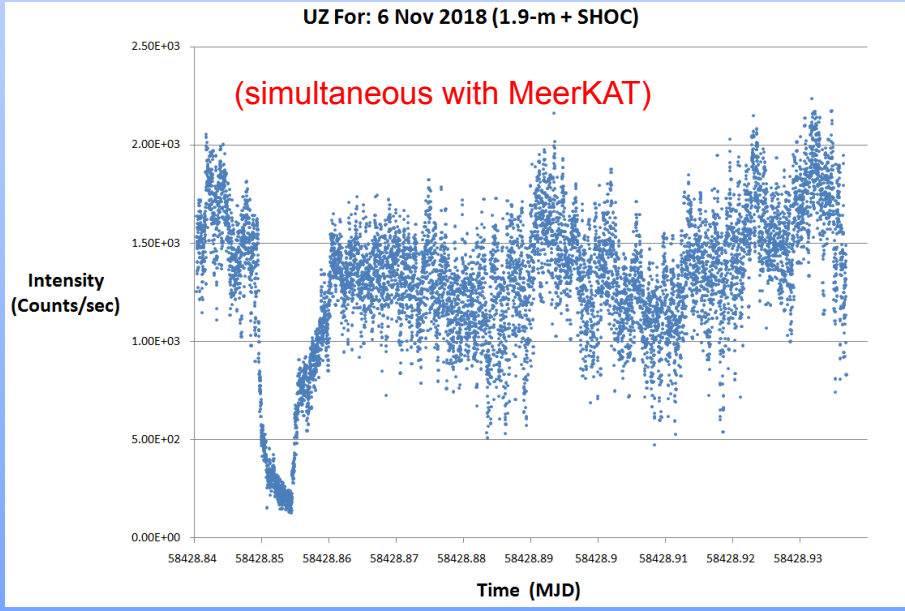
MASTER-SAAO (2015)


Swift (UV/X-ray)

SALT Transient Program

- **Covering wide range in luminosity (& distance)**
- **Variability on wide range of timescales**
  - **Sub-seconds domain a new frontier**
- **Covering many object classes**
  - **X-ray transients**
  - **Cataclysmic Variables**
  - **Novae**
  - **Intermediate luminosity transients**
  - **Tidal Disruption Events (TDEs)**
    - » **From Gaia, OGLE**
  - **Black Hole microlensing events**
  - **Flaring Blazars**
  - **Unusual supernovae (e.g. Super Luminous Supernovae)**
  - **Gamma-Ray Bursts (GRBs)**
  - ***Multi-messenger (Gravitational Wave & Neutrino) events***
  - ***Radio transients with MeerKAT (ThunderKAT programme)***

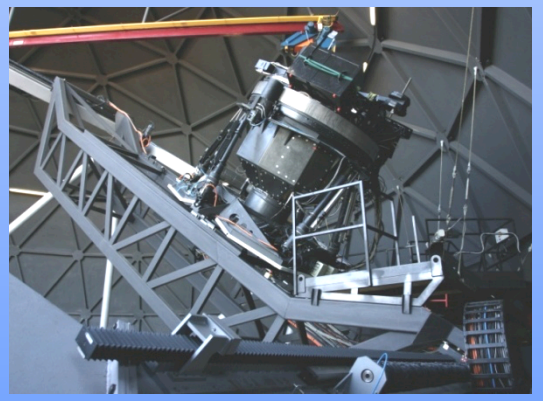


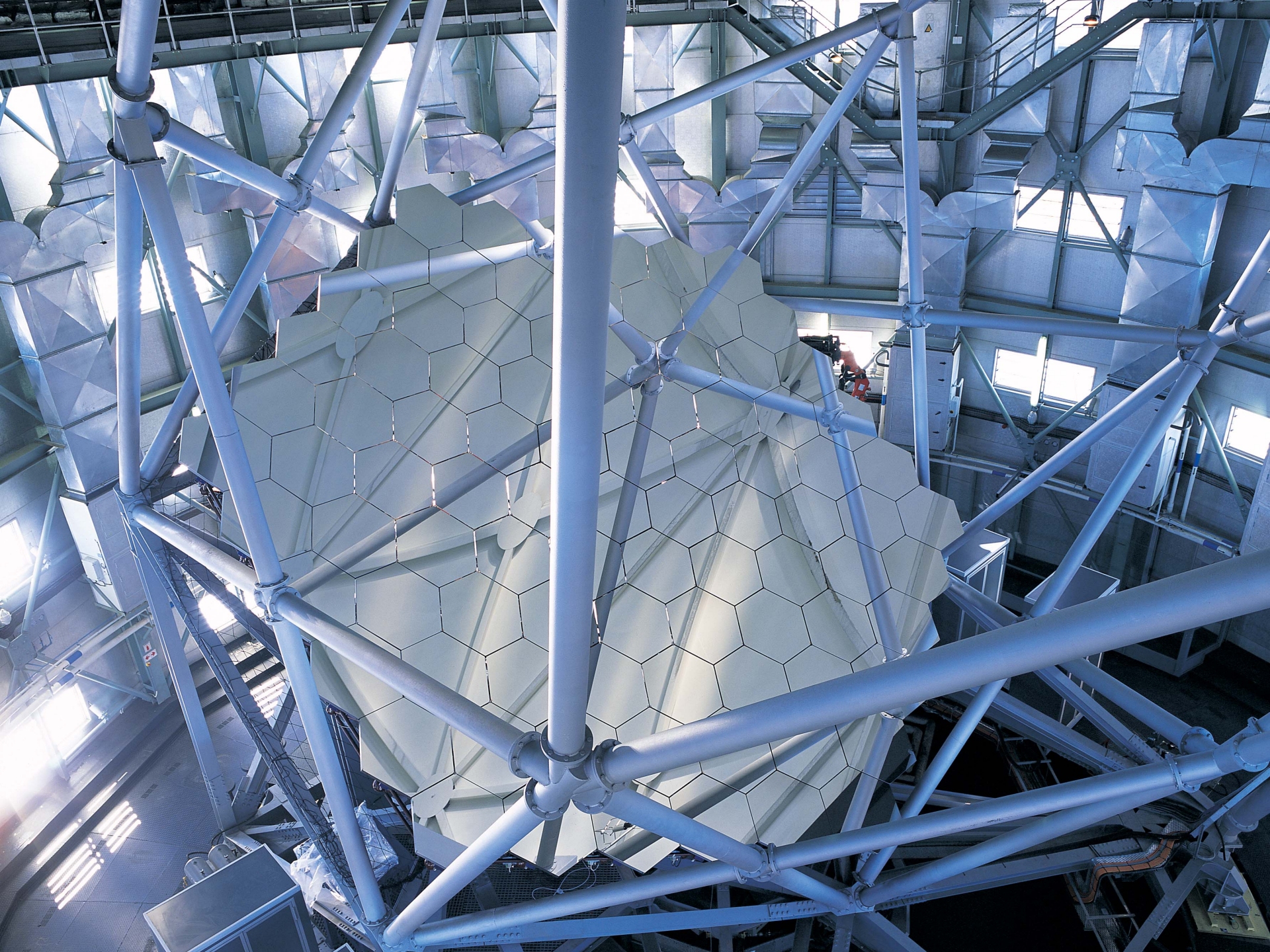


The SALT Transient Programme

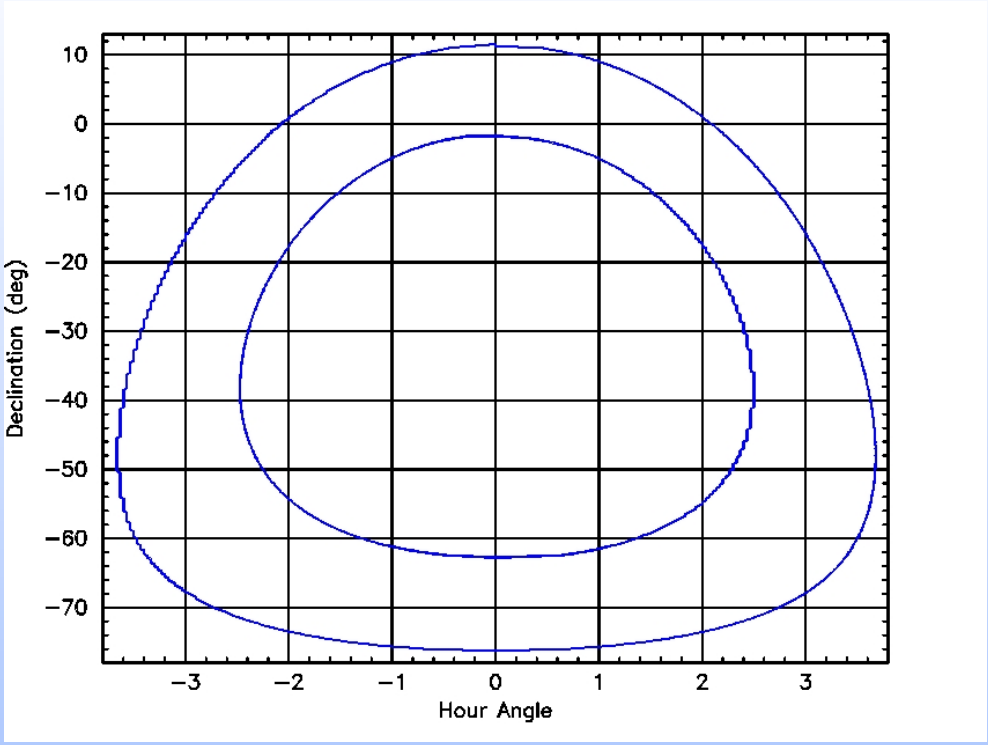
- **SALT Large Program on transients began in May 2016**
  - Large allocation 300ksec / semester
  - High fraction (60%) in highest priority (e.g. ToO) class
  - allows for rapid response to alerts
  - Can monitor objects on different cadences
  - Basic pipeline reduced data available in < 12 h (raw data immediately)
  - *Recently extended for 3 more years*

- **Multi-institutional/multi-partner program**
  - 5 South African institutions (SAAO, UCT, UFS, NWU, UJ)
  - 4 other SALT partners (Poland, India (IUCAA), UK, U. Wisconsin)
  - 32 investigators (incl. many graduate students)
  - Now being expanded to include other international participation (e.g. China, Russia)





Observing Transients With SALT



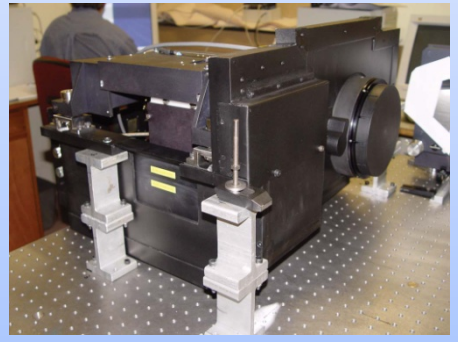
SALT Viewing Annulus

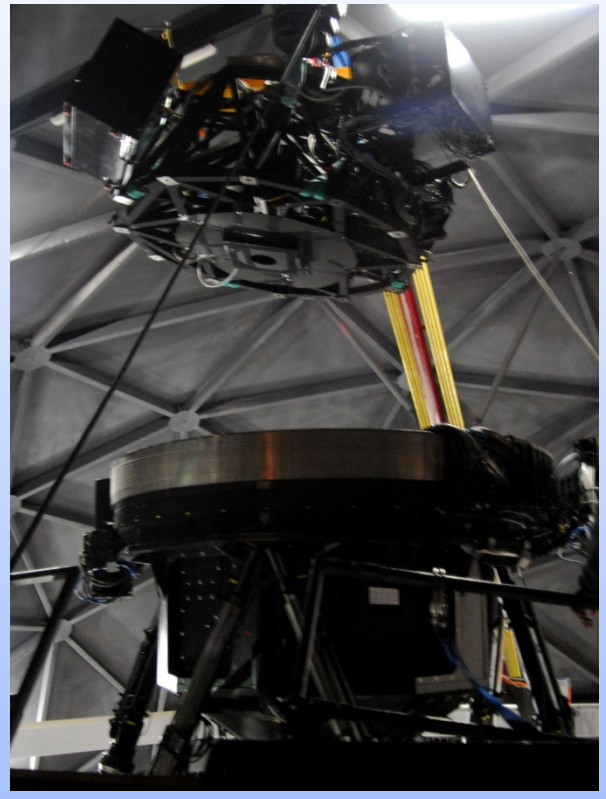
- 100% queue scheduled service observing
- Variety of instruments/modes
- Rapid instrument changes and mode configurations
- Scheduling allows for synoptic monitoring at difference cadences
- Targets of Opportunity can be done at short notice
- Ideal for followup of transients

Observing Transients With SALT

Available Instrumentation:

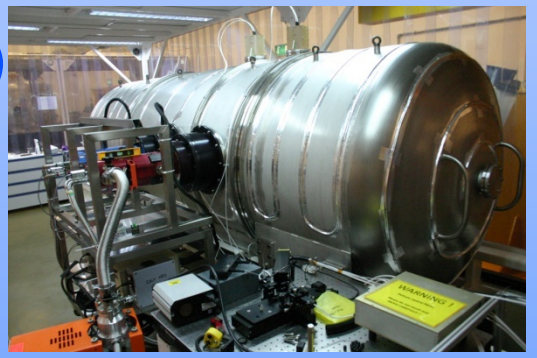
- **Robert Stobie Spectrograph (RSS)**
  - Low-medium resolution (300 – 6000)
  - 3200 – 9000Å
  - Fast spectroscopy (10 Hz)
  - Fast imaging (10 Hz)
  - Spectropolarimetry
  - Imaging polarimetry
  - Fabry-Perot imaging





- **SALTICAM**
  - Fast imaging (10Hz)
  - Deep multi-filter imaging (griz, UBVRI, Hα)

- **SALTICAM High Resolution Spectrograph (HRS)**
  - High resolution (16,000, 34,000, 60,000)
  - 3800 – 8900Å
- **Berkeley Visible Image Tube (BVIT)**
  - Photon counting MCP
  - Time tagging photon events to 50 ns



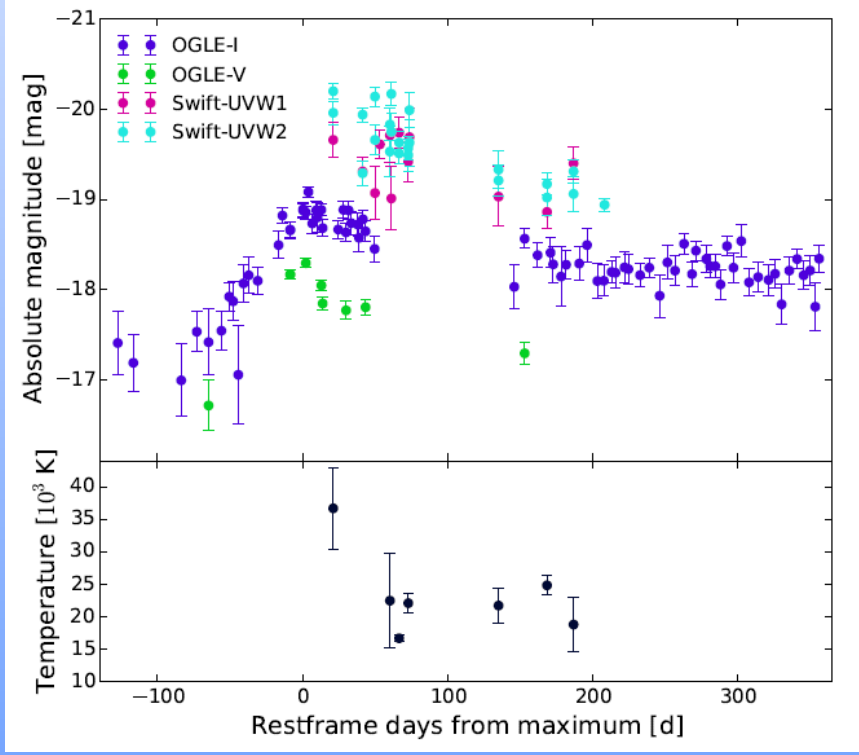
Breakdown of Observations to date (2016 – 2018)

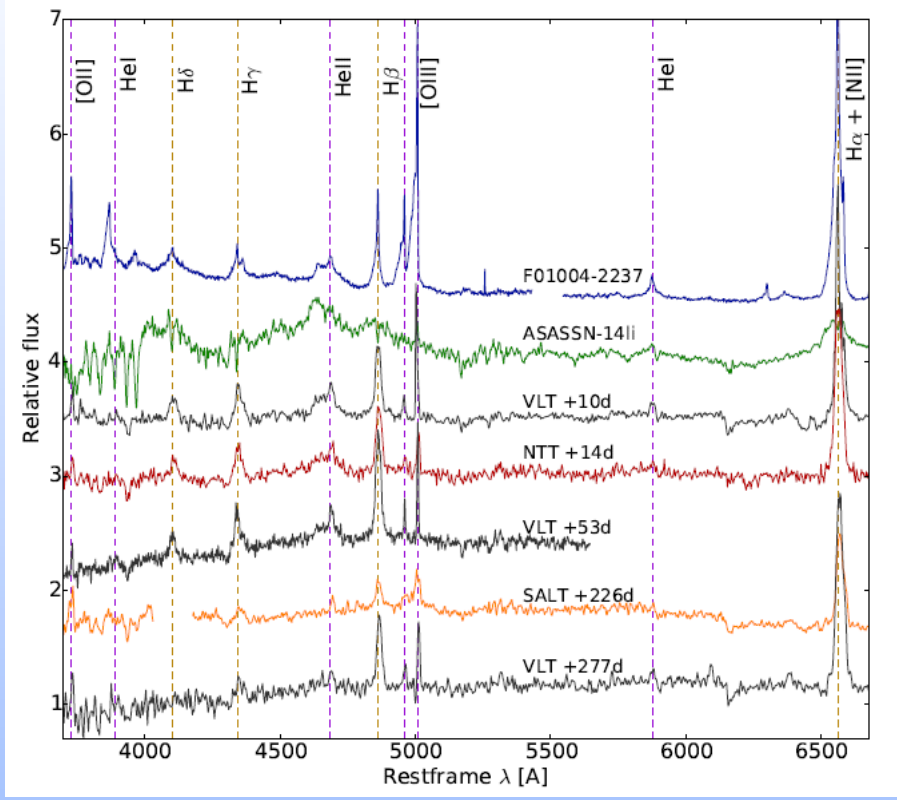
• Gaia, OGLE, ASASSN, ATLAS transients (TDE, nuclear, some SNe, microlensing events)	24.1%
• X-ray Transients (LMXBs, HMXBs)	23.8%
• Cataclysmic Variables (dwarf novae, AM CVn, SSS)	19.5%
• Supernovae (Super Luminous, core collapse)	10.6%
• AGN (mostly blazars)	9.9%
• Novae	9.5%
• GRBs	1.4%
• Swift transients	1.2%

Nuclear Transients

OGLE17aaj (Gromadzki *et al.* 2019):

- Photometric and spectroscopic monitoring
- Some TDE properties
  - Long rise time
  - no colour variation
  - high BB temperature





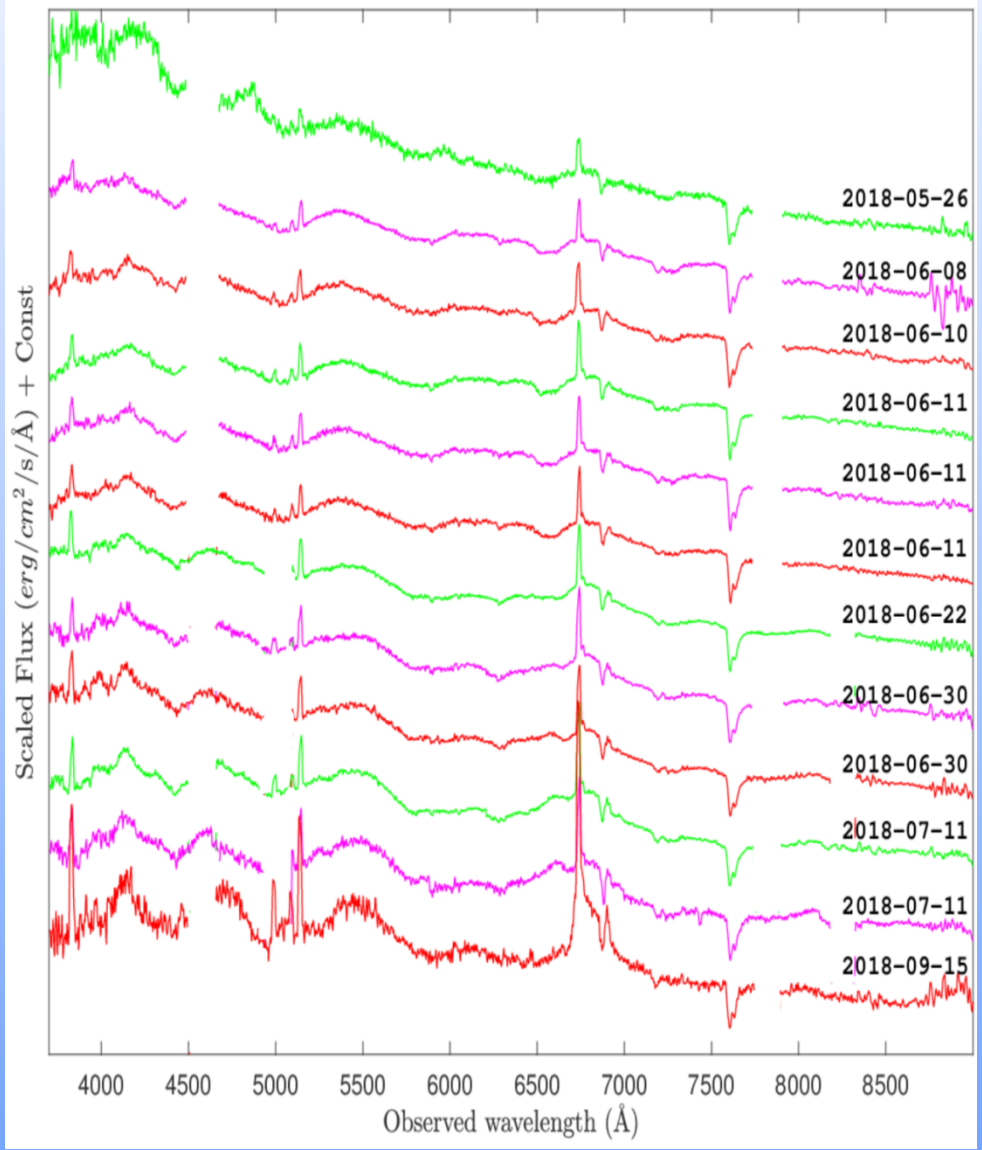
- Other properties not so typical
  - Narrow emission lines
  - Slow evolution
  - low luminosity

- Might be rather associated with supermassive black hole
  - Historical variability may support this

Super-Luminous Supernovae
IUCAA (India) & KIAA, PKU)

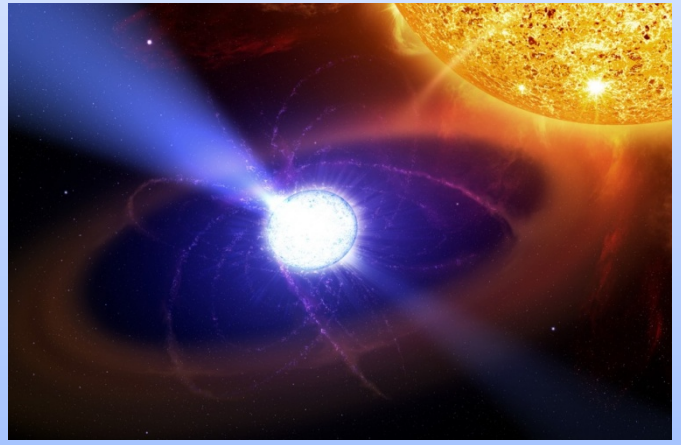
- Class only recognized in last ~decade
- 10-100 x more luminous than usual SNe
- Rare (1 in 1000)
- Closest one to date (z = 0.027)
- 12 epochs of SALT spectroscopy (from -5 to 107 days w.r.t. Peak brightness)

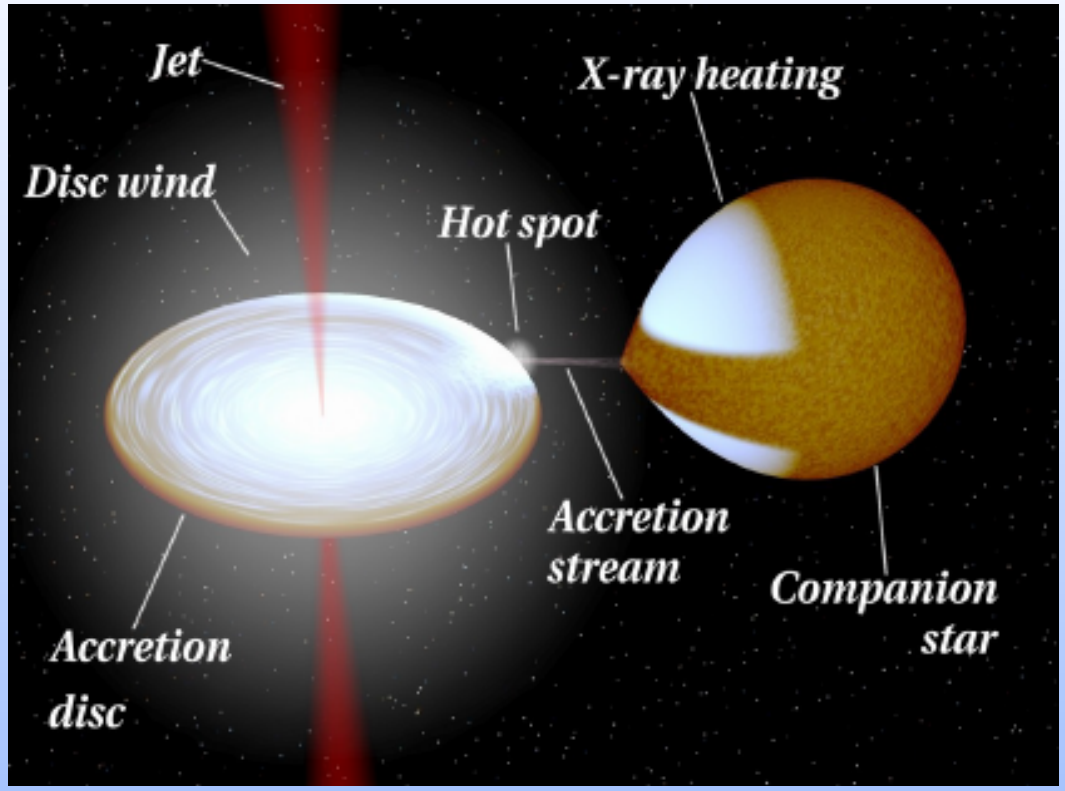
ASASSN-18km



X-ray Transients
(SA, India, UK)

- High Mass X-ray Binaries
- Low Mass X-ray Binaries
- Transitional millisec pulsars (also first observations with MeerKAT)





- Involves accretion onto either a neutron star or a black hole.
- Mass donor is usually “normal” M-S star (rare ones a sub-solar)

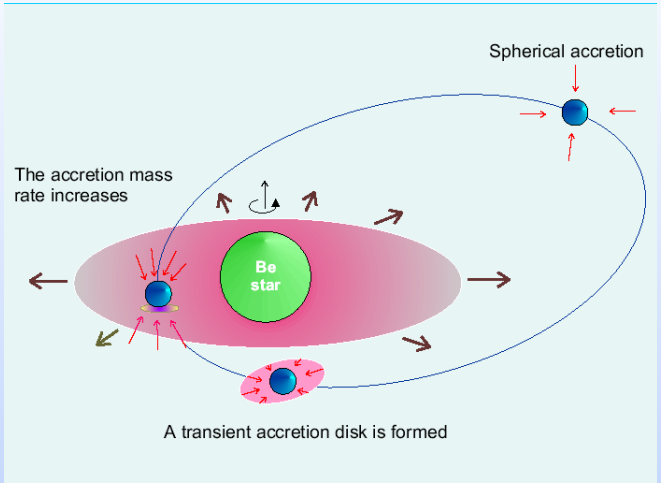
X-ray Transients results

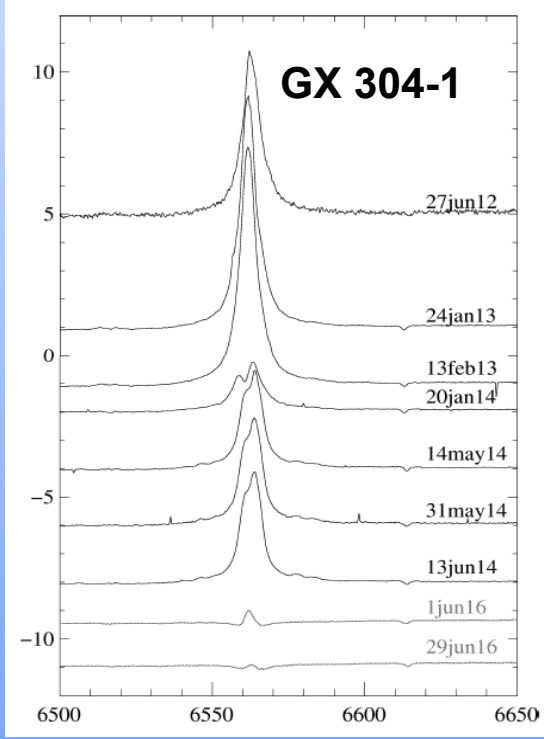
- High Mass X-ray Binaries (Be/X-ray systems; neutron stars)
- Low Mass X-ray Binaries (Black Hole or Neutron Star binaries) + transitional ms pulsars
- 16 systems observed, 9 publications, several papers in preparation, 2 objects too faint

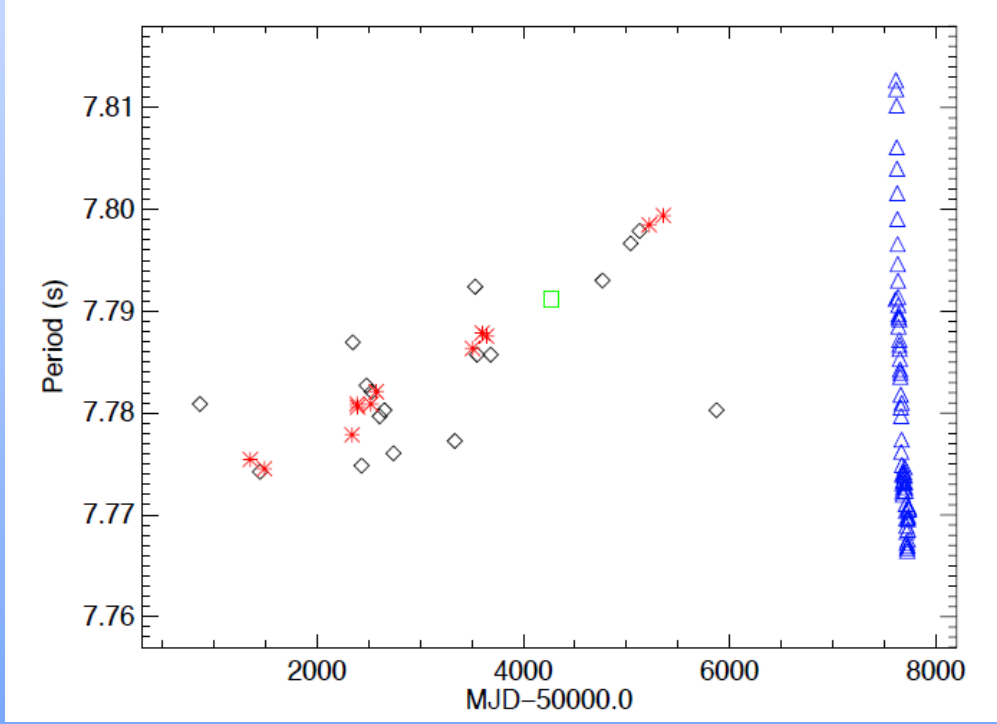
Object	Transient event	Status/Publications
SMC X-3	BeXRB; 2016.7.3 type II outburst (ULX-level) in HMXB	Townsend et al 2017 MN 471, 3878
MAXI J1957+032	LMXB likely new AMXP; 2016.10.1 V~18 ->21; SALTICAM imaging	Mata Sanchez et al 2017 MN 468, 564
ASASSN-16oh	new SSS in SMC; 2016.12.14 V~21-16; RSS	Maccarone et al 2018, Nature Ast, 3, 173
Swift J1357.2-0933	BHXB; 2017.4.21 2nd outburst (+NuSTAR) 2019.5 -.6 3° outburst (optical)	Paice et al 2019, MNRAS, 488, 512 Charles et al., 2019, MNRAS Letters, 489, L71
MAXI J1535-571	BHXB; 2017.9.8 V>20 SALTICAM, AstroSAT	Baglio et al. 2018, ApJ, 867, 114
MAXI J1808+070	BHXB; 2081.4 – 2018.11 RSS, SALTICAM	Munoz-Darius et al., 2019, ApJL, 979, L4.
CXOU J110926.4-650224	tMSP; 2018.11 RSS spectra; MeerKAT	Coti Zelati, et al. 2019, A& A, 622, id.A211, 21
SXP 91.1	Be/XRB; Type I burst; SALT RSS spectra	Monageng et al., 2019, MNRAS, 489, 993
SXP 4.78	Be/XRB; Type II burst; SALT RSS spectra	Monageng et al., 2019, MNRAS, 485, 4617

High Mass X-ray binaries

- Wind or disk accretors
- GX304-1 Be/X-ray binary outburst
- 2016 super-Eddington outburst of SMC-X3
  - Spin up
- Synoptic monitoring of Hα profiles
- Several new BeXRBs in the SMC (one new *eROSITA* source)

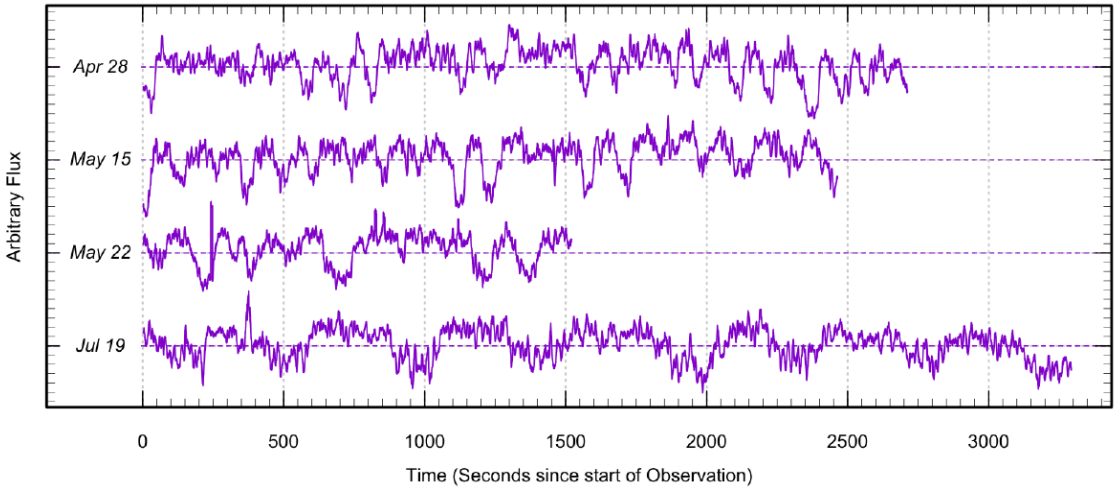


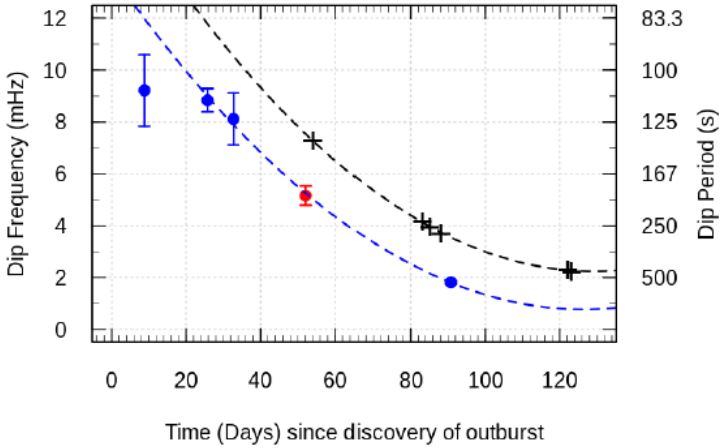




LMXB: Swift J1357-0933

- A black hole X-ray transient (discovered in 2011; M > 9.3 $M_{\odot}$)
- SALT observations during recent o/b in 2017
- 0.15 s sampling
- No correlation between optical & X-ray
- Dips seen in light curves at few 100s timescale, which evolves

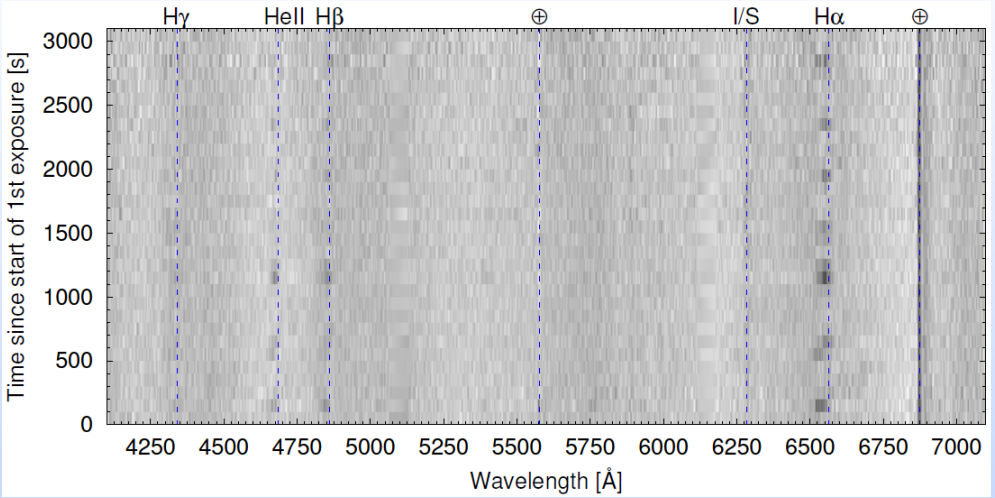


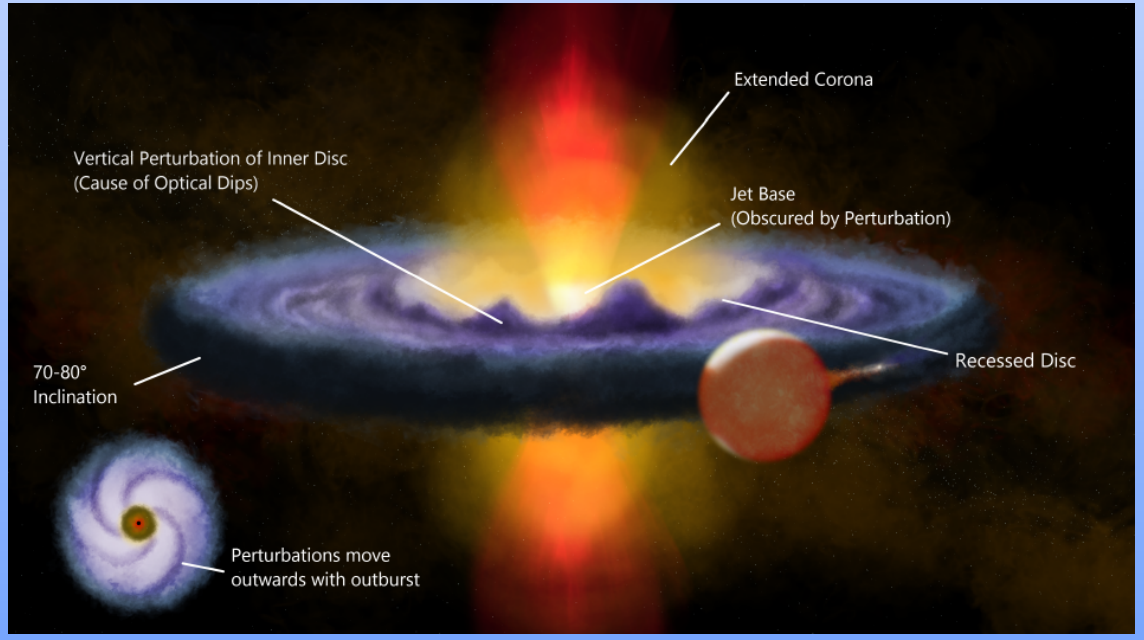


SALT high-speed (0.15 s) photometry of Swift_J1357.2-0933

Swift J1357-0933

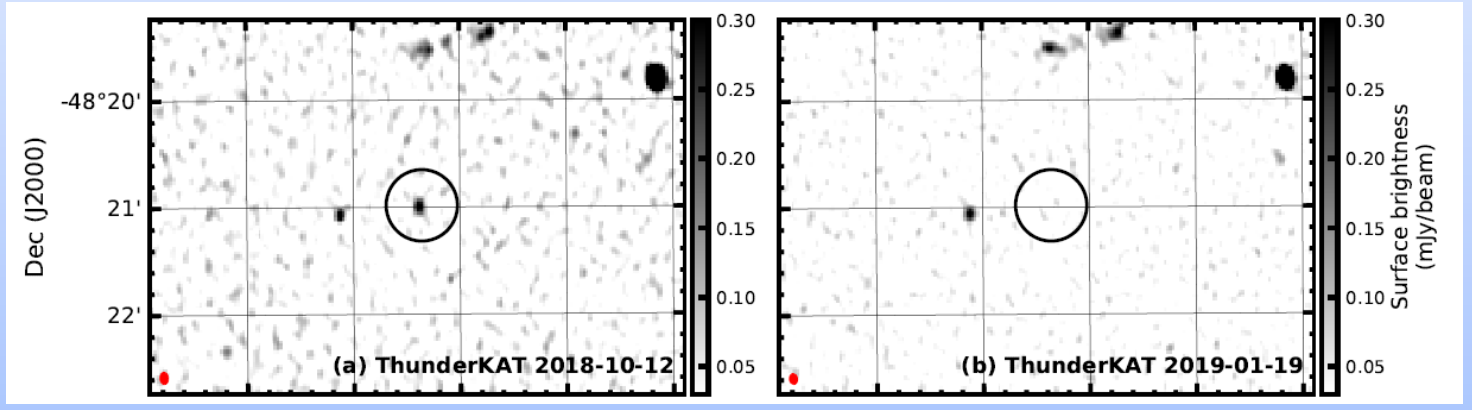
- **Time resolved (30 s) spectroscopy during 2017 & 2019 outbursts revealed transient absorption lines on same timescale as photometric dips**
- **Unusually, HeII 4686Å is seen in absorption. Interpreted as evidence for a hot, dense wind**
- **Vertically extended structures of inner disk torus occult the inner regions**

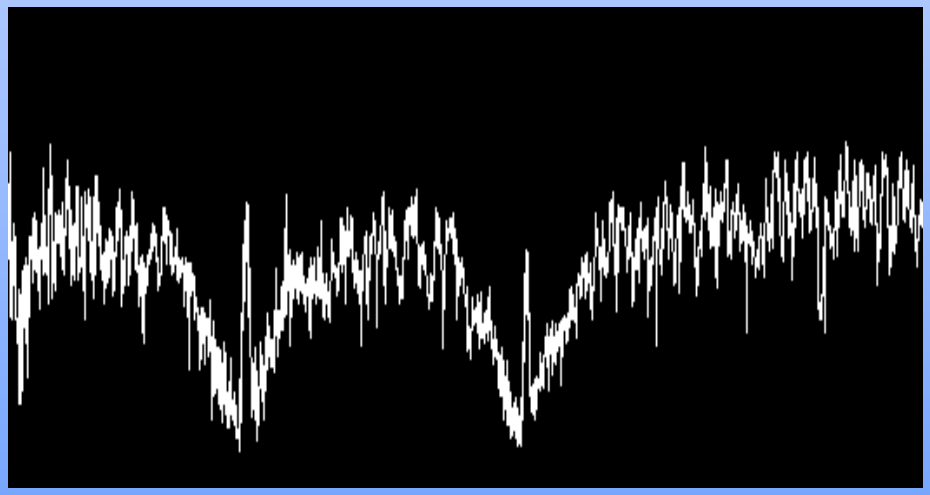


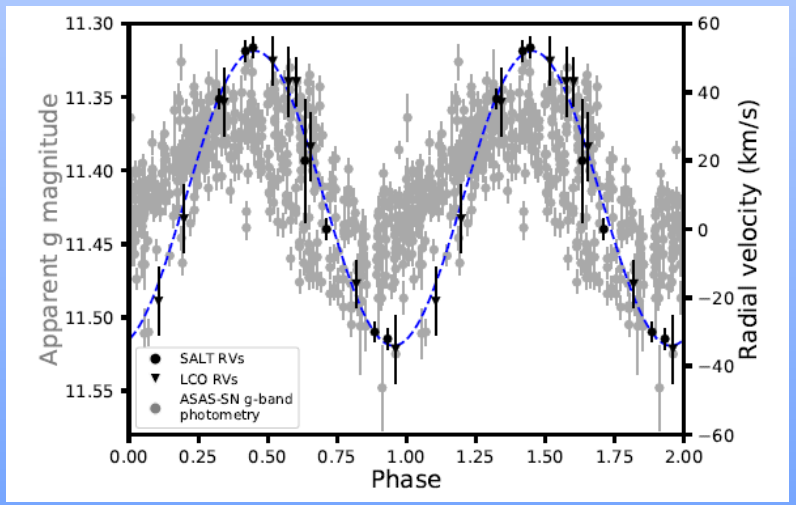


Followup of first radio transient from *MeerKAT*

- **Transient found in *ThunderKAT* programme of GX339-4 monitoring**
- **The radio source (MKT J170456.2-482100) is coincident with a V = 11 Tycho star, TYC 8332-2529-1**
- **SALT & LCO spectroscopy and reveals system to be RS CVn binary with 21 d orbit. Also see photometric variations on this period.**







SAAO Sutherland plateau: An Intelligent Transient Observatory

Future aspirations at SAAO: make the whole Sutherland site an integrated intelligent machine for transient followup

This work is beginning now with several recent initiatives:

- funding for a new highly efficient red arm for RSS spectrograph
- resources being provided to allow development of SW scheduling tools in collaboration with other groups (e.g. LCO)
- South African participation in LSST on Transients and Variable Stars

New SAAO Followup Opportunities

Follow-up selected objects (e.g. CVs, blazars) with robotic facilities and SALT

Photometric monitoring (orbital periods):

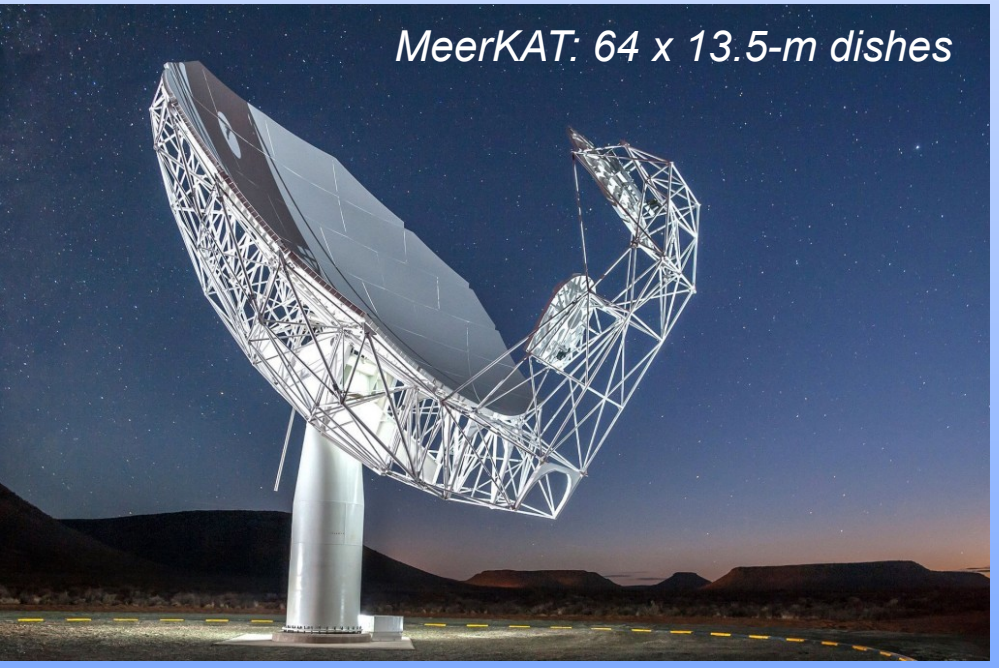
- LCOGT 1.0-m (+ other longitudes)
- MONET 1.2m
- new SAAO 1.0 m robotic telescope (*Lesedi*)
- instruments including CCD and high speed EM-CCD cameras and spectrograph(s)

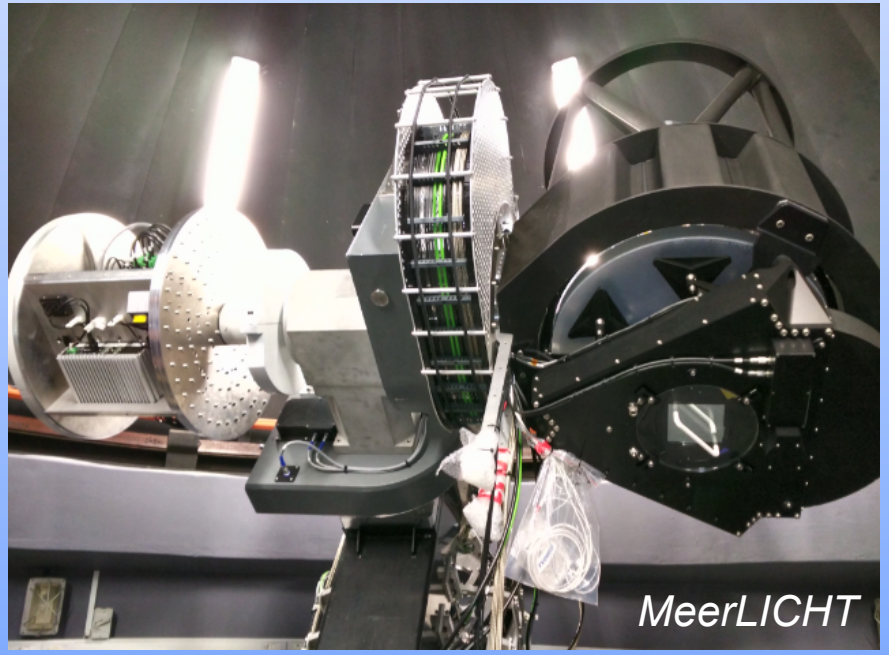
MONET-South

New 1-m robotic telescope (*Lesedi)*

Transient Observation Opportunities

- ***MASTER-SAAO*** **will be joined in 2017 by** ***MeerLICHT*** **(0.65 m; 2 sq ° FoV)**
  - **Joint Dutch-SAAO venture**
  - **Optical monitoring of** ***MeerKAT*** **fields**
  - **Correlate with** ***radio transients*** **to identify optical counterparts**



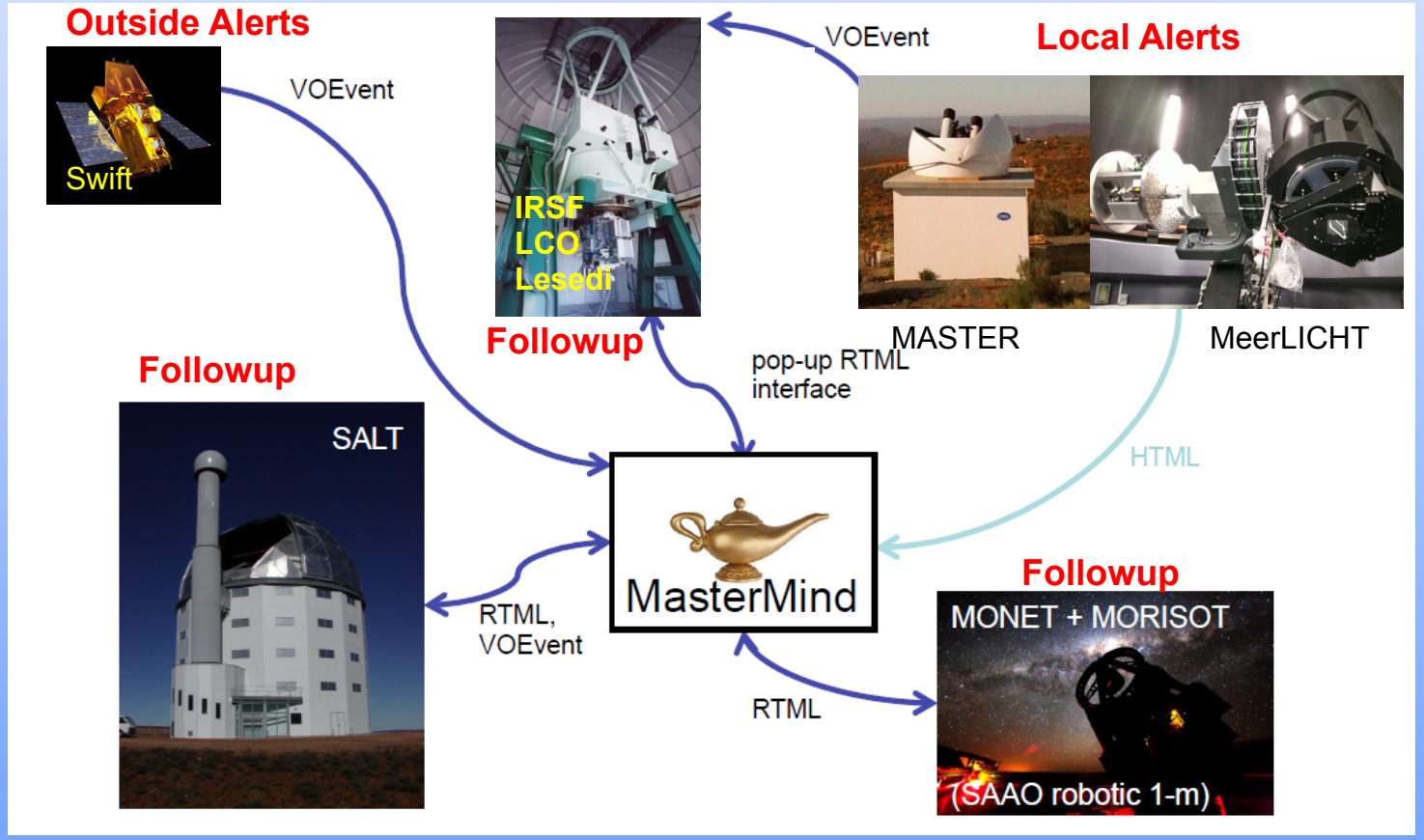


PRIME: Wide Field Infrared Telescope
(SAAO PI: DB)

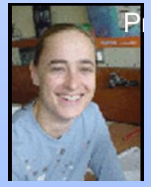
- University of Osaka, Astro Biology Centre of Japan, University of Maryland/NASA-GSFC, SAAO (20% access)
- 1.8-m with 1.3 x 1.3 degree FoV, 4 x Hawaii 4RG arrays & zyJH filters
- Same IR arrays as WFIRST
- Main science driver: microlensing survey in the bulge for exoplanets (50%)
- Other science: exoplanets, variable stars & transients (with ToO overide)
- Completion expected in 2020/21
- Similar telescope to MOA in NZ

Automated Transient Followup Project

- Trigger automated requests for followup observations from alert triggers
- Will allow for the automated selection of telescopes, instruments & modes and appropriate observation setup and scheduling
- GCN socket, VOEvents, APIs for robotic & queue-scheduled telescopes
- Efforts are underway in developing toolkits for automated scheduling, e.g. Target & Observation Manager (TOM) and Astronomical Event Observatory Network (AEON), used to coordinate observing requests across multiple participating facilities (LCO initiatives)



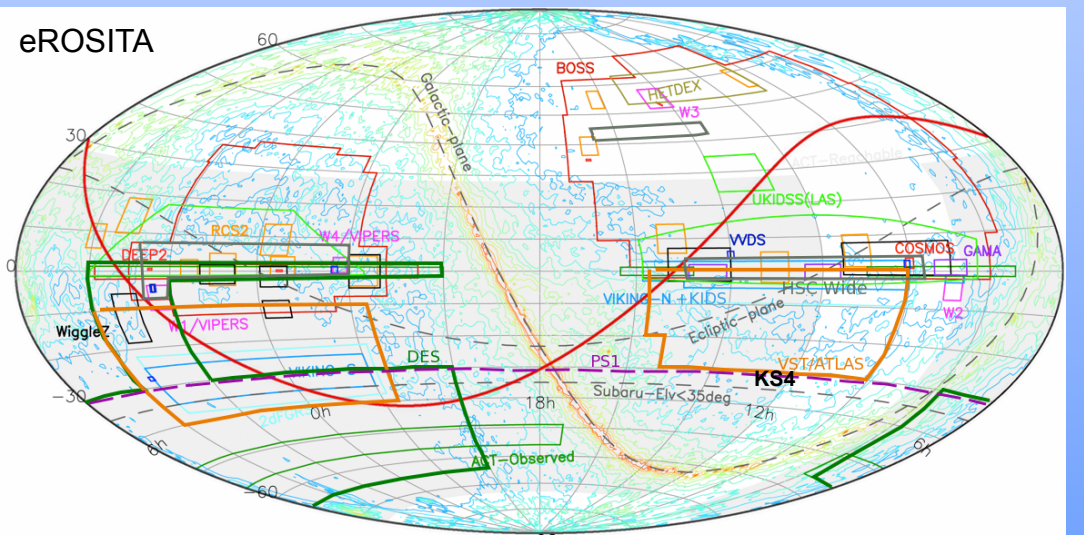
South African LSST Transient Programme

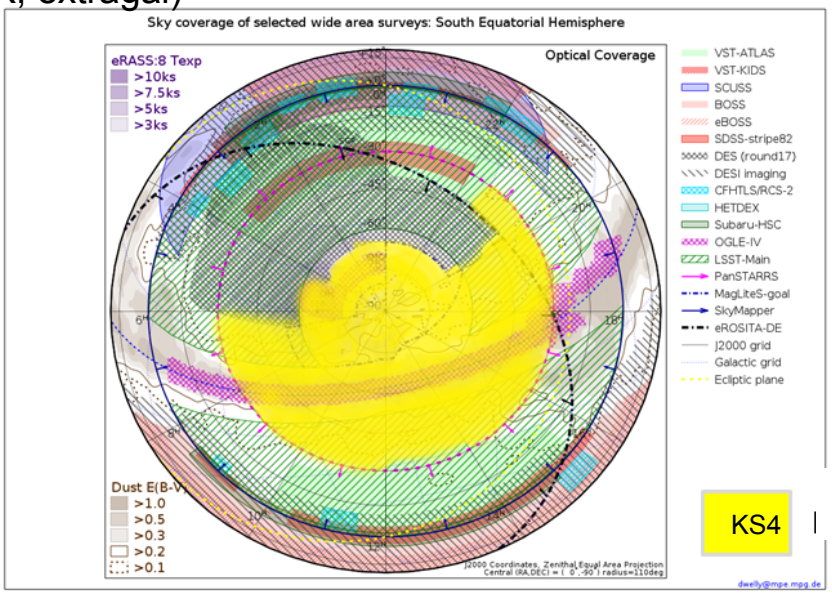
- One of 3 approved South African programmes which will run initially for 3 years (with expectation of renewal)
- Participation in various task forces and activities (particularly in the *Transient & Variable Star* and *Stars, Milky Way and Local Volume* collaborations)
- Team of up to 9 individuals of which 4 will be students (MSc or PhD)
  - PI is DB 
  - Other astronomers: Patrick Woudt (UCT), Steve Potter (SAAO), Retha Pretorius (SAAO), Enrico Kotze (SAAO)
    
    
    
    
  - Current students: Dante Hewitt (UCT), Hanno Marais (UFS)
  - 2 more students to become involved in 2020

- South African "in kind" contribution will mostly involve follow-up facilities (SALT, MeerKAT & SAAO Intelligent Observatory)

Multi-wavelength investigations of Galactic *MeerKAT* transient sources

- **Exploit initial commissioning and early science data not part of LSPs**
  - SARAO initiated observations of Galactic plane and ~20 cluster fields
- **Multi-wavelength counterparts**
  - Cross-correlate source positions with catalogues/surveys (e.g. *TESS, SkyMapper, CRTS, MASTER*)
  - Look for past optical transient detections
- **Leverage access to optical and X-ray facilities/surveys**
  - Spektr-RG: *eROSITA-DG / ART-XC (X-ray transients)*
    - » *eROSITA-DG* Galactic plane region *l = 250° - 360°* (overlaps *MeerKAT coverage*)
  - KS4 survey: *KMTNet Synoptic Survey of the Southern Sky* (beginning 2020)
    - » Deep (≤ 23) imaging survey (-30° ≥ Dec ≥ -90° ≠ DES)
    - » Reference imaging (e.g. for GW counterparts, preparation for *LSST*, etc.)
    - » Complement to *SPHEREx, Euclid, PRIME...* (NIR, extragal)
  - Transients from *ThunderKAT/MeerLICHT/PRIME?*





A BRICS Transient Programme

- **Flagship proposal for a BRICS key astronomy programme on transients:**

  "BRICS Intelligent Telescope and Data Network"

- **Adopted at Rio meeting of BRICS Astronomy Working Group (Oct 2019)**
- **A global multi-site, multi-wavelength approach**
- **Programme would involve:**
  - **Automating networks of *existing* and *new* telescopes within BRICS countries**
  - **Developing new dedicated telescopes, instruments, software (scheduling, data pipelines & analysis), development & training**
  - **Focus on initially on followup but move towards ambitious all-sky (4π ster) detection**
    - » **Cadence of <1 h simultaneously in 3-filters (*g, r, i)***
    - » **Deploy 72 x 1-m telescopes (each with 25 sq deg FoV) globally**
  - **Build on proposed Chinese *Sitian* and Russian *Phobos* networks**
  - **Total cost estimated at €280M**


THE END

Future Developments

- Efficiency improvements to existing RSS
- IFU slit mask (14”x 24” FoV)
- RSS-Near IR spectrograph (to 1.7 microns) with fibre IFU is arriving in 2021
- MaxE project (low dispersion efficient red arm for RSS spectrograph for transient and survey classification) is funded and has started
  - delivery in 2021/22
- HRS-HS and Exoplanets
  - laser frequency comb is funded

SALT Access Costs

1. Through share purchase (long term access and seat on SALT board):

Cost of 10% share - new shareholders:		
Share Capital	$7,647,104	R110,883,015
Development Fund	$1,108,612	R16,074,869
Annual Levy 2019/20	$307,681	R4,461,381
Total cost of 10% share	$9,063,398	R131,419,264

This would give 10% of observing time (only used time is counted, so no weather losses are charged)

2. Through ad hoc observing time purchase (no seat on board):

Cost of useable telescope time* per hour

2017/18 time purchase by non-shareholders (50 hours minimum purchase)	$1,898	R27,527
2017/18 premium time purchase by non-shareholders (50 hours minimum purchase)	$2,531	R36,702

* ~2100 observation hours per year for 65% useable time

Assuming rate of exchange of R14.50 = $1.00
Premium time is higher priority (P0 or P1) time