MULTI-WAVELENGTH ASTRONOMY IN SOUTH AFRICA

Brian van Soelen

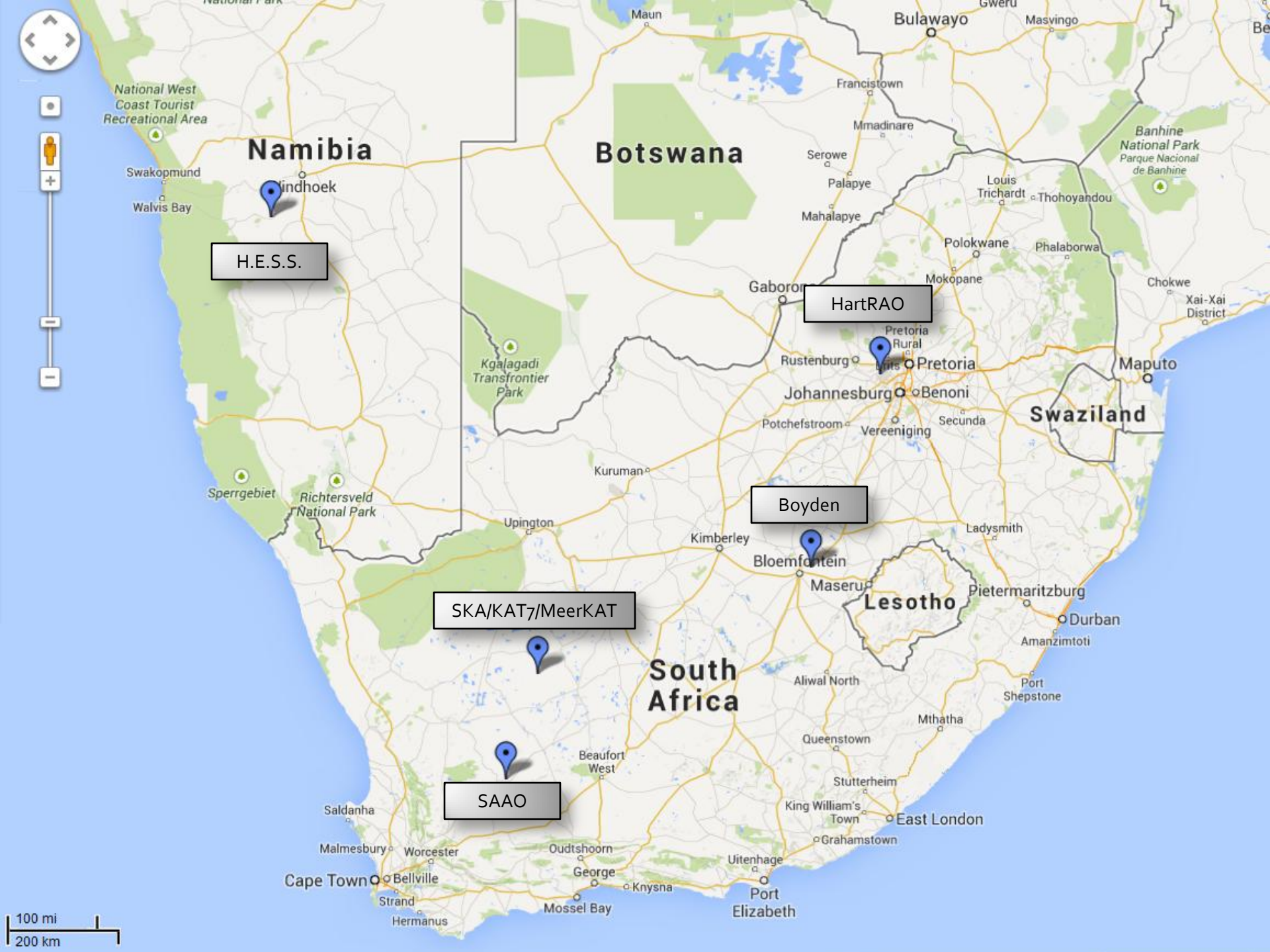
University of the Free State, South Africa

Southern African Large Telescope (SALT), Petri Väisänen,

MeerLICHT, Patrick Woudt

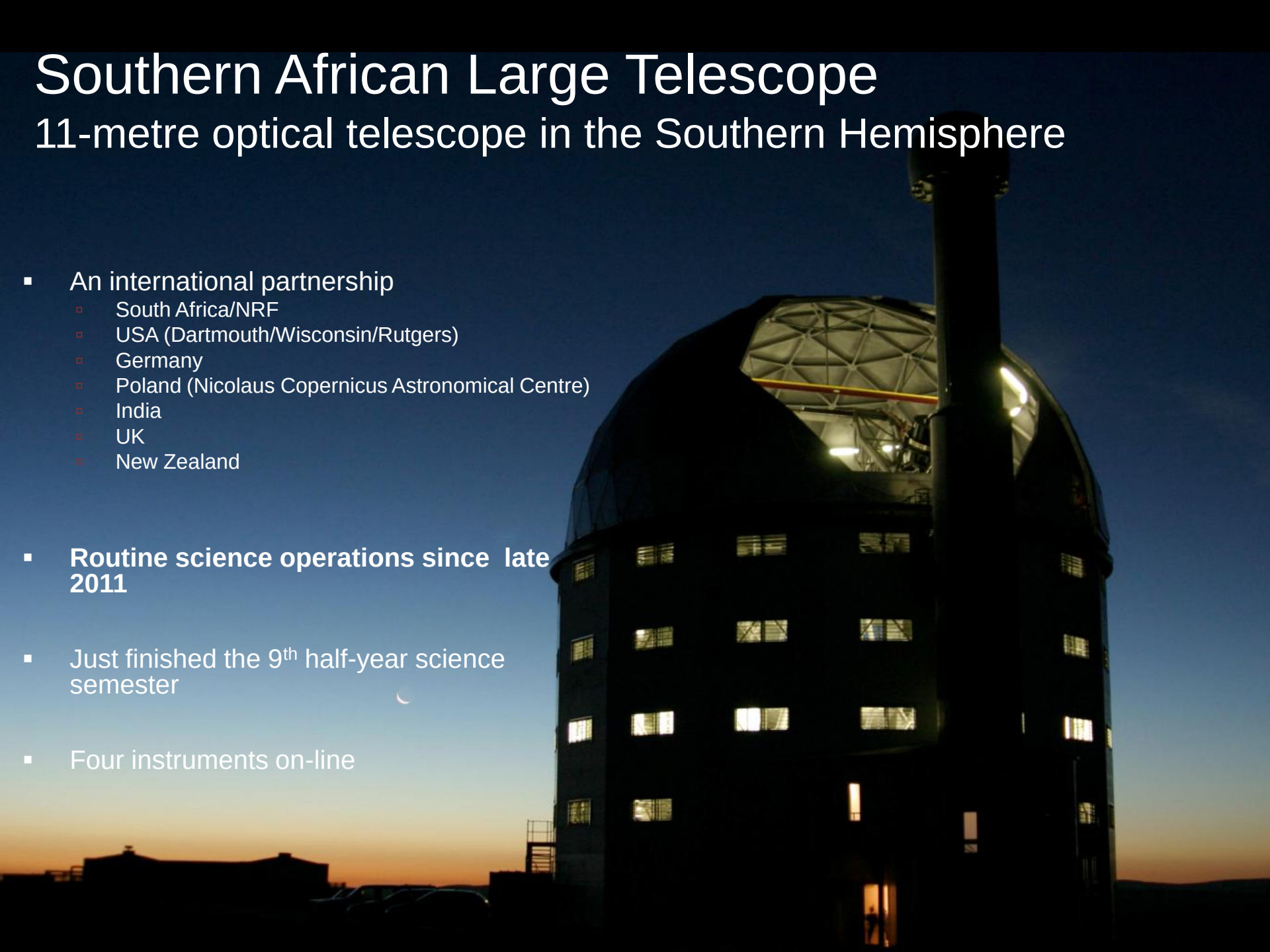
LSST, Patricia Whitelock

Virtual Observatory, Sudhanshu Barway

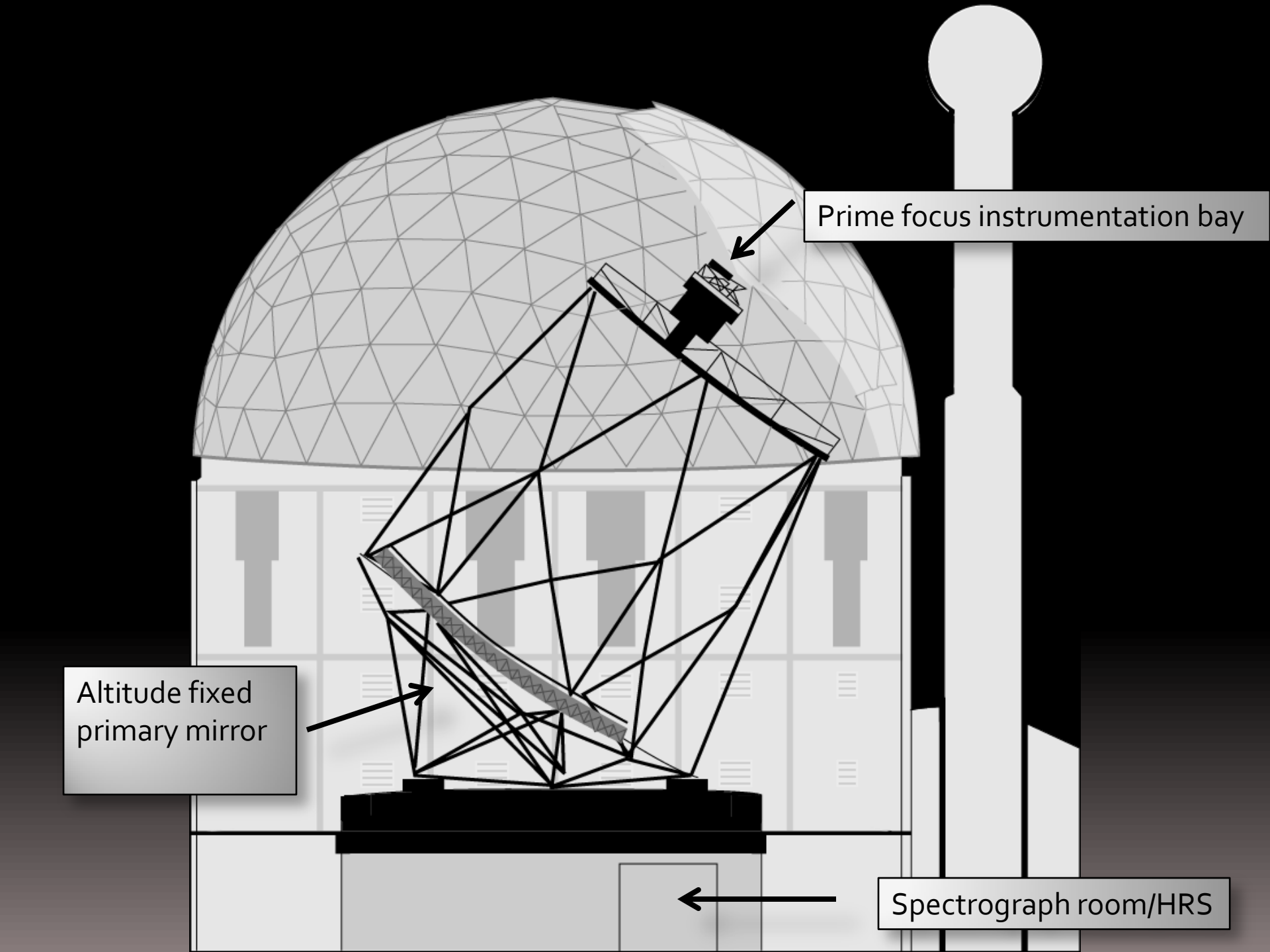

H.E.S.S.
HartRAO
Boyden
SKA/KAT7/MeerKAT
SAAO
Namibia
Botswana
South Africa
Lesotho
Swaziland
Windhoek
Swakopmund
Walvis Bay
Gaborone
Francistown
Bulawayo
Masvingo
Maun
Serowe
Palapye
Mahalapye
Mmadinare
Louis Trichardt
Thohoyandou
Polokwane
Phalaborwa
Mokopane
Chokwe
Xai-Xai
Maputo
Pretoria
Johannesburg
Benoni
Rustenburg
Potchefstroom
Vereeniging
Secunda
Kuruman
Kimberley
Upington
Bloemfontein
Maseru
Ladysmith
Pietermaritzburg
Durban
Amanzimtoti
Port Shepstone
Aliwal North
Mthatha
Queenstown
Stutterheim
King William's Town
East London
Grahamstown
Port Elizabeth
Uitenhage
Knysna
Mossel Bay
George
Oudtshoorn
Beaufort West
Saldanha
Malmesbury
Worcester
Cape Town
Bellville
Strand
Hermanus
Sperrgebiet
Richtersveld National Park
Kgalagadi Transfrontier Park
National West Coast Tourist Recreational Area
Banhine National Park
Parque Nacional de Banhine
100 mi
200 km

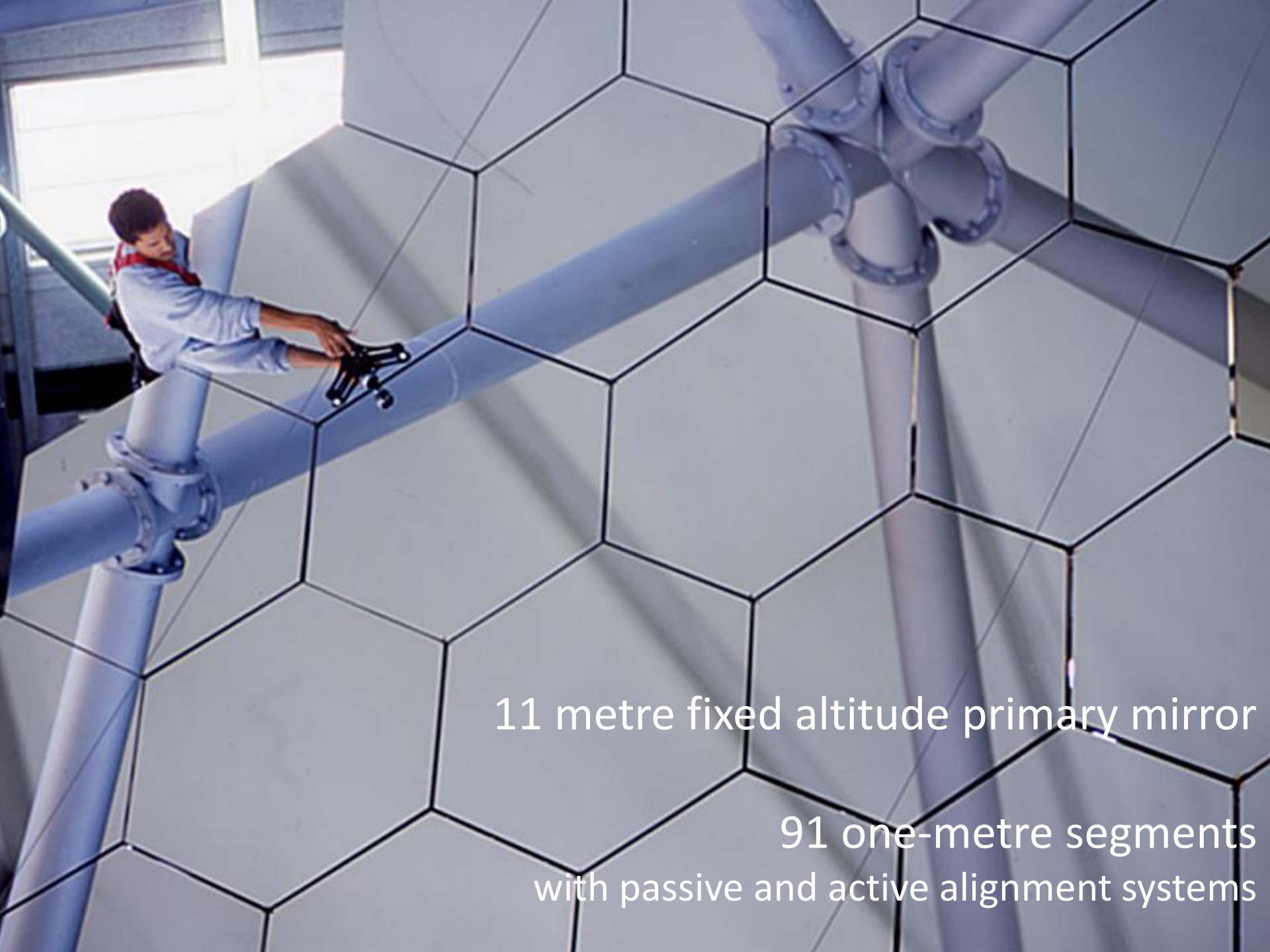
Southern African Large Telescope

11-metre optical telescope in the Southern Hemisphere



- An international partnership
  - South Africa/NRF
  - USA (Dartmouth/Wisconsin/Rutgers)
  - Germany
  - Poland (Nicolaus Copernicus Astronomical Centre)
  - India
  - UK
  - New Zealand
- **Routine science operations since late 2011**
- Just finished the 9th half-year science semester
- Four instruments on-line


Prime focus instrumentation bay
Altitude fixed primary mirror
Spectrograph room/HRS

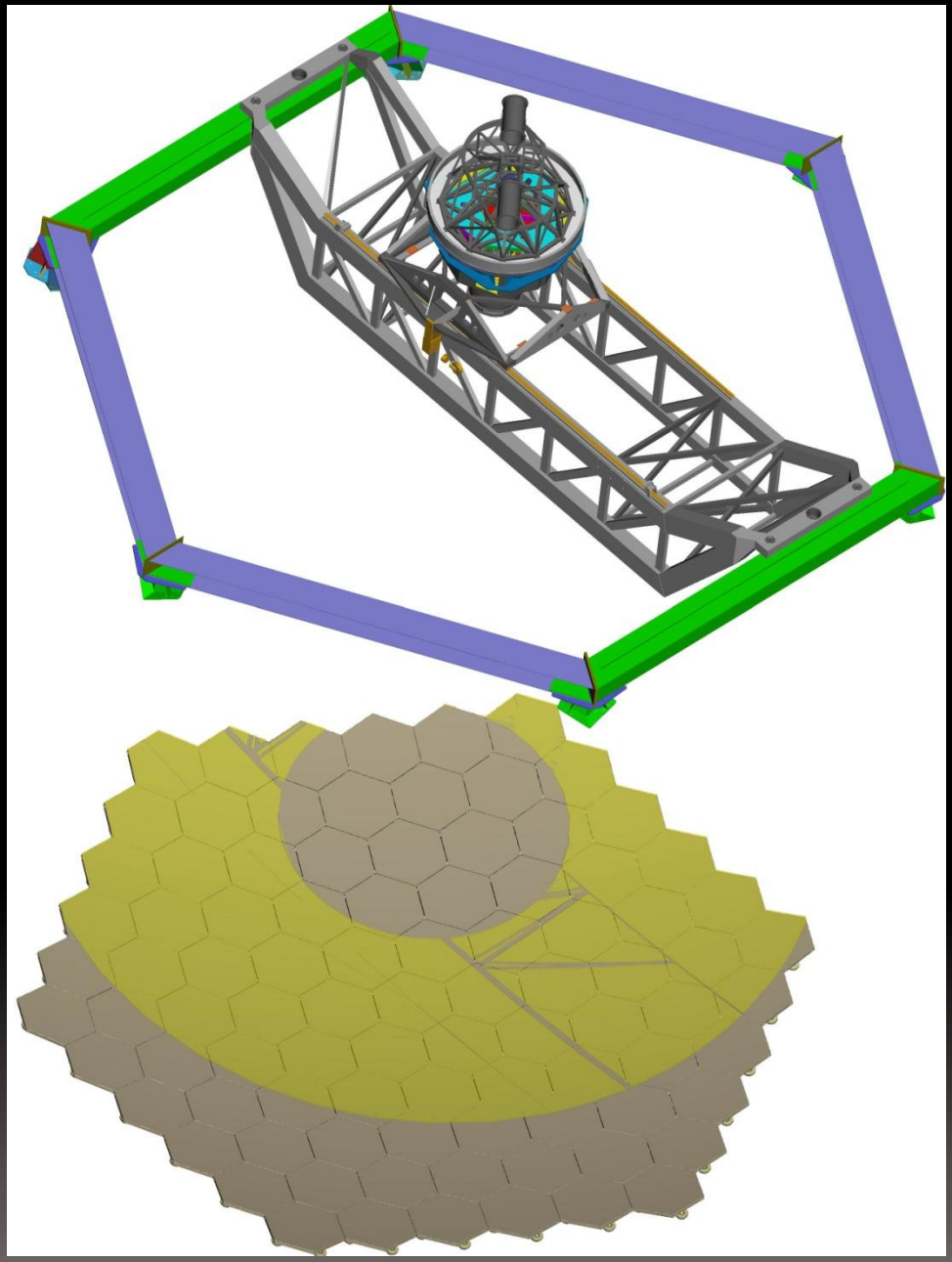

11 metre fixed altitude primary mirror
91 one-metre segments
with passive and active alignment systems

SALT Tracking Principle

With tracker and 11-m pupil centred on primary mirror array and central obstruction, equivalent to a 9 metre telescope.

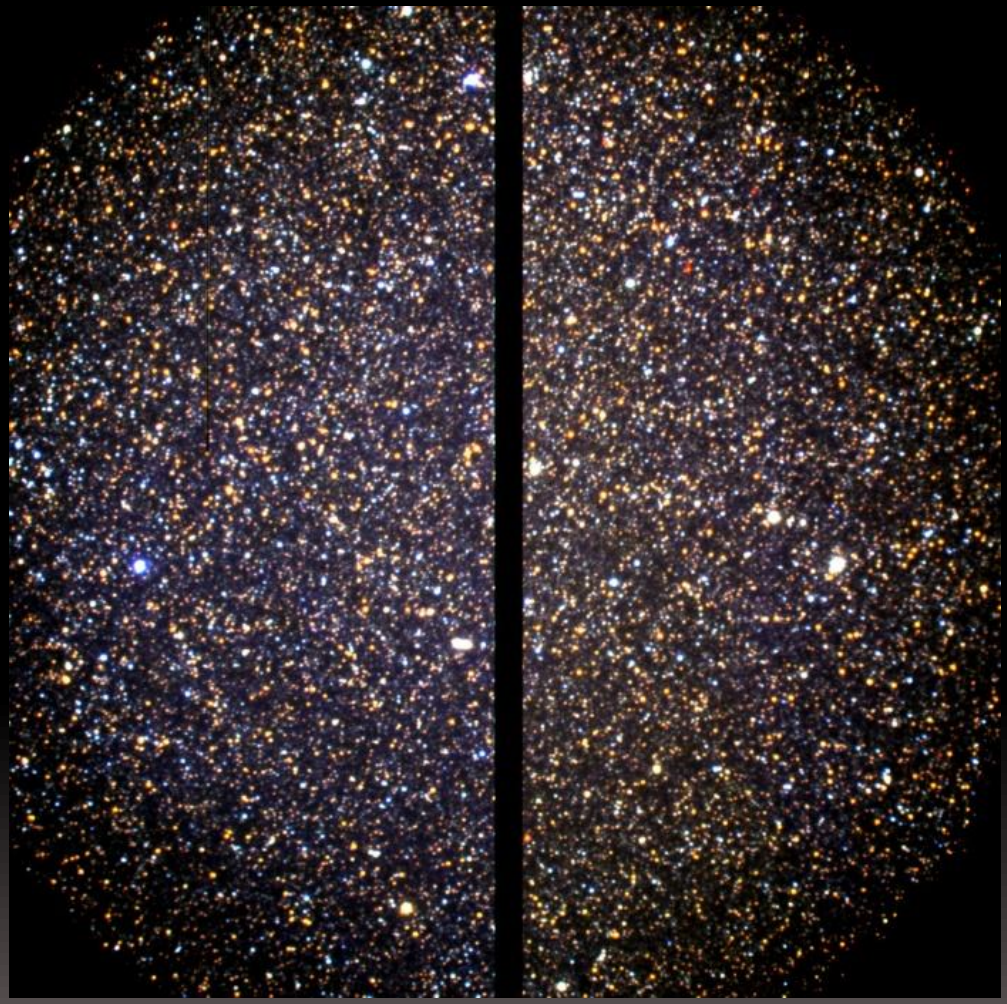
Tracker off-centre and pupil partially on primary mirror array.
At extreme, a ~7 metre telescope.

Field of view of SALT (8 arcmin)

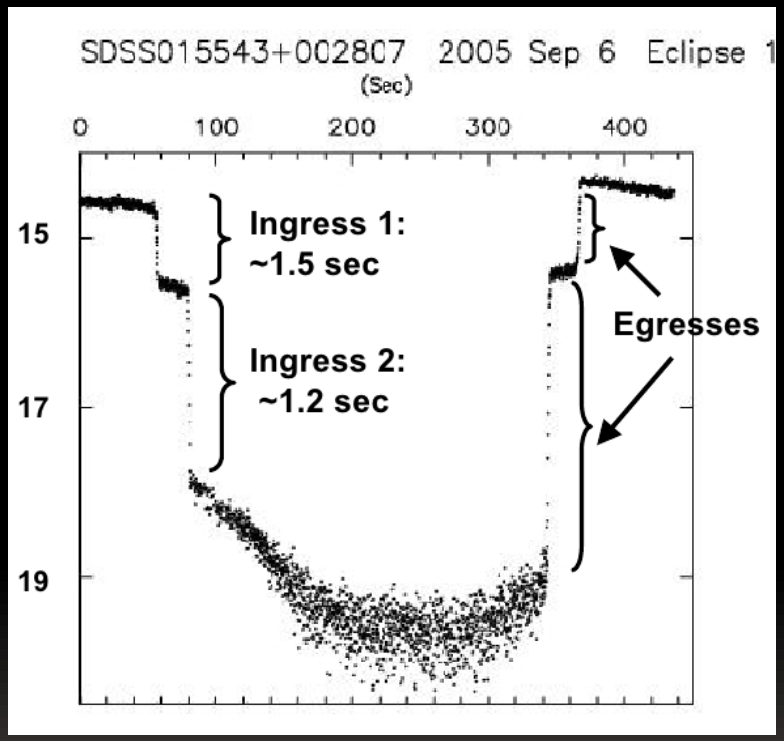


SALTICAM (SAAO)

Broad and intermediate-band imaging, incl. *high time-resolution photometry* (50+ ms).
Down to 320 nm



First Science with SALT was differential photometry



112 millisecond exporeure
95% of light from the 2 accretion points

Darragh O'Donoghue
Principal Investigator

RSS: Robert Stobie Spectrograph

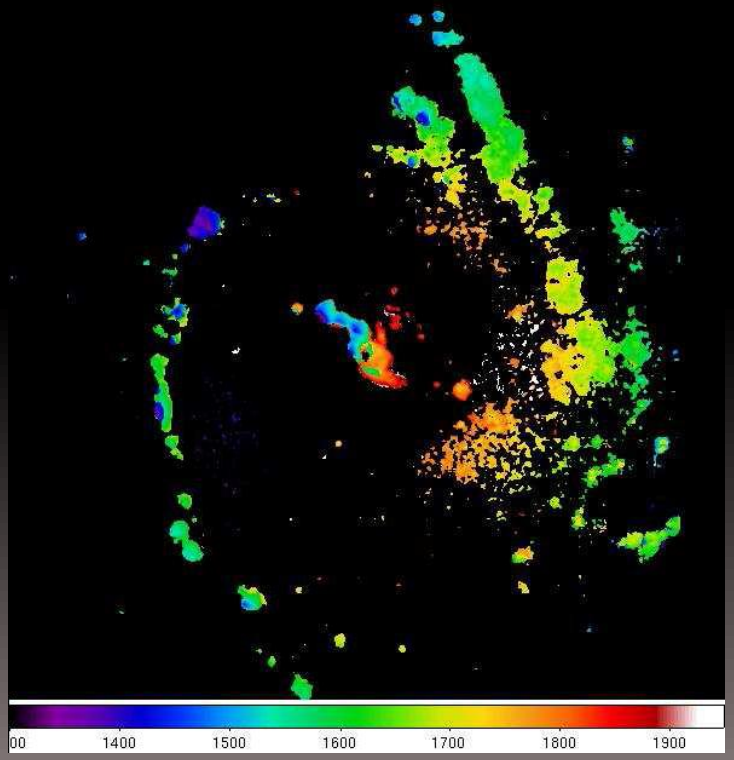
(University of Wisconsin-Madison)

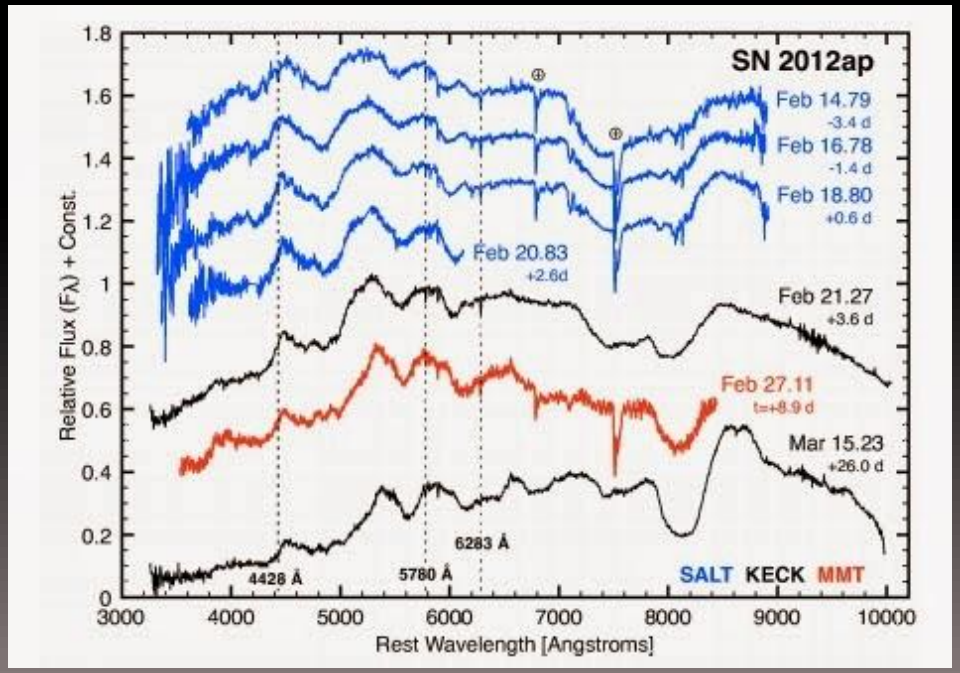
Long slit and multi-object spectroscopy $R < 10{,}000$

Fabry-Perot imaging spectroscopy
Polarimetry (imaging and spectropol.)
High Time resolution ~100 ms spectroscopy

The work-horse instrument on SALT

Upgrade to near-IR beam IFU unit (J,H) in 2018

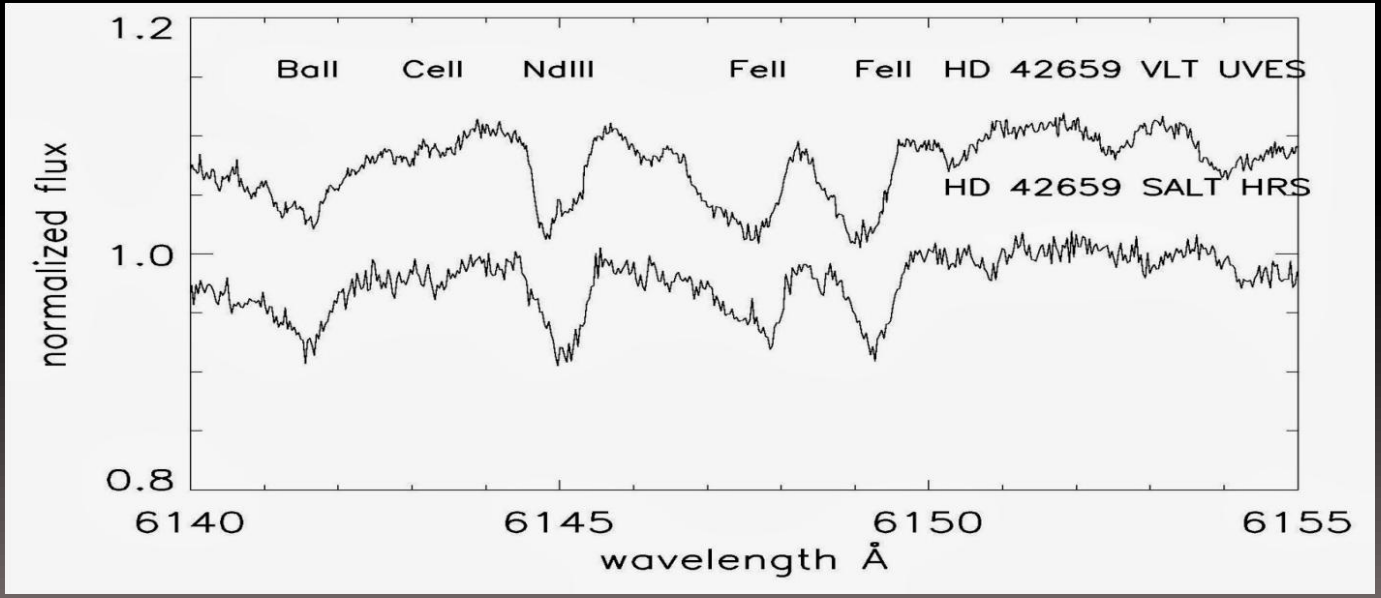




HRS: High Resolution Spectrograph

(Durham University)

Low Resolution R ~ 14000
Medium Resolution R ~ 40000
High Resolution R ~ 65000
High Stability as HR, but high velocity stability m/s level



What is SALT especially good at?

Telescope: Huge collecting power.

Site: Skies are very dark (22 mag/arcsec^2). Seeing only modest (median 1.4”)

- Diffuse low-surface-brightness spectroscopy very competitive.
- Objects above background observed very efficiently.
- Can change instruments and observing modes in seconds.
- Rapid reaction to ToOs.
- Some rare modes for large telescopes (FP, Pol, mixed modes, high-time res)

- SALT as a *spectroscopic survey telescope.* Most efficient programs are surveys with large pools of targets over the sky.

What kinds of MeerKAT programs would be efficient at SALT?

Redshifts, redshifts, redshifts:

For the past 2 yrs have done redshifts:

en masse to 20th mag with short expt

lots with full-track obs to 21st mag

22nd mag in good conditions.

Long-slit for large amounts of targets spread around the sky, or for very rapid follow-up (e.g. ThunderKAT, other transient progs).

MOS for e.g. clusters or for mapping <1 sq.deg fields. Constraints:

- 8 arcmin fov, can get ~30 sources per shot realistically

Simultaneous radio-optical observations of astrophysical transients

PIs: Paul Groot (Radboud/U) and Patrick Woudt (U/Cape Town)

MEERLICHT

Project managers: Vanessa McBride / Steven Bloemen
Project scientist: Elmar Körding
Instrument scientist: Retha Pretorius
Consortium reps: Rob Fender (Oxford)
Ben Stappers (Manchester)
[Rudy Wynands (Amsterdam)]

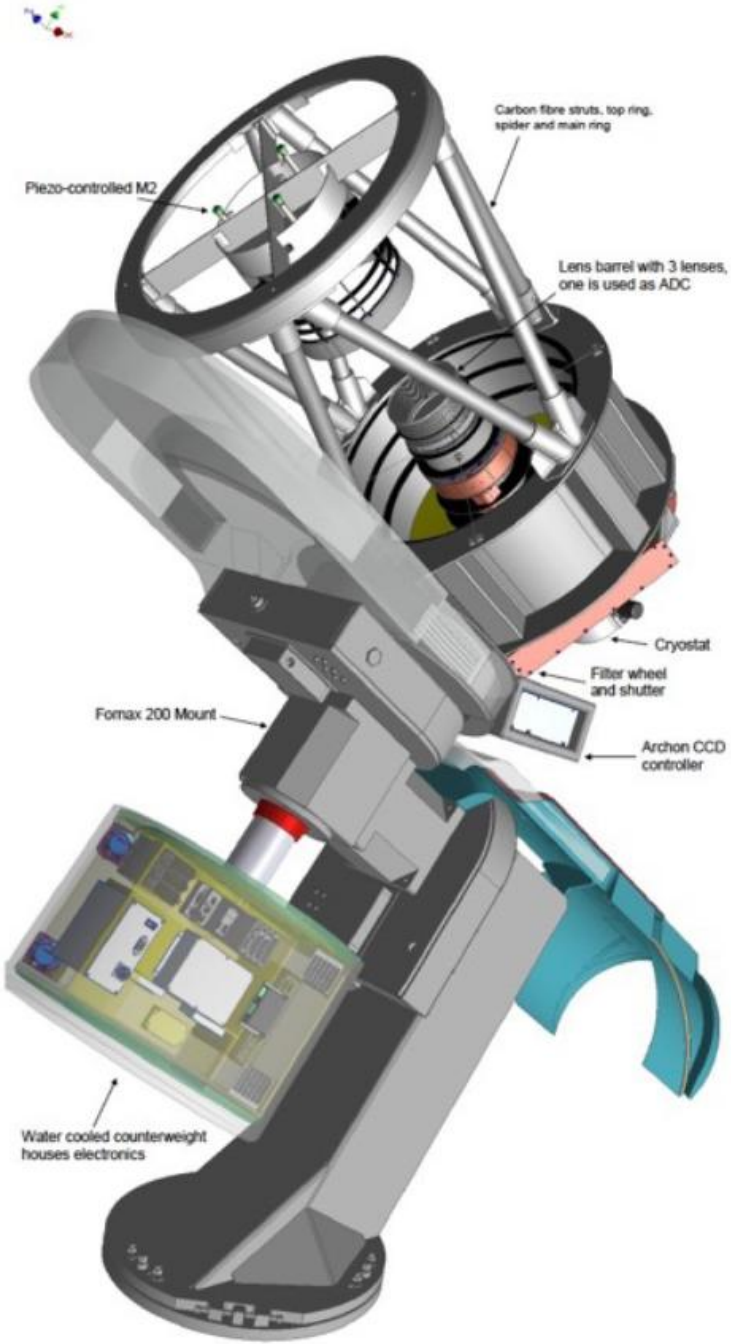
Closely related to the **BlackGEM project**

Housing - 20-inch dome @ SAAO Sutherland

Telescope - 65-cm modified Dall-Kirkham design (CASTOR optical design)

Detector - 10k x 10k STA CCD [~2.7 deg^2 at 0.56" per pixel] - *cf MeerKAT f.o.v.*

Telescope control - linked to MeerKAT pointing (in real time)



MeerLICHT telescope structure as of **22 August 2016**

ThunderKAT 2016

Synopsis

ThunderKAT PIs: Patrick Woudt (UCT) & Rob Fender (Oxford)

ThunderKAT membership (open): 60 co-investigators from 10 countries (32% ZA)

ThunderKAT is the image-plane transients programme for MeerKAT. The goal is to find, identify and understand high-energy astrophysical processes via their radio emission (often in concert with observations at other wavelengths).

> *"Through a comprehensive and complementary programme of surveying and monitoring Galactic synchrotron transients (across a range of compact accretors and a range of other explosive phenomena) and exploring distinct populations of extragalactic synchrotron transients (microquasars, supernovae (SNe) and possibly yet unknown transient phenomena) – both from direct surveys and commensal observations – we will revolutionise our understanding of the dynamic and explosive transient radio sky." (ThunderKAT 2010 Science Case)*

As well as proposing for targeted programmes of their own, ThunderKAT has made agreements with the other LSPs to search their data for transients. This **commensal** use of the other surveys, which remains one of the key ThunderKAT programme goals in 2016, means that the combined MeerKAT LSPs will produce by far the largest GHz-frequency radio transient programme to date. ThunderKAT will focus on Target-of-Opportunity (ToO) and monitoring programmes of a set of well-defined transients.

ThunderKAT 2016

Science Themes

Relativistic Accretion

- Black holes and neutron stars in X-ray binaries, Tidal Disruption Events, Ultra-luminous X-ray sources

White Dwarf Accretion

- Outflows from accretion-power outbursts of white dwarfs, outflows from thermonuclear eruptions on white dwarfs

Cosmic Explosions

- Gamma-ray bursts; Core-collapse supernovae; Type Ia supernovae

Fast and Coherent Transients

- Fast radio bursts (imaging)

Gravitational Wave Sources

- Gravitational wave events and electro-magnetic counterparts

ThunderKAT 2016

Innovations: MeerLICHT

MeerLICHT: simultaneous optical-radio
monitor of the transient sky

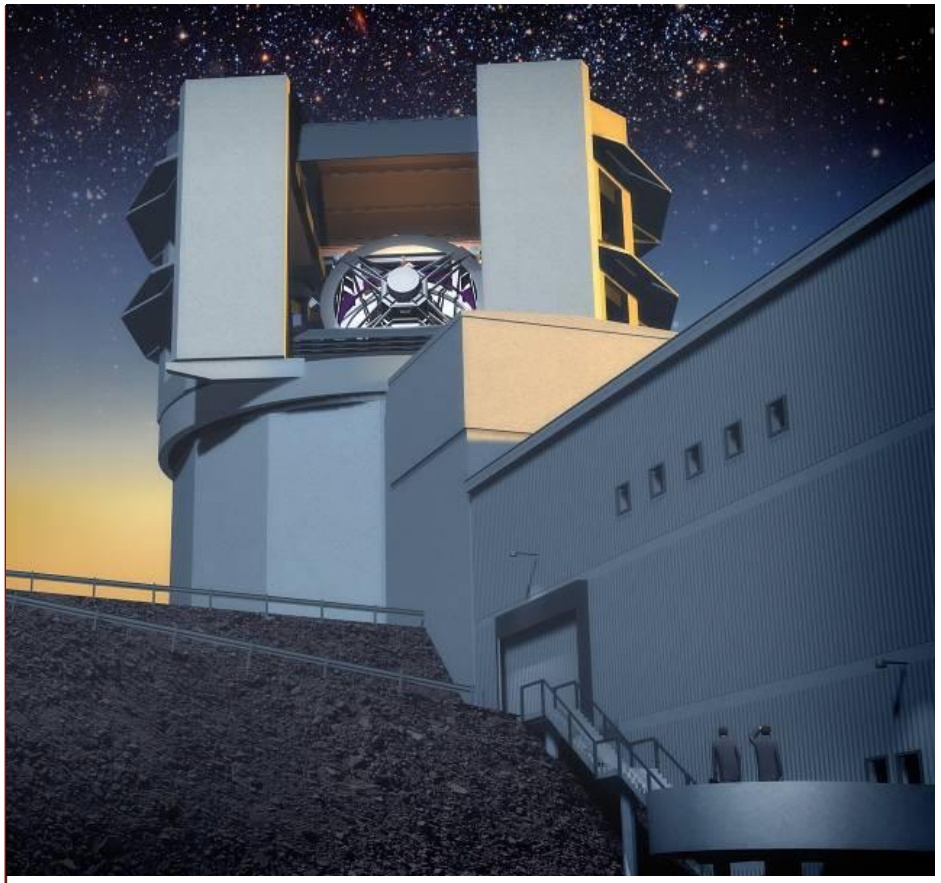
-1 million Euro investment in MeerKAT science
- static data products feed back to all MeerKAT LSPs
- connects radio and optical communities in ZA

All ThunderKAT science benefits from MeerLICHT overlap
implication for fraction of night time observing

Whatever MeerKAT observes, MeerLICHT observes [at the same time]

Large Synoptic Survey Telescope

The case for South African involvement in the Large Synoptic Survey Telescope (LSST)



Patricia Whitelock

(thanks to Tony Tyson & Steve Kahn et al.)

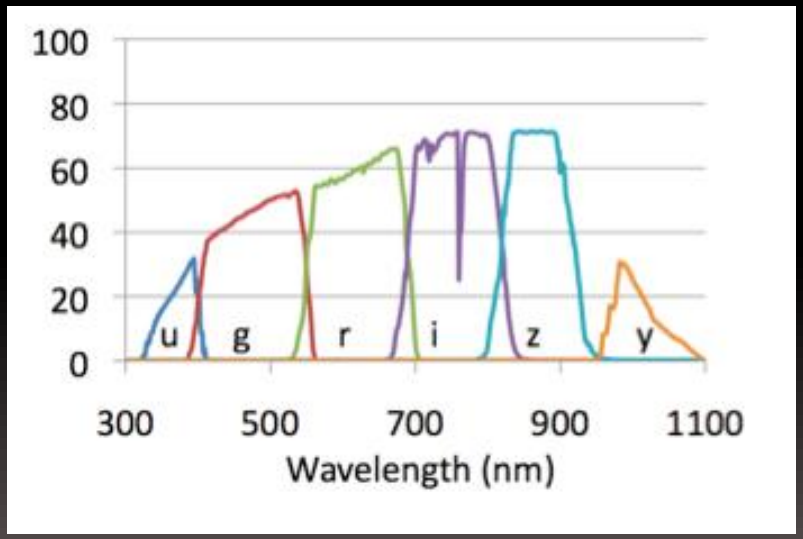
University of Cape Town • iYunivesithi yaseKapa • Universiteit van Kaapstad

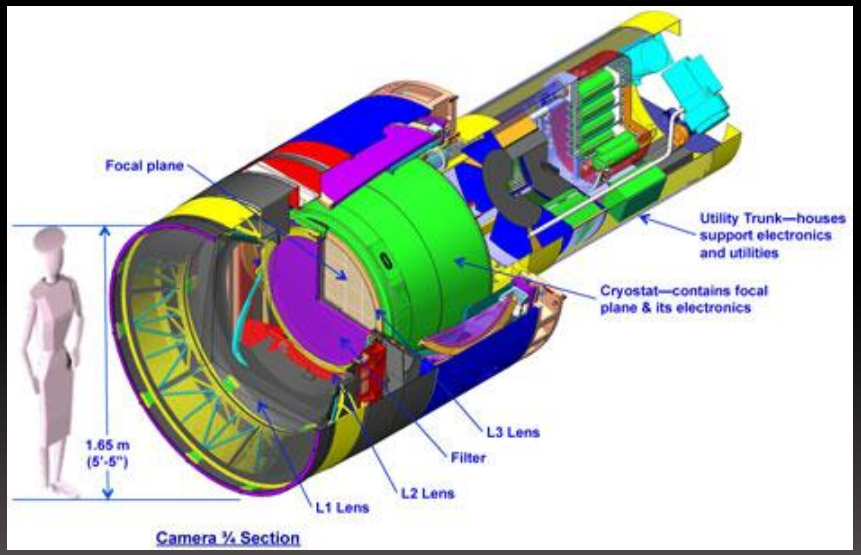
LSST

Site: Cerro Pachón, Chile
median seeing 0".7

LSST key features

- Primary: D=8.4m (6.5m effective)
- FOV: 9.6 sq deg (3.2 Gpix with 0".2 pixels)





Filters: 6 SDSS-like

LSST Observing Cadence

Pairs of 15 second exposures (*to 24.5 mag*) per visit to a given position in the sky.

Visit the same position again within the hour with another pair of exposures.

Number of 9.6 sq.deg field-of-view visits per night: 850

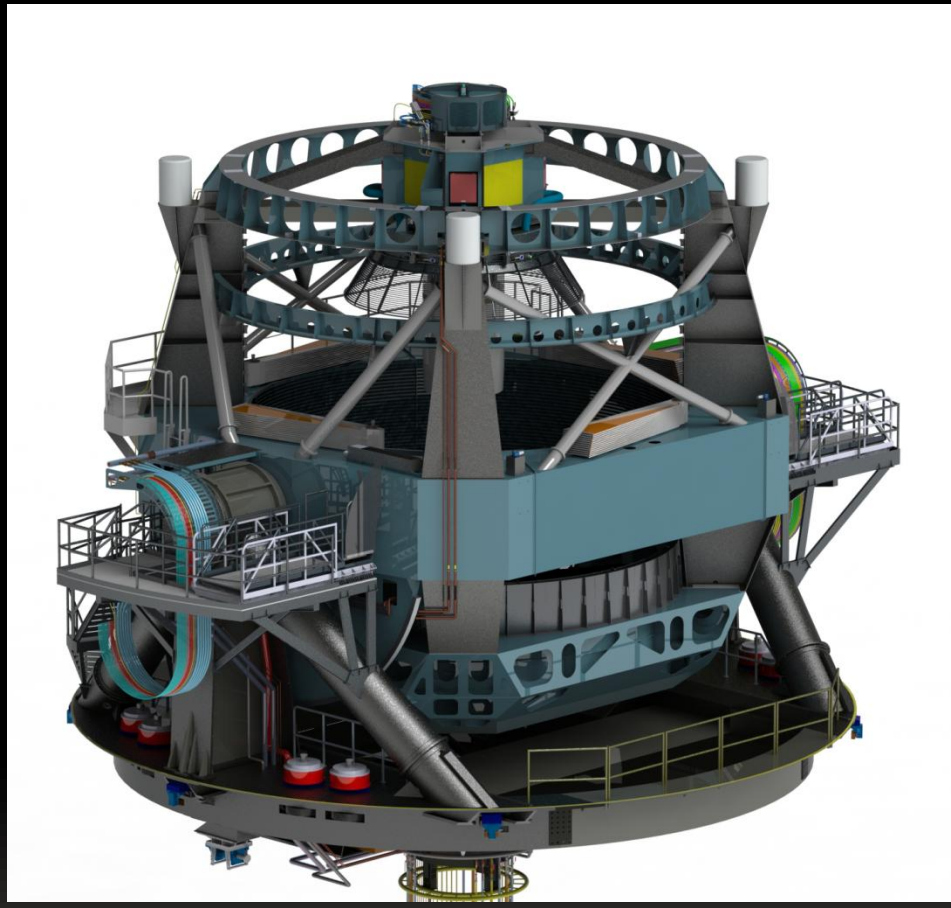
Detection of transients announced within 60 seconds
1 million supernovae
1 million galaxy lenses
Expect 1-2 million transients per night (100k alerts via VO)!
New phenomena

LSST: Deep, Wide & Fast

Ranked highest in USA decadal survey:"*astro2010*"
A survey for everyone (parallel astrophysics)

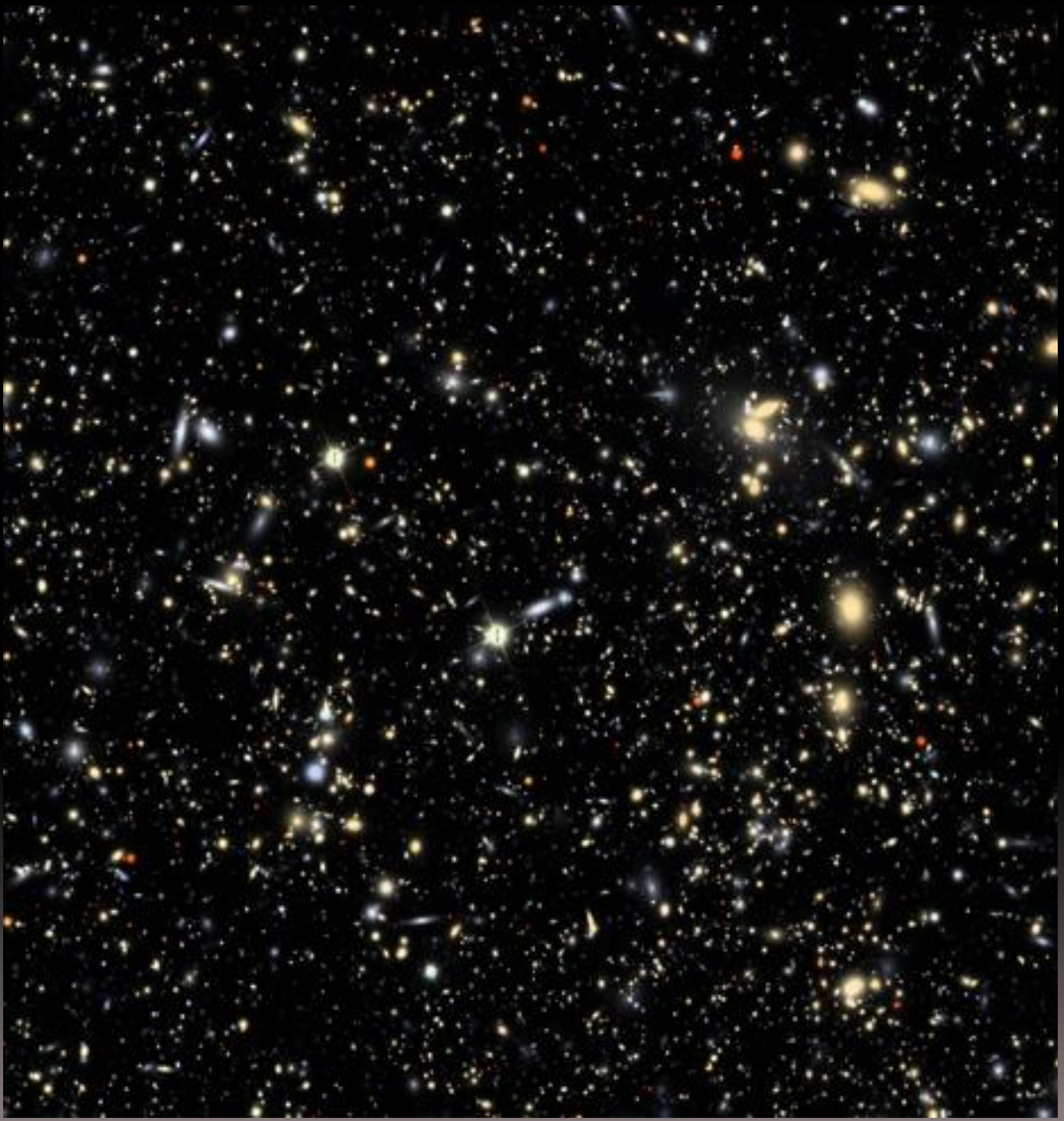
Science Case:

- Taking an Inventory of the Solar System
- Mapping the Milky Way
- Exploring the Transient Optical Sky
- Probing Dark Energy and Dark Matter.



A movie of the southern Sky produced over 10 years **starting in 2021**

- ✧ 10 billion galaxies
- ✧ 10 billion stars
- ✧ Vast numbers of solar system objects



Simulation:
15s exposure
One 4kx4k CCD
through 3 filters

LSST camera: 189 CCDs

Produce 2 x 10^9 single-band images over 10 years

(Image Credit: LSST simulations team)

Why Should SA join LSST?

SALT

e.g. early spectroscopic follow up on groups of objects (i.e. stars, galaxies, …) in unusual parameter space

- new phenomena: discovery science

MeerKAT and SKA

e.g. key science for radio continuum studies depends on redshifts – LSST will provide photometric redshifts for 4 billion galaxies

Galaxy evolution: need colours, morphology etc

Transients: discovered by SKA/MeerKAT want instant access to optical (LSST) data

General: dealing with big data and learning from those who do it well, test-bed for machine learning, astro-informatics …

LSST will produce Big Data

- 20 Terabytes of astronomical imaging every night
- 100-200 Petabyte image archive after 10 years
- 20-40 Petabyte database
- 2-10 million new sky events nightly that need to be characterized and classified – potential new discoveries!

SA-GAMMA

The South African Gamma-ray Astronomical Programme

- North-West University
  - Markus Böttcher
  - Sabrina Casanova
  - Tania Garrigoux
  - Paulus Krüger
  - Felix Spanier
  - Iurii Sushch
  - Johan van der Walt
  - Zorawar Wadiasingh
  - Christo Venter
- University of the Witwatersrand
  - John Carter
  - Sergio Colafrancesco
  - Andreas Faltenbacher
  - Max Jingo
  - Nukri Komin
  - Paolo Marchegiani
  - Elias Sideras-Haddad
- University of the Free State
  - Pieter Meintjes
  - Brian van Soelen
  - Richard Britto
- University of Johannesburg
  - Simon H. Connell
  - Chris A. Engelbrecht
  - Reetanjali Moharana
  - Azwinndini Muronga
  - Soebur Razzaque
  - Hartmut Winkler
- South African Astronomical Observatory
  - Stephen Potter
  - David Buckley

H.E.S.S.

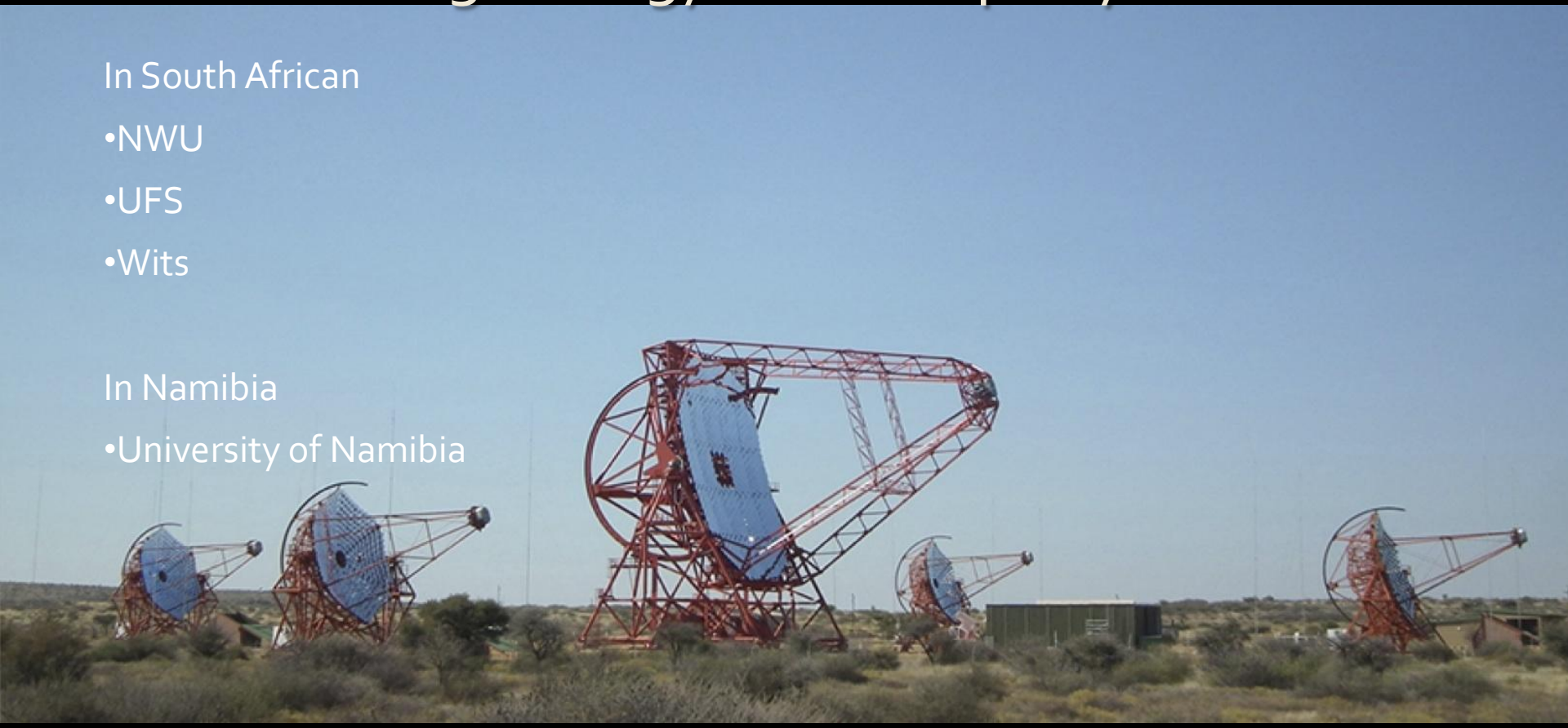
High Energy Stereoscopic System

In South African

- NWU
- UFS
- Wits

In Namibia

- University of Namibia

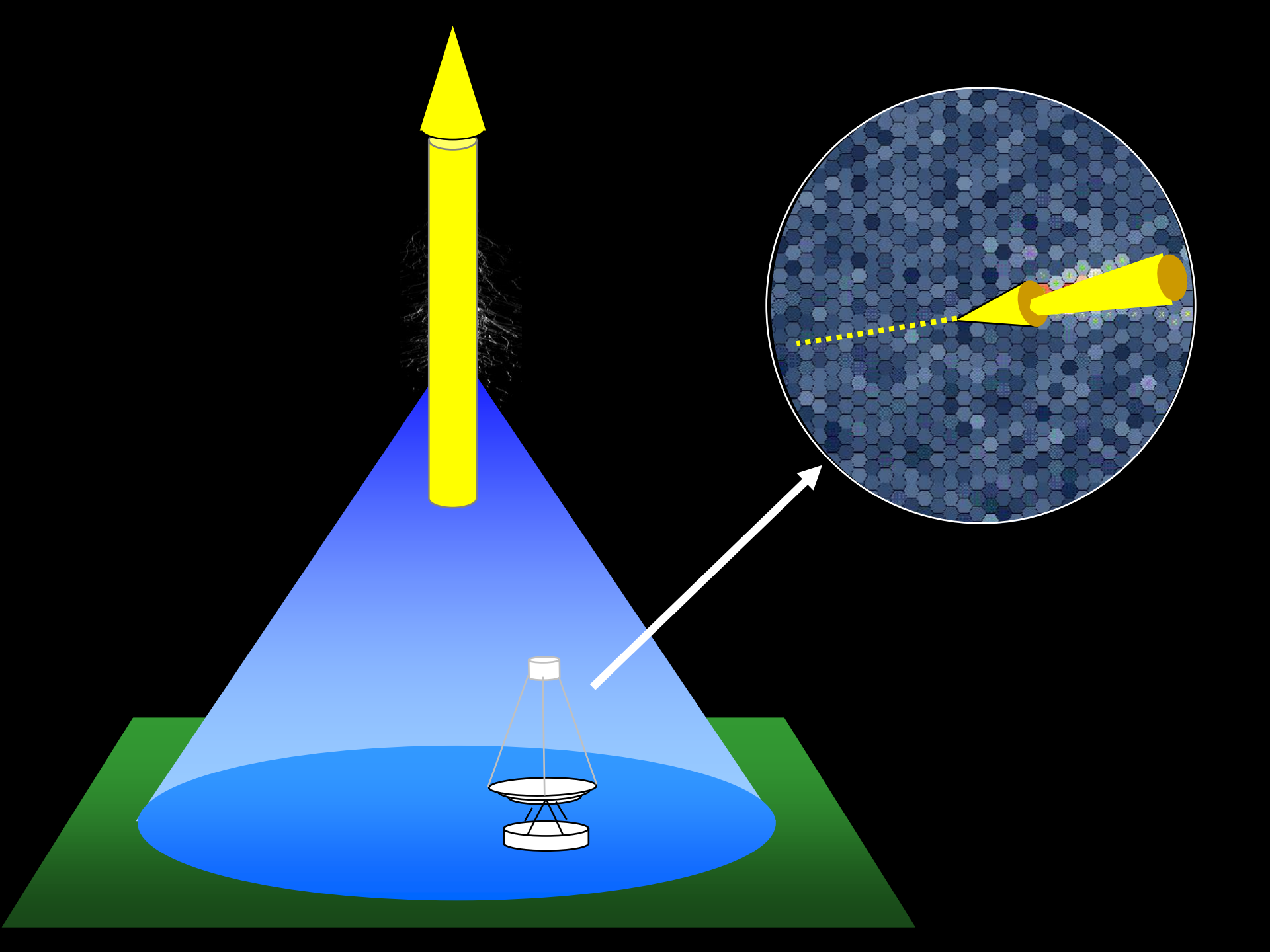


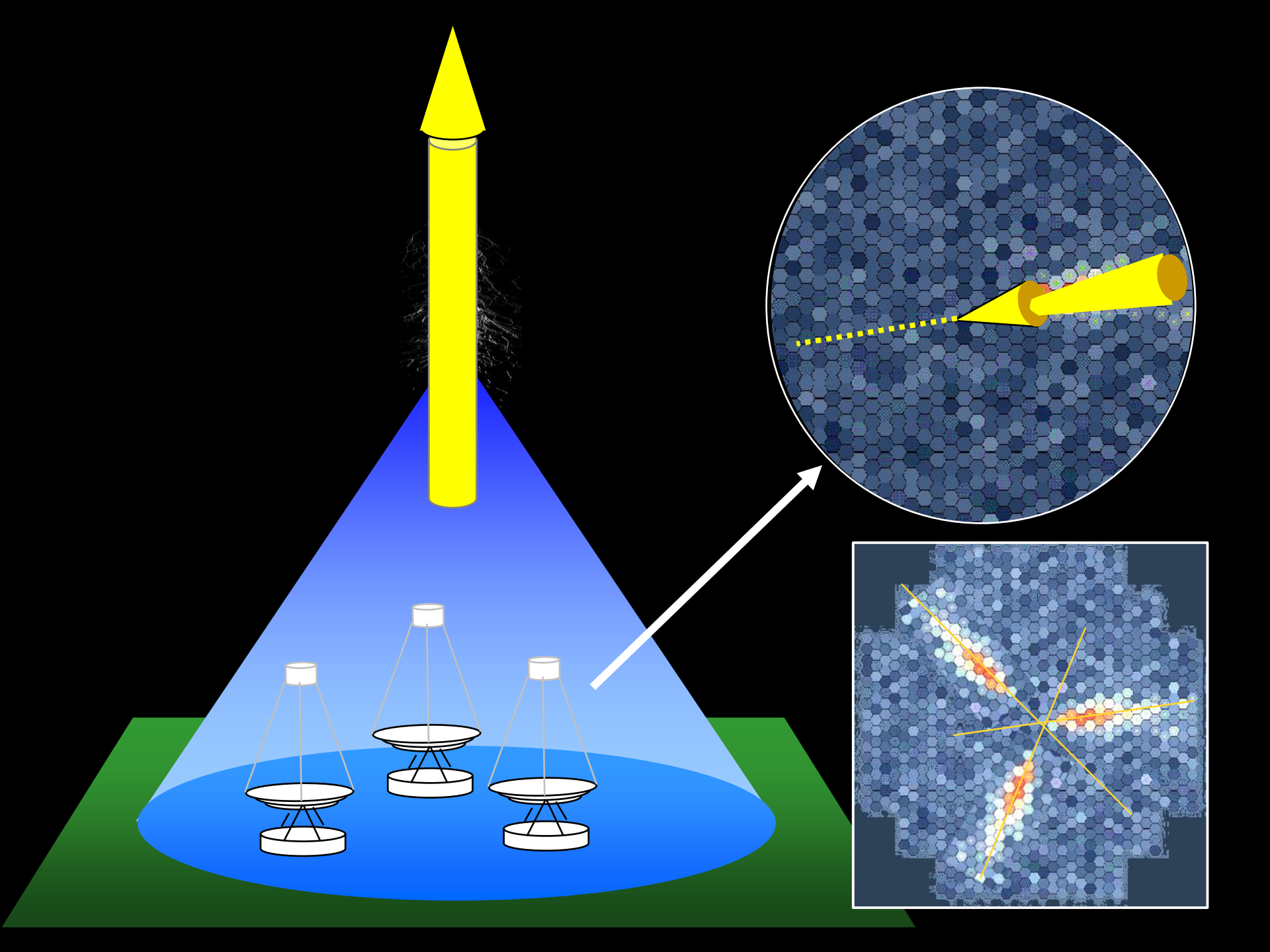
H.E.S.S.

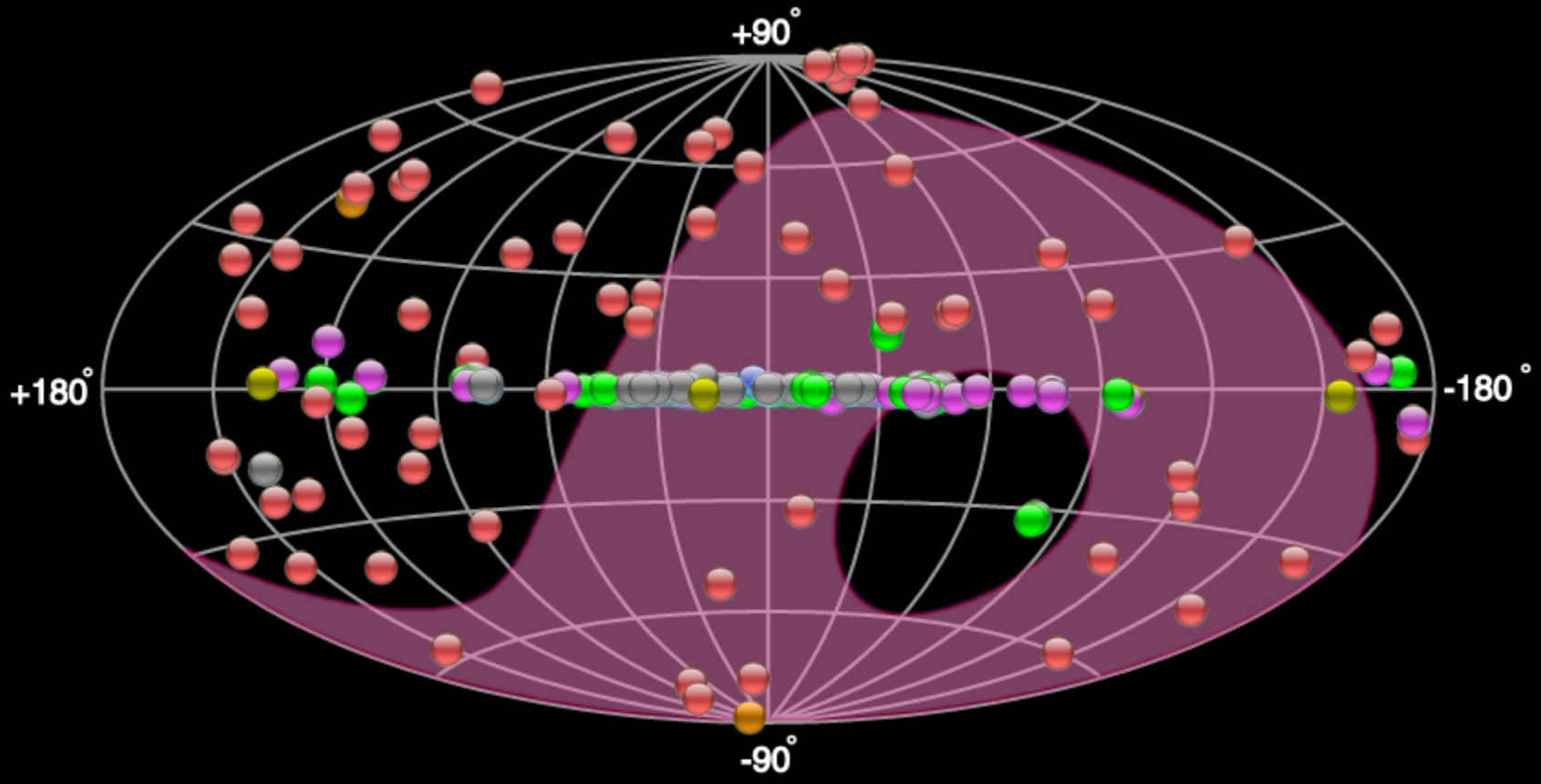
244 members from 42 institutions in 12 countries
Major contributions from
MPIK Heidelberg, Germany,
CEA and CNRS, France.

H.E.S.S.

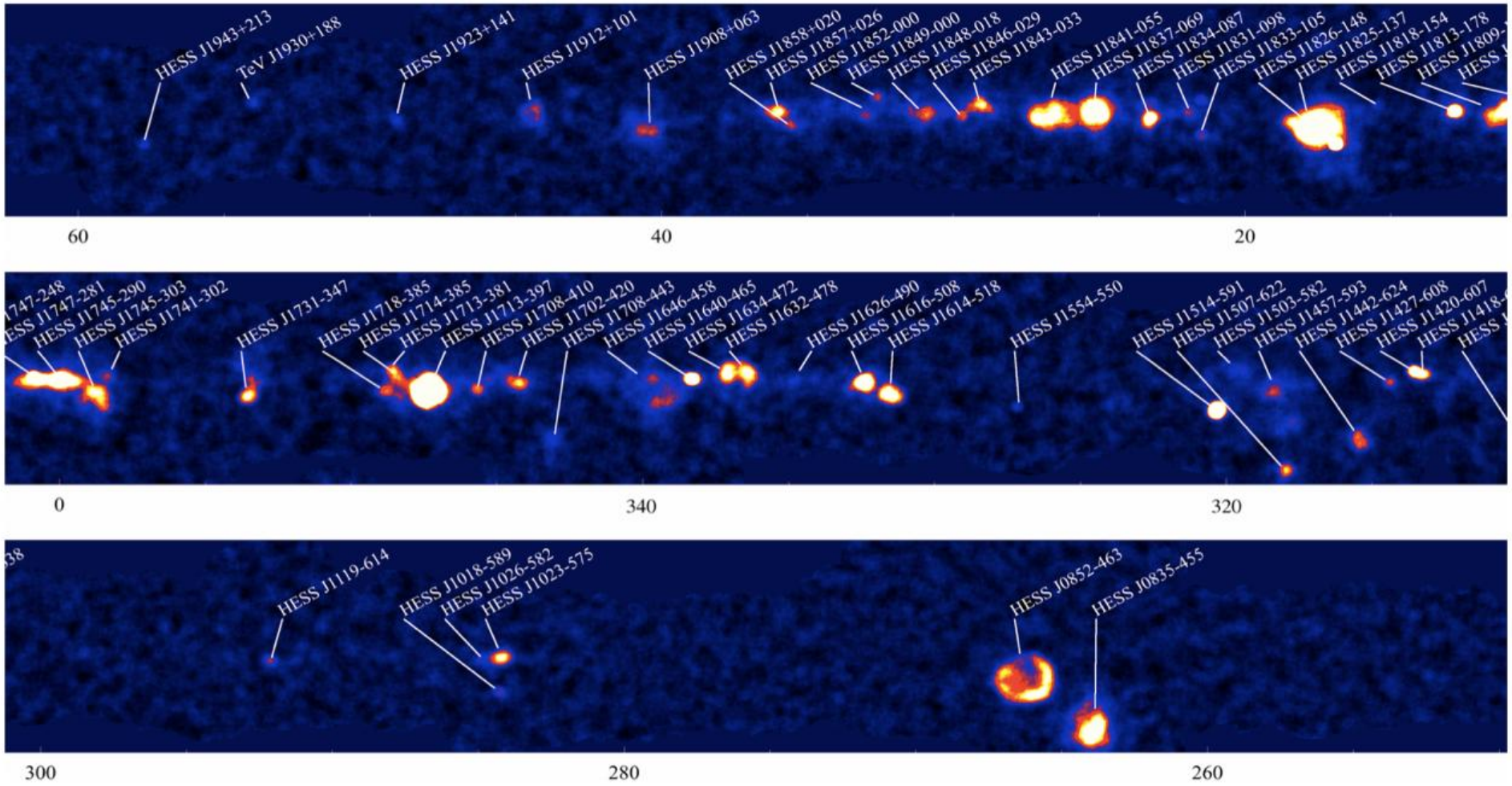
- ● Four 12 meter telescopes
- ● One 28 meter telescope (first light 2012)
- ● Energy regime: 0.03 – 100 TeV

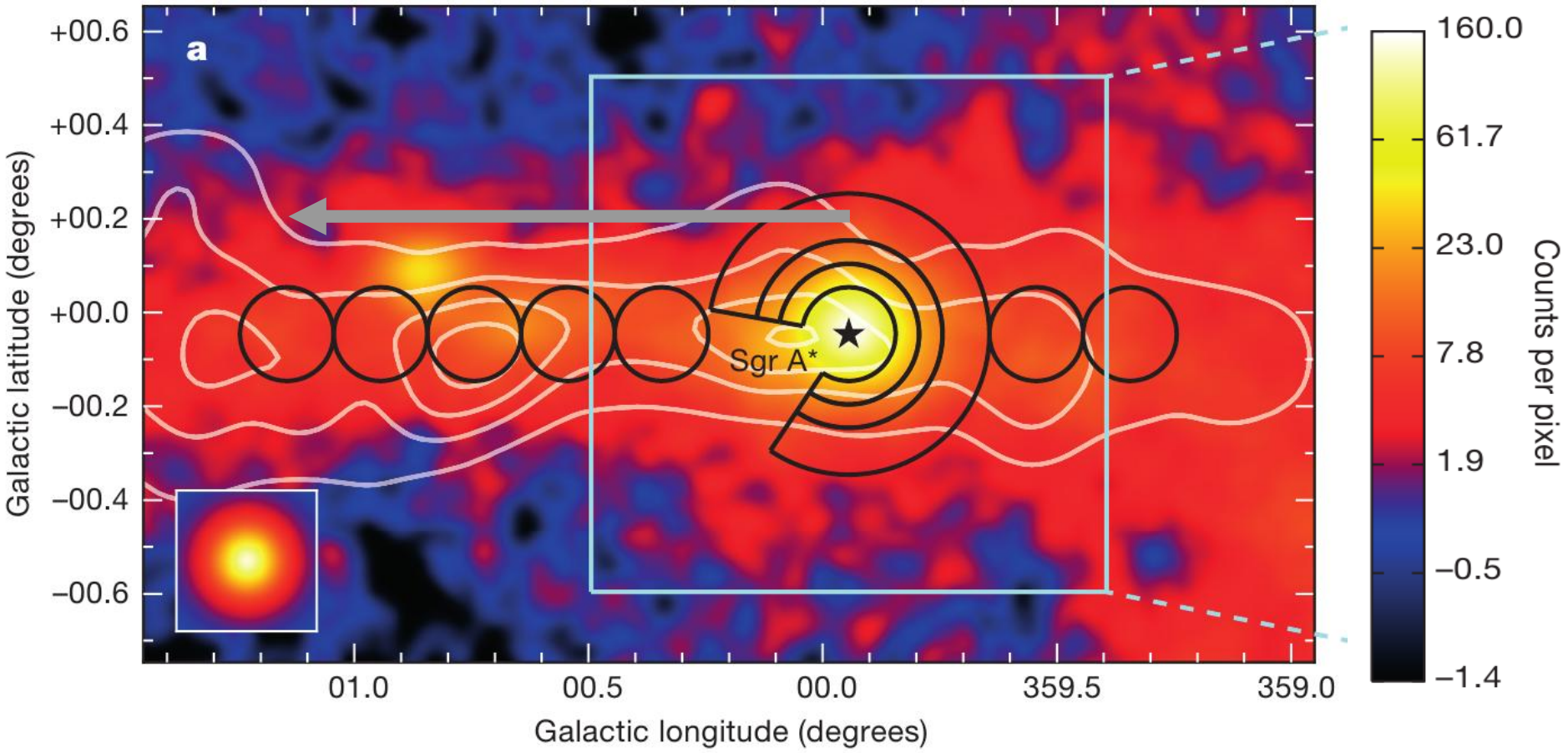




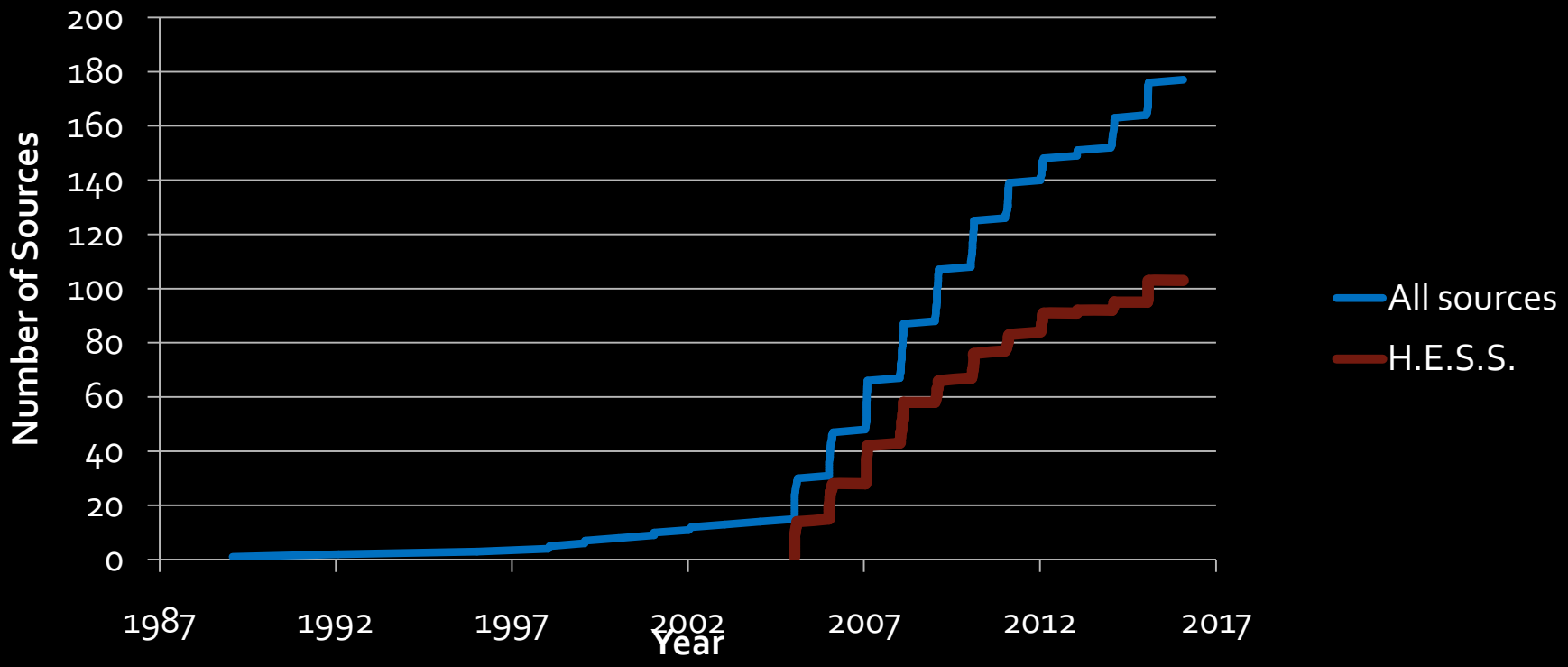


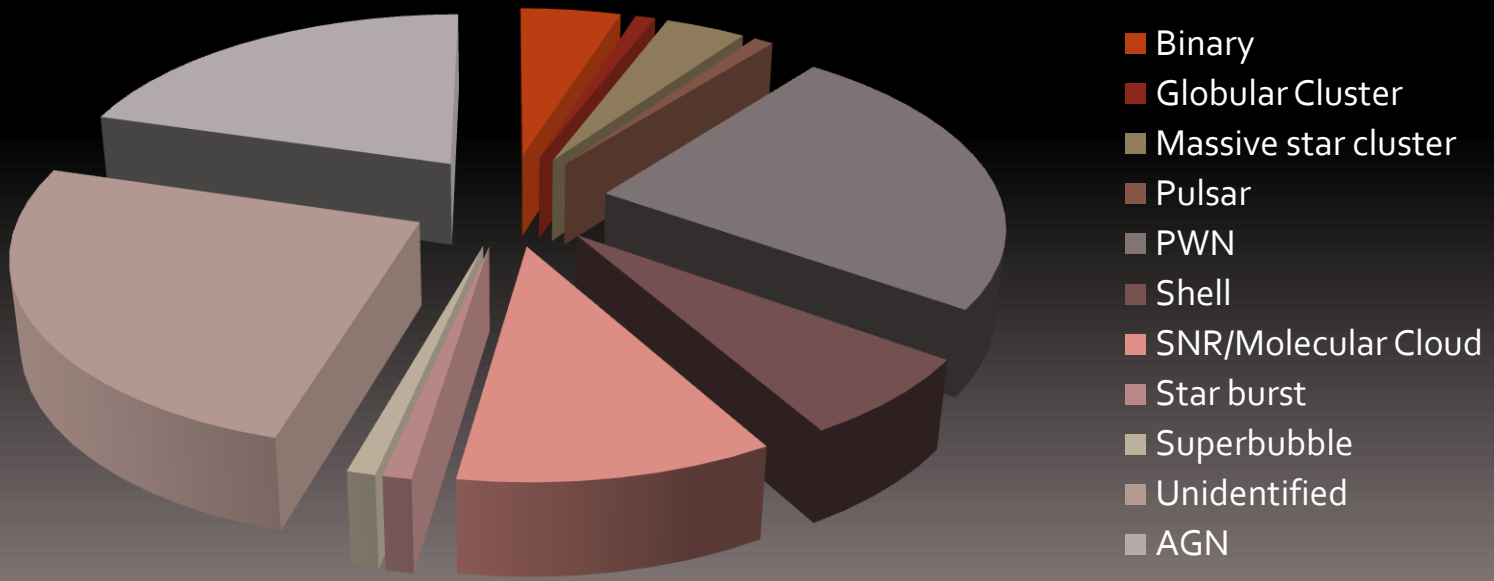
TeVCat


HESS J1943+213
TeV J1930+188
HESS J1923+141
HESS J1912+101
HESS J1908+063
HESS J1858+020
HESS J1857+026
HESS J1852-000
HESS J1849-000
HESS J1848-018
HESS J1846-029
HESS J1843-033
HESS J1841-055
HESS J1837-069
HESS J1834-087
HESS J1831-098
HESS J1833-105
HESS J1826-148
HESS J1825-137
HESS J1818-154
HESS J1813-178
60
40
20
HESS J1731-347
HESS J1718-385
HESS J1714-385
HESS J1713-381
HESS J1713-397
HESS J1708-410
HESS J1702-420
HESS J1708-443
HESS J1646-458
HESS J1640-465
HESS J1634-472
HESS J1632-478
HESS J1626-490
HESS J1616-508
HESS J1614-518
HESS J1554-550
HESS J1514-591
HESS J1507-622
HESS J1503-582
HESS J1457-593
HESS J1442-624
HESS J1427-608
HESS J1420-607
0
340
320
HESS J1119-614
HESS J1018-589
HESS J1026-582
HESS J1023-575
HESS J0852-463
HESS J0835-455
300
280
260



- Recent discovery of a PeVatron source in the galactic centre!

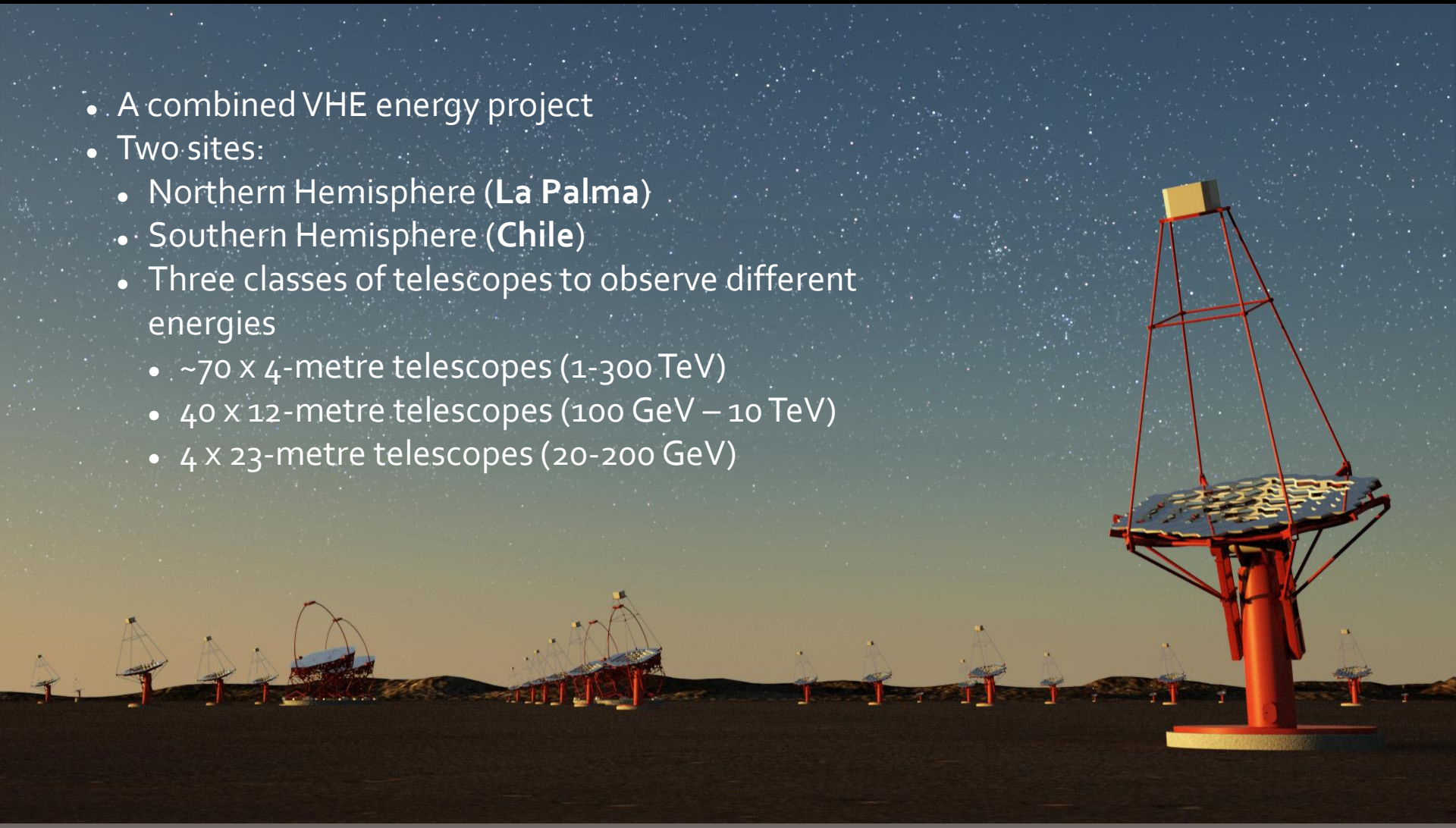

Number of Sources
200
180
160
140
120
100
80
60
40
20
0
1987
1992
1997
2002
2007
2012
2017
Year
All sources
H.E.S.S.


Binary
Globular Cluster
Massive star cluster
Pulsar
PWN
Shell
SNR/Molecular Cloud
Star burst
Superbubble
Unidentified
AGN

TeVCat

Cherenkov Telescope Array

- A combined VHE energy project
- Two sites:
  - Northern Hemisphere (**La Palma**)
  - Southern Hemisphere (**Chile**)
  - Three classes of telescopes to observe different energies
    - ~70 x 4-metre telescopes (1-300 TeV)
    - 40 x 12-metre telescopes (100 GeV – 10 TeV)
    - 4 x 23-metre telescopes (20-200 GeV)

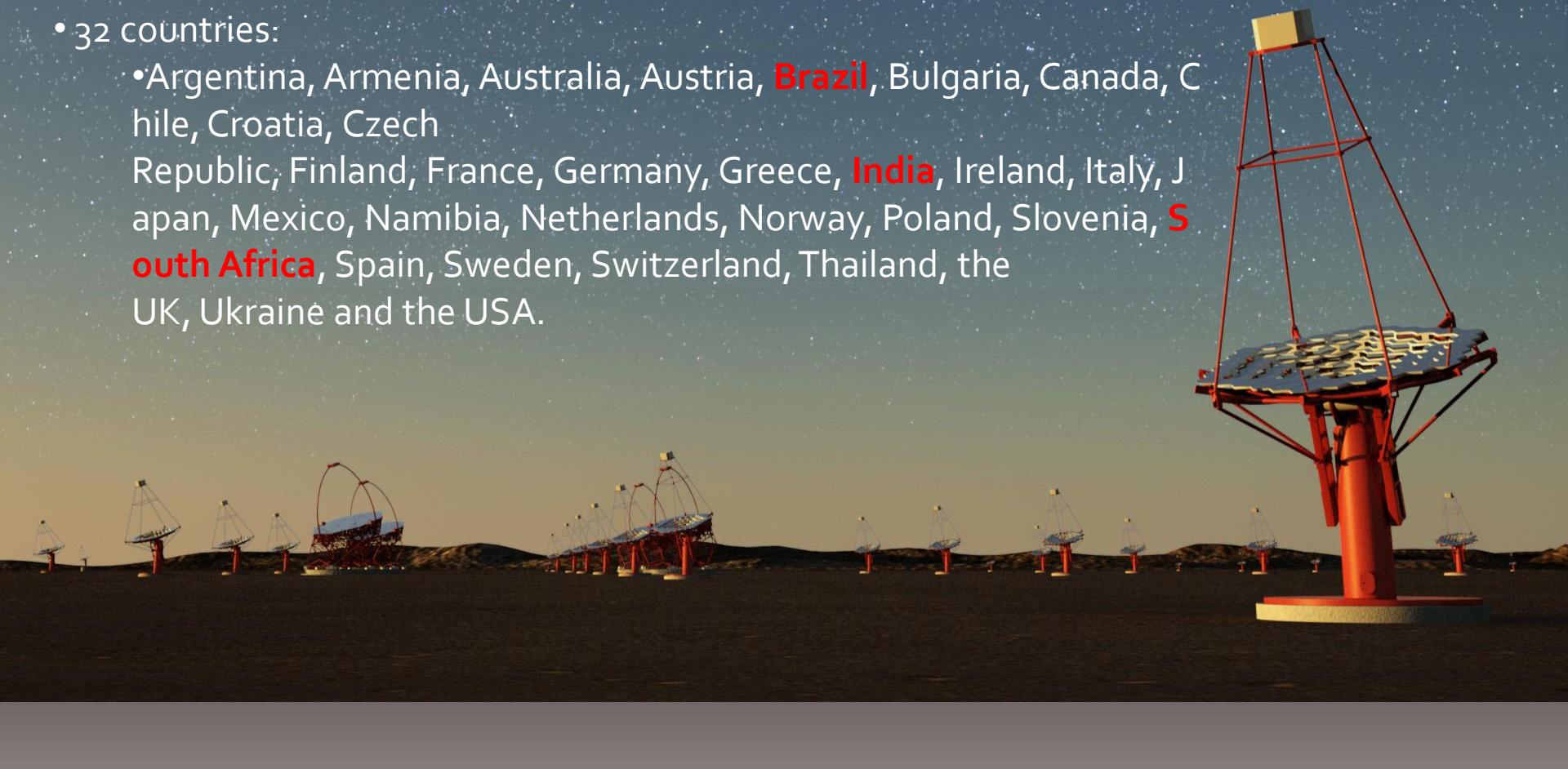


Cherenkov Telescope Array

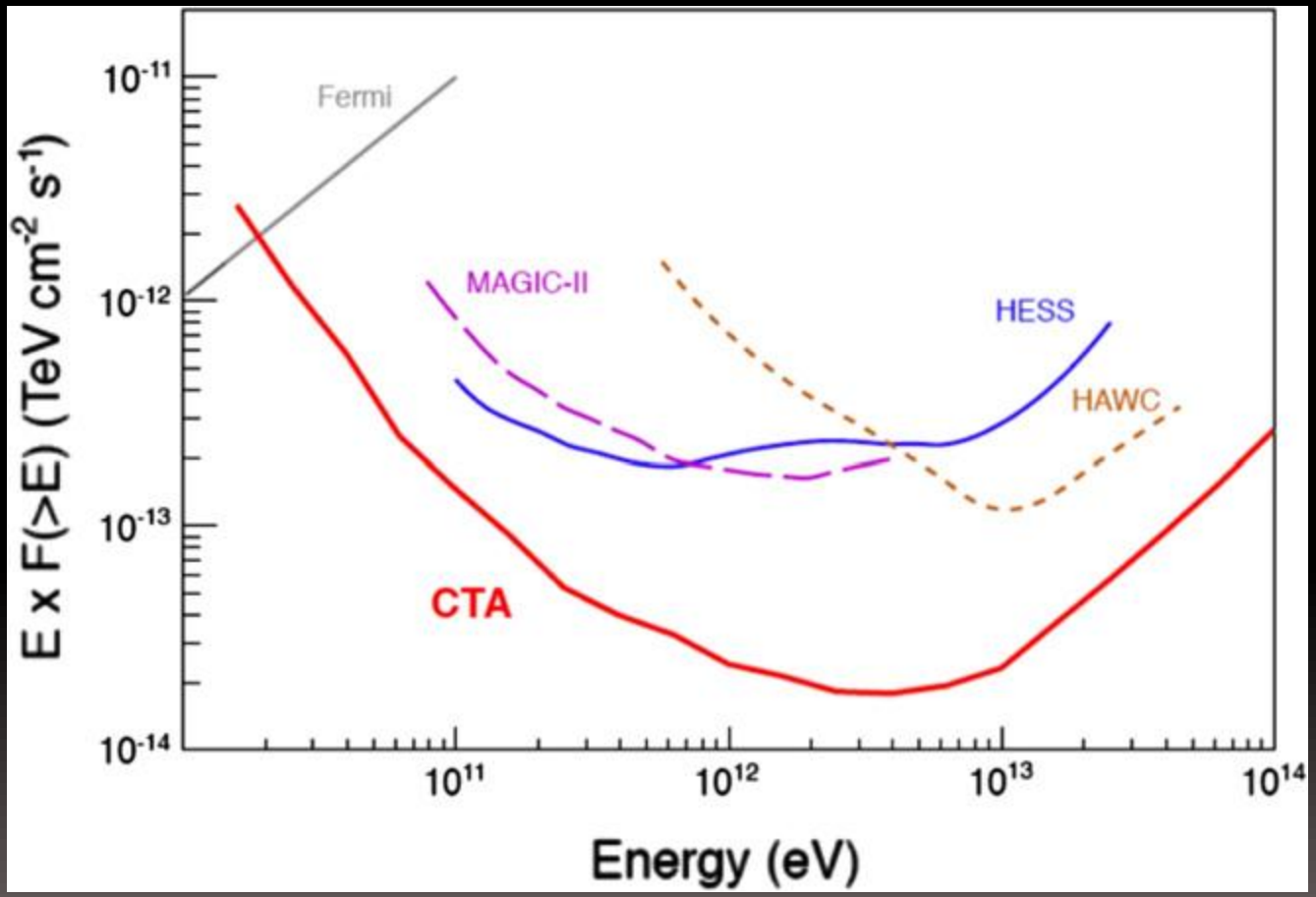
- Included in the 2008 roadmap of the European Strategy Forum on Research Infrastructures (ESFRI).
- One of the "Magnificent Seven" of the European strategy for astroparticle physics
- High ranking in the "strategic plan for European astronomy"
- A recommended project in the US Decadal Review.

Cherenkov Telescope Array

- The CTA Consortium
- 1200 individuals
- 200 institutes
- 32 countries:
  - Argentina, Armenia, Australia, Austria, **Brazil**, Bulgaria, Canada, Chile, Croatia, Czech Republic, Finland, France, Germany, Greece, **India**, Ireland, Italy, Japan, Mexico, Namibia, Netherlands, Norway, Poland, Slovenia, **South Africa**, Spain, Sweden, Switzerland, Thailand, the UK, Ukraine and the USA.



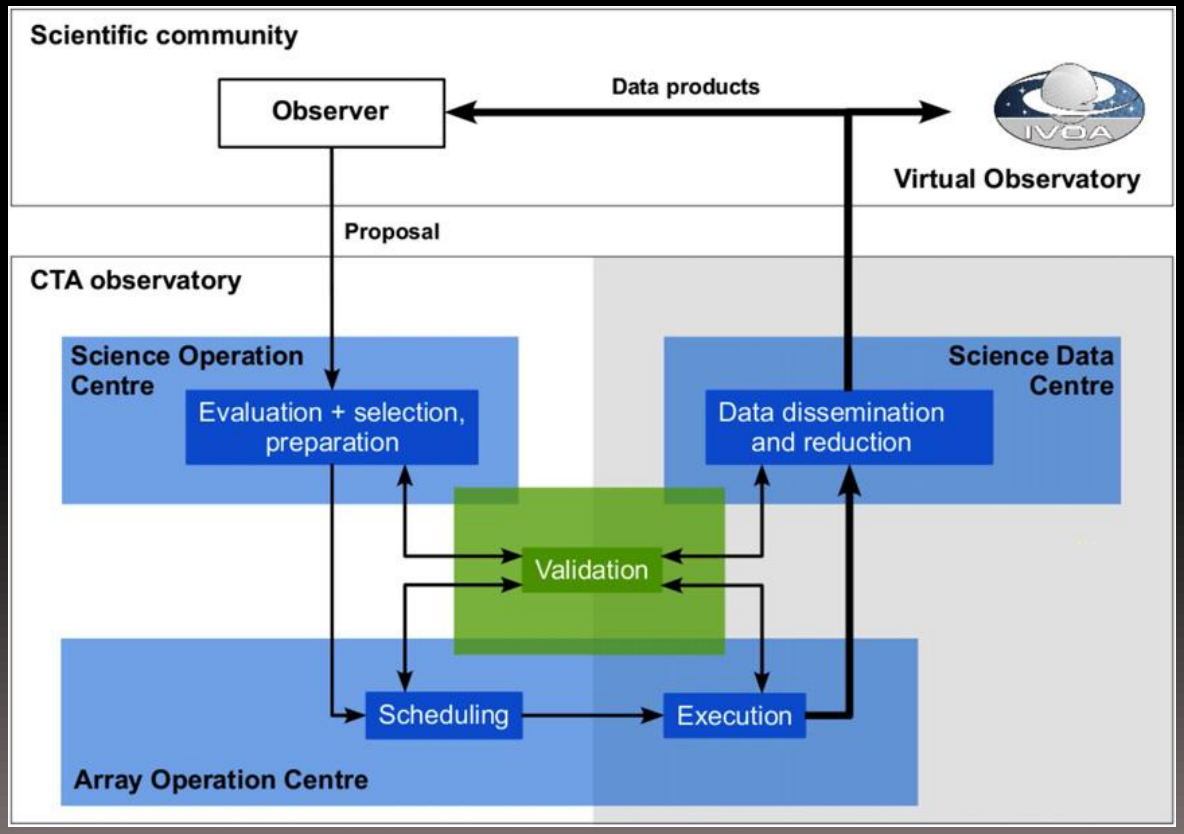
Cherenkov Telescope Array



B.S. Acharya et al. / Astroparticle Physics 43 (2013) 3–18

Cherenkov Telescope Array

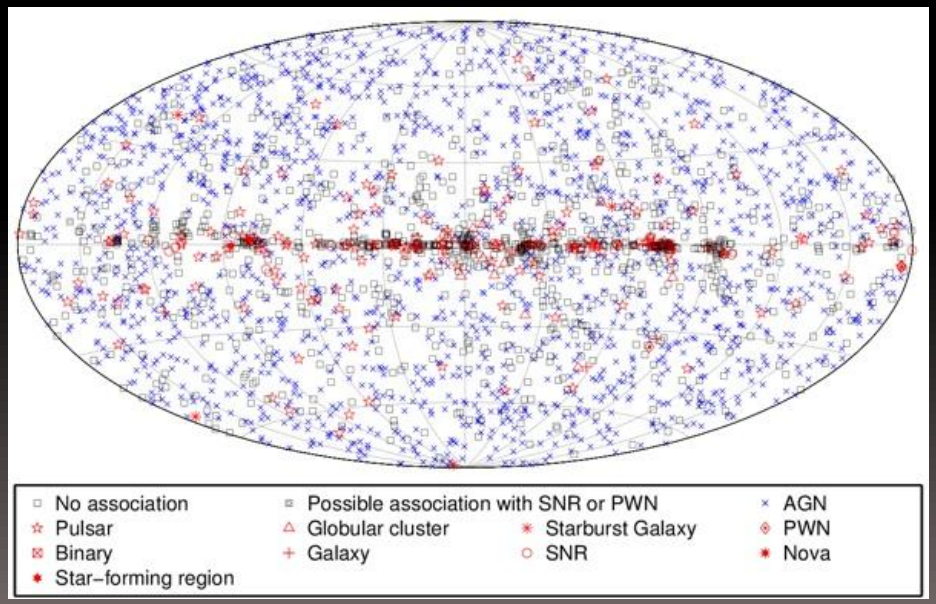
- CTA will have a rapid data analysis
- User will have access to the output from the standard data analysis
- Data handling will be performed by the CTA EGI Virtual Organisation (20 sites/7 countries)
- Typically ~10 TB per night -> a few ~10s MB of high level data within hours.



B.S. Acharya et al. / Astroparticle Physics 43 (2013) 3–18

Fermi -LAT

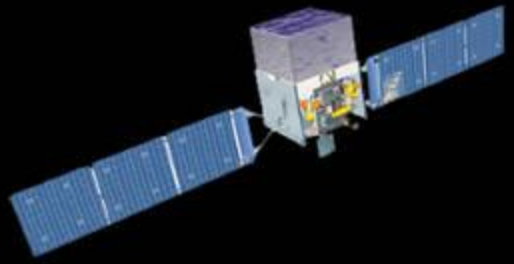
- Space based gamma-ray telescope
- Two instruments
  - LAT –Large Area Telescope
  - GBM – Gamma-ray burst Monitor
- Continuously scans the sky collecting data in the 0.100 – 100 GeV energy range
- 3033 sources have, so far, been identified.

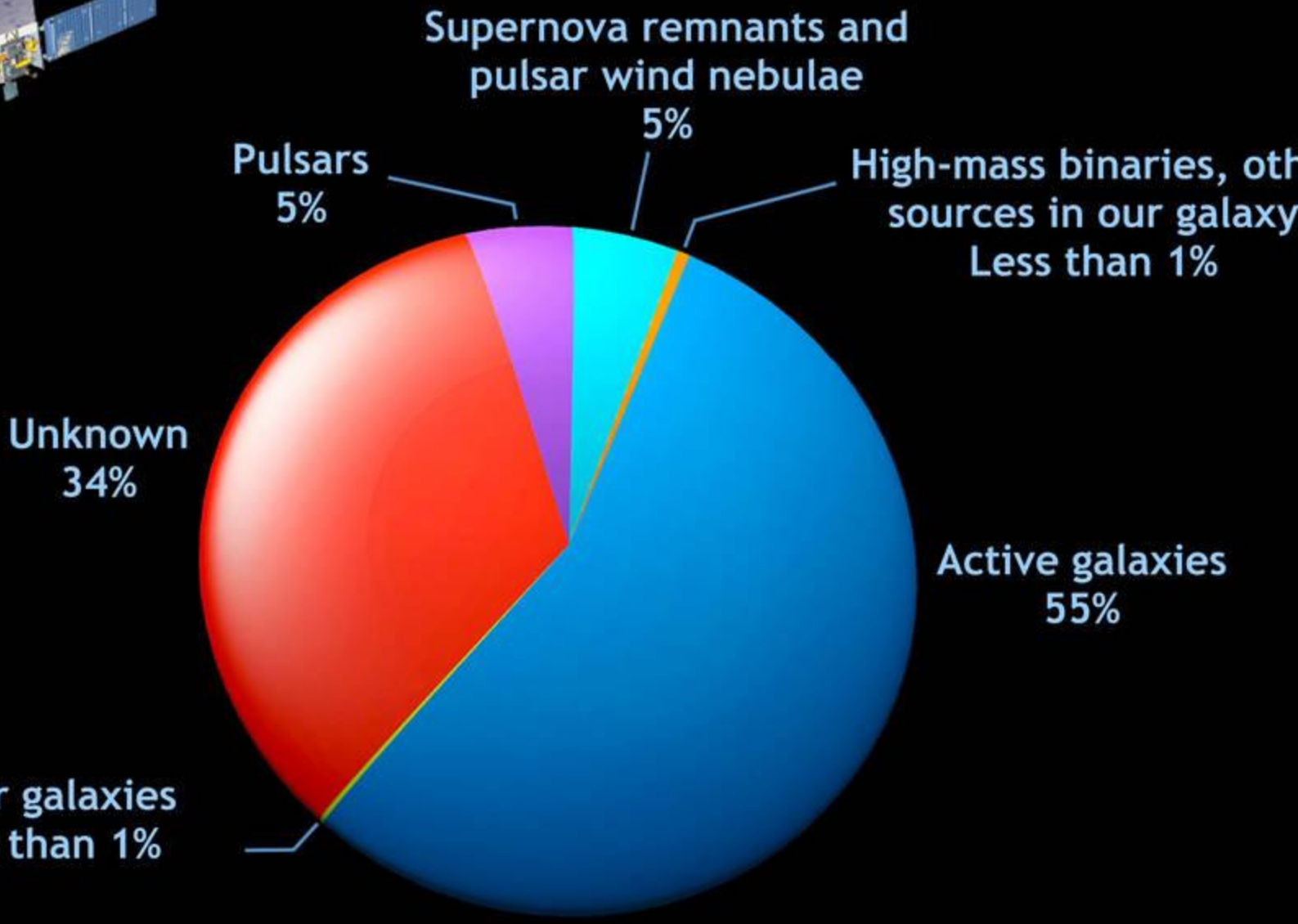


Currently RSA has four Fermi members

- Soebur Razzaque (UJ) full member
- Andrew Chen (Wits) affiliated member
- Christo Venter (NWU) affiliated member
- Richard Britto (UFS) affiliated memeber

Fermi reveals the universe above 10 GeV





A National South African Virtual Observatory

South African Astro-informatics Alliance (SA^3)

A New Era of Data Intensive Astronomy in Africa

- South African Astronomical Observatory (SAAO)
- South African Square Kilometre Array (SKA-SA)
- Inter University Centre for Data Intensive Astronomy (IDIA)
- Hartebeestheok Radio Observatory (HartRAO)

Team:

Lindsay Magnus (SA^3 Chairperson, SKA-SA)
Patricia Whitelock (SAAO)
Russ Taylor (IDIA)
Sudhanshu Barway (SAAO)

NRF National Research Foundation | SA^3 South African Astro-informatics Alliance

The Changing Face of Observational Astronomy

Major Data Avalanche

Large digital sky surveys are the dominant source of data in astronomy today and growing rapidly; Multi-Petabyte Sky Surveys, Billions of Detected Sources, Hundreds of Measured Attributes per Source

- Current Surveys:
SDSS, 2MASS, WISE, Planck, GALEX, DPOSS, GSC, FIRST, NVSS, RASS, IRAS; CMBR experiments; Microlensing experiments; NEAT, LONEOS, and other searches for Solar system objects……

- Digital Libraries: ADS, astro-ph, NED, Simbad, NSSDC…….

- Data Archives: HST Legacy archives, SDSS, IPAC IR, CXO, ESO, UKIRT, space and ground-based……

- Future Surveys: LSST, QUEST2, GAIA, MeerKAT surveys, GW detectors……..

- Future Big telescopes: SKA, JWST, TMT, GMT, E-ELT……..

The Changing Style of South African Observational Astronomy

The Old Way

- Pointed, heterogeneous Observations (~ MB-GB)
- Small samples of objects (~10-1000 sources)

Now

- Large & homogeneous observations & surveys (~10^6 - 10^9 sources)
- Archives of pointed observations (~TB)

Future

Multiple sky surveys (10^6 sources per night) and archives (~PB)

South African Large Telescope (SALT) ~1 TB/Year

Square Kilometer Array (SKA) ~10^6 TB/second (raw data)

Virtual Observatory

Virtual Observatory

A Virtual Observatory (VO) provides a scientific research environment with a collection of interoperable complex data sets, software tools and applications which utilize the power of Internet or WWW to conduct astronomical research, education and outreach projects.

WWW - all the docs in the world inside your PC

VO - all the database in the world inside your PC

South African Astro-informatics Alliance (SA^3)

SA^3 roadmap -

- 1. Excellence in Research
  - Combine world class multi-wavelength data with SALT & MeerKAT
- 2. Human Capital Development / Astronomy technology development
  - Take a lead in defining data management standards and protocols & software development
- 3. Astronomy education/outreach & Marketing of Astronomy & Astrophysics
  - VO tools/applications (WWT, Google Earth, Galaxy Zoo….)
  - VO for University research & education
- 4. National/International partnership
  - African Astronomy Data Centre, CHPC, Astrogrid, VO-India, AVO, CDS……..

South African Astro-informatics Alliance (SA^3)

Activities

- Data archive system development
  - SALT VO DATA Archive - http://vodas.salt.ac.za/
- VO tools development
  - SALT Visibility Calculator Android App
- Astronomical data Mirror
  - ADS - http://ads.idia.ac.za/
  - Vizier - http://viziersaao.chpc.ac.za/viz-bin/VizieR
- Teaching, education and public outreach
- SA^3 web page -http://www.sa3.ac.za/

CONCLUSION

This is a very exciting time for South African & Southern African astronomy

In addition to MeerKAT/SKA RSA researchers are involved or getting involved with

- SALT
- MeerLICHT
- LSST
- H.E.S.S.
- CTA
- Fermi-LAT
- Etc.

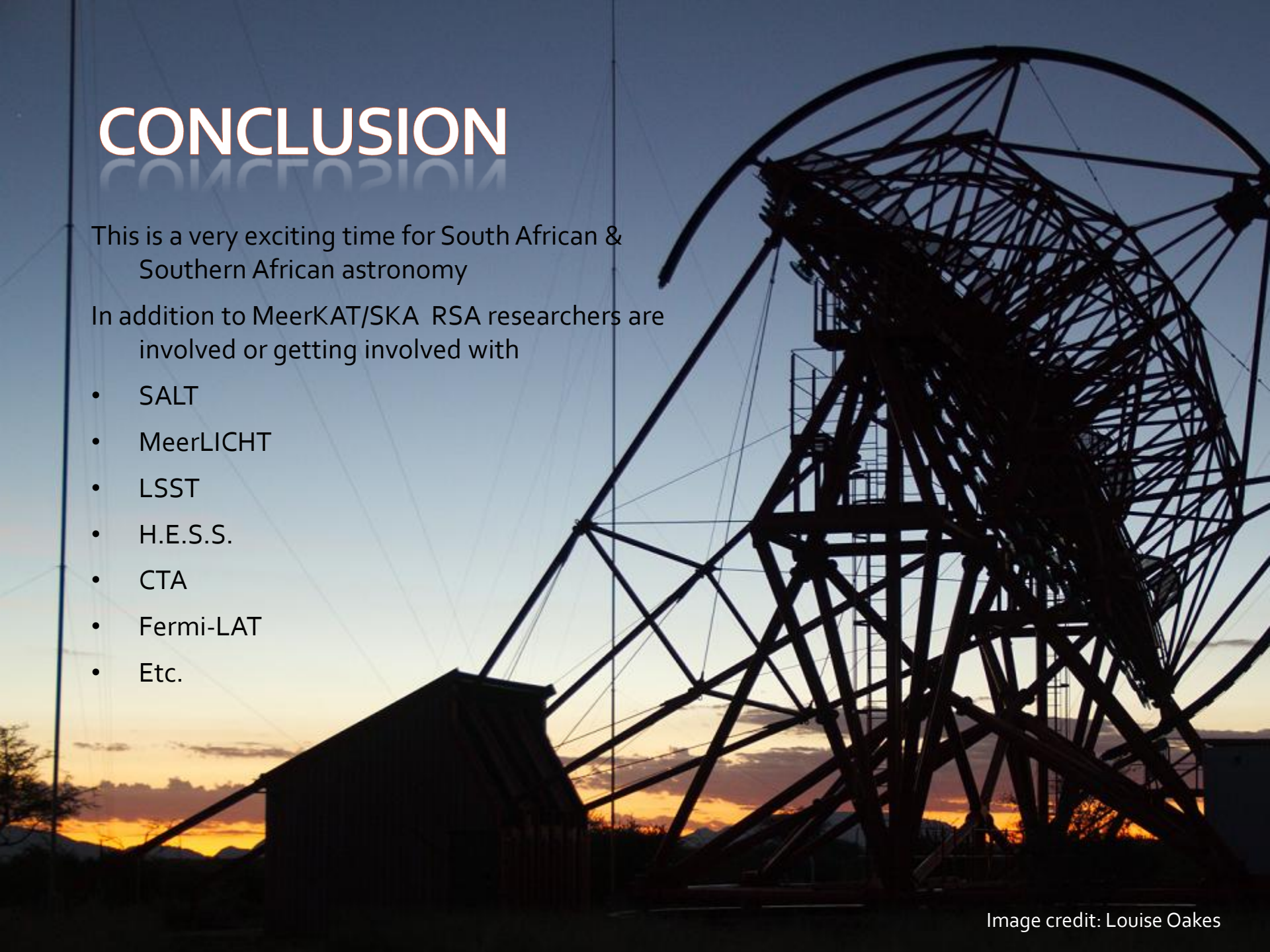


Image credit: Louise Oakes

THANKYOU