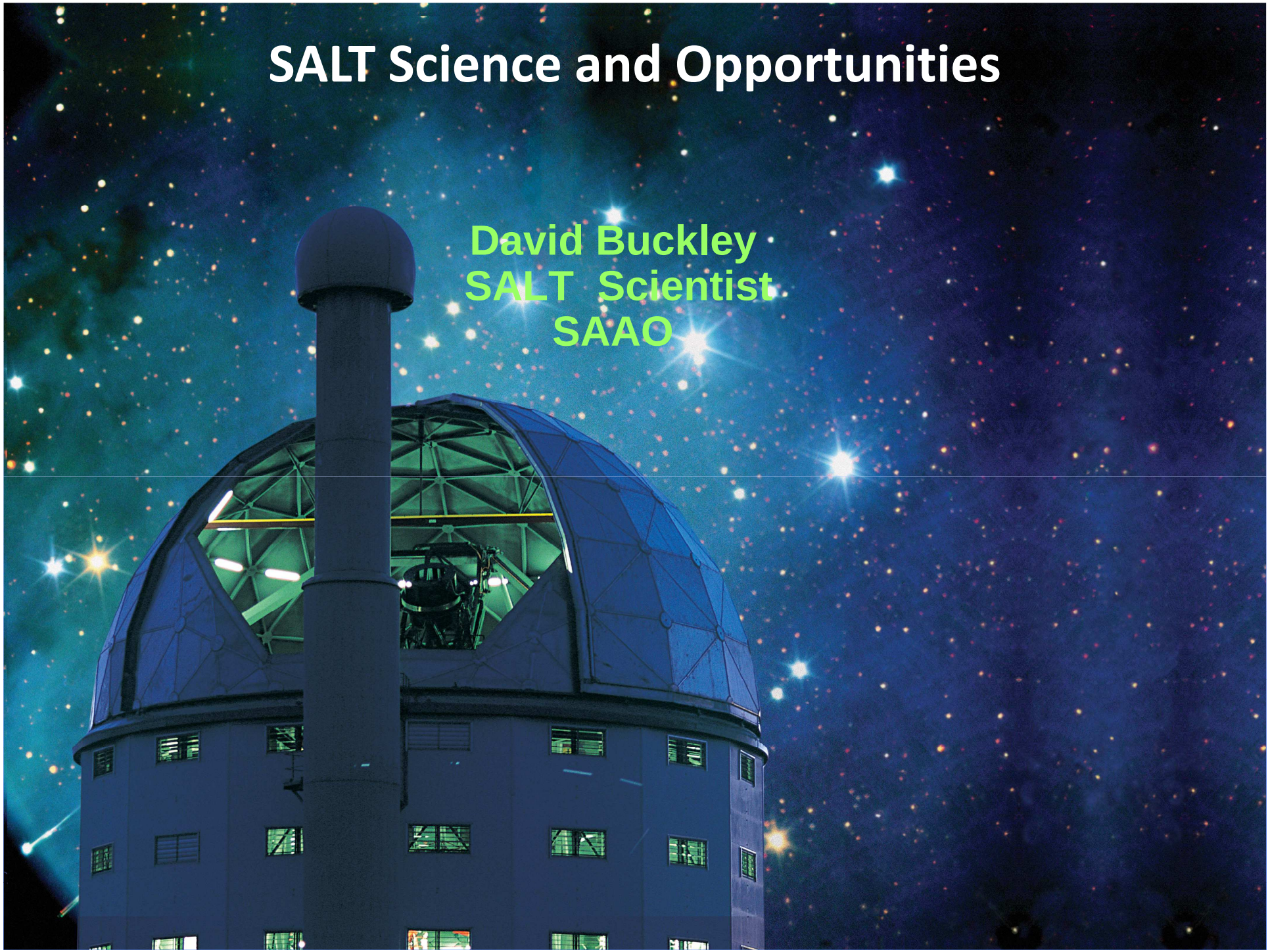
# SALT Science and Opportunities



David Buckley
SALT Scientist
SAAO

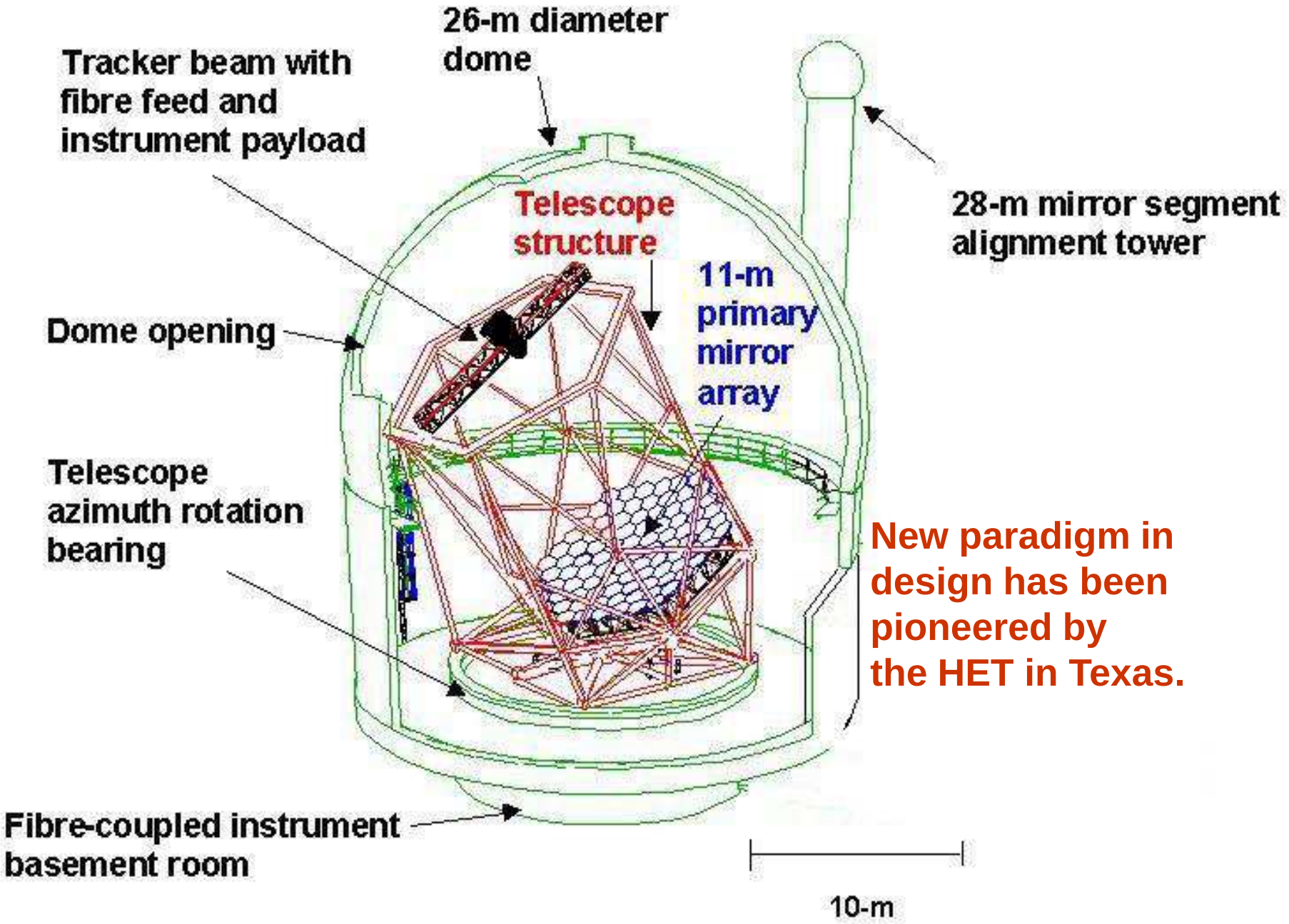
# SALT

## One of the "Big Five": Segmented Mirror Telescopes

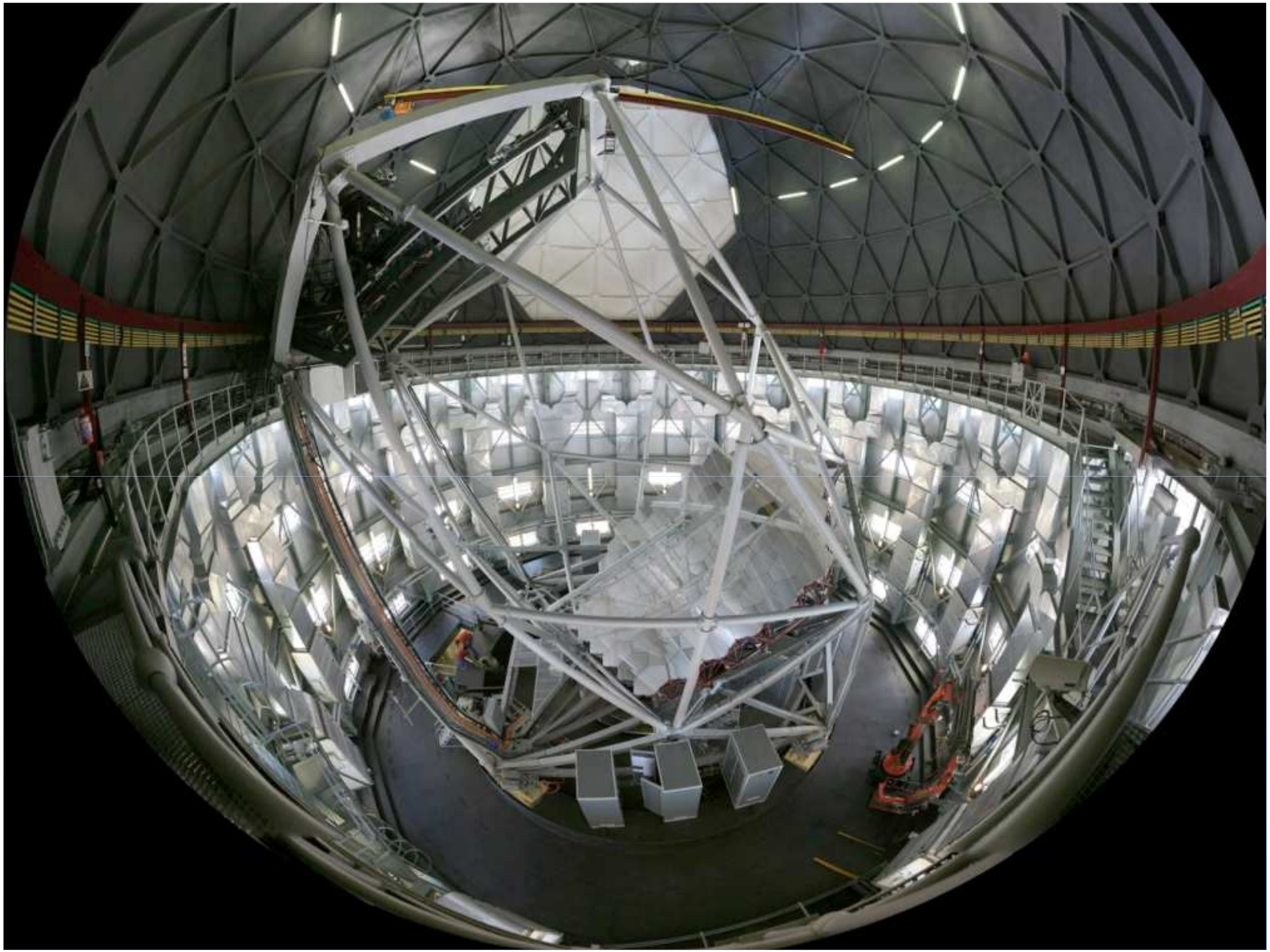
- Keck I (1993) & Keck II (1996): Hawaii, USA
- HET (1999): Texas, USA
- SALT (2005): South Africa
- GRANTECAN (2009): Canary Islands, Spain

These telescopes currently have the largest light grasp

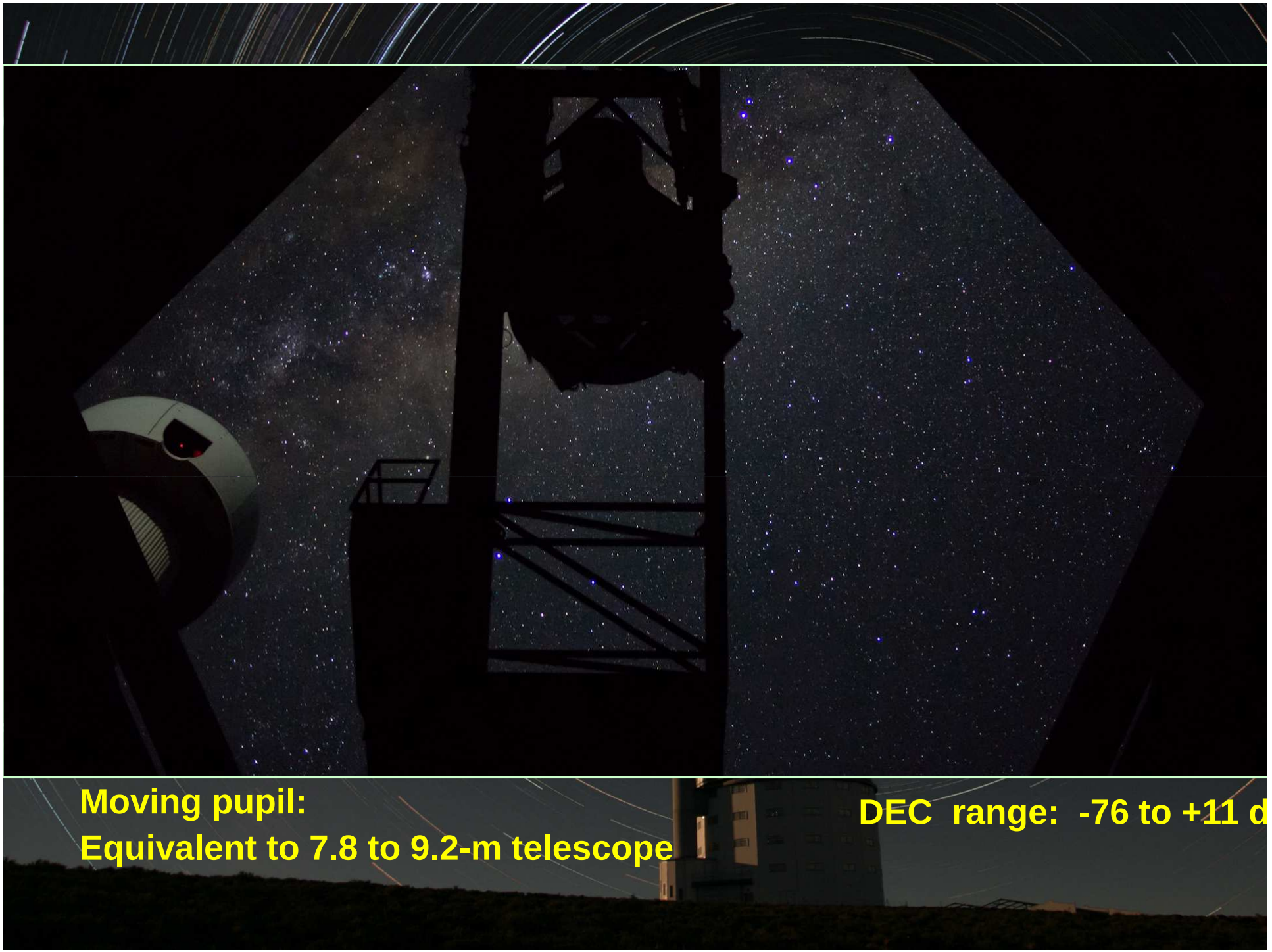
# Southern African Large Telescope



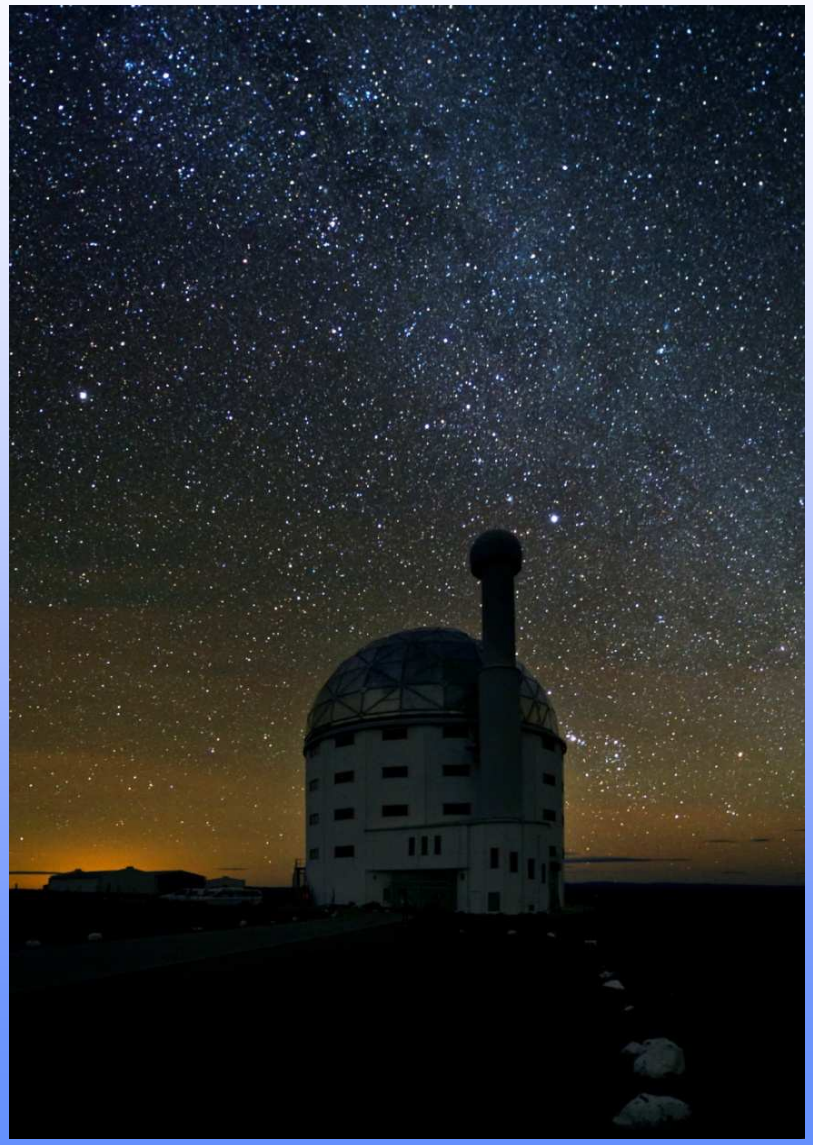

**New paradigm in design has been pioneered by the HET in Texas.**



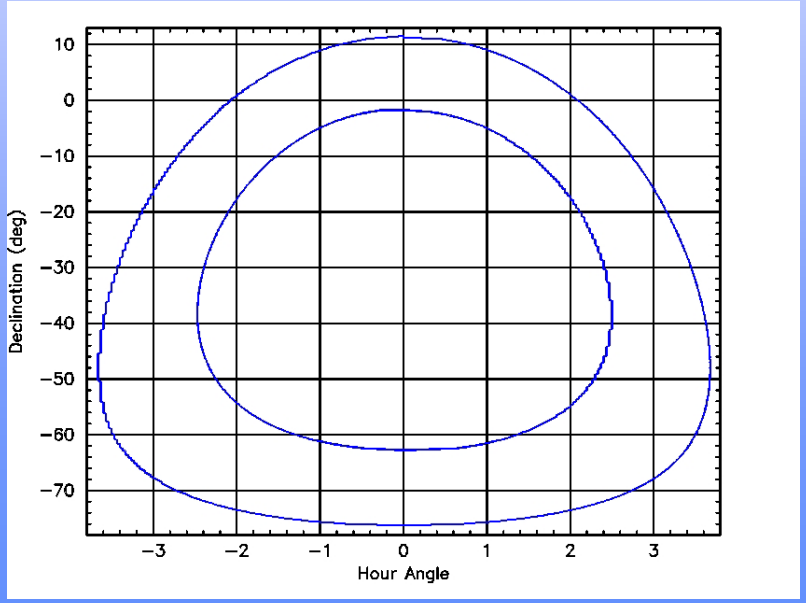

11 metre primary mirror
91 one-metre segments
with an *active alignment* system


Moving pupil:
Equivalent to 7.8 to 9.2-m telescope
DEC range: -76 to +11 d

# Observing With SALT



- 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



# SALT – a brief history

- **First light and inauguration in Nov 2005**
  - **Some science (~50%) done while diagnosing tech/opt issues**
  - **Off-line for repairs for 2009-2010, fixed late 2010.**

- **Second light in September 2011**

**In full science operations since late 2011.**

**Eleven half-year “Science semesters” completed to date, on our 12$^{th}$ now.**

# SALT Partners

NRF National Research Foundation | SAAO South African Astronomical Observatory

The Open University

IUCAA

Keele University

Nicolaus Copernicus Astronomical Center

uclan

Dartmouth

The University of Nottingham

The University of North Carolina at Chapel Hill

University of Southampton

Armagh Observatory

WISCONSIN

Rutgers The State University of New Jersey

American Museum of Natural History

It is a good time to be a SALT Partner.

New collaborations sought (~10% opportunity)

South Africa is a 35% Partner

Poland is a 10%Partner

# SALT First-Generation Science Instruments

- Instruments chosen to give SALT a wide range of capabilities
- Ensure competitiveness with niche operational modes
  - UV, Fabry-Perot, high-speed, polarimetry
- Take advantage of SALT design and *modus operandii*
- Nominally budgeted for 3 "first generation" instruments
- First two ('first light') instruments:
  - SALTICAM: a sensitive "video camera" (up to ~15 Hz)
  - Robert Stobie Spectrograph (RSS):a versatile imaging spectrograph
  - Both installed in 2005
- Last one, a fibre-fed High Resolution Spectrograph
  - Delivered and installed in Sep 2013
  - Science Verification through to Apr 2014
  - Now fully operational

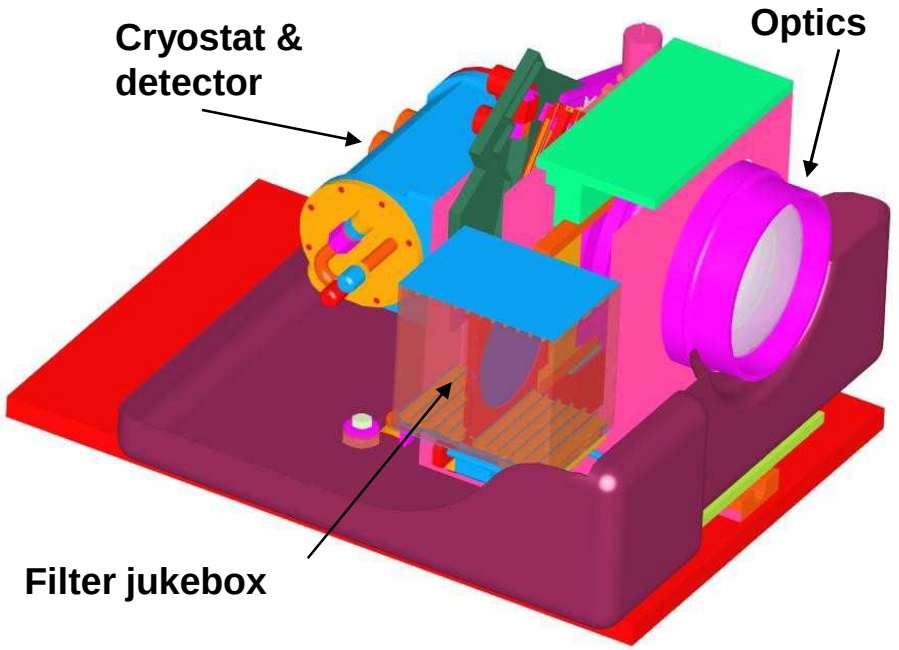
# SALTICAM

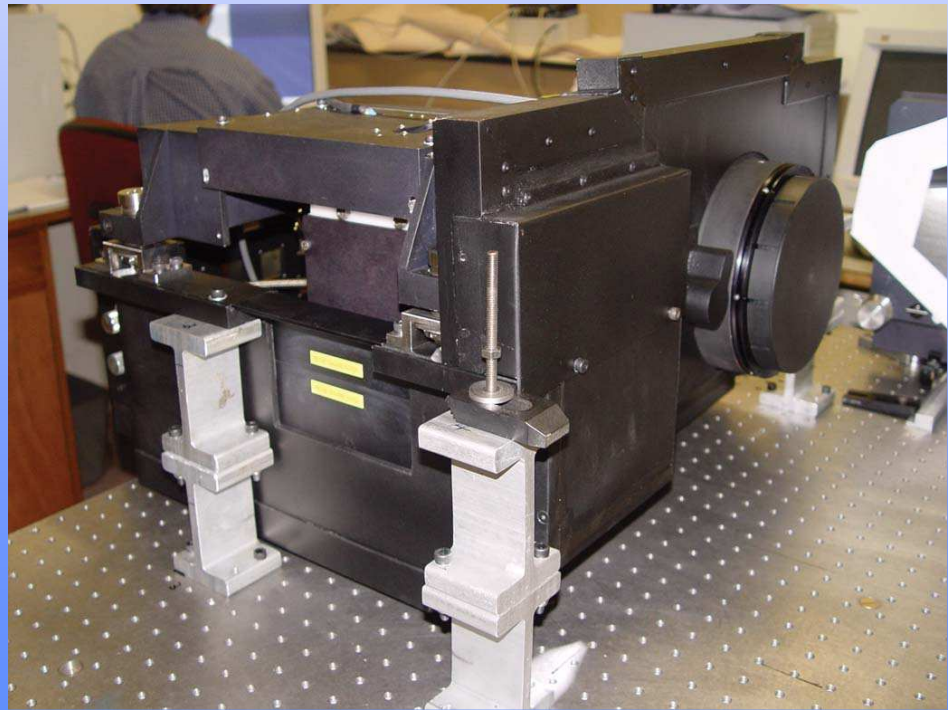
An efficient "video" camera over entire science FoV (8 arcmin).

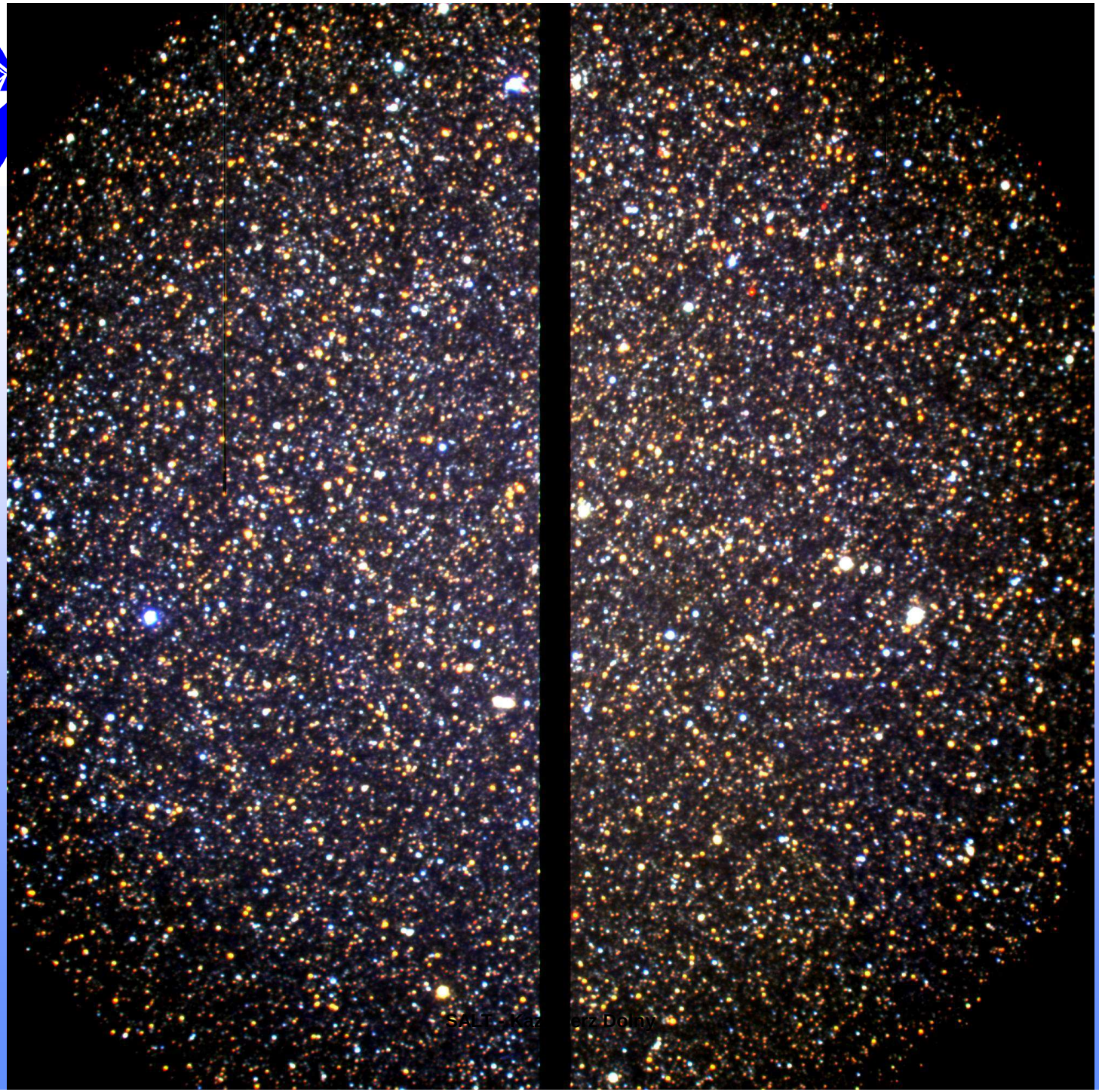
Efficient in the UV/blue (capable down to atmospheric cutoff at 320nm)

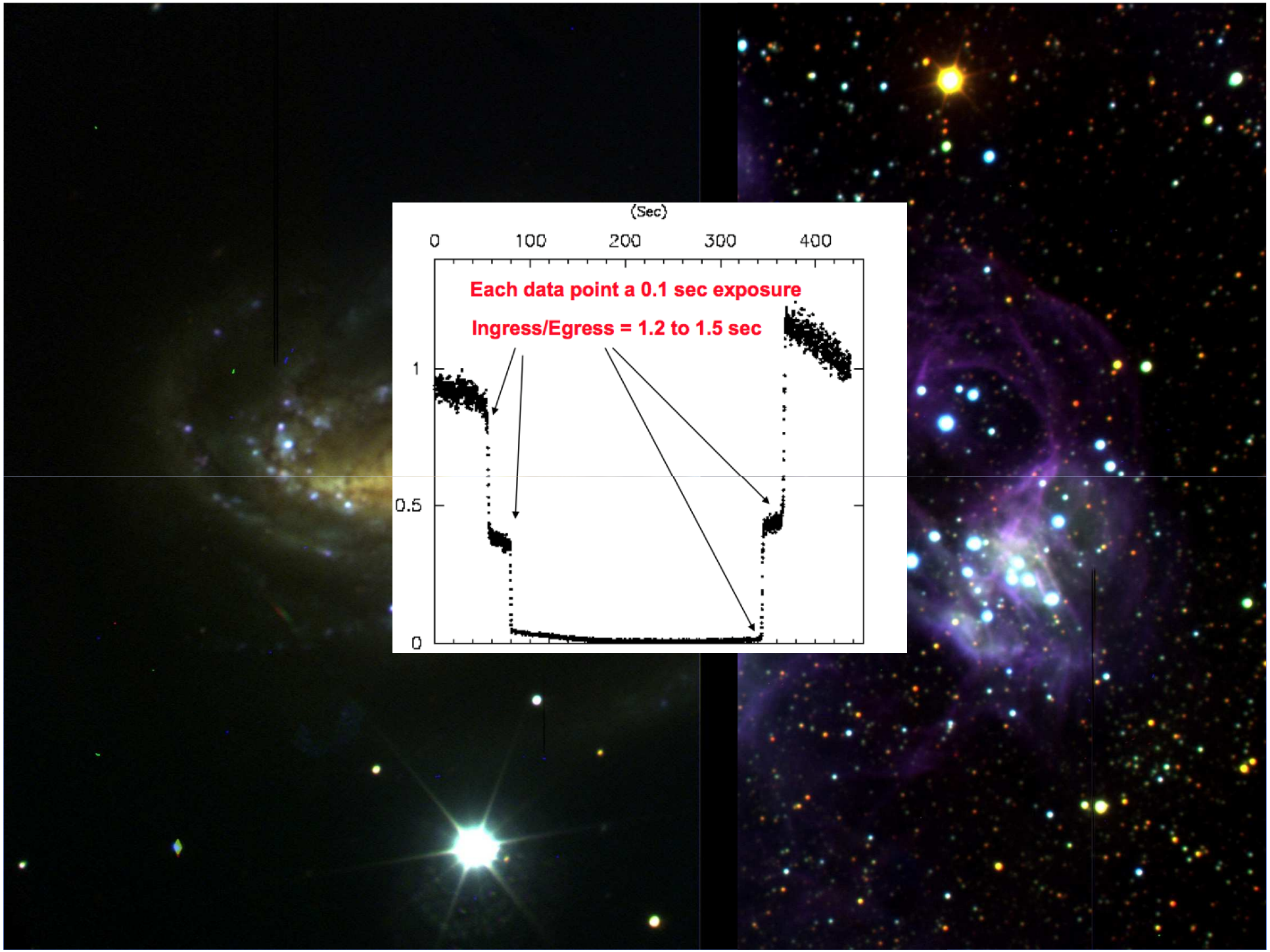
Capable of broad and intermediate-band imaging and high time-resolution (to ~70 ms) photometry.

Fulfills role as both an acquisition camera and science image (ACSI) and commissioning/verification instrument (VI).






(Sec)
0
100
200
300
400
Each data point a 0.1 sec exposure
Ingress/Egress = 1.2 to 1.5 sec
1
0.5
0

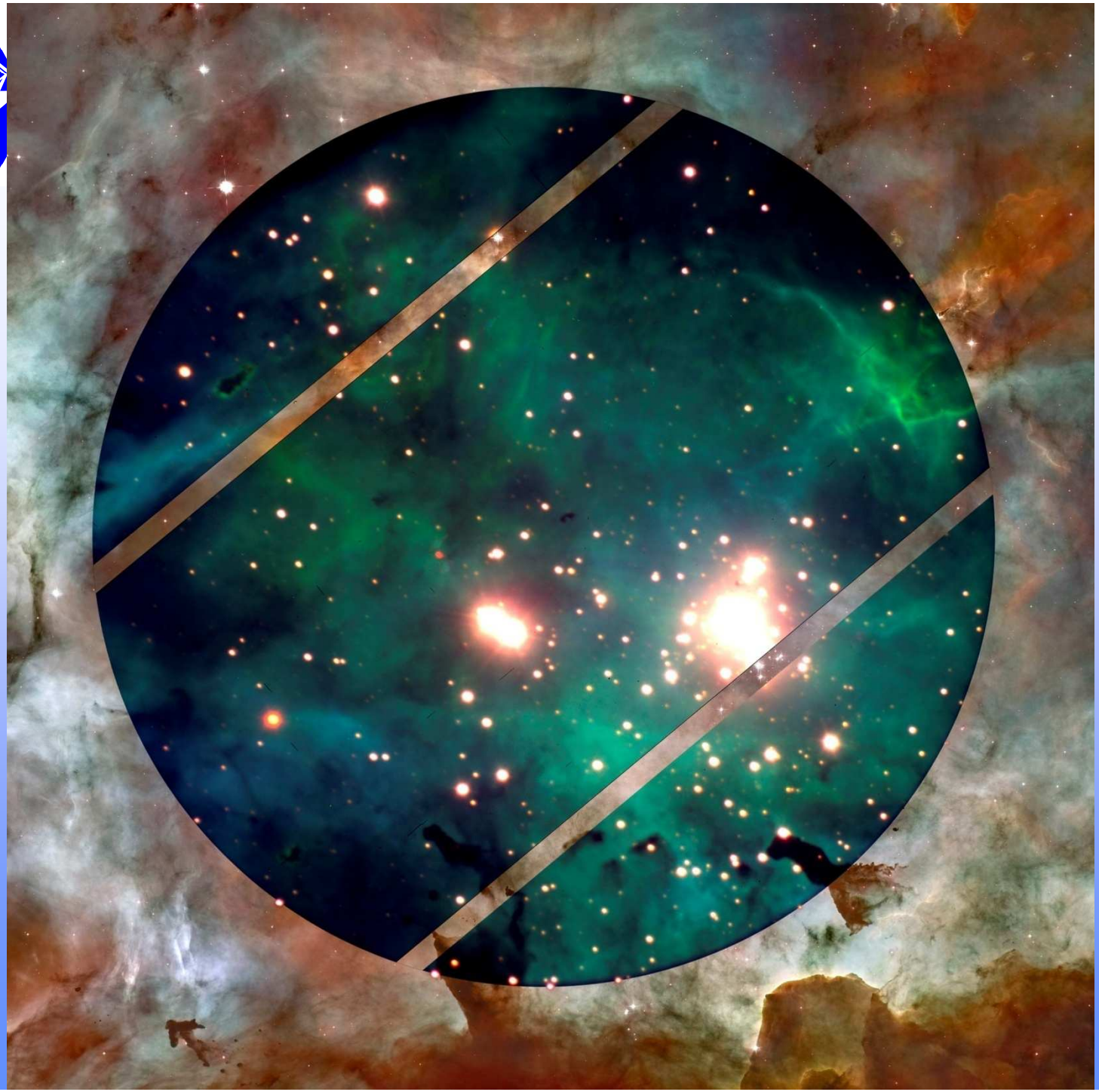
# RSS:Robert Stobie Spectrograph

**[University of Wisconsin-Madison]**

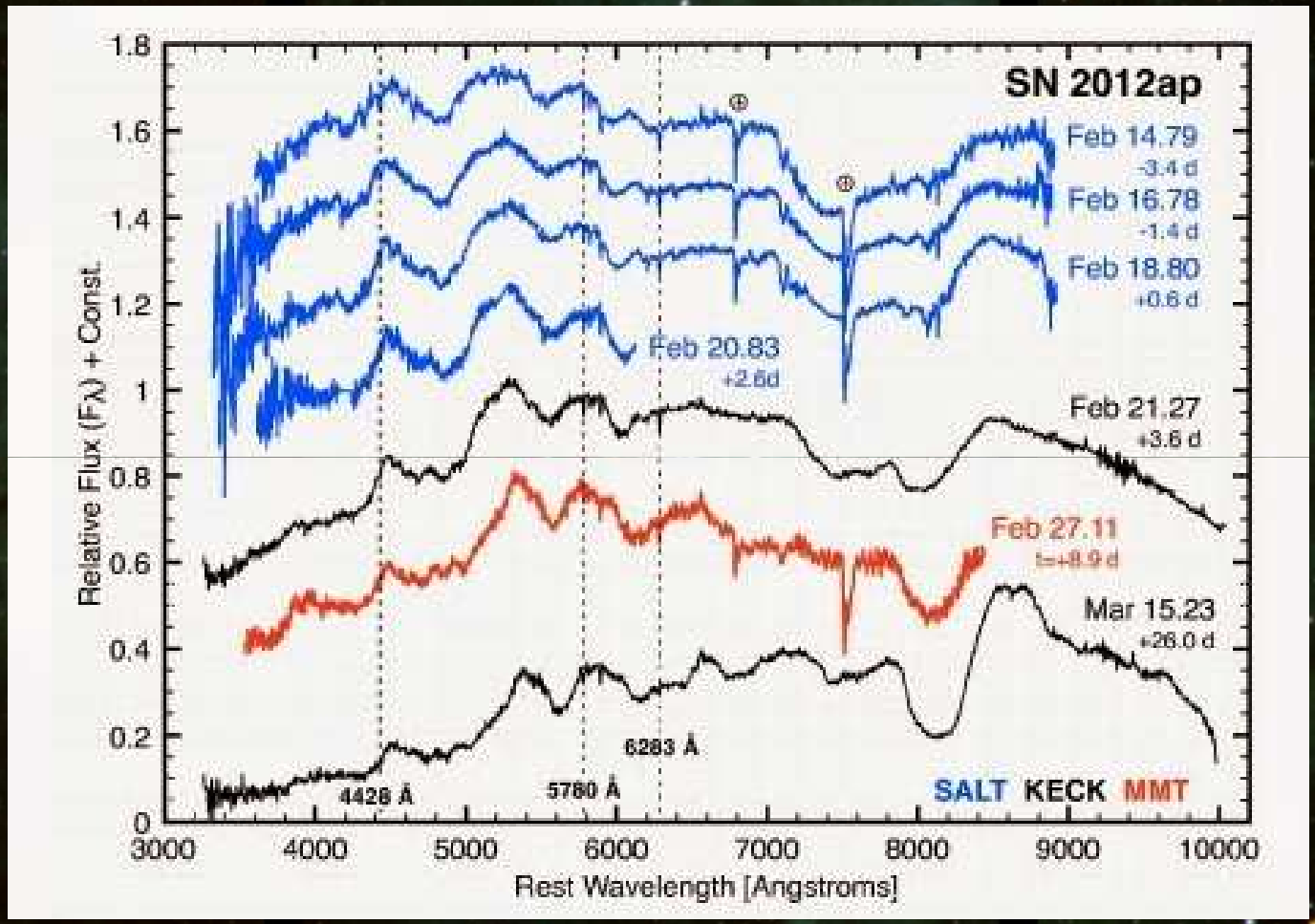
- **Efficient Prime Focus spectrograph**
- **Covers ~320 – 900nm**
- **Long slit and multi-object (~50) spectroscopy medium resolution, *R* ~ 350 to 10,000**
- **Very flexible Resolution and wavelength coverage.**
- **Fabry-Perot imaging spectroscopy**
- **Imaging polarimetric and spectropolarimetric modes**
- **High Time resolution ~100 ms spectroscopy**

- **The work-horse instrument on SALT**

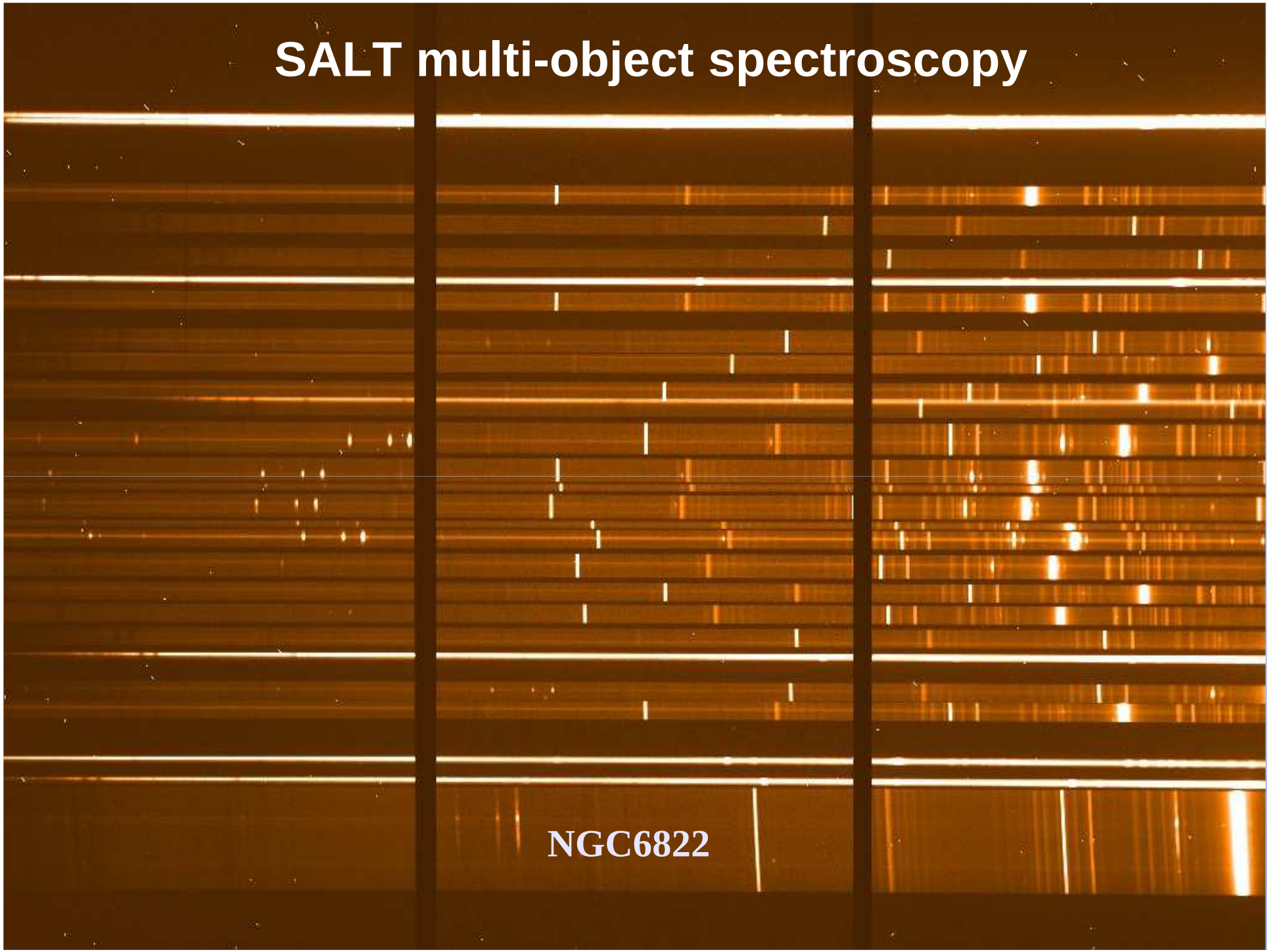
- **Upgrade to near-IR beam IFU unit (J,H) in 2019**


S·A·L·T

# SALT long-slit spectroscopy

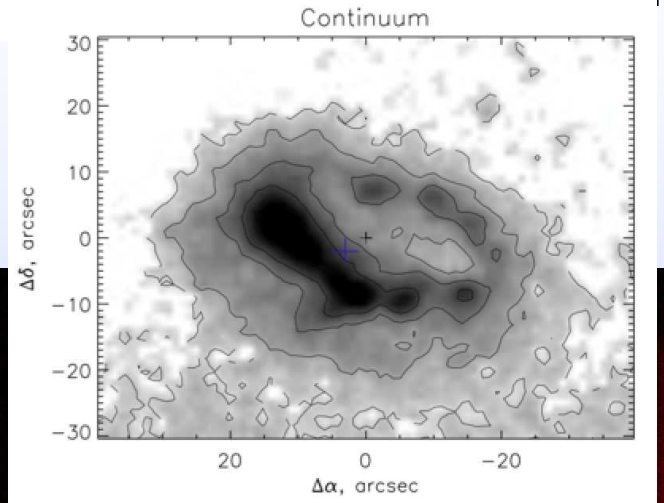


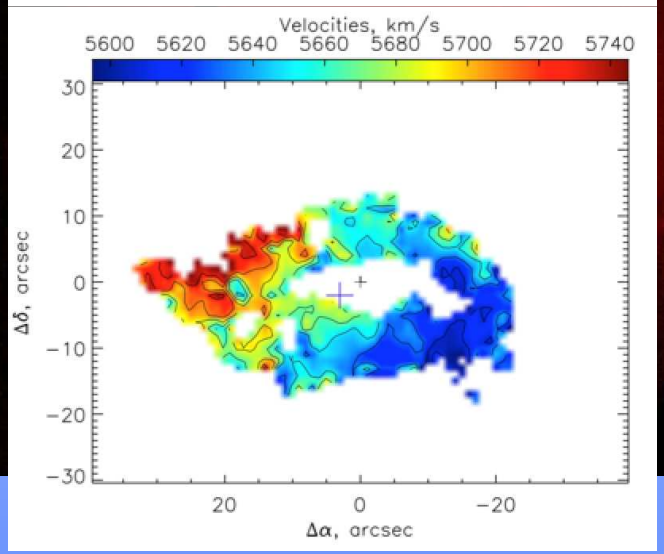
# SALT multi-object spectroscopy



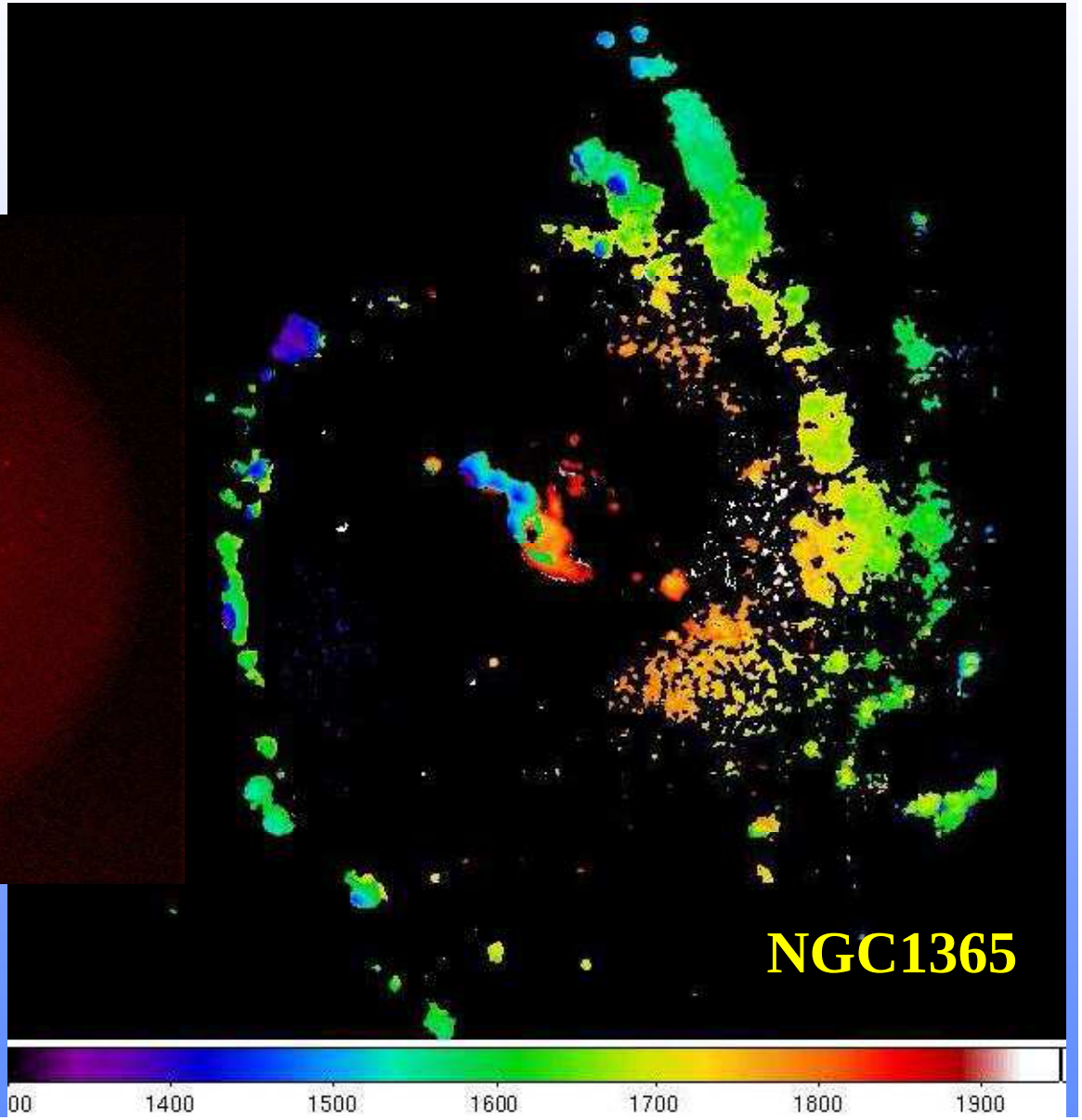
# Using Fabry-Perot imaging spectroscopy

**spectral resolutions between 300 and 9000**
**Velocity fields of ionised gas in galaxies**




**Blue- approaching;**
**Red- receding**



# RSS sensitivities

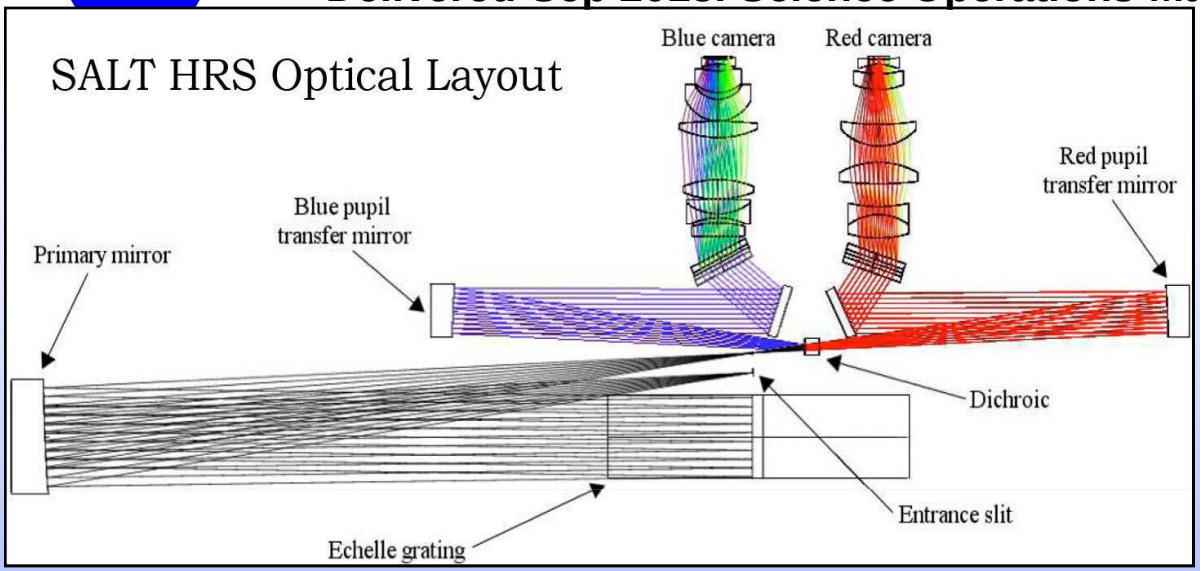
**Roughly, in dark median-seeing conditions:**

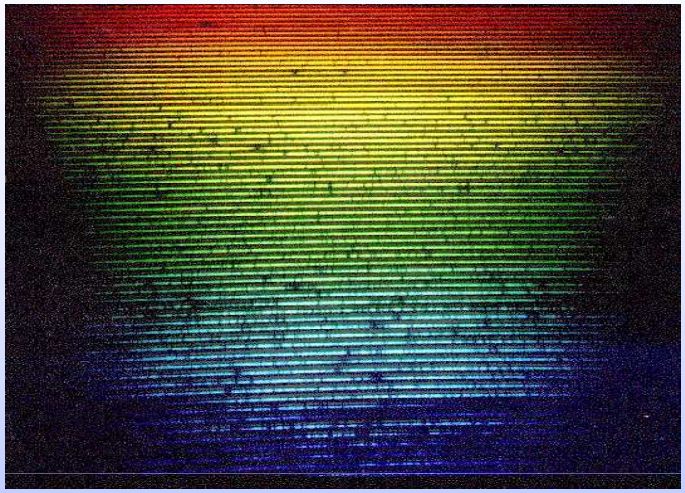
- **You can get S/N ~ 5 on r ~ 21.5 mag points sources in 30 min in medium-resolution**

- **22-23 mag emission-line redshifts also secured (e.g. z ~ 1 galaxy clusters)**

# SALT High Resolution Spectrograph (HRS): (built by Durham University; PI: Ray Sharples)

**Delivered Sep 2013. Science Operations May 2014.**



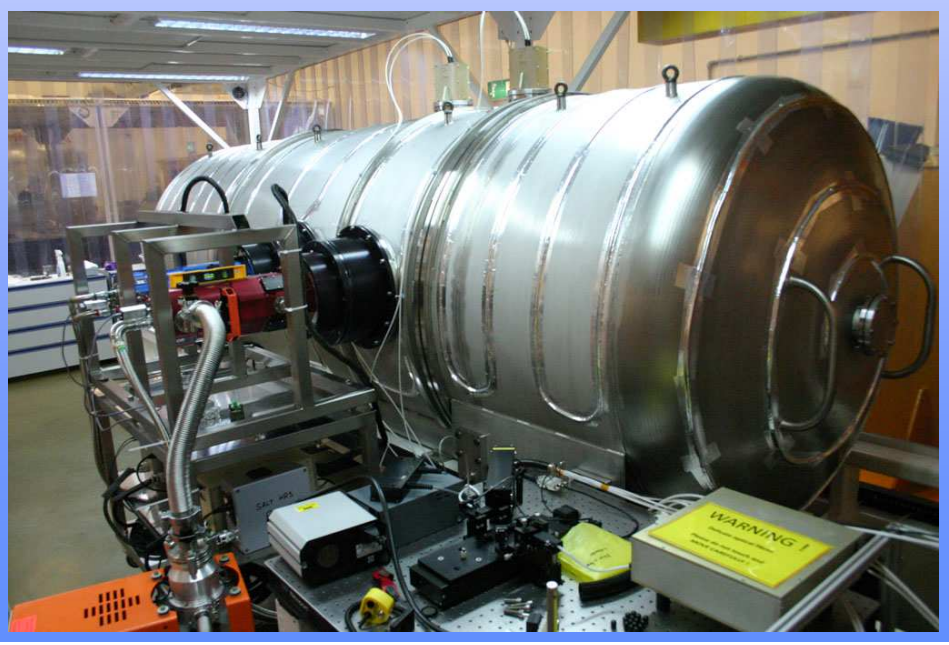



**Fibre-fed with dual fibres for star/sky**

**Three resolution modes R ~ 16,000 – 70,000**
**λ ~ 380 – 890 nm**

**Designed for very *high stability***

- **Housed in vacuum tank**
- **Temperature stabilized**
- **Minimize air index effects**
- **Minimize dimension changes**
- **Precision radial velocities (m/s)**
  - **extra-solar planets**



# HRS sensitivities

**Roughly, in good seeing conditions:**

- **You can get S/N ~ 5-10 on V ~ 17-17.5 mag point sources in one hour in LR**

- **You can get S/N ~ 10 on V ~ 16.5 mag point sources in one hour in HR**

# What is SALT especially good at?

**Telescope: Huge collecting power.**

**Site: Skies are very dark (V ~ 22 mag/arcsec$^2$).**

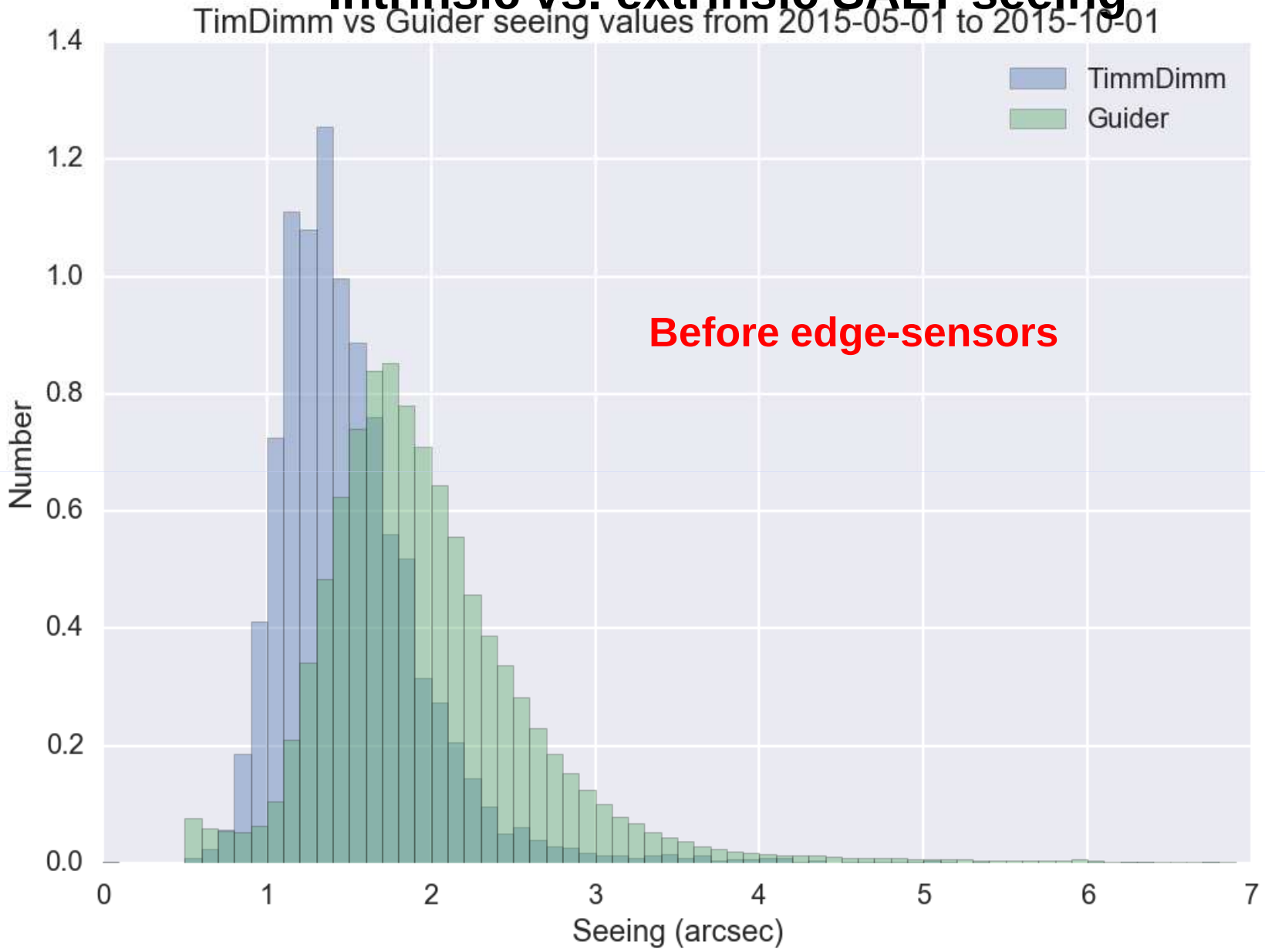
- **Diffuse low-surface-brightness spectroscopy very competitive.**
- **Objects above background observed very efficiently.**
- **Can change instruments and observing modes in seconds.**
- **Rapid reaction to transients and ToOs**
- **Some *rare modes for large telescopes* (FP, Pol, mixed modes, high-time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

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

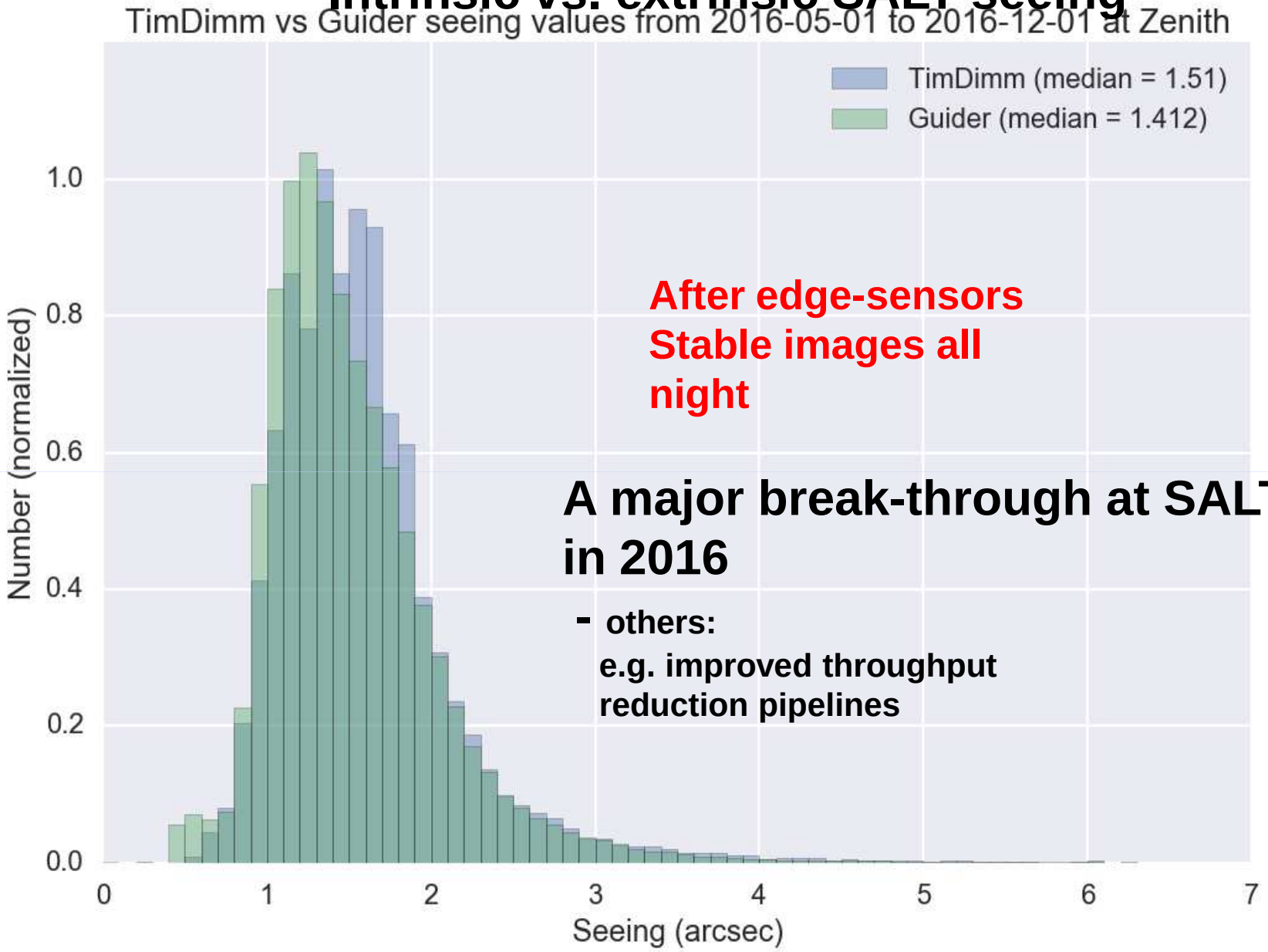
# SALT STATUS

## - PRACTICALLY ALL MODES IN OPERATION

# Intrinsic vs. extrinsic SALT seeing



# Intrinsic vs. extrinsic SALT seeing



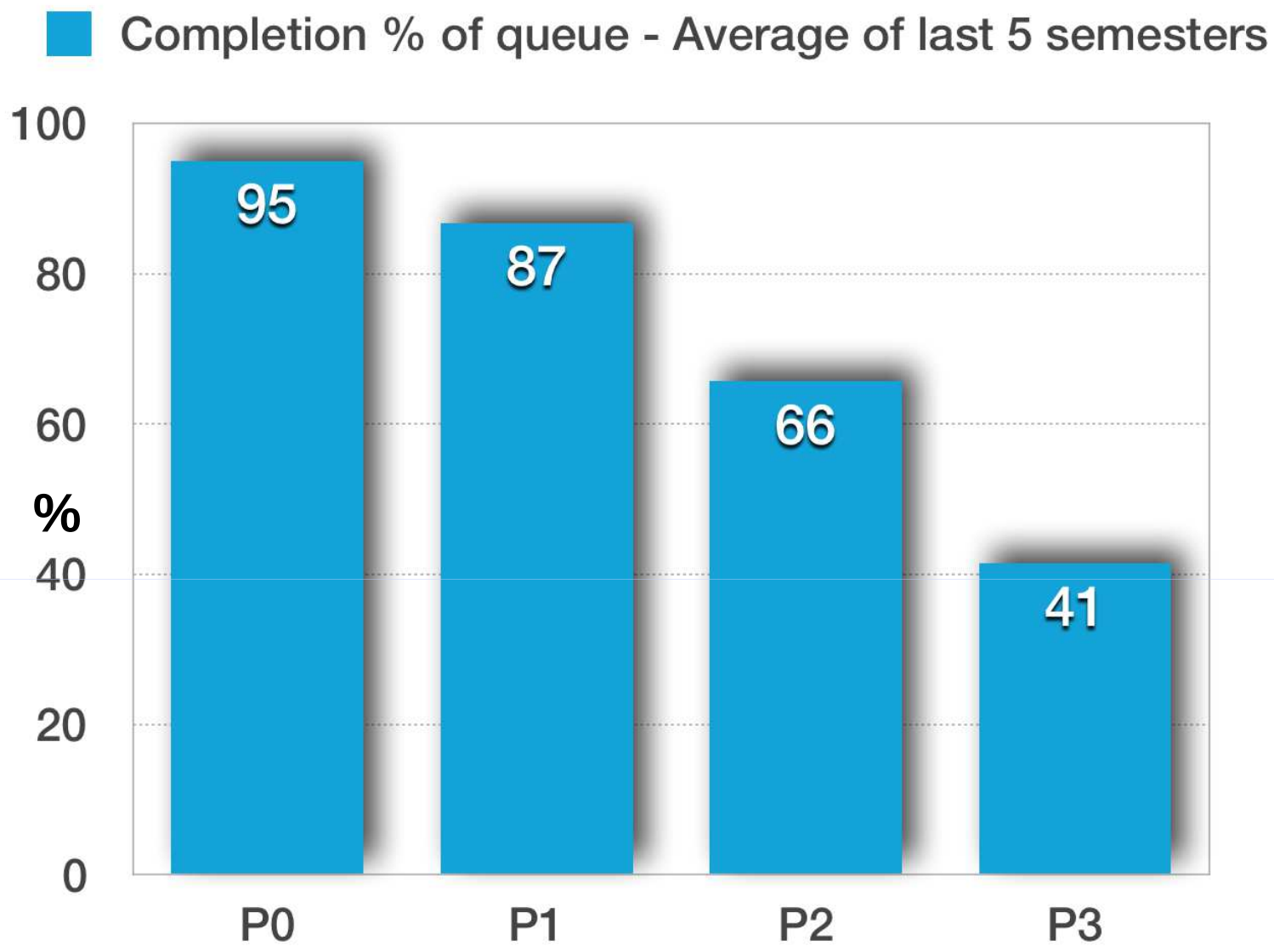

**After edge-sensors**
**Stable images all night**

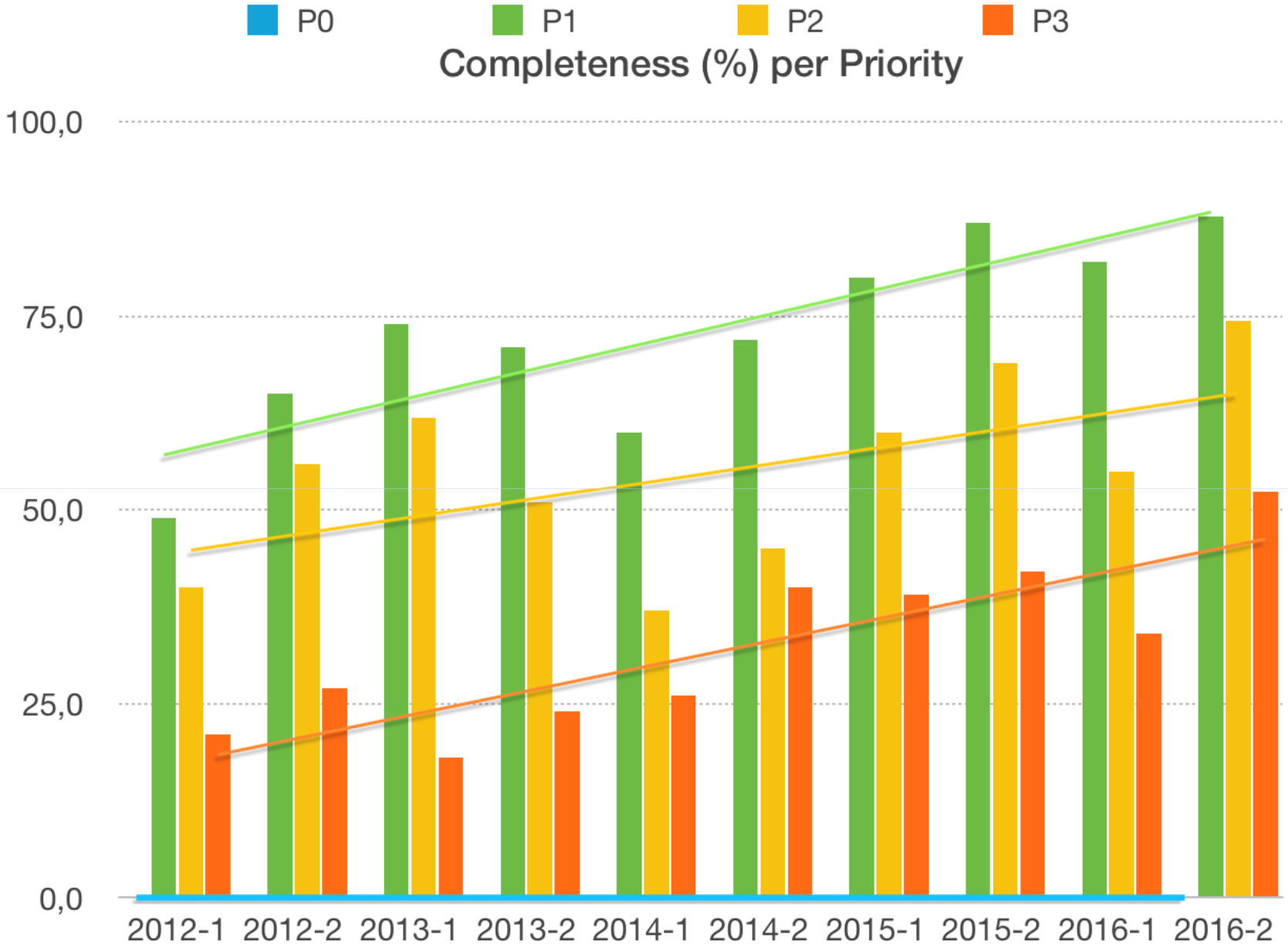
**A major break-through at SALT in 2016**

- **others:**
  **e.g. improved throughput**
  **reduction pipelines**

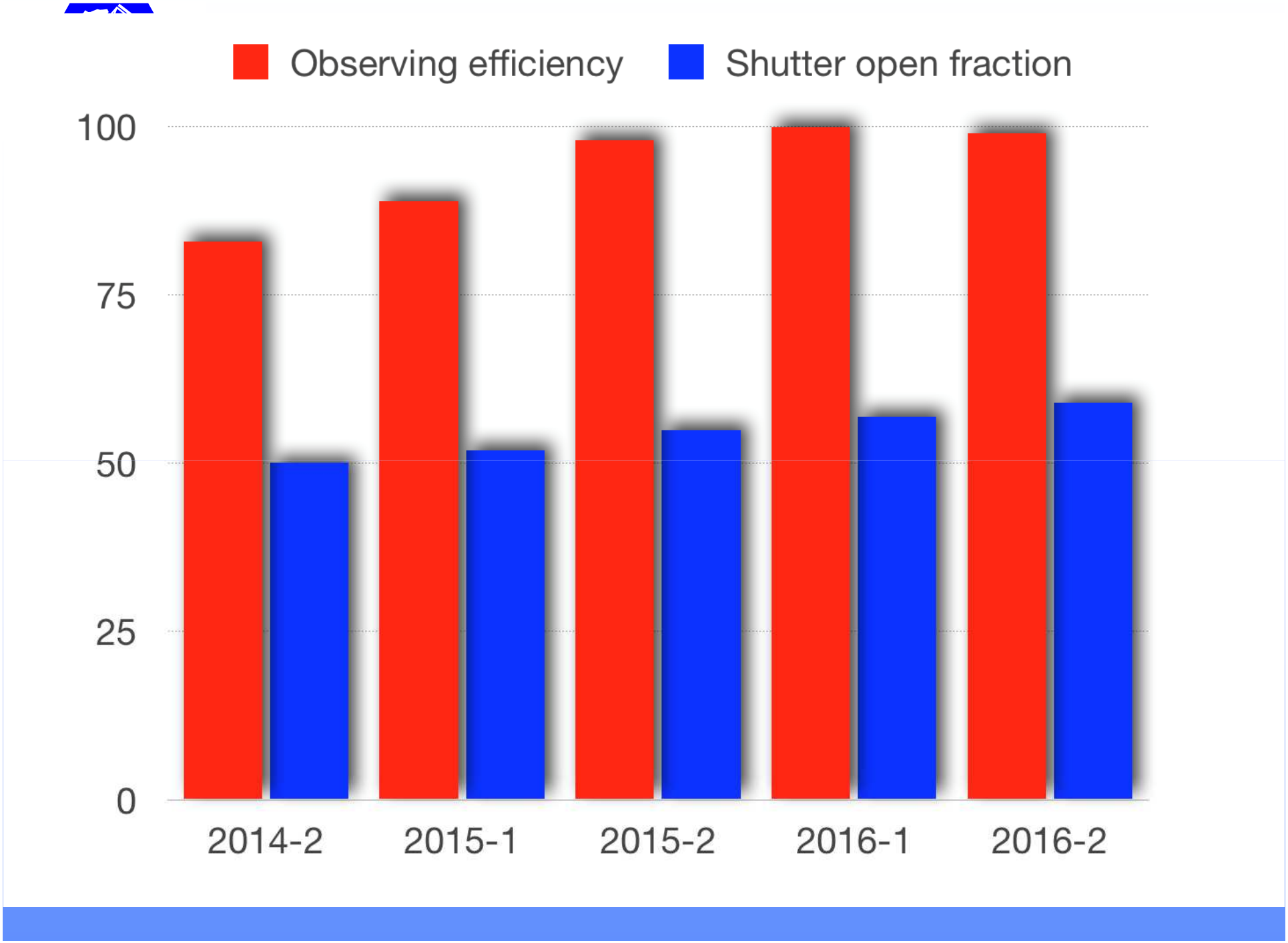
# SALT Operations Mode

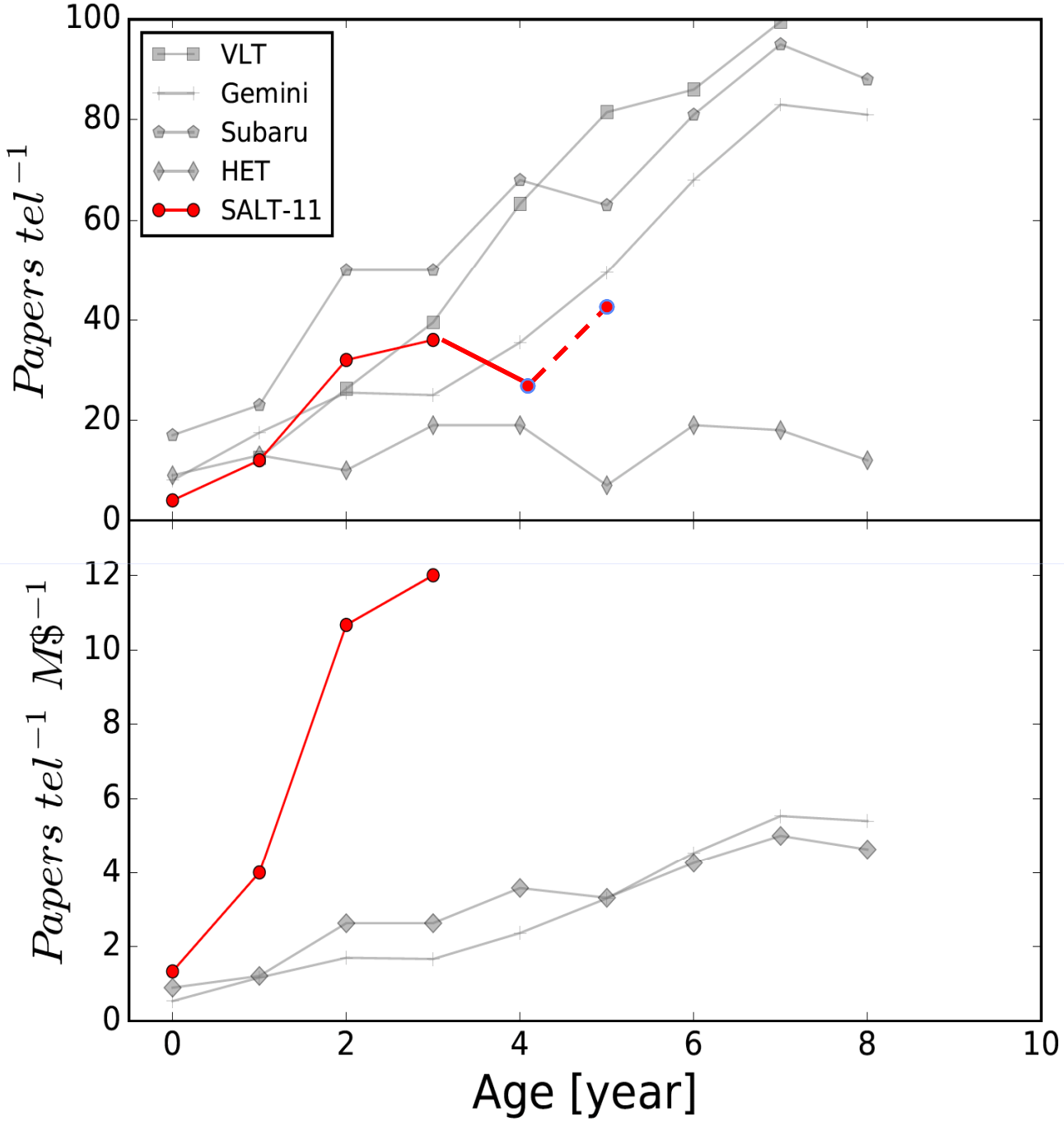
- **Fully queue-scheduled**
- **Service observing**
- **Data available the day after observation**
- **Partners allocate their own time. P0, P1, P2, P3. Plus P4 filler**
  - **P3 and P4 are over-filled**
  - **Plus optional targets**
- **Target distribution is driving what can be completed**
  - **Observing Block Scoring Algorithms and Semester Simulations facilitate efficient completion of time**
  - **PIs given tools to make smart decisions**


Completion % of queue - Average of last 5 semesters
100
80
60
%
40
20
0
95
87
66
41
P0
P1
P2
P3




**Notes: P3 is overfilled by x3. e.g. 33% completeness expected**


Observing efficiency
Shutter open fraction
100
75
50
25
0
2014-2
2015-1
2015-2
2016-1
2016-2




## SALT Publication Rate

**So far following Major Telescope trends when counting stats from start of science observations (late 2011).**

**When normalized by operating costs, SALT is seen to be very cost-effective!**

# What kind of science is done ?

| N = 150 refereed SALT data *publications* (03/2017) | |
|---|---|
| Stellar | 59% |
| Extragalactic | 27% |
| Supernova follow-up | 10% |
| Solar System | 4% |
| Target-of-opportunity (ToO) | 15% |
| More than 10 targets/observations | 11% |

*Quo Vadis* , SALT ?

# Looking to the future

# RSS Upgrade

- Collimator upgrade
- RSS Guider
- 600 line/mm grating
- CCD upgrade
- RSS efficiency
- Pipelines for all the modes

- 70% of the telescope usage is RSS longslit
- >20% improvements in RSS performance
- Improved MOS performance

# Slit IFU

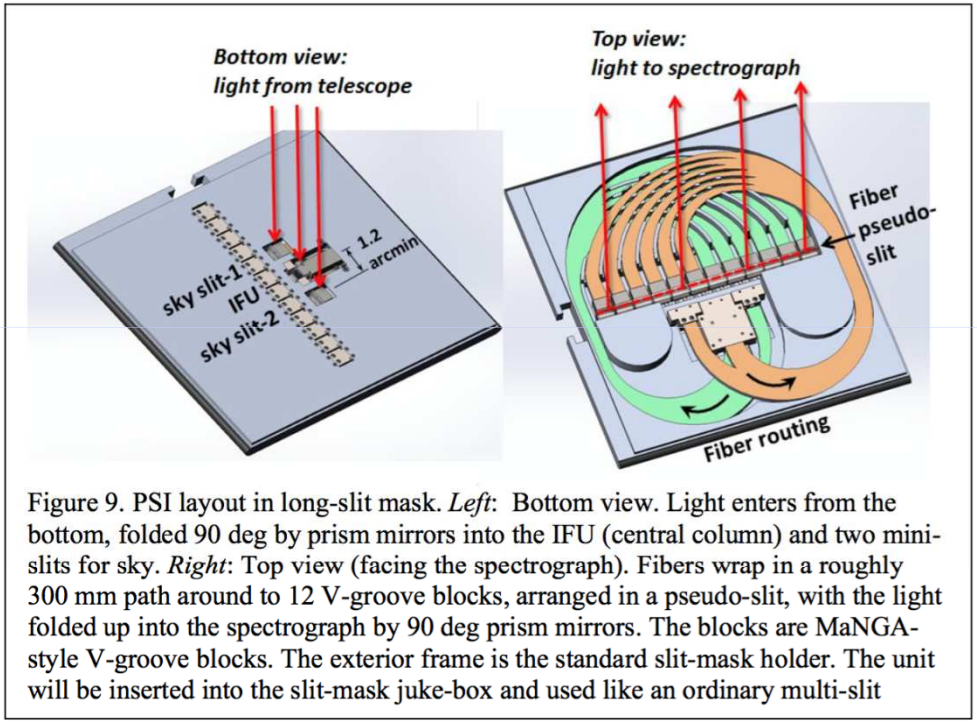



Figure 9. PSI layout in long-slit mask. *Left*: Bottom view. Light enters from the bottom, folded 90 deg by prism mirrors into the IFU (central column) and two mini-slits for sky. *Right*: Top view (facing the spectrograph). Fibers wrap in a roughly 300 mm path around to 12 V-groove blocks, arranged in a pseudo-slit, with the light folded up into the spectrograph by 90 deg prism mirrors. The blocks are MaNGA-style V-groove blocks. The exterior frame is the standard slit-mask holder. The unit will be inserted into the slit-mask juke-box and used like an ordinary multi-slit

- design by UW
- 14x24” FOV
- ~$18k hardware costs
- New capabilities and better performance (better sky subtraction)

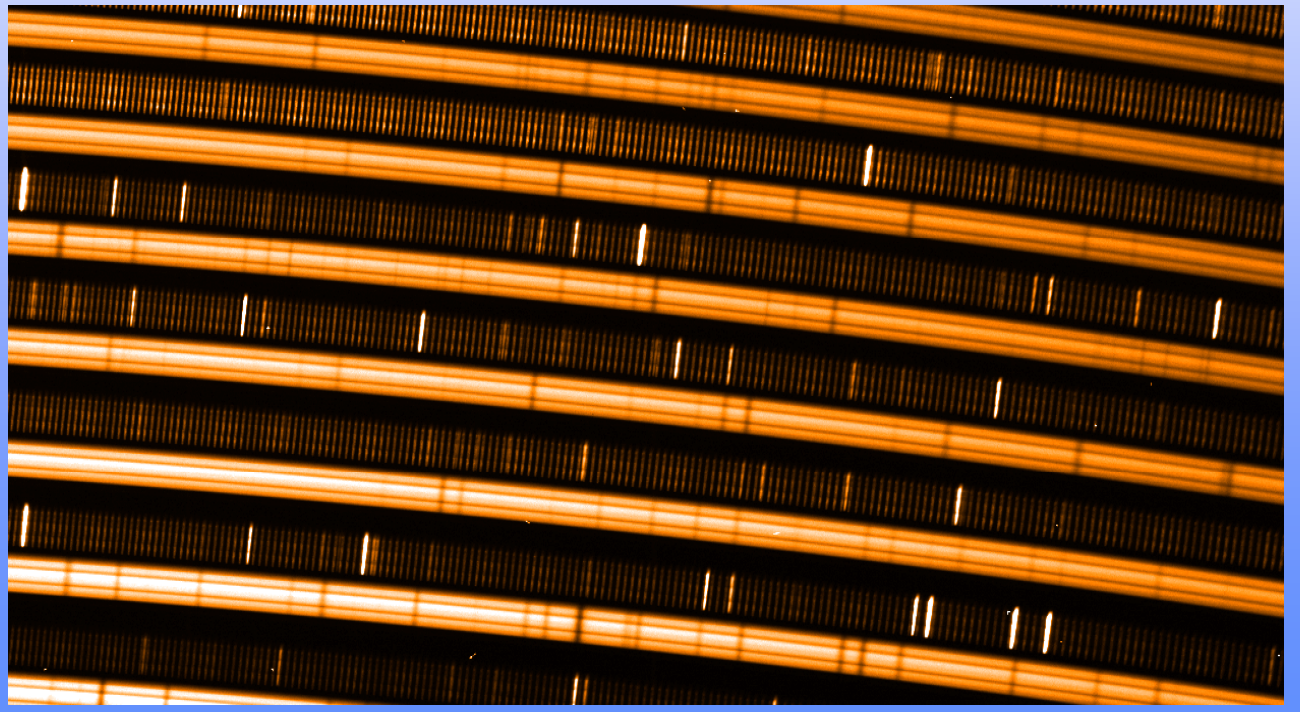
# HRS High Stability Mode

**HS pipeline : Current pipelines need radical improvement to reach <10 m/s accuracy**

**Lack of expertise in current SALT Astro Ops**

**Laser Frequency Comb options / contacts : Would be a unique capability on 10m class telescope**

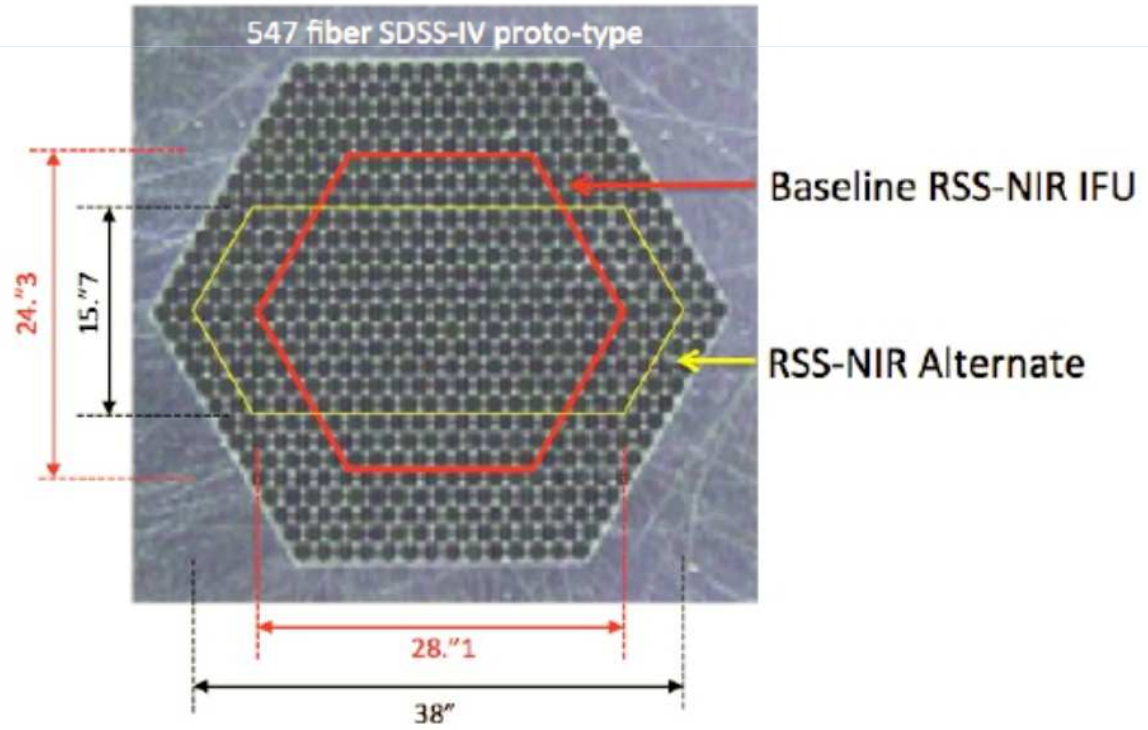
**Significant interest** in pursuing the capability



# RSS Near-Infrared IFU

217 fibers in a hexagon (28” on-sky) or elongated hexagon (16” x 38”)
2 sets of 15 sky fibers
1.33” core fibers spaced at 1.65”
Achieves R ~ 2000 – 6000 over λ = 900-1700 nm
Slit V-groove blocks (25 fibers each) tilted for telecentricity
Final fiber size selection will interplay with the collimator design

**Early 2019**



# Future major 2nd generation instruments

**In the process of thinking future strategy.**

**Many possibilities.  Do you go for wide-use approach, or niche?**

**Science-driven white papers have been written**

- **transients & variables**
- **extragalactic astronomy**

**Goal is to have 2-3 well defined options to present to the SALT Board in November 2017**

**Aligning both SALT and SAAO goals and purposes to be competitive in the 2020s**

# SALT Summary

**SALT is working well, with many recent developments.**

**SALT is the most cost-effective large telescope science producer in the world**

**In the process of thinking future strategy, aligning both SALT and SAAO goals and purposes to be competitive in the 2020s**

**We welcome new collaborations !**

**BRICS could join as a bloc, maybe for a key science program?**

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*Janus Brink*