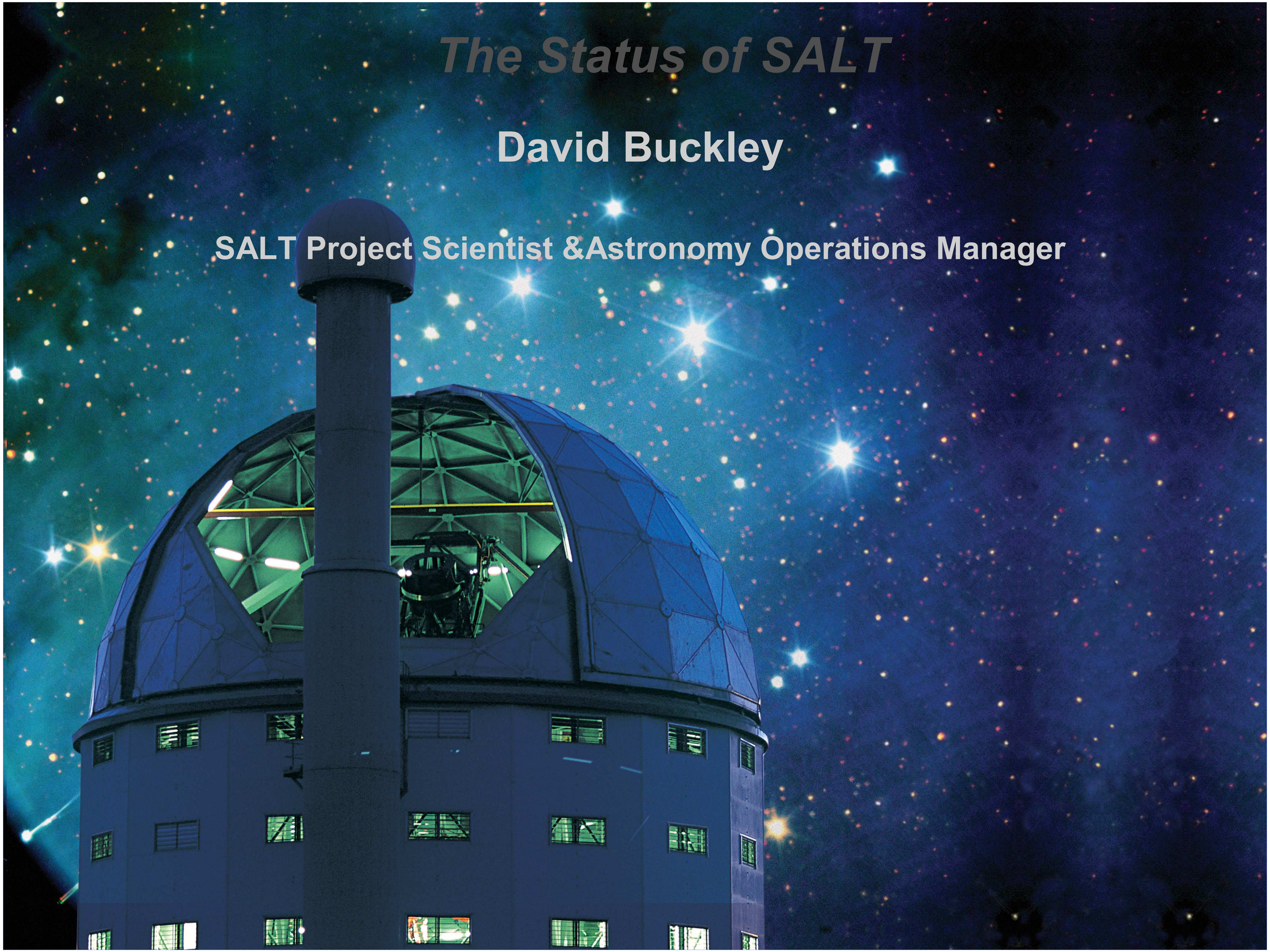
The Status of SALT

David Buckley

SALT Project Scientist &Astronomy Operations Manager

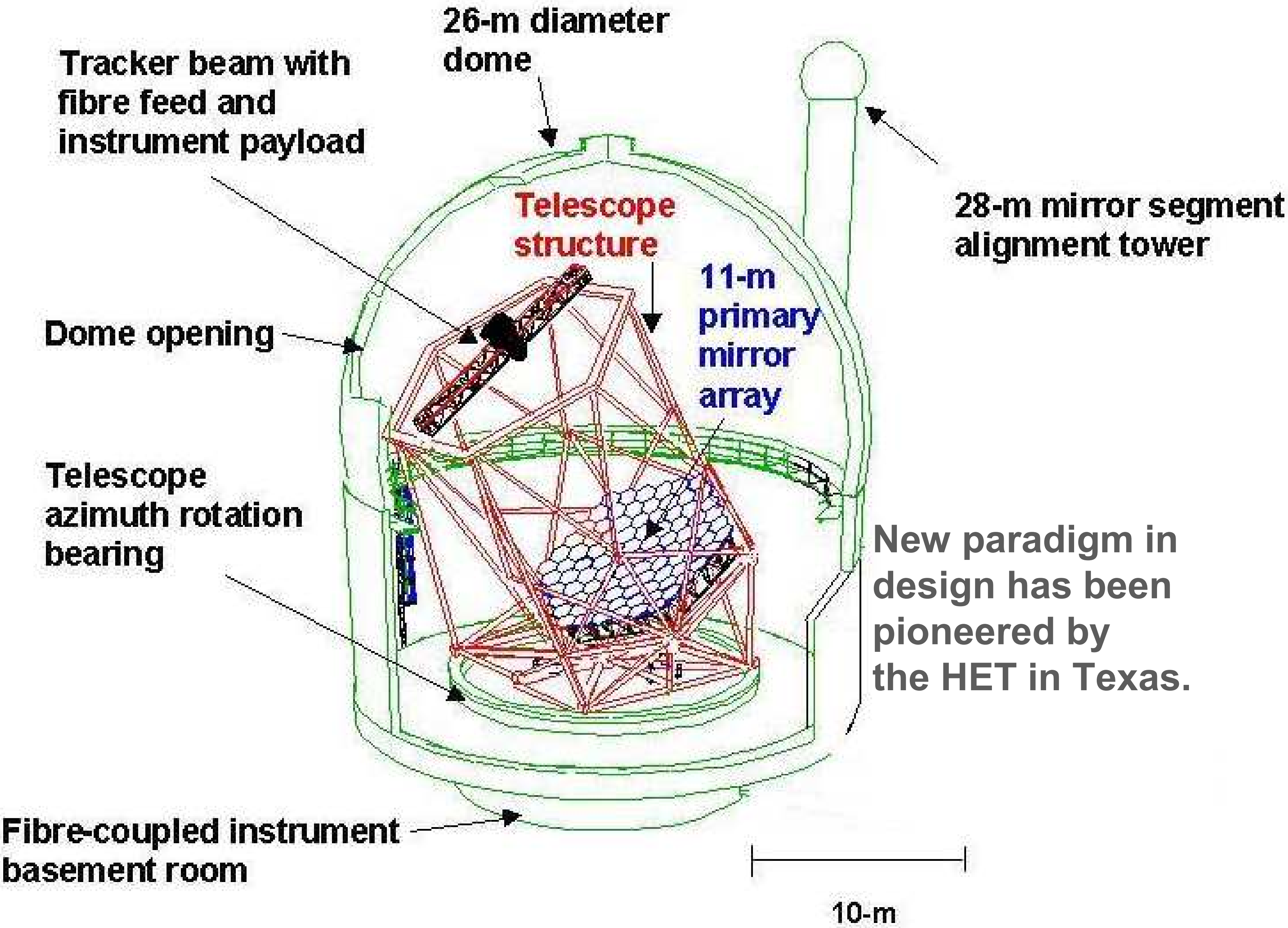


SALT Construction Phase completed in Nov 2005


SALT Inauguration: 10 Nov 2005

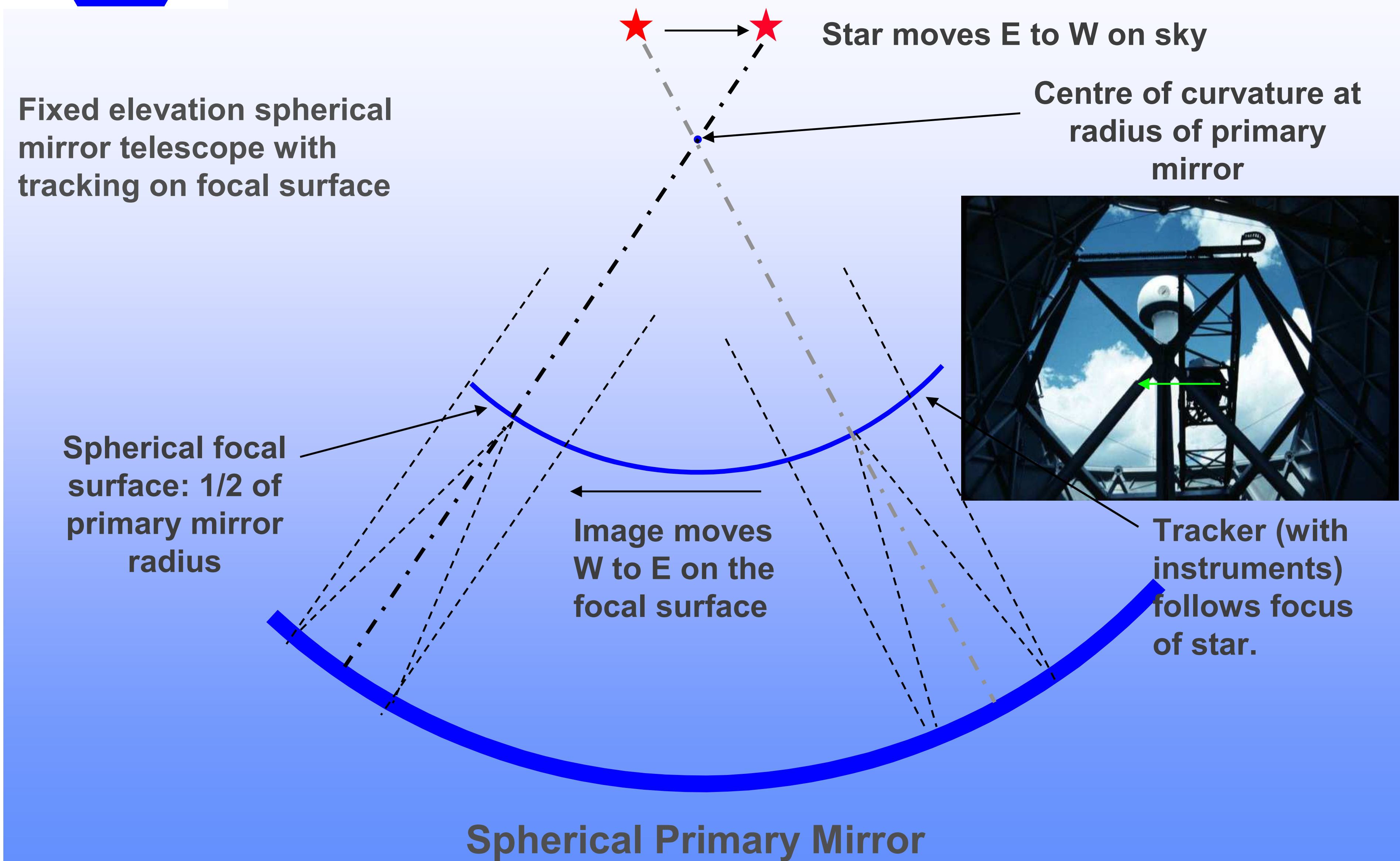

Southern African Large Telescope (SALT)
Inaugurated by the President
of the Republic of South Africa,
Mr TM Mbeki
on 10 November 2005

Southern African Large Telescope



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

The Arecibo Concept:



SALT Tracking Principle

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

With tracker and 11-m pupil centred on primary mirror array and central obstruction (from SAC optics), equivalent to a 8.5 metre telescope.

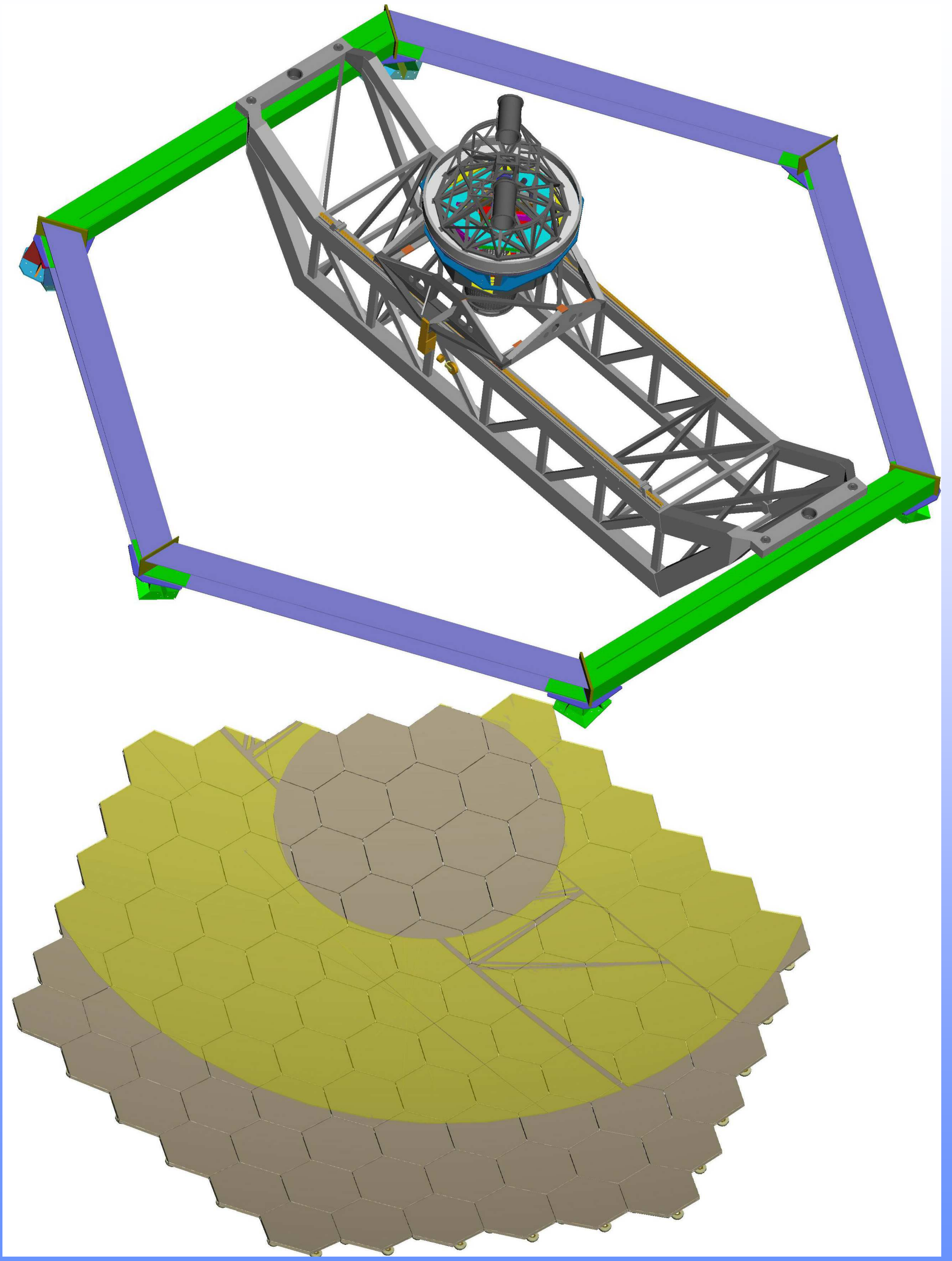
Pupil is always under-filled and constantly varies with time

⇒ **photometry is difficult (differential only)**

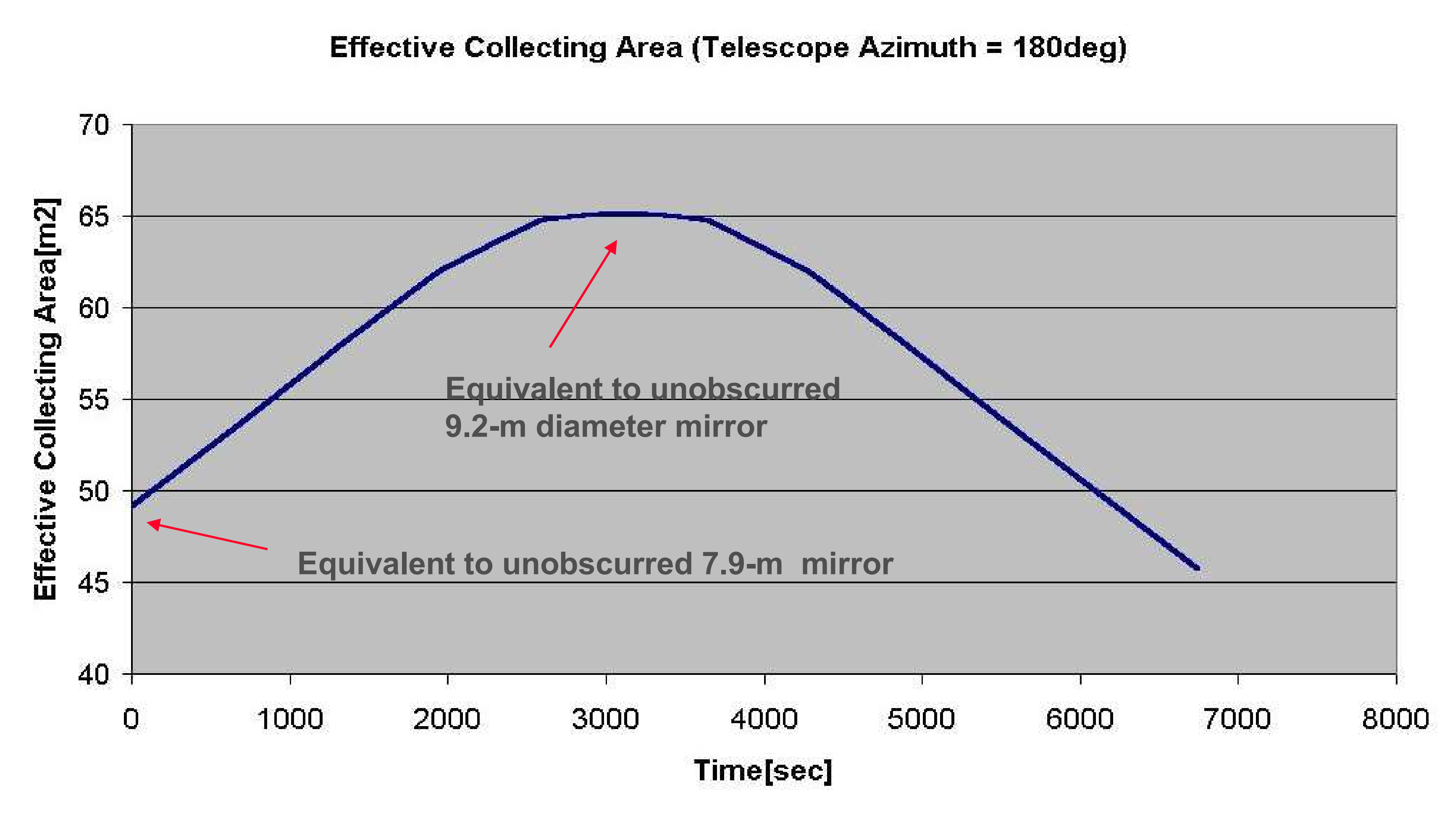
⇒ **Local (within field) 'standards' (comarison stars) should be defined if 'real' mags/colours are important**

Pupil is baffled at exit pupil

- **can 're-play' pupil filling function for later calibrations (e.g. flat fields)**



SALT characteristics



Annulus of visibility for SALT:

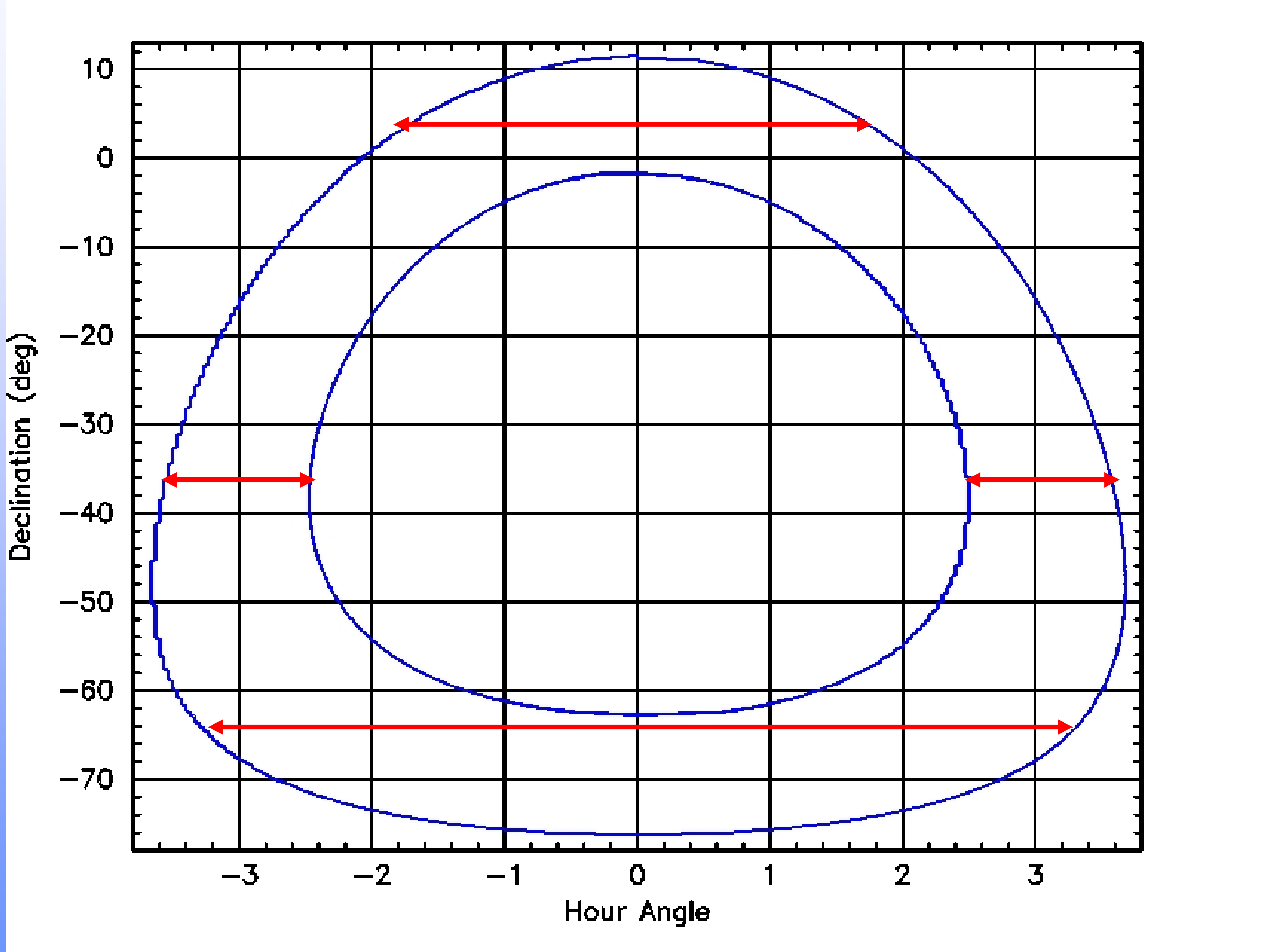
Annulus represents 12.5% of visible sky

Declination range: +10º to -75º

Observation time available = time taken to cross annulus

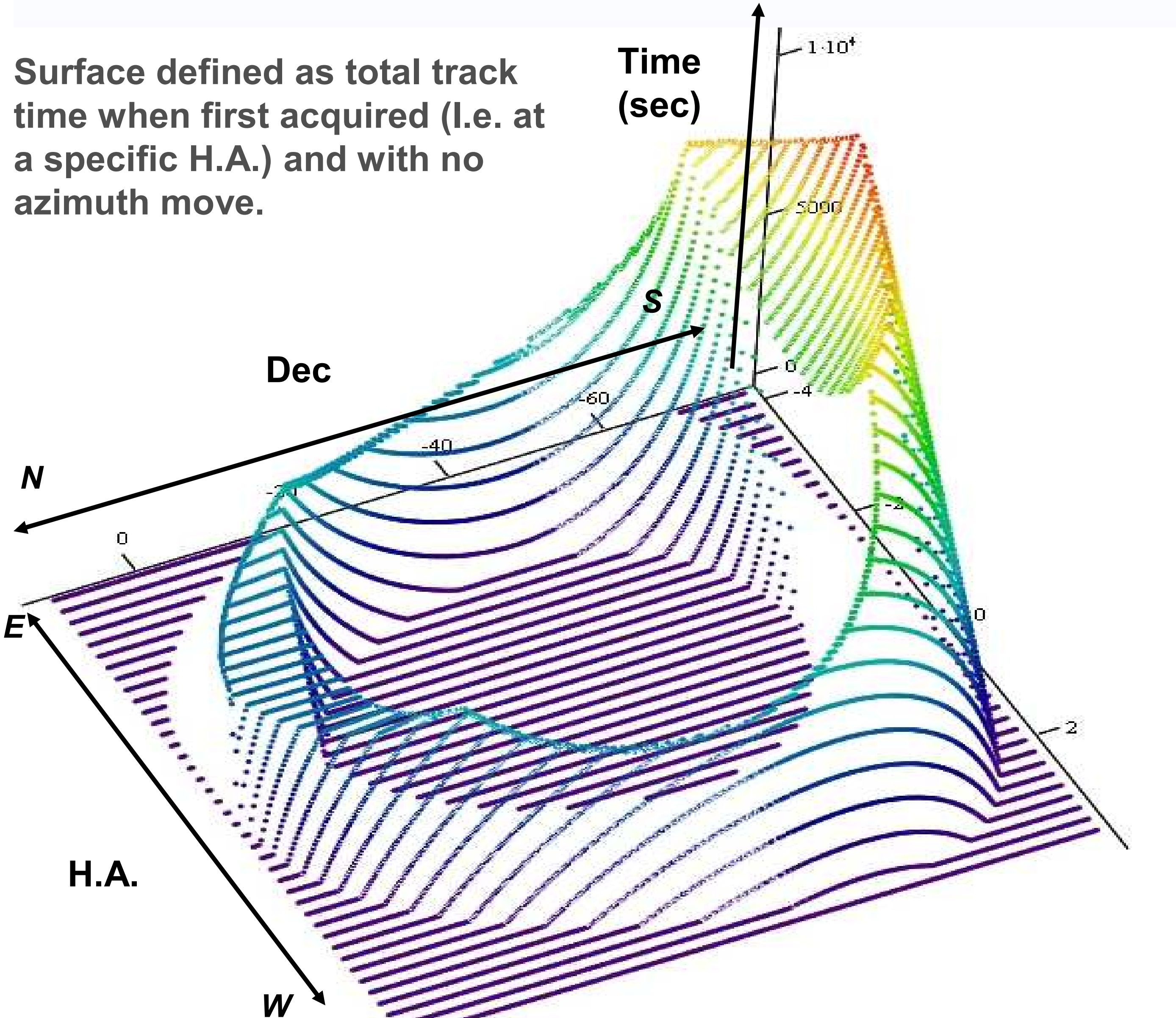
***But* tracker only has limited range ⇒**

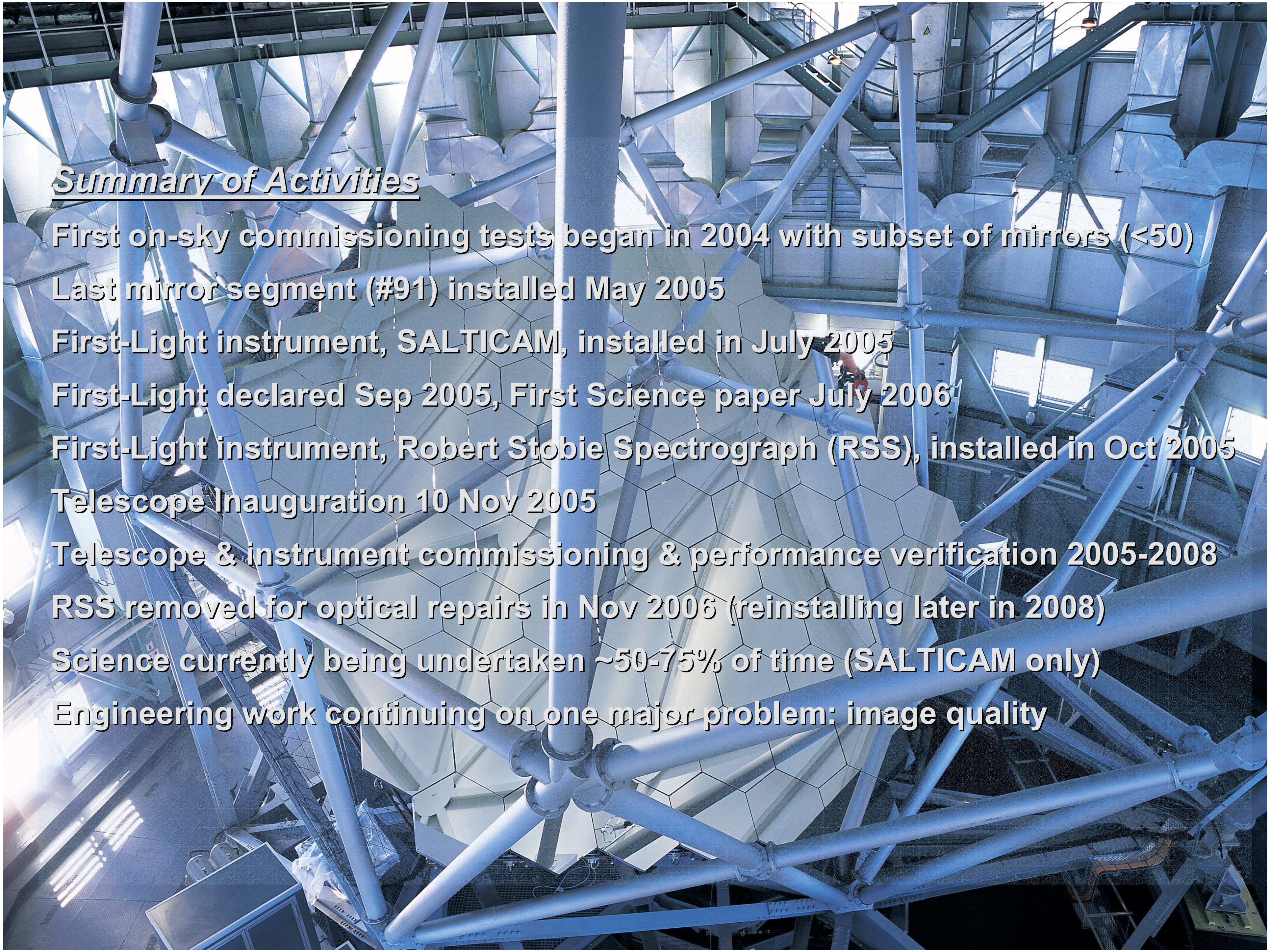
Additional azimuth moves needed to achieve full obs. time



SALT Track Surface

Surface defined as total track time when first acquired (I.e. at a specific H.A.) and with no azimuth move.





Summary of Activities

- First on-sky commissioning tests began in 2004 with subset of mirrors (<50)
- Last mirror segment (#91) installed May 2005
- First-Light instrument, SALTICAM, installed in July 2005
- First-Light declared Sep 2005, First Science paper July 2006
- First-Light instrument, Robert Stobie Spectrograph (RSS), installed in Oct 2005
- Telescope Inauguration 10 Nov 2005
- Telescope & instrument commissioning & performance verification 2005-2008
- RSS removed for optical repairs in Nov 2006 (reinstalling later in 2008)
- Science currently being undertaken ~50-75% of time (SALTICAM only)
- Engineering work continuing on one major problem: image quality

Completed Telescope

- Dome
- Shutter
- Tracker & Payload
  - 2 FIRST-LIGHT INSTRUMENTS
  - ACQUISITION, GUIDANCE & FOCUS CAMERAS
  - CALIBRATION SYSTEM
  - ATMOSPHERIC DISPERSION CORRECTOR
  - MOVING EXIT PUPIL BAFFLE
- Structure
  - TUBE
  - BASE WEDGE
  - MIRROR TRUSS
- Facility Building
  - CAT-WALK FOR TRACKER ACCESS
  - AIR CONDITIONING DUCTS
  - VENTILATION LOUVRES
- Primary Mirror Array
  - EDGE SENSORS
  - ACTUATORS

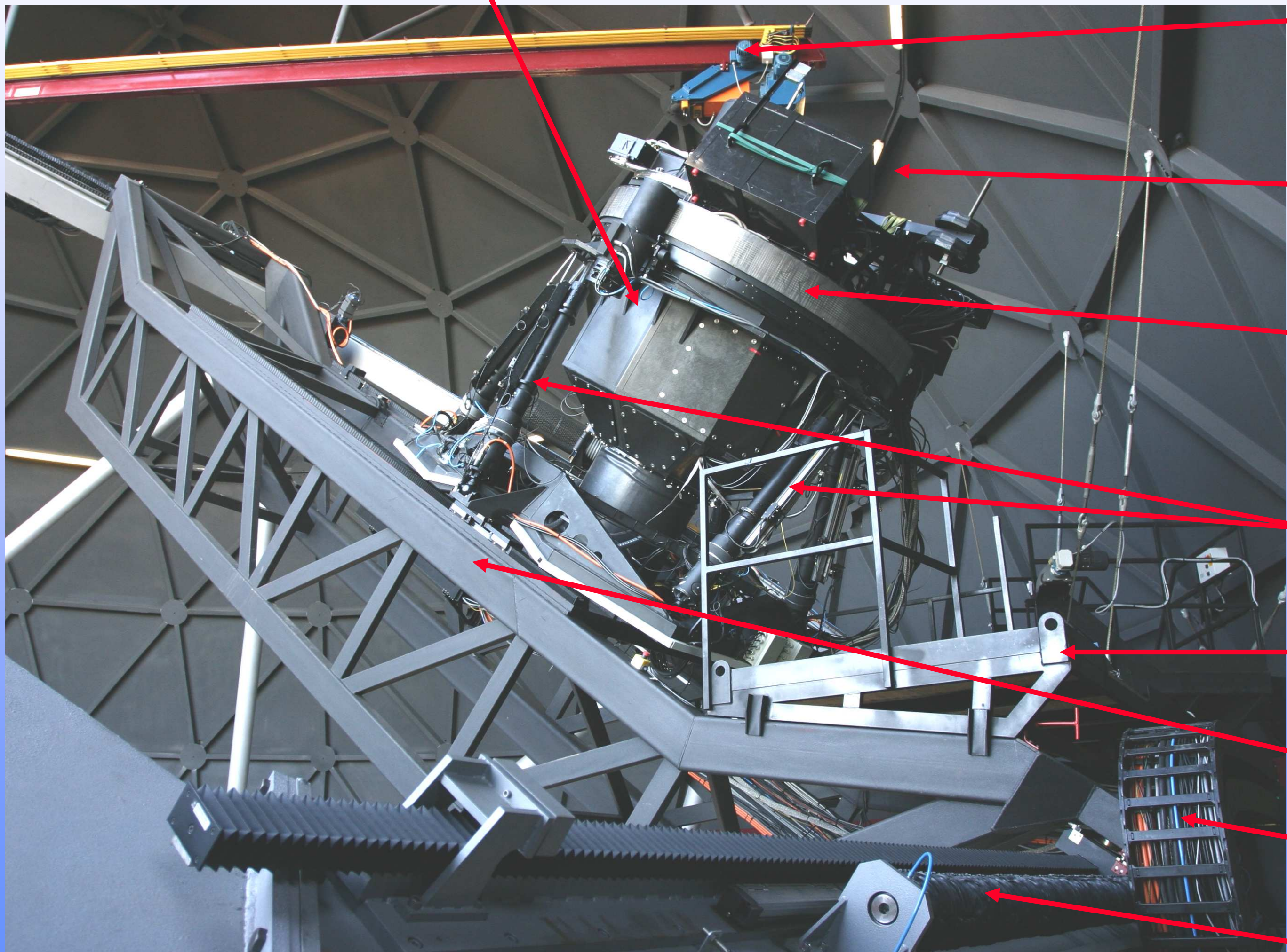
Design innovations for SALT

Because of the valuable lessons learnt from H.E.T., plus a systems engineering approach and improvements made possible by technological advances and sourcing products globally, SALT has benefited and is expected to have greatly improved performance:

- **Improved optical design (the Spherical Aberration Corrector) by Darragh O'Donoghue** ***delivering larger field, better image quality.***
- **Larger effective collecting area by increasing pupil size (11-m diameter):** ***15% increase in light collecting power.***
- **More efficient protected silver-aluminium multi-layer coatings (LLNL) for mirrors offer** ***much improved blue/UV performance ($320 < \lambda < 450$ nm).***
- **Holistic integrated payload design, increased mass budget (~1000 kg) and use of carbon composites.** ***Enhanced capabilities, 4 foci, relatively easy access.***
- **Prime focus instruments (e.g. Wisconsin's *PFIS*) planned from the outset and with larger mass/volume envelope.** ***Very versatile instrument delivering unique science (UV, polarimetry, Fabry-Perot, high time resolution, VPH gratings).***
- **Different primary mirror segment alignment system (e.g. Shack-Hartmann camera) and the use of capacitive edge sensors on the mirror segments will give** ***more stable, sharper, images.***
- **Use of natural ventilation (e.g. louvres) and aggressive attitude to heat sources will lead to** ***better image quality.***
- **Used graphical programming language LabVIEW to do all telescope control (rapid prototyping & development, quick to debug, easy to integrate, good graphics)**

Facility Instruments are all mounted on Prime Focus Payload

Payload structure (rotating & non-rotating components) made of carbon composite



Dome crane

Robert Stobie Spectrograph (RSS)

Instrument rotator ring

Hexapod legs

Access platform (removable)

Tracker beam

X Cable wrap

X drive

Telescope Completion Experience:

SALT took ~1 year longer to build than initially estimated (original project completion date was 17 Dec 04, i.e. <5 years from hiring Project Team to completion of commissioning). Reasons were:

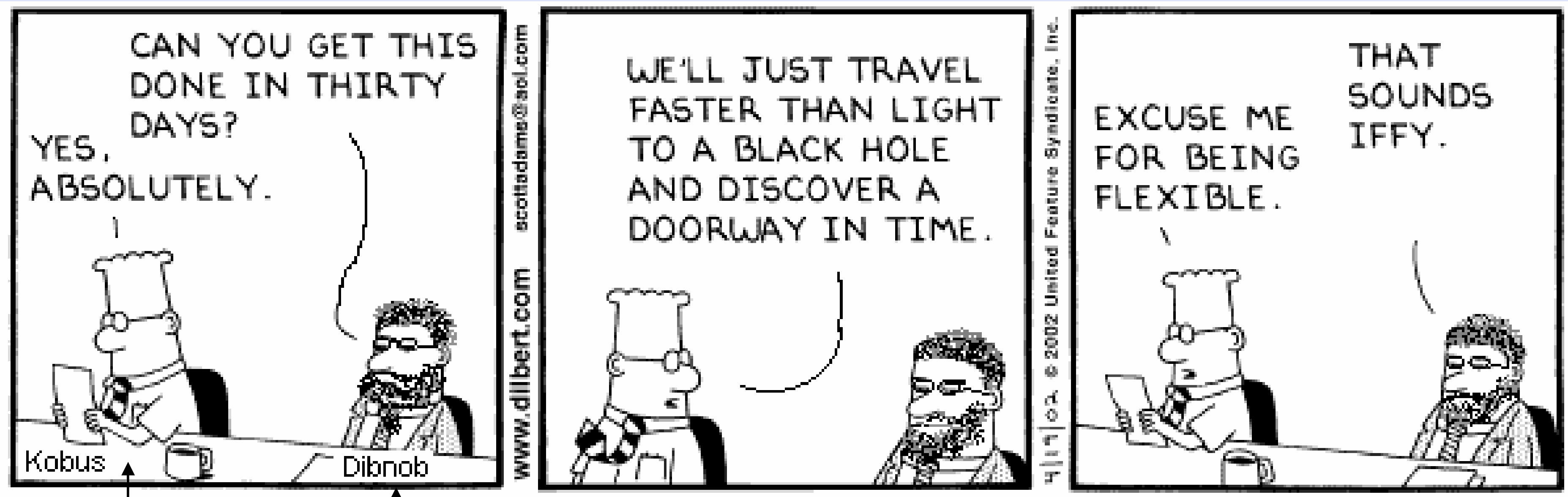
- **Difficulty multi-tasking of dependent jobs**
  - Intertwined and mutually dependent tasks
- **Competition for people/resources/telescope time**
  - Highlighted too few people in some critical areas (e.g. engineering and design effort for Payload subsystems)
- **Lots of parallel tasks to be done and not always enough people/time to do them**
- **Systems Engineering a success, *but…* full acceptance testing not completed before Project Team finished**
  - 90% completed, but the hard 10% had to be completed by the SAAO & SALT Operations Team

But, the phased approach of TCS has been a real success

- LabVIEW helped a lot.
- Only ~5 FTE software people at any one time

Reality of Commissioning / Completion

- **Underestimate of time to complete complex/first-time systems**
  - Including the Prime Focus Payload
  - Science instruments (both took ~1 year longer than CDR estimates)
  - Not enough time for integration and thorough testing

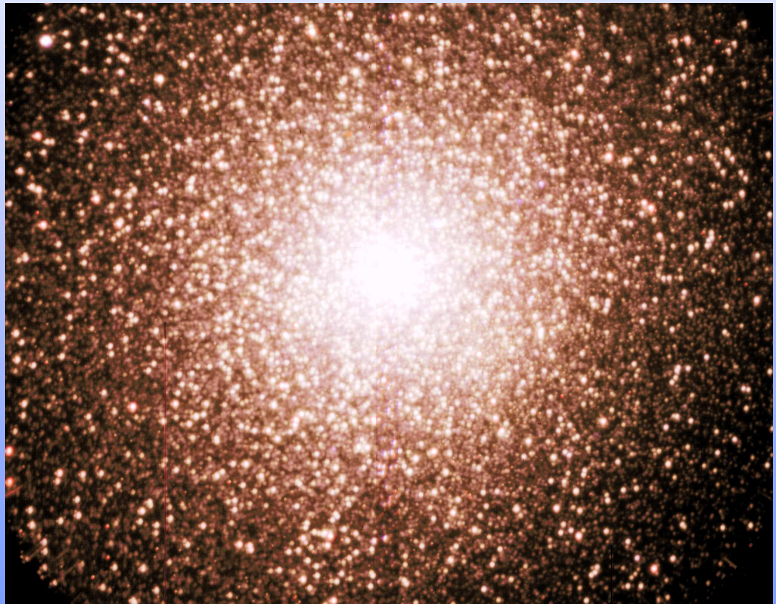


PM **PS**

- **Two major problems have unfolded:**
  - Telescope Image Quality
  - Spectrograph throughput (particularly in the UV)

But, success… SALT "First Light": 1 Sep 2005

- With all segments installed
- With SALTICAM and filter set
- No active optics (edge sensors)
- No guiding or autofocus



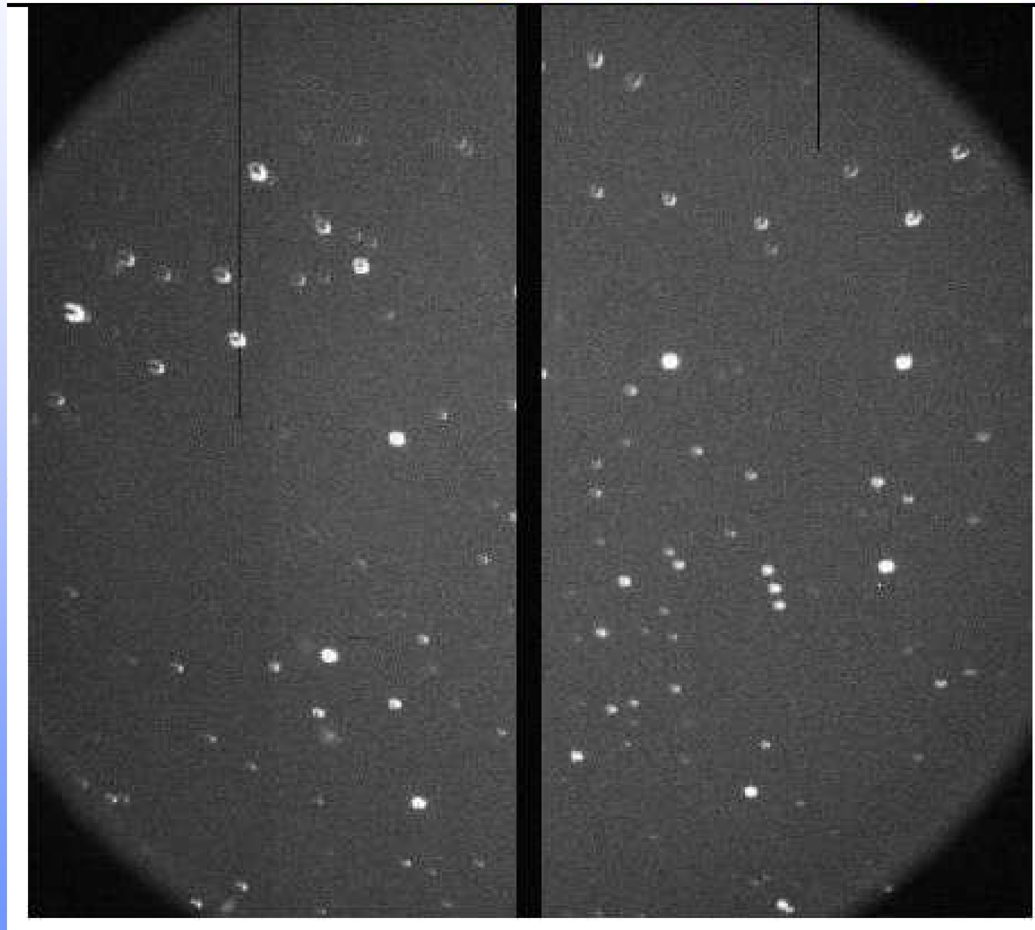
47 Tuc:
Combined U,V,I (120 sec total)

Lagoon Nebula: 180 sec total (U, V, I)

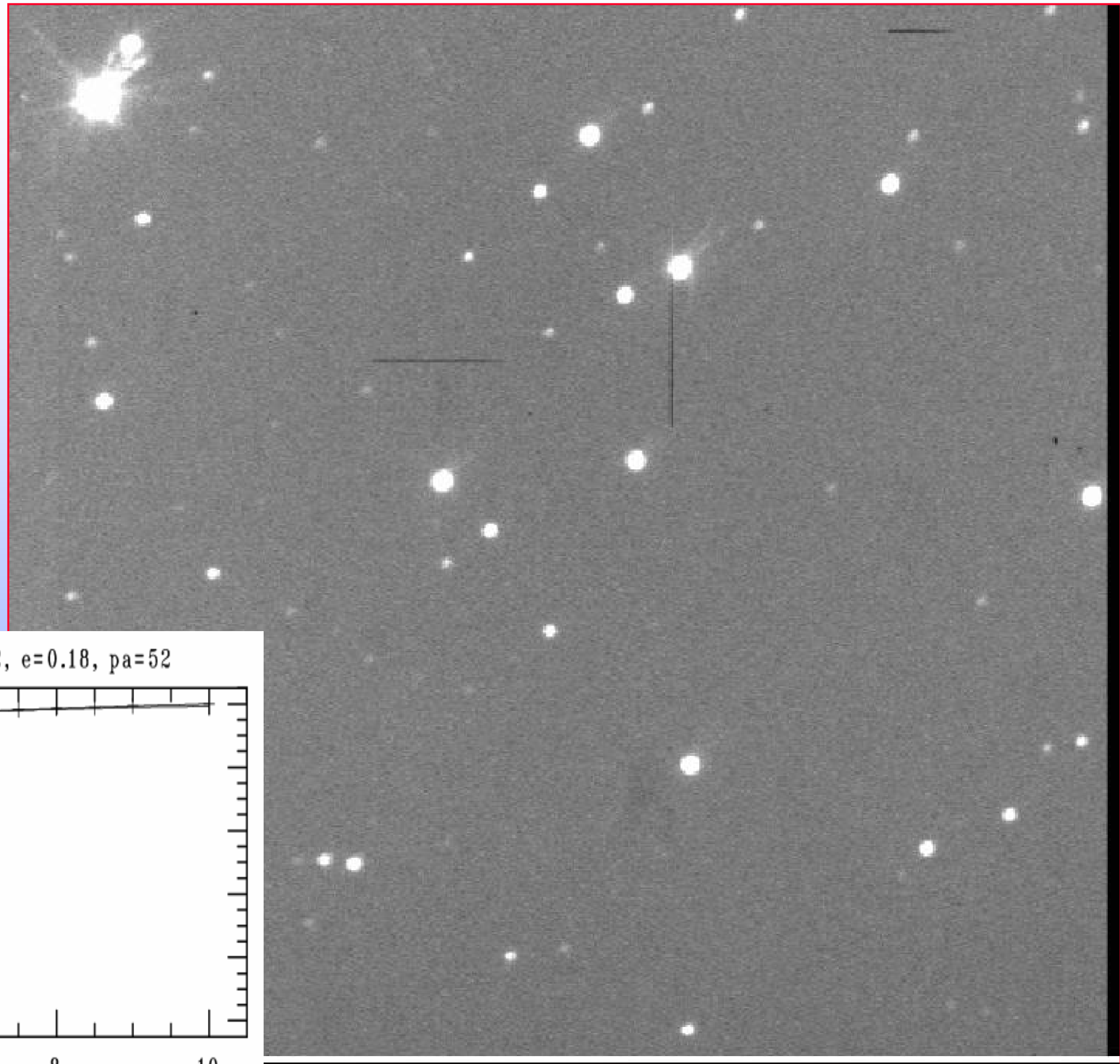
But….SALT's Image Quality Not to Spec

- Focus gradient
- Rho dependency
- Field dependency of aberrations
- Diagnosing cause has been a long (~2 yr) process

  (see SPIE7018-40 for all the gorey details)
- Recent results point to SAC interface problem
  - New interface being designed
- Hope to cure by end 2008

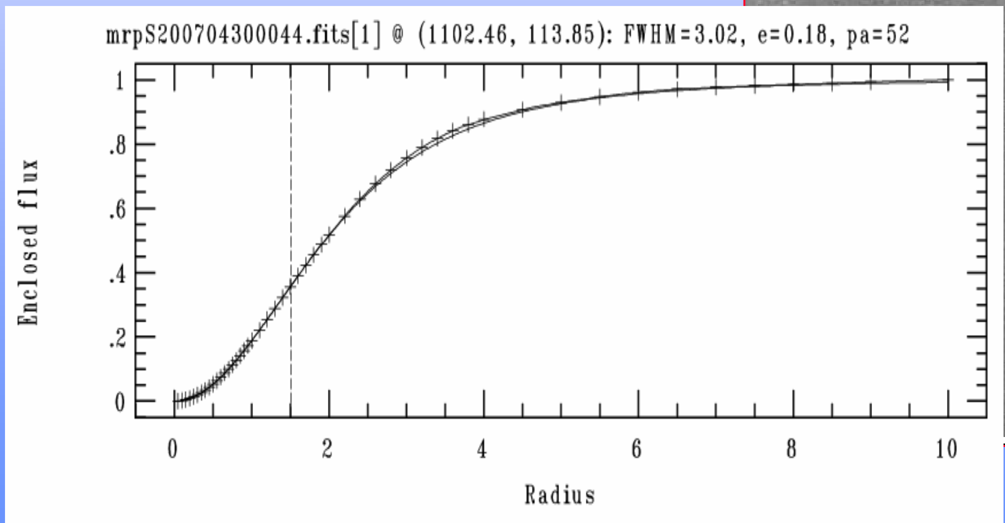


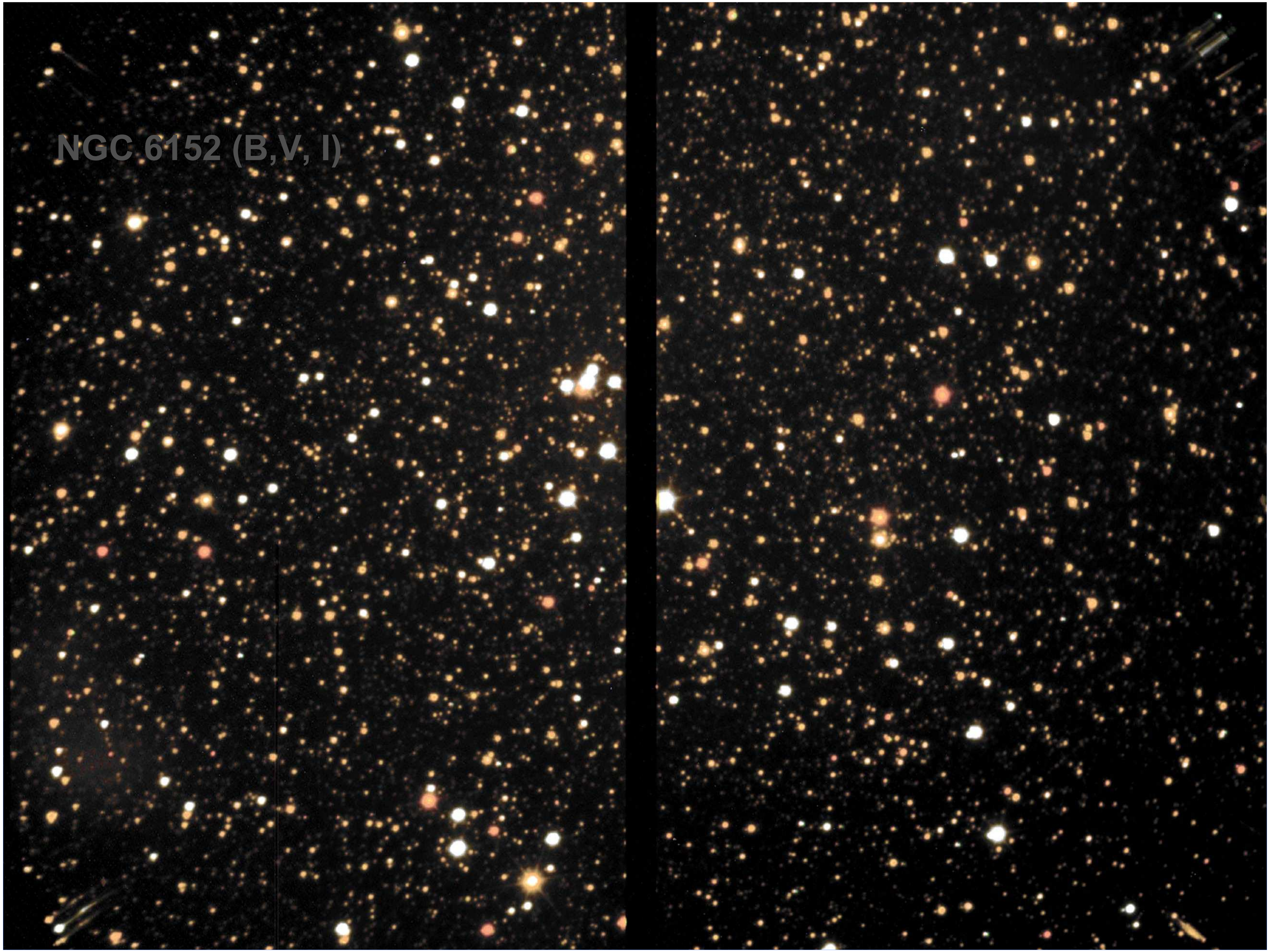
Good images do occur - sometimes!



Good images over a 1.5 -2 arcmin FoV

e.g. good fit with a Moffat function
EE50 = 0.85 arcsec




NGC 6152 (B,V, I)

SALT First-Generation Science Instruments

- Instruments chosen to give SALT a wide range of capabilities
- Ensure competitiveness
- Take advantage of SALT design and *modus operandii*
- Budgeted for 4 “first generation” instruments
- First two completed & installed, third being built
- First two (‘first light’) instruments:
  - SALTICAM: a UV-VIS CCD camera
  - Robert Stobie Spectrograph (RSS): an imaging spectrograph with many different modes
- Third main instrument is the fibre-fed High Resolution Spectrograph
  - Design completed 2005
  - Construction has begun at Durham University
  - Commissioning due to begin end 2009
  - Fed by the Fibre Instrument Feed (4th instrument, nearly completed)
- RSS Near IR beam is “Gen 1.5”, now under development

SALTICAM:
UV-Vis imager (built at SAAO)

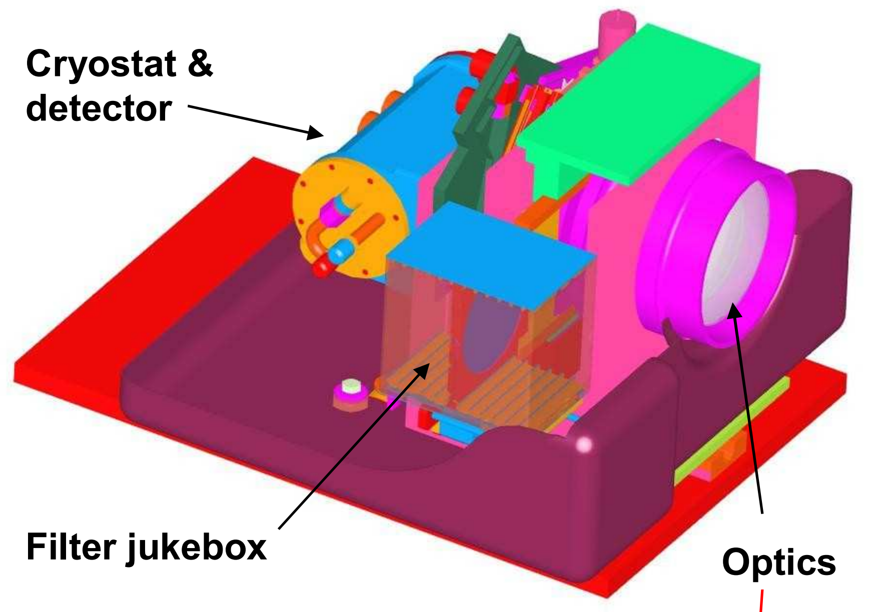
An efficient "video" (~10 Hz) camera over entire science FoV (8 arcmin).

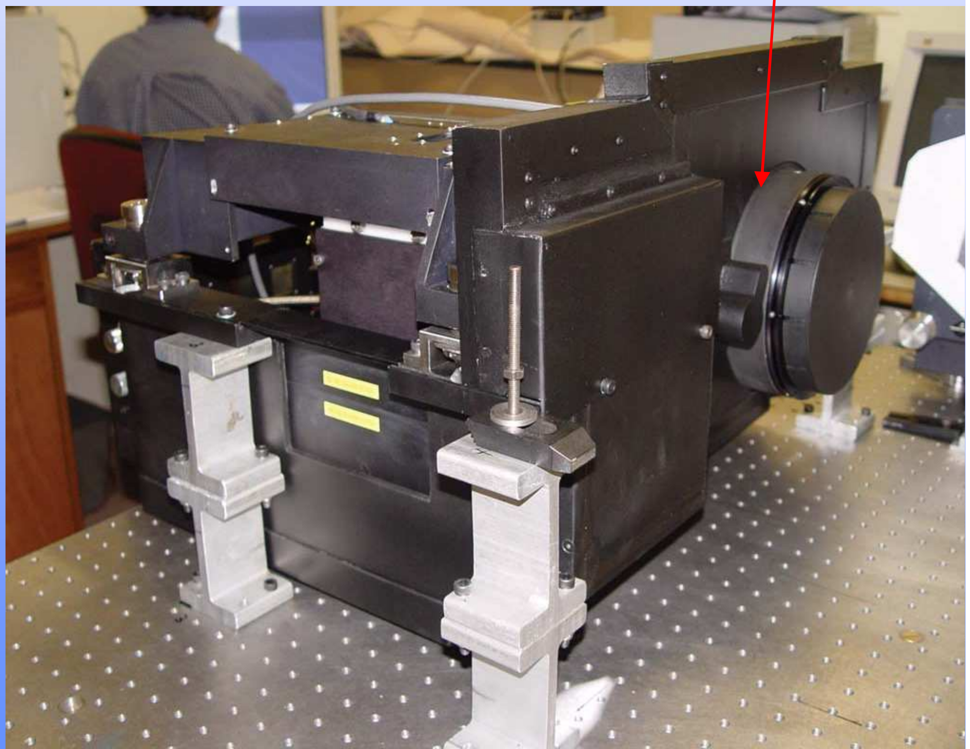
Efficient in the UV/blue (capable down to atmospheric cutoff at 320nm (sun-burn territory!).

Capable of broad and intermediate-band imaging and high time-resolution (to ~50 ms) photometry.

Fulfills role as both an acquisition camera and science image. First installed, sans optics, as a commissioning and verification instrument.

SALTICAM enables unique science, particularly UV and fast photometry (~70-50 ms).

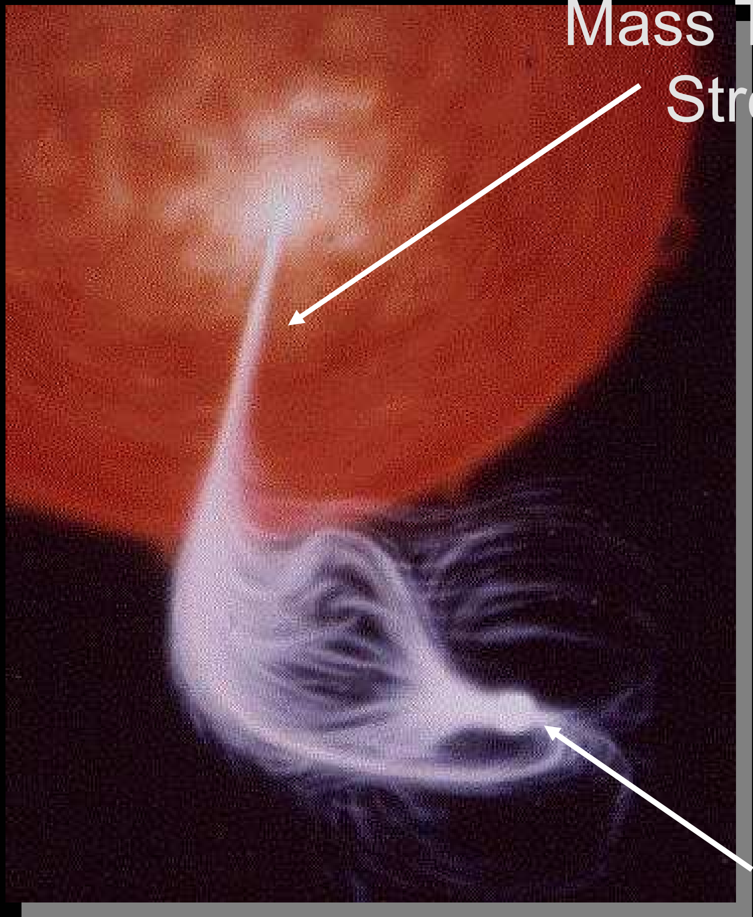




SALTICAM in the lab

First Science: Observing magnetic cataclysmic variables with SALT + SALTICAM

Mass Donor

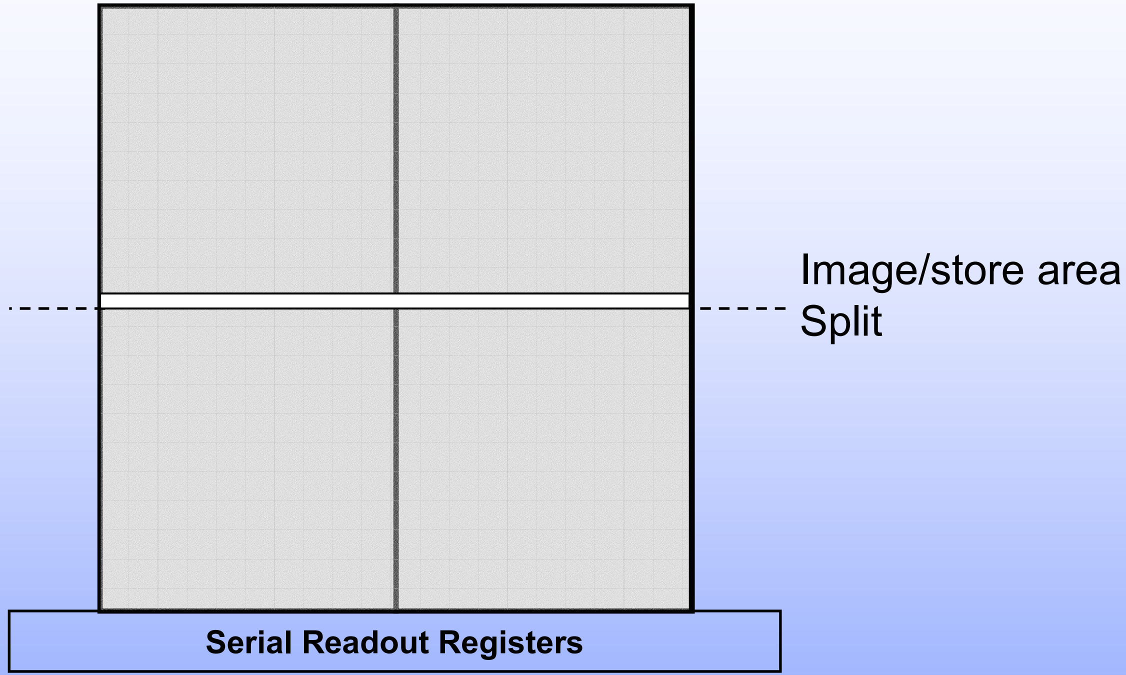


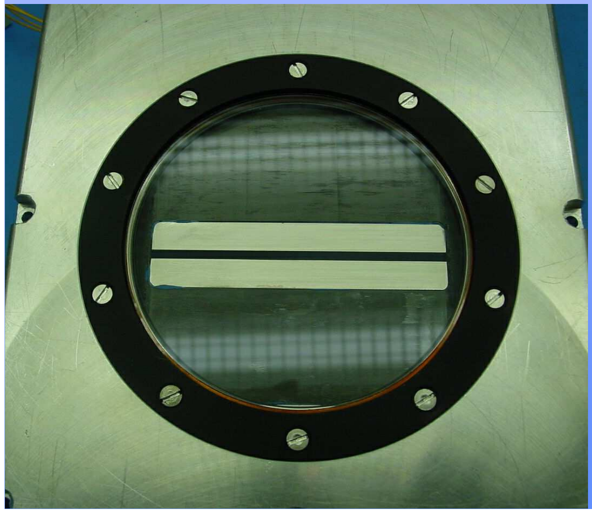
Mass Transfer Stream

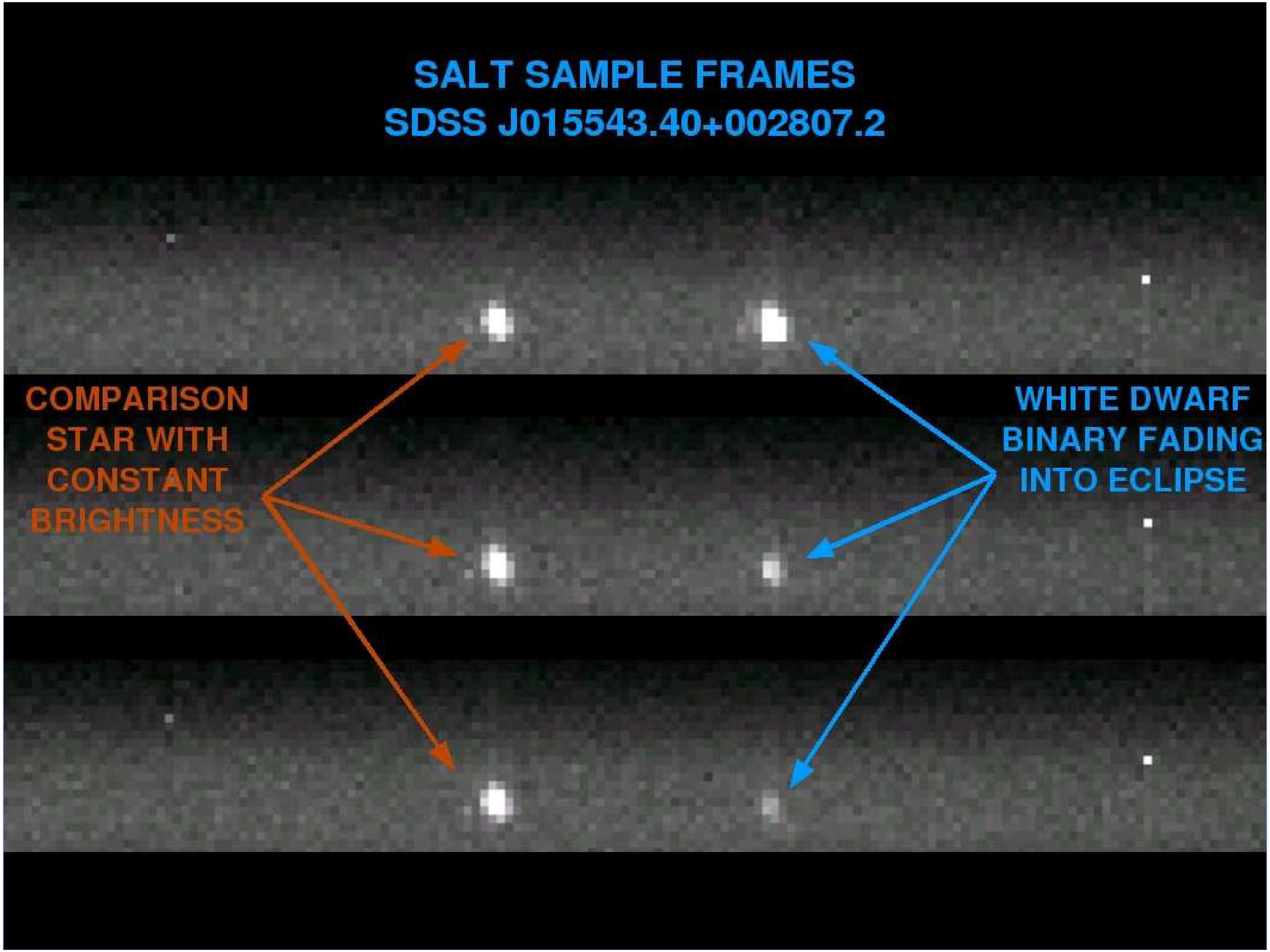
Magnetic White Dwarf Primary Star

- Strongly magnetic white dwarf inhibits accretion disc formation
- Instead, magnetic field channels accretion directly to magnetic poles of white dwarf
- White dwarf magnetic field is huge: 10-200 Megagauss

SALTICAM Frame Transfer Mask in Slot Mode

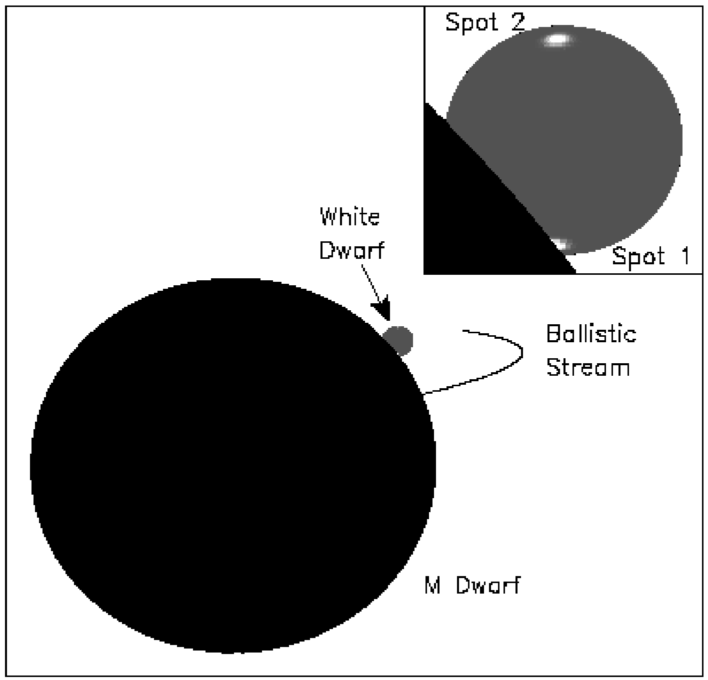


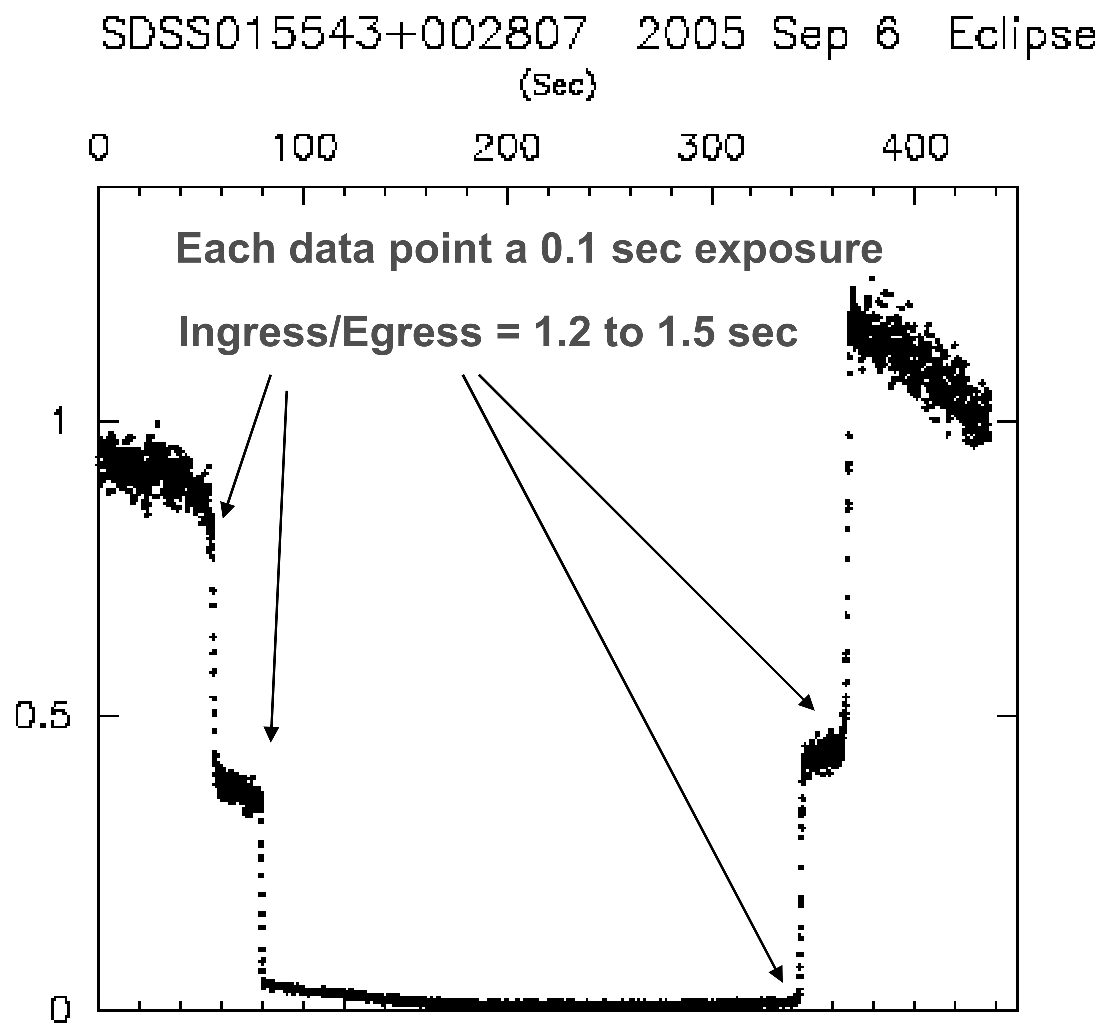



SALT SAMPLE FRAMES
SDSS J015543.40+002807.2
COMPARISON STAR WITH CONSTANT BRIGHTNESS
WHITE DWARF BINARY FADING INTO ECLIPSE

SALT First- Science

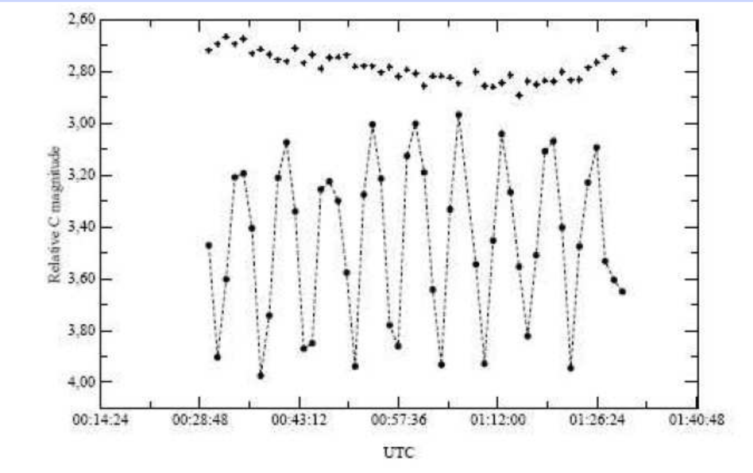
An example: a light curve of an eclipsing magnetic CV (Polar) taken with SALTICAM

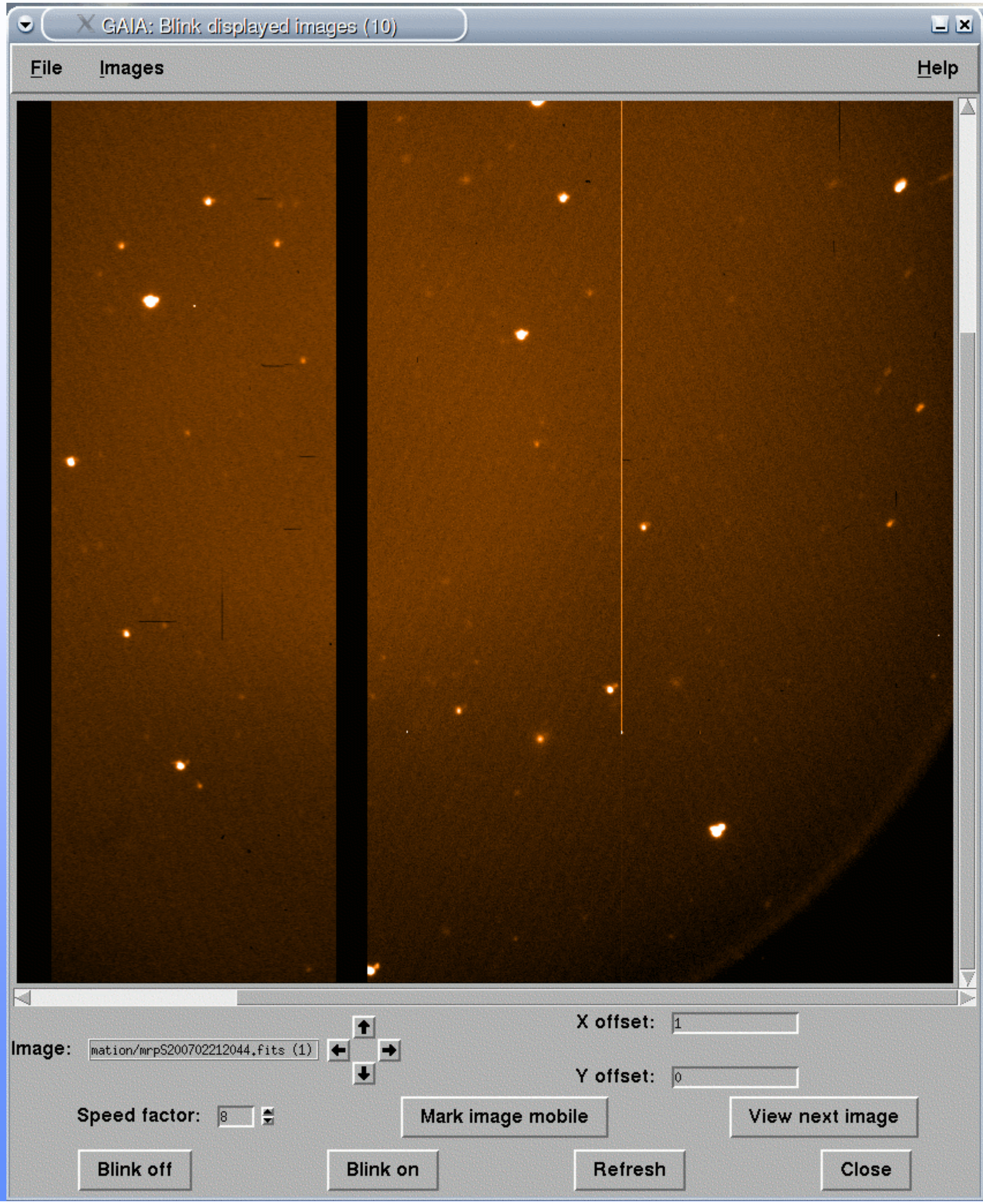


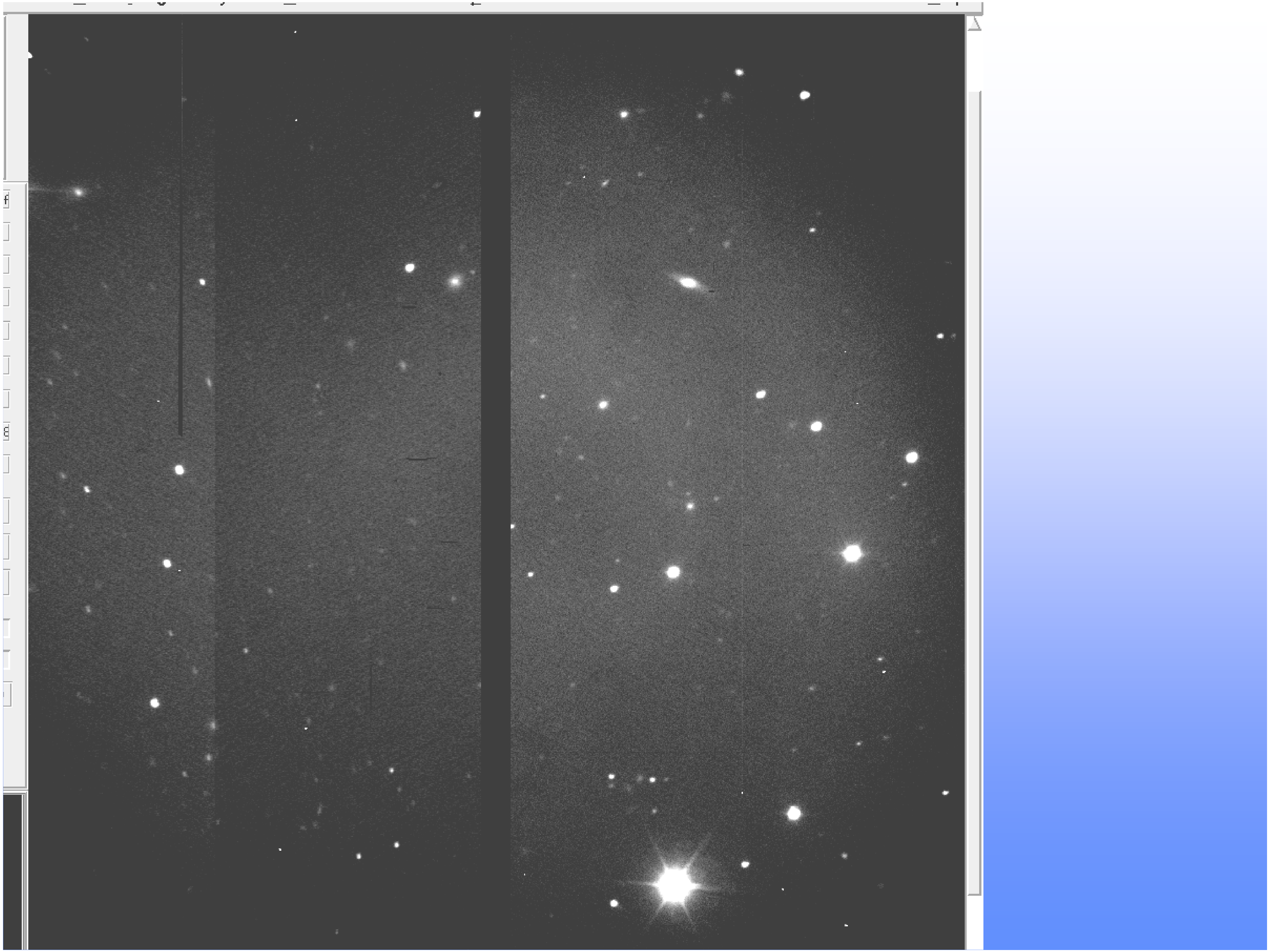


Observations of Asteroids

- Looking for Near Earth Objects
  - Potential threats!
- Deriving spin periods
- A V = 20.5 asteroid with a 12.76 min spin period (60 sec exposures)

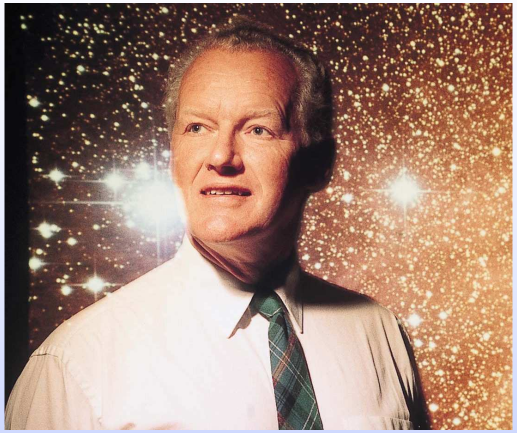






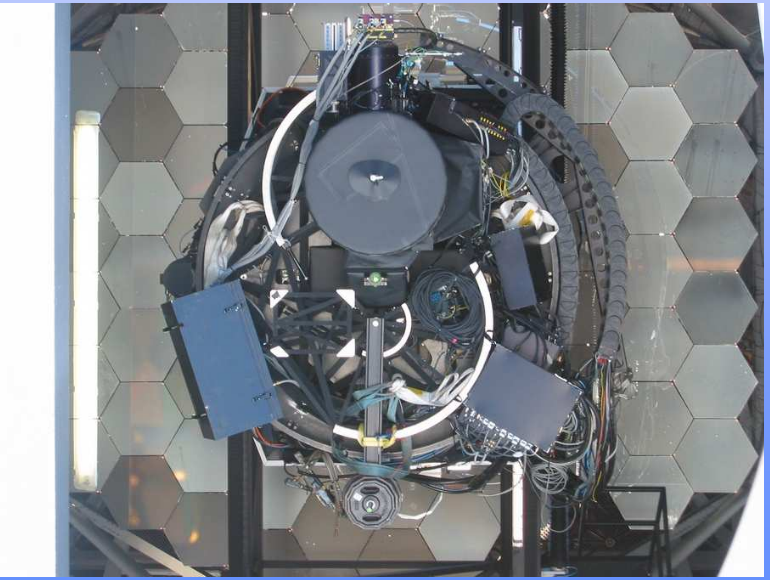
The Robert Stobie Spectrograph (RSS)
(built at Wisconsin, Rutgers & SAAO)

An efficient and versatile Imaging Spectrograph
- capable of UV spectroscopy
- high time resolution ablility
- polarimetry capability
- Fabry Perot imaging (many narrow filters)
- multiple object spectroscopy
    - Can observe ~100 objects at once



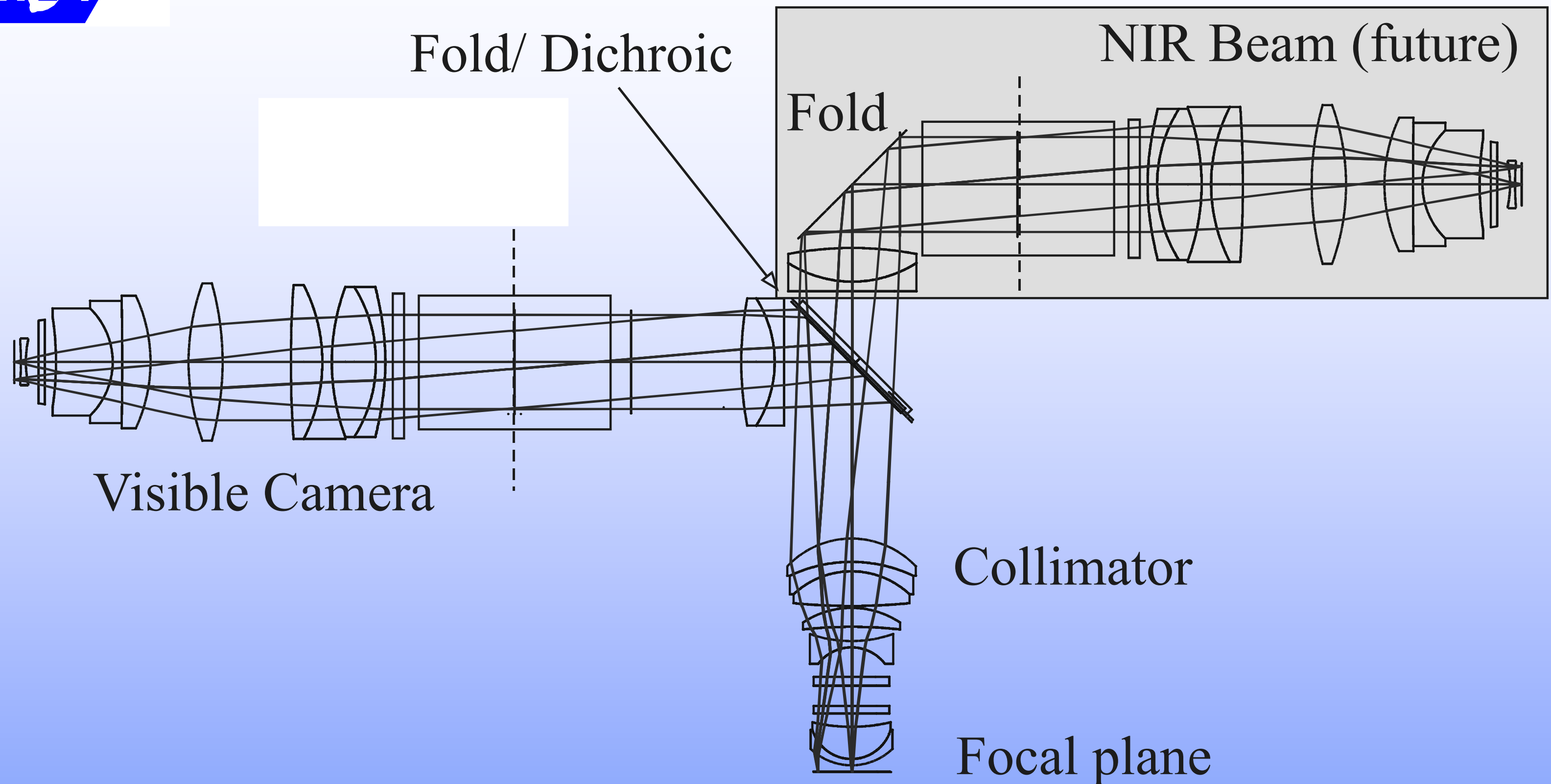
Named in memory of Bob Stobie, previous SAAO Director.

RSS in lab at Wisconsin (Feb 2005)



RSS installed on SALT (Oct 2005)

Optics

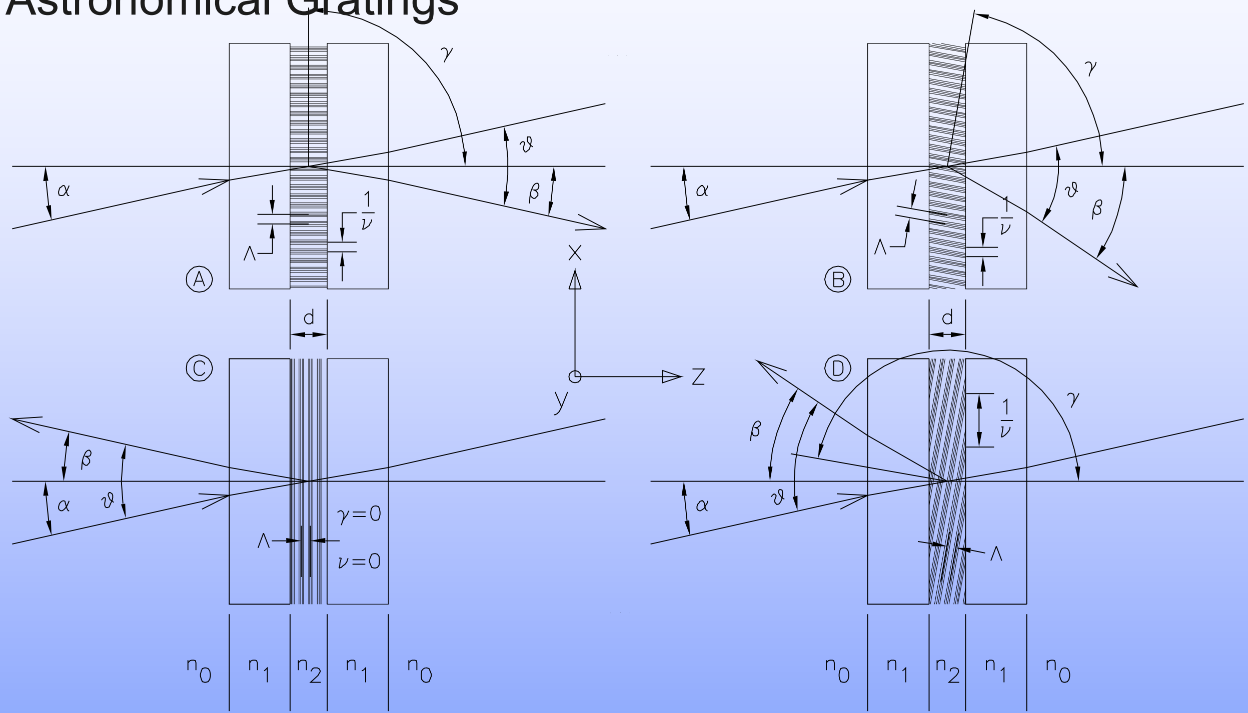


- **All-refractive UV optics for high throughput**
- **At prime focus for UV and full-field access**
- **NIR upgrade path: simultaneous 3200 Å – 1.7 μ**

How VPH Gratings Work

VPH Gratings. From Barden, et al, 2000, PASP

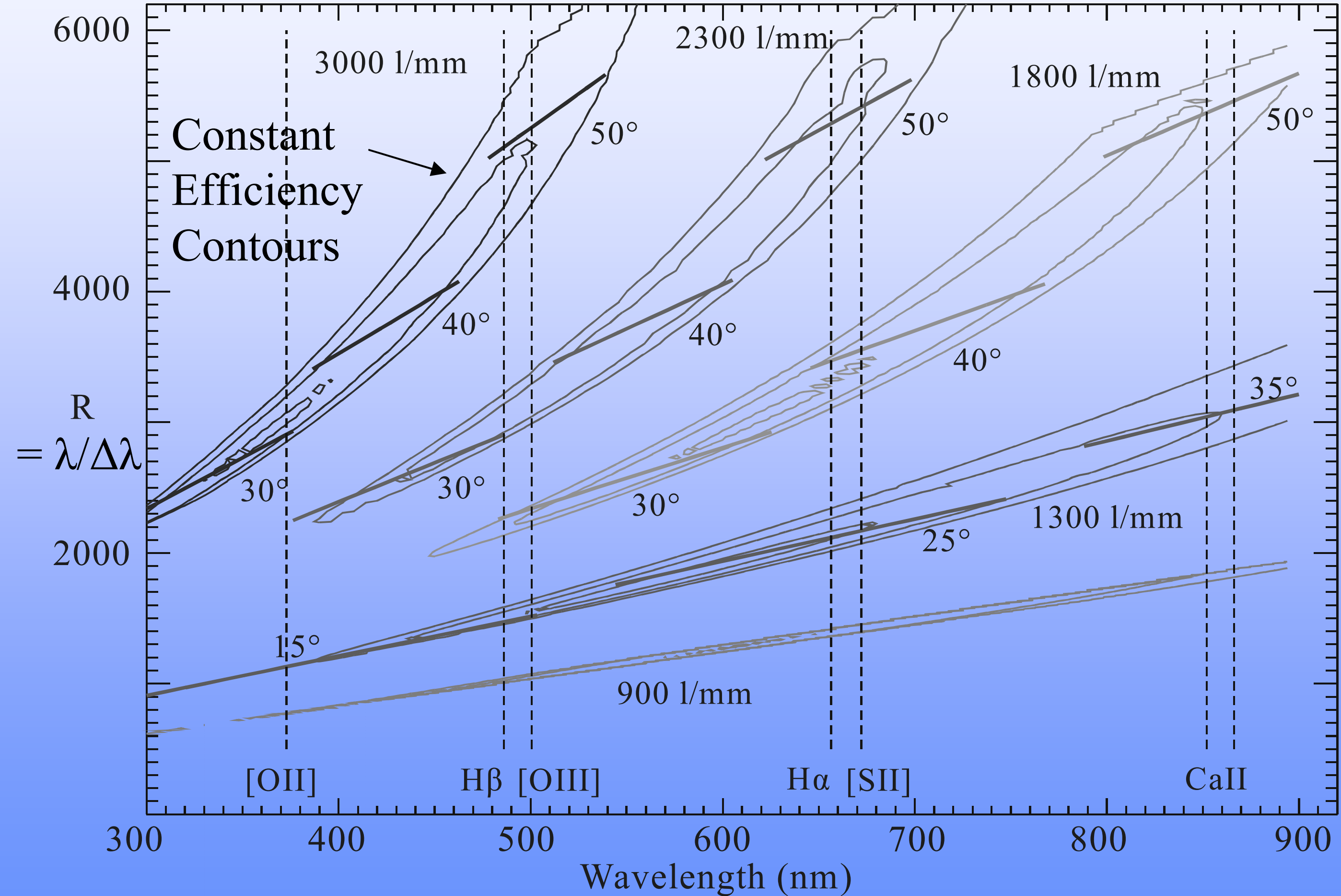
Astronomical Gratings



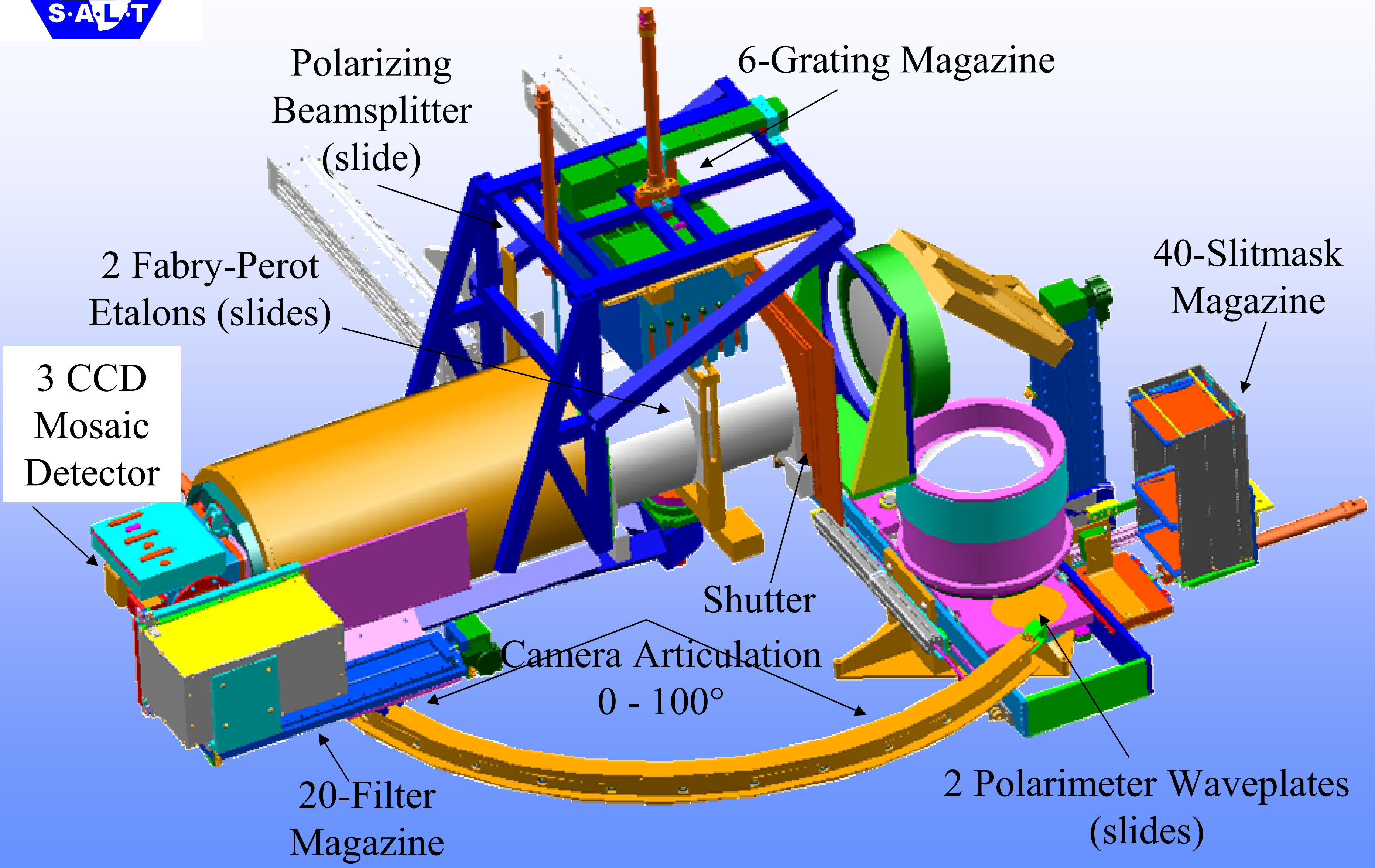
- **Created by exposing holograph material (“DiChromated Gelatin") to interference pattern from laser**
- **Index of refraction of DCG is modulated in space**
- **Large; inexpensive; custom design; efficient at high groove density**

High Efficiency with Volume Phase Holographic Gratings

Resolution vs wavelength for 1.2 arcsec slit



Mechanisms



Polarizing Beamsplitter (slide)
6-Grating Magazine
2 Fabry-Perot Etalons (slides)
40-Slitmask Magazine
3 CCD Mosaic Detector
Shutter
Camera Articulation 0 - 100°
20-Filter Magazine
2 Polarimeter Waveplates (slides)

RSS Performance Tests

- **Passed pre-ship & pre-installation testing, excepting:**
  - **Some camera roll flexure (fixed)**
  - **Some grating rotation flexure (fixed)**

  But, not exhaustive mechanism exercising

  Throughput not directly measured

- **Installed on telescope Oct 2005**
  - **Long-slit mode, start polarimetry comm.**
  - **F-P tests, MOS tests**
  - **on-sky throughput tests**

  Significant throughput underperformance, particularly in the blue (<400 nm)

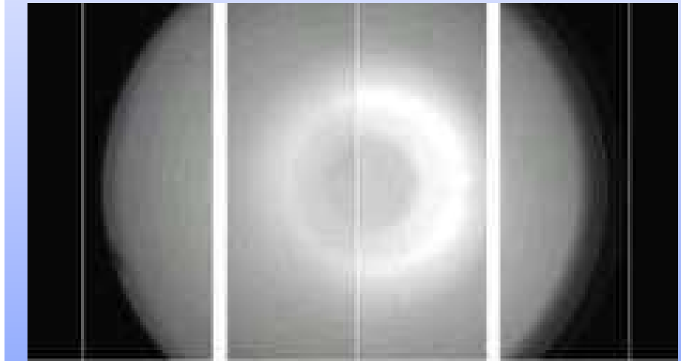
  Interference filter ghosts

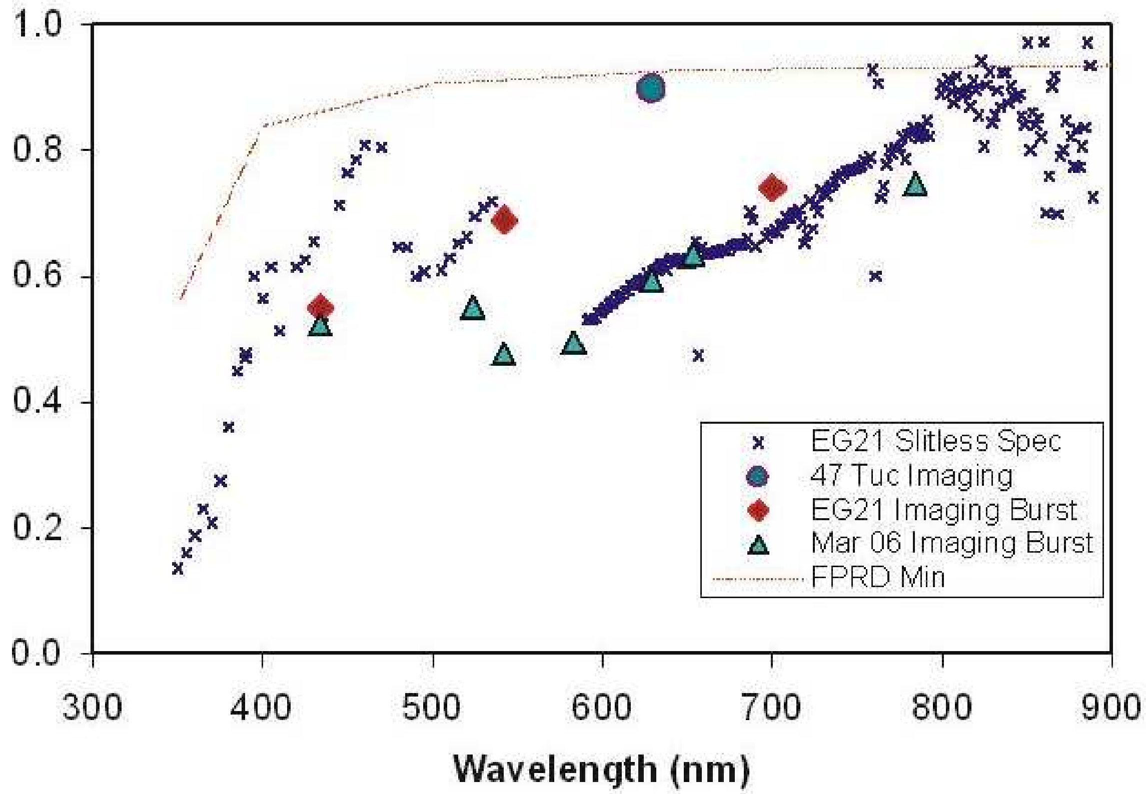
  Also some problems with slit-mask mechanism

- **Took off telescope Nov 2006**
  - **Removed optics and sent back to US for diagnosis & repair**

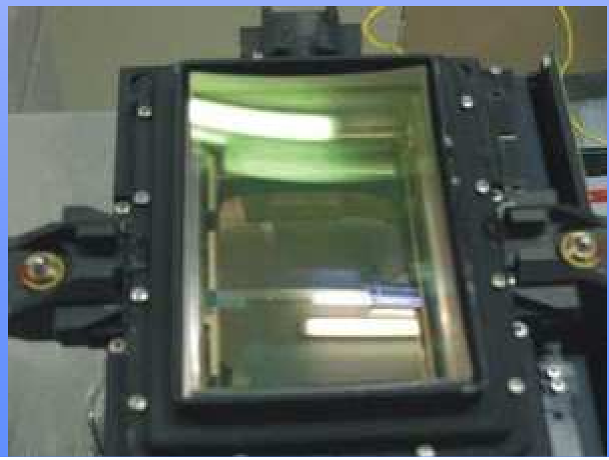
RSS Throughput Problem

- UV (<400 nm) precipitous drop-off
- Other throughput 'dips'
- Ghost seen in F-P interference filters
  - Image of pupil
  - Worse at ~550 nm





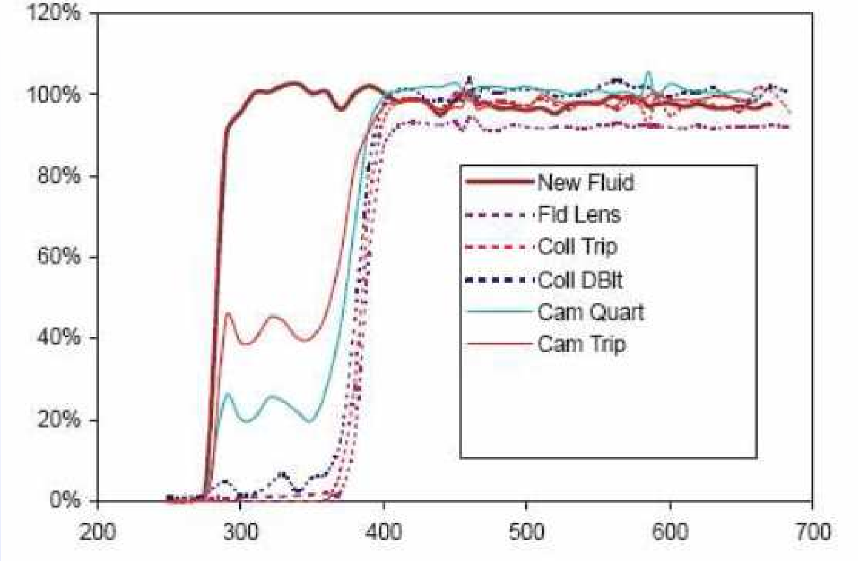
Attributed to poor multi-layer A-R coating on camera field flattener (dewar window), which looked greenish to eye.



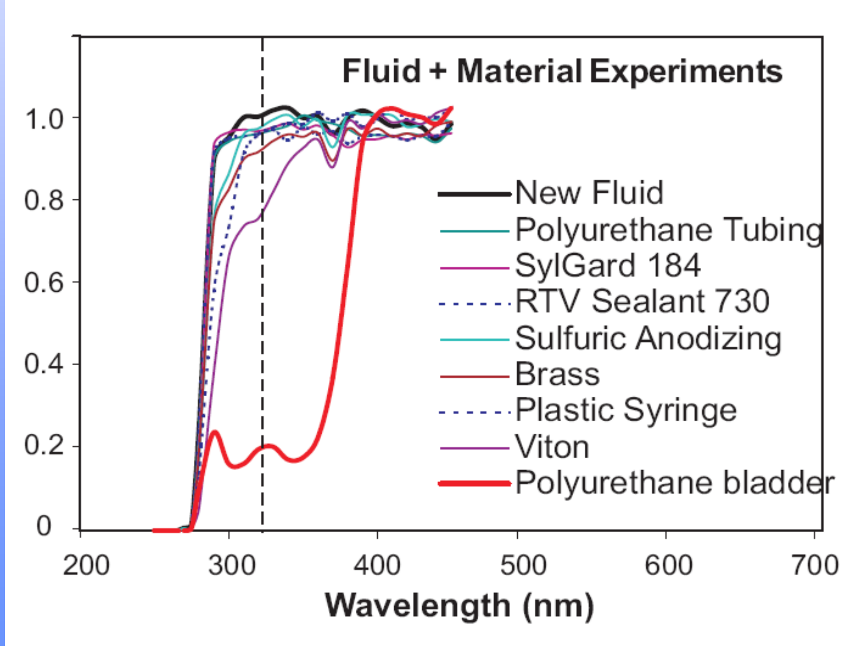
Cause of UV drop-off

Cause found by process of elimination

- **Laser (375 & 650 nm) and diodes used to measure all major optical components in situ**
  - ***Effect seen in all lens groups with multiplets***
  - **Assembled lens groups removed & returned to US**
  - **Disassembled & measured with monochromator**



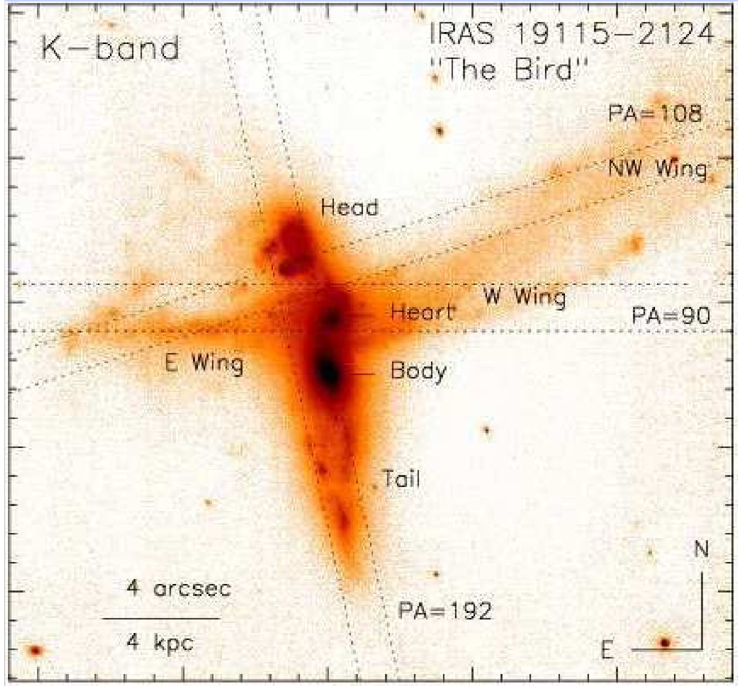
- **No coatings or lens materials were in common**
  - **CaF2, fused silica, NaCl (but uncoated and inside elements)**
  - **MgF2, Solgel+ MgF2, multi-layers**

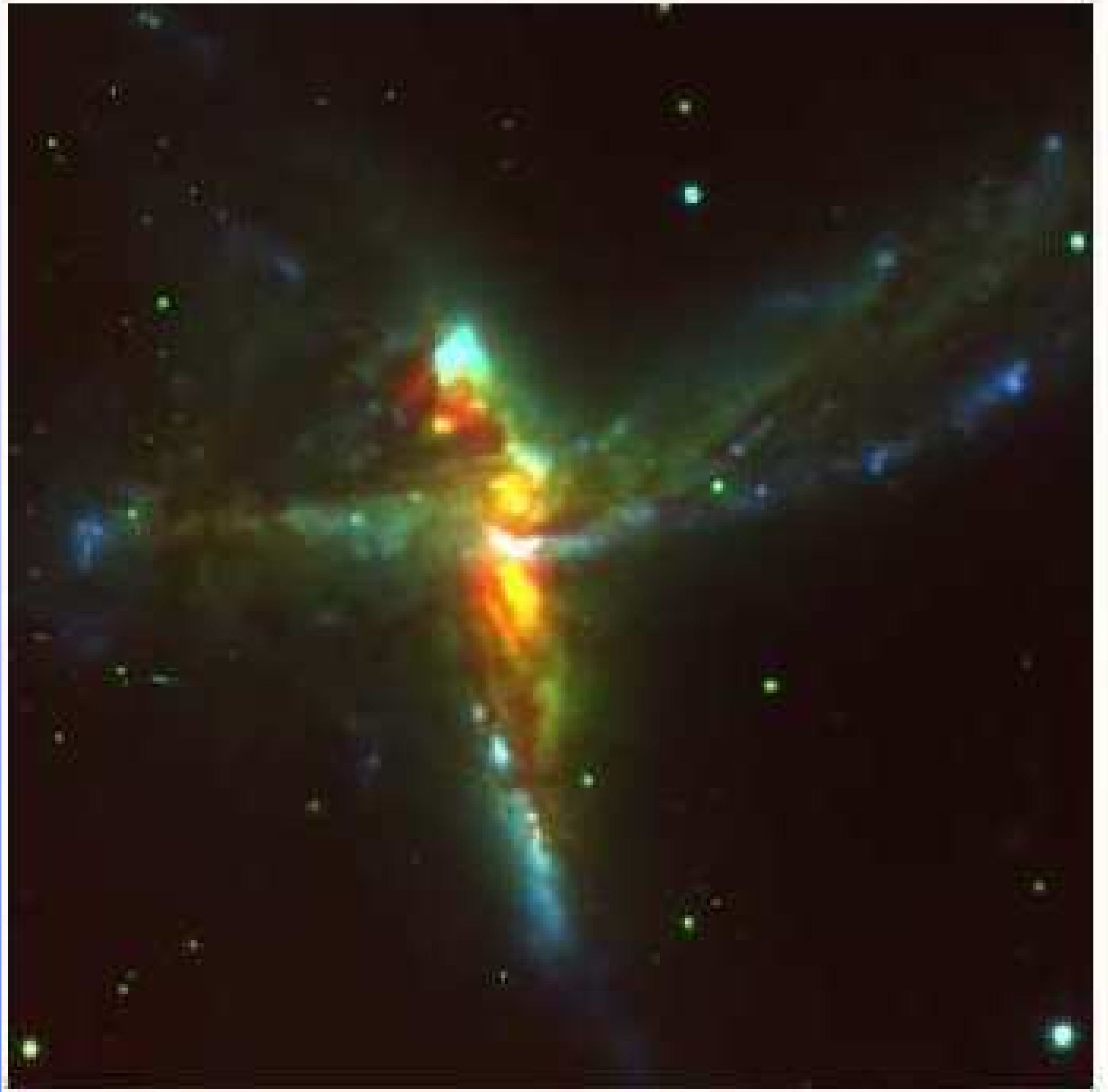


- **Only common factor:**
  - **Cargille LL5610**
  - **Extracted samples & measured**
  - ***All showed large UV absorption!***
  - **Compatibility experiments showed problems with polyurethane & viton**
- **Repaired using new materials after conducting accelerated testing.**
- ***Performance now looks good.***

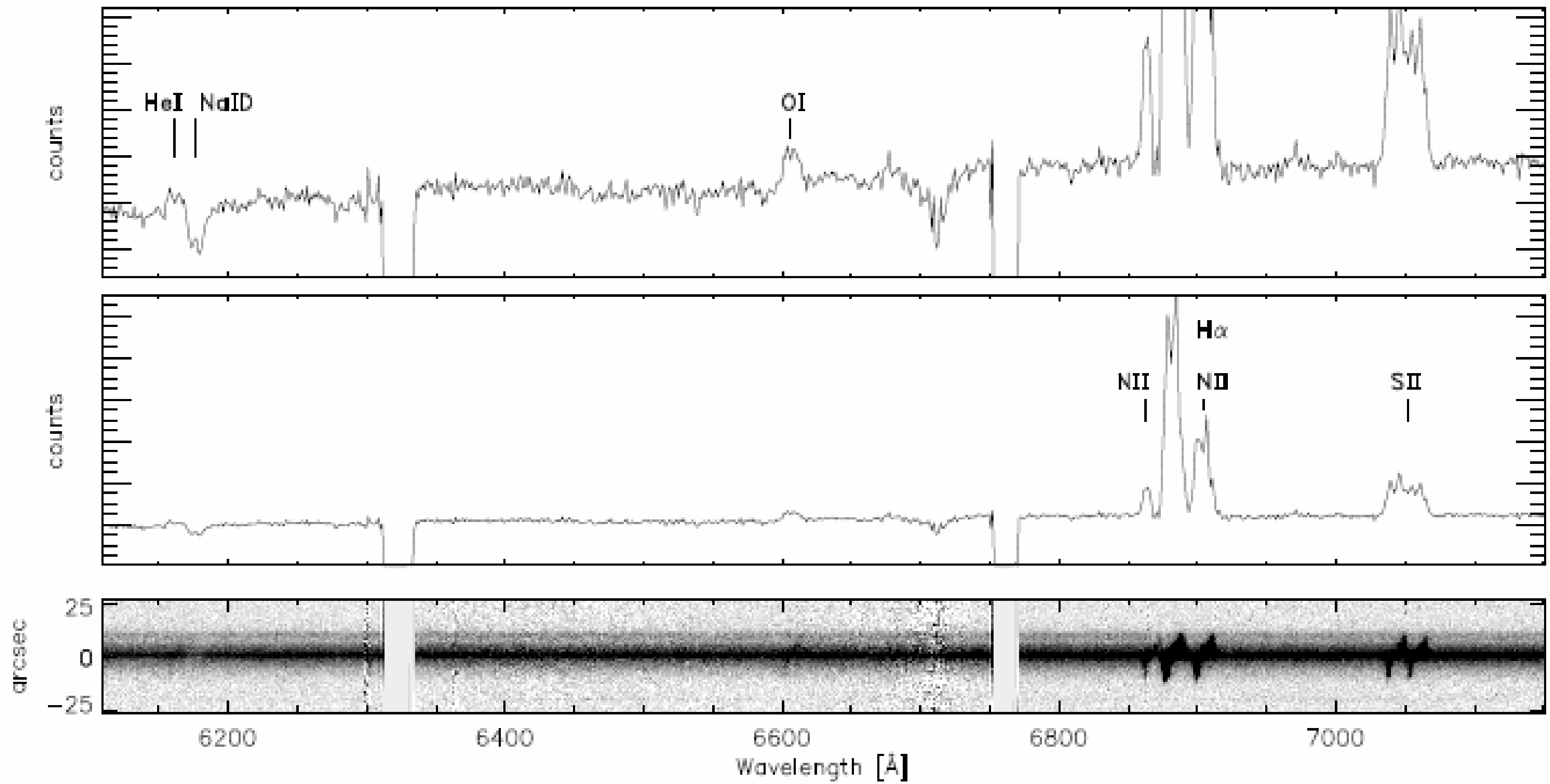
RSS Long-Slit commissioning:
1. Anatomy of “The Bird”: a triple galaxy collision

- **A-O images from the VLT**
- **Spectroscopy from SALT**
  - **Kinematics point to a 3-galaxy collision**

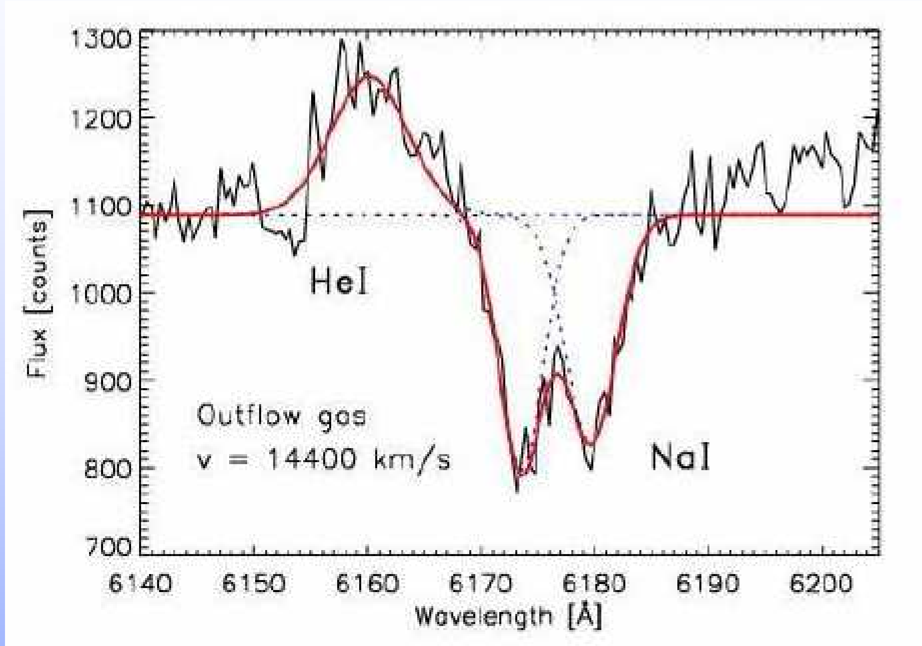


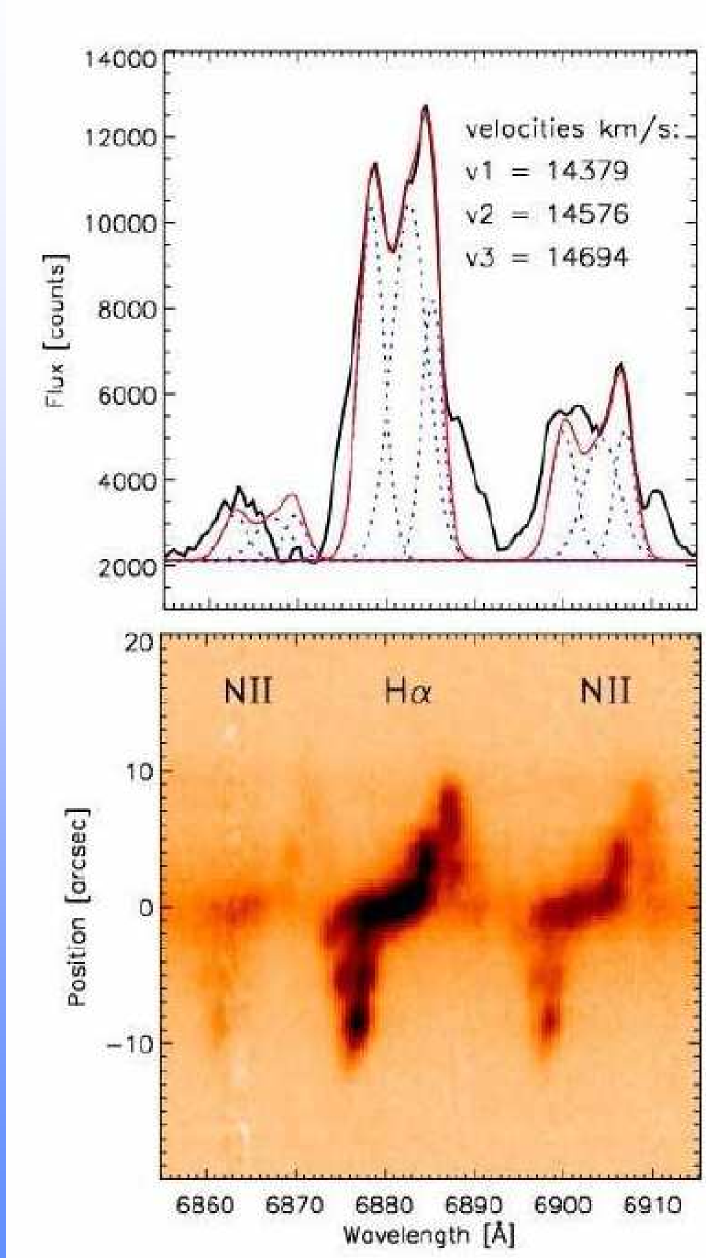


Anatomy of “The Bird”: a triple galaxy collision



Anatomy of "The Bird": a triple galaxy collision

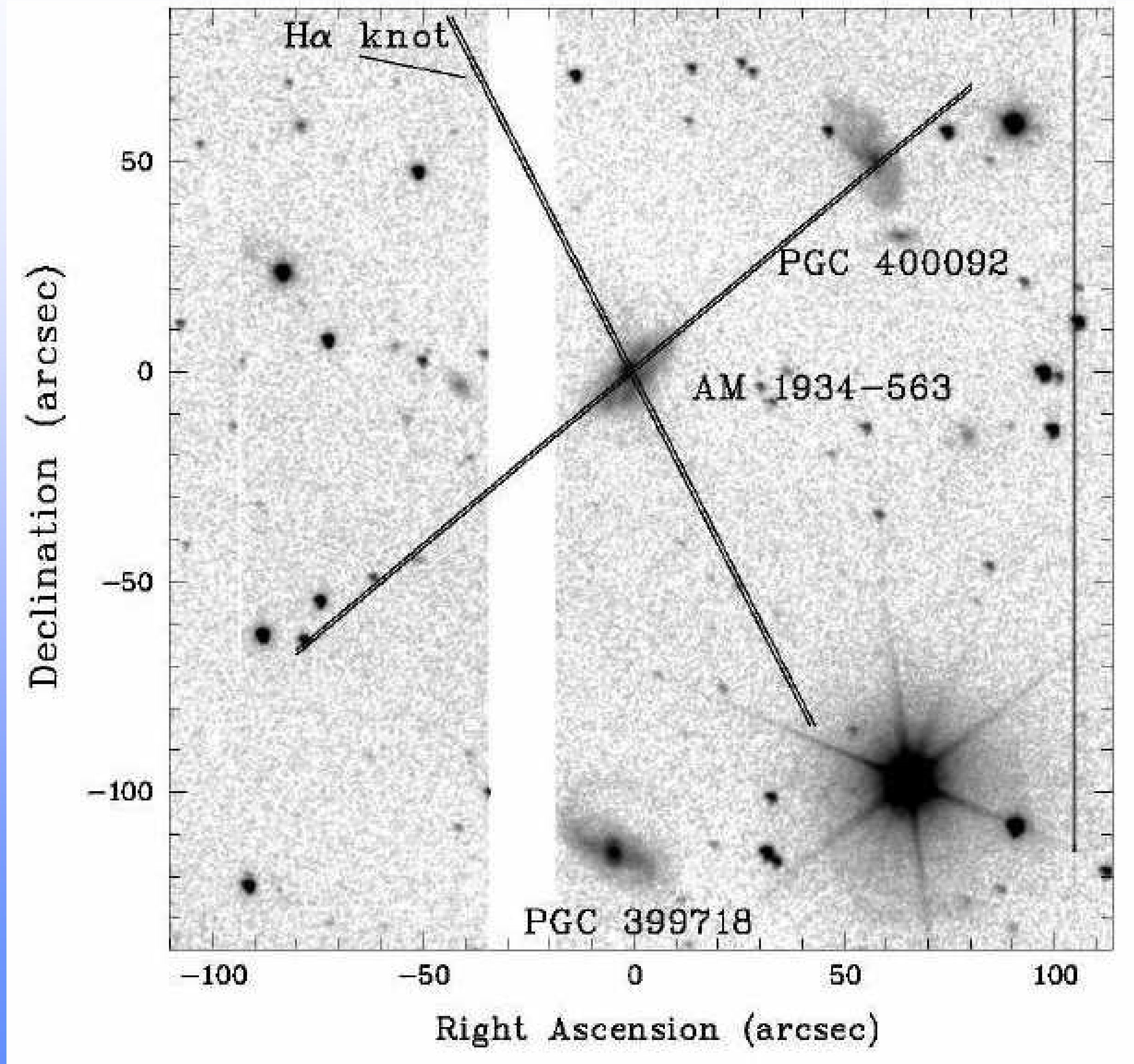




2. Galaxy Mergers and Dark Matter Halos:

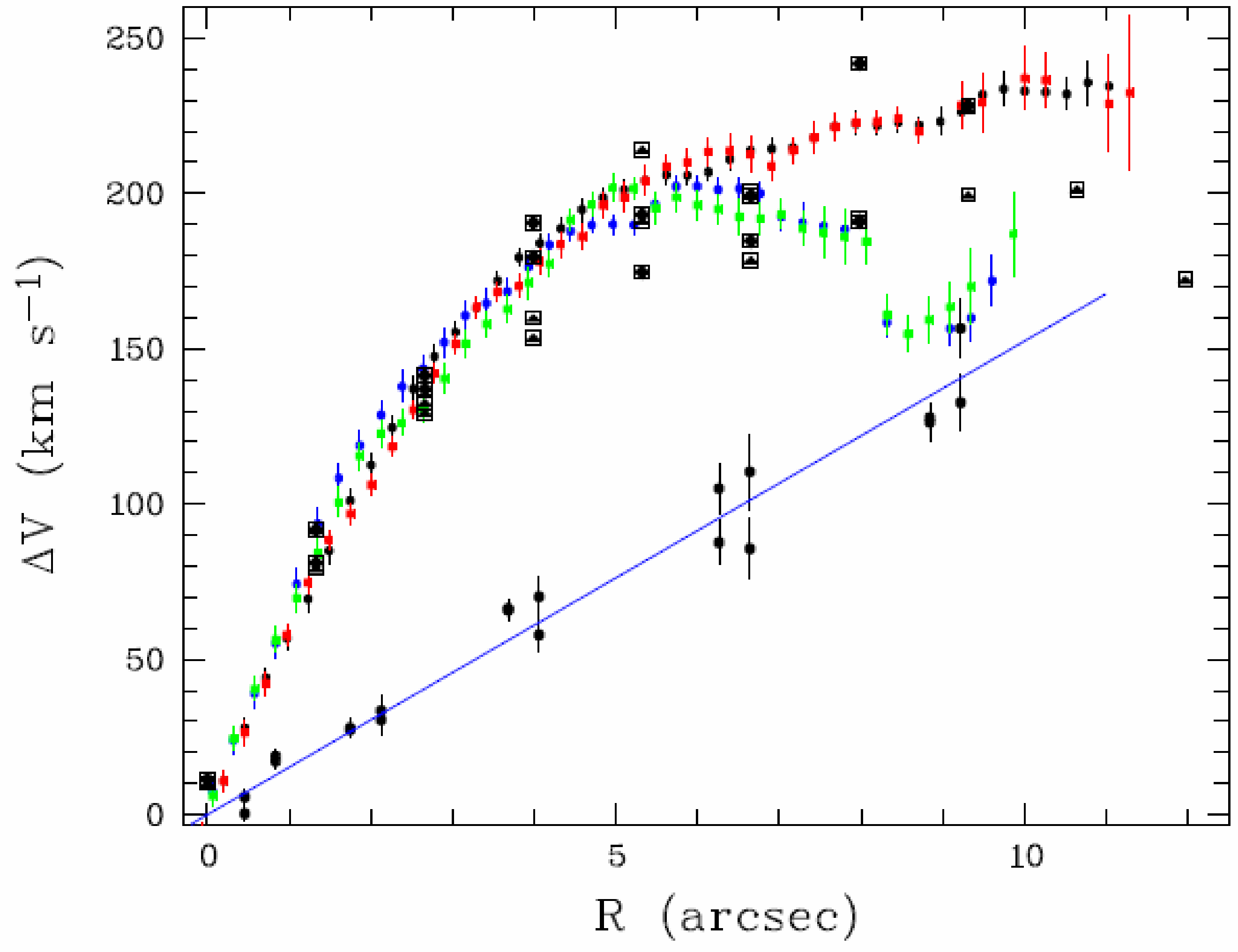
Polar Ring Galaxy: AM 1934-563

- RSS spectroscopy of a Irr/Polar Ring Galaxy
- Kinematics of components differ
- "Solid body" rotation of ring



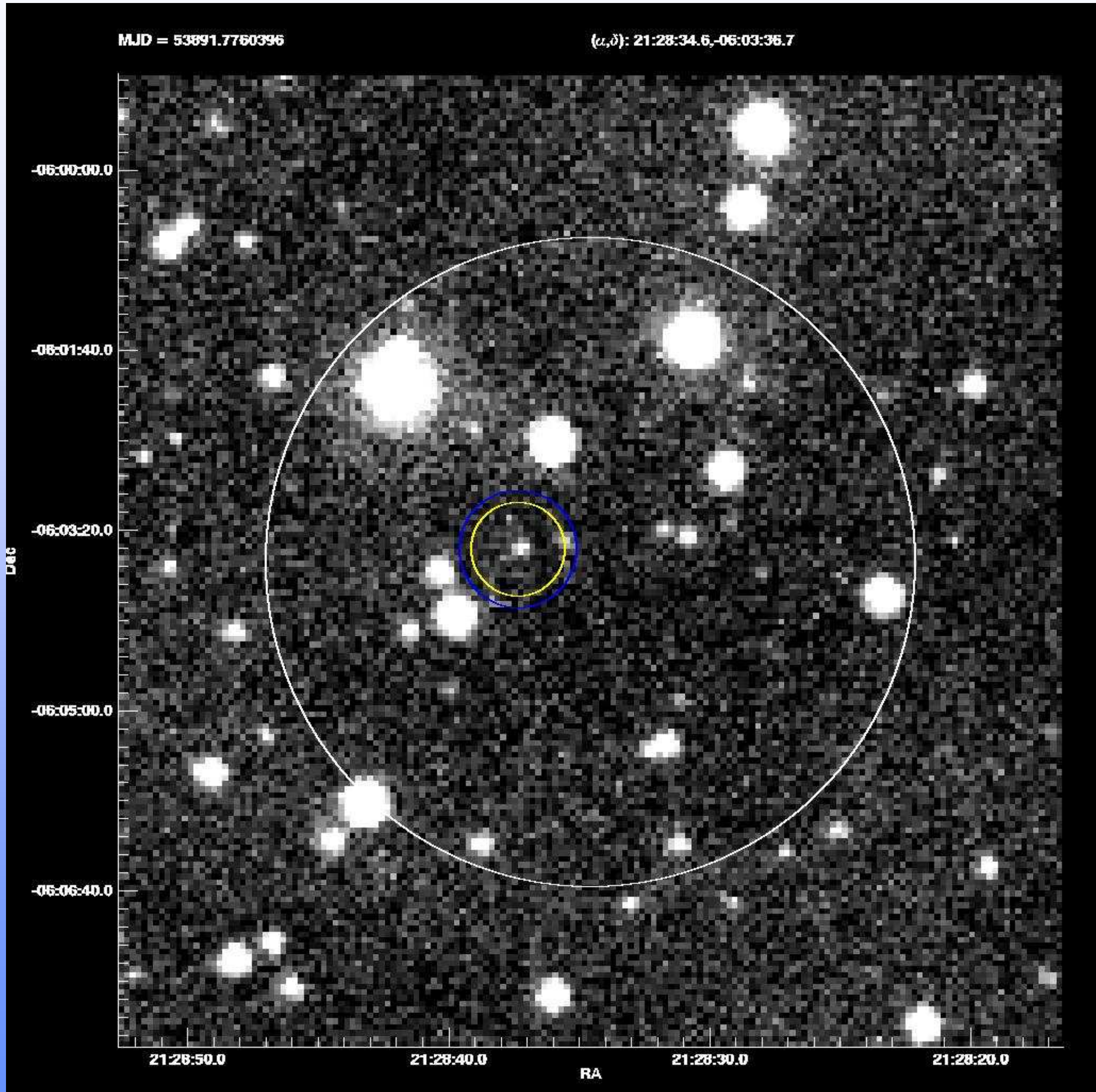
2. Polar Ring Galaxy: AM 1934-563

- **The results show that then polar ring rotates slower than the galaxy at similar distances from the center.**
- **This indicates that the halo DM is more concentrated toward the galaxy than toward the ring, and does not have a spherical shape or is concentrated toward the polar ring**

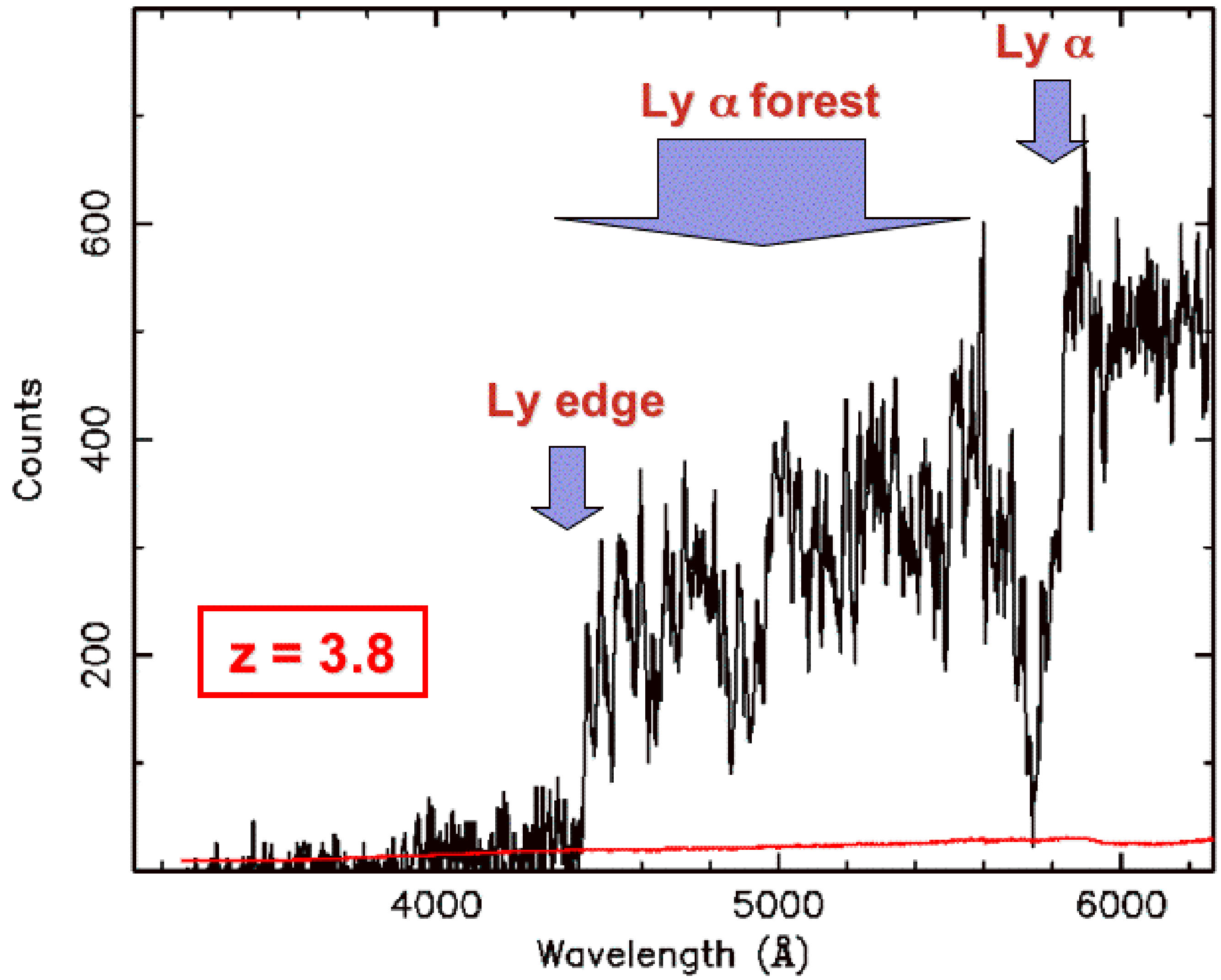


3. SALT Observation of GRB 060605

SALT Observations ~8 hours
After alert
- MSSSO obs. at V ~ 15
- SAAO obs. at V ~ 20

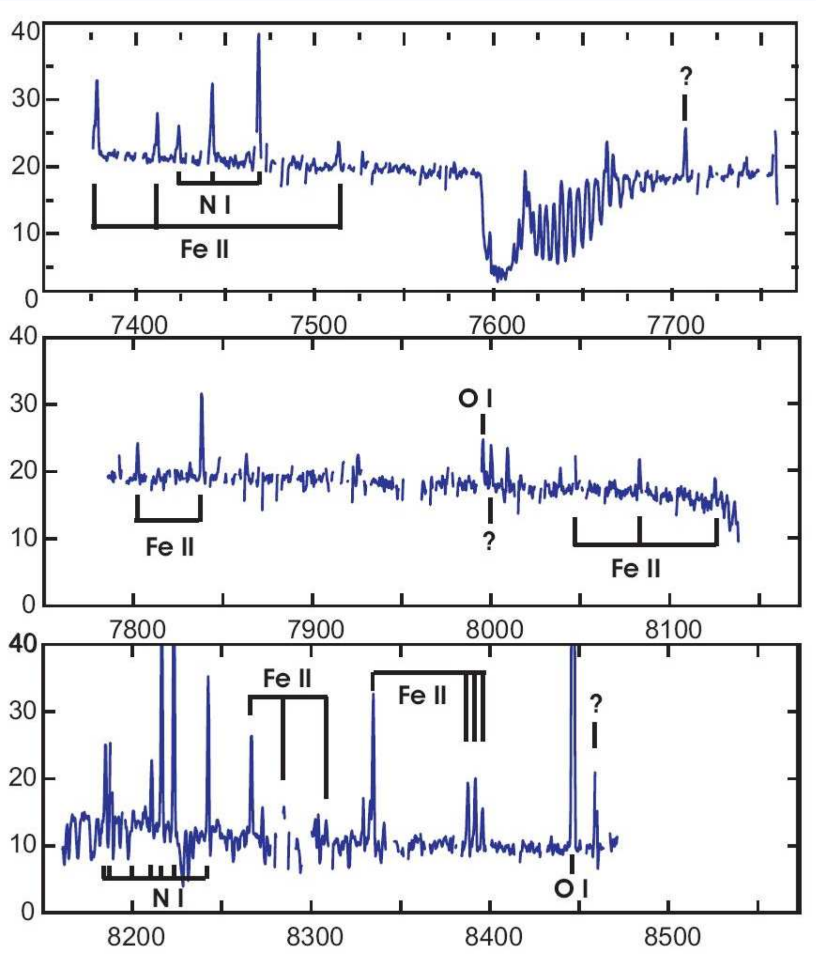


GRB 060605



Ly α
Ly α forest
Ly edge
z = 3.8
600
400
200
Counts
4000
5000
6000
Wavelength (Å)

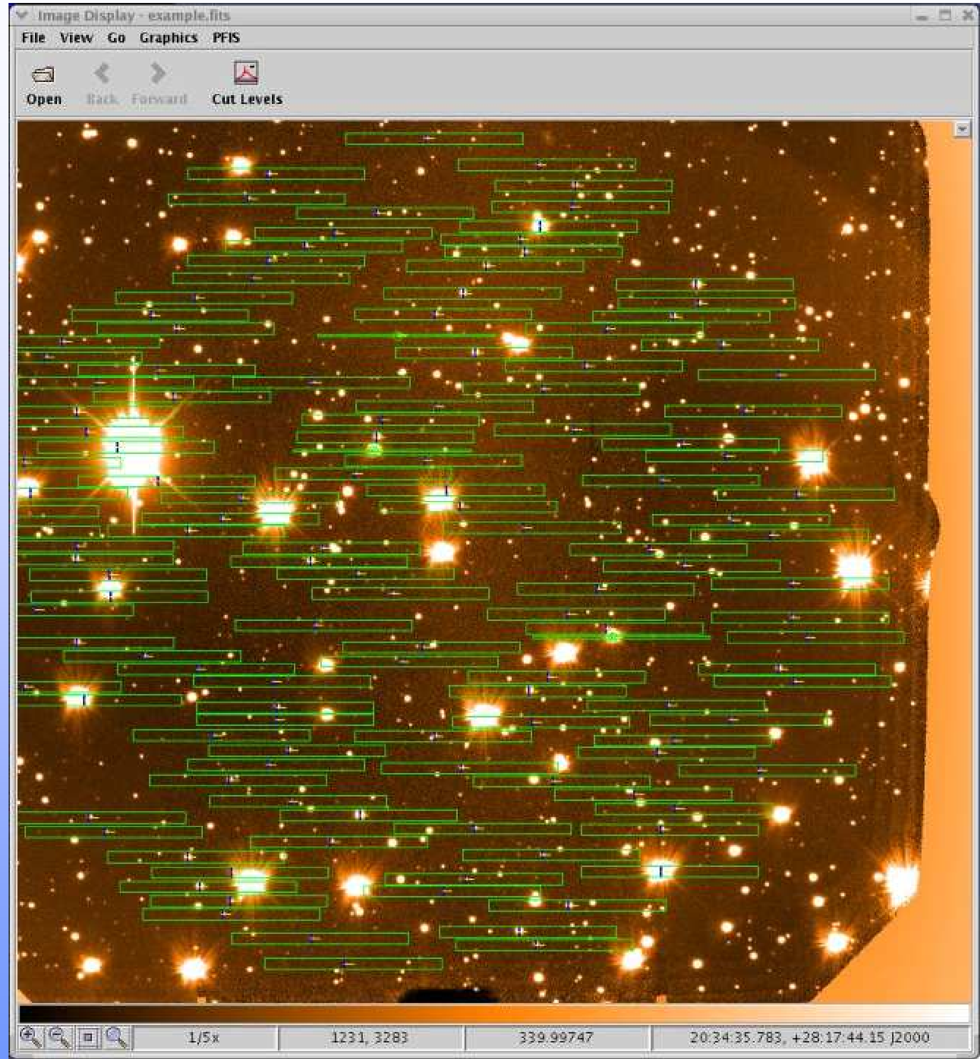
4. Spectroscopy of a Reflection Nebula



NGC2023:
Lines from photoexcitation by FUV photons

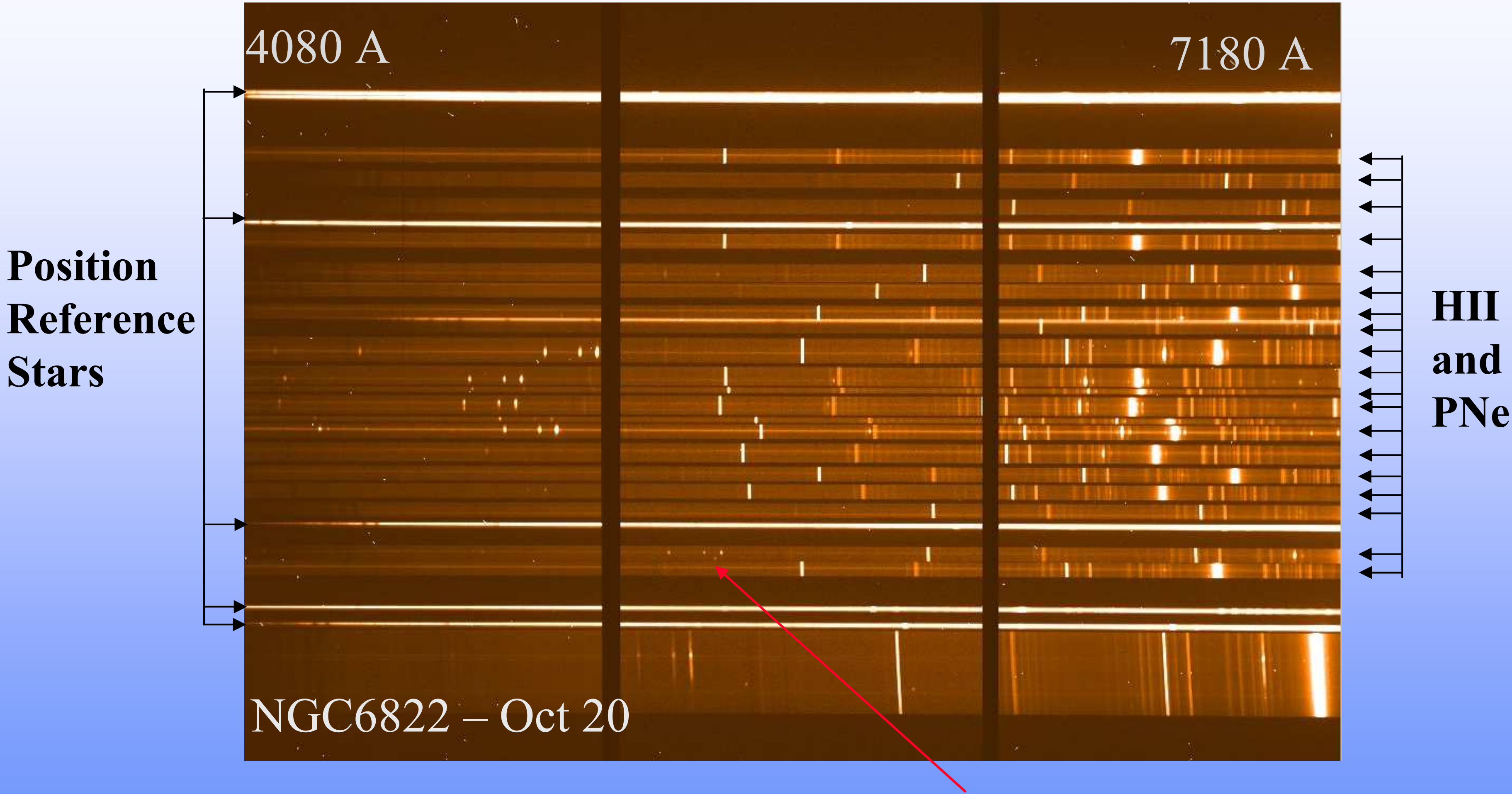
RSS Commissioning: MOS laser cut slit-masks

Slit mask cutter



Slit mask cutter software GUI

MOS Test Run Spectra



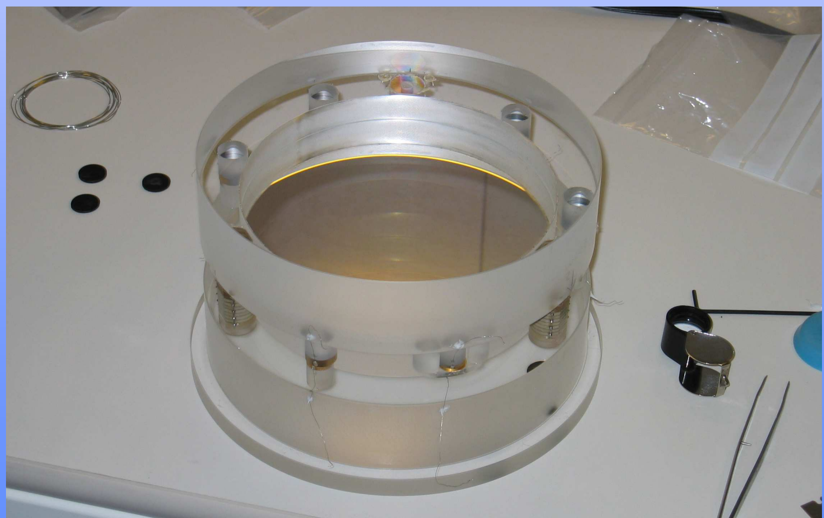
800 sec. See Hβ, OIII 4949 & 5007 triplet. Faintest PNe m[OIII] = 23.2

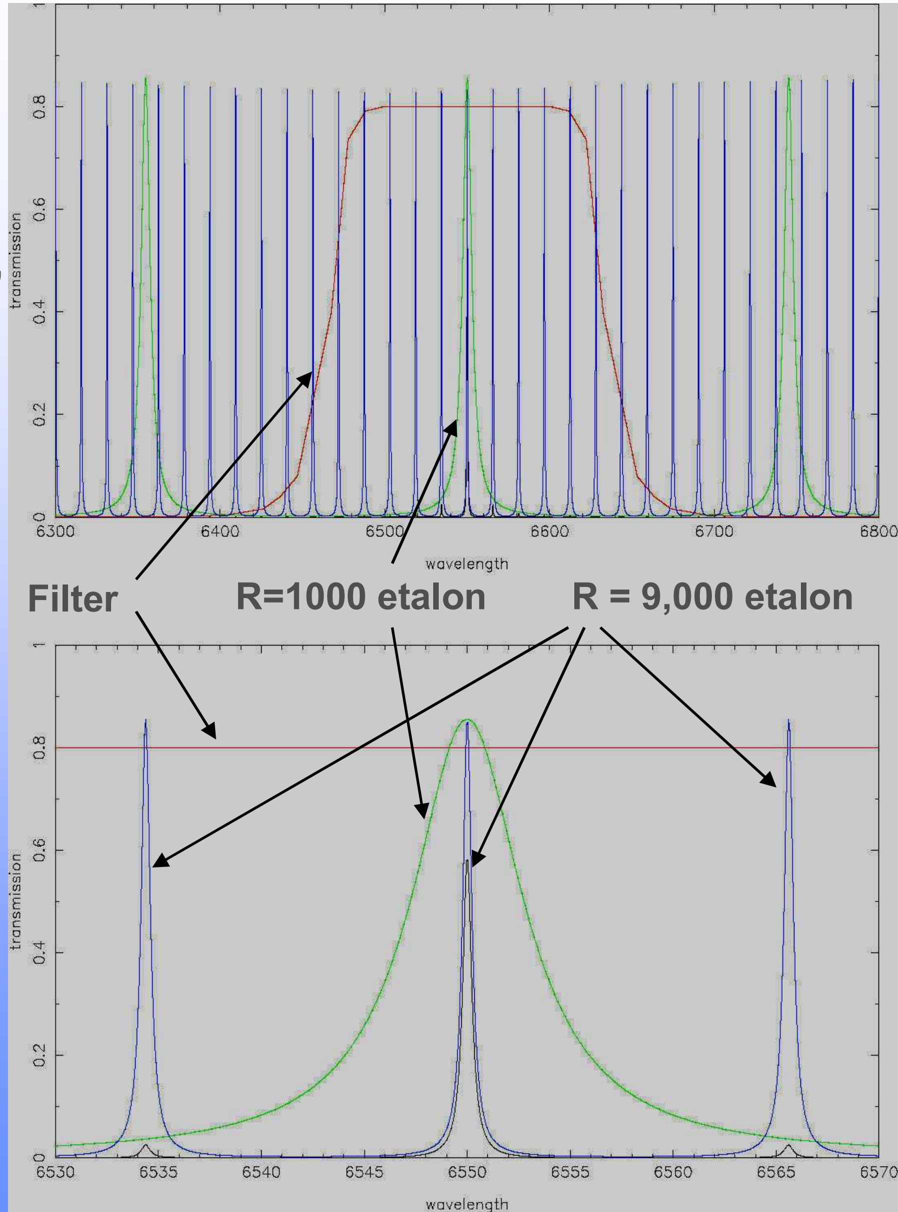
Commissioning RSS Fabry-Perot mode

3 resolution modes:

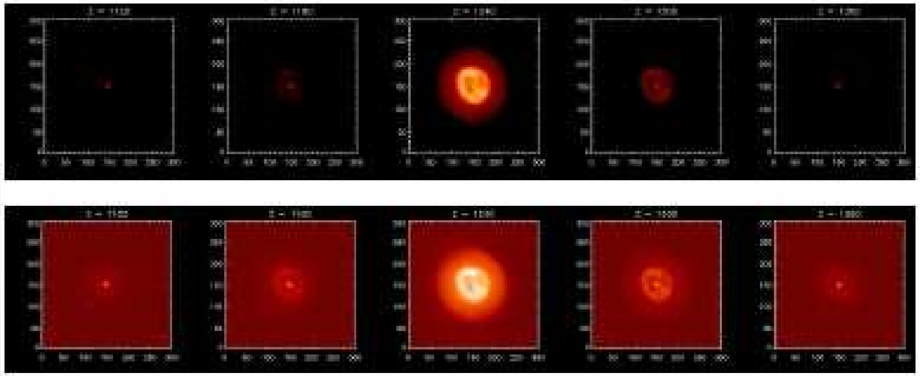
- low (R = 320-770) ‘tuneable filter’ (full field)
- medium (R = 1250 – 1650) bullseye 3.8’ – 3.3’
- high (R ~ 9,000) bullseye ~1’

High R modes in dual etalon mode
Tests began Sep-Oct 2006





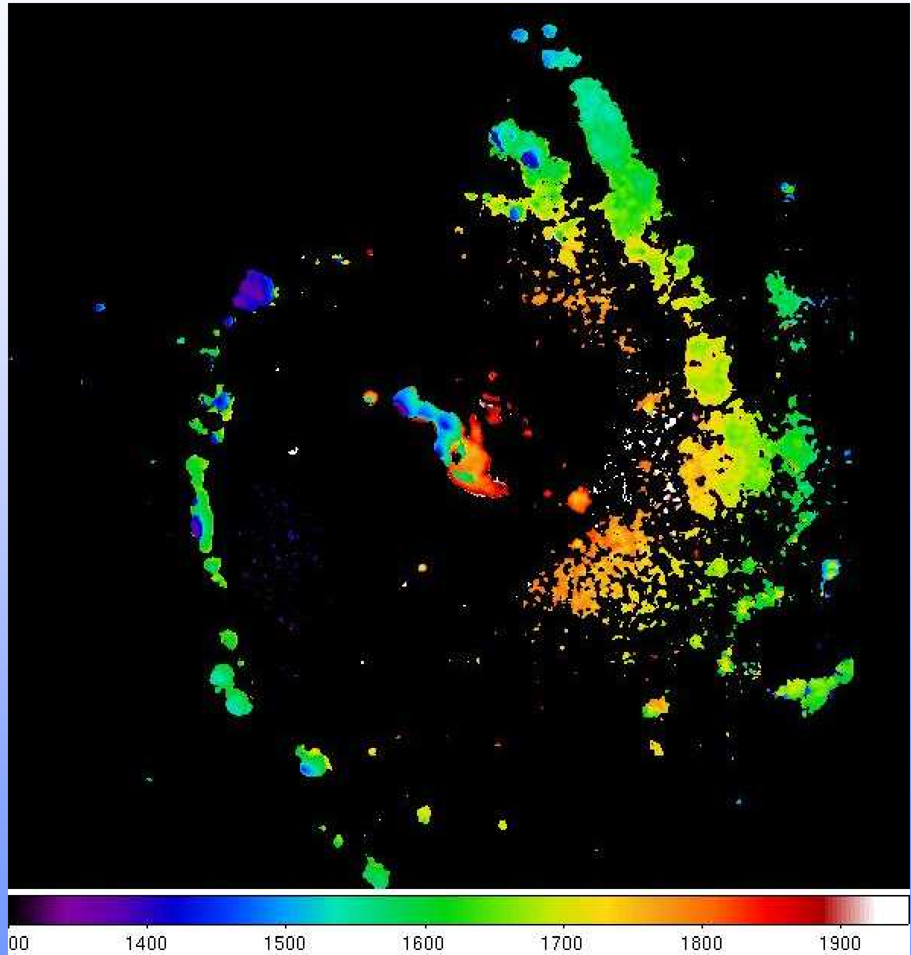
Fabry-Perot Commissioning



NGC 1535: Planetary Nebula in H-alpha

NGC 1365

Fabry-Perot Commissioning Observations

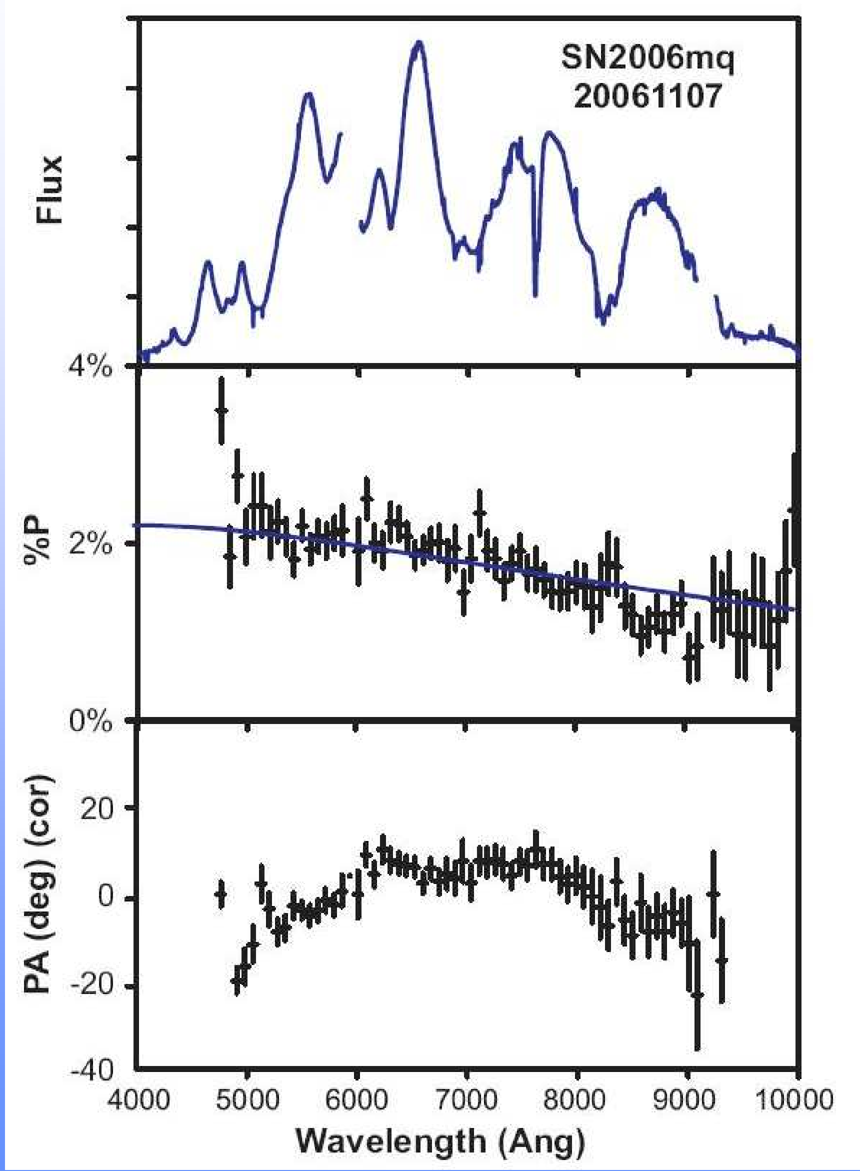


H-alpha image

Velocity Map

Spectropolarimetry Tests

- Began in Oct 2006, just weeks before RSS was removed
- Observed several types of objects
  - Supernovae
  - Star forming regions
  - Reflection nebula
  - Magnetic CVs



SALT High Resolution Spectrograph

SALT will utilize fibre-fed high-resolution spectroscopy of point sources (<2 arcsec) plus background (fibre pairs)

Under construction at Centre for Advanced Instrumentation, Durham University (UK)

- **Started in late 2007, completion early 2010**
- **Based on University of Canterbury CDR level design**
- **Design is dual beam (370-550 nm & 550 – 890 nm) white-pupil R4 duplex echelle, with VPHG, giving R = 16,000 to 65,000 (depending on image slicer).**
- **Single object spectroscopy with single fibre sky subtraction (single fibre) and nod/shuffle.**
- **Precision radial velocities (to few m/s using Iodine cell, simultaneous Th-Ar, or EDI)**
- **Housed in a vacuum tank (remove large r.v. error due to P,T variations).**

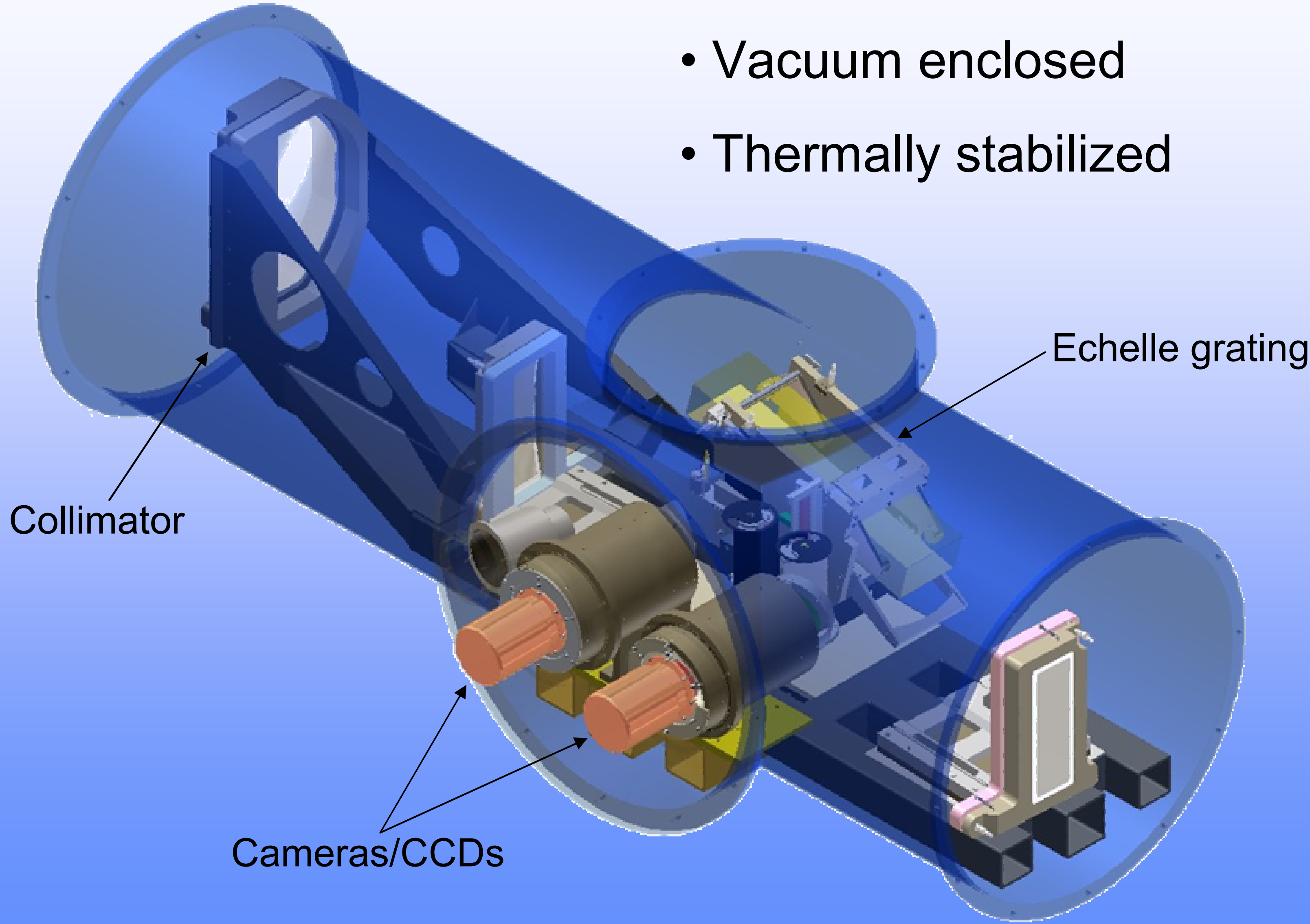
Fibre mode	Resolving Power ($\lambda/\delta\lambda$)	Transmission (SPC + SLT + TEL)	
		480nm	650nm
Low	16,000	13.4%	17.4%
Medium	~37,000	9.4%	12.1%
High	~65,000	6.0%	7.7%

A new high precision mode will be implemented

Incorporating iodine cell and double scrambler

(See 7014-51, Barnes et al.)

SALT High Resolution Spectrograph



- Vacuum enclosed
- Thermally stabilized

FINAL REMARKS

- Telescope & Instrument commissioning ongoing and expected to be concluded in 2009
- Two major technical hurdles have been:
  - 1.) image quality (now diagnosed and about to be solved)
  - 2.) spectrograph throughput (solved)
- Commissioning science has still been possible and on-going SALTICAM science programs, at ~50-75% level
  - to date 11 papers published; several in preparation
- RSS optics expected to be reinstalled in late 2008 and instrument fully tested on ground before reinstalling on telescope in mid-2009
- SALT and its First Generation instrument have diversity of modes and some rare/unique opportunities (some excellent for CVs, etc.)
- RSS Near IR arm is now funded and will be the next instrument installed, after HRS.
- Consortium now considering Second Generation instruments