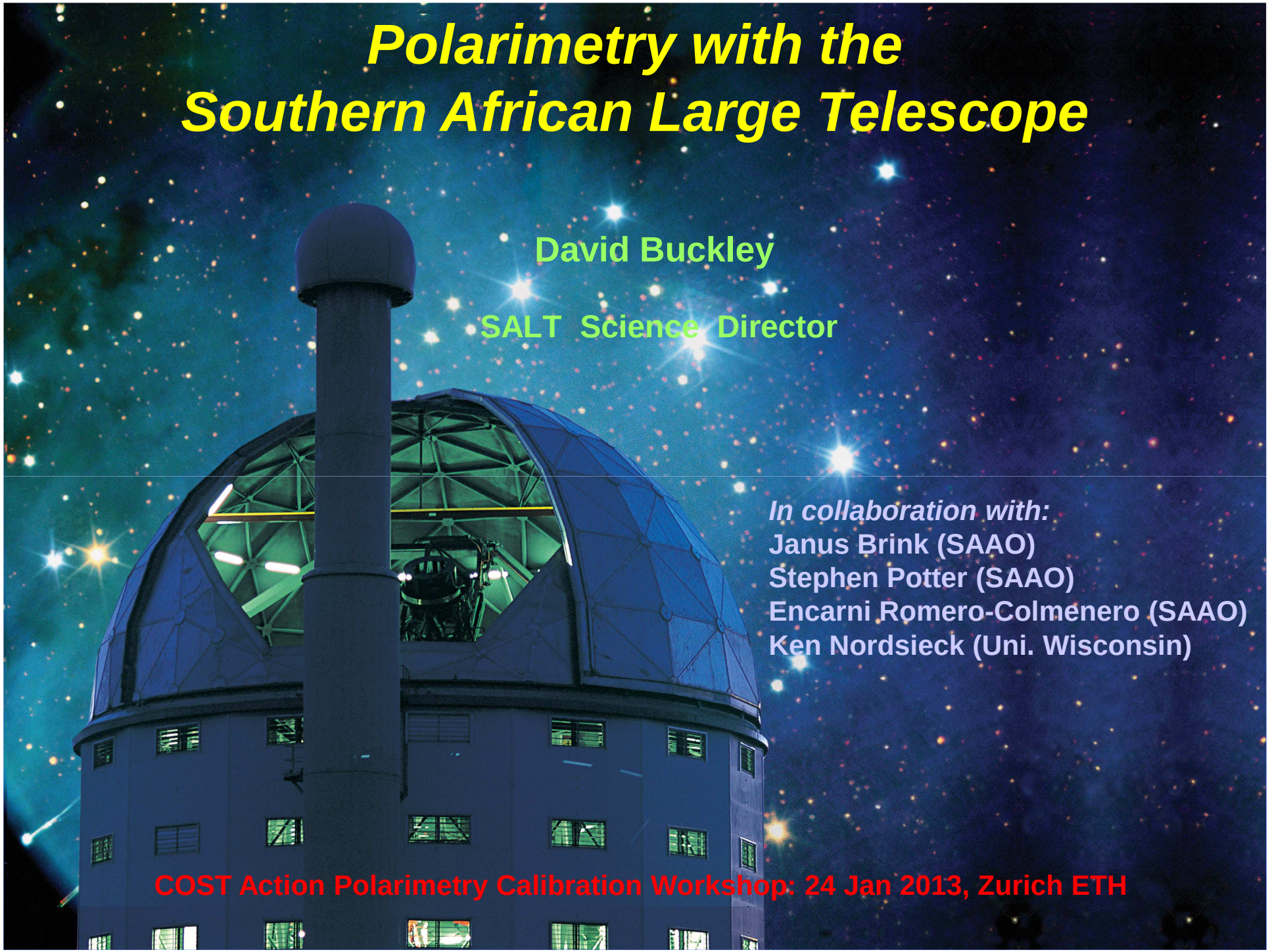


Polarimetry with the Southern African Large Telescope

David Buckley

SALT Science Director

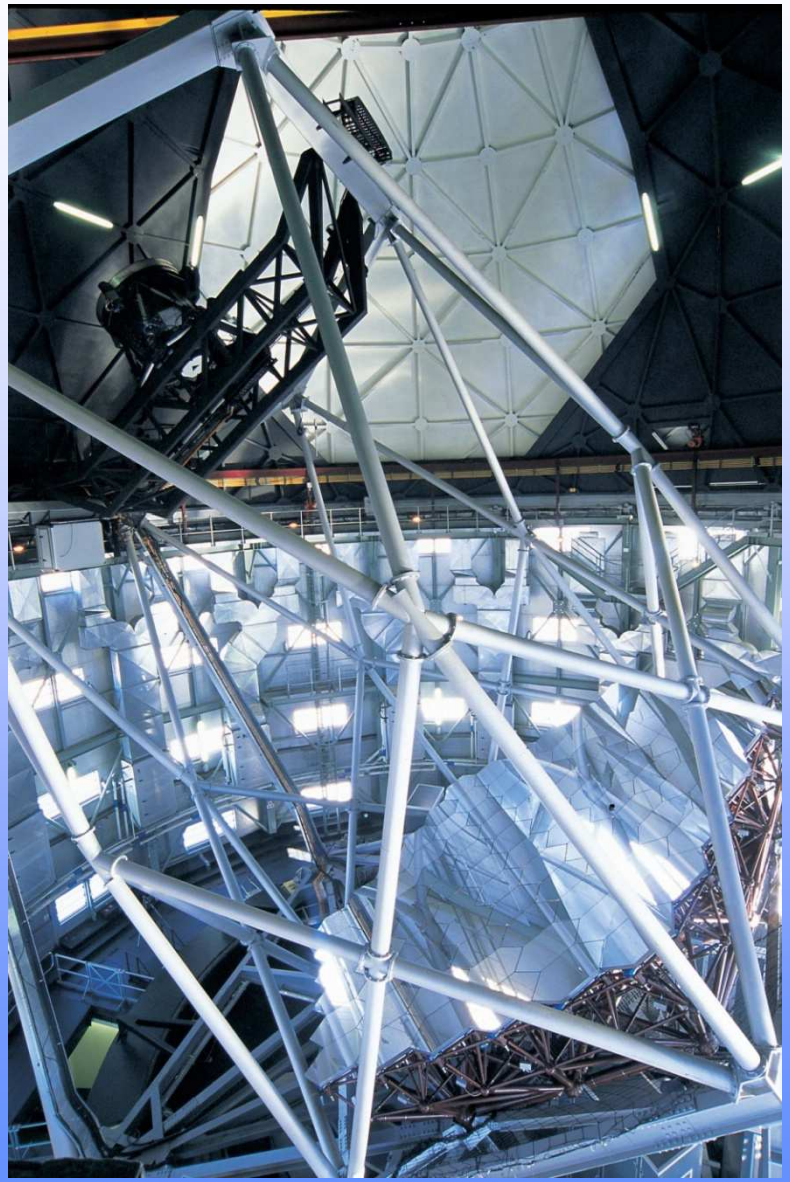
In collaboration with:
Janus Brink (SAAO)
Stephen Potter (SAAO)
Encarni Romero-Colmenero (SAAO)
Ken Nordsieck (Uni. Wisconsin)

COST Action Polarimetry Calibration Workshop: 24 Jan 2013, Zurich ETH

SALT: A Tilted Arecibo-like Optical-IR Telescope modelled on the Hobby-Eberly Telescope (HET)

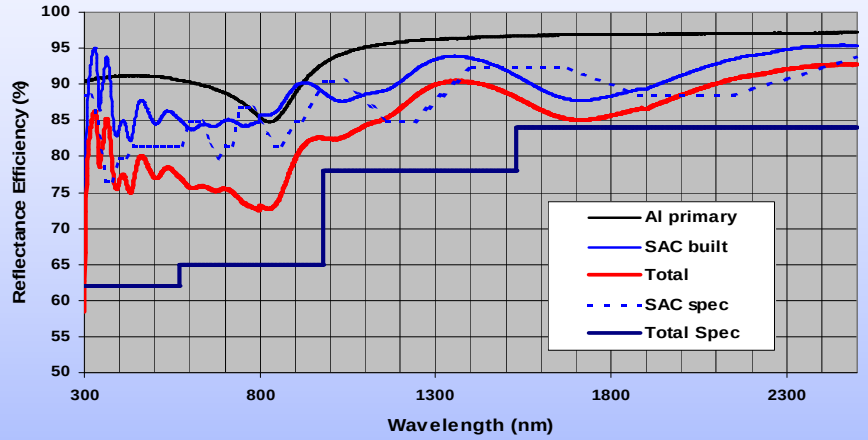
BASIC ATTRIBUTES

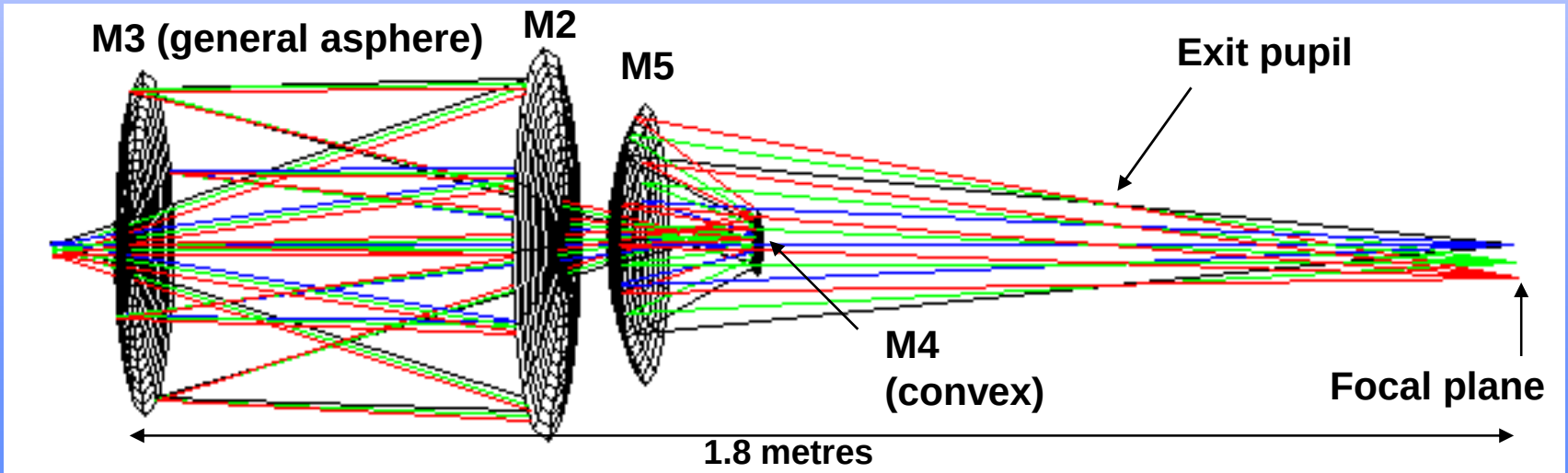
- **10m x 11m PRIMARY MIRROR ARRAY**
  - Spherical Figure (correct spherical aberration at prime focus)
  - 91 identical hexagonal 1.2-m segments
  - Unphased (i.e. not diffraction limited 10-m, just 1-m)
  - Mirrors (*Sitall:* low expansion ceramic) supported on a steel structure
- **TELESCOPE TILTED AT FIXED 37^{o}**
  - Declination Coverage $+10^{o} < \delta < -75^{o}$
  - Azimuth rotation for pointing only
- **OBJECTS TRACKED OVER 12^{o} FOCAL SURFACE**
  - Tracker executes all precision motions (6 d.o.f.)
  - Tracker contains Spherical Aberration Corrector (SAC) with 8 arcminute FoV (*Prime Focus*)
  - Track objects for ~1 – 3 hours duration
- **IMAGE QUALITY**
  - Telescope error budget of ~0.7 arc-second FWHM
  - Designed to be seeing limited (median = 1 arcsec)



SALT Spherical Aberration Corrector

- Contracted to SAGEM/REOSC (France)
- All mirrors coated with LLNL multilayer coating (Ag/Al)





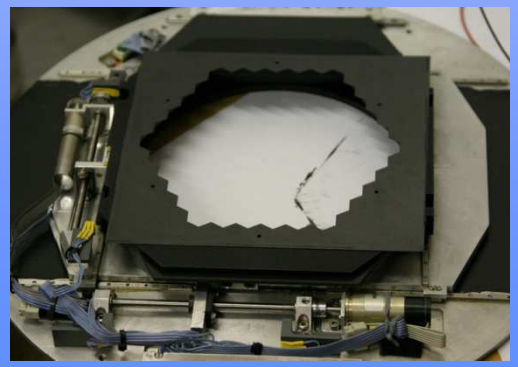
Peculiarities of SALT

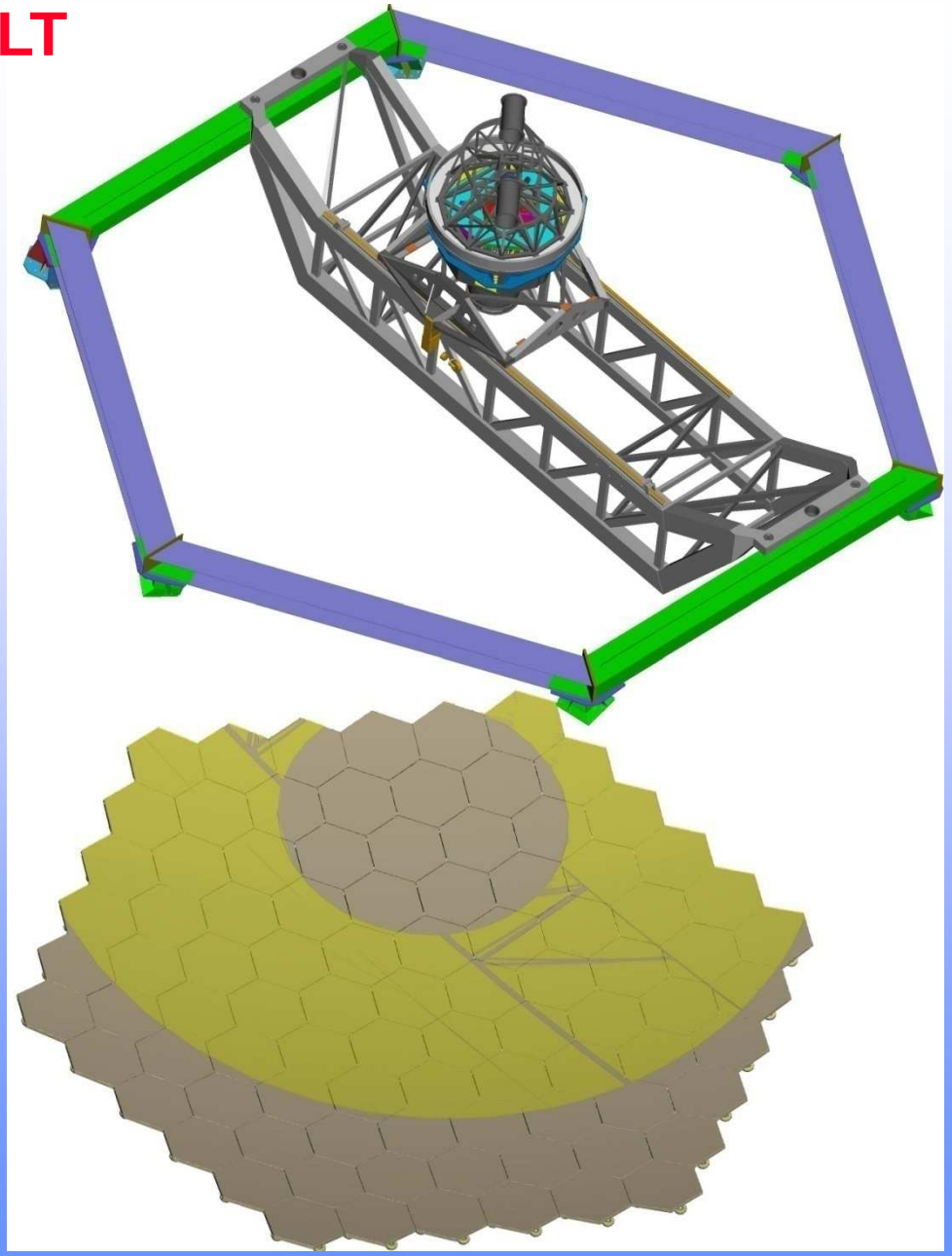
SALT/HET Tracking Principle

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

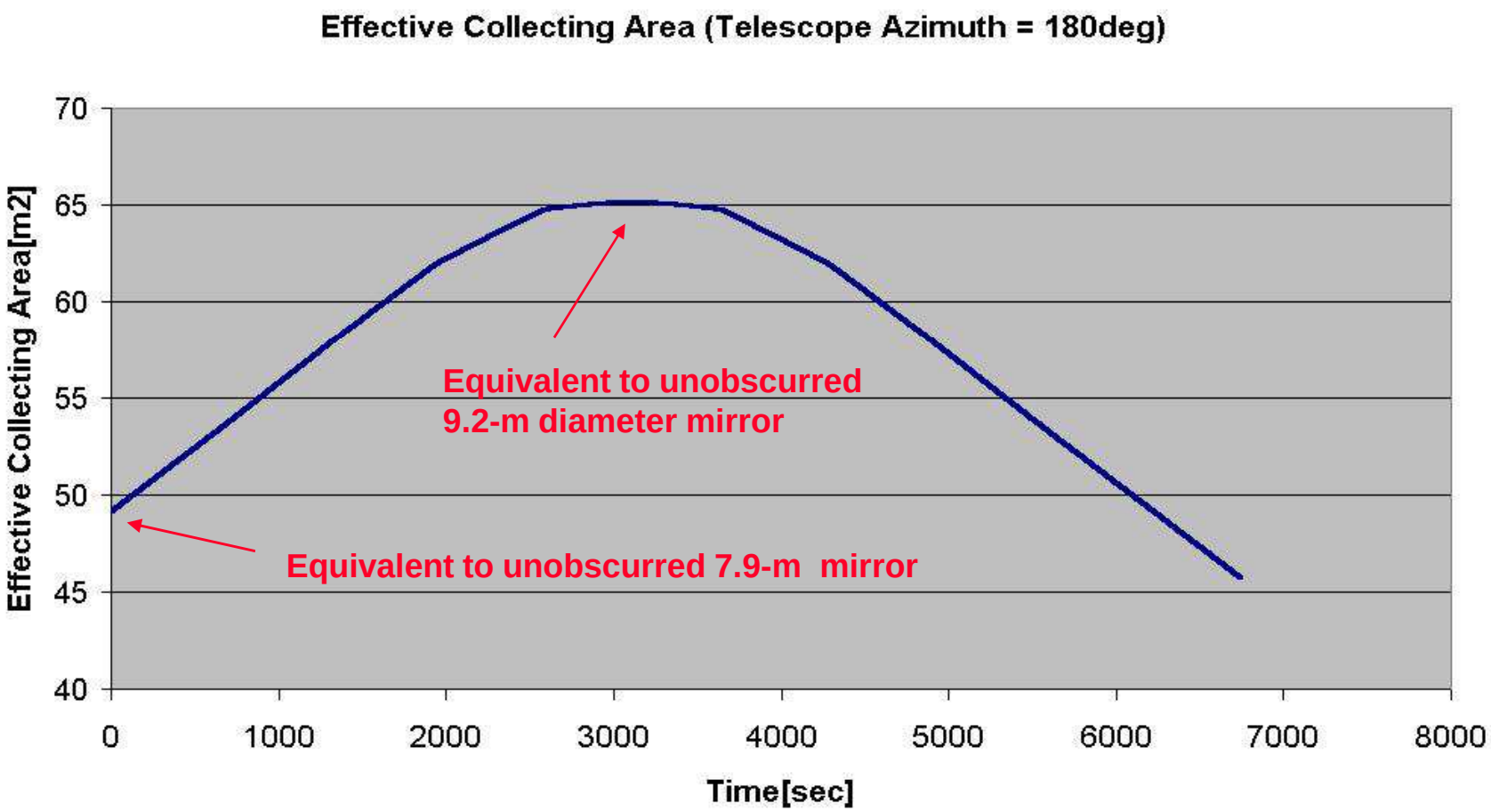
With tracker and 11-m pupil centred on primary mirror array and central obstruction (from SAC optics), equivalent to a 9 metre telescope.

Pupil is always underfilled
Pupil is baffled at exit pupil
- **controls stray light**
- **used to simulate pupil for calibrations**





SALT tracking characteristics



How SALT Observes: Restricted Viewing Window

Annulus of visibility for SALT:

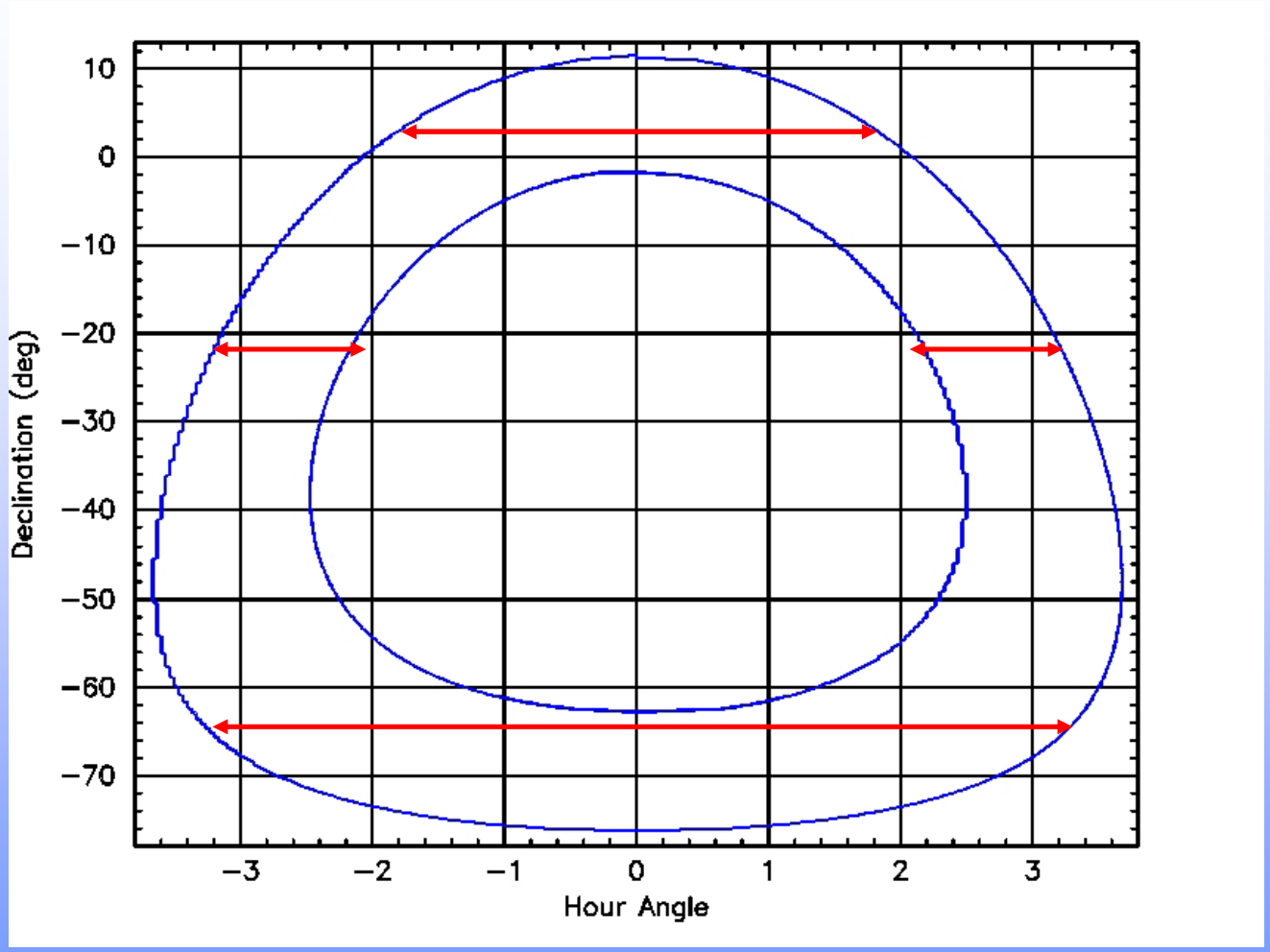
Annulus represents 12.5% of visible sky

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



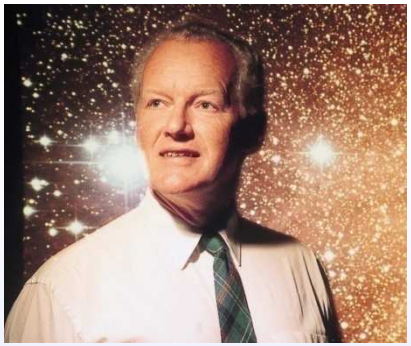
Implies that all SALT observations have to be queue-scheduled

SALT's Current Science Instruments

First Generation Instruments chosen to give SALT a wide range of capabilities in UV-VIS range (320 – 900 nm)

- **Ensure competitiveness with niche operational modes**
  - **UV, Fabry-Perot, high-speed, polarimetry, precision RV**
- **Take advantage of SALT design and *modus operandii***
  - **100% queue scheduled telescope**
  - **Capability to react quickly to events, *but* restricted viewing window**
- **First two completed & installed from 2005 ("First Light" instruments)**
  - **SALTICAM: a UV-VIS sensitive "video camera" (up to ~15 Hz)**
  - **Robert Stobie Spectrograph (RSS): a UV-VIS versatile imaging spectrograph**
- **Third is the fibre-fed High Resolution Spectrograph (HRS)**
  - **Design completed 2005 by UC. Construction by Durham University began in 2007**
  - **Commissioning due to begin April 20**

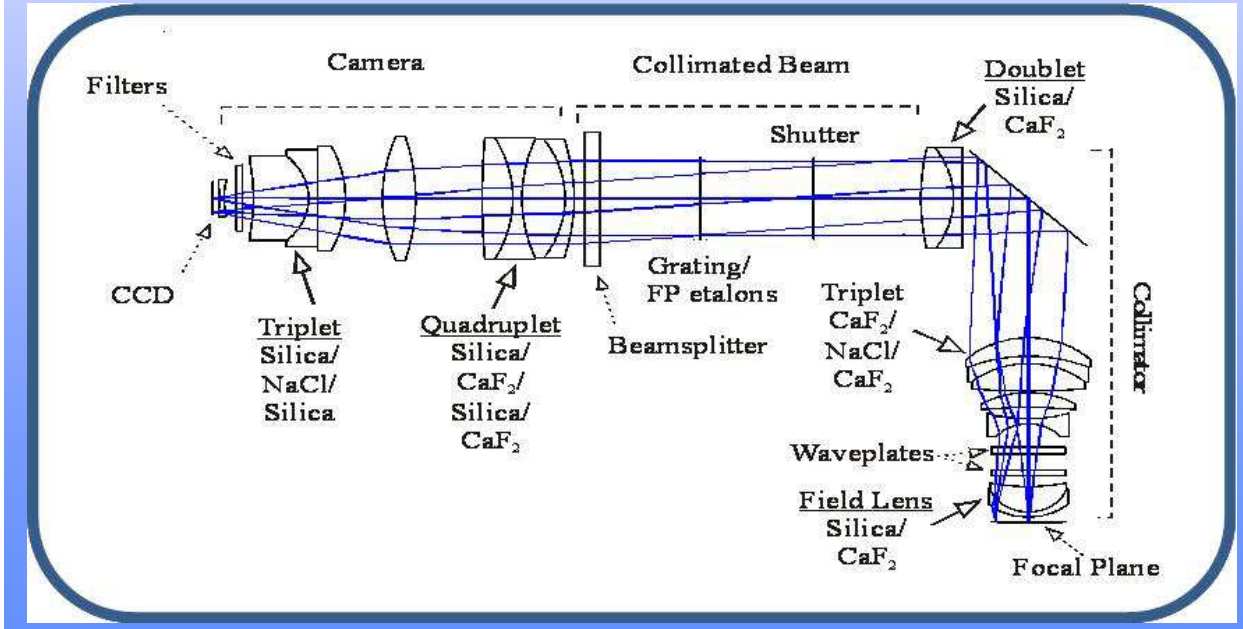
The Robert Stobie Spectrograph (RSS) (built at Wisconsin, Rutgers & SAAO)



Named in memory of Bob Stobie, previous SAAO Director & one the instigators of SALT.

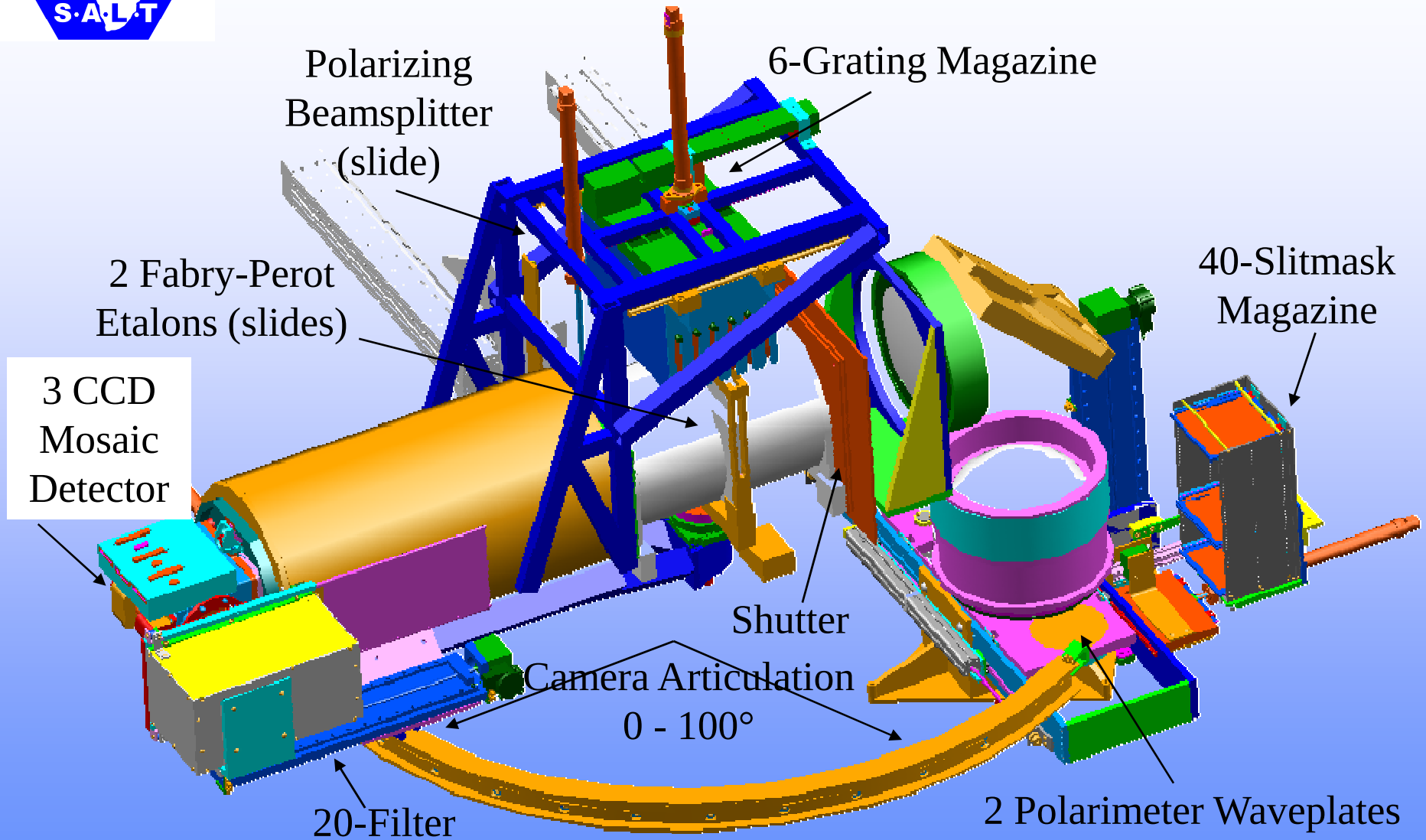
An efficient and versatile Imaging Spectrograph

- **capable of UV-Vis spectroscopy from 310 – 900nm using VPHGs *(red extension to 1.7μm, using a dichroic, is under construction)***
- **high time resolution ablility (~0.1 s)**
- **specto- and imaging polarimetric capability**
- **Fabry Perot imaging (incl. with pol.)**
- **multiple object spectroscopy**
  - **Can observe ~100 objects at once**



RSS reinstalled on SALT (Apr 2011)

RSS Mechanisms

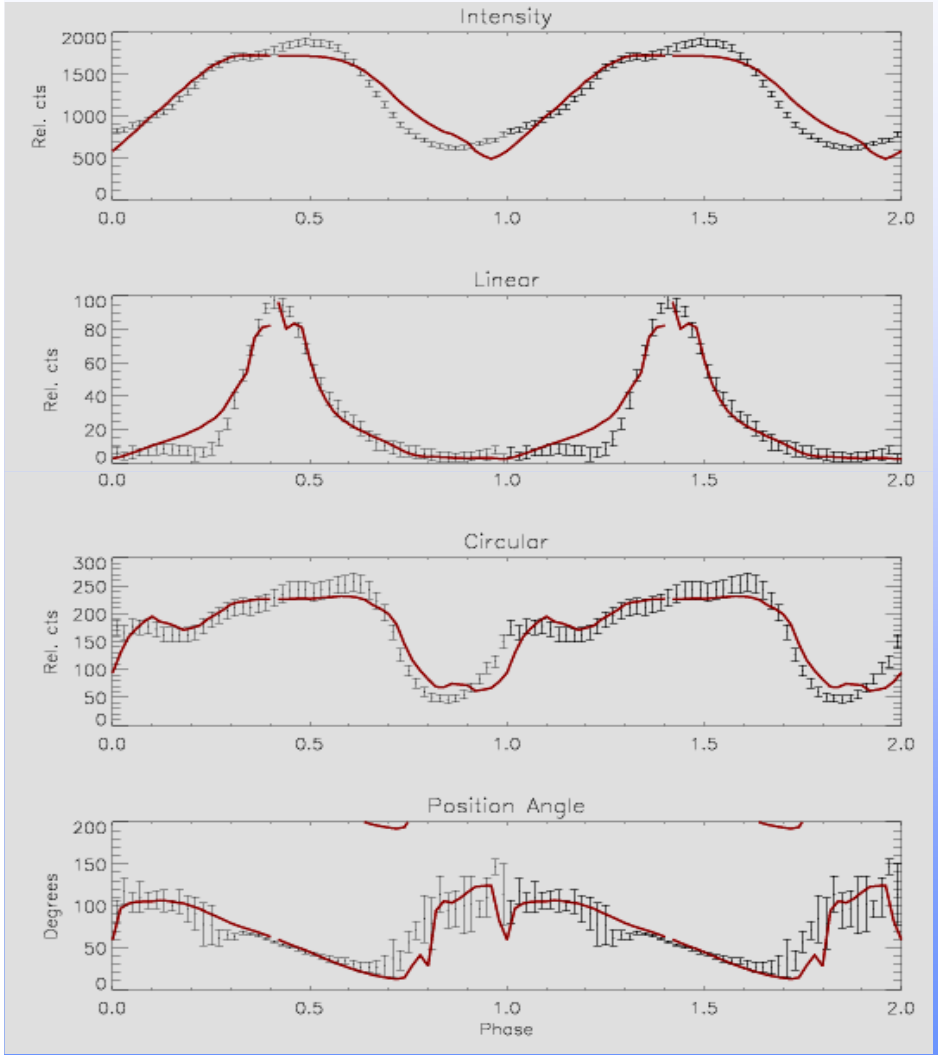


RSS Polarimetric Science Drivers

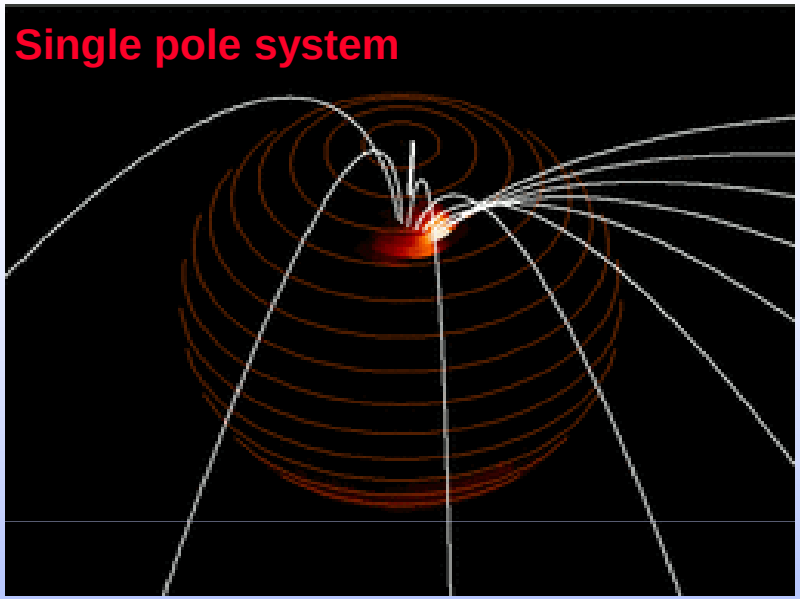
Multiple science drivers for RSS polarimetric modes (imaging and spectropolarimetry):

- **Polarimetry of "point sources":**
  - **Stars (CVs, Be disks, symbiotics, etc)**
  - **AGN, blazars**
  - **Supernovae & GRBs**
  - **Asteroids**
- **Polarimetry of "extended sources":**
  - **Galaxies**
  - **Reflection nebulae**
- **Variability**
  - **including High Time Resolution (~seconds)**
  - **Phase resolved (binaries)**

Determining Magnetic Field Strength & Geometry in Polars: Fitting cyclotron model fits to All-Stokes broadband polarimetry



Example: V834 Cen, P_{orb}= 101 min
SAAO 1.9-m photopolarimetry

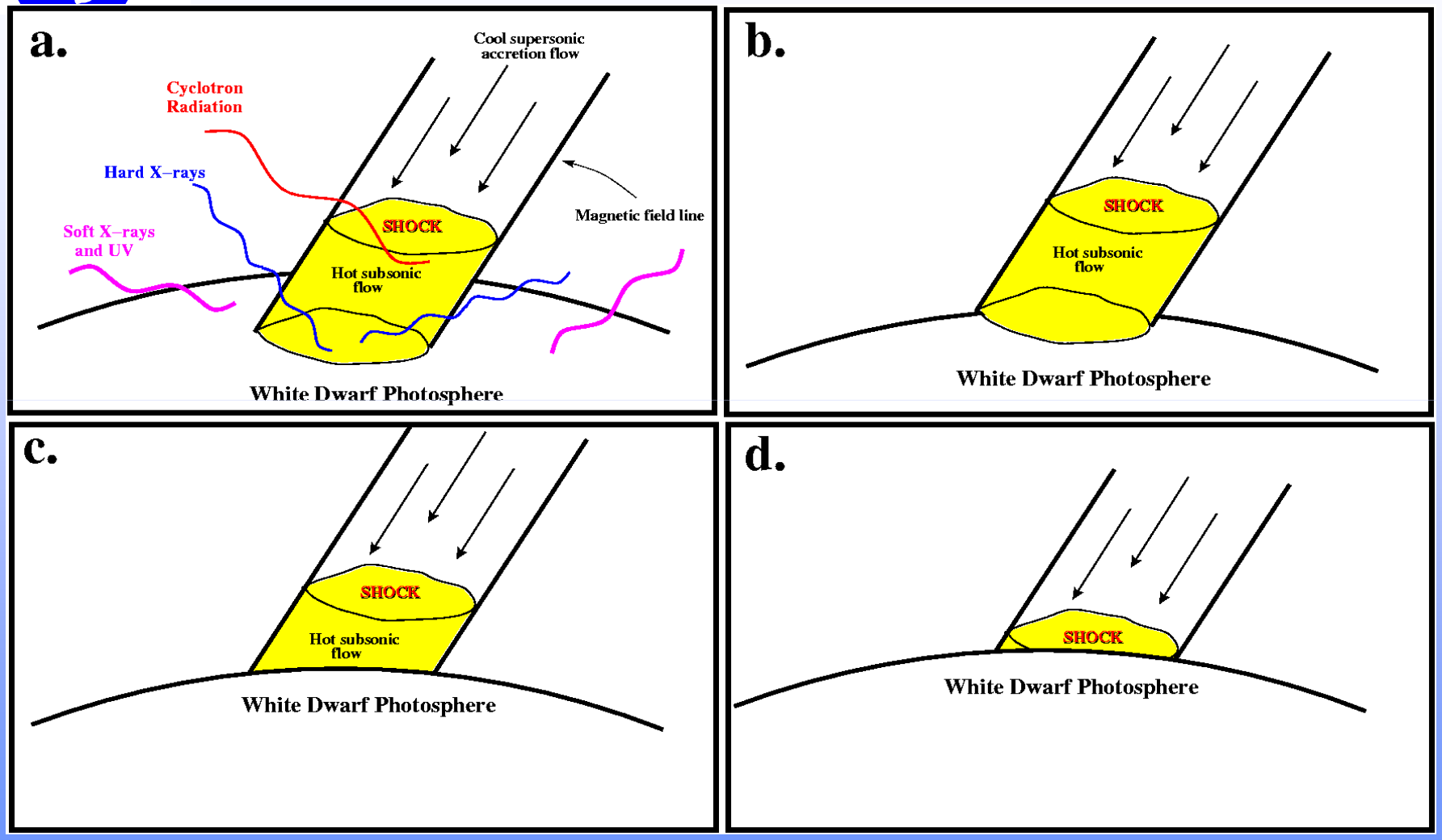


Fit cyclotron parameters (plasma temp & density, cyclotron opacity, B & θ)

- **using Potter's Stokes imaging technique**
- **fits model to data using a genetic algorithm**

Extend to spectropolarimetry

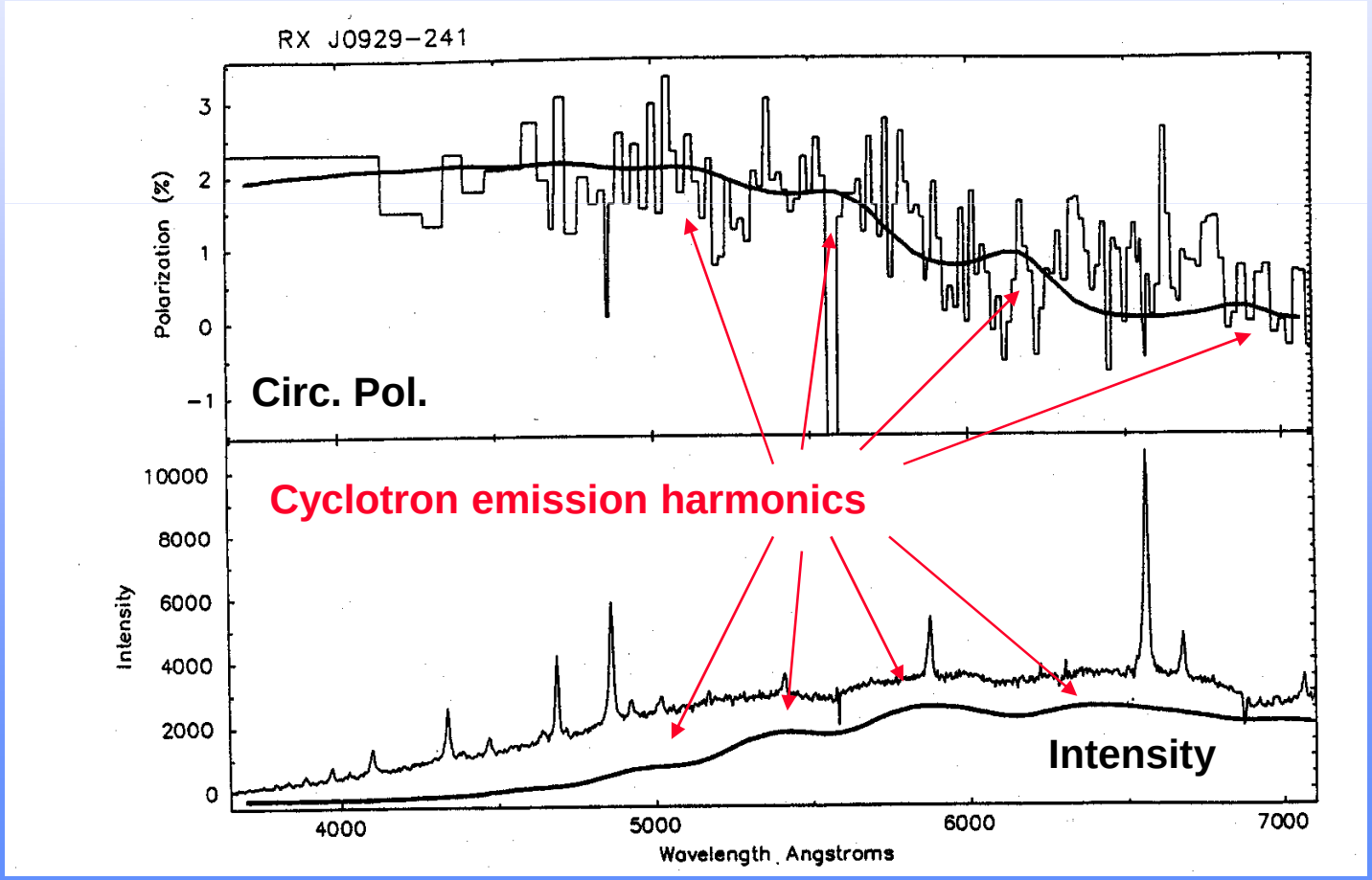
Spectropolarimetry with SALT



Spectropolarimetric possibilities:

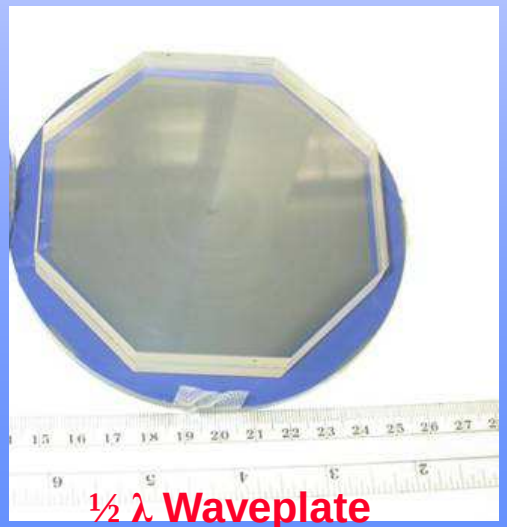
Time resolved, all-Stokes mode (simultaneous circular + linear)
Faint objects (polars + intermediate polars)

e.g. MN Hya: a ~3.4h Polar

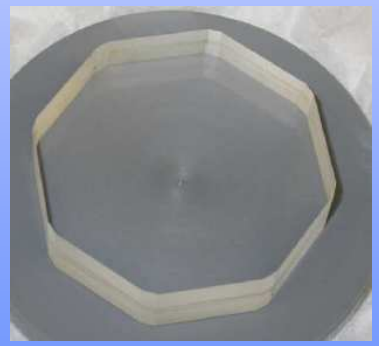


RSS Polarimetry

- **Uses ½ and ¼ λ Pancharatnam superachromatic waveplates**
  - **½ is made of a 4 x 4 mosaic of 52mm wavelplates with effective 102mm diameter**
  - **¼ is a single 60mm waveplate**
- **3 x 3 mosaic of calcite beamsplitters**
  - **High birefringence separates O & E beams completely on detector**
  - **Can't get single large enough calcite crystals**
  - **Mosaic keeps beamsplitter thin, so improves throughput and decreases need for collimated space**



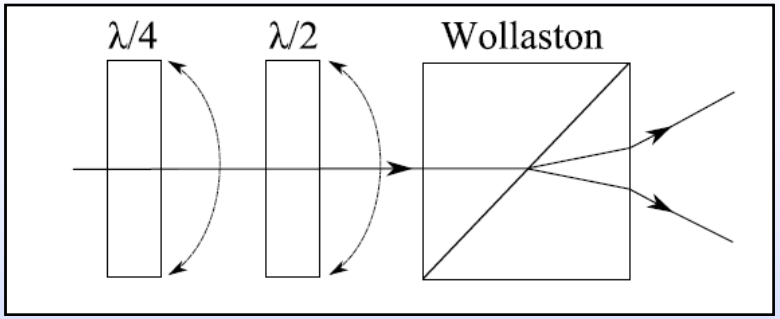
½ λ Waveplate



¼ λ Waveplate

Mosaic beamsplitter

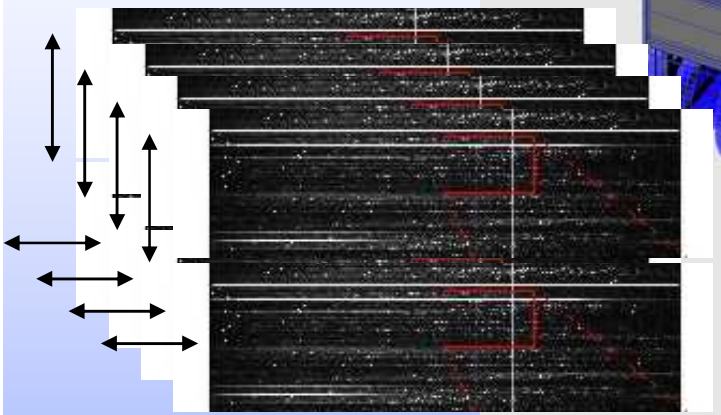
Waveplate Configurations for Polarimetry Modes



Waveplates Rotated to specific positions

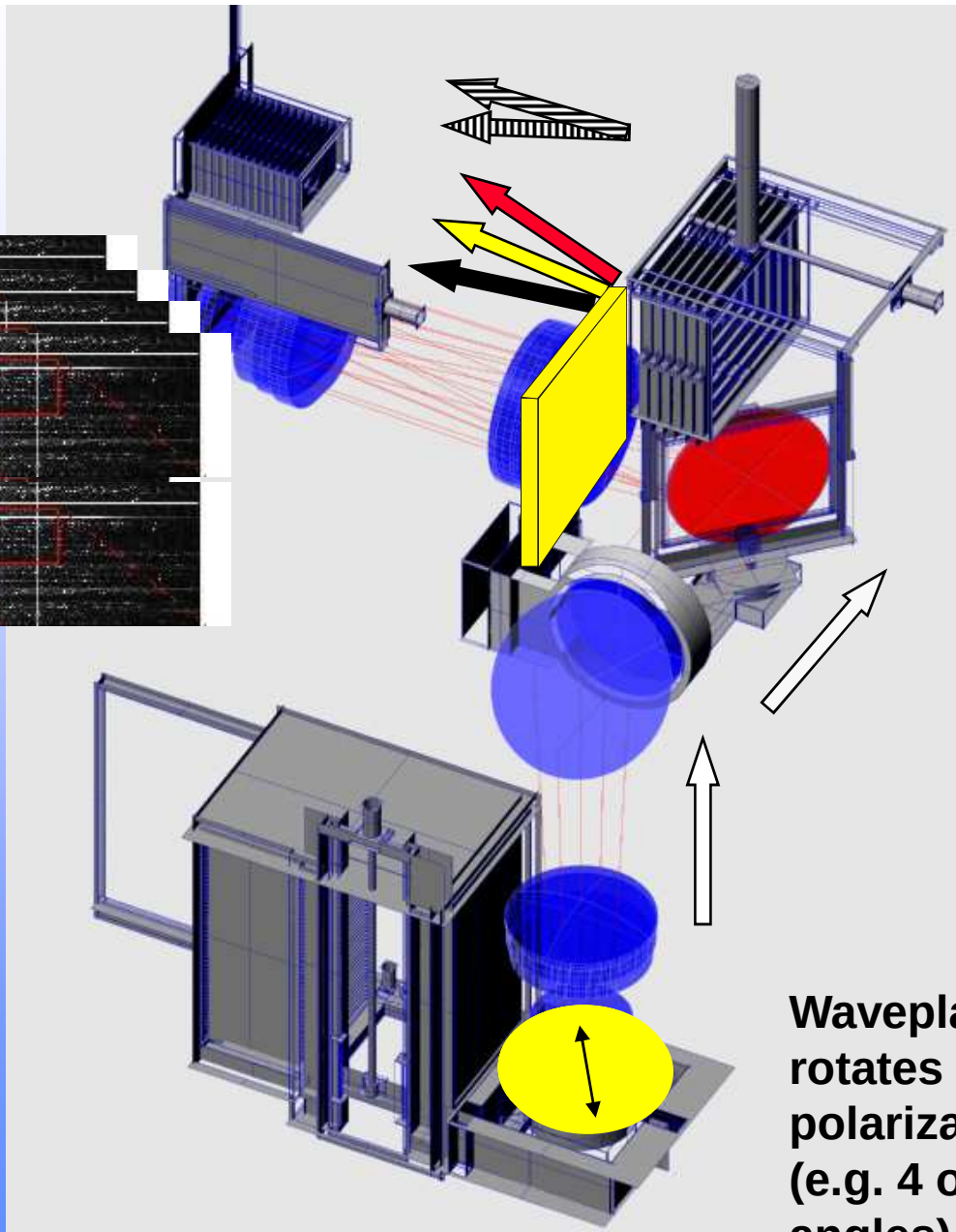
Linear		Circular		All-Stokes	
1/2 λ	1/4 λ	1/2 λ	1/4 λ	1/2 λ	1/4 λ
0	-	0	+45	0	0
45	-	0	-45	45	67.5
22.5	-	22.5	-45	90	135
67.5	-	22.5	+45	135	202.5
11.25	-	45	+45	180	270
56.25	-	45	-45	225	337.5
33.75	-	67.5	-45	270	45
78.75	-	67.5	+45	315	112

RSS Spectro-/Imaging Polarimetry mode



Polarization of spectra

Also works in Imaging/ Fabry-Perot Modes

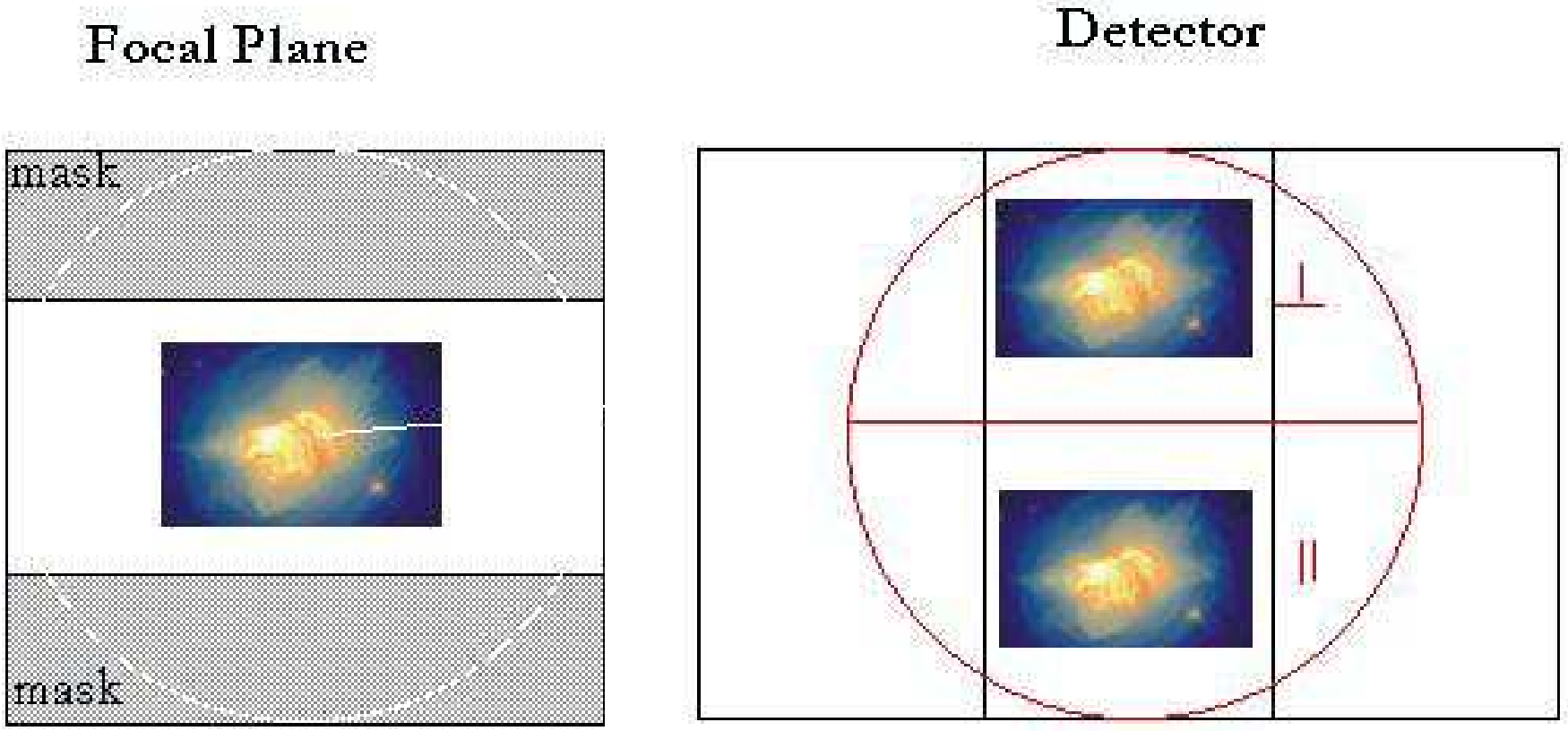


Beamsplitter splits 2 polarizations

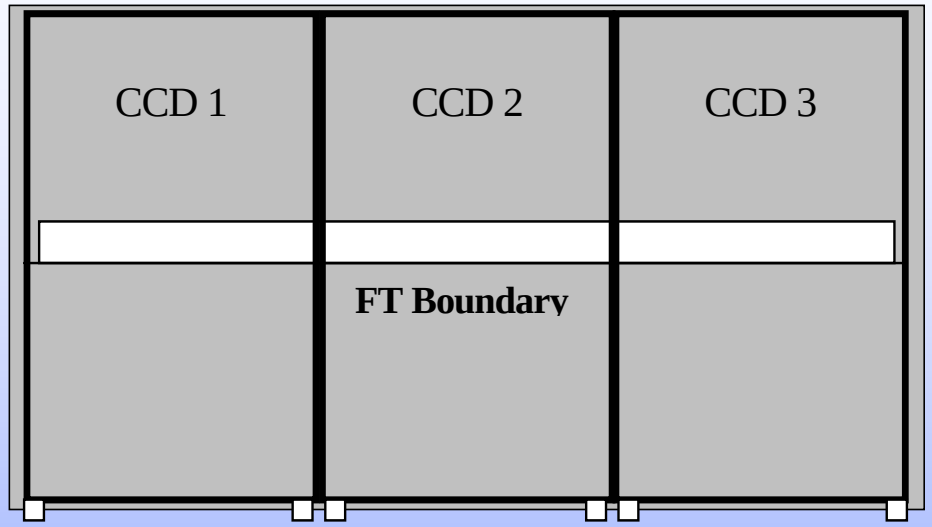
Waveplate rotates polarization (e.g. 4 or 8 angles)

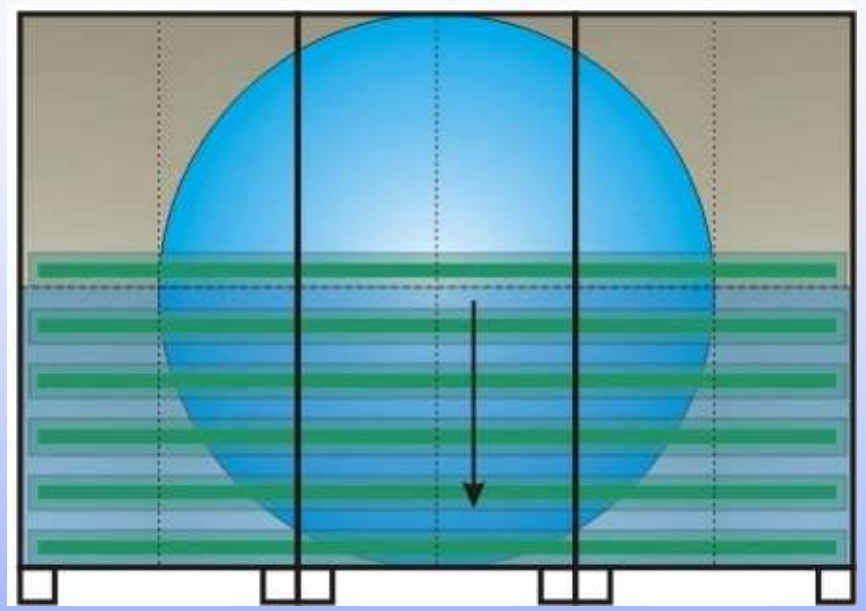
RSS Polarimetry

- **Imaging polarimetry**



RSS High Speed modes: up to 10 Hz

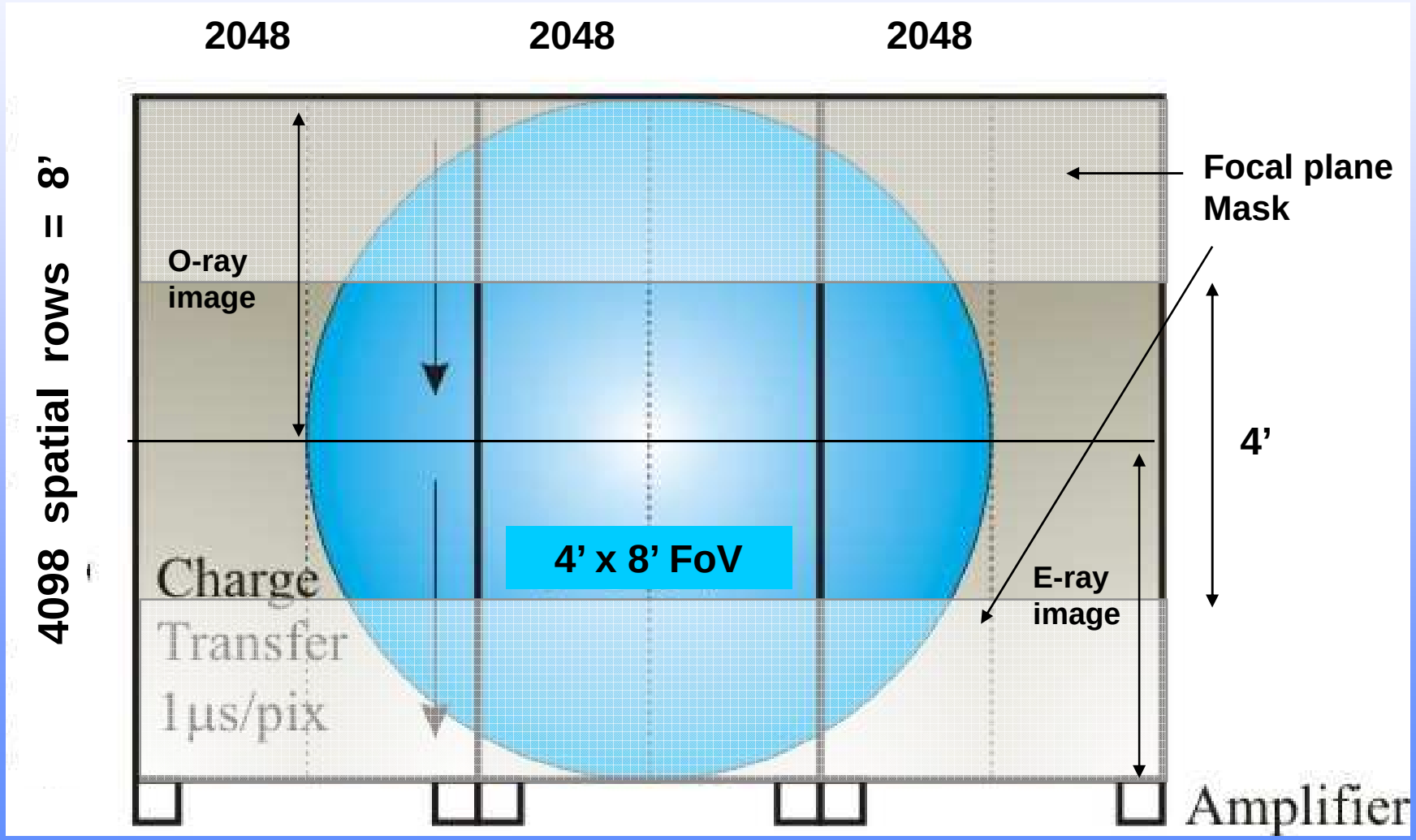




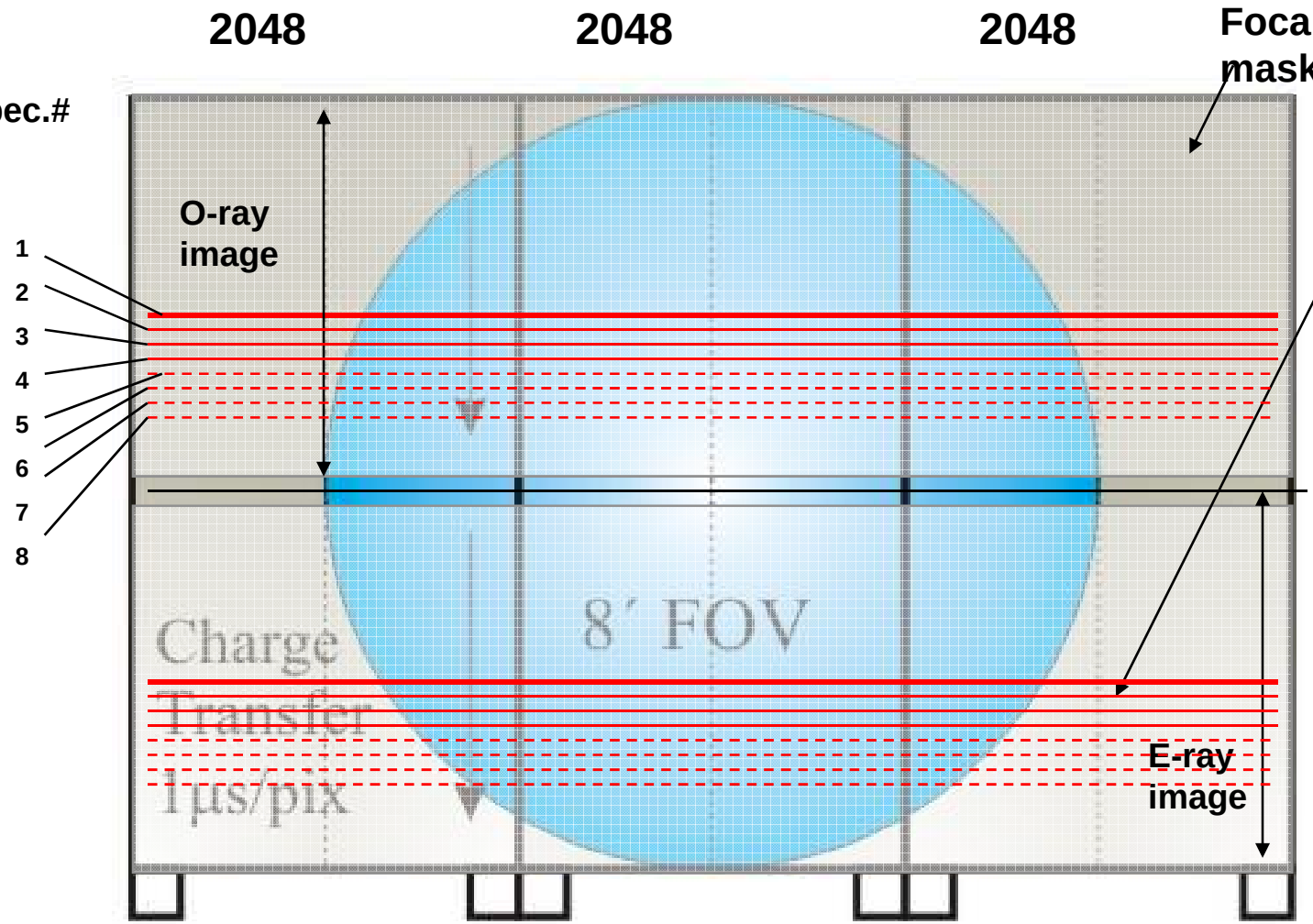
Allows for:

- **Fast spectroscopy**
- **Fast narrow band imaging**
- **imaging polarimetry**

Configuration for imaging polarimetry



Configuration for high time speed & time averaged All-Stokes mode spectropolarimetry



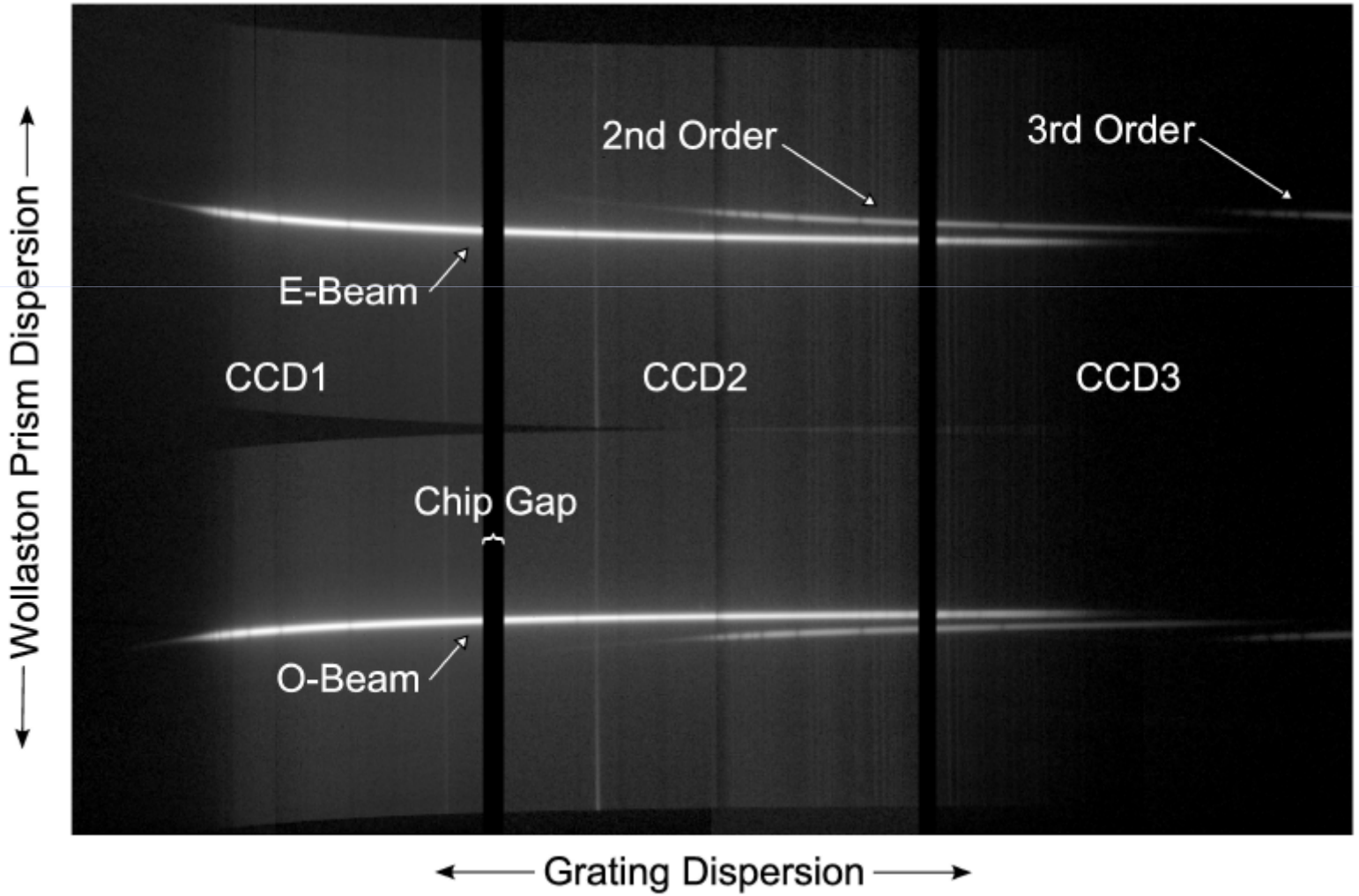
Waveplate angles

Spec	½	¼
1	0	0
2	22.5	33.75
3	45	67.5
4	67.5	101.25
5	90	135
6	112.5	168.75
7	135	202.5
8	157.5	236.25

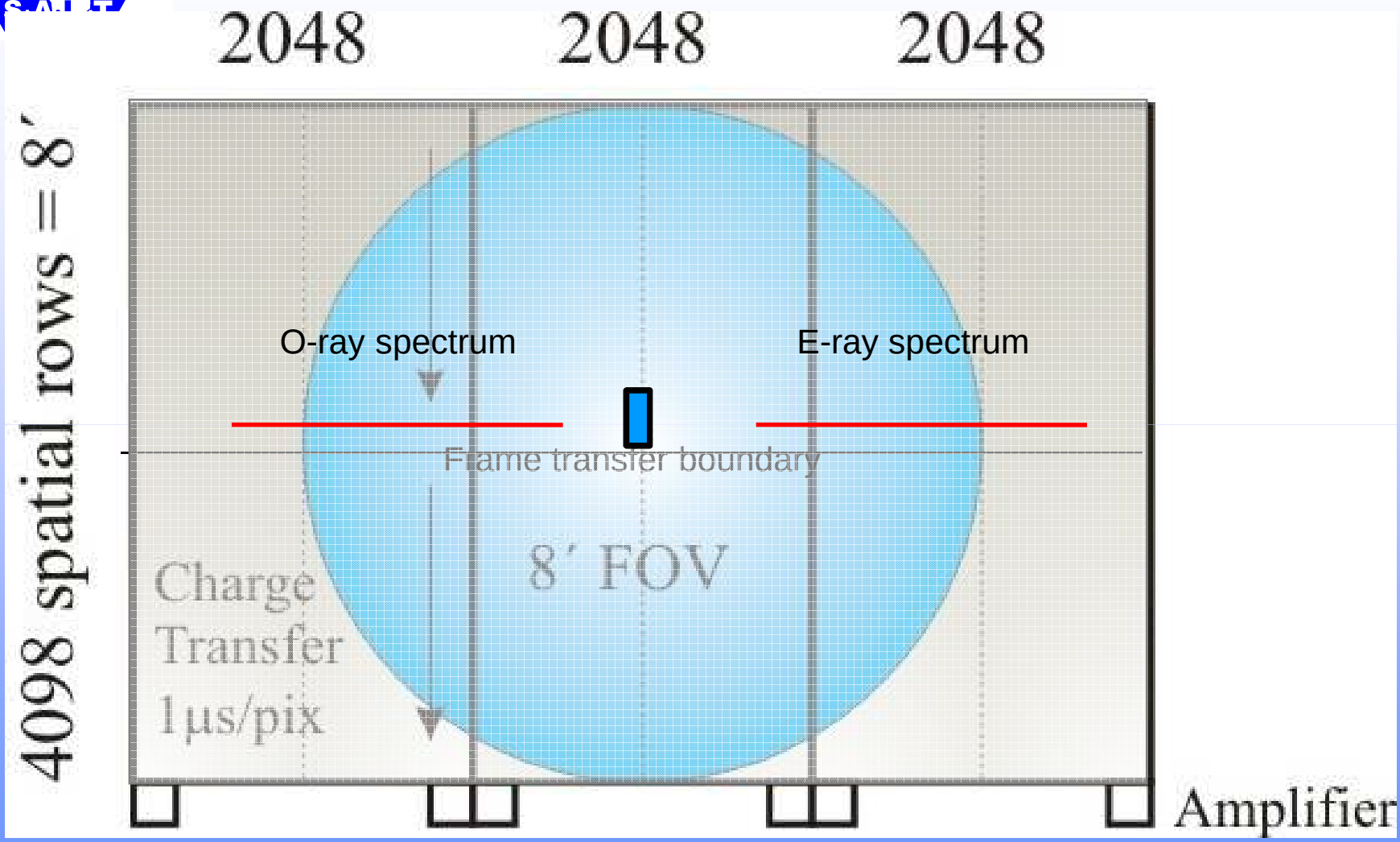
Modification of Serkowski's "all-Stokes" mode, with ¼ waveplate Rotating at 1.5 frequency of ½ waveplate, both in same direction.

Spectropolarimetry

- **O & E beams displaces spatially perpendicular to dispersion**



High Speed Spectropolarimetry

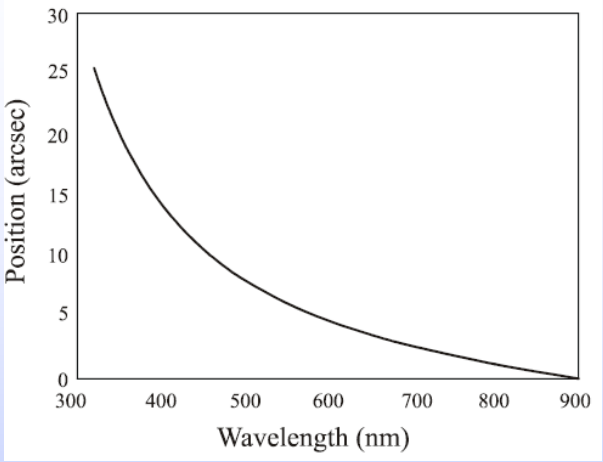


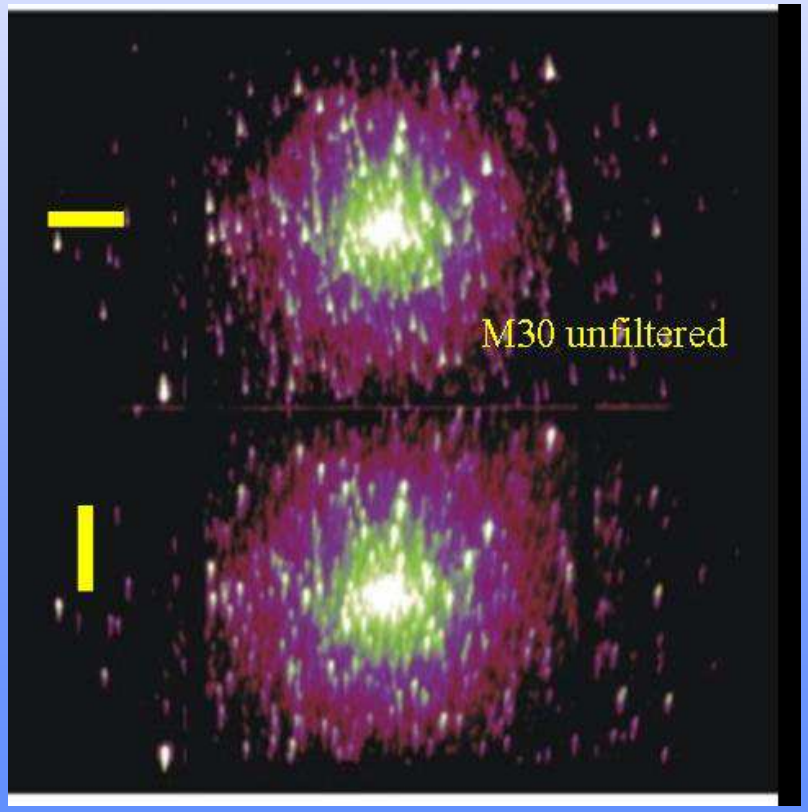
Rotated beamsplitter slot mode spectro-polarimetry

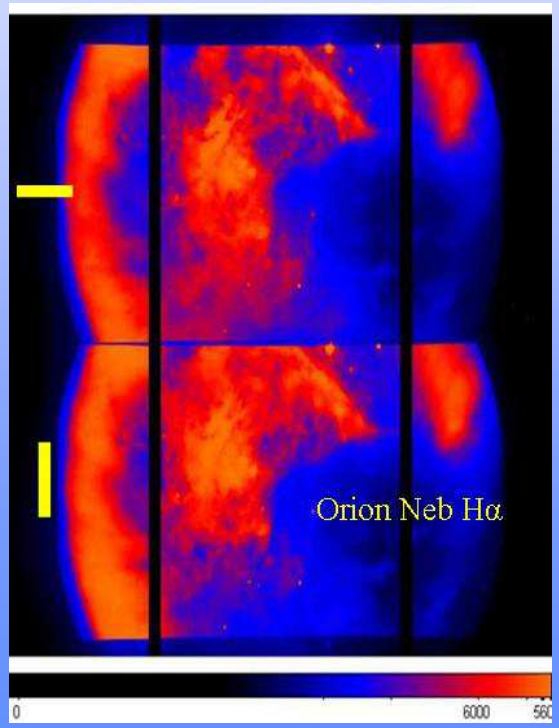
Other Relevant SALT Polarimetric Capabilities (for the study of SNe, mass accreting binaries & SNR)

Some unusual/unique modes:

- **Low resolution "objective prism" style spectropol imaging (R ~ 50)**
  - **Survey mode for strongly pol. objects?**
- **Fabry-Perot imaging spectropolarimetry**





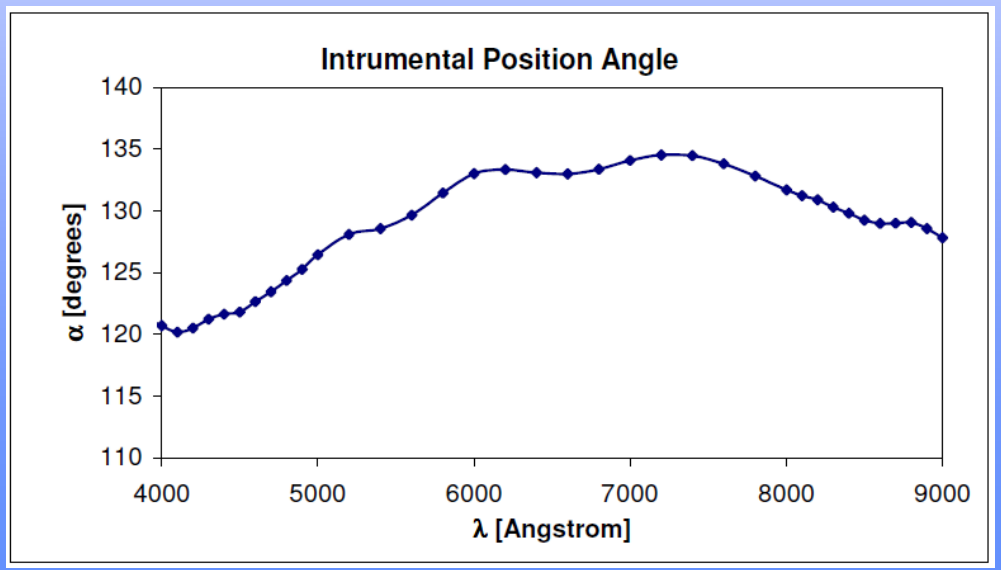


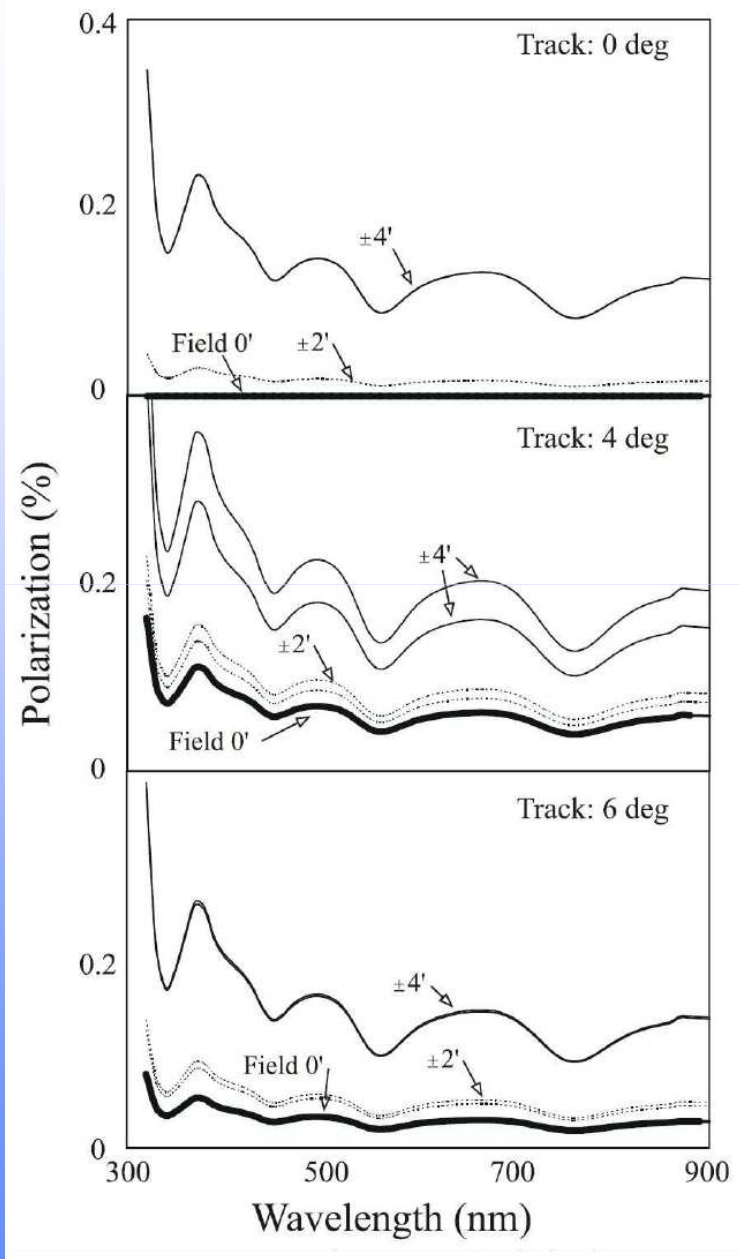
Polarimetry Commissioning

- Began in 2006
- Observations of polarimetric standards (unpolarized & linearly polarized)
- Hampered by optical problems
  - Instrument throughput issues (particularly <400 nm)
  - Appearance of bubbles in Wollaston beamsplitter mosaic
- Instrument removed Nov 2006 for optical repair (fluid coupling issues; A/R coating of one element; sealing of beamsplitter mosaic)
  - Returned in 2010; recommissioning started April 2011
- Polarimetric recommissioning began in Nov 2011
  - Curtailed after discovery of catastrophic fluid loss & elastomer de-bonding
  - Beamsplitter returned to supplier for refurbishment
  - New design replaces fluid coupling with pliant glueing
- Expect beamsplitter retrurn in mid-2013 & completion of polarimetric commissioning

Instrumental Polarization

- **Predicted instrumental polarizatised on as function of tracker/pupil geometry**
- **Based on optical design (segmented M1 & 4 mirrors in aberration corrector)**
- **Uses Al coatings on hexagonal segments & multi-layer LLNL coatings (more like dielectric than metal)**





Polarimetry Calibration Observations

Standards observed:

- **Unpolarized**

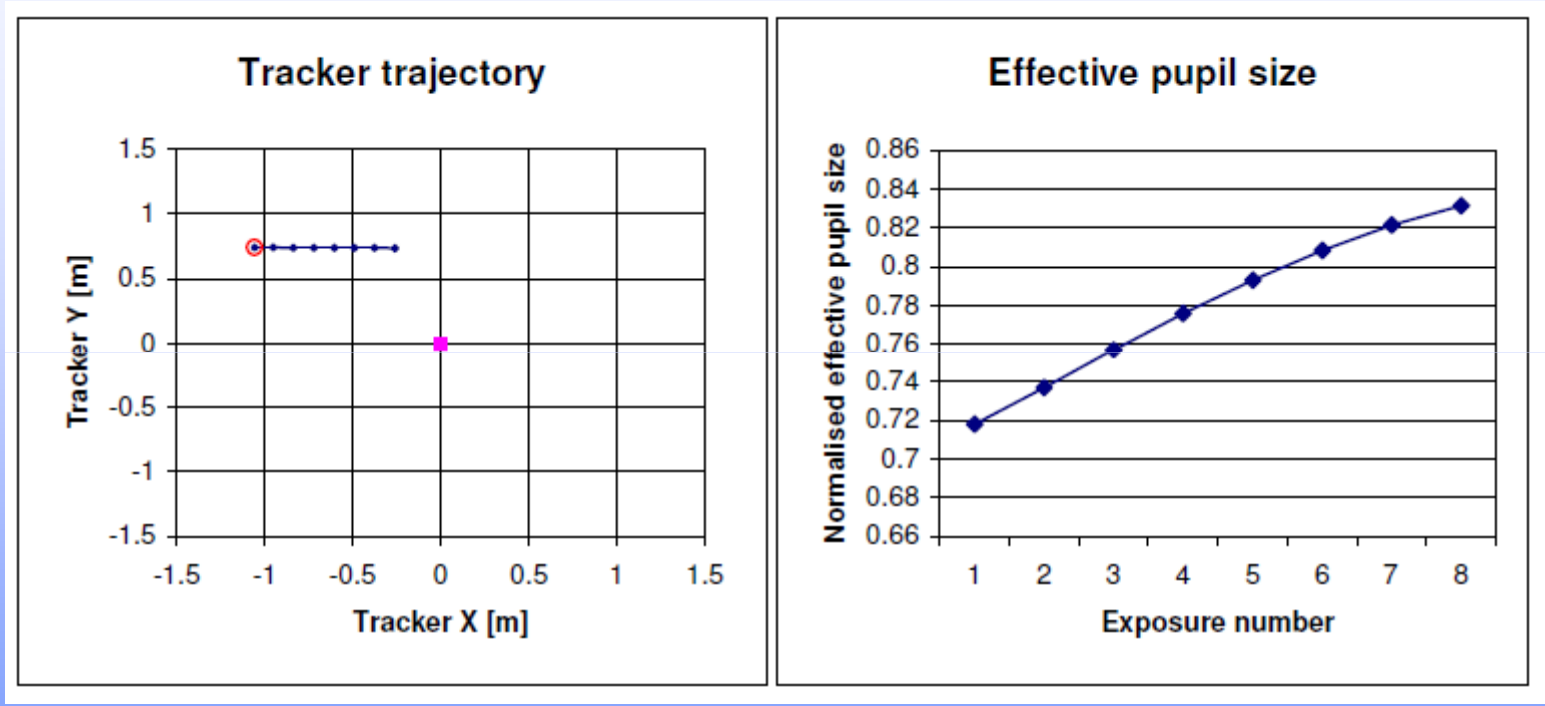
Object	P_L	PA
HD14069	0.03%	17.8°
HD12021	0.06%	152.4°

- **Polarized**

Object	P_L(average)	PA (average)
HD73882	$2.0 \pm 0.05\%$	$164.25 \pm 1.09°$
Vela1 #95	$7.49 \pm 0.06\%$	$172.0 \pm 0.28°$

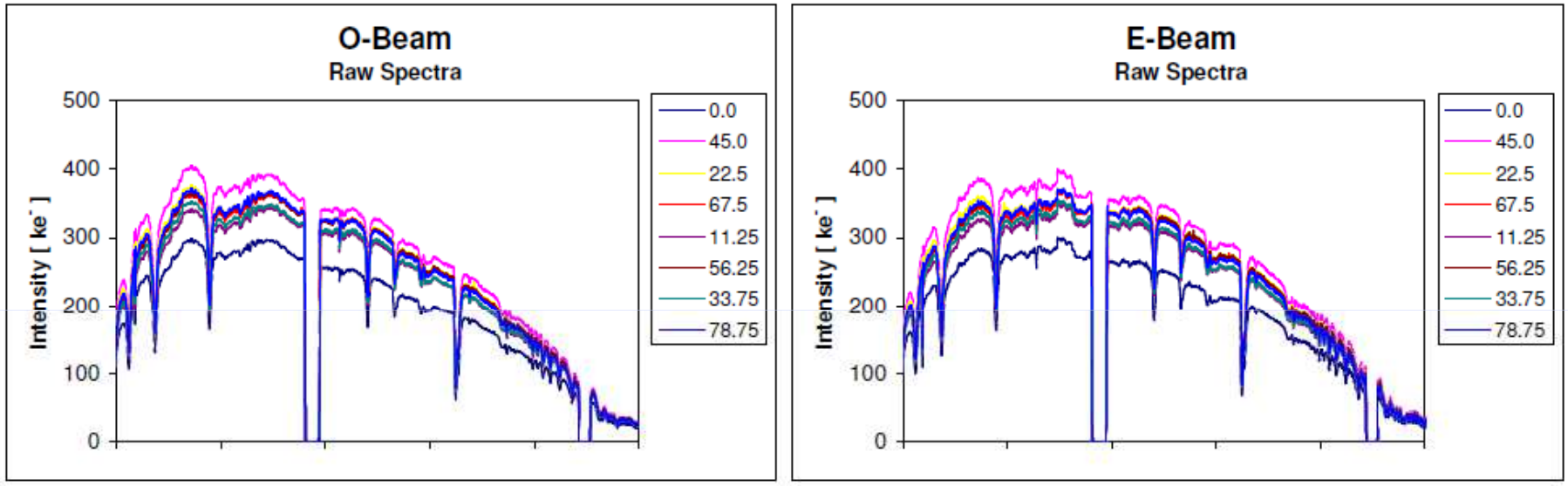
Polarimetry Commissioning

- **Typical tracker trajectories**



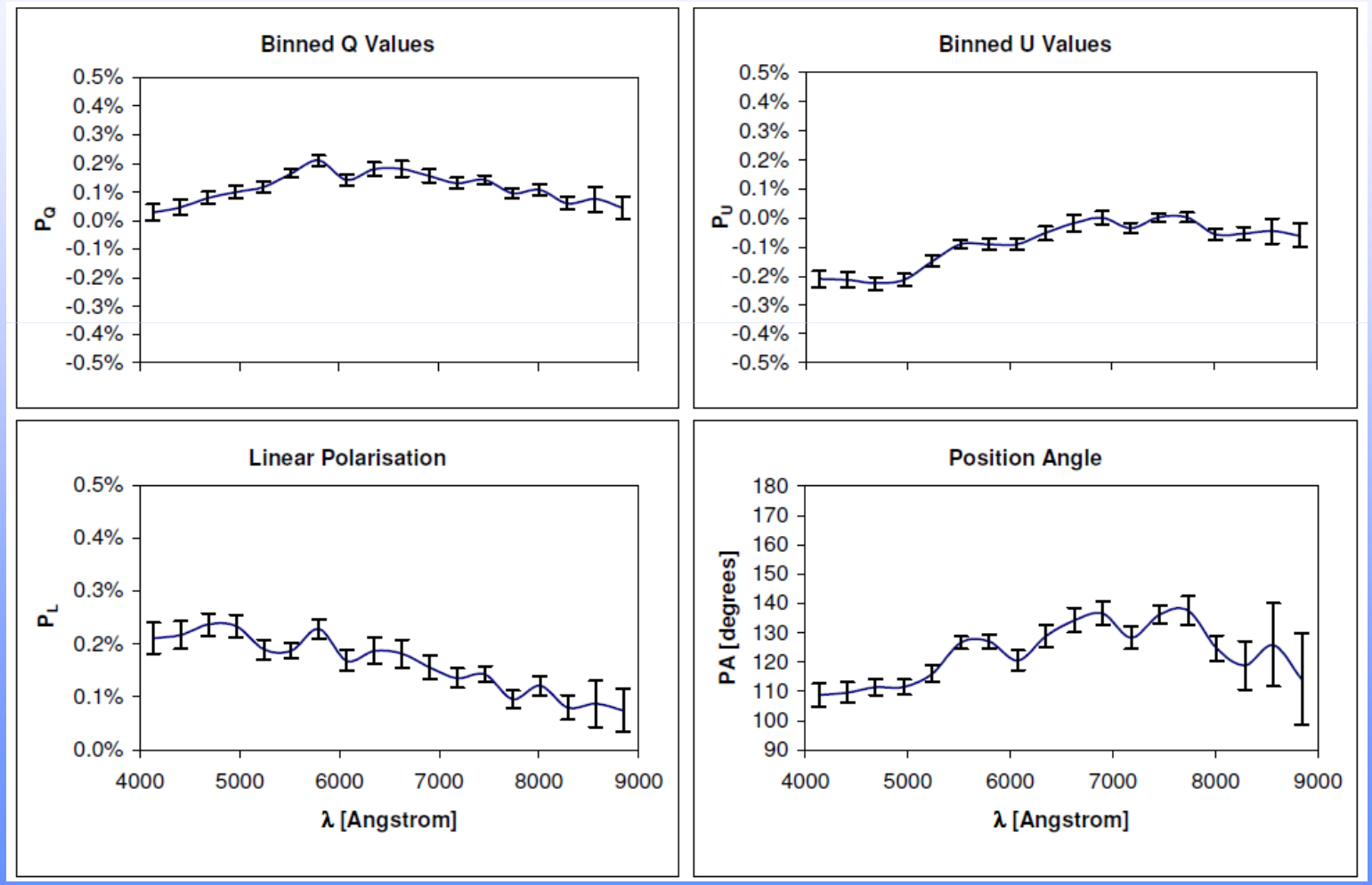
Polarimetry Commissioning

- **Results**



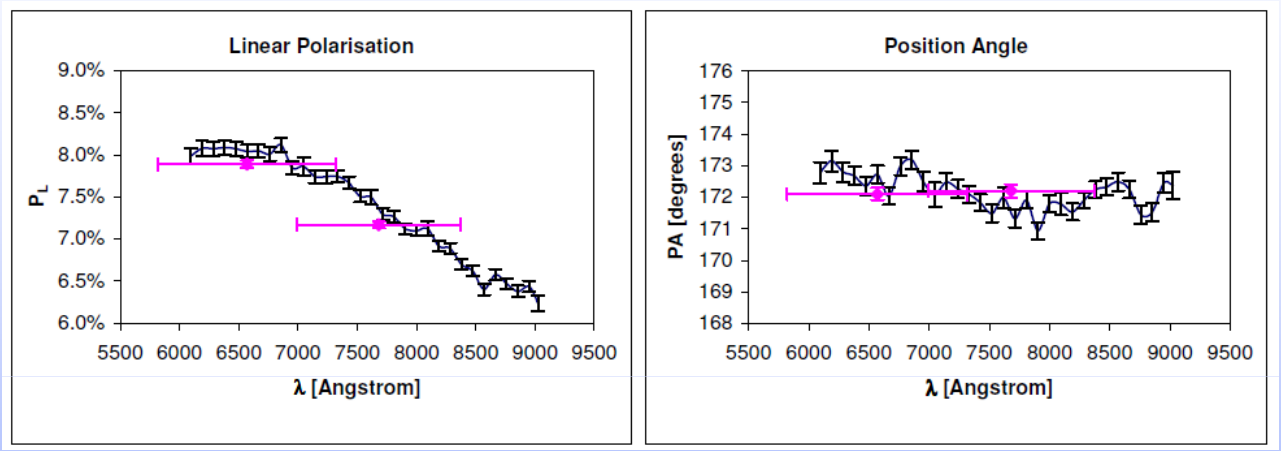
Polarimetry Commissioning

- **Results: unpolarized (HD14069); PG300 grating**

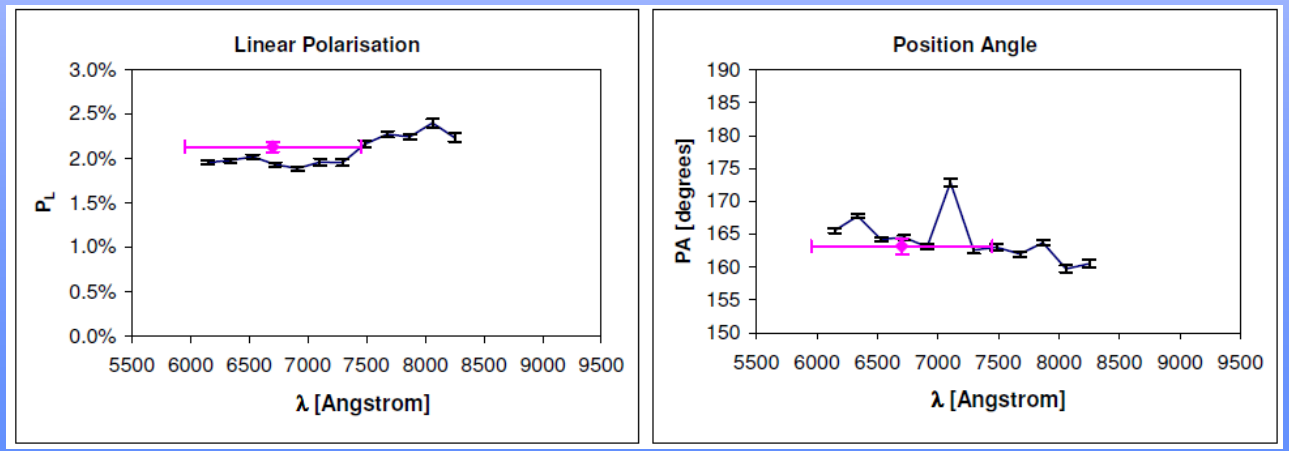


Polarimetry Commissioning Results

- **Results: polarized (Vela1 #95); PG900**

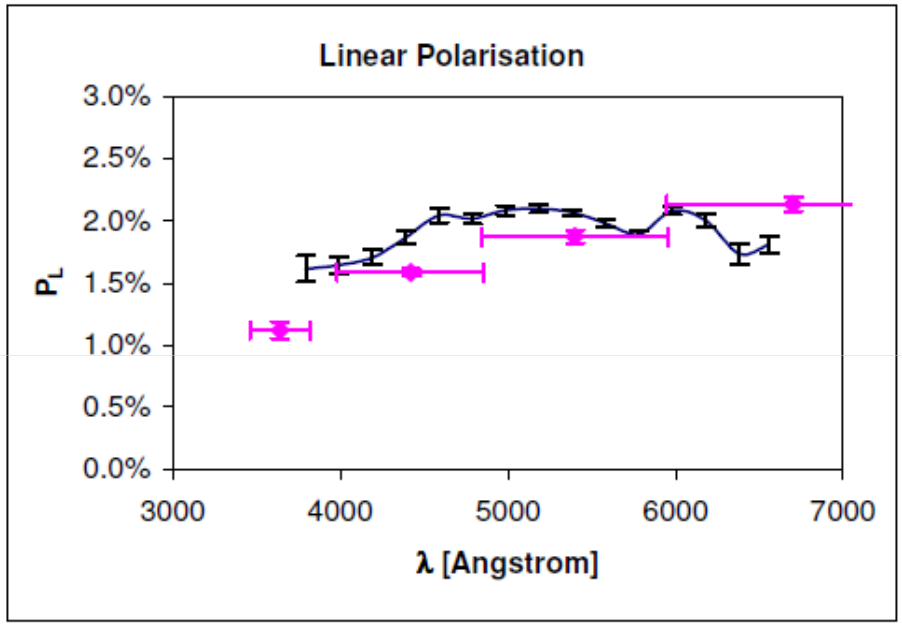


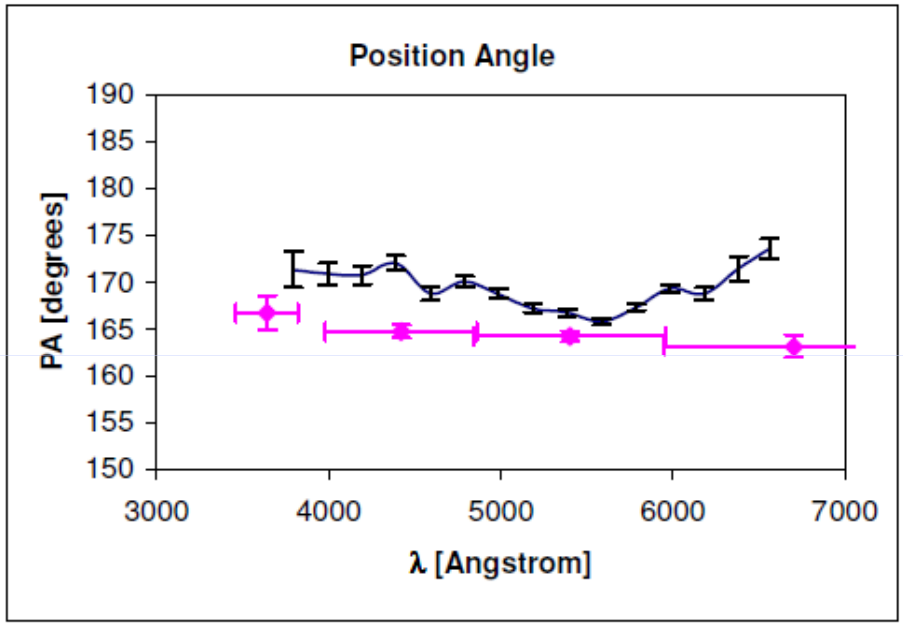
- **Results: polarized (HD73882); PG900**



Polarimetry Commissioning Results

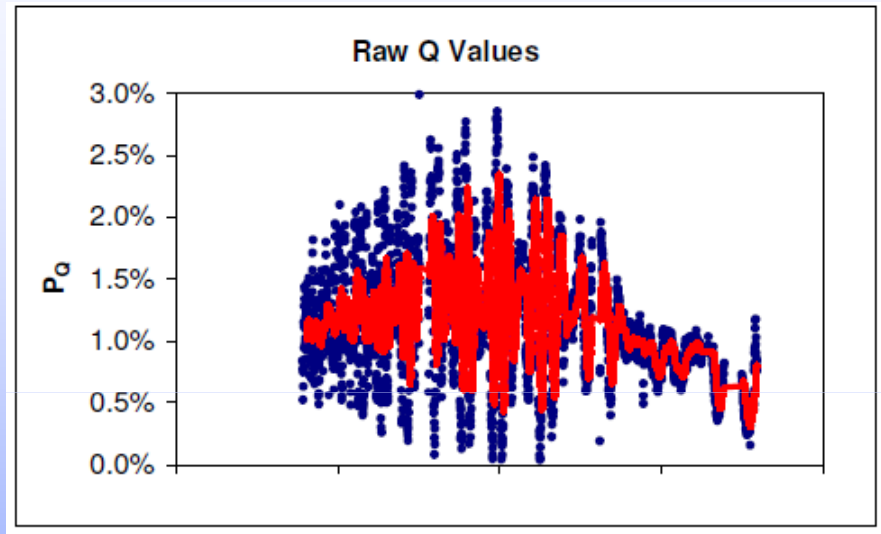
- **Results: polarized (HD73882); PG900**

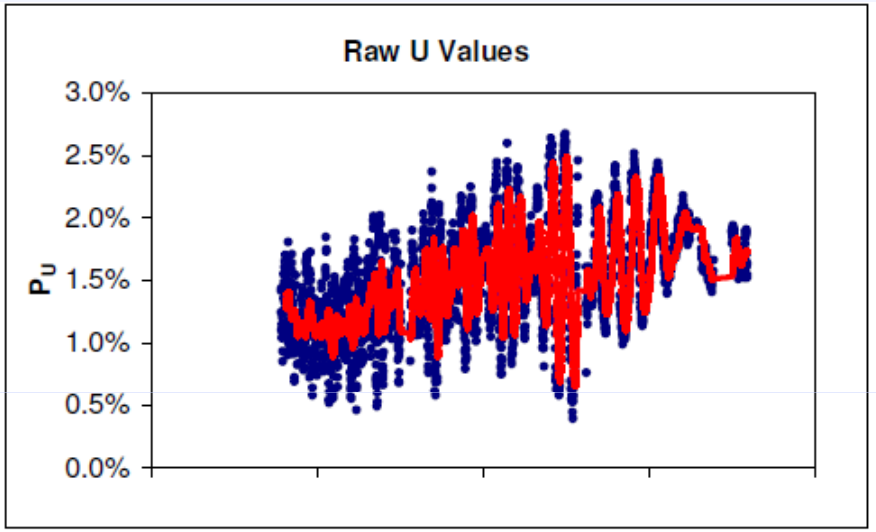




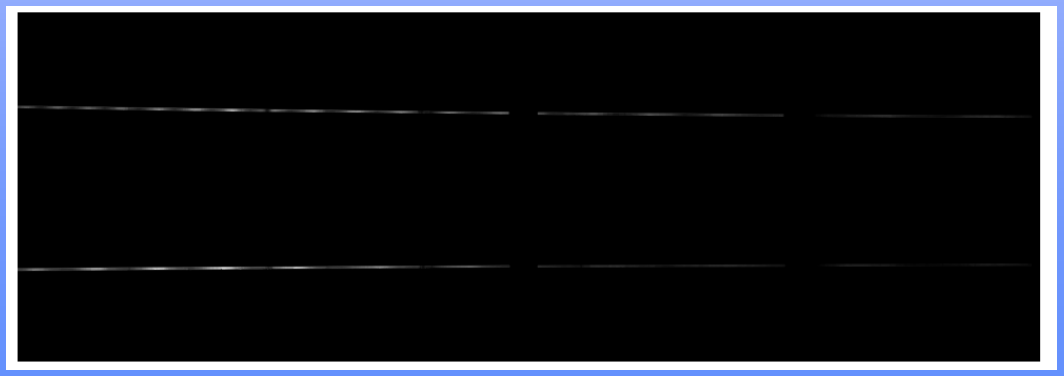
Fringing & Stability Issues

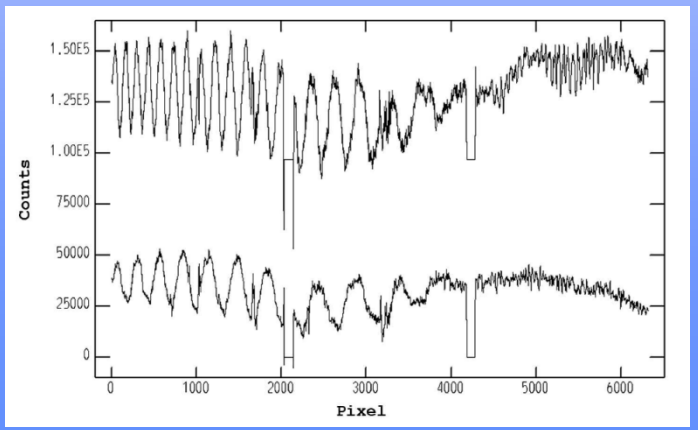
- **Fringing seen in derived Stokes parameters**





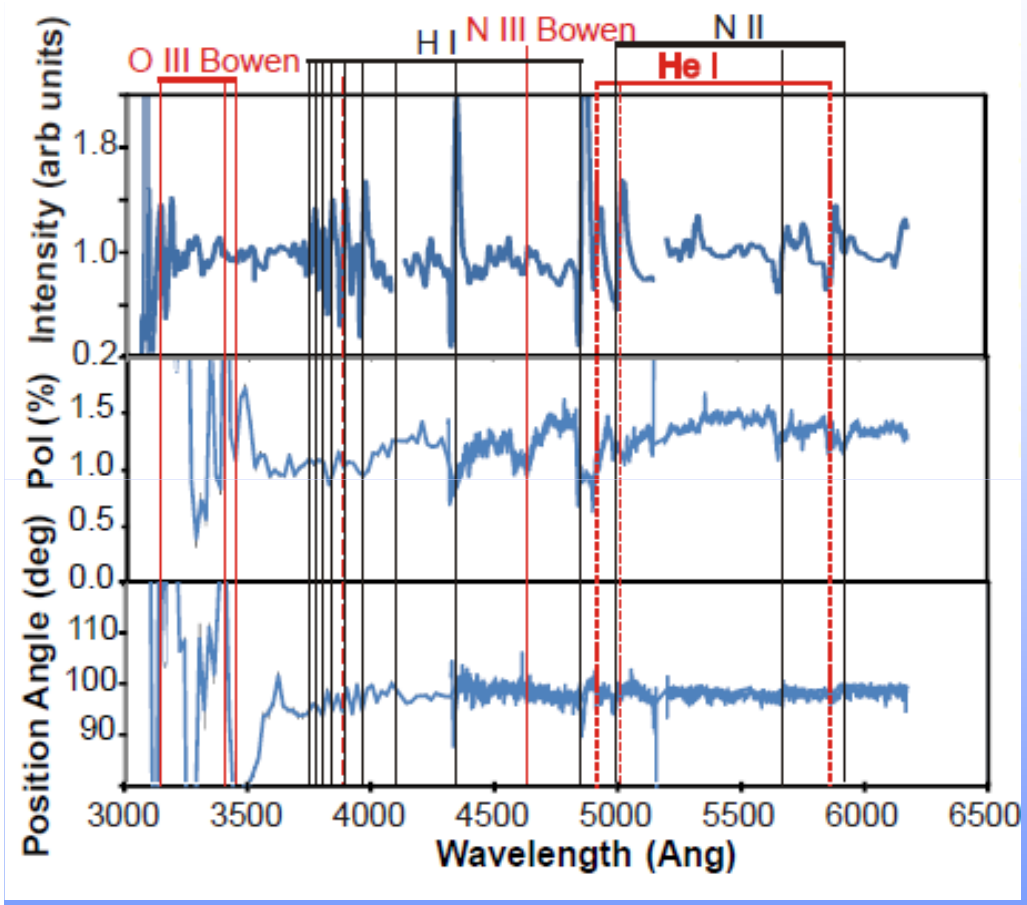
- **Due to bubbles in beamsplitter causing interference, which varies over time (e.g. residual for same geometry)**

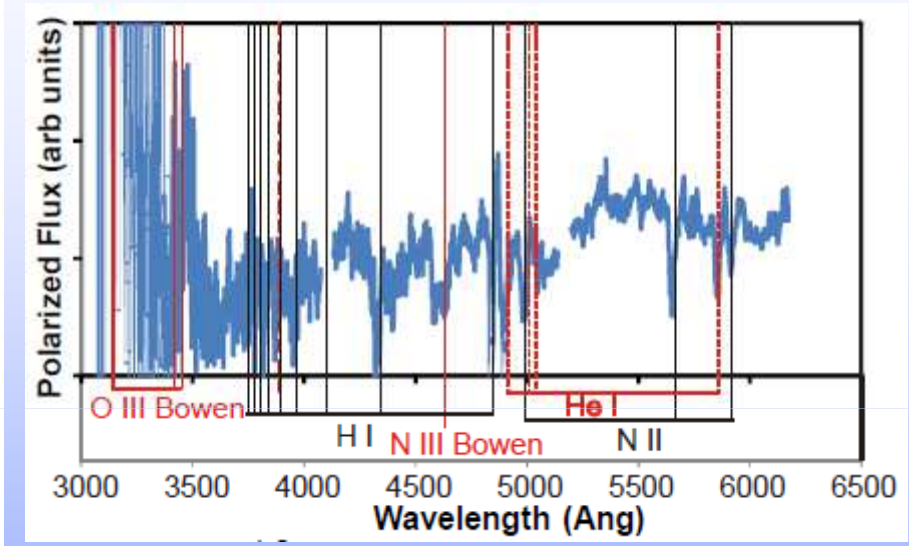




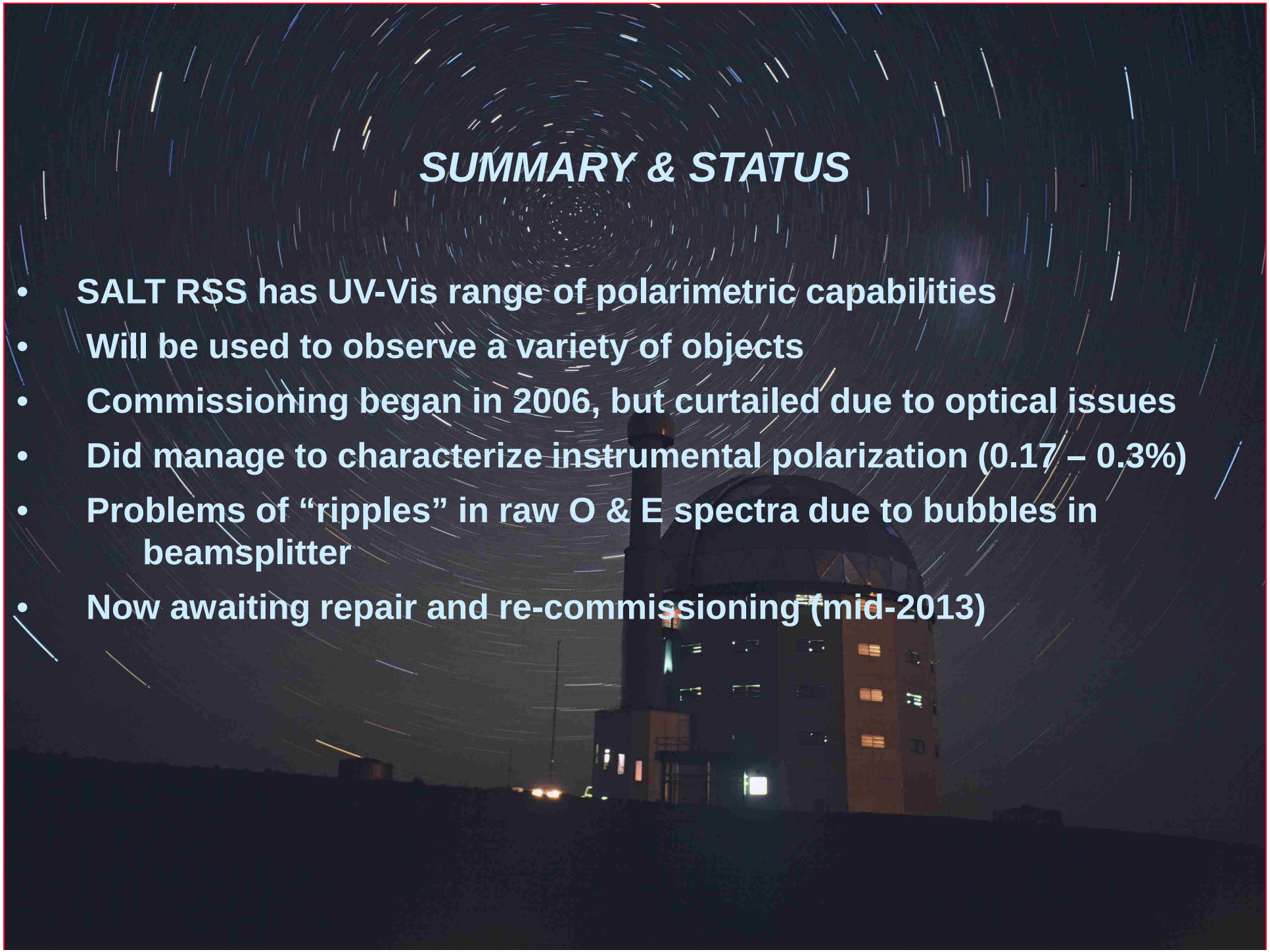
Promise of the future:

Example of spectropolarimetric observations of T Pyx outburst during Apr 2011 recommissioning





- lines all show depolarization => intrinsic polarization (magnitude 0.6%). Likely electron scattering polarization in distorted Nova atmosphere (like in supernova polarization).



SUMMARY & STATUS

- SALT RSS has UV-Vis range of polarimetric capabilities
- Will be used to observe a variety of objects
- Commissioning began in 2006, but curtailed due to optical issues
- Did manage to characterize instrumental polarization (0.17 – 0.3%)
- Problems of “ripples” in raw O & E spectra due to bubbles in beamsplitter
- Now awaiting repair and re-commissioning (mid-2013)