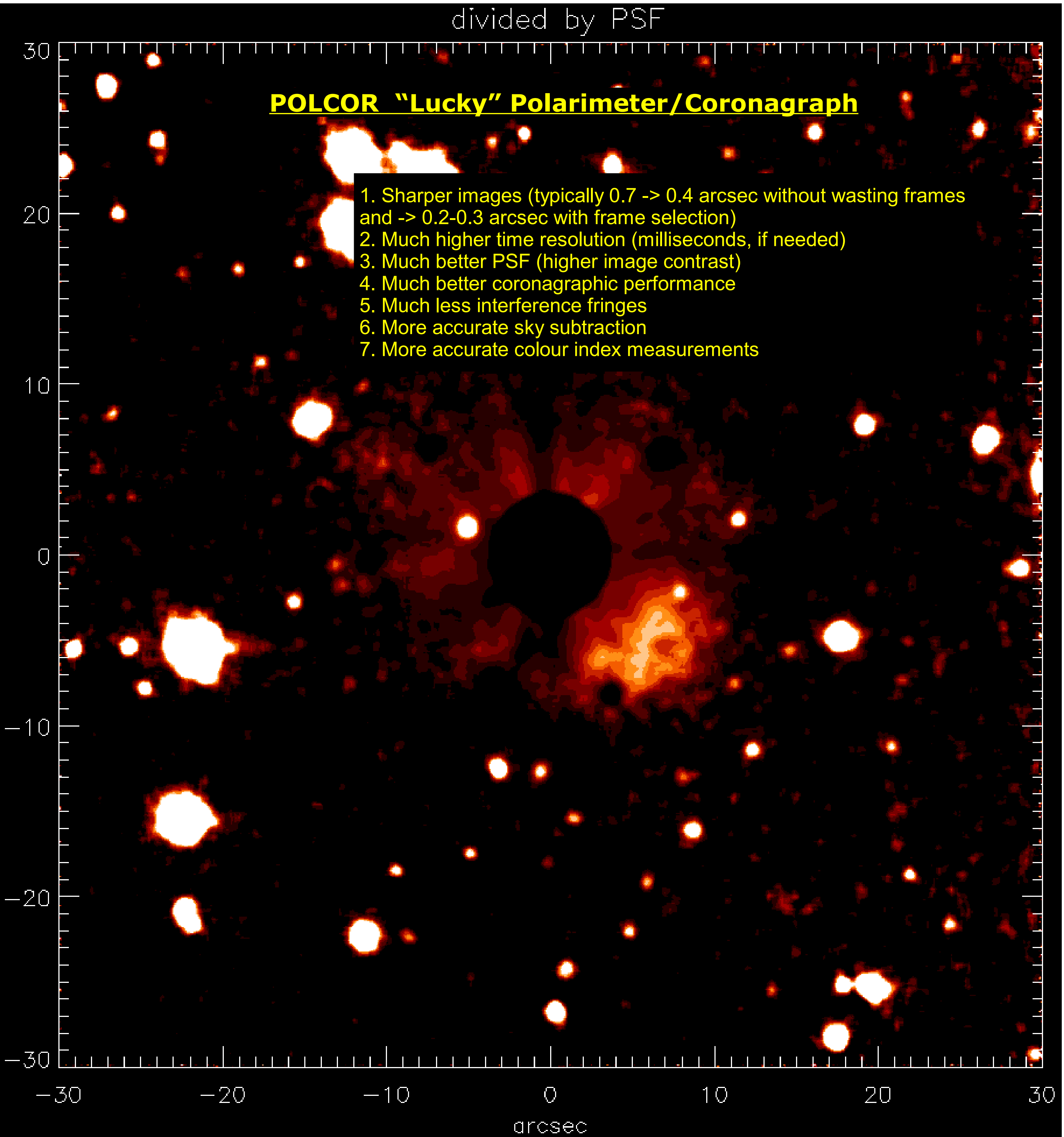
POLCOR "Lucky" Polarimeter/Coronagraph



1. Sharper images (typically 0.7 -> 0.4 arcsec without wasting frames and -> 0.2-0.3 arcsec with frame selection)
2. Much higher time resolution (milliseconds, if needed)
3. Much better PSF (higher image contrast)
4. Much better coronagraphic performance
5. Much less interference fringes
6. More accurate sky subtraction
7. More accurate colour index measurements

Contact:
Stockholm Observatory

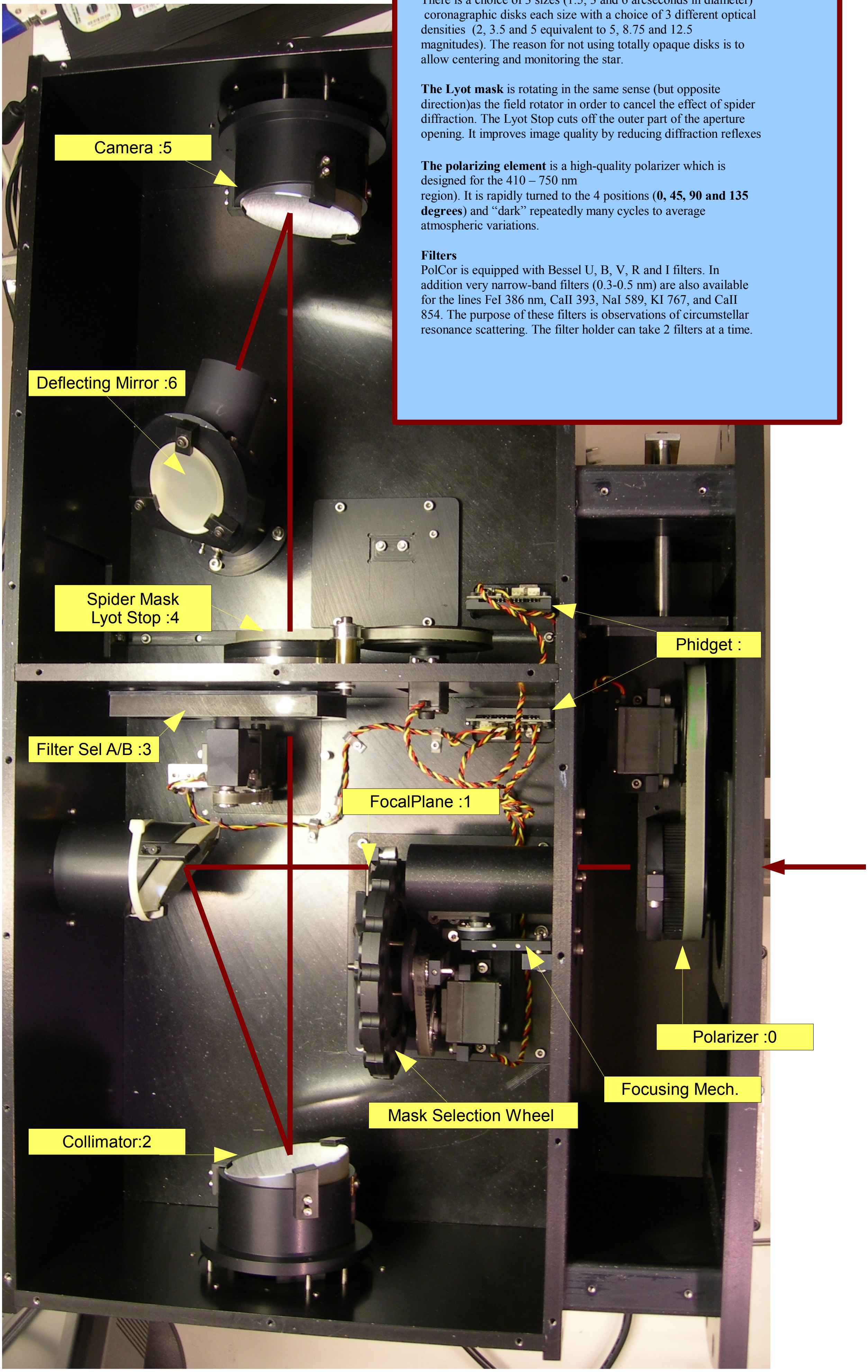
Göran Olofsson olofsson@astro.su.se
H-G Florén floren@astro.su.se

Coronagraphy Mask Selection Wheel
There is a choice of 3 sizes (1.5, 3 and 6 arcseconds in diameter) coronagraphic disks each size with a choice of 3 different optical densities (2, 3.5 and 5 equivalent to 5, 8.75 and 12.5 magnitudes). The reason for not using totally opaque disks is to allow centering and monitoring the star.

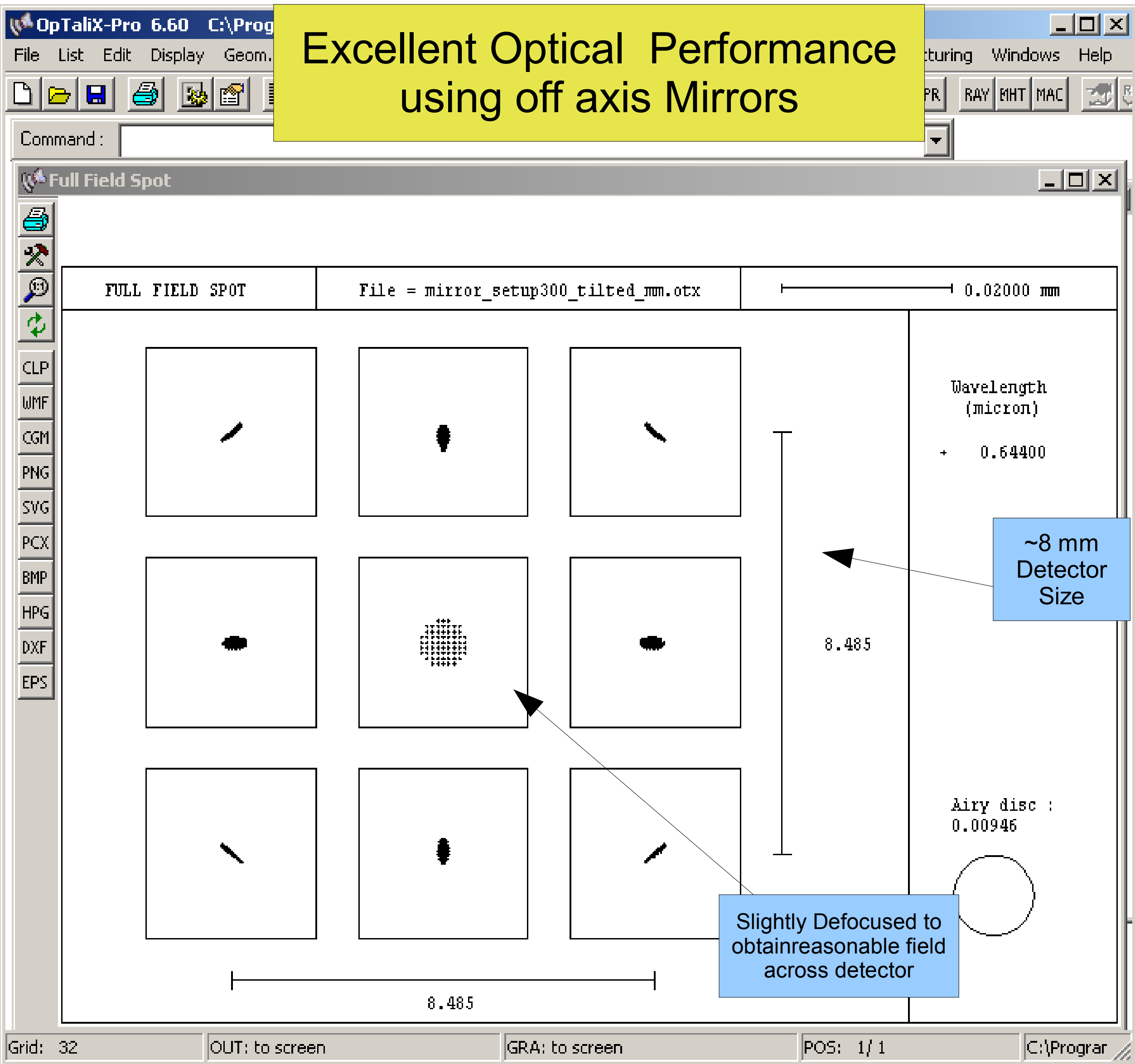
The Lyot mask is rotating in the same sense (but opposite direction)as the field rotator in order to cancel the effect of spider diffraction. The Lyot Stop cuts off the outer part of the aperture opening. It improves image quality by reducing diffraction reflexes

The polarizing element is a high-quality polarizer which is designed for the 410 – 750 nm region). It is rapidly turned to the 4 positions (**0, 45, 90 and 135 degrees**) and "dark" repeatedly many cycles to average atmospheric variations.

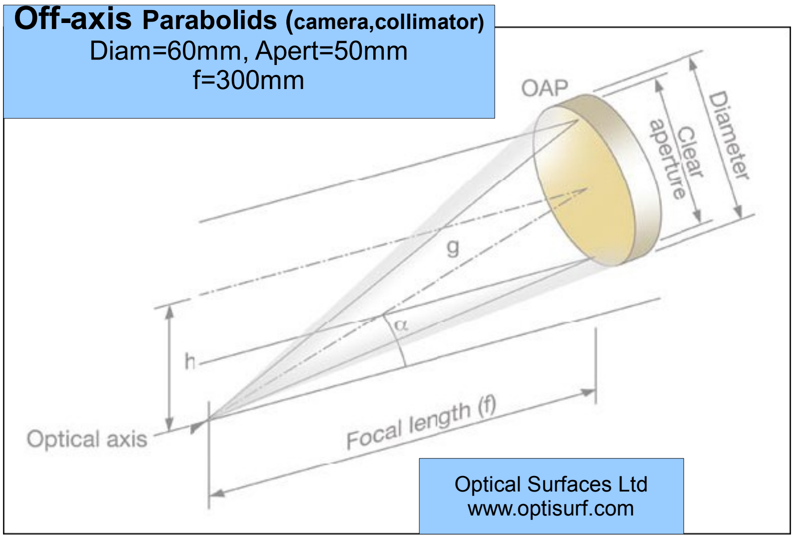
Filters
PolCor is equipped with Bessel U, B, V, R and I filters. In addition very narrow-band filters (0.3-0.5 nm) are also available for the lines FeI 386 nm, CaII 393, NaI 589, KI 767, and CaII 854. The purpose of these filters is observations of circumstellar resonance scattering. The filter holder can take 2 filters at a time.



Excellent Optical Performance using off axis Mirrors

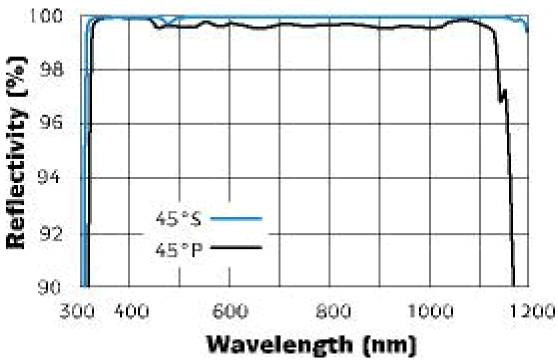


Off-axis Parabolids (camera,collimator)
Diam=60mm, Apert=50mm
f=300mm



Optical Surfaces Ltd
www.optisurf.com

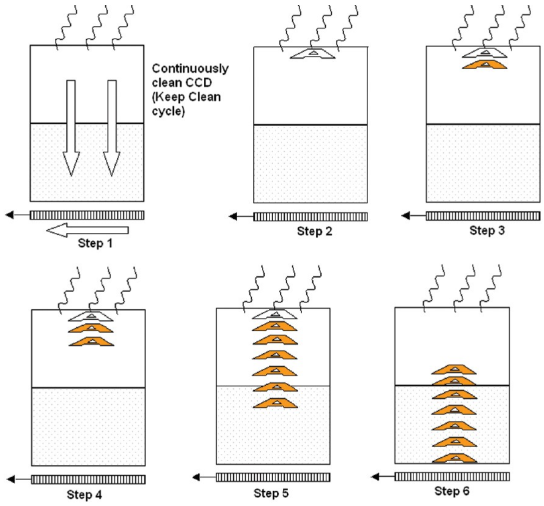
Deflecting Mirror Reflectivity



Reflectivity vs. Wavelength of BBDS 350-1100nm
0-45° Laser Mirror. CVI laser Optics
www.cvilaser.com

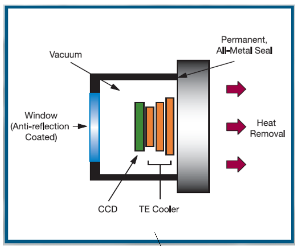
Diameter tolerance:	+0/-1mm
Thickness tolerance:	+0/-2mm
Focal length:	+-1%
Off-axis distance:	+6mm -0mm (mirrors above 100mm diameter) +/- 1mm (mirrors =<100mm diameter)
Surface accuracy:	lambda /10 p-v@633nm across entire clear aperture. Slope errors <lambda /10 per cm Interferograms and analysis showing surface accuracy are supplied with all mirrors using industry standard software
Micro-roughness:	1.2nm rms. Measurements of roughness are not included in price
Surface quality:	60/40 to MIL-0-13830 Rev H in which 60=60microns and 40=0.40mm
Materials:	Zerodur is atandard for mirrors of 125mm diameter or less. Mirrors above 125mm are made from fine-annealed low expansion glass unless otherwise requested
Coating:	Al+MgF is included in our standard list price. Spectral scans free if requested at the time of order. Silver, gold high-power laser, and Femto-second laser coatings quoted for on request

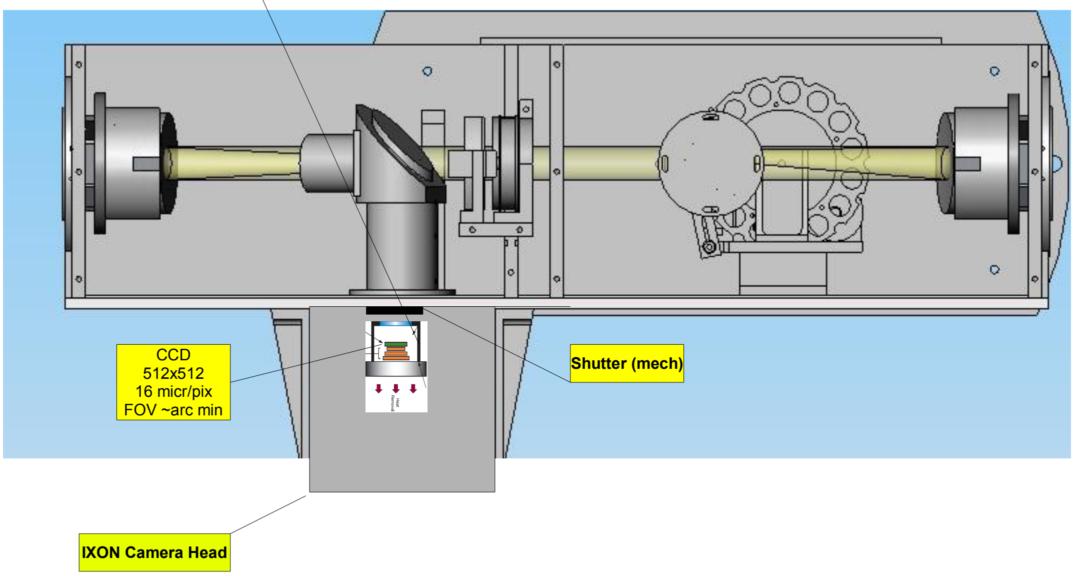
IXON EMCCD
(back illuminated)



Points to consider for Fast Kinetics Mode:

- Light MUST only be allowed to fall on the specified sub-area. Light falling anywhere else will contaminate the data.
- The maximum number of images in the sequence is set by the position of the sub-area, the height of the sub-area and the number of rows in the CCD (Image and Storage area)
- There are no Keep Cleans during the acquisition sequence.
- The industry fastest vertical shift speeds of the iXon^{EM}+ enables fastest time resolution with minimal vertical smearing.
- A range of internal trigger and external trigger options are available for Fast Kinetics Readout.



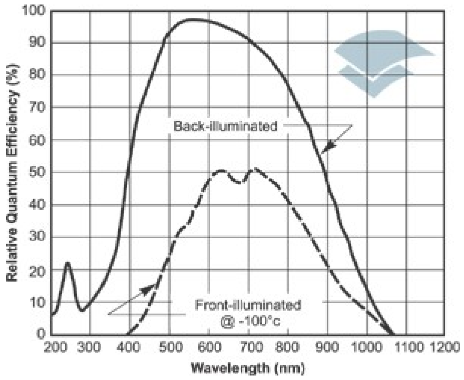


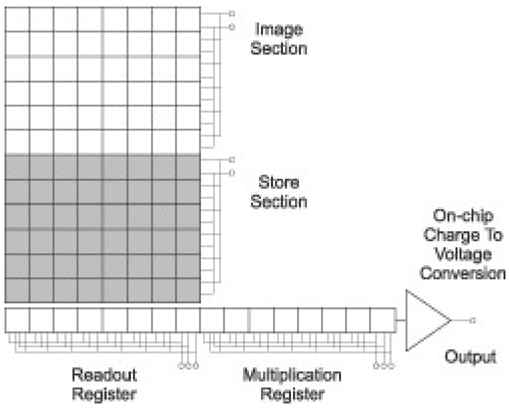
The detector

For low light levels it can be used in a photon counting mode (fastest full-frame readout rate 33 Hz), which is in principle noise-less, but in practice limited by clock induced pulses, which occur typically once for 200 readouts. With broad band filters the sky emission is too high for photon counting, but it has been found that the EM mode is linear over a wide range and this is the normal mode of operation. In practice, all frames are stored, so the mode of operation is a post-processing decision.

Th QE is not particularly high (around 30%) in the UV, but on the other hand, the AR coating is efficient at longer wavelengths and we have seen no interference fringes caused by the OH sky emission.

Very high time resolution can be achieved by limiting the readout area of the chip, making speckle interferometry possible.

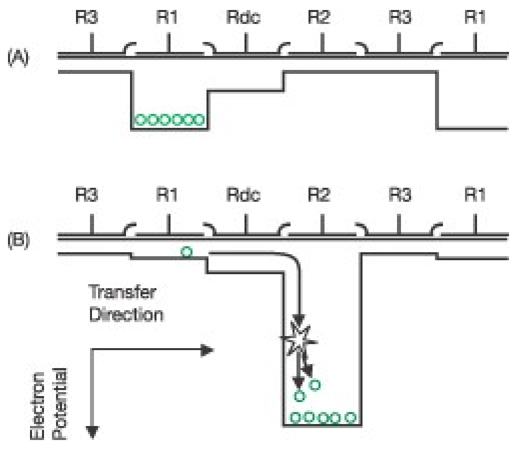


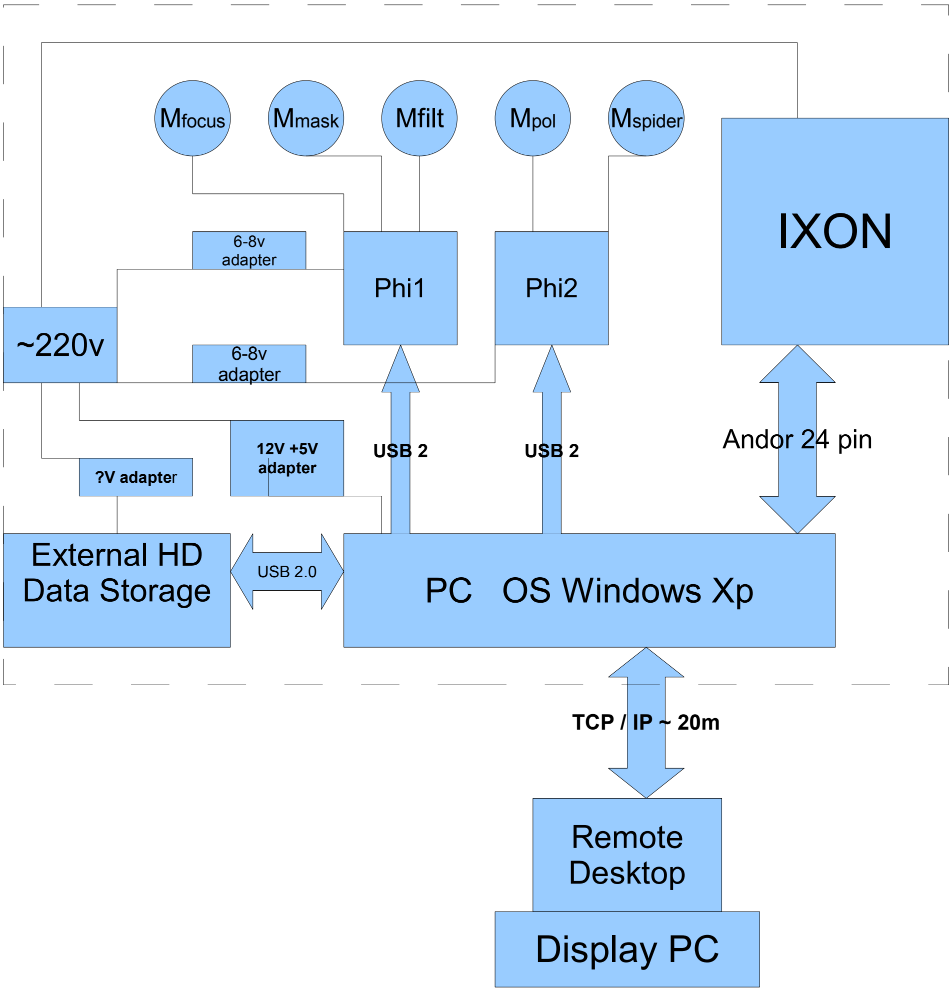


The Spectral Response (or QE) of the CCD is governed by the ability of the photons to be absorbed in the Depletion Region of the detector. It is only in the depletion region that photons are converted into electronic charges and subsequently can be held by the electric fields which form the pixel.

Most EMCCDs utilise a Frame Transfer CCD structure shown in the diagram. Frame Transfer CCDs feature two areas – the sensor area which captures the image and the storage area, where the image is stored prior to read out. The storage area is normally identical in size to the sensor area and is covered with an opaque mask, normally made of aluminium. During an acquisition, the sensor area is exposed to light and an image is captured – this image is then automatically shifted downwards behind the masked region of the chip, and then read out. While this is happening the sensor area is again exposed and the next image is acquired. The aluminium mask therefore acts like an electronic shutter. To readout the sensor the charge is shifted out through the readout register and through the multiplication register where amplification occurs prior to readout by the charge amplifier.

The amplification occurs in the multiplication register through the scheme highlighted in the second digram on the right. The multiplication register contains many hundreds of cells and the amplification process occurs in each cell by harnessing a process which occurs naturally in CCD's known as Clock-Induced Charge or Spurious Charge. Clock-induced charge has traditionally been considered a source of noise and something to minimise but not in EMCCD's. When clocking the charge through a register there is a very tiny but finite probability that the charges being clocked can create additional charges by a process known as 'impact ionization'. Impact ionization occurs when a charge has sufficient energy to create another electron-hole pair and hence a free electron charge in the conduction band can create another charge. Hence amplification occurs. To make this process viable EMCCD's tailor the process in two ways. Firstly the probability of any one charge creating a secondary electron is increased by giving the initial electron charge more energy by clocking the charge with a higher voltage. Secondly the EMCCD is designed with hundreds of cells in which impact ionization can occur and although the probability of amplification or multiplication in any one cell is small over the register of cells the probability is very high and gains of up to thousands can be achieved.The probability of charge multiplication varies with temperature – the lower the temperature the higher the probability and hence gains of the EMCCD. This probability also increases with increasing voltage applied to the multiplication register. By adjusting the temperature and voltage applied to the sensor the EMCCD camera can achieve gains from practically unity with voltages ~20V to thousands by applying voltages of 25–50V depending on the sensor





System Design

Standard Motors(   )

Standard PC

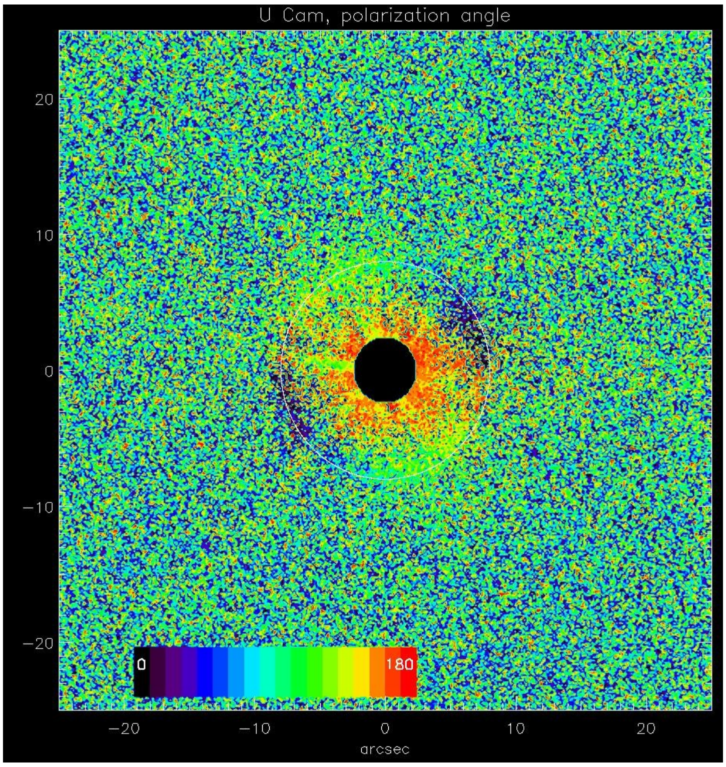
Compact and easy to mount on telescope (~50 kg)

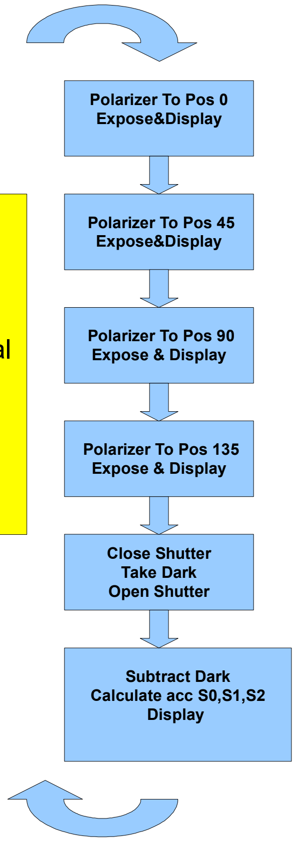
Independent

GUI I/F (online monitoring of Obs)
Online Analysis/Display Tools

M= Servo Motors

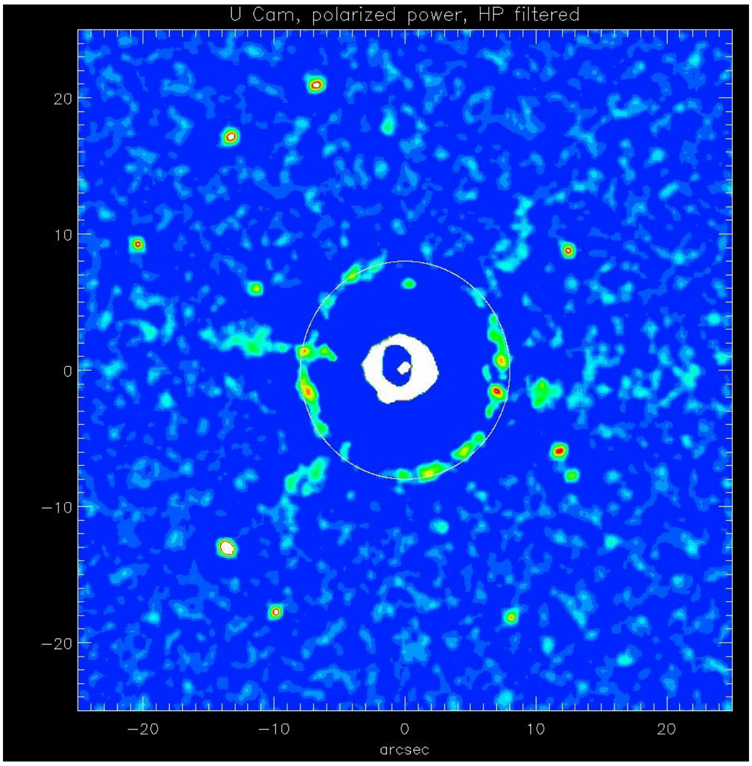
Polarizing Mode (UCAM)





Polarizing Mode Normal Data retrieval Cycle

All Images are stored



$$S_0 = \frac{Im0 + Im45 + Im90 + Im135}{4}$$

$$S_1 = Im0 - Im90$$

$$S_2 = Im45 - Im135$$

Stokes Equations

$$S_0 = I$$

$$S_1 = Ip\cos(2\psi)$$

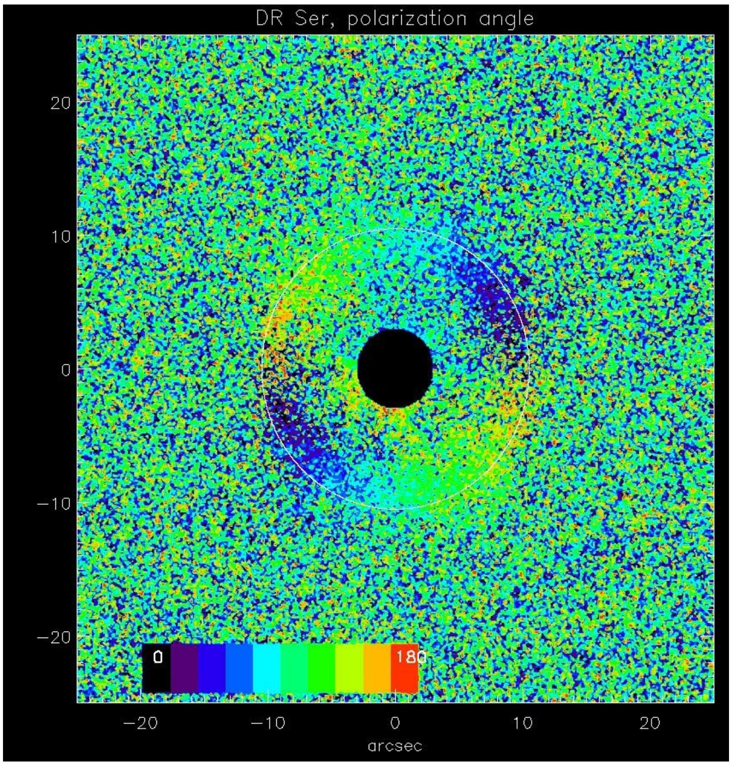
$$S_2 = Ip\sin(2\psi)$$

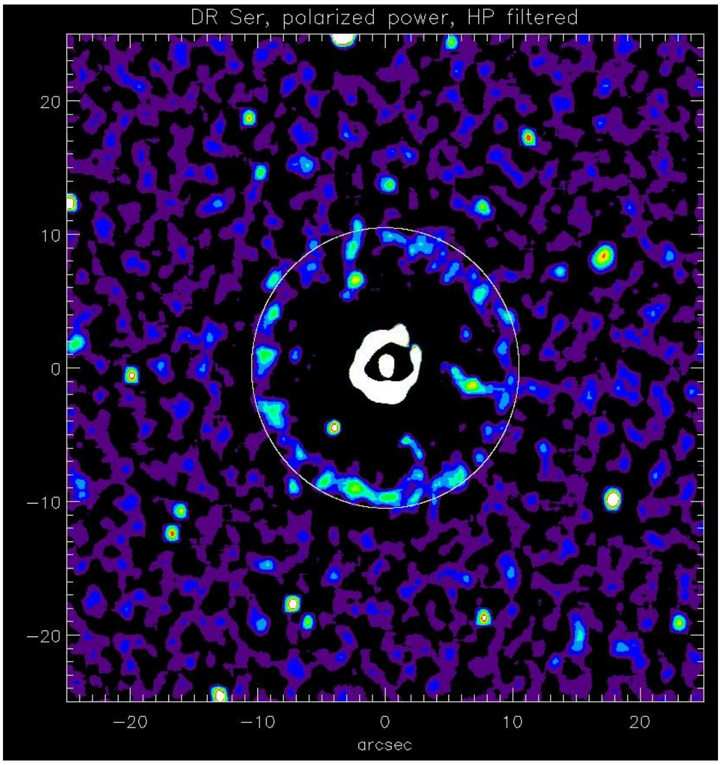
$I = S_0$ Power of polarization

$$p = \frac{\sqrt{S_1^2 + S_2^2}}{S_0}$$ (0-1 Degree of Polarization)

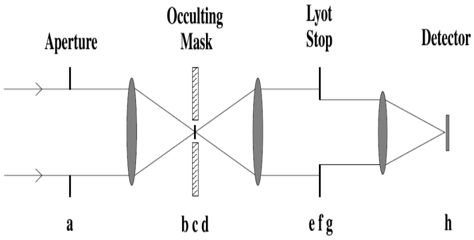
$$2\psi = \arctan\left(\frac{S_2}{S_1}\right)$$ Polarizing angle 0-180^0

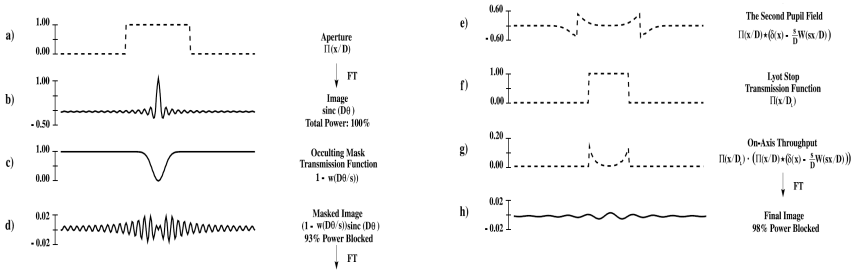
DR Ser


DR Ser, polarization angle
20
10
0
−10
−20
0
180
−20
−10
0
10
20
arcsec

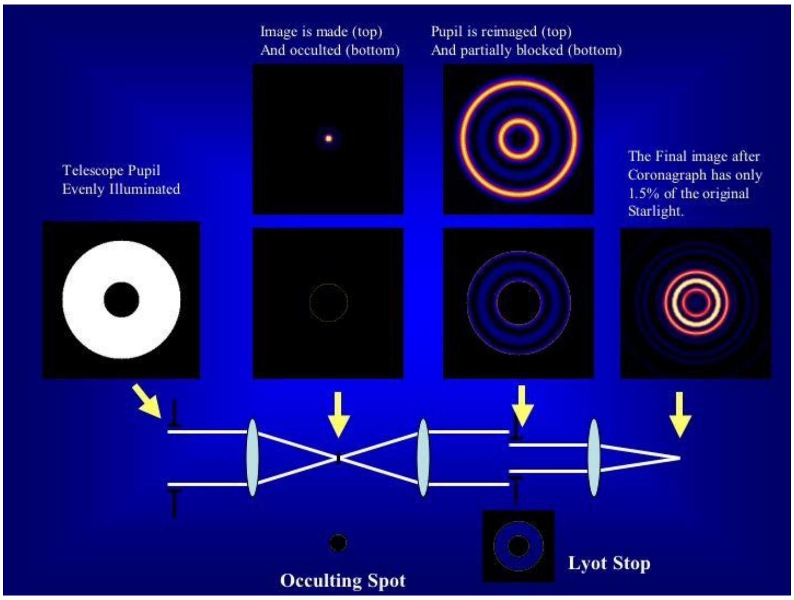

DR Ser, polarized power, HP filtered
20
10
0
−10
−20
−20
−10
0
10
20
arcsec

Lyot coronagraph principles





(Sivaramakrishnan et al. 2001)



The principles of how a coronagraph works are above. Light enters the telescope aperture, or pupil, as an evenly-illuminated source, blocked in this case by the secondary mirror at the center. A lens images the light, and here where a camera or detector would usually record the image, an occulting spot, or focal plane mask, is placed instead. This spot absorbs most of the light from the center of the field of view, so that when the pupil is reimaged by another lens any remaining light from the central source is concentrated around the edges of the telescope pupil - in this case forming rings around the edge of the aperture image and the secondary mirror image.

The next stage of the coronagraph is the Lyot stop, which blocks out the remaining rings of light from the central star whilst allowing most of the light from surrounding sources to pass through to the final image, created by a final lens. This technique is ideally suited to studying exoplanets and debris disks around stars, since it greatly increases the contrast in the final image: in an ideal Lyot coronagraph only about 50% of the surrounding (exoplanet) light is removed, compared to nearly 99% of the starlight. Coronagraphy therefore makes seeing extremely dim objects very close to bright nearby stars possible, in an ideal situation, as depicted below.

Unfortunately, the incoming light at the telescope pupil is, in practice, disturbed by atmospheric turbulence. Even in spacecraft (such as the Hubble Space Telescope) the light entering the coronagraph will be disrupted by optical imperfections or changes in the optics due to temerature changes over time. These effects substantially degrade the coronagraph's ability to remove the starlight. For this reason adaptive optics are required in order to effectively image exoplanets and debris disks in conjunction with a coronagraph, no matter whether the telescope is in space or on the ground.