Considering
Precise Polarimetry by ELTs

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Introduction

- Polarimetry is one of unique methods in observational astronomy.
- Typically 0.1 % precision is crucial especially for optical polarimetry.
- Proposed ELTs have no Cassegrain focus, which is compatible with precise polarimetry.
- We consider the precise polarimetry in the ELT's era based on Tinbergen (2007), PASP, 119, 1371.

Precision of 0.1% is crucial for optical polarimety !

Optical spectropolarimery of SN 2009dc

Tanaka et al. (2009)
arXiv:0908.2057

SUBARU FOCAS

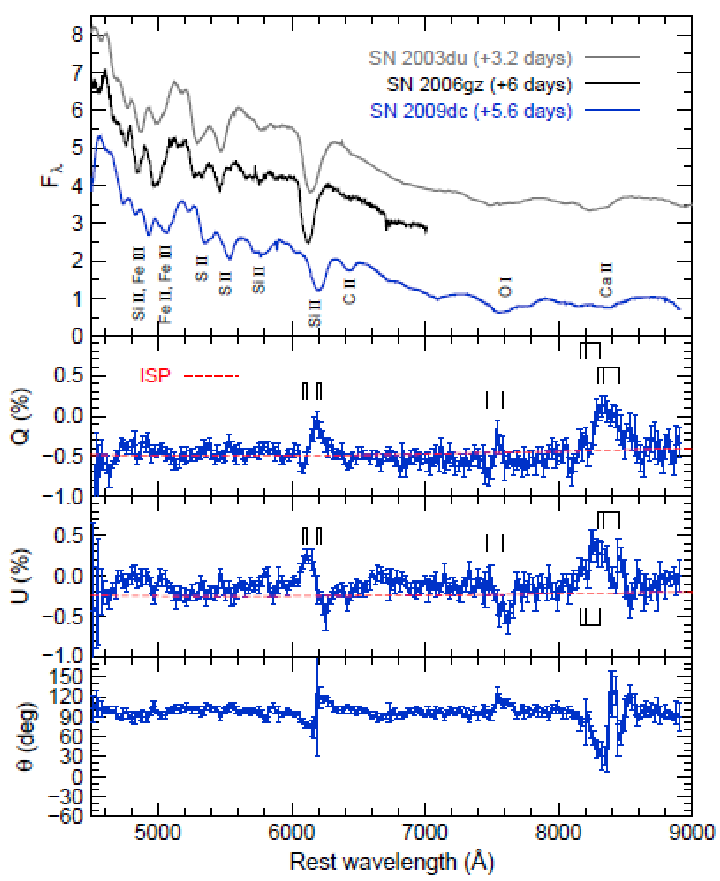


FIG. 1.— Total flux and polarization spectrum of SN 2009dc at t = +5.6 days (blue lines). In polarization spectrum, ISP is *not* corrected for. Polarization data are binned into 20 Å. In the top panel, the total flux of SN 2009dc (in 10^{-15} erg s^{-1} cm^{-2} $Å^{-1}$) is compared with the normal Type Ia SN 2003du (scaled flux, shifted by 3.0, Stanishev et al. 2007) and the overluminous Type Ia SN 2006gz (scaled flux, shifted by 1.5, Hicken et al. 2007). The red dashed lines show the estimated ISP (Section 3.3). Vertical lines at the Si II (λ6347, 6371), O I λ7774, and Ca II (λ8498, 8542, 8662) lines show 7,200 km s^{-1} and 12,000 km s^{-1} position.

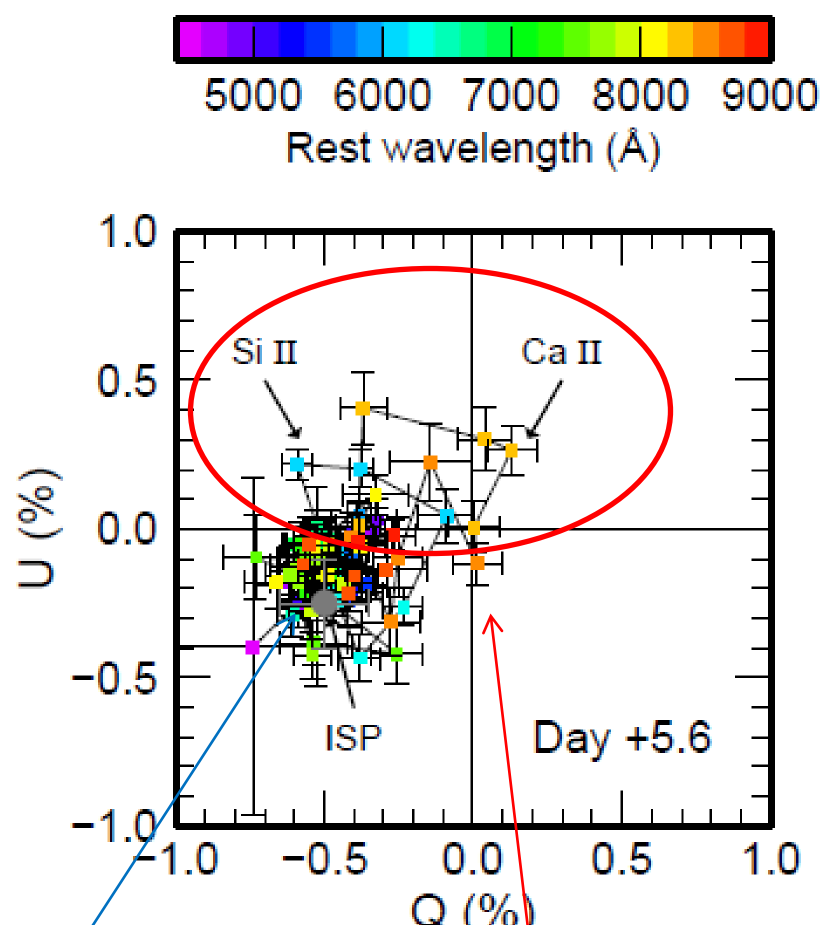
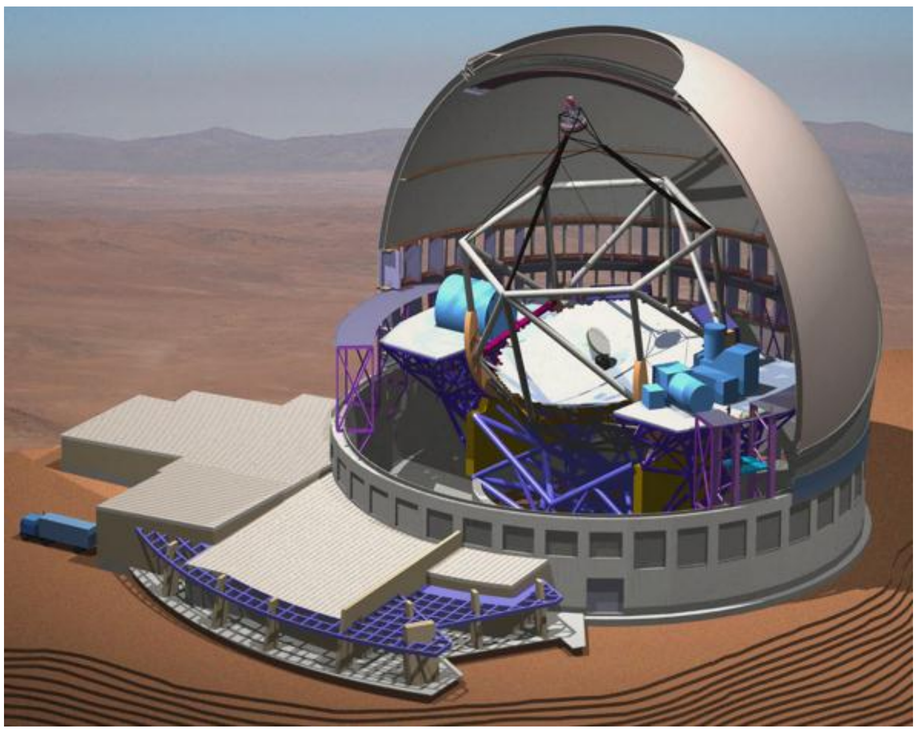


FIG. 3.— Polarization data at t = +5.6 days in the Q-U plane. Different colors show the wavelength according to the color scale bar. ISP at 5500 Å is marked with the gray point. The data are binned into 40 Å.

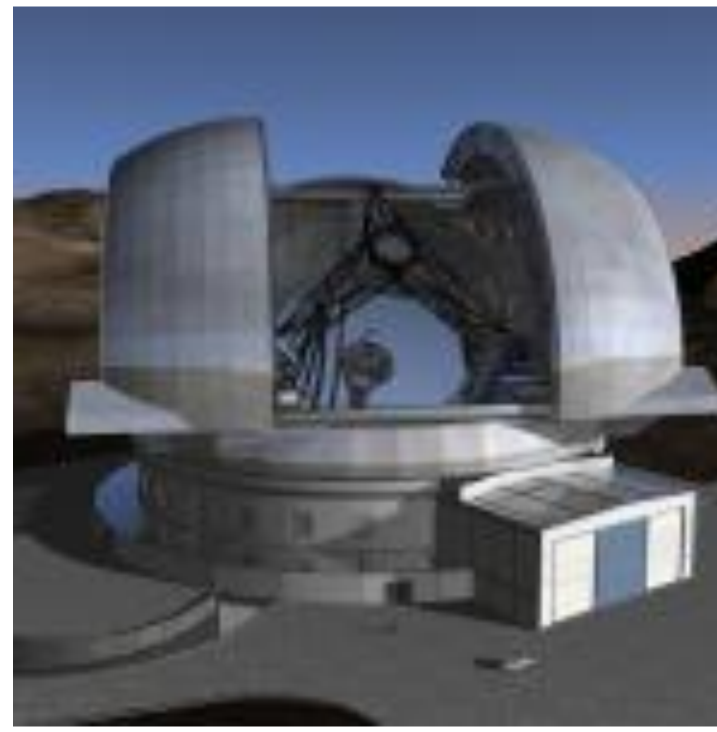
Foreground Interstellar polarization
~0.3%

Intrinsic polarization of emission lines
several x 0.1 %

We can find no Cassegrain focus in ELTs!



TMT



E-ELT

GMT has an Cassegrain focus.

But when will it built ... ?

What's the probrem ?

Large telescope polarization with a Nasmith Mirror

Mueller Matrix of the inclined mirror

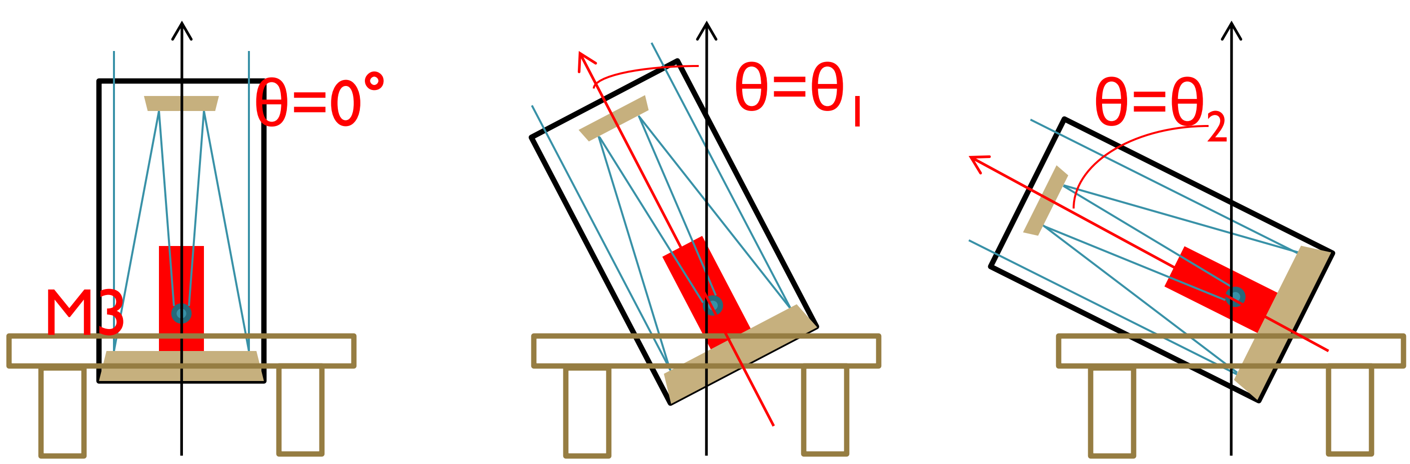
$$M_{M3}(\lambda)= \begin{pmatrix} \overline{R_a} & p & 0 & 0 \\ p & \bar{R}_a & 0 & 0 \\ 0 & 0 & \overline{R_g}\cos\Delta & \overline{R_g}\sin\Delta \\ 0 & 0 & -\overline{R_g}\sin\Delta & \overline{R_g}\cos\Delta \end{pmatrix}$$

$R_{//}$, $R_{\perp}$, R_a, R_g : reflectance parameters
$p=(R_{//}-R_{\perp})/2$
$\Delta=\delta_{//}-\delta_{\perp}$ ($\delta_{//}$, $\delta_{\perp}$:phase delay)

(e.g.) 45° alminium mirror
p = 0.047 @ 800nm (peak)
Δ = 40° (blue/violet)~5° (1μm)

→ large artificial linear polarization and cross talks between linear and circular polarizations

... and it rotates!

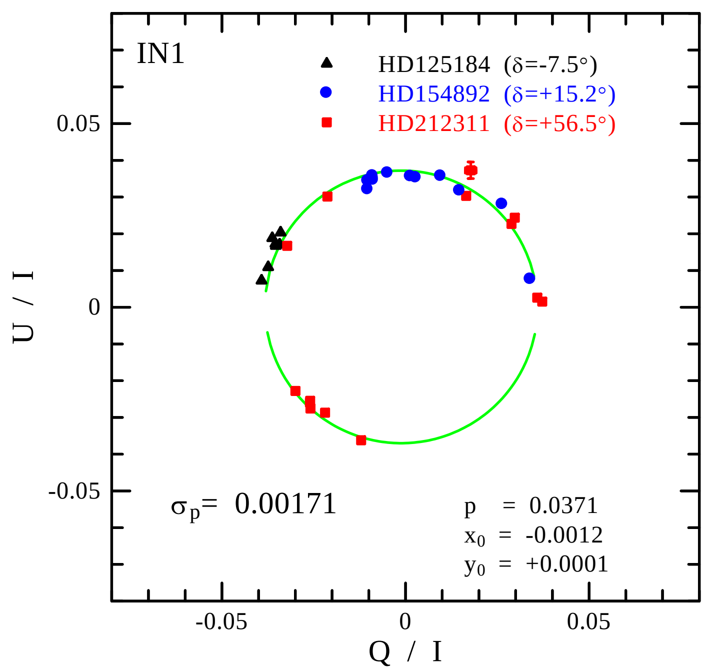


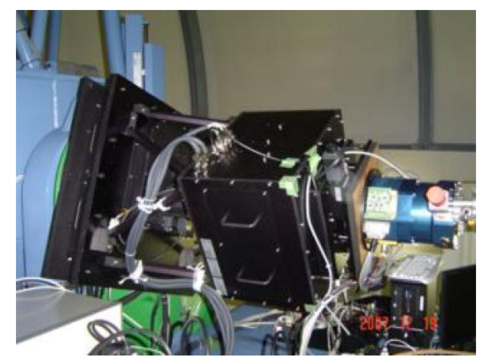
$$M_{M3}(\lambda,\theta)= \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta & 0 \\ 0 & -\sin 2\theta & \cos 2\theta & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \overline{R_a} & p & 0 & 0 \\ p & \bar{R}_a & 0 & 0 \\ 0 & 0 & \overline{R_g}\cos\Delta & \overline{R_g}\sin\Delta \\ 0 & 0 & -\overline{R_g}\sin\Delta & \overline{R_g}\cos\Delta \end{pmatrix}$$

Difficulty for calibrating large telescope polarization

HowPol (at Nasmyth focus on Kanata Telescope)

modulation of the telescope polarization





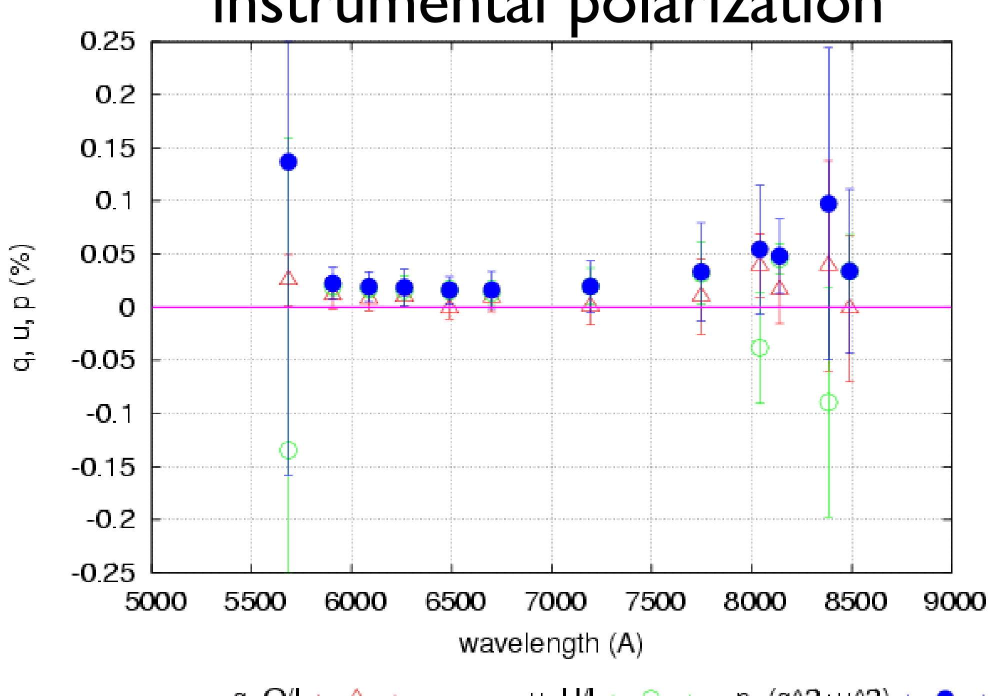
Komatsu et al. (2009)

stability of the tel. pol. : σp ~ 0.14-0.17 %

... not so bad, but not enough

(cf.) LIPS (at Cassegrain focus on UH2.2-m)

instrumental polarization



σ_P ~ 0.02%

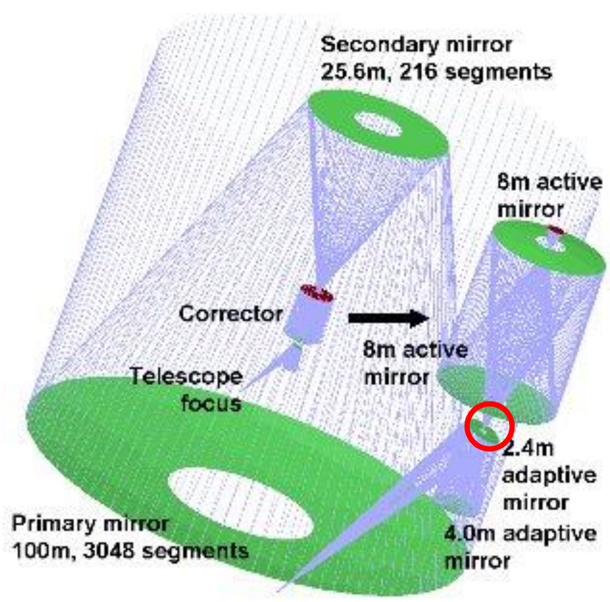
negligeble in many cases

How should we avoid the telescope polarization?

(1) The polarization modulator before the Nasmyth Mirror

Gregorian telescope

OWL(100m)



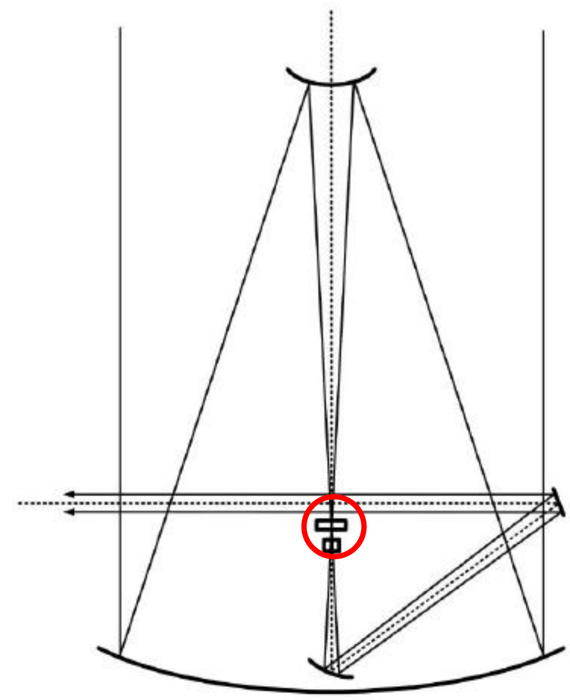


FIG. 2.—Cassegrain-like telescope, as modified for sensitive polarimetry without having to remove the Cassegrain instrument. The units near the relocated Cassegrain focus are the polarization switch (upstream) and the polarizer (downstream). For clarity, the focus is shown much further from the primary mirror than would, in fact, be the case. See Tinbergen (2003) for other layout examples.

Telescopes with particular designs

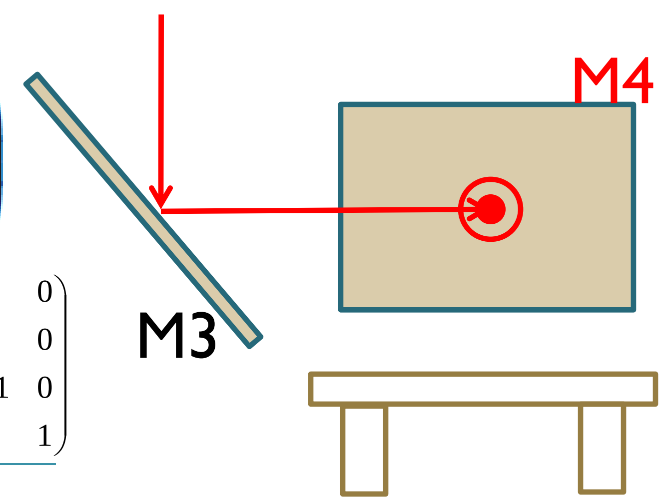
- Optical components for a modulator are usually small.
  → Focal planes are candidates for their site
- Difficult to use polarization beam splitters.

→ limited for special cases

(2) Compensating the telescope polarization by another oblique mirror

Adding "M4" to compensate M3 polarization

$$M_{M3}=\begin{pmatrix} \overline{R}_a & p & 0 & 0 \\ p & \overline{R}_a & 0 & 0 \\ 0 & 0 & \overline{R}_g\cos\Delta & \overline{R}_g\sin\Delta \\ 0 & 0 & -\overline{R}_g\sin\Delta & \overline{R}_g\cos\Delta \end{pmatrix}$$



$$M_{M4}=\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}\begin{pmatrix} \overline{R}_a & p & 0 & 0 \\ p & \overline{R}_a & 0 & 0 \\ 0 & 0 & \overline{R}_g\cos\Delta & \overline{R}_g\sin\Delta \\ 0 & 0 & -\overline{R}_g\sin\Delta & \overline{R}_g\cos\Delta \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

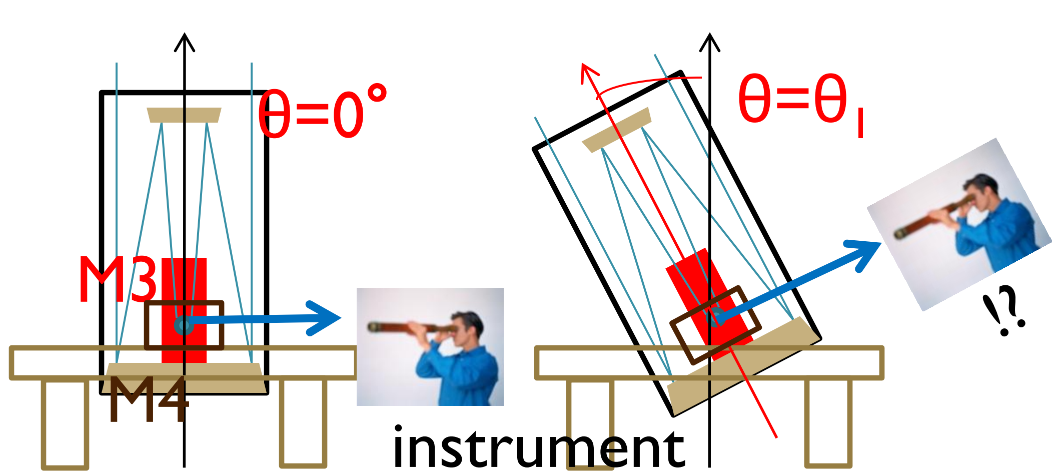
$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta & 0 \\ 0 & -\sin 2\theta & \cos 2\theta & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad \theta=-90^\circ \qquad \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta & 0 \\ 0 & -\sin 2\theta & \cos 2\theta & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad \theta=90^\circ$$

$$\rightarrow M_{M4}\,M_{M3}=\begin{pmatrix} \overline{R}_a^{\,2}-p^2 & 0 & 0 & 0 \\ 0 & \overline{R}_a^{\,2}-p^2 & 0 & 0 \\ 0 & 0 & \overline{R}_g^{\,2} & 0 \\ 0 & 0 & 0 & \overline{R}_g^{\,2} \end{pmatrix}$$

Telescope polarization is completely cancelled

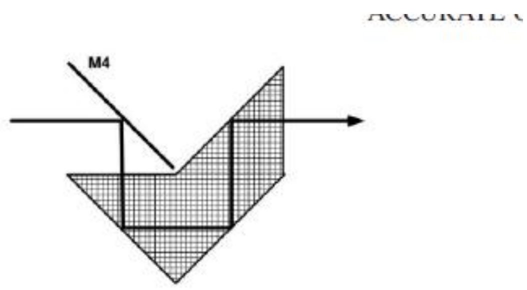
But...

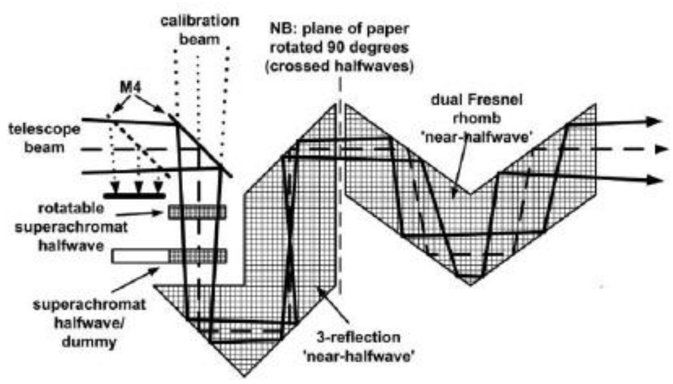
- Mirror surface quality of the both mirrors shoud be precisely controlled.
- The optical path (i.e. instrument) rotates with telescope.



(3) Further ideas

(a) bending the optical path using a Fresnel Romb





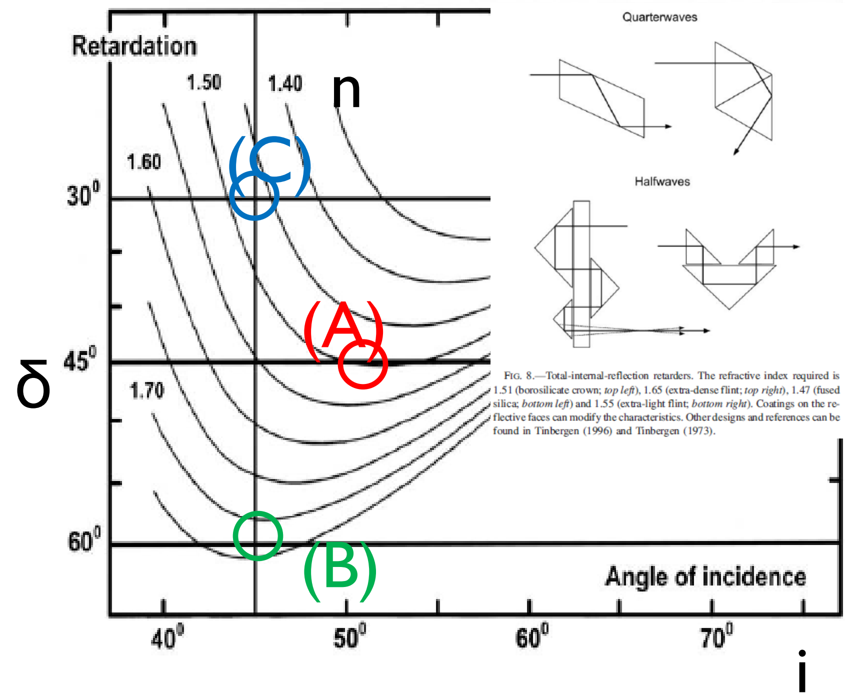


FIG. 8.—Total-internal-reflection retarders. The refractive index required is 1.51 (borosilicate crown; *top left*), 1.65 (extra-dense flint; *top right*), 1.47 (fused silica; *bottom left*) and 1.55 (extra-light flint; *bottom right*). Coatings on the reflective faces can modify the characteristics. Other designs and references can be found in Tinbergen (1996) and Tinbergen (1973).

FIG. 7.—Total internal reflection: retardance as a function of angle of incidence for various refractive indices. The term "retardance" is used in polarization literature for the numerical value of the property "retardation"; retardation is the phase difference between two opposite polarizations, as induced by a "retarder."

(b) approximate compensator

(for limited wavelengths)

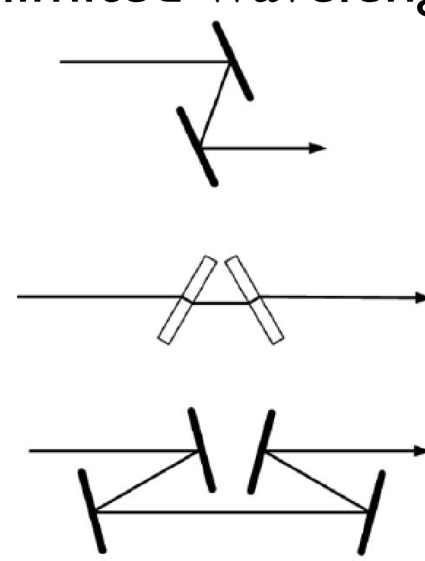
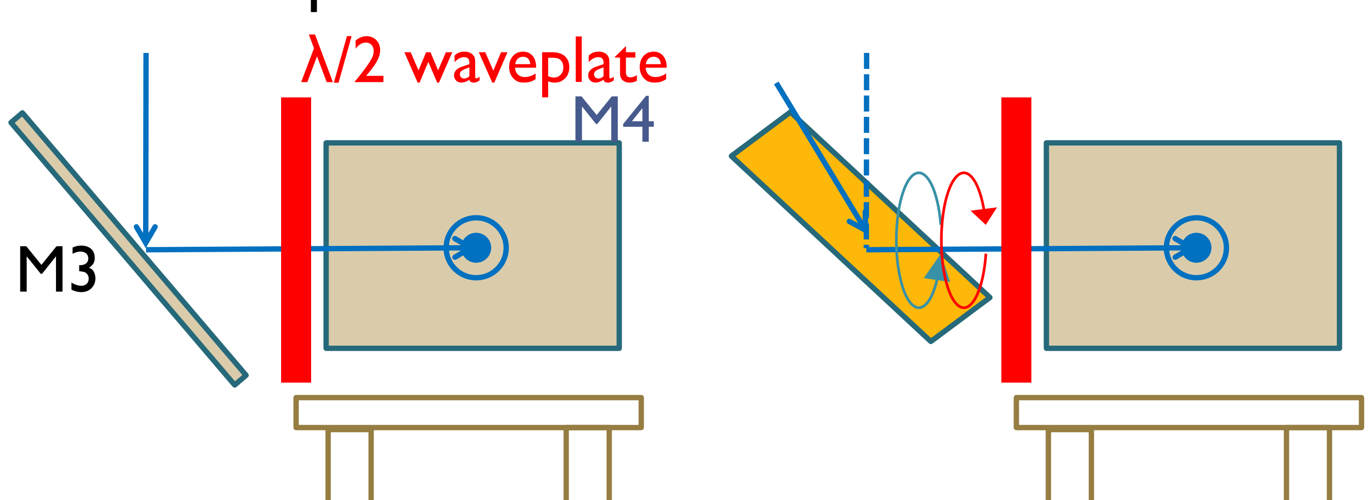


FIG. 4.—Alternative M3-compensators; the tilted plates may be very thin indeed. In all these cases, compensation of M3 is only approximate. Note that the compensator has to rotate with telescope elevation, resulting in changing exit beam translation for the top solution. All three options have been used successfully at the McMath-Pierce solar telescope (C. U. Keller 2007, private communication).

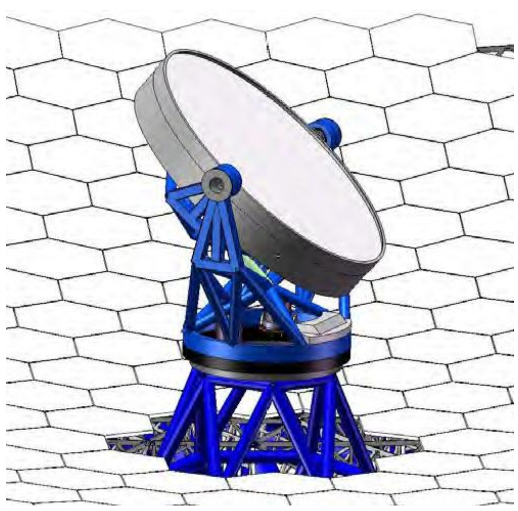
(c) compensating rotation of the telescope polarization using an half-wave plate



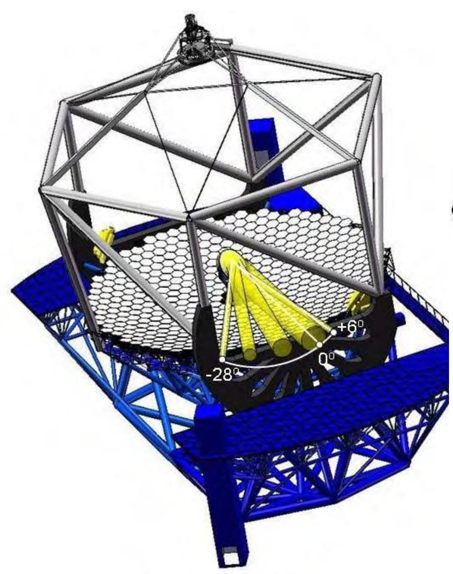
- The λ/2 waveplate should be completely achromatic.

Final Remarks

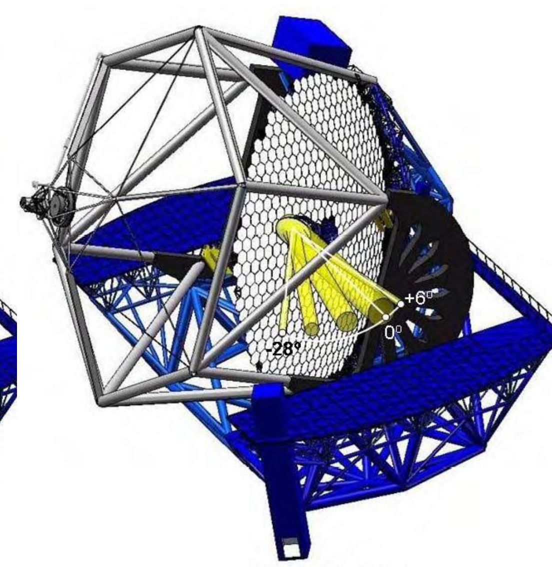
- Many ideas have been suggested to compensate large telescope polarization by the Nasmyth mirror.
- But application of them to ELTs seems not simple.
  - “extremely” large M3 (TMT: 2.4x3.4m)
  - TMT’s M3 is not a simple fixed Nasmyth mirror. It rotates on the two axes !



TMT M3



Zenith Pointing



65° Pointing

- There is no proposal of optical polarimeters for ELTs so far, but polarimety with a large telescope will be an unique method in the future.
- “nasmyth problem” is now a common issues for 8-m class telescopes, which equips an AO system on their Nasmyth focus.

偏光観測に関心をお持ちの方，ELT時代の偏光観測について一緒に考えて行きましょう！