Calibration of polarimetric data

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4. Polarimetry with ESO telescopes: a survey
5. Polarimetric mode of FORS1 (and EFOSC2)
6. Near-IR Nasmyth instruments
7. The future polarimetric mode for the SPHERE planet finder

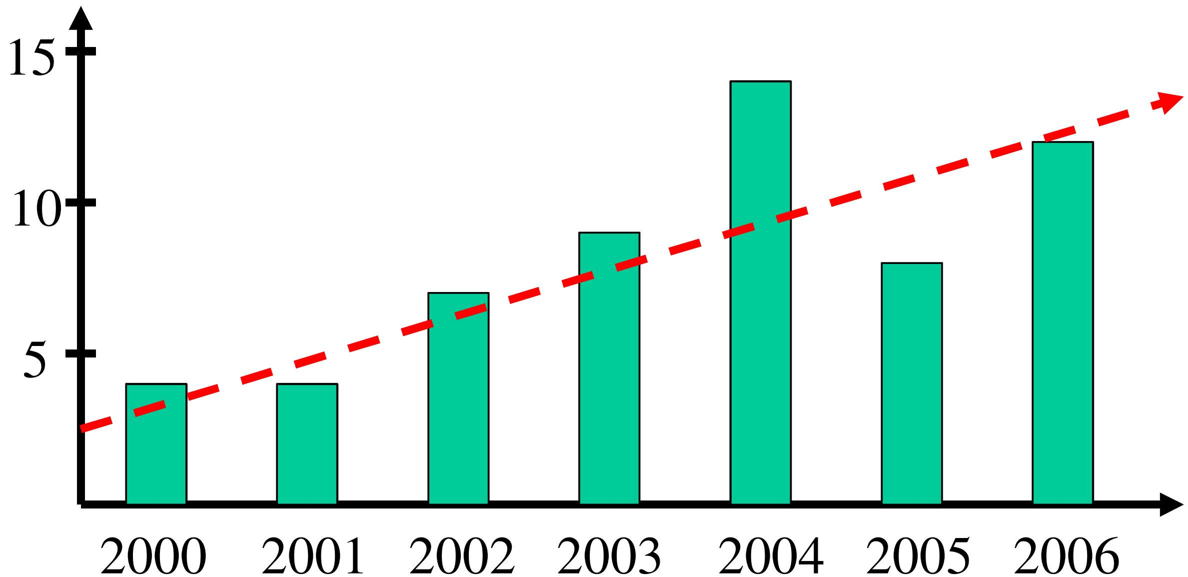
Critical review of a happy ESO user

goal: suggestions for further improvements

Publications survey 2000 to 2006:

Papers based on polarimetry with ESO telescopes

Refereed papers (A&A, MNRAS, AJ, ApJ, PASP, Nature)
Search via:
-ESO annual reports (list of refereed papers based on ESO observations)
-ADS search for keywords like
- polarization + VLT, ESO, FORS1, NACO, ISAAC, SOFI, EFOSC
- magnetic + VLT
- not complete, but should be better than 80%



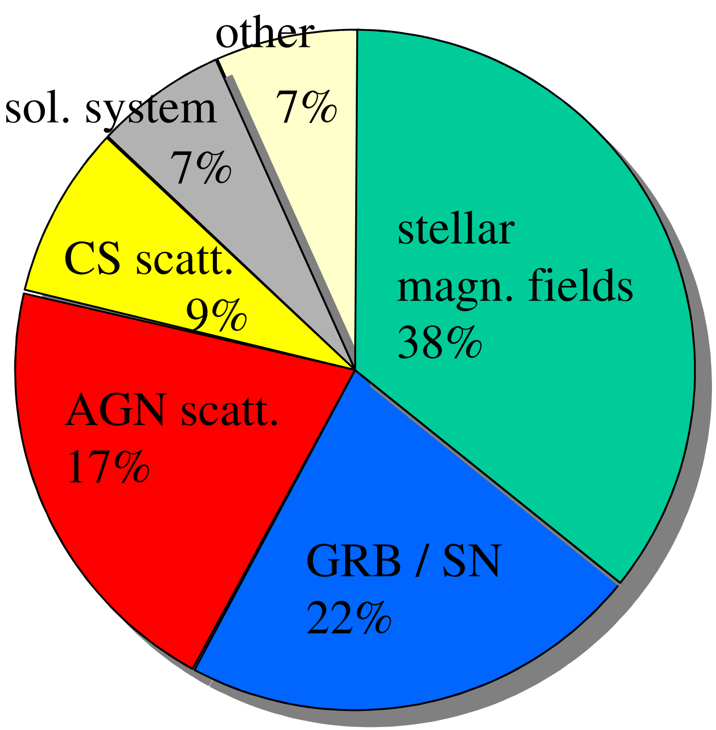
in total 58 papers

(4 posters = 10% at this conference)

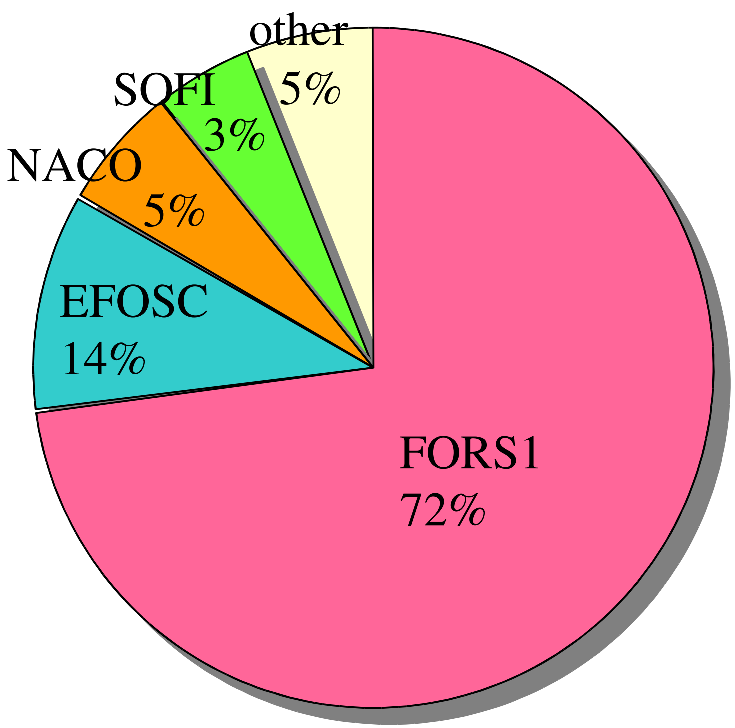
Publications survey 2000 to 2006:

Distribution of polarimetric papers with respect to:

scientific topic

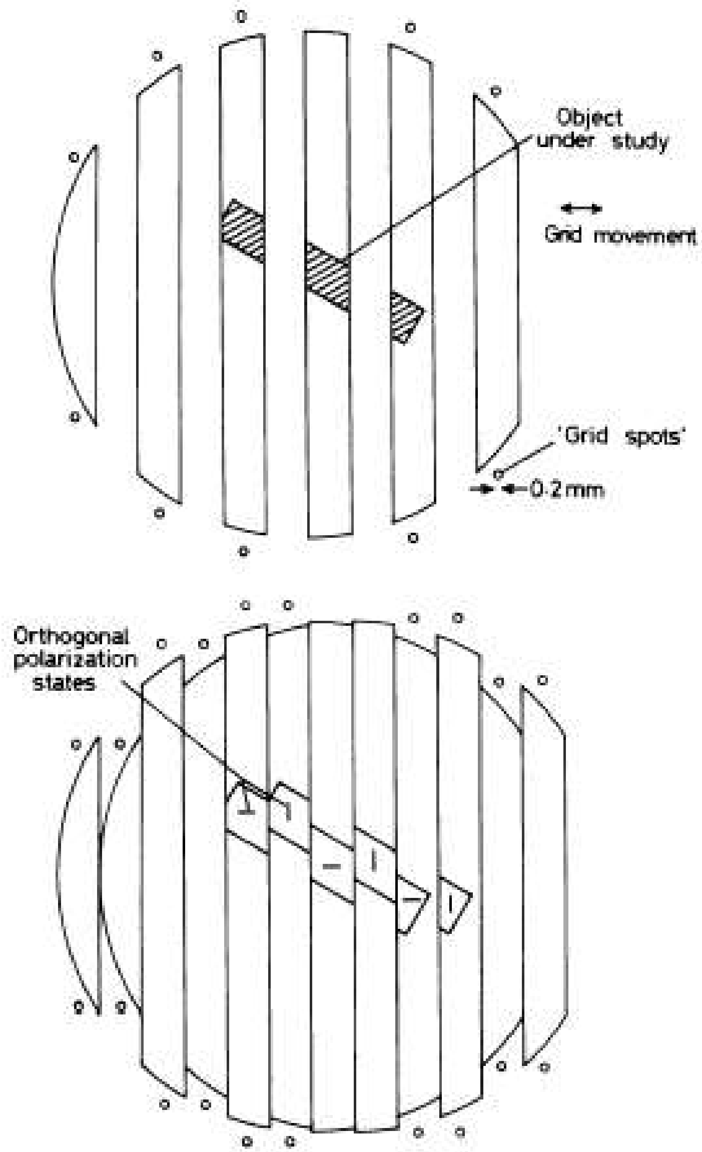


instrument used



measuring principle, e.g. FORS1

S. M. Scarrott et al.



FORS1 – polarization optics

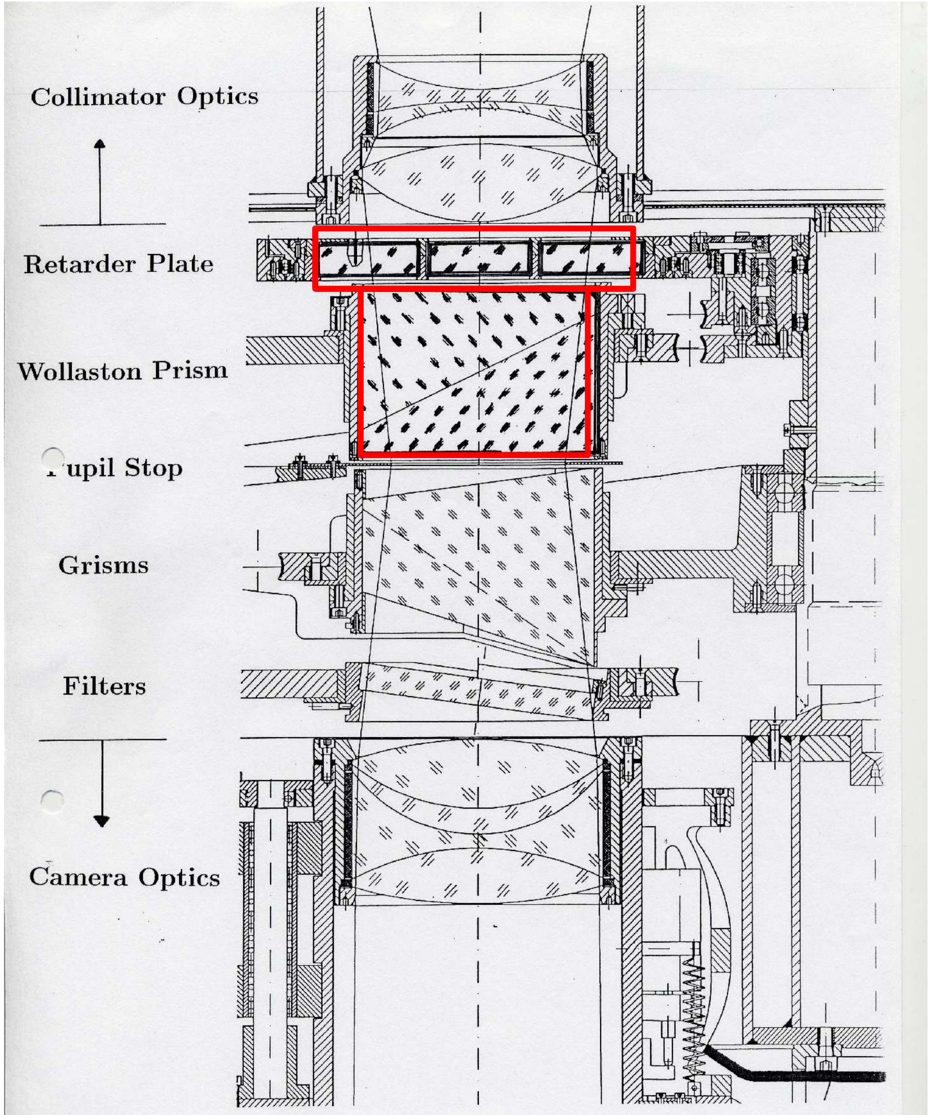
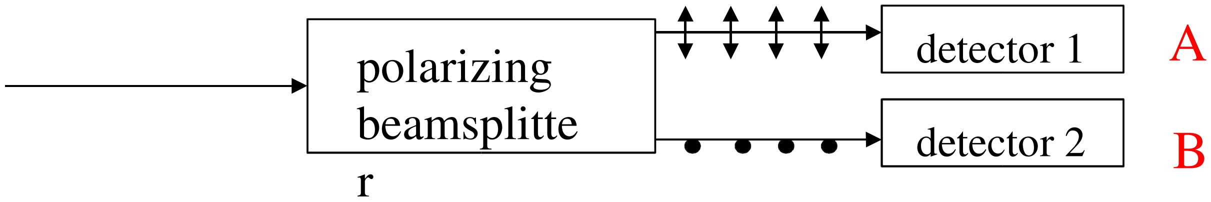


FIGURE 2: The collimated beam of the instrument. The polarization optics (red) are located in front of the internal pupil stop, followed by the grism wheel and the filter wheel.

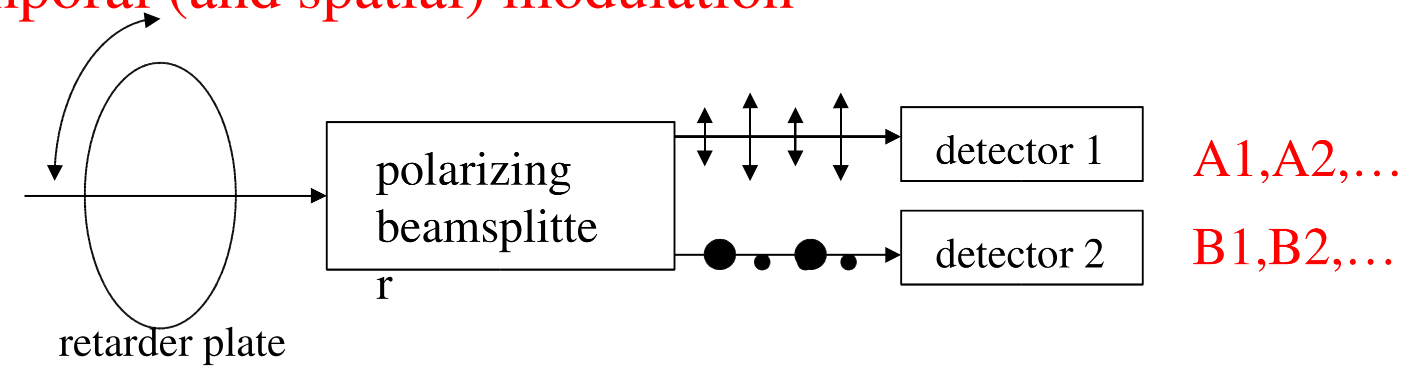
basic polarimetric techniques

spatial modulation



$p = (A-B)/(A+B)$ (but flat-fielding and differential aberrations)

temporal (and spatial) modulation



$p = (A1-A2)/(A1+A2)$ (one detector)

$p = (R-1)/(R+1)$, $R^2= A1/B1*B2/A2$ (two detectors)

- slow modulation: residual temporal, aberrations and flat-fielding effects (e.g. Appenzeller 1967, FORS1)

Systems with retarder plate (FORS1, EFOSC2)

Reminder:

$Q = I_0 - I_{90}$ → $p = ((Q/I)^2 + (U/I)^2)^{1/2}$

$U = I_{45} - I_{135}$ → $\theta = 0.5 \operatorname{atan}(U/Q)$

$V = I_{left} - I_{right}$ (see Patat & Romaniello 2006)

Two exposure yield:

- Q/I, U/I (HWP), or, V/I (QWP)
- I if system is flux calibrated

Reduction according to ESO manuals

$$p_{Q,U,V} = 0.5 \left(\left(\frac{fo - fe}{fo - fe}\right)_{\alpha} - \left(\frac{fo - fe}{fo - fe}\right)_{\alpha\ (\text{switched})} \right)$$

Reduction according to WHT, AAO user manuals

$$R^2 = \left(\left(\frac{fo - fe}{fo - fe}\right)_{\alpha} \Big/ \left(\frac{fo - fe}{fo - fe}\right)_{\alpha\ (\text{switched})} \right)$$

$$p_{Q,U,V} = (R - 1)/(R+1)$$

FORS 1: Some examples for polarimetric observations

Weak magnetic field measurements for “faint” white dwarfs

Have all WD amplified (kG) fields from their progenitors?

→ FORS1 observations: 3 out of 12 WD have ~5 kG fields

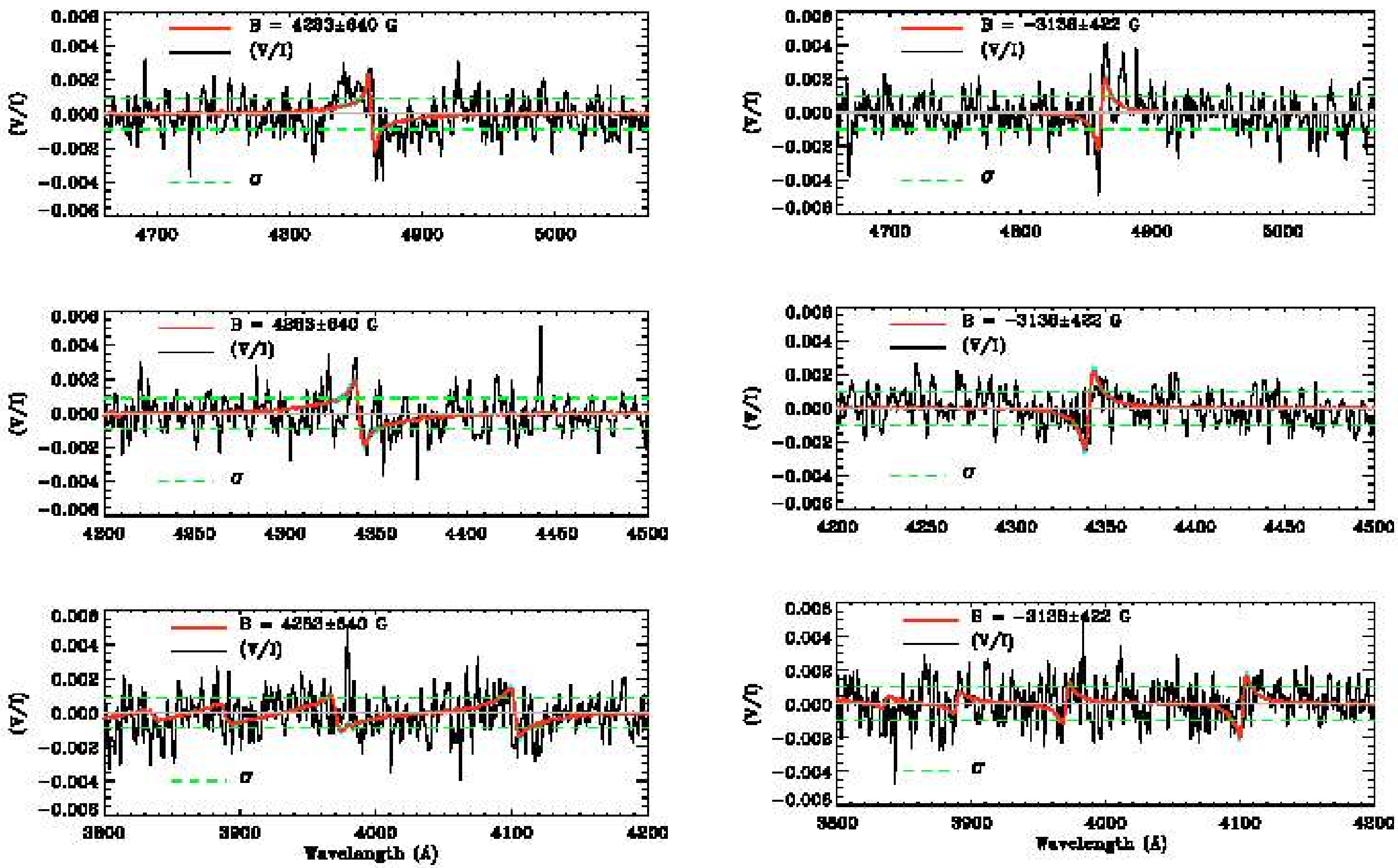


Fig. 3. Circular polarisation spectra (V/I) of WD 0446−789 (average of observations from 30/11/03 and 28/01/03, thin solid line) in the region of Hβ (*top*), Hγ (*middle*) and close to the Balmer jump (*bot-*

Fig. 4. As in Fig. 3 but for WD 2359−434 (average of observations from 04/11/03 and 29/11/03), where the best fit is at $\langle B_z \rangle = -3138 \pm 422$ G.

Stellar magnetic fields = (rel.) circular spectropolarimetry

Achieved

- High precision $\Delta p = \pm 0.1\%$

main problem:

- spectral resolution rather low
  - R >> 10000 to resolve Stokes V profiles → G1400 grims

Calibration issues

- Polarization efficiency V→ V (or is there V→ U etc.)
- photons noise limit for typical targets would be $\Delta p < \pm 0.1\%$

  → is higher precision possible (systematic errors, faster read out mode)
- How can the performance of the instrument in this mode be monitored and quantified
  - How important?
  - suitable standard stars for this type of monitoring?

Future directions

- Higher resolution (G2000 grisms ??)
- Higher precision

  →Q,U (<< V) measurements could be possible (scientific need; Cross talk V → U)

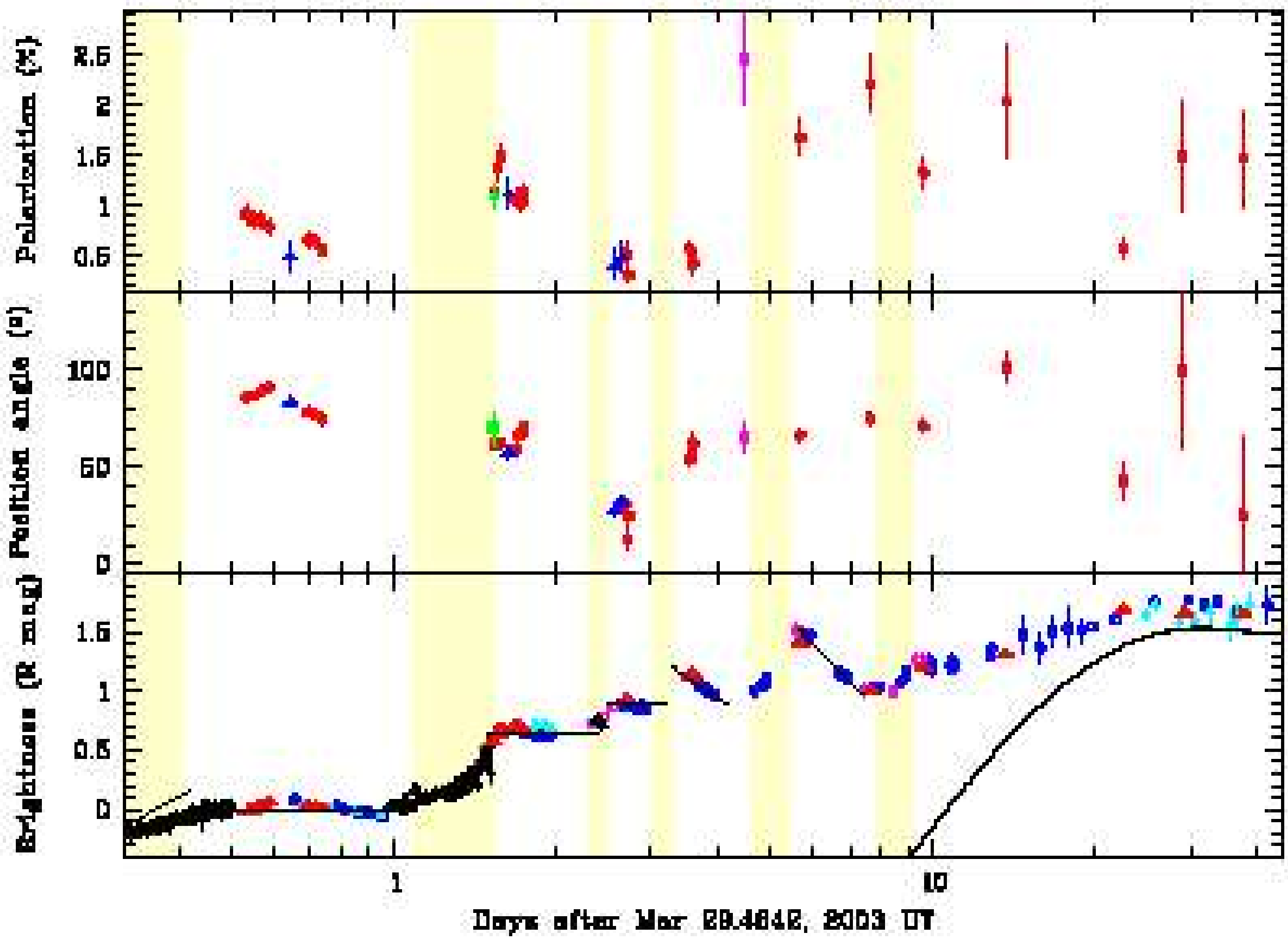
→ Data reduction pipeline

Polarimetric mode for a high resolution spectrograph!

– see instrument survey in Poster 12 (Hubrig & Ilyin)

FORS 1: Some examples for polarimetric observations

Polarimetric evolution of GRB 030329 (Greiner et al.)
Are there ordered magnetic fields in the rel. jet?



(Absolute) Polarimetry/Spectropolarimetry GRB, SN, AGN, stars etc.

Achieved:

- High sensitivity $\Delta p_{rel} = \pm 0.2\%$ with
- good absolute calibration $\Delta p_{sys} = \pm 0.2\%$, $\Delta \theta_{sys} = \pm 2^{o}$, if enough photons can be collected

Main problem:

- calibration of instrument for each run
  - not efficient (→ monitoring by ESO-staff)
  - Improved standard star lists (fainter, distribution)

Calibration issues

- Calibration plan → higher precision (for bright objects)
  → less overhead
  - Enough photons for higher polarimetric precision $\Delta p < \pm 0.1\%$ → is higher precision possible (systematic errors)
  - Tests for (Spectro)-Polarimetry in fast read-out mode
  - Better results for defocussed images?

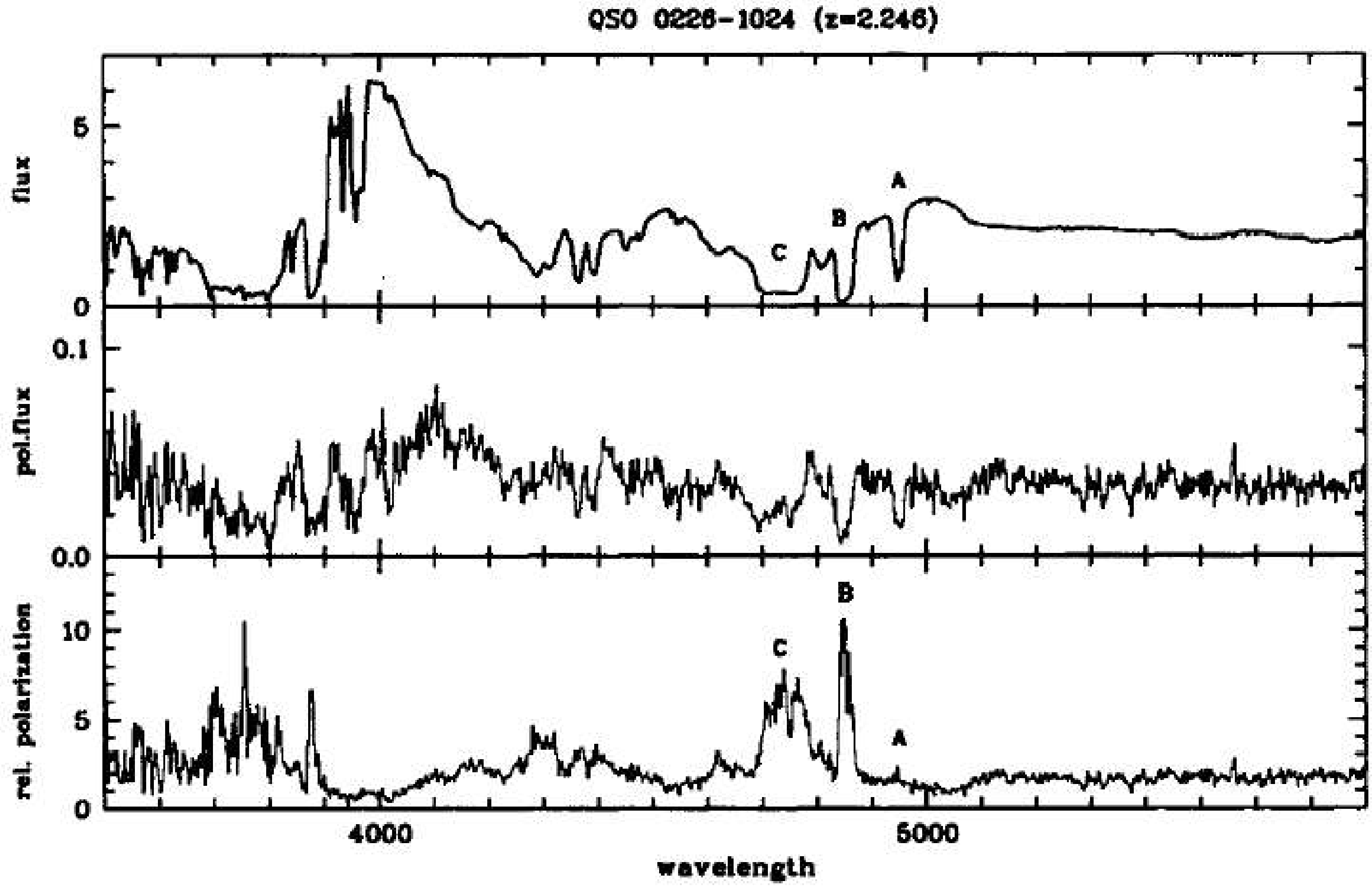
Future directions:

- AGN, GRB, SN (polarimetrically interesting targets)
  - Take photometry or spectroscopy in polarimetric mode
  → you get polarization for free
- calibration must be supported!

FORS 1: Some examples for polarimetric observations

Scattering geometry in Active Galactic Nuclei

Are BAL quasars borderline cases between Type 1 and Type 2 quasars?

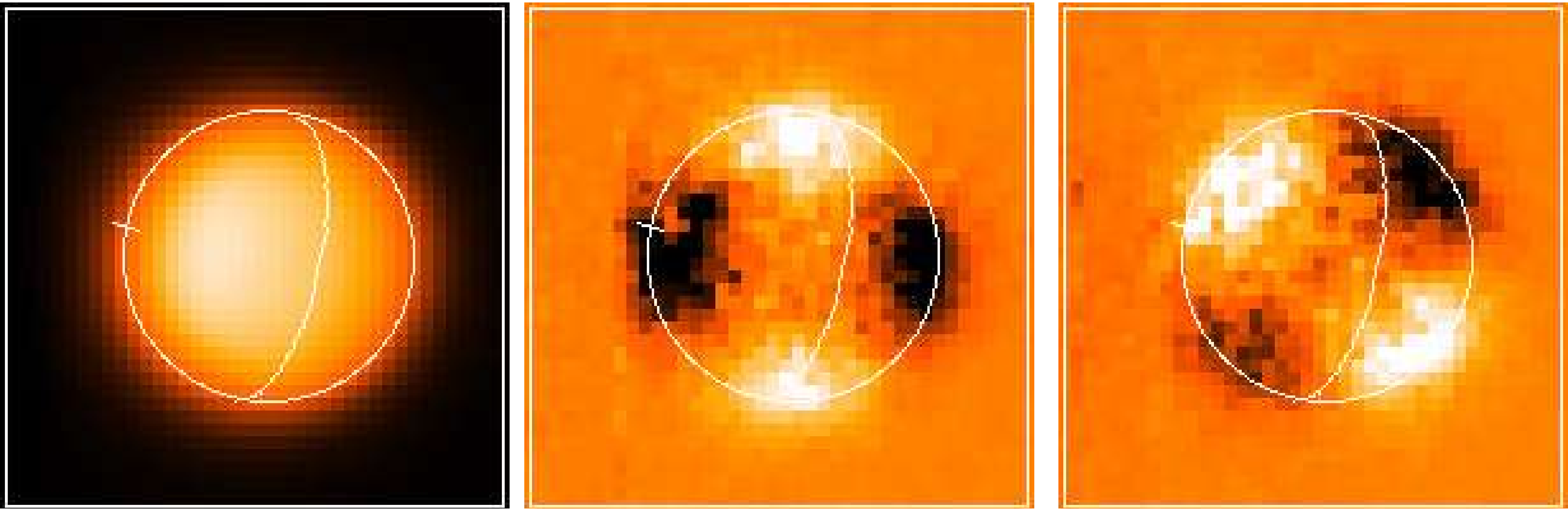


hot science topic: spectropolarimetry (asymmetry) of SN (Baade, Patat, Wang, ...)

Uranus and Neptune: Polarimetric Imaging with ESO 3.6m and EFOSC

- filters R (680 nm) , I (800 nm) , z (900 nm)
- Wollaston and rotating half-wave plate

Uranus: I-band, seeing: 0.8” (diameter: 3.6”)



Stokes I = $I_0 + I_{90}$ or $= I_{45} + I_{135}$

Stokes Q = $I_0 - I_{90}$

Stokes U = $I_{45} - I_{135}$

→ everywhere a polarization perpendicular to the limb

Imaging polarimetry

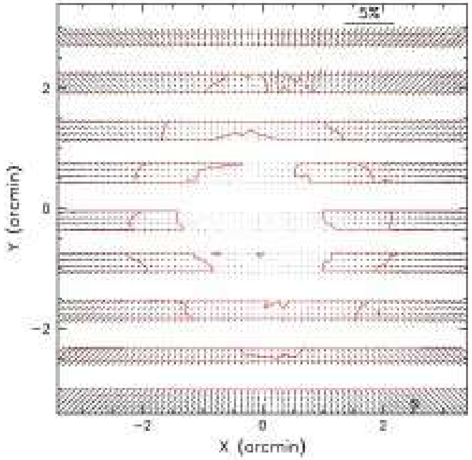
Achieved:

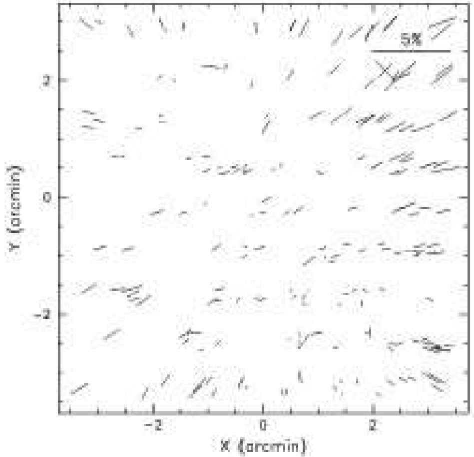
- Good performance for small central field (1’x 1’)

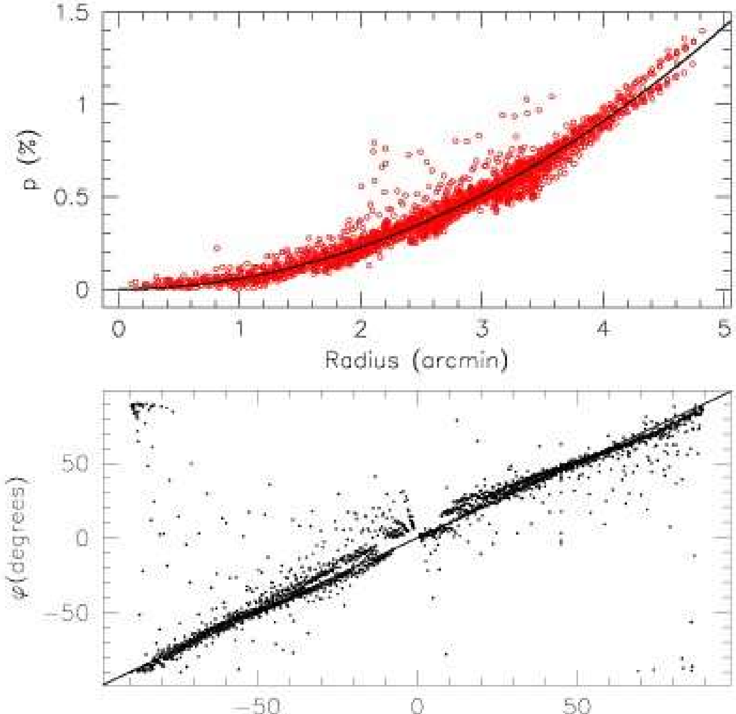
Main problem:

- Field dependent instrument polarization (curvature of lenses)
- Calibration of polarimetry requires quite some pioneering efforts for a potential user

GOAL: Polarization maps of Galaxies







FORS1 (and EFOSC2)

are excellent (state of the art) instrument for astrophysical polarimetry

- Versatile polarimetric instrument
  - Small instrumental polarization (centro-symmetric Cassegrain instrument)
  - circular and linear polarizations
  - Spectropolarimetry and imaging polarimetry

Possible Improvements (← if science drivers are present)

- calibration support to attract more astronomers
- monitoring of instrument polarization zero points → less overhead
- cook-book for calibration of “wide field” polarimetry
- pushing the polarimetric precision for bright targets (faster read-out mode, defocussing?)

VLT limiting magnitudes for one Stokes parameter in 1h exposure

Δp	N(photons)	polarimetry	spectropolarimetry		
		B or V	R=100	R=1000	R=30000
1%	10^4	23^m	20^m	$17.^m5$	14^m
0.1%	10^6	18^m	15^m	$12.^m5$	9^m
0.01%	10^8	13^m	10^m	$7.^m5$	4^m
0.001%	10^{10}	8^m	5^m		
0.0001%	10^{12}	3^m			

(from: Schmid, Appenzeller, Stenflo, Kaufer, 2002)

Polarimetry with SOFI, ISAAC and NACO

- Not frequently used → not many papers and science case examples
- More difficult due to hardware design
- not well documented – pioneering efforts required from observer
- calibration targets in near IR are not well established

Instrument	Focal station	Folding mirror in instrument	Wollaston	Rot. retarder plate (switch)
FORS1 (EFOSC2)	Cassegrain (p_{tel}<0.1%)	No	Yes	Yes
SOFI	Nasmyth ($p_{tel}\approx 1\%$)	No	Yes	No
ISAAC	Nasmyth ($p_{tel}\approx 1\%$)	Yes	Yes	No
NACO	Nasmyth ($p_{tel}\approx 1\%$)	Yes	Yes	comps. in different orientations

Stokes vectors and Mueller calculus

Stokes vectors describe the polarization of light

$$\begin{pmatrix} \mathbf{I} \\ \mathbf{Q} \\ \mathbf{U} \\ \mathbf{V} \end{pmatrix} = \begin{pmatrix} \mathbf{I} \\ \mathbf{I_0 - I_{90}} \\ \mathbf{I_{45} - I_{135}} \\ \mathbf{I_l - I_r} \end{pmatrix} = \begin{pmatrix} \text{total intensity} \\ \text{linear polarization in direction 0/90 degr.} \\ \text{linear polarization in direction 45/135 degr.} \\ \text{circular polarization} \end{pmatrix}$$

Mueller matrices describe the effects of optical components on the Stokes vector

$$\mathbf{I' = M\ I}$$

$$\begin{pmatrix} \mathbf{I'} \\ \mathbf{Q'} \\ \mathbf{U'} \\ \mathbf{V'} \end{pmatrix} = \begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{pmatrix} \begin{pmatrix} \mathbf{I} \\ \mathbf{Q} \\ \mathbf{U} \\ \mathbf{V} \end{pmatrix} = \begin{pmatrix} I \rightarrow I & Q \rightarrow I & U \rightarrow I & V \rightarrow I \\ I \rightarrow Q & Q \rightarrow Q & U \rightarrow Q & V \rightarrow Q \\ I \rightarrow U & Q \rightarrow U & U \rightarrow U & V \rightarrow U \\ I \rightarrow V & Q \rightarrow V & U \rightarrow V & V \rightarrow V \end{pmatrix} \begin{pmatrix} \mathbf{I} \\ \mathbf{Q} \\ \mathbf{U} \\ \mathbf{V} \end{pmatrix}$$

For an ideal telescope or instrument there is:
(e.g. Cassegrain telescope)

$$\mathbf{M} = c \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Mueller matrix for an inclined mirror:

$$\mathbf{M} = c\begin{pmatrix} \mathbf{m_{11}} & \mathbf{m_{12}} & \mathbf{0} & \mathbf{0} \\ \mathbf{m_{21}} & \mathbf{m_{22}} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{m_{33}} & \mathbf{m_{34}} \\ \mathbf{0} & \mathbf{0} & \mathbf{m_{43}} & \mathbf{m_{44}} \end{pmatrix} = c\begin{pmatrix} \mathbf{I \rightarrow I} & \mathbf{Q \rightarrow I} & \mathbf{0} & \mathbf{0} \\ \mathbf{I \rightarrow Q} & \mathbf{Q \rightarrow Q} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{U \rightarrow U} & \mathbf{V \rightarrow U} \\ \mathbf{0} & \mathbf{0} & \mathbf{U \rightarrow V} & \mathbf{V \rightarrow V} \end{pmatrix}$$

Aluminum mirror with angle of incidence 45 degrees (Nasmyth mirror):

wl = 800nm

$$\mathbf{M} = \begin{pmatrix} 0.95 & 0.05 & 0 & 0 \\ 0.05 & 0.95 & 0 & 0 \\ 0 & 0 & -0.94 & -0.14 \\ 0 & 0 & 0.14 & -0.94 \end{pmatrix}$$

wl = 1700 nm

$$\mathbf{M} = \begin{pmatrix} 0.99 & 0.01 & 0 & 0 \\ 0.01 & 0.99 & 0 & 0 \\ 0 & 0 & -0.99 & -0.08 \\ 0 & 0 & 0.08 & -0.99 \end{pmatrix}$$

Rotation matrix (angle α)

$$\mathbf{R}(\alpha) = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2a & \sin 2a & 0 \\ 0 & -\sin 2a & \cos 2a & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Instrument **Telescope**

$$\mathbf{M} = \mathbf{R'}(\beta(t))\, \mathbf{M}_{inst}\, \mathbf{R}(\beta(t)) \quad \mathbf{R'}(\alpha(t))\, \mathbf{M}_{tel}\, \mathbf{R}(\alpha(t))$$

FORS1: $\mathbf{M}_{tel} \approx \mathbf{1}$ (Cass.), $\mathbf{M}_{inst} \approx \mathbf{1}$,

$$\mathbf{M}_{VLT+FORS1} \approx \mathbf{1}$$

SOFI: $\mathbf{M}_{tel} = \mathbf{M}_{45\text{-mirror}} \neq \mathbf{1}$ (Nasmyth), $\mathbf{M}_{inst} \approx \mathbf{1}$?

$$\mathbf{M}_{NTT+SOFI}(Q) \approx \mathbf{1} \quad \mathbf{R'}(\alpha(t,Q))\, \mathbf{M}_{tel}\, \mathbf{R}(\alpha(t,Q))$$

$$\mathbf{M}_{NTT+SOFI}(U) \approx \mathbf{1} \quad \mathbf{R'}(\alpha(t,U))\, \mathbf{M}_{tel}\, \mathbf{R}(\alpha(t,U))$$

ISAAC: $\mathbf{M}_{tel} = \mathbf{M}_{45\text{-mirror}} \neq \mathbf{1}$ (Nasmyth), $\mathbf{M}_{inst} \neq \mathbf{1}$??????

$$\mathbf{M}_{VLT+ISAAC}(Q) = \mathbf{R'}(\beta(t,Q))\, \mathbf{M}_{inst}\, \mathbf{R}(\beta(t,Q)) \quad \mathbf{R'}(\alpha(t))\, \mathbf{M}_{tel}\, \mathbf{R}(\alpha(t))$$

$$\mathbf{M}_{VLT+ISAAC}(Q) = \mathbf{R'}(\beta(t,Q))\, \mathbf{M}_{inst}\, \mathbf{R}(\beta(t,Q)) \quad \mathbf{R'}(\alpha(t))\, \mathbf{M}_{tel}\, \mathbf{R}(\alpha(t))$$

Required for calibration of polarimetric modes:

- $\mathbf{M}_{tel}$ Mueller matrix for the telescope (M3)
- $\mathbf{M}_{inst}$ Mueller matrix for the instrument
- $\mathbf{R}(\alpha(t))$ $\mathbf{R}(\beta(t))$ appropriate rotation matrices

How to determine best $\mathbf{M}_{tel}$ and $\mathbf{M}_{inst}$ with calibrations??

Current Status:

- calibration of polarimetry not supported for SOFI and ISAAC
- severe lack of suitable (polarized) standard stars for the IR
  (see Poster P2 by Barrena et al.)

Still – there are successful observations made; e.g.

SOFI: Ks-band mapping of bipolar reflection nebula
(Ageorges and Walsh 2000)
$p_{target} \approx 20 - 50\ \%$, $p_{inst} \approx \pm 1\ \%$

NACO: Polarimetry of near-IR flares in Sgr A* (Eckart et al. 2006)
$p_{target} \approx 20\ \%$, p_{inst} (unclear to me, could be several %)

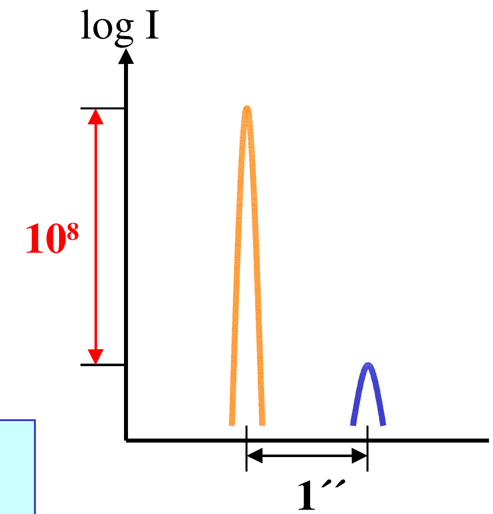
ESO Planetfinder

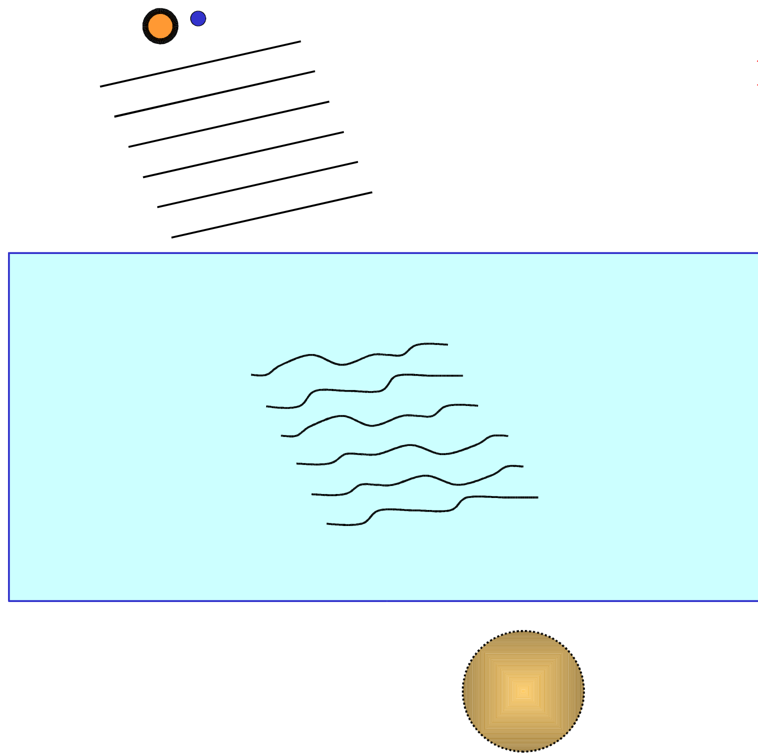
- 2nd generation VLT instrument for the direct imaging of extra-solar planets
- extreme AO-system + stellar coronagraph
- differential imaging technique for detecting signal from planet in the residual halo

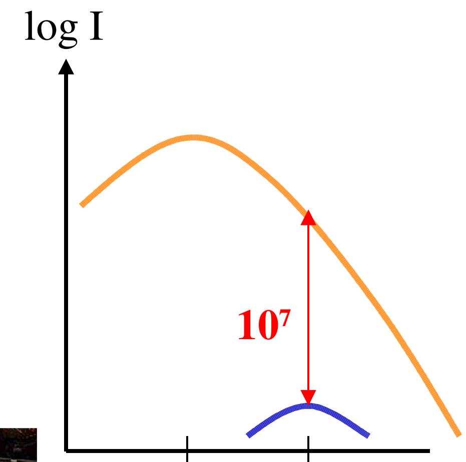
→ ZIMPOL polarimetry system, ETH Zurich

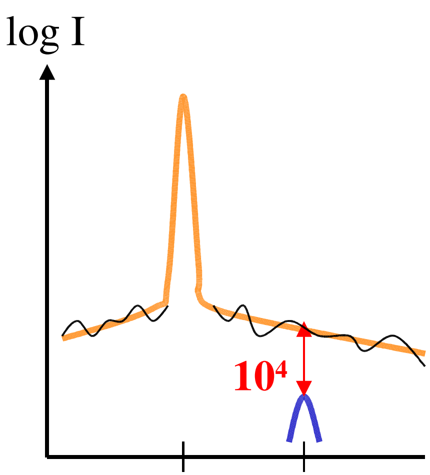
currently the most precise imaging polarimeter in the astronomical world (H.P. Povel et al.)

Example: Sun – Jupiter system at 5 pc



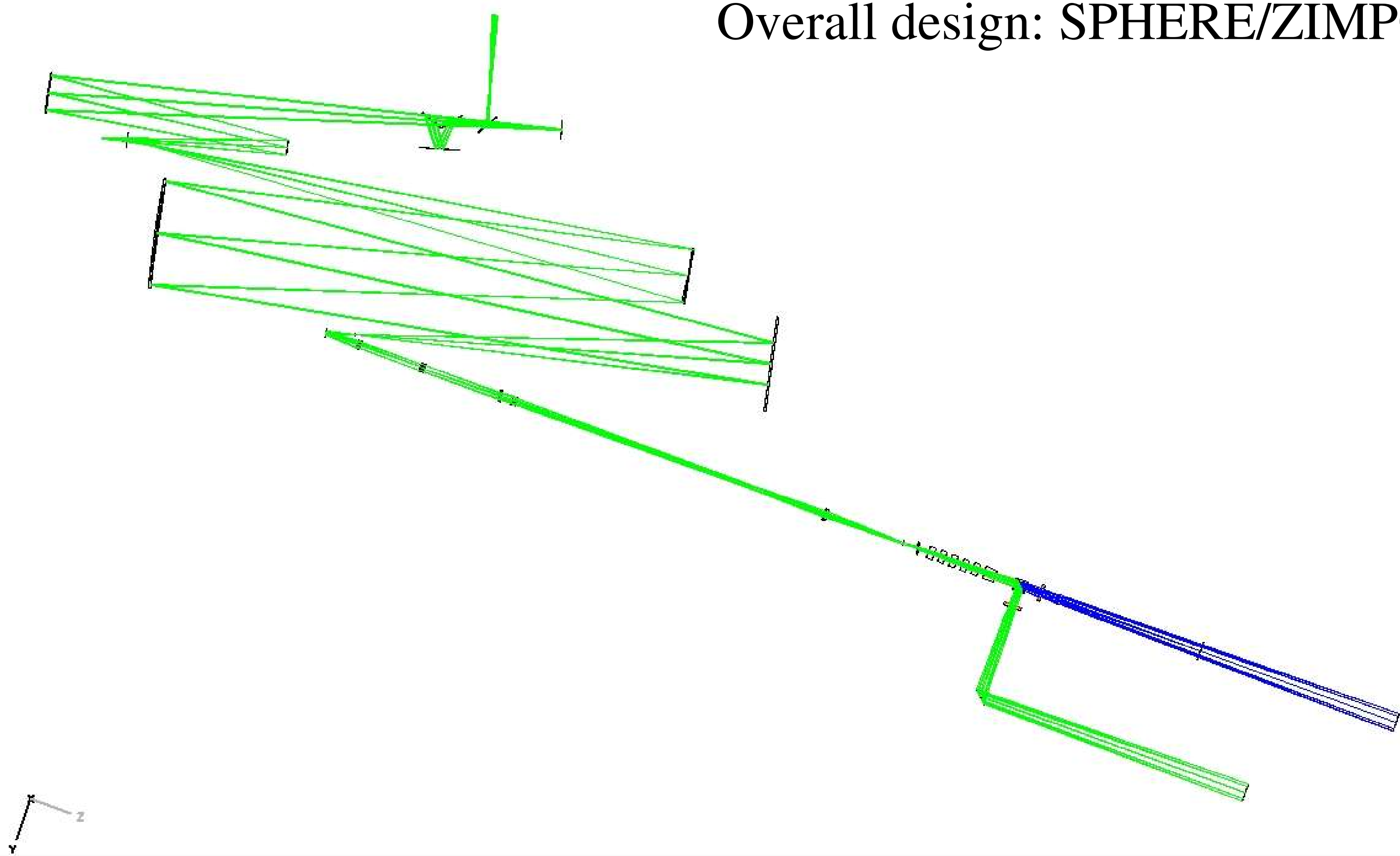






tiny planetary signal in bumpy
and variable PSF halo

Overall design: SPHERE/ZIMPOL



3D LAYOUT

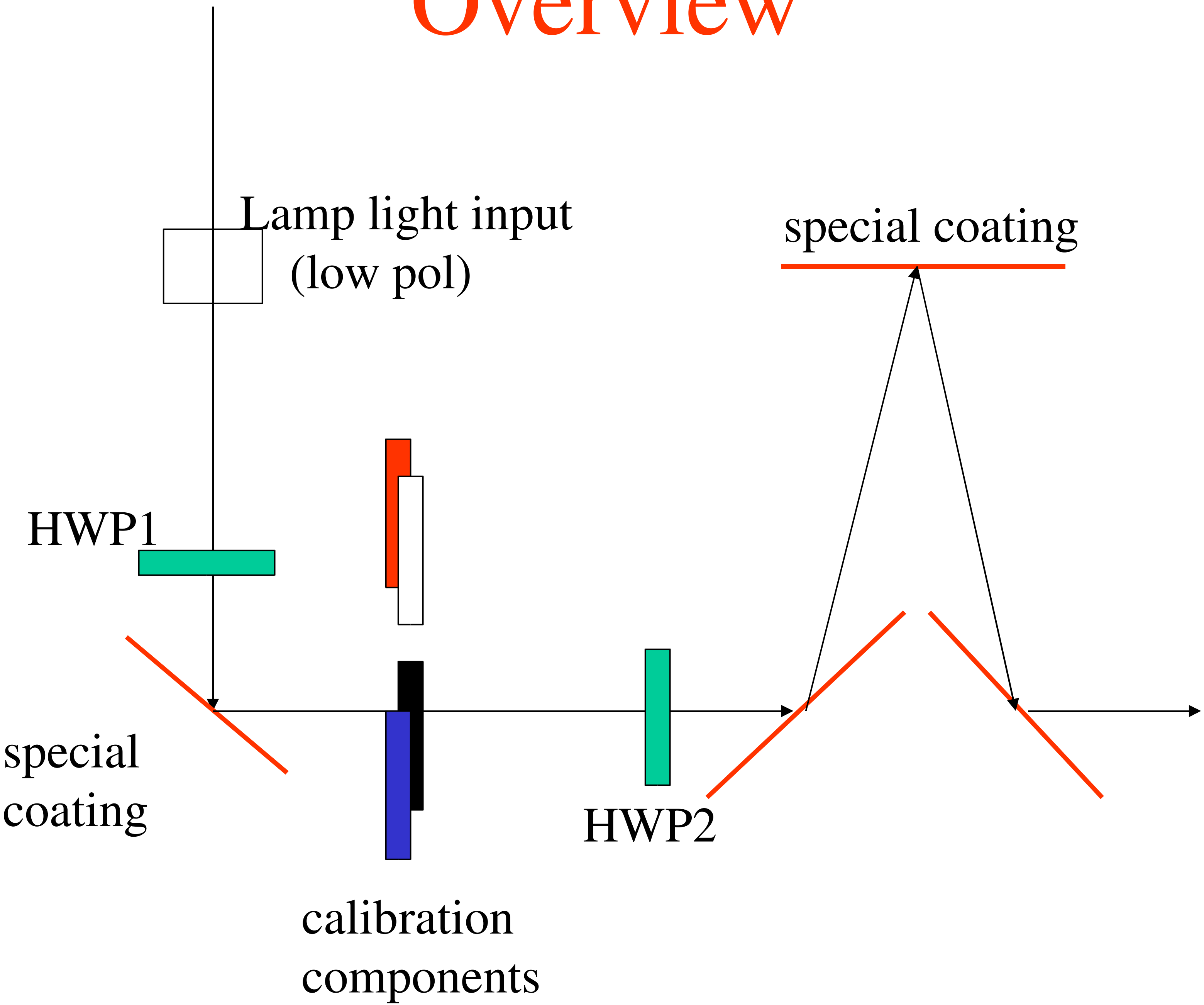
THU JUL 20 2006
SCALE: 0.0500

400.00 MILLIMETERS

ASTRON-DWINGELOO-NL
NETHERLANDS FOUNDATION FOR RESEARCH IN ASTRONOMY
FLORENCE RIGAL

X-SHOOTER-NIR
CONFIGURATION: ALL 2

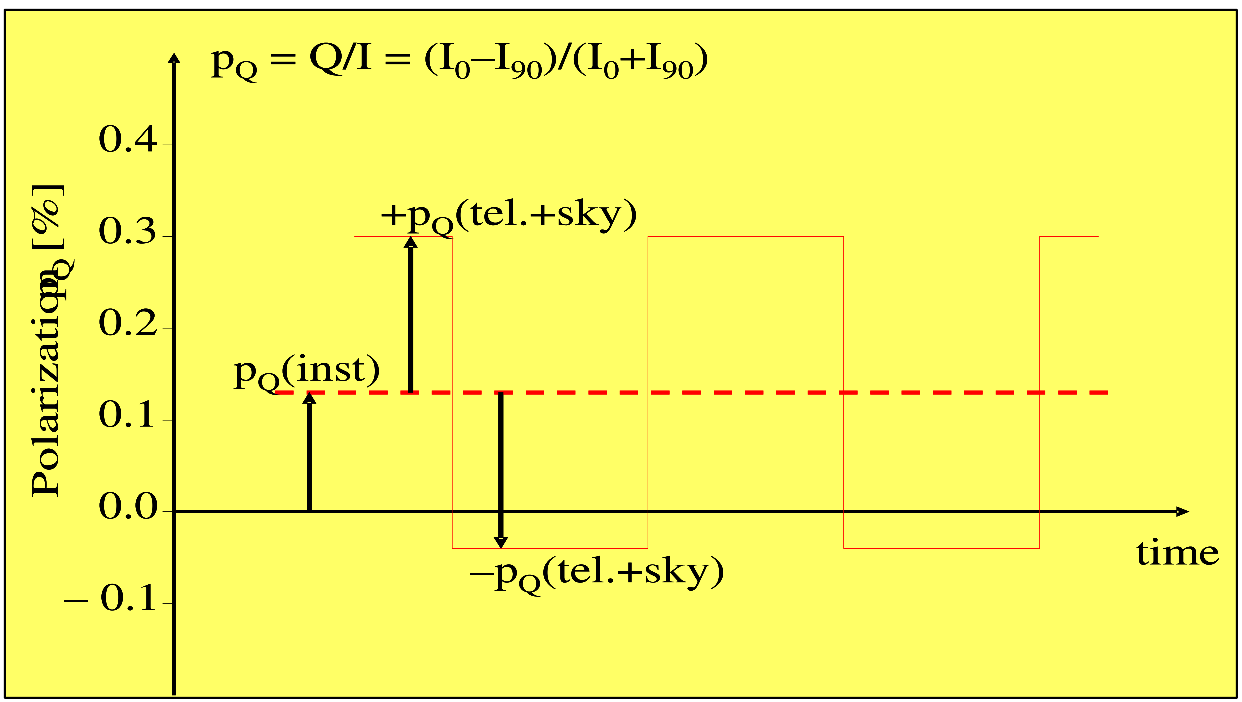
Overview

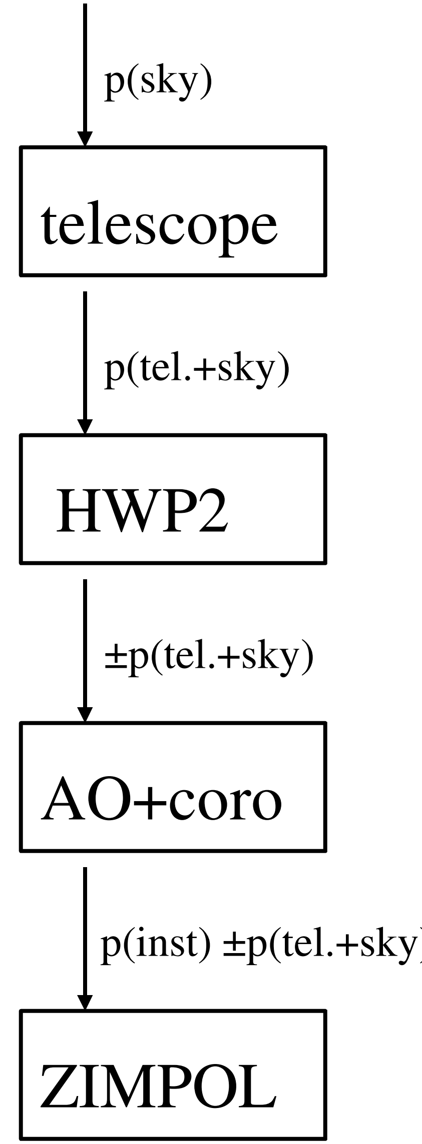


Lamp light input
(low pol)
special coating
HWP1
special
coating
HWP2
calibration
components

ZIMPOL/SPHERE measuring principle

- ZIMPOL measures polarization of
  - sky + telescope + instrument
- HWP2 = polarization switch to separate polarization from
  - sky + telescope
  - instrument (AO + coronagraph)





ZIMPOL achieves only a high precision if polarization is less than 1%

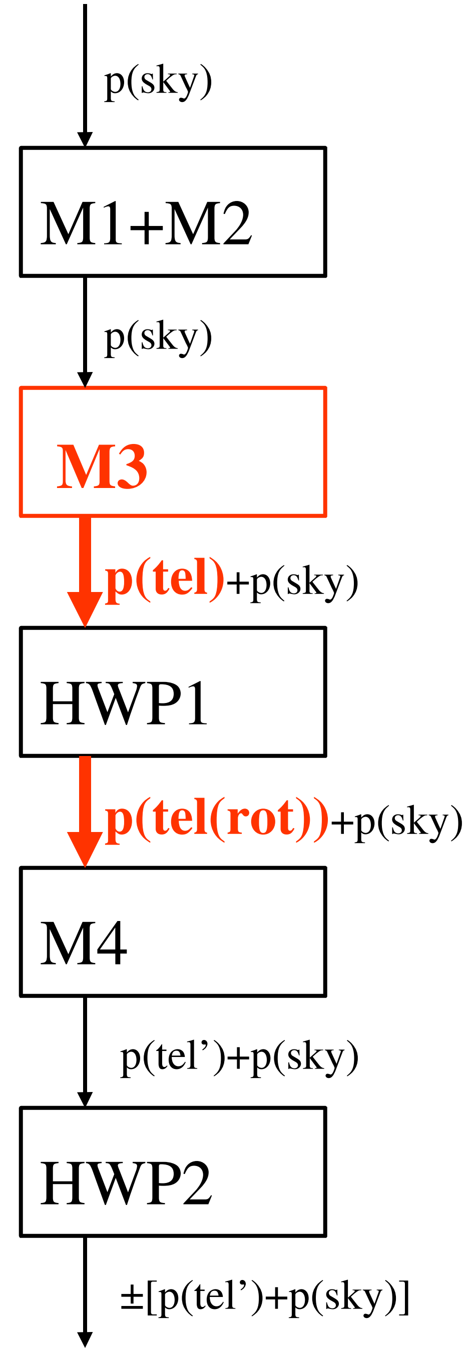
→p(tel.+sky) < 0.5%

→p(inst.) < 0.5%

Telescope polarization

- Introduced by mirror M3 (p=3-5%)
- HWP1 rotates the M3 instrument polarization into a direction parallel to M4
- M4 = crossed mirror to M3

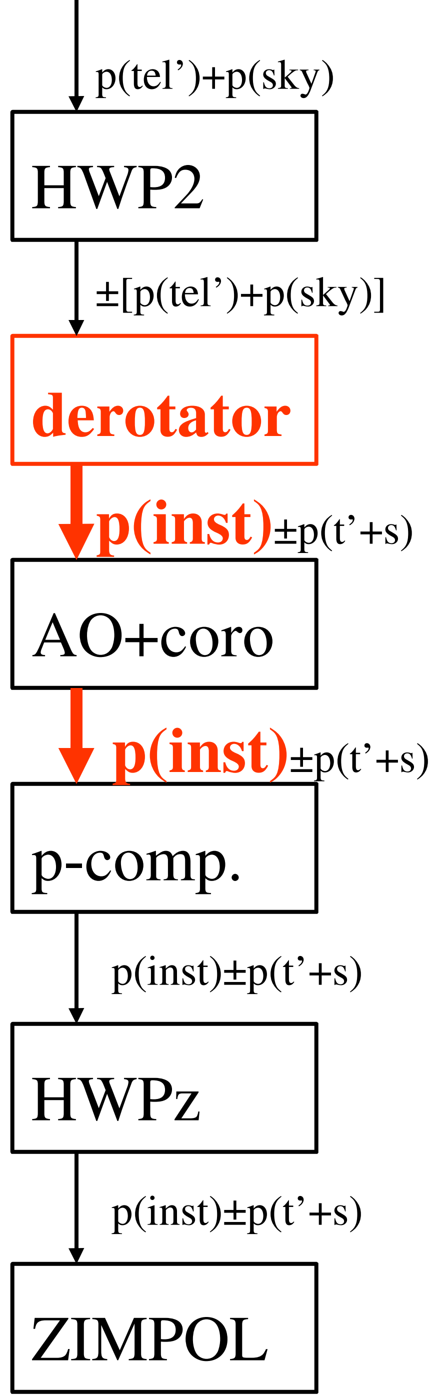
→instrument polarization is compensated (to less than 0.5%)



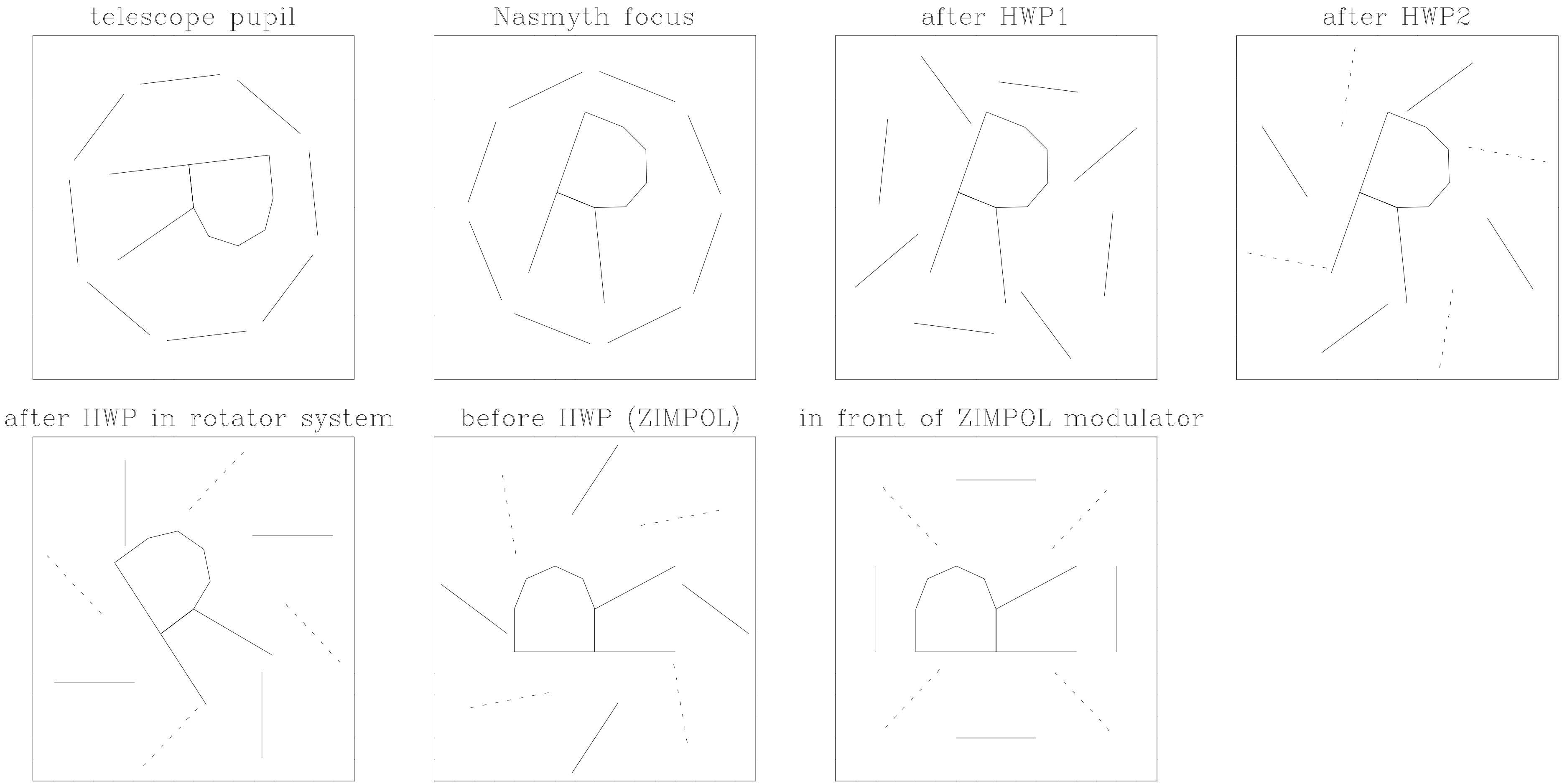
HWP1 rotates in step with telescope zenith angle

Instrument (common path) polarization

- strong polarization due to derotator (p=2-3%)
- derotator introduces strong cross-talk U→V
  - this requires that selected polarization is rotated into a direction parallel or perpendicular to derotator
  - this rotation is done with HWP2
- AO and coronagraph have no important effects
  - careful selection of coatings required (small angles)
- Polarization compensator
  - corrects the instrument polarization introduced by the derotator
    - P1 mode: fix (or in an active loop)
    - P2 mode: rotating in step with derotator
- HWPz (in ZIMPOL)
  - rotates selected polarization into ±Q direction of ZIMPOL
    - P1 mode: out
    - P2 mode: rotating in step with derotator



Rotations in mode P2 (Stokes Q)



Rotation of field and polarization for a particular case (a=–84 degr, z=27 degr, γ =0 degr, η =0 degr) in observing mode P2. This is equivalent to a Stokes Q measurement.

Calibration plan for ZIMPOL/SPHERE

- **Science Calibrations**
  - **Astrometric calibrations**
  - **Photometric calibrations**
  - **Telescope polarization calibrations (unpolarized standard stars)**
  - **Telescope zero point polarization angle (polarized standard stars)**
- **Technical Calibrations**
  - **Bias**
  - **Dark**
  - **Polarization flat**
  - **Intensity flat (bad pixels)**
  - **Sky flat**
  - **Modulation/demodulation efficiency**
- **Instrument monitoring**
  - **AO+C polarization efficiency**
  - **AO+C instrument polarization**
  - **AO+C polarization crosstalk**
  - **ZIMPOL modulation crosstalk (missing)**
  - **Telescope crosstalk**
- **Archive of spurious polarization features from telescope and instrument**

Summary

FORS1/EFOSC1 are great polarimetric instruments

- calibration support (for on axis targets) would attract more users
- FORS1 polarimetry in service mode
- could be pushed to higher precision and efficiency
- polarization maps of Galaxies should be possible

Near IR/Nasmyth instruments

- currently only for enthusiasts and pioneers
- Significant effort required for making polarimetric mode useful for a larger community
  - Determine instrument polarization (Mueller matrices)
  - description for the polarimetric calibration

Much will be learned from ZIMPOL/SPHERE for Nasmyth instruments

→ required, if polarimetry shall be possible at ELT

Example:

Stellar magnetic fields (38% of all pol. papers)

most (>80%) are based circular spectropolarimetry with FORS1 in order to resolve the Zeeman splitting of absorption lines

typical:

- often bright targets (m<12 mag) → EFOSC2 now equipped for circular polarimetry
- often high precision required pV < 1%
- Good spectral resolution is required →grism 1400??
- differential polarimetry, measurements relative to the continuum

Critical:

- reliable wavelength calibration required
- overhead can be substantial (bright targets)

Polarimetry with FORS1 and EFOSC2

- Cassegrain instrument (low telescope polarization!!!)
- No inclined folding mirror in the instrument
- Wollaston for simultaneous registration of opposite polarization modes
- Rotatable retarder plates to switch polarization between channels

Magnetic fields in stars = (relative) circular spectropolarimetry

Achieved

- High precision $\Delta p = \pm 0.1\%$ in measuring polarization signals in absorptions lines (with respect to continuum = no zero point calibration required)

main problem:

- higher spectral resolution is desirable (R >> 10000) to resolve Stokes V profiles

→ Degradation of the polarization signal due to the limited resolution

FORS was not designed for that (new G1400 grism could be very useful)

Calibration issues

- Polarization efficiency (instrumental degradation of the Stokes V signal → underestimate of the magnetic field? Comparison with higher resolution spectropolarimetry required!)
- Enough photons for higher polarimetric precision $\Delta p < \pm 0.1\%$ → is higher precision possible (systematic errors)
- Relative large overhead for bright stars
  - Tests for Spectropolarimetry in fast read-out mode
- How can the performance of the instrument in this mode be monitored and quantified:
  - Are there suitable standard stars for this type of monitoring

Future directions

- Measurement of the linear polarization profiles may be desirable to determine magnetic field structure in rotating stars (about an order of magnitude weaker than V signal → instrumental cross talk V→Q,U must be known)

Similar considerations are valid for the measurements of polarimetric line profiles due to scattering (linear polarization relative to continuum)

- Standard stars exist

(Absolute) Polarimetry/Spectropolarimetry GRB, SN, AGN, stars etc.

Achieved:

- High sensitivity $\Delta p_{rel} = \pm 0.2\%$
- good absolute calibration $\Delta p_{sys} = \pm 0.2\%$, $\Delta \theta_{sys} = \pm 2^{o}$, (if enough photons can be collected)

Main problem:

- Polarimetric calibration repeated for each run (no monitoring by ESO-staff)
  - not efficient
- Not many suitable standard stars
  - too bright
  - Not well distributed on sky (polarized standard stars)

Calibration issues

- Precision and efficiency could be substantially improved with a dedicated calibration plan
- Enough photons for higher polarimetric precision $\Delta p < \pm 0.1\%$
  - is higher precision possible (systematic errors)
  - Faster readout modes
  - Better results for defocussed images

Future directions:

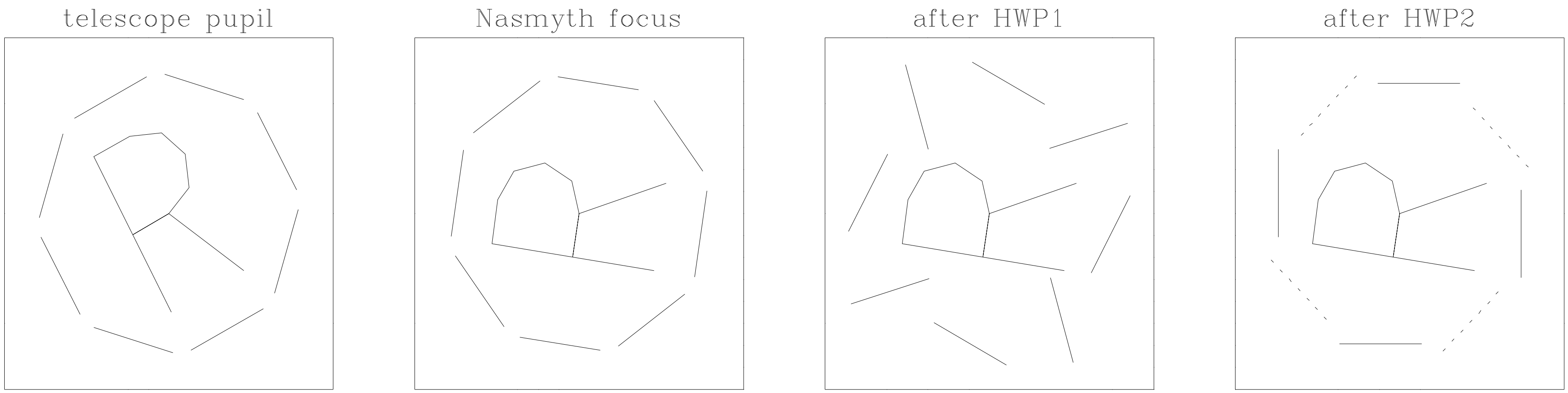
- For many observations of polarimetrically interesting targets (AGN, GRB, SN, etc.) the polarimetric information could be obtained routinely with little additional effort, without compromising the spectrophotometric or photometric measurement.

  → However, astronomer will only do that if the calibration of these data is also supported!

Summary:

- Telescope polarization is corrected with HWP1 and mirror M4
- HWP2 is used
  - as polarization switch to separate Instrument polarization and sky+telescope polarization
  - to orientate the selected polarization into the correct direction for the derotator
- The derotator polarization is corrected with a (co-rotating) polarization compensator
- HWPz rotates the polarization into the ZIMPOL system
- ZIMPOL performs the high precision measurement

Rotations in mode P1 (Stokes Q)

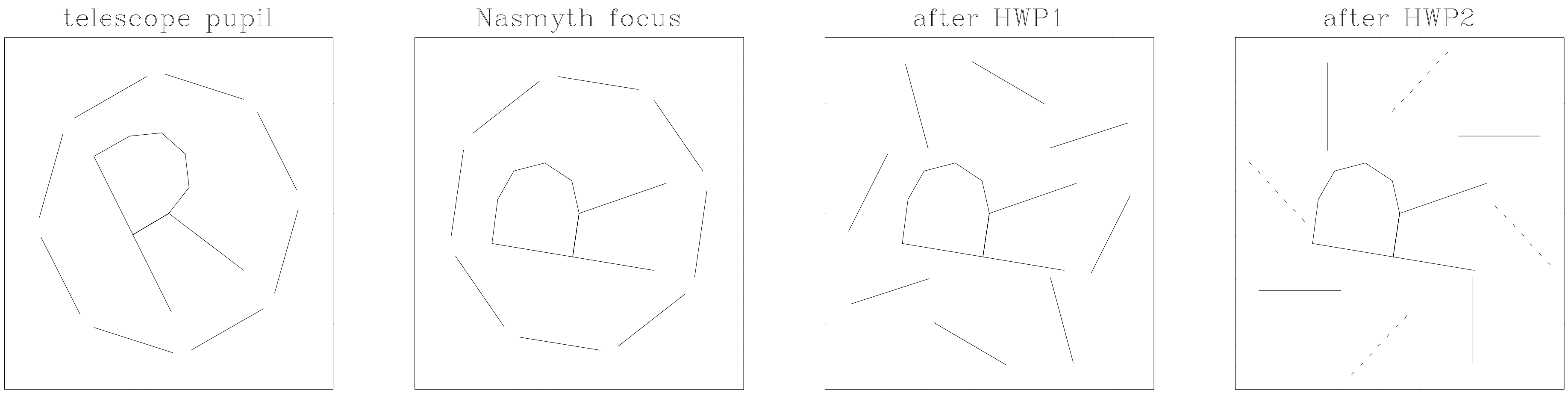


field: +a	f: a+(90-z)	f: a+(90-z)	f: a+(90-z)
pol: +a	p: a+(90-z)	p: “wild”	p: 90

Rotation of field and polarization for a particular case (a=28 degr, z=37 degr, γ =0 degr) in observing mode P1. This is equivalent to a Stokes Q measurement.

→After HWP2 only the perpendicular and parallel polarization will pass unaffected through derotator and compensator

Rotations in mode P1 (Stokes U)

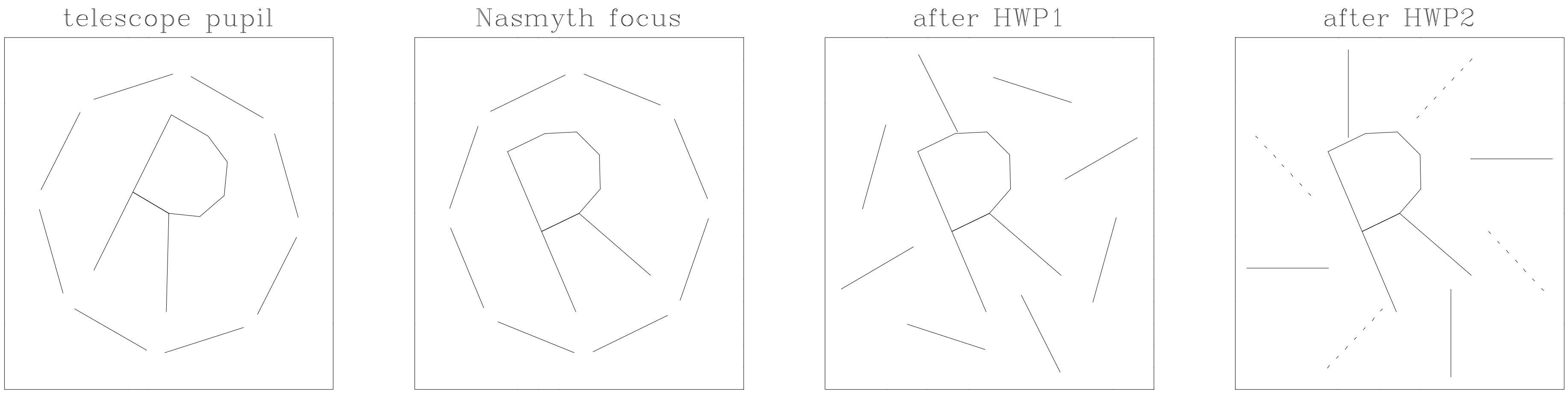


field: +a	f: a+(90-z)	f: a+(90-z)	f: a+(90-z)
pol: +a	p: a+(90-z)	p: “wild”	p: 90+45

Rotation of field and polarization for a particular case (a=28 degr, z=37 degr, γ =0 degr) in observing mode P1. This is equivalent to a Stokes U measurement.

→After HWP2 only the perpendicular and parallel polarization will pass unaffected through derotator and compensator

Rotations in mode P1 (Stokes Q)

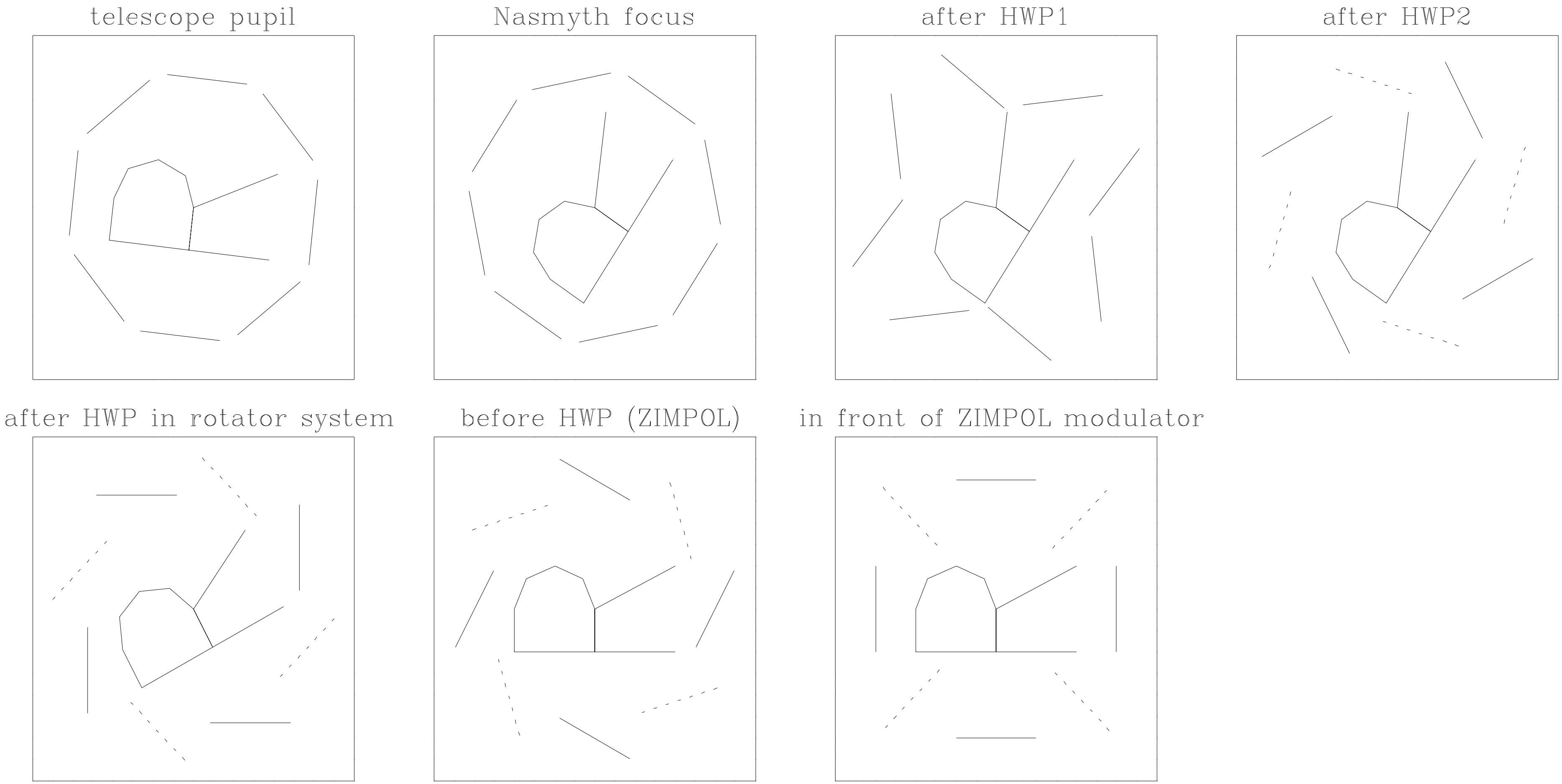


field: +a	f: a+(90-z)	f: a+(90-z)	f: a+(90-z)
pol: +a	p: a+(90-z)	p: a+90	p: 90

Rotation of field and polarization for a particular case (a= –28 degr, z=37 degr, γ =0 degr) in observing mode P1. This is equivalent to a Stokes Q measurement.

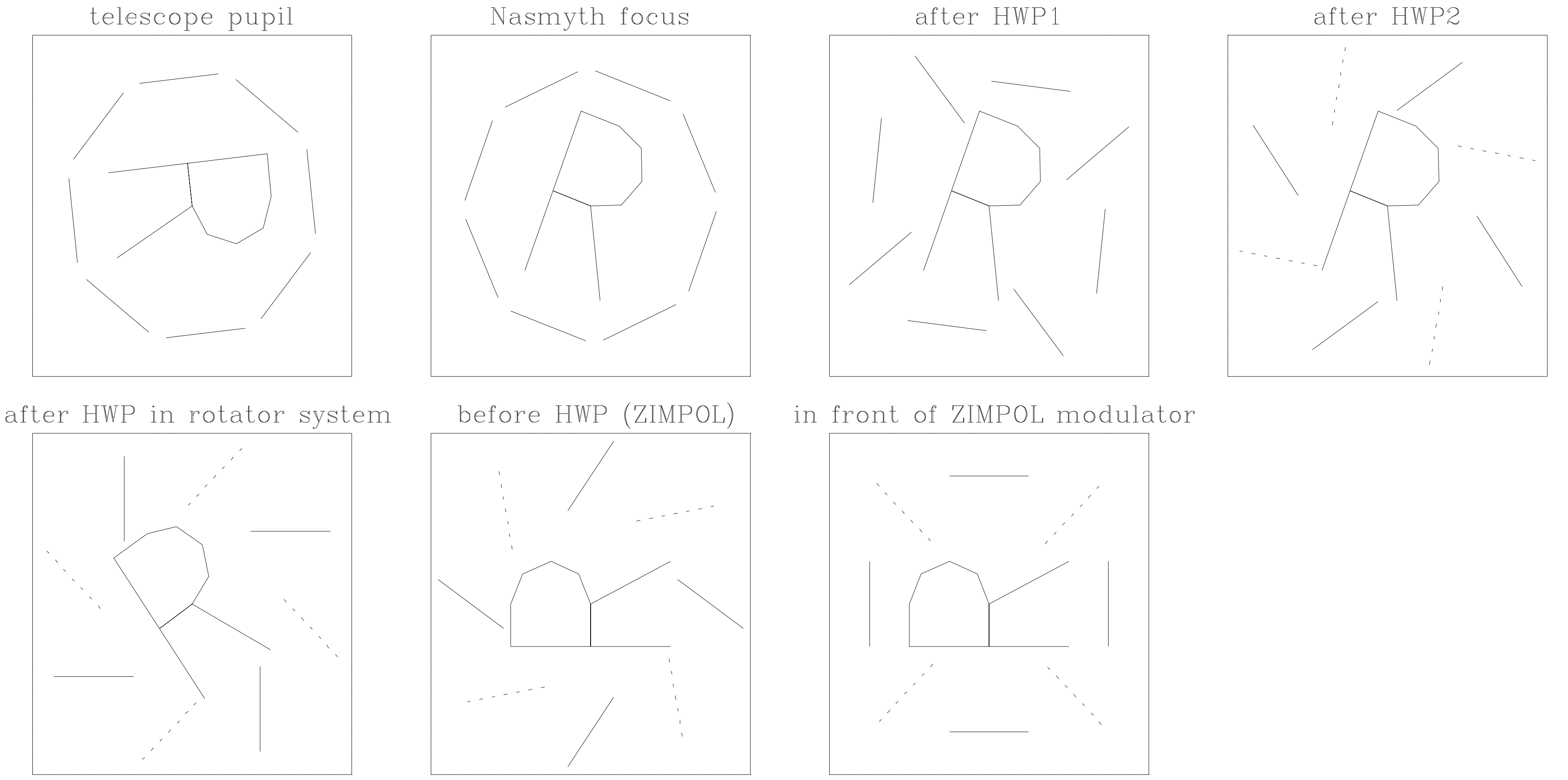
→After HWP2 only the perpendicular and parallel polarization will pass unaffected through derotator and compensator

Rotations in mode P2 (Stokes Q)



Rotation of field and polarization for a particular case (a=84 degr, z=27 degr, γ =0 degr, n =0 degr) in observing mode P2. This is equivalent to a Stokes Q measurement.

Rotations in mode P2 (Stokes Q)



Rotation of field and polarization for a particular case (a=–84 degr, z=27 degr, γ =0 degr, n =0 degr) in observing mode P2. This is equivalent to a Stokes Q measurement.

FORS 1: Some examples for polarimetric observations

Scattering geometry in Active Galactic Nuclei (HMS, Appenzeller et al.)

Is F51 a borderline case between Seyfert 1 and Seyfert 2?

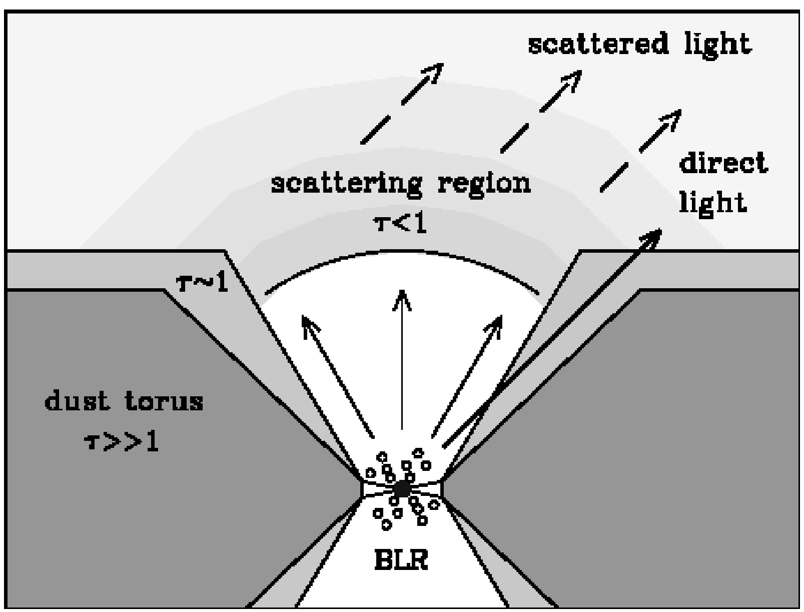
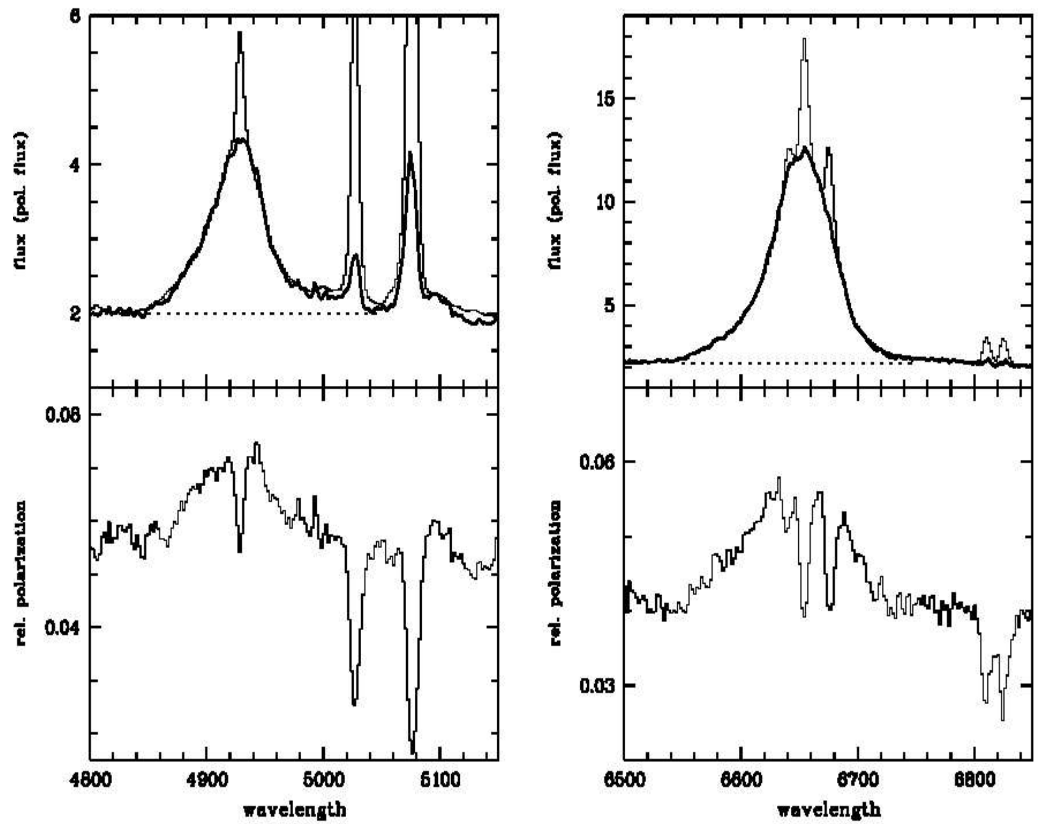


Fig. 6. Schematic scattering geometry suggested for F51. The black dot in the middle of the BLR clouds is the continuum source.



Summary on rotating components

For P1 mode:

- Rotation introduced by telescope, M3 and HWP1 are defined by target position
- Rotation speed of HWP2 is also defined by target position
- User has the freedom to choose a HWP offset angle γ (polarization offset angle 2γ)
- Recommended HWP2 offset angles: γ = 0,45,22.5,67.5 degrees (standard polarimetry)

For P2 mode:

- Rotation introduced by telescope, M3 and HWP1 are defined by target position
- Rotation speed of HWP2, derotator and HWP (ZIMPOL) is defined by target position
- HWP2 orientation depends on the orientation of the field derotator and the polarization offset angle 2γ.
- User has the freedom to choose a HWP2 offset angle γ and the field orientation offset angle n
- Recommended offset angles:
  - HWP2 offset angles: γ = 0,45,22.5,67.5 degrees (standard polarimetry)
  - Field offset angles n:
    - Case A: n =0 degr, North always in the same direction on detector)
    - Case B: $n \approx$a+(90-z), similar to P1 mode but allows derotation