Imaging polarimetry of exo-planets with the VLT and the E-ELT

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EPICS phase A: M. Kasper, C. Verinaud, C.U. Keller, L.B. Venema, F. Kerber, et al.

- Introduction: Why polarimetry?
- VLT SPHERE planet finder
- E-ELT EPICS planet finder

Why polarimetry? Reflected light from planets is polarized

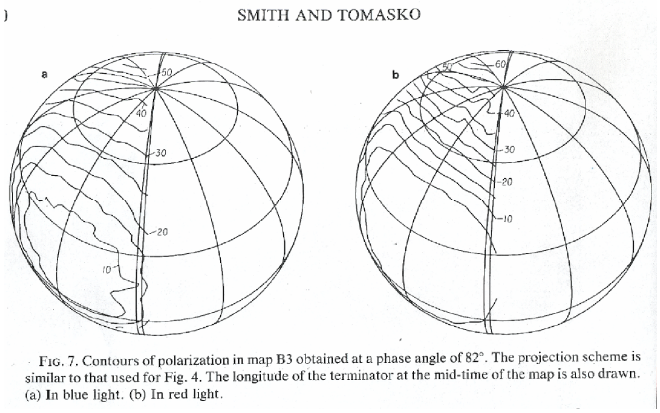


FIG. 7. Contours of polarization in map B3 obtained at a phase angle of 82°. The projection scheme is similar to that used for Fig. 4. The longitude of the terminator at the mid-time of the map is also drawn. (a) In blue light. (b) In red light.

at the poles:
- haze scattering

at equator:
- cloud reflection
- thin layer of Rayleigh scattering

Jupiter in blue light
p > 40 % at poles
p ~ 5-10 % at equator
p ~ 19 % integrated

Jupiter in red light
p > 40% at poles
p < 5% at equator
p ~ 11% integrated

Why polarimetry?

- reflected light from planets is polarized p ~ 5 – 50 %

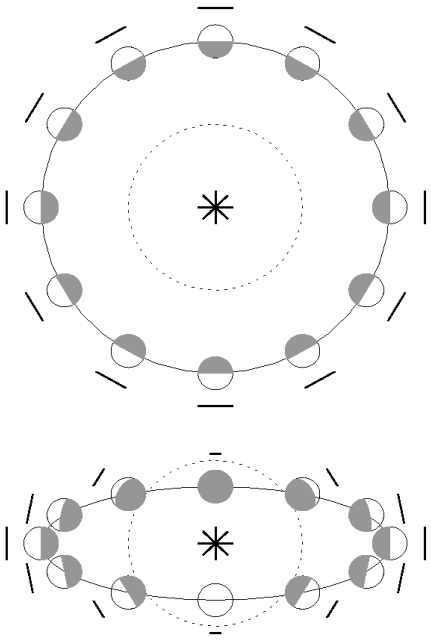
- planets and reflected light
  - relatively faint for young (hot), self-contracting planets
  - the only emission component for old giant planets or terrestrial planets in the visual / near-IR range
  - complementary to the thermal light
    → characterization of planets
- polarimetry vs. spectroscopy
  - polarimetry
    - color (spectral) dependence of singly scattered photons, $\tau < 1$
    - scattering phase matrix of particles (gas, haze/dust, clouds)
    - surface texture (terr. planets)
  - spectroscopy
    - Color (spectral) dependence of all reflected photons τ = 0-3
    - absorbing molecules
    - surface color (terr. planets)
- good method for speckle suppression (see later)

Phase dependence

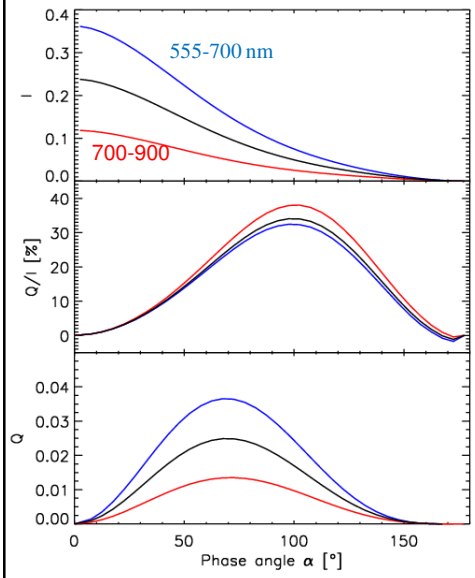
for Rayleigh-like scattering by molecules or haze particles

inclination = 0°
  p = constant & high
  θ rotates steadily
inclination = 70°
  p = high for large separation
  θ fast and slow rotation

direct light from star is unpolarized



Intensity and polarization phase curves



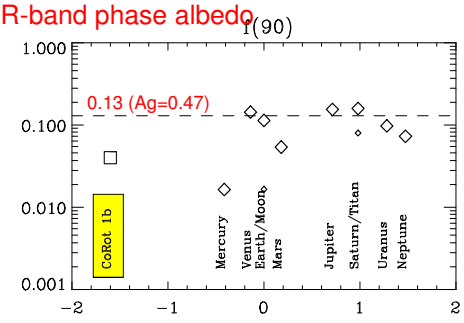
Intensity I
high for α = 0
(conjunction!)
I(90) ≈ 0.3 I(0)

Fractional polarization p (Q/I)
maximum near α =90

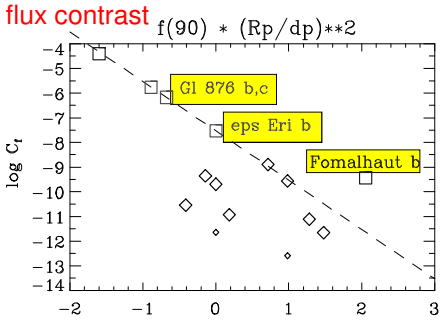
Polarization flux p x f (Q)
maximum near α =70

α =90 → representative signal

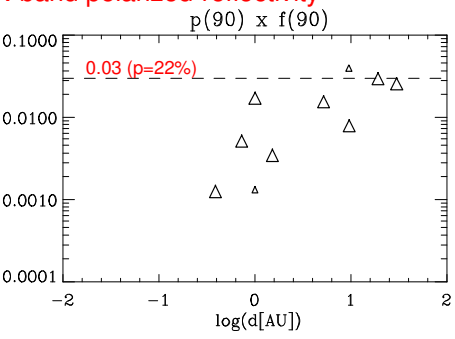
R-band phase albedo



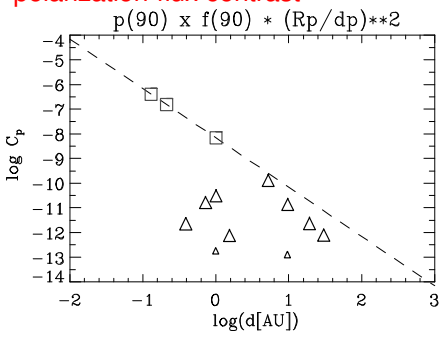
flux contrast



R-band polarized reflectivity



polarization flux contrast



Polarimetry with VLT / SPHERE

ZIMPOL (Zurich Imaging Polarimeter)

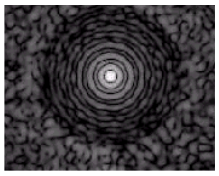
- FoV (detector): 3.5 x 3.5 arcsec
- wavelength range 600-900 nm
- in broad-band and narrow band filters
  600-900nm, r, i, narrow R, narrow I
- Polarimetric sensitivity 10^{-5}

SPHERE

- resolution: 15mas at 600nm
- XAO, Strehl ~50% for 600-900nm
- coronagraphy (Lyot coro., 4QPM)
- best search region: 0.1“ – 0.3“

Goals:

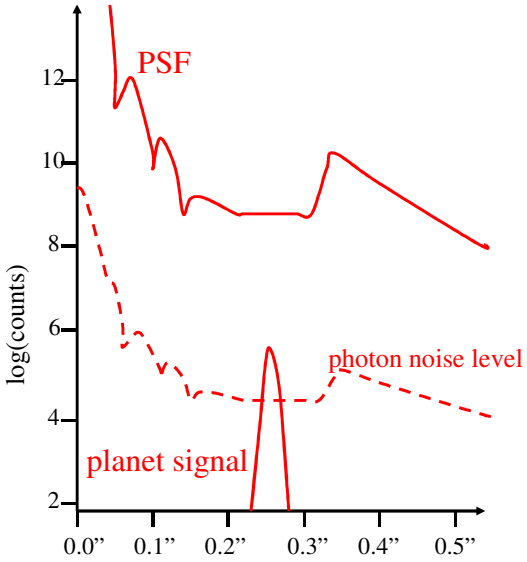
- polarization contrast limit 10^{-8} for bright stars
- detect planet around nearby stars d < 5pc
- characterize scattered light from circumstellar disks



simulated PSF

basic problem:

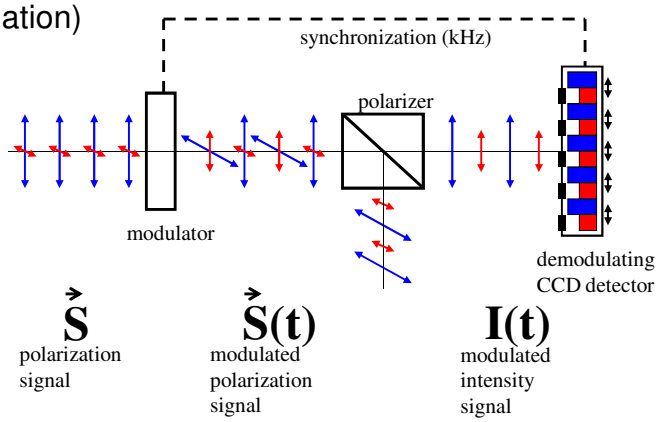
planet much fainter than residual PSF halo!



→differential technique:
search for signal of planet which is not present in the PSF (central star)

ZIMPOL: basic polarimetric principle

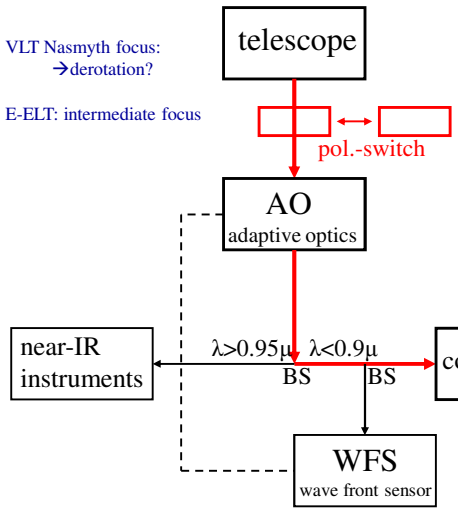
(fast modulation)



Advantages:

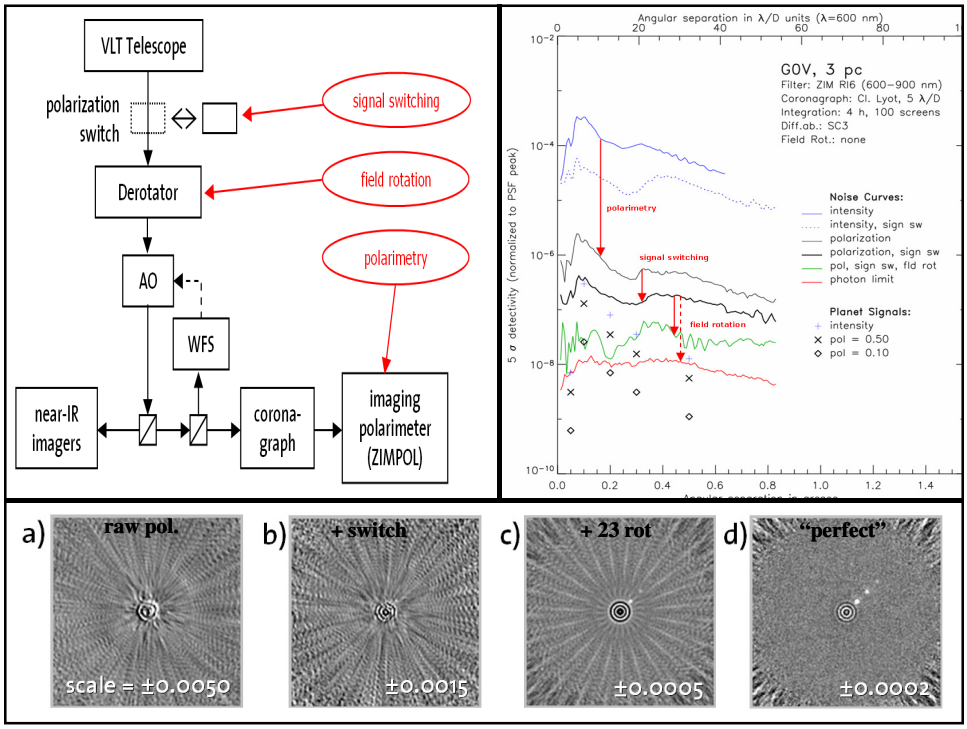
- images of two opposite polarization modes are created almost simultaneously
  → modulation faster than seeing variations
- both images are recorded with same pixel (buffers are different)
- both images are subject to almost exactly the same aberrations
- integration over many modulation cycles without readout (low RON)

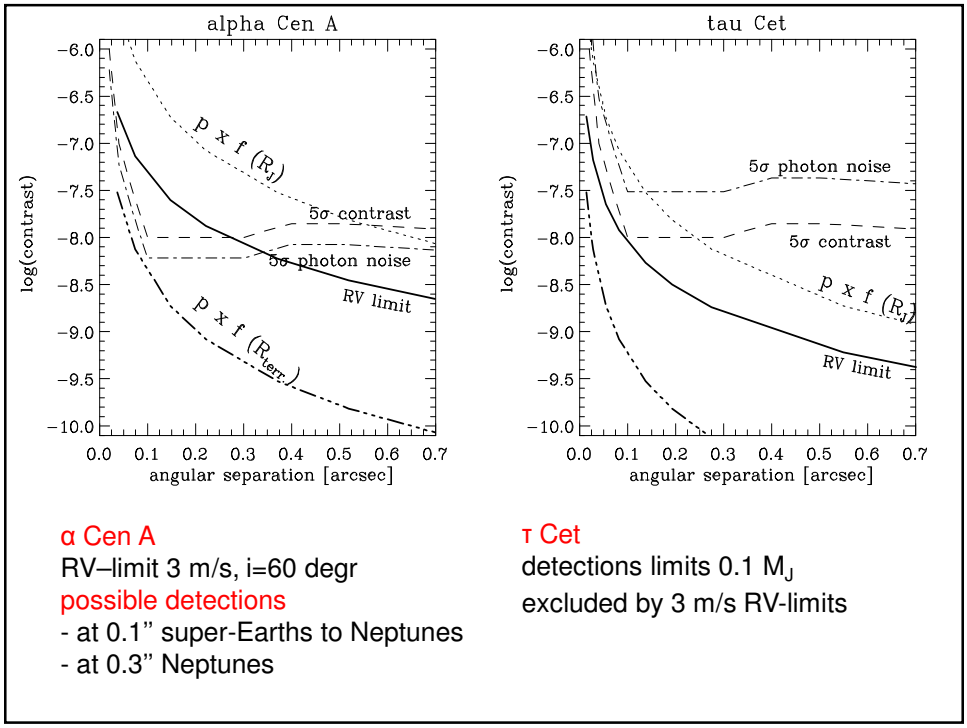
Polarimeter implementation in a planet finder instrument



mutual constraints:

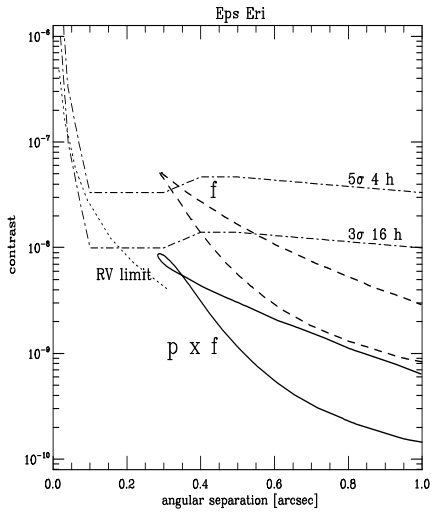
- Polarimeter should not affect the AO system
- AO design, telescope, etc. should not destroy polarization signal
- instrument polarization is controlled/compensated with rotating λ/2-plates (pol. switch)



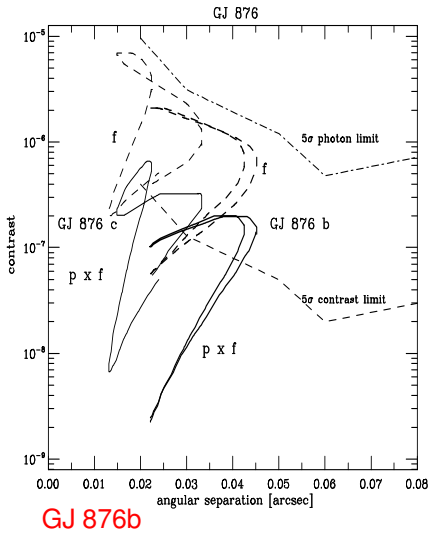


α Cen A
RV–limit 3 m/s, i=60 degr
possible detections
- at 0.1" super-Earths to Neptunes
- at 0.3" Neptunes

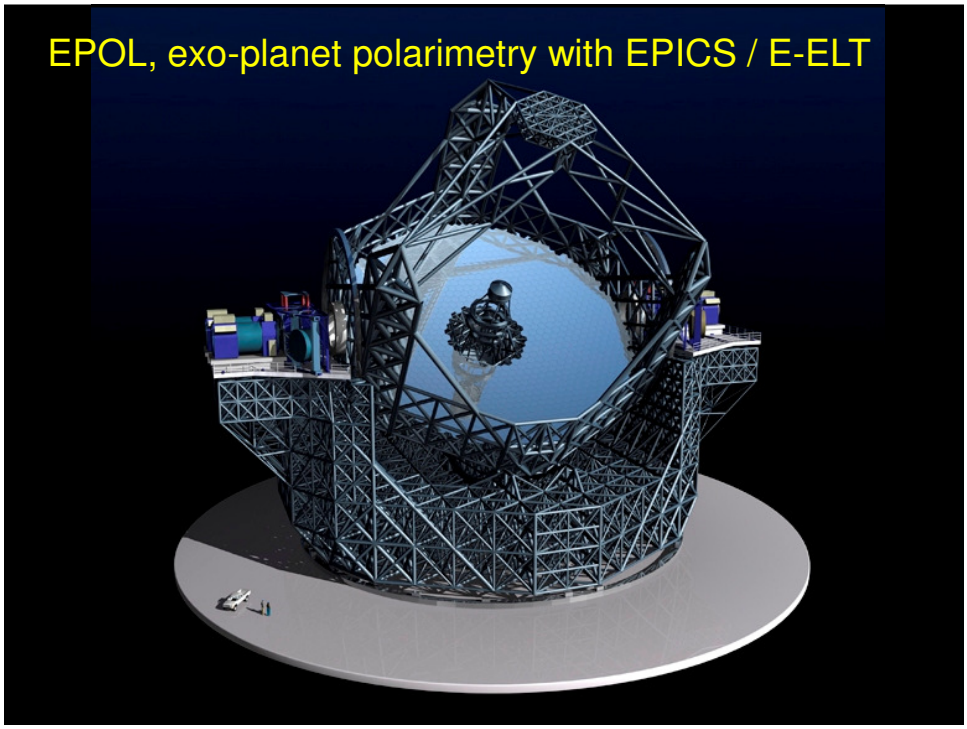
τ Cet
detections limits 0.1 M_J
excluded by 3 m/s RV-limits



Eps Eri b
detection at periastron phase
in 2014 could be possible with
very long integration



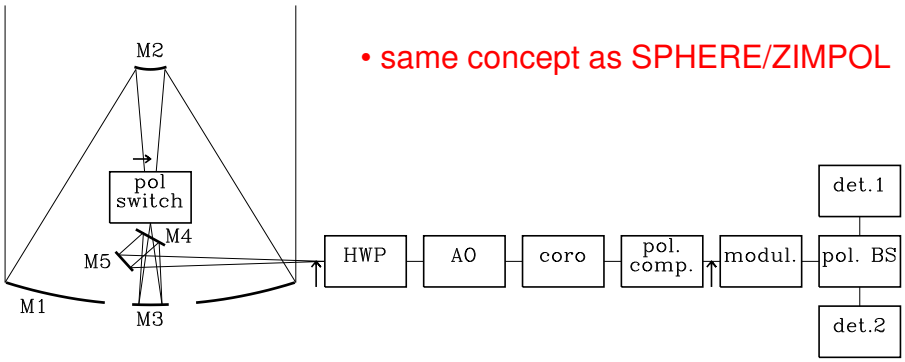
GJ 876b
separation 40 mas (2 λ/D)
4QPM coronagraph (820 nm)
An optimized coronagraph
could make the difference

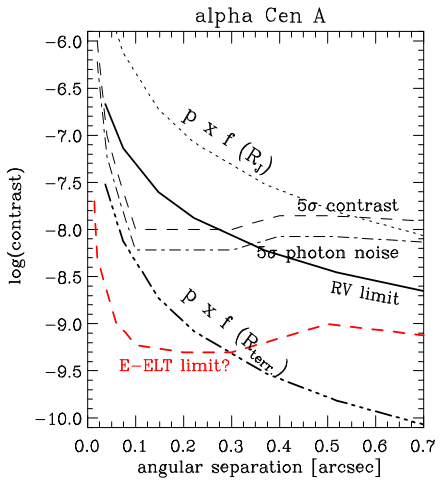


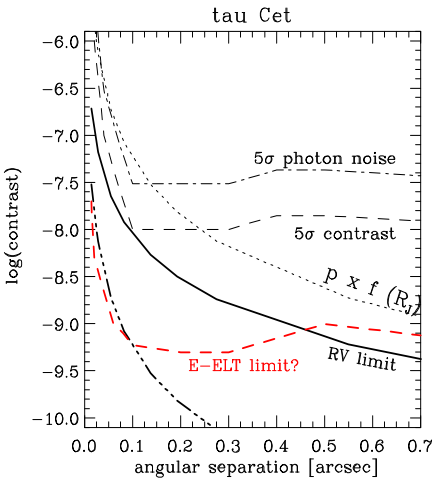
Basic concept for EPOL / EPICS

- HWP in IF
- HWP to rotate polarization direction
- polarization compensator
- modulator after AO

- same concept as SPHERE/ZIMPOL



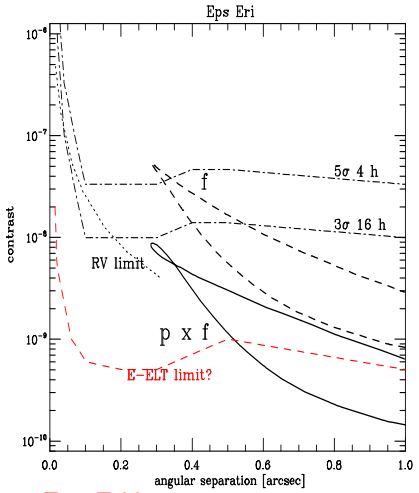




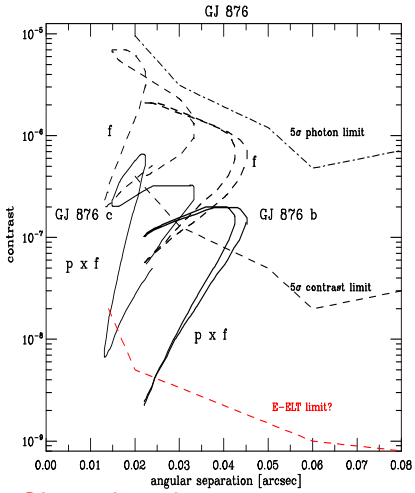
α Cen A
- ``moons" at 0.1" possible
- Earth-sized planet out to 0.3"

τ Cet
Earth-sized object out to 0.1"

→just using techniques foreseen for ZIMPOL/SPHERE
→further improvements in AO and coronagraphy expected!!



Eps Eri b
detailed planet characterization possible
(investigate strong seasonal changes)



GL 876 b and c
can be followed during entire orbit
detailed polarimeric characterization

Summary

- polarimetry is useful for the investigation
  - reflected light from extra-solar planets
  - reflected light from circumstellar disks
- ZIMPOL/SPHERE at VLT is a first test
  - a few planets within 5 pc may be detected
  - scattered light from disks
- E-POL: EPICS polarimeter for E-ELT
  - Characterization of many giant planets within 20 pc
  - some Earth-sized planets within 5pc may be detected