Polarimetric direct detection of extra-solar Planets with SPHERE/ZIMPOL

"In the spirit of Bernard Lyot"
Berkeley, 4.-8. June 2007

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SPHERE/ZIMPOL

- SPHERE is a second generation ESO-VLT instrument with three complementary focal plane instruments aiming to directly detect and analyze giant extra-solar planets
- Two near-IR instruments searching for self-luminous young planets. The third is a high-precision imaging polarimeter **ZIMPOL** detecting and analyzing reflected light from older planets

- There will be an overview talk on SPHERE by **Jean-Luc Beuzit** (PI) tomorrow
- Poster by **Anthony Boccaletti**: development of coronagraphs for SPHERE
- I will concentrate on the polarimetric instrument ZIMPOL which is the Zürich contribution to SPHERE

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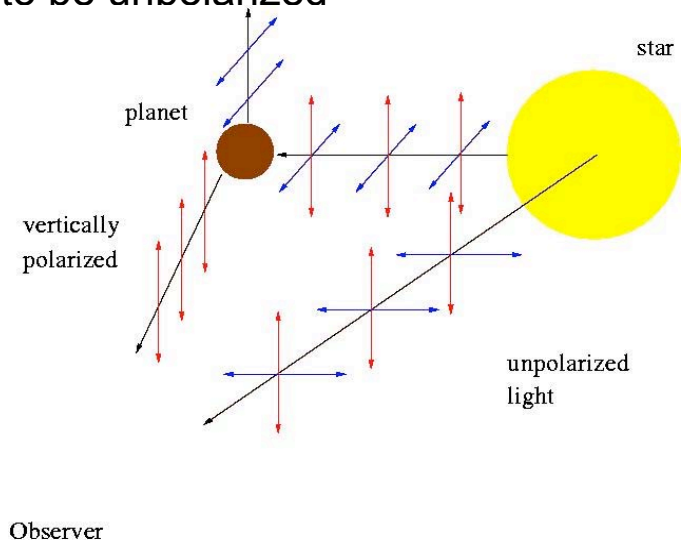
imaging polarimetry

- Light reflected by a planet can highly be polarized, whereas the starlight can be assumed to be unpolarized



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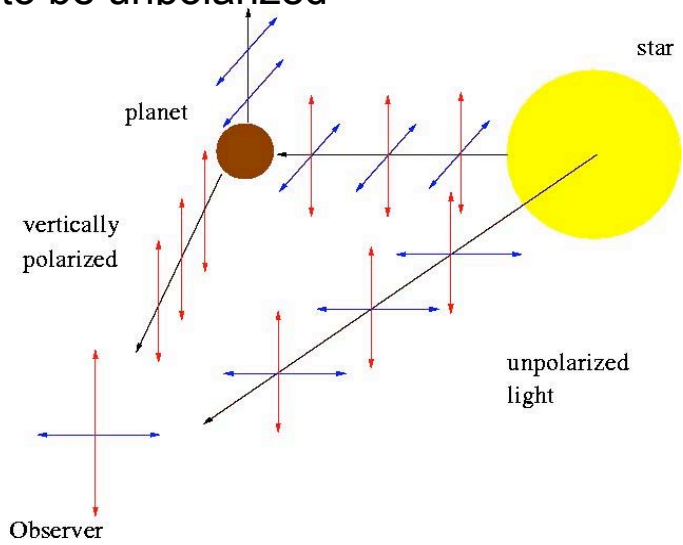
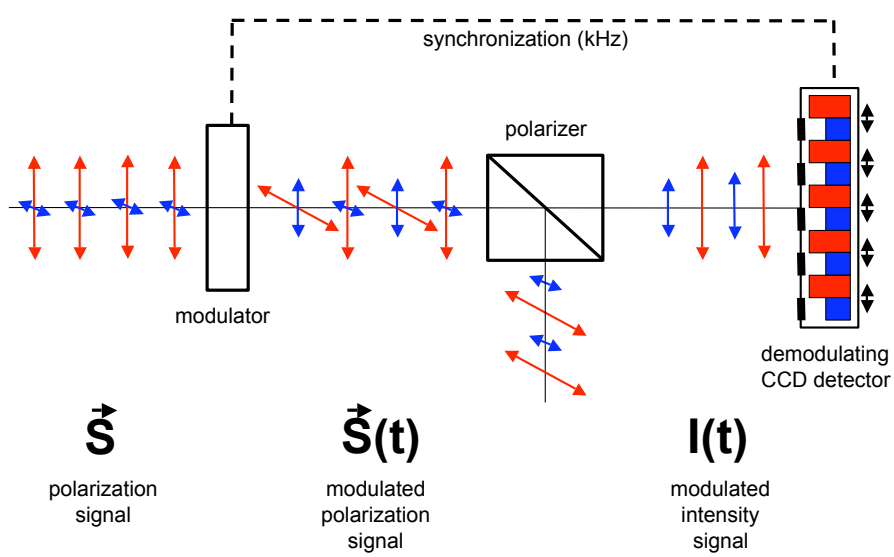
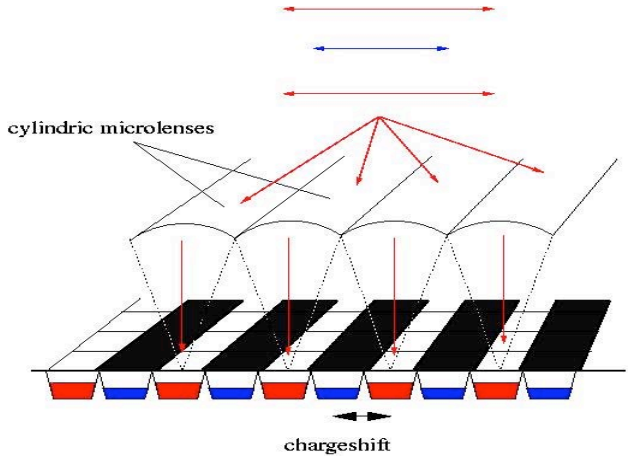
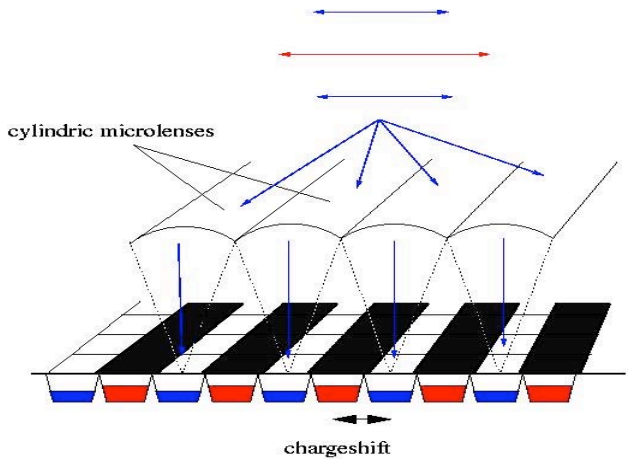


- A polarimetric measurement is obtained by taking the difference of the two intensities at orthogonal polarization directions ($I_{/\!/} - I_{\perp}$). The normalized difference gives the polarization degree: $p = Q/I = (I_{/\!/} - I_{\perp})/(I_{/\!/} + I_{\perp})$.
- ZIMPOL (Zürich IMaging POLarimeter) is a high-precision imaging polarimeter providing a polarimetric precision of better than 10^{-5} working in the range of 600 to 900nm for SPHERE

ZIMPOL measuring principle:

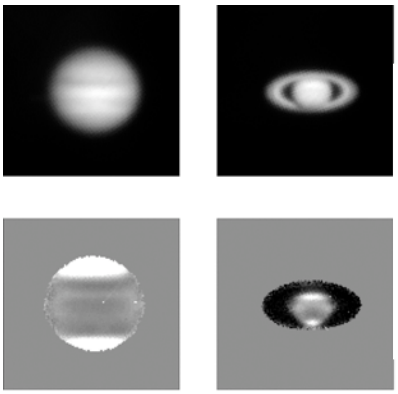



cylindric microlenses
chargeshift


cylindric microlenses
chargeshift

- After thousands of modulation cycles the CCD is read out in less than a second
- ZIMPOL image contains two sub-images of the same object at orthogonal polarization directions
- Compute the difference and normalize → Q/I

Example: Jupiter and Saturn



I

Q/I

ZIMPOL polarization measurements at 630nm for Jupiter and Saturn at Mc Math Pierce telescope, Kitt Peak

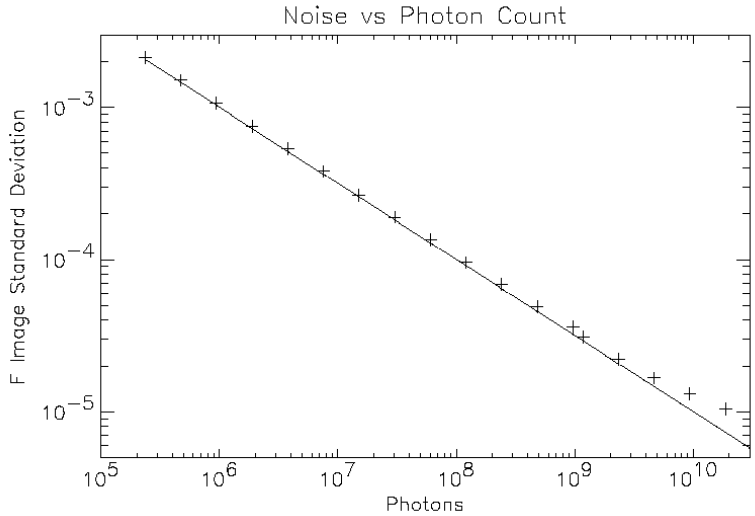
Summary of the ZIMPOL technique:

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

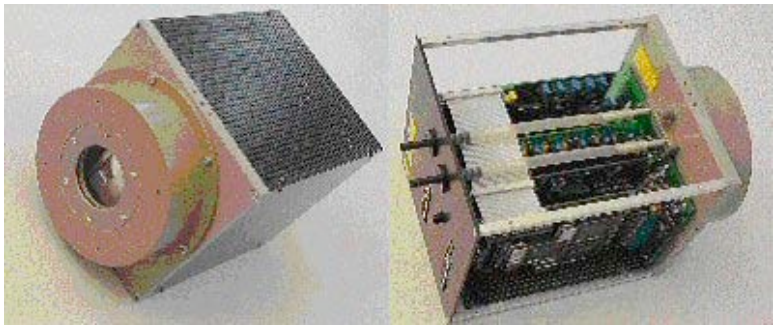
Precision of 10^{-5} is routinely achieved in solar applications

THE END

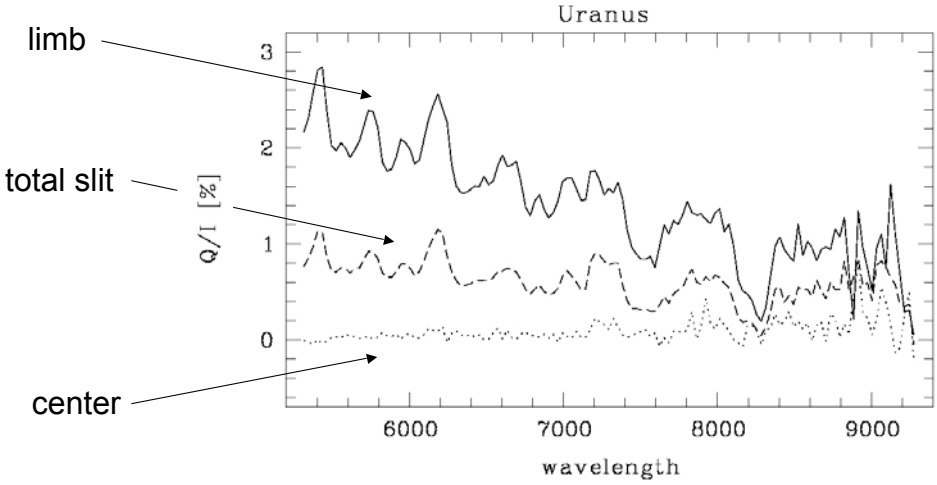
Noise Curve



ZIMPOL camera (1. generation)



Example of “long-slit” spectropolarimetry of Uranus

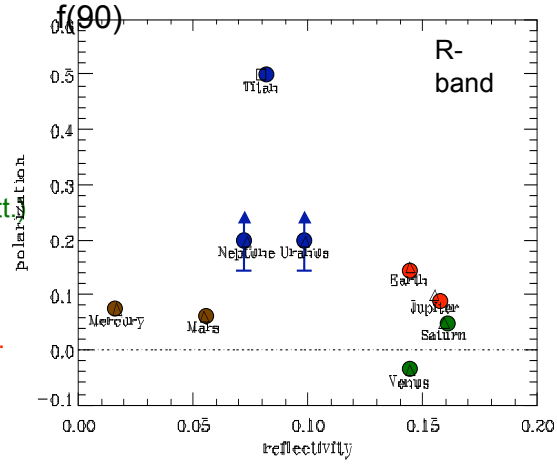


Joos & Schmid, 2007, A&A

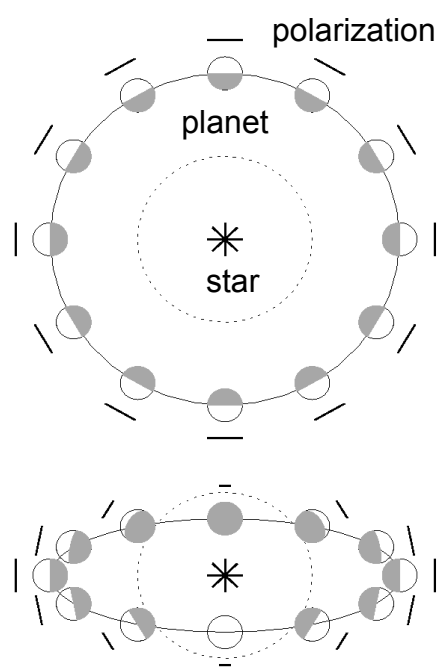
Solar system planets surface properties

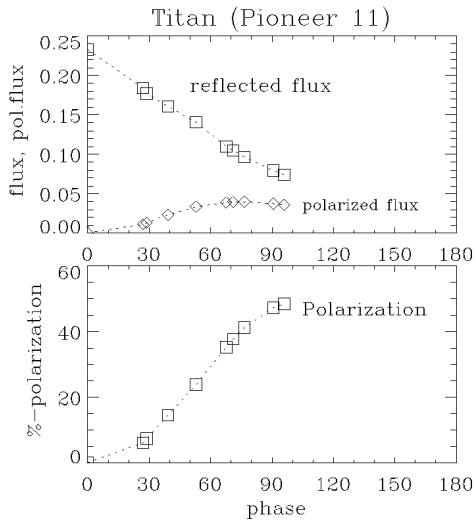
	p(90)	f(90)
rocky		
Mercury	5-10%	low
Mars	5-10%	low
cloudy (little Rayleigh scatt.)		
Venus	<5% (–)	high
Saturn	<5%	high
cloudy and Rayleigh scatt.		
Jupiter	5-20%	high
Earth	5-20%	high
strong Rayleigh scattering		
Uranus	>15%	med.
Neptune	>15%	med.
Titan	50%	med.

polarization p(90) vs. reflectivity f(90)

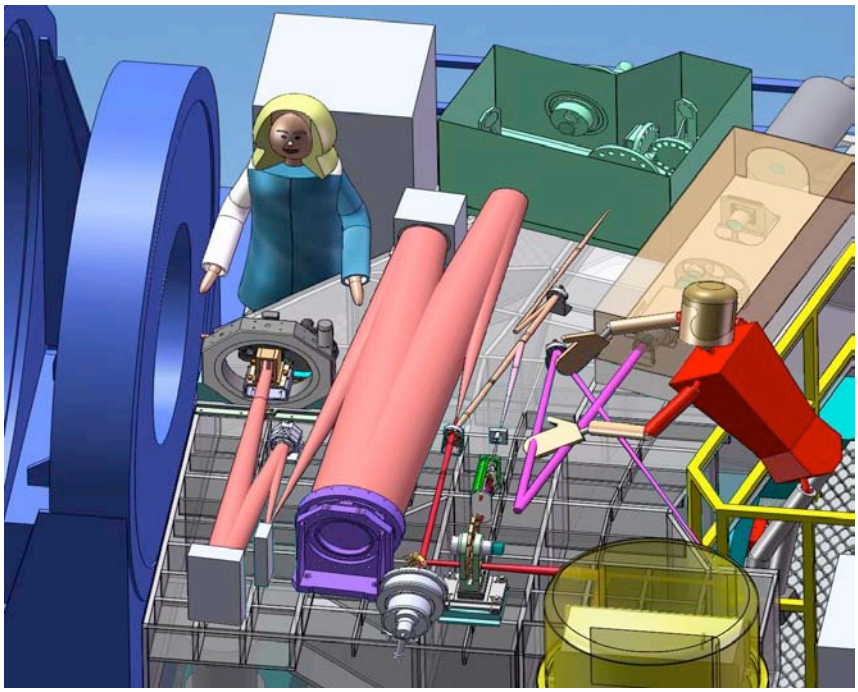


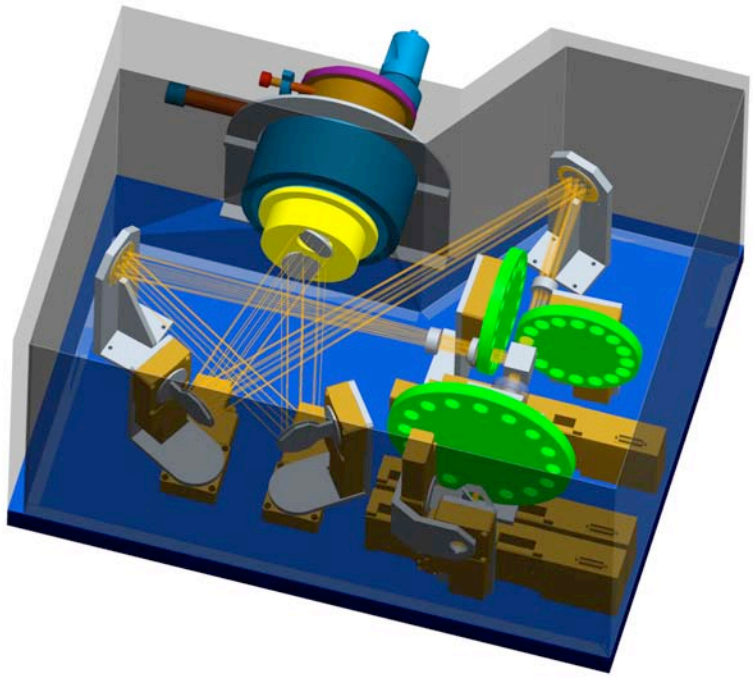
- The orientation of the exo-system matters, because the polarization depends on the phase angle:
  - always perfect for a face-on system
  - twice a year perfect for an inclined system

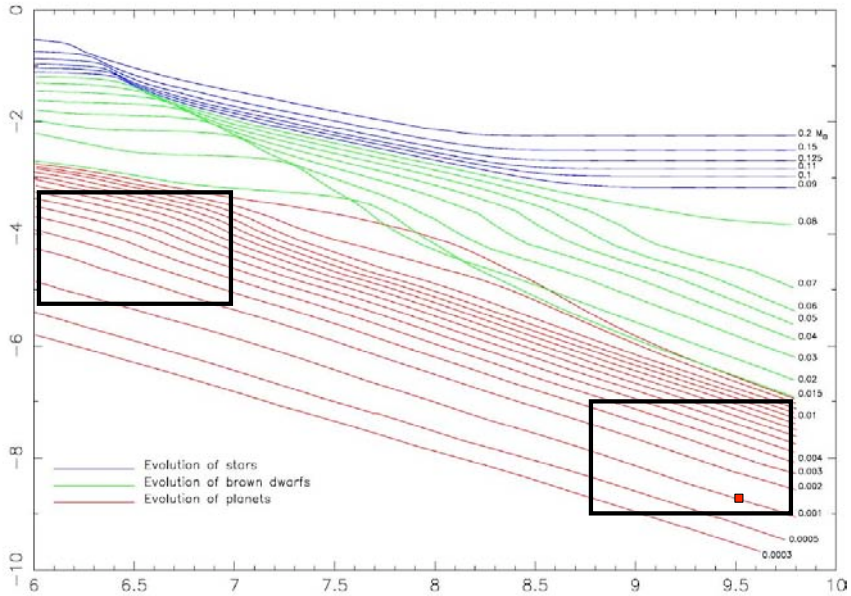




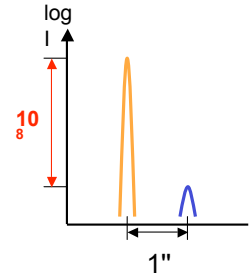
(Tomasko & Smith, 1982, Icarus 51,65)






0.2 $M_\odot$
0.15
0.125
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.015
0.01
0.004
0.003
0.002
0.001
0.0005
0.0003
Evolution of stars
Evolution of brown dwarfs
Evolution of planets
0
−2
−4
−6
−8
−10
6
6.5
7
7.5
8
8.5
9
9.5
10

Example: Jupiter-Sun system at 5pc



Intensity ratio of exo-Sun and exo-Jupiter at 1" separation $\approx 10^8$.

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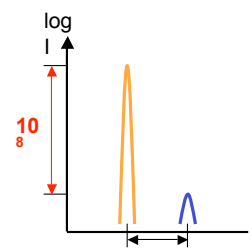

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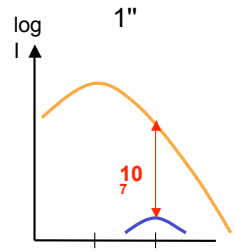
Degradation of the point-like sources due to
the atmosphere
→ bright halo of the star
→ overlapping of the two intensities
→ contrast at the position of the planet $\approx 10^7$
→ too large for an imaging polarimeter



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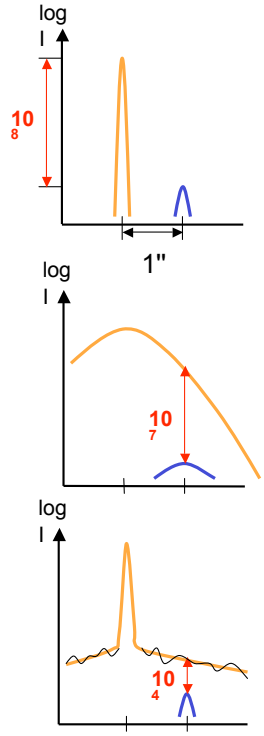
Reducing the contrast by extreme AO and coronagraphy to $\approx 10^4$. Contrast in the regime of the most sensitive imaging polarimeters.



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