



Introduction: Scattering & Formalisms

How To measure Polarized Light: Instruments

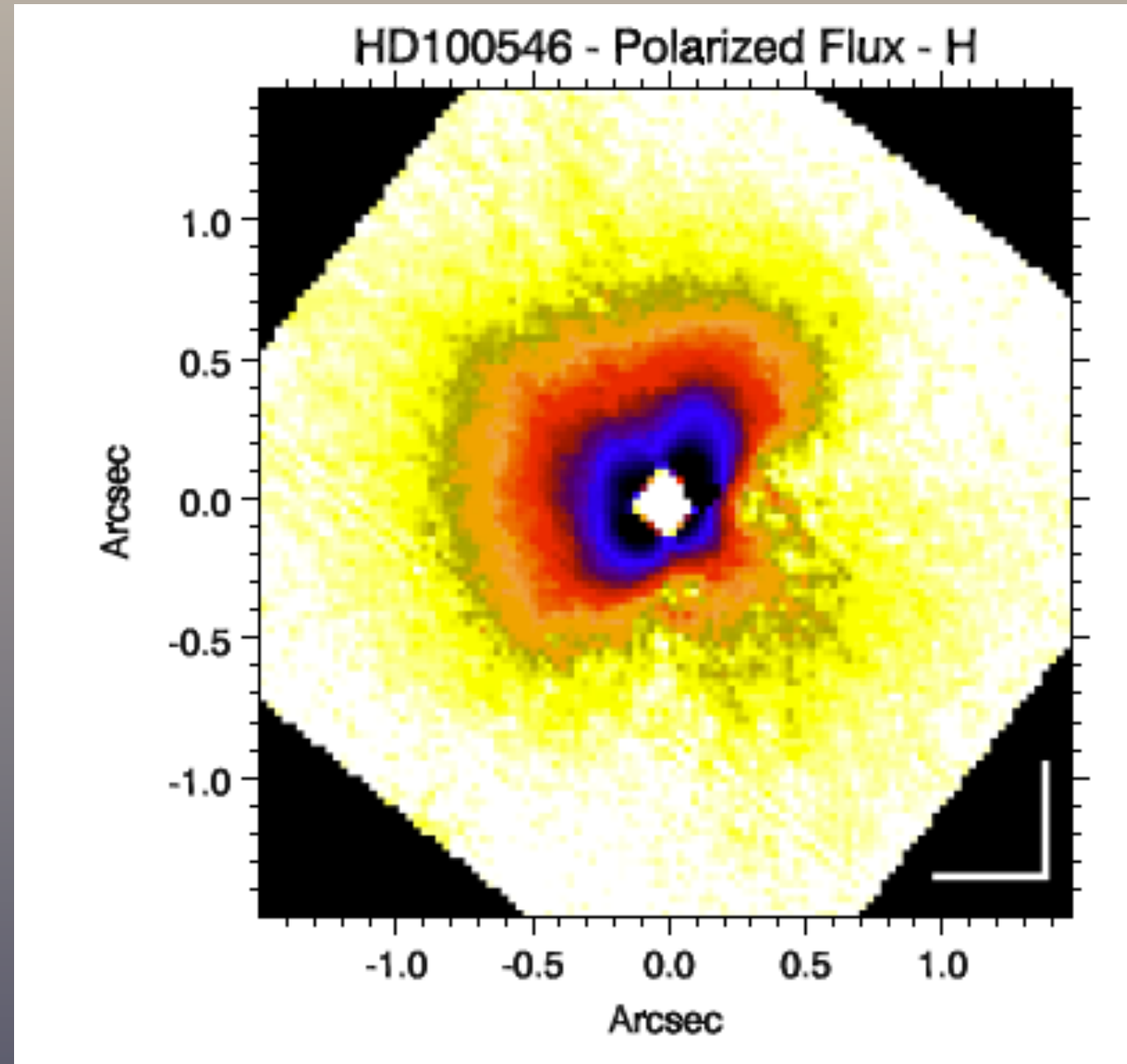
Observations

Some nice Images..



Photometry, Spectroscopy,
Interferometry...

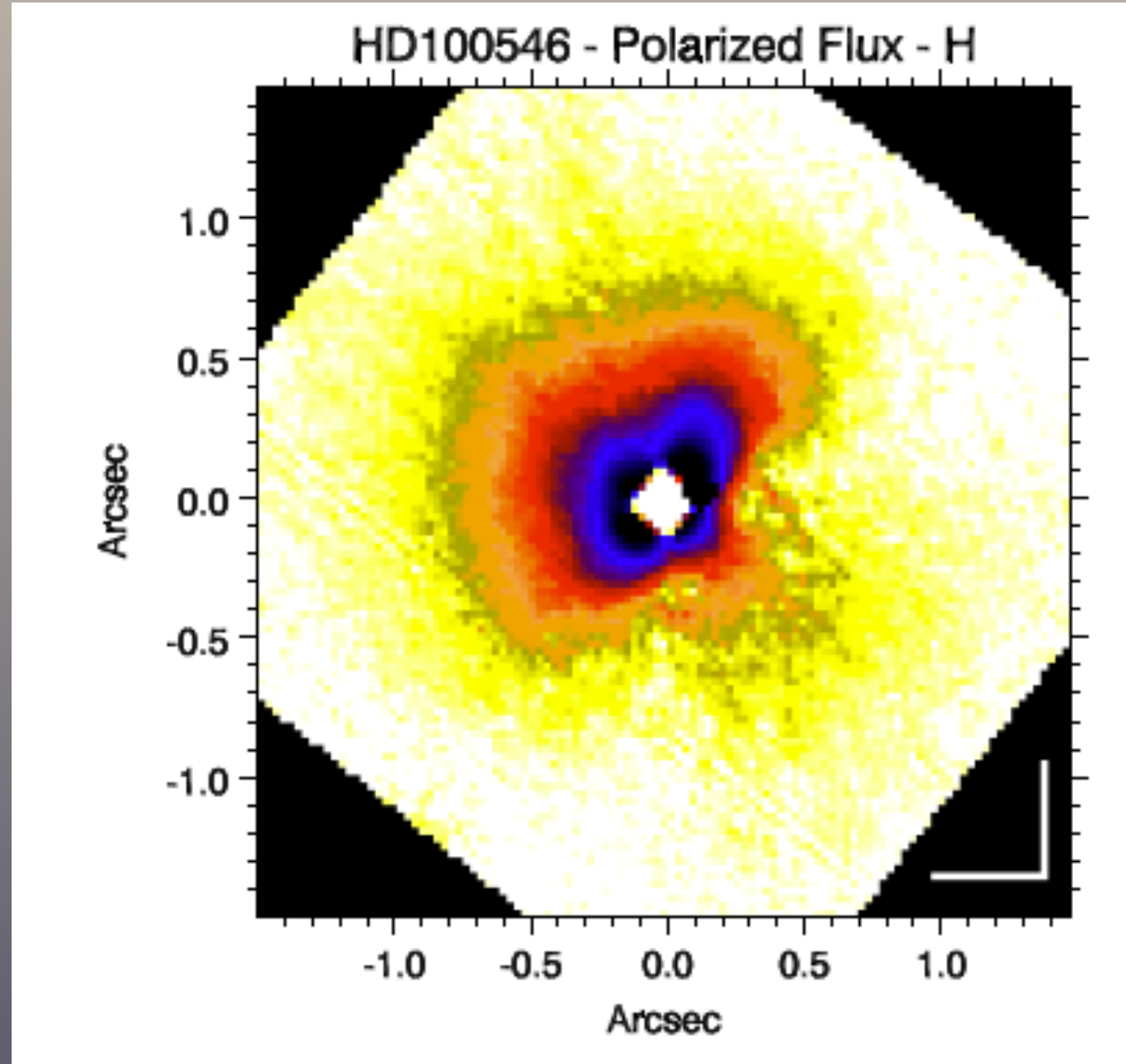
Why Polarimetry?





Imaging Polarimetry: Introduction

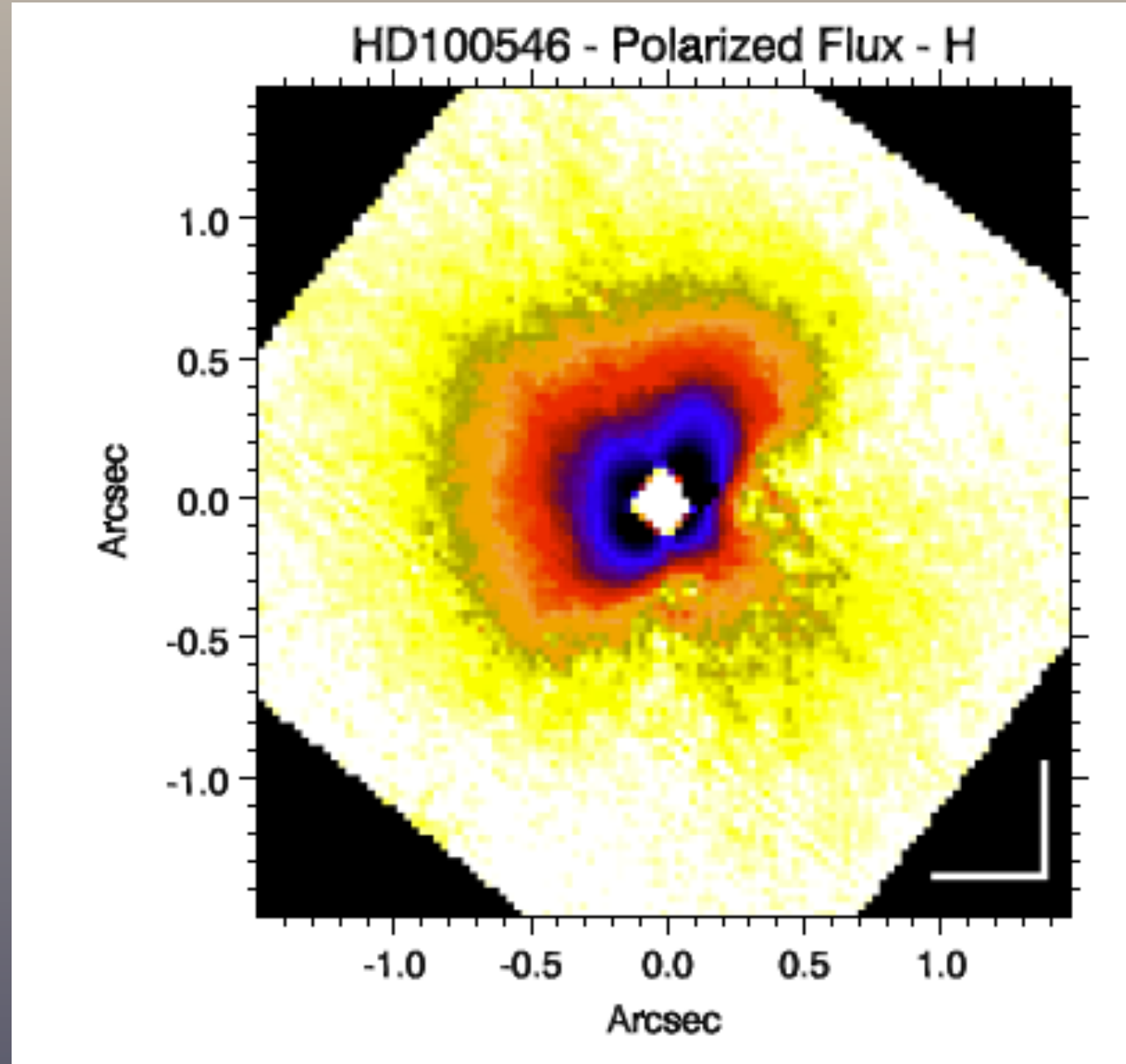
REMOVE





Imaging Polarimetry: Introduction

REMOVE

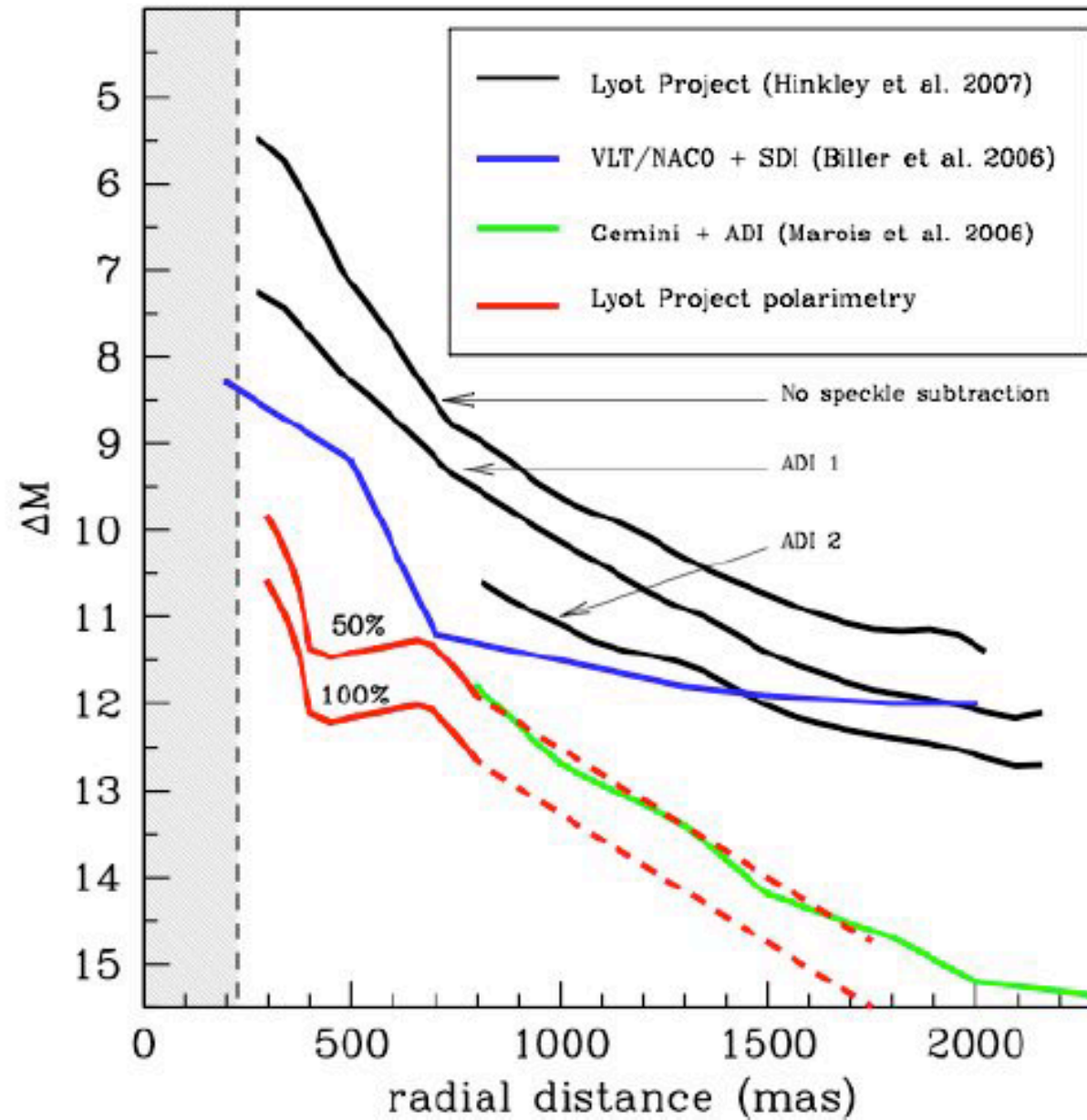


STARLIGHT



Imaging Polarimetry: Introduction

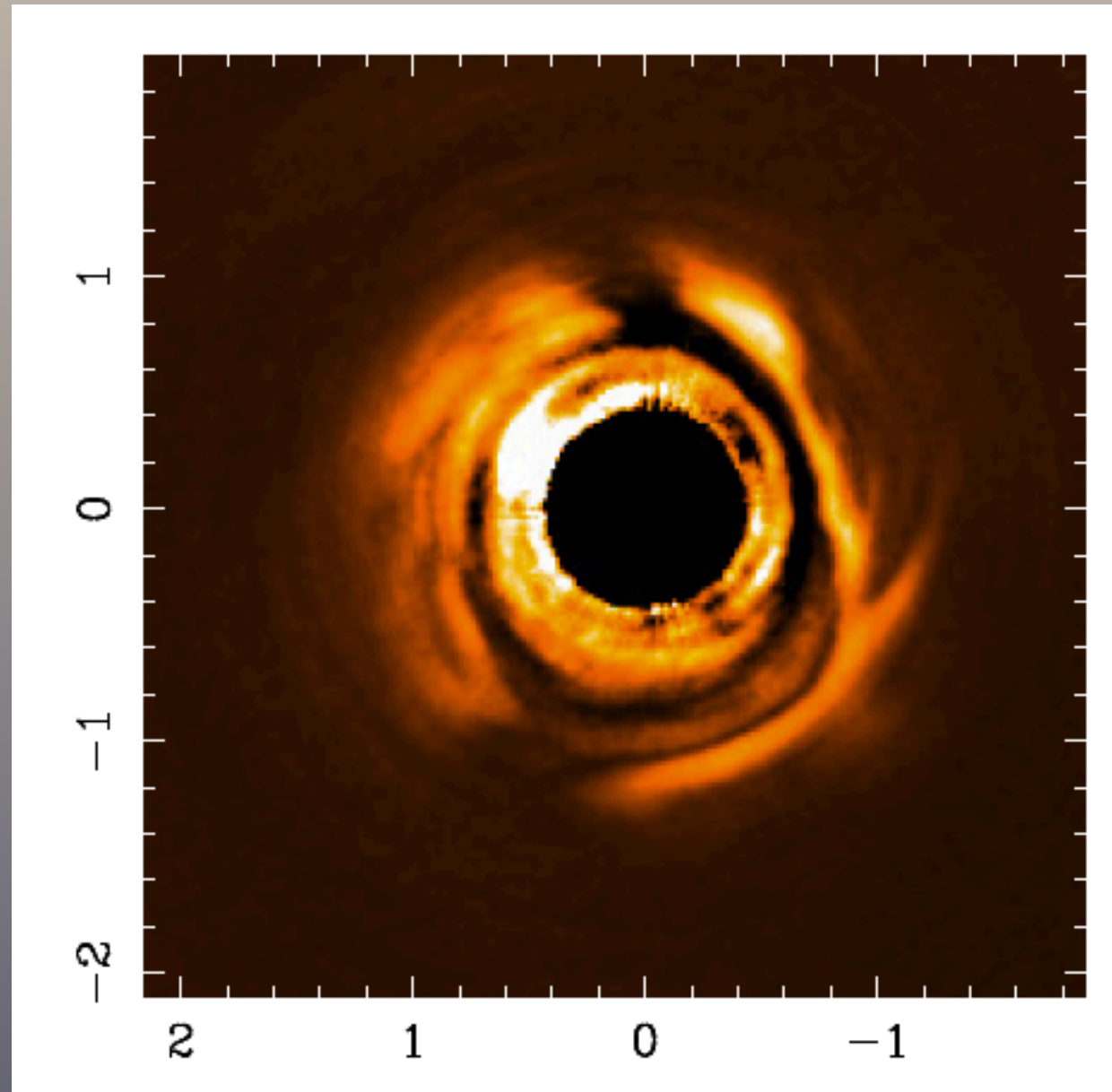
REMOVE



STARLIGHT

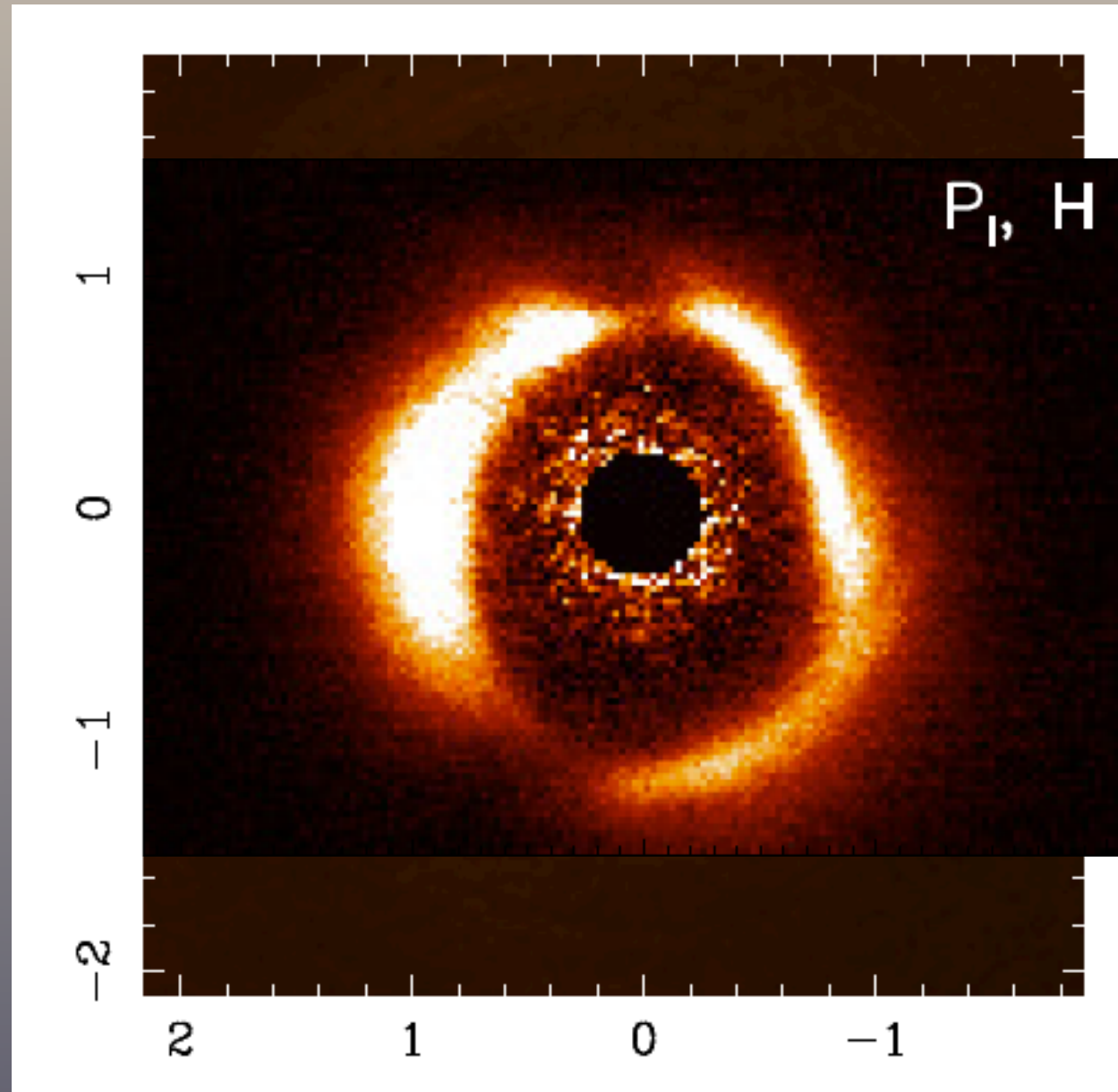


Imaging Polarimetry: Introduction





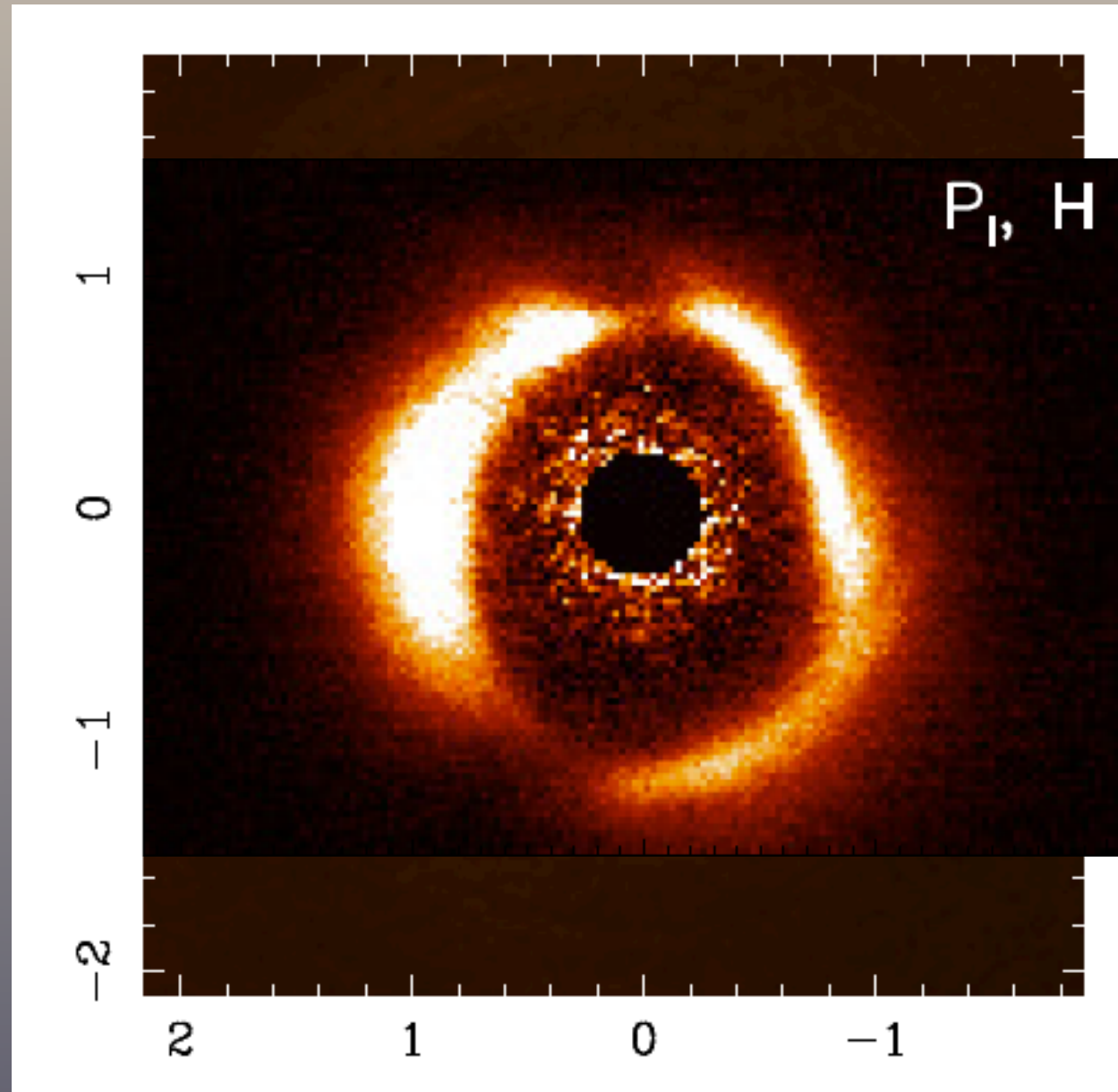
Imaging Polarimetry: Introduction





Imaging Polarimetry: Introduction

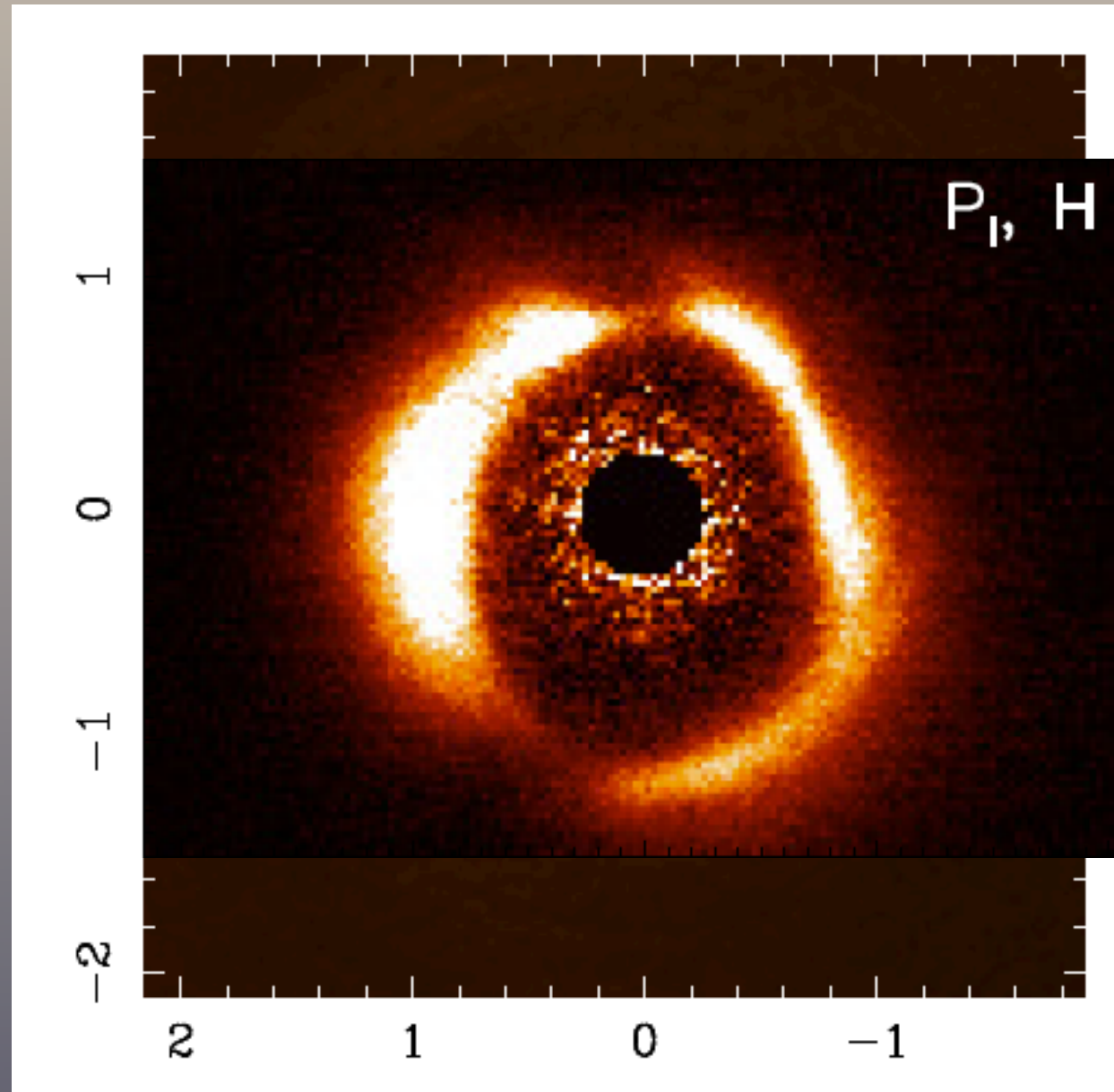
REMOVE





Imaging Polarimetry: Introduction

REMOVE

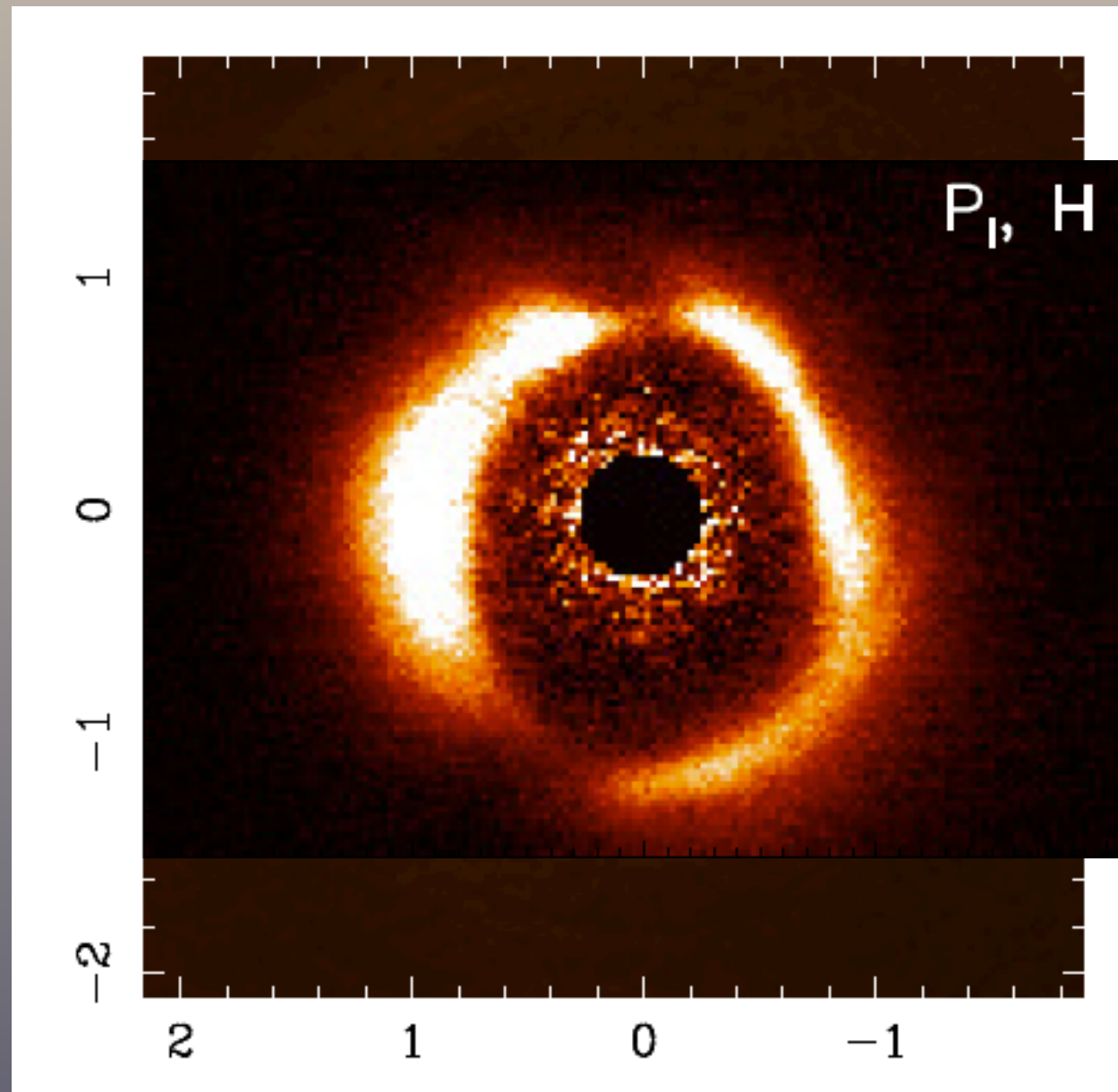


ARTIFACTS



Imaging Polarimetry: Introduction

REMOVE



ARTIFACTS



You can combine it!!!

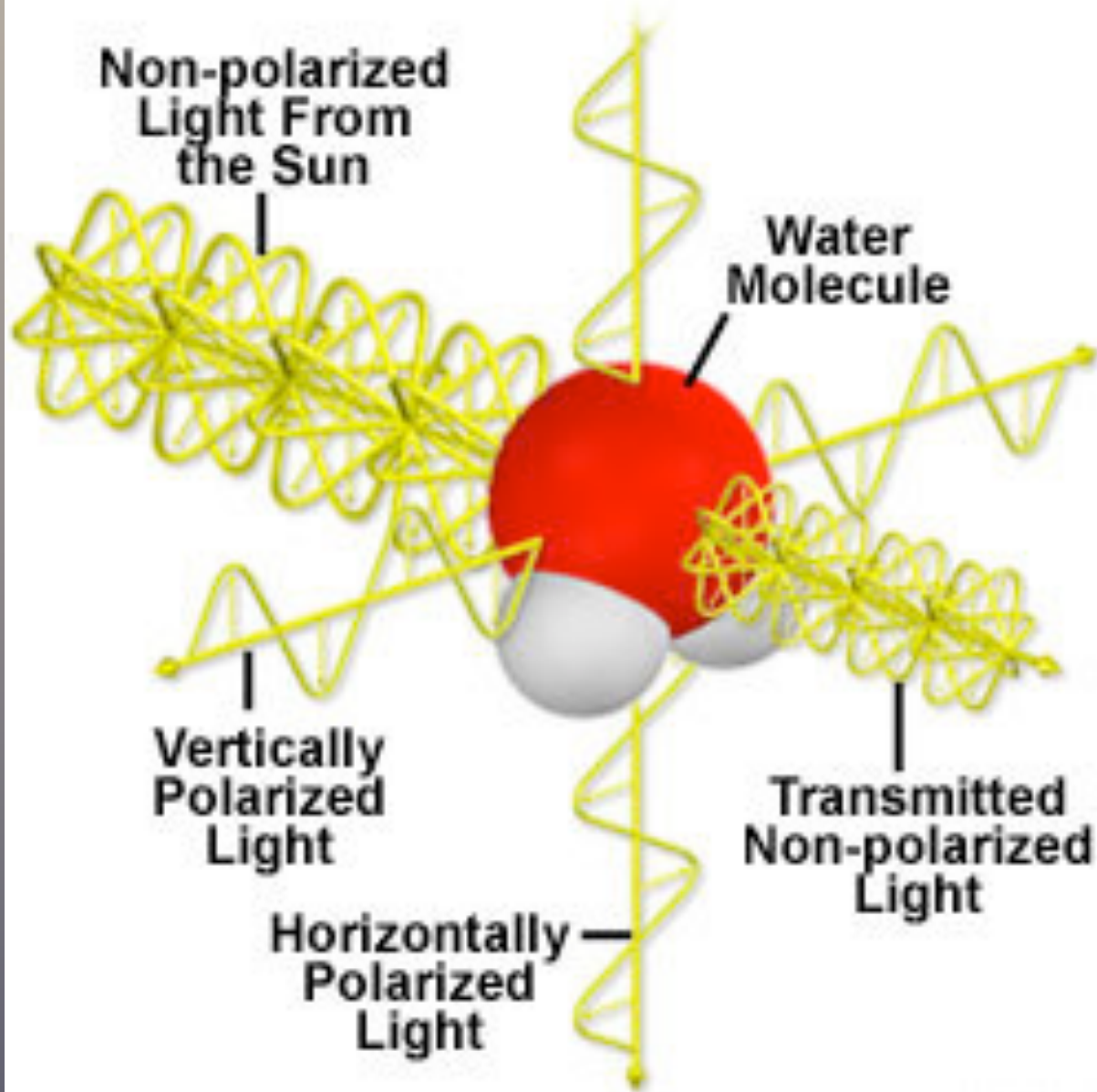
Photometry + Polarimetry = Imaging Polarimetry

Spectroscopy + Polarimetry = SpectroPolarimetry

Interferometry + Polarimetry = Whatever you call it,
but you can also do it

Light Scattering

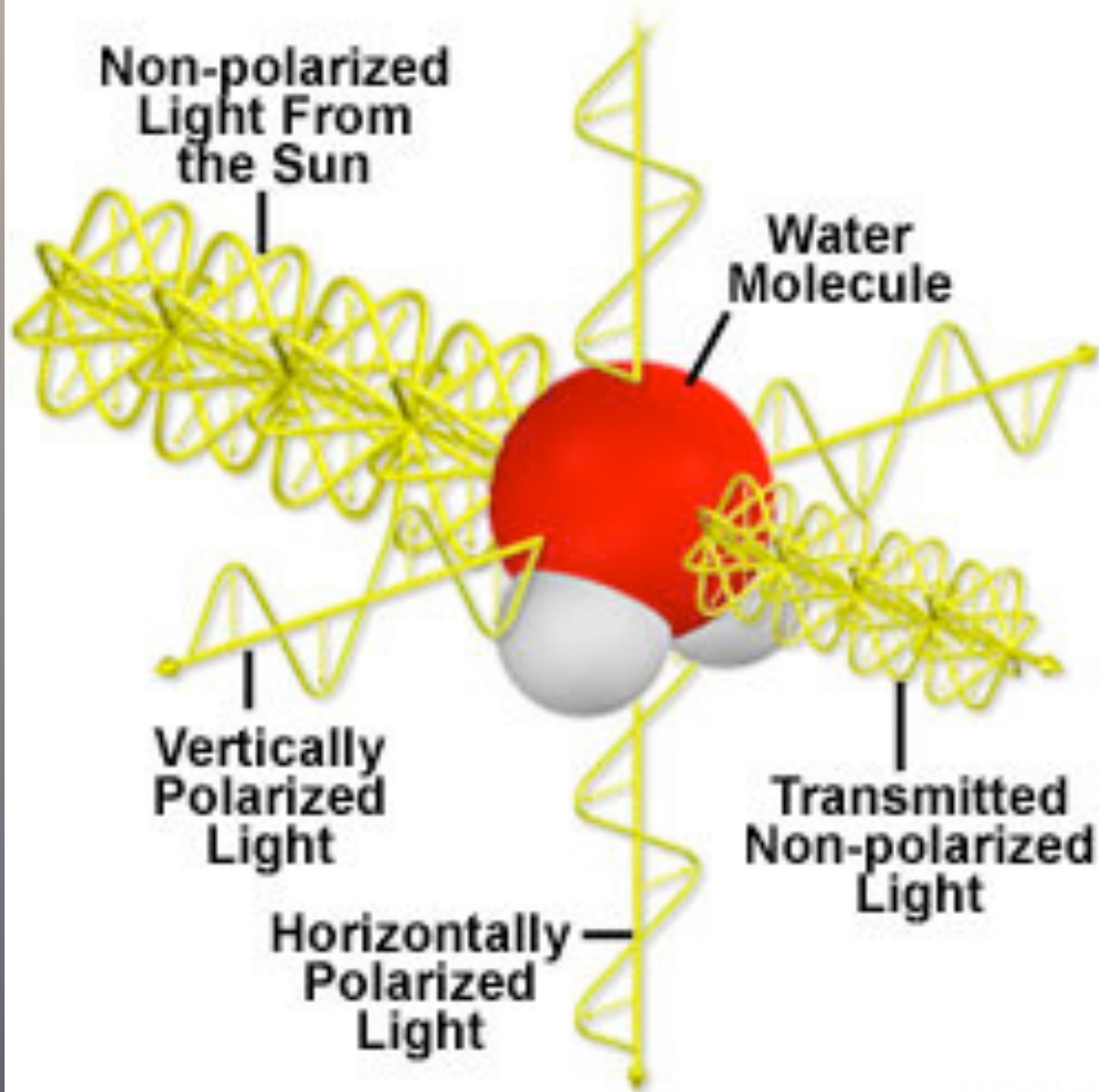
Polarization of Scattered Sunlight



Everything is polarized
(to a certain degree...)

Light Scattering

Polarization of Scattered Sunlight

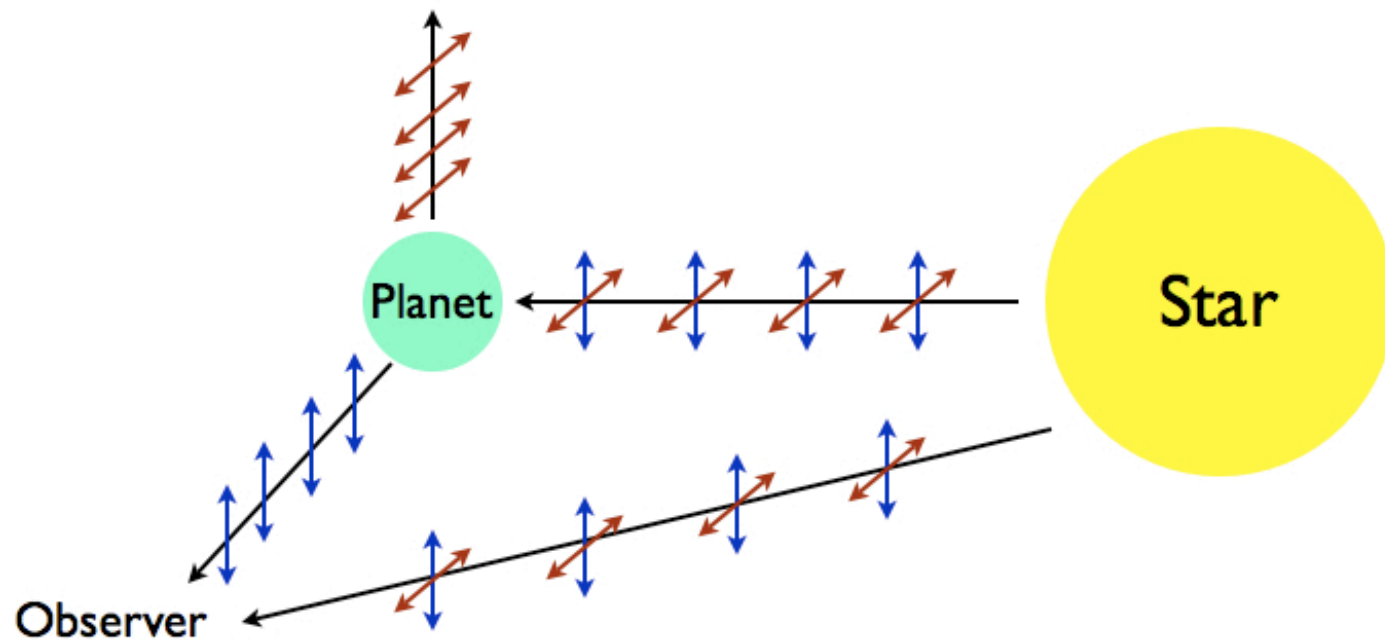


Everything is polarized
(to a certain degree...)

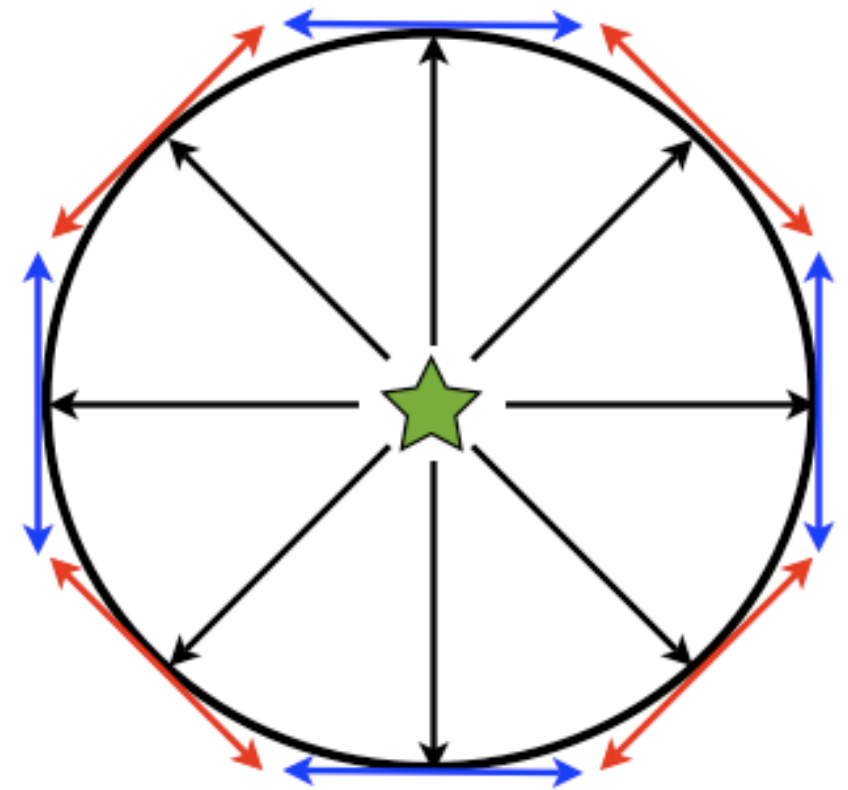
Scattered light
can be
highly polarized

Very basic cartoon...

PLANET...



DISK...





Very basic Equations...

Jones Formalism:
Amplitudes

$$\begin{pmatrix} E_x(t) \\ E_y(t) \end{pmatrix} = E_0 \begin{pmatrix} E_{0x} e^{i(kz - \omega t + \phi_x)} \\ E_{0y} e^{i(kz - \omega t + \phi_y)} \end{pmatrix}$$

Stokes Formalism:
Intensities

$$I = \langle |E_x|^2 + |E_y|^2 \rangle$$

$$Q = \langle |E_x|^2 - |E_y|^2 \rangle$$

$$U = 2 \langle |E_x| |E_y| \cos \phi \rangle$$

$$V = 2 \langle |E_x| |E_y| \sin \phi \rangle$$

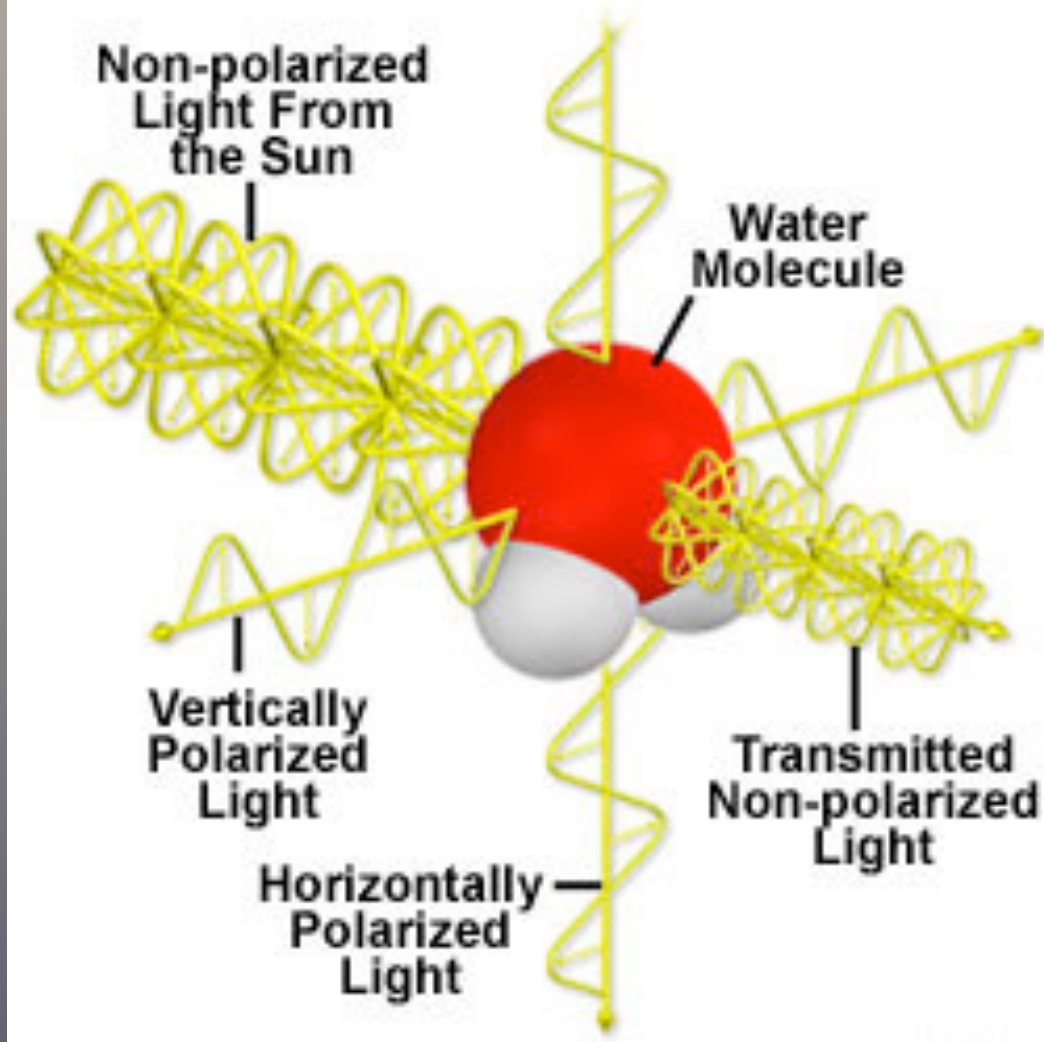


The Stokes Parameters = The Holy Grail

100% Q	100% U	100% V
<p>+Q</p> <p>$Q > 0; U = 0; V = 0$</p> <p>(a)</p>	<p>+U</p> <p>$Q = 0; U > 0; V = 0$</p> <p>(c)</p>	<p>+V</p> <p>$Q = 0; U = 0; V > 0$</p> <p>(e)</p>
<p>-Q</p> <p>$Q < 0; U = 0; V = 0$</p> <p>(b)</p>	<p>-U</p> <p>$Q = 0; U < 0; V = 0$</p> <p>(d)</p>	<p>-V</p> <p>$Q = 0; U = 0; V < 0$</p> <p>(f)</p>

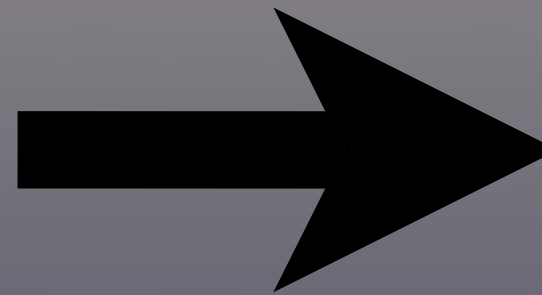
Polarization Degree = The Holy Grail (II)

Polarization of Scattered Sunlight



$$P_I = \sqrt{Q^2 + U^2}$$

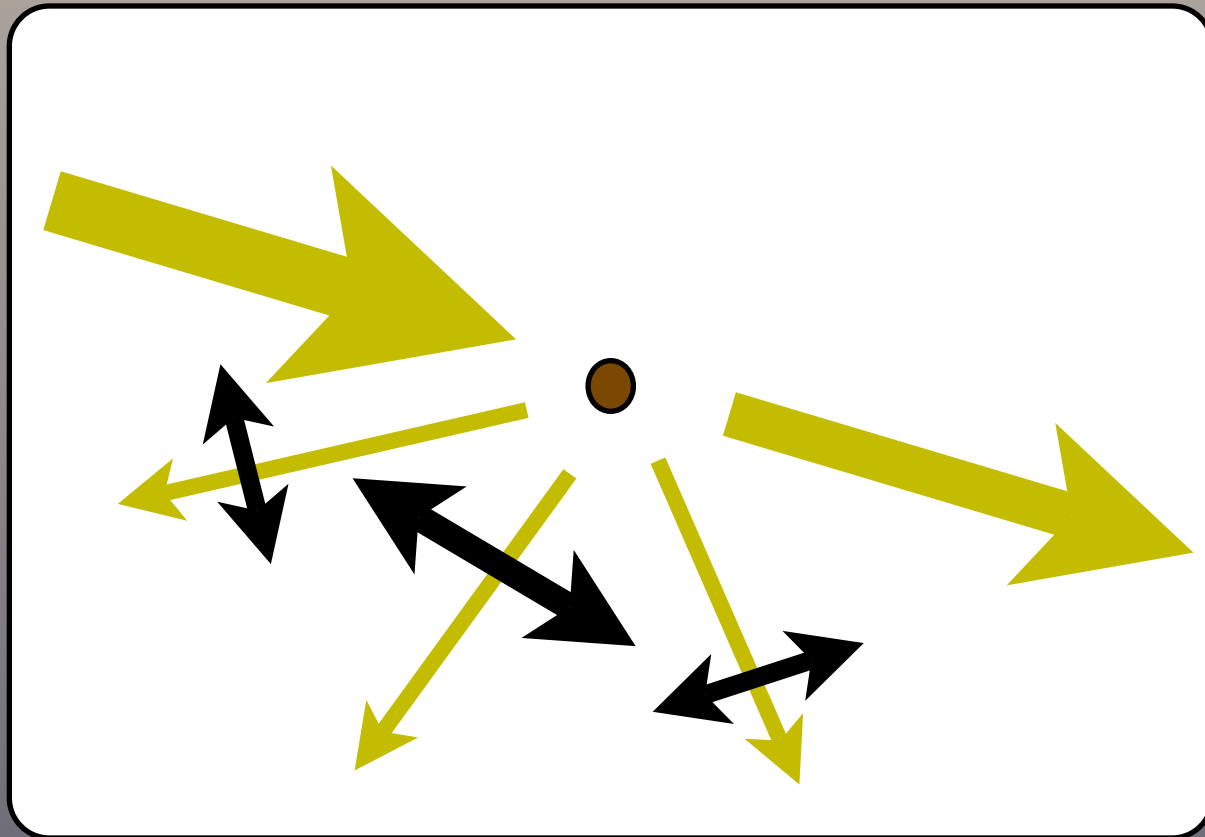
$$P_{\Theta} = 0.5 \cdot \arctan\left(\frac{U}{Q}\right)$$



$$P = P_I / I$$

Dust Tracer

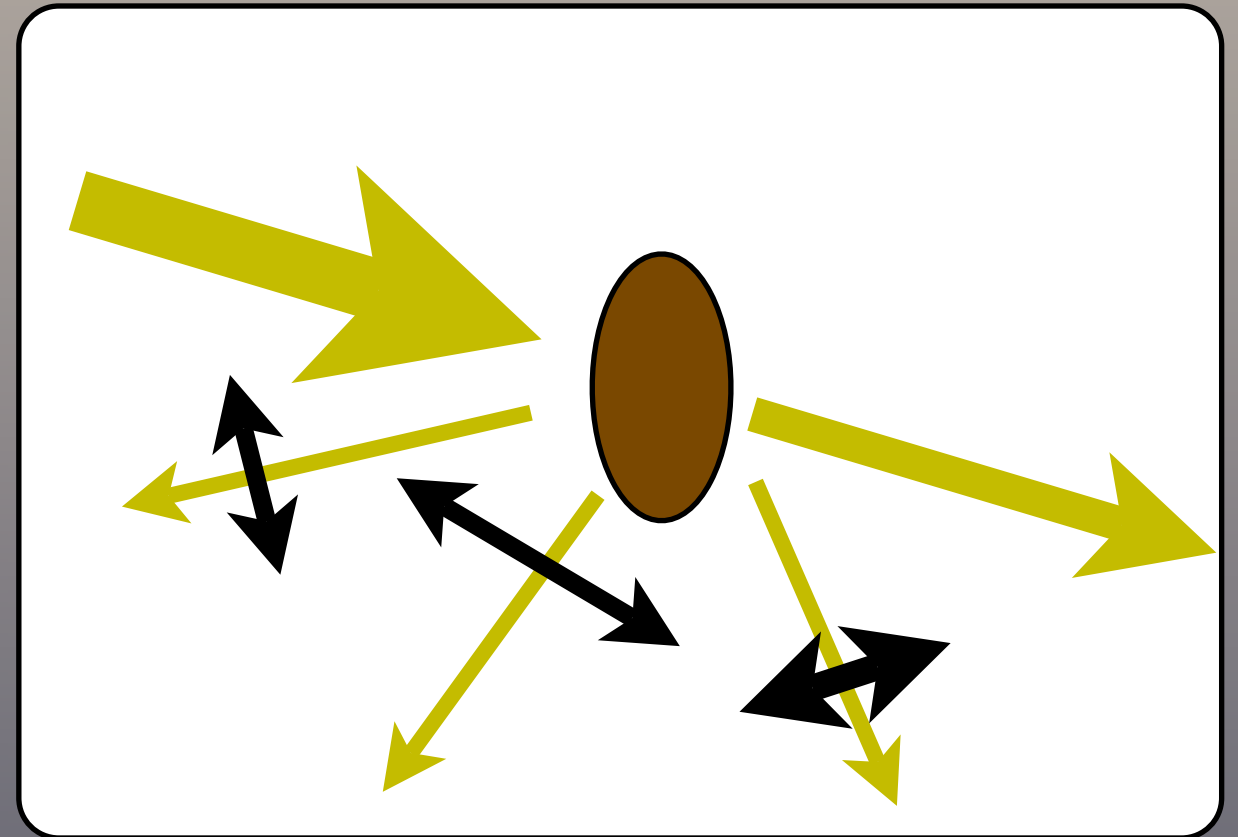
Small Grains



Simmetry

VS

Big Grains



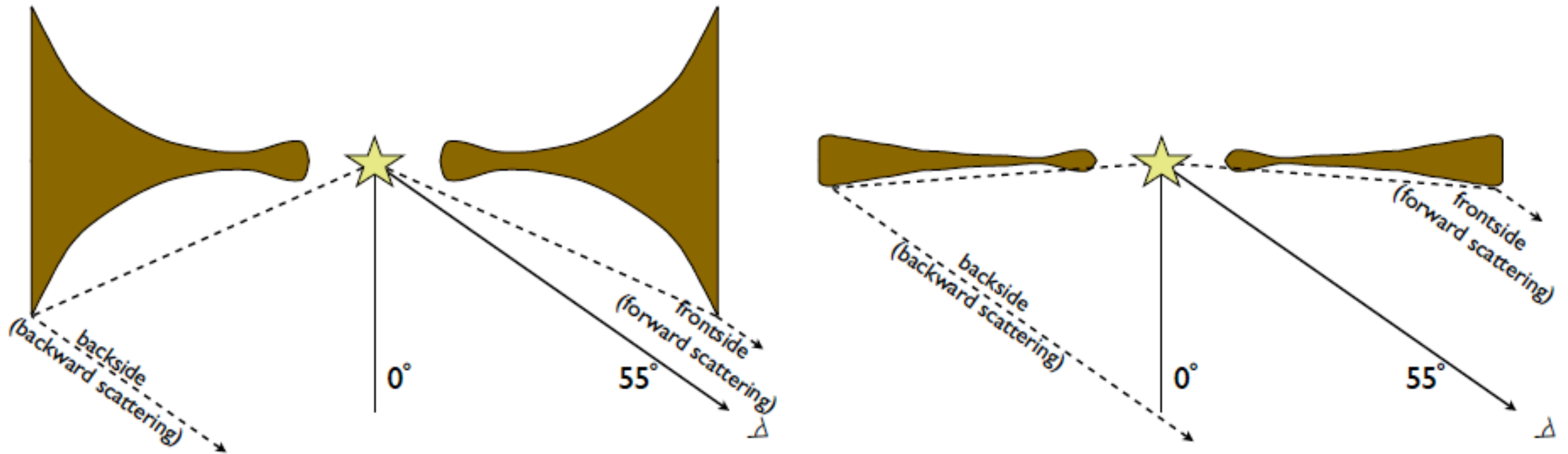
Asimmetry

Geometry Tracer

Understanding Disk Geometry

Flaring (Young??) Disk

Settled (old??) Disk

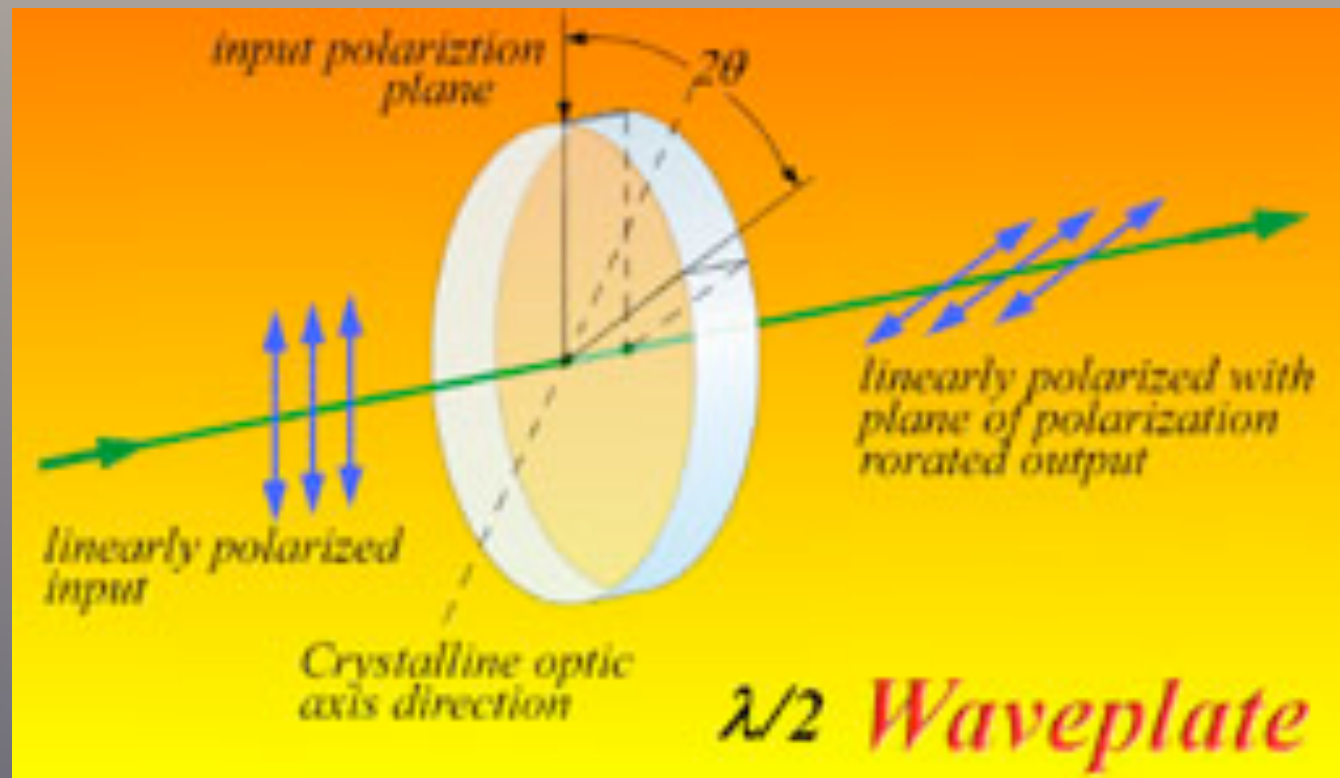




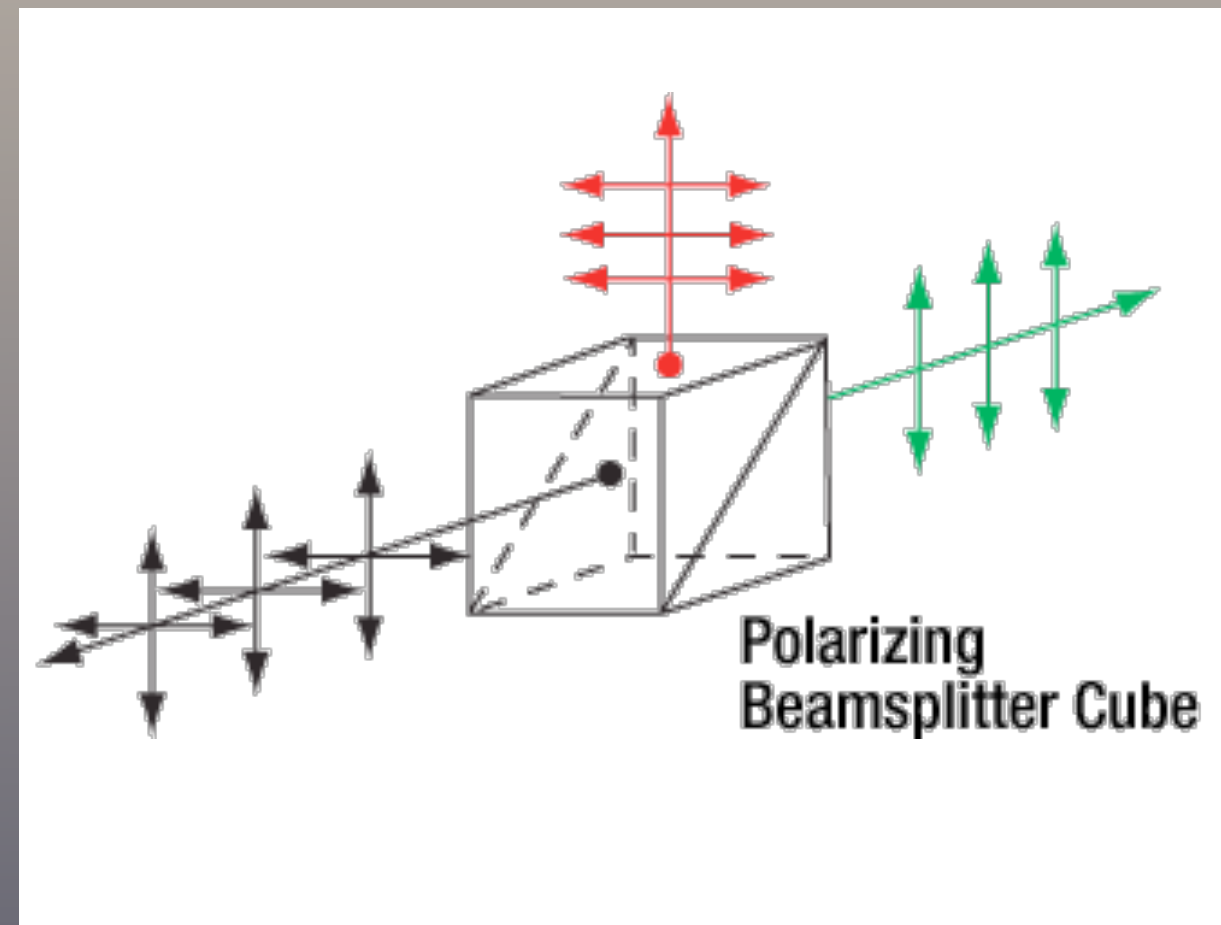
HOW DO WE
MEASURE IT???

Basics...

Half -Wave Plate

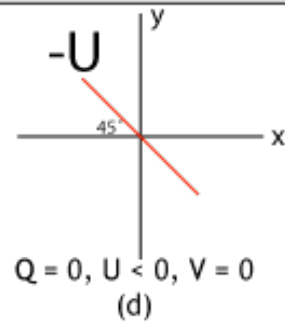
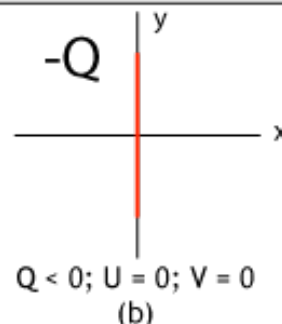
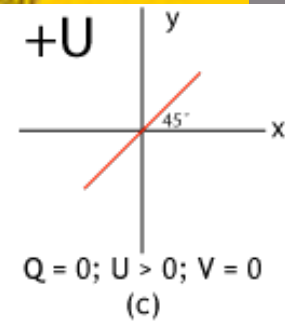
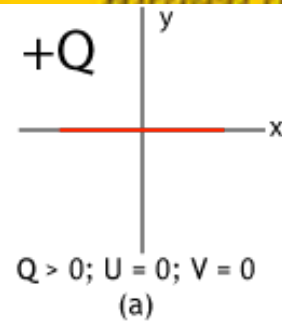
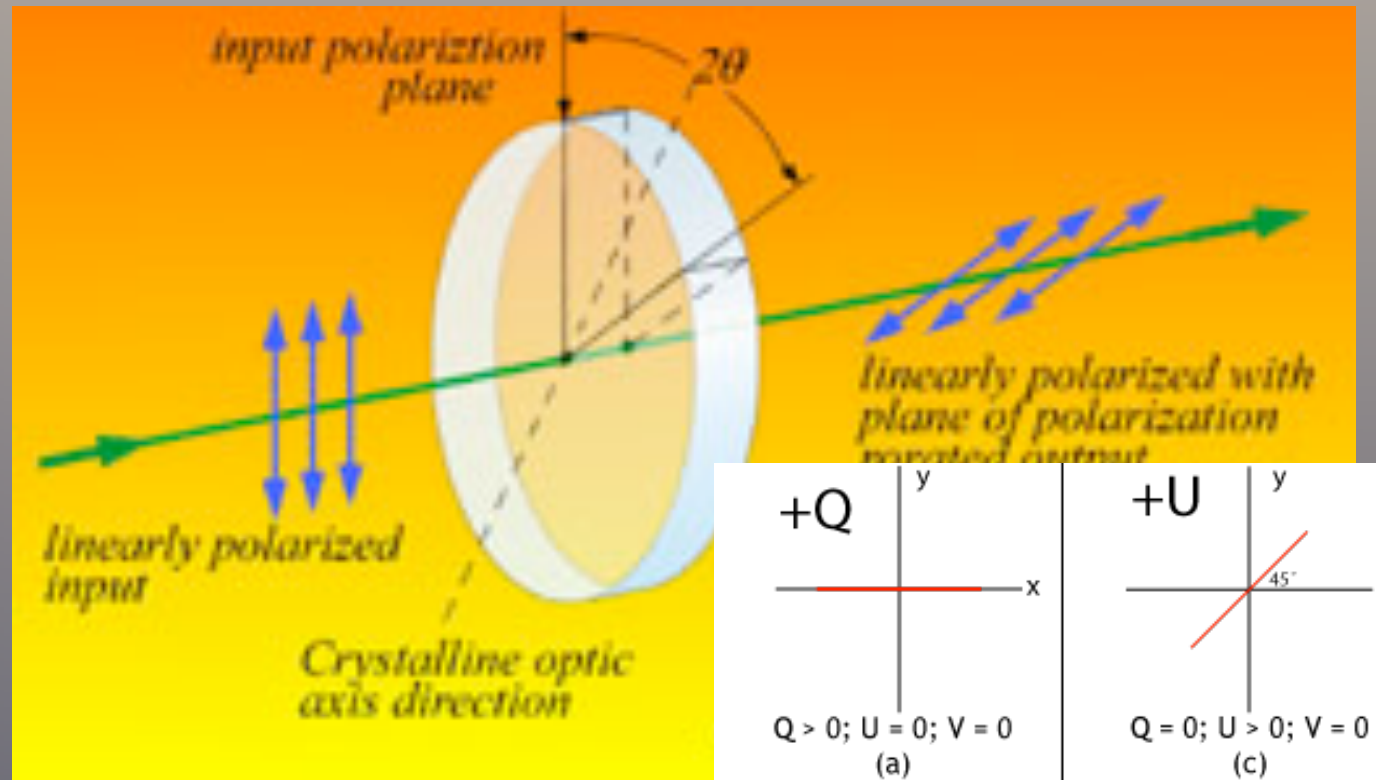


Beamsplitter

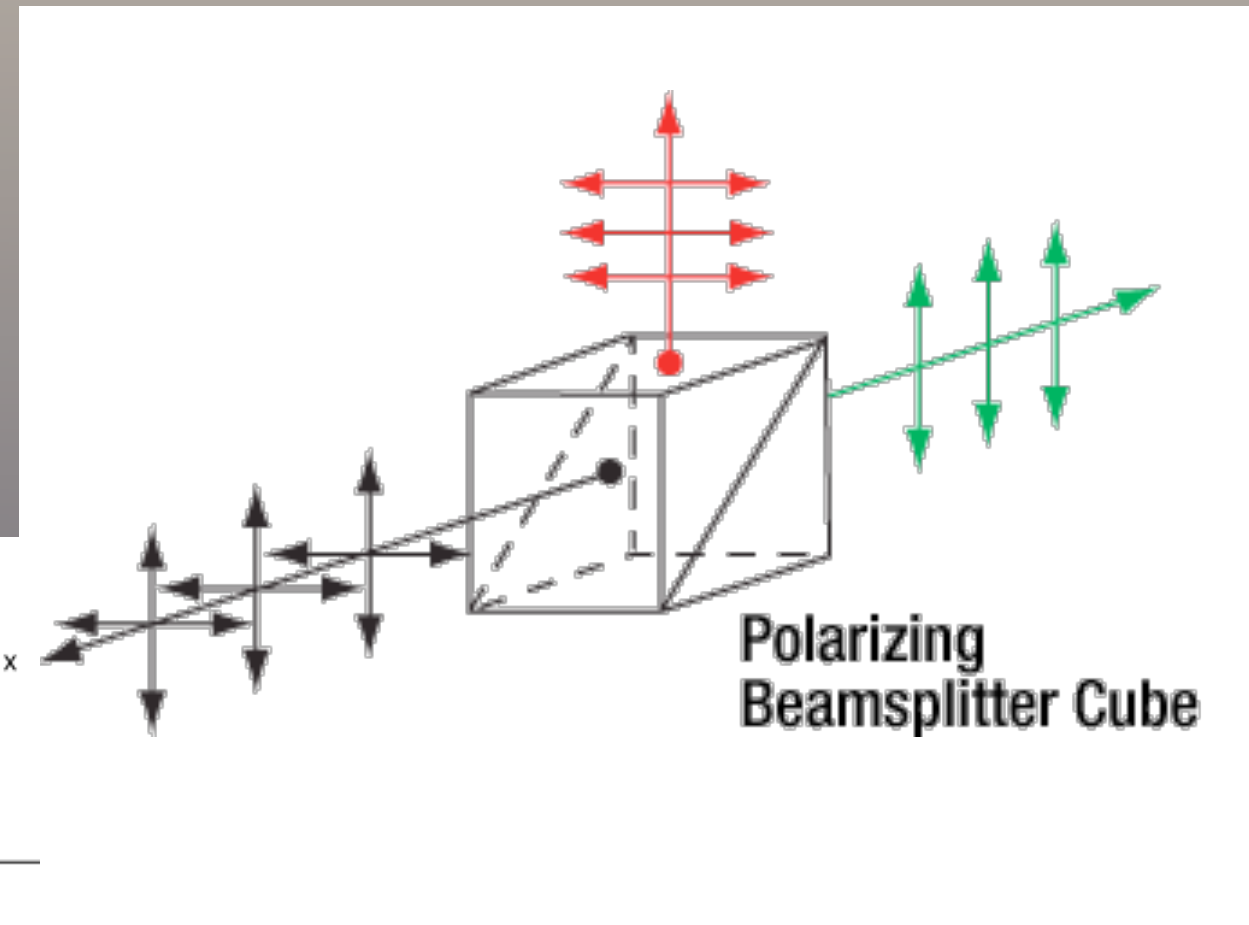


Basics...

Half -Wave Plate

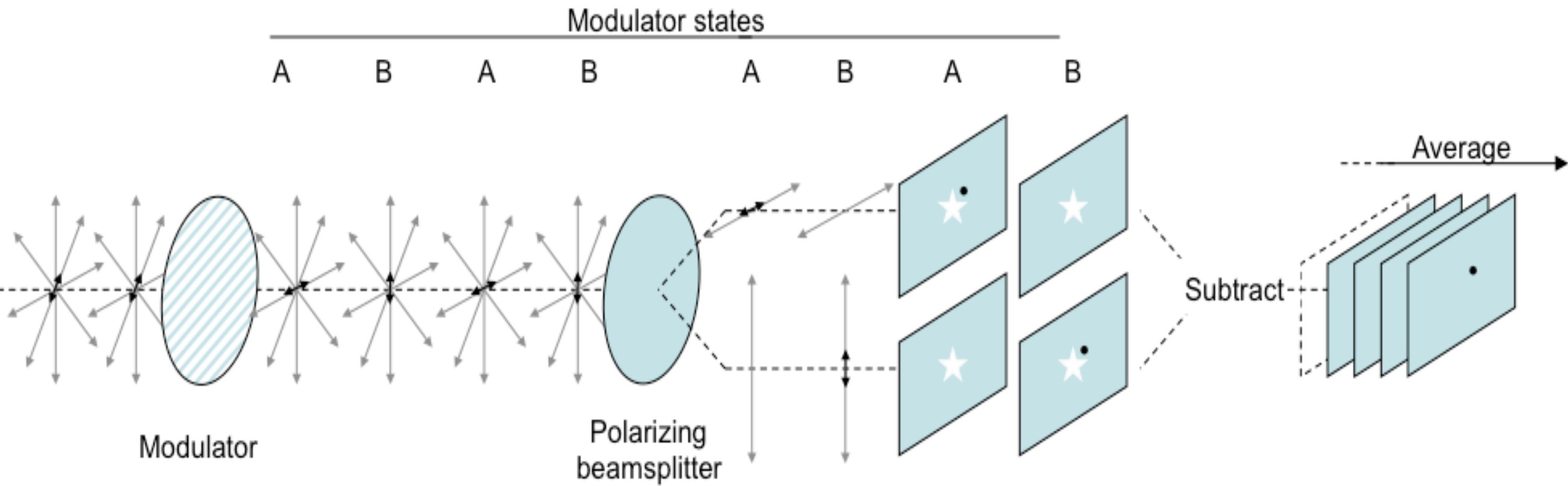


Beamsplitter



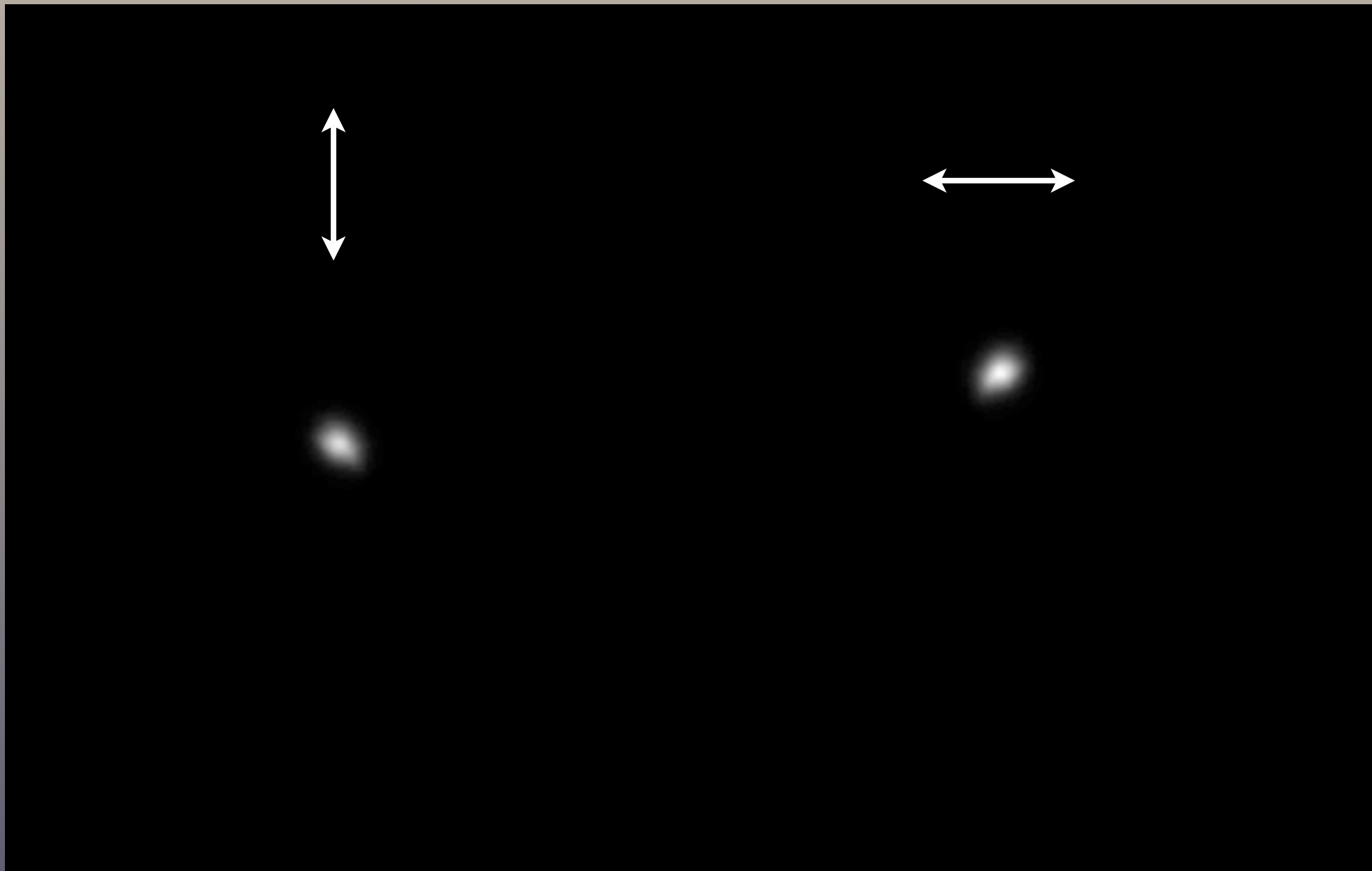
Differential technique

Dual-Beam Exchange Technique



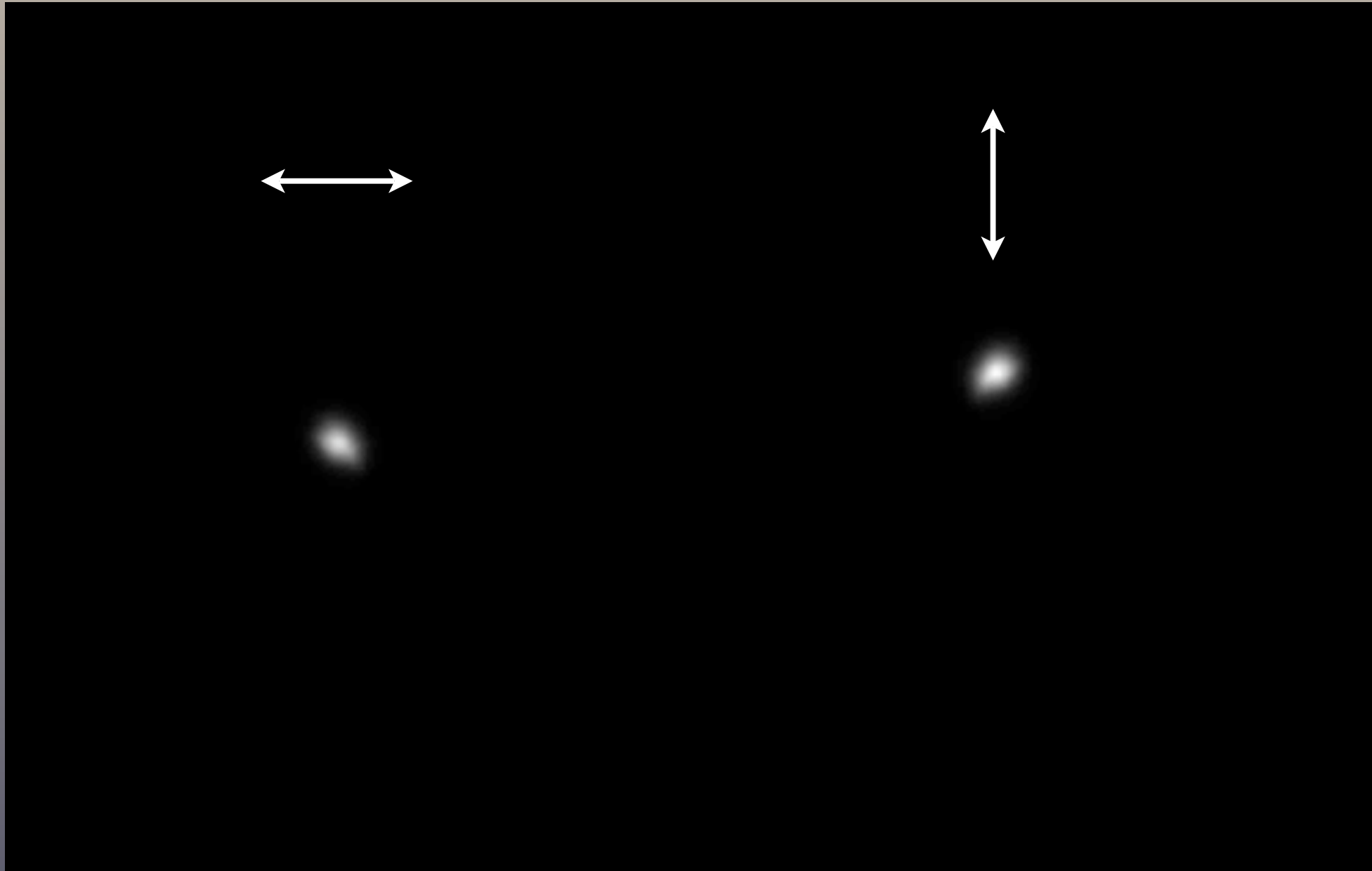


Differential technique



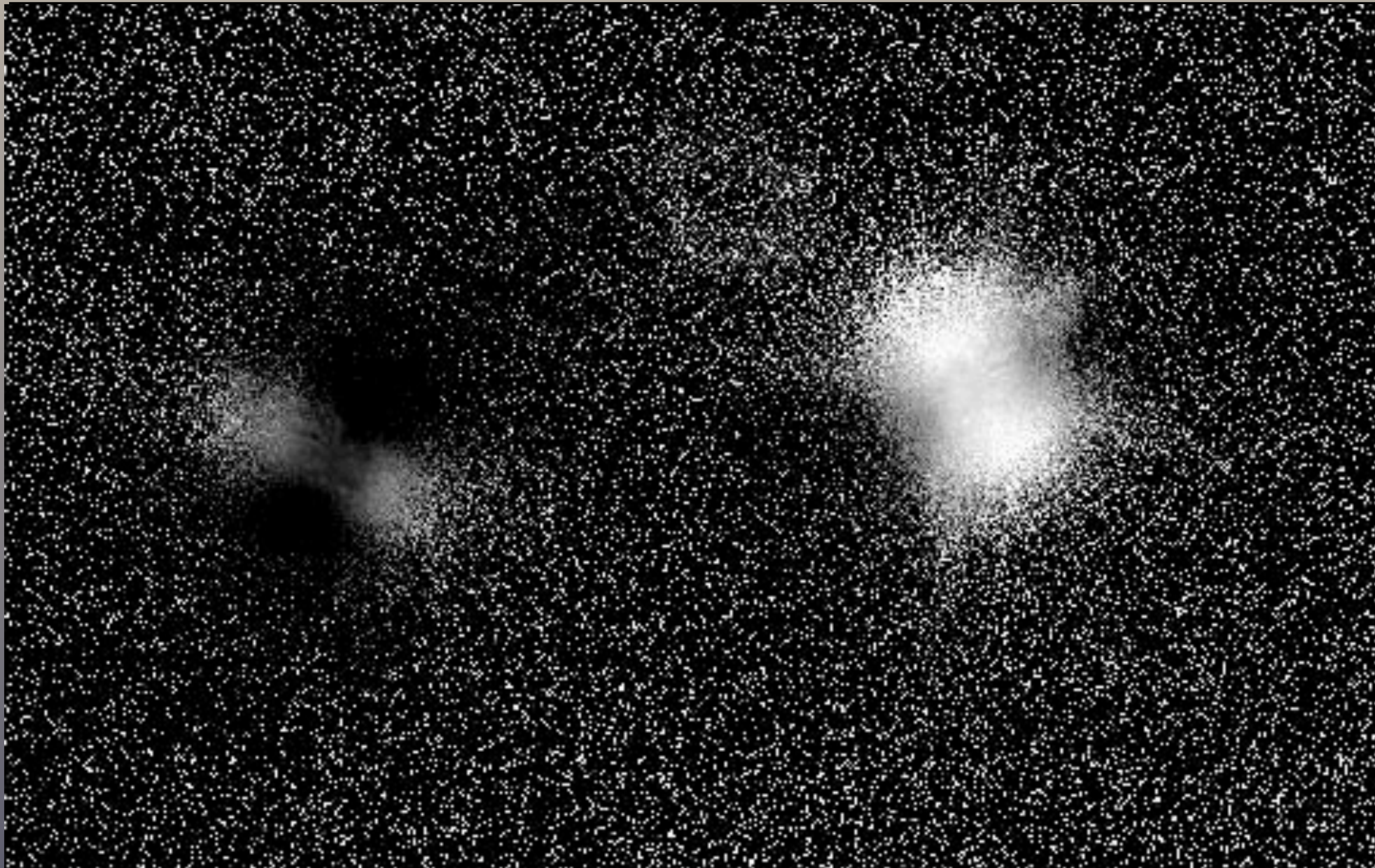


Differential technique





Differential technique





Imaging Polarimetry: Instrumentation

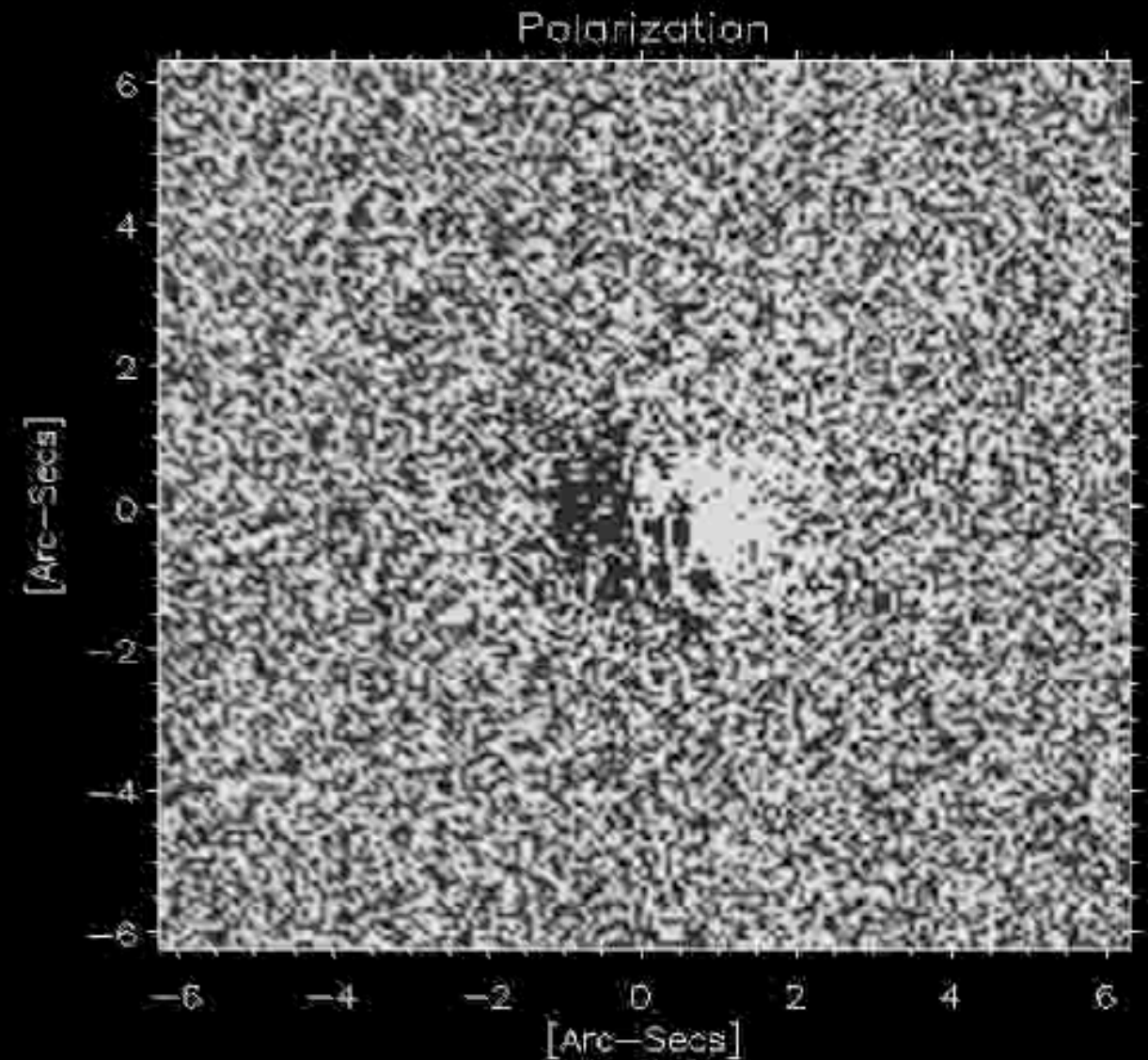
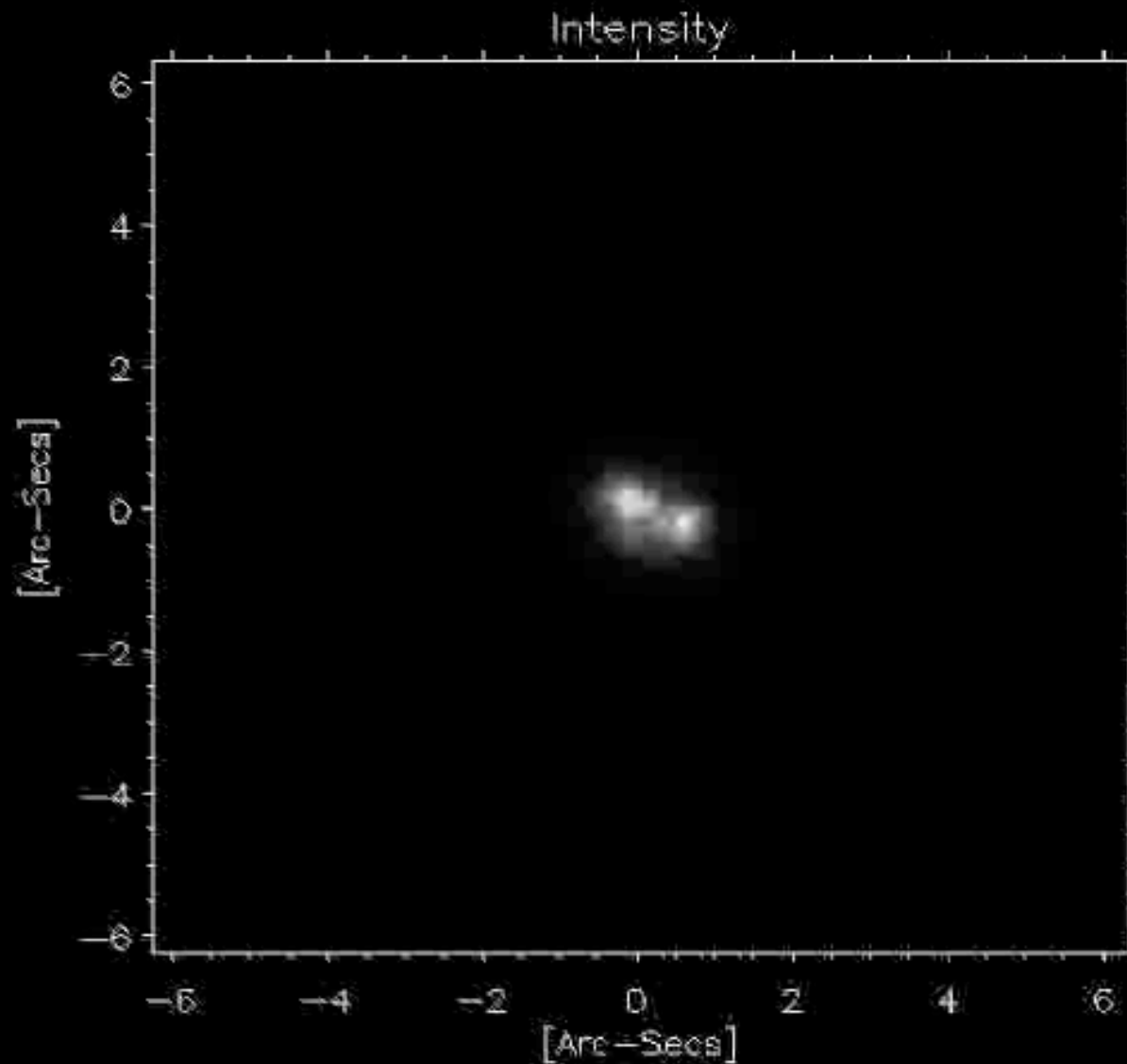
“One video” is worth 1000 words...



Imaging Polarimetry: Instrumentation

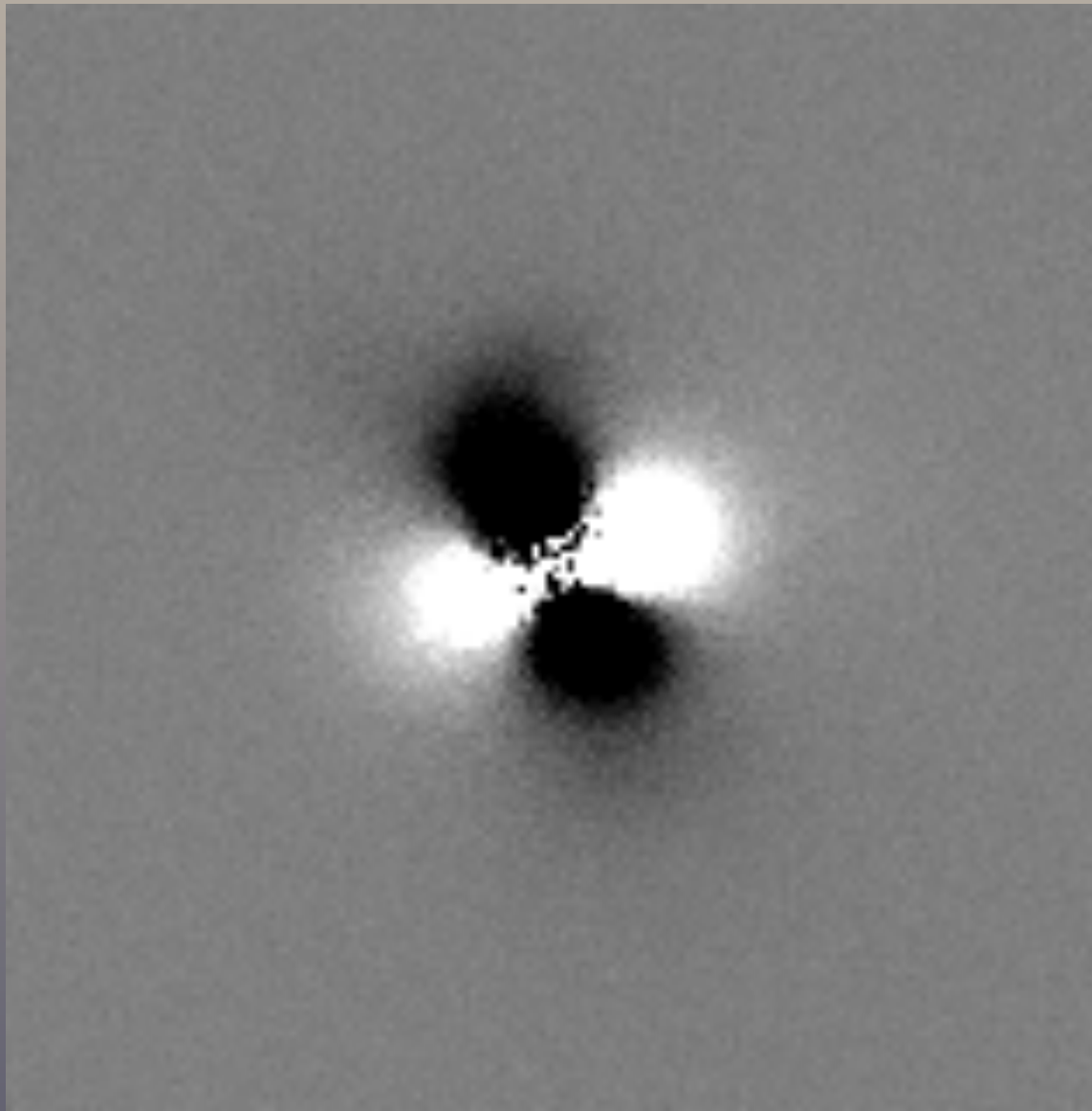
“One video” is worth 1000 words...

Exposure Time: 0.0560000 [seconds]

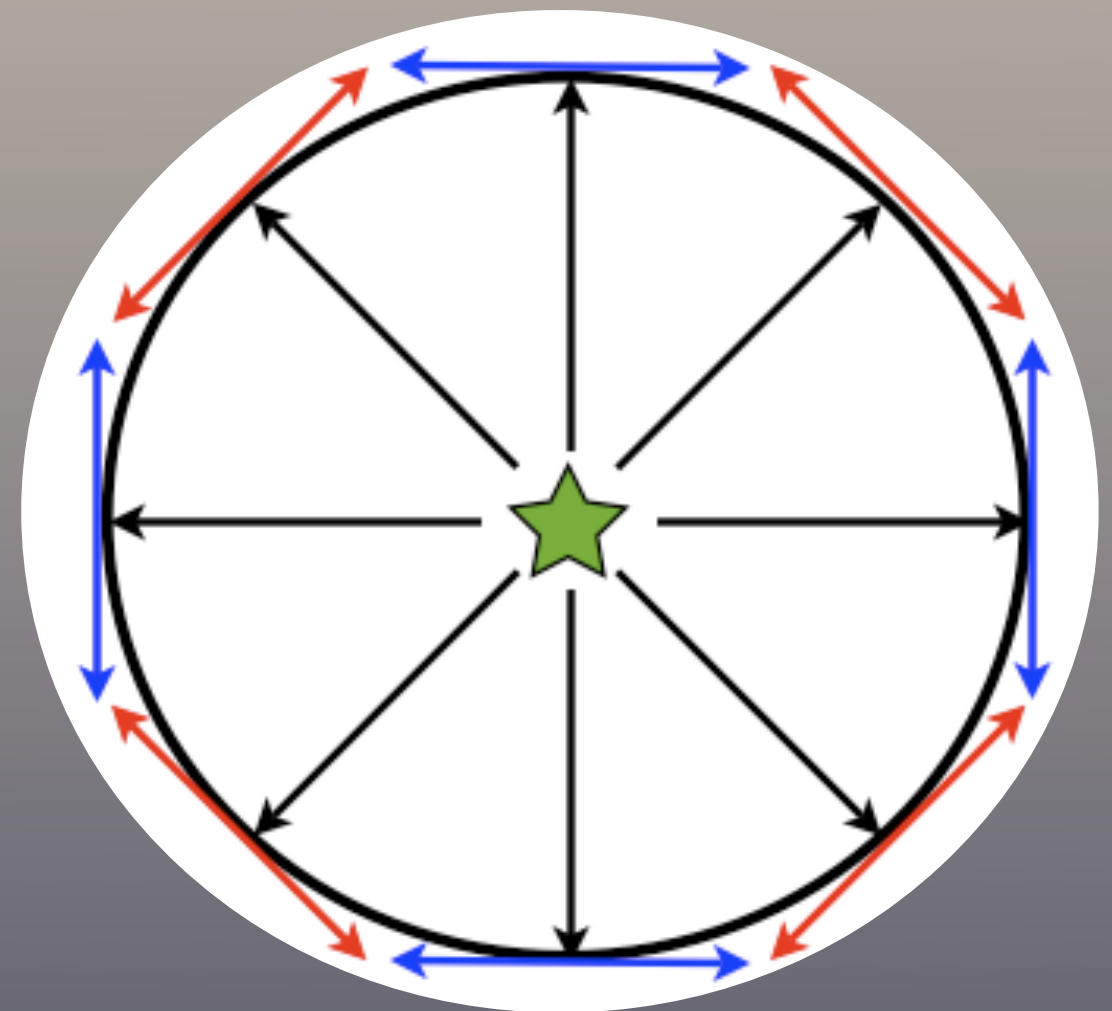
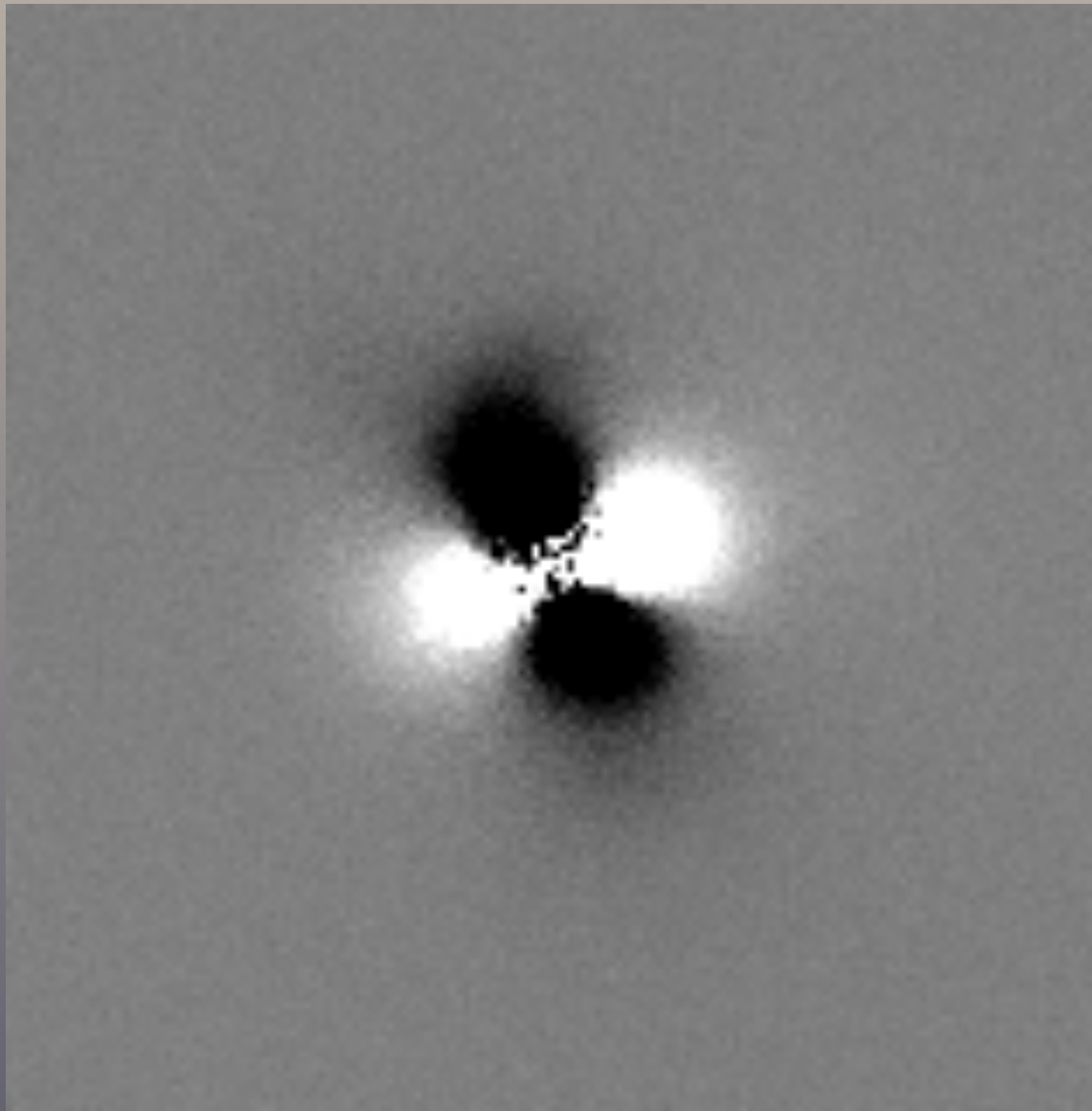




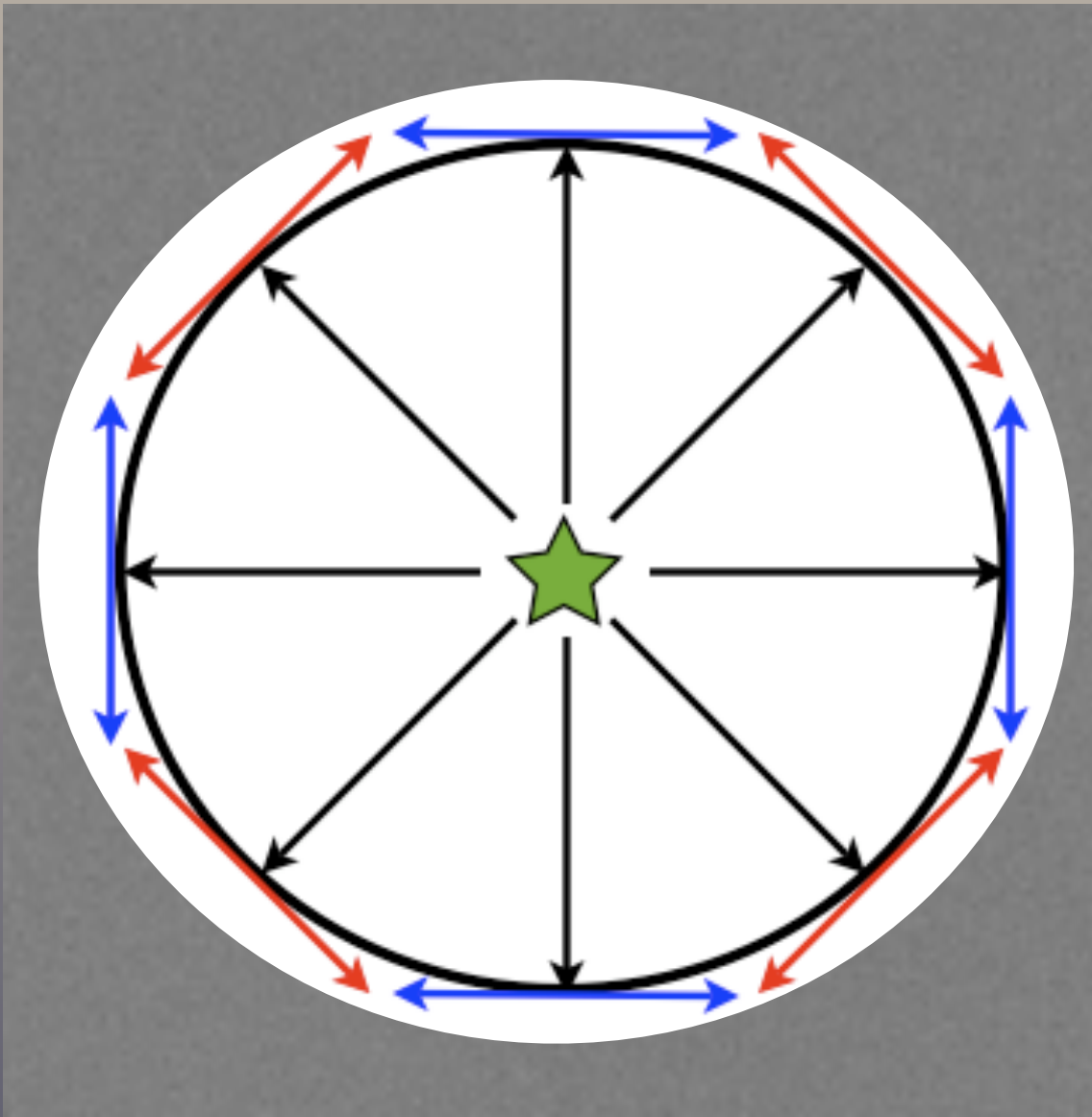
What are we talking??



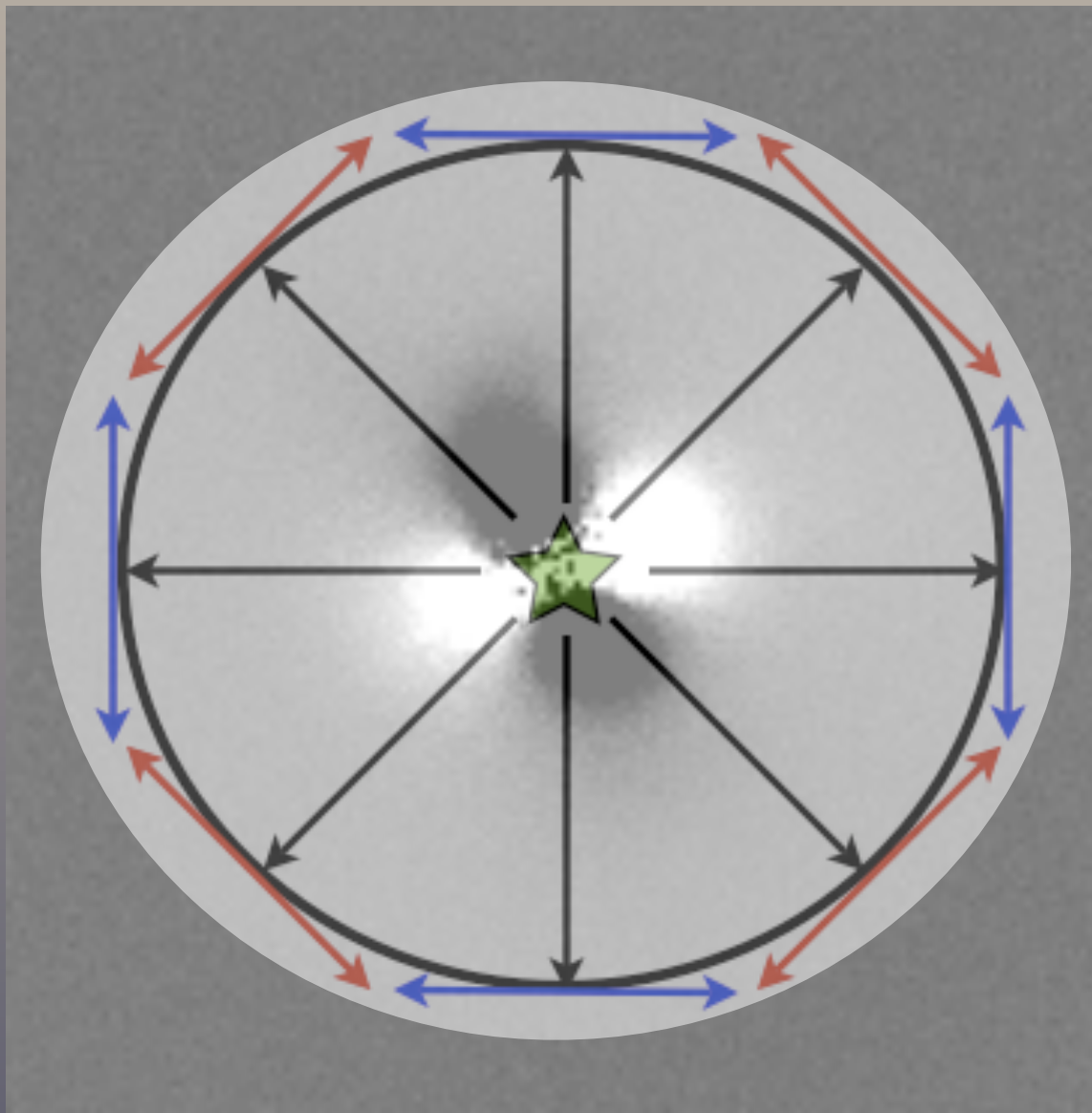
What are we talking about??



What are we talking??

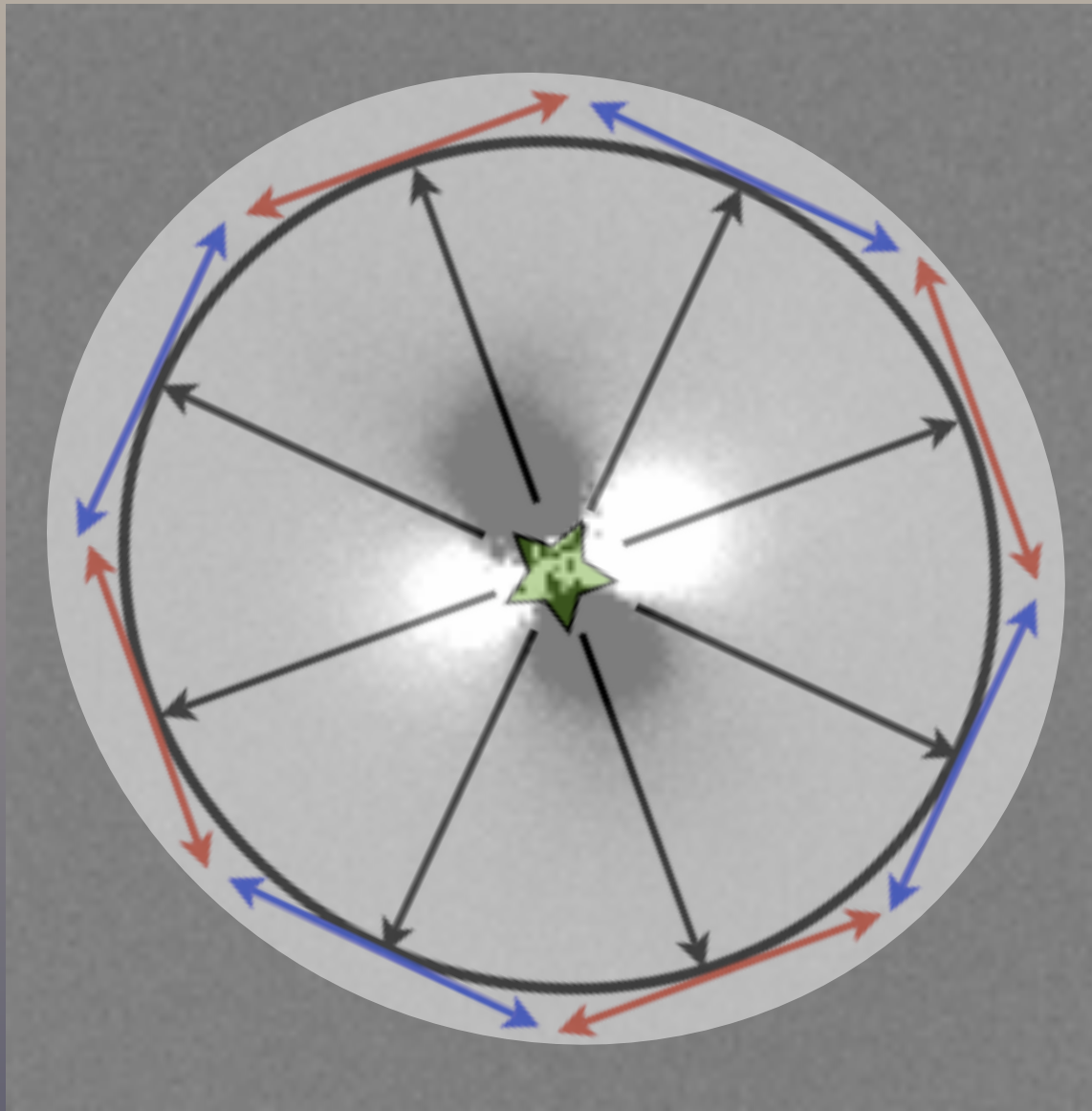


What are we talking??

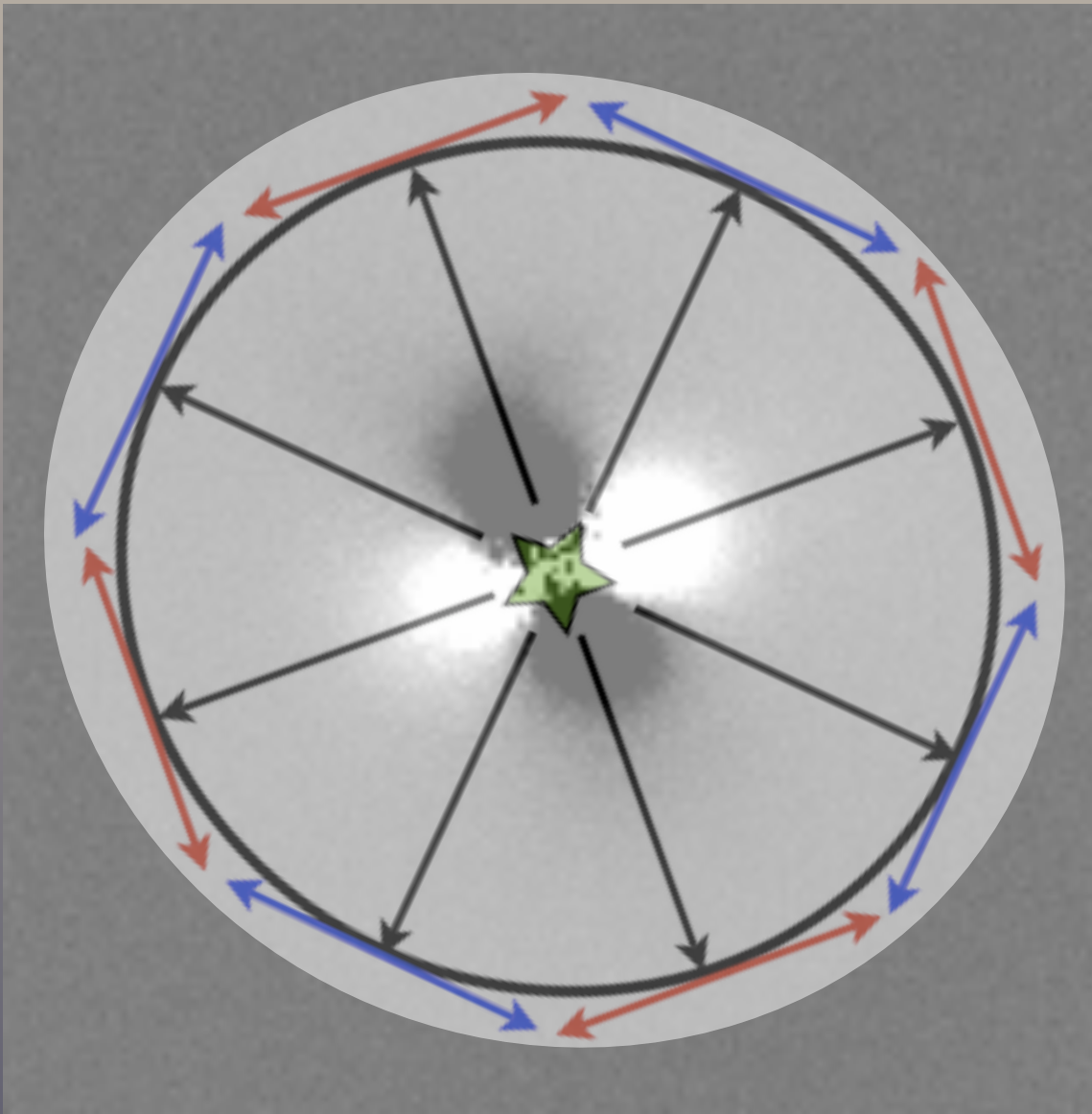




What are we talking??

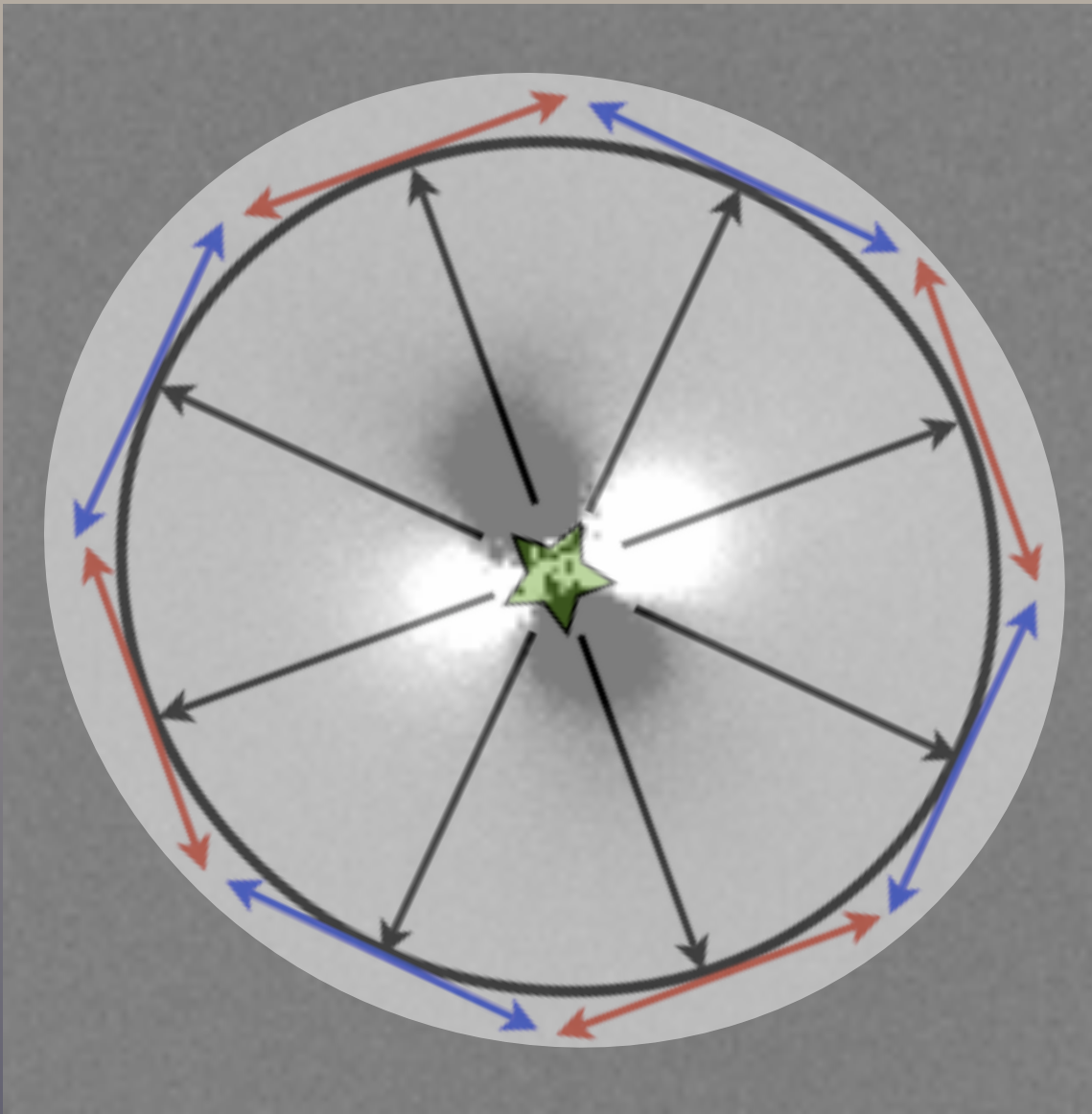


What are we talking??

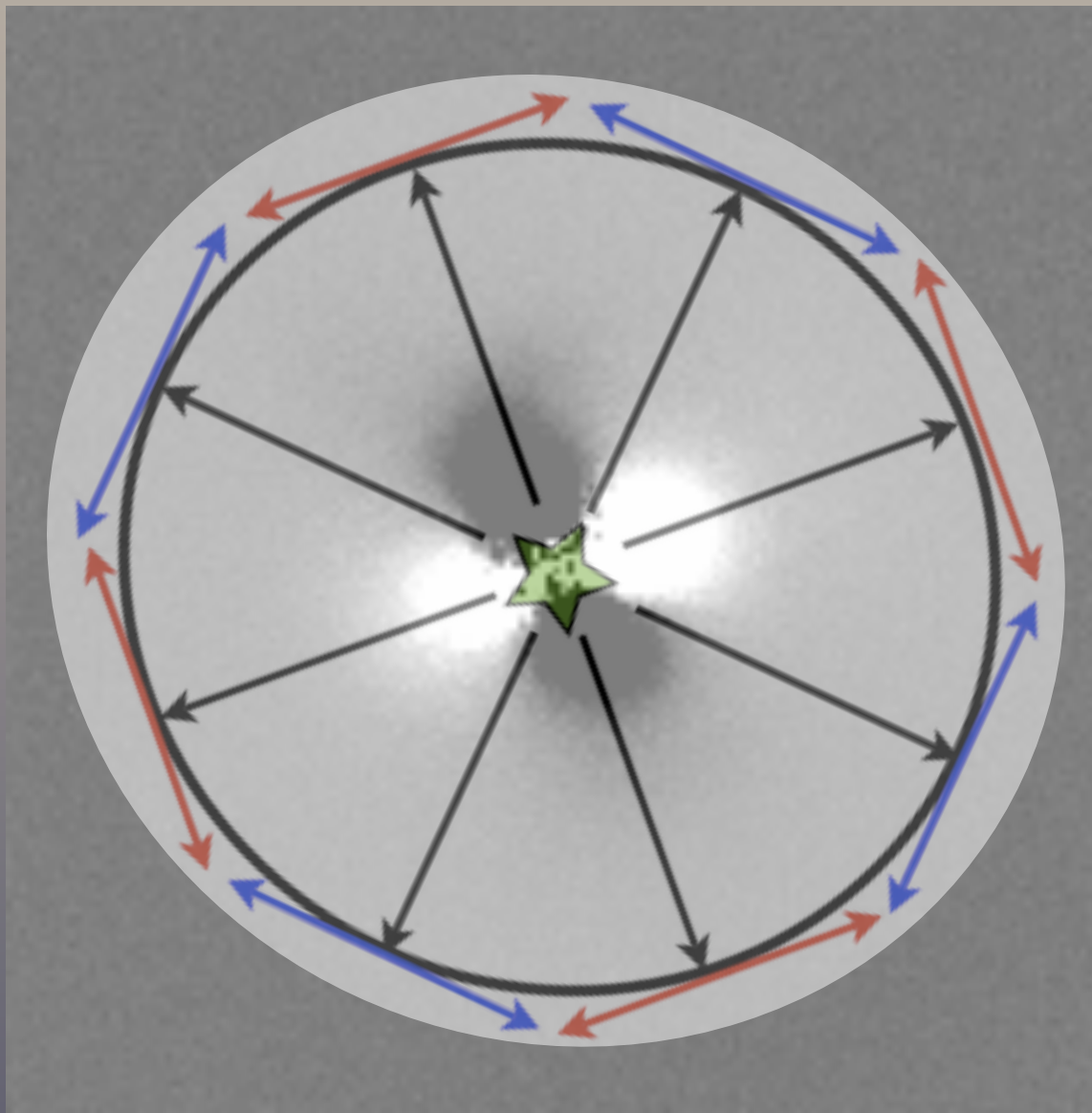


What are we talking about??

OK. Polarimetry works fine.
SO WHAT????



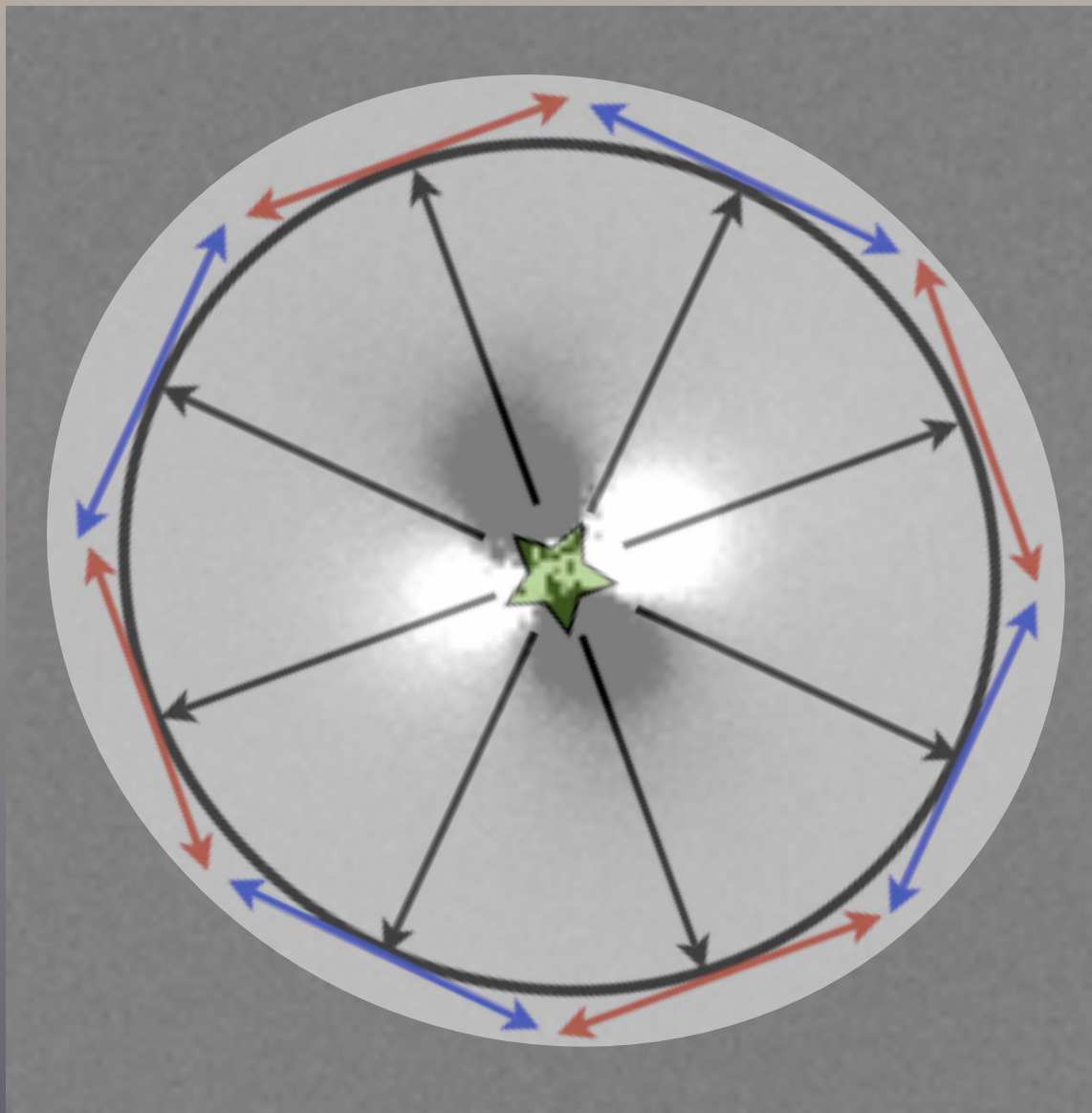
What are we talking about??



OK. Polarimetry works fine.
SO WHAT????

- Dust Properties
- Disk Orientation
- “Invisible Dust”
- Planets’ signature
- + Coronagraphs
- + Spectroscopy
- It is always hungry.... Photons!!

What are we talking about??



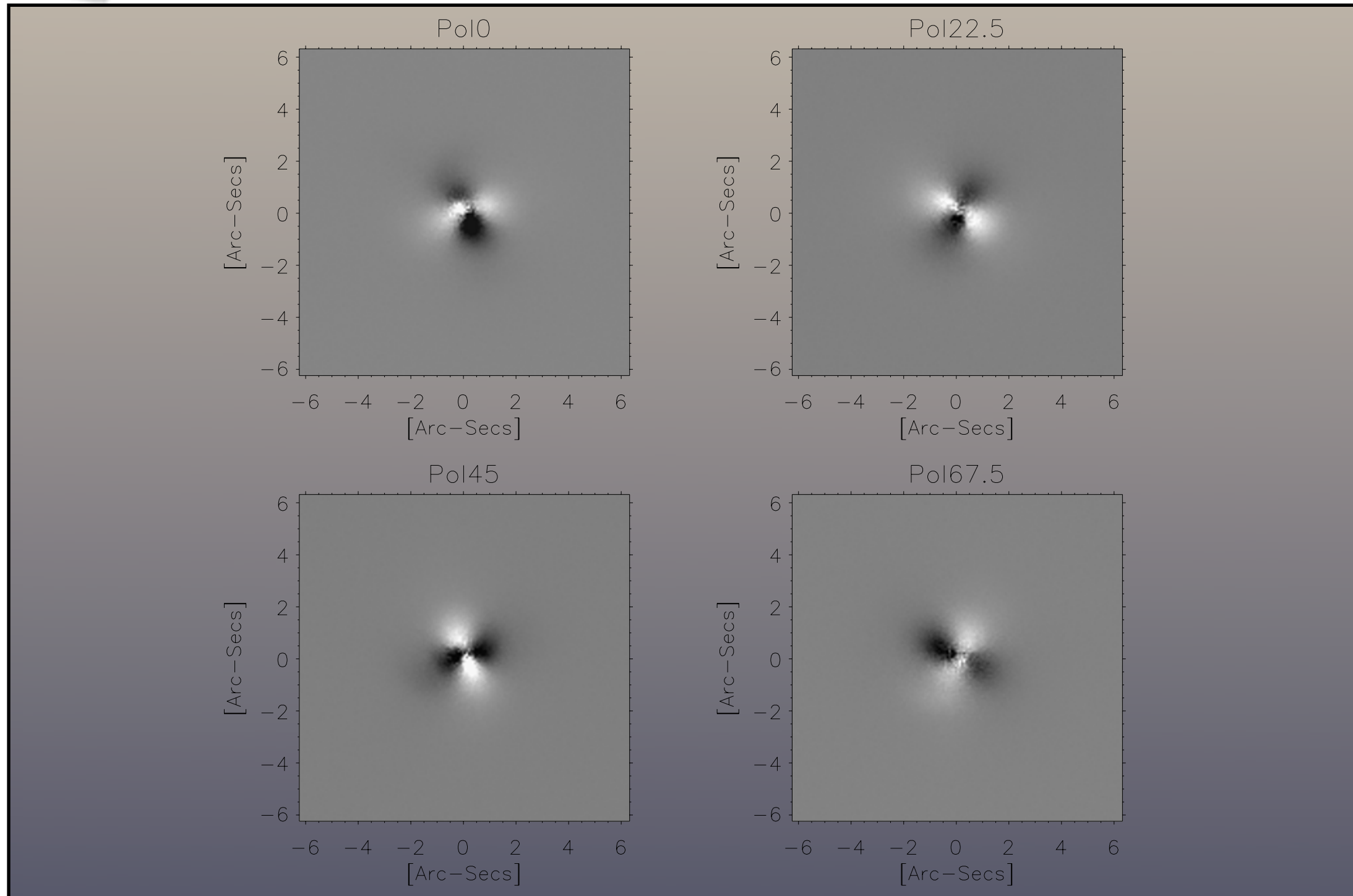
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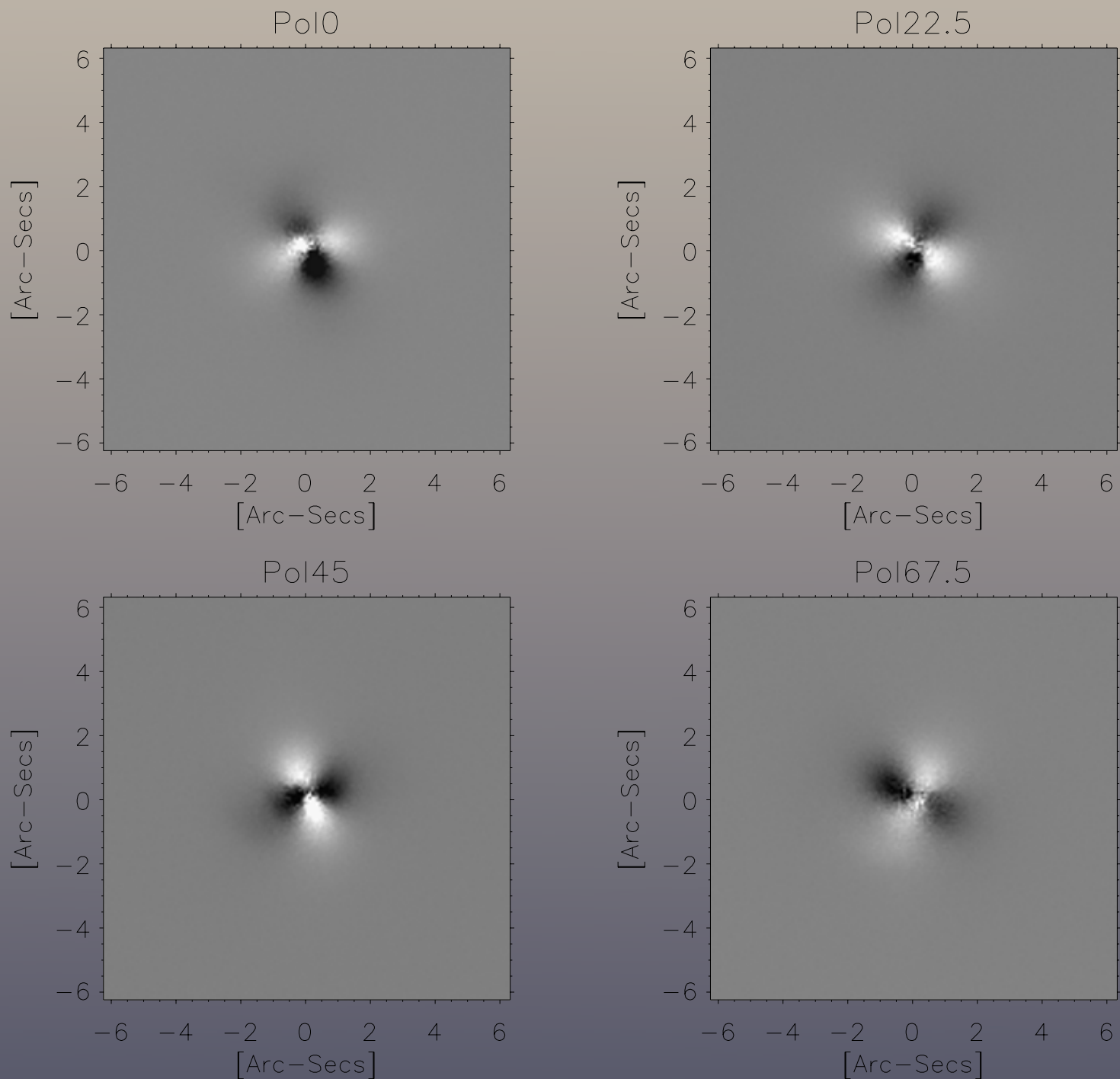
Differential technique





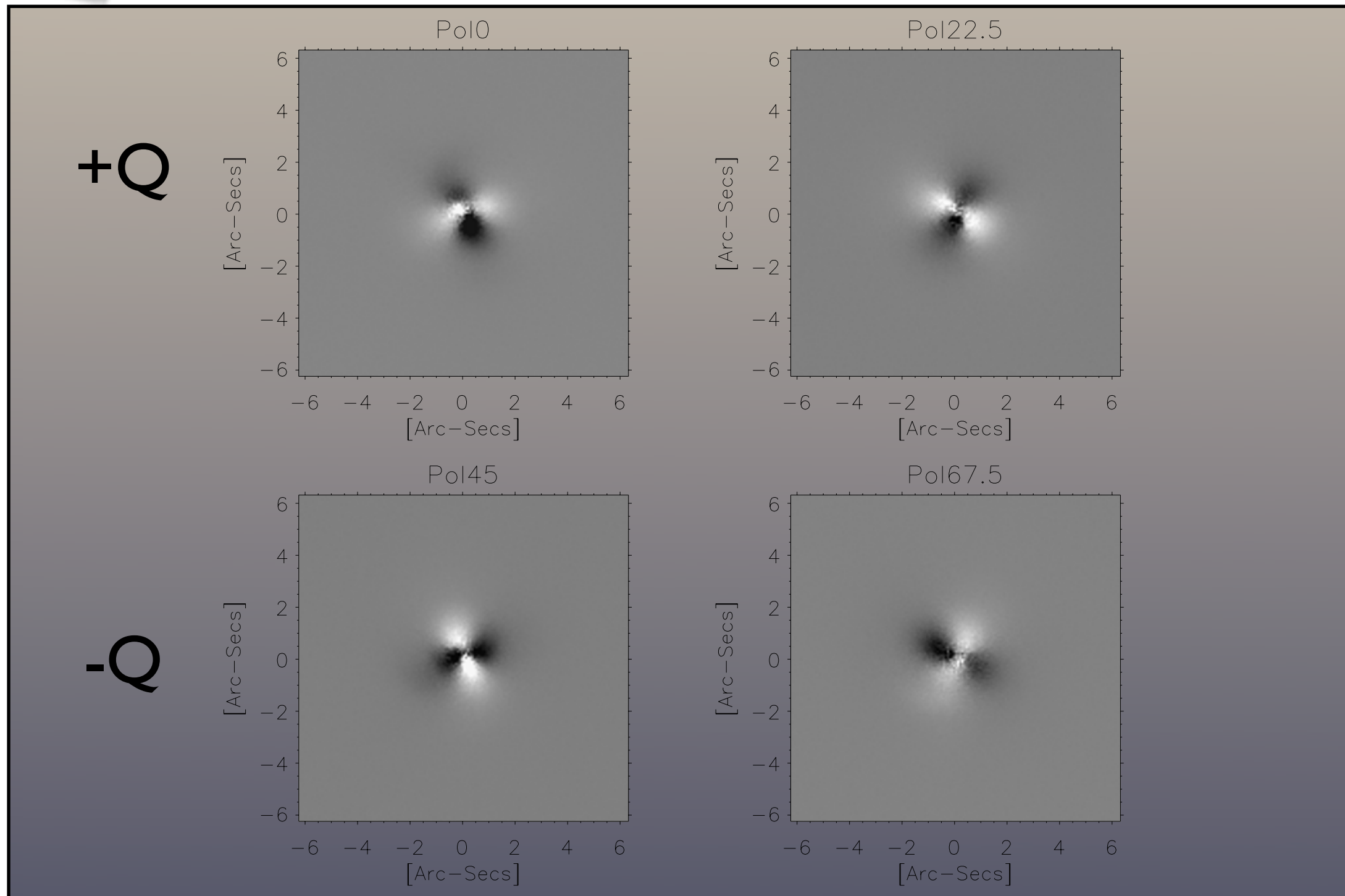
Differential technique

$+Q$



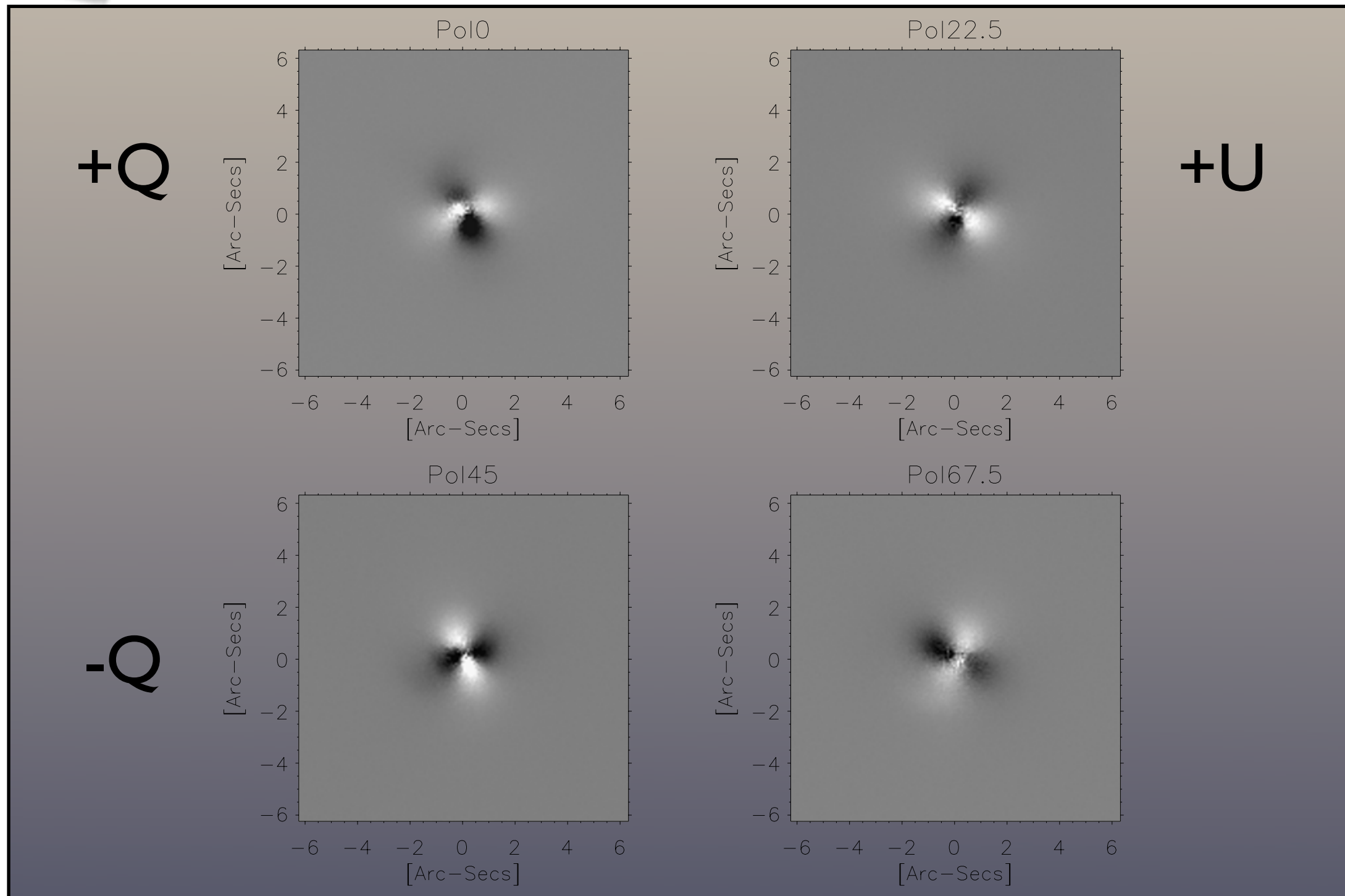


Differential technique



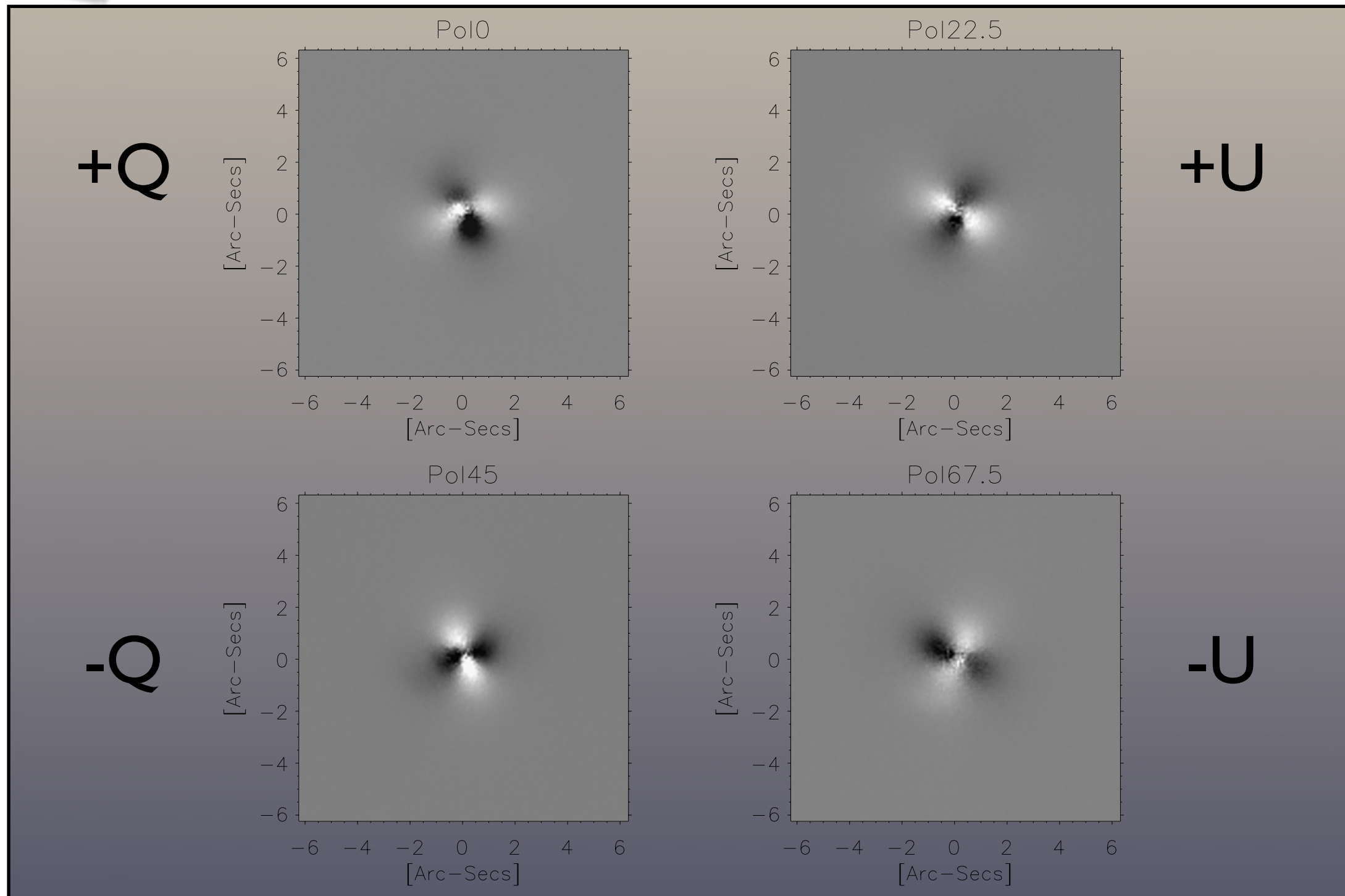


Differential technique



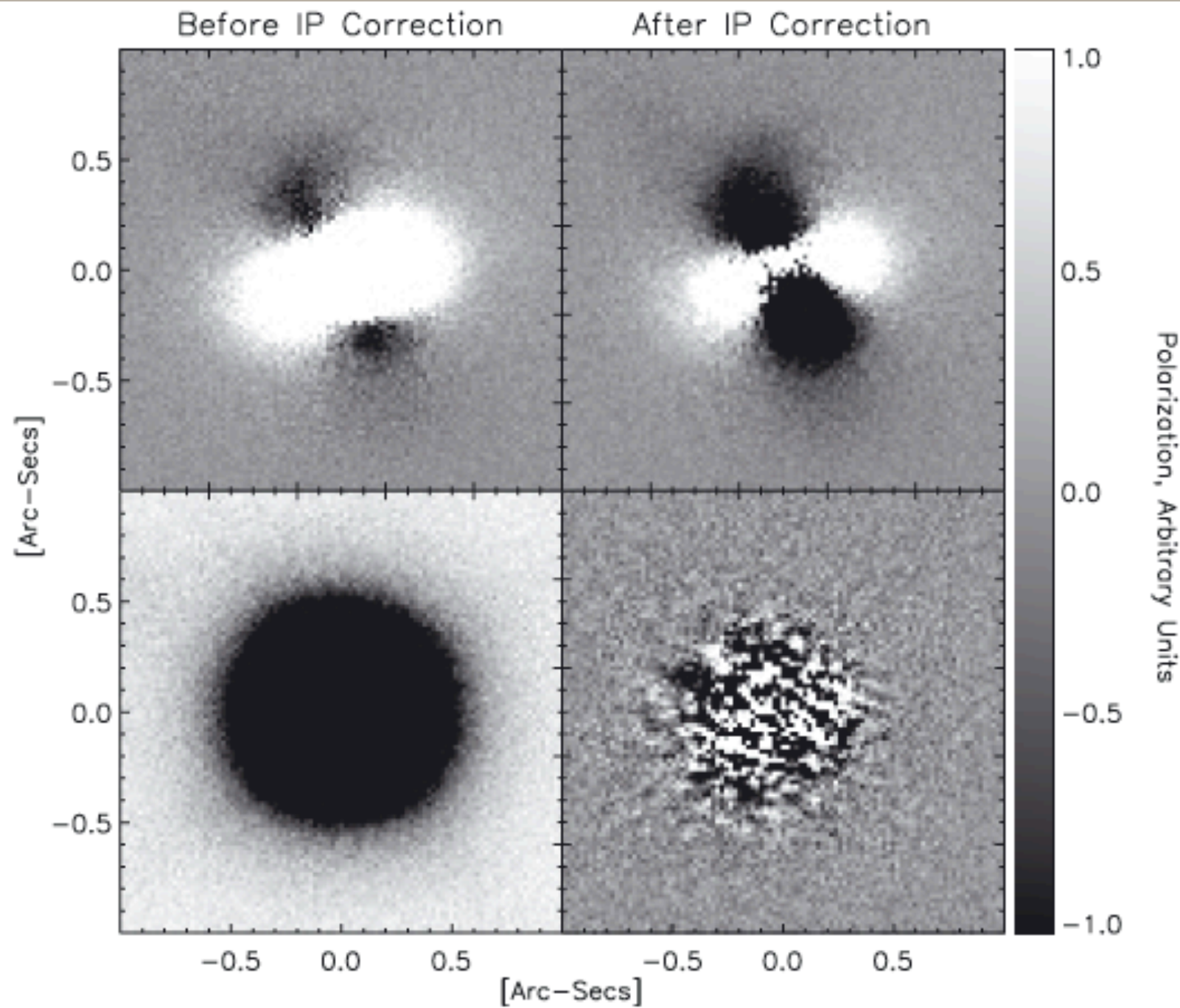


Differential technique





Instrumental Polarization: your enemy





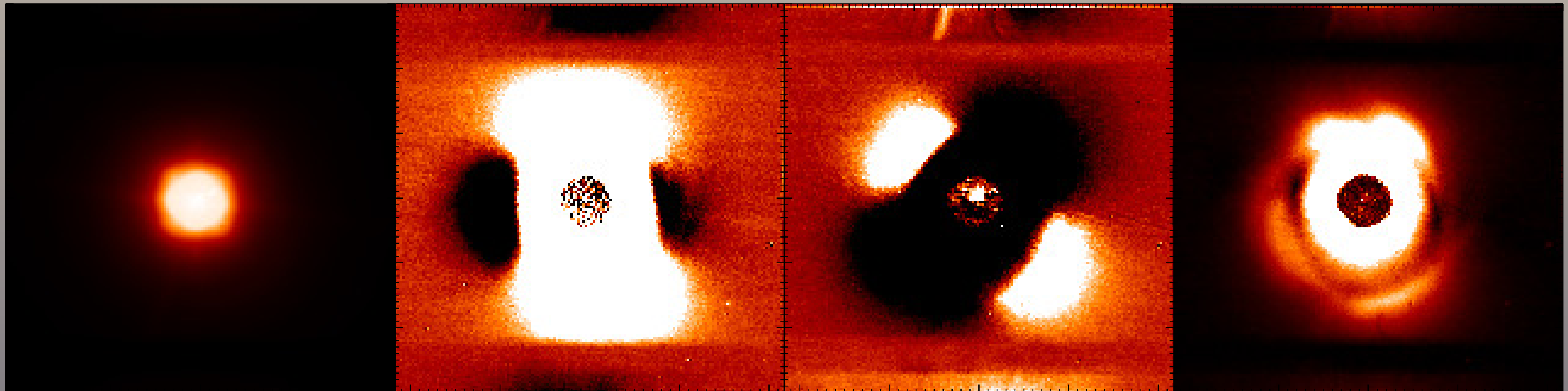
Instrumental Polarization: your enemy

Int

Stokes Q

Stokes U

P



-2 -1 0 1 2
[Arc-Secs]

-2 -1 0 1 2
[Arc-Secs]

-2 -1 0 1 2
[Arc-Secs]

-2 -1 0 1 2
[Arc-Secs]



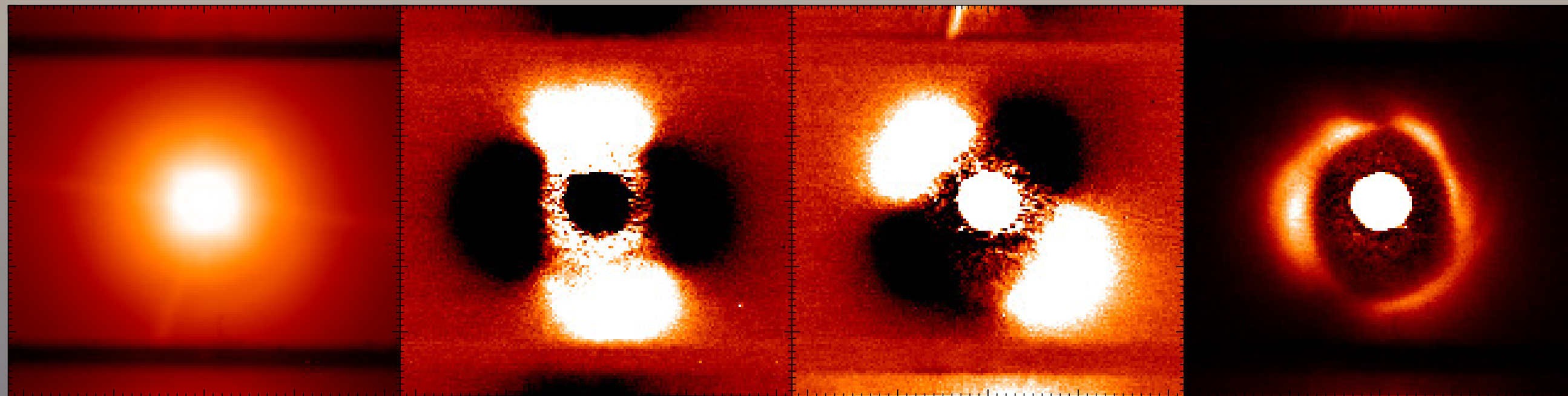
IP corrected...

Int

Stokes Q

Stokes U

P



-2 -1 0 1 2
[Arc-Secs]

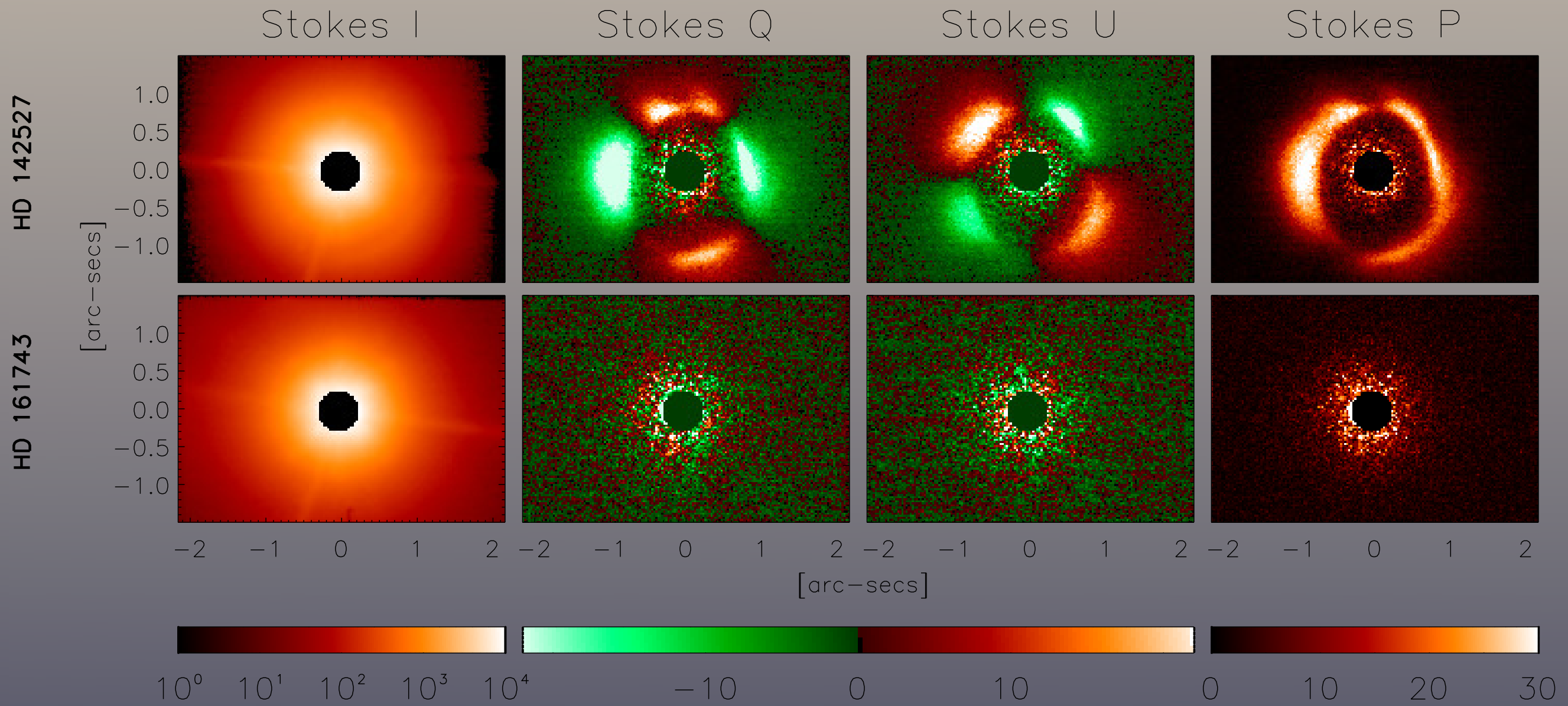
-2 -1 0 1 2
[Arc-Secs]

-2 -1 0 1 2
[Arc-Secs]

-2 -1 0 1 2
[Arc-Secs]



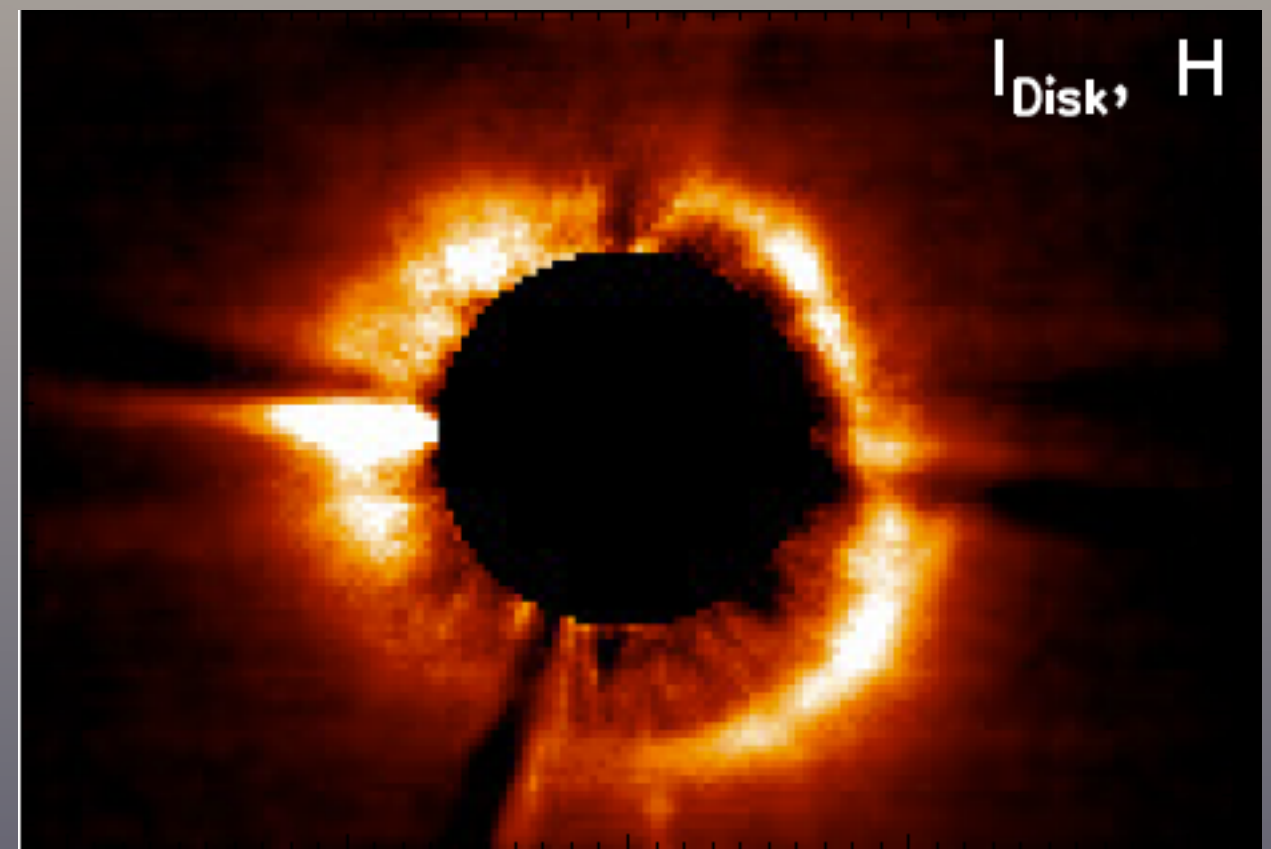
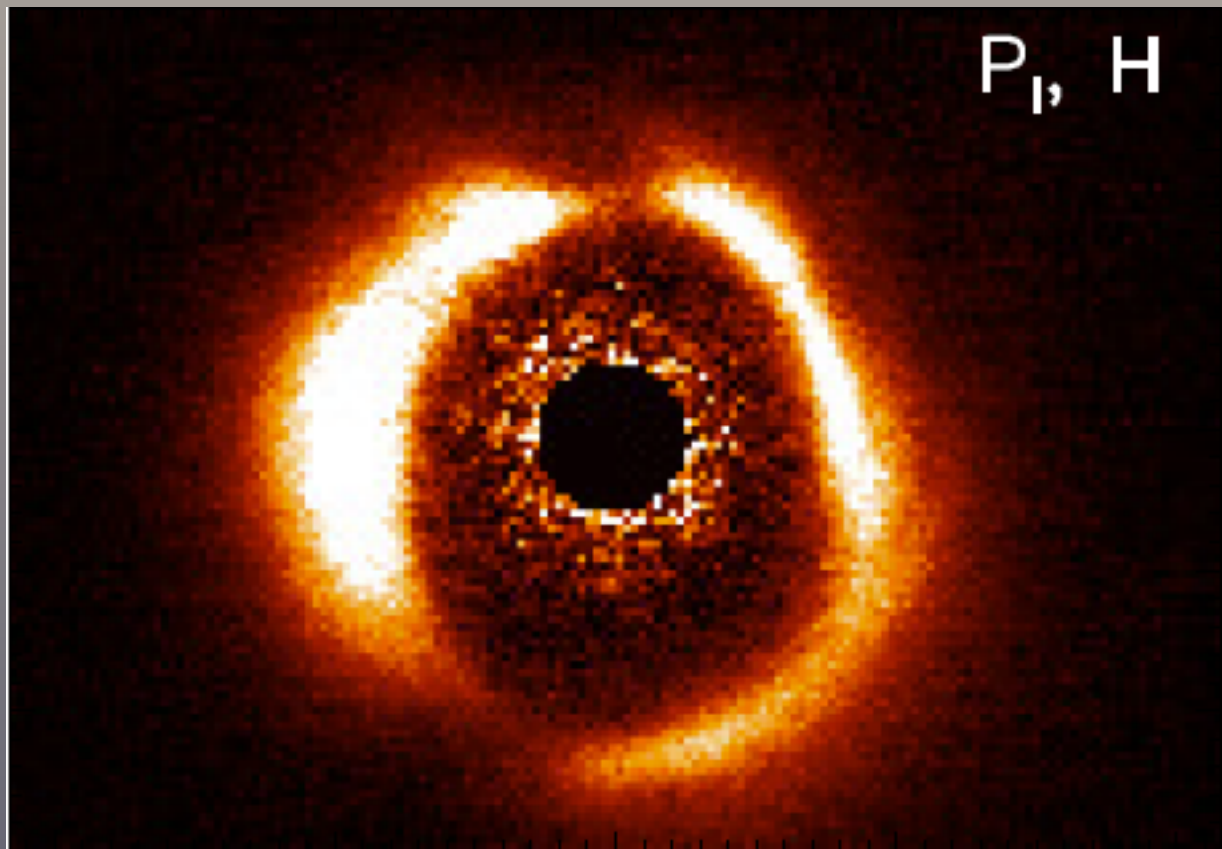
How do we know is well corrected???



Hunting the Polarization Degree

$$P_I = \sqrt{Q^2 + U^2}$$

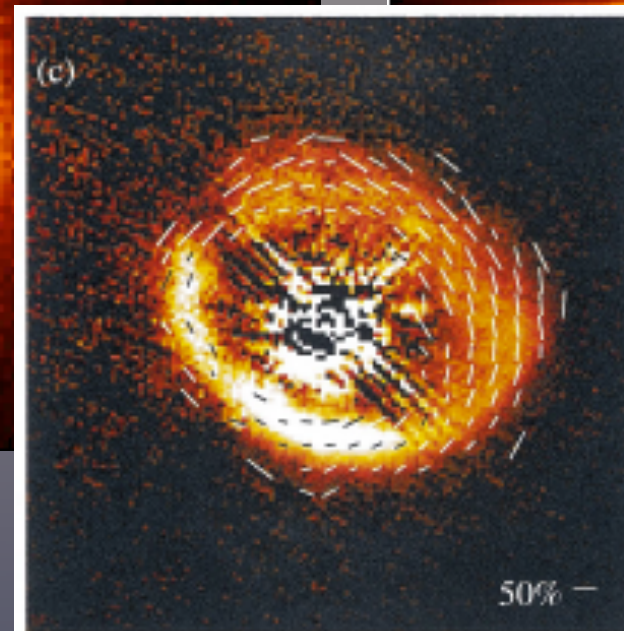
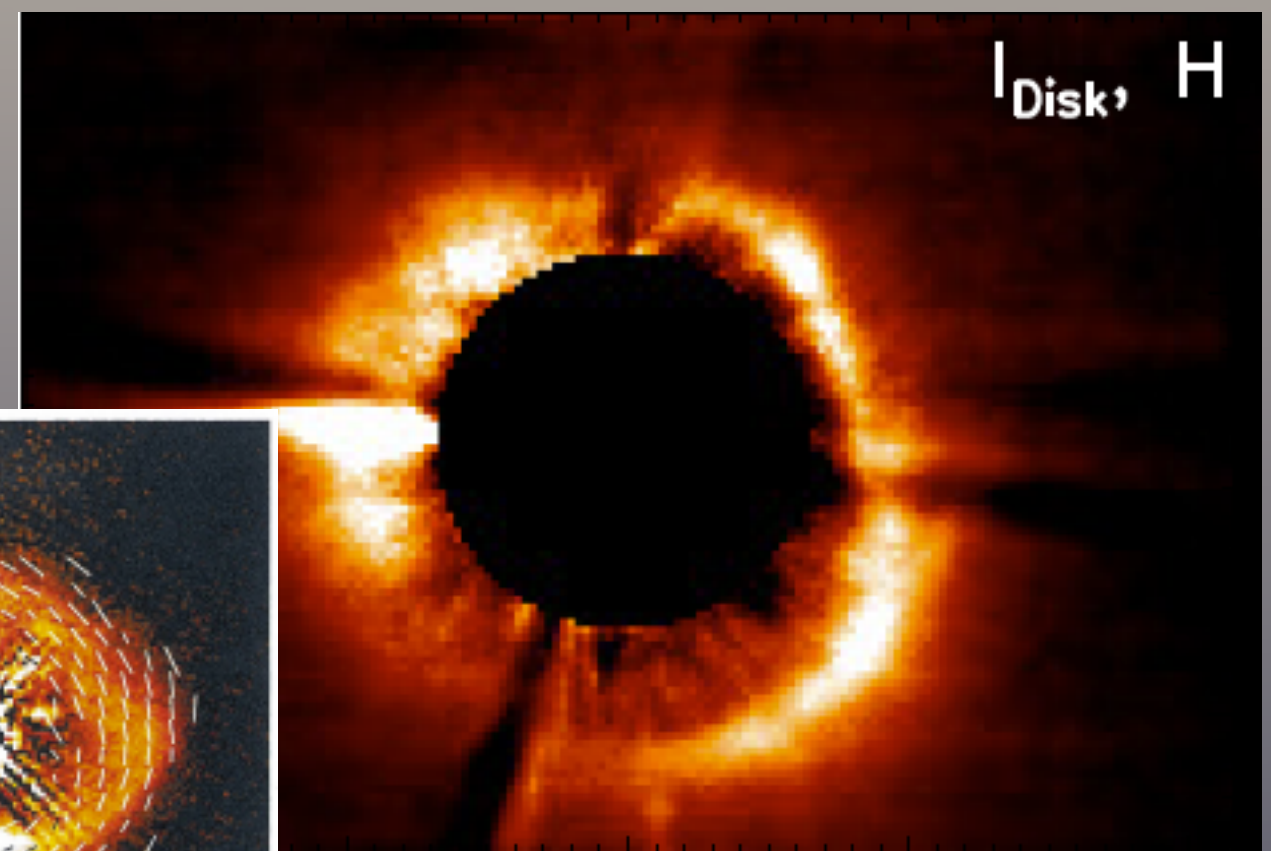
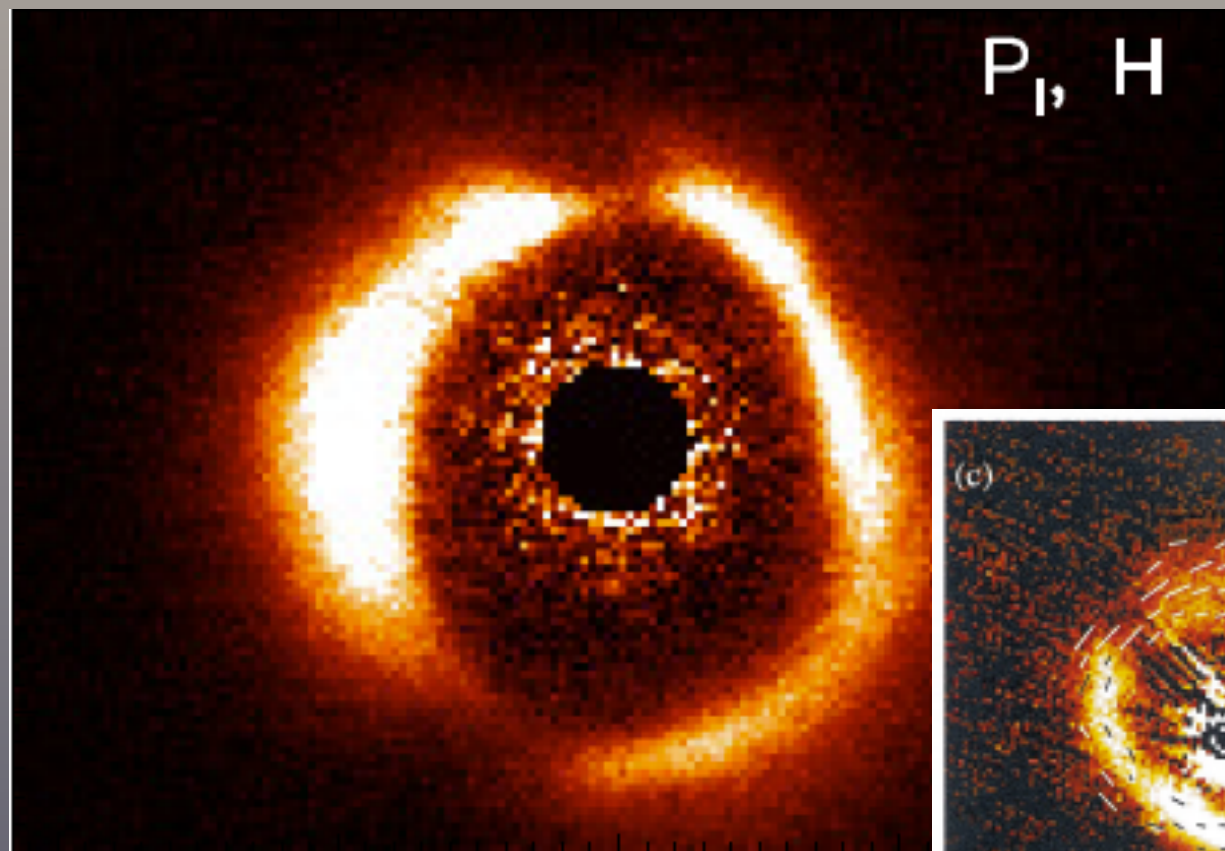
PSF-subtracted



Hunting the Polarization Degree

$$P_I = \sqrt{Q^2 + U^2}$$

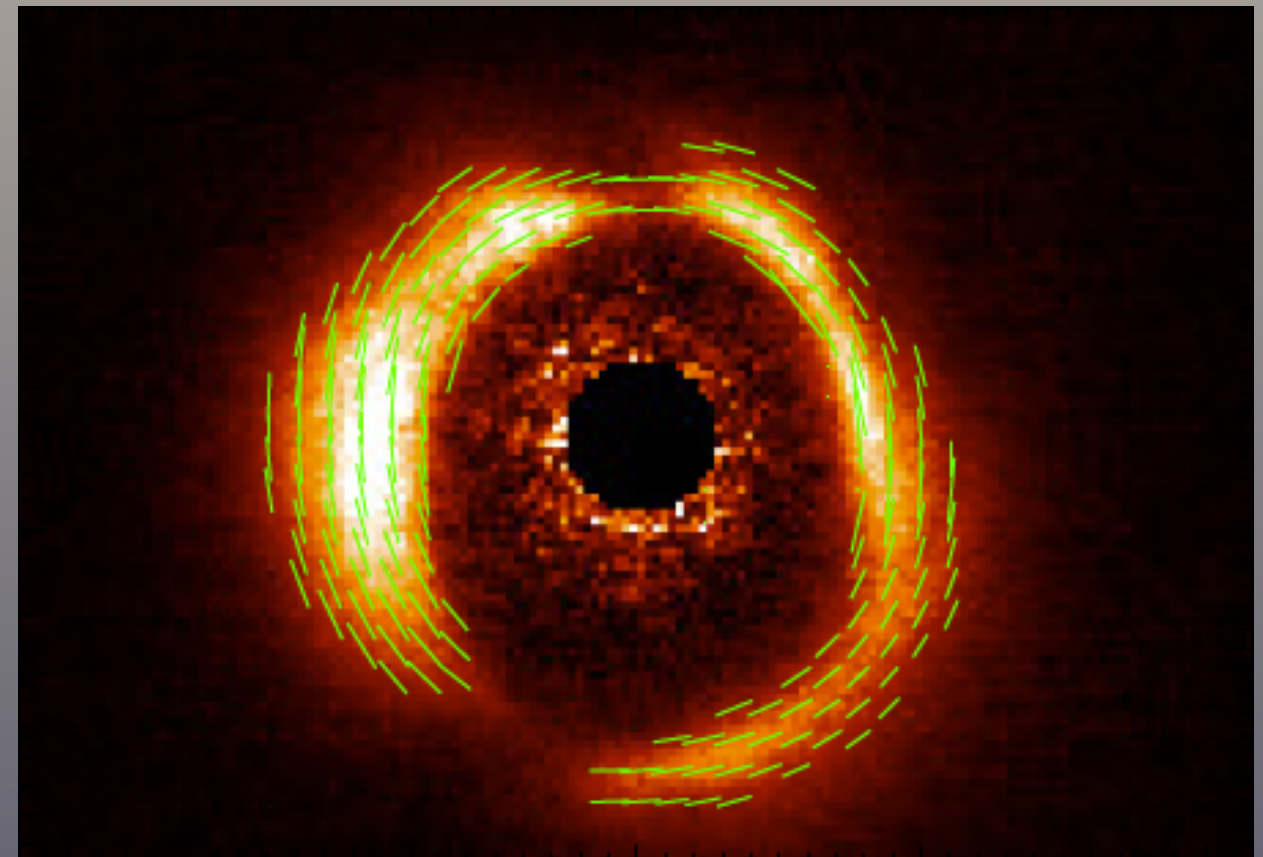
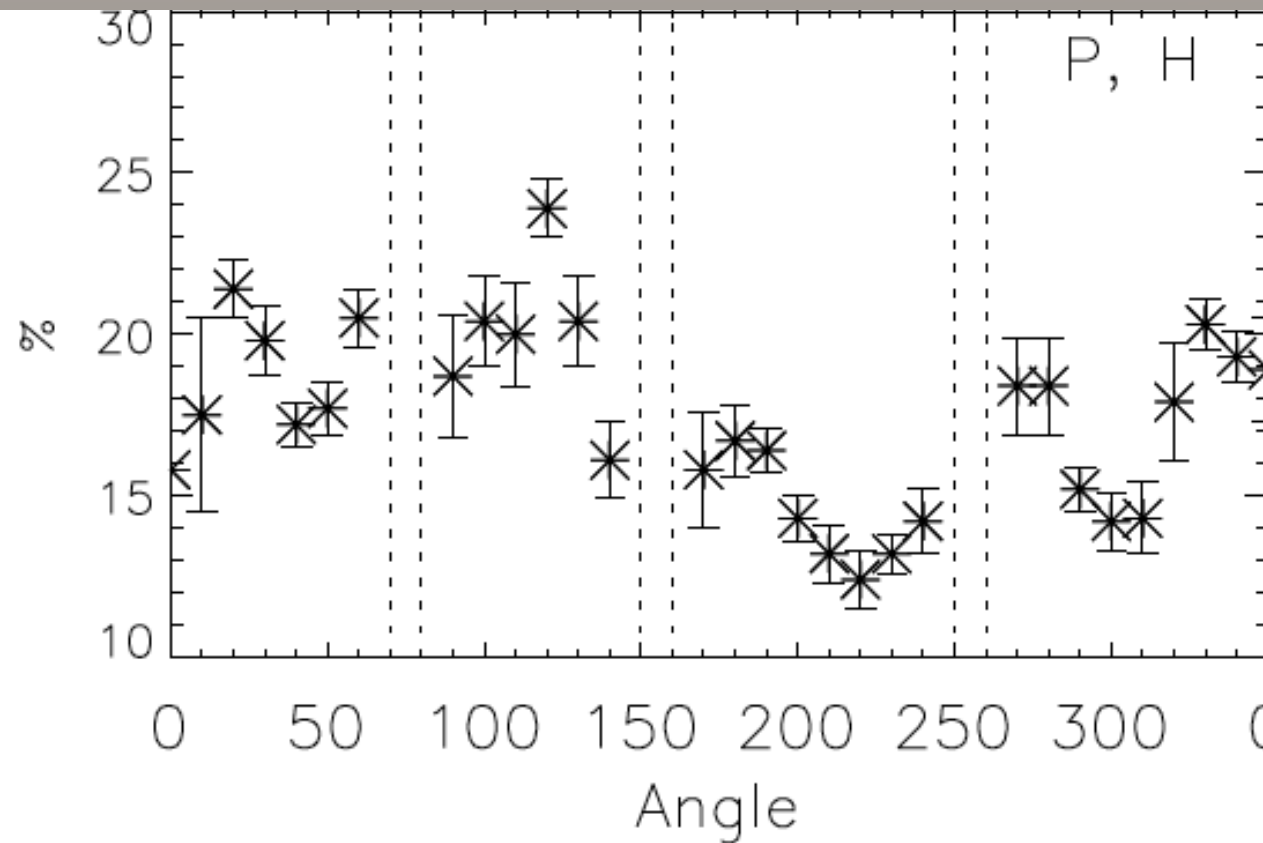
PSF-subtracted



Hunting the Polarization Degree

$$P = P_I / I$$

$$P_{\Theta} = 0.5 \cdot \arctan\left(\frac{U}{Q}\right)$$



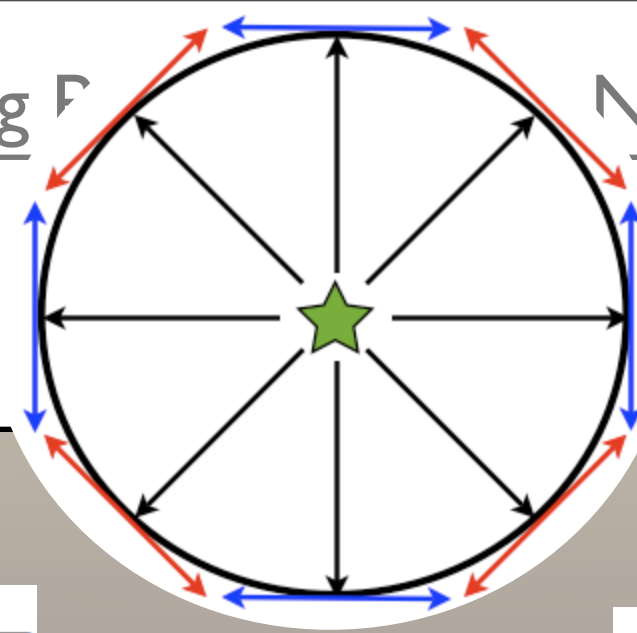


Imaging P

Nice Images

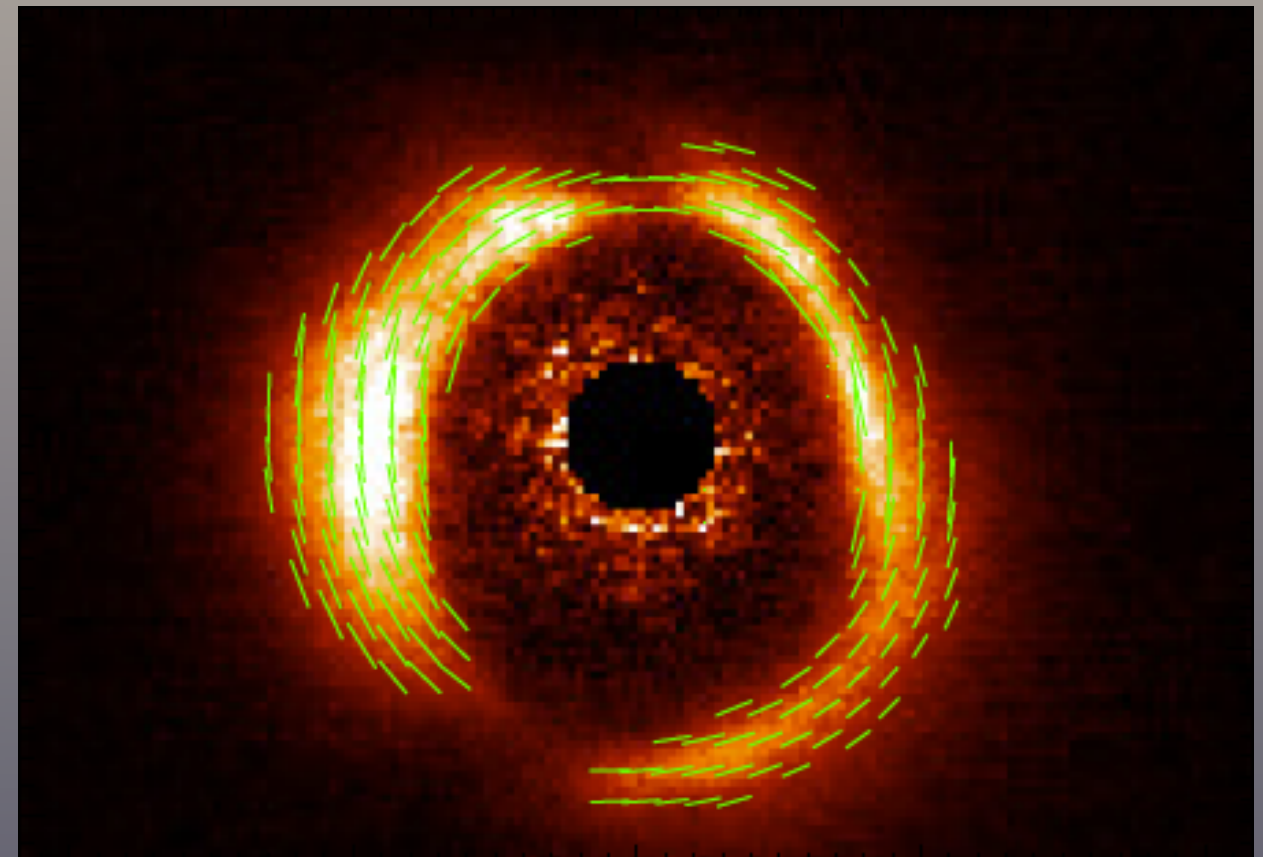
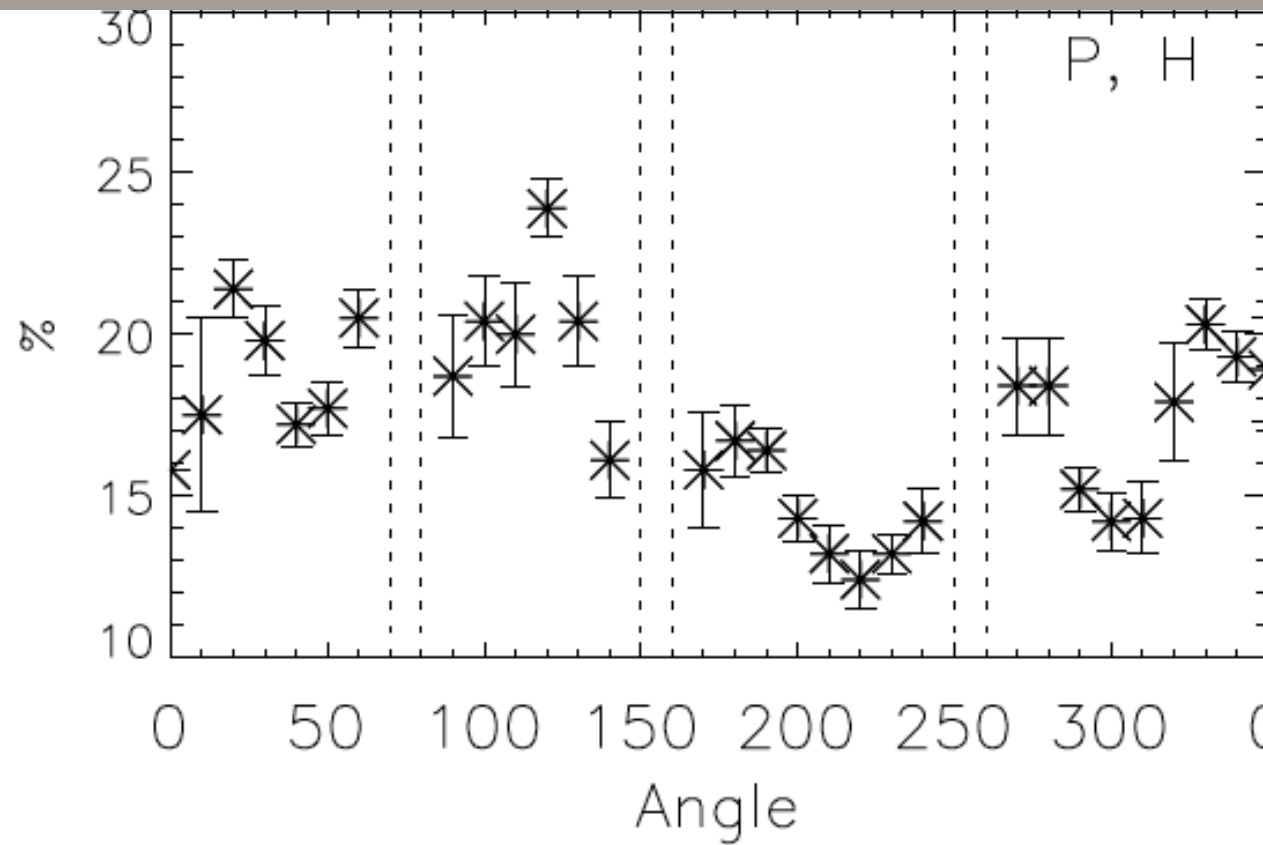
Hunt

tion Degree



$$P = P_I / I$$

$$P_{\Theta} = 0.5 \cdot \arctan\left(\frac{U}{Q}\right)$$



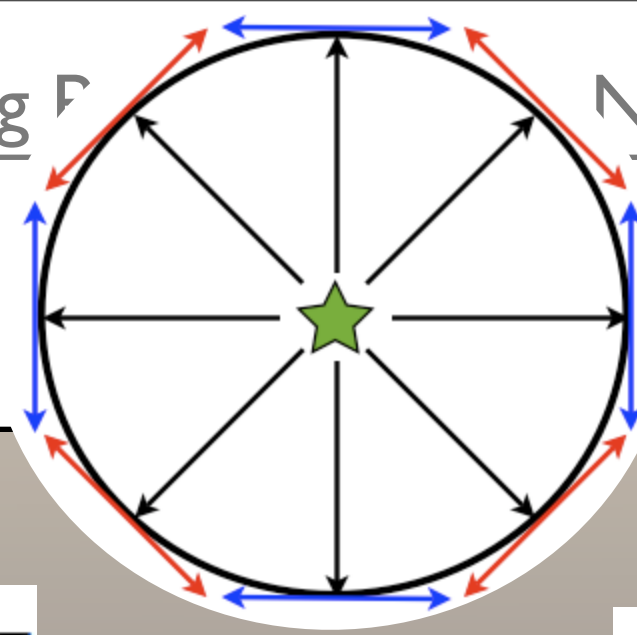


Imaging P

Nice Images

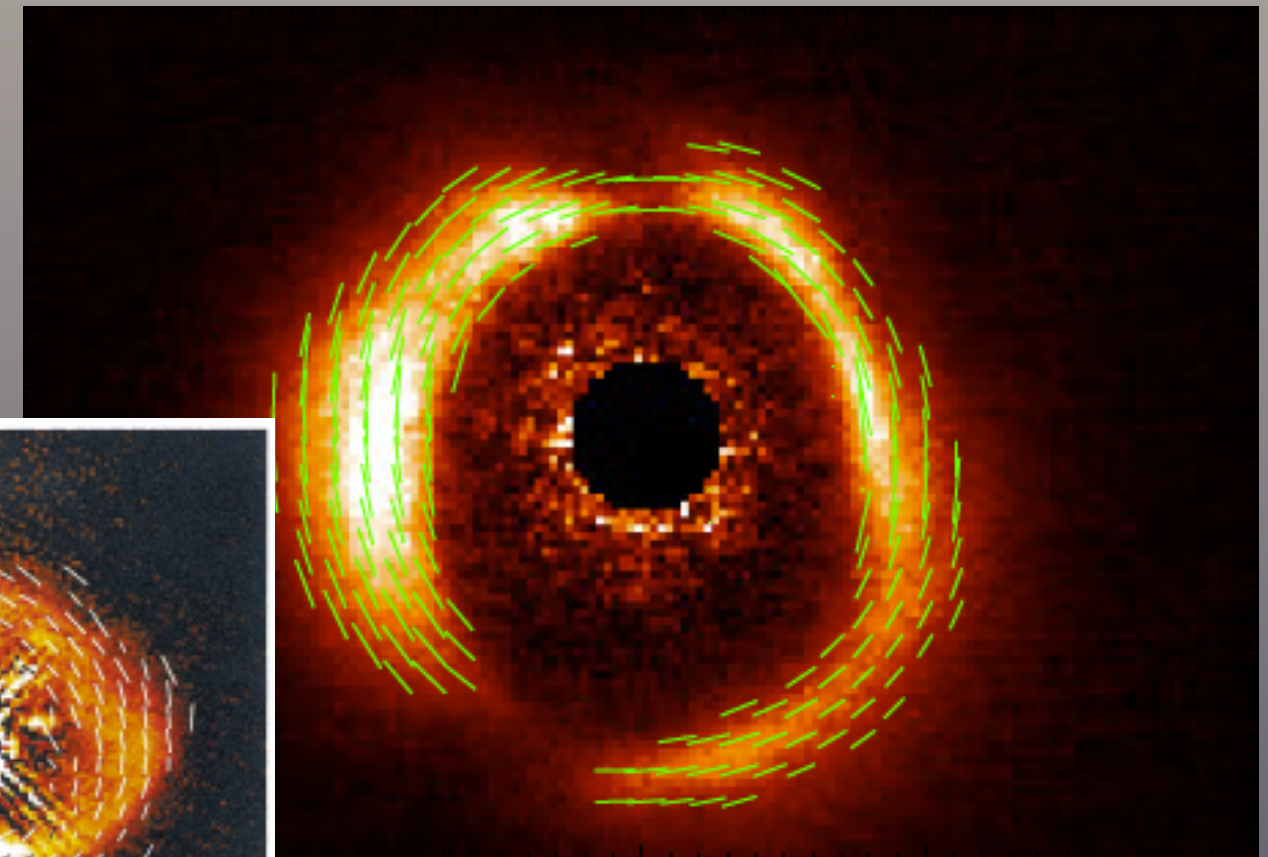
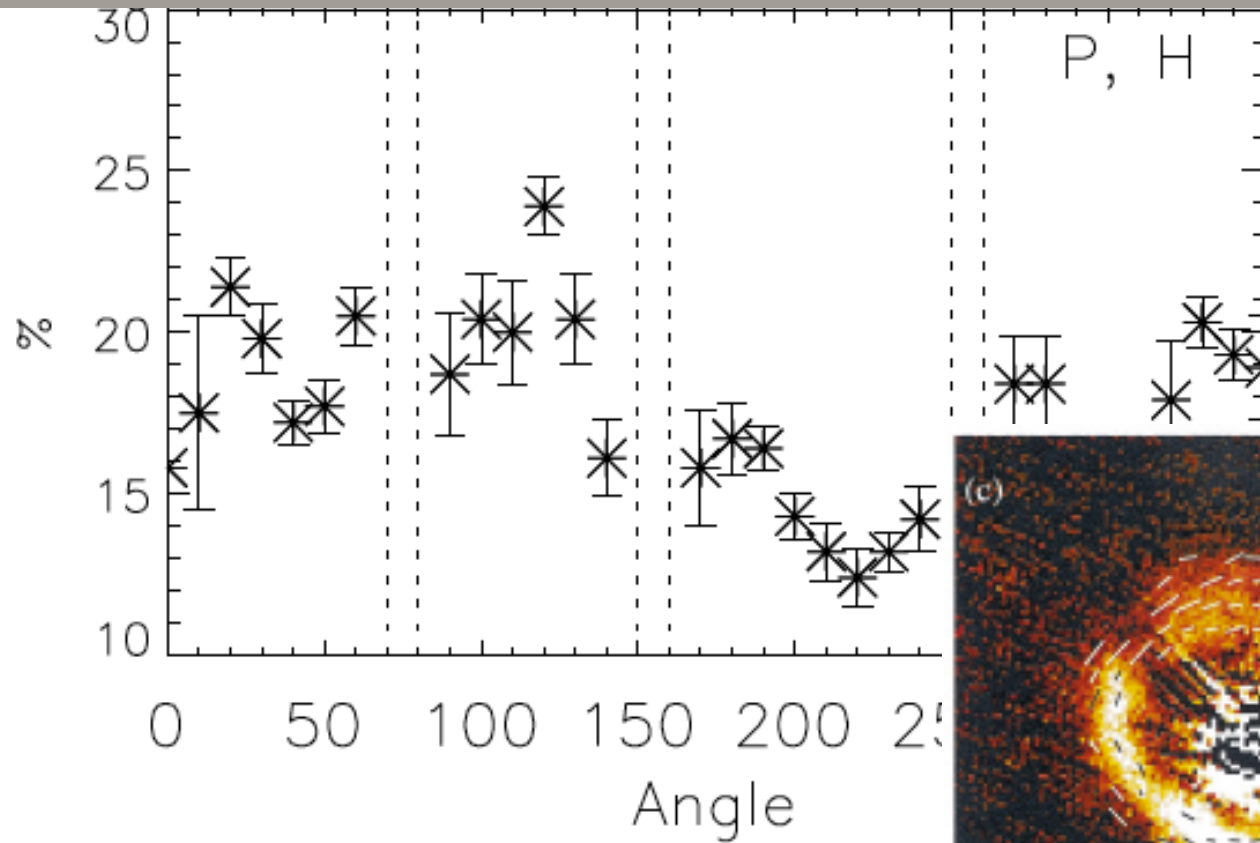
Hunt

tion Degree



$$P = P_I / I$$

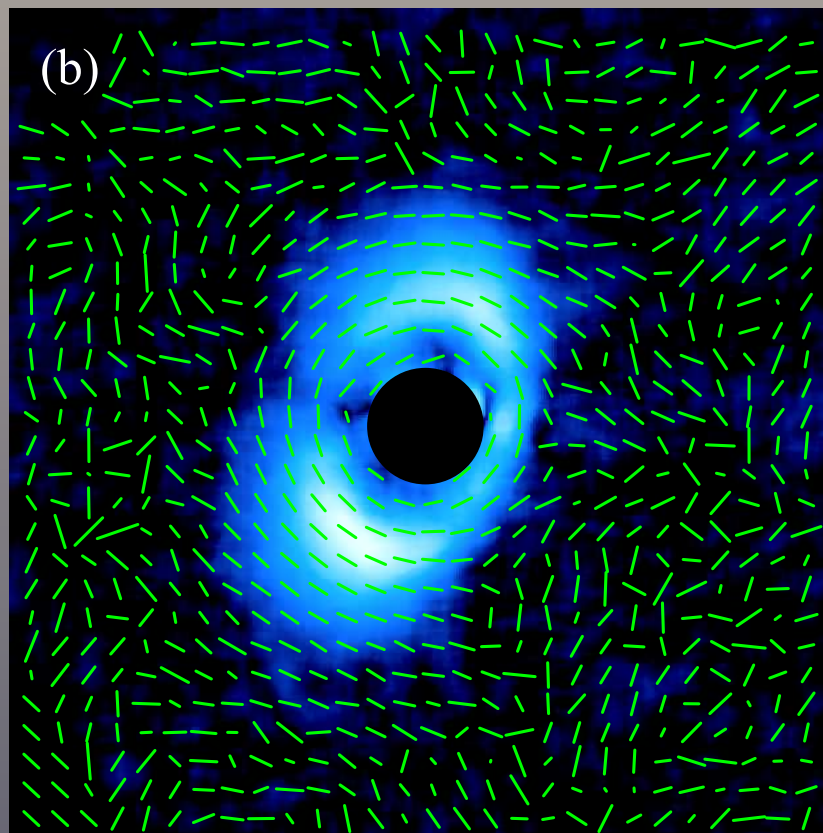
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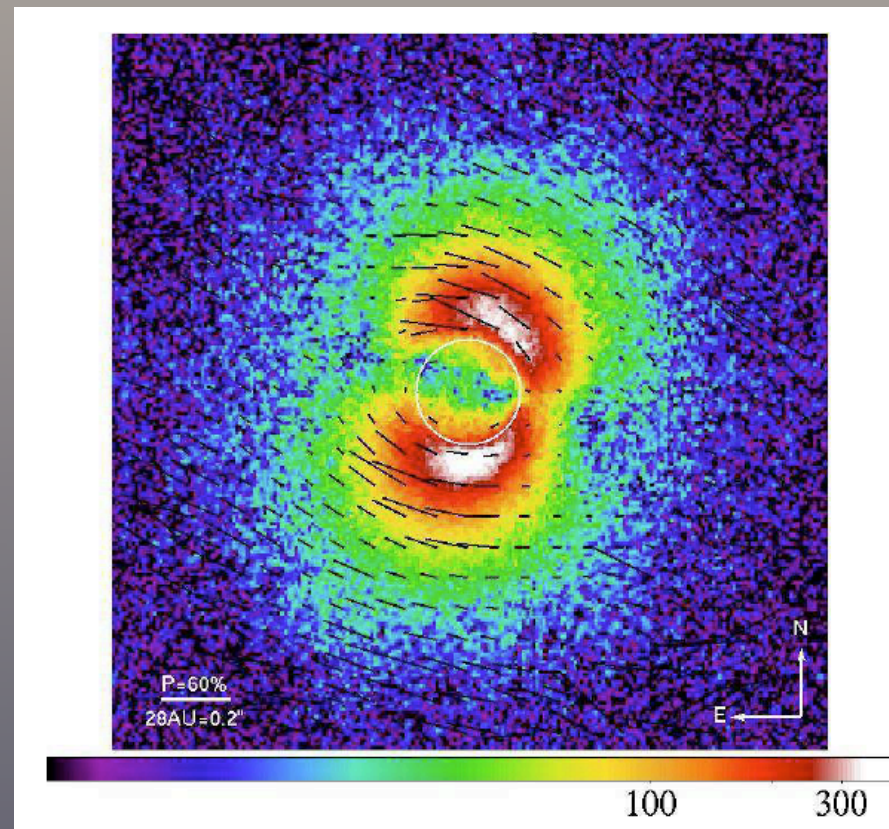


HiCIAO (Subaru): my (your??) personal enemy...

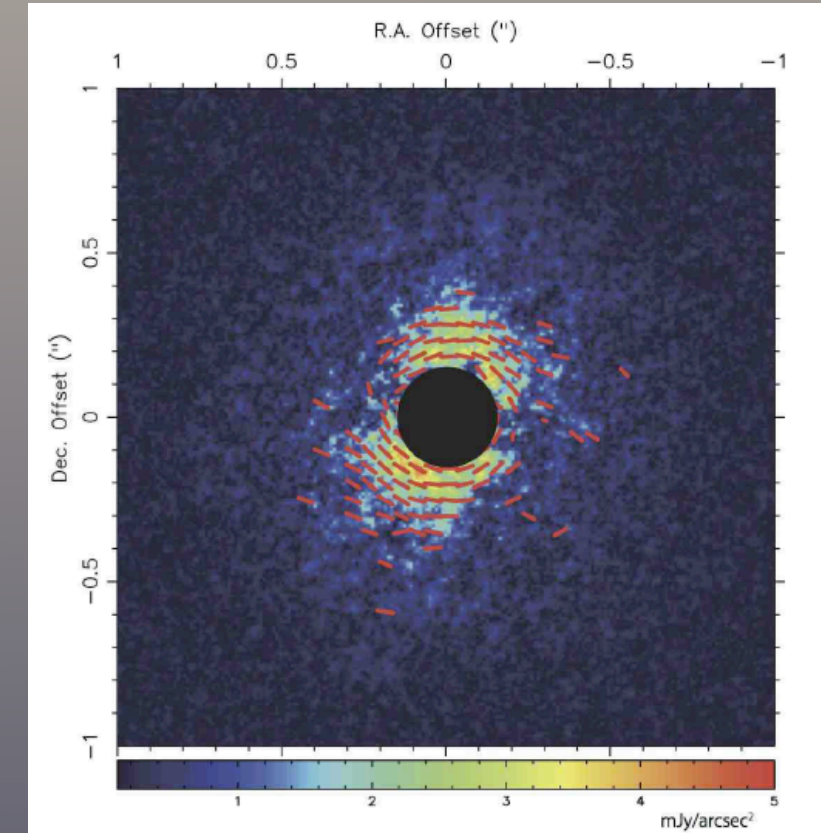
PDS 70



UX Tau X



MWC 480

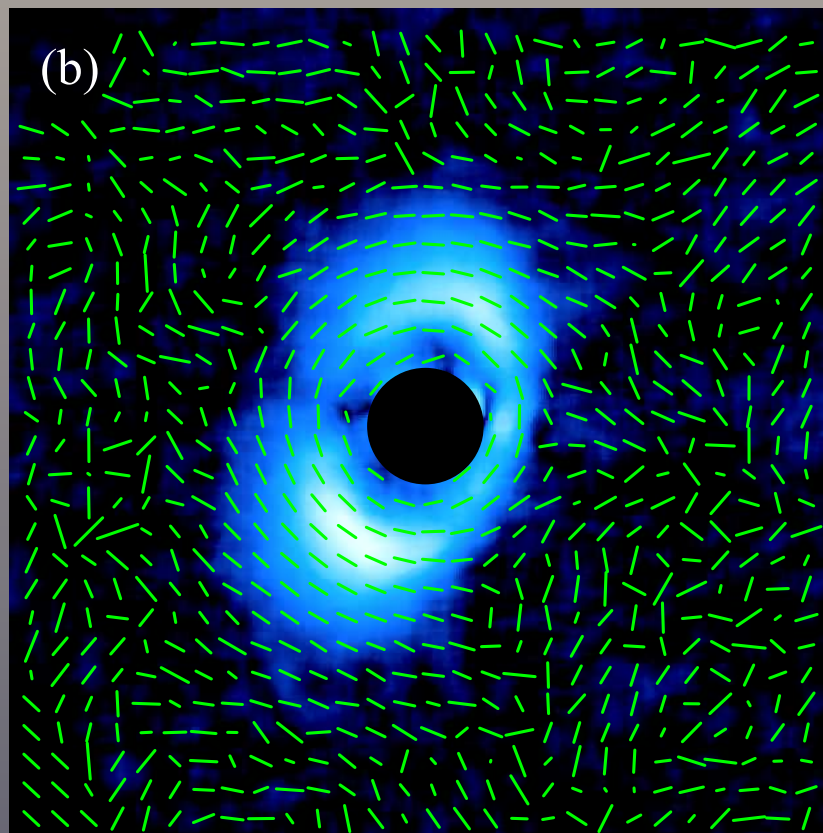




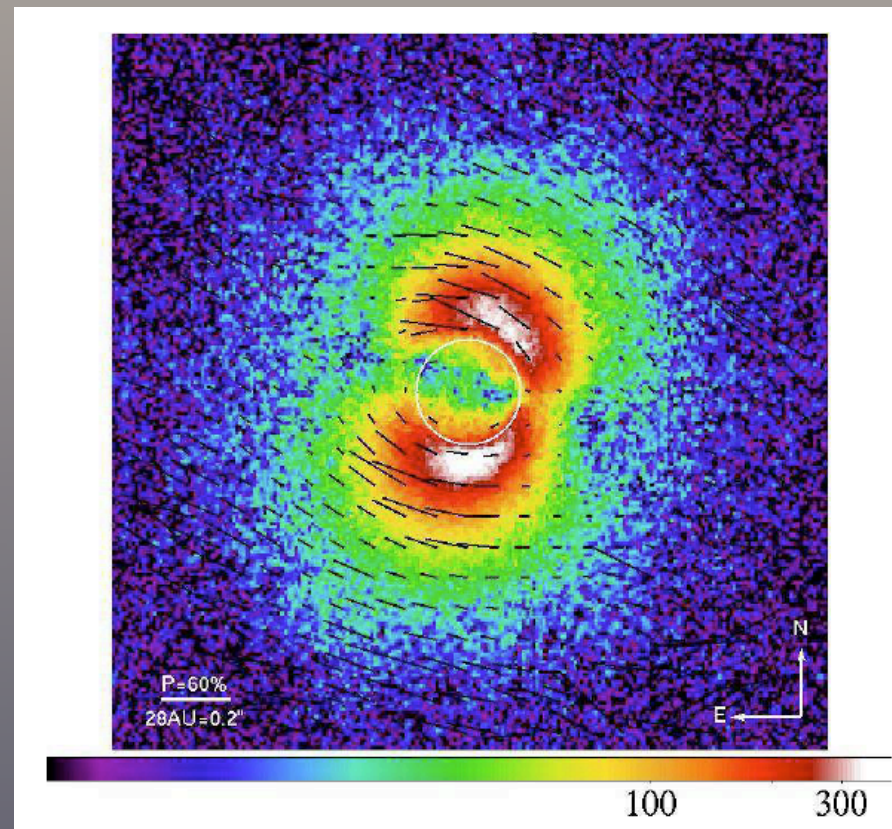
HiCIAO (Subaru): my (your??) personal enemy...



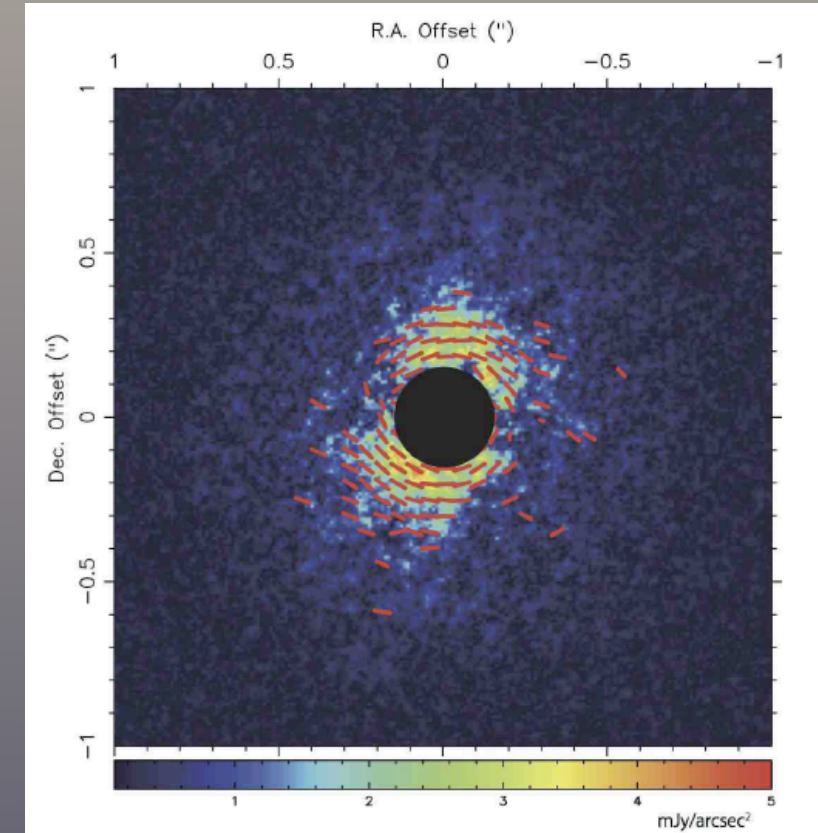
PDS 70



UX Tau X



MWC 480





Future Imaging Polarimeters are
coming to Chile...

SPHERE @ VLT

GPI @ Gemini S

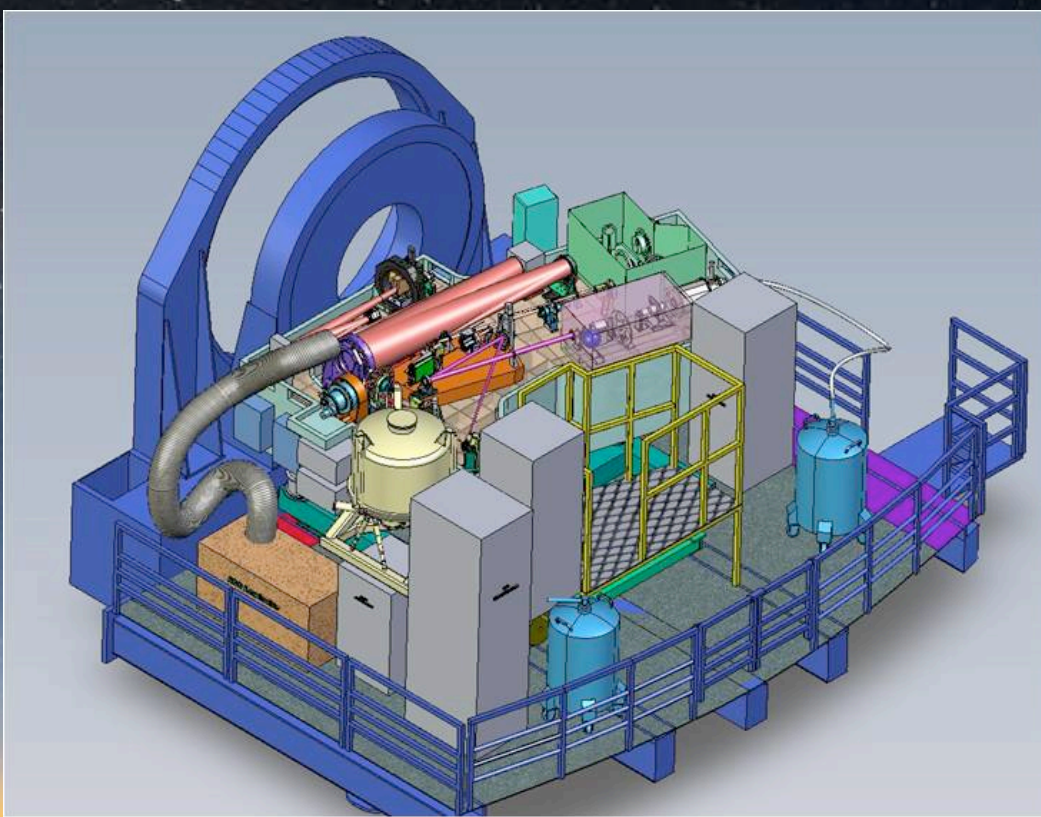




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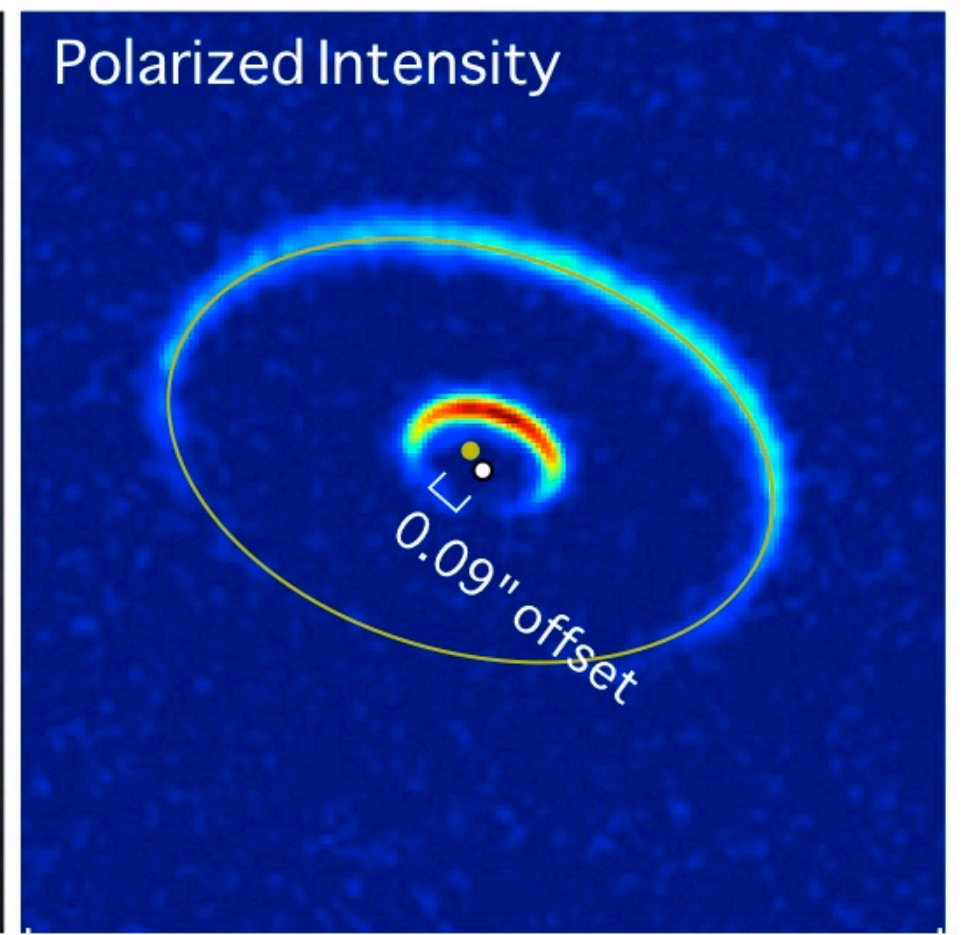
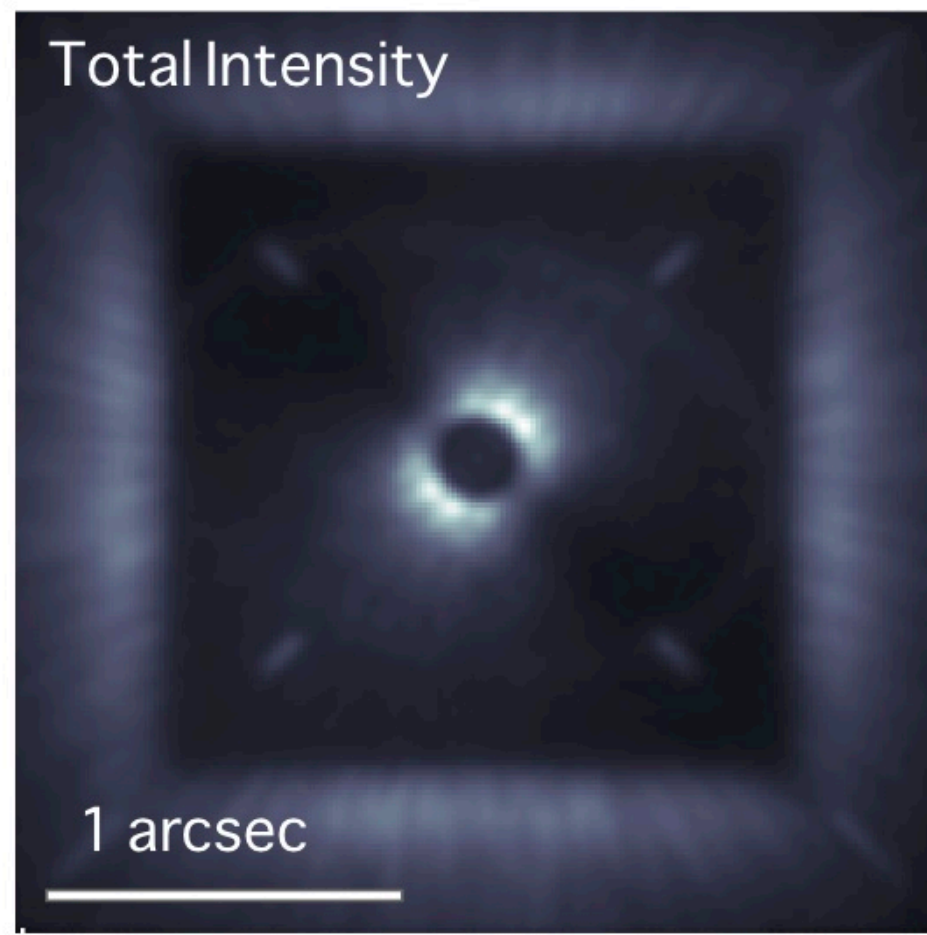
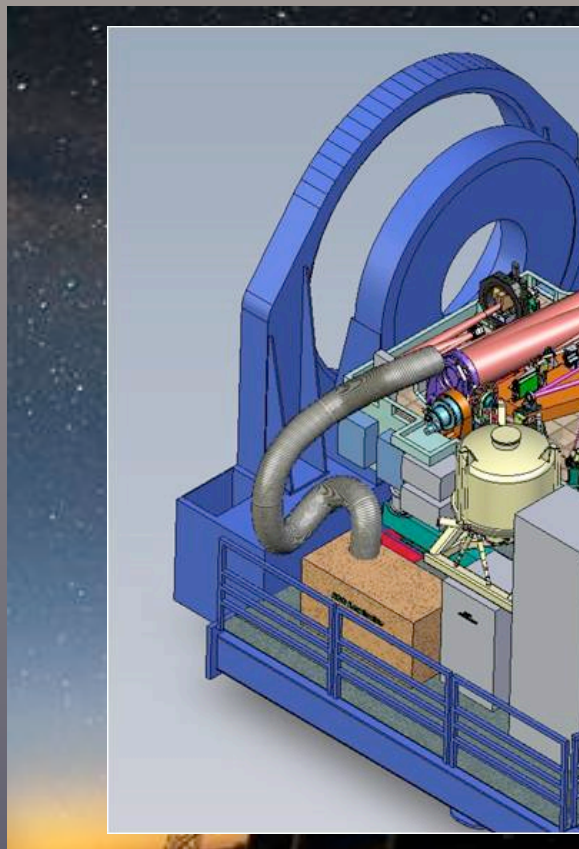




Future Imaging Polarimeters are coming to Chile...

SPHERE @ VLT

GPI @ Gemini S





Imaging Polarimetry: PRESENT & FUTURE

