Astronomical Techniques I

Lecture 14

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Jan-Feb 2015

Focussing hard X-rays

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- Can one make the effective refractive index lower so that θ_c increases?

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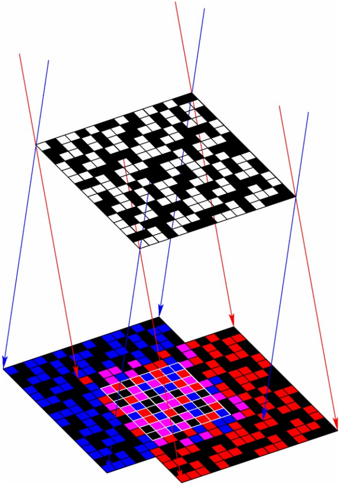
- hard because grazing angles are too small - telescopes are impracticably long and have a small field of view. Effective collecting area also decreases.
- Can one make the effective refractive index lower so that θ_c increases?
- Yes, in principle. By using Bragg reflection from depth-graded multilayers. Alternate layers of a high Z (like W, Mb, Ni) and a low Z (C, Si) materials with high and low refractive indices, and with bilayer thickness varying over a wide range have to be used. NuStar uses this technology.
- this technology is under further development.

Hard X-ray detector technologies

CZT - CdZnTe crystals used as detectors. useful above 10 keV. CZT imager on Astrosat is one such. NuSTAR also uses CZT detectors. These are not CCDs. But they have readout on each pixel like CMOS devices. Current generation CZT detectors have small number of pixels e.g. 64×64 on NuSTAR.

Coded masks for Gamma ray imaging



Two of the four X-ray instruments aboard ASTROSAT use coded masks(i) Scanning Sky Monitor (SSM) (ii) Cadmium Zinc Telluride Imager (CZTI)

For more details read

Arnaud et al. *Handbook of X-ray astronomy*

Polarisation indicates anisotropy

studied mostly in the optical and the radio, although other wavebands are catching up.

- geometry (not everything is spherically symmetric)
- temperature gradients
- magnetic fields
- electrical fields

Polarised astronomical sources

- planets (scattering by atmospheric clouds in Jupiter and Saturn)
- interstellar dust (possibly aligned by a magnetic field)
- Zeeman effect in stars with magnetic field
- supernova asymmetries
- quasars and radio jets
- CMB

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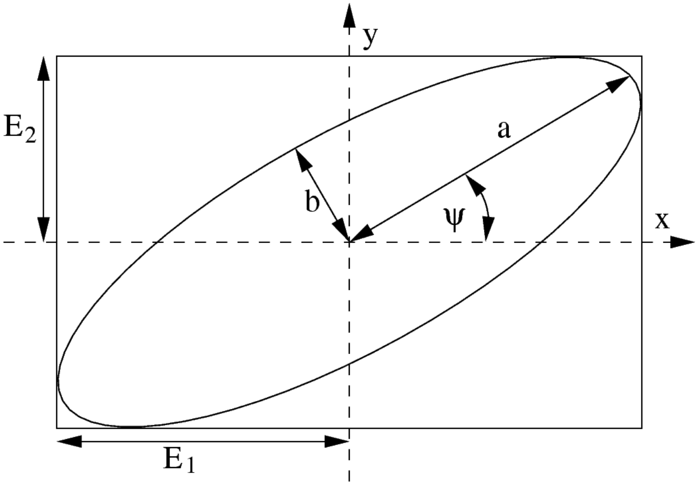
  E_1, E_2: arbitrary complex scalars
- If E_1 and E_2 have identical phases, $\vec{E}$ oscillates in fixed plane

Polarisation ellipse - time variation of $\vec{E}$ at fixed $\vec{x}$



$$\vec{E} = \vec{E_0} e^{i(\vec{k}\cdot\vec{x} - \omega t)}$$
$$E_0 = E_1 e^{i\delta_1} \vec{e_x} + E_2 e^{i\delta_2} \vec{e_y}$$

Quasi monochromatic light

- monochromatic light: purely theoretical concept
- monochromatic light wave always fully polarized
- real life: light includes range of wavelengths $\Rightarrow$ quasi-chromatic light
- quasi-monochromatic: superposition of mutually incoherent monochromatic light beams whose wavelengths vary in narrow range $\delta\lambda$ around central wavelength λ

$$\frac{\delta\lambda}{\lambda} \ll 1$$

- measurement of quasi-monochromatic light: integral over measurement time t_m
- amplitude, phase (slow) functions of time for given spatial location
- slow: variations occur on time scales much longer than the mean period of the wave

Polarisation of quasi-monochromatic light

electric field vector for quasi-monochromatic plane wave is sum of electric field vectors of all monochromatic beams that comprise it.

Polychromatic or white light

- wavelength range comparable to wavelength
- incoherent sum of quasi-monochromatic beams that have large variations in wavelength
- cannot write electric field vector for the whole wave in a plane-wave form
- must take into account frequency-dependent material characteristics eg. refraction changes with wavelength.
- intensity of polychromatic light is given by sum of intensities of constituting quasi-monochromatic beams

Stokes formalism for quasi-monochromatic light

$$\vec{I} = \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} = \begin{pmatrix} E_1^2 + E_2^2 \\ E_1^2 - E_2^2 \\ 2E_1E_2\cos\delta \\ 2E_1E_2\sin\delta \end{pmatrix}$$

where $\delta = \delta_1 - \delta_2$ and

$$I^2 \geq Q^2 + U^2 + V^2$$

Interpreting the Stokes Vectors

$$\vec{I} = \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} = \begin{pmatrix} \text{intensity} \\ \text{linear } 0 - 90 \text{ degrees} \\ \text{linear } 45 - 135 \text{ degrees} \\ \text{circular left or right} \end{pmatrix}$$

- degree of polarization

$$P = \frac{\sqrt{Q^2 + U^2 + V^2}}{I}$$

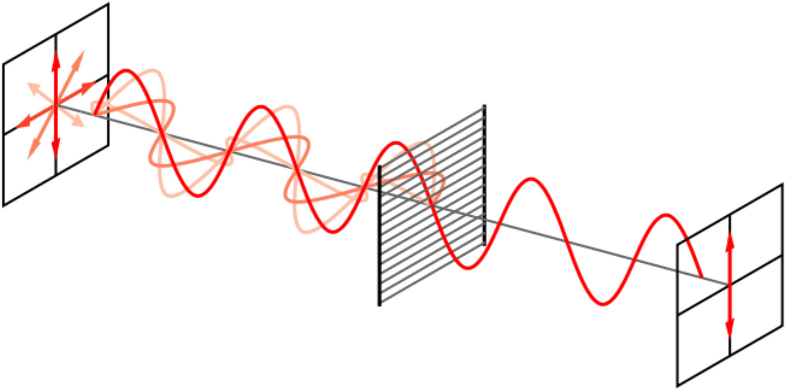
  equals 1 for fully polarised light, 0 for unpolarised light
- summing of Stokes vectors = incoherent adding of quasi-monochromatic light waves

Percentage of polarised light

- 45 degree reflection off aluminum mirror: 5%
- clear blue sky: up to 75%
- 45 degree reflection off glass: 90%
- LCD screen: 100%
- exoplanet signal: 0.001%

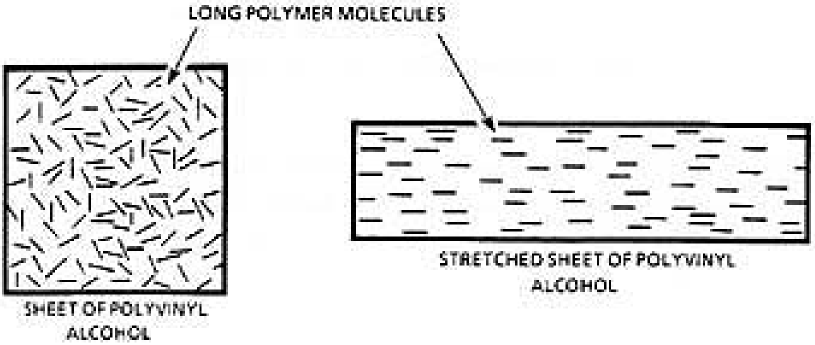
Polarisers - linear polarisers are the most common

Wire grid polariser



polarization perpendicular to wires ($d \lesssim \lambda$) is transmitted because electric field parallel to wires induces electrical currents in wires, which strongly attenuates transmitted electric field parallel to wires induced electrical current reflects polarization parallel to wires.

Polaroid Polariser



sheet polarizers: stretched polyvinyl alcohol (PVA) sheet, laminated to sheet of cellulose acetate butyrate, treated with iodine. PVA-iodine complex analogous to short, conducting wire

IMPOL - A imaging polarimeter made at IUCAA

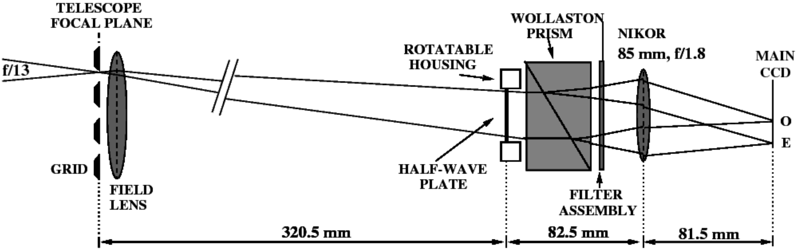


Figure 2.1: Block schematic of the IMPOL optical system

Rotating half-wave plate by angle α turns the light through 2α. Thus both Q and U can be measured.

for more details

Astronomical polarimetry by Jaap Tinbergen

Closing

Assignment 2 to be given later today. - includes questions on noise, CCDs, photometry, spectroscopy, X-ray astronomy.
Seminar talks scheduled for 2 pm - 6 pm on Thursday 26 Feb and 9 am - 11 am Friday 27 Feb.
Any questions or feedback regarding this course?