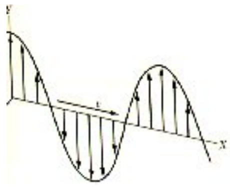
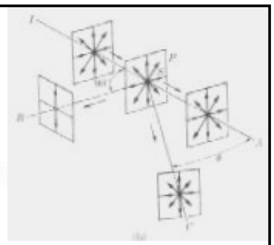
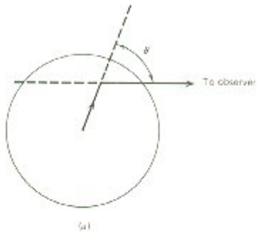
Polarization

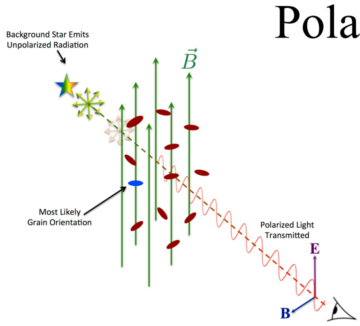




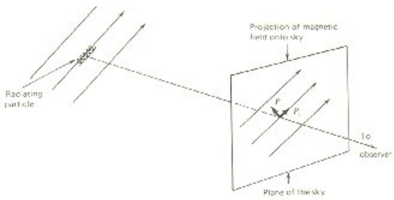
- Electron scattering produces a scattered wave with a degree of polarization that depends upon the viewing angle with respect to the incident radiation. 100% polarization is obtained looking perpendicular to the incident wave.
- Linear polarization also arises from scattering of photons on asymmetrical surfaces like gas clouds, stellar winds (net polarization from a spherical shell is zero).



Polarization

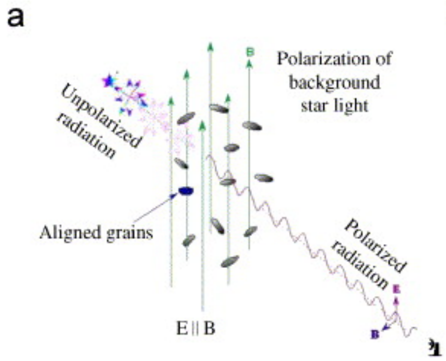


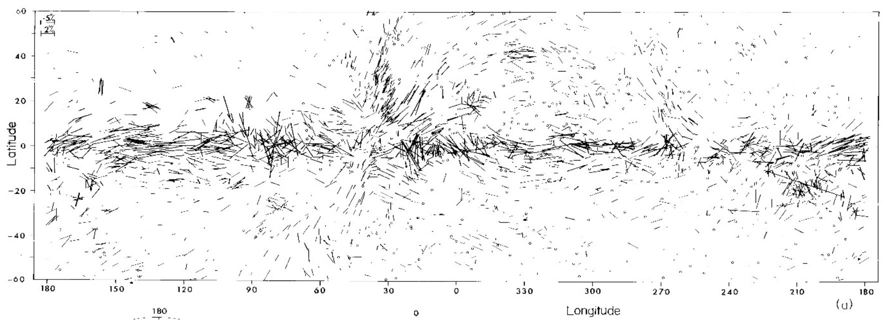
- Elongated dust grains *scatter* preferentially the electric field vector parallel to the long axis, thereafter *transmitting* polarized light parallel to the minor axis of the grains.



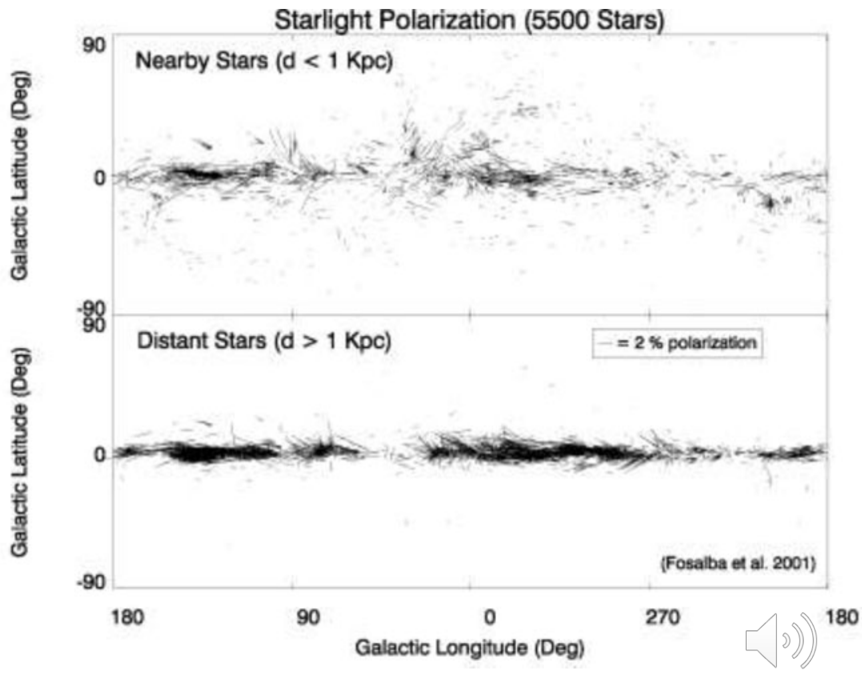
- Radiation emitted from within a magnetic field is circularly polarized (cyclotron or synchrotron emission)

Grains align with short axis parallel to magnetic field
Transmitted light is polarized parallel to magnetic field
Thermally emitted radiation polarized perpendicular to magnetic field

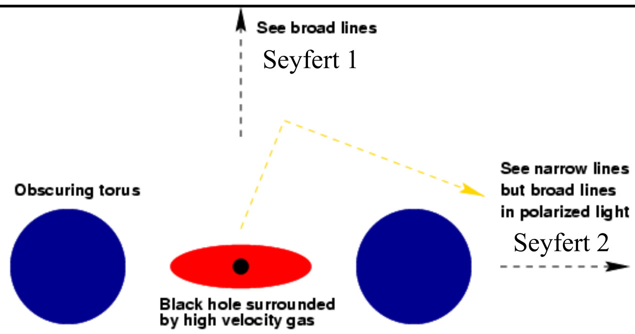




Polarization of background starlight is parallel to magnetic field



Use of polarization in AGNs



- Unified model for Active Galactic Nuclei: different classes of object are similar sources viewed at different angles
- Seyfert 1 galaxies: broad emission lines from material moving rapidly near the black hole
- Seyfert 2 galaxies: narrow lines only – obscuring material blocks our view of the central regions
- But in polarized light, Seyfert 2 galaxies show broad lines from radiation scattered into our line of sight
- Can also see hard X-ray radiation that can pass through the obscuring gas

Radiative diffusion

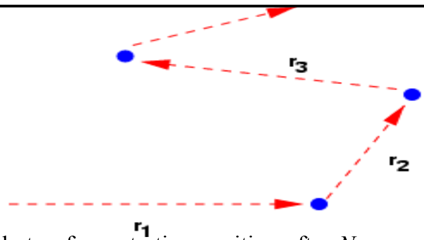
- Mean free path:
- For a homogeneous absorbing material, $I_\nu(\tau_\nu) = I_\nu(0)e^{-\tau_\nu}$
- The probability of a photon travelling at least an optical depth τ_ν is $e^{-\tau_\nu}$
- The mean optical depth travelled is $\langle \tau_\nu \rangle = \int_0^\infty \tau_\nu e^{-\tau_\nu} d\tau_\nu = 1$
- Define mean free path, l_ν = mean physical distance travelled before absorption :

$$\langle \tau_\nu \rangle = \alpha_\nu l_\nu = 1 \Rightarrow l_\nu = \frac{1}{\alpha_\nu}$$

- Defines local mean free path even in an inhomogeneous material.
- For true absorption plus scattering, net absorption coefficient is $\alpha_\nu + \sigma_\nu$ (called the extinction coefficient), and

$$l_\nu = \frac{1}{\alpha_\nu + \sigma_\nu}$$

Random walks



Net vector displacement of a single photon from starting position after N mean free paths between scatterings is:

$$\mathbf{R} = \mathbf{r}_1 + \mathbf{r}_2 + \ldots. + \mathbf{r}_N$$

Square and average to get distance $|R|$ travelled :

$$l_*^2 \equiv \langle \mathbf{R}^2 \rangle = \langle \mathbf{r}_1^2 \rangle + \langle \mathbf{r}_2^2 \rangle + \ldots + \langle \mathbf{r}_N^2 \rangle + 2\langle \mathbf{r}_1 \cdot \mathbf{r}_2 \rangle + \ldots$$

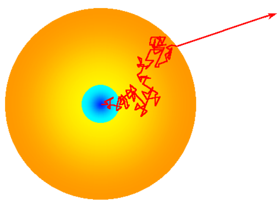
The cross terms are all of the form:

$$2\langle \mathbf{r}_1 \cdot \mathbf{r}_2 \rangle = 2\langle |\mathbf{r}_1||\mathbf{r}_2| \cos\delta \rangle$$

where δ is the angle of deflection during the scattering.

For isotropic scattering, $\langle \cos\delta \rangle = 0$, cross-terms vanish.

For a random walk from centre to edge of sphere of radius l_*, we can determine average number of scatterings, N, from



$$l_*^2 \equiv \langle \mathbf{R}^2 \rangle = \langle \mathbf{r}_1^2 \rangle + \langle \mathbf{r}_2^2 \rangle + \ldots + \langle \mathbf{r}_N^2 \rangle$$

$$\alpha^2 l_*^2 = \tau_{\max}^2 = N\alpha^2 \langle \mathbf{r}^2 \rangle = N \langle \tau^2 \rangle$$

$$N = \tau_{\max}^2 / \langle \tau^2 \rangle = \tau_{\max}^2 / 2$$

Using: $\langle \tau^2 \rangle = \int_0^\infty p(\tau)\tau^2 d\tau = \int_0^\infty e^{-\tau}\tau^2\, d\tau = 2$

If the medium is optically thin, then the probability of scattering is $1 - e^{-\tau}$

Using $1 - e^{-\tau} \cong \tau$ then $N \approx \tau \;, \tau << 1$

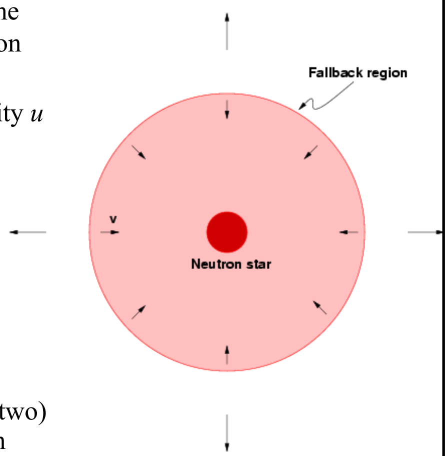
Therefore $N \approx \tau + \tau^2 / 2$ is a more accurate approximation

Fallback onto a neutron star after a supernova

Following a Type II supernova explosion, some gas remains bound to the newly formed neutron star and falls back onto it.

Timescale for gas at radius r with infall velocity u to reach neutron star of mass M is

$$t_{infall} \sim r / u$$



In free fall, $u^2 = 2GM / r$, so

$$t_{\mathrm{infall}} \sim \frac{r^{3/2}}{\sqrt{2GM}}$$

If mean free path is l, then (within a factor of two) photons random-walk out of collapsing gas on timescale

$$t_{\mathrm{escape}} \sim \frac{Nl}{c} \sim \left(\frac{r}{l}\right)^2 \frac{l}{c} \sim \left(\frac{r}{c}\right)\left(\frac{r}{l}\right) \sim \left(\frac{r}{c}\right)\tau$$

If the gas is dense enough that $\tau > \dfrac{c}{(2GM/r)^{1/2}}$

detailed analysis shows that we can have $t_{escape} > t_{infall}$ so photons are dragged inwards faster than they can random walk out

Defines a *trapping radius* within which photons are dragged inwards by the flow

Eddington limit (radiative pressure equals gravity) does not apply for sufficiently large accretion rates

$$\dot{M} >> \dot{M}_{Edd}$$

When flow strikes neutron star, kinetic energy is radiated via neutrinos which have very small cross sections for interaction with matter, so they can escape

Lecture 11 revision quiz

- Using a sketch, show that the net polarization is zero from a spherically symmetric nebula illuminated by an isotropic source at its centre.
- A photon is emitted at the centre of a homogeneous, spherical region of radius 2 pc, in which it undergoes isotropic scattering with a mean free path of 0.04 pc.
  - Determine the optical thickness from the central source to the edge of the region.
  - Determine the average time taken for photons to diffuse out of the region.