AXIONS-LIKE PARTICLES & POLARISATION OF QUASARS

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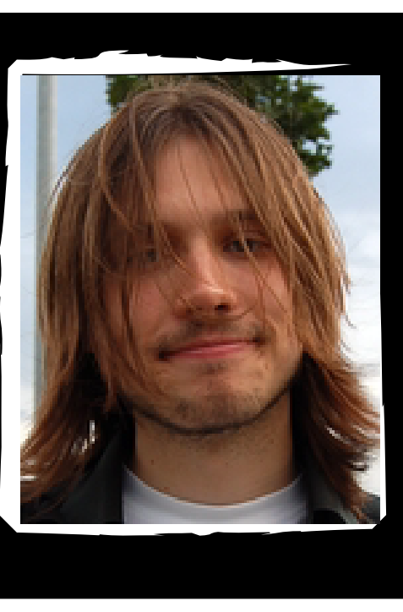
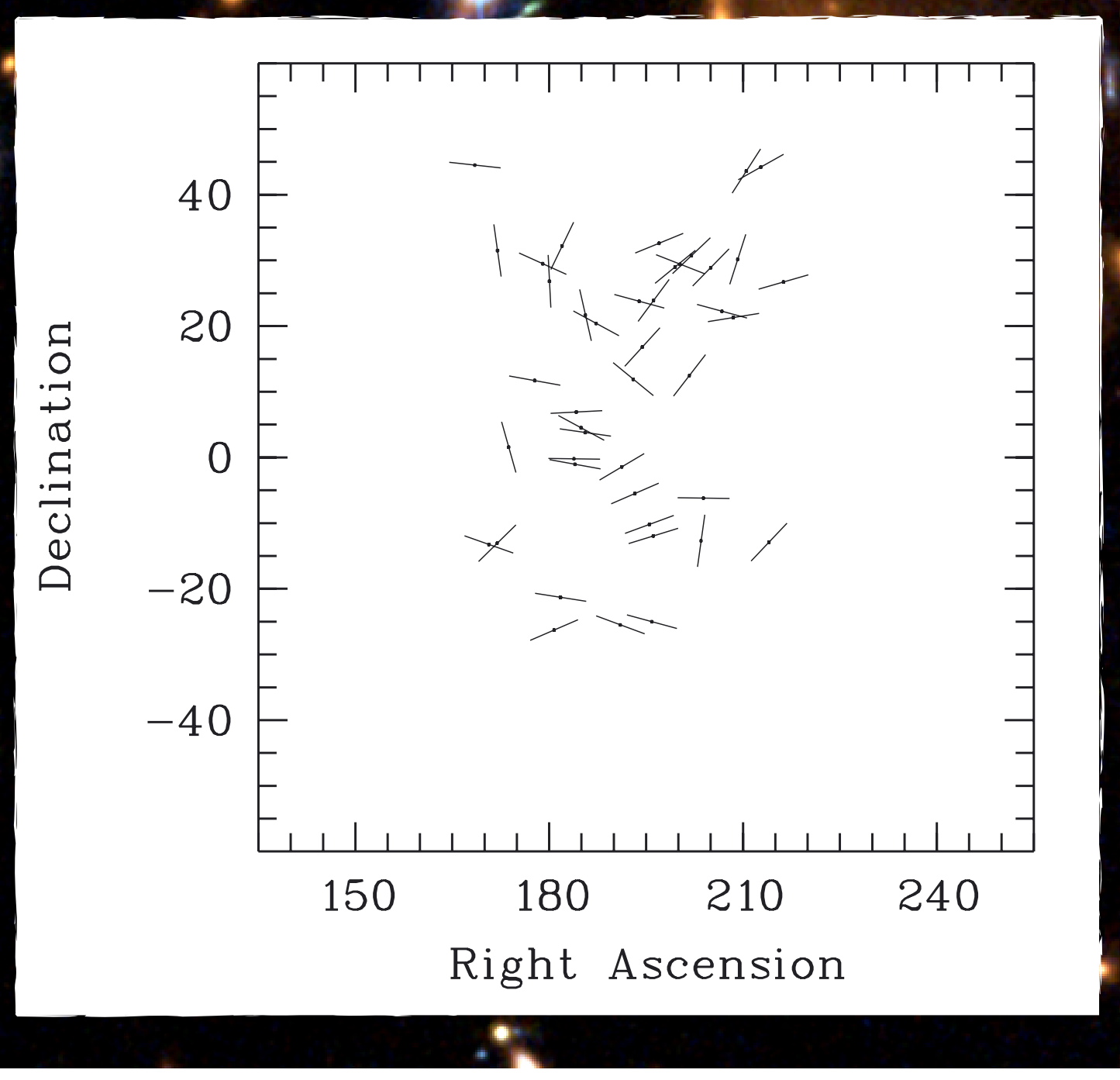


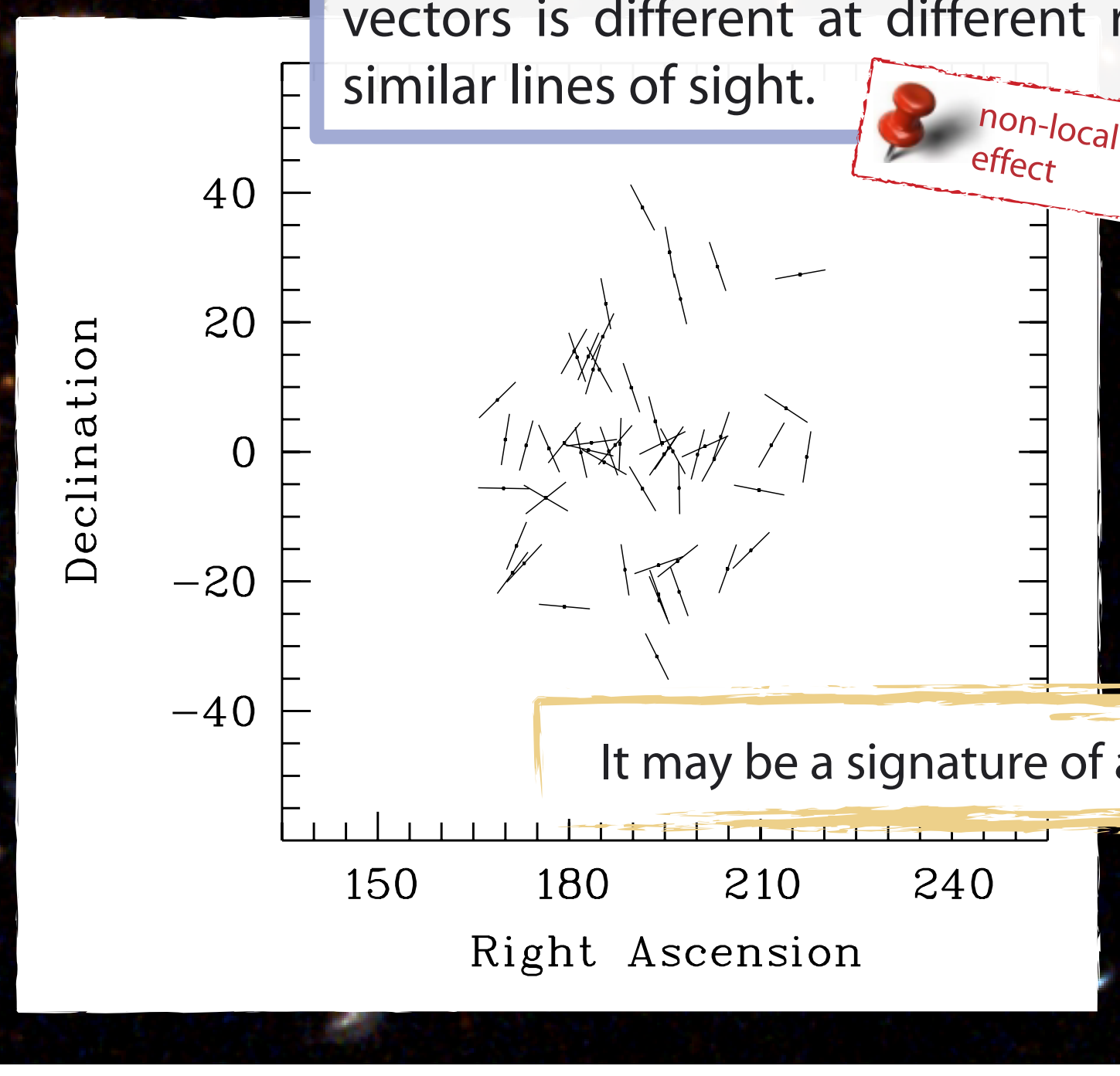
[arXiv:astro-ph/0805.3946v1]

QUASARS

In some regions of the sky, there are very large-scale alignments of polarisation vectors for visible light coming from quasars.

The probability for coincidental alignments is around 0.01%.





Also, the preferred orientation of polarisation vectors is different at different redshifts for similar lines of sight.

non-local effect

It may be a signature of axion-like particles !

Maps of polarisation vectors of quasars in the same region but at different redshifts (between 0 and 1 in the left-hand figure and between 1 and 2.3 in the right-hand one).

The mean direction in the first is $\phi = 79°$ and $\phi = 8°$ in the second. The declination and right ascension are given in degrees.

NB: The typical value of quasar polarisation is at the percent level.

AXIONS

The Strong CP Problem (SCPP)

The CP-violating term entering the QCD Lagrangian

$$L_\theta = \theta \frac{g^2}{64\pi^2} \varepsilon^{\alpha\beta\mu\nu} F^c_{\alpha\beta} F_{c\mu\nu},$$

is highly suppressed, as measurements of the neutron electric dipole moment give $\theta < 10^{-9}$. We do not have a definite answer why it is so small.

The most elegant solution to this has been given by Peccei and Quinn in 1977 who postulated a new continuous symmetry

$$U(1)_{P-Q};$$

its spontaneous breaking solves the strong CP problem by an automatic compensation of the θ-term.

Weinberg and Wilczek noted in 1978 that, due to this spontaneous symmetry breaking, a new elementary particle, a pseudo-Goldstone boson, must appear: the axion.

Axion ID
- pseudoscalar particle
- couples with light
- very small mass
- very weakly interacting
- almost stable

to be observed

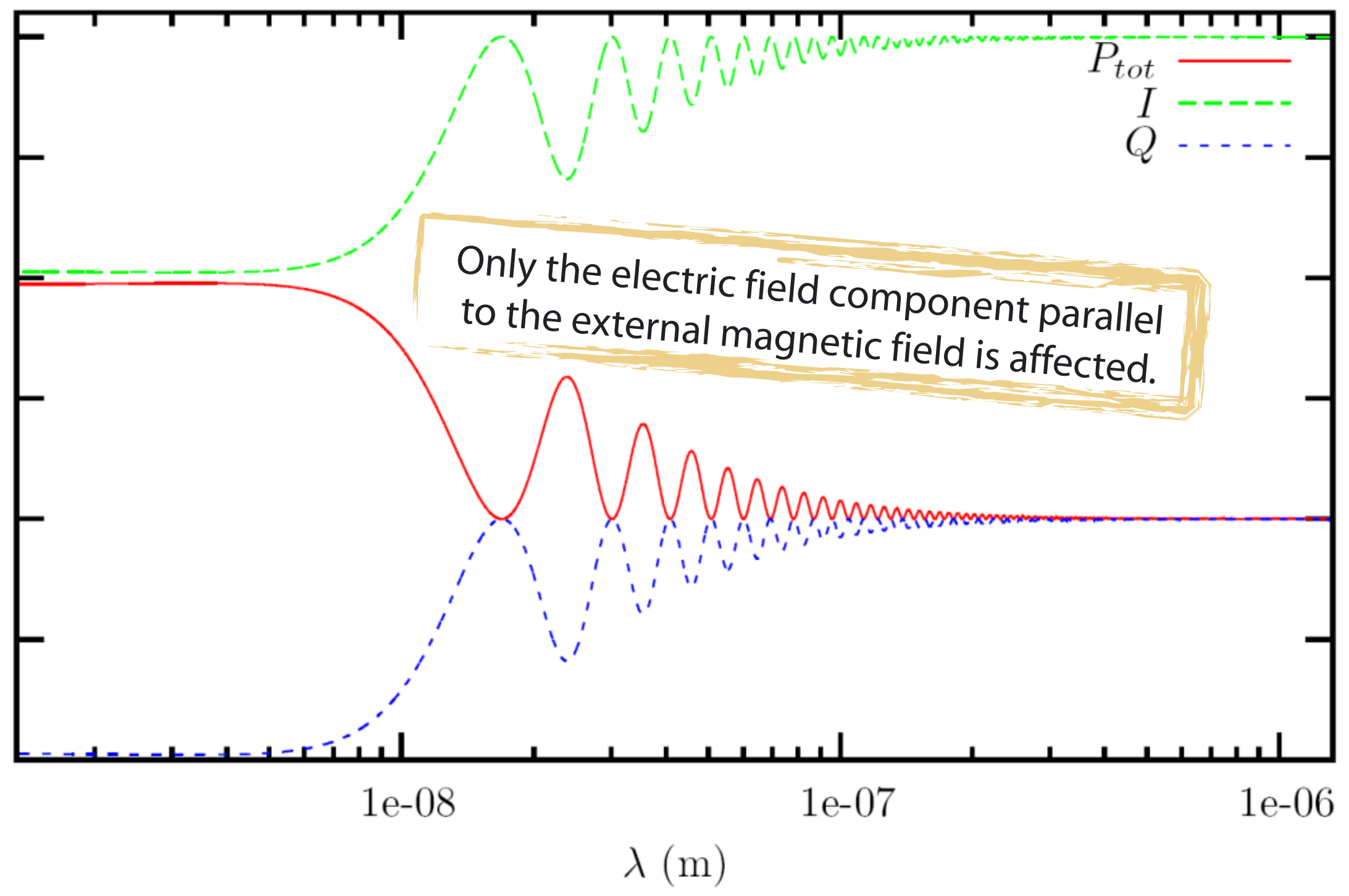
AXIONS AND POLARISATION

Axion-photon mixing in external magnetic fields creates/modifies polarisation

When an initially unpolarised light beam (which can always be seen as a sum of two orthogonal linearly polarised ones) enters an external magnetic field, axion-photon mixing depletes only one of the electric field components (dichroism), leading to a spontaneous generation of polarisation.

This can be seen in this figure which shows the polarisation state of such an unpolarised beam, for different wavelengths, at the end of a 10 Mpc magnetic field region (typical for superclusters of galaxies). I is the total intensity, Q is a Stokes parameter measuring the linear polarisation and P_{tot} gives the total polarisation.

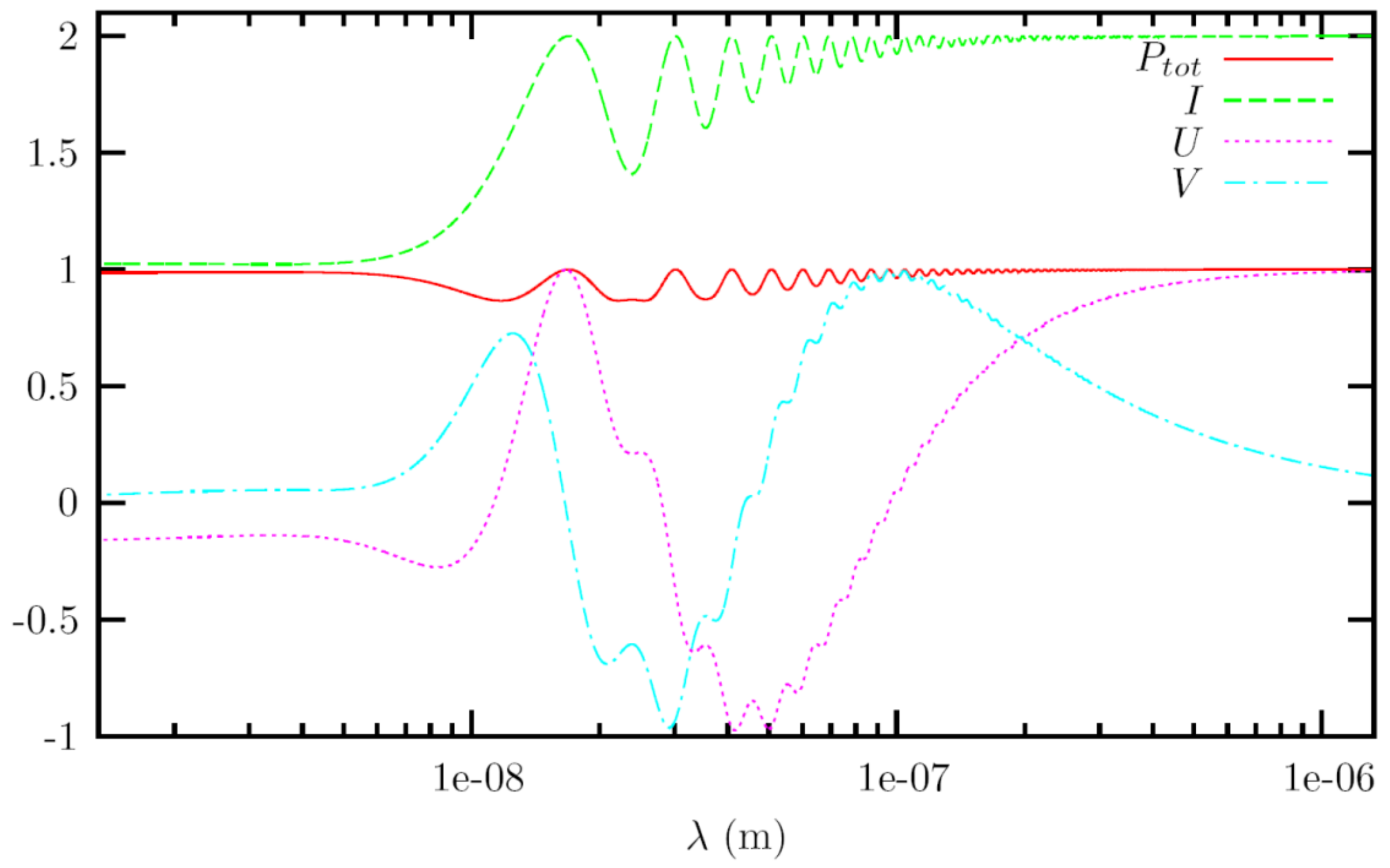
We see that, at some wavelengths, due to this dichroism, we indeed have a generation of polarisation.



Only the electric field component parallel to the external magnetic field is affected.

Parameters used here:
- $B = 0.1\ \mu G$
- $\omega_p \sim 4\ 10^{-14}$ eV (plasma frequency)
- $m_a \sim 10^{-14}$ eV (axion mass)
- $g \sim 7\ 10^{-12}\ GeV^{-1}$ (axion coupling)

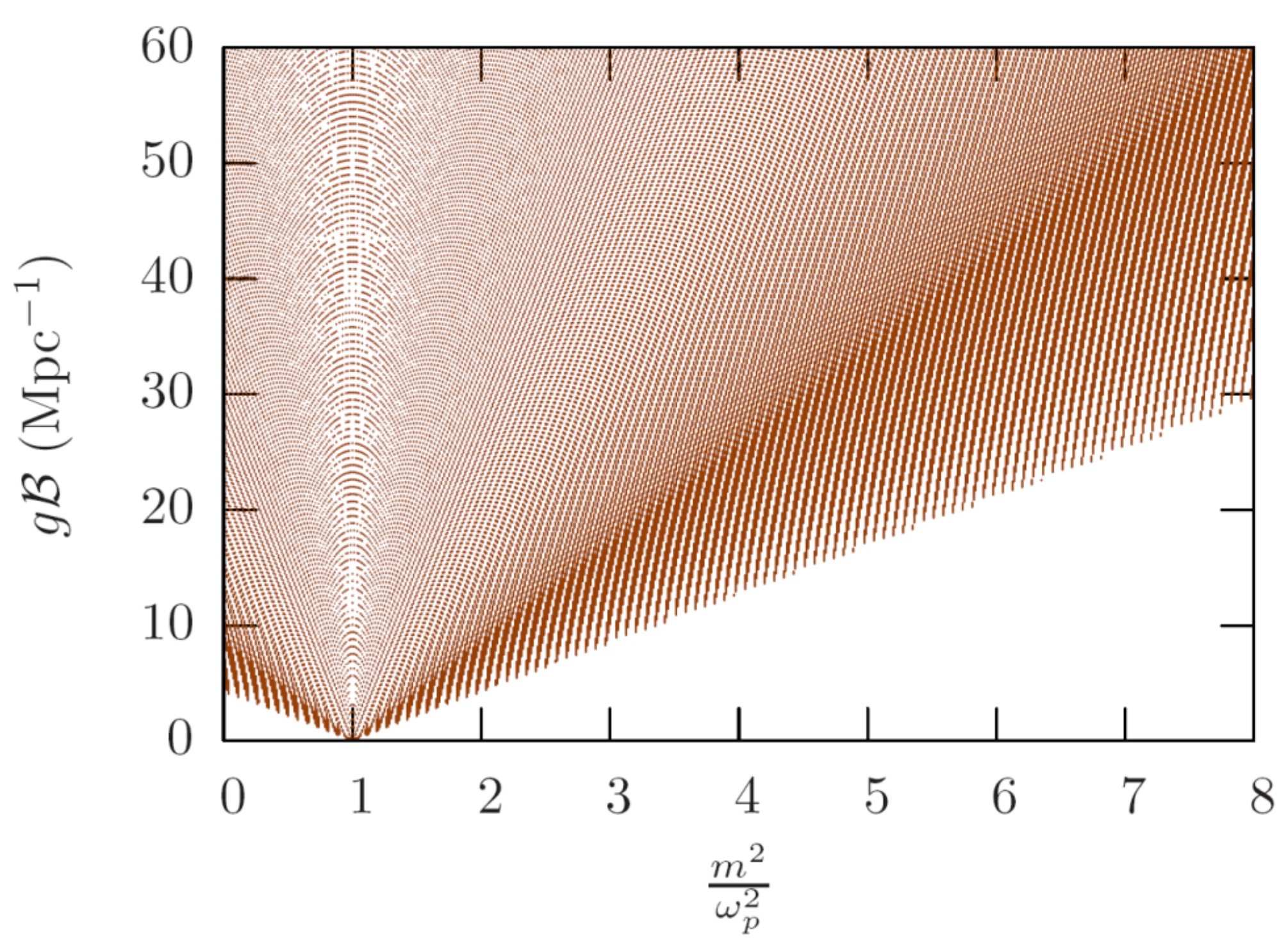
Extremely light axion-like particle.



Another consequence of axion-photon mixing is birefringence: as one of the components of the electric field picks up, for some time, the mass of the axion, there will be a phase shift between the polarisations of the light beam, generally leading to the appearence of elliptical polarisation.

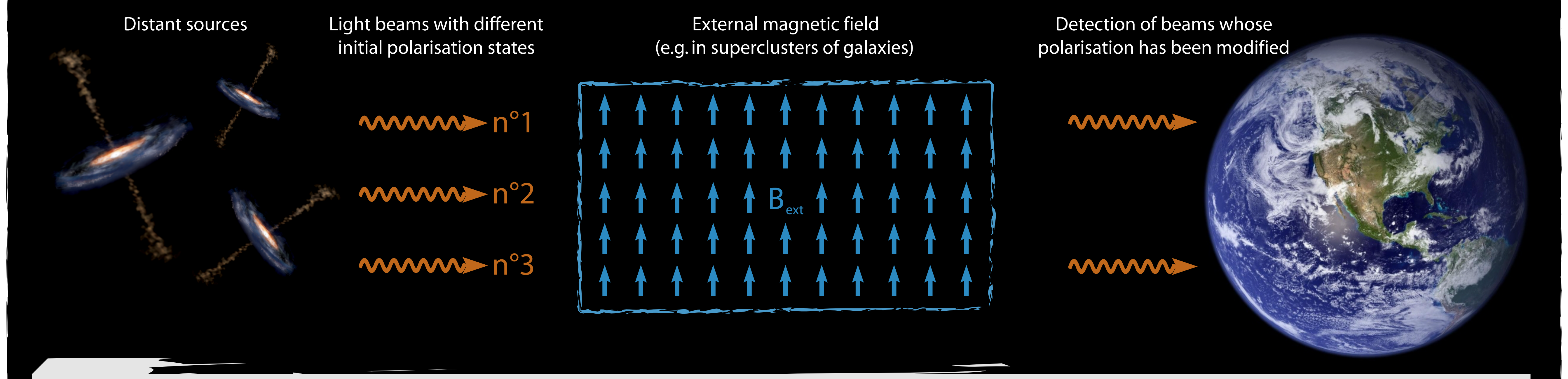
In this figure, we show the behaviour of U, the other Stokes parameter measuring the linear polarisation, and of V, that measuring the circular polarisation. In this case, initially, U has been chosen to be non-zero, while V=0 (Q, not shown here, has strictly the same behaviour as before).

We see that the wavelength dependence of U and V is non-trivial and that, at most wavelengths, a non-zero U leads to the appearance of circular polarisation.



Parameter space compatible with data on quasar polarisation vectors.

It has been computed for the observed wavelength (λ = 500 nm), in the case of a constant external magnetic field of size 10 Mpc and using a typical value of the plasma frequency in clusters and superclusters of galaxies, $\omega_p \sim 4\ 10^{-14}$ eV (which acts as an effective mass for the photons).

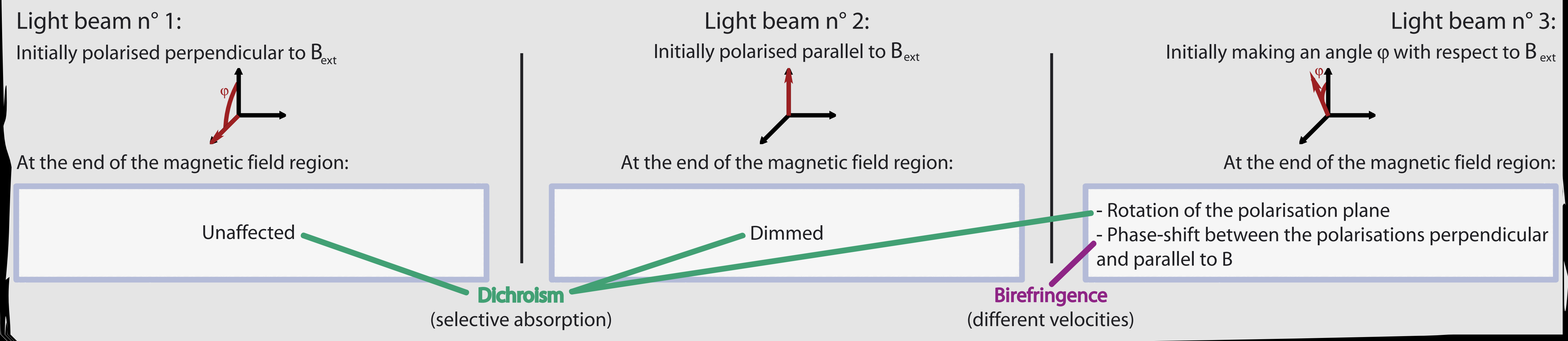


Distant sources

Light beams with different initial polarisation states

External magnetic field (e.g. in superclusters of galaxies)

Detection of beams whose polarisation has been modified



Light beam n° 1:
Initially polarised perpendicular to B_{ext}
At the end of the magnetic field region:
Unaffected

Light beam n° 2:
Initially polarised parallel to B_{ext}
At the end of the magnetic field region:
Dimmed

Light beam n° 3:
Initially making an angle φ with respect to B_{ext}
At the end of the magnetic field region:
- Rotation of the polarisation plane
- Phase-shift between the polarisations perpendicular and parallel to B

Dichroism
(selective absorption)

Birefringence
(different velocities)

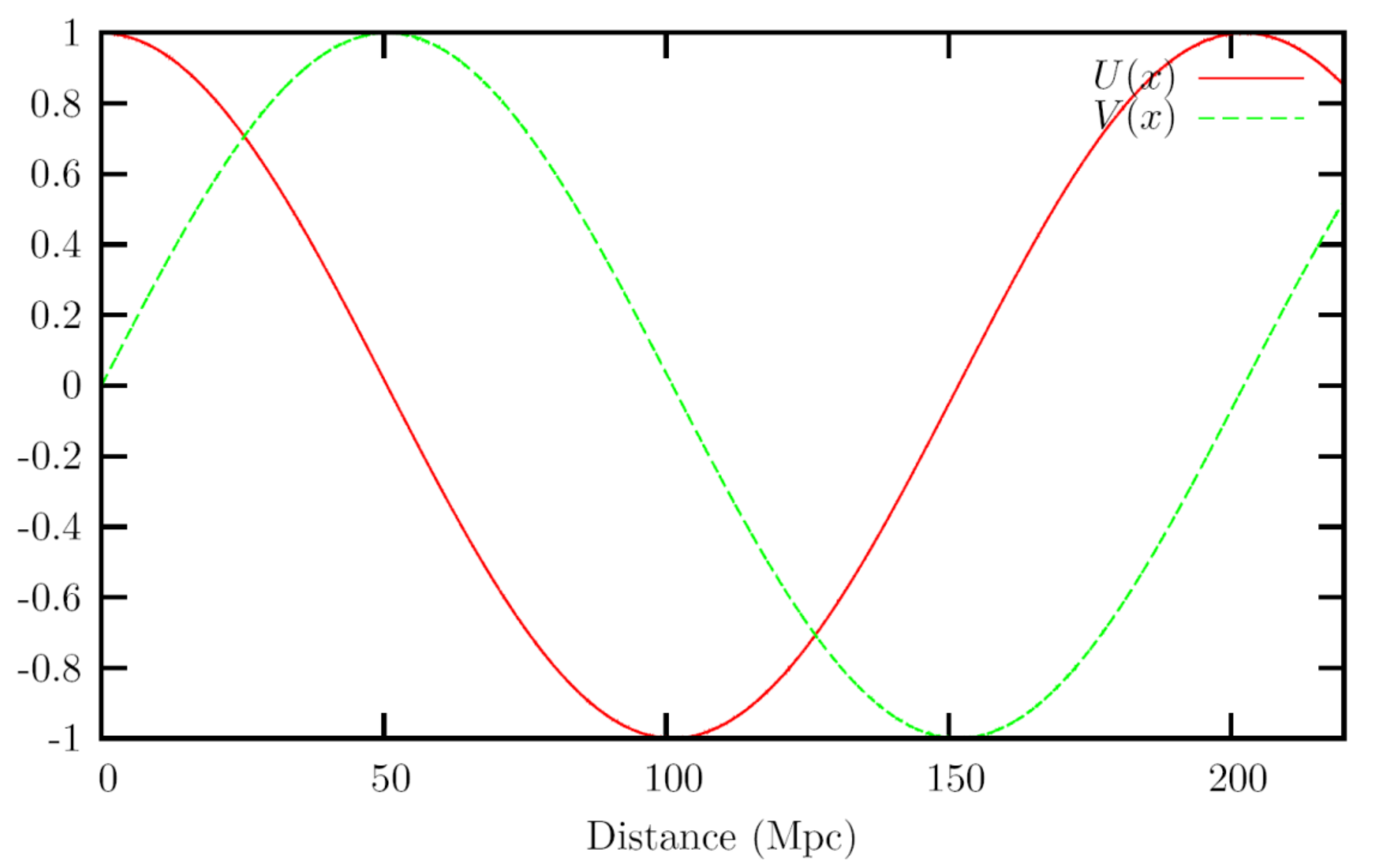


Illustration of birefringence as a function of the distance travelled through an external magnetic field: starting with a plane of polarisation initially making an angle φ with respect to the direction of this magnetic field, we would have an alternance of linear (U = +-1) and circular (V = +-1) polarisations.
The wavelength used here is the observed one: λ = 500 nm.

Other references:

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