

Astronomy 537



Lecture 6: Magnetic Fields in the Milky Way Galaxy

Key concepts:

Polarimetry

Faraday Rotation

Background Sources

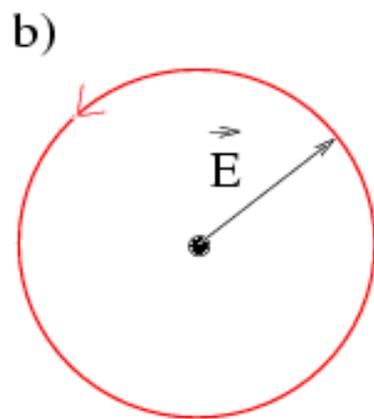
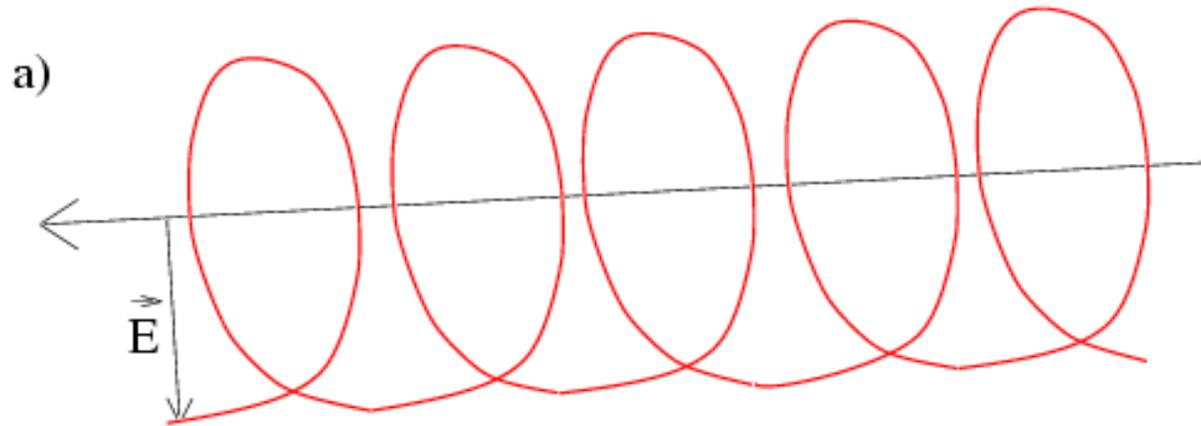
Interstellar magnetic fields

Studies began in 1949 when it was discovered that starlight was polarized by interstellar dust (Hall & Hiltner).

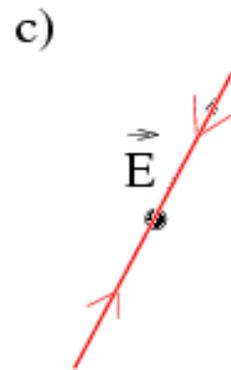
Explanation: grains spinning around their short axes aligned with the magnetic field - preferred direction of scattered photons.

Detected also via the Zeeman effect in molecular lines, and implied by Faraday rotation.

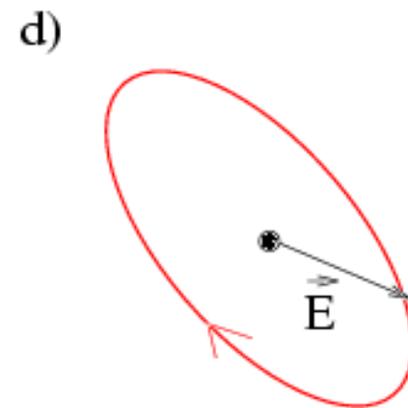
Polarization of Light



Circular



Linear



Elliptical

What is Polarized Light?

- Light is oscillating electric and magnetic fields
- Polarization is labeled by the shape of the trace of the tip of the **E** vector
- Each polarization has an orthogonal state
- Incoherent light can contain many polarization states

Stokes Parameters describe partially polarized light

$$I = RR + LL$$

$$Q = RL + LR$$

$$U = i(LR - RL)$$

$$V = LL - RR$$

For circular feeds

Alternate representation:

- | | |
|-----------------------|---------------------------------------|
| • pol. angle (EVPA) | $\phi = 0.5 \operatorname{atan}(U/Q)$ |
| • polarized intensity | $p = \operatorname{sqrt}(Q^2 + U^2)$ |
| • fractional linear | $m = p / I$ |
| • fractional circular | $v = V / I$ |

Faraday rotation

Rotation of the plane of linear polarization during propagation through a magnetized, ionized medium.

Why? Because normal modes are circularly polarized: you have an equal RH and LH mode. In the presence of a magnetic field along the LOS, RH and LH modes travel with different velocity.

A linearly polarized wave is superposition of two circularly polarized waves with some phase difference. If they propagate at different speeds, combining them back will give you a linearly polarized wave but with a rotated position angle.

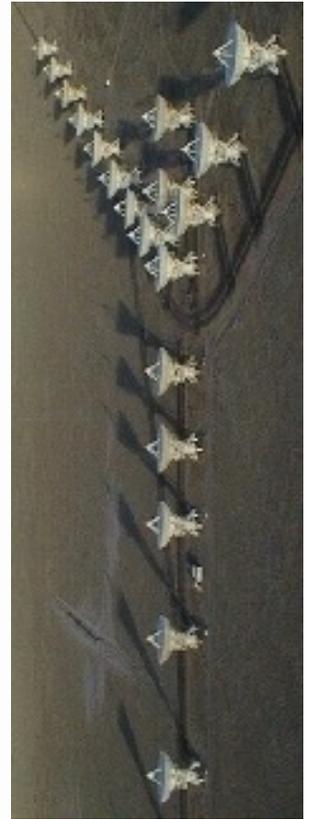
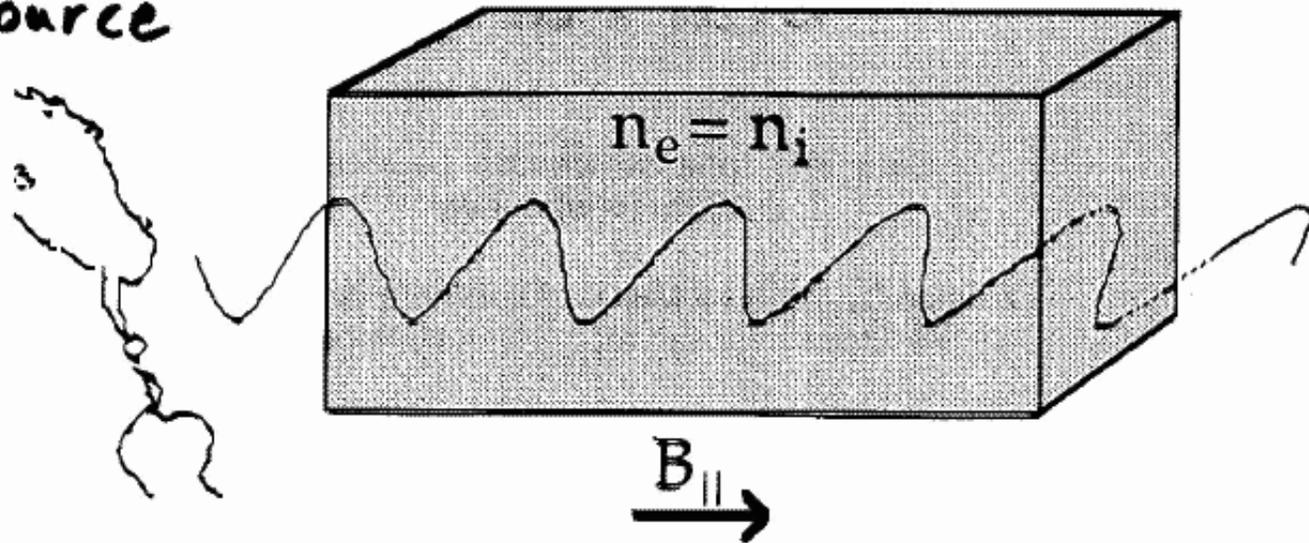
Phase difference after traveling a distance dl :

$$\Delta\phi = \frac{2\pi\nu}{c} \Delta n dl$$

Faraday Rotation

Polarized
Source

Plasma



$$\Psi = \Psi_0 + RM\lambda^2$$

$$RM = 812 \int_0^L n_e B_{||} dl \text{ radians/m}^2$$

Handwritten annotations for the equation above:
- L is labeled with rpl
- $B_{||}$ is labeled with mGauss
- n_e is labeled with cm^{-3}

ROTATION MEASURES FOR 555 EXTRAGALACTIC RADIO SOURCES

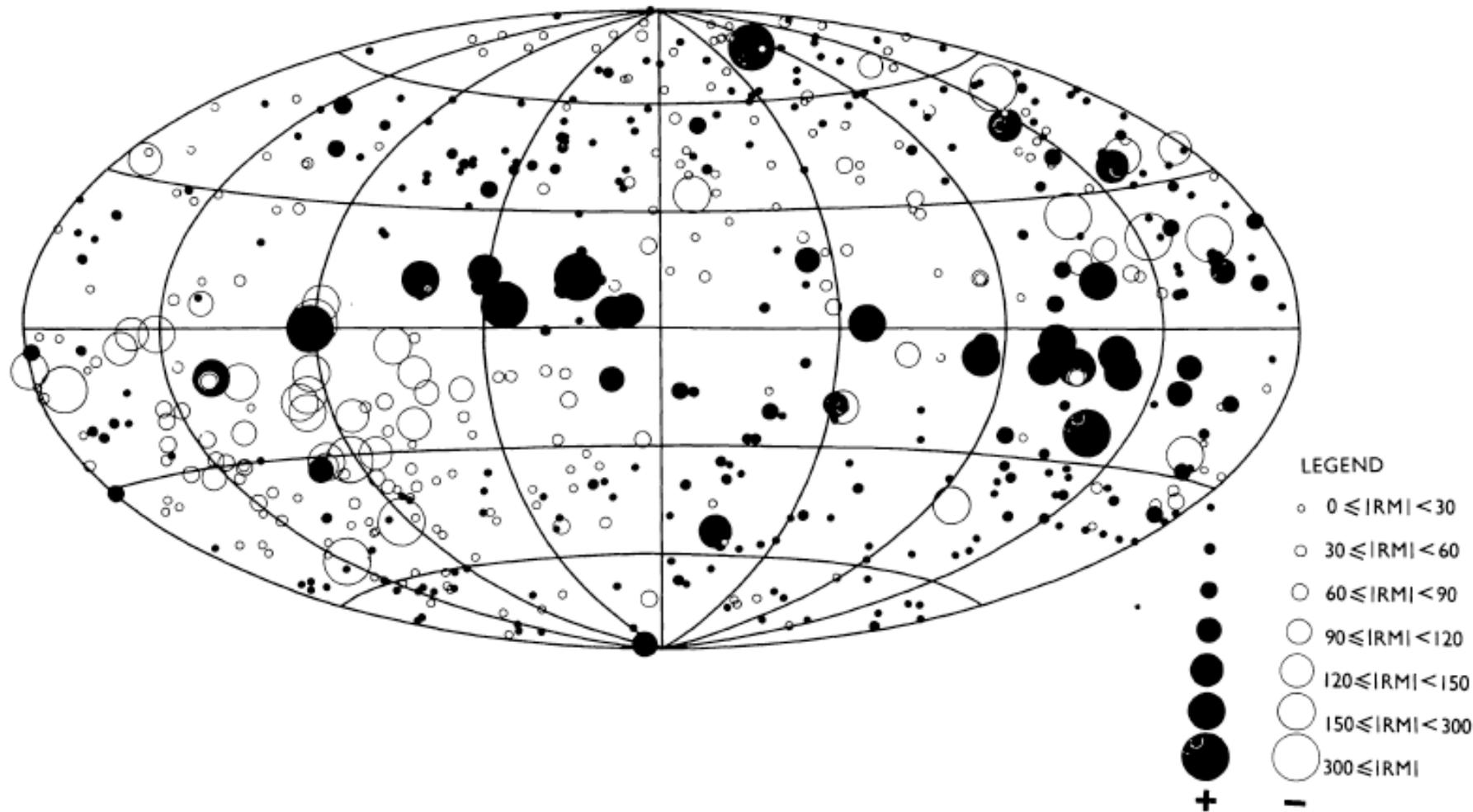
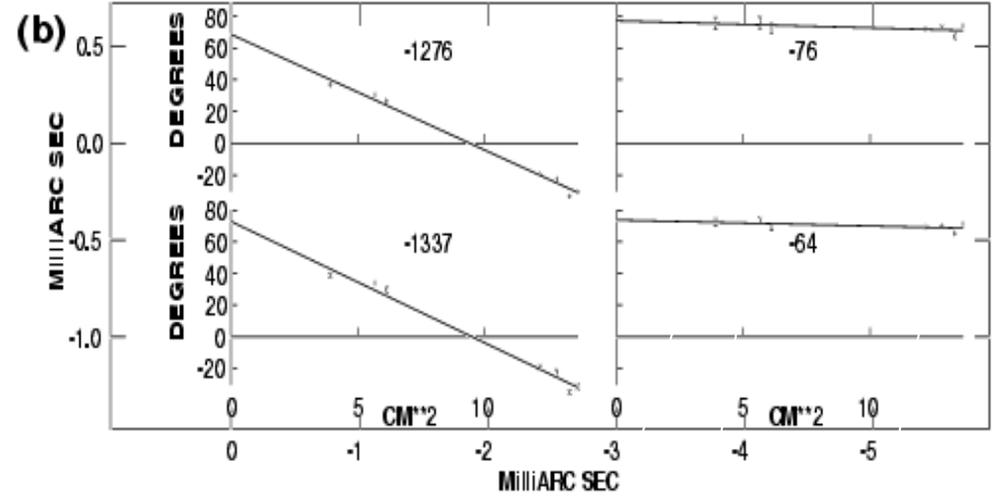
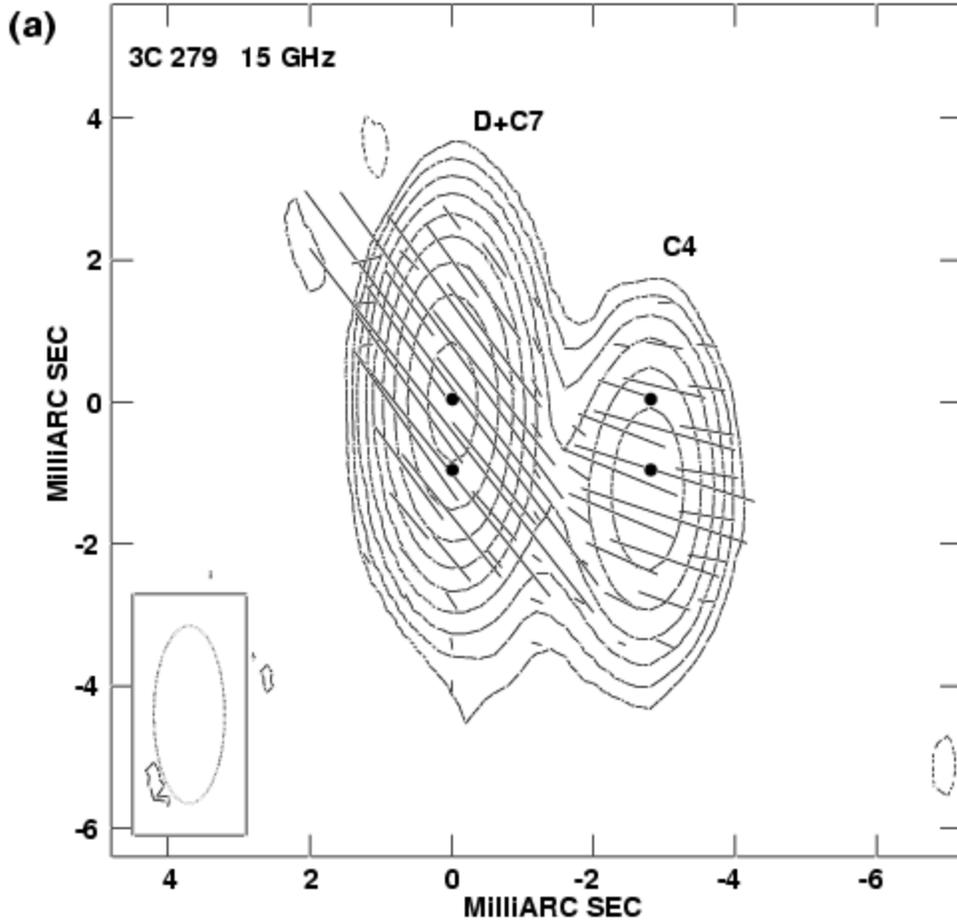


FIG. 2.—Hammer-Aitoff equal area plot of the RMs of 555 extragalactic radio sources. The galactic center is at the center, and longitude increases leftward.

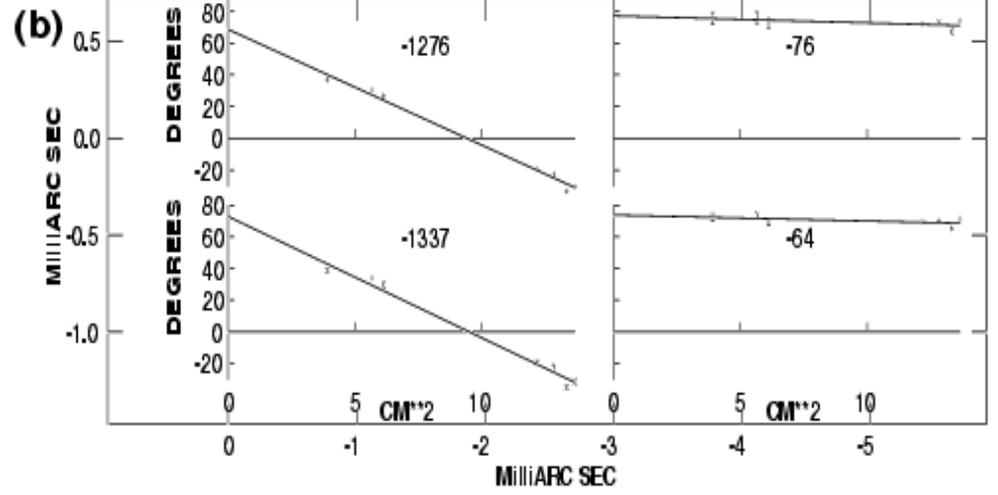
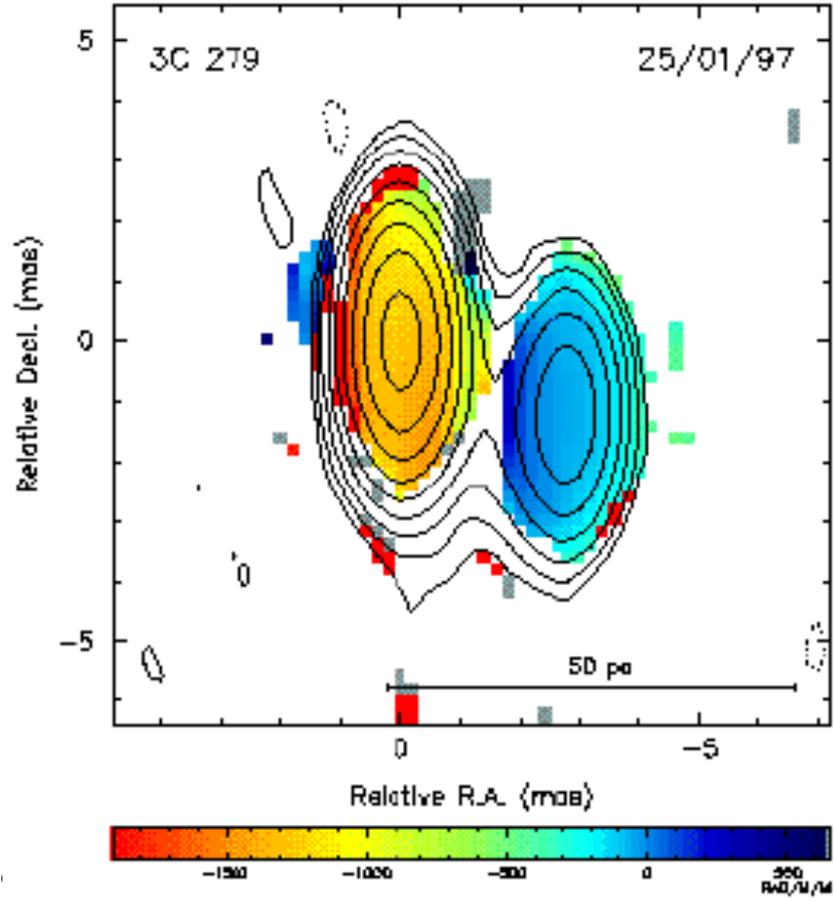
Simard-Normandin et al. 1981

Faraday Rotation Measures

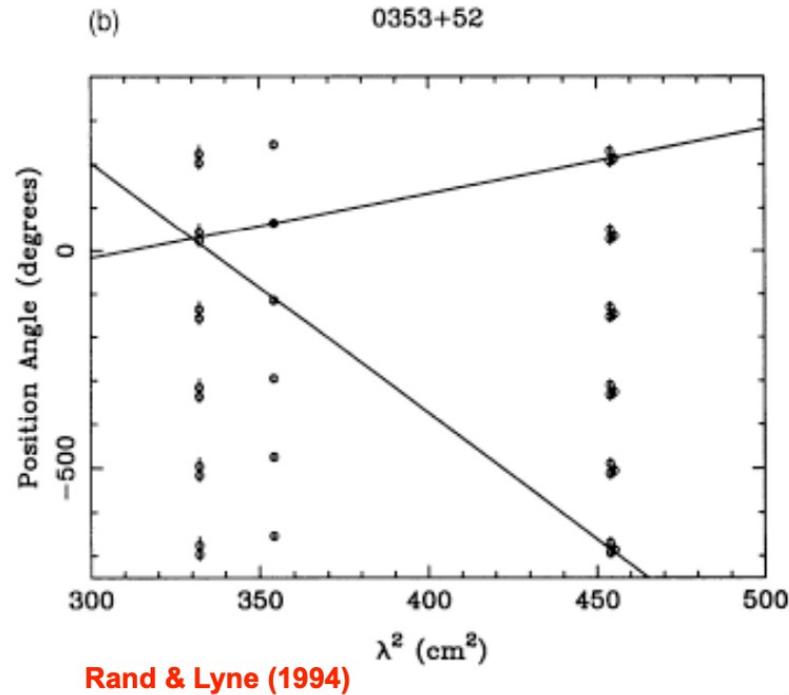
Taylor (1998) 9



15 12 8 GHz



- The $n\pi$ ambiguity



Worksheet: (a) Calculate the Faraday Rotation Measure for a radio source with a polarization angle of 102 degrees at 8 GHz and a polarization angle of 175 degrees at 15 GHz. (b) assume that the 8 GHz measurement is instead rotated by 180 degrees so it is really at -78 degrees, now what RM do you derive? How would more measurements help to eliminate this $n\pi$ ambiguity?

RM Synthesis

Brentjens & de Bruyn (2005) define the Faraday Depth as

$$\phi(\mathbf{r}) = 0.81 \int_{\text{there}}^{\text{here}} n_e \mathbf{B} \cdot d\mathbf{r} \text{ rad m}^{-2},$$

$$\text{RM} = \frac{d\chi(\lambda^2)}{d\lambda^2}, \quad \vec{P} = p I e^{2i\chi} \quad (4)$$

where

$$\chi = \frac{1}{2} \tan^{-1} \frac{U}{Q}. \quad (5)$$

Burn (1966) also introduces the complex Faraday dispersion function $F(\phi)$, which is defined through

$$P(\lambda^2) = \int_{-\infty}^{+\infty} F(\phi) e^{2i\phi\lambda^2} d\phi. \quad (6)$$

This looks like a Fourier Transform !

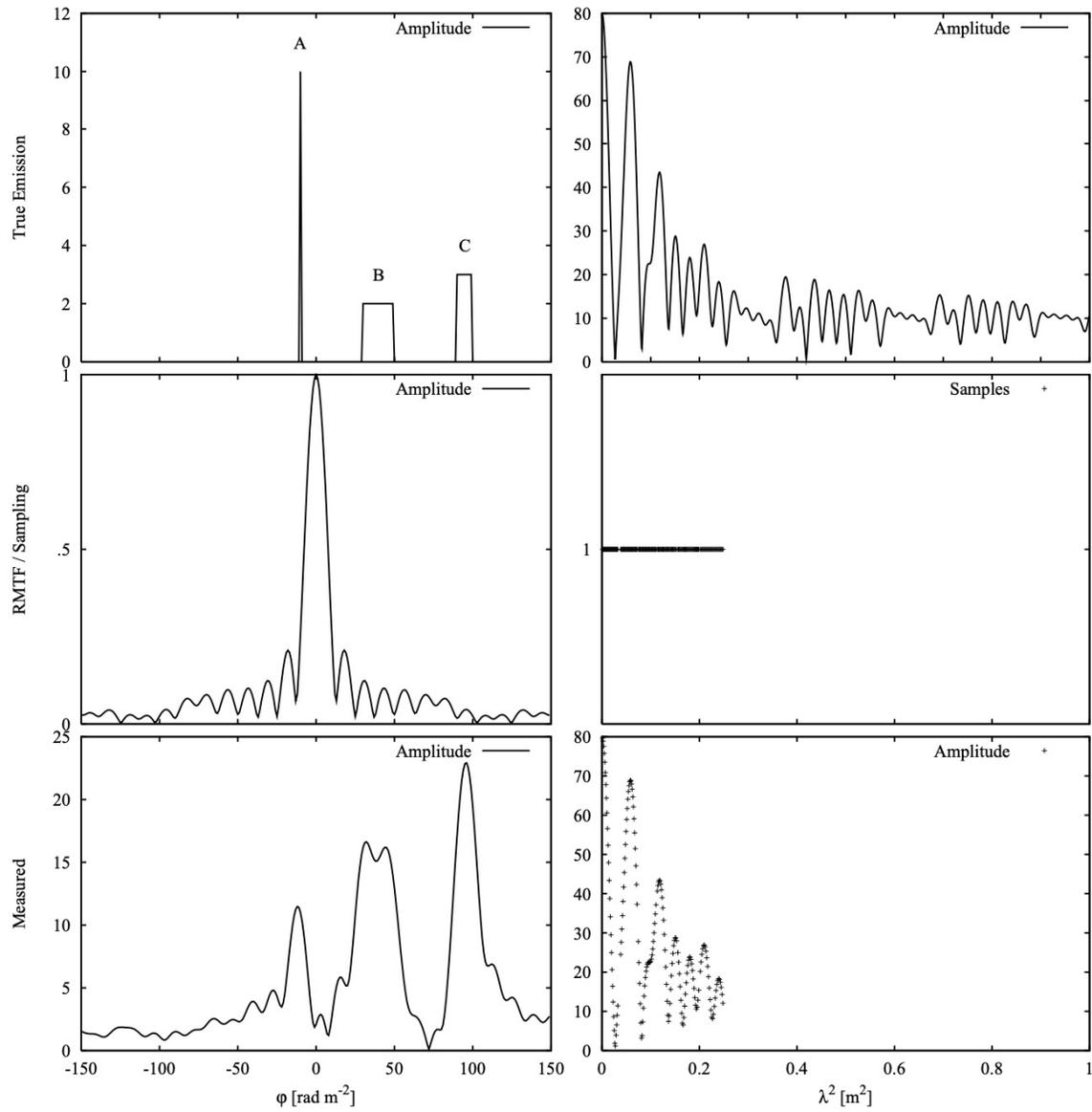


Fig. B.1. Wavelength range: 3.6–50 cm.

<- FT ->

Journal Class

- **The Thousand-Pulsar-Array programme – mapping the galactic magnetic field**

Oswald et al. 2025

Discussion leader: **Ella Hort**

Note: To encourage discussion everybody must pose at least one question during the group discussion

Journal Class:

- Everybody reads paper (skip the appendices)
- Leader (for Paper 2 **Ella Hort**)
 - Gives a summary of the important points in the paper (~ 10 min) referring to interesting figures
 - Defines any unusual terminology
- **Group discussion**
 - Is the paper well motivated?
 - Points out any major assumptions or flaws
 - Are the results plausible? Important?

Announcements

- Teaching topics due Wed Feb 11
 - Turn in hardcopy with two topics

Teaching Exercise:

See also

https://leo.phys.unm.edu/~gbtaylor/astr537/topic_instructions.pdf

- Decide on a topic by Feb 11. Provide a hard-copy in class (so I can mark it up)
- Draft slides by Apr 15. 6/page, provide hard copy in class (so I can mark it up)
- Aim for 25 minutes + Q&A

Sample topics:

- Advances in instrumentation to measure galaxies at any wavelength
- galactic magnetic fields in starburst galaxies or Ellipticals
- warps in galaxies
- Globular clusters
- Black holes and their accretion disks
- Supernovae and role as cosmic accelerators
- JWST's Little Red Dots