

## Outline

- 1 The Universe in Polarized Light
- 2 Overview of Lectures
- 3 Recommended Books

## Polarized Light in the Universe

*Polarization* indicates *anisotropy*  $\Rightarrow$  not all directions are equal

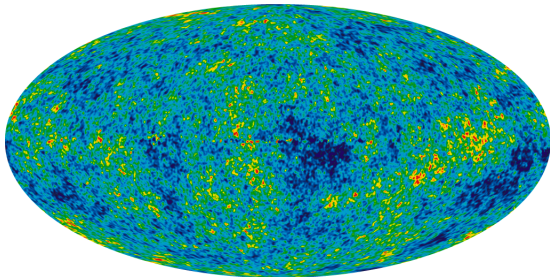
Typical anisotropies introduced by

- geometry (not everything is spherically symmetric)
- gradients (temperature, density, etc.)
- magnetic fields
- electrical fields

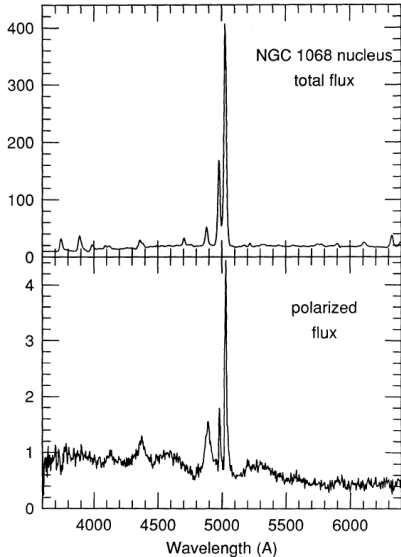
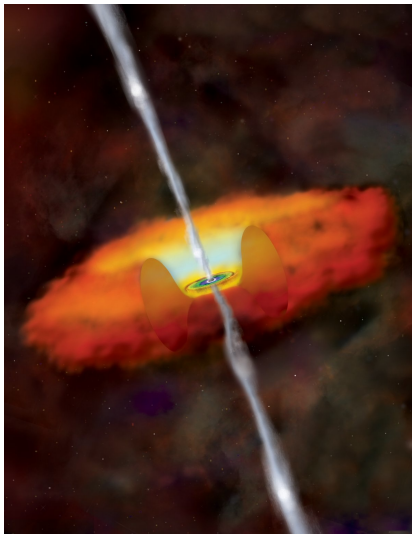
## Polarized Light from the Big Bang

- Cosmic Microwave Background (CMB) is red-shifted radiation from Big Bang  $14 \times 10^9$  years ago
- age, geometry, density of universe from CMB intensity pattern
- first 0.1 seconds from polarization pattern of CMB
- inflation  $\Rightarrow$  gravitational waves  $\Rightarrow$  polarization signals
- polarization expected at (or below)  $10^{-6}$  of intensity

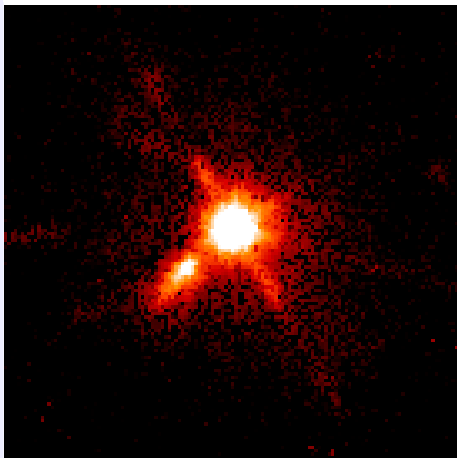
## 13.7 billion year old temperature fluctuations from WMAP



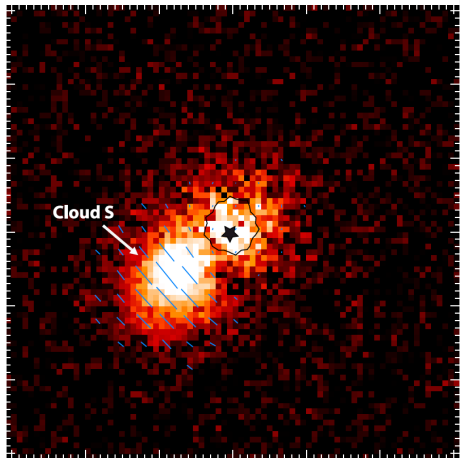
# Unified Model of Active Galactic Nuclei



## R Coronae Borealis



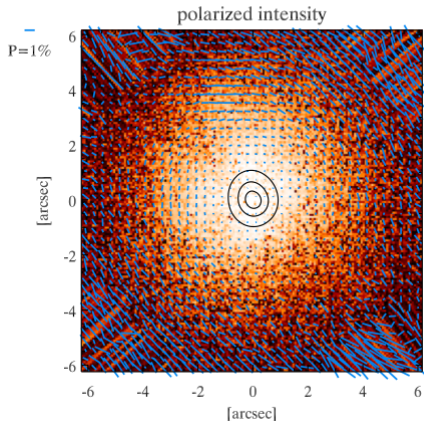
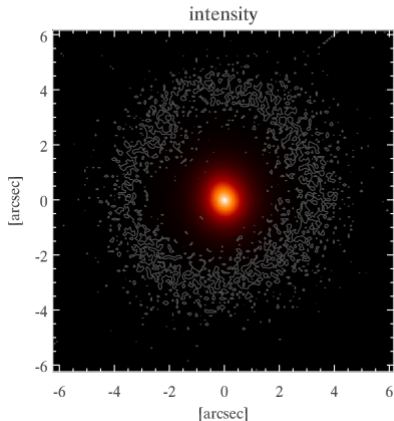
HST WFPC2 at 555 nm



ExPo at 4.2-m WHT

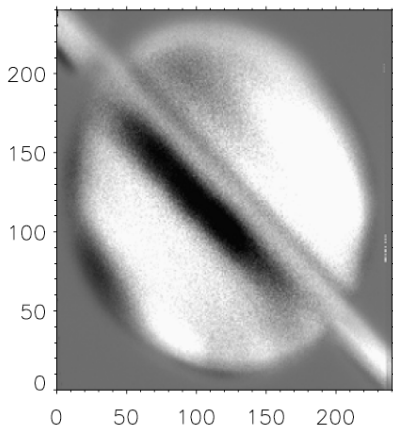
# Protoplanetary Disk in Scattered Light (ExPo at 4.2-m WHT)

ExPo observation of AB Aurigae @ WHT - 825nm filter

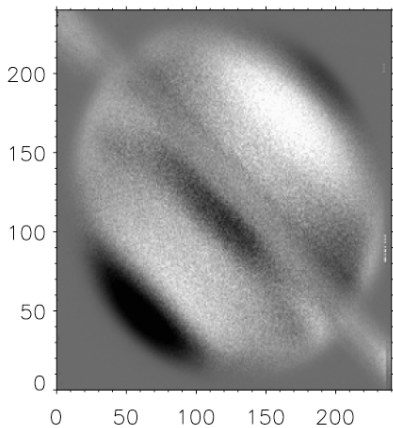


## Planetary Scattered Light (ExPo at 4.2-m WHT)

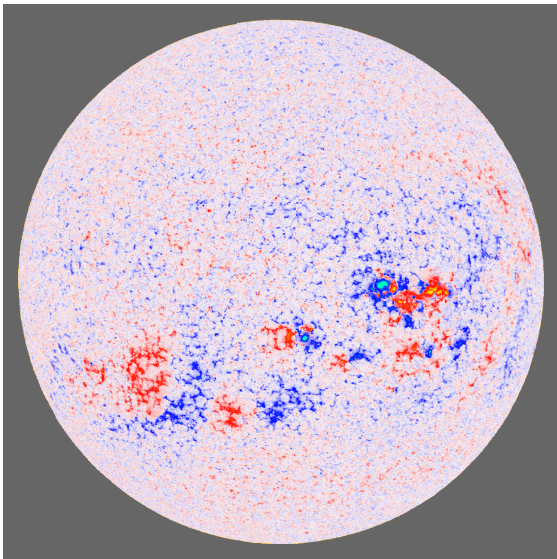
Po10



Po122.5

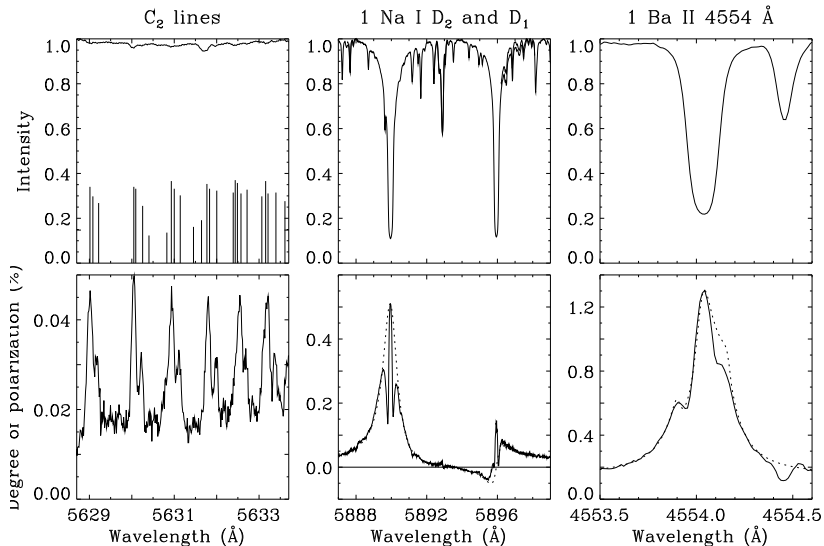


## Solar Longitudinal Zeeman Effect (SOLIS VSM)

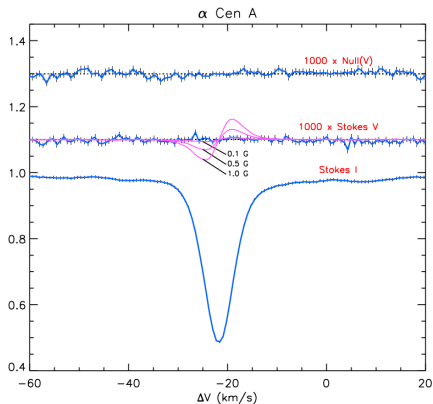




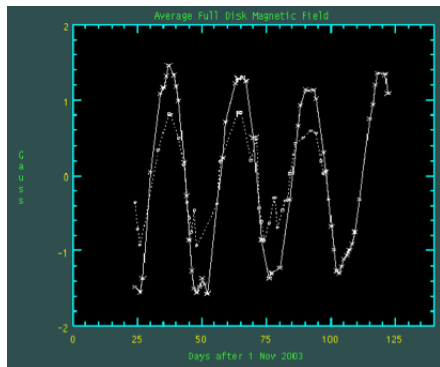
## Second Solar Spectrum from Scattering Polarization



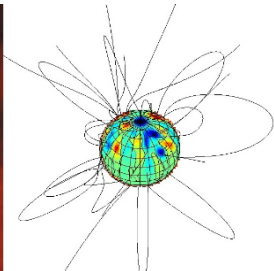
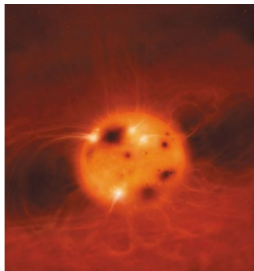
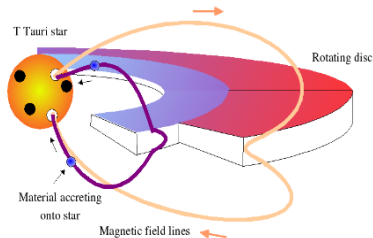
## $\alpha$ Cen A with HARPSpol at ESO's 3.6-m



## Sun with 50-cm SOLIS VSM



## Zeeman Doppler Imaging of T Tauri Stars



## Other astrophysical applications

- interstellar magnetic field from polarized starlight
- supernova asymmetries
- galactic magnetic field from Faraday rotation

- 1 Introduction and Overview
- 2 Electromagnetic Waves in Isotropic Media 1
- 3 Electromagnetic Waves in Isotropic Media 2
- 4 Thin Films
- 5 Crystal Optics
- 6 Anisotropic Media
- 7 Linear Polarizers
- 8 Fixed Retarders
- 9 Variable Retarders
- 10 Polarimetry Systems Engineering 1
- 11 Polarimetry Systems Engineering 2
- 12 Rotating Retarder Polarimeters
- 13 Liquid Crystal Polarimeters
- 14 Advanced Polarimeters

## Outline

- 1 Electromagnetic Waves
- 2 Electromagnetic Waves Across Interfaces
- 3 Snell's law

## Outline

- 1 Fresnel Equations
- 2 Brewster Angle
- 3 Total Internal Reflection

## Outline

- 1 Thin Films
- 2 Calculating Thin Film Stack Properties
- 3 Jones Matrices for Thin Film Stacks
- 4 Mueller Matrices for Thin Film Stacks
- 5 Mueller Matrix for Dielectrics
- 6 Mueller Matrix for Metals
- 7 Applications to Solar Polarimetry

## Outline

- 1 Homogeneous, Anisotropic Media
- 2 Crystals
- 3 Plane Waves in Anisotropic Media
- 4 Wave Propagation in Uniaxial Media
- 5 Reflection and Transmission at Interfaces



## Outline

- 1 Dichroism
- 2 Stress Birefringence
- 3 Form Birefringence
- 4 Electro-Optics

## Outline

- 1 Jones and Mueller Matrices for Linear Polarizers
- 2 Wire Grid Polarizers
- 3 Polaroid-type Polarizers
- 4 Crystal-based Polarizers
- 5 Thin-Film Polarizers
- 6 Polarizer Selection Guide

## Outline

- 1 Jones and Mueller Matrices for Linear Retarders
- 2 Zero and Multiple Order Linear Retarders
- 3 Crystal Retarders
- 4 Polymer Retarders
- 5 Achromatic Retarders
- 6 Angle-Dependence of Linear Retarders
- 7 Temperature Dependence of Fixed Retarders
- 8 Spectral Fringes in Retarders
- 9 Linear Retarder Selection Guide

## Outline

- 1 Liquid Crystal Retarders
- 2 Piezo-Elastic Modulators (PEMs)
- 3 Achromatic Variable Retarders
- 4 Comparison of Variable Retarders

## Outline

- 1 Systems Engineering for Polarimetry
- 2 Errors in Polarimetric Measurements
- 3 Polarization Sensitivity and Accuracy
- 4 Polarimetric Efficiency
- 5 Photon Budget
- 6 Systematic Errors
- 7 Polarimeter Design

## Outline

- 1 General Polarimeter
- 2 Temporal and Spatial Modulation
- 3 Double-Ratio Technique
- 4 Calibration
- 5 Polarized Ray Tracing

## Outline

- 1 Rotating Waveplate Polarimeters
- 2 ASP
- 3 Hinode SOT
- 4 HARPSpol

## Outline

- 1 Liquid Crystal Polarimeters
- 2 SOLIS VSM
- 3 S5T

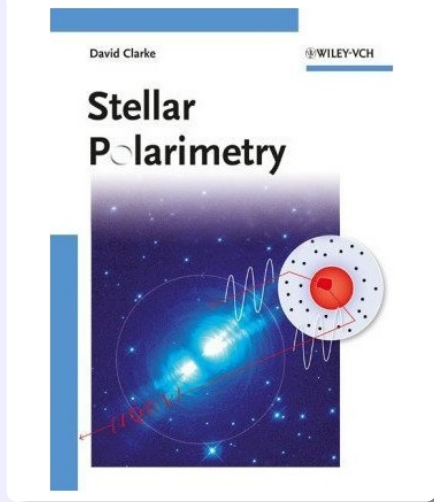


## Outline

- 1 ZIMPOL
- 2 C3Po
- 3 SPEX

# Recommended Books

## Stellar Polarimetry David Clarke



## Astronomical Polarimetry Jaap Tinbergen

