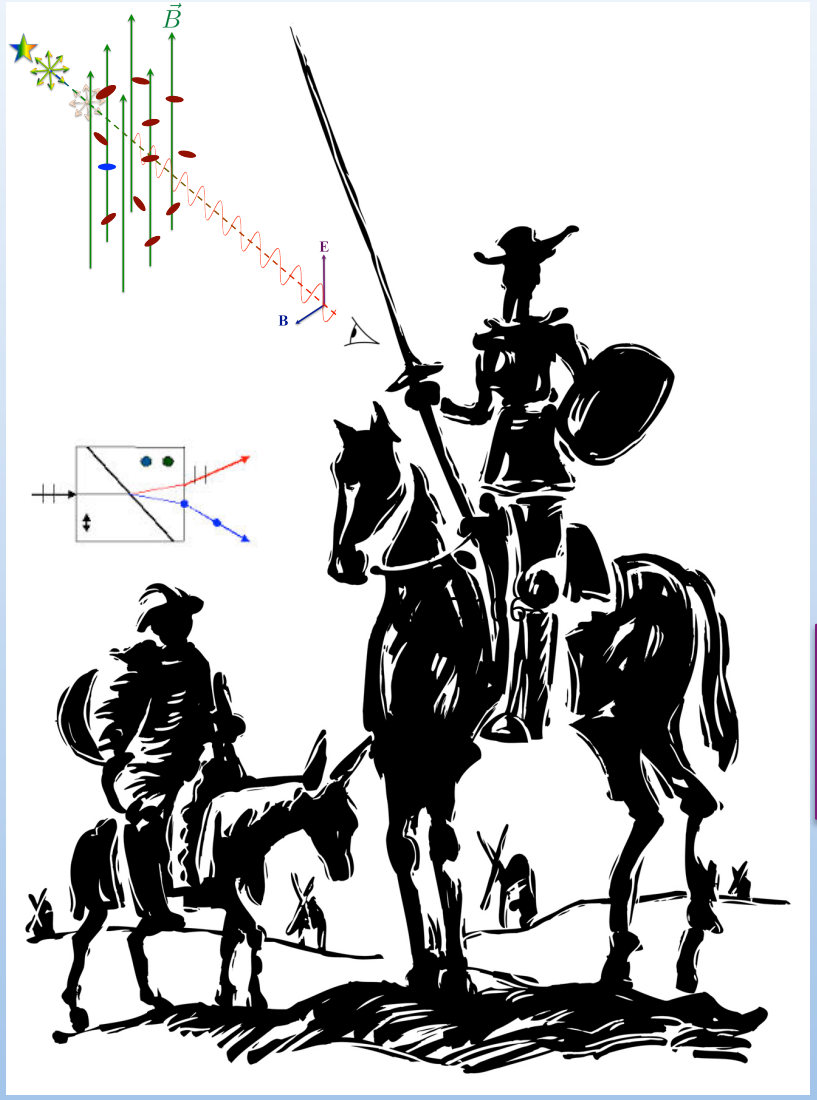
A few Science cases for space UV Polarimetry in the 21st century



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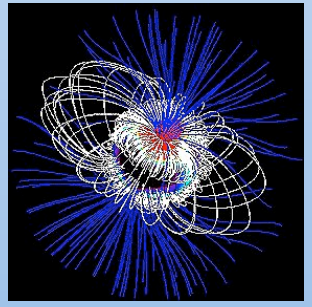
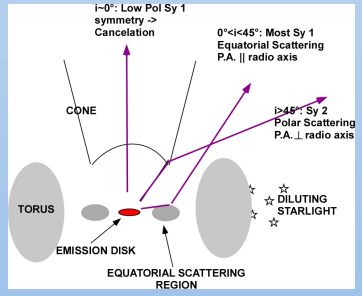
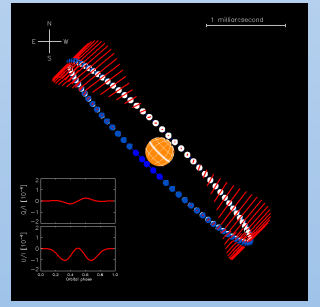
"Polarization is the crucial third leg of the astronomer's light-analysis tripod"

D.P. Clemens







(UV) Polarimetry Provides Unique Discovery Space

- Probes ISM magnetic fields, radiation and dust
  - Dichroic extinction
  - Line polarization
- Reveals structure in unresolved, asymmetric, objects
  - Accretion processes and circumstellar disk properties
  - Stellar magnetism
  - Exo-planets
- Allows study of obscured phenomena
  - AGN engines

Full wavelength coverage (UV-IR) provides critical constraints on the astrophysics

Need for large apertures

- Polarimetry is photon intensive

$$\sigma_p = \sqrt{2} / (S/N)_{phot}$$

So, for e.g. a "typical" ISM p=1% (0.01) at 5σ detection:

$$(S/N)_{Phot} = 700$$

But, $I=\sqrt{(Q^2+U^2+V^2)}$, so the intensity (photometry or spectroscopy) can be recovered from polarimetry data, and polarization can [often] use lower $\lambda/\Delta\lambda$.

- The polariziation spectrum carries information about physical processes and the state of the gas and dust
- UV polarimetry has been poorly explored
- Significant discovery space with large aperture telescopes, sensitive instruments and modern understanding of polarization mechanisms

Interstellar Medium Polarimetry

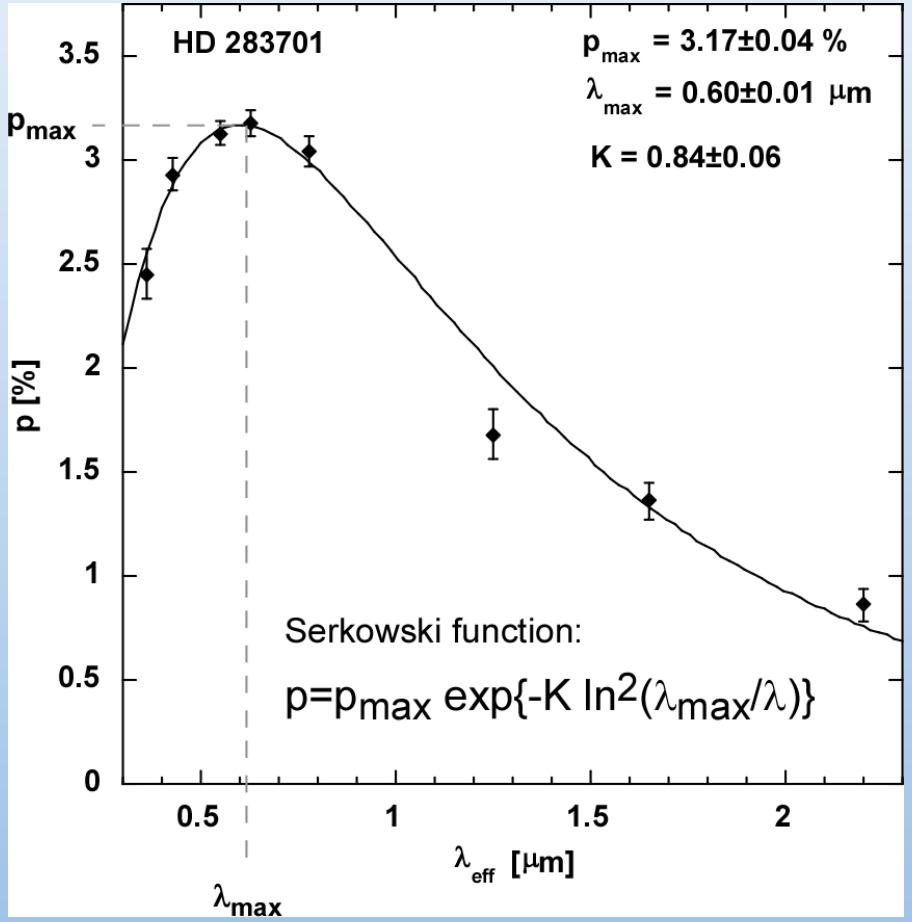
Interstellar Grain Alignment

- *Radiative Alignment Torque* (RAT) theory provides a quantitative, observationally well tested, mechanism for ISM grain alignment (Andersson, Lazarian & Vaillancourt, ARA&A 2015).
  - Grains will be spun-up and aligned with the magnetic field, by the radiation, if they are:
    - Irregular, and of paramagnetic material
    - Exposed to an anisotropic radiation field with $\lambda < 2a$
      - Carbonaceous grains are spun up but, since they're diamagnetic don't align with the magnetic field*
- Provides tools to probe magnetic & radiation fields, grain size distribution, mineralogy, etc.

* Not yet fully observationally verified

Interstellar Polarization I

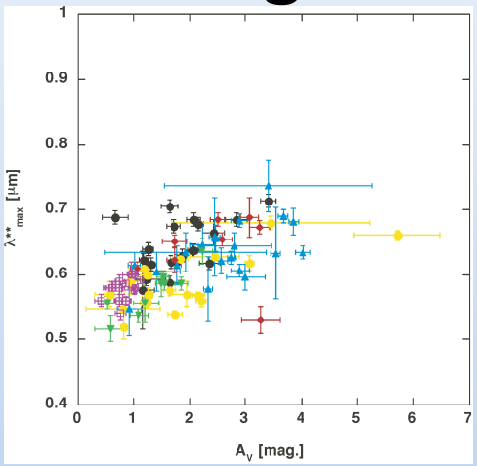
- The polarization curve traces the convolution of grain sizes and the SED of the radiation field

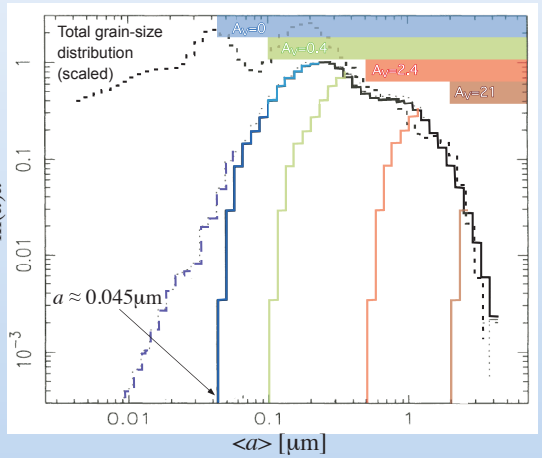


Can be generally parametrized by the "Serkowski function" with parameters p_{max}, λ_{max} and K

Interstellar Polarization II

- The polarization curve traces the convolution of grain sizes and the SED of the radiation field





Paramagnetic relaxation alignment becomes more efficient for the smallest grains and may dominate at a<<0.1μm. If so, the magnitude of UV polarization is proportional to the magnetic field strength (Hoang, Lazarian & Martin 2014)

Line polarization from aligned atoms (/ions) could provide probes of the geometry and strength of the B-field (e.g. Yan & Lazarian, 2008)

The value of λ_{max} in the diffuse ISM is characteristic of the cut of in the diffuse UV field at the Lyman limit (912Å)

For 2 out of the ~30 l.o.s. studied by WUPPE and HST/FOS the pol. curve is enhanced in the UV and the 2175Å bump is polarized. – Why?

This could be due to hard UV sources (λ^{ISRF} < 900Å; sdO, hot WD) along the l.o.s. towards the background source.

UV Polarimetry of the ISM allows studies of magnetic fields, grain size distributions and mineralogy and local FUV radiation fields

Discovery Space of [UV] Polarimetry

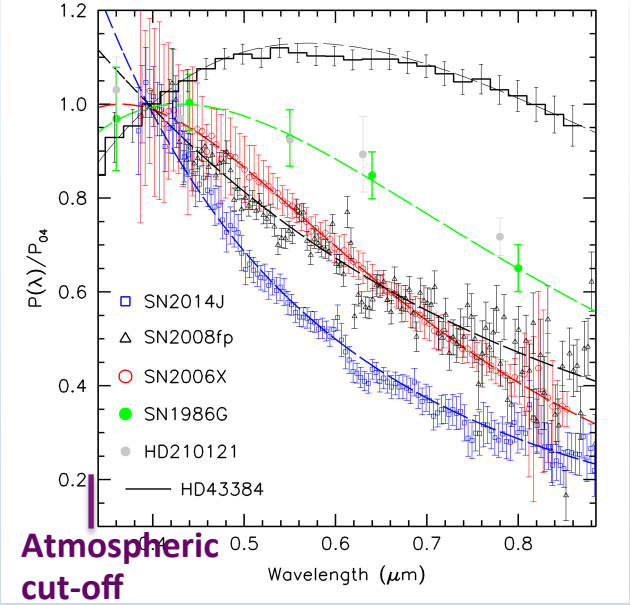
Unresolved, asymmetric, objects

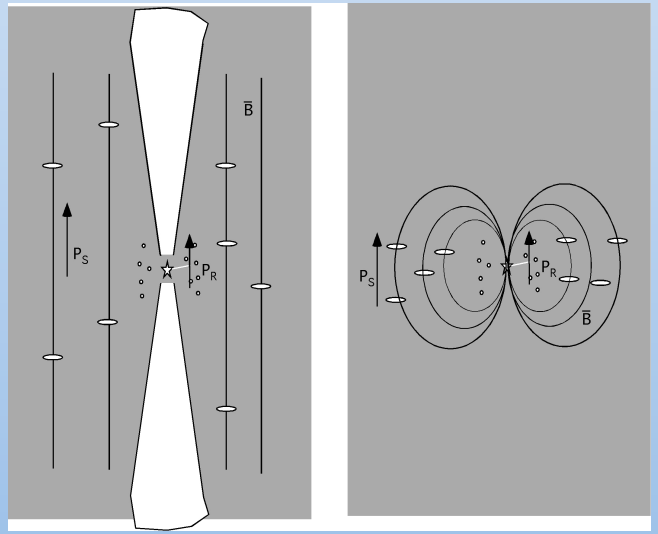
Resolving the unresolved through polarimetry

- Polarization – being a [pseudo] vector - allows structure to be derived in unresolved asymmetric source by interpreting
  - Scattering
    - Electron (Thompson) scattering
    - Rayleigh scattering by polarizable molecules; $p \sim \lambda^{-4}$
    - Dust scattering in the small particle limit; $p \sim \lambda^{-4}$
  - Spectral line features including Zeeman effect and Cyclotron lines

For objects with known rotational/orbital periods time resolved polarization can be used to build 3D models of structures and magnetic fields

SN Ia Source Structure Constraints

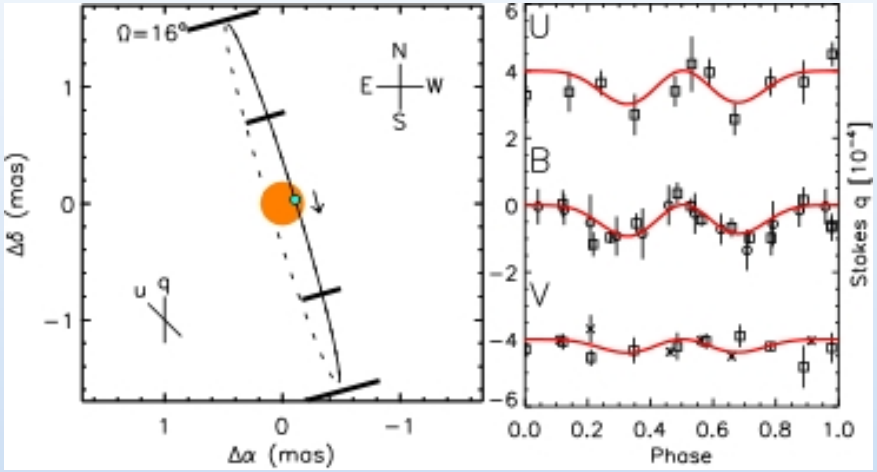




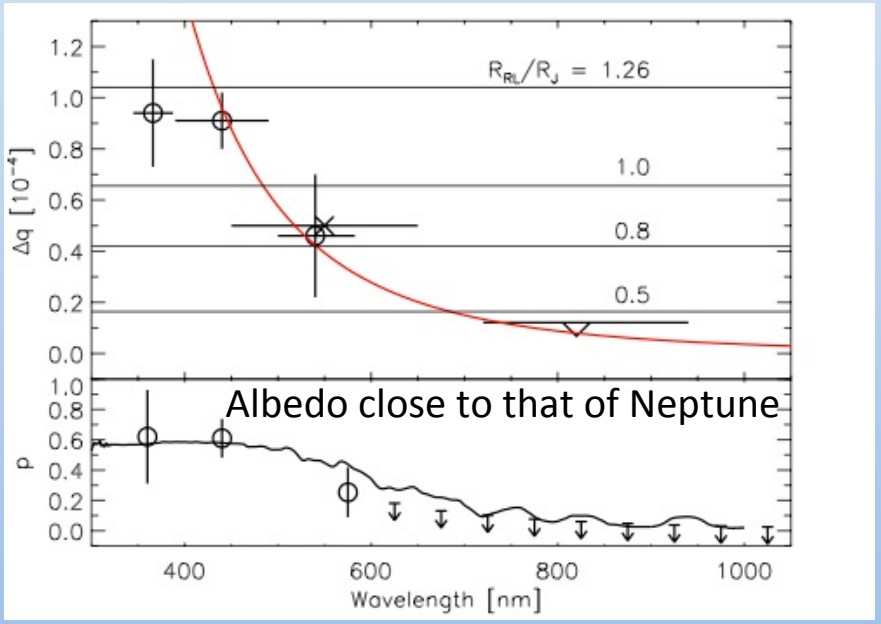
- Patat et al. (2015) have shown that the polarization spectrum of several SN Ia rise to [beyond?] the (blue) atmospheric cut-off.
- Serkowski fits yield λ_{max} values that are inconsistent with alignment of Galactic grain size distributions (Hoang priv. communication).
- In Galactic reflection nebulae combination of Serkowski and "Rayleigh" scattering has been seen (Matsumura et al. 2011; Andersson et al. 2013)
- A toy model of a SN precursor source structure – a magnetized white dwarf with a mid-plane disk of small grains – *could* explain the observations, without invoking extreme dust size distributions

UV (time-resolved) polarimetry, extending the wavelength coverage, allows dichroic extinction and "Rayleigh" scattering to be decoupled and source structure to be inferred

Exo-Planet Polarimetry



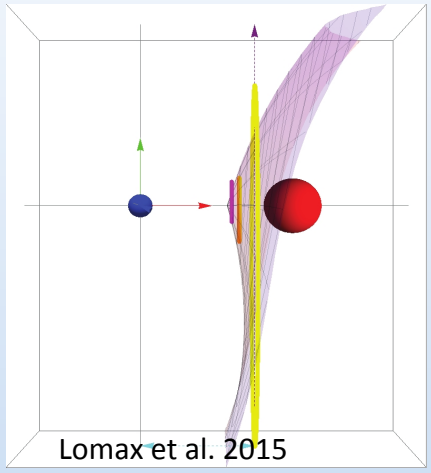
Berdyugina et al. 2008, 2011



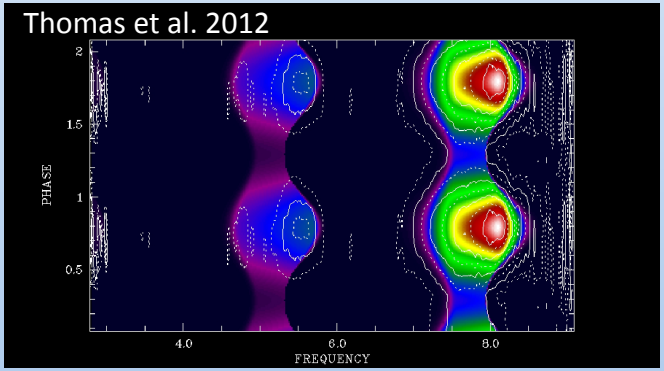
- Rayleigh scattering in the extended atmospheres of exo-planets provide a novel way to characterize the atmospheres and a unique method to establish the orientation of the exo-planet orbital plane
- Because of the spectral dependence of the polarization ($p \sim \lambda^{-4}$), sensitive UV polarimetry is critical to maximize contrast at the low polarization levels expected
- The effect has been reported for HD189733b Berdyugina et al. 2008; 2011), but with null-result attempts of confirmation (Wiktorowicz, 2009)

Time-resolved (UV) spectro-polarimetry, will allow unique characteristics of exo-planet orbit and atmospheric parameters

Accretion and Wind Interactions in Hot Binaries


Lomax et al. 2015

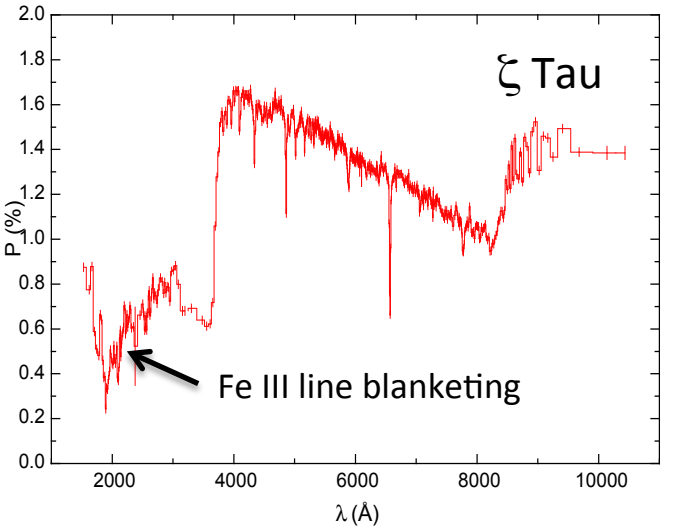
- Most massive stars (~75%) occur in binary systems which are likely to produce SNe and GRBs
- UV polarimetry of the wind collision regions of high-mass binaries would allow detailed characterization of their shock structures and provide constraints on the effects of binary interactions in massive stellar evolution



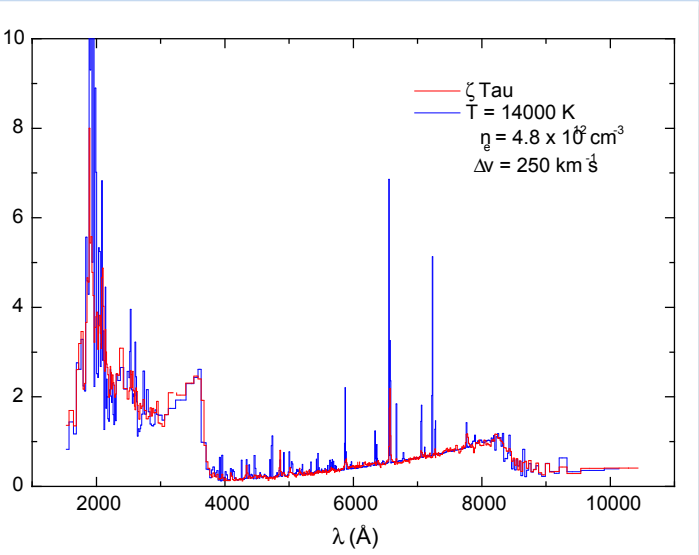
Magnetized evolved binaries, including Polars, are likely precursors to SN Ia explosions. Polarimetry of Zeeman and Cyclotron lines from these object provide unique information on the magnetic field characteristics of these systems, and it's influence on their evolution.
Stokes spectroscopy of the Cyclotron features allow full physical analysis, including temperature, density, accretion rate and white dwarf mass, as well as magnetic field strengths

UV spectropolarimetry provides unique constraints on the evolution of [hot] interacting binary stars and their evolution into SNe and GRBs

Gas disk characteristics



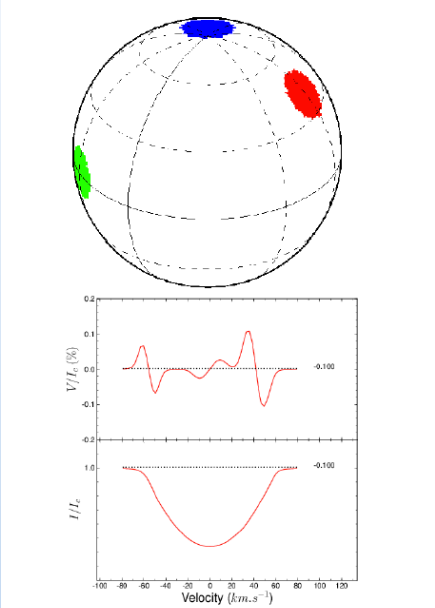
Bjorkman, Bjorkman & Wood (2000)



- Be stars are rapidly rotating massive stars, and may be the precursors of gamma ray bursts
  - Excellent laboratories for understanding the physics of circumstellar gas disks
- Polarization from Be star disks can be used to derive the disk temperature and structure
  - Electron scattering (polarized) modulated by line-blanketing depolarization
- Over-all level of polarization depends on disk geometry and inclination
- Using LTE modeling of the level population of Fe III (T>13,000K; λ~1800Å) or Fe II (T<13,000K; λ~2200Å), the disk temperature can be determined to ±1000K (7%)

UV spectropolarimetry provides a direct probe of the physical state of circumstellar matter, unresolved by other techniques, for many types of stellar environments.

Stellar UV Polarimetry



- Spectropolarimetry in the UV allows to study the stellar environment:
  - wind, magnetosphere, chromosphere, etc.
  - Interactions with binary companions and exo-planets
- Spectropolarimetry in the visible allows to study the stellar surface:
  - magnetic field, chemical spots, etc.
  - Fosil vs. dynamo-generated magnetic fields
- → Spectropolarimetry in the UV+visible over a rotation period allows the reconstruction the full 3D maps of the star from its surface to its environment

Time resolved UV spectropolarimetry allows the study of the generation and role of magnetic fields on the evolution of stars and stellar systems over the HR diagram, and its effect on stellar evolution.

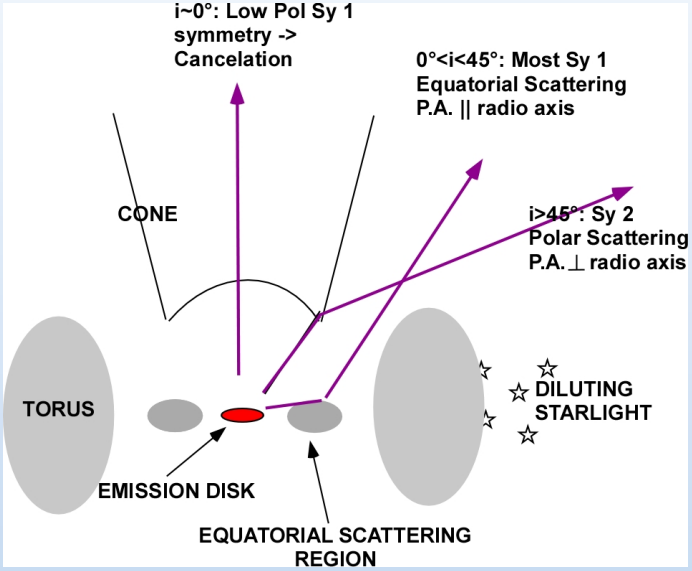
A large aperture telescope will allow stellar magnetism studies to be extended to the local group, including low metalicity galaxies

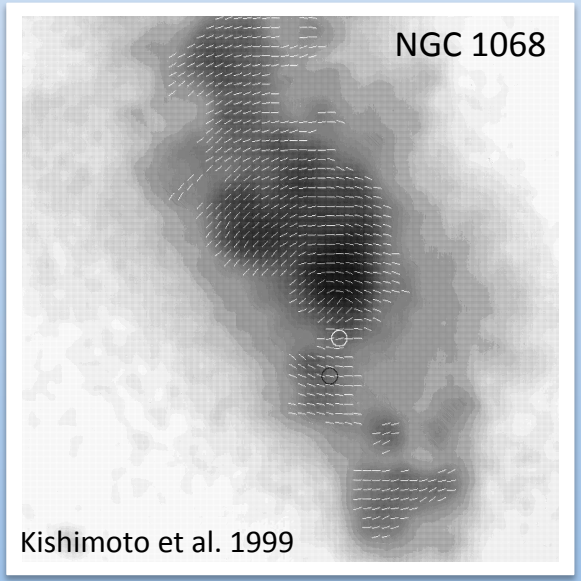
Discovery Space of [UV] Polarimetry

USRA

Revealing Obscured Sources

Probing the Engine of AGNs





- Polarized light from AGN originates as
  - Synchrotron emission from jets extending up to several kpcs from the nucleus
  - Scattering by dust or electrons in the viscinity of the AGN, obscured in direct light by the torus
- The accretion disk in AGN has peak emission in the UV, so polarimetry at these wavelengths is crucial.
- For optically thin scattering by small particles, $p \sim \lambda^{-4}$. Hence, the polarized component is more easily distinguished from other emission in the UV
  - Enhances the contrast between AGN structures, such as scattering cones, and unpolarized regions for imaging polarimetry.
- The polarized spectrum elucidates the nature and opacity of the scatterers and the dynamics of the disk
- UV polarimetry of AGN with HST stretched its capability

UV polarimetry on large telescopes allows studies of the 3D structure of the central engines, accretion disks and surrounding dusty tori, and the evolution of AGN

Summary

- Significant new discovery space exists for UV polarimetry
  - Large apertures, high total photon counts
  - Hitherto poorly explored area
  - New theories guide observations and interpretation
- Polarized light (Stokes Q, U, V) can be combined to recover photometric S/N (Stokes I)
  - Polarization application often doable with lower resolution data and therefore spectroscopy and spectro-polarimery SNRs are complementary
- “Bad” optical design choices can preclude polarimetry, but “good” choices are possible