IMPS: A compact and robust approach to spectropolarimetry

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The Future of Polarimetry
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Preaching to the Choir

- Applications for space polarimetry: Solar System and beyond
  - Phase angle, resolution, wavelength range; telescopic, robotic / remote sensing, in-situ
  - Aerosols
  - Scattering surfaces
  - Dust – composition and texture
  - Extrasolar planets – detection, characterization
  - Stellar and Galactic magnetic fields
  - Non-thermal processes across EM spectrum
    - Etc.
  - *Biosignatures*

- Challenges to precision polarimetry in space
  - Fragile components
  - Moving parts
  - Modulating parts
  - Time dependent data acquisition (sequential)
  - Target in motion/variable
  - Instrument in motion

- To measure $10^{-4}$ needs $10^8$ photons but CCD well depth only $10^5$
  - Solution: spread the light out
The phenomenon of homochirality – a powerful biosignature

Building blocks of life (amino acids, sugars) are chiral – mirror image cannot be superimposed on original; life uses only one handedness - **homochirality**

All known self-replicating life forms, including archaea, bacteria, eukaryotes and even viruses, encode left handed amino acids into proteins and right handed sugars into multiple biopolymers including DNA and RNA

Likely **generic to all biochemical life** as consequence of self-replication, relaxes terrestrial assumptions

Biological molecules are optically active - influence polarization of light, linear but especially circular polarization

>A pure biosignature; Wald (1957)

Circular polarization probes protein structures (circular dichroism)

Circular polarization spectra permit derivation of protein structure; for our purposes sufficient that biomolecules produce circular polarization features.

Circular polarization spectroscopy may be used to infer the presence of chiral molecules on a macroscopic scale, thus providing a pure biosignature
Chirality, microbes and circular polarization

Circular polarization correlates with absorption in biological samples

**Microbes:** cyanobacterium *Synechococcus* WH8101 (Sparks et al 2009); *Chloroflexus aurantiacus* (in prep): polarization signature correlates with spectral features

**Controls:** no polarization features

(Results from Hinds dual PEM polarimeter at National Institute of Standards and Technology)
Preaching to the Choir

Applications for space polarimetry & ELTs, Solar System and beyond

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- Non-thermal processes across EM spectrum
  - Etc.
  - Biosignatures

Challenges to precision polarimetry in space

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Precision photometry with HST spreads the light out to acquire the photons (1.5% transit shown)
IMPS: a compact and robust approach to spectropolarimetry

  - full Stokes spectropolarimetry on a single two-dimensional data frame

- Time or relative motion; no concern, rapid or slow, complete information on a single data frame

- Multiwavelength; polarization optics effective from the FUV to mid-IR.

- Compact, no moving parts, robust. Fits within ~2U or smallsat
  
  extremely well-suited to space application

- Practical instrumentation

  IMPS @ University of Florida (cubesat/smallsat – lead: Prof. C. Telesco)
  
  Integrated Miniature Polarimeter and Spectrograph

  UVMAG/Arago @ Meudon; ESA; (P.I., C. Neiner; see also Martin Pertenais talk)
Implementation: configuration options

Combine retardance gradient along slit with polarization analyzer downstream

Simulations: Q, U, V versus wavelength, red to the right.

Stokes parameters are coefficients of orthogonal polynomials, perpendicular to spectrum
Laboratory validation

Combine retardance gradient along slit with polarization analyzer downstream

Preferred: full Stokes dual beam version, all crystal optics. Birefringent FUV to MIR.

Proof of concept laboratory full Stokes spectropolarimetry
Laboratory validation: example results

Green glass filter, face-on, and tilted by \( \approx 30^\circ \). Derived polarization of 6.2; theoretical value 6.3%.

Full Stokes spectropolarimetry noise level \( \sim 10^{-3} \)

Left and right “eyes” of a pair of 3D cinema glasses.
Ongoing projects IMPS
Integrated Miniature Polarimeter and Spectrograph

- IMPS breadboard at U Fl; first prototype basic functionality completed; next generation prototype funded by STScI for construction at U Fl underway – rigorously test optical performance & tweak design; subsequent prototypes for TRL

Multiple design options:
- Compact; no moving parts
- Suitable for smallsat or cubesat

- Analysis/retrieval methods
Application of circular polarization as a biosignature

Wouldn’t it be cool to get circular polarization spectroscopy at Europa?

- Probably the current best astrobiological target in the Solar System
- NASA’s Europa Multiple Fly-by Mission recently approved flagship 2020s

- **Target** plumes, base of plumes
- **Target** upwelling from ocean below, cracks, puncture wounds
CHARACTERISTICS OF INSTRUMENTATION

• **Rapid** – All polarization information on a *single data frame*.
  - Rapid or time averaged as needed
  - No issues with time dependence of source, relative motion of source and instrument, nor limitations from assimilation of sequentially acquired data

• **Robust** – *no moving parts*
  - No complex electronics for demodulation
  - No mechanisms for rotating optics

• **Compact & lightweight**
  - A standard 2D spectrograph with a small additional foreoptic and polarization analyzer (e.g. Wollaston prism)

• **Sensitive**
  - The large numbers of photons needed for precision polarimetry are available since data spread over multiple CCD pixels

• **Multiwavelength**
  - FUV, NUV, optical, NIR, MIR depending on choice of birefringent material
  - Spectroscopy and polarimetry optimized independently

• **Full Stokes polarimetry**
  - Provides complete Stokes vector \((I,Q,U,V)\) as a function of wavelength, or just linear if desired \((I,Q,U)\)
  - Includes Stokes \(I\), hence standard spectroscopic diagnostics

*Practical instrumentation under development with view to space application*
Controls: sulphur, iron oxide: no polarization features

Microbes: cyanobacterium *Synechococcus* WH8101 (Sparks et al 2009); *Chloroflexus aurantiacus* (in prep): polarization signature correlates with spectral features

Constituent molecules: polarization correlates with spectral features in UV

Null results for mineral controls

Circular polarization correlates with absorption in biological samples