IMPS: A compact and robust approach to spectropolarimetry

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The Future of Polarimetry
Brussels, September 2015

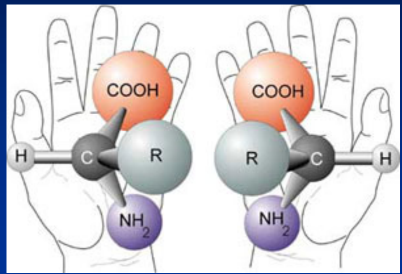
Preaching to the Choir

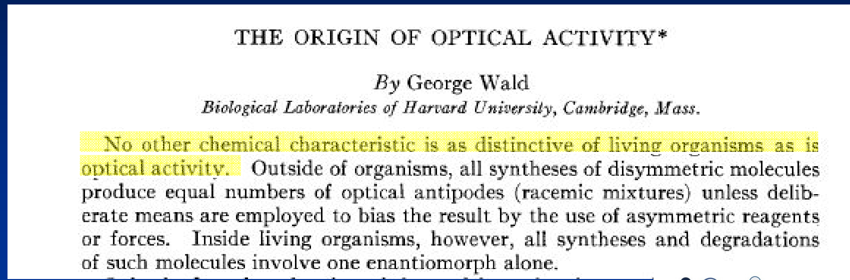
- Applications for space polarimetry: Solar System and beyond
    - Phase angle, resolution, wavelength range; telescopic, robotic / remote sensing, in-situ
  - Aerosols
  - Scattering surfaces
  - Dust – composition and texture
  - Extrasolar planets – detection, characterization
  - Stellar and Galactic 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



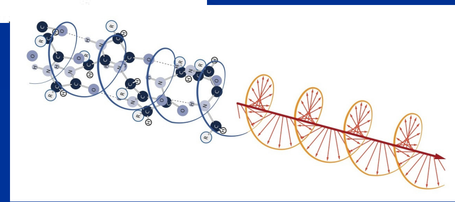


THE ORIGIN OF OPTICAL ACTIVITY*

By George Wald

Biological Laboratories of Harvard University, Cambridge, Mass.

No other chemical characteristic is as distinctive of living organisms as is optical activity. Outside of organisms, all syntheses of disymmetric molecules produce equal numbers of optical antipodes (racemic mixtures) unless delib-erate means are employed to bias the result by the use of asymmetric reagents or forces. Inside living organisms, however, all syntheses and degradations of such molecules involve one enantiomorph alone.



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 archea, bacteria, eukaryotes and even viruses, encode left handed amino acids into proteins and right handed sugars into multiple biopolymers including DNA and RNA

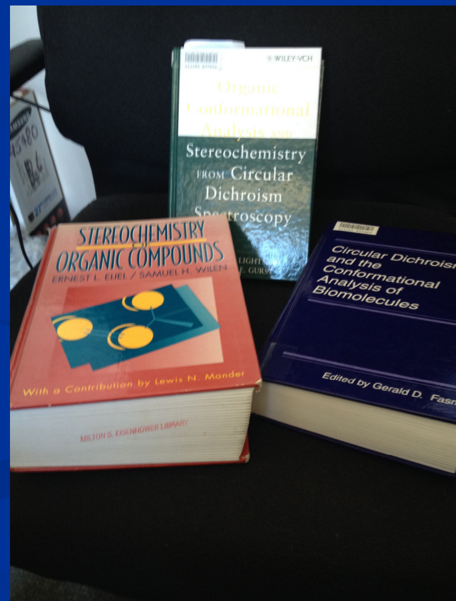
Likely ***generic to all biochemical life*** as consequence of self-replication, relaxes terrestrial assumptions

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)

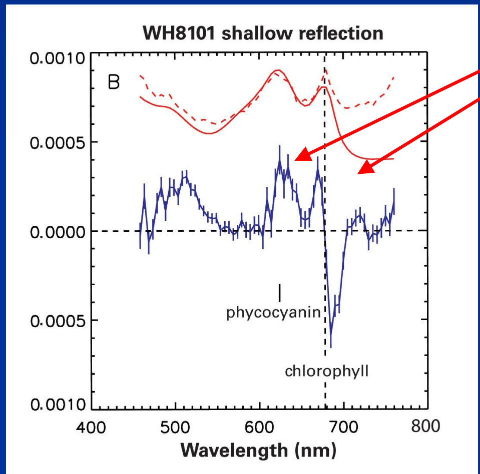
Circular polarization spectra permit derivation of protein structure; for our purposes sufficient that biomolecules produce circular polarization features.

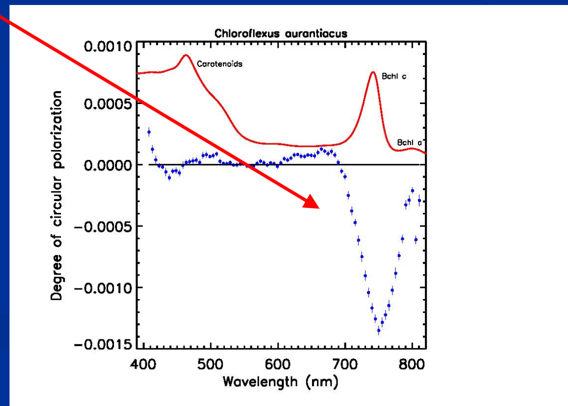


Circular polarization spectroscopy may be used to infer the presence of chiral molecules on a macroscopic scale, thus providing a pure biosignature

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)

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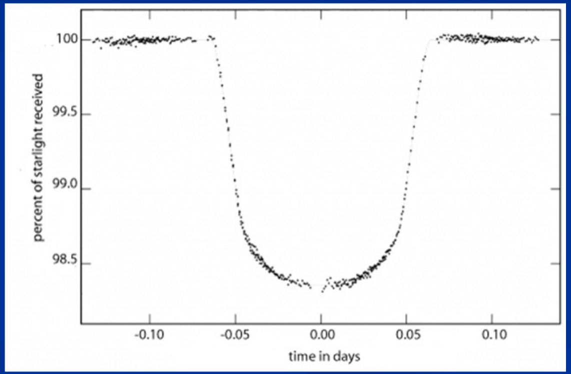

Precision photometry with HST spreads the light out to acquire the photons (1.5% transit shown)
Brown et al 2001 ApJ 552, 699-709

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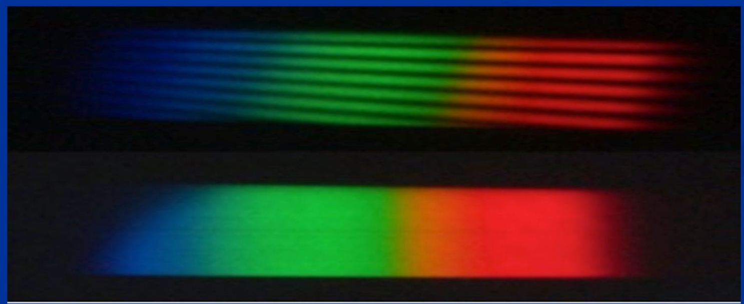
IMPS: a compact and robust approach to spectropolarimetry

- Sparks, Germer, MacKenty & Snik (2012) Applied Optics, http://arxiv.org/abs/1206.7106
  - 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***

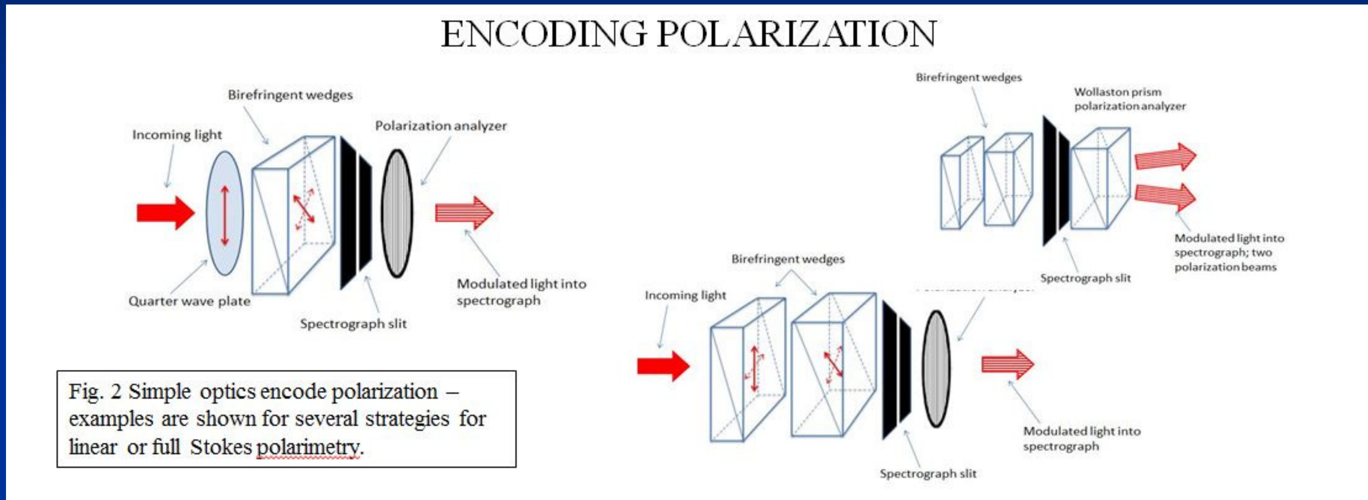
  IMPS @ University of Florida (cubesat/smallsat – lead: Prof. C. Telesco)

  Integrated Miniature Polarimeter and Spectrograph

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

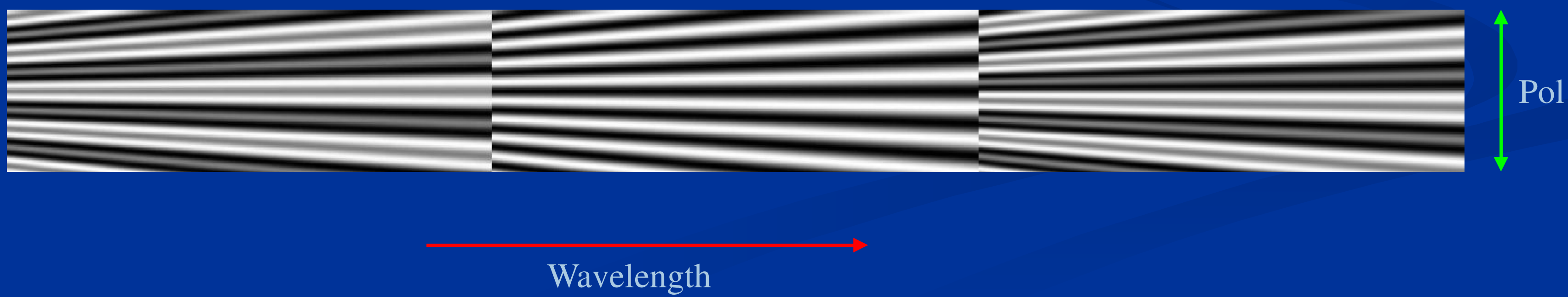
Implementation: configuration options

Combine retardance gradient along slit with polarization analyzer downstream



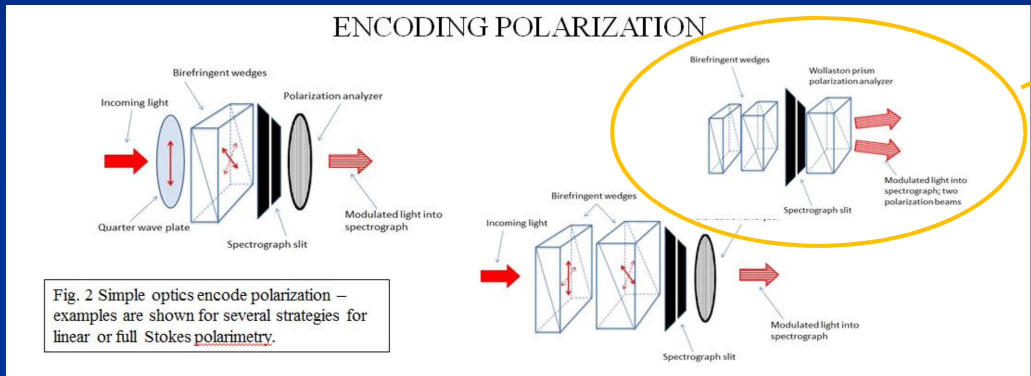
Simulations: Q, U, V versus wavelength, red to the right.

Stokes parameters are coefficients of orthogonal polynomials, perpendicular to spectrum

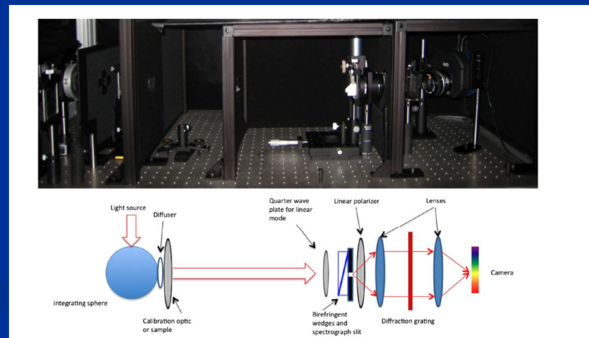


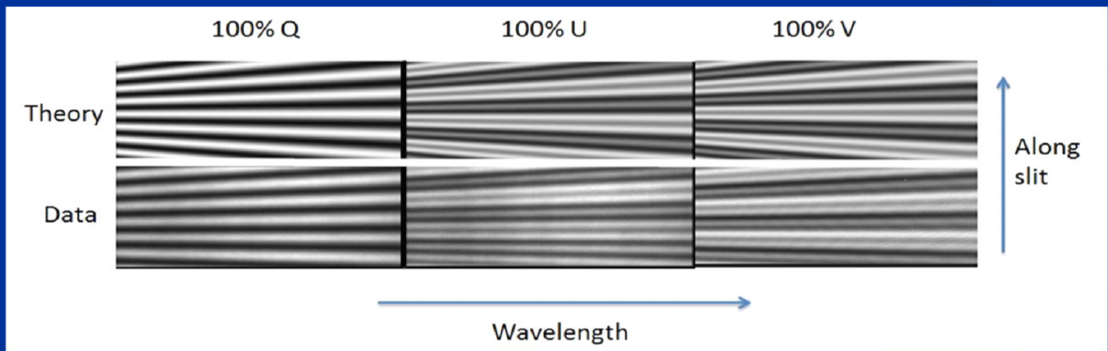
Laboratory validation

Combine retardance gradient along slit with polarization analyzer downstream



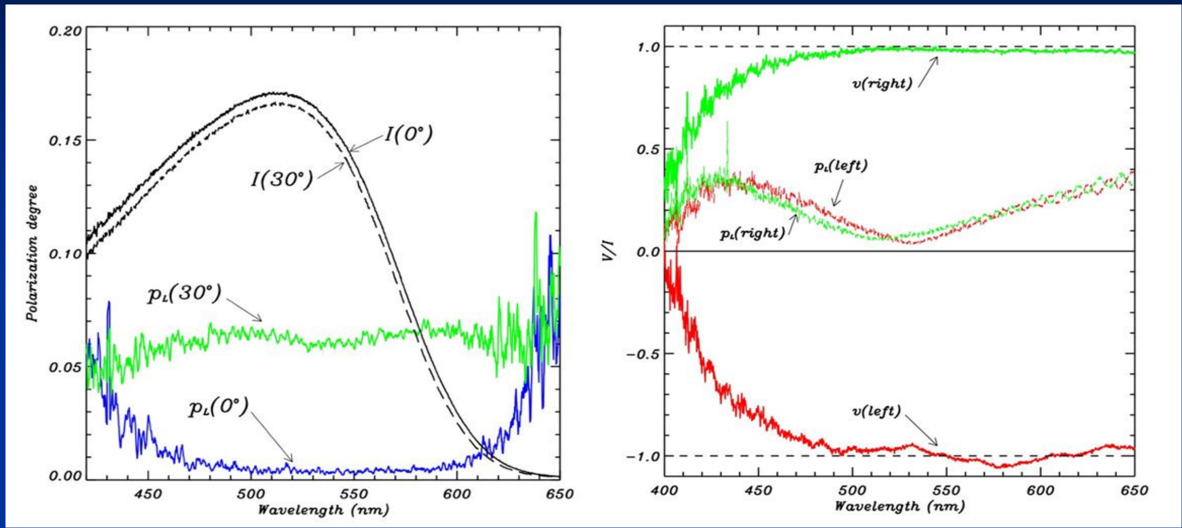
Preferred: full Stokes dual beam version, all crystal optics. Birefringent FUV to MIR.





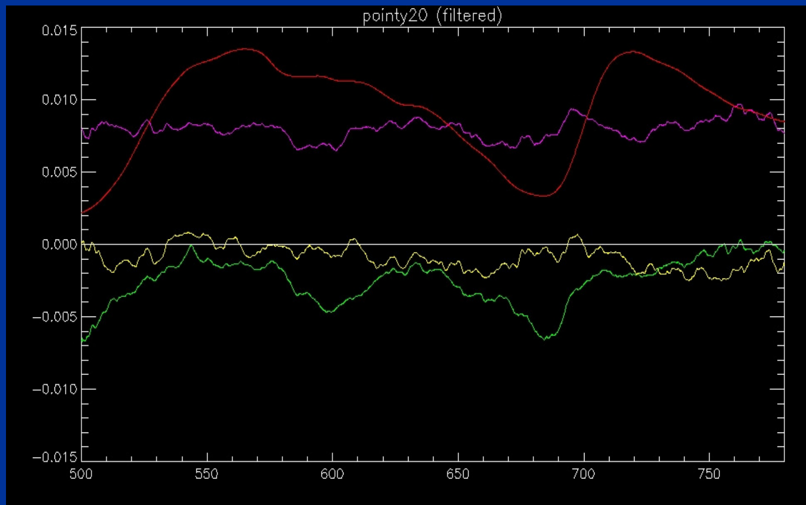
Proof of concept laboratory full Stokes spectropolarimetry

Laboratory validation: example results



Left and right "eyes" of a pair of 3D cinema glasses.

Green glass filter, face-on, and tilted by ≈30^0. Derived polarization of 6.2; theoretical value 6.3%



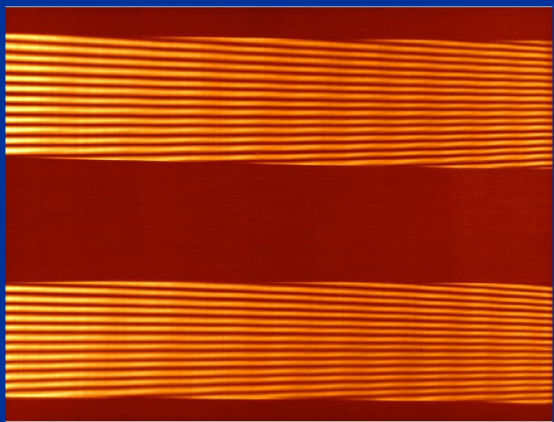
Full Stokes spectropolarimetry noise level ~10^{-3}

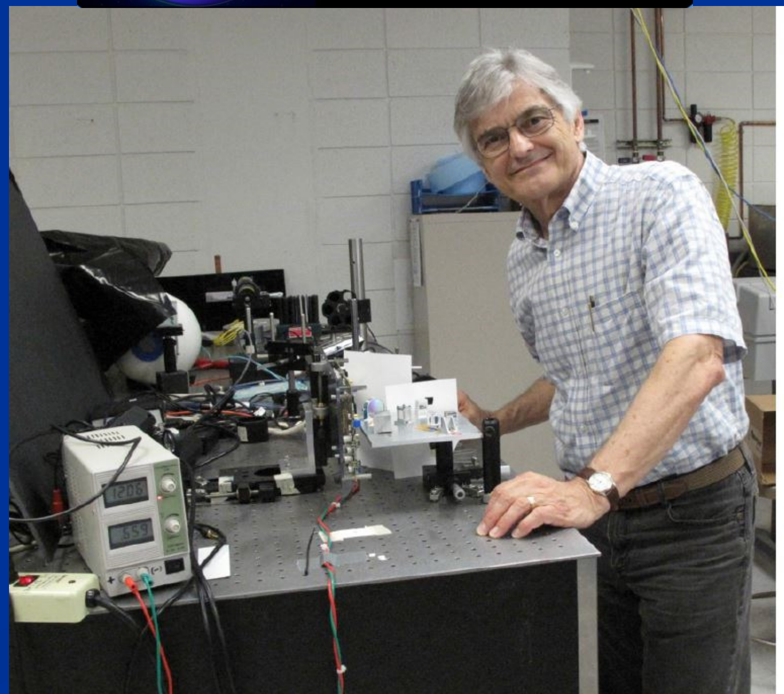
Ongoing projects IMPS

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

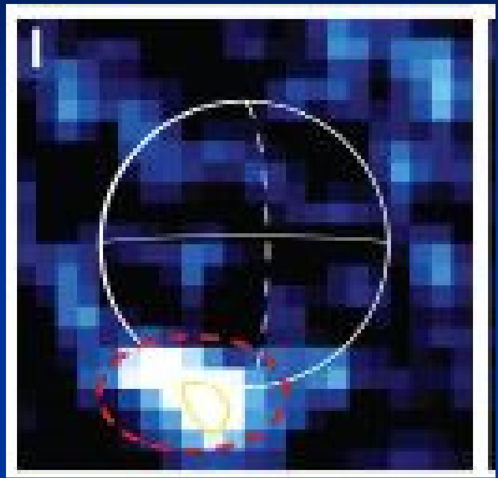
Multiple design options:
Compact; no moving parts
Suitable for smallsat or cubesat

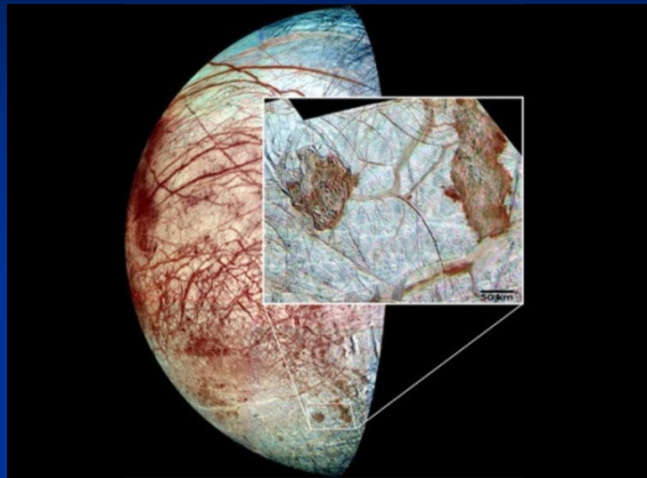




- Analysis/retrieval methods

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*** – ***<u>no moving parts</u>***
  - 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

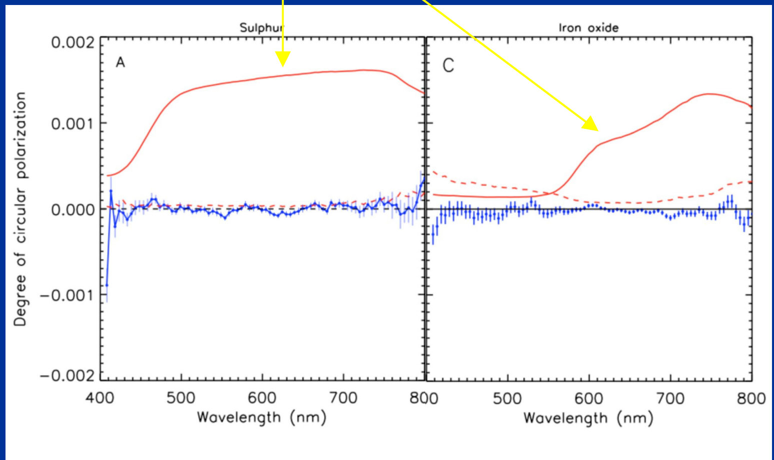
Practical instrumentation under development with view to space application

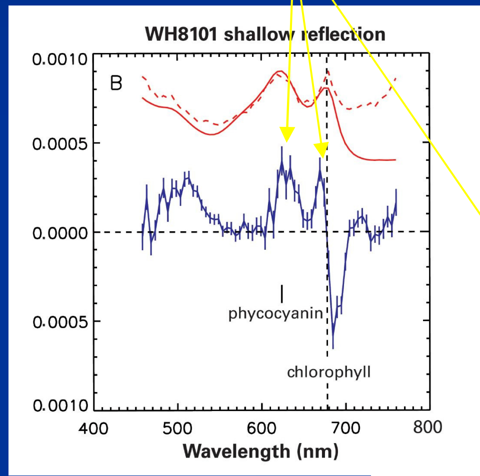
BACKUP

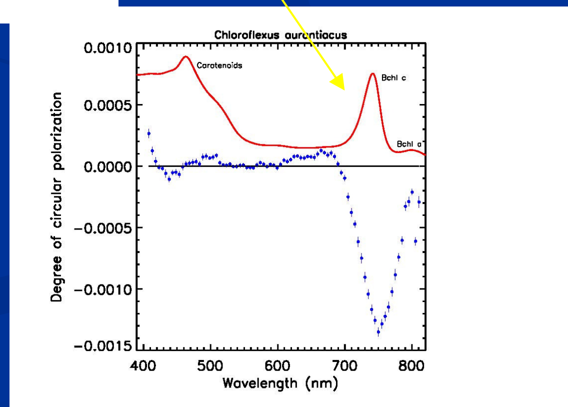
Controls, microbes and molecules

Null results for mineral controls

Circular polarization correlates with absorption in biological samples







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