Polarimetry of AGB star Envelopes

Unique information from optical to sub-mm – some aspects

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Why Polarimetry?

- Polarization provides unique information about magnetic fields, radiation fields, grain sizes and mineralogy, etc.
- With the development and testing of RAT theory we now have a quantitative, predictive paradigm under which to interpret the observations, in terms of physical parameters.

Polarization of Background Starlight

\[ \lambda \sim \text{UV - NIR} \]

Polarization of Thermal Radiation

\[ \lambda \sim \text{FIR - MM} \]

Diagrams after A. Goodman: http://cfa-www.harvard.edu/~agoodman/ppiv/
RAT Alignment in a nut shell

- Alignment
  - Internal
  - External
- Driven by radiative torques
- Paramagnetic grains
- B-RAT vs. k-RAT
- Super-paramagnetic inclusions
- RAT-D, etc.
If the radiation field is strong enough (and strongly anisotropic), RAT predicts that the reference direction for alignment should change from the magnetic field (B-RAT) to the radiation field direction (k-RAT). But, again, for this to be efficient the grains must be paramagnetic.
Are Carbon Grains Aligned?

- Radiative spin-up does not depend on grain mineralogy
  - RAT torques are effective (Abbas et al. 2004)
- Both internal and external alignment relies on the Barnett effect – active in *paramagnetic* materials (Silicates)
- The 9.7$\mu$m Silicate feature is strongly polarized
- Carbon grains are diamagnetic – do not have this effect
- The 3.4$\mu$m aliphatic CH feature does not show polarization.
- However, we may be “trying to hear a string quartet over a heavy metal band” in ISM studies
Why AGB star Envelopes?

- In the interstellar medium different dust mineralogical components are mixed
- In AGB stars the chemistry/dust mineralogy is “cleanly” separated into Oxygen or Carbon dominated
- The radiation field is well characterized
- The most near-by AGB stars are bright and well studied at many wavelengths and tracers.
  - The circumstellar envelopes (CSE) can be resolved
- Carbon-rich AGB CSE provide an ideal laboratory for studying carbon grain alignment.
- Oxygen rich AGB CSE provide the “placebo”
The case of IRC+10°216 - FIR

- SOFIA polarimetry shows a centro-symmetric polarization where the polarization fraction is proportional to $T_{\text{dust}}$
- Mechanical (Gold) alignment is not expected to follow this dependence
- Theory predicts MET alignment (azimuthal) to be much stronger than Gold alignment

Andersson et al. 2022a, submitted
The case of IRC+10°216 – Alignment Mechanism

• Grains without internal alignment can be weakly aligned by intense radiation fields, in two directions, relative to the k-vector (Hoang & Lazarian 2008)

• The supersonic AGB star gas-dust drift then preferentially disaligns the “perpendicular” grains
  – Agrees with FIR polarization geometry
  – Agrees with $p_{\text{FIR}} \propto T_{\text{dust}}$
  – Predicts a small polarization fraction
The case of IRC+10°216 - Optical

- Optical polarization also show grains aligned with their long axis in the radial direction
  - With one exception

- From Stokes I spectra the stars can be classified, allowing accurate extinctions
  - For the IRC+10°216 CSE:
    \[ p/A_V < 1 \%/\text{mag} \]

R: FIR  
G: H I  
B: UV  
W: R  
Y: Pol

Andersson et al. 2022c, in prep.

Jeffers et al. 2014 (pol: 0.5-0.9\(\mu\)m)
The case of IK Tau – Oxygen rich

Consistent with a projected dipole pattern.
For the IK Tau CSE: $p/A \approx 3.1 \text{ %/mag (} \approx \text{ISM)}$
AGB stars provide ideal laboratories for understanding the effects of mineralogy on grain alignment.

There are C-, O – and S-type CSEs that are resolved by (e.g.) IRAM, JCMT, SOFIA, etc.

Multi-wavelength data provide complementary information.

Large telescope with polarimeters allow mapping of background-star (UV/O/NIR) spectro-polarimetry.
The case of IRC+10°216

- Optical spectro-polarimetry can constrain the grain size distribution, given the SED of the central star and the RAT alignment condition of $\lambda < d$

- Large $\lambda_{\text{max}}$ and $K^*$ parameters indicate large grains with a narrow size distribution

*Poorly determined, but much bigger than the ISM value of 1.15
The case of IRC+10°216 – Sub-mm wave

- 850mm polarimetry does not show a radial geometry
- Can be fitted by a projected dipole pattern
- Iron is heavily depleted in the CSE.
- The “magnetic” pol. geometry may be because the largest grains have acquired “super-paramagnetic inclusions” of FeC$_3$ etc.
The case of IRC+10°216

Our Galactic Ecosystem - B-G Andersson

Multi-Wavelength Polarimetry

Optical

FIR