Polarimetry of AGB star Envelopes

Unique information from optical to sub-mm – some aspects

B-G Andersson

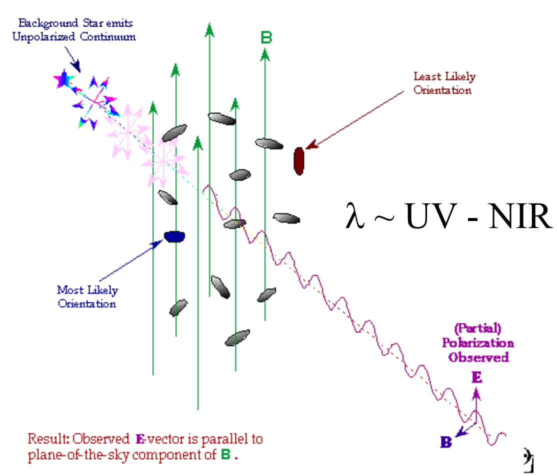
SOFIA Science Center, USRA

With: Archana Soam, Janik Karoly, Simon Coudé, Pierre Bastien, Mehrnoosh Tahani, Andrei Berdyugin, Sydney Fox-Middleton, Christer Sandin, Alex Lazarian, Thiem Hoang etc.

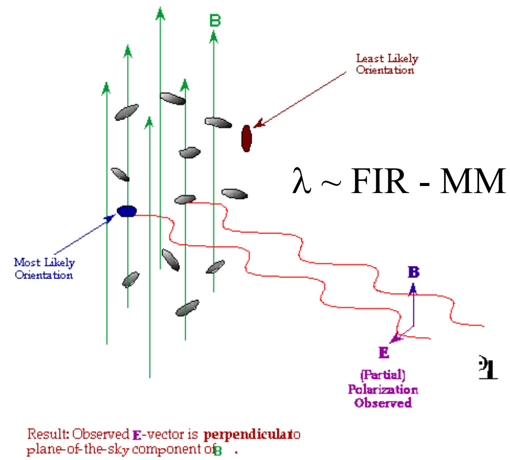
Why Polarimetry?

- 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



Polarization of Thermal Radiation

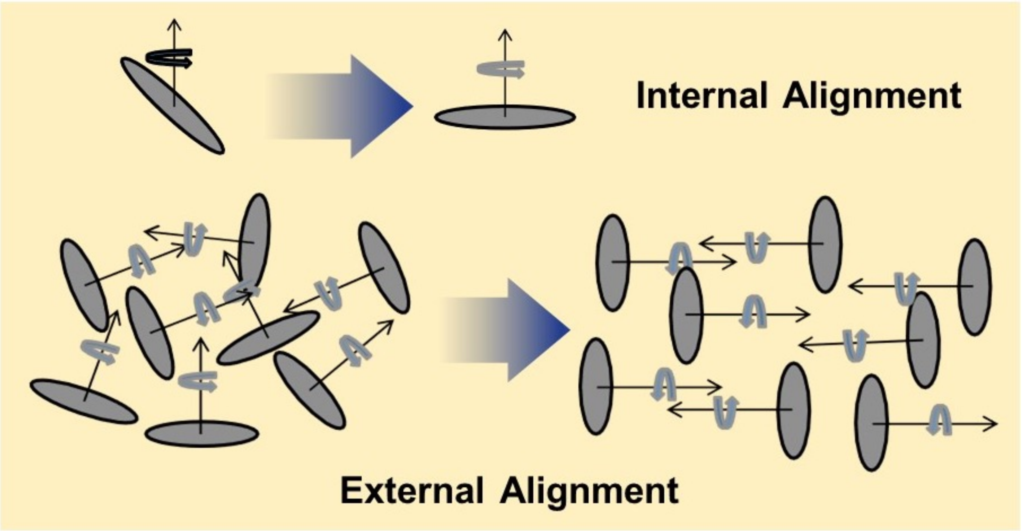


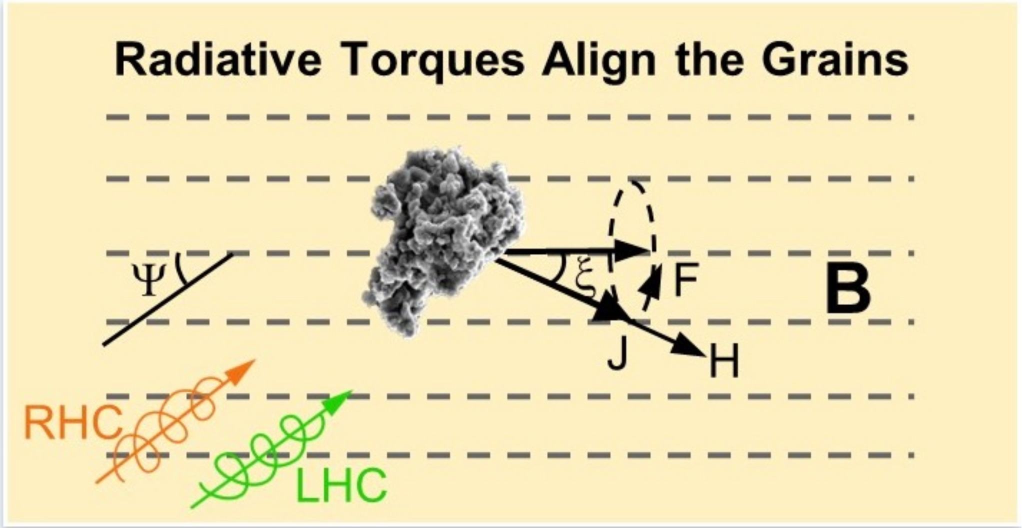
Diagrams after A. Goodman: http://cfa-www.harvard.edu/~agoodman/ppiv/

RAT Alignment in a nut shell

RAT Alignment

- Alignment
  - Internal
  - External
- Driven by radiative torques
- **Paramagnetic** grains
- B-RAT vs. k-RAT
- Super-paramagnetic inclusions
- RAT-D, etc.

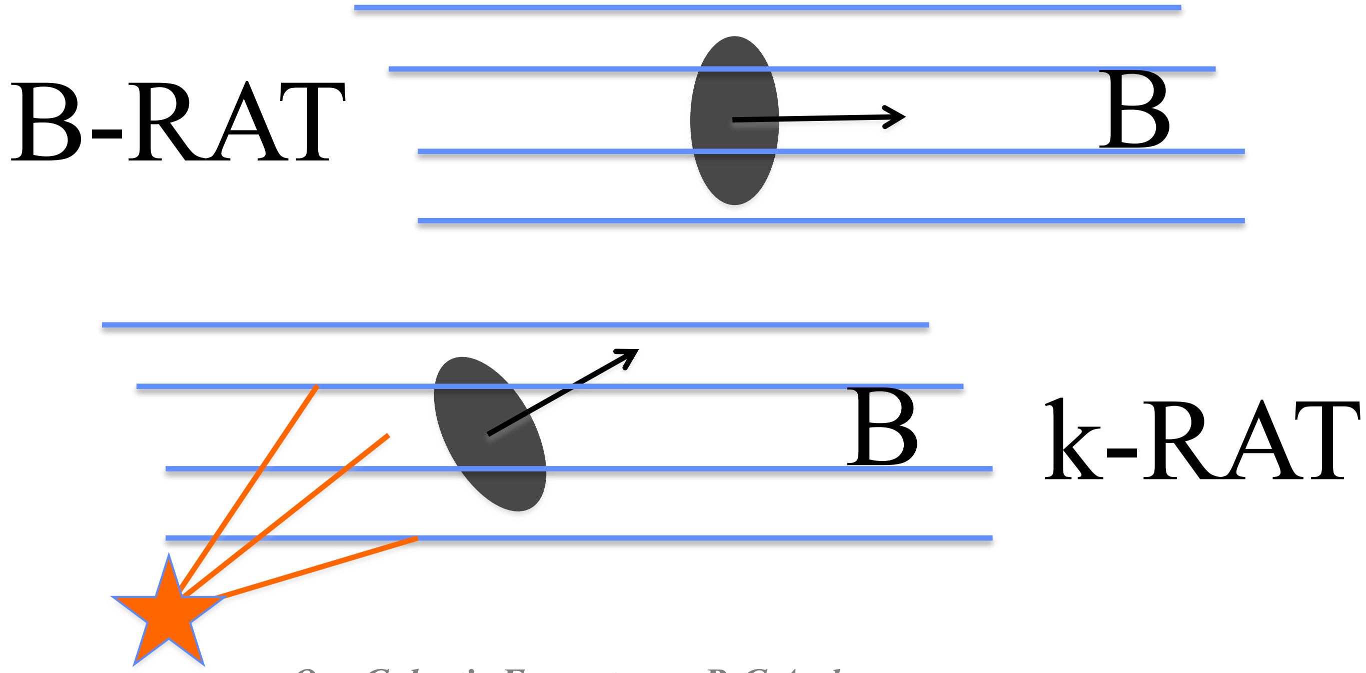




B-RAT vs. k-RAT

RAT Alignment

- If the radiation field is strong enough (and strongly anisotropic), RAT predicts that the reference direction for alignment should change form 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?

Carbon Grain Alignment

- 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 9.7μm Silicate feature is strongly polarized
- Carbon grains are diamagnetic – do not have this effect
- The 3.4μm 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

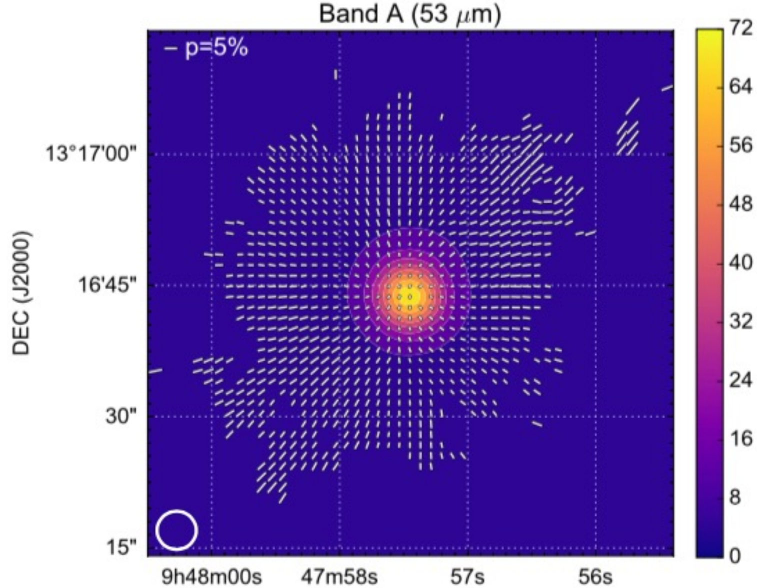
Why AGB star Envelopes?

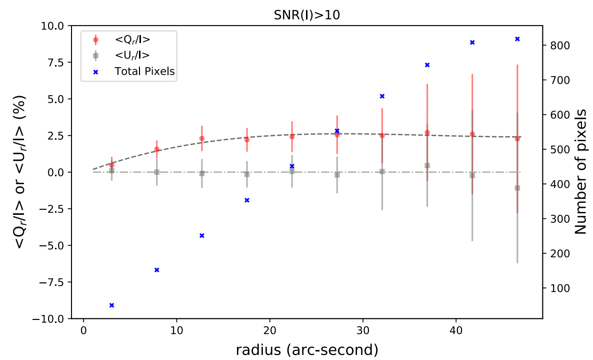
- In the interstellar medium different dust mineralogical components are mixed
- In AGB stars the chemistry/dust mineralogy is "cleanly" separated into Oxygen or Carbon dominated
- The radiation field is well characterized
- The most near-by AGB stars are bright and well studied at many wavelengths and 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"

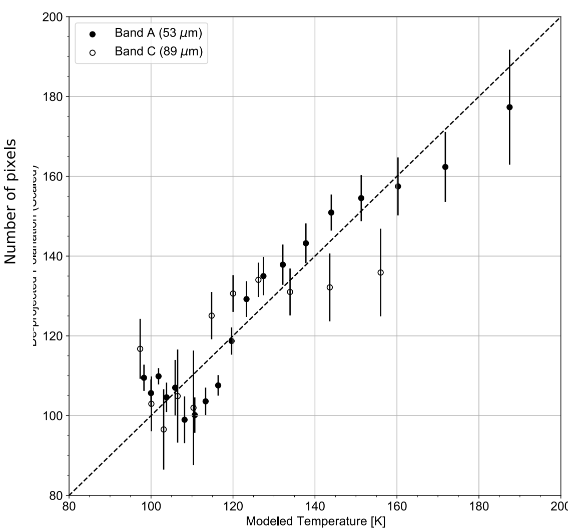
The case of IRC+10˚216 - FIR

Carbon Grain Alignment

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





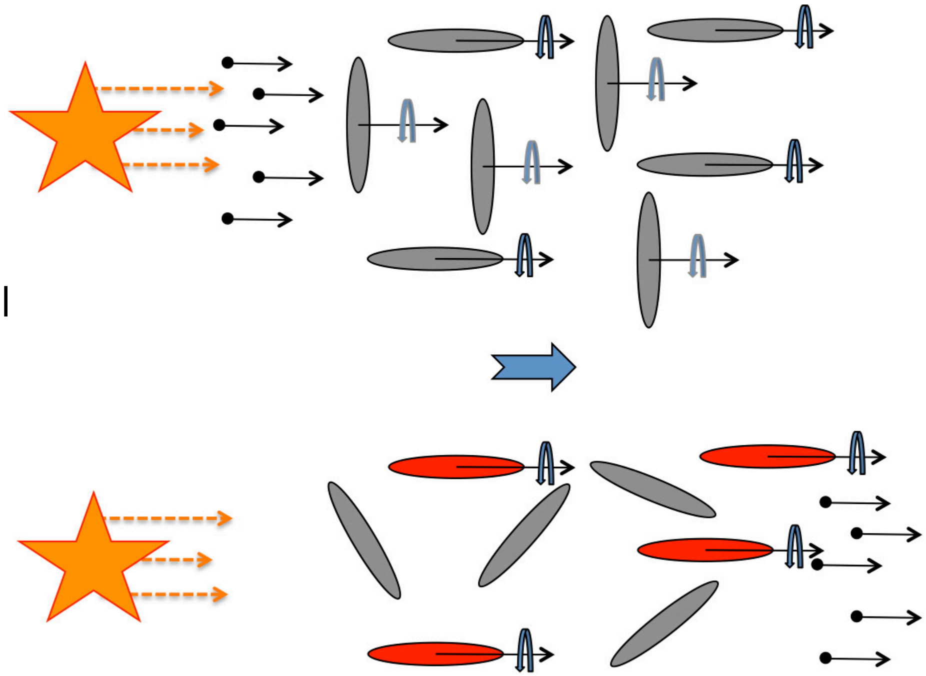


Andersson et al. 2022a, submitted

The case of IRC+10˚216 – Alignment Mechanism

Carbon Grain Alignment

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

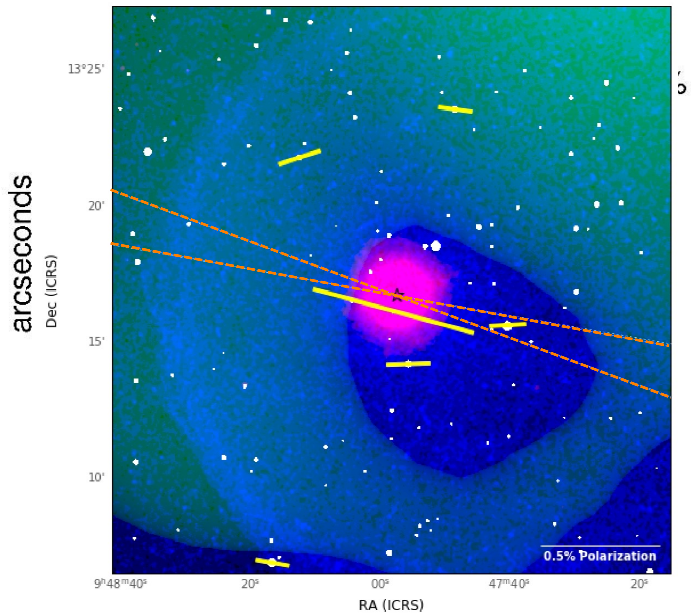


- The supersonic AGB star gas-dust drift then preferentially disaligns the "perpendicular" grains
  - Agrees with FIR polarization geometry
  - Agrees with $p_{FIR} \propto T_{dust}$
  - Predicts a small polarization fraction

The case of IRC+10˚216 - Optical

Carbon Grain Alignment

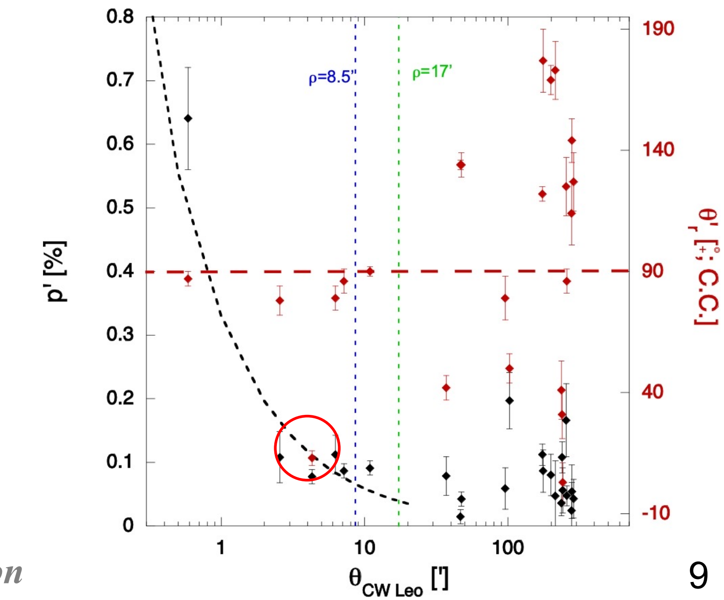
- Optical polarization also show grains aligned with their long axis in the radial direction
  - With one exception
- From Stokes I spectra the stars can be classified, allowing accurate extinctions
  - For the IRC+10˚216 CSE:
    $p/A_V<1$ %/mag



Jeffers et al. 2014
(pol: 0.5-0.9μm)

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

Andersson et al. 2022c, in prep.



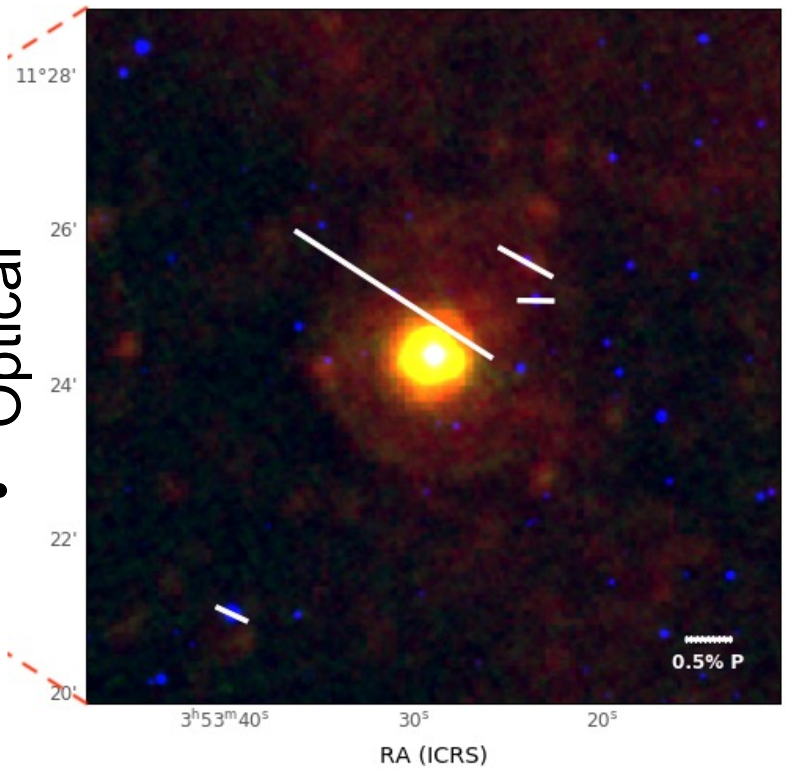
USRA

SOFIA-USRA Polarimetry

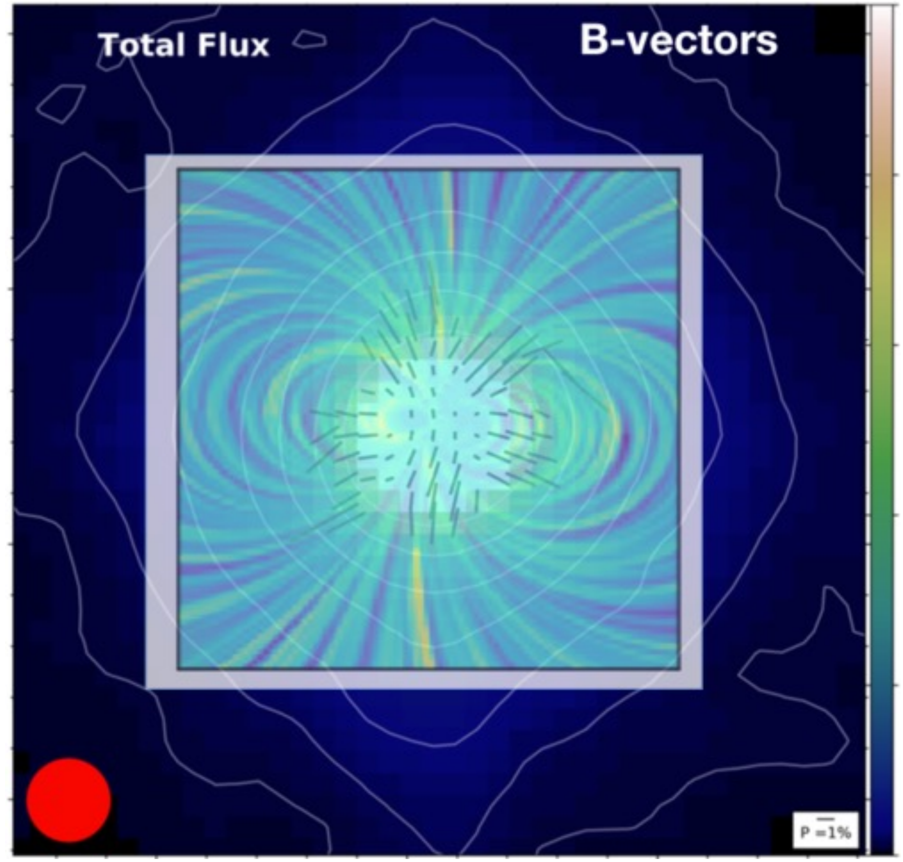
The case of IK Tau – Oxygen rich

Multi-Wavelength Polarimetry

- Optical



- FIR



Consistent with a projected dipole pattern.

For the IK Tau CSE: $p/A_V \approx 3.1$ %/mag (≈ISM)

Summary

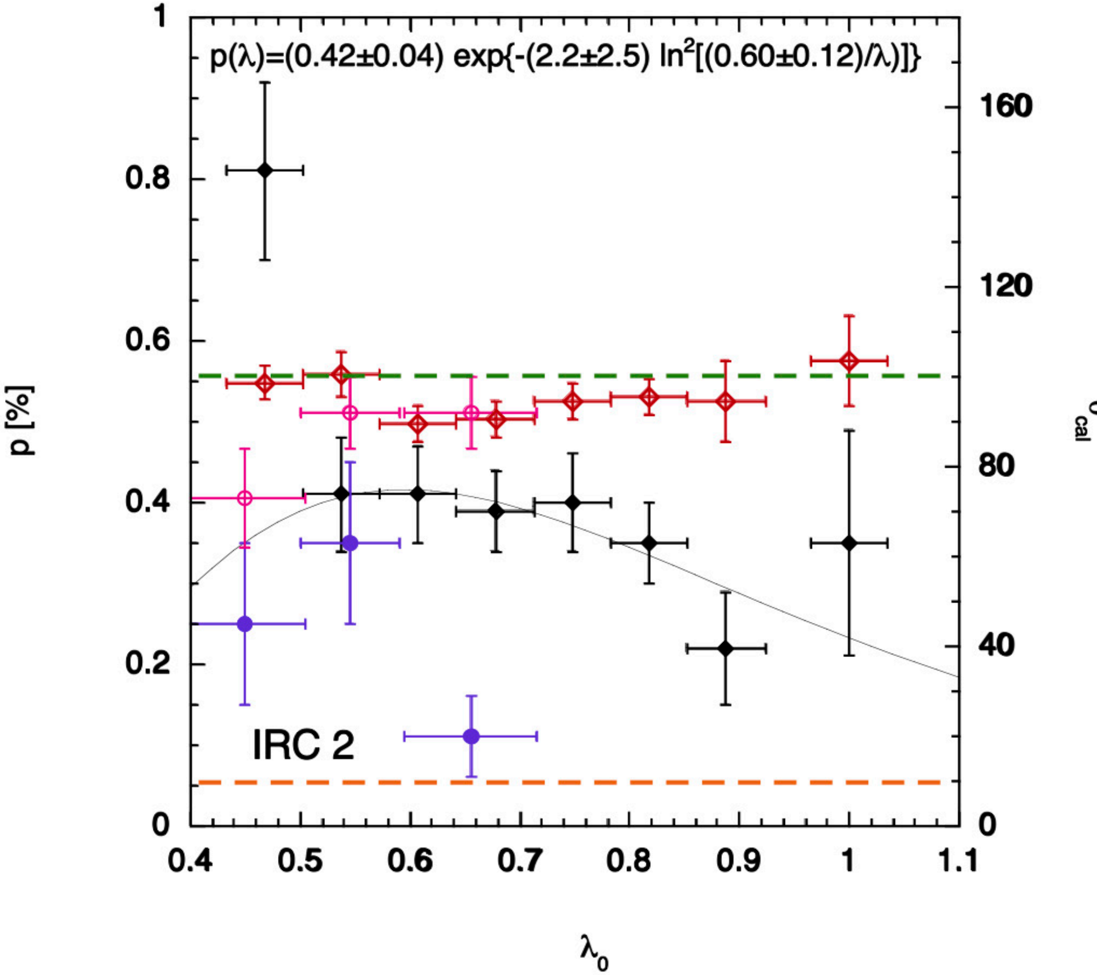
Conclusion

- 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

Multi-Wavelength Polarimetry

- Optical spectro-polarimetry can constrain the grain size distribution, given the SED of the central star and the RAT alignment condition of λ<d
- Large λ_{max} and K* parameters indicate large grains with a narrow size distribution

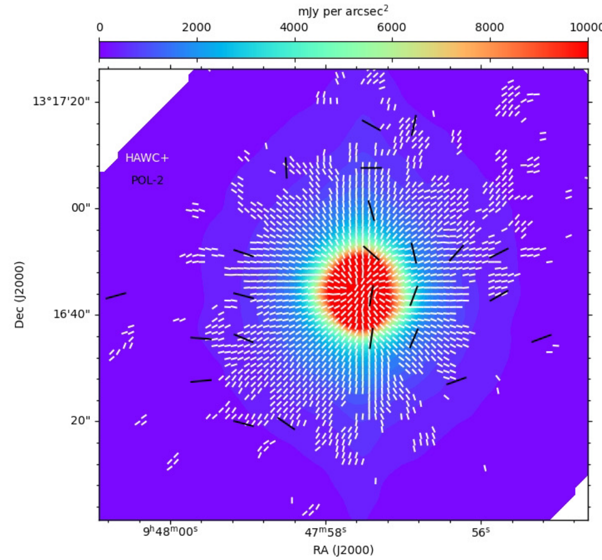


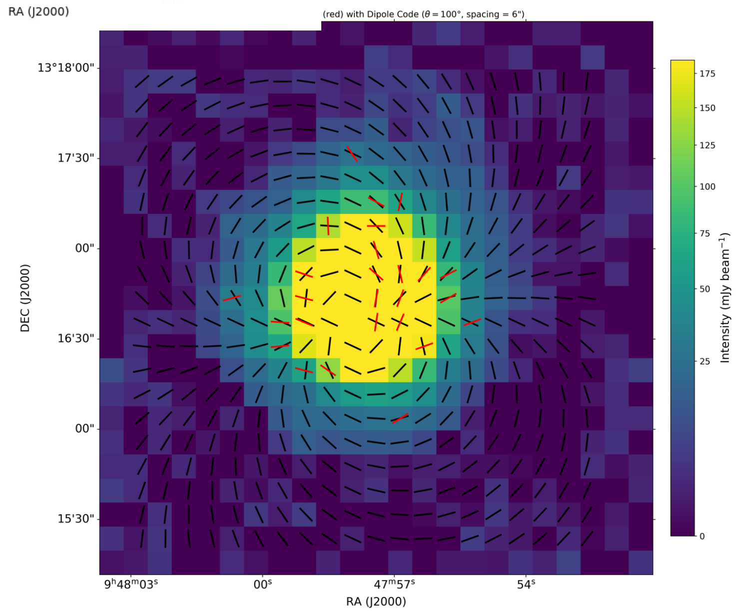
* Poorly determined, but much bigger than the ISM value of 1.15

The case of IRC+10˚216 – Sub-mm wave

Multi-Wavelength Polarimetry

- 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.

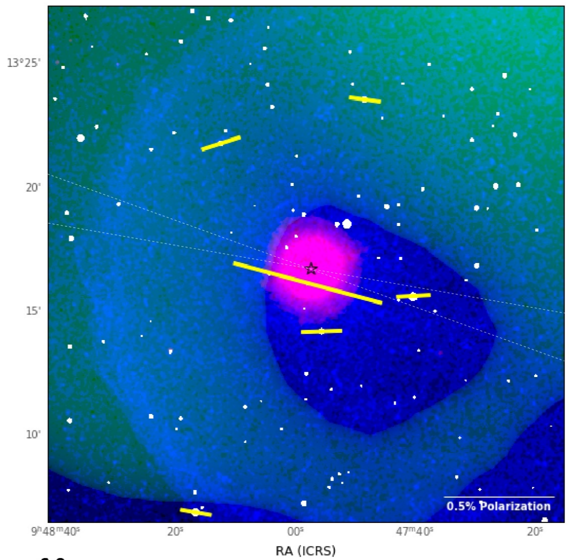


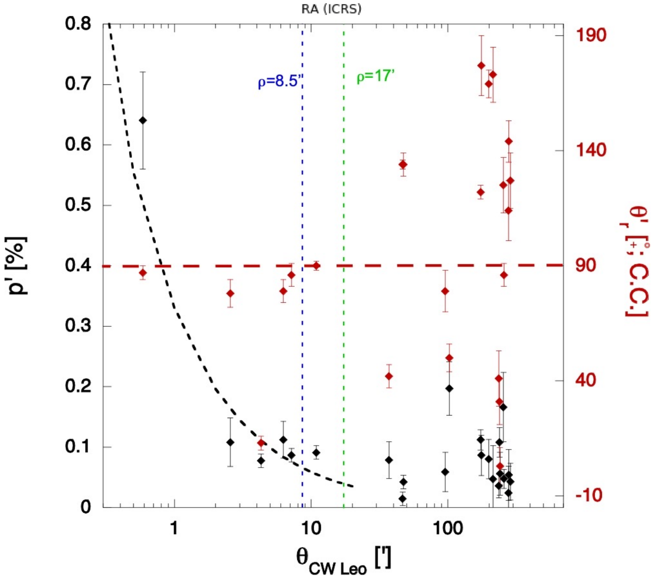


The case of IRC+10˚216

Multi-Wavelength Polarimetry

- Optical





- FIR