Polarimetric modeling of brown dwarf atmospheres

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Outline

1. Motivation
2. Background
3. Modeling studies

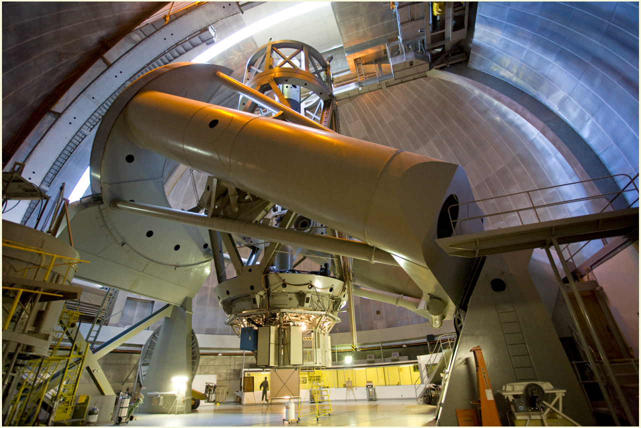
Table of Contents

1 Motivation

2 Background

3 Modeling studies

Need for brown dwarf (BD) modeling



- WIRC+Pol team currently involved in a spectro-polarimetric survey of over 100 BDs and EGPs using 200" Hale telescope on Mt. Palomar

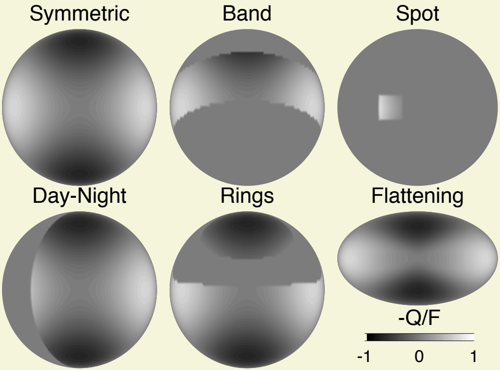
Table of Contents

1 Motivation

2 Background

3 Modeling studies

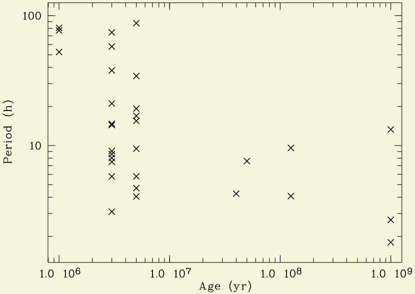
Need for brown dwarf (BD) modeling



(de Kok et al. 2011)

- Polarimetry makes BD measurements sensitive to asymmetric features like oblateness and patchy clouds

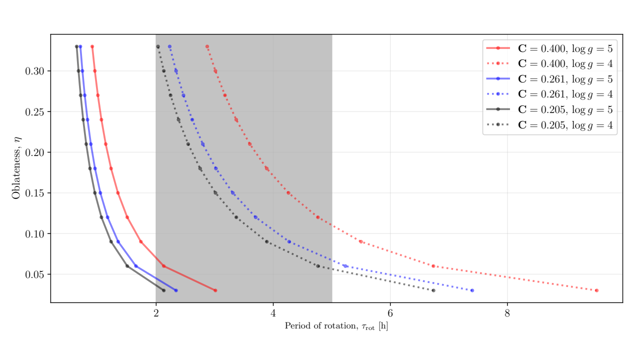
Need for brown dwarf (BD) modeling: oblateness



(Herbst et al., Scholz & Eislöffel 2004)

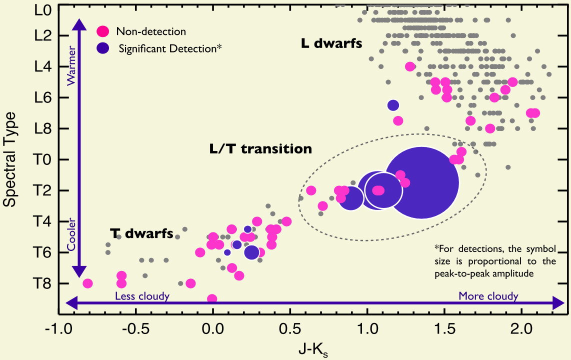
- L-dwarfs (∼2200-1600 K) and T-dwarfs (∼1600-500 K) have undergone radiative cooling with age (∼ 1 Gyr), shrinking to the size of Jupiter.
- Lack of efficient braking mechanisms cause them to conserve momentum by spinning increasingly faster, so that some BDs approach the Roche break-up limit

Need for brown dwarf (BD) modeling: oblateness



- Many brown dwarfs have a period of rotation between 2-5 hrs, covering the full range of oblateness between $\eta = 0 - 0.33$

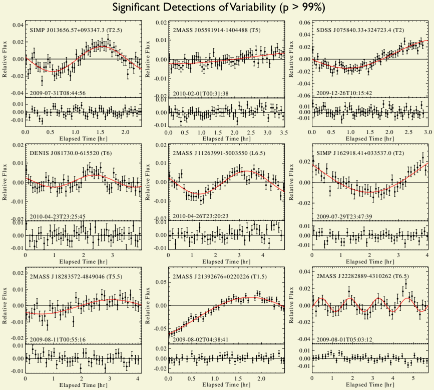
Need for brown dwarf (BD) modeling: patchy clouds



(Radigan et al. 2014)

- Late L- and early T-dwarfs start seeing the fragmentation and precipitation of clouds near the photosphere, revealing deeper layers of the atmosphere

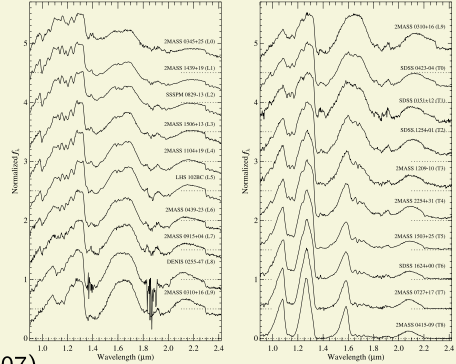
Need for brown dwarf (BD) modeling: patchy clouds



(Radigan et al. 2014)

- High quality observations of photometric variability confirm patchy clouds to be a dominant feature of BDs in L/T-transition

Need for brown dwarf (BD) modeling: patchy clouds



(Burgasser et al. 2007)

- L-dwarfs are only affected by weak absorption due to H_2O in the NIR, while the deeper atmospheric column of T-dwarfs feature strong pressure-broadened alkali lines in the optical, near-saturation CH_4 absorption in the NIR, and H_2 CIA near the K-band.

Table of Contents

1 Motivation

2 Background

3 Modeling studies

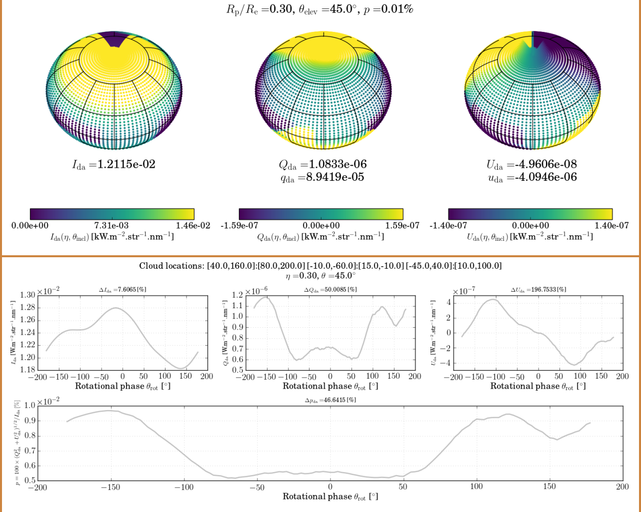
Need of a framework to model oblate BDs with patchy clouds

- Semi-analytical 3D framework based on the 1D polarized RTM vSmartMOM (Sanghavi et al. 2014)
- Fast and accurate modeling of scattering by distributions of spherical cloud grains (Sanghavi 2013, Sanghavi et al. 2015)
- Allows for the first time simultaneous, polarized simulations of oblateness and any number of cloud patches at a given inclination angle

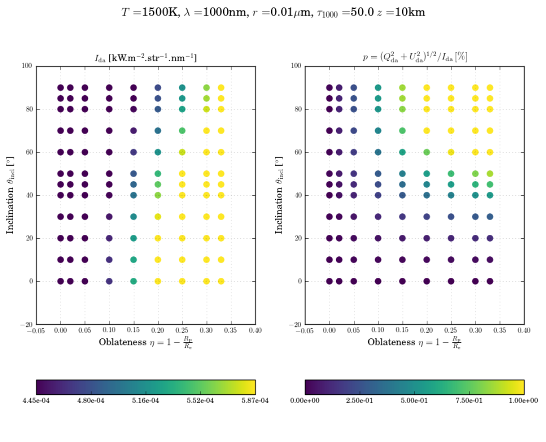
Preliminary assumptions

- For generality, we assume a gray atmosphere, so that the BD emits as a black body of temperature T_{eff}.
- To deal with the spectral variations in photospheric depth due to atmospheric opacities, we currently assume two extreme cases:
  1. A completely non-absorbing atmosphere, for which the photosphere is at the bottom of the atmospheric (gaseous) column (BOA)
  2. An almost completely opaque atmosphere, for which the photosphere is almost at the TOA
- The modeled cloud consists of a log-normal distribution of spherical, Mie-scattering, silicate grains and always occurs above the photosphere

vSmartMOM: first simulations of patchy clouds on oblate BDs (Sanghavi et al., under review, ApJ)

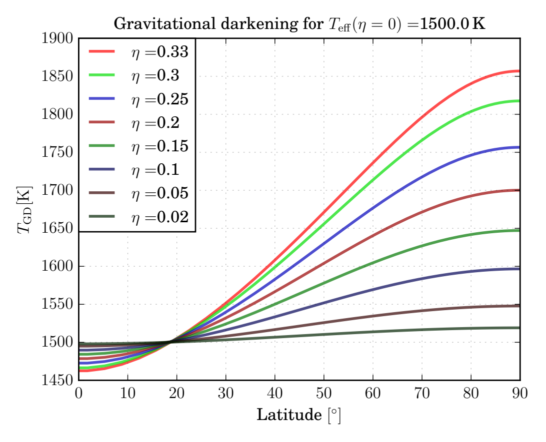


Effect of oblateness and inclination angle

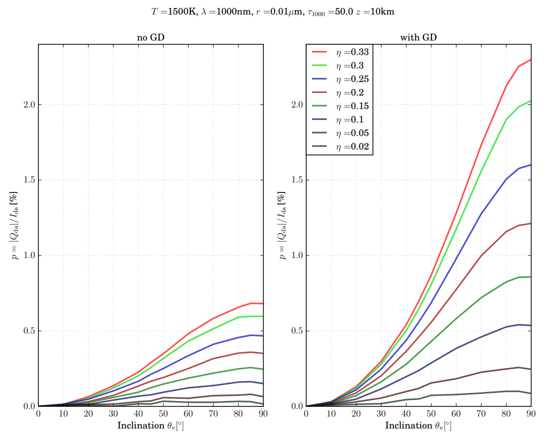


- Both intensity and polarization are functions of obalteness, η, and inclination angle, θ_{incl}

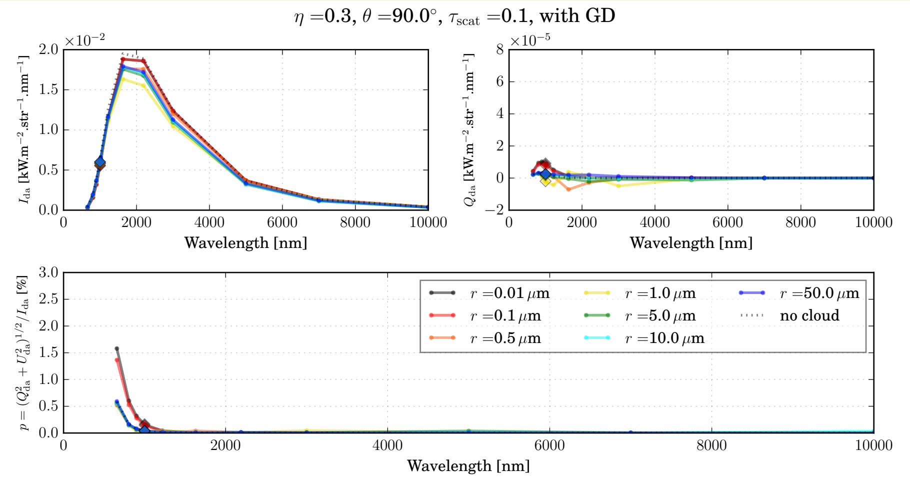
Gravitational darkening



Gravitational darkening



Effects of cloud properties: optical thickness, cloud grain size



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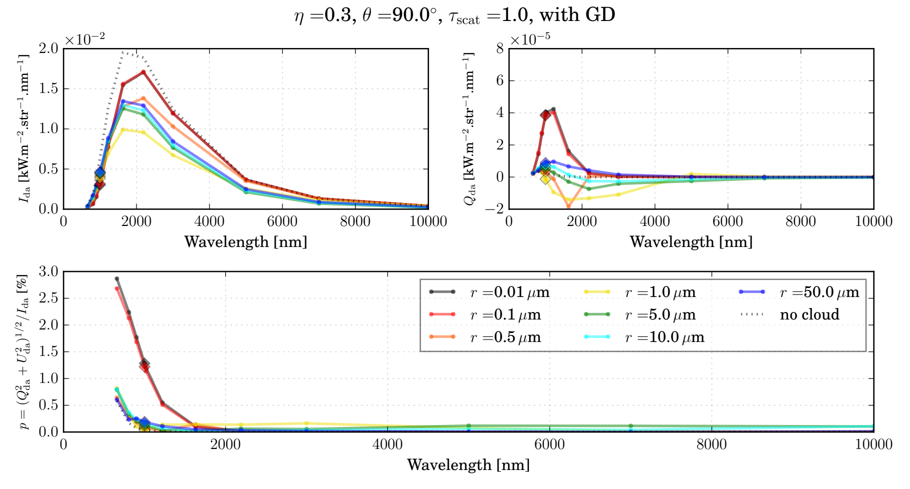
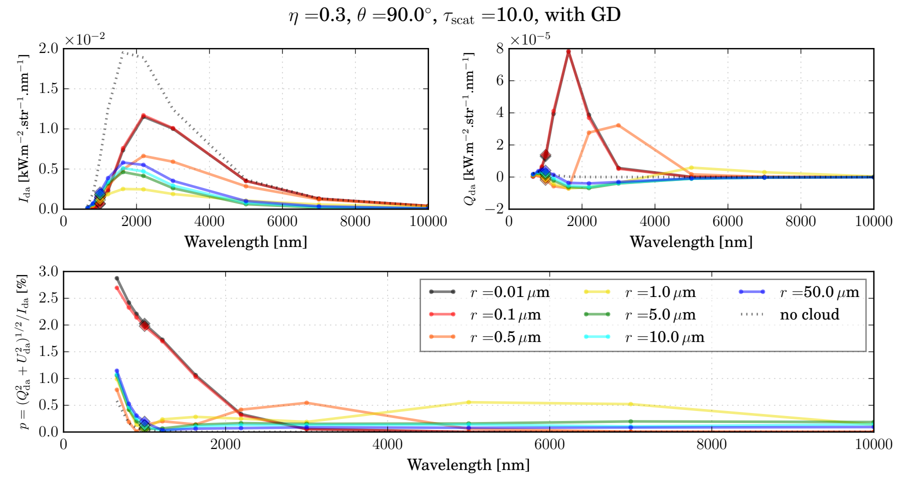
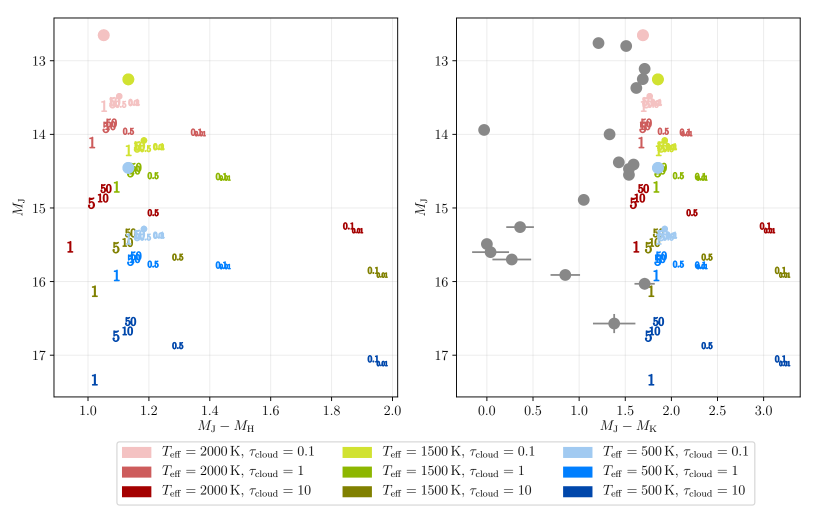


Effects of cloud properties: optical thickness, cloud grain size

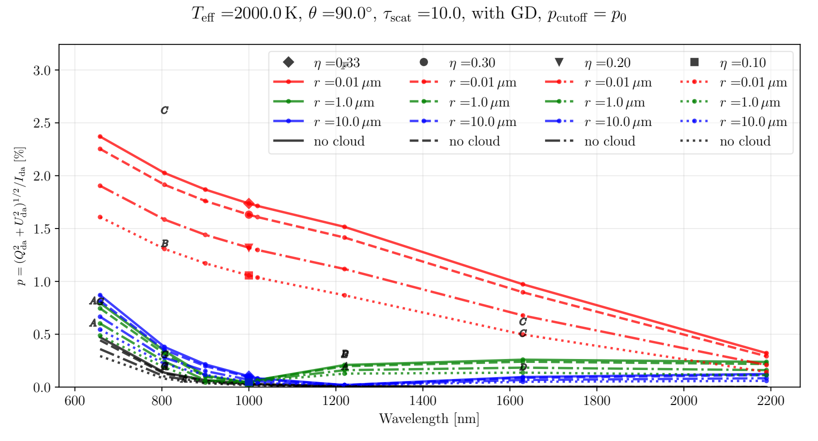


Photometry: Need for detailed consideration of opacity



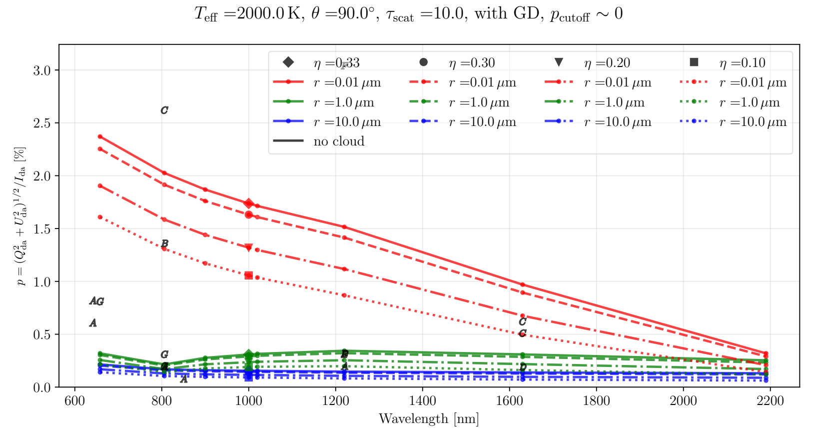
Polarimetry: Effect of clouds

Photosphere at BOA, $T_{\text{eff}} = 2000\,\text{K}$



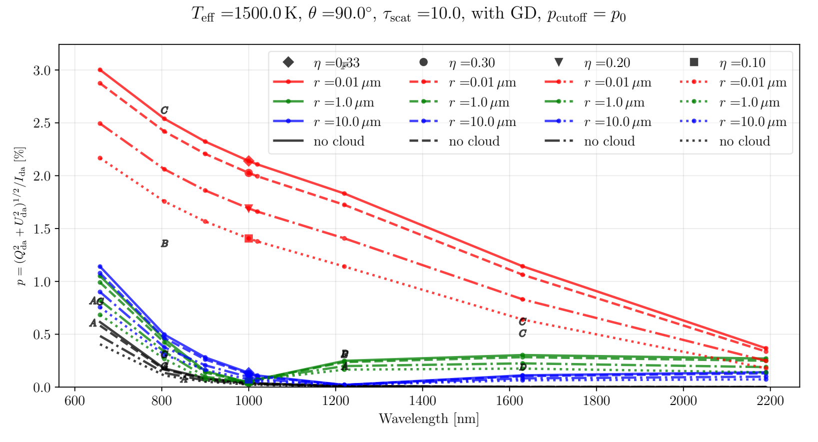
Polarimetry: Effect of clouds

Photosphere at TOA, $T_{\rm eff} = 2000\,$K



Polarimetry: Effect of clouds

Photosphere at BOA, $T_{\rm eff} = 1500\,\mathrm{K}$



Polarimetry: Effect of clouds

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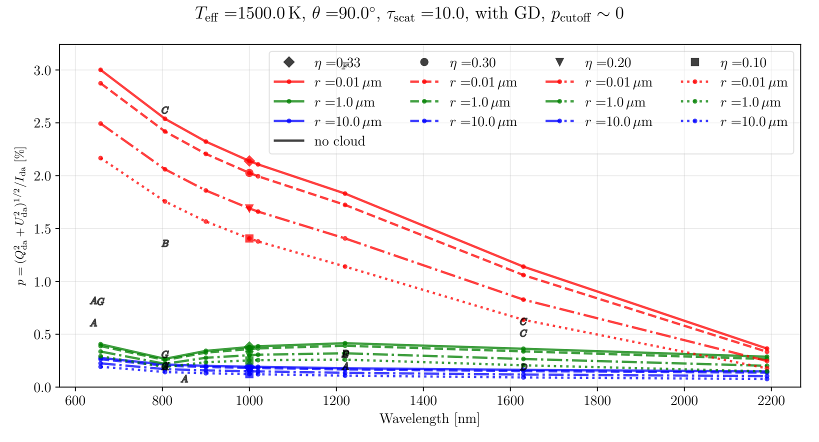
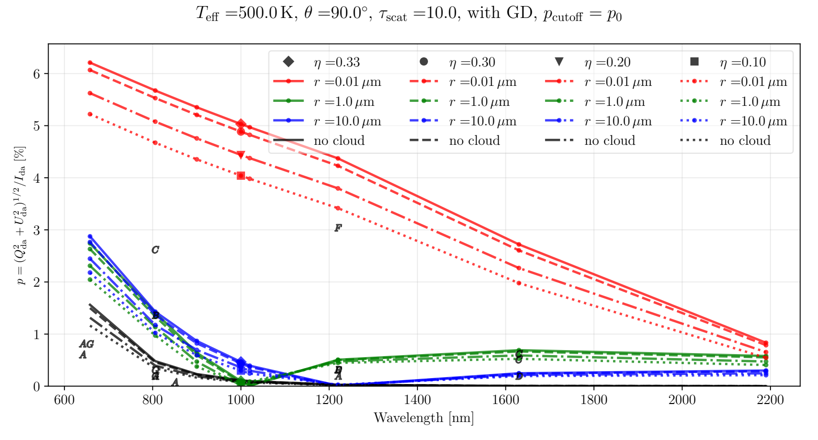


Polarimetry: Effect of clouds

Photosphere at BOA, $T_{\rm eff} = 500\,$K



Polarimetry: Effect of clouds

Photosphere at TOA, $T_{\text{eff}} = 500\,\text{K}$

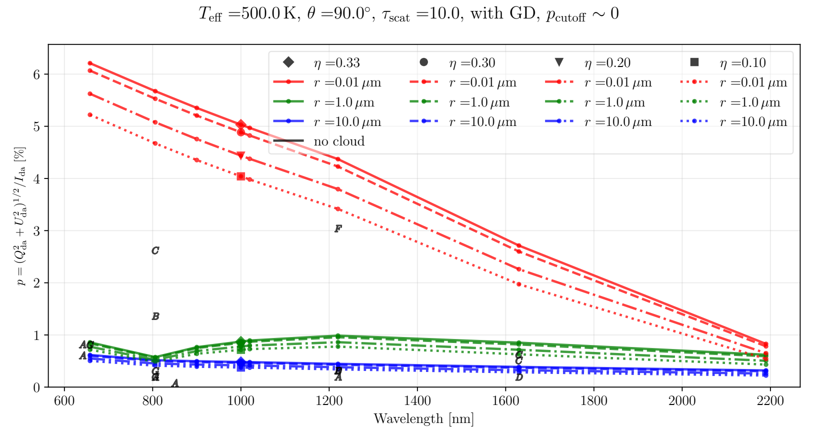


Table of Contents

1. Motivation
2. Background
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Summary

- Gravitational darkening can significantly amplify the polarization due to oblate BDs, allowing for the first time polarimetric measurements of over 2% to be simulated
- DoP increases with increasing oblateness and inclination angle (edge-on viewing is most polarizing)
- Optically thick clouds cause more dimming, larger cloud grains cause blueing of the SED
- Polarization due to small grains is most effective at optical-NIR wavelengths, because of which this spectral region is most sensitive to the location of the photosphere in the atmospheric column
- Effects of atmospheric opacity need to be accounted for, especially for simulations of T-dwarfs - this is currently underway using Renyu Hu's thermochemistry model EPACRIS