Modeling extinction and reddening effects by circumstellar dust in the Betelgeuse envelope in the presence of radiative torque disruption

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in the framework of Vietnam Astronomy Research NETwork (VARNET)

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I. ABSTRACT

- Our study focuses on the impacts of stellar feedback from evolved stars on circumstellar dust. Applying the RAdiative Torque Disruption (RATD) mechanism induced by stellar radiation, we find that:
  - The grain size distribution (GSD) becomes steeper and contains smaller grains than the original dust.
  - Grain internal structure affects the disruption level.
- Using the GSD constrained by RATD, we model the dust extinction and reddening in the stellar spectrum

→ **The extinction is weaker at optical-IR wavelengths and higher at far-UV wavelengths**

- The consequent flux well reproduces the observations of Betelgeuse at UV-NIR range

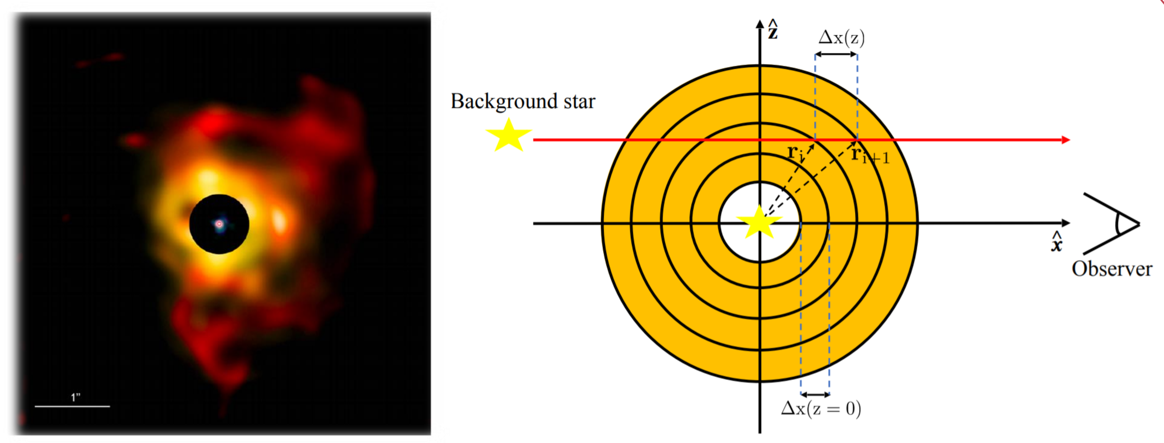
II. BACKGROUND

- During AGB/RSG stages, circumstellar dust is formed by nucleation and evolved by grain-gas collisions (Velhoelst et al. 2006; Cherchneff et al.2013)
- Circumstellar dust is essential for interpreting AGB/RSG observations and determining high-mass RSG progenitors of core-collapse supernovae.
- Circumstellar dust properties are affected by mechanical and radiative feedback

→ **Modifying the GSD of circumstellar dust**

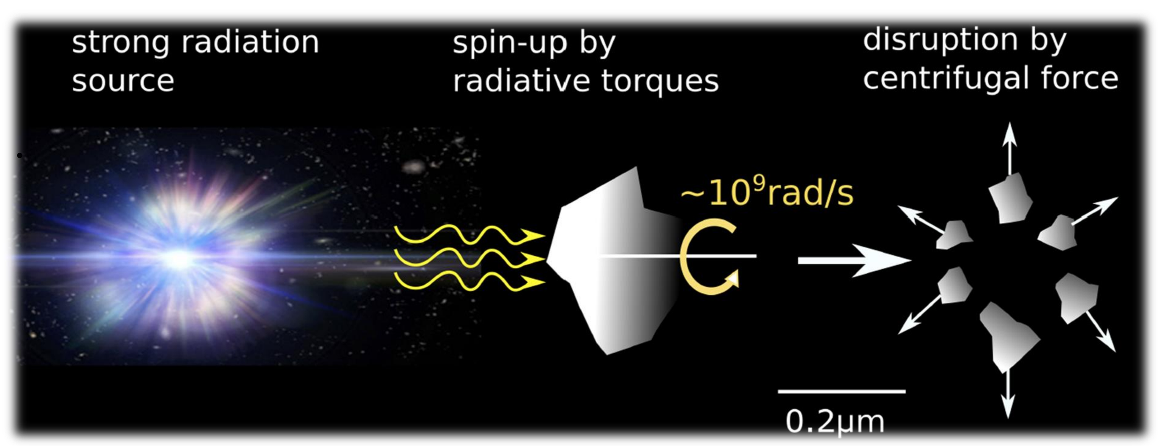
- The RATD mechanism plays a crucial role in determining the proper GSD in the circumstellar envelope (CSE)
  - it's effective in intense radiation fields
  - it can fragment large grains into smaller species

III. NUMERICAL MODELING



Left panel: The Betelgeuse CSE taken by VLT/VISIR from Kervella et al. (2011). Right panel: Schematic of radiative transfer-modeling of dust grains along the line-of-sight across the circumstellar envelope.

- Choose the Betelgeuse as a case of study with a spherical geometry of the envelope.
- Divide the envelope into sub-layers; each sub-layer has a specific grain size distribution
- Consider the extinction from background stars by dust grains along the line-of-sight (LOS) across the envelope.



Intense radiation from the star spins up large grains as a fast rotation until exceeding the centrifugal stress (Hoang et al. 2019)

- Large grains are disrupted into smaller species by RATD

→ **Determine maximum grain size after disruption (a_{disr})**

- Modify the original GSD with $a_{max} = 0.5$ μm (Scicluna et al. 2015)

→ **Determine new GSD from the a_{disr}**

- Calculate the optical depth produced by dust and gas from the GSD

→ **Determine the extinction properties**

- Apply to the stellar spectrum

→ **Determine dust reddening and reproduce the spectrum**

IV. RESULTS & DISCUSSION

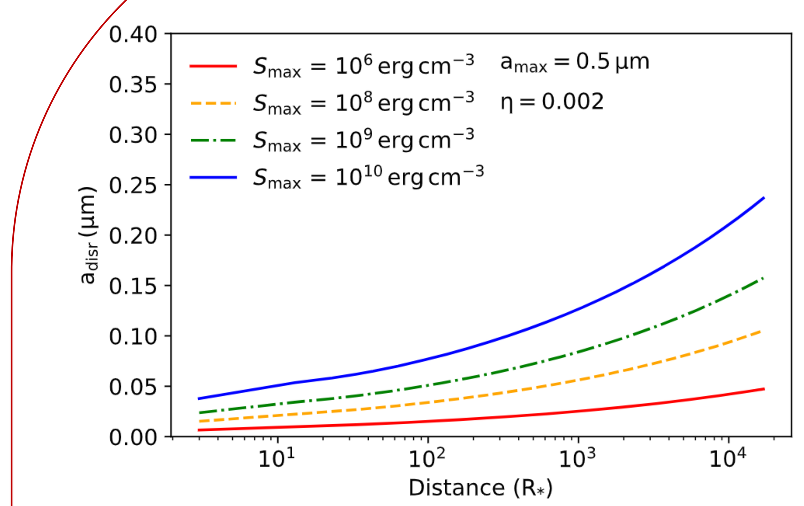


Figure 1. Grain disruption size (a_{disr}) vs radial envelope distance, assuming different values of S_{max}

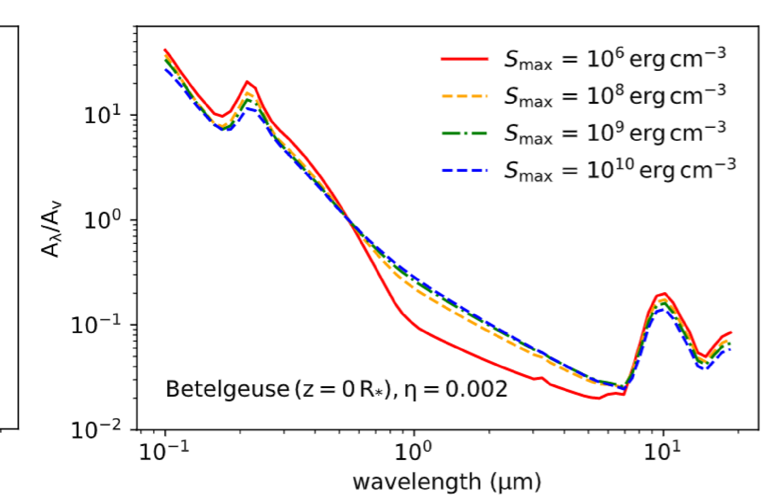


Figure 2. The normalized extinction curve A_λ/A_V along the LOS toward Betelgeuse with different values of tensile strength S_{max}

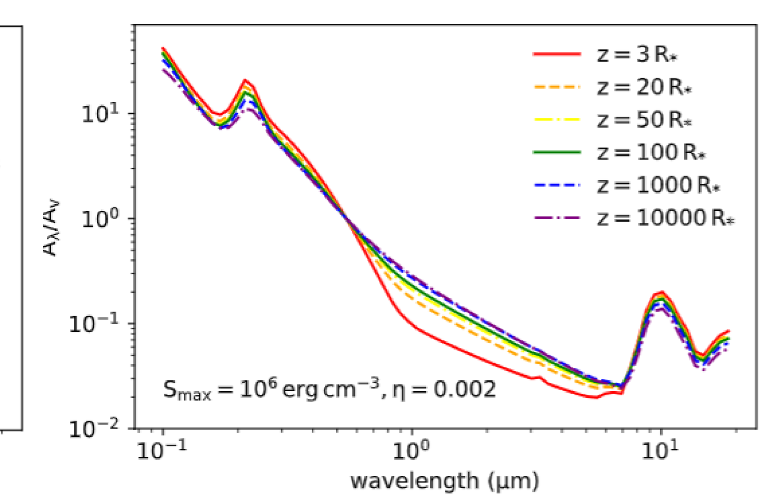


Figure 3. The normalized extinction curve A_λ/A_V by grains with $S_{max} = 10^6$ erg cm^{-3} along the LOS at different positions z

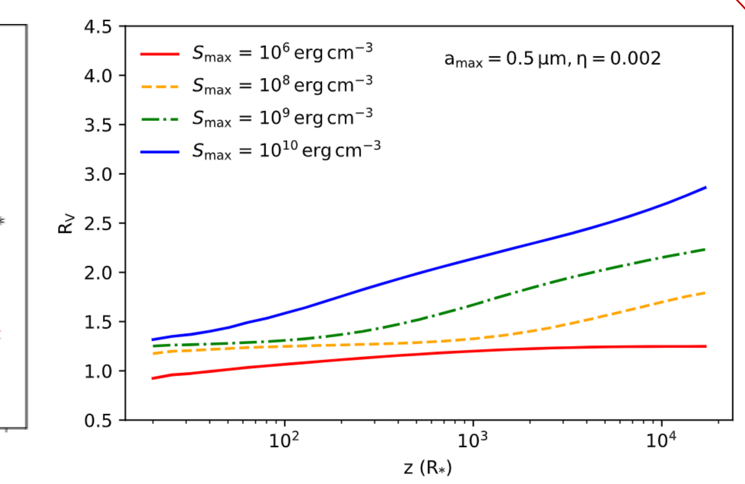


Figure 4. The total-to-selective extinction ratio R_V vs. the projected height z of the LOS towards background stars

- The RATD mechanism disrupts large grains and enhances small grains $a_{disr} < a_{max}$.
- Grain disruption size increases with increasing the radial distance or the tensile strength S_{max}

Note: η: dust-to-gas mass ratio

- Porous grains (lower S_{max}) are easy to be disrupted → Enhance smaller grains

→ **Lower extinction at optical-IR wavelengths and higher extinction at far-UV wavelengths**

- The abundance of small grains close to the central star due to the RATD effect

→ **Reduce extinction at optical-IR and enhance extinction at far-UV.**

- The extinction becomes steeper when observing at close regions of the CSE (lower z) or produced by porous grains (lower S_{max})

→ **R_V decreases with decreasing z and S_{max}**

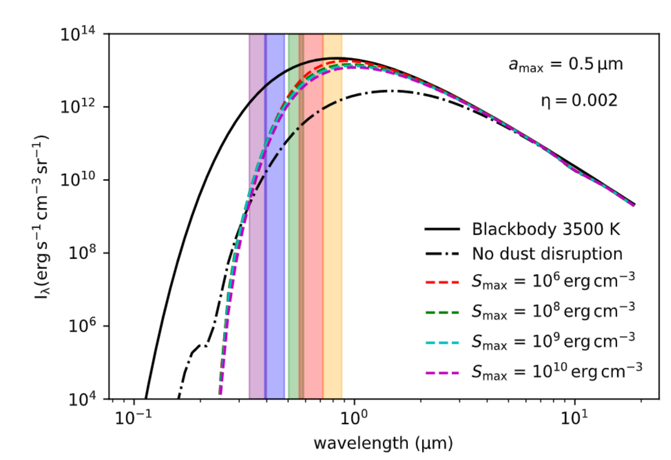


Figure 5. The reddened spectra of Betelgeuse in two cases: with RATD (dashed color lines) and without RATD (dash-dotted black line)

- With the RATD effects, circumstellar dust attenuates more far-UV radiation and less UV-NIR radiation compared with the case of no RATD

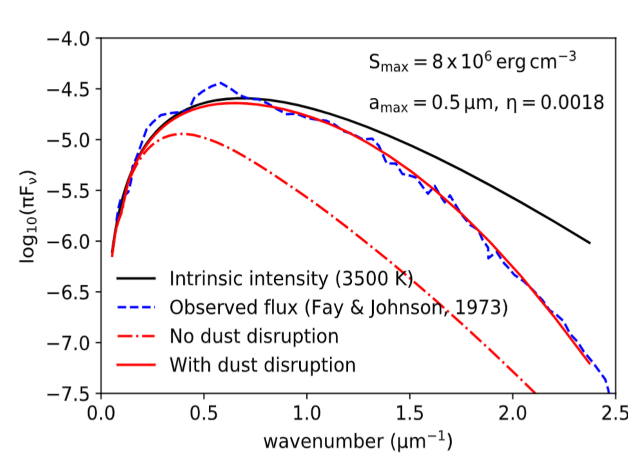


Figure 6. Observed flux of Betelgeuse (dashed blue line; Fay et al. 1973) and our best model (solid red line).

- $S_{max} = 8 \times 10^6$ erg cm^{-3} → **Original large grains have porous structure**
- $\eta = 0.0018$ → **Low fraction of dust (Verhoelst et al. 2006)**

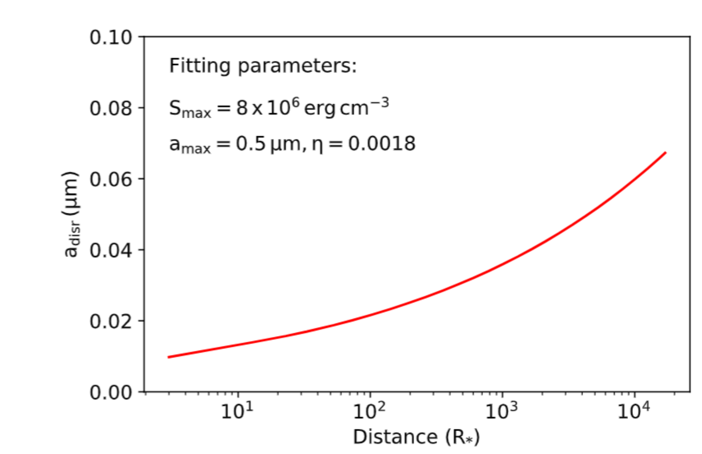


Figure 7. Grain size distribution in the Betelgeuse from our best fit

- Suggestion: **Radiation-driven winds by small grains $a < 0.1$ μm**

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