Radiative Transfer Simulations and Interferometric Observations of AGB Stars

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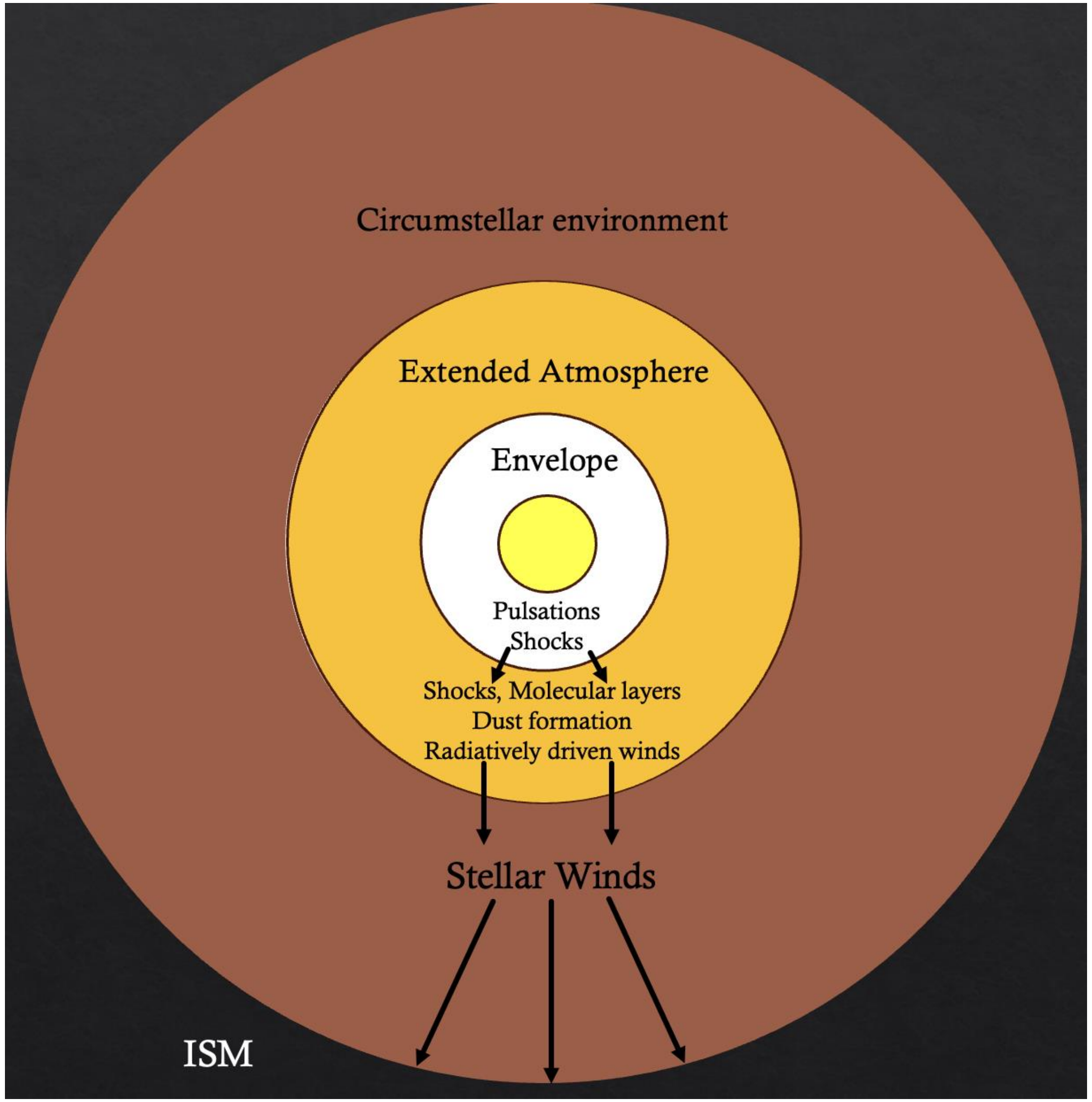
C-rich AGB Stars

- Cool effective temperatures and extended atmospheres
  - amC and SiC dust
  - Extended molecular layers – C_2H_2, HCN, CO
- Dynamic extended atmosphere often leads to interferometric variability.
- Want to be able to measure the distributions of dust and gas
  - How does it change over pulsation period of the star?
- VLTI/MATISSE observations of V Oph*



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Observations and Radiative Transfer Simulations of the Carbon-rich AGB Star V Oph with VLTI/MATISSE*

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Abstract

Carbon-rich asymptotic giant branch (AGB) stars are among the most important contributors of enriched materials to the interstellar medium due to their strong stellar winds. To fully characterize mass loss on the AGB, it is necessary to determine the distributions of dust and gas around the stars, where the dust begins to condense from the gas, and how this extended atmospheric structure evolves over the pulsational period of the star. We present an analysis of L-band (2.8–4.2 μm) interferometric observations of the carbon-rich AGB star V Oph made with the MATISSE instrument at the Very Large Telescope Interferometer at the maximum and minimum of the star's visual light curve. Using the radiative transfer software RADMC-3D, we model the circumstellar dust shell, and find stellar radii of 395 and 495$R_\odot$ at the two phases, and dust radii of 790 and 742.5$R_\odot$ at the two epochs, respectively. By adding C_2H_2 and HCN gas to the RADMC-3D models, we are able to fit the visibility spectra well, with some deviations at the 3.11 μm feature. Reasons for this deviation and interpretation of the best fitting models are discussed in the text, and we discuss motivations for follow-up imaging observations of V Oph.

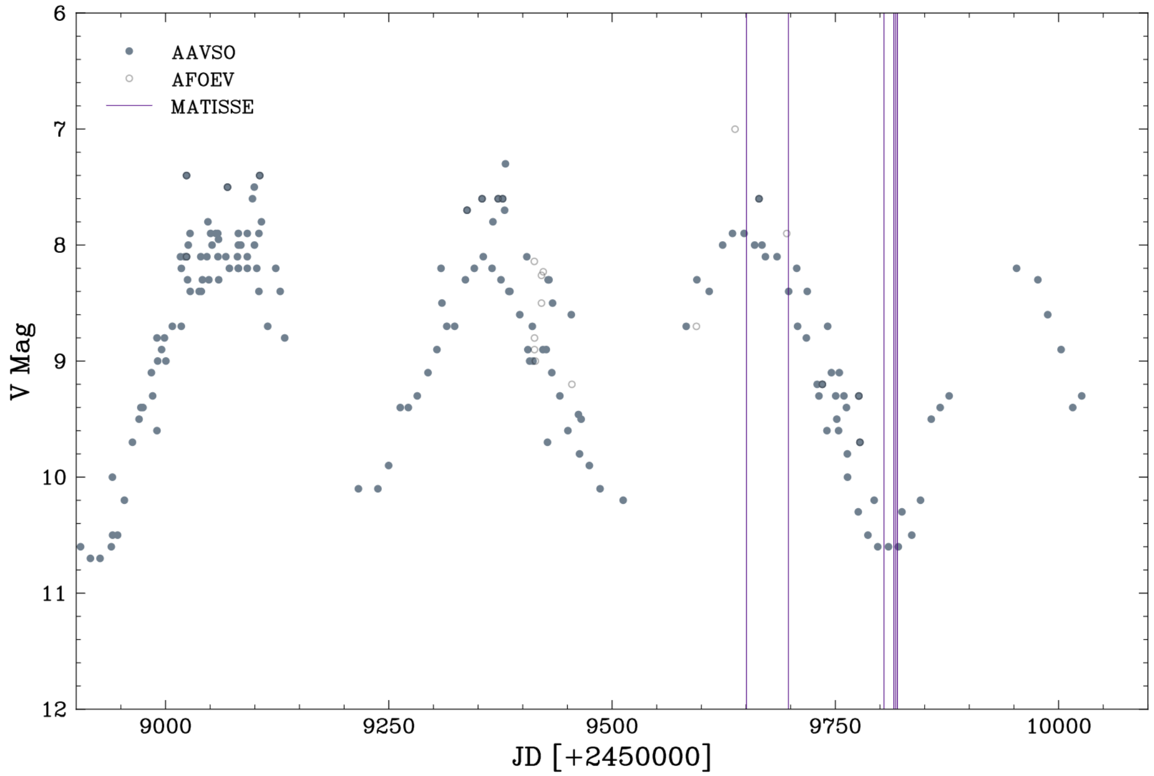
Unified Astronomy Thesaurus concepts: Asymptotic giant branch stars (2100); Stellar mass loss (1613); Stellar winds (1636); Stellar evolution (1599)

Hulberg et al. 2025, ApJ

Hulberg et al. 2025

Observations and Goals

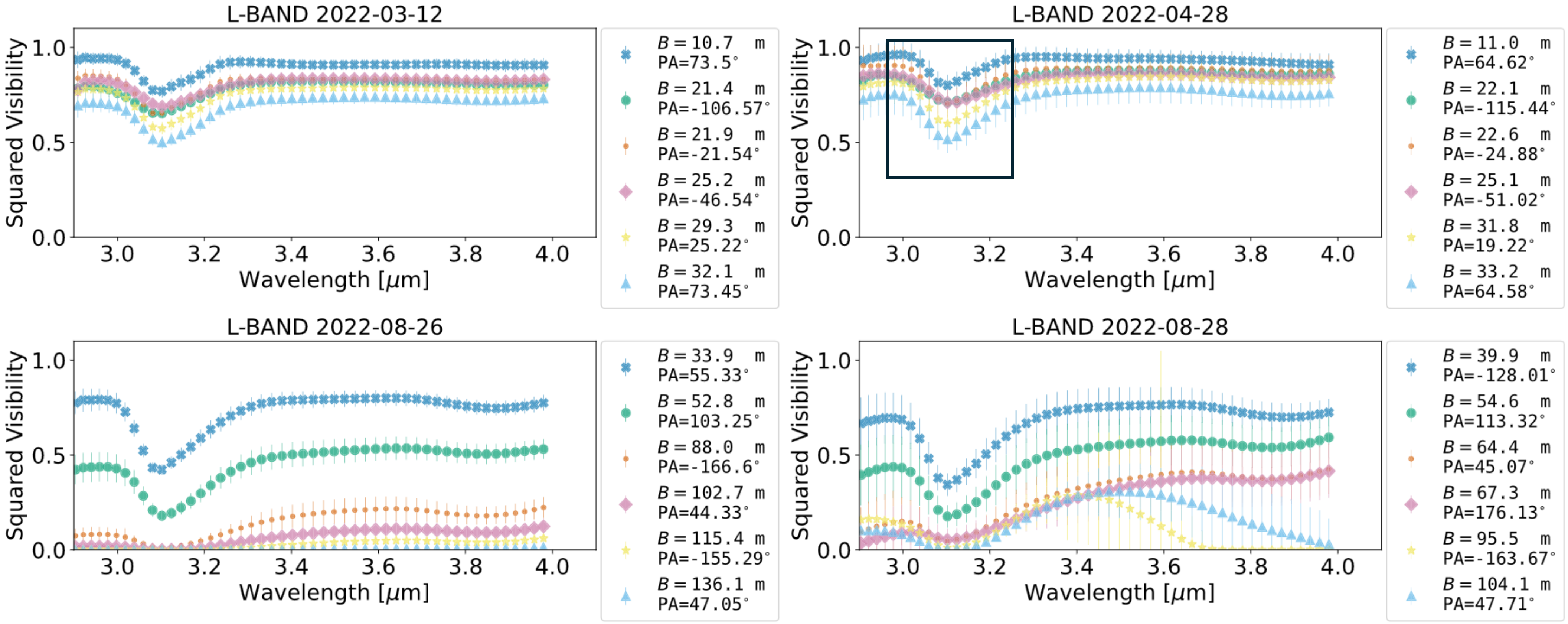
- Snapshot observations of V Oph
  - Spread over V-band period of ~ 300 Days
- Goal: characterize circumstellar environment at minimum and maximum V-band light.



Observation Date	Julian Date (+2450000)	Phase	Binned Phase	Array Configuration	Resolving Power $[\frac{\lambda}{\Delta\lambda}]$
2022-03-12	9650.5	0.96	0.04	Small	34(*L*)/30(*N*)
2022-04-28	9697.5	0.12	0.04	Small	34(*L*)/30(*N*)
2022-08-13	9804.5	0.47	0.51	Small	506 (*M*)
2022-08-24	9815.5	0.51	0.51	Small	506 (*L*)
2022-08-26	9817.5	0.52	0.51	Medium	34(*L*)/30(*N*)
2022-08-28	9819.5	0.53	0.51	Large	34(*L*)/30(*N*)

L-band

C_2H_2 +HCN!



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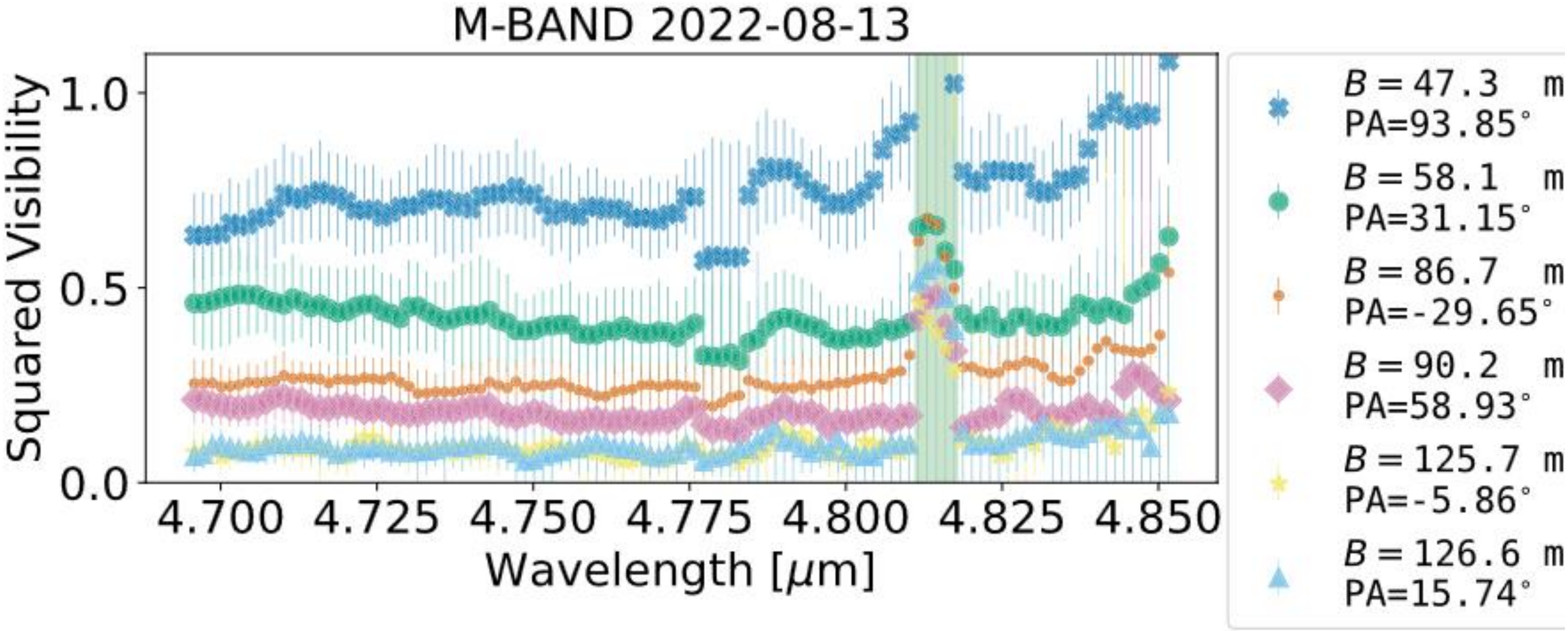
M-Band



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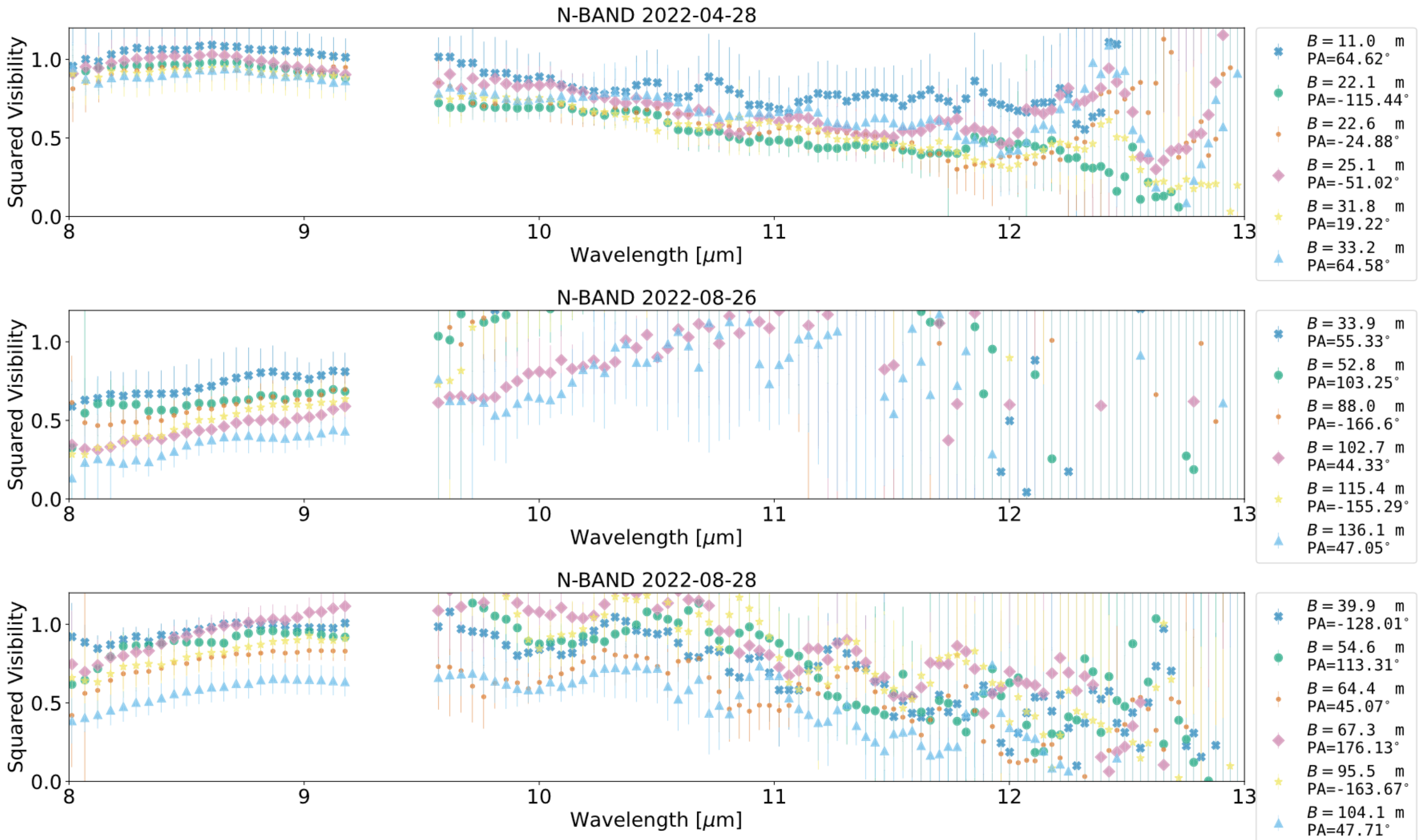
N-band

V Oph close to
MATISSE flux limits.



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Tool: RadMC-3D

- Radiative transfer software
  - Dust Monte-Carlo simulation
  - Line radiative transfer
- Two step fitting process
  - 1) Determine dust shell only parameters with grid search
  - 2) Add gas shell of C_2H_2 +HCN
    - Requires ~0.1 Å spectral resolution

Best-fitting Star + Dust Shell Models

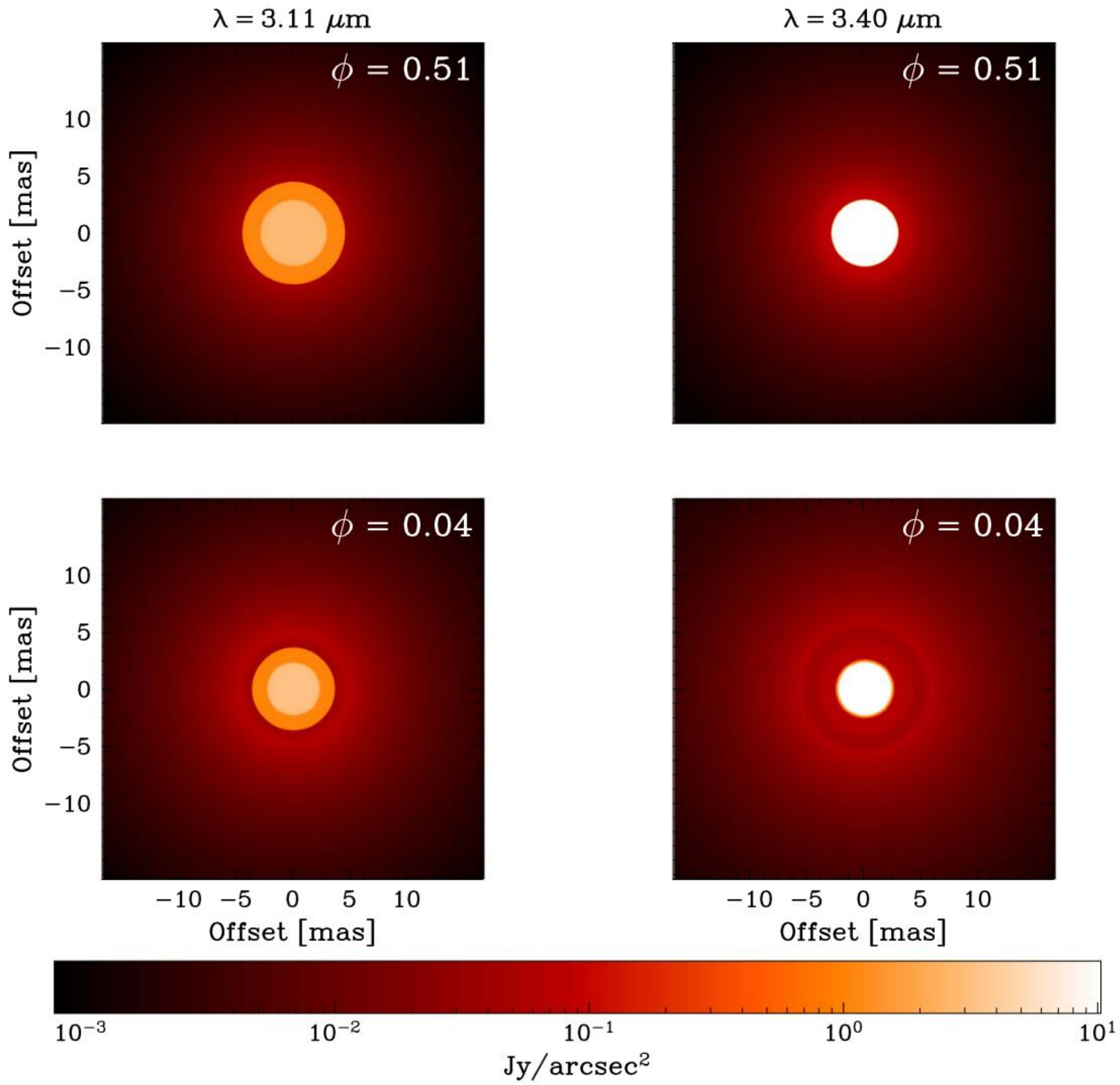
Phase	Photospheric Radius ($R_\odot$)	Dust Radius (R_*)	Dust Mass ($M_\odot$)	L Band χ^2_{red}
0.04	395	2.0	1.4×10^{-9}	0.40
0.51	495	1.5	6.5×10^{-10}	0.18

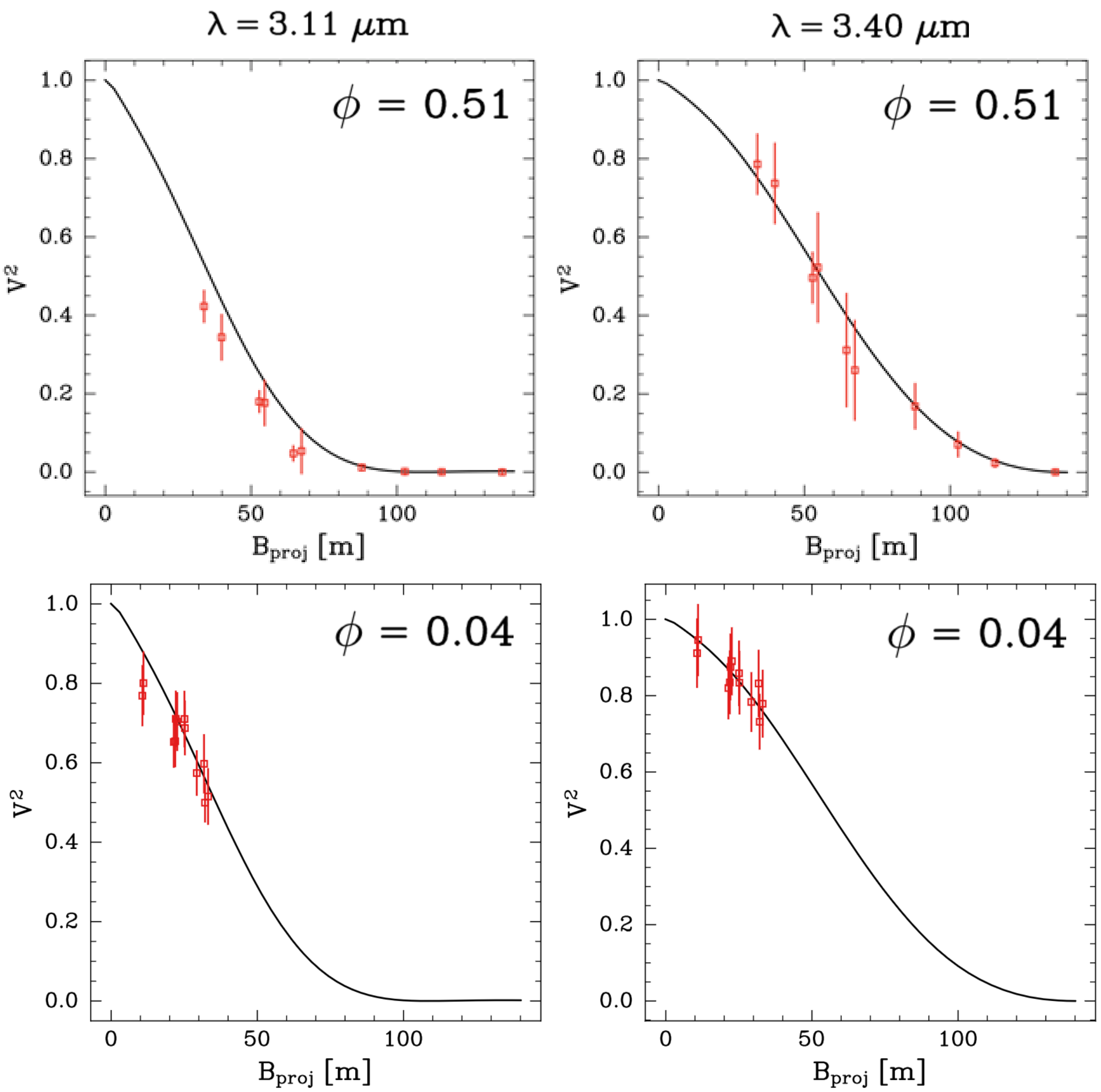
Parameters for Dust + Gas Shell Models

Phase	Photospheric Radius ($R_\odot$)	Dust Radius (R_*)	Gas Shell Width (R_*)	log $N(C_2H_2)$ (cm^{-2})	log N(HCN) (cm^{-2})	L Band χ^2_{red}
0.04	395	2.0	1.5	22.8	20.2	0.43
0.51	495	1.5	1.5	22.6	19.9	0.48

Stellar radius variability is consistent with O-rich AGB results (e.g, R Peg, Wittkowski et al. 2018)

Models





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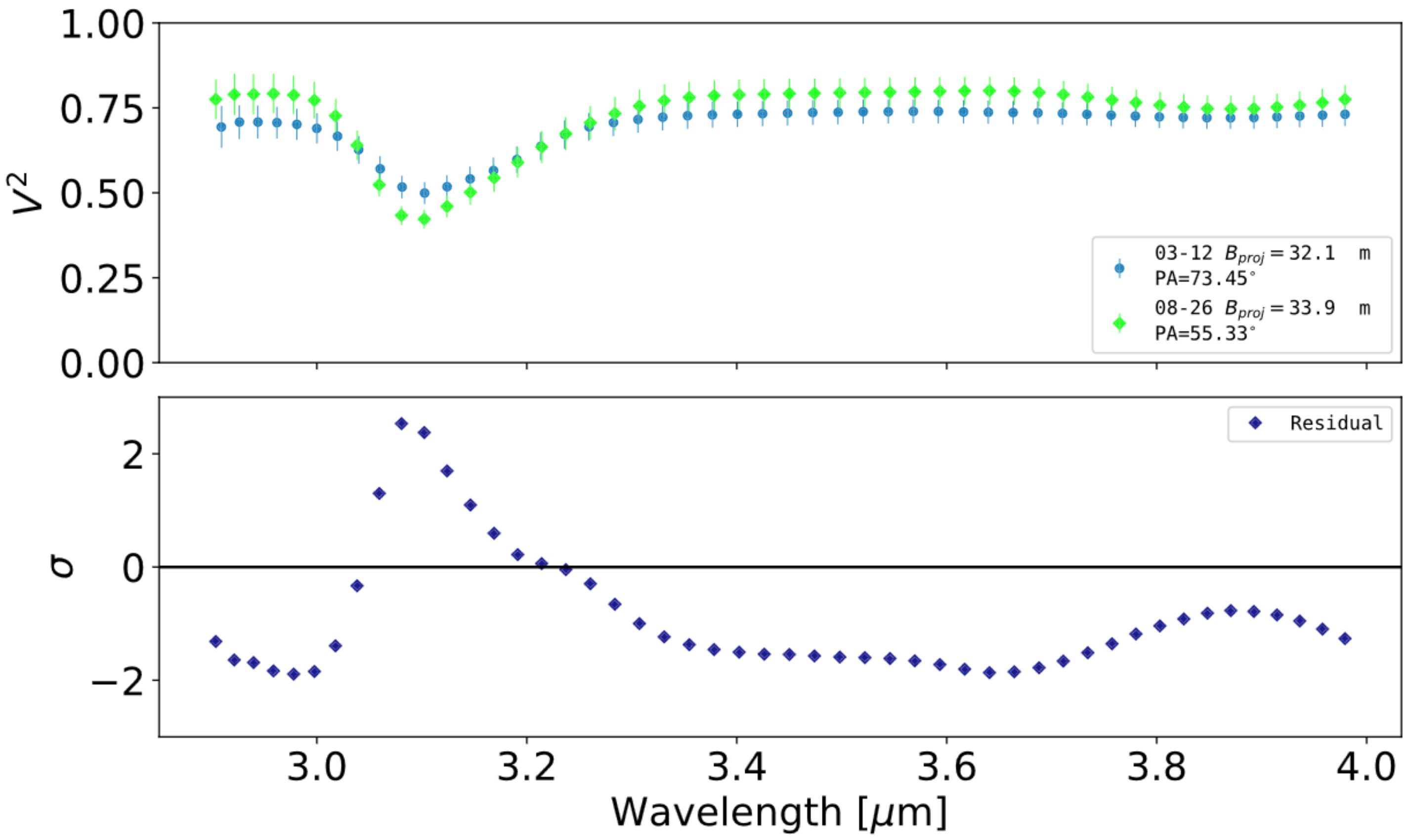
Variability and Imaging

Interferometric variability is too great over half the V-band light curve period.

But over periods of 50 days or less, the variability was not significant

Imaging proposal



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Conclusions

- MATISSE observations of C-rich AGB V Oph
- Modeled with RadMC-3D to constrain dust shell, gas shell
- Future
  - Apply RadMC-3D modeling to CHARA data
  - MIRC-X/MYSTIC observations of O-rich Mira X Aur
    - H_2O layers?
  - Optimize RadMC-3D for mid-IR/AGB stars

Thanks + Questions