Dust extinction-curve variation in the translucent interstellar medium is driven by PAH growth

Xiangyu Zhang[1] Brandon S. Hensley[2] and Gregory M. Green[1]

[1] Max Planck Institute for Astronomy, Königstuhl 17, 69117 Heidelberg, Germany
[2] Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA

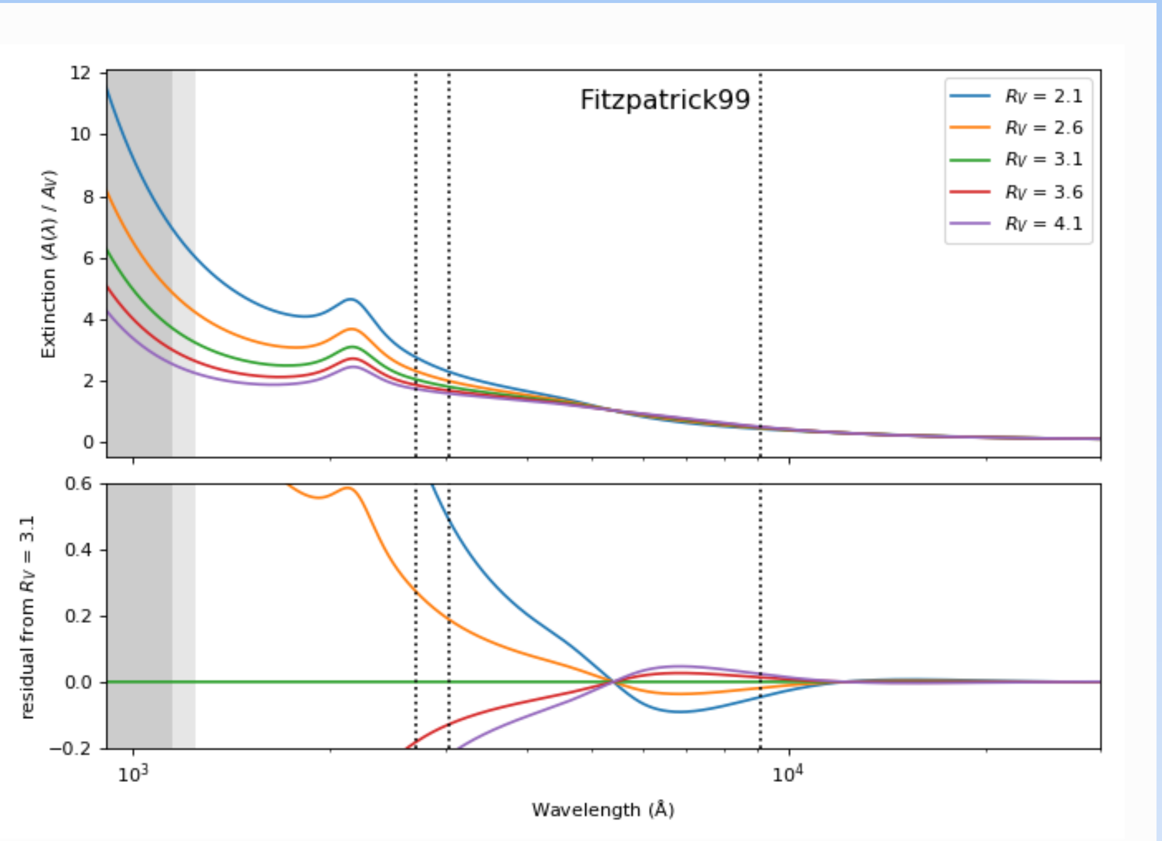
Helong Guo (郭贺龙，hlguo@ynu.edu.cn)

Yunnan University

2024-12-30

Introduction

- Dust Extinction Curve: Extinction from dust as a function of wavelength is a key observable for constraining dust composition and evolution.
- $R(V) = A(V)/E(B - V)$ is a single parameter that describes the shape of the extinction curve in the optical through near-infrared (NIR) wavelengths.
- Larger R(V) values indicate flatter extinction curves, generally associated with larger dust grains, while smaller R(V) values indicate steeper curves, associated with smaller grains.
- Previous studies have shown variations in R(V) across the Milky Way, but the physical causes were not fully understood.



Fitzpatrick 1999 et al.

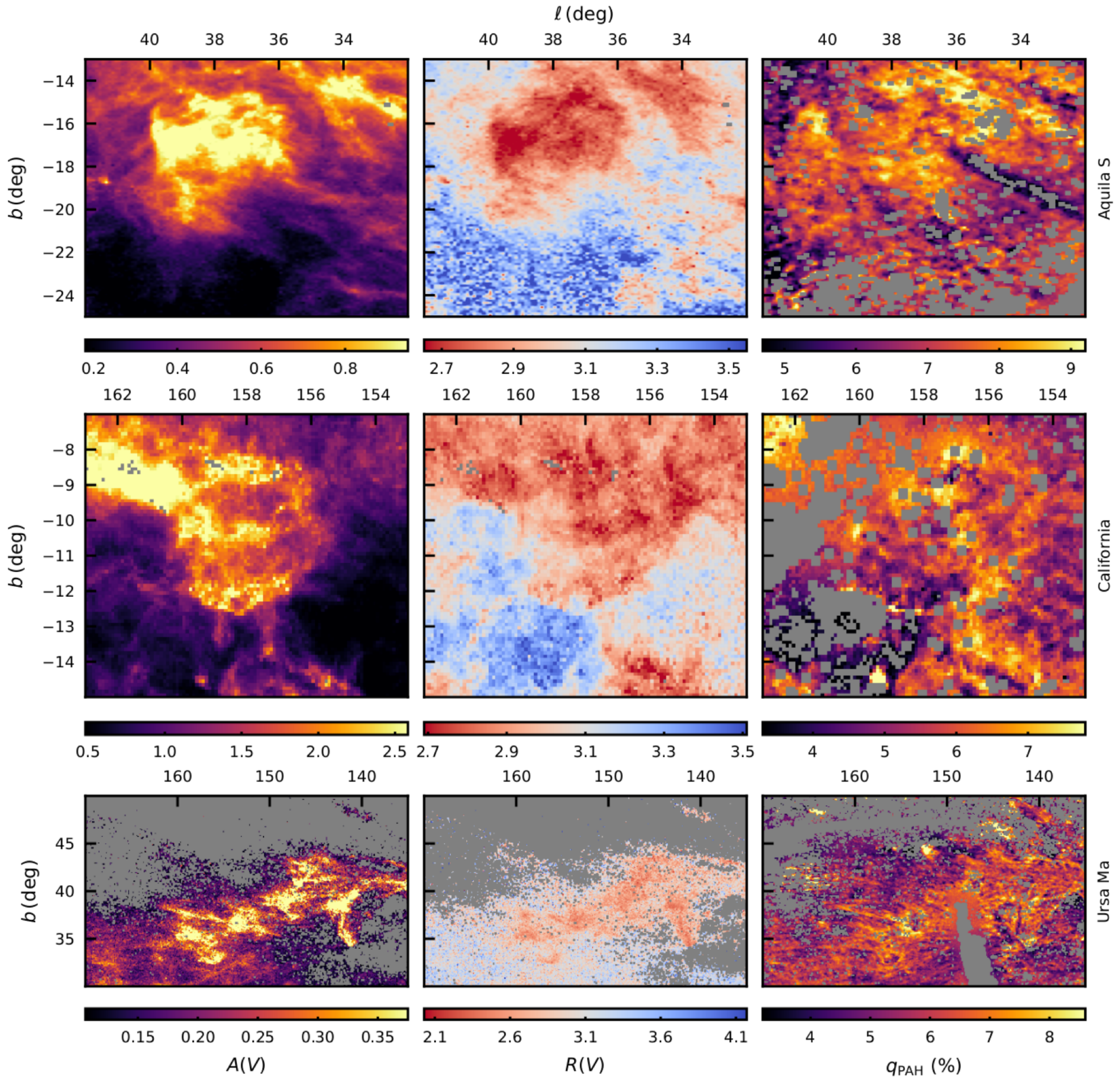
New opportunities with Gaia XP spectra

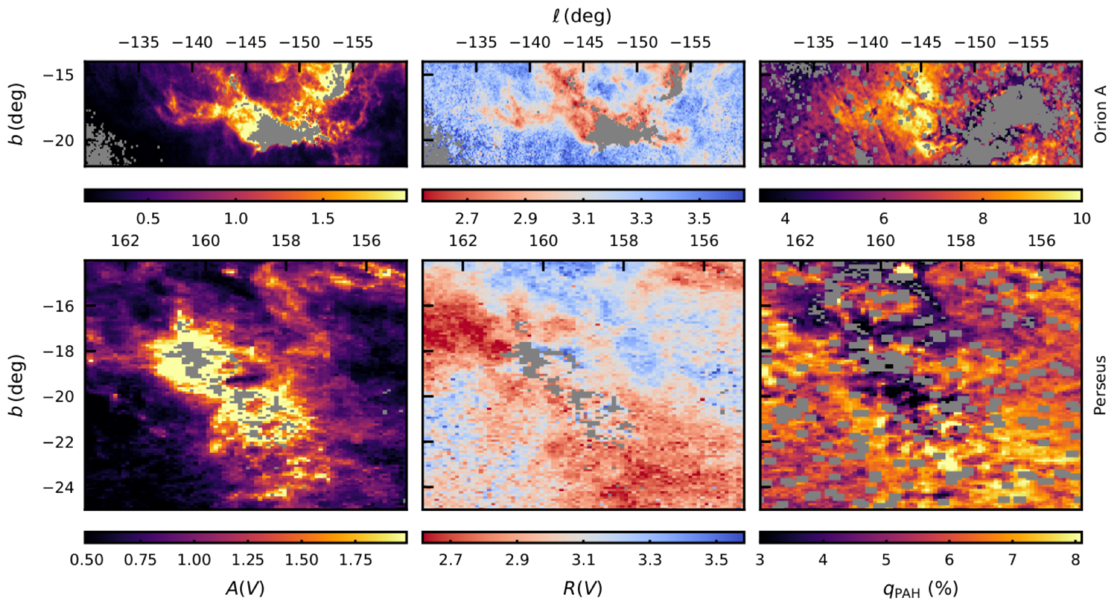
- Measurements of R(V) have historically been limited to a number of lines of sight along which R(V) has been determined.
- Zhang & Green (2024) used Gaia XP spectra produced the largest catalog (over 130 million stars) of R(V) in the Milky Way.
- A key finding contrary to expectations: R(V) decreases with increasing A(V) in the translucent ISM before increasing again in dense molecular clouds.

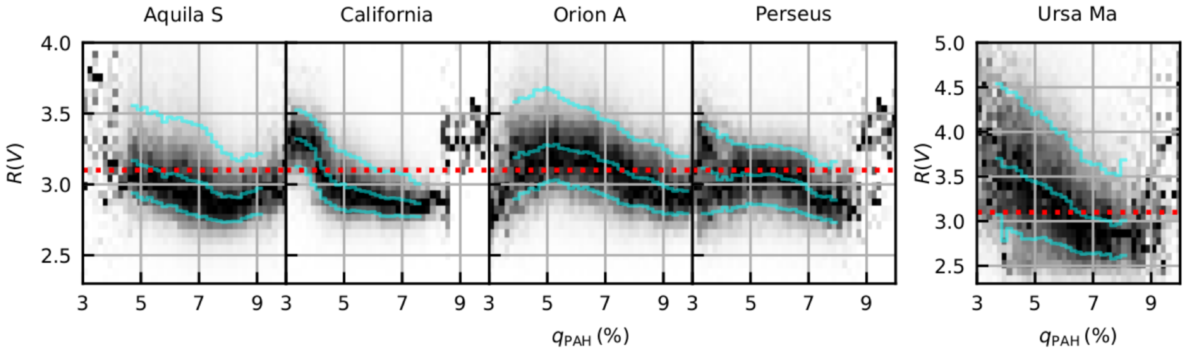
Anti-Correlation Between R(V) and PAH Abundance

- Polycyclic aromatic hydrocarbons (PAHs) are common organic molecules in the universe, known for their characteristic infrared emission features.
- PAHs have been proposed as the carrier of the 2175 Å bump, the most prominent feature in the UV region of the extinction curve.
- An anti-correlation between the strength of the 2175 Å feature and R(V) has long been recognized (e.g. Cardelli et al. 1989), but its physical explanation has been unclear.
- In the regions where R(V) decreases with A(V) in ZG24, They generally find an anti-correlation between qPAH and R(V) from the maps of Planck Collaboration et al. (2016) and Zhang & Green (2024).
- They do comparison of R(V) and qPAH maps in various molecular clouds (Aquila S, California, Orion A, Perseus, Ursa Major). The 2D maps showing the anti-correlation between R(V) and qPAH in these regions.

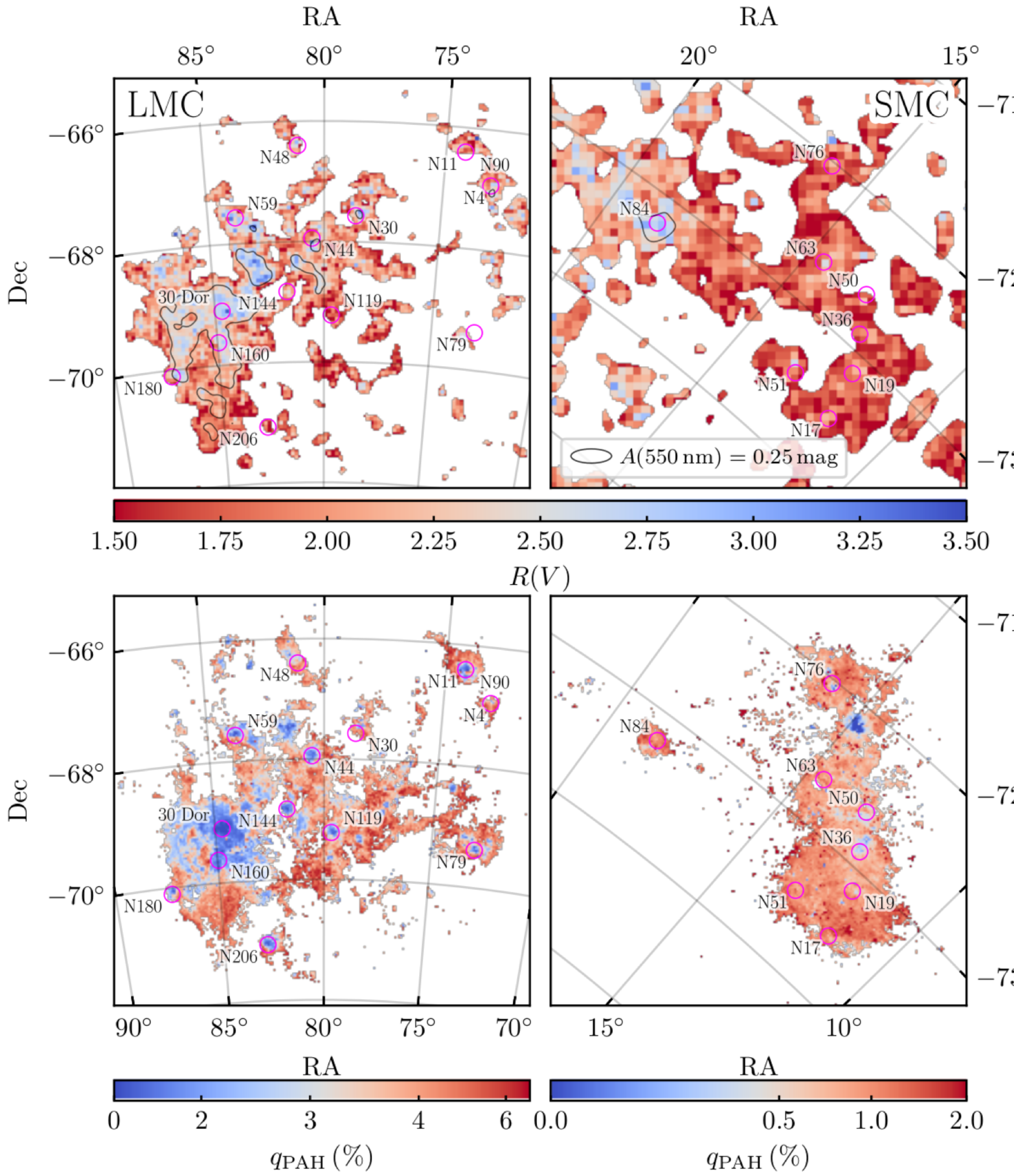
Anti-Correlation Between R(V) and PAH Abundance







Anti-Correlation Between R(V) and PAH Abundance



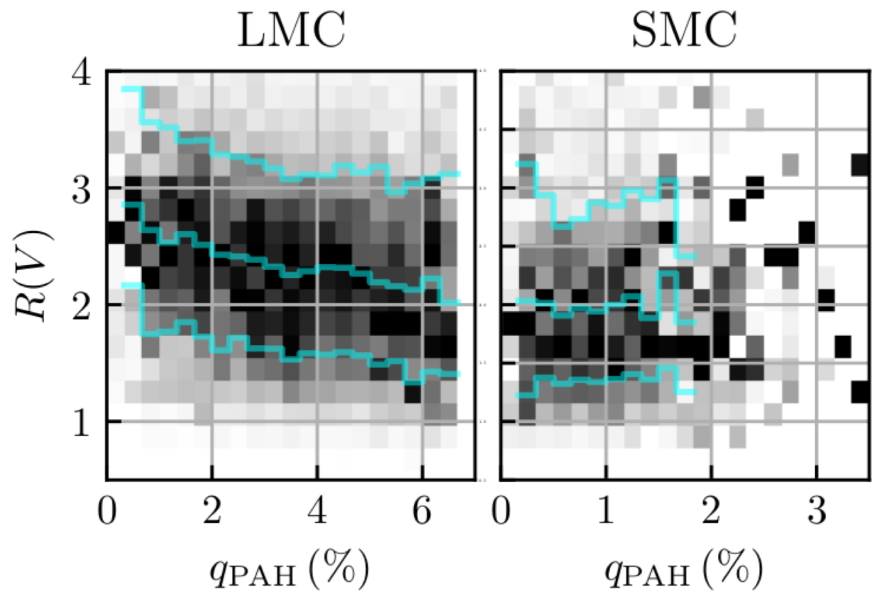
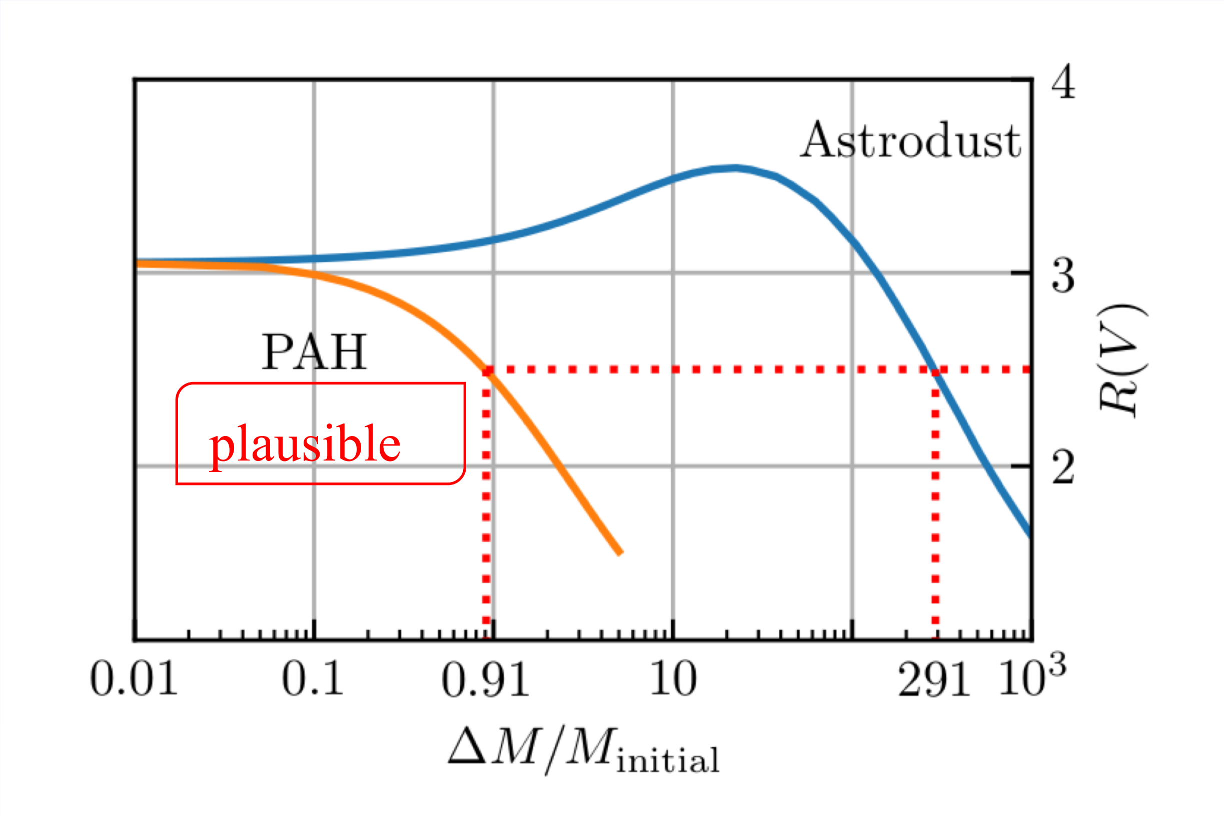


Figure 5. Quantitative comparison on the per-star basis between $R(V)$ and q_{PAH} in LMC (left panel) and SMC (right panel). The median value of $R(V)$ decreases by 0.4 as q_{PAH} increases from 1% to 6% in the LMC. In the SMC, the trend is not clear because of small variation range of q_{PAH} as well as the difference in spatial coverage of both maps.

In addition to the Milky Way, the anti-correlation between qPAH and R(V) is also observed in the LMC.

Theoretical Explanation of R(V) Variation

- Hypothesis: The variation in R(V) in the translucent ISM is driven by the growth of PAHs.
- Mechanism: As PAH mass increases, the strength of the 2175 Å feature (a prominent UV extinction feature) is enhanced, which affects the slope of the extinction curve in the optical-NIR region.
- Quantitative Analysis: They adopt the dust grain model by Hensley & Draine (2023), which consists of two components, "astrodust" and PAHs. Astrodust is a composite material to account for large grains ($\gtrsim$ 500Å) while Small grains are accounted for by PAHs.



- For accretion to significantly change R(V) from 3.1 to 2.5, the mass of astrodust would need to increase by a factor of 291, which is not feasible given the available carbon budget.
- Comparison: PAH growth requires only a 91% increase in mass, which is within the available carbon budget.

PAH Growth Timescales

- Although allowed by the mass budget, the question then arises as to whether PAHs can double in mass within a reasonable timescale?
- Based on accretion models, PAHs can double in mass within ~2 Myr, much shorter than the typical lifespan of molecular clouds (~10–20 Myr).

Typical types of PAH	Time scale of accretion to double the mass (Myr)
Naphthalene ($C_{10}H_8$)	1.28
Phenalene ($C_{13}H_{10}$)	1.46
Pyrene ($C_{16}H_{10}$)	1.61
Corannulene ($C_{20}H_{10}$)	1.80
Coronene ($C_{24}H_{12}$)	1.98

Open Questions and Future Research

- Importance of PAH Growth: PAH growth plays a crucial role in the carbon cycle of the interstellar medium.
- Unresolved Questions:
  - Do PAHs form in situ or migrate from denser regions?
  - How do carbon atoms assemble onto PAHs?
  - What factors influence the growth or destruction rates of PAHs?
- Future Research:
  - The JWST can test the PAH-R(V) correlation by observing PAH emission features at 6.2, 7.7, 8.6, 11.2, 12.7, and 16.4 μm.
  - Targeting translucent ISM regions with similar A(V) but varying R(V) to trace the evolutionary phases of PAHs.
  - Combining observational data with theoretical models to better understand PAH behavior in different ISM environments.

Conclusion and Summary

- R(V) decreases with increasing A(V) in the translucent ISM due to PAH growth.
- PAH growth enhances the 2175 Å feature, leading to a steeper extinction curve.
- Accretion onto larger grains cannot explain the observed R(V) variation.
- PAH growth is rapid enough to account for the observed changes in R(V).
- Future Work: Testing the hypothesis with JWST observations and exploring broader implications for interstellar chemistry and dust evolution.

Thanks!