Dust Production in Galactic & Magellanic Carbon Stars

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SOFIA Tele-Talk May 27, 2020

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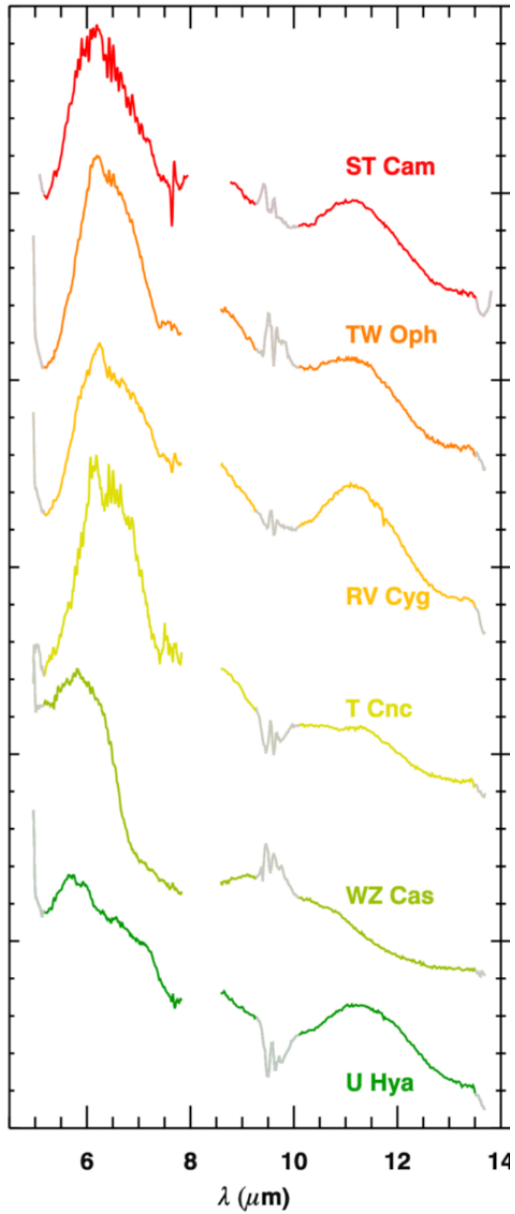
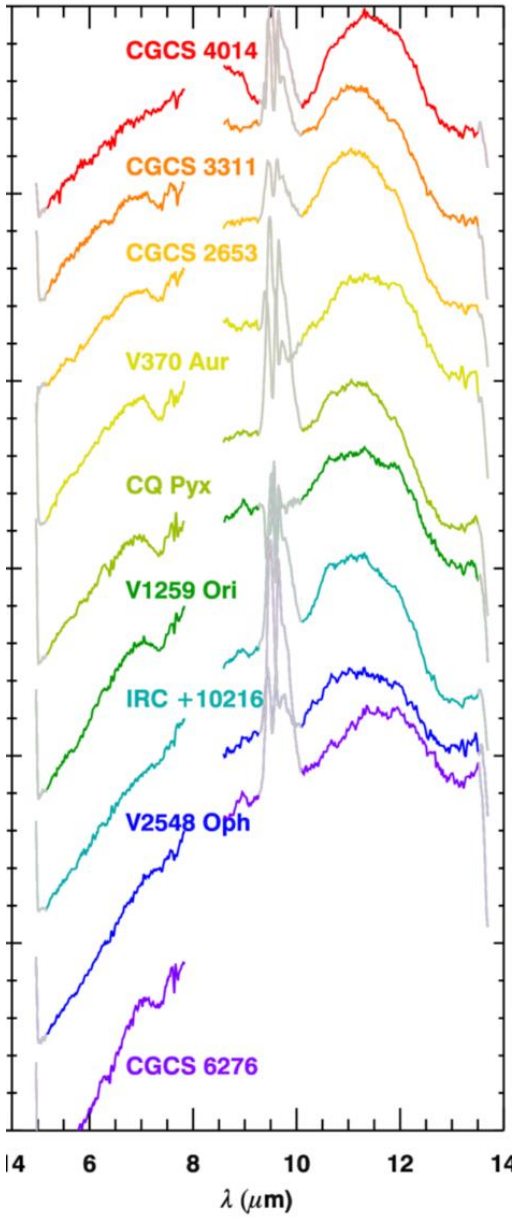
Takeaways



Mira carbon stars produce (lots of) amorphous carbon dust & C_2H_2

Semi-regular carbon stars produce (some) silicon-carbide dust & CS

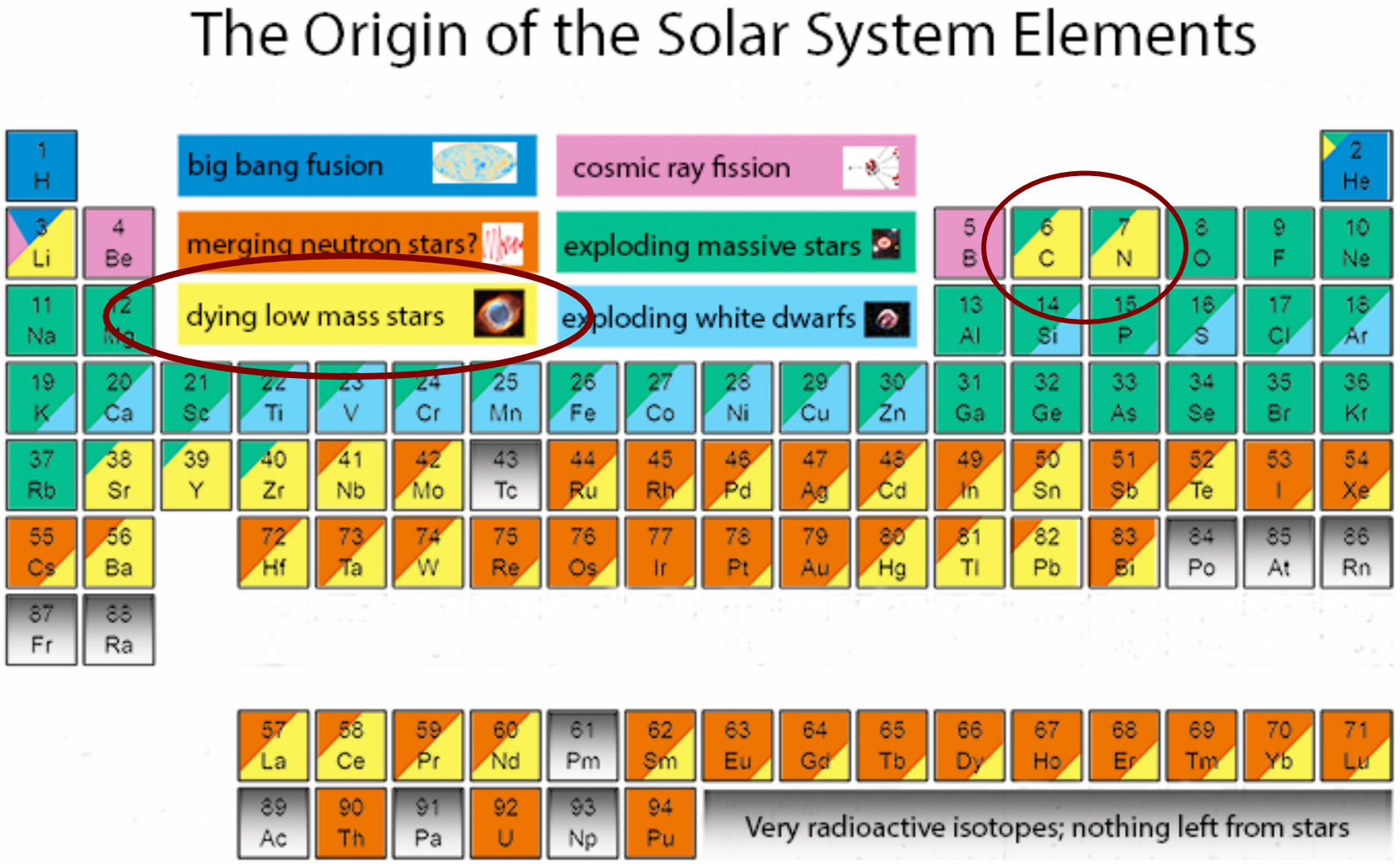


Kraemer et al. 2019

Outline

- **Background: what are carbon stars & why should we care about evolved stars?**
- **Observations: *SOFIA*/FORCAST (& *Spitzer* & *ISO*)**
- **Results: spectra & diagrams galore**
- **Summary: see previous slide**

Dying Stars & Nuclear Enrichment



Graphic created by Jennifer Johnson
http://www.astronomy.ohio-state.edu/~jaj/nucleo/

Astronomical Image Credits:
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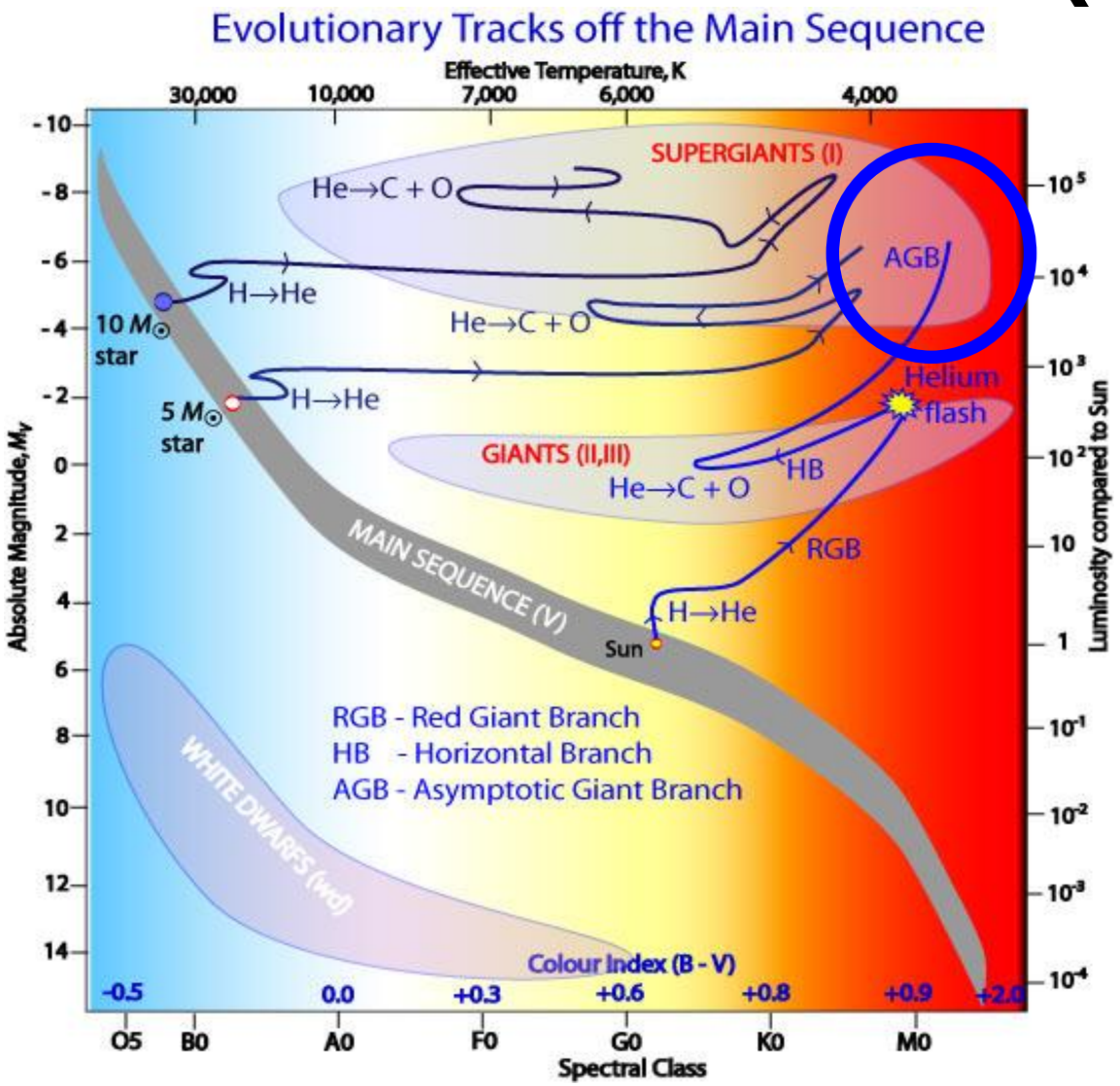
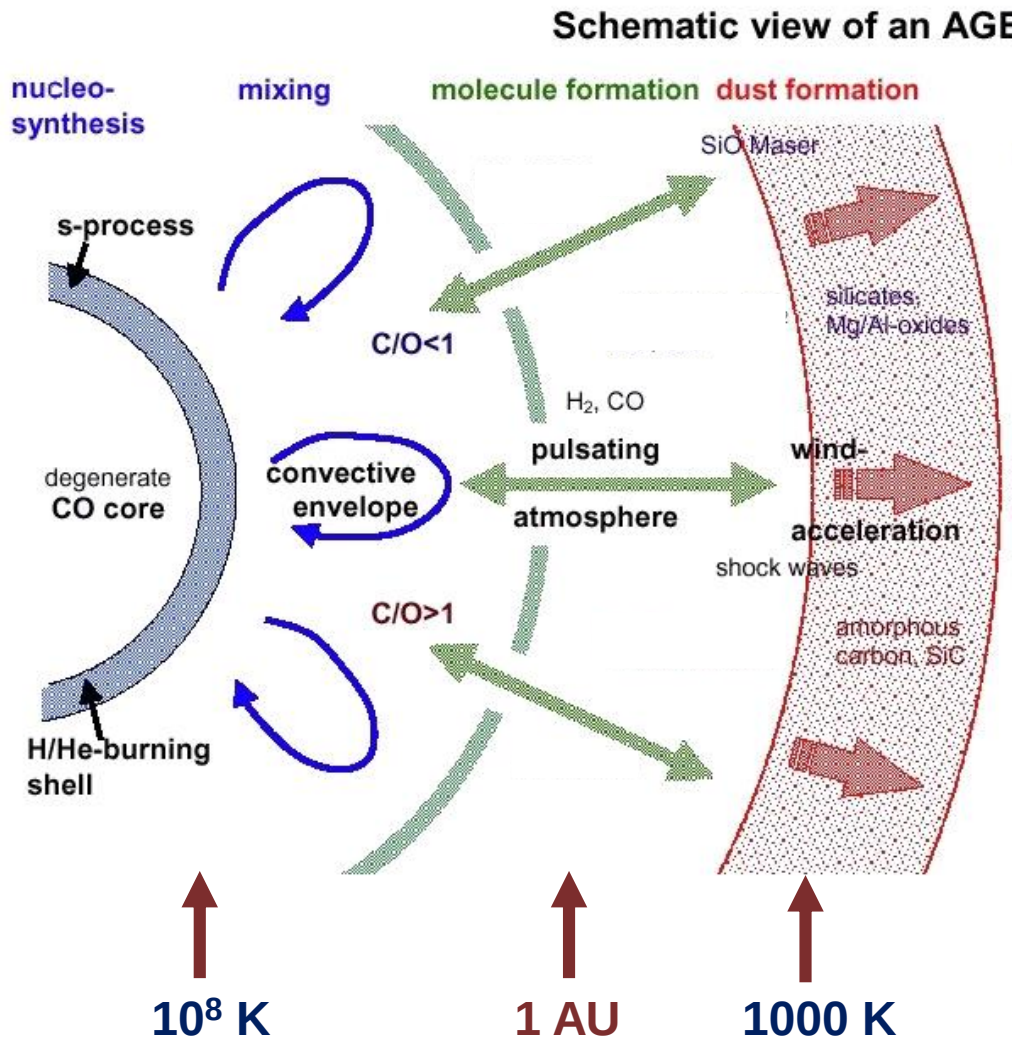
Asymptotic Giant Branch (AGB) Stars



- Dead C/O core
- He-shell burning
- Pulsations
- Winds & superwinds:
  - M_{init} ~1-8ish $M_\odot$
  - M_{WD} <1.4 $M_\odot$

Asymptotic Giant Branch (AGB) Stars

CO paradigm – CO forms until C or O exhausted



C/O < 1 **M giant**

OH, H_2O, Al/MgO, SiO, other oxides, silicates

thermal CO

interstellar radiation field

circumstellar envelope with stellar wind → ISM

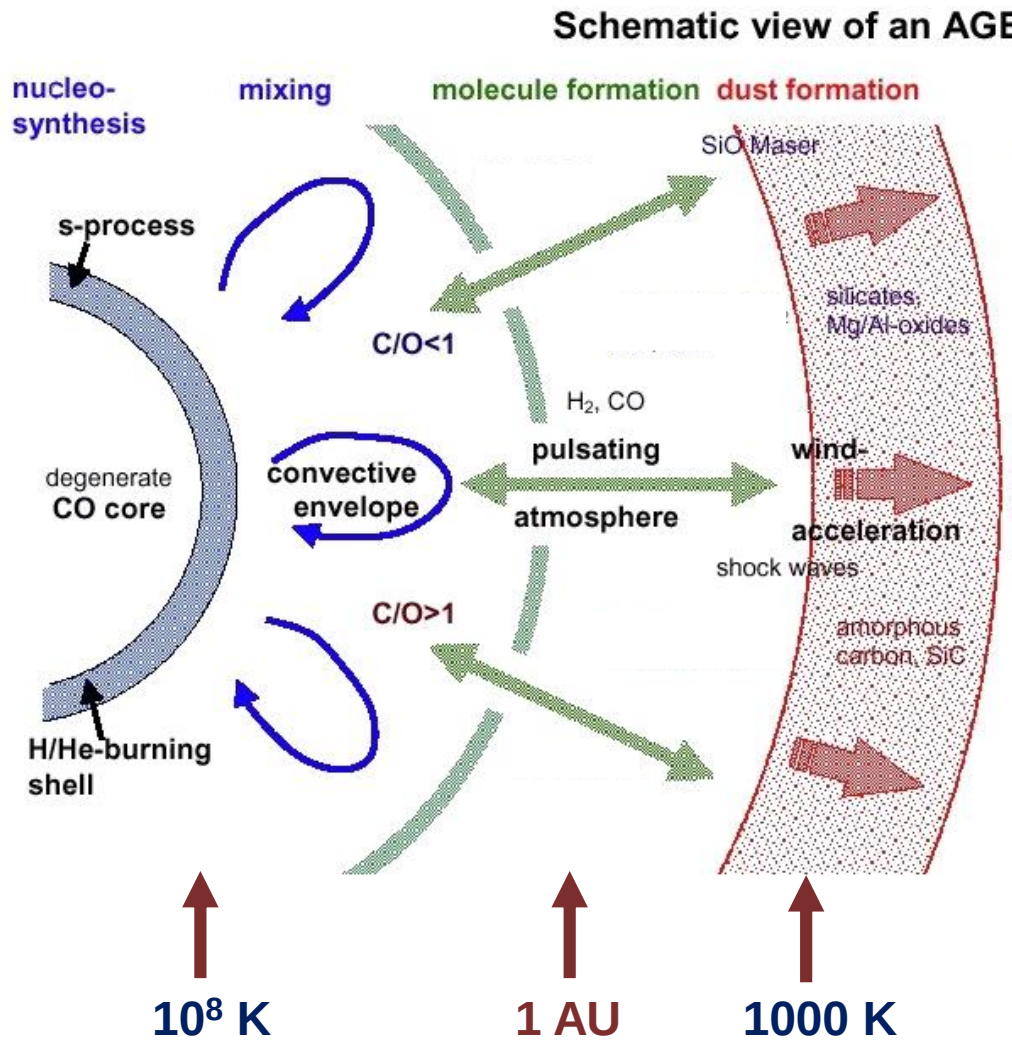
C/O > 1 **Carbon star**

C_2H_2, HCN, CS, hydrocarbons, carbides, sulfides

J. Hron (U. Vienna)

Asymptotic Giant Branch (AGB) Stars

Carbon Stars produce ~30-50% of the carbon in the Universe



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C/O > 1 **Carbon star**

C_2H_2, HCN, CS, hydrocarbons, carbides, sulfides

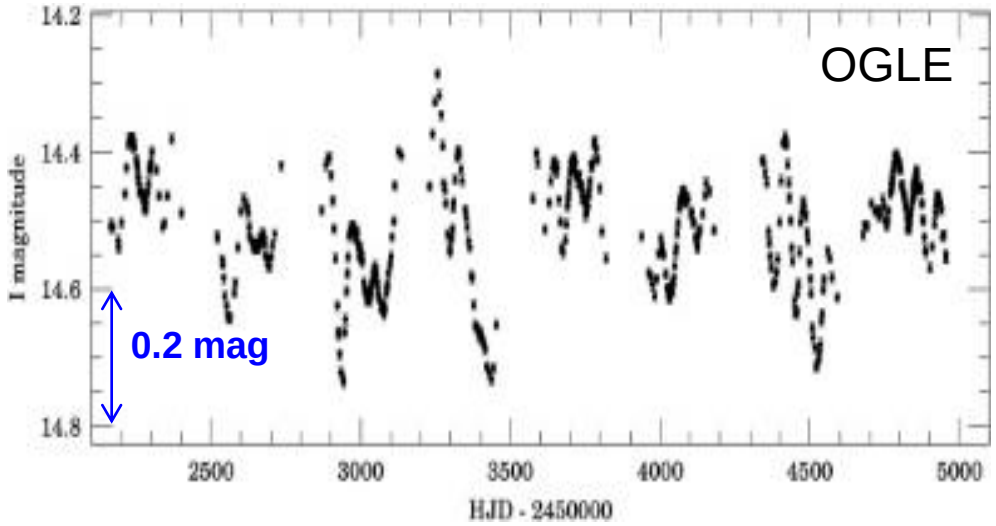
e.g., Matsuura et al. 05, Karakas & Lattanzio 14

Asymptotic Giant Branch (AGB) Stars

Long Period Variables

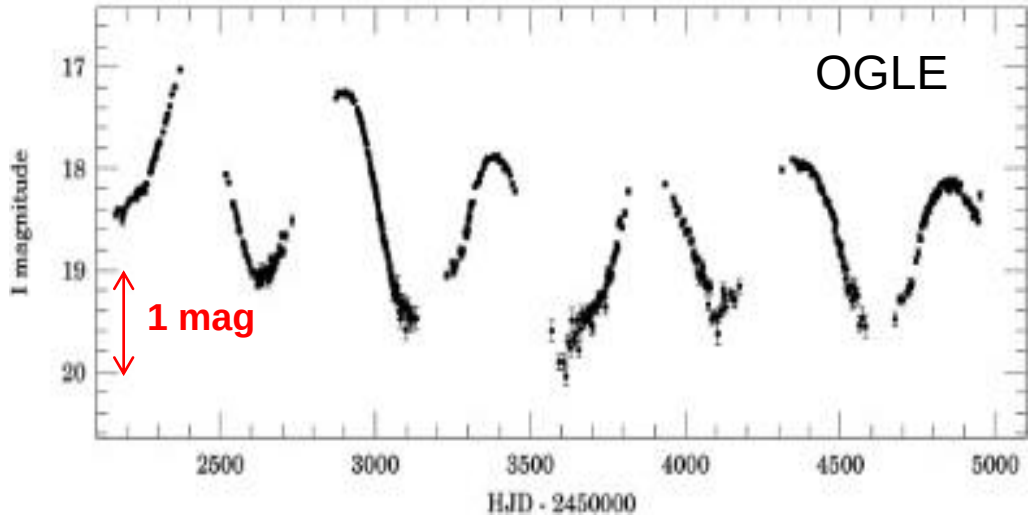
Semi-Regulars (SR)

- P~80-500 days
- smaller amplitudes
- overtone or fundamental mode



Miras

- P ~200-1000 days
- large amplitudes
- fundamental mode pulsations



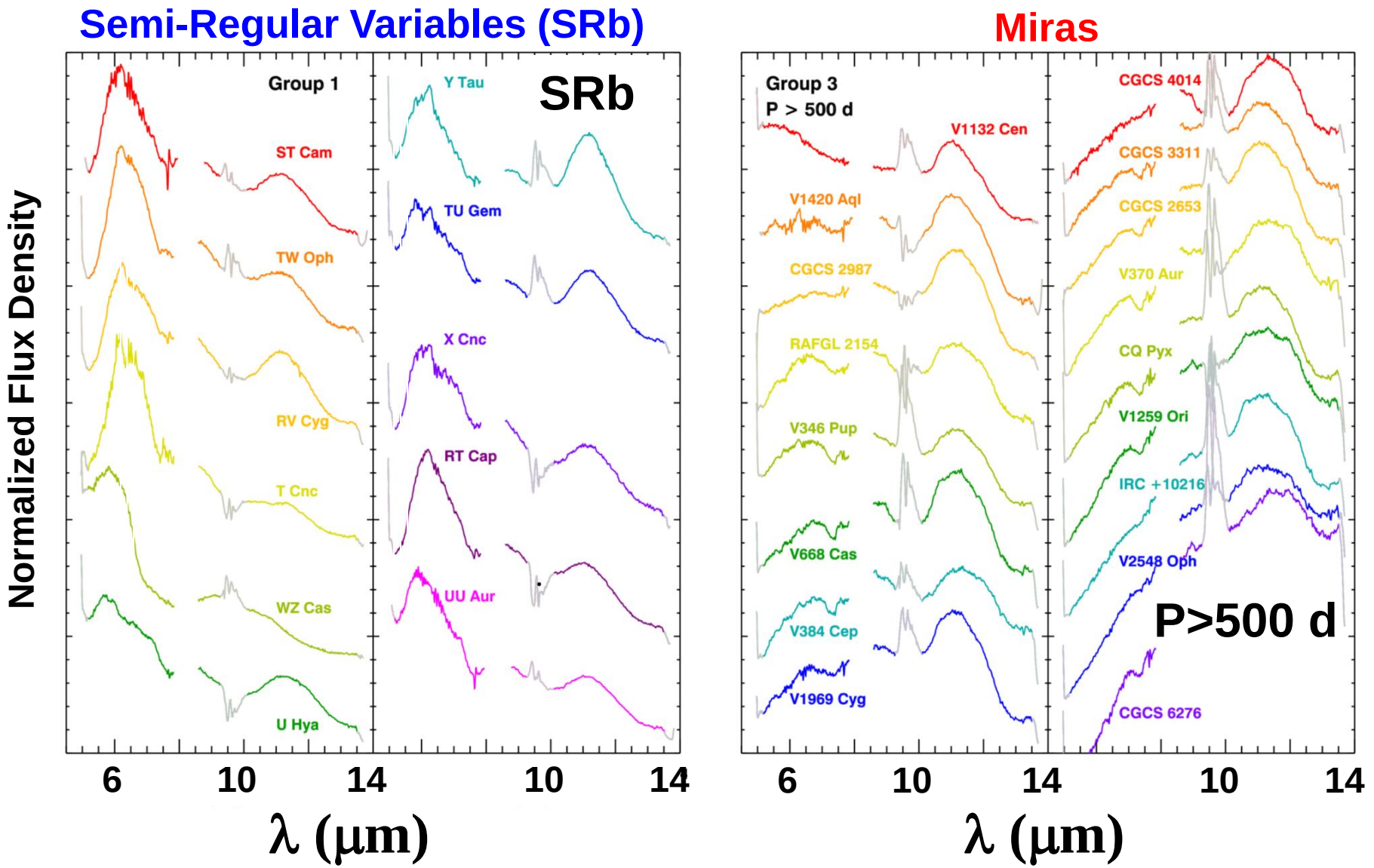
OGLE: Soszynski et al. 09

Theory: Wood & Sebo 95, Wood et al. 99

The SOFIA Program

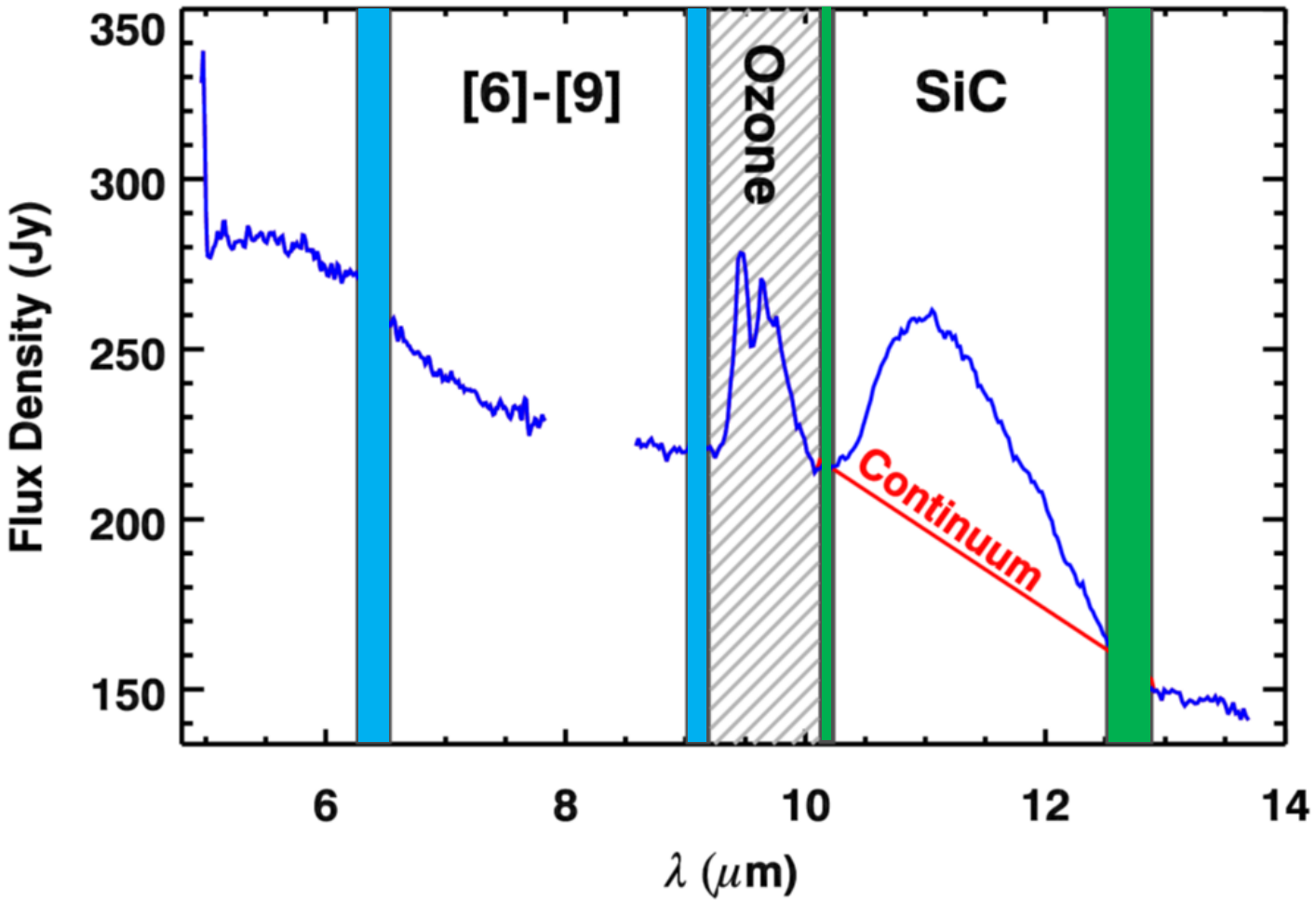
33 FORCAST Spectra:

- Remove biases in existing Galactic samples
- Enable comparison with the Magellanic Clouds



The Dust

The Dust Features

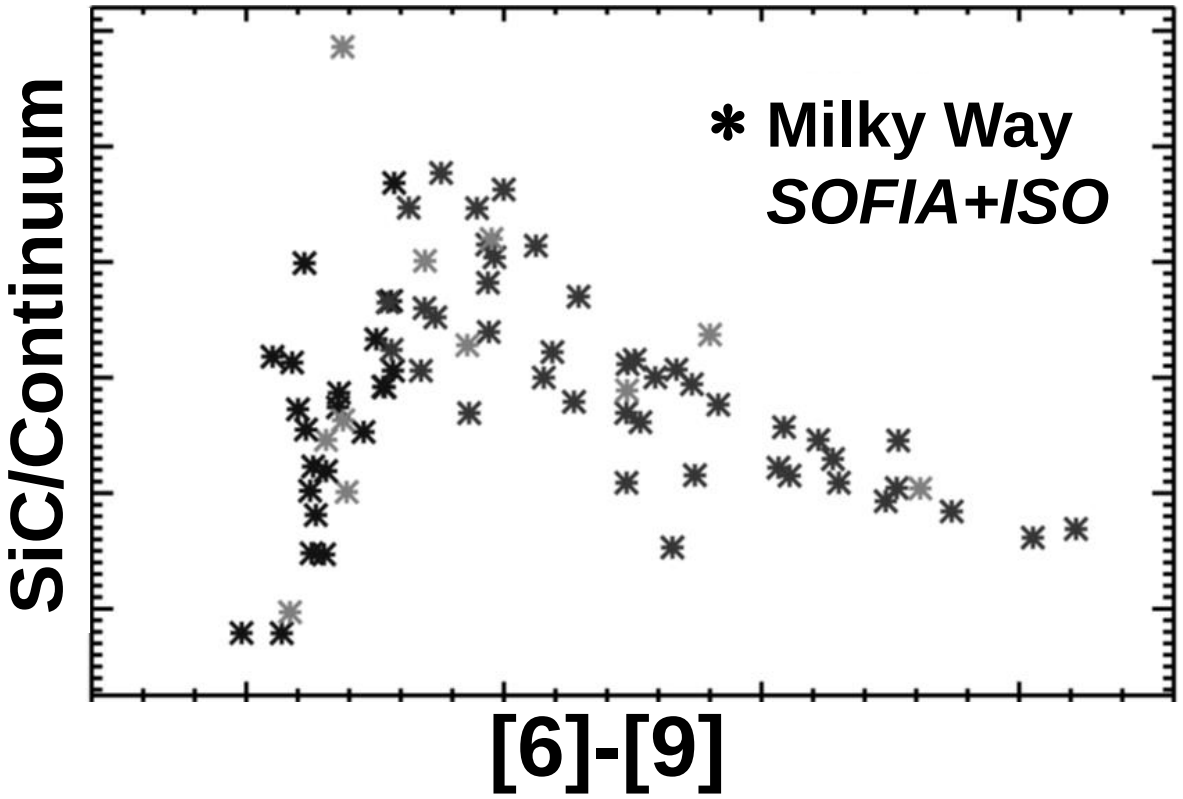


Extracting the Dust

- **[6]-[9] ~ Total Dust (amorphous carbon)**
- **SiC = Silicon Carbide (crystalline(?) dust)**

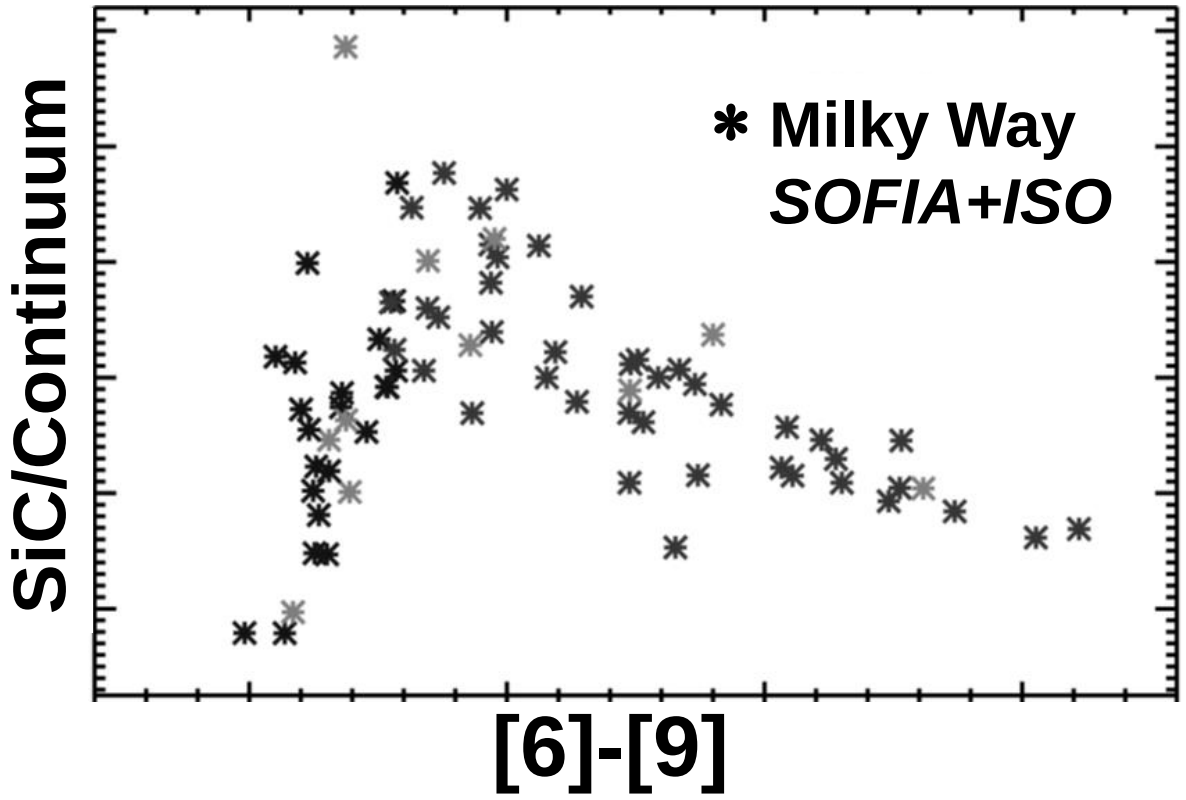
Sloan et al. 2006, Zijlstra et al. 2006; Groenewegen et al. 2007

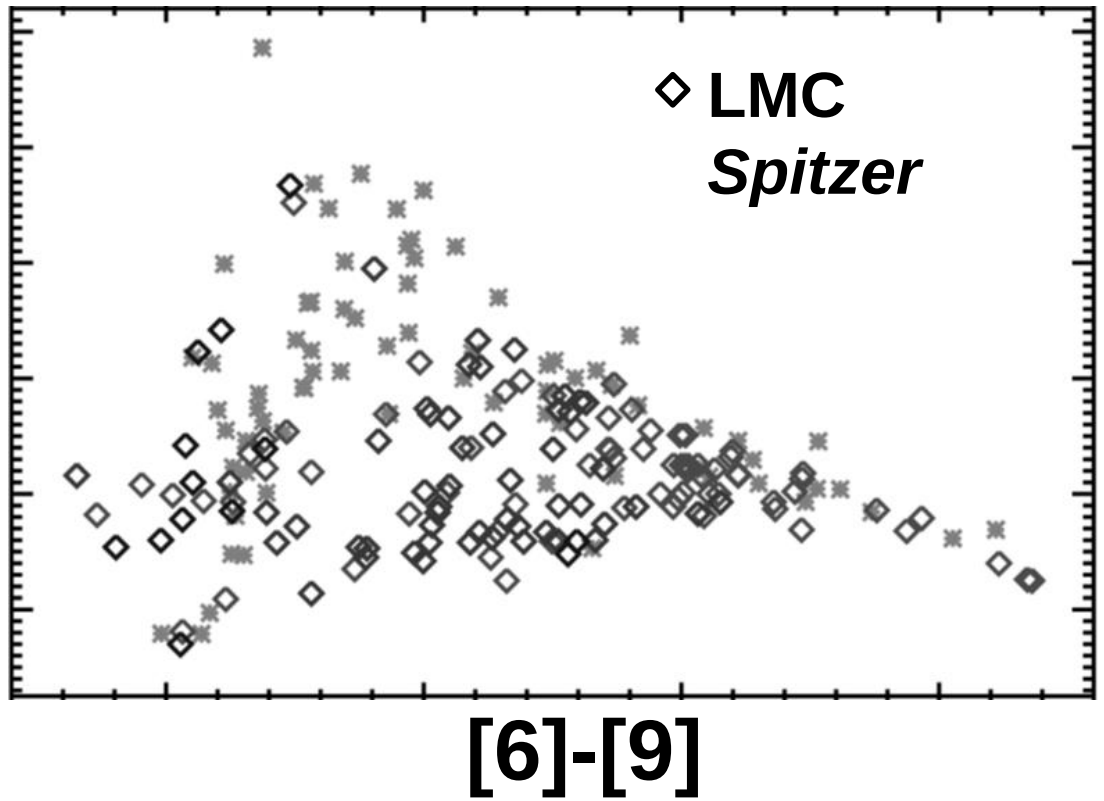
The Dust Features



- MW: SiC grows rapidly then falls as total dust [6]-[9] increases

The Dust Features

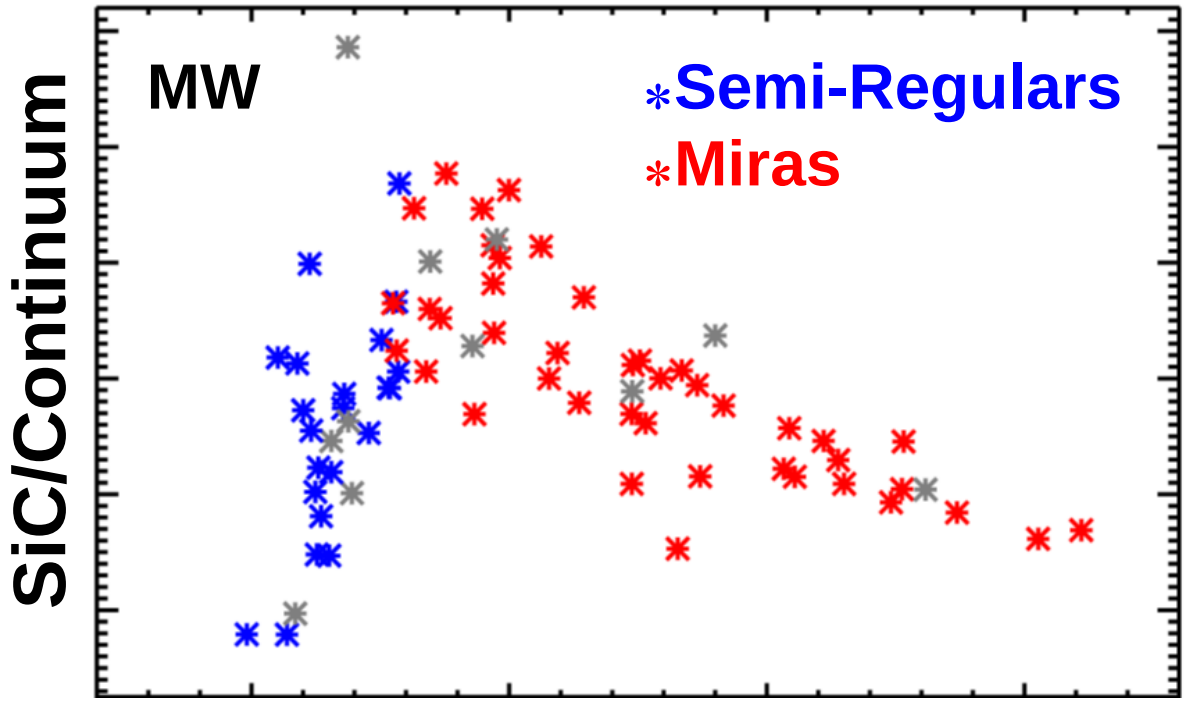


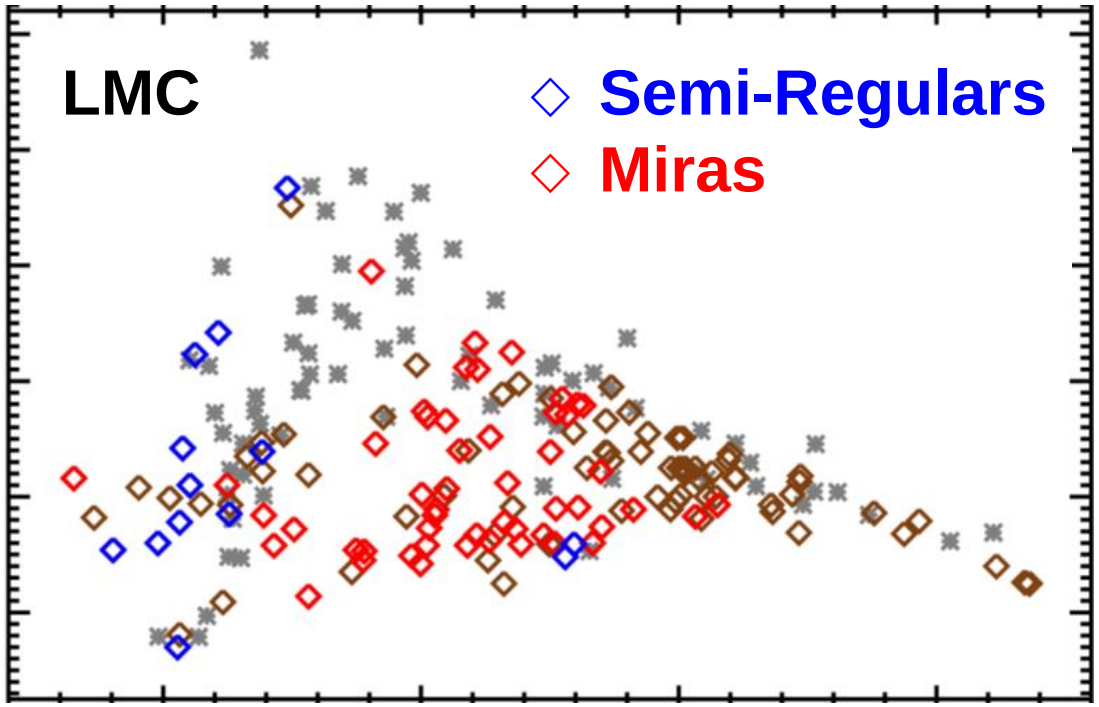


- MW: SiC grows rapidly then falls as total dust [6]-[9] increases
- LMC: many stars with weak SiC
- SMC: even fewer with SiC

Sloan et al. 16

The Dust Features

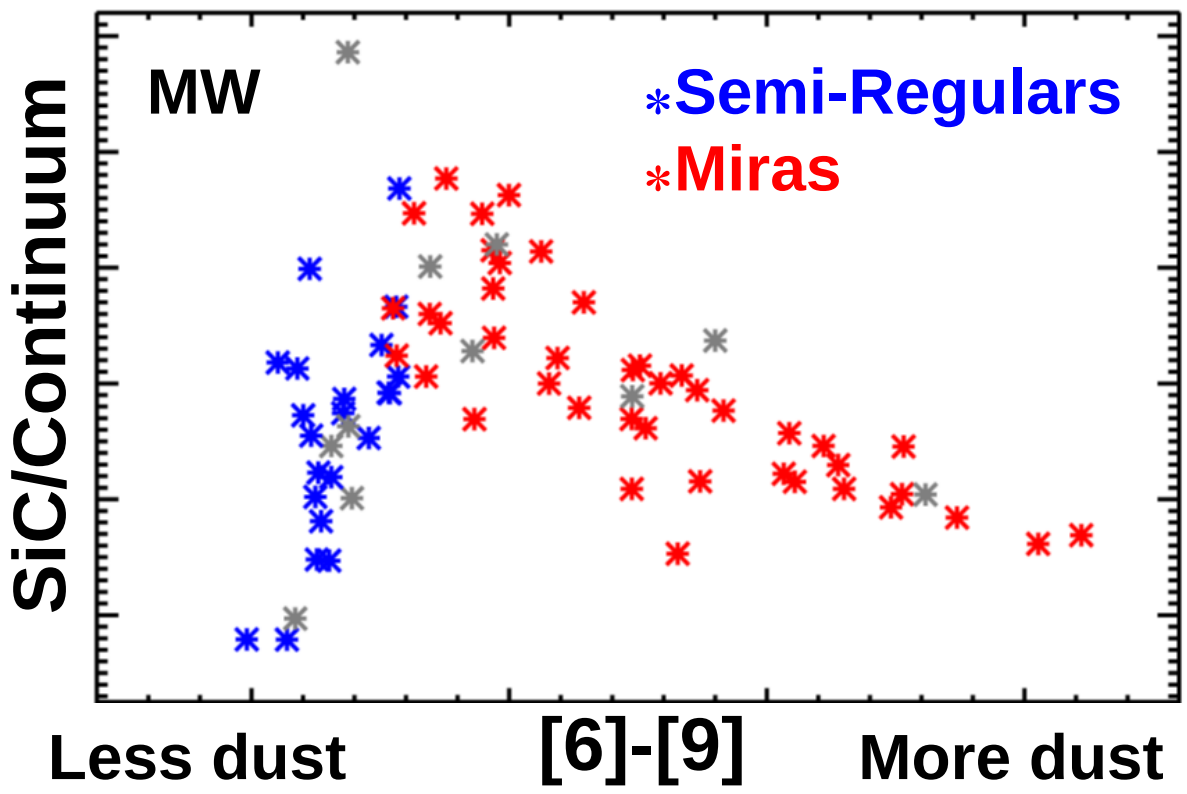


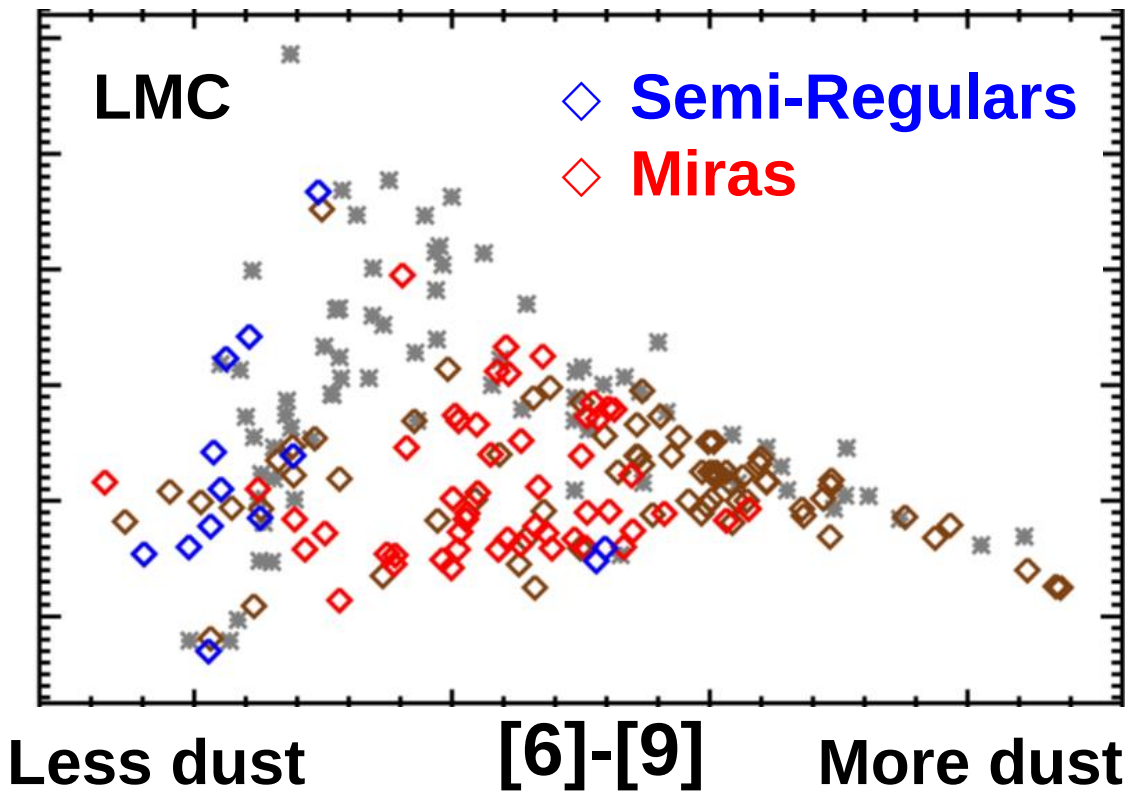


- SiC grows rapidly in SRbs
- SRb stage – earlier than Mira

➢ SiC Dust Condenses First
✓ Theoretical predictions
✓ Meteorite isotopic evidence

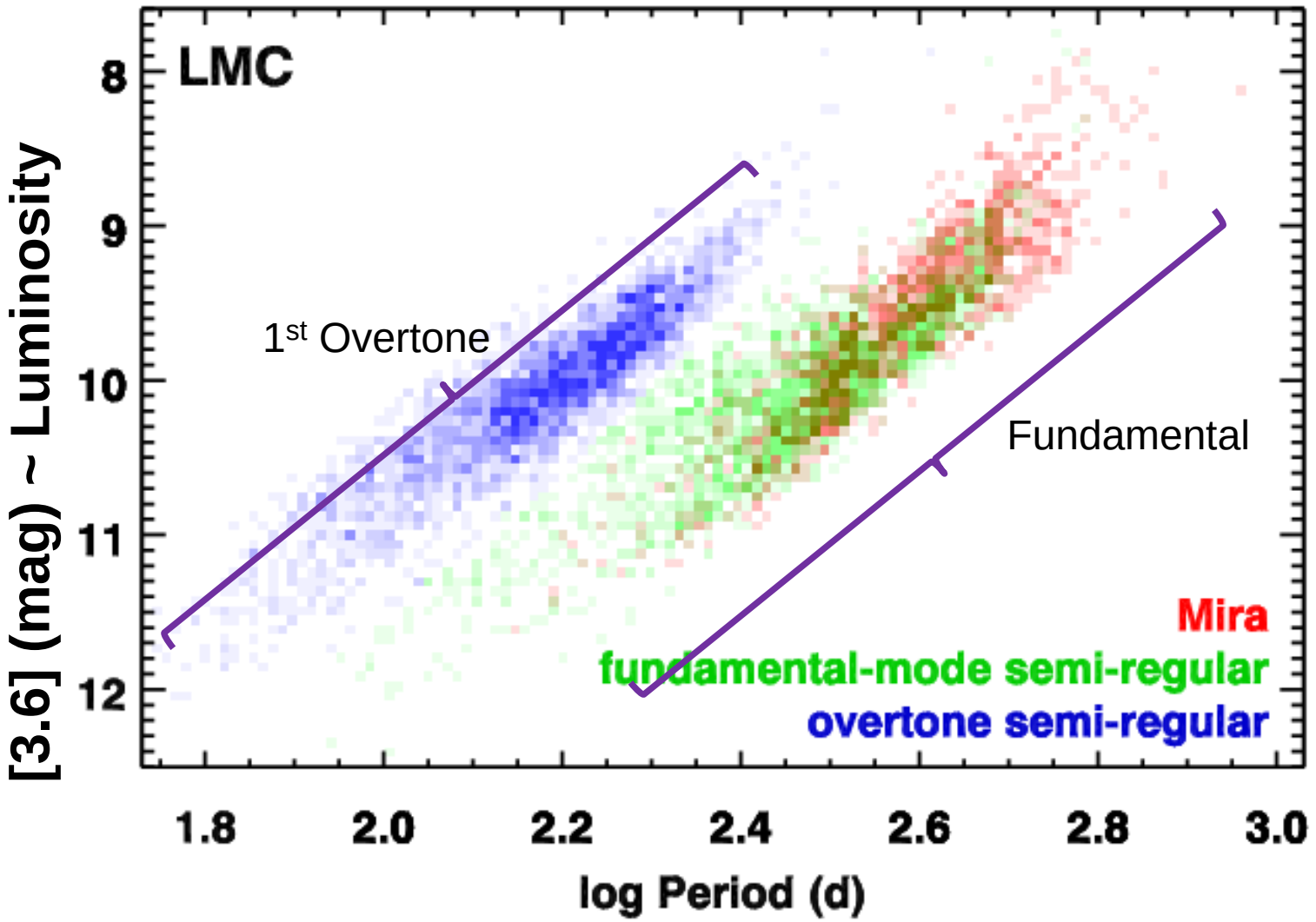
The Dust Features





- **Miras dominate the dust production – amorphous C**

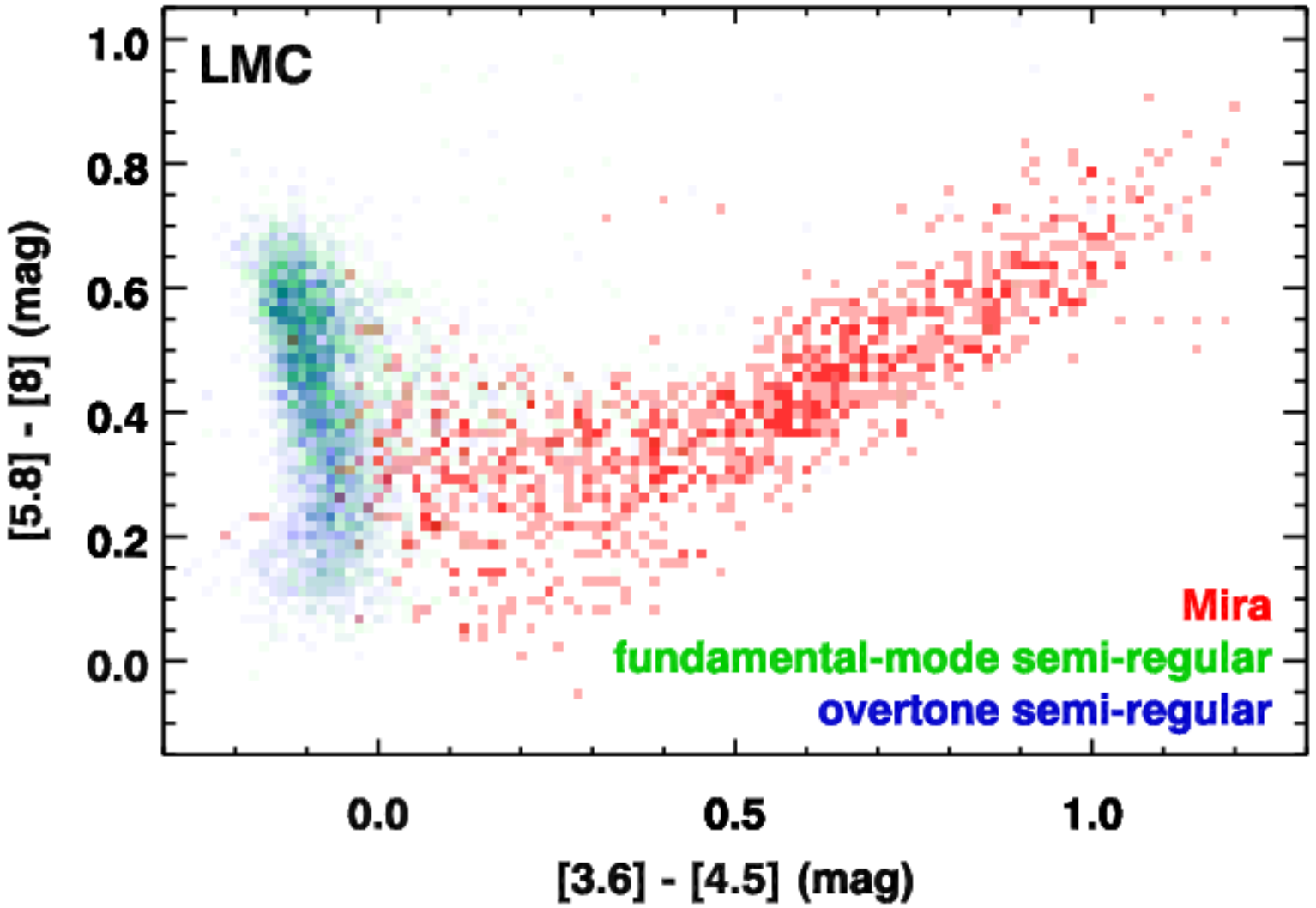
Pulsation Modes



- **Miras**
  - large amplitudes
  - fundamental mode pulsations
- **Semi-Regulars**
  - smaller amplitudes
  - overtone or fundamental

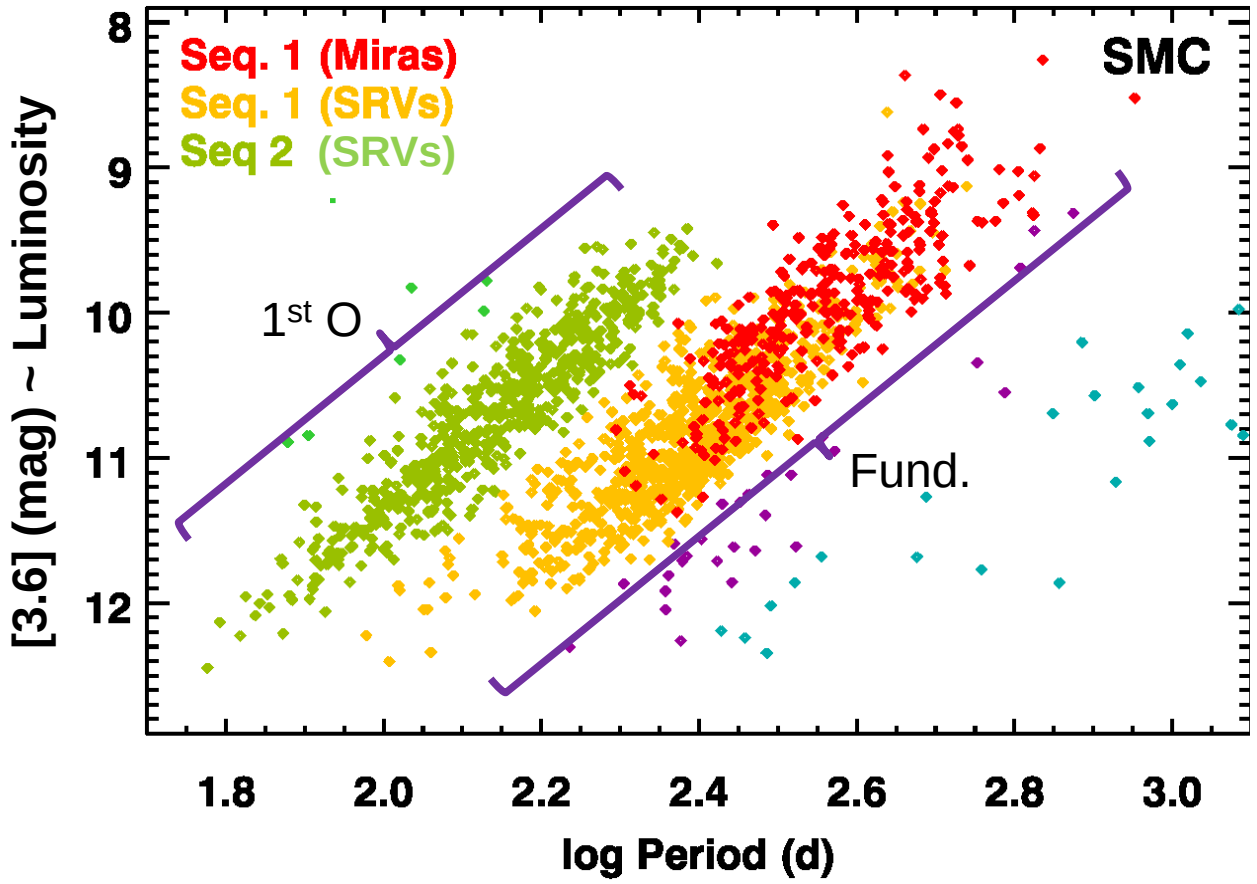
Meixner et al. 06; Soszynski et al. 09

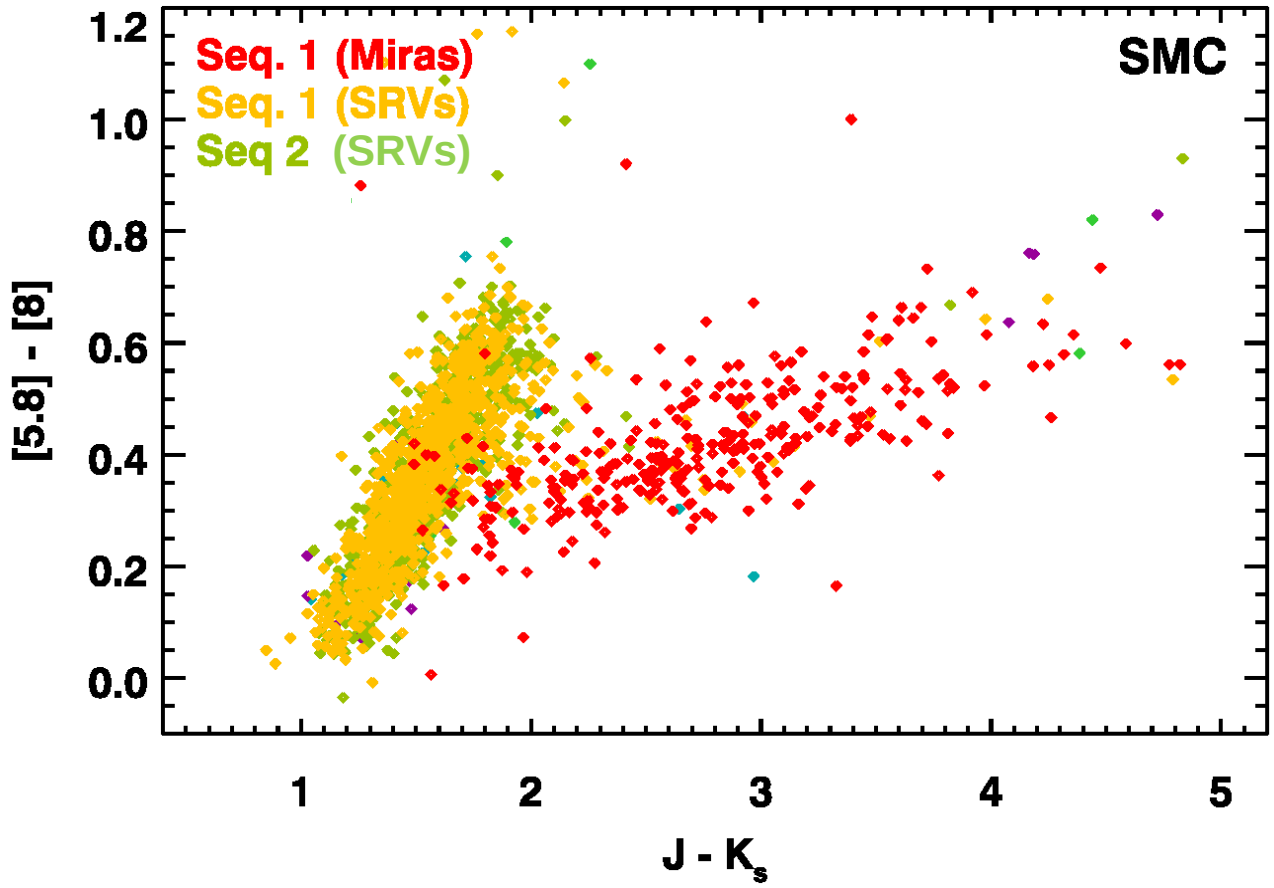
Dust Production



- **Miras**
  - High dust production rates
- **Semi-Regulars**
  - Little dust production, *regardless of mode*

Dust Production

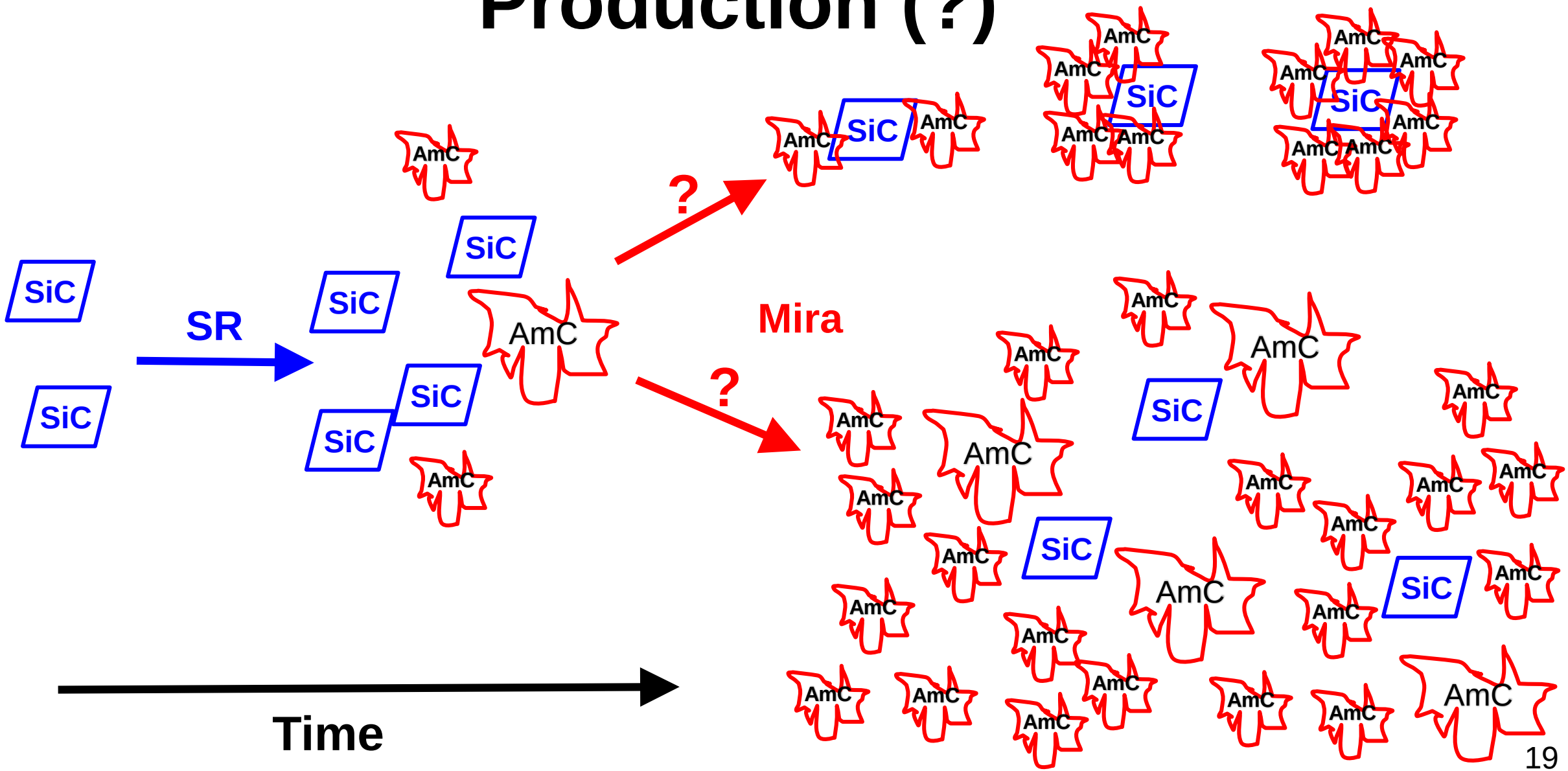




Same seen in the SMC

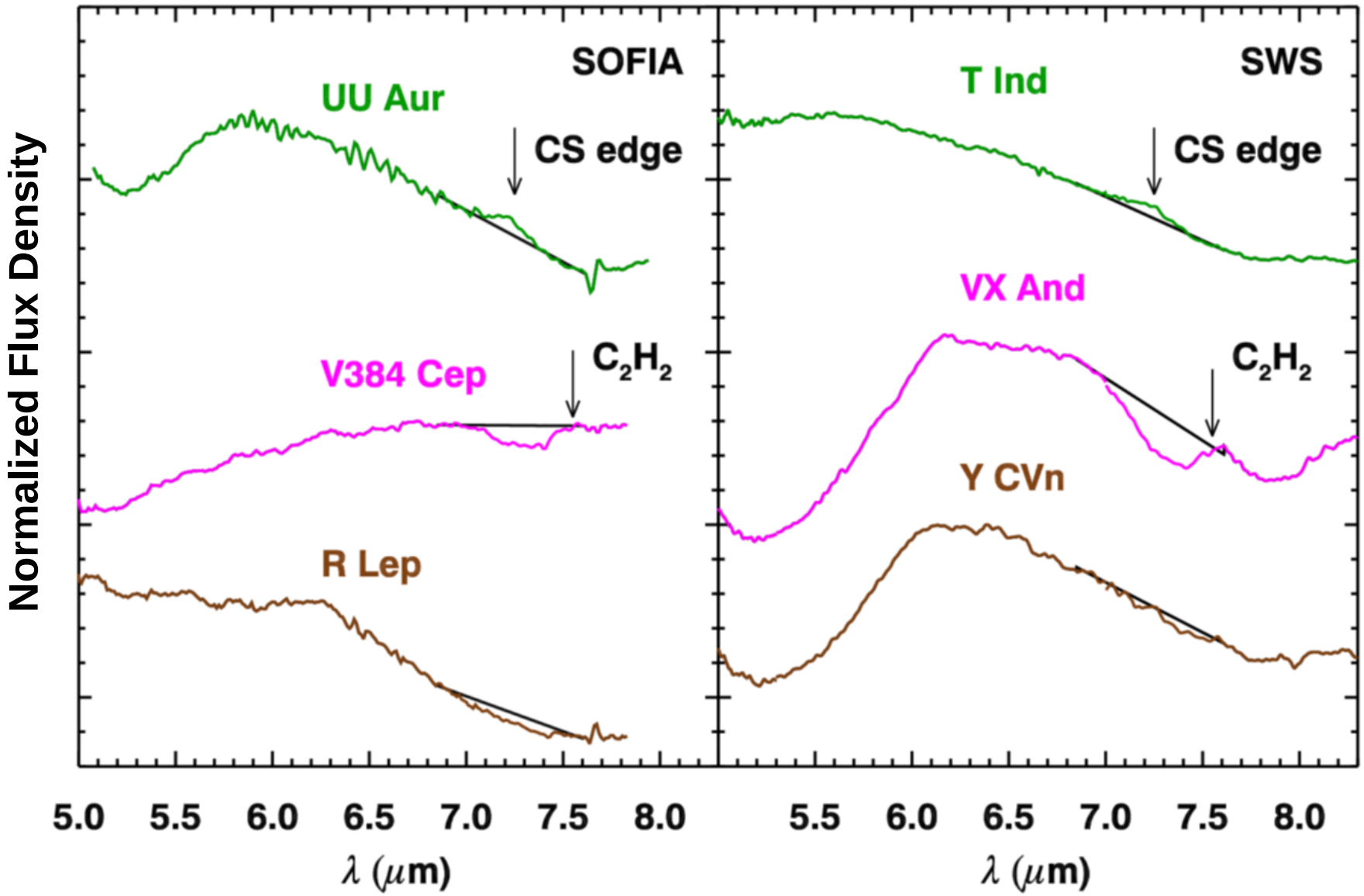
Sloan et al. 2015; Gordon et al. 11, Soszynski et al. 11

SR vs. Mira Dust Production (?)

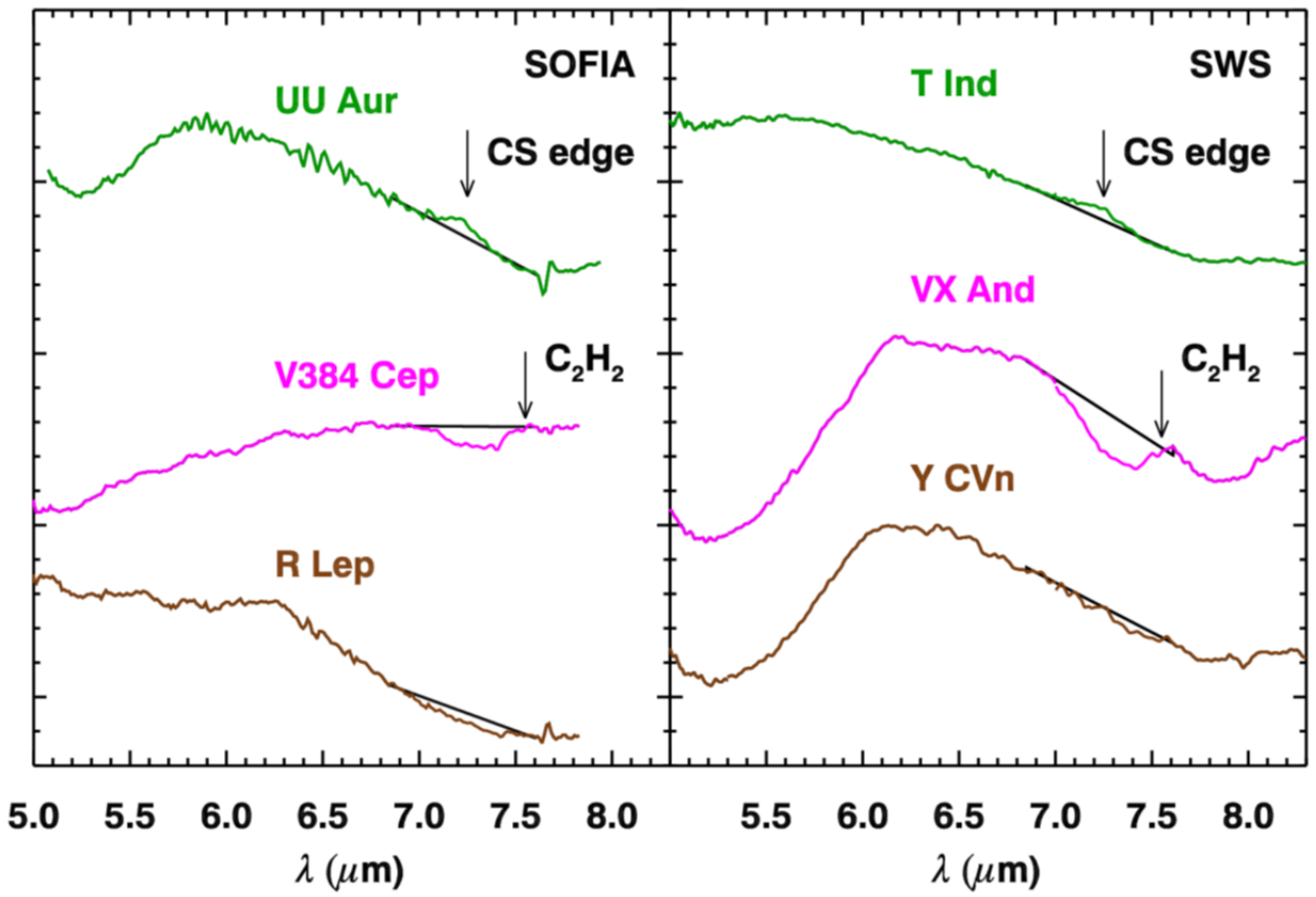


The Molecular Gas

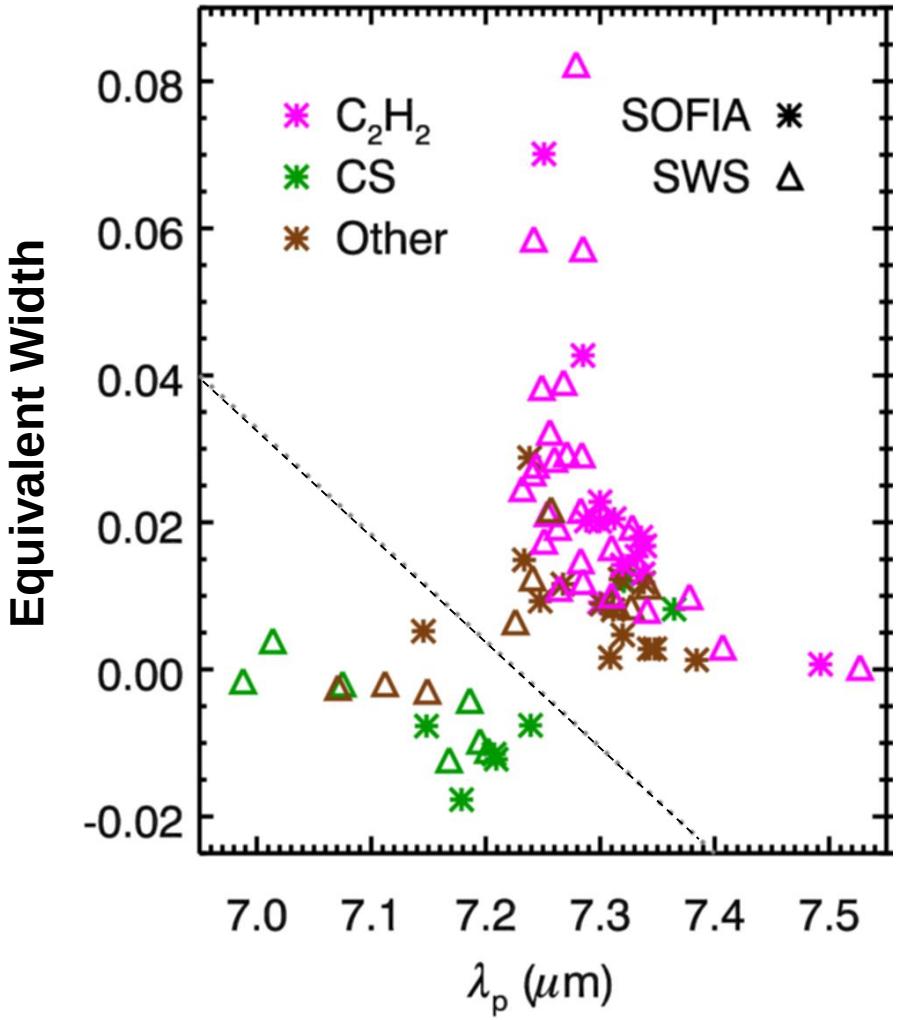
The Molecular Gas



The Molecular Gas



(qualitative)



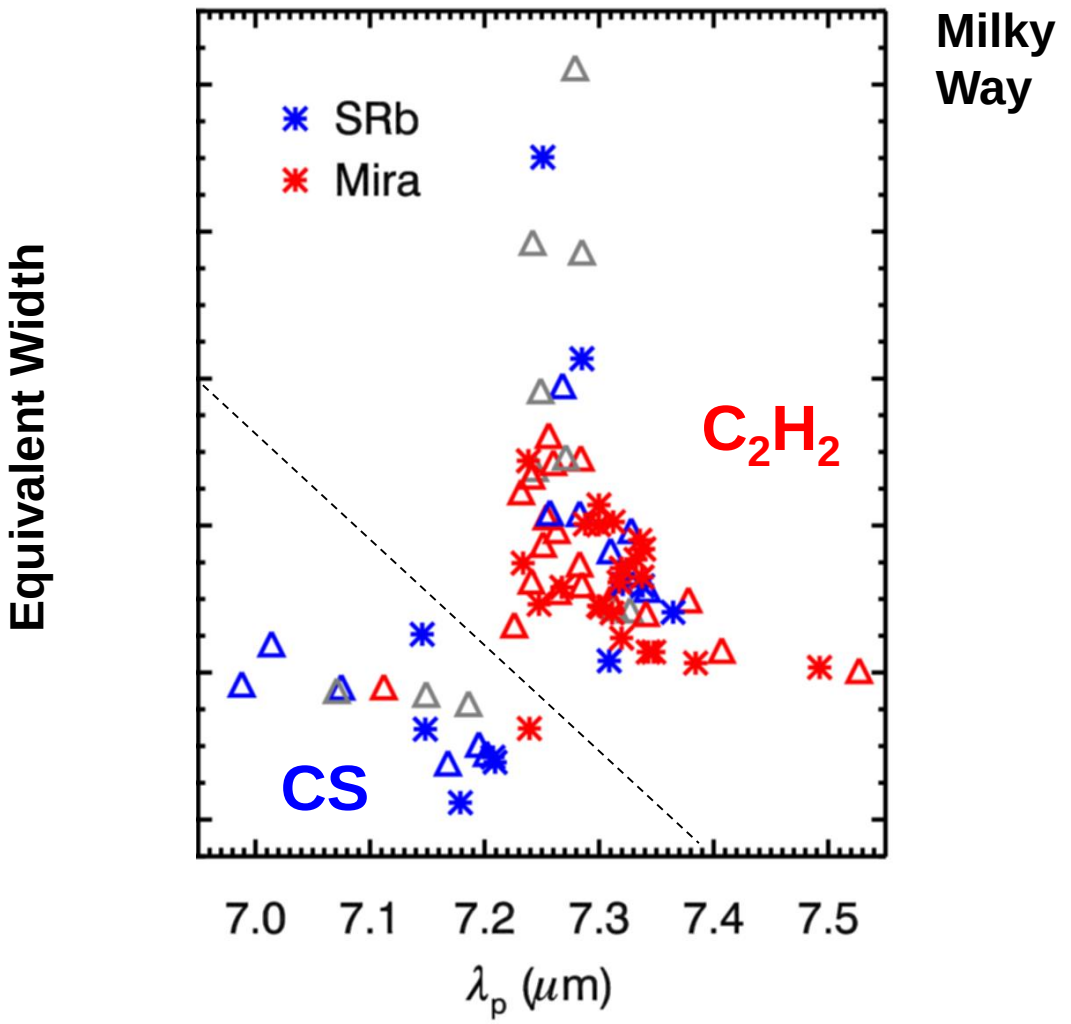
(quantitative)

The Molecular Gas

- **Only 2% of the Galactic Miras have CS**

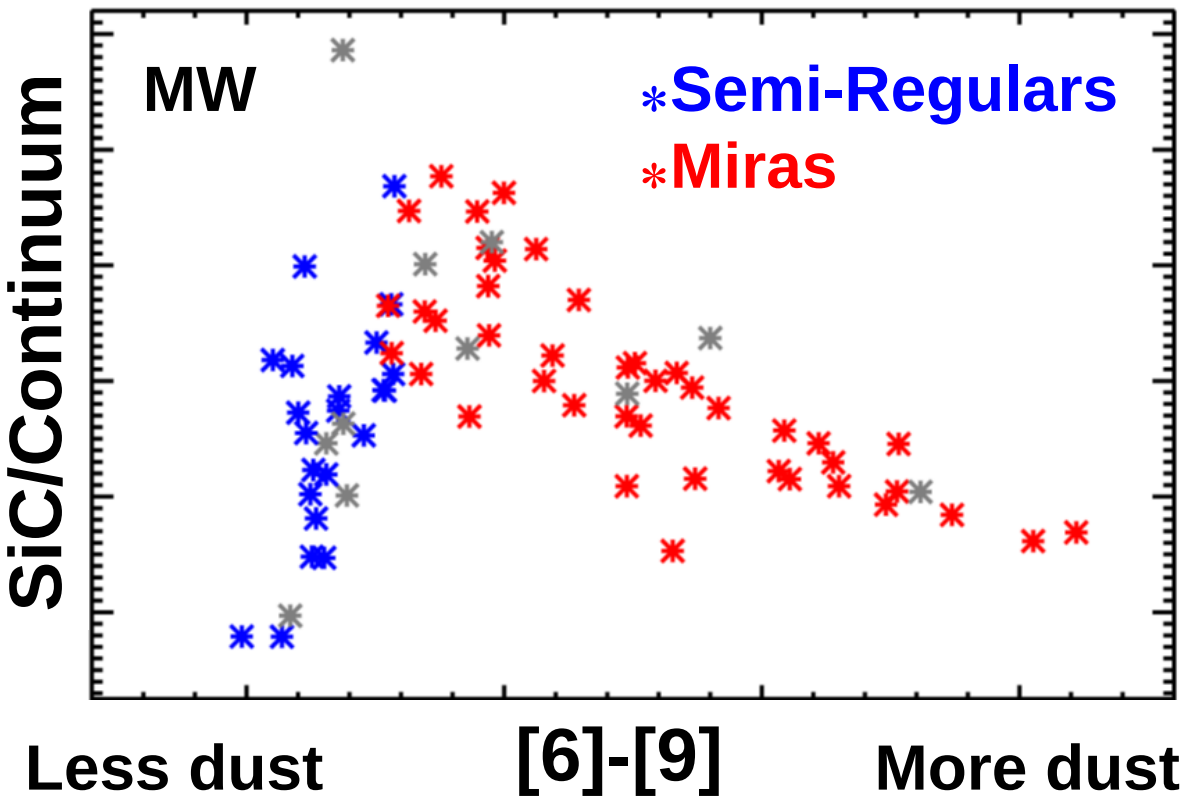
➢ **Different Processes in SRb vs. Miras for Molecular Formation, too**

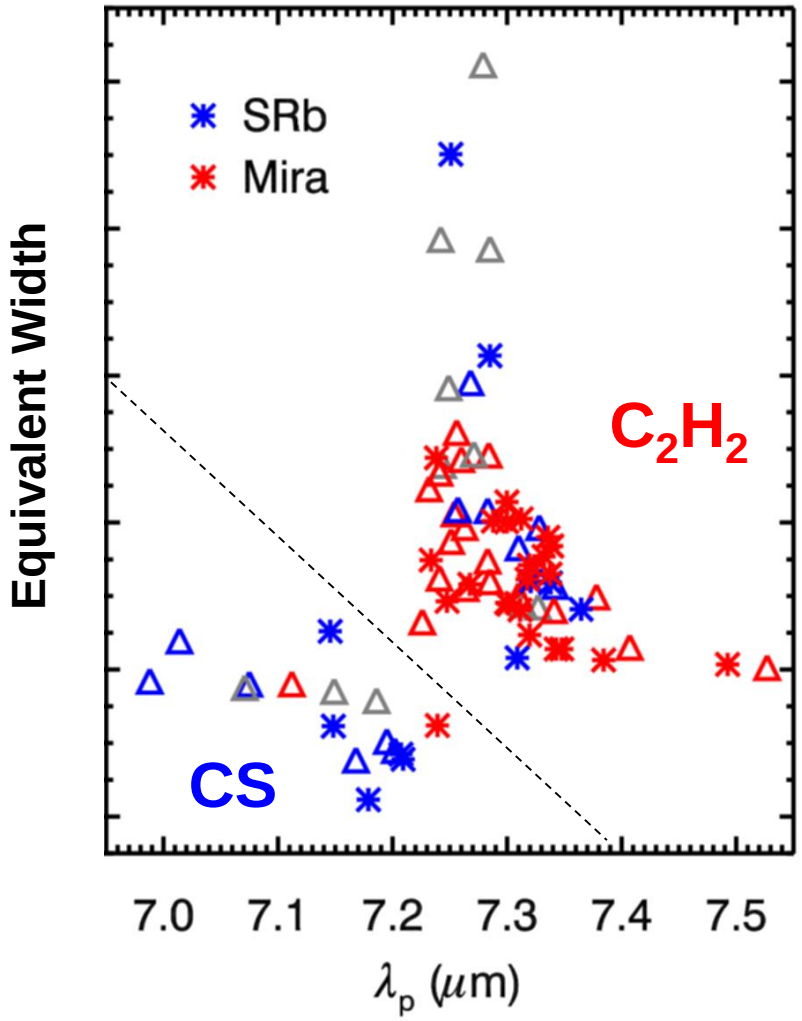
▪ **Magellanic Clouds: C_2H_2 only, no CS**



Zijlstra et al. 06
Matsuura et al. 06

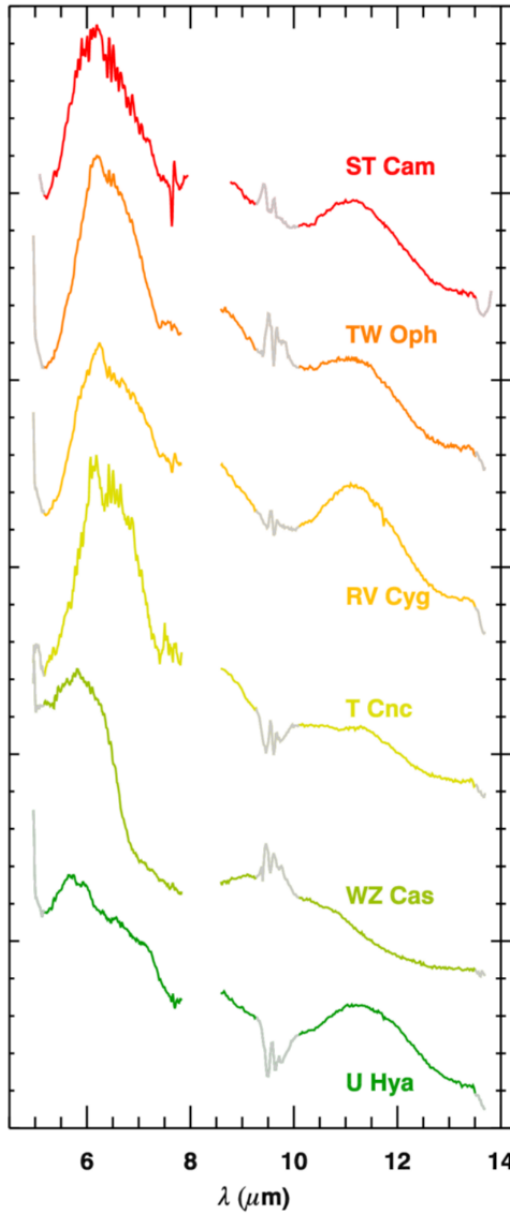
SR vs. Mira





- **Can distinguish variable types with a single spectrum**

Takeaways



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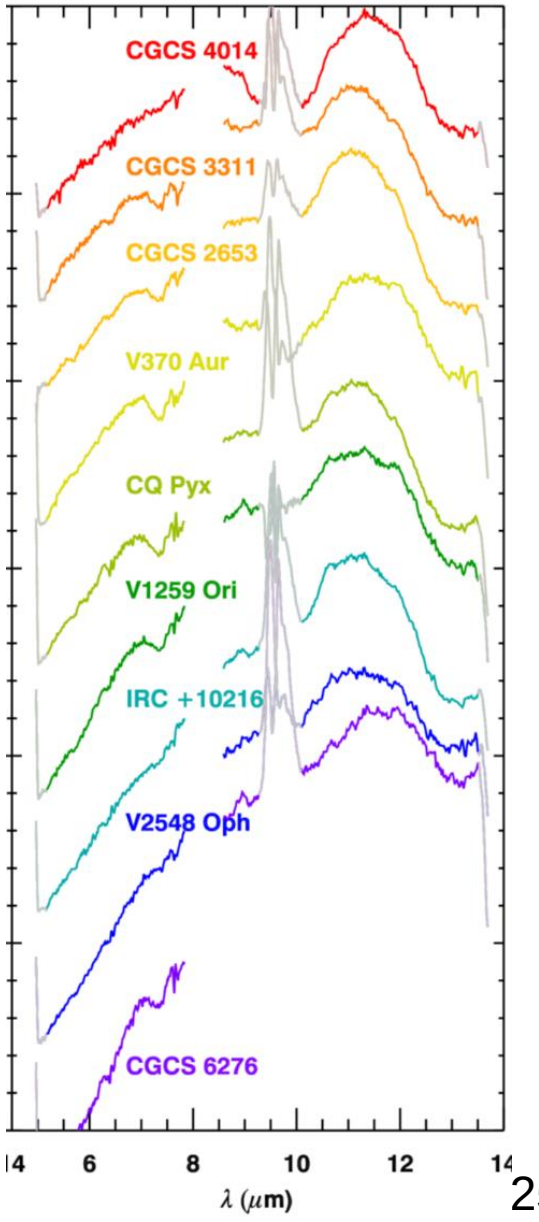
Semi-regular carbon stars produce (some) silicon-carbide dust & CS



Kraemer et al. 2019

Thank you