THE ROLE OF AGB STARS IN THE LIFECYCLE OF DUST

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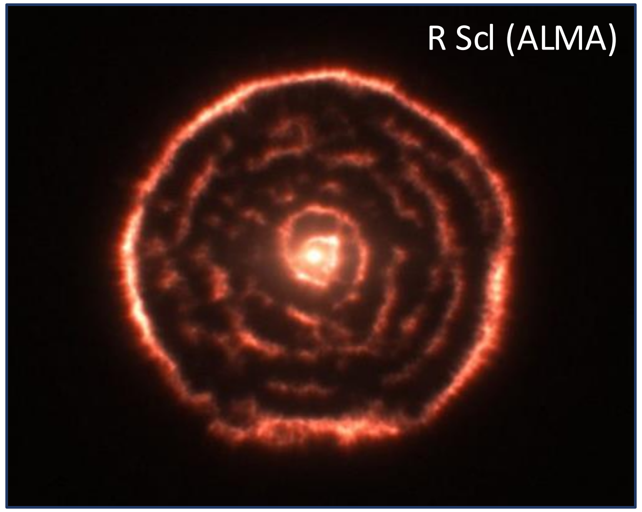
STScI

2025 Nov 14

The Dusty Universe
Pan Dust #5

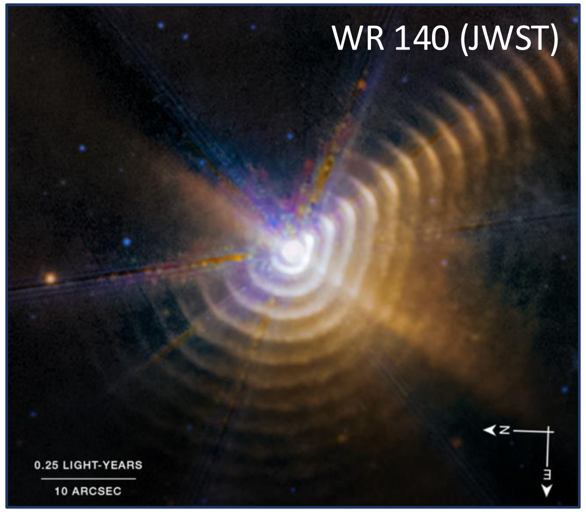
What is the Dominant Source of Dust?

AGB Stars



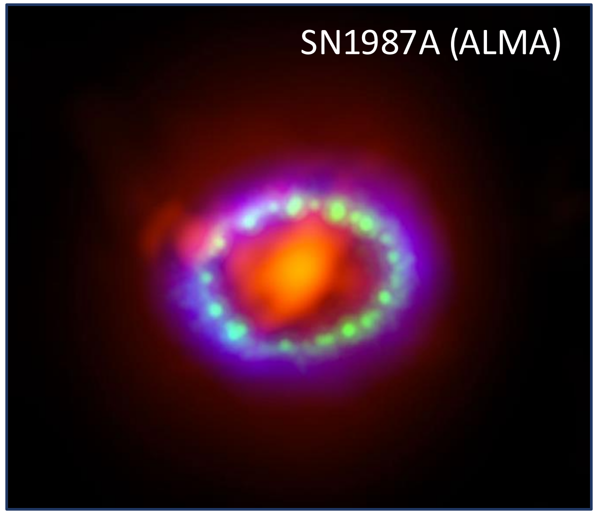
Maercker et al. (2012)

Wolf Rayet Stars



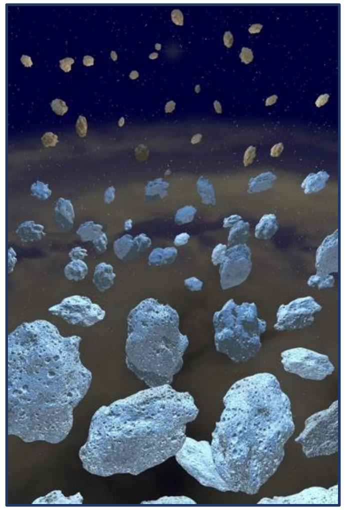
Lieb et al. (2025)

Supernovae



Indebetouw et al. (2013)

Growth in the ISM

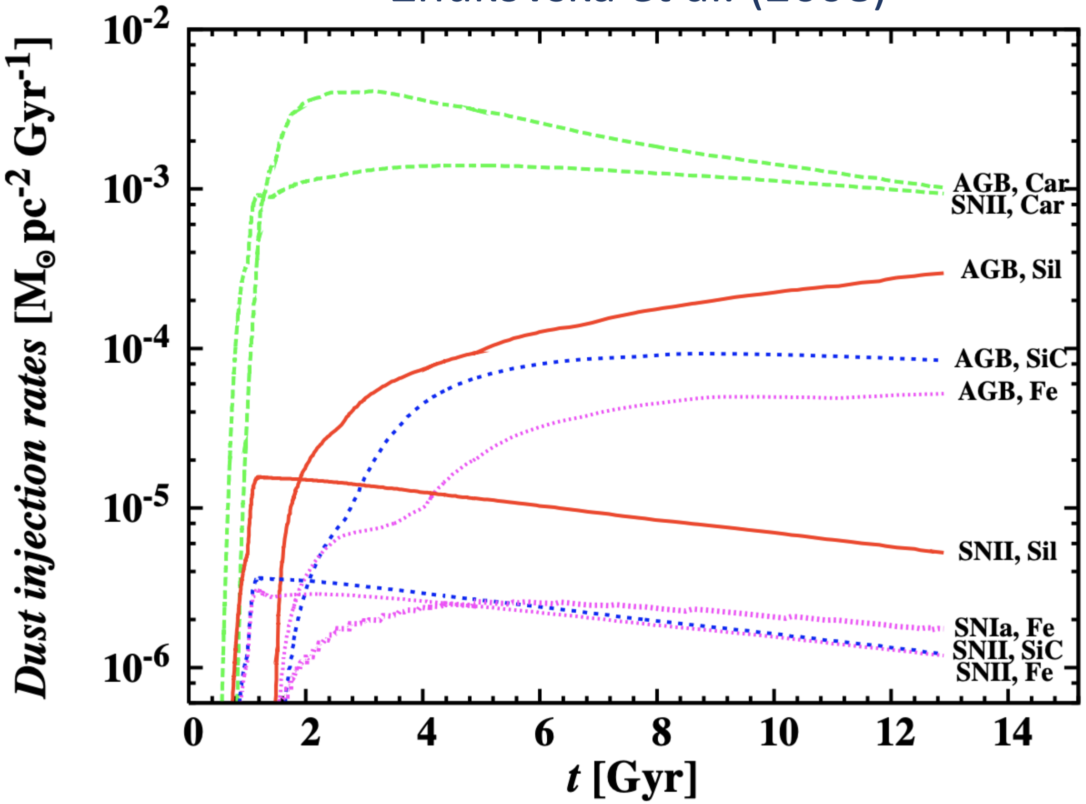


Dartois et al. (2024)

AGB and SNe in Dust Evolution Models

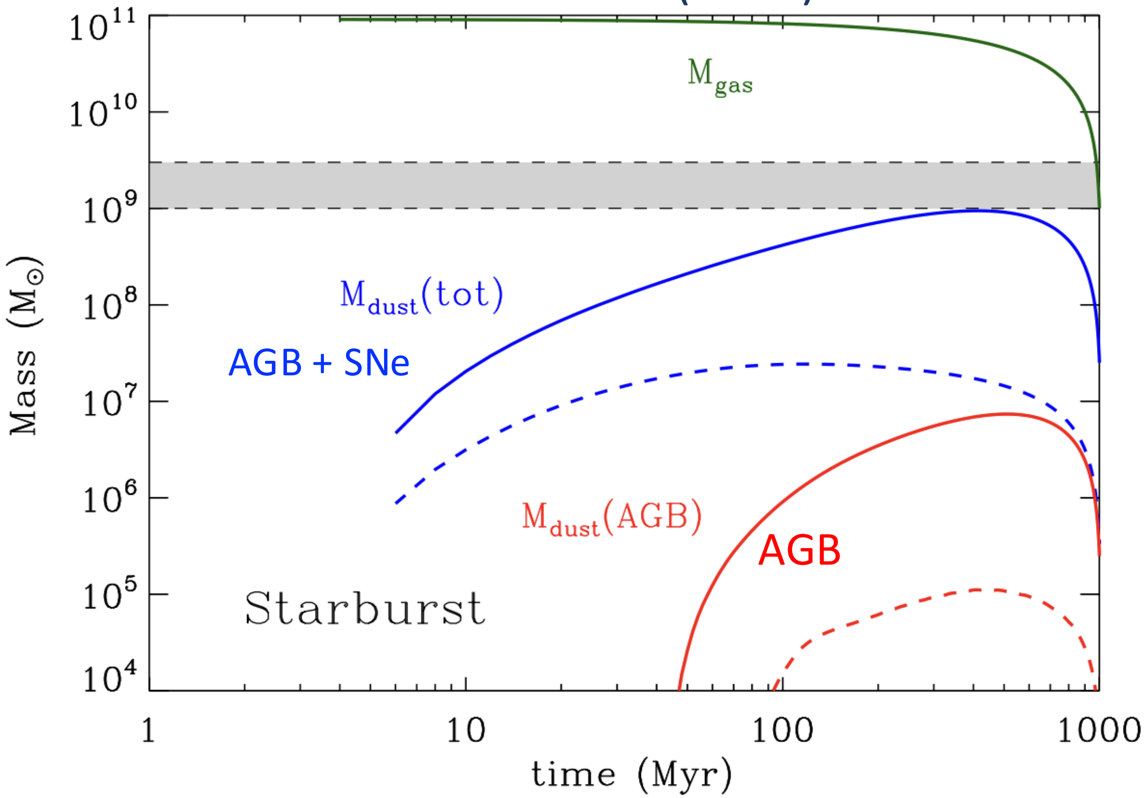
Similar AGB & SNe input

Zhukovska et al. (2008)



SNe dominate

Dwek et al. (2011)



AGB and SNe in Dust Evolution Models

Similar AGB & SNe input

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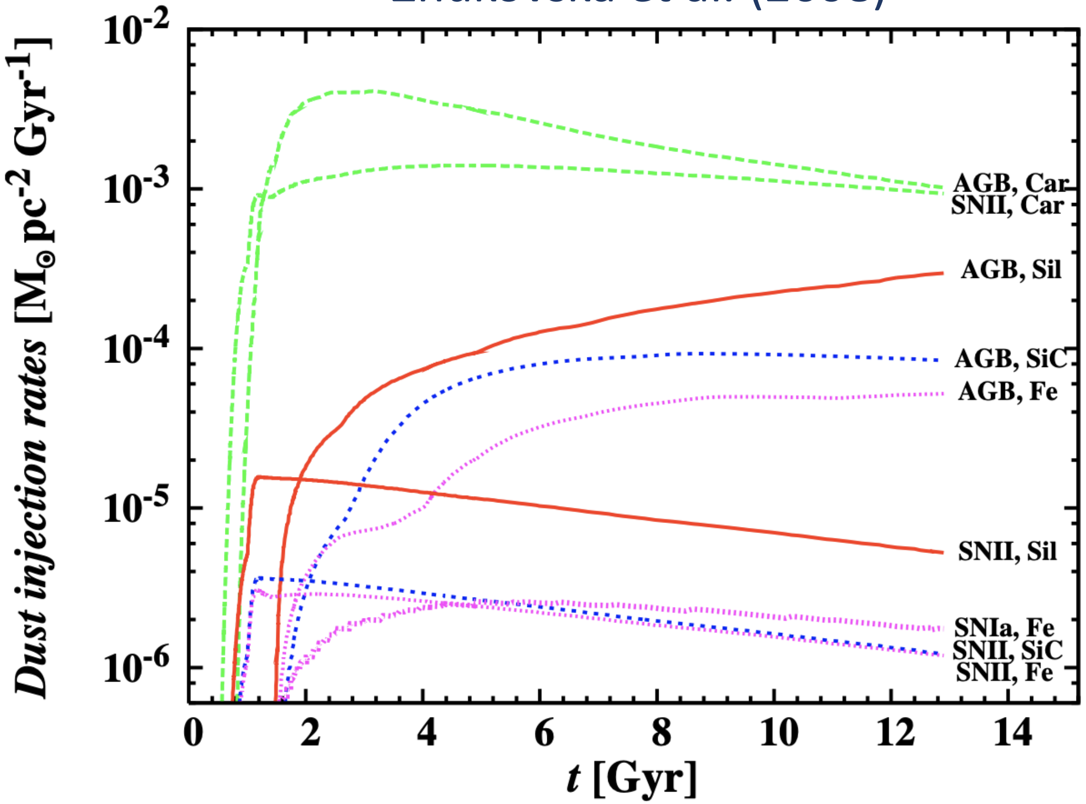
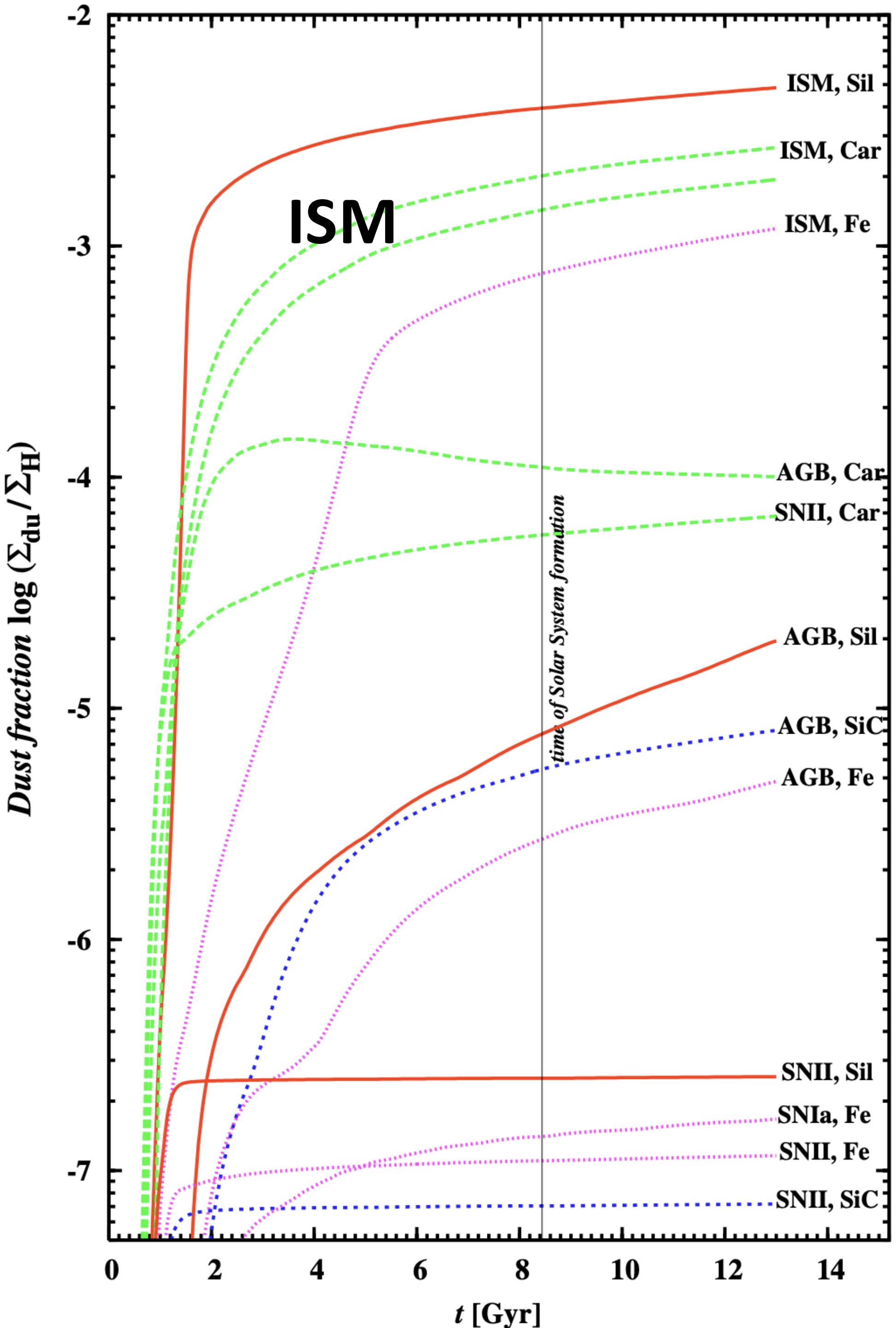
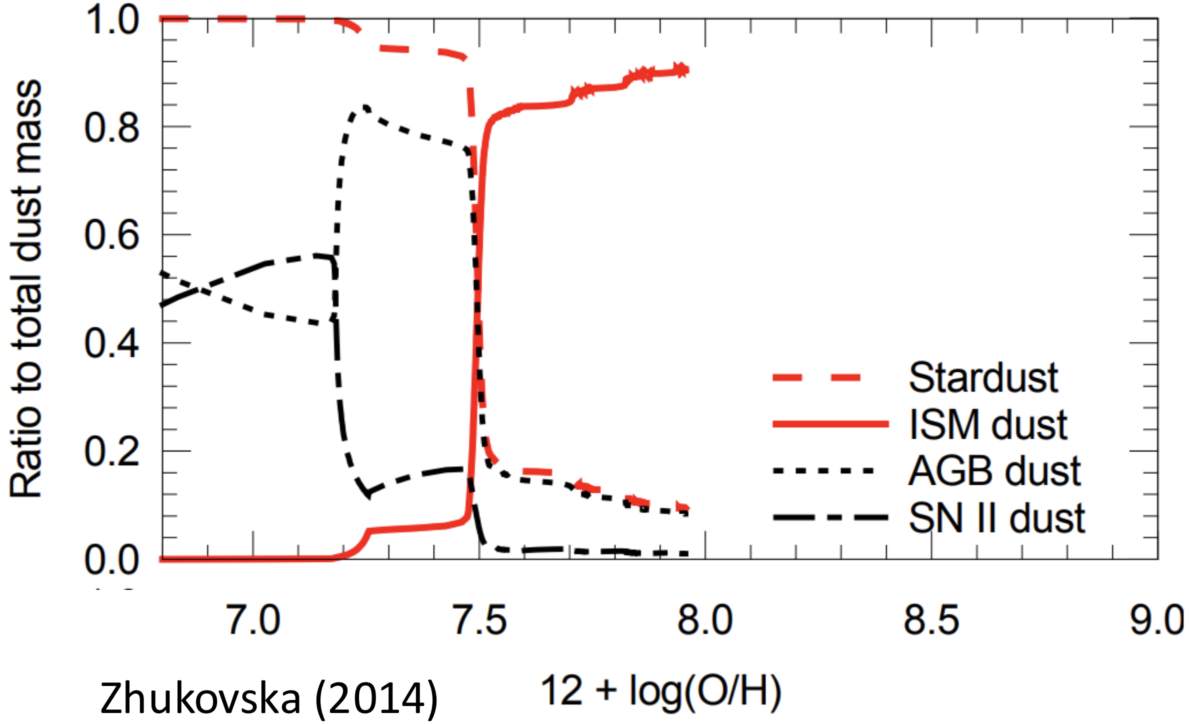




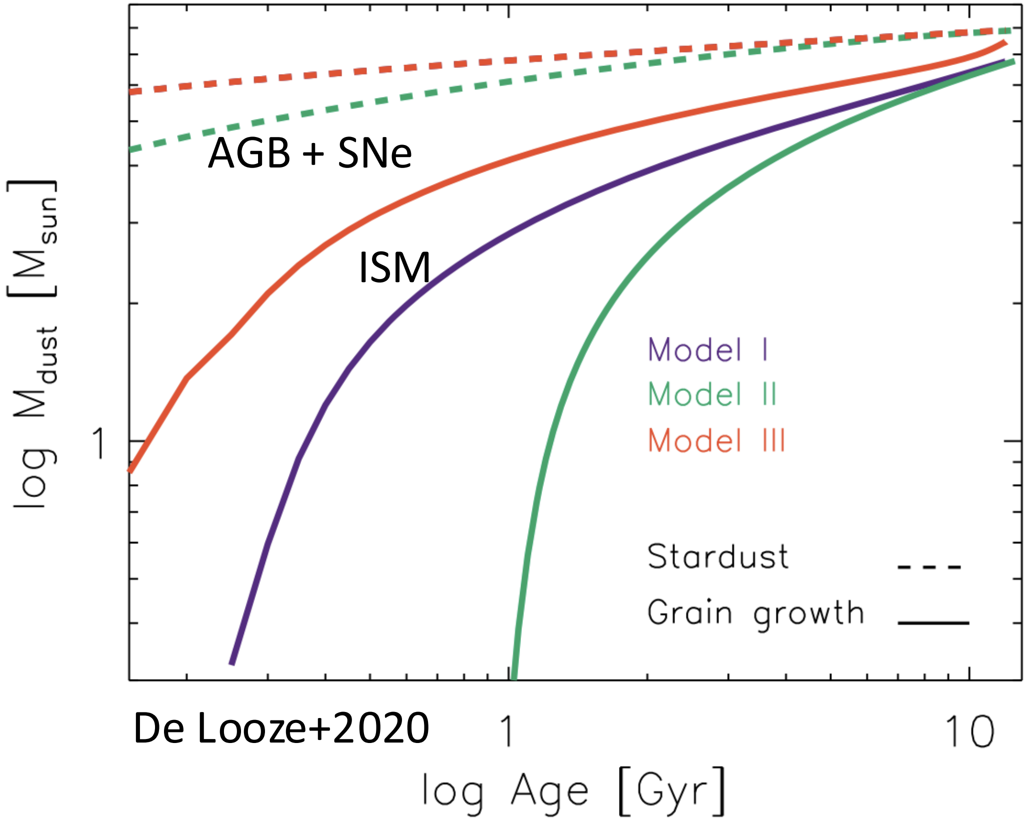
ISM Grain Growth in Dust Evolution Models

Some models show that AGB stars can dominate dust production over ISM grain growth and/or Type II SNe at low OR high metallicity



Zhukovska (2014)

High Metallicity

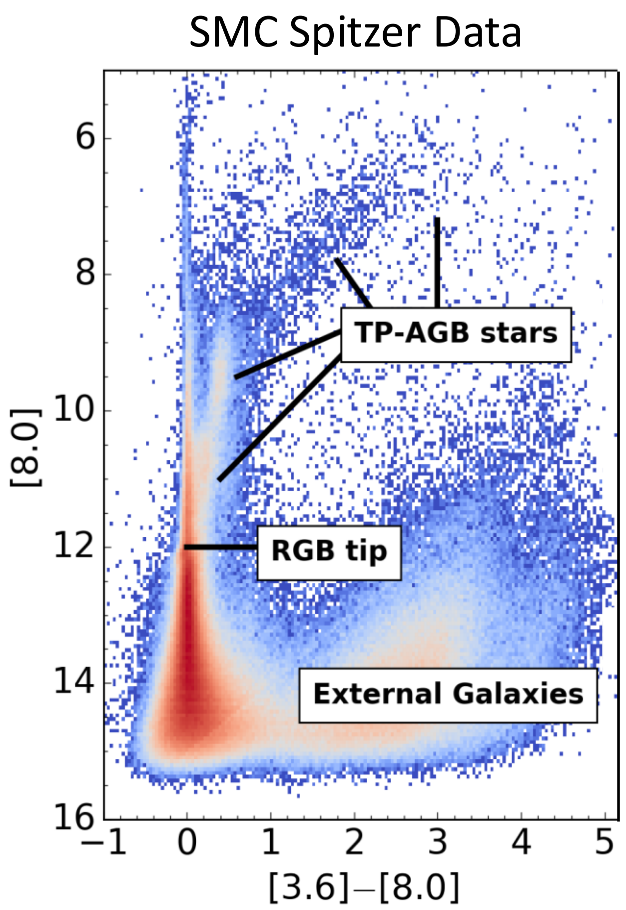


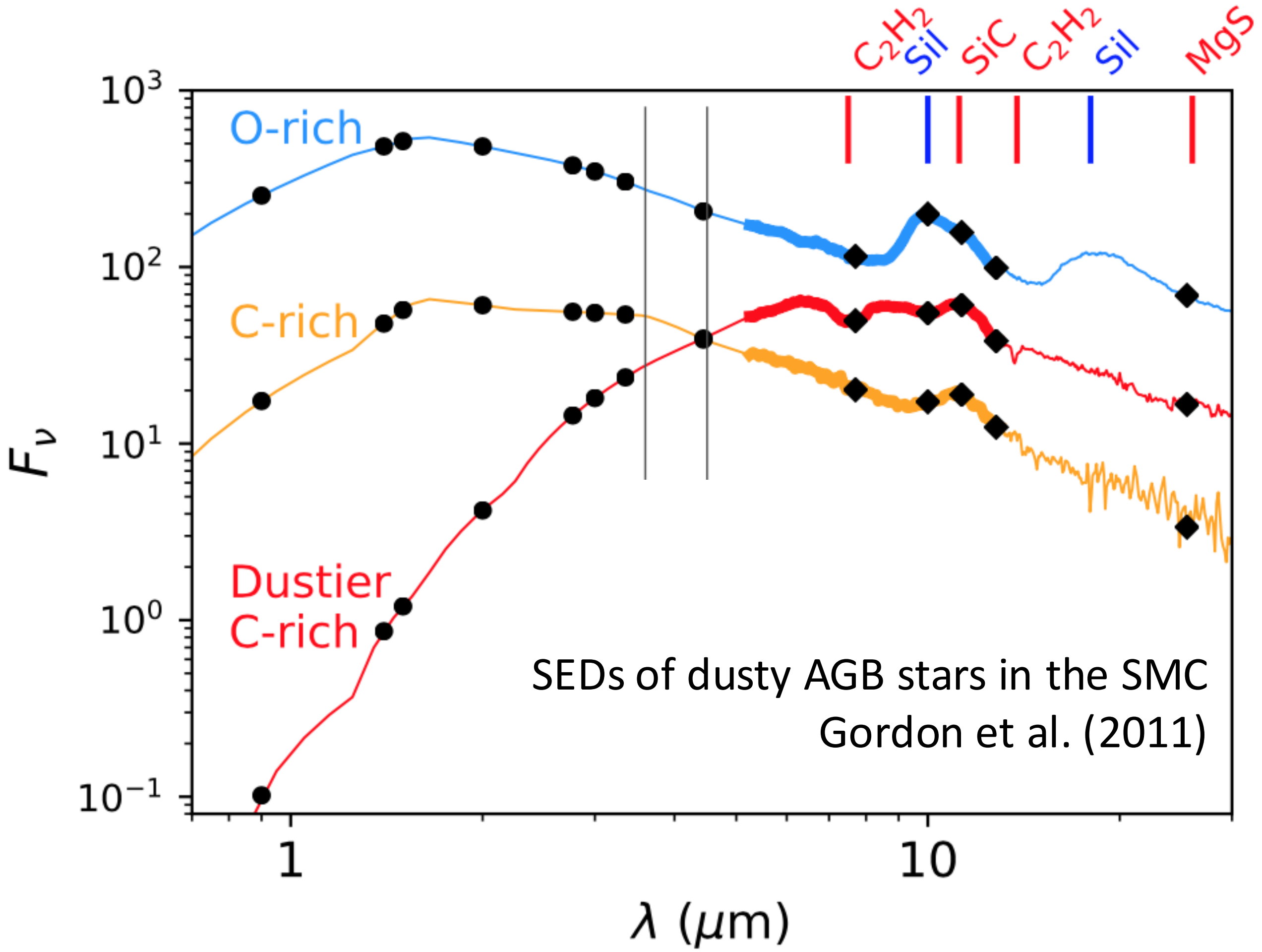
De Looze+2020

Also see poster #98 by Dian Triani

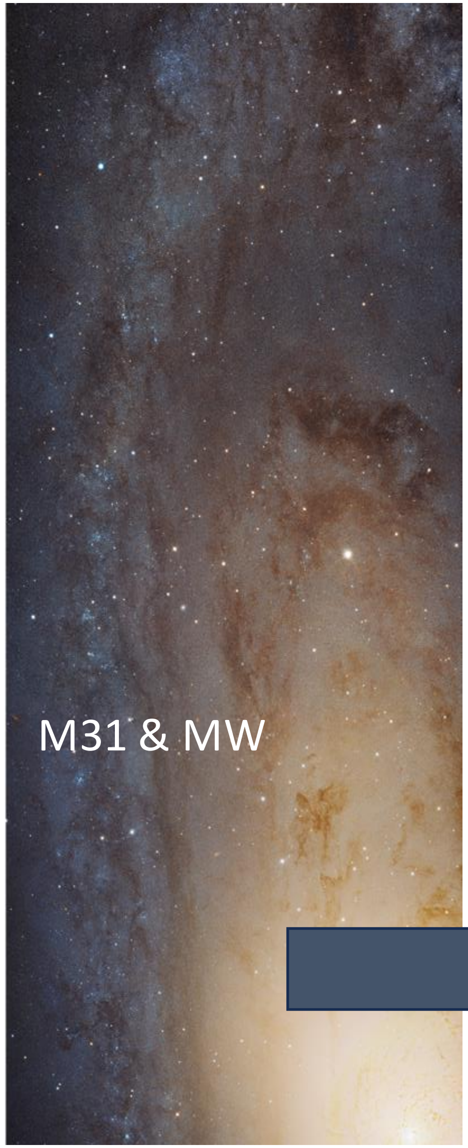
Measuring the AGB Dust Input

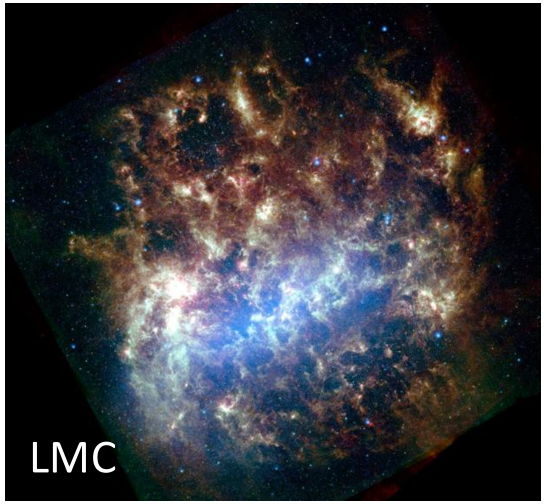
Requires multiwavelength data from optical to mid-IR

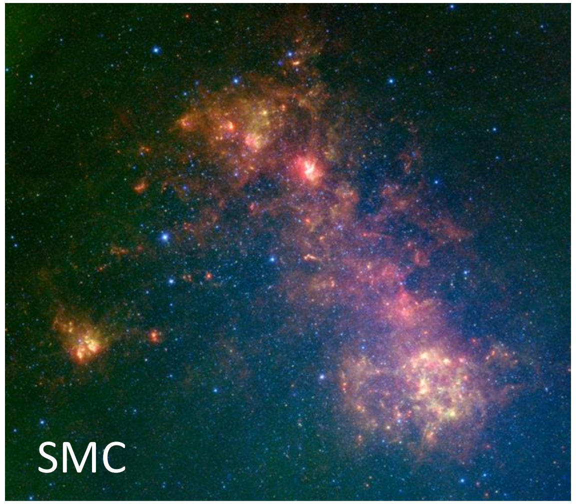




Measuring the AGB Dust Input



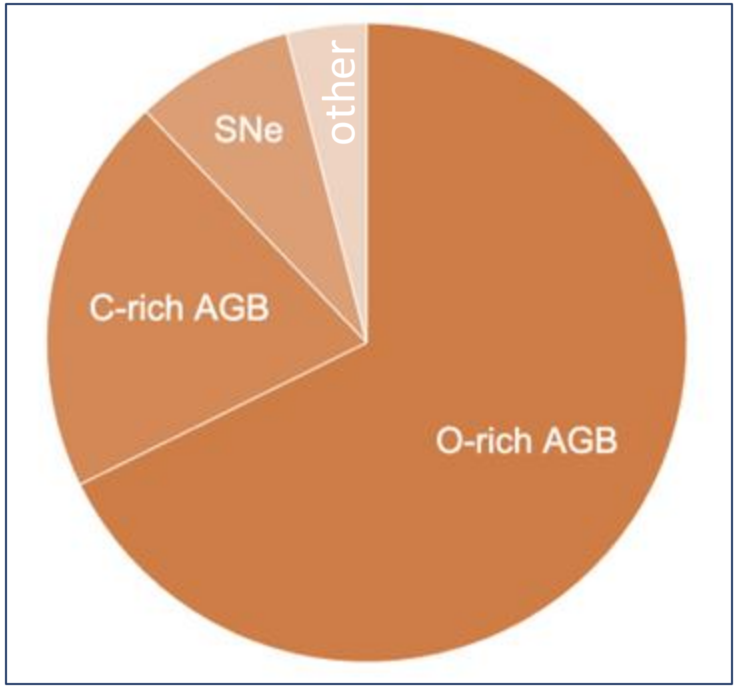




Decreasing Metallicity

AGB Dust in the Milky Way

Inventory of Milky Way
Dust Producers



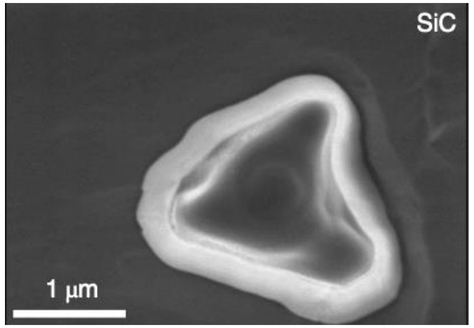
Gehrz (1989)
(also Tielens et al. 2005)

Inventory of Milky Way dust producers showed AGB stars dominating over SNe

O-rich AGB stars are the primary source of dust (silicates)

Total dust input is up to about 20% of the ISM dust mass

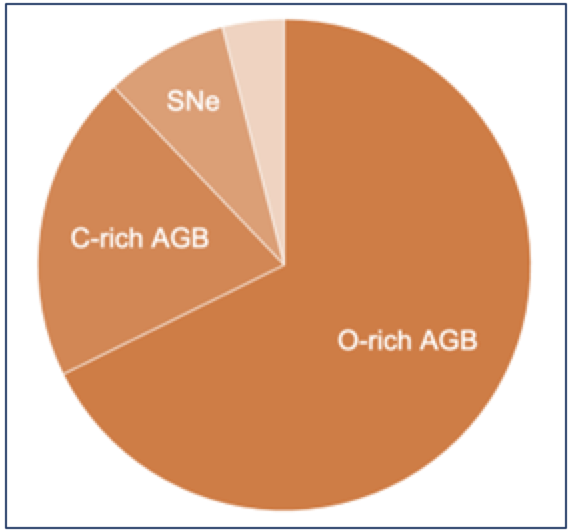
AGB Dust in the Milky Way



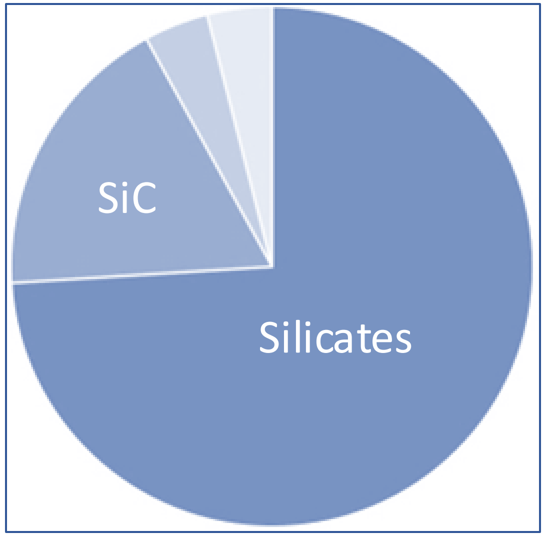
Presolar grains appear to be primarily from AGB stars

Most grains are silicates (O-rich AGB) and SiC (C-rich AGB)

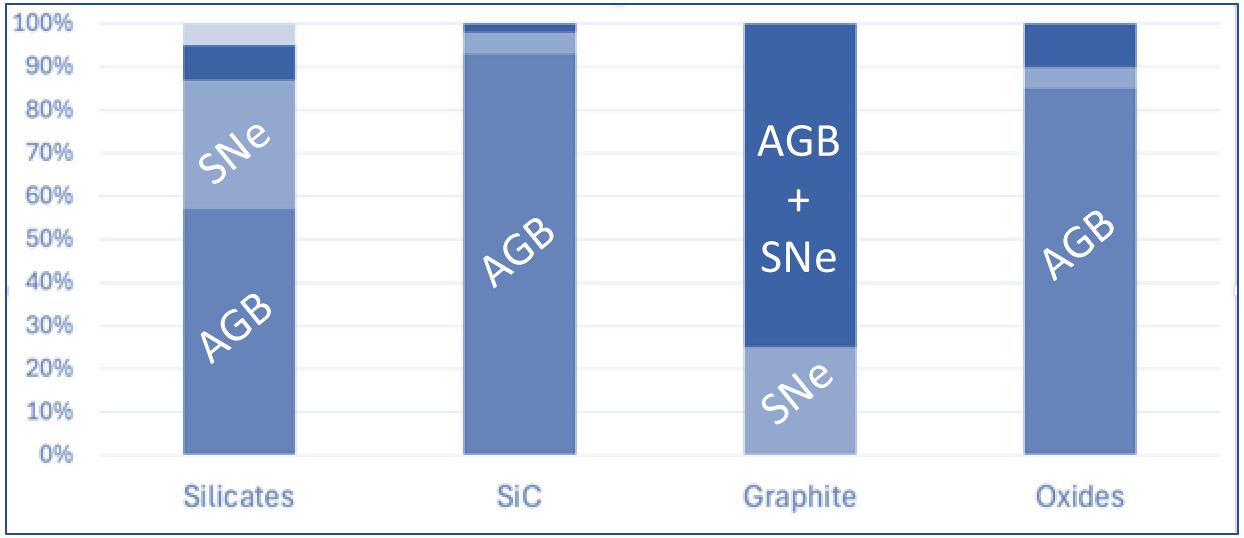
Inventory of Milky Way Dust Producers



Presolar Grain Type



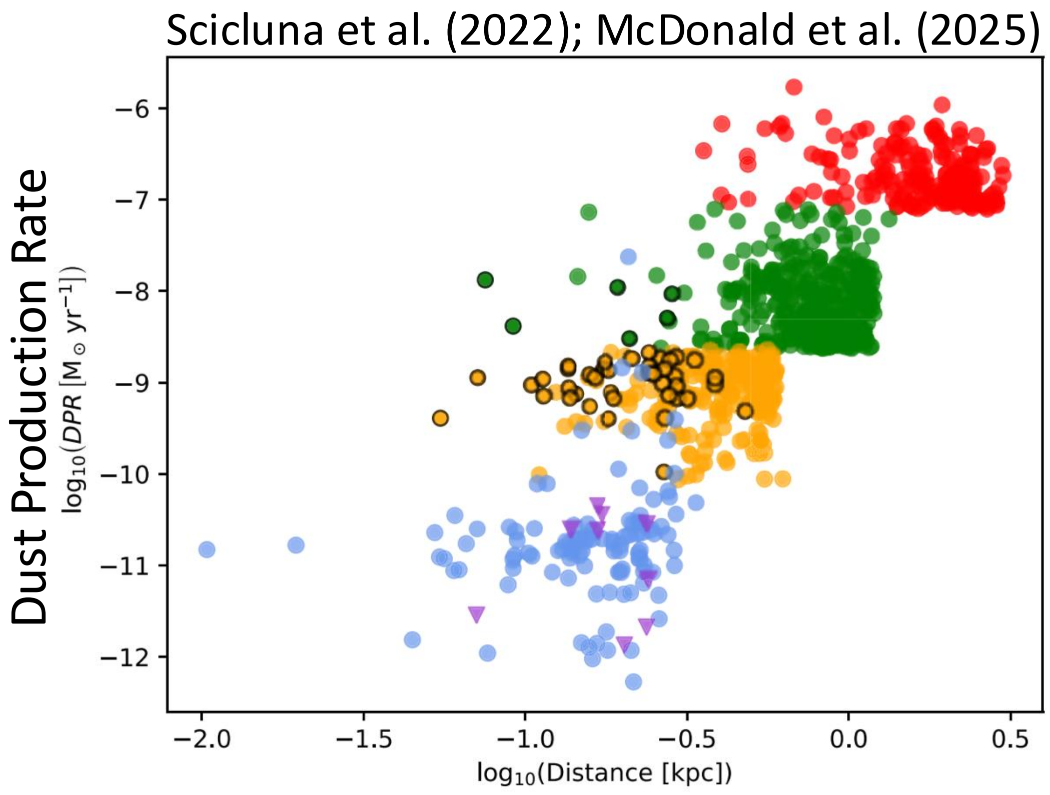
Presolar Grain Breakdown



Gehrz (1989)

Hoppe (2010, 2022)

New Dust Estimates for Milky Way AGB Stars

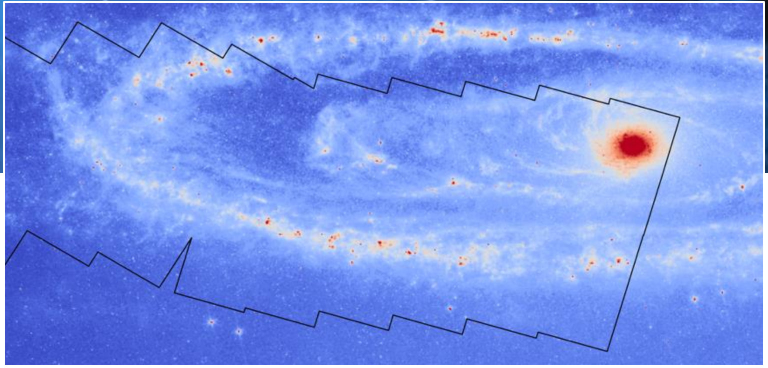


The Nearby Evolved Star Survey (NESS): a volume-limited sample of ~850 dust-producing evolved stars within 3 kpc

☆ O-rich stars account for **~80-90%** of the total AGB dust input

☆ Total dust input is similar to Gehrz (1989) when volume-averaged dust-production rate is extrapolated to entire disk

Global AGB Dust Input in M31



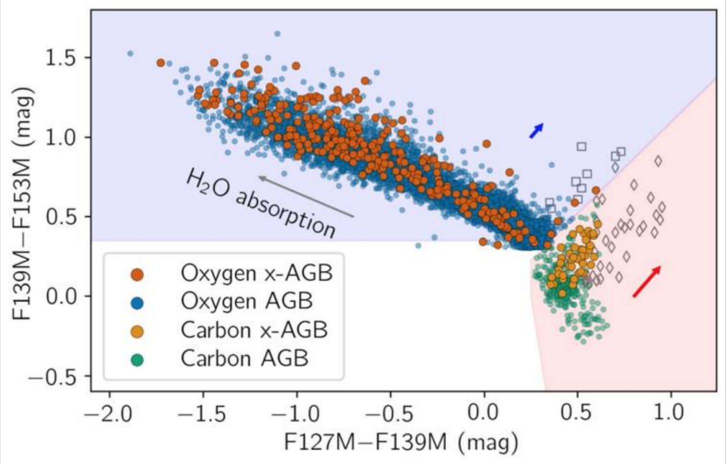
Spitzer + HST photometry indicate:

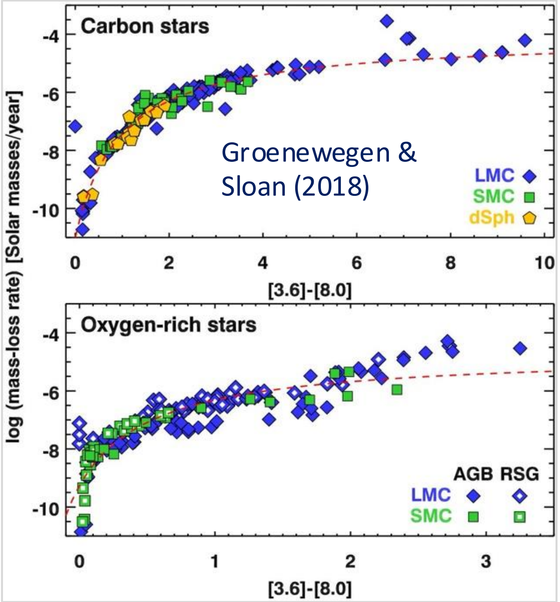
☆ Dust is primarily from O-rich stars

☆ *AGB dust accounts for up to 35% of the ISM dust*

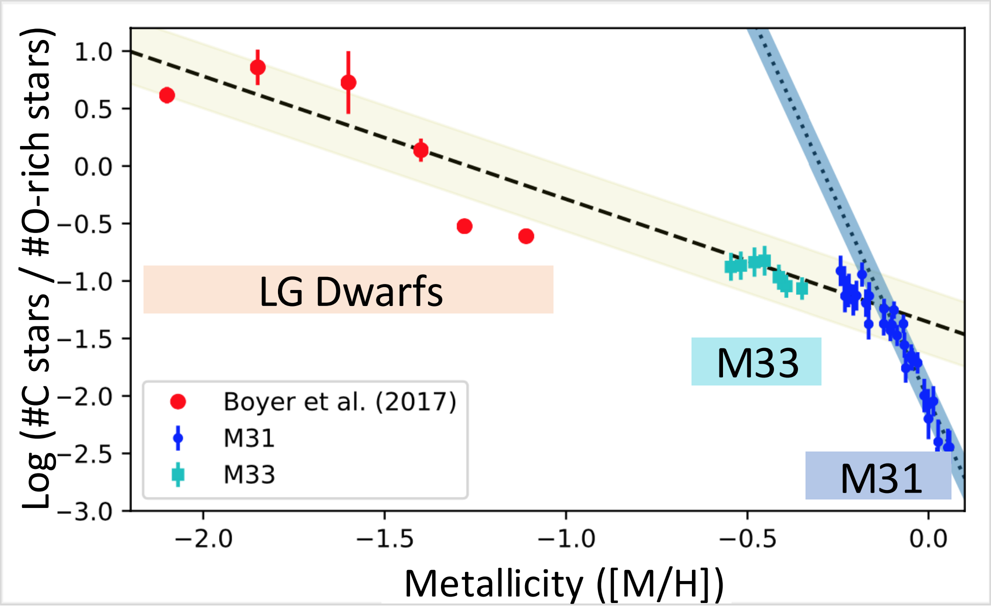
Dramatic decrease in C/M at high metallicity
→ More O-rich dust

HST colors → dust type
Spitzer colors → dust-production rate



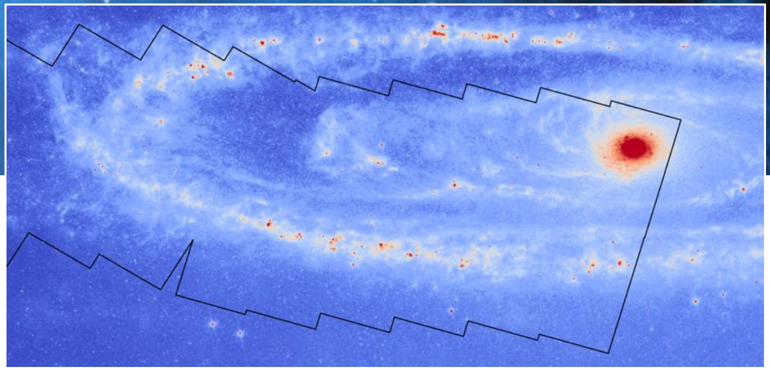


Goldman et al. (2022)

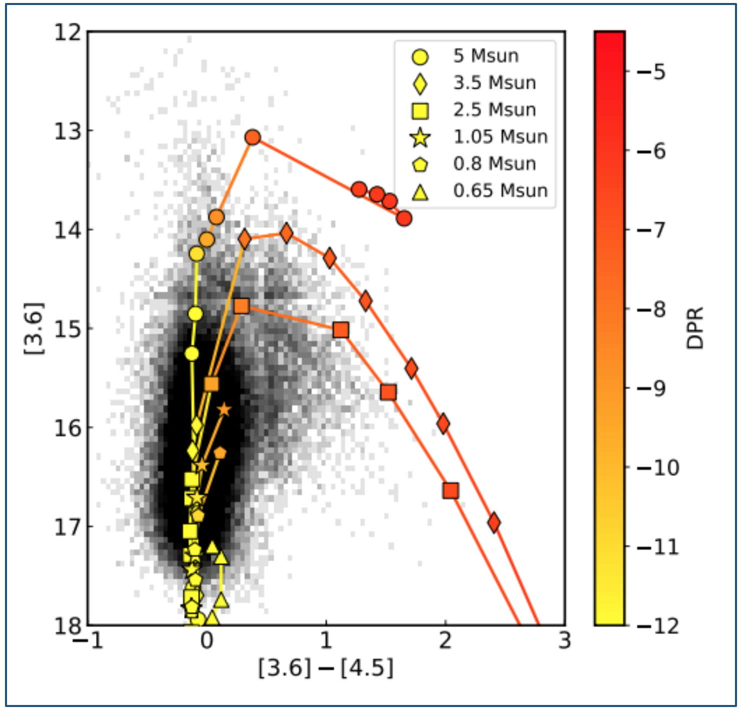


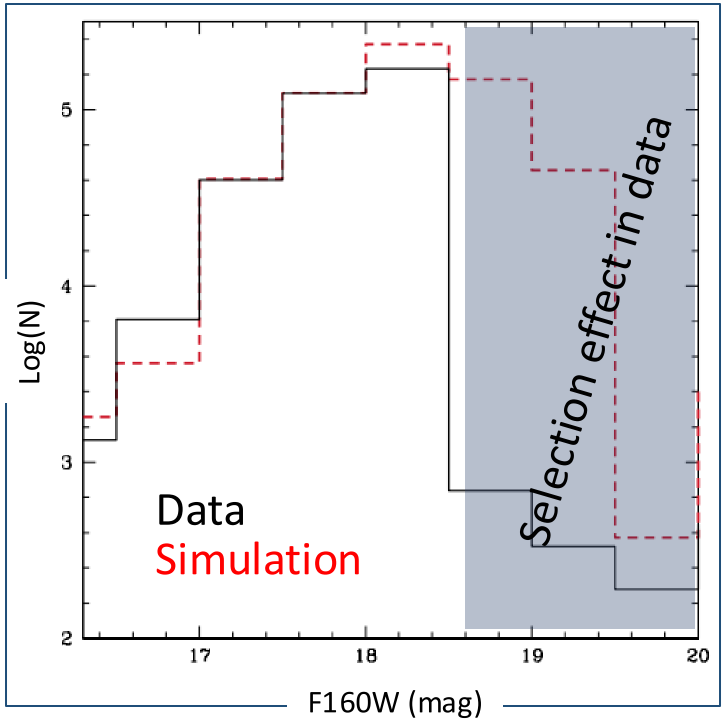
Boyer et al. (2019 & in prep)

Carbon Dust in M31?

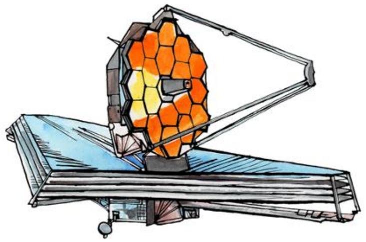


Metal-rich ATON models:
Provide a good fit to the Spitzer & HST data
Imply that C-rich dust dominates (Gavetti et al. 2025)





High-resolution Mid-IR data (λ > 5 μm) are needed to constrain the dust-production rates in M31

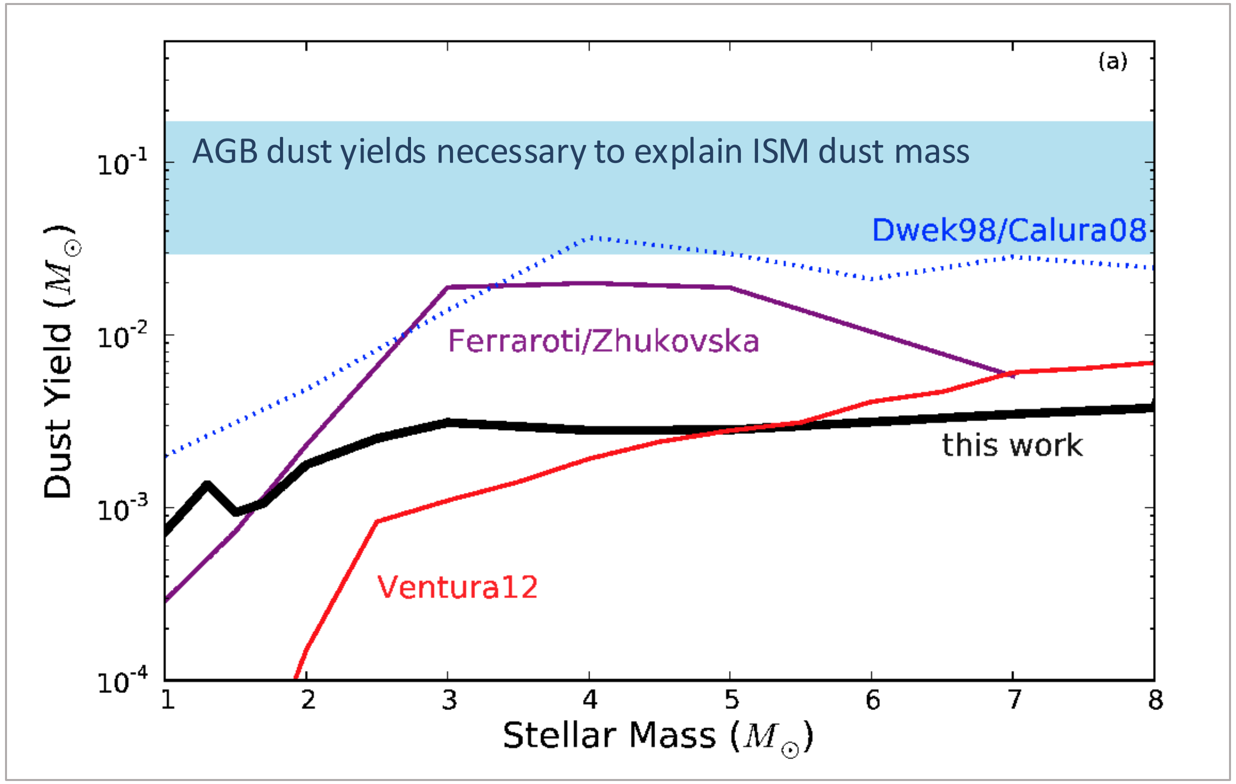


AGB Dust at Low Metallicity / High Redshift

Observations: Massive dust reservoirs (up to 10^8 $M_\odot$) are now being detected out to z≈8.

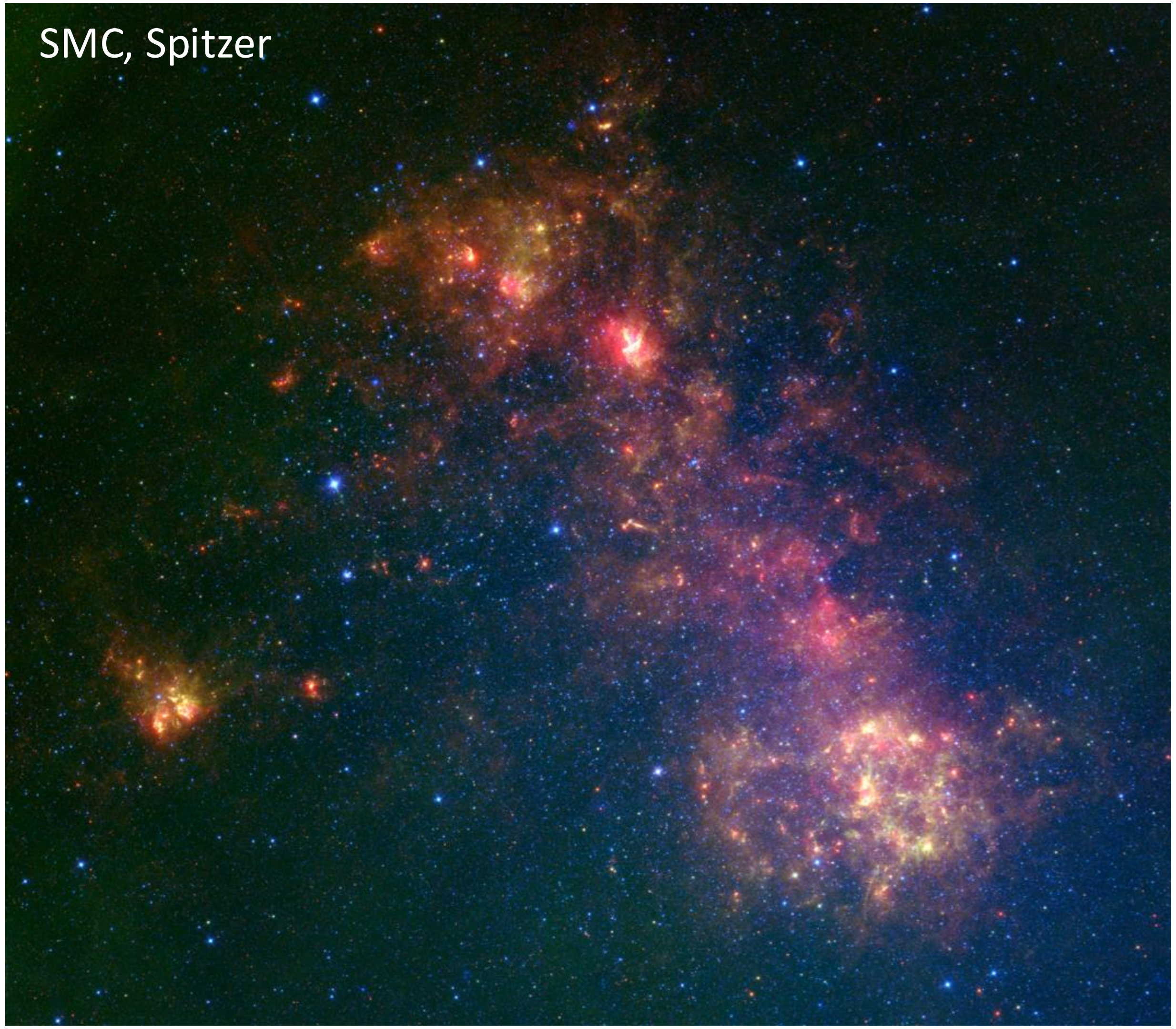
Watson et al. (2015), Tamura et al. (2019), Witstock et al. (2023)

Problem: Most models predict that metal-poor AGB stars don't make enough dust in high-redshift galaxies.

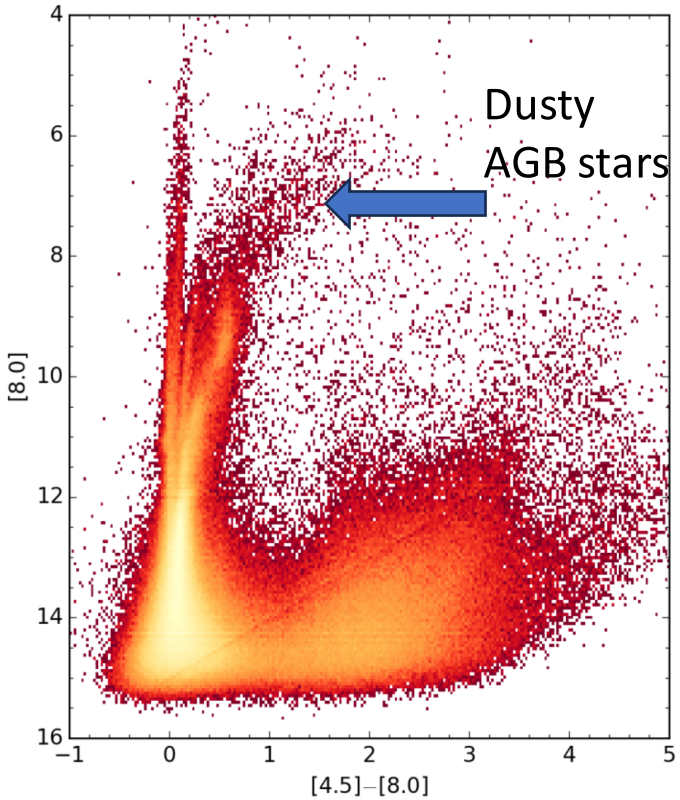


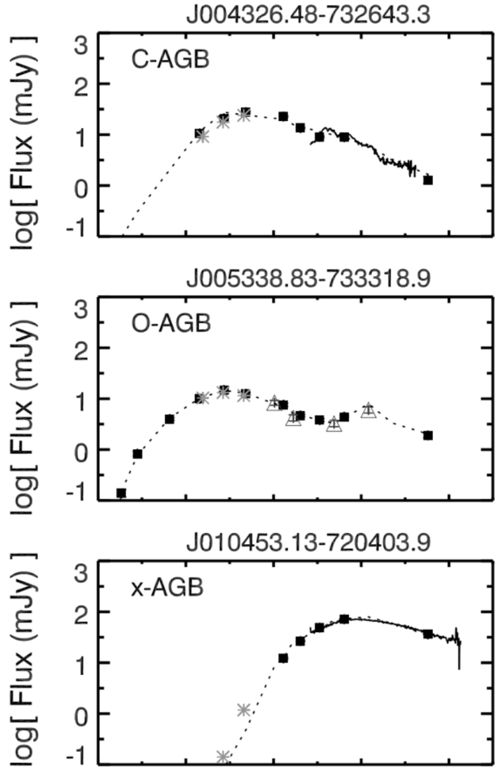
Rowlands et al. (2014)

AGB Dust at Low Metallicity / High Redshift



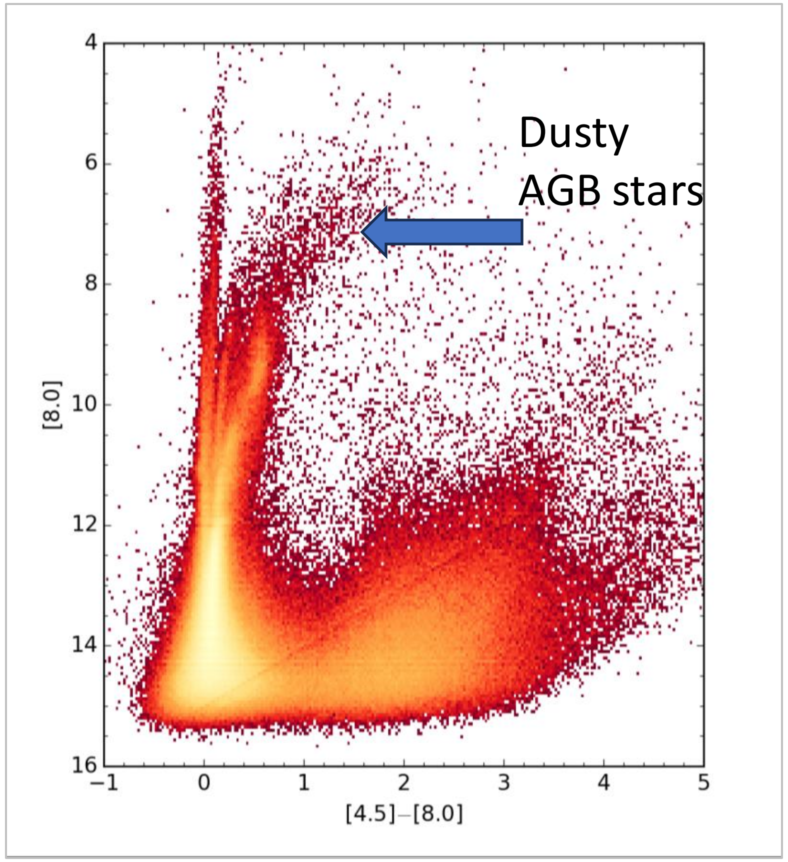
Gordon et al. (2011)





Boyer et al. (2012)

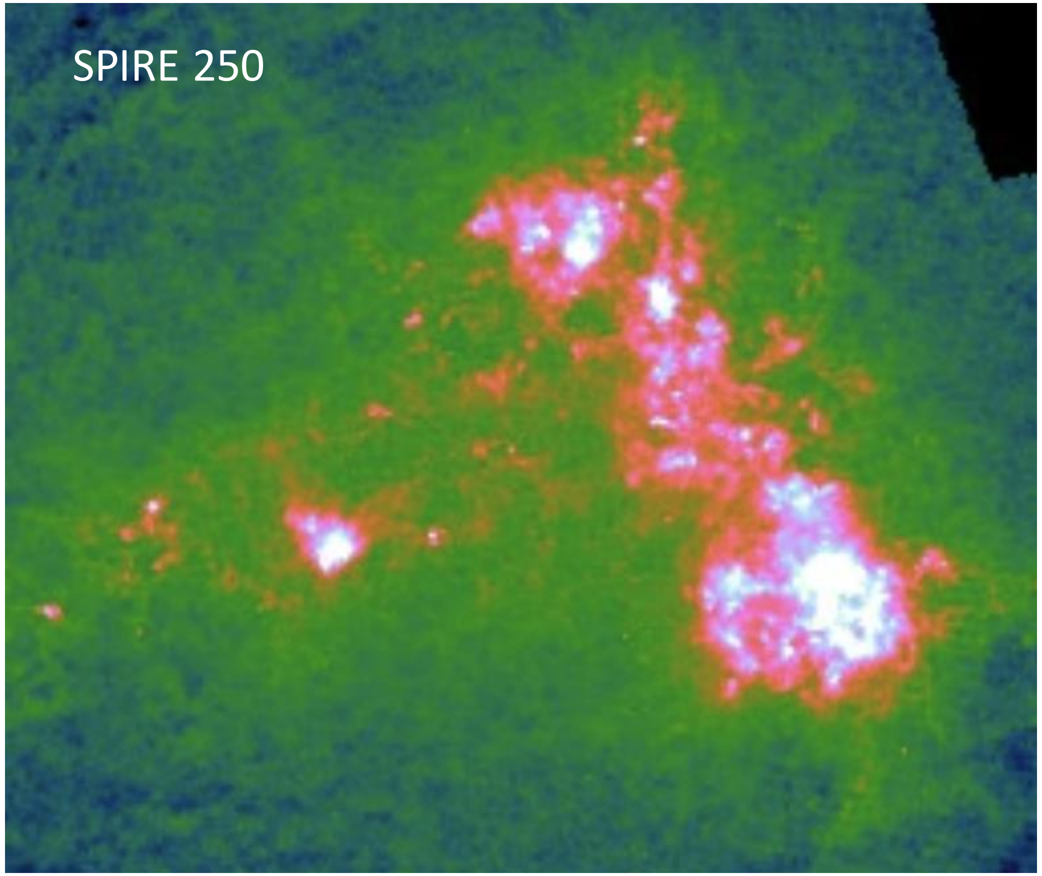
AGB Dust in the Magellanic Clouds



SMC: Boyer et al. (2011, 2012); Srinivasan et al. (2016)
LMC: Matsuura et al. (2009); Srinivasan et al. (2009); Riebel et al. (2012); Jing et al. (2024)

SAGE: AGB stars account for 1-2% of ISM Dust

AGB Dust in the Magellanic Clouds

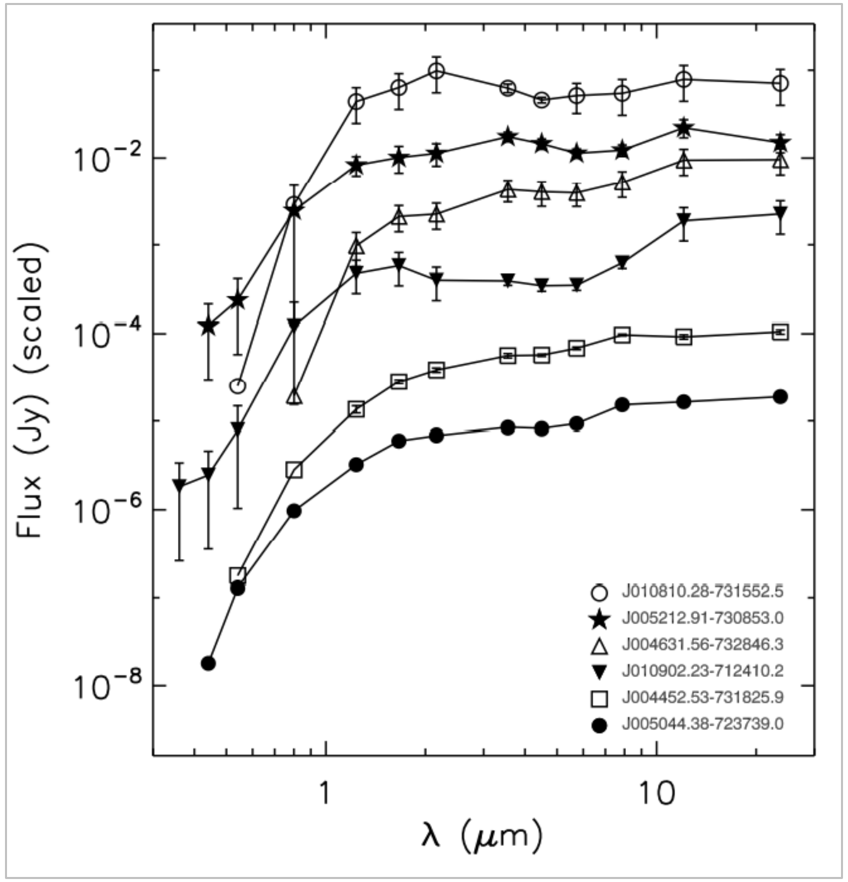


Gordon et al. (2014)

SAGE: AGB stars account for 1-2% of ISM Dust

HERITAGE: ISM dust mass decreased 10x

AGB Dust in the Magellanic Clouds

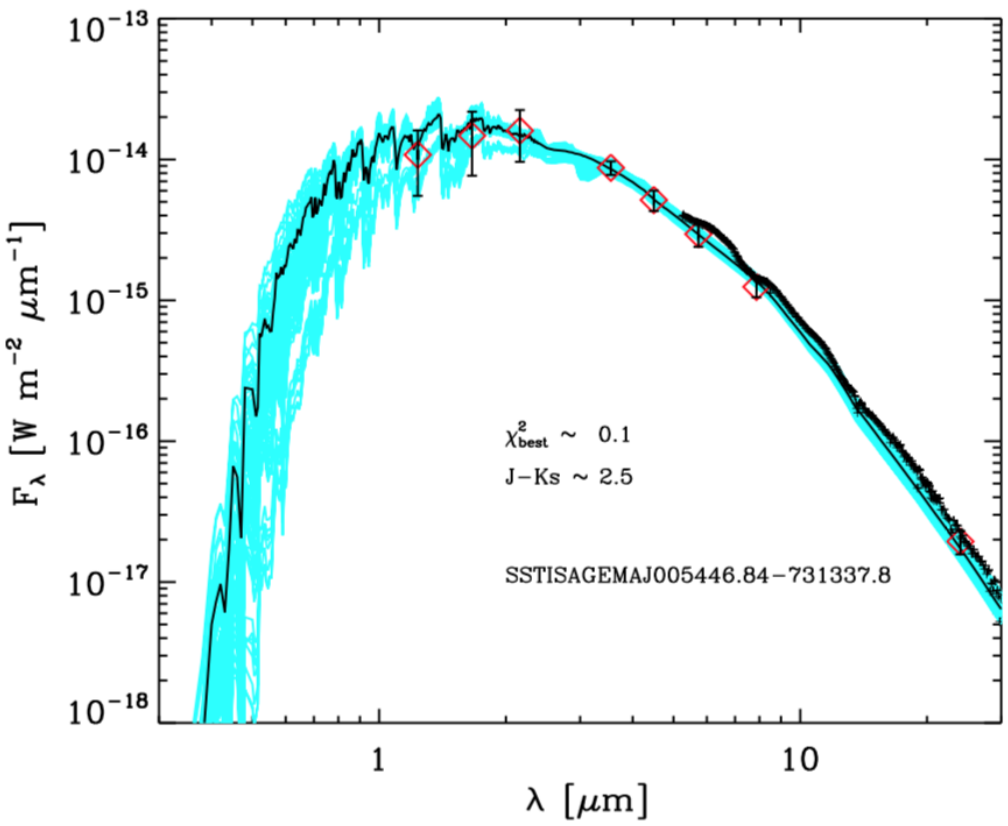


Srinivasan et al. (2016)

SAGE: AGB stars account for 1-2% of ISM Dust

HERITAGE: ISM dust mass decreased 10x
Far-IR Stars: AGB dust input increased 2x

AGB Dust in the Magellanic Clouds

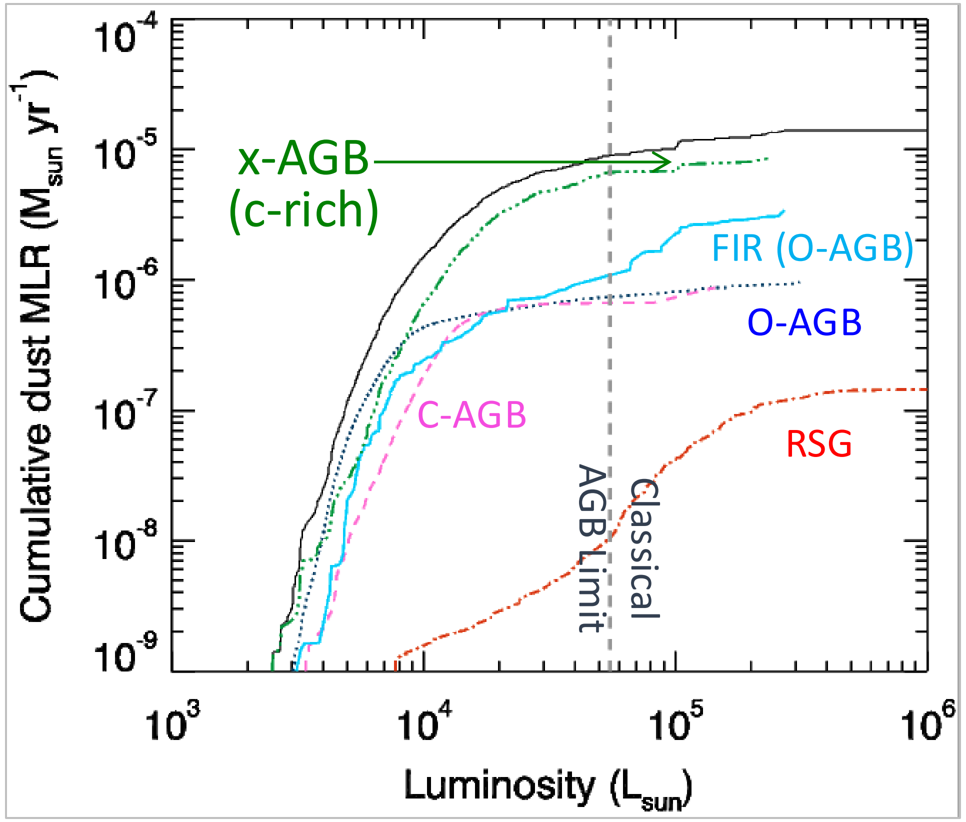


Nanni et al. (2018)

SAGE: AGB stars account for 1-2% of ISM Dust

HERITAGE: ISM dust mass decreased 10x
Far-IR Stars: AGB dust input increased 2x
Updated Models: Increase AGB dust estimate 5x

AGB Dust in the Magellanic Clouds



Only 380 x-AGB stars (C-rich AGB)
Only 17 FIR stars (O-rich AGB)

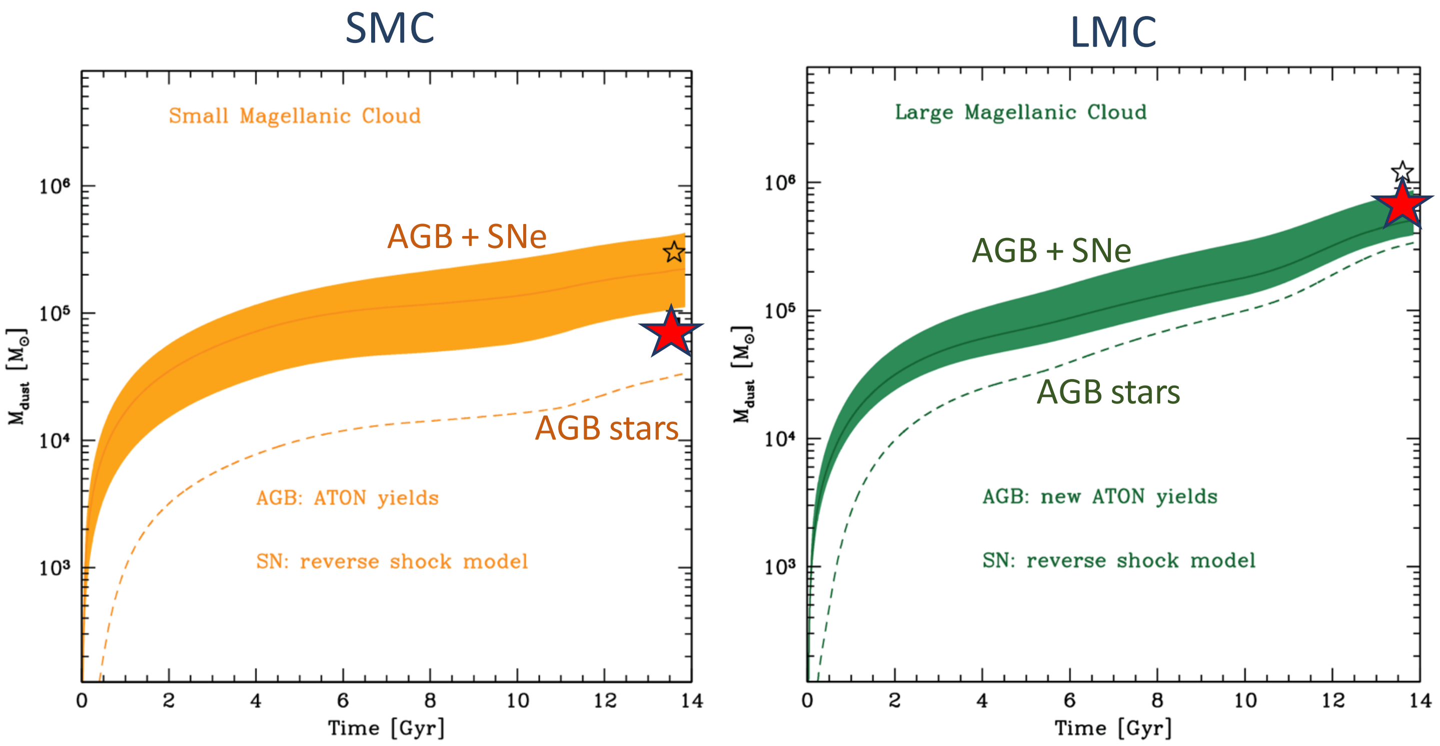
SAGE: AGB stars account for 1-2% of ISM Dust

HERITAGE: ISM dust mass decreased 10x
Far-IR Stars: AGB dust input increased 2x
Updated Models: Increase AGB dust estimate 5x

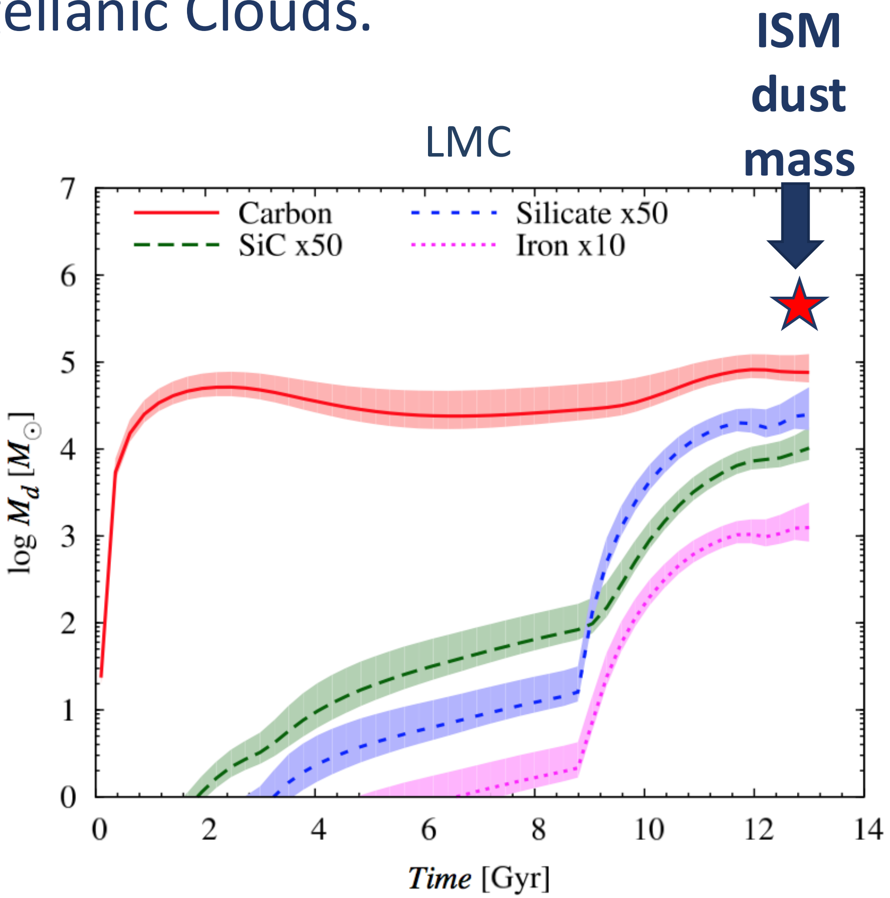
☆ AGB stars *could* account for most ISM dust
☆ Dominant dust species is highly stochastic
- 5% of the population produces most dust
  - 5% of that is O-rich & produces ~30% of the dust.

Dust Evolution Models in the Magellanic Clouds

Models agree that AGB dust can account for a significant fraction of today's ISM dust in the Magellanic Clouds.

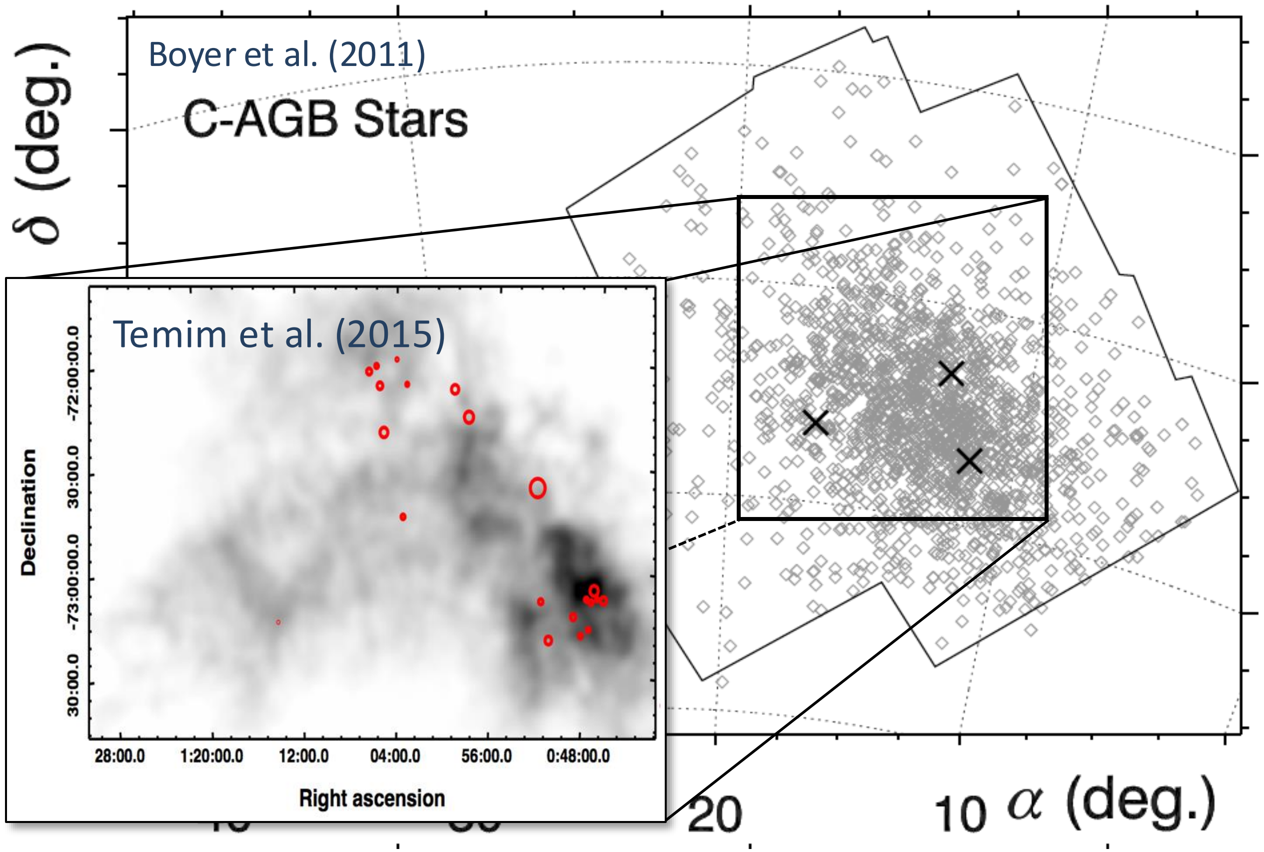


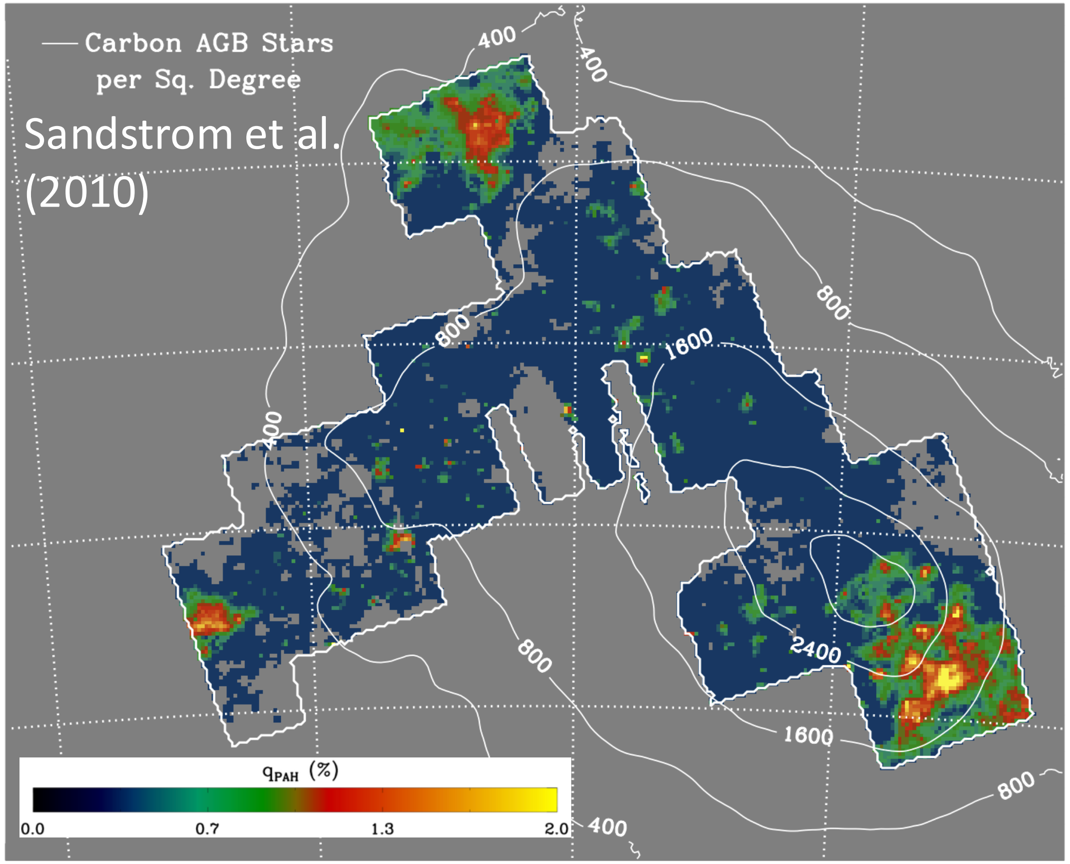
Schneider et al. (2014)



Zhukovska & Henning (2013)

AGB Dust Distribution





AGB stars have migrated away from the dust destroyers before they reach the dust-producing phase

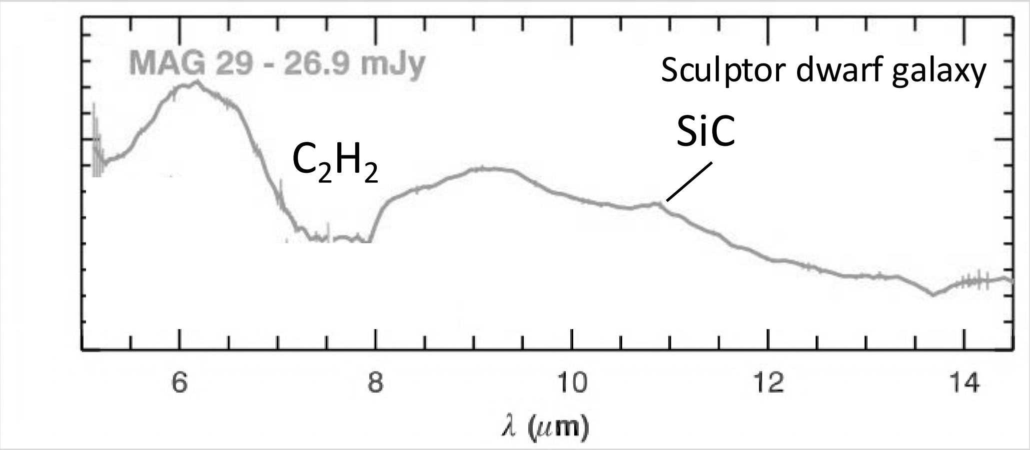
… but they don’t match the dust distribution in the ISM (PAHs shown compared to C stars)

AGB Dust at Very Low Metallicity?

Spitzer spectra of stars in metal-poor galaxies show carbon dust

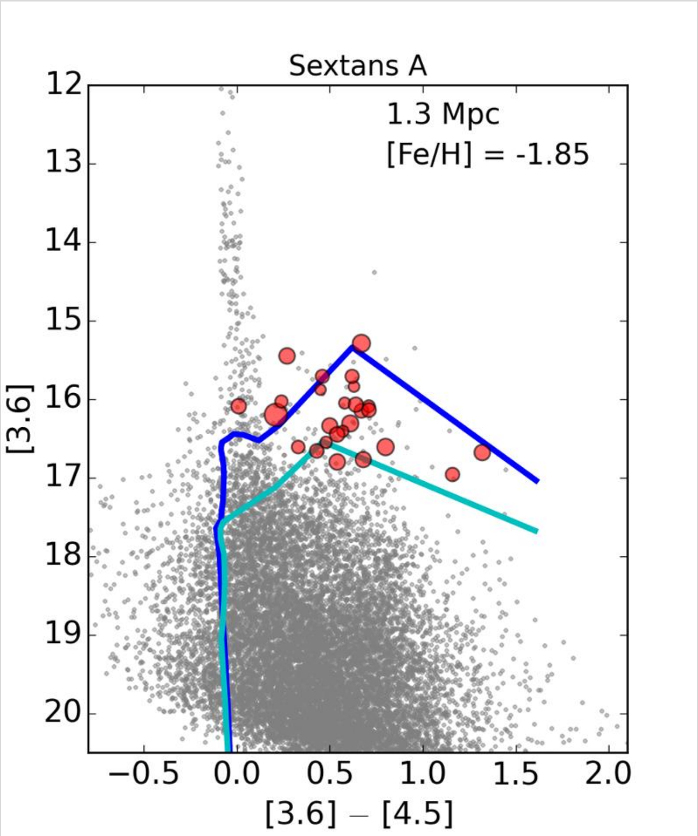
Only **5** examples with dust with [Fe/H]<-1 dex

Sloan et al. (2012) ; Matsuura et al. (2007); Lagadec et al. (2008); Sloan et al. (2009)



Adapted from Sloan et al. (2009)

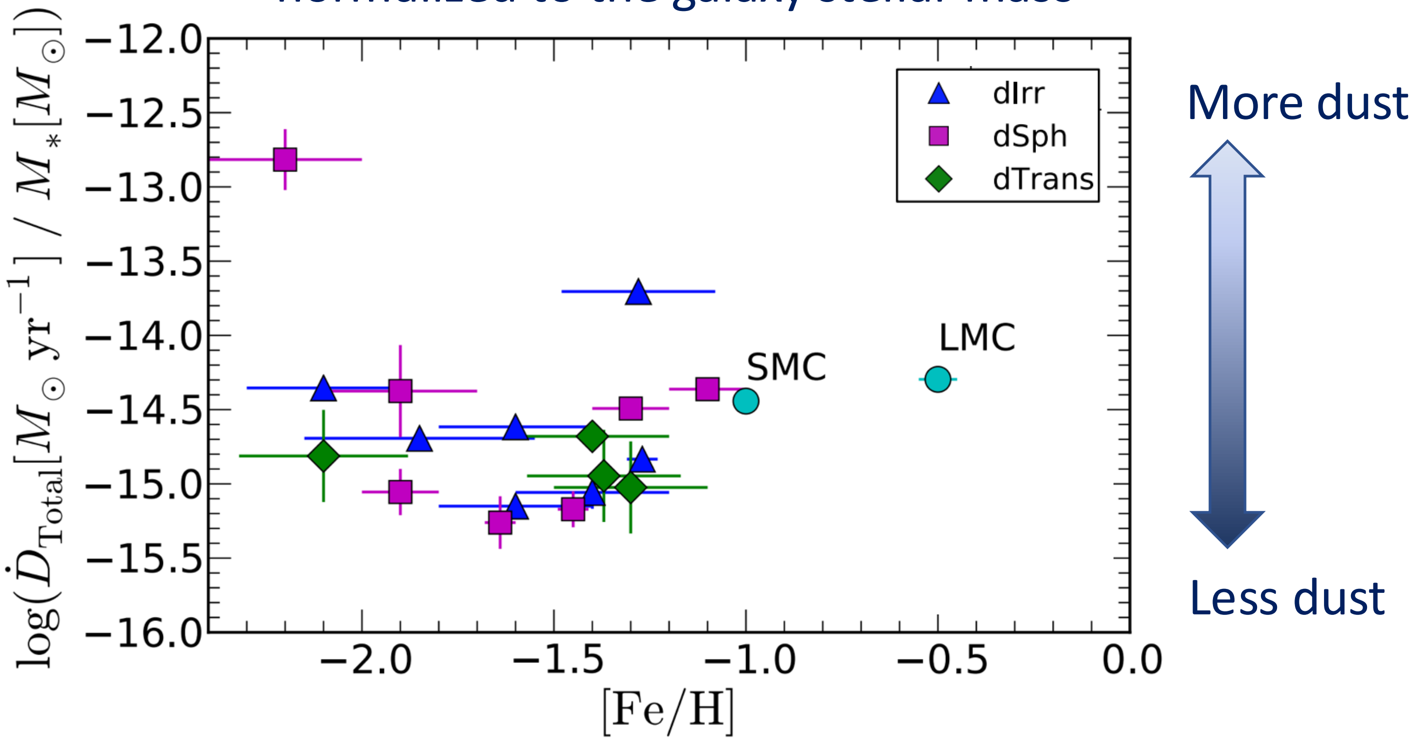
Motivated an imaging survey of all nearby dwarf galaxies with warm Spitzer (DUSTiNGS)



Adapted from Boyer et al. (2015)

Dust Forms Efficiently at Very Low Metallicity

Total dust input for each galaxy, normalized to the galaxy stellar mass



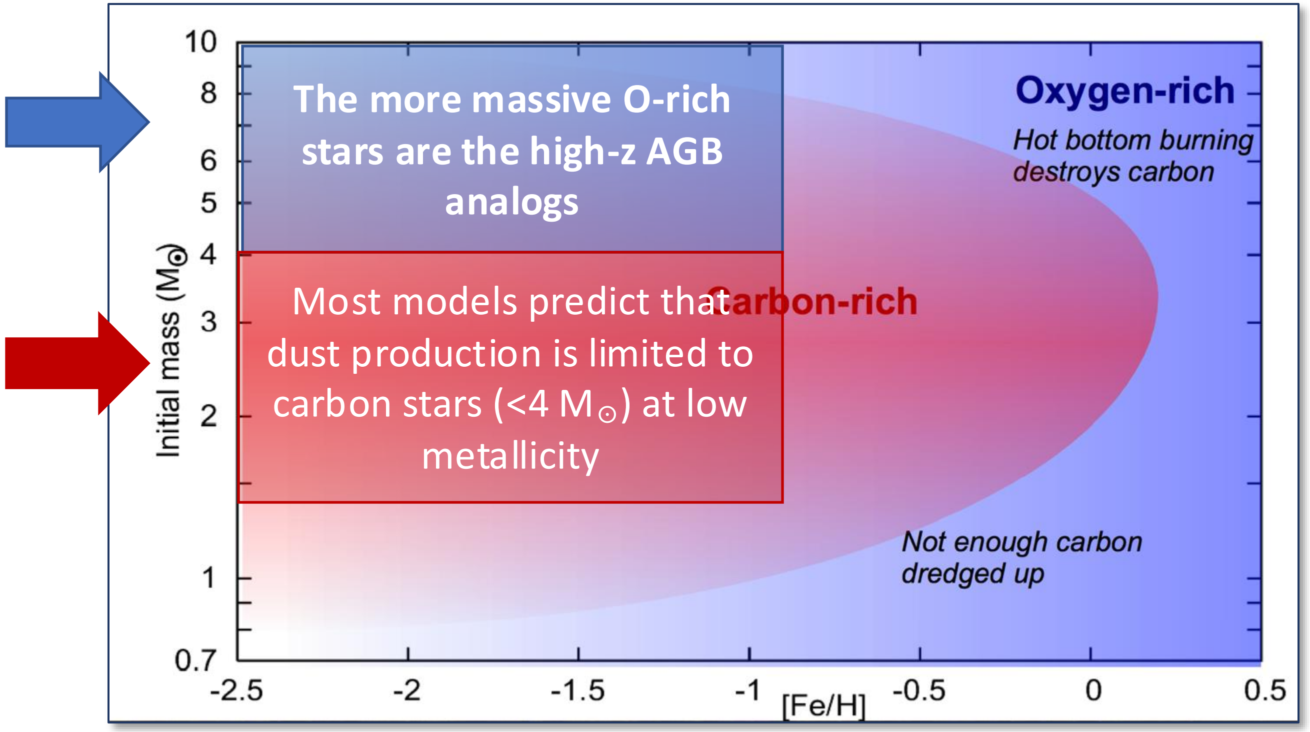
Fewer metals ⟷ More metals

Stars with ~1% solar metallicity can make as much dust as LMC stars

…**However**…
These may all be ***low-mass*** carbon stars that can't contribute in the early Universe

Boyer et al. (2015), Goldman et al. (2019)

Dust at High Redshift – Are AGB stars too slow?



Graphic by Iain McDonald, models from Karakas & Lattanzio (2007)

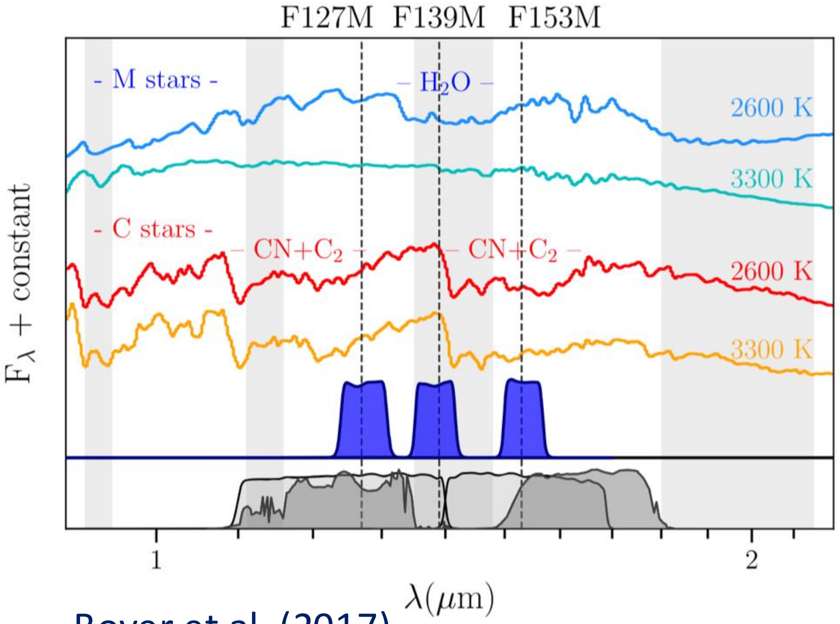
Carbon stars are too slow to produce dust (**100s of Myr**).

The most massive AGB stars produce dust as early as **30-50 Myr** after they form, but these are O-rich stars.

Can O-rich stars make dust at low metallicity?

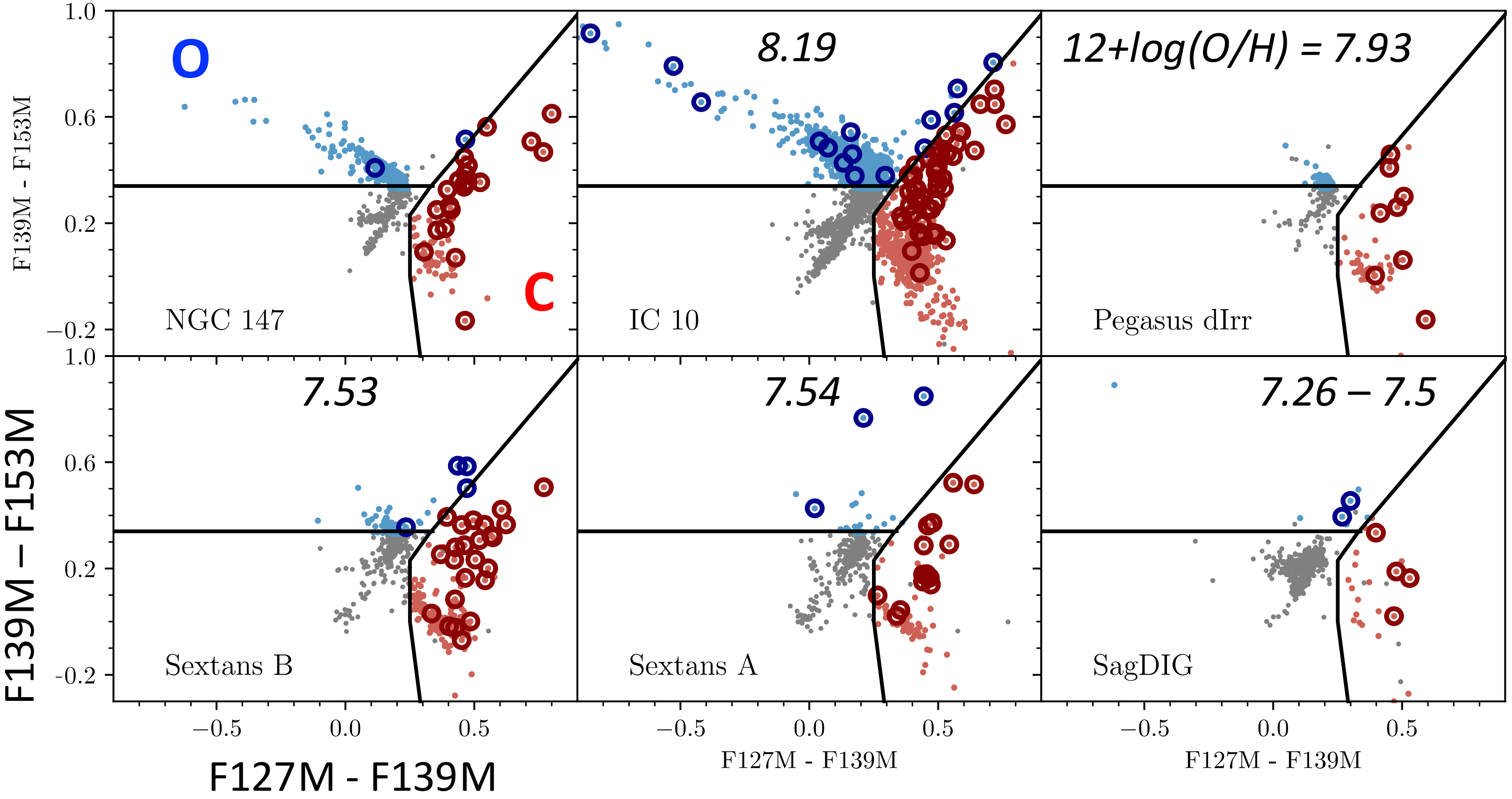
Yes! Dust forms efficiently in metal-poor O-rich stars

☆ AGB dust is not limited to carbon stars at low metallicity

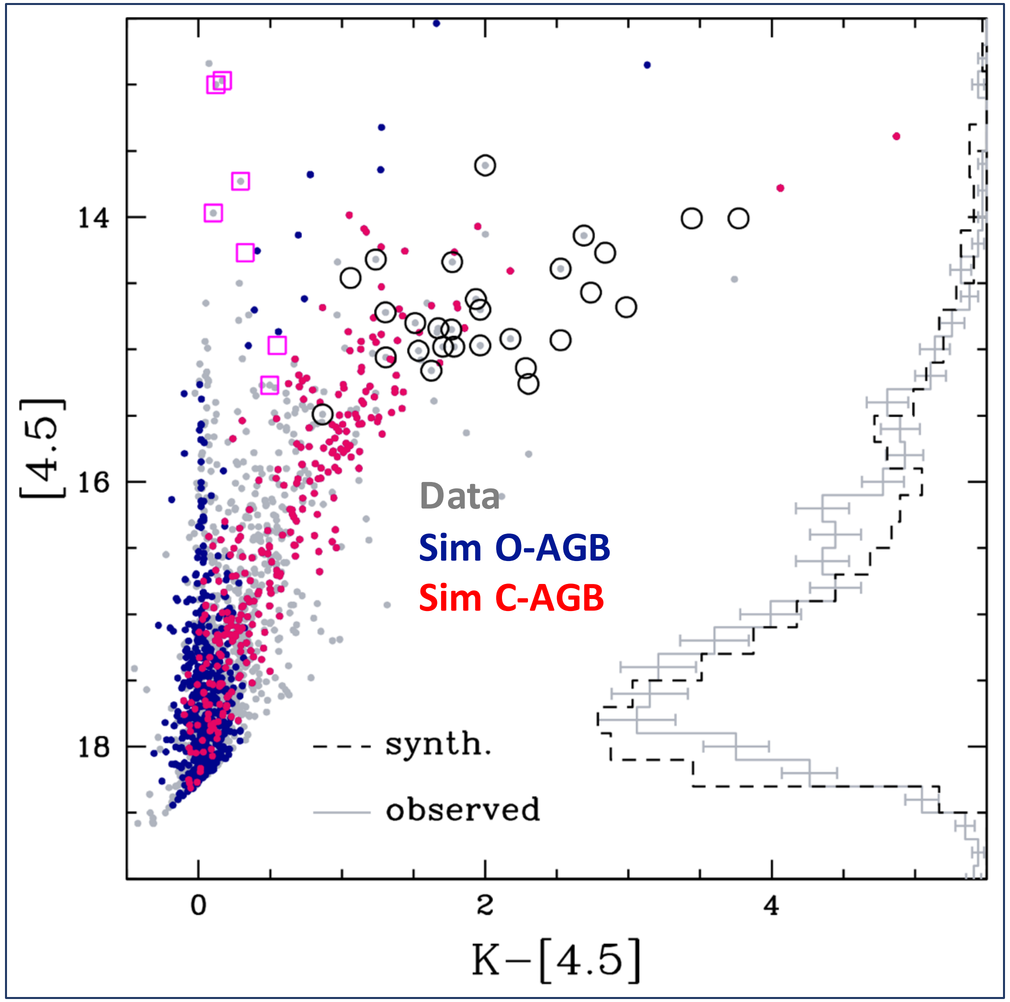


Boyer et al. (2017)

↓ Dusty stars identified with Spitzer are circled



Can metal-poor O-rich stars produce dust?



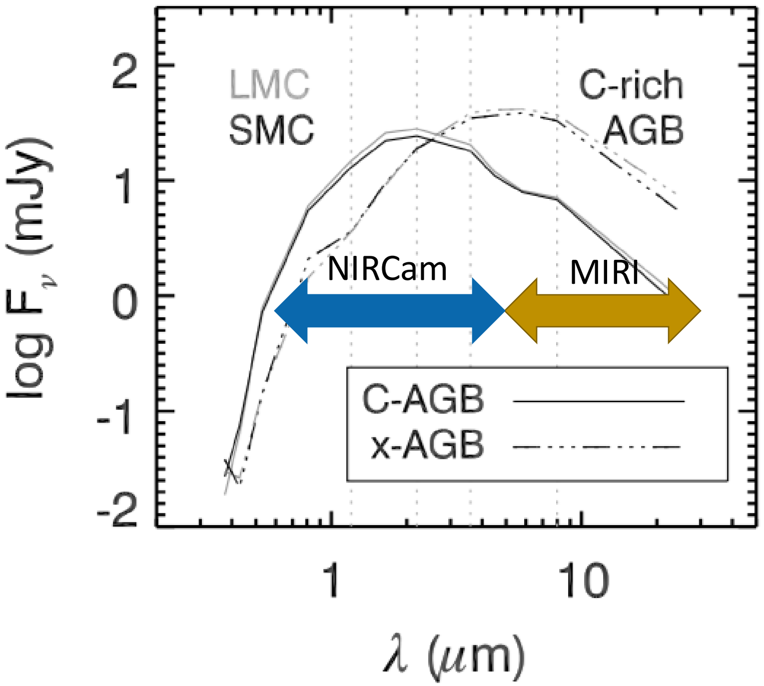
Simulations that provided the best fit to the Spitzer data show that massive O-rich stars can produce a sizeable fraction of the total dust input:

≈15% in IC 1613 (≈15% $Z_\odot$)

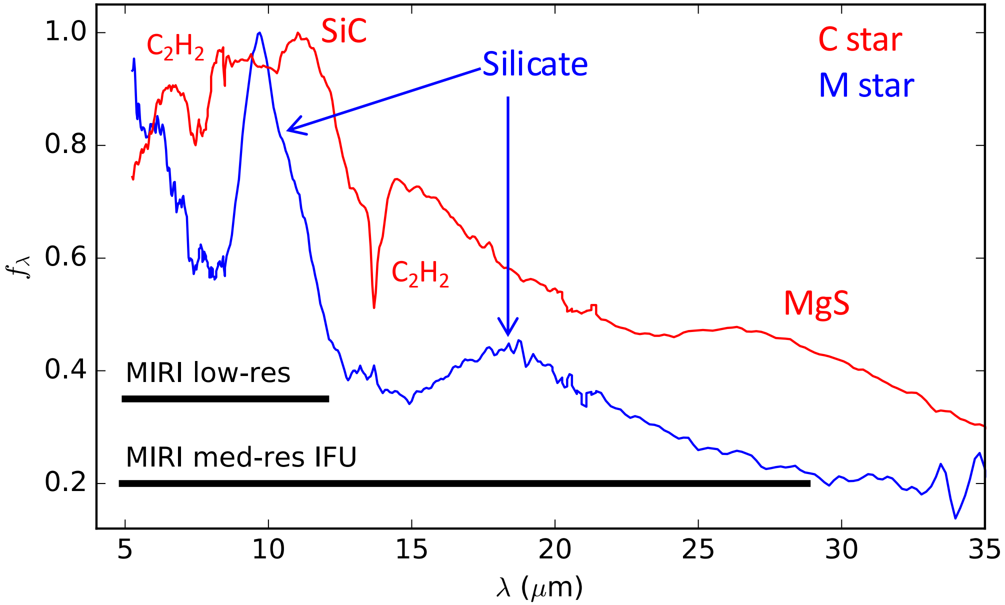
≈6% in Sextans A (≈7% $Z_\odot$)

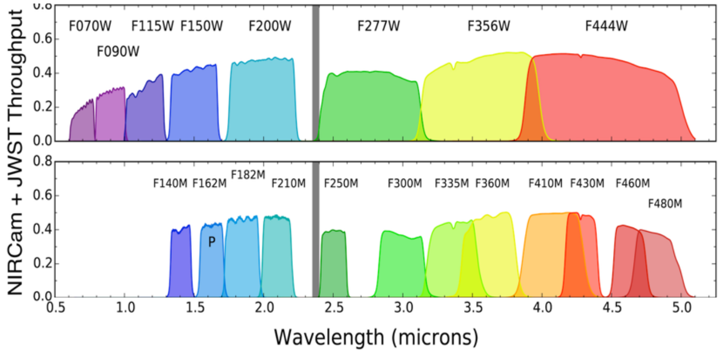
Dell'Agli et al. (2016, 2019)

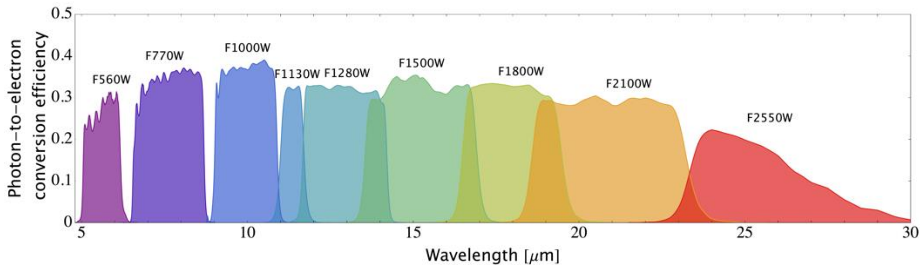
JWST is Fantastic for AGB Dust



SMC AGB Spectra from Ruffle et al. (2015)





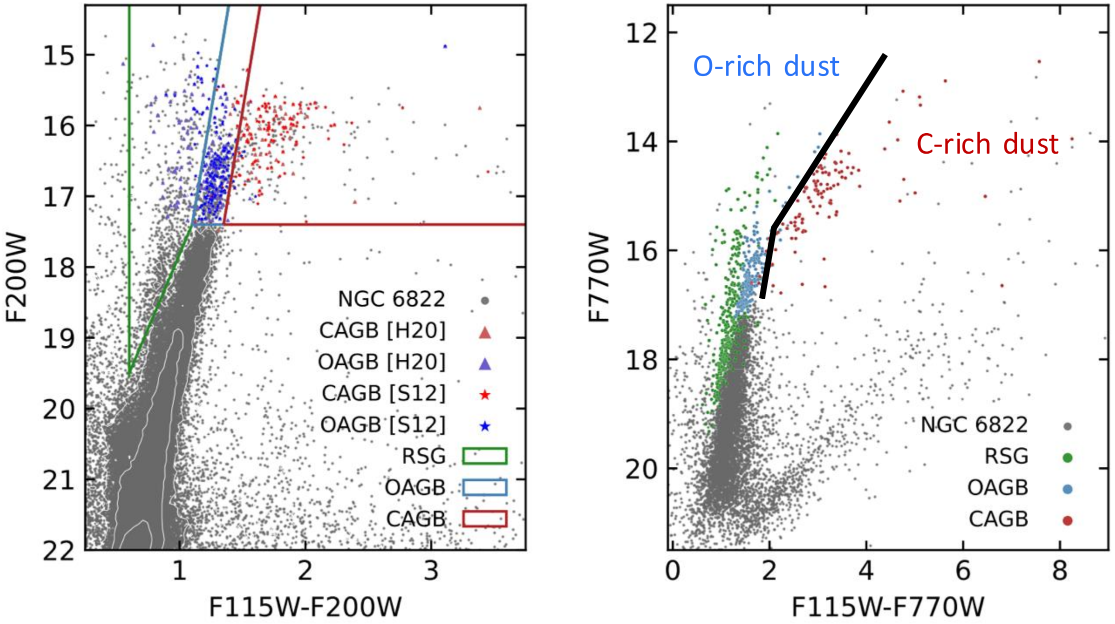


AGB Dust in Nearby Galaxies with JWST

JWST observations of galaxies in and around the Local Group are easily detecting dusty AGB stars out to 15-25 μm

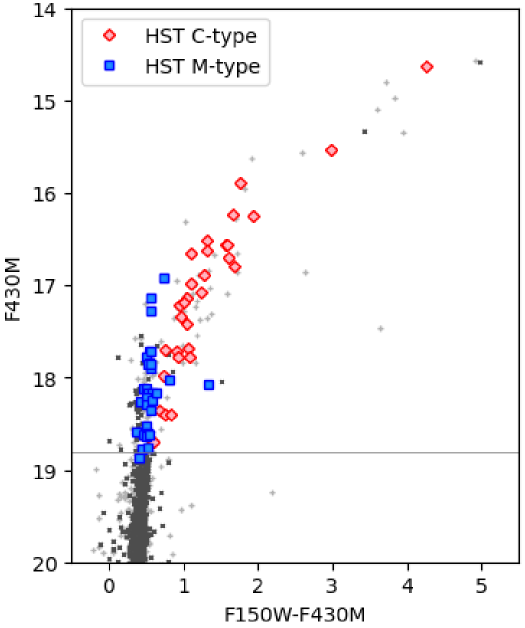
Follow up studies are fitting SEDs to quantify dust production at low metallicity

NGC 6822: D = 490 kpc; $Z \approx 0.2\ Z_\odot$



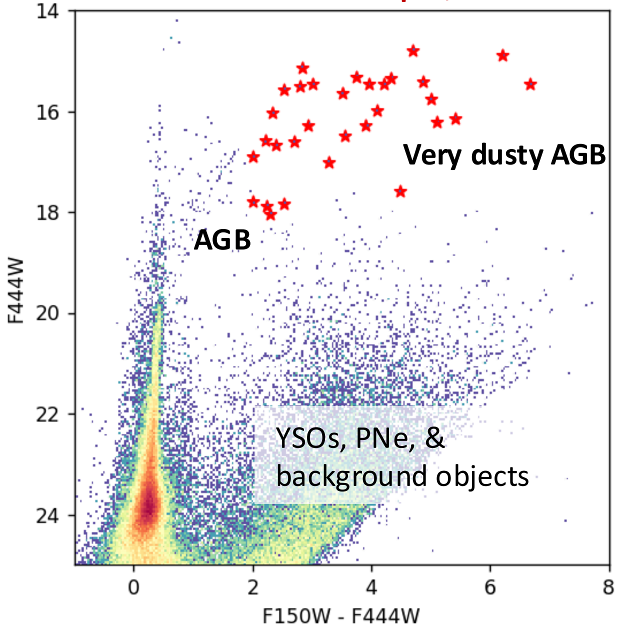
Nally et al. (2024)

WLM: 989 kpc; $\approx 0.14\ Z_\odot$



Boyer et al. (2024)

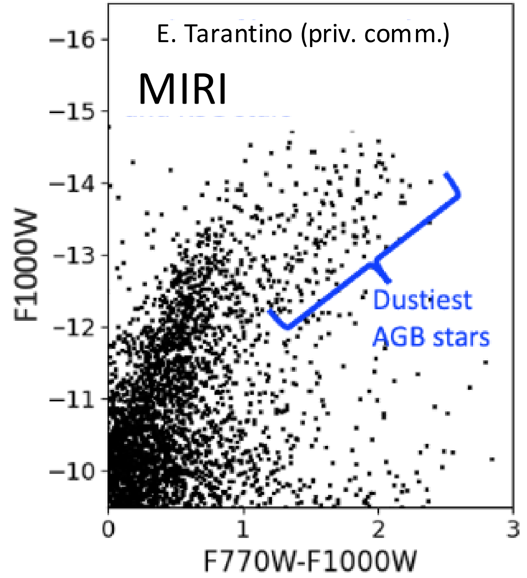
Sextans A: 1.4 Mpc; $<0.07\ Z_\odot$



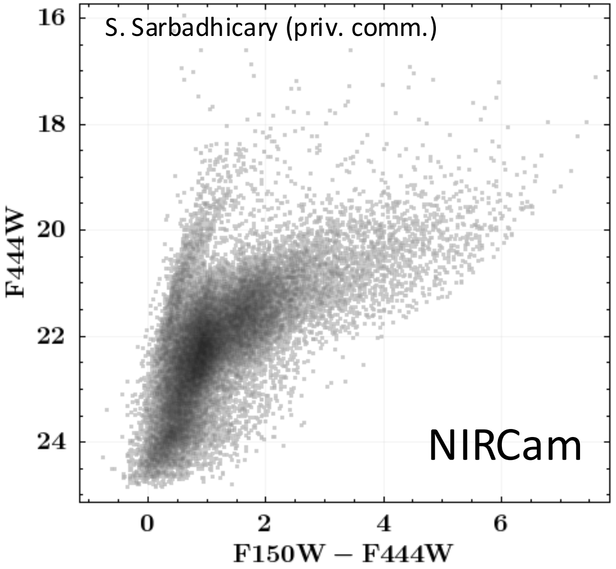
Tarantino et al. (in prep)

Dusty AGB stars detectable to at least 20 Mpc

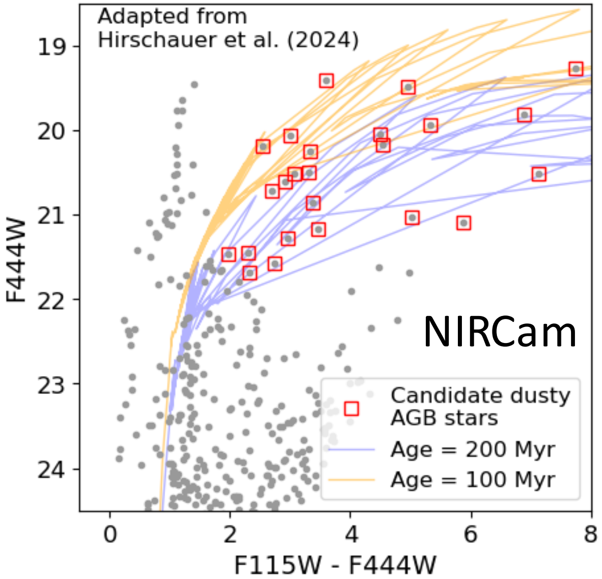
NGC 5068: 5.2 Mpc; ≈0.43 $Z_\odot$



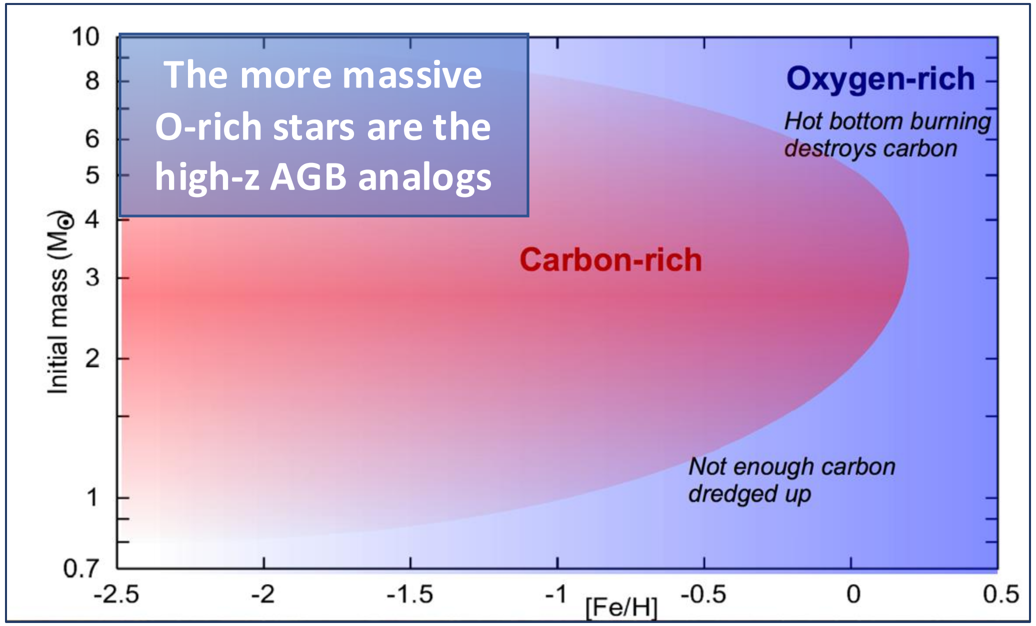
NGC 1637: 11 Mpc; ≈1-2.5 $Z_\odot$

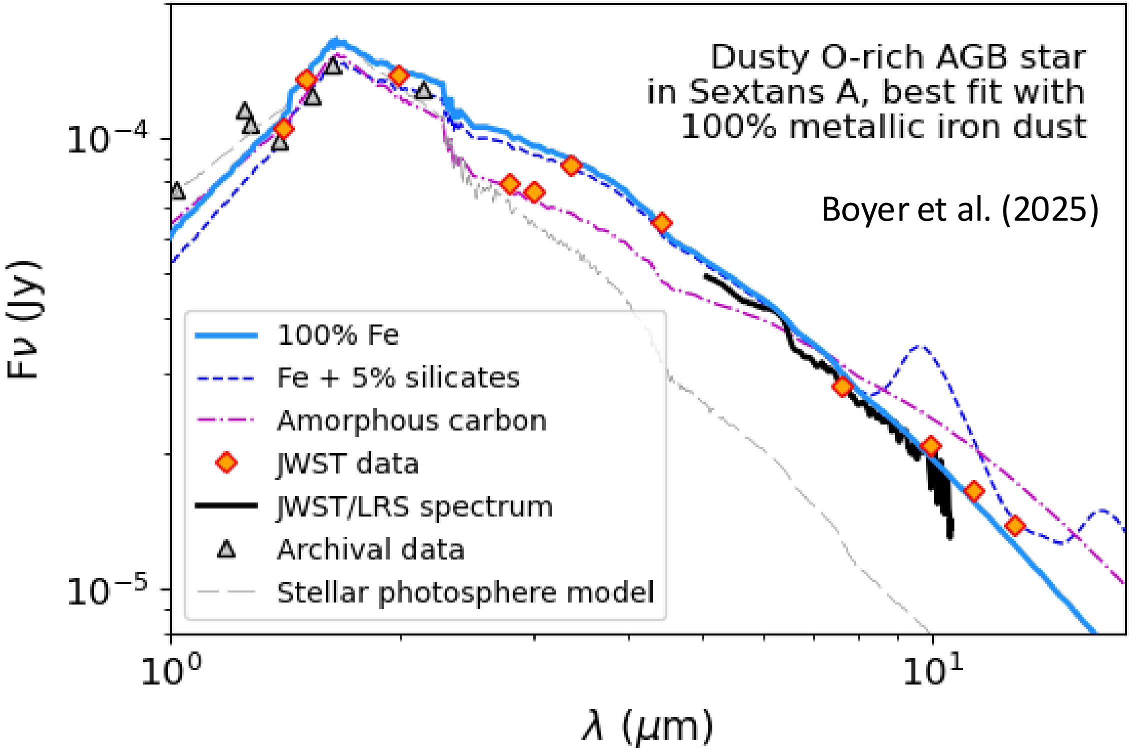


I Zw 18: 18.2 Mpc; ≈0.03 $Z_\odot$



Oxygen-rich Dust in Sextans A





→ This O-rich star is massive (4-5 M$_\odot$)

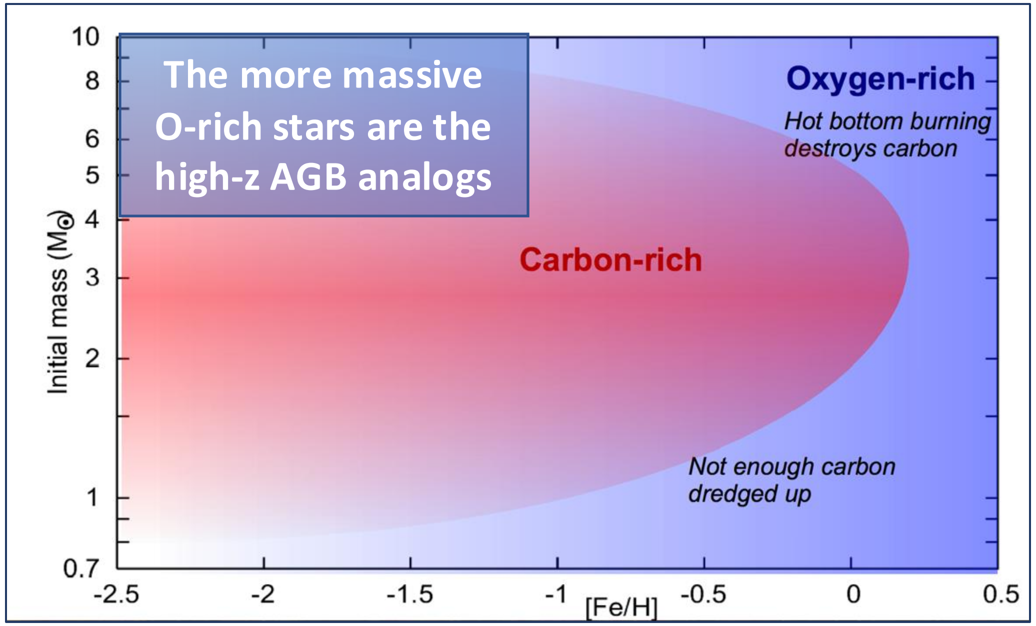
→ Its metallicity is ~3% solar, based on metallicities of massive stars

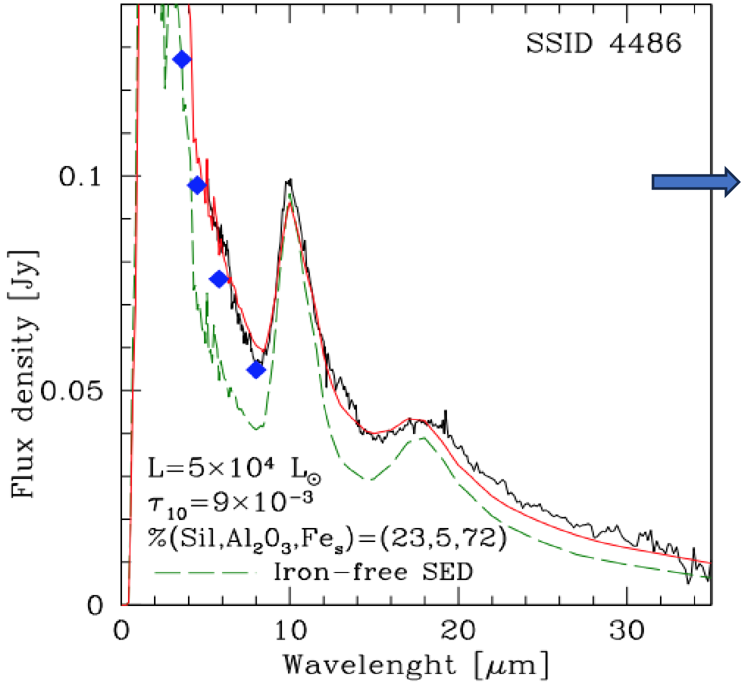
→ Metallic iron fits best

→ 2-5 similar stars in Sextans A (based on photometry)

→ ***Iron dust may be common at high z?***

Oxygen-rich Dust in Sextans A





→ Metallic iron also dominates in some LMC stars

Marini et al. (2019)

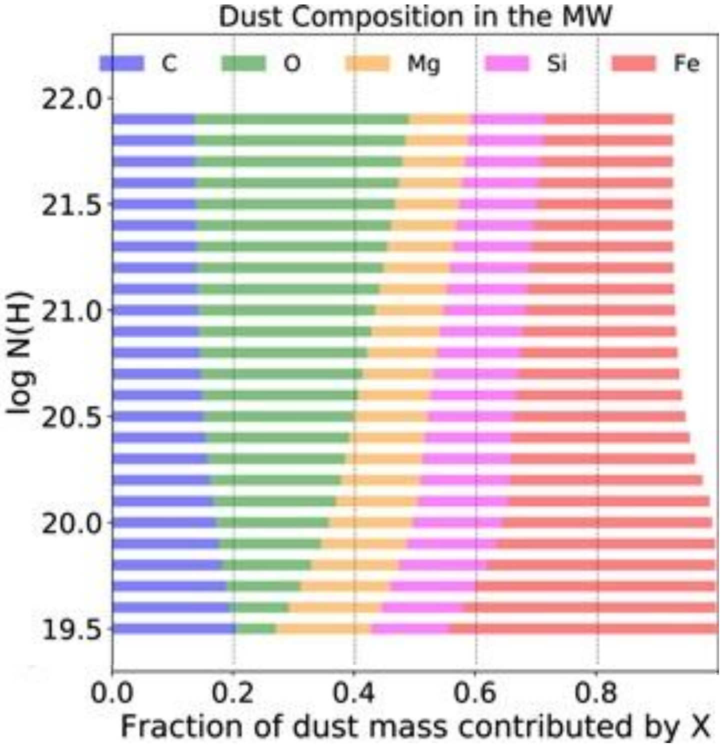
- → This O-rich star is massive (4-5 $M_\odot$)
- → Its metallicity is ~3% solar, based on metallicities of massive stars

- → Metallic iron fits best
- → 2-5 similar stars in Sextans A (based on photometry)
- → ***Iron dust may be common at high z?***

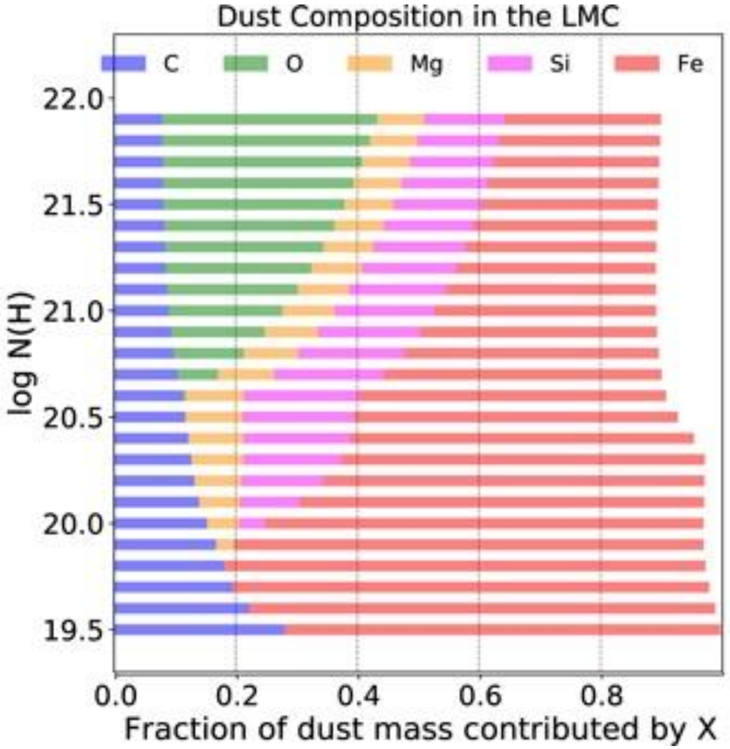
Iron in ISM dust increases at low metallicity

☆ Depletions show that the fraction of ISM dust mass contributed by iron increases at low metallicity

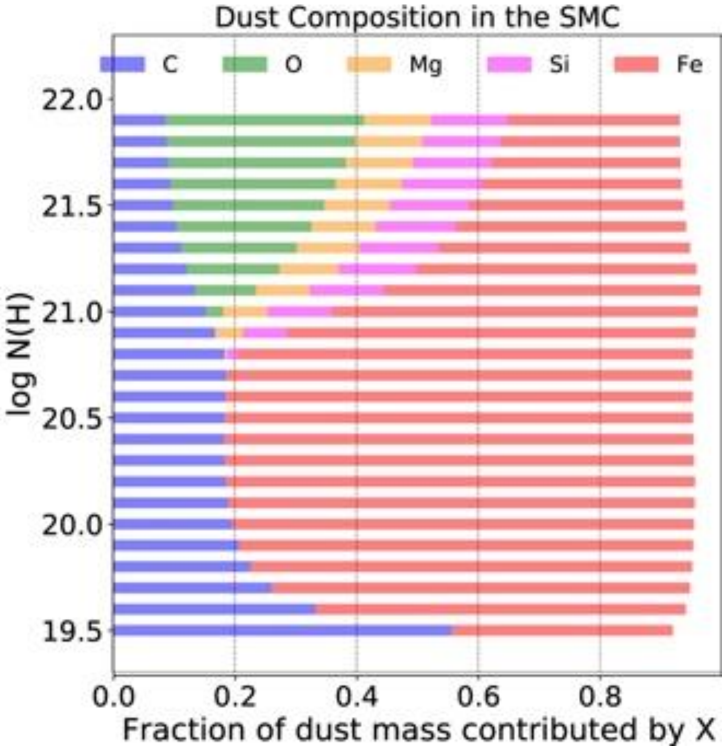
Milky Way



LMC

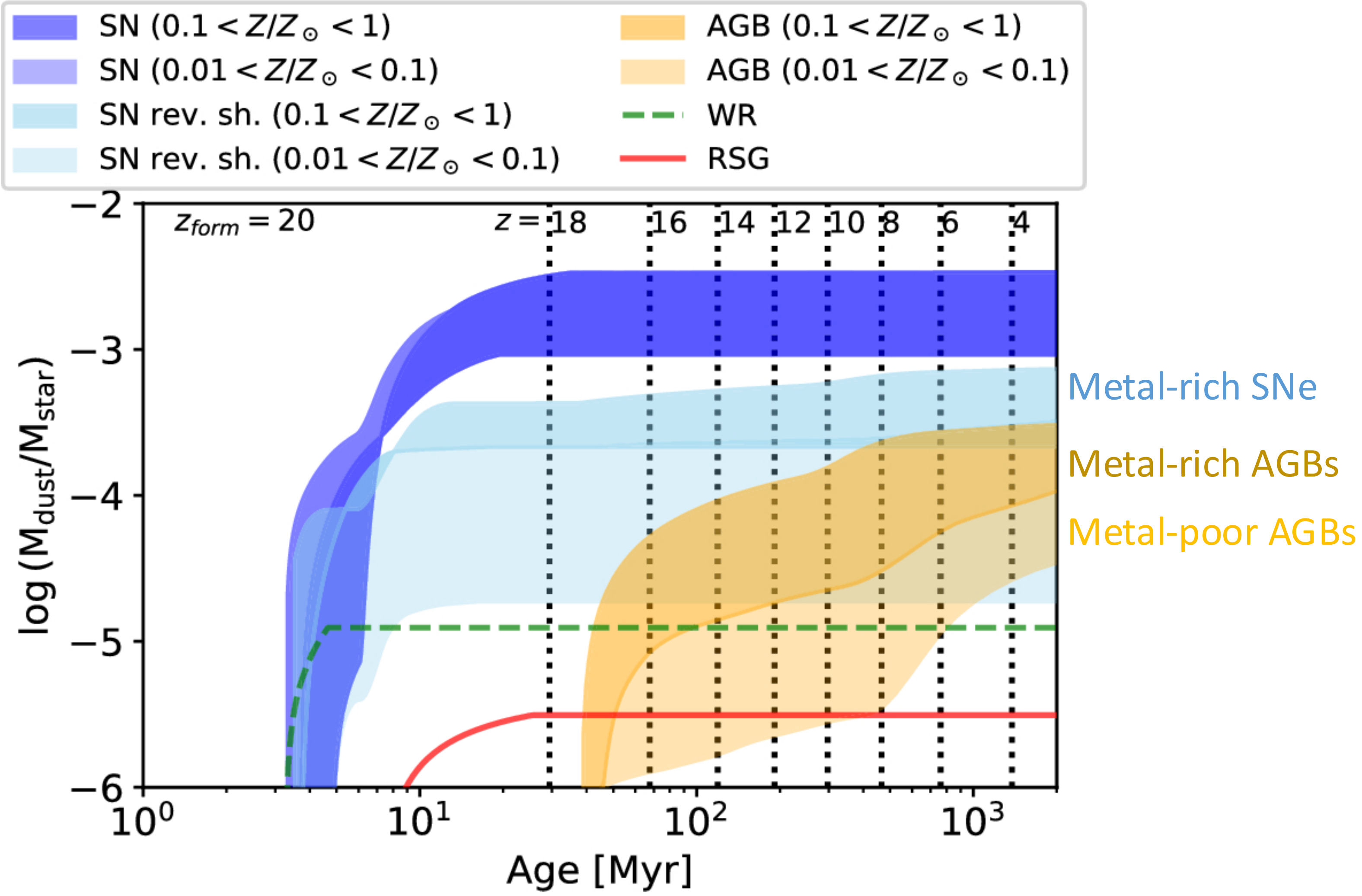


SMC



Roman-Duval et al. (2022)

Dust Production Across Cosmic Time

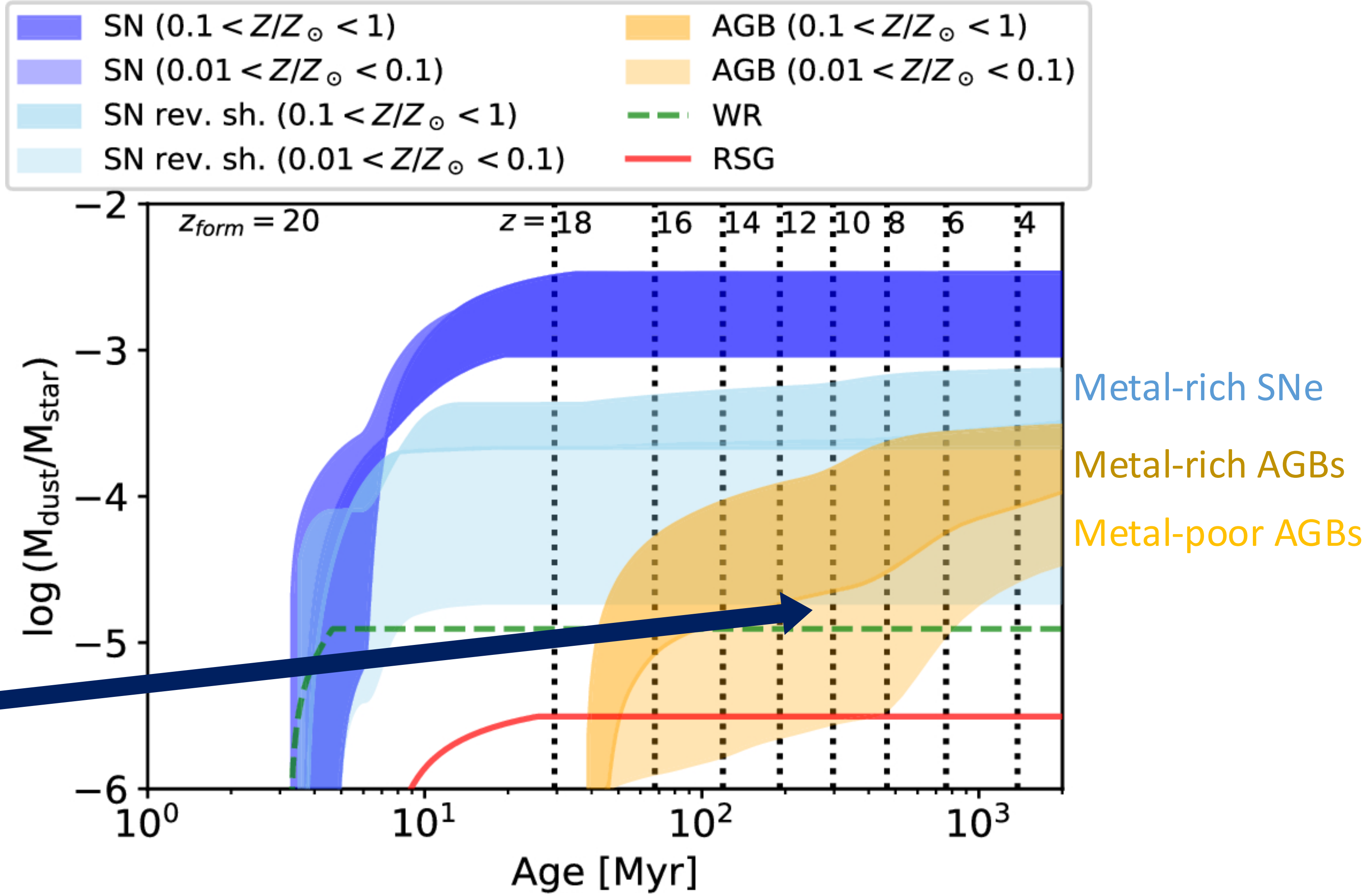


Schneider & Maiolino (2024)

Dust Production Across Cosmic Time

Only carbon and silicate dust is included here.

If iron dust is included, the metal-poor AGB dust contribution will be higher at earlier times, ***potentially similar to SNe at z>10.***



Schneider & Maiolino (2024)

Summary

MW & M31: AGB stars contribute up to a third of the dust budget

☆ O-rich dust dominates at high metallicity

Magellanic Clouds: AGB stars might dominate the dust budget

☆ C-rich dust dominates, but the dominant dust type is highly stochastic

Dust forms easily in metal-poor nearby galaxies

☆ Both carbon- AND oxygen-rich dust forms in metal-poor galaxies

Metallic iron dust may be important at high redshift

☆ A significant amount of dust is forming around a Sextans A O-rich AGB star.

☆ The SED and spectrum are consistent with metallic iron dust

JWST data abound!

☆ JWST data can provide AGB dust estimates for galaxies out to at least 20 Mpc