Unveiling Carbon Stars Properties in the Milky Way and the Magellanic Clouds

a homogeneous characterization of AGB Carbon-rich stars
in the Milky Way and the Magellanic Clouds

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STARS II current challenges, upcoming solutions JUNE 16-20, 2025 Bologna, Italy

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INTRODUCTION

What are AGB Carbon stars

- **AGB (Asymptotic Giant Branch) stars with atmospheric C/O > 1**, spectra dominated by carbon molecules
- **Variable stars**, strong pulsators regular (**Miras**) and semi-regulars
- **High mass-loss rate stars**, strong stellar winds (likely linked to pulsations)

The importance of AGB Carbon stars

- Key contributors **to cosmic dust production** (carbonaceous dust, e.g. amorphous carbon)
- Important contributors to the **total IR light of galaxies**
- **Galactic distance estimators** through the J-AGB method (Freedman&Madore2020, Magnus+2024, Siyang+2024)

Previous work mainly focused on AGB C-stars in the MCs
An extensive study of the MW AGB Carbon stars is still missing

(e.g., Groenewegen+09,18, Riebel+12)

GOAL OF THE RESEARCH

Characterize MW AGB Carbon stars' stellar and dust properties through photometric SED fitting

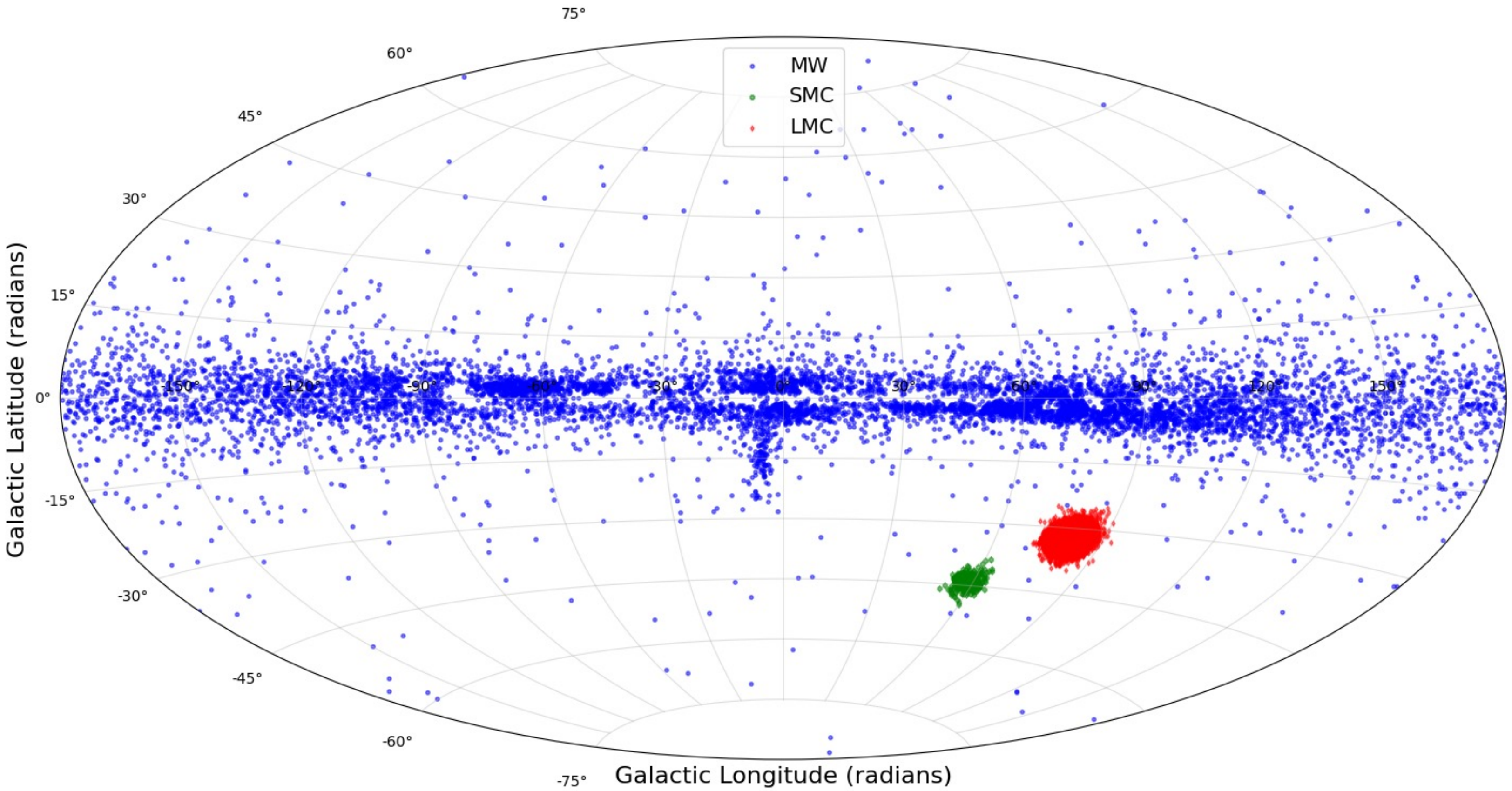
Outline

- Gaia Golden Sample of carbon stars (>14,000 stars)
- **Extinction correction**
- **Magnitude correction** for *Gaia* photometry (accounting for pulsations)
- **Creation of Models grid (SEDs)**
- **SED fitting** to derive stellar & dust properties (MW, LMC, SMC) + uncertainties

Gaia GOLDEN SAMPLE

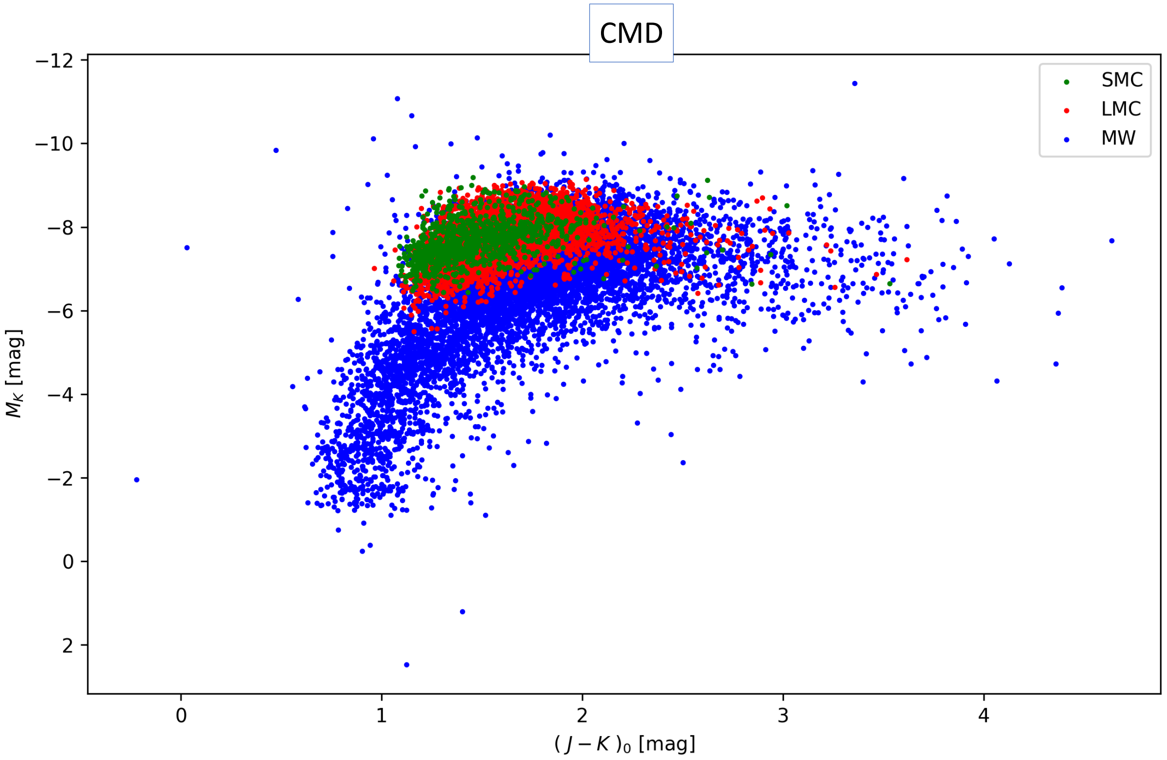
Gaia Golden Sample of carbon stars

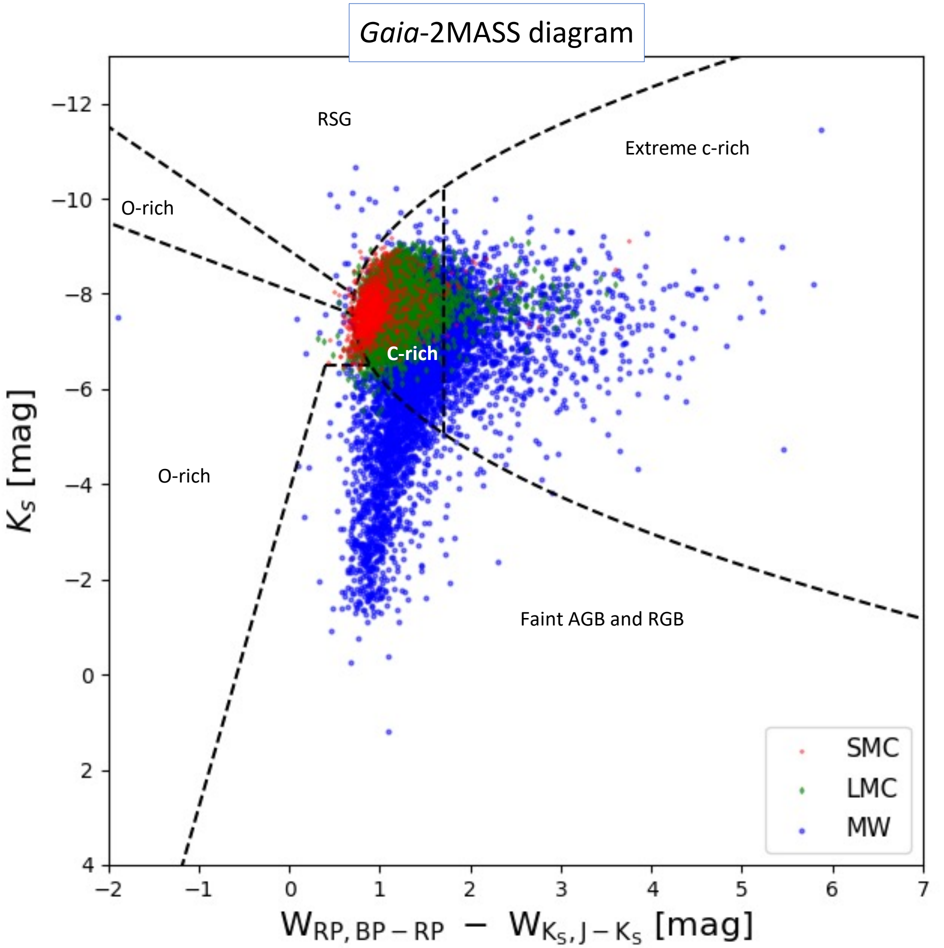
LMC: 5214 SMC: 971 MW: 9515



Gaia GOLDEN SAMPLE

- Photometric data from *Gaia*, 2MASS, WISE, SPITZER
- Integrated reddening using Lallement et al. 2022 3D dust map + Bailer-Jones et al. 2021 distances





Lebzelter+18

$$W = \left(G_{RP} - 1.3 \cdot (G_{BP} - G_{RP})\right) - (K_s - 0.686 \cdot (J - K_s))$$

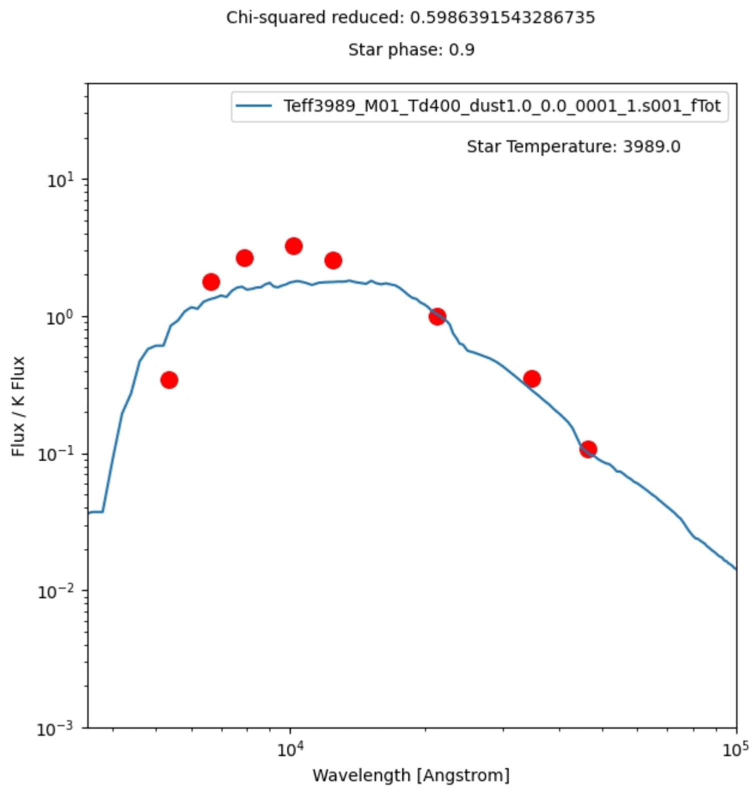
Distance and reddening free

PHOTOMETRIC VARIABILITY

AGB Carbon stars are variable stars (e.g. Miras)

Star's properties change considerably during the pulsation cycle

Pulsation phase can affect the result of the SED fit

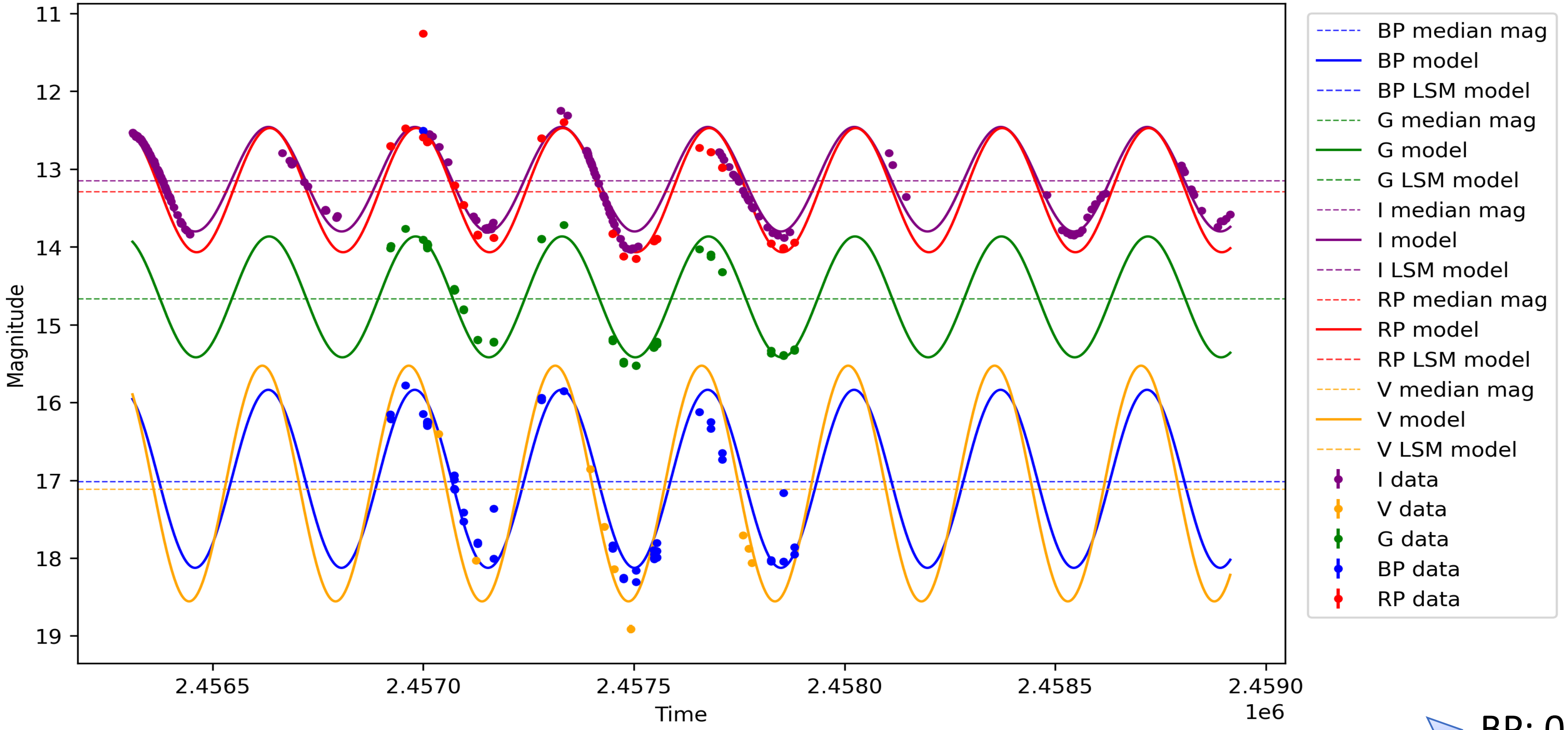


Fit reliable for **regular** pulsators

Magnitude correction only to Miras (2650 in total)

MULTIBAND LIGHTCURVE FIT

Magnitude correction only to Miras (2650 in total)



Gaia photometric bands correction → Mean fitted mag: average correction → BP: 0.15 mag, RP: 0.13 mag, G: 0.1 mag

Special thanks to Michele Trabucchi

MODELS GRID

Models created with **DUSTY** using input **COMARCS** models

COMARCS models (*Aringer et al. 2019*)

theoretical models from MARCS, designed for atmospheres and spectral properties of carbon stars

- $Surface\ Temperature = [2600\,;5000K]$
- $[M/H] = [-1.5\,;\ +0.5]$
- Masses: $0.5\ - 5M_{\odot}$
- C/O ≥ 1

DUSTY *Ivezic & Elitzur (1997)*

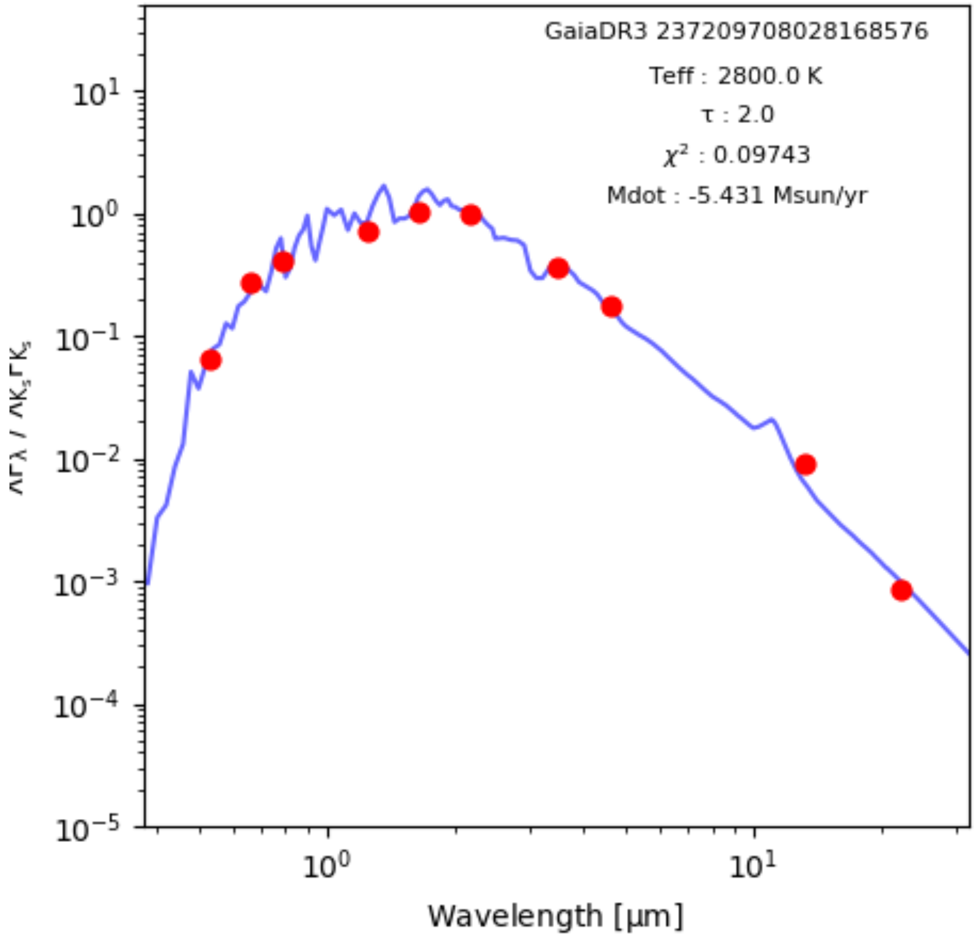
software calculating SEDs including extinction and emission from dust

- $Dust\ Temperature = [300\,;1200K]$
- Optical depth $\tau = [10^{-4}; 30]$
- Dust compositions : AmC and SiC

N_{MODELS} : 148,768

SED FITTING

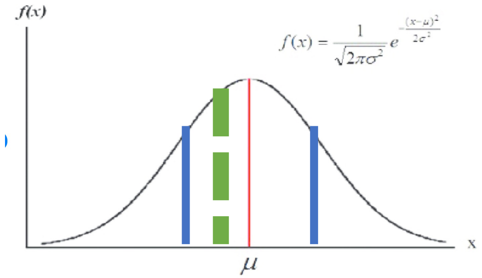
Classical reduced χ^2 fit



Parameters fitted:

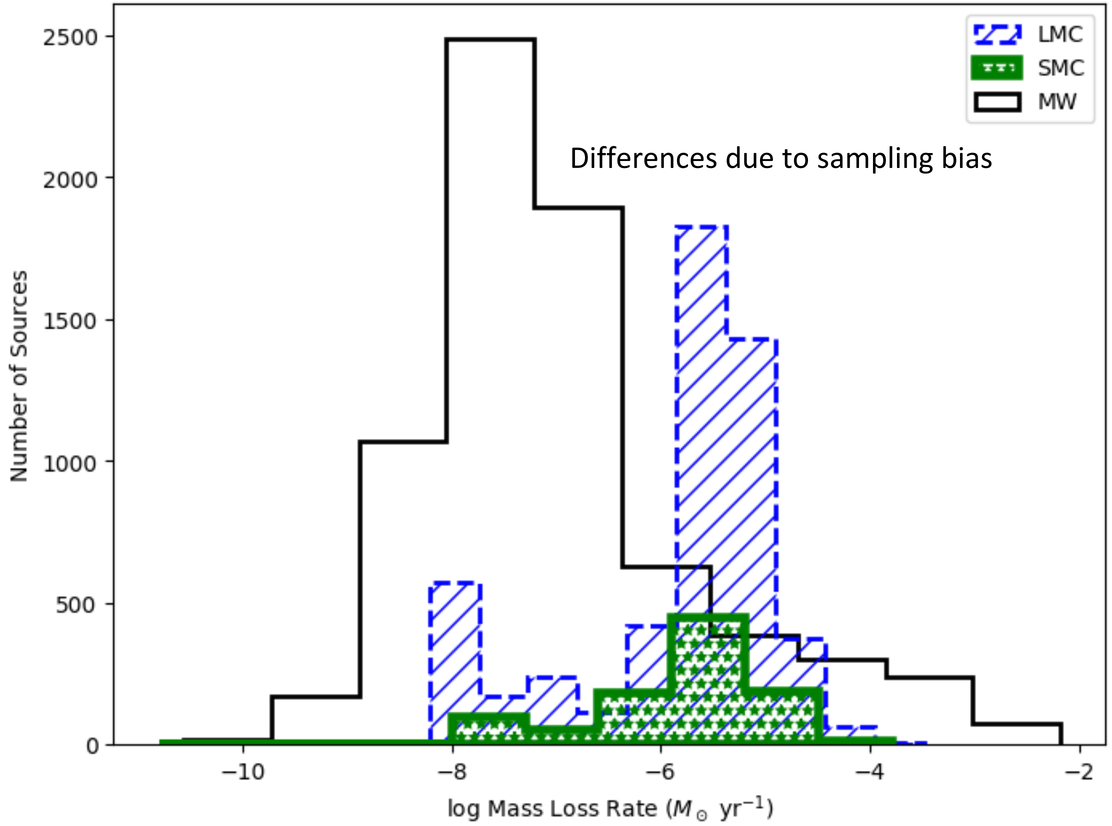
- Effective temperature
- Optical depth τ
- Dust composition
- Dust Temperature
- Mass-loss rate

Uncertainties from Gaussian randomization using photometric errors as 1σ

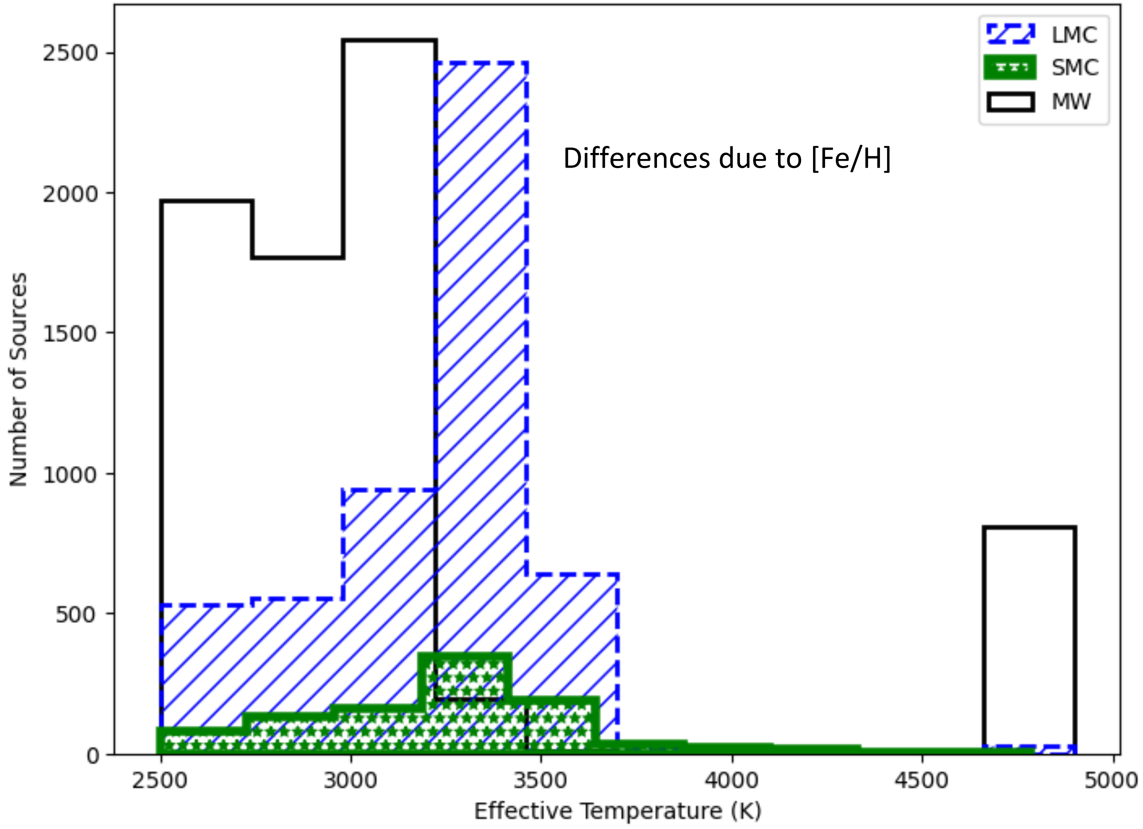


RESULTS

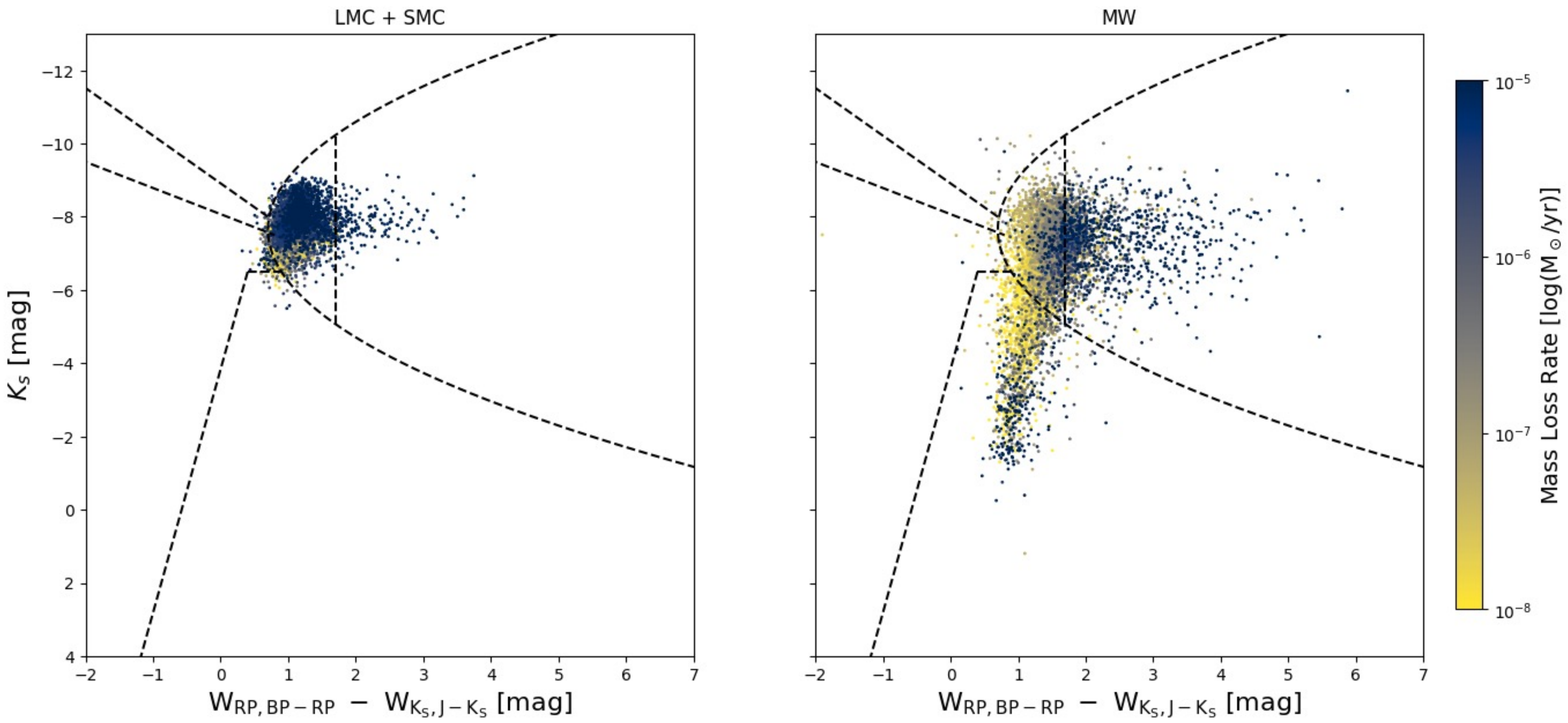
Mass-loss rate



Effective Temperature

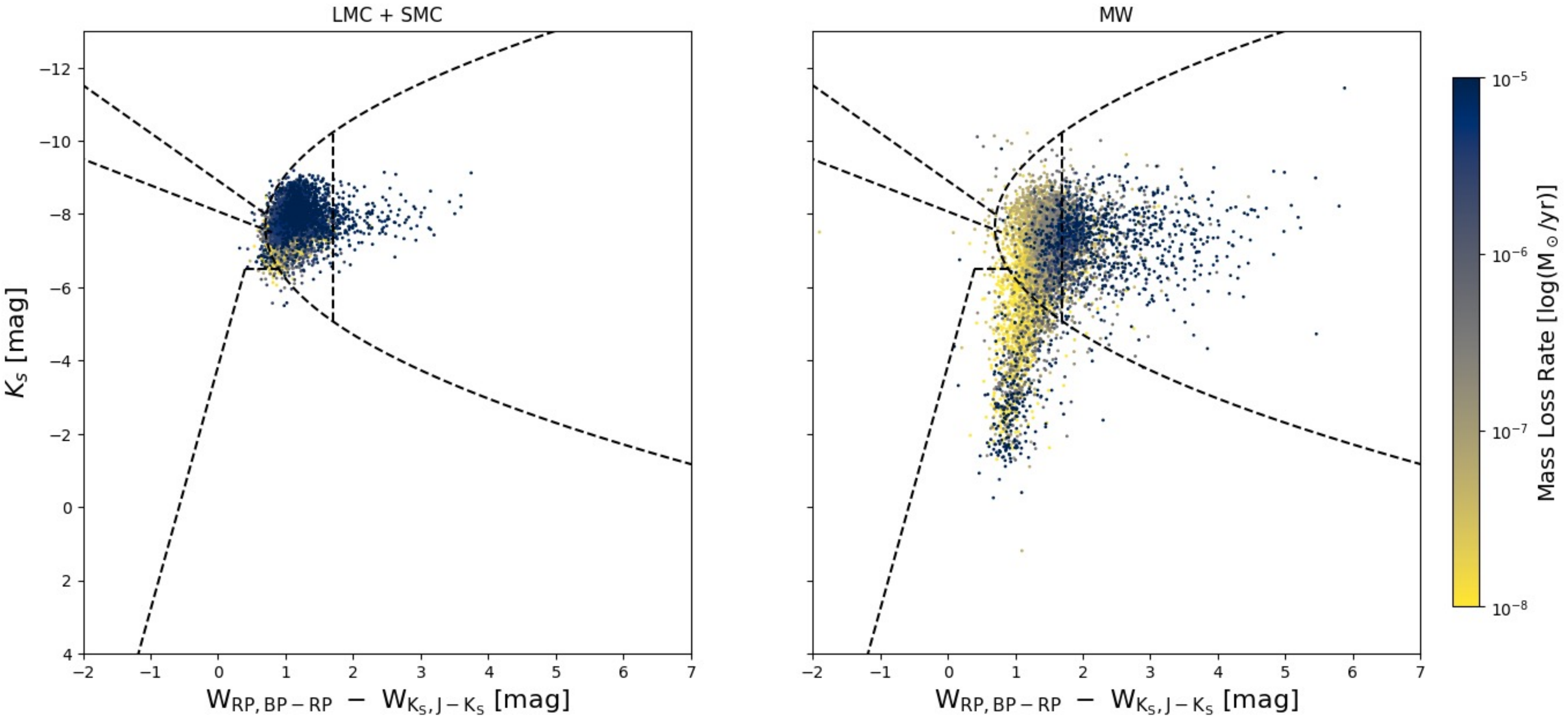


RESULTS



LMC + SMC
MW
−12
−10
−8
−6
−4
−2
0
2
4
−2
−1
0
1
2
3
4
5
6
7
K_s [mag]
$W_{RP, BP-RP} - W_{K_S, J-K_S}$ [mag]
10^{-5}
10^{-6}
10^{-7}
10^{-8}
Mass Loss Rate [log($M_\odot$/yr)]

RESULTS

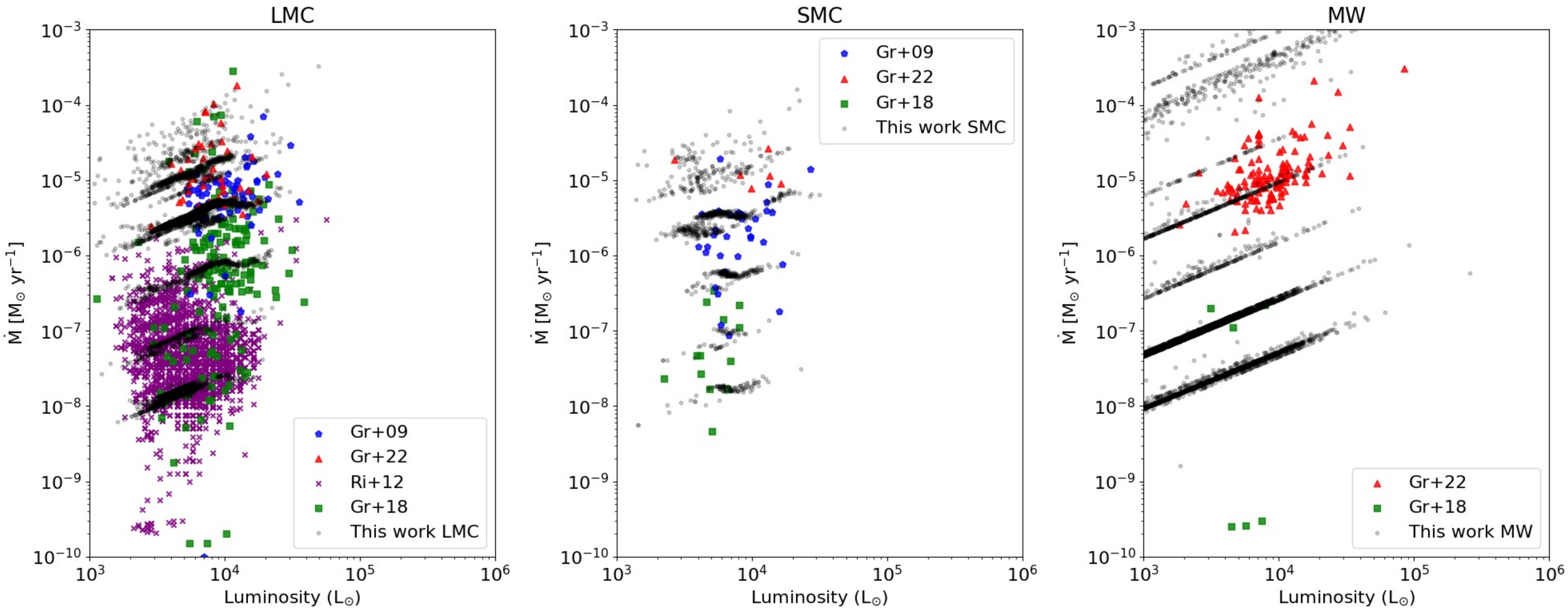


GaiaDR3_id	MinChisquared	MinChisquared_sigma	Teff	Teff_sigma	Tdust	Tdust_sigma	Mass	Mass_sigma	AmC	AmC_sigma	Lsun	Tau	Tau_sigma	Mass_Loss_Rate	Mass_Loss_Rate_sigma
14547844505574400	0.04998	0.79865	3700.	43.03563	800.	331.00252	1.	0.	0.	0.44919	7.93835	0.01	7.70801	3.622652E-9	7.64831
34334969292335488	0.09803	0.01359	3080.	146.83451	400.	0.	1.	0.08138	0.	0.	1.65107	0.01	1.776	3.029608E-9	1.54242
45546070886222592	0.02071	0.00956	3000.	63.21832	1200.	89.2537	2.	0.51485	0.	0.35383	22.63334	0.1	1.44913	2.915868E-8	1.28782
70373524480086784	0.02737	0.03376	2900.	87.26807	1200.	99.99111	3.	0.95733	1.	0.28867	26.53631	0.1	1.	2.958019E-8	1.18499
121689759370599680	0.05404	0.021	2800.	31.40418	1200.	0.	2.	0.4899	0.2	0.25551	99.51473	0.1	1.91138	8.633086E-8	1.64826
127514250419448576	0.01747	0.0389	3000.	82.46815	1200.	331.19313	2.	0.90355	0.8	0.42085	13.87523	0.01	6.39052	1.394703E-8	3.71003
135520962812986368	0.0522	0.01928	3080.	54.25034	1200.	128.88582	1.	0.	1.	0.23797	57.21474	0.0001	1.57839	1.984629E-10	1.69825
143300007579891584	0.01167	0.00628	3200.	0.	1200.	398.62207	2.	0.	0.	0.4871	201.71255	0.0001	2.79043	8.028621E-10	4.46056
146753848479844992	0.21224	0.03431	2850.	189.60885	1200.	42.18478	2.	0.49782	0.5	0.24944	272.8123	0.5	2.03749	6.383788E-7	1.66278
148416683722156544	1.80932	0.22207	3160.	77.13095	1200.	0.	2.	0.56174	0.	0.08138	3080.08655	0.5	2.66851	4.258527E-6	2.35937
150183397046402688	0.23989	0.04768	3250.	7.61898	1200.	16.27541	2.	0.2247	0.	0.13713	1321.83492	0.5	1.13994	2.367591E-6	1.10532
150754936935958016	0.03702	0.01044	3400.	46.11098	1200.	133.43996	2.	0.43107	0.	0.028	539.52948	0.1	1.62526	3.772605E-7	1.20309
150975389014887424	0.1141	0.04562	2800.	93.32679	1200.	98.24233	2.	0.52531	0.	0.17954	946.86308	0.1	1.94781	6.298567E-7	1.60557
155132191506964480	4.62001	0.49771	3000.	142.69388	1200.	16.27541	3.	1.15854	0.	0.	9217.36502	1.	1.18224	1.937860E-5	1.17643
156076951170135680	0.23702	0.08858	2850.	164.3405	1200.	45.87907	1.	0.35377	0.	0.12924	5441.6947	0.5	1.20274	6.969367E-6	1.10659
156100315793870976	0.33316	0.46366	3200.	250.87501	1200.	166.19132	1.	0.8437	0.	0.14214	8369.98782	0.5	1.95283	9.713295E-6	1.61708
157259231112403328	0.24027	0.03698	3240.	4.42217	1200.	0.	1.	0.44222	0.	0.03919	340.70839	0.5	1.	8.406070E-7	1.0134
160435896298700544	0.23893	0.02483	3240.	13.18315	1200.	0.	1.	0.40966	0.	0.09442	937.95202	0.5	1.20689	1.796558E-6	1.15373
168708759226404736	0.13029	0.01885	2850.	38.58612	1200.	42.18478	2.	0.4714	0.2	0.21851	14.09624	0.5	1.83901	6.962085E-8	1.57815
173223560127109376	0.34192	0.06544	3150.	6.74283	1200.	0.	2.	0.35377	0.	0.	2827.35871	0.5	1.	3.954903E-6	1.00313

Publicly available soon
(Liberatori et al., in prep)

COMPARISON WITH LITERATURE

Mass-loss rates



Literature: Groenewegen+09, 18, 22, Riebel+12

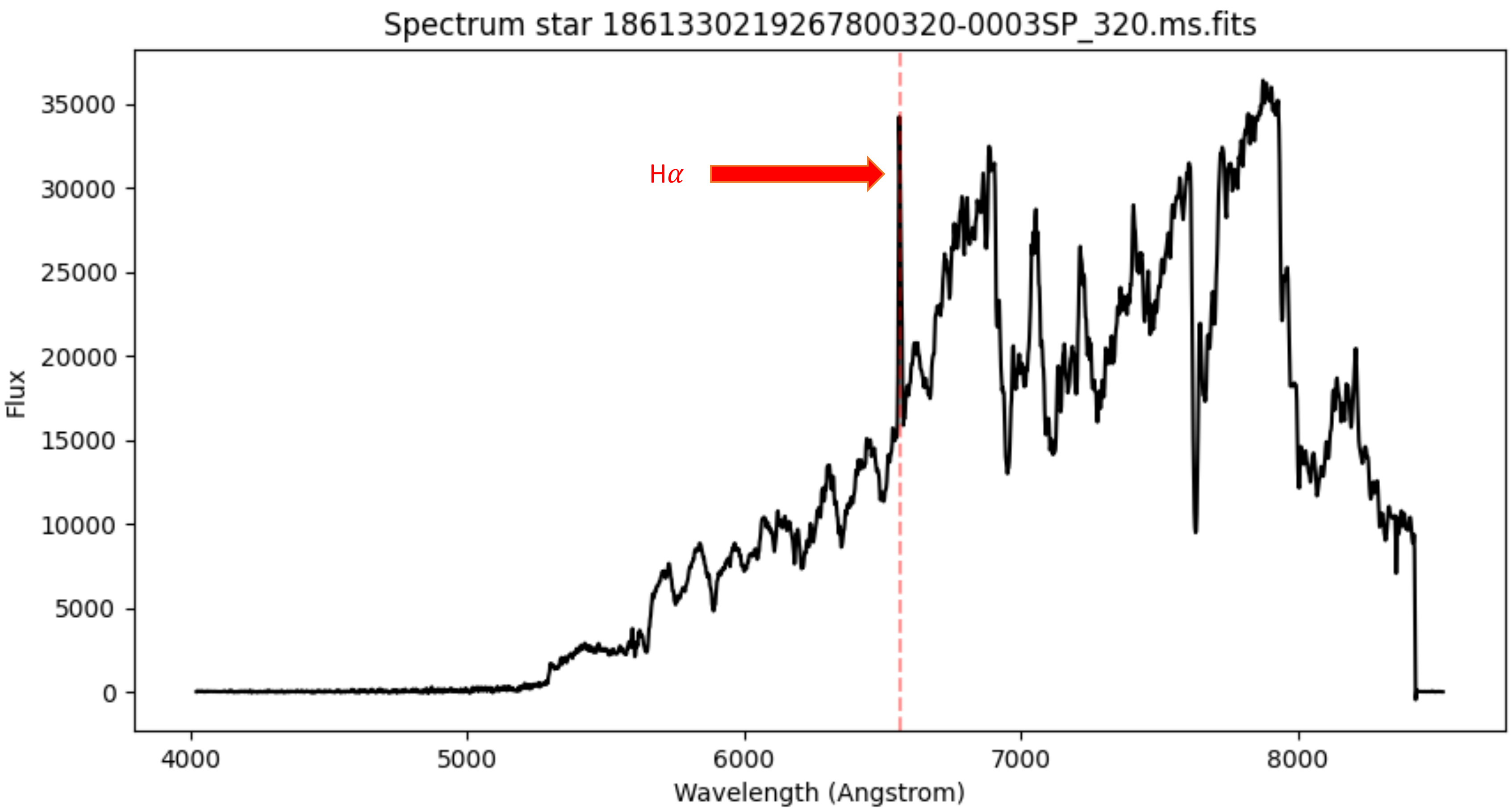
SUMMARY

- Generated ~150,000 **COMARCS+DUSTY synthetic models**
- Computed **average Gaia magnitudes for Miras** via multiband light curve fitting
- Derived **stellar and dust parameters** for AGB C-stars in the MW and MCs

Hα emission in carbon stars

Observed 8 AGB Carbon stars' spectra (Skinakas Observatory, Crete, Greece)

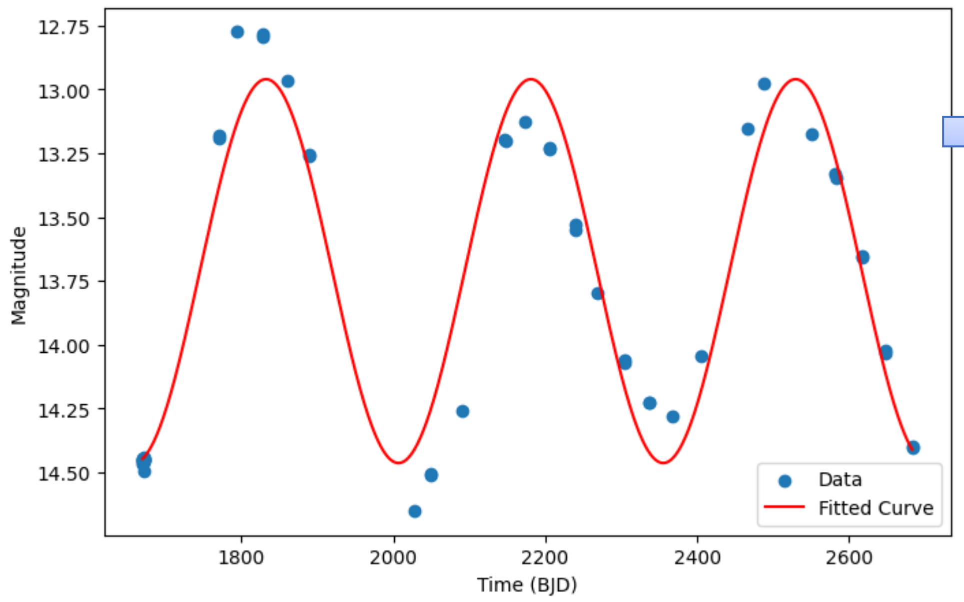
Some of them showed strong Hα line emission

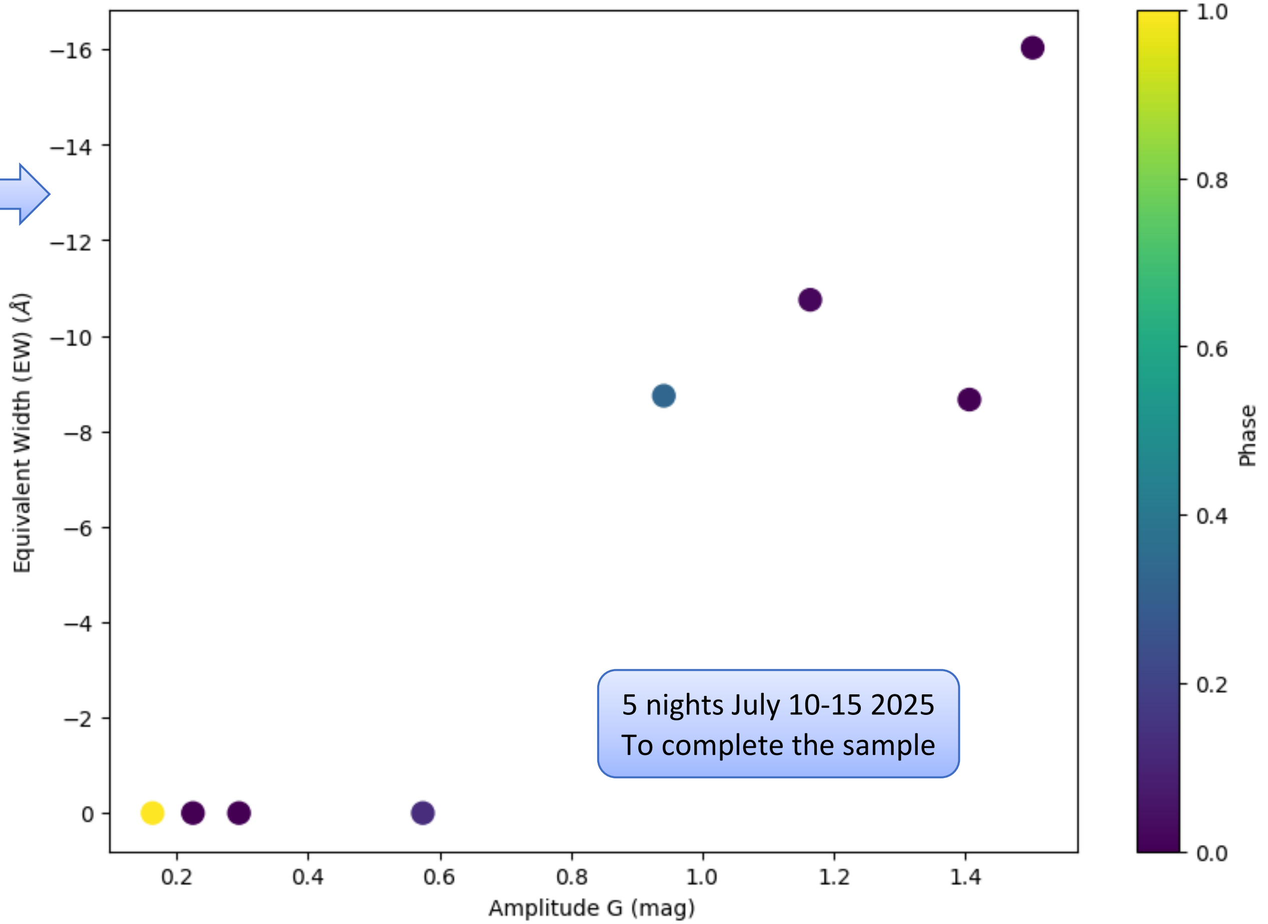


PI: Liberatori

Hα emission in carbon stars

Derived the pulsation phase of each spectra at the time of the observation for each star





Previously found in Maizels&Morris1990, Barnbaum92, Mikulášek & Gráf 2005 → **Shocks due to pulsation**

Which physical explanation can we give?
Proper model is still missing (Liberatori et al., in prep.)

THANK YOU FOR THE ATTENTION

OPEN TO SUGGESTIONS & COLABS