Discovering High-Redshift AGB Analogs in Nearby Metal-Poor Dwarf Galaxies

Steven Goldman, Martha Boyer, & the DUSTiNGS team

STScI | SPACE TELESCOPE SCIENCE INSTITUTE

Overview

- Evolved Stars
- Effects of Metallicity
- Nearby samples
- DUSTiNGS survey
- Leo P
- The DESK

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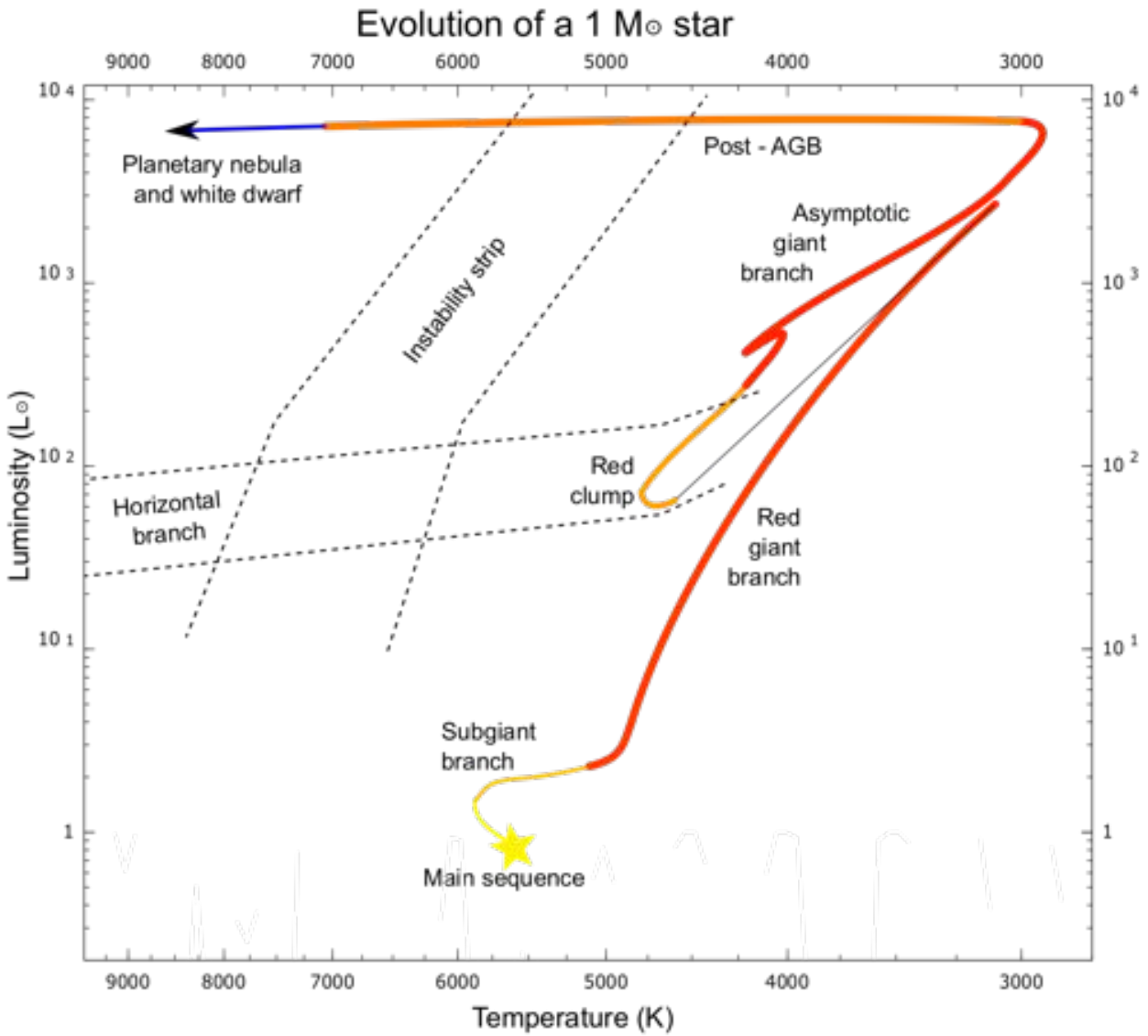
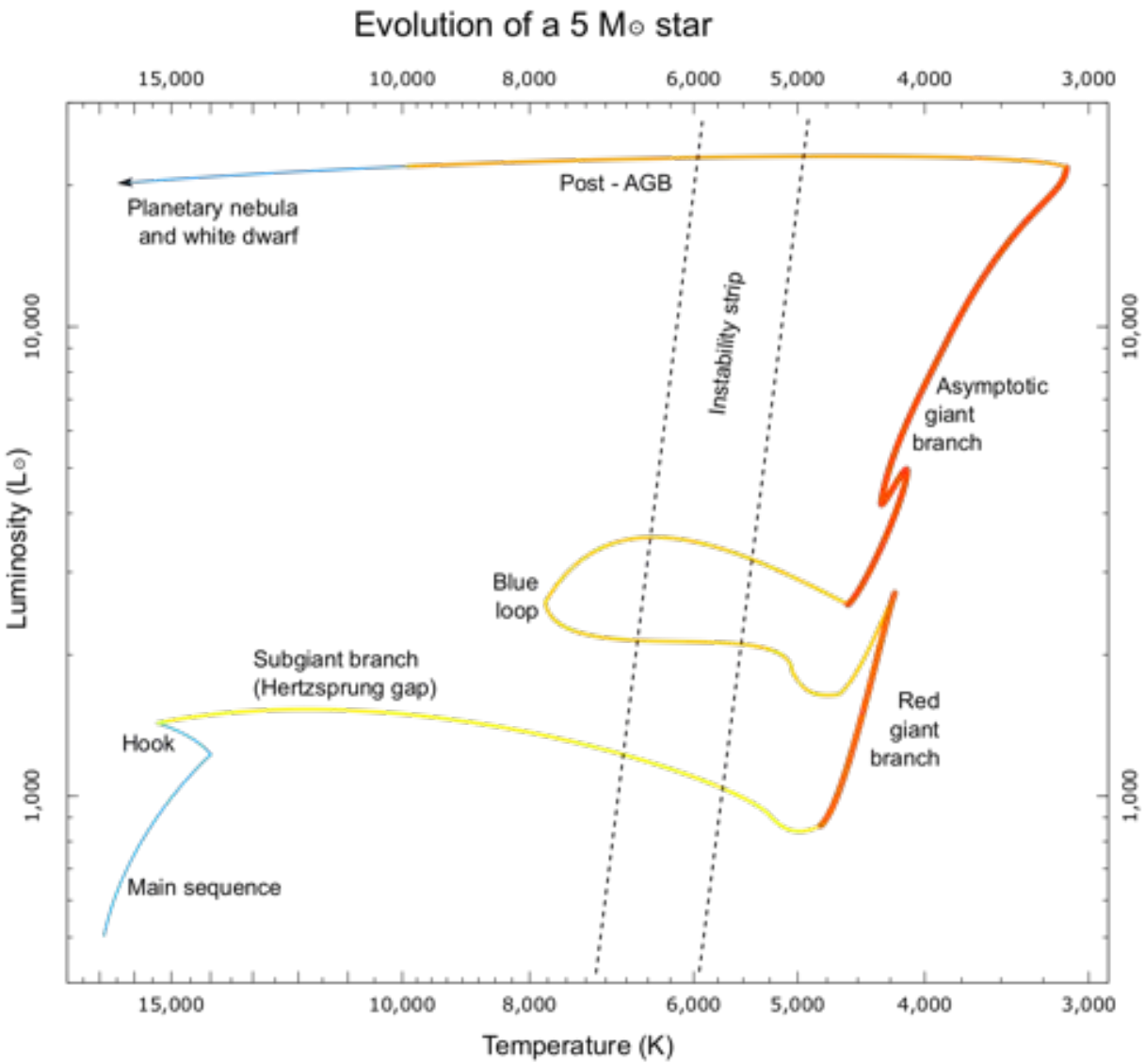
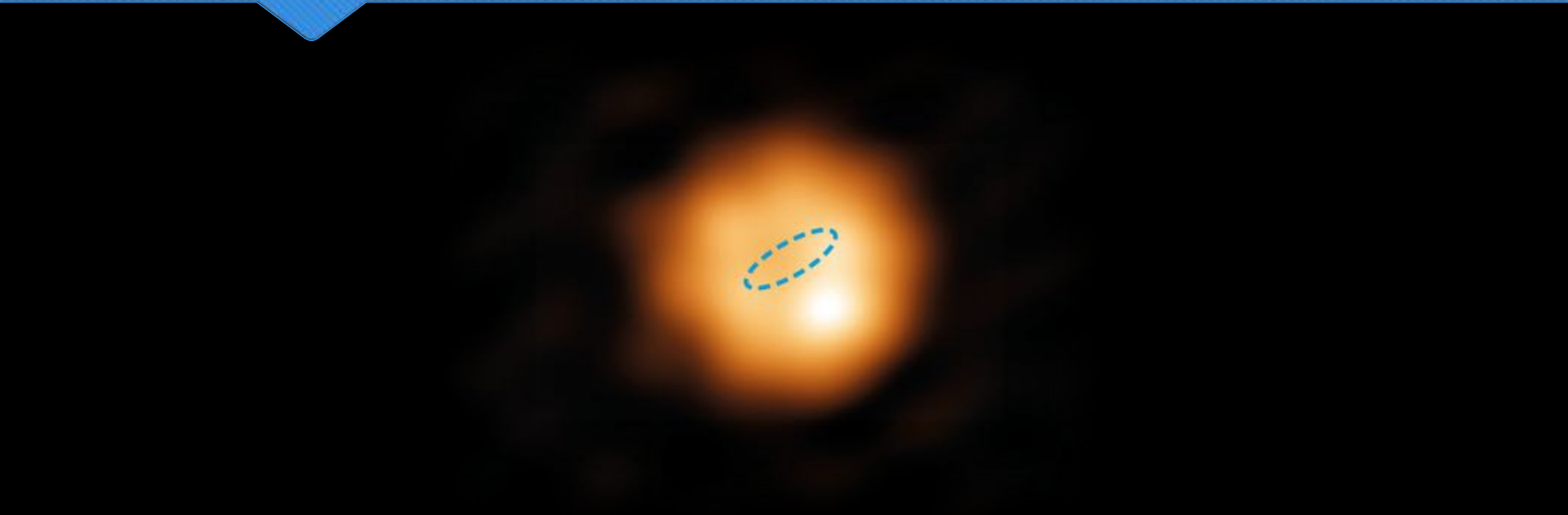

Evolution of a 1 M⊙ star
9000
8000
7000
6000
5000
4000
3000
Planetary nebula
and white dwarf
Post - AGB
Asymptotic
giant
branch
Instability strip
Red
clump
Horizontal
branch
Red
giant
branch
Subgiant
branch
Main sequence
Luminosity (L⊙)
Temperature (K)

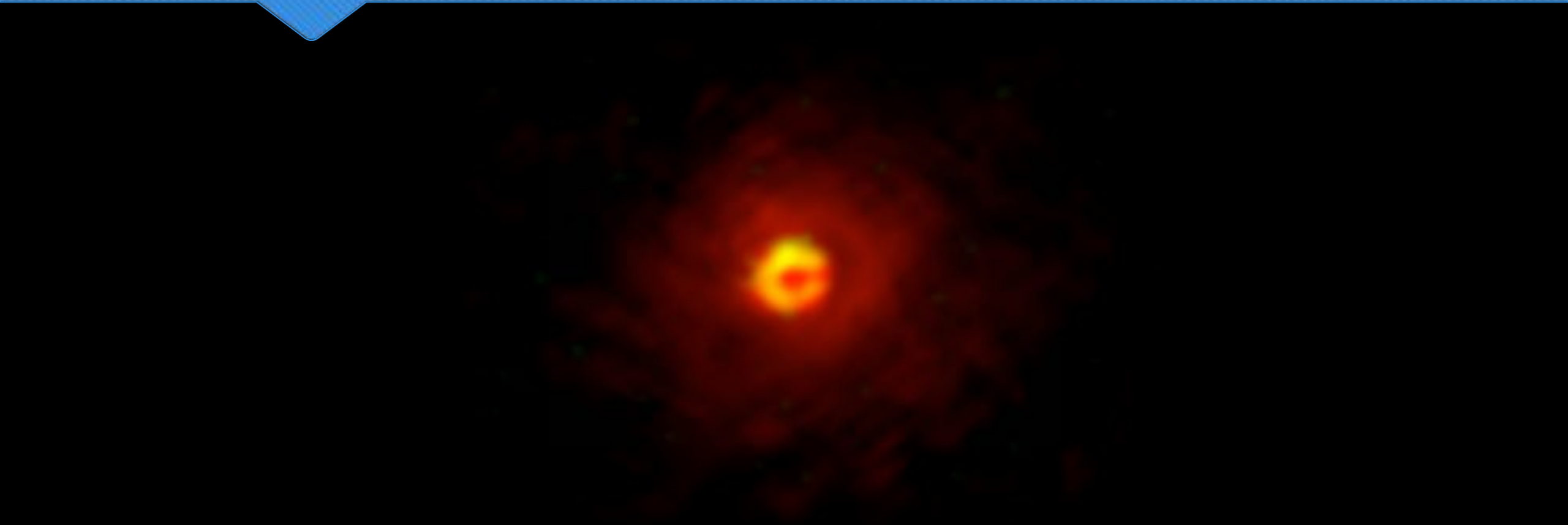

Evolution of a 5 M⊙ star
15,000
10,000
8,000
6,000
5,000
4,000
3,000
Planetary nebula
and white dwarf
Post - AGB
Instability strip
Asymptotic
giant
branch
Blue
loop
Subgiant branch
(Hertzsprung gap)
Hook
Red
giant
branch
Main sequence
Luminosity (L⊙)
Temperature (K)

W Hydrae



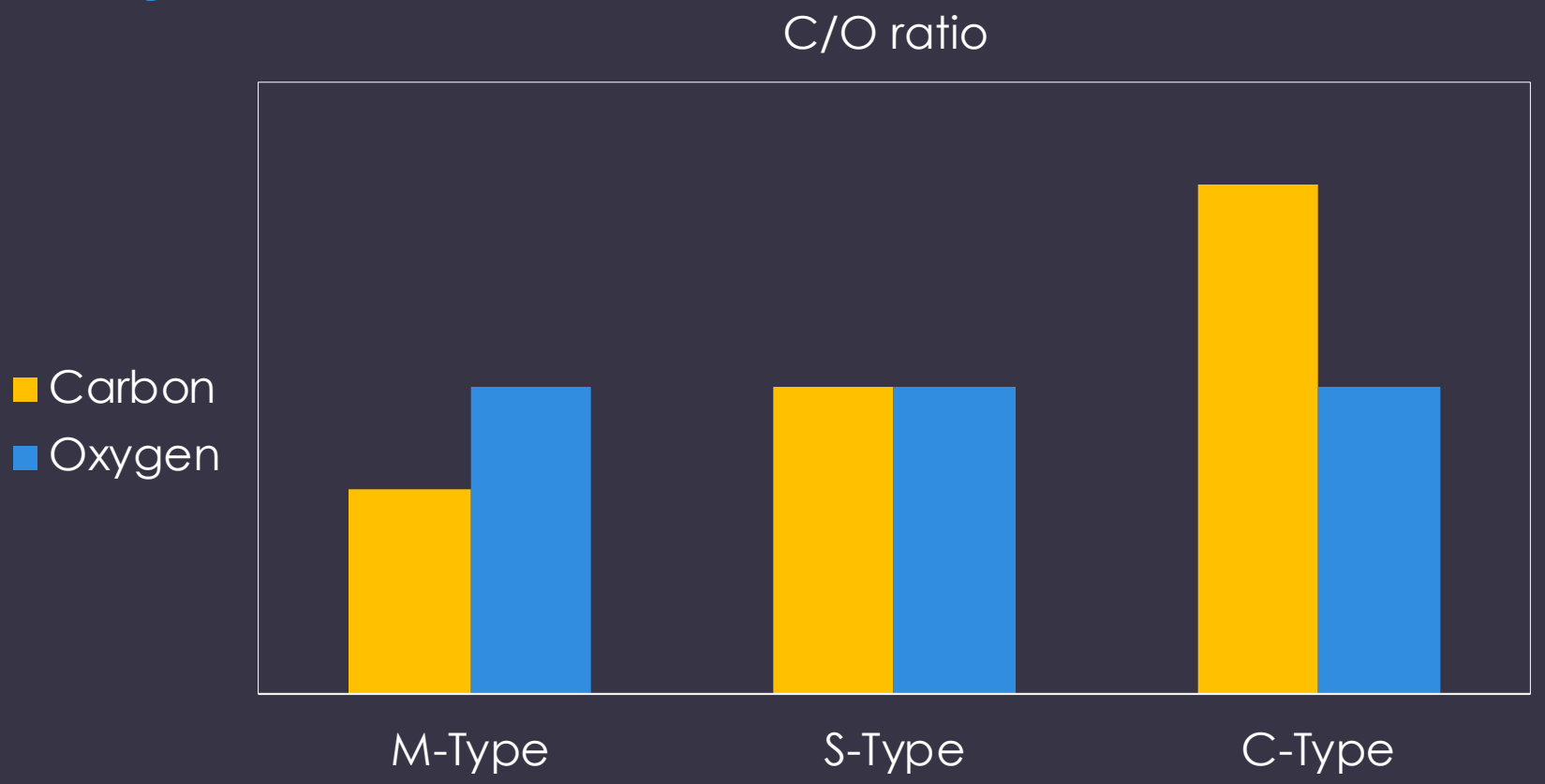
Credit: ALMA (ESO/NAOJ/NRAO)/W. Vlemmings

W Hydrae

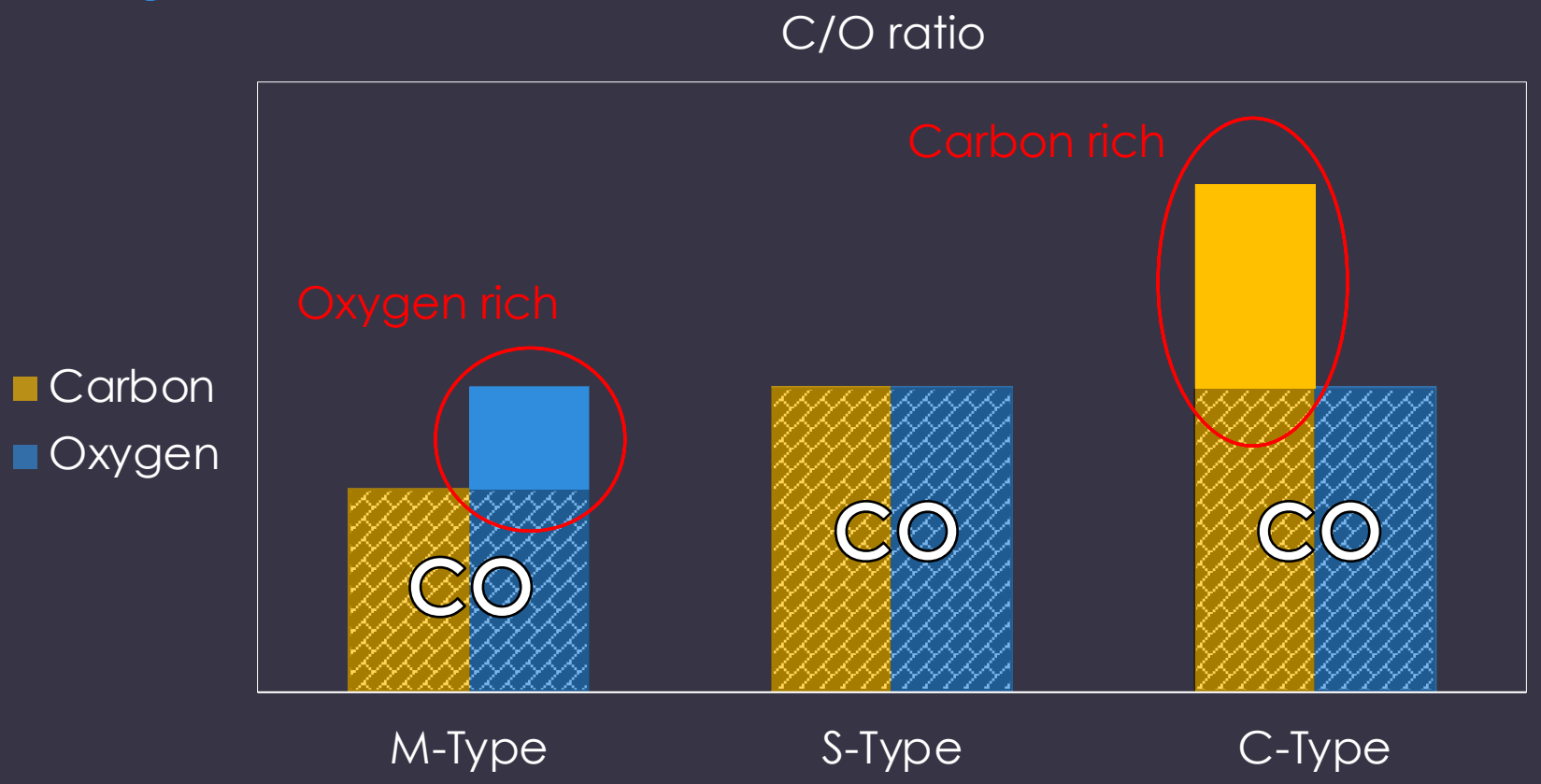


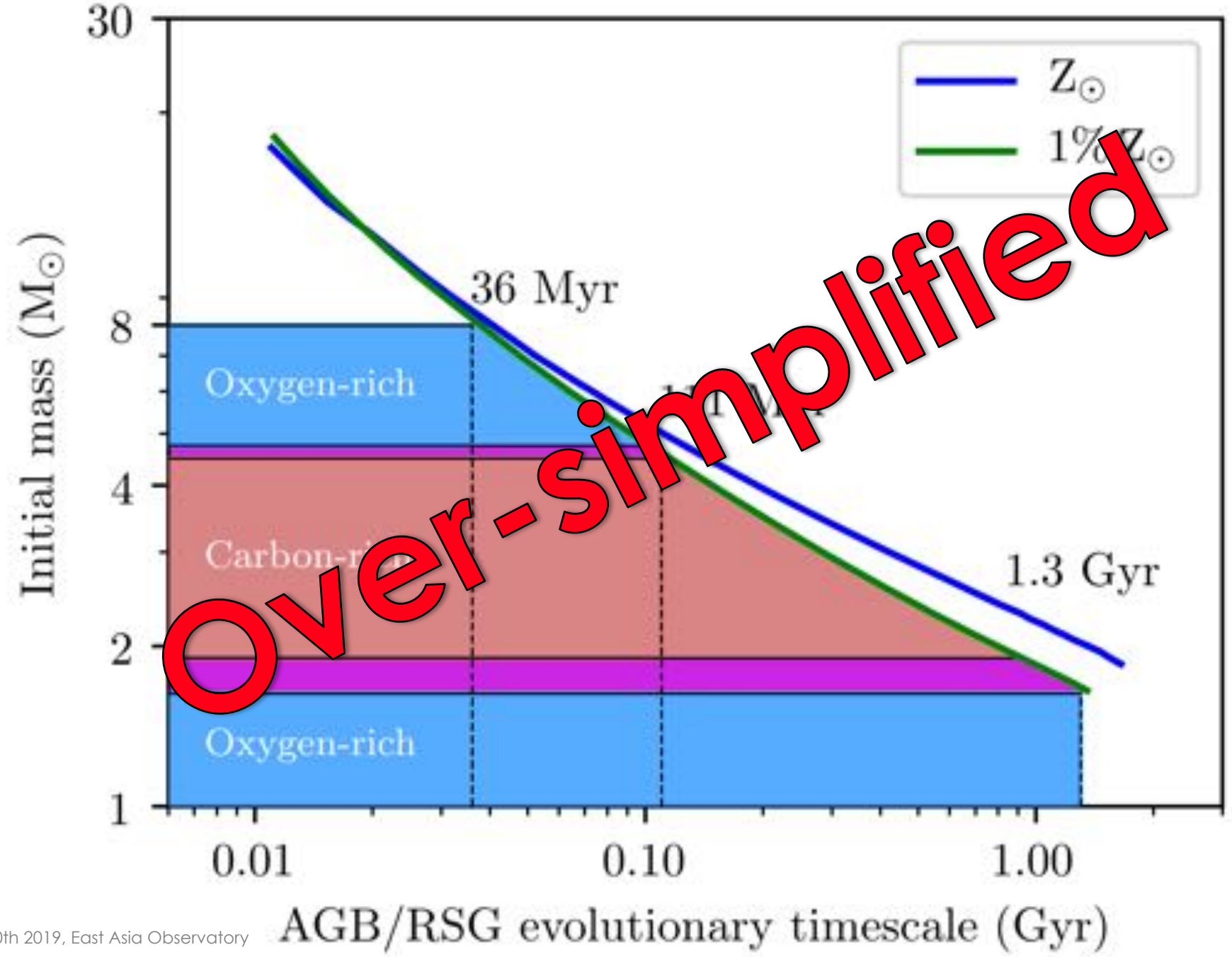
Credit: ALMA (ESO/NAOJ/NRAO)/W. Vlemmings

Circumstellar Chemistry



Circumstellar Chemistry



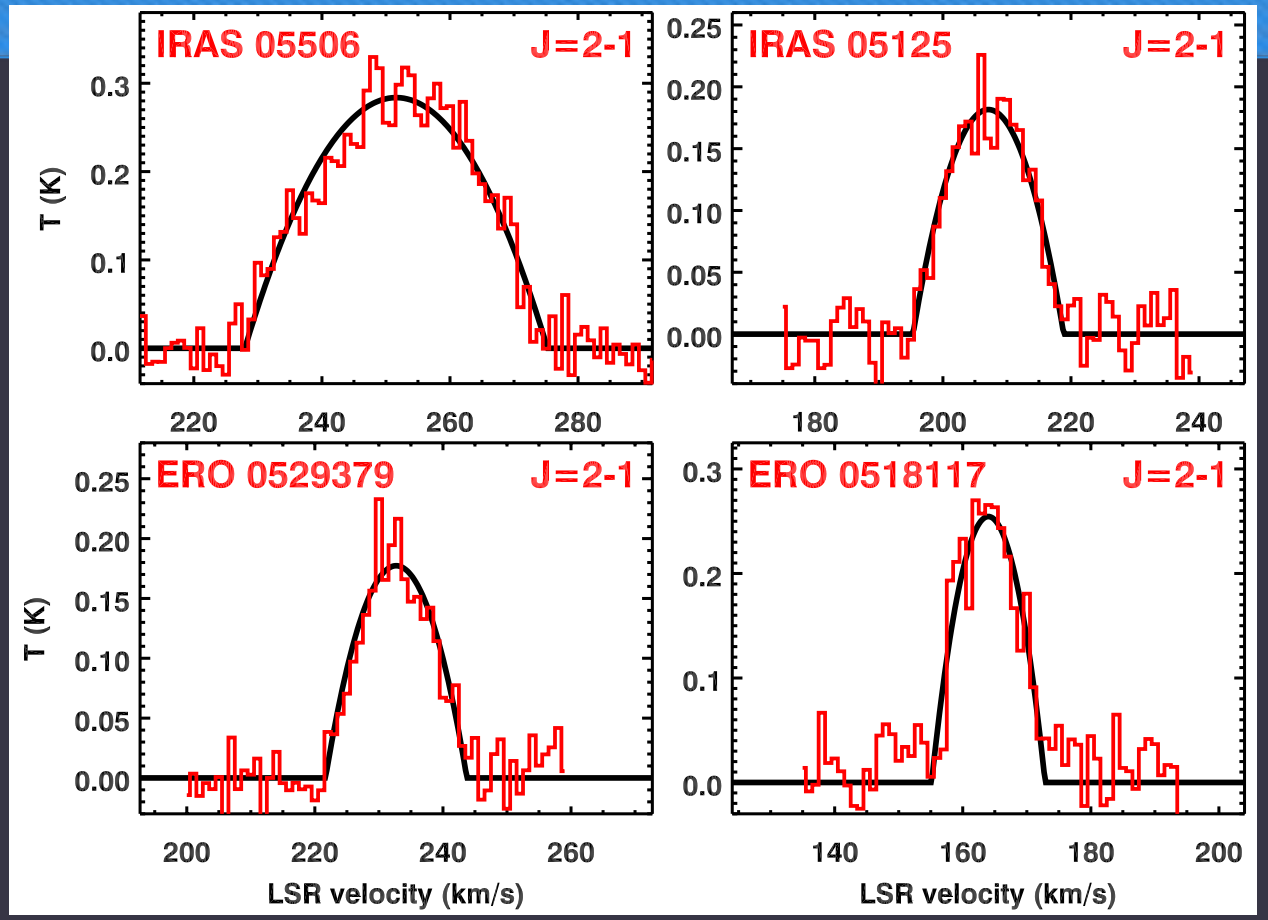


Over-simplified

AGB Interior

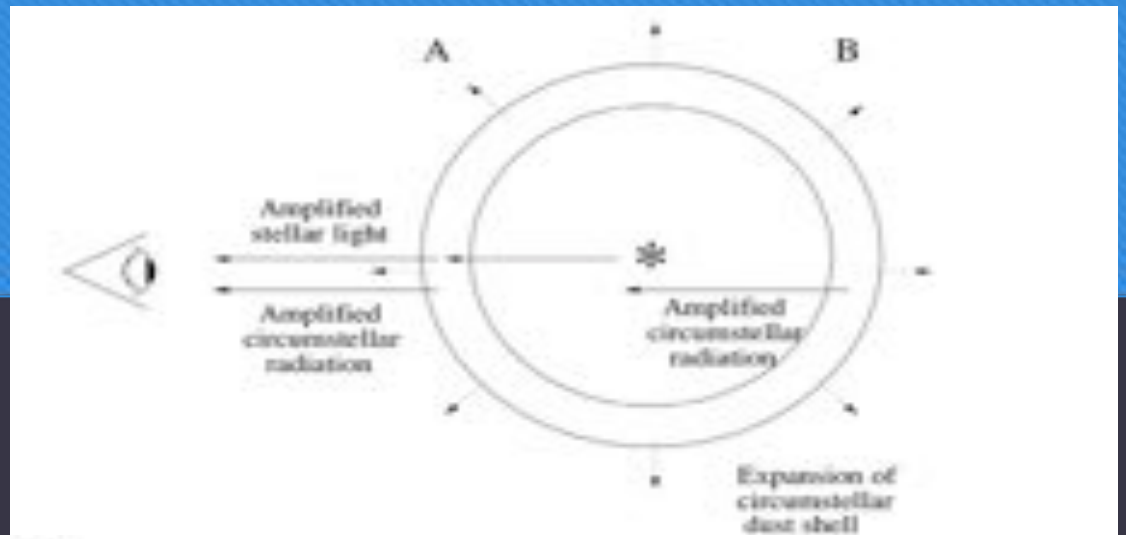
How does dust it form?

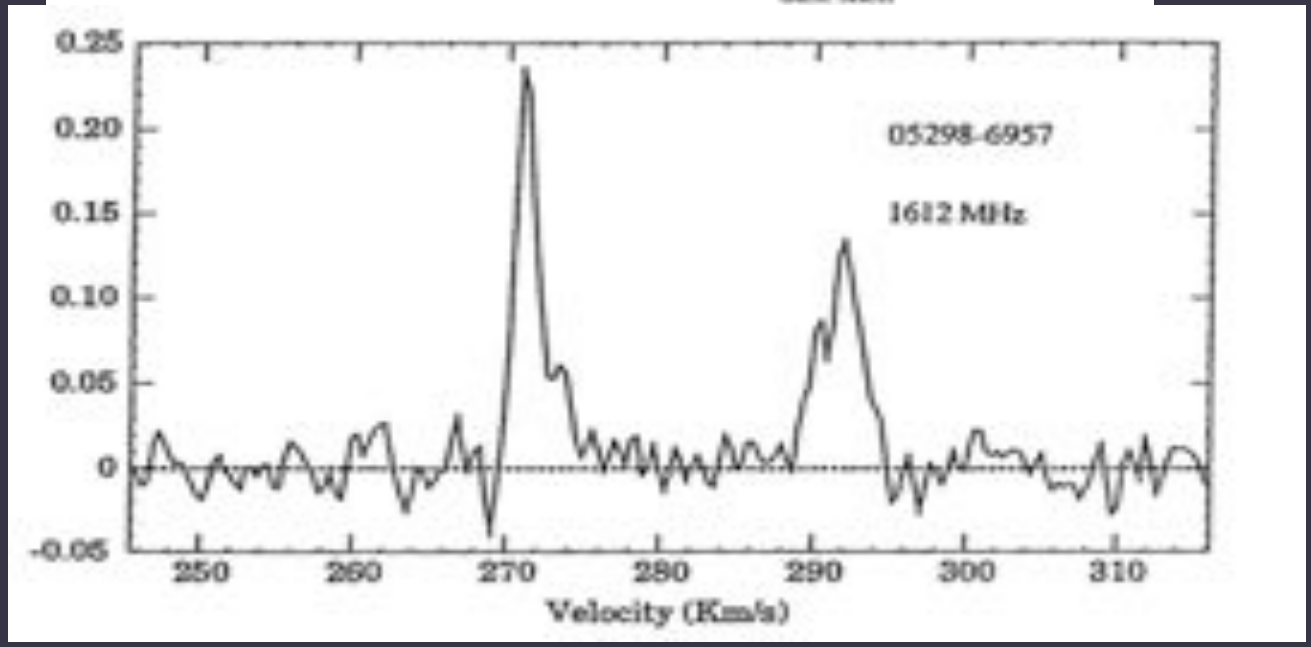
CO line emission



Groenewegen et al. 2016

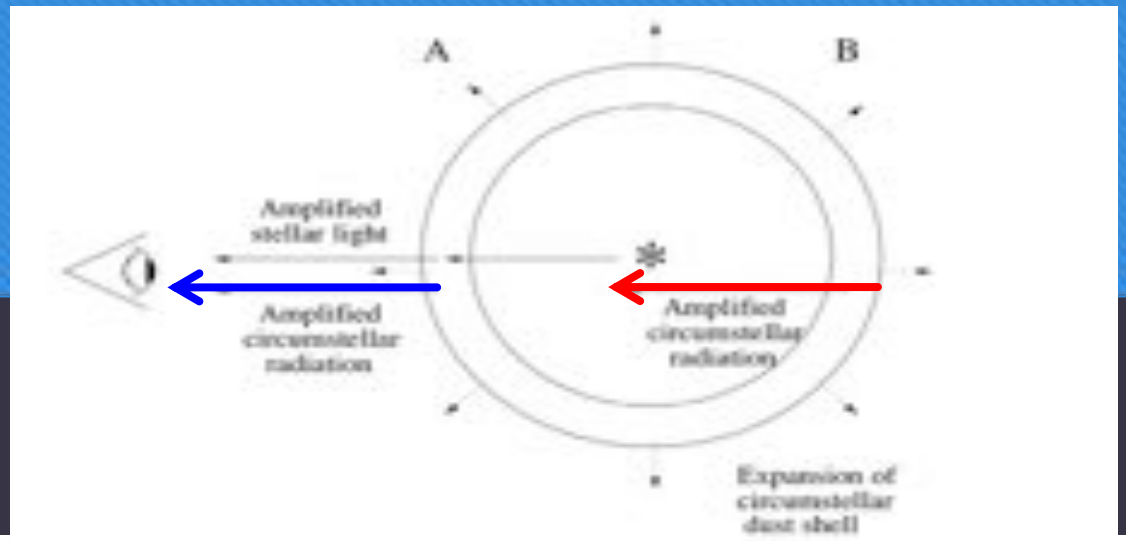
OH maser

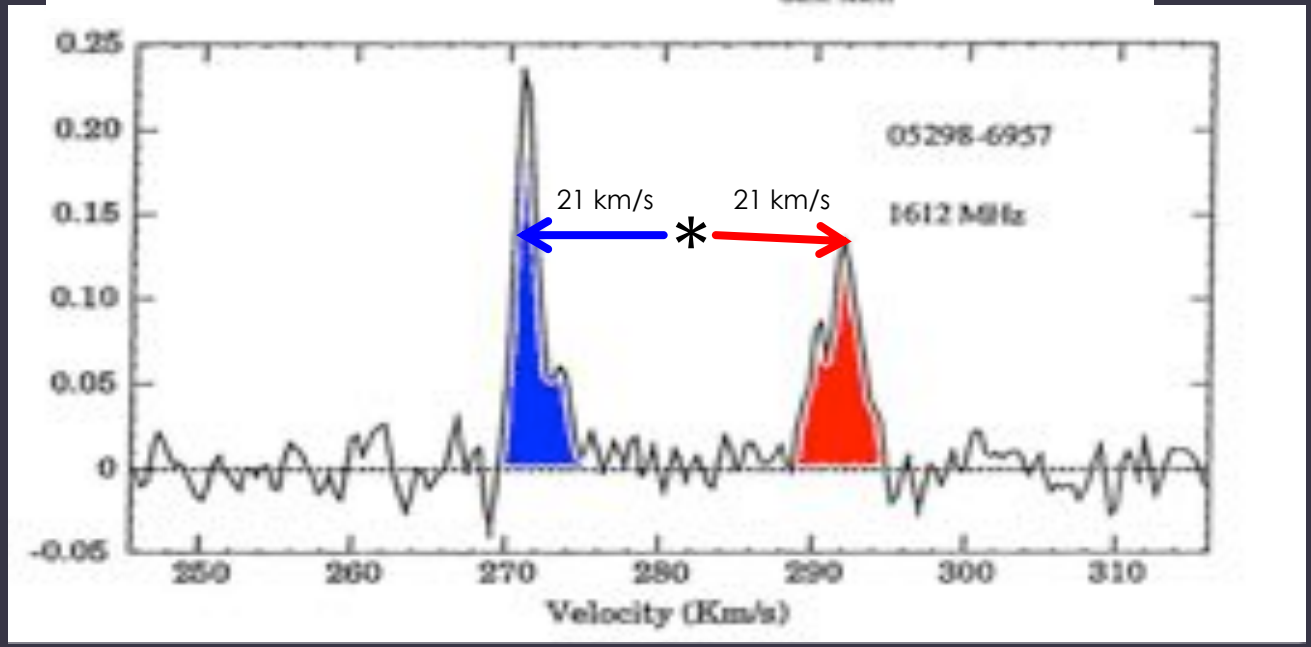




Wood et al. 1992; Marshall et al. 2004

OH maser





Wood et al. 1992; Marshall et al. 2004

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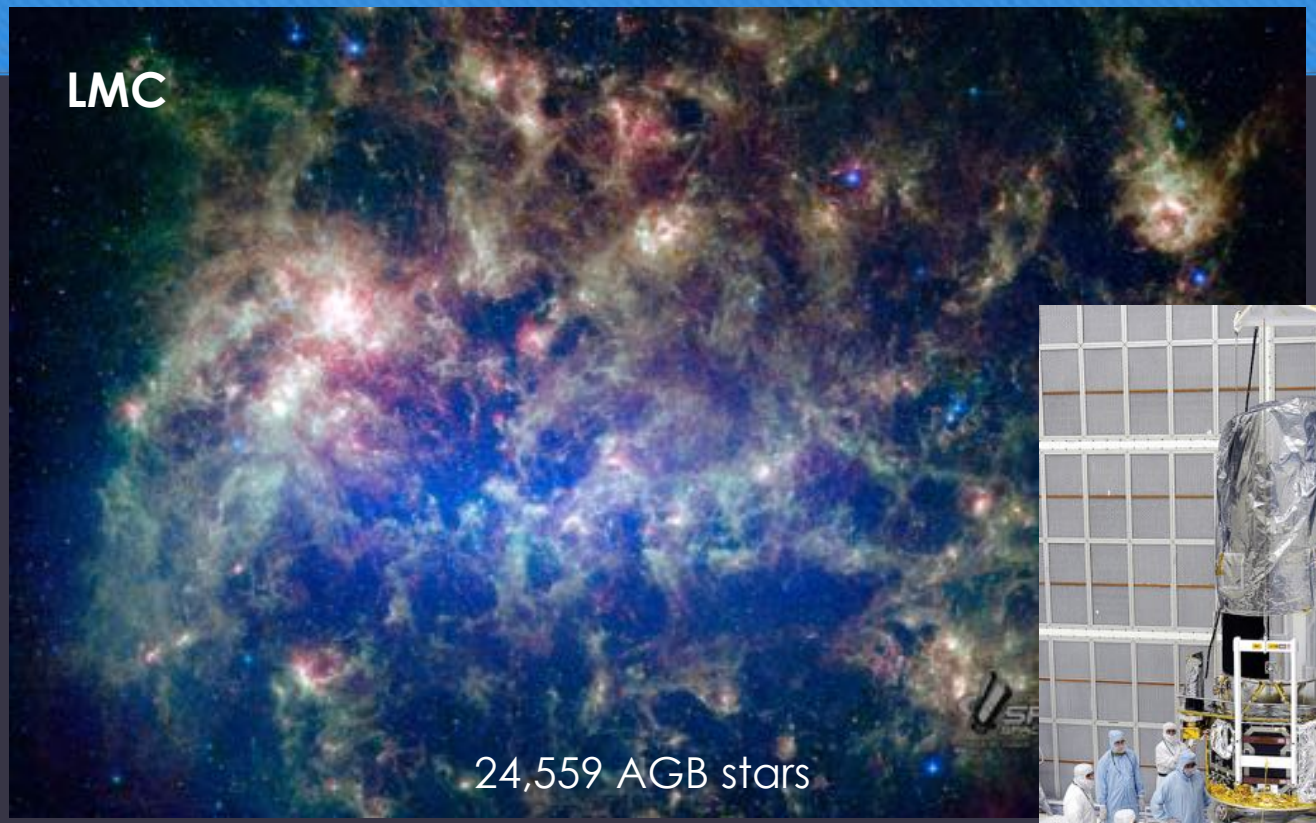
Carbon and Oxygen samples

Effects of metallicity



24,559 AGB stars

70% Oxygen
25% Carbon
5% x-AGB stars

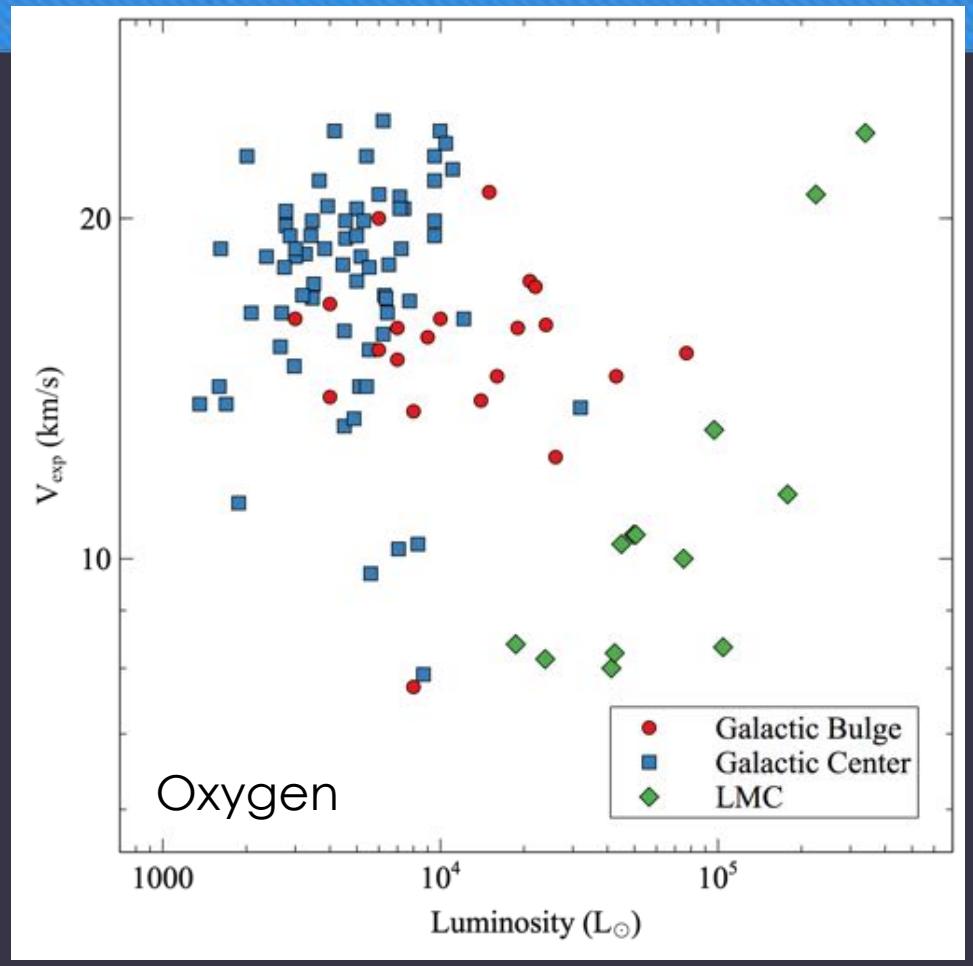
5,800 AGB stars

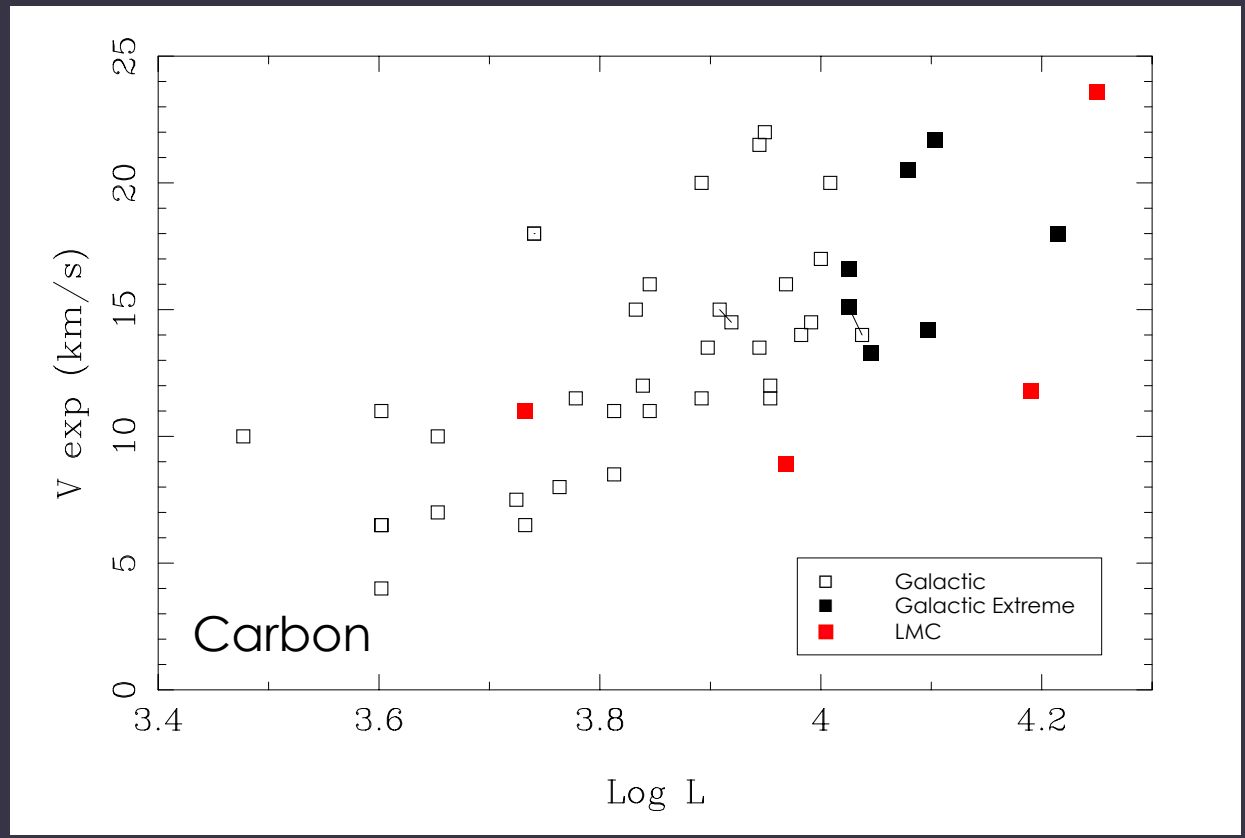
64% Oxygen
30% Carbon
6% x-AGB stars

Blum et al. 2006; Boyer et al. 2011

Gas contribution

Effects of metallicity

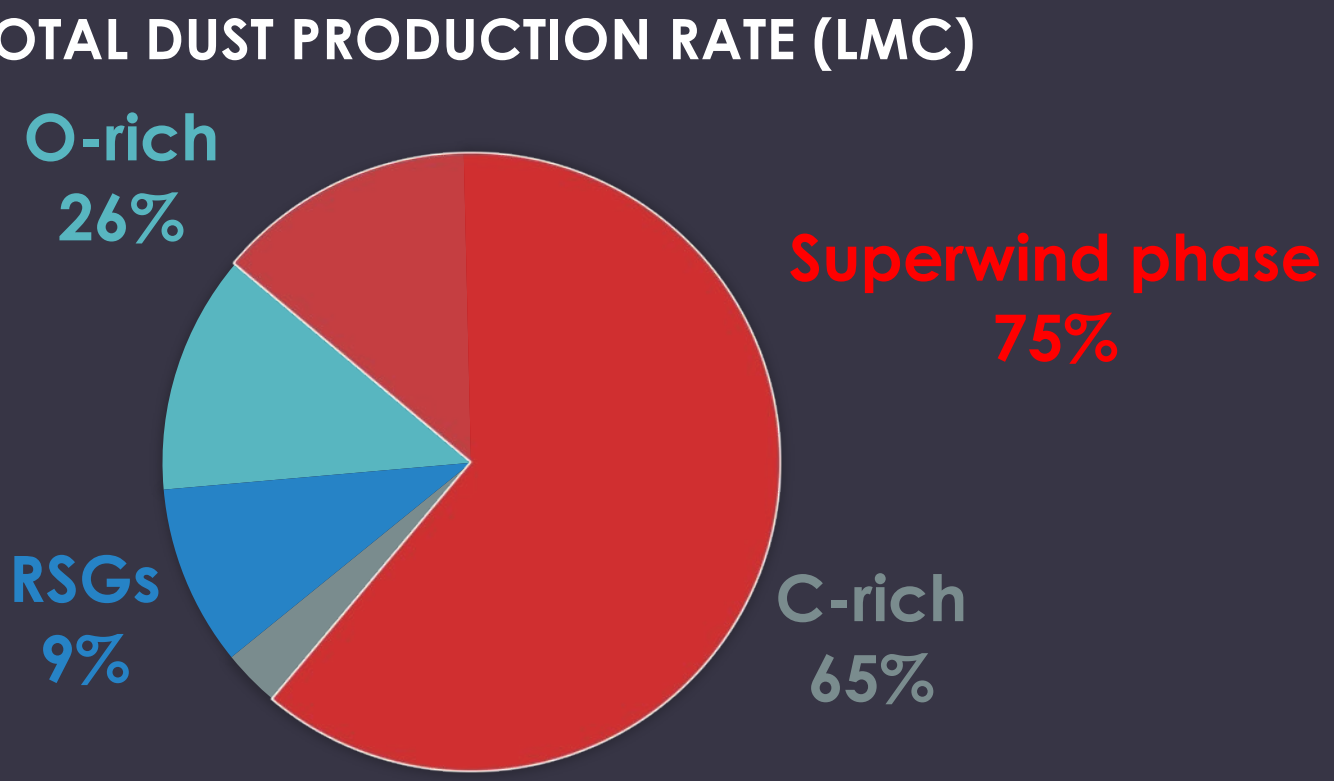




Goldman et al. 2017; Groenewegen et al. 2016

Dust contribution

Super Novae?



Data from Riebel et al. (2012)

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Most metal poor

	Fe/H	Sources
Fornax	-0.99	7
NGC 6822	-1.0	50+
NGC 147	-1.1	168
NGC 185	-1.3	419
Phoenix	-1.37	1
Leo I	-1.43	26
IC 1613	-1.6	9
Sculpter	-1.68	2
Sag DIG	-2.1	3
M15	-2.37	2

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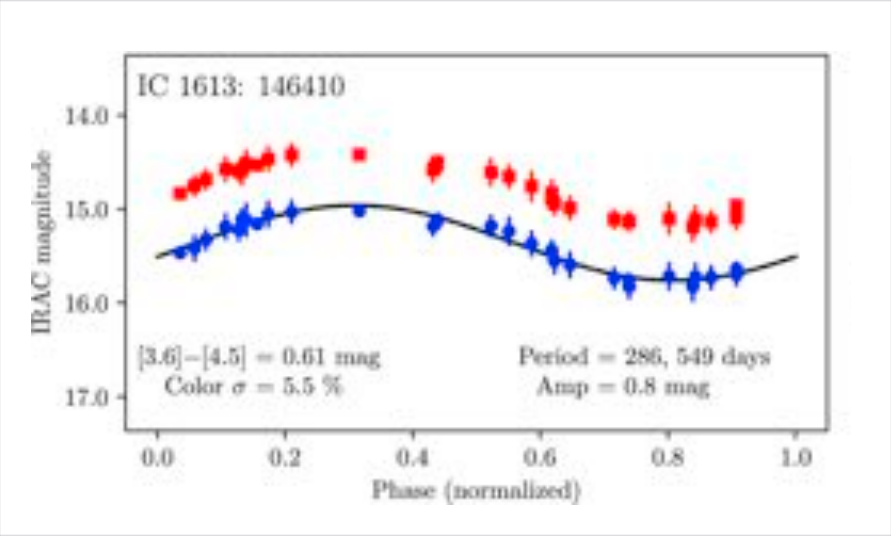
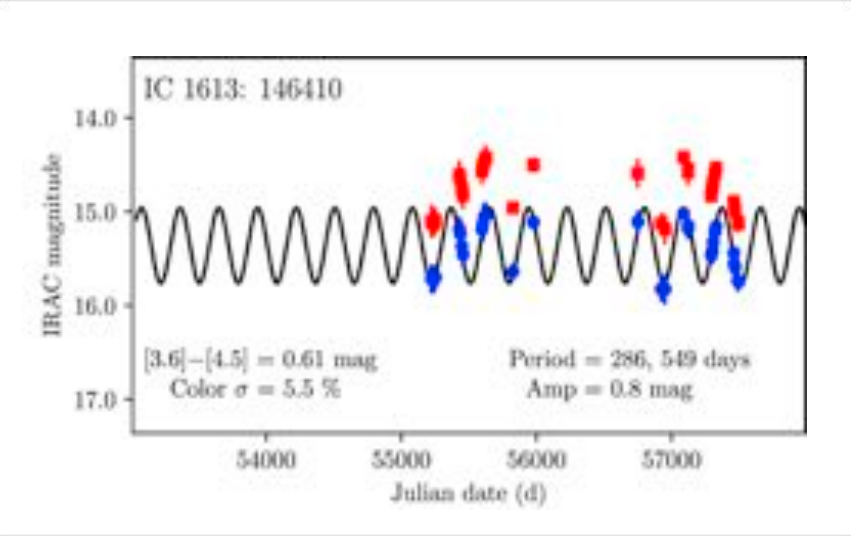
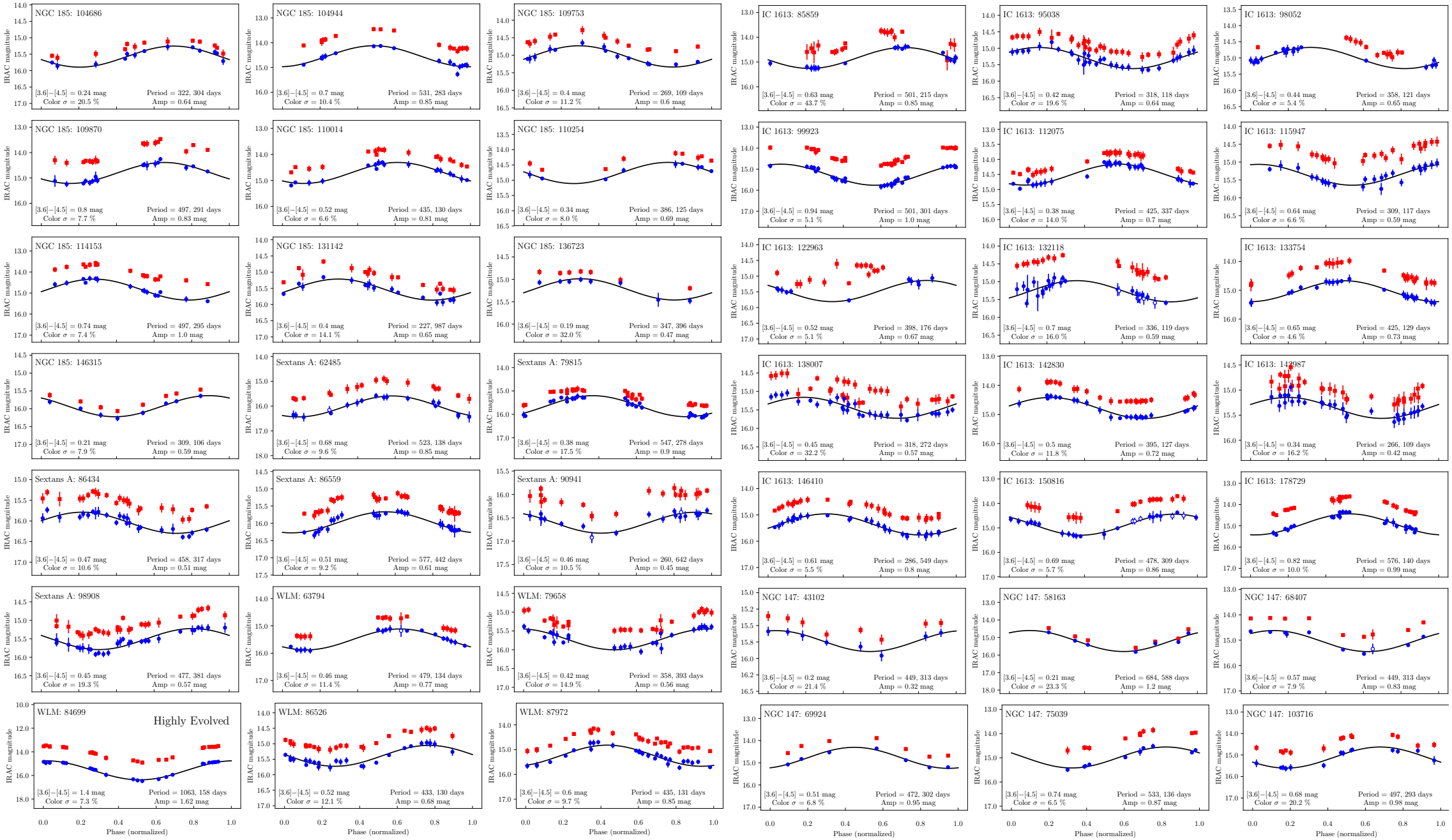
Example lightcurve

DUSTiNGS Survey





Goldman et al. 2019


NGC 185: 104686
[3.6]−[4.5] = 0.24 mag
Color σ = 20.5 %
Period = 322, 304 days
Amp = 0.64 mag
NGC 185: 104944
[3.6]−[4.5] = 0.7 mag
Color σ = 10.4 %
Period = 531, 283 days
Amp = 0.85 mag
NGC 185: 109753
[3.6]−[4.5] = 0.4 mag
Color σ = 11.2 %
Period = 269, 109 days
Amp = 0.6 mag
IC 1613: 85859
[3.6]−[4.5] = 0.63 mag
Color σ = 43.7 %
Period = 501, 215 days
Amp = 0.85 mag
IC 1613: 95038
[3.6]−[4.5] = 0.42 mag
Color σ = 19.6 %
Period = 318, 118 days
Amp = 0.64 mag
IC 1613: 98052
[3.6]−[4.5] = 0.44 mag
Color σ = 5.4 %
Period = 358, 121 days
Amp = 0.65 mag
NGC 185: 109870
[3.6]−[4.5] = 0.8 mag
Color σ = 7.7 %
Period = 497, 291 days
Amp = 0.83 mag
NGC 185: 110014
[3.6]−[4.5] = 0.52 mag
Color σ = 6.6 %
Period = 435, 130 days
Amp = 0.81 mag
NGC 185: 110254
[3.6]−[4.5] = 0.34 mag
Color σ = 8.0 %
Period = 386, 125 days
Amp = 0.69 mag
IC 1613: 99923
[3.6]−[4.5] = 0.94 mag
Color σ = 5.1 %
Period = 501, 301 days
Amp = 1.0 mag
IC 1613: 112075
[3.6]−[4.5] = 0.38 mag
Color σ = 14.0 %
Period = 425, 337 days
Amp = 0.7 mag
IC 1613: 115947
[3.6]−[4.5] = 0.64 mag
Color σ = 6.6 %
Period = 309, 117 days
Amp = 0.59 mag
NGC 185: 114153
[3.6]−[4.5] = 0.74 mag
Color σ = 7.4 %
Period = 497, 295 days
Amp = 1.0 mag
NGC 185: 131142
[3.6]−[4.5] = 0.4 mag
Color σ = 14.1 %
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Amp = 0.65 mag
NGC 185: 136723
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Color σ = 32.0 %
Period = 347, 396 days
Amp = 0.47 mag
IC 1613: 122963
[3.6]−[4.5] = 0.52 mag
Color σ = 5.1 %
Period = 398, 176 days
Amp = 0.67 mag
IC 1613: 132118
[3.6]−[4.5] = 0.7 mag
Color σ = 16.0 %
Period = 336, 119 days
Amp = 0.59 mag
IC 1613: 133754
[3.6]−[4.5] = 0.65 mag
Color σ = 4.6 %
Period = 425, 129 days
Amp = 0.73 mag
NGC 185: 146315
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Color σ = 7.9 %
Period = 309, 106 days
Amp = 0.59 mag
Sextans A: 62485
[3.6]−[4.5] = 0.68 mag
Color σ = 9.6 %
Period = 523, 138 days
Amp = 0.85 mag
Sextans A: 79815
[3.6]−[4.5] = 0.38 mag
Color σ = 17.5 %
Period = 547, 278 days
Amp = 0.9 mag
IC 1613: 138007
[3.6]−[4.5] = 0.45 mag
Color σ = 32.2 %
Period = 318, 272 days
Amp = 0.57 mag
IC 1613: 142830
[3.6]−[4.5] = 0.5 mag
Color σ = 11.8 %
Period = 395, 127 days
Amp = 0.72 mag
IC 1613: 142987
[3.6]−[4.5] = 0.34 mag
Color σ = 16.2 %
Period = 266, 109 days
Amp = 0.42 mag
Sextans A: 86434
[3.6]−[4.5] = 0.47 mag
Color σ = 10.6 %
Period = 458, 317 days
Amp = 0.51 mag
Sextans A: 86559
[3.6]−[4.5] = 0.51 mag
Color σ = 9.2 %
Period = 577, 442 days
Amp = 0.61 mag
Sextans A: 90941
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Color σ = 10.5 %
Period = 260, 642 days
Amp = 0.45 mag
IC 1613: 146410
[3.6]−[4.5] = 0.61 mag
Color σ = 5.5 %
Period = 286, 549 days
Amp = 0.8 mag
IC 1613: 150816
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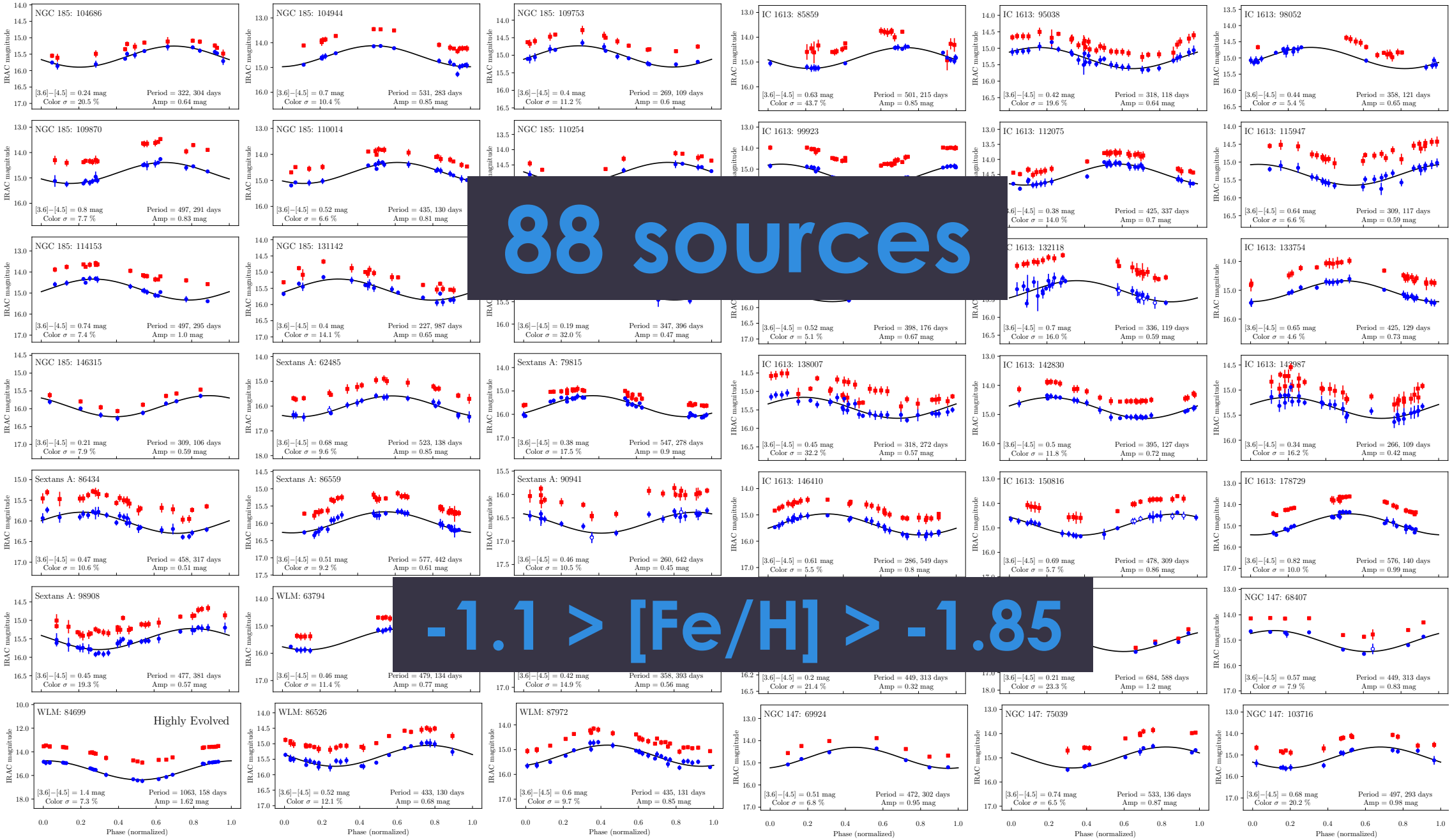
Color σ = 5.7 %
Period = 478, 309 days
Amp = 0.86 mag
IC 1613: 178729
[3.6]−[4.5] = 0.82 mag
Color σ = 10.0 %
Period = 576, 140 days
Amp = 0.99 mag
Sextans A: 98908
[3.6]−[4.5] = 0.45 mag
Color σ = 19.3 %
Period = 477, 381 days
Amp = 0.57 mag
WLM: 63794
[3.6]−[4.5] = 0.46 mag
Color σ = 11.4 %
Period = 479, 134 days
Amp = 0.77 mag
WLM: 79658
[3.6]−[4.5] = 0.42 mag
Color σ = 14.9 %
Period = 358, 393 days
Amp = 0.56 mag
NGC 147: 43102
[3.6]−[4.5] = 0.2 mag
Color σ = 21.4 %
Period = 449, 313 days
Amp = 0.32 mag
NGC 147: 58163
[3.6]−[4.5] = 0.21 mag
Color σ = 23.3 %
Period = 684, 588 days
Amp = 1.2 mag
NGC 147: 68407
[3.6]−[4.5] = 0.57 mag
Color σ = 7.9 %
Period = 449, 313 days
Amp = 0.83 mag
WLM: 84699
Highly Evolved
[3.6]−[4.5] = 1.4 mag
Color σ = 7.3 %
Period = 1063, 158 days
Amp = 1.62 mag
WLM: 86526
[3.6]−[4.5] = 0.52 mag
Color σ = 12.1 %
Period = 433, 130 days
Amp = 0.68 mag
WLM: 87972
[3.6]−[4.5] = 0.6 mag
Color σ = 9.7 %
Period = 435, 131 days
Amp = 0.85 mag
NGC 147: 69924
[3.6]−[4.5] = 0.51 mag
Color σ = 6.8 %
Period = 472, 302 days
Amp = 0.95 mag
NGC 147: 75039
[3.6]−[4.5] = 0.74 mag
Color σ = 6.5 %
Period = 533, 136 days
Amp = 0.87 mag
NGC 147: 103716
[3.6]−[4.5] = 0.68 mag
Color σ = 20.2 %
Period = 497, 293 days
Amp = 0.98 mag
IRAC magnitude
Phase (normalized)


88 sources
-1.1 > [Fe/H] > -1.85
NGC 185: 104686
NGC 185: 104944
NGC 185: 109753
IC 1613: 85859
IC 1613: 95038
IC 1613: 98052
NGC 185: 109870
NGC 185: 110014
NGC 185: 110254
IC 1613: 99923
IC 1613: 112075
IC 1613: 115947
NGC 185: 114153
NGC 185: 131142
IC 1613: 132118
IC 1613: 133754
NGC 185: 146315
Sextans A: 62485
Sextans A: 79815
IC 1613: 138007
IC 1613: 142830
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Sextans A: 86434
Sextans A: 86559
Sextans A: 90941
IC 1613: 146410
IC 1613: 150816
IC 1613: 178729
Sextans A: 98908
WLM: 63794
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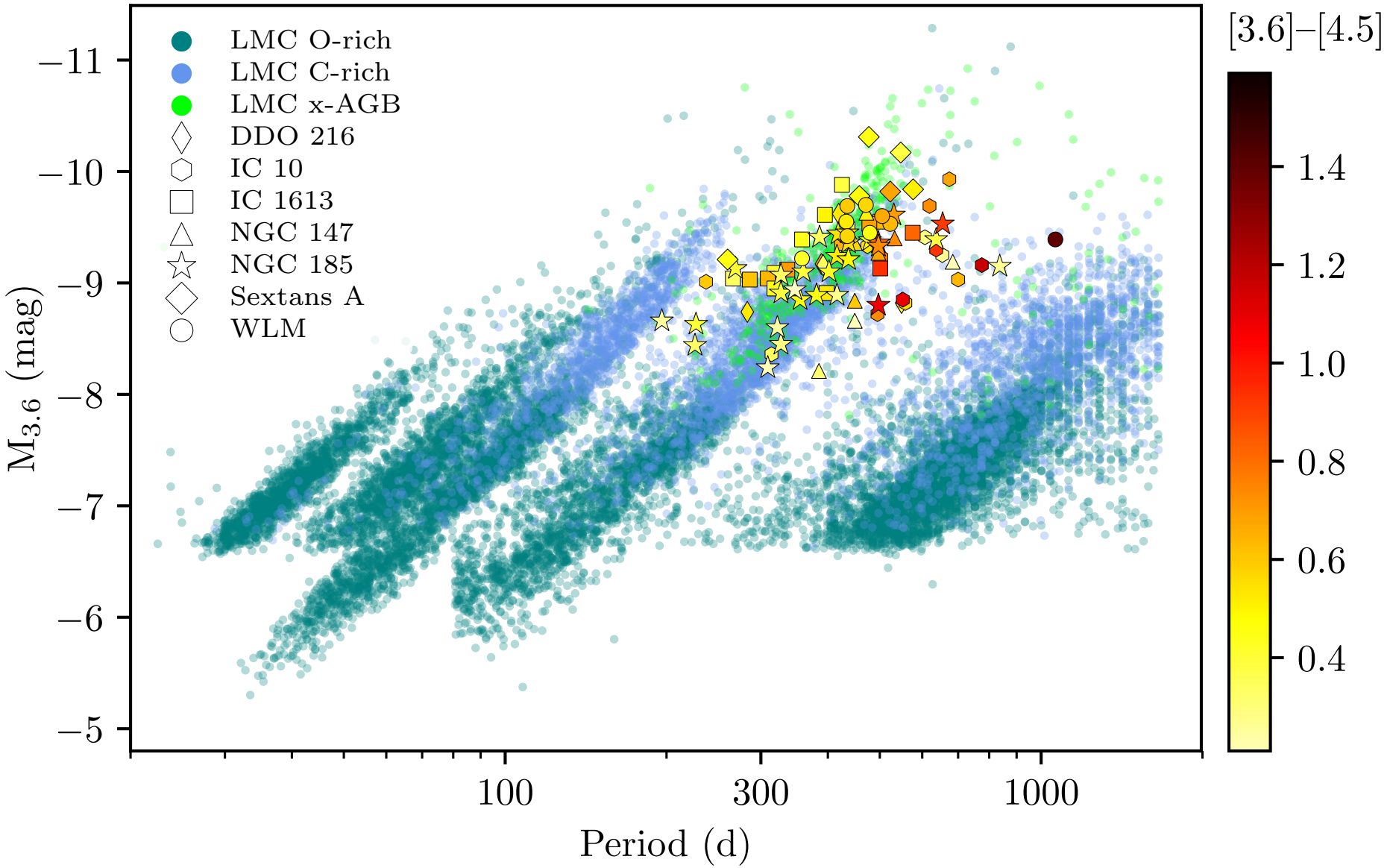
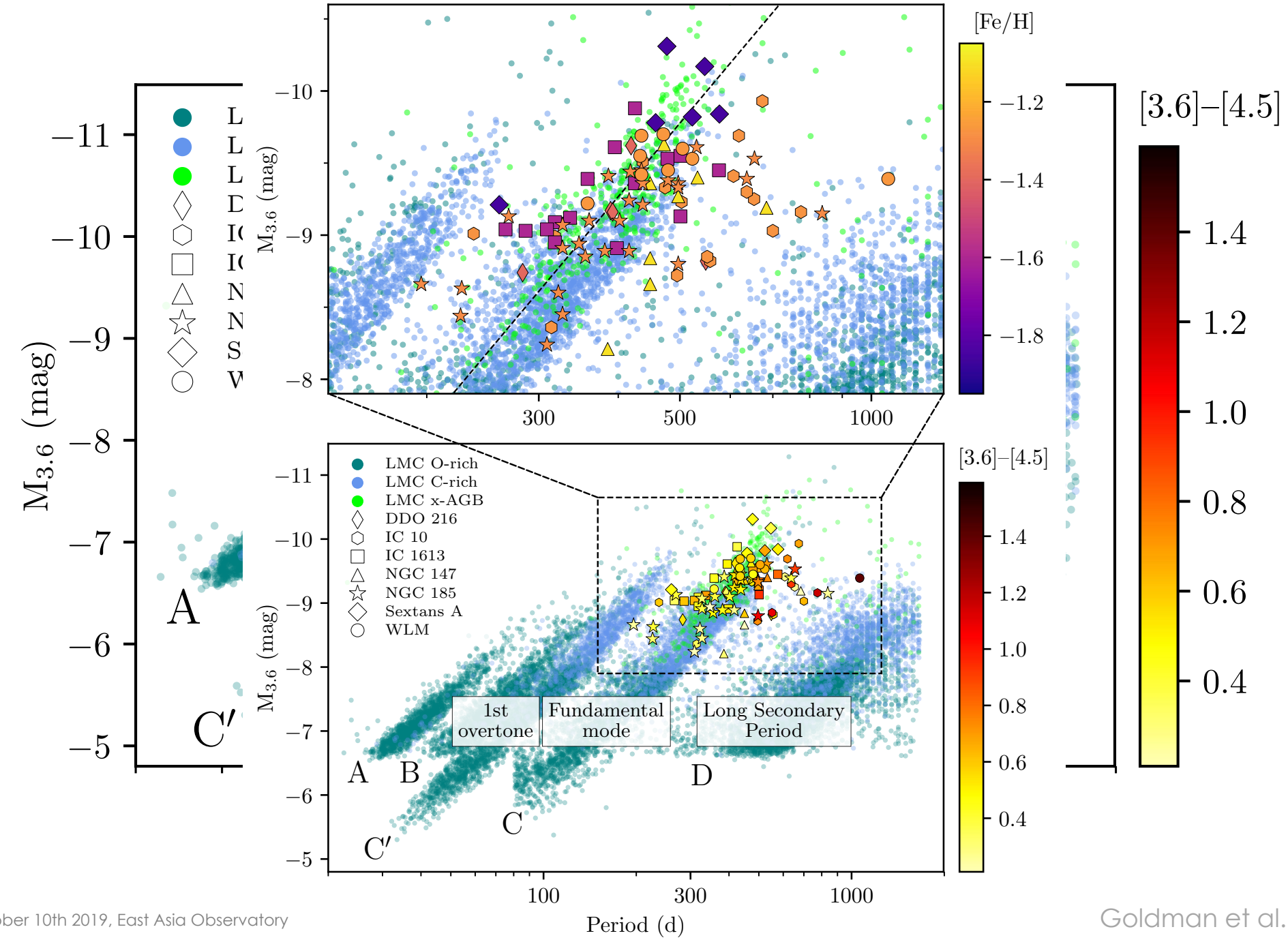
WLM: 84699
Highly Evolved
WLM: 86526
WLM: 87972
NGC 147: 69924
NGC 147: 75039
NGC 147: 103716
IRAC magnitude
Phase (normalized)



Goldman et al. 2019



Goldman et al. 2019

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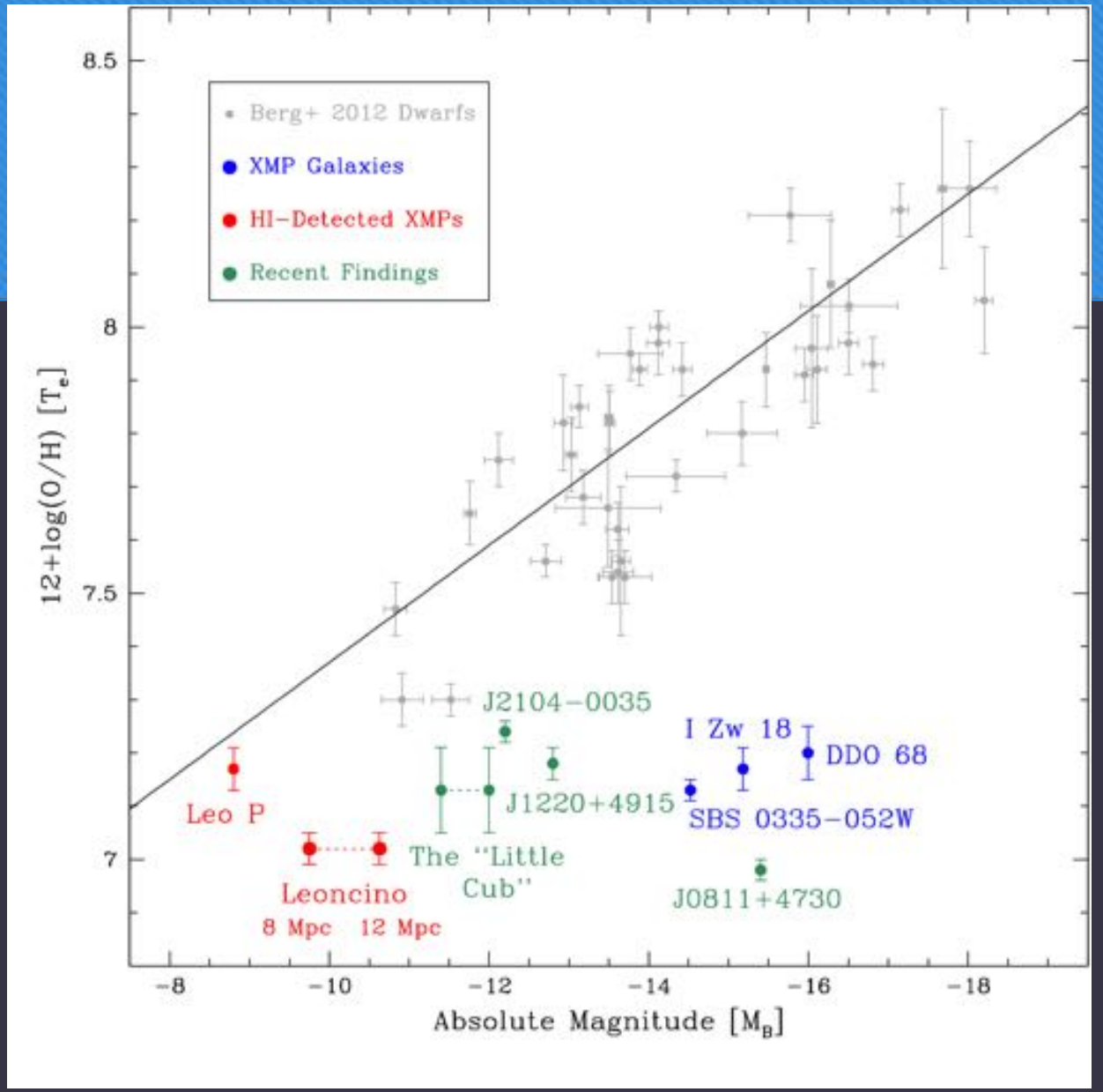
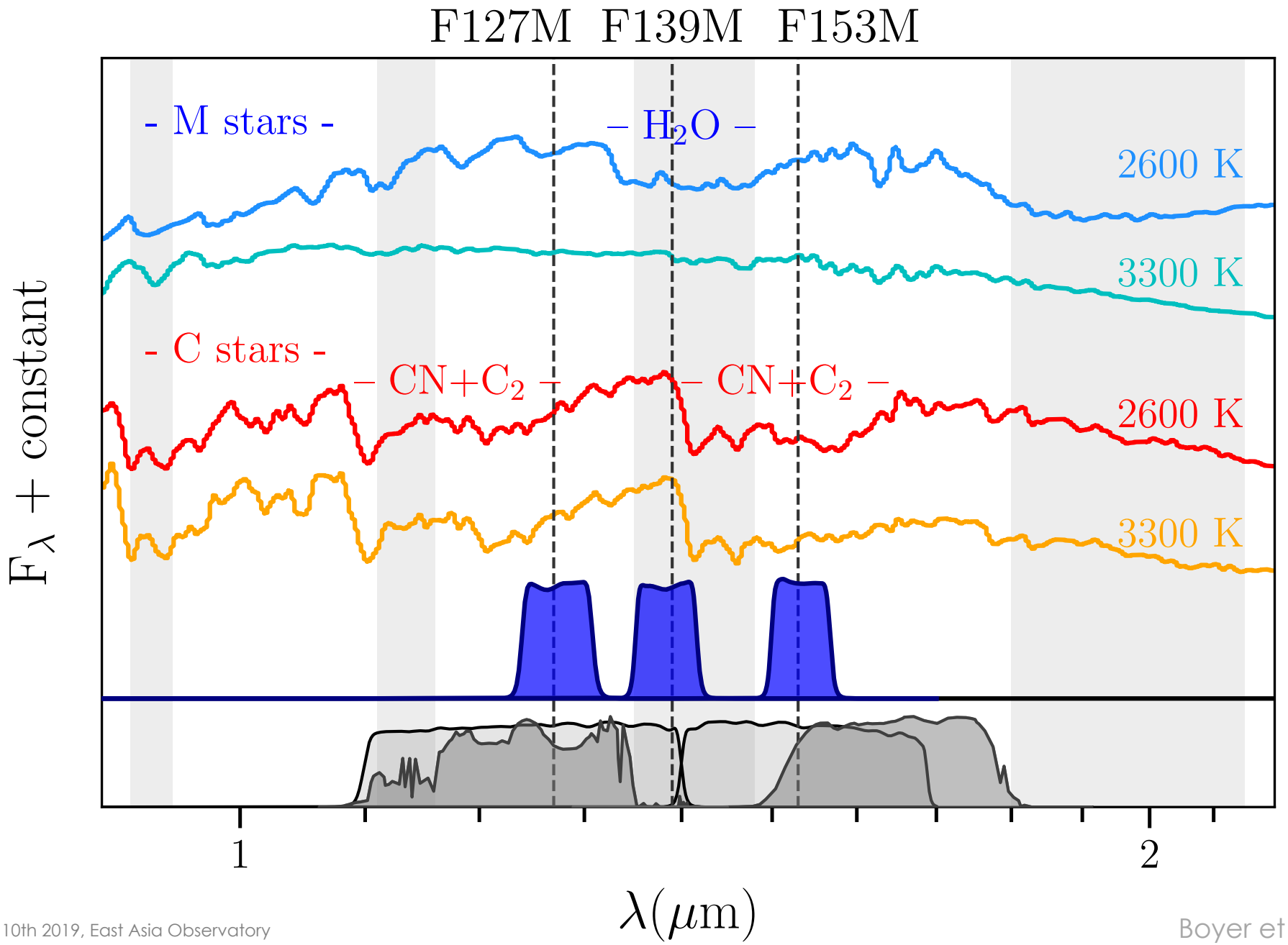
Leo P

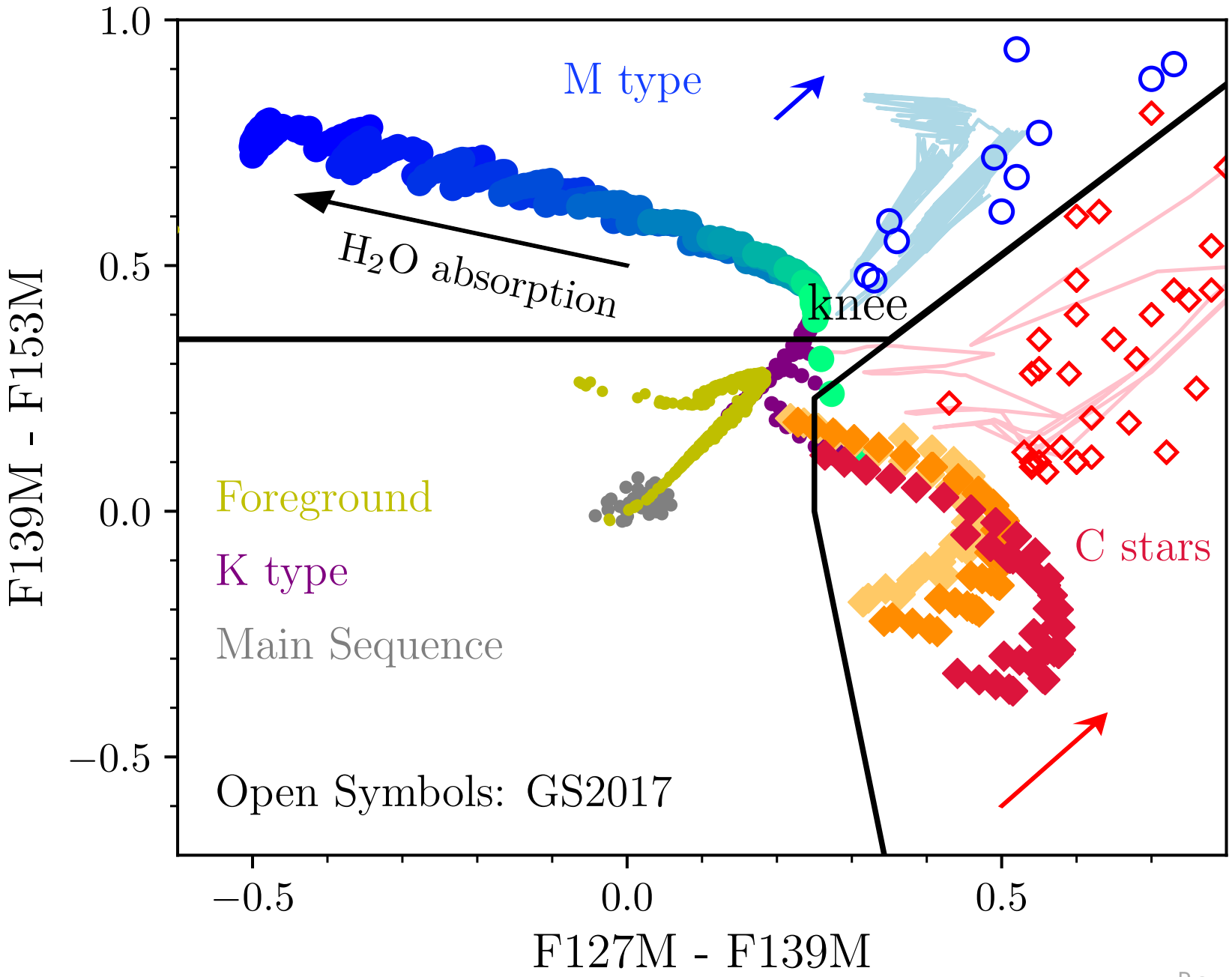
Leo P:
12+log(O/H) = 7.17 ± 0.04



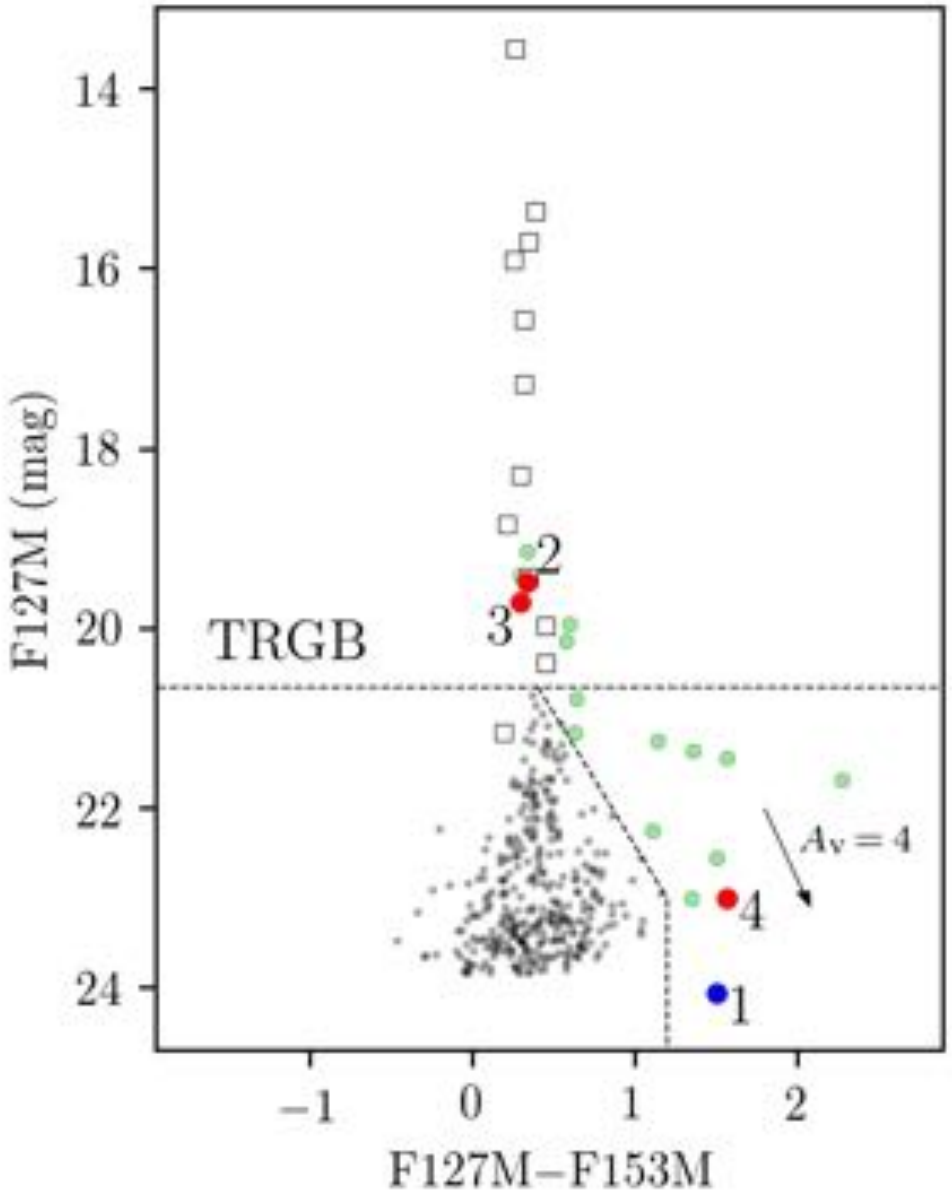
Skillman et al. 2013; Alec Hirschauer (private communication)

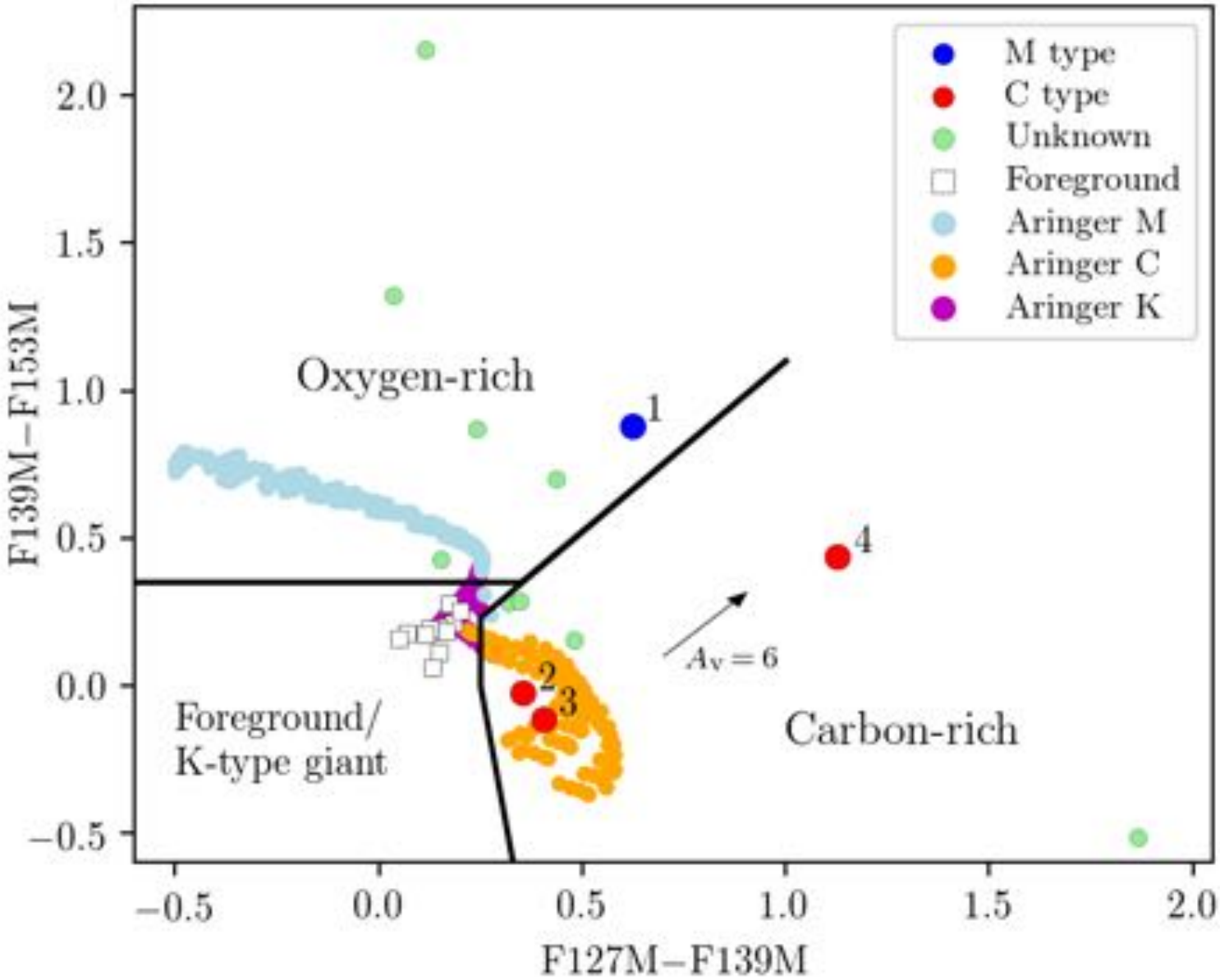


Boyer et al. 2017

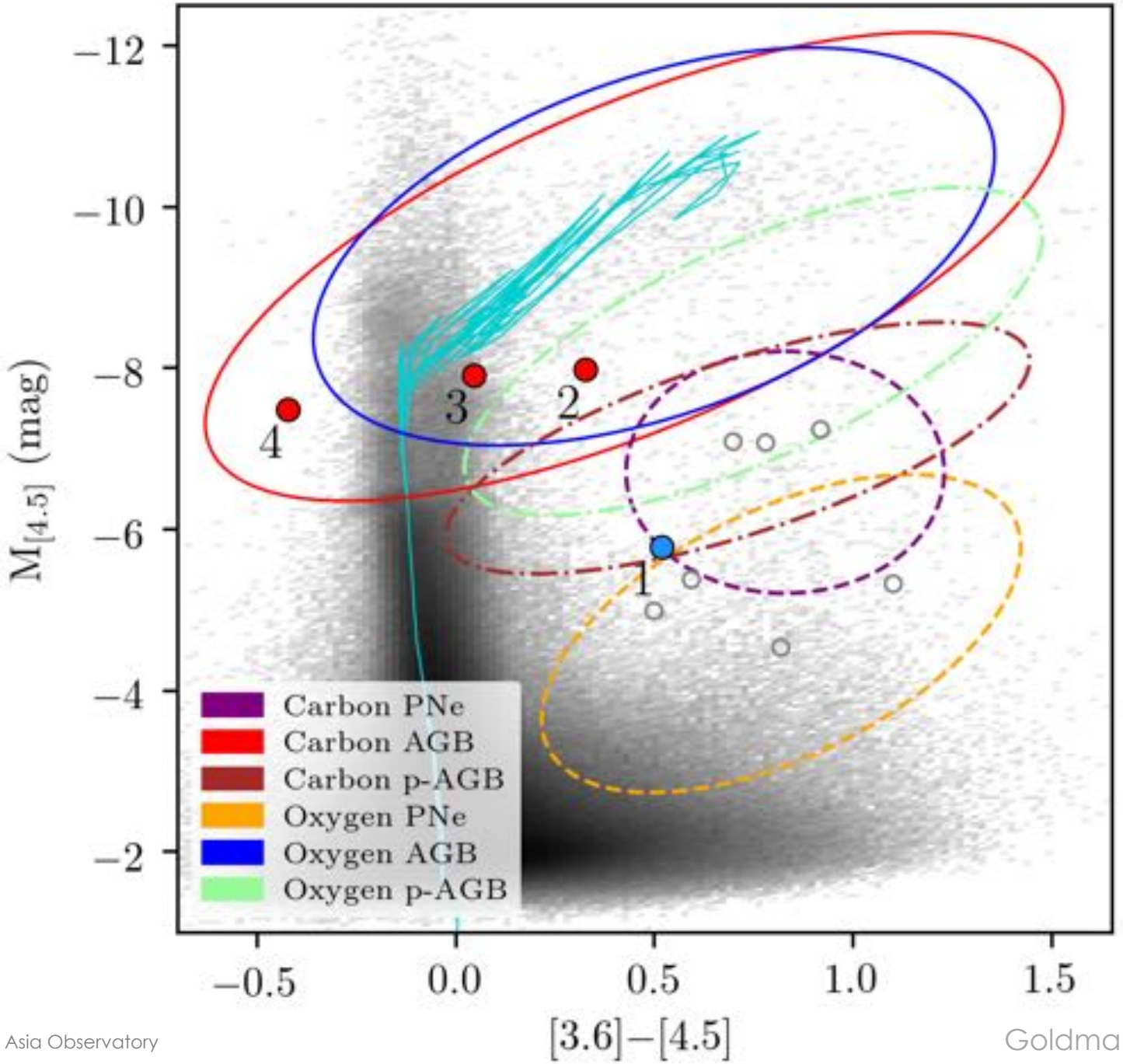


Boyer et al. 2017





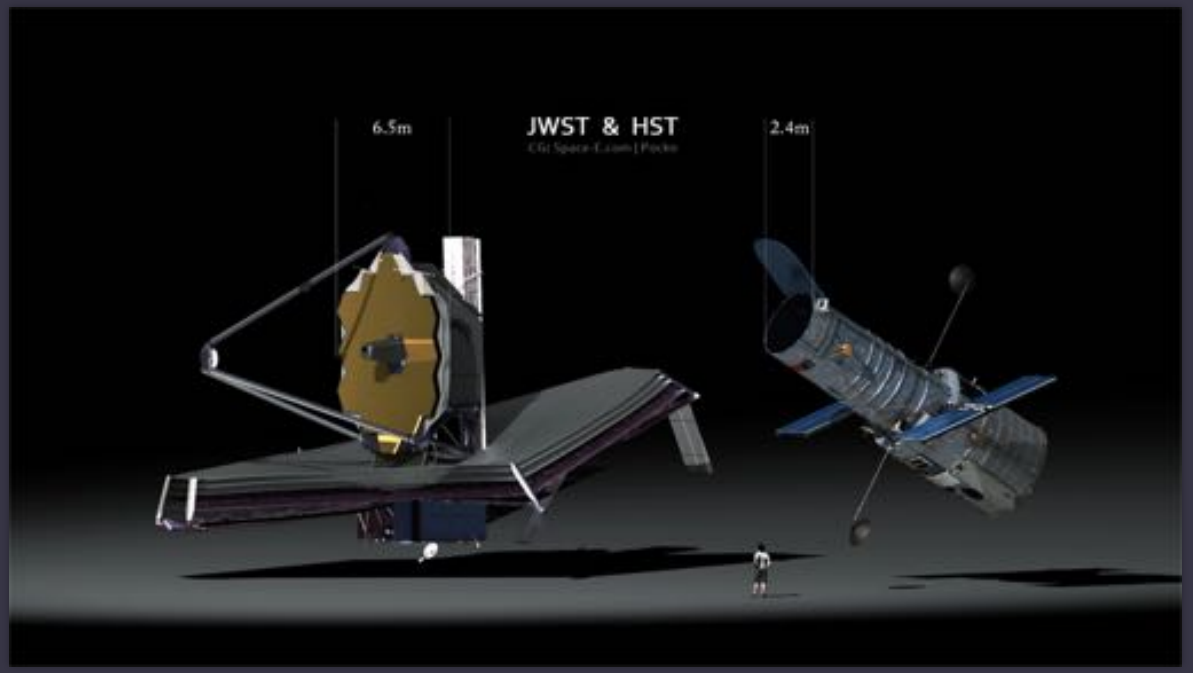
Goldman et al. Submitted

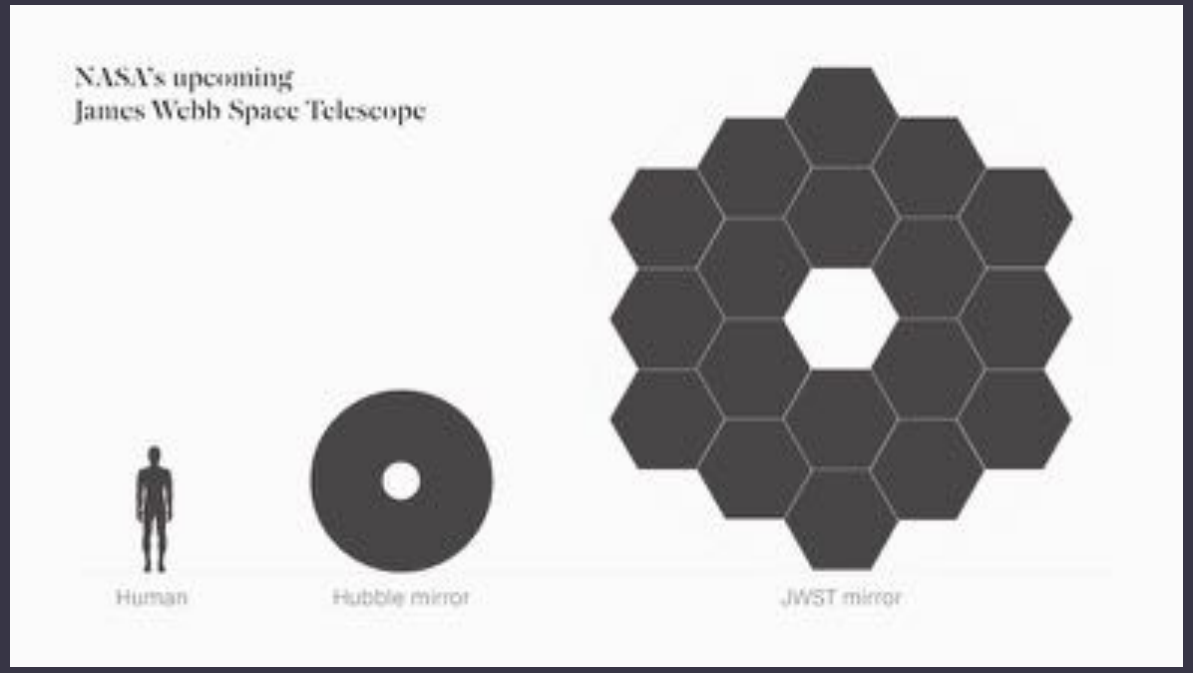


Goldman et al. Submitted

Instruments

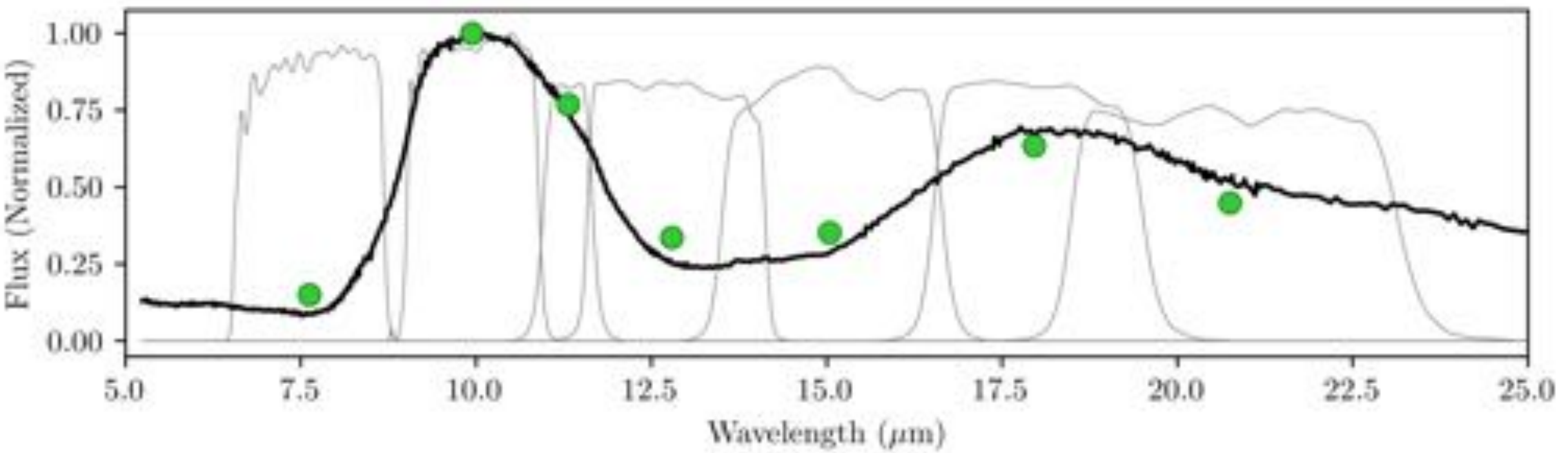
Leo P





Spectra

Leo P



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README.md

Dusty-Evolved-Star-Kit

pypi DESK | docs passing | build passing | arXiv 1610.05761 | STScI Steve Goldman

The DESK is an SED-fitting python package for fitting data from evolved stars (photometry or spectra) with radiative transfer model grids. The package is currently in development and all contributions are welcomed. For current progress, see the Issues tab at the top of the page.

Input: A csv file with the first column as wavelength in um and second column as flux in Jy. To fit multiple csv files, put them in a directory, and use the directory name as the input.

Output: Two results files including the best fit model and corresponding stellar parameters, as well as an optional figure of the fit SED.

Available model grids: Several grids are **already available**. You can also specify the state-of-the-art dust growth models by Nanni et al. (2019) which are automatically downloaded and used when selected. New grids will include the 2D GRAMS model grid based on the 2DUST code.

A module for creating your own DUSTY grid is under development, but for now please email me (Dr. Steven Goldman) directly for grid requests or for help with the package.

Documentation

The documentation can be found on readthedocs.

Install Using Python

1). Install the package with the command `pip install desk`.

2). Go to the directory where your target csv file (or target directory of files) is.

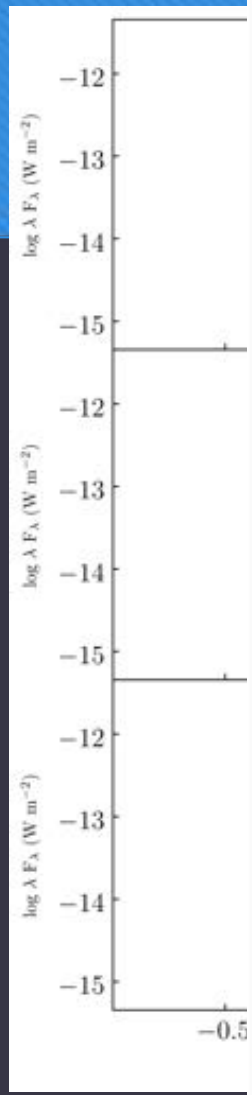
3). Use the command (without starting python)

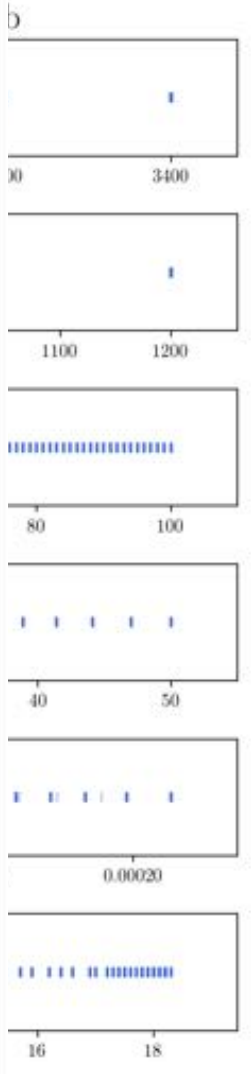
```
desk fit --source='target_name.csv'
```

or if you have a folder of csv files

```
desk fit --source='folder_of_csvs'
```

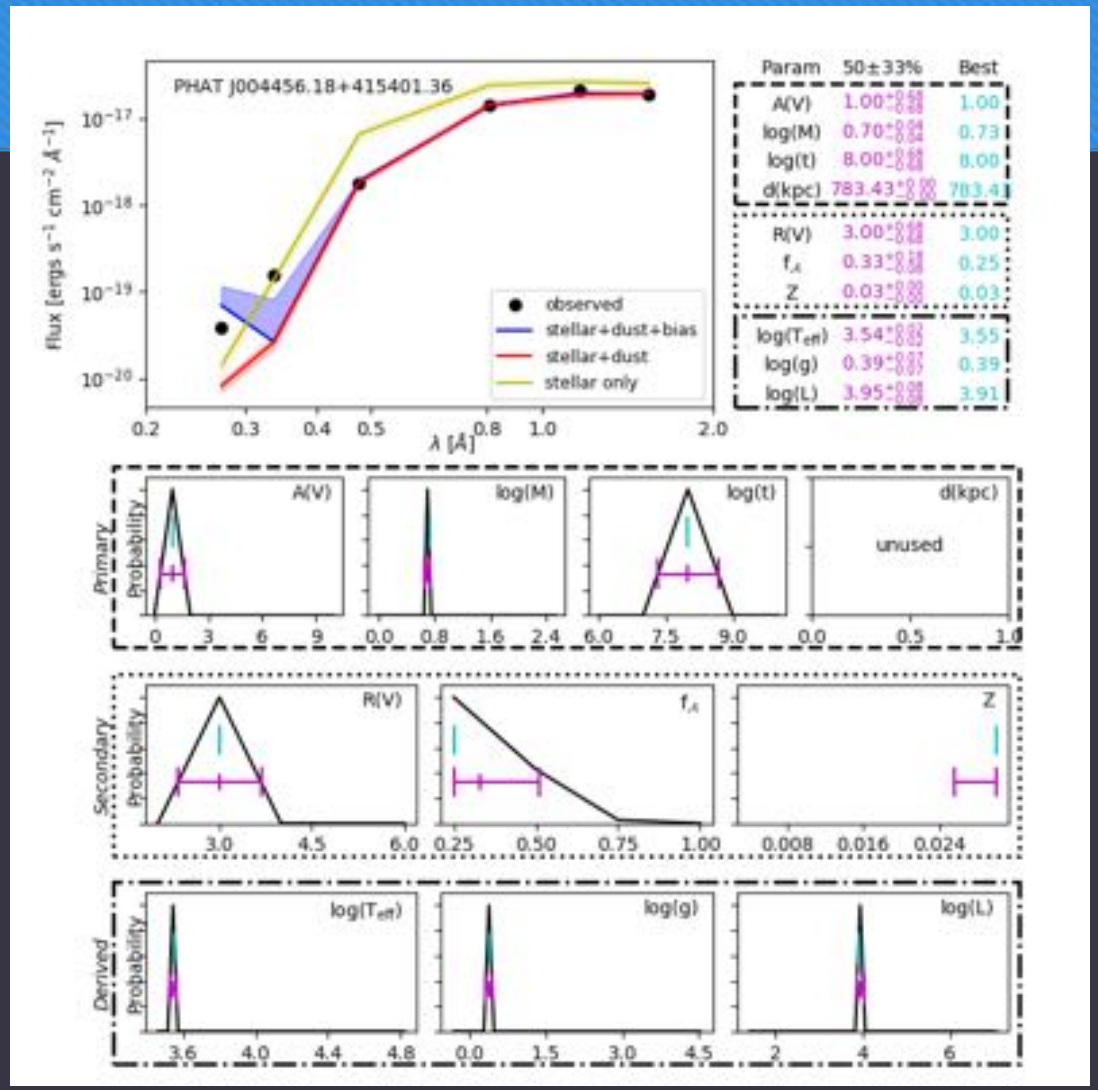
additional options are:





DESK

The Bayesian Extinction and Stellar Tool (BEAST)



Gordon et al. 2016

Overview

- Effects of Metallicity → Important for understanding dust contribution
- Nearby samples → Laboratories for high-redshift galaxies
- DUSTiNGS survey → 88 new TP-AGB detections
- Leo P → Most metal-poor dusty AGB candidates
- The DESK → Easy to use SED fitter

Thanks for listening

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