A NEWLY DISCOVERED STELLAR TYPE: DUSTY POST-RED GIANT BRANCH (POST-RGB) STARS IN THE MAGELLANIC CLOUDS

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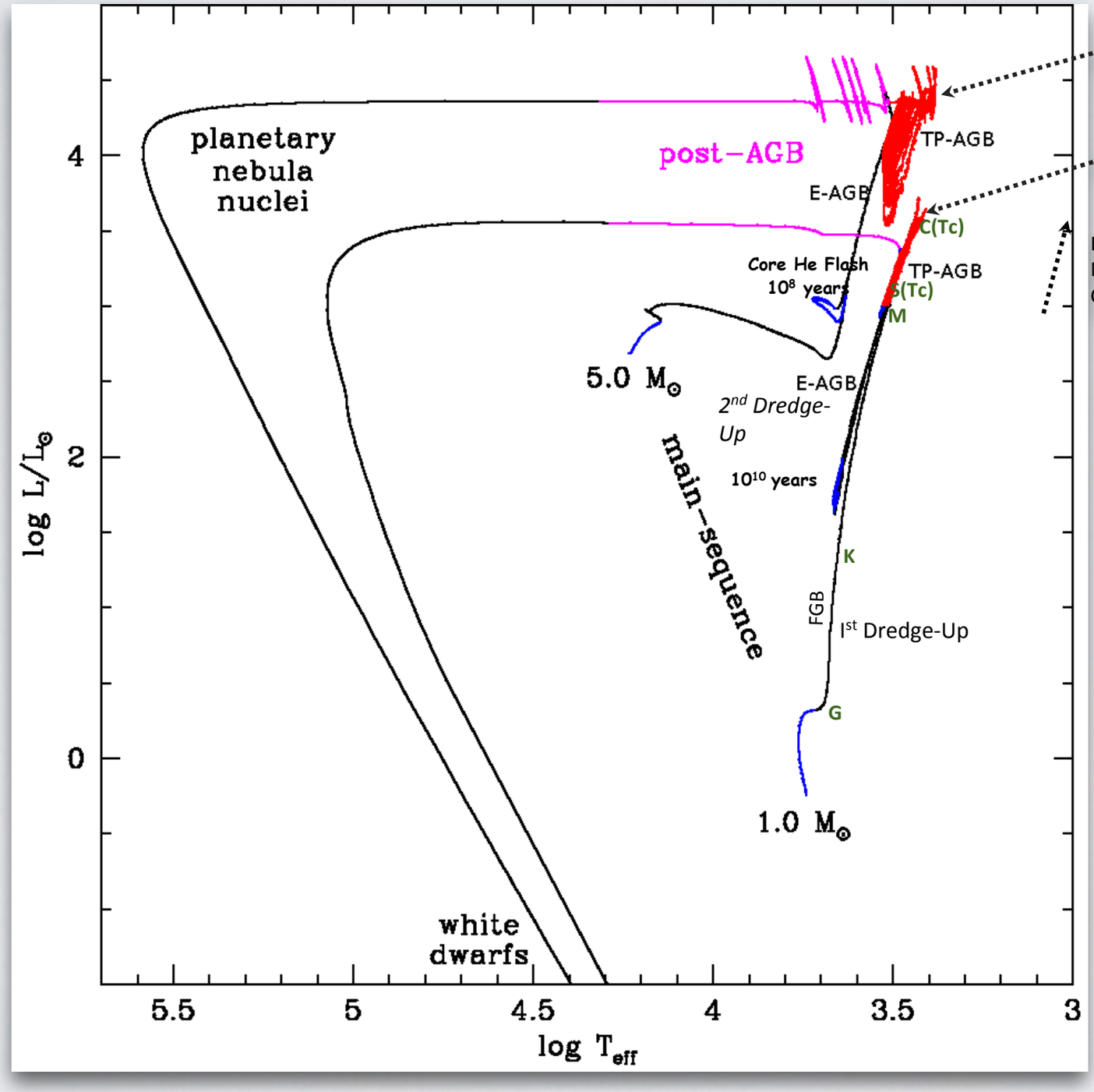
PHYSICS OF EVOLVED STARS, 2015, Nice

In Memory of Olivier Chesneau…

Weather = ☀️, blue skies, NICE!

EVOLUTIONARY FATE OF A SINGLE STAR

Nuclear burning lives are terminated on the AGB with a *'Superwind'* mass-loss (mass-loss rates up to $10^{-4} M_{\odot}\,yr^{-1}$)



Surface Enrichment, Variability & Mass-loss

Heavy element Nucleosynthesis C/O, [s/Fe]

/3rd Dredge-Up

AN ALTERNATIVE EVOLUTIONARY CHANNEL

Great majority of PNe are not spherical: axi-symmetry; point-symmetry

jet-like structures are common… NOAM :)

(Balick & Frank, 2002; De Marco 2008, Zijlstra 07)

BINARITY!

Binary interaction can determine the ultimate of the star …

INTERMEDIATE PERIOD BINARIES

A-SPHERICITY

BIPOLAR

UNSTABLE MASS TRANSFER

MERGERS

LONG PERIOD BINARIES

ROCHE LOBE OVERFLOW

SINGLE STARS

CLOSE PERIOD BINARIES

WIND ACCRETION

COMMON ENVELOPE

DOUBLE-DEGENRATE

MASS-LOSS

PLANETARY NEBULAE

JETS

WHEN DOES THE STAR FILL IT'S ROCHE LOBE???

DISCLAIMER: THE PHYSICS OF THE POST-ROCHE LOBE FILLING EVOLUTION ARE VERY UNCERTAIN…

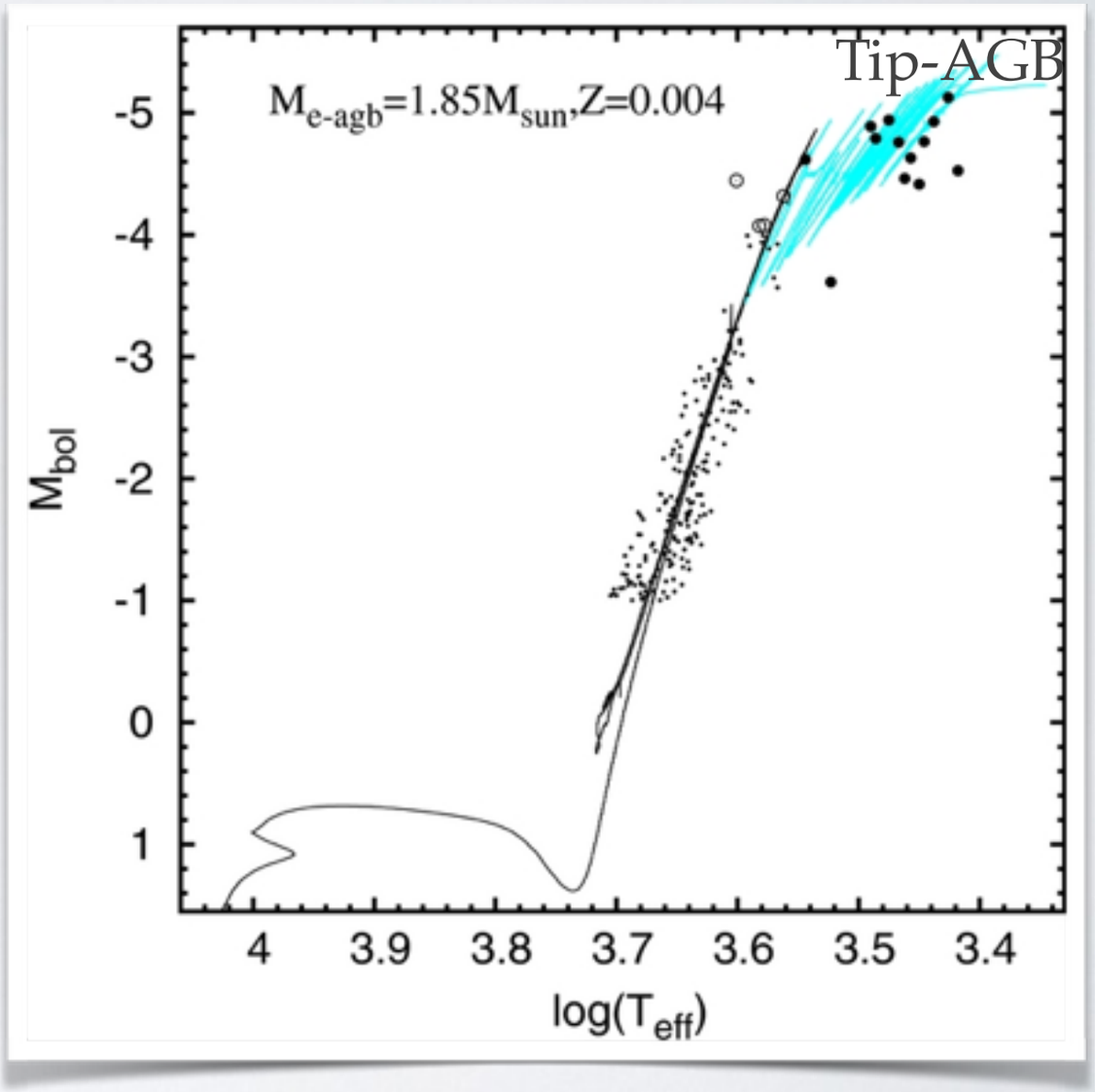
WHEN DOES THE STAR FILL IT'S ROCHE LOBE???

Stars reach the tip of the AGB (TAGB) without filling its Roche lobe…

OUTCOME ~ they likely evolve as single stars do

RESULT ~ formation of a PN with wide orbits

(Moe & De Marco 2006)



WHEN DOES THE STAR FILL IT'S ROCHE LOBE???

Roche lobe filling occurs on the AGB but above the RGB-tip...

OUTCOME 1 ~ common envelope (CE) event

RESULT ~ close binary or stellar merger

(Ivanova et al. 2013)

OUTCOME2 ~ some sort of a stable mass transfer

RESULT 2~ Formation of an intermediate period binary

e.g.: Post-AGB binaries surrounded with DUSTY circumbinary discs (Van Winckel 2007)

WHEN DOES THE STAR FILL IT'S ROCHE LOBE???

Roche lobe filling occurs below the RGB-tip…

(e.g., Han et al. 1995; Heber 2009; Nie et al. 2012)

OUTCOME 1 ~ common envelope (CE) event

RESULT ~ close binary or stellar merger

(Paczynski 1976; Webbink 1984)

OUTCOME2 ~ some sort of stable mass transfer

RESULT 2 ~ Formation of an intermediate period binary

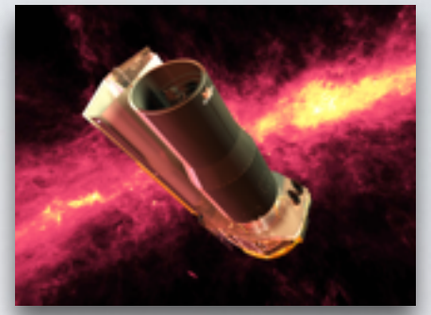
e.g., "Post-RGB" binaries surrounded with DUSTY circumbinary discs!!!

THE DISCOVERY OF DUSTY POST-RGB STARS…

OPTICALLY VISIBLE POST-AGB STARS IN THE

SMC* & LMC**

**Kamath et al. 2014 MNRAS, 439, 2211*
***Kamath et al. 2015 MNRAS (Accepted)*



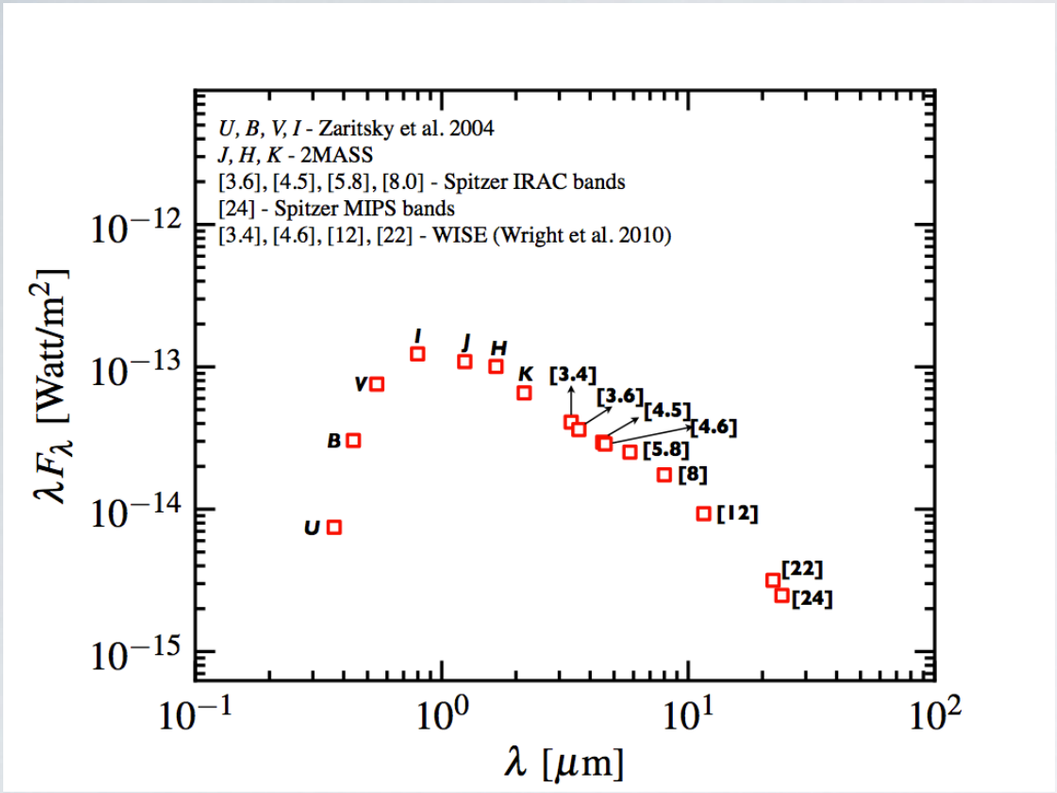
Mid-IR Spitzer Space Telescope Surveys

Candidates with Mid-IR excess selected from the Mid-IR SST survey

SMC: **S^{3}MC** (Bolatto et al. 2007) & **SAGE-SMC** (Gordon et al. 2010)

LMC: **SAGE** (Meixner et al. 2006) & (Blum et al. 2006)

✓ Candidate Selection
✓ Spectroscopic Examination
✓ SED Analysis
✓ Variability Analysis
✓ Spectroscopically verified Catalogues of Post-AGB, “Post-RGBs* and other interesting objects



1) CANDIDATE SELECTION:

Mid-IR excess

Optical colour

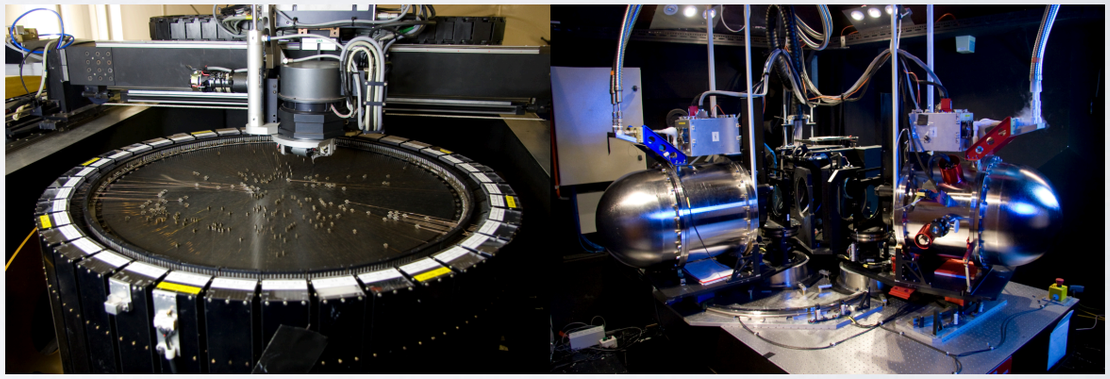
Suitable luminosity

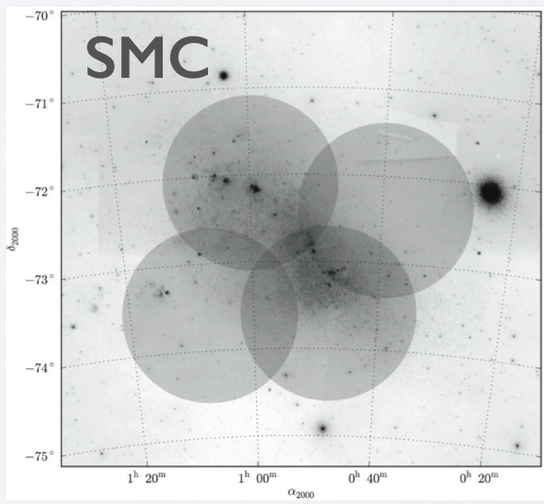
2) OPTICAL SPECTROSCOPY

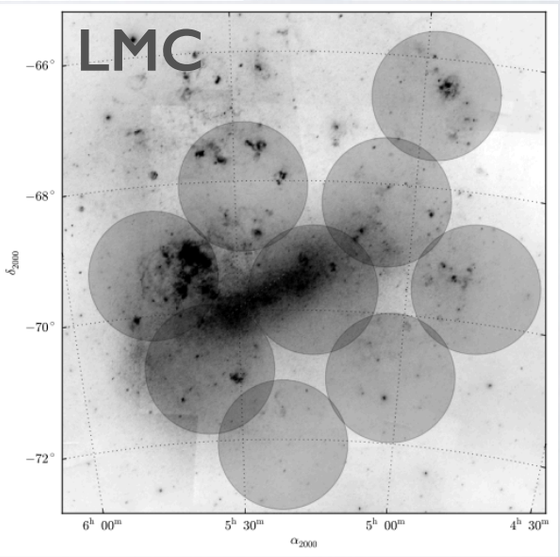
AAOmega on the 3.9m AAT

Optical Low Resolution Spectra R~1300

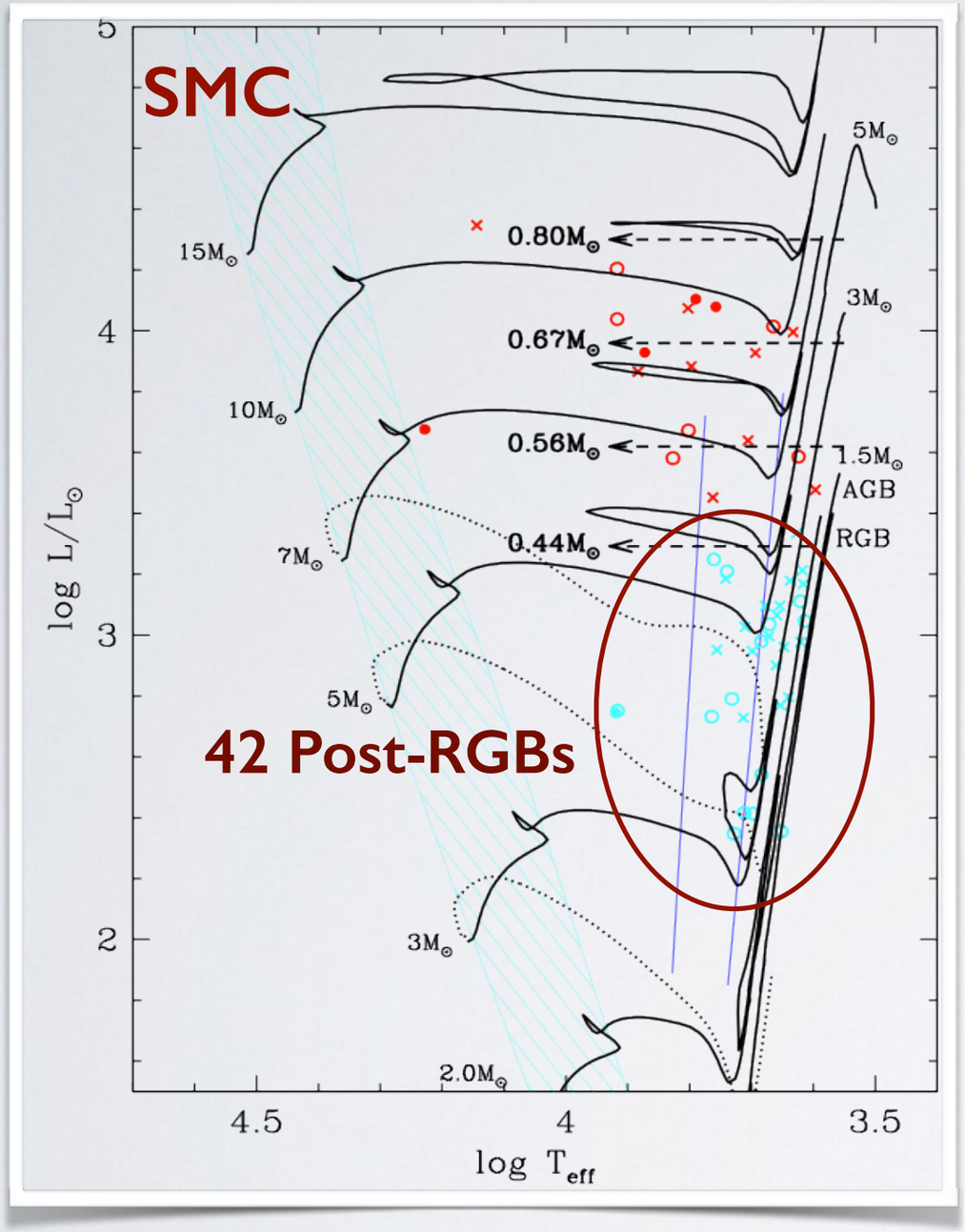
Wavelength Coverage = 3700 Å - 8700 Å



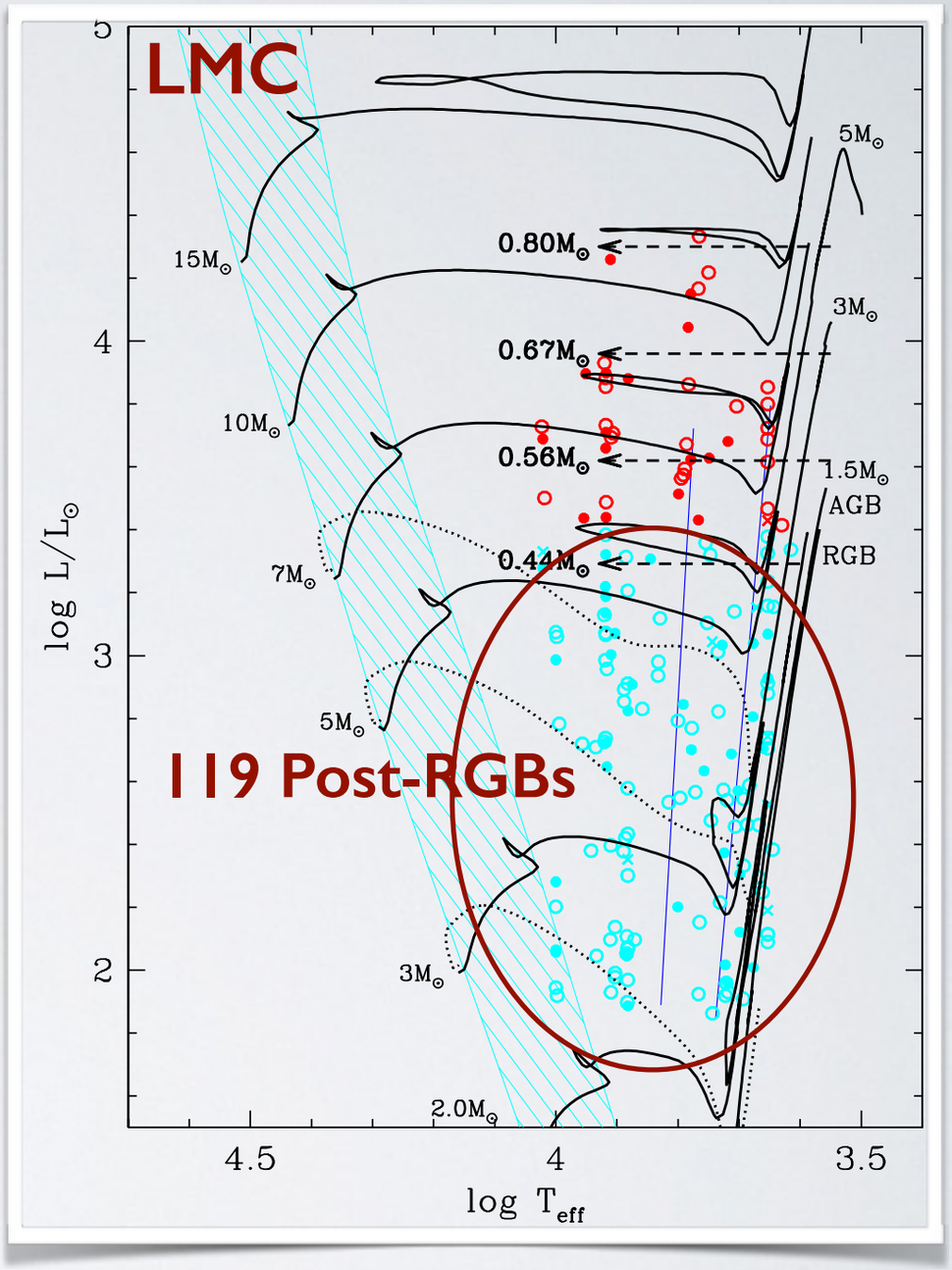




A NEWLY-DISCOVERED STELLAR TYPE: DUSTY POST-RGB STARS



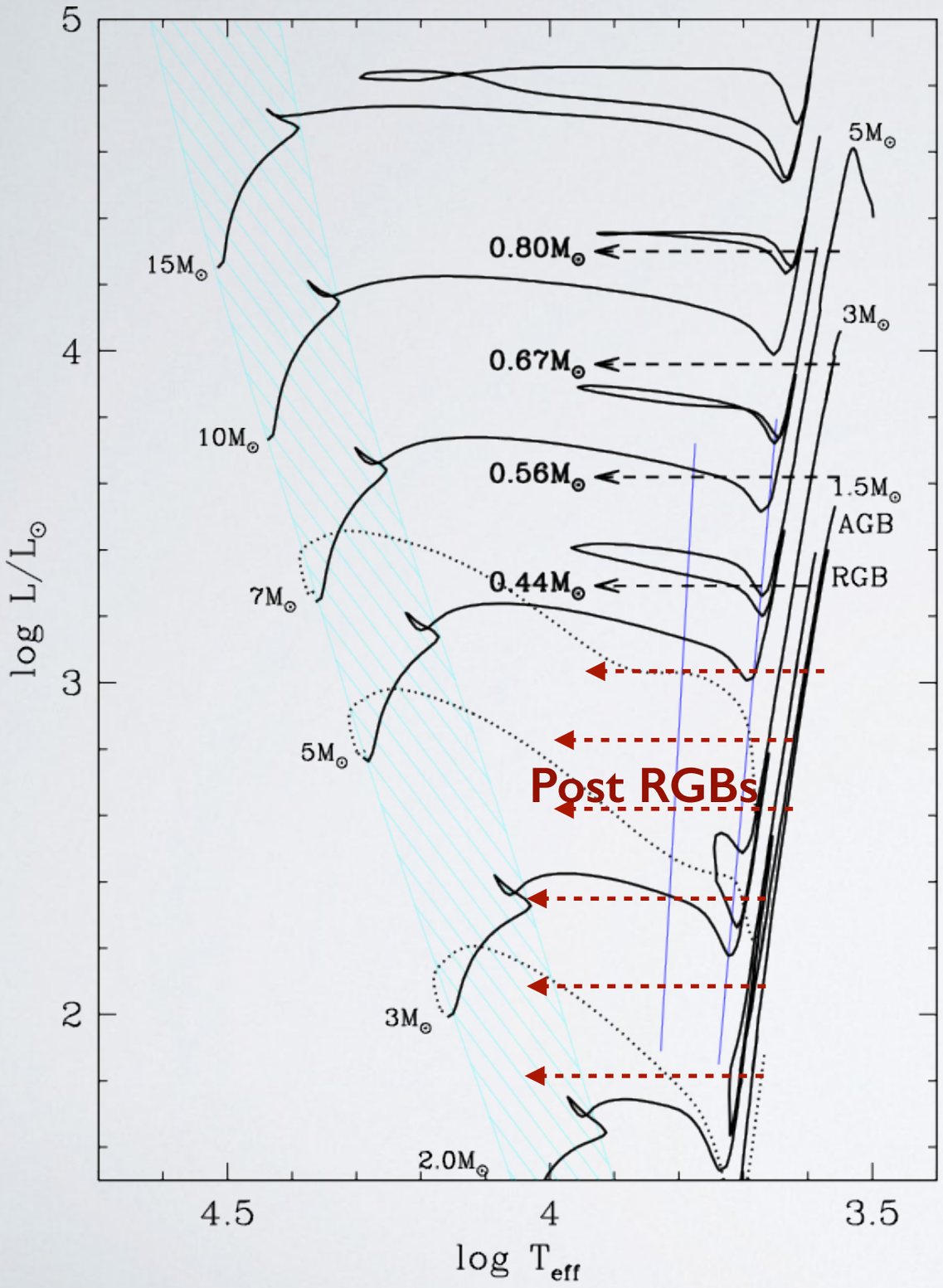
- ✓Mid-IR excess
- ✓A- K spectral types
- ✓Low log g
- ✓low [Fe/H]
- ✓low -luminosity (< 2500 L⊙)



Note: These numbers are not complete due to incompleteness of the survey…

MINIMUM Expected numbers: SMC ~ 30 more, LMC ~ 750 more

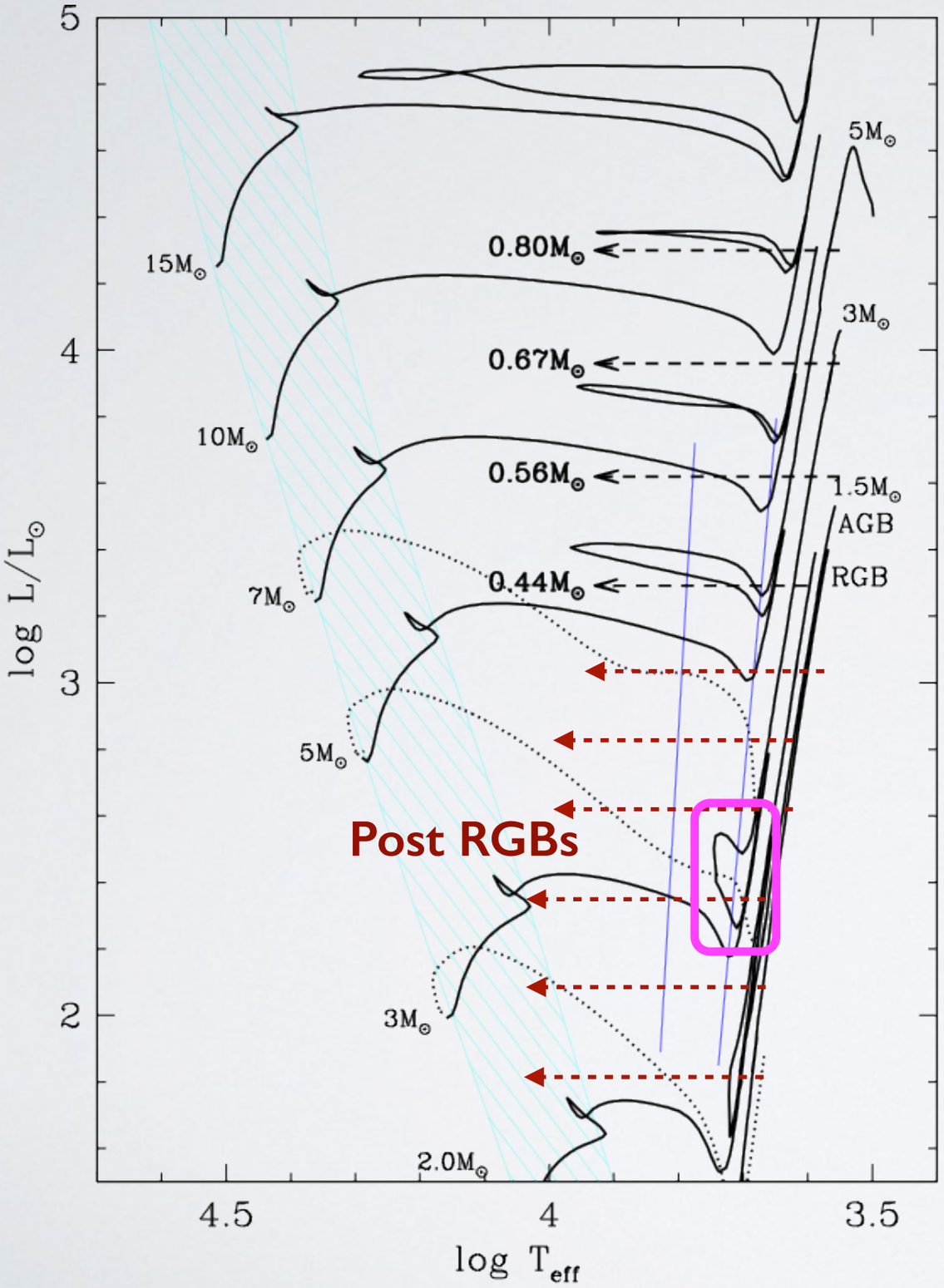
WHAT ARE THESE POST-RGBs???



- Pre-mature evolution off the RGB via mass-loss
- Single star mass loss
  - too weak!
- **Mass loss induced via binary**
  - **Way to go!**

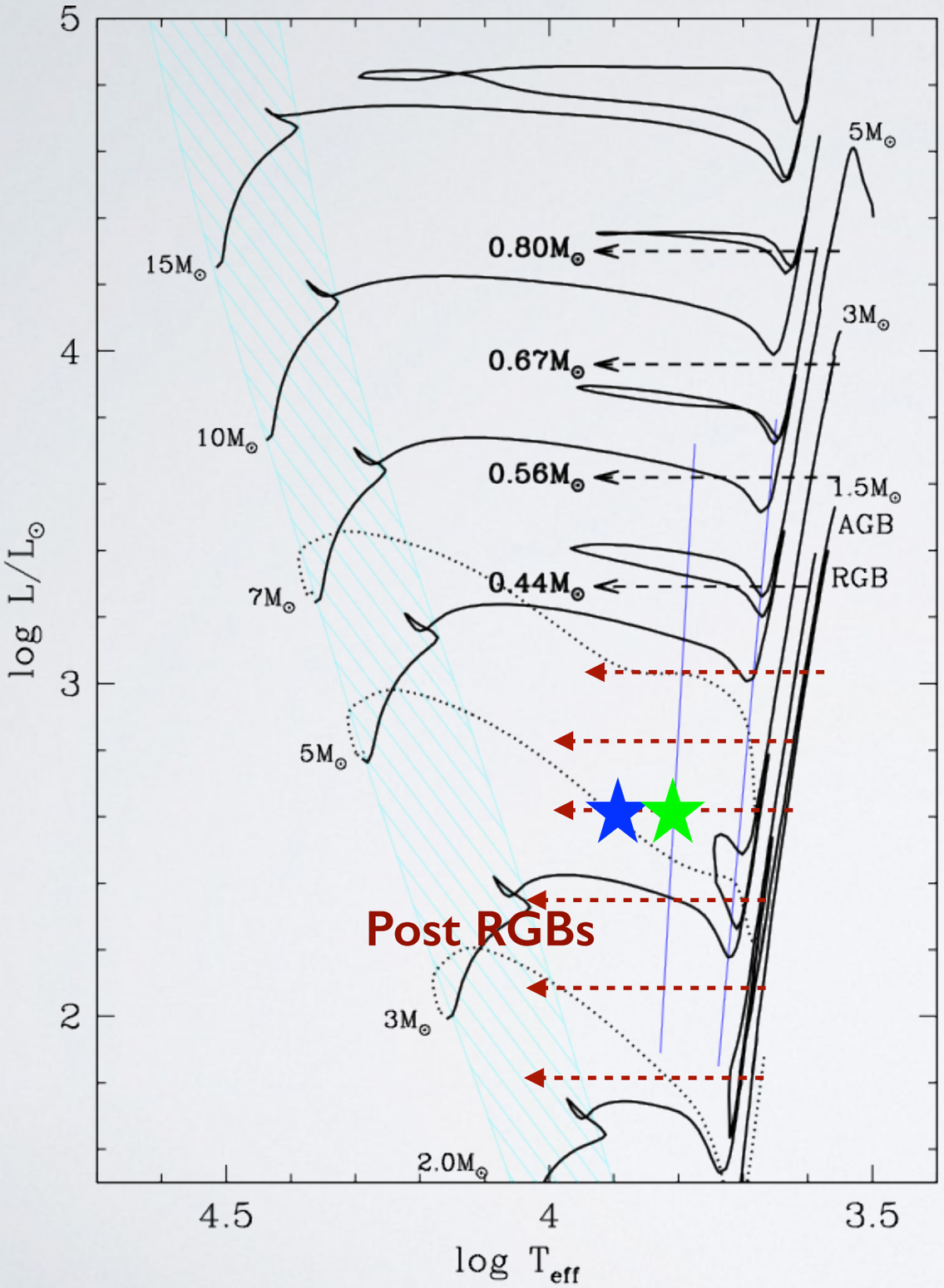
- Very like to be Binaries!
- Can they be Mergers… ?

INTERLOPING OBJECTS IN OTHER EVOLUTIONARY STAGES…

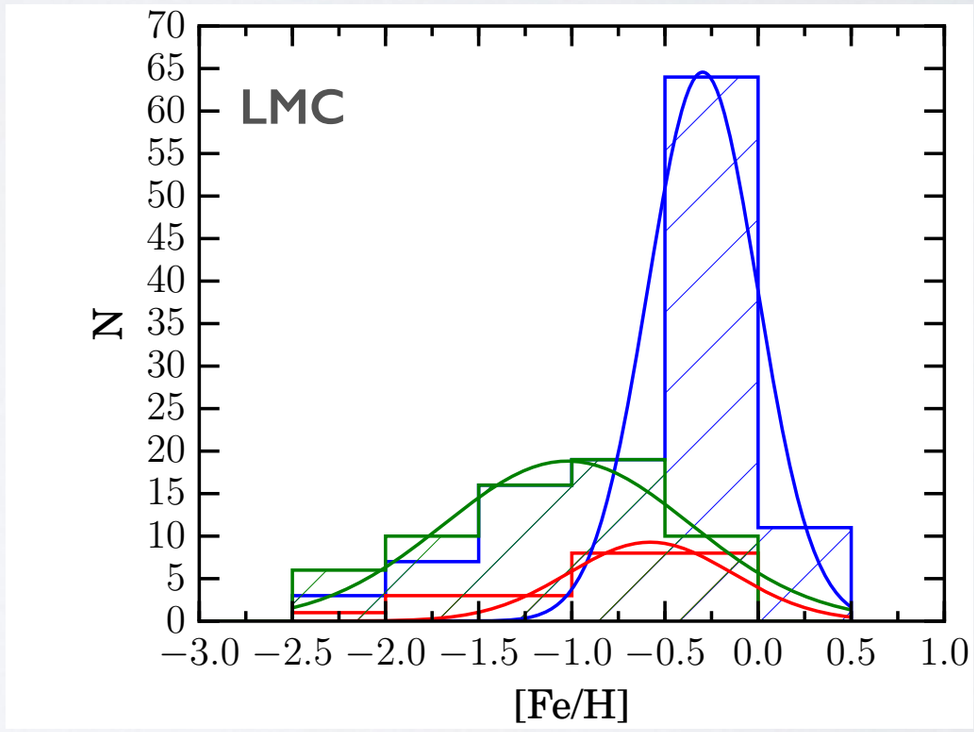


- **Core He Burning ?**
- No! Too Dusty…

INTERLOPING OBJECTS IN OTHER EVOLUTIONARY STAGES…

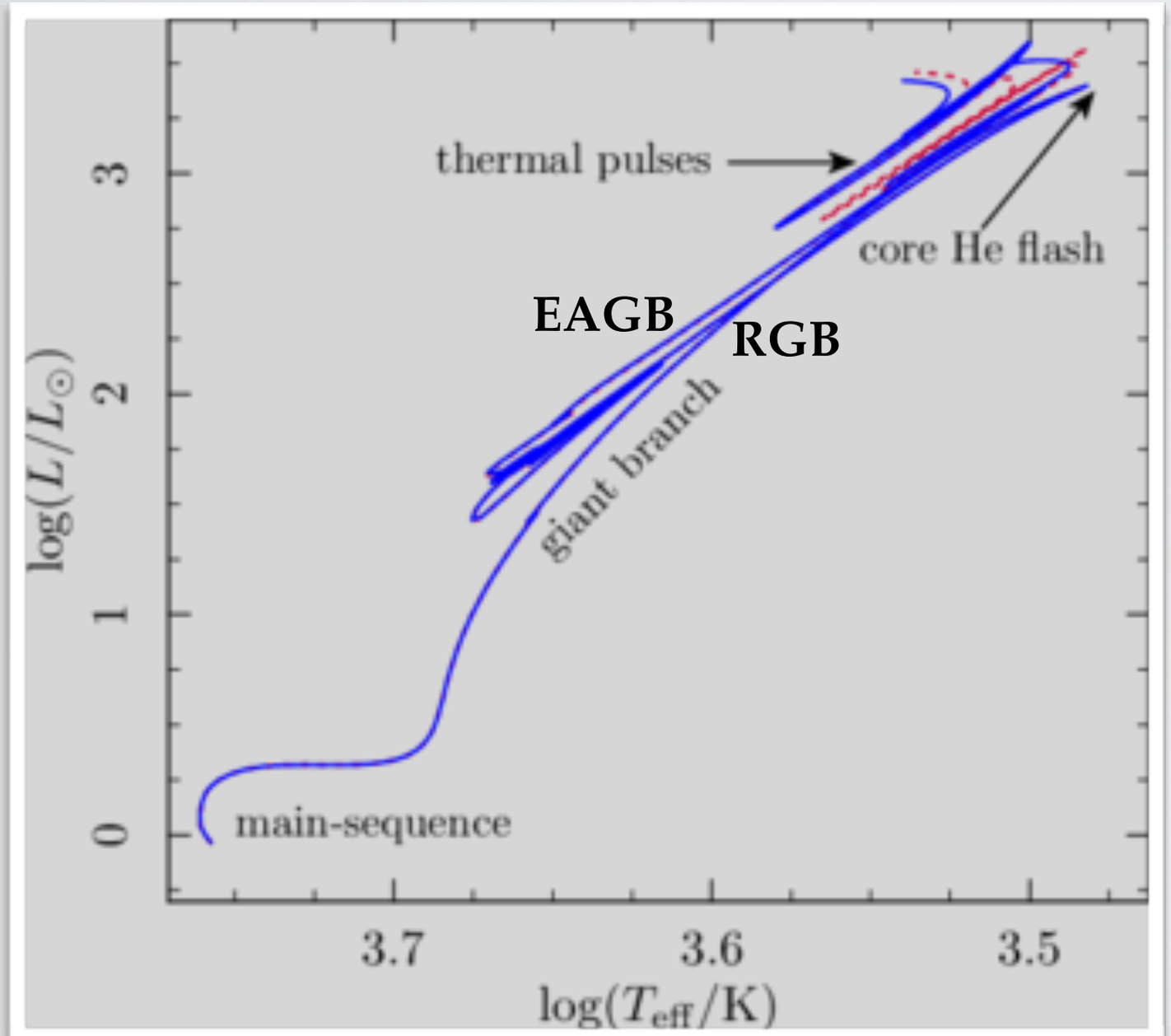


- **Pre-main sequence?**
  - No!
  - Low Log g and [Fe/H]



The Post-RGB stars (old) have [Fe/H] peaking at about -1.0 dex
The Post-AGB stars (old) have [Fe/H] peaking at about -0.7 dex
The PMS are a younger population peaking at >-0.5 dex

INTERLOPING OBJECTS IN OTHER EVOLUTIONARY STAGES…



- **Early AGB stars?**
  - Initial masses M <1.85 Msun
    - Unlikely!
  - Initial masses M <1.85 Msun
  - Maybe!!!

Binary interaction depends on when the star attains its ‘largest radii…

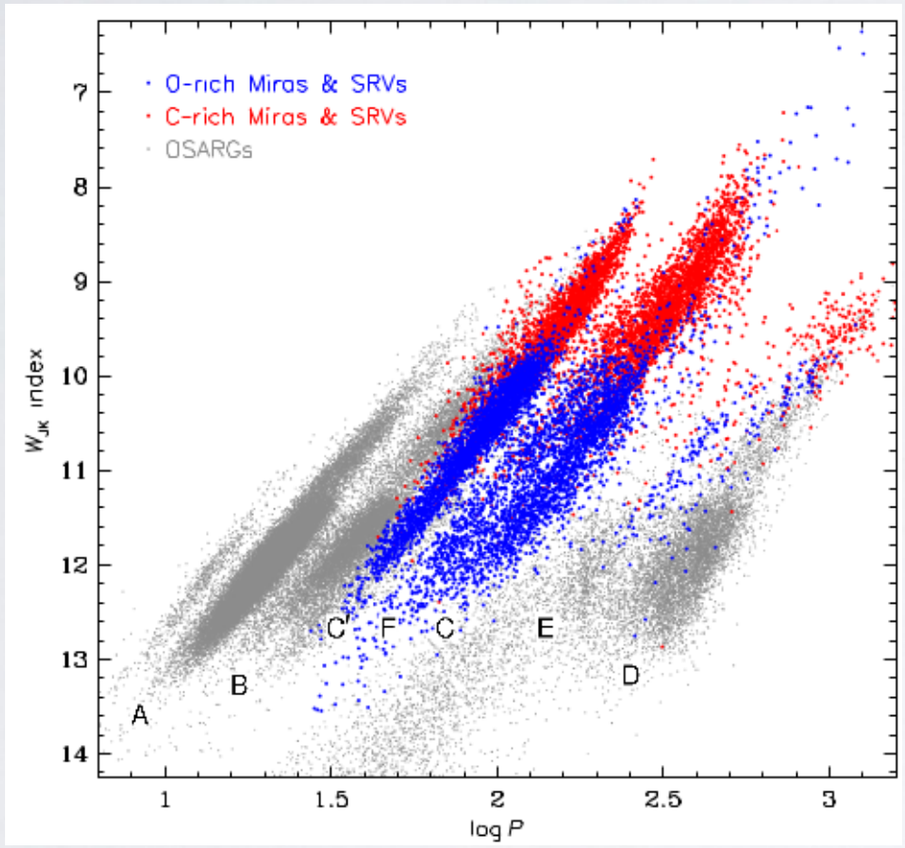
Establish connections to possible precursors and progeny….

ESTABLISHING THEIR EVOLUTIONARY STATUS - PRECURSORS

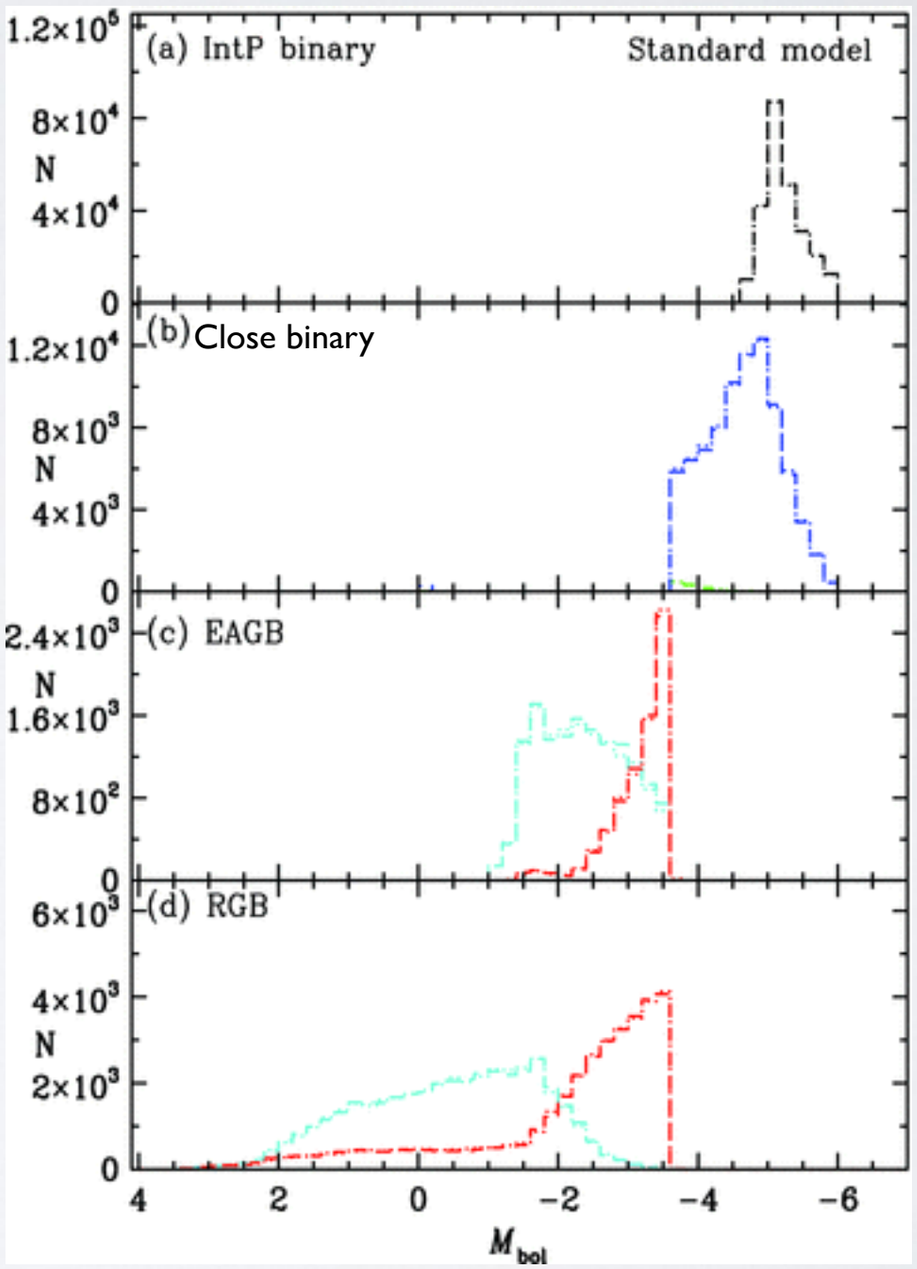
SEQUENCE-E Variables

Close binary red giants that show ellipsoidal light variations

Nicholls et al. 2010



Soszynski & Wood 2012



Nie et al., 2012

Luminosities of the TAGB

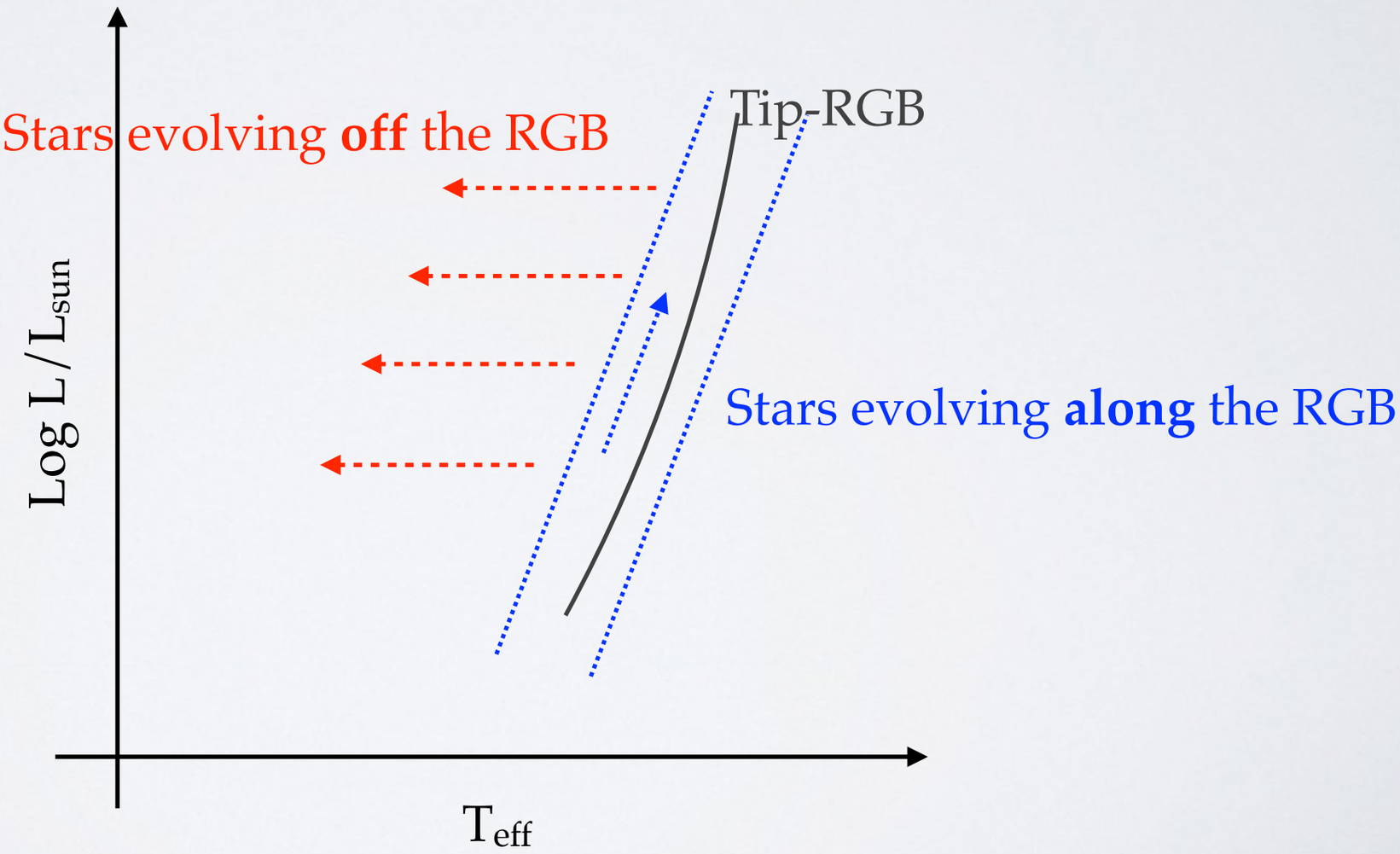
Close binary PNNe have AGB luminosities above the TRGB,

EAGB and RGB binaries undergoing a CE event but not merging have luminosities below the TRGB

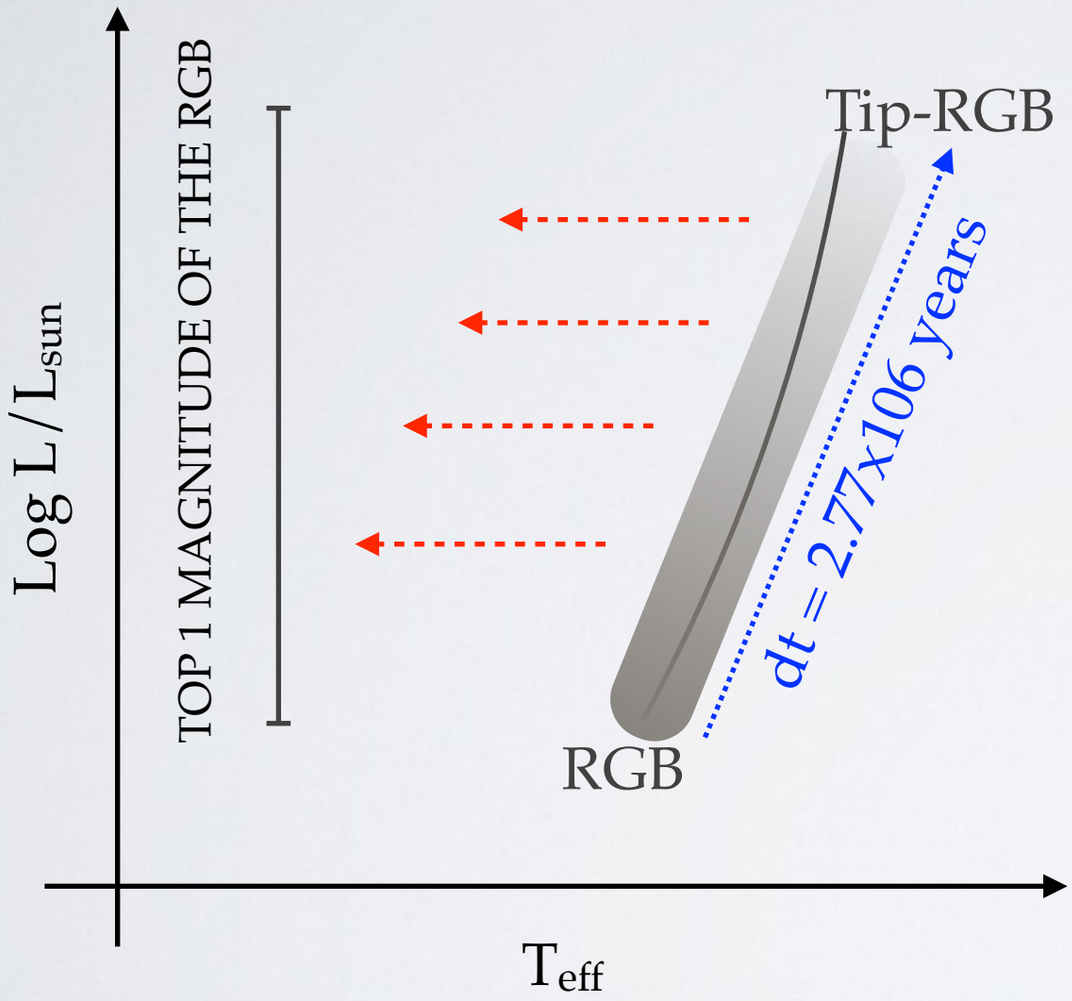
Mbol(TRGB) = −3.6

EVOLUTIONARY CONNECTION BETWEEN THE SEQUENCE- E STARS AND POST-RGB STARS

Method: Comparing theoretically predicted birthrates Nie et al. (2012) with the observationally determined birthrates of our new sample of dusty post-RGB stars



THEORETICAL BIRTHRATES…



Relative theoretical birthrates (PRGB, PEAGB, MERGERS, tip-RGB) in arbitrary units, come from population synthesis models, Nie et al, 2012

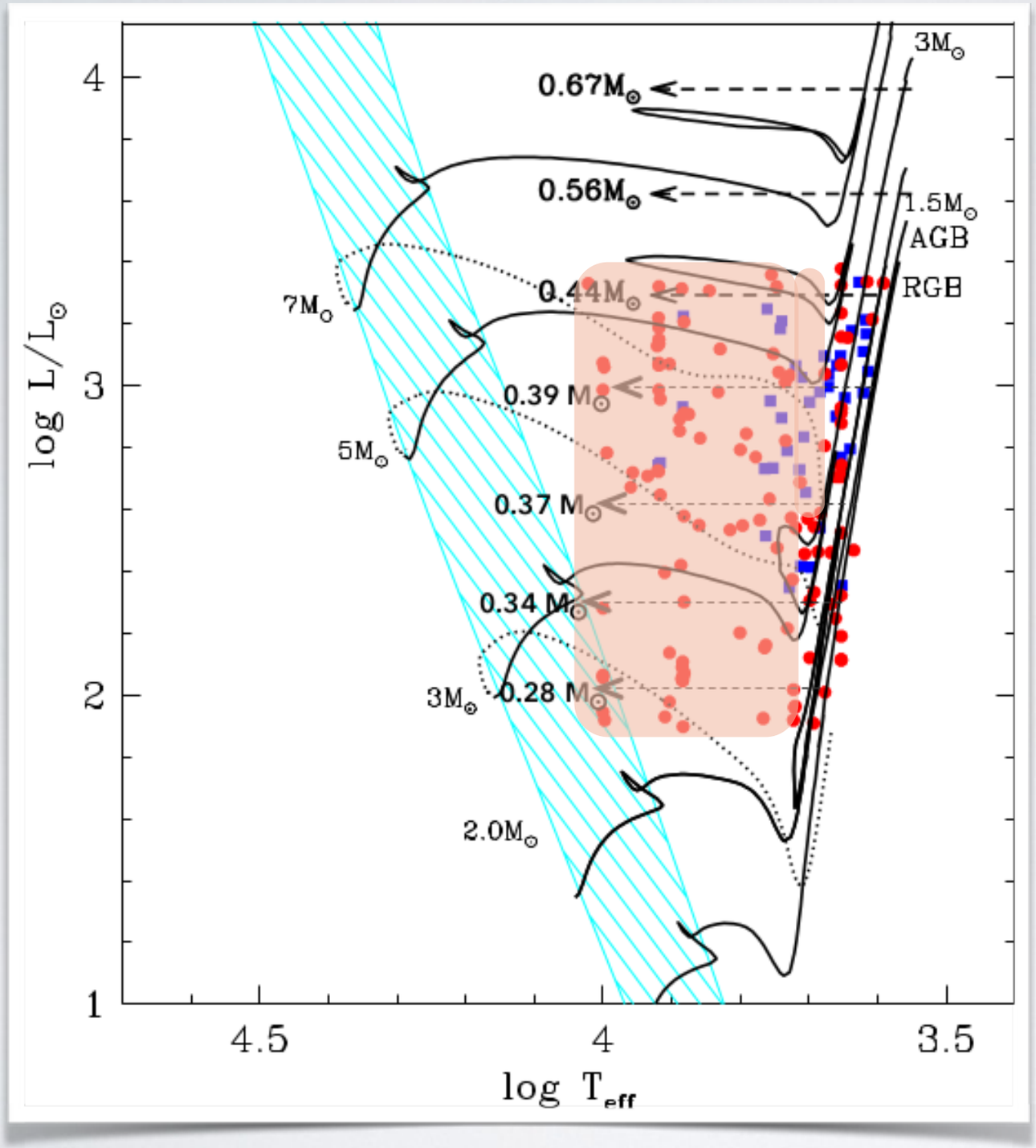
BUT WE NEED TO SCALE THEM TO THE OBSERVATIONAL FIELDS OF THE POST-RGB STARS

The number of stars we expect to see at any given time in the top 1 magnitude of the RGB is $k = 2.77 \times 10^6 \times$ birthrate tip-RGB

Total number of stars observed in the top 1 magnitude of the RGB in the fields searched for post-RGB stars is 118927 (from SAGE)

Total predicted birthrates = 118927*(birthrate/k)

OBSERVATIONAL BIRTHRATES OF POST-RGB STARS



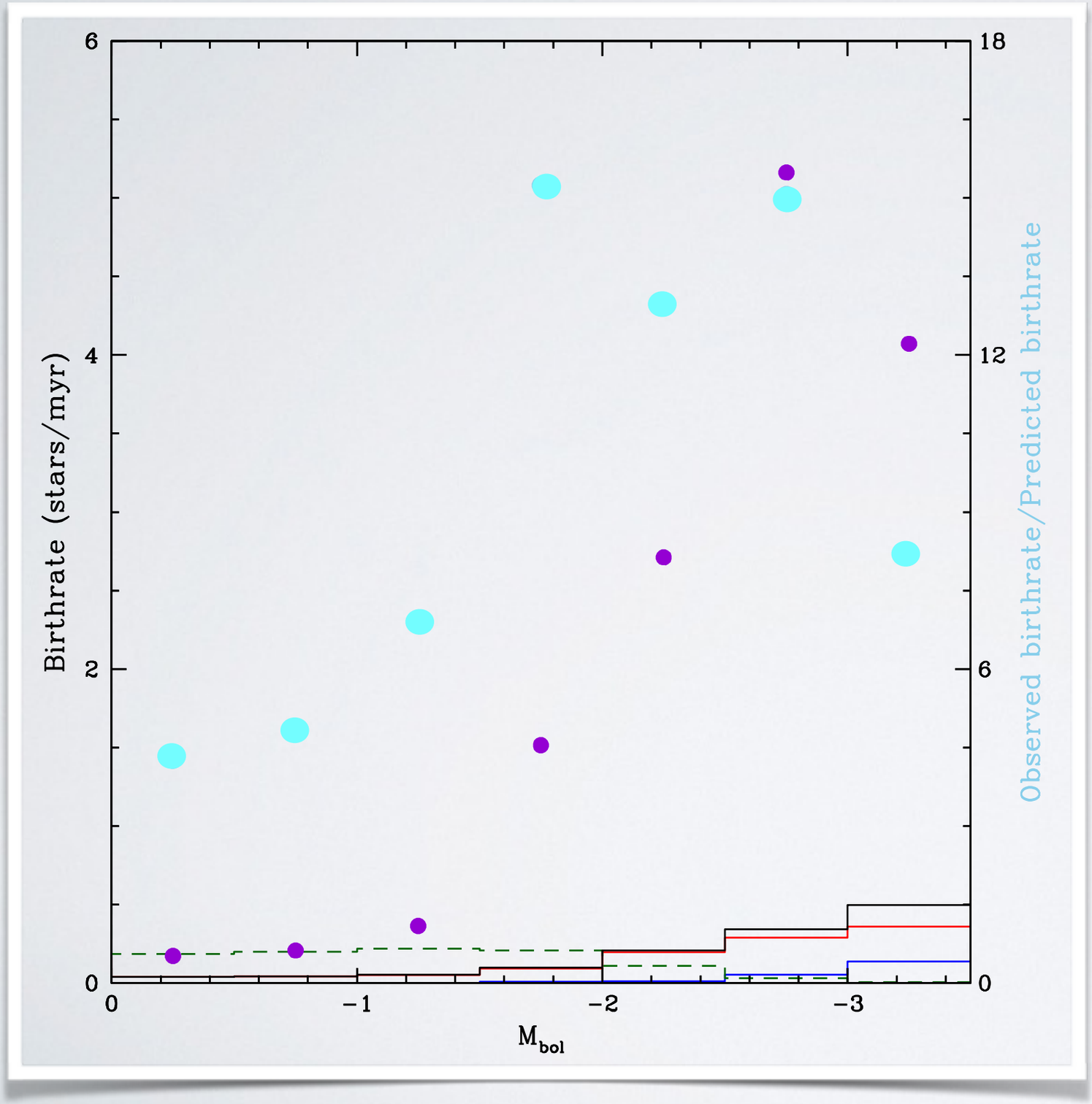
Number of observed post-RGB stars

Estimated evolutionary lifetime

RGB log Teff range = log Teff(RGB) + 0.05 and continues to log Teff = 4.

Note: We take into account the incompleteness of the survey… (incompleteness factor of 7.3)

CONNECTION TO POPULATION MODELS OF RGB BINARIES



Post-RGB production rates

Post-EAGB production rates

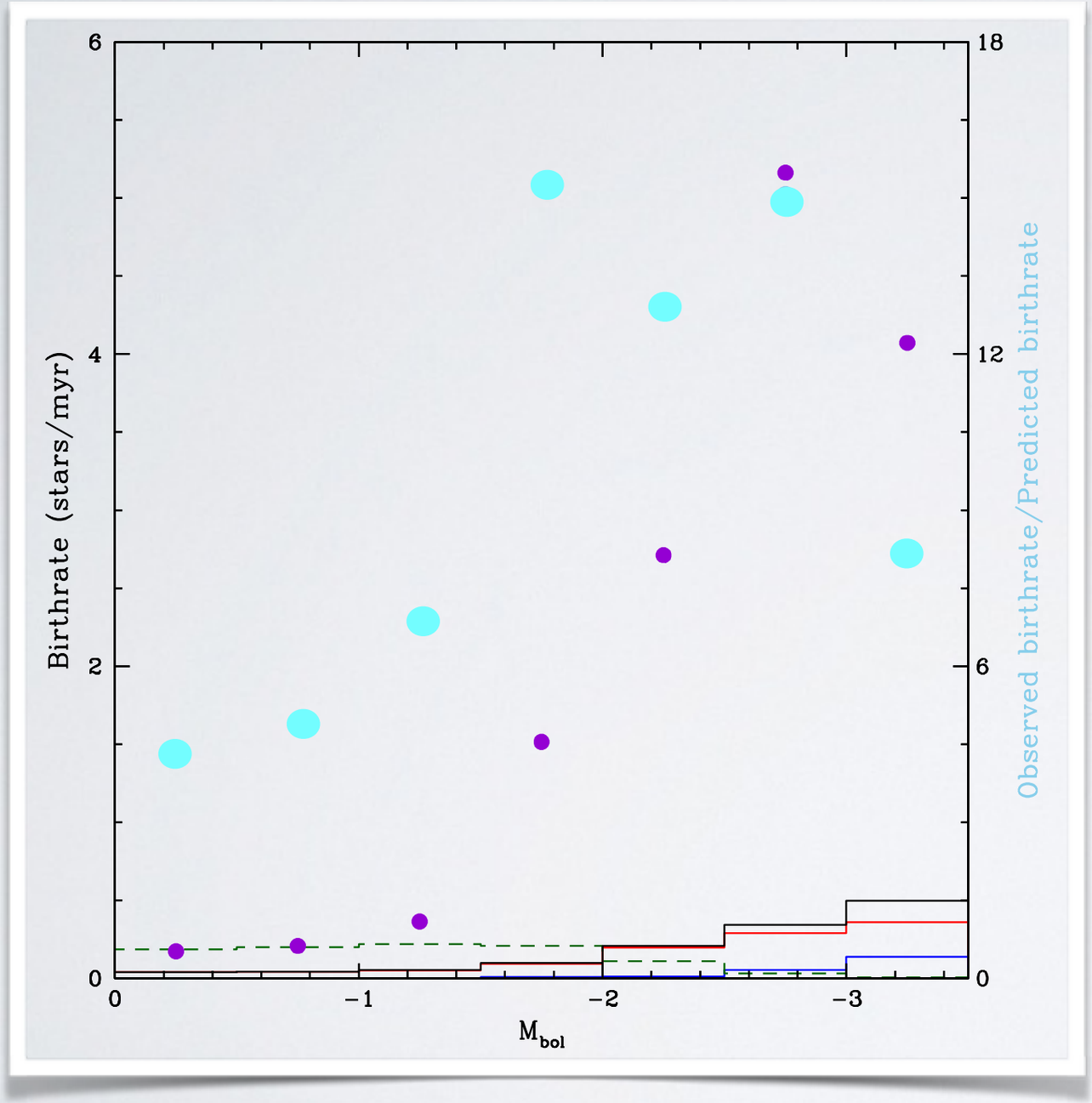
Birthrates of mergers on the RGB

Total predicted rate of production

OBSERVED BIRTHRATES

Ratio of the observed to the total predicted birthrate

CONNECTION TO POPULATION MODELS OF RGB BINARIES



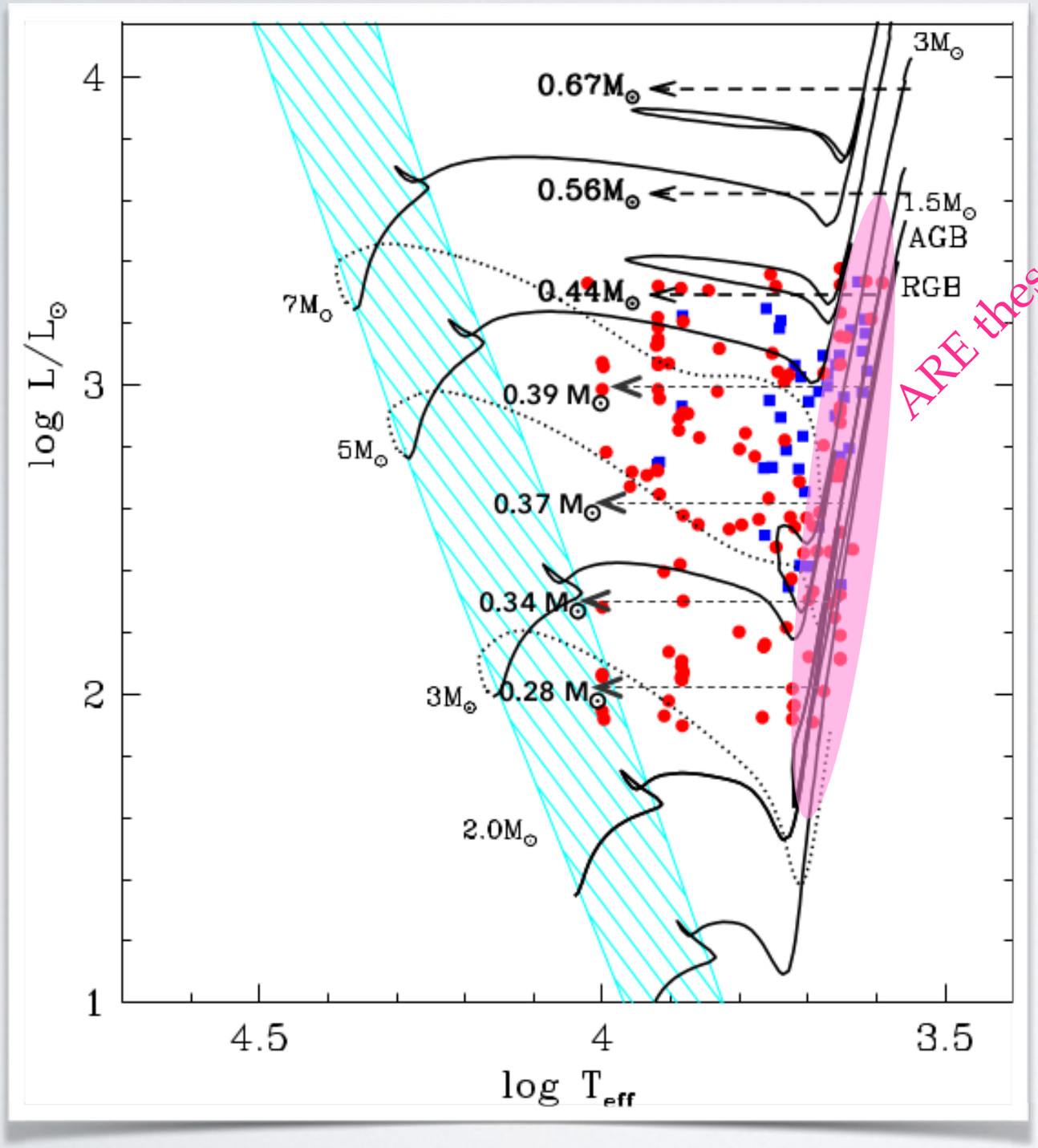
Observationally estimated post-RGB birthrate is much higher than the theoretically predicted birthrate

The average ratio of observed to predicted birthrate is 9.6

At lower metallicities, mergers dominate

Post-EAGB birthrates increases to about 25% of the total birthrate at the highest luminosities

OBSERVATIONAL BIRTHRATES OF POST-RGB STARS



Number of observed post-RGB stars

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RGB log Teff range = log Teff(RGB) + 0.05 and continues to log Teff = 4.

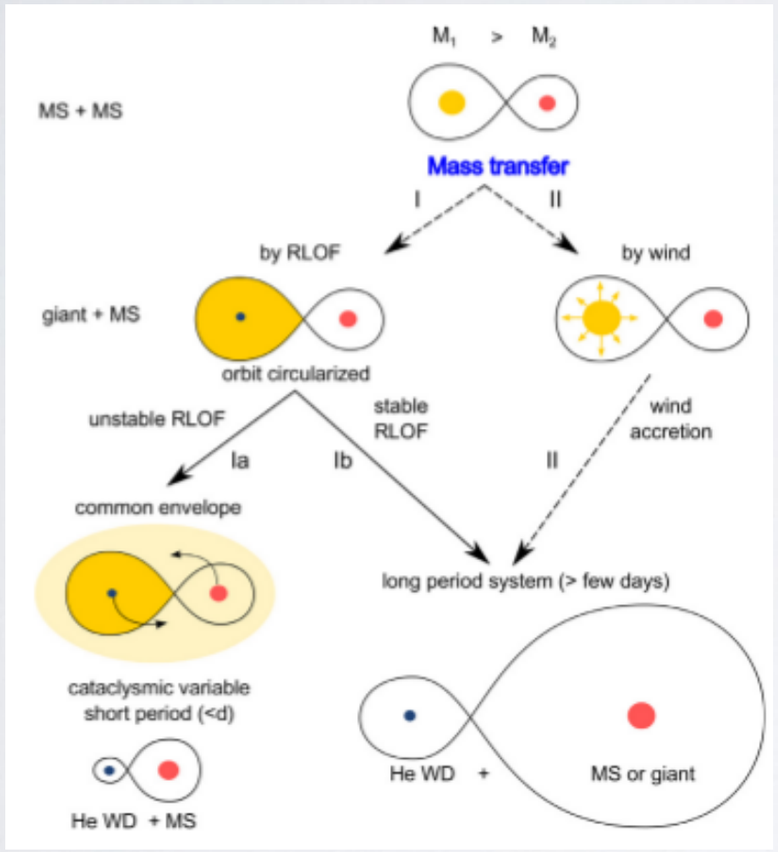
Note: We take into account the incompleteness of the surgery….

UNCERTAINTIES

- An over-estimation of the incompleteness factor
- An underestimate of the post-RGB evolution time
- Interlopers in the post-RGB sample
- Uncertainties in the model post-RGB birthrate

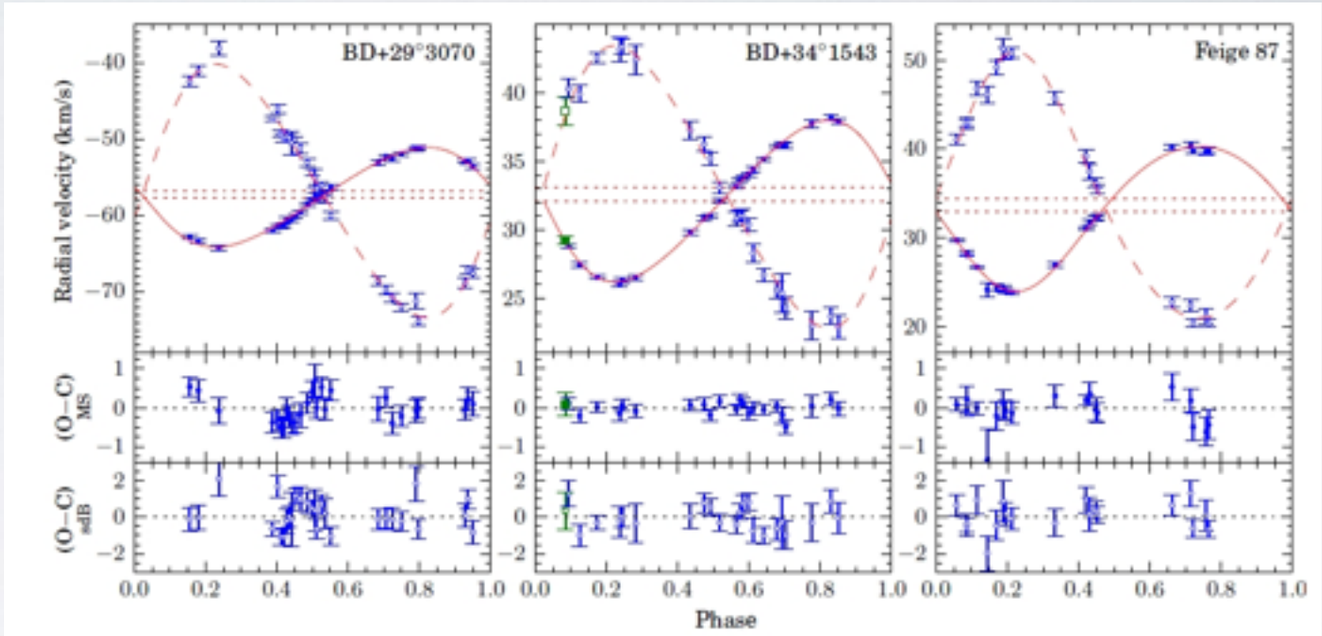
EVOLUTIONARY STATUS -PROGENY

Binary He WDs/ Cataclysmic Variables



Merle.T et al., 2014

Sub-dwarf B stars

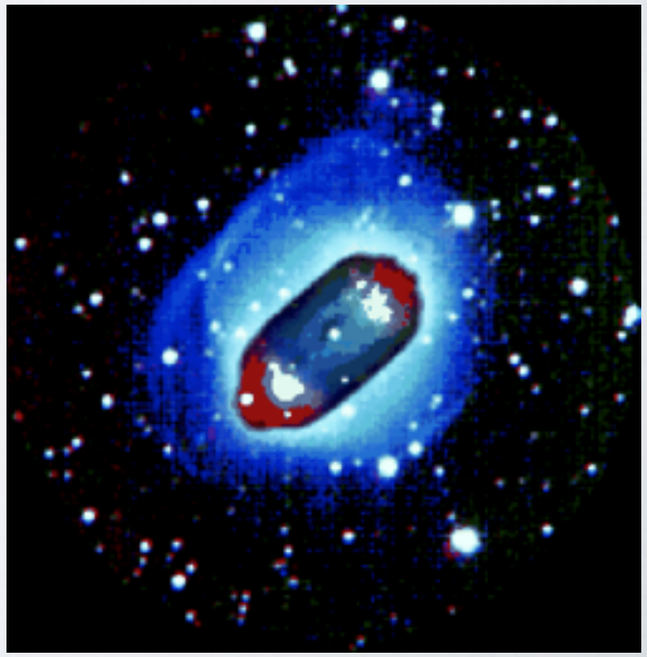


Vos et al., 2013, TALK OF JORIS VOS… coming soon!!!

Low-luminosity Planetary Nebulae

(Bond & Livio 1990; Yungelson et al. 1993; Soker 1997; Bond 2000; Zijlstra 2007; de Marco 2009)

(Bond 1994, 2000; Miszalski et al. 2009)



CONCLUSIONS

- **Newly discovered low-luminosity, dusty post-RGB stars**
  - An unexplored phase of binary stellar evolution
  - Termination of RGB evolution via binary interaction
- **Precursors - Sequence-E stars**
  - The observationally estimated post-RGB birthrate is much higher than the theoretically predicted birthrate
  - Some of these objects are likely to be products of mergers. Models predict that mergers dominate at lower luminosities
- **Progeny - Binary He WDs, SdBs, Low-luminsoity PNe???**

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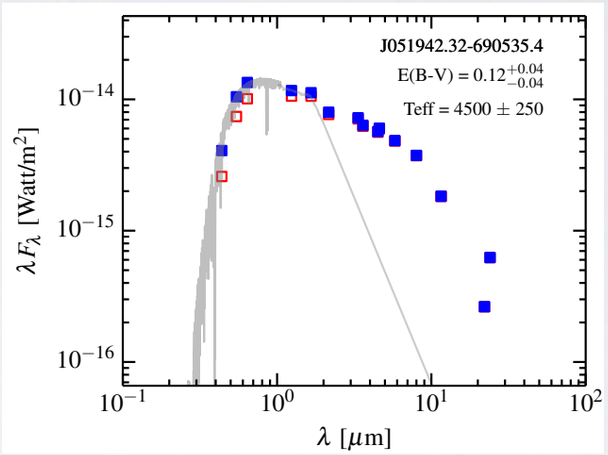
HAPPY 'BIRD'DAY RAJEEV!!!!!

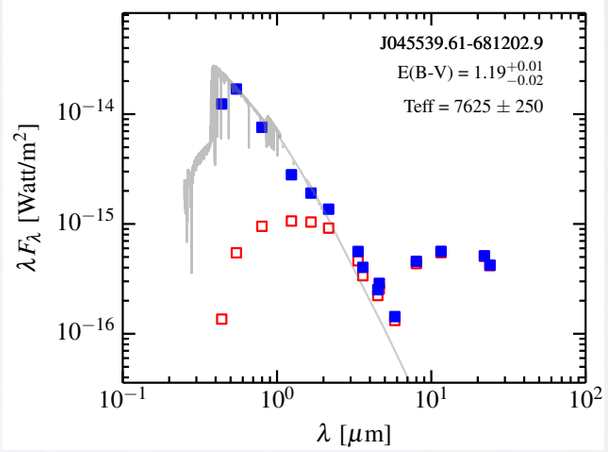
ESTABLISHING THE BINARY NATURE OF THESE POST-RGB SYSTEMS

- **Radial Velocity Estimates**
  - On-going…
- **SED Characteristics**
  - Majority of them show disc-like SEDs (=> binaries)
  - but a small number show shell-like SEDs (=> evolved discs with cooler dust???)
- **Chemical Abundance Analysis**
  - On-going… BUT challenging as these objects are rather faint…

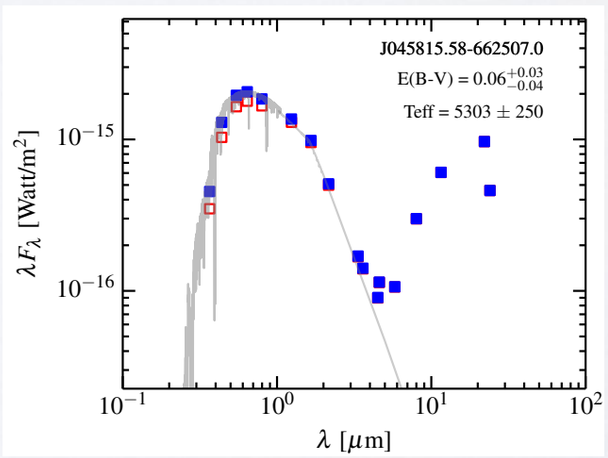
Post-RGB SEDs



Disc-type SED with hot dust



Disc-type SEDs (evolved discs)



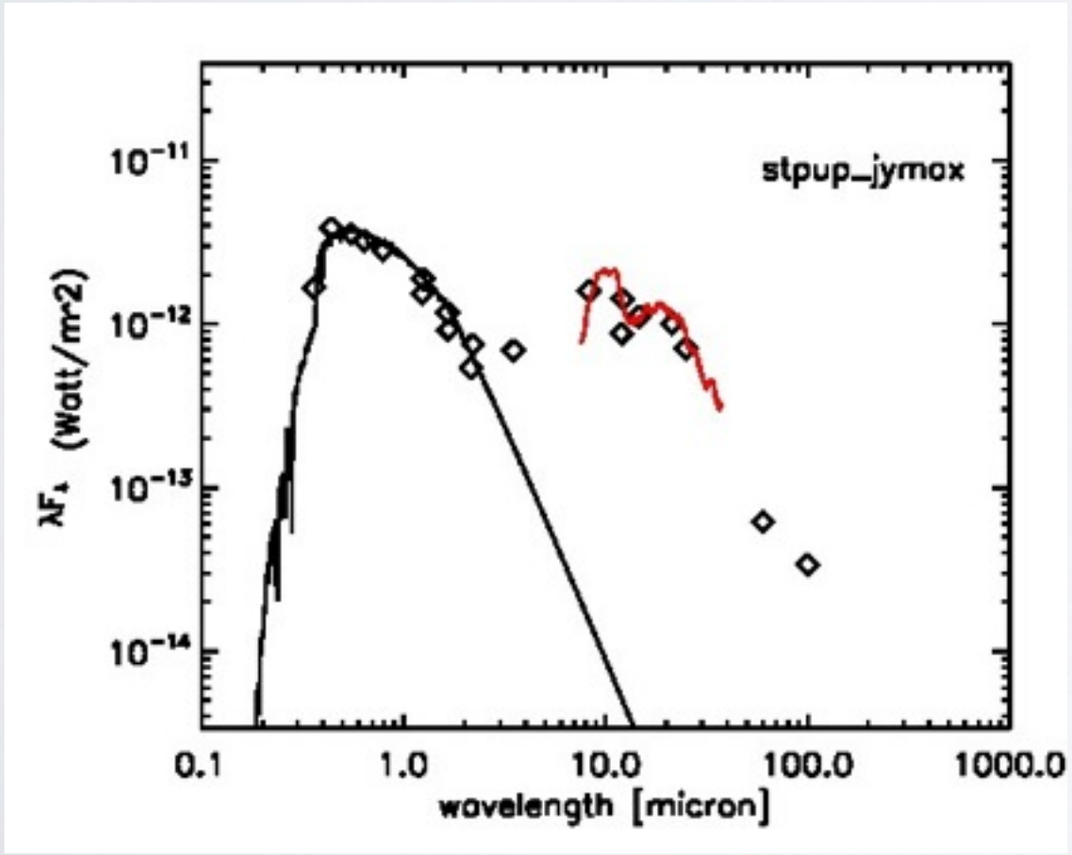
Shell-type SED?

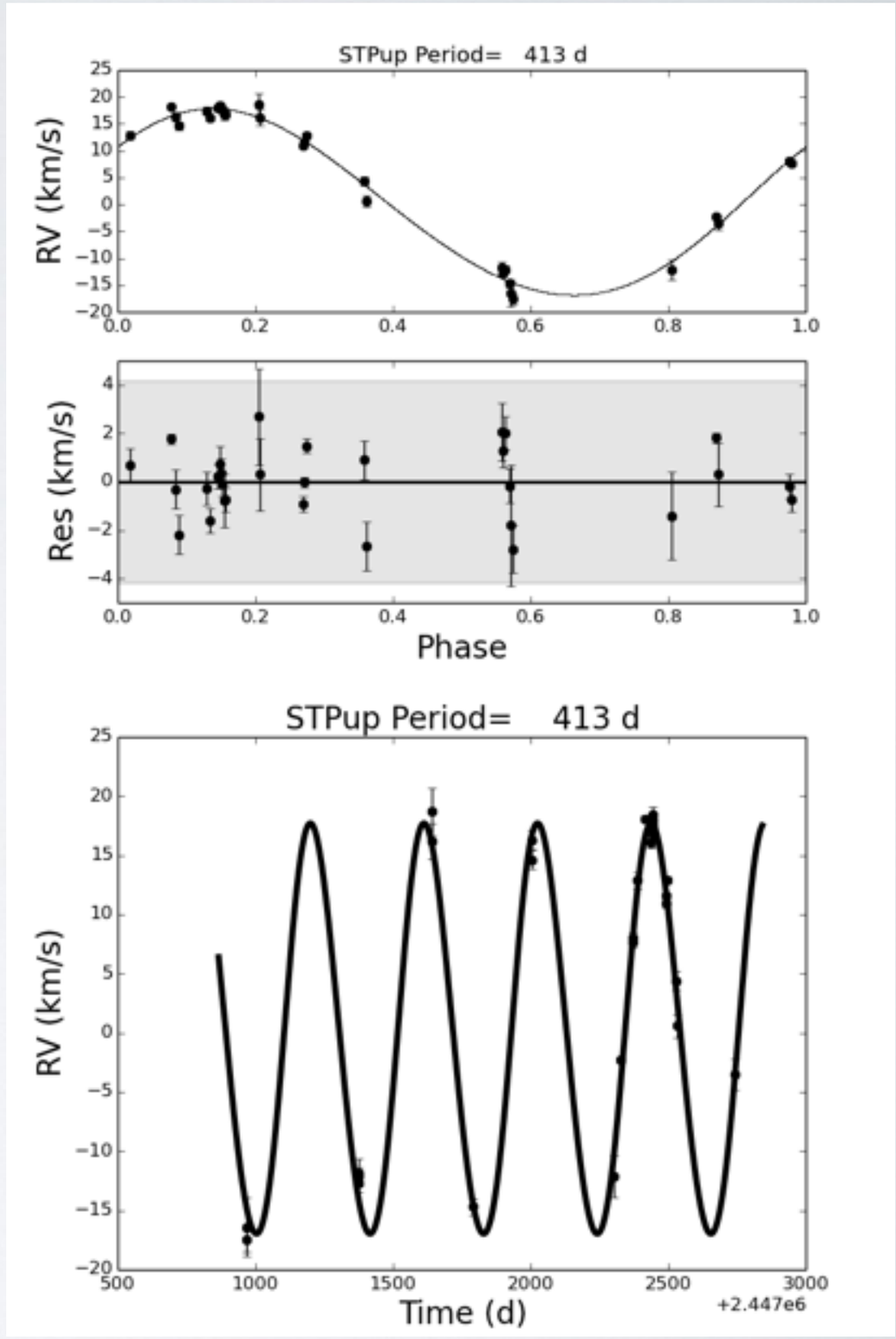
GALACTIC POST-RGBs???

The poorly constrained distances to Galactic objects currently classified as post-AGB stars means that it is ***not possible to identify*** post-RGB systems among them…

POSSIBLE GALACTIC POST-RGBS I : ST PUP

- Chemical pattern: Depletion (characteristic of binaries)
- Pop II Cepheid - W-Vir star with (P ~19 days)

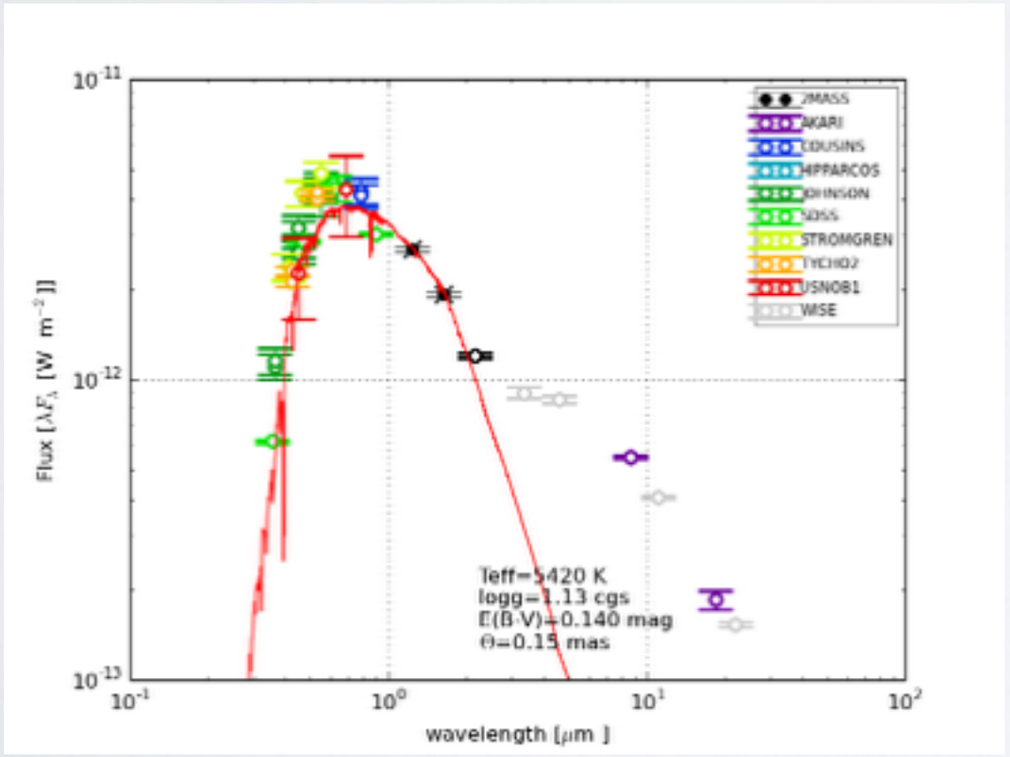


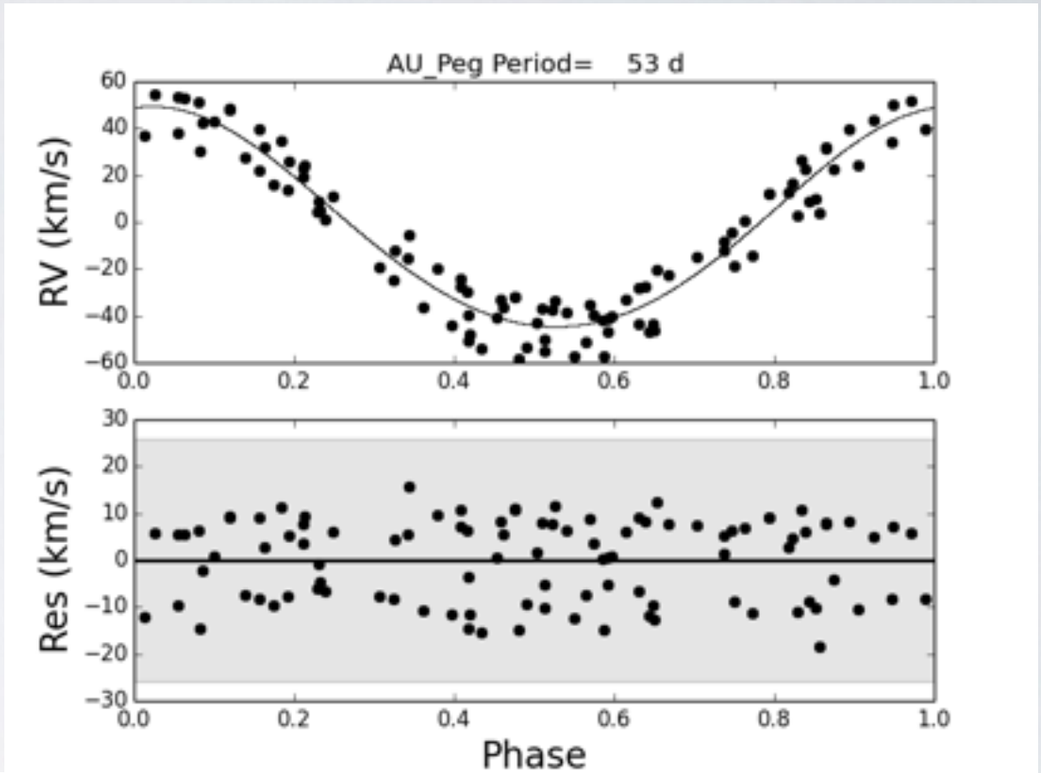


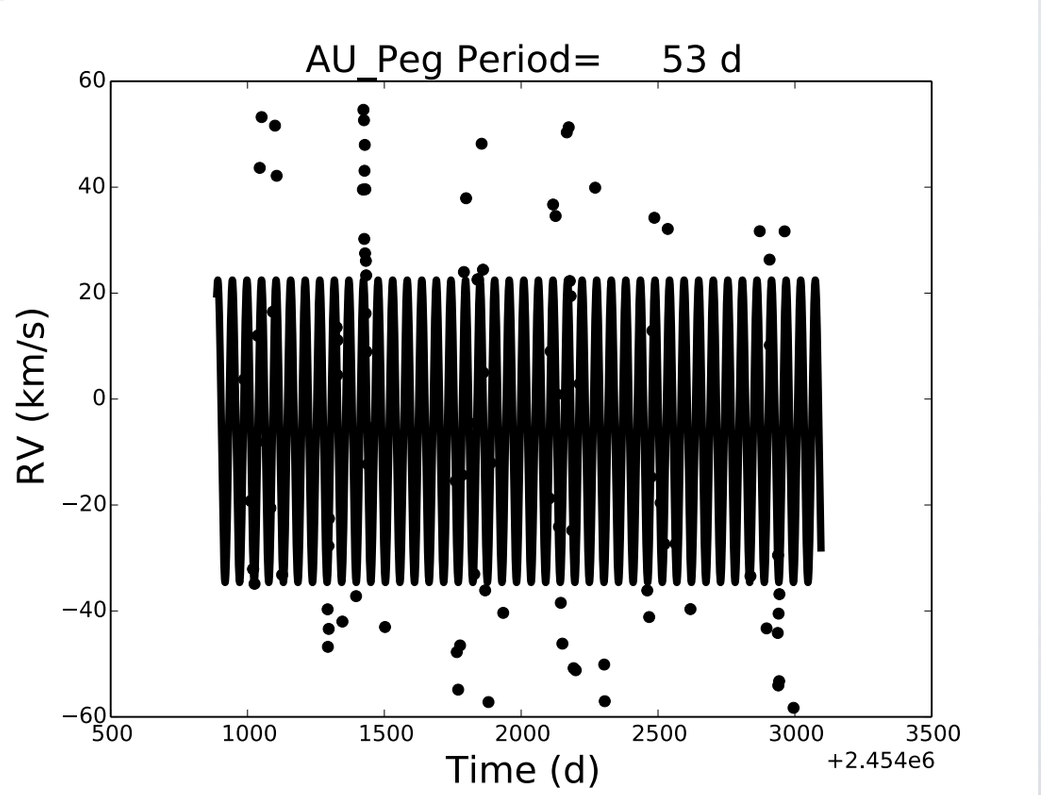
Gonzalez & Wallerstein et al 1996

POSSIBLE GALACTIC POST-RGB II : AU PEG

- Pop II Cepheid - W-Vir star with pulsation period of 2 days…
- Mass function of 0.57 Msun (m1 ~0.3 to 0.65 Msun) and (m2 ~ 0.9 to 1.4 Msun)
- Chemical pattern: No signs of depletion







Jurkovic M. et al., 2007