Including WR, TP-AGB, and Binary Stars in Population Synthesis Models

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Z/Y (PARSEC tracks)

0.0000/0.230	0.0001/0.249	0.0002/0.249	0.0005/0.249	0.001/0.250
0.002/0.252	0.004/0.256	0.006/0.259	0.008/0.263	0.014/0.273
0.017/0.279	0.010/0.267	0.020/0.284	0.030/0.302	0.040/0.321

- Fine grid of stellar mass from 0.10 to 400 Mo
- Usually > 26,000 points in the HRD per Z

PARSEC Evolutionary Tracks: (PAdova & TRieste Stellar Evolution Code) by:

- Chen et al. (2015) for massive stars up to 350 Mo (WR phase)
- Bressan et al. (2012) for lower masses (includes TP-AGB treatment)

Stellar Spectra

- WM-Basic (Leitherer+ 2010) for MS stars hotter 20,000K
- Tlusty models (Lanz & Hubeny, 2003+2007) for O and B stars
- PoWR models (Gräfener+ 2002, Hamman+ 2004) for WR stars
- MILES (Sánchez-Blázquez+ 2006) in available range
- IRTF (Rayner+ 2009) for cool giants
- Aringer+ 2009 models for C stars
- DUSTY Code (Ivezic+ 1999) as in González-Lopezlira+ 2010 for TP-AGB

Binary star evolution computed with the BSE code by Hurley+ 2002
(see Hernández-Pérez & Bruzual 2013, 2014 for details)

PoWR - The Potsdam Wolf-Rayet Models

- High resolution models

  Hainich et al. (2015)

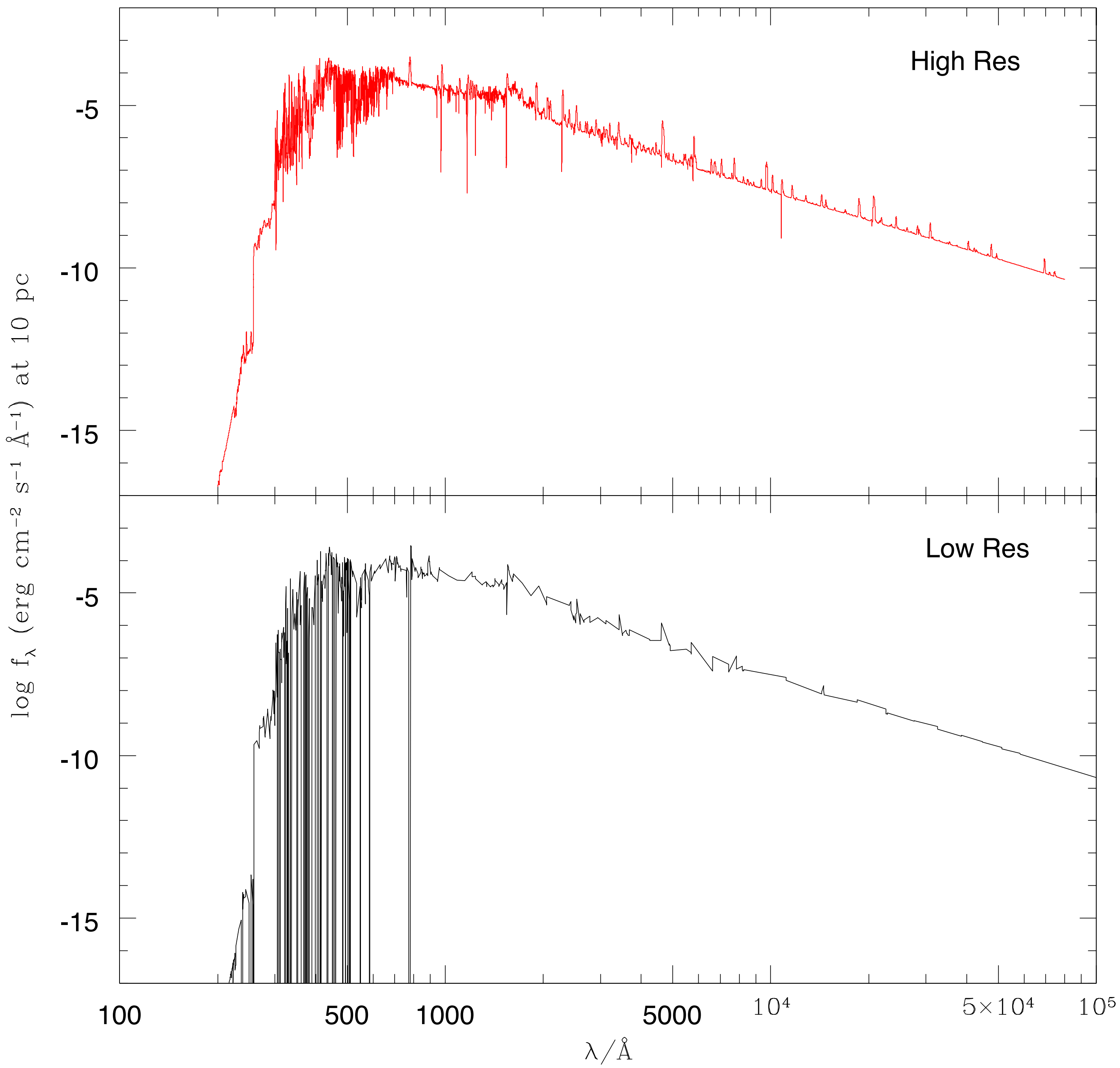
  Todt et al. (2015, private communication)

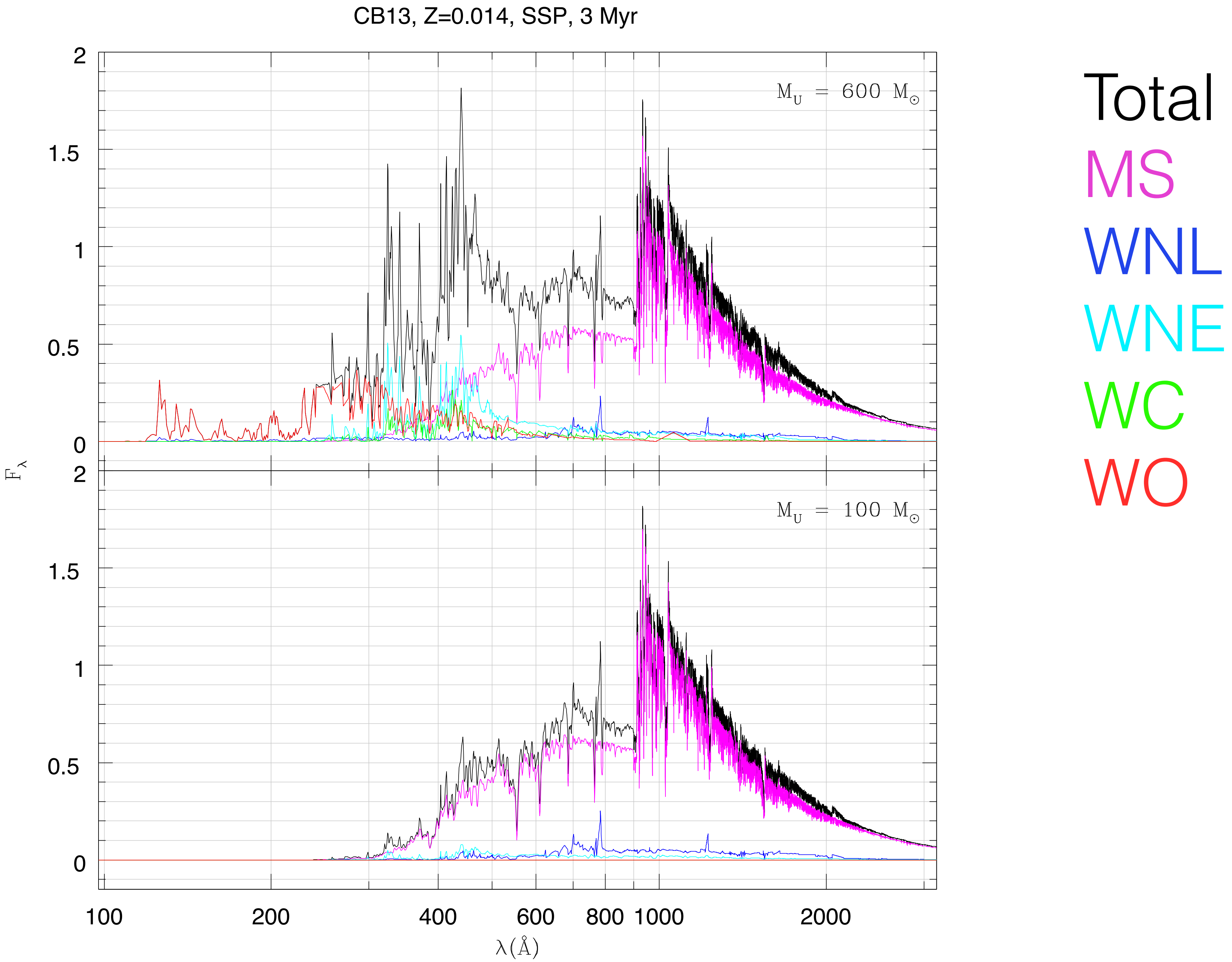
- WC, WNE, WNL, WO types

- Z/Zo = 1 (MW), 0.5 (LMC), 0.2 (SMC), 0.07 (sub-SMC)

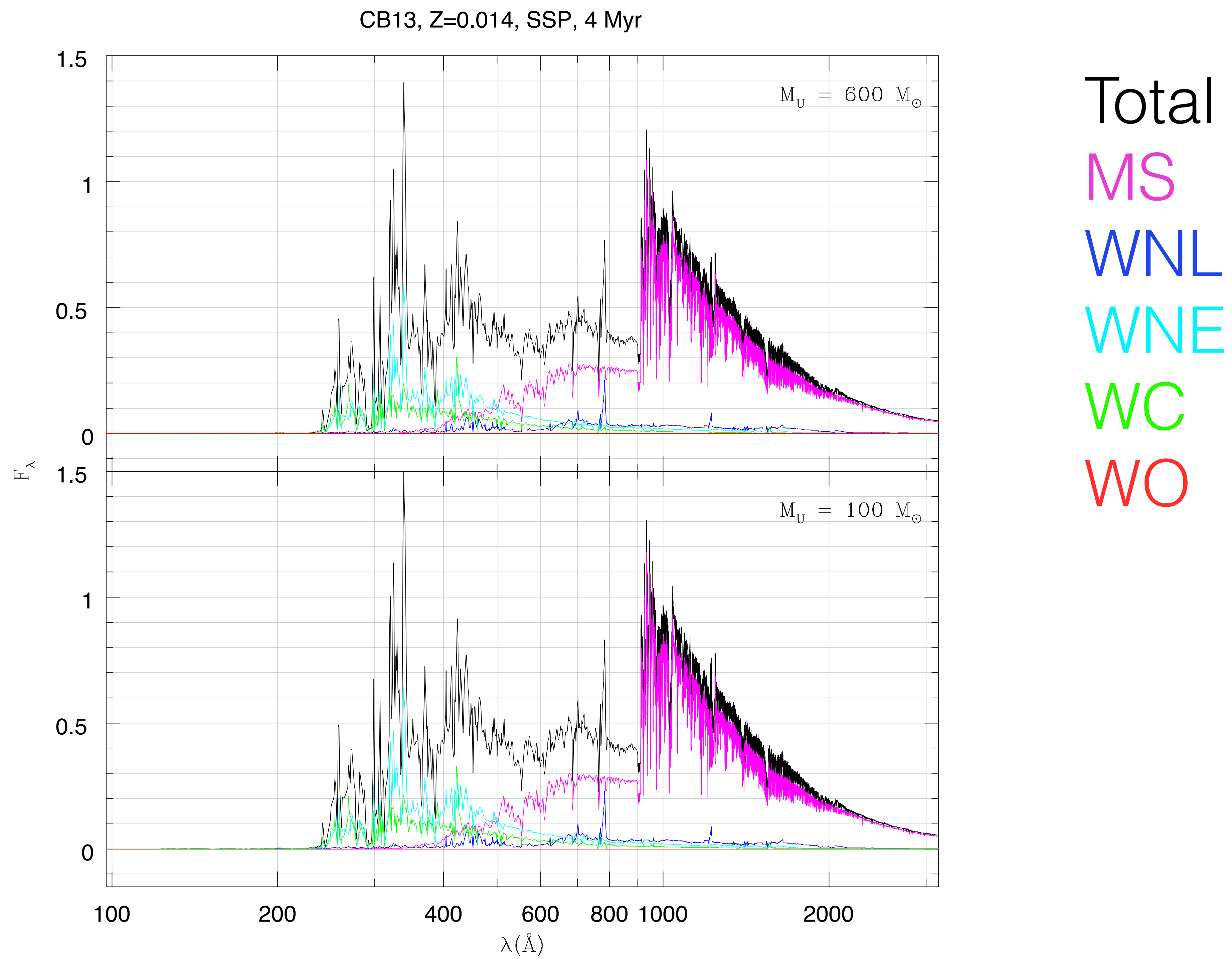
- Wavelength coverage: 200 - 80,000 A, resolution 0.30 A

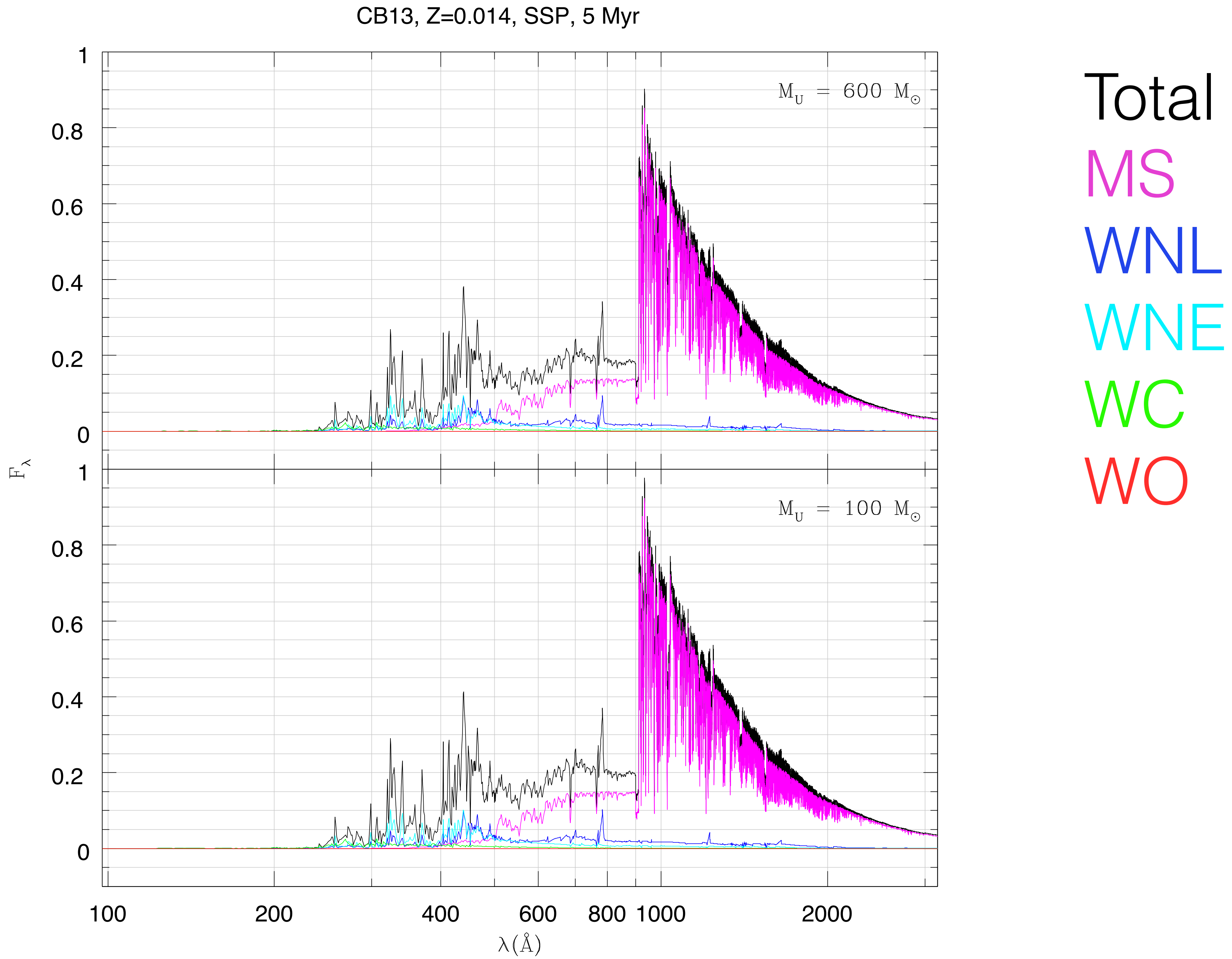
WC model for T_{eff} = 79,000 K, log $R_t/R_\odot$= 0.50

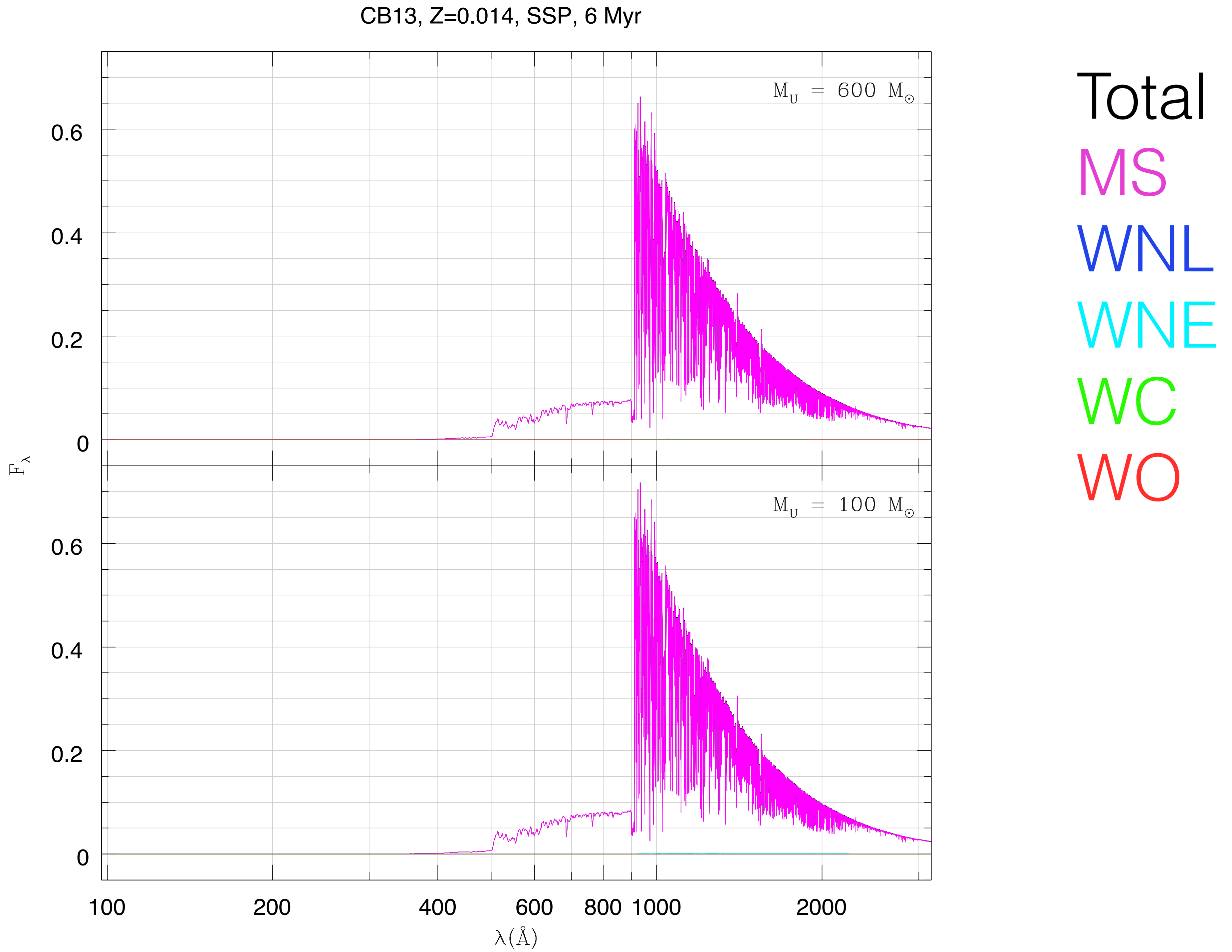


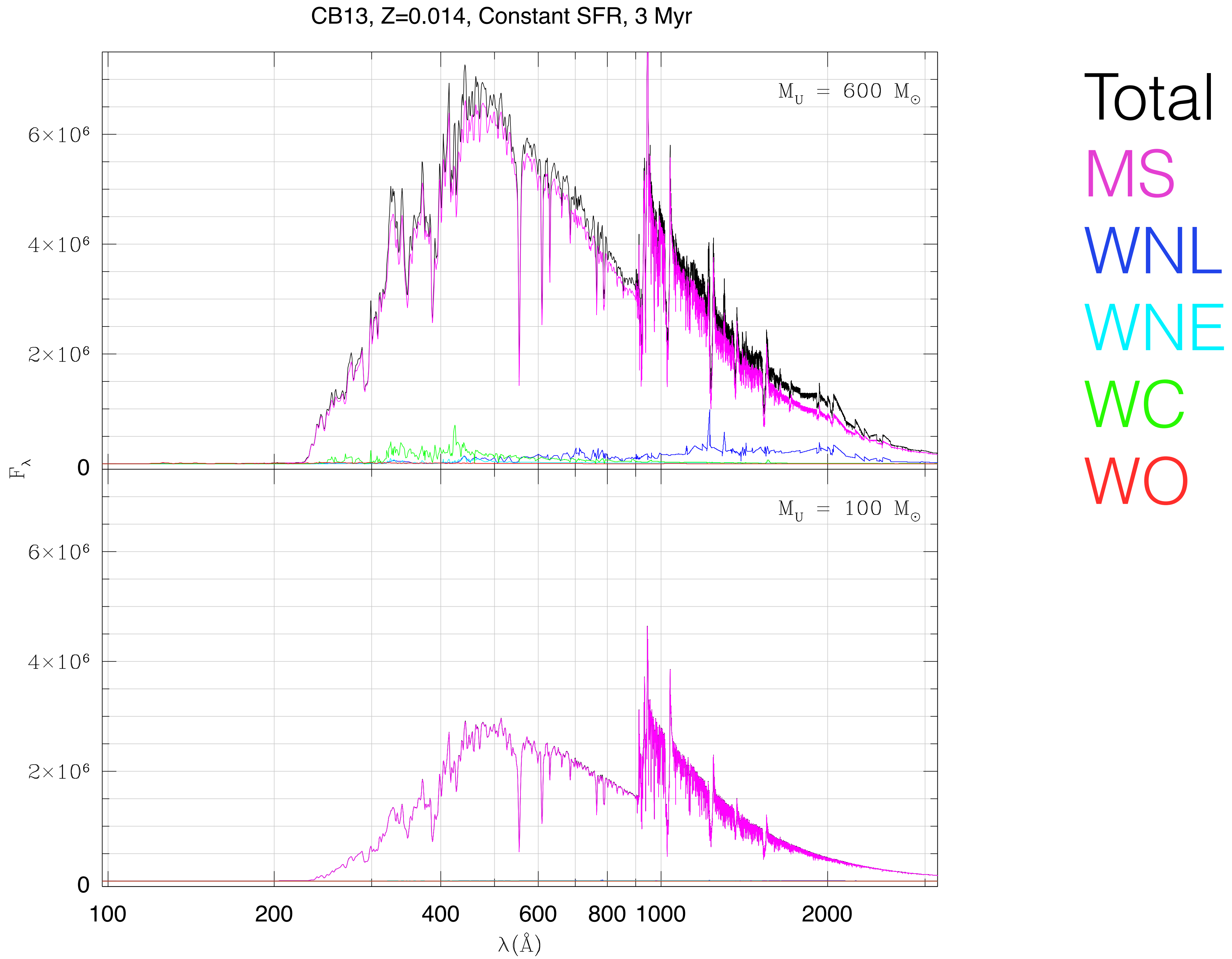


CB13, Z=0.014, SSP, 3 Myr
M_U = 600 $M_\odot$
M_U = 100 $M_\odot$
F_λ
λ(Å)
2
1.5
1
0.5
0
100
200
400
600
800
1000
2000
Total
MS
WNL
WNE
WC
WO

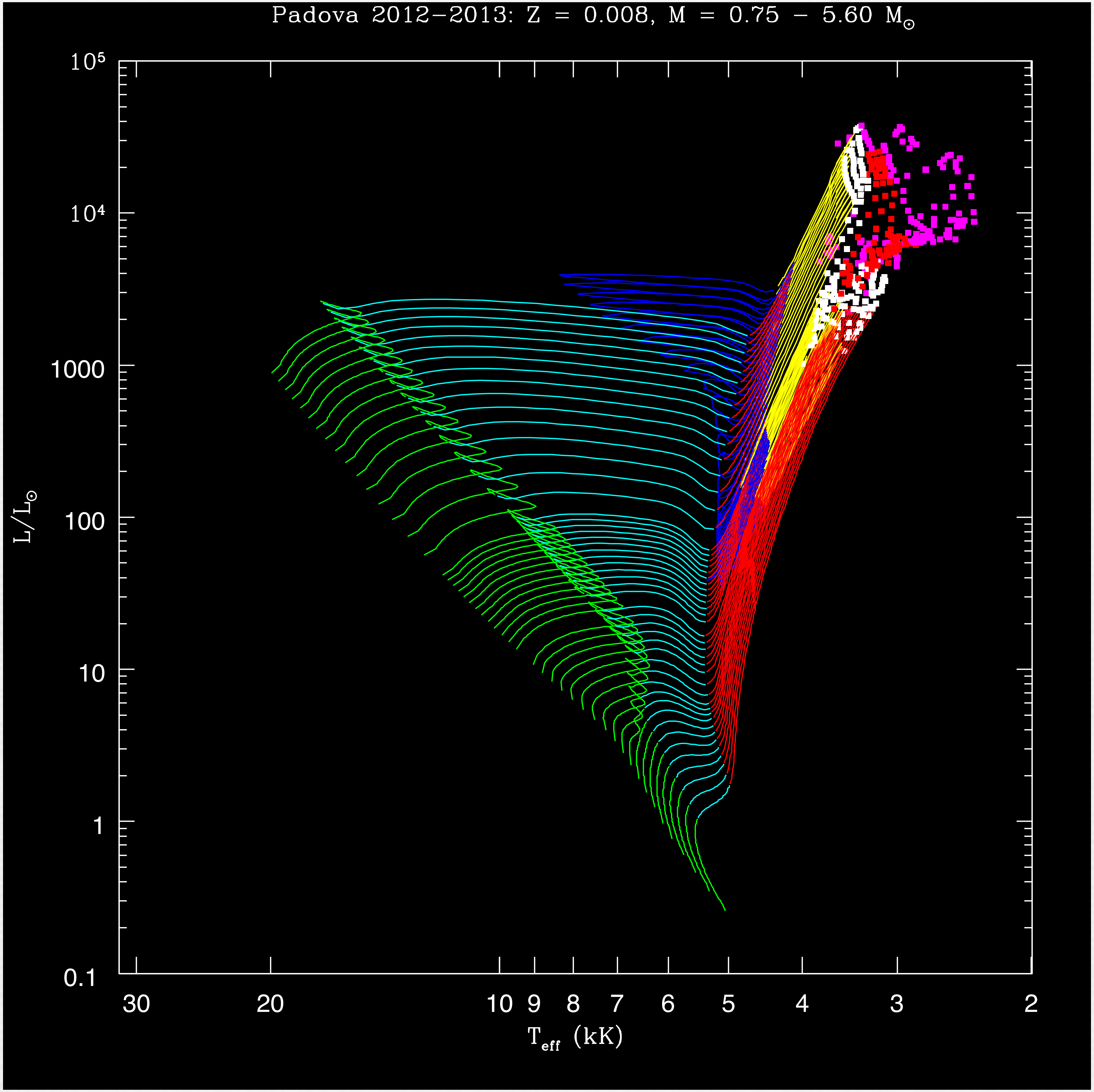

CB13, Z=0.014, SSP, 4 Myr
1.5
1
0.5
0
M_U = 600 $M_\odot$
M_U = 100 $M_\odot$
F_λ
100
200
400
600
800
1000
2000
λ(Å)
Total
MS
WNL
WNE
WC
WO


CB13, Z=0.014, SSP, 5 Myr
M_U = 600 $M_\odot$
M_U = 100 $M_\odot$
F_λ
λ(Å)
1
0.8
0.6
0.4
0.2
0
100
200
400
600
800
1000
2000
Total
MS
WNL
WNE
WC
WO

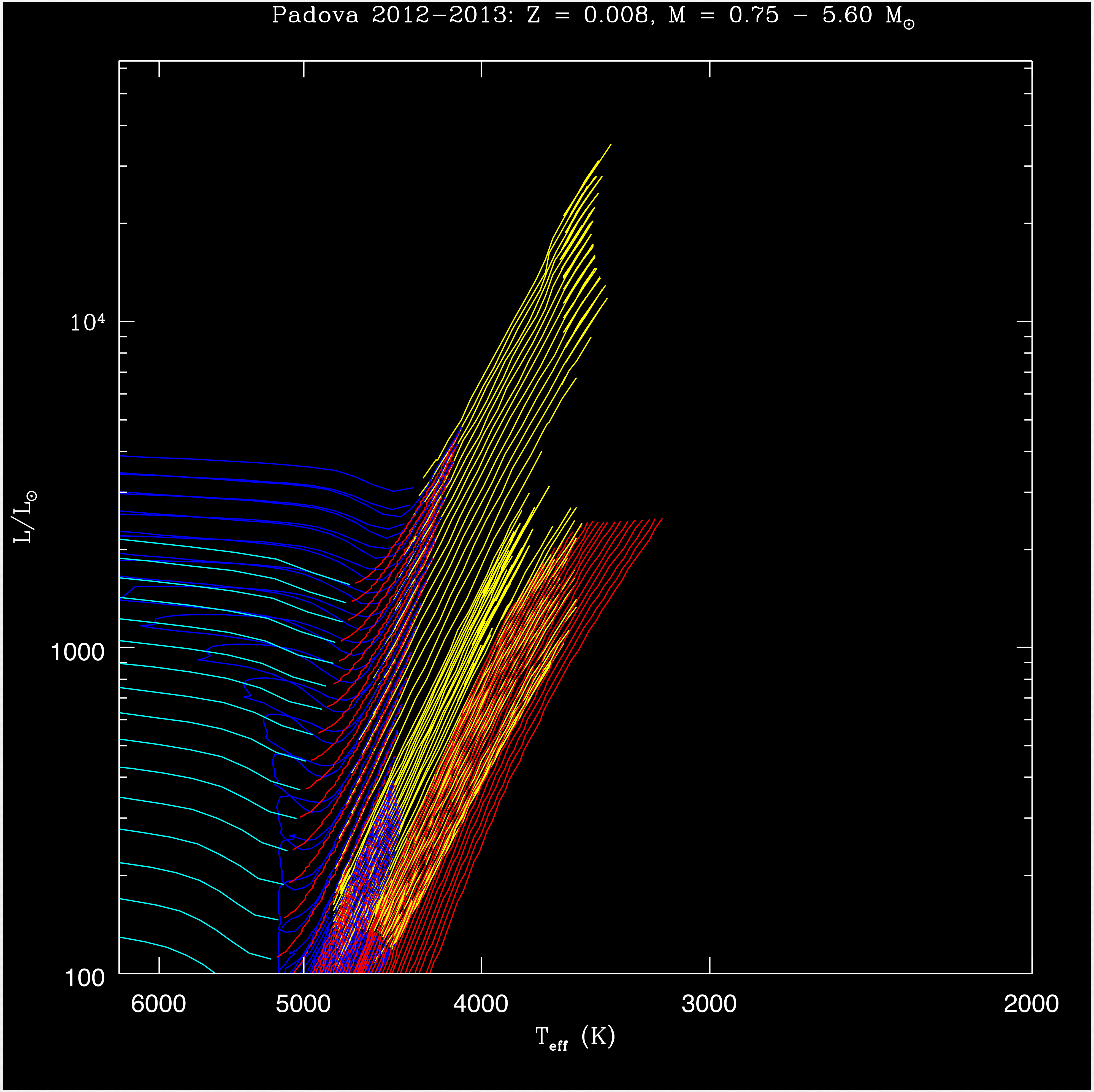

CB13, Z=0.014, SSP, 6 Myr
M_U = 600 $M_\odot$
M_U = 100 $M_\odot$
0.6
0.4
0.2
0
F_λ
100
200
400
600
800
1000
2000
λ(Å)
Total
MS
WNL
WNE
WC
WO


CB13, Z=0.014, Constant SFR, 3 Myr
M_U = 600 $M_\odot$
M_U = 100 $M_\odot$
6×10^6
4×10^6
2×10^6
0
F_λ
100
200
400
600
800
1000
2000
λ(Å)
Total
MS
WNL
WNE
WC
WO

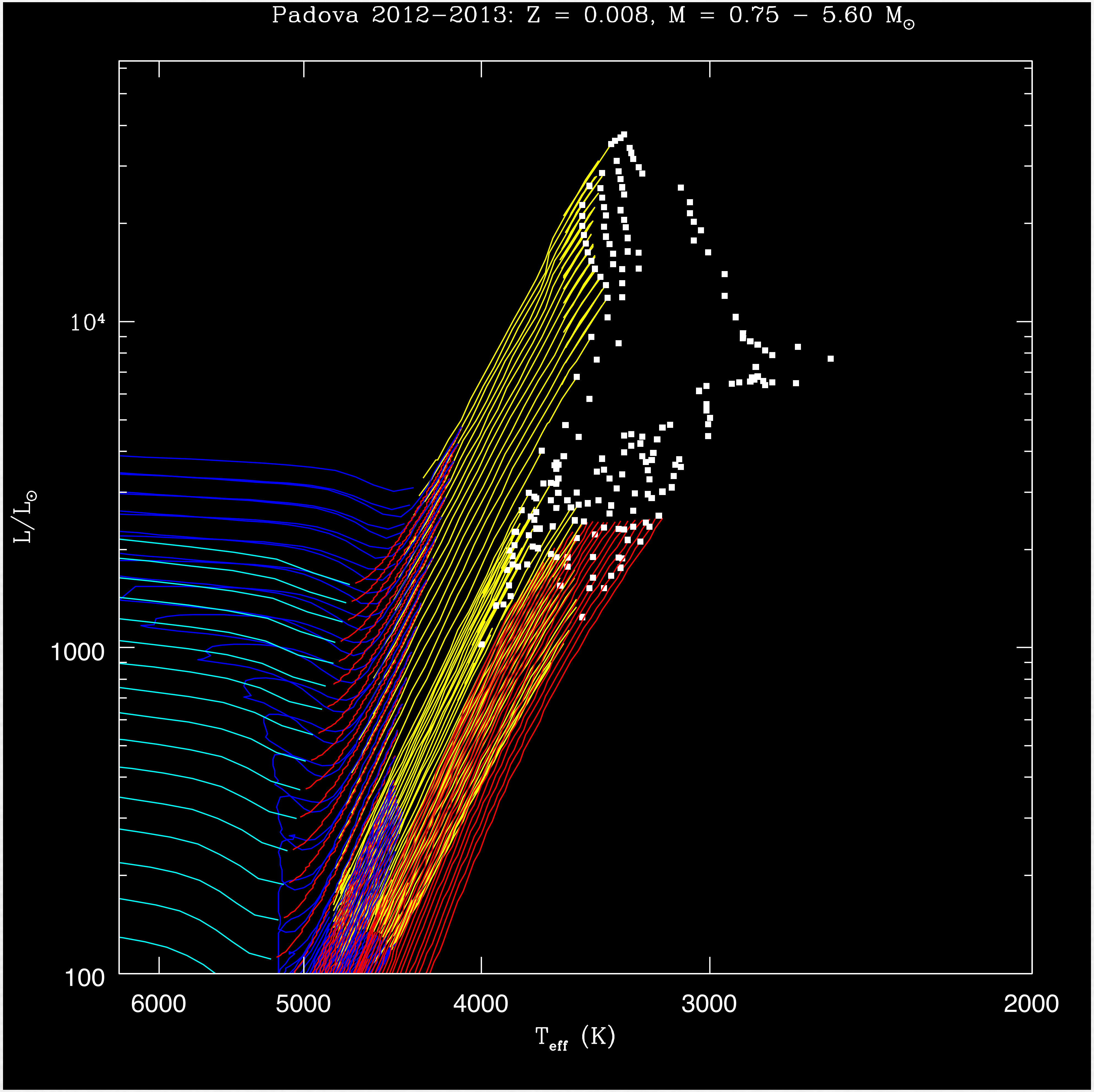
TP-AGB stars



Padova 2012–2013: Z = 0.008, M = 0.75 – 5.60 M⊙
L/L⊙
10⁵
10⁴
1000
100
10
1
0.1
30
20
10
9
8
7
6
5
4
3
2
Teff (kK)

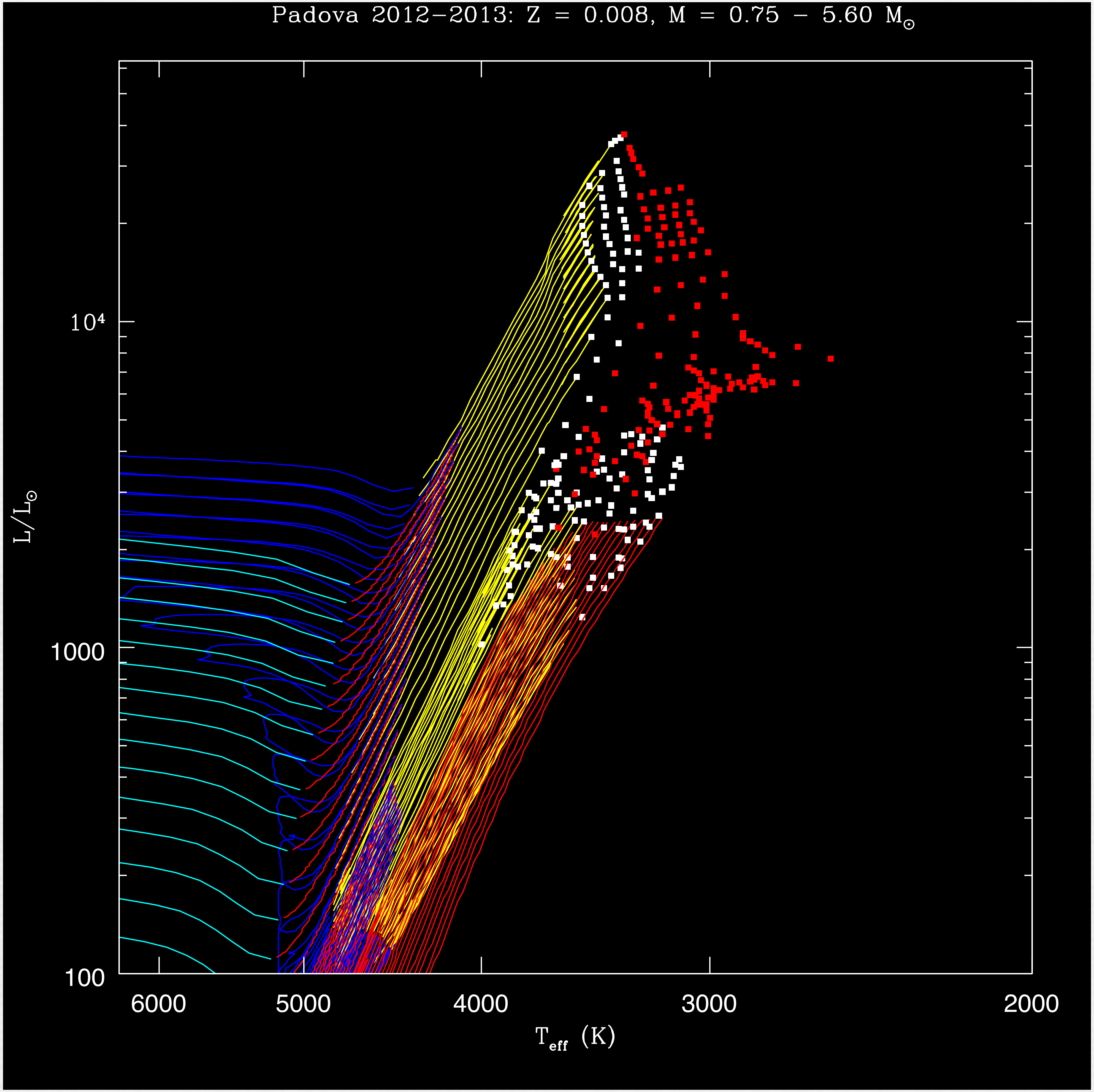

Padova 2012–2013: Z = 0.008, M = 0.75 – 5.60 M$_\odot$
$L/L_\odot$
10^4
1000
100
6000
5000
4000
3000
2000
T_{eff} (K)

AGB


Padova 2012–2013: Z = 0.008, M = 0.75 – 5.60 M☉
L/L☉
10⁴
1000
100
6000
5000
4000
3000
2000
T_eff (K)

TP-AGB:

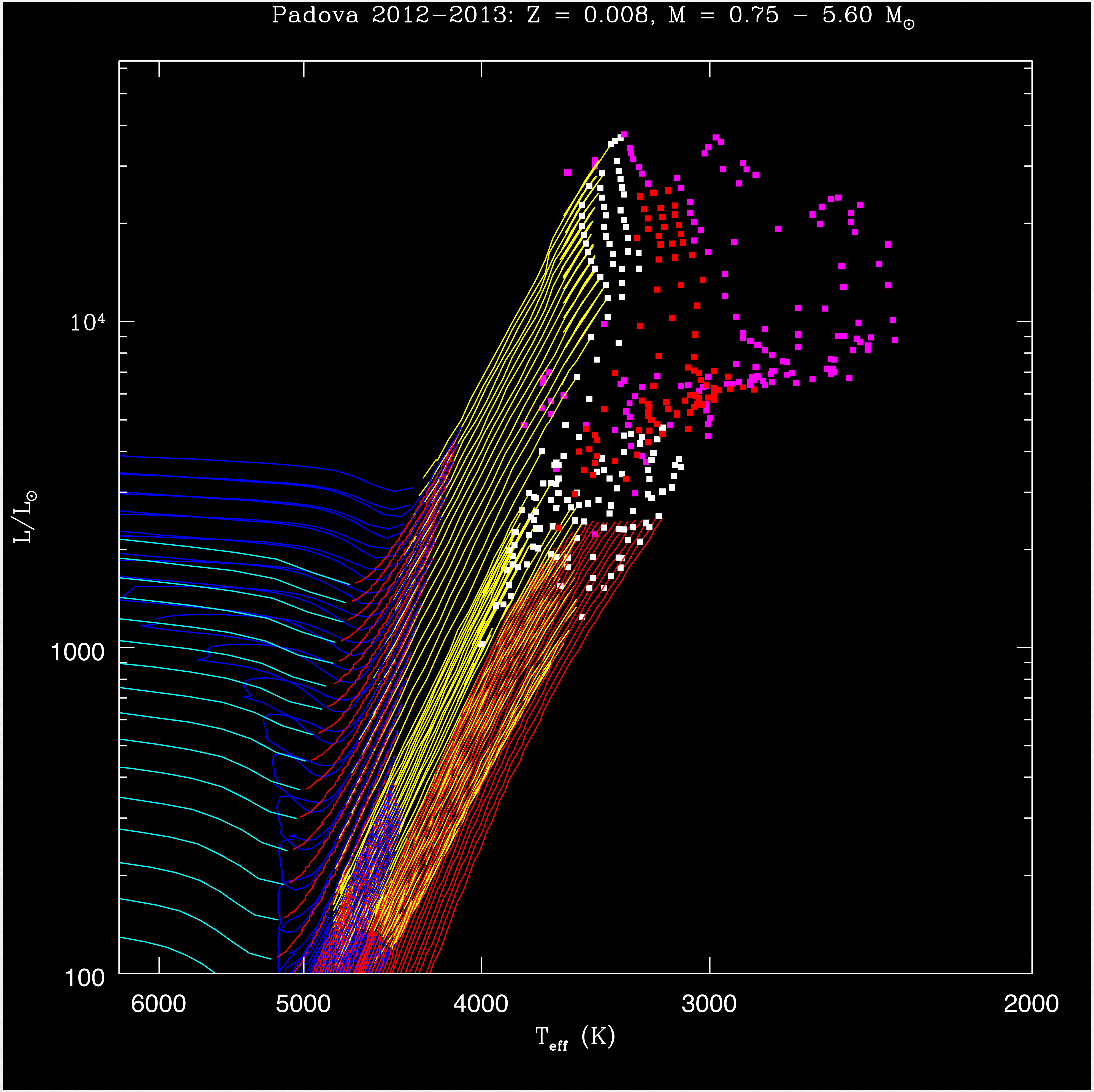
O-Rich



TP-AGB:

O-Rich

C-Rich

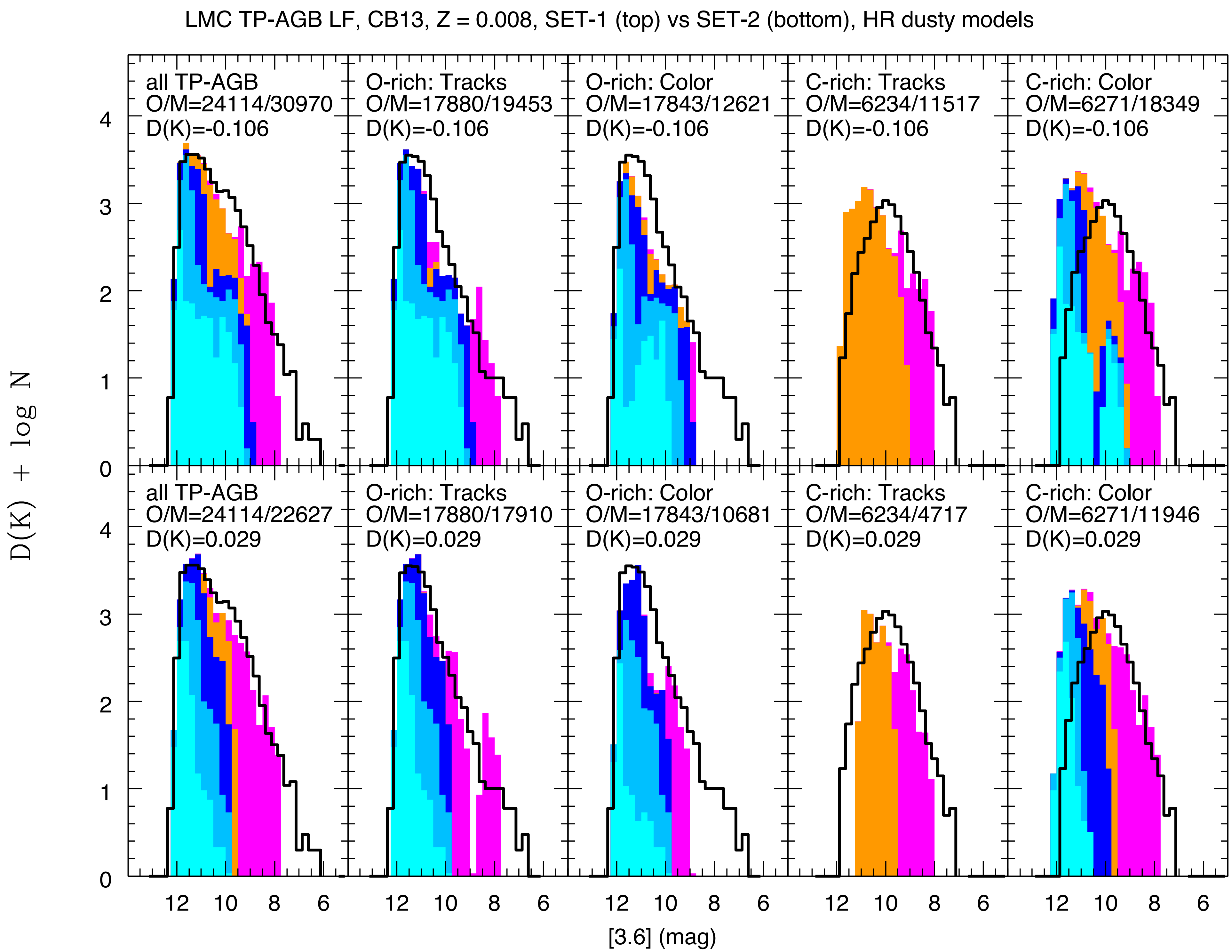


TP-AGB:

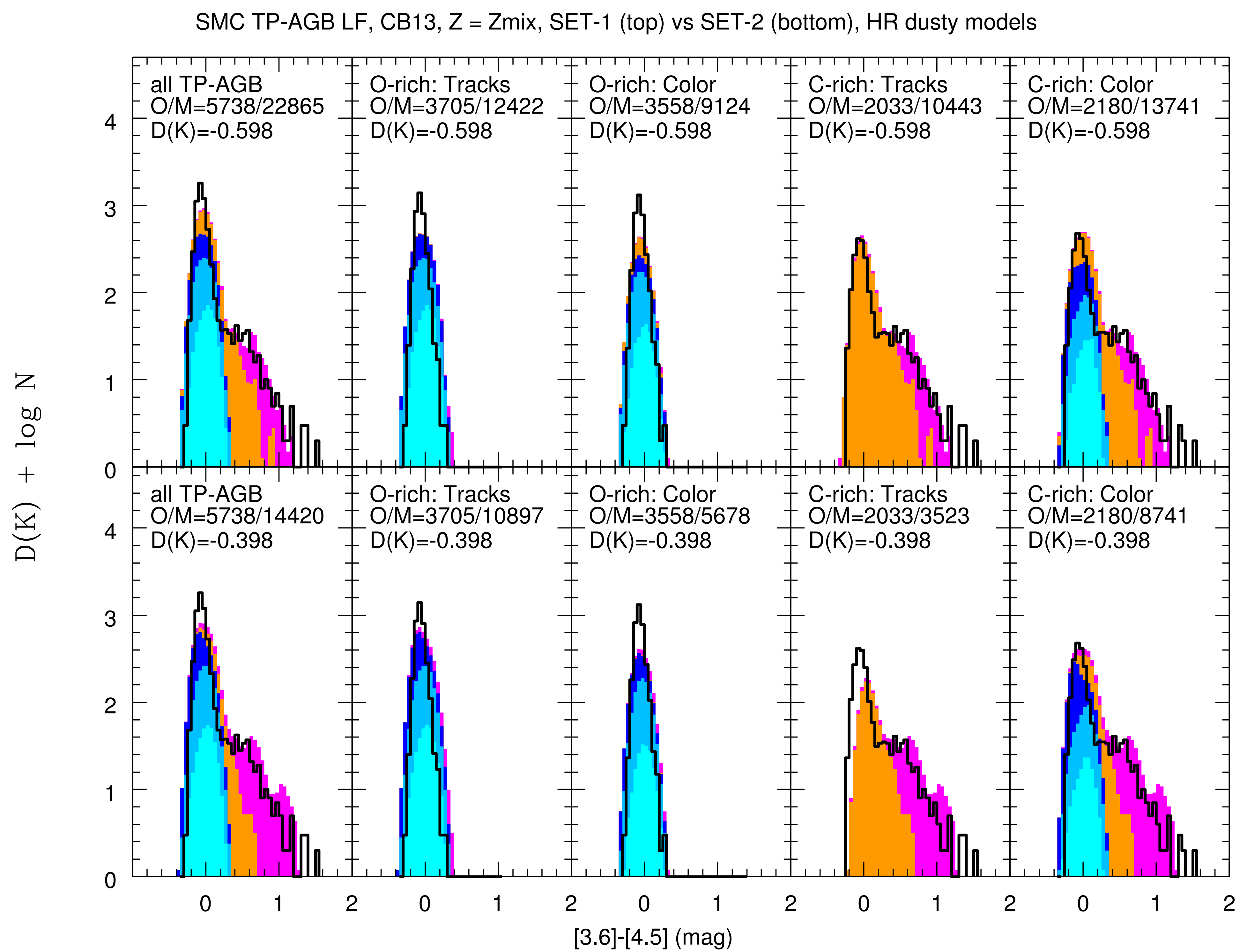
O-Rich

C-Rich

SW-phase



LMC TP-AGB LF, CB13, Z = 0.008, SET-1 (top) vs SET-2 (bottom), HR dusty models
all TP-AGB
O/M=24114/30970
D(K)=-0.106
O-rich: Tracks
O/M=17880/19453
D(K)=-0.106
O-rich: Color
O/M=17843/12621
D(K)=-0.106
C-rich: Tracks
O/M=6234/11517
D(K)=-0.106
C-rich: Color
O/M=6271/18349
D(K)=-0.106
all TP-AGB
O/M=24114/22627
D(K)=0.029
O-rich: Tracks
O/M=17880/17910
D(K)=0.029
O-rich: Color
O/M=17843/10681
D(K)=0.029
C-rich: Tracks
O/M=6234/4717
D(K)=0.029
C-rich: Color
O/M=6271/11946
D(K)=0.029
D(K) + log N
[3.6] (mag)



SMC TP-AGB LF, CB13, Z = Zmix, SET-1 (top) vs SET-2 (bottom), HR dusty models
all TP-AGB
O/M=5738/22865
D(K)=-0.598
O-rich: Tracks
O/M=3705/12422
D(K)=-0.598
O-rich: Color
O/M=3558/9124
D(K)=-0.598
C-rich: Tracks
O/M=2033/10443
D(K)=-0.598
C-rich: Color
O/M=2180/13741
D(K)=-0.598
all TP-AGB
O/M=5738/14420
D(K)=-0.398
O-rich: Tracks
O/M=3705/10897
D(K)=-0.398
O-rich: Color
O/M=3558/5678
D(K)=-0.398
C-rich: Tracks
O/M=2033/3523
D(K)=-0.398
C-rich: Color
O/M=2180/8741
D(K)=-0.398
D(K) + log N
[3.6]-[4.5] (mag)

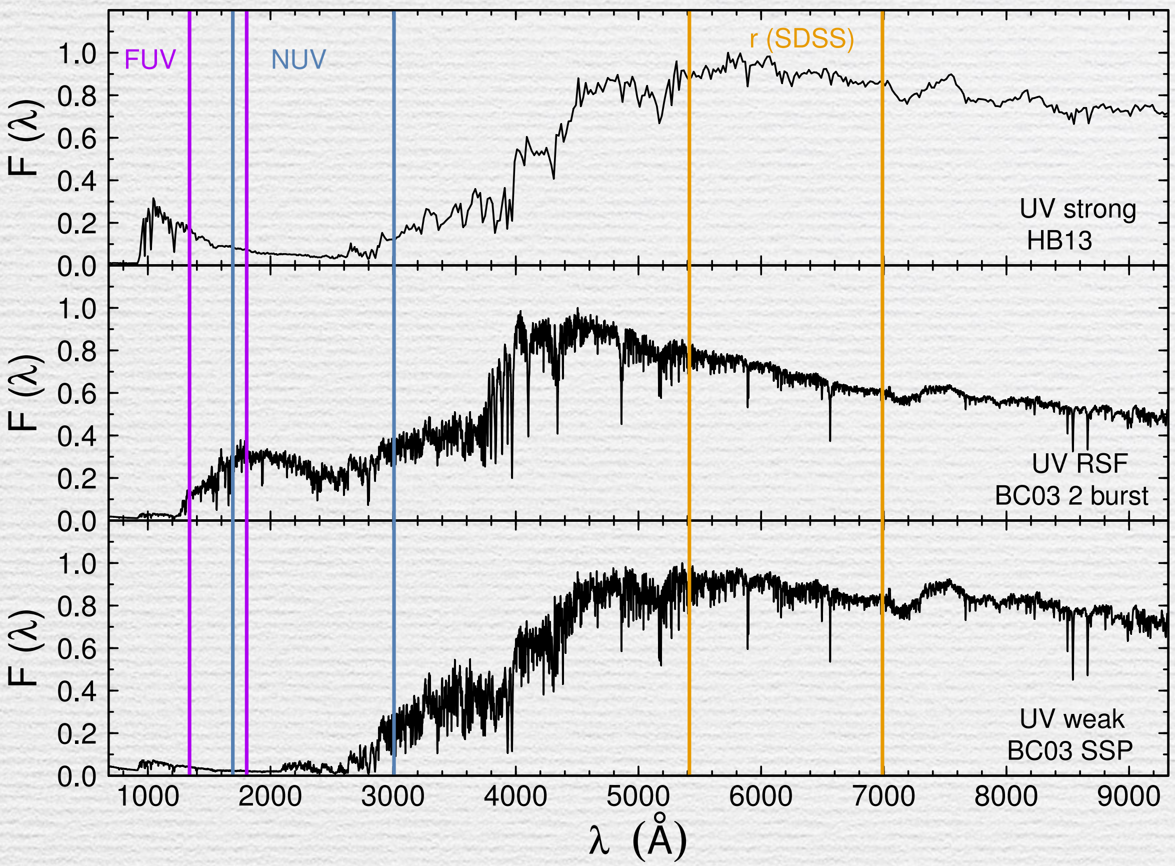
Including binary star evolution in PS models

Motivation: UVX in Early Type Galaxies

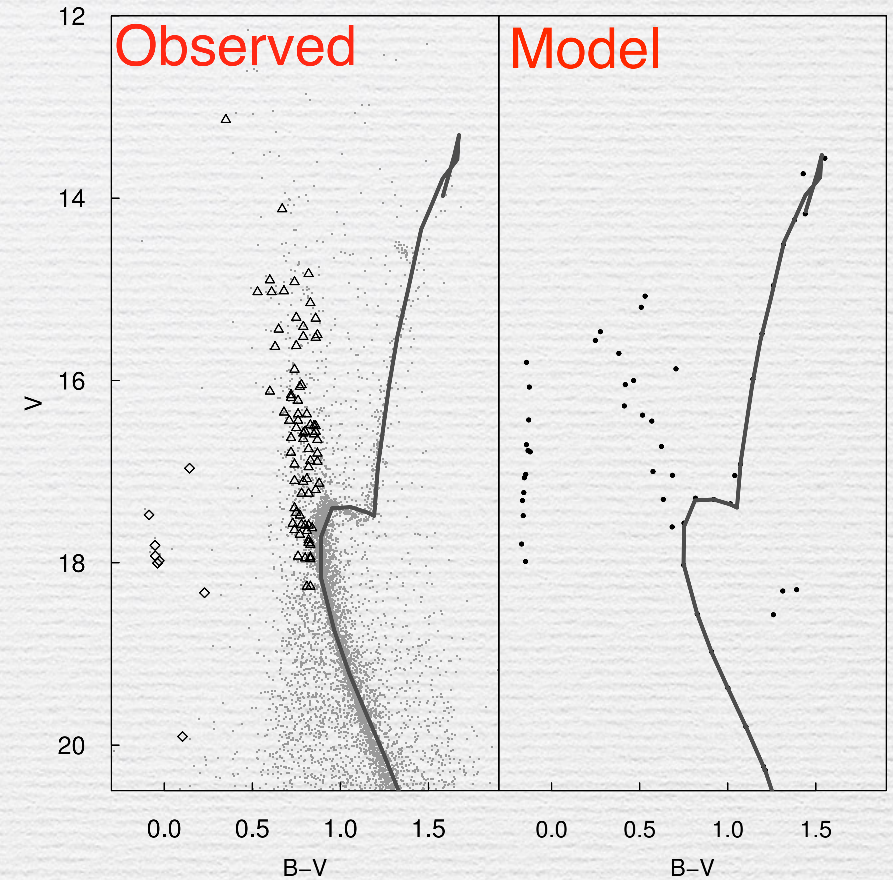
Use the Hurley et al. (2002) code to compute the evolution of binary stars in the HRD.

Hernández-Pérez & Bruzual (2013, 2014)

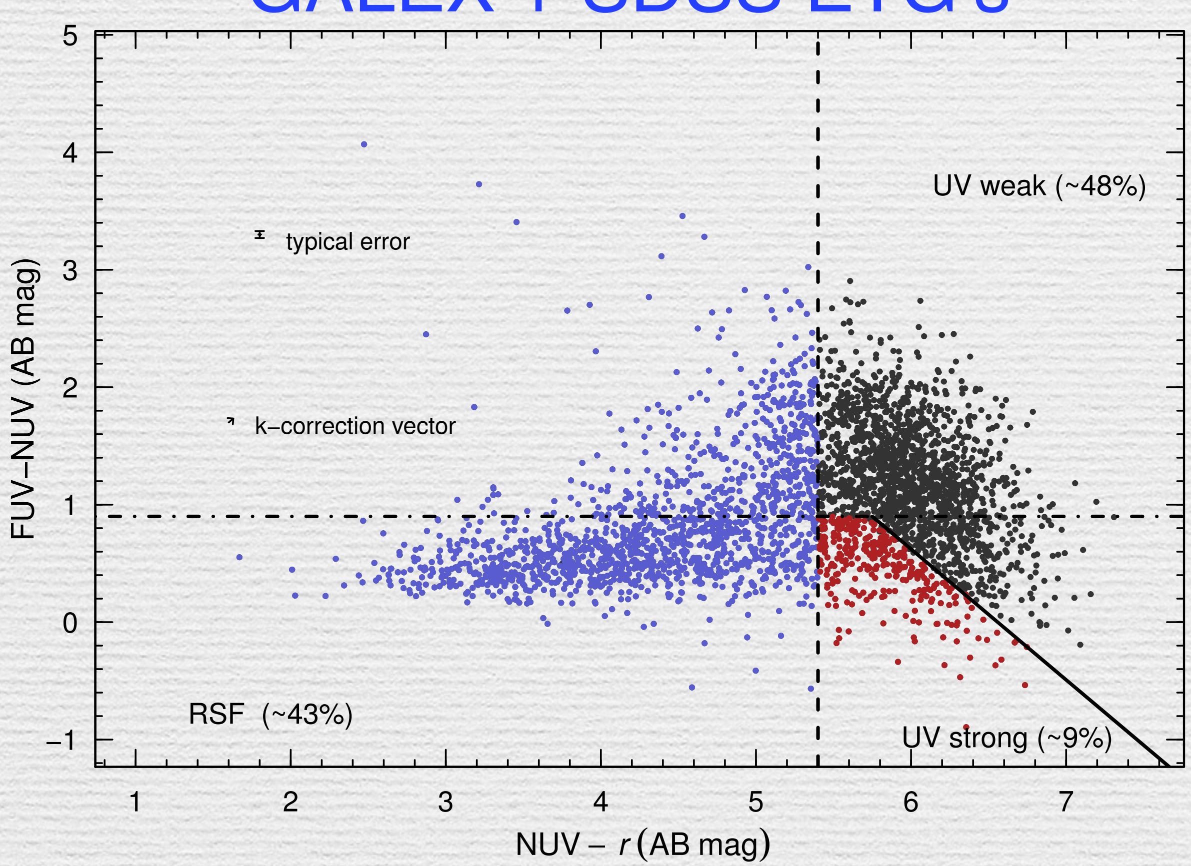
UVX in Early Type Galaxies



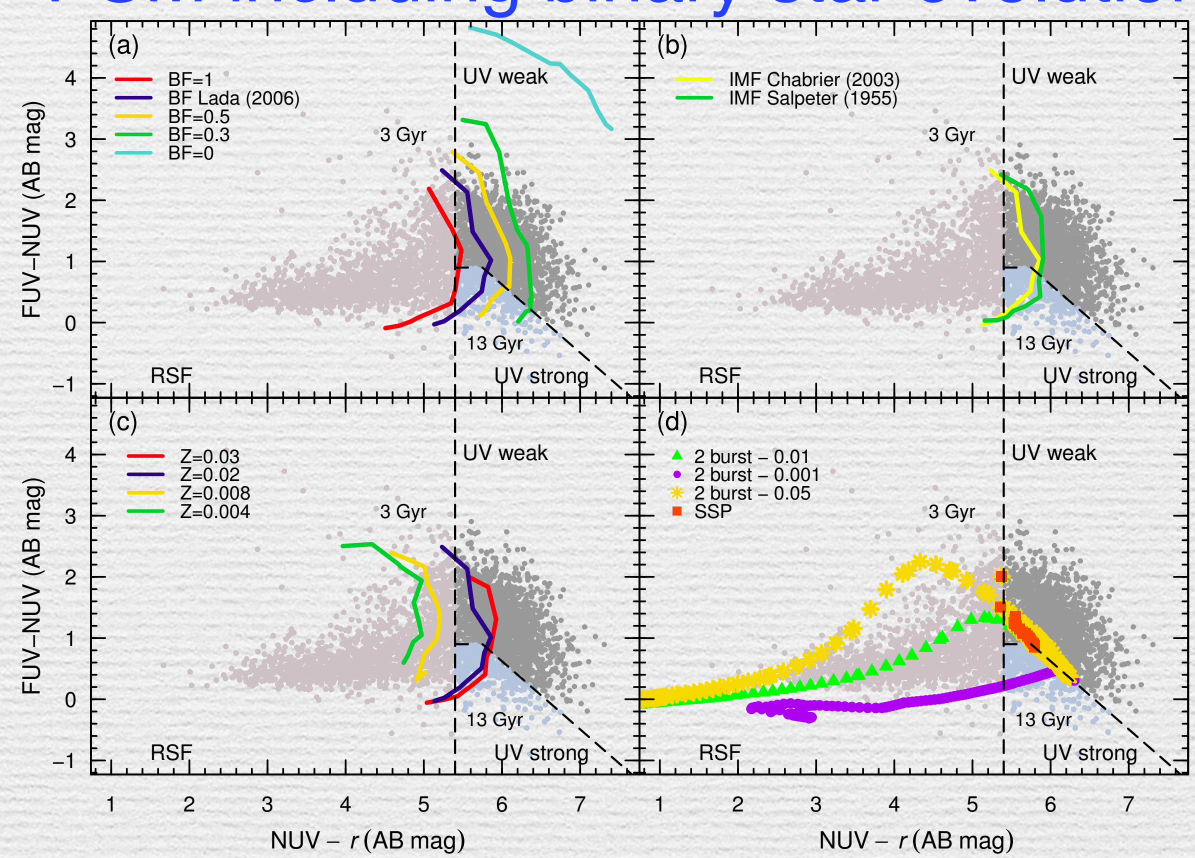
NGC 6791: open cluster with UVX



GALEX + SDSS ETG's



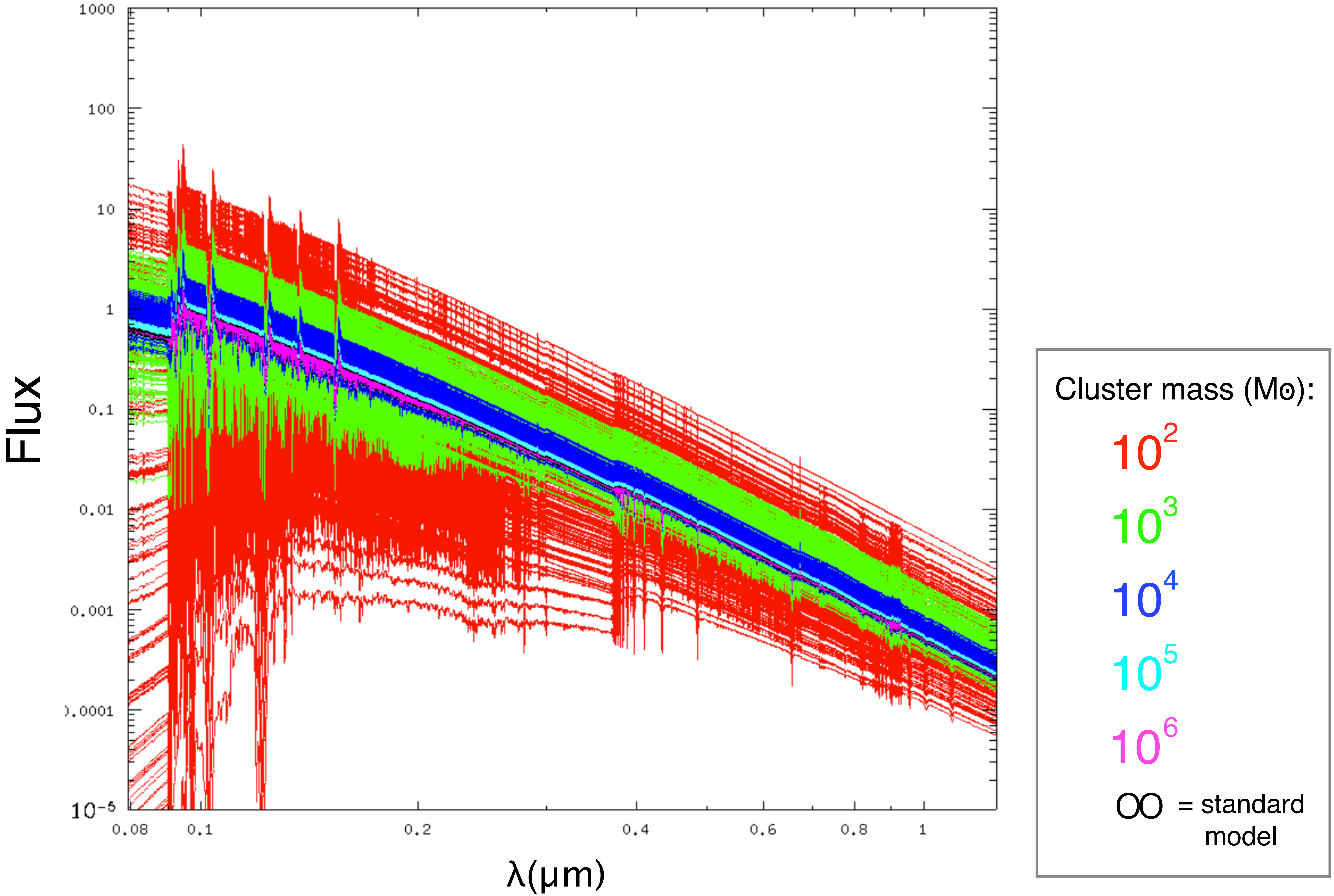
PSM including binary star evolution



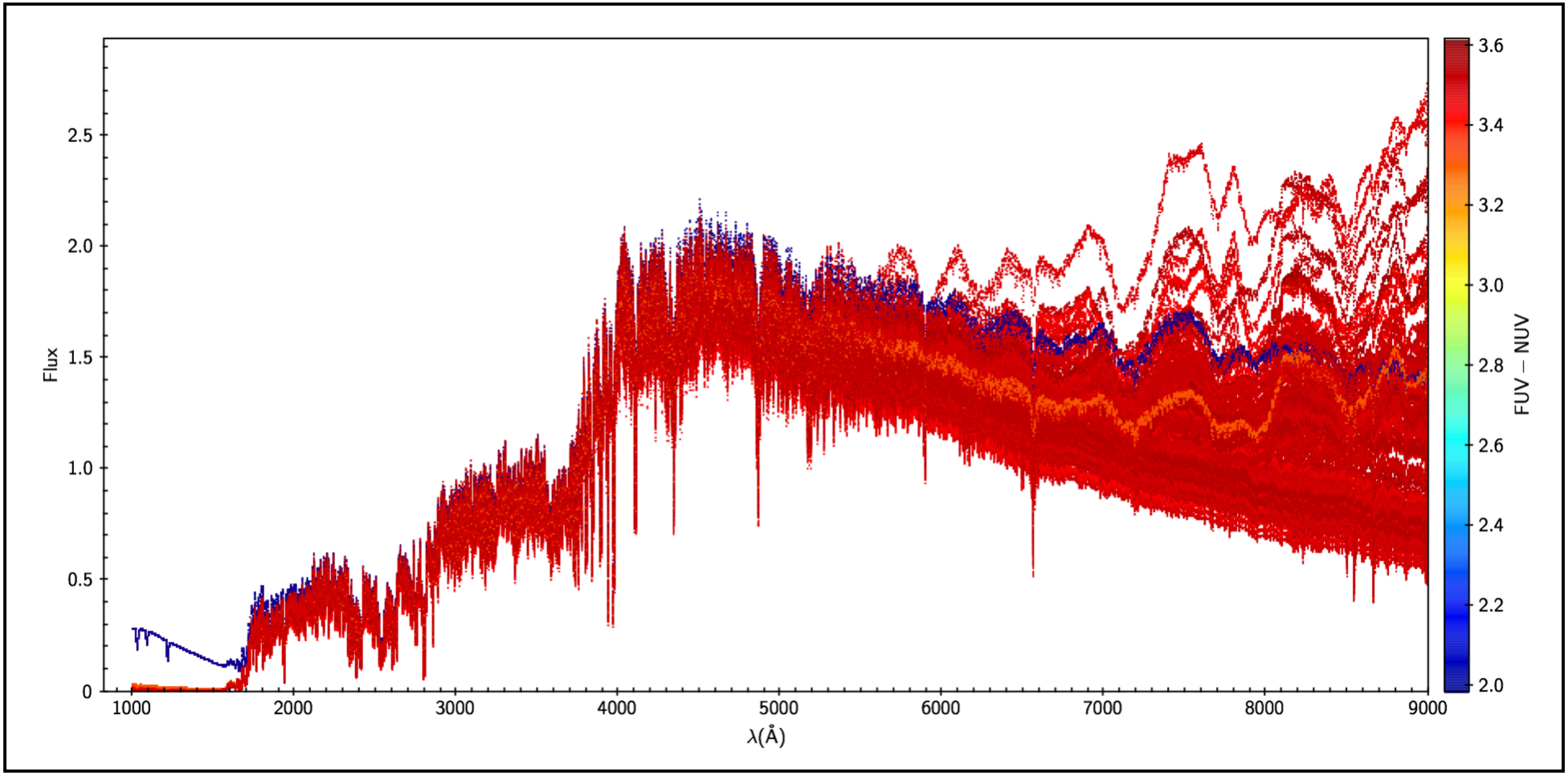
Stochastic sampling of IMF

- Important for low mass stellar populations
- Fluctuations dominate number of stars in short lived stellar evolutionary phases

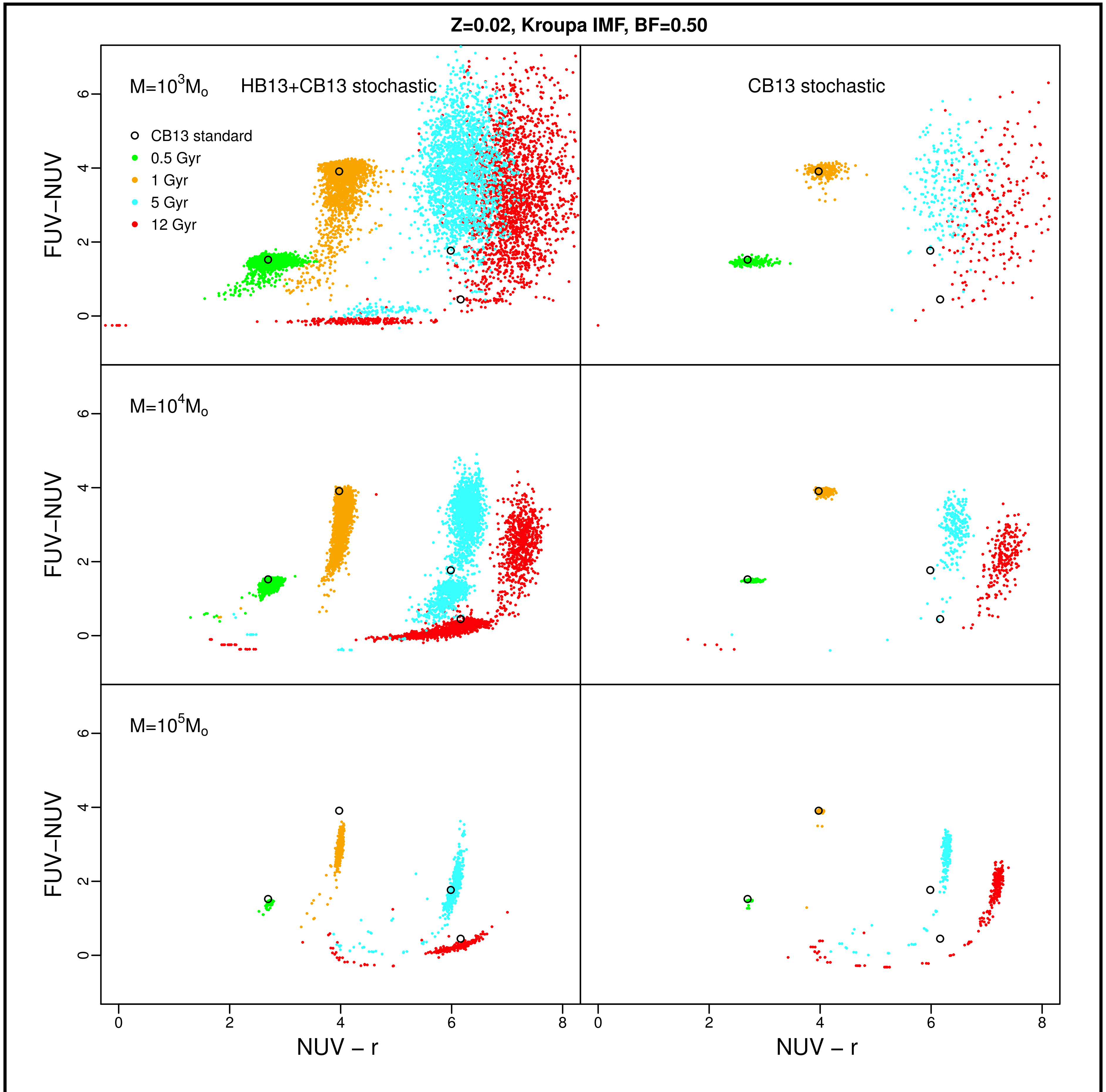
Stochastic sampling of Chabrier IMF, t=1 Myr, Z = Z⊙



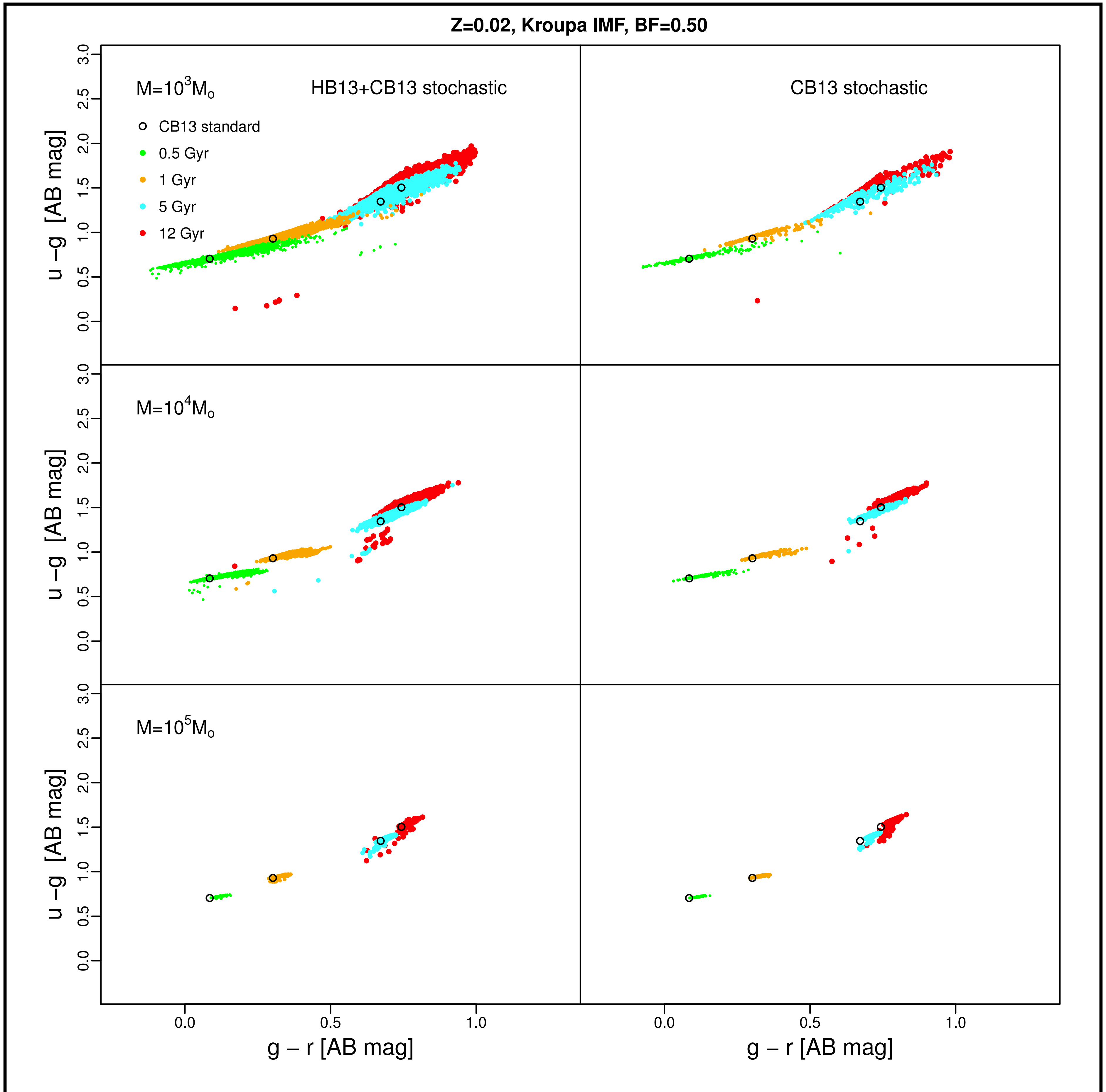
Stochastic sampling of Chabrier IMF, M=5000 M⊙, t=1 Gyr, Z = Z⊙



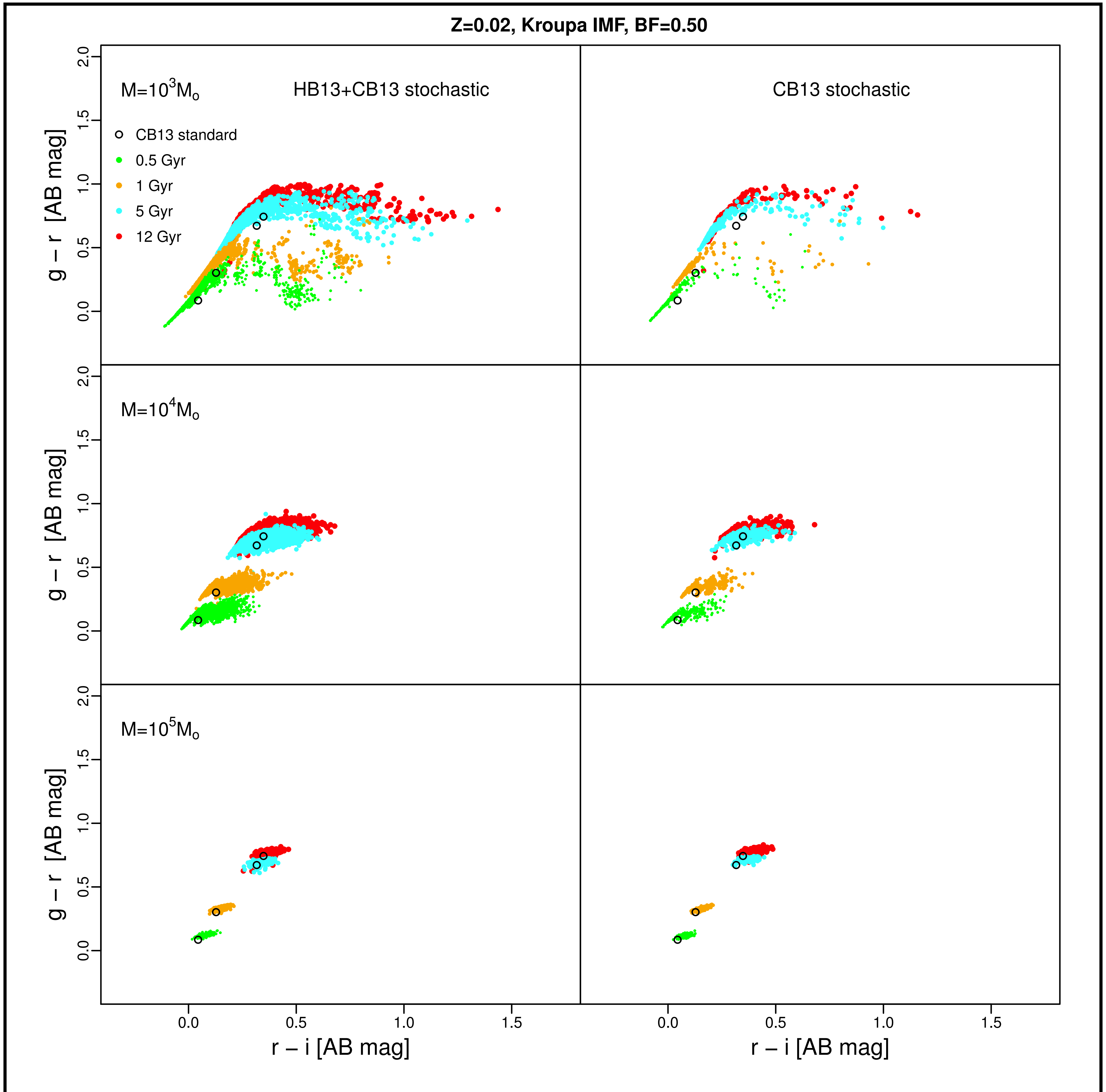
Stochastic sampling of IMF + binary star evolution



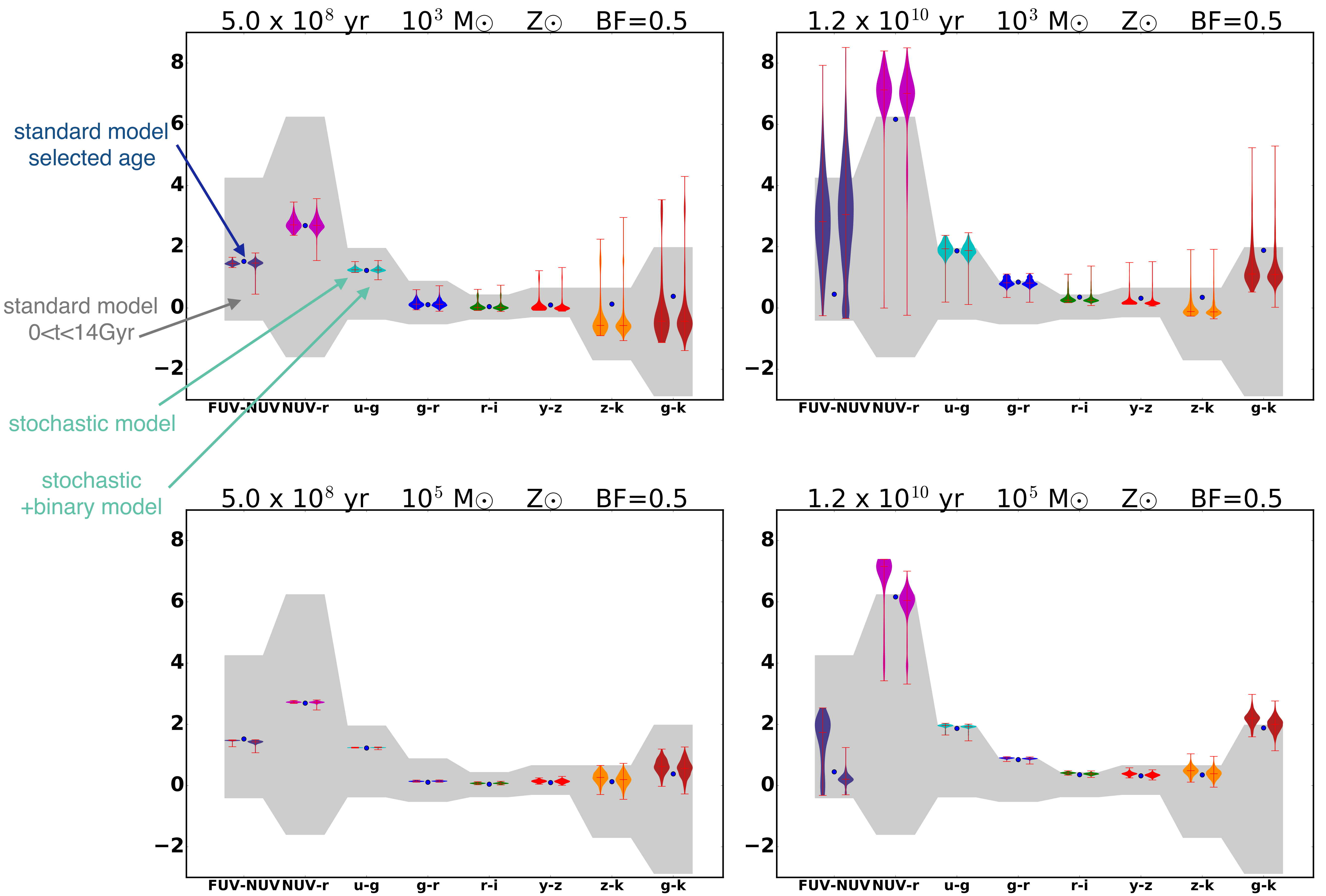
Stochastic sampling of IMF + binary star evolution



Stochastic sampling of IMF + binary star evolution



Stochastic sampling of IMF + binary star evolution



Conclusions

- Prospects are good both at the UV and NIR ends
- Considerable progress in evolutionary tracks and spectral libraries
- Lots of observations have allowed to improve calibration of SPS models
- Stochastic fluctuations and binary evolution play an important role in photometric properties of stellar populations, especially in low mass systems
- It is important to take these effects into account in PSM's and not extrapolate behaviour of infinite mass models to low mass