Refining the Stellar and Nebular UV together with the NIR Emission in Population Synthesis Models

G. Bruzual, IRyA, UNAM, Campus Morelia, México

Work in collaboration with:

S. Charlot

Julia Gutkin (PhD thesis, IAP)

Alba Vidal-García (PhD Thesis, IAP)

Motivation:

Why more SPS models?

- Produce a comprehensive library of state of the art models to be used in the interpretation of high-redshift observations

- Implement a Bayesian analysis methods, to develop a public tool to compare with observations (BEAGLE)

- Derive conclusions about nature of star formation and interstellar gas in galaxies

To accomplish these goals we need:

- SPS models with updated evolutionary tracks and as complete as possible higher resolution spectral libraries.

Evolutionary Tracks

PARSEC (PAdova & TRieste Stellar Evolution Code) by

- Chen et al. (2015) for massive stars up to 400-500 Mo, including WR phase
- Bressan et al. (2012) for lower masses, includes P. Marigo treatment of TP-AGB stars

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

Stellar Spectra

In the UV:

- WM-Basic models for MS stars hotter 20,000K (Leitherer et al. 2010)
- Tlusty models for O and B stars (Lanz & Hubeny, 2003+2007)
- Martins et al. (2005) models for A type stars
- UV-Blue models (Rodríguez-Merino et al. 2005)
- Rauch (2002) models for CSPN
- PoWR (Potsdam Wolf-Rayet) Models for WR stars (Gräfener et al. 2002, Hamman et al. 2004)

In the visible:

- Miles (Sánchez-Blázquez et al. 2006; Falcón-Barroso et al. 2011; Prugniel et al. 2011)
- IndoUS (Wu et al. 2011)
- HNGSL (Heap & Lanz 2003)
- STELIB (Le Borgne et al. 2003)

PoWR - The Potsdam Wolf-Rayet Models

- High resolution models

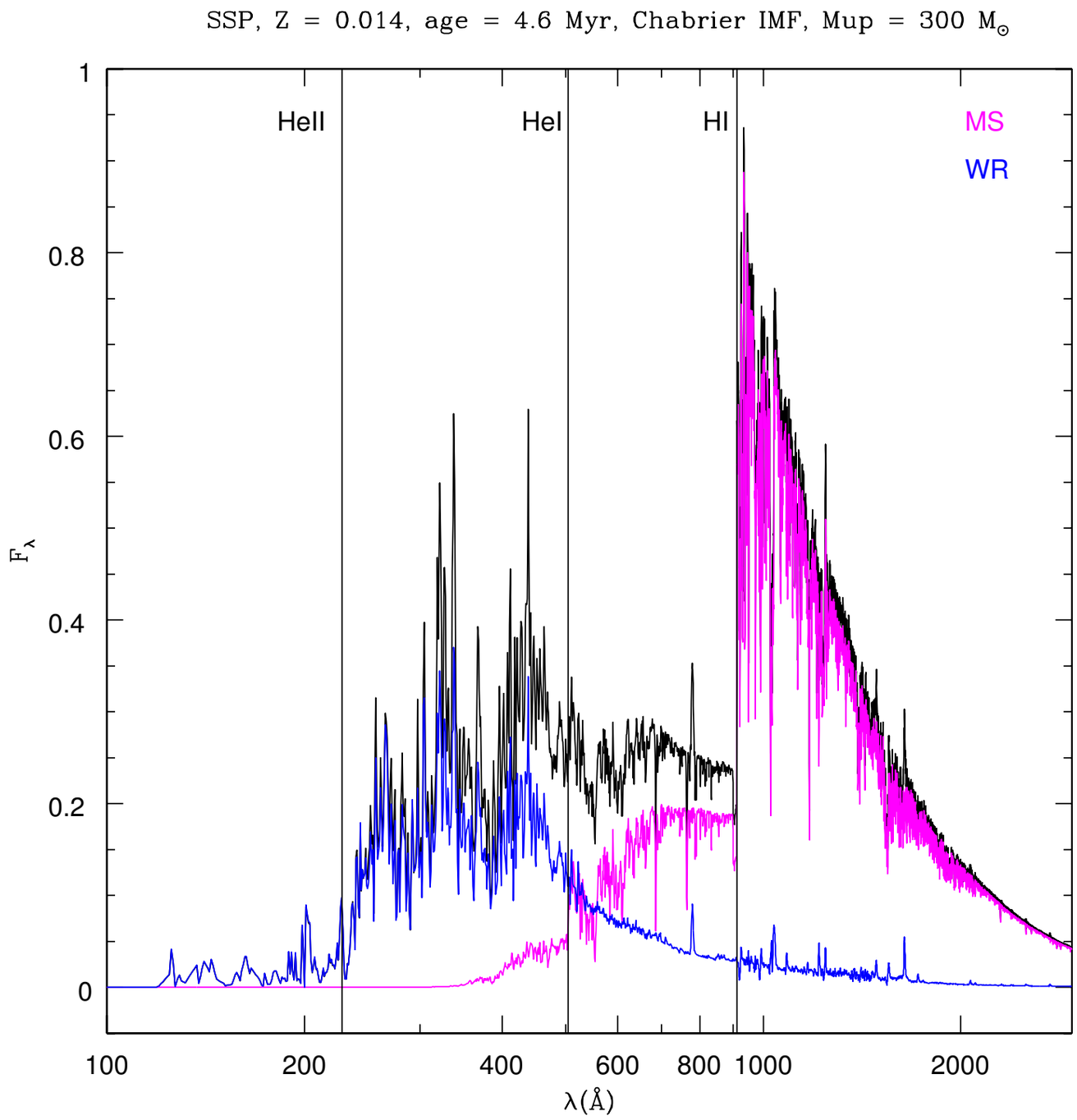
  Hainich et al. (2015)

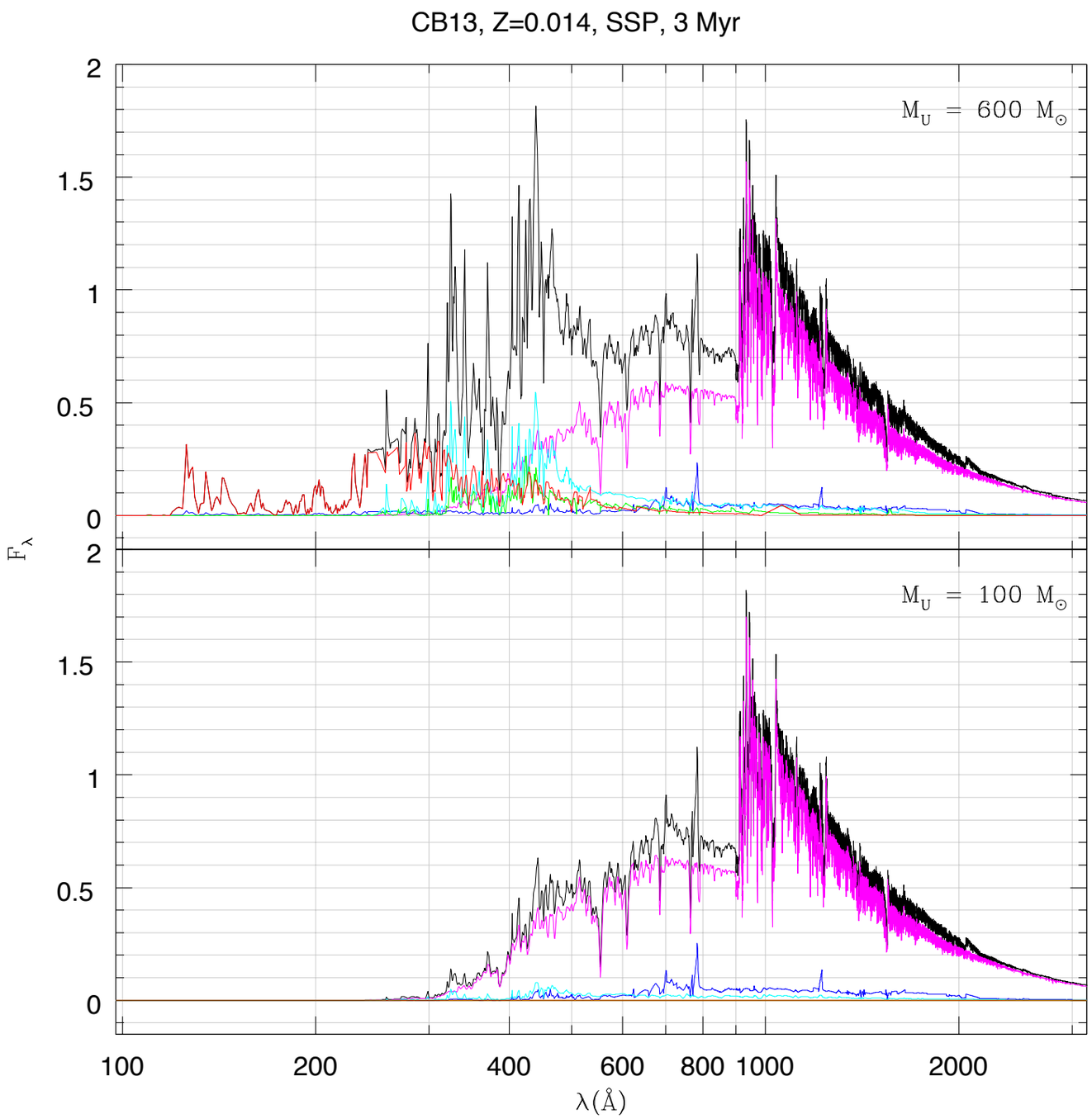
  Todt et al. (2015, private communication)

- 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


SSP, Z = 0.014, age = 4.6 Myr, Chabrier IMF, Mup = 300 M⊙
HeII
HeI
HI
MS
WR
1
0.8
0.6
0.4
0.2
0
Fλ
100
200
400
600
800
1000
2000
λ(Å)



Total

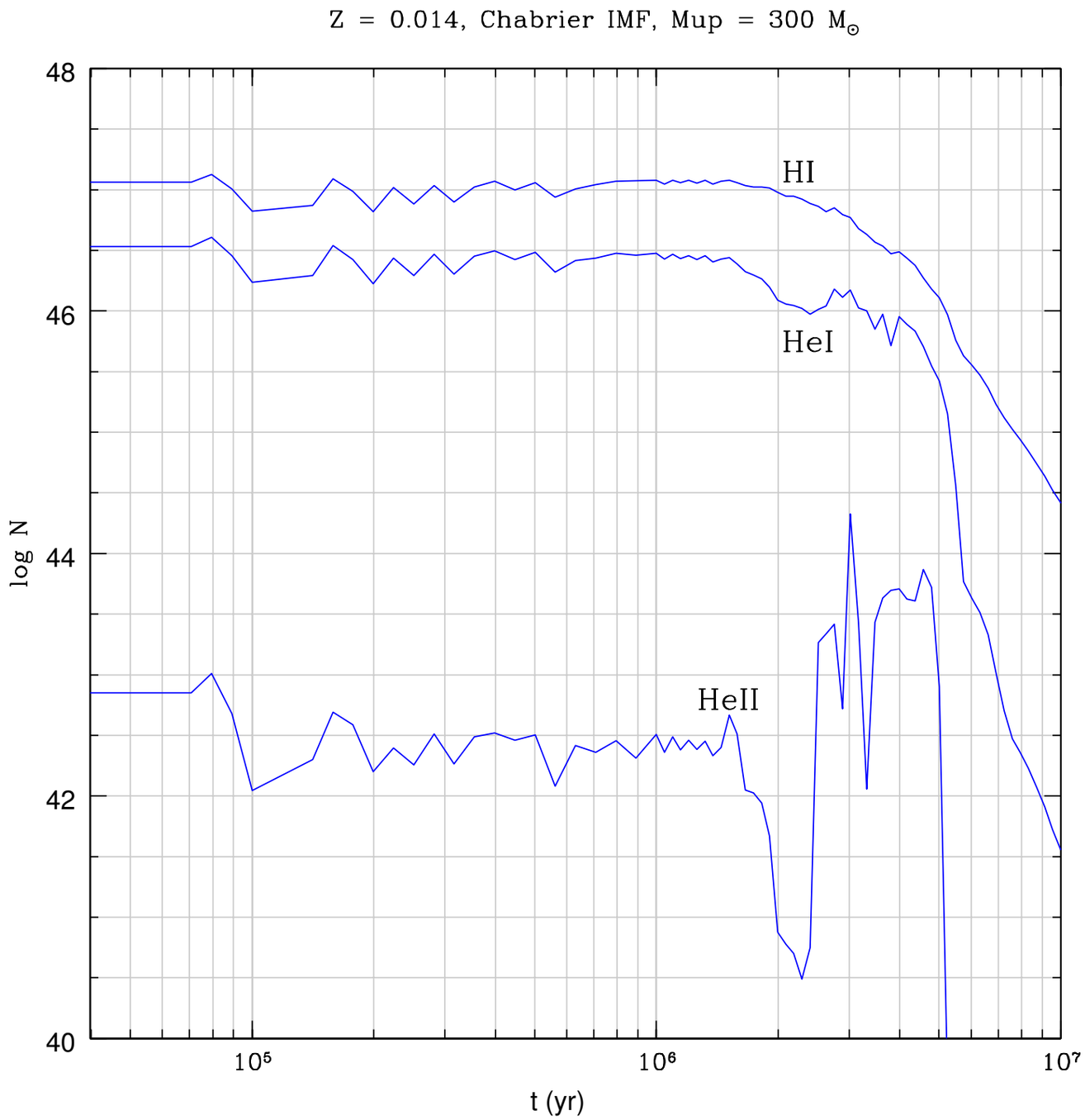
MS

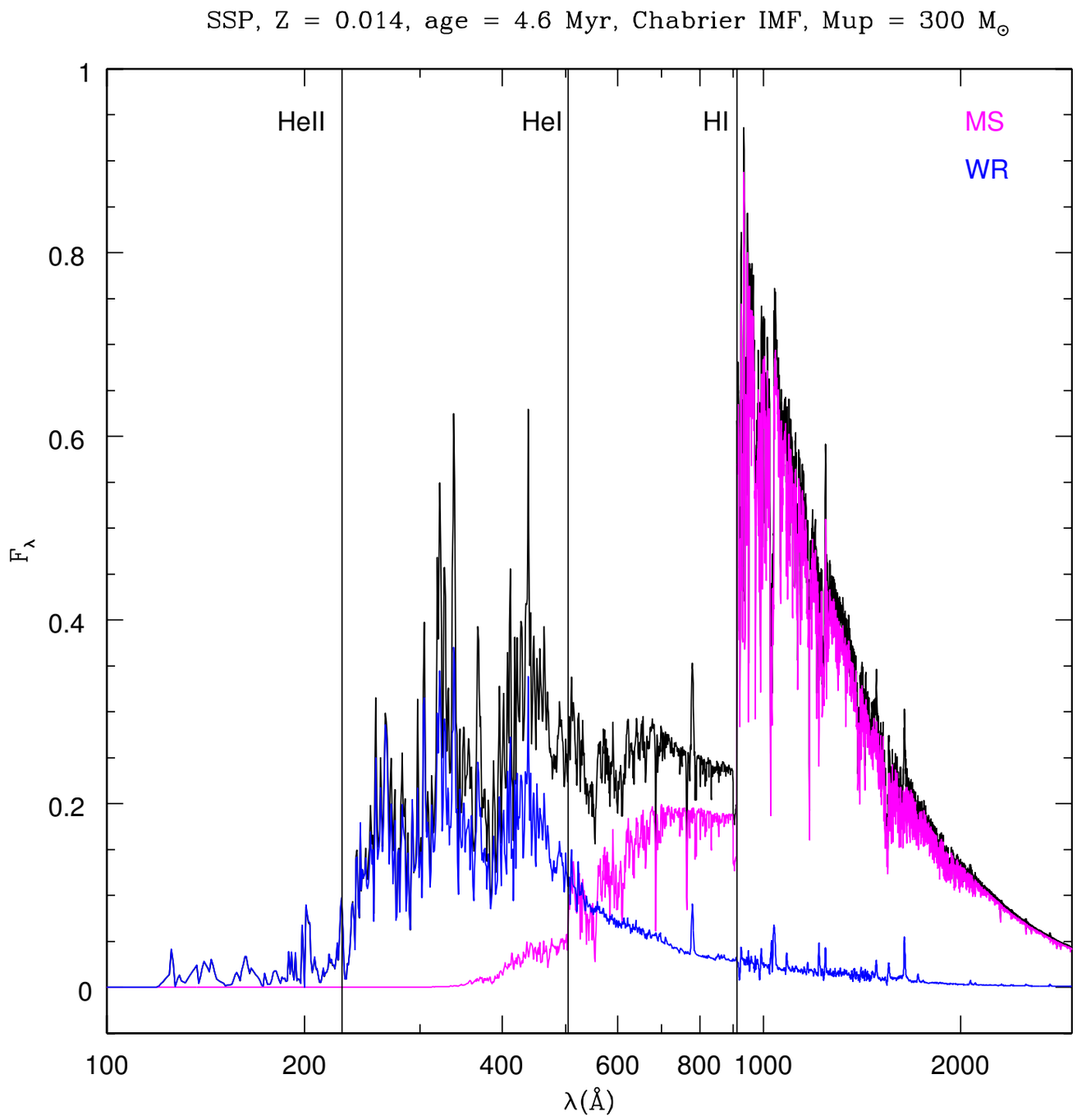
WNL

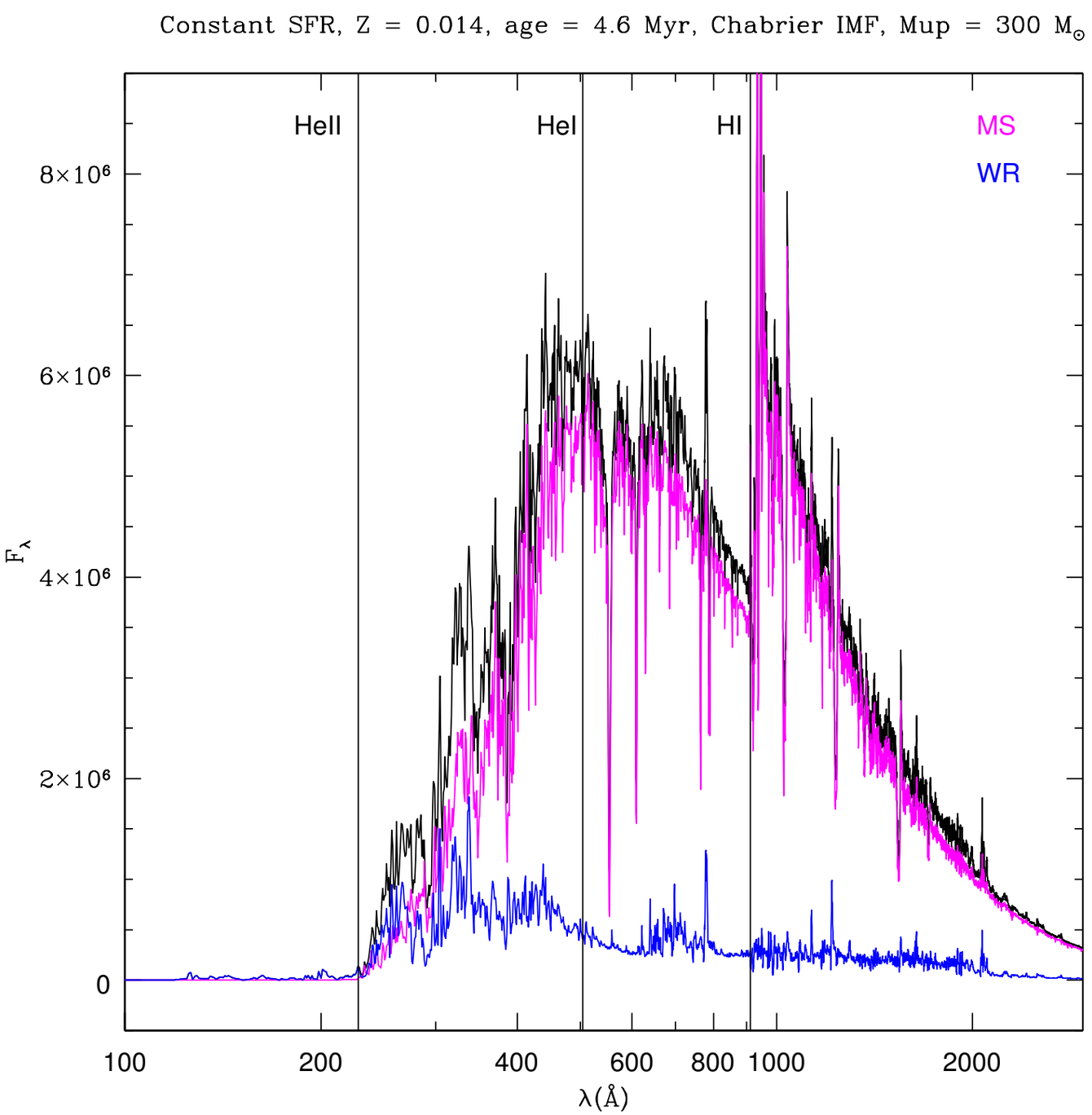
WNE

WC

WO


Z = 0.014, Chabrier IMF, Mup = 300 M⊙
HI
HeI
HeII
log N
48
46
44
42
40
10⁵
10⁶
10⁷
t (yr)


SSP, Z = 0.014, age = 4.6 Myr, Chabrier IMF, Mup = 300 M⊙
HeII
HeI
HI
MS
WR
1
0.8
0.6
0.4
0.2
0
Fλ
100
200
400
600
800
1000
2000
λ(Å)


Constant SFR, Z = 0.014, age = 4.6 Myr, Chabrier IMF, Mup = 300 M⊙
HeII
HeI
HI
MS
WR
8×10⁶
6×10⁶
4×10⁶
2×10⁶
0
Fλ
100
200
400
600
800
1000
2000
λ(Å)

Applications

Self-consistent modelling of the SED and nebular emission lines of star forming galaxies

Objectives:

- model the emission of the gas ionized by massive stars
- constrain physical properties and early chemical enrichment of the gas in high-redshift galaxies

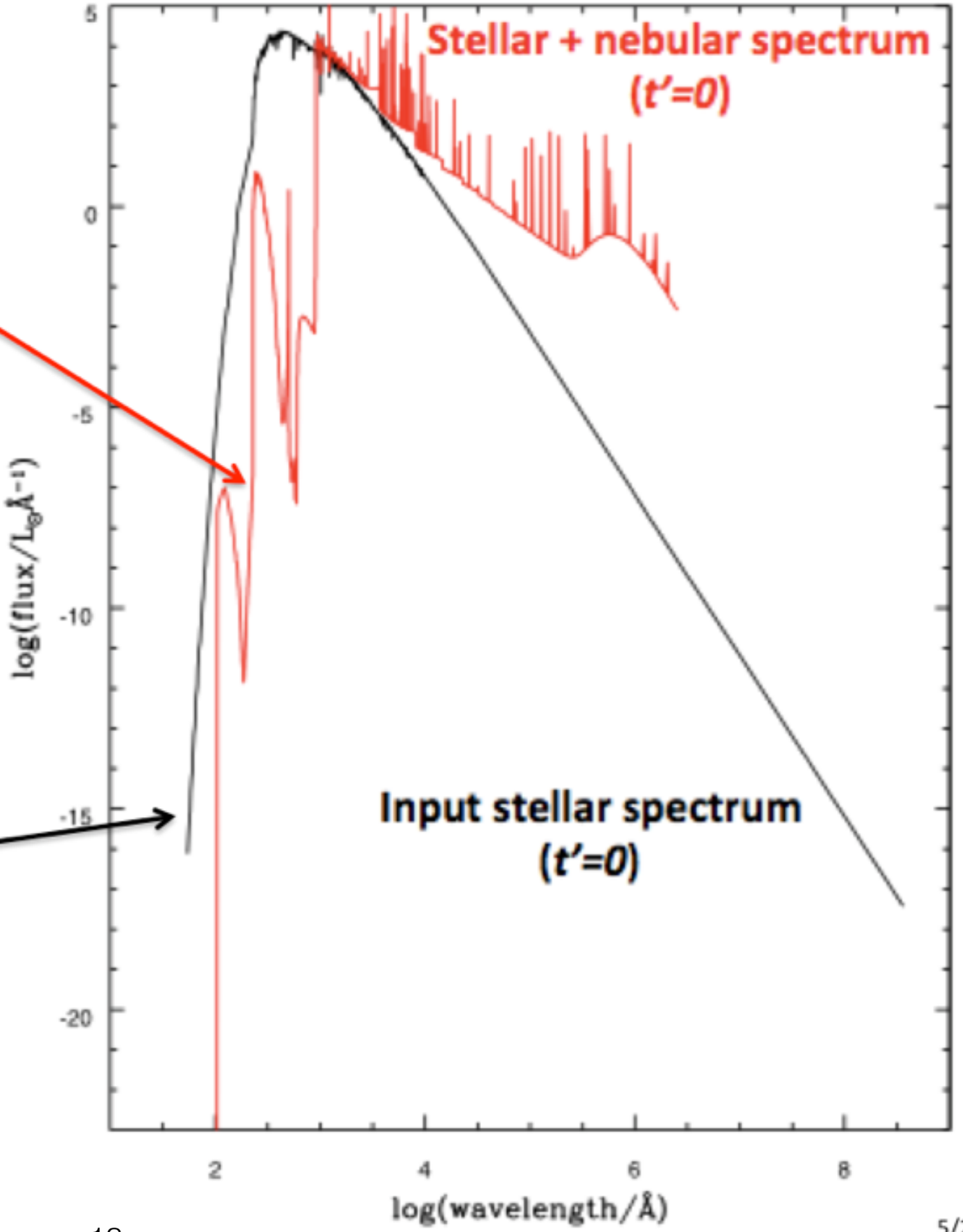
Method:

- Couple output from evolutionary population synthesis models with photoionization code Cloudy.

See poster or talk to Julia Gutkin

photoionization code

ionizing spectrum



6 main adjustable parameters :

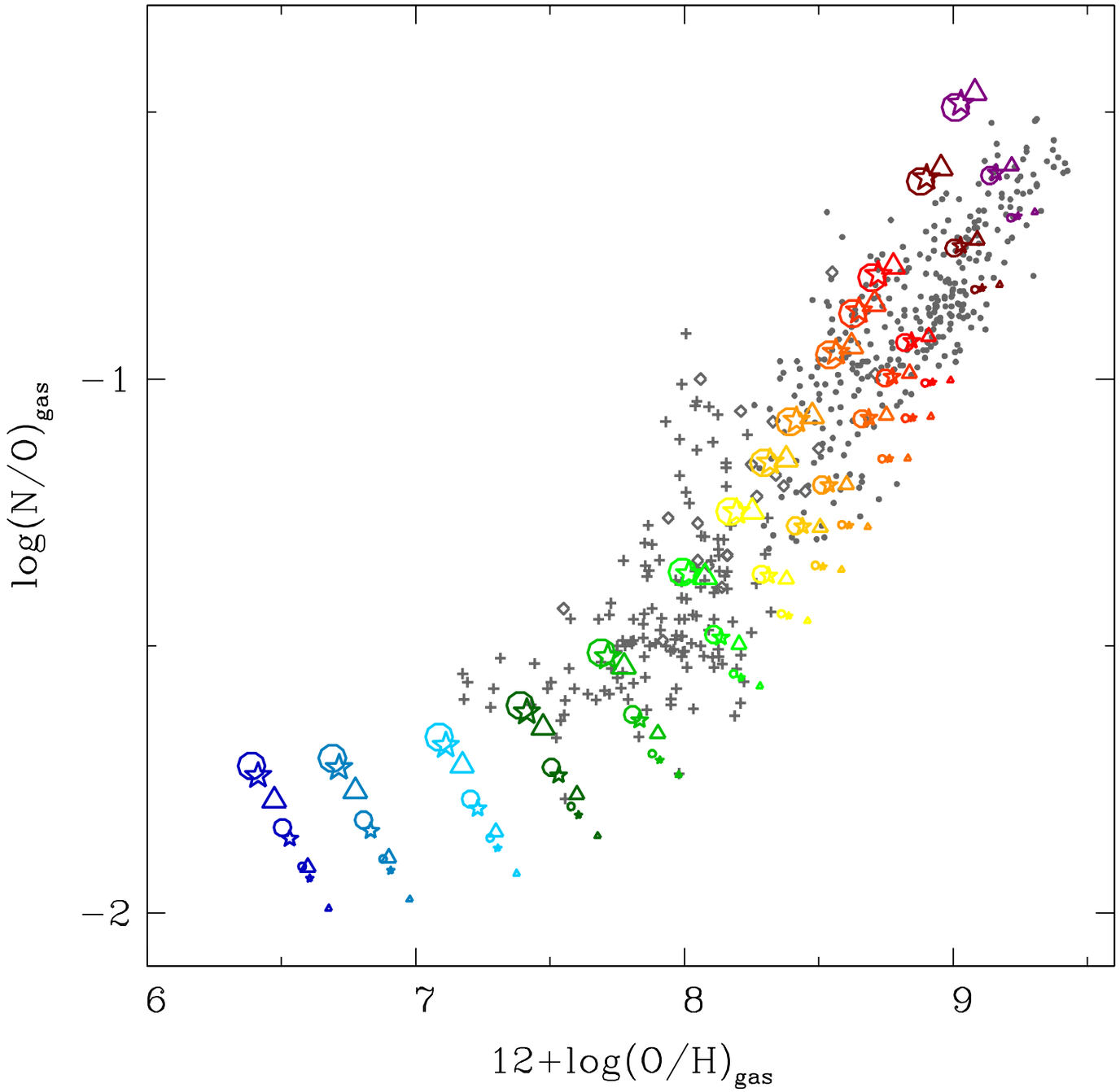
- metallicity Z (same for stars and gas)
- ionization parameter U (at the edge of the Strömgren sphere)
- dust-to-metal mass ratio ξ_d
- gas density n_H
- C/O abundances (in reduced factors)
- upper cut-off mass of the IMF M_{up}

Comprehensive range of adjustable parameters (beyond simply Z, U) appropriate for high-redshift galaxies

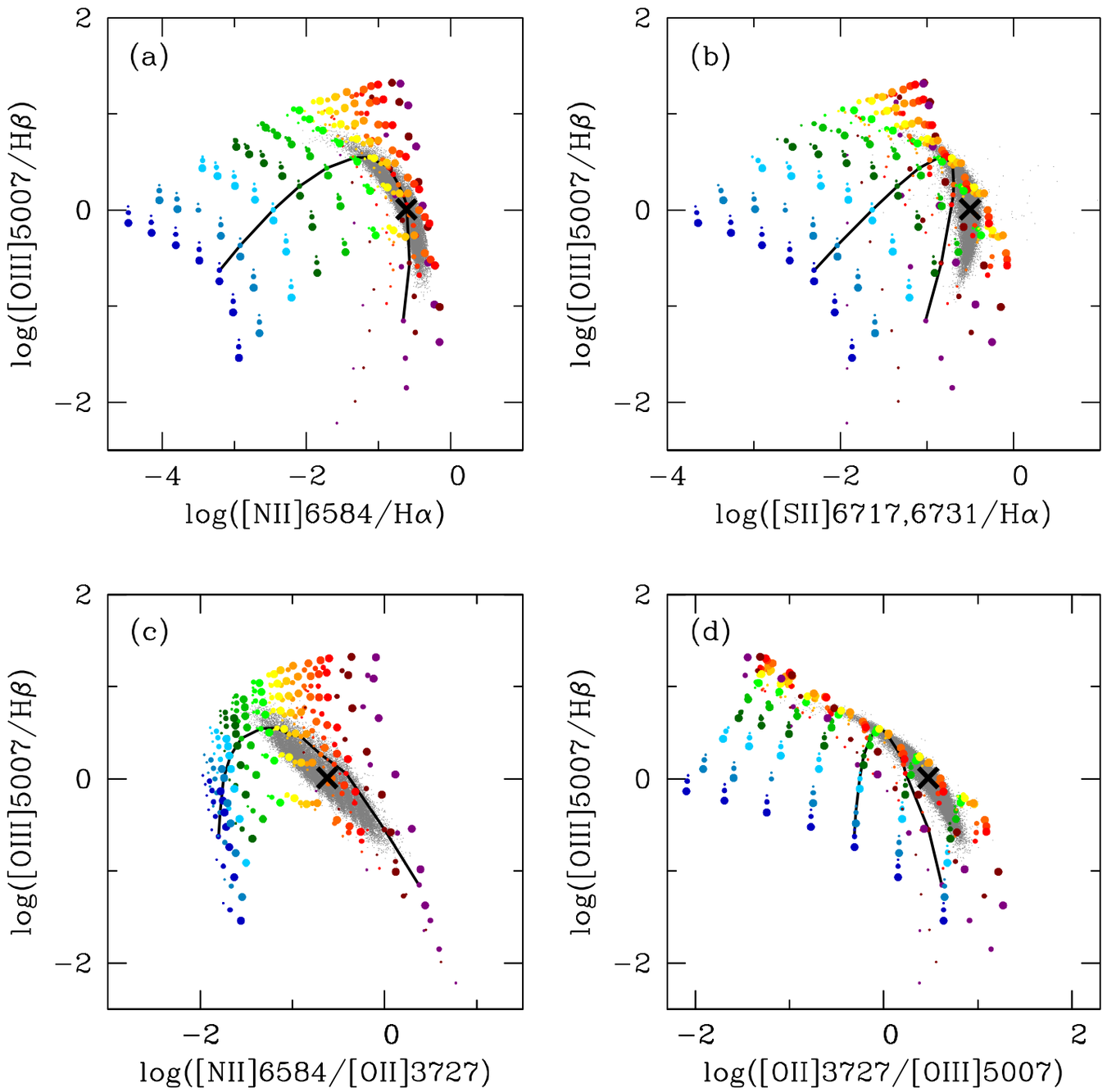
Careful treatment of individual element abundances and depletion onto dust grains in ionized gas

parameter	G15 models values
Z	0.0001, 0.0002, 0.0005, 0.001, 0.002, 0.004, 0.008, 0.010, 0.014, 0.017, 0.020, 0.030
$\log(U)$	-1.0, -1.5, -2.0, -2.5, -3.0, -3.5, -4.0
ξ_d	0.1, 0.3, 0.5
$\log(n_H)$ [cm^{-3}]	2.0, 3.0, 4.0
factor of (C/O)	1, 0.72, 0.52, 0.38, 0.27, 0.20, 0.14, 0.10
m_{up}	$100M_\odot$, $300M_\odot$

Results from Gutkin et al. (2016, submitted)



Results from Gutkin et al. (2016, submitted)



Applications

Modelling the SED of stars, neutral and ionized gas in star forming galaxies

Objectives:

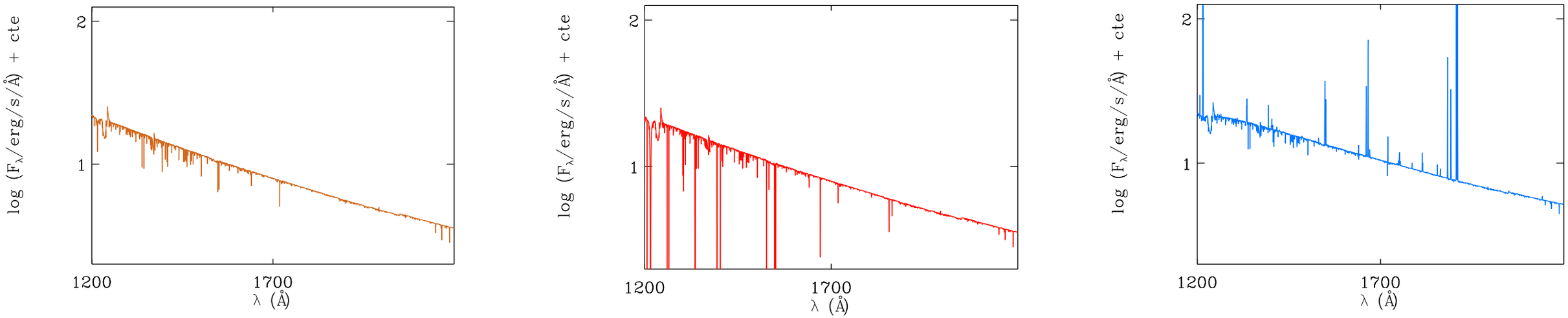
- interpret simultaneously the UV spectral signatures of stars, ionised and neutral gas in star forming galaxies

Method:

- Couple output from evolutionary population synthesis models with photoionization code Cloudy and radiative transfer through the ISM code SYNSPEC

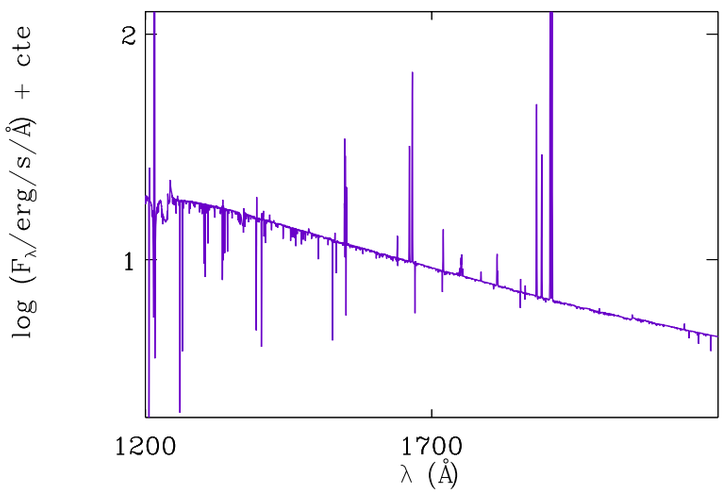
See poster or talk to Alba Vidal-García

stars + neutral gas + ionized gas



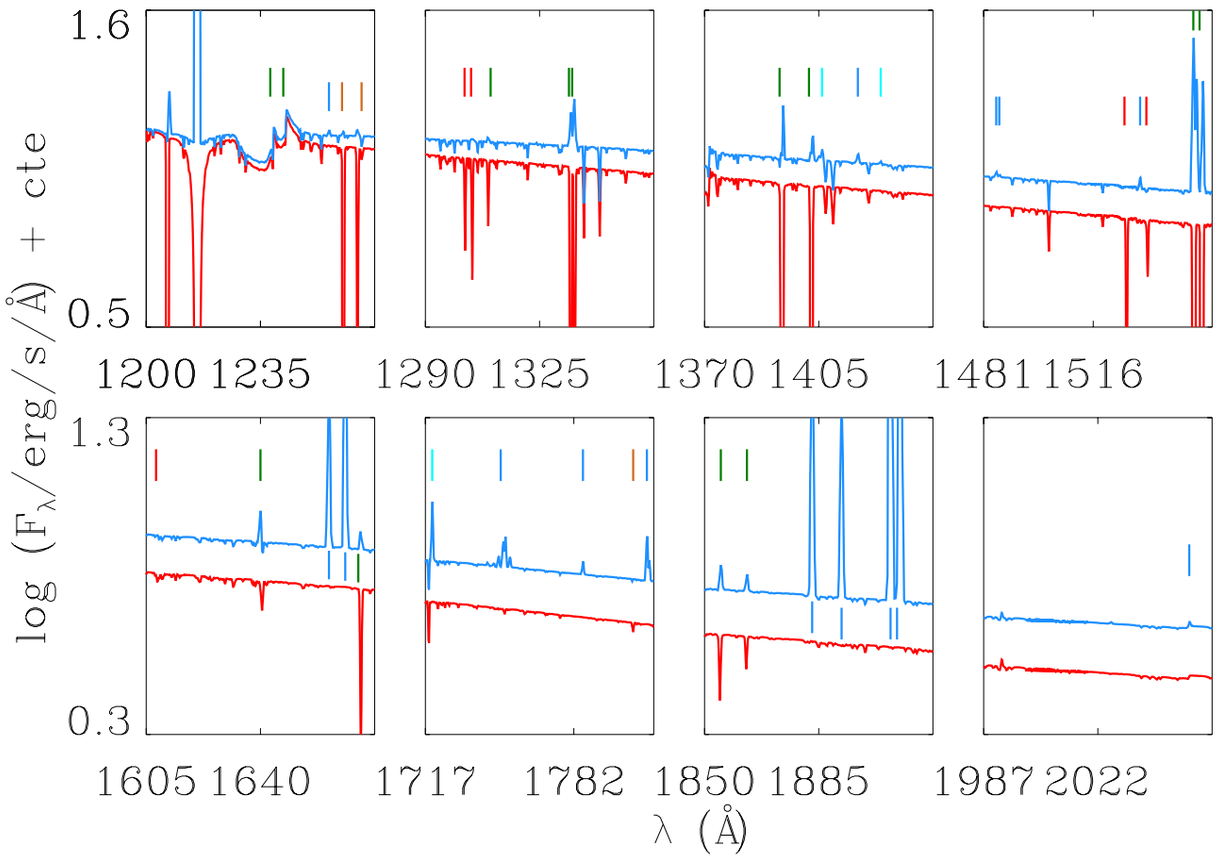
star forming galaxy model

=



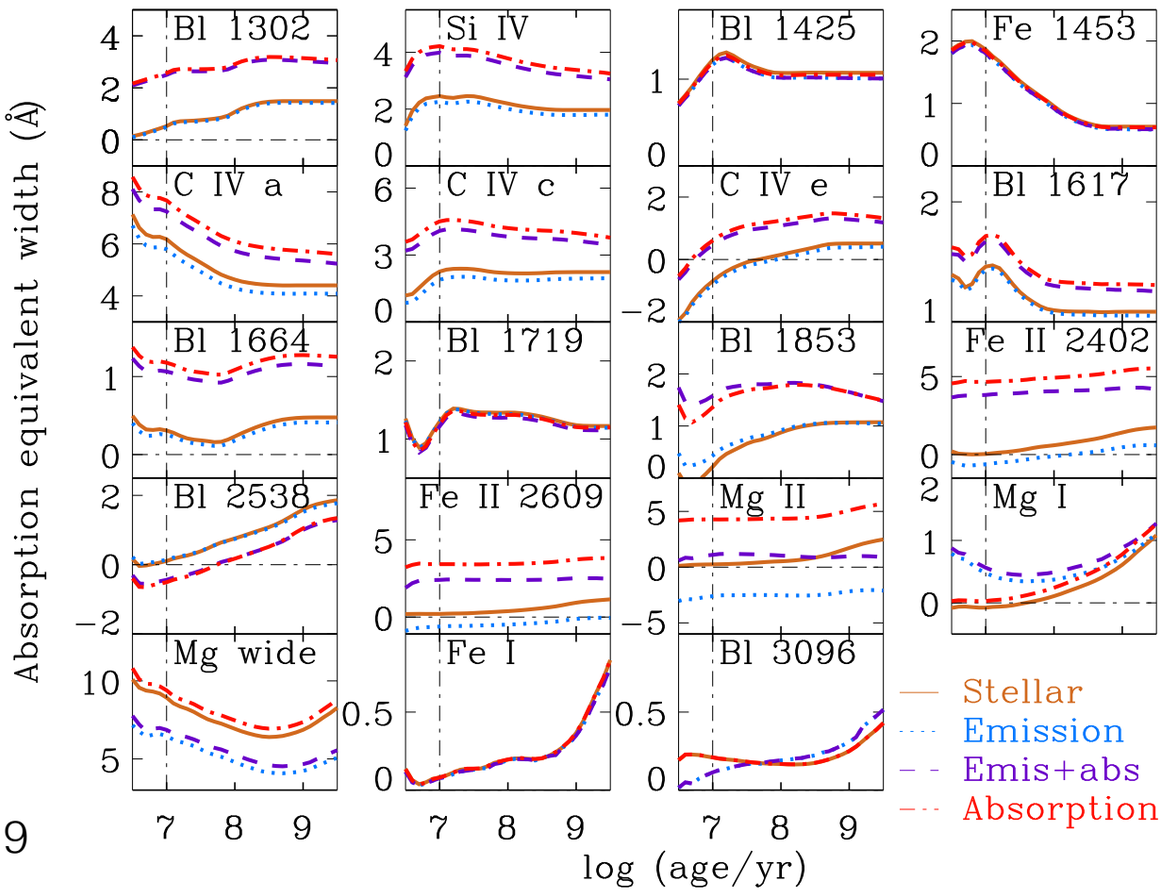
Results from Vidal-García et al. (2016, in prep.)

Results from Vidal-García et al. (2016, in prep.)

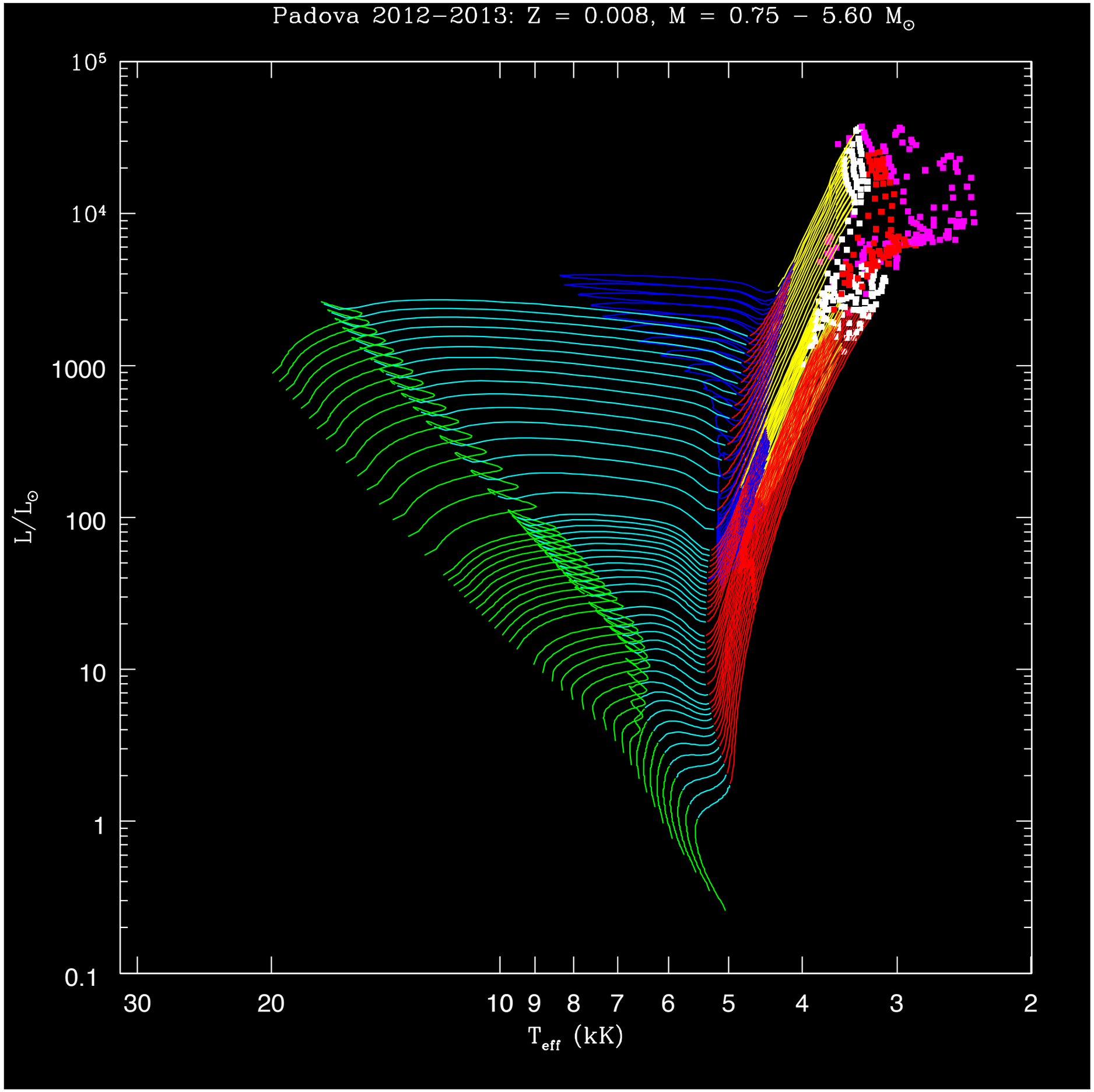


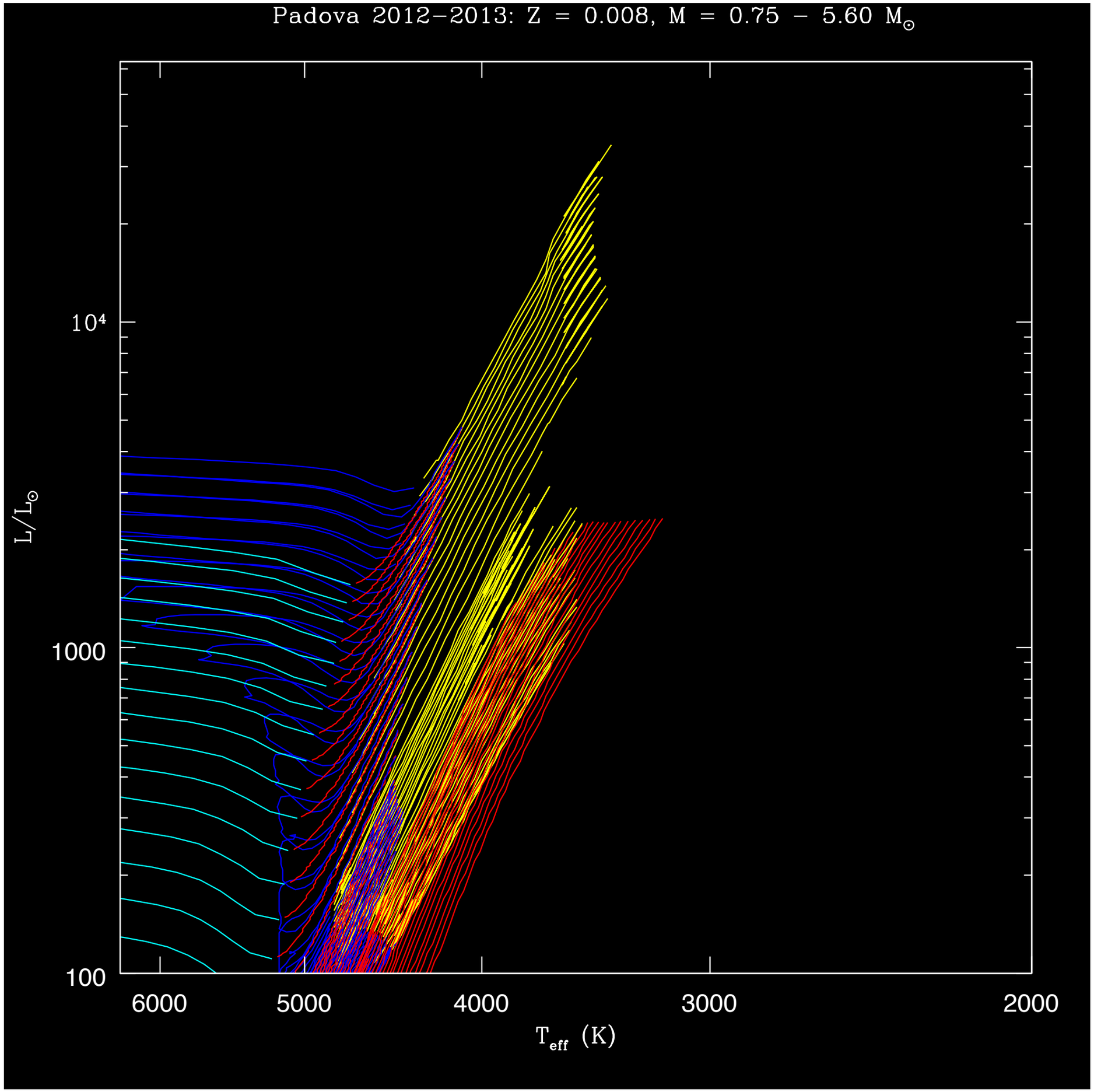
<= Details of spectral lines in SFG model

UV line strength index evolution =>

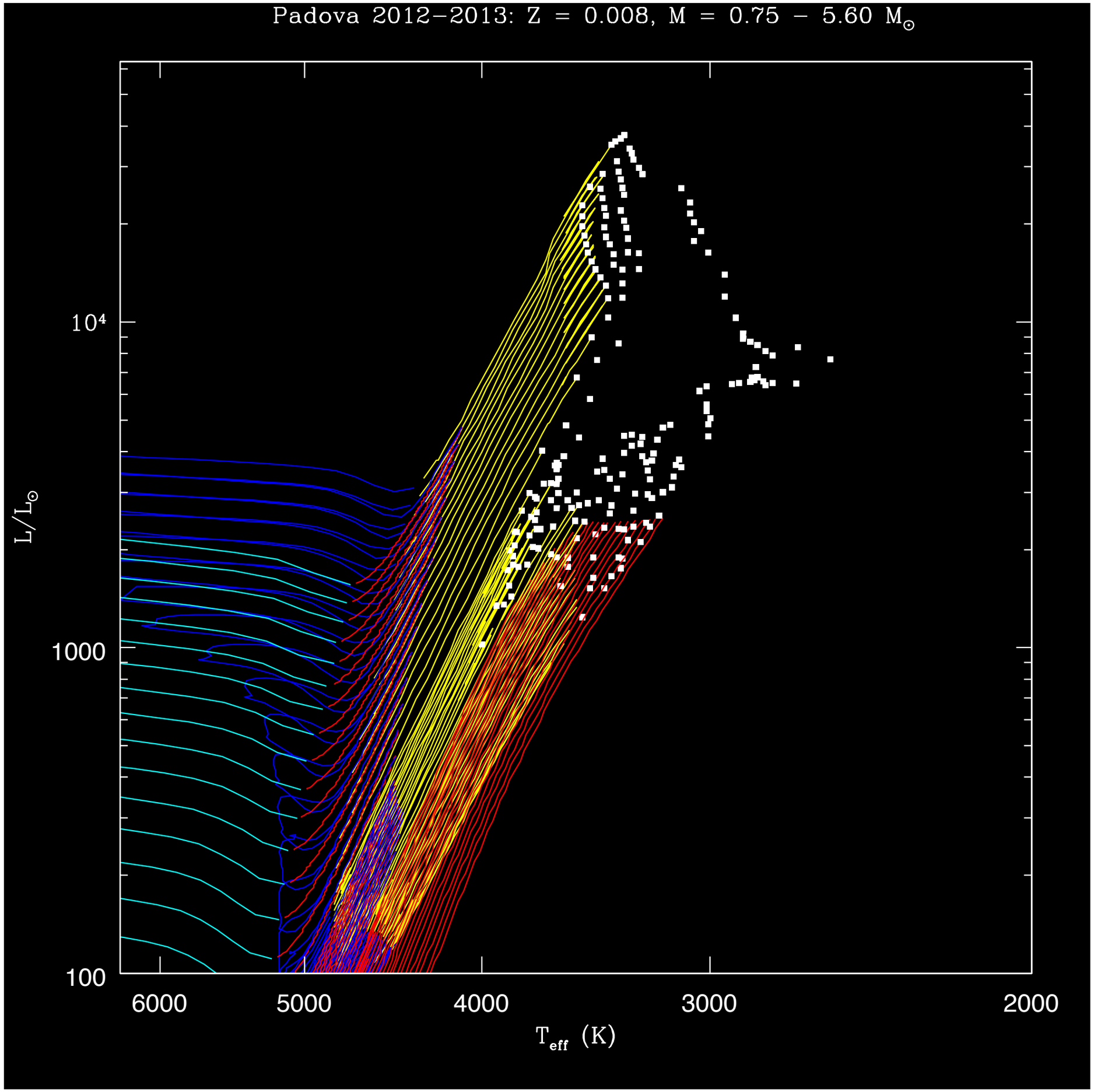


TP-AGB Stars (update)

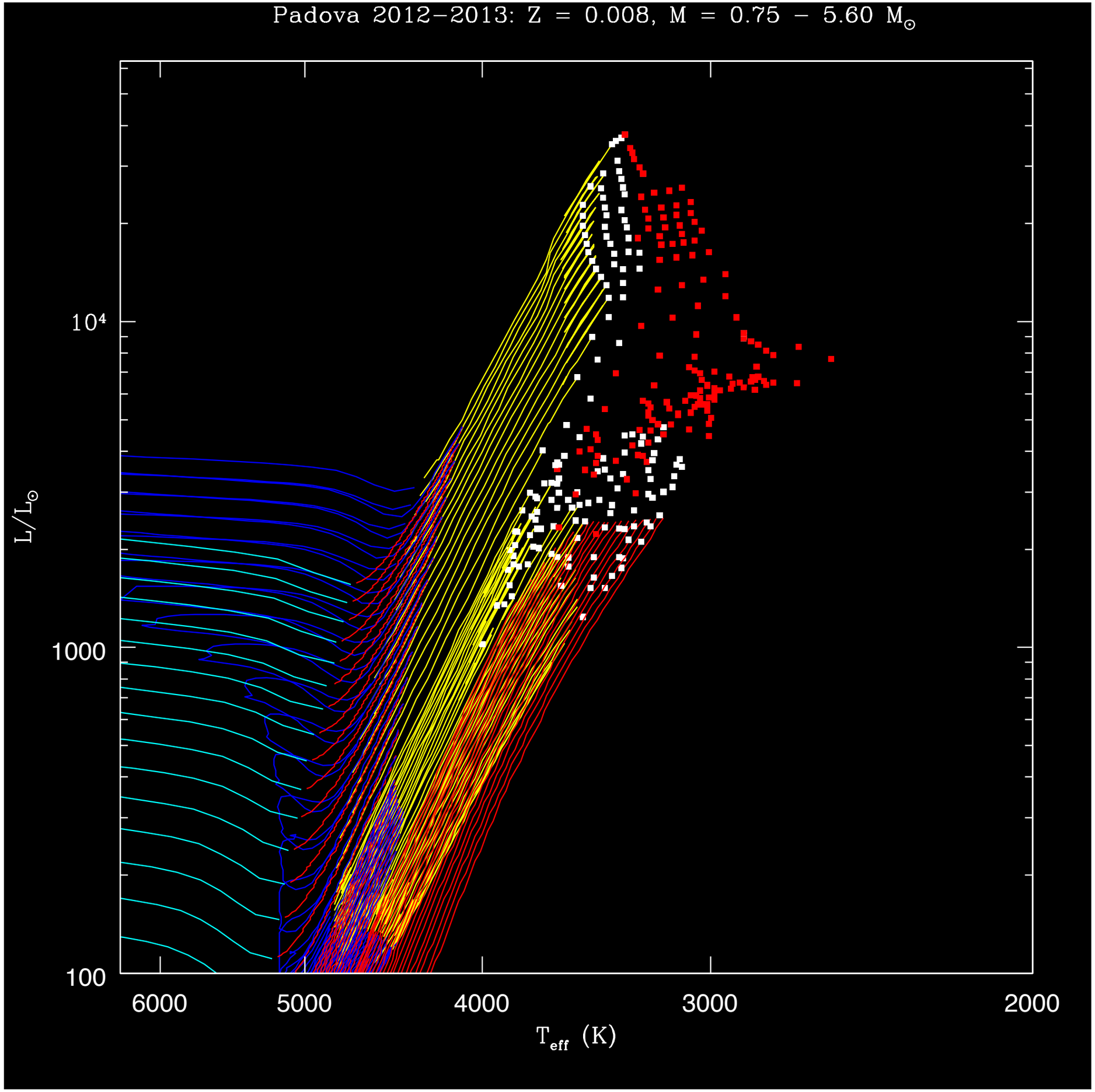

Padova 2012−2013: Z = 0.008, M = 0.75 − 5.60 M⊙
10⁵
10⁴
1000
100
10
1
0.1
L/L⊙
30
20
10
9
8
7
6
5
4
3
2
T_eff (kK)


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

AGB


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

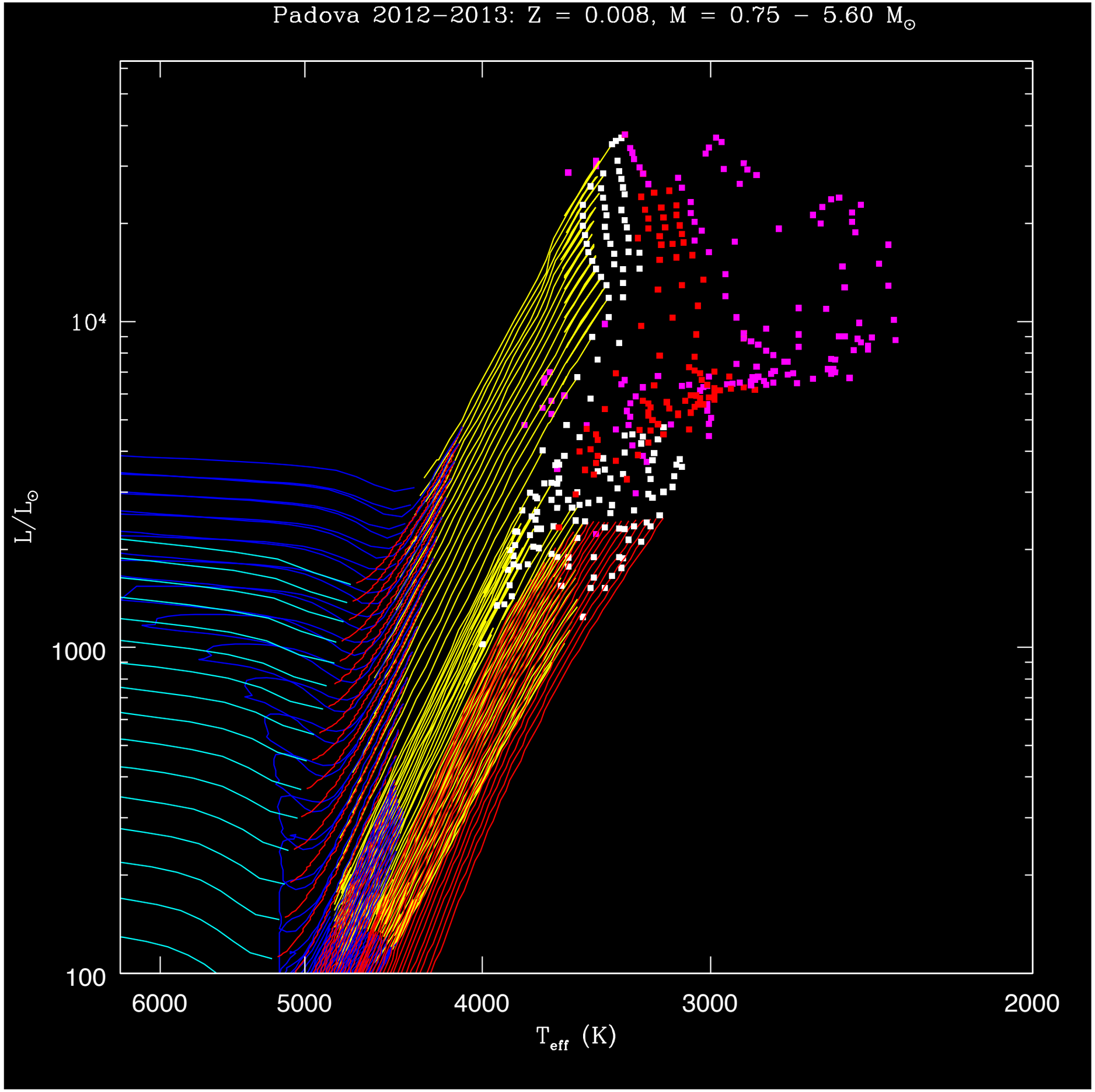
TP-AGB:
O-Rich



TP-AGB:

O-Rich

C-Rich

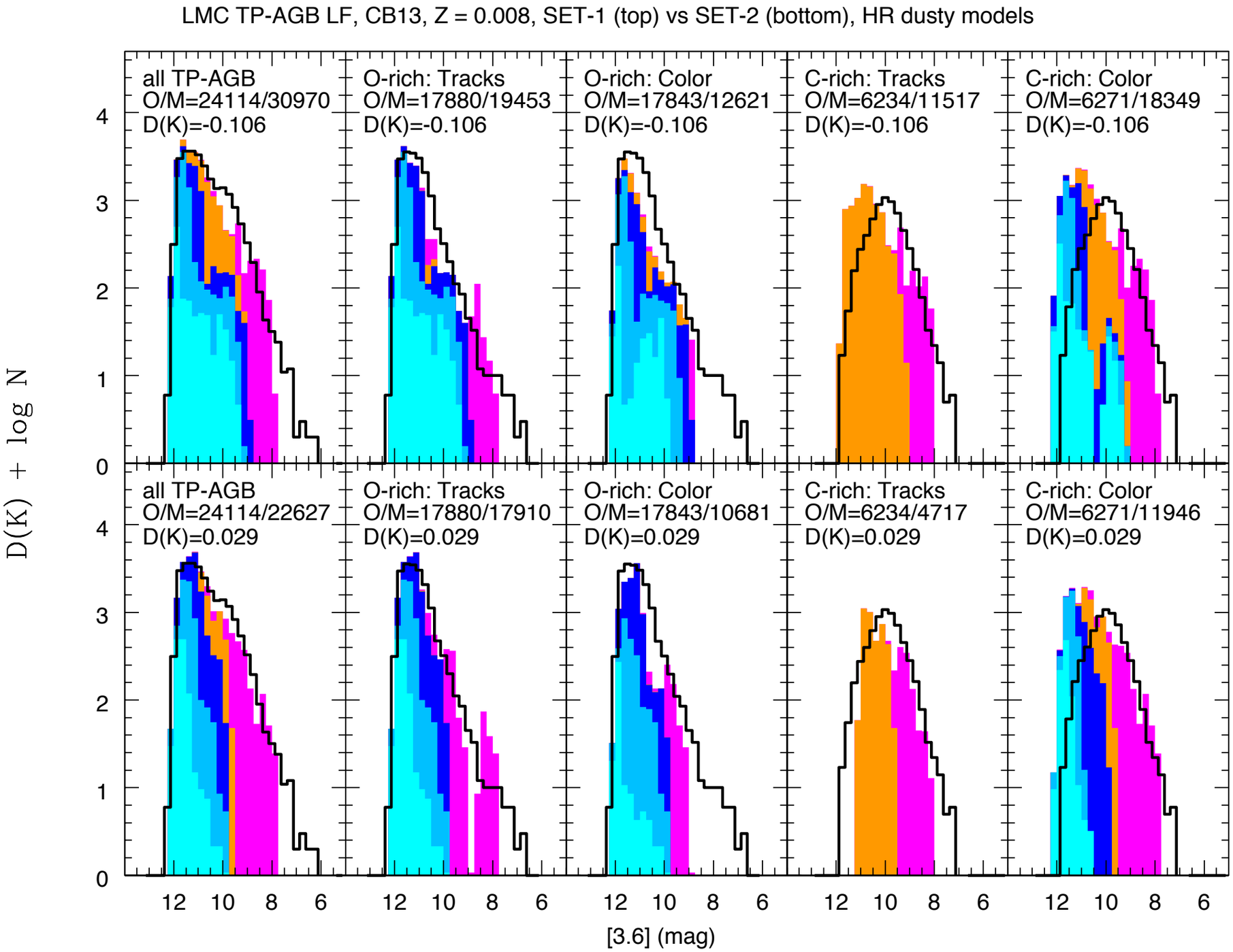


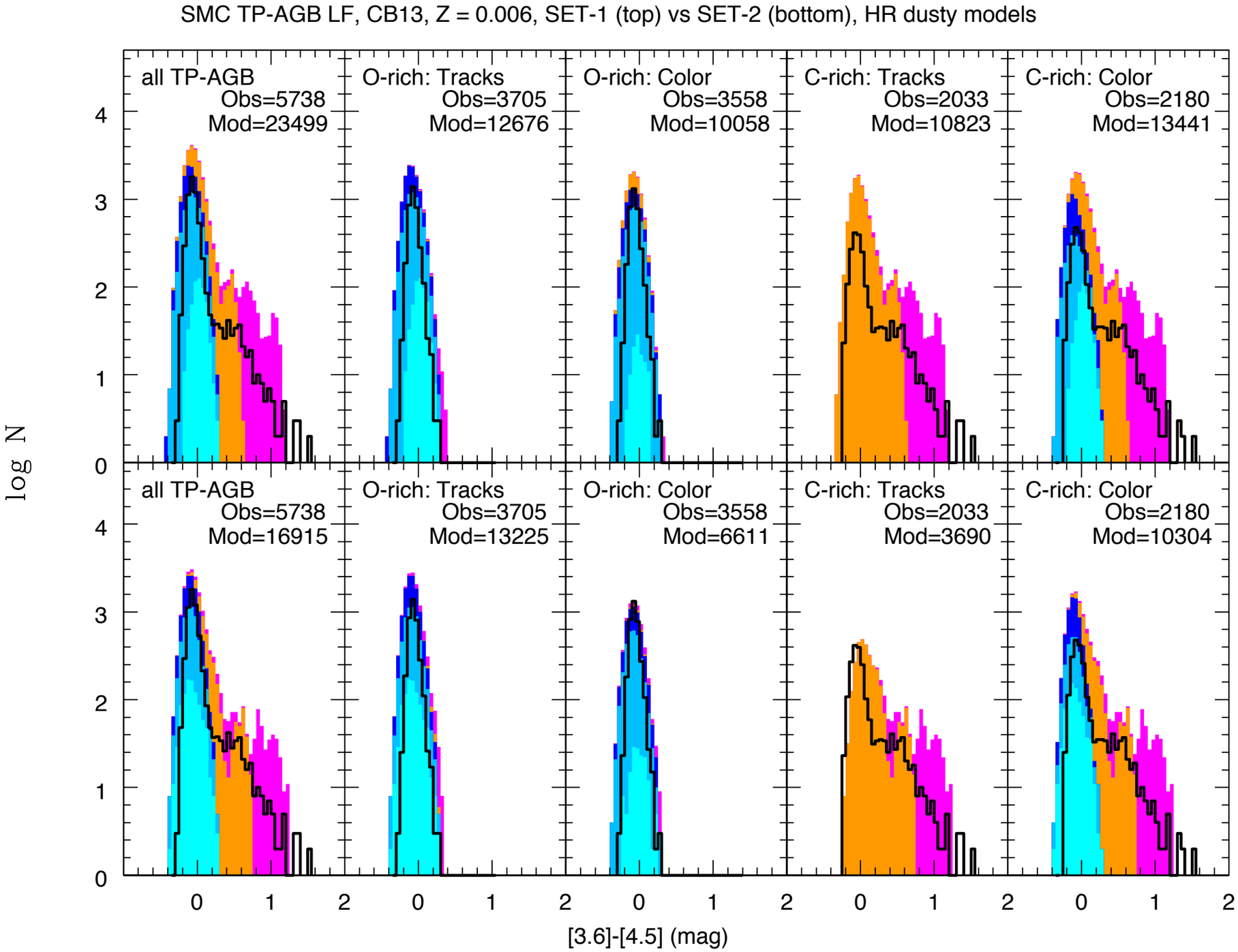
TP-AGB:

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 = 0.006, SET-1 (top) vs SET-2 (bottom), HR dusty models
all TP-AGB
Obs=5738
Mod=23499
O-rich: Tracks
Obs=3705
Mod=12676
O-rich: Color
Obs=3558
Mod=10058
C-rich: Tracks
Obs=2033
Mod=10823
C-rich: Color
Obs=2180
Mod=13441
all TP-AGB
Obs=5738
Mod=16915
O-rich: Tracks
Obs=3705
Mod=13225
O-rich: Color
Obs=3558
Mod=6611
C-rich: Tracks
Obs=2033
Mod=3690
C-rich: Color
Obs=2180
Mod=10304
log N
[3.6]-[4.5] (mag)

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 calibrate and understand better SPS models
- Bayesian techniques at work for galaxy data analysis