

A New Set of Stellar Population Evolutionary Synthesis Models

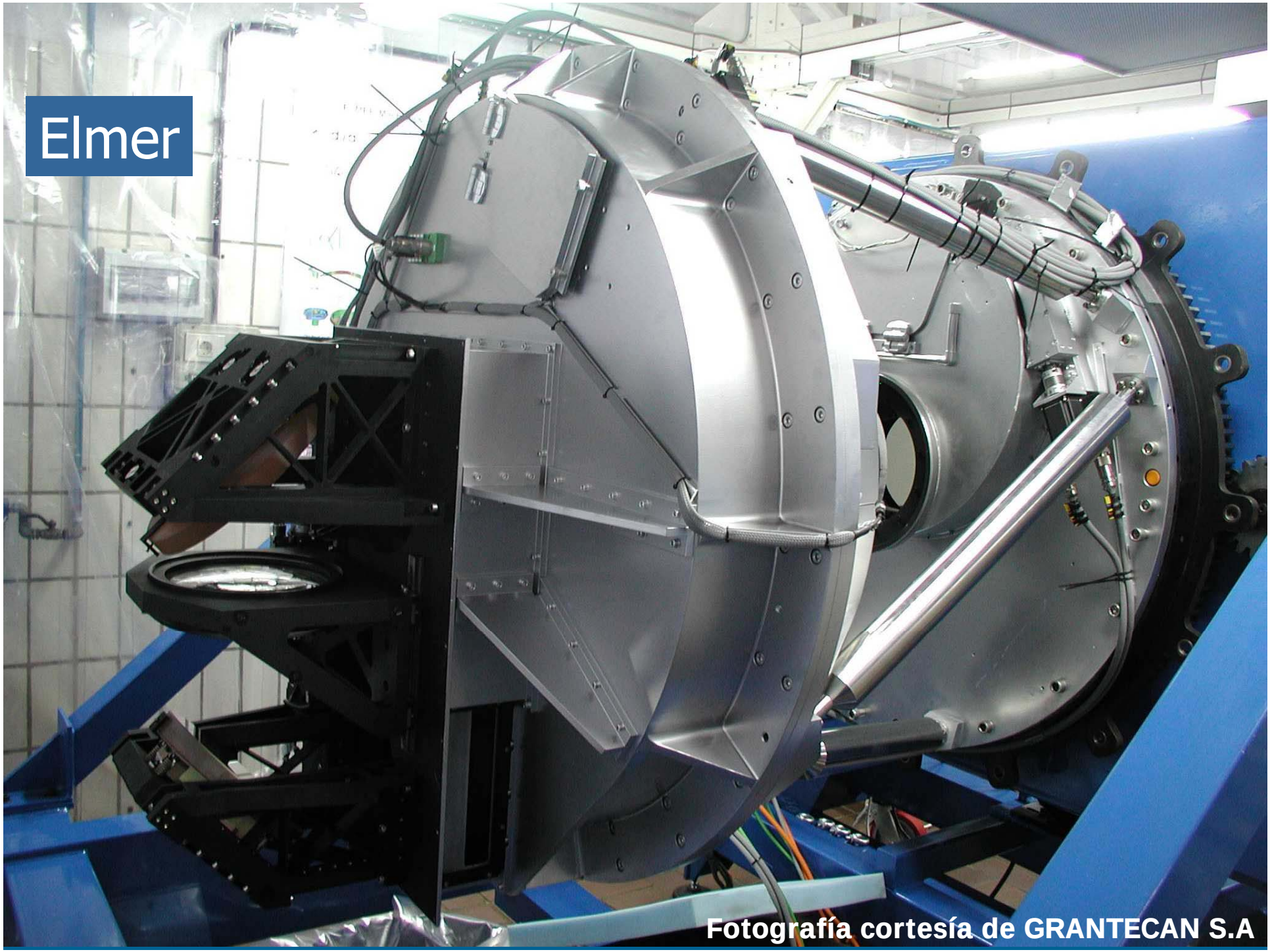
Estallidos V, Granada, 2-March-2007

Marisa García-Vargas — FRACTAL SLNE & Colaboradora IAC

Mercedes Mollá Lorente — CIEMAT

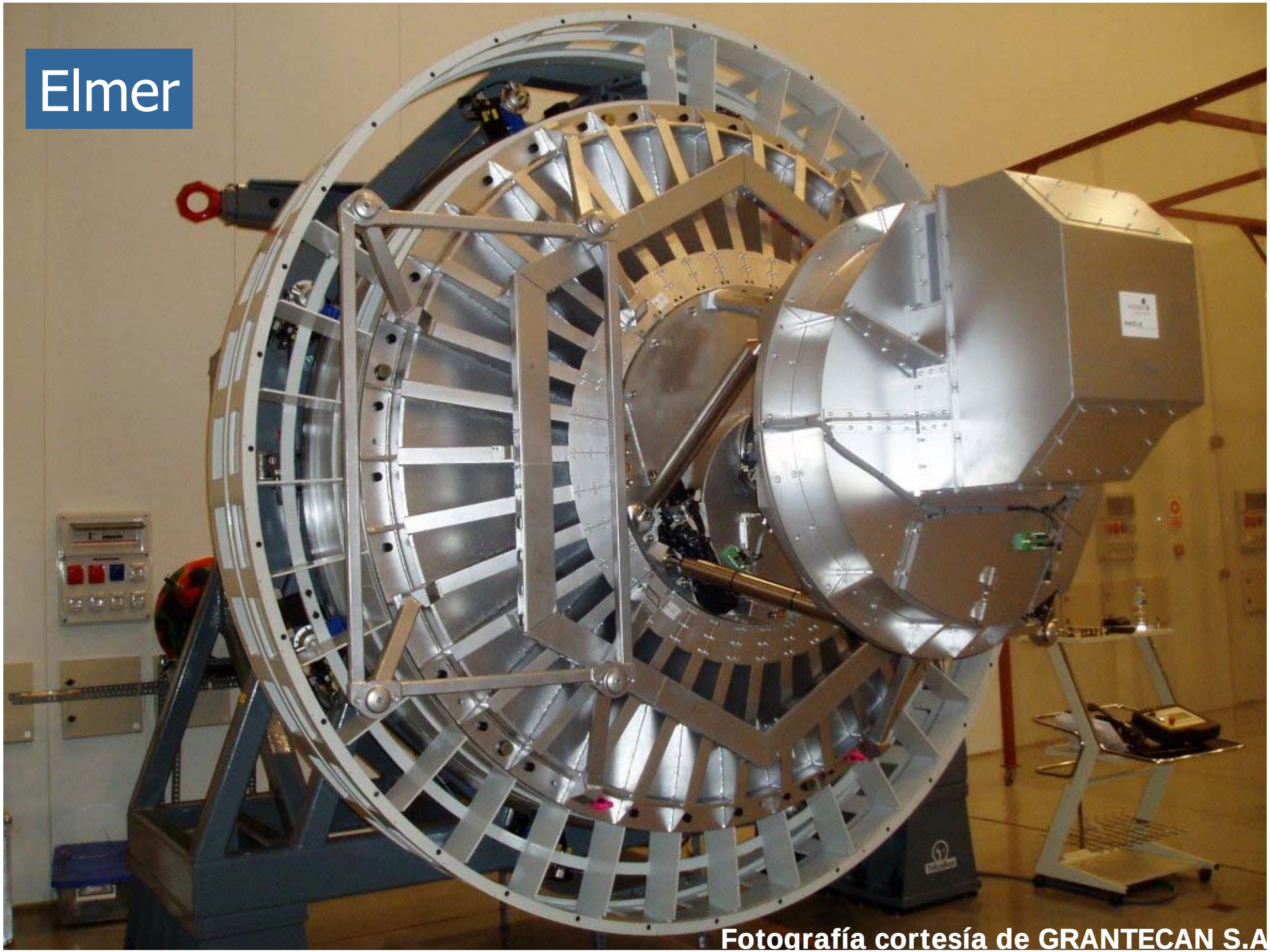
Alessandro Bressan — OSSERV. ASTR. DI PADOVA

Elmer



Fotografía cortesía de GRANTECAN S.A

Elmer



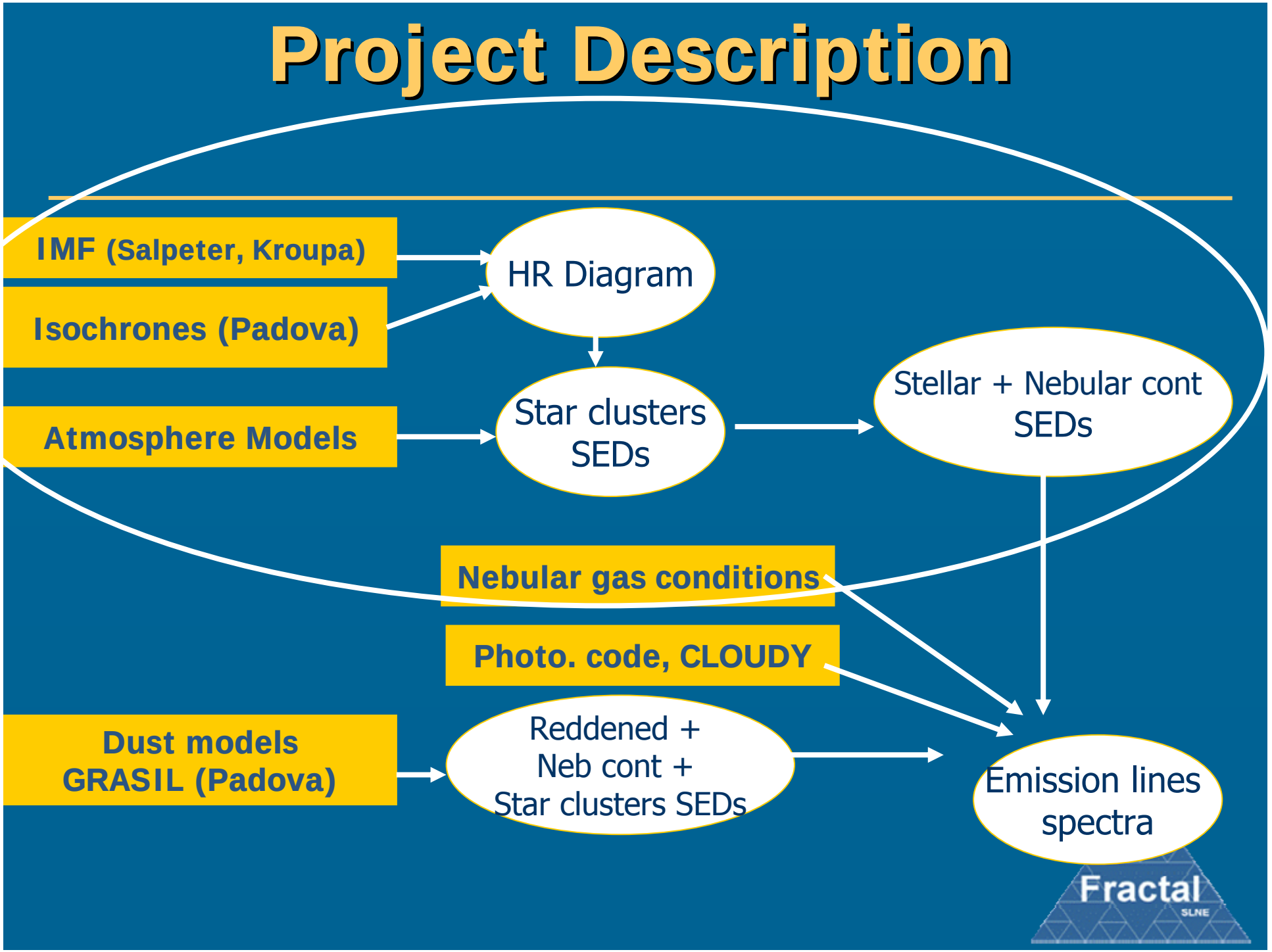
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Project Description

- To **update our evolutionary synthesis code**
- To calculate **new theoretical SEDs** (Stellar + Nebular + emission lines spectra for Estallidos)
- To **include empirical libraries in the optical range** for optical spectral at R ≤ 2500
- To update the **Stellar Indices** (Mollá & García-Vargas 2000 A&A 359, 18) (including Mercedes's chemical evolutionary models plus new synthesis models)
- To include La Palma sky + GTC + Elmer parameters in both Imaging and Spectroscopy modes to build a set of **models ready-to-use together with the observations with Elmer@GTC**
- To include our models in the **Virtual Observatory**



Project Description



Model Parameters: IMF

- Salpeter (1955, ApJ 121, 161)

  IMF x=1.35

  m_{low} = 0.15 $M_\odot$

  m_{up} = 100.00 $M_\odot$

- Kroupa (2001, MNRAS 322, 231)

(We can change IMF parameters: slope and limits up to 120 $M_\odot$)

The models do not include binaries, either statistical effects (mass segregation)

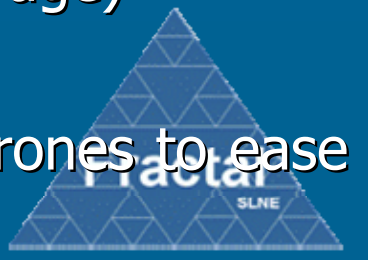
The basic grid will be Single Stellar Populations

We will include some models with different SFR values



Model Parameters: Isochrones

- Isochrones selection: New Padova set specifically computed for this piece of work.
- Broad age and metallicity coverage and detailed treatment of mass-loss at both, young ages (O, B, WR) and old ages (post-AGB until planetary nebula)
- Z = 0.0004, 0.001, 0.04, 0.008, 0.02 and 0.05 (1/50 to 2.5 solar)
- Ages, logt = 5.00 to 10.30
  High age resolution (up to logt=0.01, depending on the age)
- Specific stars: WN, WC, etc. are identified in the isochrones to ease the spectra assignation.



Model Parameters: Atmospheres

For stars with Teff < 25.000 we use the models by
Lejeune Th. Cuisinier F. & Buser R. 1997 A&AS 125, 229.
Excellent coverage in Teff, Z and logg.

For O, B and WR stars we use models by
Smith, Norris & Crowther (2002, MNRAS 337, 1309)
230 models non-LTE line blanketed

- 110, O-B calculated with the code by Pauldrach etal. 2001).
  Teff range 25.000 – 51500, logg (2.95 – 4.00)

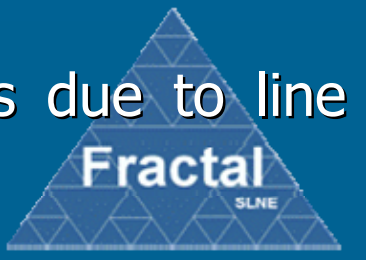
- 120 WR (60 WN + 60 WC) models calculated with the code CMFGEN Hillier & Miller (1998).
  T* and R* are Temperature and Radius at a Rosseland optical depth of 10)
  30.000 < T* < 120000 K (WN) and 40.000 < T* < 140000 K (WC)
  20.3 $R_\odot$ < R* < 1.3 $R_\odot$ (WN) and 9.3 $R_\odot$ < R* < 0.8 $R_\odot$ (WC)

Z = 0.05, 0.02, 0.4, 1 and 2 $Z_\odot$



WR models

- The models do not include very hot stars (few observations) with weak winds and significant flux above 54ev.
- Main differences with previous models for WR.
- Above 54ev emergent flux is determined by the wind density as a function of metallicity and in this set of models the hardness of ionizing radiation decreases.
- The models produce a lower flux of HeI continuum, with important implications for nebular ratios, for Z>0.4Zo and Age < 7 Myr
- HeII 4686 is very low
- HeI 5786 / Hβ decreases when metallicity increases due to line blanketing



Consequence of WR models

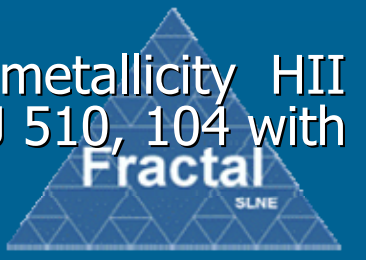
- Equivalent Teff of clusters (related to the cluster age) increases with metallicity decreases.

- To explain the diagnostic diagrams (for example log η' vs log R23) with previous models we had to:

  - Propose an IMF upper mass limits - Z dependent (lower for higher metallicity)

  - Considering mass-segregation instead a larger one (as proposed by Garcia-Vargas & Diaz, 1991 trying to explain the observations for high metallicity regions with evolutionary models – we used Clegg & Middlemass 87 models for WR). This is not in agreement with statistical models (Cerviño and col) either the observational evidence – massive stars are found in low massive clusters- as shown yesterday by Jesús Maíz)

- Smith et al. 2002 fits perfectly the observational high metallicity HII regions diagram by Bressolin, Kennicutt & Garnett 1999, ApJ 510, 104 with SB99+WR models



WR model assignation

- We use the equations:

$$d\tau = -\kappa(r)\,\rho\,(r)\,dr$$

$$dM/dt = 4\pi r^2 \rho(r) v(r) dr$$

$$V(r) = V_\infty\,(1-R_s/r)^\beta\ ;\ \beta = 1$$

$$\kappa = 0.2(1+X_s);\ X_s = 0.7$$

We integrate the equations and find R_* from the Rs (from the isochrones), and then we look at the T_* corresponding to that R_*

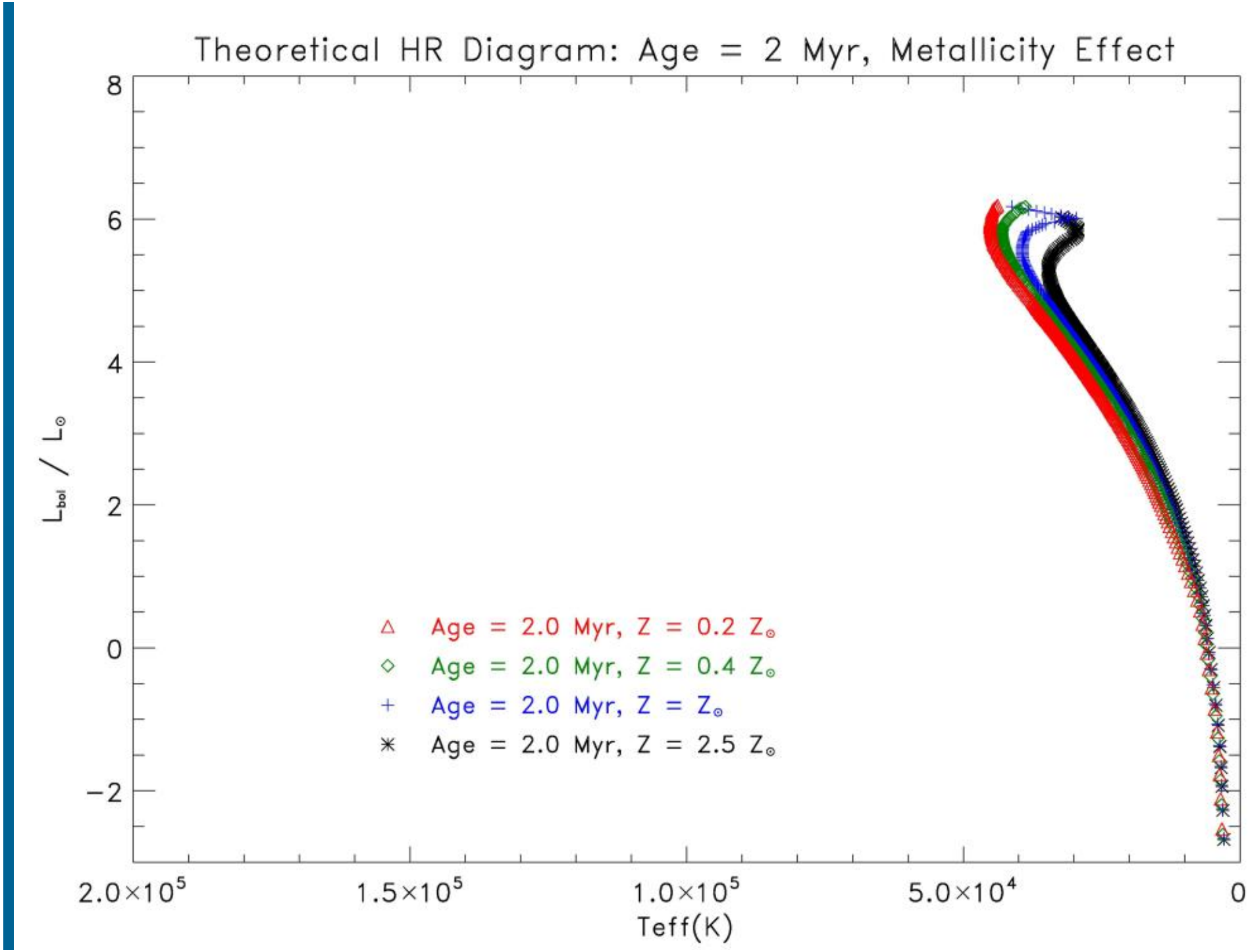


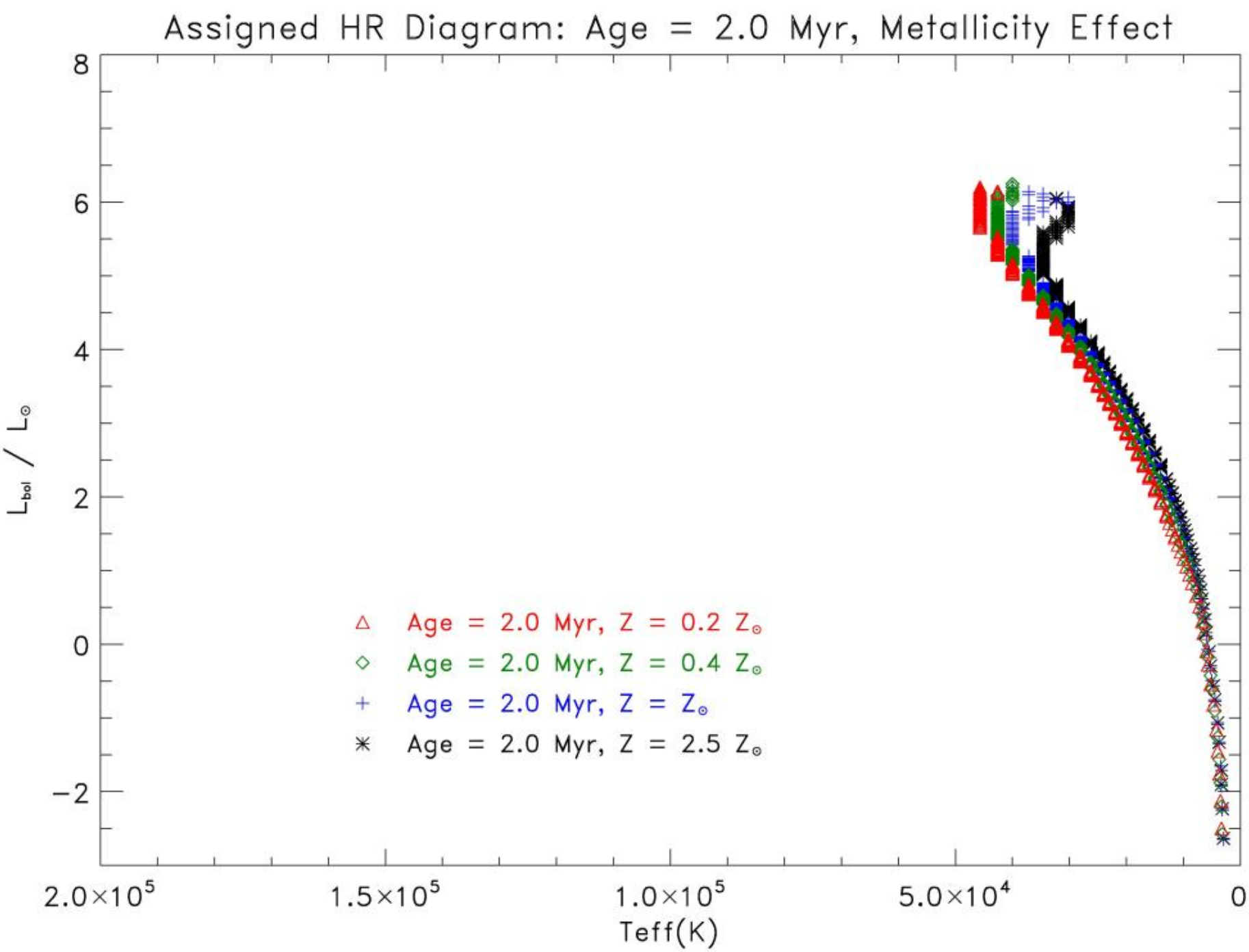
Open points

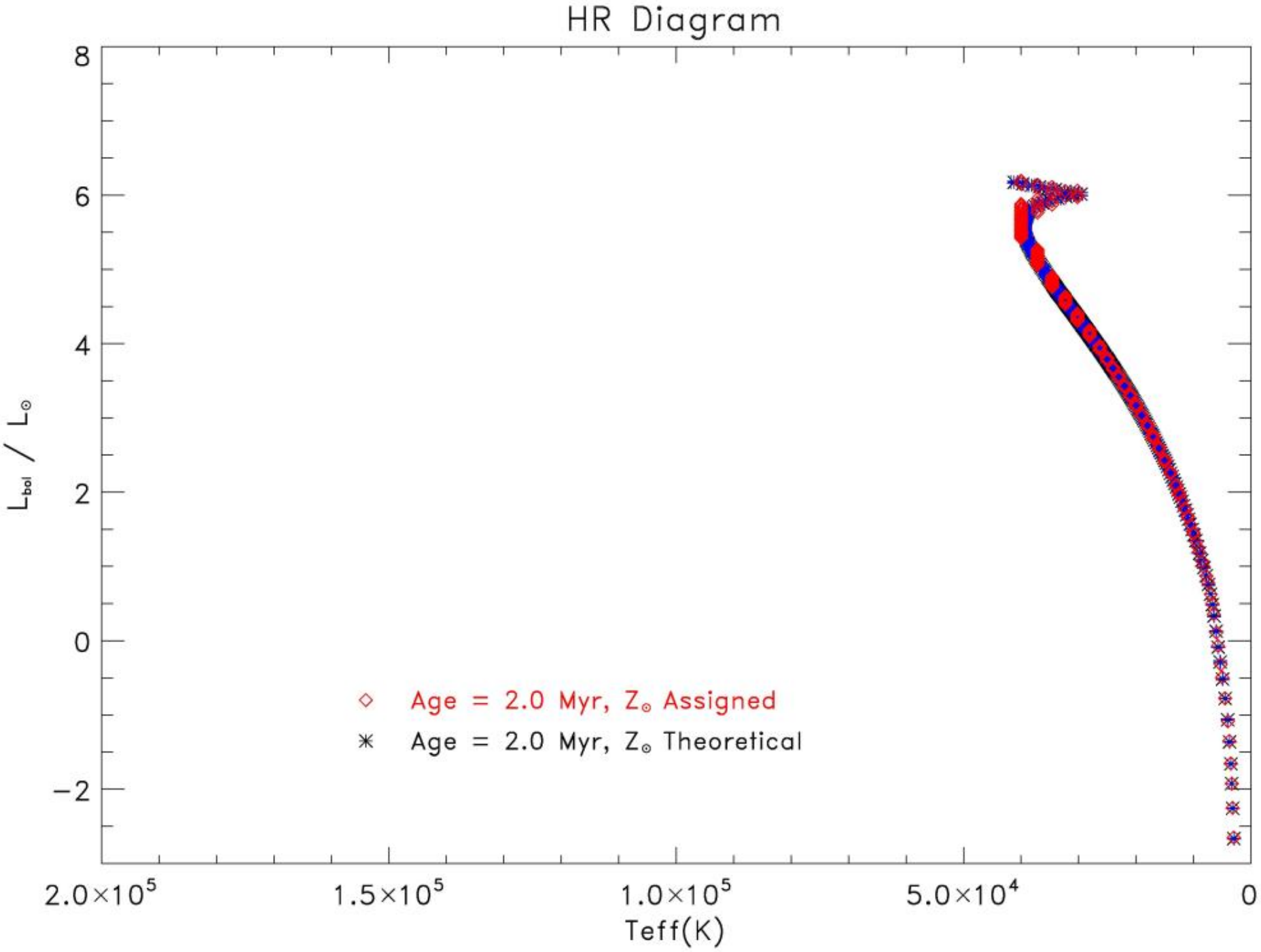
- Select the most appropriate atmosphere models for post-AGB (O-B type) and planetary nebula (WR-type - re-born hypothesis -, Clegg & Middlemass models, blackbodies (¿?). We are in the process of studying the available UV/X-ray data from these objects in the literature to make the appropriate selection

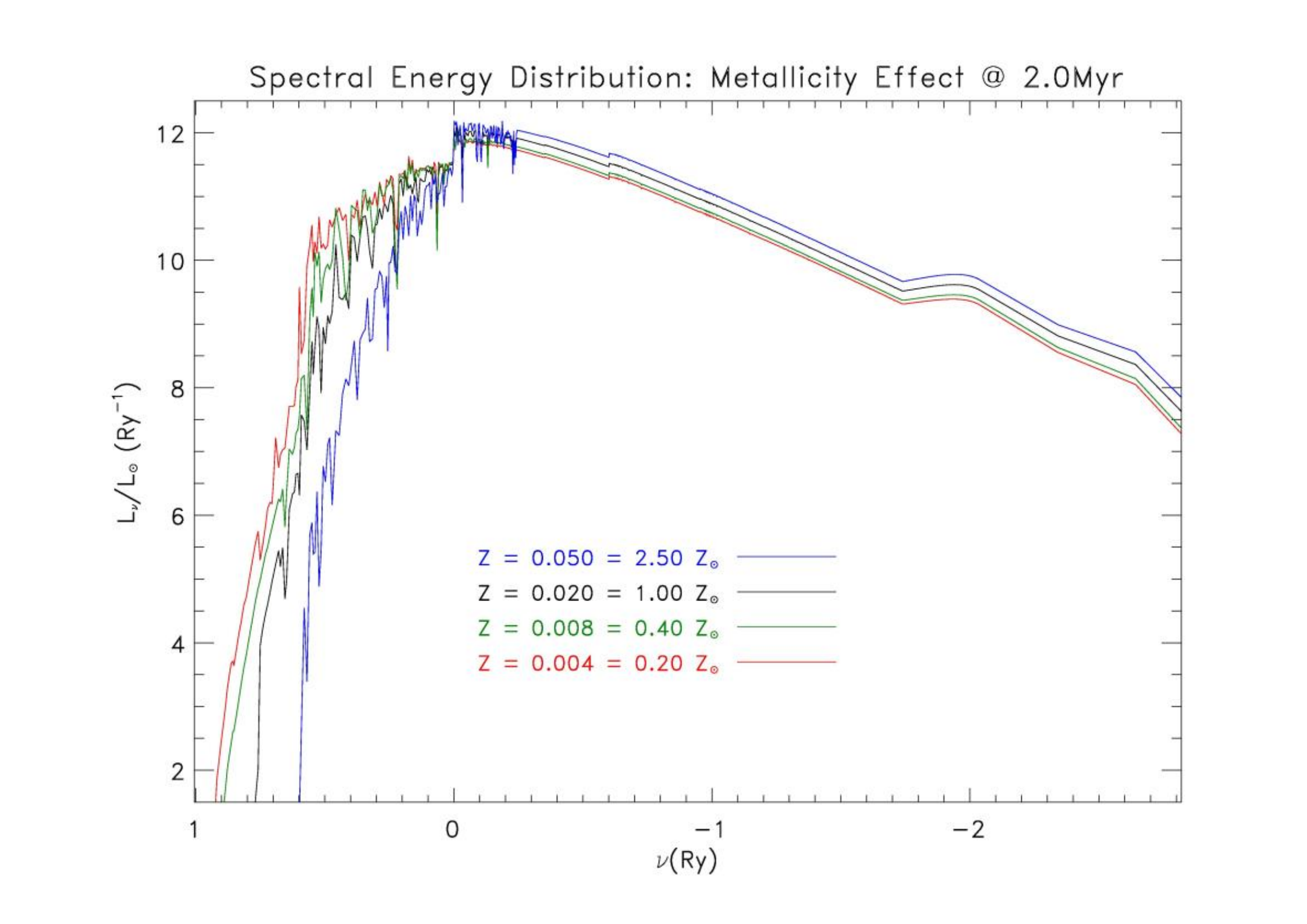
- These stars provides the ionizing spectrum for SSP older than 10^9 yr

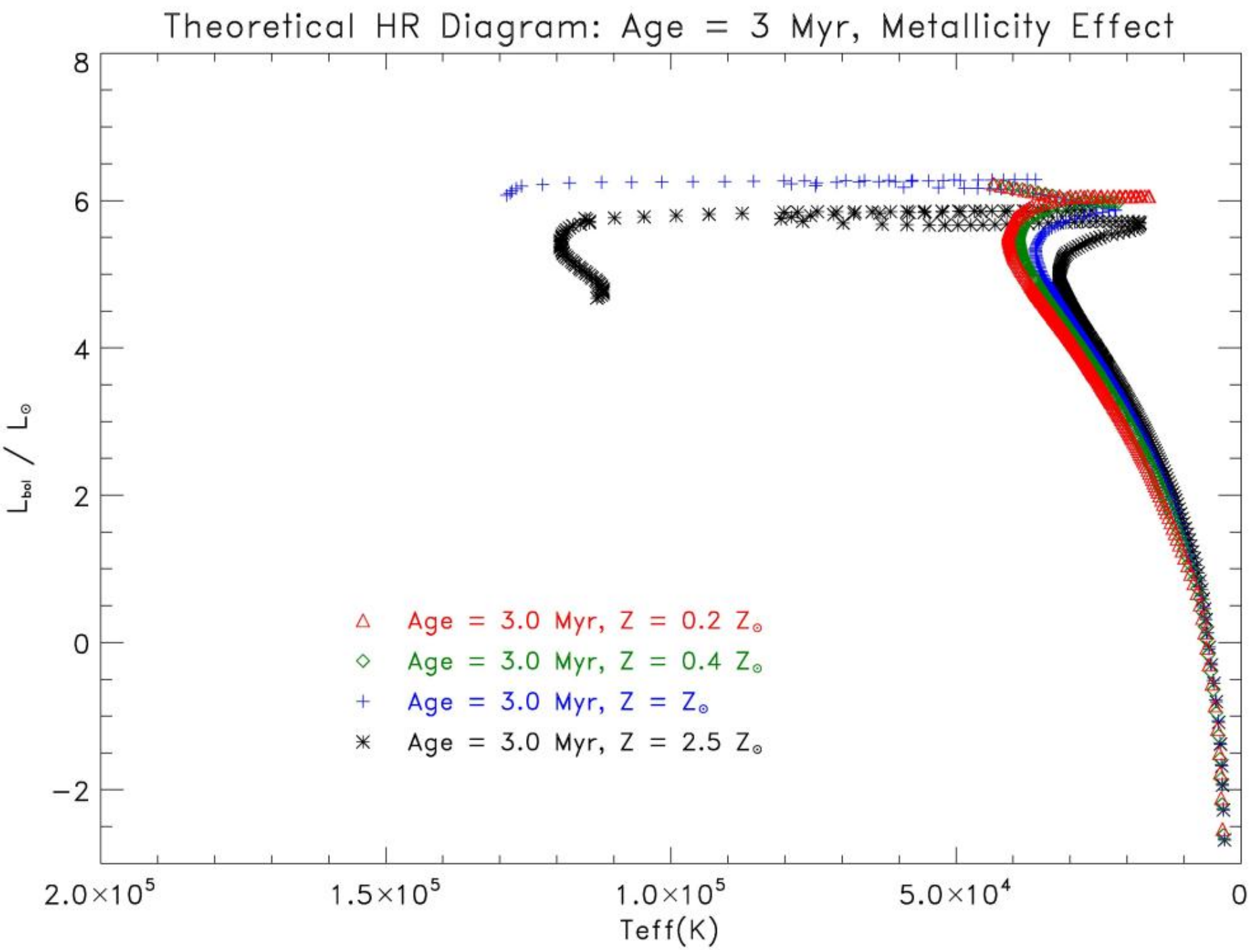


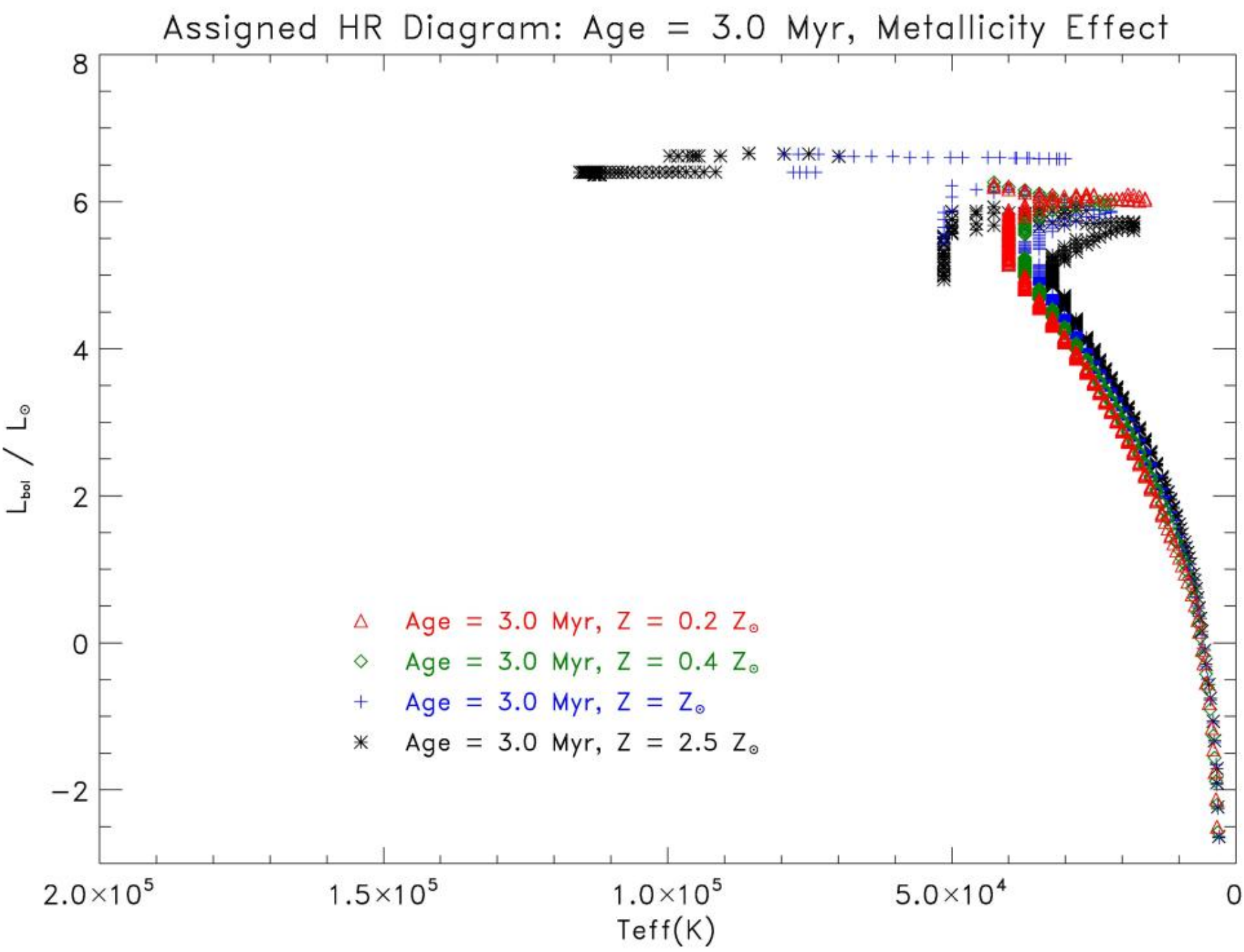

Theoretical HR Diagram: Age = 2 Myr, Metallicity Effect
8
6
4
2
0
−2
L_{bol} / $L_\odot$
2.0×10^5
1.5×10^5
1.0×10^5
5.0×10^4
0
Teff(K)
Age = 2.0 Myr, Z = 0.2 $Z_\odot$
Age = 2.0 Myr, Z = 0.4 $Z_\odot$
Age = 2.0 Myr, Z = $Z_\odot$
Age = 2.0 Myr, Z = 2.5 $Z_\odot$

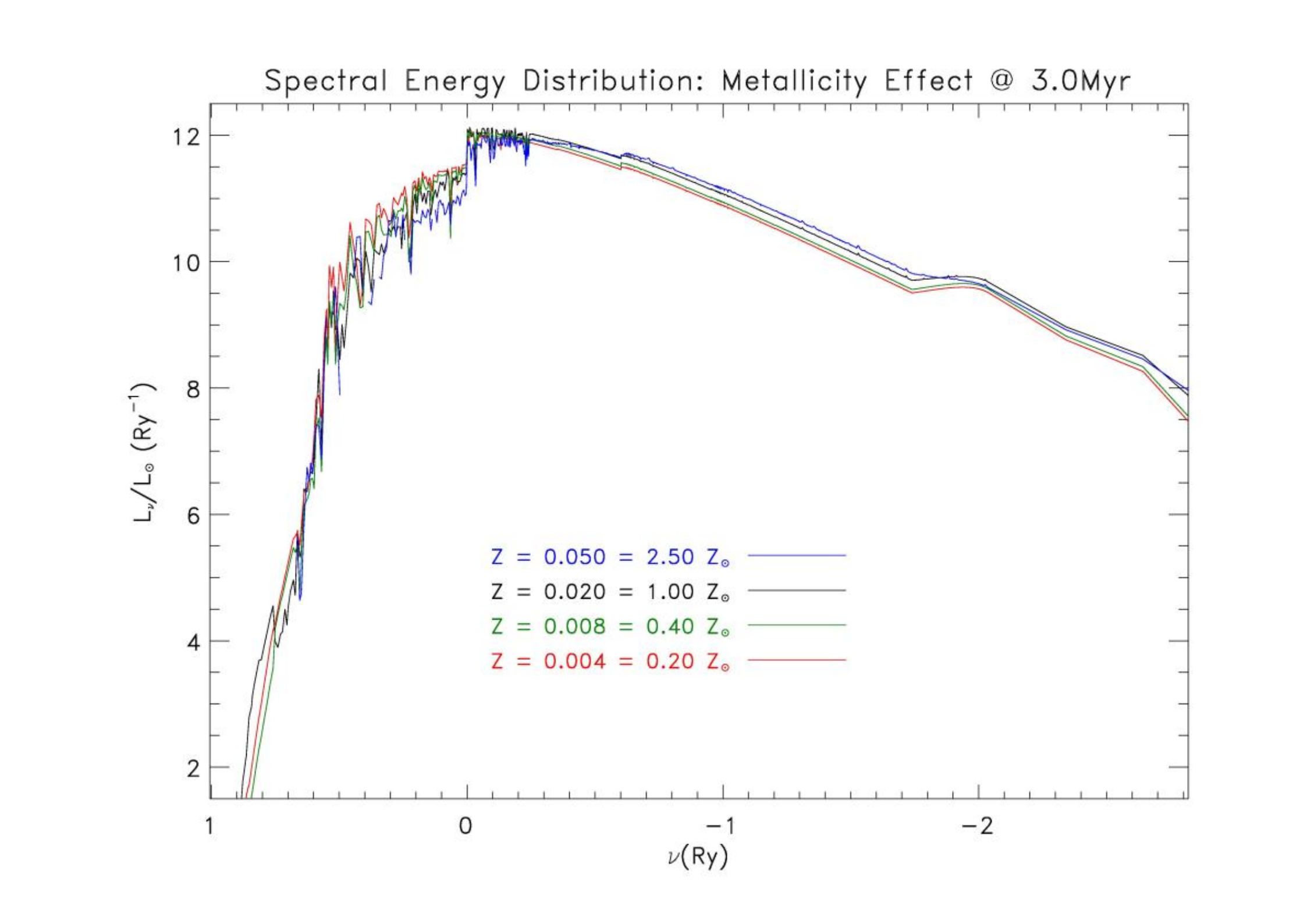

Assigned HR Diagram: Age = 2.0 Myr, Metallicity Effect
8
6
4
2
0
−2
L_{bol} / $L_\odot$
2.0×10^5
1.5×10^5
1.0×10^5
5.0×10^4
0
Teff(K)
Age = 2.0 Myr, Z = 0.2 $Z_\odot$
Age = 2.0 Myr, Z = 0.4 $Z_\odot$
Age = 2.0 Myr, Z = $Z_\odot$
Age = 2.0 Myr, Z = 2.5 $Z_\odot$

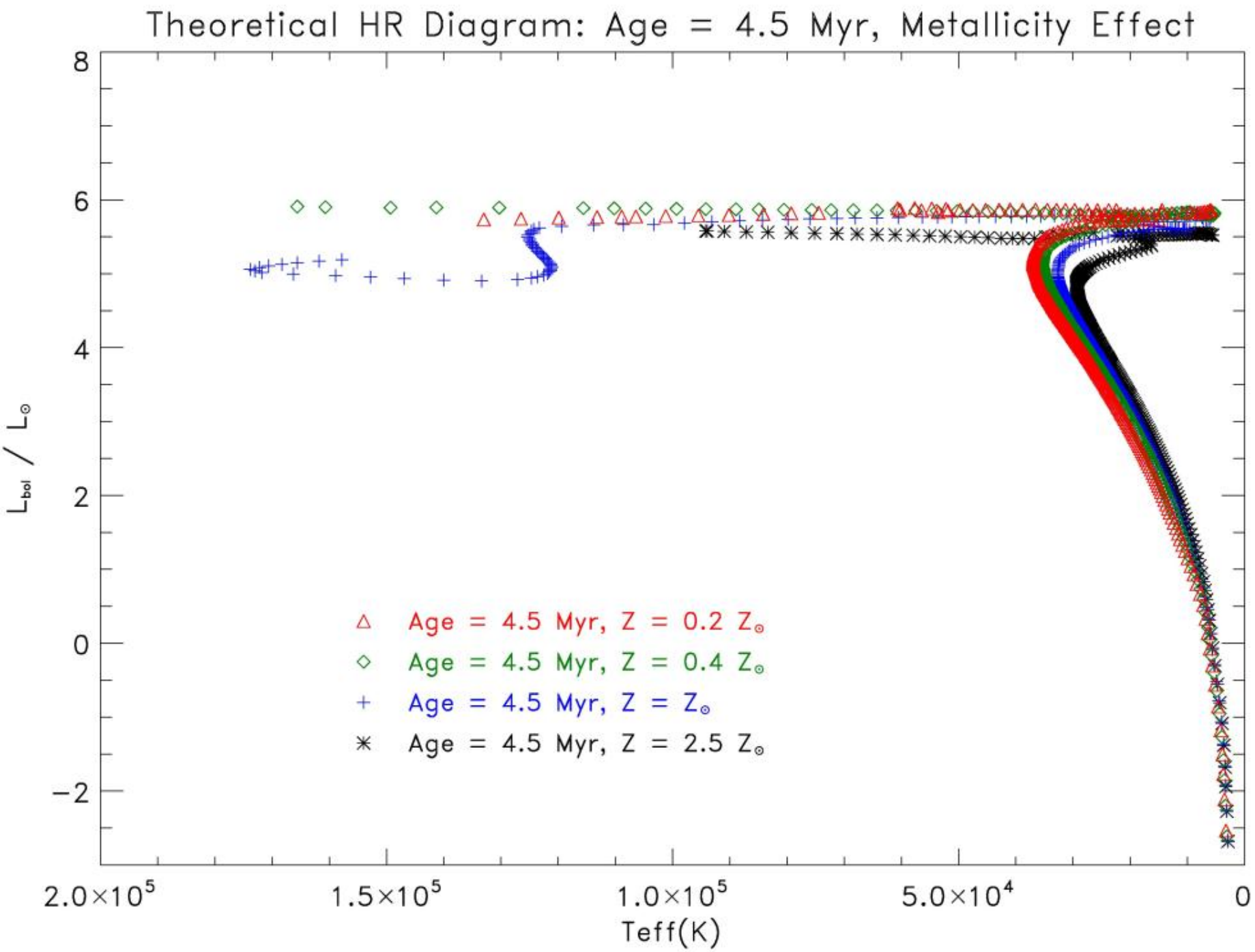

HR Diagram
8
6
4
2
0
−2
L_{bol} / $L_\odot$
Age = 2.0 Myr, $Z_\odot$ Assigned
Age = 2.0 Myr, $Z_\odot$ Theoretical
2.0×10^5
1.5×10^5
1.0×10^5
5.0×10^4
0
Teff(K)

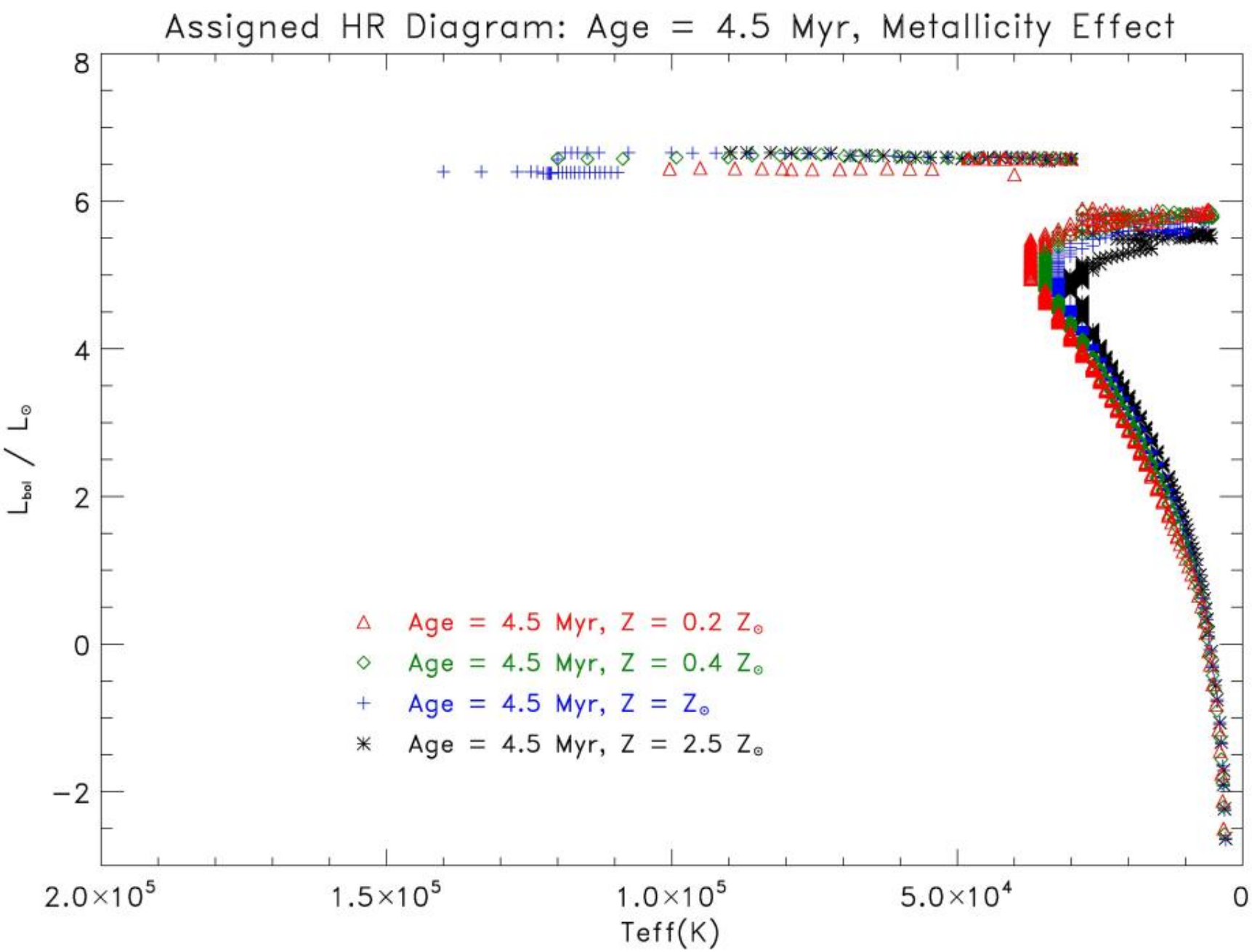

Spectral Energy Distribution: Metallicity Effect @ 2.0Myr
12
10
8
6
4
2
$L_\nu/L_\odot$ (Ry^{-1})
1
0
−1
−2
ν(Ry)
Z = 0.050 = 2.50 Z$_\odot$
Z = 0.020 = 1.00 Z$_\odot$
Z = 0.008 = 0.40 Z$_\odot$
Z = 0.004 = 0.20 Z$_\odot$

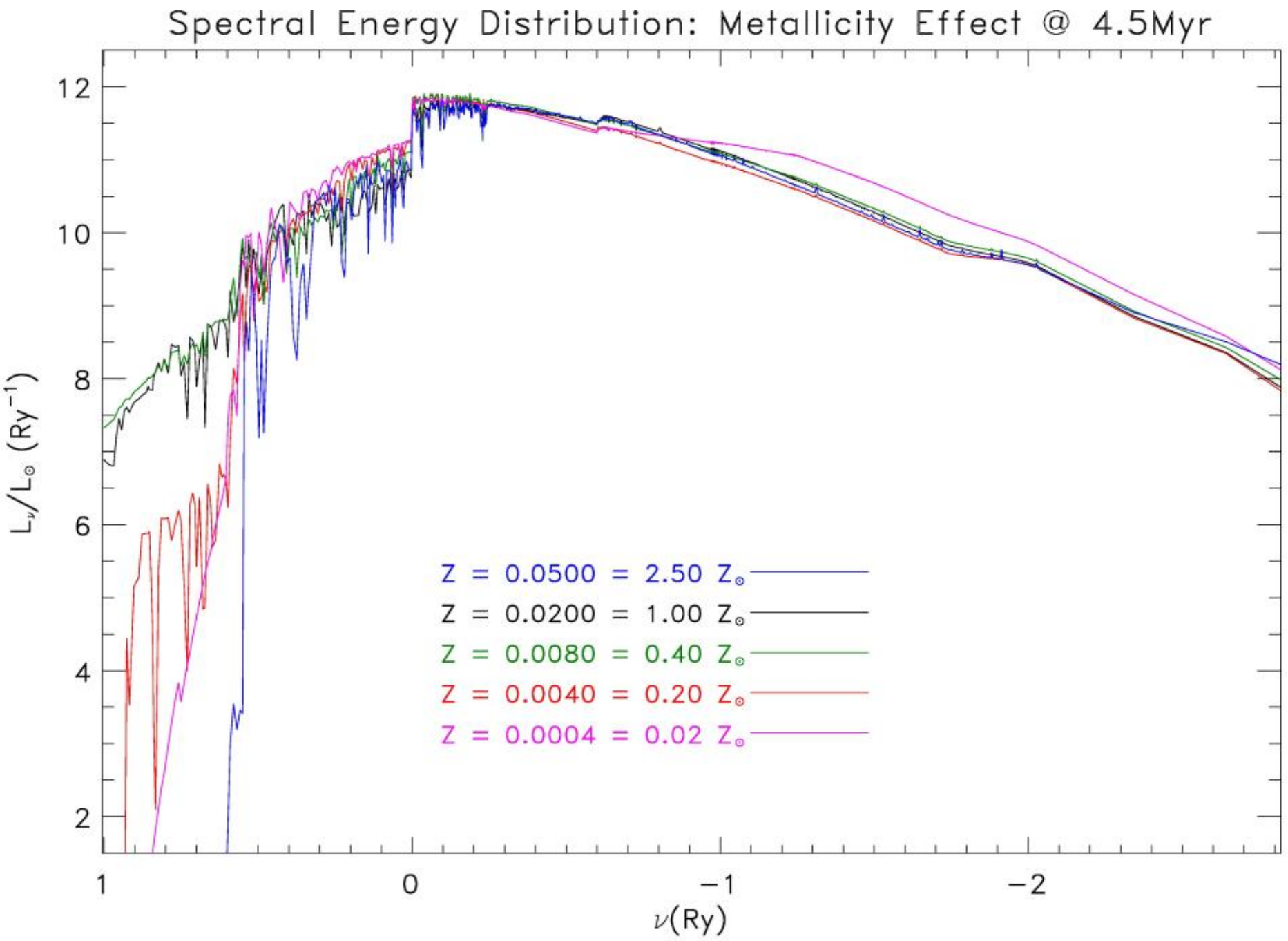

Theoretical HR Diagram: Age = 3 Myr, Metallicity Effect
8
6
4
2
0
−2
L_{bol} / $L_\odot$
2.0×10^5
1.5×10^5
1.0×10^5
5.0×10^4
0
Teff(K)
Age = 3.0 Myr, Z = 0.2 $Z_\odot$
Age = 3.0 Myr, Z = 0.4 $Z_\odot$
Age = 3.0 Myr, Z = $Z_\odot$
Age = 3.0 Myr, Z = 2.5 $Z_\odot$

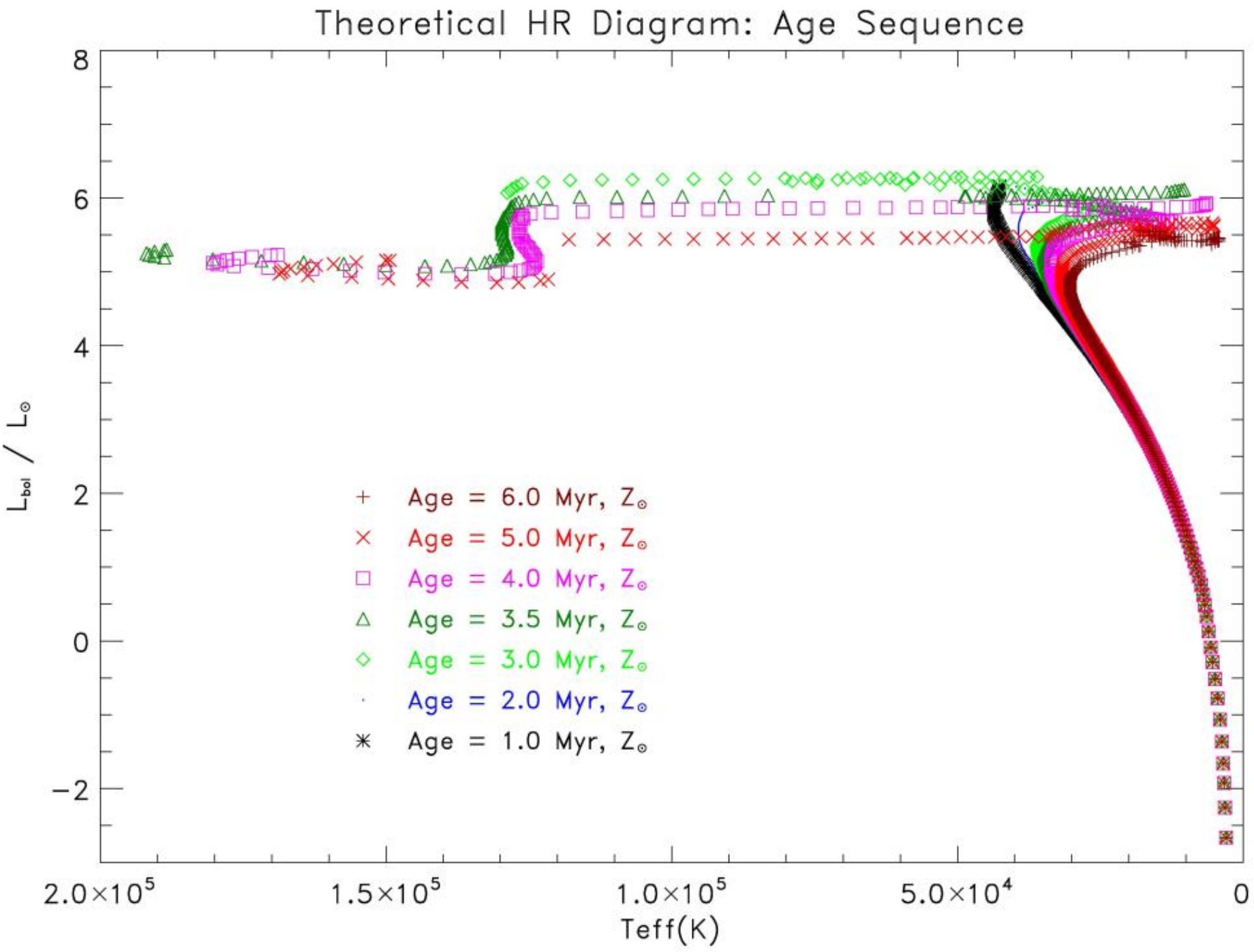

Assigned HR Diagram: Age = 3.0 Myr, Metallicity Effect
8
6
4
2
0
−2
L_{bol} / $L_\odot$
2.0×10^5
1.5×10^5
1.0×10^5
5.0×10^4
0
Teff(K)
Age = 3.0 Myr, Z = 0.2 $Z_\odot$
Age = 3.0 Myr, Z = 0.4 $Z_\odot$
Age = 3.0 Myr, Z = $Z_\odot$
Age = 3.0 Myr, Z = 2.5 $Z_\odot$

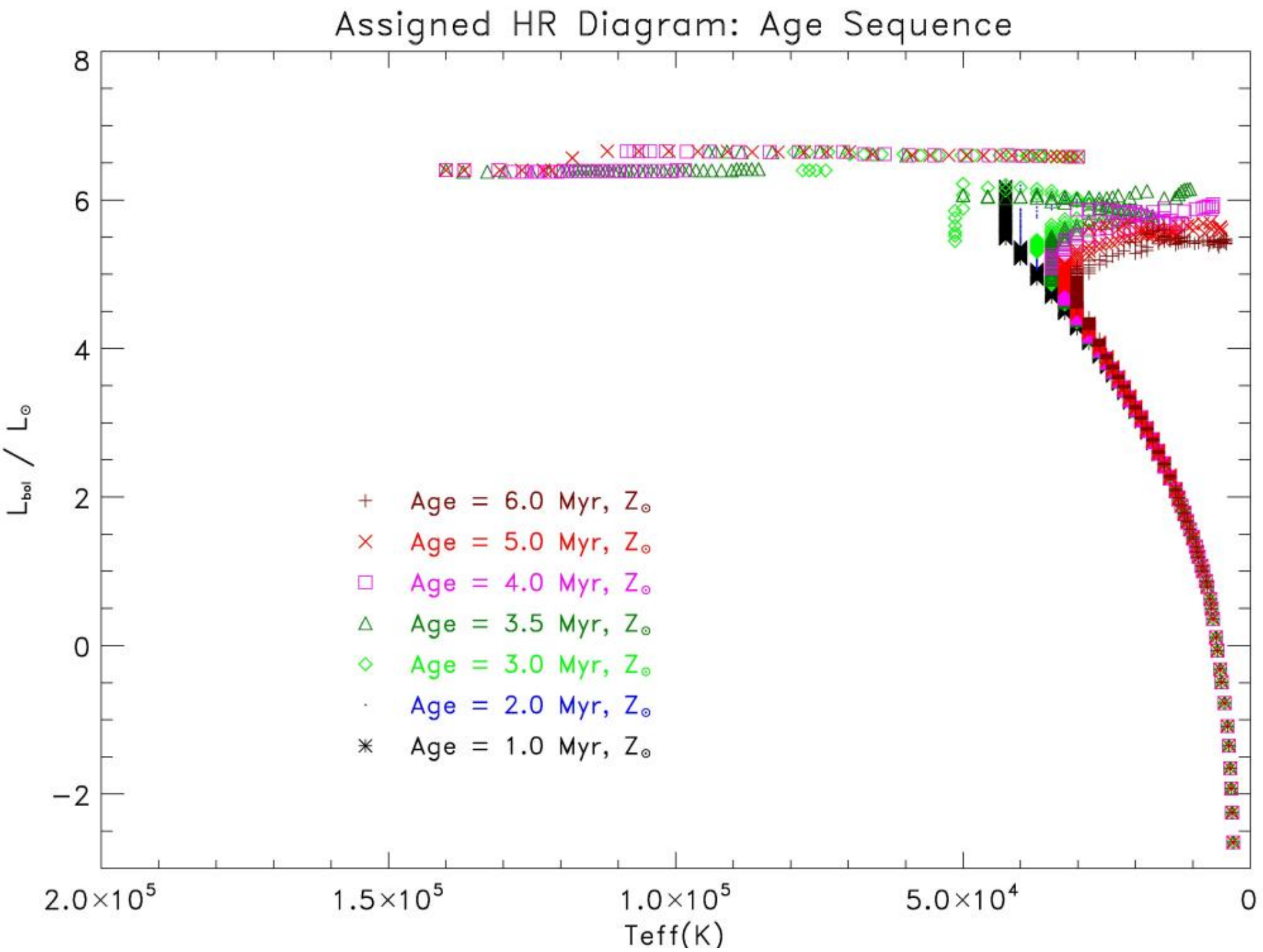

Spectral Energy Distribution: Metallicity Effect @ 3.0Myr
12
10
8
6
4
2
$L_\nu/L_\odot$ (Ry^{-1})
1
0
−1
−2
ν(Ry)
Z = 0.050 = 2.50 Z$_\odot$
Z = 0.020 = 1.00 Z$_\odot$
Z = 0.008 = 0.40 Z$_\odot$
Z = 0.004 = 0.20 Z$_\odot$

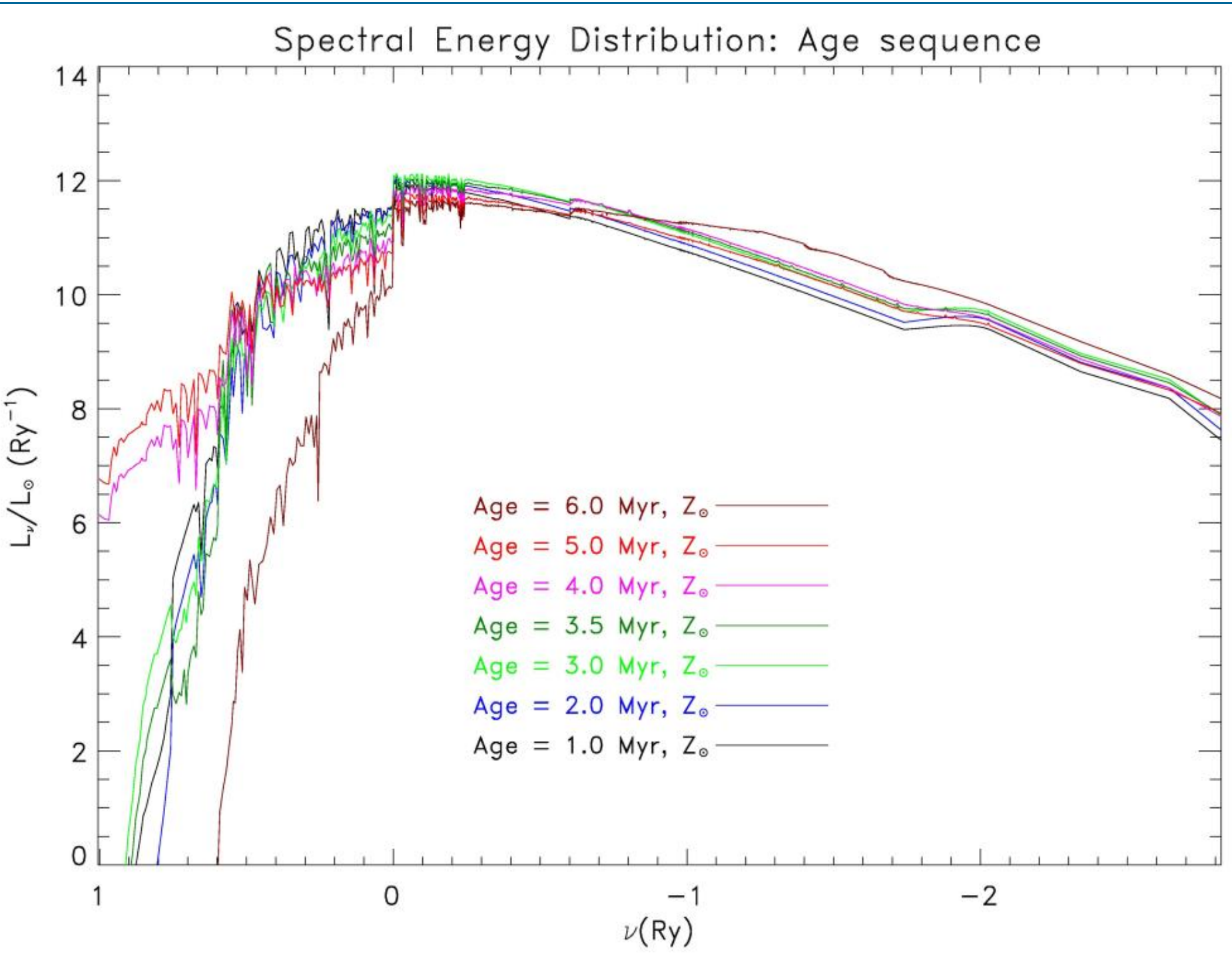

Theoretical HR Diagram: Age = 4.5 Myr, Metallicity Effect
8
6
4
2
0
−2
L_{bol} / $L_\odot$
2.0×10^5
1.5×10^5
1.0×10^5
5.0×10^4
0
Teff(K)
Age = 4.5 Myr, Z = 0.2 $Z_\odot$
Age = 4.5 Myr, Z = 0.4 $Z_\odot$
Age = 4.5 Myr, Z = $Z_\odot$
Age = 4.5 Myr, Z = 2.5 $Z_\odot$

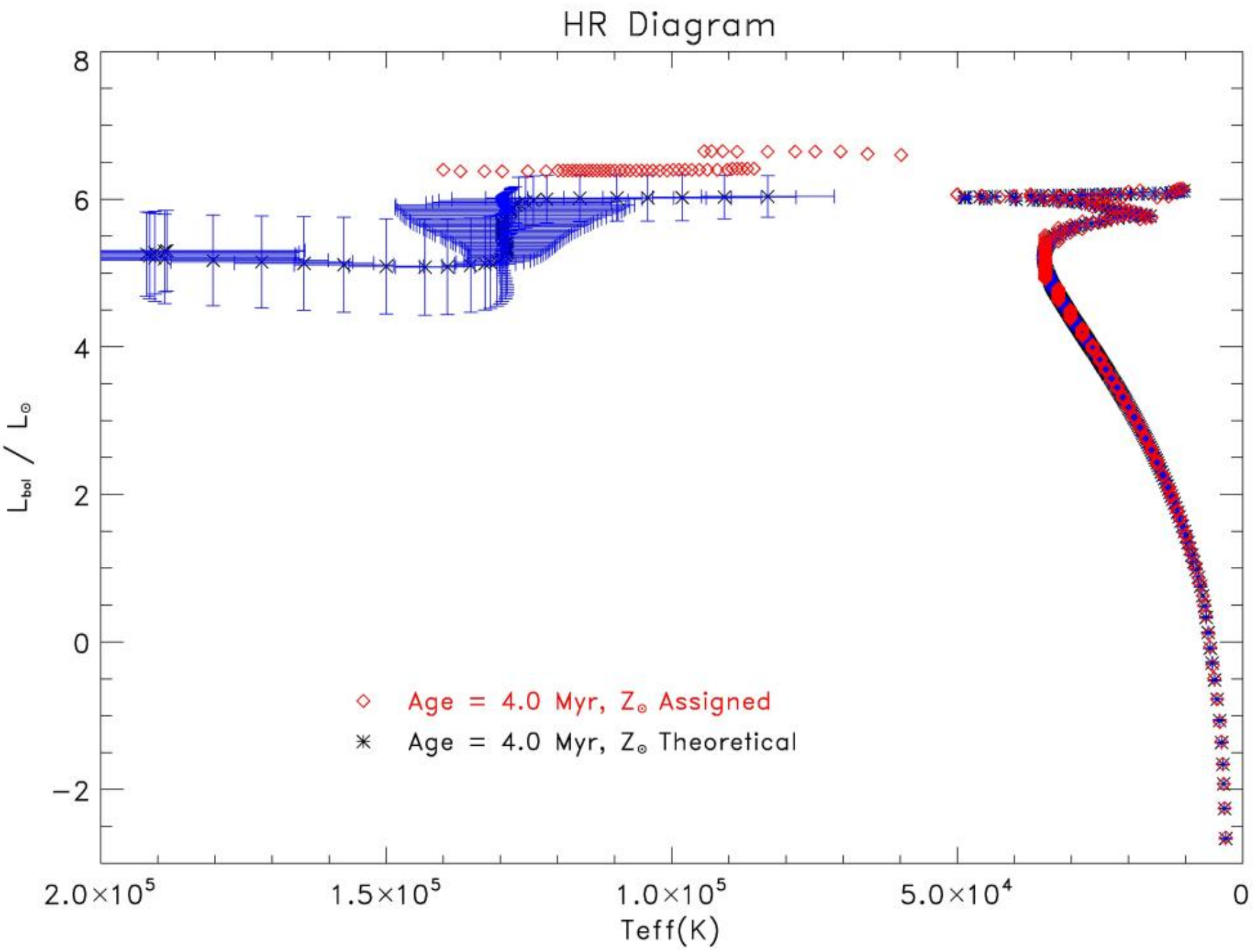

Assigned HR Diagram: Age = 4.5 Myr, Metallicity Effect
8
6
4
2
0
−2
L_{bol} / $L_\odot$
2.0×10^5
1.5×10^5
1.0×10^5
5.0×10^4
0
Teff(K)
Age = 4.5 Myr, Z = 0.2 $Z_\odot$
Age = 4.5 Myr, Z = 0.4 $Z_\odot$
Age = 4.5 Myr, Z = $Z_\odot$
Age = 4.5 Myr, Z = 2.5 $Z_\odot$

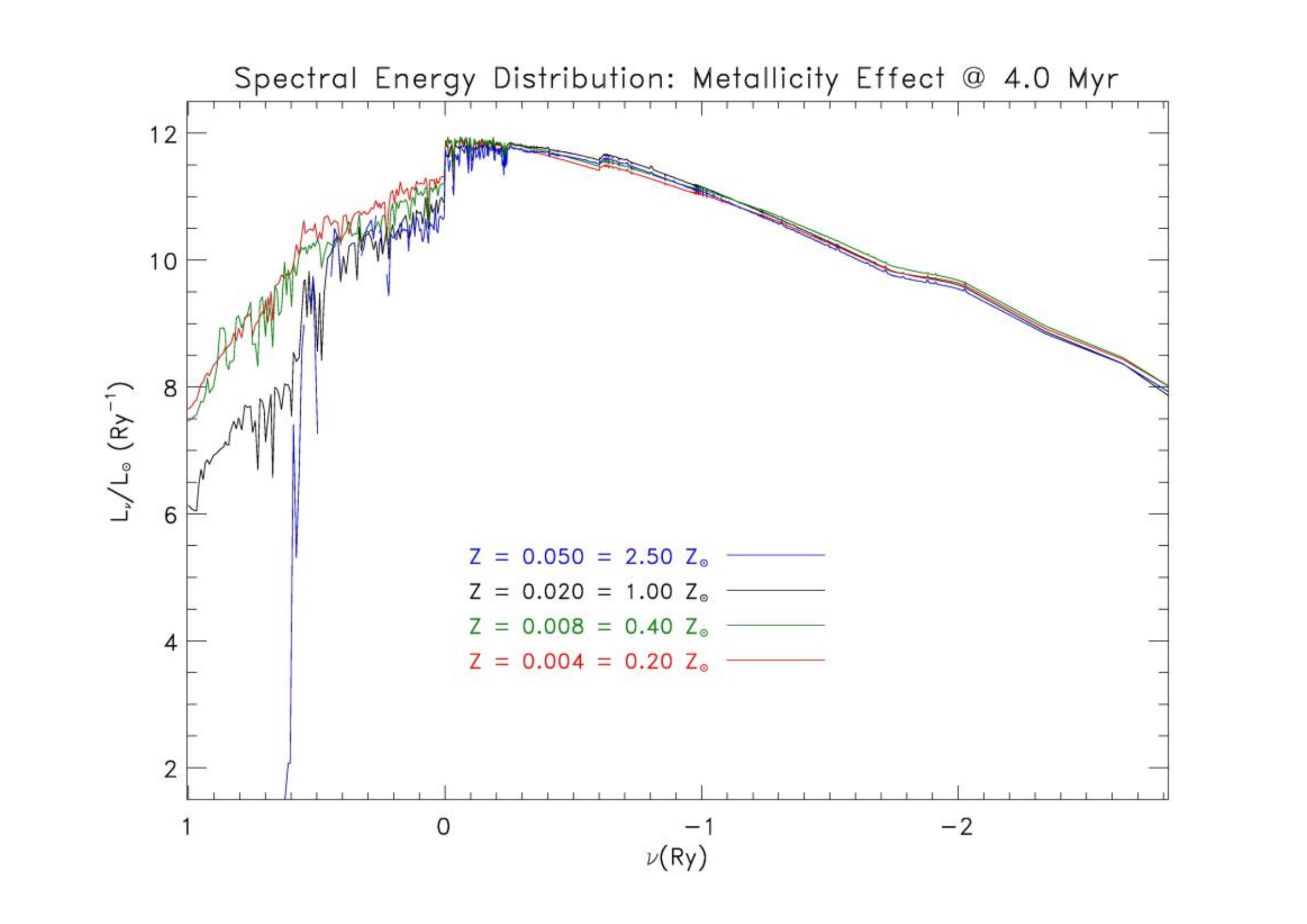

Spectral Energy Distribution: Metallicity Effect @ 4.5Myr
12
10
8
6
4
2
$L_\nu/L_\odot$ (Ry^{-1})
1
0
−1
−2
ν(Ry)
Z = 0.0500 = 2.50 $Z_\odot$
Z = 0.0200 = 1.00 $Z_\odot$
Z = 0.0080 = 0.40 $Z_\odot$
Z = 0.0040 = 0.20 $Z_\odot$
Z = 0.0004 = 0.02 $Z_\odot$

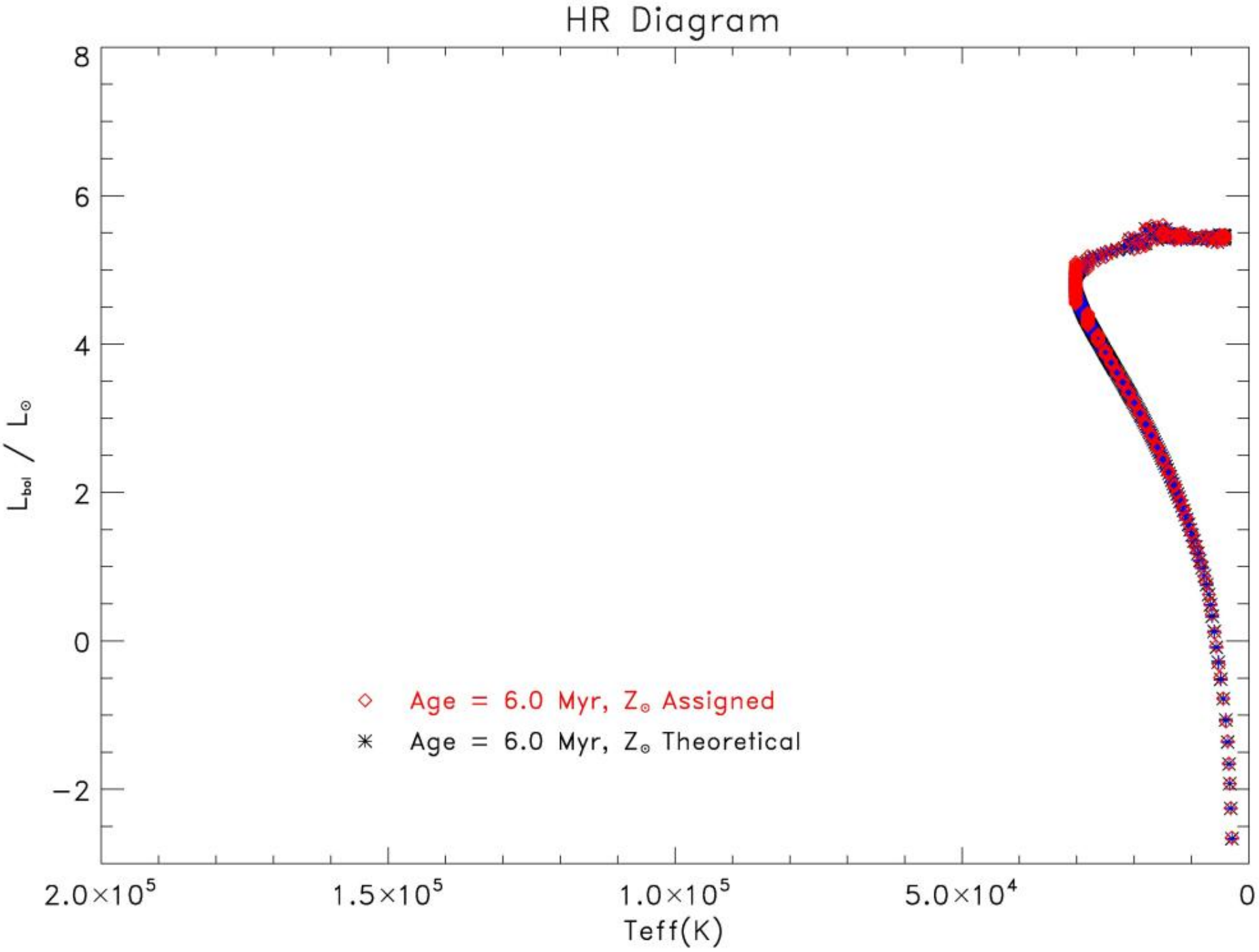

Theoretical HR Diagram: Age Sequence
8
6
4
2
0
−2
L_{bol} / $L_\odot$
Age = 6.0 Myr, $Z_\odot$
Age = 5.0 Myr, $Z_\odot$
Age = 4.0 Myr, $Z_\odot$
Age = 3.5 Myr, $Z_\odot$
Age = 3.0 Myr, $Z_\odot$
Age = 2.0 Myr, $Z_\odot$
Age = 1.0 Myr, $Z_\odot$
2.0×10^5
1.5×10^5
1.0×10^5
5.0×10^4
0
Teff(K)

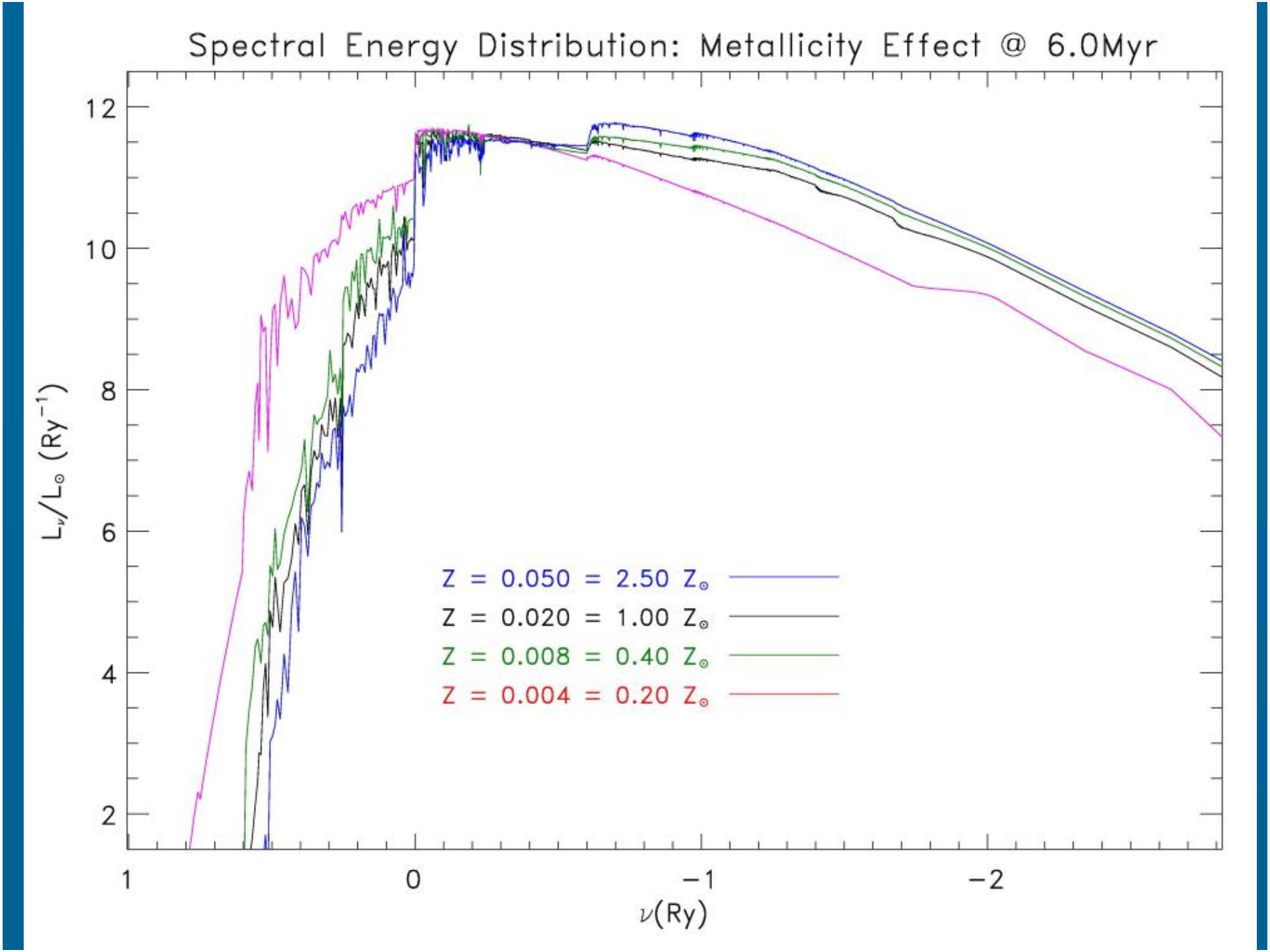

Assigned HR Diagram: Age Sequence
8
6
4
2
0
−2
L_{bol} / $L_\odot$
+ Age = 6.0 Myr, $Z_\odot$
× Age = 5.0 Myr, $Z_\odot$
□ Age = 4.0 Myr, $Z_\odot$
△ Age = 3.5 Myr, $Z_\odot$
◇ Age = 3.0 Myr, $Z_\odot$
· Age = 2.0 Myr, $Z_\odot$
✳ Age = 1.0 Myr, $Z_\odot$
2.0×10^5
1.5×10^5
1.0×10^5
5.0×10^4
0
Teff(K)

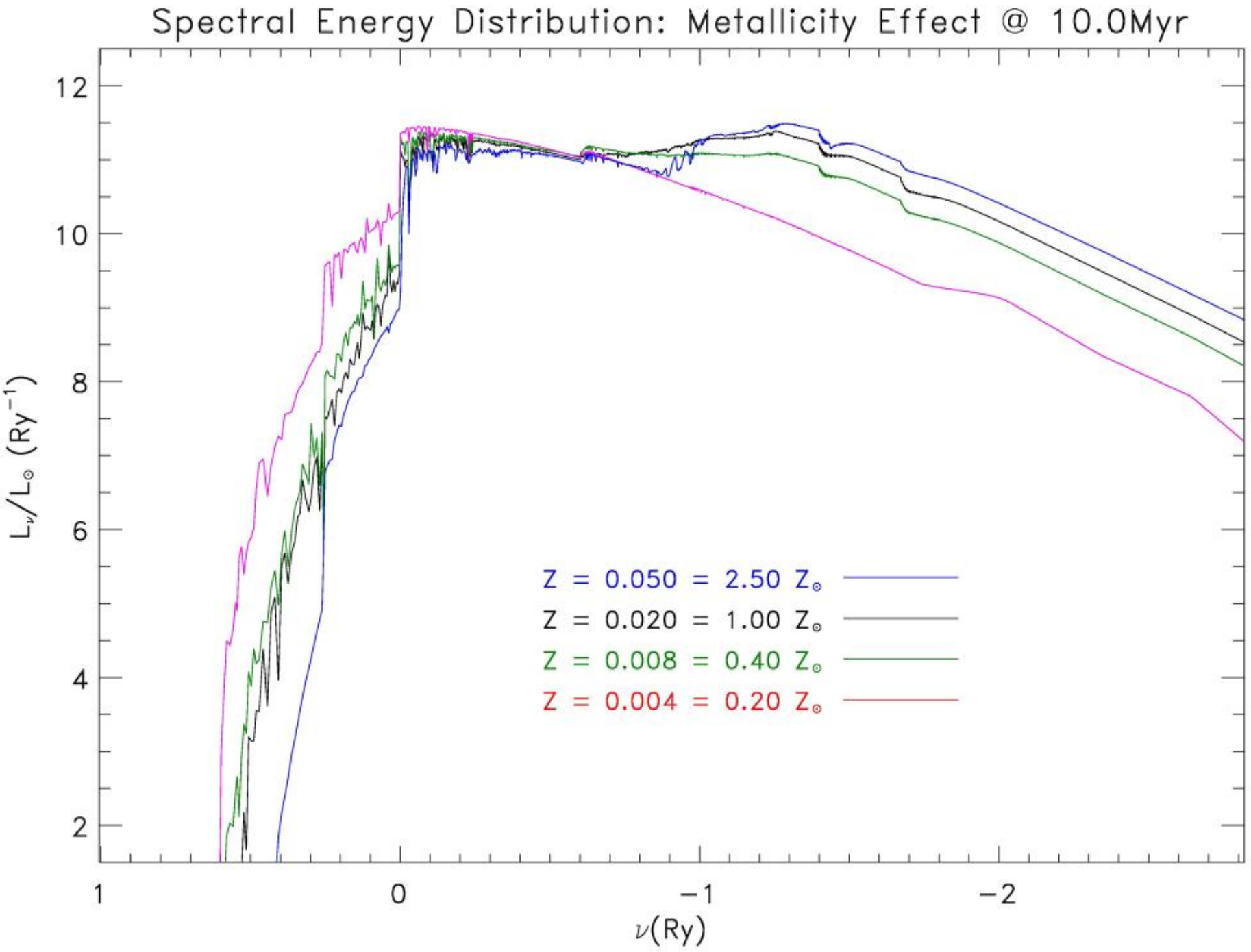

Spectral Energy Distribution: Age sequence
14
12
10
8
6
4
2
0
1
0
−1
−2
$L_\nu/L_\odot$ (Ry^{-1})
ν(Ry)
Age = 6.0 Myr, $Z_\odot$
Age = 5.0 Myr, $Z_\odot$
Age = 4.0 Myr, $Z_\odot$
Age = 3.5 Myr, $Z_\odot$
Age = 3.0 Myr, $Z_\odot$
Age = 2.0 Myr, $Z_\odot$
Age = 1.0 Myr, $Z_\odot$


HR Diagram
8
6
4
2
0
−2
L_{bol} / $L_\odot$
2.0×10^5
1.5×10^5
1.0×10^5
5.0×10^4
0
Teff(K)
Age = 4.0 Myr, $Z_\odot$ Assigned
Age = 4.0 Myr, $Z_\odot$ Theoretical


Spectral Energy Distribution: Metallicity Effect @ 4.0 Myr
12
10
8
6
4
2
$L_\nu/L_\odot$ (Ry^{-1})
1
0
−1
−2
ν(Ry)
Z = 0.050 = 2.50 Z$_\odot$
Z = 0.020 = 1.00 Z$_\odot$
Z = 0.008 = 0.40 Z$_\odot$
Z = 0.004 = 0.20 Z$_\odot$


HR Diagram
8
6
4
2
0
−2
L_{bol} / $L_\odot$
◇ Age = 6.0 Myr, $Z_\odot$ Assigned
✳ Age = 6.0 Myr, $Z_\odot$ Theoretical
2.0×10^5
1.5×10^5
1.0×10^5
5.0×10^4
0
Teff(K)


Spectral Energy Distribution: Metallicity Effect @ 6.0Myr
12
10
8
6
4
2
$L_\nu/L_\odot$ (Ry^{-1})
1
0
−1
−2
ν(Ry)
Z = 0.050 = 2.50 Z$_\odot$
Z = 0.020 = 1.00 Z$_\odot$
Z = 0.008 = 0.40 Z$_\odot$
Z = 0.004 = 0.20 Z$_\odot$

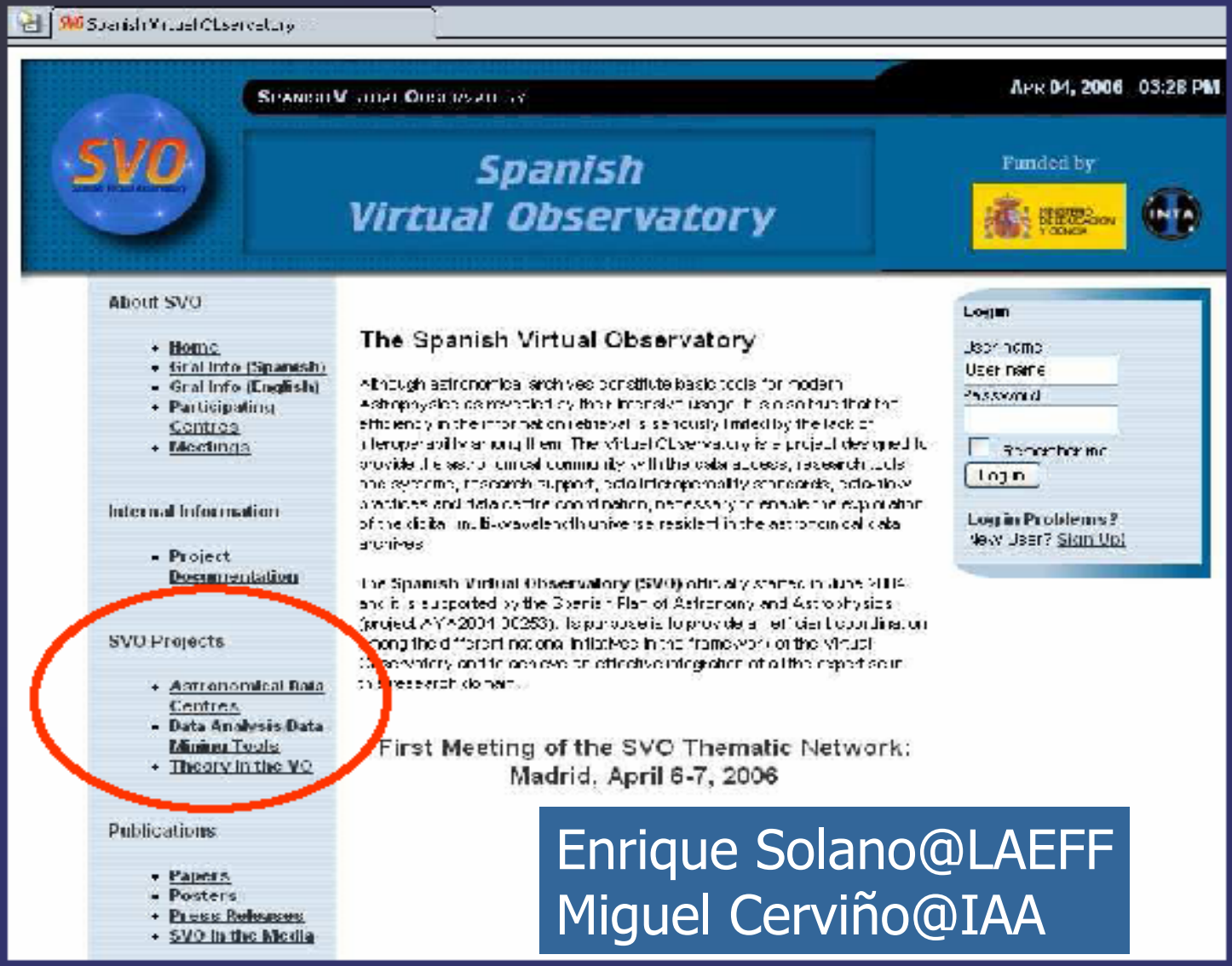

Spectral Energy Distribution: Metallicity Effect @ 10.0Myr
12
10
8
6
4
2
1
0
−1
−2
$L_\nu/L_\odot$ (Ry^{-1})
ν(Ry)
Z = 0.050 = 2.50 Z$_\odot$
Z = 0.020 = 1.00 Z$_\odot$
Z = 0.008 = 0.40 Z$_\odot$
Z = 0.004 = 0.20 Z$_\odot$

Conclusions

- We have computed a new set of evolutionary synthesis models with the state-of-the-art inputs found in the market
- For young ages, WR models determine the hardest ionizing cluster spectrum and therefore the emission line spectrum.
- New Non-LTE blanketed models produce less hard ionizing photons more energetic than 54ev, which implies less excitation in high metallicity HII regions, in agreement with observations (no need of changing IMF parameters either mass segregation)
- For older ages, post-AGB and planetary nebula, although transient phases, have a significant impact in the UV and ionizing spectrum
- We will make the models available in the Virtual Observatory (To be presented in the ESA Conference 21-23 March 2007)



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Fractal
SLNE