A multipurpose 3-D grid of stellar models

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1. Questions every stellar astronomer has to answer from time to time

- What is the UV-optical-NIR spectral energy distribution of a solar-metallicity 9000 K main-sequence star at a distance of 700 pc and an A_V of 1.3 magnitudes?
- What about its *JHK* magnitudes as a function of metallicity?
- A star with LMC metallicity has an unreddened *B-V* color of -0.05 and its luminosity is 10^5 $L_\odot$. How well constrained is its mass from that information?

2. Possible sources of answers

- Textbooks or textbook-like references (e.g. Carroll & Ostlie 1996):
  - ★ Information may be outdated and/or incomplete.
  - ★ Sources are sometimes unclear.
- Modern references and websites with stellar atmospheres, evolutionary tracks, and others:
  - ★ But each source provides only part of the puzzle: $T_{\rm eff}$ + log g but not luminosity, photometry but not mass...
  - ★ Different sources cover only partial ranges in $T_{\rm eff}$, mass, L... What about consistency over the full range?
  - ★ Photometry is usually limited to one or a few systems.

3. What do we want?

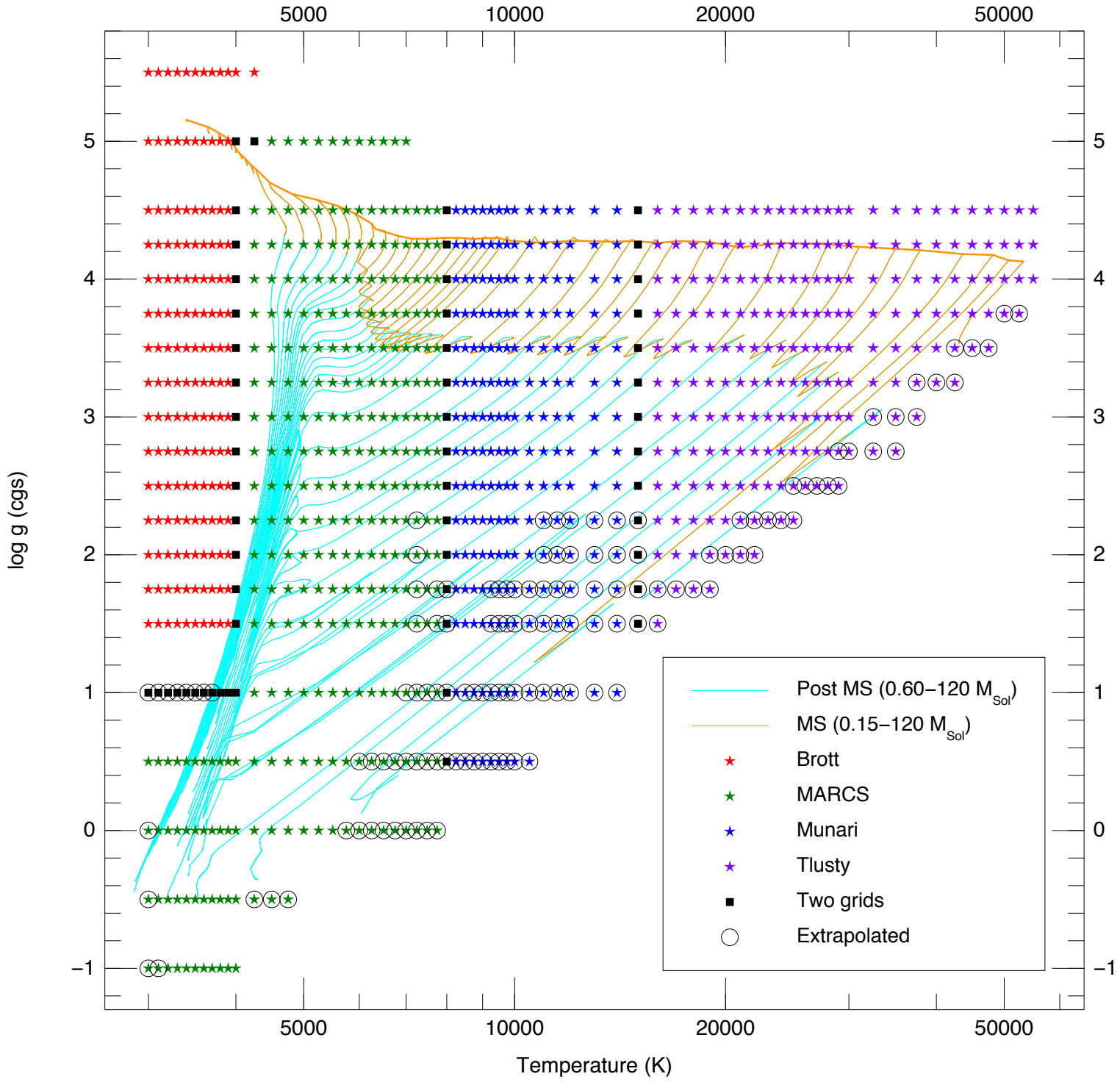
- A 3-D cartesian grid with coordinates:
  - ★ $T_{\rm eff}$
  - ★ Luminosity class (LC): A parameter equivalent to the spectroscopic one that ranges from 0 (hypergiants) to 5.5 (ZAMS).
  - ★ Z
- What should go at each point in the grid?
  - ★ Distance-calibrated SEDs at least from 1000 Å to 2.5 μm
  - ★ log L
  - ★ log g
  - ★ m_i (mean initial mass)
  - ★ σ_{m_i} (range of initial masses)
  - ★ m (mean current mass)
  - ★ Evolutionary phase
  - ★ Mean age
  - ★Time spent at a given point (cell)
  - ★ IMF + age range weight
- Plus photometry:
  - ★ Magnitudes, colors, indices, bolometric corrections ...
  - ★ ... which require filter throughputs, zero points, and extinction laws.

4. What do I use? Stellar atmospheres

- Four regions in the $T_{\rm eff}$ + log g plane for three metallicities (MW, LMC, and SMC) (Fig. 1):
  - ★ TLUSTY (Lanz & Hubeny 2003, 2007).
  - ★ Munari (Munari et al. 2005).
  - ★ MARCS (Gustaffson et al. 1975, 2003, Plez et al. 1992).
  - ★ Brott (Brott & Hauschildt 2005).
- Interpolations checked at boundaries to avoid jumps.
- Some extrapolations into low gravity are needed due to the lack of publicly existing models at the present time.

Figure 1. Grid coverage in the $T_{\rm eff}$ - log g plane for the MW metallicity. Different colors and symbols are used to indicate the source of the used SED at each point, with solid black squares for the cases where the average of two SED families were used. Empty circles indicate those points where the SED was extrapolated (i.e. it did not exist in the original grid and it could not be interpolated): those SEDs should be considered of lower accuracy than the rest.

The Geneva evolutionary tracks for Z = 0.020 with standard mass-loss rates (9 $M_\odot \leq m_{\rm i} \leq$ 120 $M_\odot$) and the Padova evolutionary tracks for Z = 0.019 (0.15 $M_\odot < m_{\rm i} \leq$ 7 $M_\odot$) are also plotted.



5. What do I use? Evolutionary tracks + luminosity classes

- Two mass ranges:
  - ★ Geneva (Lejeune and Schaerer 2001) $m_i \geq 9\ M_\odot$.
  - ★ Padova (Girardi et al. 2000, Salasnich et al 2000) $m_i \leq 7\ M_\odot$.
- Luminosity classes (Fig. 2):
  - ★ Follow spectroscopic equivalents approximately.
  - ★ Top [LC=0.0], left [T_{eff} = Max(T_{eff})], and bottom [LC=5.5] edges of the grid are constant.
  - ★ Right edge is irregular and metallicity-dependent (Figs. 4-9).

Figure 2. Building the MW metallicity grid. The black lines are the Geneva/Padova evolutionary tracks between 0.15 $M_{\odot}$ and 120 $M_{\odot}$ (a label at the beginning of the track shows the initial mass). Different symbols are used for the luminosity types 0.0... 5.5. Note that luminosity types are defined in the grid at 0.1 intervals but only those at 0.5 intervals are shown for clarity.

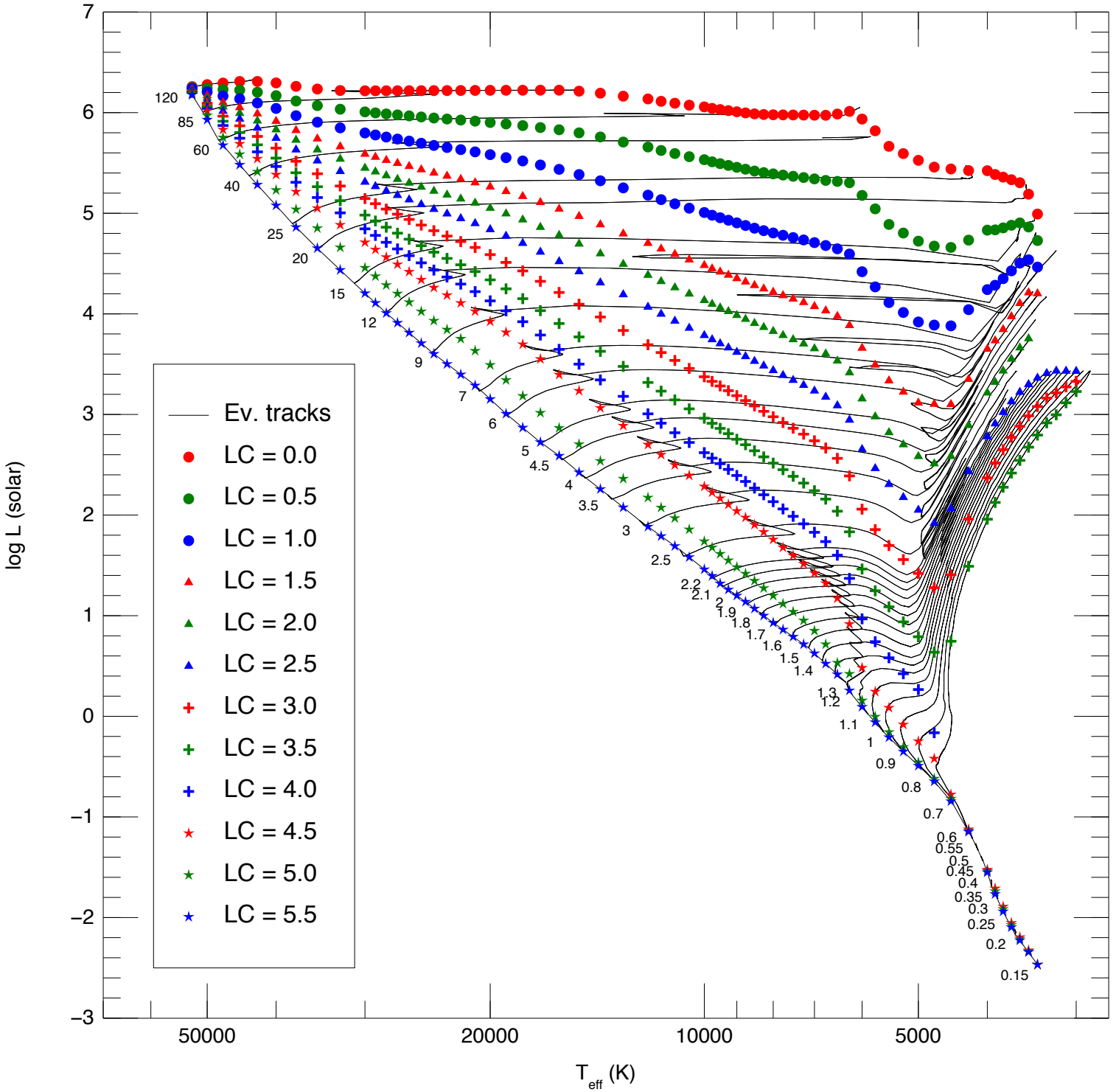
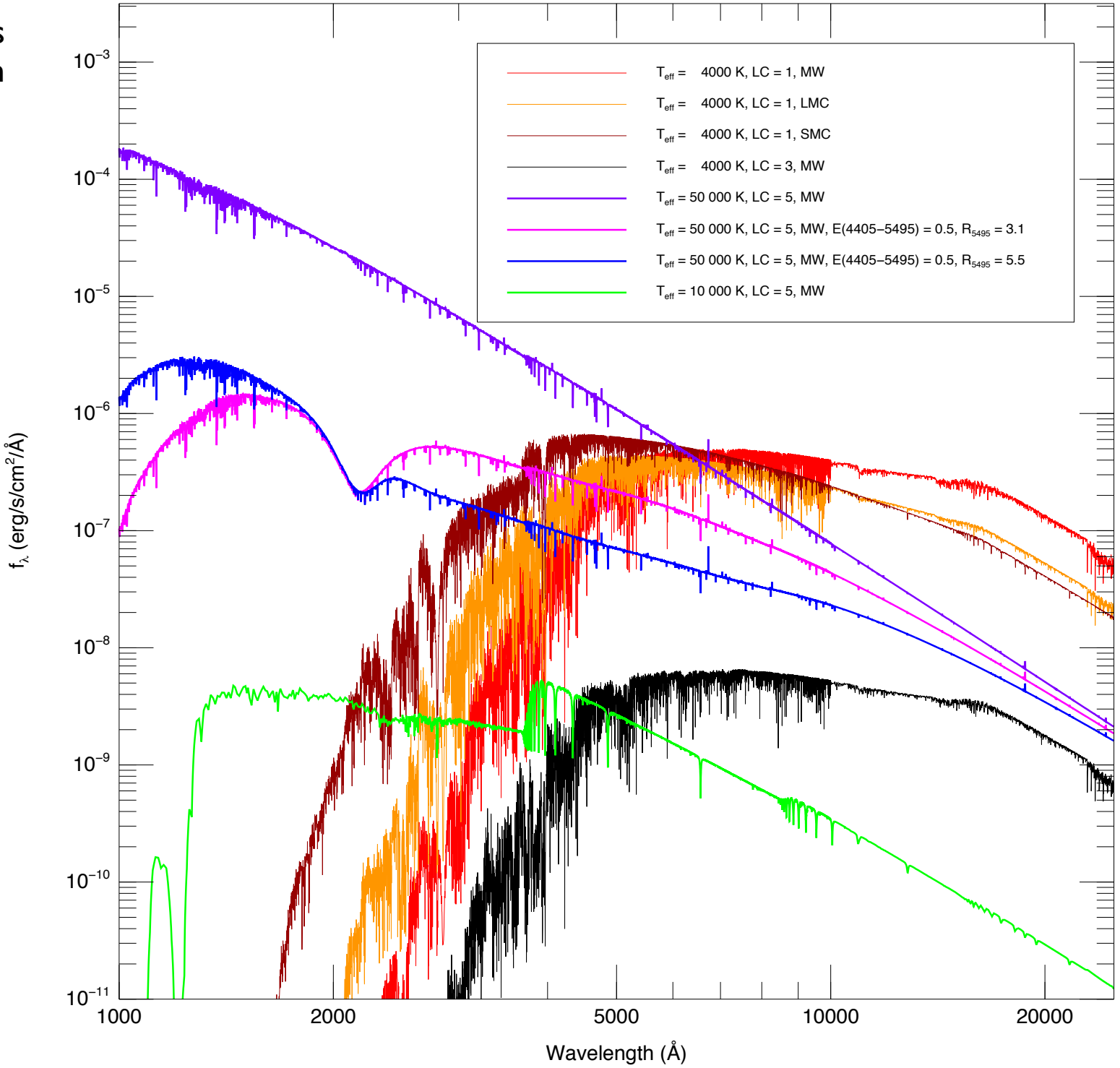


Figure 3. Sample SEDs from the grid. Fluxes shown for a distance of 10 pc.



6. What do I use? Photometry and extinction

- Photometry: jmasynphot.
  - ★ Written in IDL.
  - ★ Developed for CHORIZOS (Maíz Apellániz 2004).
  - ★ 145 different filters (Johnson-Cousins, Strömgren, HST, SDSS, IPHAS, Galex, Tycho-2).
  - ★ Self-consistent calibration (Maíz Apellániz 2005, 2006, 2007).
  - ★ Bolometric corrections calculated.
- Extinction: Maíz Apellániz et al. (talk at this meeting).
  - ★ Single-parameter (R_{5495}) family of extinction laws.
  - ★ Similar to Cardelli et al. (1989) but with lower residuals.

7. Applications

- Reference and education.
- Filter selection for observational projects.
- Exposure time calculators.
- Input for CHORIZOS (Maíz Apellániz 2004):
  - ★ Bayesian photometric code: you give me photometry, I give you which SEDs are compatible with it.
  - ★ New version (3.x) has distance as independent parameter and needs SEDs with absolute flux calibration.
  - ★ Processing of multi-filter Galactic photometry: from magnitudes to distances, extinction, and physical properties.

8. What is currently not there but may be in the future

- More recent evolutionary tracks with finer grids.
- Rotation, stellar winds...
- Late evolutionary phases: Wolf-Rayet, post-He flash, white dwarfs...
- More metallicity points.
- Extension to the MIR.
- Interested in collaborating? Look for me!

References

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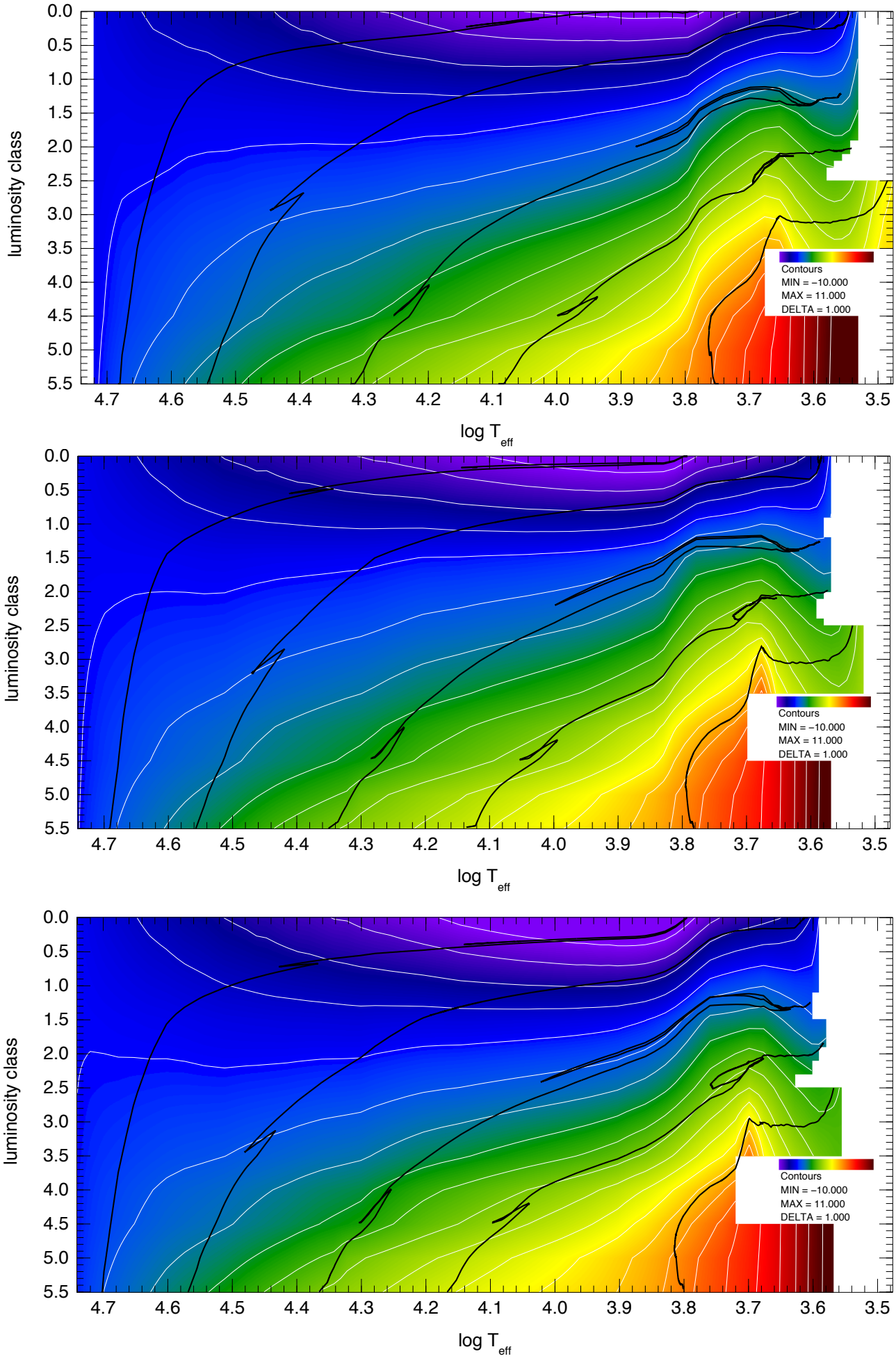

Figure 4. Johnson *V* magnitude for the MW (top), LMC (center), and SMC (bottom) $T_{\rm eff}$ - LC grids. In all cases the contours are spaced at 1 magnitude intervals between $V = 11.0$ and $V = -10.0$. The evolutionary tracks for $m_{\rm i} = 1, 3, 7, 20$, and 60 $M_{\odot}$ are also plotted.

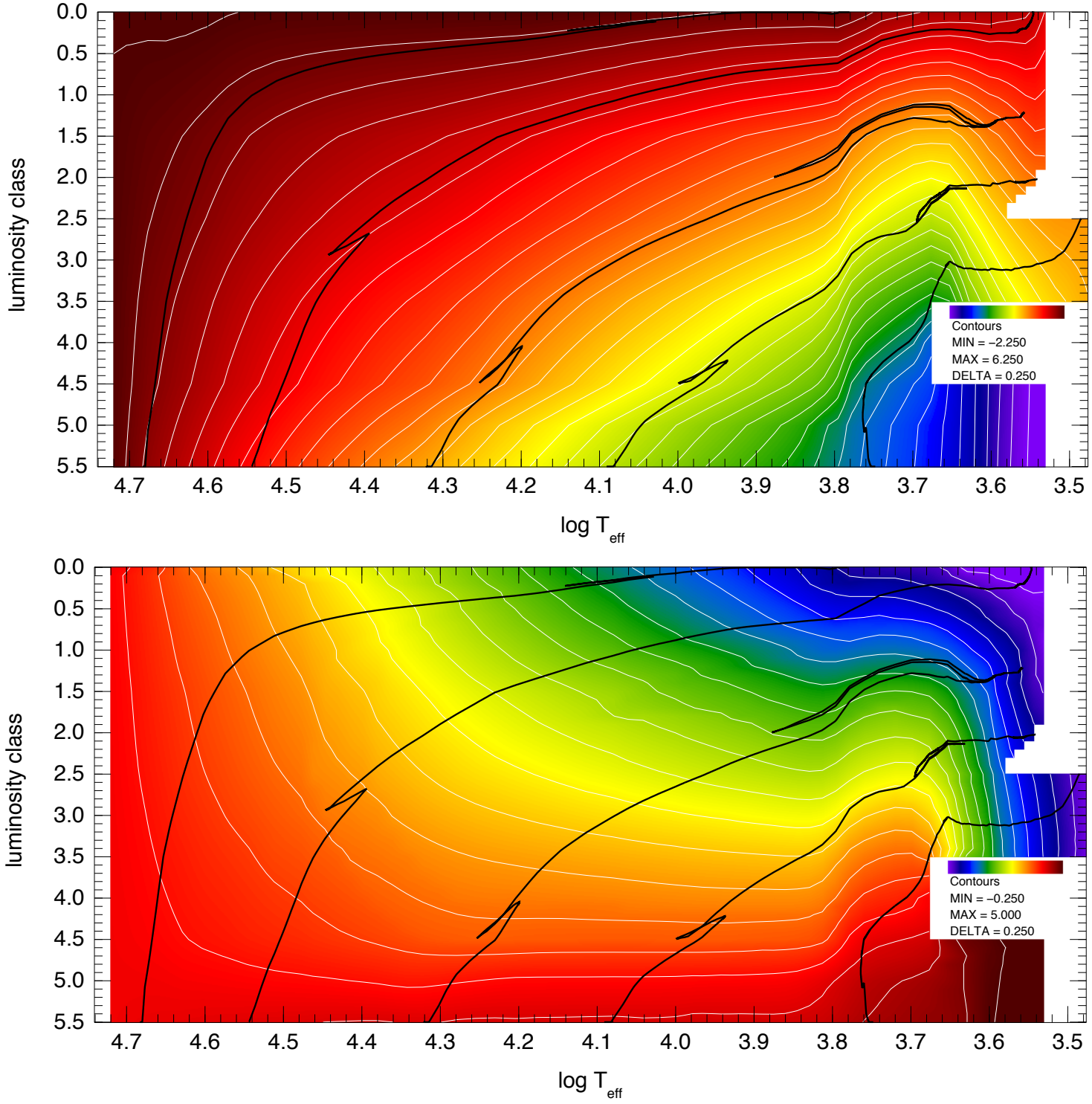

Figure 5. log *L* (top) and log *g* (bottom) $T_{\rm eff}$ - LC grid for the MW. The log *L* contours range from -2.25 to 6.25 (solar units) with a spacing of 0.25. The log *g* contours range from -0.25 to 5.00 (cgs) with a spacing of 0.25. The evolutionary tracks for $m_{\rm i}$ = 1, 3, 7, 20, and 60 $M_{\odot}$ are also plotted.

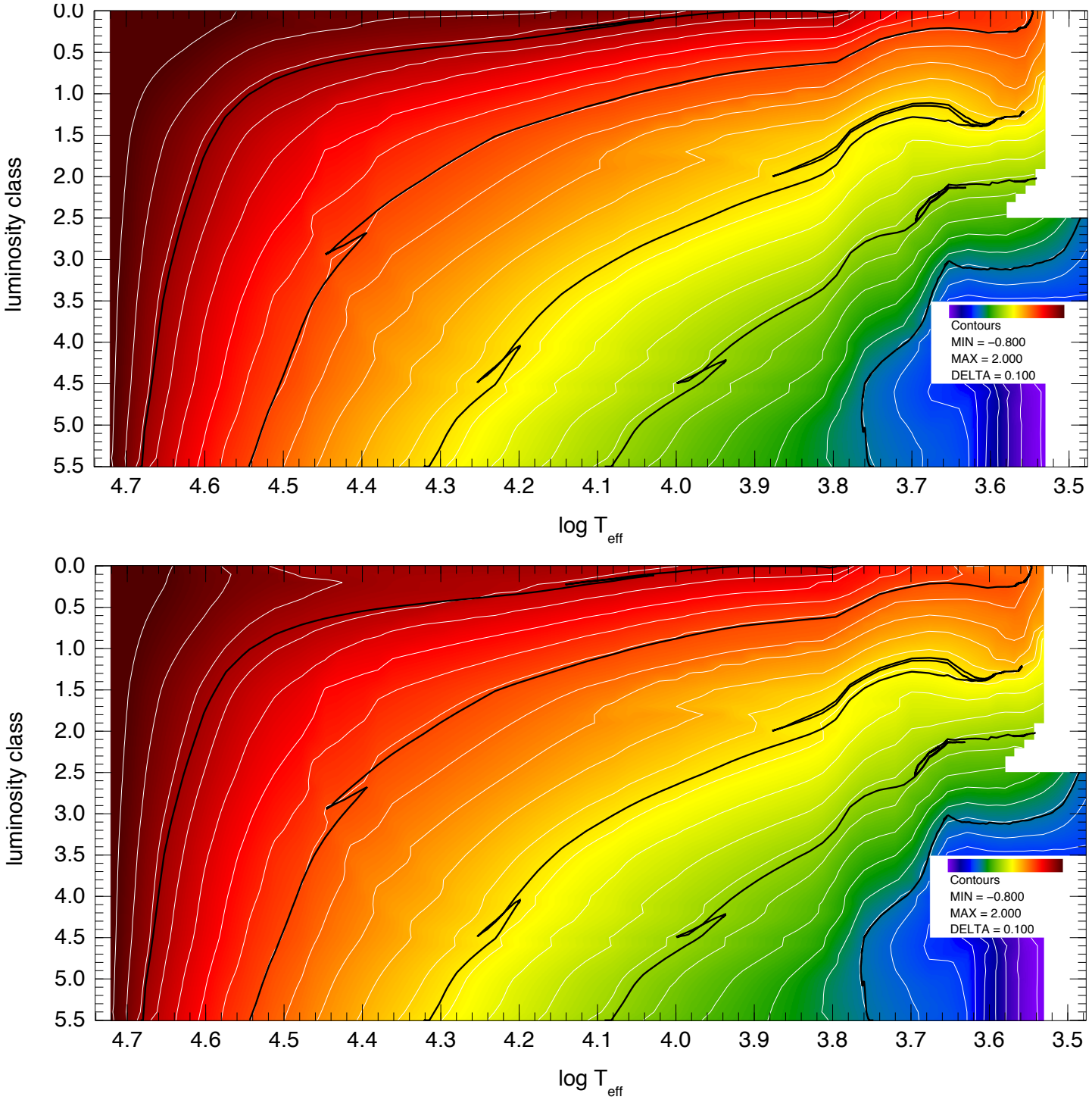

Figure 6. log m_i (top) and log m (bottom) T_{eff} - LC grid for the MW. The contours range from -0.8 to 2.0 (solar units) with a spacing of 0.1. The evolutionary tracks for m_i = 1, 3, 7, 20, and 60 $M_\odot$ are also plotted.

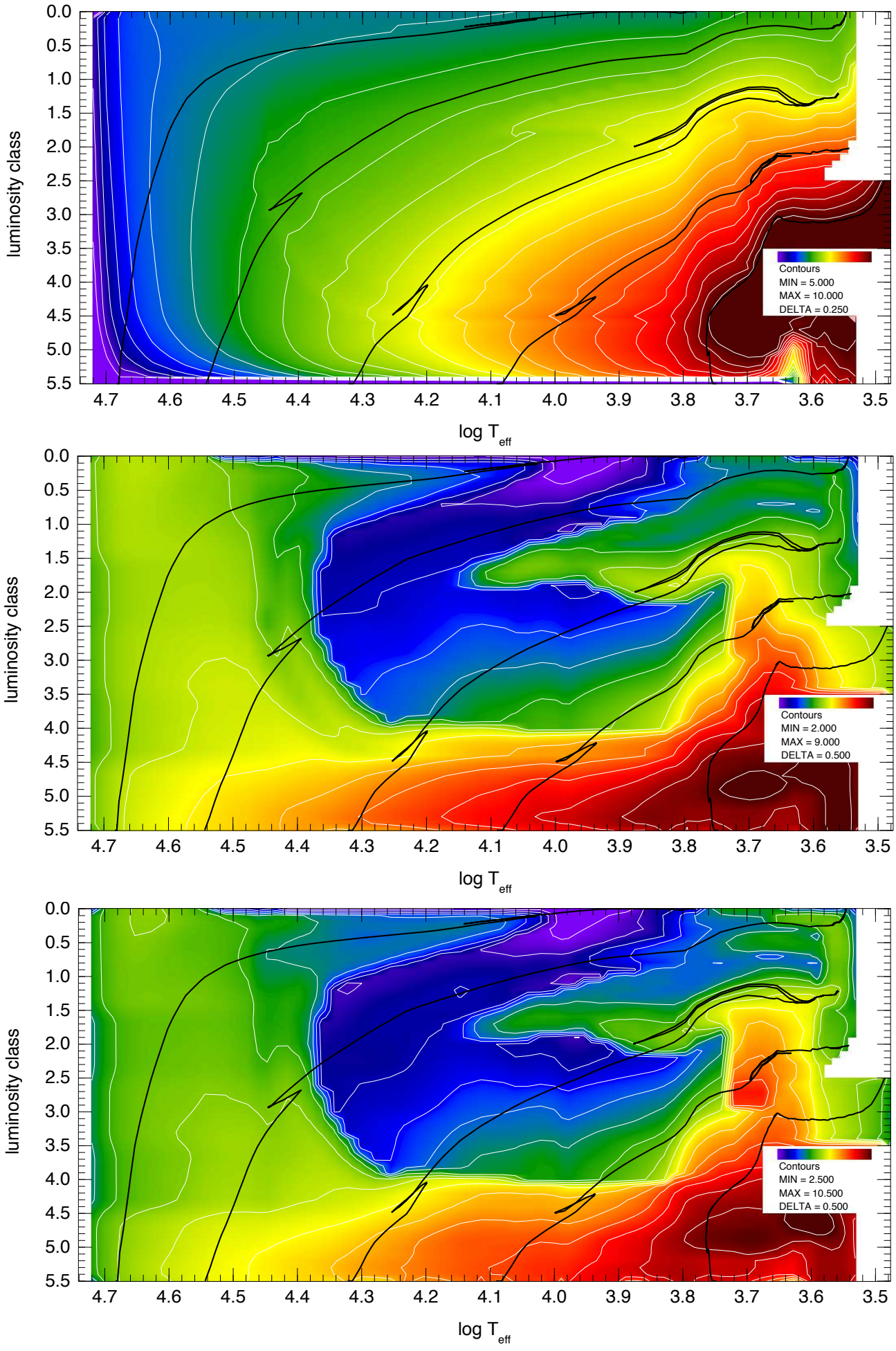

Figure 7. Mean age (top), time spent in a cell (center), and IMF + age range weight (bottom) $T_{\rm eff}$ - LC grid for the MW. The top and center panels are shown in log a with minima of 5 and 2, maxima of 10 and 9, and spacings of 0.25 and 0.50, respectively. The evolutionary tracks for $m_{\rm i}$ = 1, 3, 7, 20, and 60 $M_{\odot}$ are also plotted.

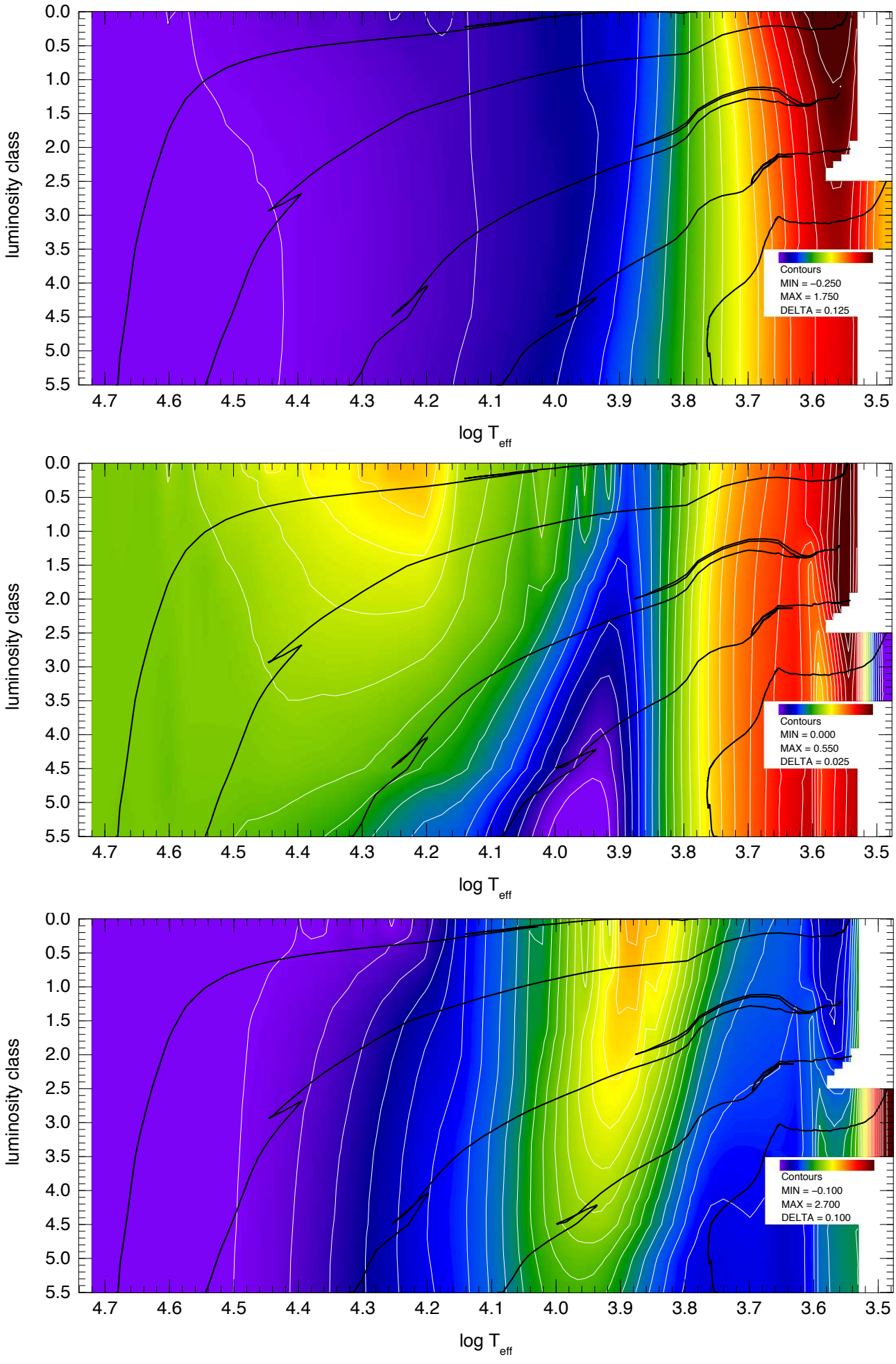

Figure 8. Johnson *B-V* (top), Cousins *R* - WFPC2 F656N (center), and Strömgren c_1 (bottom) $T_{\rm eff}$ - LC grid for the MW. All panels are shown in magnitudes with minima of -0.25, 0.00, and -0.10; maxima of 1.75, 0.55, and 2.70; and spacings of 0.125, 0.025, and 0.100, respectively. The evolutionary tracks for $m_{\rm i}$ = 1, 3, 7, 20, and 60 $M_{\odot}$ are also plotted.

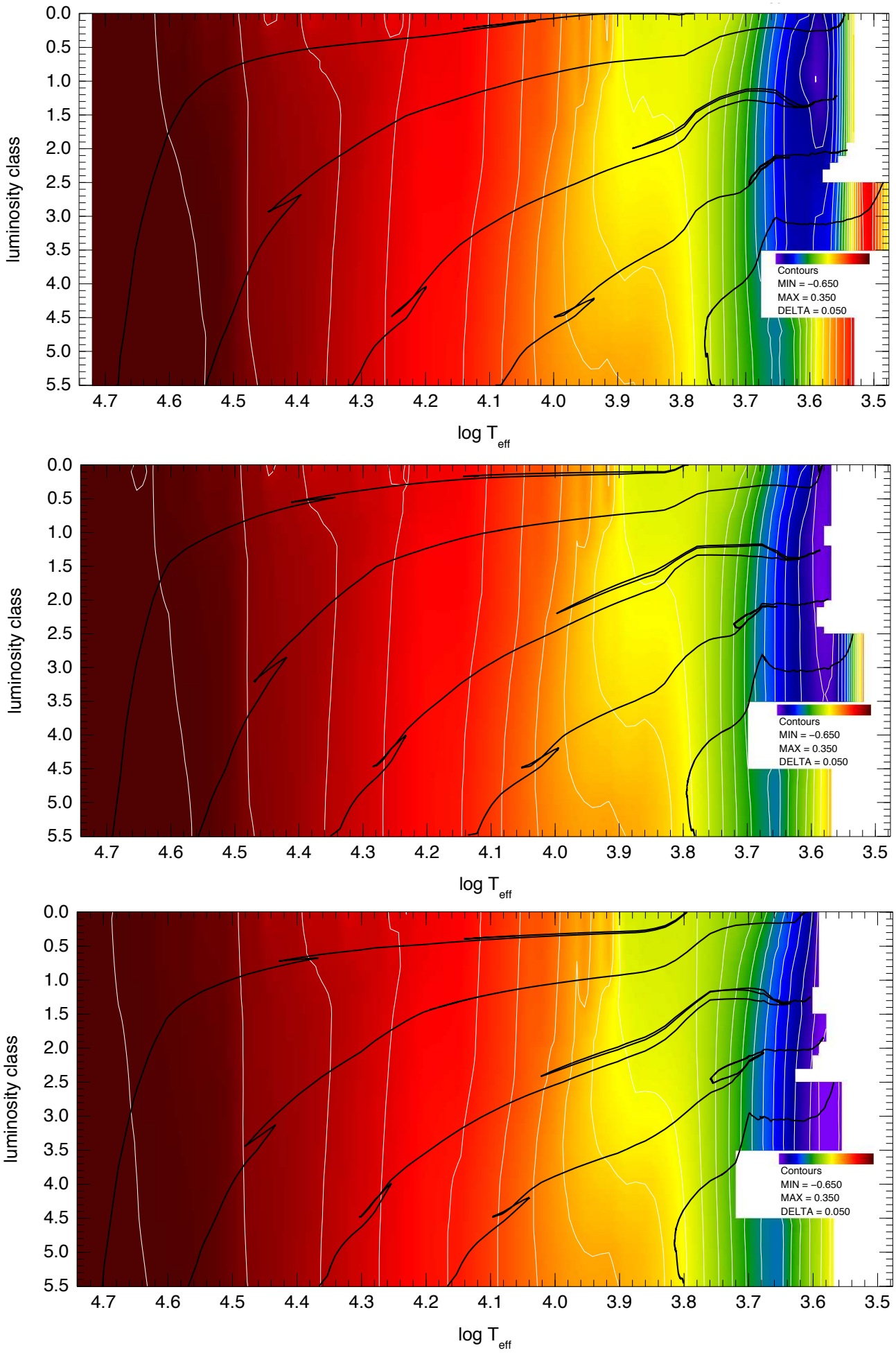

Figure 9. Johnson-Cousins-2MASS *V*-2*I*+*K* index for the MW (top), LMC (center), and SMC (bottom) $T_{\rm eff}$ - LC grids. In all cases the contours are spaced at 0.05 magnitude intervals between -0.65 and 0.35. The evolutionary tracks for $m_{\rm i}$ = 1, 3, 7, 20, and 60 $M_{\odot}$ are also plotted.