CHORIZOS: A chi-square code for photometry and spectrophotometry

Maíz-Apellániz (2004), PASP **116**, 859

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A crash course on acronyms

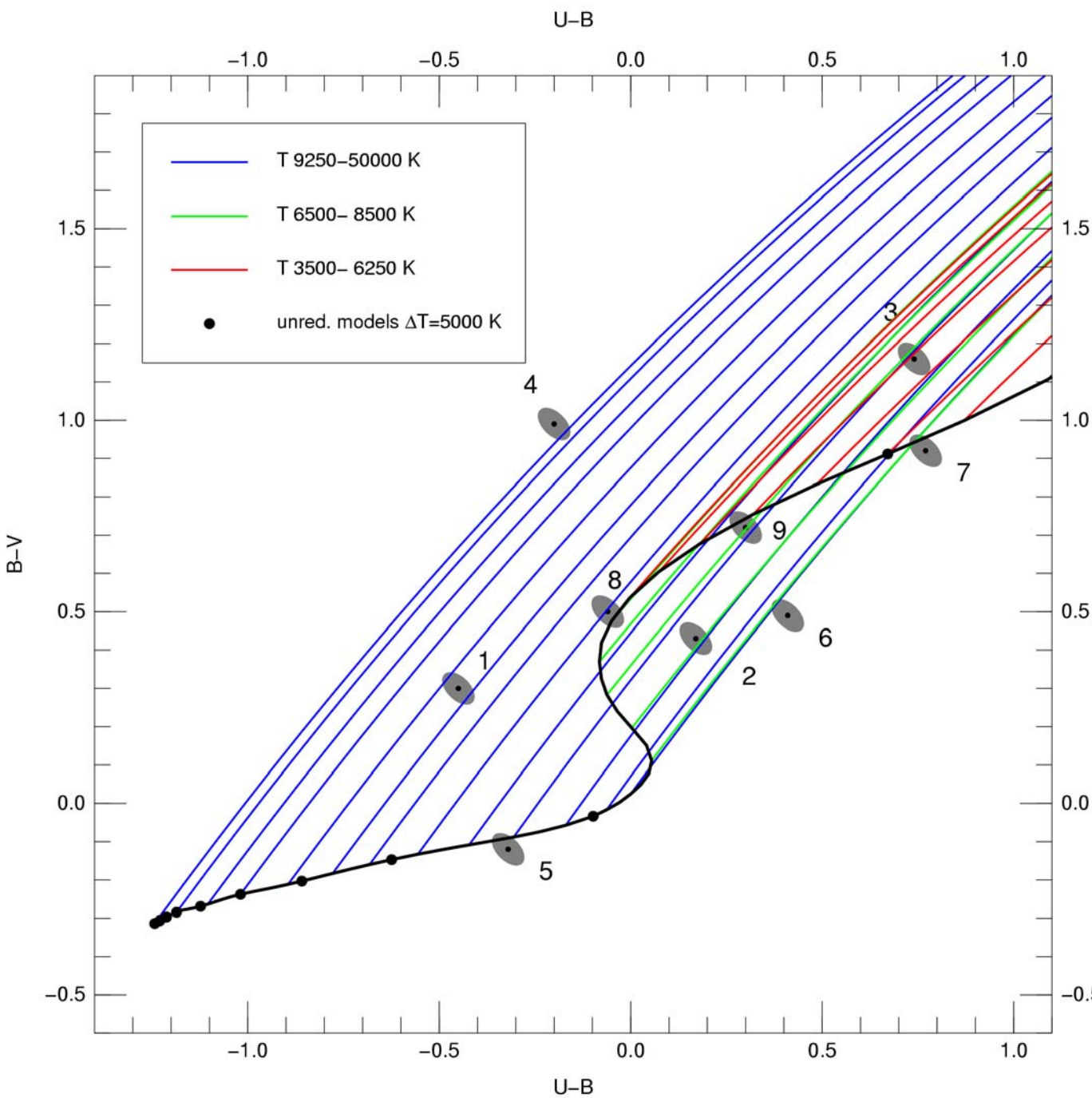
CHORIZOS: a CHi-square
cOde for
paRameterized
modelIng and
characteriZation of
phOtometry and
Spectrophotometry

Description of the problem

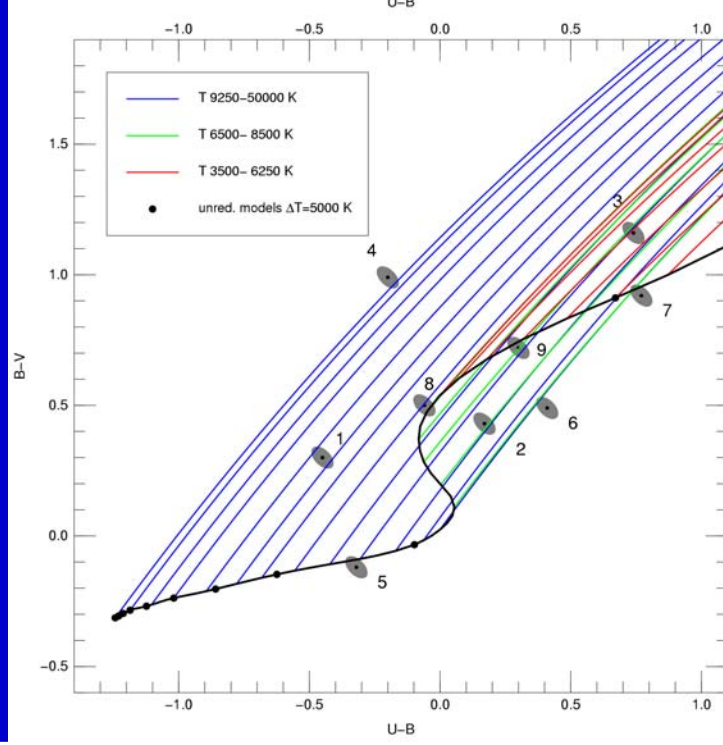
- M+1 magnitudes: $m_1, m_2 \ldots m_{M+1}$ + uncertainties: $s_1, s_2 \ldots s_{M+1} \Rightarrow$
  M independent colors: $c_1, c_2 \ldots c_M$ + uncertainties: $\sigma_1, \sigma_2 \ldots \sigma_M$
- SED family/ies: $f_1(\lambda; p_1, p_2 \ldots p_N)$ e.g. stars (Kurucz…)
  $f_2(\lambda; p_1, p_2 \ldots p_N)$ e.g. clusters (Starburst99…)

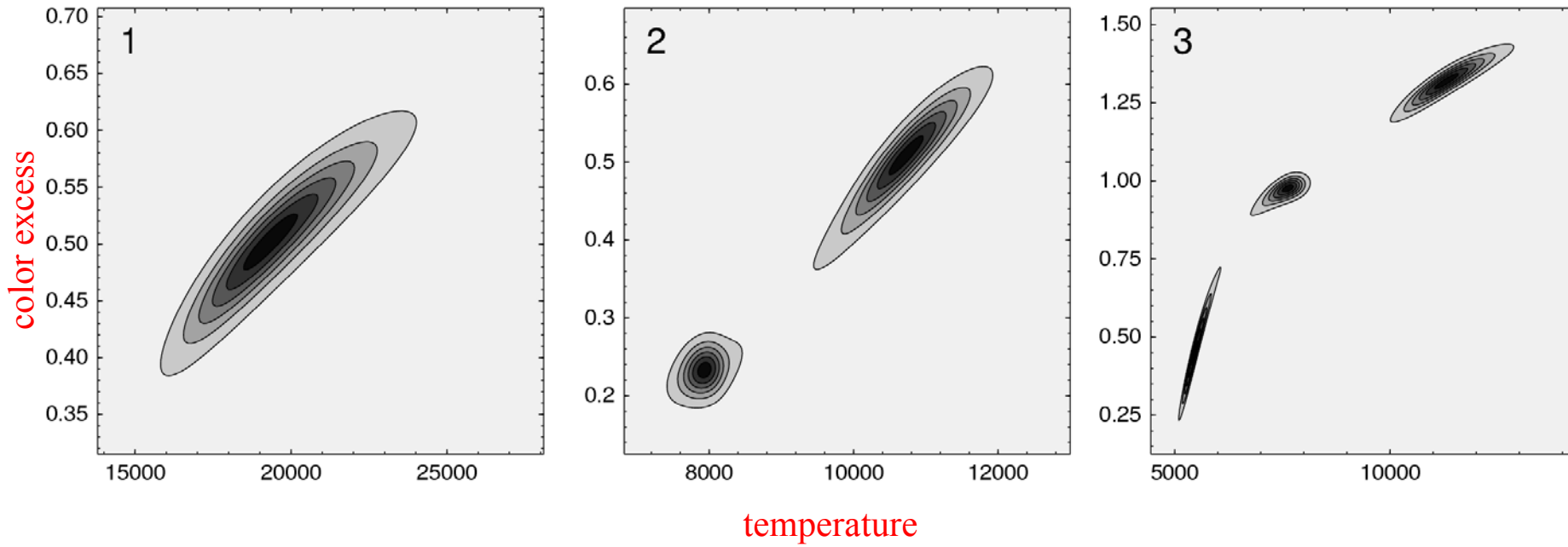
  with N parameters
  - Intrinsic: temperature, age, gravity…
  - Extrinsic: color excess, extinction law, redshift…
- What SEDs (if any) are compatible with the observed colors?
- $M = N \Rightarrow$ usually consistent (1+ solutions) $\Rightarrow$ solve (non-linear) system
- $M > N \Rightarrow$ usually inconsistent (0 solutions) $\Rightarrow \chi^2$ minimization
- ndf = $M - N$

Measuring temperature and color excess with Johnson *UBV* photometry (*M*=2, *N*=2)

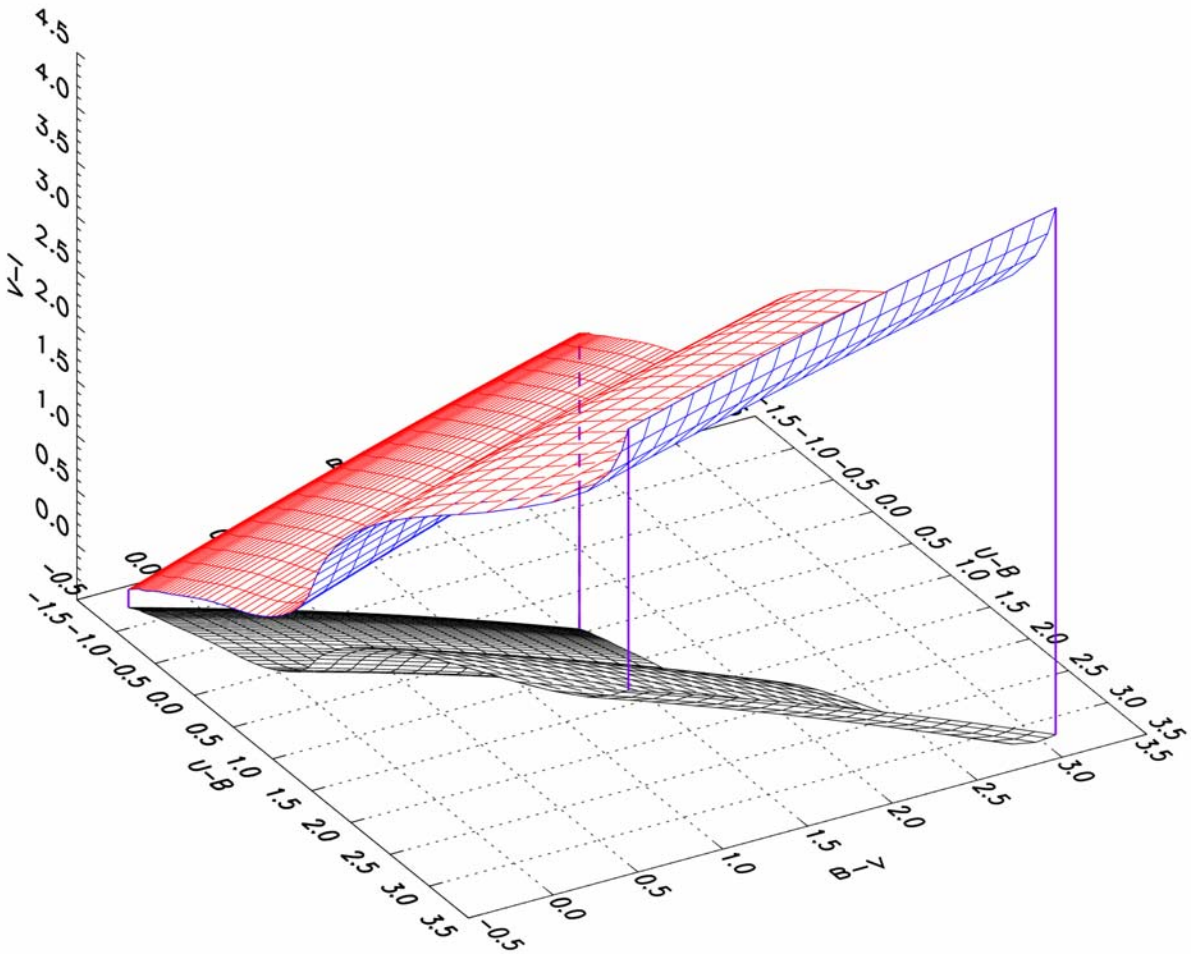


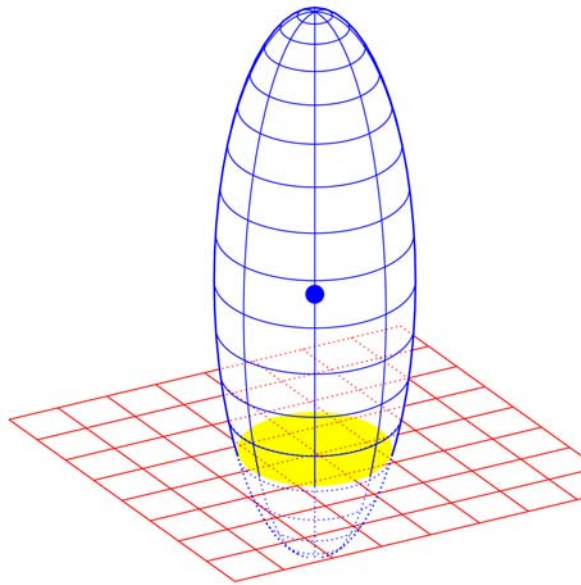
Measuring temperature and color excess with Johnson *UBV* photometry (*M*=2, *N*=2)





Adding a third color (M=3 > N=2)





CHORIZOS at work

- χ^2 minimization for either $M=N$ or $M>N$.
- Full calculation of colors in N-dimensional grid (no Q-parameter linearization) with N=1,2,3,4 using 82+ specific filter throughputs (no transformations) and many SED families (stars, clusters, galaxies).
- Likelihood evaluation for the full parameter space (not simple most-likely solution search) with multiple solution search, parameter uncertainty evaluation, possible conditions (Bayesian priors), derived quantities, and graphical output.
- Beta version available (jmaiz@stsci.edu), full version next year (http://www.stsci.edu/~jmaiz).

CHORIZOS, step by step

1. QUICKSYNPHOT: Calculation of the 4-D color grid for the SED family/ies.
2. CHORIZOS: SED family choice, input data reading, possible parameter restrictions (range or fixed value), and chi-square calculation.
3. STATPLOTS: Further parameter restrictions (range, fixed value, Bayesian priors), calculation of derived quantities ($M_{\rm bol}$, cluster masses), and graphical output (likelihood plots, photometry-spectra comparisons, H-R diagrams).

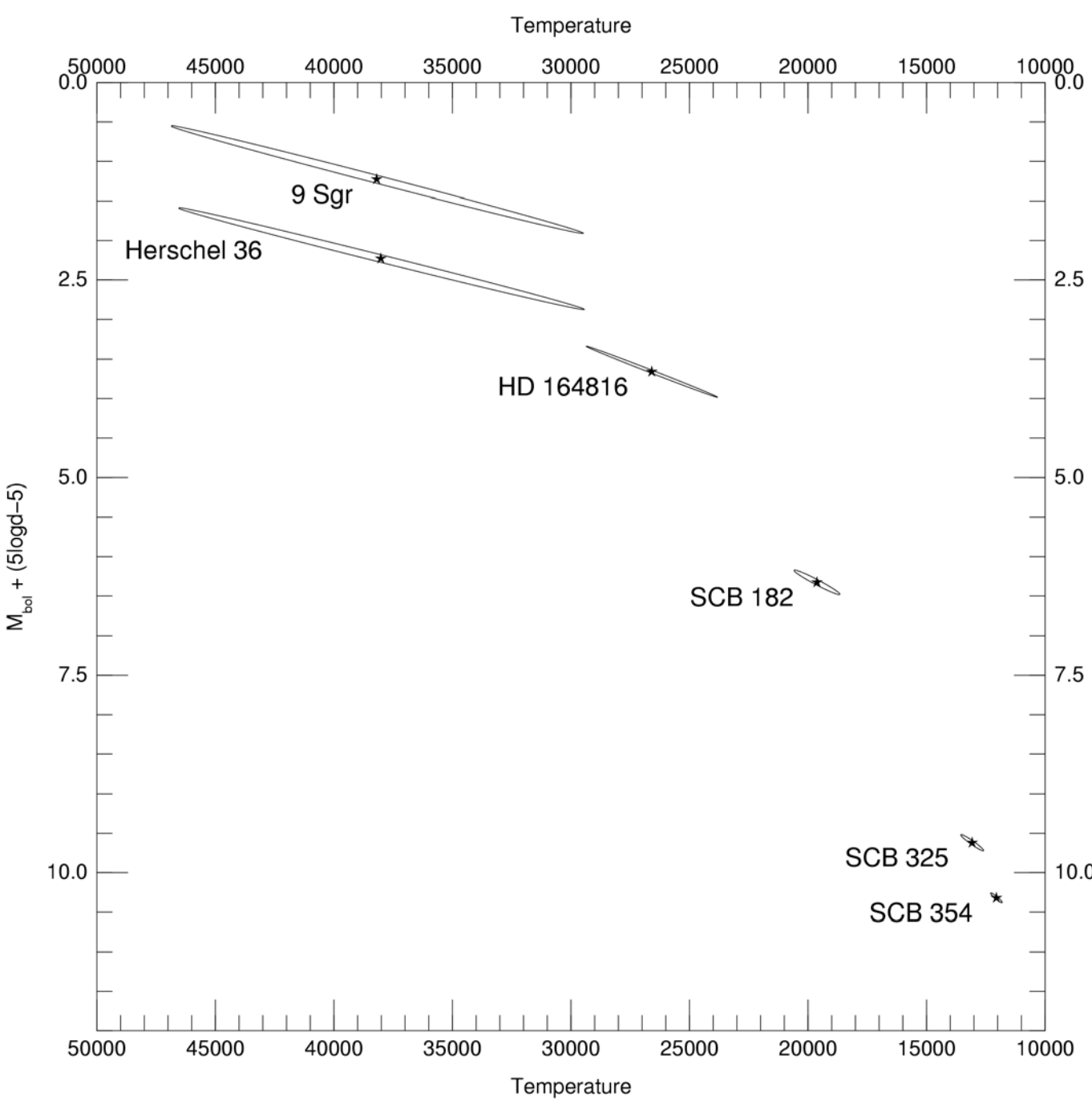
Sample applications

- Testing
  - Continuum of stellar atmospheres ⇒ Measuring precise hot-star temperatures from photometry alone
  - Filter sensitivities and zero points
- Measurements
  - Building theoretical H-R diagrams
  - Calculation of ages, metallicities, and extinctions of star clusters
  - Determination of the nature of an object
  - Detection of anomalous objects in a sample (binaries, IR excesses…)
  - Choice of filters for observations
  - Calculation of extinction laws
  - Calculation of photometric redshifts

EXAMPLE 1:
Theoretical H-R diagrams

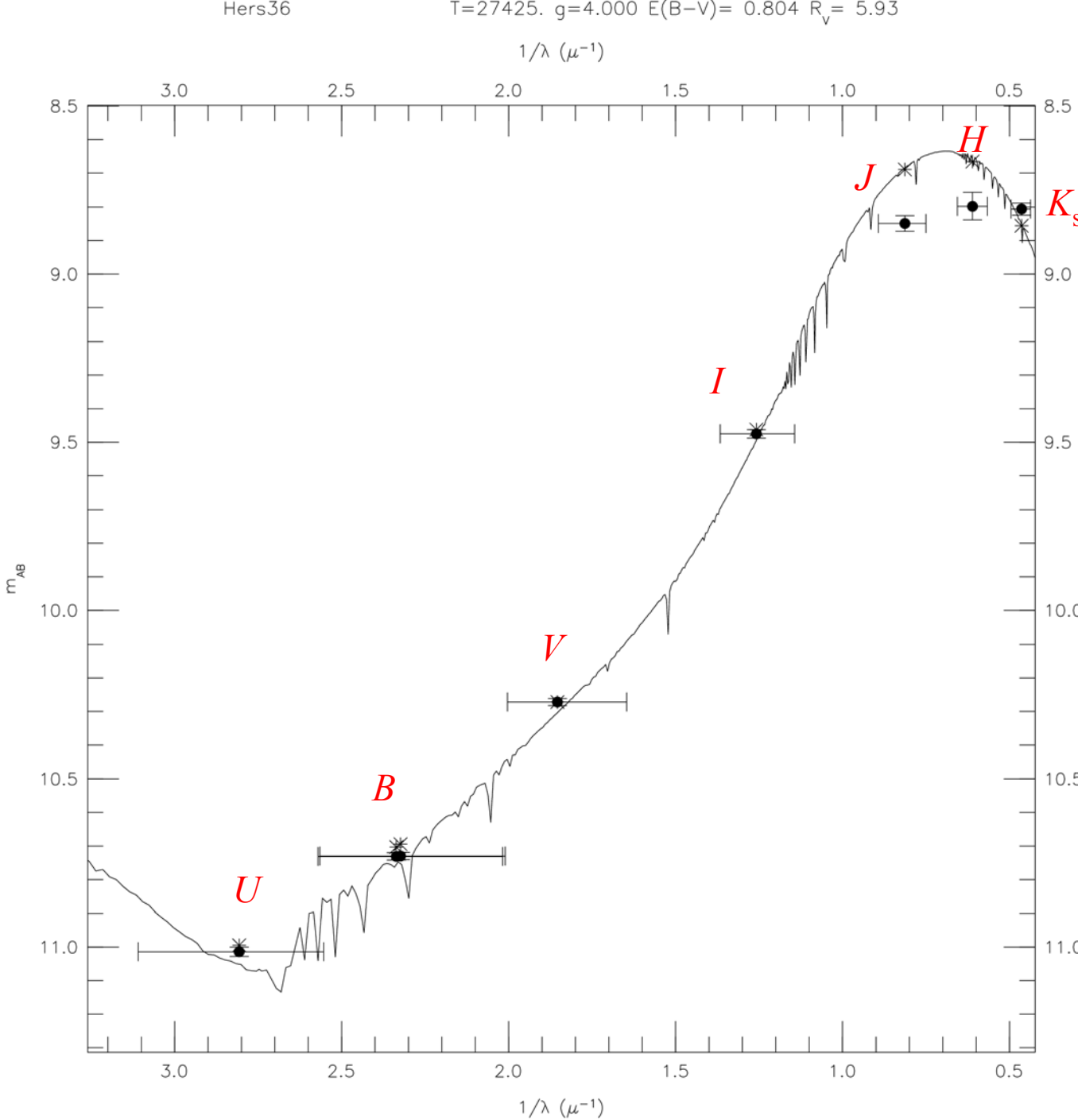
- Magnitudes $\Rightarrow$ Temperature and $M_{\rm bol}$
- M8: Galactic H II region with several O and B stars
- Highly variable extinction and with anomalous values of R_V
- Several superimposed OB associations?
- $UBVIJHK_{\rm s}$ photometry of six stars

Theoretical H-R diagram of six stars in and around M8



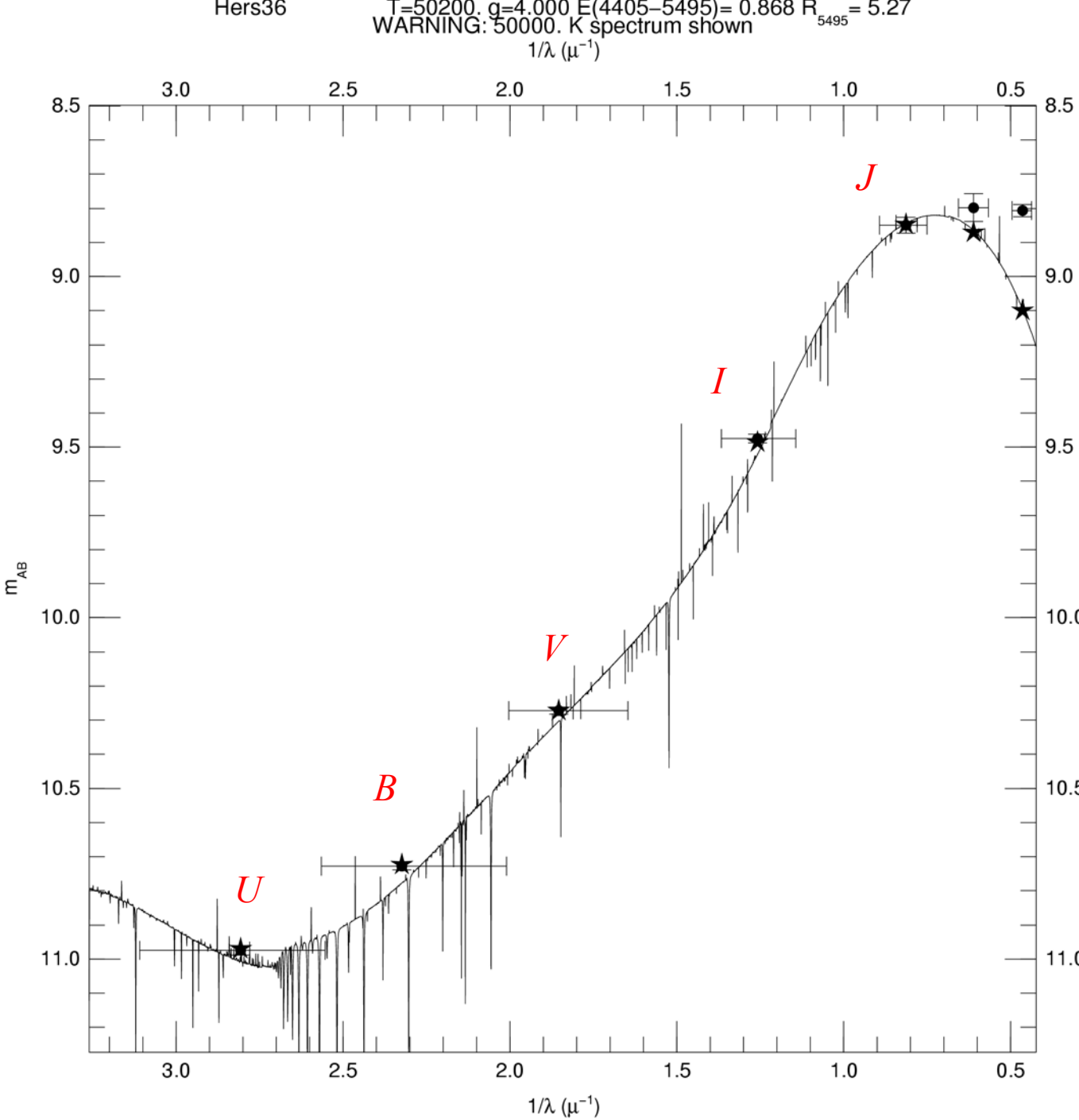
Herschel 36: photometry and fitted spectrum

$\chi^2/\mathrm{gdl} = 21$

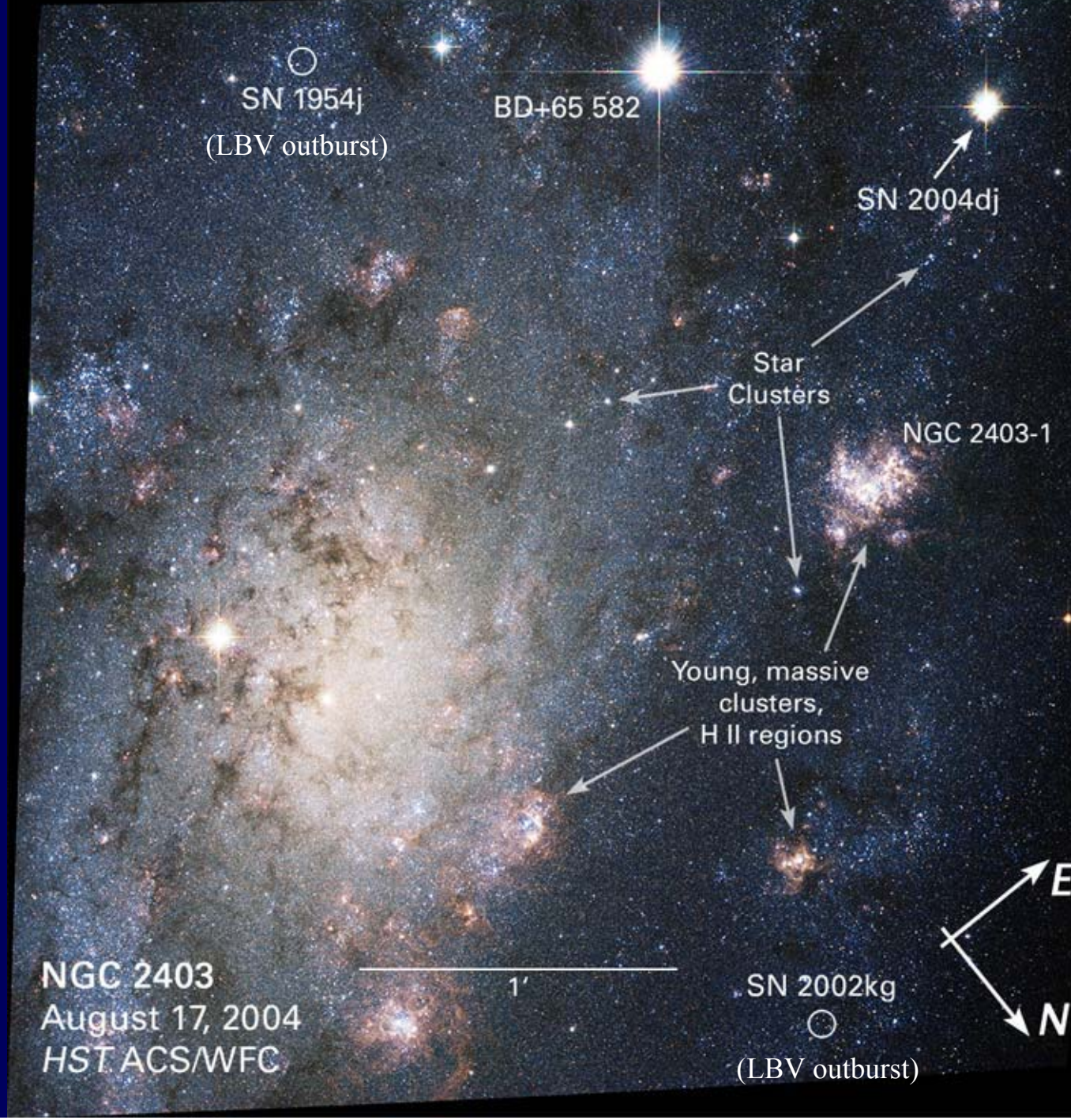


Herschel 36: photometry and fitted spectrum

χ^2/gdl = 0.50



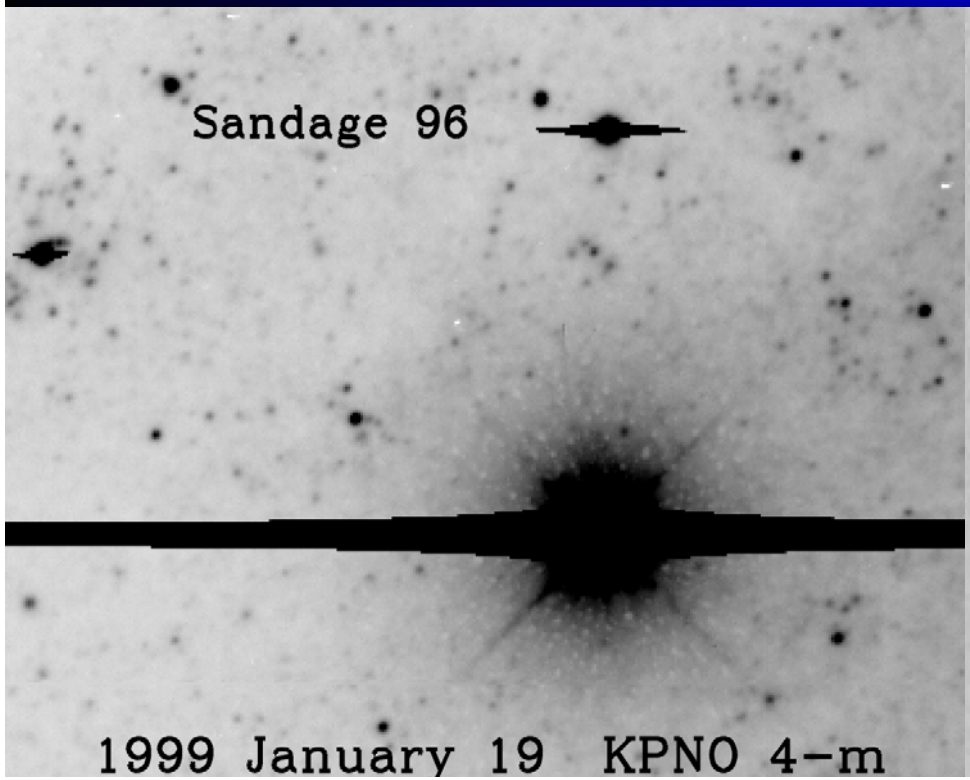
EXAMPLE 2: Identification of the progenitor of SN 2004dj

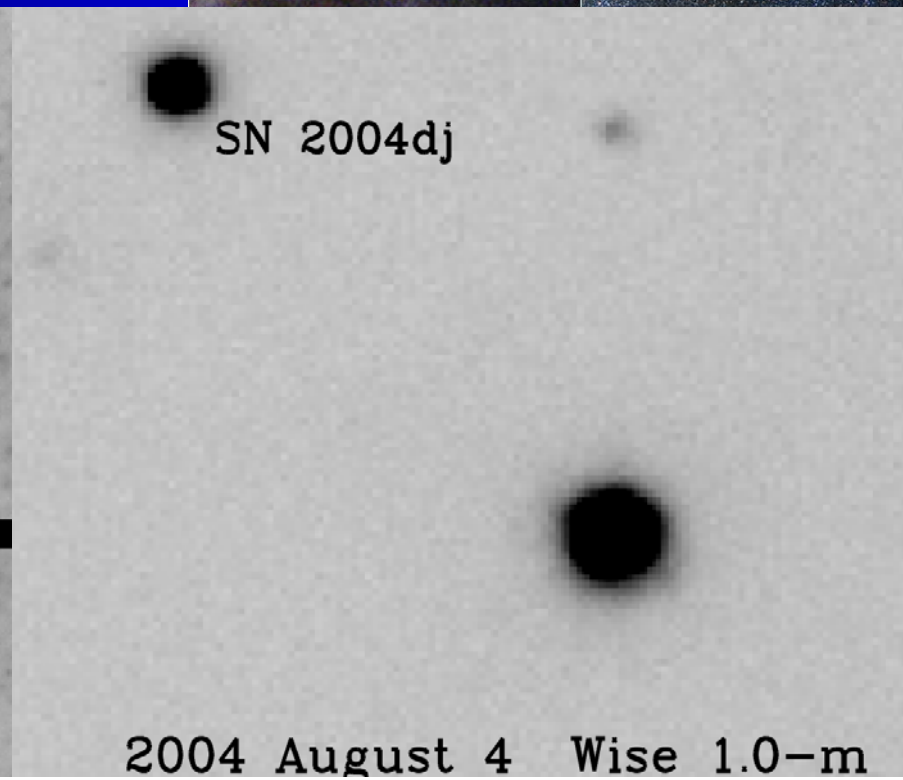


Sandage 96 before and after







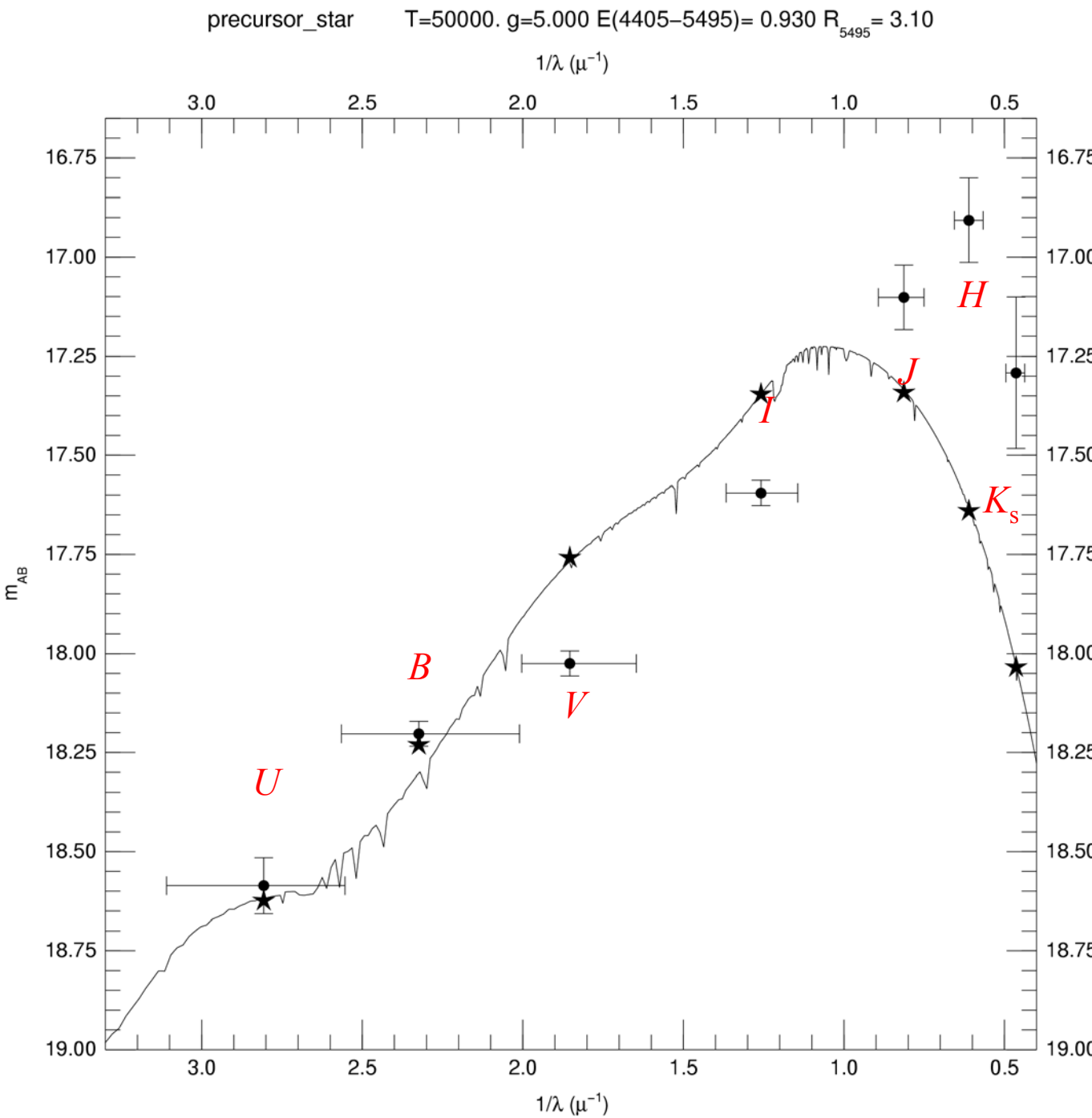


Sandage 96 data and CHORIZOS

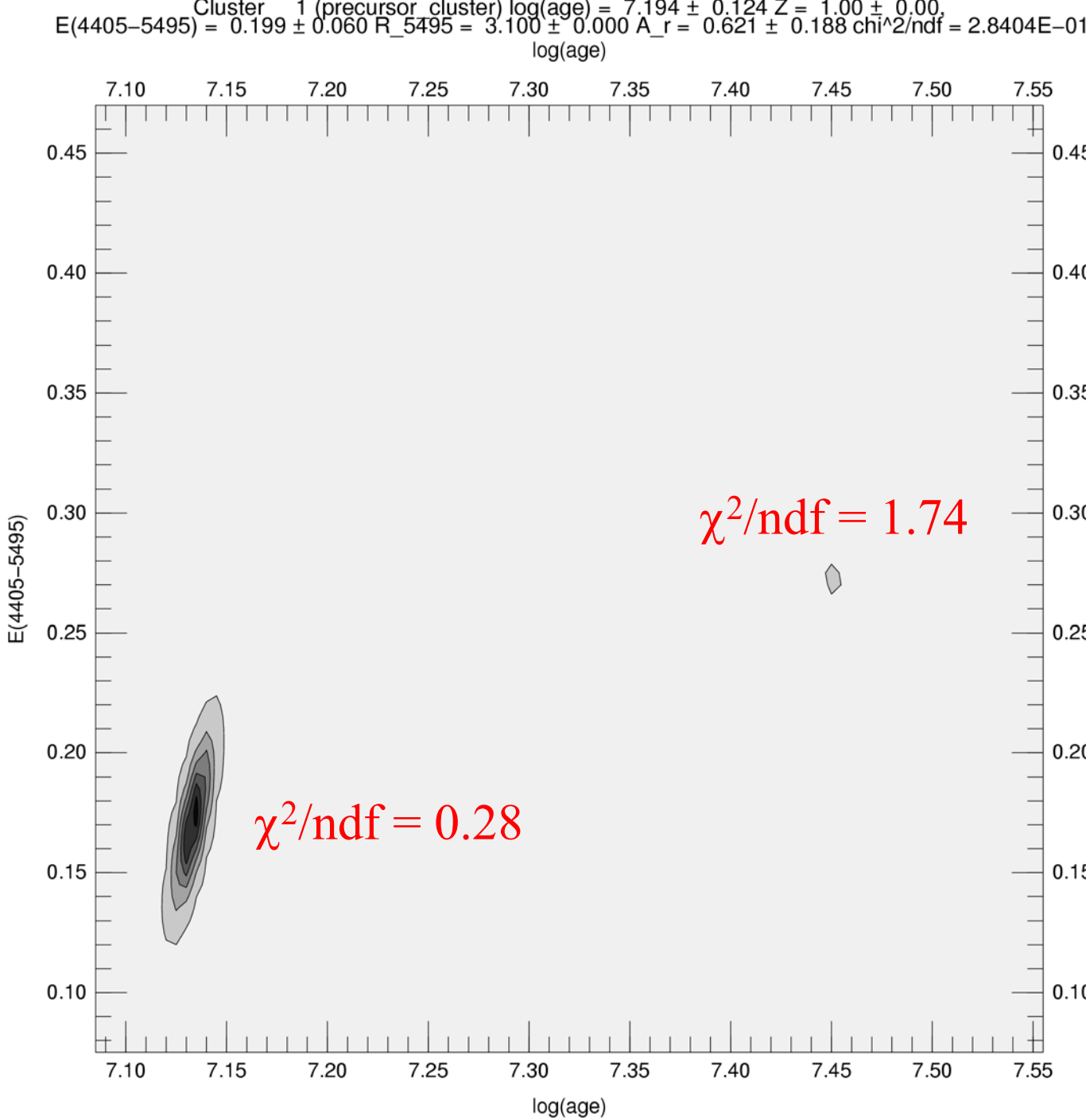
- Johnson-Cousins *UBVI* photometry: Larsen (1999) catalog of stellar cluster candidates
- 2MASS JHK_s photometry
- Stellar SED family: Kurucz supergiants with $Z_\odot$ (temperature and color excess)
- Cluster SED family: Starburst99 with $Z_\odot$ (age and color excess)
- $M = 6$, $N = 2$, ndf = 4

Best stellar fit

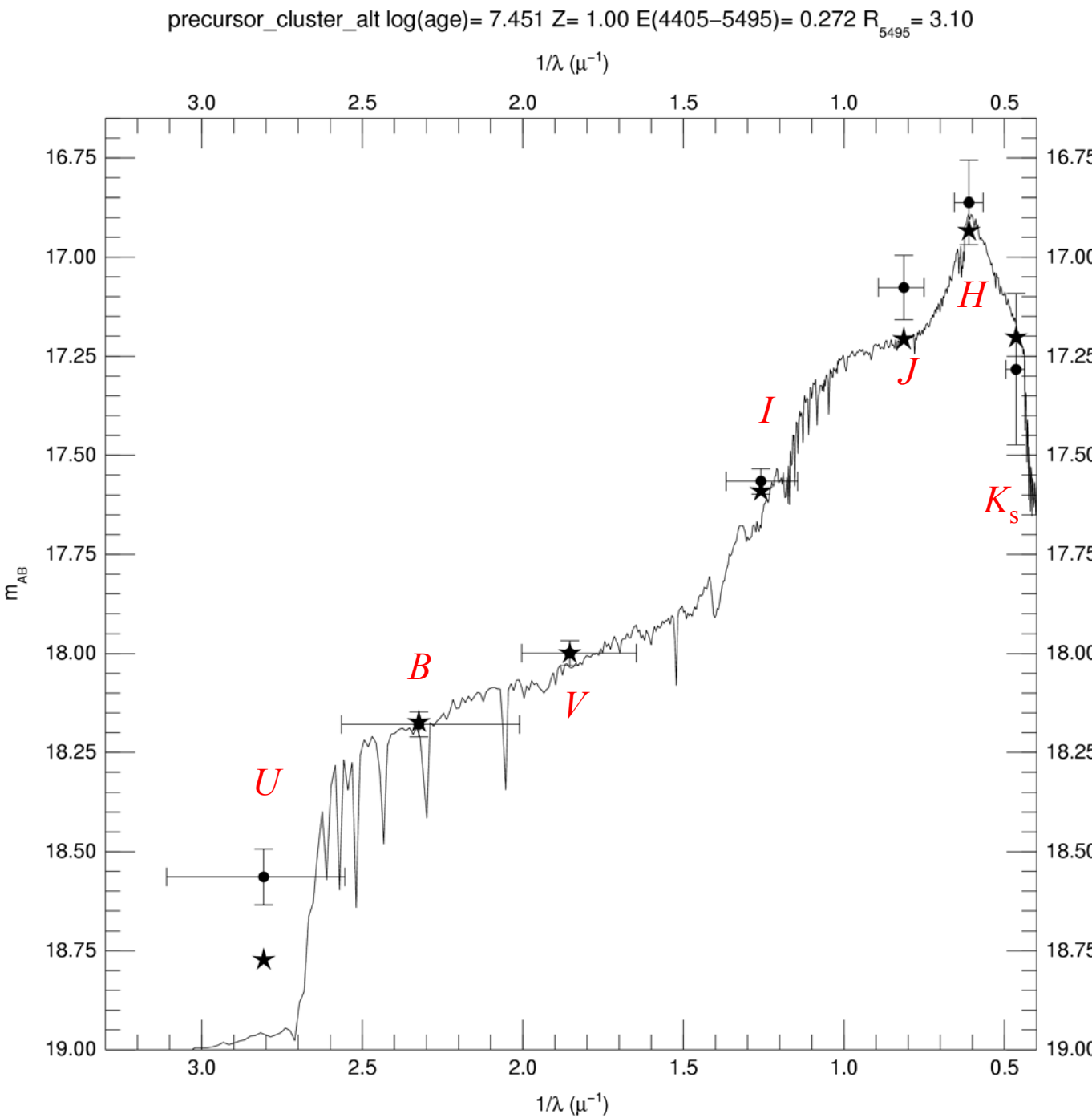
$\chi^2/\mathrm{ndf} = 43$



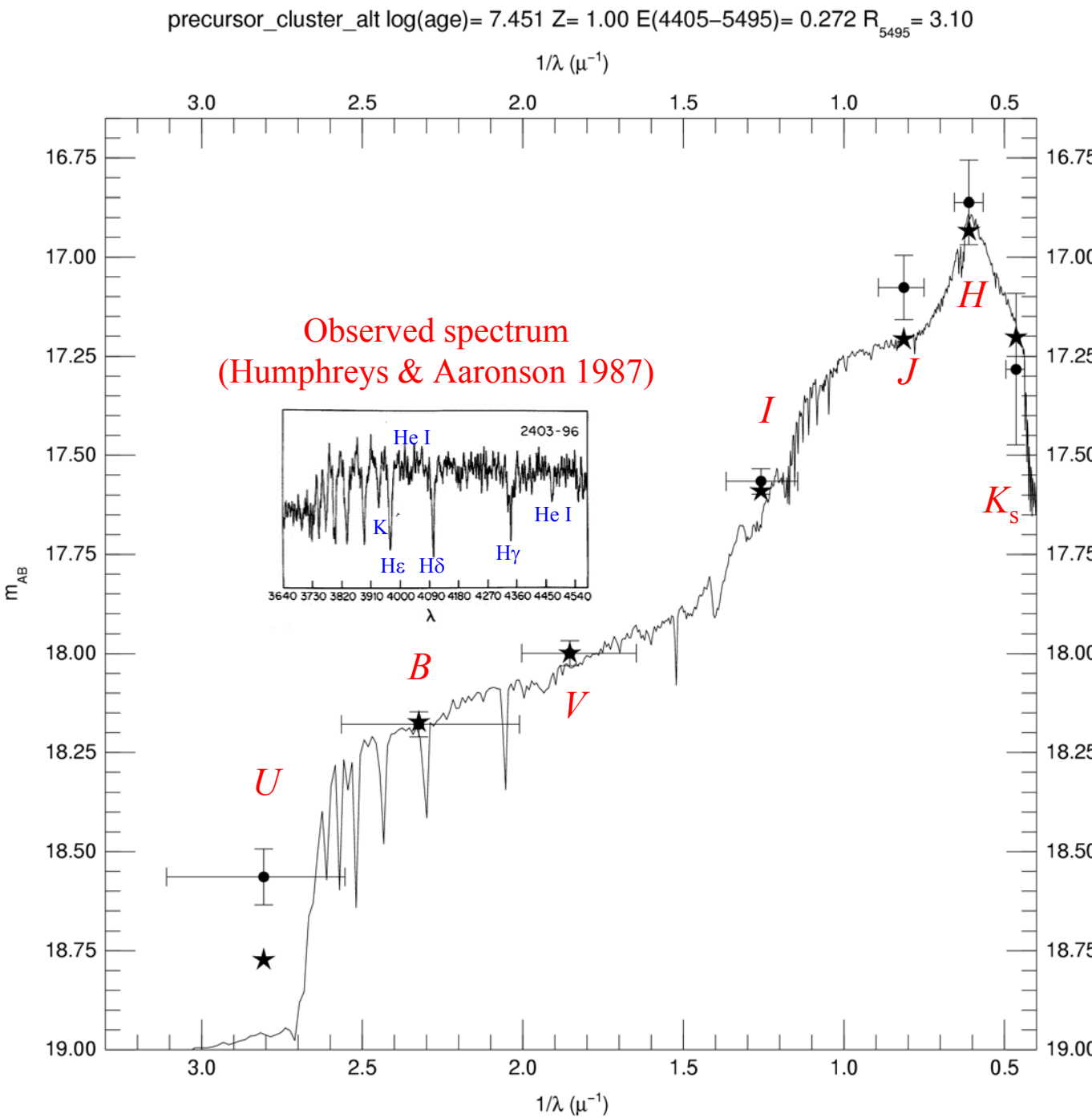
Likelihood contour plot for cluster models



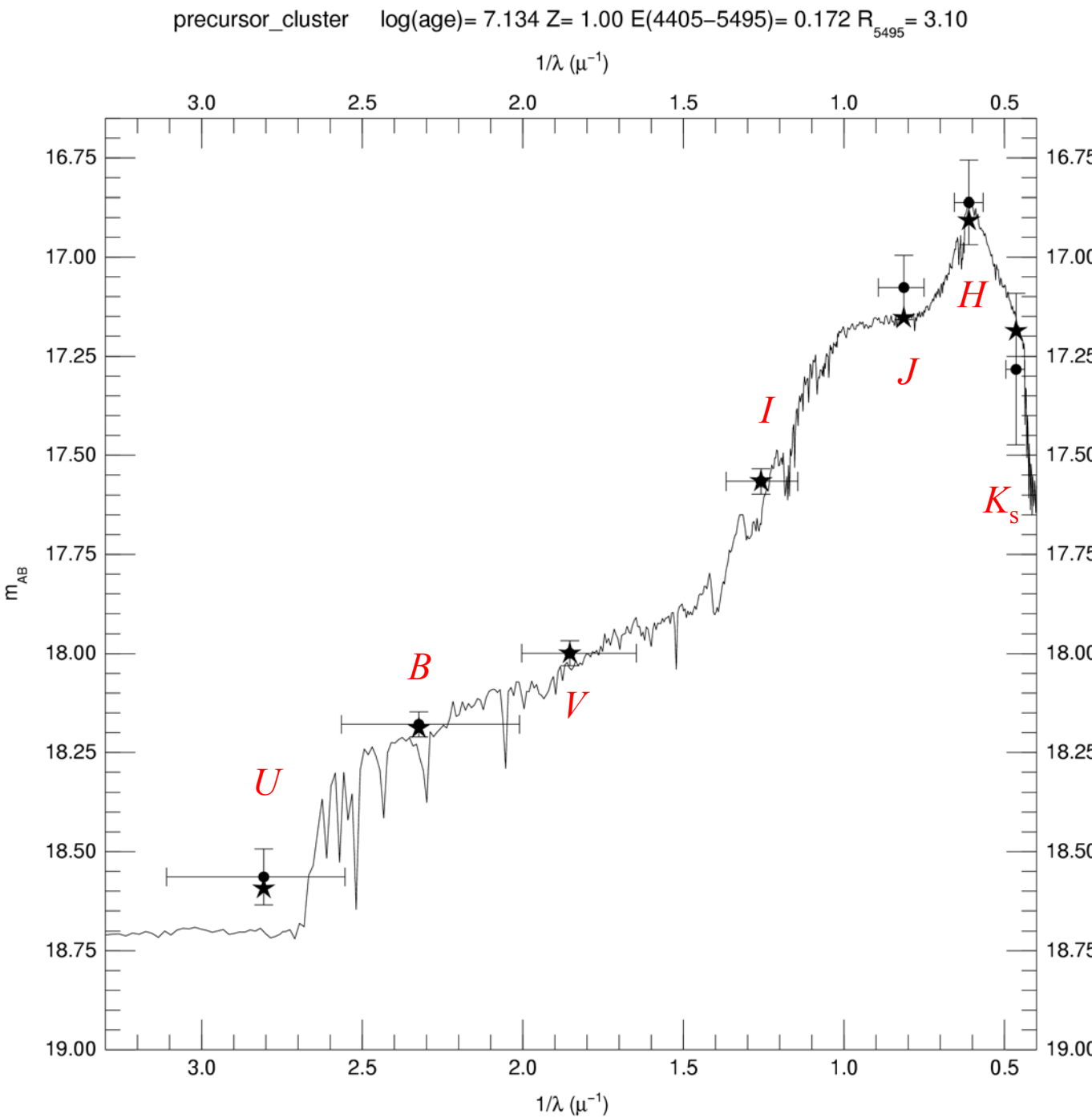
"Old" cluster solution



"Old" cluster solution



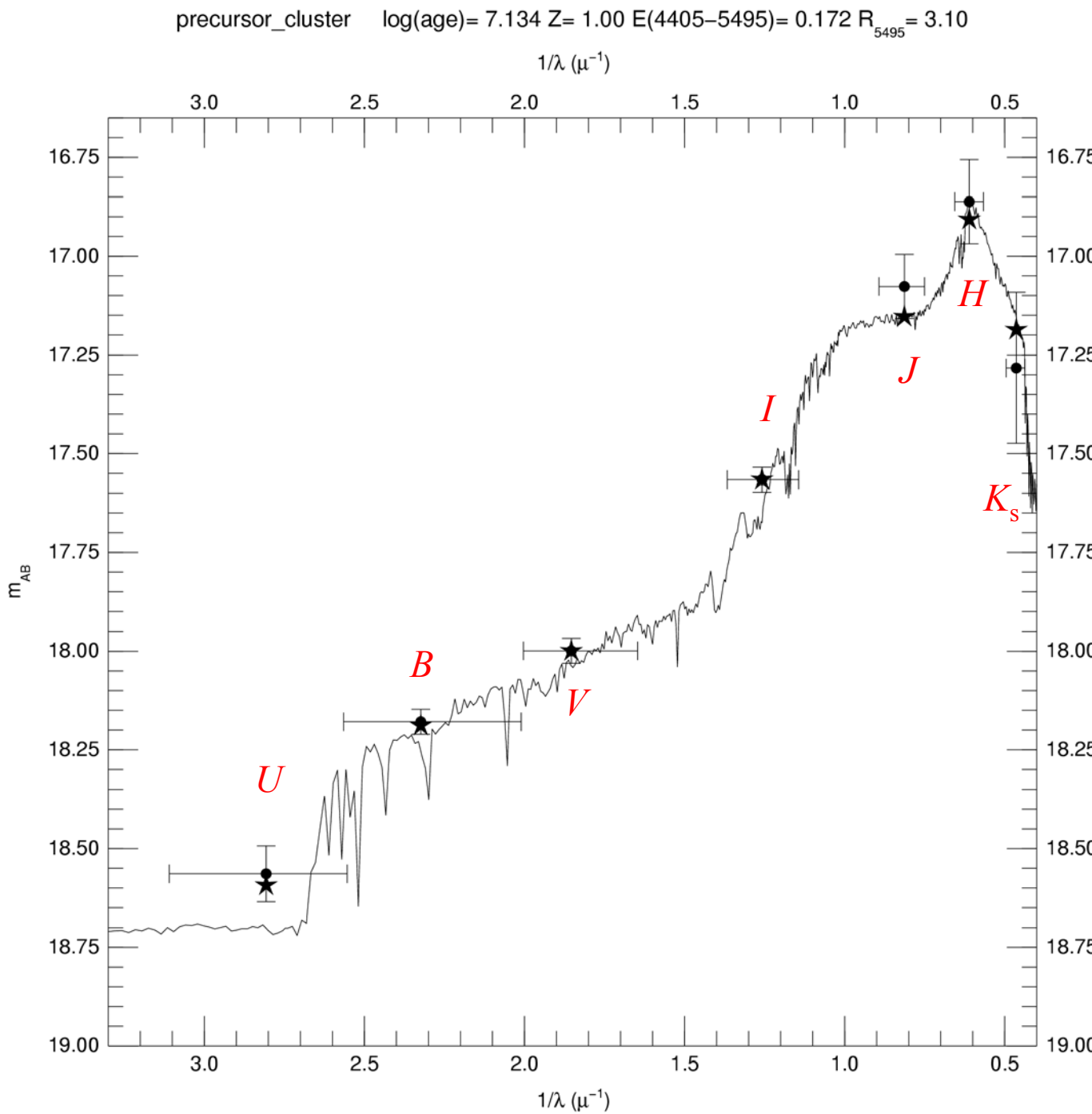
"Young" cluster solution



Calculated values

- Age: 13.6 ± 0.2 Ma
- E(4405-5495): 0.172 ± 0.022
- M_V: -10.08 ± 0.09
- Mass: 24.0 ± 1.1 10^3 $M_\odot$
- K+M I stars: 12
- B I+II stars: 2.5
- B III stars: 24
- Turnoff mass: 15 $M_\odot$

What was the progenitor?



CHORIZOS is being used for…

- Calcuation of ages and extinctions in M82 (NICMOS/WFPC2)
- Obtention of theoretical H-R diagrams of resolved stellar clusters (WFPC2/ACS/STIS)
- Calibration of Johnson *U* photometry
- Uniform re-analysis of Galactic extinction using the new O star catalog (Maíz-Apellániz et al. 2004)