

Galaxy Spectral Synthesis

Theory-theory Interoperability in the Virtual Observatory

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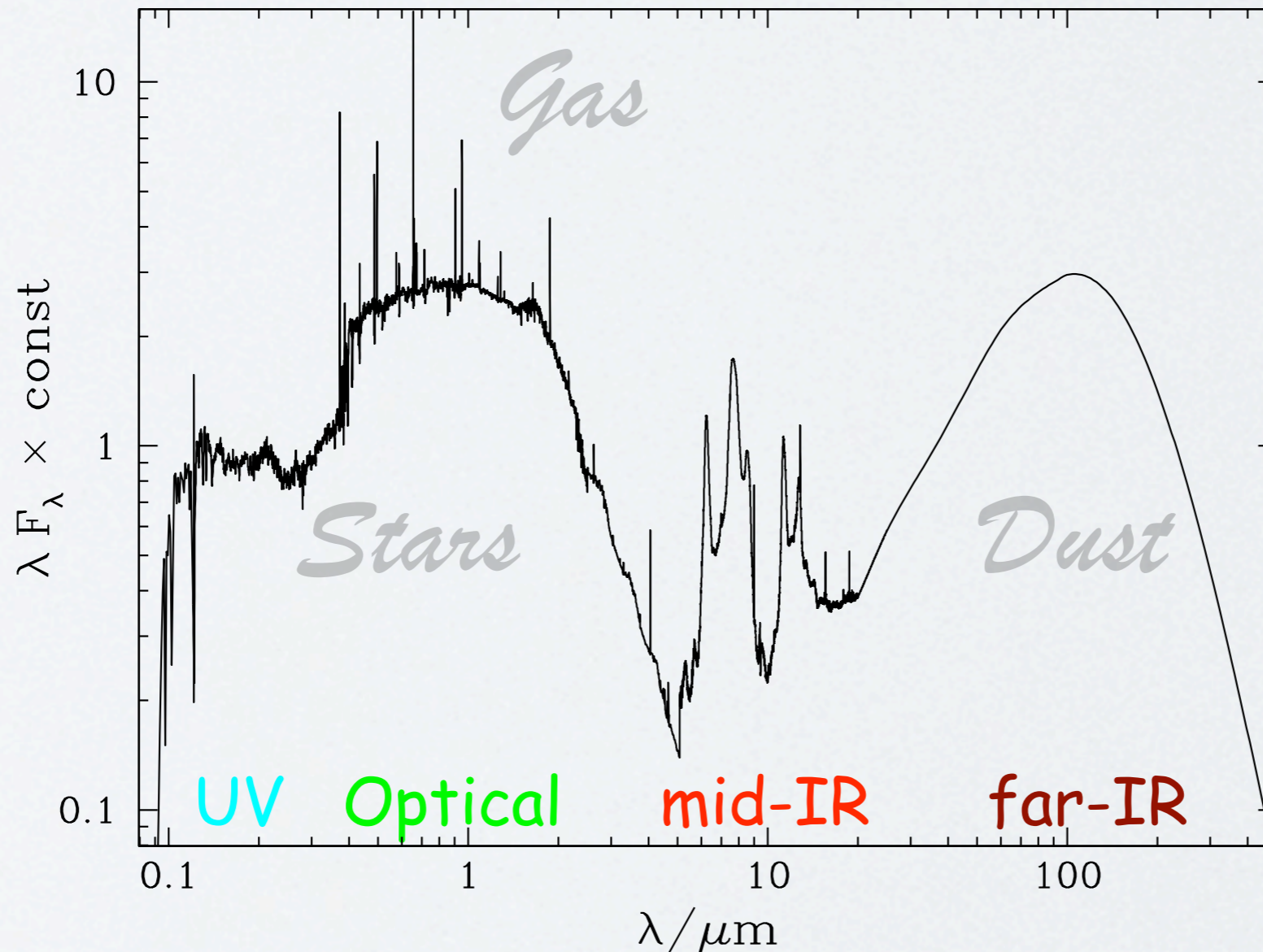
Outline



- **Goals and principle of galaxy spectral synthesis**
- **Challenges linked to the building of models: stars, gas, and dust emission**
 - **prospect for theory-theory interoperability**

Main aim of galaxy spectral synthesis

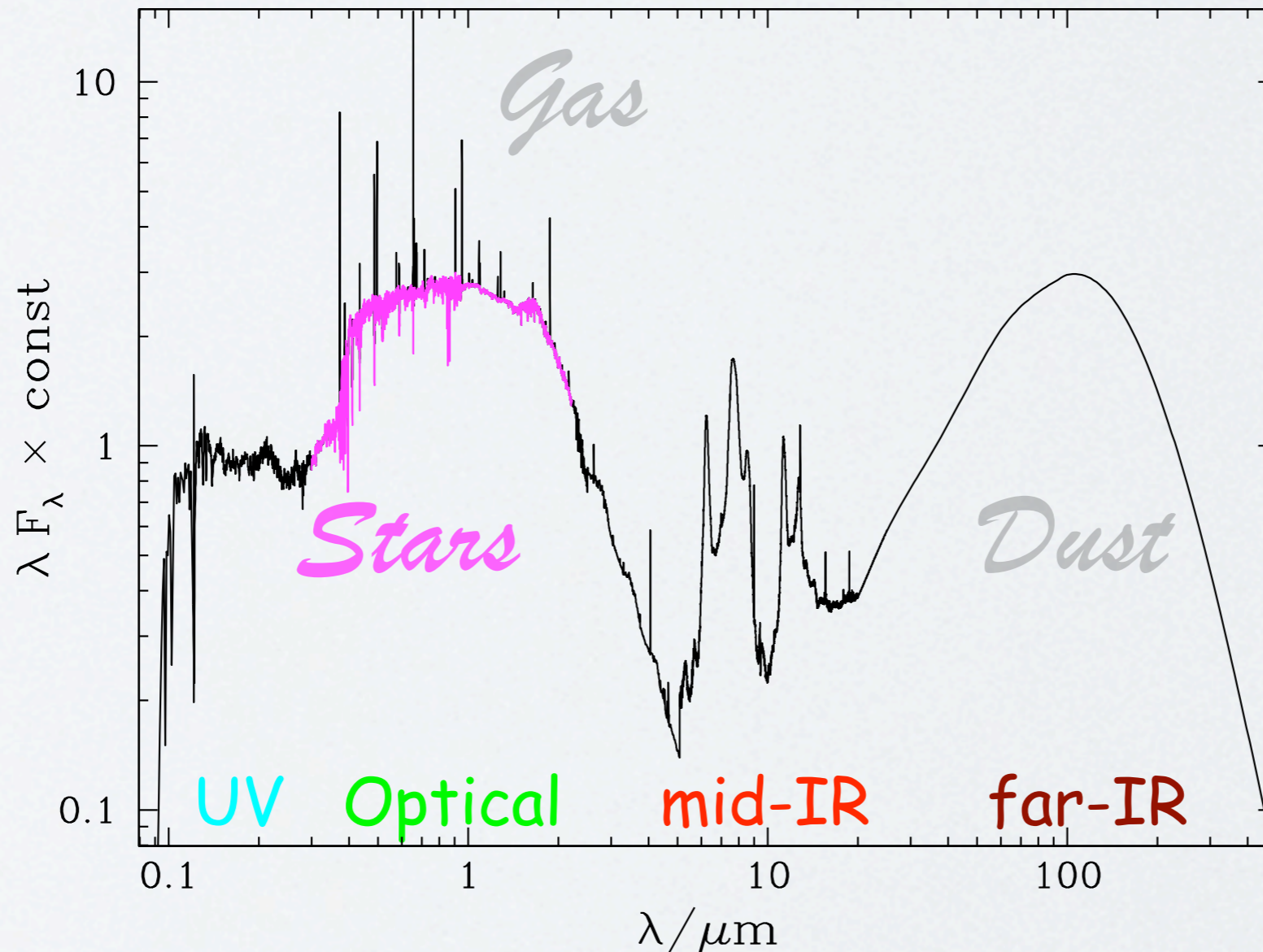
spectral energy distribution of a normal star-forming galaxy:



⇒ Extract constraints on star formation (SF) history, metallicity, dust attenuation

Main aim of galaxy spectral synthesis

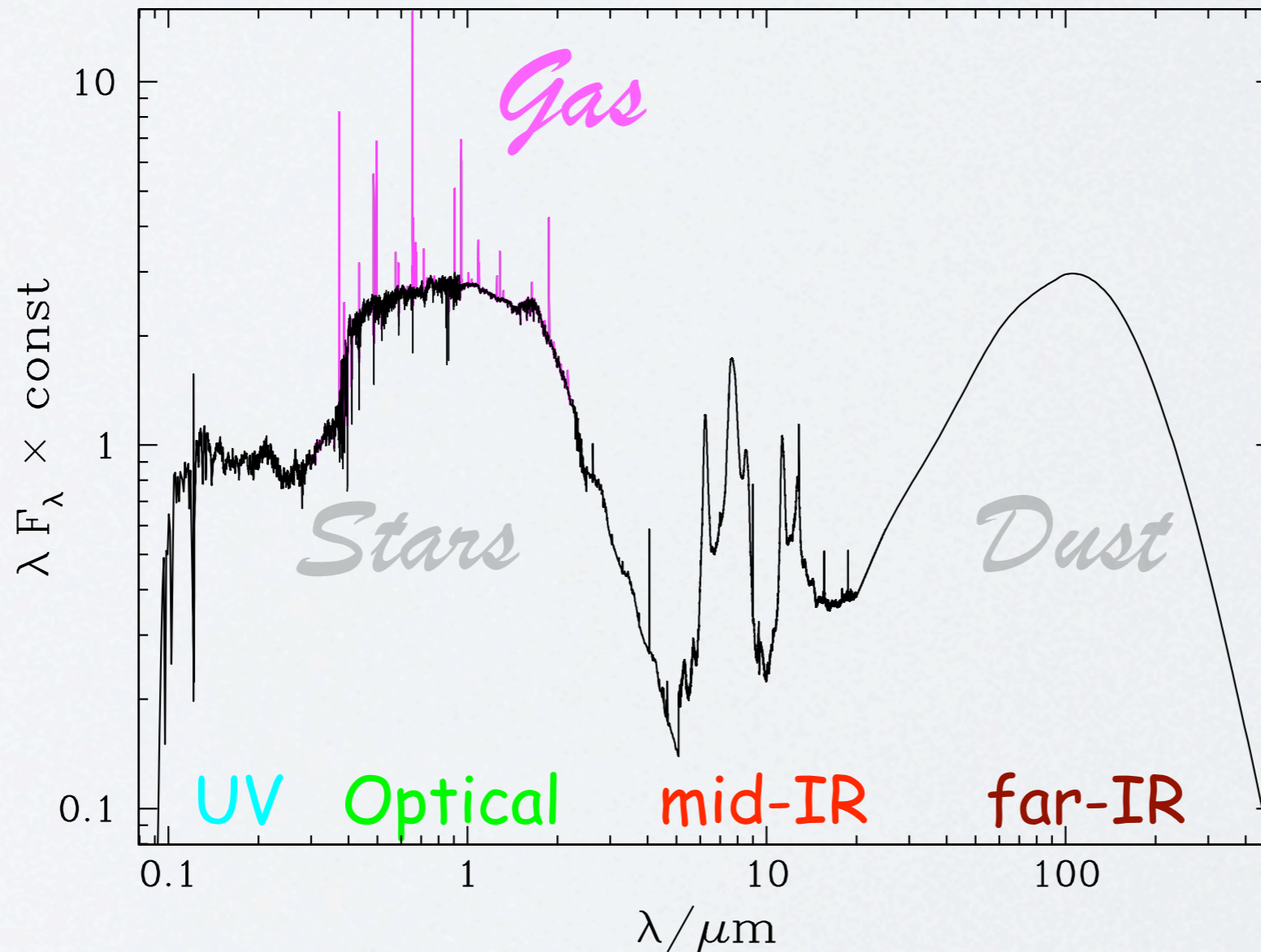
spectral energy distribution of a normal star-forming galaxy:



Optical/NIR stellar emission \Rightarrow **SF history, metallicity, stellar mass**

Main aim of galaxy spectral synthesis

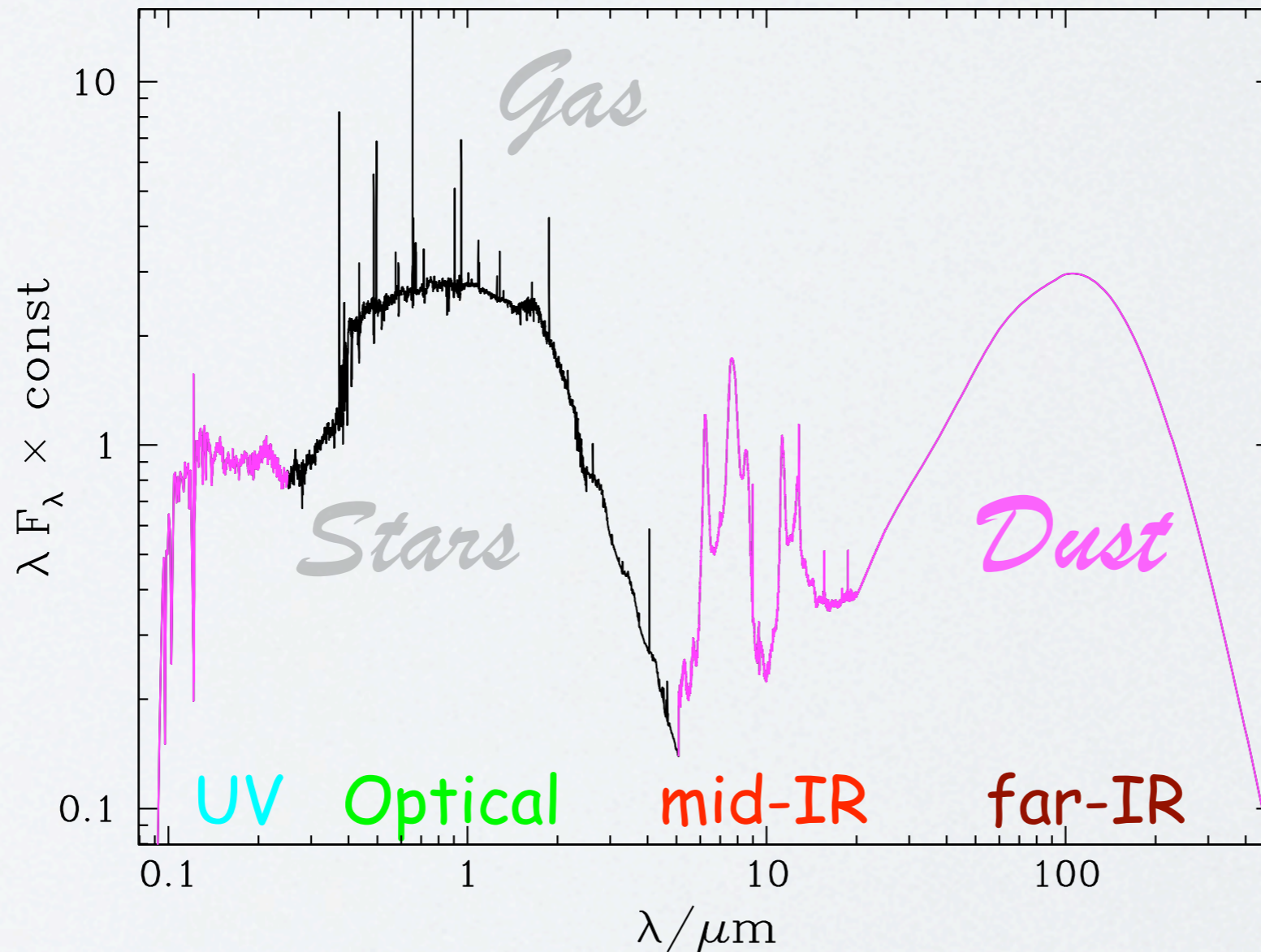
spectral energy distribution of a normal star-forming galaxy:



Nebular emission lines \Rightarrow current SF rate, gas parameters

Main aim of galaxy spectral synthesis

spectral energy distribution of a normal star-forming galaxy:



UV/mid-IR/far-IR emission \Rightarrow absorption and reradiation of starlight by dust

Principle of galaxy spectral synthesis



- Every galaxy expandable in a series of **Simple Stellar Populations** (SSP = population of stars all born at a same age)
- Flux emitted per unit wavelength λ at time t by a galaxy:

$$F_{\text{obs}}(\lambda, t) = \int_0^t d\tau f_{\text{SSP}}(\lambda, \tau; Z, \dots) \text{SFR}(t - \tau) T(\lambda, t, \tau)$$

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f_{SSP} \implies flux emitted per unit λ per unit mass by a single stellar generation of age τ , metallicity Z , ... \implies **theory-theory interoperability (stellar evolution and stellar spectra)**

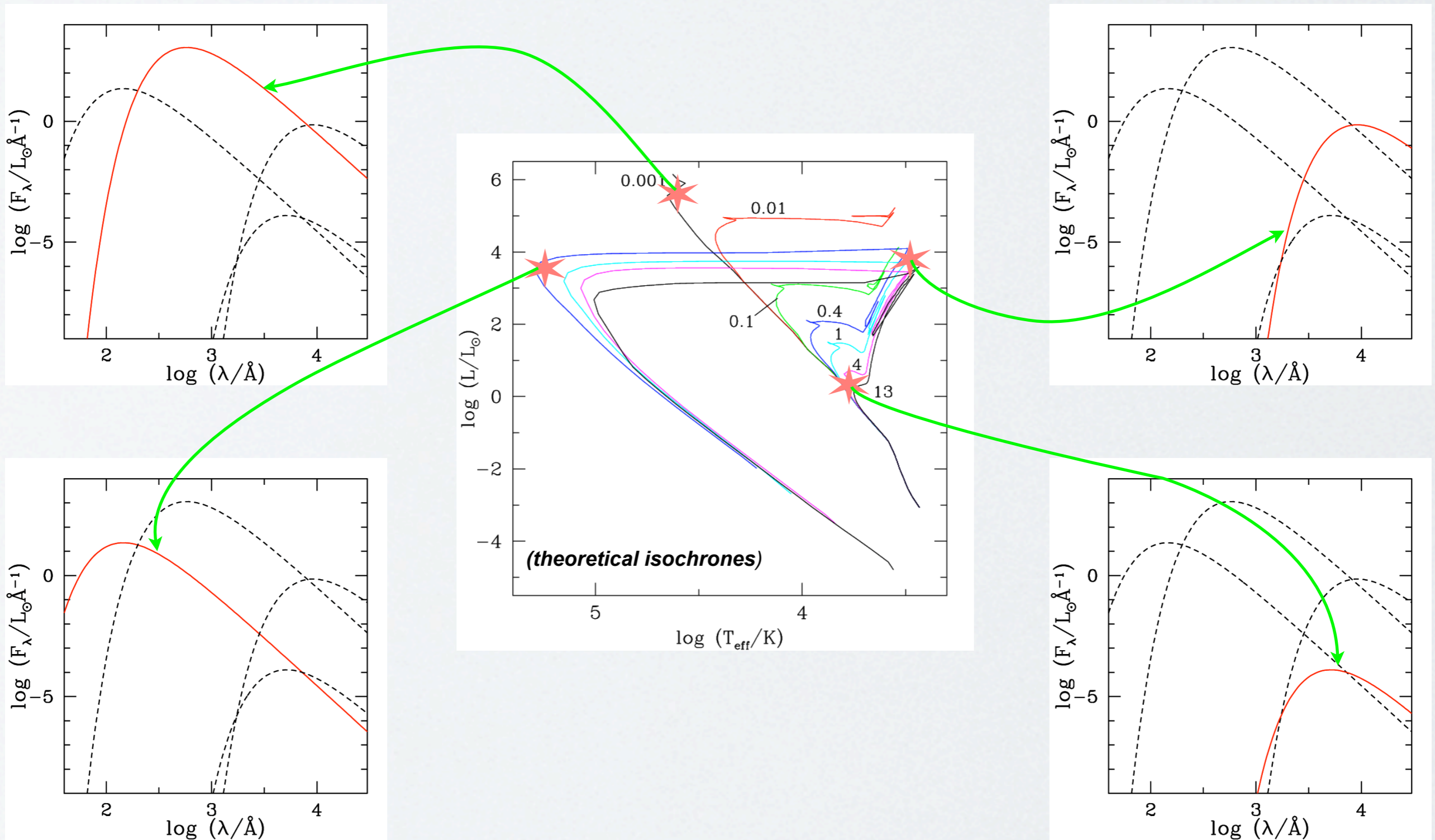
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\implies **theory-theory interoperability (radiative transfer and photo-ionization codes)**

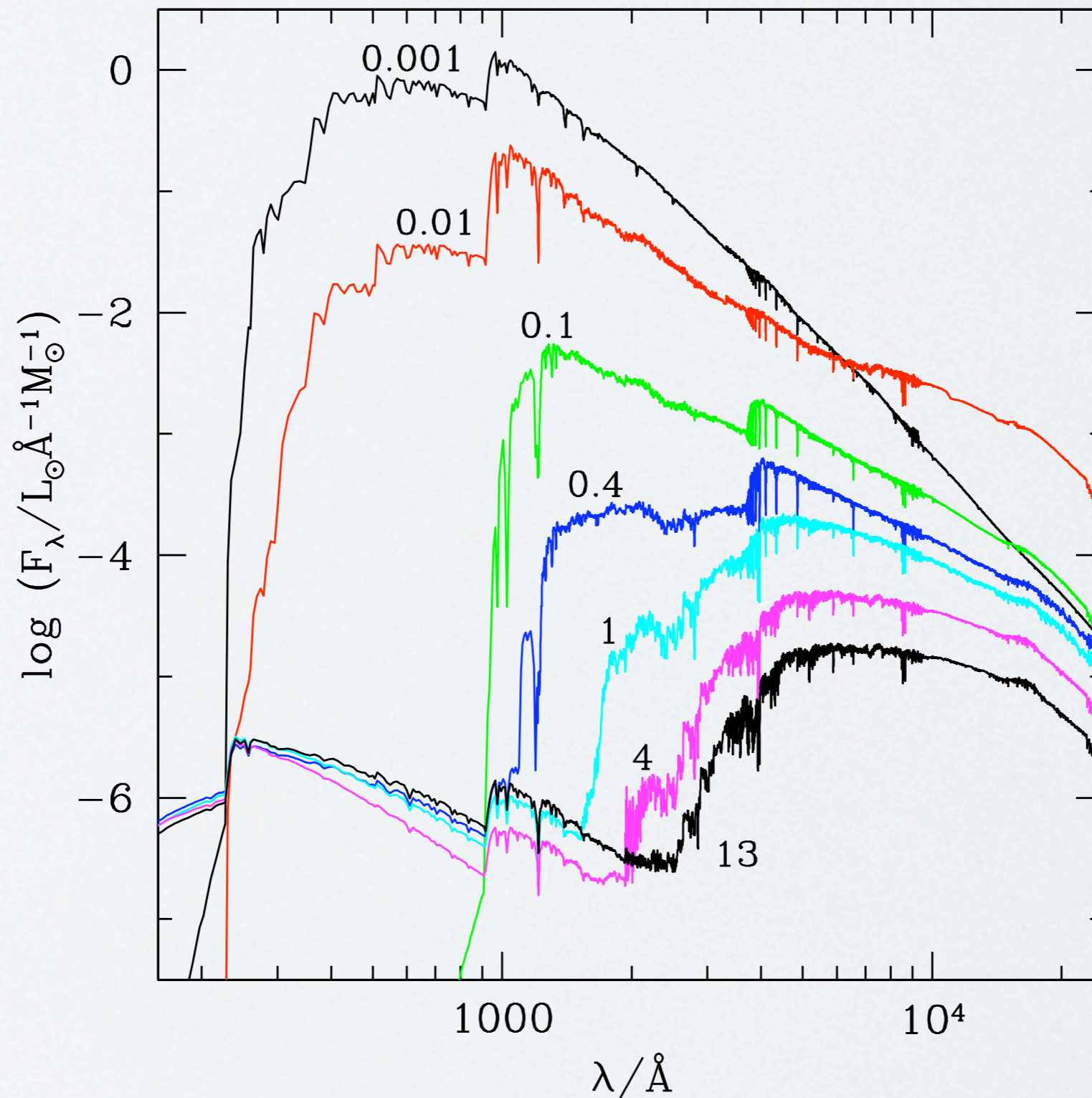
Spectral evolution of a Simple Stellar Population

Stellar evolutionary tracks (→isochrones) + stellar spectra library



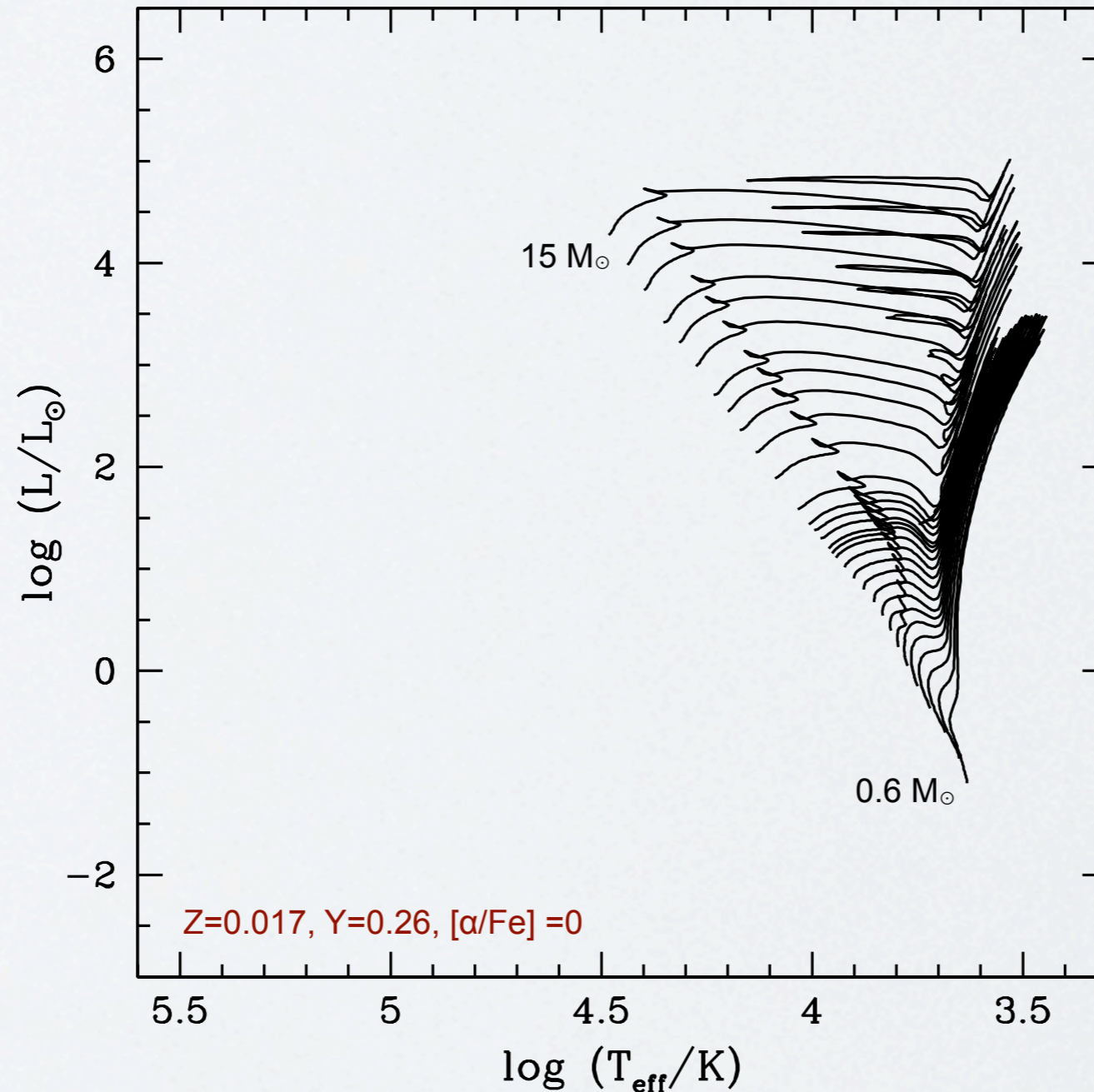
Spectral evolution of a **S**imple **S**tellar **P**opulation

Resulting **SSP** evolution (f_{SSP})



A Challenge: assemble library of stellar tracks

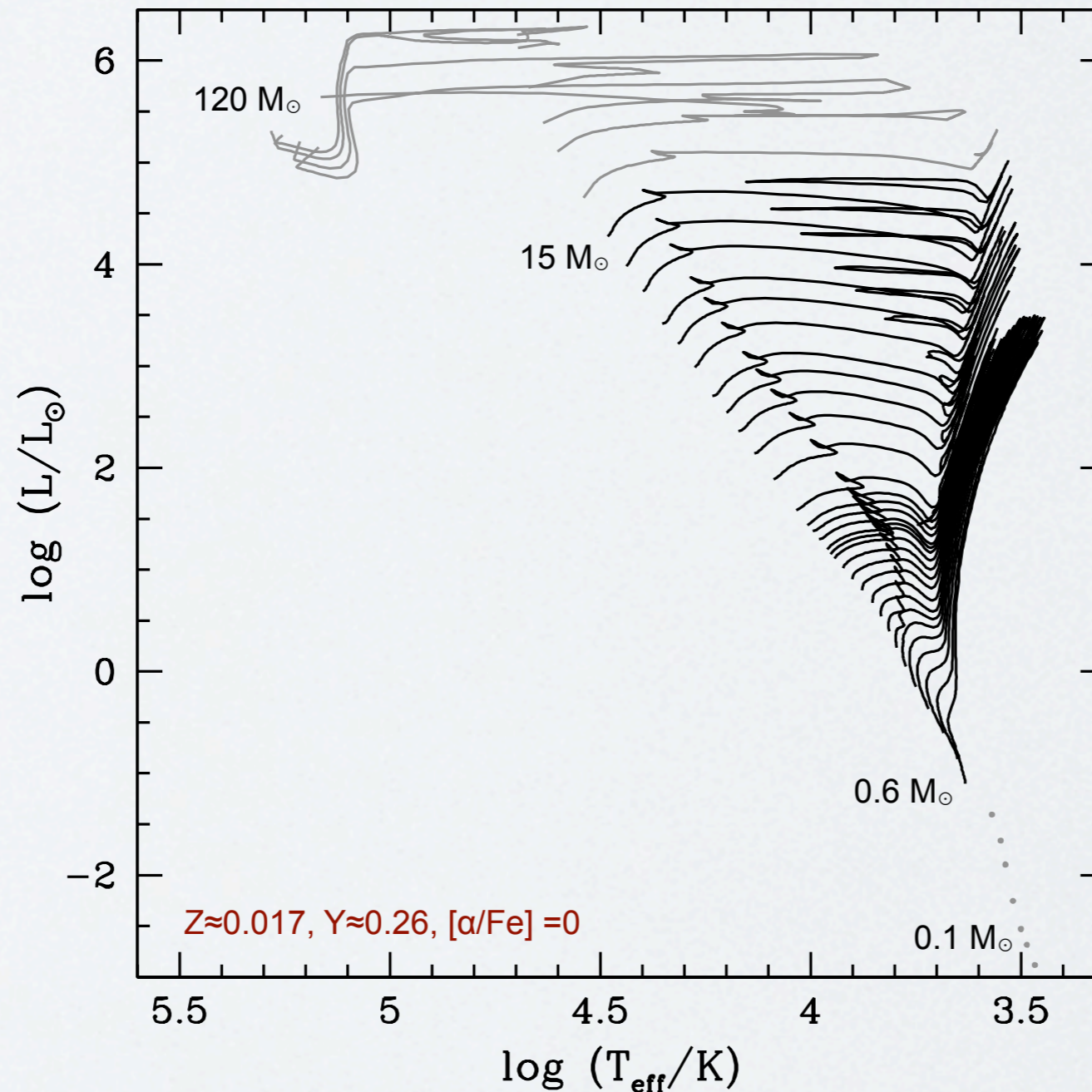
Different groups tend to compute evolution in different phases, over different initial mass ranges, for different chemical compositions



Example: Padova 2008

A Challenge: assemble library of stellar tracks

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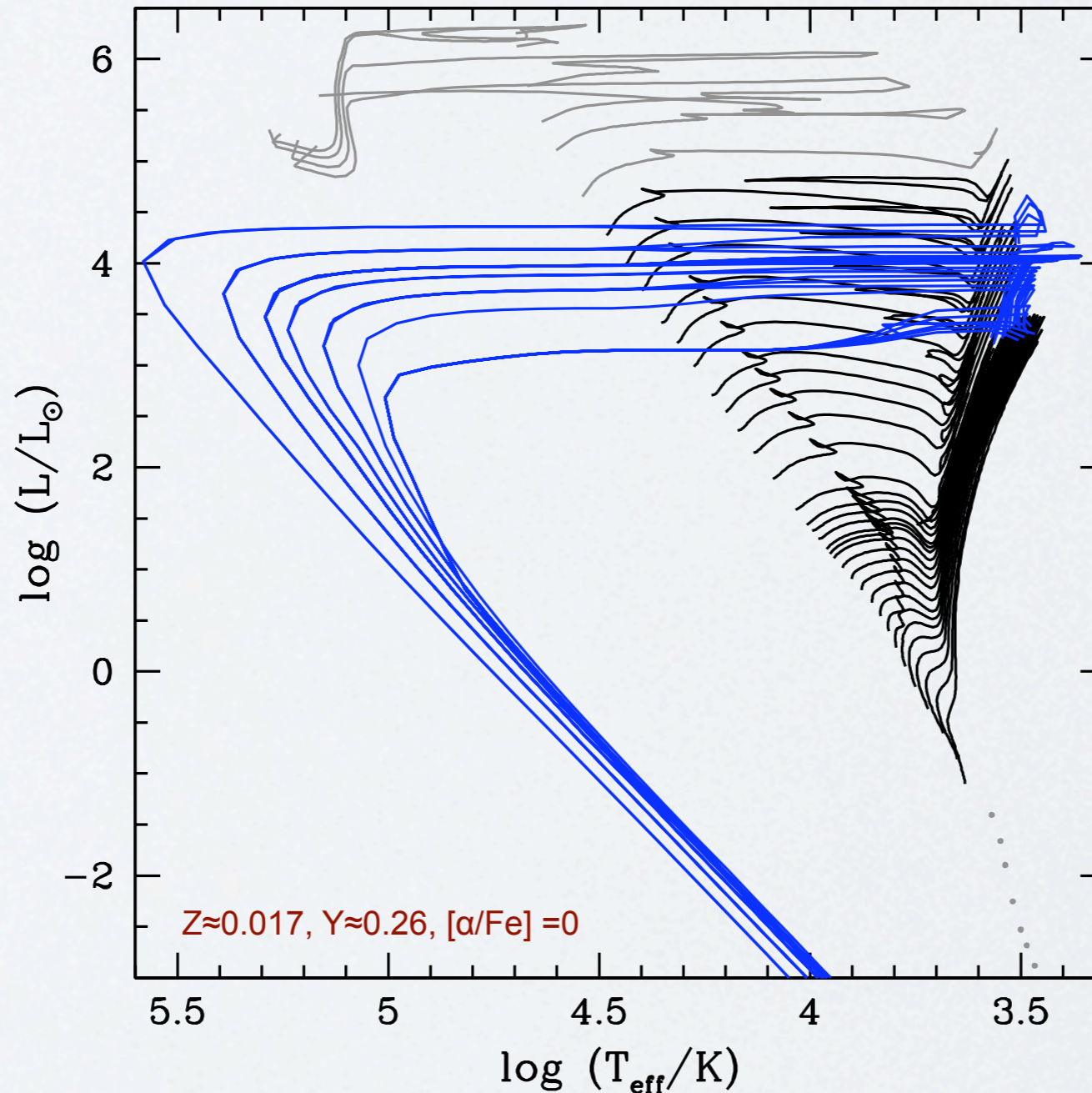


Example: Padova 2008

**+ low/high-mass stars
(earlier calculations)**

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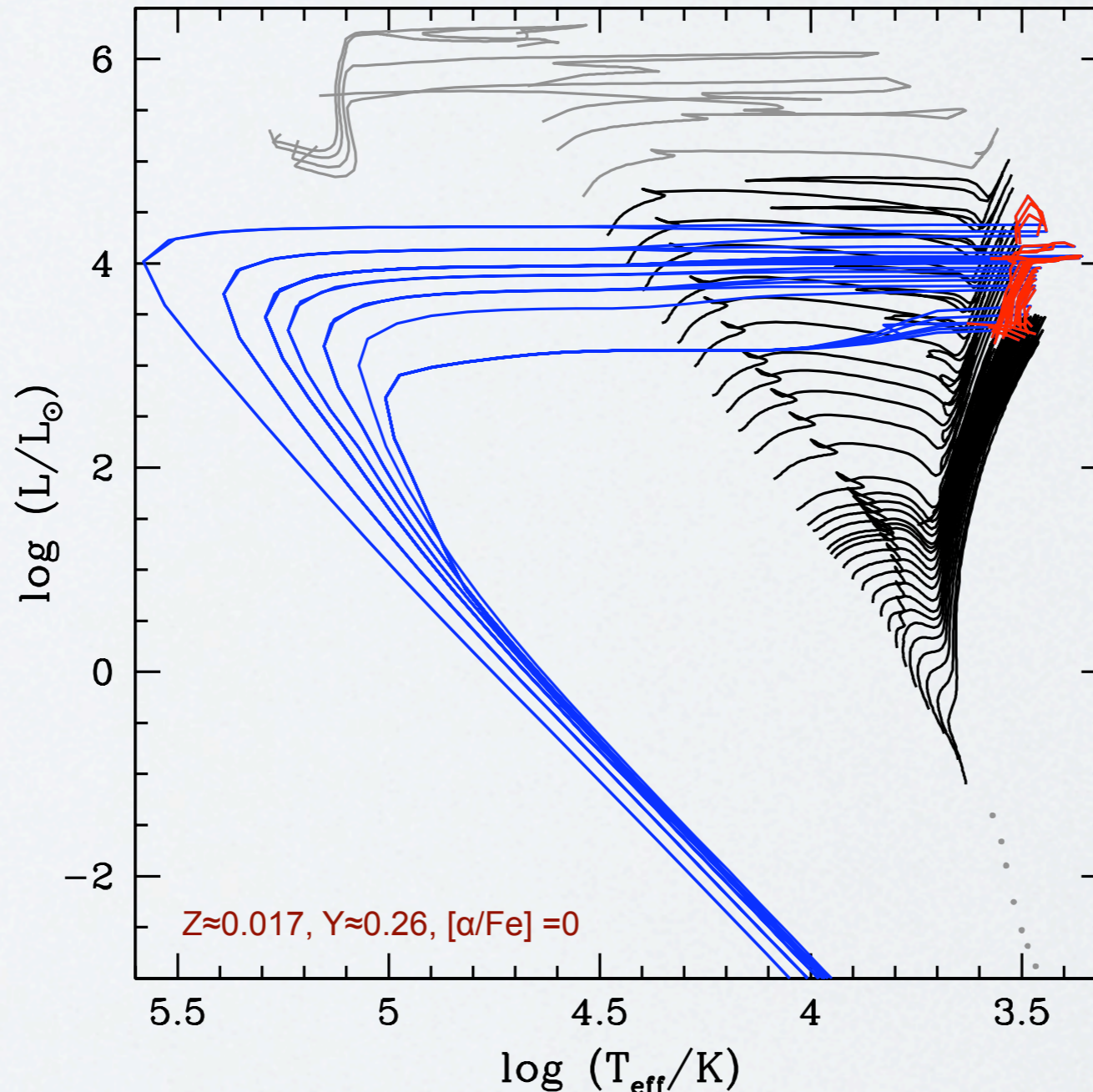
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**+ post-AGB
(from various sources)**

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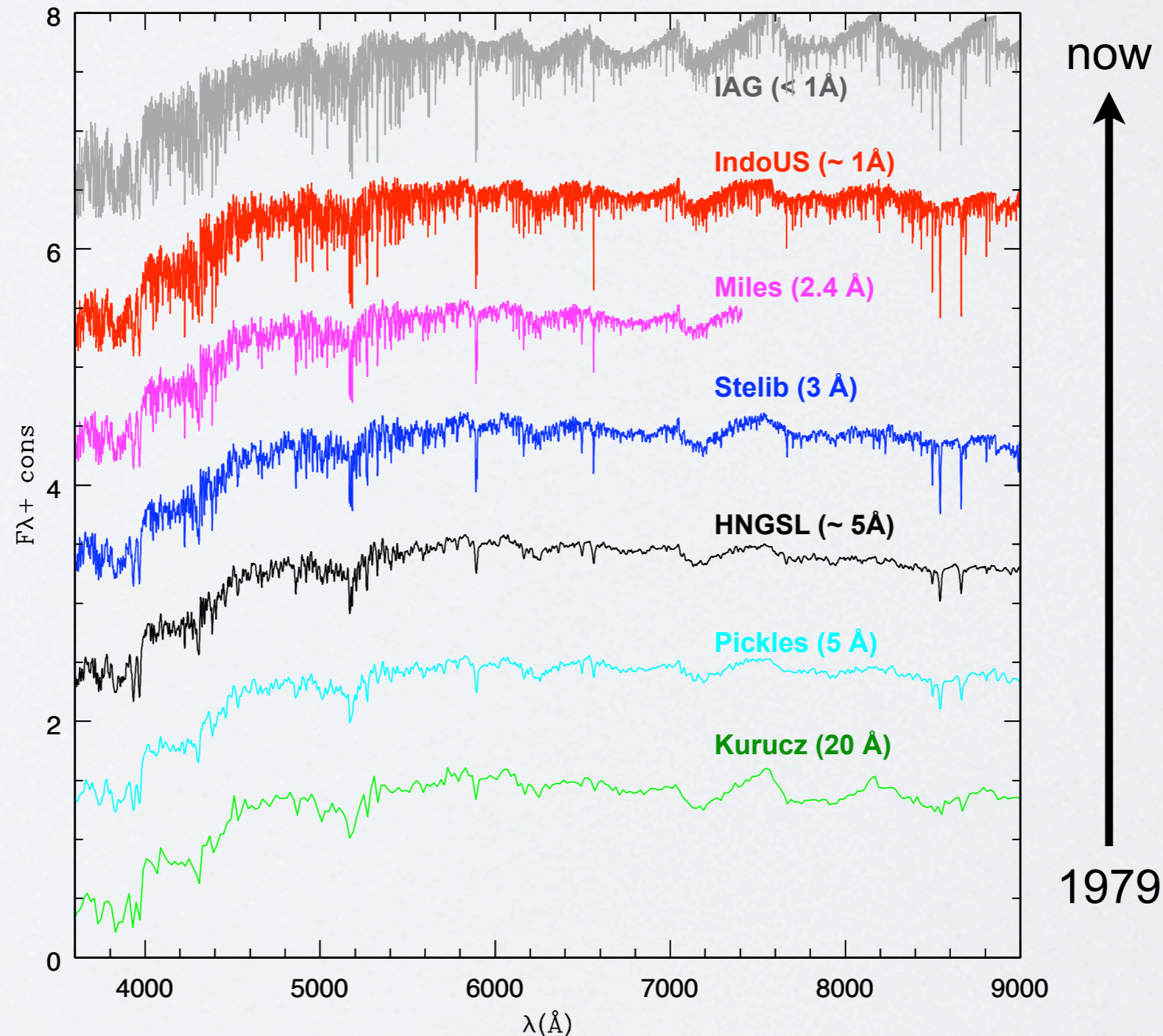
**Note: even short-lived
phases are important
(example of TP-AGB)**

- ➡ would benefit from **standardization of data format** (toward many different sets)
- ➡ **limitation: theoretical uncertainties & physical inconsistencies between sets**

Another challenge: assemble library of stellar spectra

Recent progress in the production of large spectral libraries (mostly optical)

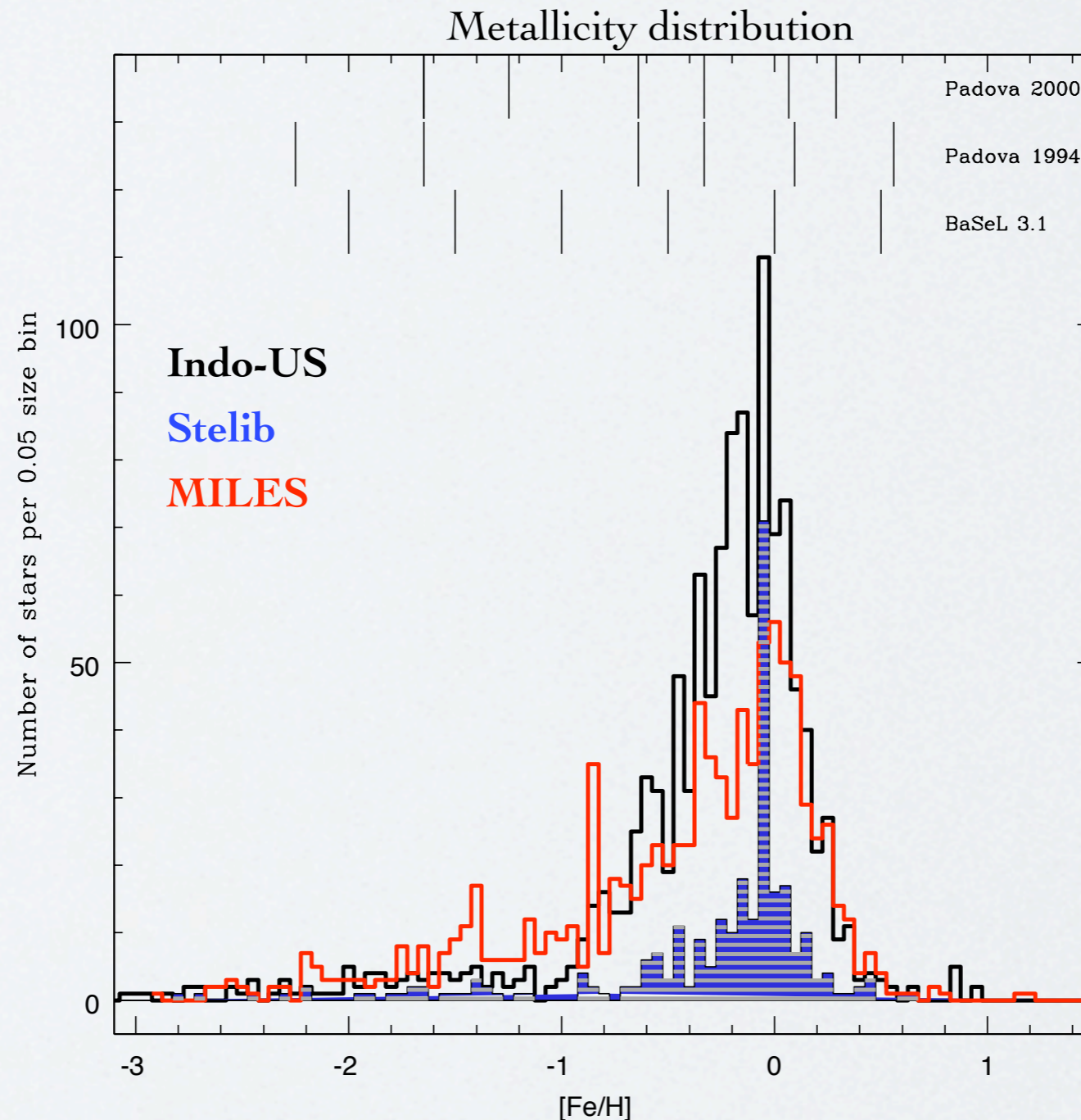
Various libraries, $Z = Z_{\odot}$, 13 Gyr



➡ need spectra for stars of all T_{eff} 's, luminosity classes, chemical compositions

Another challenge: assemble library of stellar spectra

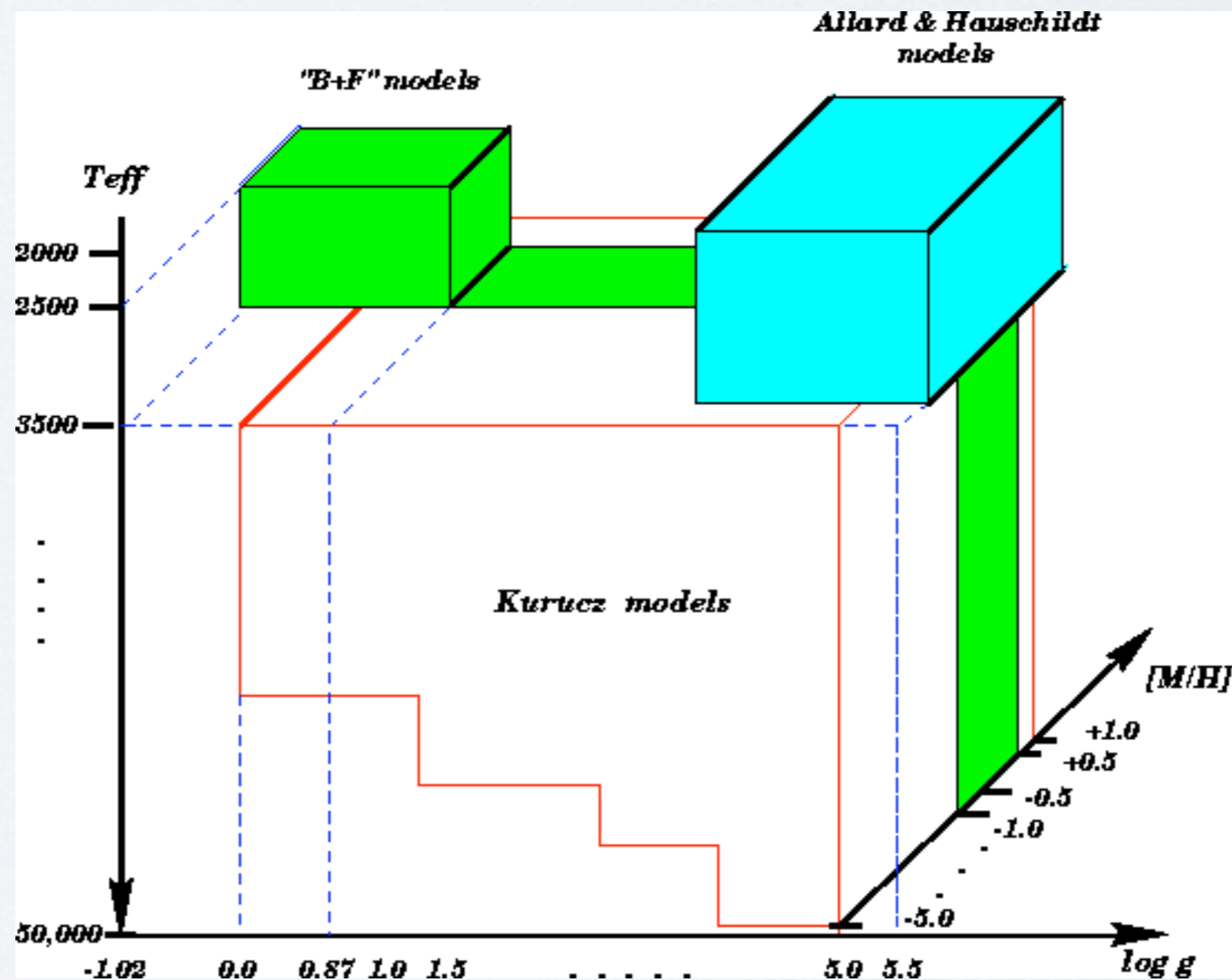
Observational libraries have limited wavelength coverage and biased toward chemical composition of Milky Way stars



⇒ need spectra for stars of all T_{eff} 's, luminosity classes, chemical compositions

Another challenge: assemble library of stellar spectra

Theoretical stellar libraries provide full wavelength coverage for arbitrary chemical compositions (although models not perfect yet)



Example:
Basel 2.2

- ⇒ very large data sets to handle (10,000-point spectra for each T_{eff} , $\log g$, $[X/H]$)
- ⇒ another area of **interoperability** and need for **standardization of data format**

Our spectral synthesis software



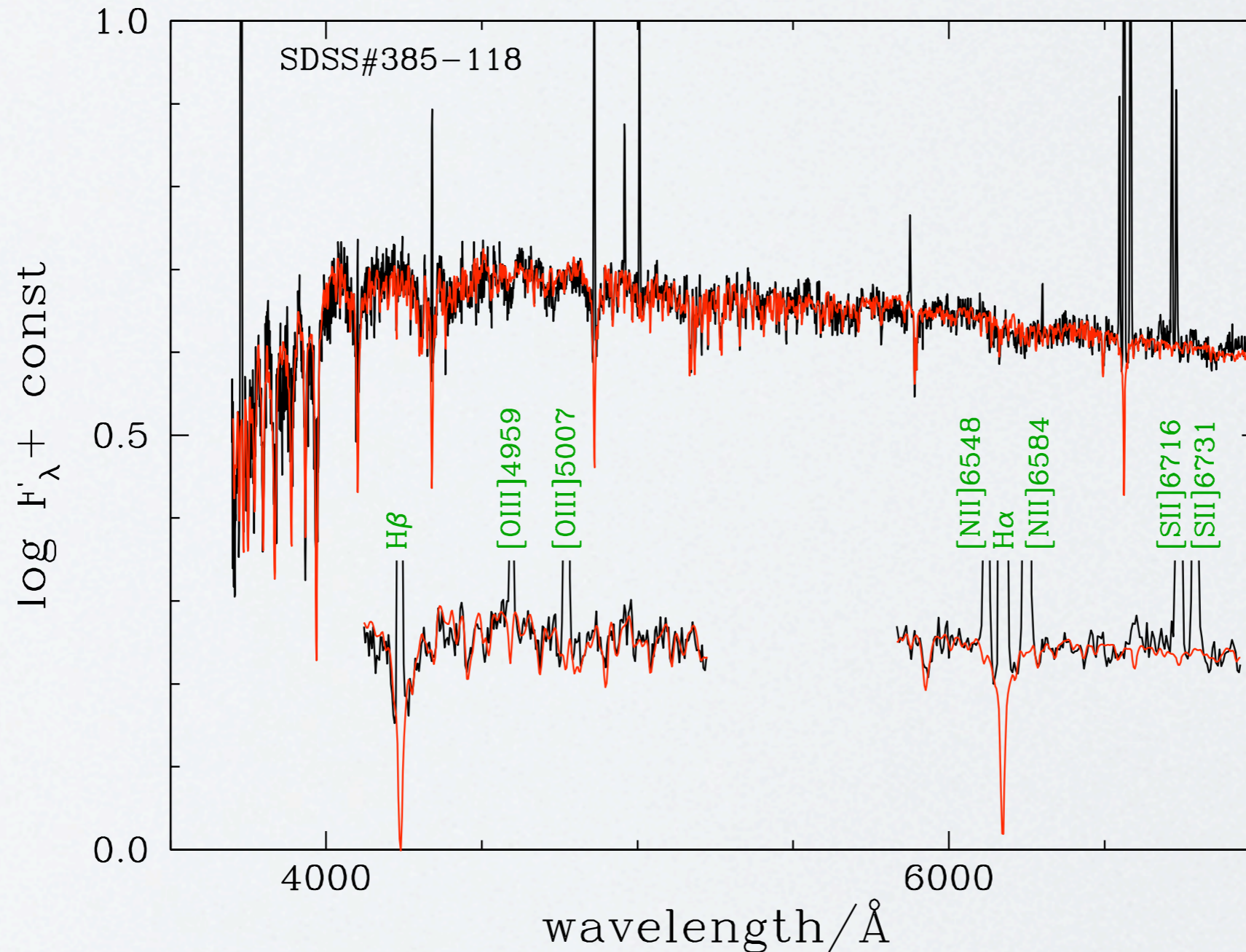
BC03/CB08 allow various combinations of stellar tracks and spectra:

- **Stellar tracks libraries:** *Geneva 1992; Padova 1994, 2000, 2008; BaSTI 2007, Weiss 2008 ; ...*
- **Empirical stellar spectra libraries:** *STELIB; MILES; Indo-US; ...*
- **Theoretical stellar spectra libraries:** *Basel 1.0, 2.2, 3.1; IAG; MARCS; ...*

⇒ extension to new libraries is time-consuming and requires many manipulations of data sets: **area where VO interoperability could help**

Nebular emission from gas heated by young stars

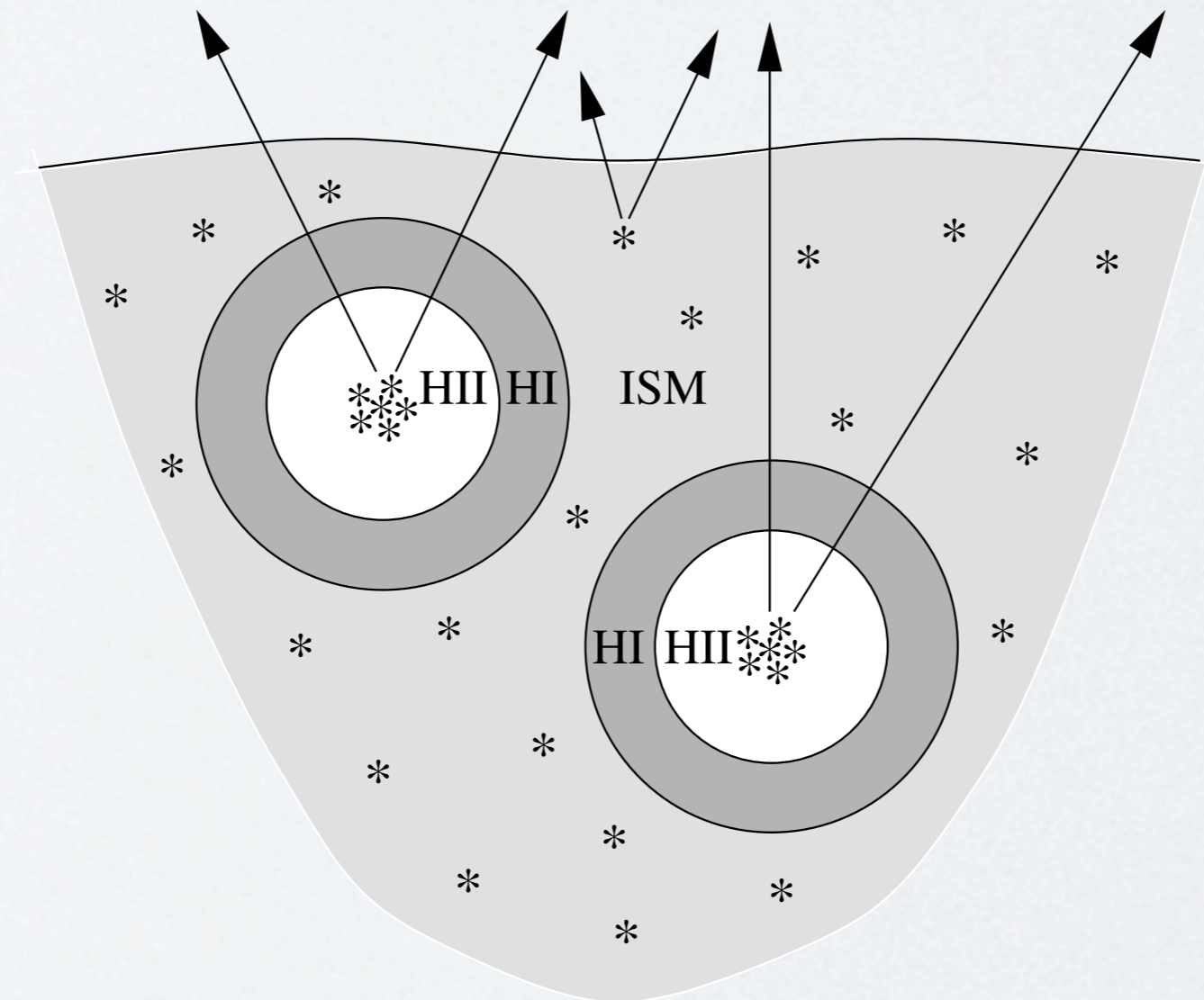
This modeling can be decoupled from that of continuum emission since accurate fitting of stellar continuum allows precise measurements of emission line fluxes



- ⇒ emission line fluxes can be interpreted separately using photo-ionization code
- ⇒ **interoperability requirements are simple** (details of stellar ionizing spectrum)

Infrared emission from dust heated by young stars

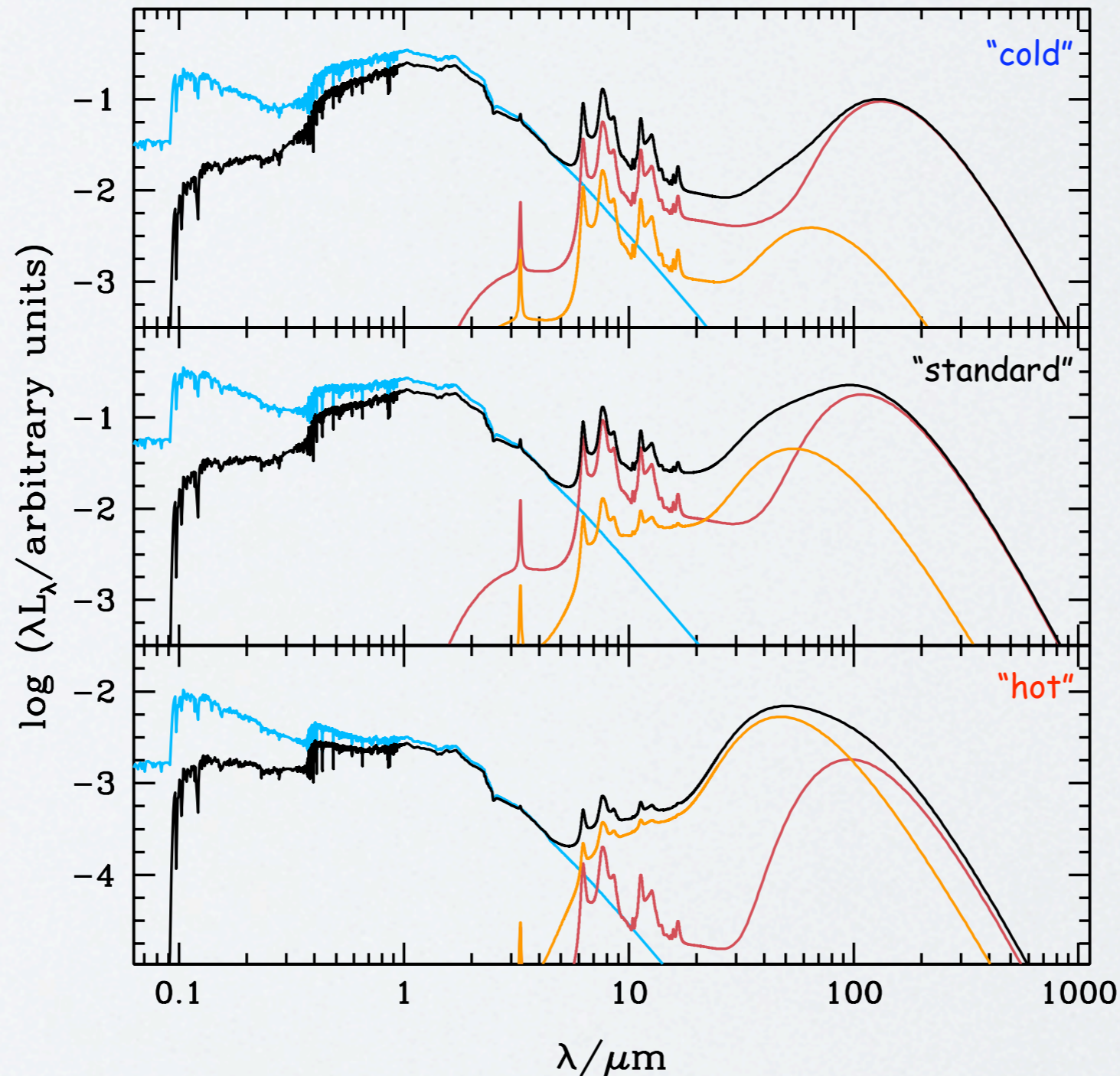
Absorption of starlight by dust intimately related to details of star formation history: emission from young and old stars attenuated differently in a galaxy



⇒ modeling of dust emission cannot be decoupled from that of stellar emission

Infrared emission from dust heated by young stars

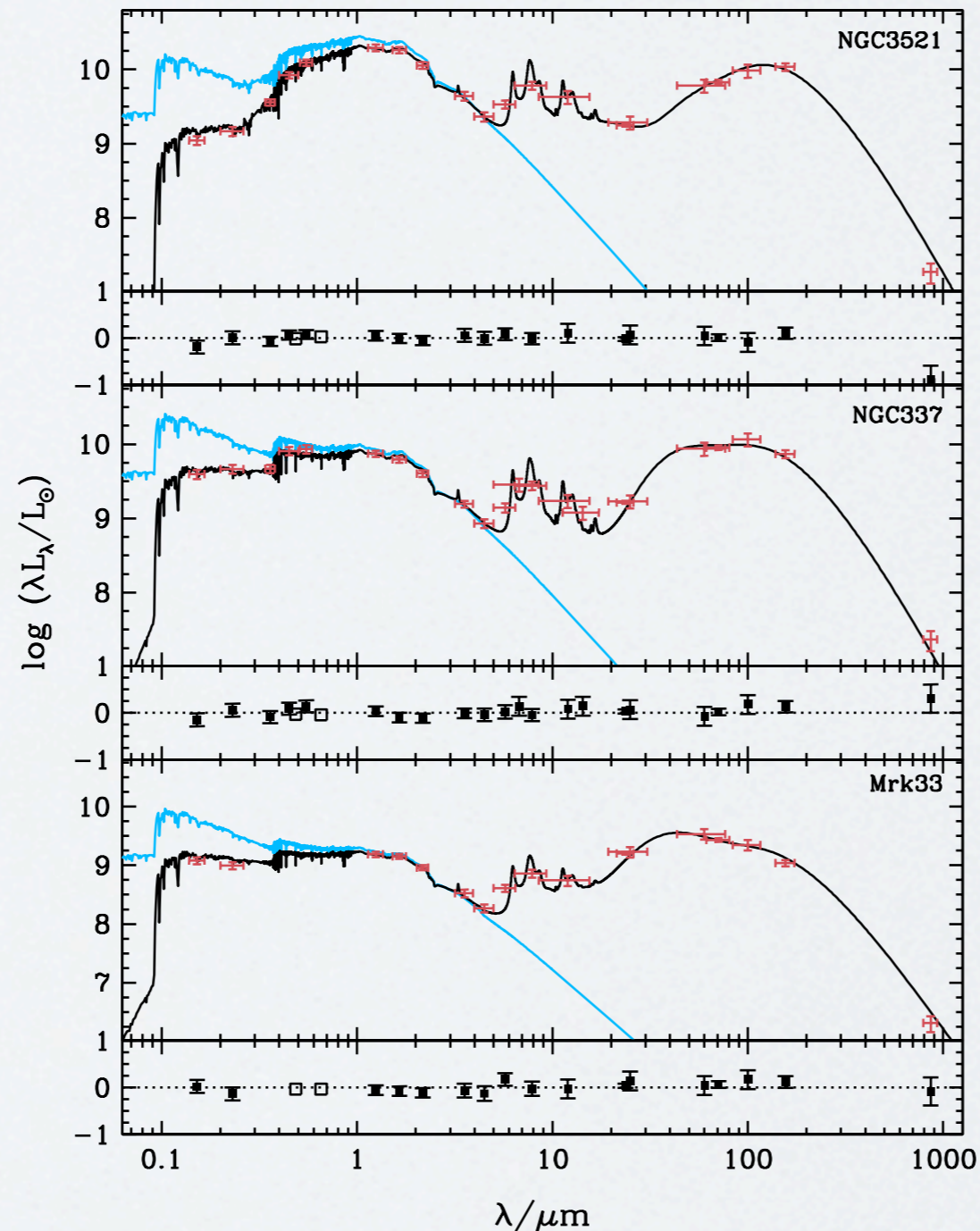
Example of simple models of infrared emission from galaxies (Da Cunha et al. 08)



- ⇒ **interoperability** could be achievable through a **few key ISM parameters**
- ⇒ *Note:* more sophisticated dust models also available (e.g. Silva et al. 98)

Infrared emission from dust heated by young stars

Example of global fits to UV, optical and IR galaxy spectra (Da Cunha et al. 08)



- ⇒ **interoperability** could be achievable through a **few key ISM parameters**
- ⇒ **Note:** statistical estimates of physical parameters require large model libraries

Conclusions



- **Modern galaxy spectral synthesis requires handling of large libraries of stellar evolutionary tracks and spectra**
- **The necessary inclusion of the effects of interstellar gas and dust on the emission from a galaxy requires interfacing additional codes at various levels of complexity**
- **VO theory-theory interoperability** would help one build versatile tools of galaxy spectral synthesis if it allowed standardization of the connections between codes of **stellar evolution, stellar atmospheres, photo-ionization and dust emission**