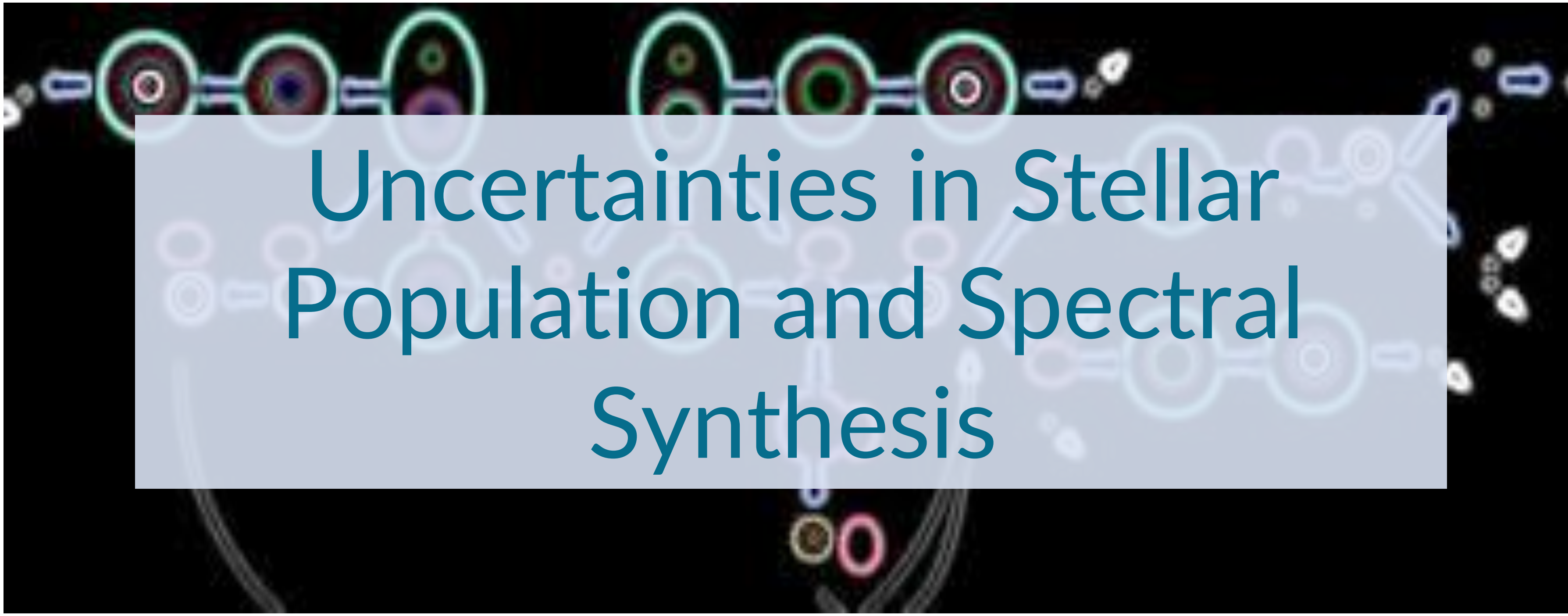
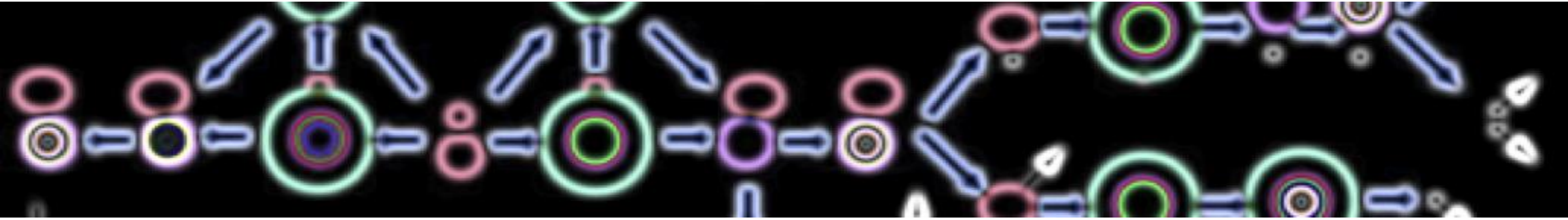


Uncertainties in Stellar Population and Spectral Synthesis

Elizabeth Stanway

University of Warwick



- Astronomy is often a data-starved science
- We can measure ***part*** of the spectrum of light emitted from complex environments, seen from a ***single*** viewing angle, at a single point in ***time***.
- To interpret those data, we usually rely on fitting to a physical model to fill in the gaps and determine the underlying physics.
- For interpreting any group of stars, galaxy or statistical sample of galaxies, this often means population and spectral synthesis.

Population & Spectral Synthesis

Stellar evolution tracks (isochrones)

Initial Mass Function

Stellar spectra (atmospheres or observations)

Sun-like stars

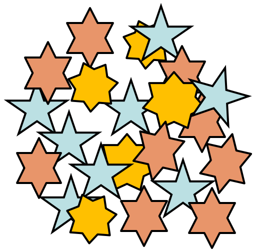
Post-Main Sequence

Massive stars

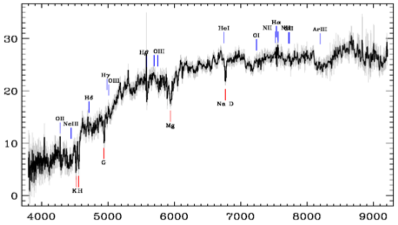
Stellar remnants

Population Synthesis

Composite Stellar Population at given age



Spectral Synthesis

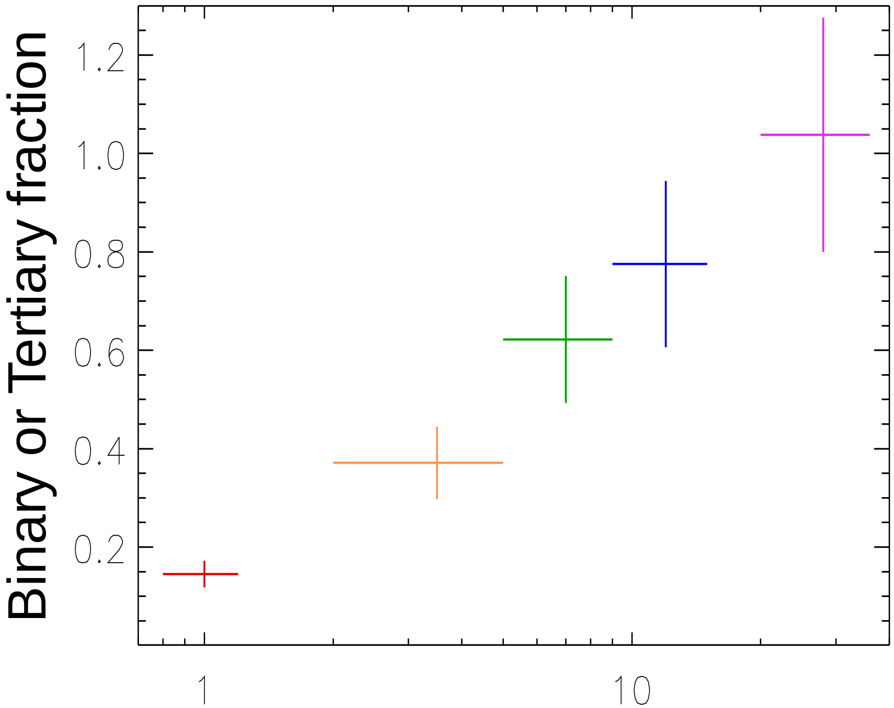


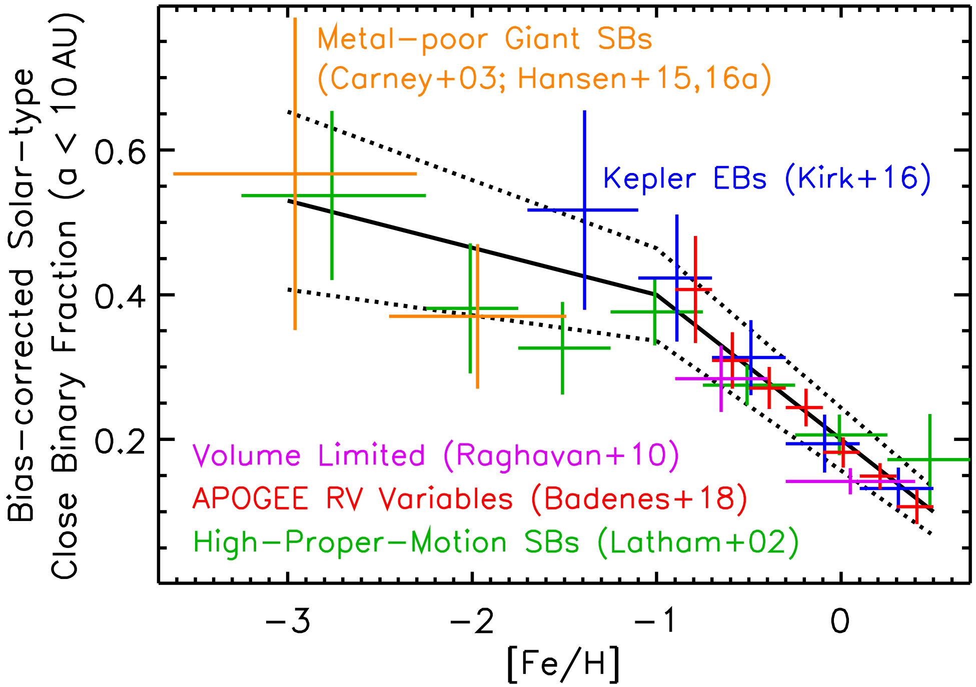
- Stellar type ratios (e.g. WR/O etc)
- Lum-Temp HR diagrams
- Supernova rates
- Stellar mass

- Composite spectra
- Photometric colours
- Colour-Mag HR diagrams
- Stellar absorption and emission lines

Binaries in the Universe

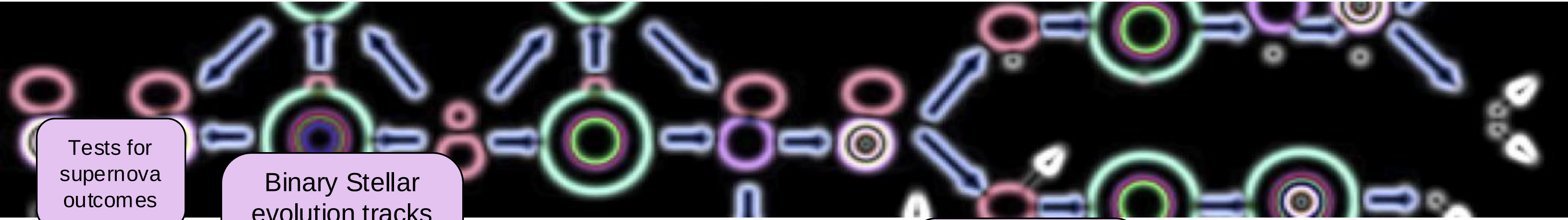
Most stars are not isolated!





"Mind your P's and Q's"
Moe & di Stefano (2017)

"The Close Binary Fraction of Solar-type Stars Is Strongly Anticorrelated with Metallicity"
Moe et al (2019)



Tests for supernova outcomes

Rejuvenation and mixing

Stripping and CEE

Binary parameter evolution (P,a)

Binary Stellar evolution tracks (function of mass, period, mass ratio, Z)

Stellar evolution tracks (isochrones)

Sun-like stars

Post-Main Sequence

Massive stars

Stellar remnants

Initial period and mass ratio distributions

Initial Mass Function

Inputs

Stripped and He star atmospheres

Stellar spectra (atmospheres or observations)

Population Synthesis

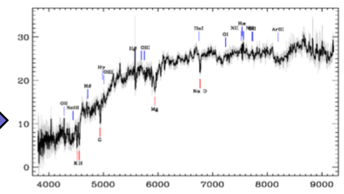
Identify GRBs, accreting compact objects, compact object mergers

Composite Stellar Population at given age

- Stellar type ratios (e.g. WR/O etc)
- Lum-Temp HR diagrams
- Supernova rates
- Stellar mass

- GRB + GW chirp rates
- XRB number counts
- SN distributions/kicks
- Remnant masses

Spectral Synthesis



- Composite spectra
- Photometric colours
- Colour-Mag HR diagrams
- Stellar absorption and emission lines

- Bluer, harder spectra
- Stronger stellar absorption lines

Rapid vs Detailed Stellar Models

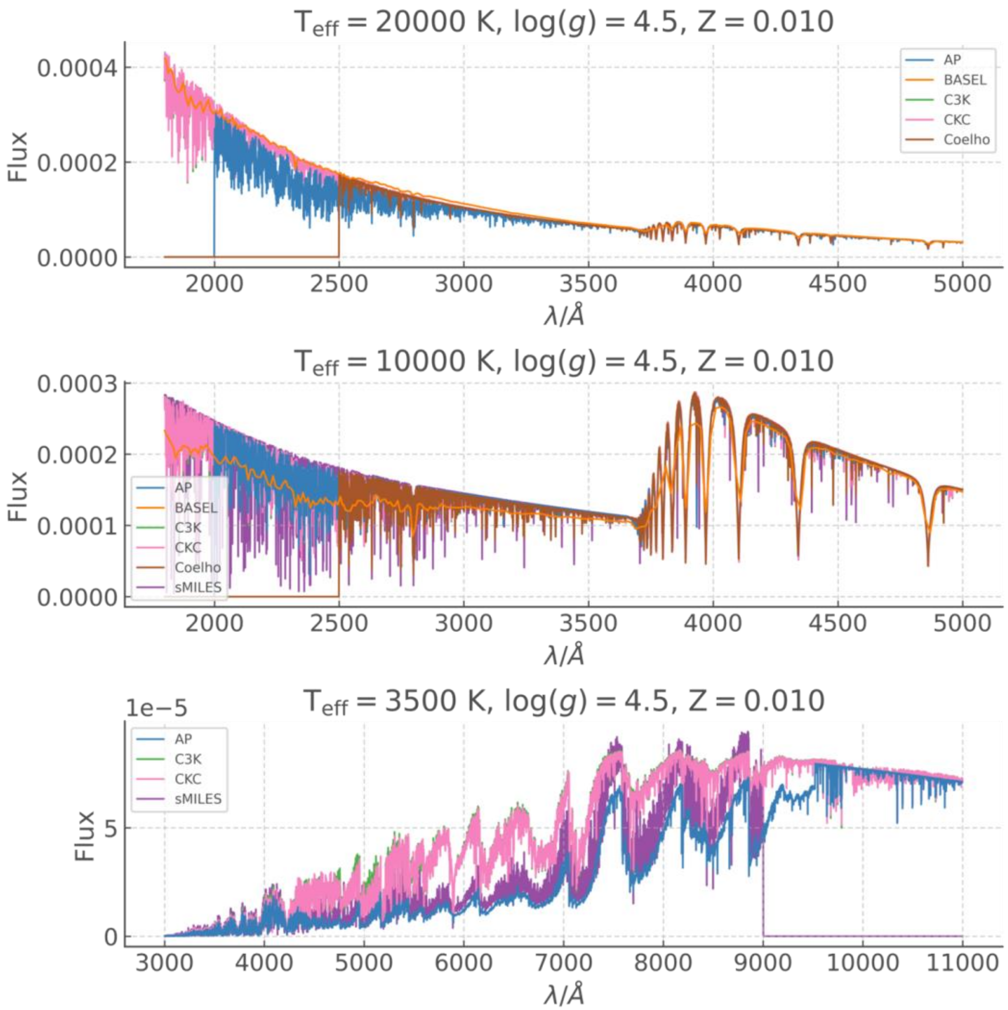
- Detailed Models:
  - Structure equations solved iteratively at every time step and depth in star
  - Slow, but accurate

MESA, BPASS

- Rapid Models:
  - A small grid of detailed models used to derive analytic approximations to evolution
  - Less accurate, but much faster
  - Most based on Hurley et al (2000, 2002)

BSE, SSE

Stellar Spectral Libraries



Different stellar spectral libraries would assign different spectra to the same evolution model.

Empirical vs Theoretical?

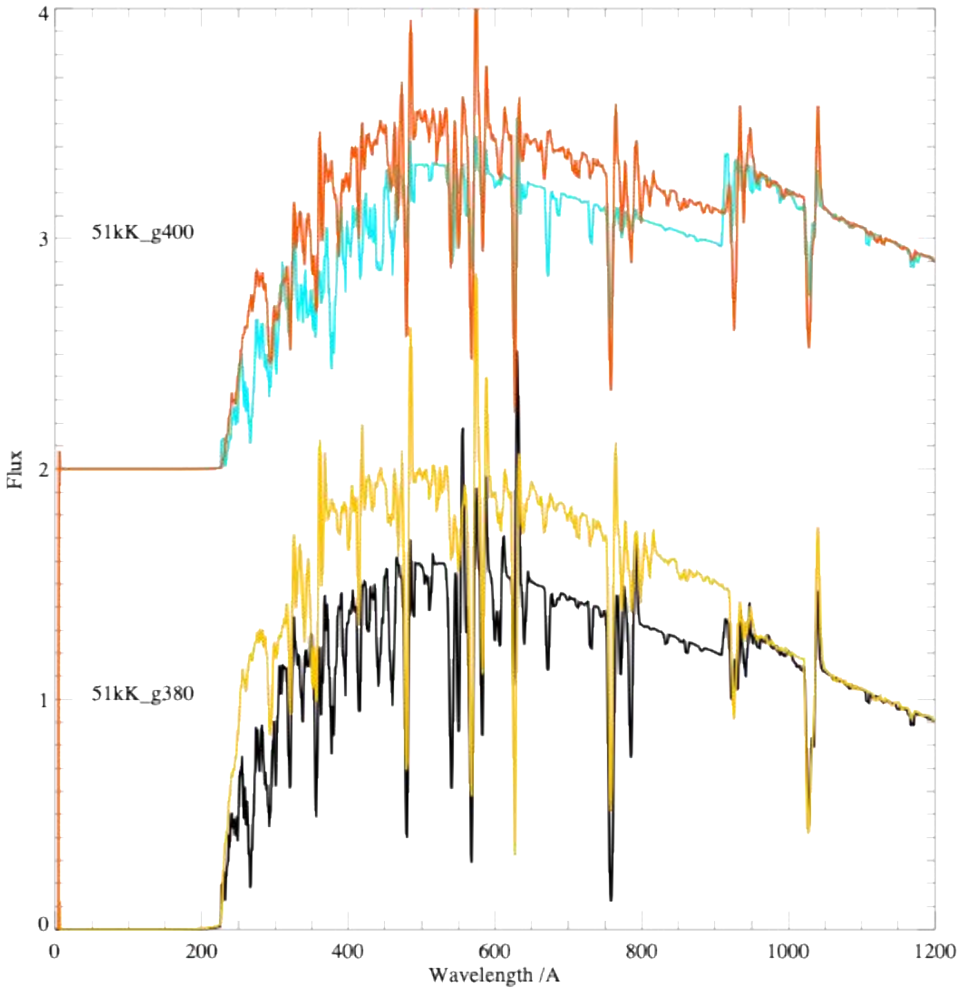
LTE vs Non-LTE?

See e.g. Byrne et al (2022, 2023)

The Ionizing Spectrum of Hot Stars

… can only be inferred indirectly, or modelled theoretically

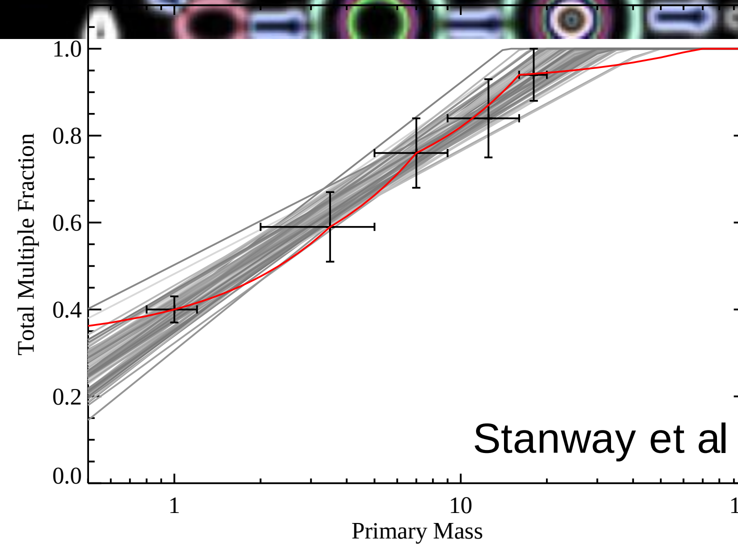
Significant differences between models (e.g. CMFGEN vs WMBASIC) which are nominally the same temperature and gravity



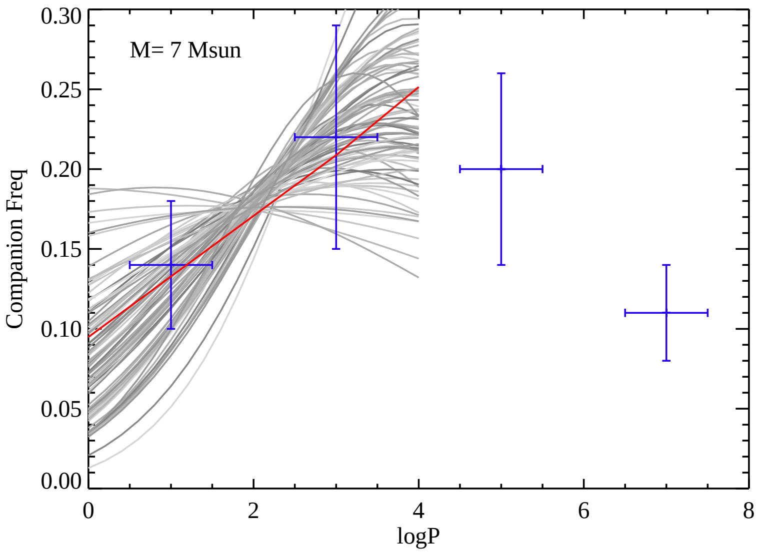
Binary Parameter Distributions

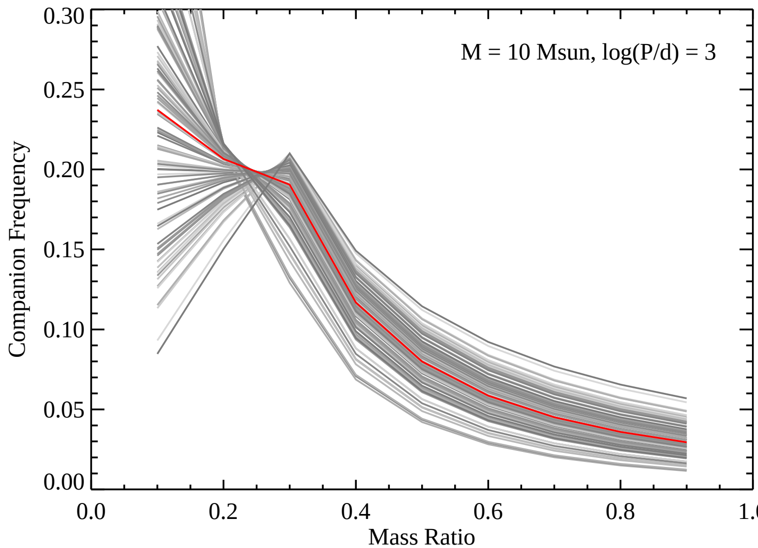
Binary pop synth needs input distributions in binary fraction, period and mass ratio – these are all fixed empirically

e.g. Moe & di Stefano (2017), ongoing work from BLOeM team

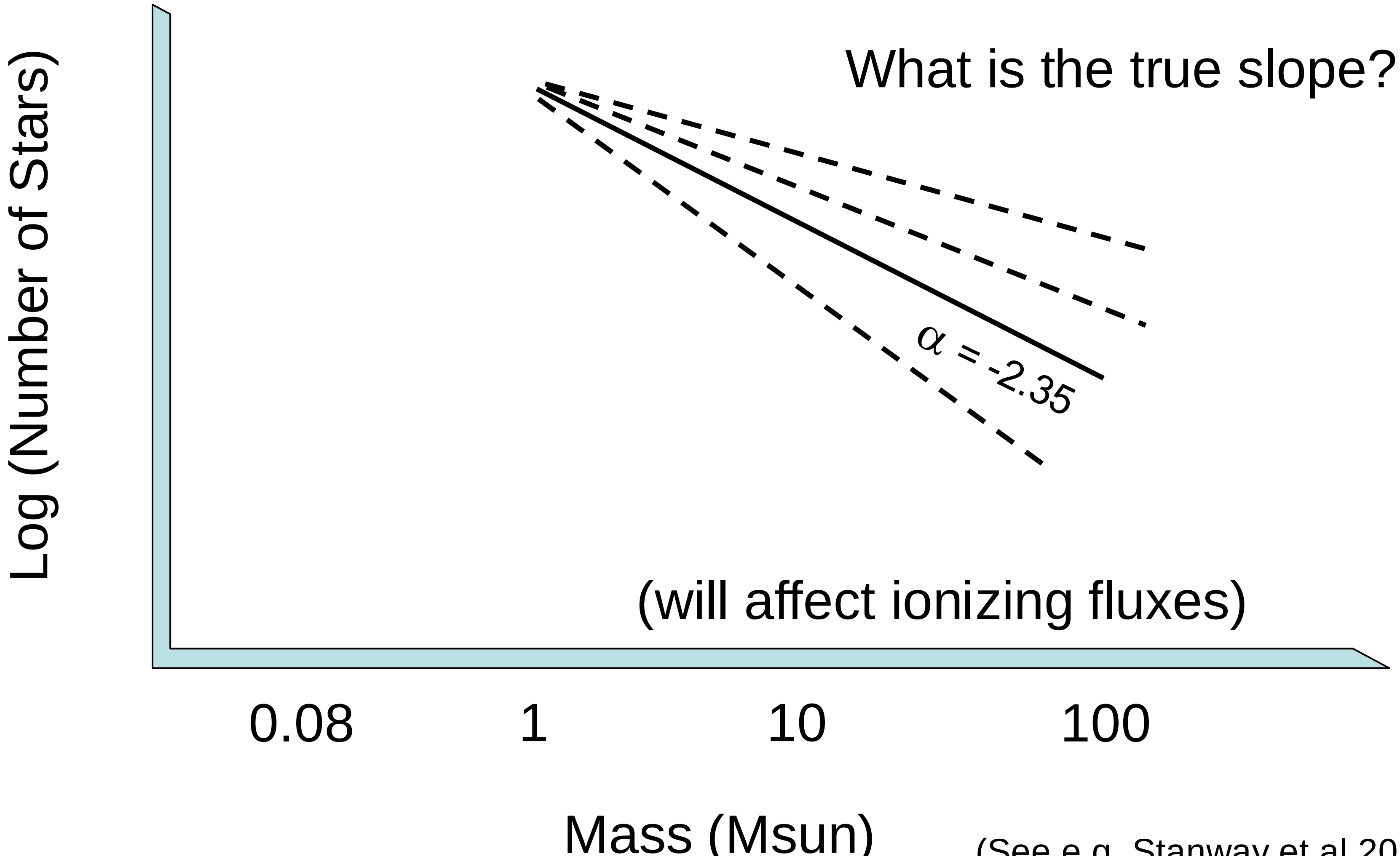


Stanway et al (2020a)



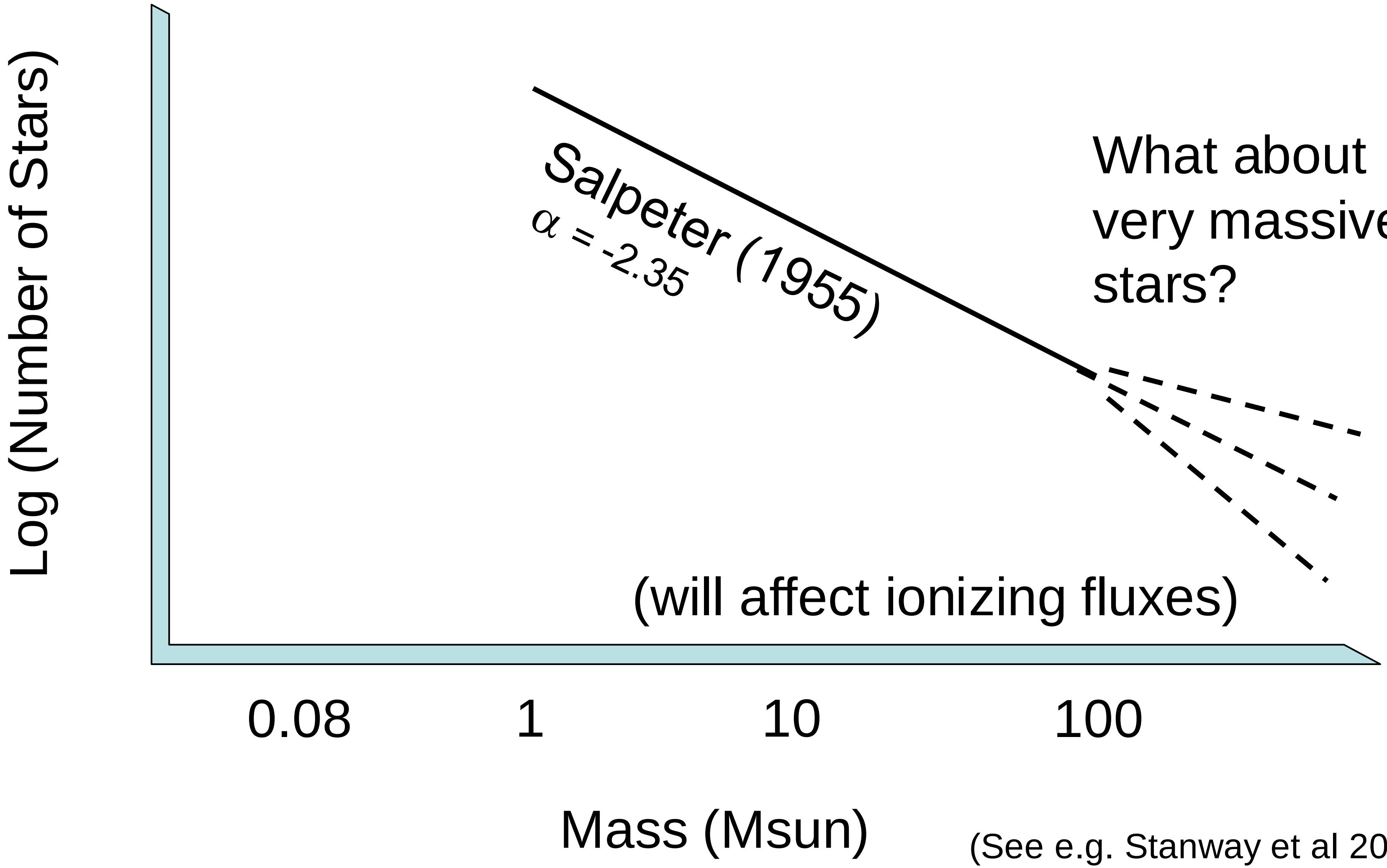


Initial Mass Functions



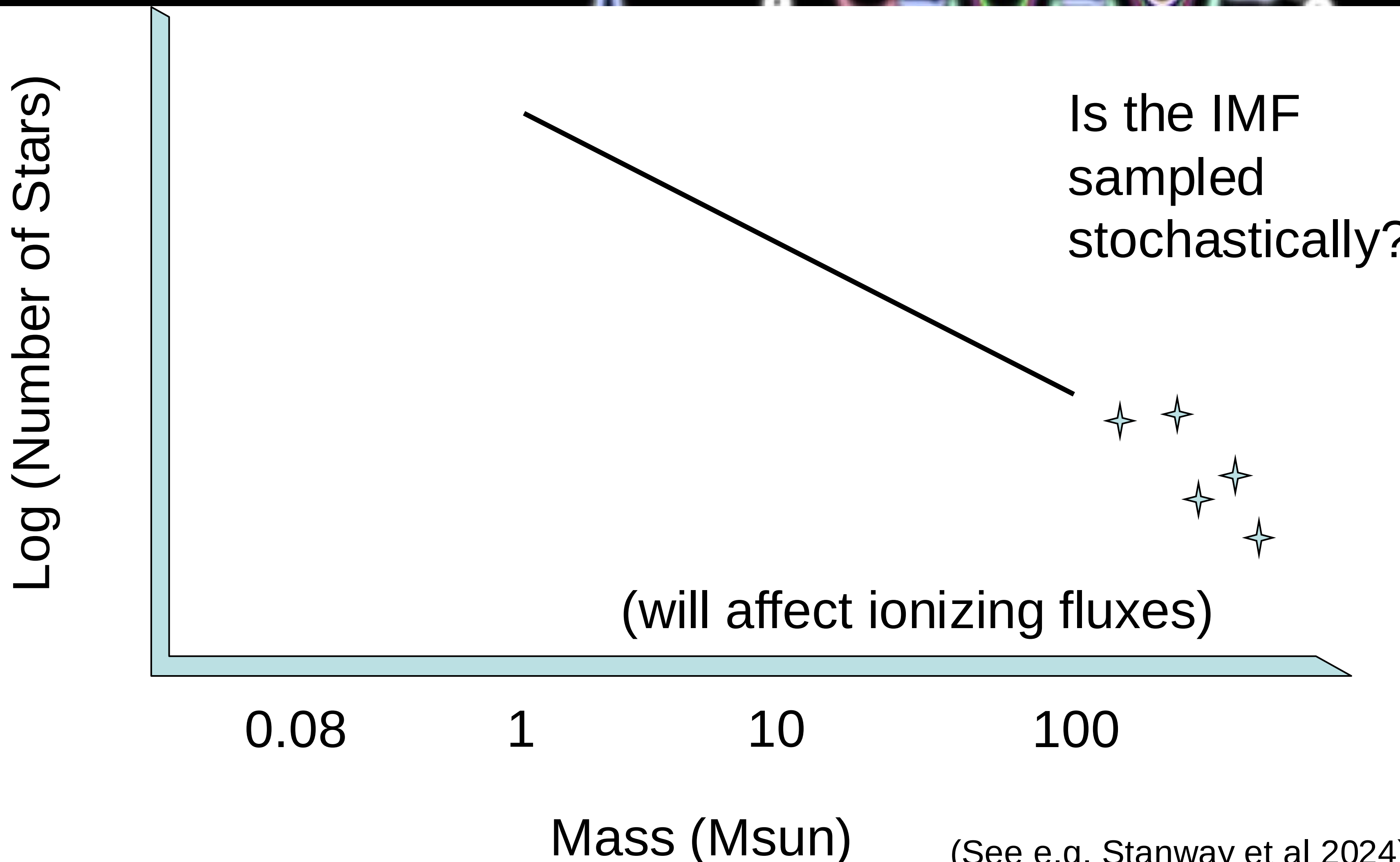
(See e.g. Stanway et al 2019)

Initial Mass Functions



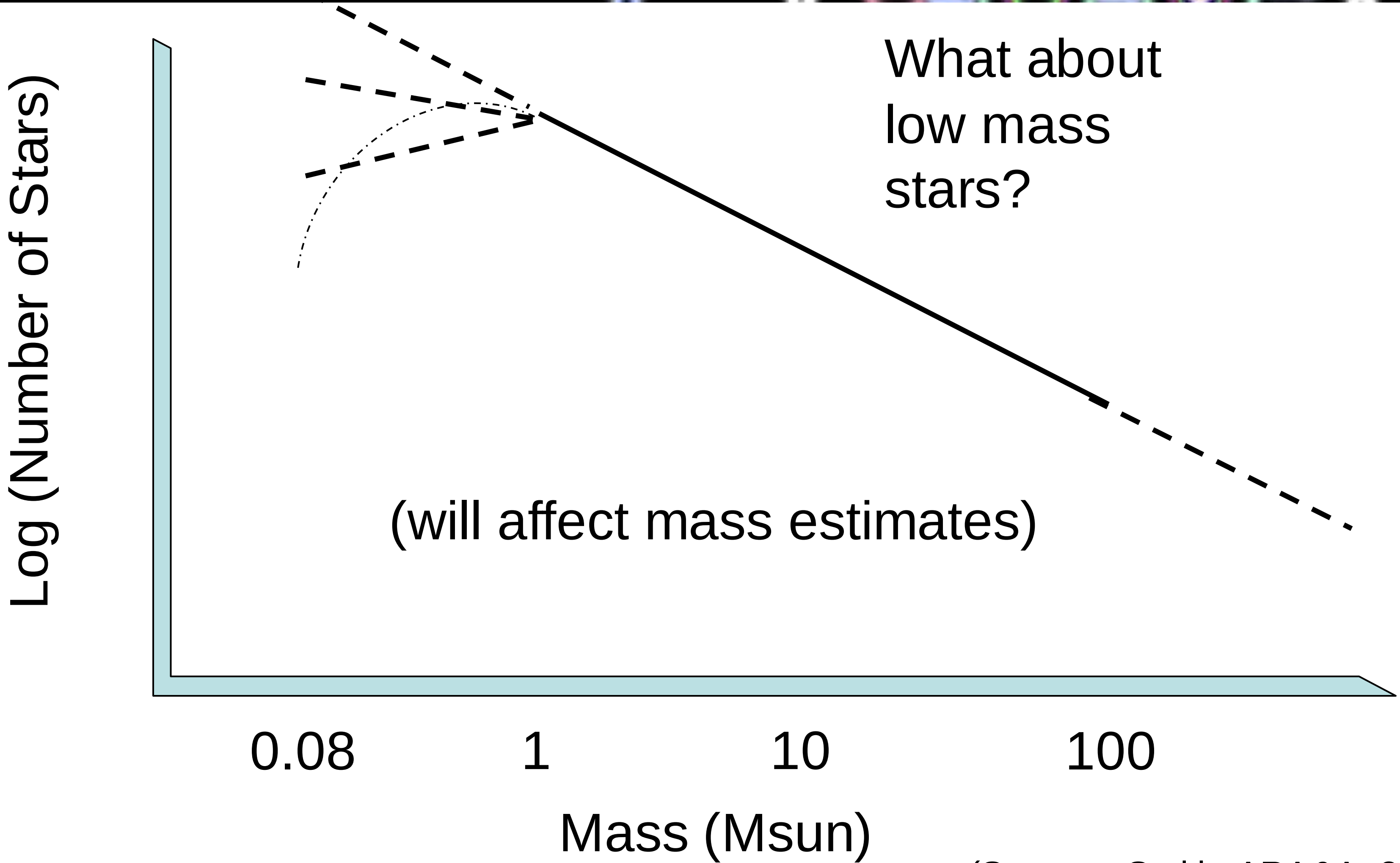
(See e.g. Stanway et al 2019)

Initial Mass Functions



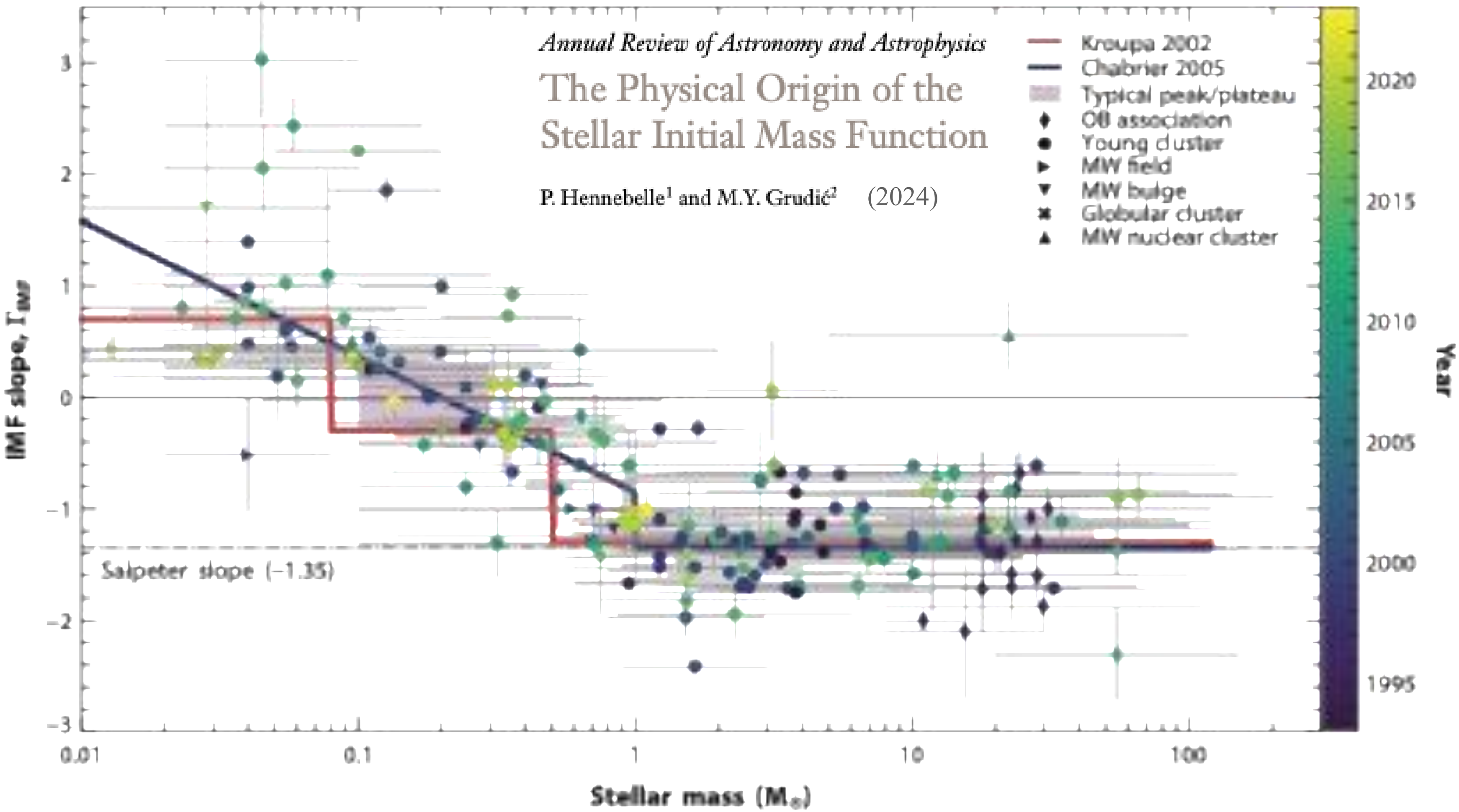
(See e.g. Stanway et al 2024)

Initial Mass Functions

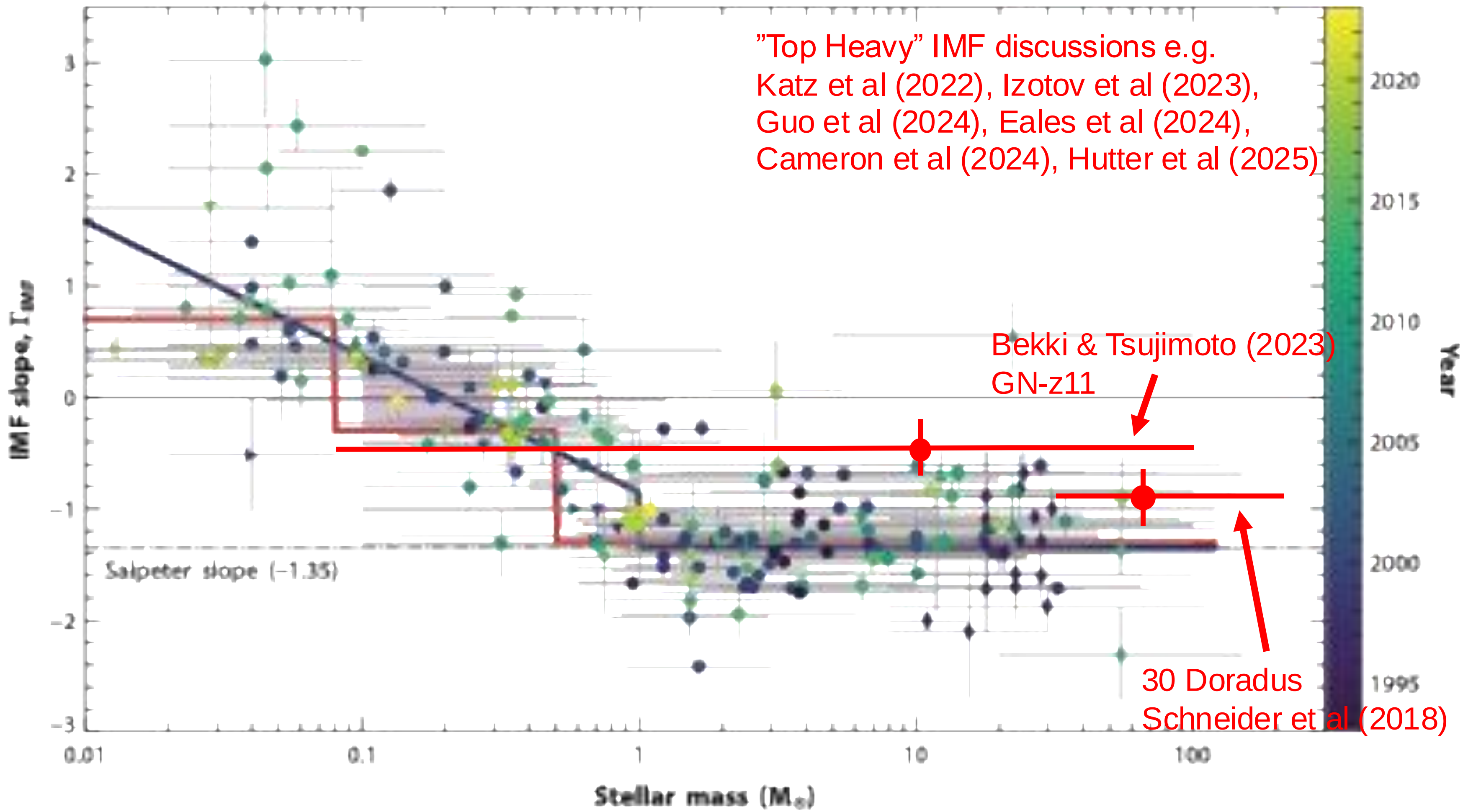


(See e.g. Smith, ARA&A, 2020)

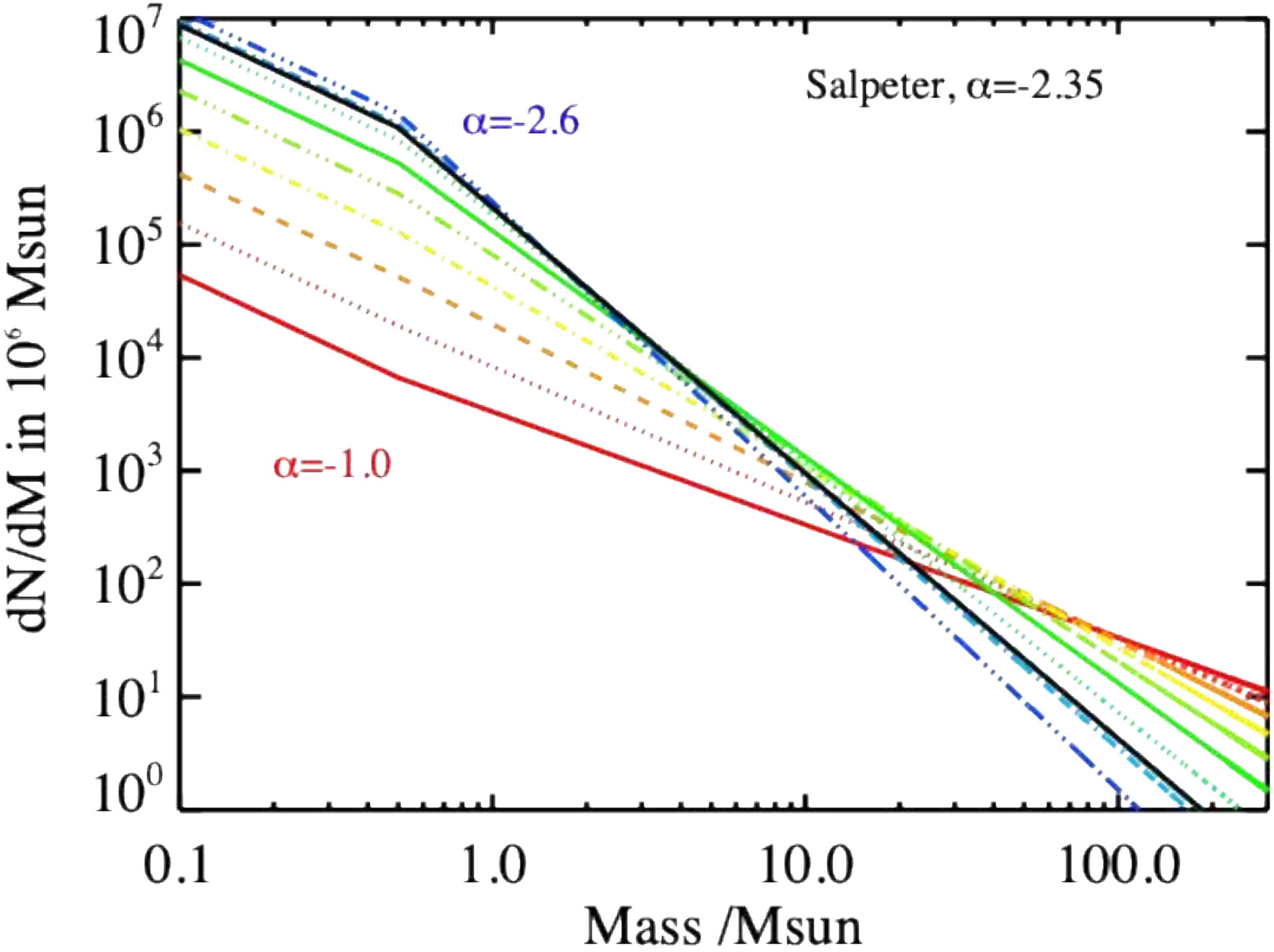
Initial Mass Functions



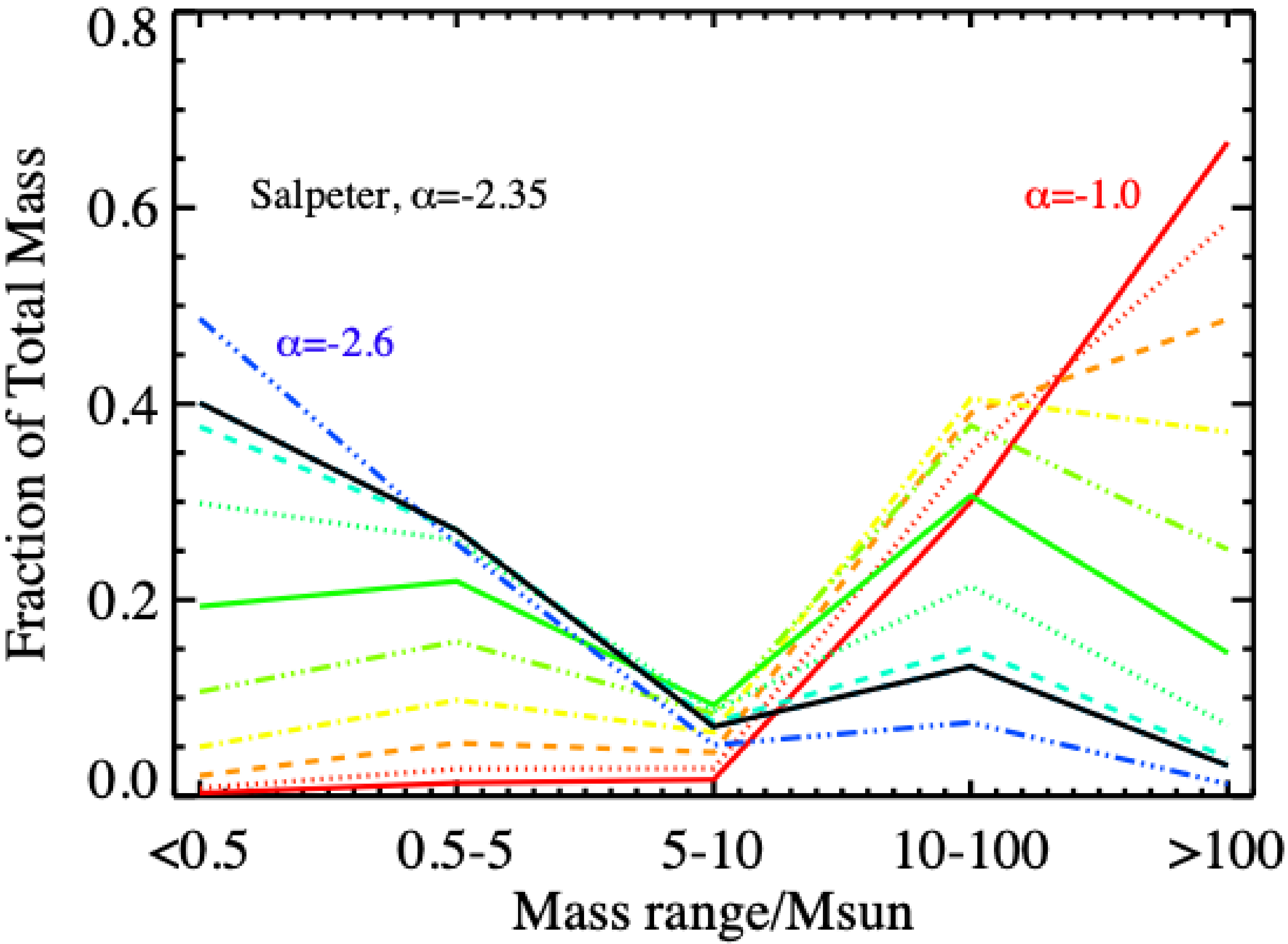
Initial Mass Functions



Initial Mass Functions



Initial Mass Functions

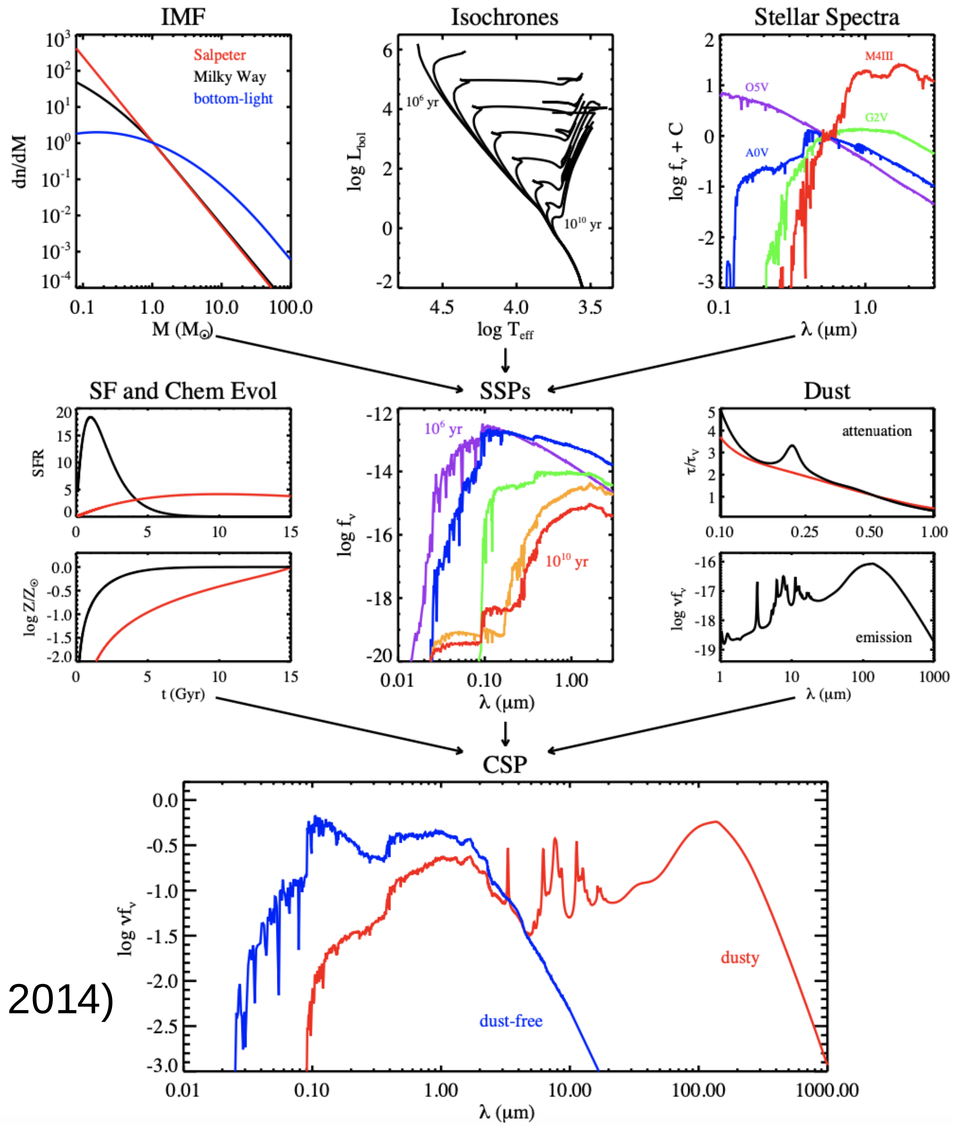


Full SED Modelling

Combining SSPs with:

- star formation history
- metallicity history
- nebular gas
- dust absorption and emission

produces a full synthetic spectral energy distribution (SED)



(image: Conroy 2014)

Nebular Gas and Dust

To fit real stellar populations gas and dust must also be considered

⇒ absorbs away blue light, produces nebular continuum and line emission (gas), far infrared emission (dust)

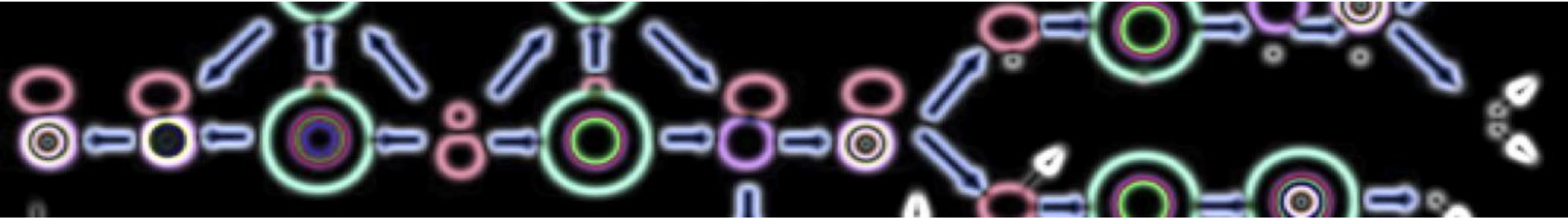
⇒ Key parameters: gas density (n_e), ionizing spectrum, gas composition, ionization parameter (n_{ion} per gas particle), dust extinction curve(k_λ), dust emission curve)

Specialist radiative transfer codes (e.g. Cloudy) must be used

Questions to Ask

So, you're using an SSP? You should ask what it's using for:

- Stellar evolution models
- Stellar atmosphere models
- Initial mass function and model mass range
- Initial composition/metallicity
- Binary parameters
- Nebular gas or dust assumptions



Any Questions?

Contact email: e.r.stanway@warwick.ac.uk