ASTR 511

Galactic Astronomy

Lecture 05

Mass & Luminosity Functions

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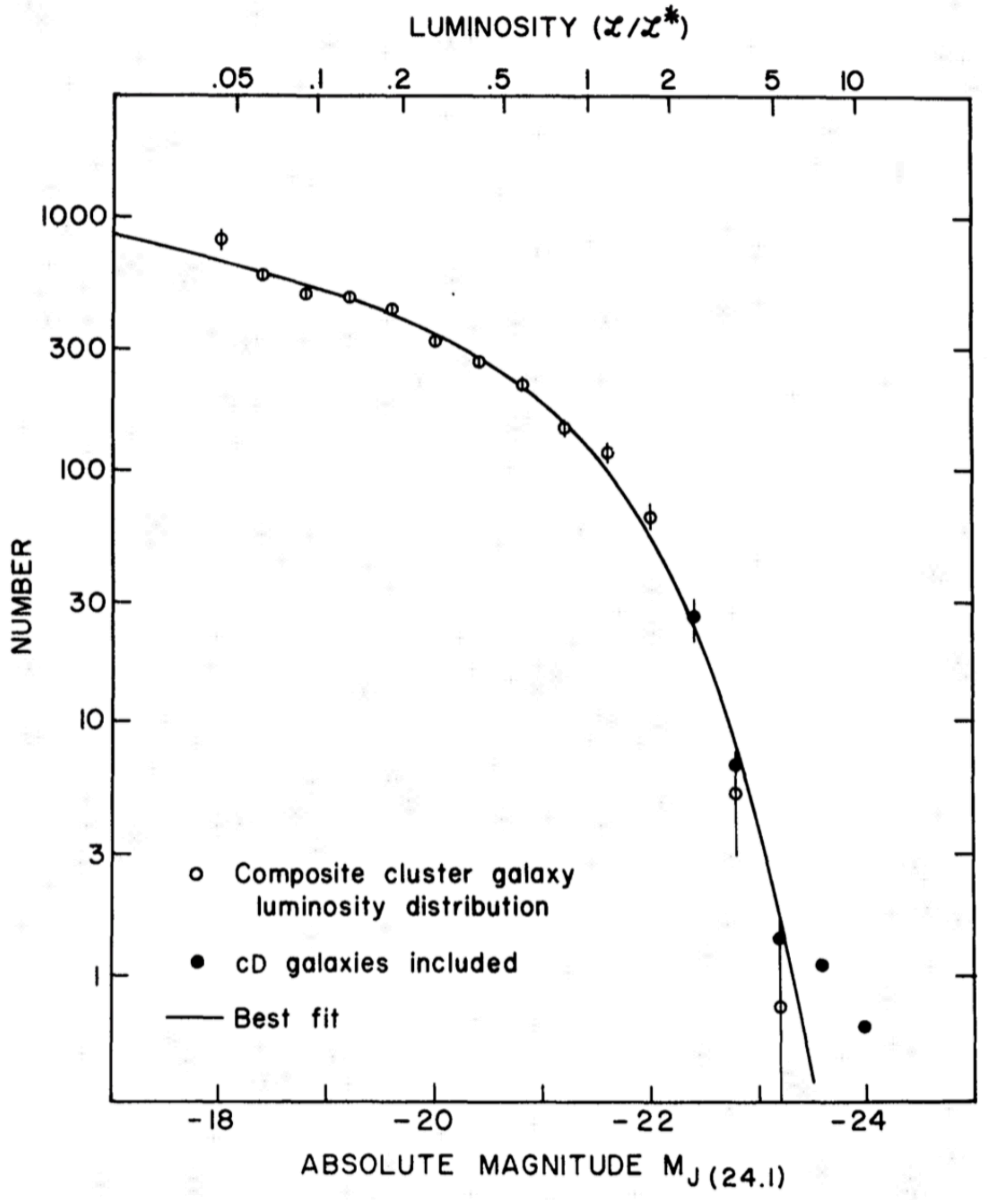
Winter 2023

Homework 2

- Let's open some time up to talk about the homework… Any early questions?
- **How do you fit an isochrone?!**
    - Some <u>packages</u> can help!
    - Can be <u>done with simple least-squares</u>… but be careful with interpolation
    - Can be done *very* hacky (each parameter tuned manually)
- Any neat things you've found so far?

WTF is a LF or MF?

- **Luminosity Function**: really a distribution of objects as a function of their luminosity, can be per unit volume
- **Mass Function:** distribution of objects as a function of their mass, can be per unit volume.
- a fancy histogram



Schechter (1976)

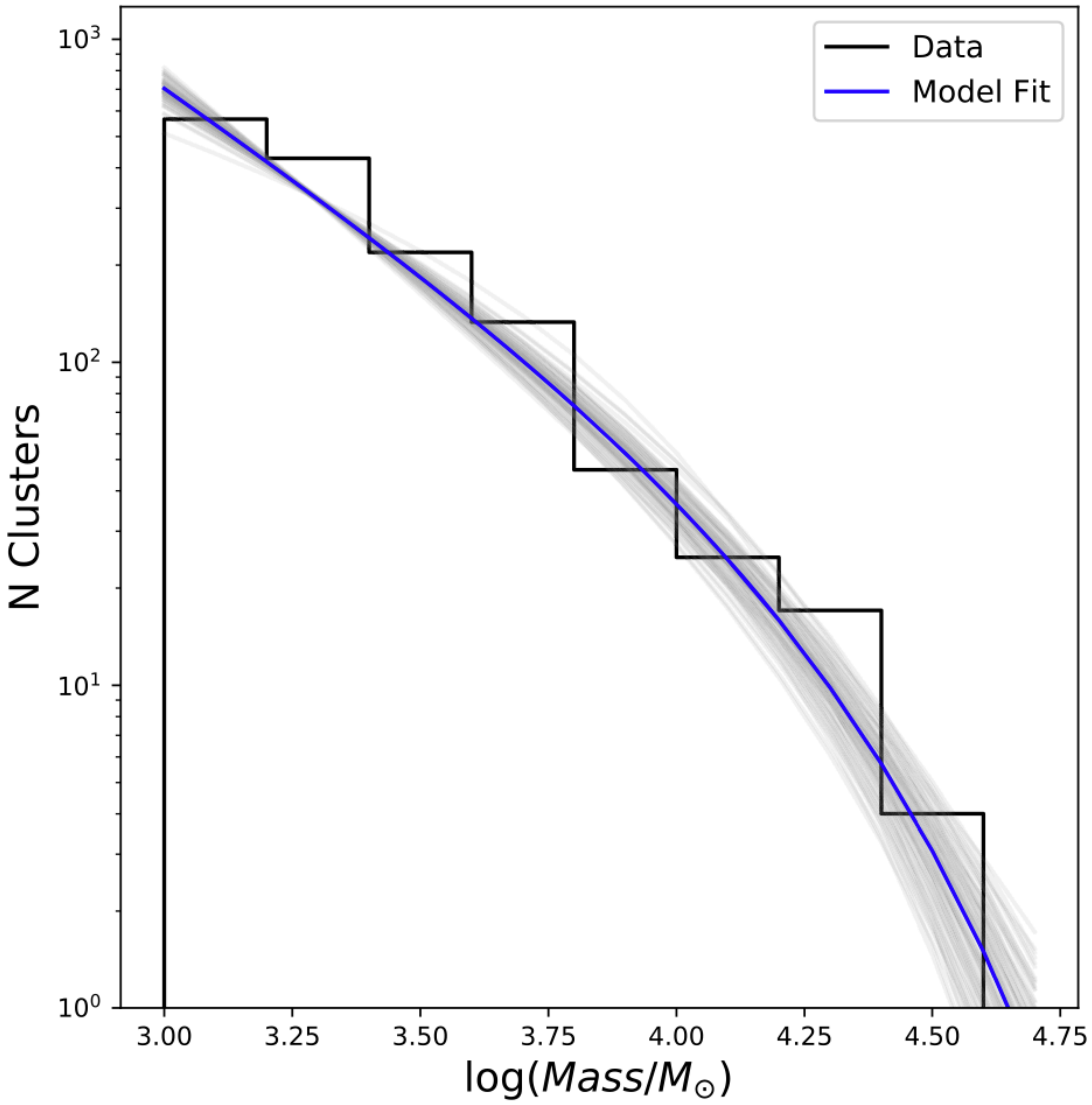
WTF is a LF or MF?

- **A histogram of *what?***
    - Galaxies?
    - Star Clusters?
    - Stars?
- **YES**

- **LF or MF?**
    - More massive things usually more luminous, so for *most* cases they are conceptually the same.
    - Luminosity for the observers
      Mass for the theorists
        - Mix & match for the adventurous

WTF is a LF or MF?

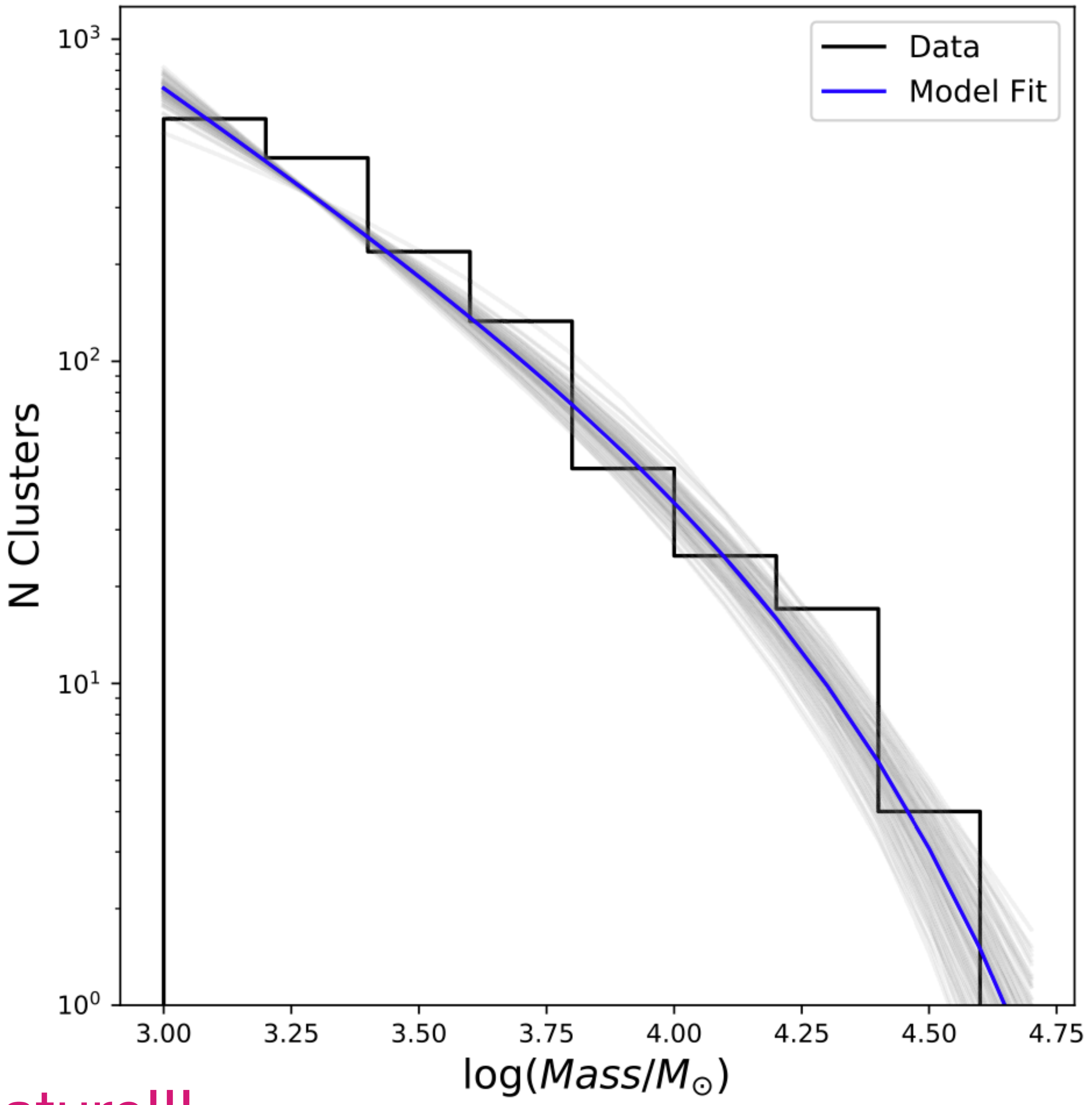
- **Why do we care?**
  - We can't plausibly recreate the actual stars/galaxies we observe with simulations
  - LF a very testable measurement!
  - Tells us lots about the underlying physics
    - Incl. formation, history, evolution…



Wainer+2022

WTF is a LF or MF?

- **What is this function telling us?**
  - Nature produces lots of small things, fewer big things.
  - Is it all self-similar or "self-organized criticality"? (e.g. a power law)
  - Is there a maximum mass?
  - Is there a minimum mass?
  - Is there a "break" or critical mass, or different regimes?

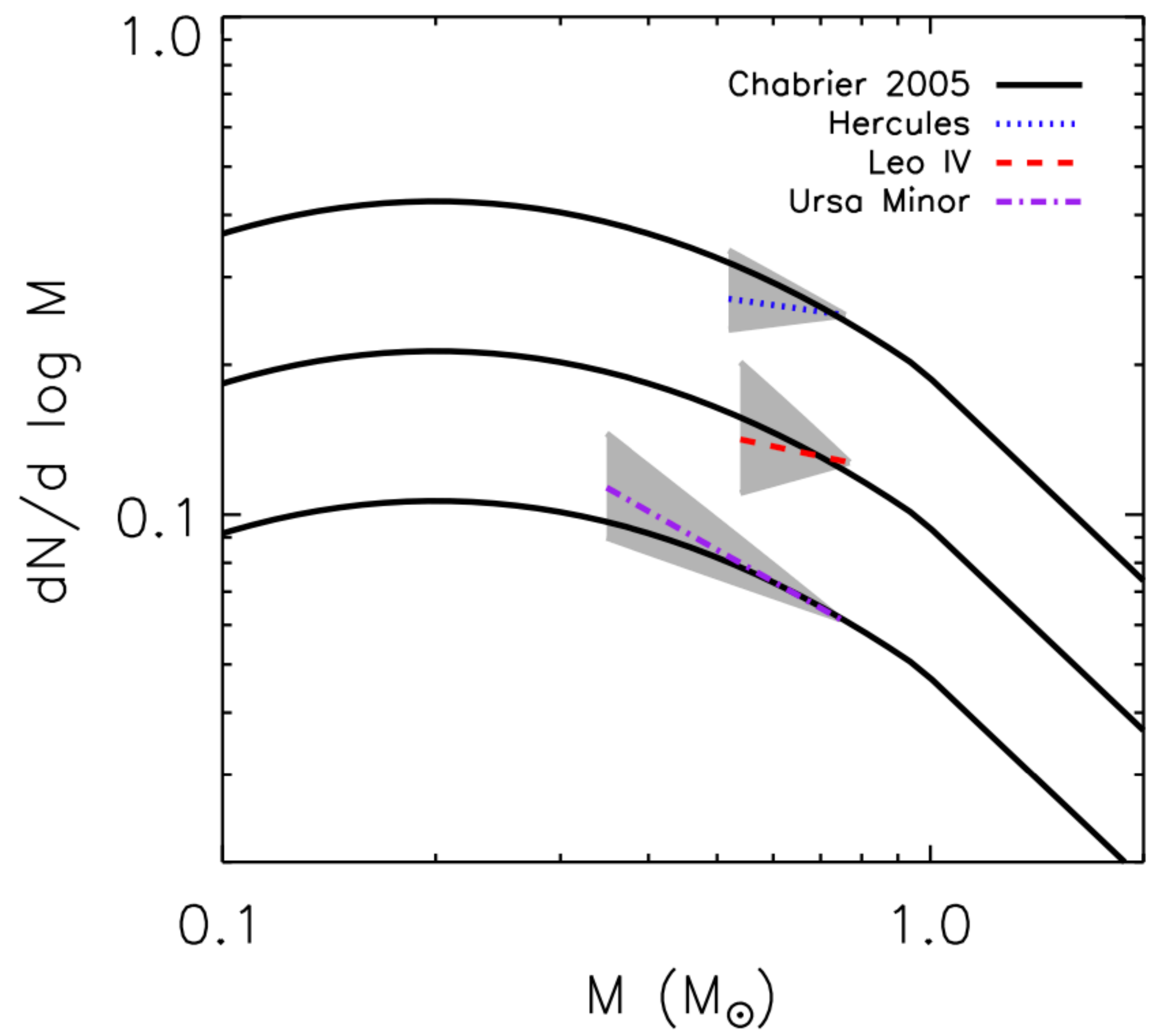


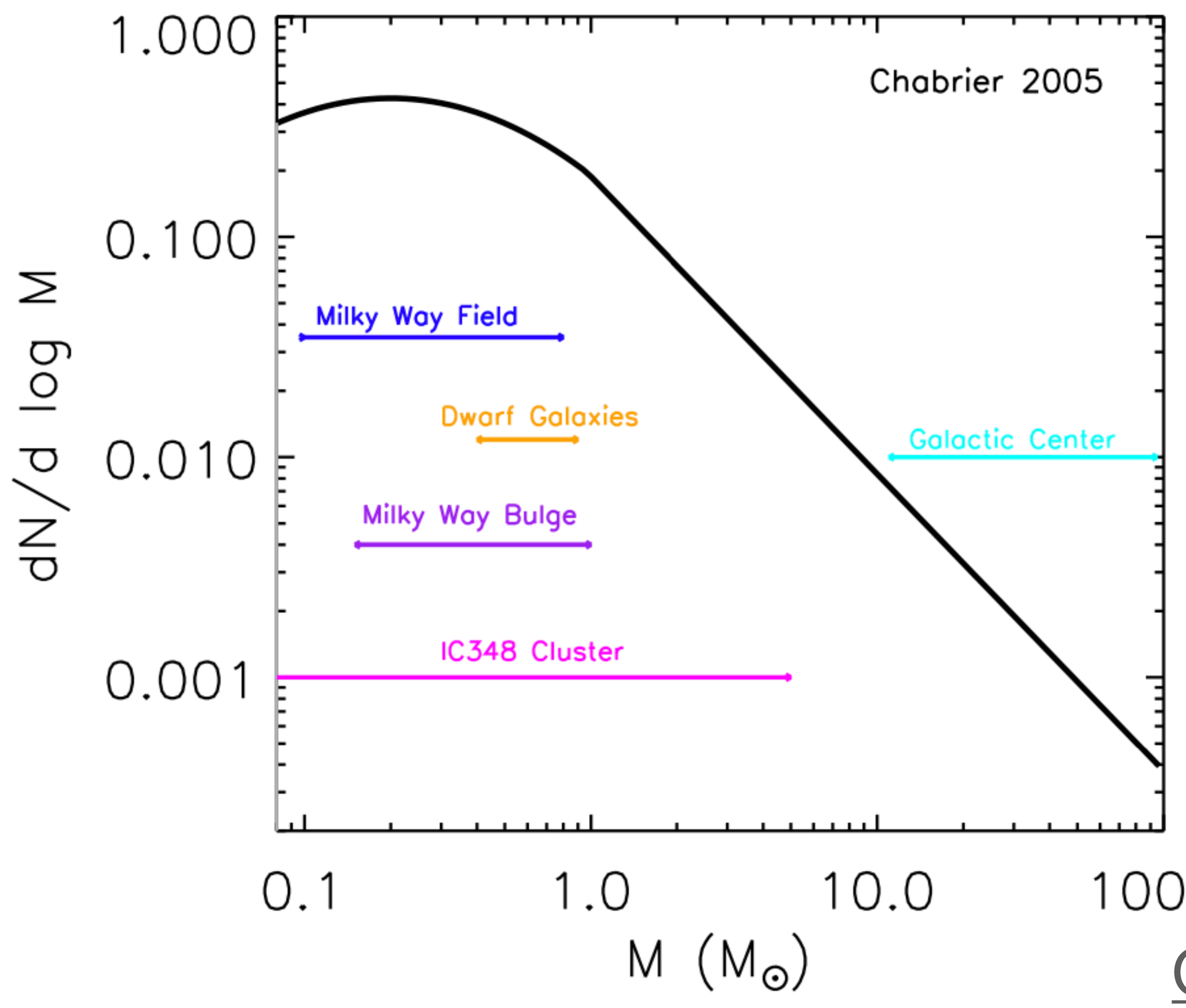
This shows up in all kinds of distributions in nature!!!

Wainer+2022

WTF is a LF or MF?

- **Why is this hard to measure?**
  - Maximum: Always fighting against small number stats
  - Minimum: Detection incompleteness and some interesting/famous biases
  - Breaks: *lots of problems historically*
    - Bad fitting, small samples, mixed samples (apples & oranges)

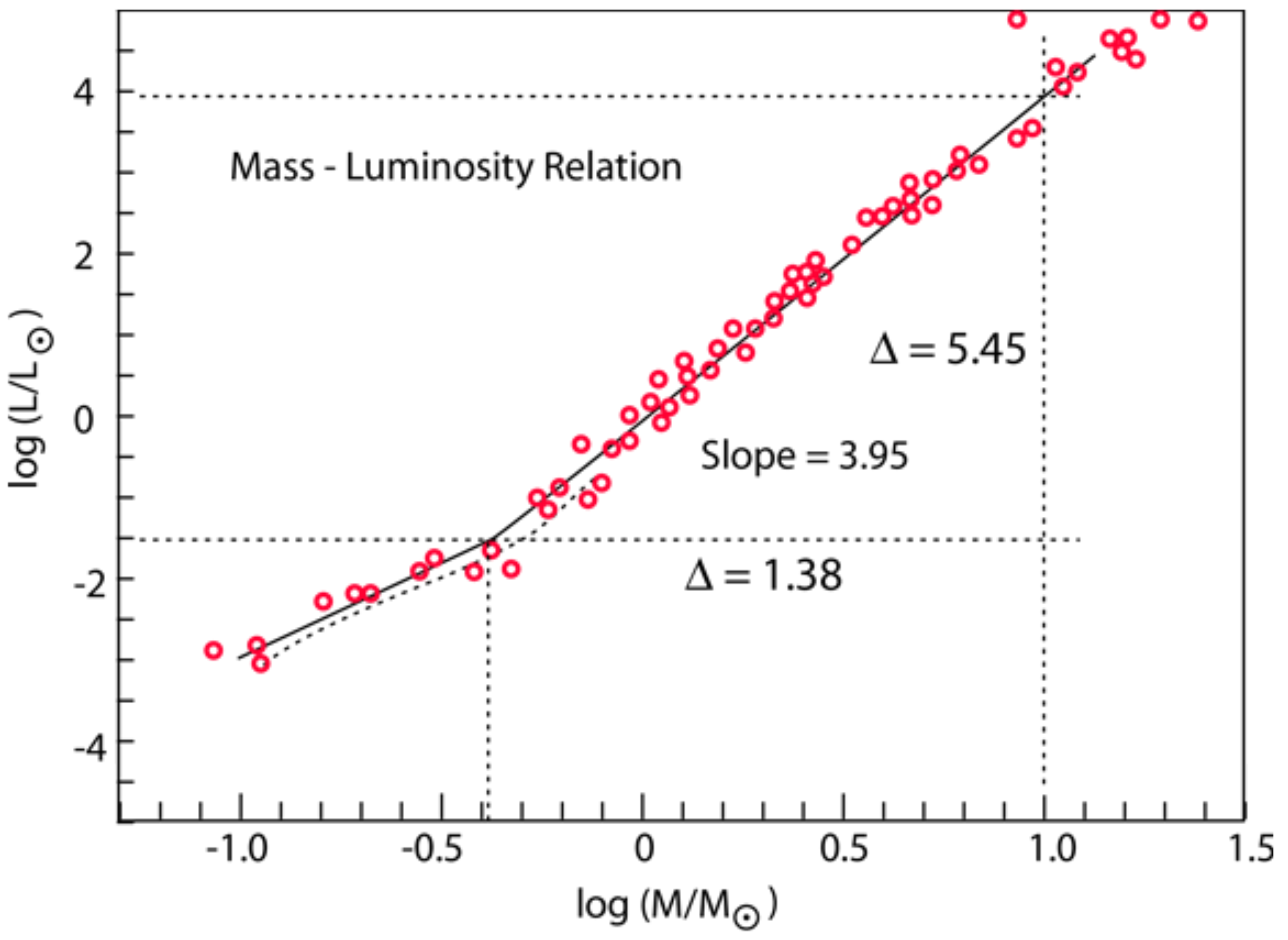




Offner (2016)

Stars: MF – LF

- Mass is *the* defining property of a star (the so-called Vogt-Russell theorem)
- For *main sequence* stars, mass turns into luminosity fairly easily
- Clearly not true beyond 1st order
  - Metallicity & age have significant effects on luminosity



http://hyperphysics.phy-astr.gsu.edu/hbase/Astro/herrus.html

Stellar IMF, the original MF

- The stellar “Initial Mass Function” - what is the distribution of star masses that nature creates?
- Classical reference here is Salpeter (1955)
    - (the other Edwin)
    - Quite a paper!
    - Discusses 10% H->He, giants vs WDs, SFR…

THE LUMINOSITY FUNCTION AND STELLAR EVOLUTION

EDWIN E. SALPETER*
Australian National University, Canberra, and Cornell University
Received July 29, 1954

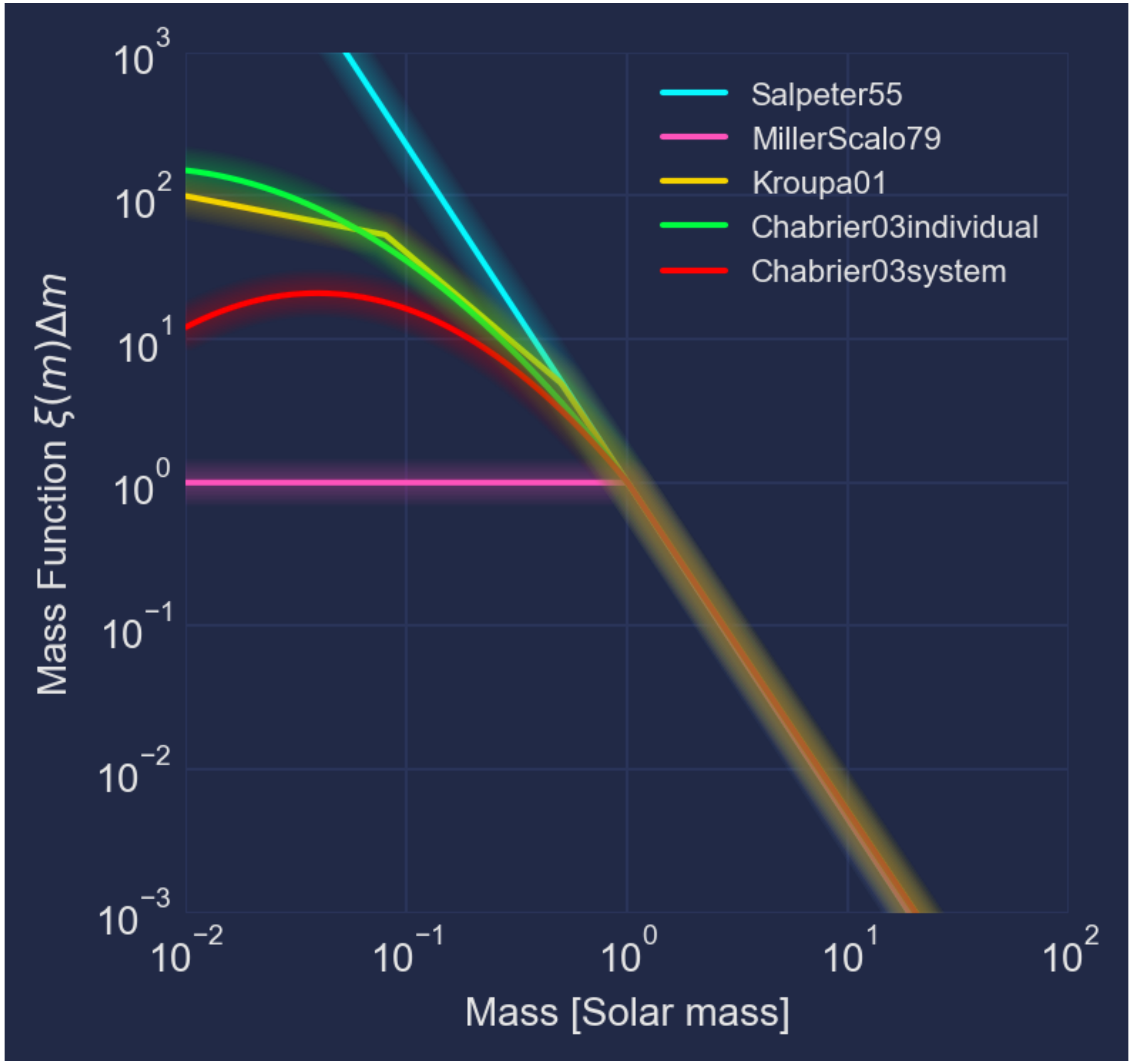
ABSTRACT

The evolutionary significance of the observed luminosity function for main-sequence stars in the solar neighborhood is discussed. The hypothesis is made that stars move off the main sequence after burning about 10 per cent of their hydrogen mass and that stars have been created at a uniform rate in the solar neighborhood for the last five billion years.

Using this hypothesis and the observed luminosity function, the rate of star creation as a function of stellar mass is calculated. The total number and mass of stars which have moved off the main sequence is found to be comparable with the total number of white dwarfs and with the total mass of all fainter main-sequence stars, respectively.

Stellar IMF

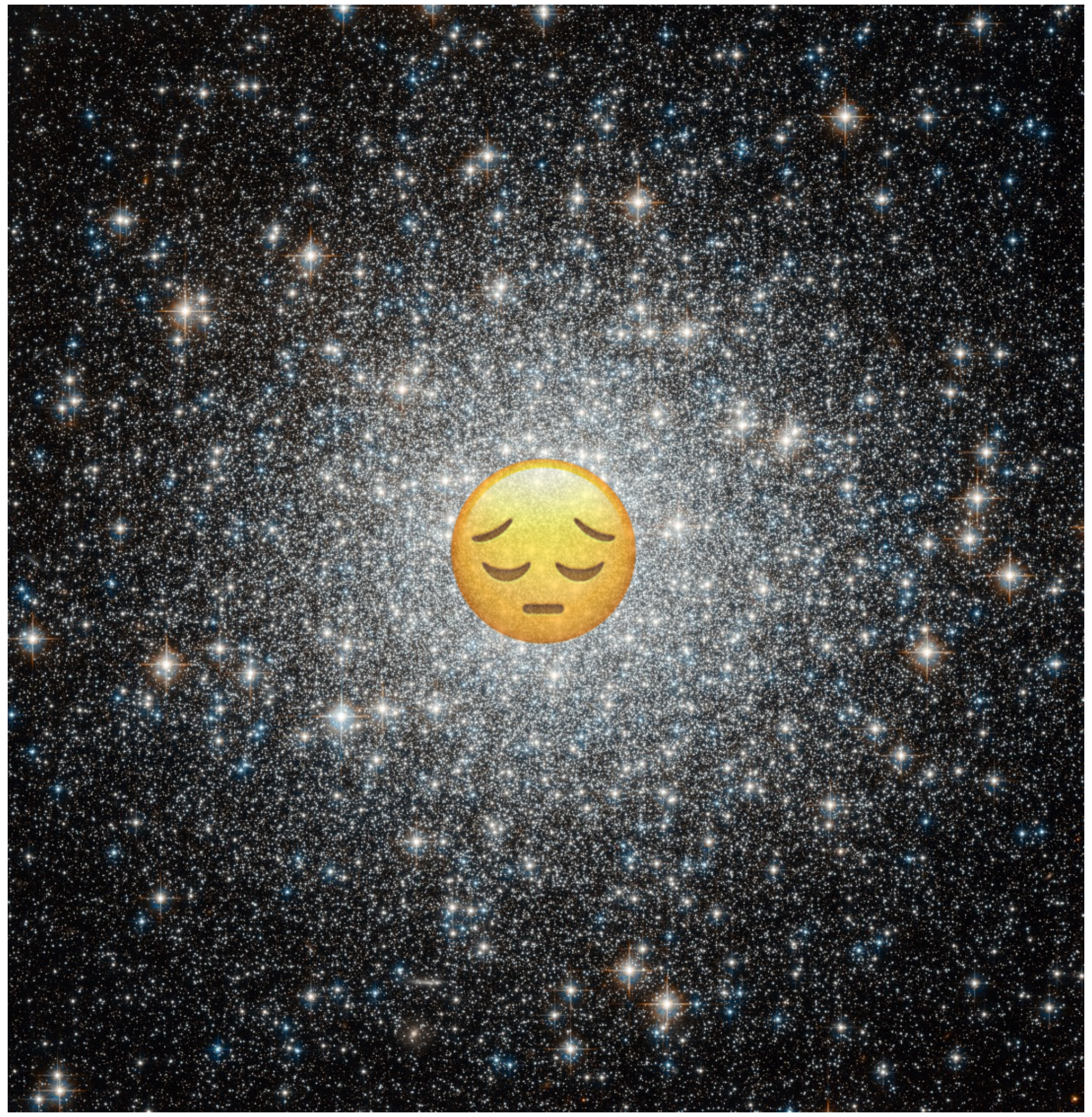
- Active area of work since 1950's, both observationally and theoretically!
- Big questions include:
  - What is the canonical shape? (slope, breaks, etc)
  - What is the max/min
  - Are these properties universal? Or do they depend on e.g. [Fe/H]?



Adapted from https://commons.wikimedia.org/wiki/File:Plot_of_various_initial_mass_functions.svg

You can never measure the actual IMF for a cluster

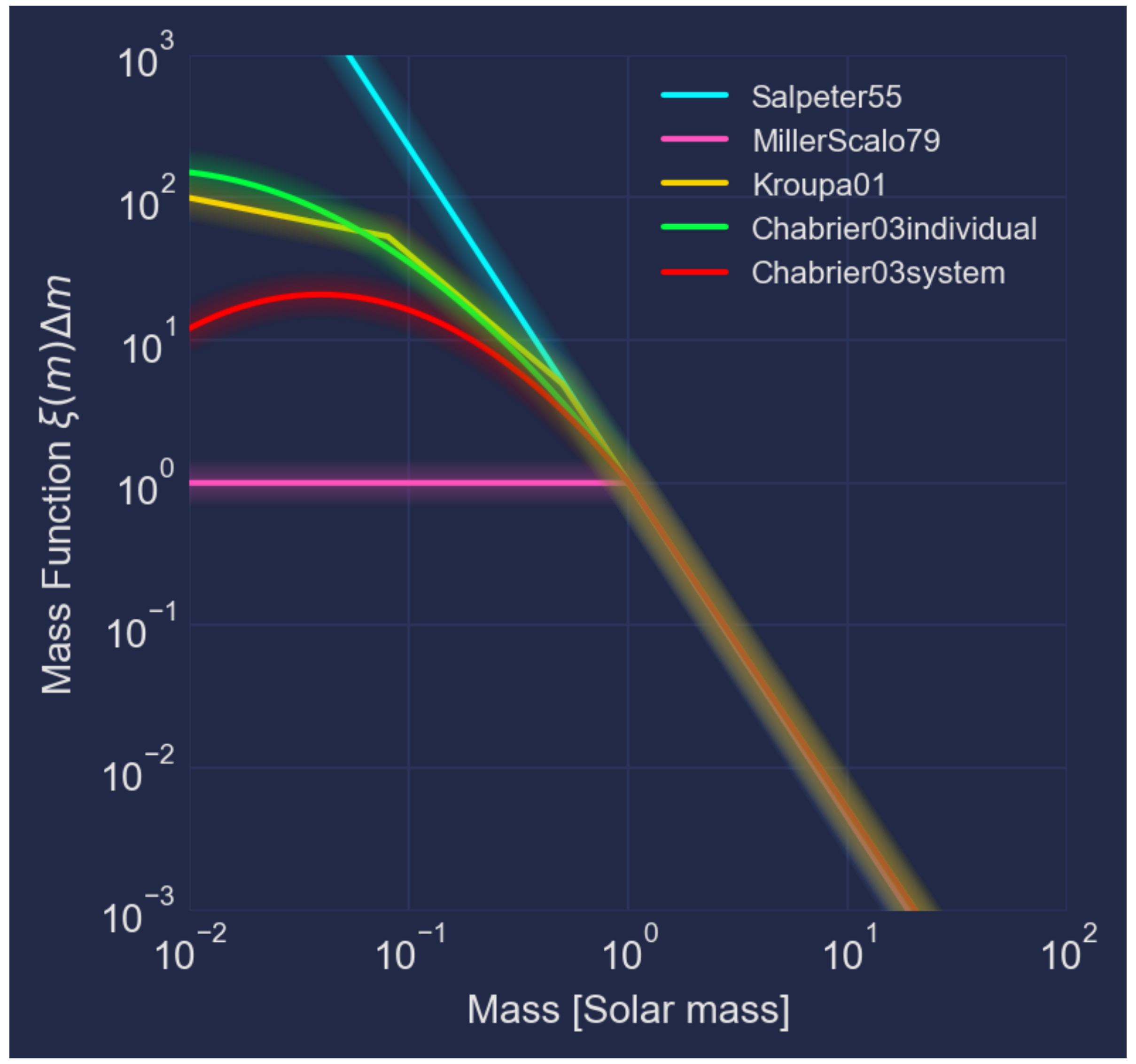
- The "Cluster IMF Theorem" (e.g. Kroupa 2008)
  - For young clusters: low-mass stars still forming
  - Intermediate age clusters: dynamics & gas-loss wrecking the population
  - Old clusters: stellar evolution (+ continued dynamics)

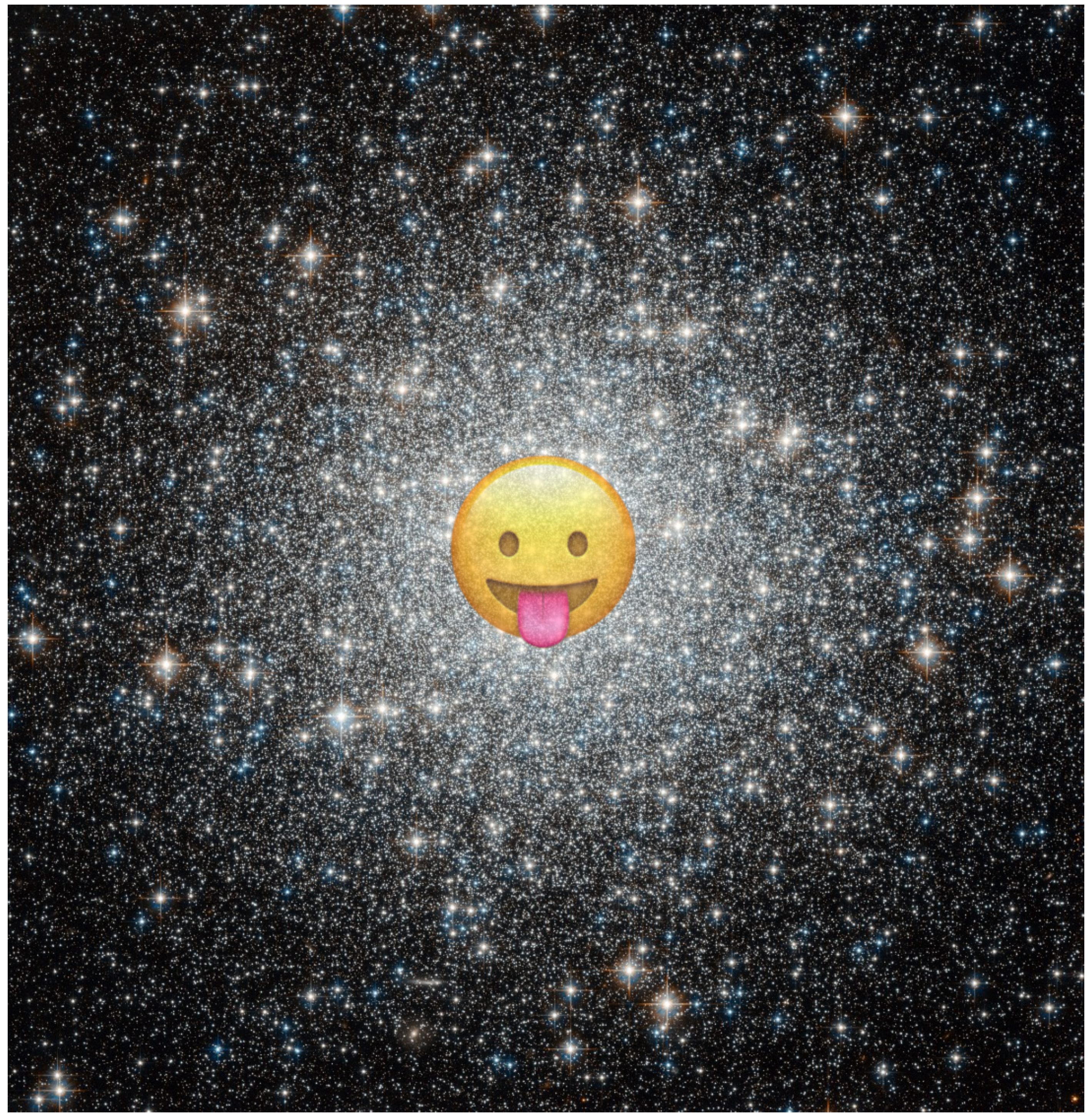


Count the Stars (*carefully*)

- If you want to measure the IMF (or any MF) you need to count things

- Think carefully about all kinds of biases that can ruin your measurement



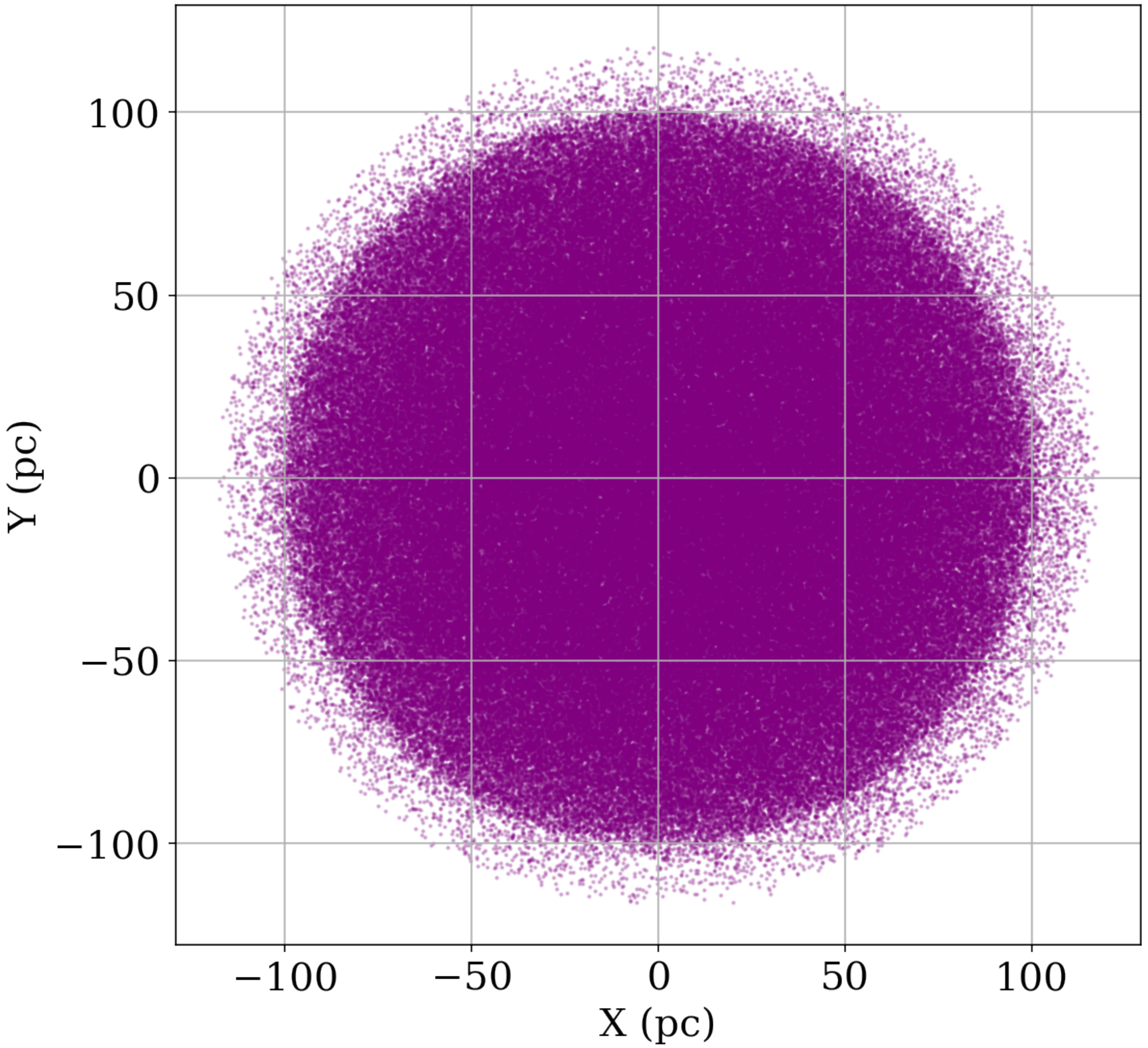


Malmquist Bias

- First outlined in Malmquist (1922) (w/ some credit to Eddington 1915)
  - In this paper he also concludes there's no appreciable dust extinction/ reddening in space… oops!
- Very famous form of *selection bias*
- Impacts magnitude (brightness) limited samples
(i.e. detection floor at a limiting magnitude, e.g. human eyes, fancy surveys)
- **Bright things show up even when very far away**
  - Leads to bad statistics, spurious correlations between things that are really just distance related

Lutz-Kelker Bias

- Bias introduced in selecting a “volume-limited” sample using parallaxes
- e.g. if you have small parallax values with large errors
  - Negative parallax is discarded (non-physical)
  - Positive errors scatter even smaller measurements into your sample
  - i.e. see GCNS here. 100pc sample has stars seemingly outside 100pc
- Not as big a deal anymore, just be careful with “volume-limited” sample selection

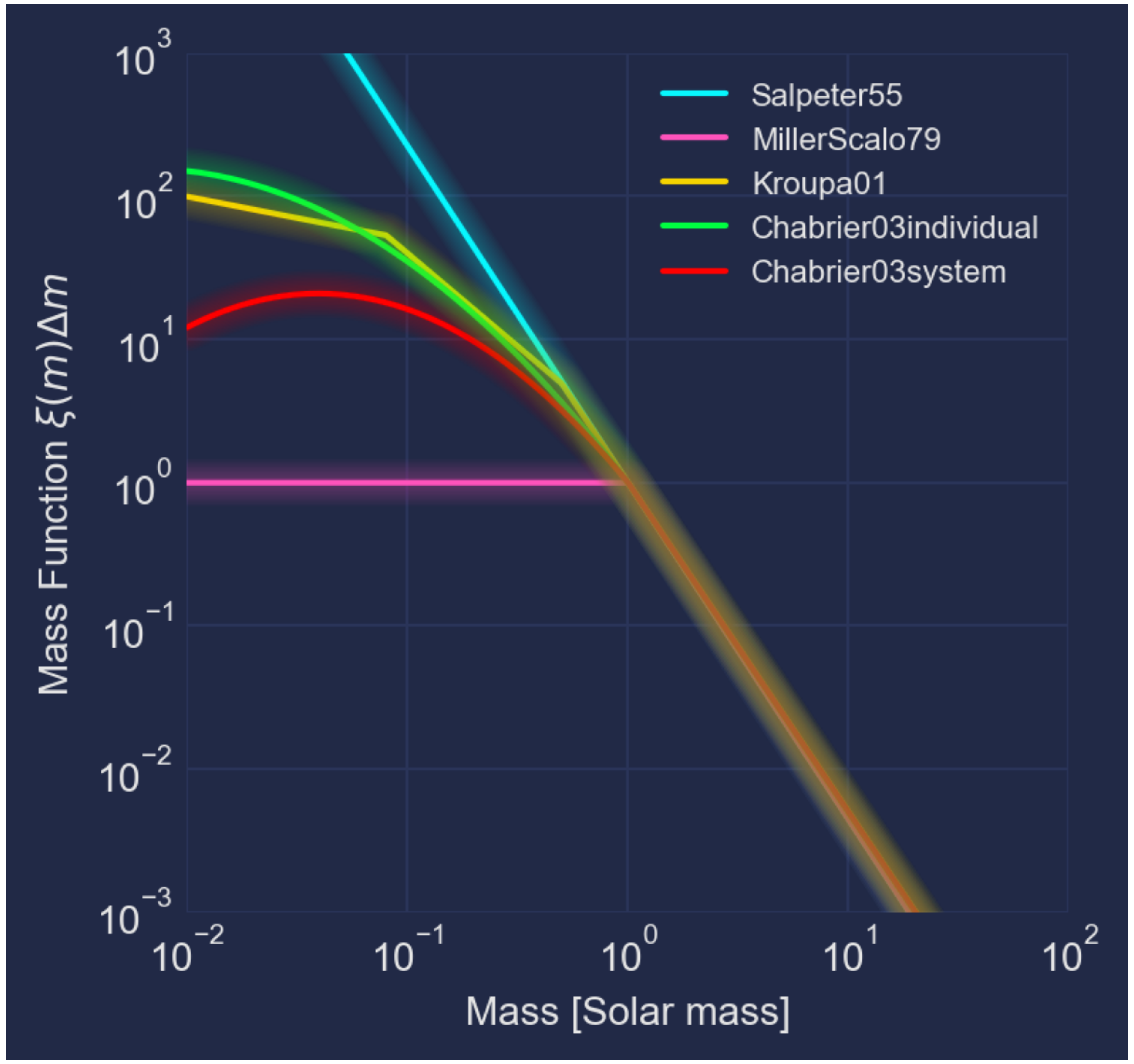


Bias Correction

- This is a tricky subject… depends entirely on the underlying distribution!
- Early efforts (e.g. Malmquist) used a correction factor based on the observed mean versus the “true mean” brightness to scale the sample
    - This DOES NOT WORK if your distribution is non-Gaussian
- Many attempts to correct LF’s especially (a nice review in Ilbert+2004)
    - Most famous: 1/Vmax method for determining limiting distance for completeness (Schmidt 1968), still actively advocated for by some!

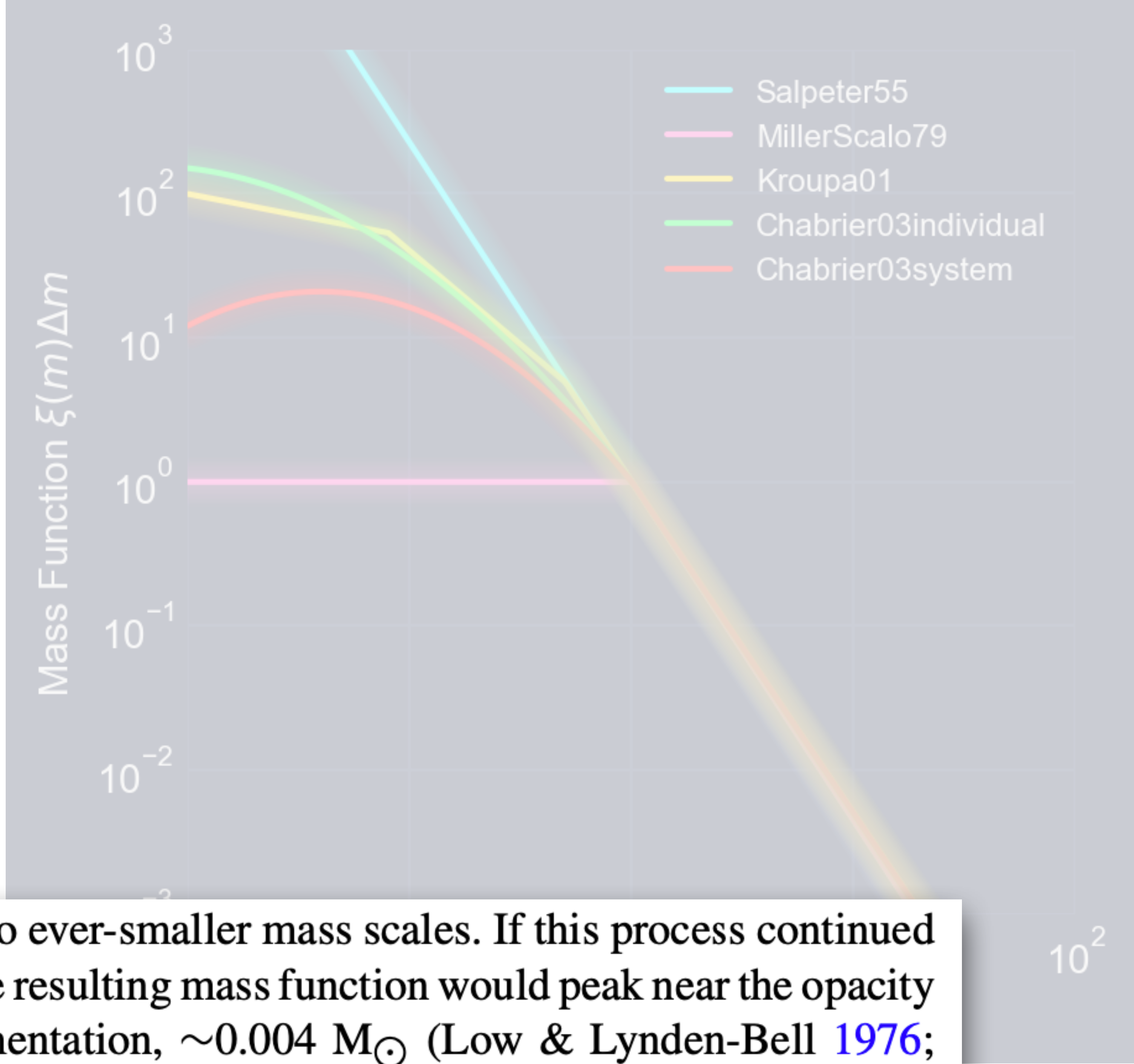
Origin of the IMF

- Nice review by Offner+2014
- **What sets the slope (usually called α)?**
  - Does GMC fragment into cores w/ IMF mass distribution?
  - Or do prestellar cores "compete" for gas, lots of dynamics: merge/exchange?
  - These models still debated…



Origin of the IMF

- **What sets the peak?**
  - Something to do with the gas cooling efficiency… Then why is it so insensitive to metallicity?
  - Byproduct of turbulence in GMC? Feedback? **B** fields? Something more simple?
  - Nice overview by Krumholz+2016, they suggest lack of BDs is due to thermal feedback, halting small core collapse



tion proceeds to ever-smaller mass scales. If this process continued unimpeded, the resulting mass function would peak near the opacity limit for fragmentation, $\sim$0.004 $M_\odot$ (Low & Lynden-Bell 1976; Rees 1976; Whitworth et al. 2007). The actual peak of the IMF, which is $\sim$2 orders of magnitude larger than this, is determined by whatever arrests this cascade of fragmentation. Put more succinctly, it is helpful to rephrase the question 'what sets the peak of the IMF?' as the question 'what suppresses the formation of brown dwarfs?'

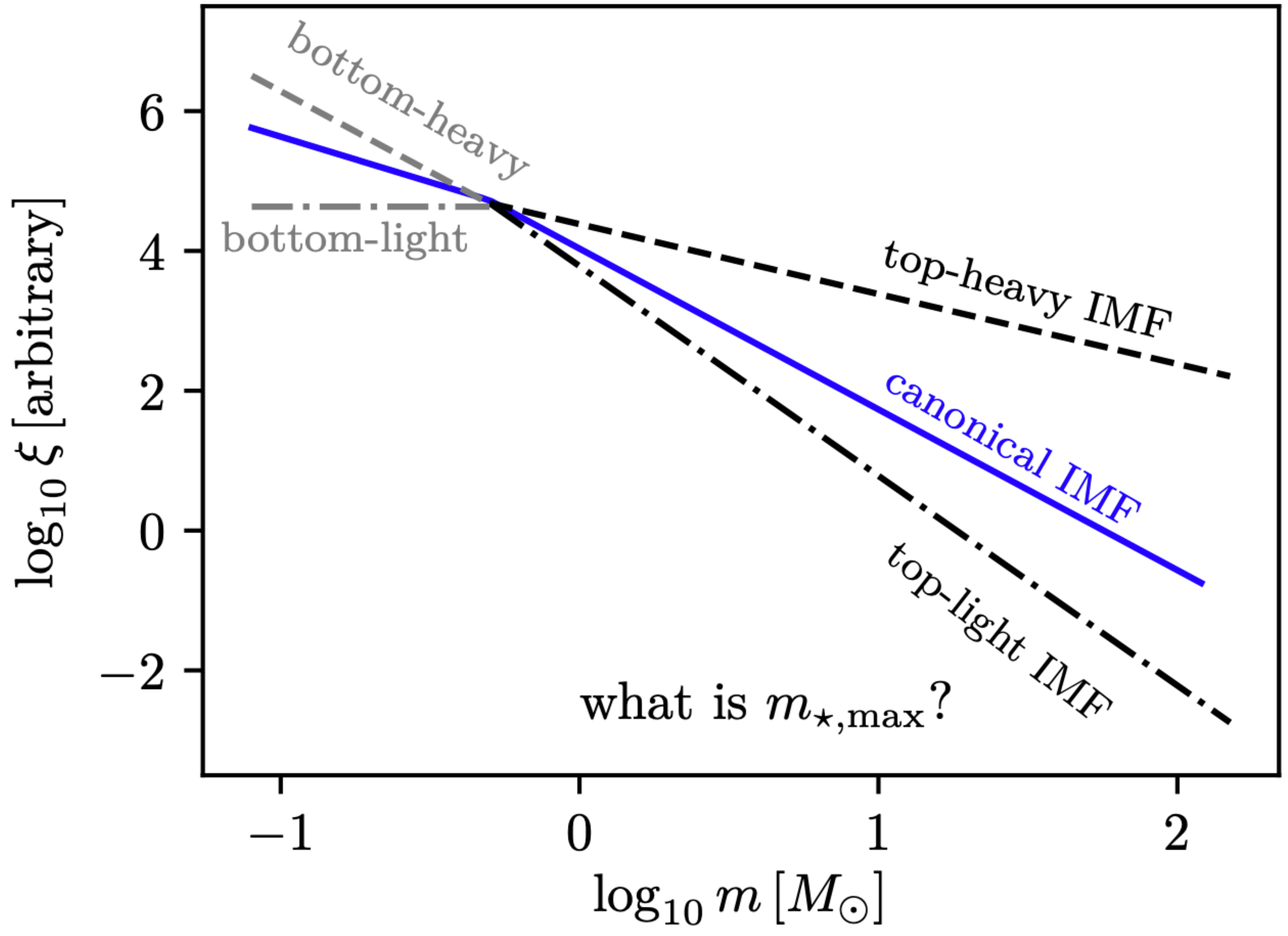
Varying IMF?

- Obviously observed (sometimes called "present day mass function: PDMF 😩) changes with time.

- General wisdom is IMF *should* be impacted by stellar metallicity

  - Lower metallicity -> less efficient cooling -> harder for gas to collapse into stars -> need more mass for collapse -> Top-Heavy IMF

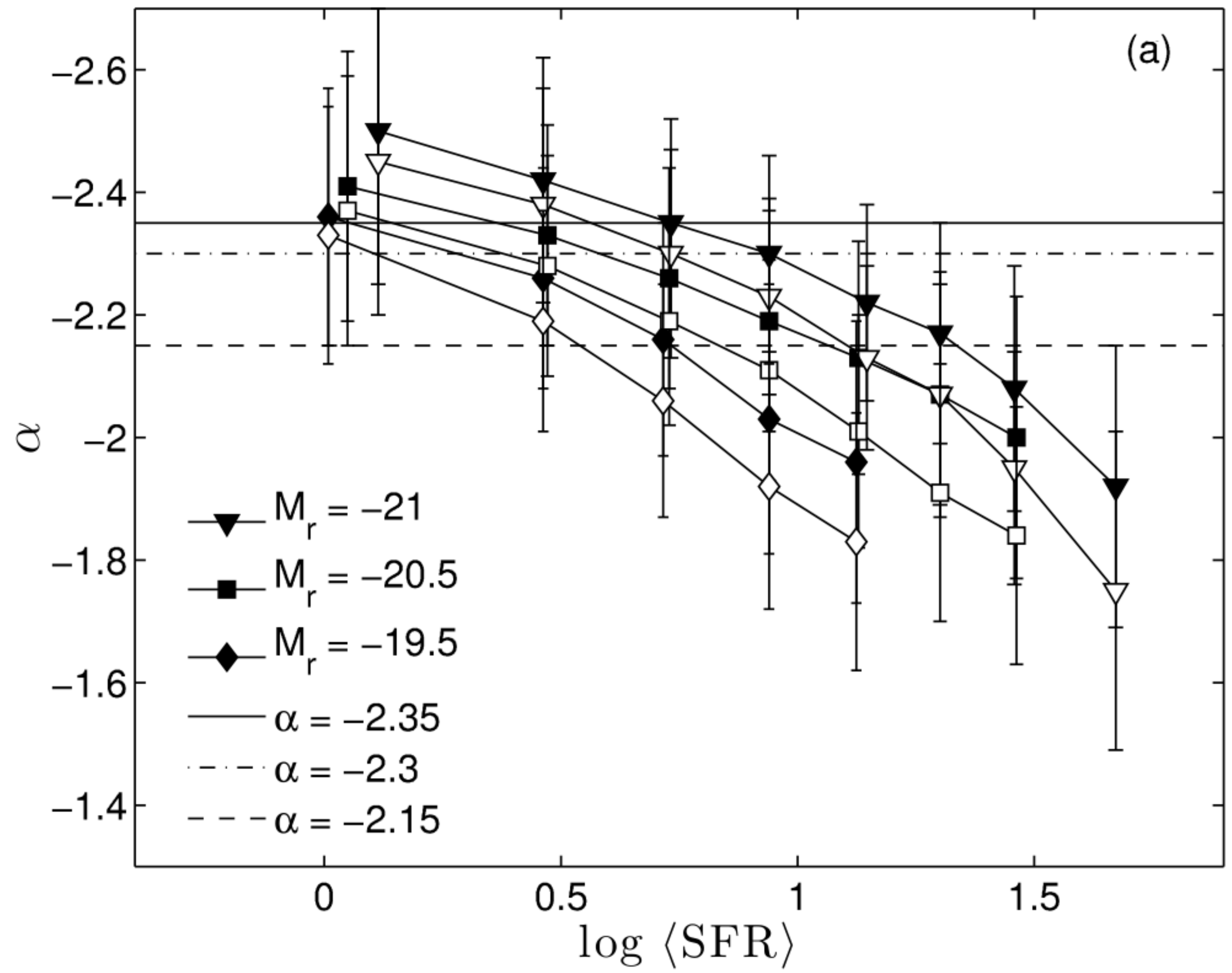
  - Surprisingly hard to find evidence of this (statistics are hard!)



Kroupa & Jerabkova (2021)

Varying IMF?

- Other sneaky effects at work:
  - Maximum star mass clearly set by total cluster and therefore GMC mass (e.g. Weidner & Kroupa 2006)
  - Star formation rate also seems to impact the high-mass IMF slope (e.g. Gunawardhana+2011)
    - High SFR -> Flatter IMF



High- vs Low-Mass IMF

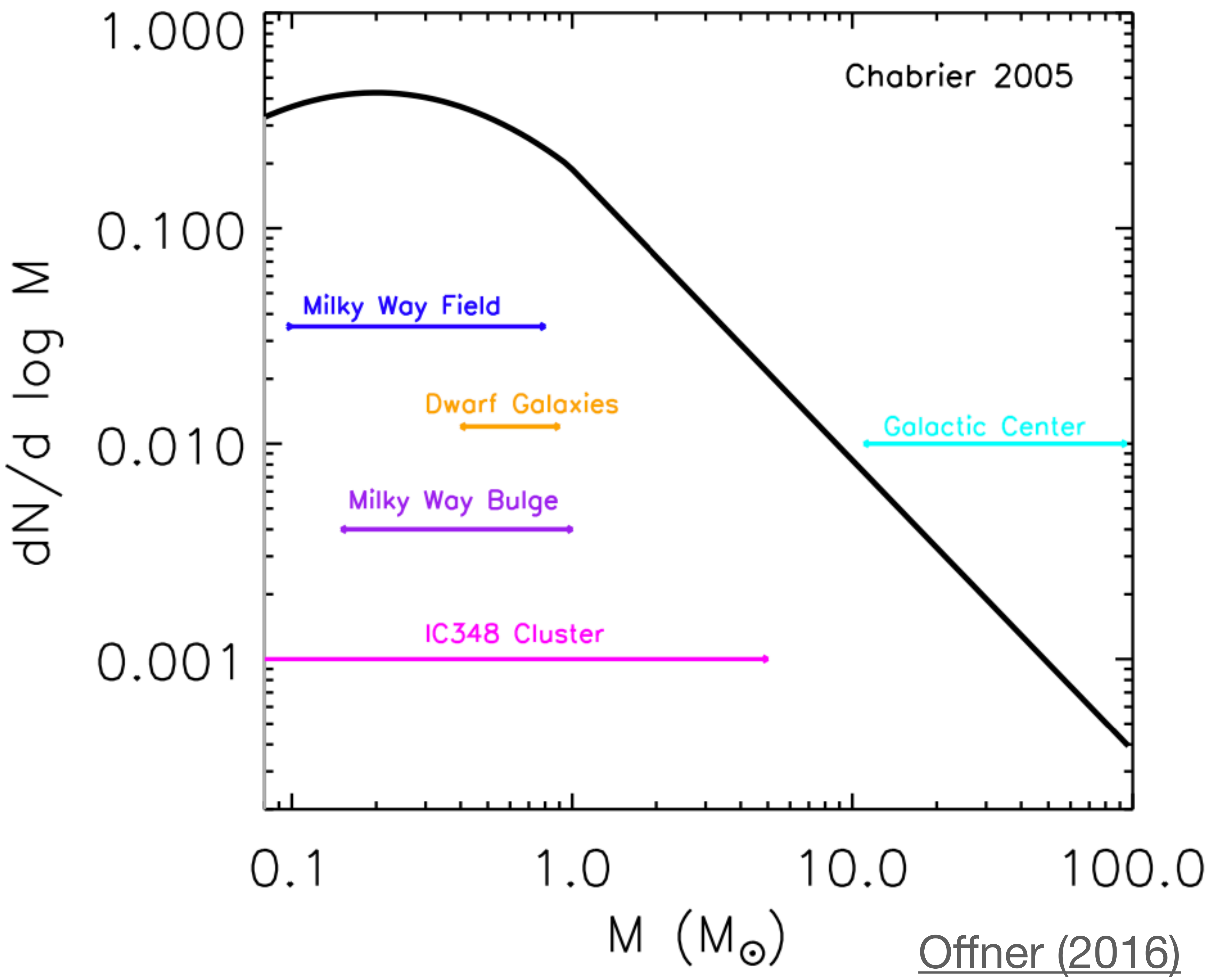
- Different sub-sets of stellar mass are available for MWY vs clusters vs nearby galaxies

- Sub-solar probably best constrained by MWY field

    - Helpfully: no low-mass stars have evolved off the main sequence… yet

- Massive star regime well studied with nearby galaxies

    - Can explore more extreme star formation environments than we find in MWY today, seems to (weakly) impact IMF slope



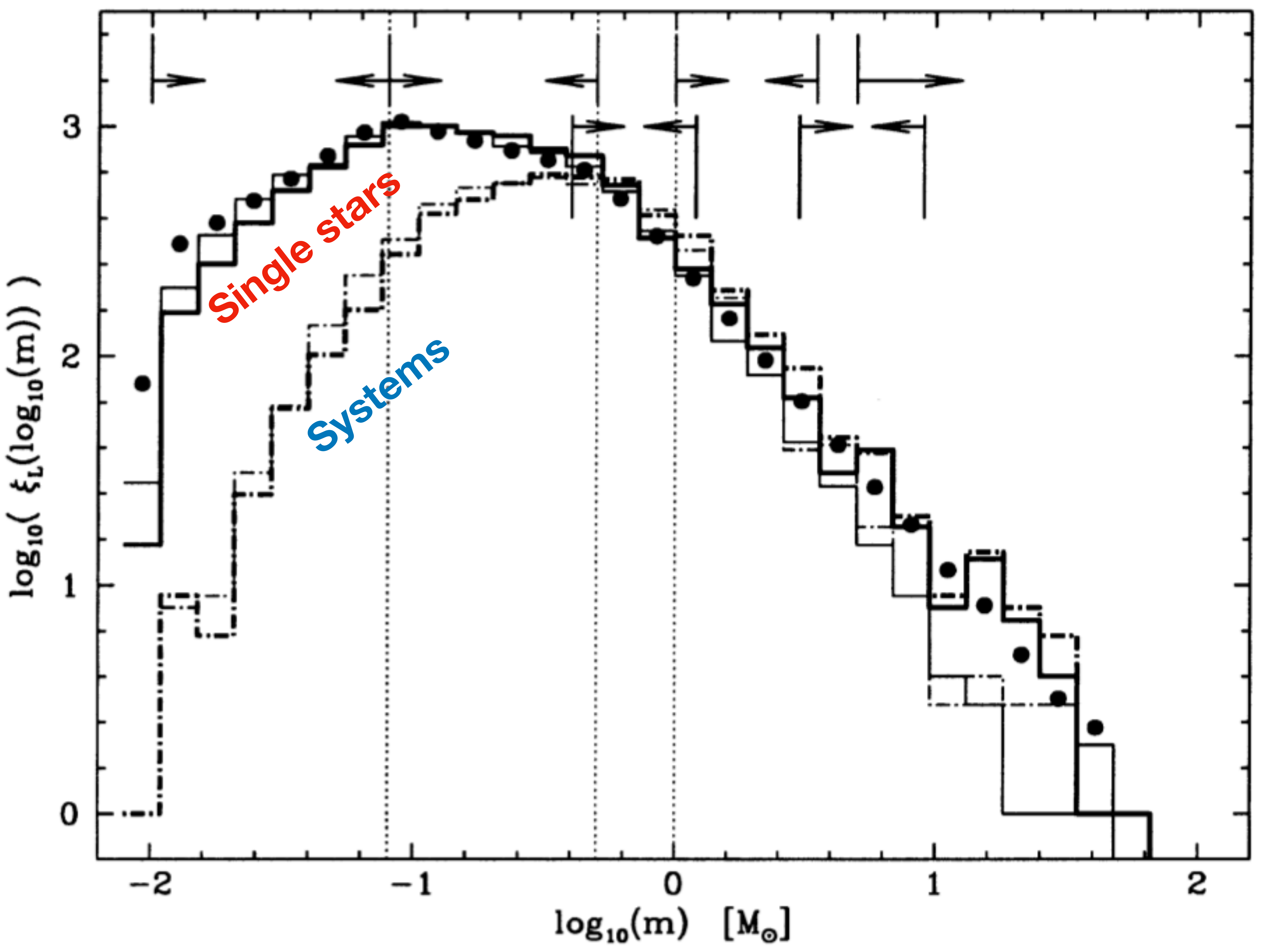
Offner (2016)

Other issues…

- Binary stars
  - Planets?
- Intrinsic age/property spread (clusters)
- Magnetic fields
- Metallicity

Binary Stars

- Can be hard to get complete binary counts
    - Especially with extreme mass ratios (brown dwarf + O star?!)
- Massive stars *more likely* to be in binary systems (hint @ physics?)
- Definitely a contaminant for studies of the field & clusters



Kroupa 2001

Not Just Stars: Clusters & Galaxies

- Physics governs formation of things! Same conceptual rules at work for everything here…
  - What is the distribution of material needed for formation (gas)?
  - How efficient is formation? What external forces or pressure change that efficiency?
  - Is it scale invariant and/or self-organizing? Self regulating?
  - Is there a limit (max or min)?
  - Do conditions (e.g. composition, evolution) change with time?

Next time:

- Structure & Properties of the Milky Way