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THE STELLAR INITIAL MASS FUNCTION, UNIVERSAL … OR NOT?

History and status of resolved stellar populations, *and lessons from weighing your dogs*

The “Original” mass function

Salpeter (1955)

THE LUMINOSITY FUNCTION AND STELLAR EVOLUTION

GCs were “missing” massive stars at that time

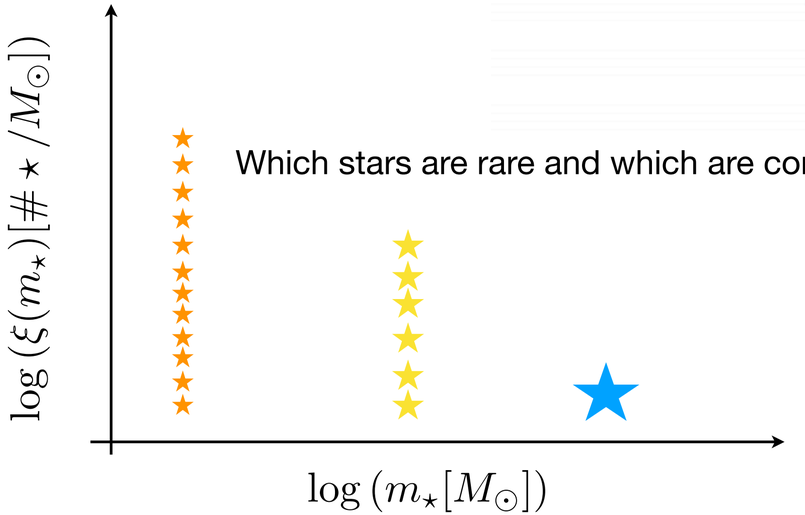
EDWIN E. SALPETER*
Australian National University, Canberra, and Cornell University
Received July 29, 1954

We defined the “original mass function,” $\xi(\mathfrak{M})$, by

★ ↓ Mass bin

$$d\,N = \xi\,(\mathfrak{M})\;d\,(\log_{10}\mathfrak{M})\,\frac{dt}{T_0},$$

Stars form over T_0



Which stars are rare and which are common?

The “Original” mass function

Salpeter (1955)

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Stars form over T_0

Salpeter 1955: Connected the *new* theory of quantum mechanics to cosmology and addressed the cosmic matter cycle and chemical enrichment over time

(along with the work of Eddington (1920), F. Hoyle, M. & G. Burbidge (1950s))

Kroupa & Jerabkova (2019)

Correction for dead stars (and other effects) is statistical

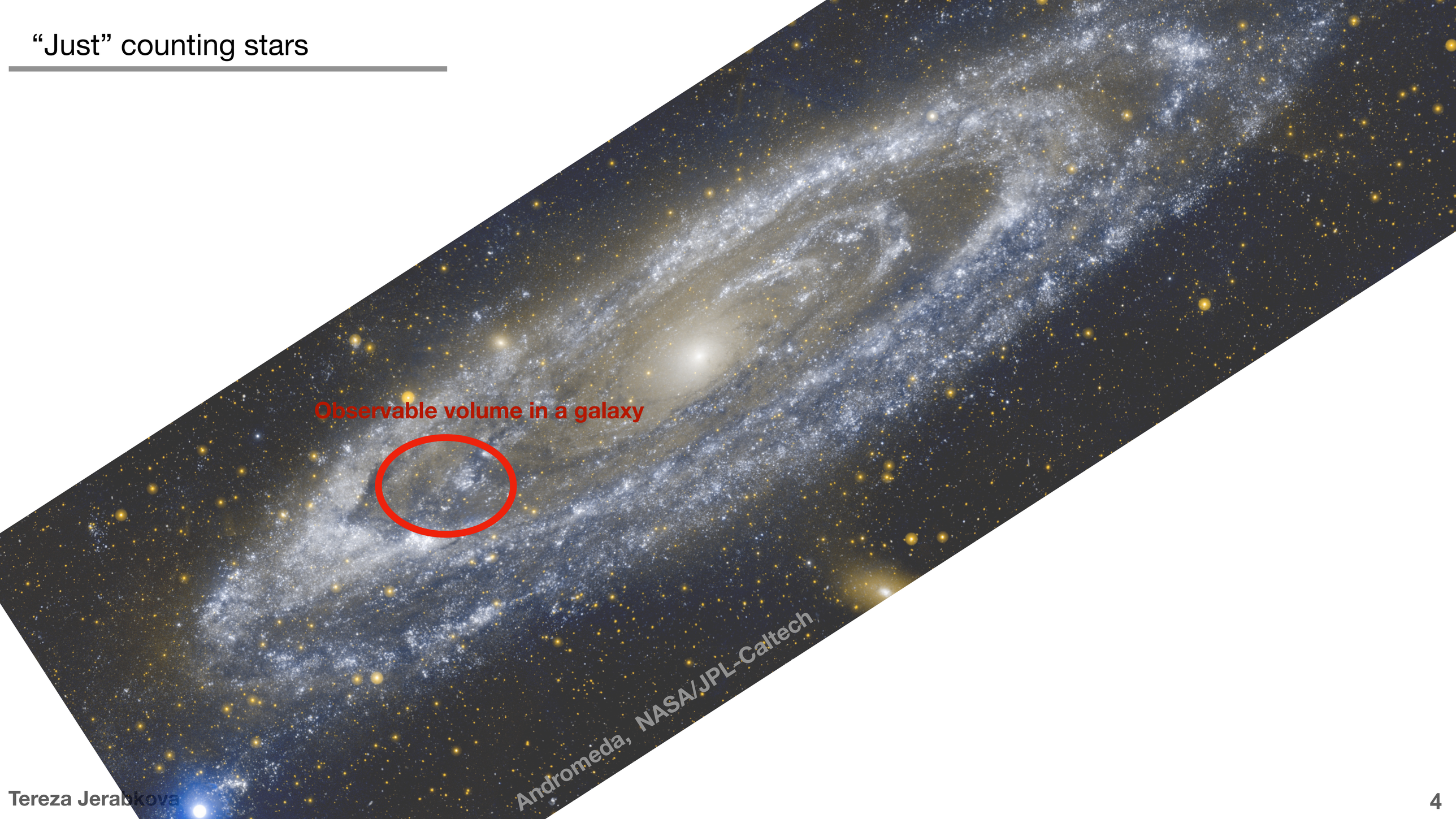
First mention of the “Initial” in 1957?

OBSERVATIONAL APPROACH TO EVOLUTION
I. LUMINOSITY FUNCTIONS

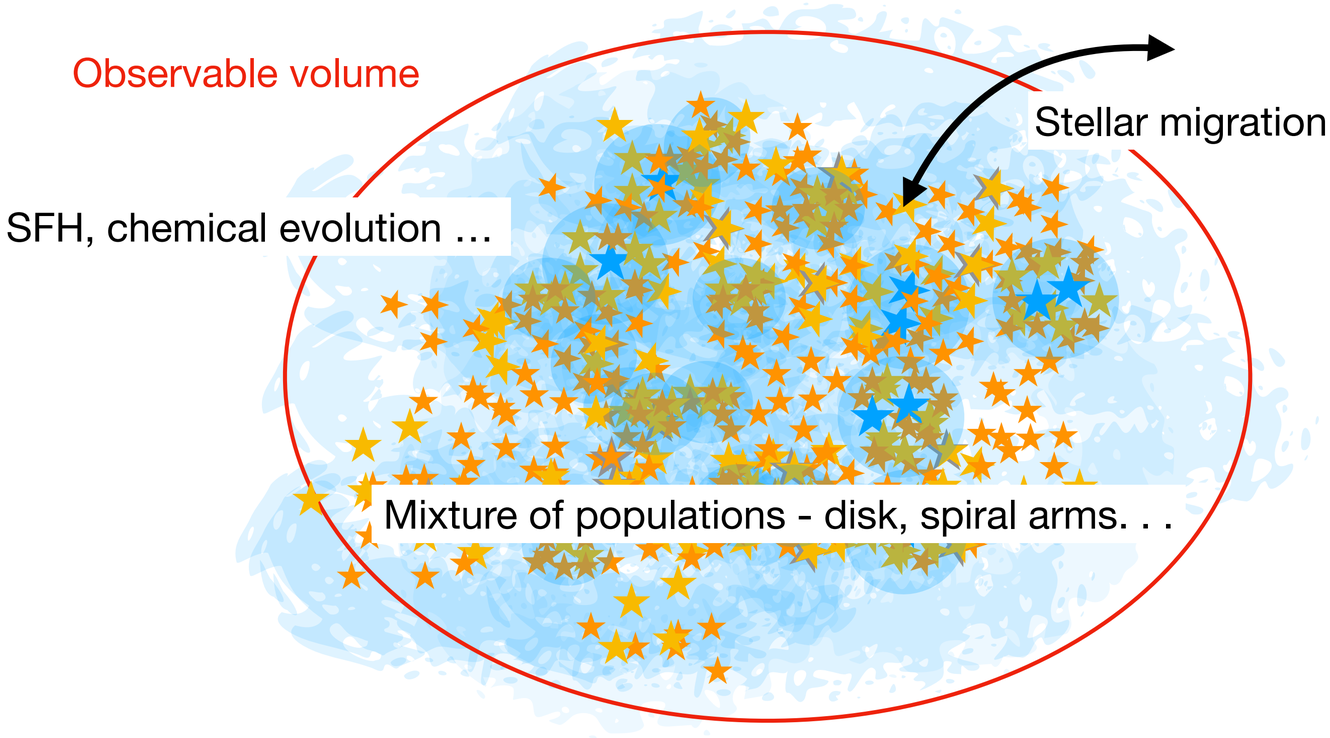
ALLAN SANDAGE
Mount Wilson and Palomar Observatories
Carnegie Institution of Washington, California Institute of Technology

Scalo: Jashek&Jashek (1957), van den Bergh (1957)?

“Just” counting stars



“Just” counting stars



“Just” counting stars

The measured quantity

1) Present day luminosity function

need to correct for biases!

2) Salpeter (1955) Scalo(1986)
Miller & Scalo(1979) Kroupa, Tout, Gilmore(1990-93)

Stellar mass-luminosity relation (its derivative)

Scale height distribution as a function luminosity (age)

Main sequence brightening

Correction for evolved (still alive stars)

Metallicity variations

Unresolved binaries (important issue by itself!)

Embedded stars , extinction

~~?The stellar Initial Mass Function?~~

Present day mass function

$$\Phi_m(\log_{10} m_\star) = \Phi(M_V)\left|\frac{\mathrm{d}M_V}{\mathrm{d}\log_{10} m_\star}\right| 2H(M_V) f_{ms}(M_V)$$

By counting stars one looks into the internal structure of stars!

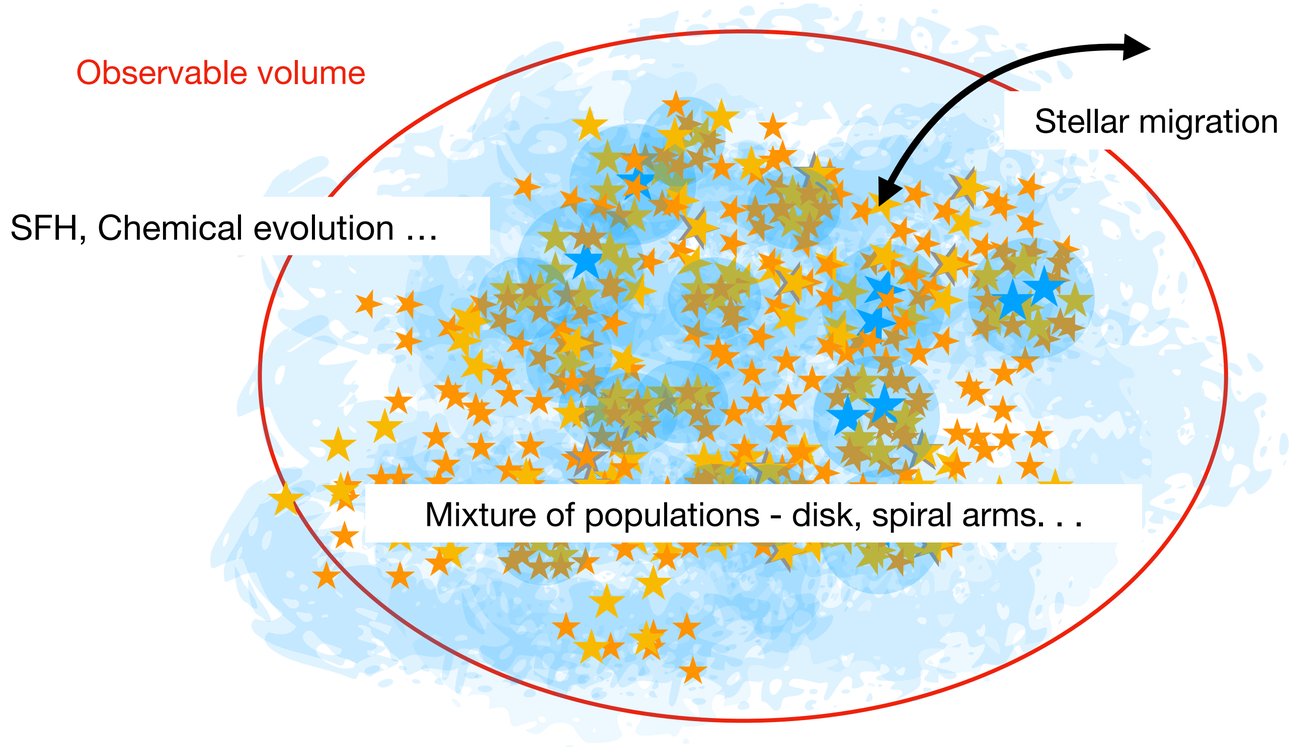
Kroupa, Tout & Gilmore (1990)

Correction for finite stellar lives, SFH

Salpeter (1955)

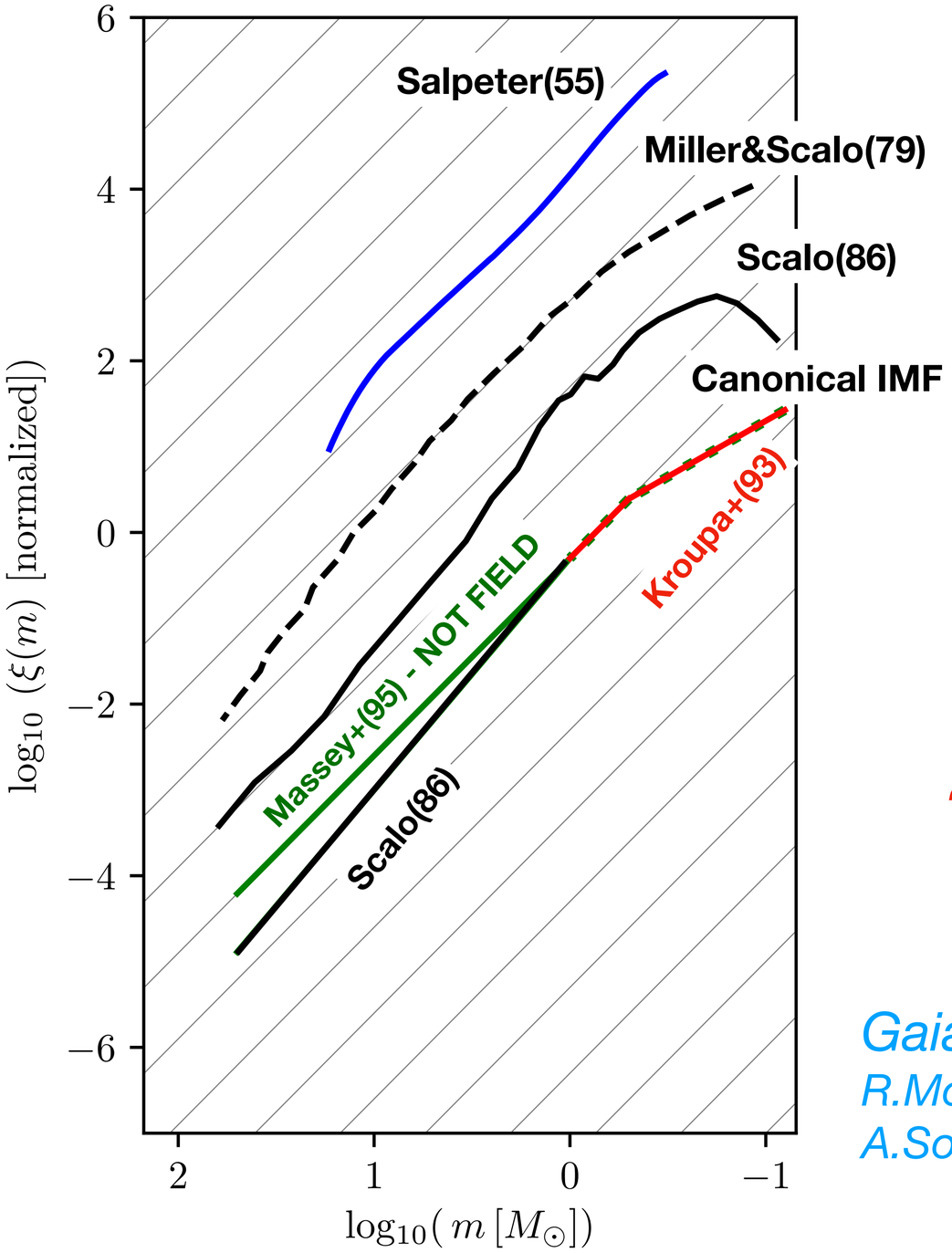
→

Empirical stellar Initial Mass Function
(with all the issues connected to the SHF, stellar migration, …)



Kroupa & Jerabkova (2017)

IMF does not exist in nature (it's a Hilfskonstrukt),
we need to *infer* the IMF to interpret measurements and make calculations



1) Salpeter 1955: Is the "slope" -2.35 or -2.05? Depends on the age of MW!

Zinnecker (1984), Zinnecker (2011)

2) Field star IMF for $m_\star > 1\,M_\odot$: Miller&Scalo(79) and Scalo(86), slope = -2.7

used in the Kroupa, Tout & Gilmore (93) IMF

Kroupa, Tout & Gilmore 90-93: mass-luminosity relation, unresolved binary stars —> the established value of low-mass IMF

3) Massey, Johnson & DeGioia-Eastwood 1995: spectroscopic survey of high-mass stars, not in the field! See also Weisz (2015)

IMF slope for $m_\star > 1\,M_\odot$, -2.1 (MW), -2.3 (LMC) , *BUT Massey 1995a for extreme field IMF, also Lamb+(2006) with slopes up to -4!*

"Measured"/infered Canonical IMF: Massey+(95)&Kroupa+(93)

can have different fits (power-laws, power-law+lognormal)

e.g. Kroupa (2001), Chabrier (2003)

Gaia!

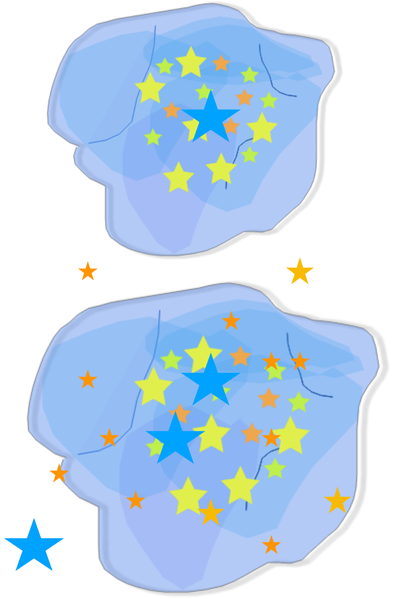
R.Mor+(2018,2019) - first estimate of the IMF and SFH simultaneously!

A.Sollima(2019)

“Just” counting stars

What about star clusters?

- *Small number statistics*
- *dynamical effects, mass segregation —> initial conditions!*
(ejections, mergers) Kroupa (1995), De Marchi, Paresce, Portegies Zwart (2010)
- *binary stars* Oh & Kroupa (2016, 2018)
- *field contamination*
- *cluster’s SFH* Elmegreen & Scalo (2005), Beccari+2017, Jerabkova+2017



observer: IMF?
Cluster: not, yet

observer: IMF?
Cluster: too late

1) MW & nearby clusters: consistent with no variations within (large) uncertainties

Massey+1995ab, Weisz+2015 —> see also Oh & Kroupa (2016)

Scalo (1986): Average over star clusters is well defined if IMF is universal

What variations of the IMF are consistent with the data?

See Dib (2014), and use KDE as Prisinzano+ (2001)

2) Variations detected in extreme environments - high densities, low metallicity

Dabringhausen+2008,2012, Bartko+2010, Marks+2012, Schneider+2018, Kalari+2018, Hosek+2019

More massive stars relative to the canonical IMF

+ more evidence from unresolved stellar populations, stellar population synthesis and chemical evolution

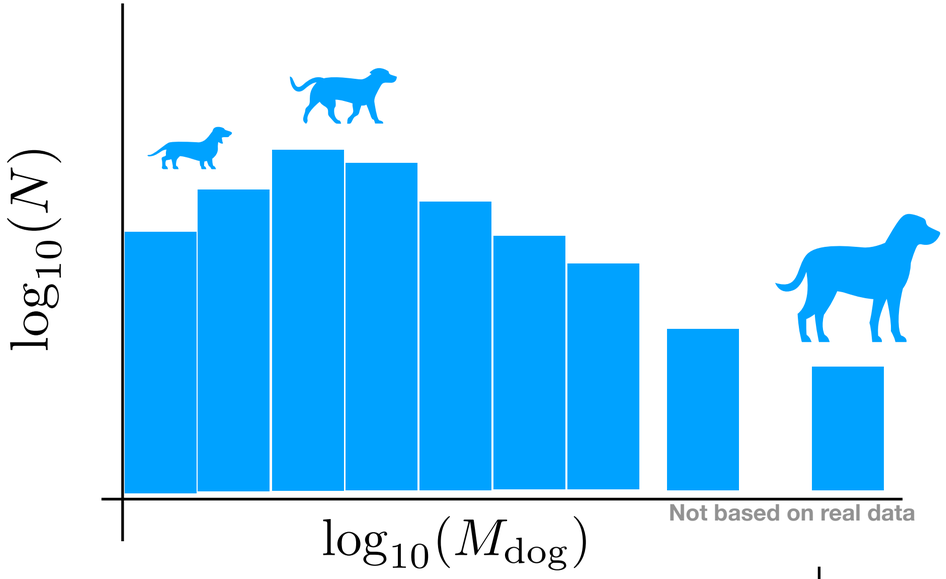
3) Low density environments

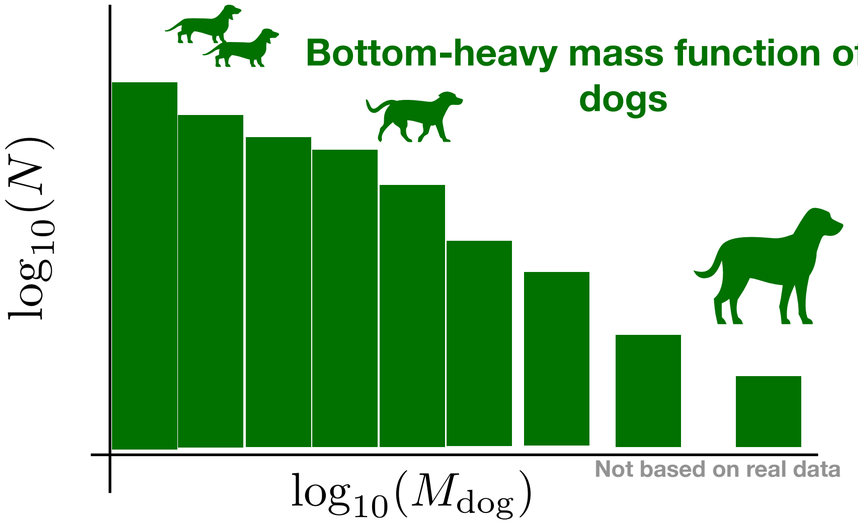
Hsu, Hartmann+2012,2013, Megeath+2012, Watts+2017

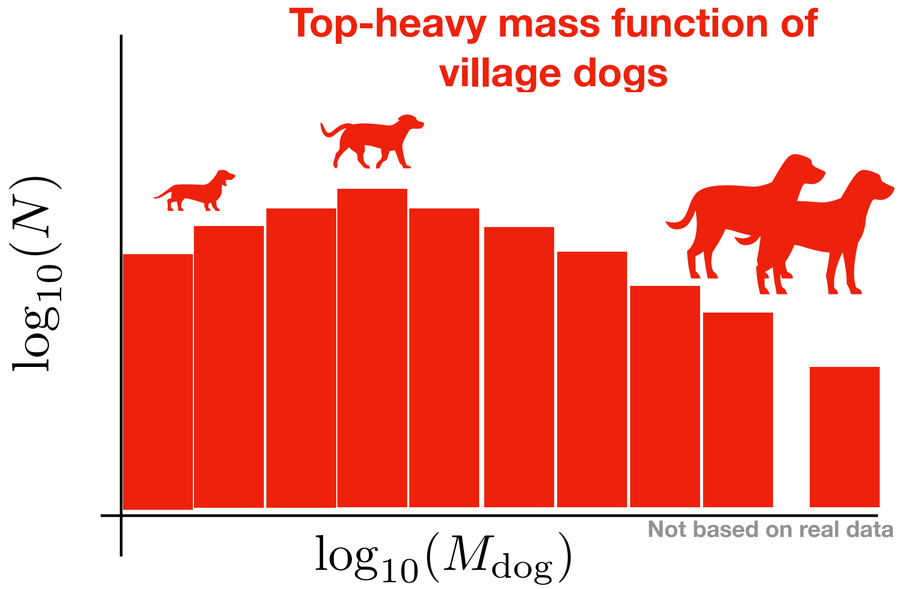
Lack of massive stars relative to the canonical IMF

Study: Formation and evolution of dogs based on their measured mass distribution function

We get to know how common or rare dogs of different masses are, but what else?







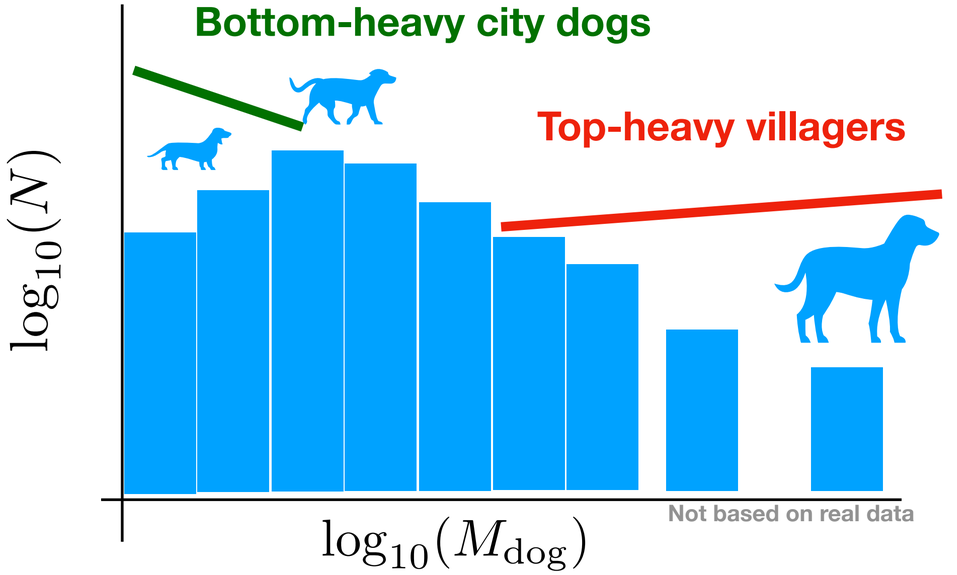
(Probability) distribution function

Study: Formation and evolution of dogs based on their measured mass distribution function

We get to know how common or rare dogs of different masses are, but what else?

We can randomly draw from a given distribution to obtain statistically equivalent sample.
But can we randomly sample individual systems (dog to family/stars to clusters), ignoring any physical constraints?

Randomly sampled too big dog for a house



Massive stars form stochastically with low probability

Applying bulk properties of stars to individual cases does not work - we need to consider physical conditions required for massive star-formation.

Physical conditions required for massive star formation are rare

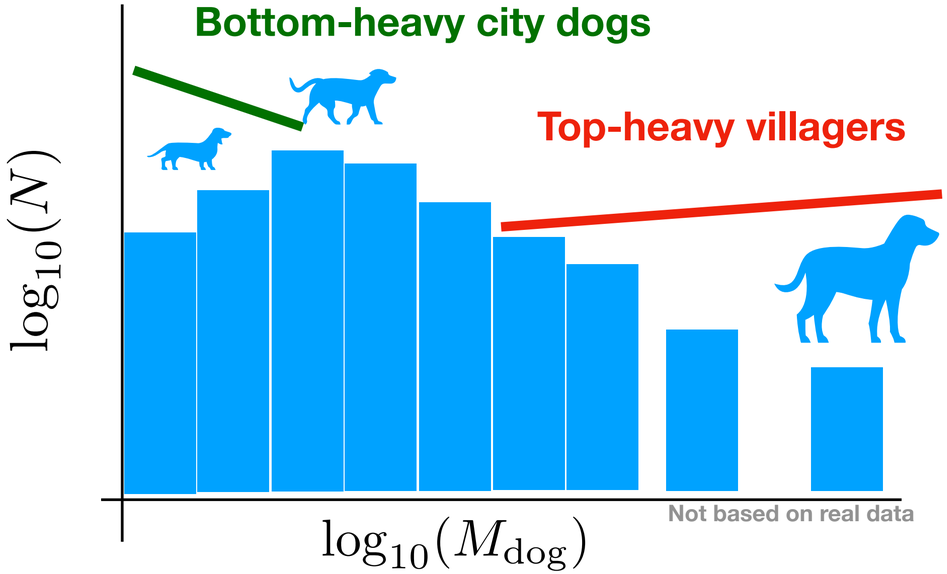
Formation of massive stars is physically determined, not random

(Beware of “scatter” from binaries and nbody interactions!)

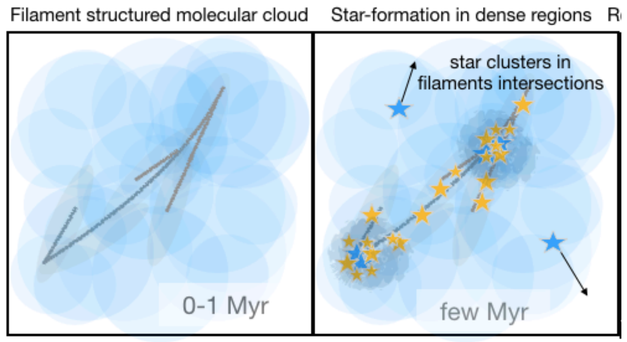
Study: Formation and evolution of dogs based on their measured mass distribution function

We get to know how common or rare dogs of different masses are, what else?

Randomly sampled too big dog for a house



> Astronomers working on the IMF, like scientists in other fields, have always been rather desperate to arrive at a definite result, as evidenced by the trend in recent years to re-institute the Salpeter IMF despite the abundant evidence to the contrary in the literature reviewed here. Part of this urge, I think, is a result of a hope, or faith, that the complex and varied physical processes involved in star formation should somehow result in universal statistical properties. This belief is perhaps rooted in results from the velocity distribution found in kinetic theory and statistical mechanics and the power spectrum found in incompressible turbulence. However the IMF is by nature very different from these cases. Scalo(1998)

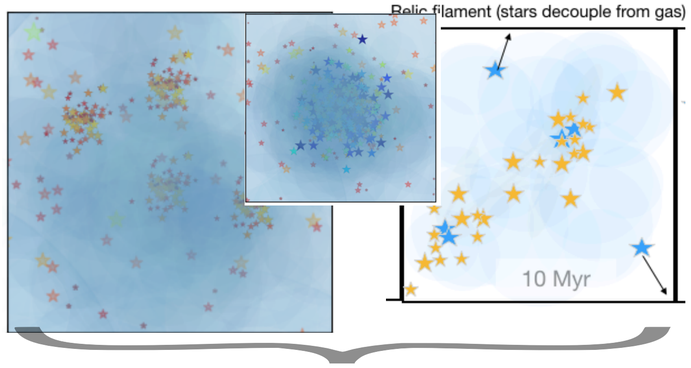


Embedded filament-structured star-formation (Herschel, ALMA)

Lada&Lada (2003) — embedded stellar cluster: a group of 35 stars with density above the Galactic field

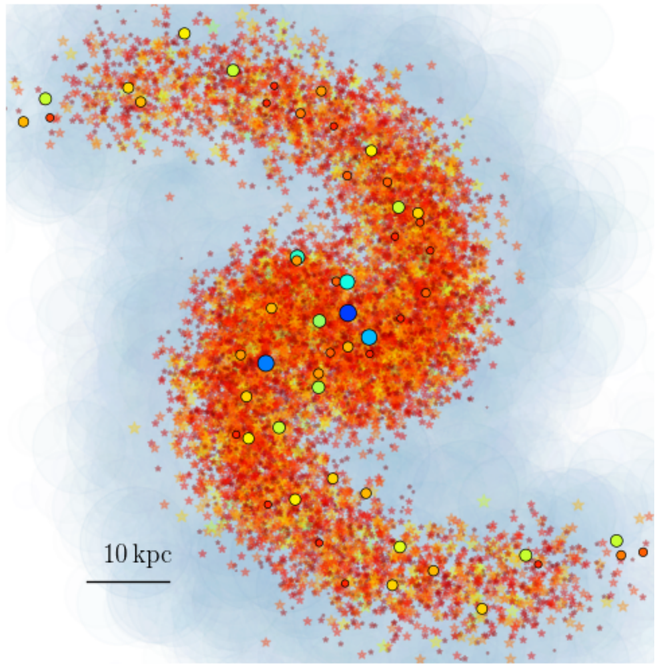
Andre+(2014), Andre+(2019), Hacar+(2017,2018)

Stellar feedback
stellar dynamics
stellar evolution



"Naked" products of star formation, clustered associations, relic filaments

Pfalzner (2019),Kuhn+(2019), Wright&Mamajek+(2018), Jerabkova+(2019), Beccari+(2020)



Building-up the galactic stellar populations and up to cosmic scales with variable IMF

Chemical models + kinematics + initial non-uniform stellar distributions

Yan, Jerabkova, Kroupa (2017, 2018,2019ab)+EMILES (Vazdekis+2016),
Dib & Basu (2018), Kamdar,Conroy+ (2019), Fontanot+(2017,18,19), De Masi+(2018)
Pocci+(2019), Zhu,van de Ven+(2020) **—> Kinematics**
Mor+(2018,2019), Zonoozi+(2019) **—> buildup of the Galactic stellar population using Gaia**
Chruslinska, Jerabkova+(2020) **—> Cosmic star-formation with variable IMF**

Observational evidence from larger scales:

Top-heavy galaxy-wide IMF at high SFR e.g. Zhang+(Nat,2018), Romano+(2017, 2019, 2020)

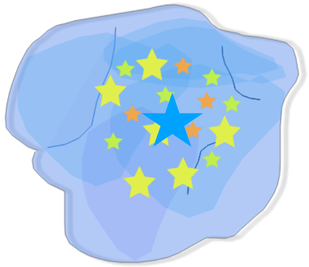
Bottom-heavy composite IMF at super-Solar Z e.g. Parikh+(2018),Martin-Navarro+(A&A,2019)

Take-aways

Salpeter 1955: groundbreaking concept of the stellar initial mass function (IMF) - quantum mechanics in the sky!

IMF is a "Hilfskonstrukt" that does not exist in nature

Kroupa & Jerabkova (2017)



observer: IMF?
Cluster: not, yet

observer: IMF?
Cluster: too late

Salpeter and Zinnecker (2005)

Star-formation to IMF

Zinnecker(1984), Adams&Fatuzzo(1996), Essex+(2020)

Reproducing bulk properties by a theory

$\neq$

IMF to star-formation

Applying bulk properties of stars to individual cases does not work - we need to consider physical conditions required for massive star-formation.

Scalo, Chabrier, Kroupa (2005)

Images taken from book: The IMF 50 years later (Corbelli, Palla, Zinnecker)

Many thanks to Hans Zinnecker for pointing this book out and the discussions!

2005, Salpeter: There surely will be variations but just what is still not clear.

2020: Significant variations confined to extreme environments evident. Possible variations in our neighbourhood (more uniform physical conditions) to be explored.