Constraining the stellar IMF
of
unresolved stellar populations with SHARP

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LAYOUT

- Introduction
- IMF variations: current view
- IMF constraints with SHARP

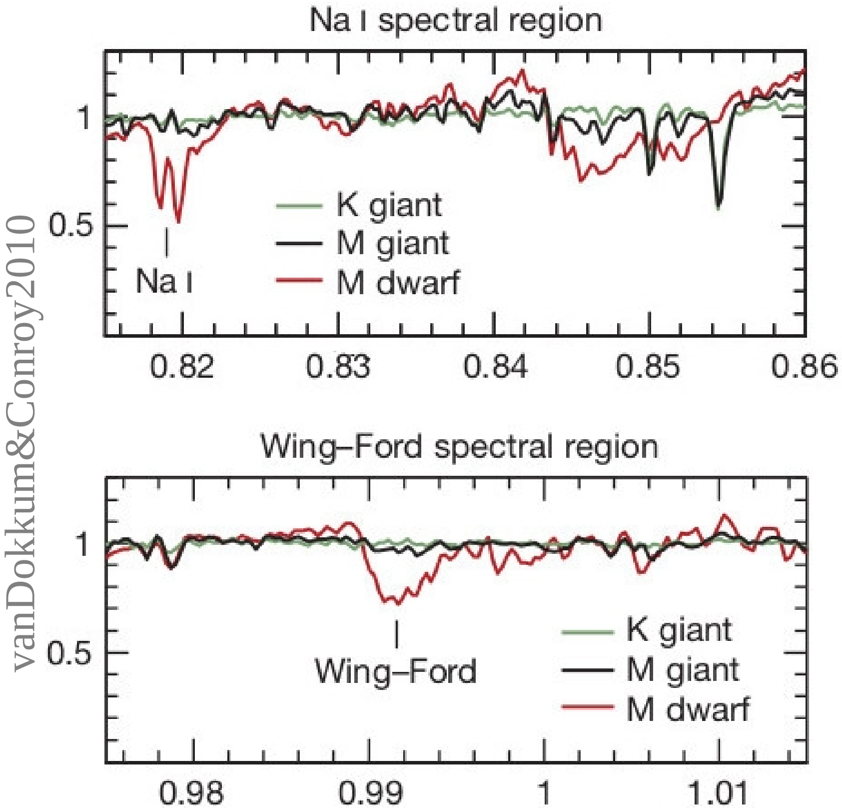
IMF-sensitive features

The stellar IMF is the mass distribution of stars born in one event of star formation.

Star clusters and OB associations in the MW and LMC → universal IMF (Kroupa/Chabrier)

For early-type galaxies, we cannot resolve individual stars below the turnoff.

However, some absorption features vary with log g, at fixed T_{eff} (Spinrad'62).



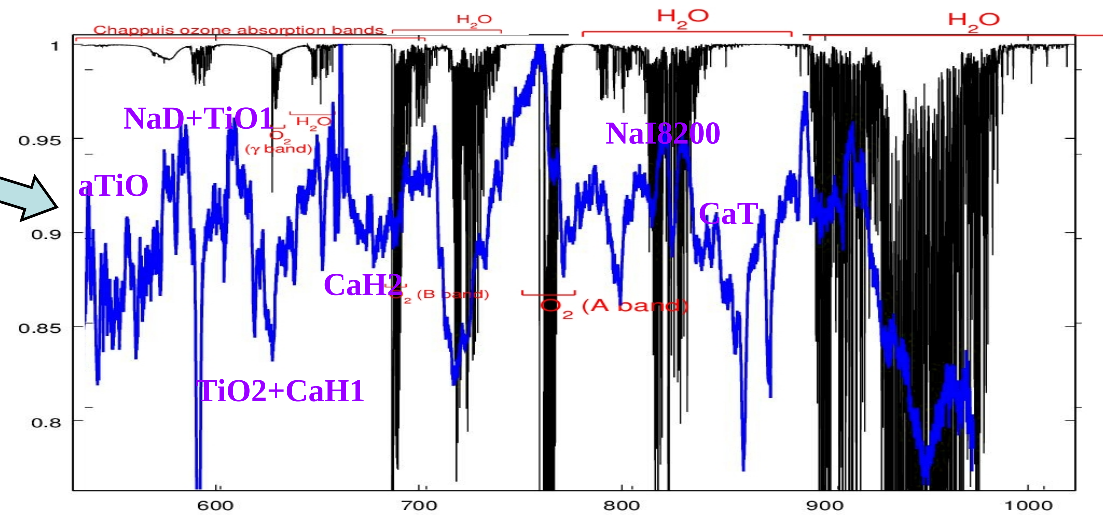
Each feature responds to gravity in a different way

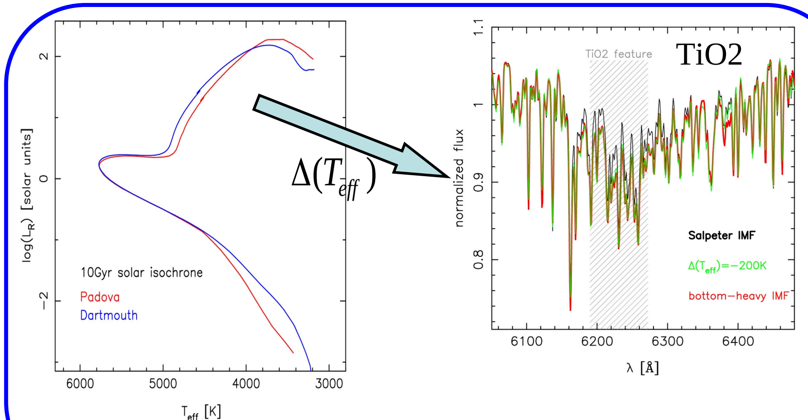
Possibility to constrain the IMF shape from integrated light (Faber&French1980)

Constraining the low-mass end: a difficult task !!

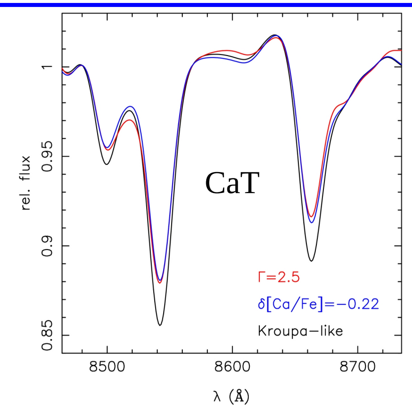
We want to measure few percent variations for features (e.g. NaI8200) affected by tellurics/sky at >10-20%

Challenging, but possible, with current instrumentation/observing techniques





Uncertainties on stellar population models



Degeneracy between IMF and abundance ratios

- We can break the degeneracies, in principle, using suitable sets of indicators (Conroy+2012a; Tang&Worthey2015).
- <u>It is crucial to study several features, from different chemical species, over a large spectral range.</u>

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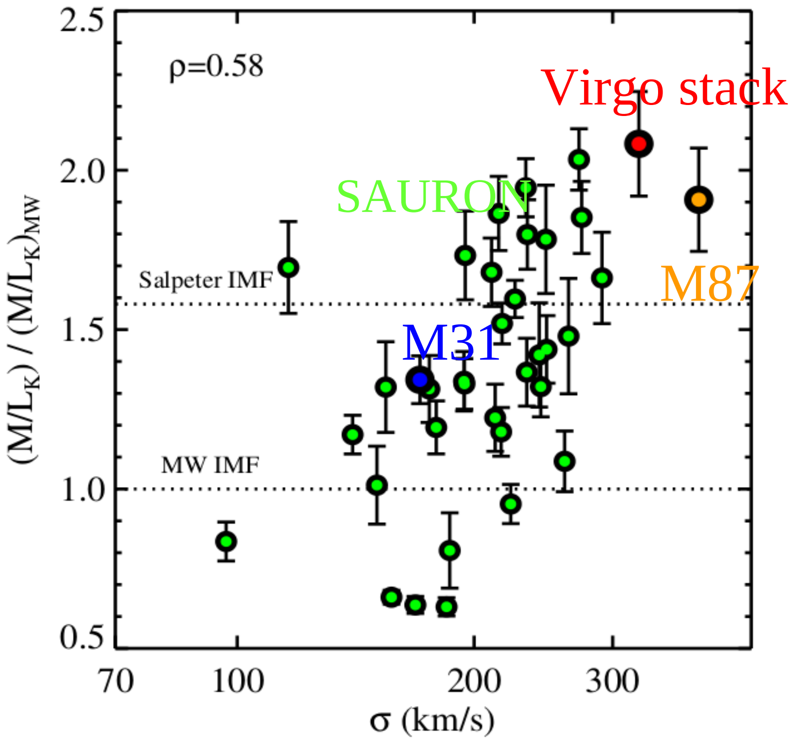
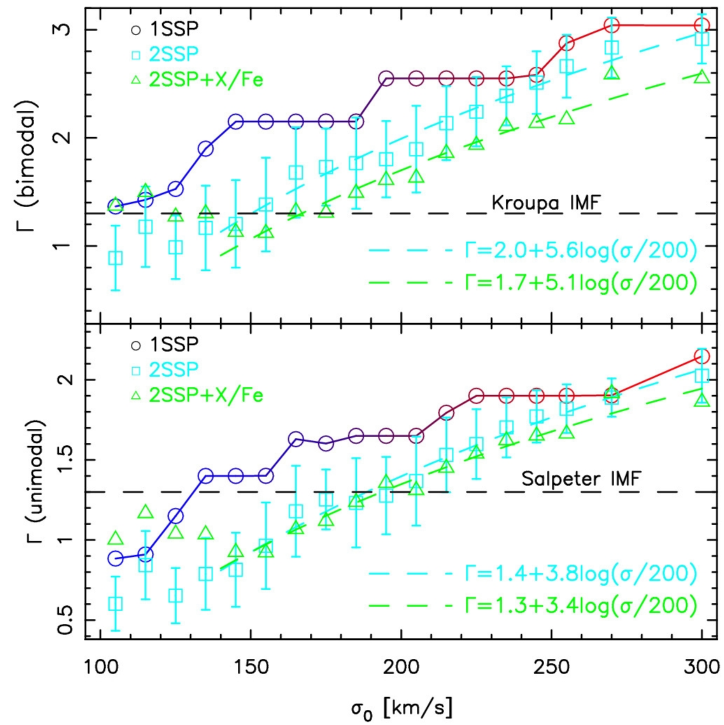
A bottom-heavy IMF in luminous ETGs

34 nearby ETGs at z~0
CvD SSP models
(van Dokkum&Conroy 2010; Conroy+2012b)



SDSS stacked spectra of 39993 ETGs @z<0.1
Vazdekis+ SSP models
(Ferreras+2013: La Barbera+2013)

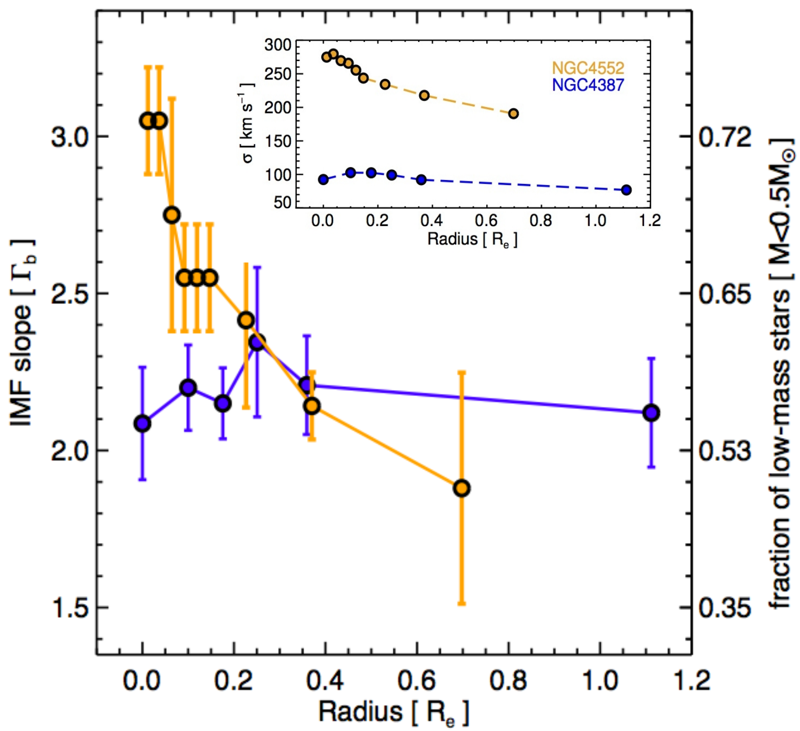


➡ Trend from a Kroupa-like IMF (σ≤150km/s), to a bottom-heavy IMF at high σ.

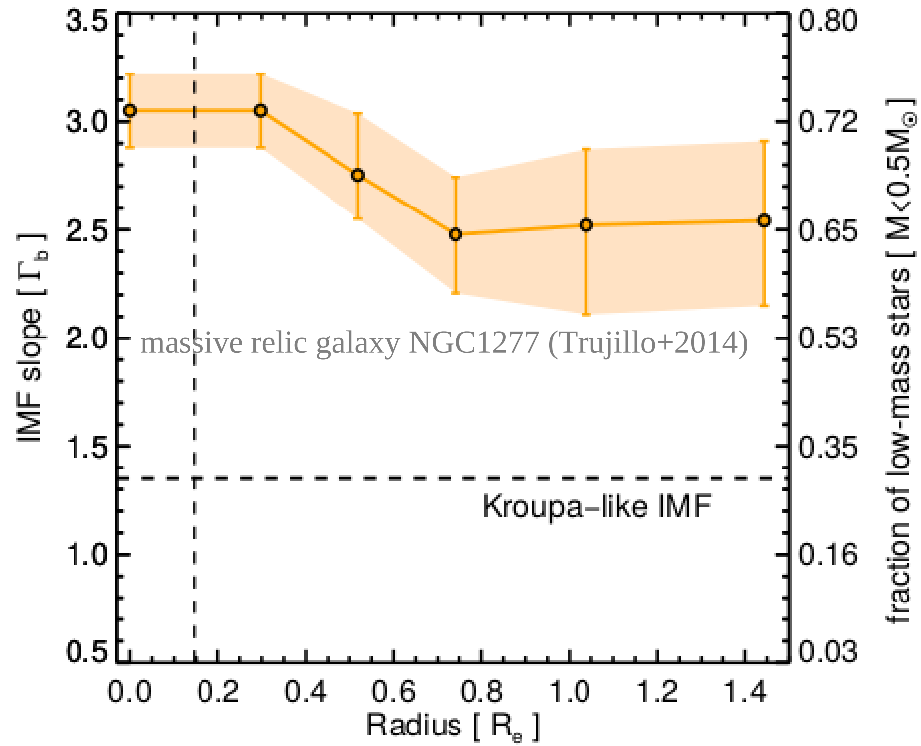
The relation is consistent with M_*/L trends from
- dynamics (Cappellari+2012, 2013a, J. Thomas+2011, Dutton+2012, Wegner+2012, Tortora+2013)
- lensing (Auger+2010, Treu+2010, Barnabé+2011), but see Smith&Lucey(2013), Smith+2015 including the contribution of low-mass stars and remnants

A bottom-heavy IMF in the cores of ETGs ?

Martín-Navarro et al. 2015a



Martín-Navarro et al. 2015c



IMF-slope radial gradients with optical+NIR (OSIRIS@10.4m-GTC) spectroscopy

- IMF gradient detected, for the first time, in the high-σ ETG NGC4552
- No IMF radial gradient for NGC4387

Many other papers have found IMF radial gradients at z~0

Sarzi+2018; van Dokkum+2017; La Barbera+2016, 2019, 2021; Barbosa+2021; Marti'n-Navarro+2019, 2021; Feldmeier-Kraus+2020, 2021; Parikh+2019; Zhou+2019; Domi'nguez-Sa'nchez+2019; Lonoce+2021 (but see Zieleniewski+2017, 2017; McConnell+2016)

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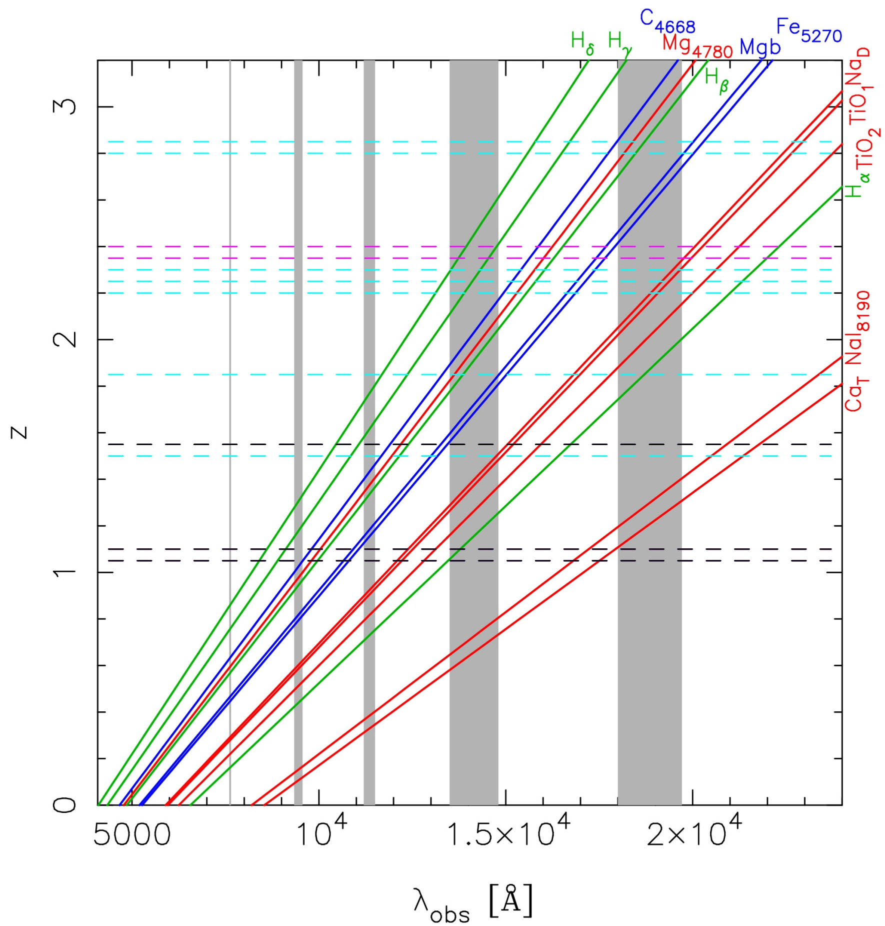
IMF-sensitive features with SHARP

Absorption features considered here:

age	IMF (4700<λ<8600Å)	Metallicity and abundances
H_β, H_γ, H_δ	Mg4780, NaD, TiO1, TiO2, NaI8190, CaT	C4668, Fe5270, Mgb



Requiring that features do not overlap telluric bands, and fall within the SHARP wavelength range, we can constrain the IMF:

- Up to **z~1.6** with optical+NIR features (i.e. the same as at z~0).
- Up to **z~2.4** with optical features only (i.e. no NaI8190 and no CaT).
- Up to **z~2.8** with the TiO's only.

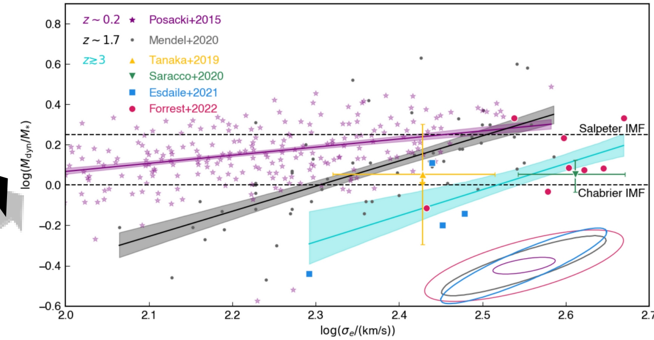
- No K-band: z ≤ 1.1, 1.6, 1.8
- K band allows us to add FeH0.99 and NaI1.14 at z≤1.1

Why to push IMF studies at higher redshift

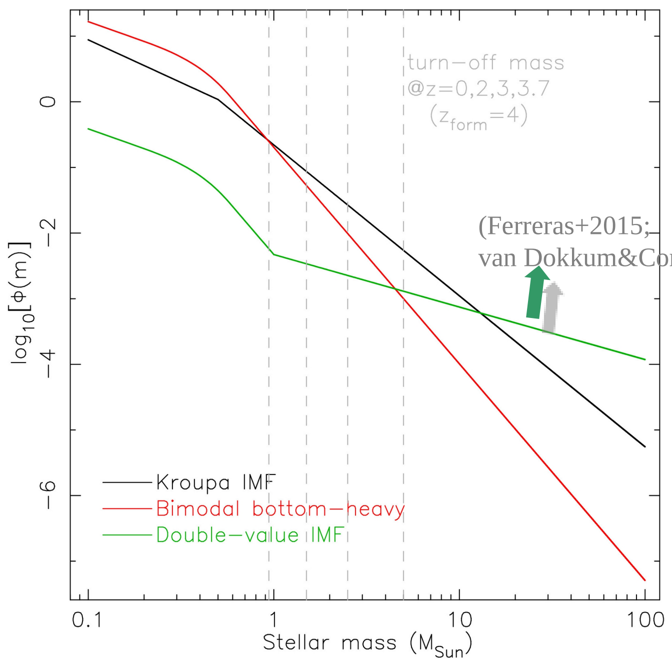
A bottom-heavy IMF in the center of massive ETGs at z~0 requires that the IMF changes with time (Weidner+2013; Ferreras+2015)

Theoretical works point to coupled variations at low- and high-mass in the IMF (Fontanot+2018, 2024; Chabrier+2014), or to low-mass star formation modes at later times (Fabian+2024).

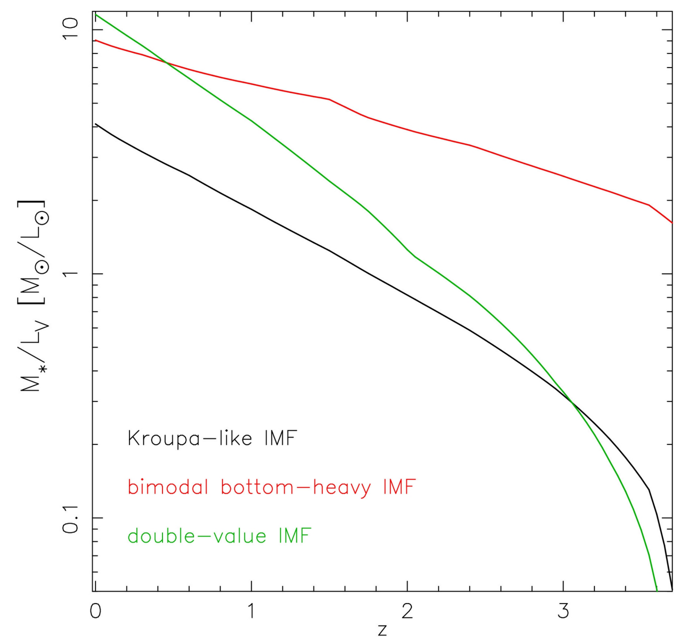
It seems that Mdyn/M* for high-z massive ETGs leaves little room for M*/L variations wrt a Kroupa-like IMF (e.g. Forrest+2022; Kriek+2024; but see Belli+2017). <u>However, systematics (e.g. rotation) on M_{dyn} should be accounted for</u>!



from Forrest+2022



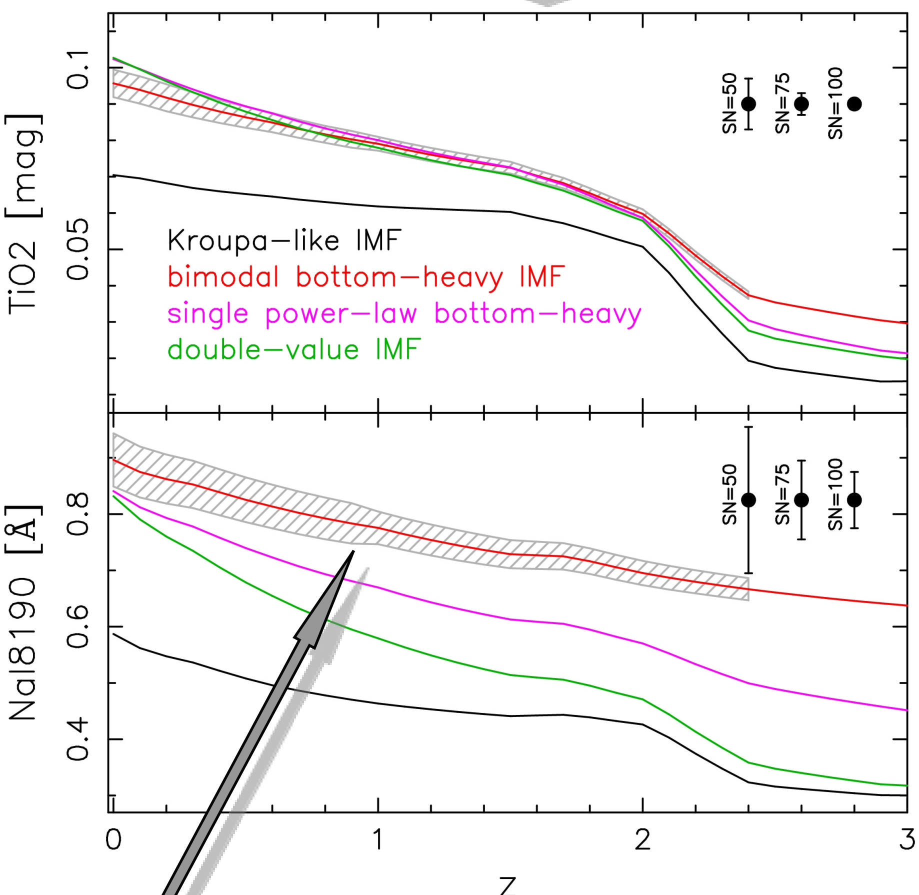
Different IMF parametrizations



Corresponding evolution of the M*/L with z
(EMILES 1SSP models, solar [Z/H], z_{form}~4)

IMF constraints vs. redshift

IMF-sensitive features vs, redshift for 1SSP models with $[Z/H]_{Solar}$, z_{form}~4, and different IMFs.



The effect of abundance ratios is smaller at higher z.

NaI8190 is very effective to single out bottom-heavy and double-value IMF models.

For indices like TiO2, the effect of SFH should be properly taken into account.

In principle, <u>with high-S/N and excellent-quality spectra at z$\gtrsim$1</u>, we can distiguish among different models.

Hatched regions reflect possible uncertainties (~0.05dex) on the estimates of abundance ratios ([α/Fe], [C/Fe], [Na/Fe]) and metallicity.

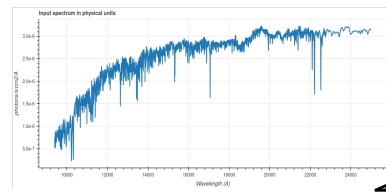
Exposure times with SHARP – IMF in the center

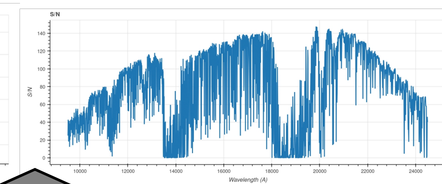
- Massive quiescent galaxies ($M_* > 10^{11} M_{Sun}$) at z=1.6, z=2.4, and z=2.8, respectively.

- We assume (typical) structural parameters with Sersic n=4, and
(i) R_e=1kpc (~125mas), (ii) Re=2kpc (~250mas), and (iii) Re=4kpc (~500mas).

- We use the SHARP NEXUS ETC (v.0.2,https://sharp.lambrate.inaf.it/), with slit width of
(i) 70mas, (ii) 140mas, and (iii) 280mas (extraction radius of $1/3R_e$).

- We require S/N=50 (per Å, restframe).





NEXUS

@z=1.6, we assume H=20.8 → T_{exp}=(i) 3hrs, (ii) 8hrs, and (iii) 20hrs

@z=2.4, we assume H=21.2 → T_{exp}=(i) 4hrs, (ii) 13hrs, and (iii) 29hrs

@z=2.8, we assume H=21.6 → T_{exp}=(i) 6hrs and (ii) 18hrs, (iii) 43hrs

Assuming to extract the spectra within R_e/3, and assuming -30% efficiency for VESPER,
T_{exp} should be multiplied by a factor of ~1.2 (i), 1.5 (ii), and 1.3 (iii).

"Competition" with JWST (9gals/40hrs) →

2024jwst.prop.5629K 2024/02

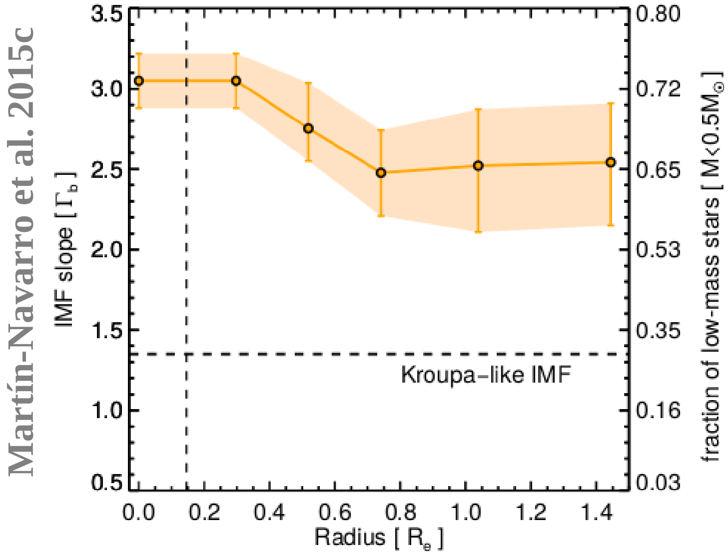
Extremely deep spectroscopy of quiescent galaxies at z 0.7: A direct measurement of the stellar initial mass function beyond the low-redshift universe

Kriek, Mariska; Beverage, Aliza G.; Cheng, Chloe M. *and 19 more*

Exposure times with SHARP – IMF gradients

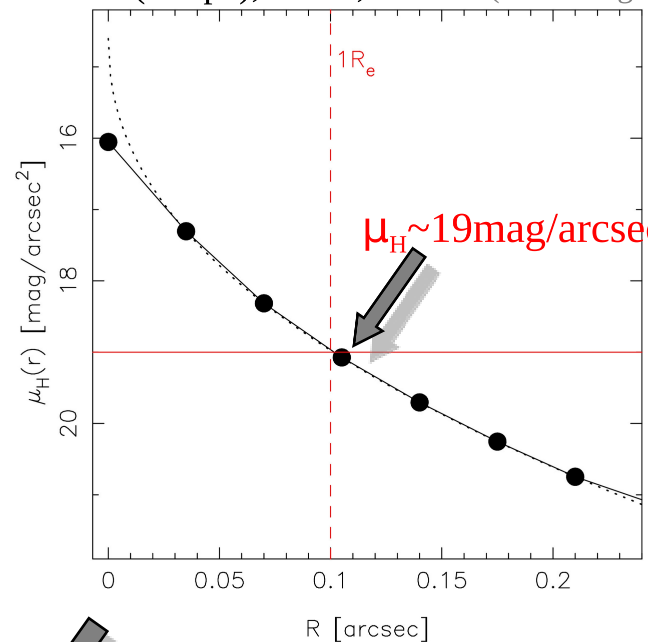
Testing the two-phase formation scenario

NGC1277, z~0, R_e~2kpc, n~2.2



Massive quiescent galaxy at z~1.2

R_e~100mas(1~kpc), n~2.2, H=20.9(from Gargiulo+2012)



NEXUS: slit width of 70mas, 3 pixels from both sides of the slit → T_{exp}=30hrs

VESPER: all spaxels within an annulus of 0.5-1.5R_e → T_{exp}=10hrs

SHARP will allow us to study IMF radial gradients, at least for some massive ETGs, at z>1.

SHARP multiplexing – IMF constraints

- Number densities of quiescent galaxies from Muzzin+2013 (COSMOS/UltraVista)
- SHARP-NEXUS FOV of 1.2’x1.2’

Expected number of quiescent galaxies (N_Q) per NEXUS field at $1 \leq z \leq 3$

$N_Q = 0.4 \pm 0.2$ (0.9 ± 0.3) gals for $M_* > 10^{11} (10^{10.5}) M_{Sun}$

- Kriek+2024 obtained spectra for 9 quiescent galaxies with H<21.8, 1.9<z<2.3, within two MOSFIRE@Keck fields (6.1’x6.1’ each).
- We rescale the number densities of Muzzin+2013 to match this number

$N_Q = 1.0 \pm 0.3$ gals per NEXUS field

- We consider the rich galaxy cluster of Newman+2014, at z~1.8
- $N_Q = 7$ quiescent galaxies with H<21.8, within ~1 NEXUS FOV.

T_{exp}~20-30hrs with NEXUS (x7 larger without multiplexing)

Summary

*Take home message

Thanks to its angular resolution and wavelength range, SHARP@ELT will allow us to probe the IMF in the center of massive quiescent galaxies up to z~2.8, with optical+NIR spectroscopic features, as in ETGs at z~0

For some of the brightest galaxies, it will be possible to constrain IMF radial gradients, out to ~1Re, at z≳1.

Other avenues:

- IFS kinematics to constrain the (overall) M/L within $1R_e$
- Exploiting UV IMF-sensitive features (e.g. MgII2800 @z≳2.4 with SHARP)
- Fluctuation spectroscopy (ETGs at z~0)