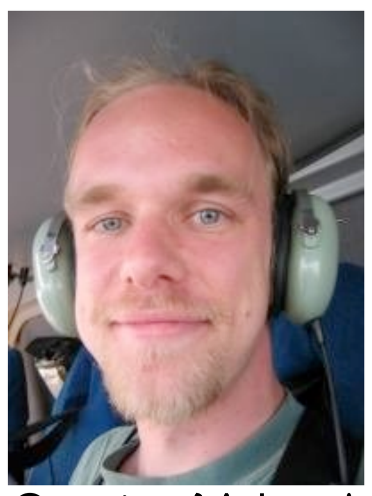

Questions? Ask me!
Or see my talk at Sp12

Bottom-heavy Initial Mass Function

Läsker et al. 2013, MNRAS-L

in a nearby compact L*-galaxy

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Abstract

We present orbit-based dynamical models and stellar population analysis of a low-redshift ($z = 0.116$) early-type galaxy (ETG) which, for its moderate luminosity ($L_i \approx 4.7\times10^{10}L_\odot \approx L^*$), has an exceptionally high stellar velocity dispersion ($\sigma_\star$=360 kms^{-1}). We aim to determine the central black hole mass ($M_\bullet$), the stellar mass-to-light ratio (Υ=$\Upsilon_{\star,i}$≡$M_\star/L_i$), and the slope (Γ) of the initial mass function (IMF). Combining the constraints from HST imaging and long-slit kinematic data with those from fitting the spectrum with stellar population models of varying IMF, we show that this galaxy has an extremely high fraction of low-mass stars. The concurrent Υ is ~ 50% higher even than implied by a Salpeter IMF. We also find strong indications for super-solar metallicity and α-abundance. Although these results conform to known correlations with $\Upsilon(\Gamma)$, our study demonstrates that a very bottom-heavy IMF can exist even in an L*-ETG. Moreover, the combination of density, morphology and kinematics of this galaxy is rare in the local universe, but typical of the compact ETGs ubiquitous at z~2. We surmise that it is a merger-deprived survivor of said era of early rapid star formation, and that its compliance with the local $\Upsilon(\Gamma)$-correlations (especially with $\sigma_\star$) supports the view that massive ETGs grew mainly by intermediate-to-minor and dry merging over the last ~ 10 Gyr. Improved kinematic data for this target is currently under analysis and expected to constrain $M_\bullet$ better than the current upper limit of $10^{10.5}M_\odot$.

The Target: "b19"

- morphologically early-type
- a rare galaxy in the local universe:
  - extremely high velocity dispersion (360 km/s), plus significant rotation
  - but only average luminosity (≈ L*)
  - very dense (compact)
  - flattened (see Fig. 1) with embedded disk

This raises the following questions:

- how is the high dispersion explained?
- how did it evolve in comparison to most (local) ETGs of similar dispersion or luminosity?

The dynamics of the system (see Fig. 2) must result from a high central mass density, such as:

- an extremely massive central Black Hole (BH) ?
- high stellar mass-to-light ratio ?
- Dark Matter (DM): unlikely to be significant at these spatial scales (~1 kpc)

Dynamical models

- Schwarzschild method (code: van den Bosch et al. 2008): fully general, orbit-based, hence accommodates for the possibly peculiar orbital structure of b19
- distance ~500 Mpc → require high-resolution imaging (HST/ACS) to model surface brightness
- kinematic data (Fig. 2): HET long-slit and SDSS
- include central BH (mass $M_\bullet$) and DM (NFW profile)
- vary Υ, $M_\bullet$, f_{DM}=$M_{200}/M_\star$ and inclination (i)
- we cover a wide range in DM mass: $f_{DM} \in$ [1, 100]
- marginalize over f_{DM} and i → $\chi^2(\Upsilon, M_\bullet)$ (Fig. 3)

Stellar Population, IMF

- we analyze the SDSS spectrum of b19 using MIUSCAT stellar population models
- fit metallicity, age, dust extinction and IMF slope (Γ) to the full spectrum, plus line indices Hβ_0, Hγ_F, [MgFe], TiO$_{1/2}$, NaD and Na8190 using the "Hybrid Method" (Ferreras et al. 2013)
- we test unimodal and bimodal IMF shapes (Fig. 4)

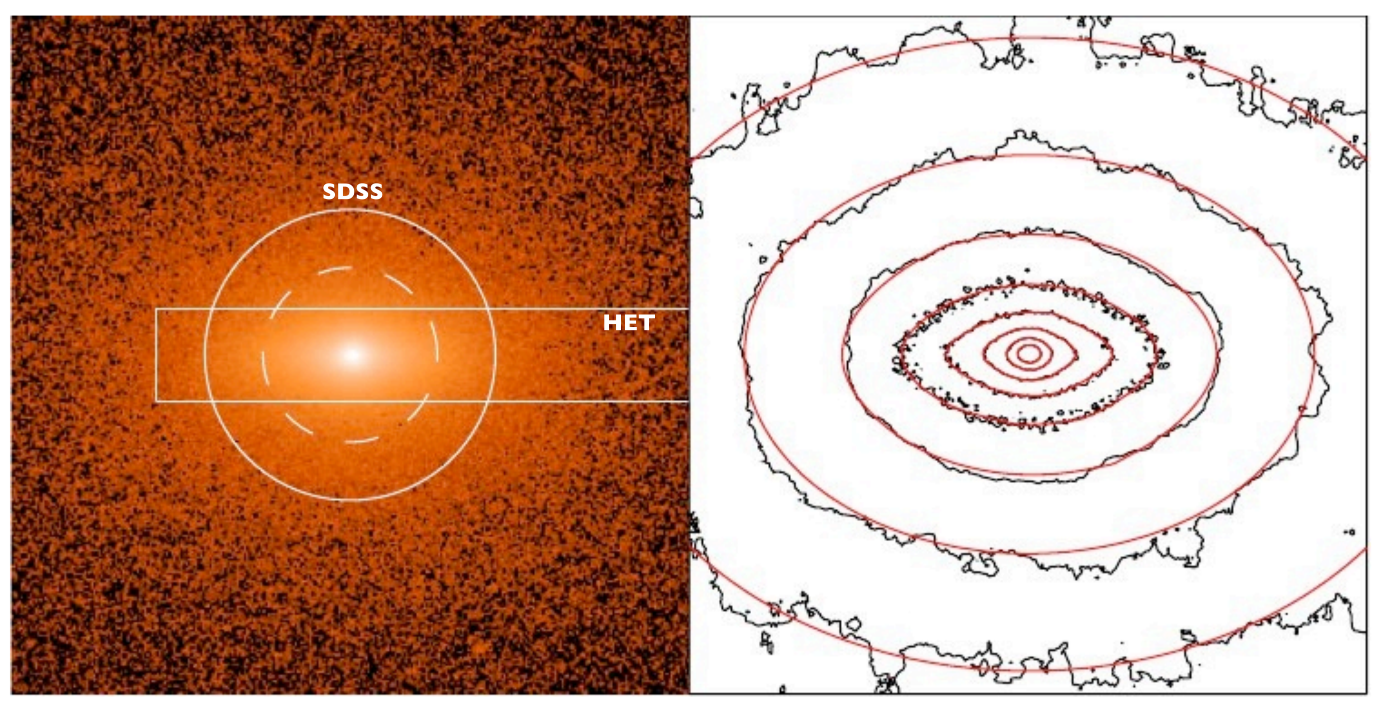


Fig. 1, Left Panel: HST/ACS F775W (i-band) image of our target galaxy ("b19"). Shown is an area 7" across (15kpc at 500Mpc distance). The dashed circle represents the effective radius (1.9kpc). Solid circle and rectangle are the kinematic apertures (SDSS fibre and HET slit, respectively). b19 is quite flattened (q=0.6) and probably harbours an embedded disk. The galaxy image is smooth and no spiral arms, dust or other irregular features are present. Right panel: Isophotes of the MGE model of the same image (red contours) overlaid on the data (black).

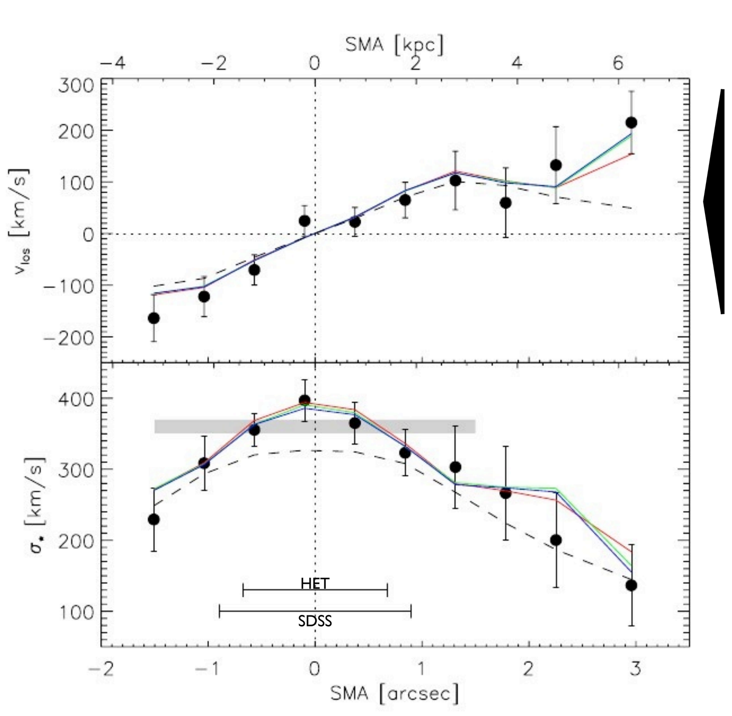
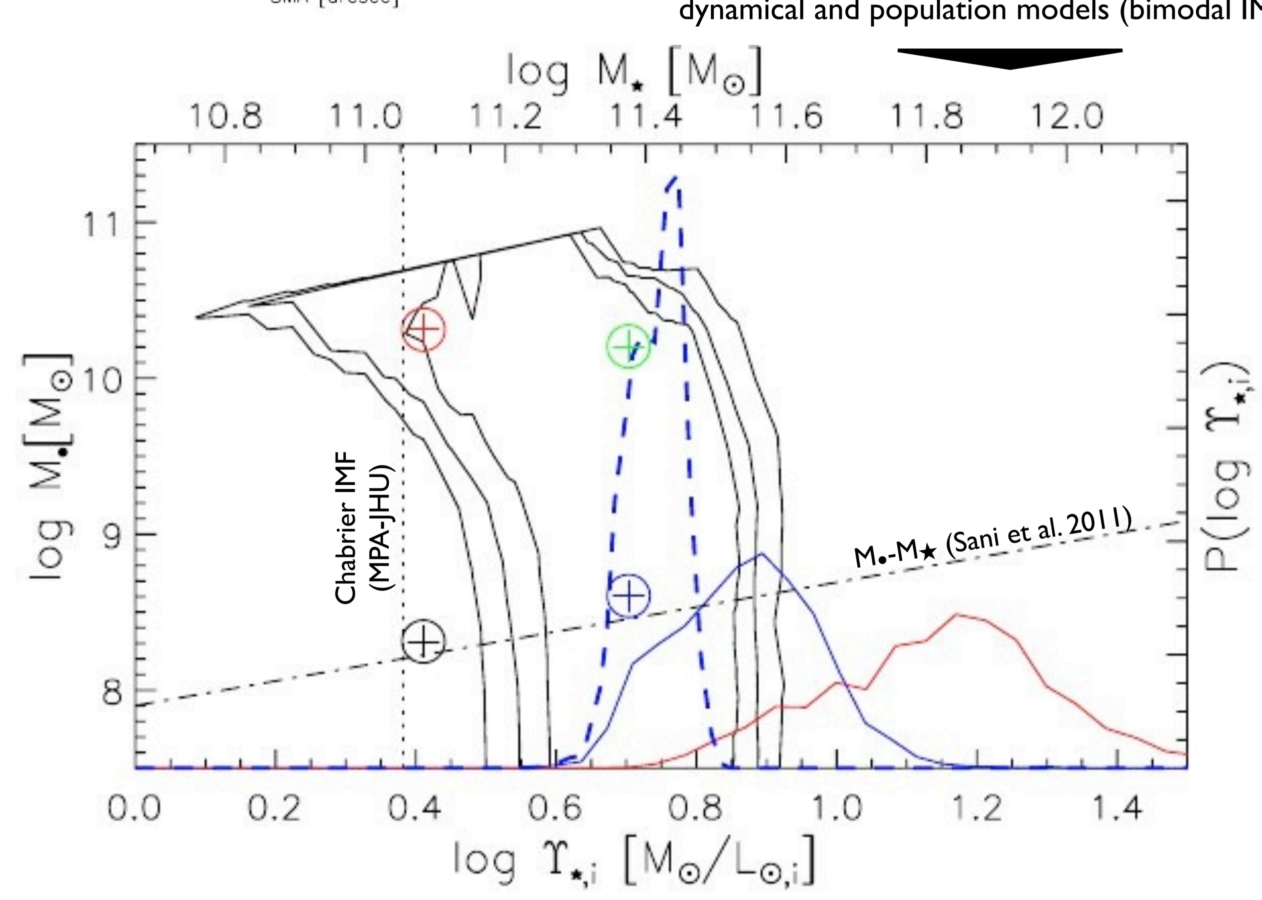


Fig. 2: Kinematics of b19 (symbols and vertical bars: HET long-slit data; grey area: SDSS fibre). Horizontal bars indicate the FWHM. Red/green/blue curves show kinematics of dynamical models with either $M_\bullet$~$10^{10}M_\odot$ or Υ~5, which fit the data well. Excluded are models with $M_\bullet$~$10^{8.5}M_\odot$ and Υ~2.5 (grey dashed curve), which would be expected from the $M_\bullet$-$M_\star$ BH scaling relation and a Chabrier/Kroupa IMF.

Fig. 3 (below): 1-, 2- and 3-σ confidence regions (black contours) of dynamical models in the $M_\bullet$-Υ plane. Coloured symbols correspond to the curves in Fig. 2. Red/blue curves: Probability distribution of Υ as obtained by our stellar population analysis (uni-/bimodal IMF). Blue dashed: The joint probability for Υ from dynamical and population models (bimodal IMF).



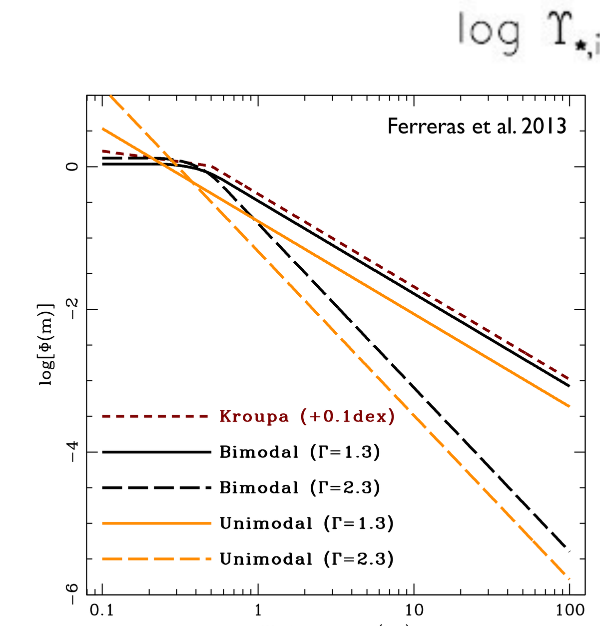


Fig. 4 (adapted from Ferreras et al. 2013): Comparison of unimodal and bimodal IMF shapes. A unimodal IMF with Γ=1.3 is equivalent to the Salpeter IMF.

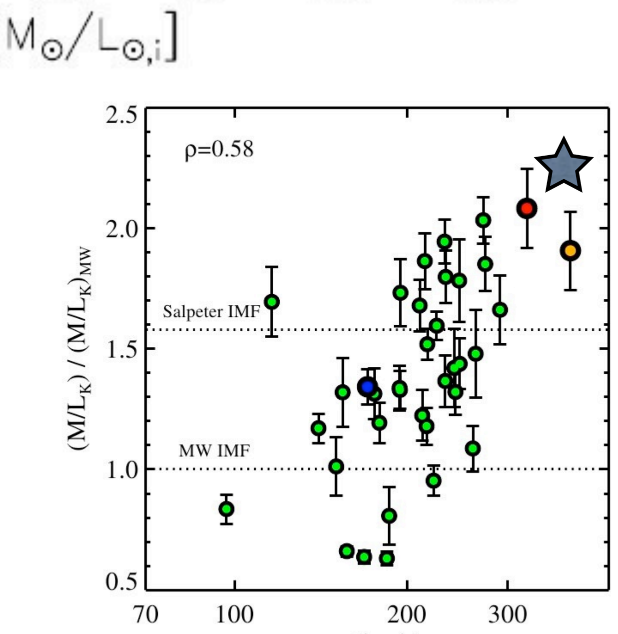


Fig. 5 (adapted from Conroy & van Dokkum 2012): b19 (grey star) follows the previously established trend of Υ with σ, despite being much smaller and fainter than other high-σ galaxies (red: stacked spectra, orange: M87).

Results

- The dynamical analysis shows that either an extremely large BH ($M_\bullet$ ~ $10^{10}M_\odot$) or high Υ (about twice the value obtained using a Chabrier IMF[1]), but cannot distinguish between both scenarios due to limits in the available spectra.
- stellar population modeling of the Spectrum with variable IMF strongly favours the high-Υ scenario, and yields a very steep IMF (Γ > 3.2 (90% confidence)
- combining both methods rules out a unimodal (single-powerlaw) IMF in b19, and Υ=5±1 at the 3σ-level
- b19 is old (>8.5Gyr), dust-free, and shows indications of high α-abundance (Mg)

[1] MPA-JHU analysis, http://www.mpa-garching.mpg.de/SDSS/DR7/Data/stellarmass.html

Discussion

We demonstrate that very bottom-heavy IMFs are not restricted to the largest and most massive Elliptical galaxies (see Fig. 5). At face value, our study strongly confirms a trend of Υ with σ (and correlated quantities), rather than with mass. b19 resembles the most massive ETGs at z~2, and one may suspect that those also feature bottom-heavy IMFs. If massive present-day Ellipticals have subsequently grown their envelopes mostly by minor dry merging, and if the IMF slope is basically related to the density at the epoch of star formation (see e.g. Smith & Lucey 2013), they should show IMF gradients. When investigating those, dynamical (and lensing) models can improve results from population analysis, by reducing assumptions about the IMF shape at the low-mass end.