Probing merger history of galaxies with stellar shells

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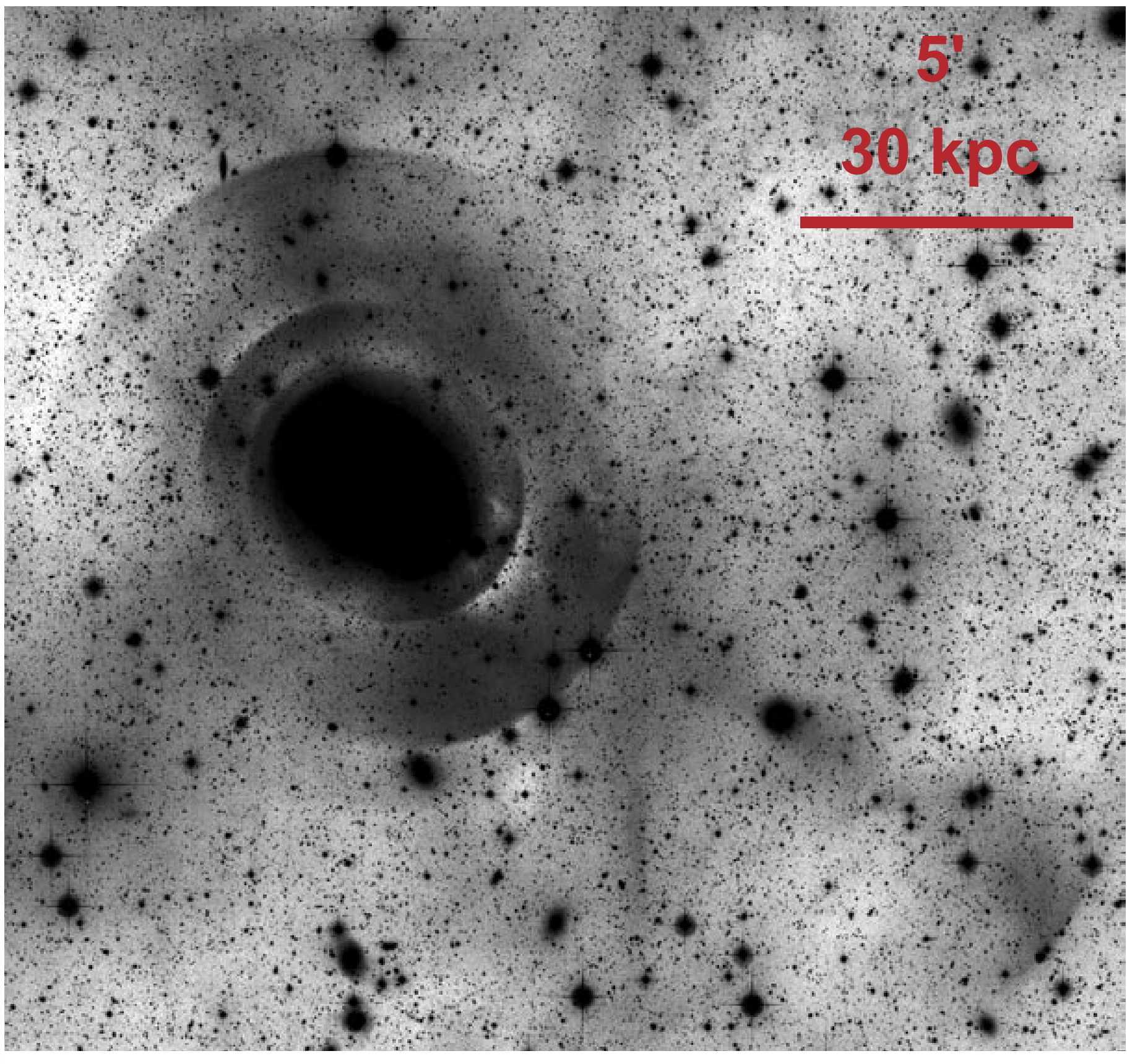
Shell galaxies

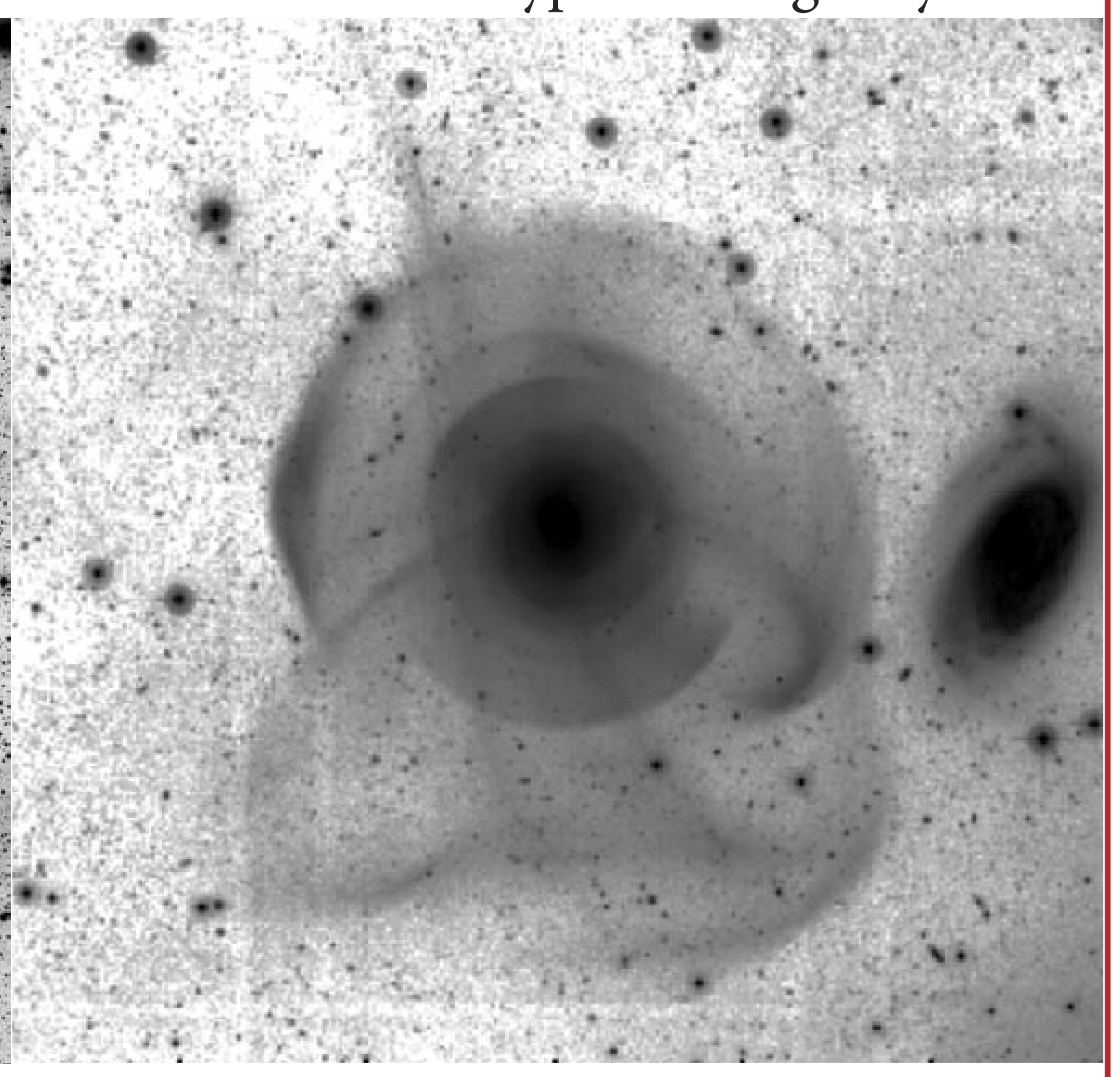
Shell galaxies account for 10–20% of all early-type galaxies; more frequent in low density environments and among massive galaxies (e.g., Malin & Carter 1983, Tal et al. 2009, Atkinson et al. 2013, Bílek et al. 2020); one to tens of shells per galaxy; galactocentric radii from ~1 kpc to over 100 kpc; made of stars from a galaxy accreted on a close-to-radial trajectory (Quinn 1984). Their unique kinematics enables measurements of the host gravitational potential and/or the time since the galactic merger using line-of-sight velocity distribution (Merrifield & Kuijken 1998, **Ebrová et al. 2012**) or distribution of shell radii (Quinn 1984; Dupraz & Combes 1986; Hernquist & Quinn 1987a,b). In **Bílek et al. (2013, 2014)**, we developed 'shell identification method' testing the consistency of a given gravitational potential with the observed shell radii and applied it on NGC 3923 — the richest known shell system.

NGC 3923 – a Type I shell galaxy



*CFHT/MegaCam ultra deep image, host-light model subtracted, **Bílek et al. (2016)***

NGC 474 – a Type II shell galaxy



MATLAS — a deep imaging survey (Duc et al. 2015, Bílek et al. 2020)

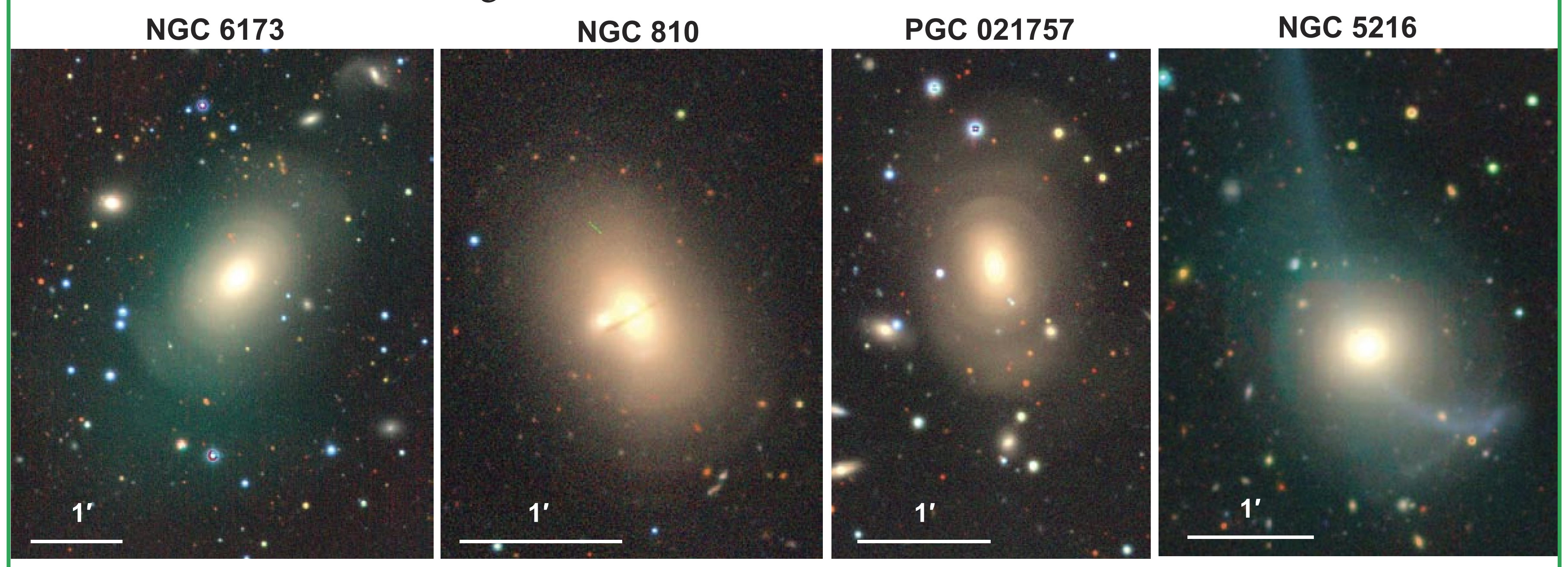
Shell galaxies and LSST

Rubin Obs/NSF/AURA

Vera C. Rubin Observatory will acquire data with a unique combination of the image depth and sky coverage. The data will contain thousands or even tens of thousands of shell galaxies suitable for the merger-time estimates.

That brings challenges of an automatic (pre-)selection of the galaxies and merger-time analysis for such a large number of galaxies. When successful, it will mean a huge qualitative leap in our knowledge of the merger history of the nearby universe.

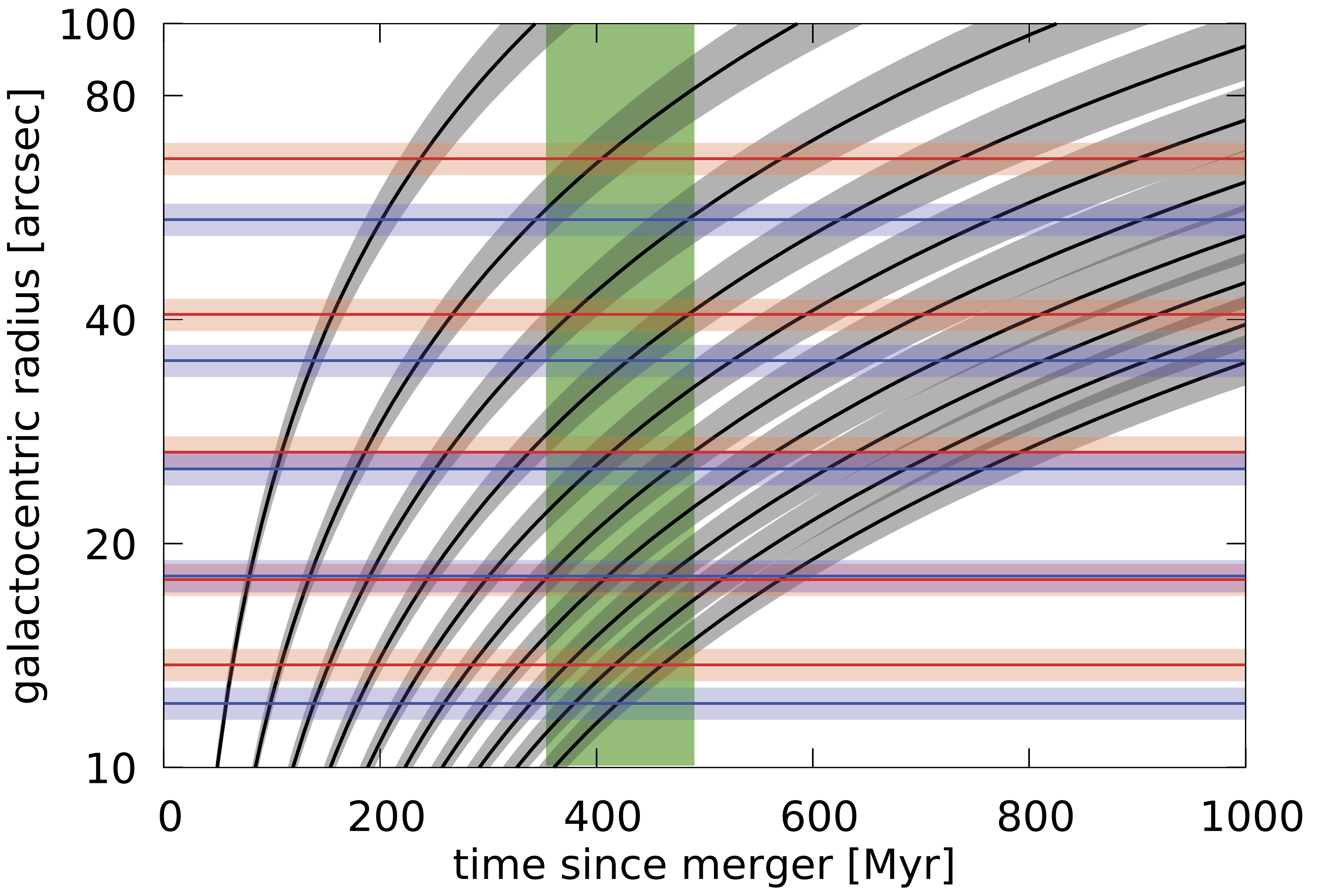
Mergers are an important part of galaxy evolution. In **Ebrová et al. (2021)**, we proved a link between mergers and prolate rotation on a sample of 19 galaxies. LSST data will allow for such analyses on much larger samples for a variety of phenomena as a function of the time merger.



Four out of 11 known prolate rotators with multiple shells, Ebrová et al. (2021); imagas: DESI Legacy Imaging Surveys (Dey et al. 2019)

Merger time from shell radii distribution

An example of NGC 4993 — the shell galaxy host of the binary neutron star (BNS) coalescence and the accompanying gravitational-wave event GW170817 (Abbott et al. 2017). The galaxy shows signs of a recent merger with a smaller late-type galaxy. In **Ebrová et al. (2020)**, we modelled the stellar mass distribution of NGC 4993 using HST/ACS archival data, assumed an adequate dark matter halo, and, using the shell identification method of Bílek et al. (2013), inferred the merger time arnoud 400 Myr (see fig. below) — a probable lower limit on the BNS age, as the host galaxy was probably quenched before the galactic merger, and the merger has likely shut down the star formation in the accreted galaxy. We roughly estimate the probability that the BNS originates in the accreted galaxy to be around 30%. In **Bílek et al. (2022)**, we used similar procedure when investigating the evolution of the spectacular shell galaxy NGC 474 (image above).

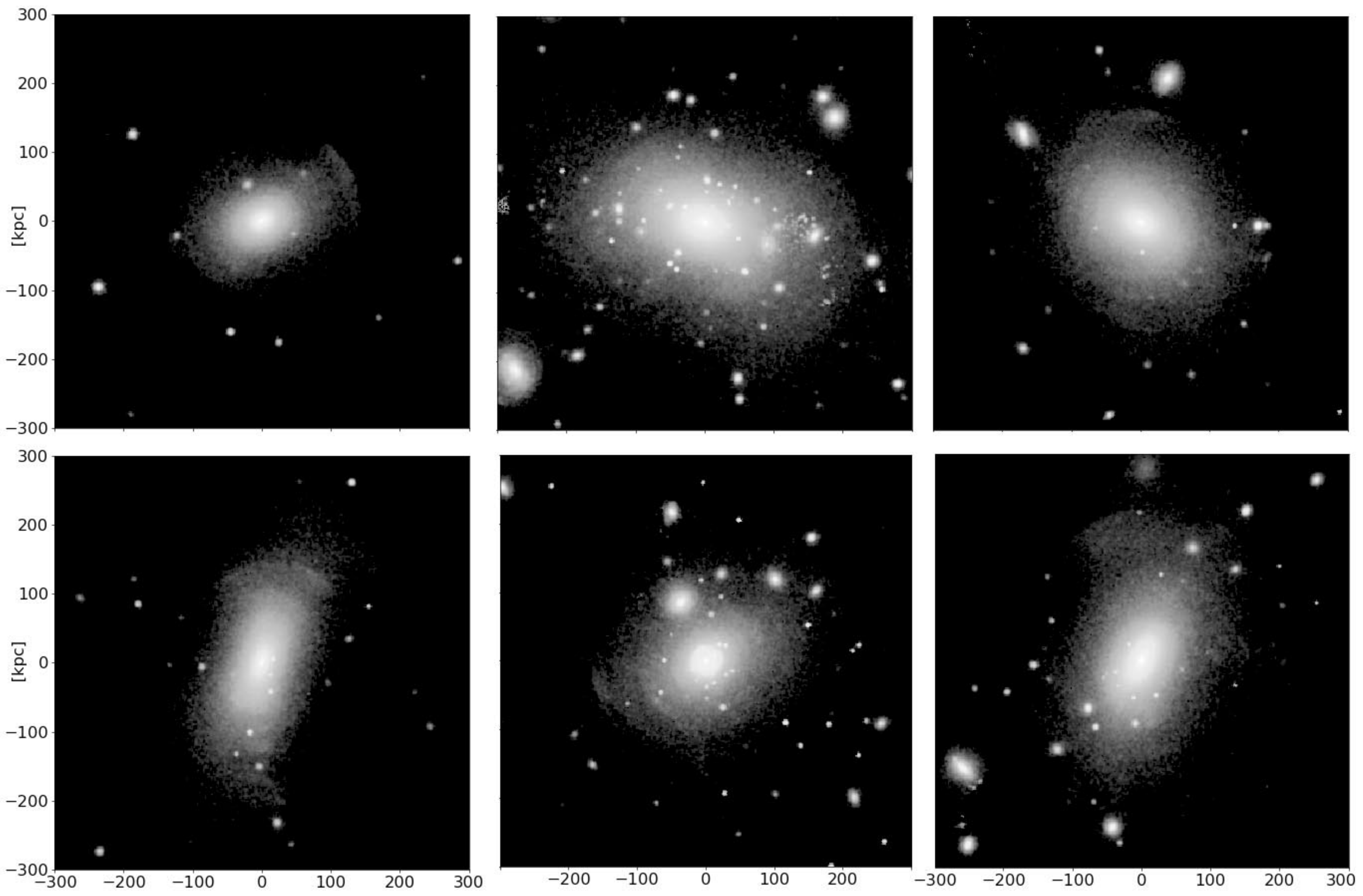


Evolution of shell radii in a given potential (black curves) compared to the observed shell radii (color lines) for NGC 4993 — as a Type II shell galaxy, it does not reproduce the exact positions of the shells, but from the outermost observed shell and overall shell number, the most probable merger time is around 400 Myr, Ebrová et al. (2020)

Shell sizes in IllustrisTNG

The sizes of the biggest shells in the Universe depend on masses of host galaxies, pericentric velocities of the mergers, and the internal stellar velocities of the accreted galaxies. Therefore the biggest shells can serve as an important test of cosmological models.

We examined IllustrisTNG large-scale cosmological simulations (Nelson et al. 2019) and searched for the largest shells in g-band images with the surface brightness limit of 28 mag/arcsec^2. We found that 10–20% of 300 most massive galaxies in TNG100 contain a shell larger than 100 kpc **(Ebrová et al. , in prep.)**. This is a surprisingly high rate compared to the sample of 179 ETGs in MATLAS examined by Bílek et al. (2020) and Sola et al. (2022). None of the shells found there exceeds 90 kpc, with the majority being smaller than 40 kpc. Finding the missing big shells will be an important test of the current cosmological models.



Six examples of TNG100 galaxies with large shells, Ebrová et al. (in prep.)

References: Abbott et al. 2017, ApJ, 848, L12; Atkinson et al. 2013, ApJ, 765, 28; **Bílek et al. 2013, A&A, 559, A110; Bílek et al. 2014, A&A, 566, A151; Bílek et al. 2016, A&A, 588, A77;** Bílek et al. 2020, MNRAS, 498, 213; **Bílek et al. 2022, A&A, 660, A28;** Dey et al. 2019, AJ, 157, 168; Duc et al. 2015, MNRAS, 446, 120; Dupraz & Combes 1986, A&A, 166, 53; **Ebrová et al. 2012, A&A, 545, A33; Ebrová et al. 2020, A&A, 634, A73; Ebrová et al. 2021, A&A 650, A50;** Hernquist & Quinn 1987a, ApJ, 312, 1; Hernquist & Quinn 1987b, ApJ, 312, 17; Malin & Carter 1983, ApJ, 274, 534; Merrifield & Kuijken 1998, MNRAS, 297, 1292; Nelson et al. 2019, CompAC, 6, 2; Quinn 1984, ApJ, 279, 596; Sola et al. 2022, A&A 662, A124; Tal et al. 2009, AJ, 138, 1417

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