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BIG-SPARC: The new SPARC database

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Abstract. The Surface Photometry and Accurate Rotation Curves (SPARC) database has provided the community with mass models for 175 nearby galaxies, allowing different research teams to test different dark matter models, galaxy evolution models, and modified gravity theories. Extensive tests, however, are hampered by the somewhat heterogeneous nature of the HI rotation curves and the limited sample size of SPARC. To overcome these limitations, we are working on BIG-SPARC, a new database that consists of about 4000 galaxies with HI datacubes from public telescope archives (APERTIF, ASKAP, ATCA, GMRT, MeerKAT, VLA, and WSRT) and near infrared photometry from *WISE*. For these galaxies, we will provide homogeneously derived HI rotation curves, surface brightness profiles, and mass models. BIG-SPARC is expected to increase the size of its predecessor by a factor of more than 20. This is a necessary step to prepare for the additional order of magnitude increase in sample size expected from ongoing and future HI surveys with the Square Kilometre Array (SKA) and its pathfinders.

Keywords. astronomical data bases: miscellaneous, galaxies: evolution, galaxies: interactions, galaxies: kinematics and dynamics, dark matter, cosmology: observations, radio lines: galaxies

1. Introduction

The study of rotation curves (RCs) has been central to establishing the missing mass problem in galactic systems, one of the biggest open questions in modern physics (Rubin et al. 1978; Bosma 1981; van Albada et al. 1985). While these mass discrepancies are commonly explained via dark matter (DM) halos, the physical nature of this matter remains unclear. As a result, the study of RCs continues to provide some of the strongest constraints on the nature and properties of DM. In this context, HI observations represent one of the best tools to study galaxy RCs for two main reasons. First, the HI disks of galaxies often extend beyond their stellar disks, therefore probing deep into the DM-dominated regions. Second, compared to stellar and ionized gas disks, HI disks are dynamically cold with velocity dispersions of $\sim$10 km s^{-1}, so the observed rotation velocity is a close proxy of the circular velocity tracing the gravitational potential. However, on the downside, resolved HI studies require time-costly interferometric radio observations, which have been limiting the overall sample sizes of RC studies so far.

In this regard, a large step forward came from the SPARC database, which combines 175 RCs collected from the literature with near infrared (NIR) surface photometry from the *Spitzer* space telescope (Lelli et al. 2016a). Thanks to the limited effects of internal dust extinction and recent star formation, NIR photometry is the best proxy for the stellar mass distributions of galaxies (e.g., Verheijen 2001). As a result, SPARC enabled new investigations of the baryonic Tully-Fisher relation (BTFR, Lelli et al. 2016b, 2019, Desmond et al. 2019, McGaugh et al. 2021) and a measurement of the Hubble constant H_0 (Schombert et al. 2020). In addition, it was crucial for establishing two new scaling relations, the central density relation (Lelli et al. 2016c) and the radial acceleration relation (RAR, McGaugh et al. 2016, Lelli et al. 2017b, Li et al. 2018). In the context of ΛCDM cosmology, SPARC allowed to investigate the properties of DM halos (Katz et al. 2017, 2019; Li et al. 2019a,b, 2020, 2022a,b) and the related missing baryons problem (Katz et al. 2018), while beyond that, it enabled tests of alternative theories such as Emergent Gravity (Lelli et al. 2017a) and Modified Newtonian Dynamics (Petersen & Lelli 2020; Chae et al. 2020, 2021, 2022). Furthermore, SPARC has also been used to investigate stellar mass-to-light ratios (Schombert et al. 2019, 2022), maximum disk fits (Starkman et al. 2018), and the pitfalls of Bayesian RC fits (Li et al. 2021).

Despite its versatility, SPARC still suffers from two limitations. First, with 175 galaxies, the statistical power is limited. For example, at fixed galaxy mass, one cannot extensively study the effects of secondary properties such as environment, gas fraction, and so on. Second, the RCs in SPARC were compiled from the literature, so some inhomogeneity unavoidably persists despite the undertaken homogenization efforts (see Lelli et al. 2016a). In particular, this limits the ability to study the very small intrinsic scatter around the scaling relations, which requires a perfect control of the observational uncertainties. To address these issues and to pave the way for the analysis of large future HI surveys with the Square Kilometre Array (SKA) and its pathfinders, we are currently working on the successor of SPARC.

2. Source finding and identification

Differently from the previous SPARC database, we decided to derive RCs in a fully homogeneous way, starting from the HI data cubes. Table 1 lists the surveys and individual studies from which we culled our data. In total, we have 7914 cubes. To identify sources and produce HI moment maps, we ran the source finding task `SEARCH` of the ^{3D}Barolo software (Di Teodoro & Fraternali 2015) on all data cubes and crossmatched the resulting detections with the Principal Galaxies Catalogue (PGC, Paturel et al. 2003). If this did not provide a match, we crossmatched with the NASA/IPAC Extragalactic Database (NED)†. We then visually inspected all detections to remove artifacts. This procedure resulted in a list of almost 4000 galaxies. Due to the large sample size, we call the new data base the Broad Inventory of Galaxies with Surface Photometry and Accurate Rotation Curves (BIG-SPARC). The number of galaxies contributed by each survey or literature study is given in the last column of Table 1

† https://ned.ipac.caltech.edu/

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Table 1. Sources from which the BIG-SPARC data cubes were collected.

Literature source	Telescope	# of cubes	# of unique galaxies
APERTIF[1]	WSRT-APERTIF	5954	1740
WALLABY DR1[2]	ASKAP	592	486
WHISP[3]	WSRT	272	360
Atlas^{3D} [4]	WSRT	142	289
BLUEDISK[5]	WSRT	49	175
PPZoA[6]	WSRT	317	153
Hickson Compact Groups[7]	VLA	25	83
LVHIS[8]	ATCA	79	72
VIVA[9]	VLA	42	56
VGS[10]	WSRT	65	43
HALOGAS[11]	WSRT	24	39
PHANGS-VLA[12]	VLA	23	39
LITTLE THINGS[13]	VLA	40	38
EDGES[14]	VLA	24	29
EveryTHINGS[15]	VLA	38	26
Ursa Major Cluster[16]	WSRT	42	26
HIX[17]	ATCA	23	25
SAURON[18]	WSRT	10	23
LSB Galaxies[19]	VLA, WSRT	32	22
FIGGS[20]	GMRT	22	22
THINGS[21]	VLA	33	22
Starburst Dwarfs[22]	VLA, WSRT	18	14
MeerKAT Fornax Cluster[23]	MeerKAT	2	3
Individual studies	Arecibo, ATCA, VLA, WSRT	46	97
Total		7914	3882

Notes: [1]Adams et al. (2022); Hess et al. (in prep.), [2]Koribalski et al. (2020); Westmeier et al. (2022); Deg et al. (2022), [3]Swaters et al. (2002), [4]Serra et al. (2012), [5]Wang et al. (2013), [6]Ramatsoku et al. (2016), [7]Jones et al. (2023), [8]Koribalski et al. (2018), [9]Chung et al. (2009), [10]Kreckel et al. (2012), [11]Heald et al. (2011), [12]Sun et al. (2020), [13]Hunter et al. (2012), [14]Richards et al. (2016, 2018), [15]Chiang et al. (2024), [16]Verheijen (2001), [17]Lutz et al. (2018), [18]Morganti et al. (2006), [19]van der Hulst et al. (1993); de Blok et al. (1996); Pickering et al. (1997); Trachternach et al. (2009), [20]Begum et al. (2008), [21]Walter et al. (2008), [22]Lelli et al. (2014), [23]Serra et al. (2023)

3. All-sky distribution and distances

Figure 1 shows the all-sky distribution of the BIG-SPARC galaxies in equatorial coordinates, where the gray band indicates the disk of the Milky Way. The galaxies are color-coded based on the telescopes that obtained their HI data. In general, the northern hemisphere is covered more densely than the southern one, which is mainly an effect of the Westerbork Synthesis Radio Telescope (WSRT) and its upgraded version APERTIF. Compared to WSRT, the Very Large Array (VLA) reaches lower declinations and connects with the coverage of the Australia Telescope Compact Array (ATCA) and the Australian SKA Pathfinder (ASKAP) in the south.

Figure 2 shows the systemic velocity histogram of the BIG-SPARC galaxies in red and that of the first SPARC database in blue. Compared to SPARC, BIG-SPARC provides an order-of-magnitude improvement in sample size. On the upper axis, we show the Hubble distances calculated with $H_0 = 75\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ (Tully et al. 2016). While the farthest galaxy in SPARC, NGC 6195, has a distance of $\sim$128 $\mathrm{Mpc^{-1}}$, BIG-SPARC reaches distances almost twice as large. The final BIG-SPARC database will contain direct distance measurements taken from the Cosmicflows-4 database (Tully et al. 2023) where available and Hubble distances in the remaining cases.

4. Outlook

The kinematic fits to the BIG-SPARC galaxies will be performed with the `3DFIT` task of ^{3D}Barolo. Two extreme examples are shown in Fig. 3: a well resolved spiral galaxy from

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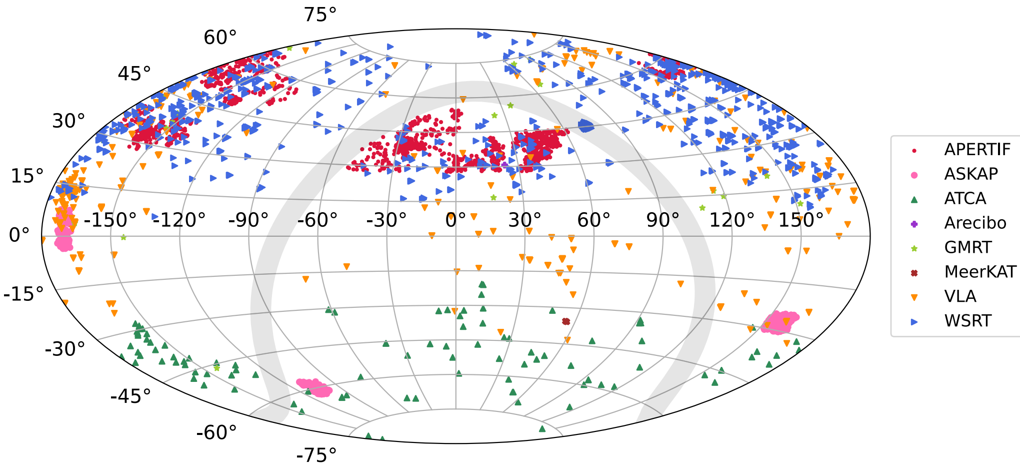

Figure 1. All-sky distribution of BIG-SPARC galaxies, color-coded by the telescopes that obtained their HI data. The gray band indicates the disk of the Milky Way.

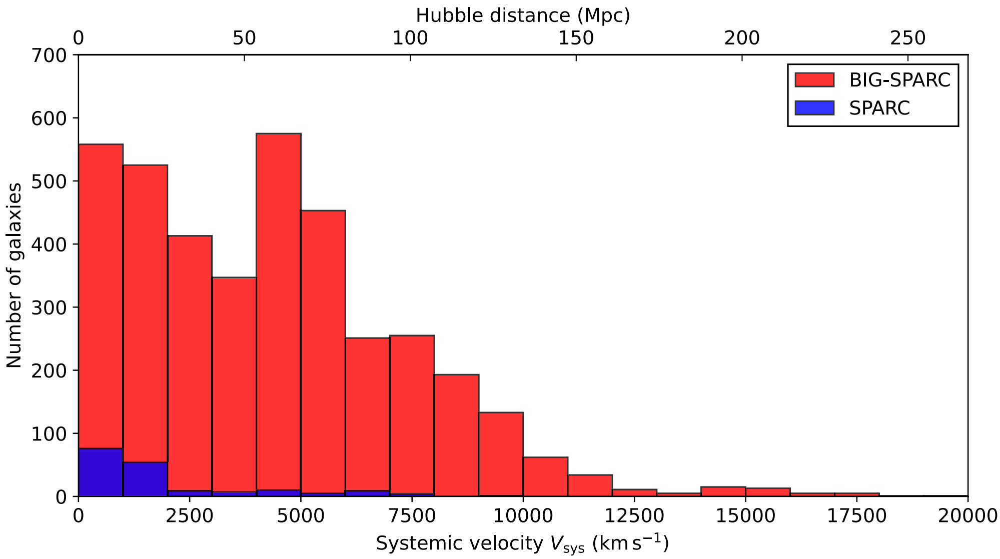

Figure 2. Systemic velocities of BIG-SPARC galaxies (red histogram) compared to those of SPARC (blue histogram). The upper axis shows the corresponding Hubble distances.

THINGS (NGC 3198) and a poorly resolved dwarf galaxy from Atlas^{3D} (AGC 740301). The fit outputs highlight one of the main advantages of ^{3D}Barolo, namely its ability to produce reasonable kinematic models for diverse data qualities. In addition, to allow the calculation of baryonic mass models, BIG-SPARC will contain NIR surface photometry wherever available. Since *Spitzer* imaging is available for only a fraction of the BIG-SPARC galaxies, we will also exploit *WISE* W1 photometry, which has full sky coverage (Duey et al. 2024, in prep.).

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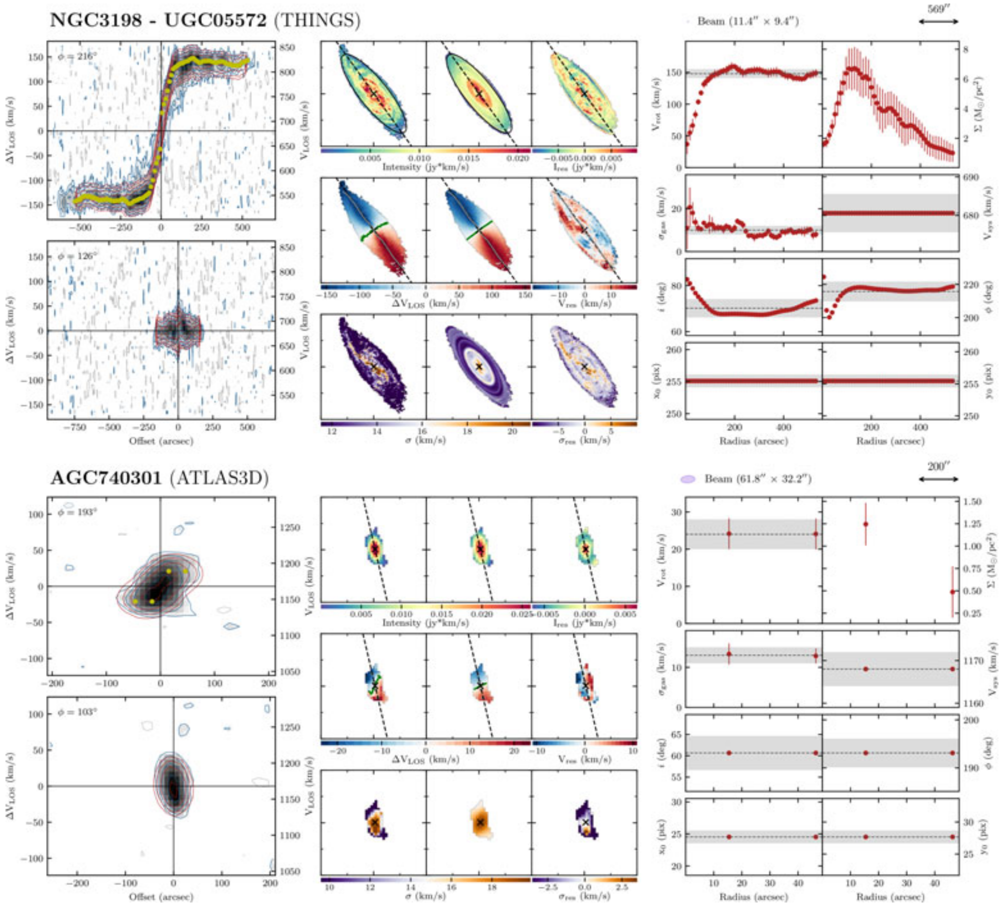

Figure 3. Outputs of `3DFIT` for two BIG-SPARC galaxies: NGC 3198 (*upper panel*, well resolved) and AGC 740301 (*lower panel*, poorly resolved). The left column shows position-velocity diagrams along the galaxies' major and the minor axes. The middle column shows moment-0, -1, and -2 maps from observations (left), best-fit models (middle), and residuals (right). The right column shows best-fit parameters at different radii R (from left to right and top to bottom): rotation velocity $V_{\rm rot}$, HI surface density Σ, velocity dispersion $\sigma_{\rm gas}$, systemic velocity $V_{\rm sys}$, inclination i, position angle ϕ, and coordinates of the kinematic center (x_0, y_0).

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