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`galkin`: A new compilation of Milky Way rotation curve data

Miguel Pato [a,*], Fabio Iocco [b]

[a] *The Oskar Klein Centre for Cosmoparticle Physics, Department of Physics, Stockholm University, AlbaNova, SE-106 91 Stockholm, Sweden*

[b] *ICTP South American Institute for Fundamental Research, and Instituto de Física Teórica - Universidade Estadual Paulista (UNESP), Rua Dr. Bento Teobaldo Ferraz 271, 01140-070 São Paulo, SP, Brazil*

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ABSTRACT

We present `galkin`, a novel compilation of kinematic measurements tracing the rotation curve of our Galaxy together with a tool to treat the data. The compilation is optimised to Galactocentric radii between 3 and 20 kpc and includes the kinematics of gas, stars and masers in a total of 2780 measurements carefully collected from almost four decades of literature. A simple, user-friendly tool is provided to select, treat and retrieve the full database.

Code metadata

Current code version	v1.0
Permanent link to code/repository used for this code version	https://github.com/ElsevierSoftwareX/SOFTX-D-16-00063
Legal Code License	GNU General Public License 3
Code versioning system used	Git
Software code languages, tools, and services used	Python
Compilation requirements, operating environments & dependencies	Python packages: matplotlib, numpy, wx (when using the graphic interface, see Section 3), astropy (if desired by the user, see Section 2.1)
If available Link to developer documentation/manual	None
Support email for questions	galkin.tool.mw@gmail.com

1. Motivation and significance

The rotation curve of a spiral galaxy provides far-reaching insight into its properties, as noticeably explored for decades now (see e.g. Refs. [1–5]). Data on the rotation curve of the Milky Way – a spiral itself – have also been available for several decades [6–11]. However, the data are rather disperse throughout the literature and groups of references are often neglected. We therefore set out to assemble a comprehensive compilation of the decades-long observational effort to pinpoint the rotation curve of the Milky Way. The compilation improves upon existing ones (e.g. Refs. [12,13]) on several aspects, including most notably: (i) an enlarged database of observations appropriately treated for unified use, and (ii) the release of a simple out-of-the-box tool to retrieve the data.[1] This compilation has been first used in Ref. [14] and later adopted in other works in the literature — see Section 4 for more on the impact of `galkin`. Without venturing into any analysis of the Galactic structure or dynamics (as done in `galpy` [15]), here we provide instead a thorough description of the data sets as well as the features of an out-of-the-box tool to access the database and output the desired data for independent analyses. The open source code provided is simple, flexible and can be easily modified to include new data sets or other types of measurements. The latter feature is particularly relevant on the eve of the precision era soon to be introduced by the Gaia satellite [16] and an array of optical and near-infrared ground-based surveys such as APOGEE-2 [17,18], GALAH [19], WEAVE [20] and 4MOST [21]. Our compilation can be regarded as a step forward in unifying the current state of the art, yet it is certainly susceptible of further

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* Corresponding author.
E-mail address: migpato@gmail.com (M. Pato).

[1] To download your copy of `galkin`, please refer to our GitHub page github.com/galkintool/galkin or contact us at galkin.tool.mw@gmail.com.

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Table 1
The list of all kinematic measurements of the Milky Way included in `galkin`. For each reference, the range of Galactocentric radius is reported assuming $R_0 = 8$ kpc along with the Galactic quadrant(s) covered and the number of tracers selected out of the total original samples. In this context, the term "tracers" denotes observed objects or regions (i.e. terminal points, clouds, clusters, stars or masers) which allow for a measurement of the rotation curve of the Galaxy. For the sources signalled with †, in addition to the line-of-sight velocities, we also process the measured proper motions.

	Tracer type	R [kpc]	Quadrants	Tracers
Gas kinematics	HI terminal velocities			
	Fich+ '89 [10]	2.1–8.0	1, 4	149/149
	Malhotra '95 [22]	2.1–7.5	1, 4	110/110
	McClure-Griffiths & Dickey '07 [23]	2.8–7.6	4	701/761
	HI thickness method			
	Honma & Sofue '97 [24]	6.8–20.2	–	13/13
	CO terminal velocities			
	Burton & Gordon '78 [7]	1.4–7.9	1	284/284
	Clemens '85 [8]	1.9–8.0	1	143/143
	Knapp+ '85 [9]	0.6–7.8	1	37/37
	Luna+ '06 [25]	2.0–8.0	4	272/457
	HII regions			
	Blitz '79 [6]	8.7–11.0	2, 3	3/3
	Fich+ '89 [10]	9.4–12.5	3	5/104
	Turbide & Moffat '93 [26]	11.8–14.7	3	5/8
	Brand & Blitz '93 [27]	5.2–16.5	1, 2, 3, 4	148/206
	Hou+ '09 [28]	3.5–15.5	1, 2, 3, 4	274/815
	Giant molecular clouds			
	Hou+ '09 [28]	6.0–13.7	1, 2, 3, 4	30/963
Star kinematics	Open clusters †			
	Frinchaboy & Majewski '08 [29]	4.6–10.7	1, 2, 3, 4	60/71
	Planetary nebulae			
	Durand+ '98 [30]	3.6–12.6	1, 2, 3, 4	79/867
	Classical cepheids			
	Pont+ '94 [11]	5.1–14.4	1, 2, 3, 4	245/278
	Pont+ '97 [31]	10.2–18.5	2, 3, 4	32/48
	Carbon stars			
	Demers & Battinelli '07 [32]	9.3–22.2	1, 2, 3	55/103
	Battinelli+ '13 [33]	12.1–24.8	1, 2	35/36
Masers	Masers †			
	Reid+ '14 [34]	4.0–15.6	1, 2, 3, 4	80/103
	Honma+ '12 [35]	7.7–9.9	1, 2, 3, 4	11/52
	Stepanishchev & Bobylev '11 [36]	8.3	3	1/1
	Xu+ '13 [37]	7.9	4	1/30
	Bobylev & Bajkova '13 [38]	4.7–9.4	1, 2, 4	7/31

inclusions — please see our own extensive caveats and notes throughout the manuscript. We encourage the community to adopt `galkin` and participate in its extension as new data sets arise.

2. Software description

The `galkin` compilation has three main categories of data: (i) *gas kinematics*, including HI terminal velocities [10,22,23], HI thickness [24], CO terminal velocities [7–9,25], HII regions [6,10,26–28], and giant molecular clouds [28]; (ii) *star kinematics*, including open clusters [29], planetary nebulae [30], classical cepheids [11,31], and carbon stars [32,33]; and (iii) *masers* [34–38]. Table 1 recaps the key features of each data set. Appendix A gives a full account of our data selection and treatment for each reference listed in Table 1.

Our compilation consists of 2780 tracers distributed in Galactocentric radius R, Galactic longitude ℓ and height z above Galactic plane as shown in Fig. 1. Each object is specified by its coordinates (ℓ, b), heliocentric distance d and heliocentric line-of-sight velocity $v_{\rm h}^{\rm los}$. The uncertainties on ℓ and b are largely subleading and hence neglected, whereas the uncertainties on d and $v_{\rm h}^{\rm los}$ are taken from the original references (cf. details in Appendix A). In radio observations, it is customary to report measurements of $v_{\rm h}^{\rm los}$ in terms of the line-of-sight velocity in the local standard of rest (LSR) $v_{\rm lsr}^{\rm los}$ for a fixed peculiar solar motion $(U, V, W)_\odot$ (where the subscript $\odot$ denotes a solar value). In these cases, we infer $v_{\rm h}^{\rm los}$ by subtracting the peculiar solar motion used in the reference off the reported $v_{\rm lsr,0}^{\rm los}$ (cf. Appendix A). Once $v_{\rm h}^{\rm los}$ is obtained, this is summed to the adopted peculiar solar motion to get the final LSR line-of-sight velocity $v_{\rm lsr}^{\rm los}$. Each object has an associated measurement $(\ell, b, d \pm \Delta d, v_{\rm lsr}^{\rm los} \pm \Delta v_{\rm lsr}^{\rm los})$. The corresponding Galactocentric radius follows from simple geometry as

$$R = (d^2 \cos^2 b + R_0^2 - 2R_0 d \cos b \cos \ell)^{1/2}, \tag{1}$$

where R_0 is the distance of the Sun to the Galactic centre. Under the assumption of circular orbits, the angular circular velocity of the object ω_c is found by inverting

$$v_{\rm lsr}^{\rm los} = (R_0\omega_c - v_0) \cos b \sin \ell, \tag{2}$$

where v_0 is the local circular velocity. The uncertainties on d and $v_{\rm lsr}^{\rm los}$ are propagated to R and ω_c, respectively. We shall also provide the familiar circular velocity $v_c \equiv R\omega_c$ and corresponding uncertainties, but note that the errors of R and v_c are strongly positively correlated, while those of R and ω_c are independent. All uncertainties currently implemented in `galkin` are symmetric following the information available in each reference; future data might provide the full distribution of observables, which would then be treated in upcoming versions of `galkin` and would be of great value for Bayesian studies. The procedure described above is common to all object types in Table 1, with some modifications in two cases. For terminal velocities, we set $b = 0$ and $R = R_0|\sin \ell|$ (or, equivalently, $d = R_0|\cos \ell|$) in Eqs. (1) and (2), and each measurement reads $(\ell, v_{\rm lsr}^{\rm los} \pm \Delta v_{\rm lsr}^{\rm los})$. For the HI thickness method, the measured quantity is $W \equiv R_0\omega_c - v_0$ instead of $v_{\rm lsr}^{\rm los}$, so each data point is defined by $(R/R_0 \pm \Delta R/R_0, W \pm \Delta W)$, cf. Refs. [24,40]. We also process the proper motions $\mu_{\ell *}, \mu_b$