Spatial motion of the Magellanic Clouds – tidal models ruled out?

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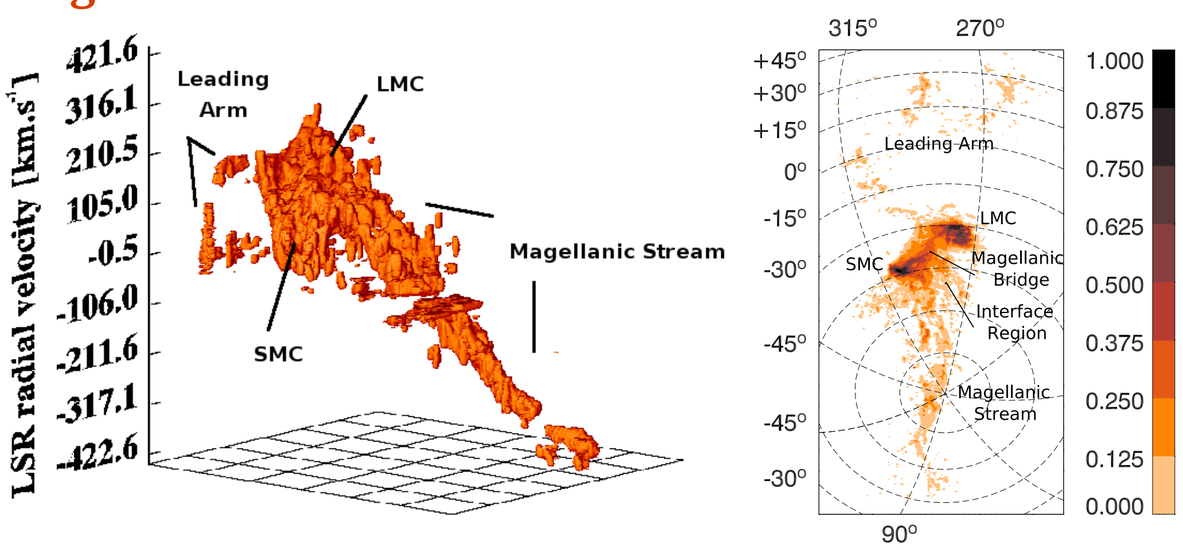
ABSTRACT. Recently, Kallivayalil et al. derived new values of the proper motion (PM) for the Large and Small Magellanic Clouds (LMC and SMC, respectively). The spatial velocities of both Clouds are unexpectedly higher than their previous values resulting from agreement between the available theoretical models and the observations of neutral hydrogen (H I) associated with the LMC and the SMC. Such PM estimates do not seem to conflict with the widely accepted ΛCDM cosmology, but they are likely to be at odds with the scenarios for creation of the large–scale structures in the Magellanic System suggested so far. We investigated this hypothesis for the tidal models, as they were the first ones devised to explain the evolution of the Magellanic System, and the tidal stripping is intrinsically involved in every model assuming the gravitational interaction. The entire parameter space for the Magellanic interaction (*over 20 independent parameters*) was analyzed by a robust search algorithm (genetic algorithm, GA) combined with a fast restricted 3 D N–body model of the interaction involving a flattened dark matter halo of the Milky Way (MW). Our method substantially extended the known variety of evolutionary scenarios satisfying the observed kinematics and morphology of the Magellanic structures, including the Magellanic Stream and the Leading Arm. Nevertheless, assuming the tidal interaction, no satisfactory reproduction of the H I data available for the Magellanic Clouds was achieved for the new PMs. We conclude that for the PM data by Kallivayalil et al., the dynamical evolution of the Magellanic System cannot be explained within the framework of pure tidal models.

Magellanic Clouds

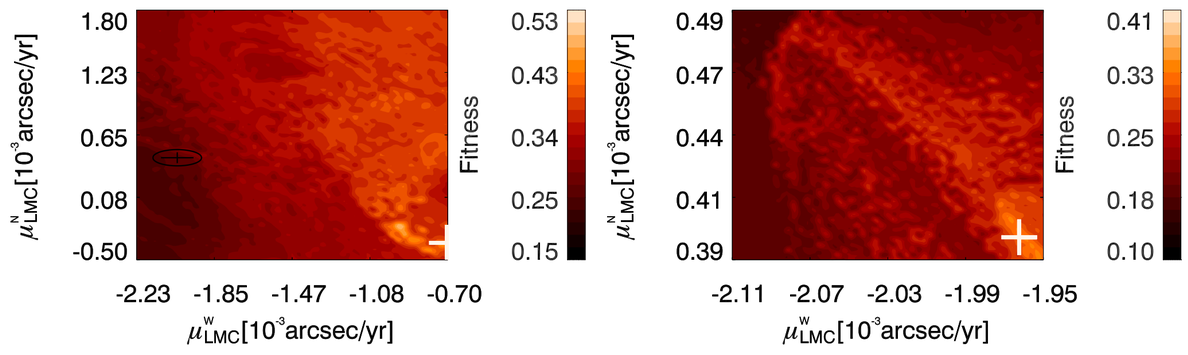


Left plot: The figure depicts the original 3 D H I data cube of the Magellanic System by Brüns et al. (2005); we offer 3 D visualization of the column density isosurface $\Sigma_{\mathrm{HI}} = 0.2 \cdot 10^{18}\,\mathrm{cm}^{-2}$. Right plot: Contour map of the observed H I integrated relative column density in the Magellanic System. Data by Brüns et al. (2005) is projected on the plane of sky. Galactic coordinates are used.

Evolutionary search – Fitness function

The GA is driven by the **fitness function** (F) comparing the modeled and observed H I distribution (Brüns et al., 2005) and returning a floating–point number between 0 (complete disagreement) and 1 (perfect match). Fitness is a function of all input parameters, since every parameter set determines the resulting simulated H I data–cube. The F consists of three different comparisons, including search for structures and analysis of local kinematics.

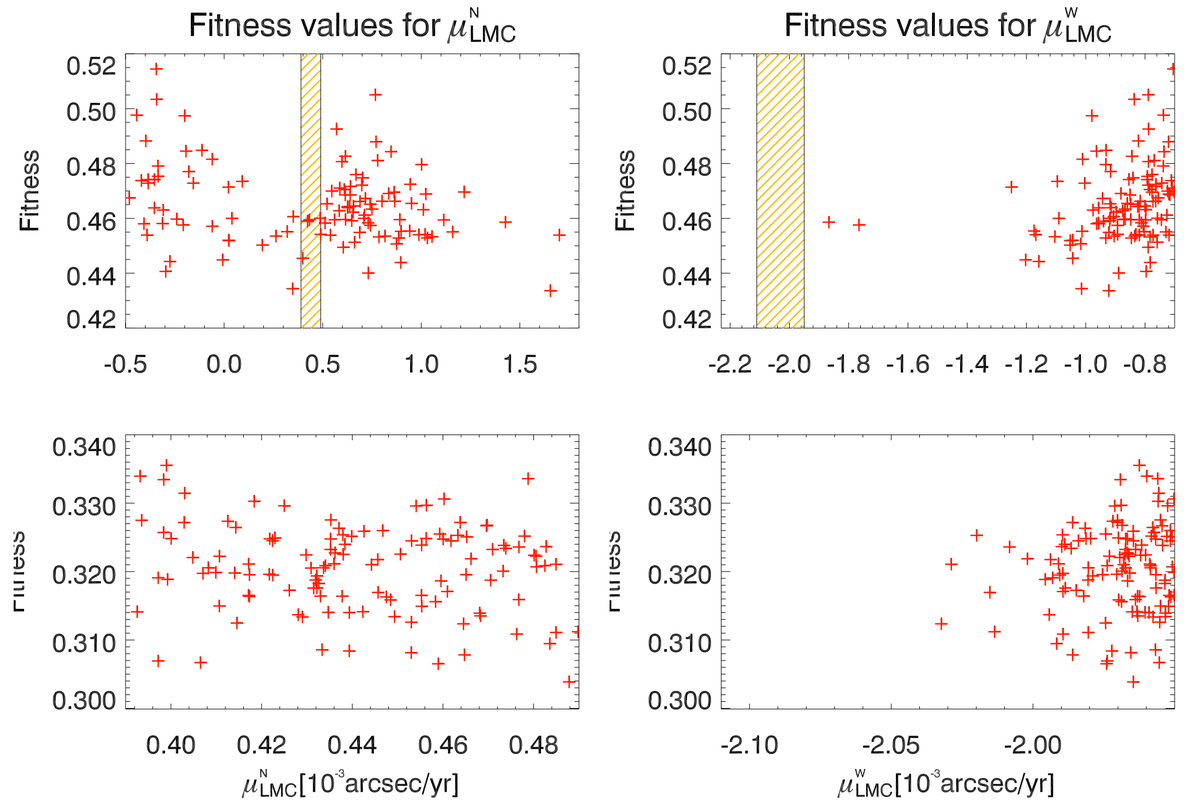
In terms of the fitness function, no model of $\mathrm{F} \lesssim 0.4$ can be considered successful, as it always fails to reproduce the Magellanic Stream in its projected angular length, LSR radial velocity profile and the estimated total mass.



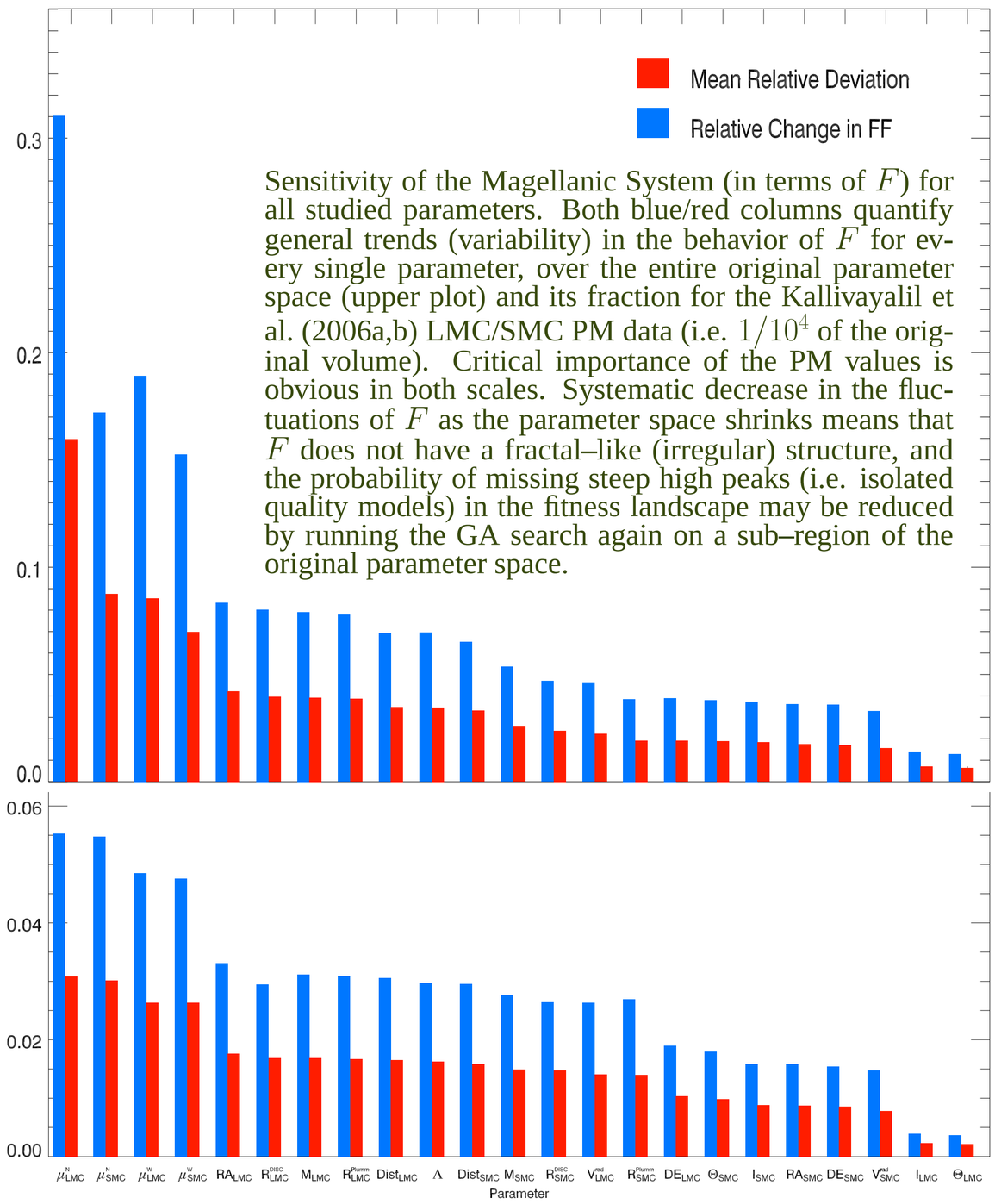
The ($\mu_{\mathrm{N}}^{\mathrm{LMC}}$, $\mu_{\mathrm{W}}^{\mathrm{LMC}}$)–planes for the 2 D projections of the function F. For the moment, the remaining parameters are fixed to the values corresponding to the best models for the original (left plot) or the reduced PM ranges, respectively. The best models are marked by the white crosses. The black ellipse in the left plot indicates the LMC PM by Kallivayalil et al. (2006a) and roughly corresponds to the entire ($\mu_{\mathrm{N}}^{\mathrm{LMC}}$, $\mu_{\mathrm{W}}^{\mathrm{LMC}}$)–plane depicted in the right plot.

The parameter space includes:
spatial coordinates of the Clouds (RA, DE, $Dist$), their velocity (μ_{N}, μ_{W}, V_{rad}), LMC/SMC particle disk inclination, position angle and radius (I, Θ, R^{disk}), LMC/SMC halo scale–lenght (R^{Plumm}), LMC/SMC total mass (M), MW halo flattening (q), and the Coulomb logarithm for MW–LMC/SMC dynamical friction (Λ)

With the use of GA, $\approx 10^6$ parameter combinations were tested in total, and 120 sets providing quality reproduction of the H I Magellanic large–scale structures were collected:



Distribution of all GA fits of the Magellanic System over the analyzed ranges for the LMC PM components $\mu_{\mathrm{N}}^{\mathrm{LMC}}$ and $\mu_{\mathrm{W}}^{\mathrm{LMC}}$. The upper row presents the low–resolution search of the original volume of the parameter space. The color–filled areas indicate the PM intervals by Kallivayalil et al. (2006a,b) studied subsequently. The resulting distribution of the 120 identified GA fits is depicted in the lower row.
No model of $\mathrm{F} > 0.35$ was identified for the PM by Kallivayalil et al. (2006a).



Sensitivity of the Magellanic System (in terms of F) for all studied parameters. Both blue/red columns quantify general trends (variability) in the behavior of F for every single parameter, over the entire original parameter space (upper plot) and its fraction for the Kallivayalil et al. (2006a,b) LMC/SMC PM data (i.e. $1/10^4$ of the original volume). Critical importance of the PM values is obvious in both scales. Systematic decrease in the fluctuations of F as the parameter space shrinks means that F does not have a fractal–like (irregular) structure, and the probability of missing steep high peaks (i.e. isolated quality models) in the fitness landscape may be reduced by running the GA search again on a sub–region of the original parameter space.

References

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