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От Сильченко О.К.

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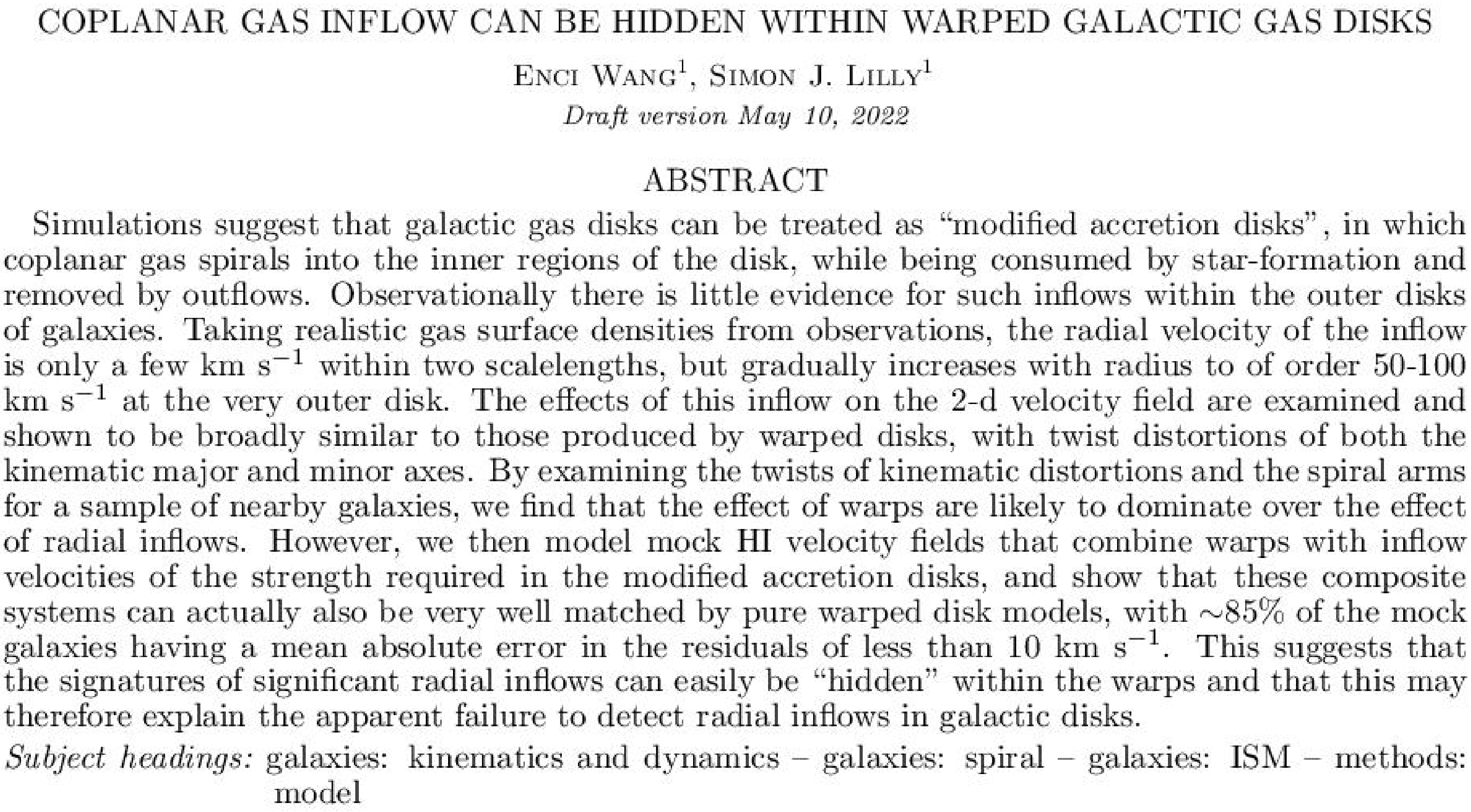

COPLANAR GAS INFLOW CAN BE HIDDEN WITHIN WARPED GALACTIC GAS DISKS

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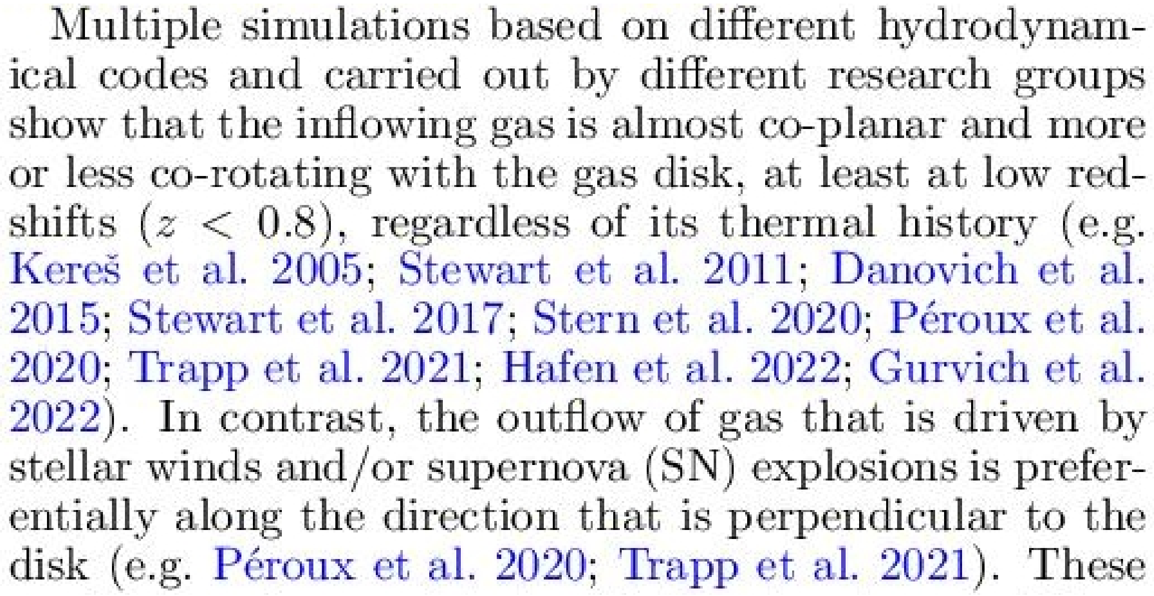
ABSTRACT

Simulations suggest that galactic gas disks can be treated as "modified accretion disks", in which coplanar gas spirals into the inner regions of the disk, while being consumed by star-formation and removed by outflows. Observationally there is little evidence for such inflows within the outer disks of galaxies. Taking realistic gas surface densities from observations, the radial velocity of the inflow is only a few km s^{-1} within two scalelengths, but gradually increases with radius to of order 50-100 km s^{-1} at the very outer disk. The effects of this inflow on the 2-d velocity field are examined and shown to be broadly similar to those produced by warped disks, with twist distortions of both the kinematic major and minor axes. By examining the twists of kinematic distortions and the spiral arms for a sample of nearby galaxies, we find that the effect of warps are likely to dominate over the effect of radial inflows. However, we then model mock HI velocity fields that combine warps with inflow velocities of the strength required in the modified accretion disks, and show that these composite systems can actually also be very well matched by pure warped disk models, with ~85% of the mock galaxies having a mean absolute error in the residuals of less than 10 km s^{-1}. This suggests that the signatures of significant radial inflows can easily be "hidden" within the warps and that this may therefore explain the apparent failure to detect radial inflows in galactic disks.

Subject headings: galaxies: kinematics and dynamics – galaxies: spiral – galaxies: ISM – methods: model

А мужики-то и не знали…



Multiple simulations based on different hydrodynamical codes and carried out by different research groups show that the inflowing gas is almost co-planar and more or less co-rotating with the gas disk, at least at low redshifts ($z < 0.8$), regardless of its thermal history (e.g. Kereš et al. 2005; Stewart et al. 2011; Danovich et al. 2015; Stewart et al. 2017; Stern et al. 2020; Péroux et al. 2020; Trapp et al. 2021; Hafen et al. 2022; Gurvich et al. 2022). In contrast, the outflow of gas that is driven by stellar winds and/or supernova (SN) explosions is preferentially along the direction that is perpendicular to the disk (e.g. Péroux et al. 2020; Trapp et al. 2021). These

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2.2. *The inflow velocity required by the MAD model*

The radial velocity of co-planar inflowing gas can be written as:

$$v_{\rm r} = \frac{\Phi(r)}{2\pi r \Sigma_{\rm gas}(r)}. \qquad (1)$$

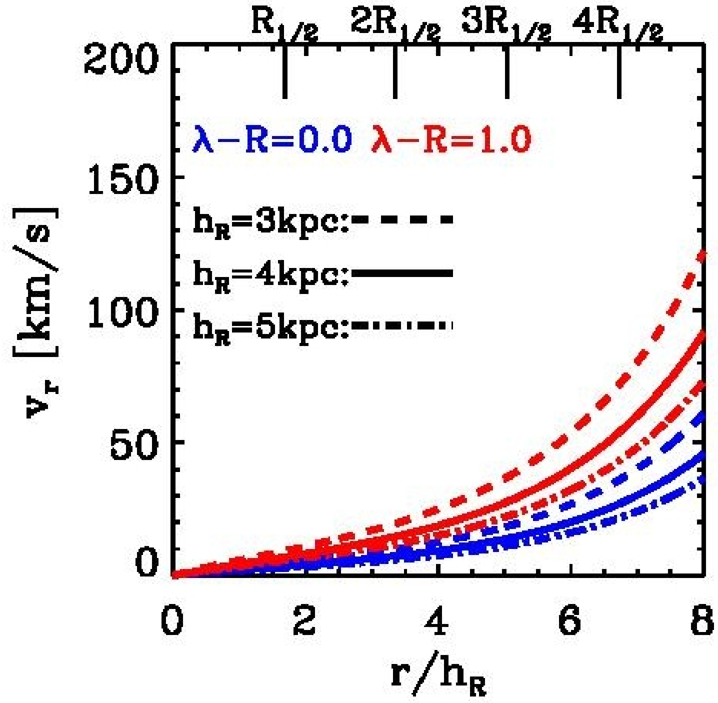
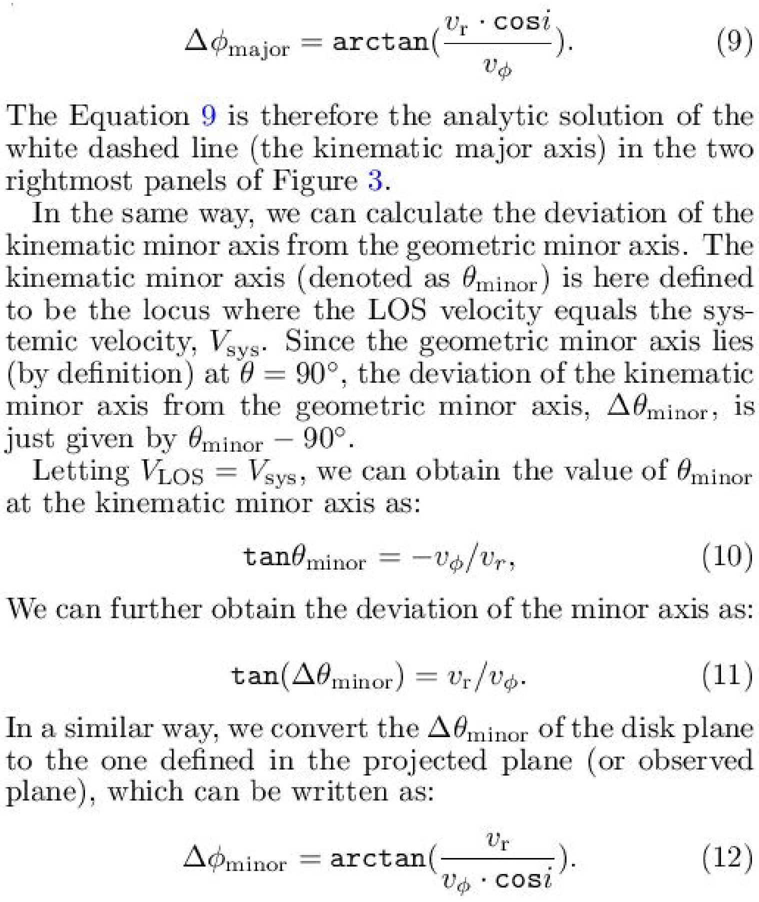


FIG. 1.— The required radial inflow velocity as a function of radius for a typical disk galaxy of $M_* = 3 \times 10^{10} {\rm M}_\odot$ in the MAD framework. Different colors indicate two different mass-loading factors, λ, and the three different line-styles indicate different exponential scale-lengths assumed for this galaxy. The $h_{\rm R}$-dependence of the radial inflow velocity follows from Equation 1, provided that the assumed $\Sigma_{\rm gas}$ is only a function of $r/h_{\rm R}$ (see Equation 4).

Упражнение на проекцию



$$\Delta\phi_{\mathrm{major}} = \mathtt{arctan}(\frac{v_{\mathrm{r}} \cdot \mathtt{cos}i}{v_{\phi}}). \tag{9}$$

The Equation 9 is therefore the analytic solution of the white dashed line (the kinematic major axis) in the two rightmost panels of Figure 3.

In the same way, we can calculate the deviation of the kinematic minor axis from the geometric minor axis. The kinematic minor axis (denoted as θ_{minor}) is here defined to be the locus where the LOS velocity equals the systemic velocity, V_{sys}. Since the geometric minor axis lies (by definition) at $\theta = 90°$, the deviation of the kinematic minor axis from the geometric minor axis, $\Delta\theta_{\mathrm{minor}}$, is just given by $\theta_{\mathrm{minor}} - 90°$.

Letting $V_{\mathrm{LOS}} = V_{\mathrm{sys}}$, we can obtain the value of θ_{minor} at the kinematic minor axis as:

$$\mathtt{tan}\theta_{\mathrm{minor}} = -v_{\phi}/v_{r}, \tag{10}$$

We can further obtain the deviation of the minor axis as:

$$\mathtt{tan}(\Delta\theta_{\mathrm{minor}}) = v_{\mathrm{r}}/v_{\phi}. \tag{11}$$

In a similar way, we convert the $\Delta\theta_{\mathrm{minor}}$ of the disk plane to the one defined in the projected plane (or observed plane), which can be written as:

$$\Delta\phi_{\mathrm{minor}} = \mathtt{arctan}(\frac{v_{\mathrm{r}}}{v_{\phi} \cdot \mathtt{cos}i}). \tag{12}$$

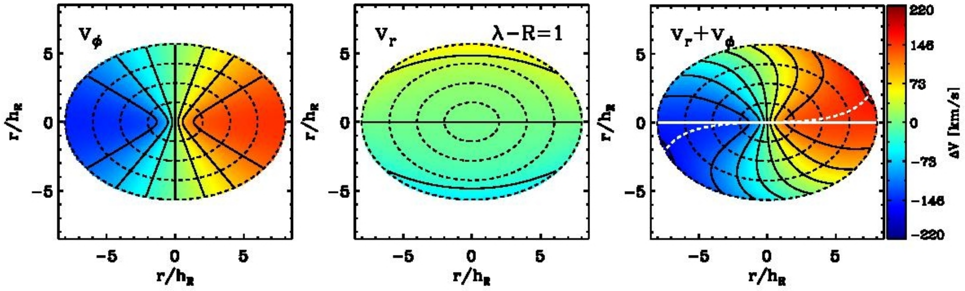


FIG. 3.— The LOS velocity map of the typical Main Sequence galaxy shown in Figure 2 as seen at an inclination (INC) of 45 degree. The upper and lower row of panels assume $\lambda - R = 0$ and $\lambda - R = 1$, respectively (the latter requiring higher inflow velocities). In each row, the leftmost panel shows the contribution of the circular motion, i.e. v_{ϕ}, and the middle panel shows the contribution of the radial motion, i.e. v_{r}. The rightmost panel shows the "observed" LOS velocity obtained by adding both v_{ϕ} and v_{r} components. In the rightmost panels, the white solid line shows the geometric major axis of this galaxy, while the white dashed line shows the kinematic major axis, defined as the locus of minimum/maximum projected velocity at each radius. In each panel, the black curves show iso-velocity contours with an interval of 40 km s^{-1}. The dashed elliptical lines indicate radii of $2h_{\mathrm{R}}$, $4h_{\mathrm{R}}$, $6h_{\mathrm{R}}$ and $8h_{\mathrm{R}}$.

Результаты мат. упражнений:

- Статистически, у всех спиральных галактик заметно искривлены внешние газовые диски.
- Геометрически, невозможно разделить по полю скоростей эффекты искривления диска и радиальные потоки газа (все модели с искривлением диска и радиальными потоками отлично фиттируются ТОЛЬКО искривлением диска).