# Galactic disc warps due to intergalactic accretion flows onto the disc

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Abstract. The accretion of the intergalactic medium onto the gaseous disc is used to explain the generation of galactic warps. A cup-shaped distortion is expected, due to the transmission of the linear momentum; but, this effect is small for most incident inflow angles and the predominant effect turns out to be the transmission of angular momentum, i.e. a torque giving an integralsign shaped warp. The torque produced by a flow of velocity ~ 100 km/s and baryon density ~  $10^{-25}$  kg/m<sup>3</sup>, which is within the possible values for the intergalactic medium, is enough to generate the observed warps and this mechanism offers quite a plausible explanation. The inferred rate of infall of matter, ~ 1 M<sub>☉</sub>/yr, to the Galactic disc that this theory predicts agrees with the quantitative predictions of chemical evolution resolving key issues, notably the G-dwarf problem.

Sánchez-Salcedo (2006) suggests that this mechanism is not plausible because it would produce a dependence of the scaleheight of the disc with the Galactocentric azimuth in the outer disc, but rather than being an objection this is another argument in favour of the mechanism because this dependence is actually observed in our Galaxy.

### 1. The mechanism

In López-Corredoira et al. (2002, hereafter LBB), we proposed a mechanism to explain the formation of warps (S-shaped or U-shaped or a combination of both) in spiral galaxies: the accretion of the intergalactic medium onto the disc. In a Milky-Way-like galaxy, the mean density of baryonic matter in the intergalactic medium needed to produce the observed warp is around  $10^{-25}$  kg/m<sup>3</sup> when the infall velocity at large distance is ~ 100 km/s (LBB). These numbers were confimed independently by Sánchez-Salcedo (2006). This hypothetical low density net flow is a very reasonable physical assumption and would explain why most spiral galaxies are warped. No massive halo is necessary nor are high values of magnetic fields nor satellite companions are necessary, and the presence of these elements would not modify qualitatively the present conclusions.

### 2. Why accretion onto the disc rather than into the halo?

If the halo axis were misaligned with respect to the disc axis due to the accretion of intergalactic matter into the disc, the disc would be torqued by the halo and this will give rise to warps too (Ostriker & Binney 1989). However, our opinion



Figure 1. Graphical representation of the orientation of the S-warp with respect to the velocity of incoming flow. The azimuthal angle  $\phi_W$  with maximum amplitude of the warp, which is not plotted, is the same as the azimuthal angle of  $\vec{e_0}$ .

is that our LBB mechanism is preferable. The direct accretion of matter by the disc is more plausible than the accretion by the halo because the low density of baryonic matter in the halo produces a very small friction to trap intergalactic flows. Moreover, there is no correlation between the amplitude of the warps and the mass of the halos (derived from rotation curves) (Castro-Rodríguez et al. 2002). The lenticular galaxies, which have discs with no gas, do not show warps (Sánchez-Saavedra et al. 2003). If the mechanism to produce warped discs were a purely gravitational interaction, such as the interaction halo-disc proposed by Ostriker & Binney (1989), it would not distinguish between gas and stars and lenticular might also have a warp. However, it seems that the gas in the disc plays an important role, in favour of our mechanism which requires the friction with the disc gas to trap the intergalactic matter, although other explanations in terms of lower mass of the halo in lenticulars are in fact possible.

Anyway, even if the accretion onto the halo were a possible mechanism, the continuous accretion of low metal gas onto the disc is also a fact (Tinsley 1980), so the mechanism proposed here can always act.

## 3. Different types of observations successfully explained by this hypothesis

The accretion of intergalactic flows with these characteristics gives rise to:

• Good agreement with the observations of the chemical evolution of the Milky Way by contributing  $\sim 1 \ M_{\odot}/yr$  of low metallicity gas to the disc (LBB). This turns out to be of the order of the accretion rate required to resolve the G-dwarf problem in our Galaxy (Tinsley 1980) as well as

explaining a number of phenomena of chemical evolution which require the long-term infall of low metallicity gas.

- The frequency of warps and its amplitude is dependent on environment (García-Ruiz et al. 2002). The most isolated galaxies are more frequently warped, although with less amplitude. It seems clear that warping is due to something related to the environment rather than to the intrinsic properties of the galaxies, to something which is not related with the proximity of other galaxies. The accretion of intergalactic matter onto the disc seems a good candidate to explain these observational facts.
- An older version of the present mechanism was proposed by Kahn & Woltjer (1959), but this was rejected because it predicted only cup-shaped (Ushape) warps. This is not a valid criticism anymore to the present model. Integral-shape (S-shape) warps with the amplitude and shape observed for instance in the Milky Way are reproduced by this theory as a consequence of the transmission of angular momentum (LBB). Even if the global angular momentum of the intergalactic medium is null, the redistribution of momentum in different rings of the galaxy due to the gravity produces a net torque in each ring (LBB). Figure 1 illustrates the relationship between the wind velocity and the S-shape warp.
- Rather than being a criticism, the fact that this scenario produces Ushaped warps is now an argument in its favour. U-shaped warps are explained by this mechanism due to a transmission of linear momentum (LBB), while the S-shaped warps are due to the transmission of angular momentum. LBB predict that the frequency of U-shaped warps should be lower than S-warps; only occurring when the flow is accreted from nearly polar directions (low angle with the rotational axis of the disc). This was corroborated with a different calculation method by Sánchez Salcedo (2006). This lower frequency of U-warps over S-warps is observed (García-Ruiz et al. 2002, Sánchez-Saavedra et al. 2003). The asymmetric cases can also be explained by the present theory as a combination of S-warps and U-warps (LBB; Saha & Jog 2006). Up to now there has not been any alternative explanation for the U-warps or the asymmetric warps.
- Sánchez-Salcedo (2006) raises the criticism that this mechanism is not plausible because it would produce a dependence of the scaleheight of the disc with the Galactocentric azimuth ( $\phi$ ; defined to be zero in the line Sungalactic center) in the outer disc. Rather than being an objection, however, it is another argument in favour of our model because this dependence is actually observed in our Galaxy: Voskes & Burton (2006, Fig. 15) and Levine et al. (2006, Fig. 5) have shown that the scaleheight of the outer disc (R > 20 kpc) is 2-3 times higher on average for  $0 < \phi < 180^{\circ}$  than for  $180^{\circ} < \phi < 360^{\circ}$ . This is in agreement with the expectations of our model: the wind comes from the direction of the southern warp,  $\phi \approx 270^{\circ}$  [to produce U-warp northwards which causes an smaller amplitude of the (S+U)-warp of the southern warp], so a higher pressure is expected for the region around the southern warp and consequently a lower thickness therein. This effect is expected to appear in the outer disc because here the

pressure dominates over the self-gravitation of the disc. Sánchez-Salcedo (2006) derived roughly a factor of 6 with our LBB mechanism between the minimum and maximum scaleheight at R = 22 kpc. There are differences as high as this in Levine et al. (2006, Fig. 4), but this factor might be somewhat lower for other reasons. For instance, it we take into account the response time  $(t_{response})$  of the disc and the rotation  $(\omega(R))$ : scaleheight corresponds to the average pressure between  $[\phi - \omega(R)t_{response}]$  and  $\phi$ . The fact that the intergalactic medium might not be continuous but with some clouds would change the factor. Also the variation of some free and unknown parameters such as the angle of the intergalactic flow with respect to the rotation axis of the galaxy ( $\theta_0$  in LBB) produce variations in the factor.

### 4. Conclusions

Several mechanisms can generate warps: intergalactic magnetic fields (Battaner et al. 1990), gravitational interaction with satellites, or with the halo misaligned by an accretion of intergalactic matter into it (Ostriker & Binney 1989); or our proposed mechanism in LBB of accretion of intergalactic flows onto the disc. This last option seems to offer a very plausible scenario: it is quantitatively consistent with many observations and works independently of other ingredients of galaxies and their structure. A key advantage of the LBB theory is that it explains facts like U-shaped warps or variations of scaleheight with azimuth which other theories do not explain.

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