# Stellar Bars in Spiral Galaxies Do Not Slow Down

Elongated bar-like features are ubiquitous, occurring at the centers of approximately two-thirds of spiral disk galaxies [1, 2]. Due to gravitational interactions between the bar and the other components of galaxies, it is expected that angular momentum and matter will redistribute between galactic components over long (Gyr) timescales in galaxies hosting a bar [3–5]. Previous simulation work has overwhelmingly provided the expectation that the bar pattern will slow its rotation over time due to a drag caused by material in the dark matter halo on orbits resonant with the tumbling bar pattern [e.g. 6–15]. Simulations have shown that bars should shed enough angular momentum to be considered "slow rotators" in a few Gyr, but most observed galaxies seem to be "fast rotators" [16–18]. We have performed a simulation of an isolated galactic disk hosting a strong bar which includes a state-of-the-art model of the interstellar medium. In this simulation, the bar pattern does not slow down over time, and instead remains at a stable, constant rate of rotation. Since gas is torqued by the bar to fall towards the center of the galaxy, it acts to increase the angular momentum of the bar. However, the pattern speed we measure is nearly constant over many Gyr, suggesting a novel equilibrium mechanism is at play - we propose such a mechanism consistent with our simulation. First, a region of the halo phase space is carved out such that no resonant drag can occur. If the pattern speed decreases, the corotation radius becomes larger and so more gas is available for infall since only gas within corotation can infall [e.g. 19]. This speeds the bar up. If the pattern speed increases, new dark matter which is resonant with the bar becomes available, slowing the bar down. Thus, the pattern speed must remain constant. The implications of this are numerous. First, we resolve a long-standing controversy between the observed fast rotators and the theoretical expectation that bars should be slow. Second, we show that the role of gas is of paramount importance in studies which attempt to uncover the nature of dark matter from its effect of slowing down the bar [20, 21]. Third, we provide an explanation for how the Milky Way's bar could be both long-lived and a fast rotator, of which there is some observational evidence [e.g. 22]. And finally, we complicate the picture of radial mixing expected to sculpt the Milky Way's disk [e.g. 23, 24]. Our work is a significant advance in our understanding of the dynamics of barred galaxies.

# References

[1] Eskridge, P.B., Frogel, J.A., Pogge, R.W., Quillen, A.C., Davies, R.L., DePoy, D.L., Houdashelt, M.L., Kuchinski, L.E., Ramírez, S.V., Sellgren, K., Terndrup, D.M., Tiede, G.P.: The Frequency of Barred Spiral Galaxies in the Near-Infrared. AJ **119**(2), 536–544 (2000) https://arxiv.org/abs/astro-ph/9910479 [astro-ph]. https://doi.org/10.1086/301203

[2] Menéndez-Delmestre, K., Sheth, K., Schinnerer, E., Jarrett, T.H., Scoville, N.Z.: A Near-Infrared Study of 2MASS Bars in Local Galaxies: An Anchor for High-Redshift Studies. ApJ **657**(2), 790–804 (2007) https://arxiv.org/abs/astro-ph/0611540 [astro-ph]. https://doi.org/10.1086/511025

[3] Lynden-Bell, D., Kalnajs, A.J.: On the generating mechanism of spiral structure. MNRAS **157**, 1 (1972). https://doi.org/10.1093/mnras/157.1.1

[4] Tremaine, S., Weinberg, M.D.: Dynamical friction in spherical systems. MNRAS **209**, 729–757 (1984). https://doi.org/10.1093/mnras/209.4.729

[5] Weinberg, M.D.: Evolution of barred galaxies by dynamical friction. MNRAS **213**, 451–471 (1985). https://doi.org/10.1093/mnras/213.3.451

[6] Hernquist, L., Weinberg, M.D.: Bar-Spheroid Interaction in Galaxies. ApJ **400**, 80 (1992). https://doi.org/10.1086/171975

[7] Debattista, V.P., Sellwood, J.A.: Constraints from Dynamical Friction on the Dark Matter Content of Barred Galaxies. ApJ **543**(2), 704–721 (2000) https://arxiv.org/abs/astro-ph/0006275 [astro-ph]. https://doi.org/10.1086/317148

[8] Athanassoula, E., Misiriotis, A.: Morphology, photometry and kinematics of N -body bars - I. Three models with different halo central concentrations. MNRAS **330**(1), 35–52 (2002) https://arxiv.org/abs/astro-ph/0111449 [astro-ph]. https://doi.org/10.1046/j.1365-8711.2002.05028.x

[9] Athanassoula, E.: Bar-Halo Interaction and Bar Growth. ApJ **569**(2), 83–86 (2002) https://arxiv.org/abs/astro-ph/0203368 [astro-ph]. https://doi.org/10.1086/340784

[10] Athanassoula, E.: What determines the strength and the slowdown rate of bars? MNRAS **341**(4), 1179–1198 (2003) https://arxiv.org/abs/astro-ph/0302519 [astro-ph]. https://doi.org/10.1046/j.1365-8711.2003.06473.x

[11] O'Neill, J.K., Dubinski, J.: Detailed comparison of the structures and kinematics of simulated and observed barred galaxies. MNRAS **346**(1),

251–264 (2003) https://arxiv.org/abs/astro-ph/0305169 [astro-ph]. https://doi.org/10.1046/j.1365-2966.2003.07085.x

[12] Holley-Bockelmann, K., Weinberg, M., Katz, N.: Bar-induced evolution of dark matter cusps. MNRAS **363**(3), 991–1007 (2005) https://arxiv.org/abs/astro-ph/0306374 [astro-ph]. https://doi.org/10.1111/j.1365-2966.2005.09501.x

[13] Martinez-Valpuesta, I., Shlosman, I., Heller, C.: Evolution of Stellar Bars in Live Axisymmetric Halos: Recurrent Buckling and Secular Growth. ApJ **637**(1), 214–226 (2006) https://arxiv.org/abs/astro-ph/0507219 [astro-ph]. https://doi.org/10.1086/498338

[14] Weinberg, M.D., Katz, N.: The bar-halo interaction - II. Secular evolution and the religion of N-body simulations. MNRAS **375**(2), 460–476 (2007) https://arxiv.org/abs/astro-ph/0601138 [astro-ph]. https://doi.org/10.1111/j.1365-2966.2006.11307.x

[15] Dubinski, J., Berentzen, I., Shlosman, I.: Anatomy of the Bar Instability in Cuspy Dark Matter Halos. ApJ **697**(1), 293–310 (2009) https://arxiv.org/abs/0810.4925 [astro-ph]. https://doi.org/10.1088/0004-637X/697/1/293

[16] Corsini, E.M.: Direct measurements of bar pattern speeds. Memorie della Societa Astronomica Italiana Supplementi **18**, 23 (2011) https://arxiv.org/abs/1002.1245 [astro-ph.GA]

[17] Aguerri, J.A.L., Méndez-Abreu, J., Falcón-Barroso, J., Amorin, A., Barrera-Ballesteros, J., Cid Fernandes, R., García-Benito, R., García-Lorenzo, B., González Delgado, R.M., Husemann, B., Kalinova, V., Lyubenova, M., Marino, R.A., Márquez, I., Mast, D., Pérez, E., Sánchez, S.F., van de Ven, G., Walcher, C.J., Backsmann, N., Cortijo-Ferrero, C., Bland-Hawthorn, J., del Olmo, A., Iglesias-Páramo, J., Pérez, I., Sánchez-Blázquez, P., Wisotzki, L., Ziegler, B.: Bar pattern speeds in CALIFA galaxies. I. Fast bars across the Hubble sequence. A&A **576**, 102 (2015) https://arxiv.org/abs/1501.05498 [astro-ph.GA]. https://doi.org/10.1051/0004-6361/201423383

[18] Guo, R., Mao, S., Athanassoula, E., Li, H., Ge, J., Long, R.J., Merrifield, M., Masters, K.: SDSS-IV MaNGA: pattern speeds of barred galaxies. MNRAS **482**(2), 1733–1756 (2019) https://arxiv.org/abs/1810.03257 [astro-ph.GA]. https://doi.org/10.1093/mnras/sty2715

[19] Hopkins, P.F., Quataert, E.: An analytic model of angular momentum transport by gravitational torques: from galaxies to massive black holes. MNRAS **415**(2), 1027–1050 (2011) https://arxiv.org/abs/1007.2647 [astro-ph.CO]. https://doi.org/10.1111/j.1365-2966.2011.18542.x

[20] Chiba, R., Friske, J.K.S., Schönrich, R.: Resonance sweeping by a decelerating Galactic bar. MNRAS **500**(4), 4710–4729 (2021) https://arxiv.org/abs/1912.04304 [astro-ph.GA]. https://doi.org/10.1093/mnras/staa3585

[21] Chiba, R., Schönrich, R.: Tree-ring structure of Galactic bar resonance. MNRAS **505**(2), 2412–2426 (2021) https://arxiv.org/abs/2102.08388 [astro-ph.GA]. https://doi.org/10.1093/mnras/stab1094

[22] Bovy, J., Leung, H.W., Hunt, J.A.S., Mackereth, J.T., García-Hernández, D.A., Roman-Lopes, A.: Life in the fast lane: a direct view of the dynamics, formation, and evolution of the Milky Way's bar. MNRAS **490**(4), 4740–4747 (2019) https://arxiv.org/abs/1905.11404 [astro-ph.GA]. https://doi.org/10.1093/mnras/stz2891

[23] Bird, J.C., Kazantzidis, S., Weinberg, D.H.: Radial mixing in galactic discs: the effects of disc structure and satellite bombardment. MNRAS **420**(2), 913–925 (2012) https://arxiv.org/abs/1104.0933 [astro-ph.GA]. https://doi.org/10.1111/j.1365-2966.2011.19728.x

[24] Hayden, M.R., Bovy, J., Holtzman, J.A., Nidever, D.L., Bird, J.C., Weinberg, D.H., Andrews, B.H., Majewski, S.R., Allende Prieto, C., Anders, F., Beers, T.C., Bizyaev, D., Chiappini, C., Cunha, K., Frinchaboy, P., García-Herńandez, D.A., García Pérez, A.E., Girardi, L., Harding, P., Hearty, F.R., Johnson, J.A., Mészáros, S., Minchev, I., O'Connell, R., Pan, K., Robin, A.C., Schiavon, R.P., Schneider, D.P., Schultheis, M., Shetrone, M., Skrutskie, M., Steinmetz, M., Smith, V., Wilson, J.C., Zamora, O., Zasowski, G.: Chemical Cartography with APOGEE: Metallicity Distribution Functions and the Chemical Structure of the Milky Way Disk. ApJ **808**(2), 132 (2015) https://arxiv.org/abs/1503.02110 [astro-ph.GA]. https://doi.org/10.1088/0004-637X/808/2/132