Exploring the Dynamics of Neutral Halo Clouds in Galactic Rain Models

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Introduction

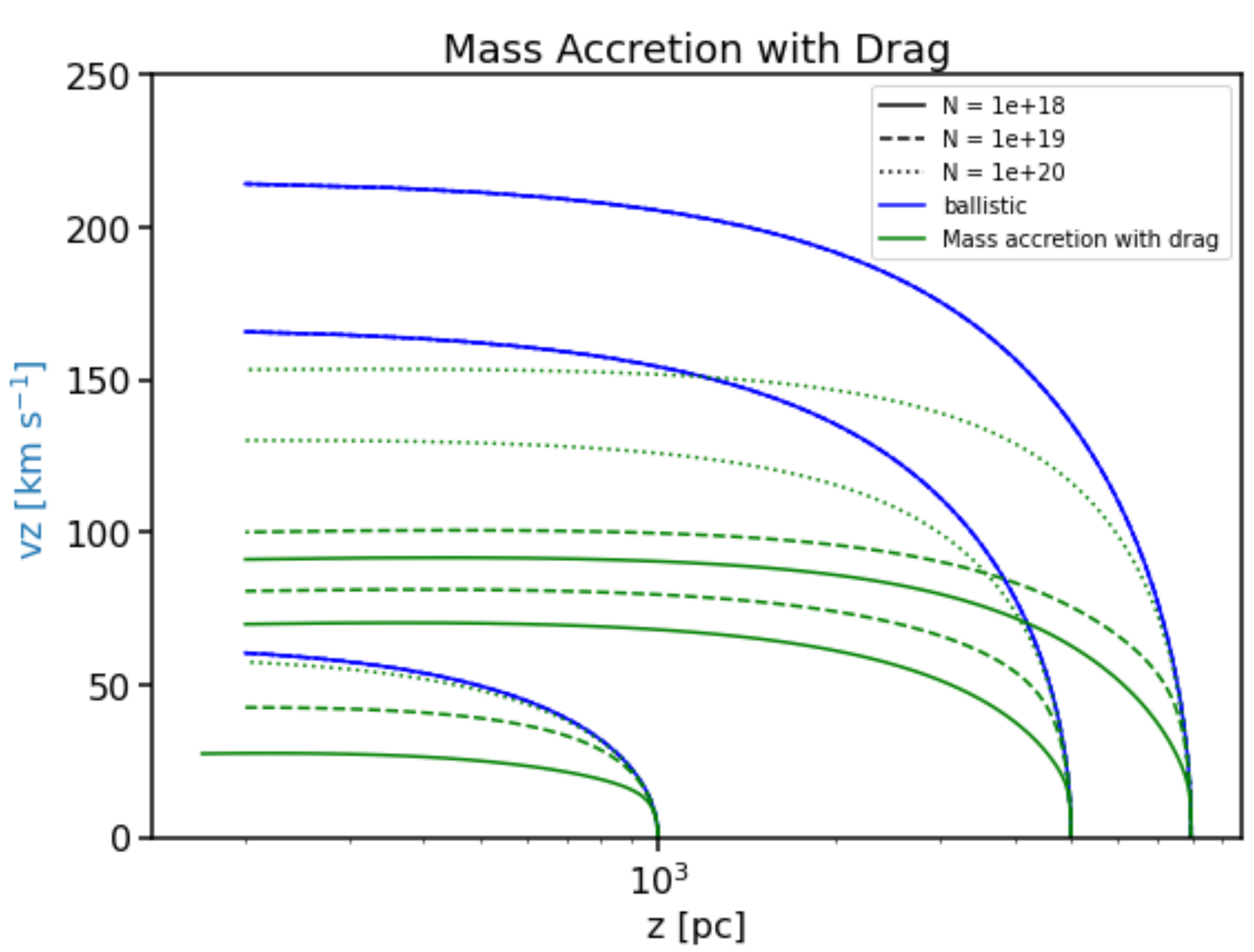
High-velocity clouds (HVCs) are fast-moving gas bodies that play a vital role in galaxy dynamics and evolution. Traditional galactic infall models, which presume ballistic motion, fail to capture the complex paths and effects of these clouds. This study aims to address these shortcomings by building upon Benjamin and Danly's (1997) work on drag-influenced terminal velocity in HVCs.

Objectives:

- remedy gaps in existing models
- enhance precision
- conduct a comparative analysis to understand broader implications.

Models Explored

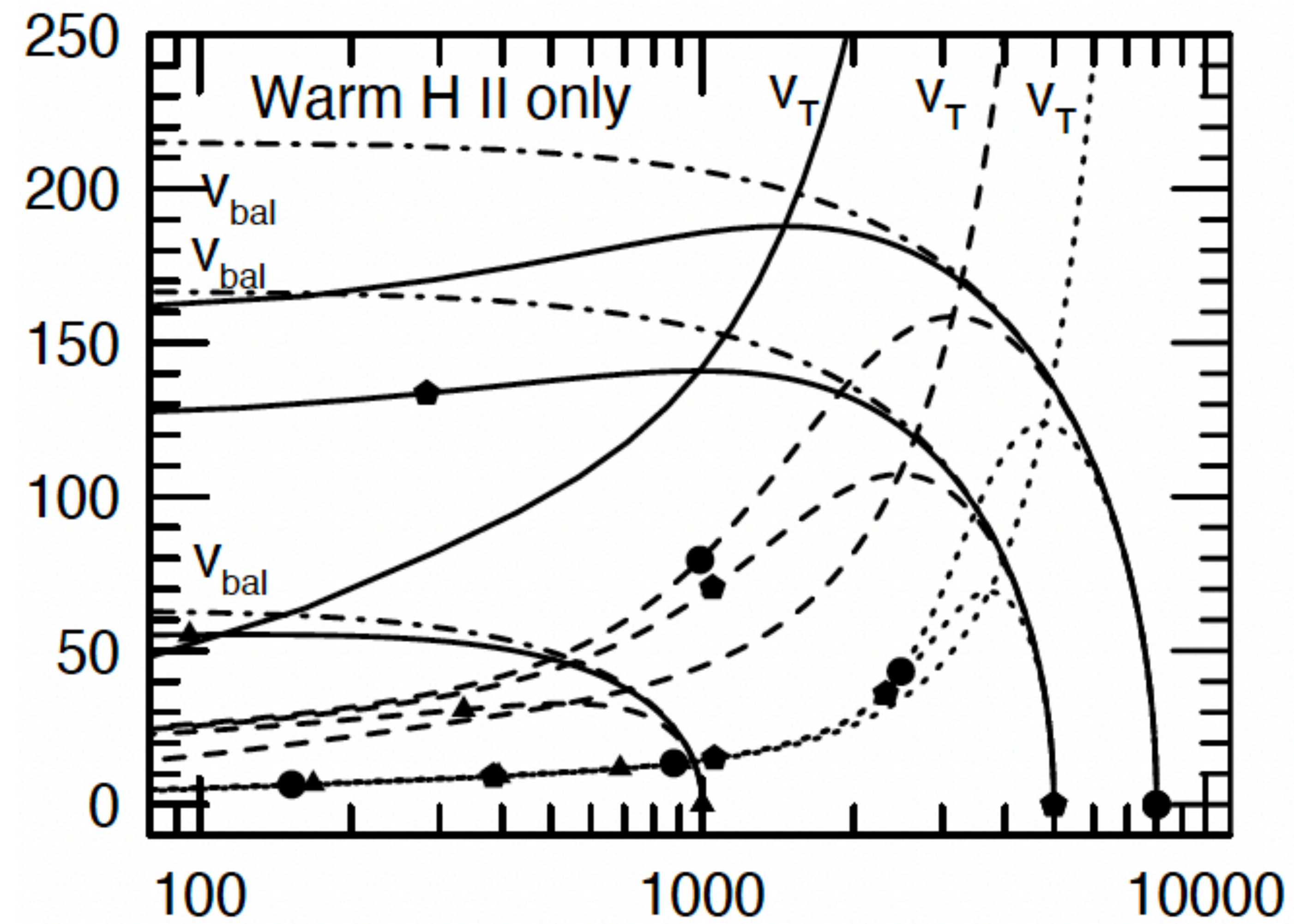
- Free fall (ballistic): $z = z_0 + v_0 t + \frac{1}{2} g t^2$
- Mass accretion: $\dot{v} = g - \frac{C m_0 \rho}{\mu N_c} \frac{v^2}{m}$
- Drag: $\dot{v} = g - \frac{C\rho}{\mu N_c} v^2$
- Mass accretion with drag: $\dot{v} = g - 2 \cdot \frac{C m_0 \rho}{\mu N_c} \frac{v^2}{m}$



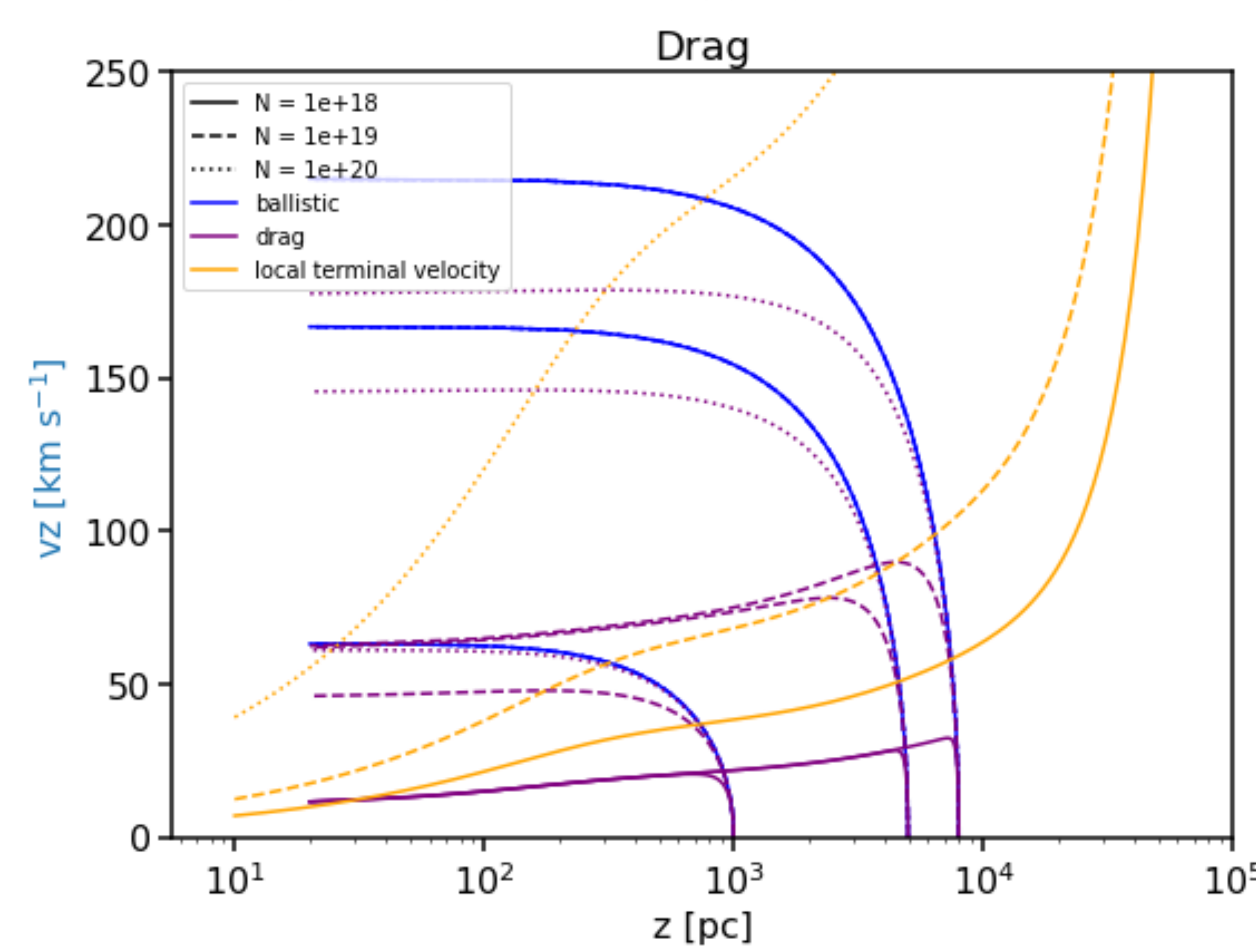
- *Trajectories show even lower peak velocities in denser settings than when each force acts alone*
- *Smoother velocity profiles with gradual increases and decreases*
- *Lower column densities are more significantly slowed down, suggesting that drag has a more substantial impact on less massive clouds.*
- *For higher column densities, the clouds' velocity increases less sharply, implying that the additional mass gained through accretion is somewhat counteracting the drag force.*
- *the velocities tend to stabilize as clouds approach the galactic plane, suggesting a controlled and steady approach towards the galactic disk.*
- *Combined reduce high initial velocities from greater altitudes, resulting in a steeper speed reduction and a safer, gradual integration into the galactic disk.*

Main Question

How do drag forces and mass accretion impact the dynamics and terminal velocity of HVCs within the galactic infall model, and how do these results compare with previous models (Benjamin and Danly, 1997) that consider only drag conditions?



Plot depicts trajectories of clouds released at rest from heights of 1, 5, and 8 kpc within a gaseous halo, accounting solely for drag forces. Cases illustrate clouds with column densities of 10^{19} cm^{-2}, 10^{20} cm^{-2}, and 10^{18} cm^{-2}. This plot serves as a benchmark for accuracy comparison with the drag plot from our study, referencing "High-Velocity Rain: The Terminal Velocity Model of Galactic Infall" by Robert Benjamin and Laura Danly (1997).



- *Higher column densities allow the clouds to maintain higher velocities as they have more momentum and are less affected by drag forces.*
- *Terminal velocity decreases as HVC approaches the galactic plane.*
- *The lower velocities of less dense clouds indicate they could be more dispersed by tidal forces, spreading their mass wider.*
- *HVCs with lower column densities might not contribute as significantly to the mass of the galactic disk due to their lower terminal velocities*

References

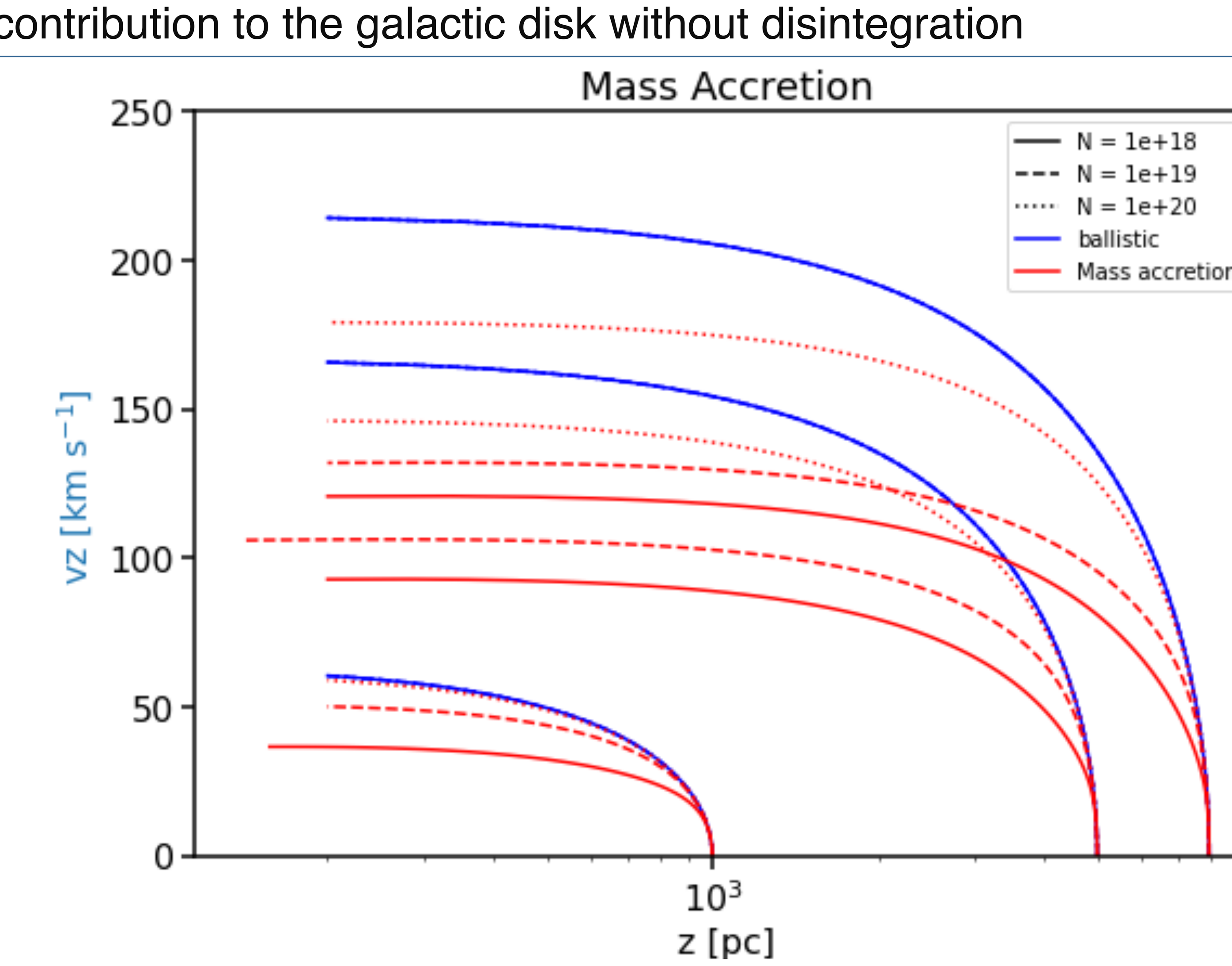
- Benjamin, R.A., & Danly, L. (1997). High-velocity rain: The terminal velocity model of galactic infall. The Astrophysical Journal, 481, 764.
- Bobylev, V.V., Bajkova, A.T., & Mishurov, Y.N. (2022). The mysterious Radcliffe wave. Astrophysics, 65(4), 579-598.
- OpenStax. (2018). Motion of an object in a viscous fluid. Retrieved May 10, 2023, from [OpenStax URL]
- Putman, M.E., & Peek, J.E.G. (2012). Gaseous galaxy halos. Annual Review of Astronomy and Astrophysics, 50, 491-529.
- Wechsler, R.H., & Tinker, J.L. (2018). The connection between galaxies and their dark matter halos. Annual Review of Astronomy and Astrophysics, 56(1), 435-487.
- Wolfire, M.G., McKee, C.F., Hollenbach, D., & Tielens, A.G.G.M. (1995). The multiphase structure of the galactic halo: High-velocity clouds in a hot corona. The Astrophysical Journal, 453, 673.

Methods and Parameters

- Used the fourth-order Runge-Kutta (RK4) ODE integrator to accurately predict and simulate trajectories.
- Employed a position-dependent gravitational acceleration from Wolfire et al. (1995)
- Utilized an exponentially decaying hydrostatic density

Conclusion

- Models including drag reach a terminal velocity, consistent with Benjamin & Danly, but mass accretion models do not.
- Mass accretion has more influence at higher column densities, while drag at lower column densities.
  - Drag's effect on reducing velocities is less pronounced in denser settings due to higher inertia in denser clouds that helps to maintain their velocities.
  - Mass accretion leads to an increase in velocities due to the enhanced gravitational pull from the additional mass, more pronounced at higher densities.
- Mass accretion's impact on velocity is more uniform across different densities, while drag's is more variable and sensitive to changes in the cloud's density.
- Clouds from higher initial posit6ions face minimal initial resistance and higher peak velocities.
- As clouds descend, drag causes sharper velocity reductions, especially at lower altitudes
- Combined effects modulates and stabilizes velocities, help prevent clouds from disintegrating due to excessive kinetic energy as they integrate with the galactic disk.
- Combined forces yield smoother deceleration profiles and lower peak velocities, preserving cloud integrity, ensuring effective mass contribution to the galactic disk without disintegration



- *Primarily increases velocity by increasing the mass of the clouds, affecting their gravitational pull*
- *Higher column densities show a more pronounced velocity increase as they fall -> more massive clouds accrete more mass and hence speed up more significantly*
- *Facilitates acceleration towards the galactic plane, more so in clouds with higher column densities.*
- *Results in smoother and higher peak velocities compared to drag effects.*