

Vertical evolution of exocometary gas – II. MRI-driven viscous evolution and diffusion of gas in debris discs

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INTRODUCTION

Debris discs are circumstellar discs of dust and gas orbiting main-sequence stars. Recent observations reveal CO gas in these systems, raising questions about its origin (primordial vs. secondary from cometary outgassing). Understanding gas dynamics is critical for interpreting disc structure and evolution. The efficiency of angular momentum transport, largely governed by magneto-rotational instability (MRI), plays a key role in shaping the distribution and long-term evolution of gas in debris discs.

METHODS

We use the Python package EXOGAS to model viscous evolution of gas driven by magneto-rotational instability (MRI).

Key components:

- CO production from cometary collisions
- CO photodissociation into C and O
- MRI-driven viscosity using the α -prescription
- Ambipolar Elsasser number (Am) as the MRI stability criterion
- Ionization balance and vertical hydrostatic equilibrium

MRI VISCOSITY MODEL

The viscosity parameter α is determined by the ambipolar Elsasser number Am :

- $Am > 10$: MRI-active, turbulent viscosity drives spreading
- $Am < 10$: MRI-suppressed, viscosity drops sharply

Am is determined by gas ionization and density. The viscosity parameter is computed as:

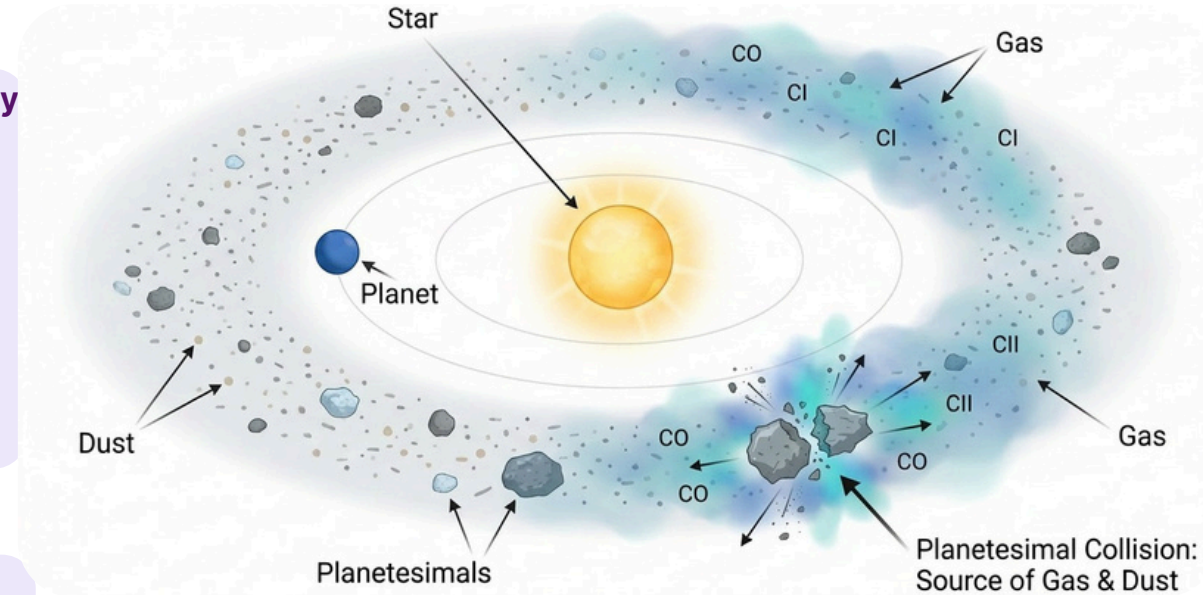
$$\alpha = \max \left[\alpha_{\min}, \alpha_{\max} \times \left(\text{Erf} \left(\frac{z_2}{\sqrt{2}H} \right) - \text{Erf} \left(\frac{z_1}{\sqrt{2}H} \right) \right) \right]$$

DISCUSSION

Model predictions are broadly consistent with observed CO surface densities in debris discs. MRI evolution depends mainly on CO production rate, with initial gas mass important only at high values.

Limitations:

- Vertical slab approximation
- No MHD wind contributions
- Simplified ionization chemistry
- Single-ring geometry assumption



CONCLUSIONS

1. Low-density debris discs remain well ionized and MRI-active, driving efficient viscous evolution
2. High gas densities suppress MRI through ambipolar diffusion, producing low-viscosity discs
3. MRI suppression slows gas diffusion, enhances CO retention, and introduces dependence on initial conditions

KEY RESULTS

- MRI viscosity evolves self-consistently with gas ionization.
- Low CO production rates sustain MRI-active discs ($\alpha \approx 10^{-2}$).
- High CO production rates suppress MRI through increased shielding.
- Reduced MRI activity slows viscous evolution and increases CO surface density.
- Initial CO abundance affects evolution only above a critical threshold.
- MRI-regulated models predict higher CO retention than constant- α models

