Mercury's exospheric magnesium: constraints from MESSENGER flyby observations

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Overview

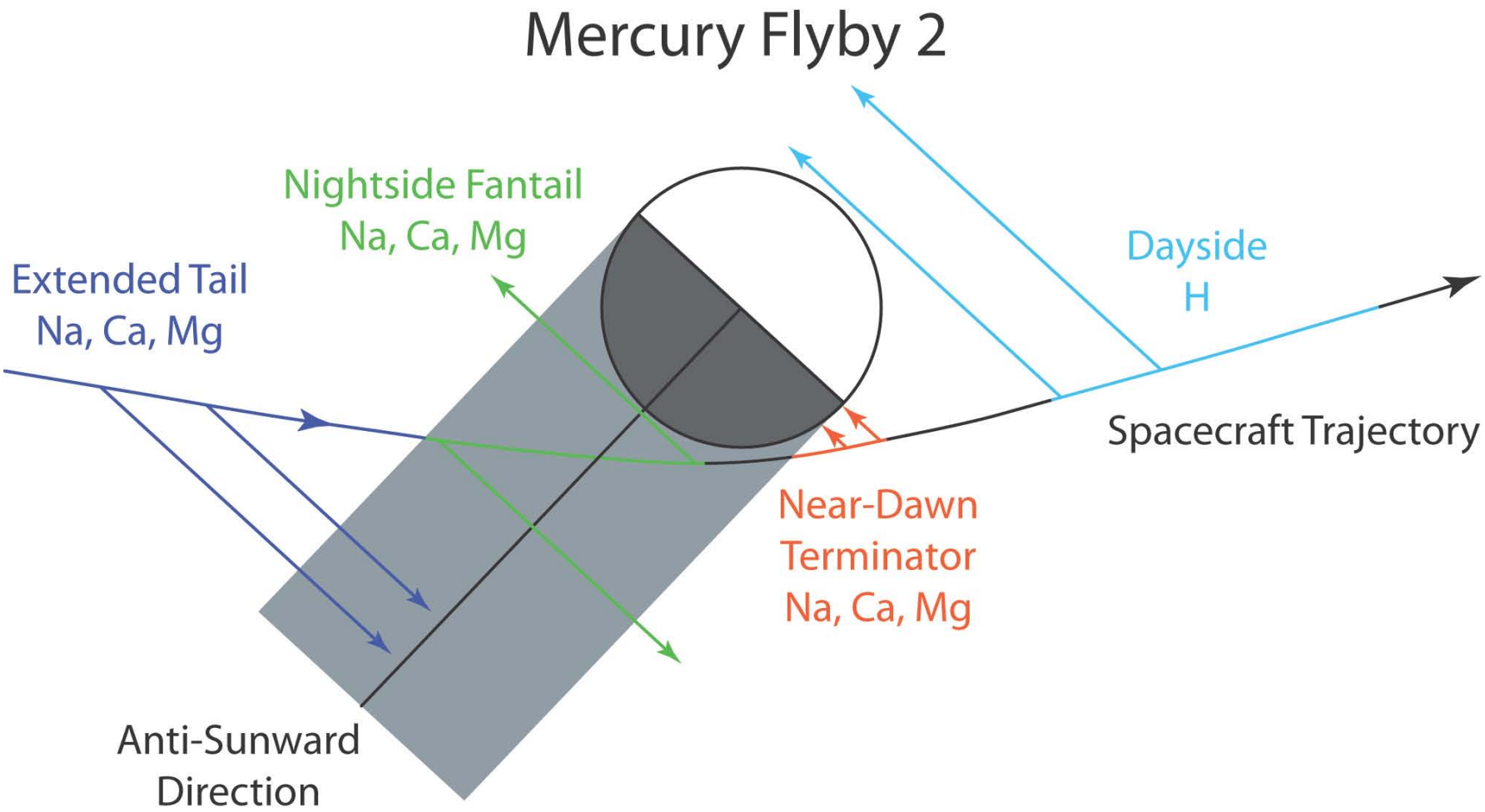
➢Analyze the measurements of Mercury's exospheric magnesium obtained by the MESSENGER probe during its second and third Mercury flybys.

➢Constrain assumed model parameters for Mercury: sticking coefficients, source and loss processes, and velocity distributions.

➢Models progress in order of complexity:

- Chamberlain models (**uniform ejection**)
- models of the expected source processes (**e.g., impact vaporization, sputtering**)
- non – uniform models and models of the energy exchange with the surface (**meteor stream? Thermal accommodation?**)

Observational Sequence



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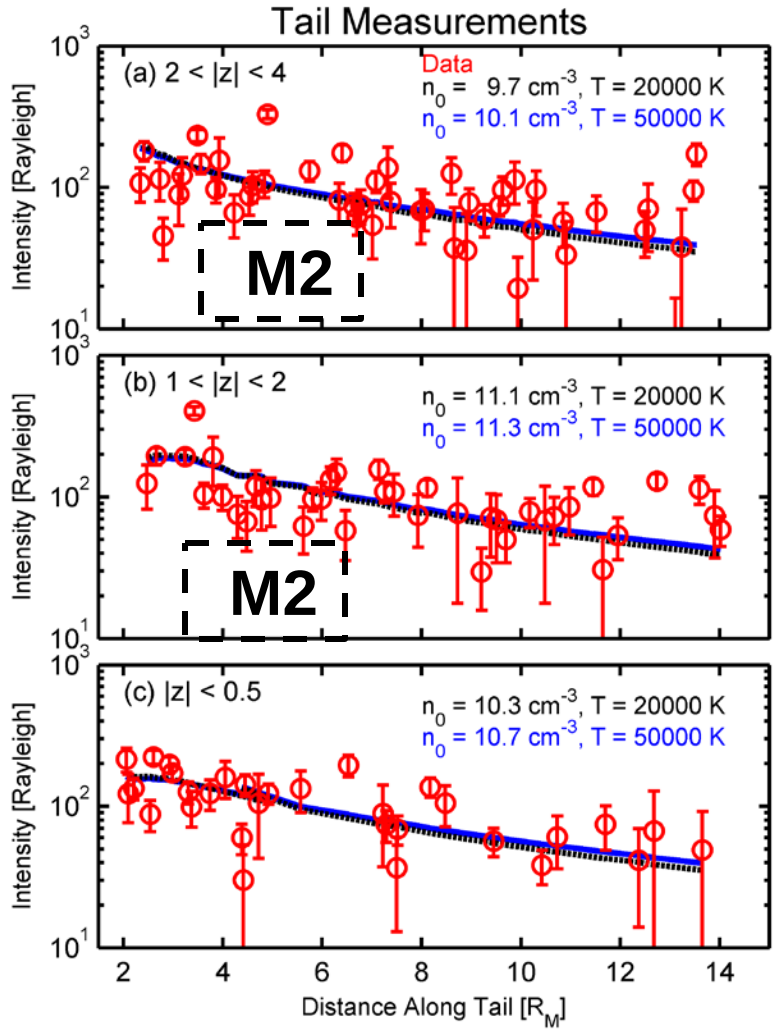
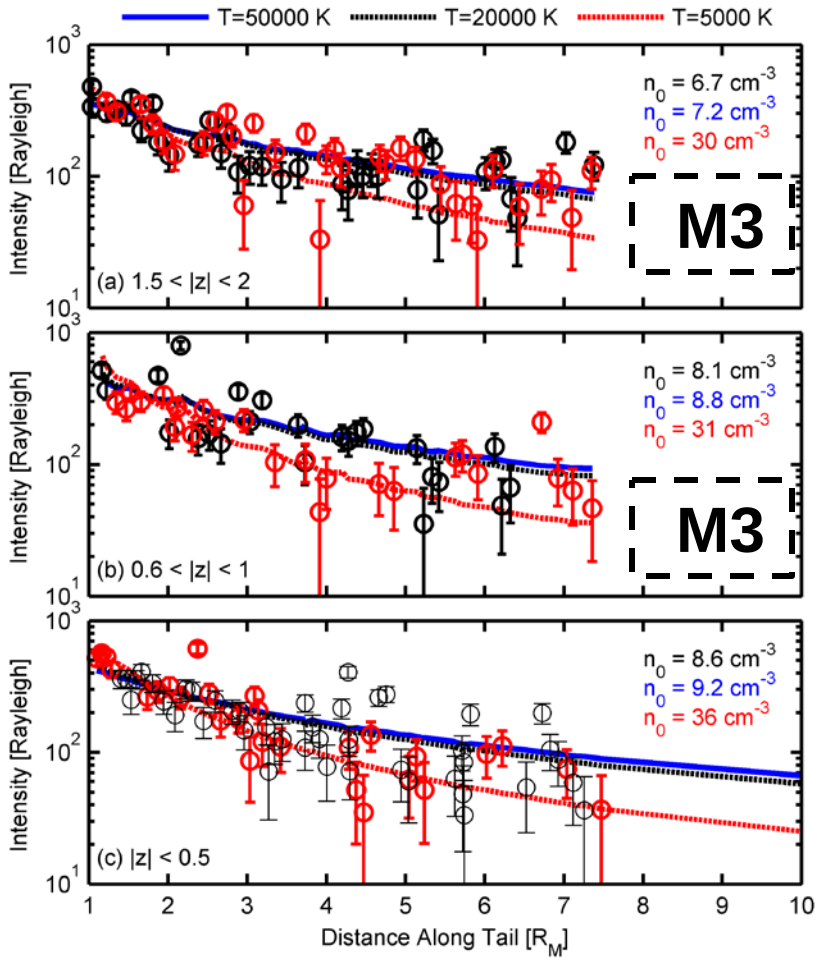
Tail Observations





- **Tail is populated by energetic ejecta**
- **"Temperature" is high, ≥ 20,000 K, but unconstrained**

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Inferred Production rates

- From tail measurements fit to Chamberlain models (uniform ejection):
- M2: 3×10^{6} atoms cm^{-2} s^{-1}

  1.1×10^{6} atoms cm^{-2} s^{-1}

  1.8×10^{6} atoms cm^{-2} s^{-1}
- M3: 1.8×10^{6} atoms cm^{-2} s^{-1}

  9×10^{5} atoms cm^{-2} s^{-1}

  1.5×10^{6} atoms cm^{-2} s^{-1}

The source rates needed to describe data are similar or actually slightly reduced

Suggests increased loss rates?

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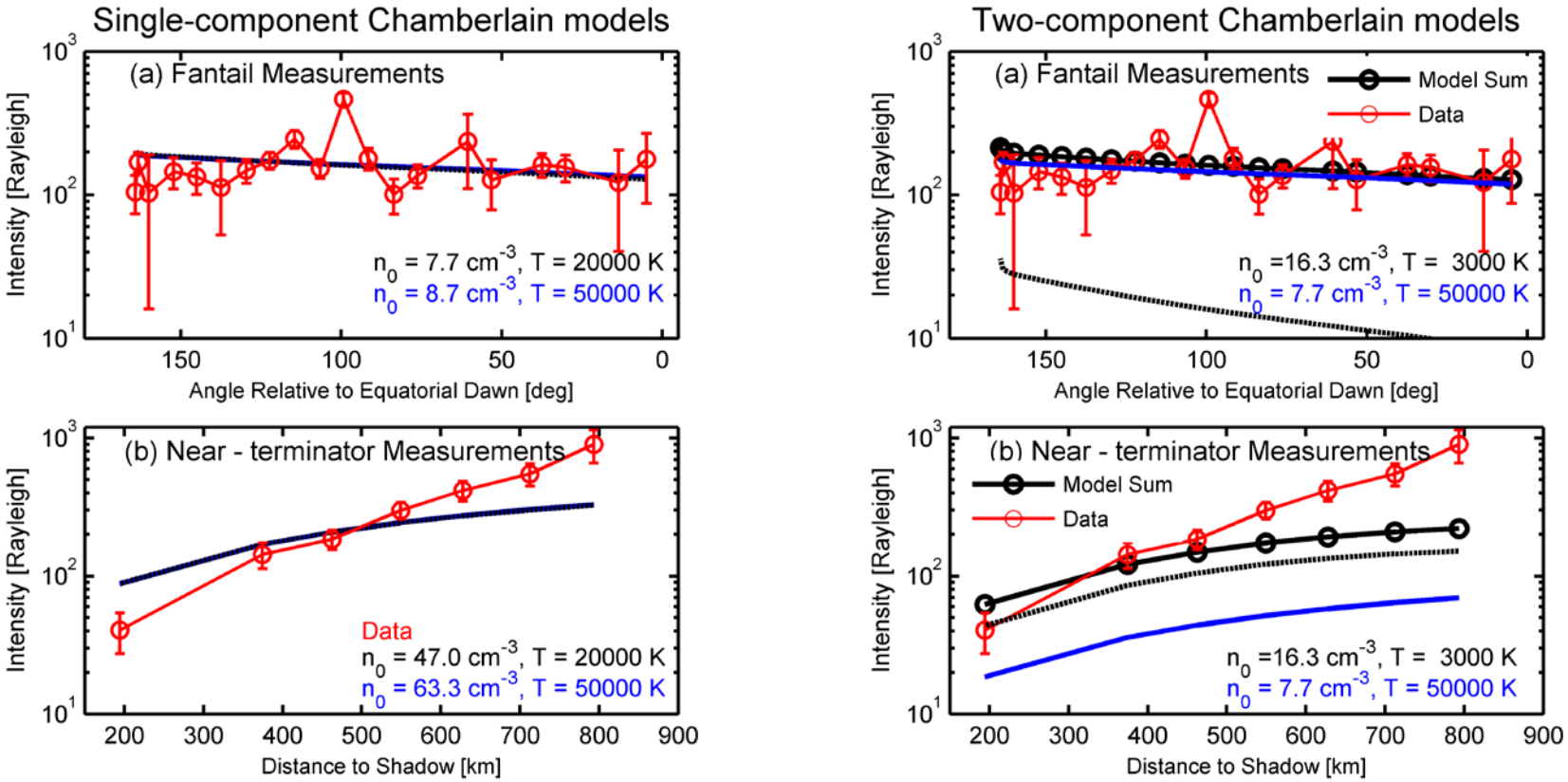
Evidence of a Two-component exosphere

M2



The source rates needed to describe data near and far from the planet with a single temperature are inconsistent with the loss rate to photoionization

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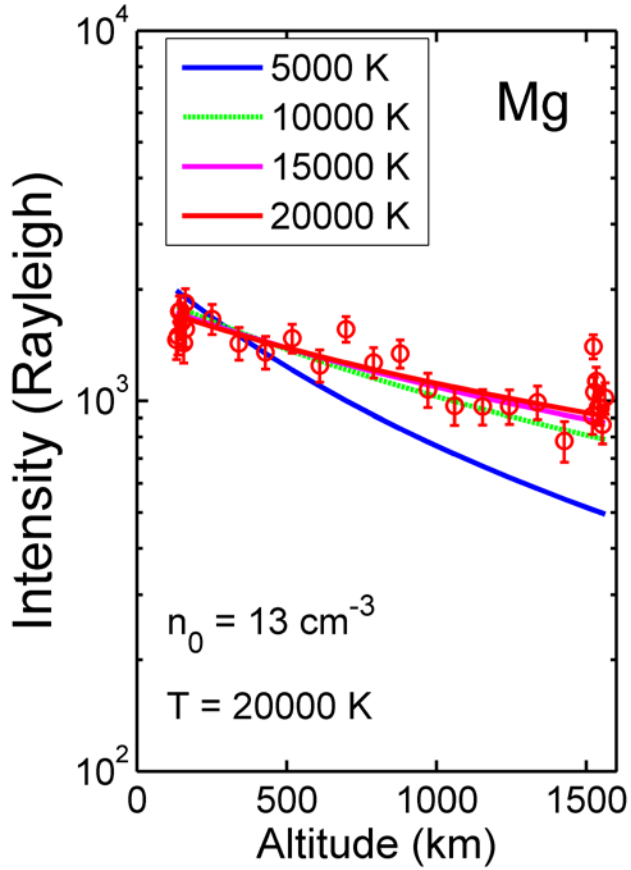
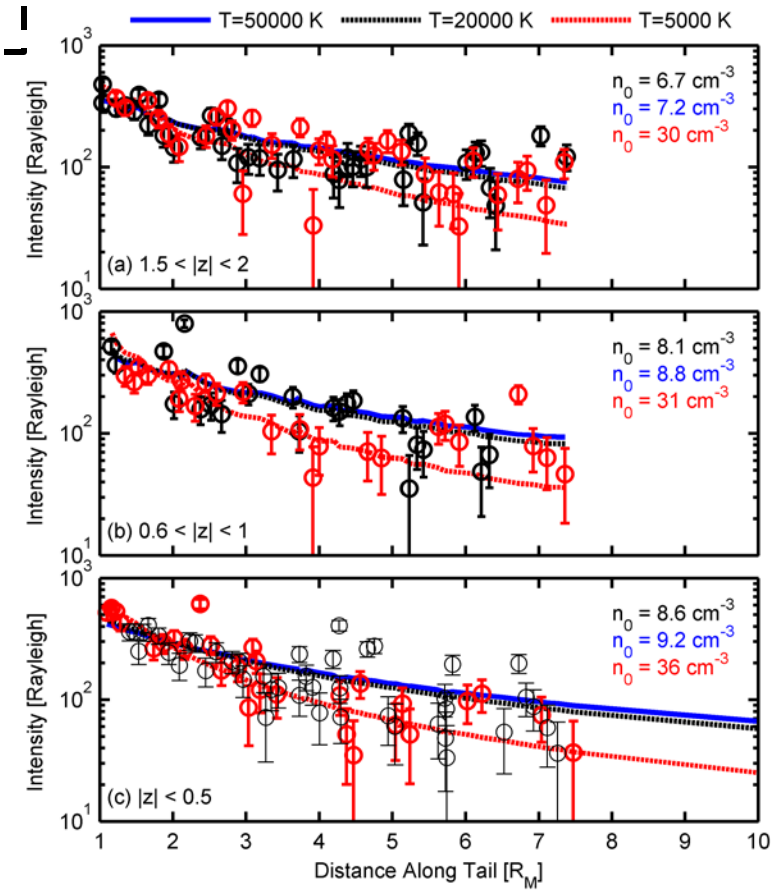
Cold components during M3?



M3



- Polar profile over the south can more or less be fitted to a single temperature

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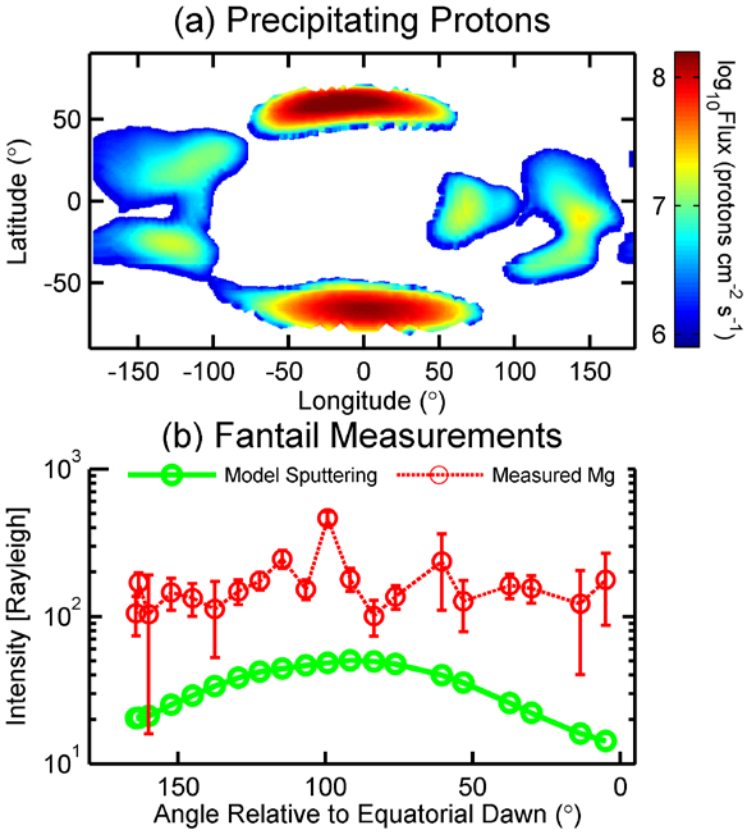
Processes that promote magnesium into the tail



Magnetosphere model: Benna et al. [2010]

While important, sputtering cannot explain amount of magnesium in tail

If so, an additional source of high-energy neutrals (e.g., molecular dissociation) is required to populate the tail

- Considerable uncertainties remain, especially:

What is the additional fraction of the surface exposed during magnetic Flux Transfer Events?

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Relative roles of Mg sources

Inferred Production Rates:

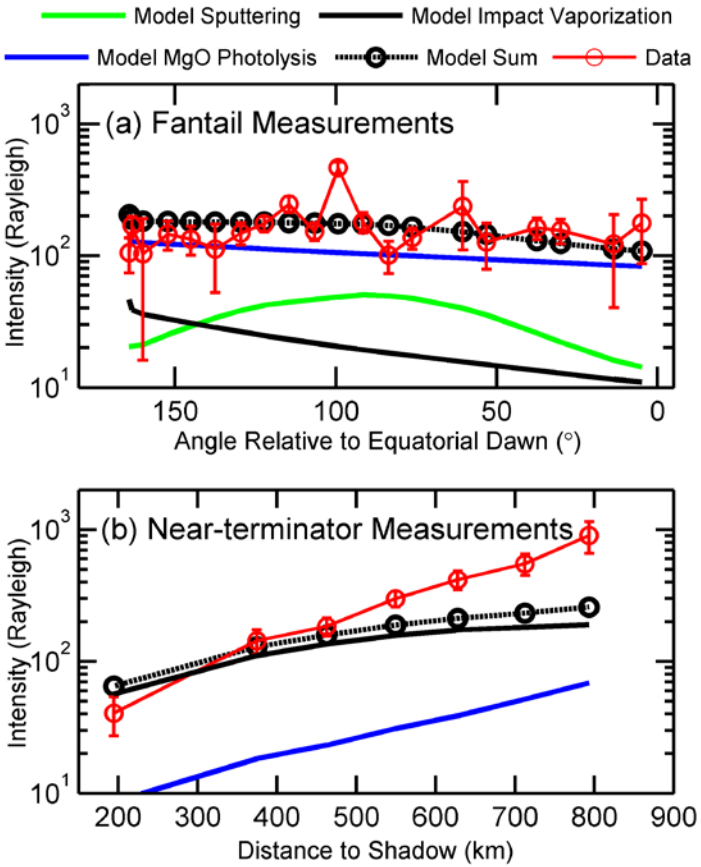
Sputtering: 2-4×10^6 cm^{-2} s^{-1} (poles)

Impact Vaporization: ≤ 1×10^6 cm^{-2} s^{-1} (global)

Photolysis: ~ 1-3×10^6 cm^{-2} s^{-1} (dayside)

Total amount of magnesium at high-altitudes is consistent with earlier estimates for impact vapor [e.g., Killen et al., 2010]:

~ (1.3–4.8) ×10^6 Mg atoms cm^{-2} s^{-1} for an abundance of magnesium in the regolith of 0.05–0.18 by number



Half the exosphere at pre-dawn is unaccounted by these processes

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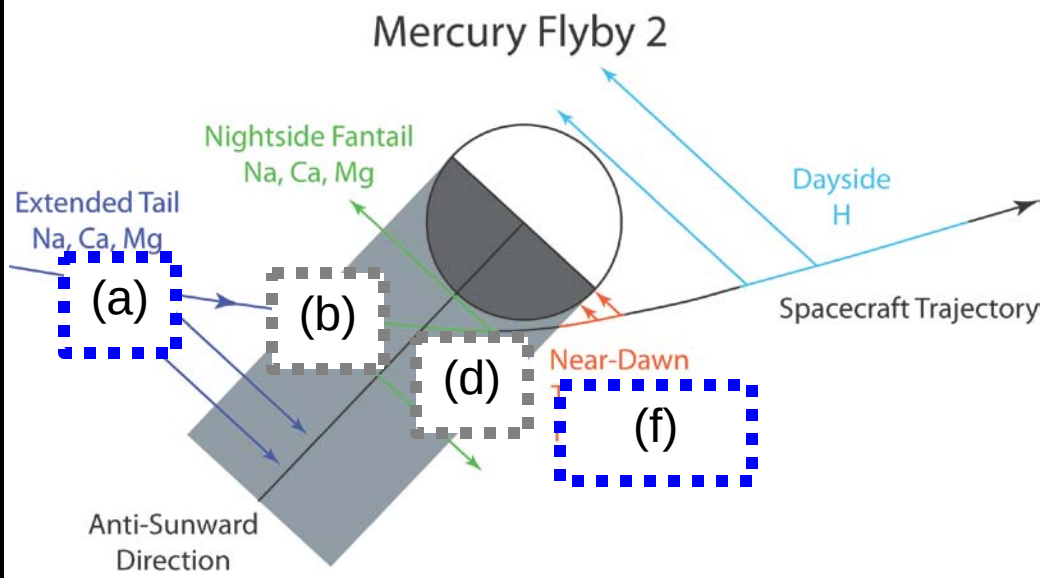
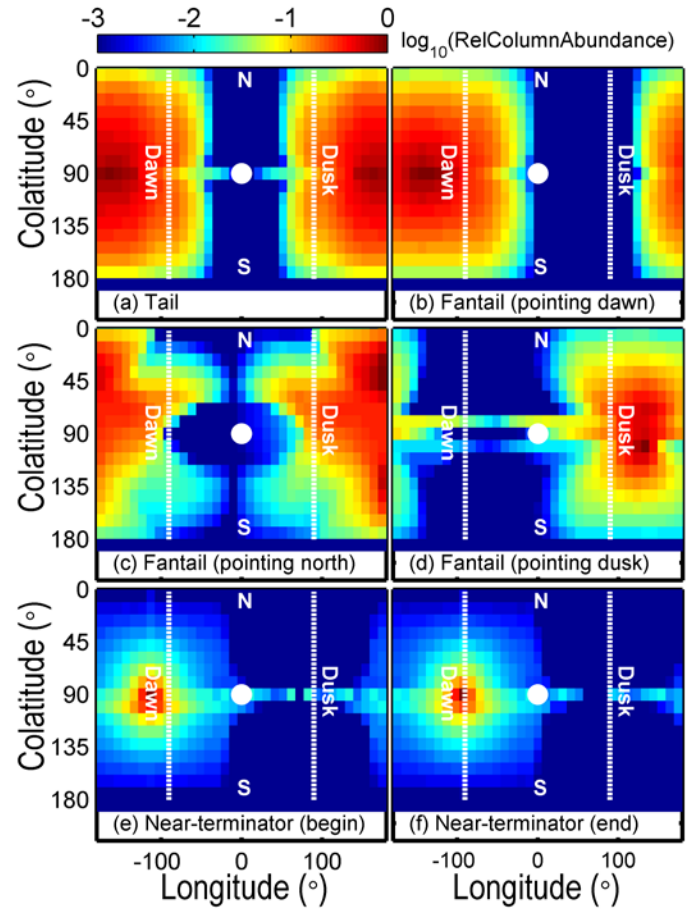
Limitations of pointing geometry





(Right) Relative contribution by planetary surface elements to the modeled column abundance due to an isotropic impact vaporization source (T = 5000 K) for selected lines of sight

We cannot differentiate between ejection at low temperatures and anisotropic ejection

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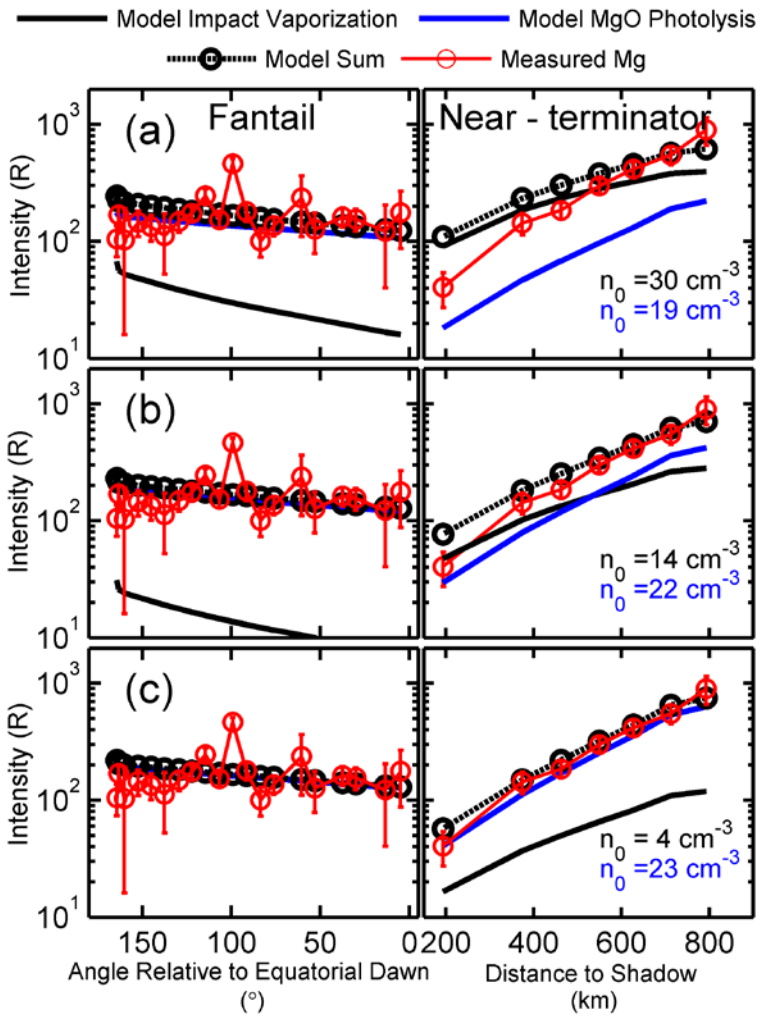
Enhancement near terminator: a meteor stream?



Models of the fantail (left) and near-terminator (right) measurements markedly improve if a meteor stream impacted Mercury within ±10° of equatorial dawn.

Consider enhancements by factors of two (upper panel), four (middle panel) and six (lower panel) over the uniform impact vaporization rate, n_0.

Black: T=3000 K; blue ,T=20000 K.

Inferred n_0 ~ 150 cm^{-3}

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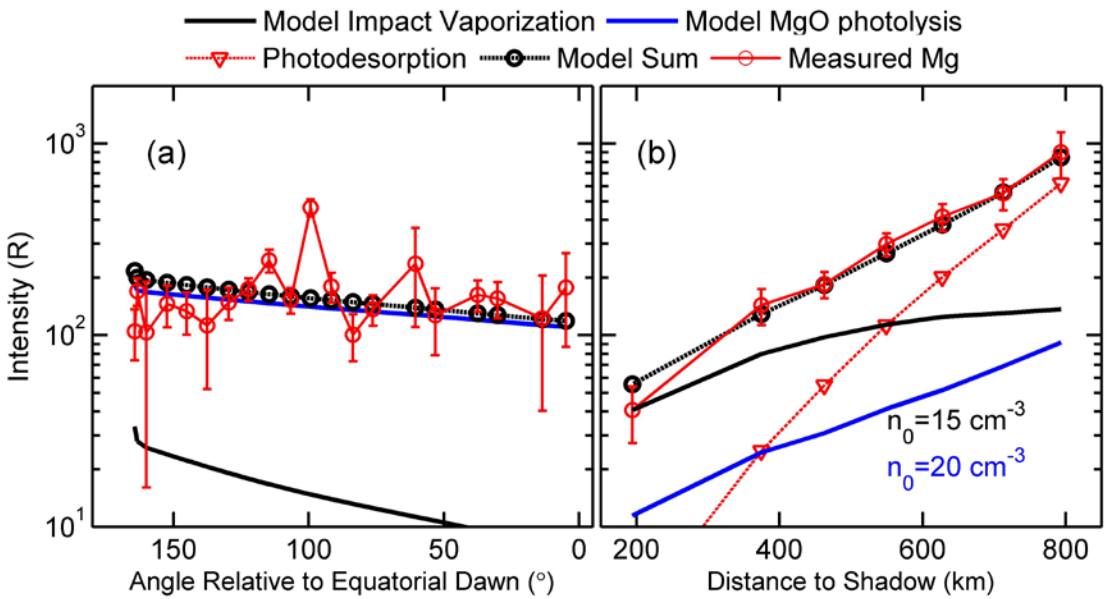
Enhancement near terminator:

a dayside source that is colder than impacts?

Assume that returning atomic Mg atoms (or nightside MgO) weakly physisorb



(a)-(b) Deviations from a uniform impact vaporization model could be attributed to possible photodesorption of atomic magnesium from Mg recycled onto the surface.

Assuming T=1200 K ➔ n_0 ~ 300 cm^{-3}

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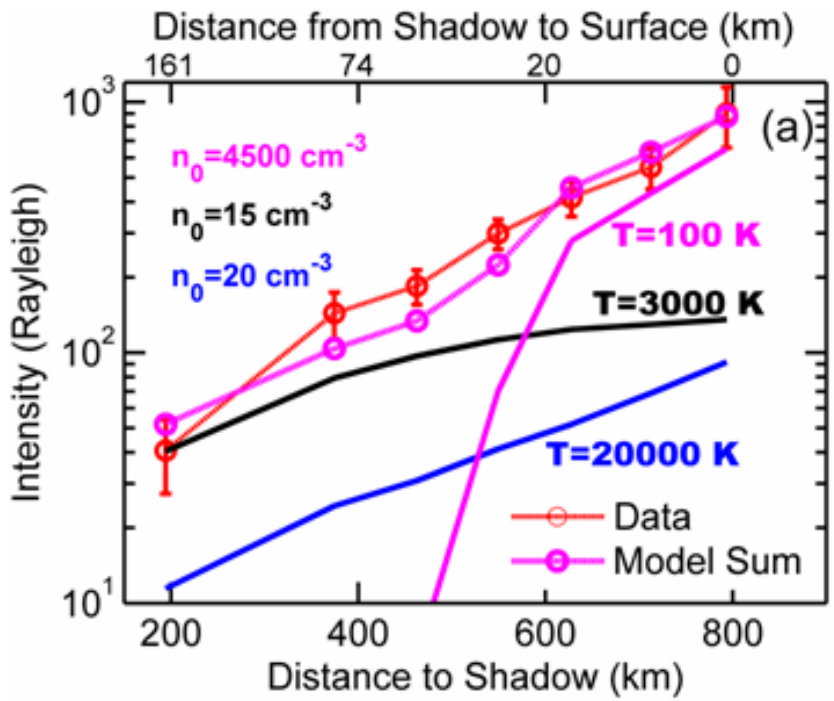
Enhancement near terminator: thermal accommodation/desoprtion?

Assume that returning Mg atoms do not stick upon impact but rebound



A thermally accommodated component (*T* = 100 K) could explain the sharp increase seen near the terminator as the observations probe altitudes that are comparable to the scale height from such a population, ≤ 20 km .

Assuming T ≤ 500 K ➔

n_0 > 3000 cm^{-3}

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Suggestions

Net Production unchanged between M2 and M3

1) Two-temperature exosphere: *a hot ejection process at temperatures >10000 K, and a competing source at lower temperatures, 3000–5000 K*

→ The cooler component is consistent with impact-driven rates

2) Tail: Sputtering can provide only 20-25% of Mg in tail

→ **Residual exosphere points to photolysis of a Mg-bearing molecule**

Data consistent with a number of source processes all contributing approximately equally to total production

3) Sharp increase in emission observed near the dawn terminator region (M2):

a "localized" meteor stream? Photodesorption of volatile Mg that is released by impacts and then recycles? Surface discontinuity in Body Fixed Coordinates? Source of rebounding particles?.

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Constraints to models needed

- Metallic Mg:

--sticking coefficients

--possibility of PSD ?

--thermal desorption?

- MgO

--Dissociation by photons and vibrational modes?

--Lifetimes?

--If adsorbed onto surface, can MgO release Mg by UV photons as by lasers in the lab?