LIMITS TO SUPPLY

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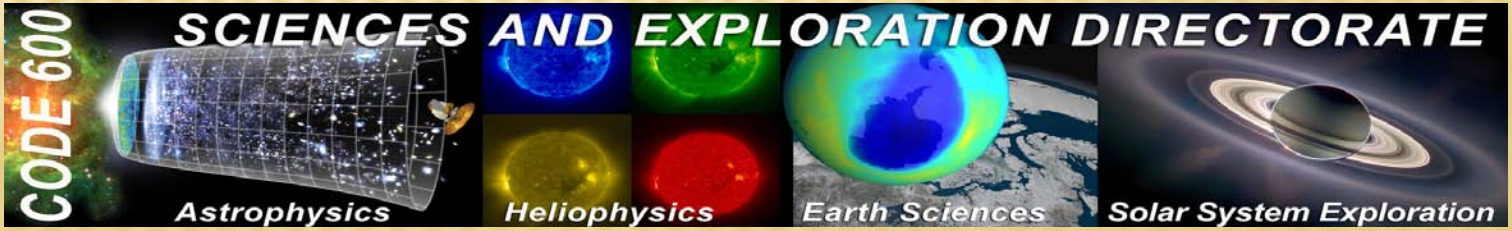


OUTLINE OF TALK

- 1. Supply of atoms to the surface
- supply from Meteoroid bombardment
- supply from solar wind
- supply by diffusion from grains
- supply by regolith gardening
- 2. Loss of atoms from the exosphere
- loss by Jeans escape
- loss by ionization

METEORITIC SUPPLY

- Flux of projectiles m<0.1 g
  - 2.86×10^{-16} g cm^{-2} s^{-1} (Cintala, 1992)
  - double this to get the total flux
  - "minimum mass model"
  - Flux~ 5.7×10^{-16} g cm^{-2} s^{-1}
  - Flux (Na atoms)~ 6×10^{4} Na atoms cm^{-2} s^{-1}
  - Note: the supply of vapor from meteoroid impact is ~23% of the flux

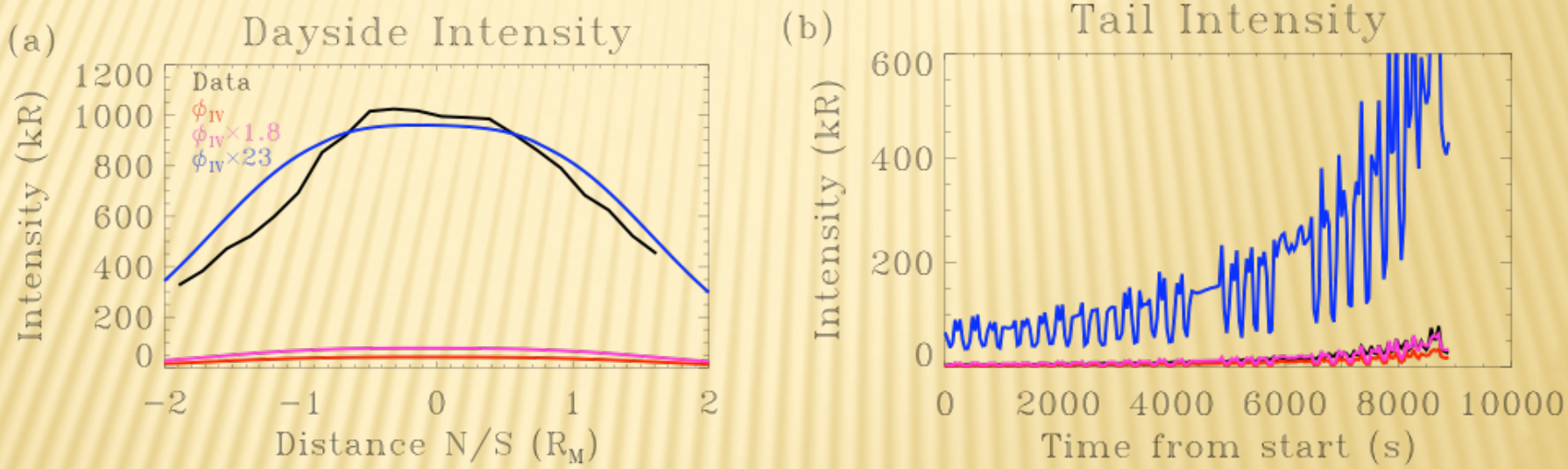
BORIN METEOROID SUPPLY

- Supply rate micrometeoroid= 2.38 $x10^{-14}$ g cm^{-2} s^{-1}
- Na supply = >2.5$x10^{7}$ atoms cm^{-2} s^{-1}
- Loss rate = 7$x10^{5}$ cm^{-2} s^{-1}
- Supply – loss = 2.4 $x10^{7}$ Na atoms cm^{-2} s^{-1}
- Gain of Na = 132 gm Na cm^{-2}
  - over the age of Mercury

LIMITS TO IMPACT VAPORIZATION

Dayside Sodium Intensity data from McMath-black models red, pink, blue

Tail Intensity from MASCS M1



Data from first MESSENGER flyby (black) constrain the impact vaporization source to be less than about 5 x the Cintala rate. A flux 23 times the Cintala rate can fit the dayside equatorial region but overwhelms the escaping component in the tail (Mouawad et al. in press, Icarus).

METEOROID FLUX AND IMPLICATIONS

- Much larger flux? (Borin et al., 2009, 2010)
- Possibly more vapor in the form of molecules
  - (Berezhnoy and Klumov, 2009)
- Possible ejecta in the form of ions
  - Kaguya found more K^+ than predicted
  - Dukes and Barragiola (submitted) predict sputter in the form of Na^+

SOLAR WIND SUPPLY

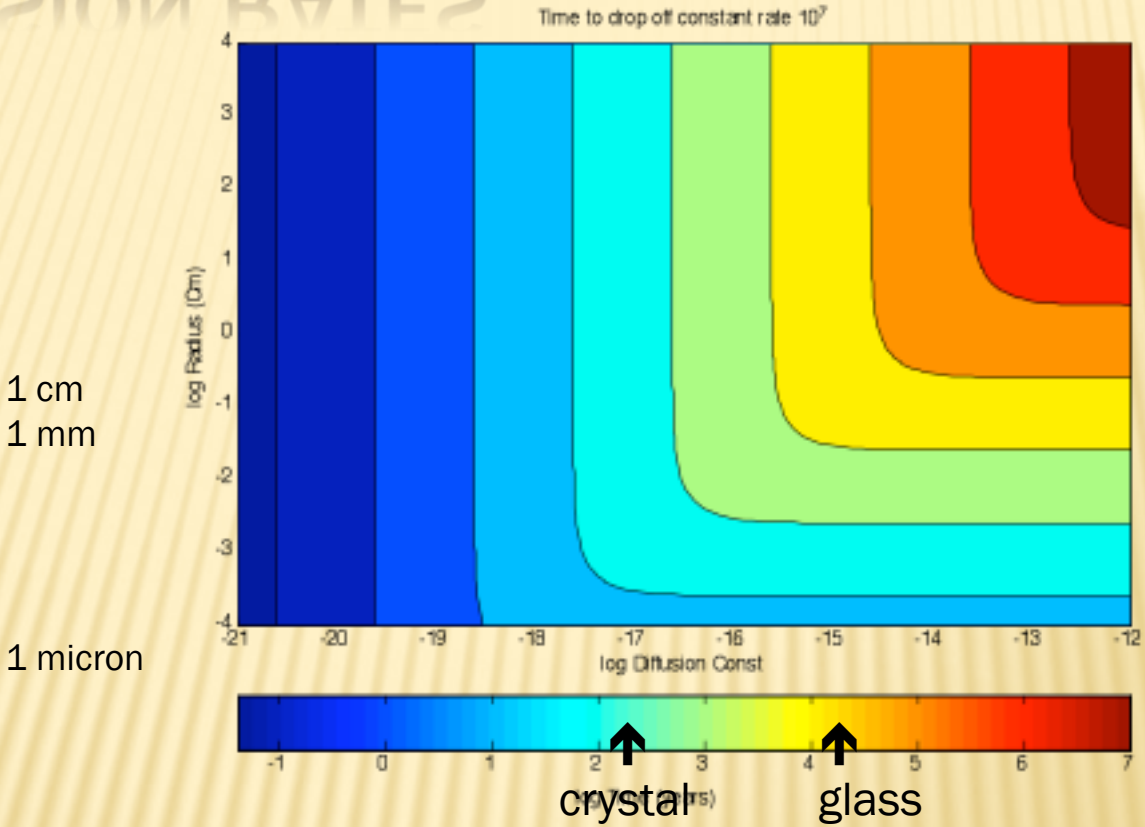
- Na fraction in solar wind

  $0.17/1975=8.6\times10^{-5}$

- Global Flux rate of solar wind ~ 10^{7} cm^{-2} s^{-1}
- Global flux of Na ~ 860 cm^{-2} s^{-1}

- Too small to be a significant source

DIFFUSION RATES



- Figure 3a. The length of time (color-coded) a spherical grain of a given radius can outgas at a rate of 10^7 atoms cm^{-2} s^{-1} (cross-sectional area) at a given diffusion coefficient before the rate drops. A 1 cm radius sphere can outgas at 10^7 atoms cm^{-2} s^{-1} for 10^4 years (its expected lifetime on the surface of Mercury) at a diffusion coefficient of 10^{-15} or larger. This constrains the grain to be glass, or the rate to be smaller than 10^7, or the timescale to be less than the lifetime of the grain for temperatures on the surface of Mercury. Smaller grains outgas for shorter periods of time or at much lower rates.
- Sarantos, M., R.M. Killen and D.Kim, Predicting the solar wind ion-sputtering source at Mercury, Planet. Space Sci., doi:10.1016/j.pss.2006.10.011, 2007.

REGOLITH TURNOVER RATE

- What is the turnover rate of the upper 1 micron
  - 1 micron/1250 years (Lunar rate)
  - (Gault et al., 1974)

How many Na atoms are there in this layer?

if ρ=1.8 g cm^{-3} and f(Na)=0.004 wt

1 micron size grain degasses in < 100 years

There are 1.9×10^{16} Na atoms cm^{-2} μm^{-1}

a possible maximum supply of 4.8×10^{5} Na atoms cm^{-2} s^{-1}

LOSS RATE OF NA

- Total source rate to exosphere= 4.8×10^6 cm^{-2} s^{-1}

- Photoionization rate= 1.8×10^5 cm^{-2} s^{-1}
- (assumes that half reimpact the surface)

- Jeans escape (including radiation pressure) ~ 5×10^5 cm^{-2} s^{-1}

- Loss rate ~ 7×10^5 cm^{-2} s^{-1}
- This is 1.4x the maximum supply rate from regolith
  + 5×10^5 cm^{-2} s^{-1}
  12 x the minimum mass model supply rate from meteoroids
- Houston we have a problem

SOLUTIONS

- faster gardening rate
  - may be >10 times faster at Mercury than at the Moon (Borin gardening rate = 380 lunar rate)
  - >1 micron per ~100 years is what we require
- More sodium in meteoroids
- >12 X Larger meteoroid flux rate
- more sodium in the regolith

GARDENING RATE AT MERCURY 10 TIMES AT MOON

- What is the turnover rate of the upper 1 micron
  - 1 micron/125 years
  - (10 x Gault et al., 1974)

How many Na atoms are there in this layer?

if ρ=1.8 g cm^{-3} and f(Na)=0.004 wt

There are 1.9×10^{16} Na atoms cm^{-2} μm^{-1}

a possible maximum supply of 4.8×10^{6} Na atoms cm^{-2} s^{-1}

COMPARE SUPPLY AND LOSS

- Total source rate to exosphere= 4.8×10^6 cm^{-2} s^{-1}

- Photoionization rate= 1.8×10^5 cm^{-2} s^{-1}
- (assumes that half reimpact the surface)

- Jeans escape (including radiation pressure) ~ 5×10^5 cm^{-2} s^{-1}

- Loss rate ~ 7×10^5 cm^{-2} s^{-1}
- The supply rate from regolith ~5×10^6 cm^{-2} s^{-1}
- The diffusion supply from the regolith is 7 times larger than required
- Why is this reasonable? Gardening should scale with meteoroid flux

CONCLUSIONS

- If the sodium is supplied from the regolith then the regolith gardening rate has to be 10 times that at the moon
  - probably scales with impact flux (~7 - 380 x lunar rate)

CHEMICAL SPUTTERING

- rate?

$2H + Na_2SiO_3 \rightarrow 2Na + SiO_2 + H_2O$

energy = -4.7 kcal/mole

$SiO_2 + OH + H_2O \rightarrow H_3O^+$

Potter (GRL, 22, 1995)

PROBLEMS WITH SPATIAL DISTRIBUTIONS

- why is calcium always seen peaked at the dawnside?
  - Ca is very refractory
  - Ca vaporizes at 5000 K (i.e. it does not evaporate at ambient temperatures)
  - If Ca builds up in the night then other species should also – why don't we see an enhancement in Mg or Na from MASCS

POSSIBLE SOLUTIONS TO MG, CA

- Mg and Ca not escaping plate out as metals
- Then ESD and PSD may become effective
- Cold Mg may have been seen at terminator
- Mg deposited as MgO and photo-sputtered?

  - see Thomas Orlando's talk – we need rates!

POLAR ENHANCEMENTS VS CUSPS

Why do we see polar enhancements?

- The cusp regions are at mid-latitudes
- The poles are cold
- There is no photon-stimulated desorption at the poles
- high energy loss processes vs. the presence of ice at the poles?

SUPPLY RATES TO THE EXOSPHERE

- Electron Stimuated Desorption

- yield/ electron = $1.x10^{-4}$ (?)
- f(Na)=0.004
- f(solar wind electrons)=10^9 cm^{-2} s^{-1}
- fraction of electrons reaching surface=5%
  - Schriver et al.

  ESD yield=$0.004(6x10^7)(10^{-4})$=24 cm^{-2}

SUPPLY RATES TO THE EXOSPHERE

- Photon Stimulated Desorption

- Qphot=10^{-20} – 10^{-21} cm^{-2}/photon
- Flux(>4 eV)=$2x10^{16}$
- atoms/cm^{-2}=$7.5x10^{14}$

- yield=0.004($7.5x10^{14}$)($2x10^{16}$)(10^{-20})=$6x10^{8}$ cm^{-2} s^{-1}
- this yield is diffusion limited to ~10^{7} cm^{-2} s^{-1}

THERMAL VAPORIZATION

- Maximum “thermal vaporization” rate is ~10^{11}
  - (this is at the sub-solar point at perihelion)
- This value is diffusion-limited to <10^{7}
- (i.e. it is choked off by limits to supply)

ELEMENTS NOT MEASURED BY MESSENGER

Neon is supplied from the solar wind

- a measurement of Ne would constrain the SW supply vs. loss rate

^{36}Argon could also be a measure of solar wind supply

^{40}Argon is a measure of radiogenic composition of the interior

SUMMARY

<u>What physical quantities do we need?</u>

- Dissociation cross sections (MgO, CaO, etc.)
- Photoionization rates
- sticking coefficients
- thermal accommodation coefficients
- excess energies/ energy distributions
- cross sections for ESD
- meteoroid impact flux
- meteor streams: TAA, flux, size distributions, velocity distributions
- surface composition
- chemical sputtering rates
- effect of regolith structure
- ion effect on photon-stimulated desorption