Mercury’s Calcium Exosphere in the MESSENGER Era

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• Dayside limb scans show persistent dawn enhancement (Burger et al. 2012, 2014)
MESSENGER
Ca Radiance at 1000 km

Ca Radiance at 1000 km (kR)

True Anomaly (°)
Source is centered at dawn equatorial point and drops off exponentially with width $= \sigma$

$$
\mathbf{r} = (x, y, z) = (\cos \lambda \cos \mu, \sin \lambda \cos \mu, \sin \mu)
$$

$$
\cos \phi = \mathbf{r} \cdot \mathbf{r}_0
$$

$$
f(\lambda, \mu) = f_0 e^{-\phi(\lambda, \mu)/\sigma}
$$
Our nominal Ca model uses a Maxwellian source distribution with $T=70,000$ K, $\sigma=50^\circ$, centered on the dawn, equatorial point (Local Time 6 hr, latitude=0º).
Orbit 0896, Temp = 70000.0 K

TAA = 301°

Dawn
Isotropic
Orbit2008, Temp = 70000.0 K

TAA = 54°

Dawn
Isotropic
Orbit3051, Temp=70000.0 K

TAA = 31°

Dawn
Isotropic
• Strong seasonal variation in source rate
• Year-to-year variability is small
  • 89% of points w/in 1σ of the black line
  • 97% of points w/in 2σ of the black line

All data
Burger et al. (2014)
Killen & Hahn (2015)
Equatorial Density, $TAA=20^\circ$

(a) Equatorial Density

(b) Calcium Content

$T = 70000 \text{ K, } \sigma = 50^\circ$

8.5-31 kg Ca
Summary of Observations

• The calcium source is concentrated on the dawn hemisphere
  • may move around a little bit, but not much
• Comes off very hot (T>50,000 K)
  • Nominal model has T=70,000 K
• Source size and temperature don’t change much if at all
• Source strength varies with Mercury’s true anomaly (position in orbit)
  • Source strongest just after perihelion
  • Source weakest just after aphelion
What is the Source?

- Not related to the surface geology
- Source is (approximately) fixed in local time and does not rotate with Mercury
- Not related to the magnetosphere (ion sputtering or electron stimulated desorption)
  - Magnetosphere is highly variable
  - Wouldn’t produce a source at dawn
  - There are possible sporadic sources that may be associated with the magnetosphere (still trying to understand these)
- Not related to Ca freezing on the nightside and vaporizing as it moves into sunlight
• The motion of the Sun in Mercury’s sky reverses near perihelion, where the source is strongest

\[
\begin{align*}
T &= 70000 \, \text{K}, \quad \sigma = 50^\circ \\
\text{Best Fit Source}
\end{align*}
\]
Current Hypothesis

- Micrometeoroid impact vaporization and molecular dissociation
  - Interplanetary Dust bombards the surface producing vapor plumes containing CaO and Ca(OH)$_2$ at ~5000 K (Berezhnoy 2013)
  - Ca-bearing molecules quickly dissociate producing hot Ca that escapes Mercury (Killen et al. 2005)

- Pros:
  - Models at Earth suggest dust impacts peak at dawn (Janches et al. 2006, Pifko et al. 2013)
  - CaO and Ca(OH)$_2$ are more likely to be produced in plumes than atomic Ca (Berezhnoy & Klumov 2008; Berezhnoy 2013)
  - Source rate consistent with dust disk + comet stream (Killen & Hahn 2015): See Rosemary’s talk later

- Cons:
  - No evidence of a dawn/dusk asymmetry in impacts at Mercury
  - Plume chemistry is very uncertain
  - Not clear that dissociation produces the >50,000 K Ca the model requires