REVIEW
GROUND-BASED OBSERVATIONS
OF MERCURY’S EXOSPHERE

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REVIEW OF SPECIES OBSERVED FROM GROUND

- Sodium (Potter and Morgan, 1985)
- Potassium (Potter and Morgan, 1986)
- Calcium (Bida et al., 2000)
- Aluminum (Bida and Killen, 2010)
- Iron (Bida and Killen, 2010)
- Ca+ (Vervack et al., 2010; Bida and Killen, 2010)
MacDonald; 2 m
Vacuum Tower Telescope, Tenerife; 70 cm
THEMIS (French-Italian), Tenerife; 90 cm
Steward (60”, 61”, 90”)
Haleakala High Altitude Observatory
Dunn Solar Telescope, Sunspot, NM (1.1 m)
NSO McMath-Pierce (KPNO); 2 m
TNG (TELESCOPIO NAIONALE GALILEO); 3.58 m
Keck (8 m)
Subaru (8.2 m)
Major Species: Sodium and Potassium

Sodium: Potter & Morgan (1985) MacDonald
Potassium: Potter & Morgan (1986) NSO
MINOR SPECIES

Keck Observations
- Calcium (Bida et al., 2000; Killen et al., 2005)
- Fe, Al, Ca+ (Bida and Killen, 2010)

THEMIS
- Al, Fe, Li (upper limits) (Doressoundiram et al., 2009)
ESCAPING SPECIES

- Tail Observations of Na
  - Potter et al., 2002
  - Mendillo et al.
  - Schmidt et al., 2010
DEFINITIONS

- Column abundance:

- Integrated abundance over the line of sight

\[ N = \int n(s) \, ds \]

- where \( n(s) \) is the density (cm\(^{-3}\))

- \( s \) is the line of sight vector
At maximum radiation pressure Na can reach 5 million km in 0.1 photoionization lifetime if it escapes at 4 km/sec or 0.3 ionization lifetime if it escapes at 0.1 km/sec. 74% of the escaping Na should survive down the tail at maximum RP.
4.88 million km

Unknown source
TAIL AND EXOSPHERE SODIUM

Solar radiation pressure is required for tail

- Radiation pressure of at least 110 cm/sec$^2$ is needed for an appreciable tail (Potter & Killen, 2008)
WHATS THE BIG DEAL?

- EXTREME VARIABILITY
  - TEMPORAL
  - SPATIAL
- EXTREME TEMPERATURE (REFRACTORIES)
- EXTREME EXTENT
- APPARENT LOW ABUNDANCE IN EXOSPHERE OF MAJOR CONSTITUENTS OF REGOLITH (O)
SOURCES AND BOUNDARIES

- PHOTON-STIMULATED DESORPTION
  - UV Radiation
  - Binding Energy at Surface
- IMPACT VAPORIZATION
  - Micrometeoroids, Meteor Streams, Meteors
  - Velocity Distributions
- SPUTTERING
  - Solar Wind
  - Bounded by Magnetosphere, IMF
REQUIRED VALUES AND Unknowns

- **PSD**
  - UV Flux, variability, cross section vs. wavelength
  - Species other than Na, K
  
  **Impact Vaporization**
  - What is the flux of micrometeoroids, meteors
  - Where are the Mercury-crossing meteor streams
  - What fraction of constituents come off as molecules, atoms, ions, direct ejection into excited states

- **Sputtering**
  - rates for each species
  - branching ratios
  - variability in solar wind
  - how much plasma impacts the surface and where?
  - sputtering into excited state?
  - sputtering to ions vs. neutrals?

- **ESD**
  - yield, flux of electrons

ALL – surface composition
Sodium exhibits high latitude enhancements but not at the poles. Note N/S asymmetry.

Suggestive of ion sputtering in open field regions, ion-enhanced sputtering, radiation pressure transport.

Leblanc et al. GRL; observations 2007/06/01 THEMIS

a) Na D2
b) Na D1
Debussy (Radar Bright Spot A)

Hokusai (Radar Bright Spot B)

High Na brightness and column abundances observed in long slit spectra (Sprague et al. 1998)

Could be Na sources

Will be thoroughly tested during the orbital phase measurements

Data taken at the 61” Mt. Bigelow, echelle spectrograph
Apparent Temperature of Sodium (Killen et al 1999)

- Analysis of sodium D$_2$ emission line profile yielded a temperature in the range 1500 K
Dawn Enhancements of Na and K
(Hunten & Sprague 2002)
Strong morning enhancements of K seen in ground based long slit spectroscopy (Sprague 1992)

Also Ca dawn side enhancements (or dusk side depletions?) seen in MESSENGER MASCS data---

Are causes the same for Ca and K? -- more data obtained during the orbital phase
Observations during the transit of 2003 show North/South enhancements AT the poles and an East/West asymmetry (Schleicher et al., A&A, 425, 2004); data from vacuum telescope on Tenerife.
POTASSIUM – TEMPORAL VARIATION

observed by Potter, Killen and Mouawad, January, 2008

SODIUM VS. POTASSIUM DISTRIBUTION

Distributions of Sodium and Potassium are different

Sodium and Potassium Observed Jan. 17, 2008

Ratio of Sodium to Potassium

- Values range from 30 to 140
Planet-wide average sodium emission is plotted against true anomaly angle. Open circles are dawnside, closed circles are duskside.

To eliminate the effect of the Doppler shift on solar flux at the rest frequency of atoms in Mercury's exosphere, the emission was normalized to conditions at true anomaly angle 143.78°. The resulting emission values would be proportional to the average column abundance of sodium in the absence of acceleration effects of solar radiation.

Major Species: Sodium and Potassium

Sodium: Potter & Morgan (1985) McDonald
Potassium: Potter & Morgan (1986) NSO
Uncorrected data:
true anomaly < 180 open circles
true anomaly > 180 filled circles

VARIATIONS ABOUT THE ORBIT

movie courtesy Matthew Burger: assumes a uniform caldium source for illustration
Calcium radiance (left), velocity (right)

Appears to be concentrated anti-sunward

Velocity blue shifted – implies high velocity

OBSERVATIONS OF AL, Fe, Ca⁺ FROM KECK

Bida and Killen, Planetary and Space Science, submitted 2010

4 $\sigma$ detection Fe

4 $\sigma$ detection Al

3 $\sigma$ detection Ca⁺
WHY ARE GROUND-BASED OBSERVATIONS IMPORTANT?

- provide a global picture
- provide a long term baseline
- pick up many species at once (Keck)
- high spectral resolution not available from spacecraft
- provide predictions for spacecraft observations