REVIEW
GROUND-BASED OBSERVATIONS OF MERCURY'S EXOSPHERE

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Andrew Potter

Exosphere-Magnetosphere Workshop
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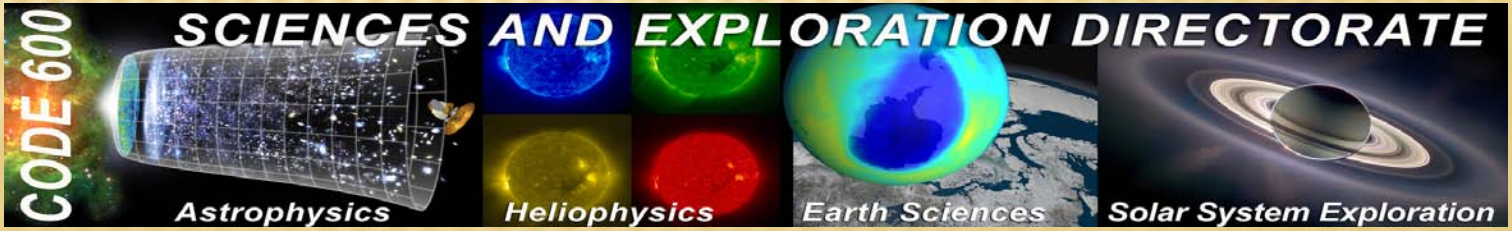


REVIEW OF SPECIES OBSERVED FROM GROUND

- 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)

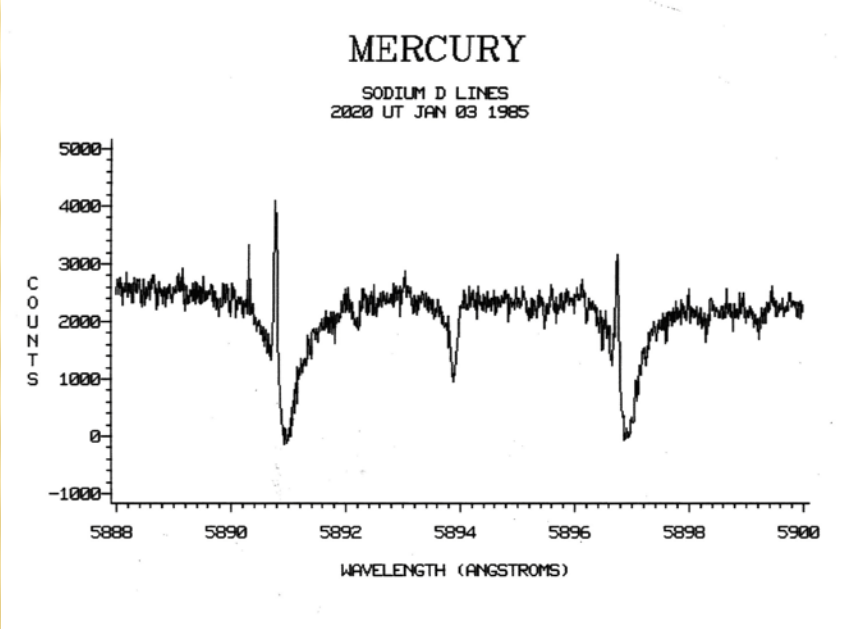
OBSERVATORIES

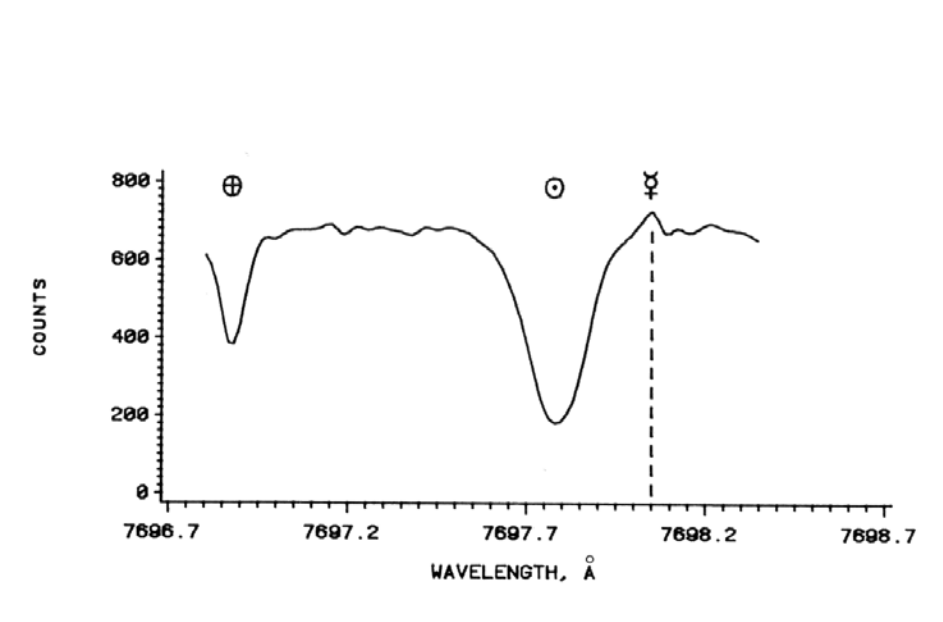
- MacDonald; 2 m
- Vacuum Tower Telescope, Tenerife; 70 cm
- THEMIS (French-Italian), Tenerife; 90 cm
- Steward (60”, 61”, 90”)
- Haleakala High Altitude Observatory
- Dunn Solar Telescope, Sunspot, NM (1.1 m)
- NSO McMath-Pierce (KPNO); 2 m
- TNG (TELESCOPIO NAIONALE GALILEO); 3.58 m
- Keck (8 m)
- Subaru (8.2 m)

Major Species: Sodium and Potassium

Sodium: Potter & Morgan (1985) MacDonald

Potassium: Potter & Morgan (1986) NSO





sodium emission at high Doppler shift

Potassium emission at high Doppler shift

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

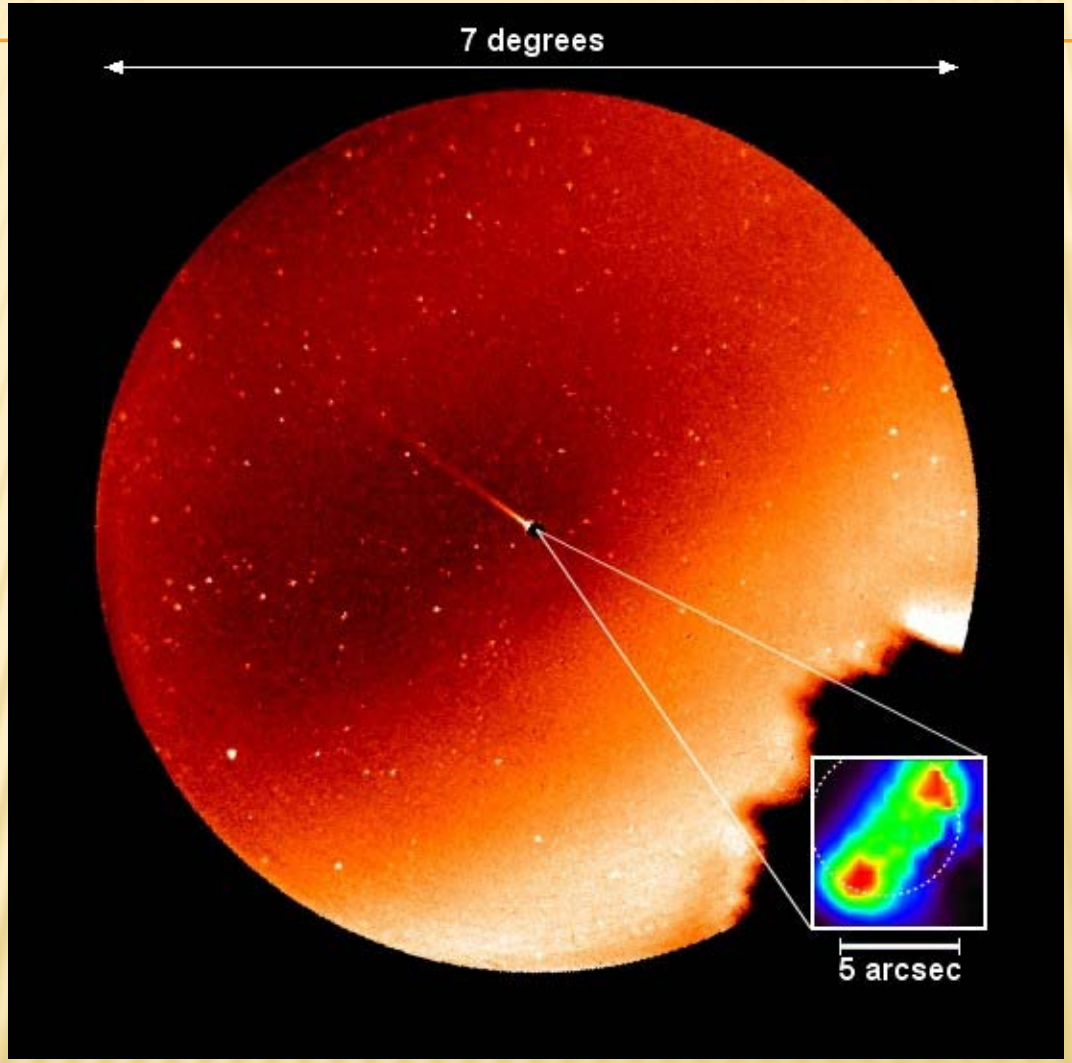
DEFINITIONS

- 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

TAIL IMAGES

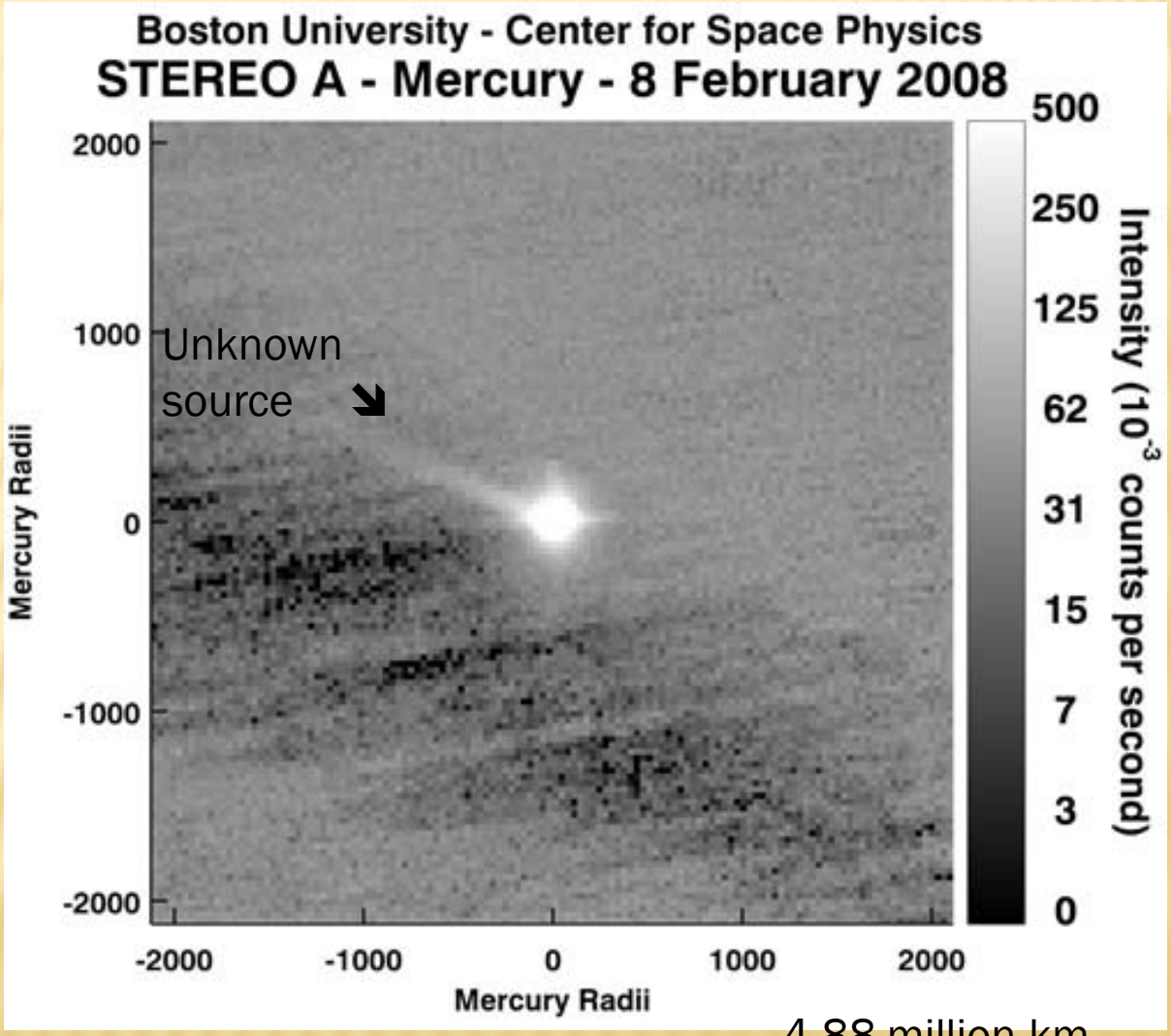
Boston University, All Sky Imager, Mendillo et al.



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

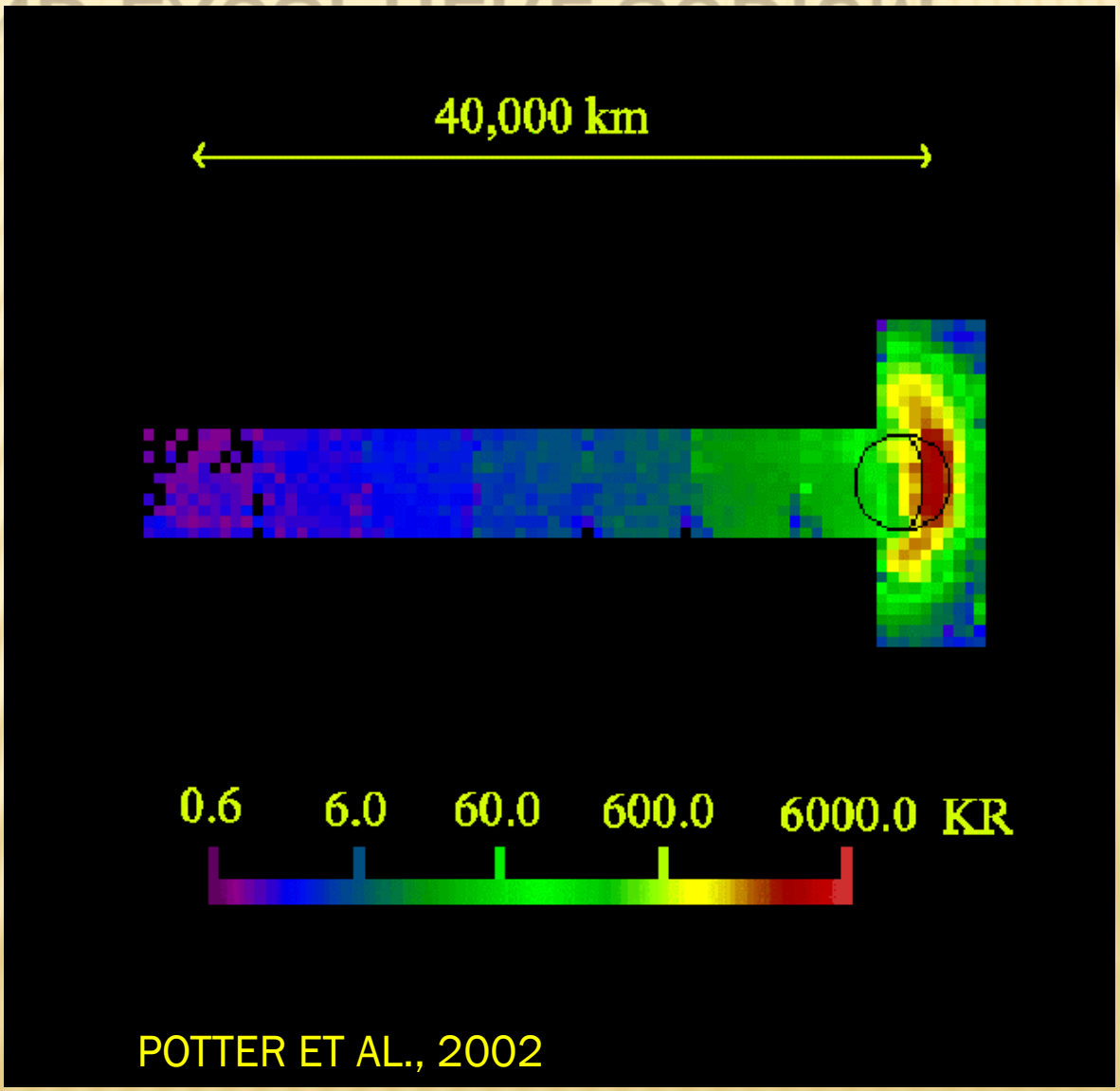
74% of the escaping Na should survive down the tail at maximum RP

TAIL IMAGE FROM STEREO (SCHMIDT, DPS, 2010)



4.88 million km

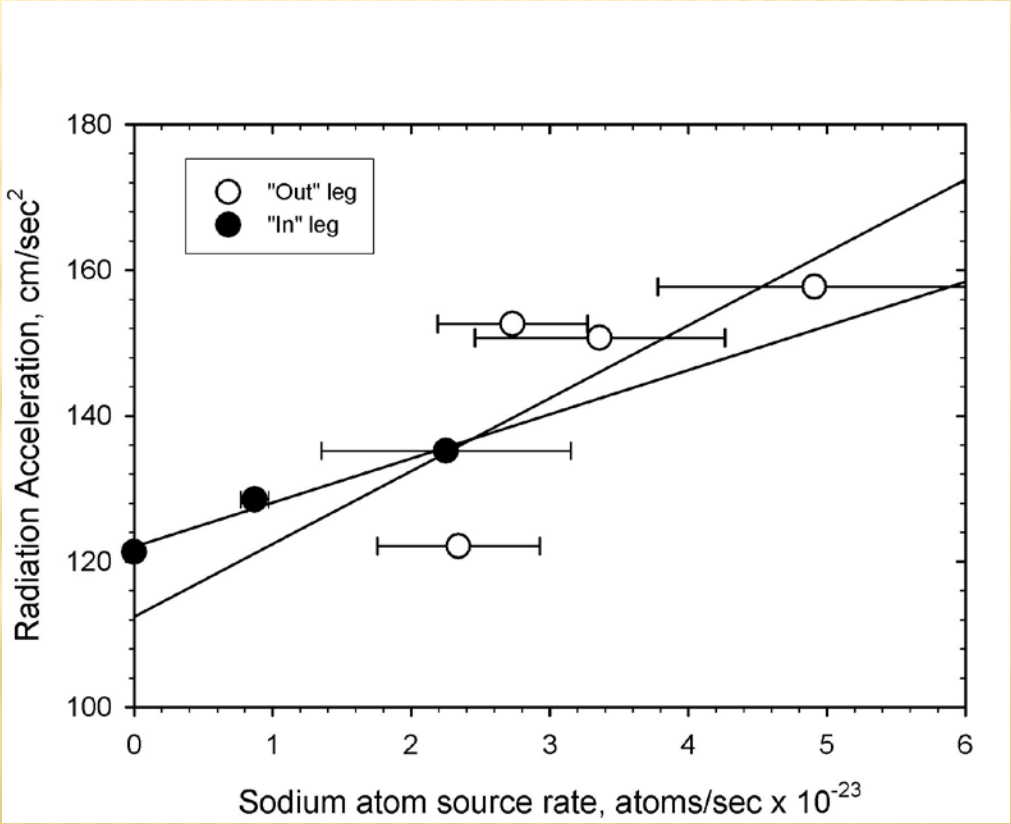
TAIL AND EXOSPHERE SODIUM



Potter, A.E., et al., The Sodium Tail of Mercury,Met. Planet. Sci., 37, 1165-1172, 2002

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?

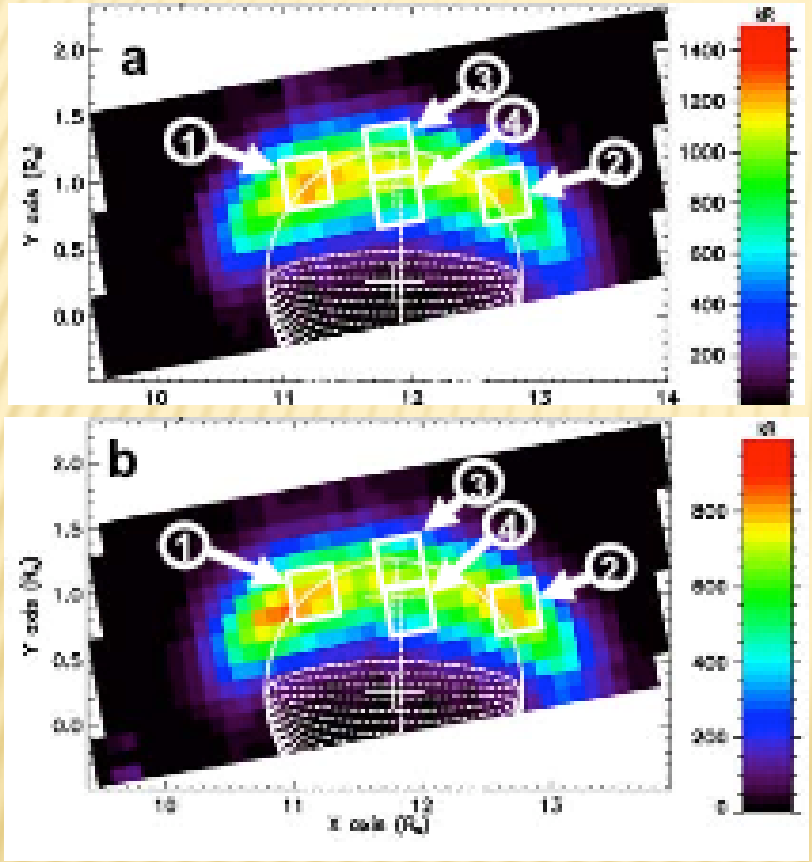
  sputtering to ions vs. neutrals?

  ESD

  yield, flux of electrons

  ALL – surface composition

SPATIAL DISTRIBUTIONS



Sodium exhibits high latitude enhancements but not AT the poles
Note N/S asymmetry

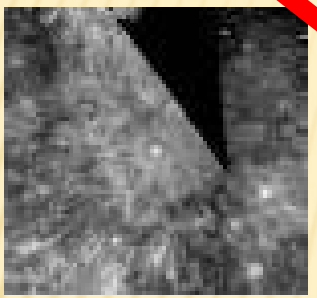
Suggestive of

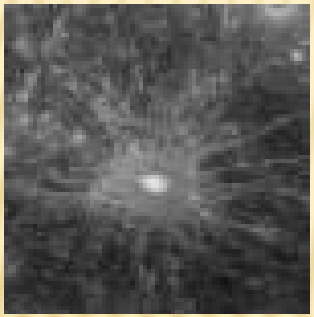
Ion sputtering in open field regions
Ion-enhanced sputtering
radiation pressure transport

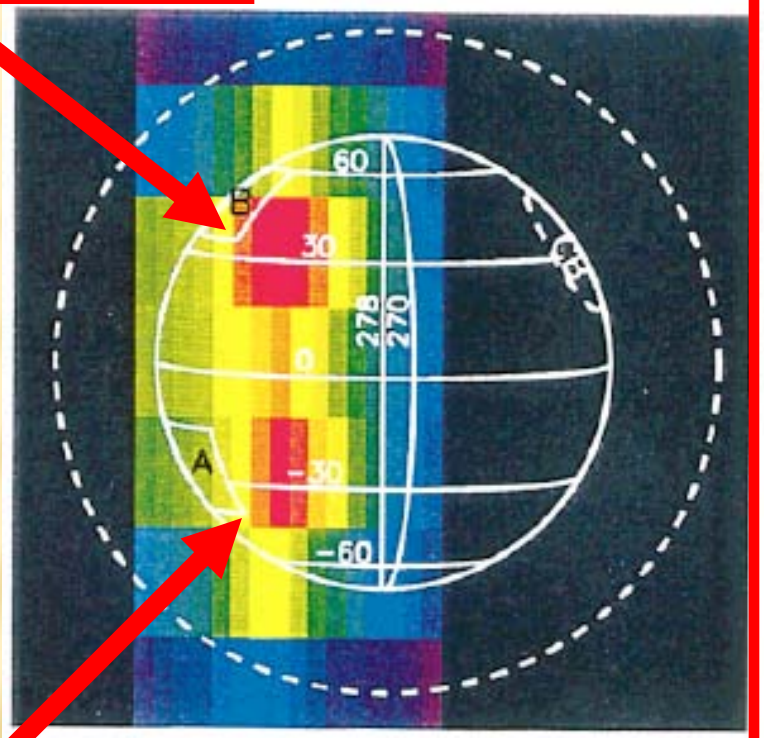
Leblanc et al. GRL; observations 2007/06/01 THEMIS
a) Na D2
b) Na D1

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

Hokusai (Radar Bright Spot B)







Debussy (Radar Bright Spot A)

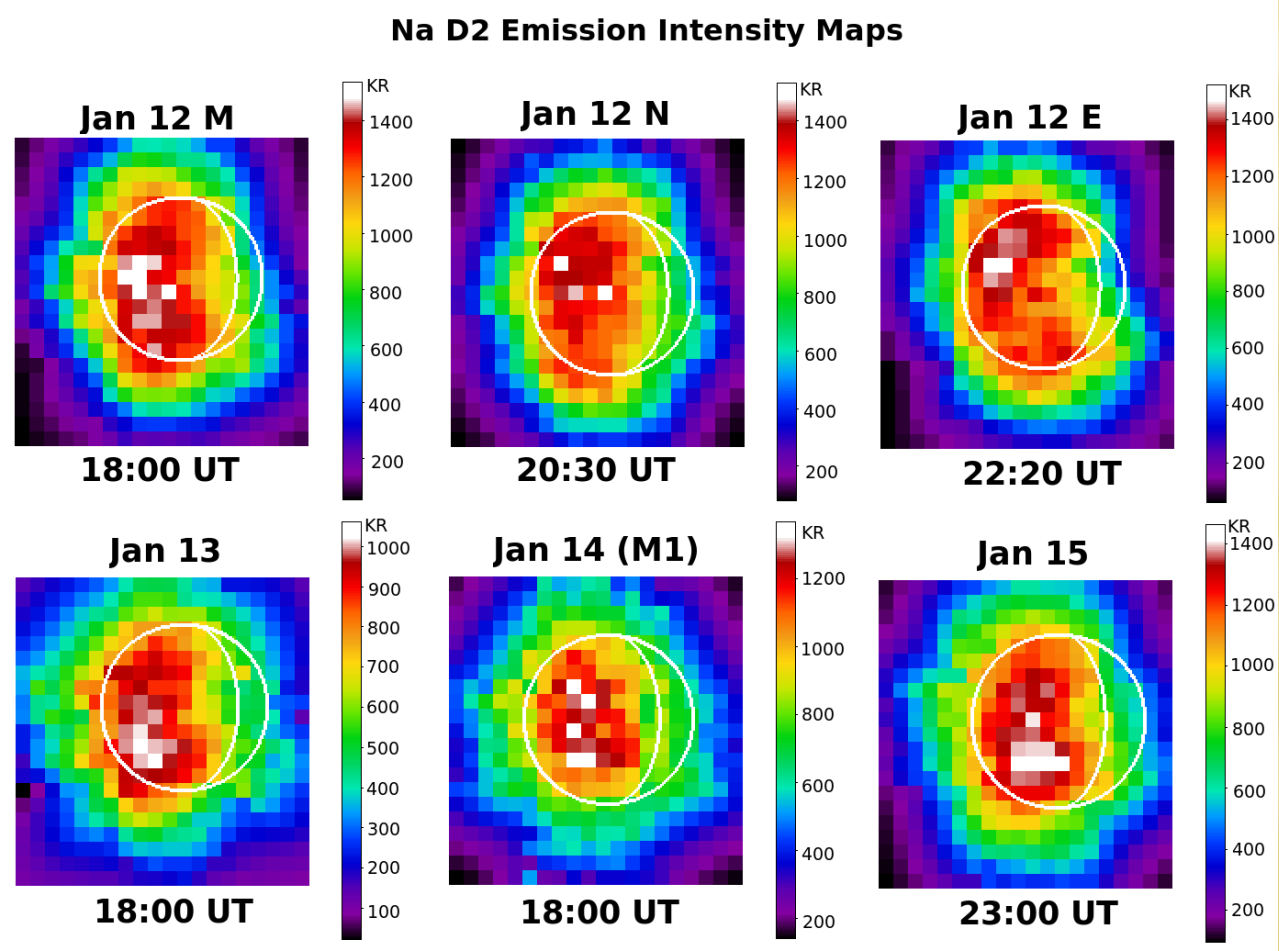
Could be Na sources

……

Will be thoroughly tested during the orbital phase measurements

data taken at the 61” Mt. Bigelow, echelle spectrograph

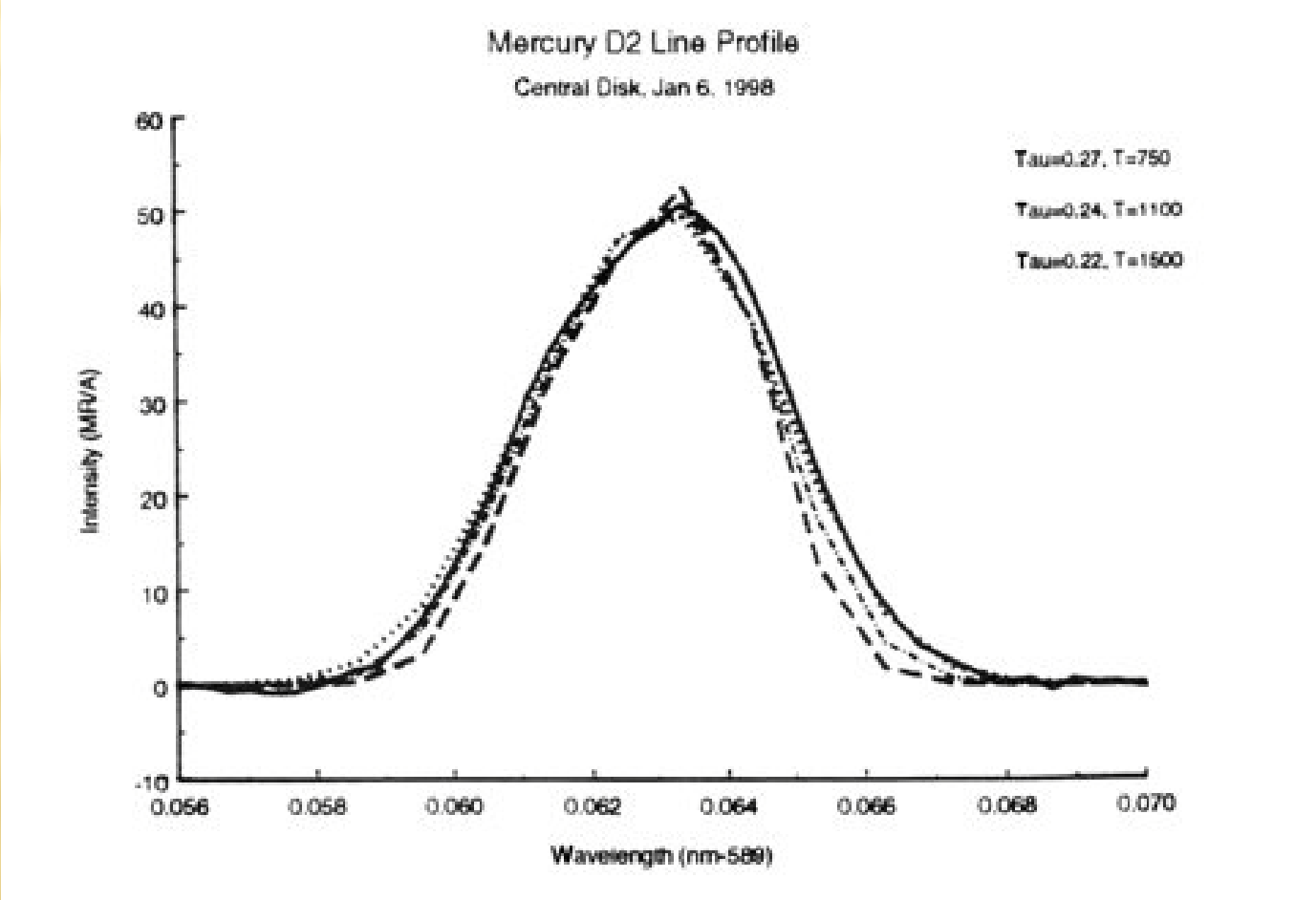
DAILY VARIATIONS, WEEKLY VARIATIONS



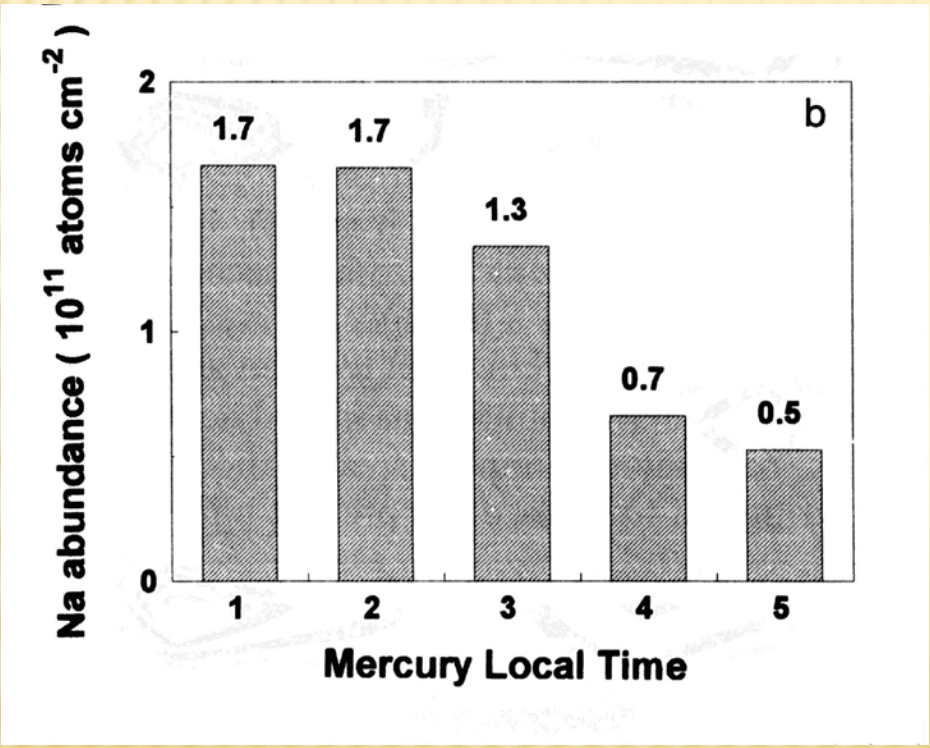
Mouawad, N., et al.. Mercury's sodium exosphere during the first MESSENGER Flyby: Simultaneous Ground-Based and Space Based Observations. Icarus. In press, 2010.

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)



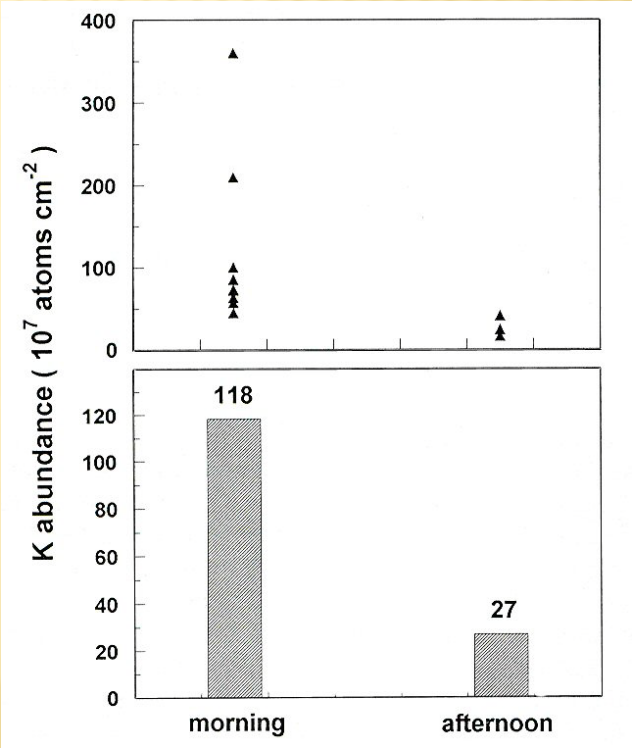


TABLE 1. Mercury Atmospheric Potassium Observations
Average Zenith Column Abundance

Date	Time, UT	Morning	Afternoon
Nov. 16, 1985*	2148	72	
June 19, 1986	0253	45	
	0301	57	
	0312	63	
June 8, 1987	2206	73	
June 9, 1987	0251	85	
Oct. 14, 1987	2132	360	
	2222	100	
Jan. 22, 1988	0110	210	
Dec. 2, 1986	1334		24
March 13, 1987	1315		41
	1341		16

Abundances are in units of 10^7 atoms cm^{-2}. Uncertainty in the measurements is discussed in the text.

*Value from *Potter and Morgan* [1986]; all others from *Sprague et al.* [1990].

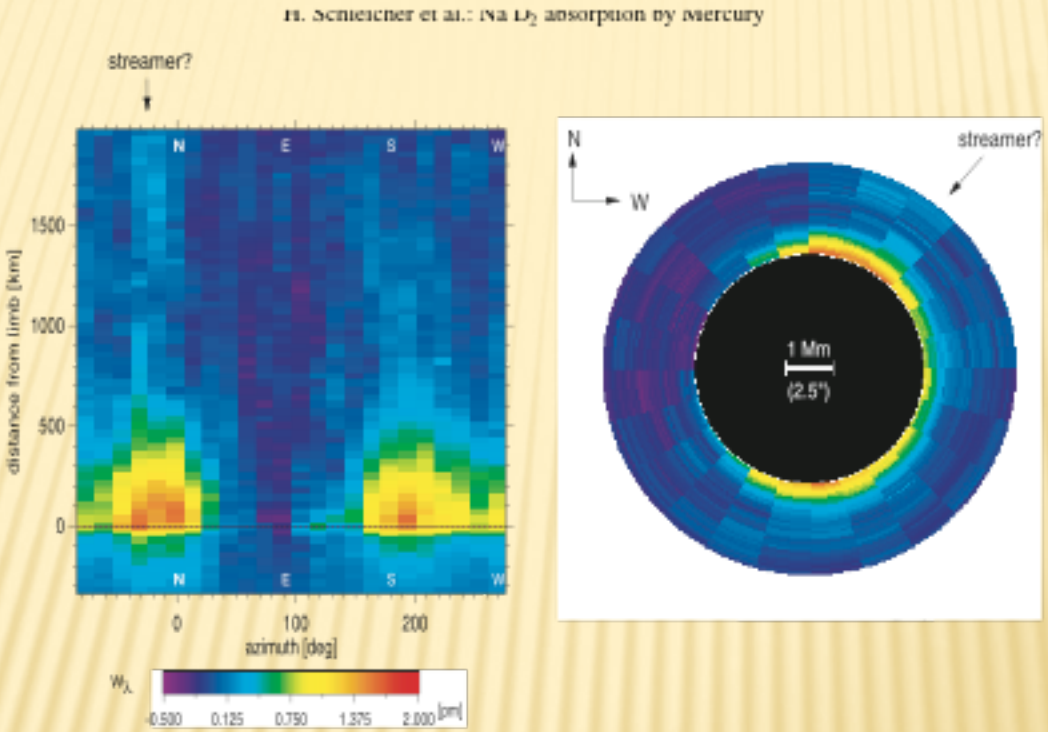
(Received December 9, 1992.)

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

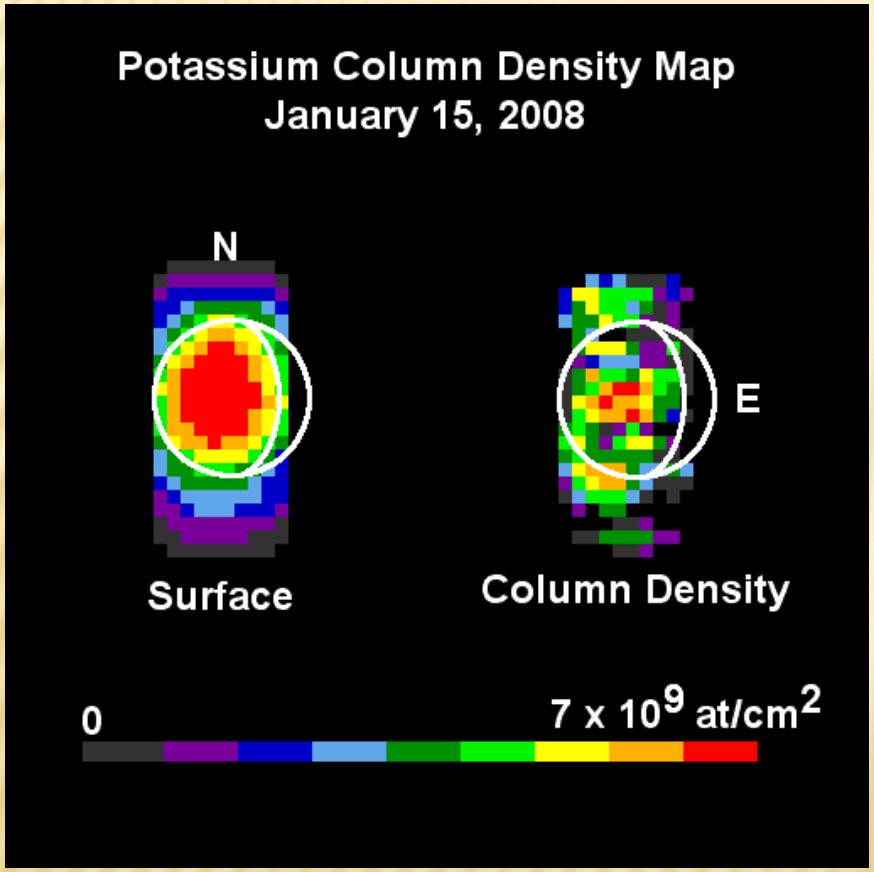
SODIUM FROM TRANSIT OF MERCURY

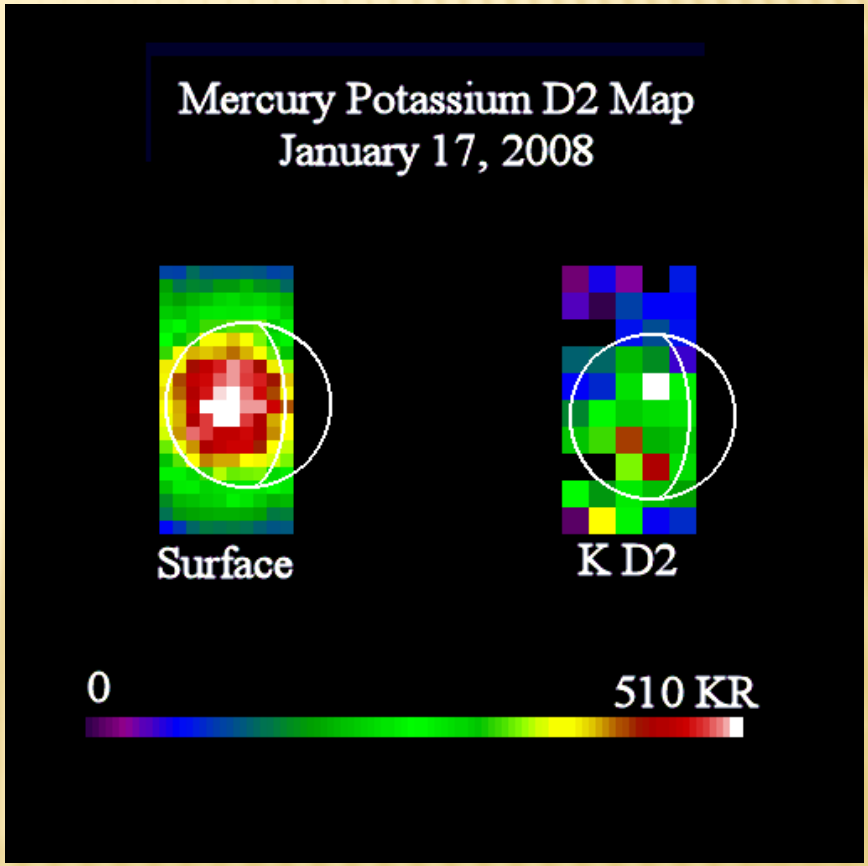


Observations during the transit of 2003 show North/South enhancements AT the poles and an East/West asymmetry (Schleicher et al., A&A, 425, 2004);
data from vacuum telescope on Tenerife

POTASSIUM – TEMPORAL VARIATION

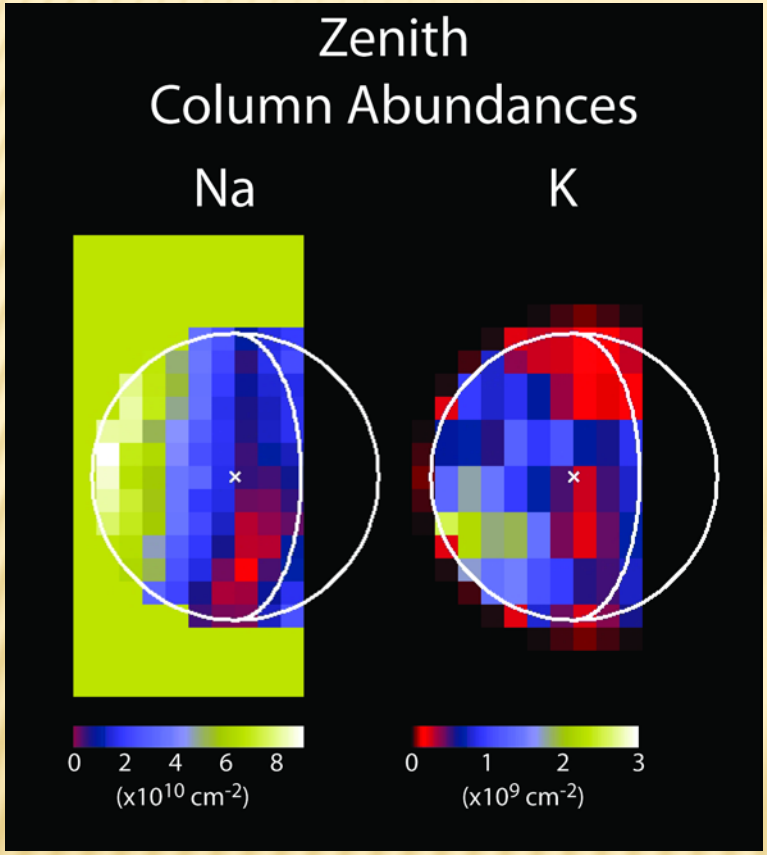
observed by Potter, Killen and Mouawad, January, 2008





Killen, R.M. et al., Observations of Metallic Species in Mercury's Exosphere, *Icarus* 209#1, 2010.

SODIUM VS. POTASSIUM DISTRIBUTION



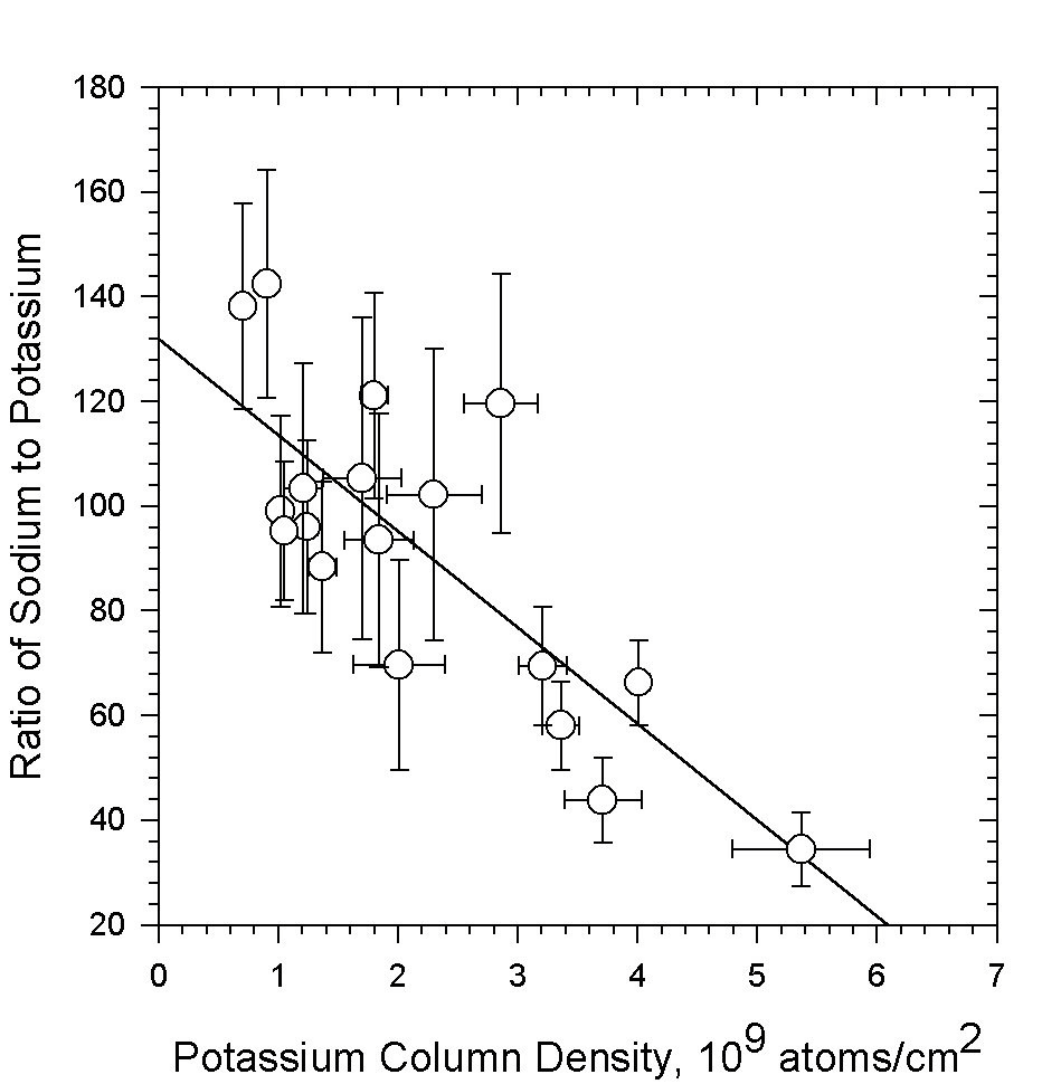
Distributions of Sodium and Potassium are different

Sodium and Potassium Observed Jan. 17, 2008

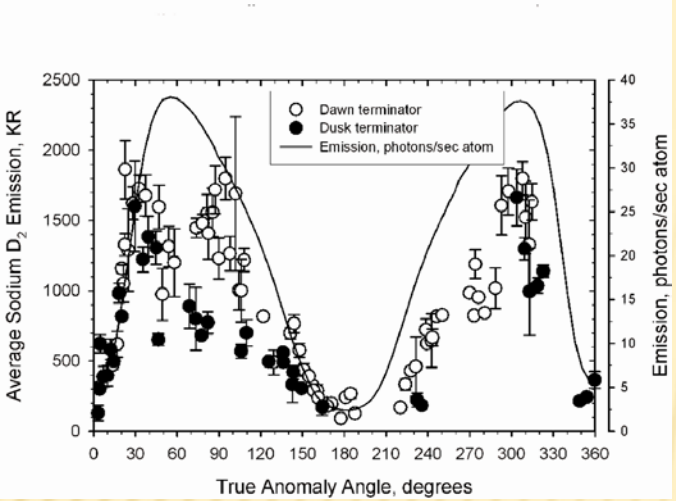
Killen, R. M. et al., Observations of Metallic Species in Mercury's Exosphere, *Icarus* 209#1, 2010.

Ratio of Sodium to Potassium

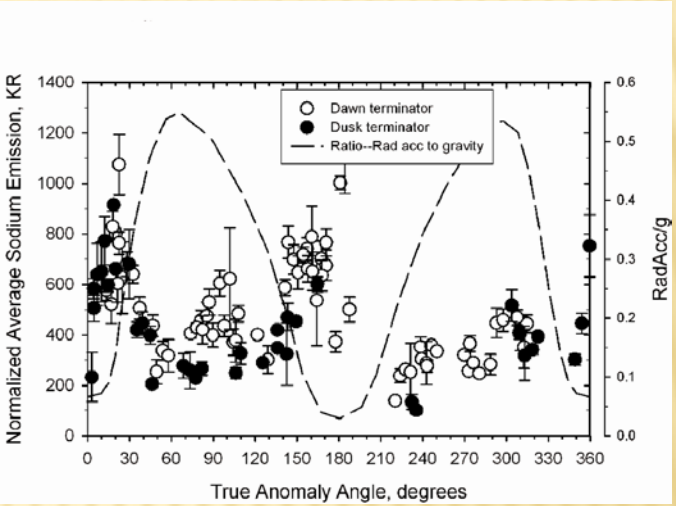
- Values range from 30 to 140



RADIATION PRESSURE EFFECTS



Planet-wide average sodium emission is plotted against true anomaly angle. Open circles are dawnside, closed circles are duskside.



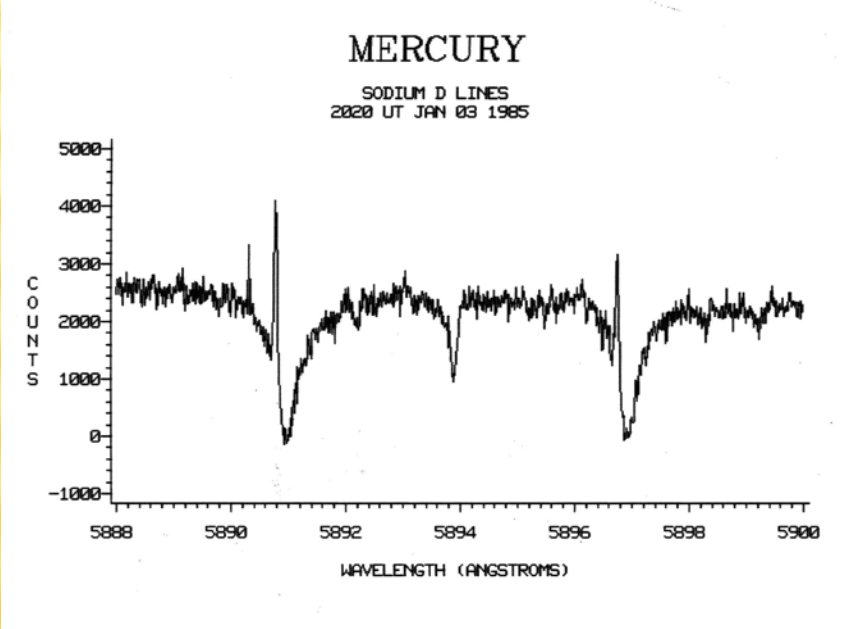
To eliminate the effect of the Doppler shift on solar flux at the rest frequency of atoms in Mercury's exosphere, the emission was normalized to conditions at true anomaly angle 143.78°.
The resulting emission values would be proportional to the average column abundance of sodium in the absence of acceleration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

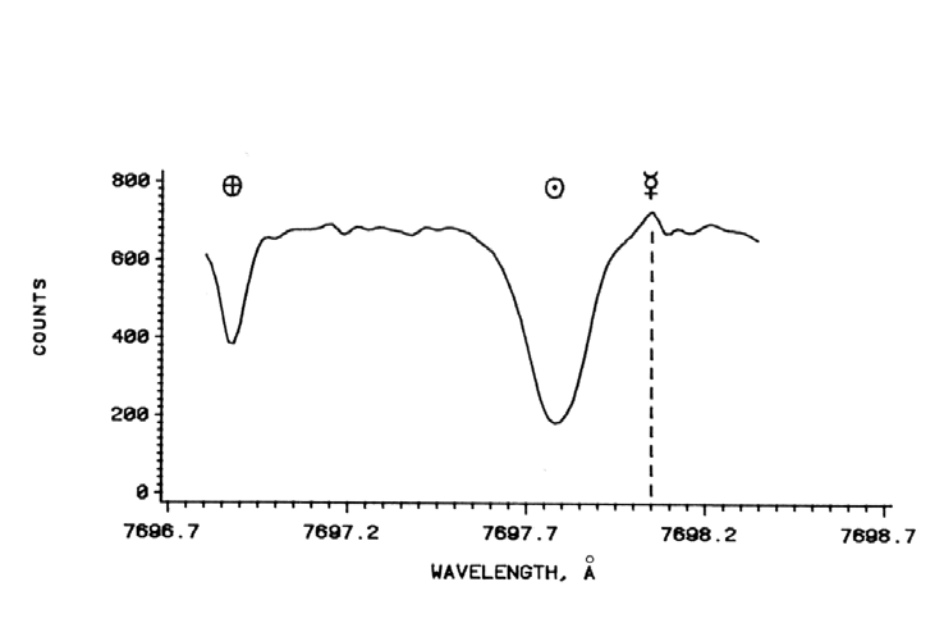
Potter, A.E., et al., Solar radiation acceleration effects on Mercury sodium emission Icarus 186 #2, 571-580, 2007.

Major Species: Sodium and Potassium

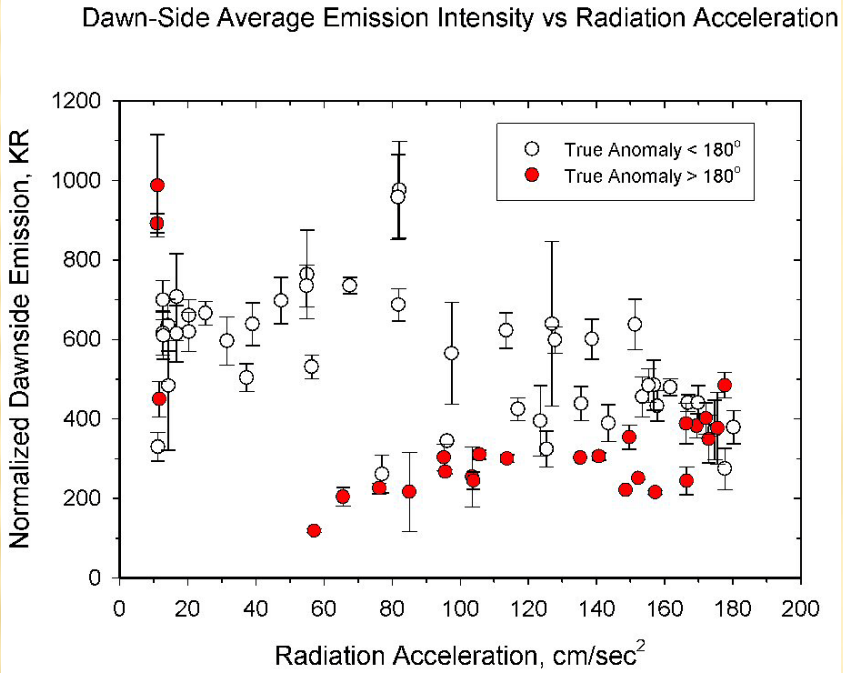
Sodium: Potter & Morgan (1985) McDonald

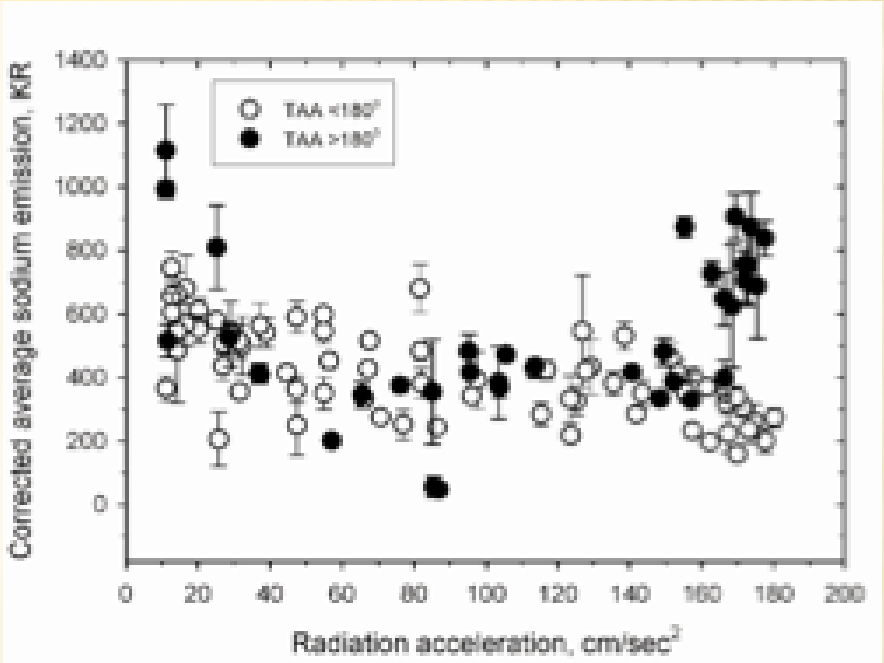
Potassium: Potter & Morgan (1986) NSO





SODIUM VS. RADIATION PRESSURE



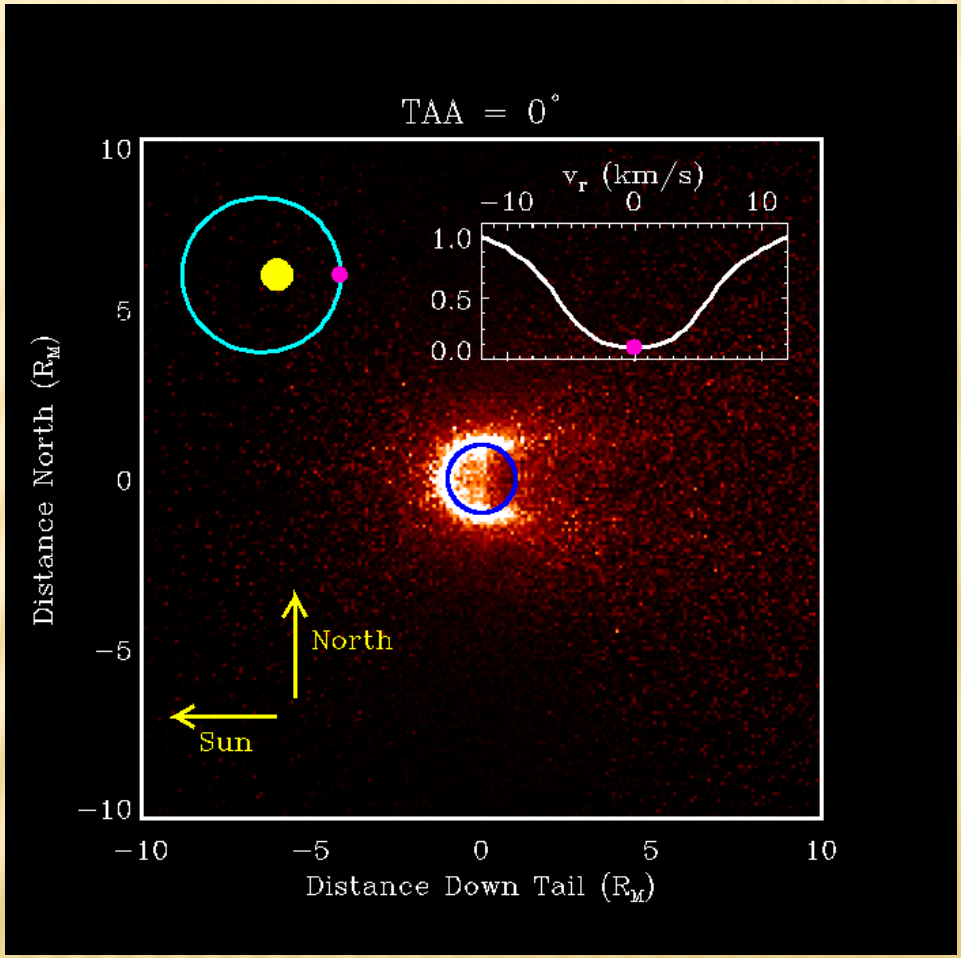


Correction factors were used to correct the normalized sodium observations for the effect of solar radiation acceleration.

Uncorrected data:
true anomaly < 180 open circles
true anomaly > 180 filled circles

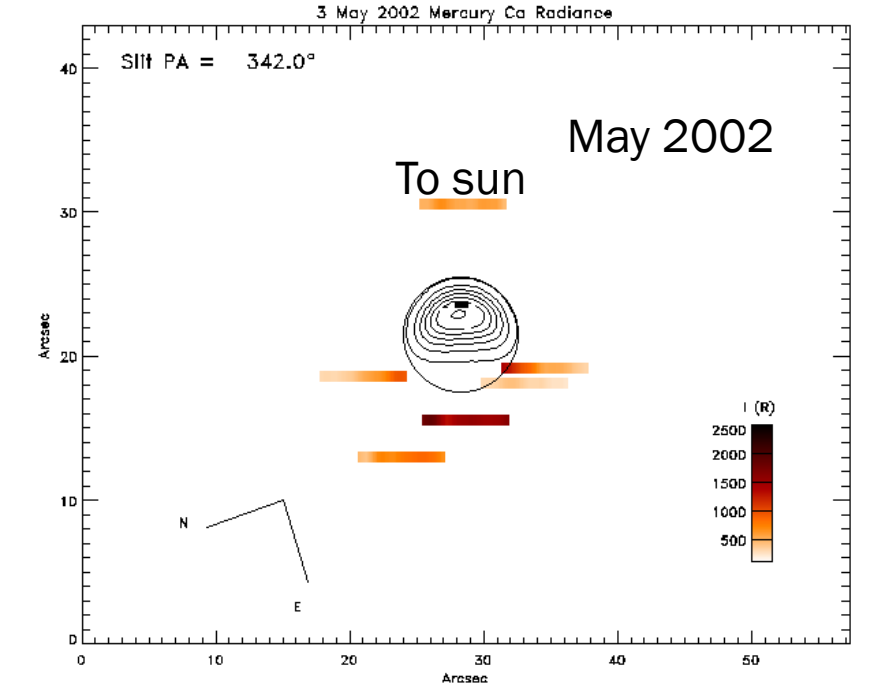
Potter, A.E., et al. Solar radiation acceleration effects on Mercury sodium emission, Icarus 186 #2, 571-580, 2007.

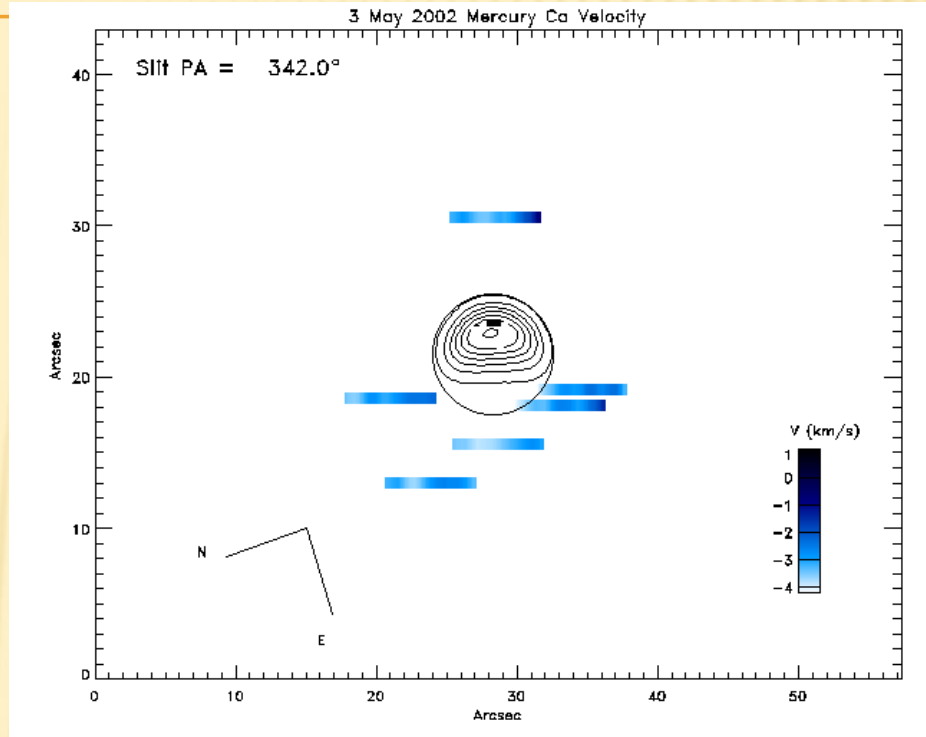
VARIATIONS ABOUT THE ORBIT

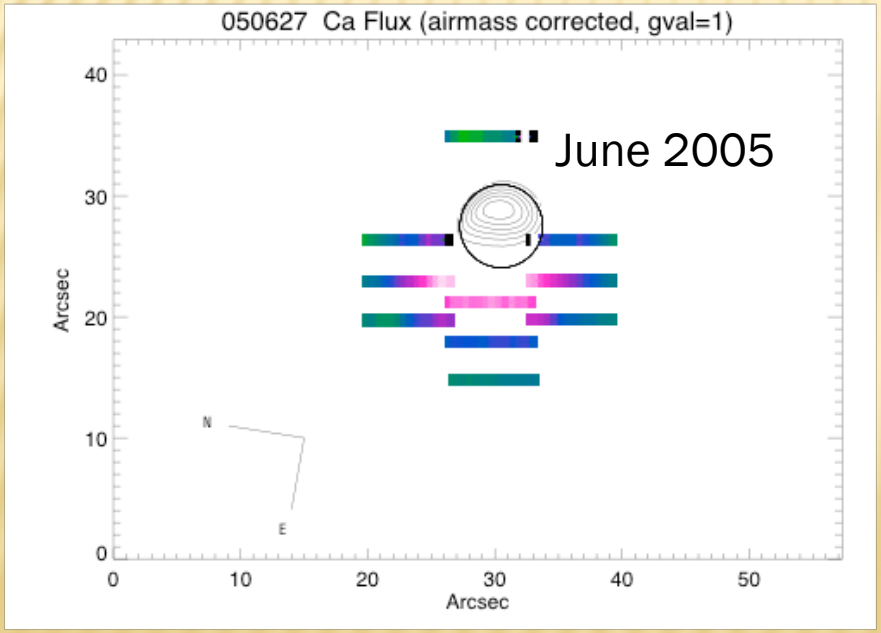


movie courtesy Matthew Burger: assumes a uniform caldium source for illustration

CALCIUM







Calcium radiance (left), velocity (right)

Appears to be concentrated anti-sunward
Velocity blue shifted – implies high velocity

Killen, R.M., et al., The calcium exosphere of Mercury, Icarus, 173#2, 300-311, 2005.

OBSERVATIONS OF AL, Fe, Ca^+ FROM KECK

Bida and Killen, Planetary and Space Science, submitted 2010

4 σ detection Fe

4 σ detection Al

3 σ 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