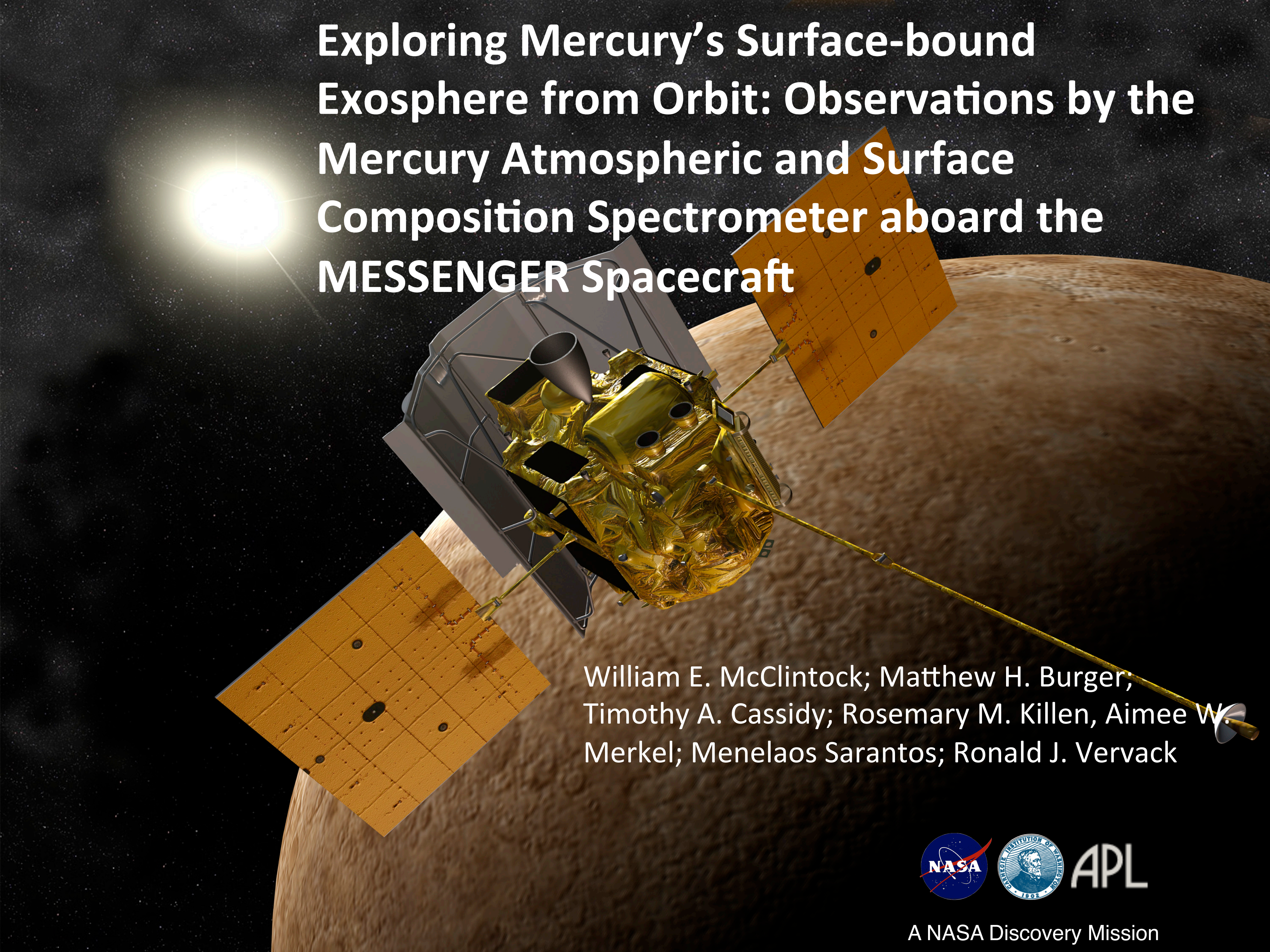
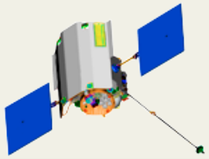
Exploring Mercury's Surface-bound Exosphere from Orbit: Observations by the Mercury Atmospheric and Surface Composition Spectrometer aboard the MESSENGER Spacecraft



William E. McClintock; Matthew H. Burger; Timothy A. Cassidy; Rosemary M. Killen, Aimee W. Merkel; Menelaos Sarantos; Ronald J. Vervack

A NASA Discovery Mission

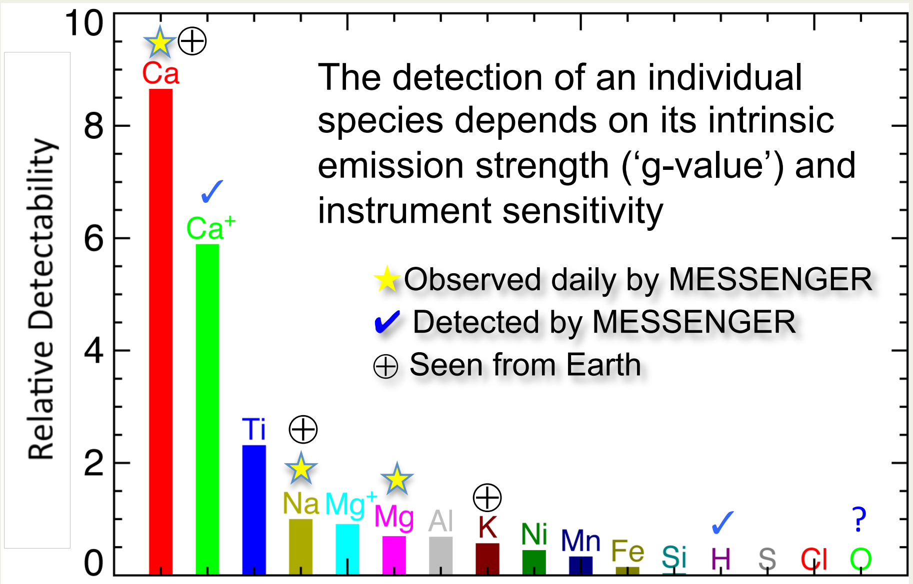


Mercury Is Surrounded by a Surface-Bounded Exosphere

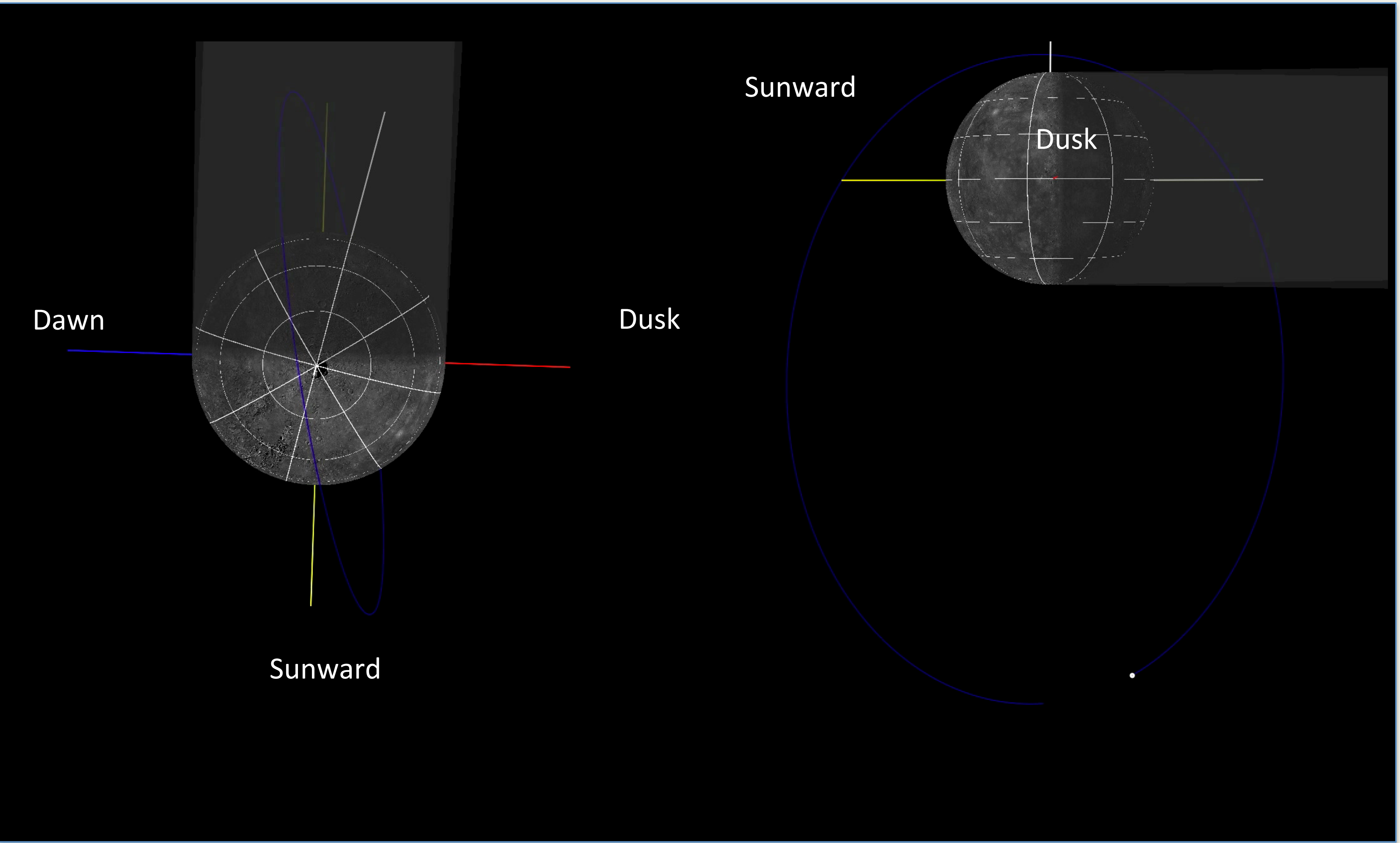
- Generated and maintained by the interaction of the space environment (solar radiation and wind and dust impacts) with the surface
- Low-density, 'collisionless' atmosphere
  - Highly variable (both spatially and temporally)
  - Driven by both seasonal and episodic processes

MESSENGER Studies Mercury's Neutral Exosphere by Remote Sensing With the Mercury Atmospheric and Surface Composition Spectrometer

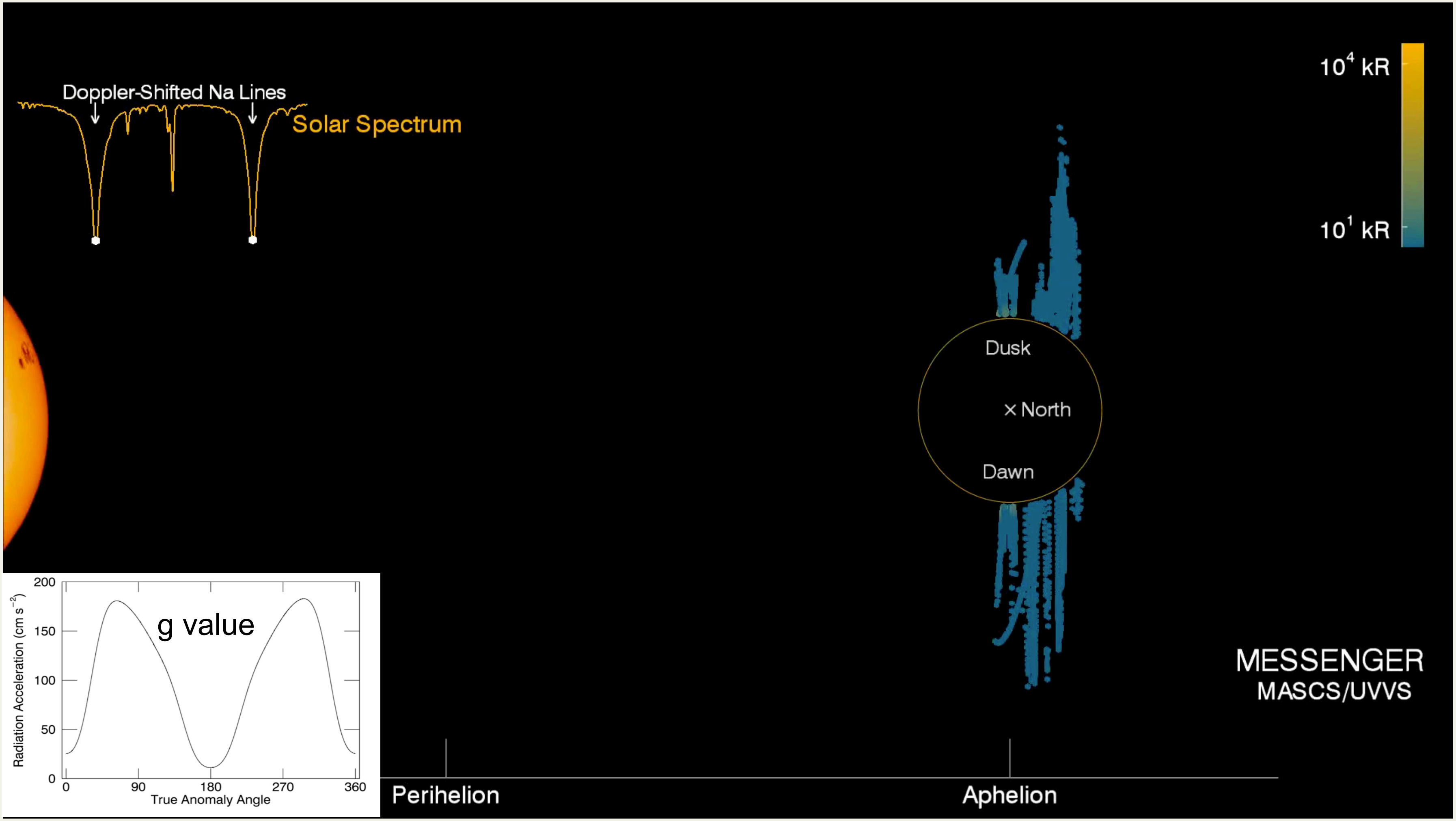
- Na, Mg and Ca: observed with daily cadence
- H: likely originates from solar wind implantation
- Ca^+: detected 2.5 R_M behind the terminator during Flyby 3
- O: previously reported detection above the subsolar point in multi-week average not substantiated by additional observations
- Al, K, Fe, S, O, etc.: upper limits

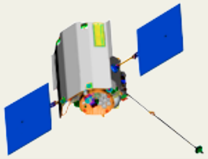


MESSENGER Orbit Enabled Both Dayside and Nightside Observations



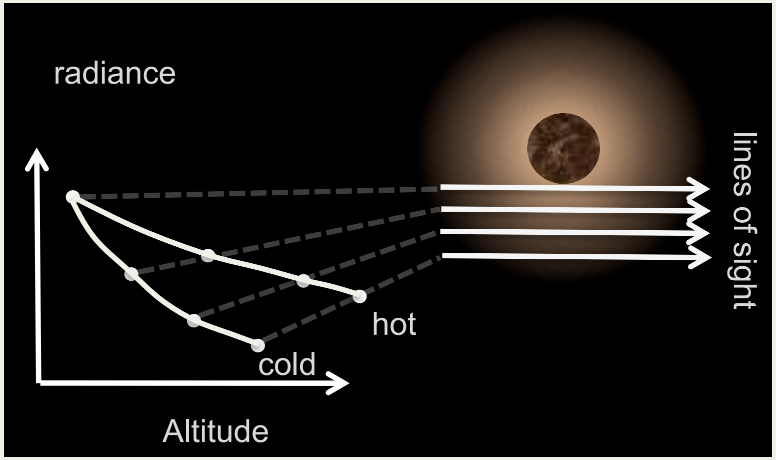
Radiation Pressure Plays an Important Role in Determining Exosphere Brightness

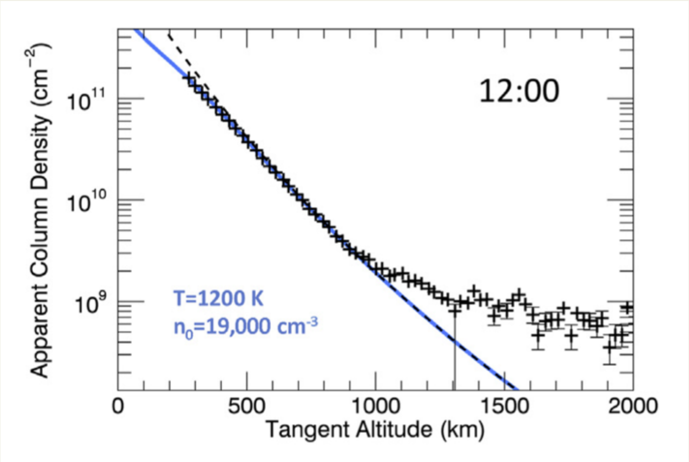




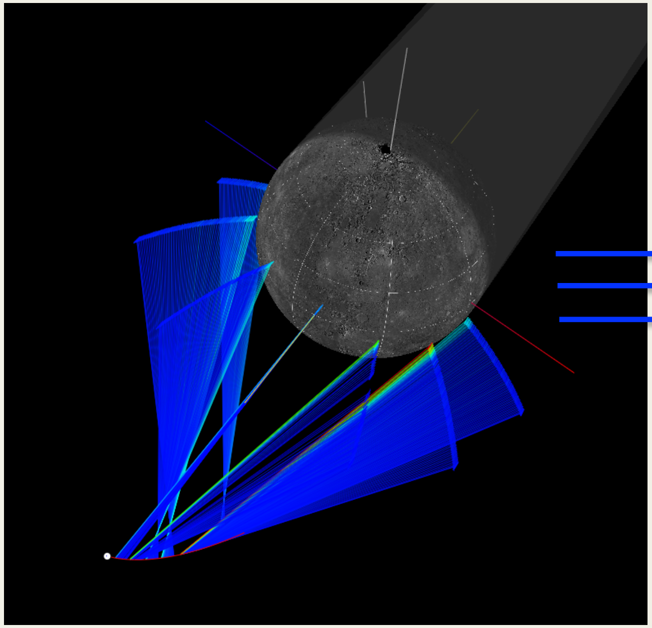
Dayside Altitude Profiles

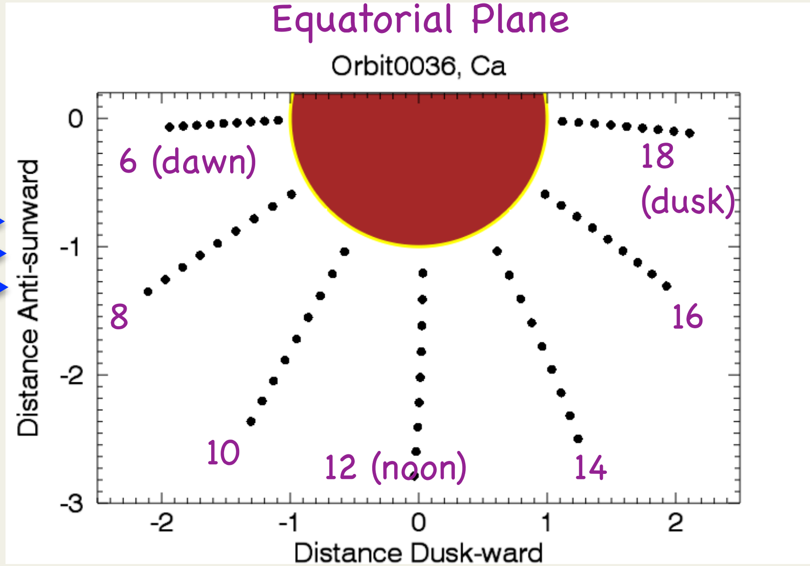
'Limb scans' measure sunlight scattered by the exosphere

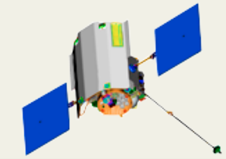




Multiple limb scans when the spacecraft is near apoapsis provide **altitude profiles near the equator** at a number of local times



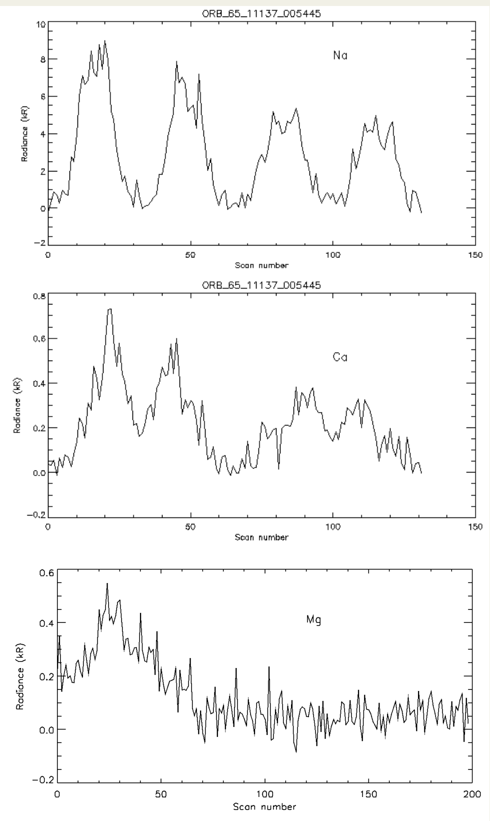


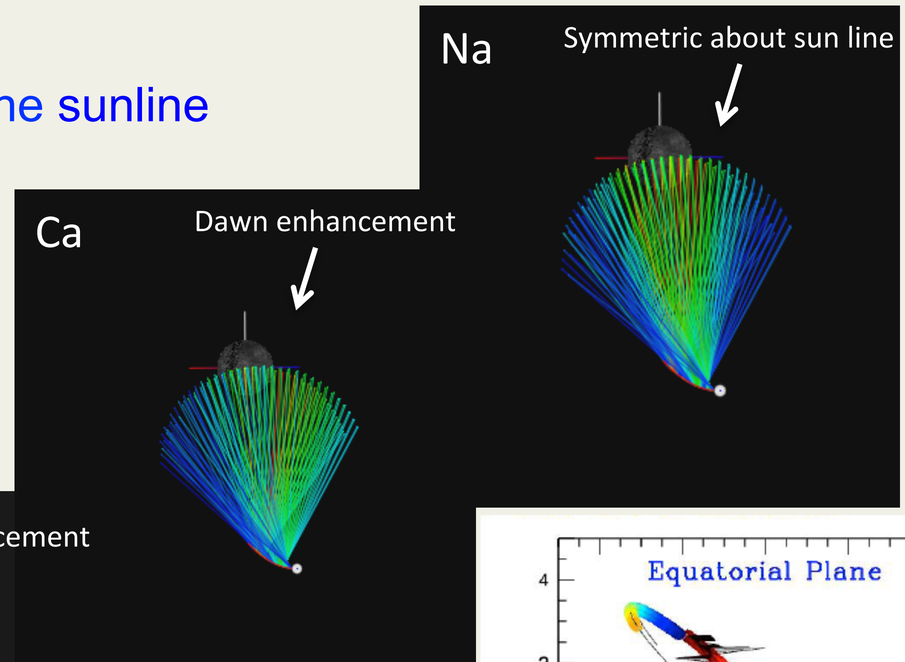


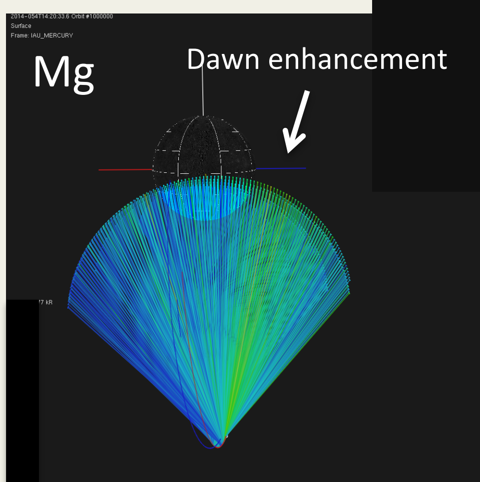
Nightside Sweep Scans

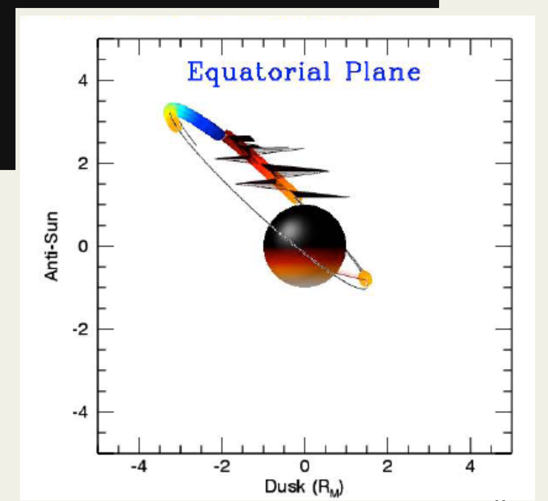
Nightside fantail scans are consistent with flyby results

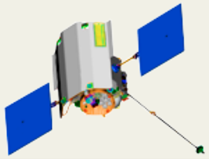
- Dawn enhancement in Magnesium
- Dawn enhancement in Calcium
- Sodium appears symmetric about the sunline







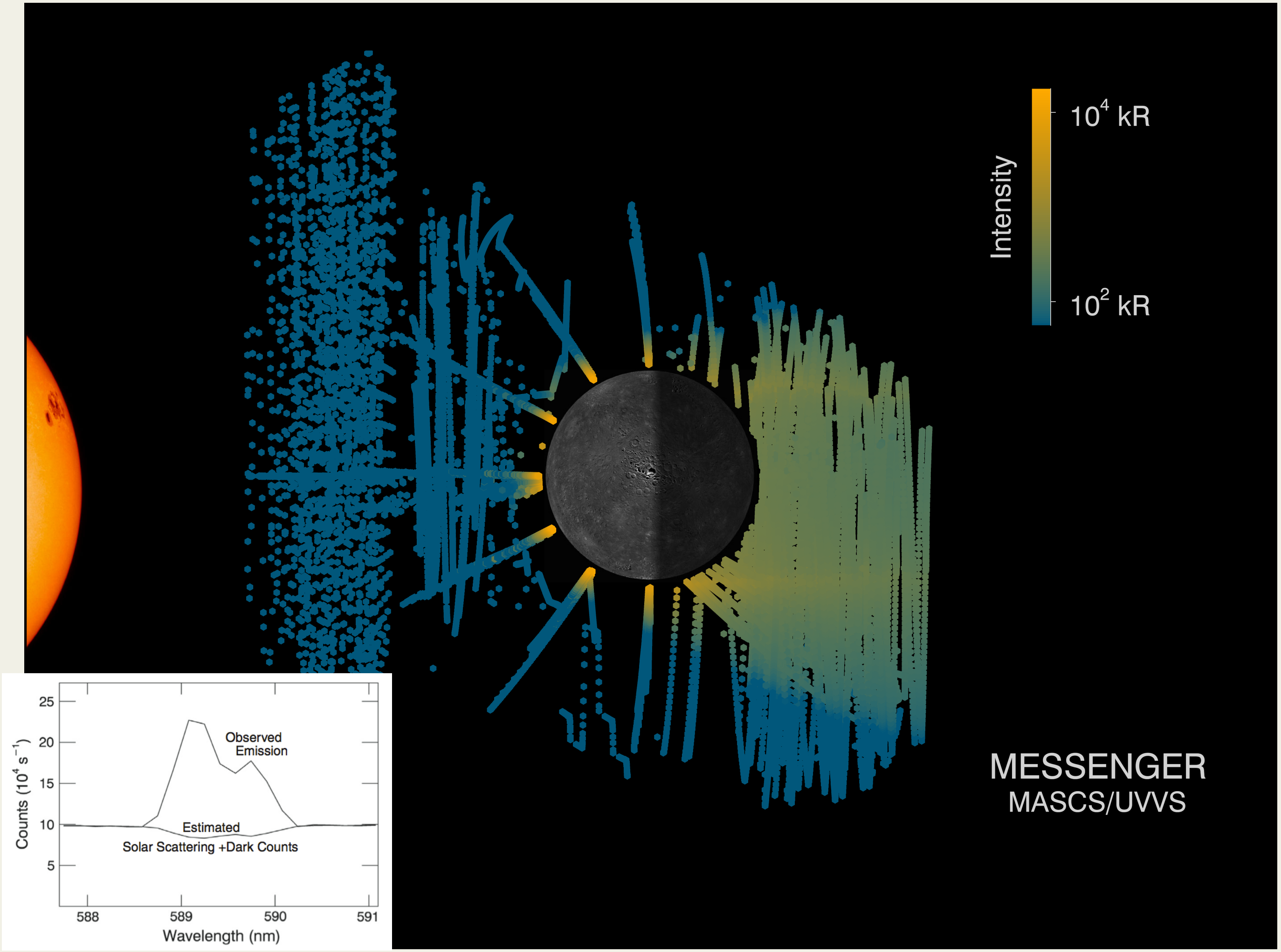




Some Quantitative Results

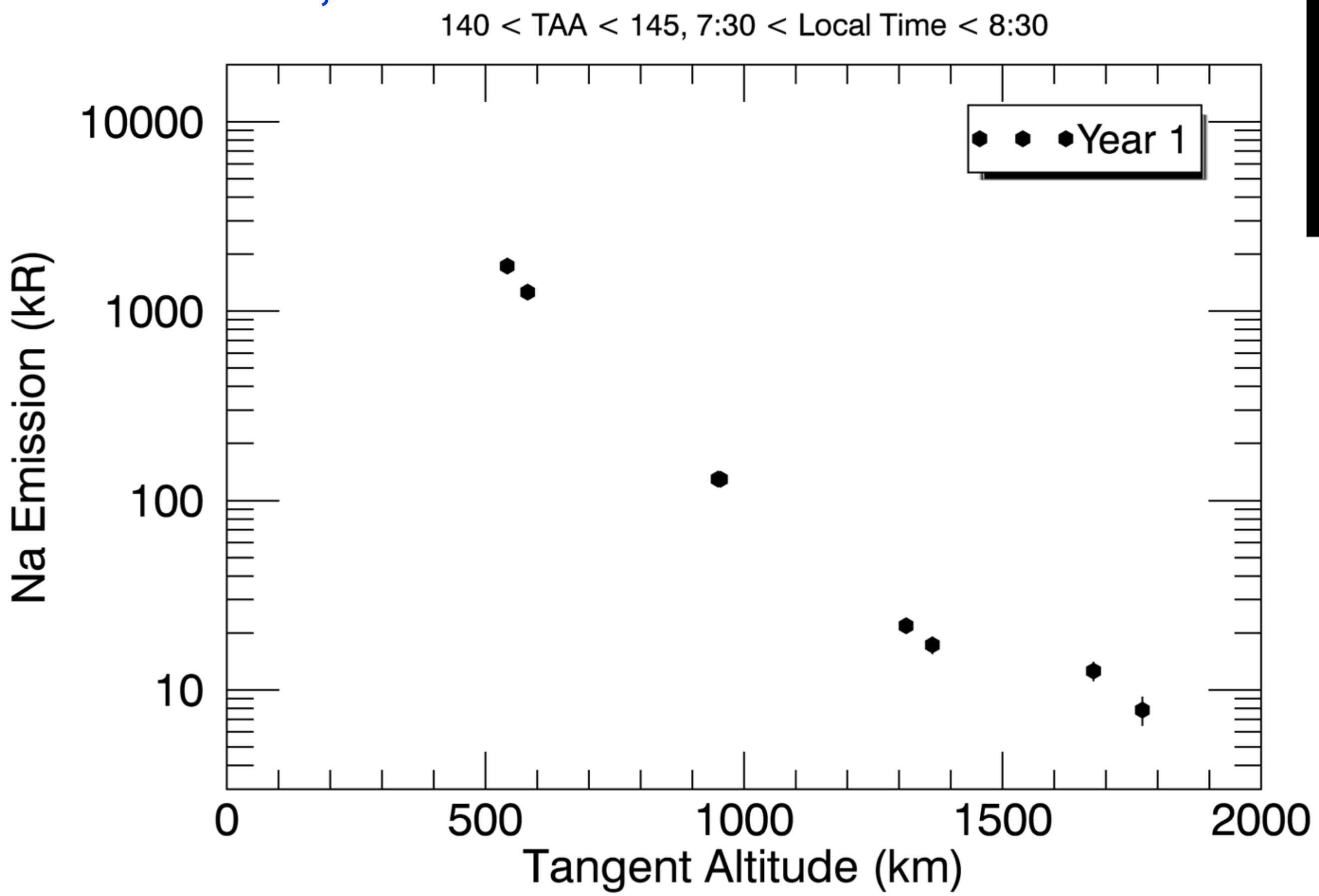
- Sodium composition and seasonal variation – Tim Cassidy
- Calcium observations and modeling – Matt Burger
- Magnesium composition and seasonal variation – Aimee Merkel
- Dayside and nightside magnesium modeling – Menelaos Sarantos
- Temporal variations – Mercury's climate and weather
- Weak species – Ron Vervack
- What we learned about the exosphere from MESSENGER ('The Top 10')

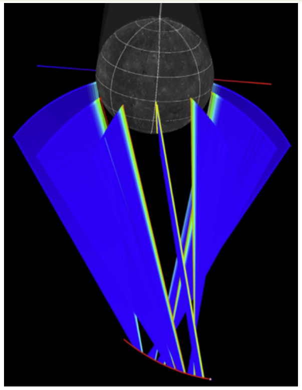
A Snapshot of the Sodium Exosphere observed by MESSENGER Just Before Aphelion, When Radiation Pressure Is Maximum



Sodium Emission Annual Variation

- 8:30 Local time, TAA ~ 140°





Sodium Emission Annual Variation

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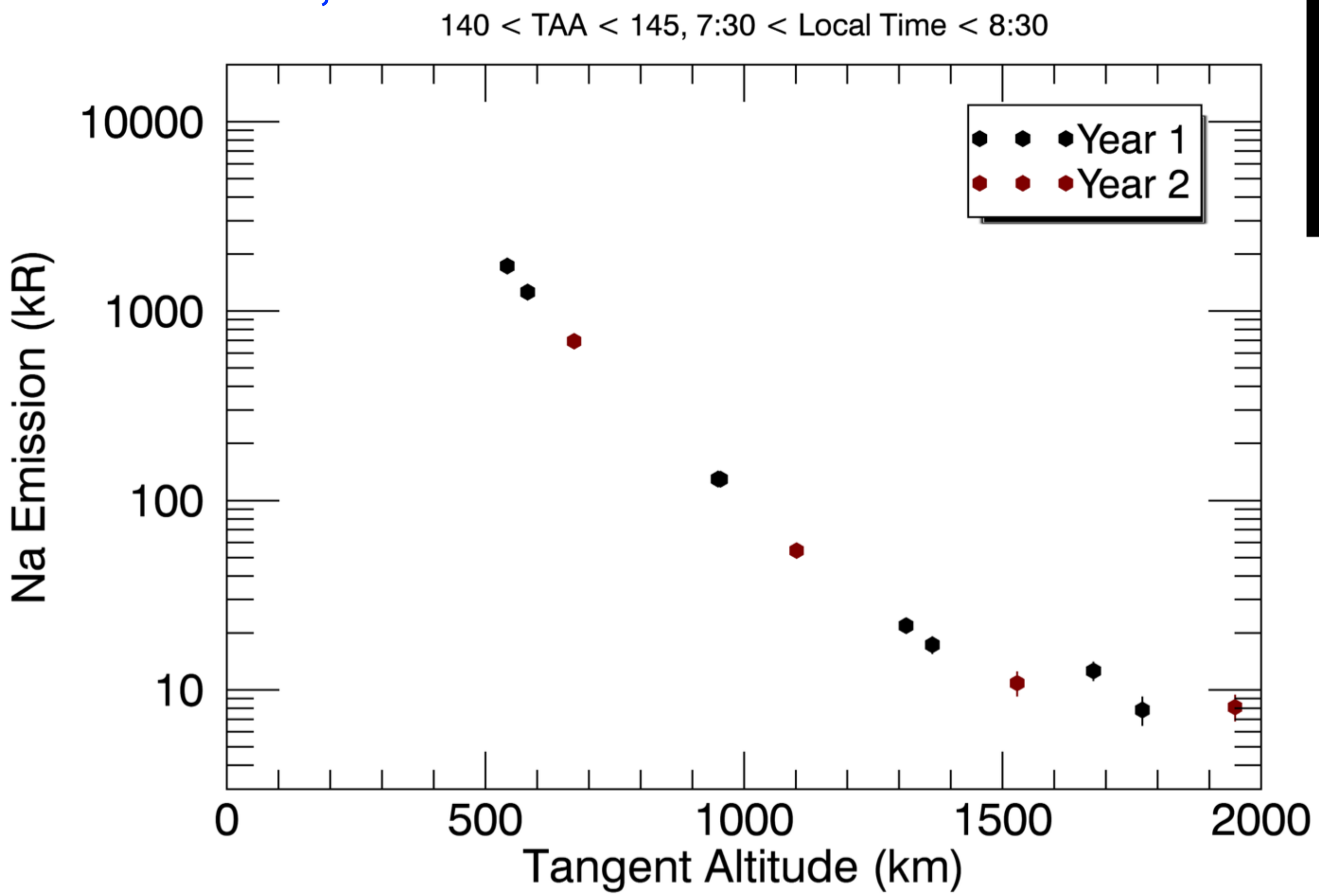

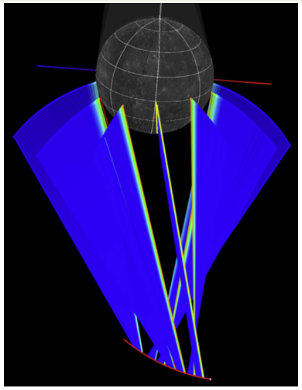

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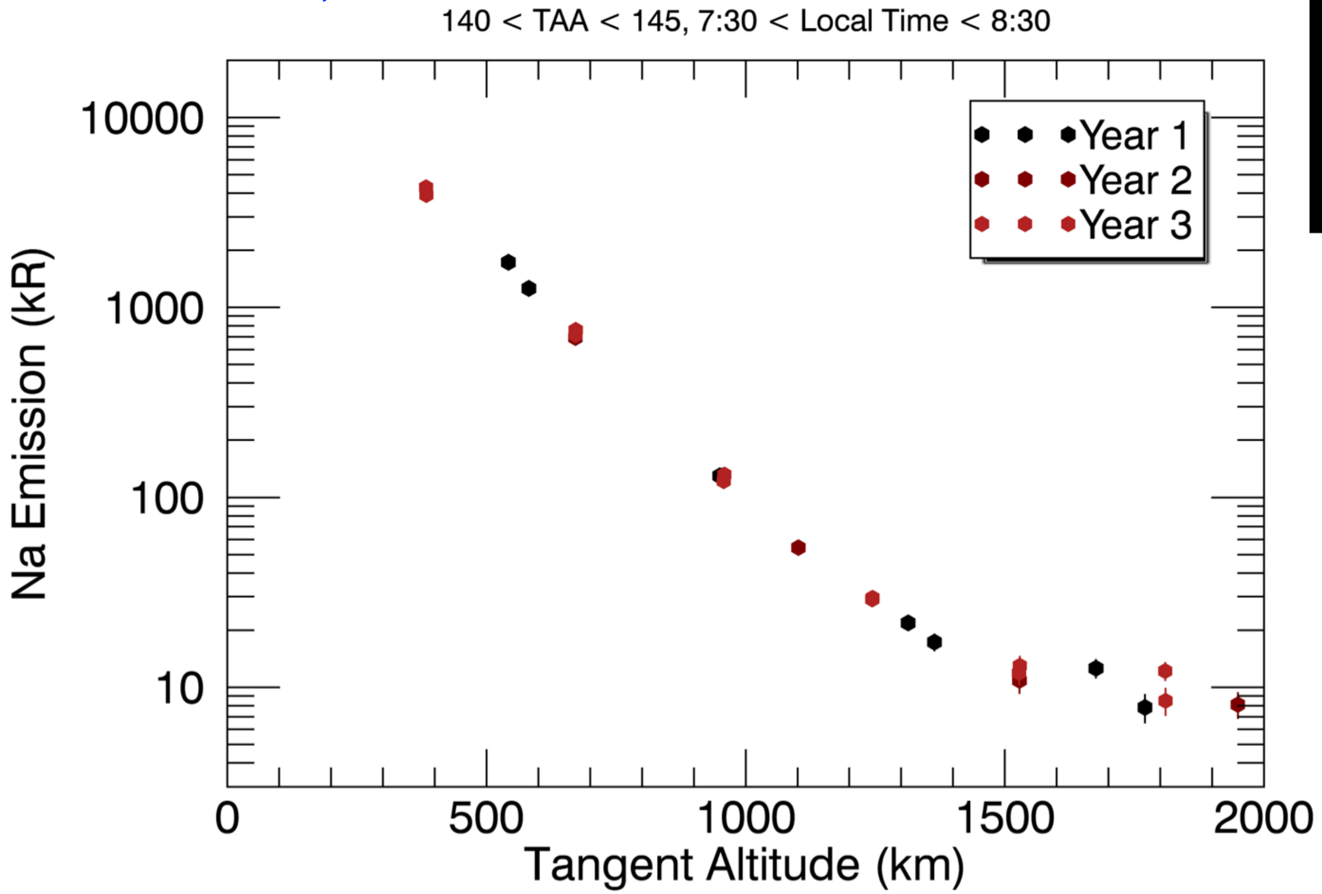

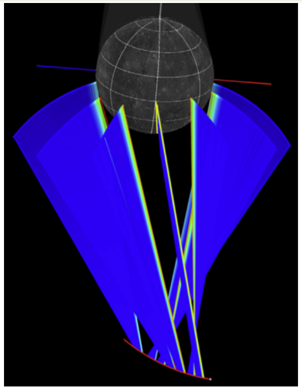

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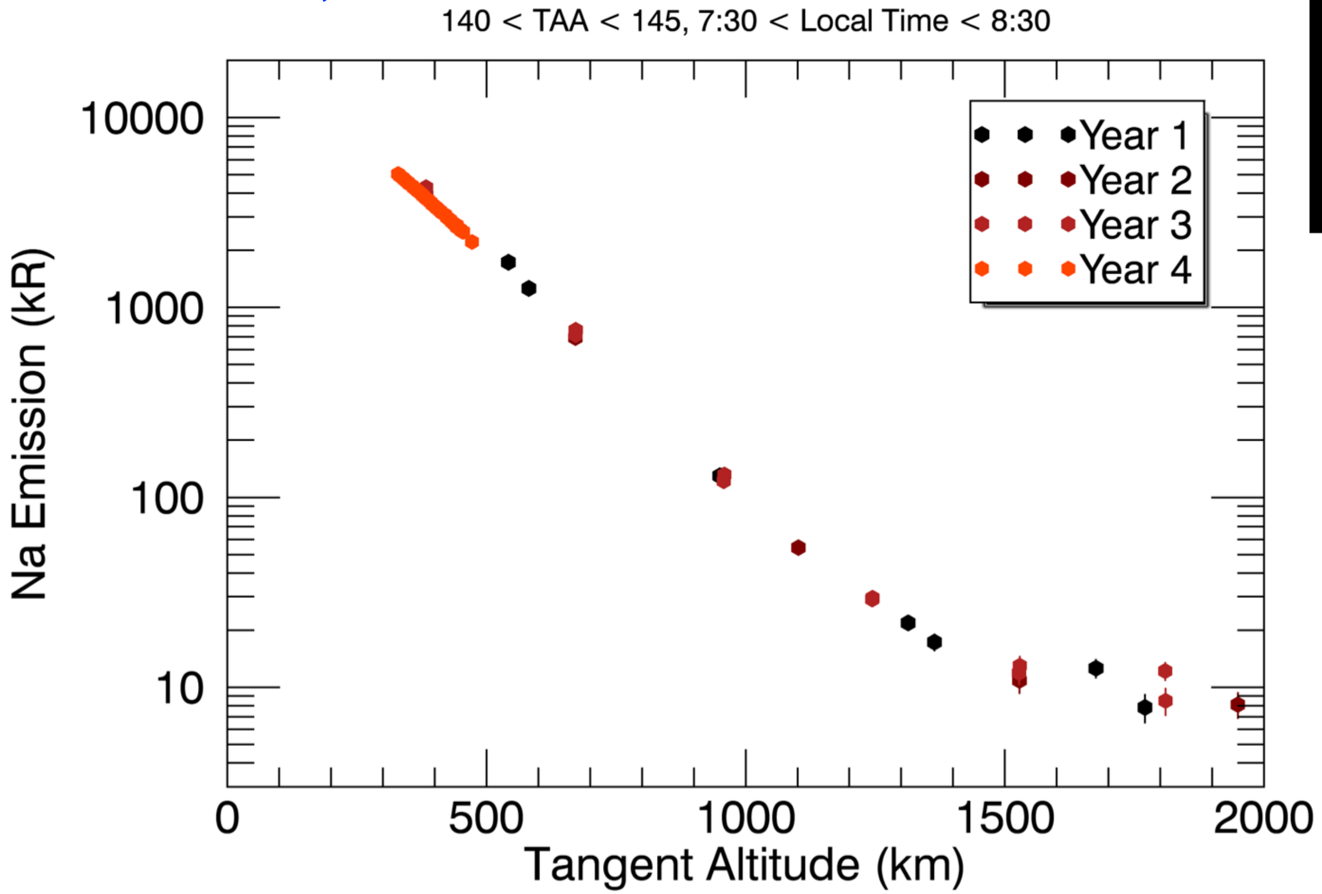
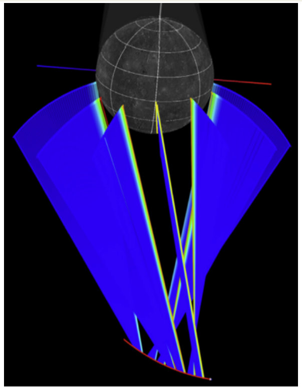
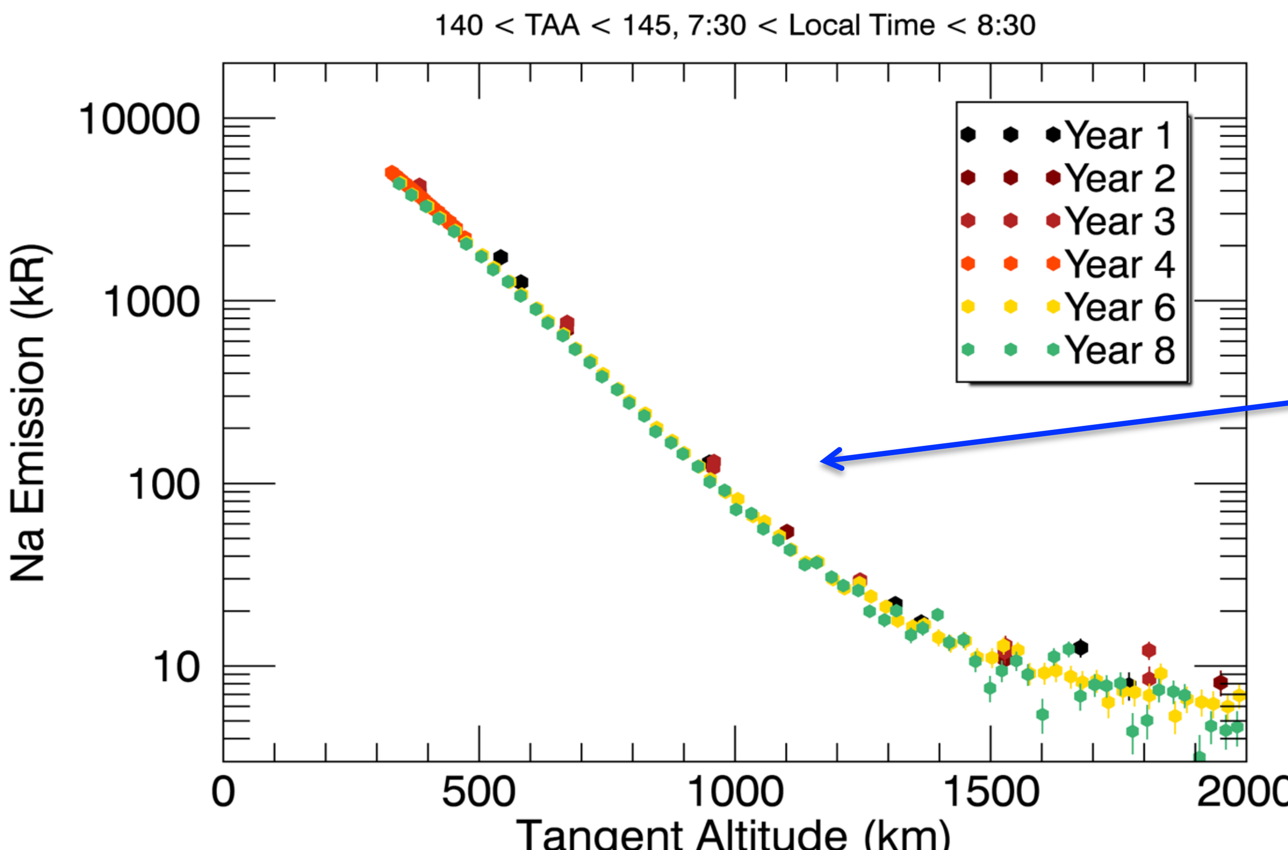
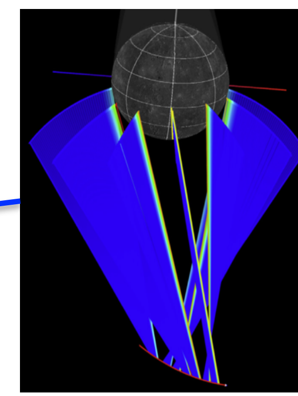


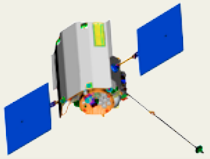


Sodium emission is remarkably consistent Mercury year after Mercury year

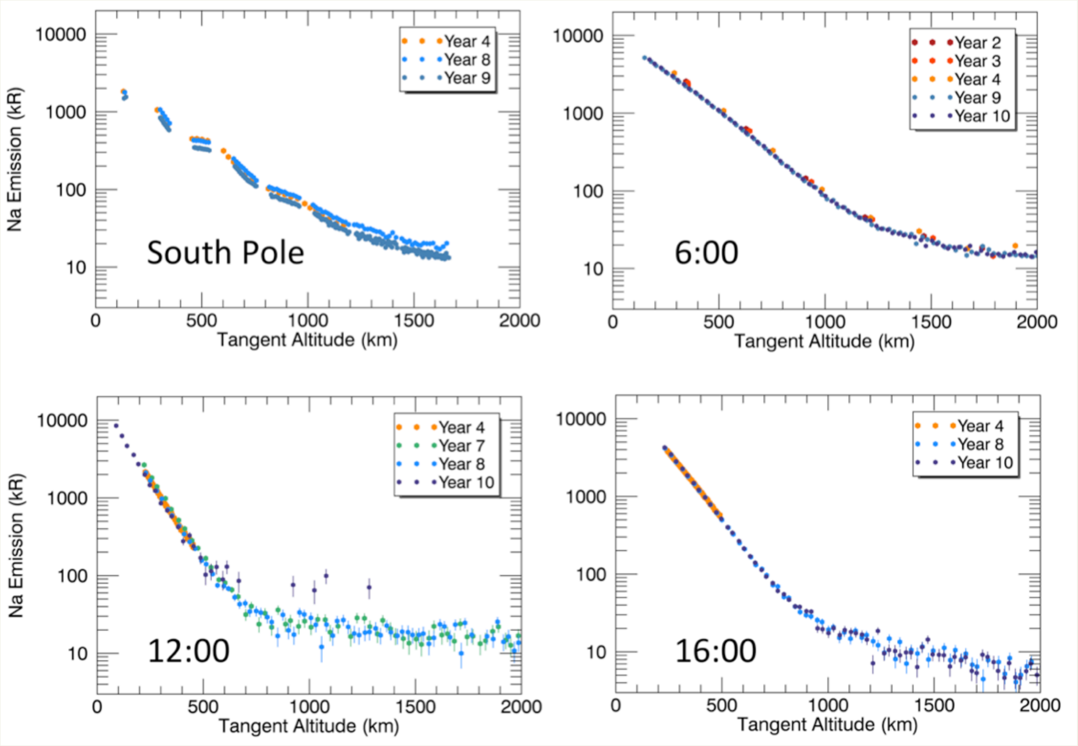
- Persistently exhibits 2 temperature (energy) components
- Example: True Anomaly ~ 140˚ ; 8:30 AM Local Time







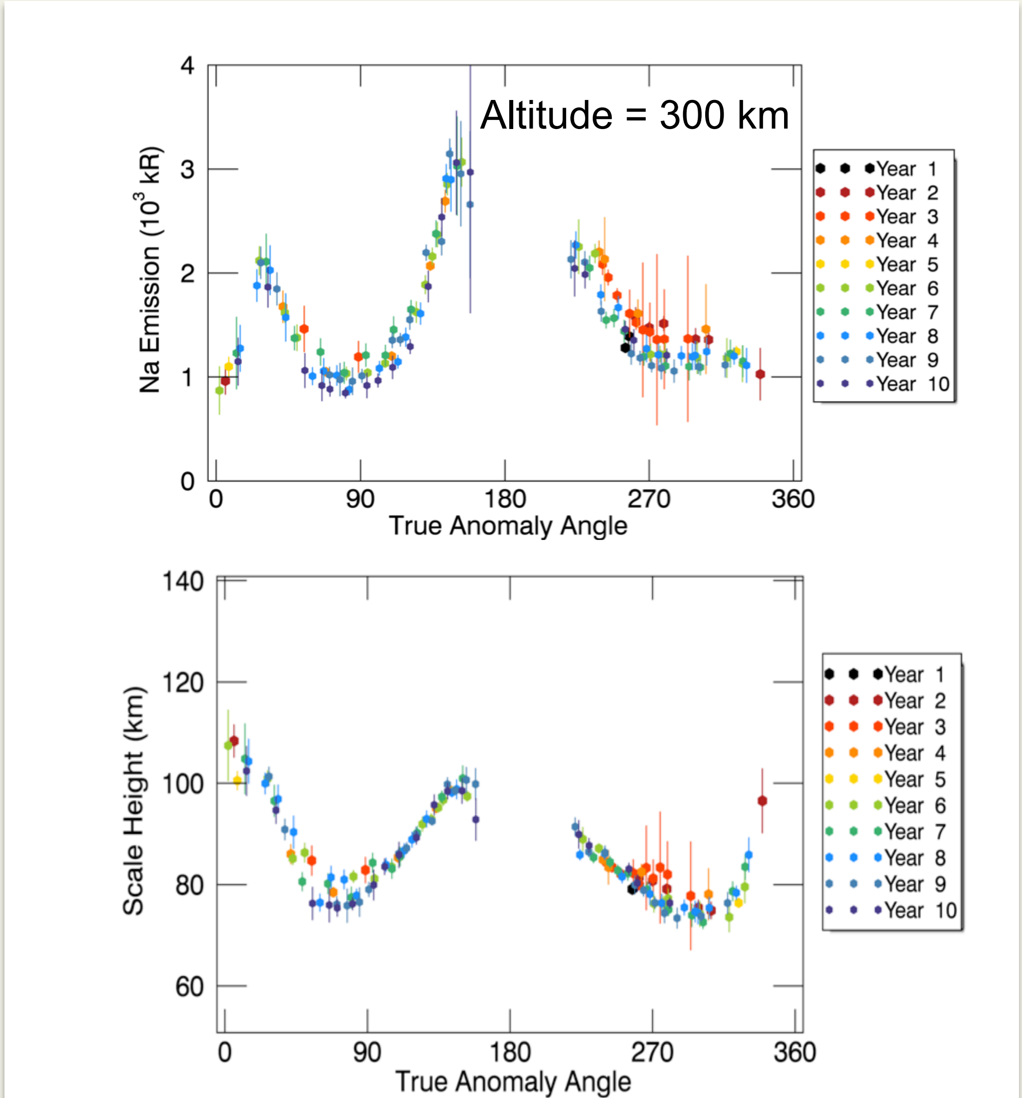
Sodium Emission Annual Variation: Local Times Are Similar

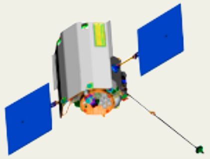


- Upper left panel: south pole limb scans for true anomaly angles 10° - 15°
- All other panels: dayside limb scans at selected local times for true anomaly angles 65° - 70°
- Dawn, dusk, and pole appear slightly warmer (1500K) than subsolar (1200K)

Sodium Emission: Seasonal Variation for H < 1000km

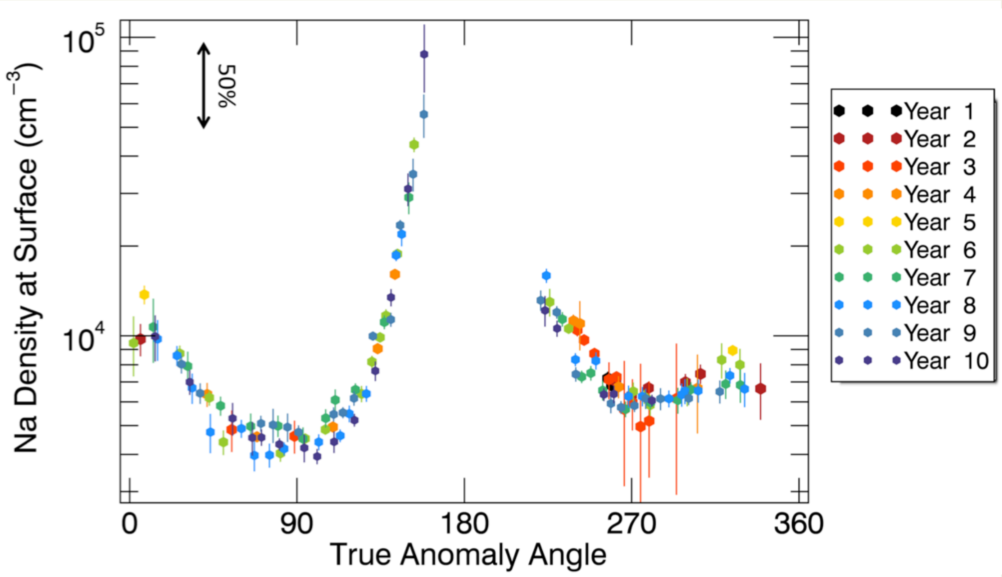
- Upper Panel: Sodium emission 300km above the surface near the subsolar point versus season (true anomaly angle). The gap near 180˚ results from restrictions in viewing geometry.
- Lower Panel: Radiation acceleration versus season
- When the radiation pressure is high sodium is pushed back to the surface and the exosphere is compressed
- Scale heights near TAA = 85˚ and 280˚ are ~ 75km whereas scale heights near TAA = 0˚ and 180˚ are ~ 110km.

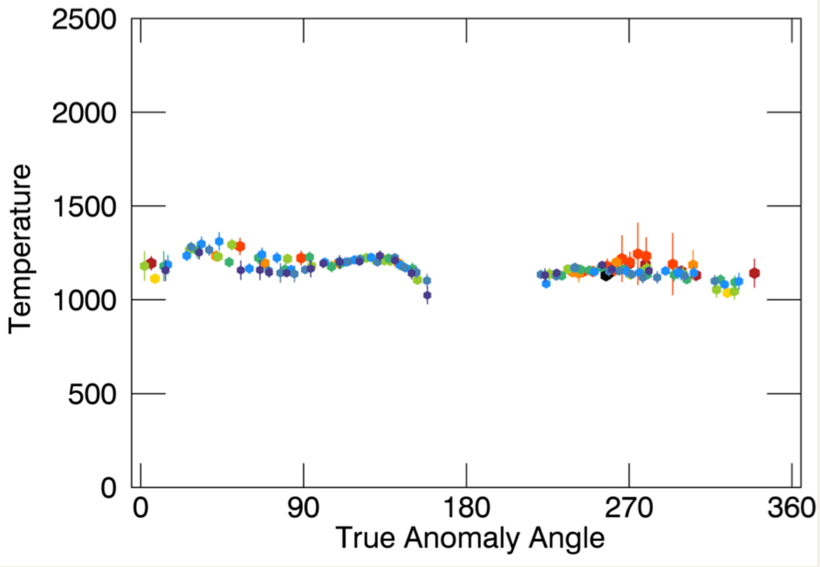




Inferred Seasonal Variation in Sodium Column Densities and Temperatures Are Persistent For H <1000km

- Results from a modified Chamberlain model that includes radiation pressure
- Subsolar point densities at 300 km altitude are lowest at periods of maximum radiation pressure (maximum tail brightness)
- Subsolar temperature nearly constant at ~1200K throughout a Mercury year

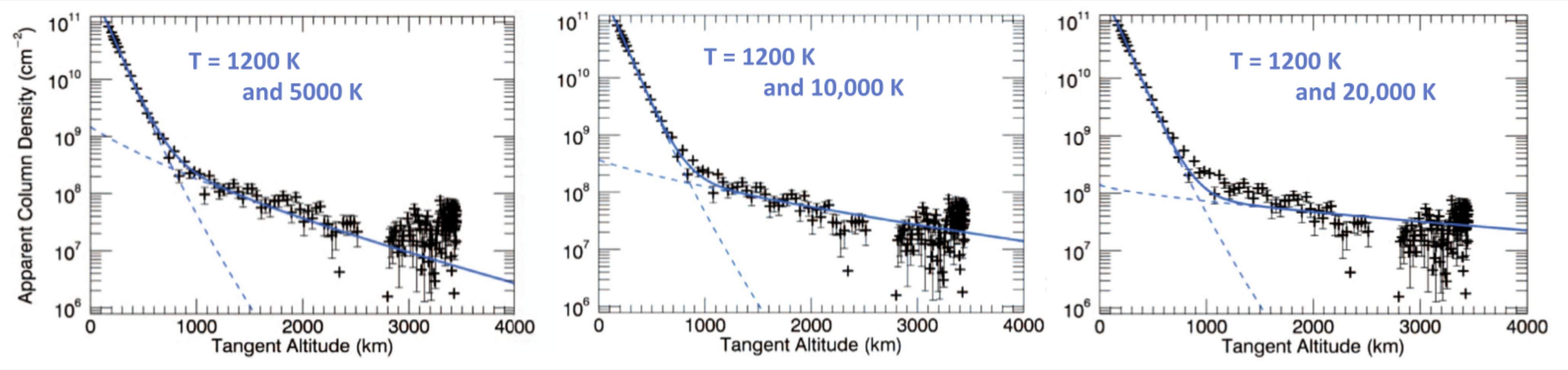




Additional Dayside Components (1)

Tenuous, low-density component

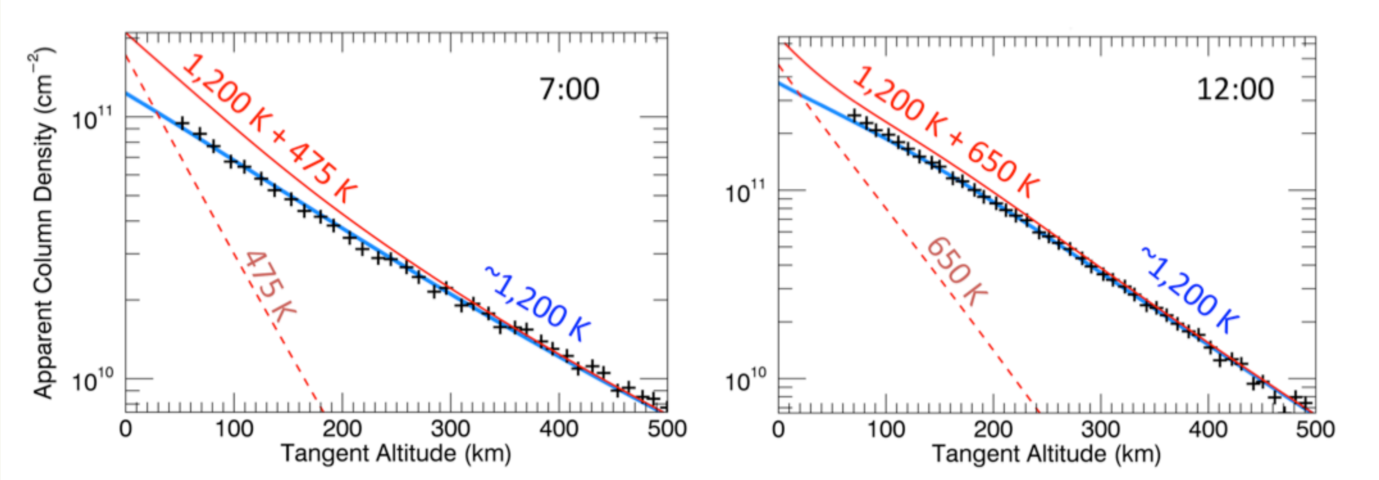
- Observed above ~ 1200km
- Temperature is not well constrained with T ~5,000K - 10,000K
- Does not correlate well with pressure in the magnetic field cusps derived from the Fast Imaging Plasma Spectrometer aboard MESSENGER

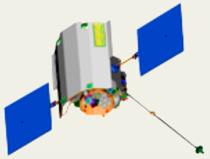


Additional Dayside Components (2)

There is little evidence for a cool component

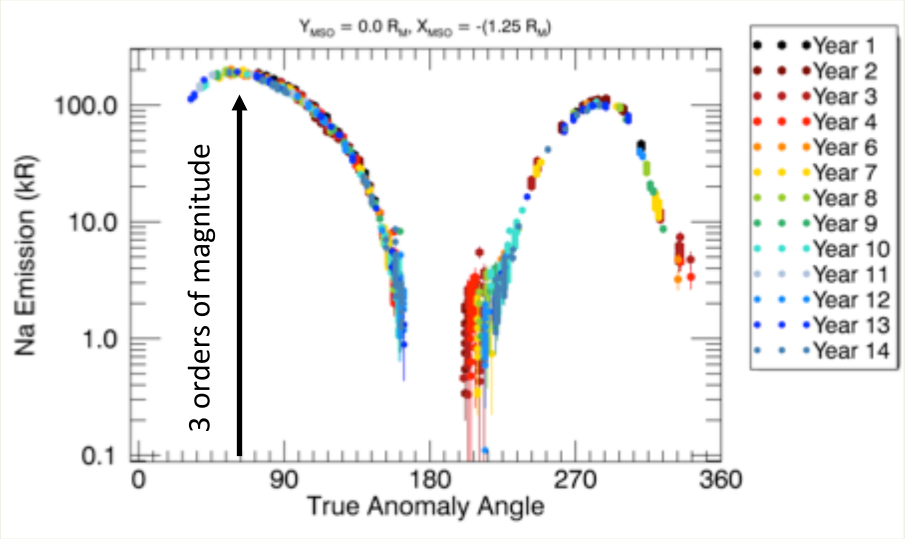
- Attempts to include a ~ 500K component at low altitudes have not been successful
- Early morning observations are more constrained than subsolar regions
- Cannot totally rule out the presence of a **weak** source that is accommodated or partially accommodated with the surface

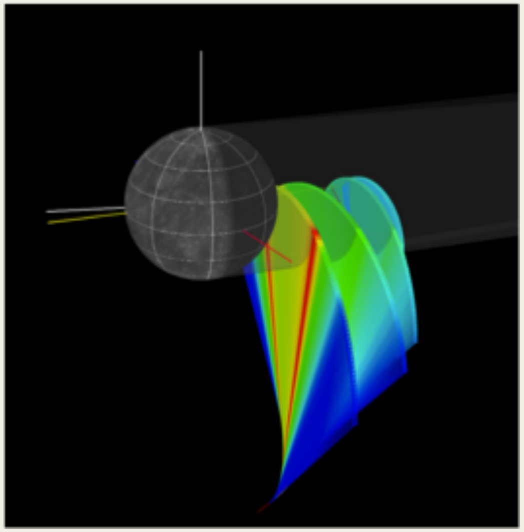


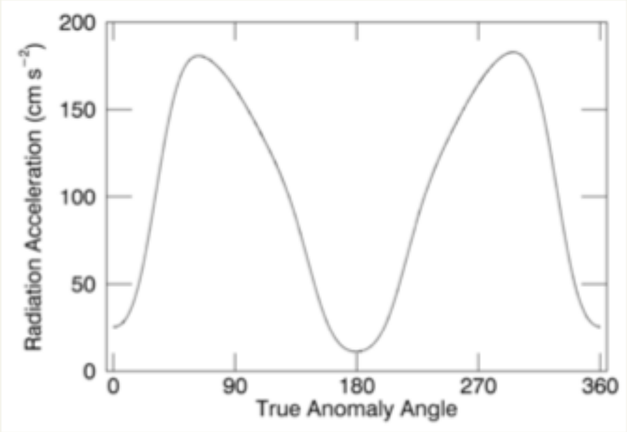


Emission near the antisolar point correlates with radiation pressure

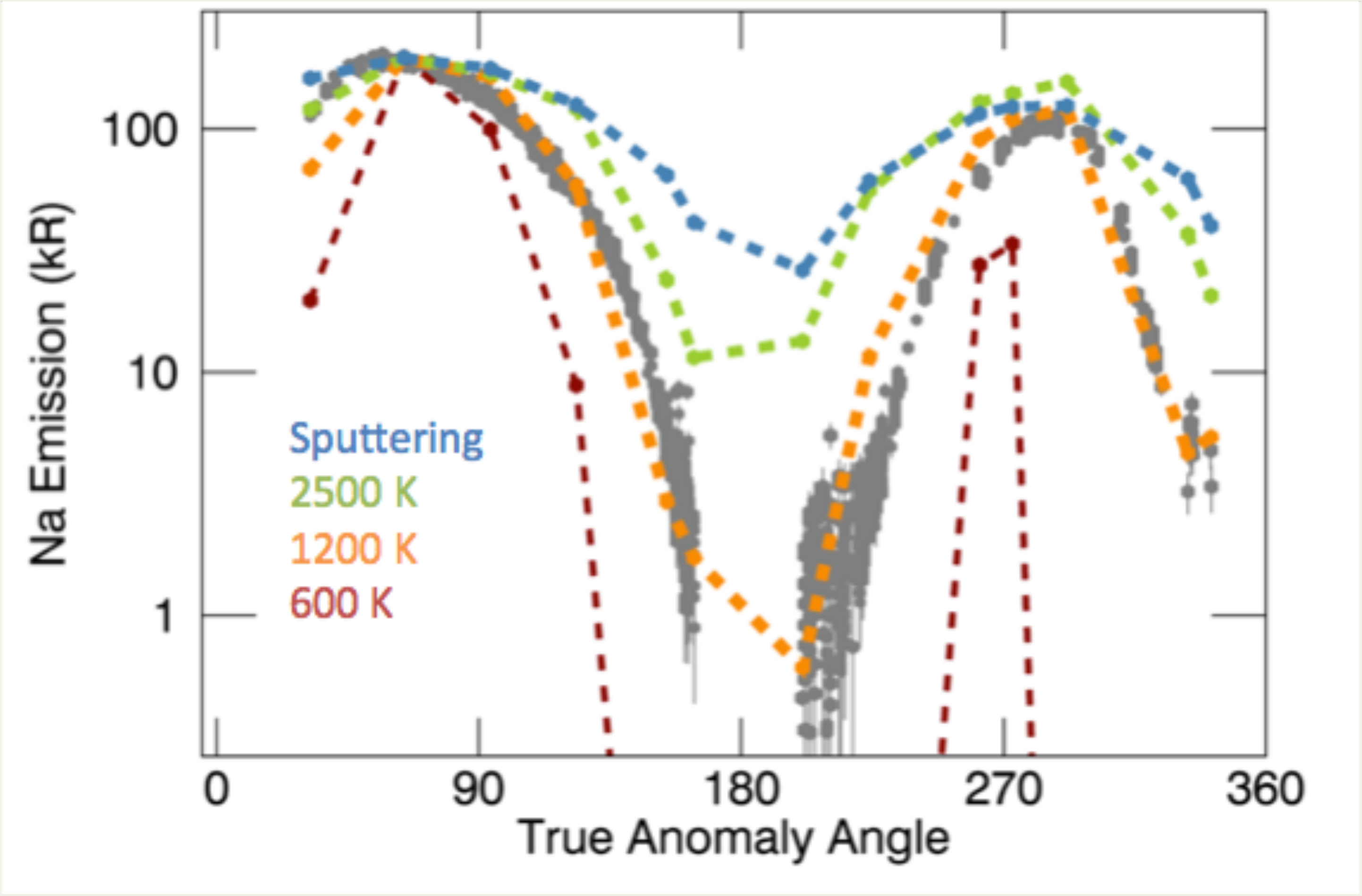
- Content of the sodium tail is a strong function of radiation pressure
- The 85˚ TAA – 270˚ TAA asymmetry was first noted and explained by Potter

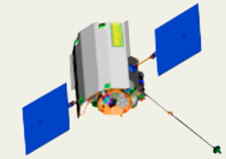




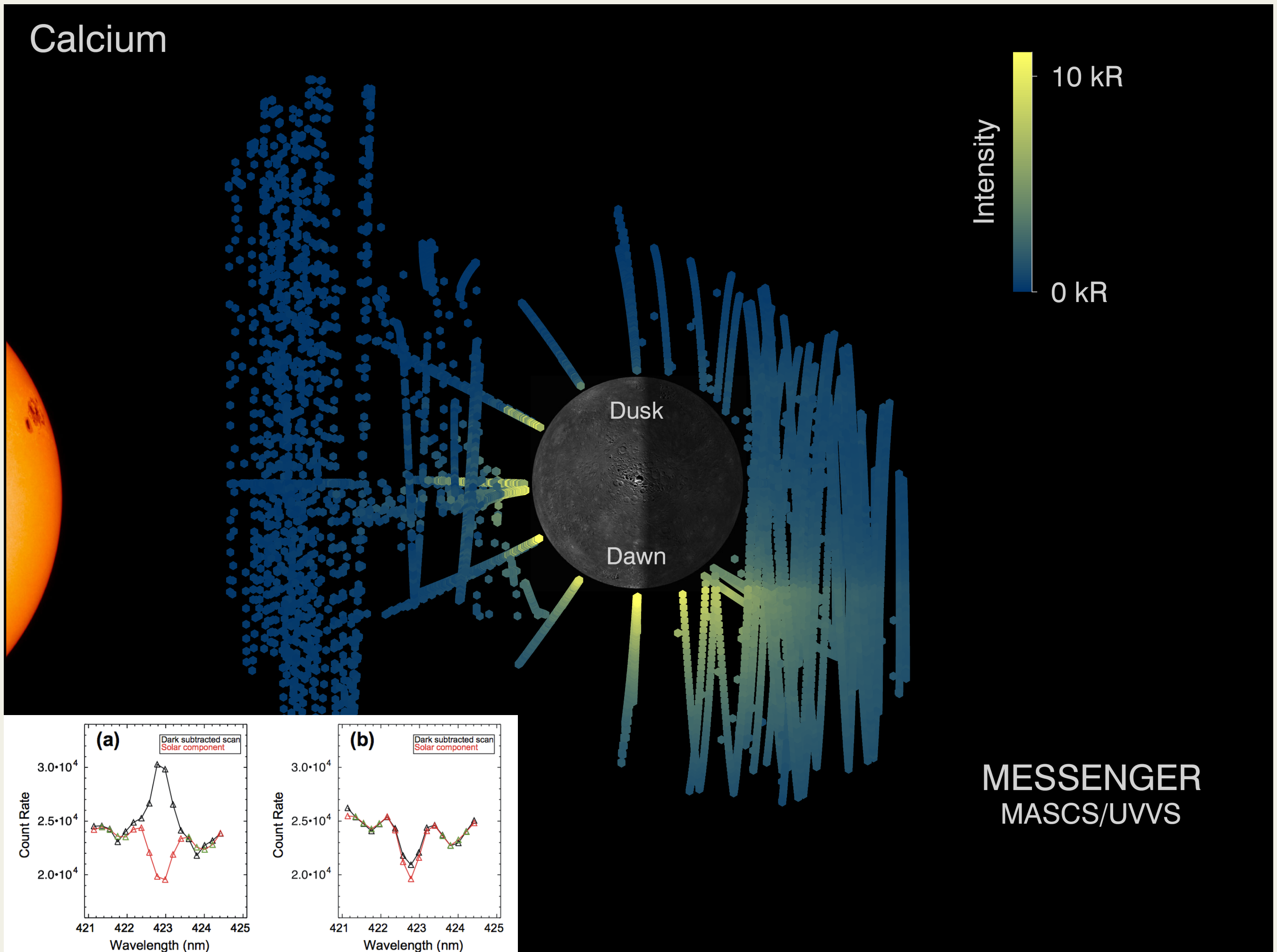


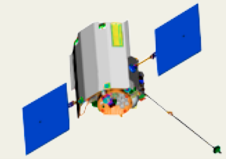
Seasonal variation can be explained with a uniform dayside distribution and supports the idea that the bulk of the dayside sodium has a temperature ~ 1200K





A Snapshot of the Calcium Exosphere observed by MESSENGER Just Before Aphelion, When Radiation Pressure Is Maximum

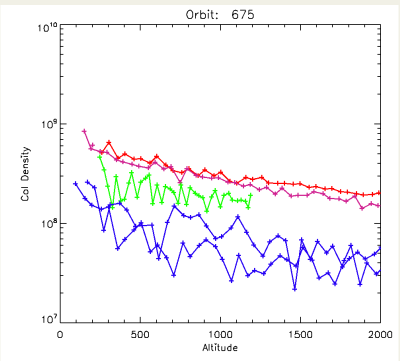




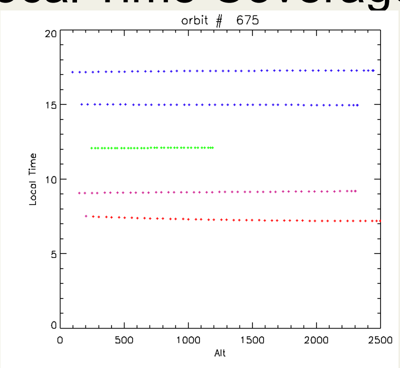
Dayside Calcium Observations

- Strong dawn – dusk gradient
- Single energetic (T ~ 70,000K) component dominates
- Searches for a colder, near-surface component not successful

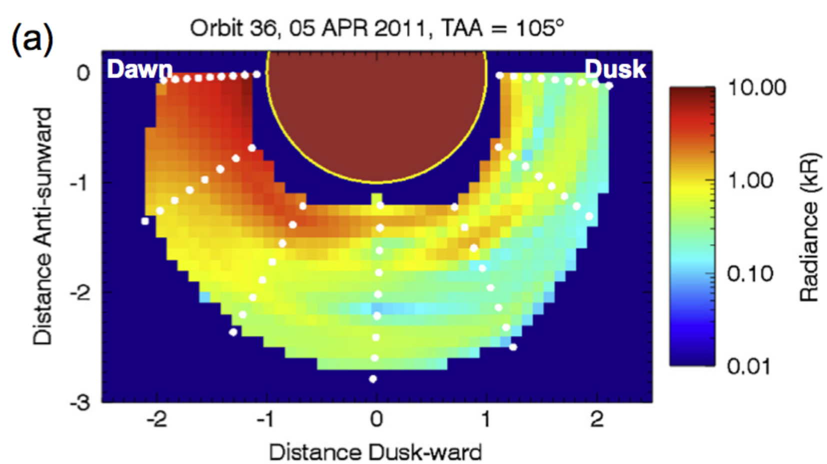
Altitude Profiles



Local Time Coverage



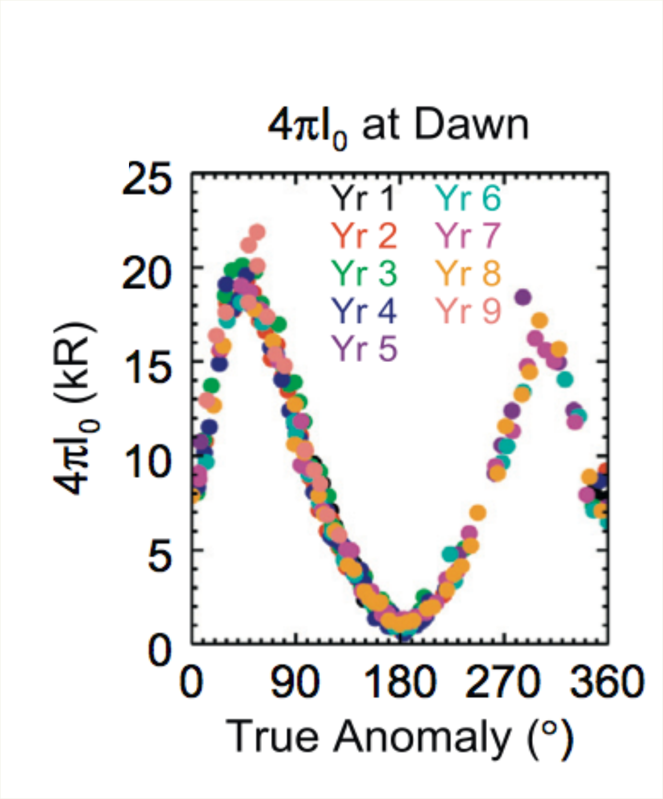
Sparsely sampled altitude profiles interpolated to produce estimated dayside Ca distribution

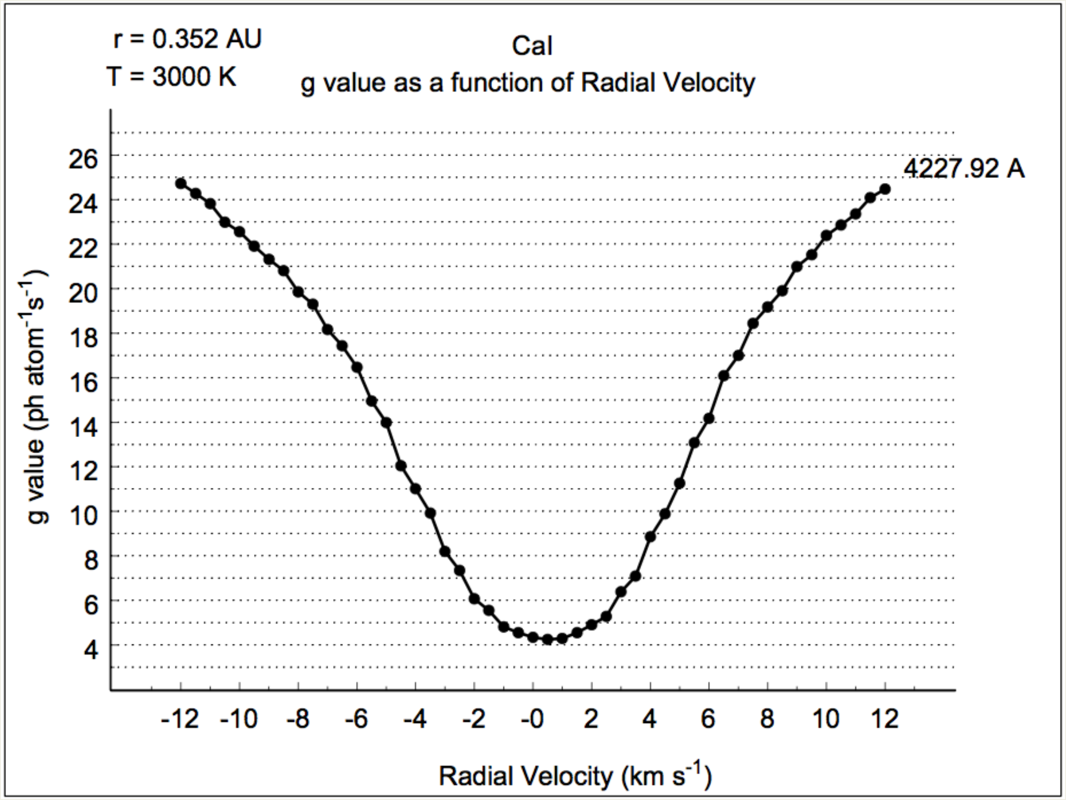


Sun

Calcium Emission: Annual/Seasonal Variation

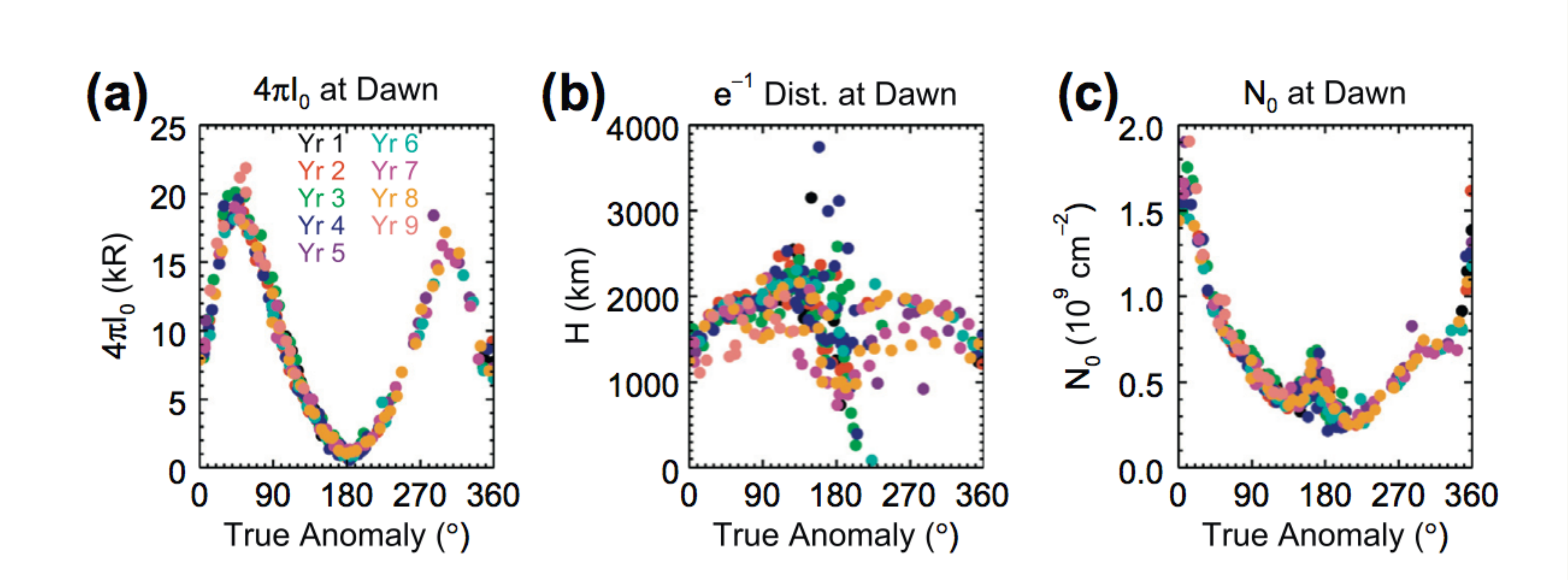
- Emission strongest near dawn terminator
- No obvious annual variation
- Seasonal variation coupled to g value to first order





Calcium Seasonal Variations Are Persistent

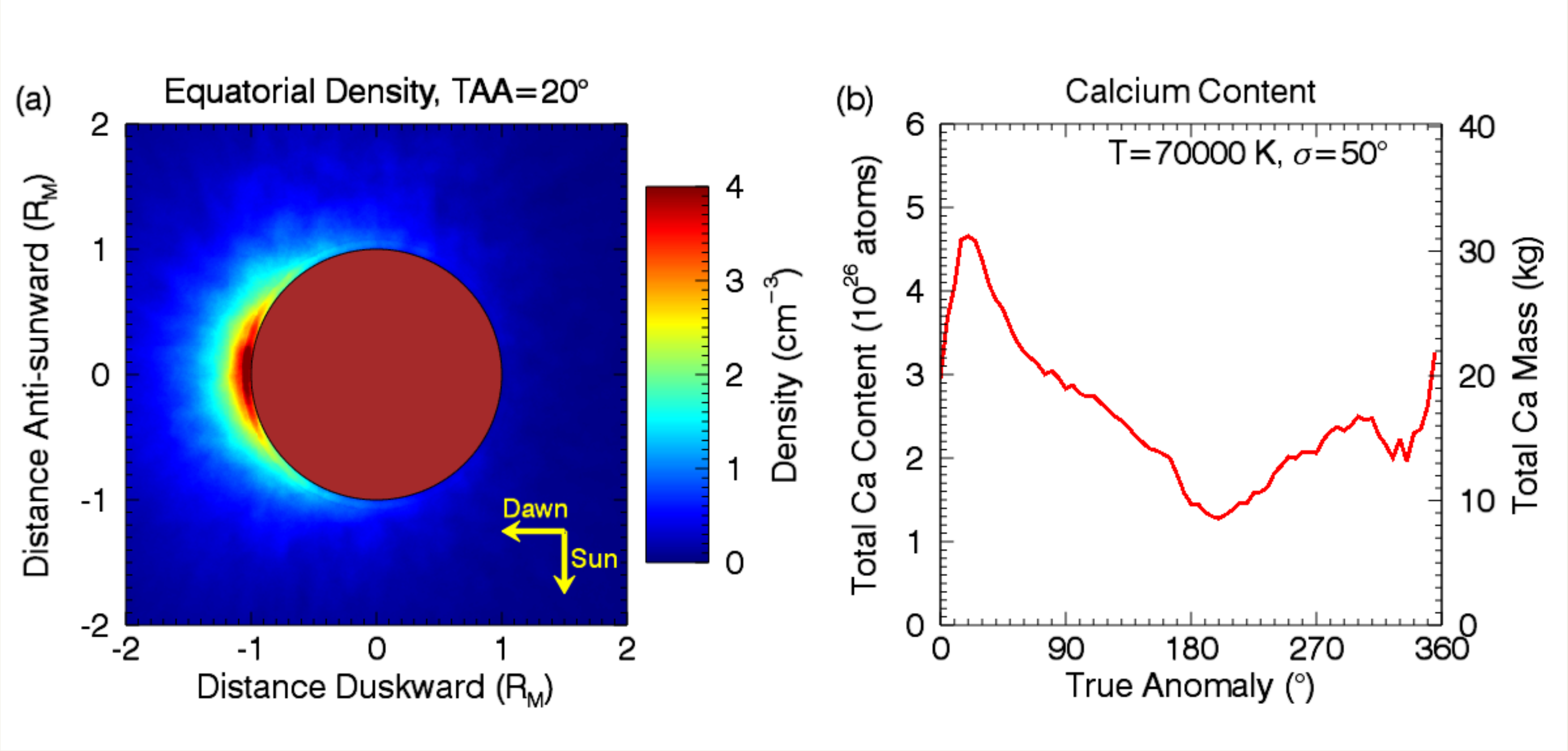
- Variation with true anomaly persistent and very different from Sodium
- Chamberlain model density peaks near True Anomaly Angle = 0°
- Chamberlain model fits suggest temperature independent/weakly dependent on True Anomaly Angle



Calcium Exospheric Model Results

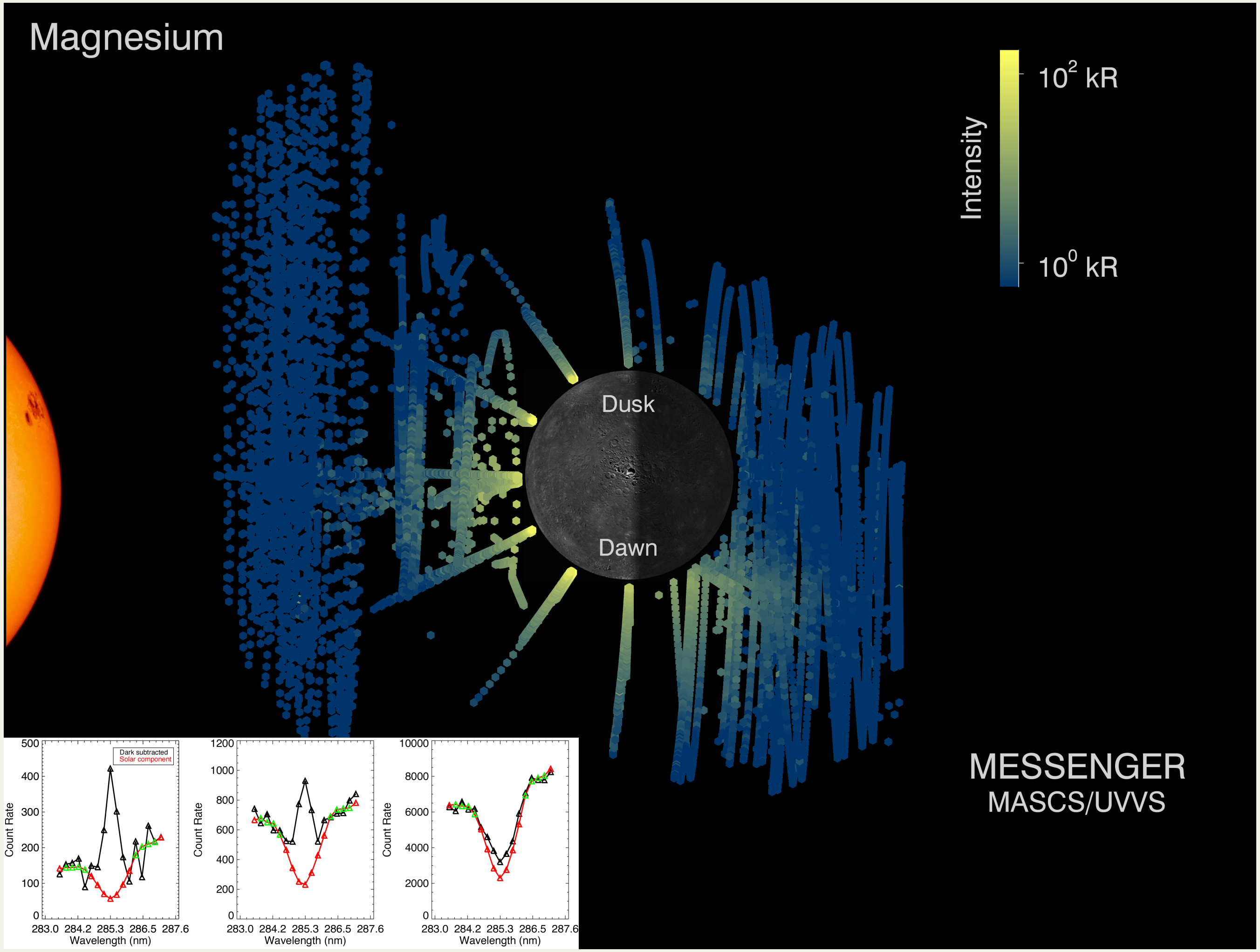
Dayside altitude profiles, nightside tail sweeps, and flyby data can be simultaneously

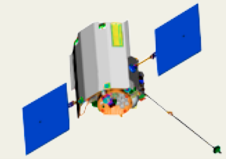
- Single, high-temperature (T ~ 70,000K)
- Source localized near the dawn terminator
- Maximum rate near TAA = 10˚



Magnesium

A Snapshot of the Magnesium Exosphere observed by MESSENGER Just Before Aphelion, When Radiation Pressure Is Maximum

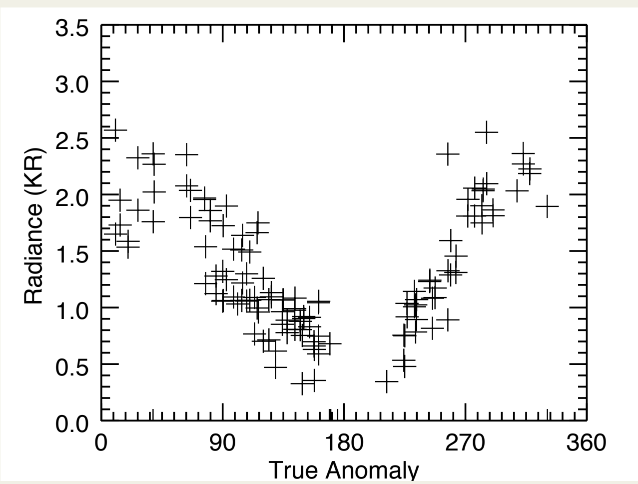




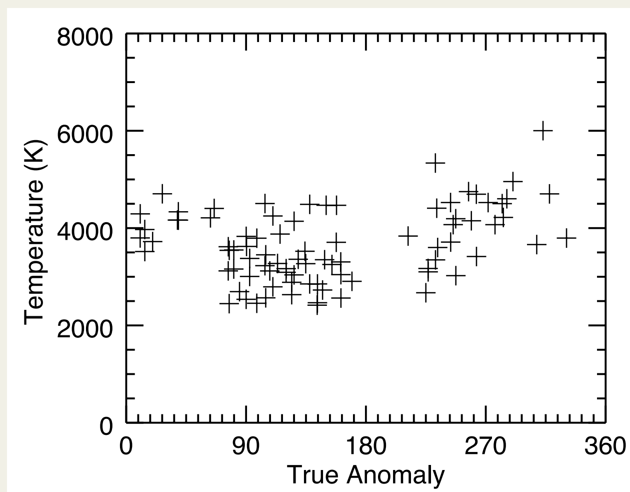
Magnesium Early-Mid Morning Seasonal Variation

- Dayside observations consistent with T~4,000 K
- Some evidence that the mid morning column density is greater on the inbound leg of Mercury's orbit

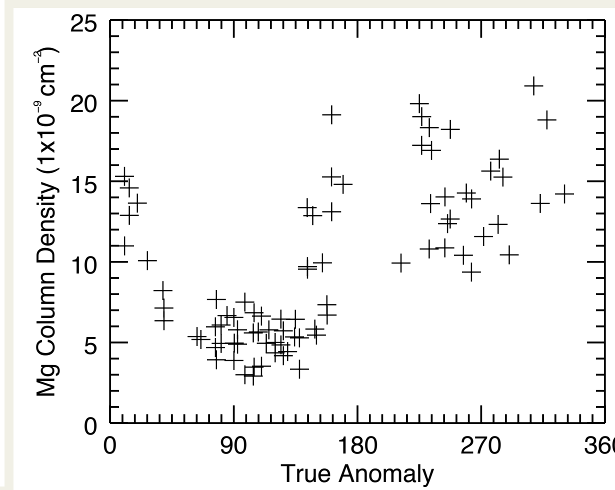
Emission Rate



Temperature



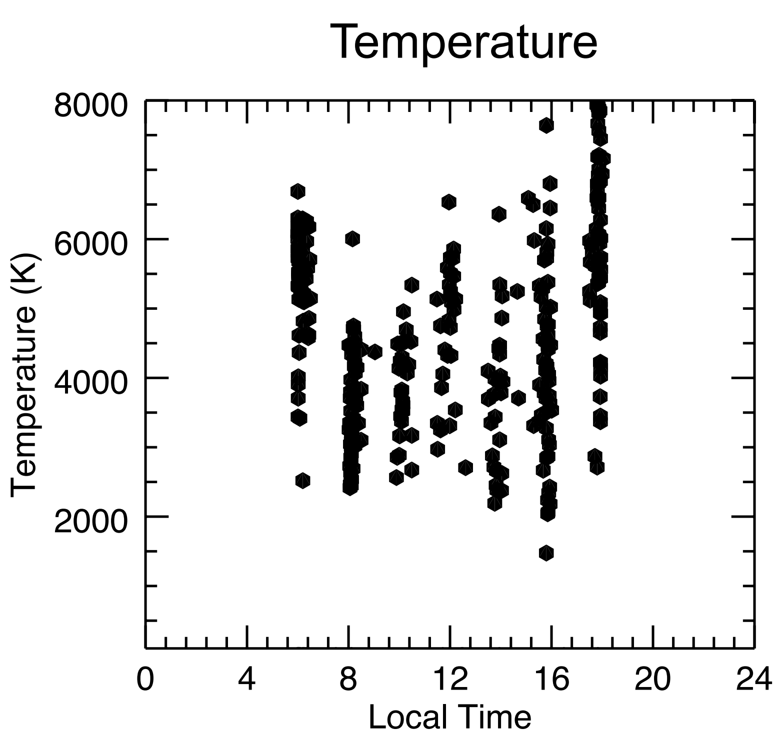
Column Density

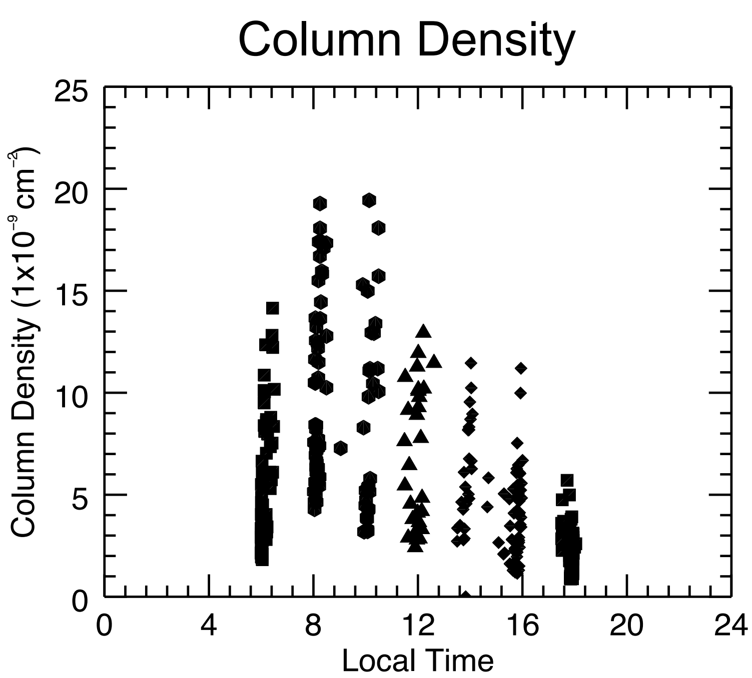


Dayside Magnesium Observations

- Dayside observations consistent with T~2000K – 8000K
- Column Density exhibits dawn – dusk gradient less pronounced than Calcium

Results from Chamberlain model fits – all TAA



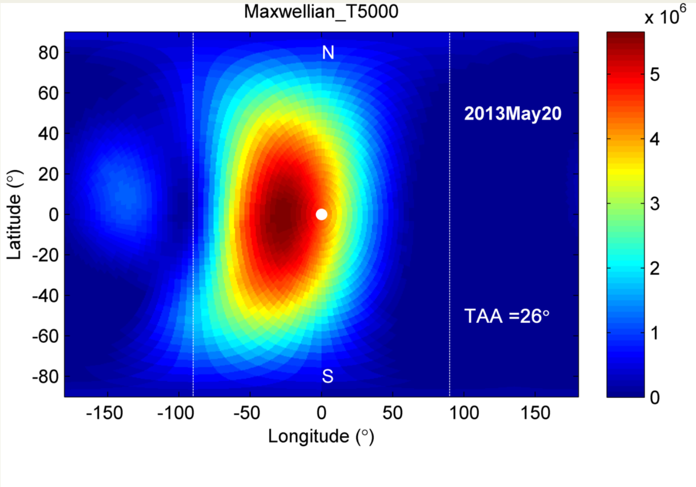


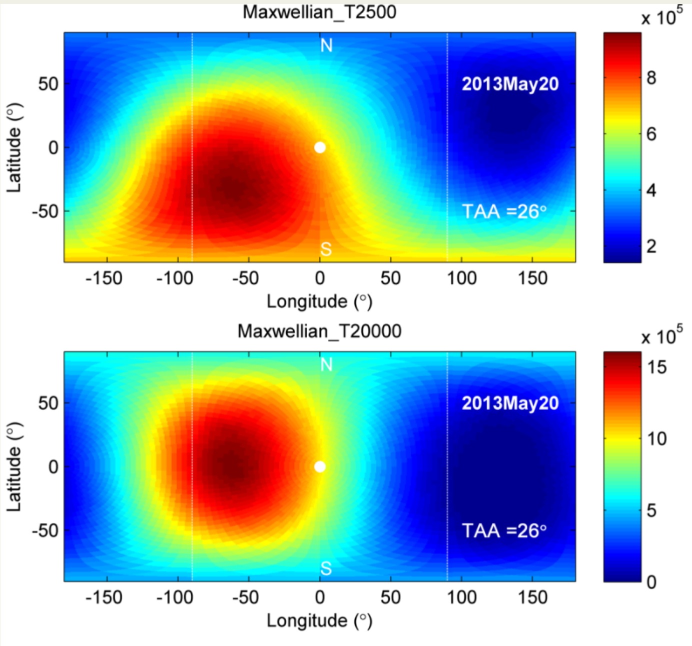
Magnesium Exosphere Models

Fits Include Both Dayside and Nightside Observations

- A single warm (T ~ 5000K), early morning source fits ~ 90% of the orbits
- Some observations can be fit equally well with a 2-component model (T ~ 2500K + T ~ 20,000K)
- Discrimination difficult due to sparse sampling and low signal-to-noise

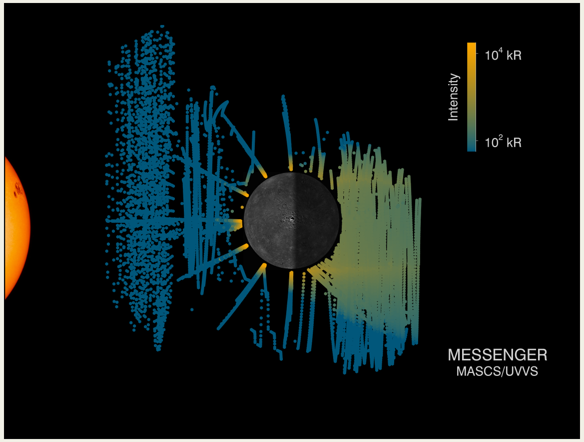
Data from 2013 May, 30 can be fit equally well using either one-component or two-component models

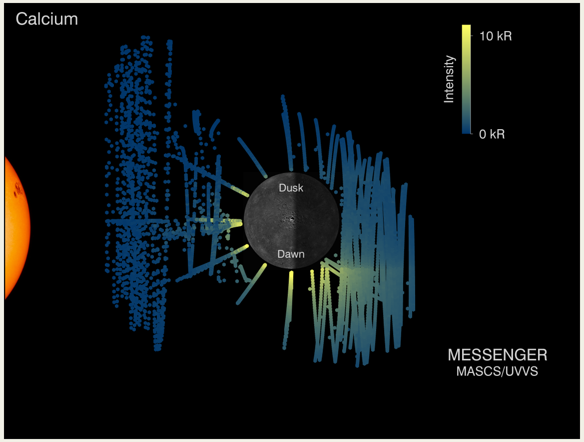


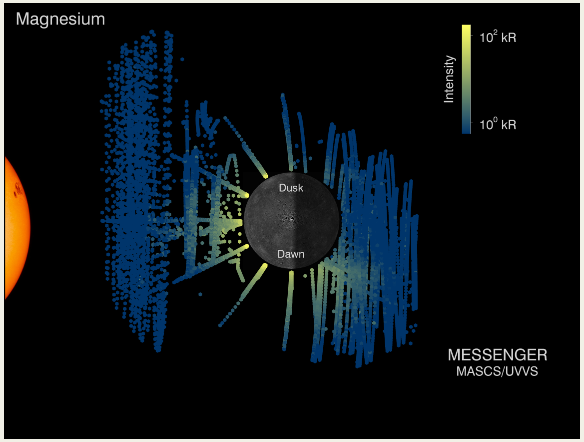


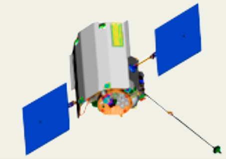
Summary of the Spatial and Temporal Distributions of the 'Big Three'

Snapshots of the Sodium, Calcium, and Magnesium Exospheres observed by MESSENGER Just Before Aphelion, When Radiation Pressure Is Maximum

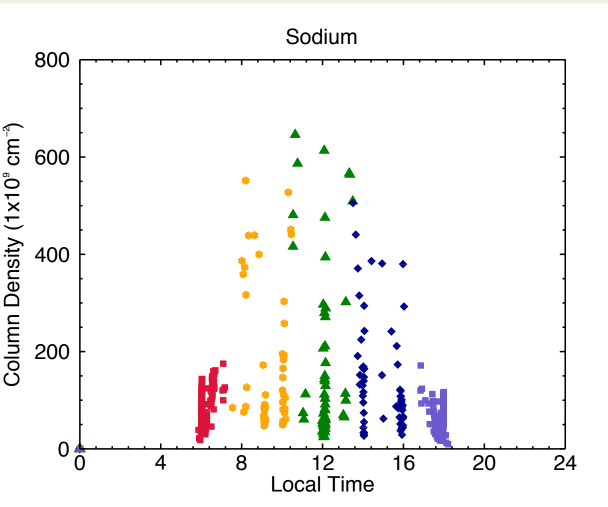


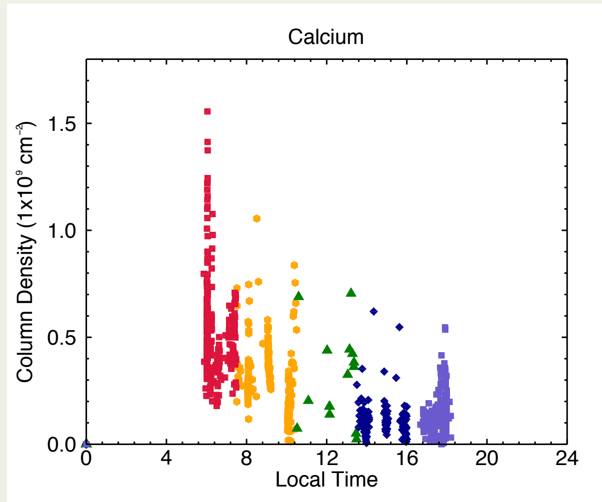


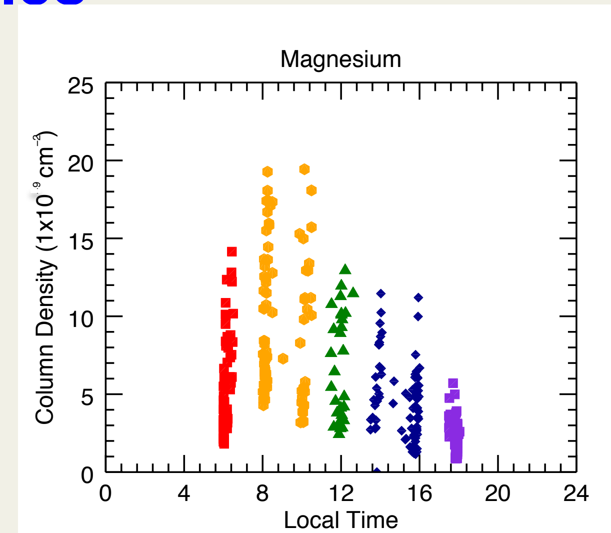




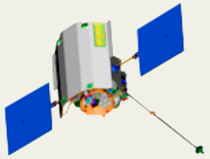
Species Summary: Dayside Column Densities for All True Anomaly Angles





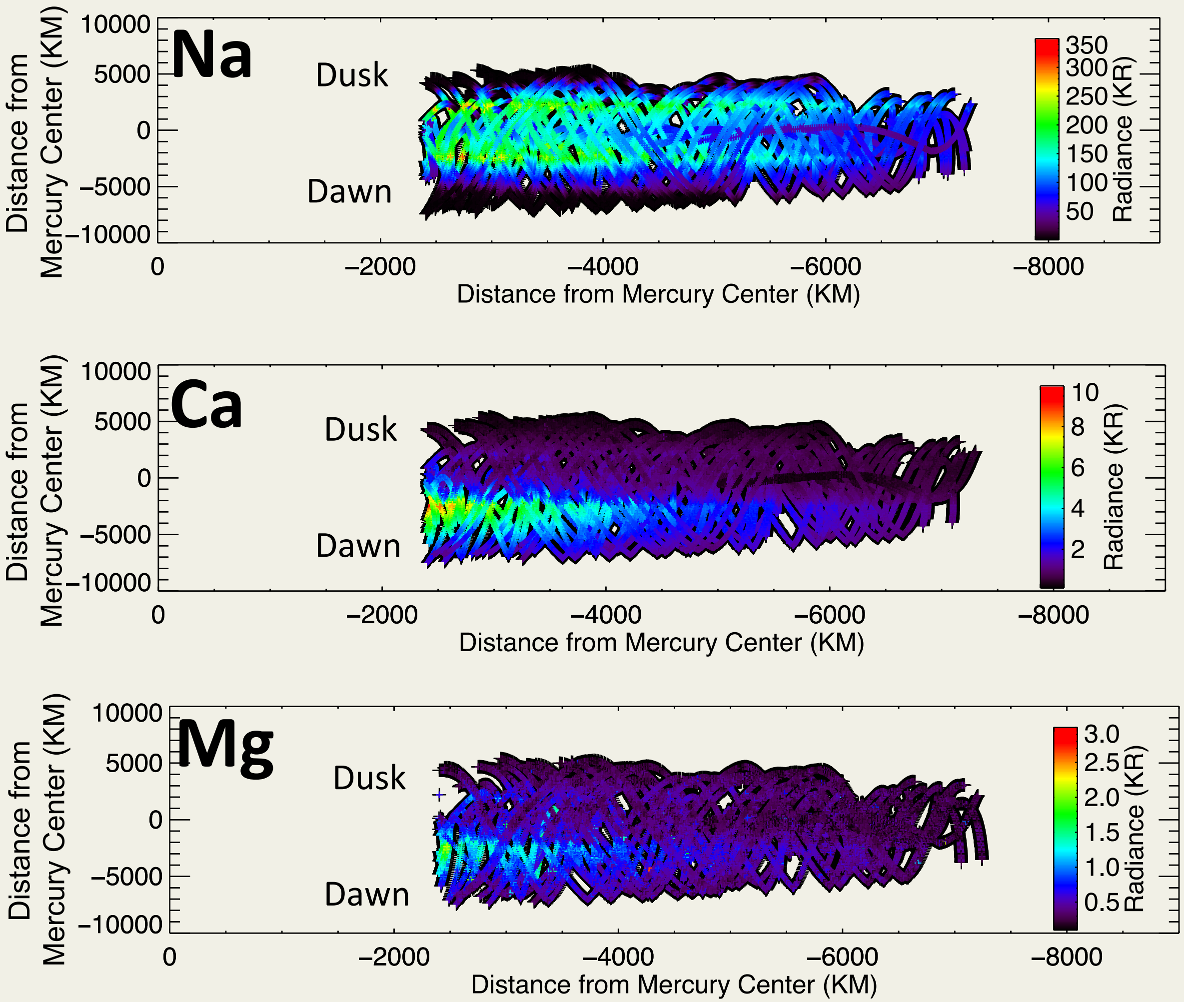


- All: repeatable seasonal patterns (over 16 Mercury years) unique to each species
- Sodium: most abundant species
  - Two unrelated energy components T ~ 1200K (persistent) T > 5000K (magnitude and variability not well constrained)
  - Densities peak near local noon but generally within a factor of 2 for fixed TAA
- Calcium: 400x less abundant than sodium
  - Single, hot (T ~ 70,000K) component with strong dawn – dusk gradient
- Magnesium: 30x less abundant than sodium
  - Densities peak near morning, dawn-dusk gradient
  - Persistent component with T ~ 2000K – 8000K with weak evidence for T ~ 20,000K



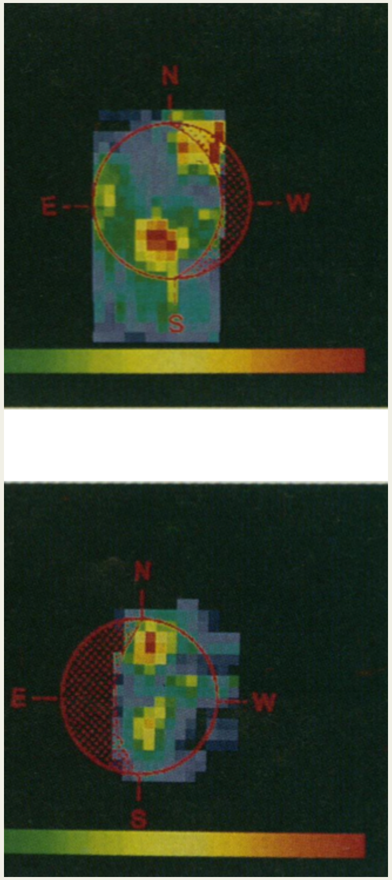
Tail Sweeps Confirm the Dayside Dawn-Dusk Distributions and Are Consistent With Dayside Temperatures

- Tail observations for TAA 0 – 90, the season of greatest solar radiation pressure
- Na is more strongly influenced by radiation pressure than Ca or Mg
- Dawn enhancements for Ca and Mg are clearly evident in the tail distributions

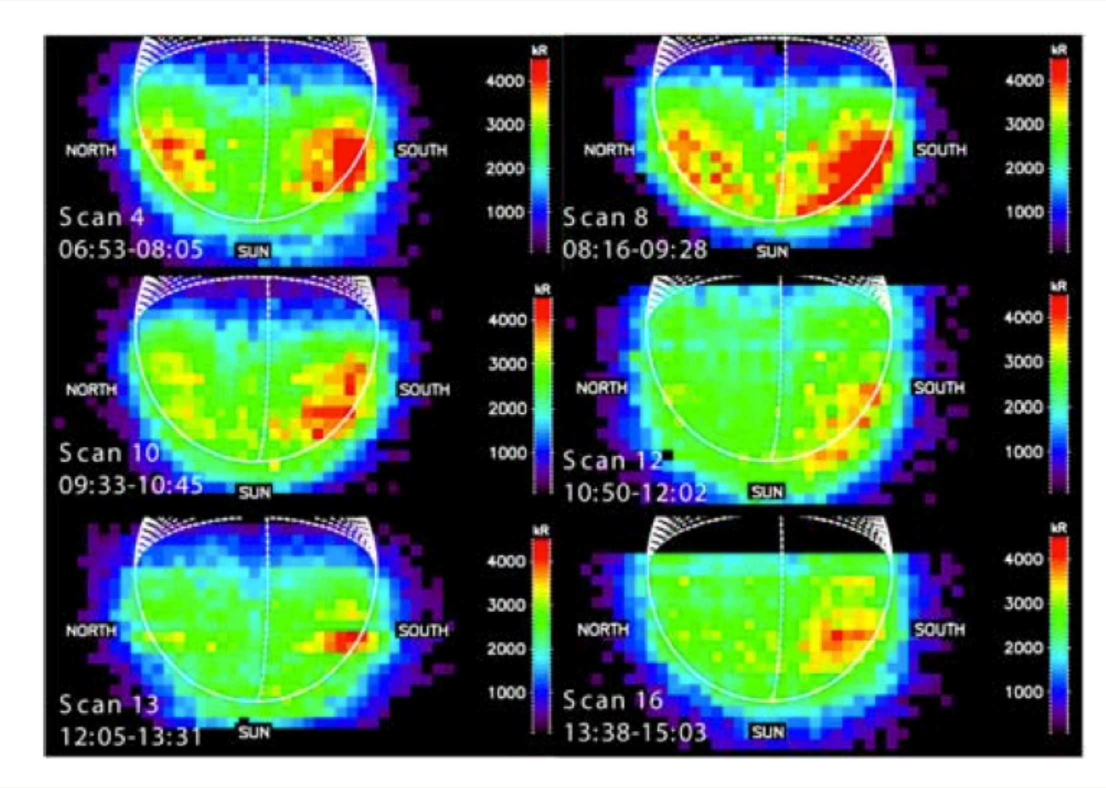


MASCS has studied the Mercury Exosphere Climate What About its Weather?

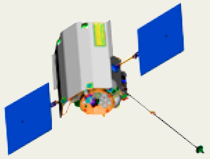
MASCS has not observed the variability in sodium emission reported by ground based observers.



Potter and Morgan (1990)

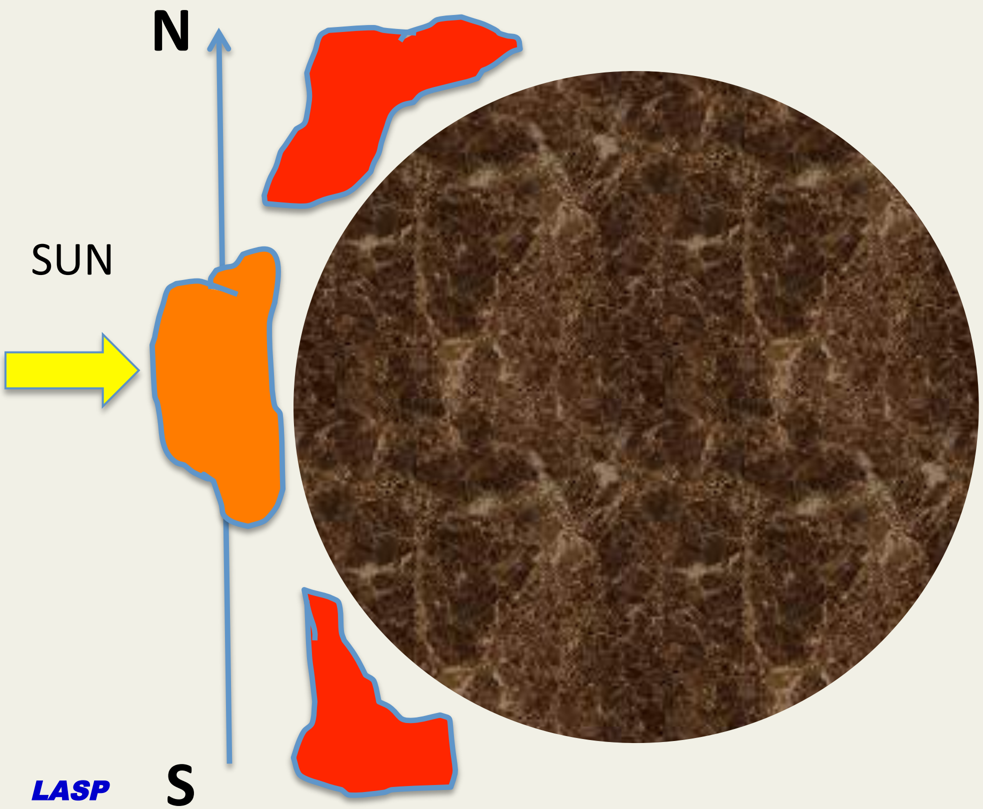


Leblanc et al. (2009)

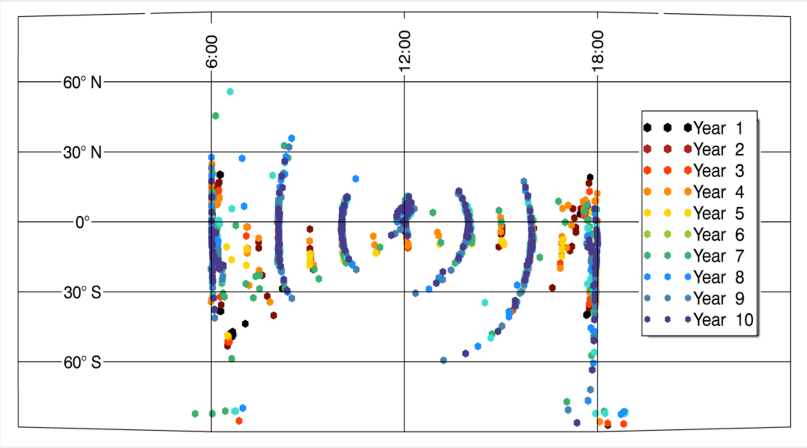


The MASCS Observing Geometry and Cadence Was Not Suited to Detecting High Latitude Emission and Their North – South Asymmetries

- Lines of sight integrate northern and southern emitting regions.
- High latitudes are viewed at high altitudes



- Minimum ray heights for the dayside limb scans are concentrated near the equator
- 8hr and 12hr orbits alias short timescale variability



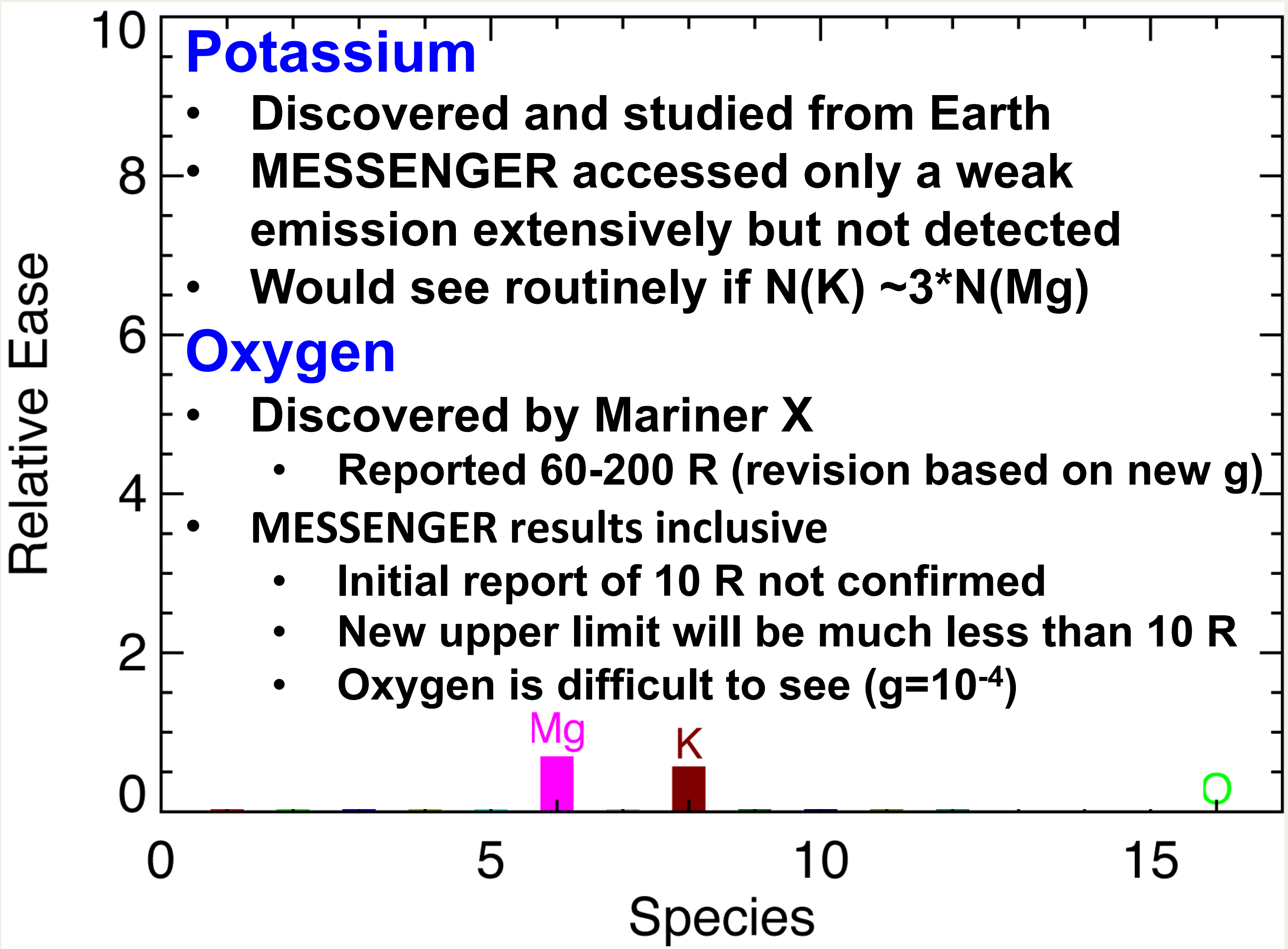
Weakly Emitting Species (1)

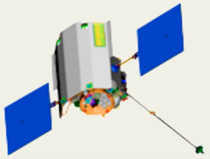
Potassium

- Discovered and studied from Earth
- MESSENGER accessed only a weak emission extensively but not detected
- Would see routinely if N(K) ~3*N(Mg)

Oxygen

- Discovered by Mariner X
  - Reported 60-200 R (revision based on new g)
- MESSENGER results inclusive
  - Initial report of 10 R not confirmed
  - New upper limit will be much less than 10 R
  - Oxygen is difficult to see ($g=10^{-4}$)

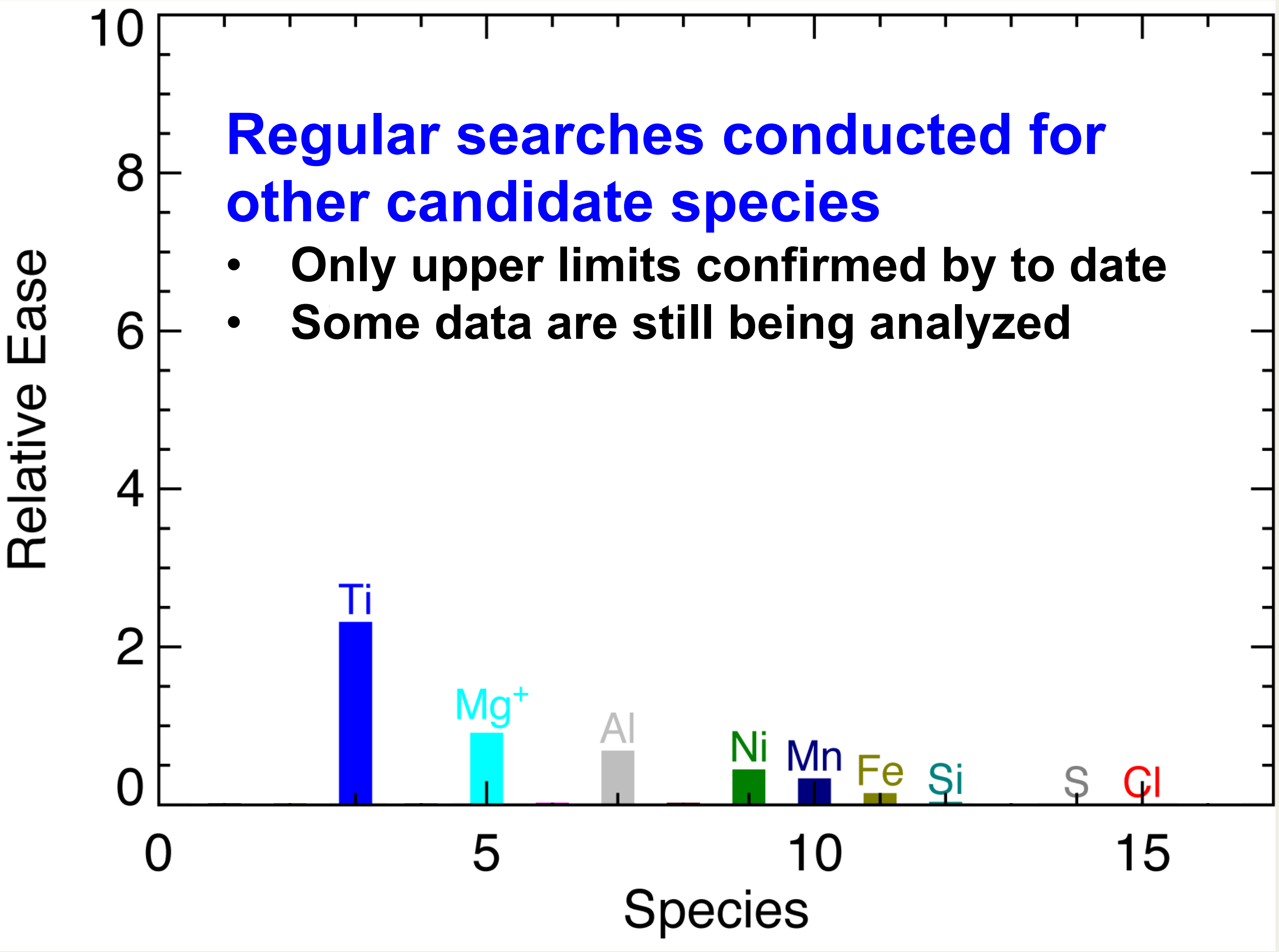




Weakly Emitting Species (2)

Regular searches conducted for other candidate species

- **Only upper limits confirmed by to date**
- **Some data are still being analyzed**



Bill's Big 10: What Have We Learned From the MESSENGER Mission About the Nature of Mercury's Exosphere?

1. MESSENGER detected and mapped Mg in the exosphere.
2. Distributions of Na, Ca, and Mg are distinct, suggesting that these species are controlled by different source, transport and loss processes.
3. Persistent, distinct, seasonal variations in dayside near-surface densities are seen in all three species.
4. There is no obvious correlation of exosphere density and surface features in the MESSENGER data.
5. Dayside temperatures are largely independent of Mercury true anomaly.
6. There are no strong episodic variations in the MESSENGER dayside data.
   a. This may result from spacecraft orbital geometry, which limited spatial coverage to low latitudes.
   b. It appears that the importance of sputtering as an exosphere source for Na has been overestimated
7. There is no evidence for a strong thermal Na source.
8. The total content of the Ca exosphere is small relative to Na and Mg.
9. Ca exhibits a very high energy dawn source.
10. MESSENGER did not detect O in the exosphere.