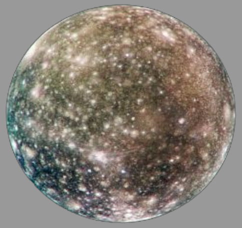
Models of Callisto's atmosphere composed of sublimated water vapor and radiolytic and photochemical products



Shane Carberry Mogan[a,b,*], Orenthal Tucker[c], Robert Johnson[a,d], Audrey Vorburger[e], Andre Galli[e], Lorenz Roth[f], Angelo Tafuni[g], Sunil Kumar[b], Iskender Sahin[a], Katepalli Sreenivasan[a,b]

[a]New York University, New York, USA; [b]New York University Abu Dhabi, Abu Dhabi, UAE; [c]NASA Goddard Space Flight Center, Greenbelt, USA; [d]University of Virginia, Charlottesville, USA; [e]University of Bern, Bern, Switzerland; [f]KTH Royal Institute of Technology, Stockholm, Sweden; [g]New Jersey Institute of Technology, Newark, USA; ***ShaneRCM@NYU.edu**

Summary: **The spatial morphology of the H corona detected at Callisto** [1] is used to place constraints on the ***undetected*** **sublimated H_2O & radiolytically produced H_2 components of Callisto's atmosphere** via 2D Direct Simulation Monte Carlo (**DSMC**) simulations [2].

❖ ***Takeaways:*** **The observed H morphology**

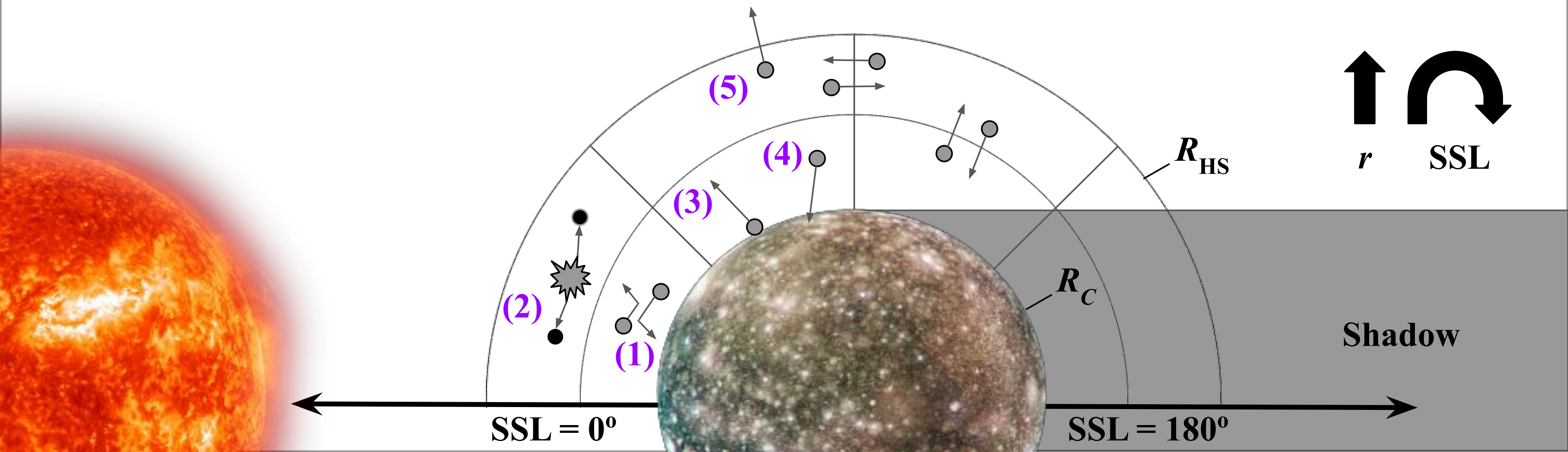
➢ ***cannot*** **be explained if sublimated H_2O is the primary source**, regardless if ice and dark, non-ice/ice-poor surface materials are assumed to be **intimately mixed** or **segregated into patches**.

- The O_2 component can scatter H produced by H_2O.
- A collisional H_2 component can significantly inflate the H produced by H_2O.

➢ ***can*** **be explained if a global radiolytic H_2 component is the primary source** [3].

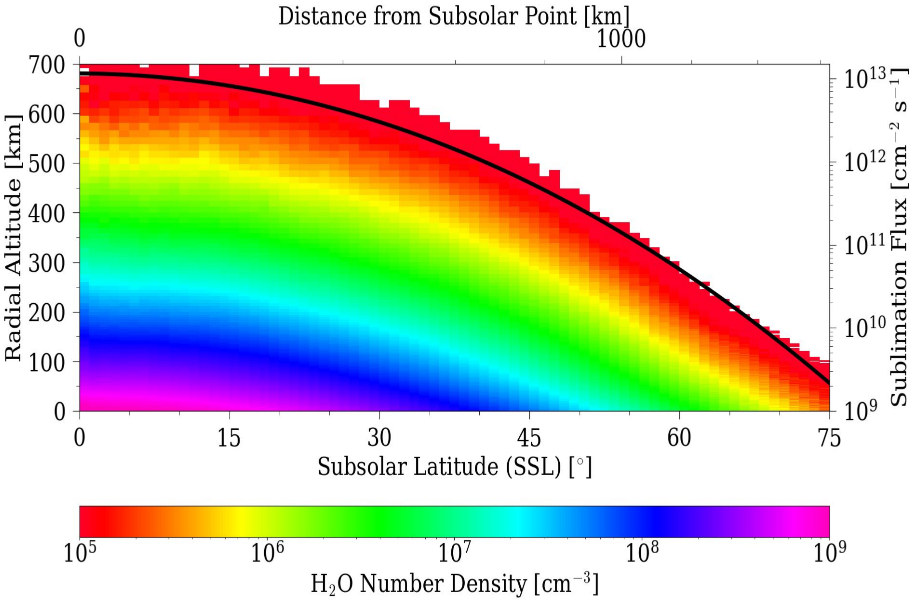
THE DIRECT SIMULATION MONTE CARLO (DSMC) METHOD

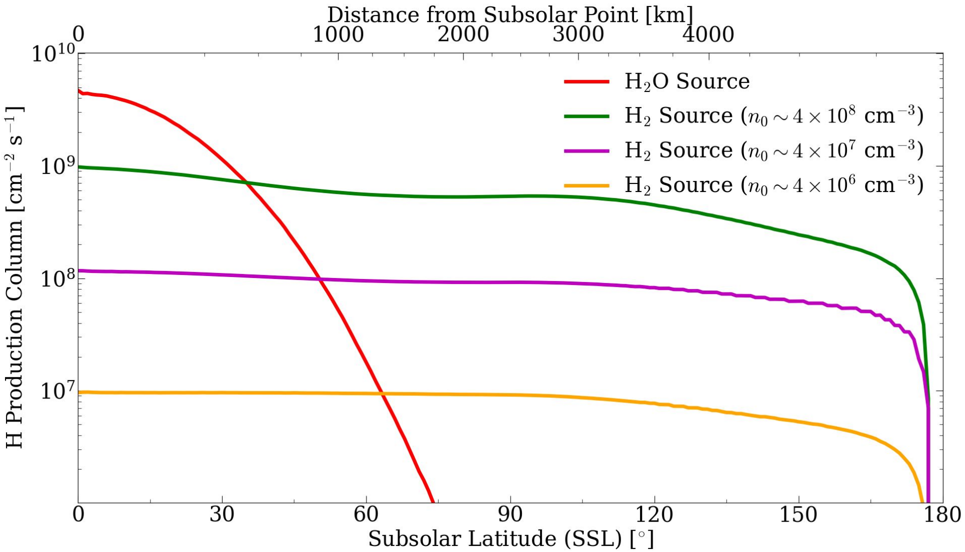
- A **2D spherical grid** is composed of cells along radial (***r***) and subsolar latitudinal (**SSL**) axes
  - Callisto's surface, R_C = 2410 km
  - Callisto's Hill sphere, R_{HS} ~ 20.8 R_C
- **Particles** subject to gravity, collisions **(1)**, and photochemical processes **(2)** are tracked
- **Production:** sublimation/thermal desorption **(3)** & photodissociation **(2)**
- **Loss:** condensation **(4)**, escape **(5)**, & photochemical destruction **(2)**



BACKGROUND WORK: DSMC MODELS OF CALLISTO'S ATMOSPHERE

- Carberry Mogan et al. (2020) [4]: **1D DSMC models** demonstrated importance of collisions & escape in Callisto's atmosphere composed of radiolytic products CO_2, O_2, and H_2.
- Carberry Mogan et al. (2021) [3]: **2D DSMC models** included a diurnal temperature gradient from 155 K (subsolar point) to 80 K (anti-solar point) and a sublimated H_2O component.
  - ➢ ***Left***: Sublimated H_2O density: extremely sensitive to Callisto's day-side temperatures
  - ➢ ***Right***: Local production of H from sublimated H_2O & radiolytic H_2 over surface density ($\boldsymbol{n_0}$) range

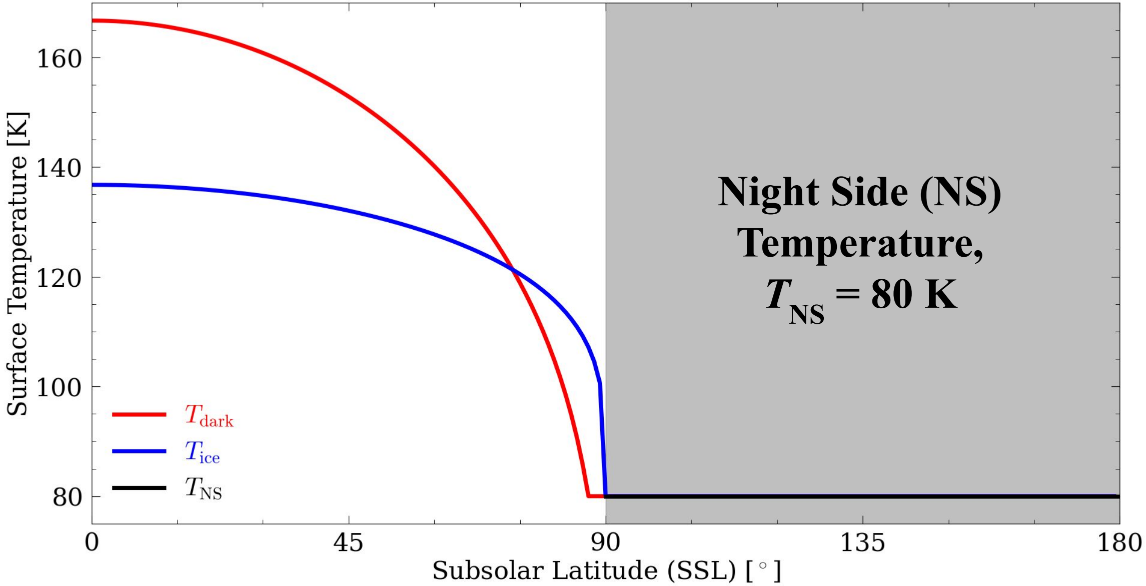




MODELING THE H CORONA: PHOTOCHEMICAL PROCESSES

- **2D DSMC models of H produced via *photodissociation* of sublimated H_2O and radiolytic H_2**
- 2 different surface models of ice & dark, non-ice/ice-poor material are considered

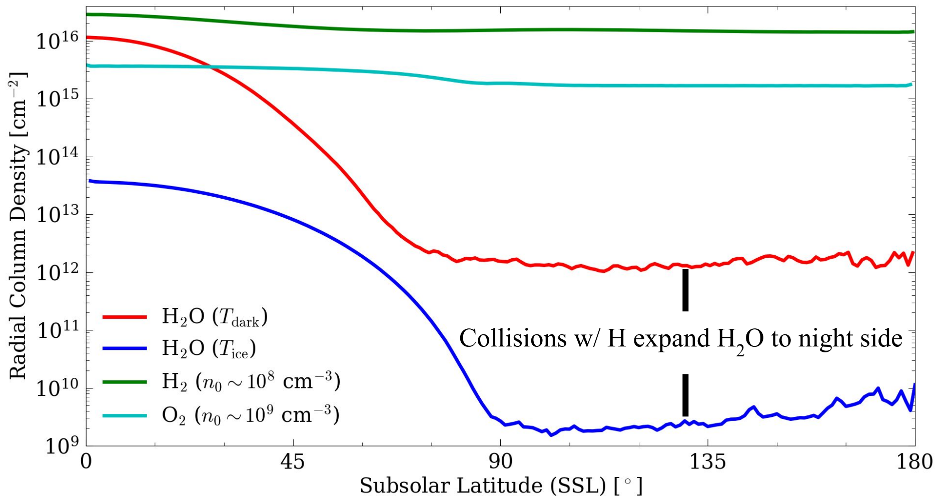
1. **Intimately mixed** [5]: H_2O sublimates at warm day-side temperatures (e.g., [3, 6-8]), T_{dark}
2. **Segregated into patches** [9]: H_2O sublimates at Callisto's "ice" temperatures [10], T_{ice}

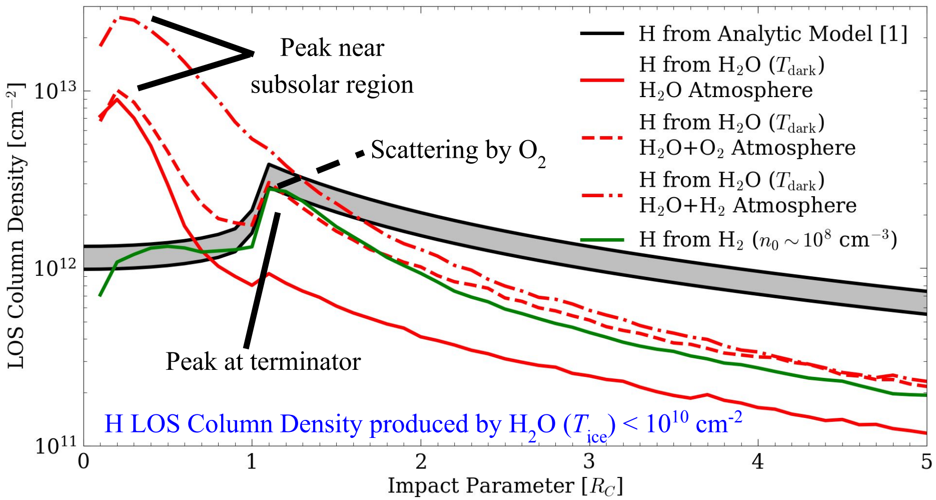


- **Global radiolytic H_2** (surface density: $n_0 \sim 10^{6-8}$ cm^{-3}) **and O_2** (surface density: $n_0 \sim 10^9$ cm^{-3}) components are assumed to be in steady-state (e.g., [3, 4])

RESULTS: COLUMN DENSITIES

- ***Left*: Radial column densities of thermal H_2O, H_2, and O_2**
  - Density of H_2O depends strongly on surface model
- ***Right*: H Line-of-sight (LOS) column densities from DSMC models vs. analytic model** [1]
  - H produced by H_2O has highly asymmetric distribution and a LOS peak on the disk
    - Scattering by O_2 generates a second, smaller LOS peak at the limb
  - H produced by H_2 has a roughly global distribution and a LOS peak at limb





CONCLUSIONS

- **H produced only by H_2O does not produce observed maximum LOS column at the terminator.**
  - This is true whether ice and dark materials are **segregated into patches** or **intimately mixed**.
  - H_2O + H collisions can inflate the H_2O component and generate H_2O corona.
  - A global O_2 component can scatter H produced by H_2O.
  - A collisional ($n_0 \sim 10^8$ cm^{-3}) H_2 component can inflate the H produced by H_2O.

- **Consistent with observation, maximum LOS column of H from H_2 occurs at the terminator.**
  - **Radiolytic H_2 with the H_2O segregated into patches** is the best case to reproduce observations.
  - Influence of H_2 could be detected in forthcoming observations & missions.

- Simulations including **electron impact dissociation of H_2 and H_2O, as additional sources of H,** are now being prepared, **which would reduce the required H_2 density**.

REFERENCES: [1] Roth, L. et al., 2017: Detection of a hydrogen corona at Callisto. *Journal of Geophysical Research: Planets*. [2] Bird, G. A., 1994: *Molecular gas dynamics and the direct simulation of gas flows*. Oxford: Clarendon press. [3] Carberry Mogan, S.R., et al., 2021. A tenuous, collisional atmosphere on Callisto. *Icarus*. [4] Carberry Mogan, S.R., et al., 2020. The influence of collisions and thermal escape in Callisto's atmosphere. *Icarus*. [5] Clark, R.N., 1980. Ganymede, Europa, Callisto, and Saturn's rings: Compositional analysis from reflectance spectroscopy. *Icarus*. [6] Liang, M.C., et al., 2005. Atmosphere of Callisto. *Journal of Geophysical Research: Planets*. [7] Vorburger, A., et al., 2015. Monte-Carlo simulation of Callisto's exosphere. *Icarus*. [8] Hartkorn, O., Saur, J. and Strobel, D.F., 2017. Structure and density of Callisto's atmosphere from a fluid-kinetic model of its ionosphere: Comparison with Hubble Space Telescope and Galileo observations. *Icarus*. [9] Spencer, J.R., 1987. Thermal segregation of water ice on the Galilean satellites. *Icarus*. [10] Grundy, W.M., et al., 1999. Near-infrared spectra of icy outer solar system surfaces: Remote determination of H2O ice temperatures. *Icarus*.