A Short Lived Trace Gas (Methane?) in the Martian Atmosphere: GCM Simulations of Source and Destruction Rates

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Outline

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- Simulations
  - Ames GCM
  - Modeling Parameter Exploration
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- Summary

Purpose:

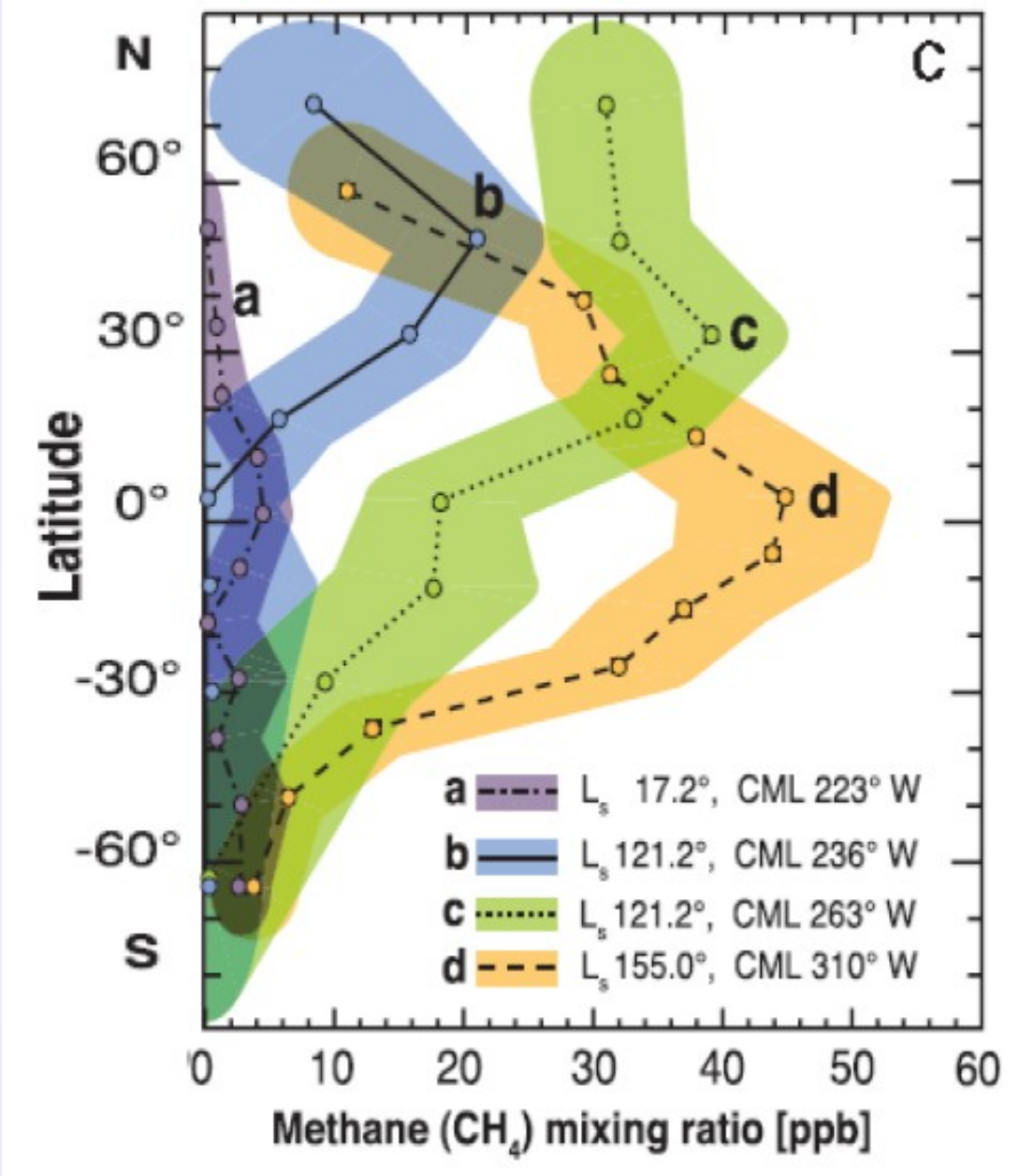
To investigate the ability of the Mumma et al. (2009) proposed source magnitude to produce their derived methane column abundances in a global scale atmospheric model.

Motivating Observations of Martian Methane

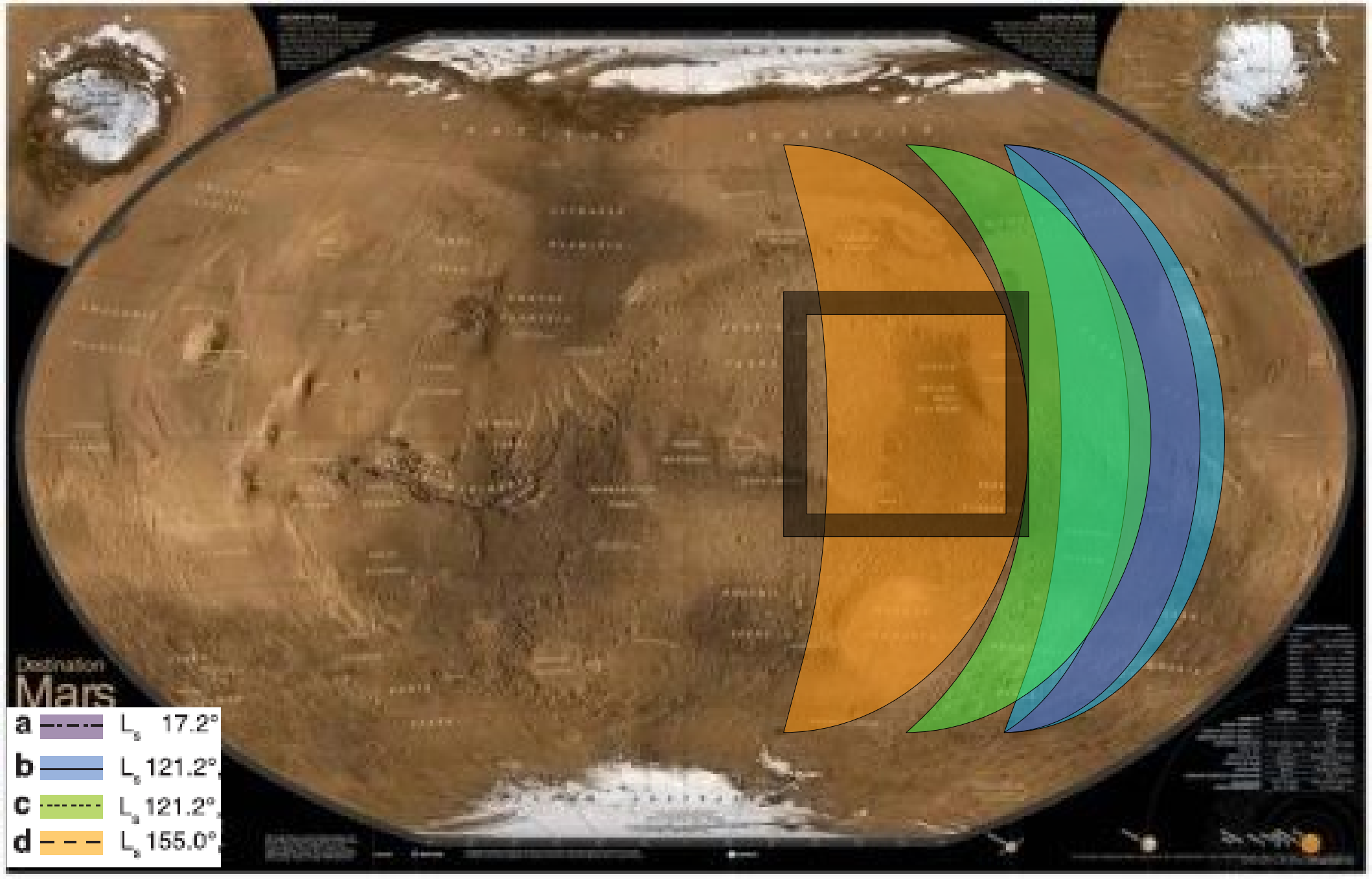
- Mumma et al. 2009
  - IRTF and Keck-2
  - Observations over 7 years (90% of planet's surface)
  - Published data from 4 dates (3 in 2003, 1 in 2006)
    - L_s 17, maximum mixing ratio ~ few ppb
    - L_s 121-122, maximum mixing ratio ~ 35 ppb
    - L_s 155, maximum mixing ratio ~ 45 ppb
    - Source in Arabia Terra
      - Magnitude of 0.6 kg/s
      - Destruction time less than 0.6 Earth years

Observed Mixing Ratios

- Latitude profiles of of observations at 3 different L_s (two observations at L_s 121) showing the increase in CH_4 mixing ratio as the year progresses



Source Region and Observed Longitudes



Simulations

- NASA Ames GCM v. 1.7.3 [7]
  - Grid Point model
  - Extends from surface to 90 km vertically
  - Spatial resolution of 5 x 6 degrees (lat x long)
  - Study several different scenarios at once (we use 7)
  - Accounts for full diurnal cycle

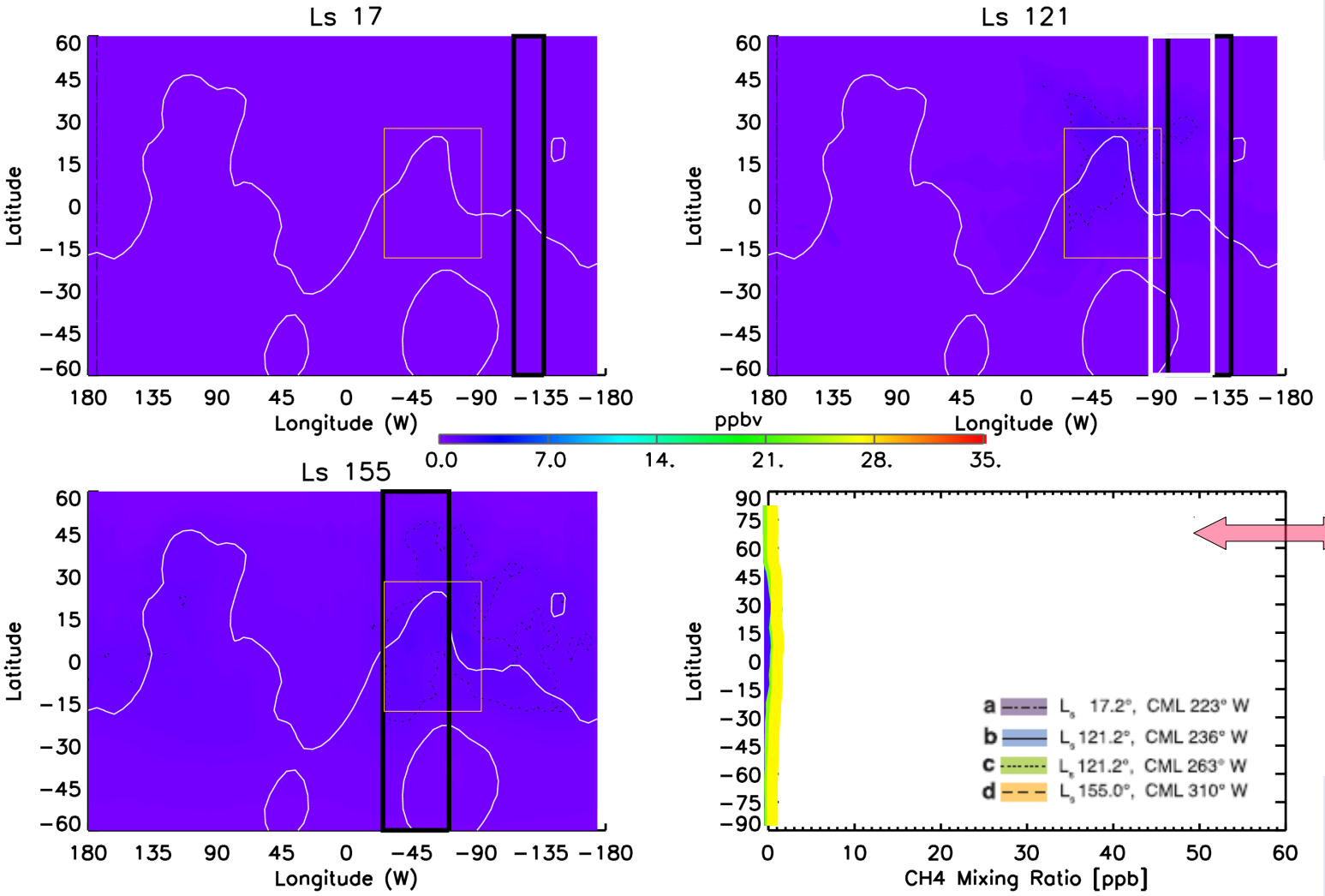
- Impose inferred source magnitude and destruction times
- Determine ability of the source magnitude to produce the observed concentrations
- What modifications can improve the column abundance comparison?

Input Parameters

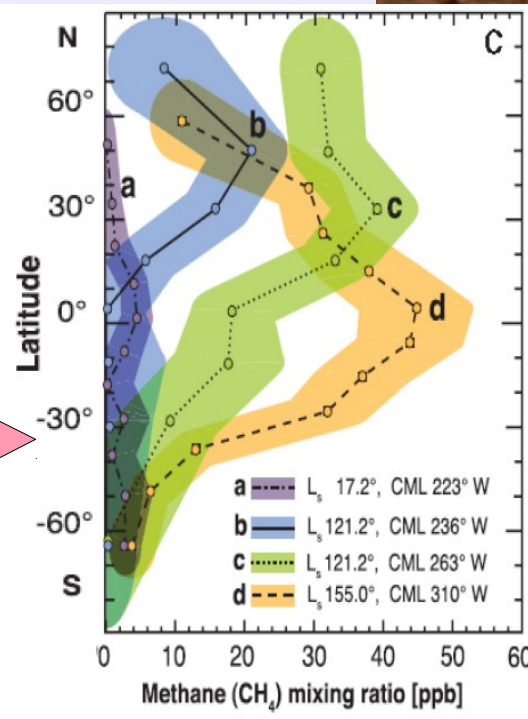
- Use suggestions from Mumma et al. (2009) for initial constraints on source location, spatial extent and magnitude; source duration; and destruction rate
  - Source Location: Box region from 270 to 330 W, 15 S to 30 N (approximately 1×10^{13} m^2, 7% surface area of Mars)
  - Surface Source Magnitude: 0.6 kg/s ~ 5.5×10^{-14} kg m^{-2} s^{-1}
  - Source Duration: L_s 90 to 180
  - Destruction Rates (in the form of an E-folding time):
    - 350 Earth years (photochemical lifetime in Martian atmosphere)
    - 4 Earth years (destruction time proposed if source activity is not annually recurring)
    - 0.6 Earth years (if source activity is annually recurring)

Results with Mumma et al.'s Suggested Parameters 0.6 kg/s Source, 0.6 Earth Year Destruction time

Model Results



Observations



Notes about the source magnitude

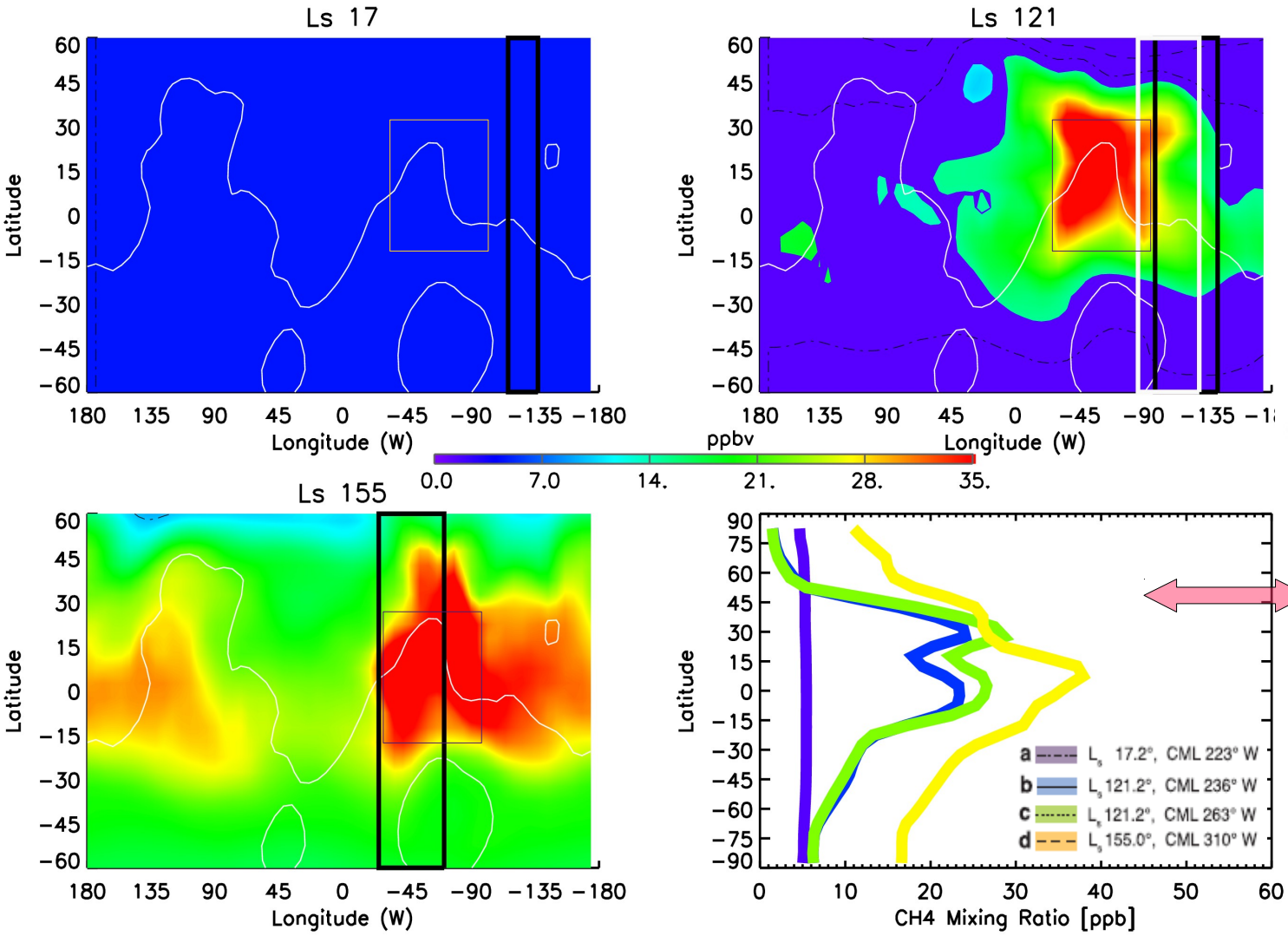
- Source magnitude and destruction rate do not produce the observed latitude profiles
- Mumma et al. estimate that the gas diffuses away from the source at ~ 3 cm/s
- GCM's transport away from the source is more rapid than the diffusive transport suggested by Mumma et al.
  - The model's more rapid transport away from the source results in a reduction of local concentrations
  - An increased source magnitude is required to produce the observed concentrations
  - An increased destruction time does not produce large enough column abundance values for the modeled latitude profiles

Source/Destruction Parameter Space Study:

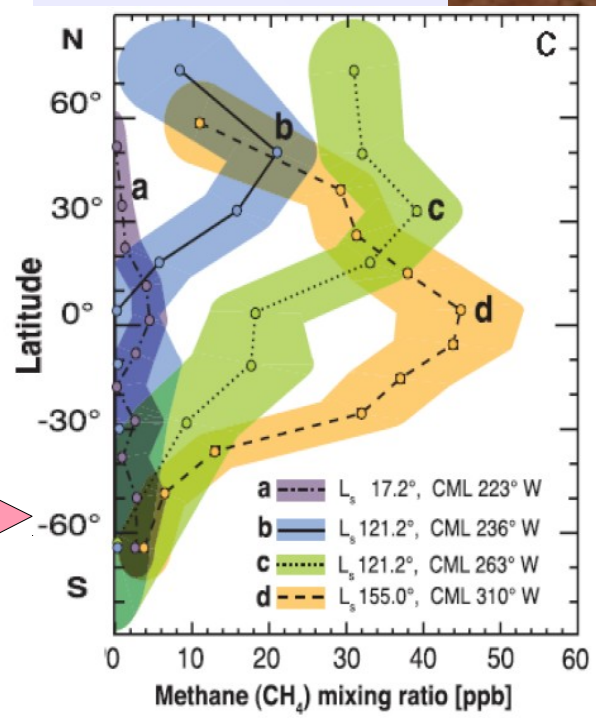
- The mixing ratios produced with 0.6 kg/s source magnitude are too low by a factor of about 30
  - New magnitude: 18 kg/s
- Destruction times of 350 years and 4 years create mixing ratios which are too uniform in latitude (no peak near the equator) to recreate the latitude profile and would produce year to year increases in the total abundance.
  - Continue to work with 0.6 years
    - from Mumma et al. (2009)
  - This agrees with results of Lefevre and Forget (2009)
    - Destruction time of ~200 days

30x Initial Source Magnitude (18 kg/s), 0.6 Earth year E-folding Destruction Time

Model Results



Observations



Results

- Increasing source magnitude by a factor of 30 (to 18 kg/s) produces better agreement with the derived values
  - There is not a perfect fit
    - Latitude structure is different from observations
      - Test spatial extent of source
- Destruction Lifetime: 0.6 Earth years (219 days)
- How much methane is this?

Earth-Based comparisons: Cattle

- How many cattle do we need, and in what population density?
  - A single cow produces ~ 300 gm/day of CH_4 [1*] (~4×10^{-3} gm/s)
    - 18 kg/s → 5 million cattle
    - Area: ~1×10^{13} square meters ~3 billion acres
    - ~0.002 cattle per acre
  - Cattle population density of Iowa:
    - Cattle Population of Iowa: 3.8 million [2*]
    - Area of Iowa: ~36 million acres [3*]
    - ~0.1 cattle per acre
- Back to the modeling...

Sensitivity Testing

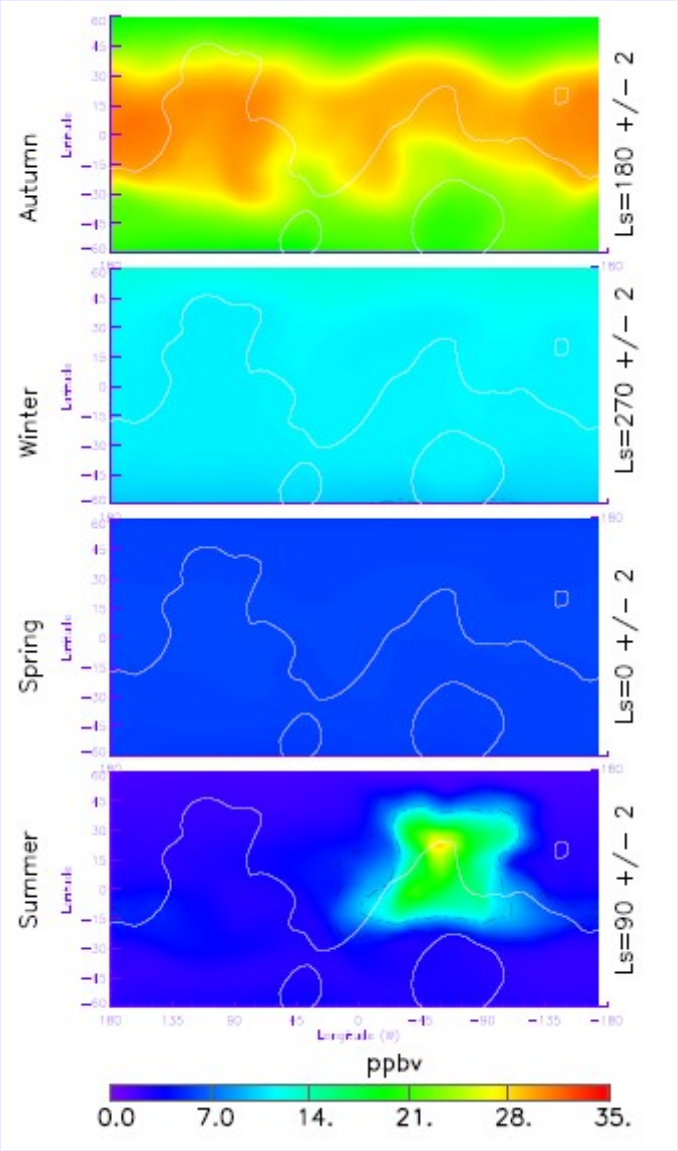
- Combination of source magnitude and destruction rate
  - Higher source magnitude + shorter destruction time
  - Lower source magnitude + longer destruction time
    - Constrain the best results to be close to 0.6 year and 18 kg/s
- Sensitivity of source spatial extent
  - Smaller source areas (in both latitude and longitude)
    - Latitude profiles have narrower peaks near the equator than the observations
  - Source must be extended (at least in latitude) to produce latitude profiles similar to the observations

Seasonality

- Seasonality is being tested
  - From the Mumma et al. results, the source appears to "turn on" around L_s 90
    - This is constrained by the derived column abundances for L_s 121 observations with peak values of 35 ppb
    - The source cannot turn off much before L_s 155; if it does turn off, then the observed L_s 155 column abundances are not reproduced
  - The source must "turn off" by L_s 180
    - The simulated column abundances at L_s 17 are greater than Mumma et al.'s results if the source remains on after L_s 180
- Additional seasonal constraints are provided by the Fonti and Marzo TES derived abundances

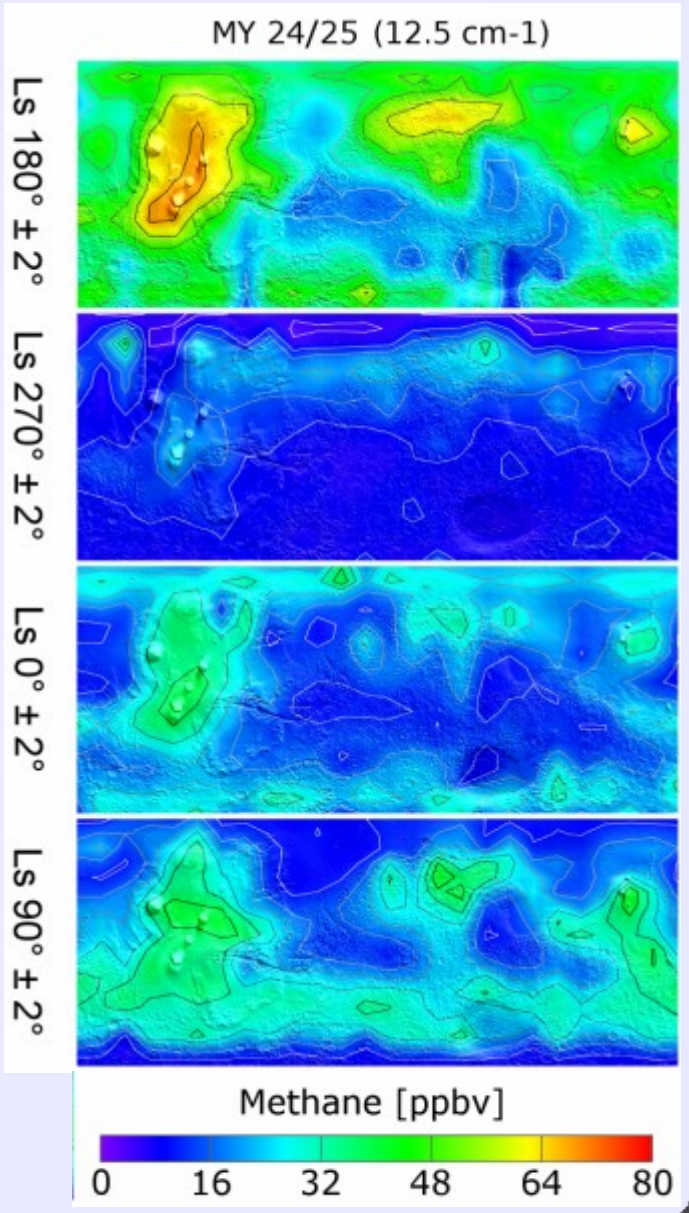
Comparison of 4 cardinal seasons

Model



Caution: color bars are not the same scale

Data



Future Work

- Additional destruction mechanisms
- Include other seasonal information in the model
  - Forti and Marzo TES
  - New observations?
- Other possible gases with different possible destruction/loss mechanisms
  - Condensation?

Summary

- The model source magnitude required to match the latitude profiles of Mumma et al. is larger than estimated
- The model suggests that methane is being destroyed about 600x more quickly than homogeneous photochemistry would be expected to produce

Acknowledgements

- New Mexico Space Grant Graduate Research Fellowship
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References

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[2] Formisano V. et al. (2004) *Science*, *306*, 1758-1761.

[3] Krasnopolsky V. et al. (2004) *Icarus*, *172*, 537-547.

[4] Fonti S. and Marzo G.A. (2009) Submitted.

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[6] Maguire, W. C. (1977) *Icarus*, *32*, 85-97.

[7] Kahre, M.A. et al. (2008) *Icarus*, *195*, 576-597.

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- (1*) Laubach and Kelliher, 2004, Measuring Methane Emission Rates of a Dairy Cow Herd by Two Micrometeorological Techniques, Agriculture and Forest Meteorology, vol 125, pp 279-303
- (2*) Iowa Agriculture Statistics 2007, www.iowaagriculture.gov/QuickFacts
- (3*) Iowa Quick Facts, www.iowadatacenter.org/quickfacts