Stellar Occultation Studies of Saturn's Stratosphere from Cassini VIMS

A Exam

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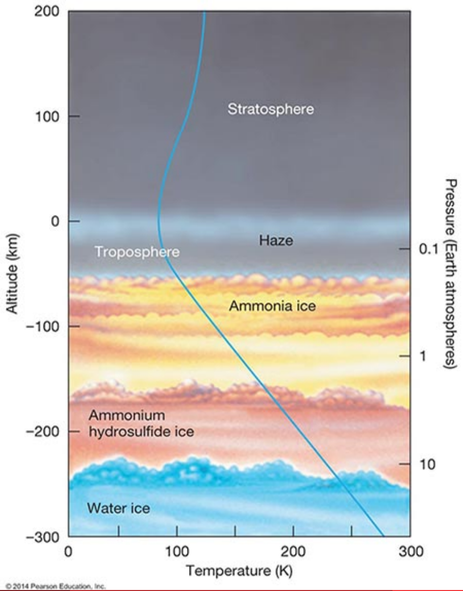
Summary

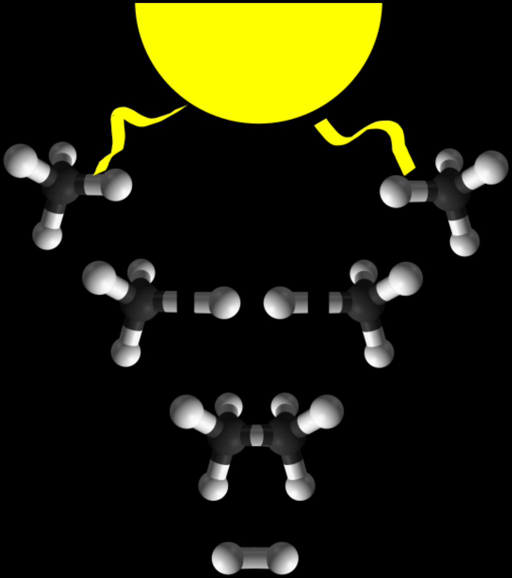
1. Saturn's Atmosphere
   - Photochemistry and Methane Cycle
   - Seasonal Variations
   - Previous Data
2. Data Overview: Anatomy of an Occultation
   - Geometry
   - Extinction Mechanisms
3. Methods, Results, and Future Work
   - Image Mode vs Occultation Mode
   - Analysis of Image Mode Data
   - Plan for Occultation Mode Data

Saturn's Atmosphere

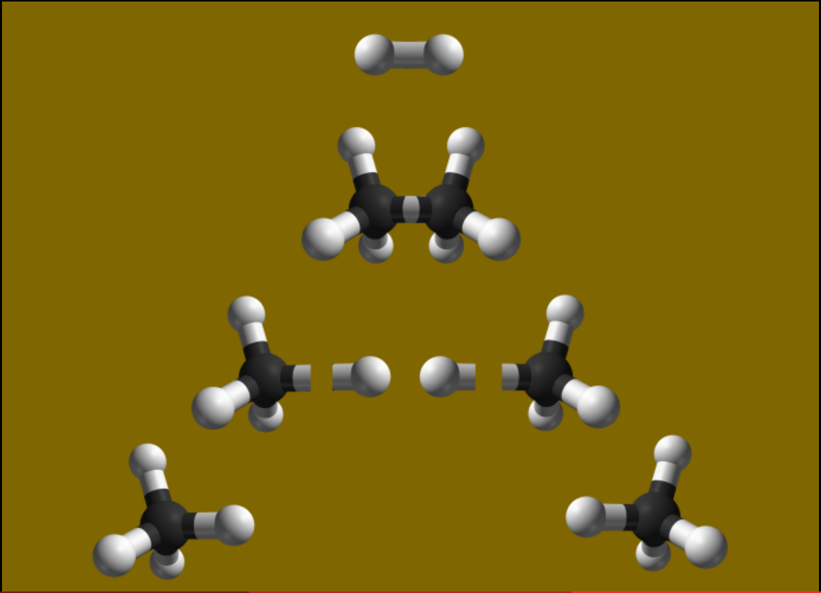
Schematic of Saturn's Atmosphere



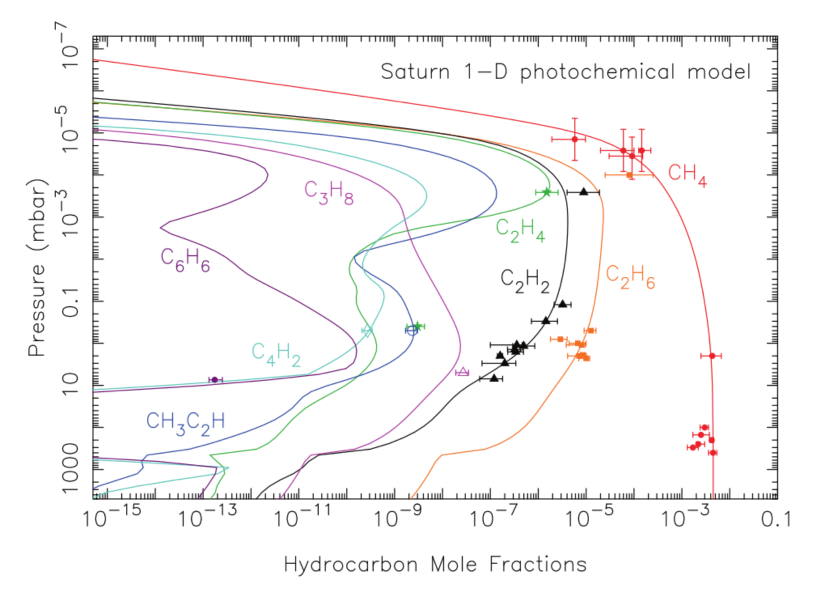
Methane Photodissociation



Methane Recreation



Chemistry Model

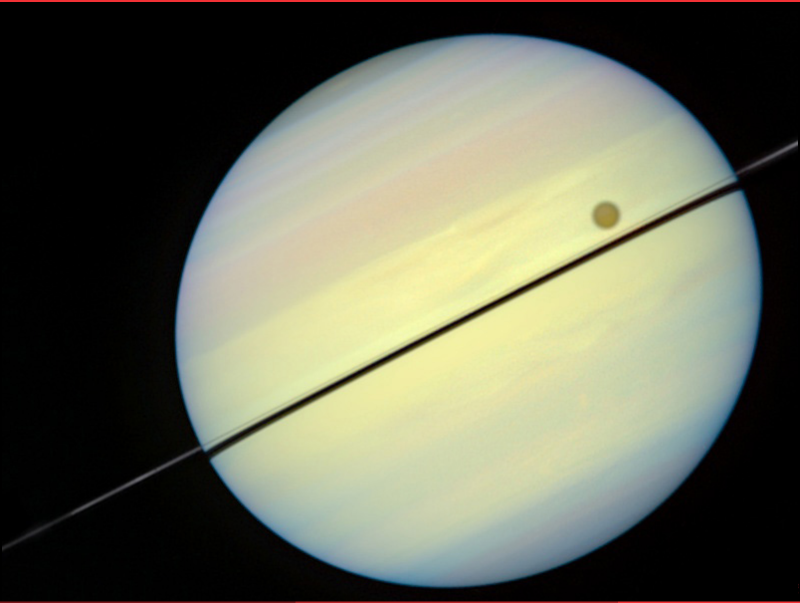


Evidence of Seasonal Variation from the Literature

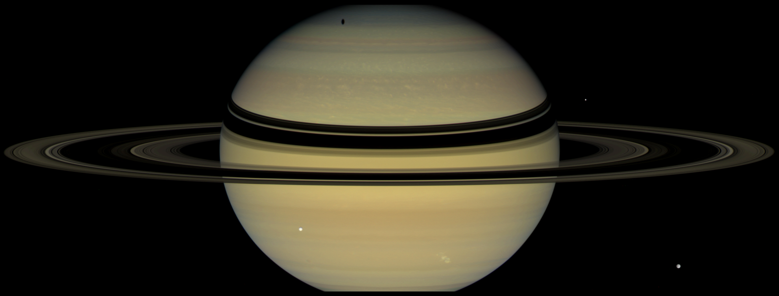
[T]he high northern latitudes showed a vibrant blue color in 2004. The interpretation (Edgington et al. 2012) is that Rayleigh scattering by gas molecules is responsible, and that the colored haze material is suppressed in the northern (winter) latitudes relative to southern (summer) latitudes. Subsequent Cassini ISS images have shown that the blue color persisted into 2008 but by 2009 (near equinox) the blue color had dissipated at northern latitudes ... At the current epoch (2014) the southern high latitudes are beginning to show a blue color as they recede into winter conditions. These observations are consistent with the idea that the blue color indicates reduced production of haze throughout the winter season.

- Fletcher et al. 2018 "Saturn in the 21st Century" Chapter 11

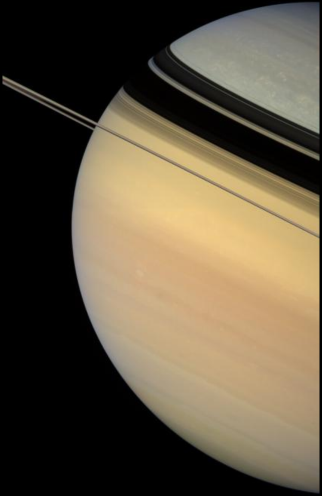
Latitudinal Chemical Variation



Saturn's Southern Summer

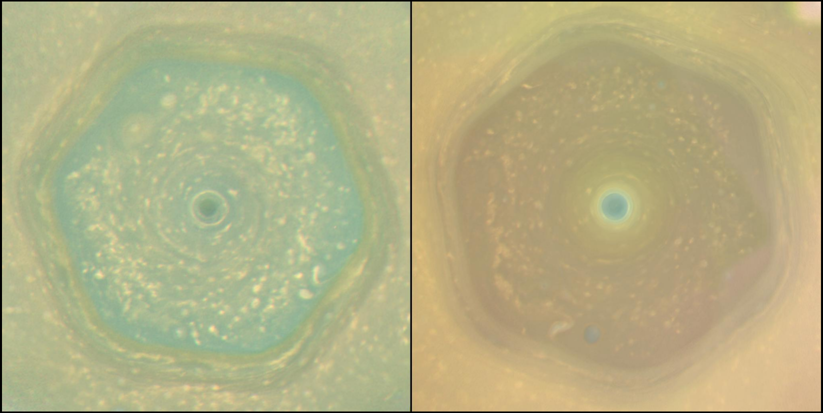


Saturn's Northern Winter Closeup



Saturn Equinox to Solstice

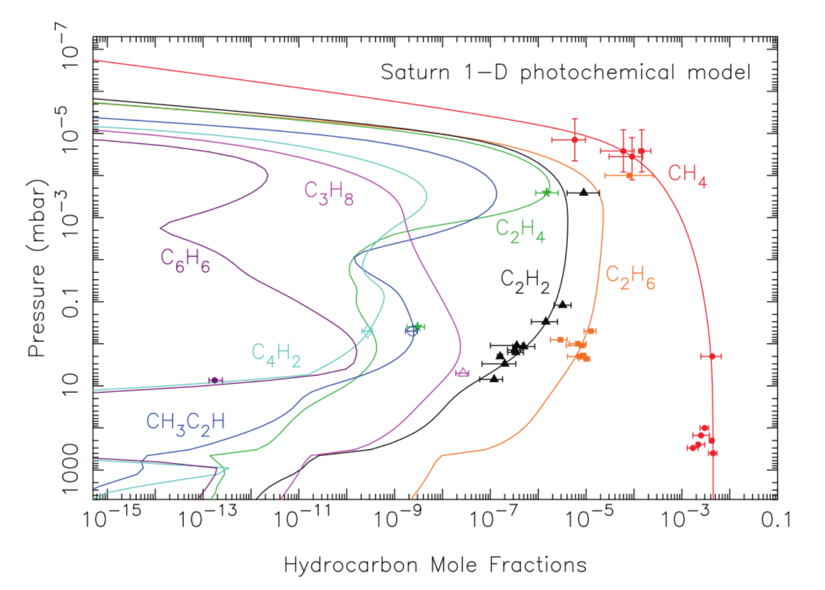
North Pole Hexagon, 2013 vs 2017



Sources of Data for Saturn

- Direct Spectroscopy
  - low radial resolution, but can cover large areas of the face of the planet (e.g. CIRS, more on this later)
- Spacecraft Radio Occultations
  - a few mbar to 1 bar, temperature/pressure profile only, lower stratosphere and upper troposphere (e.g. Kliore et al. 2004)
- Spacecraft UV Occultations
  - $\sim$1 nbar to $\sim$1 μbar, molecular absorption only, thermosphere (e.g. Broadfoot et al. 1981)
- Spacecraft IR Occultations
  - $\sim$20 μbar to $\sim$5 mbar, most of the stratosphere (our data)

Chemistry Data



CIRS Data

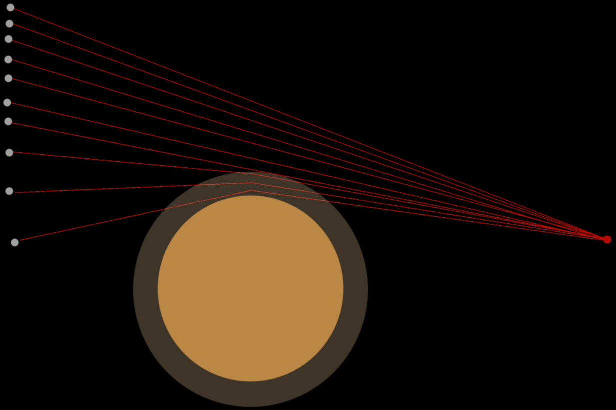
Observes 7.67 μm CH_4 emission to fit temperature profile, with 1-2 scaleheight resolution through the stratosphere.

> *If the altitude dependence of CH_4 were seasonally-variable, then this would lead to systematic offsets in the derived temperatures. As the stratospheric CH_4 distribution cannot be uniquely determined from CIRS observations alone, we assume a latitude-independent CH_4 abundance throughout the retrievals and the subsequent radiative-climate modeling.*
>
> \- Fletcher et al. 2010

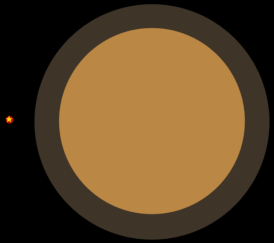
CIRS also found that 0.5-3mbar was the region of the atmosphere with the largest seasonal temperature variations

Data Overview: Anatomy of an Occultation

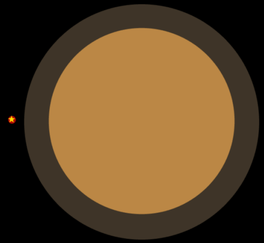
Bird's Eye View



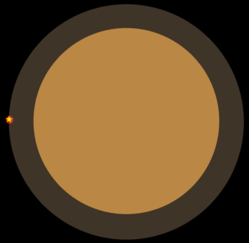
Spacecraft View



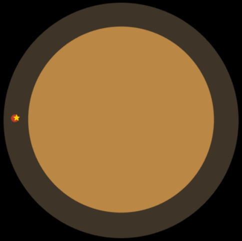
Spacecraft View



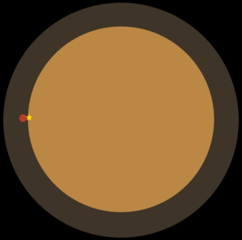
Spacecraft View



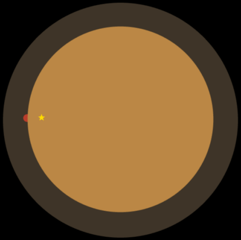
Spacecraft View



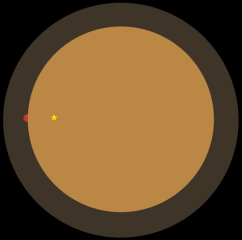
Spacecraft View



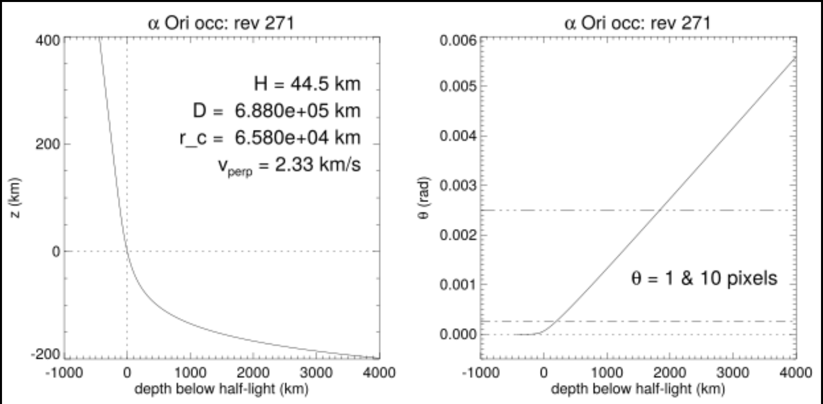
Spacecraft View



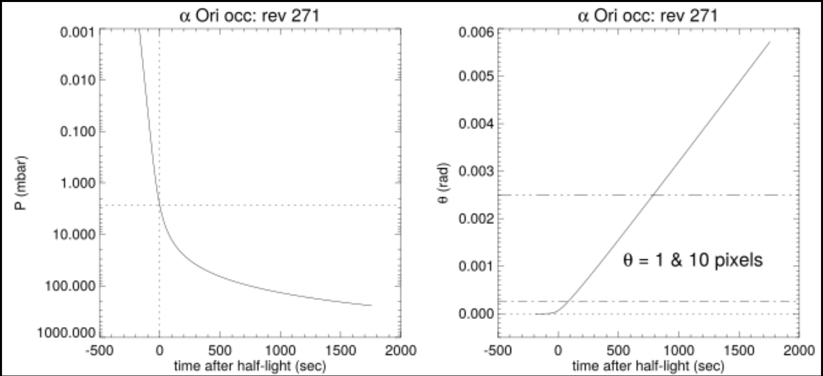
Spacecraft View



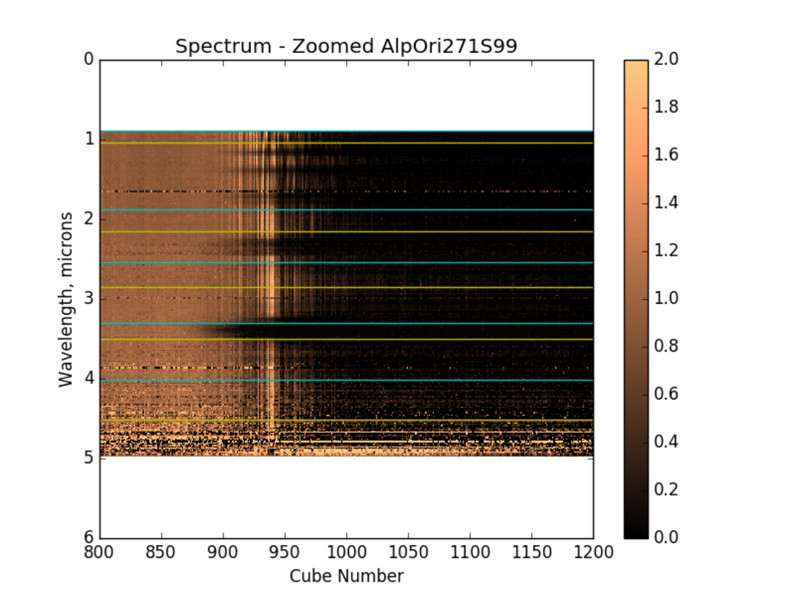
Geometry Plots



Geometry Plots



Occultation Overview

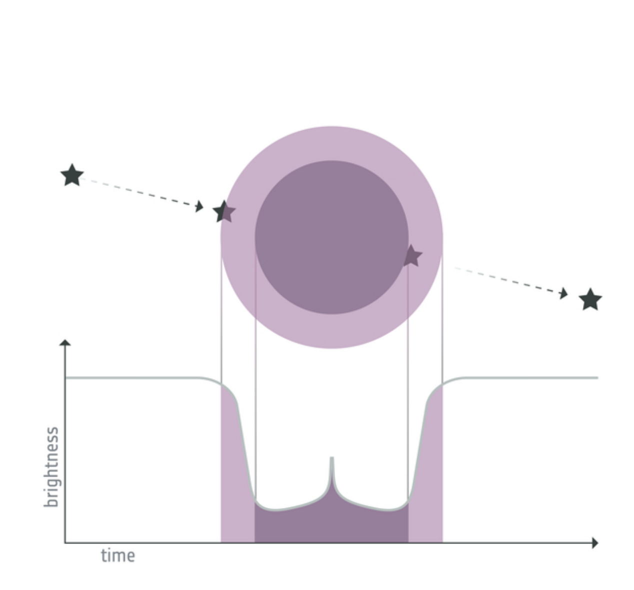


Differential Refraction

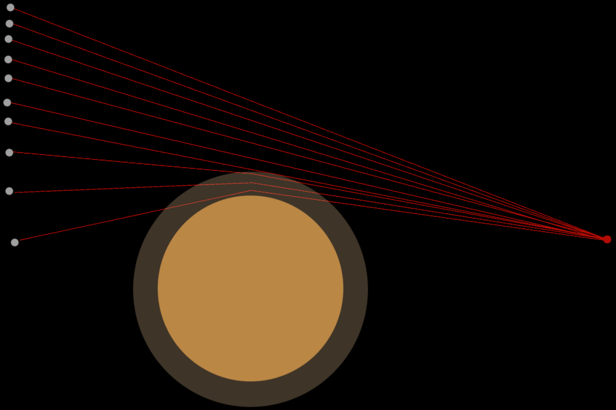
$$\theta(\rho) = -2\rho \int_{r_0}^{\infty} \frac{dn/dr}{n\sqrt{n^2r^2 - \rho^2}} dr \tag{1}$$

$$\Phi(\rho) = \left(1 - D\frac{d\theta}{d\rho}\right)^{-1} \cancel{\left(1 - \frac{D\theta}{\rho}\right)^{-1}} \tag{2}$$

Example Refraction-Driven Occultation



Differential Refraction



Molecular Extinction

$$\Phi(\lambda) = \Phi_0 e^{-\tau(\lambda)}, \tag{3}$$

$$\tau(\lambda) = \kappa(\lambda) L d \tag{4}$$

Methods, Results, and Future Work

Imaging Mode

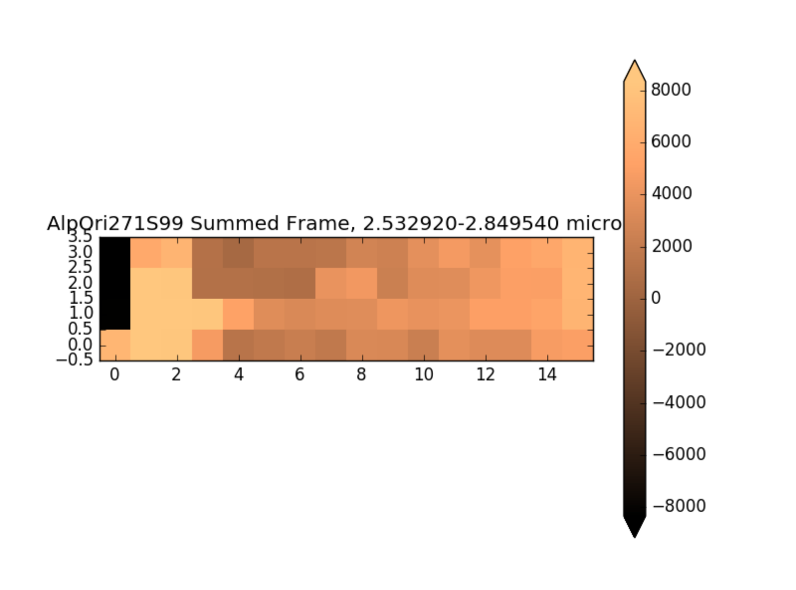
Check out this video

Analysis

Major steps of image analysis:

- background correction (spatial and temporal)
- centering algorithm

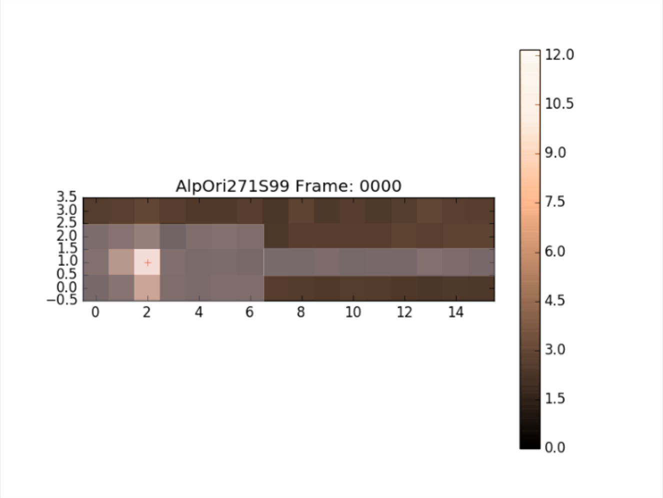
Spatial Systematics



Spatial Background Estimate

- Take only frames after the bulk of the occultation
- Set brightest pixel in each wavelength channel to nan (should be only one pixel with any stellar information
- Take average value of each pixel for each wavelength to get a wavelength-dependent "flat field"
- Divide each of these frames by its median to normalize
- Divide frame by flat-field

Temporal Background Estimate



For each

Better Background Removal

(Not yet implemented)

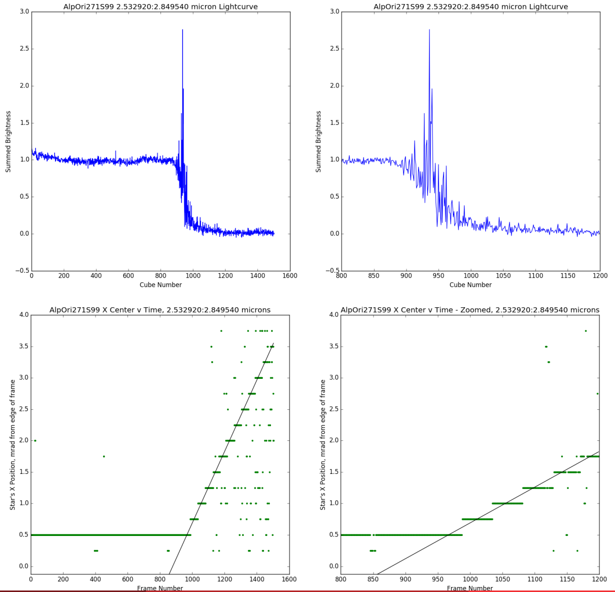
- ignore column 0
- Take spatial background frames, and scale by temporal background offset, and subtract

Centering Algorithm

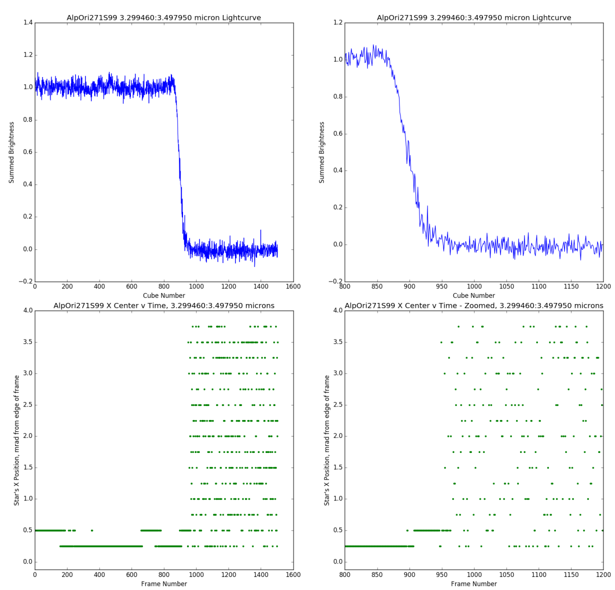
- Average frames together (usually 3)
- Select brighest pixel as the star location

I tried many other algorithms with little success. Too little information in adjacent pixels. Considering anything but the brightest just added noise to the measurement (especially near the end of the occultation).

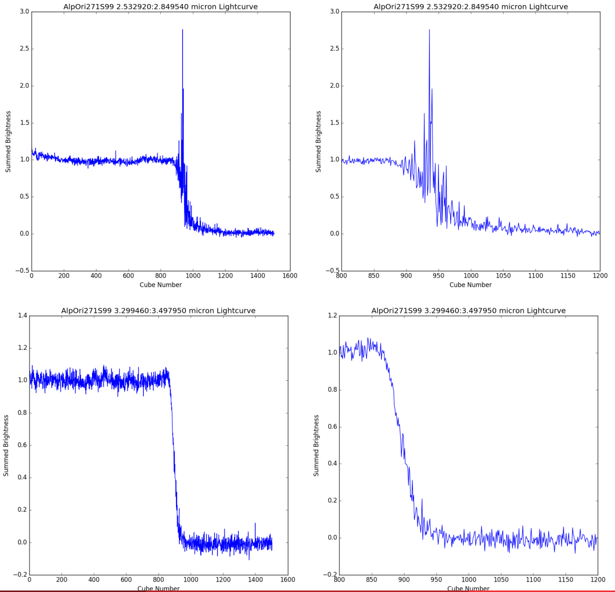
AlpOri271S99 2.7 μm (continuum)



AlpOri271S99 3.4 μm (methane)



Comparison of Photometry, 2.7 vs 3.4 μm, AlpOri271S99



Information Expected from Imaging Occs

- Estimate when occultation-mode data leaves the single pixel
- Are there aerosols, or is all of the attenuation caused by refraction?
- Methane abundance, TP profile, and planet shape (see next section, similar as for occultation-mode data)

Future Analyses

Occultation Mode Data

- Abel Transform / TP Profile
- Onion-peeling algorithm Methane/Ethane abundances

Abel Transformation for T-P Profile

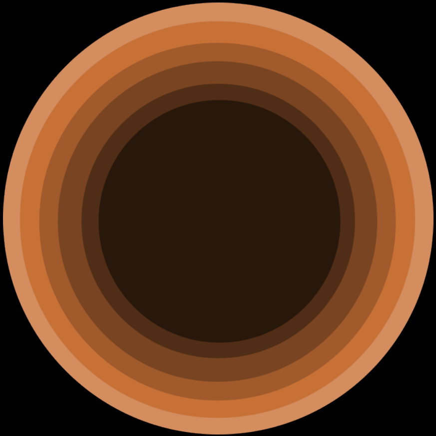
$$\Phi(\rho) = \left(1 - D\frac{d\theta}{d\rho}\right)^{-1} \cancel{\left(1 - \frac{D\theta}{\rho}\right)^{-1}} \tag{5}$$

$$\theta(\rho) = -2\rho \int_{r_0}^{\infty} \frac{dn/dr}{n\sqrt{n^2r^2 - \rho^2}} dr \tag{6}$$

via Abel transformation:

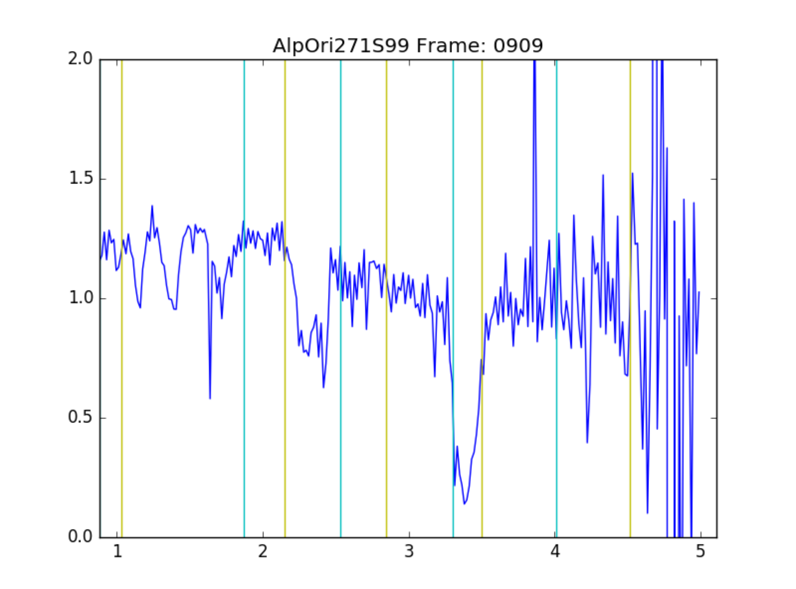
$$ln[n(\frac{\rho}{n})] = \frac{1}{\pi}\int_{\rho}^{\text{inf}} \frac{\theta(\rho')}{\sqrt{\rho'^2 - \rho^2}} d\rho' (7)$$

Onion-Peeling



$$\Phi(\lambda) = \Phi_0 e^{-\tau(\lambda)}, \text{ where the change in optical depth } \delta\tau(\lambda) = \kappa(\lambda) L d \tag{8}$$

Spectrum



Expected Results

- Shape of methane homopause
- Rate of photochemistry (ethane production) as a function of latitude, season, ring shadowing
- Eddy-diffusion rate

The End