EPIC-*Inspired* Developments in Cloud and Aerosol Remote Sensing Science Using Oxygen Absorption

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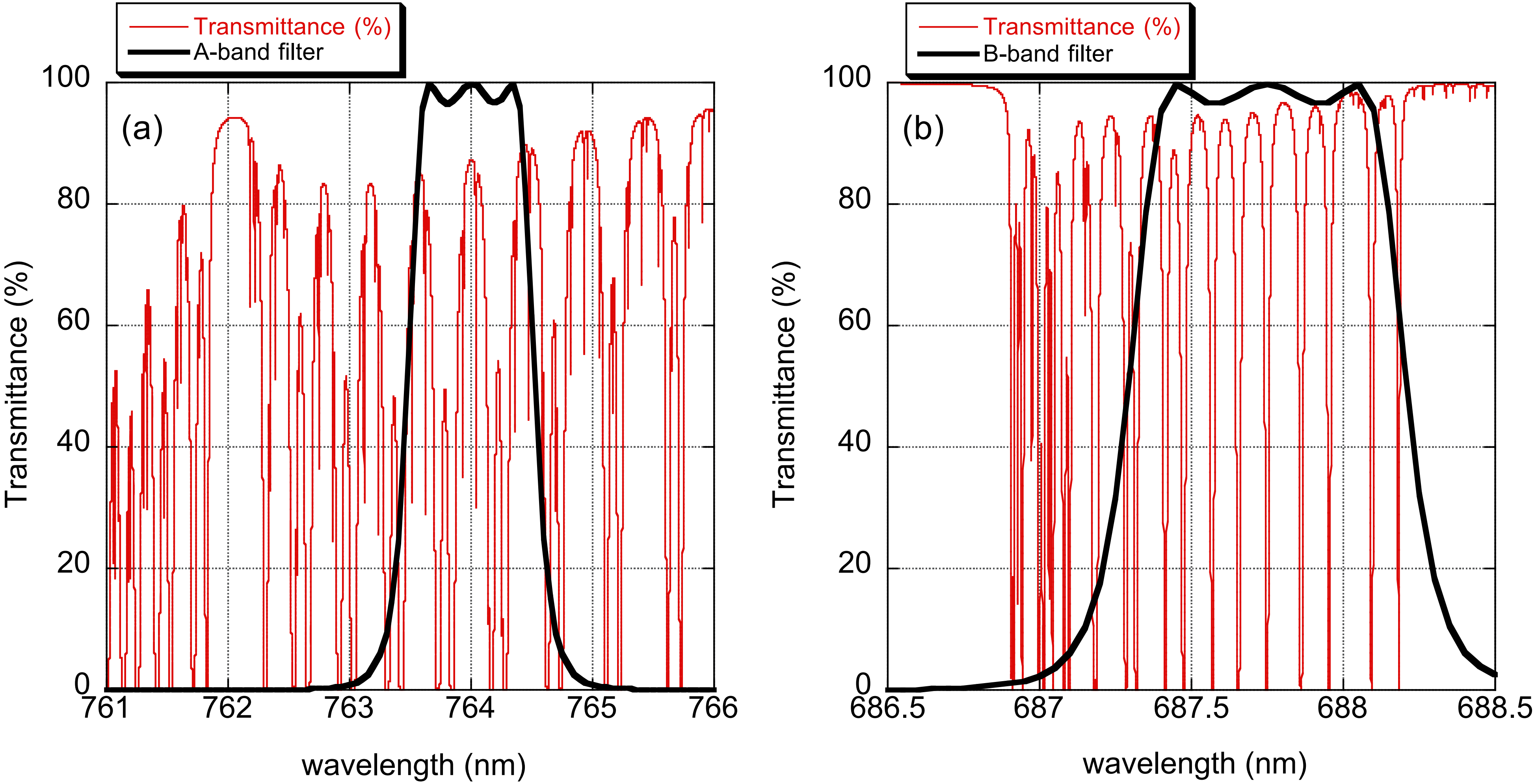
Quentin Libois (CNRS/CNRM), Nicolas Ferlay (CNRS/LOA), and Alexander Marshak *(NASA – GSFC)*

DSCOVR Science Team Meeting, NASA – GSFC, Greenbelt, Md, Sept. 27-29, 2022.

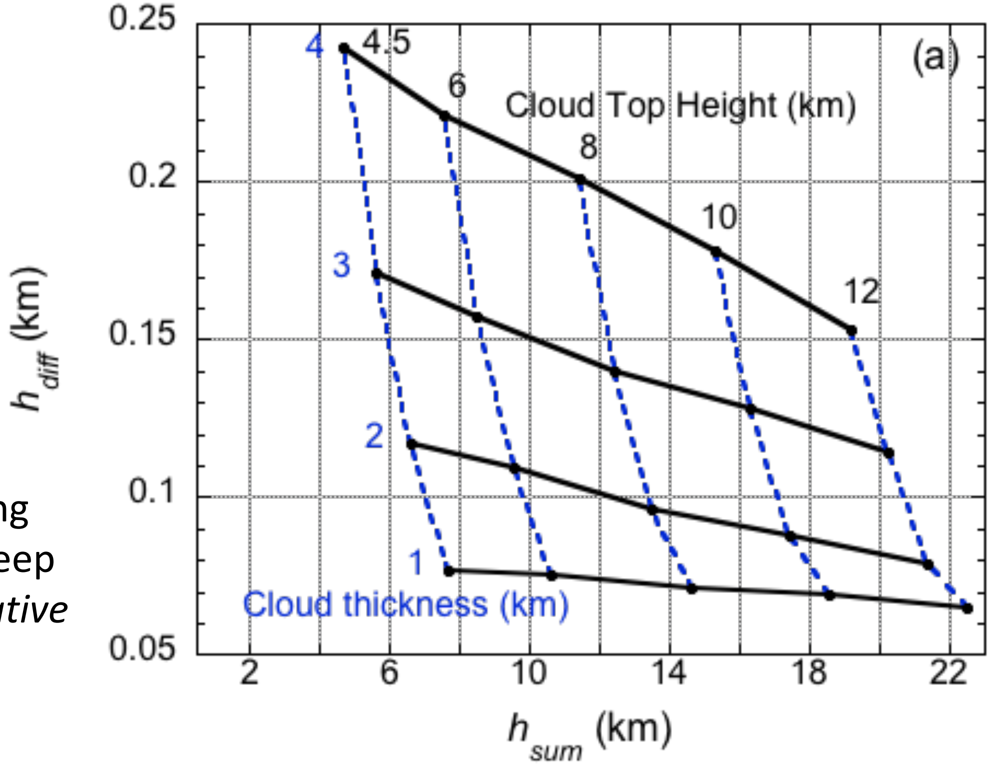
EPIC’s take on oxygen absorption



→ Two pieces of cloud information?

Cloud centroid height from A-band: h_A
Cloud centroid height from B-band: h_B
Generally,
$h_{sum} = h_A + h_B$ *more sensitive to cloud top height*
$h_{diff} = h_A - h_B$ *more sensitive to cloud geometrical thickness*

Yang, Y., Marshak, A., Mao, J., Lyapustin, A., and Herman, J. (2013). A Method of Retrieving Cloud Top Height and Cloud Geometrical Thickness with Oxygen A and B Bands for the Deep Space Climate Observatory (DSCOVR) Mission: Radiative Transfer Simulations. *J. Quantitative Spectrosc. Radiative Transfer* **122**, 141–149. doi:10.1016/j.jqsrt.2012.09.017



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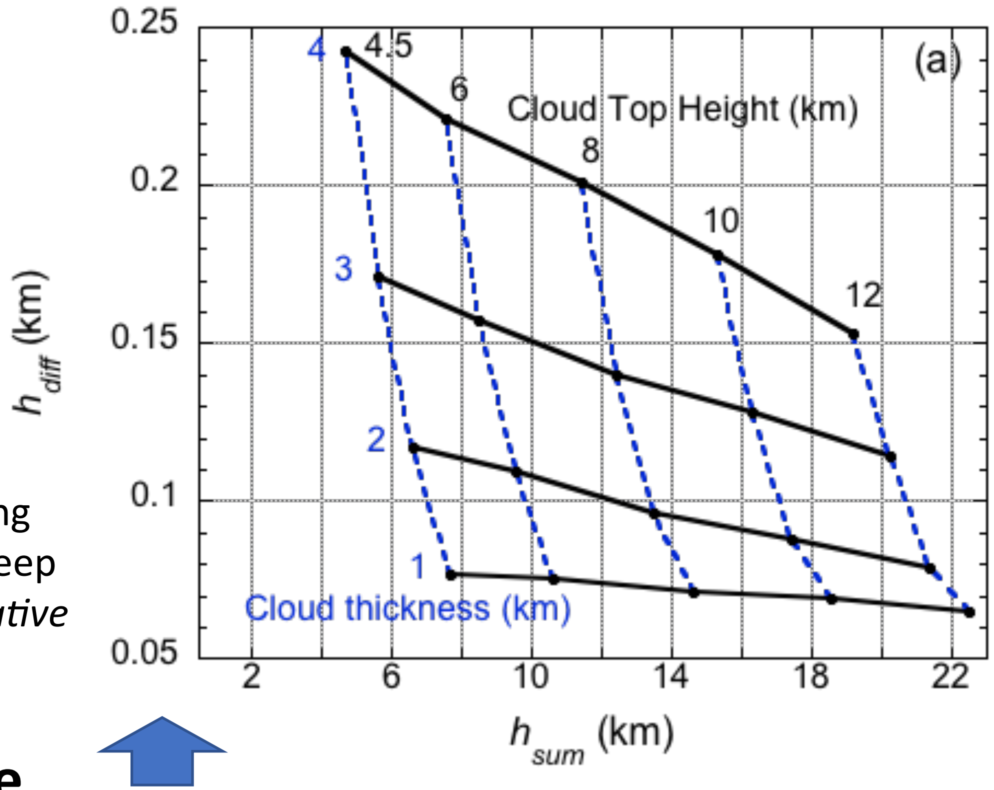


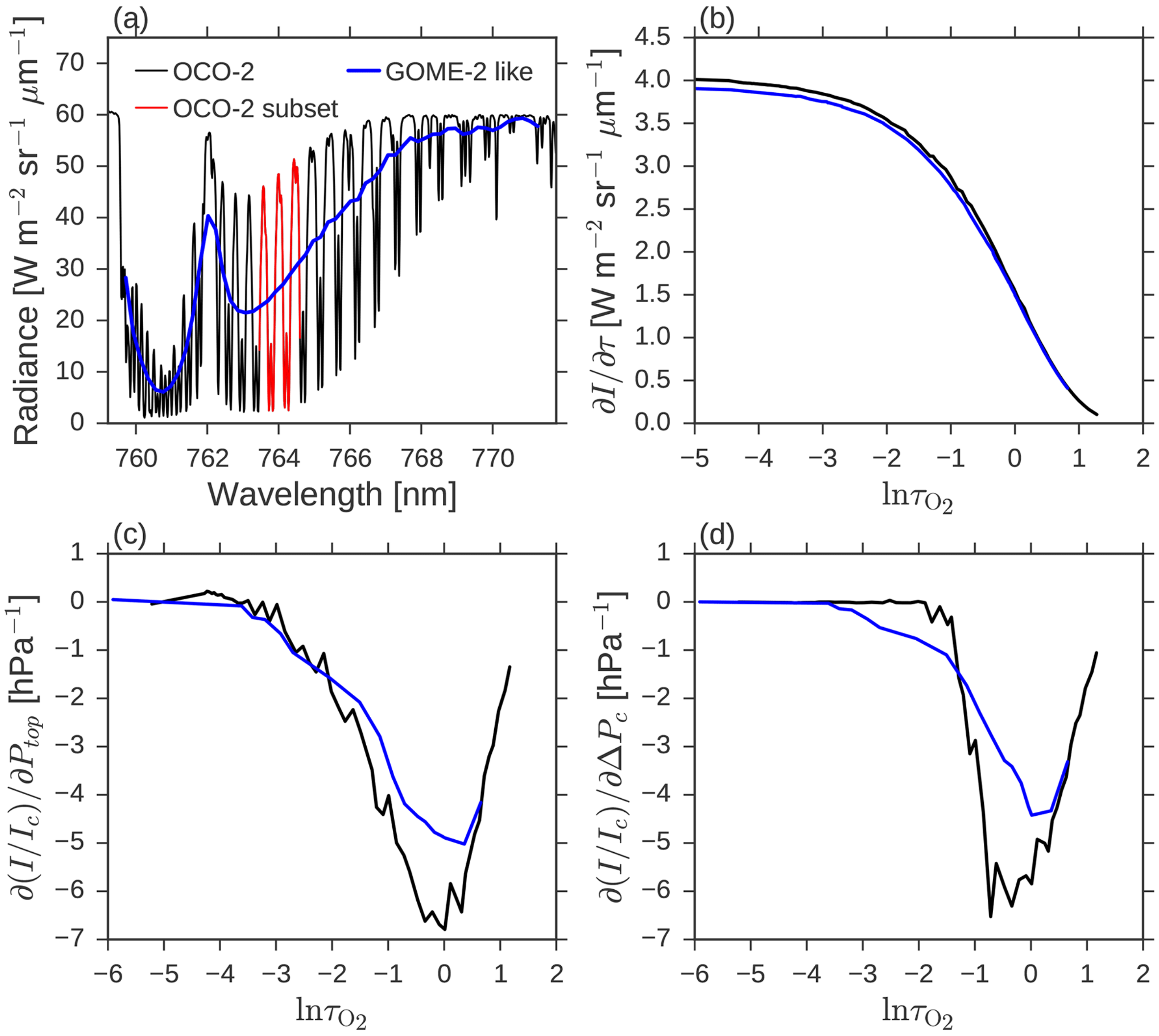
…unfortunately, sensor noise swamps this difference

Davis, A. B., Merlin, G., Cornet, C., Labonnote, L. C., Riédi, J., Ferlay, N., et al. (2018b). Cloud Information Content in EPIC/DSCOVR's Oxygen A- and B-Band Channels: An Optimal Estimation Approach. *J. Quantitative Spectrosc. Radiative Transfer* 216, 6–16. doi:10.1016/j.jqsrt.2018.05.007

Davis, A. B., Ferlay, N., Libois, Q., Marshak, A., Yang, Y., and Min, Q. (2018a). Cloud Information Content in EPIC/DSCOVR's Oxygen A- and B-Band Channels: A Physics-Based Approach. *J. Quantitative Spectrosc. Radiative Transfer* **220**, 84–96. doi:10.1016/j.jqsrt.2018.09.006

GOME-2 & OCO-2/3's takes on the oxygen A-band (~200 to ~2000 of spectral channels: $\Delta\lambda = 0.21$ & 0.02 nm)

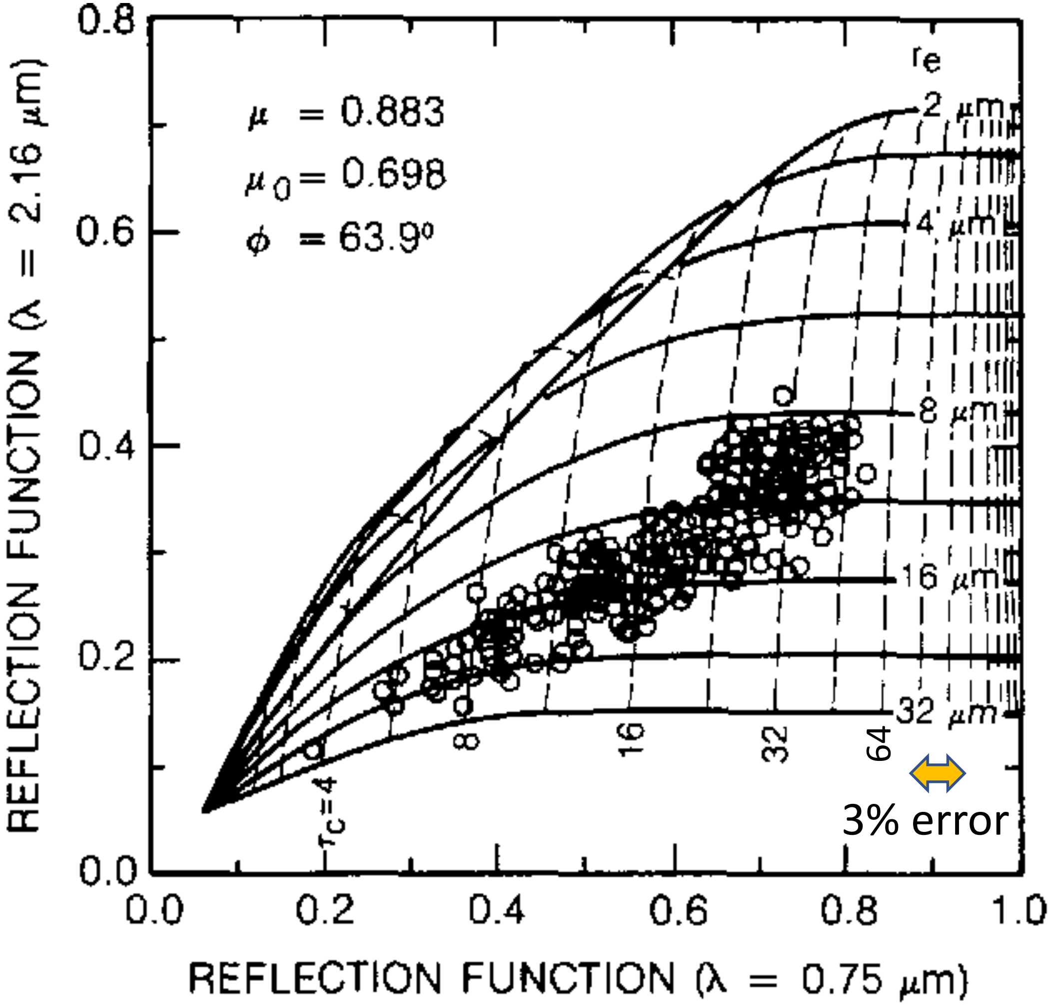
Jacobians of $[I/I_c](\tau_{O2})$ for cloud top pressure and pressure thickness →



Richardson, M., and Stephens, G. L. (2018). Information Content of OCO-2 Oxygen A-Band Channels for Retrieving marine Liquid Cloud Properties. *Atmos. Meas. Tech.* **11**, 1515–1528. doi:10.5194/amt-11-1515-2018

Richardson, M., Leinonen, J., Cronk, H. Q., McDuffie, J., Lebsock, M. D., and Stephens, G. L. (2019). Marine Liquid Cloud Geometric Thickness Retrieved from OCO-2's Oxygen A-Band Spectrometer. *Atmos. Meas. Techn.* **12**, 1717–1737. doi:10.5194/amt-12-1717-2019

Next up: cloud *optical* thickness from O_2 absorption



Sensitivity to COT decreases drastically as it exceeds ~50

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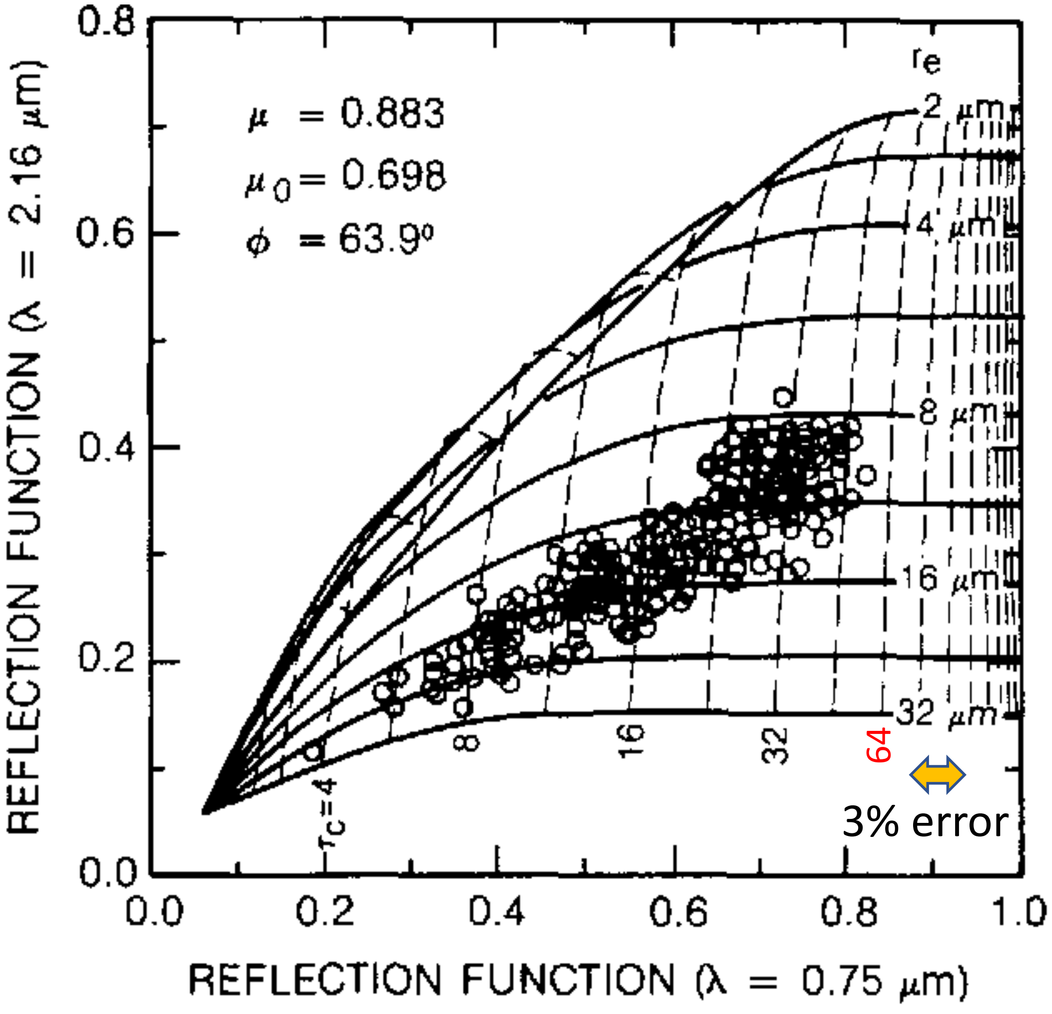

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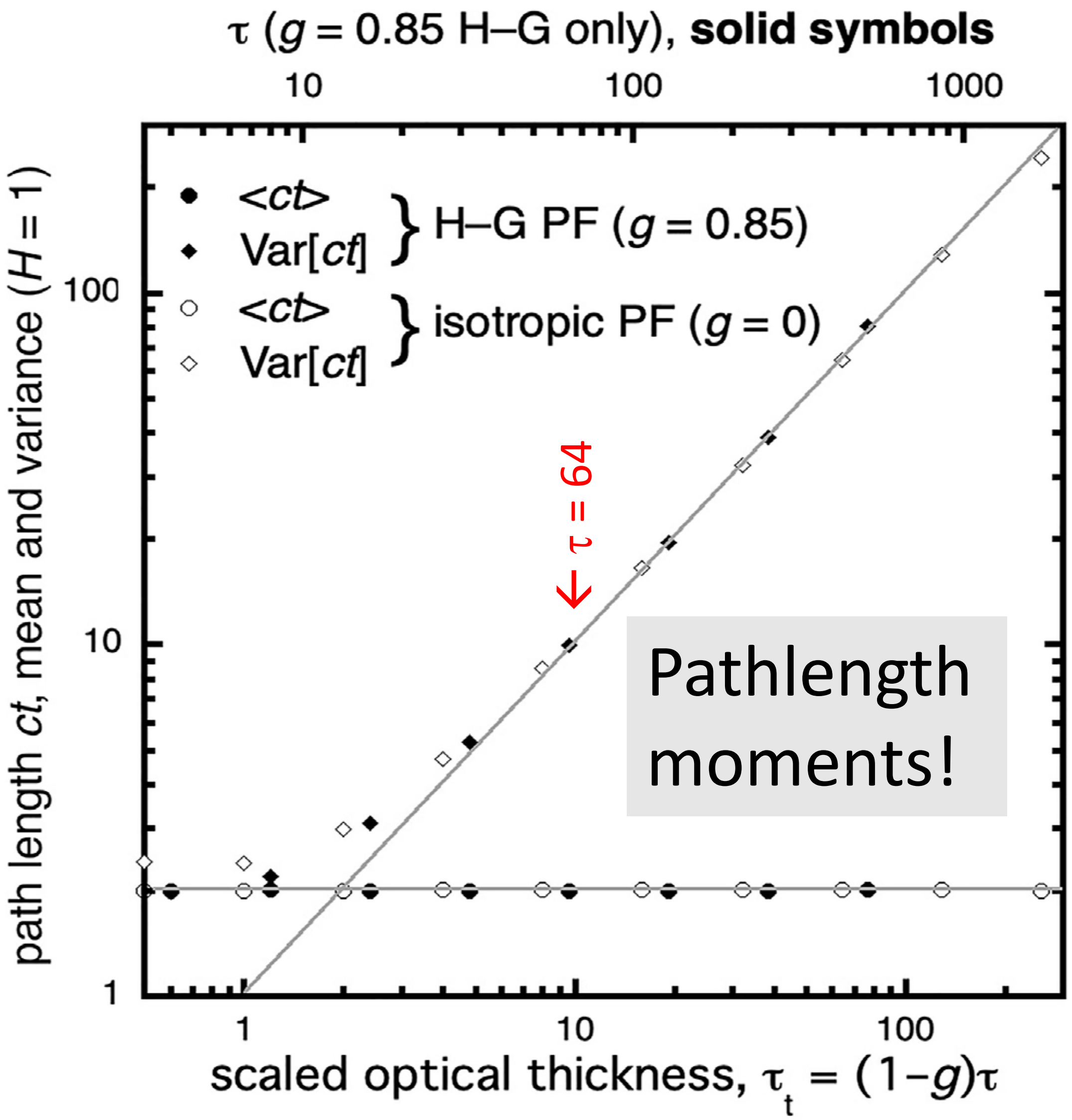
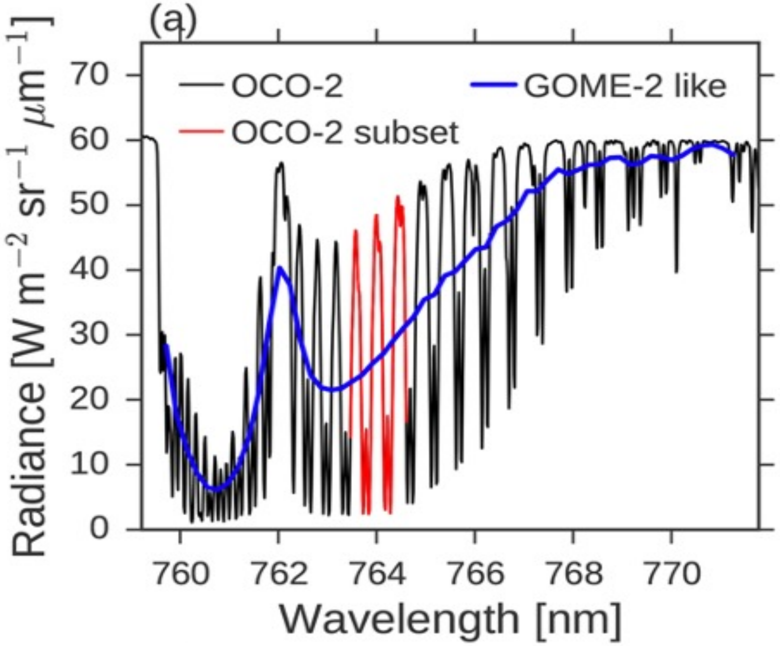


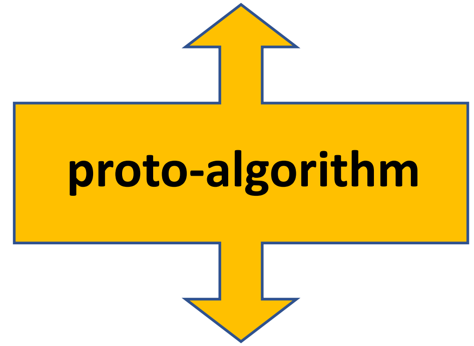
Pathlength moments!

Next up: cloud *optical* thickness from O$_2$ absorption



$$k_{O2}(\lambda) = \frac{\tau_{O2}(\lambda)}{H_{\mathrm{mol}}}$$

with $H_{\mathrm{mol}} \approx 8$ km



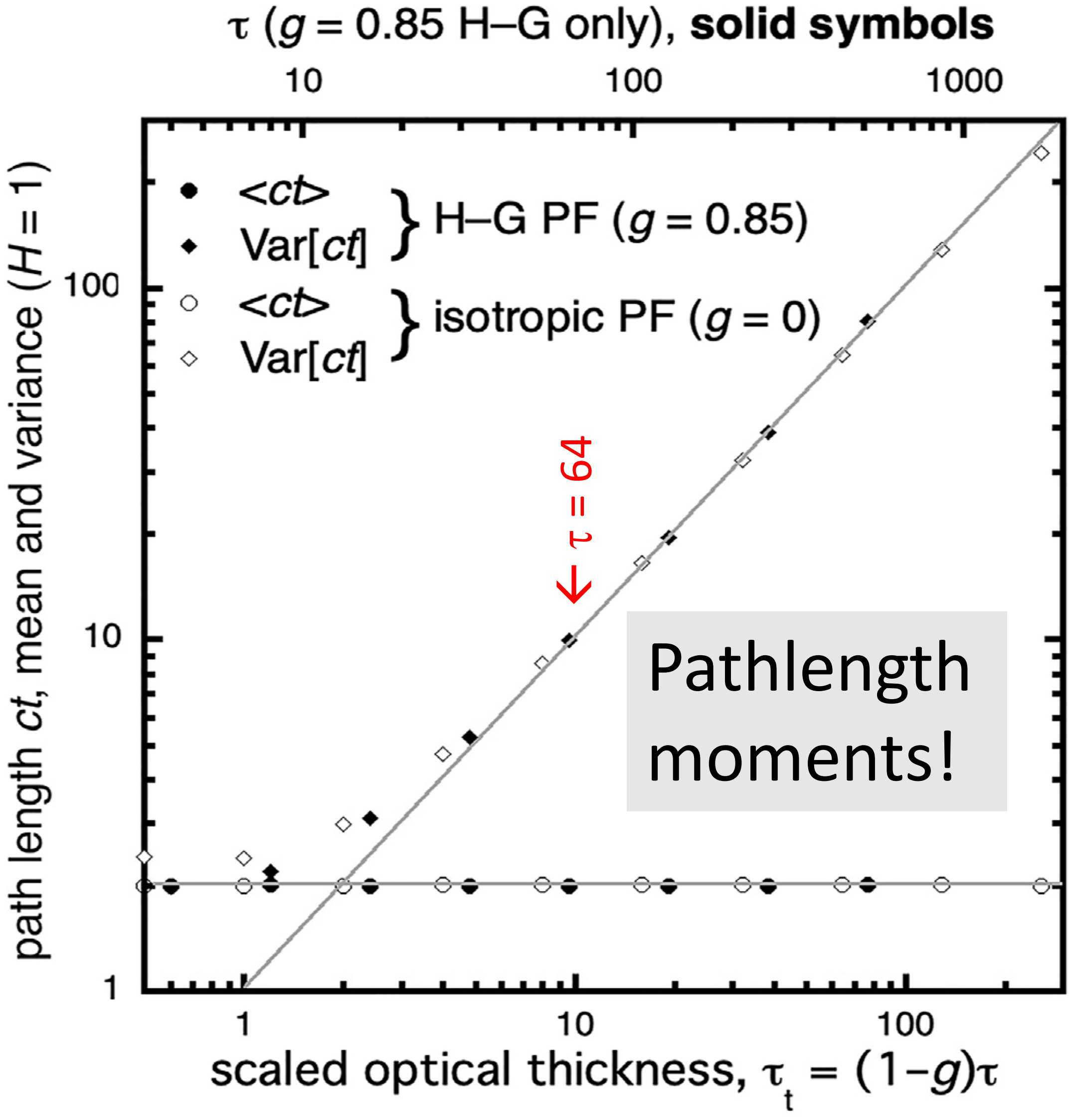
proto-algorithm

$$\ln\left(\frac{I}{I_c}\right)[k_{O2}(\lambda)] = 0 + \frac{\mathrm{d}}{\mathrm{d}k_{O2}} \ln\left(\frac{I}{I_c}\right)\Big|_{k_{O2}=0} k_{O2}(\lambda) + \frac{1}{2}\left(\frac{\mathrm{d}}{\mathrm{d}k_{O2}}\right)^2 \ln\left(\frac{I}{I_c}\right)\Big|_{k_{O2}=0} k_{O2}^2(\lambda) + \ldots$$

$$I(\lambda) = I_c \int_0^\infty p(ct)\mathrm{e}^{-ct\,k_{O2}(\lambda)}\mathrm{d}ct$$

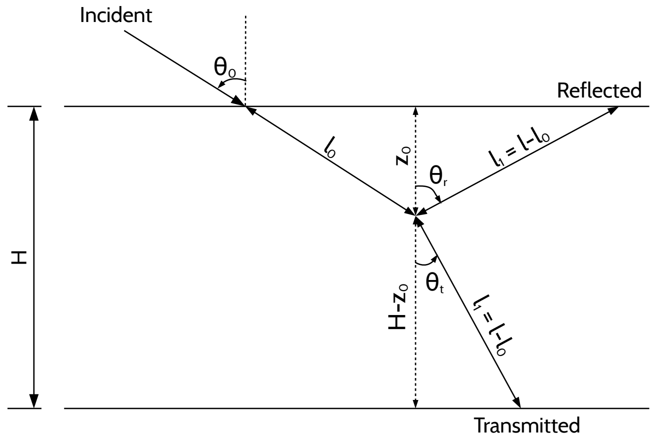
← **"equivalence" theorem**

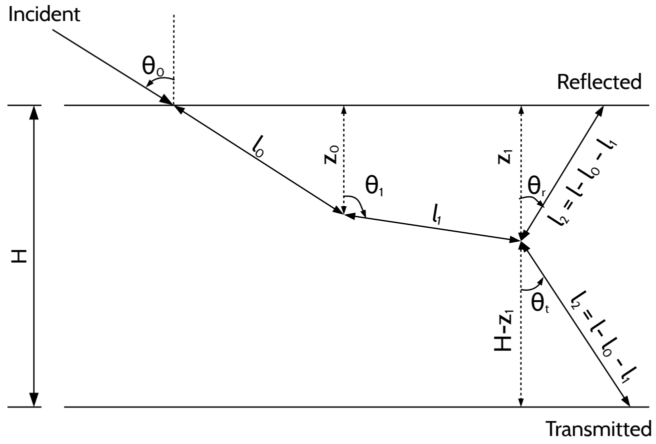
$$\Longrightarrow \ln\left(\frac{I}{I_c}\right)[k_{O2}(\lambda)] = -\langle ct\rangle\, k_{O2}(\lambda) + \langle (ct)^2 - \langle ct\rangle^2\rangle k_{O2}^2(\lambda) + \ldots$$

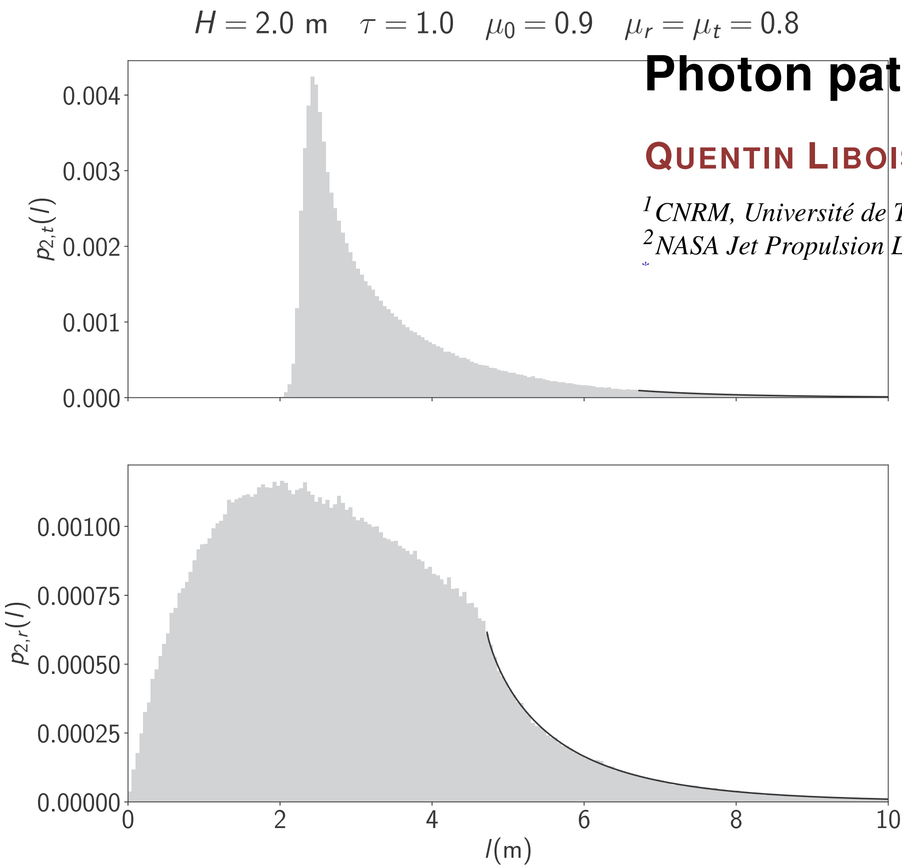


Pathlength moments!

What about optically *thin* layers, that is, cirrus or aerosols?







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Photon path distributions in optically thin slabs

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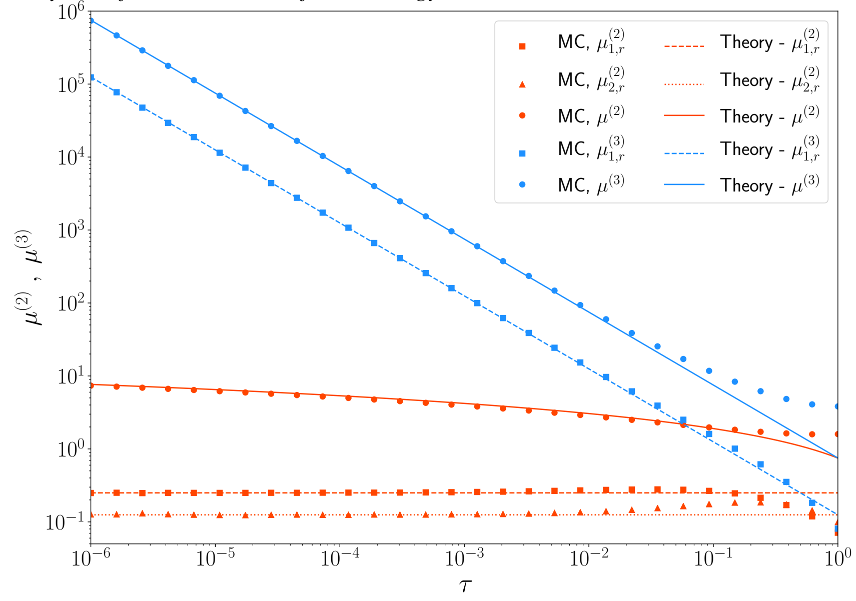
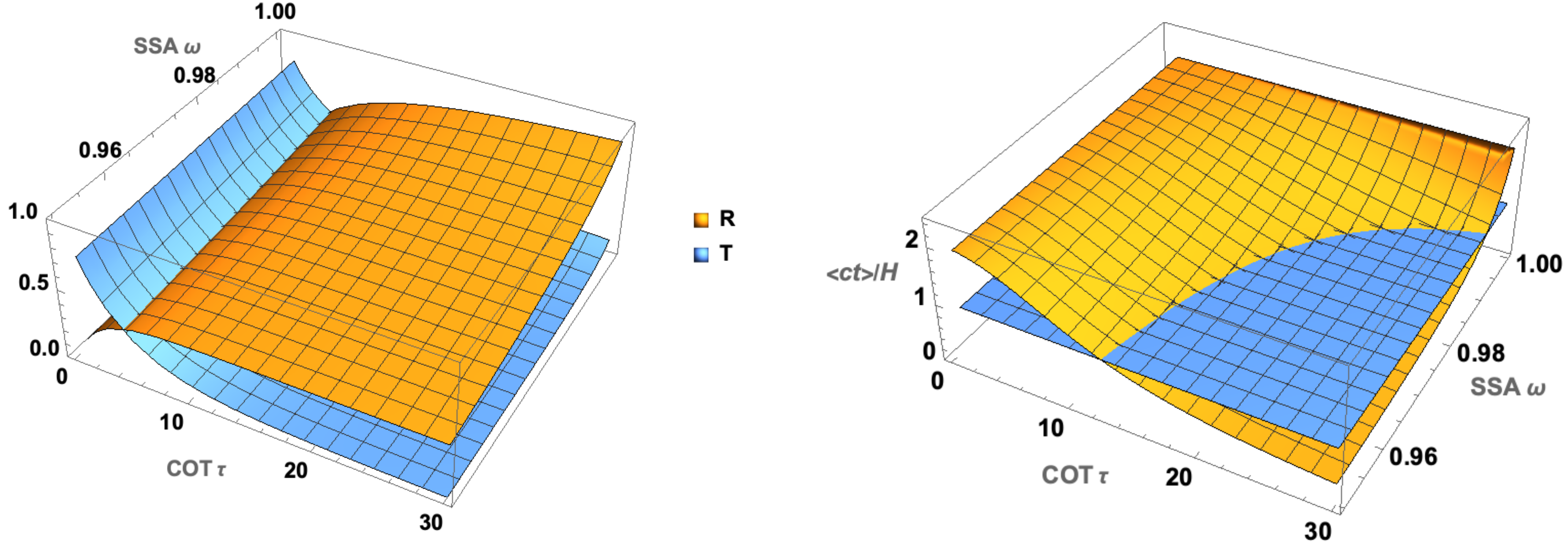
[2] *NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA*



As for clouds, geometrical and optical thicknesses can be inferred from the mean and variance of path length. Plus we have (complicated but) analytical expressions for the distributions as well as for the moments.

What about optically *thick* absorbing aerosols plumes, say, wildfire smoke or volcanic ash?

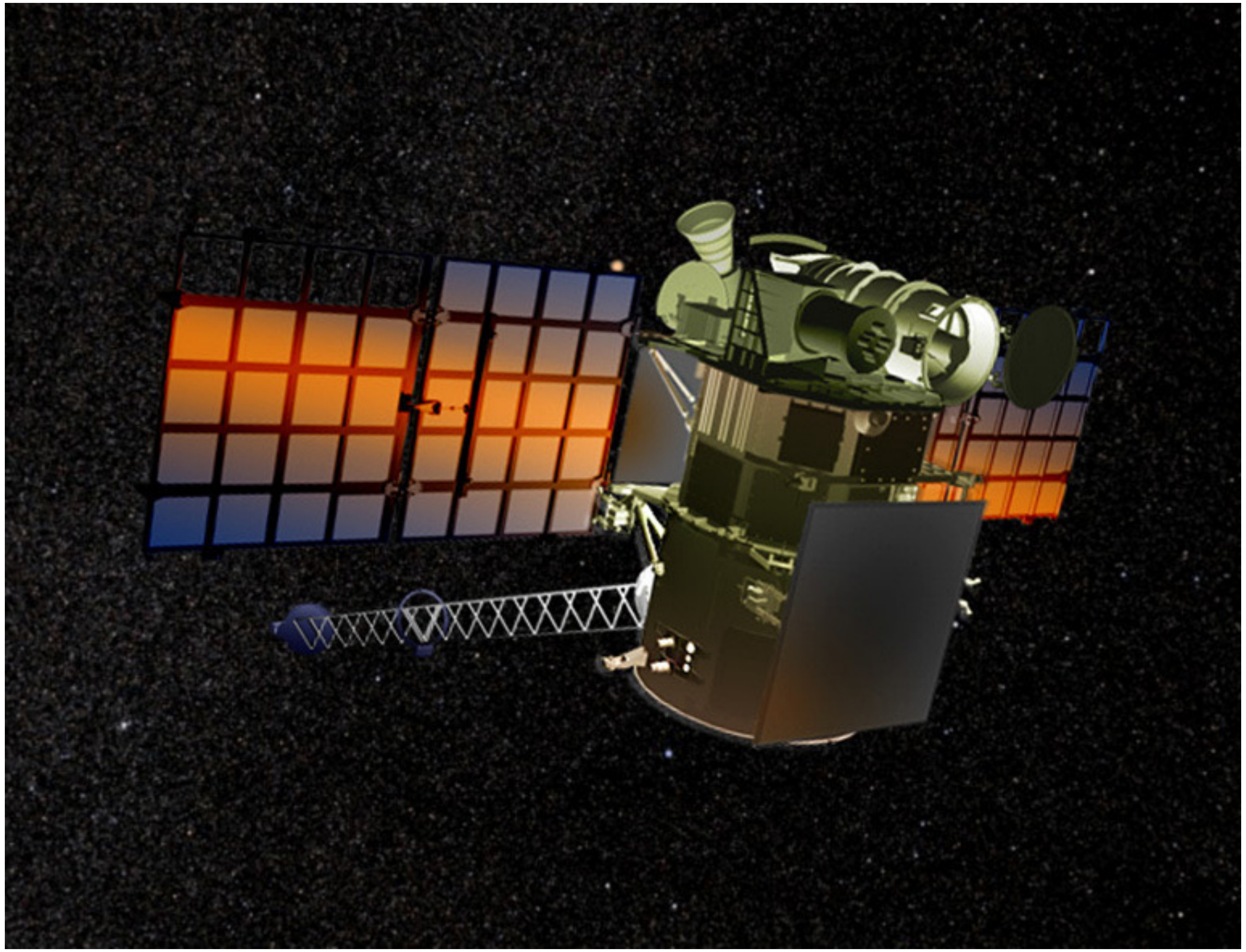


Mean pathlength <*ct*> is strongly affected by particulate absorption (SSA here, $\omega < 1$) in the optically thick regime.
→ For given (τ,*H*), <*ct*> depends mainly on the SSA.
Thus, knowing <*ct*>, puts strong constraints on the *particulate* absorption in the medium.

EPIC-inspired research on cloud and aerosol remote sensing techniques: Summary & vision

- Pathlength statistical moments for sunlight in scattering and absorbing particulate layers can be used to infer cloud-top height (CTH)/pressure, cloud geometrical/pressure thickness, and cloud optical thickness (COT). Specifically:
  - ➢ need two moments of pathlength to obtain (CTH,COT);
  - ➢ one more for CTH;
  - ➢ works for aerosols in optically thin limit as well.
- Need high-enough spectral resolution:
  - ➢ Use spatial heterodyne spectroscopic (SHS) technique to get high spectral resolving power with small imaging sensors;
  - ➢ SHS is amenable to cubesat platforms.

Thank you!



Questions?

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