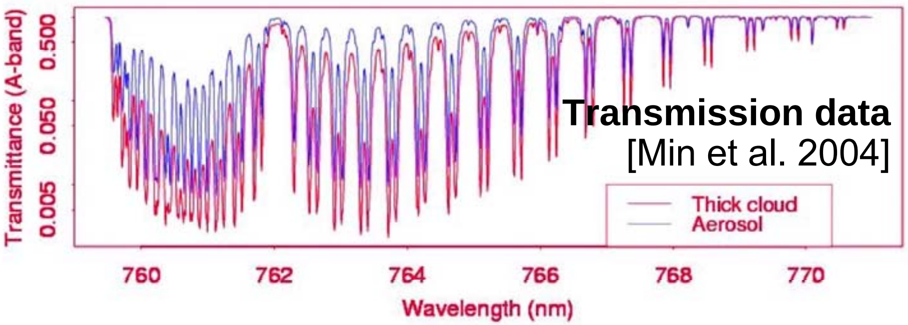
RPWG Breakout Session
ARM 2008 STM
Monday, 3/10/08

Oxygen A-band Data Exploitation

Anthony B. Davis
Los Alamos Nat'l Lab
… with input from
Qilong Min, SUNY-Albany/ASRC
Klaus Pfeilsticker, Heidelberg University

Hi-res O_2 A-band Spectroscopy, I: Cloud products are statistical



cross-section | density | path length

$$I_\nu / I_{L=0} = \exp[-\sigma_\nu \times n \times L]$$ **Application :**

known / not :

σ_ν (cross-section)	n (density)	L (path length)	
?	√	√	estimating molecular cross-sections, normally in a laboratory
√	?	√	monitoring amounts of chemical effluent in situ or remotely
√	√	?	scattering/reflection diagnostics of media permeated with gas

(e.g., CO_2 with OCO)

Impulse Response Function of cloud for "3+1 D" RT equation

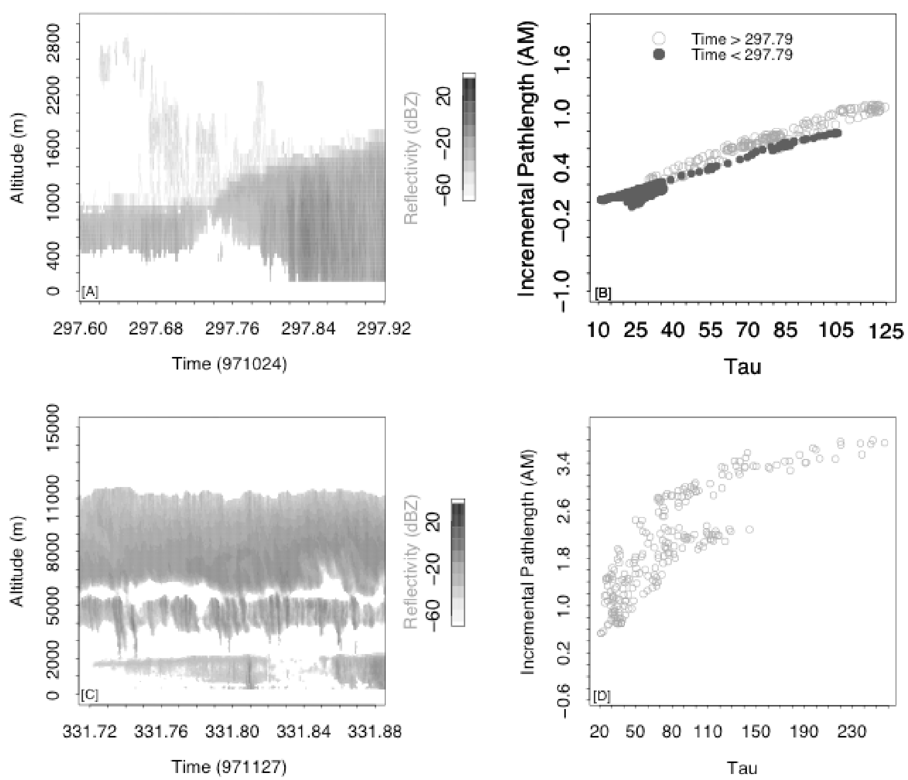
➔ Laplace Transform ➔ $I(k_\nu)$

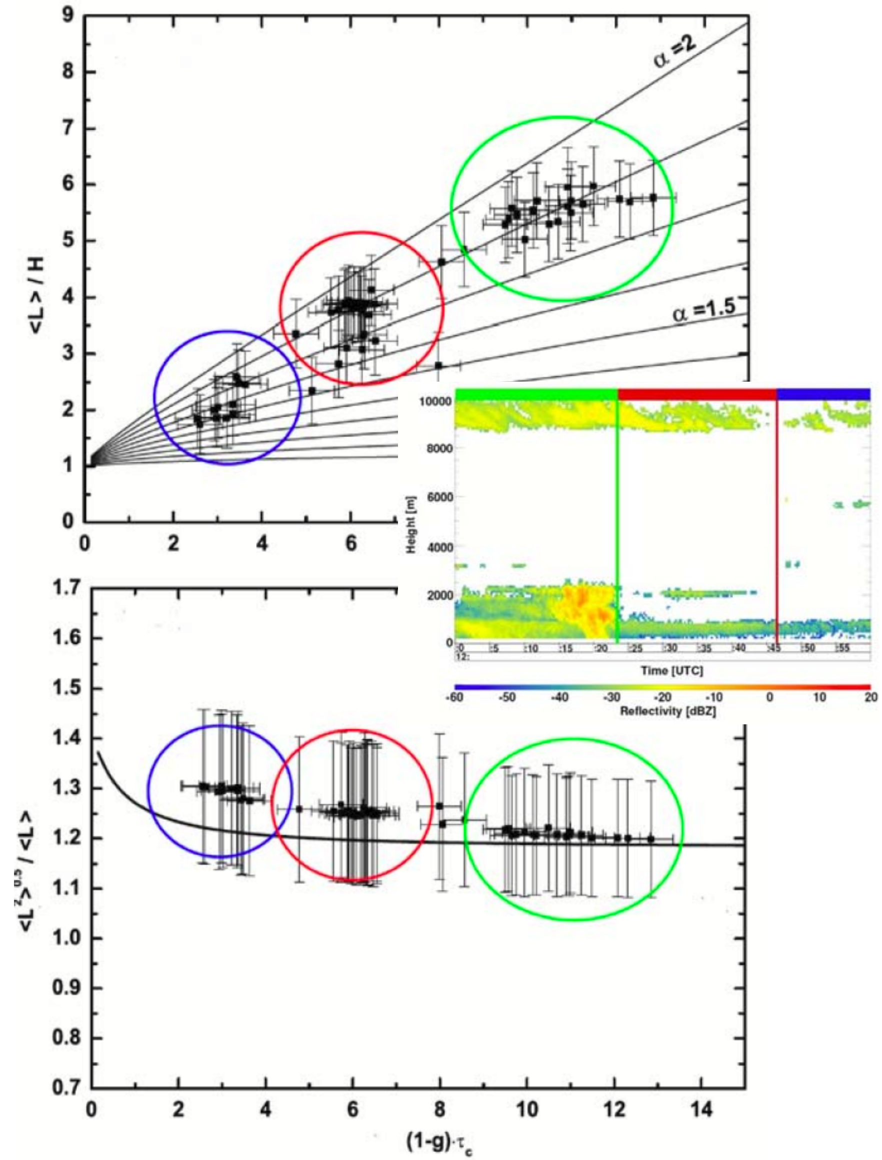
$$I_\nu \equiv I(k_\nu) = I(0)\left\langle \exp[-k_\nu L] \right\rangle = \boxed{I(0)\int_0^\infty p(L)} \exp[-k_\nu L]\,\mathrm{d}L$$

$$\Rightarrow \quad \left\langle L^q \right\rangle = \int_0^\infty L^q p(L)\,\mathrm{d}L = \frac{1}{I(0)} \times \left(-\frac{\mathrm{d}}{\mathrm{d}k_\nu}\right)^q I \Bigg|_{k_\nu = 0}$$

Hi-res O_2 A-band Spectroscopy, II: Path moments vs. cloud properties

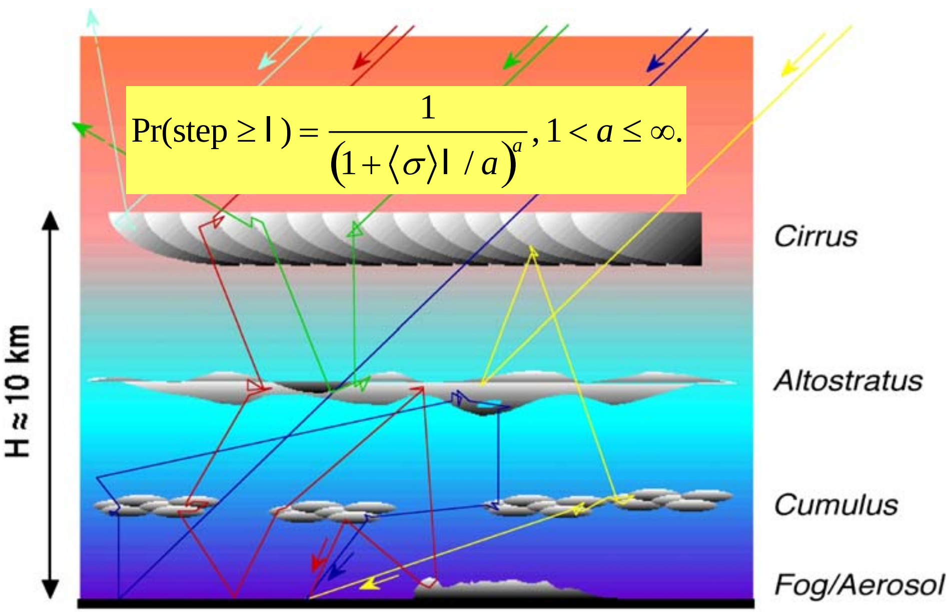
- **Heidelberg (Pfeilsticker et al.)**
- **SUNY-Albany (Min et al.)**
- **Both have achieved q = 1,2**



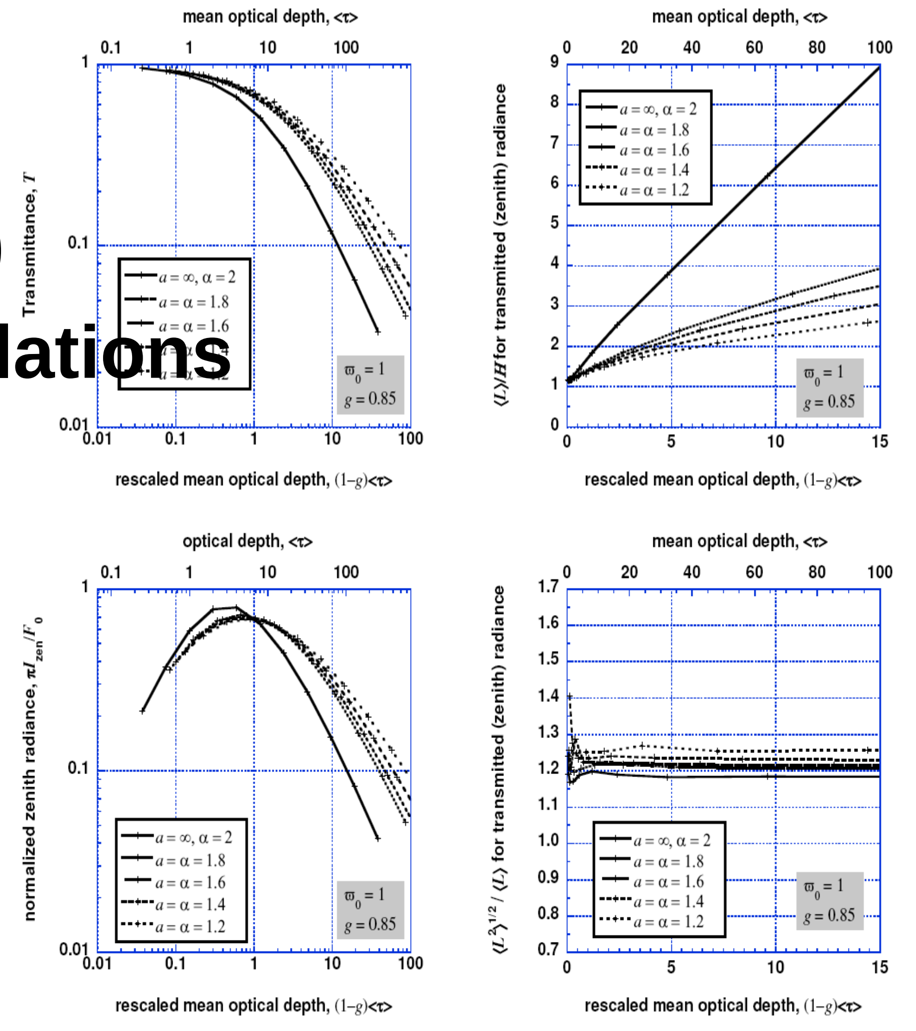


Hi-res O_2 A-band Spectroscopy, III: Hierarchy of models for path stats

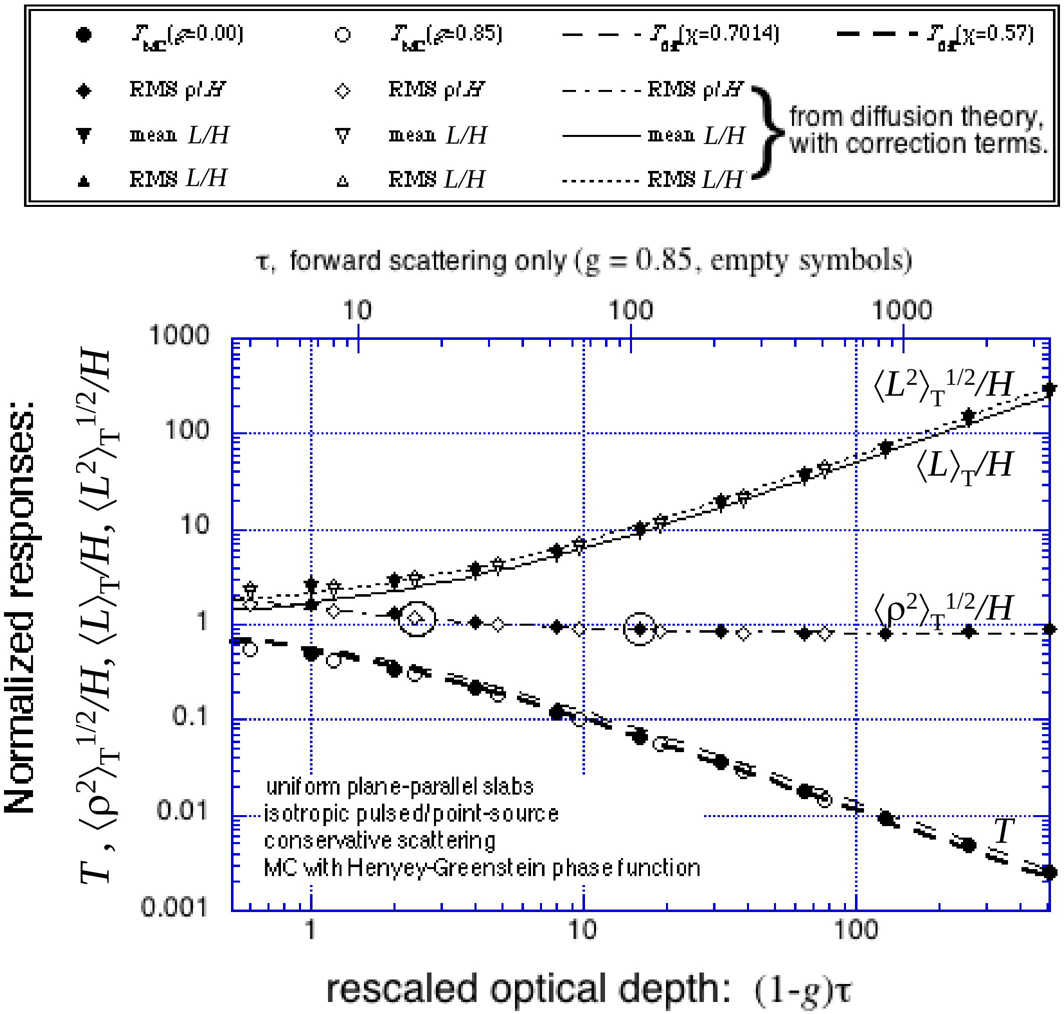
- **Random-walk scaling arguments for finite slabs**
  - **Gaussian-type steps**
  - **Steps with power-law tails**
- **PDEs (standard *diffusion*)**
- **Numerical *transport* simulations**



$$\Pr(\text{step} \geq l) = \frac{1}{\left(1+\langle\sigma\rangle l / a\right)^{a}},\ 1 < a \leq \infty.$$



Time-dependent diffusion theory for transmitted fluxes: *Exact* diffusion theory versus Monte Carlo



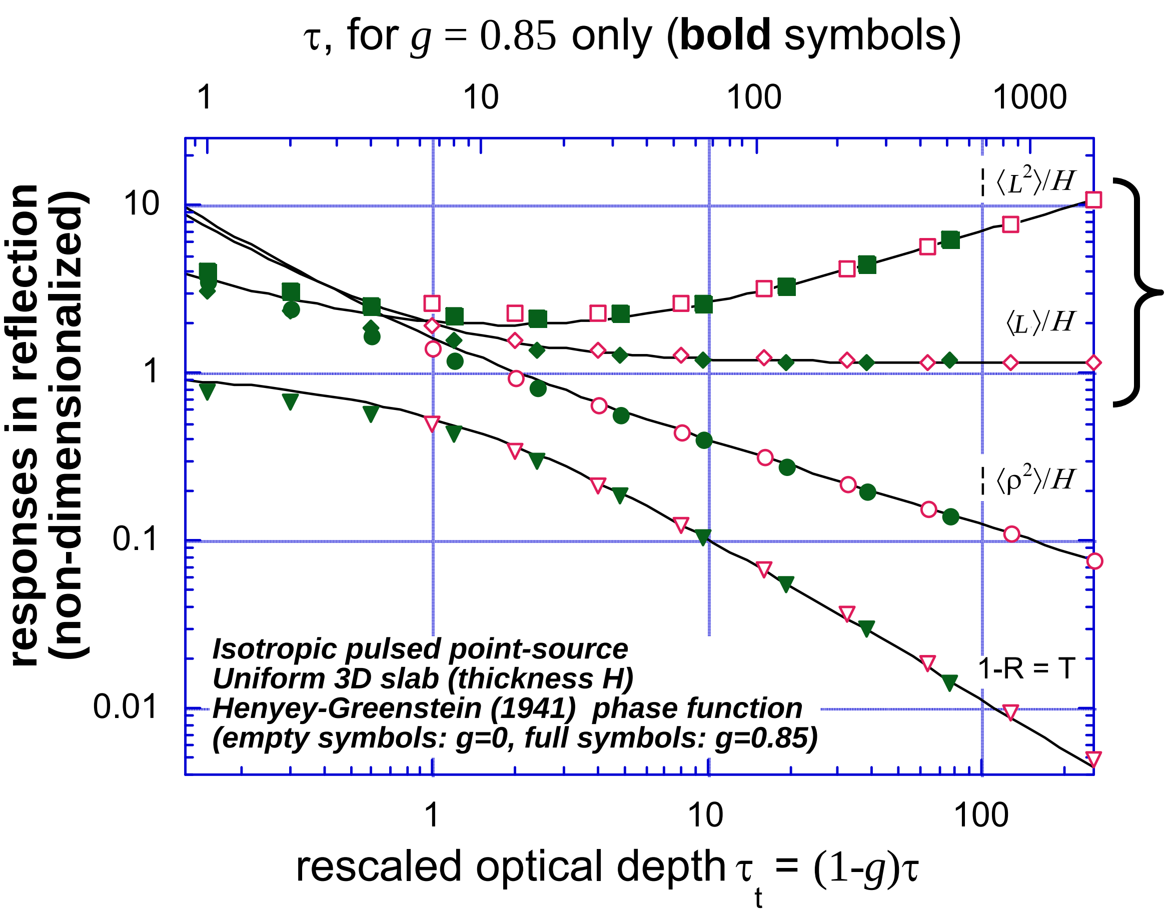
Davis, A. B., and A. Marshak, 2002: Space-time characteristics of light transmitted by dense clouds, A Green function analysis, *J. Atmos. Sci.*, **59**, 2713-2727.

New and interesting:

$$\left\langle L^2\right\rangle_T^{1/2} / \left\langle L\right\rangle_T \approx \sqrt{7/5} \approx 1.18$$

Schuster (1905)

Time-dependent diffusion theory for reflected fluxes: *Exact* diffusion theory versus Monte Carlo

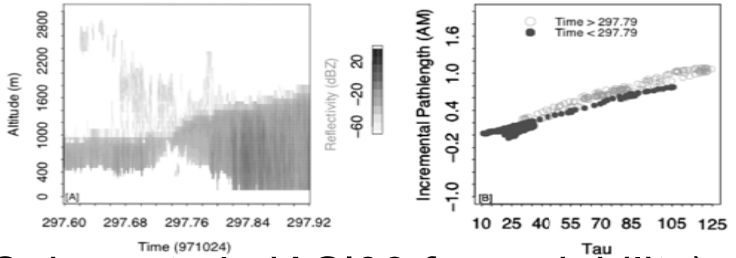


Notice the different trends (exploited in cloud remote sensing with WAIL)

Wide Angle Imaging Lidar

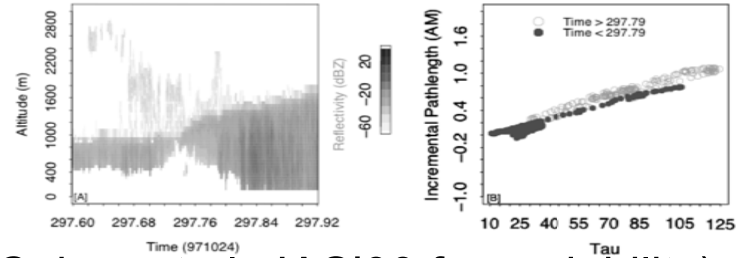
Davis, A. B., R. F. Cahalan, J. D. Spinhirne, M. J. McGill, and S. P. Love, 1999: Off-beam lidar: An emerging technique in cloud remote sensing based on radiative Green-function theory in the diffusion domain, *Phys. Chem. Earth (B)*, **24**, 177-185 (Erratum 757-765).

Hi-res O_2 A-band Spectroscopy, IV: Exploitation of path moments

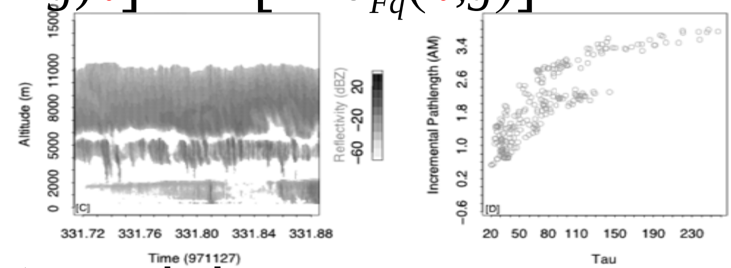


- **Cloud remote sensing**
  - *Single layer scenario*
  - Use standard diffusion theory (plus Cairns et al. JAS'00 for variability)
    - Transmission: $\langle L^q \rangle_T^{1/q} \sim H \times (1-g)\tau,\ q = 1,2,\cdots \text{ as } \tau \to \infty$
    - Reflection: $\langle L^q \rangle_R^{1/q} \sim H \times [(1-g)\tau]^{1-1/q} \quad \text{as } \tau \to \infty$
  - *Refine* $F = T,R$: $\langle L^q \rangle_F^{1/q} \,/\, H = A_{Fq} \times [(1-g)\tau]^{b_{Fq}} \times [1 + c_{Fq}(\tau,g)]$

Hi-res O_2 A-band Spectroscopy, IV: Exploitation of path moments



- **Cloud remote sensing**
  - ***Single layer scenario***
  - Use standard diffusion theory (plus Cairns et al. JAS'00 for variability)
    - Transmission: $\langle L^q \rangle_T^{1/q} \sim H \times (1-g)\tau,\ q = 1,2,\cdots$ as $\tau \to \infty$
    - Reflection: $\langle L^q \rangle_R^{1/q} \sim H \times [(1-g)\tau]^{1-1/q}$ as $\tau \to \infty$
  - *Refine $F = T,R$:* $\langle L^q \rangle_F^{1/q} \,/\, H = A_{Fq} \times [(1-g)\tau]^{b_{Fq}} \times [1+c_{Fq}(\tau,g)]$

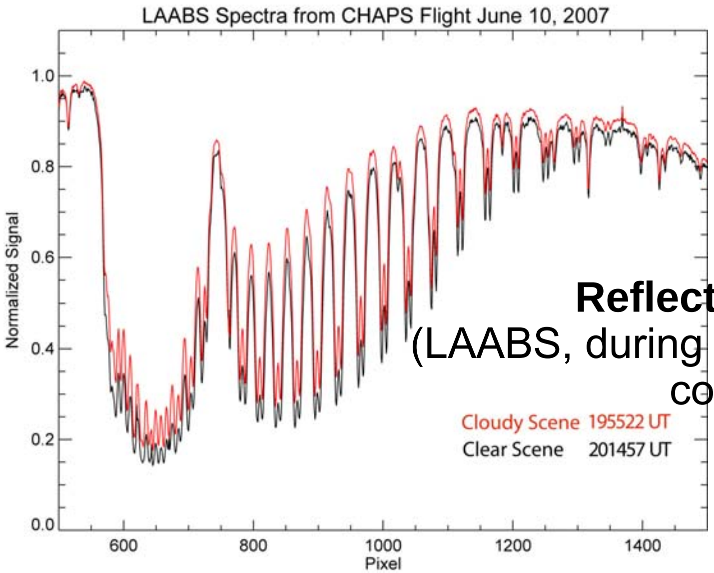


- **Cloud-radiation diagnostics**
  - ***Multi-/broken-layer scenario***
  - Use "anomalous" diffusion/transport models ($1 < \alpha \leq 2$)
    - Transmission: $\langle L^q \rangle_T^{1/q} \sim H \times (1-g)\tau^{\alpha-1},\ q = 1,2,\cdots$ as $\tau \to \infty$
    - Reflection: $\langle L^q \rangle_R^{1/q} \sim H \times [(1-g)\tau]^{(1-1/2q)\alpha-1}$ as $\tau \to \infty$

Time-domain cloud observation: Opportunities ahead … in space

- **Multiple-scattering cloud lidar: ASCENDS?**
  - **CO_2 using DIfferential Absorption Lidar (DIAL)**
  - **NASA-LaRC/ITT "lock-in" CW detection concept**
  - **Possibility of cloud (wide-FOV) channel**
- **High-resolution O_2 A-band**
  - **Langley Airborne A-band Spectrometer (LAABS)**
  - **OCO, which needs A-band to get CO_2 in ppm)**

ASCENDS concept
(courtesy M. Dobbs, ITT)



Reflection A-band data
(LAABS, during CHAPS/CLASIC, courtesy Mike Pitts, NASA-LaRC)

Orbiting Carbon Observatory (Dec-2008 launch into A-train)