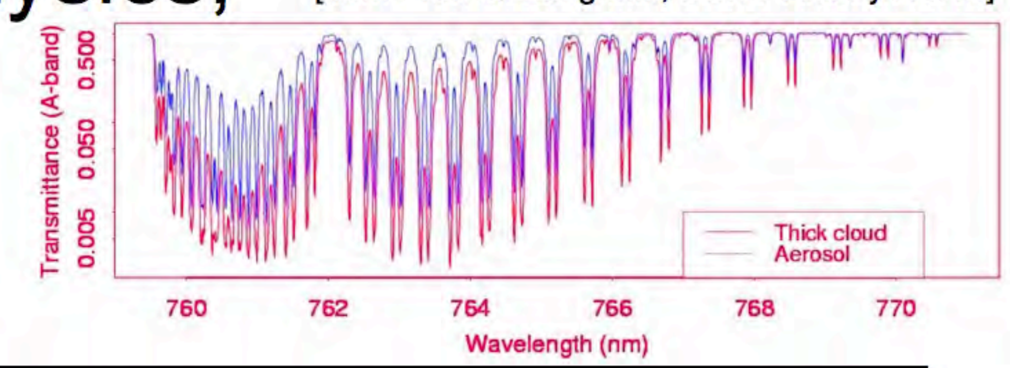
Time-Domain Three-Dimensional Radiative Transfer at Work for ARM:
Emerging Concepts in Cloud Remote Sensing and Cloud-Radiation Diagnostics

Principal Investigator: *Anthony B. Davis*, Space & Remote Sensing Group,
Co-Investigator: *Steven P. Love*, Los Alamos National Laboratory.
Collaborators: *Igor N. Polonsky*, Department of Atmospheric Science, Colorado State University. *[formerly LANL Postdoctoral Fellow]*
Klaus Pfeilsticker, Institute for Environmental Physics, Heidelberg University.

Spectra resolving individual O_2 lines in A-band [from Prof. Qi-Long Min, SUNY-Albany/ASRC]



Dense Cloud Probing with Wide-Angle Imaging Lidar (WAIL)

Summary & Outlook

WAIL has broken new ground in active probing of dense cloud from ground, at least at night. The same multiple scattering concept has been implemented for airborne (incl. in-situ) and space-based sensors.

Defeat solar background with sophisticated magnetooptical (Faraday) filter? Or synergy with O_2 A-band? Transfer engineering aspects to industry under SBIR/STTR program?

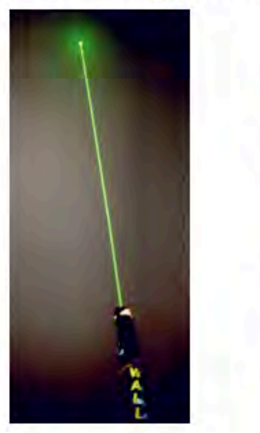
Cloud Remote Sensing Problem

After determining base height by standard laser ceilometry, find parameters

- H (cloud thickness) and
- σ (volume-average cloud extinction) or $\tau = \sigma H$ (mean cloud optical depth)

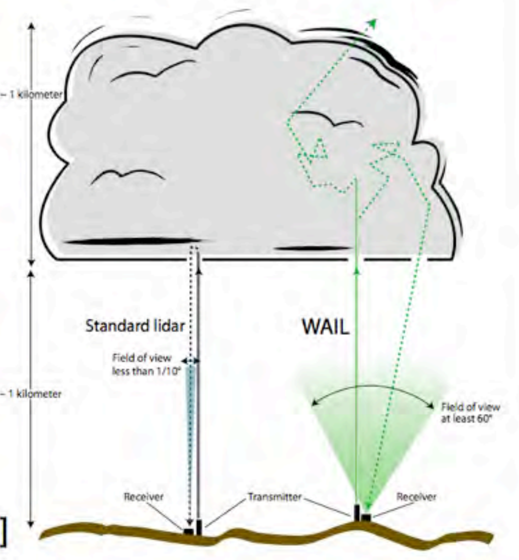
from observed $I(ct,\rho_\theta)$, averaged azimuthally; see Davis et al. [1997,1999].

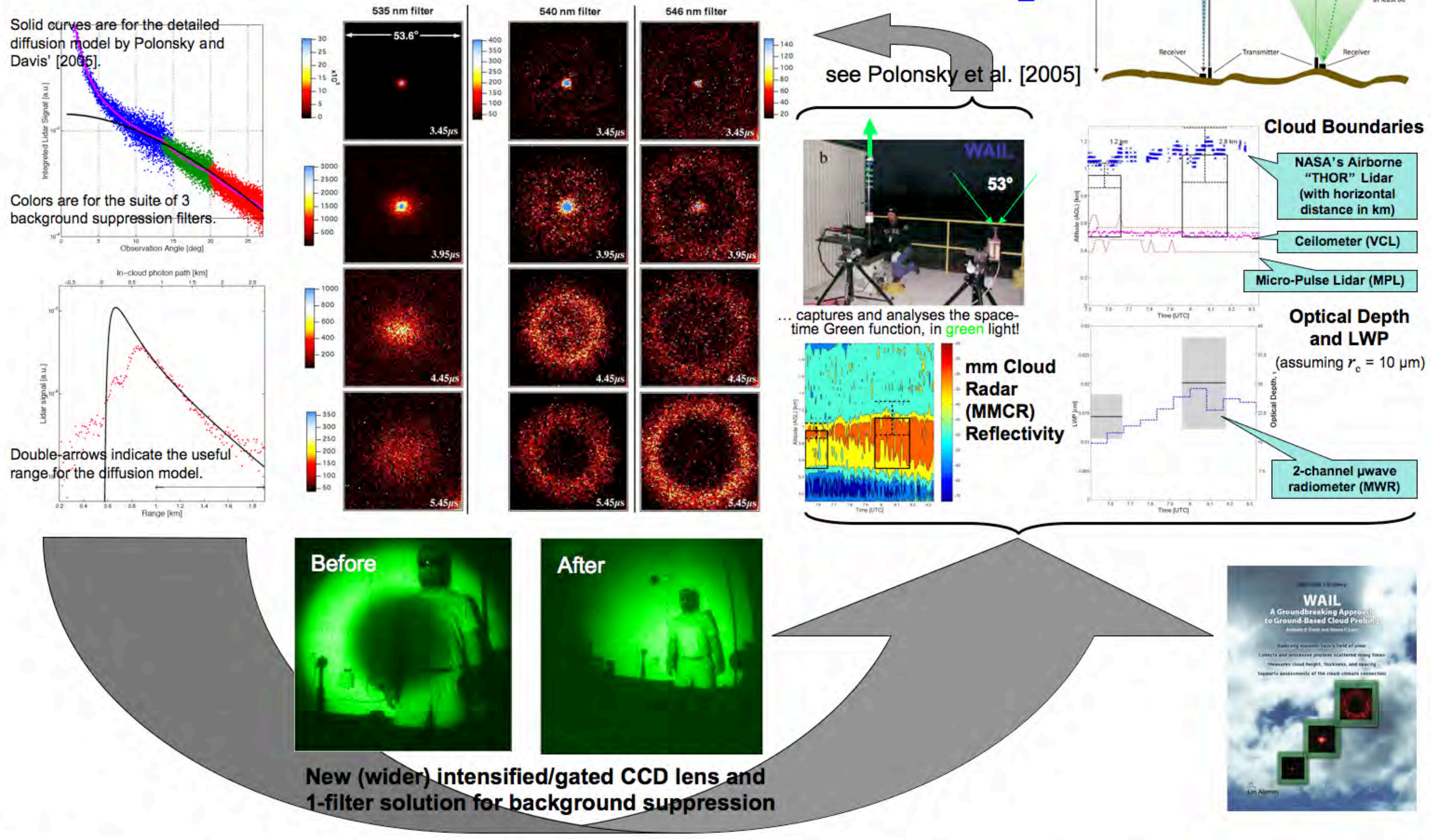
Asymptotic diffusion theory (i.e., scaling arguments based on random walk statistics):
The "asymmetry factor" of the scattering phase function is a *known* quantity: $g = \mathrm{E}(\cos\theta_s) \approx 0.85$.



prob of reflection: $R = 1 - T \propto 1 - O(1/(1-g)\tau)$ ✔
mean path length: $\langle ct \rangle_R \propto H$, independently of τ ✖
RMS path length: $\langle (ct)^2 \rangle_R^{1/2} \propto H \times \sqrt{(1-g)\tau}$ ✖
RMS spot size: $\langle \rho^2 \rangle_R^{1/2} \propto H / \sqrt{(1-g)\tau}$ ✖

Need absolute calibration?





Coarse-Scale "3+1D" RT with a Modified "1+1D" RT Equation

Summary & Outlook

State-of-the-art O_2 A-band data favors the new 1D anomalous *transport* model over its anomalous *diffusion* predecessor and its hybridization with exact standard diffusion pre-asymptotic corrections.

Can this validation procedure be applied to operational GCM shortwave parameterizations? Can A-band spectroscopy and 3+1D RT modeling bridge proposed 3D cloud tomography and climate?

Cloud Remote Sensing Problem (Mono-Layer, $\alpha = 2$ case)

Use Davis and Marshak's [2002] detailed diffusion model to estimate

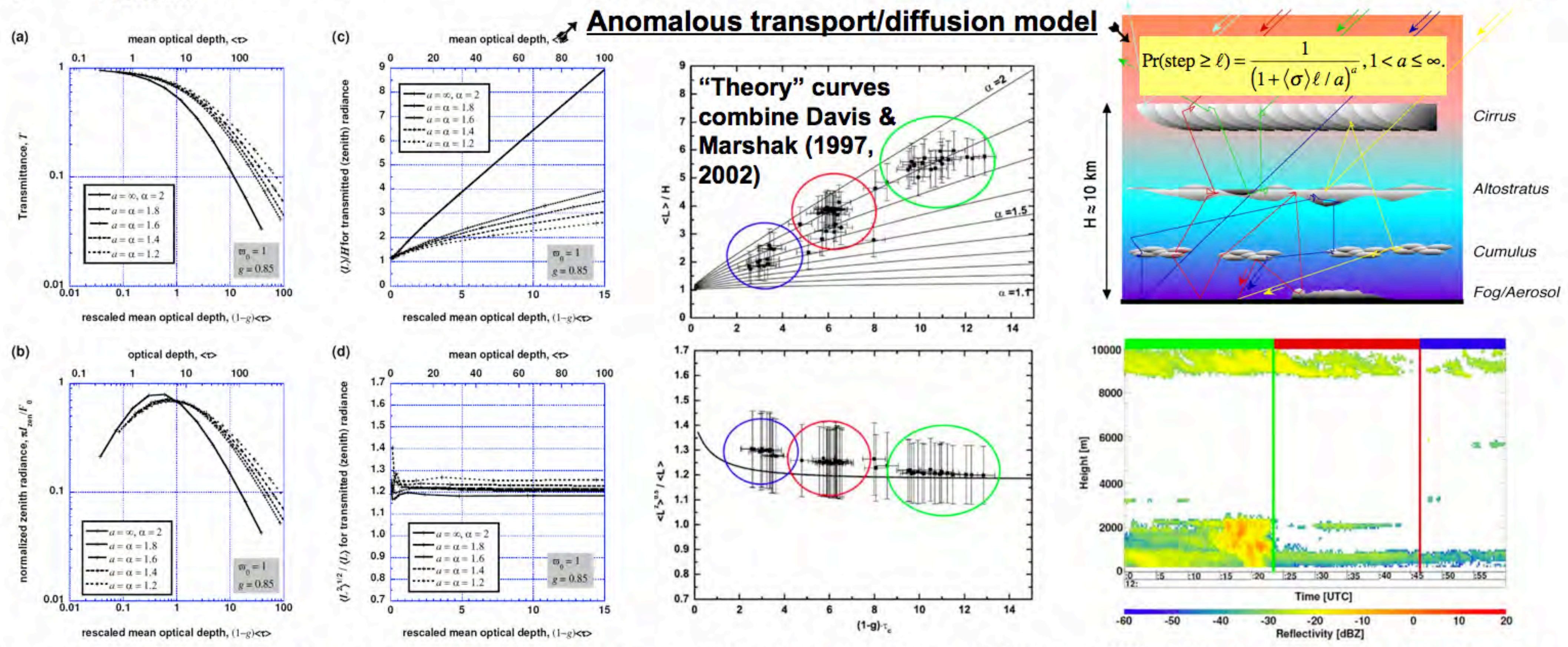
- H (cloud thickness) and
- σ (volume-average cloud extinction) or $\tau = \sigma H$ (mean cloud optical depth)

from retrieved $\langle (ct)^q \rangle_{T\text{zenith}}$, $q = 1,2$. And what about $\langle (ct)^q \rangle_{R\text{nadir}}$, $q = 1,2,3,\cdots$?

> Asymptotic trends, a.k.a. "anomalous diffusion" model ($\mathrm{E}(\text{step}^q) = \infty$ for $q \ge \alpha$):
> $T \sim \tau_{tr}^{-\alpha/2}$ and $\langle ct \rangle_T \sim H \times \tau_{tr}^{\alpha-1}$, $1 < \alpha \le 2$, as $\tau_{tr} = (1-g)\tau \to \infty$ [Davis & Marshak'97];
> $R = 1 - T$ and $\langle (ct)^q \rangle_R^{1/q} \sim H \times \tau_{tr}^{(1-1/2q)\alpha-1}$ as $\tau_{tr} = (1-g)\tau \to \infty$ [Davis'08, in progress].

Multi-/Broken-Layer Cloud Field Problem ($1 < \alpha < 2$)

1. What kind of cloud-radiation diagnostic can we do with new ground-based observables $\langle (ct)^q \rangle_{T\text{zenith}}$, $q = 1,2,3,\cdots$ derived from hi-res O_2 line spectroscopy in the A-band (760-770 nm)? *[Answer: Signature of spatial variability at q=1.]*
2. Anticipating the A-band capability in NASA's Orbiting Carbon Observatory (OCO), to be launched in 2008, what more can we do with global retrievals of $\langle (ct)^q \rangle_{R\text{nadir}}$, $q = 1,2,3,\cdots$? *[Answer: Get H, τ, and variability parameter α.]*



Numerical (Monte Carlo) solution of new 1D RTE (from Davis [2006] where *"ct"* is denoted by *"L"*)

Pathlength stats from A-band (from Scholl et al. [2006])

Millimeter-wavelength cloud radar 3 break-up phases are color-coded

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