Practical Rendering of Multiple Scattering Effects in Participating Media

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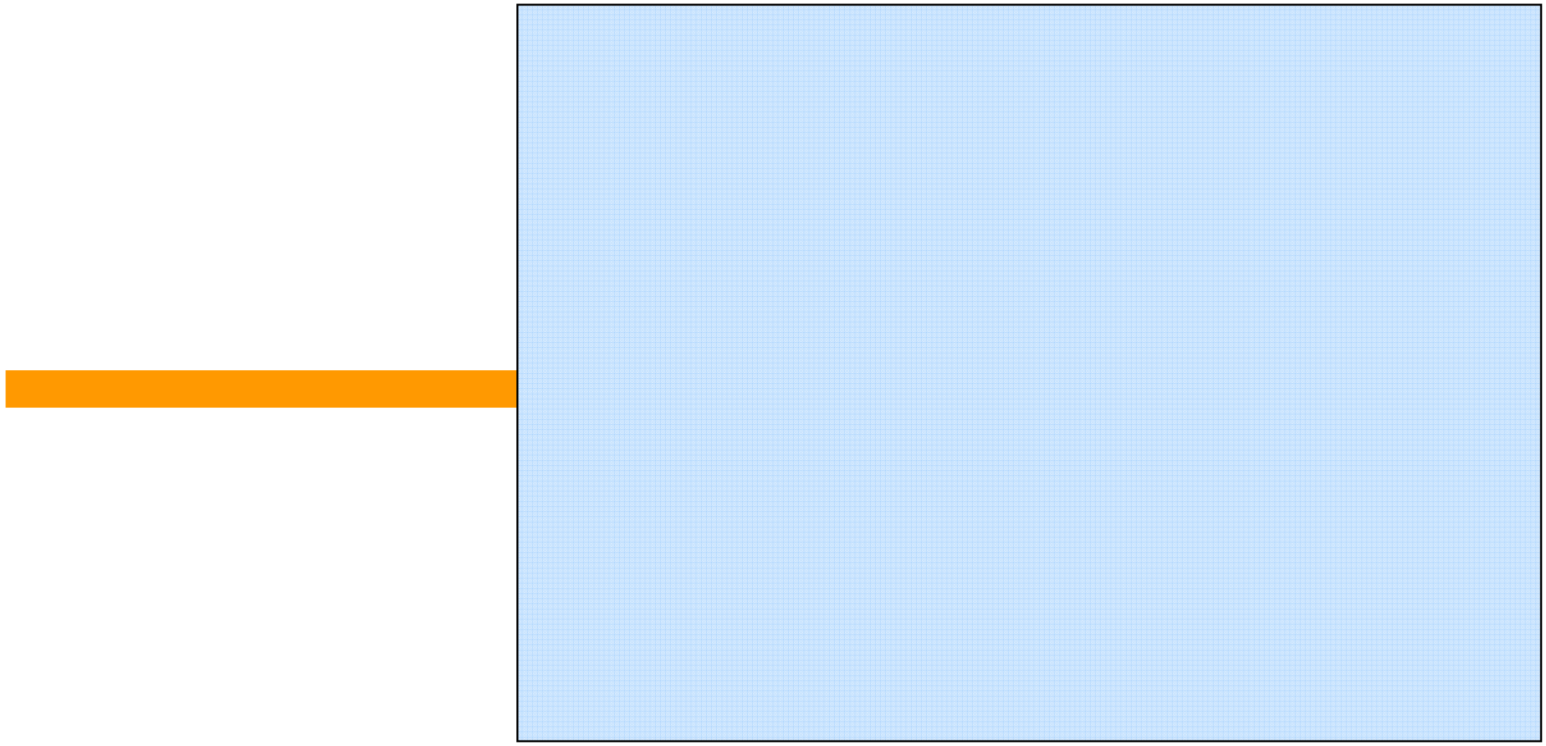
Goal

- Want to accurately and efficiently compute effects of multiply-scattered light
- Assumption: direct and single-scattered light handled separately

Monte Carlo and Participating Media

- Beam of directed light



Monte Carlo and Participating Media

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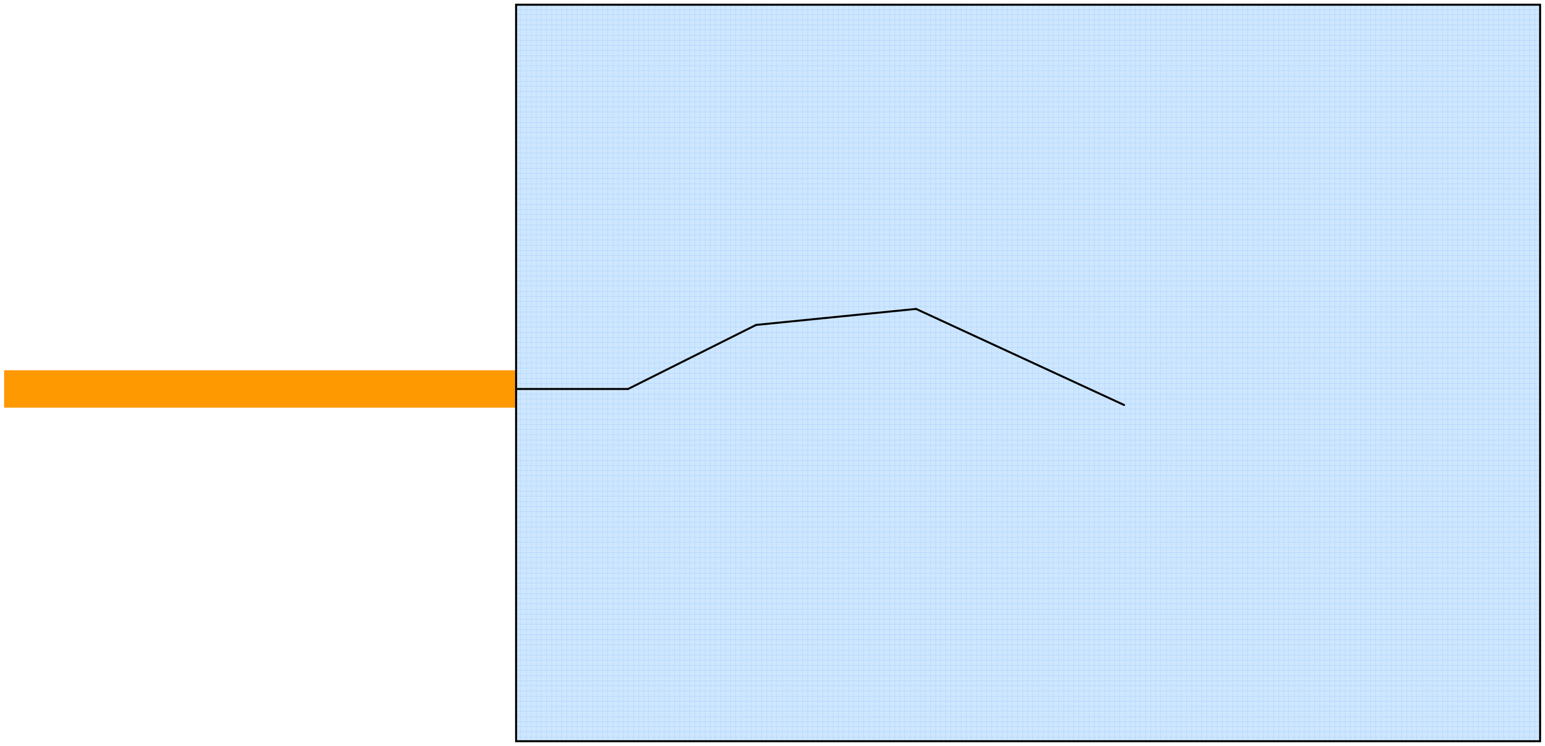

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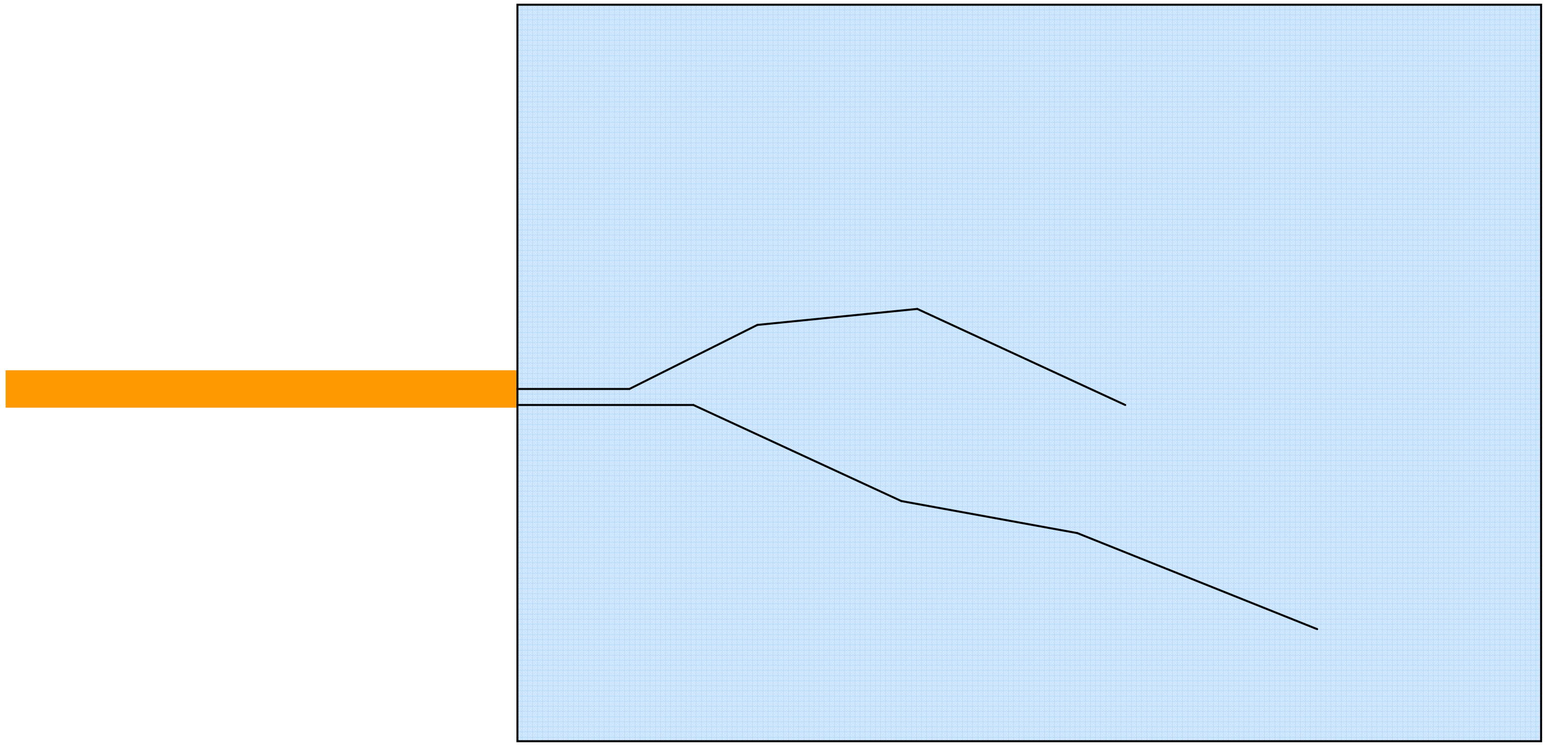

Monte Carlo and Participating Media

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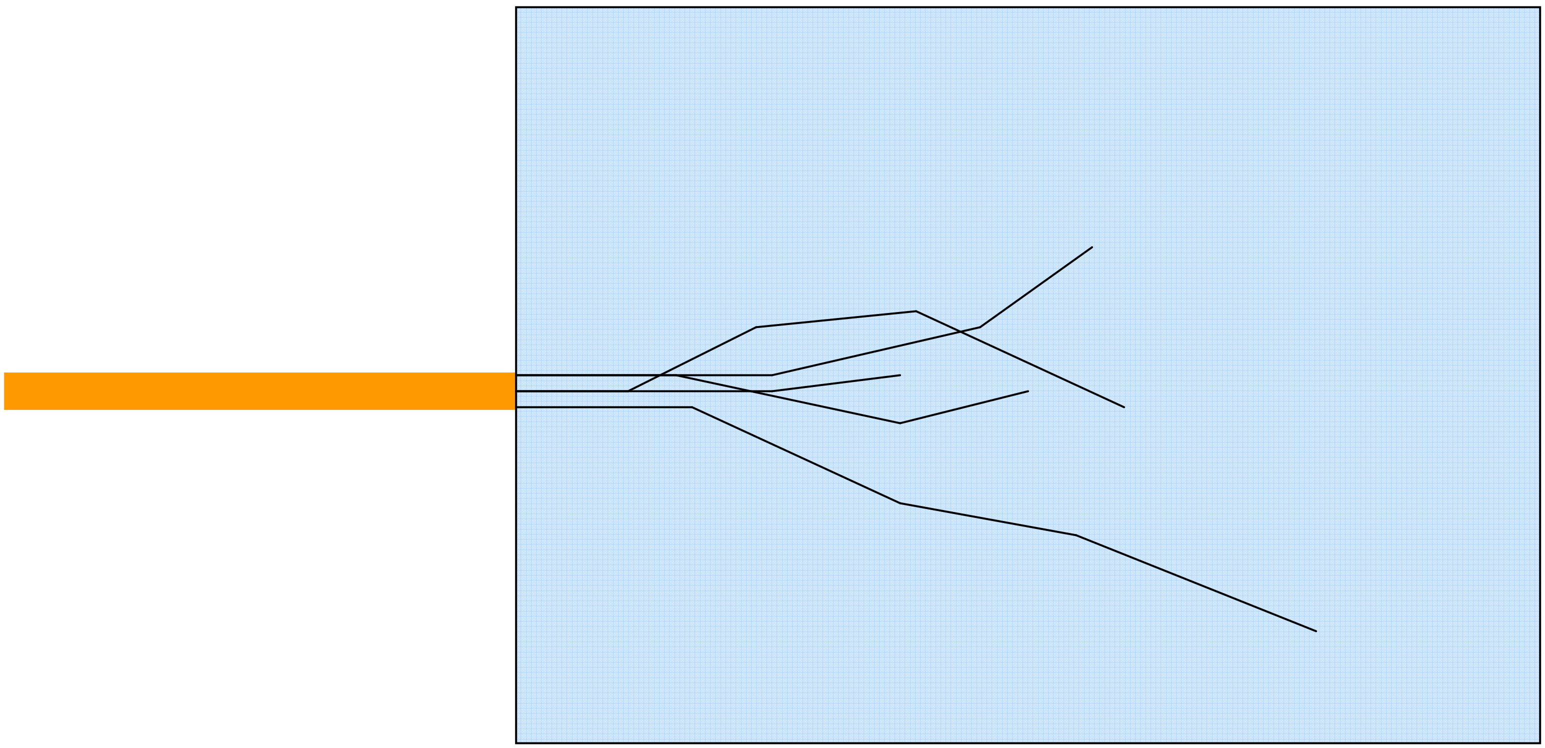

Monte Carlo and Participating Media

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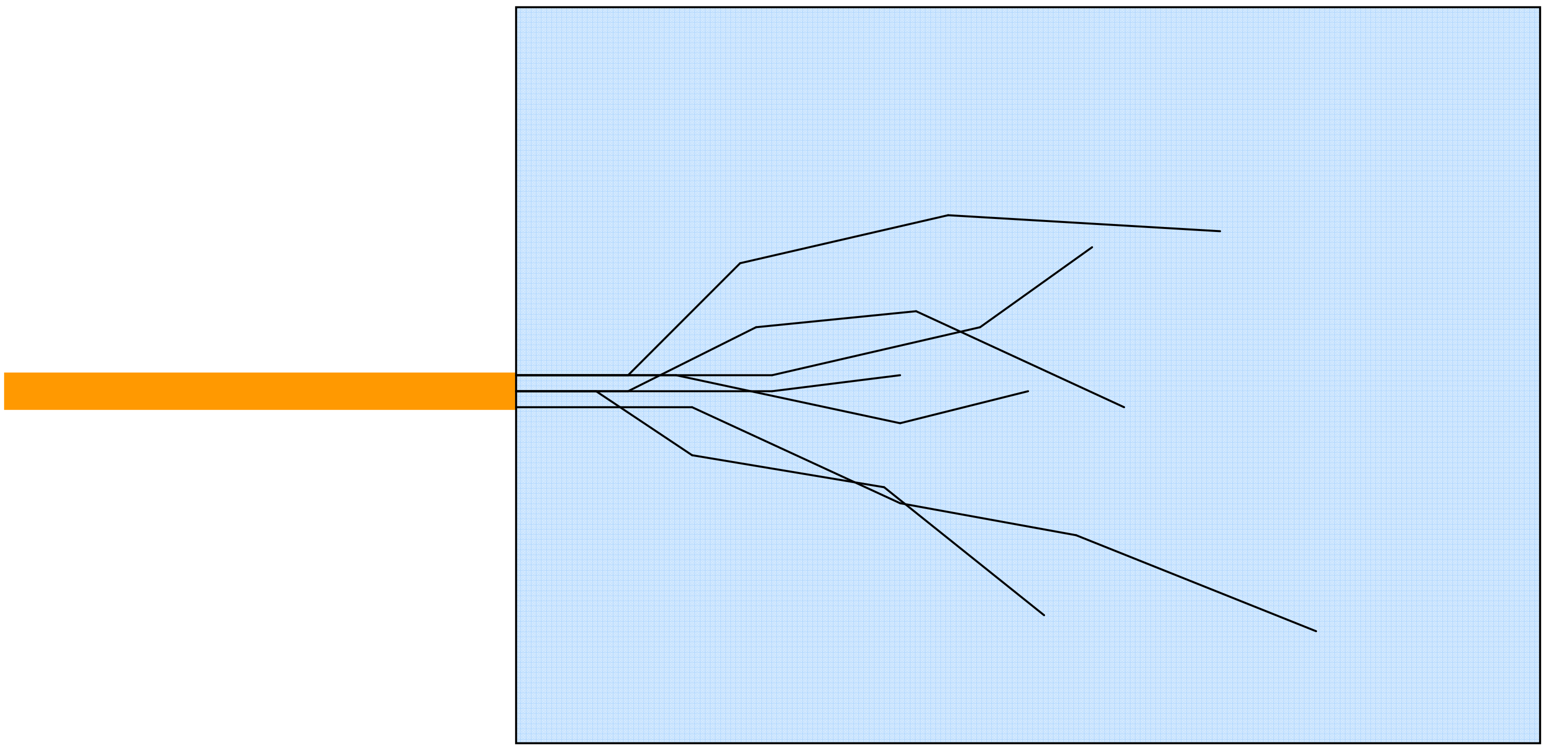

Monte Carlo and Participating Media

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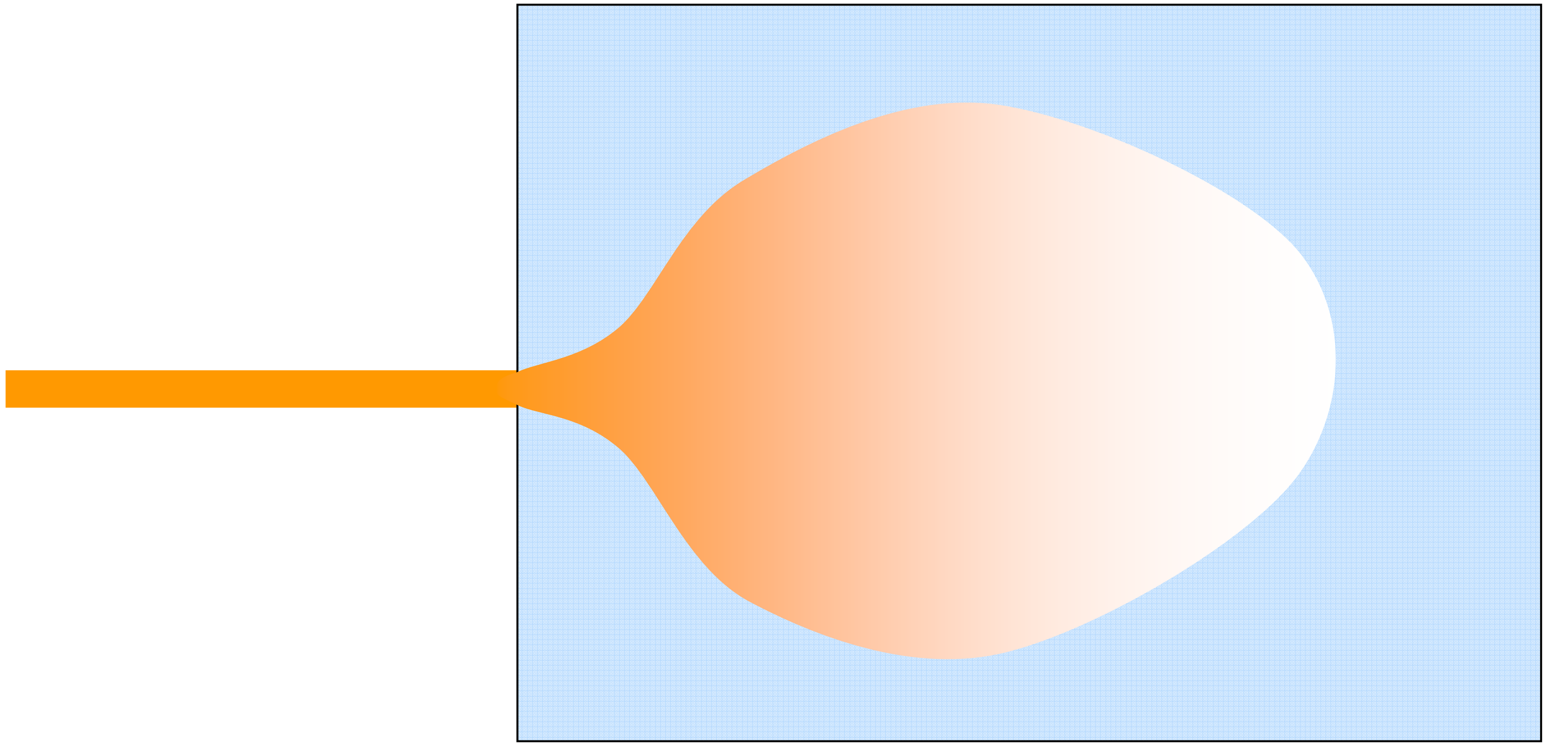
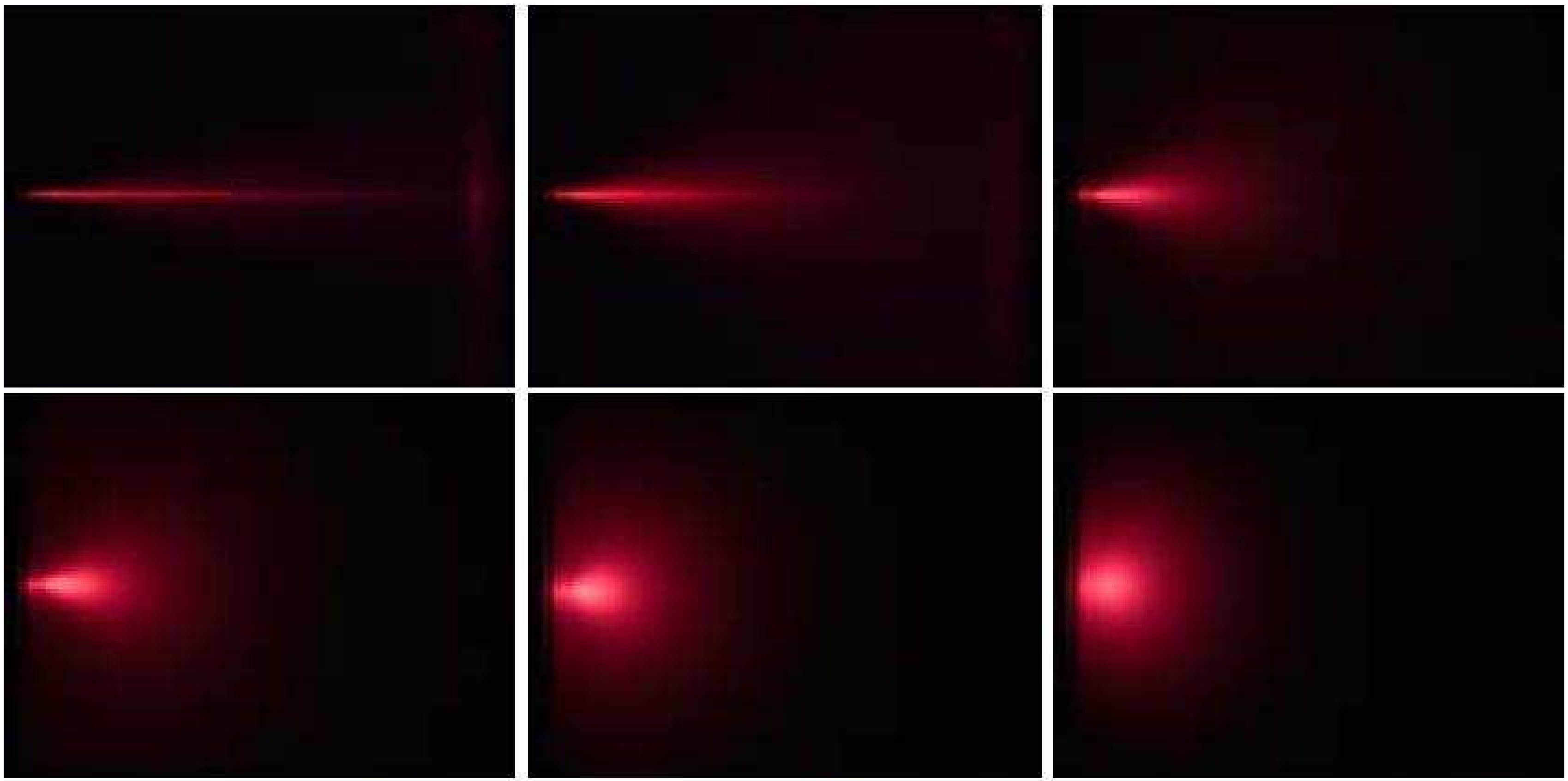


Experimental Validation



from Premoze et al, Practical Rendering of Multiple Scattering Effects in Participating Media

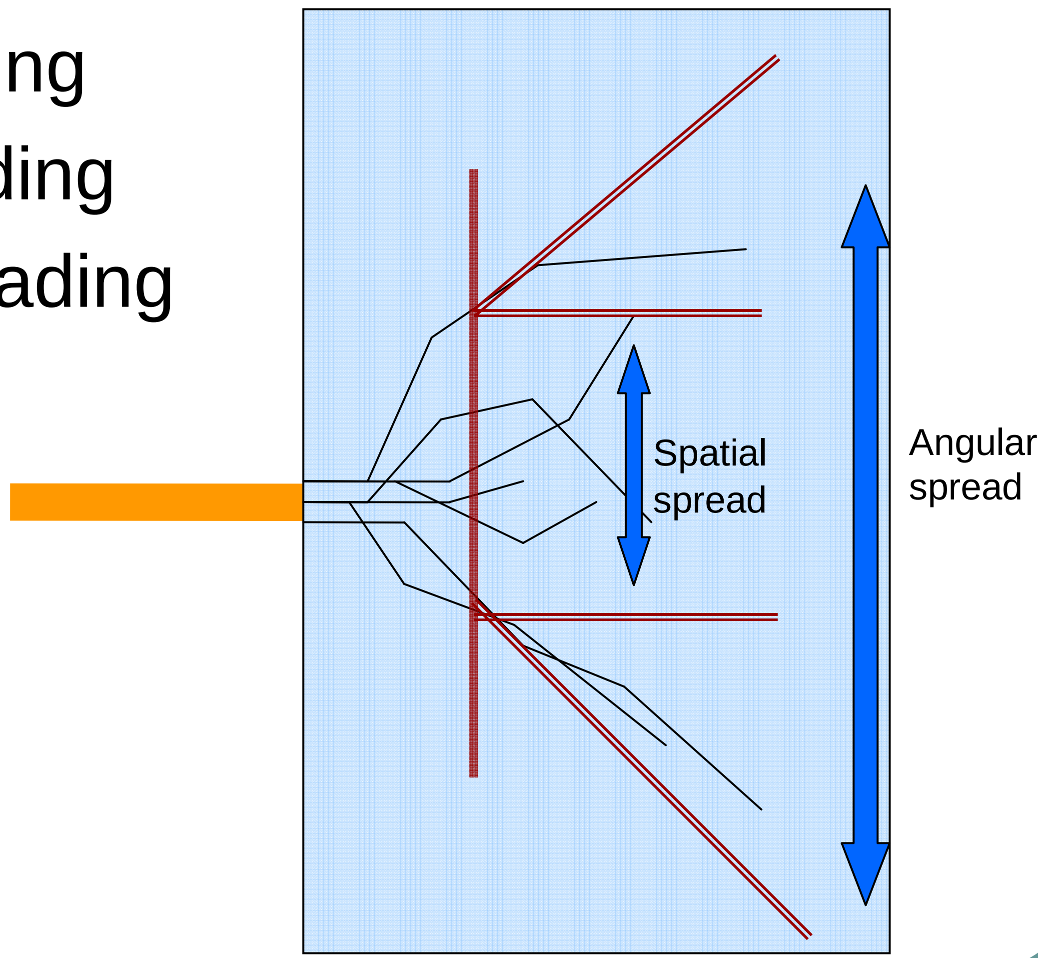
Laser beam shining into water with varying amounts of milk added

Problems

- Very Slow
  - From a few hours to a few days
- Difficult to arrive at the obvious result

Important features of the solution

- Spatial spreading
- Angular spreading
- Temporal spreading
  - Not as important



Radiative Transfer Equation

- Uses alternative (but equivalent) expression for radiative transfer

$$L(s, \mathbf{x}, \vec{\omega}) = \int_{\mathbb{H}^2} \int_{\mathbb{R}^3} G(s, \mathbf{x}, \mathbf{x}', \vec{\omega}, \vec{\omega}') L_0(\mathbf{x}', \vec{\omega}') \ \delta\mathbf{x}' \ \delta\vec{\omega}'$$

- G: Represents light at (x, ω) due to light emitted from (x’, ω’) following a path of length s

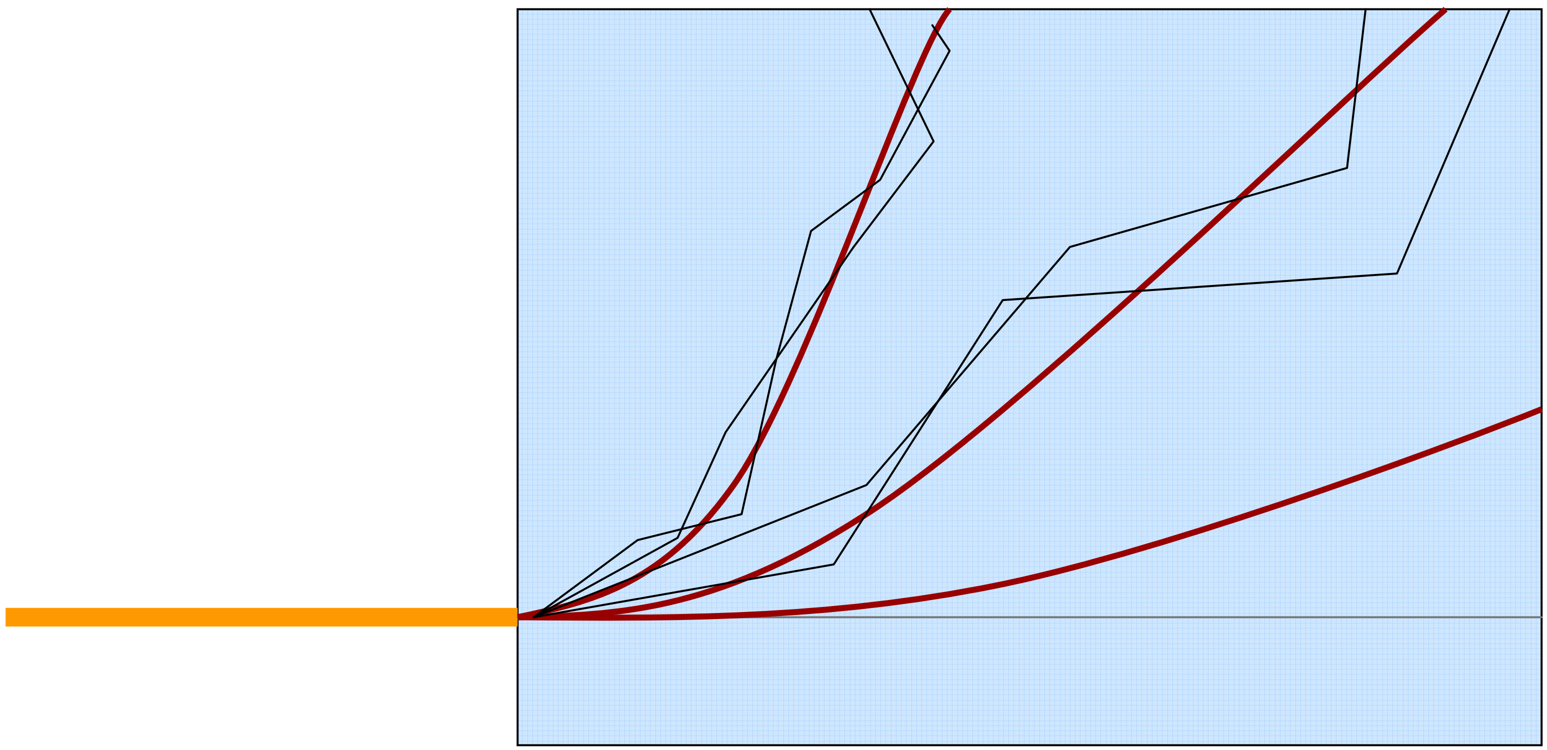
More on the Green Propagator

- Idea: Break it into multiple pieces
  - Direct / Single scattering events (G_d)
  - Multiple scattering events (G_s)
- This paper: efficient approximation of G_s

Path Integral

- Express G_s as an integral over all paths
- Integration measure: infinite-dimensional path space (very messy math)
- Only a small number of paths are actually important
  - Call these the Most Probable Paths (MPP)
  - Sample over paths “near” to MPPs

Most Probable Paths



Most Probable Paths

- Account for spatial spreading:

$$w(s) = \sqrt{\frac{\langle \theta^2 \rangle \ l \ s^2}{24(1 + \frac{\sigma_a \ l^2 \ \langle \theta^2 \rangle}{12\sigma_s})}}$$

- Angular spreading?

Inhomogeneous mediums

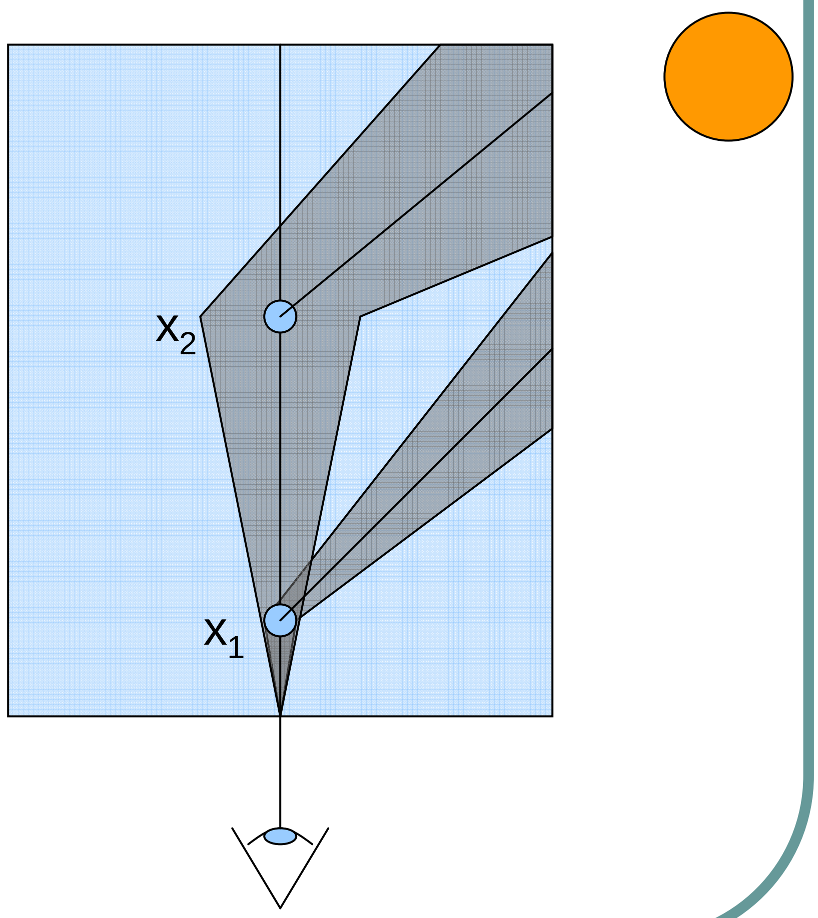
- Easy to adapt to inhomogeneous mediums (why?)
- MPPs are affected by heterogeneity

Algorithm

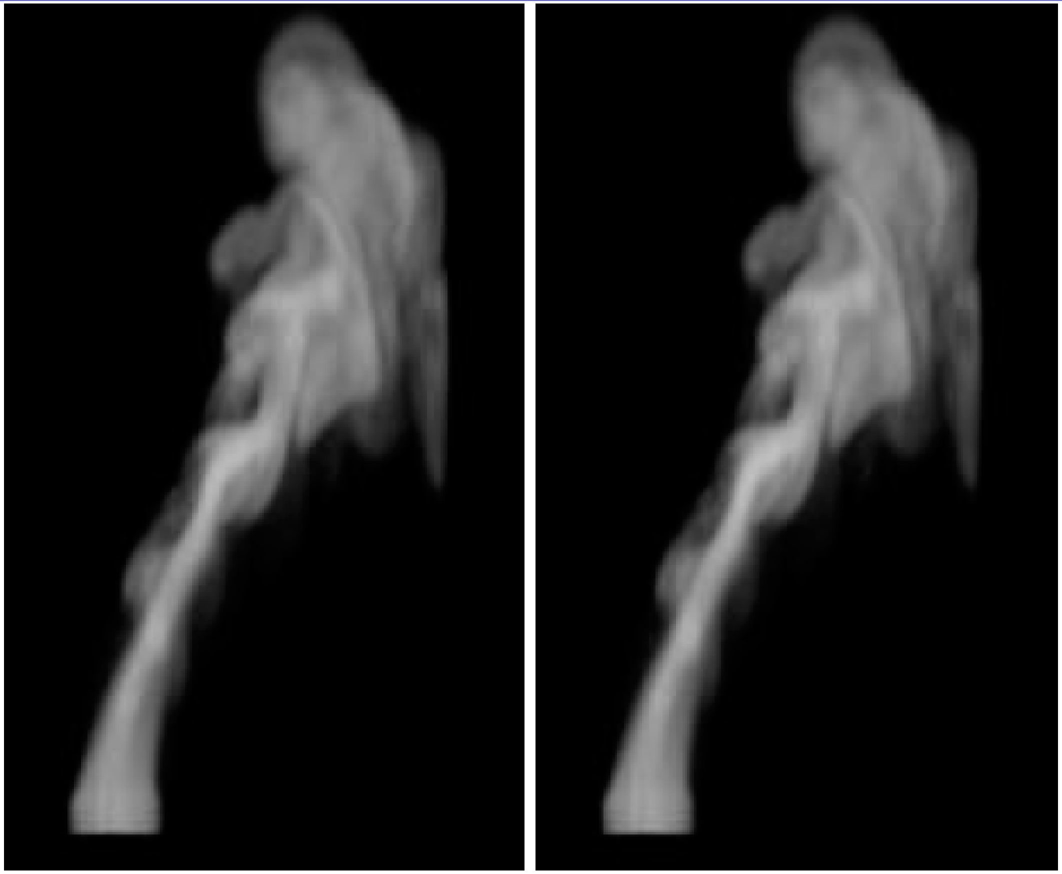
- Precomputation:
  - Light attenuation in voxel space
  - Blurred contribution per light
    - “light pyramid”
  - (Inhomogeneous mediums) Scattering coefficient l per voxel per light
  - Quick (~10 secs for 128^3 voxels)

Algorithm

- Ray marching down viewing ray
- Approximate curved MPPs from light sources with line segment
- Calculate spatial spreading along path
- Look up multiple scatter in light volume based on spatial spread



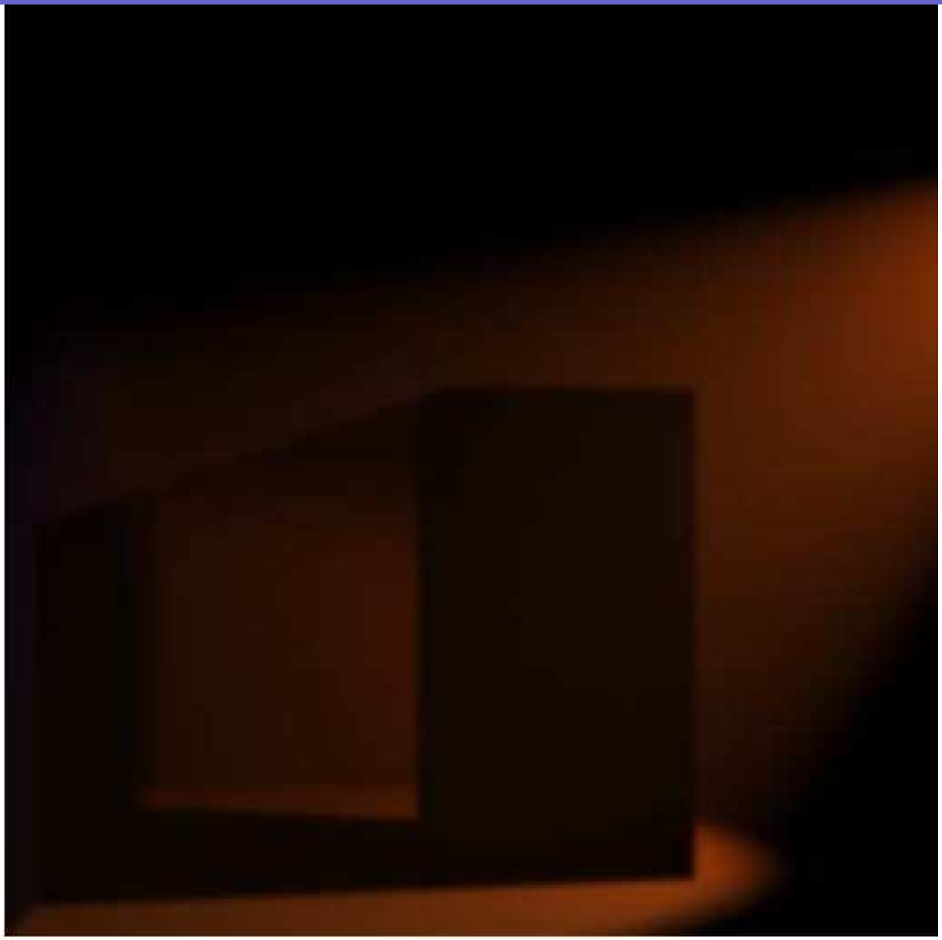
Results



Left: New algorithm (10 minutes). Right: Monte Carlo (3 hrs)

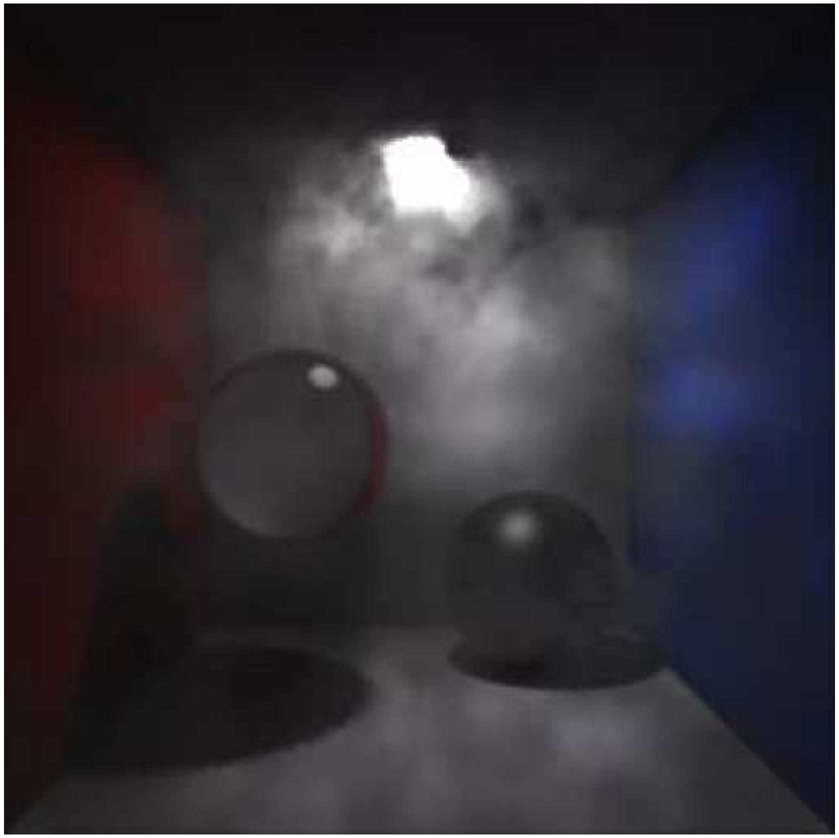
(source: Premoze et al)

Results



Homogeneous medium (source: Premoze et al)

Results



The requisite Cornell Box (30 min) (source: Premoze et al)

Potential drawbacks

- Produces some noticeable differences w.r.t Monte Carlo
- Attenuation is a very rough approximation
- Precomputation per-light per-voxel
  - Prohibitively expensive for large numbers of lights?

Conclusions

- Very fast algorithm
  - Direct / single-scatter dominates render time
- Produces very nice (but not exact) results
- Works well for both homogeneous and inhomogeneous materials
- Still need to handle direct / single-scatter light separately

Questions?

More Math for the Strong of Heart

- Average square of the scattering angle:

$$\langle \theta^2 \rangle = 2\pi \int_0^{\pi} \theta^2 P(\vec{\omega}, \vec{\omega}') \ \sin\theta \ \delta\theta$$

More Math for the Strong of Heart

- Full radiative transfer equation:

$$L(\mathbf{x},\vec{\omega}) = \int_l dl \,\mathsf{exp}(-\frac{c}{b} l(MPP_l)\,\mathsf{exp}(-A_c(MPP_l))P_{MS}(l,\vec{\omega}-\vec{\omega}')$$
$$\times \int_{plane \perp MPP} gauss(\mathbf{x}', w(l))L_0(\mathbf{x}',\vec{\omega}')\delta\mathbf{x}'$$