Remote Sensing tools from Ground, Airborne and Space: Measuring radiation and designing instruments

SPSAS on Atmospheric Aerosols

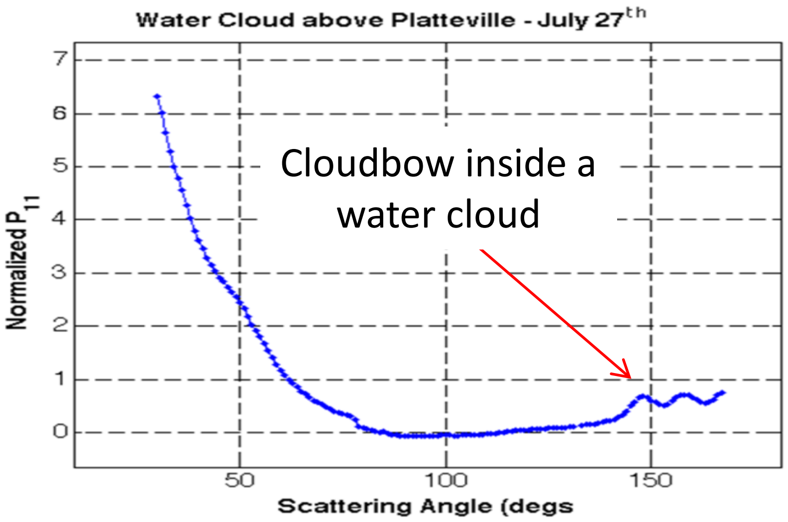
J. Vanderlei Martins
Earth and Space Institute
UMBC and NASA GSFC

UMBC   JCET UMBC NASA-GSFC   UMBC ESI EARTH AND SPACE INSTITUTE   NASA

My current home:

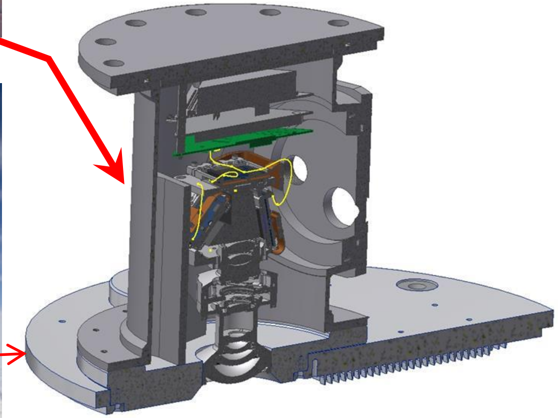
Unique Aircraft Instrumentation

OI-Neph (NASA P3)



NASA ER2 - Oct 2017

UMBC
AirHARP



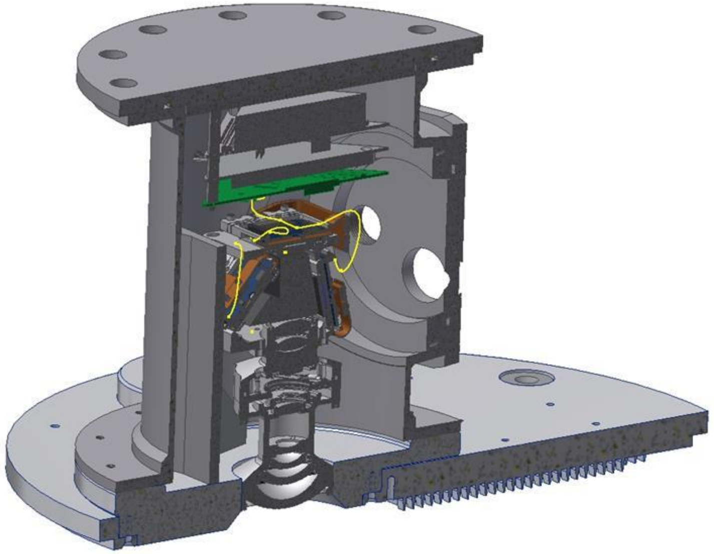
PI-Neph

Platforms:
Ground based, Langley B200, NASA P3, NASA DC8

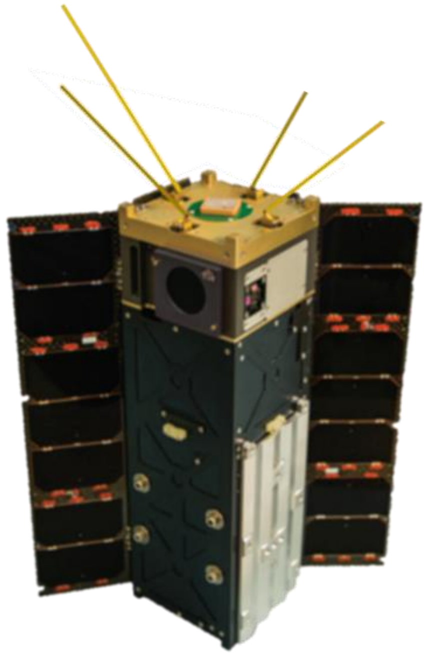
Experiments:
DEVOTE, **DC3**, DISCOVER-AQ CA, STEAR, DISCOVER-AQ CO, STEAR, **SEAC4RS**, DISCOVER-AQ CO, **UMBC Humidification Measurements**

HARP Polarimeter Family:

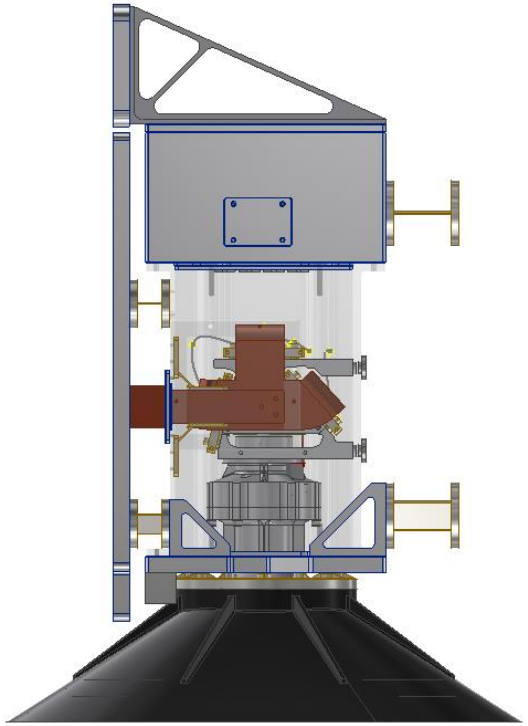
Air HARP



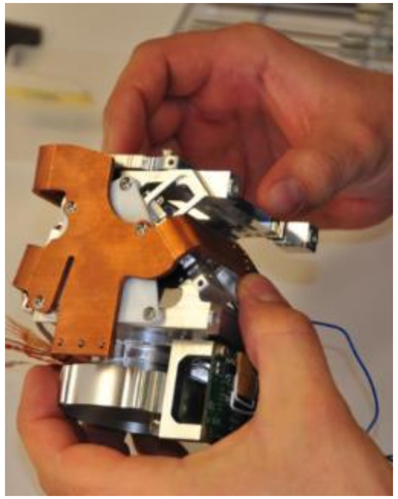
HARP CubeSat



HARP2 PACE



HARP VNIR Telescope



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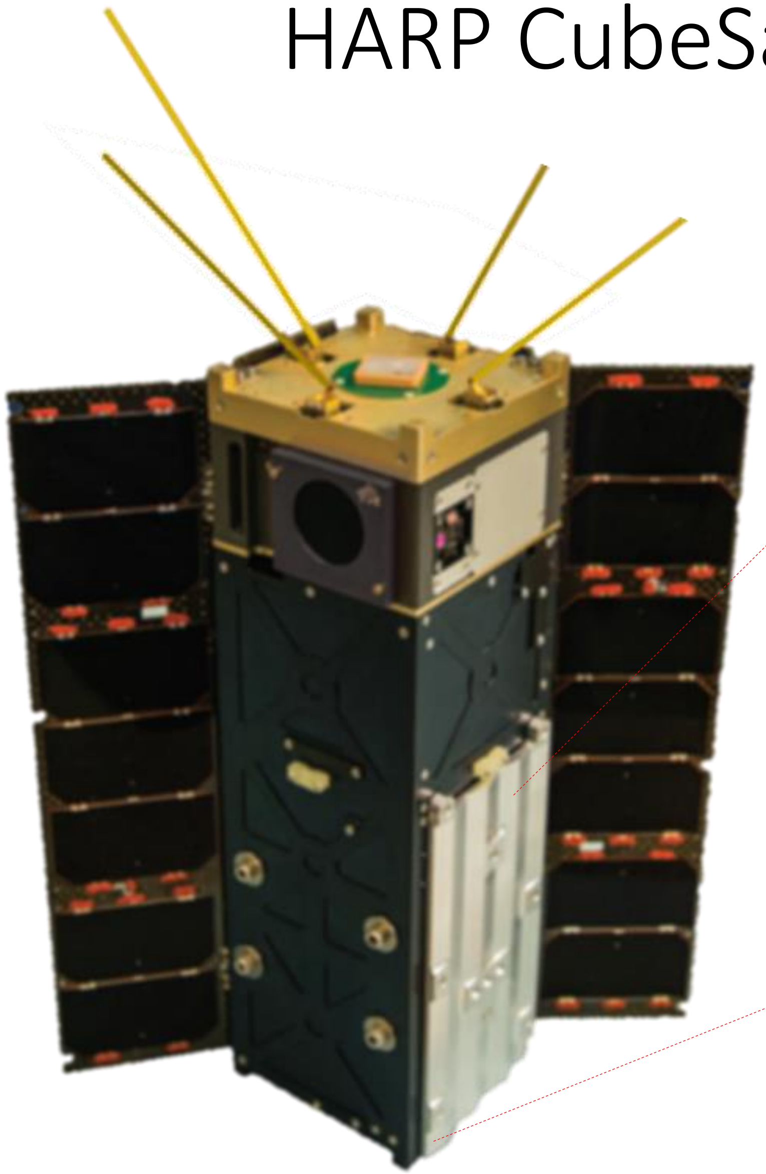
HARP CubeSat – New Technology for Future Missions

Funded by NASA-ESTO InVEST Program

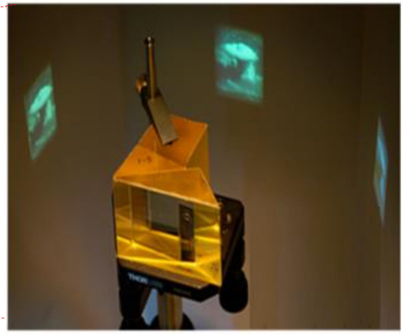


SDL Spacecraft

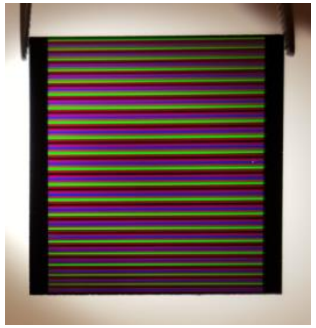
UMBC Sensor

Wide FOV Optics

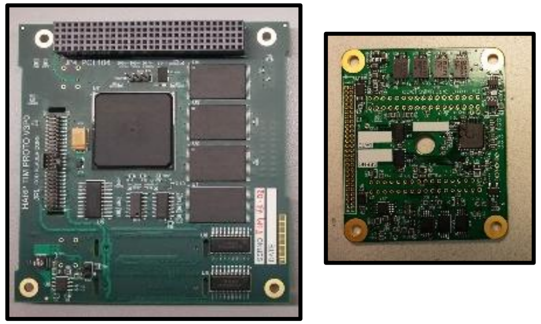
HARP Prism



HARP Stripe Filter



Camera and FPGA Electronics



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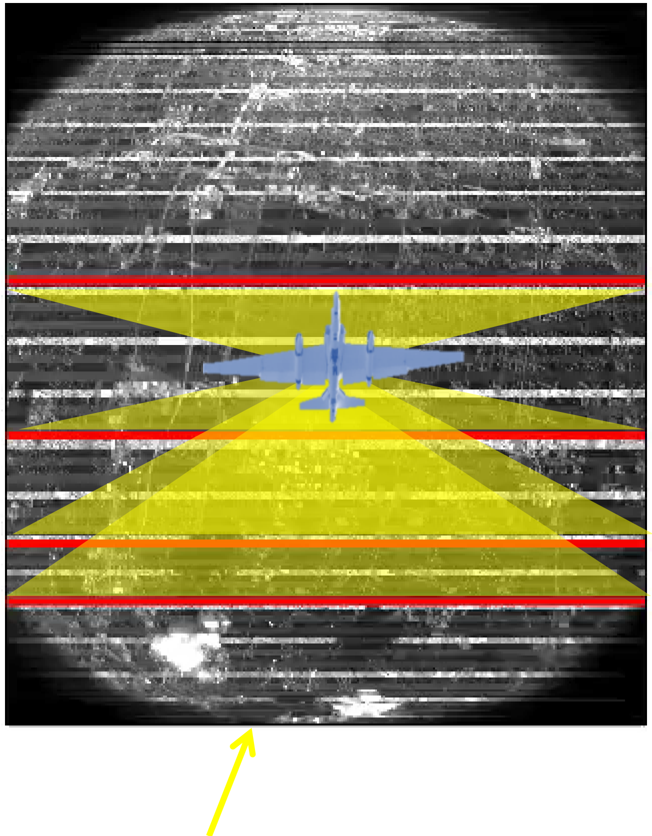
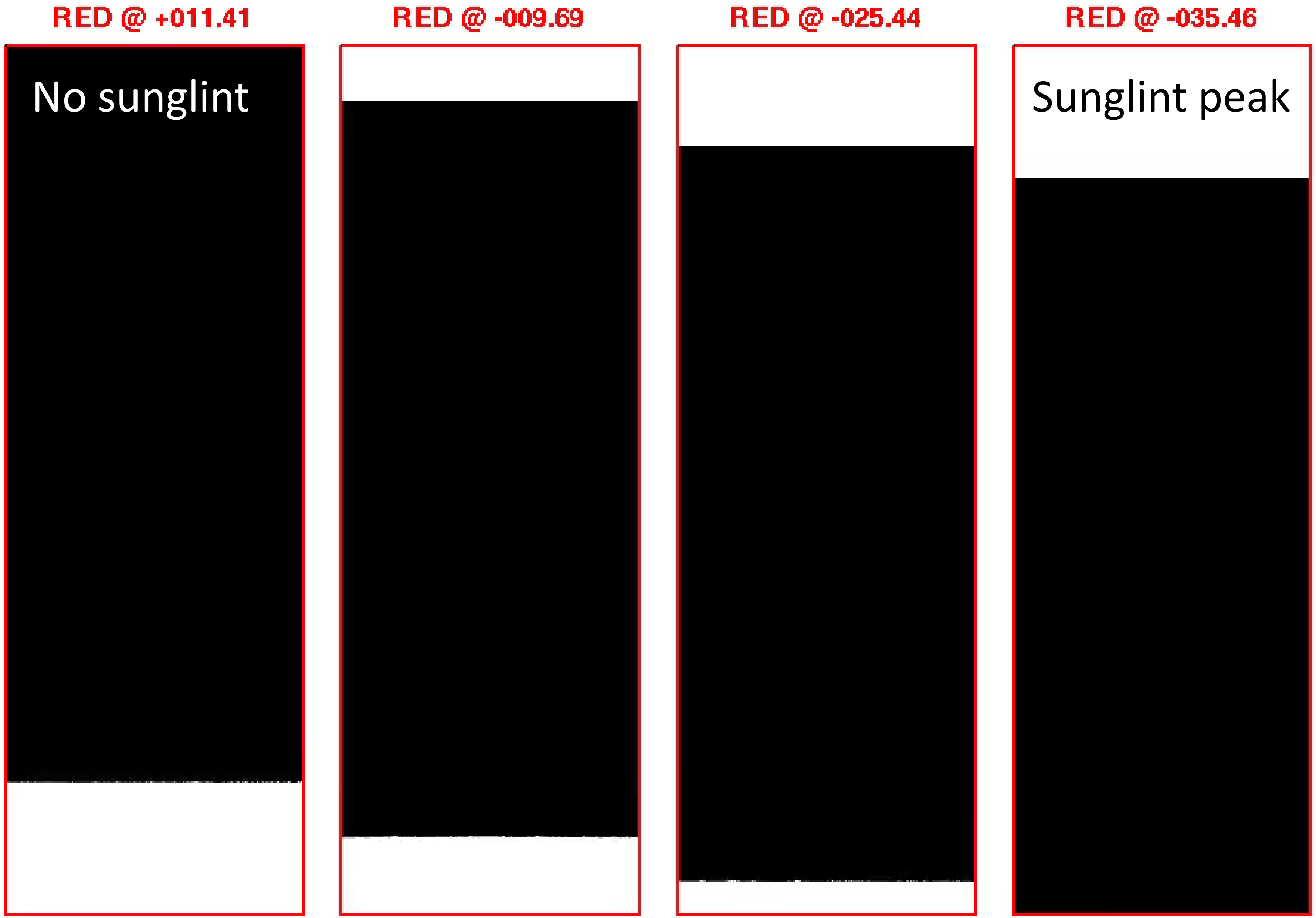
AIRHARP

Multi-Angle Observation



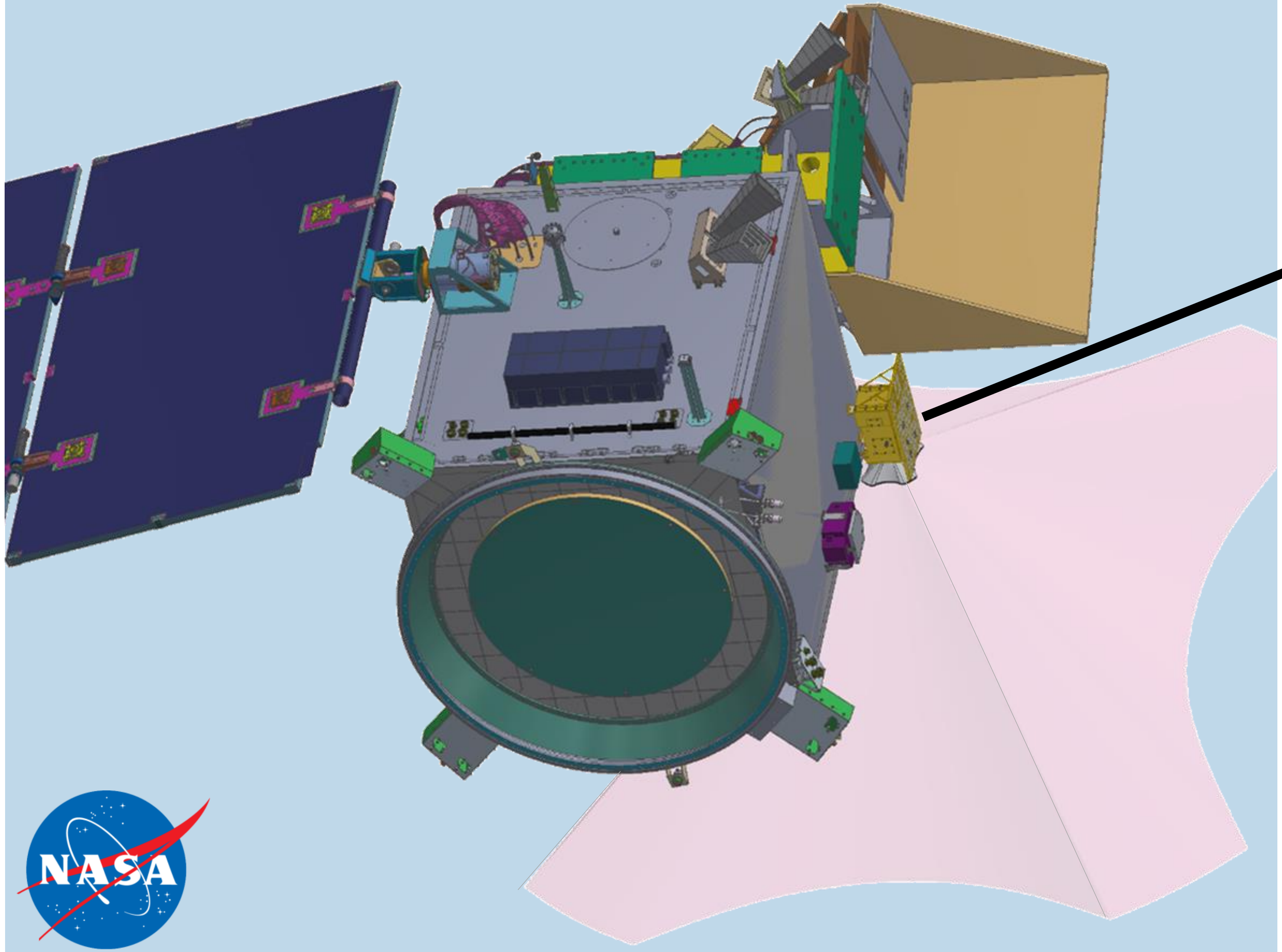
Notice that sunglint
Is not visible in all angles

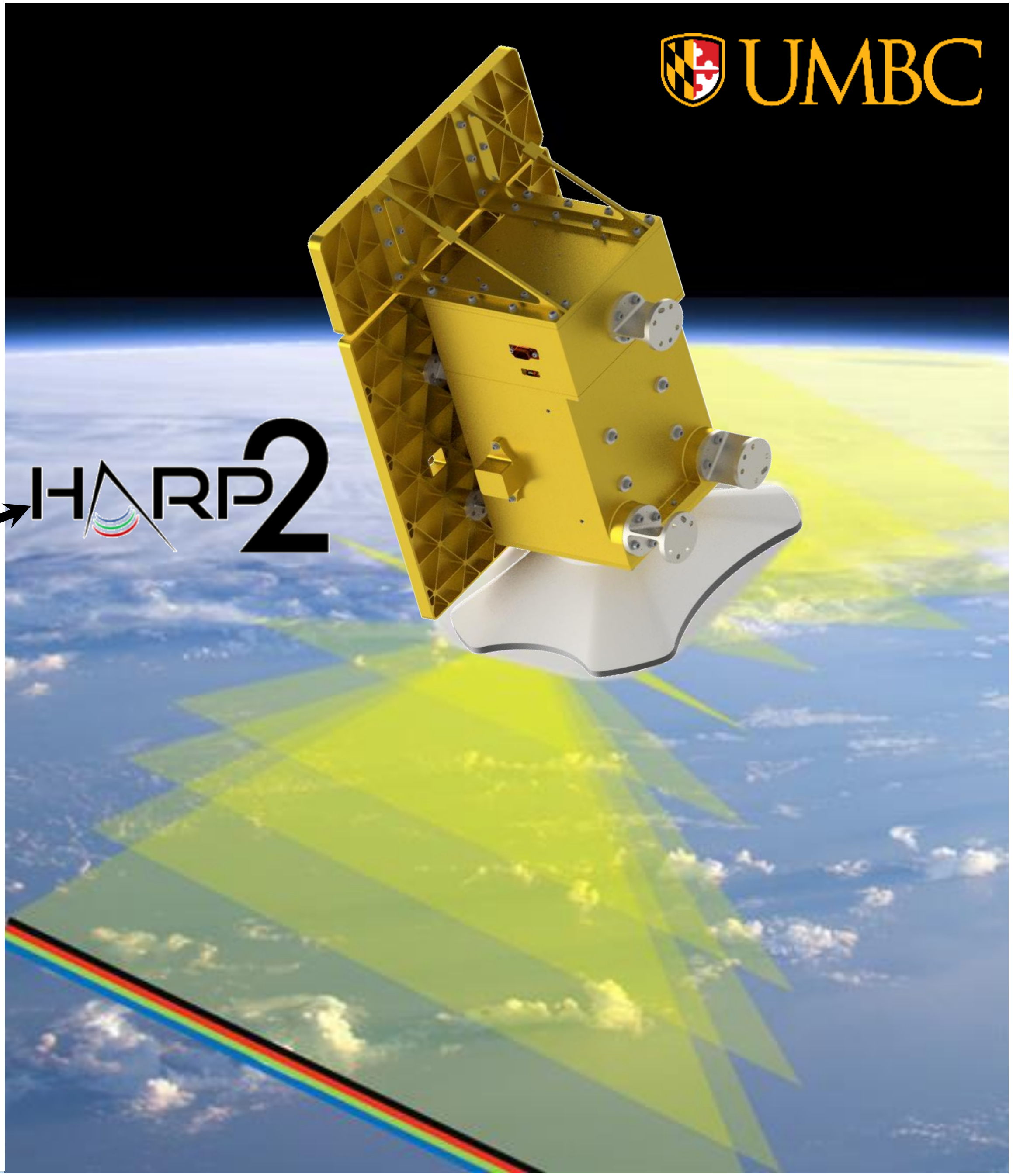


Multiple Angles

HARP2 on PACE

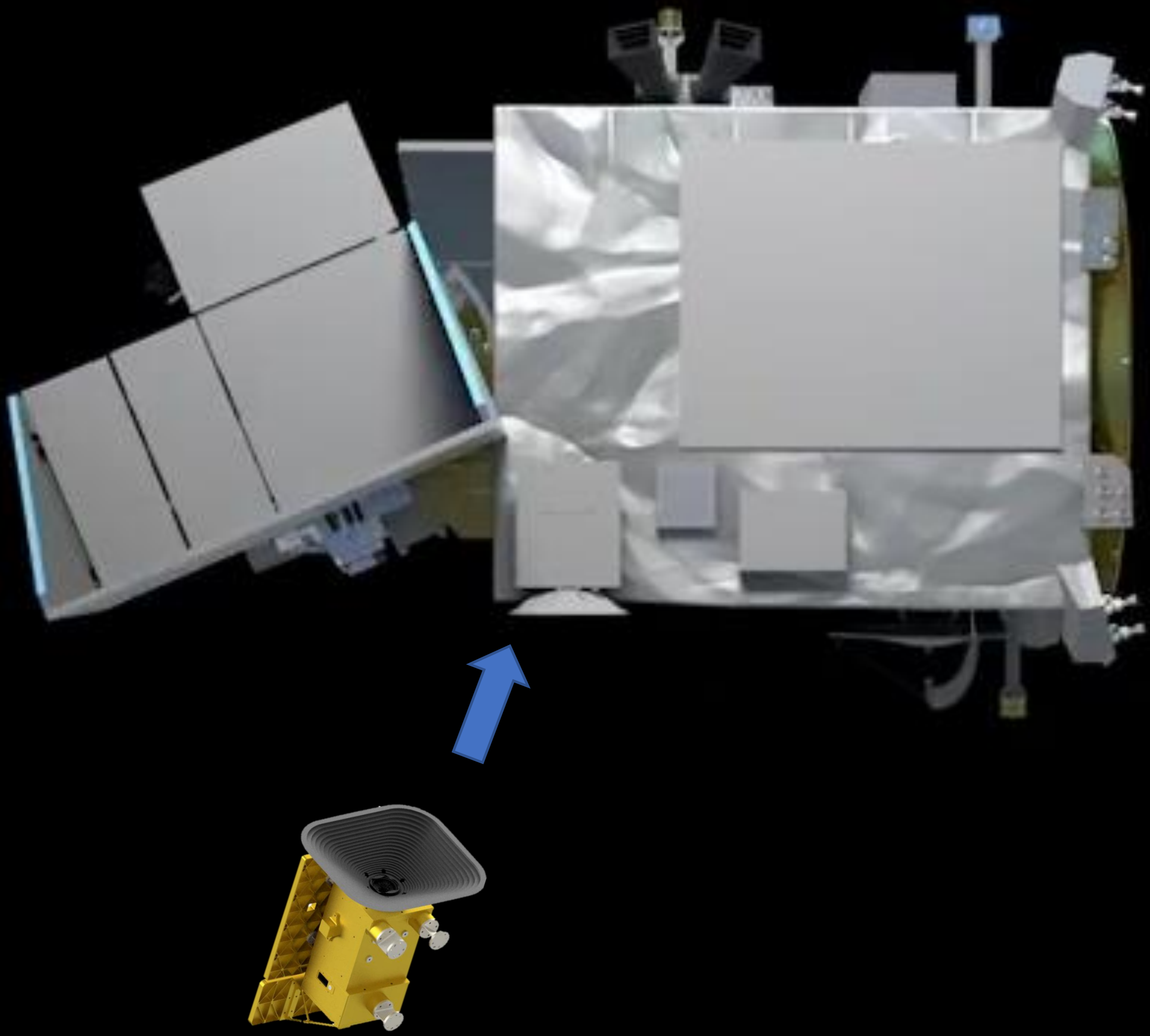
Passed CDR Review 4/24/2019



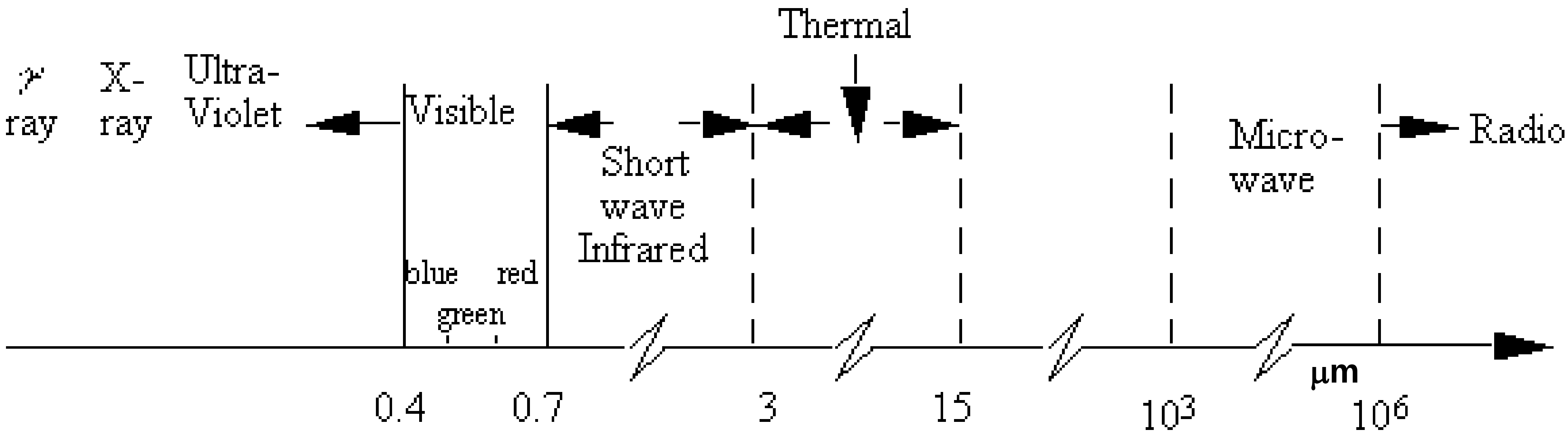


J. Vanderlei Martins – Dept. of Physics, JCET and ESI - UMBC http://esi.umbc.edu

HARP2 on PACE Satellite – Launch 2023



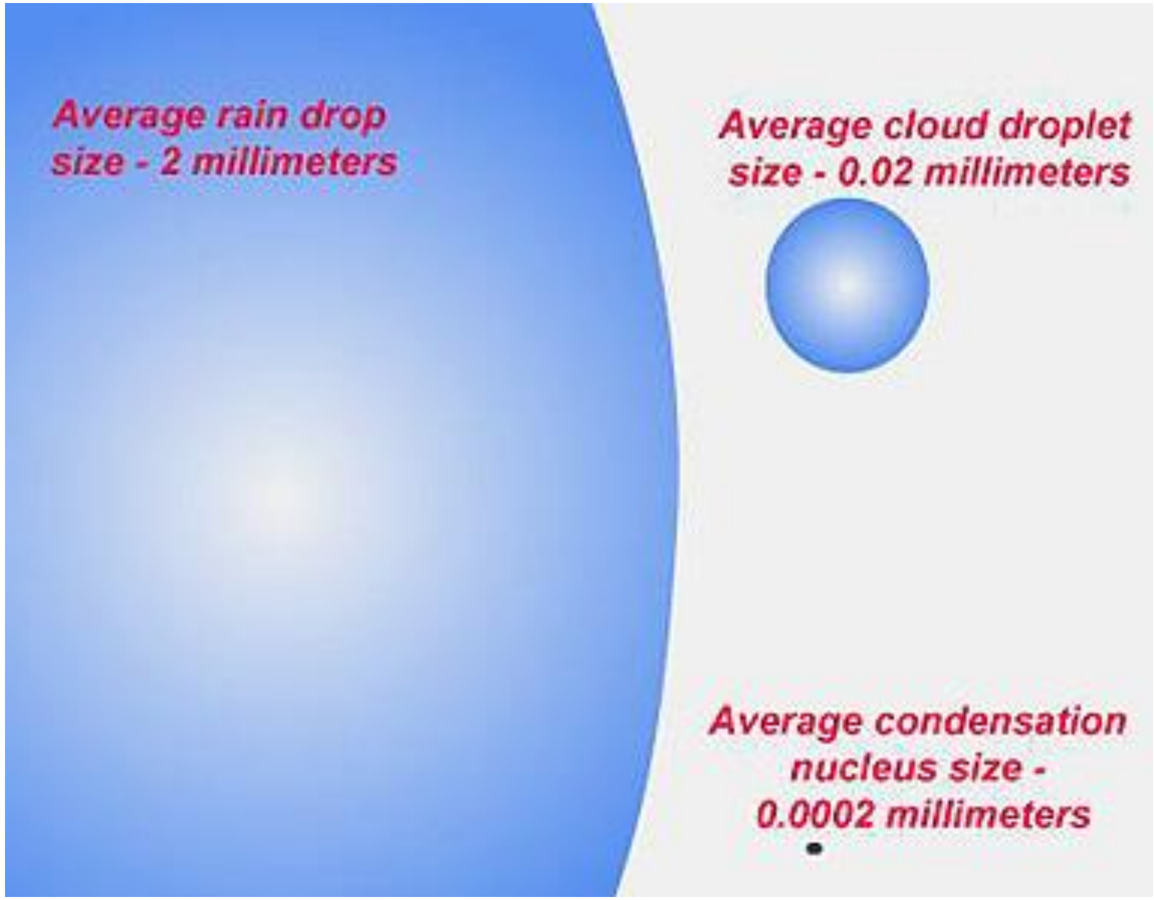
The electromagnetic spectrum



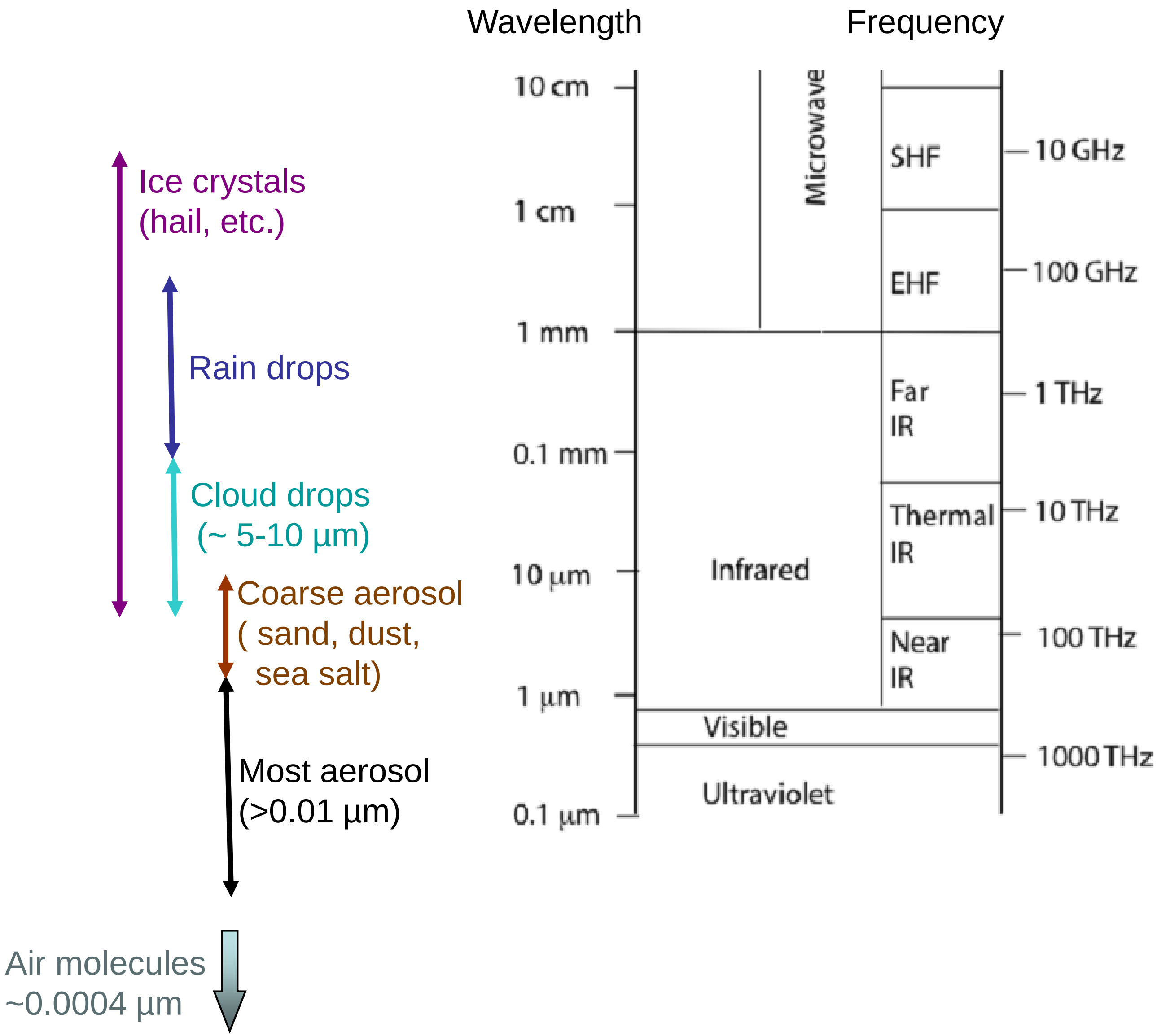
Practical but somewhat arbitrary IR classification that I like:

Near Infrared (NIR)= 0.7-1.3 μ m
Short wave infrared SWIR = 1.3-2.3 μm
Mid wave Infrared (MWIR) = 2.3-4 μm
Thermal IR (TIR) = 4-14 μm,
Far IR or extreme IR = 14 - 300 μm
Microwave = 1mm-1m

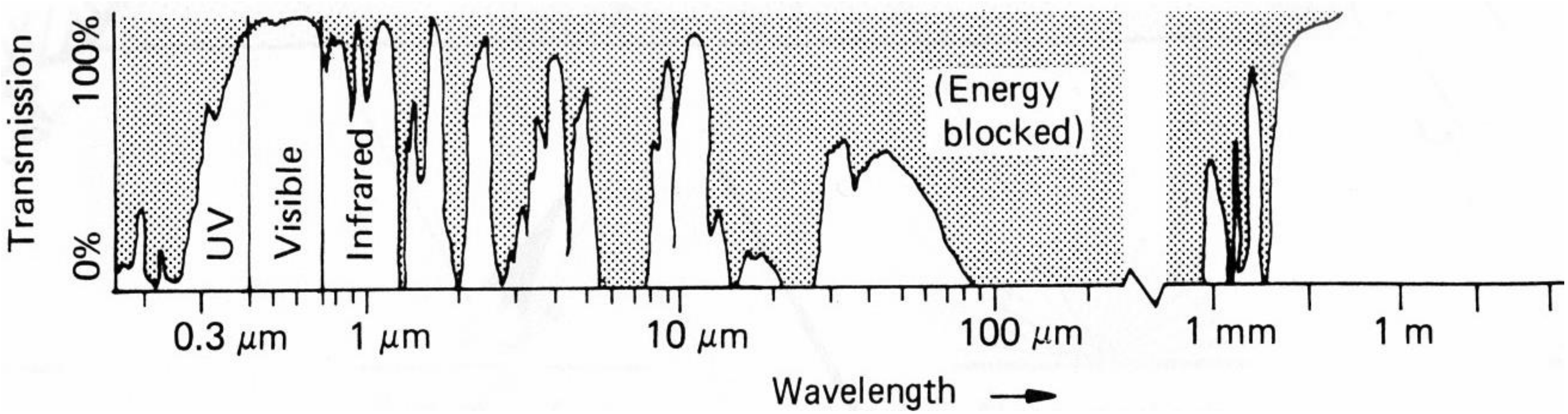
Atmospheric scatterers

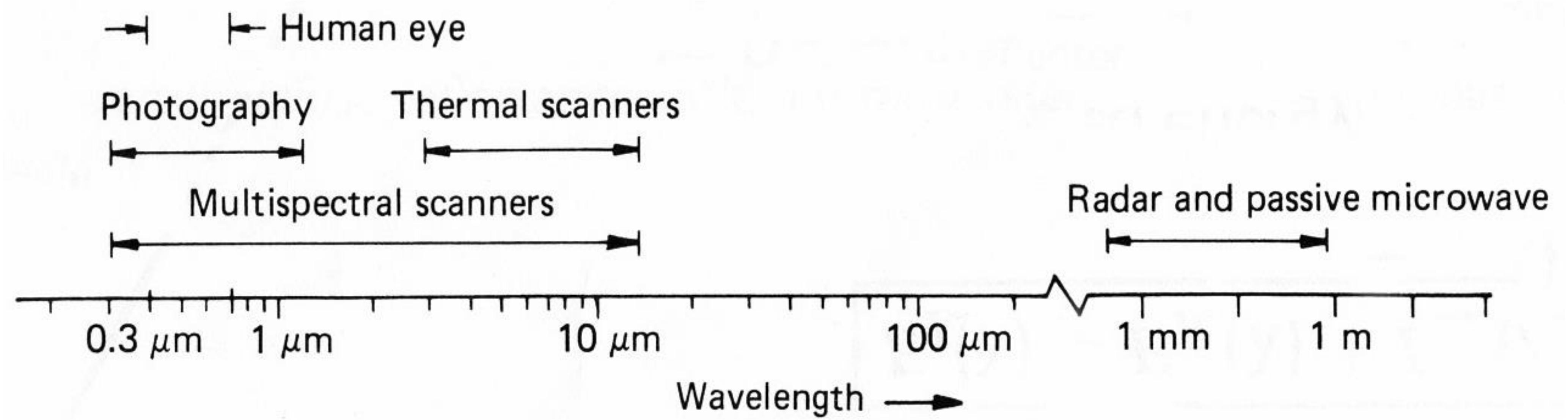


size $< \approx >$ wavelength

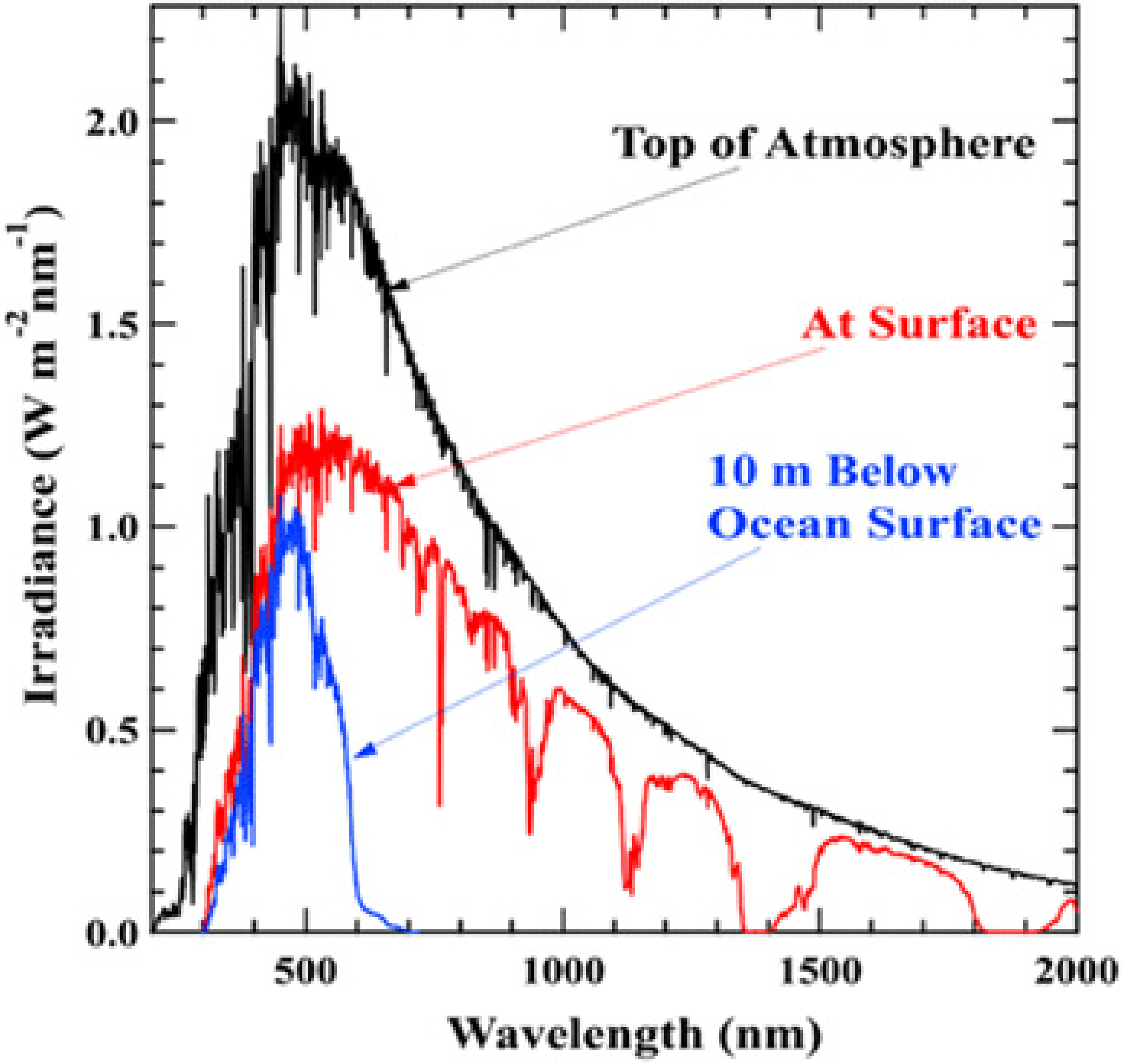


Spectral Characteristics of Atmospheric Transmission and Sensing Systems





Solar Spectrum at different levels:

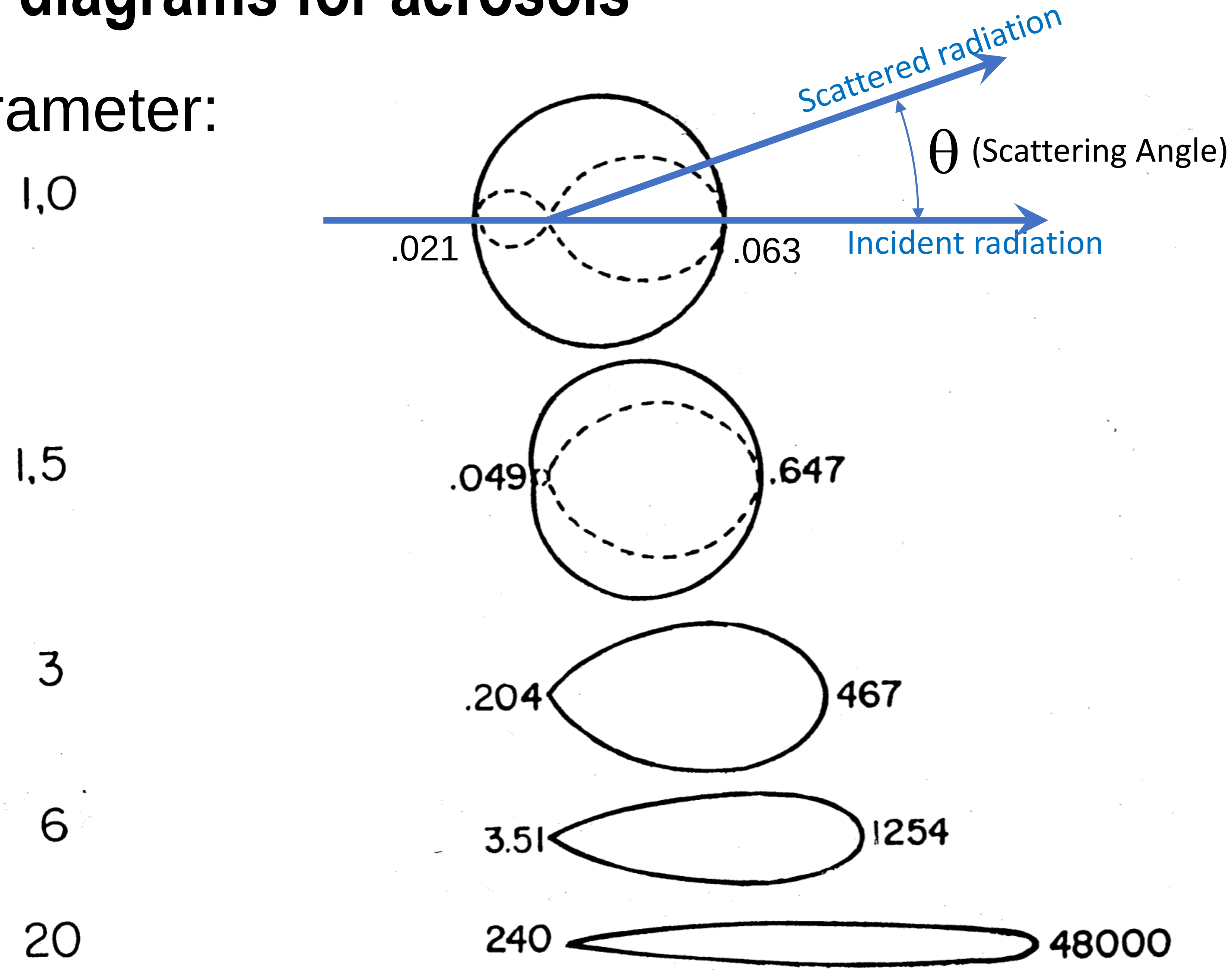


http://lasp.colorado.edu/sorce/instruments/sim/sim_science.htm

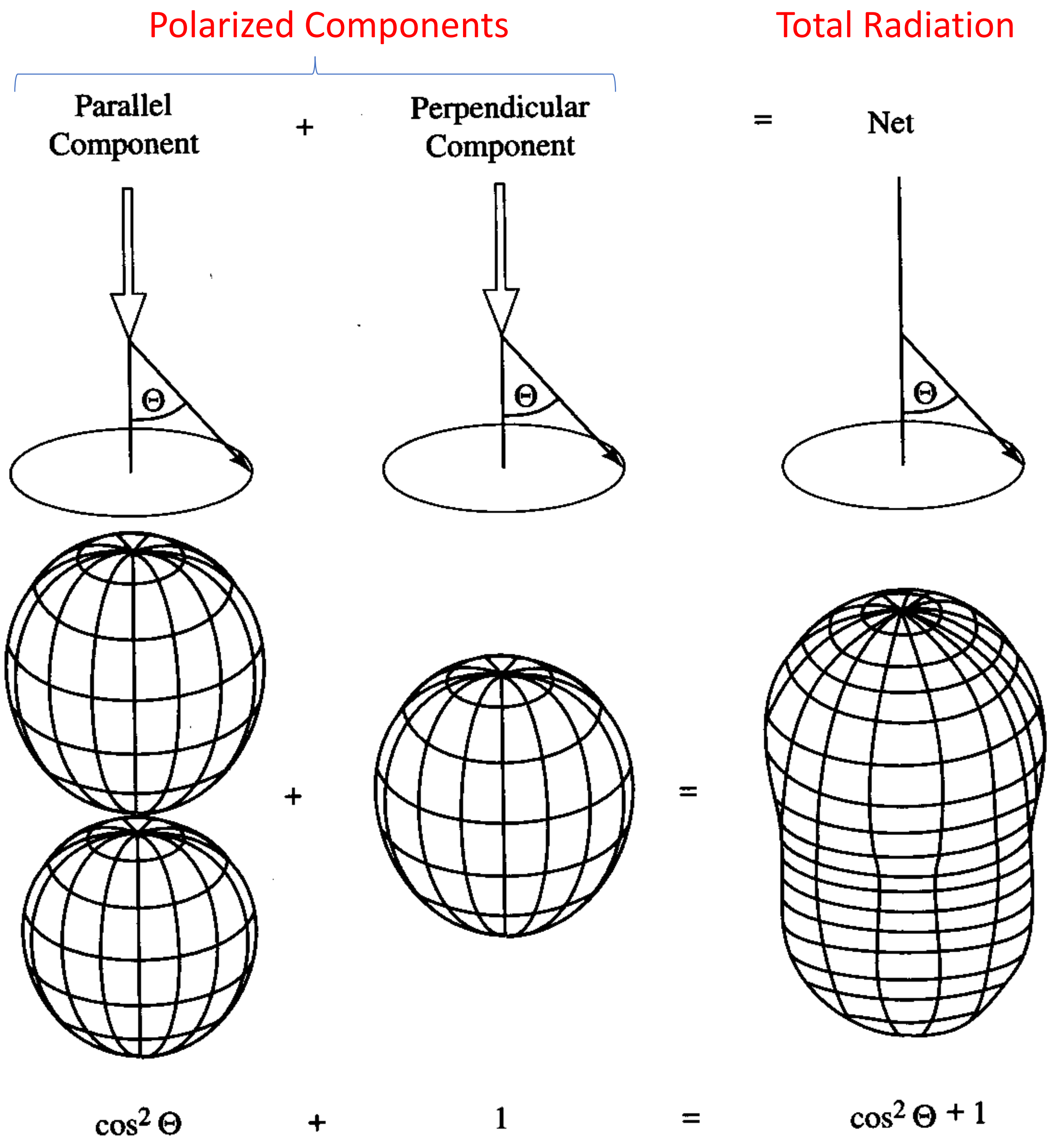
Phase Function diagrams for aerosols

Size Parameter:

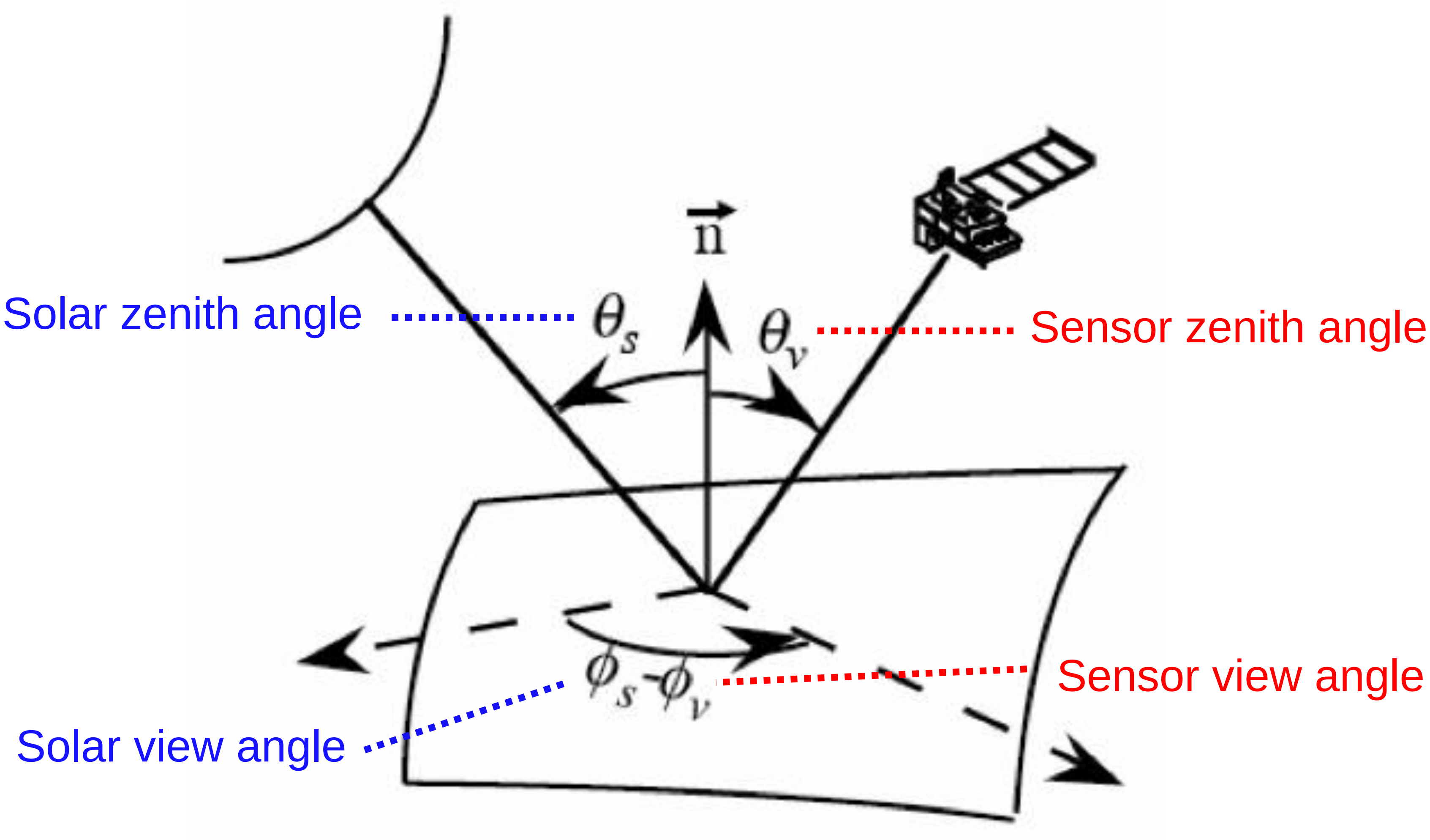
$$\frac{2\pi \cdot radius}{wavelength}$$



Phase Function diagram for Rayleigh scattering



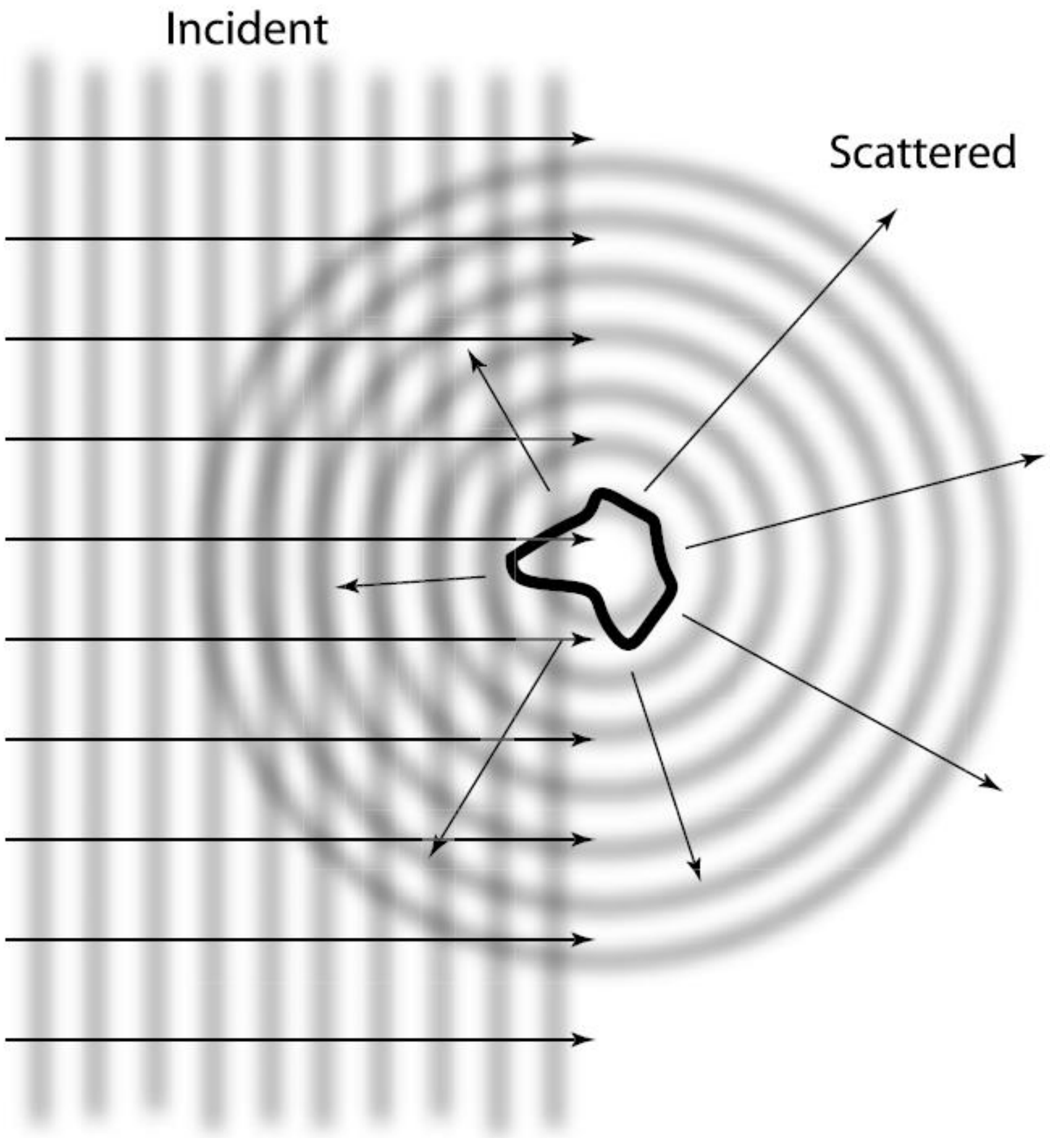
Observing geometry from Space:

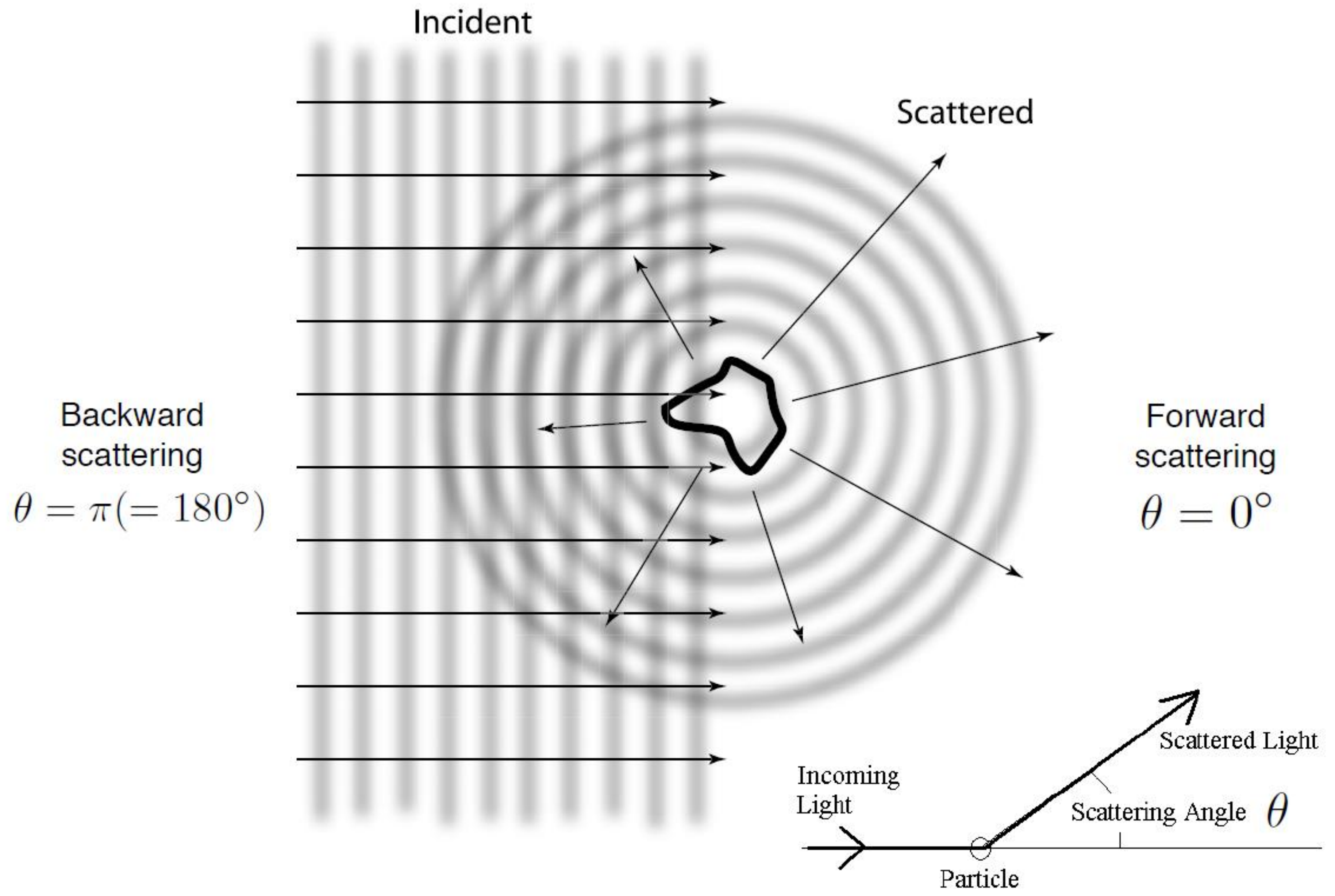


Basic Concepts of Radiation Scattering

SPSAS on Atmospheric Aerosols

- Scattering can be broadly defined as the *redirection of radiation out of the original direction of propagation*, usually due to interactions with molecules and particles
- Reflection, refraction, diffraction etc. are actually all just forms of scattering
- Matter is composed of discrete electrical charges (atoms and molecules – dipoles)
- Light is an oscillating EM field – excites charges, which radiate EM waves
- These radiated EM waves are *scattered waves*, excited by a source external to the scatterer
- The *superposition of incident and scattered EM waves* is what is observed


Incident
Scattered


Incident
Scattered
Backward scattering
$\theta = \pi (= 180°)$
Forward scattering
$\theta = 0°$
Scattered Light
Incoming Light
Scattering Angle θ
Particle

1. Elastic scattering

the wavelength (frequency) of the scattered light is the same as the incident light (Rayleigh and Mie scattering)

2. Inelastic scattering

the emitted radiation has a wavelength different from that of the incident radiation (Raman scattering, fluorescence)

3. Quasi-elastic scattering

the wavelength (frequency) of the scattered light shifts (e.g., in moving matter due to Doppler effects)

(1) The wavelength (λ) of the incident radiation

(2) The size of the scattering particle, usually expressed as the non-dimensional size parameter, **x**:

$$x = \frac{2\pi r}{\lambda}$$

r is the radius of a spherical particle, **λ** is wavelength

(3) The particle optical properties relative to the surrounding medium: the complex refractive index

Scattering regimes:

x << 1 : Rayleigh scattering
x ~ 1 : Mie scattering
x >>1 : Geometric scattering

Slide Credit: Dr. Luca Lelli – University of Bremen

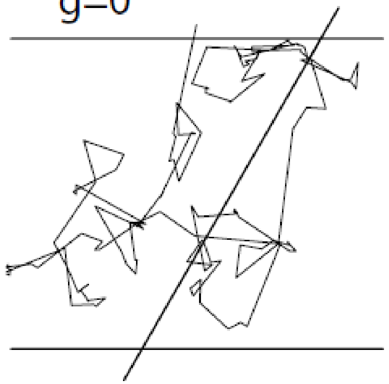
1) **Single scattering**

- Photons scattered only once
- Prevails in optically thin media ($\tau << 1$), since photons have a high probability of exiting the medium (e.g., a thin cloud) before being scattered again
- Also favored in strongly absorbing media ($\omega << 1$)

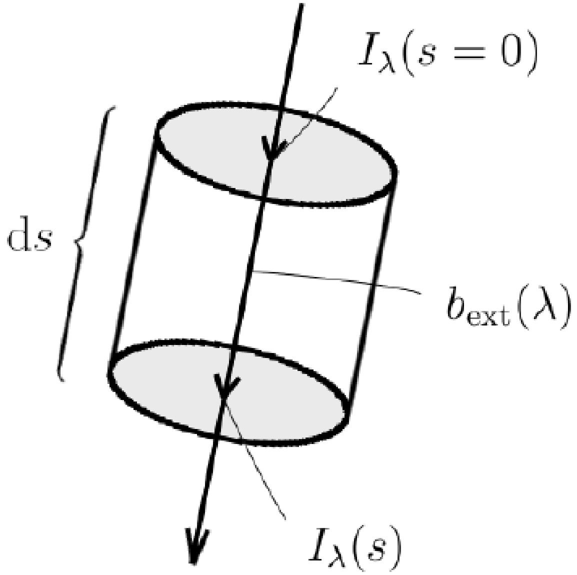
2) **Multiple scattering**

- Prevails in optically thick, strongly scattering and non-absorbing media
- Photons may be scattered hundreds of times before emerging

a) 1 photon
g=0



Extinction = removal of light from its travel path due to both **absorption** and **scattering**



I_λ	Incident light intensity
$I_\lambda(s)$	Outgoing light intensity
$\mathrm{d}s$	Differential travel path through a medium of volume dV, section area dA and radius r
$\beta_{ext}(\lambda)$	Coefficient (or strength) of attenuation

(We also define: β_{scatt} and β_{abs})

The Beer-Lambert-Bouguer extinction law

$$I_\lambda(s) = I_\lambda(0)\ e^{-\int b_{ext}(\lambda)\mathrm{d}s} = I_\lambda(0)\ e^{-\tau(\lambda)}$$

$\tau(\lambda)$ Optical thickness of the volume (unitless). Depends on the medium: absorption and scattering of both molecules and particles

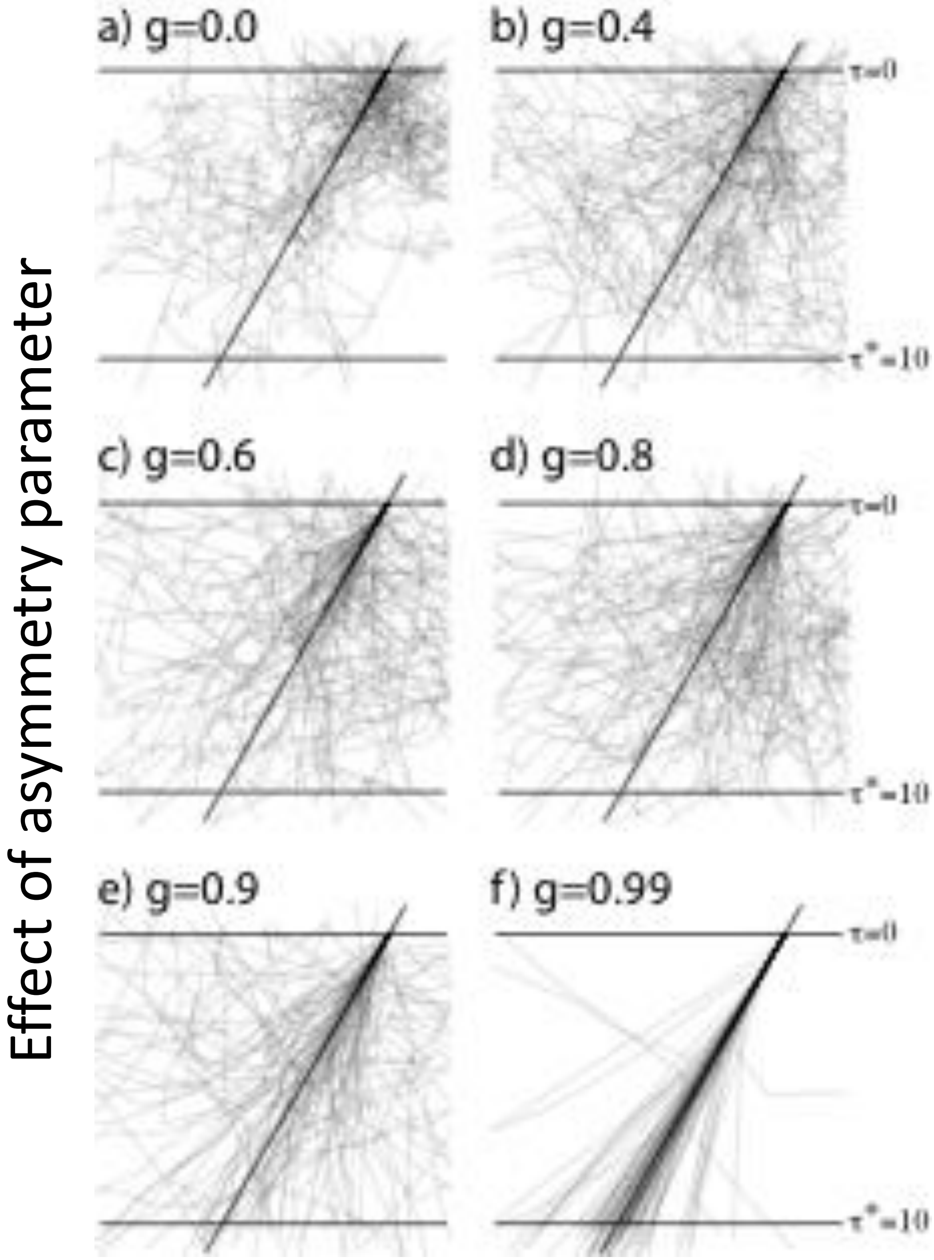
Other important parameters:

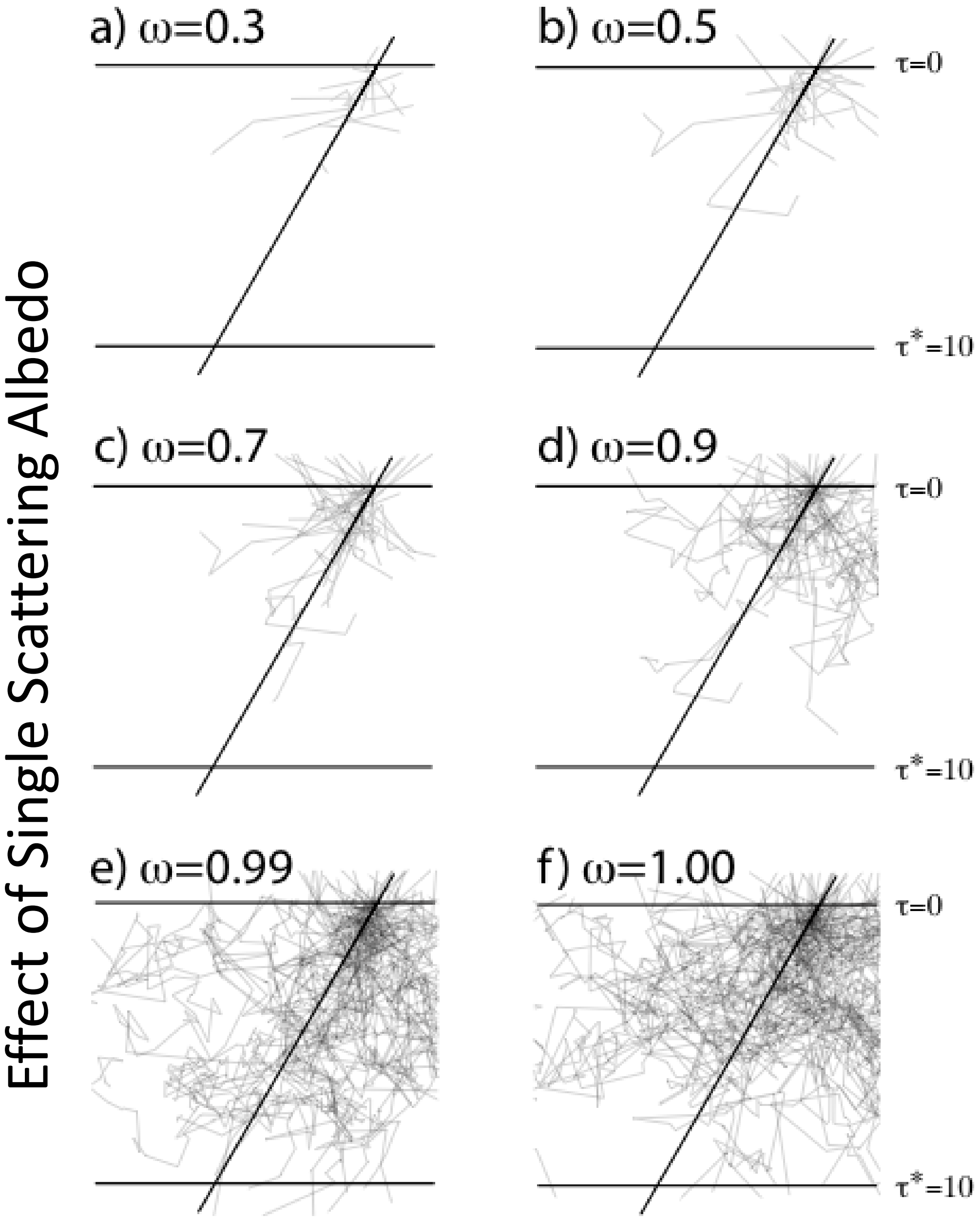
- ω_o (single scattering albedo)
  - Probability of scattering over extinction
  - Ratio between scattering coefficient and extinction coefficient

$$\omega_o = \beta_{scatt}/\beta_{ext}$$

- g (asymmetry parameter):
  - Defines the fraction of radiation scattered in the forward versus backward direction

Illustration of scattering process





Type	Size	Number concentration
Gas molecule	~10^{-4} µm	< 3×10^{19} cm^{-3}
Aerosol, Aitken	< 0.1µm	~10^4 cm^{-3}
Aerosol, Large	0.1-1 µm	~10^2 cm^{-3}
Aerosol, Giant	> 1 µm	~10^{-1} cm^{-3}
Cloud droplet	5-50 µm	10^2-10^3 cm^{-3}
Drizzle drop	~100 µm	~10^3 m^{-3}
Ice crystal	10-10^2 µm	10^3-10^5 m^{-3}
Rain drop	0.1-3 mm	10-10^3 m^{-3}
Graupel	0.1-3 mm	1-10^2 m^{-3}
Hailstone	~1 cm	10^{-2}-1 m^{-3}
Insect	~1 cm	<1 m^{-3}
Bird	~10 cm	<10^{-4} m^{-3}
Airplane	~10-100 m	<1 km^{-3}

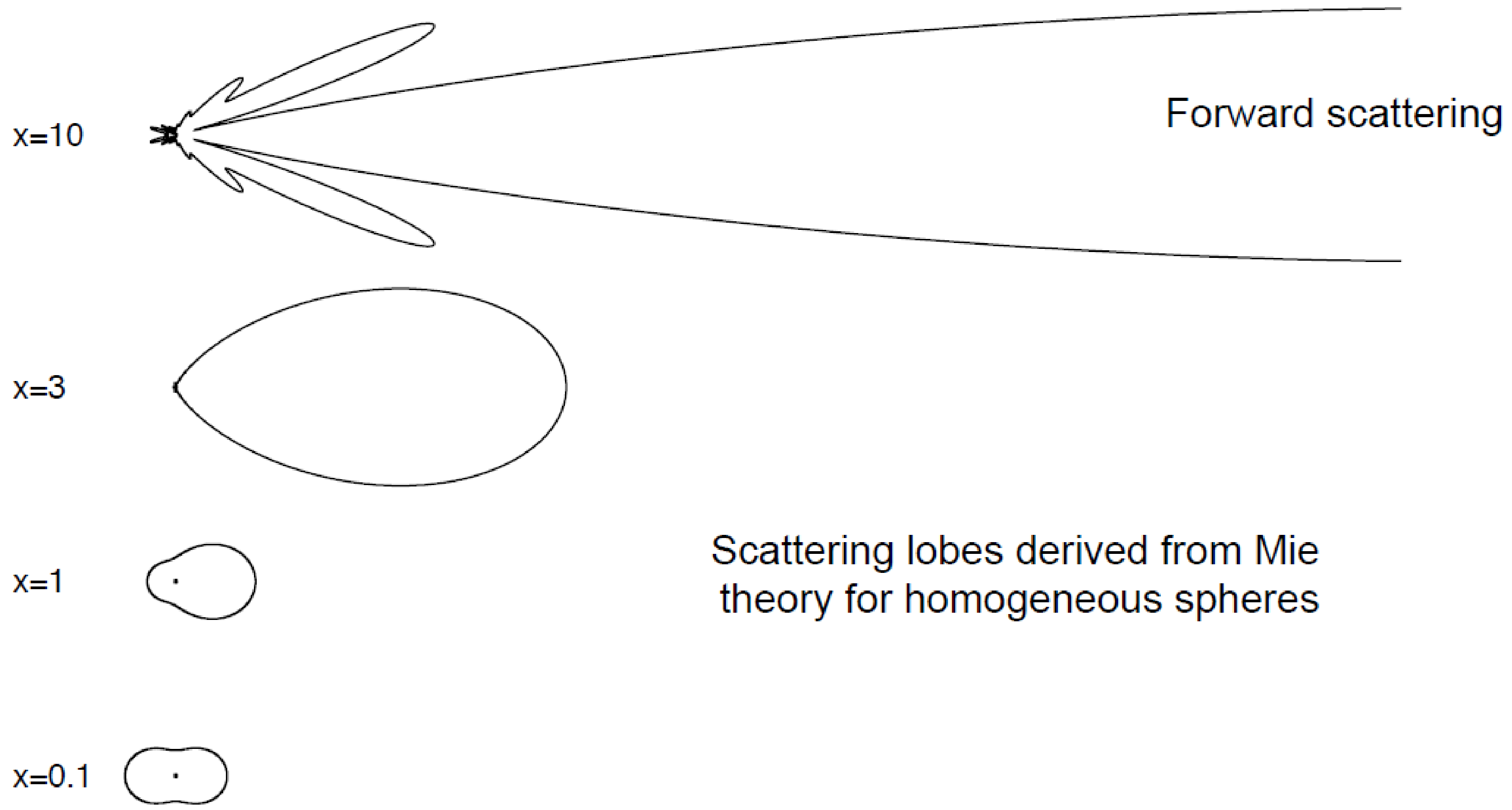
Slide credit: Dr. Luca Lelli – University of Bremen

Substance	n_r	n_i $(n = n_r + i\, n_i)$
Water	1.333	0
Water (ice)	1.309	0
NaCl (salt)	1.544	0
H_2SO_4	1.426	0
$(NH_4)_2SO_4$	1.521	0
SiO_2	1.55	0 (λ = 550 nm)
Carbon	1.95	-0.79 (λ = 550 nm)
Mineral dust	1.56	-0.006 (λ = 550 nm)

The most significant absorbing component of atmospheric particles is ***elemental carbon*** *(soot)*; reflected in the large value of the imaginary part of the refractive index.

Other common atmospheric particles are purely scattering.

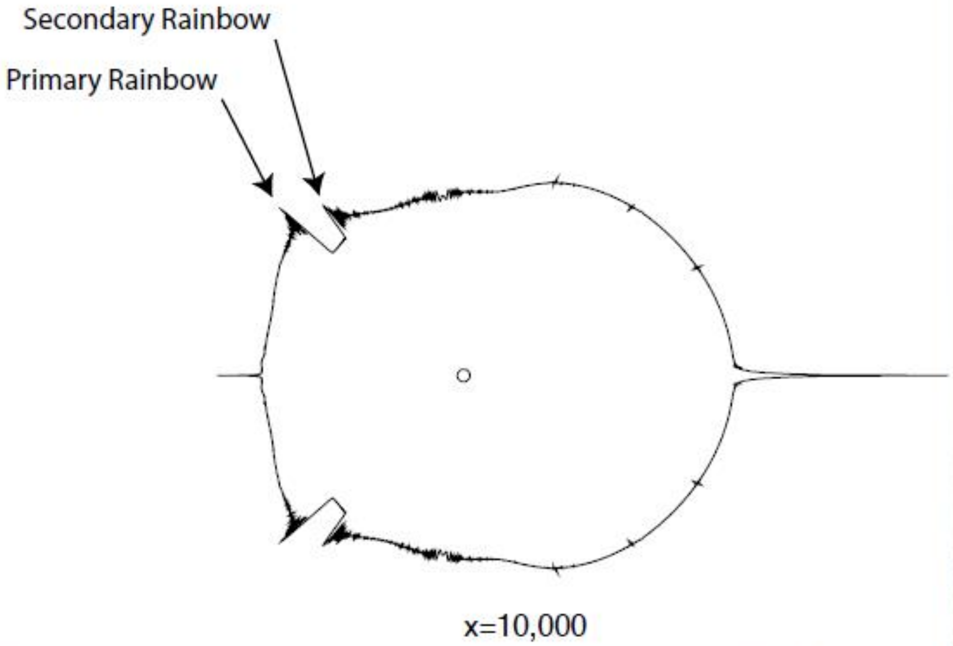
Slide credit: Dr. Luca Lelli – University of Bremen

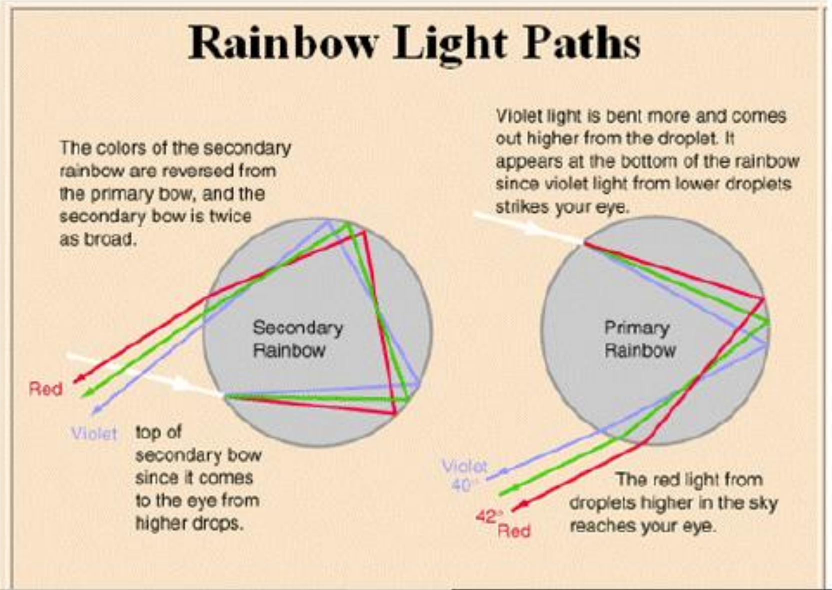


Scattering lobes derived from Mie theory for homogeneous spheres

The scattering phase function, or *phase function*, gives the angular distribution of light intensity scattered by a particle at a given wavelength

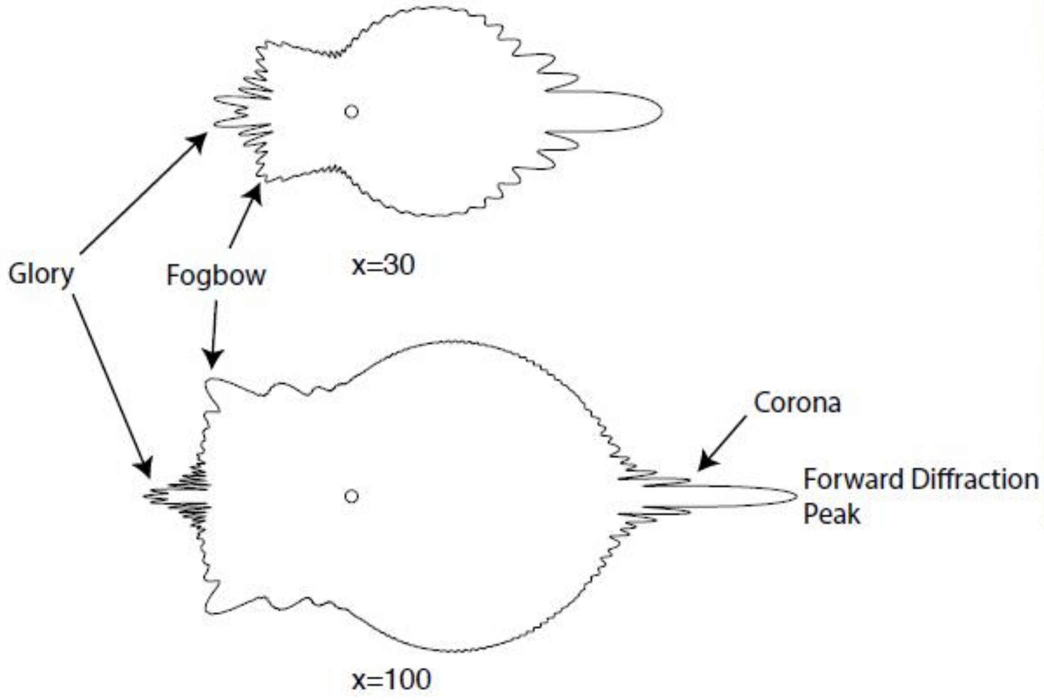
Slide credit: Dr. Luca Lelli – University of Bremen





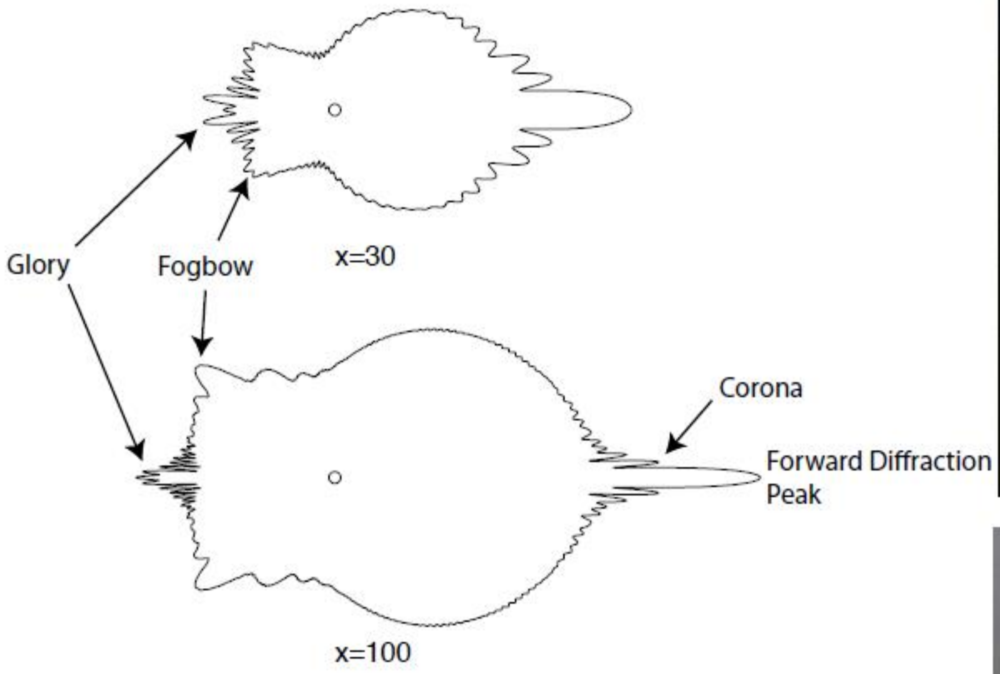
Rainbow: for large particles (x = 10,0000), the forward and backward peaks in the scattering phase function become very narrow (almost non-existent). Light paths are best predicted using geometric optics and ray tracing

Primary rainbow: single internal reflection
Secondary rainbow: double internal reflection



Fogbow

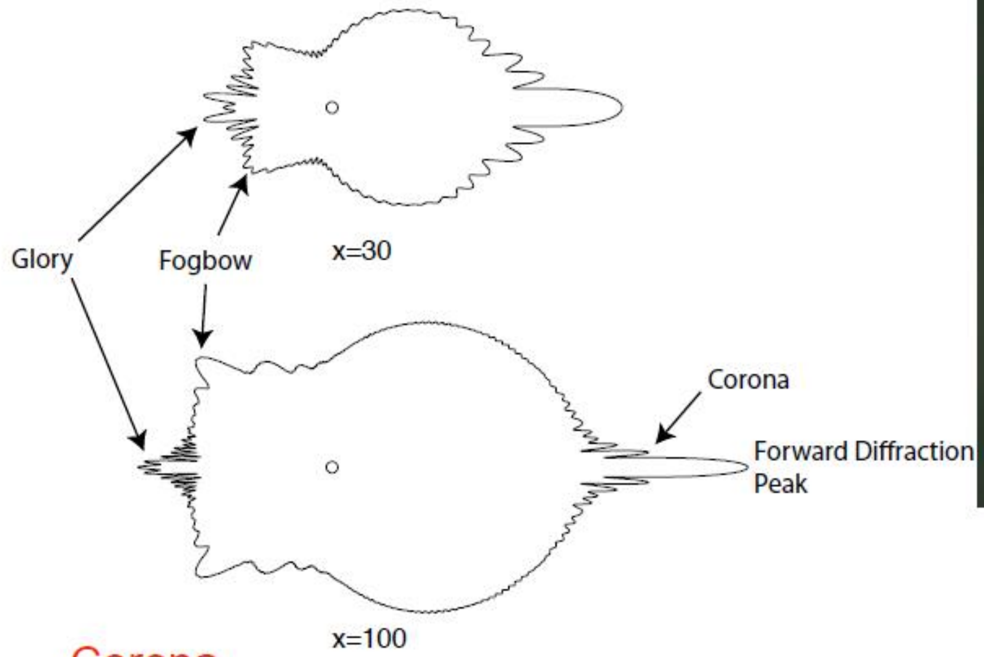
spikes in scattering phase function present but not sharp as for rainbows. Hence the separation of colors (due to varying refractive index) is not as vivid as a normal rainbow.



Glory

opposite end of the phase function from the corona. Sun at the back.

Glories have vivid colors if the range of drop sizes in the fog is relatively narrow, otherwise white



Corona

for intermediate values of the size parameter (x), the forward scattering peak is accompanied by weaker *sidelobes*.

If you were to view the sun through a thin cloud composed of identical spherical droplets (with x = 100 or less), you would see closely spaced rings around the light source. The angular position of the rings depends on wavelength, so the rings would be colored. This is a *corona*.

Because few real clouds have a sufficiently narrow distribution of drop sizes, coronas are usually more diffuse and less brightly colored.

Rainbow Measurements:

of Cloud Droplet Size Distribution

F-M. Breon, P. Goloub, 1998.

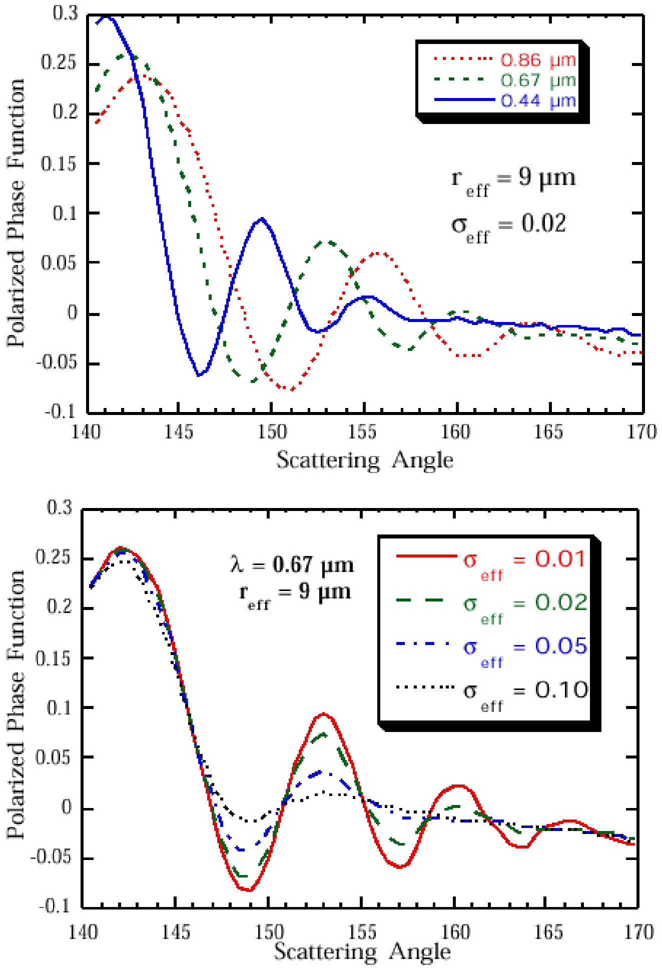
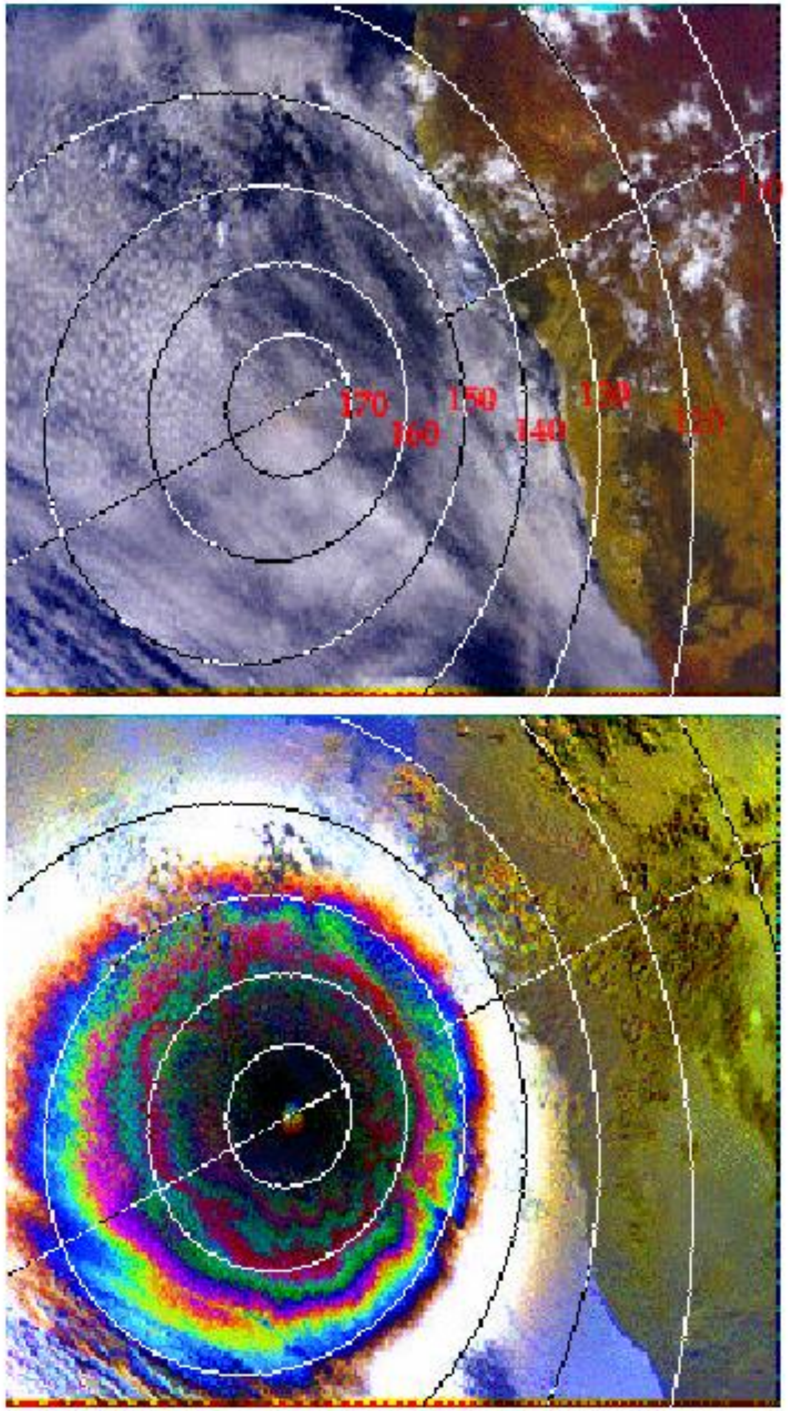
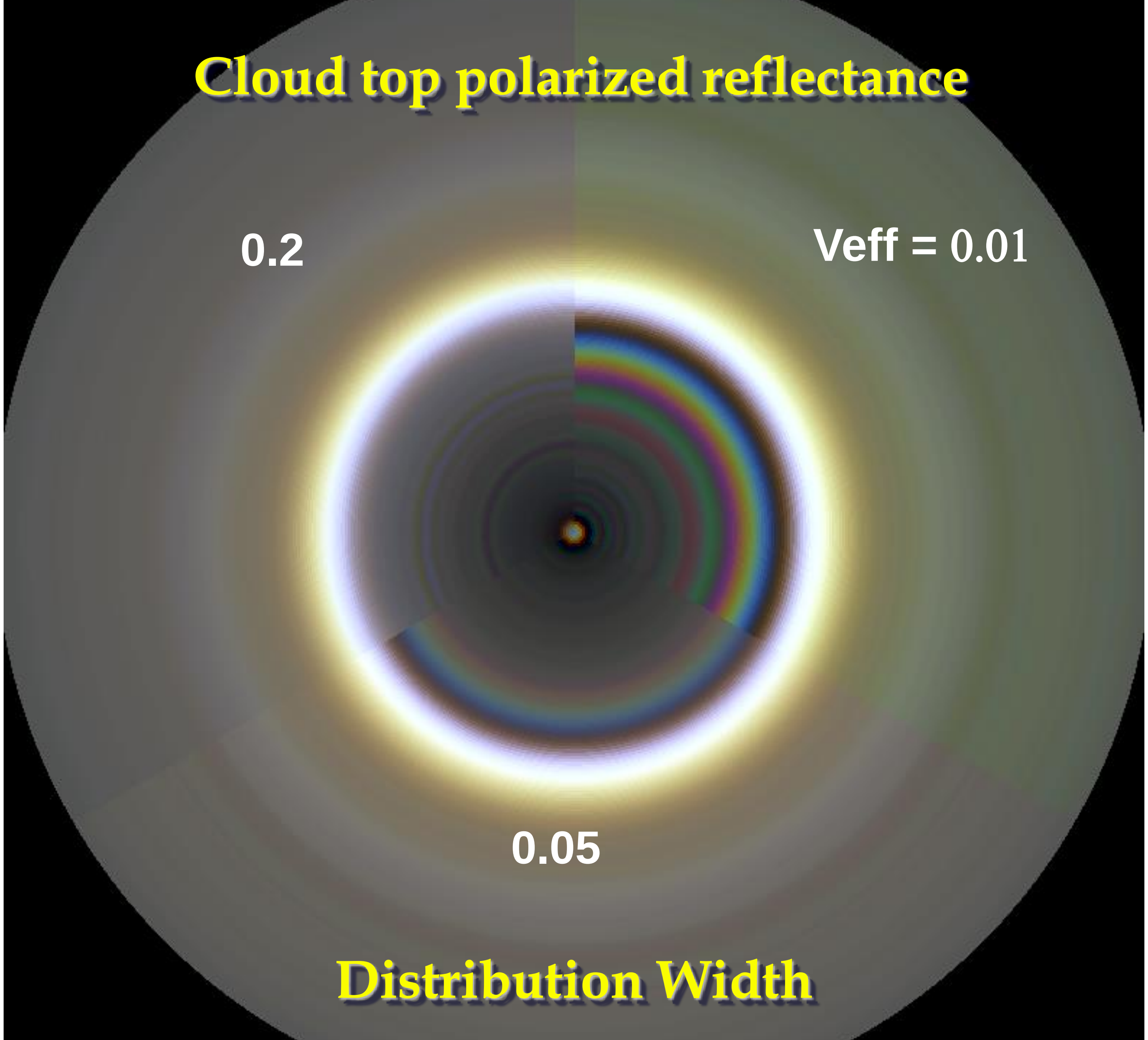


Figure 3. Polarized phase function $Pp(\gamma)$ as a function of scattering angle for cloud droplet size distributions as in eq. (3). In Fig. 3a, we show how $Pp(\gamma)$ varies with the wavelength. Fig. 3b illustrates the variation of $Pp(\gamma)$ with the size distribution variance.




Cloud top polarized reflectance
0.2
Veff = 0.01
0.05
Distribution Width

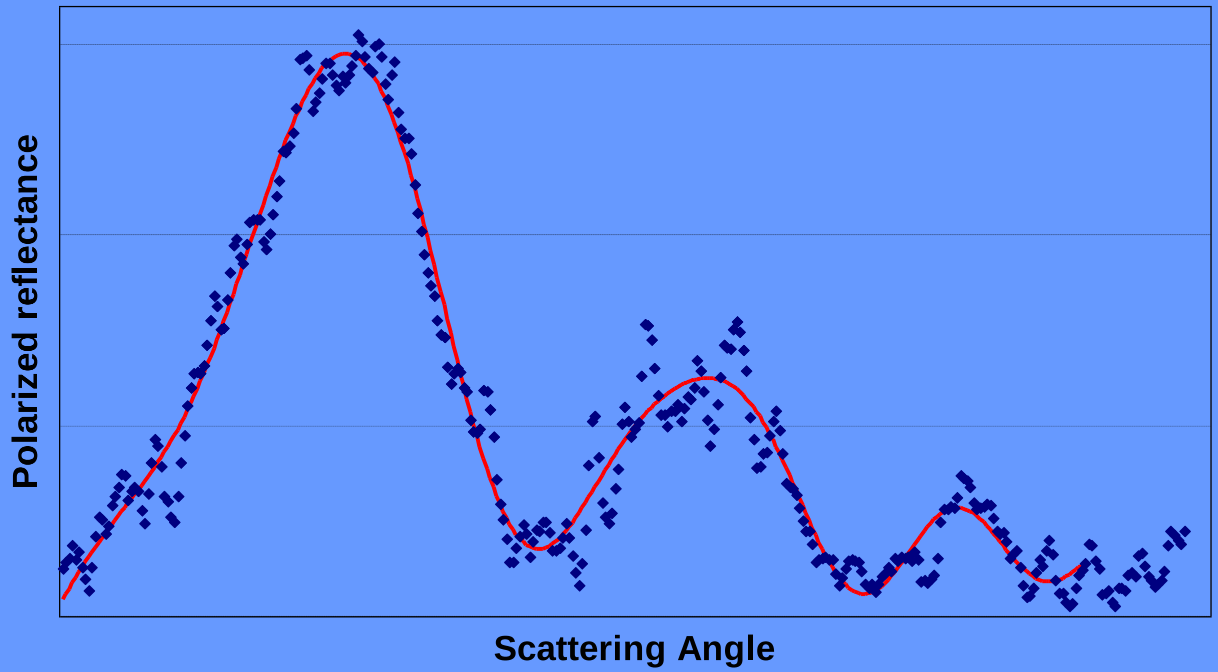
My first Measurement of Cloud Microphysics using the Polarized Cloudbow

Rainbow Camera Prototype Measurement
Commercial Flight Beijing New York - August 14 2005

Cloudbow:

Almost invisible in the regular picture but stands out in the polarized image!!!

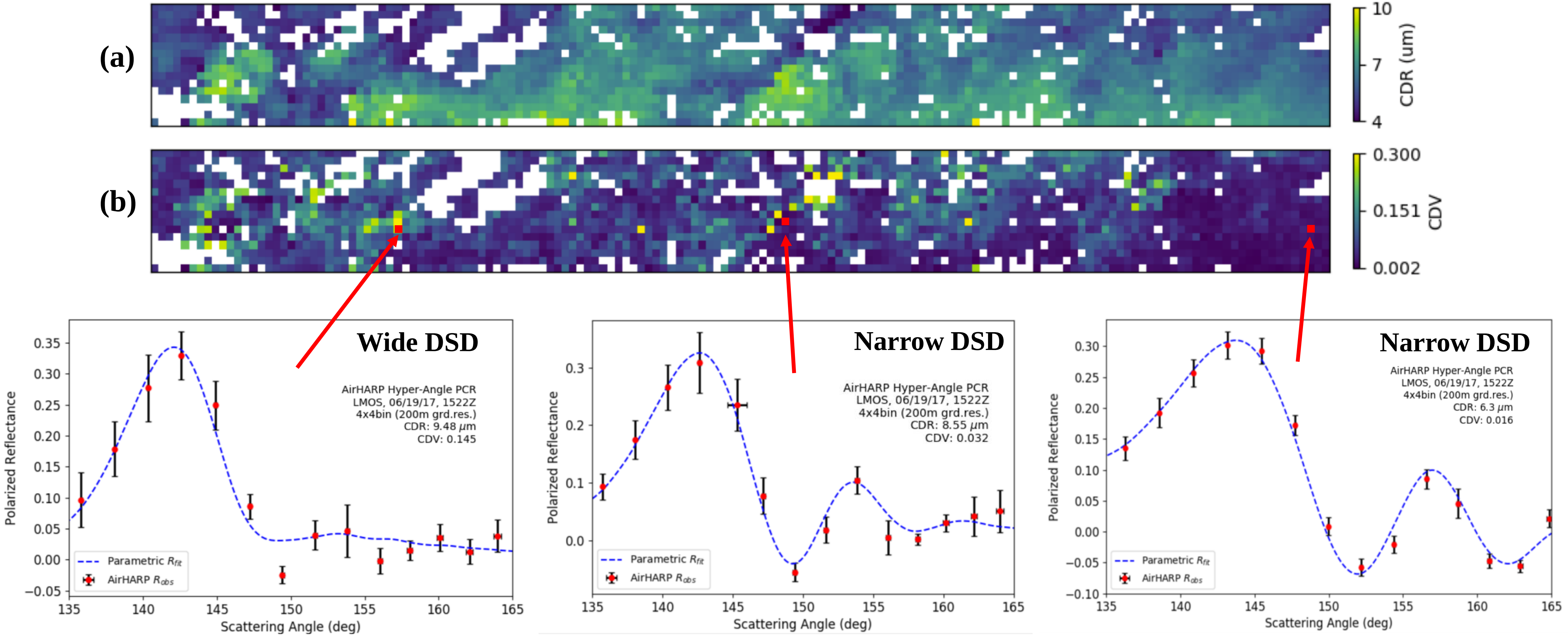
Rainbow Camera Prototype Measurement
Commercial Flight Beijing New York - August 14 2005



Measurements using
a $200 digital camera
and
a $10 polarizer sheet

HARP - Unique Aerosols and Cloud Measurements

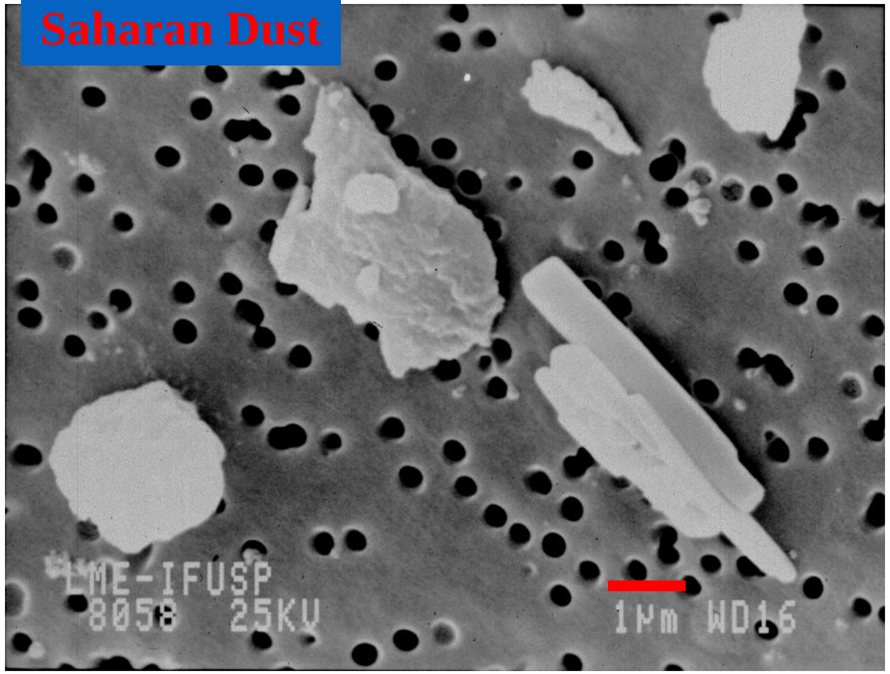
Cloud Droplet Size Retrievals



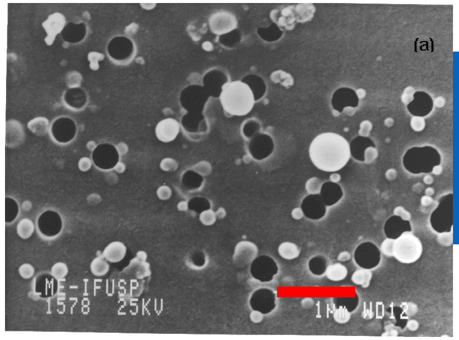
Back to Aerosols

SPSAS on Atmospheric Aerosols

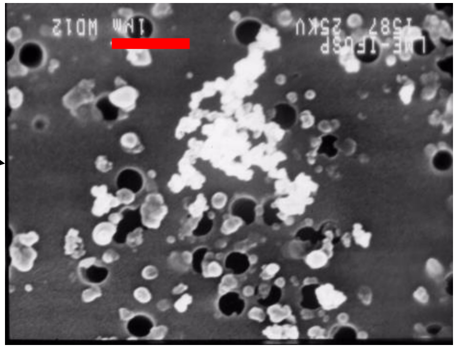
Aerosol Particles



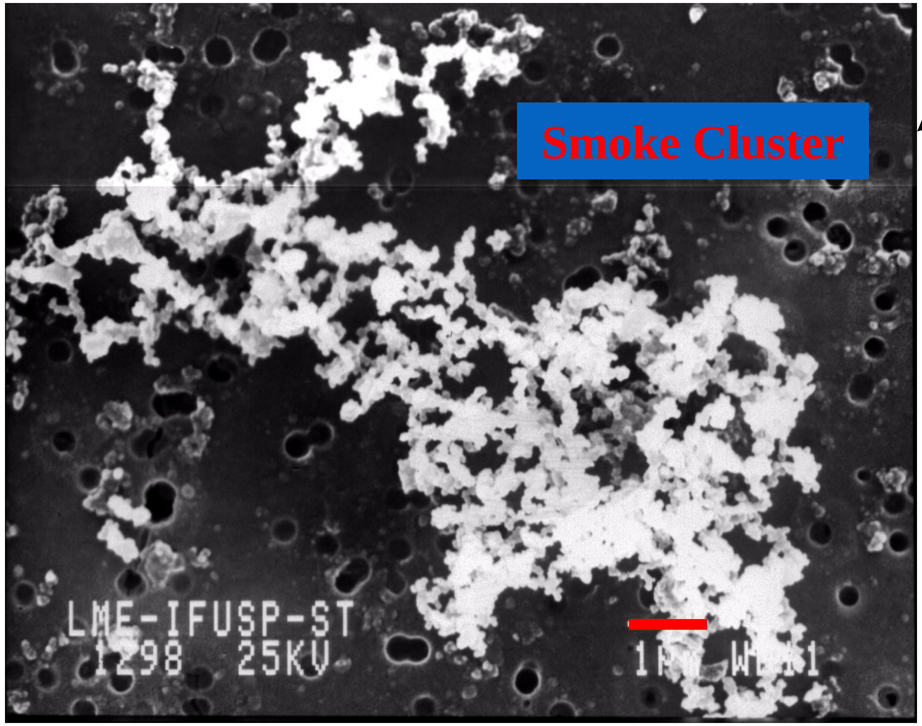
Saharan Dust



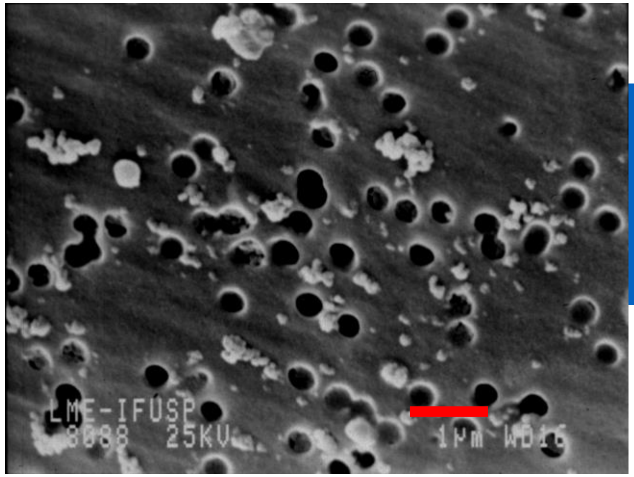
Smoke Smoldering Phase



Smoke Flaming Phase

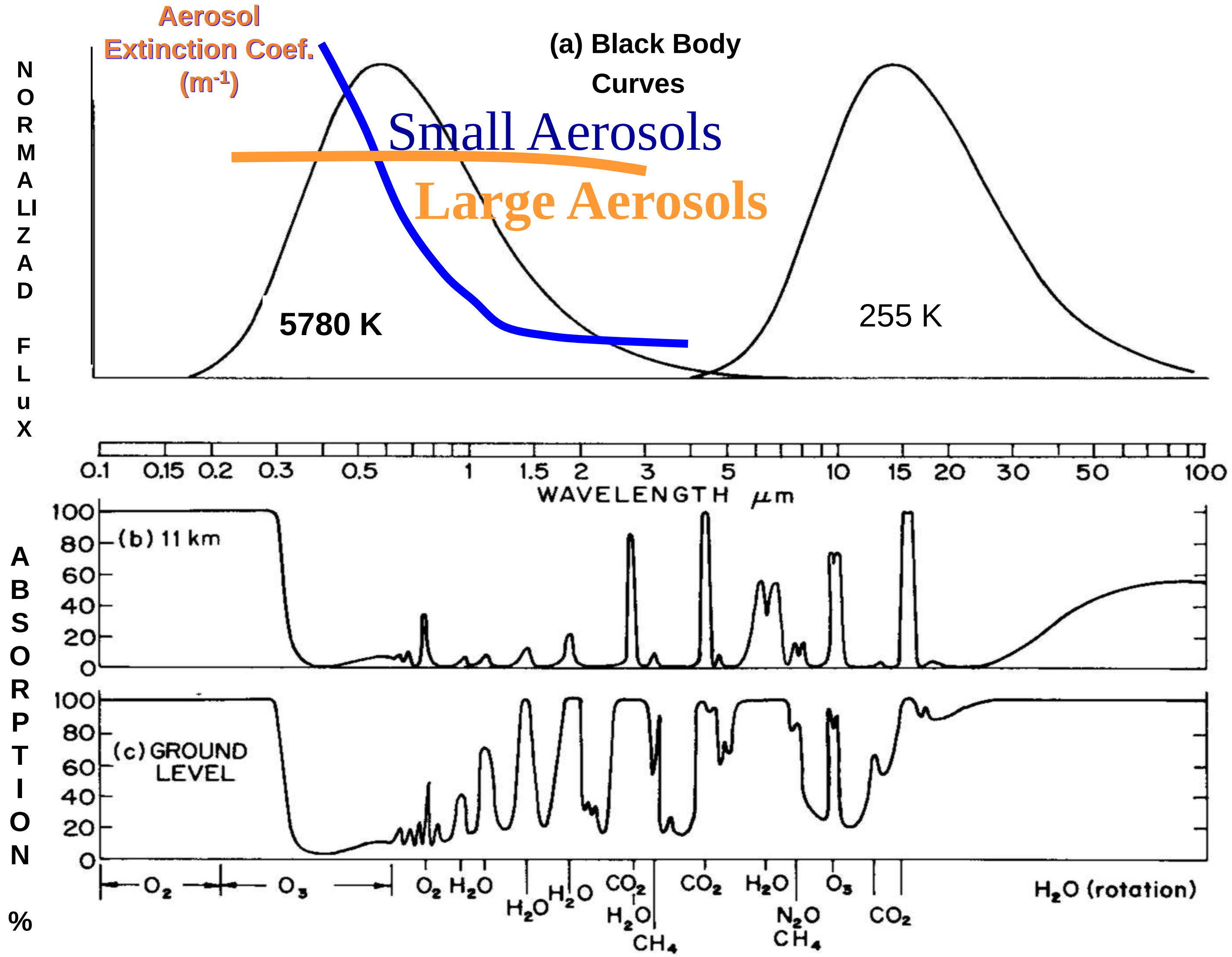


Smoke Cluster



US Urban Pollution

Interactions between Aerosols and Molecules with Radiation:

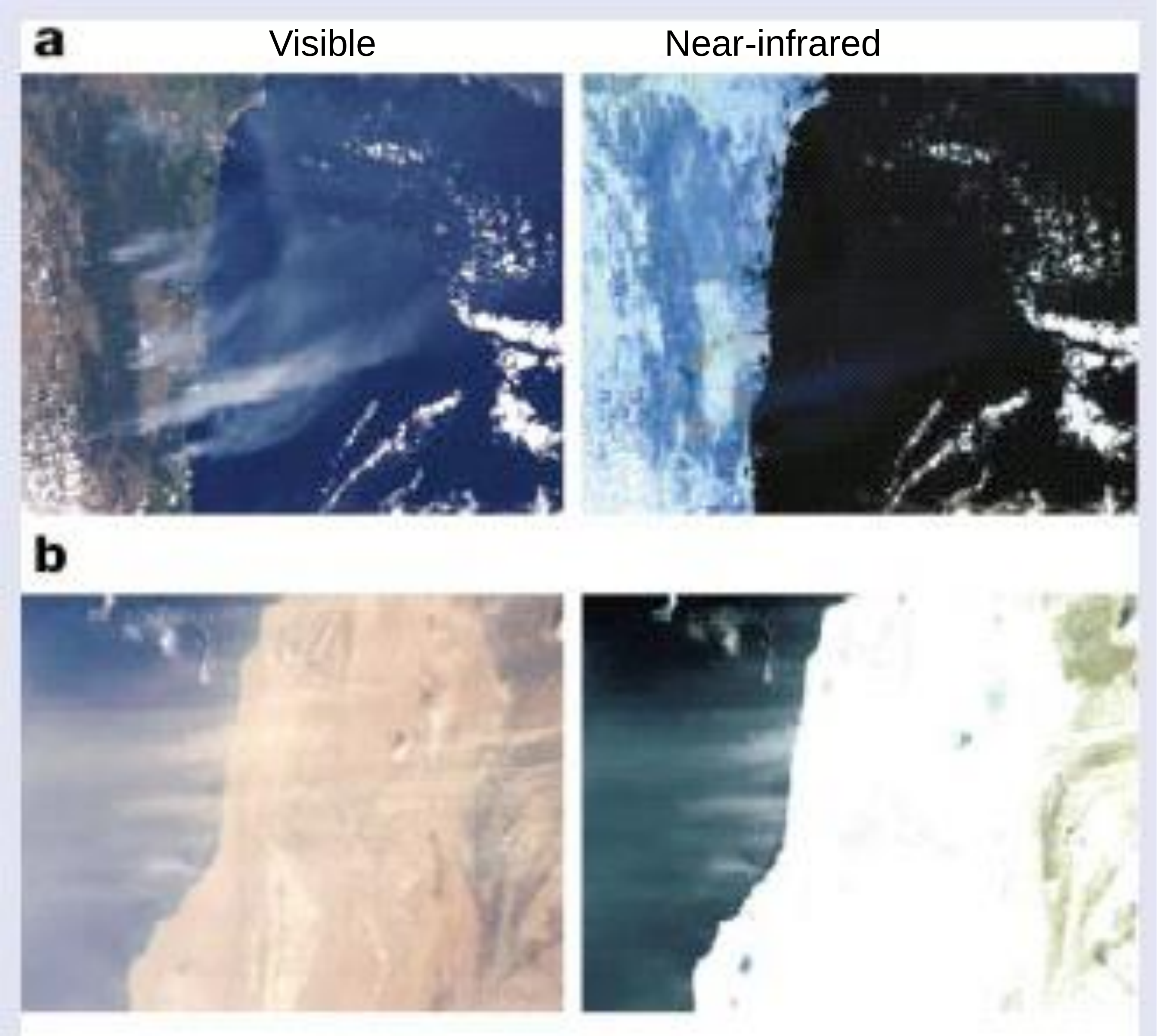


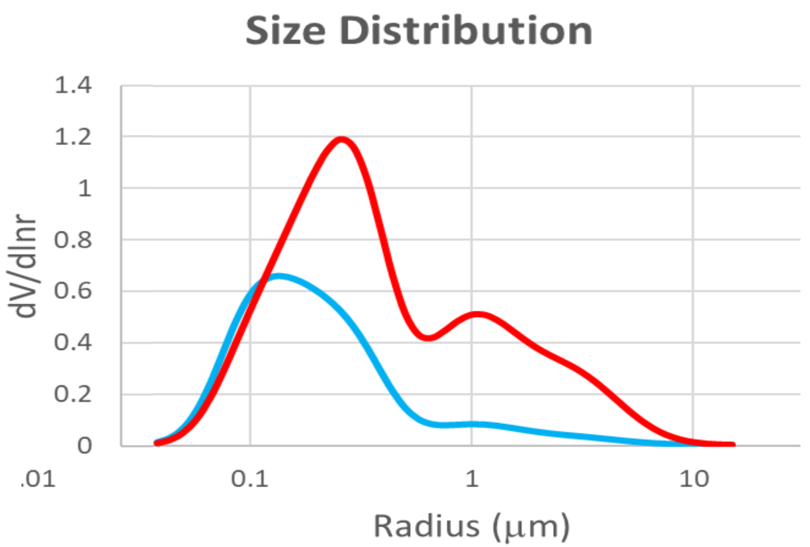
Aerosol size determination from space

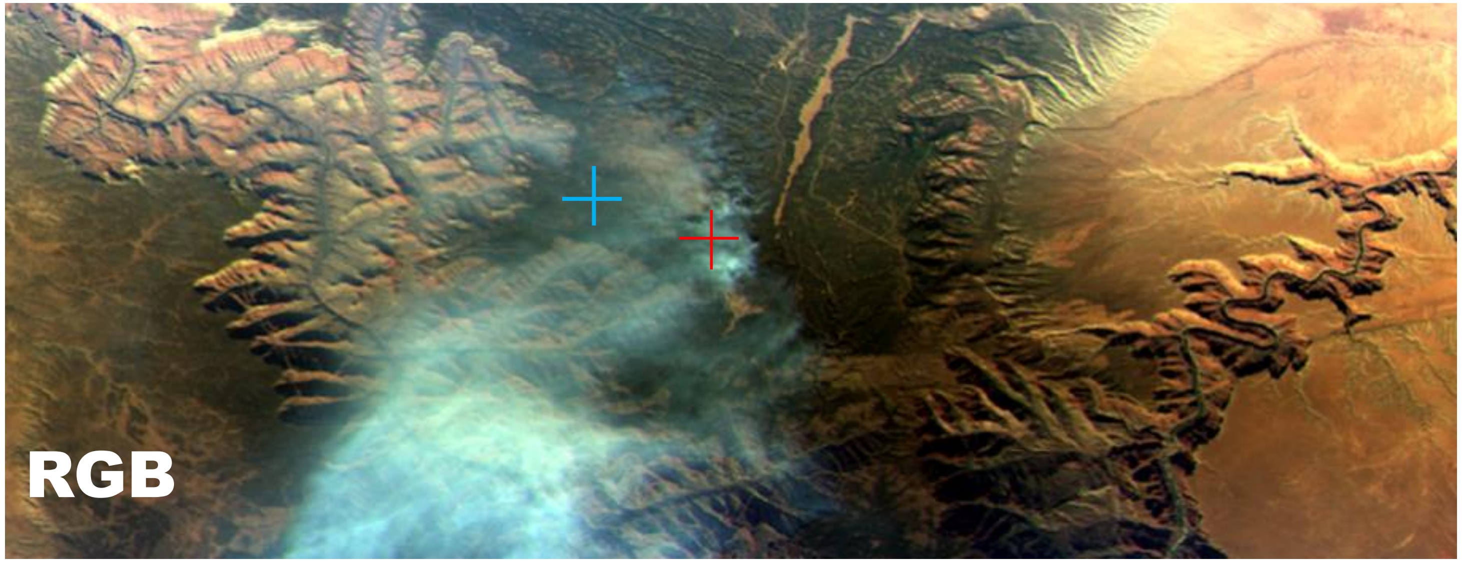
True Color | False Color

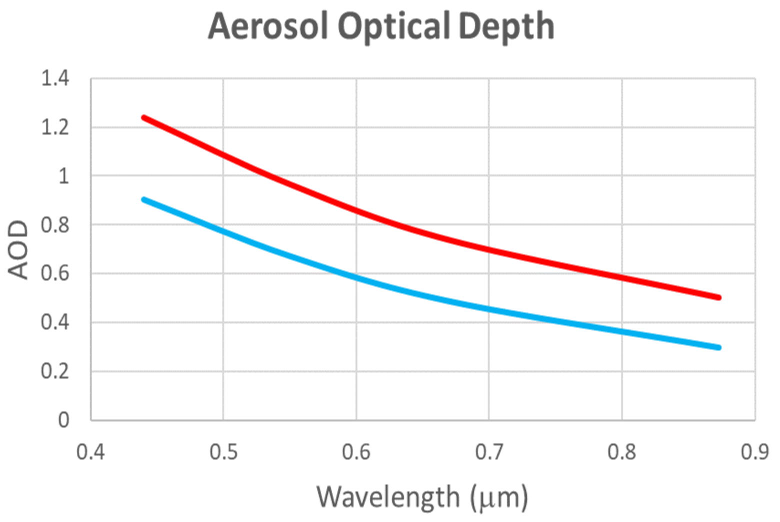
Fine particles from smoke

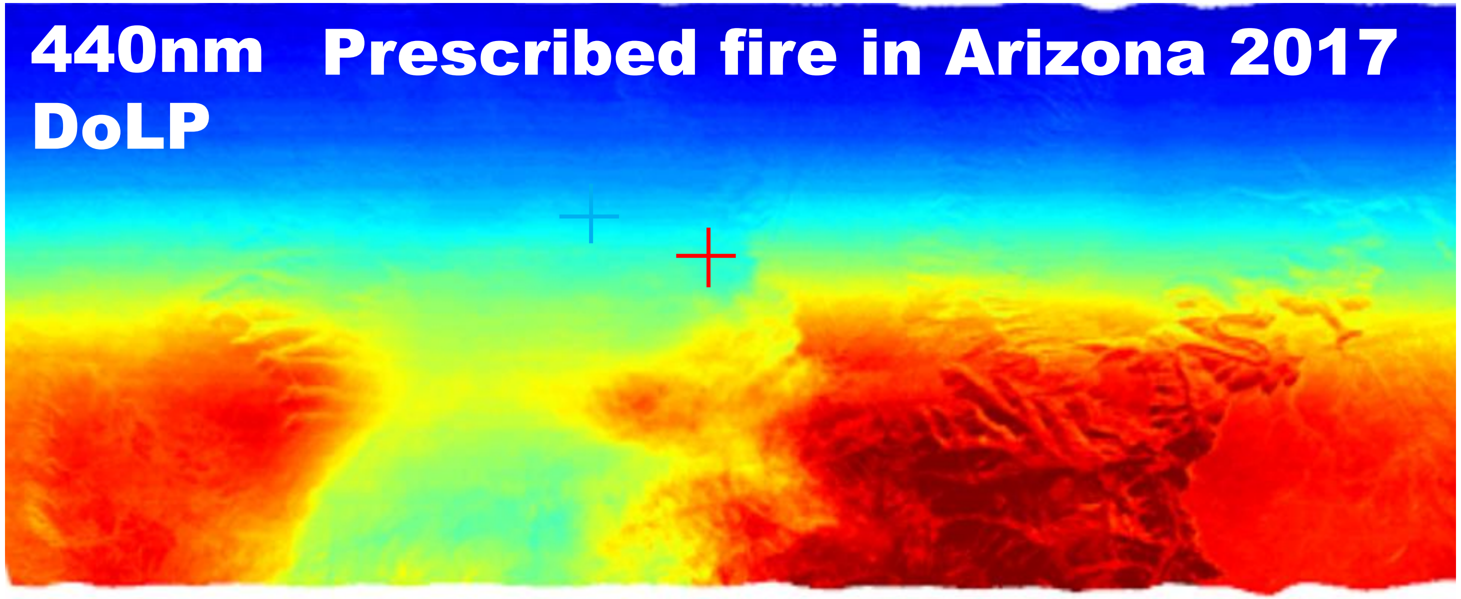
Coarse dust particles











UMBC

AirHARP

HARP – Unique Aerosol and Cloud Measurements

Light Scattering Fundamentals and Measurements

SPSAS on Atmospheric Aerosols

Electromagnetic Waves

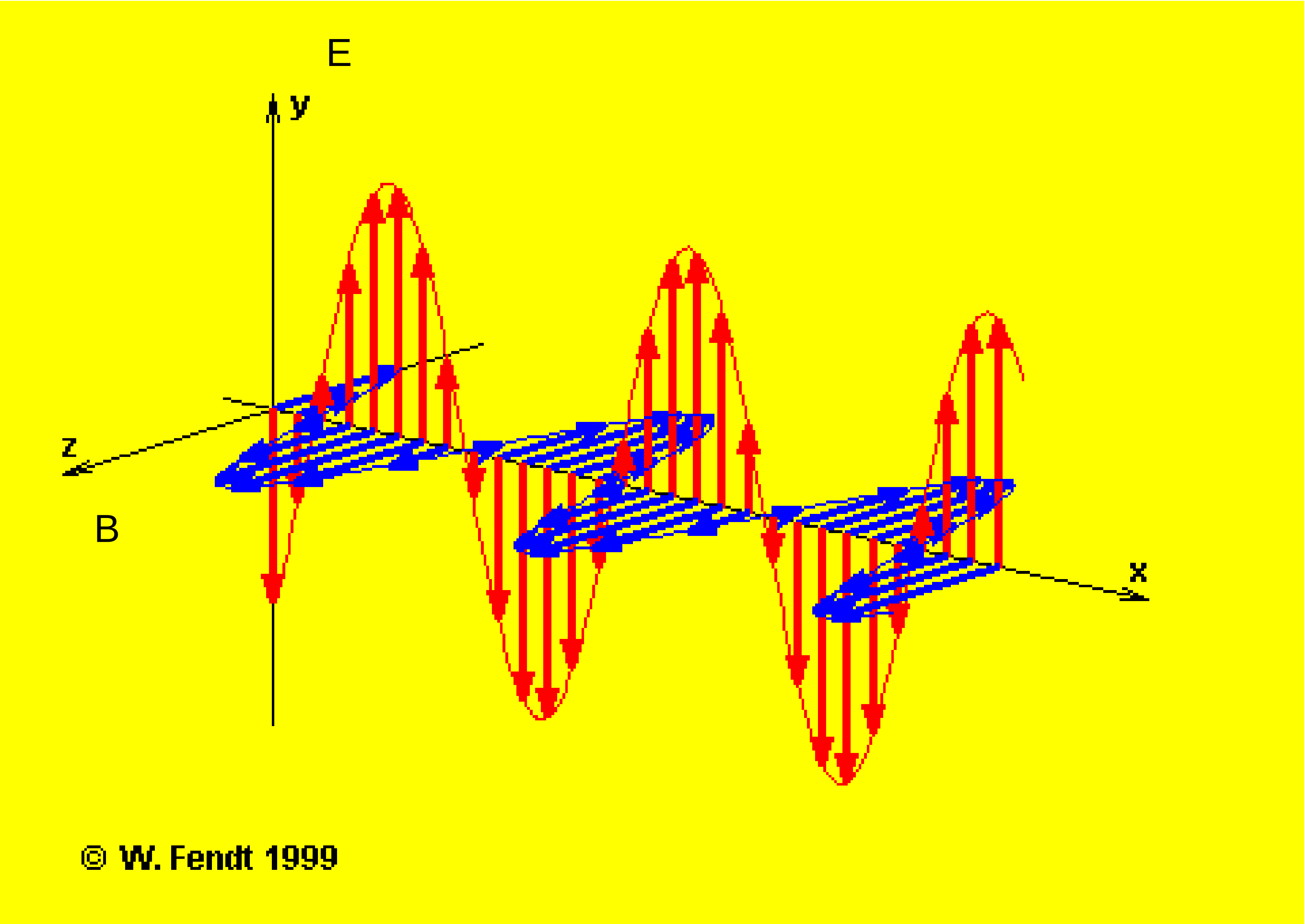
- Transverse wave with 2 components E and B

$$\vec{E} \perp \vec{B}$$

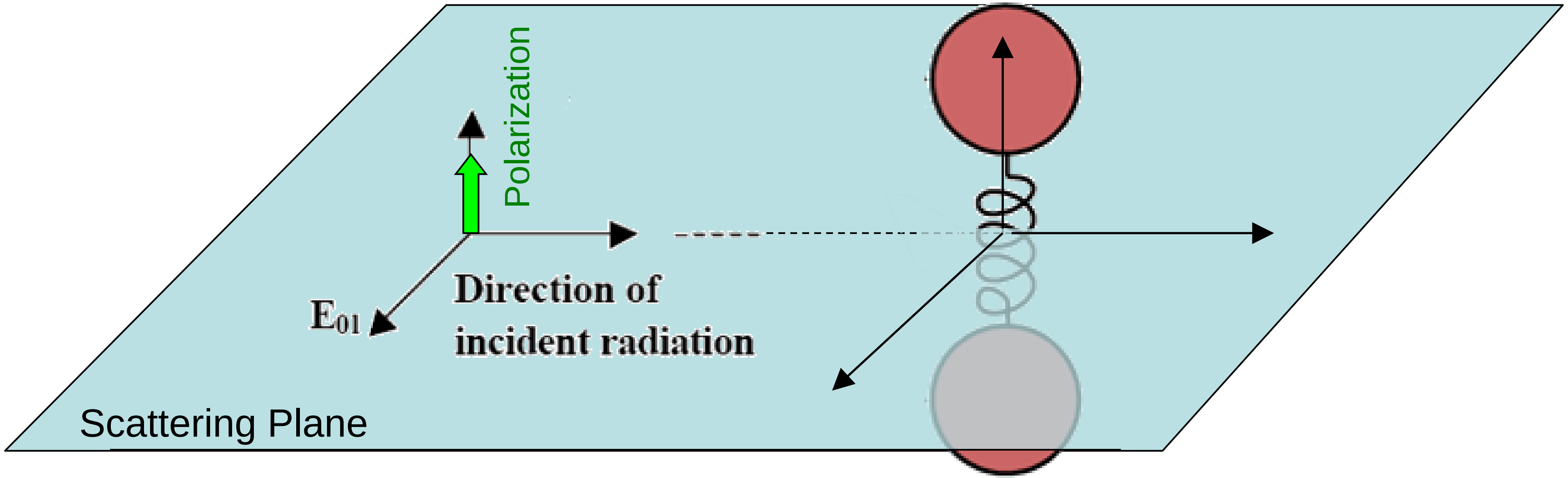
- Does not need material medium to travel

- Propagates with the speed of light in vacuum

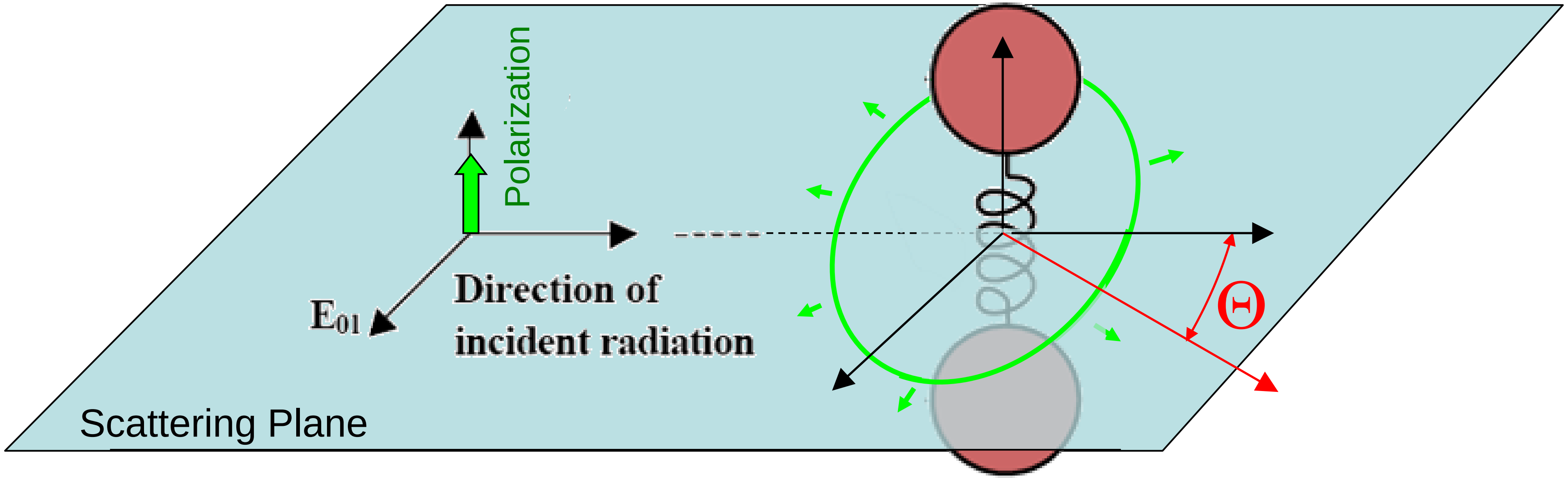
$$\vec{E} \perp \vec{B}$$



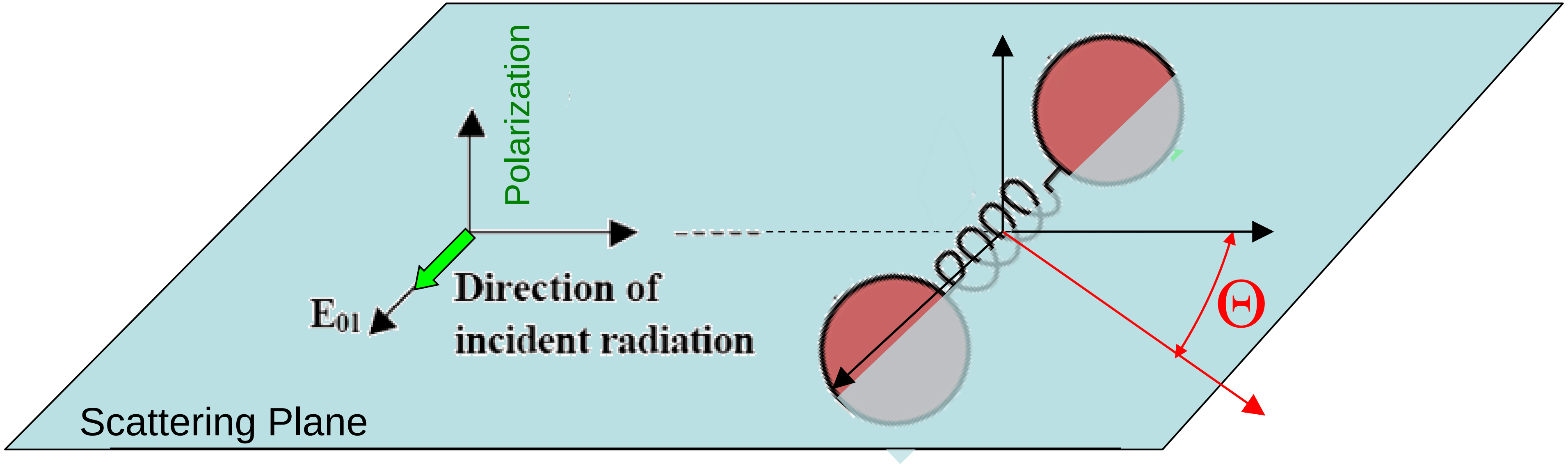
Dipole (Molecular) Scattering



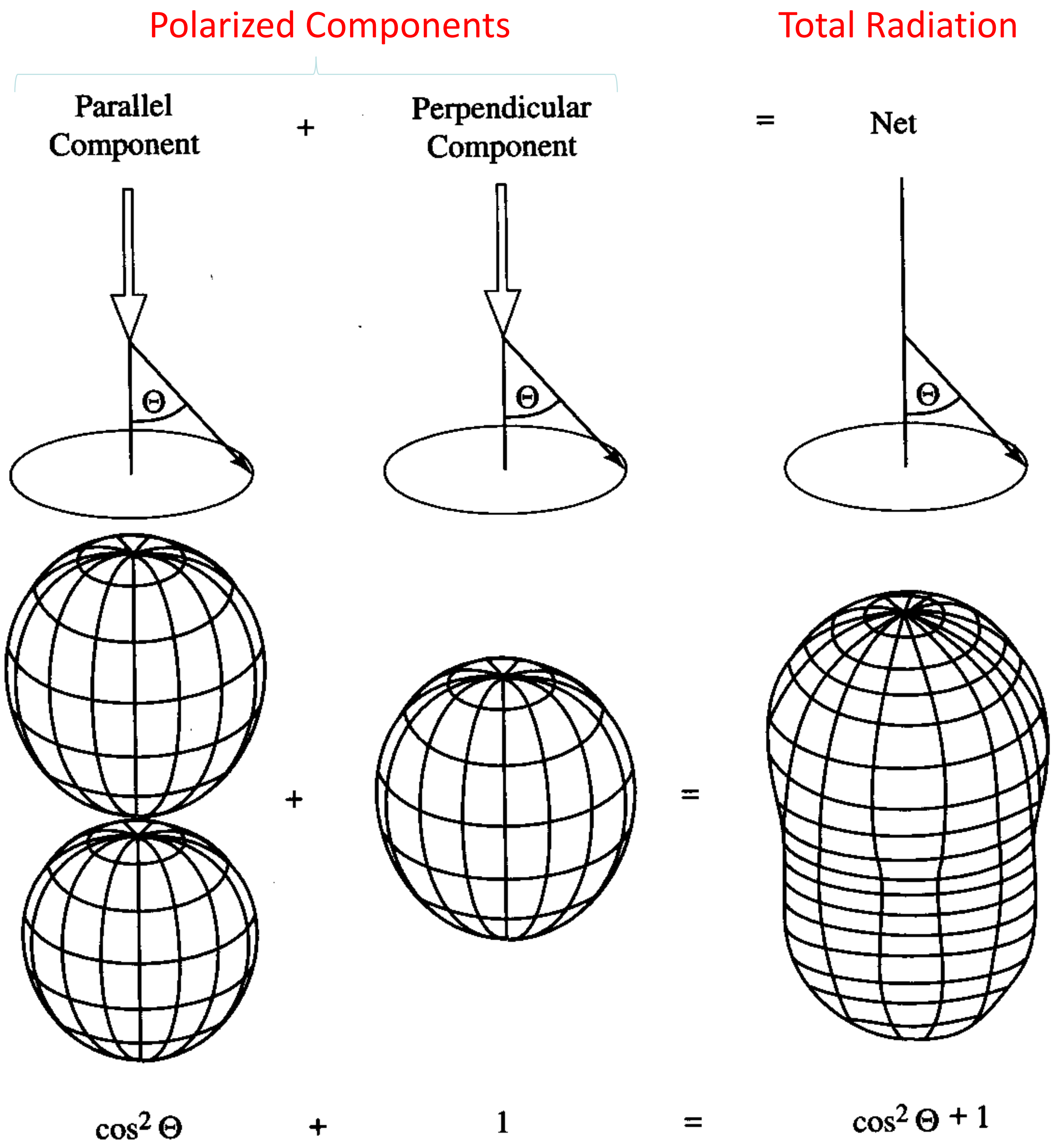
Polarization Perpendicular to Scattering Plane

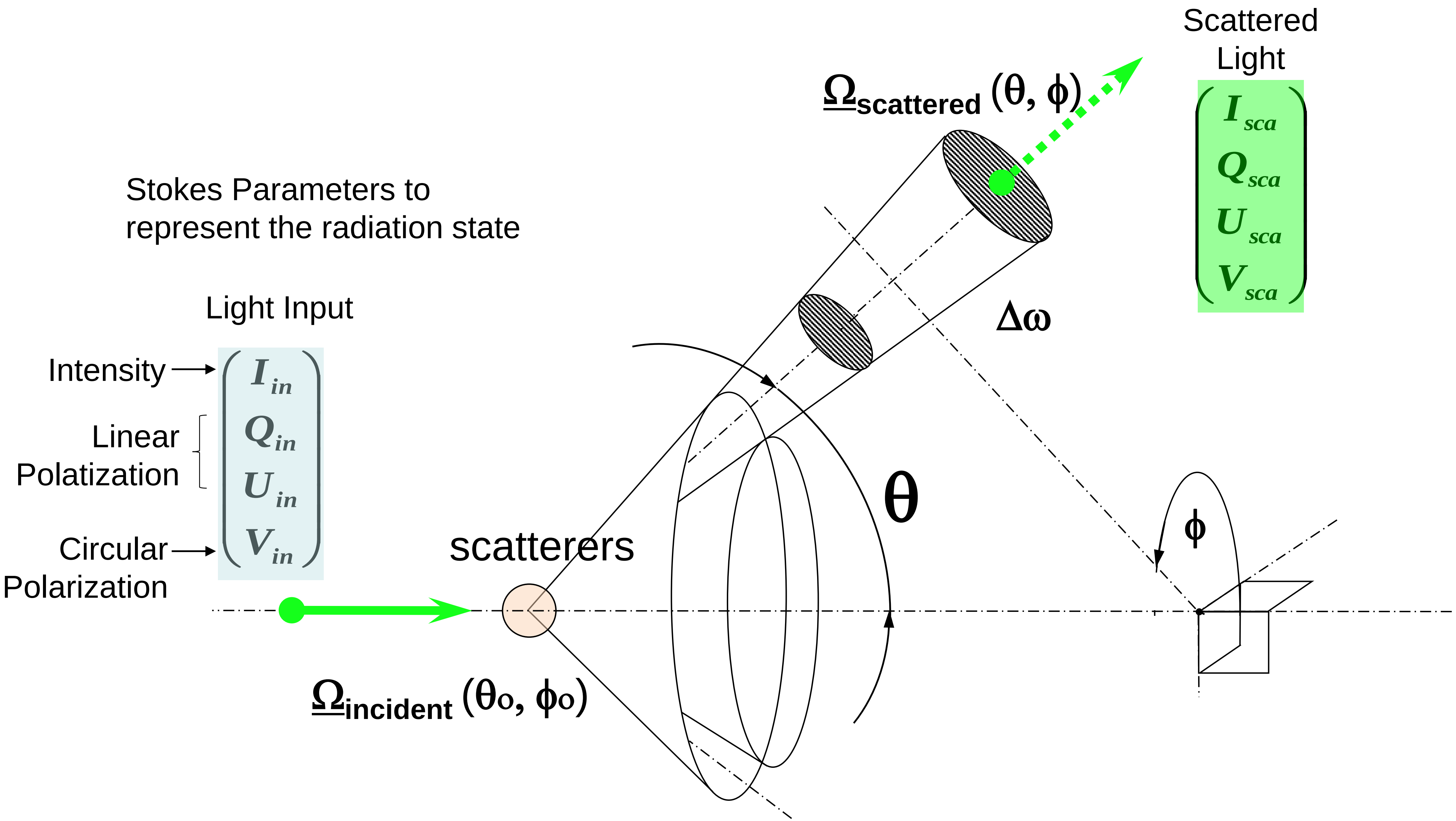


Polarization Parallel to Scattering Plane



Phase Function diagram for Rayleigh scattering




Stokes Parameters to represent the radiation state
Light Input
Intensity
Linear Polatization
Circular Polarization
I_{in}
Q_{in}
U_{in}
V_{in}
scatterers
$\underline{\Omega}_{\mathbf{incident}}$ (θ_o, ϕ_o)
$\underline{\Omega}_{\mathbf{scattered}}$ (θ, ϕ)
Scattered Light
I_{sca}
Q_{sca}
U_{sca}
V_{sca}
$\Delta\omega$
θ
ϕ

Information from Polarization

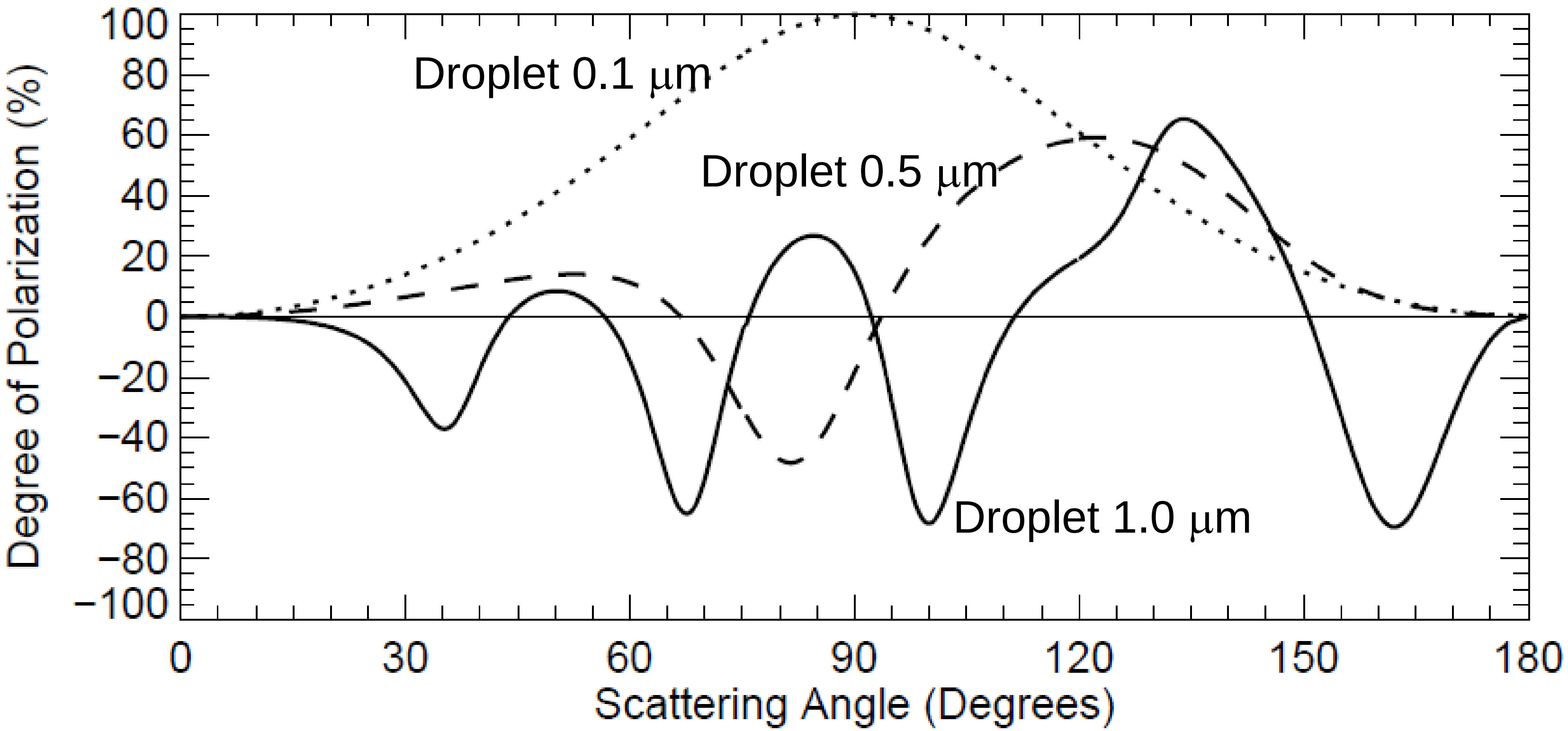
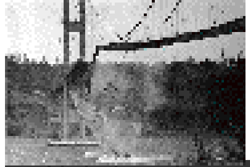


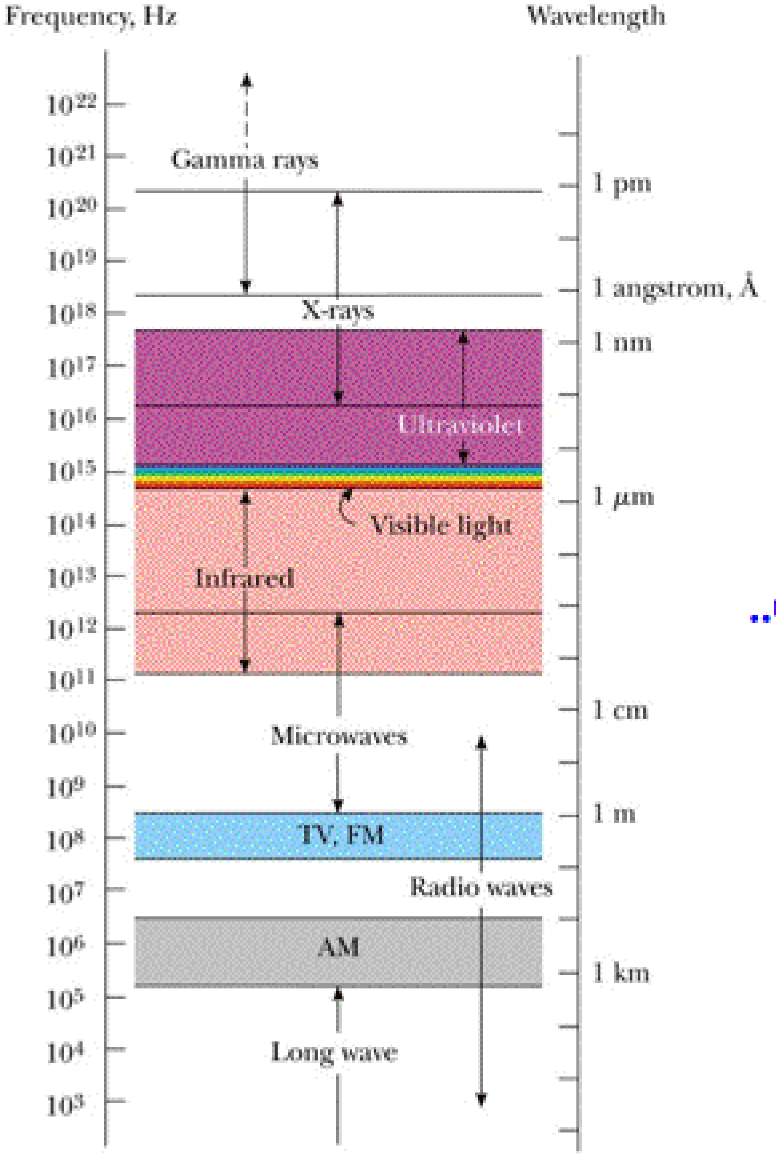
Figure 7.12: Degree of polarization of light scattered by water droplets of different size. The dotted curve is for a droplet of diameter 0.1 μm, the dashed curve for 0.5 μm, the solid curve for 1.0 μm; $\lambda = 0.55$ μm and $n = 1.33$. The incident light is unpolarized.



Electromagnetic Spectrum

Of course
(in a vacuum)

$$c = f\,\lambda$$

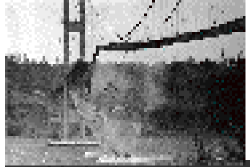


[S+F Fig 21.22]

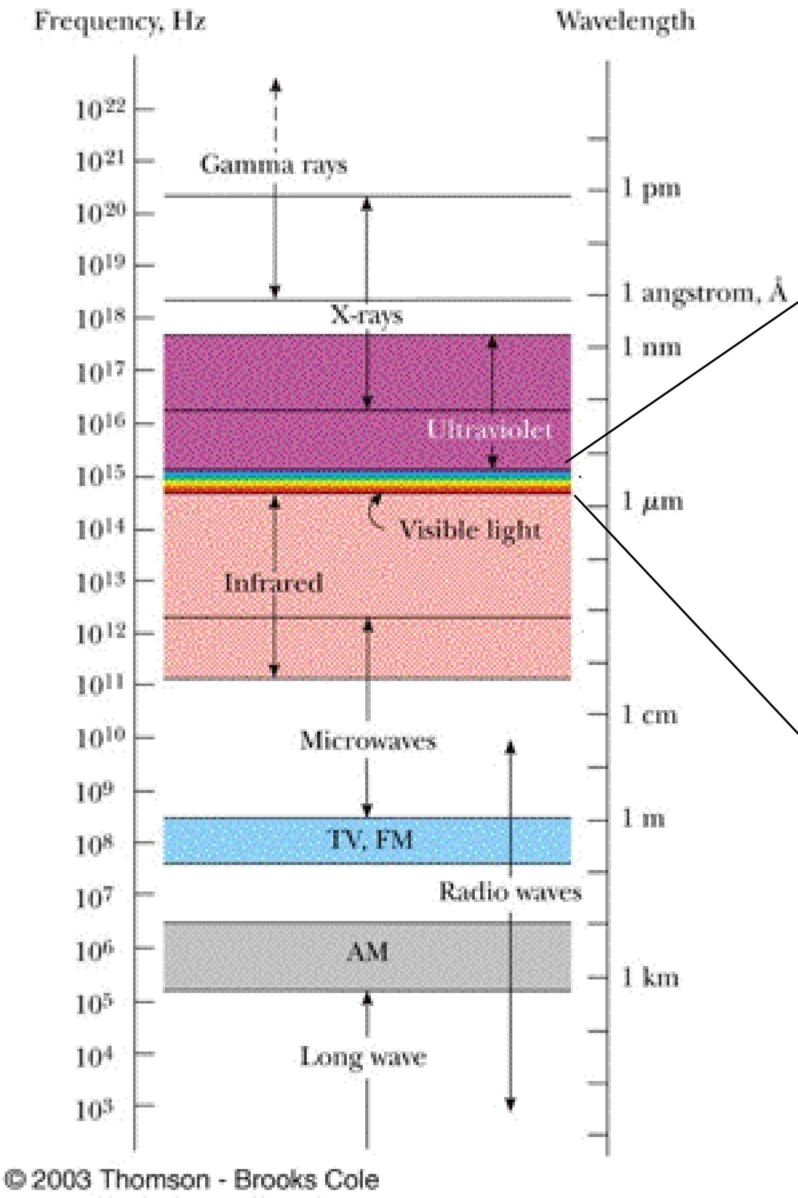
Check out
Text…

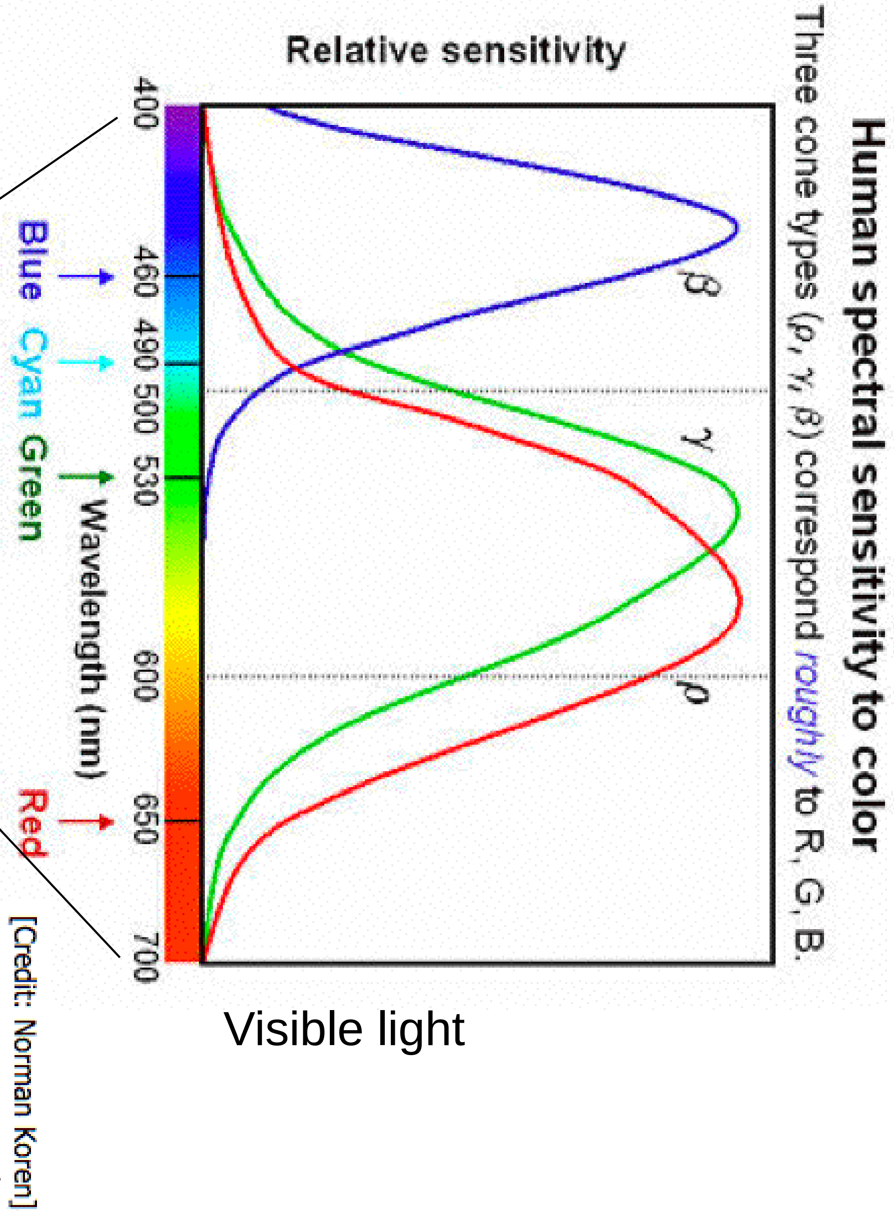
..also recall
The Doppler Effect

$$f' = f\left(1 \pm \frac{u}{c}\right)$$

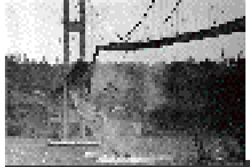


Electromagnetic Spectrum

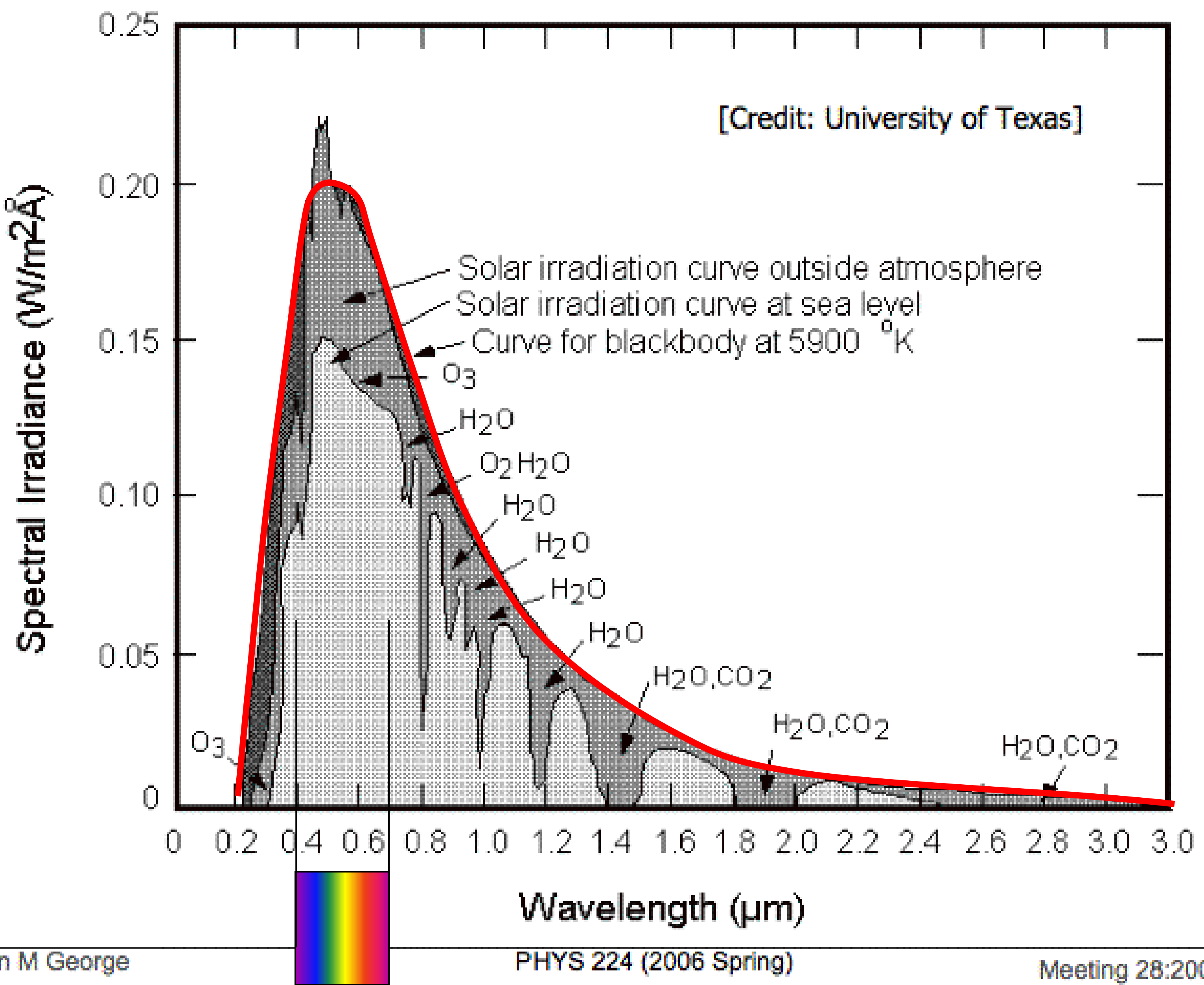




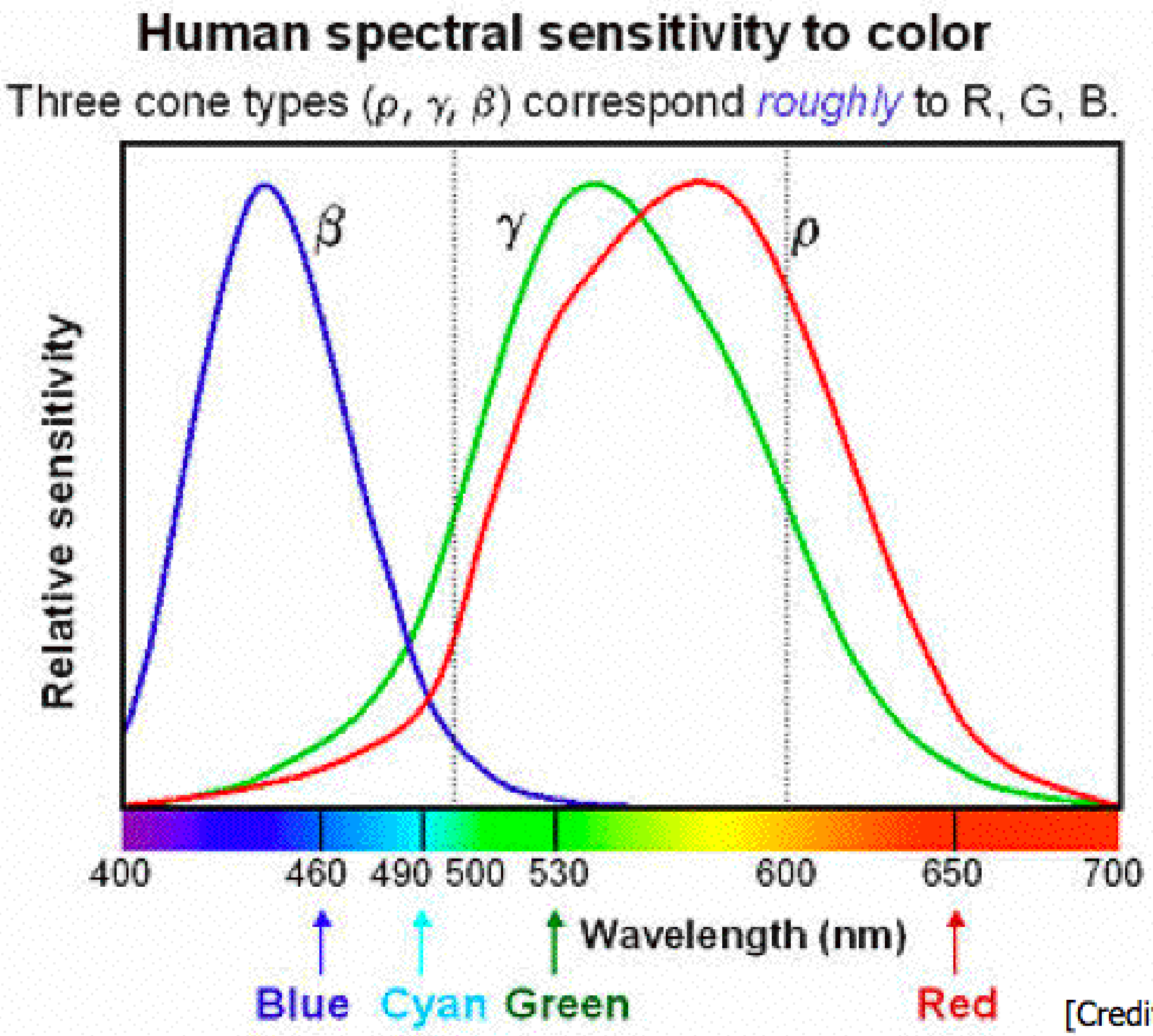
Visible light



The Solar Spectrum

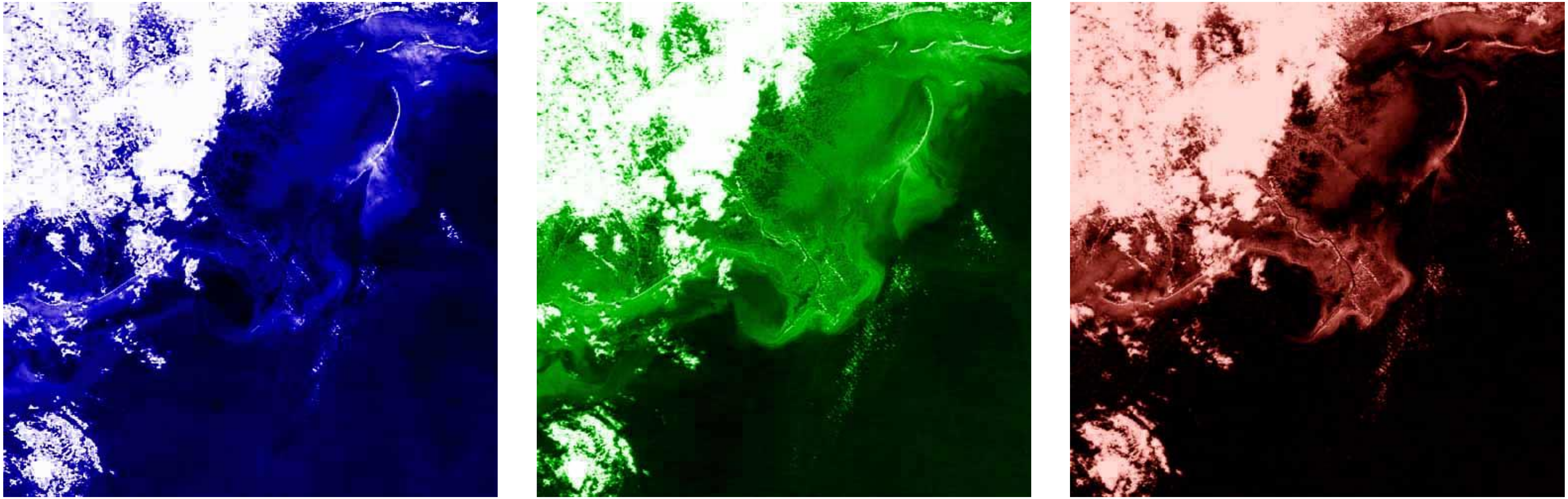


Sensitivity of Human Eye



[Credit: Norman Koren]

Color Image Reconstruction



- The radiances are measured at different wavebands, called “channels”.
- Different channels provides information on different properties of the Earth’ surface.
- One method of analysis is when the images observed at different wavebands can be combined to result in a “true color image”.

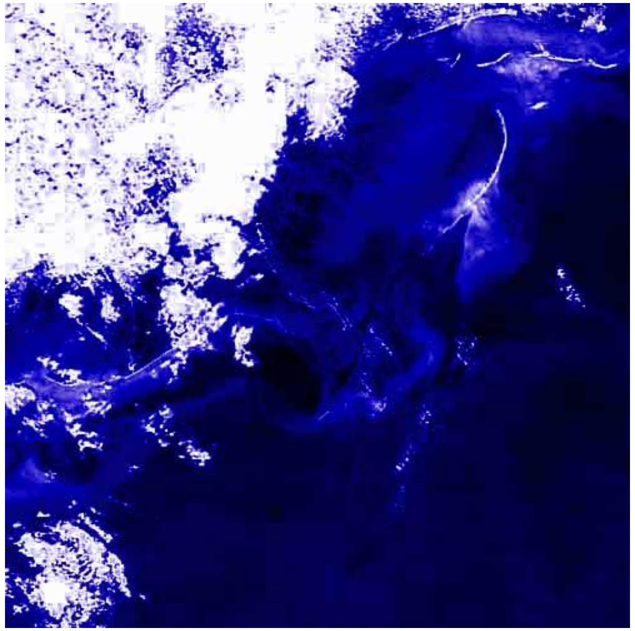
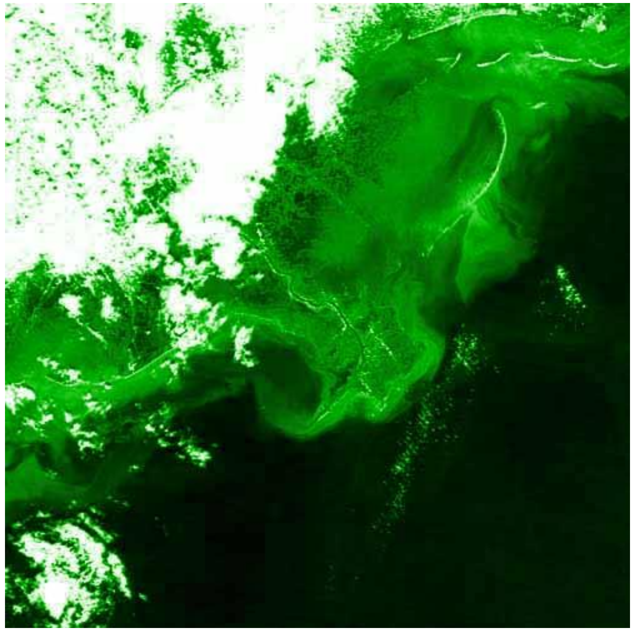
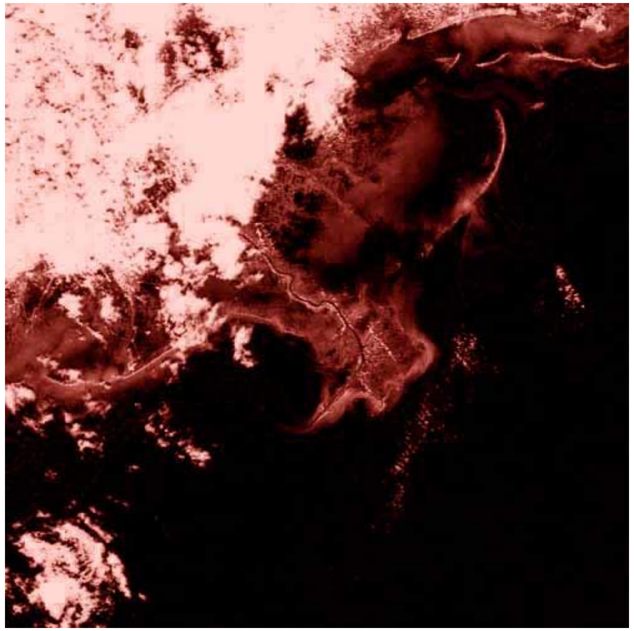
  

Image processing
RGB Image

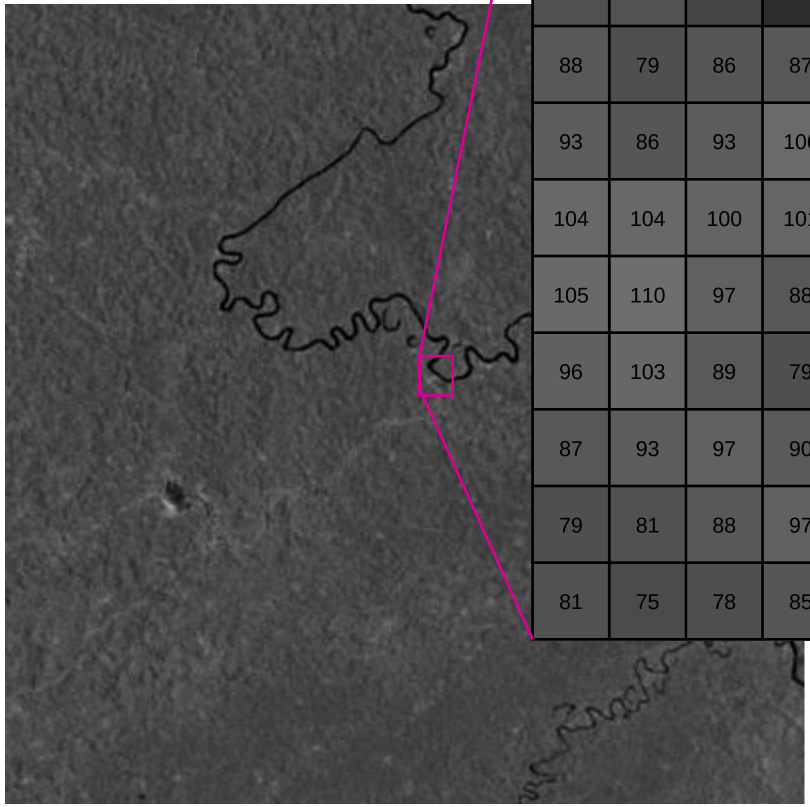
Image processing

At this MODIS image of the Mississippi River delta you can see clouds, coastline, river, the zones of phytoplankton bloom and pollution in the coastal ocean, etc.

Image processing

True color images are an important source of information about natural disasters like these wildfires in California in autumn 2003.

What is a digital image?



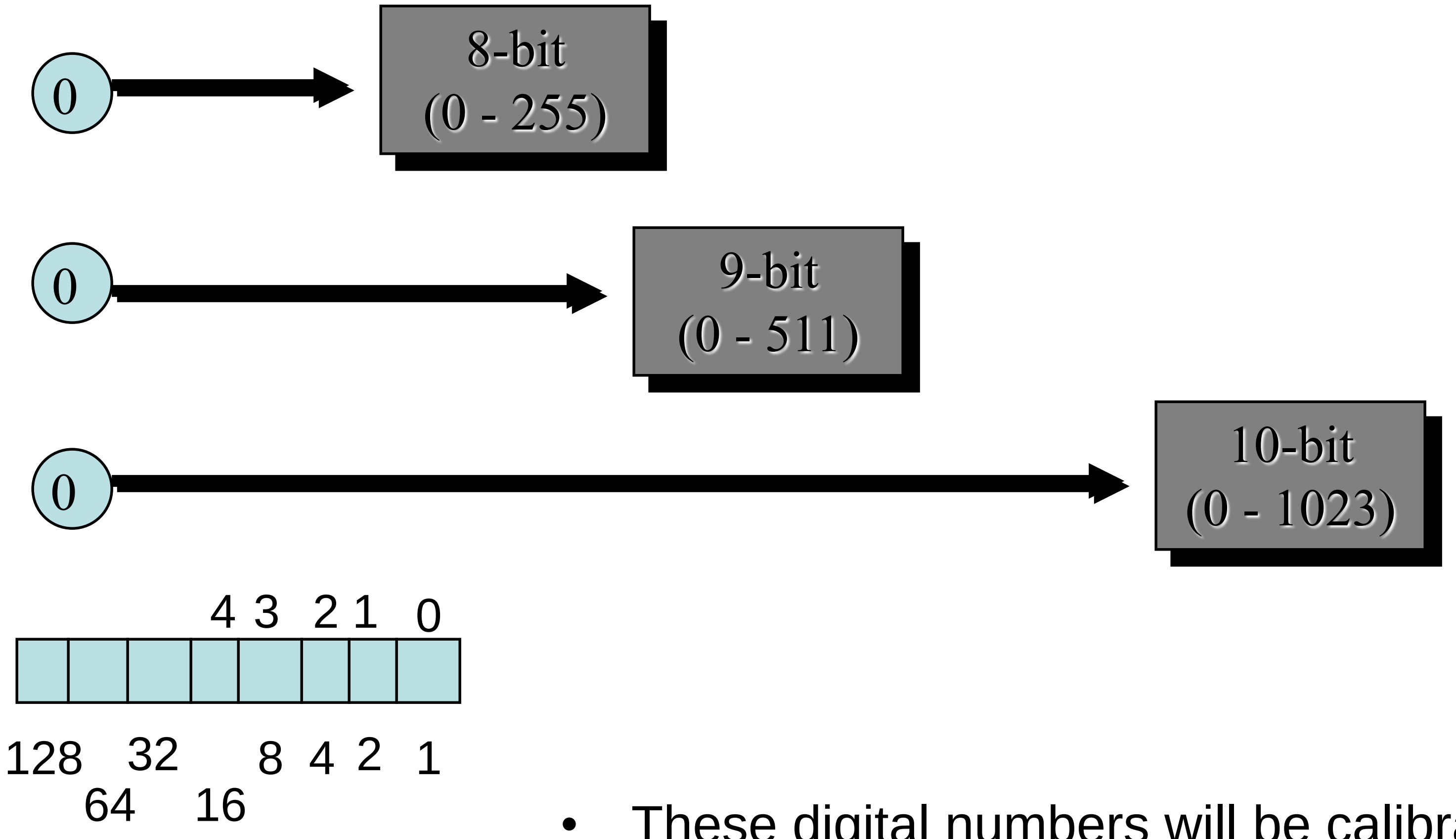
70	53	41	64	84	85	81	88	91	87
79	77	45	38	59	77	84	86	85	85
80	82	69	44	32	45	72	86	82	78
88	79	86	87	65	40	41	75	79	78
93	86	93	106	106	84	56	43	58	75
104	104	100	101	95	91	83	51	39	56
105	110	97	88	84	85	87	77	59	44
96	103	89	79	79	75	77	79	74	72
87	93	97	90	82	76	70	67	61	71
79	81	88	97	93	85	78	74	70	72
81	75	78	85	94	97	92	84	80	72

Digital Number (DN)

What your computer sees…

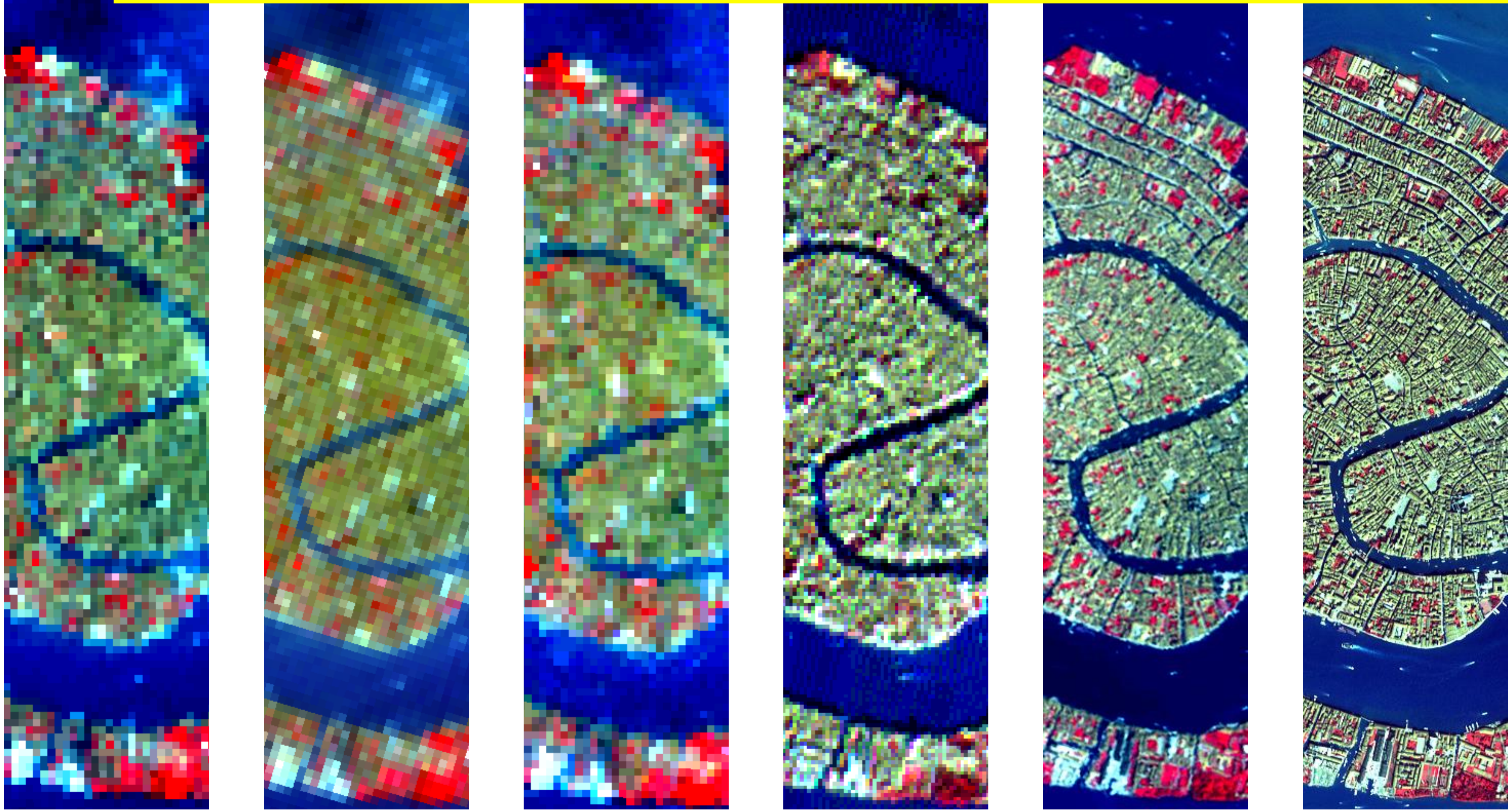
Radiometric Resolution

- The sensitivity of remote sensing detectors to differences in signal strength as it records the radiant flux.



- These digital numbers will be calibrated to absolute fluxes [W m^{-2} μm^{-1}] or radiances [W m^{-2} sr^{-1} μm^{-1}]

Examples of imaging capabilities

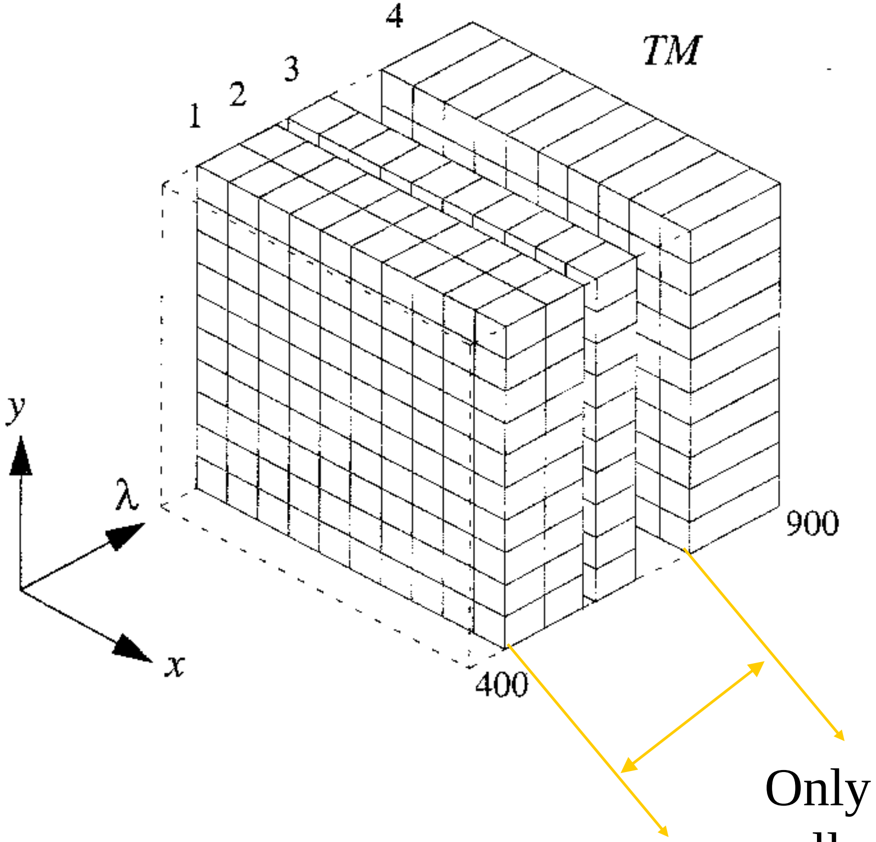


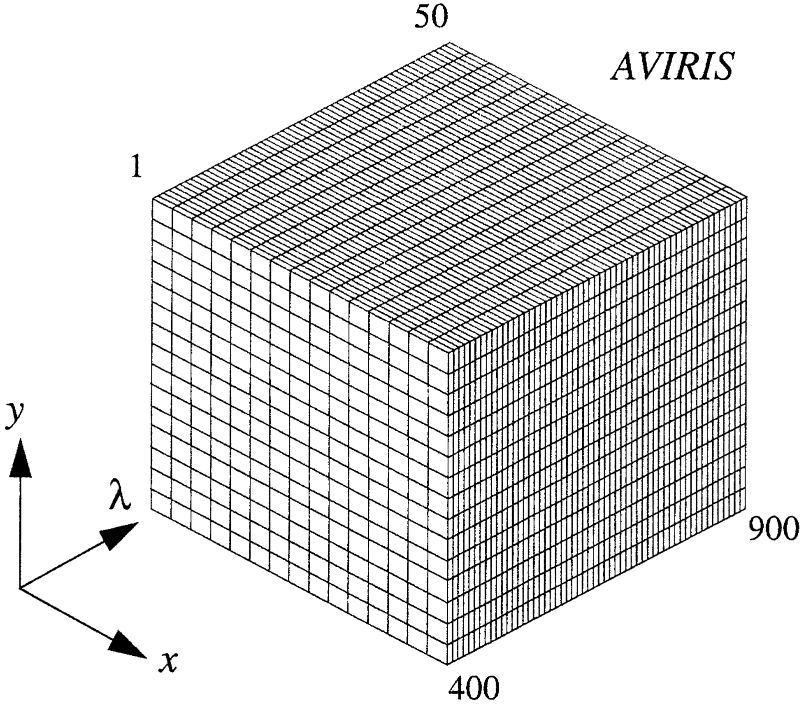
ALI	Hyperion	TM	ASTER	MIVIS	IKONOS
30m	30m	30m	15m VNIR, 30m SWIR	8m	4m
9 bands	242 bands	6 bands	9 bands	102 bands	4 bands

Michael Abrams, Jet Propulsion Laboratory

Consiglio Nazionale delle Ricerche

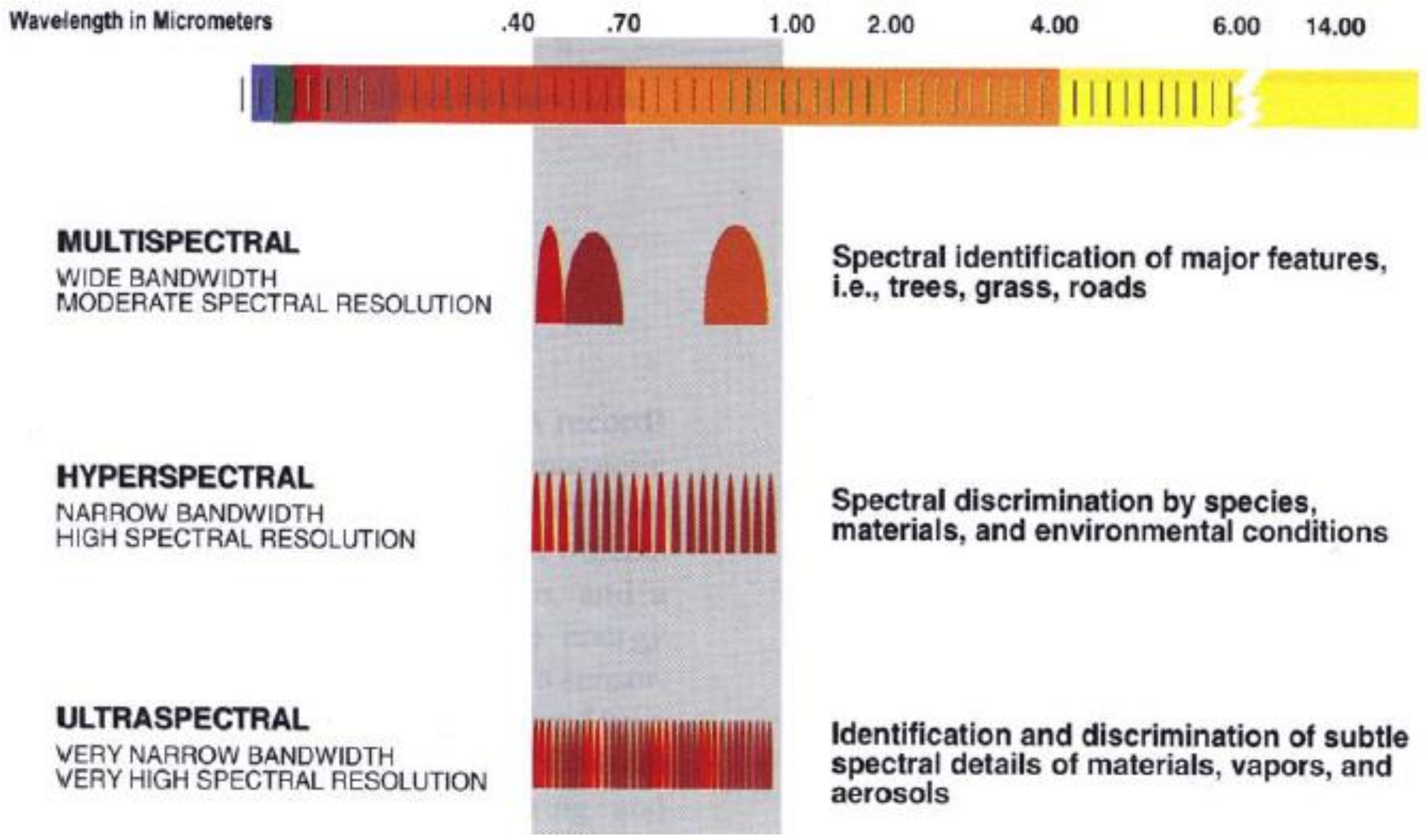
Spectral Resolution

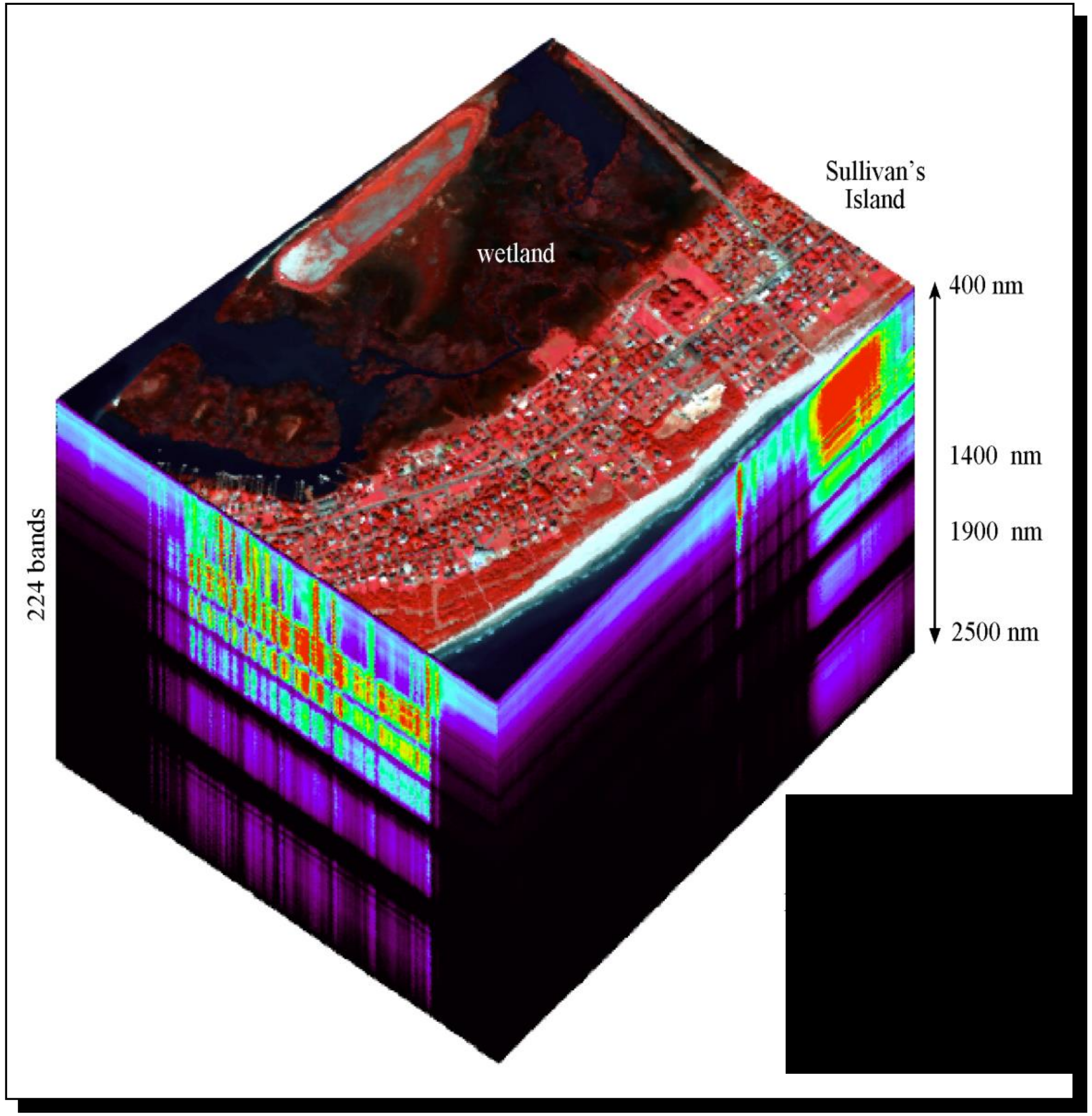




Only one band covering BGR visible range called panchromatic

Classes of Spectral Imagers





Airborne Visible Infrared Imaging Spectrometer (AVIRIS) Datacube of Sullivan's Island Obtained on October 26, 1998

$1m = 10^{6}\ \mu m = 10^{10} nm$

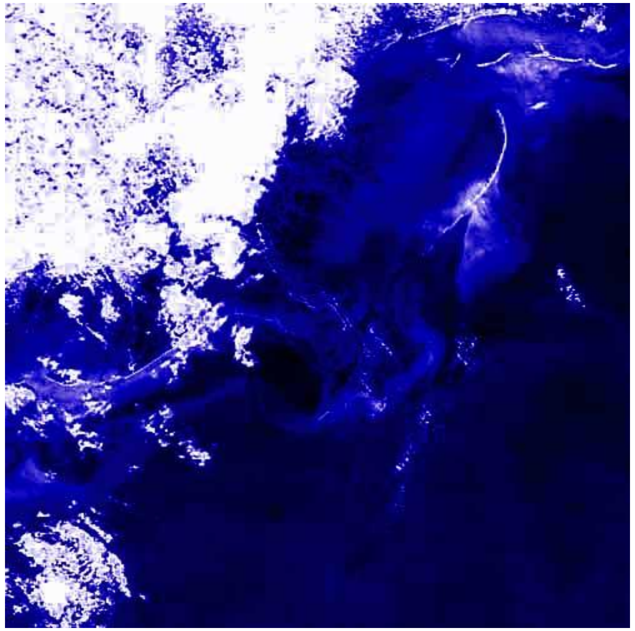
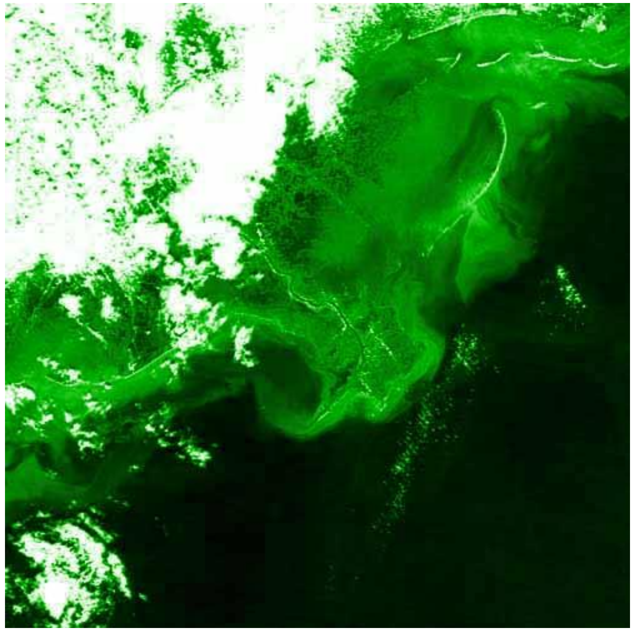
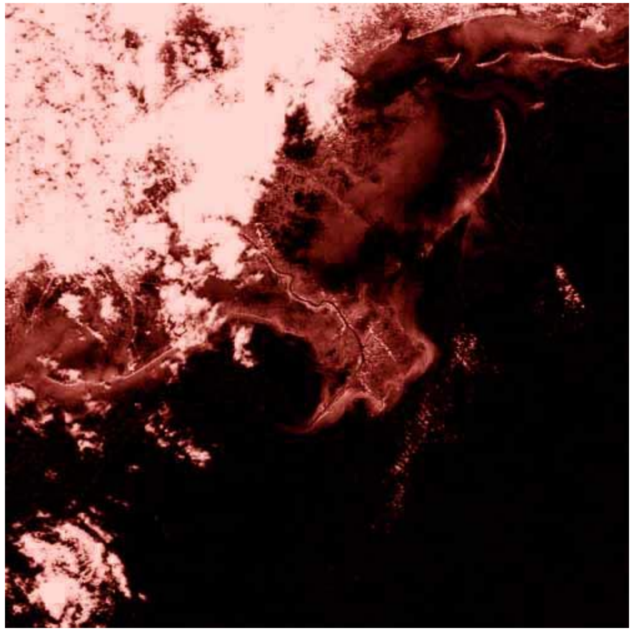
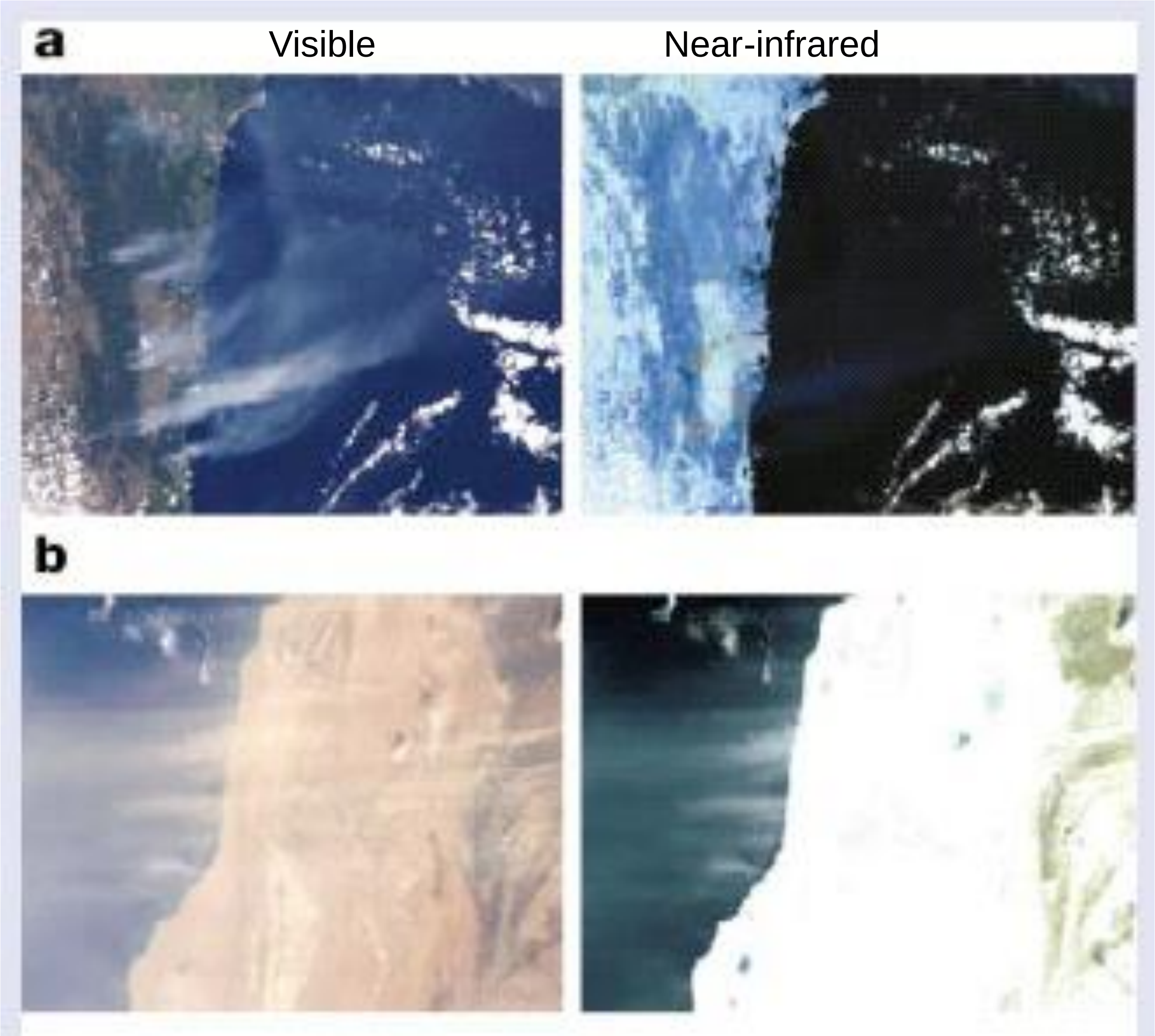




Image processing

Aerosol size determination from space

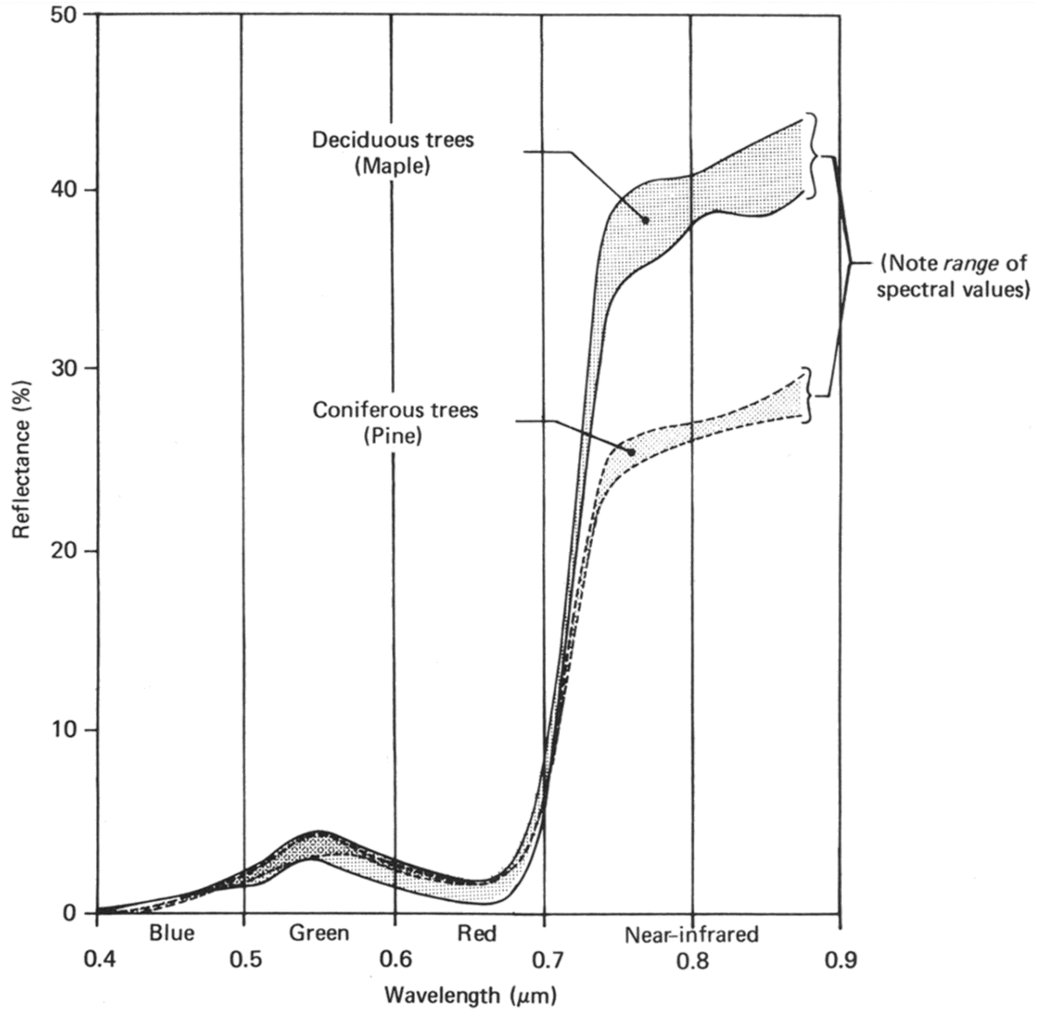
True Color | False Color



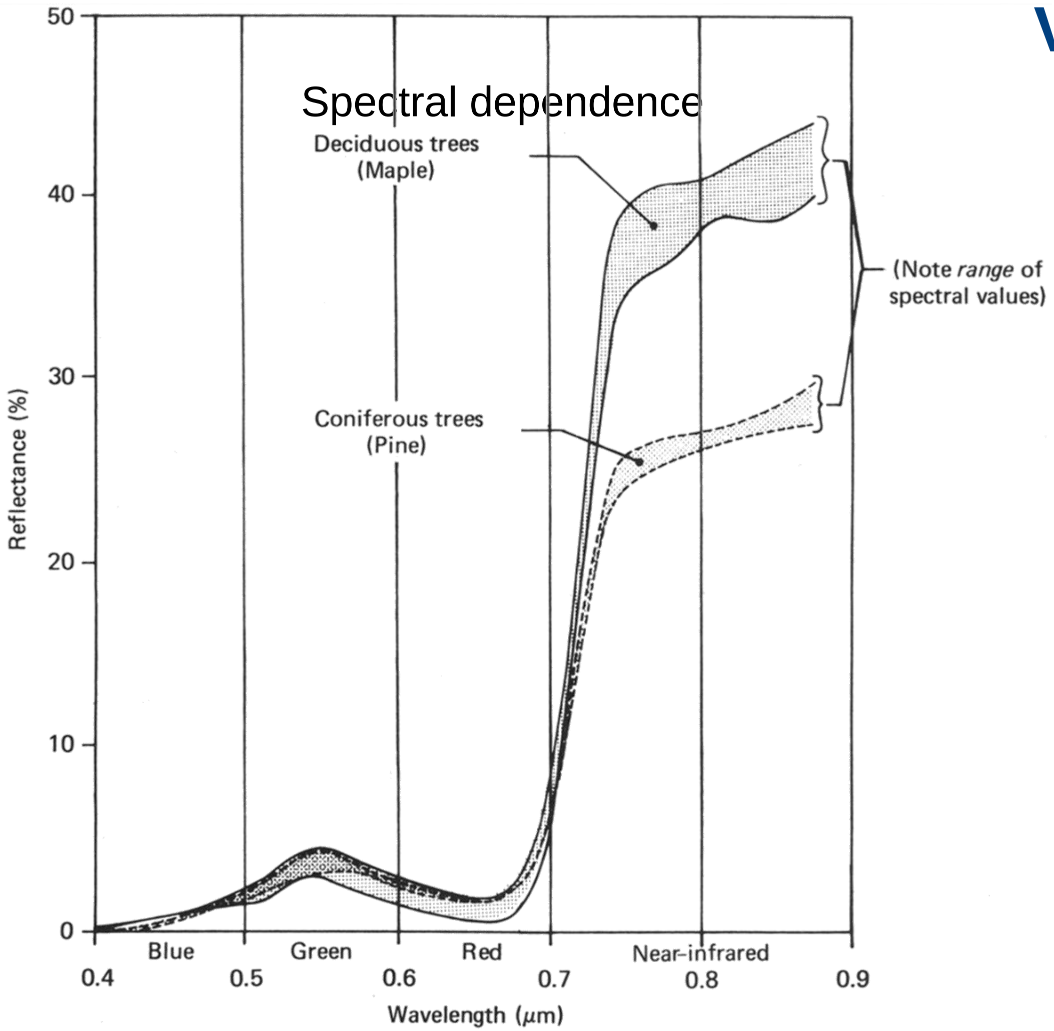
Fine particles from smoke

Coarse dust particles

Generalized Spectral Reflectance Envelopes for Deciduous and Coniferous Trees



Vegetation reflection

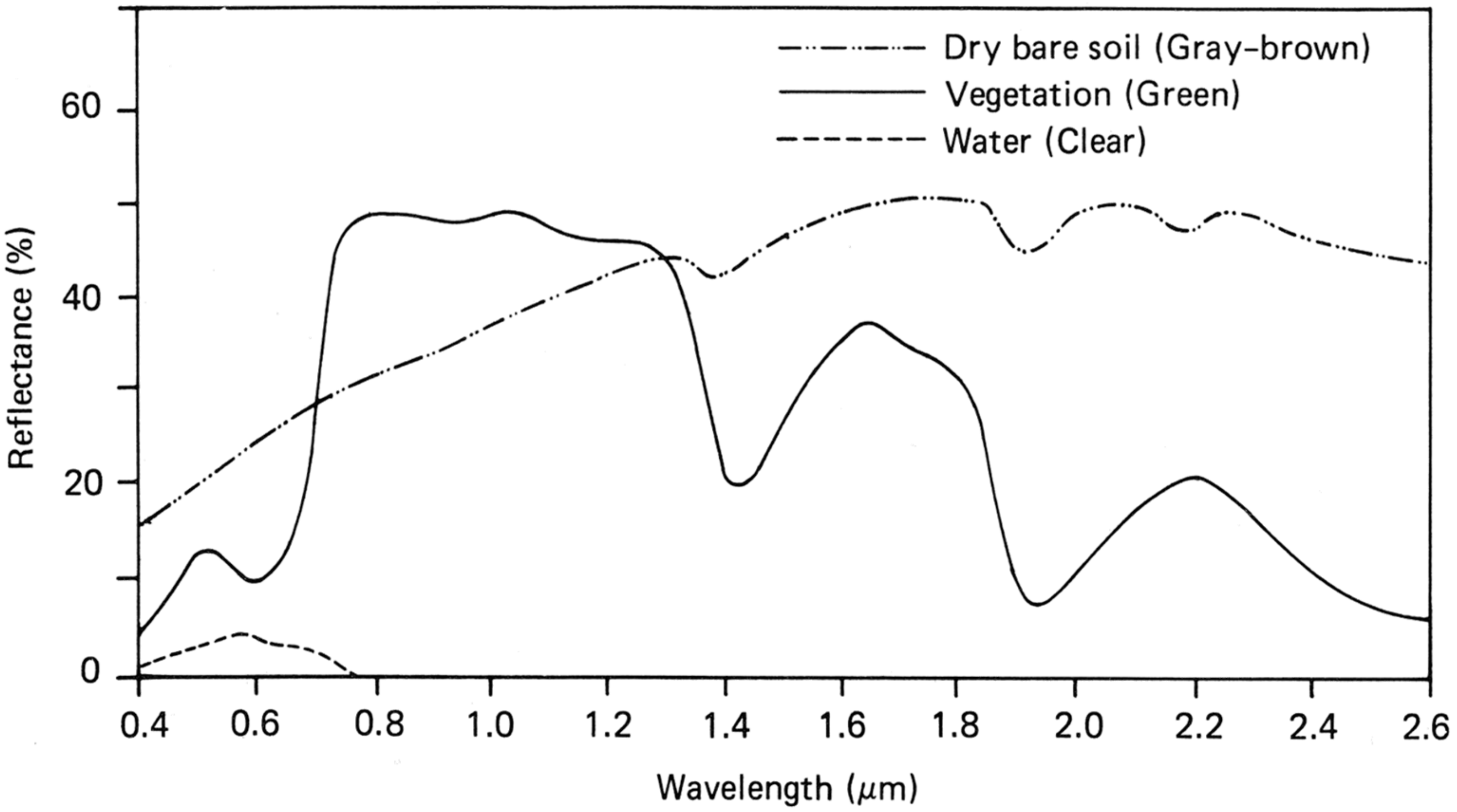


Nice indicator for vegetation:
Normalized Difference
Vegetation Index (NDVI)

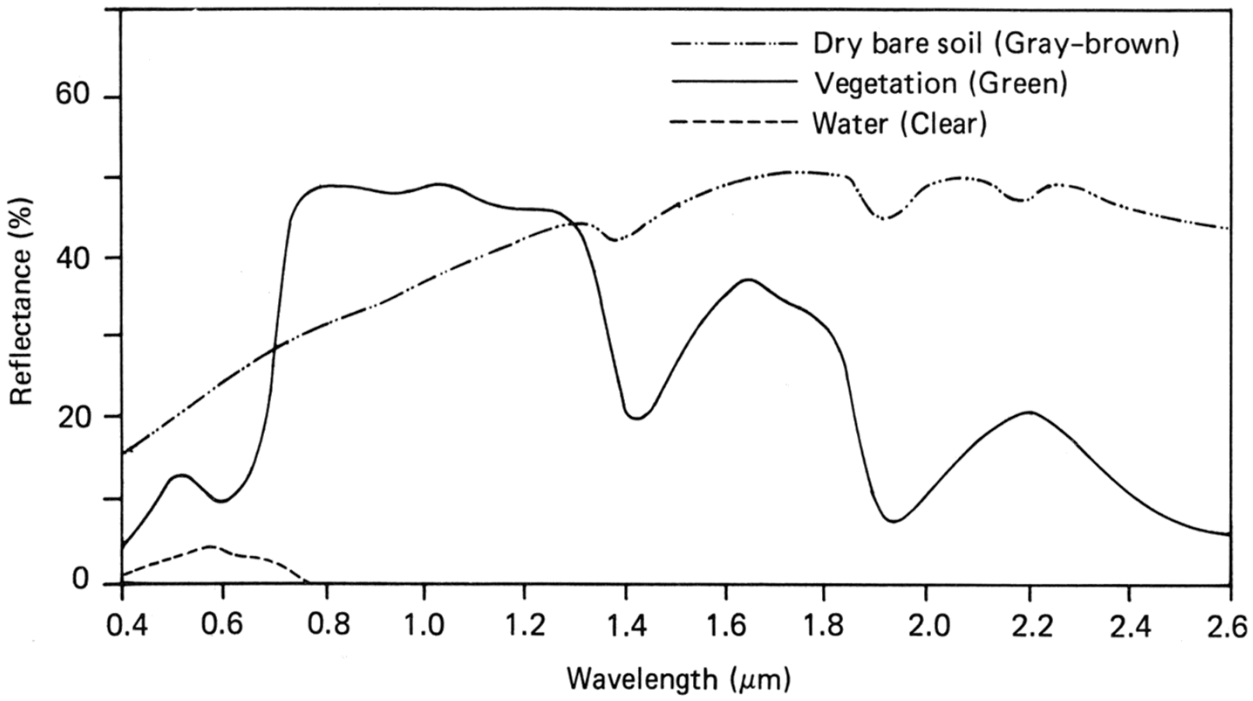
$$NDVI = \frac{R_{NIR} - R_{VIS}}{R_{NIR} + R_{VIS}}$$

VIS IR NDVI

Typical Spectral Reflectance Curves for Vegetation, Soil, and Water



Vegetation Spectral Properties:

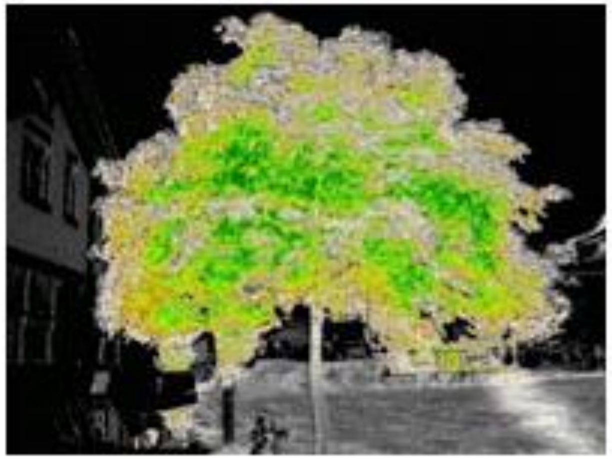


$$NDVI = \frac{R_{NIR} - R_{VIS}}{R_{NIR} + R_{VIS}}$$

VIS

IR

NDVI



Radiation measurements from the ground

SPSAS on Atmospheric Aerosols

In preparation for our experimental measurement’s day we will focus on SunPhotometers and Sky Radiometers

In particular the NASA AERONET system: https://aeronet.gsfc.nasa.gov/

GODDARD SPACE FLIGHT CENTER

+ Visit NASA.gov

https://youtu.be/i_CJW3JsBI4

+ AEROSOL OPTICAL DEPTH | + AEROSOL INVERSIONS | + SOLAR FLUX | + OCEAN COLOR | + MARITIME AEROSOL

Web Site Feature AERONET Data Synergy Tool - **Access Earth Science data sets for AERONET sites**

-Home

Home

+ AEROSOL/FLUX NETWORKS
+ CAMPAIGNS
+ COLLABORATORS
+ DATA
+ LOGISTICS
+ NASA PROJECTS
+ OPERATIONS
+ PUBLICATIONS
+ SITE INFORMATION
+ STAFF
+ SYSTEM DESCRIPTION

AERONET DATA ACCESS

DATA SYNERGY TOOL

Recent Product Releases (navigation links also available above and in left margin):

8 February 2019:
Version 3 Inversion Uncertainty Estimates for Selected Products - Estimated Uncertainty Description - Download Tool

Version 3 Lunar AOD Measurements (Provisional) - Web Display

15 October 2018:
Version 3 Level 1.5 and Level 2.0 Hybrid inversion products - Hybrid Description - Web Display

11 January 2018:
Version 3 Level 1.5 and Level 2.0 Almucntar inversion products - Almucantar Description - Web Display

5 January 2018:
Version 3 Level 2.0 AOD and SDA products - AOD and SDA Description - Web Display

MISSION

The AERONET (**AE**rosol **RO**botic **NET**work) project is a federation of ground-based remote sensing aerosol networks established by NASA and PHOTONS (PHOtométrie pour le Traitement Opérationnel de Normalisation Satellitaire; Univ. of Lille 1, CNES, and CNRS-INSU) and is greatly expanded by networks (e.g., RIMA, AeroSpan, AEROCAN, and CARSNET) and collaborators from national agencies, institutes, universities, individual scientists, and partners. For more than 25 years, the project has provided long-term, continuous and readily accessible public domain database of aerosol optical, microphysical and radiative properties for aerosol research and characterization, validation of satellite retrievals, and synergism with other databases. The network imposes standardization of instruments, calibration, processing and distribution.

AERONET collaboration provides globally distributed observations of spectral aerosol optical depth (AOD), inversion products, and precipitable water in diverse aerosol regimes. Version 3 AOD data are computed for three data quality levels: Level 1.0 (unscreened), Level 1.5 (cloud-screened and quality controlled), and Level 2.0 (quality-assured). Inversions, precipitable water, and other AOD-dependent products are derived from these levels and may implement additional quality checks.

Retrieval scheme:

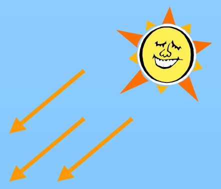
Forward model:
-Spectral and angular scattering by particles with different sizes, compositions and shapes
- Accounting for multiple scattering in atmosphere

(Dubovik and King, JGR, 2000)

Numerical inversion:
-Accounting for noise
-Solving Ill-posed problem
- Setting a priori constraints

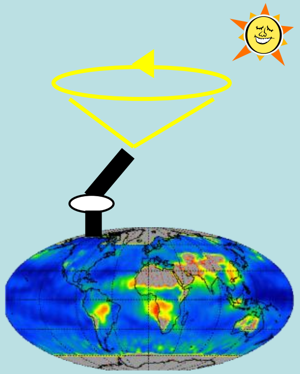
Observations

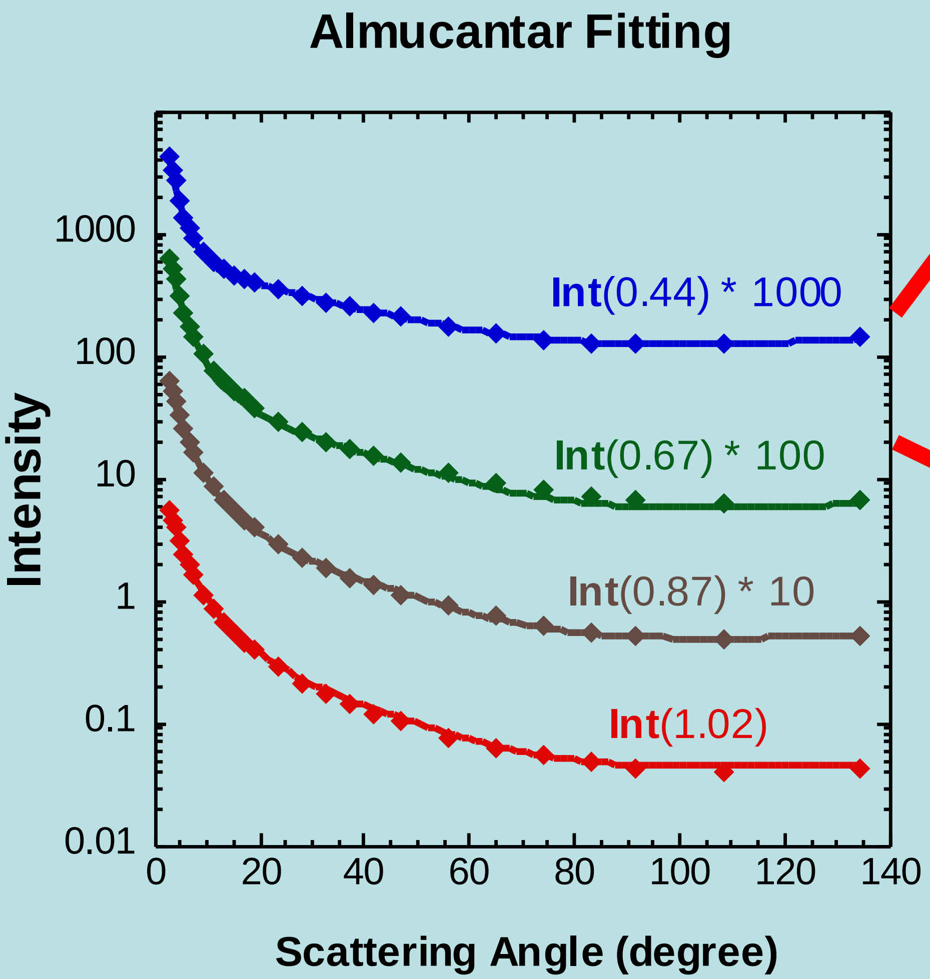
- Direct solar
- Almucantar
- Principal Plane Scan

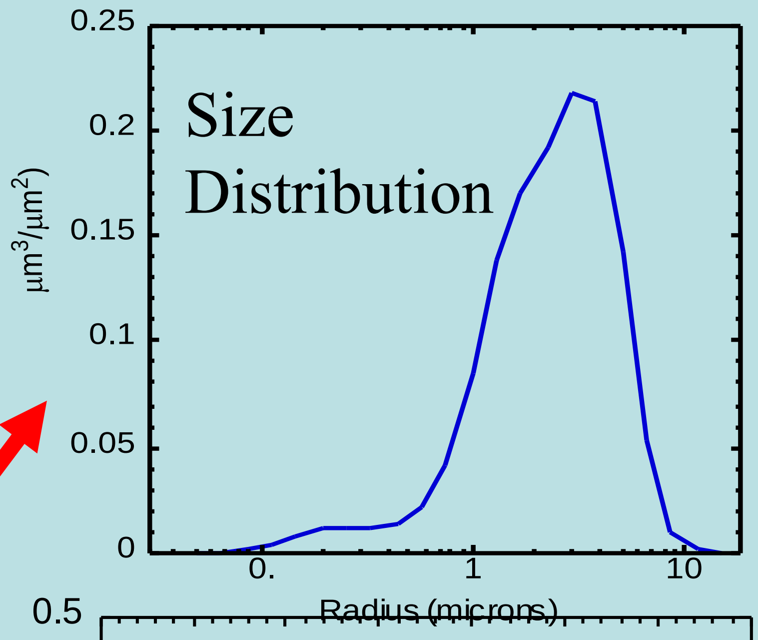


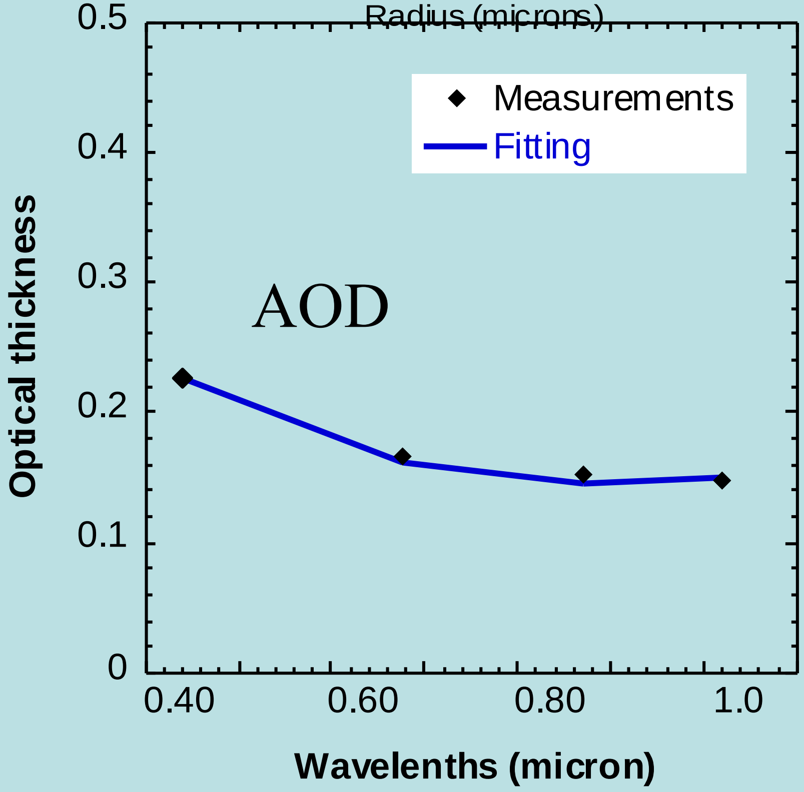
aerosol particle sizes, refractive index, single scattering albedo, etc.

Fitting as a retrieval strategy

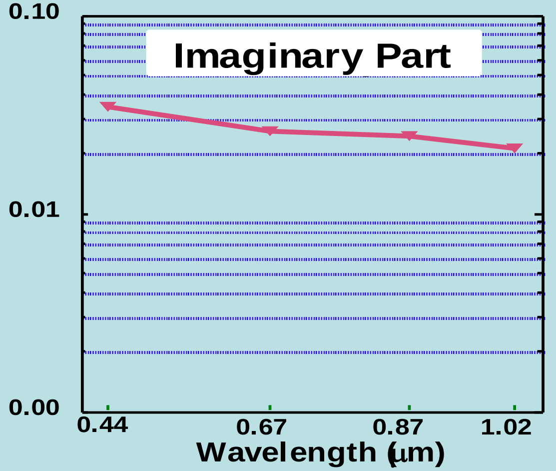


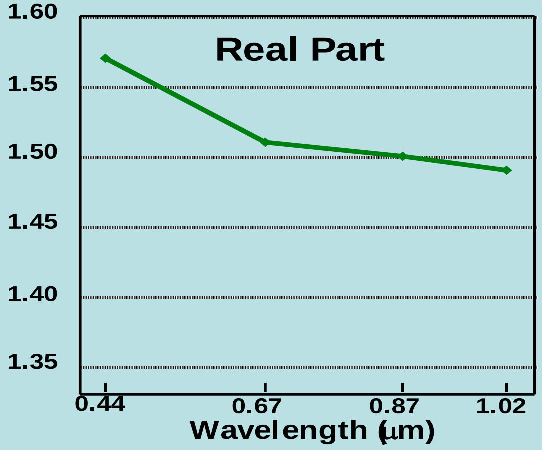






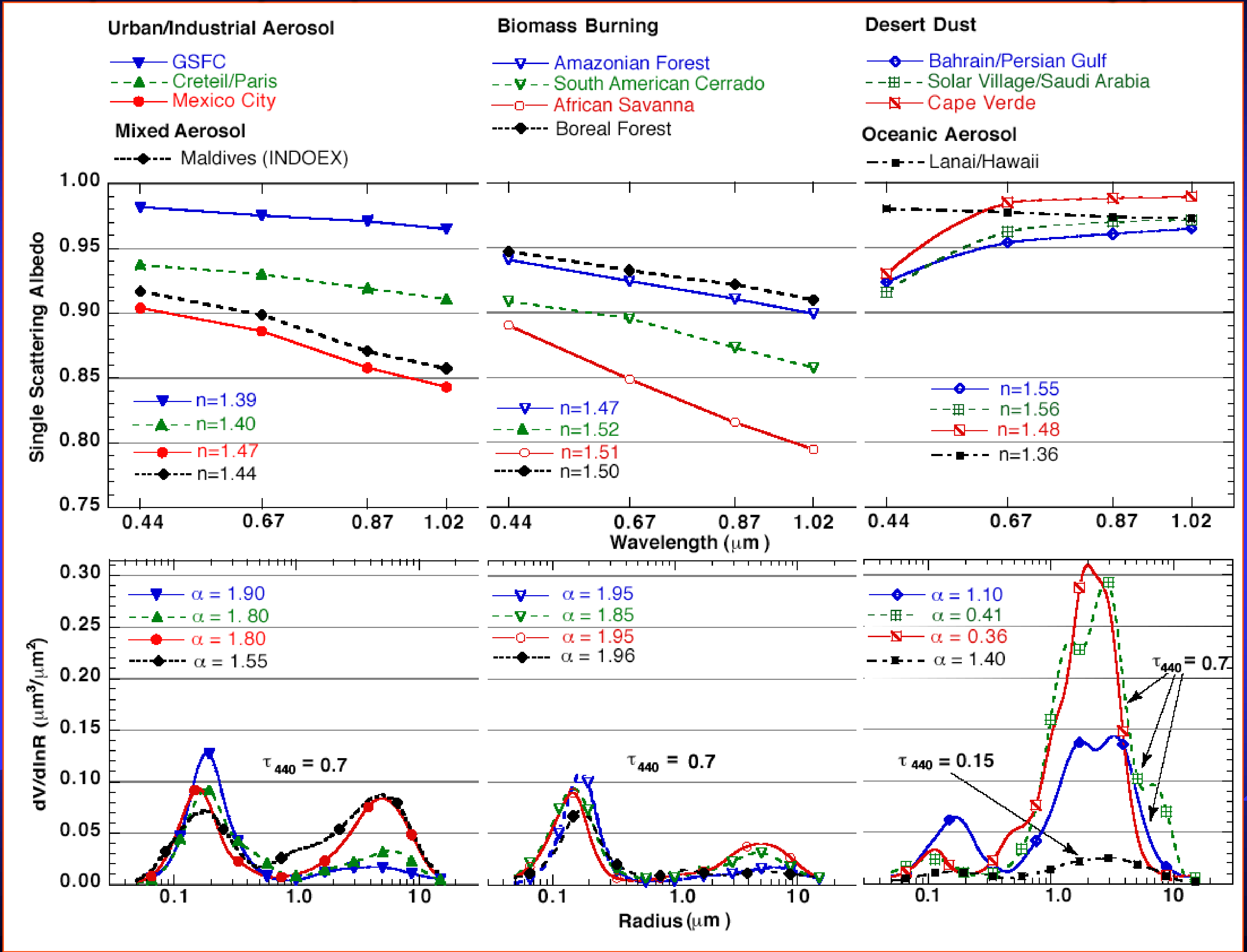
Refractive Indices





The averaged optical properties of various aerosol types

(Dubovik et al., 2002, JAS)

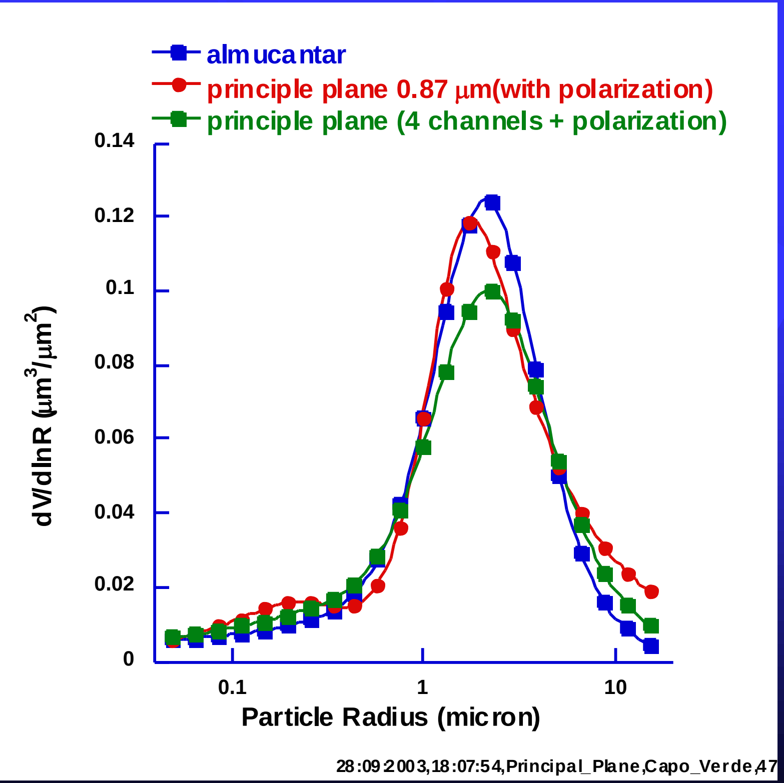


Utilizing polarization *Cape Verde aerosol*

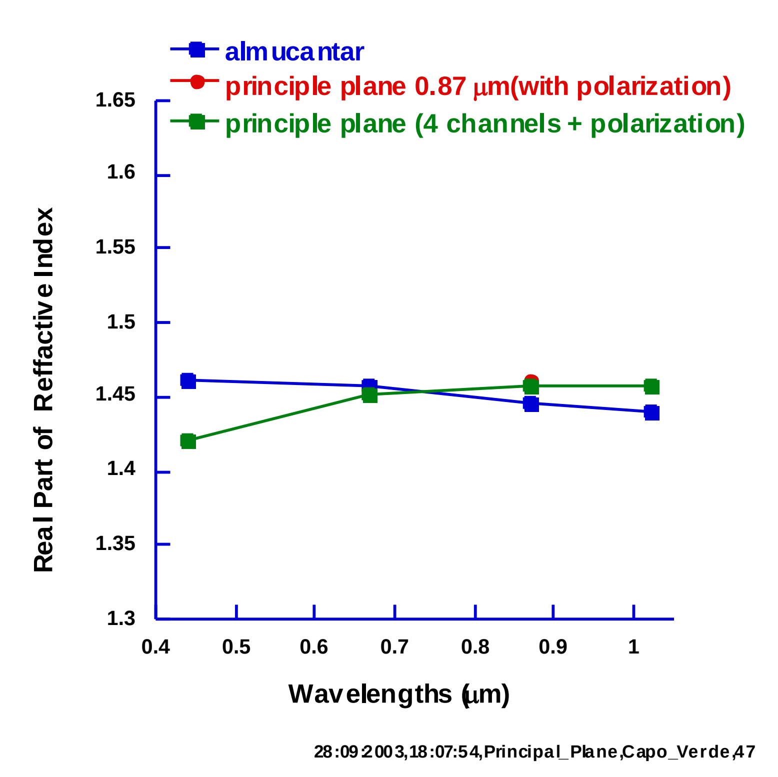
Principal Plane:
$\tau(\lambda)$, $I(\lambda,\Theta)$
λ = 0.44, 0.5, 0.67, 0.87,1.02, 1.64, μm

Polarization :
$\tau(\lambda)$, $I(\lambda,\Theta)$,$P(\lambda,\Theta)$
λ = 0.87μm

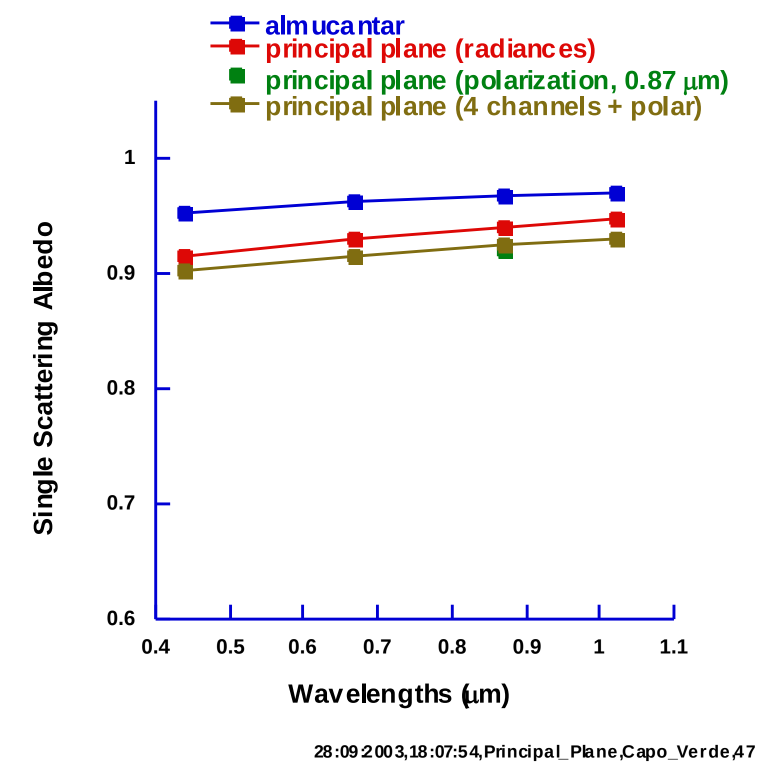
$dV/d\ln(r_i)$



$n(\lambda)$



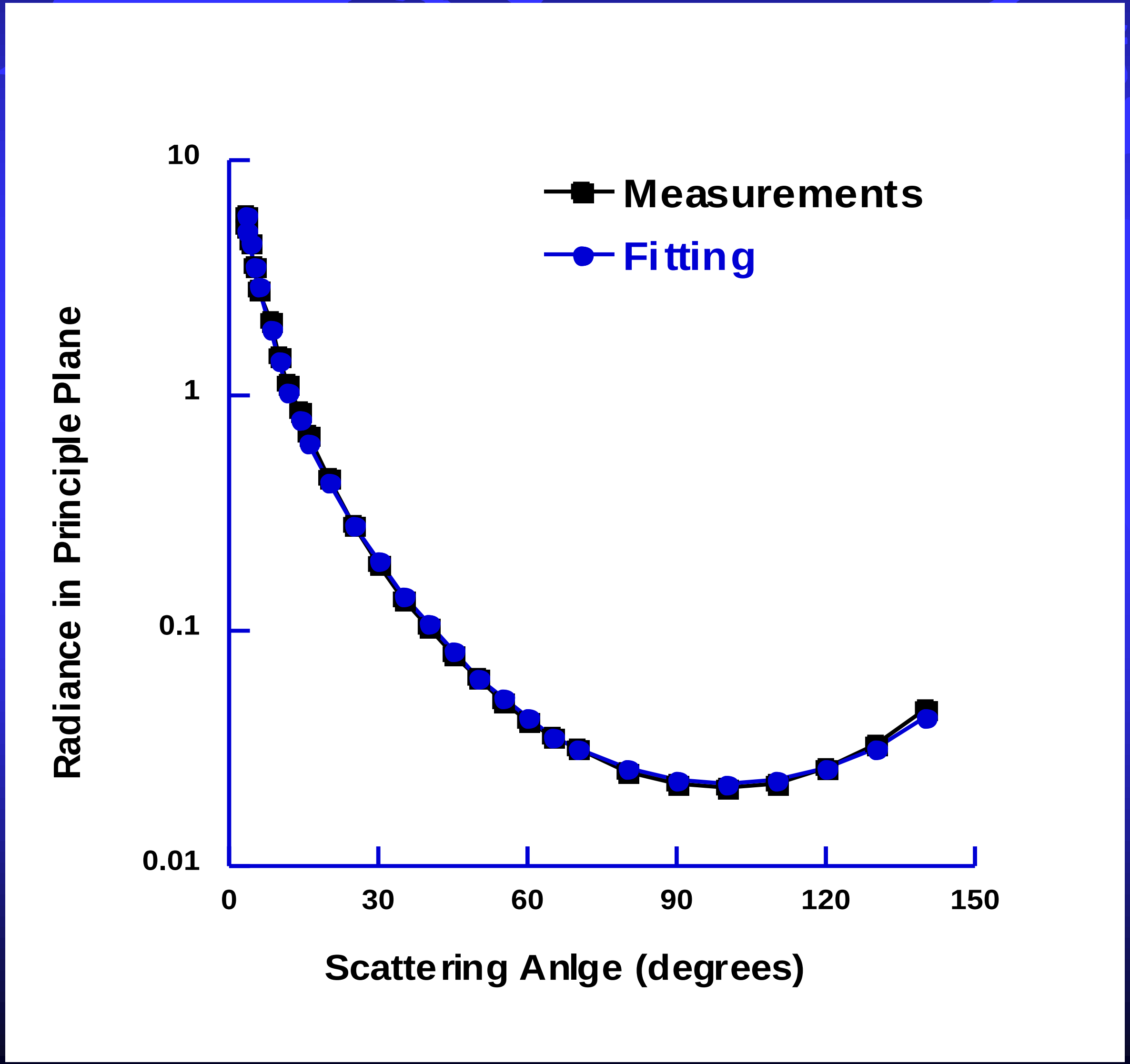
$\omega_0(\lambda)$



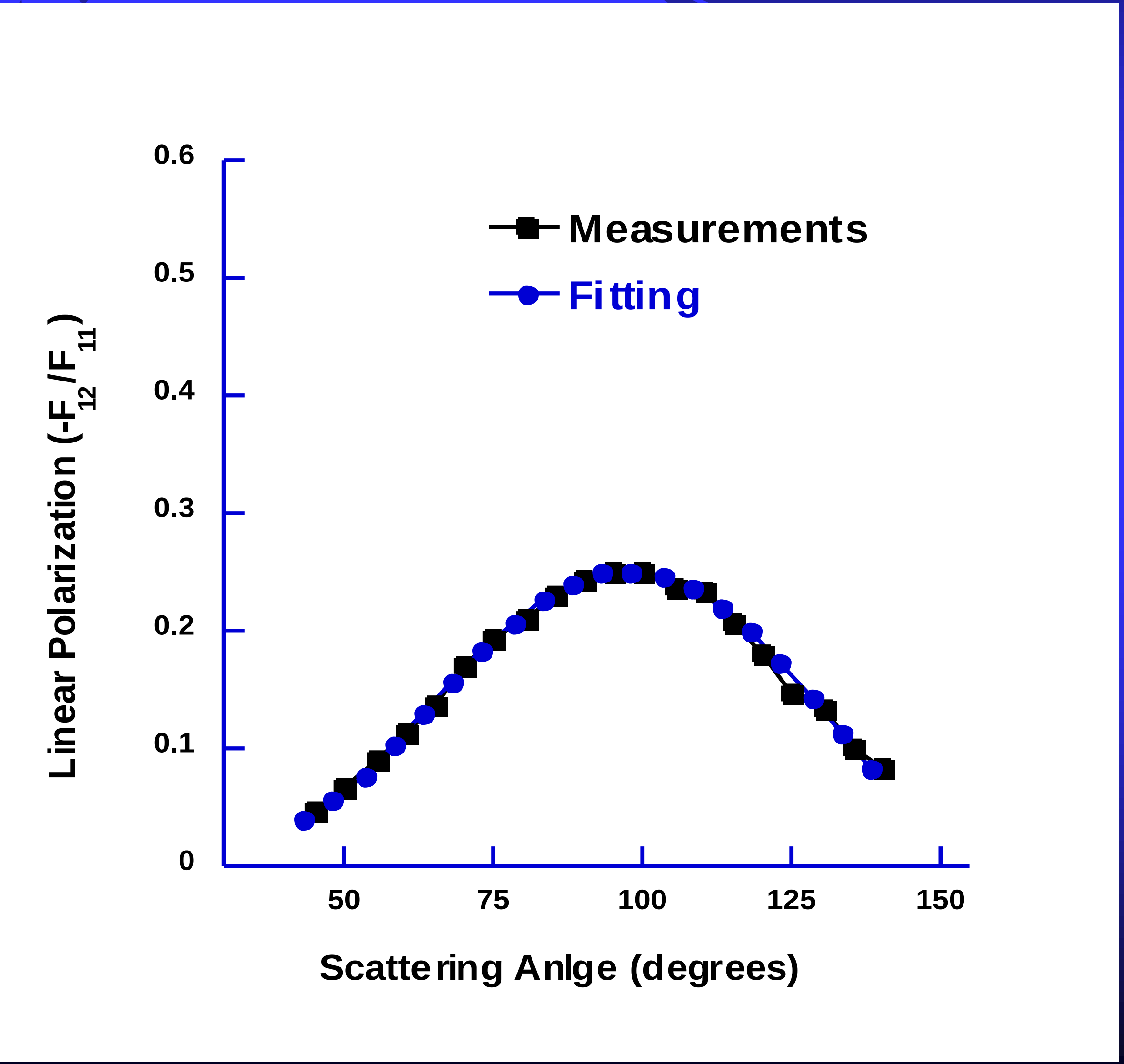
Cape Verde aerosol

Fitting polarization

Radiance

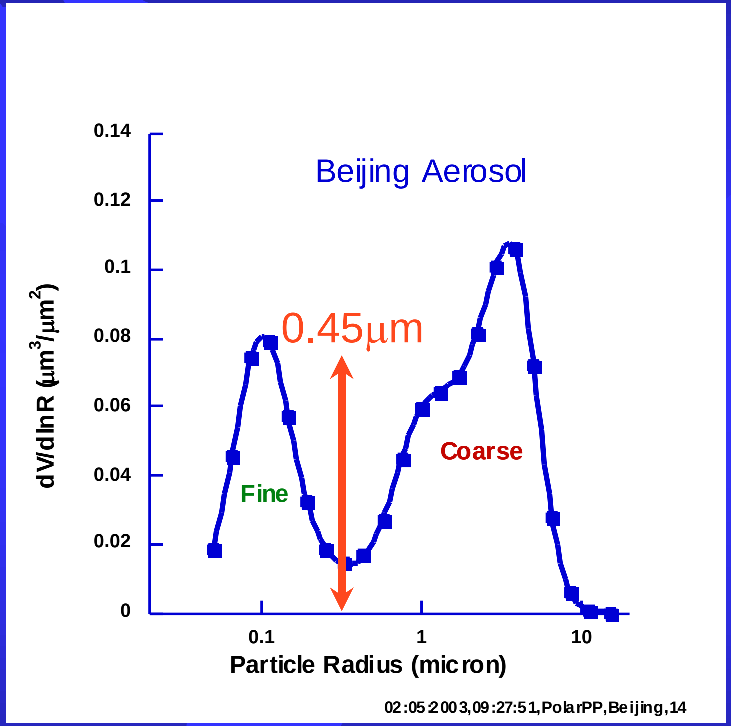


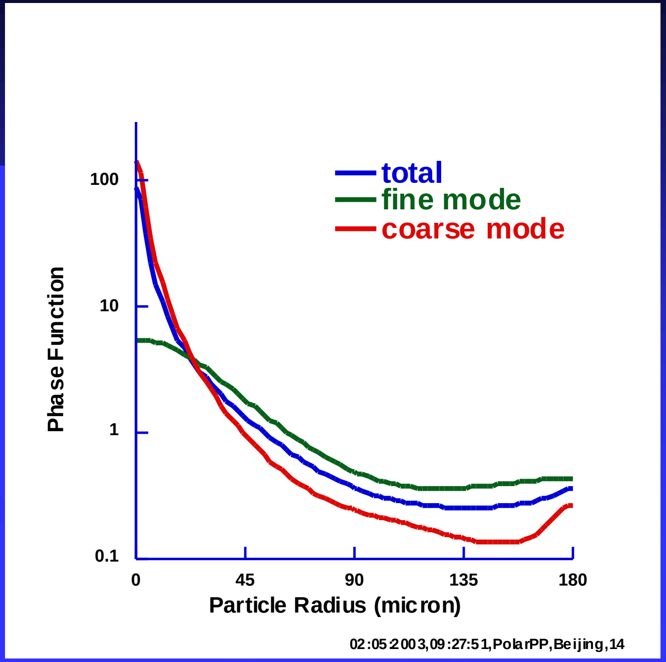
Linear Polarizartion

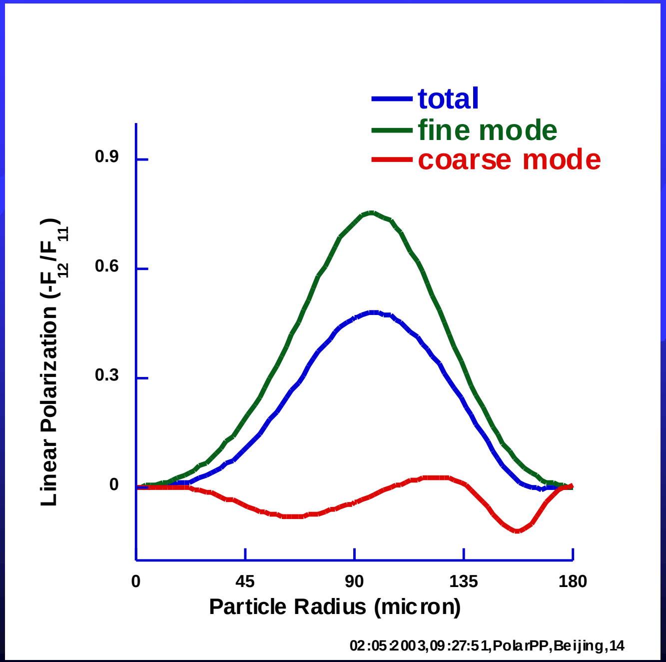


Fine and Coarse modes separations

Beijing aerosol

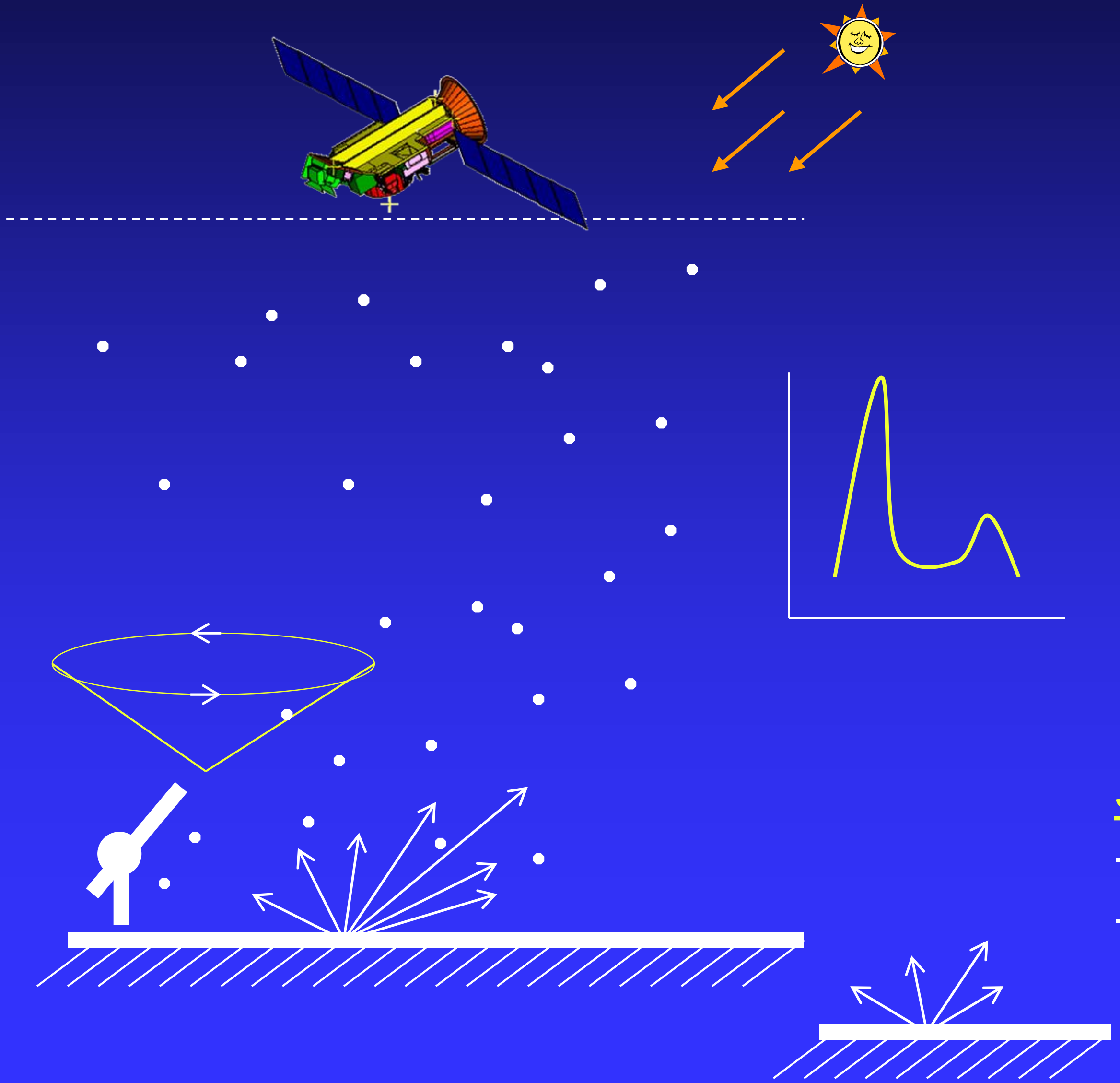






Flexible separation between fine and coarse modes (curently: ~0.6 μm)

Retrieval using combinations of up-looking Ground-based and down-looking satellite observations

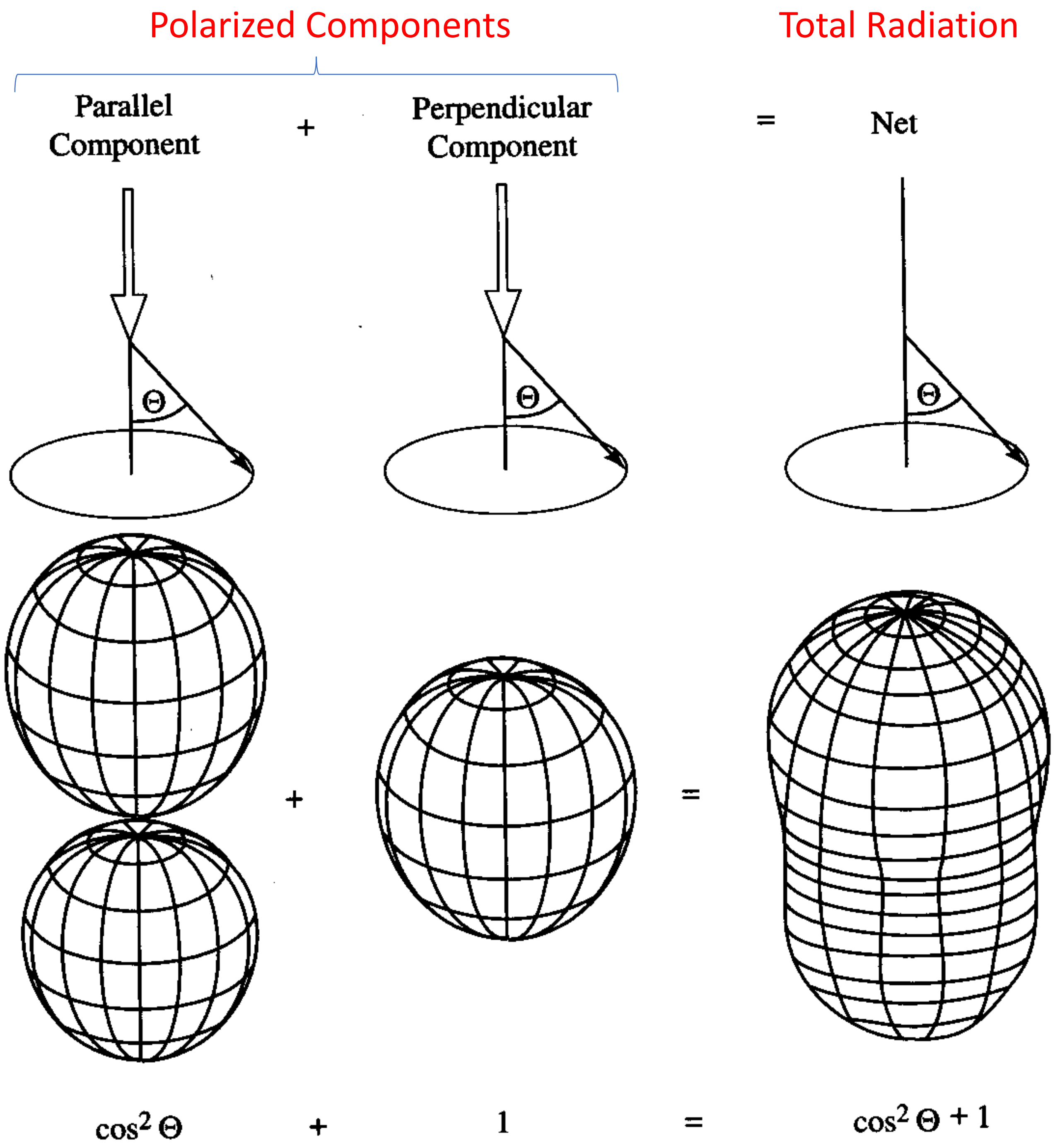


Retrieved:

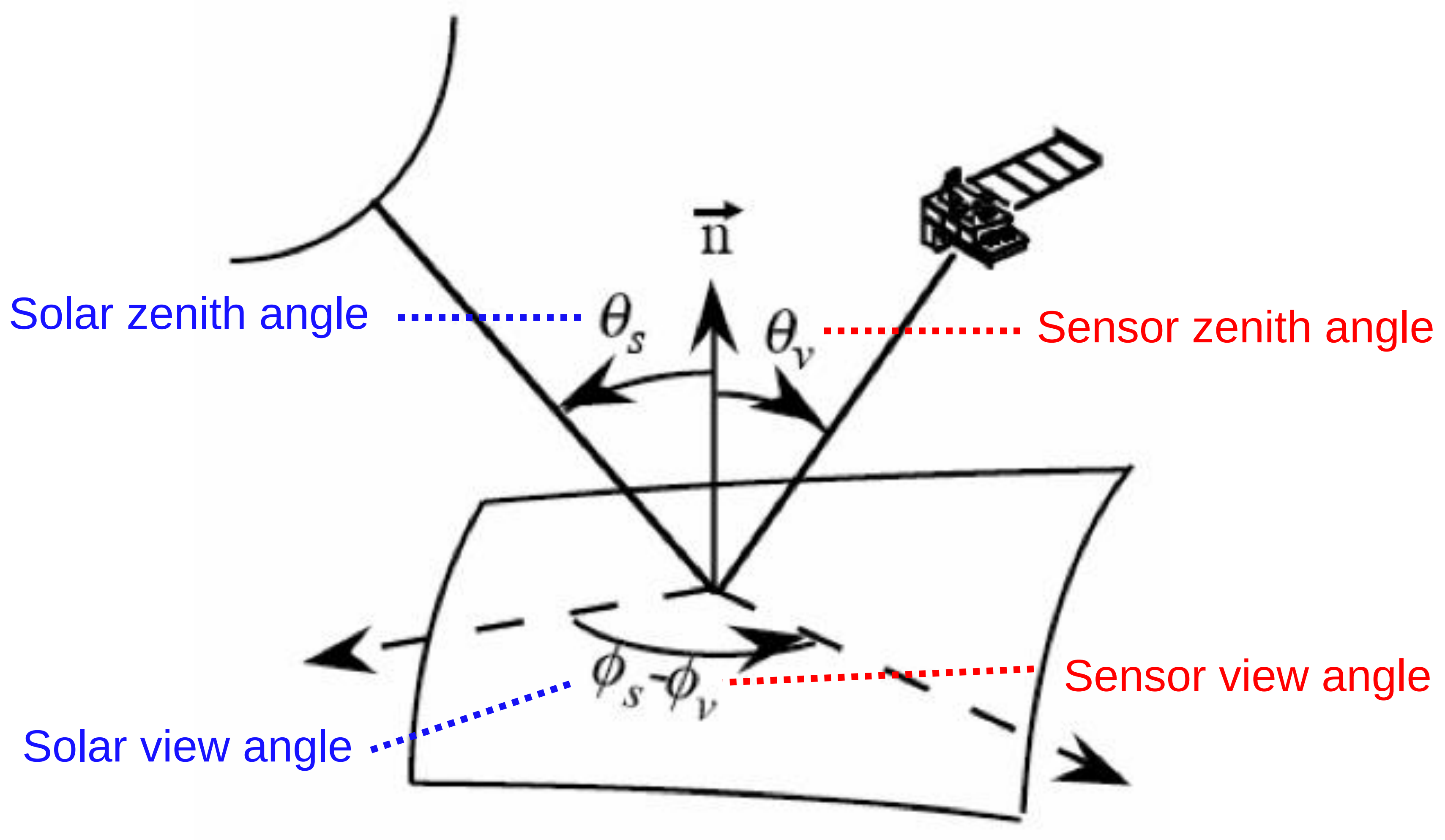
<u>Aerosol Properties</u>:
- size distribution
- real ref. ind.
- imag. ref. ind
(AERONET sky channels)

<u>Surface Parameters</u>:
-BRDF (MISR channels)
-Albedo (MODIS IR channels)

Phase Function diagram for Rayleigh scattering



Observing geometry from Space:



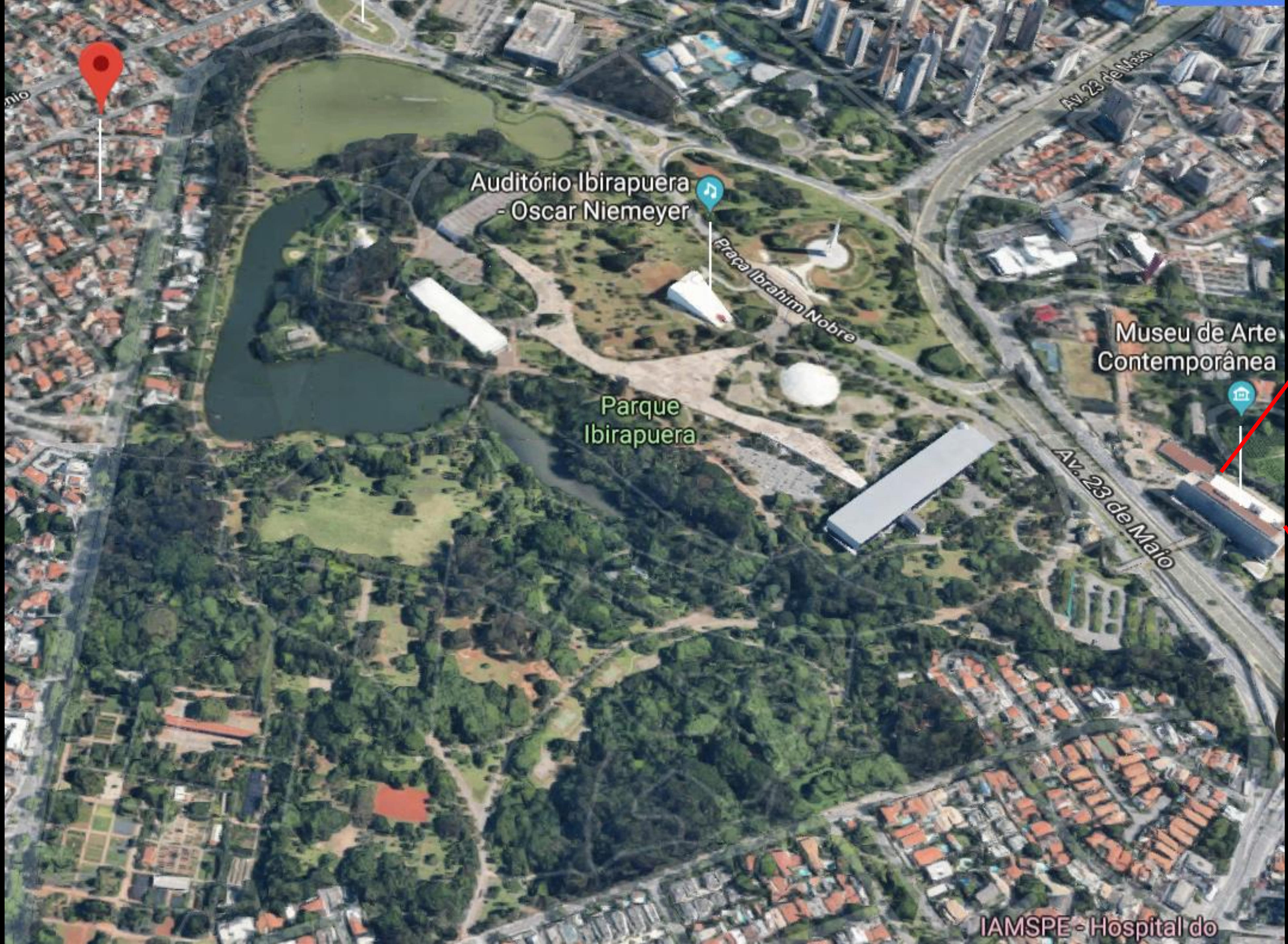
Field Measurement’s Day

SPSAS on Atmospheric Aerosols

Prof. J. Vanderlei Martins
Earth and Space Institute – UMBC
University of Maryland Baltimore County

Our Experimental Measurement's day:

- Field trip to the MAC (Contemporaneous Art Museum)
- Measurements from the roof top of the building observing solar and sky radiances with a simple manual photometer from your smart phone.
  - The intent is to illustrate how to make measurements and convert it to scientific variables but it is not to actually perform a fully calibrated scientific measurement
- First you will characterize and understand better the sensors in your Smart Phone:
  - Photometer
  - Camera
  - Inclinometers, accelerometers, compass, GPS, etc.
- Second you will perform actual atmospheric measurements and compare results with AERONET



Ibirapuera Park Across the Street from MAC

What to bring:

- We plan to use personal Smart phones for the measurement
  - Students will be divided in teams of 3 people
  - Important to have at least one smartphone per team
- Not required but very useful to have a laptop computer for data analysis (plotting, etc.).
- Sunscreen, hat, long sleeves for wind and sun blocking
- Water bottle or mug.
- Lunch boxes will be provided by the School.

Important notes:

- The museum is a safe/secure place but, keep in mind that you are bringing smartphones, laptops and other belongings at your own risk.
- You can visit the whole museum but our experimental activities will happen only the 1st and 8th floors.

Important: You are not allowed to bring backpacks to any other floors!!!
In fact, it is better to keep your backpacks in the 1st floor rooms dedicated to our group.

- Across the street from the museum there is the beautiful Ibirapuera Park that you should consider visiting. While in the Park be always careful with your belongings (computer, cameras, phones, etc.).

Apps to download to your computer:

- There are three Apps that we plan to use in this experiment:

  - Physics toolbox suite
  - GPS Status
  - Photometer PRO – Lux Light Meter & Tools

Note: Aple Iphone's will have a different photometer App but it should work similarly

If your phone is limited in memory space, start with the Photometer Pro – Lux Light Meter. You may be able to use this App only for all measurements.

Division in groups

- Students will be divided in teams of 3 people
  - There must be at least one smartphone per team.
  - It would be useful if each team had at least one laptop computer for data analysis.
- The student teams will be split into 4 groups lead by a professor and monitors.
- The Professors will coordinate the groups to perform experimental activities in the laboratories and on the roof of the museum.
- Each group will have an assigned 2 hours window to perform the laboratory characterization of their phone.

Computer and Data analysis

- A laptop computer is not required for participation in the course but it is highly recommended.
- We will have data analysis and measurement activities for which the laptop computer will be highly beneficial. The work will be done in groups of 3 students so, it is highly advisable to have at least one computer in each group.

Software requirements

- Any data analysis software (including excel) can be used to the general data analysis but we will be basin all our measurements and data analysis on Python.
- I highly recommend everybody to install and get some familiarity with Python. In particular, I recommend Python 2.7 in the Anaconda distribution.

Poster Session

- Student teams will prepare a poster with results from their experiment to present to the whole group of students. We will have a poster session in the last Thursday of the event.

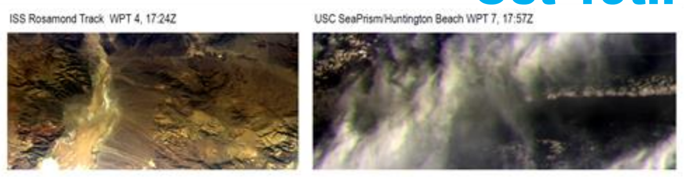
Extra slides

SPSAS on Atmospheric Aerosols

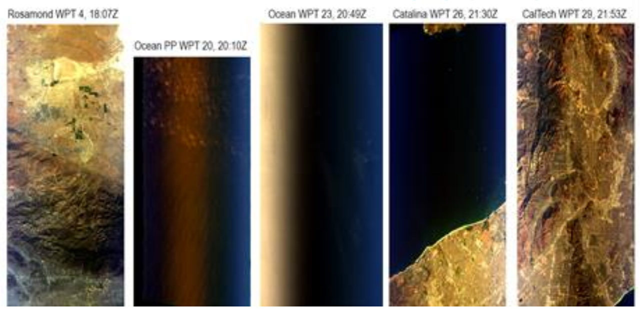
AirHARP's Image Gallery for ACEPOL

(Level 1 data under processing)

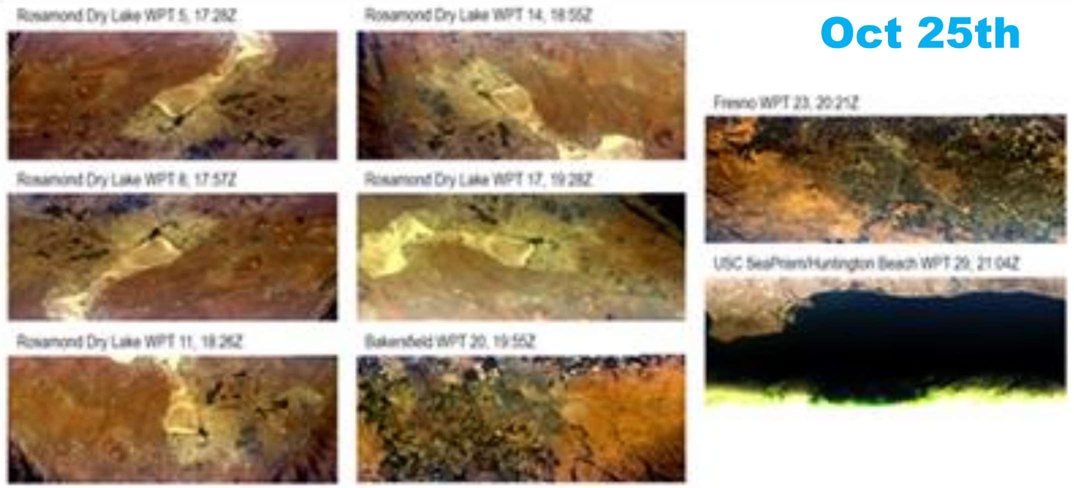
Oct 19th



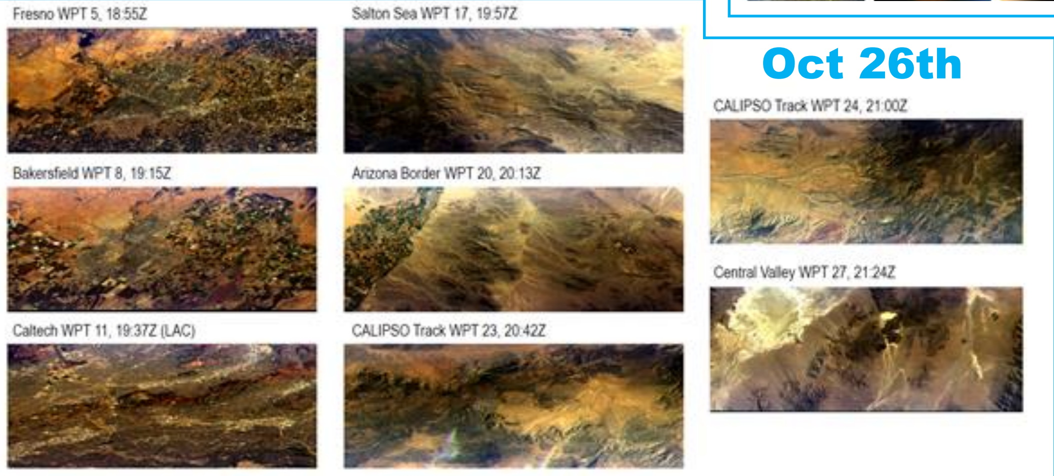
Oct 23rd



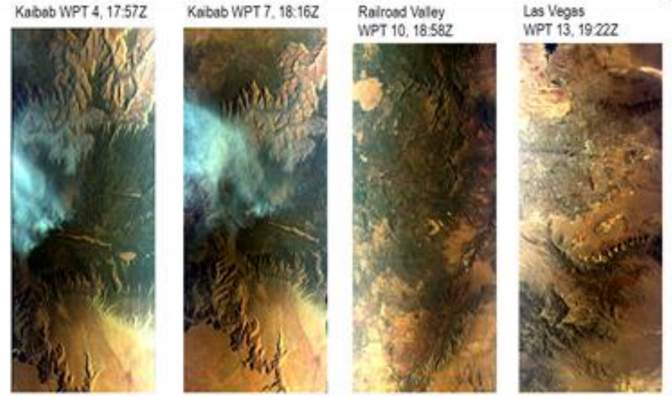
Oct 25th



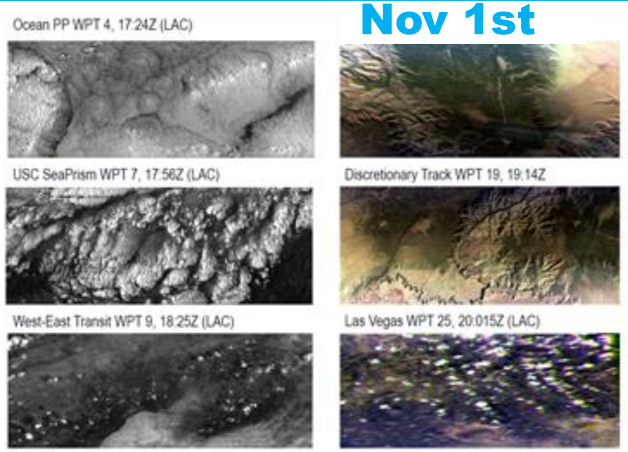
Oct 26th



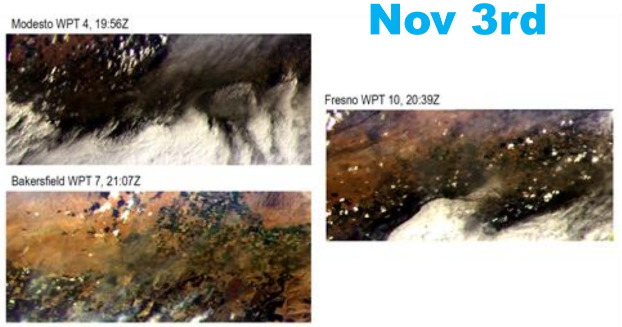
Oct 27th



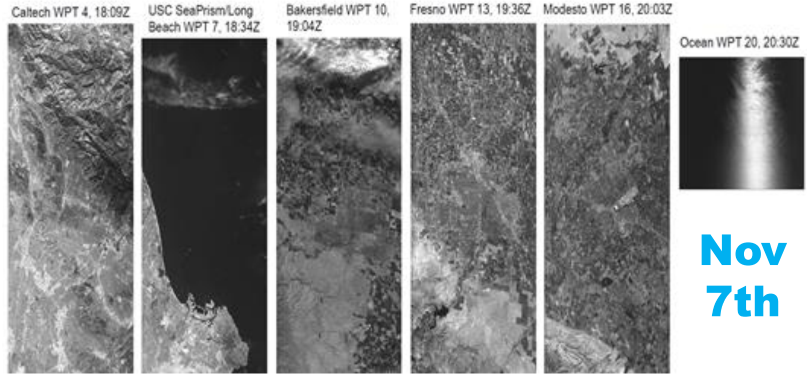
Nov 1st



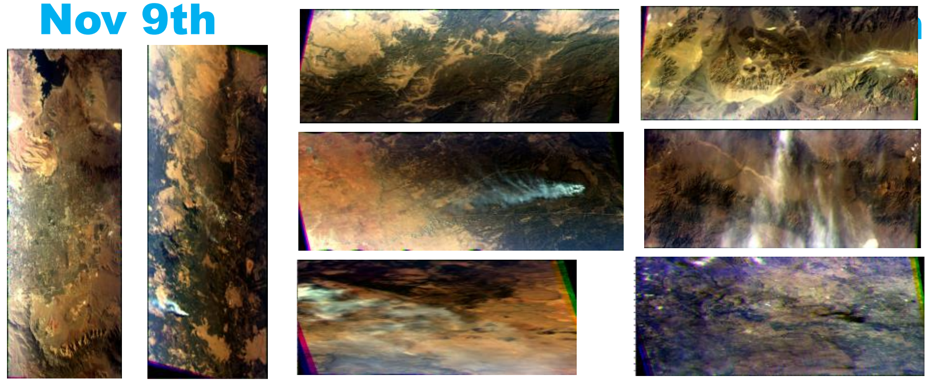
Nov 3rd



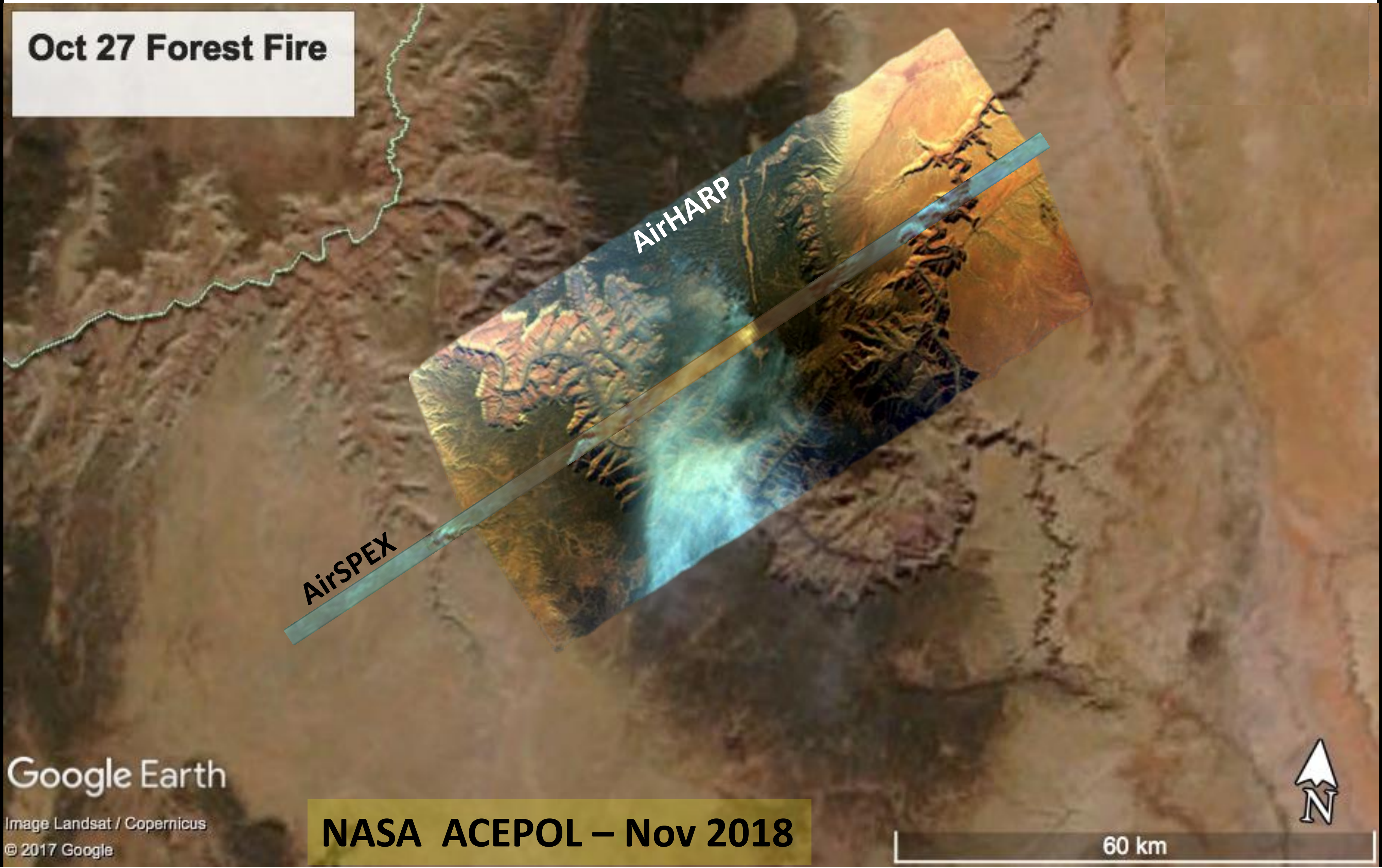
Nov 7th

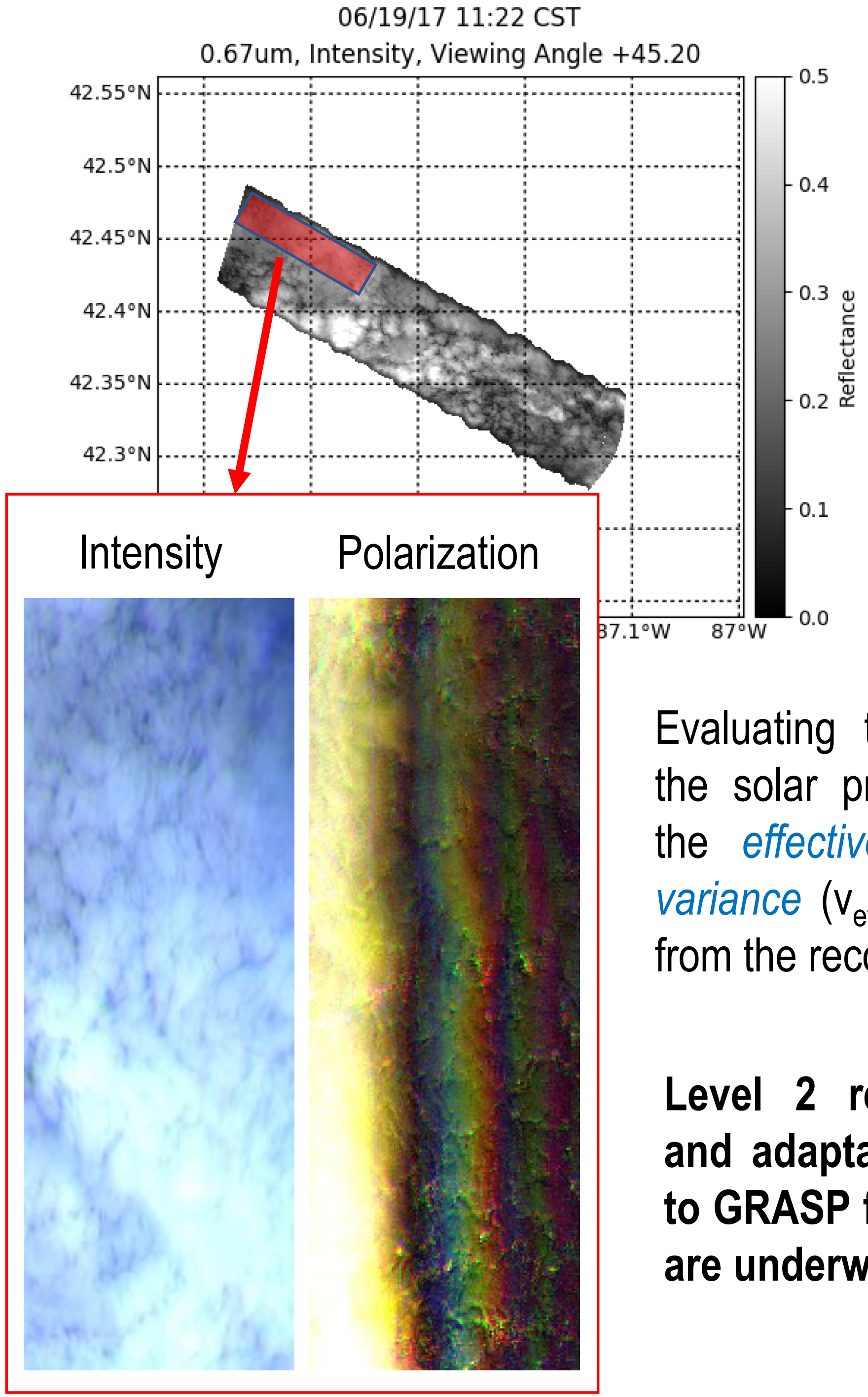


Nov 9th



UMBC AirHARP and AirSPEX from ER2





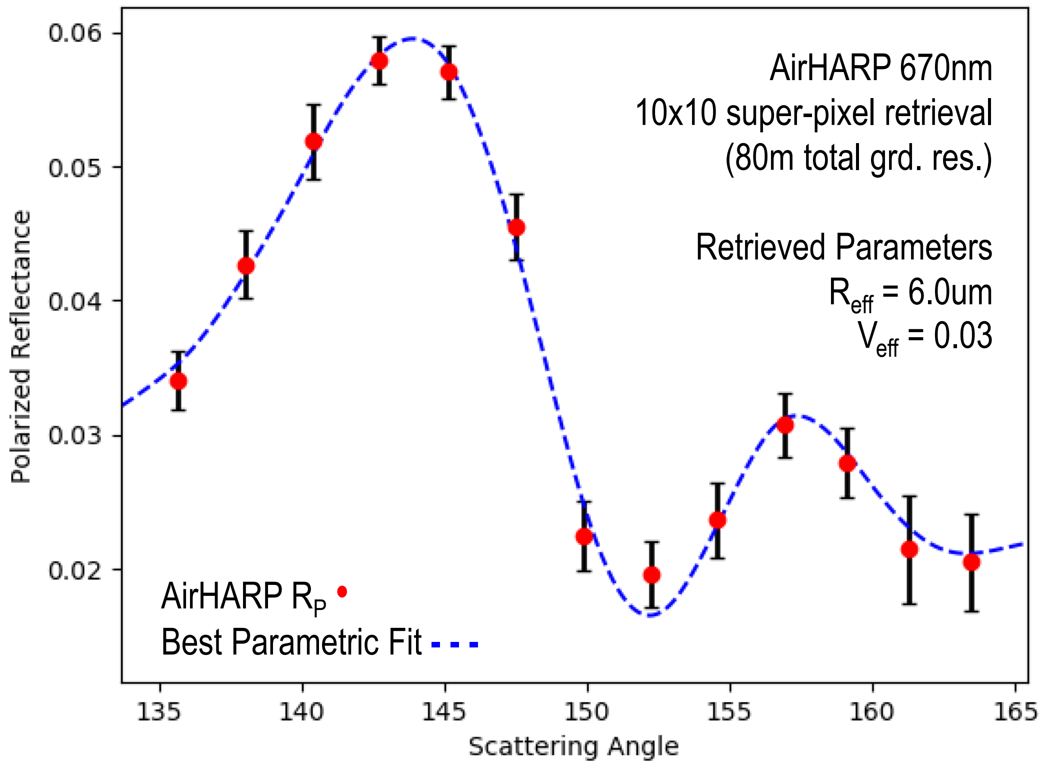
HARP cloud retrievals can be done for any pixel in the FOV, even for **heterogeneous clouds**, like this case (left) from LMOS on June 19, 2017.

Polarized radiance is converted to reflectance (*Rp*) and parametrically matched to Mie phase functions:

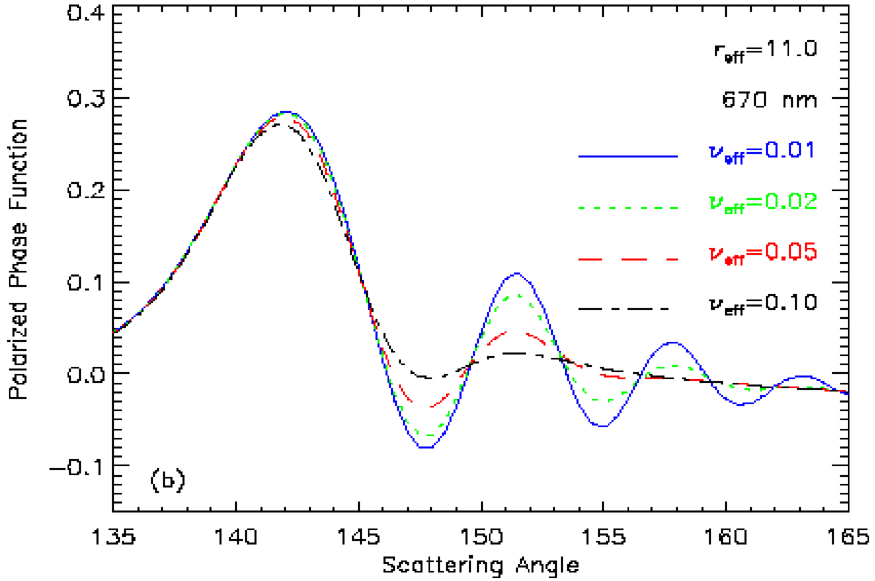
$$R_P = \frac{\pi\sqrt{Q^2 + U^2}}{F_0 \cos\vartheta_z} = \alpha\, P_{12}(\vartheta) + \beta cos^2\theta + \gamma$$

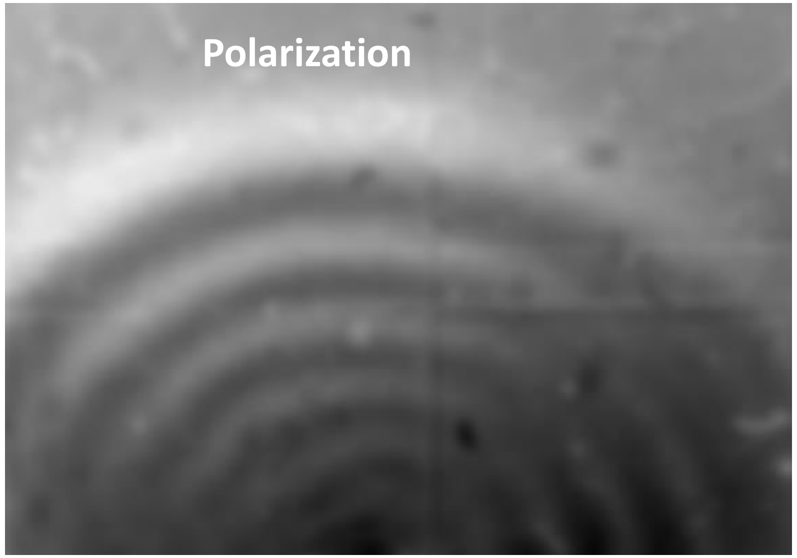
Evaluating this relationship on the solar principal plane gives the *effective radius* (r_{eff}) and *variance* (v_{eff}) of a cloud scene from the recovered Mie P_{12}.

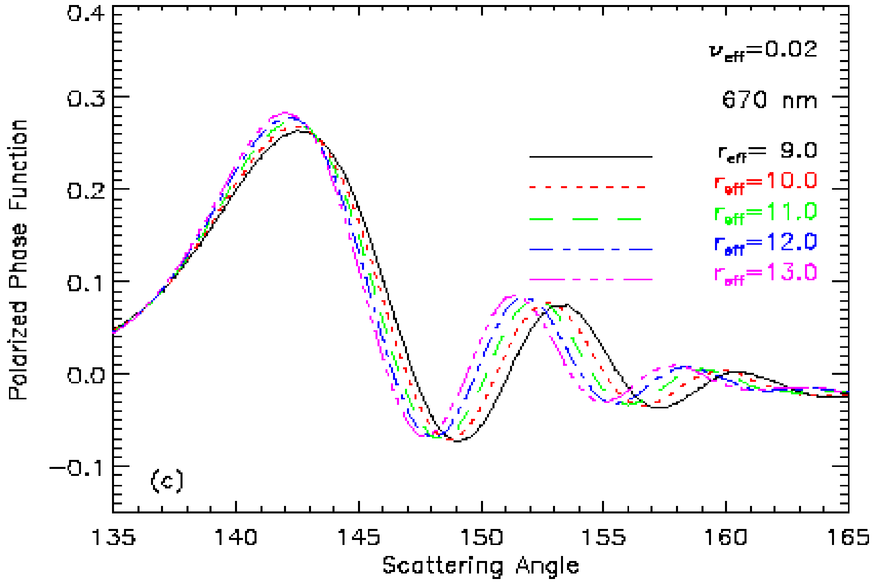
Level 2 retrieval algorithms and adaptation of HARP data to GRASP for aerosol retrieval are underway.



HARP Pioneering Hyper-Angular Capability from Space will Provide Full Cloudbow Retrievals from Small Area (~4x4km)



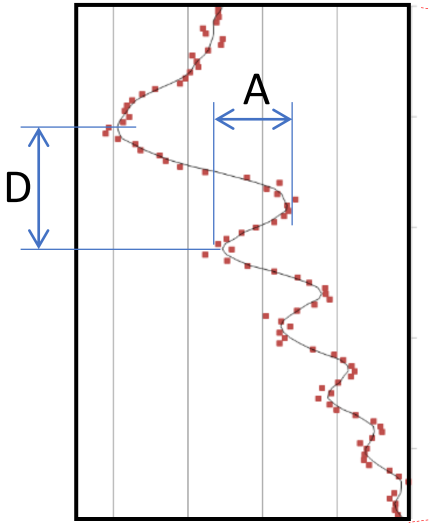


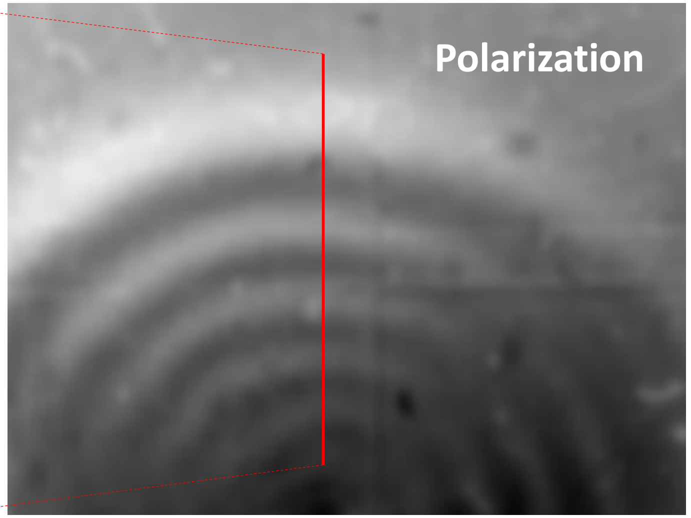


HARP CubeSat Polarimeter

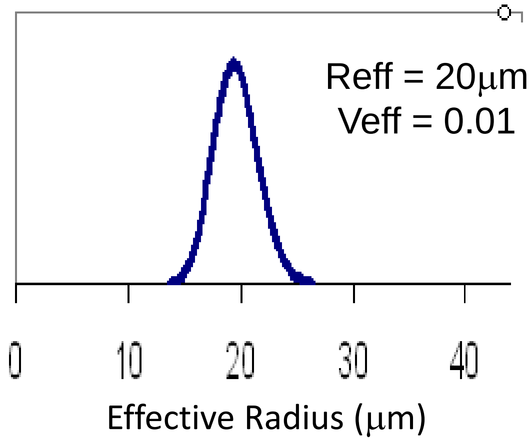
HARP Pioneering Hyper-Angular Capability will Provide Full Cloudbow Retrievals from Small Area (< 4x4km from space)

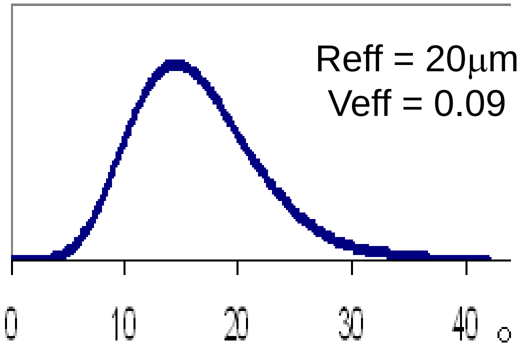
D and A produce cloud droplet effective radius and variance





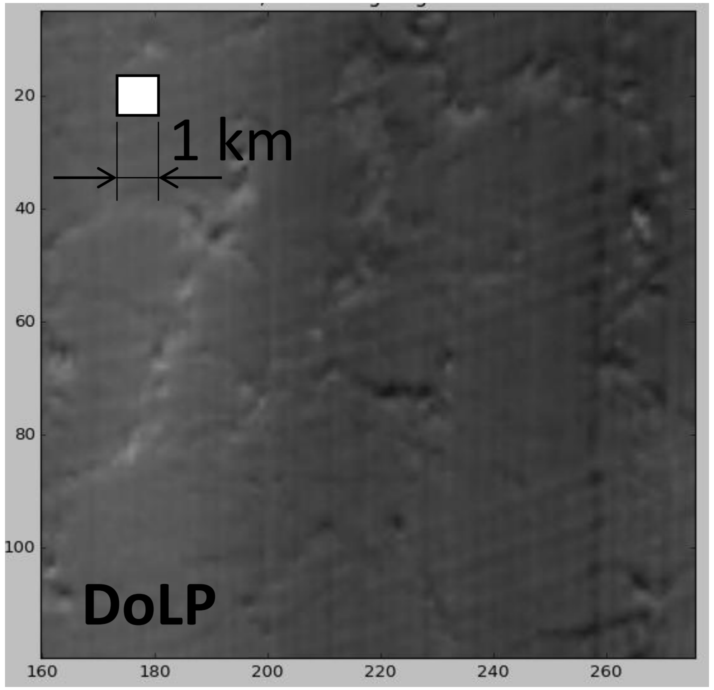
Water Droplet Distribution

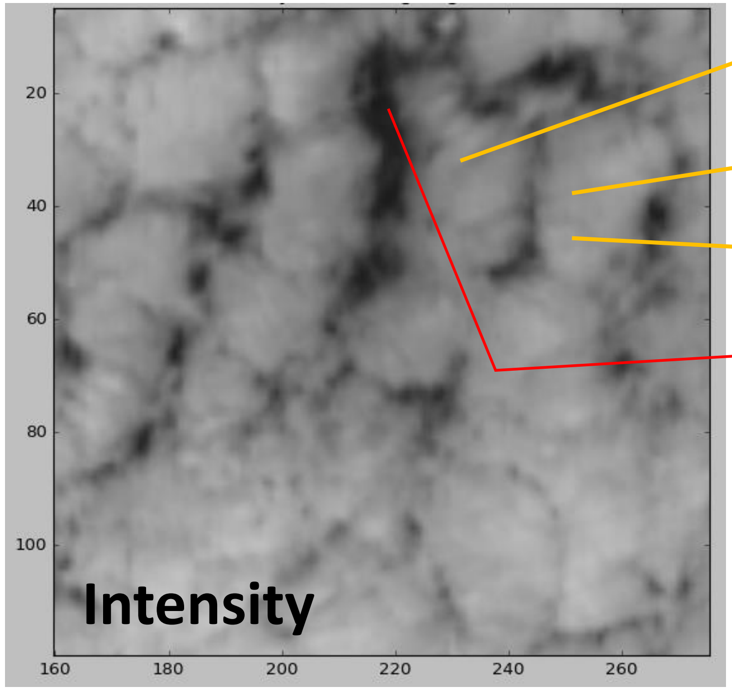


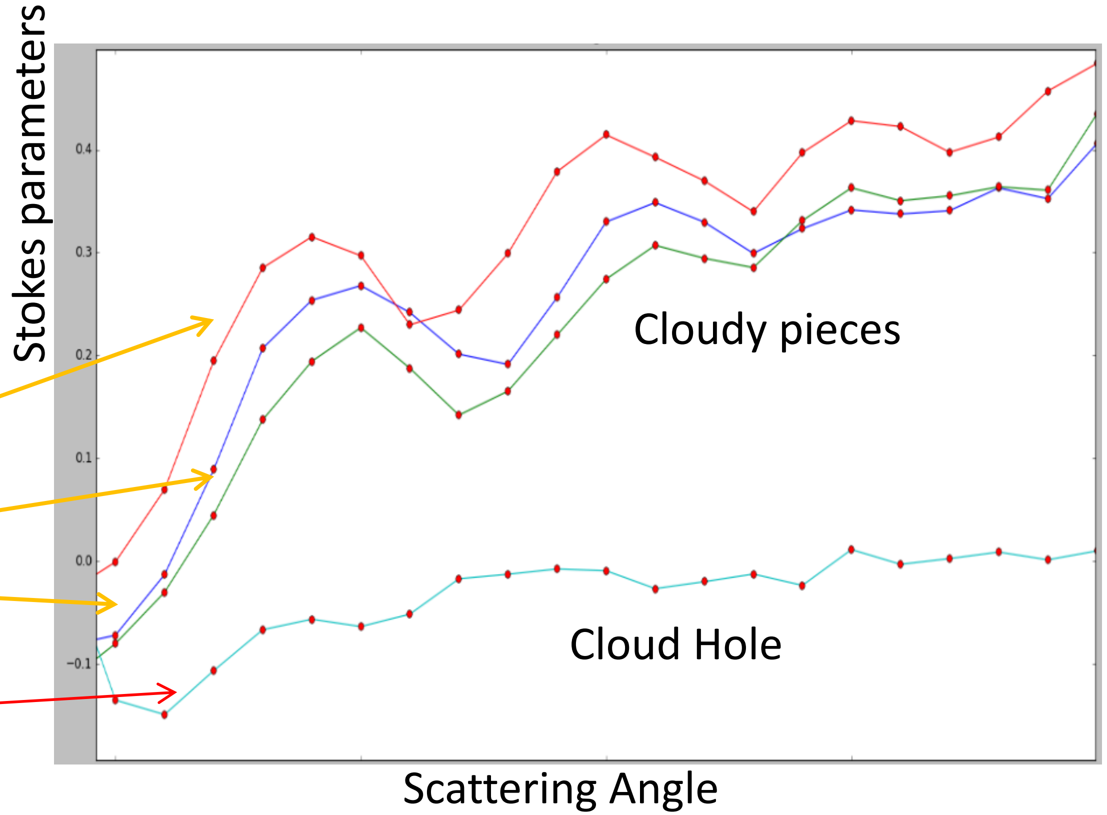


These two cases are undistinguishable from Intensity measurements only (MODIS/VIIRS)

HyperAngular High Resolution Cloudbow







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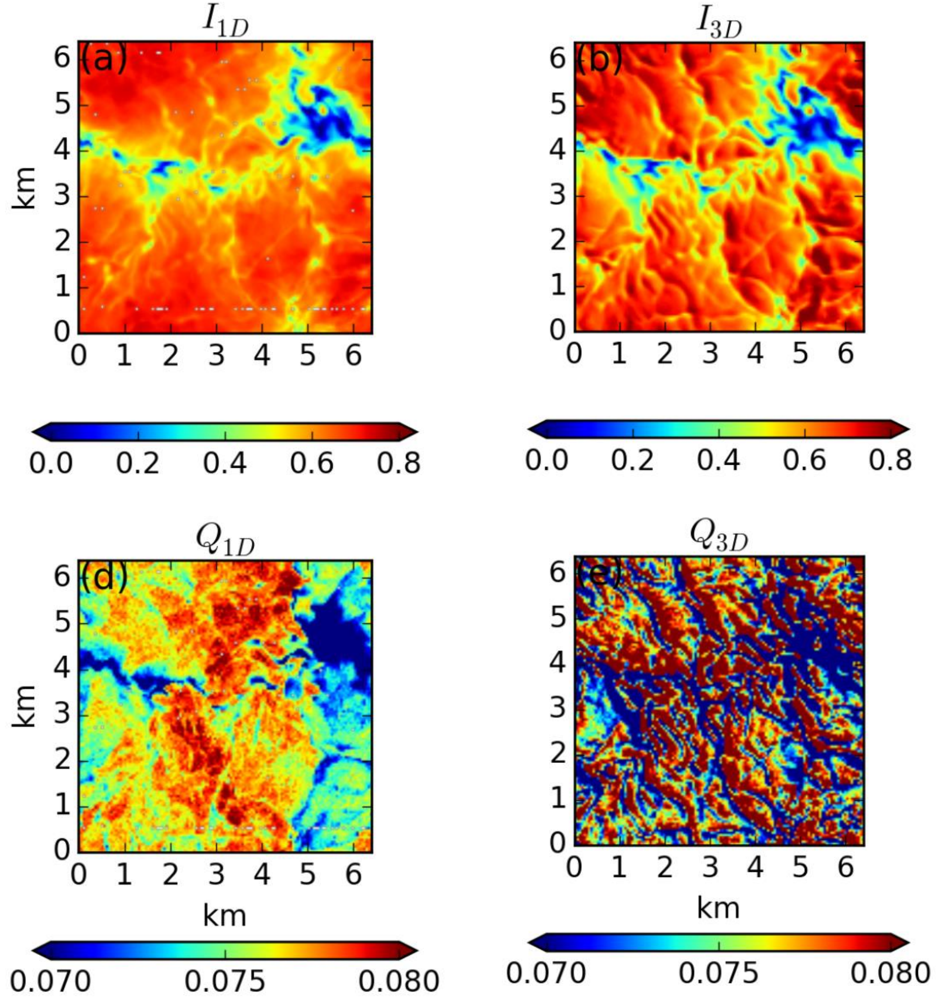
Evaluation of Cloud 3D Properties

LES and 3D RT simulations by Chamara Rajapakshe and Zhibo Zhang



AirHARP Data Set by Vanderlei Martins, Brent McBride and H. Barbosa