Characterizing Titan's haze with a balloon-borne spectropolarimeter SPEX

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Image: NASA/ESA TSSM report

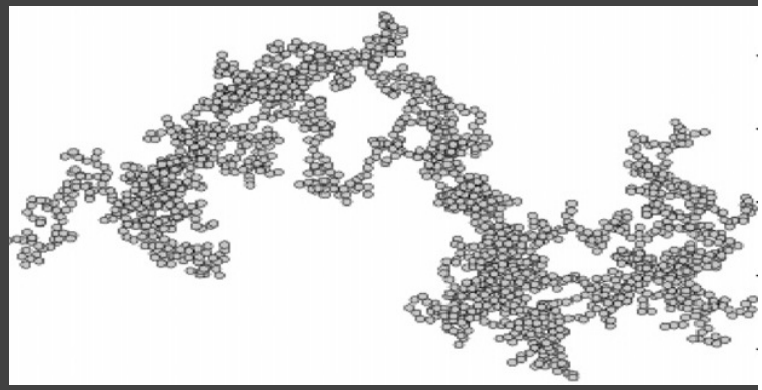
Content

- Titan's haze
- What is spectropolarimetry?
- How to do polarimetry?
- SPEX' novel polarimetry method
- SPEX on a balloon (animation)
- Conclusions

Aerosols in Titan's atmosphere

Huygens probe measurements indicate that these aerosols are aggregates of hydrocarbon monomers:

- Up to 3000 monomers
- Monomer radius → 0.04 ± 0.01 μm
- Aerosol radius → 3-6 μm



Bar-Nun 2008

What more do we want to know?

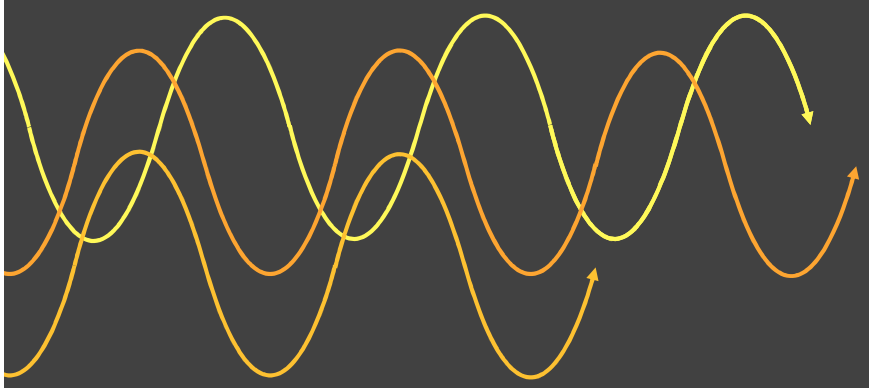
- Spatial & temporal variations in microphysical properties
- Spatial & temporal variations in 3D distribution

Wanted for aerosol characterization:

Spectropolarimetry from an airborne platform

What is spectropolarimetry?

A beam of light is *fully* described as a vector with its radiance and degree and direction of polarization:



$$\mathbf{I}(\lambda) = \begin{bmatrix} I(\lambda) \\ Q(\lambda) \\ U(\lambda) \\ V(\lambda) \end{bmatrix}$$

total radiance

linearly polarized radiance

circularly polarized radiance

The degree of (linear) polarization of the beam is:

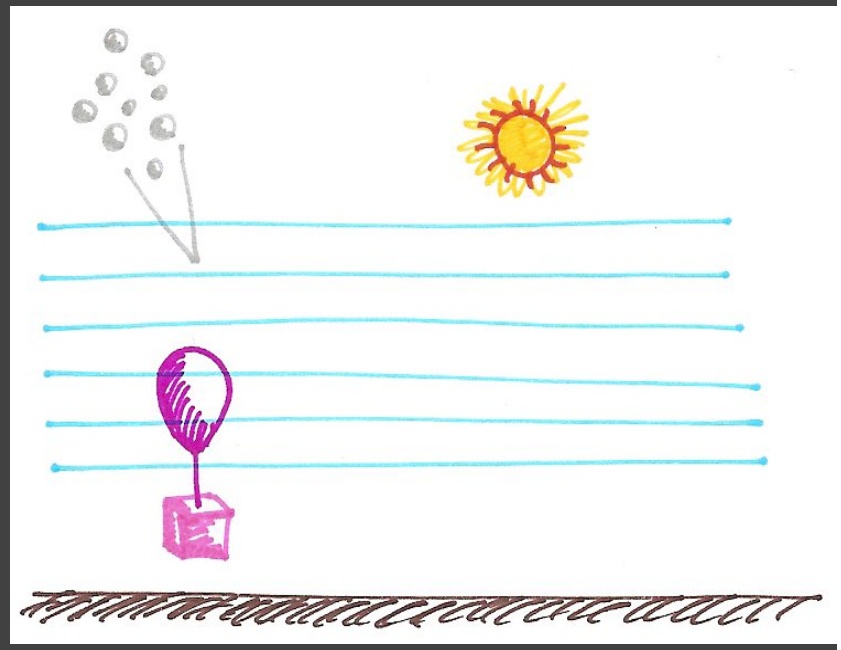
$$P(\lambda) = \frac{\sqrt{Q^2(\lambda) + U^2(\lambda)}}{I(\lambda)}$$

VERY SENSITIVE!

Calculations of scattered sunlight

We calculate *I* and *P* of sunlight that is scattered in Titan's atmosphere, as follows:

- atmosphere with 34 plane-parallel layers
- aggregate aerosol particles
- absorption by methane gas



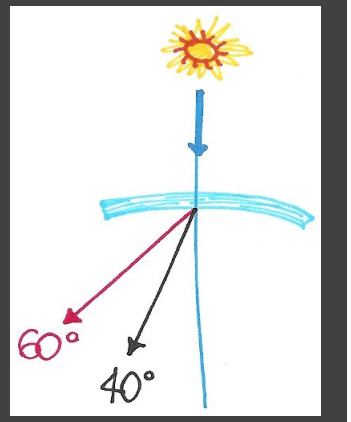
Single scattering : T-matrix

Multiple scattering : Adding-Doubling

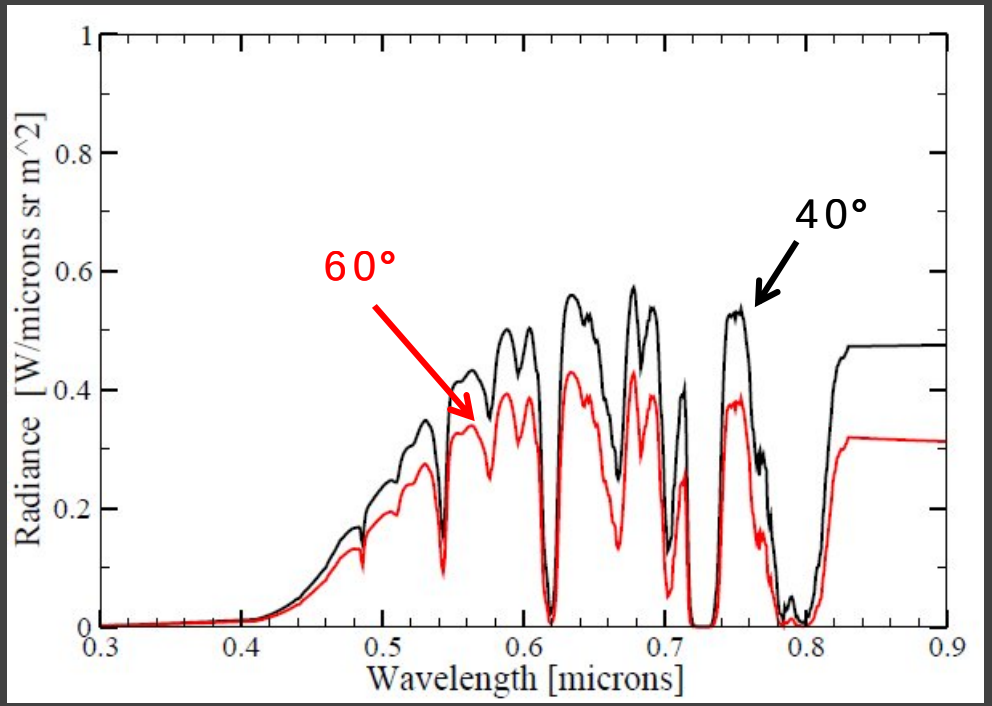
Calculated *I*- and *P*-spectra 1

Total aerosol optical thickness: 8.1 @ 0.55 µm

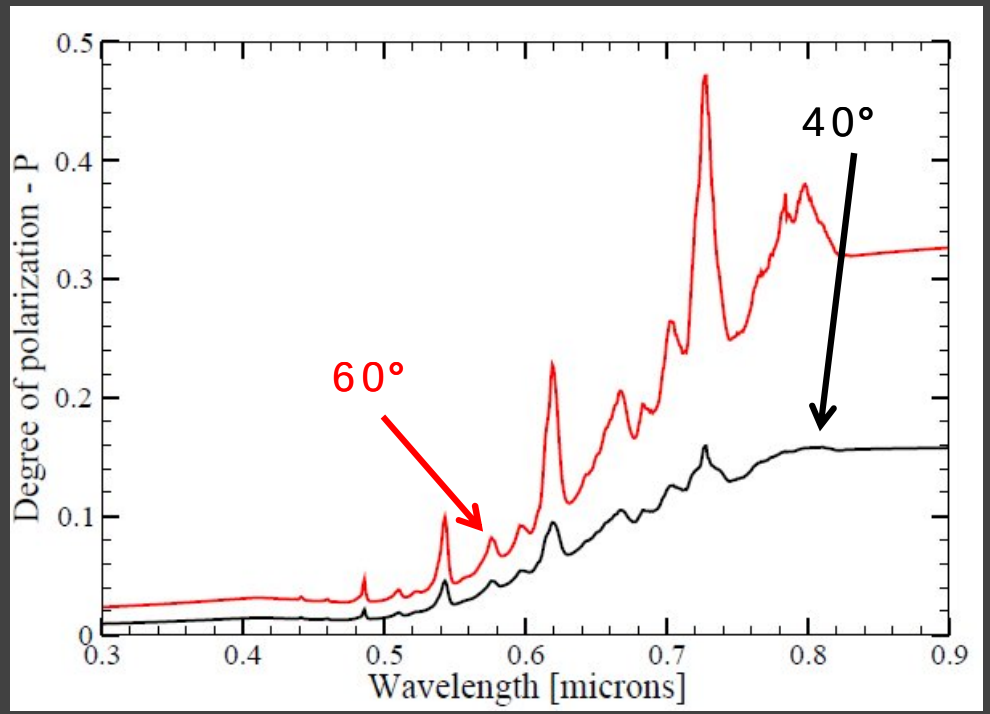
The solar zenith angle is 0°



Total radiance

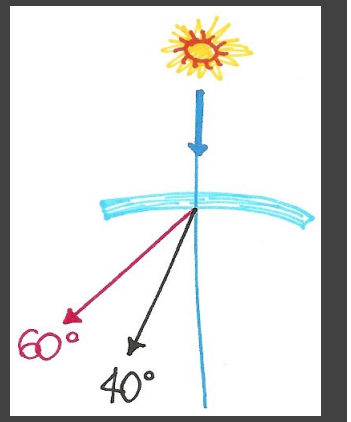


Degree of polarization

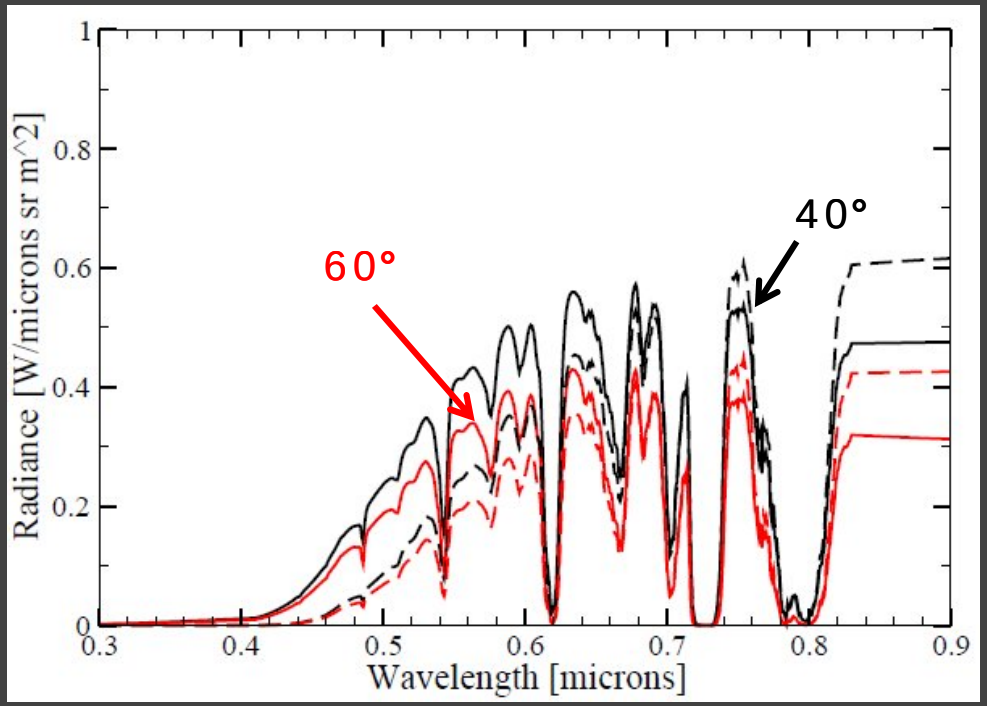


Calculated *I*- and *P*-spectra 2

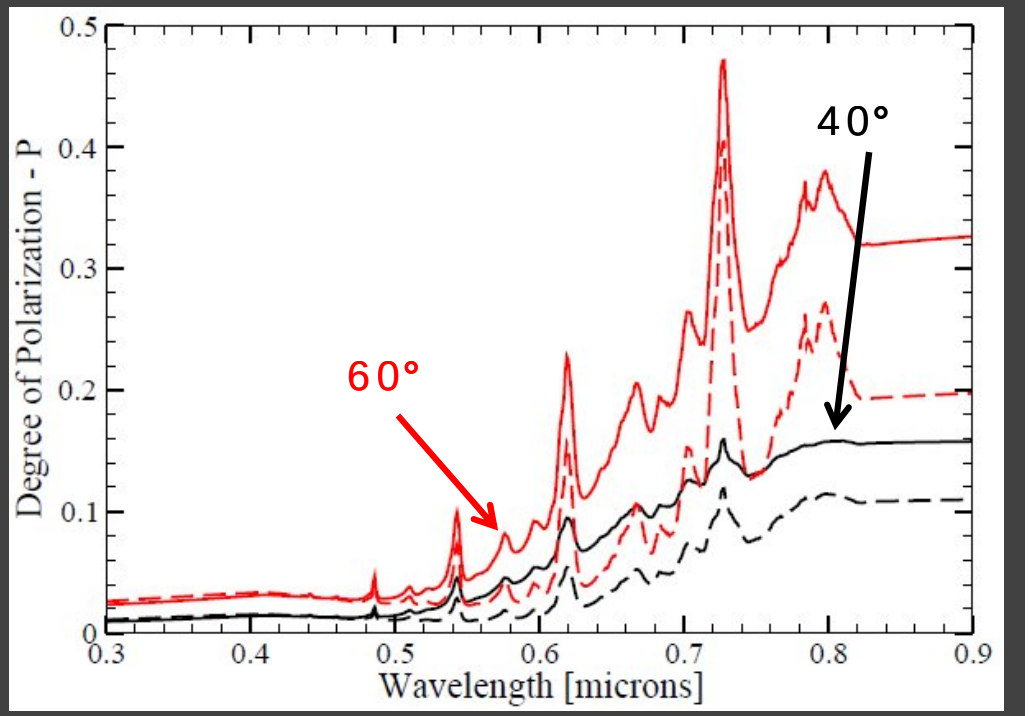
Total aerosol optical thickness: 8.1 (solid lines)
Total aerosol optical thickness: 16.2 (dashed)
The solar zenith angle is 0°



Total radiance

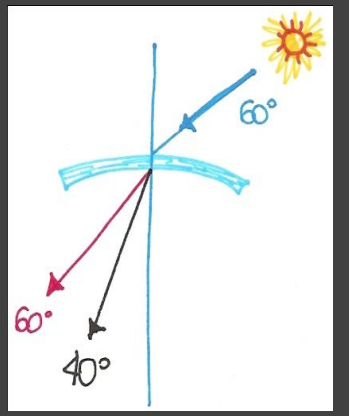


Degree of polarization

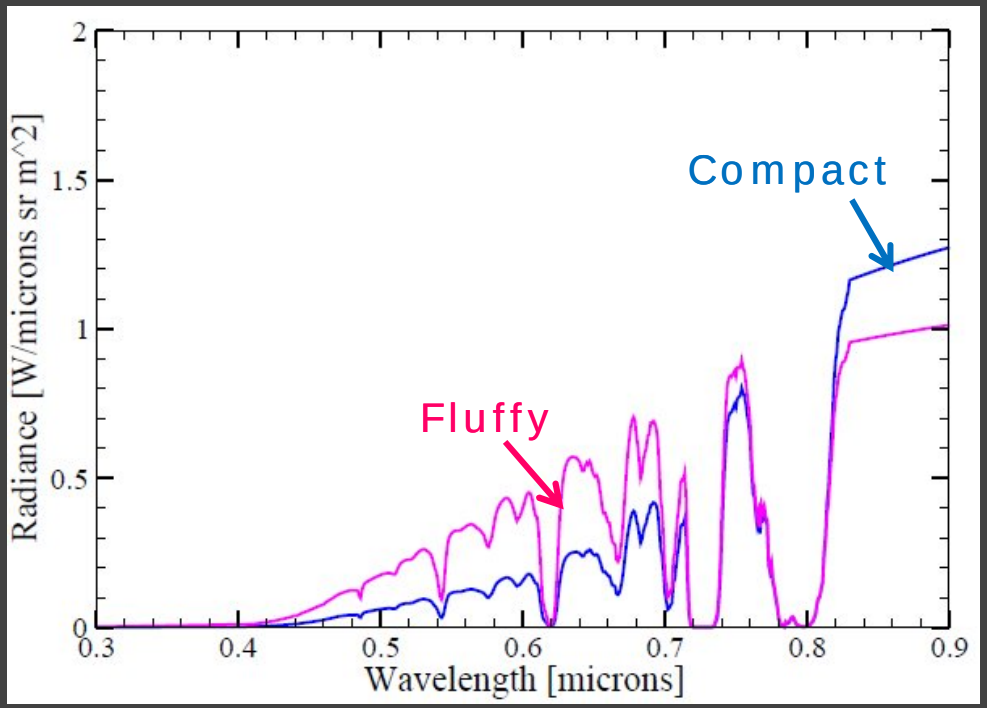


Calculated *I*- and *P*-spectra 3

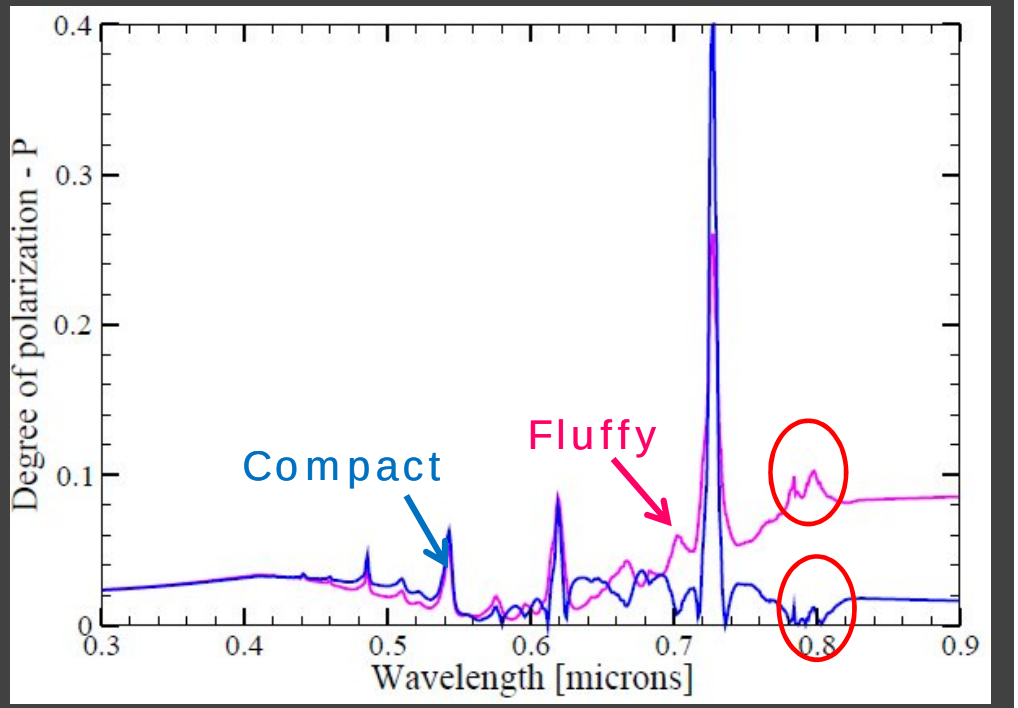
Total aerosol optical thickness: 8.1 (solid lines)
Fluffy versus compact particles
The solar zenith angle is 60°



Total radiance

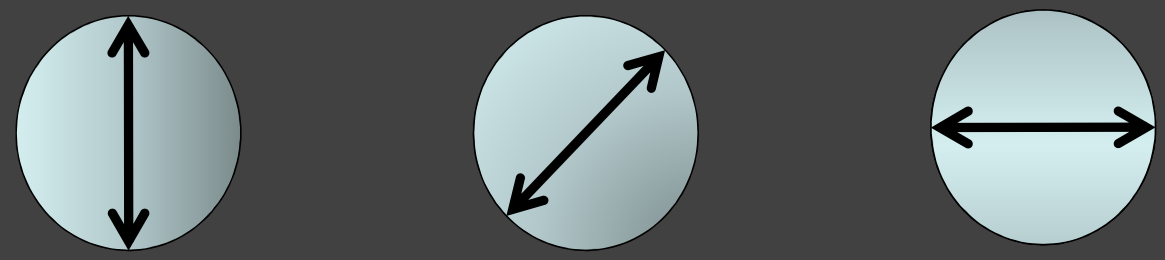


Degree of polarization



How to do polarimetry?

Classical polarimetry: derive *I*, *Q* and *U* from radiances measured through polarization filters in 3 orientations:



Disadvantages of such polarimetry for planetary missions:

- rotating polarization filters (can get stuck)
- differences in filter optical properties
- time differences between measurements
- usually a few wavelengths

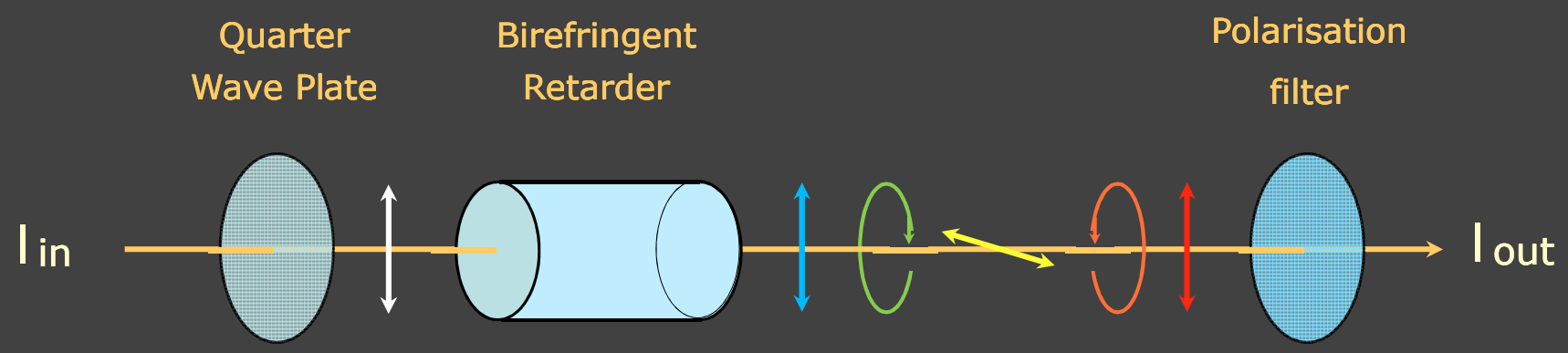
Example: DISR on Huygens probe (2 filters, 2 wavelengths)

SPEX

Spectropolarimeter for Planetary EXploration

SPEX' novel polarimetric method [Snik et al. 2009]:

With a fixed series of birefringent crystals, the *I*-spectrum is spectrally modulated with the *P*-spectrum

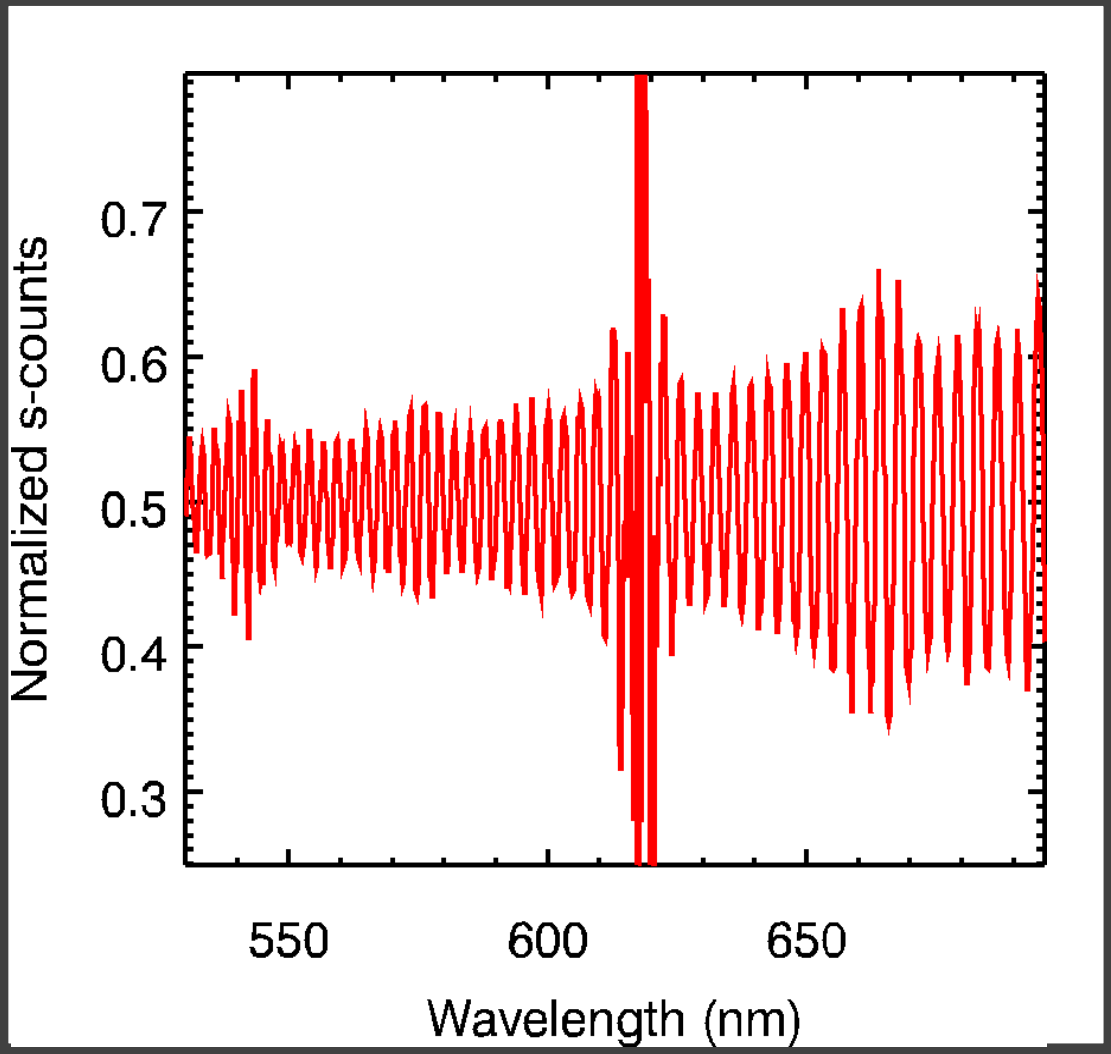


$$I_{out}(\lambda) = 0.5\, I_{in}(\lambda)\, (1 \pm P(\lambda) \cos(2\chi(\lambda) + 2\pi\delta/\lambda))$$

sign depends on the orientation of the polarisation filter

retardance of the birefringent retarder

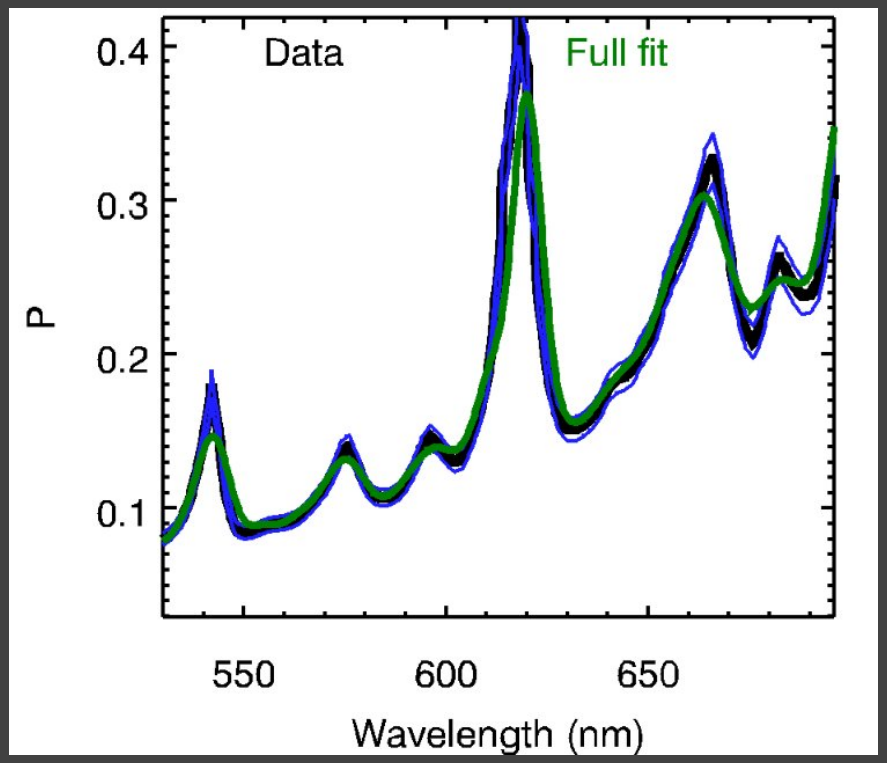
A spectrally modulated *I*-spectrum:

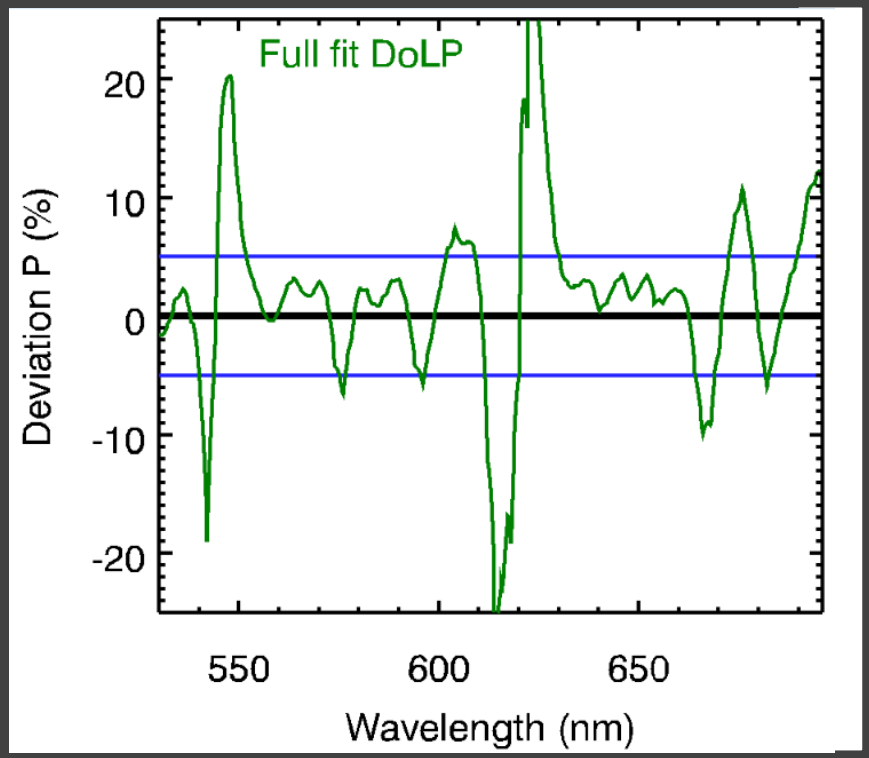


SPEX' retrieval accuracy of *P*

SPEX design for Titan (resolving methane bands):

d = 80 mm, d= 16 mm





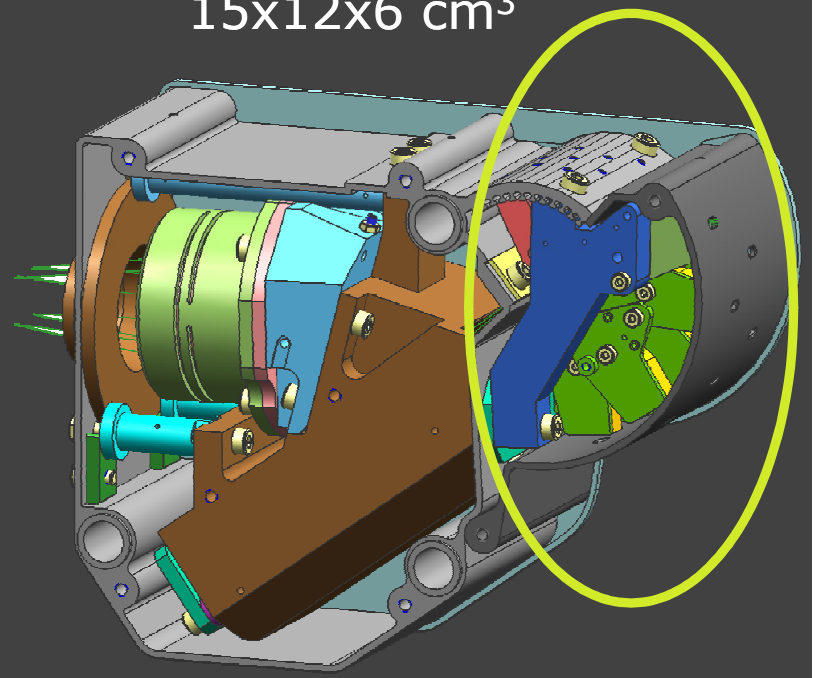
Retrieval accuracy better than about 5 %

SPEX status

SPEX method summary:

- Measures *I* and *P* simultaneously
- Continuously from ~ 400 to 800 nm
- With 2 nm (*I*) to 10 nm (*P*) resolution
- Without moving parts
- Small, robust, low-power

Dimensions:
15x12x6 cm^3



SPEX status:

- SPEX has been tested with zenith sky measurements
- A demonstration model is being build

MOVIE TIME

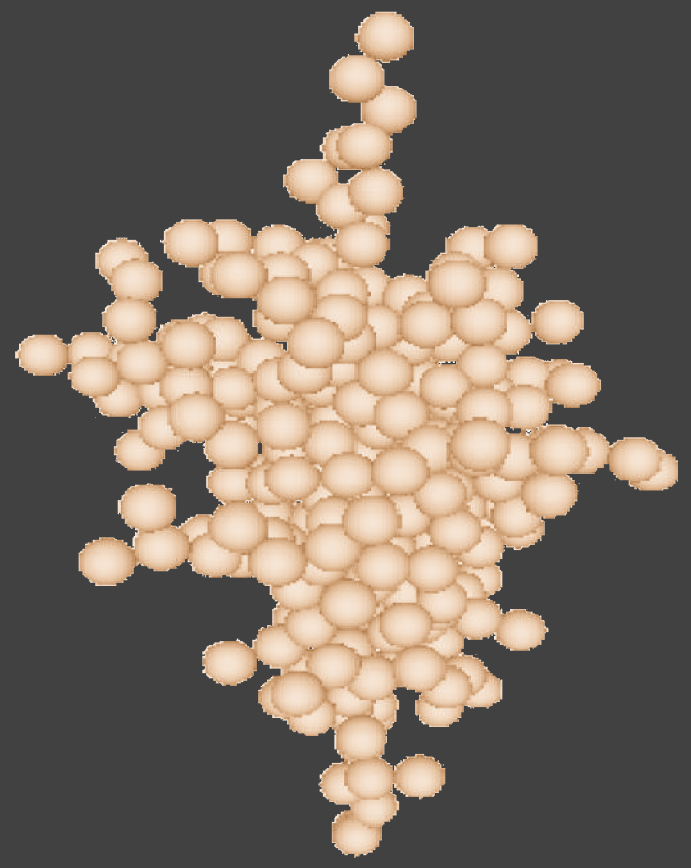
Conclusions

- *P* is very sensitive to the microphysical properties of the aerosols particles
- Needed for aerosol characterization: spectropolarimetry from an airborne platform
- SPEX' novel polarimetry method : the *I*-spectrum is spectrally modulated with the P-spectrum
- SPEX' retrieval accuracy of P is within 5%

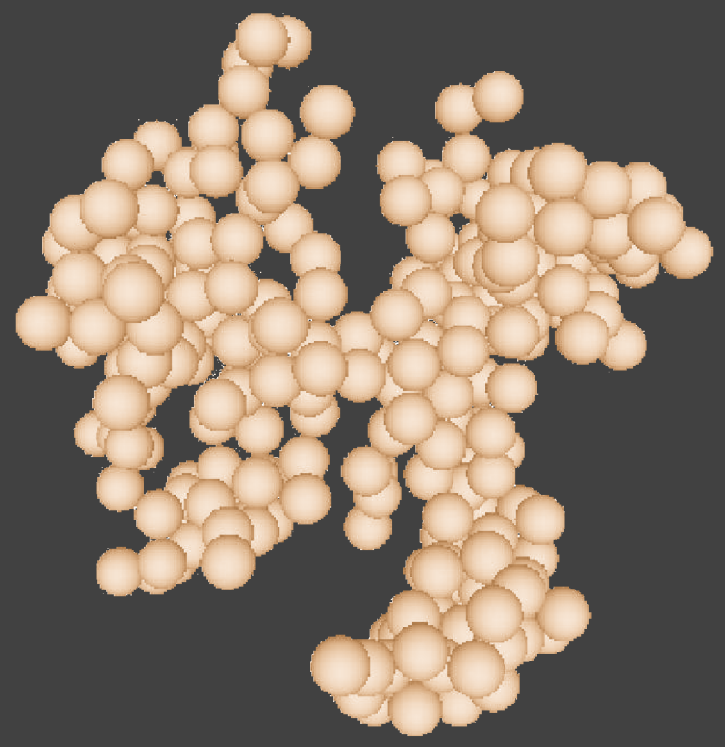
SPEX on the TSSM balloon would be a powerful tool for characterizing Titan's haze

www.sron.nl/spexinstrument

Aerosols example



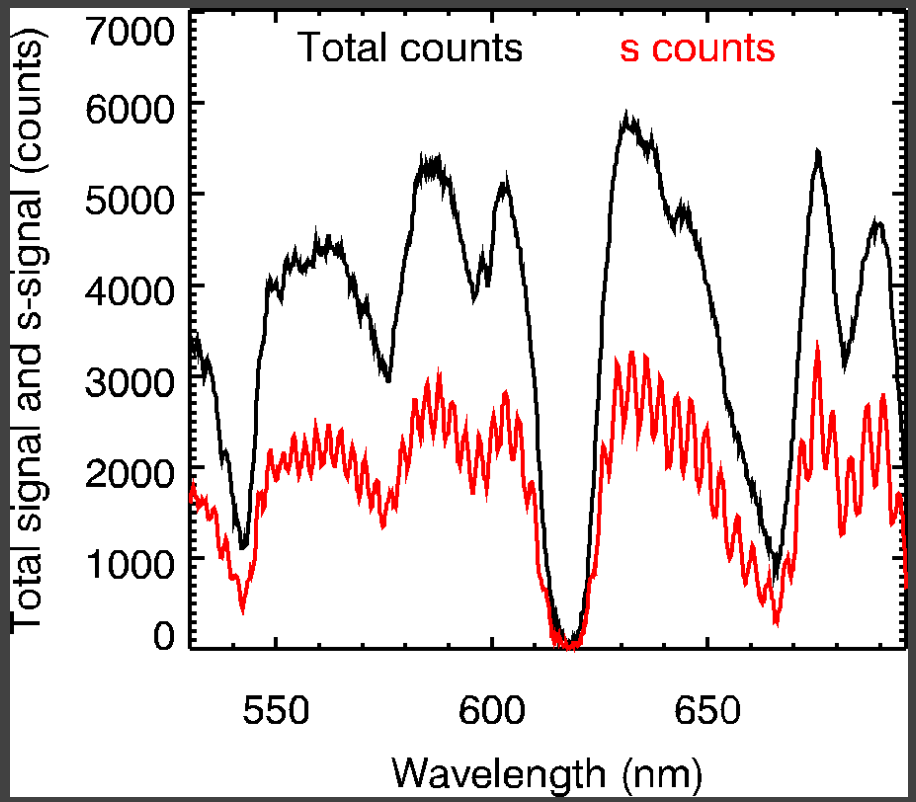
Fluffy BPCA



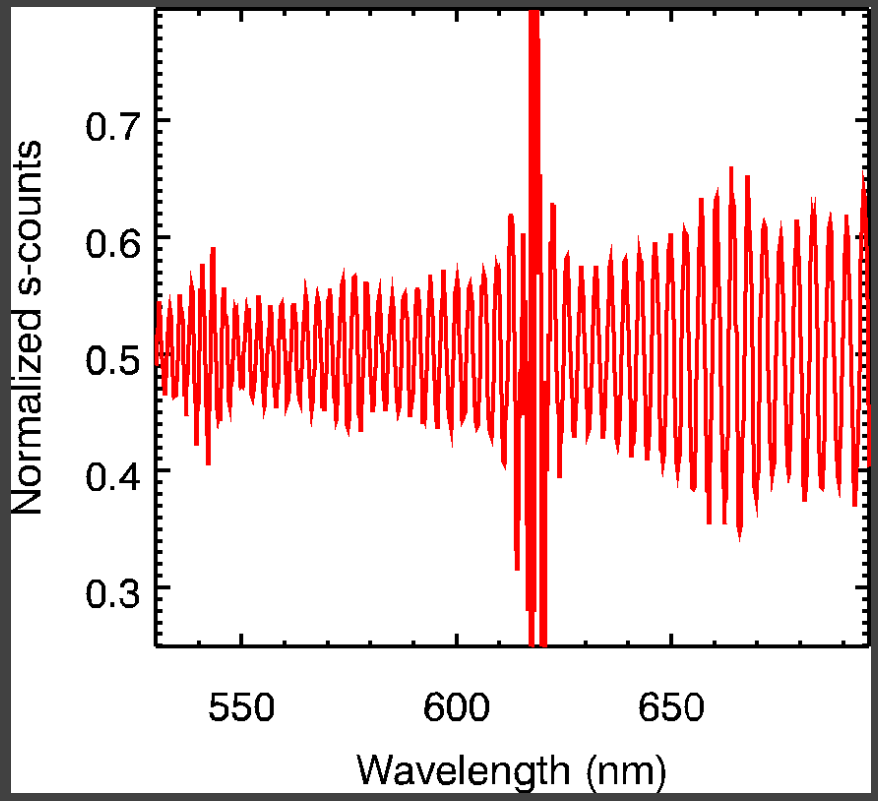
Compact DLA

- BPCA= Ballistic Particle-Cluster Aggregation , DLA= Diffusion-Limited Aggregation

Modulation example



Modulation of the incoming flux



Modulated signal
(amplitude proportional to *P*)