Cometary Dust: A Window to the Evolution of the Solar System

Yuna G. Kwon

Technische Universität Braunschweig

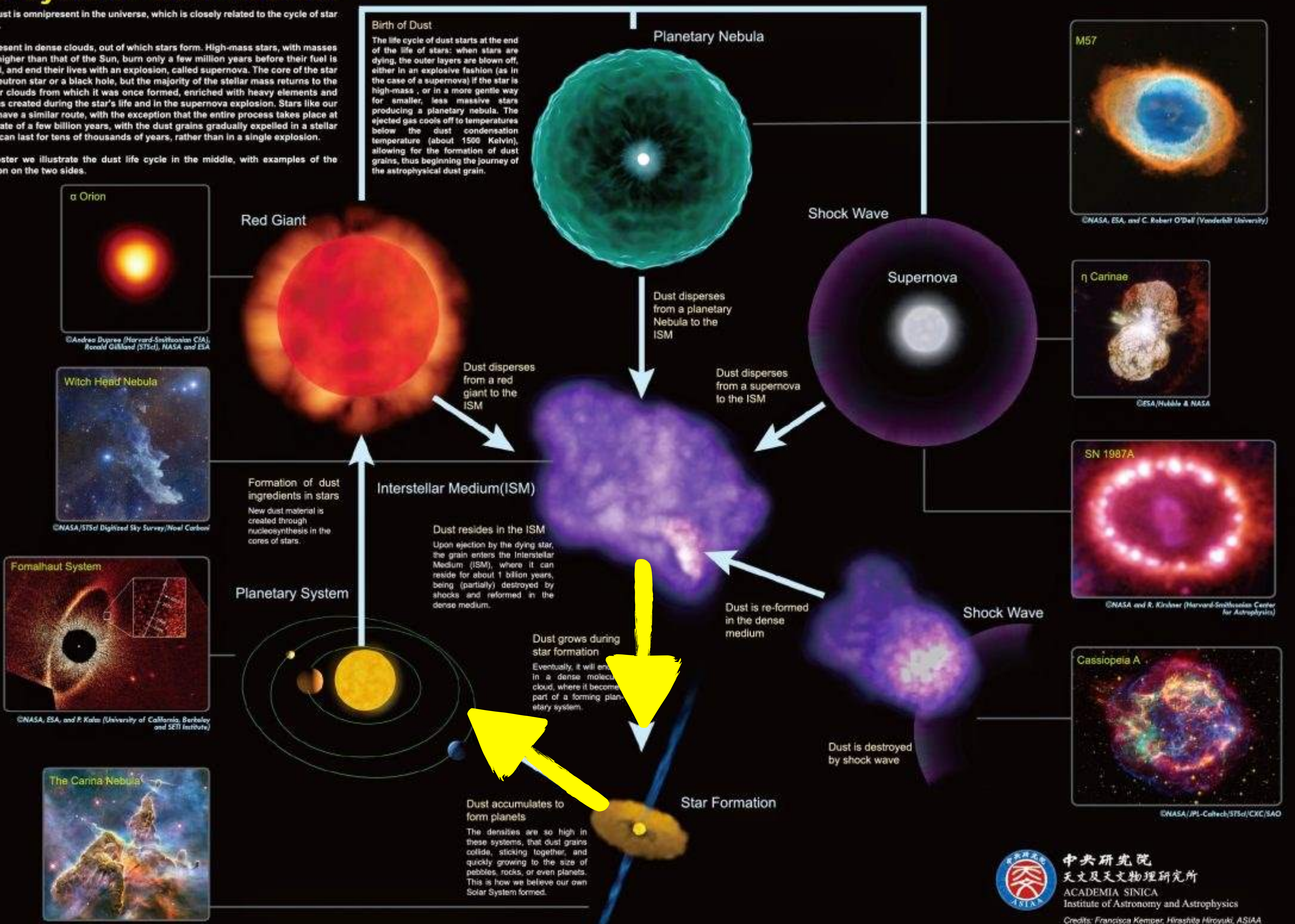
Virtual RG Mitte-Nord meeting
20:15 p.m., 23 June, 2021

Life Cycle of Cosmic Dust

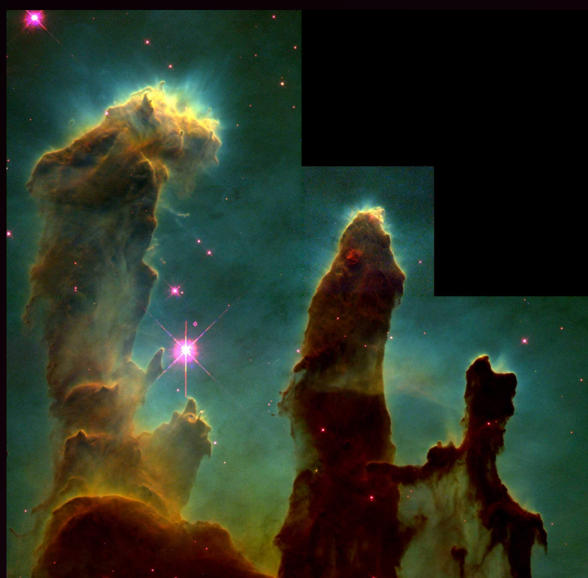
Cosmic dust is omnipresent in the universe, which is closely related to the cycle of star formation.

Dust is present in dense clouds, out of which stars form. High-mass stars, with masses 10 times higher than that of the Sun, burn only a few million years before their fuel is exhausted, and end their lives with an explosion, called supernova. The core of the star forms a neutron star or a black hole, but the majority of the stellar mass returns to the interstellar clouds from which it was once formed, enriched with heavy elements and dust grains created during the star's life and in the supernova explosion. Stars like our own Sun have a similar route, with the exception that the entire process takes place at a slower rate of a few billion years, with the dust grains gradually expelled in a stellar wind that can last for tens of thousands of years, rather than in a single explosion.

In this poster we illustrate the dust life cycle in the middle, with examples of the observation on the two sides.

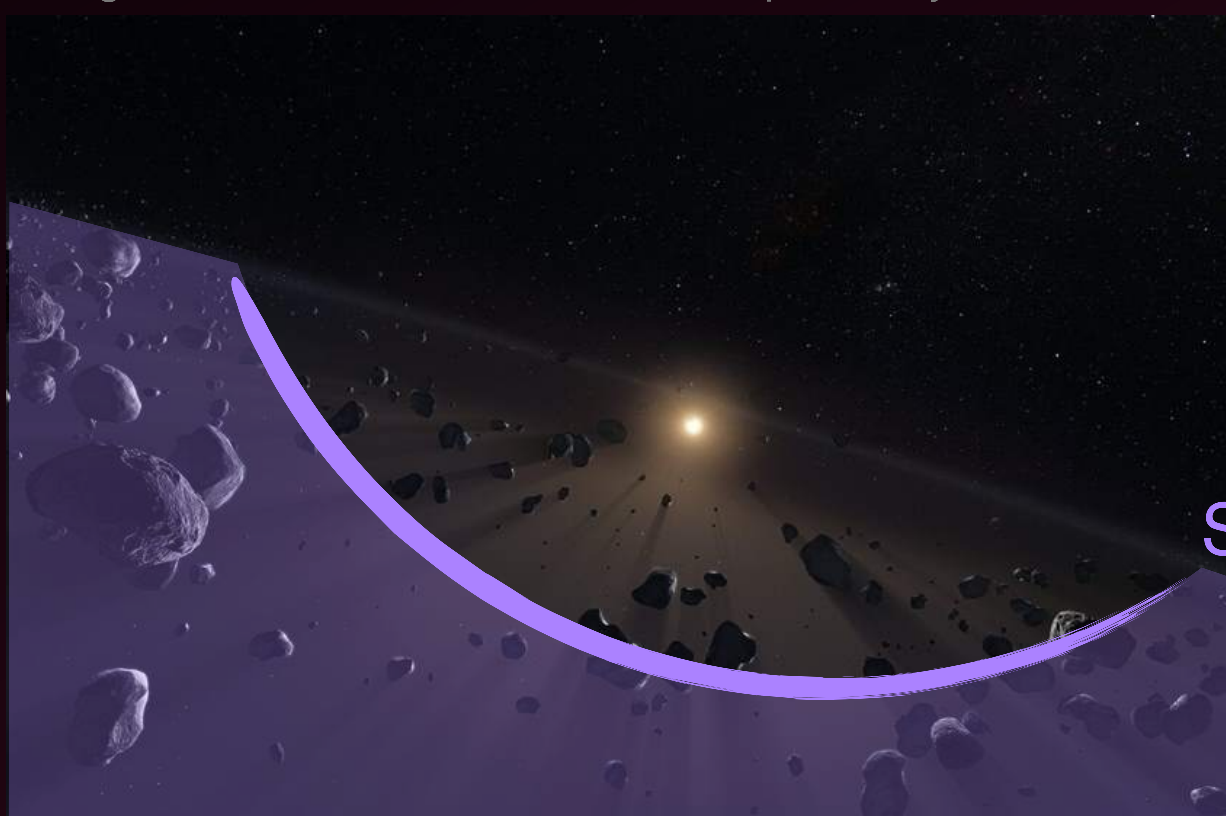


Primordial Small Bodies



Eagle Nebula, NASA/JPL

Protoplanetary disk, ESO



Young debris disk, NASA/JPL

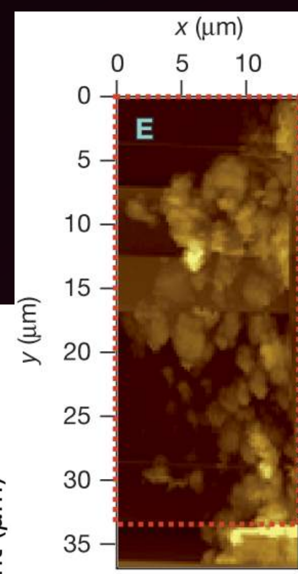
Volatile, Organic-rich
Planetesimals
Left from the
Formative Epoch
of the Solar System

↓

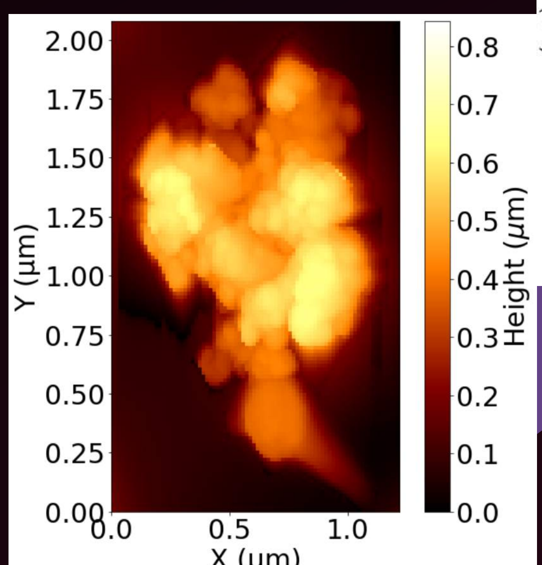
Comets

Hierarchical Structure of Dust

The ESA/*Rosetta* mission successfully detected the nature of dust constituents

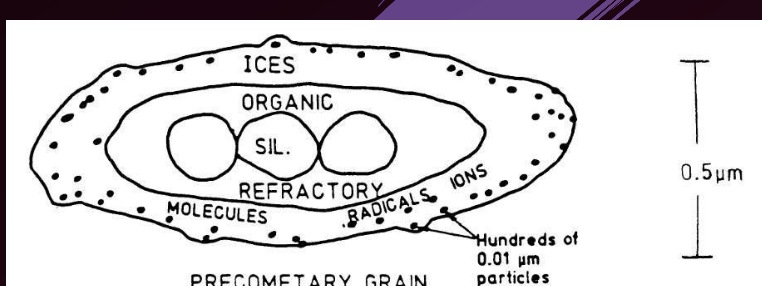


© ESA/Rosetta MIDAS



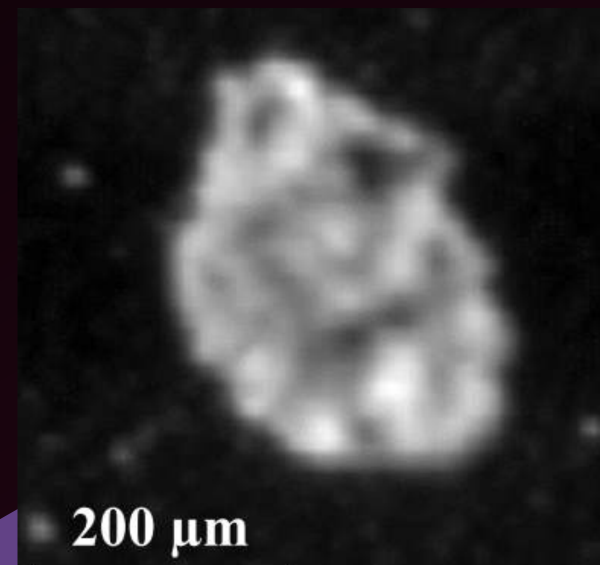
Güttler+2019, A&A

Aggregates
(~1-10 μm)



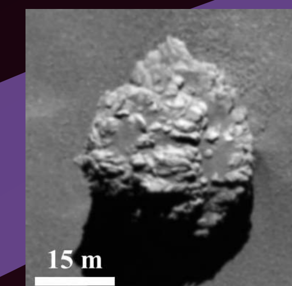
Greenberg & Hage 1990, ApJ

Monomers
(~0.1 μm)



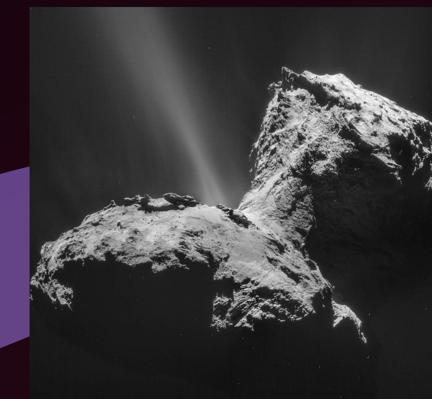
© ESA/Rosetta/COSIMA

Agglomerates
(~100 μm)



© ESA/Rosetta/ OSIRIS

Pebbles
(~0.1—1 cm)
Boulders
($\gtrsim$ 1m)



67P/Churyumov-Gerasimenko, ESO

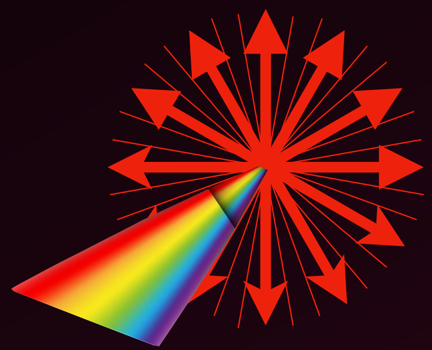
km-sized comet

- From the interstellar-sized grains to the pebbles.
- Opening up the new research field of dust aggregates

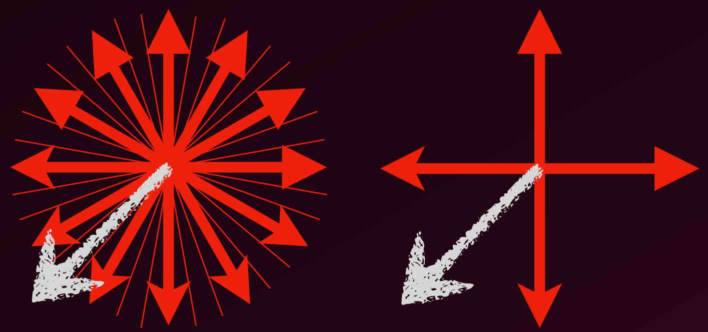
Scattered Light Observations

Photometry

Spectroscopy



Polarimetry



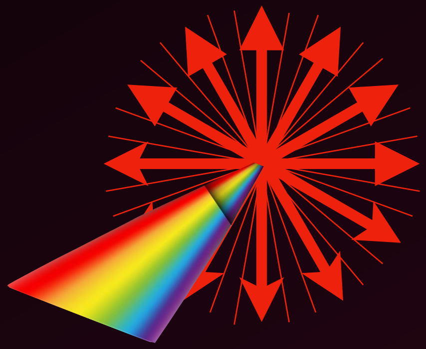
Scattered Light Observations

Photometry

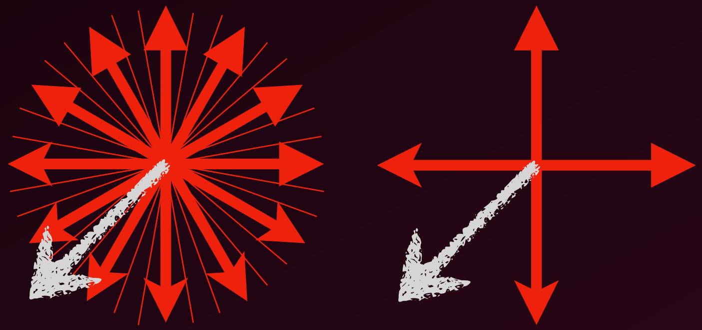
Kwon et al. (2017)

- Integration of photons over the aperture
- ∝ # of dust particles
- Changes in coma brightness and morphology
- A proxy of the activity level of a comet

Spectroscopy



Polarimetry

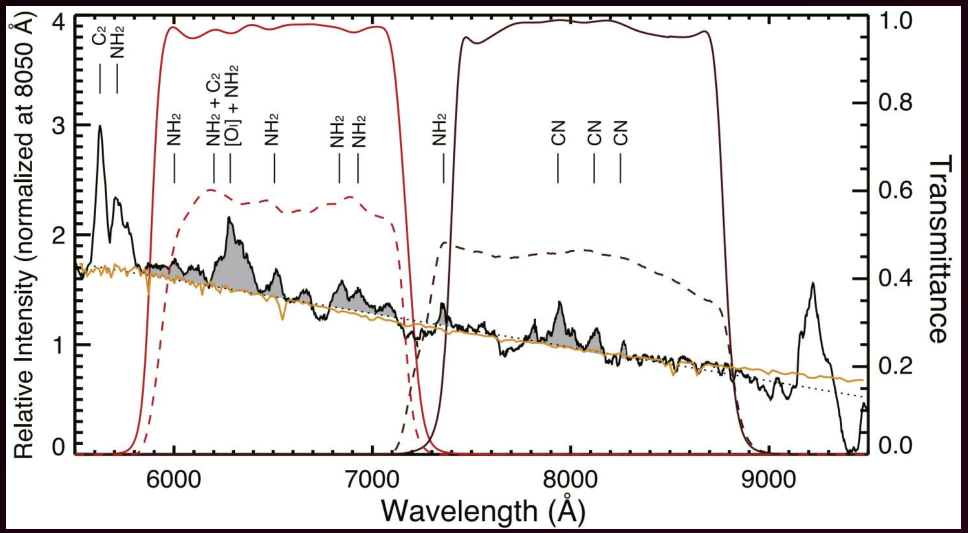


Scattered Light Observations

Photometry

Kwon et al. (2017)

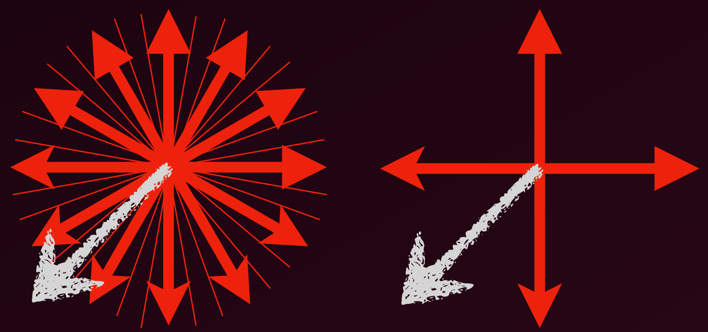
Spectroscopy



Kwon et al. (2017)

- Integration of photons over the spectral bin
- ∝ # of dust particles
- Changes in continuum and line intensities
- Coma composition, a proxy of the activity level of a comet

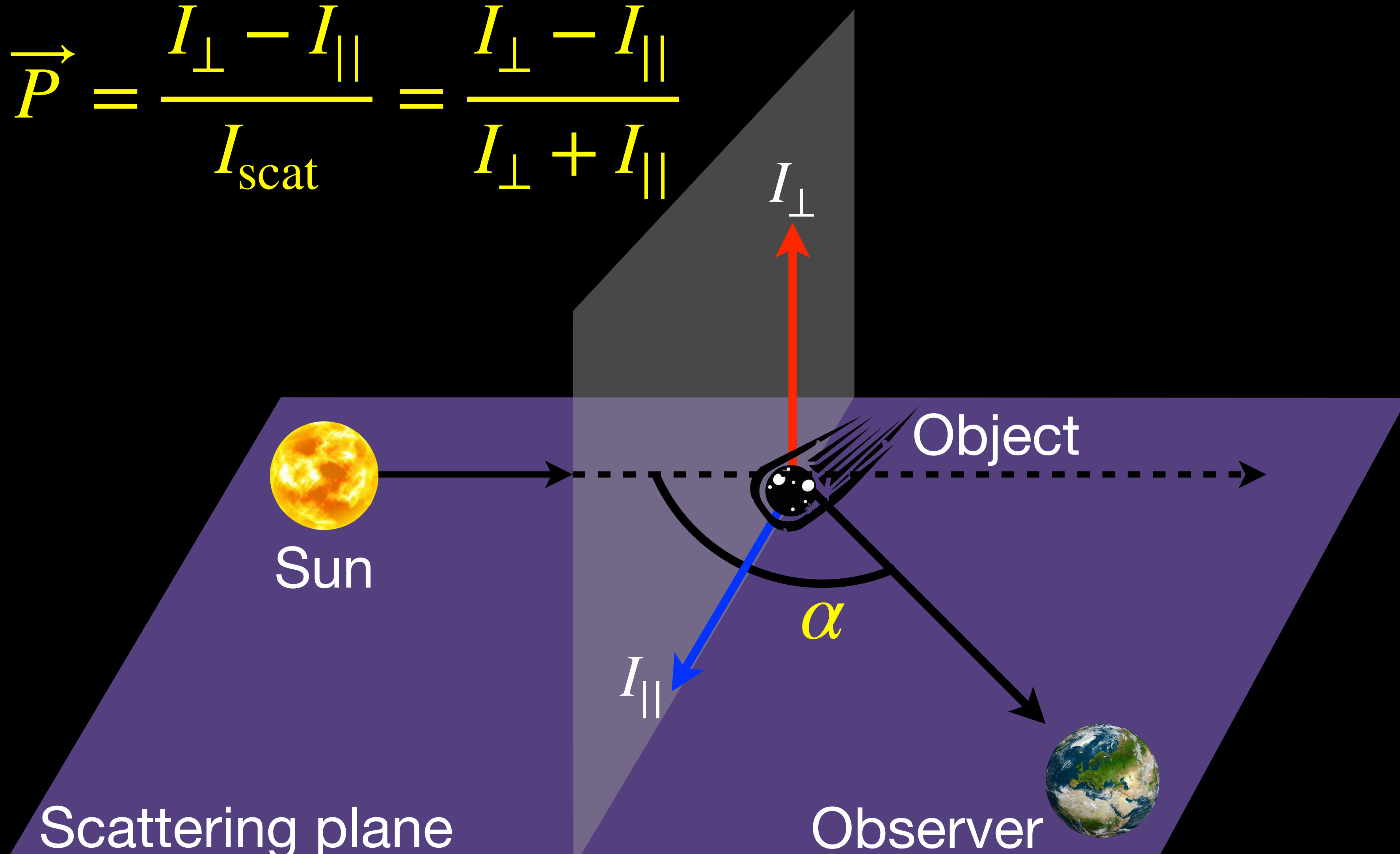
Polarimetry



Scattered Light Observations

Polarimetry for solar system small bodies

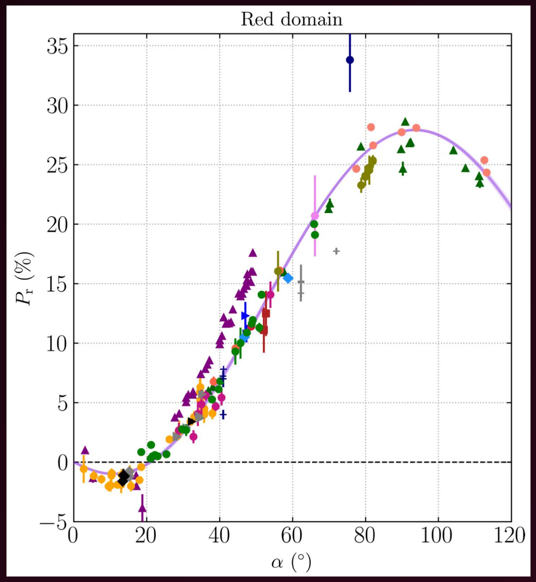
$$\vec{P} = \frac{I_{\perp} - I_{||}}{I_{\mathrm{scat}}} = \frac{I_{\perp} - I_{||}}{I_{\perp} + I_{||}}$$



(=Plane of incidence)

α : Phase angle

Polarimetry



Kwon et al. (in prep.)

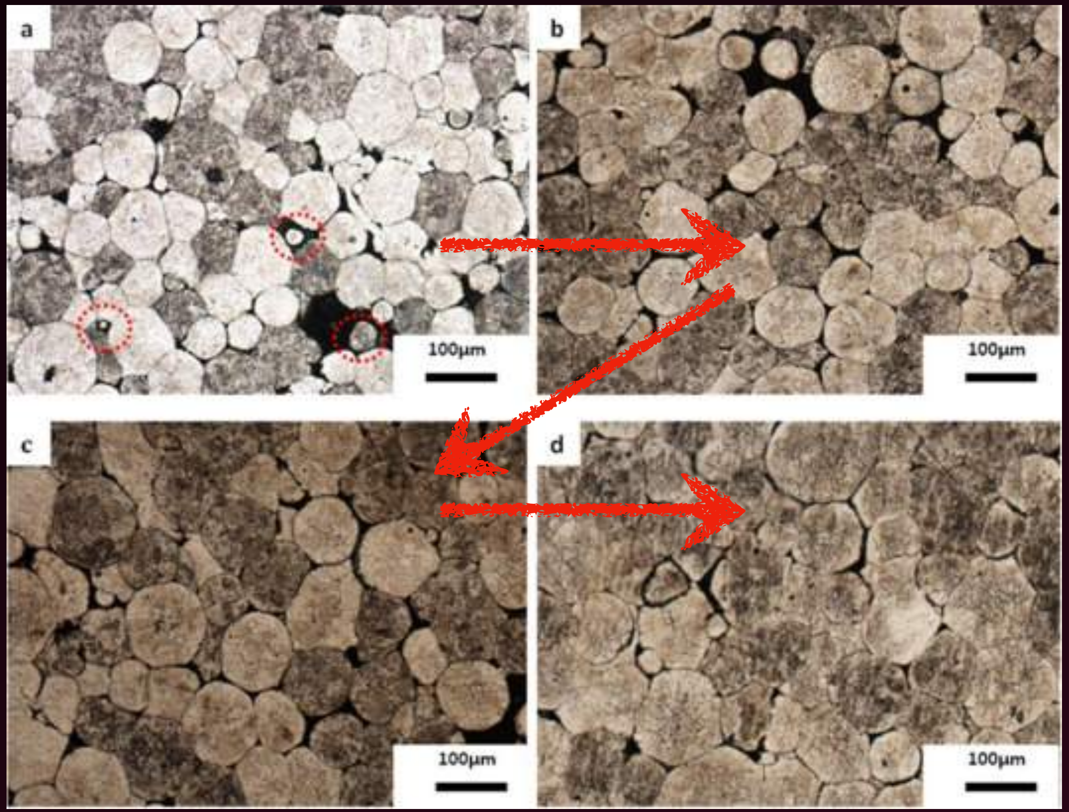
- The ratio of the intensity passing through polarizers
- Changes in dust characteristics
- The microphysical and compositional properties of dust

Dust evolution near the Sun

Once comets start orbital motions around the Sun, changes in radiative and thermal environments entail the development of unique dust features.

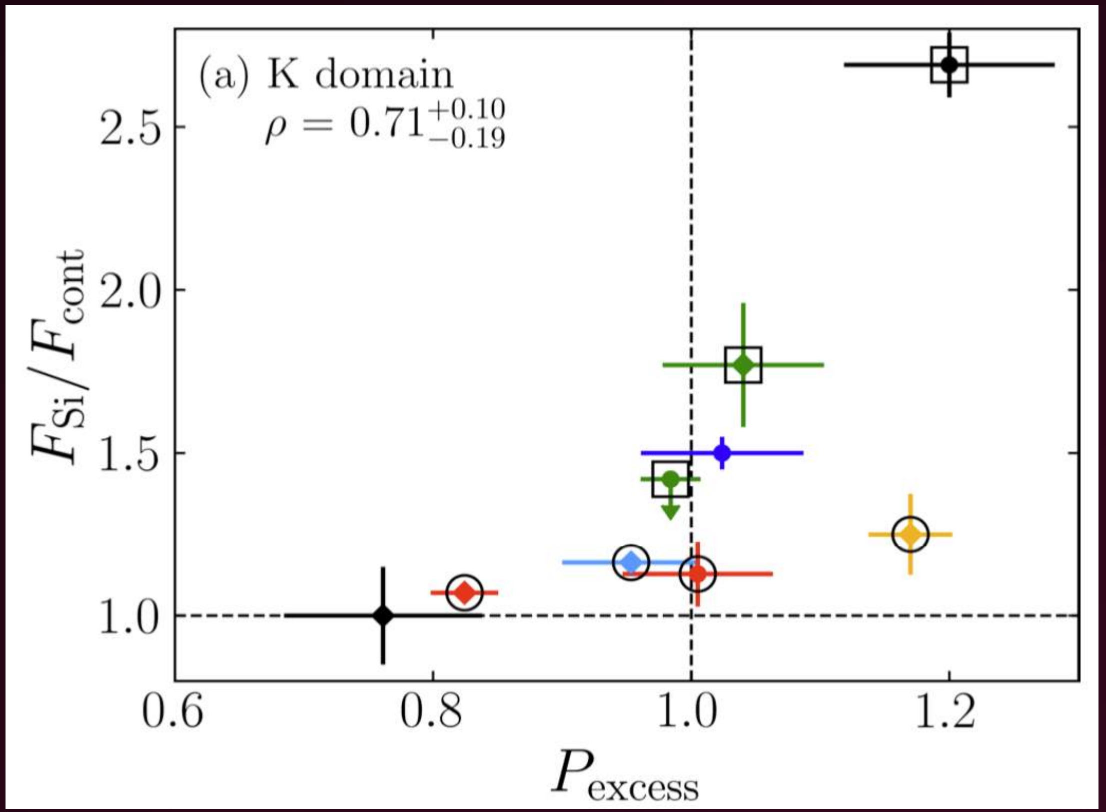
→ *changes in e.g., size, porosity, and composition*

Shongwe et al. 2015



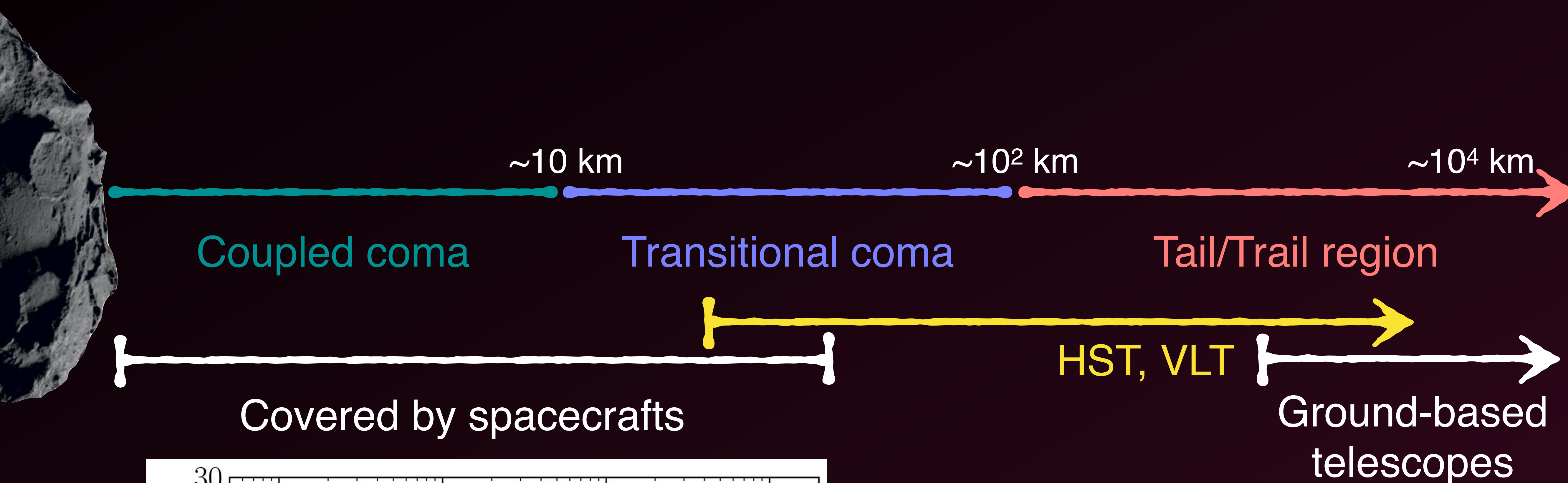
For example, the sintering effect of dust and ice particles by excessive solar heat near the perihelion, changing the thermal and mechanical properties of dust

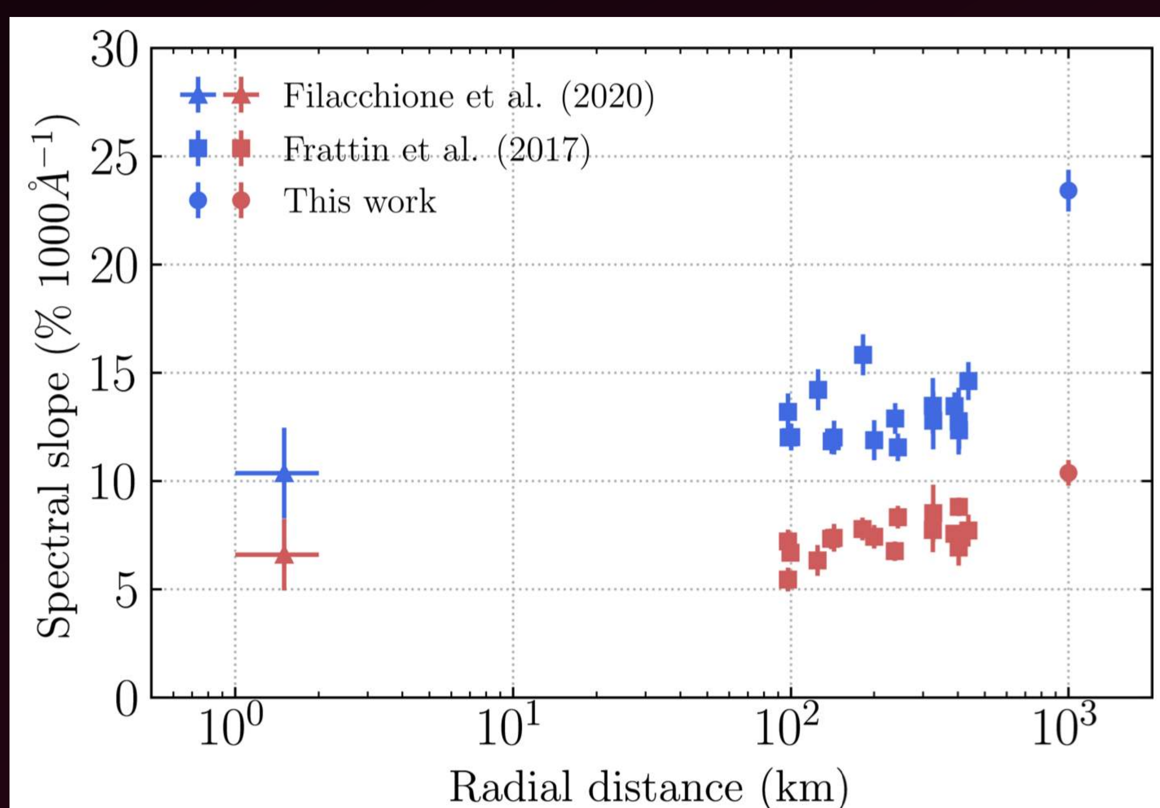
Kwon et al. 2021a



The positive correlation between polarimetric and thermal properties of cometary dust, implying the evolutionary effect on the dust porosity

Linking in-situ & ground-based





Kwon et al. (in prep.)

Establishing the connection of the in-situ data to a wider set of comets for which only ground-based observations are available

Summary

We aim to leverage cometary dust as a window to the evolution of the solar system. Ongoing projects are as follows.

- ⋆ Constraints on the microphysical and compositional properties of comets throughout the apparition
- ⋆ Establishing correlations between the observables
- ⋆ Filling the missing link in spacetime between in-situ and ground-based observations of cometary dust

To draw a more comprehensive picture for working mechanisms in the solar system

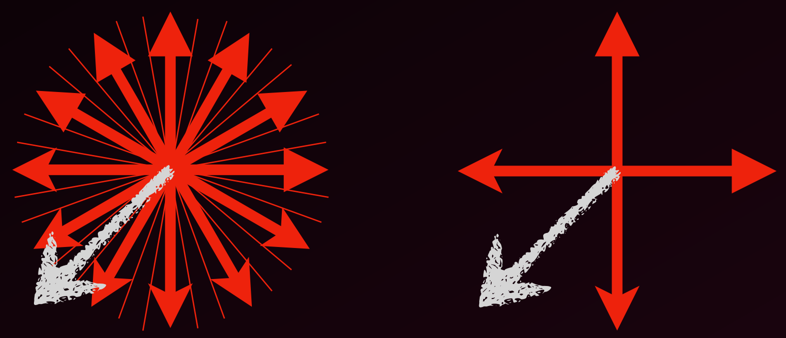
- ⋆ Preparation of the Comet Interceptor mission!

ynkwontop@gmail.com   y.kwon@tu-braunschweig.de


Supplementary Materials

Polarization of Cometary Dust

Fundamental reason for the existence: ***Heterogeneity*** → ***<u>Light scattering</u>***



$$\vec{E}(t) = \vec{E_0}(t)\exp(i\vec{k}\cdot\vec{x} - i\omega t)$$

Maxwell's *macroscopic* equations

$$\nabla \cdot \vec{E} = 0 \qquad \nabla \cdot \vec{H} = 0$$

$$\nabla \times \vec{E} = -\mu^* \frac{\partial \vec{H}}{\partial t}$$

$$\nabla \times \vec{H} = \varepsilon^* \frac{\partial \vec{E}}{\partial t}$$

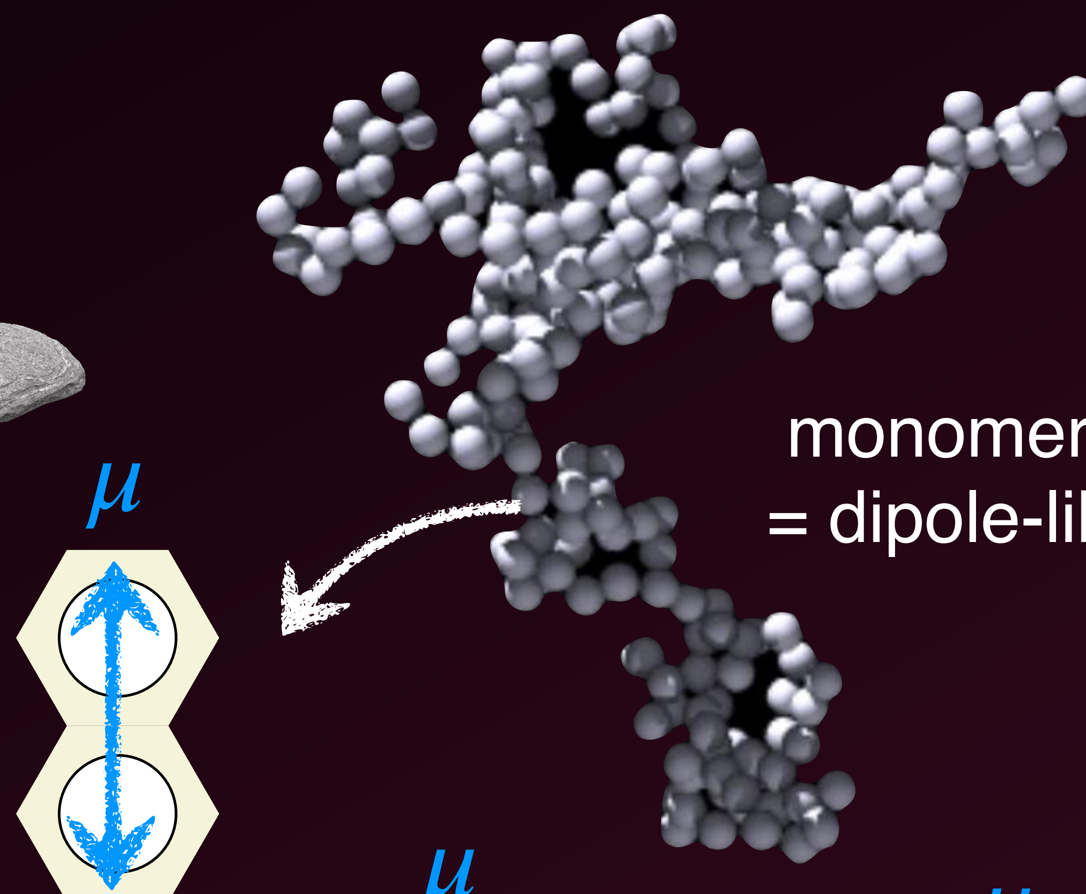
$\vec{D} = \varepsilon^* \vec{E}$ $+ \vec{P}$ (average electric dipole moment per unit volume)

$\vec{B} = \mu^* \vec{H}$

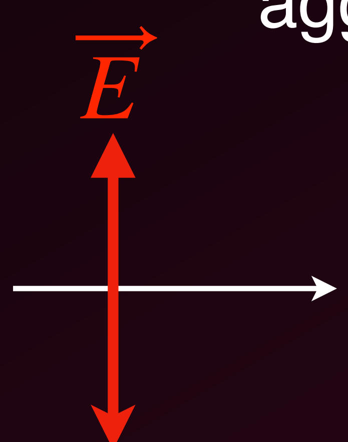
Supplementary materials

Polarization of Cometary Dust

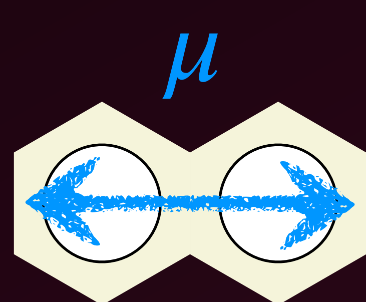
What makes the polarization (*P*)?



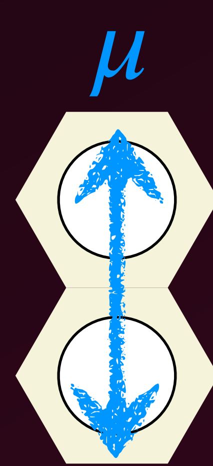
∴ *P* is a manifestation of <u>*electromagnetic interaction*</u> of incident light with monomers in the aggregate



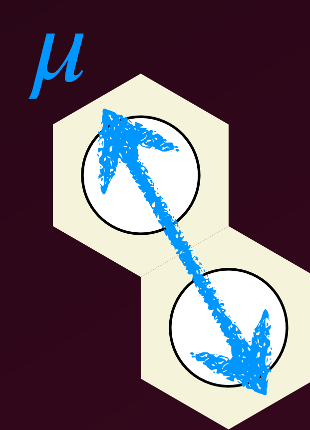
Incoming vertically polarized light



No absorption



Maximum absorption

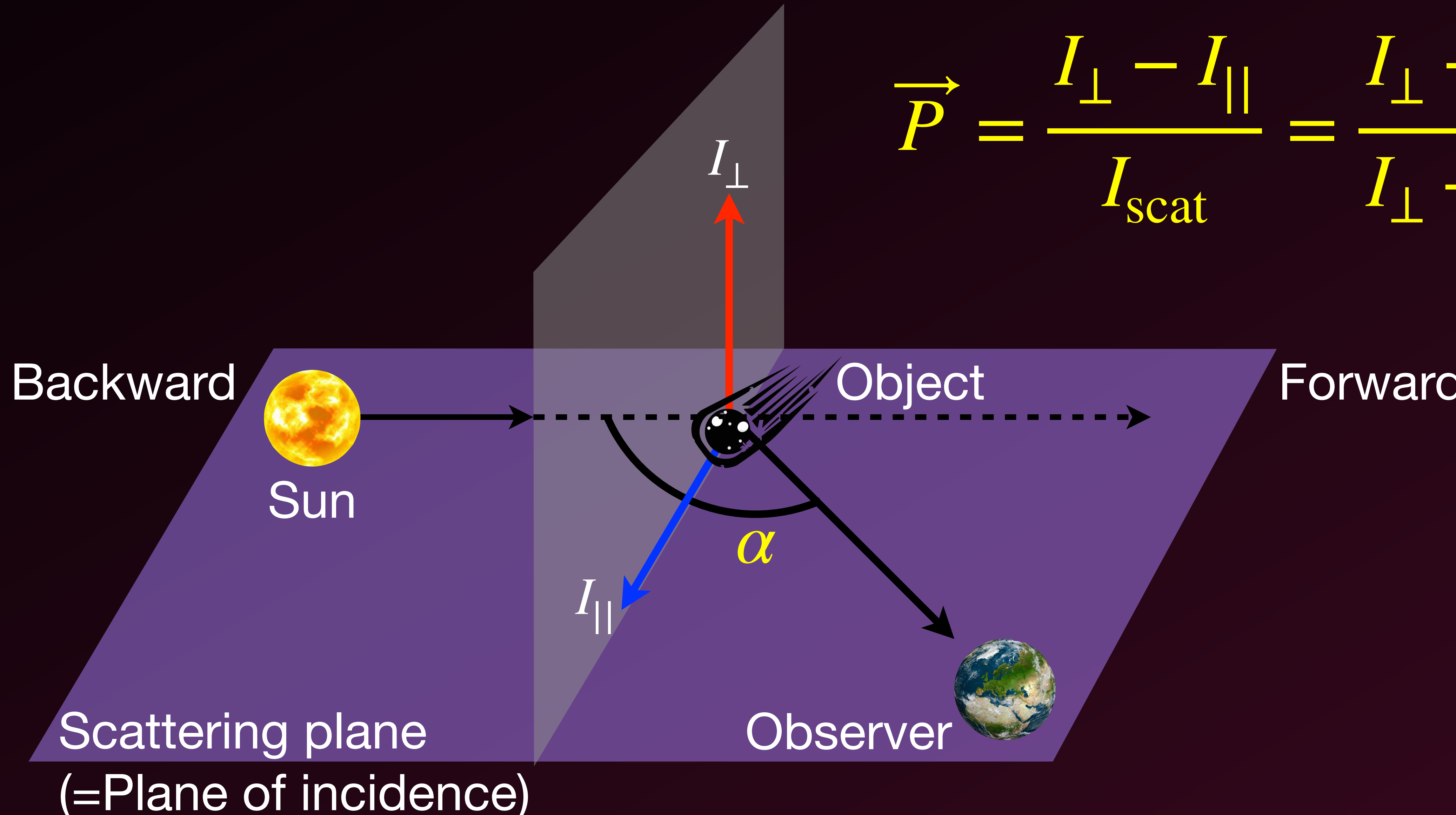


Some molecules will absorb light

Polarization of Cometary Dust

Polarimetry for solar system small bodies

$$\vec{P} = \frac{I_\perp - I_{||}}{I_{scat}} = \frac{I_\perp - I_{||}}{I_\perp + I_{||}}$$

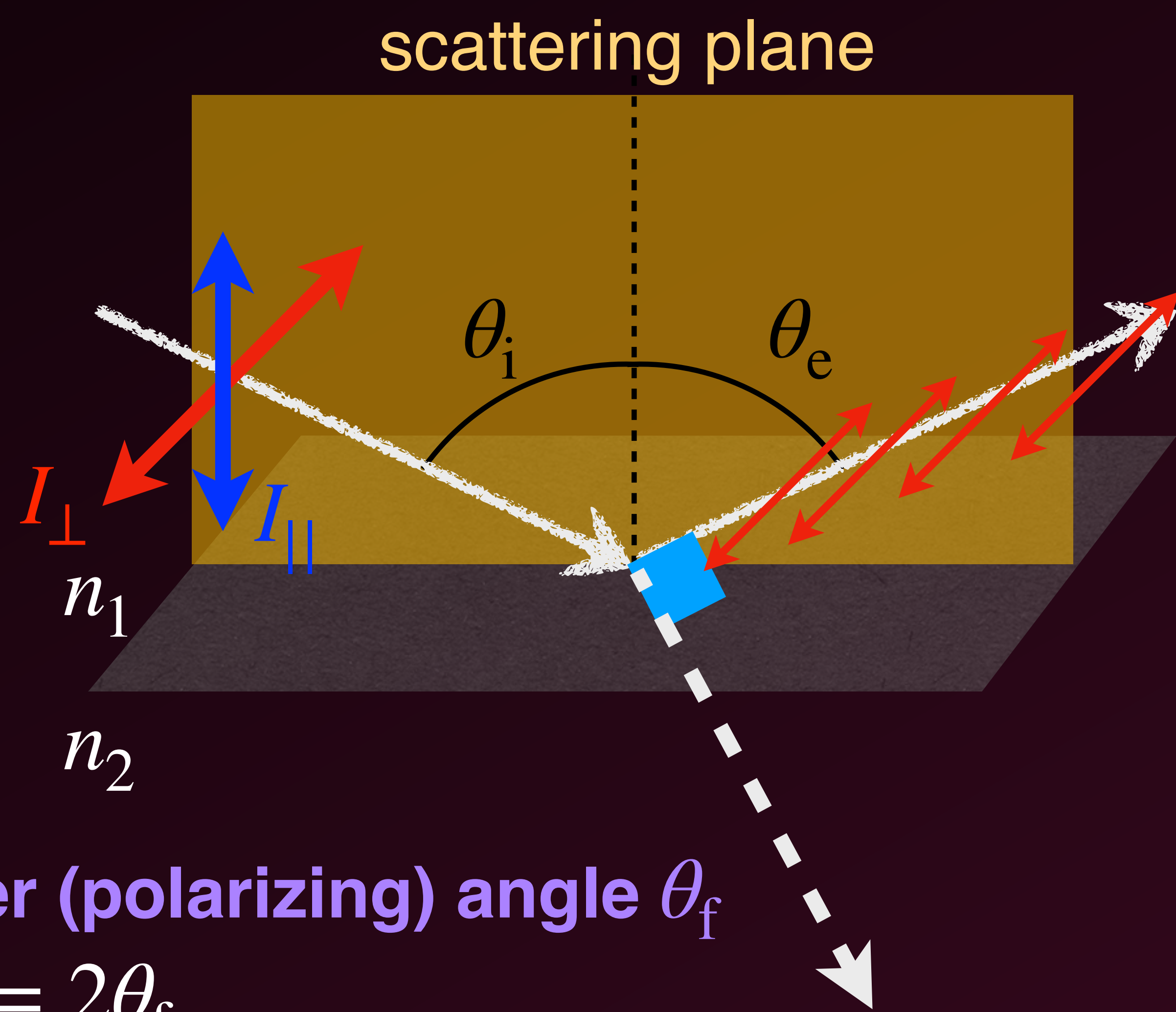


α : Phase angle

Polarization of Cometary Dust

Why does the *P*-phase curve look like?

Approximately <u>specular reflection</u>



100 % linearly polarized at the **Brewster (polarizing) angle θ_f**

→ Phase angle herein: $\alpha = \theta_f + \theta_e = 2\theta_f$

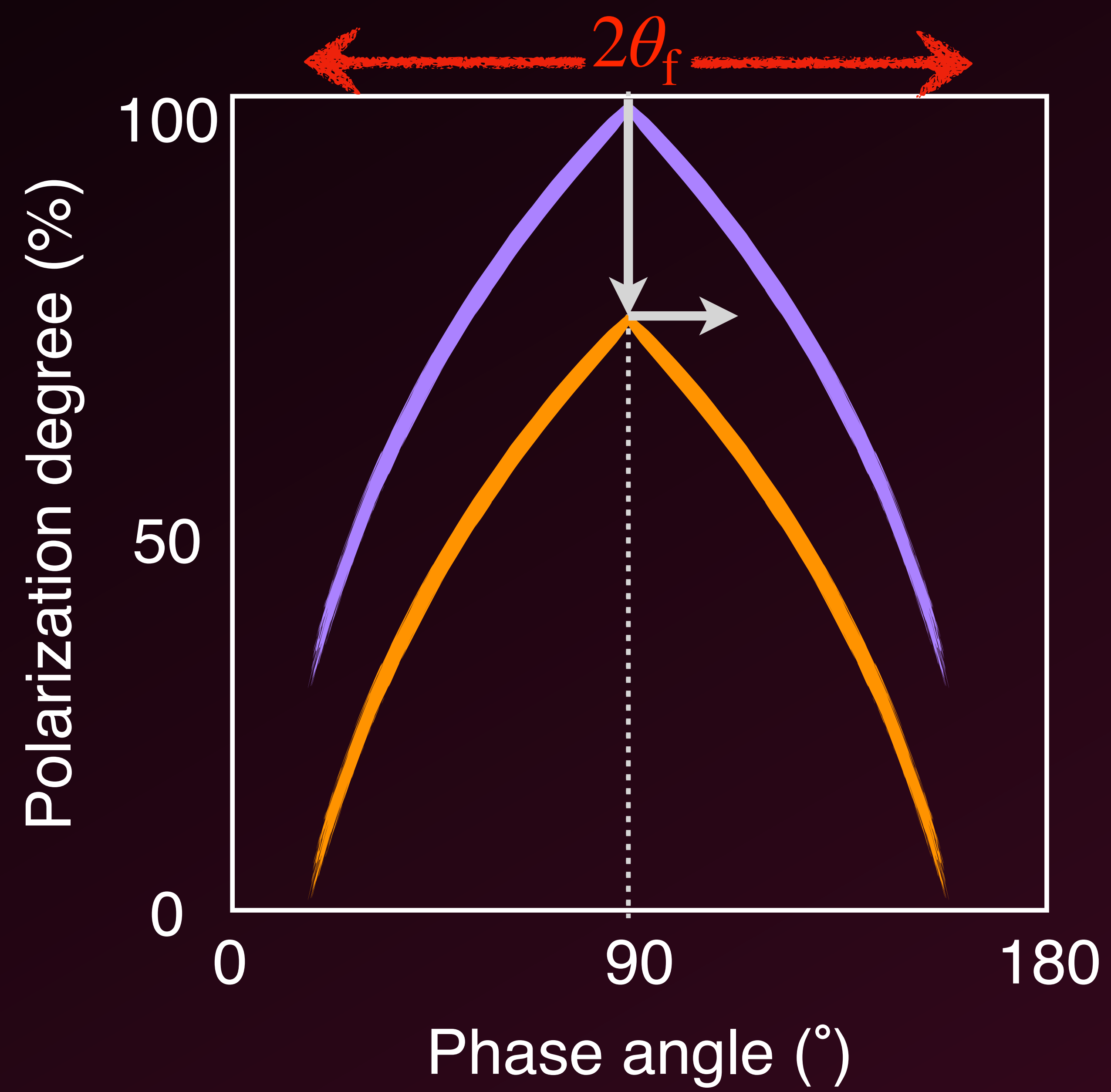
(cf. for water n = 1.33, $\theta_f \sim 53^\circ$)

Supplementary materials

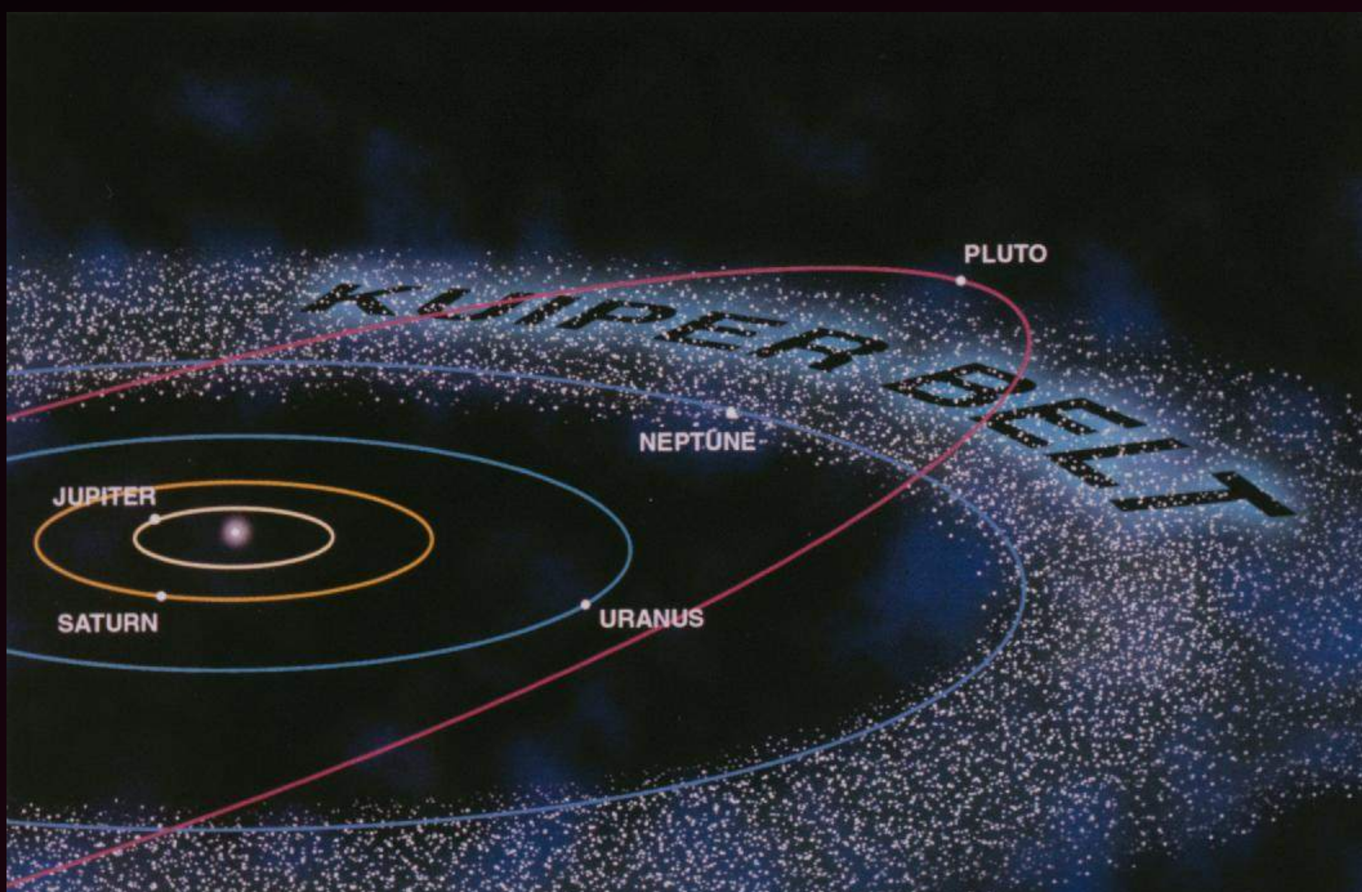
Polarization of Cometary Dust

Why does the *P*-phase curve look like?

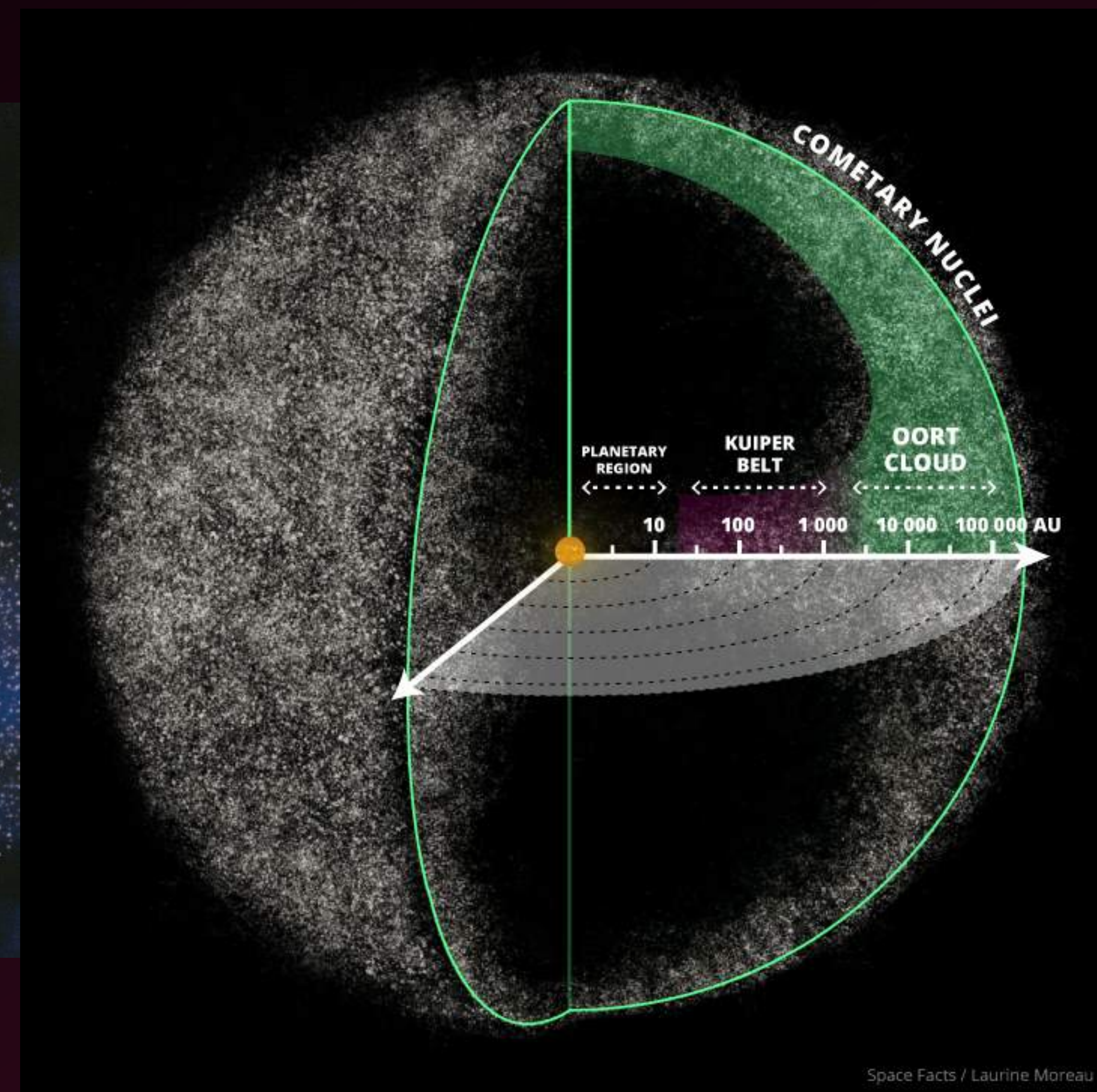
$$\vec{P} = \frac{I_\perp - I_{||}}{I_\perp + I_{||}}$$



Comet Reservoirs



theplanets.org

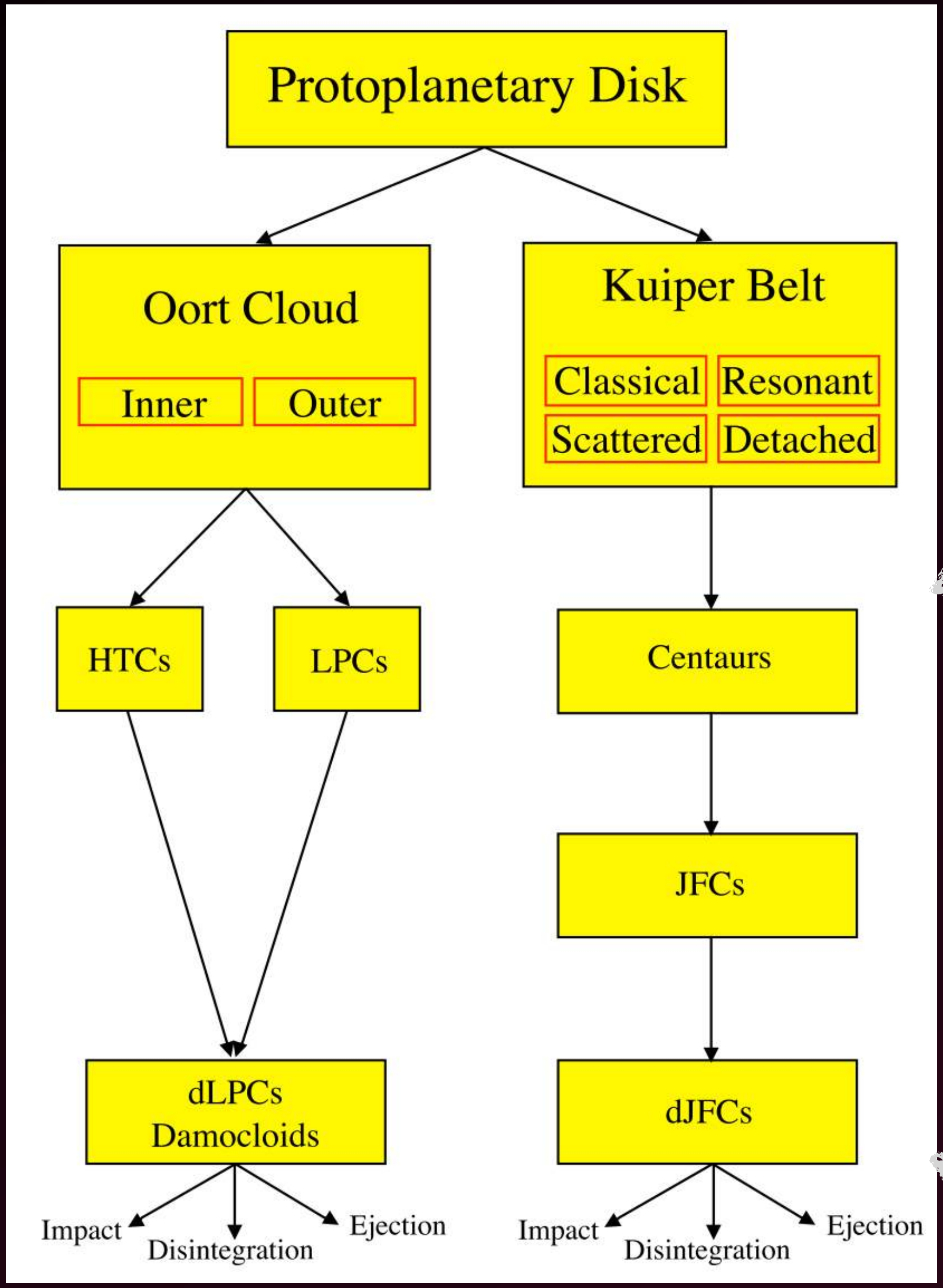


space-facts.com

Kuiper Belt (and scattered disk)

(inner and outer) **Oort Cloud**

Comet Classification



Jewitt (2015), AJ, 150, 201

: Reservoirs

: Observable via

Bare nucleus

Dust coma

Dust tail

Outburst

Opportunities to decipher the primitive information and to investigate evolution of materials under the solar heating