Journées SF2A 2026

Can Solar System dust analogs scattering properties helps the study of protoplanetary disks ?

Rémi ZERNA

2nd year PhD student at IPAG, Grenoble, France
Supervisor: François Ménard

Working with

Jean-Michel Geffrin[(1)], Elio Samara[(1)], Amélie Litman[(1)], Ryo Tazaki[(2)], Gaspard Duchêne[(3)], Maxime Roumesy[(3)], Laurine Martinien[(3)], Alexandre Aguila[(4)]

(1) Aix Marseille Univ, CNRS, Centrale Med, Institut Fresnel, Marseille, France
(2) Department of Earth Science and Astronomy, The University of Tokyo, Japan
(3) Univ. Grenoble Alpes, CNRS, IPAG, 38000 Grenoble, France
(4) SCALAE, St-Martin d'Hères, France

Journées SF2A 2026

Can Solar System dust analogs scattering properties helps the study of protoplanetary disks ?

Rémi ZERNA

2nd year PhD student at IPAG, Grenoble, France
Supervisor: François Ménard

Working with

Jean-Michel Geffrin[(1)], Elio Samara[(1)], Amélie Litman[(1)], Ryo Tazaki[(2)], Gaspard Duchêne[(3)], Maxime Roumesy[(3)], Laurine Martinien[(3)], Alexandre Aguila[(4)]

(1) Aix Marseille Univ, CNRS, Centrale Med, Institut Fresnel, Marseille, France
(2) Department of Earth Science and Astronomy, The University of Tokyo, Japan
(3) Univ. Grenoble Alpes, CNRS, IPAG, 38000 Grenoble, France
(4) SCALAE, St-Martin d'Hères, France

Journées SF2A 2026

Can Solar System dust analogs scattering properties helps the study of protoplanetary disks ?

Rémi ZERNA

2nd year PhD student at IPAG, Grenoble, France
Supervisor: François Ménard

Working with

Jean-Michel Geffrin[(1)], Elio Samara[(1)], Amélie Litman[(1)], Ryo Tazaki[(2)], Gaspard Duchêne[(3)], Maxime Roumesy[(3)], Laurine Martinien[(3)], Alexandre Aguila[(4)]

(1) Aix Marseille Univ, CNRS, Centrale Med, Institut Fresnel, Marseille, France
(2) Department of Earth Science and Astronomy, The University of Tokyo, Japan
(3) Univ. Grenoble Alpes, CNRS, IPAG, 38000 Grenoble, France
(4) SCALAE, St-Martin d'Hères, France

Journées SF2A 2026

Can Solar System dust analogs scattering properties helps the study of protoplanetary disks ?

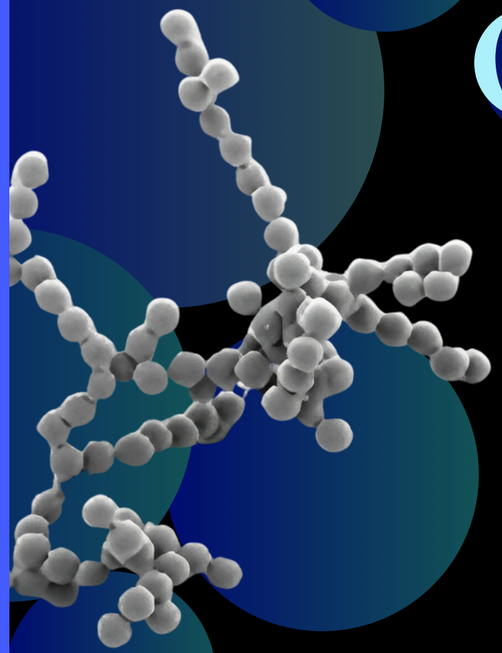
Rémi ZERNA

2nd year PhD student at IPAG, Grenoble, France
Supervisor: François Ménard

Working with

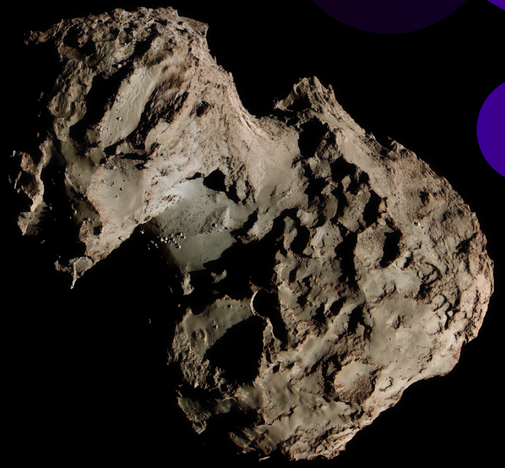
Jean-Michel Geffrin[(1)], Elio Samara[(1)], Amélie Litman[(1)], Ryo Tazaki[(2)], Gaspard Duchêne[(3)], Maxime Roumesy[(3)], Laurine Martinien[(3)], Alexandre Aguila[(4)]

(1) Aix Marseille Univ, CNRS, Centrale Med, Institut Fresnel, Marseille, France
(2) Department of Earth Science and Astronomy, The University of Tokyo, Japan
(3) Univ. Grenoble Alpes, CNRS, IPAG, 38000 Grenoble, France
(4) SCALAE, St-Martin d'Hères, France



Overwiew of the subject

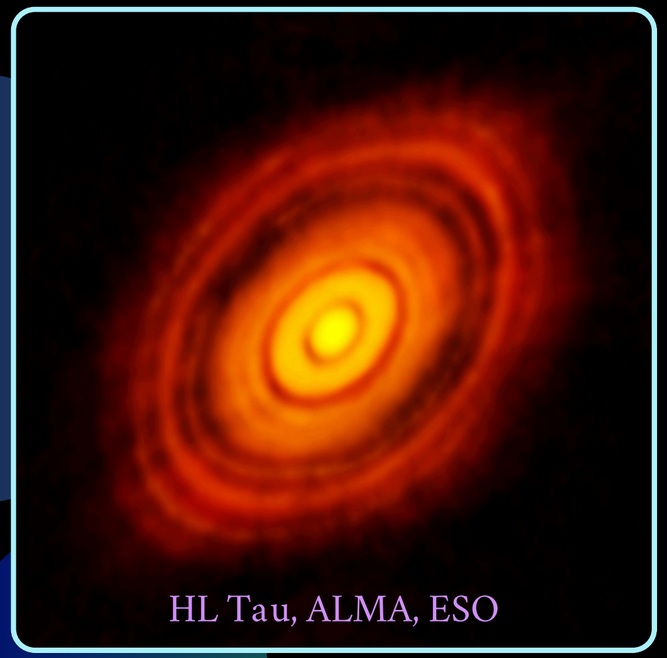
Protoplanetary disks, dust particles and our Solar System



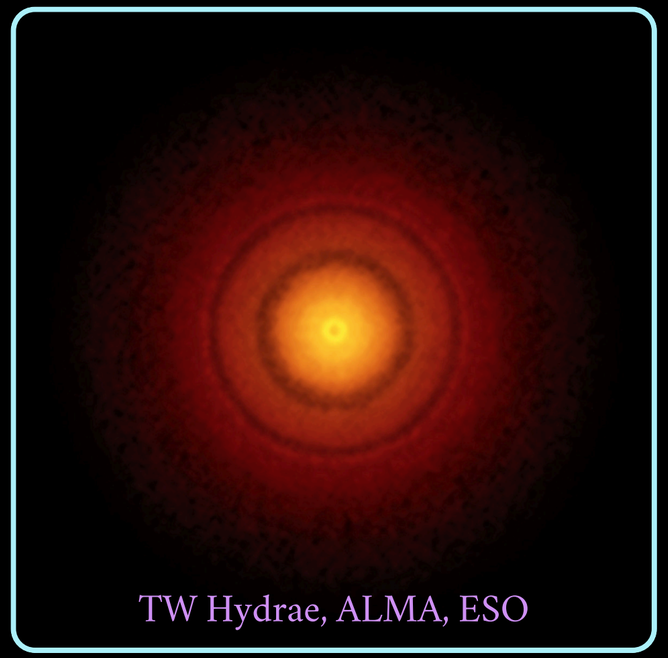
Rémi ZERNA - SF2A 2026

A bit of context

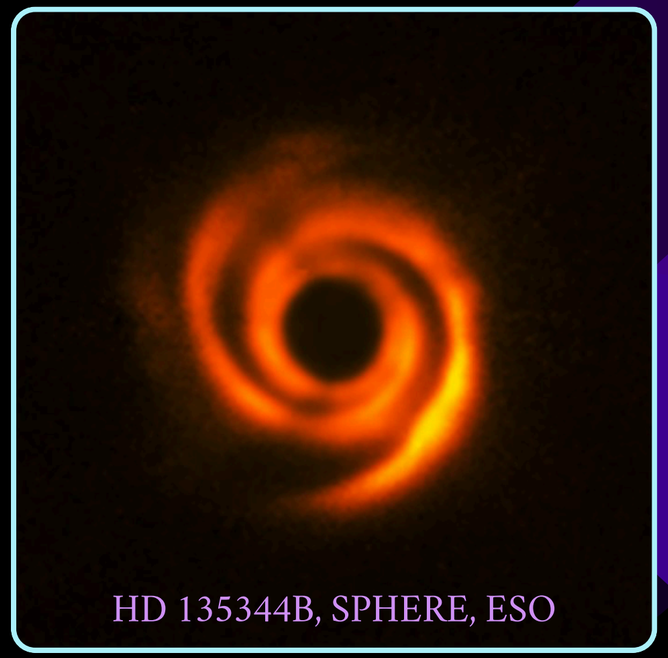
From Dust2Planets



HL Tau, ALMA, ESO



TW Hydrae, ALMA, ESO



HD 135344B, SPHERE, ESO

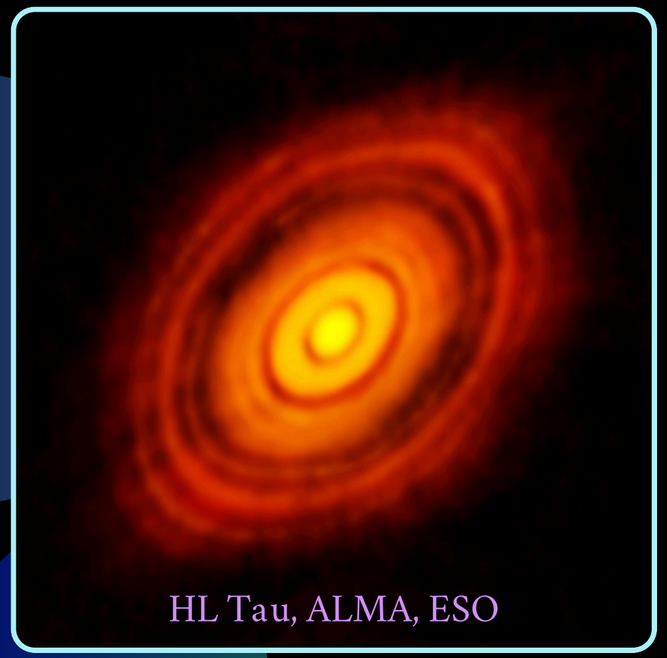
Q1 : What is the shape of dust particles inside young disks ?

Q2 : How the shape of these particles evolve with time ?

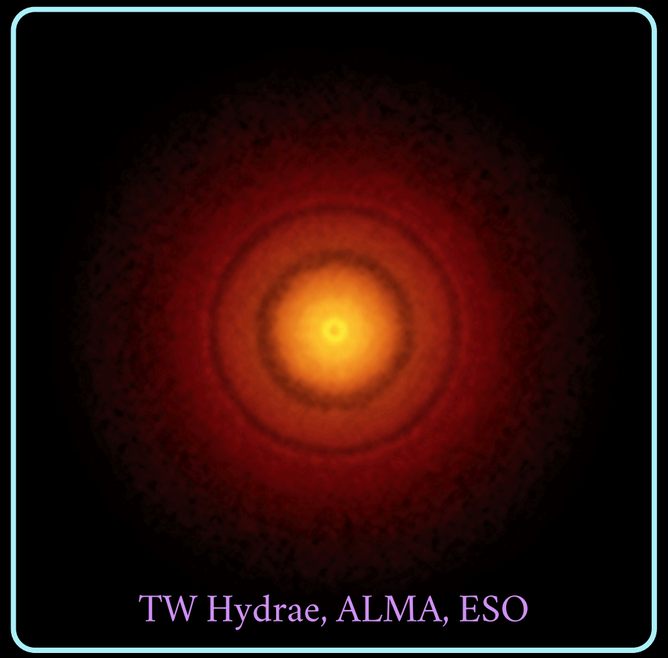
Q3 : Can we find similar dust particles in our Solar System ?

A bit of context

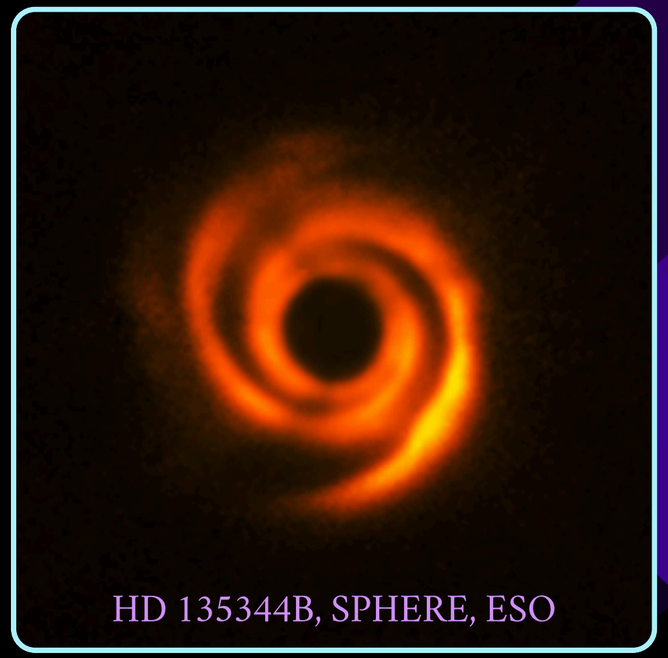
From Dust2Planets



HL Tau, ALMA, ESO



TW Hydrae, ALMA, ESO



HD 135344B, SPHERE, ESO

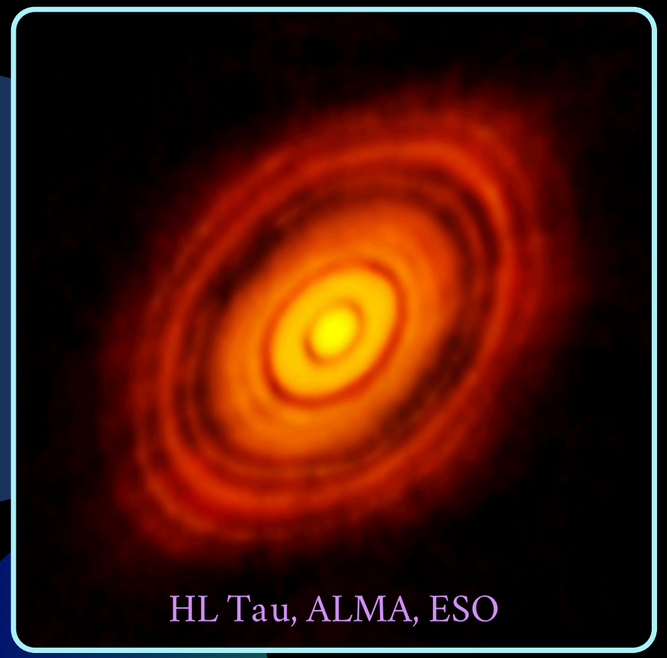
Q1 : What is the shape of dust particles inside young disks ?

Q2 : How the shape of these particles evolve with time ?

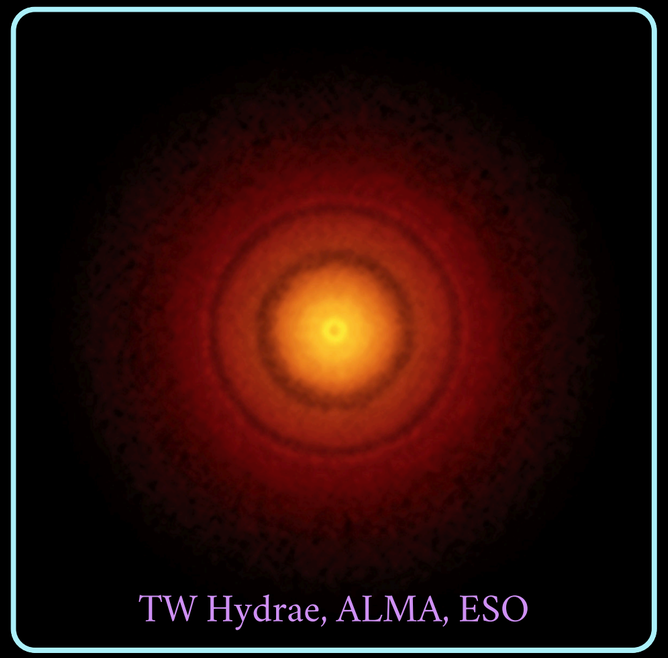
Q3 : Can we find similar dust particles in our Solar System ?

A bit of context

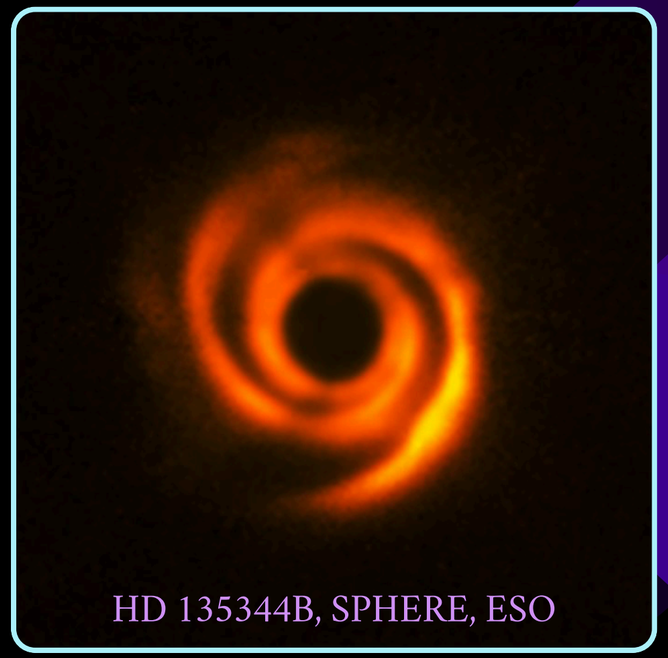
From Dust2Planets



HL Tau, ALMA, ESO



TW Hydrae, ALMA, ESO



HD 135344B, SPHERE, ESO

Q1 : What is the shape of dust particles inside young disks ?

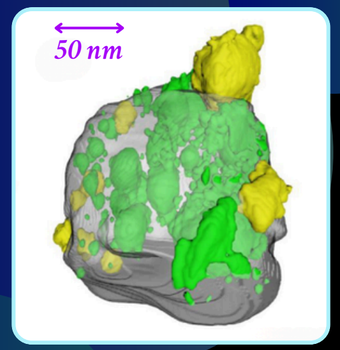
Q2 : How the shape of these particles evolve with time ?

Q3 : Can we find similar dust particles in our Solar System ?

A bit of context

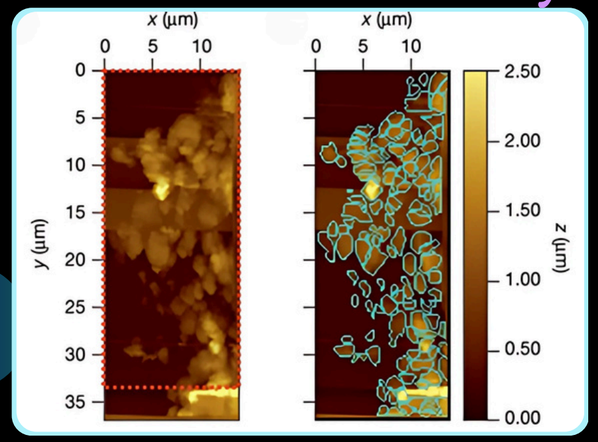
Dust particles in the solar system

IDP = interplanetary dust particles

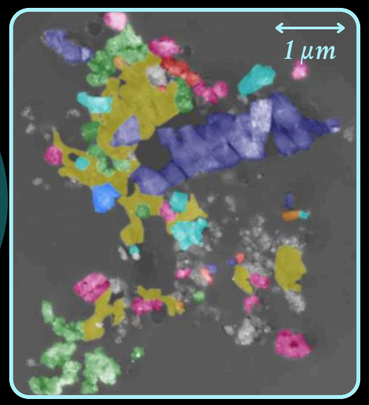


Glass with embedded Metals and Sulphide (GEMS, IDP)

Junya Matsuno + 2023



Dust from 67P comet surface
Rosetta / MIDAS mission



Stratospheric Interplanetary Dust Particles (IDP) made of different 'monomers'

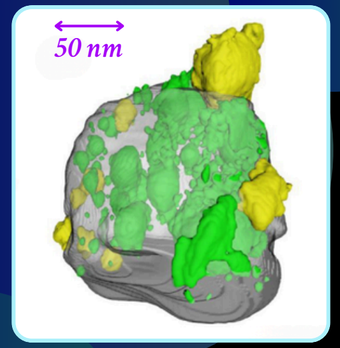
Scott Messenger + 2013

Size of the object

A bit of context

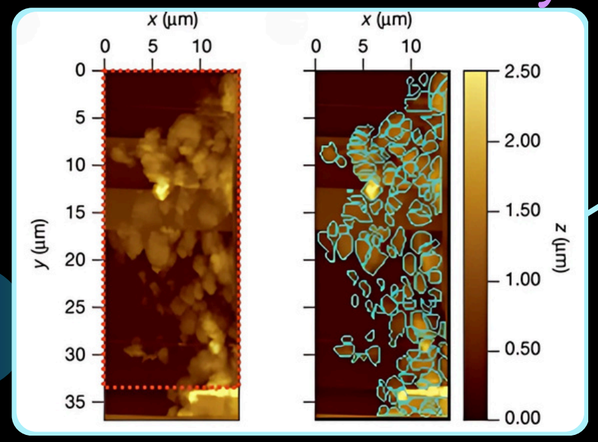
Dust particles in the solar system

IDP = interplanetary dust particles

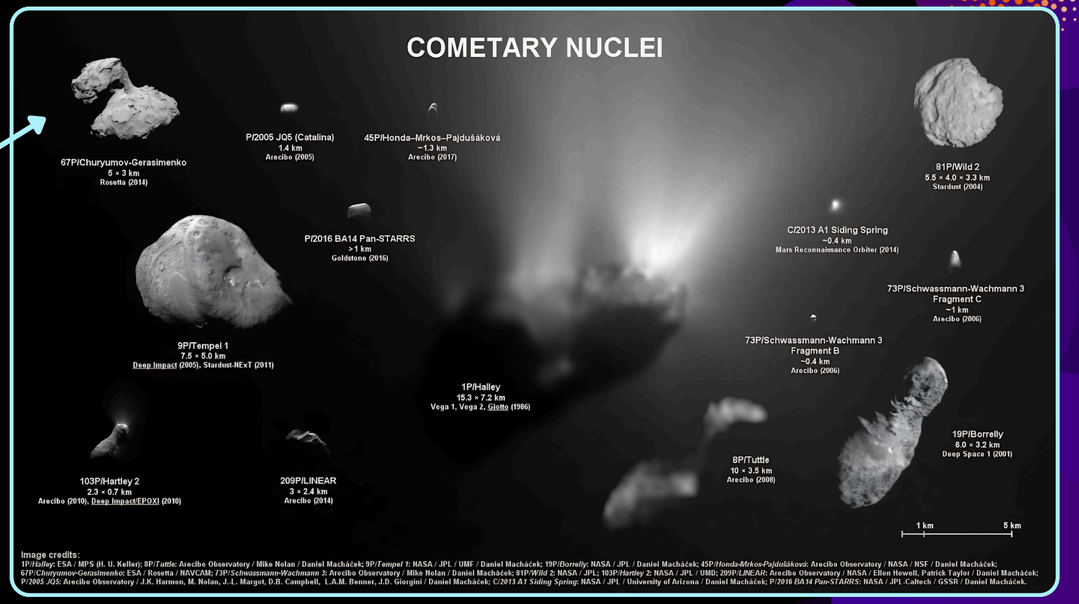


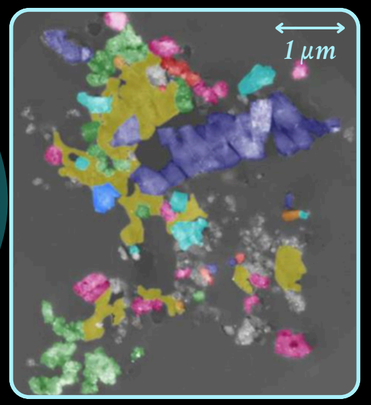
Glass with embedded Metals and Sulphide (GEMS, IDP)

Junya Matsuno + 2023



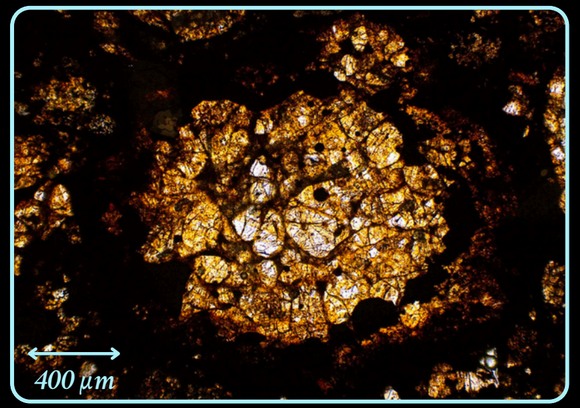
Dust from 67P comet surface
Rosetta / MIDAS mission





Stratospheric Interplanetary Dust Particles (IDP) made of different 'monomers'

Scott Messenger + 2013



Optical petrographic images of an "armored chondrule."

Christopher R. J. CHARLES + 18

Size of the object

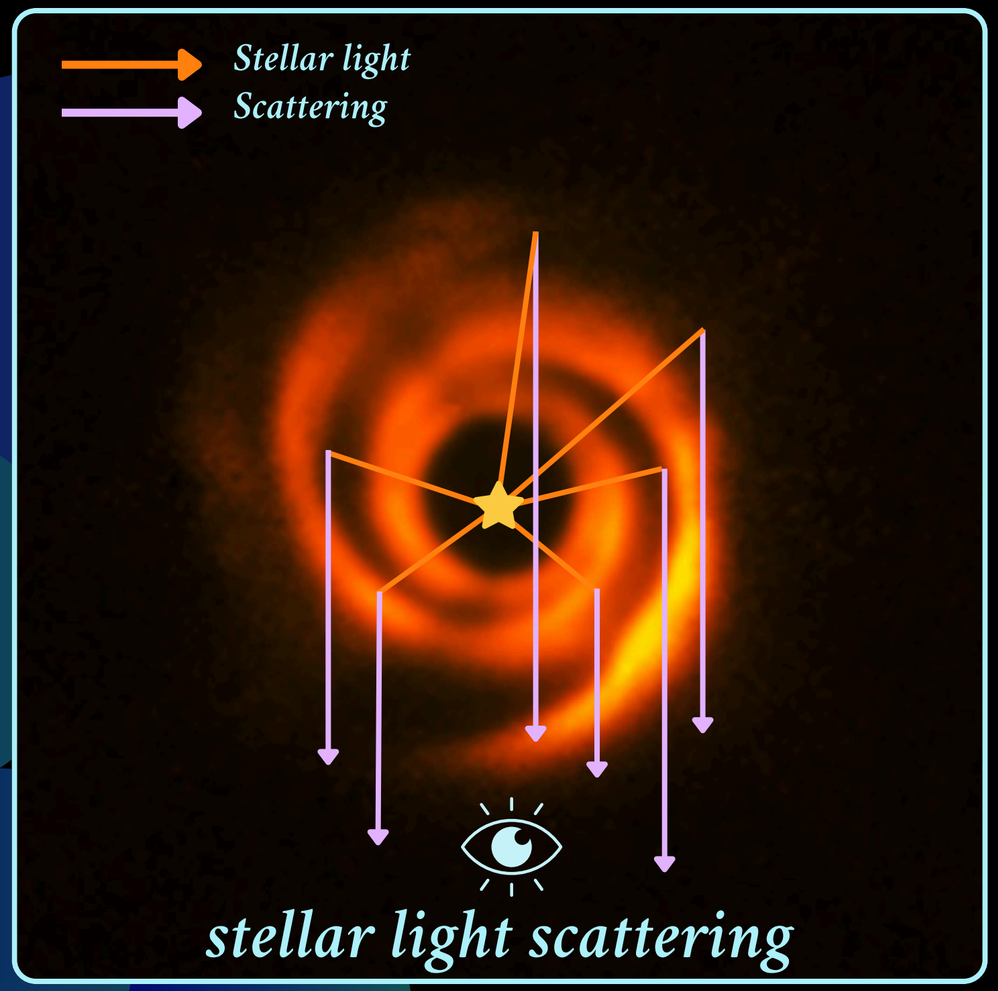
Scattering properties

What do we measure from disks to compare with analogs in the solar system ?

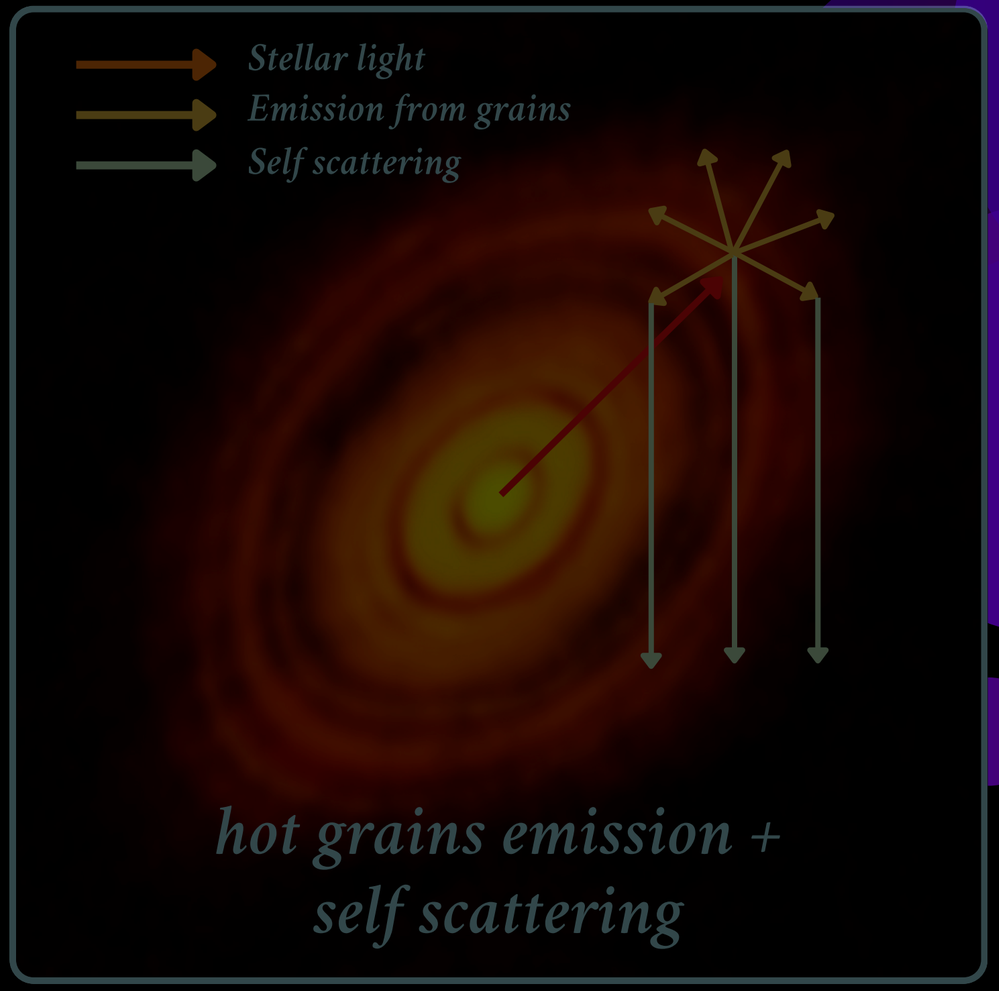
Rémi ZERNA - SF2A 2026

A bit of context

What do we mesure ?



NIR Range

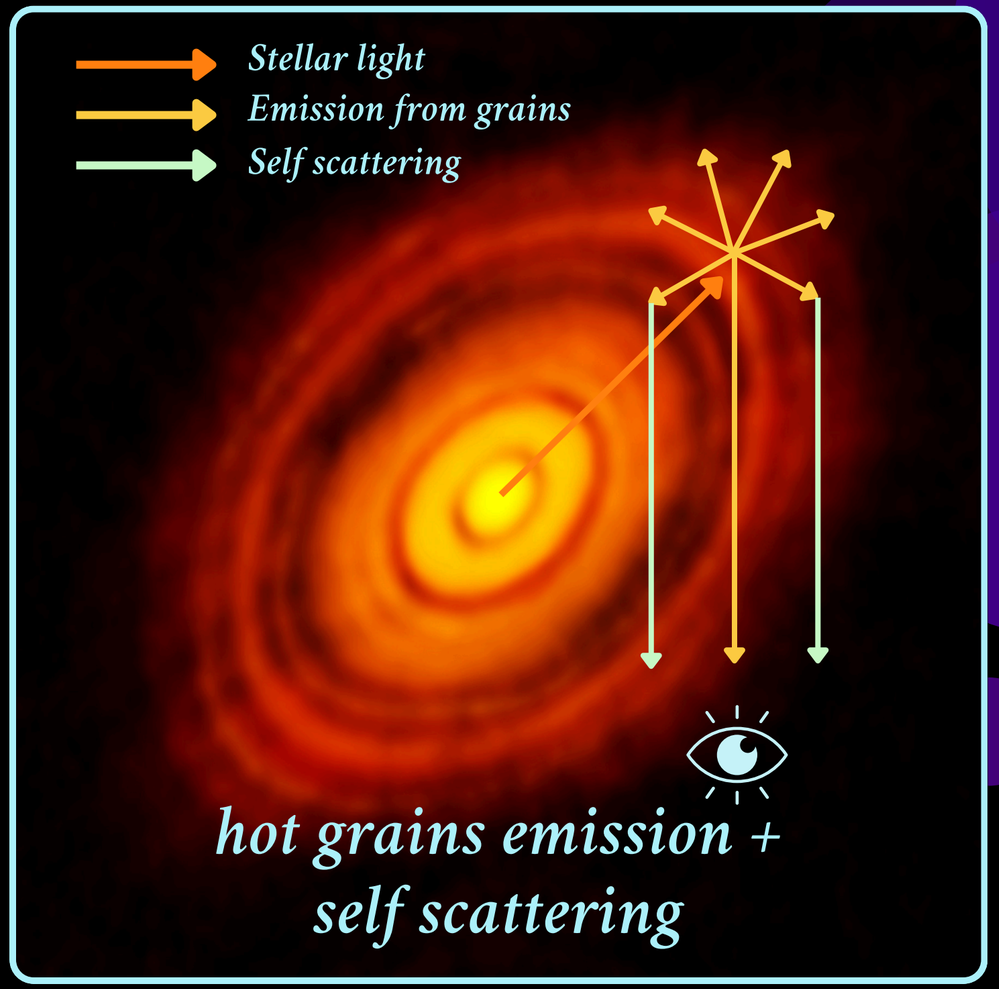


mm range

A bit of context

What do we mesure ?

NIR Range



mm range

A bit of context

What do we mesure ?

Bohren & Huffman book 1983

$$\begin{pmatrix} I_s \\ Q_s \\ U_s \\ V_s \end{pmatrix} \propto$$

Scattered Stokes parameters

A bit of context

What do we mesure ?

Bohren & Huffman book 1983

$$\begin{pmatrix} I_s \\ Q_s \\ U_s \\ V_s \end{pmatrix} \propto \begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{pmatrix} \begin{pmatrix} I_\star \\ Q_\star \\ U_\star \\ V_\star \end{pmatrix}$$

Scattered Stokes parameters

Scattering matrix or Mueller matrix

incident Stokes parameters

A bit of context

What do we mesure ?

Bohren & Huffman book 1983

$$\begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{pmatrix}$$

$$S11 = SPF$$

total scattered intensity

$$-S_{12}/S_{11} = DLP$$

Fraction of linearly polarized light after a scattering event

A bit of context

What do we mesure ?

Bohren & Huffman book 1983

$$\begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{pmatrix}$$

$$S11 = SPF$$

total scattered intensity

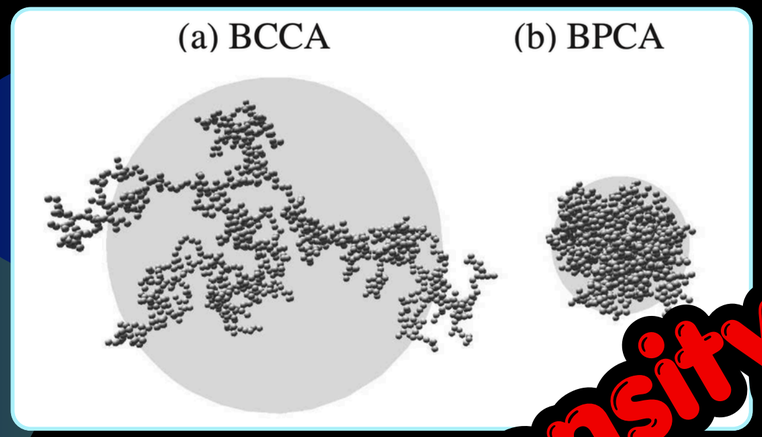
$$-S_{12}/S_{11} = DLP$$

Fraction of linearly polarized light after a scattering event

For a sphere, we know the exact solution: Mie theory

A bit of context

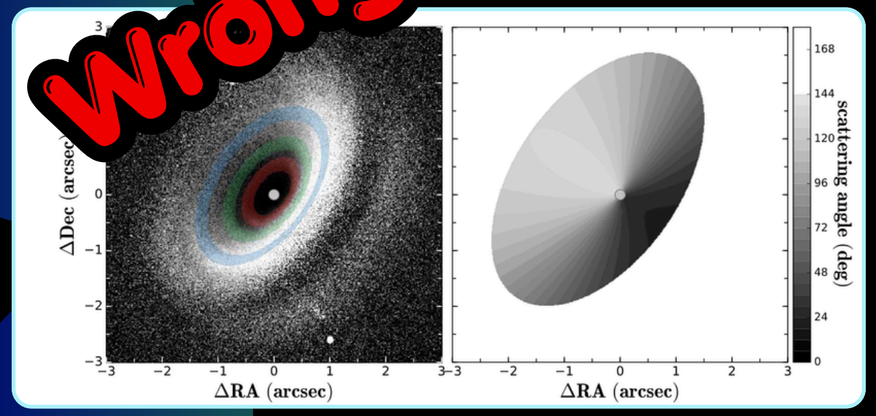
Mie theory fails in PPDs studies



Shown that : Mie theor[illegible] reproduce scattering pro[illegible] aggregates

[illegible] 2016

Wrong intensity

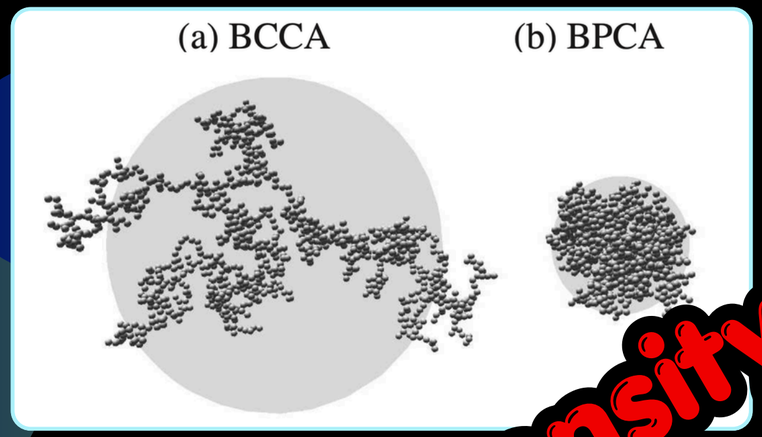


Shown that : R_{mono}~200 nm and D_f~1.5

R. Tazaki+23

A bit of context

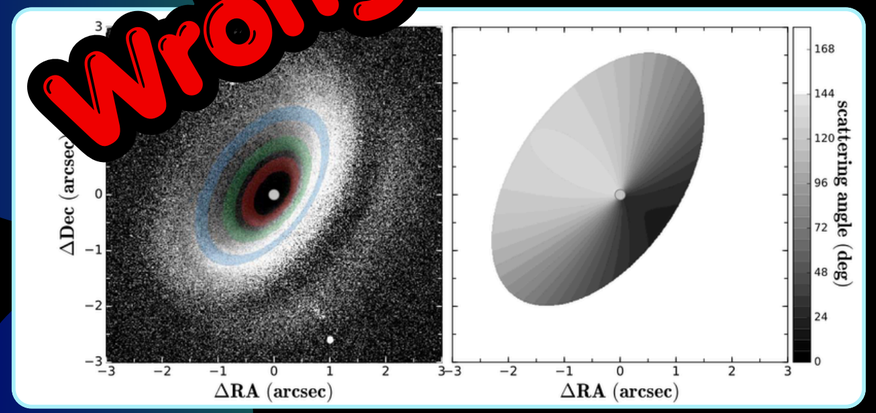
Mie theory fails in PPDs studies



Shown that : Mie theor[illegible] reproduce scattering pro[illegible] aggregates

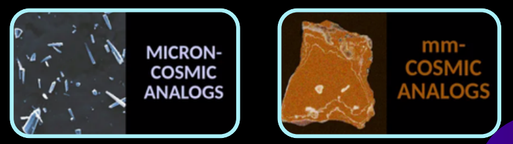
[illegible] 2016

Wrong intensity

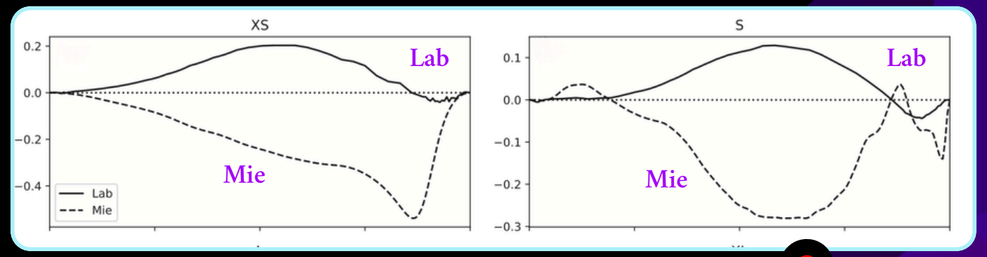


Shown that : R_{mono}~200 nm and D_f~1.5

R. Tazaki+23

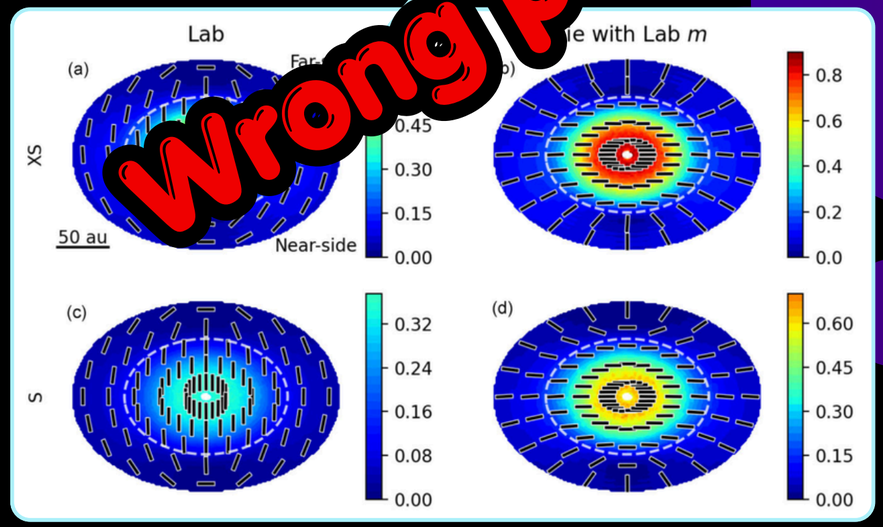


Granada-Amsterdam light scattering database



Li[illegible]ion fraction (%)

Wrong polar



Shown that : Mie theory fails to reproduce accurate values of polarization

D. Lin + 2023

METHODS

Direct measurements versus numerical simulations

Rémi ZERNA - SF2A 2026

How do we obtain the scattering properties of non spherical PPDs dust analog particles ?

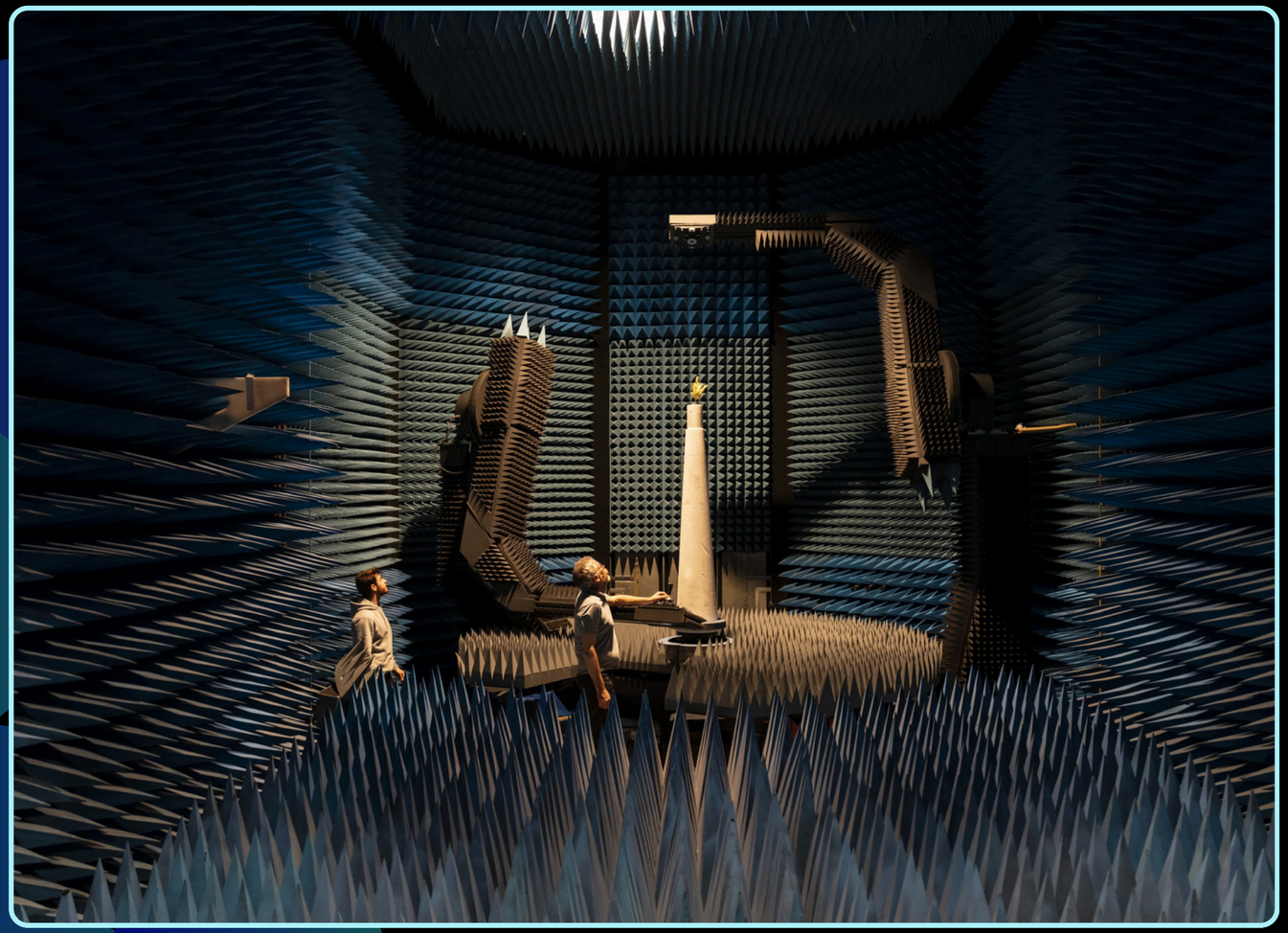
Rémi ZERNA - SF2A 2026

I - Microwave analogy (MWA)

Direct measurements

I - Microwave analogy (MWA)

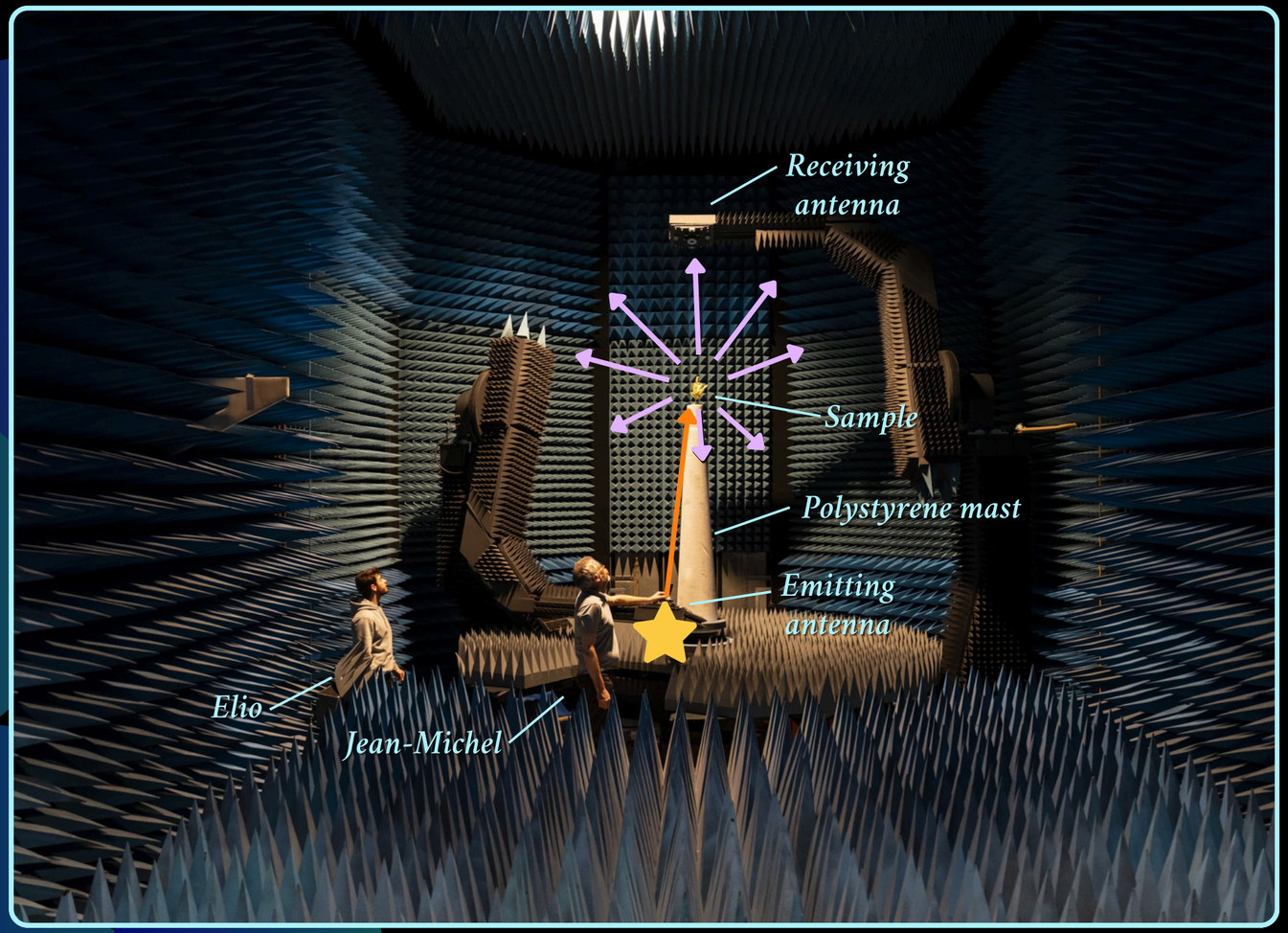
MIMOSA facility in Institut Fresnel, Marseille



The microwave analogy facility in Institut Fresnel, Marseille, France

I - Microwave analogy (MWA)

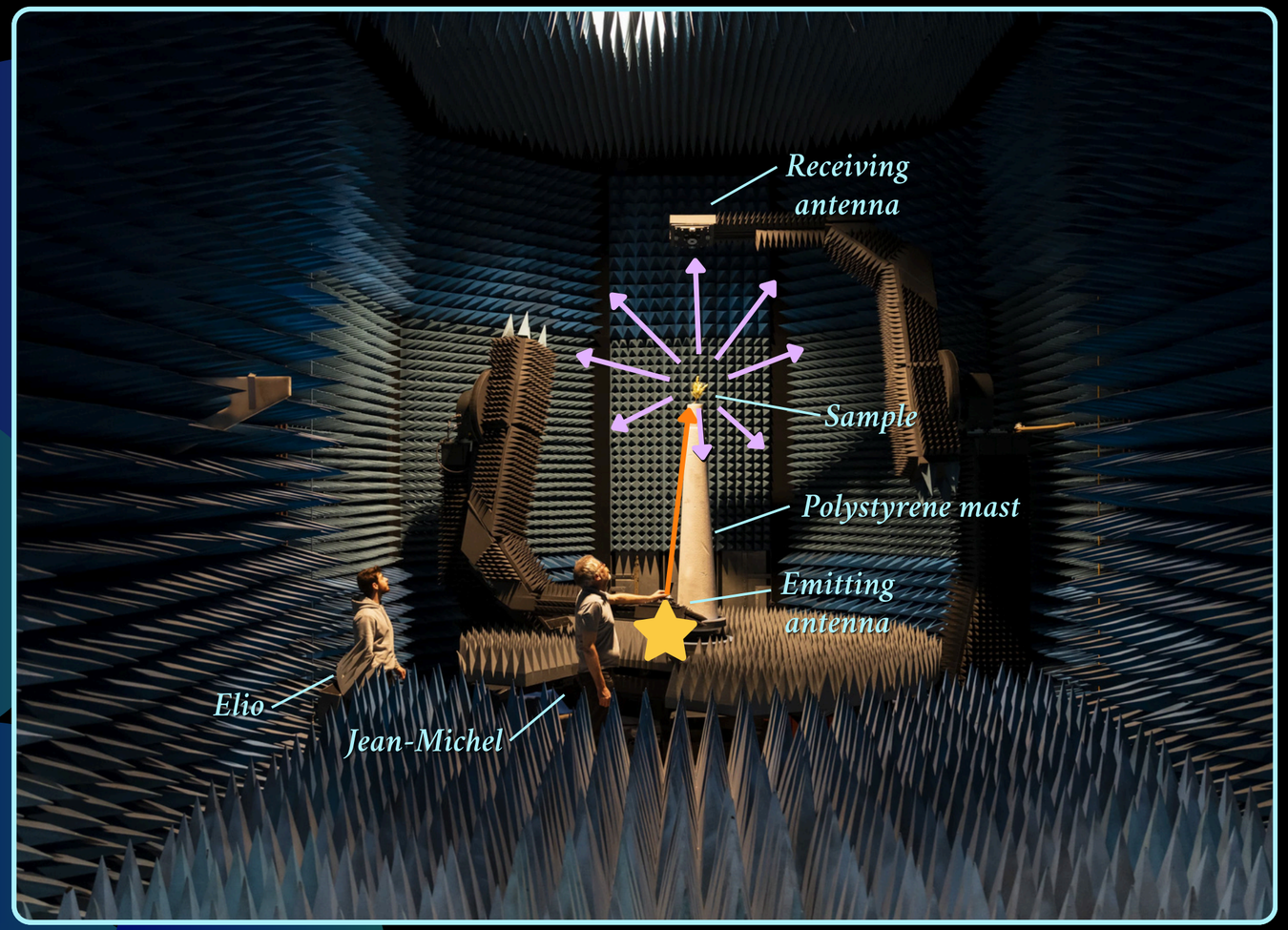
MIMOSA facility in Institut Fresnel, Marseille



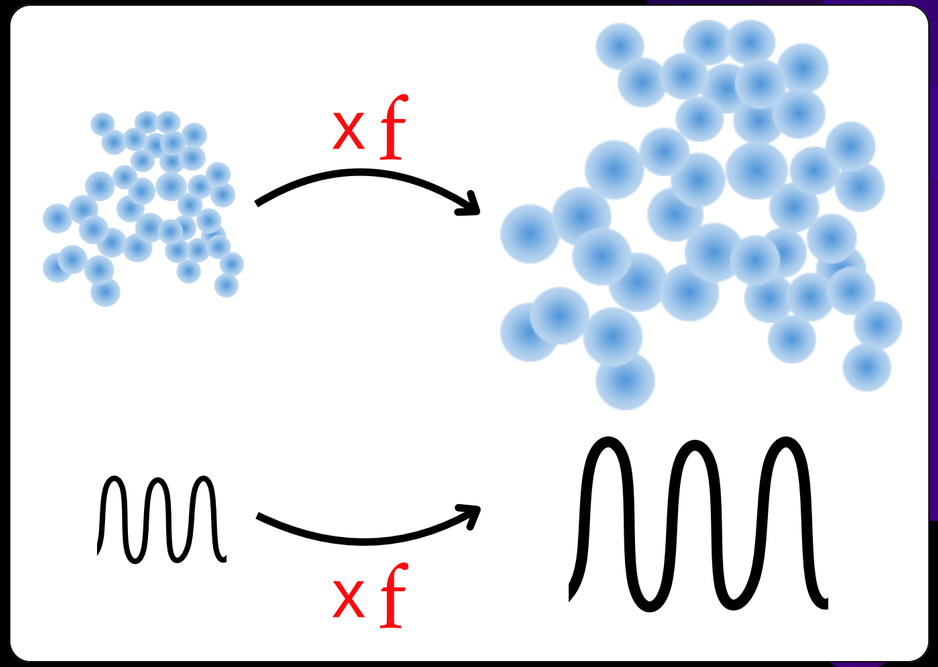
The microwave analogy facility in Institut Fresnel, Marseille, France

I - Microwave analogy (MWA)

MIMOSA facility in Institut Fresnel, Marseille



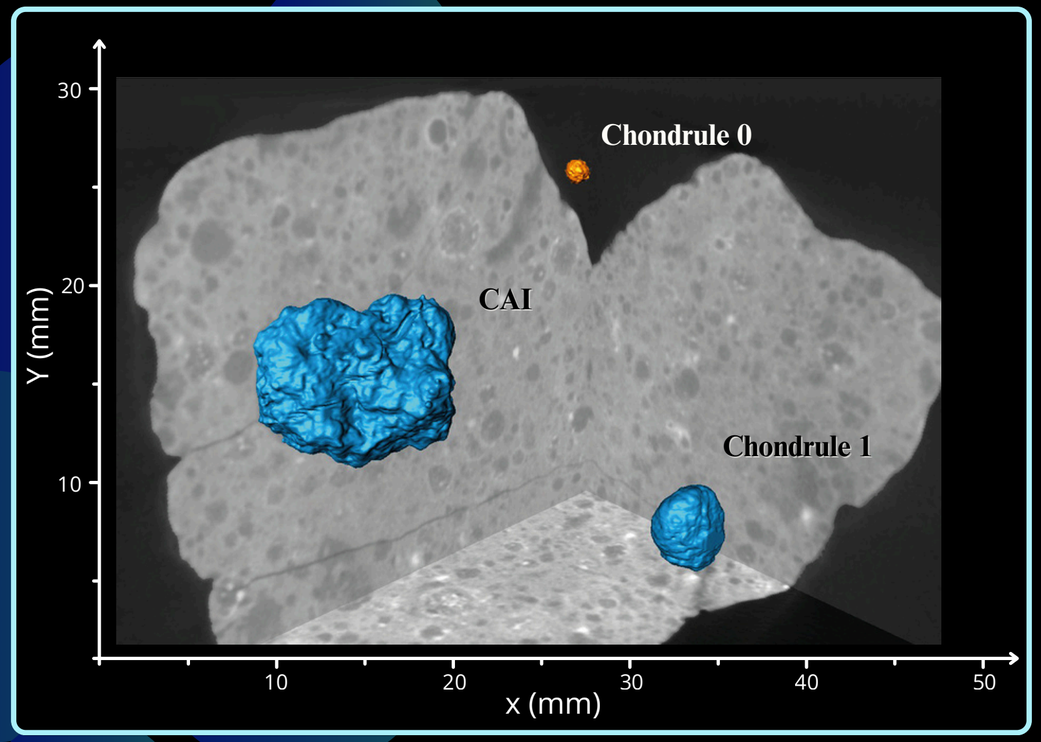
The microwave analogy facility in Institut Fresnel, Marseille, France



MWA relies on the Scale Invariance Rule of the Maxwell equations

I - Microwave analogy (MWA)

Studied analogs

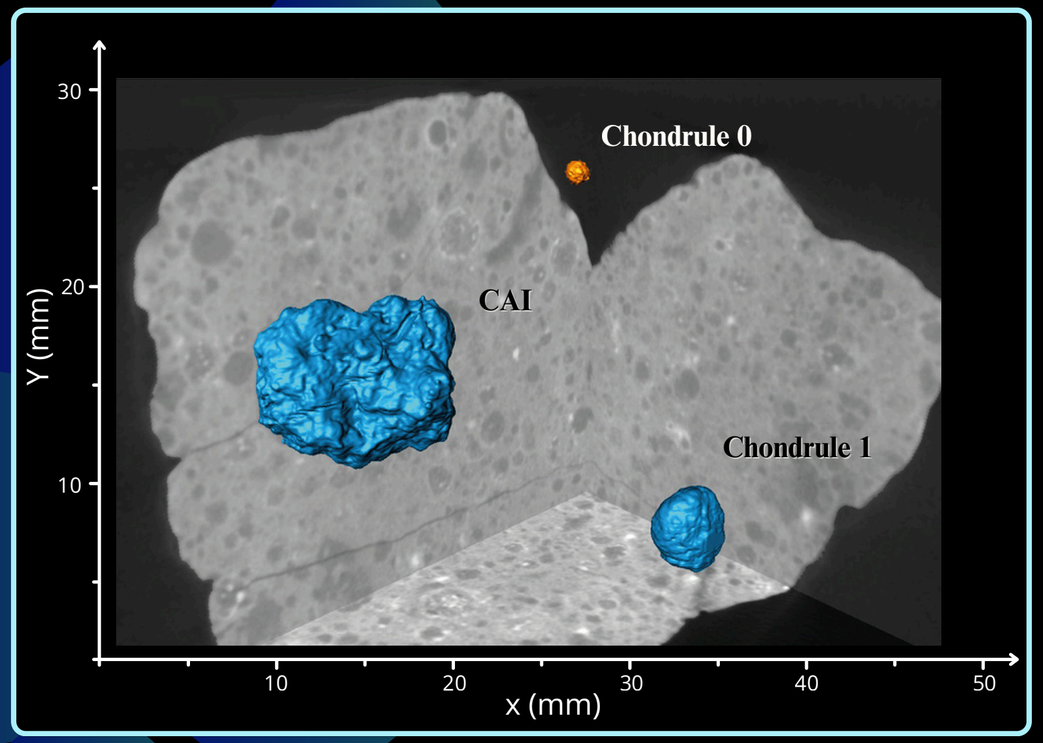


Chondrules and inclusions in a chondritic meteorite
(X ray tomography)

x f

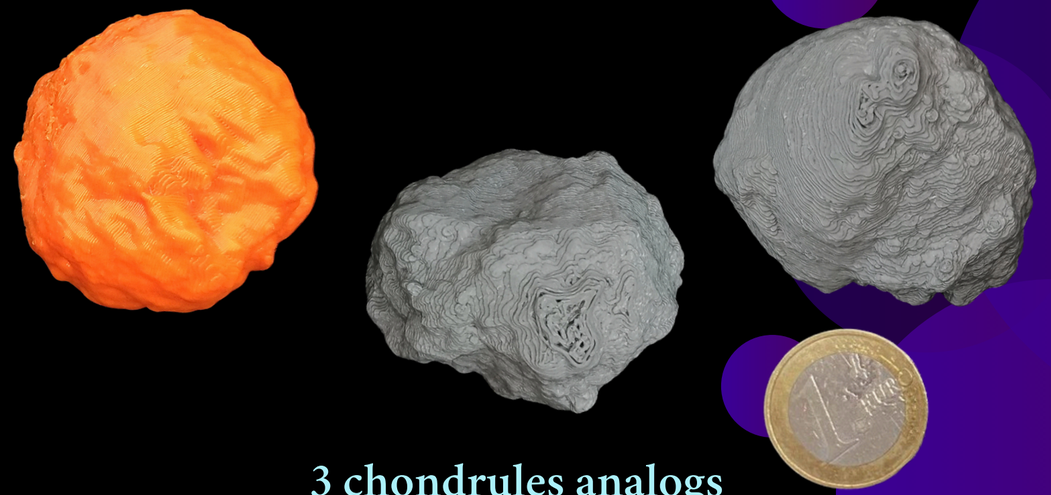
I - Microwave analogy (MWA)

Studied analogs

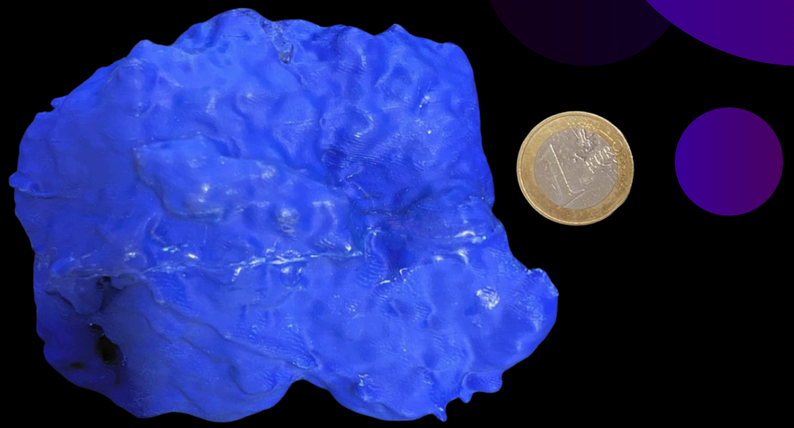


Chondrules and inclusions in a chondritic meteorite
(X ray tomography)

x f



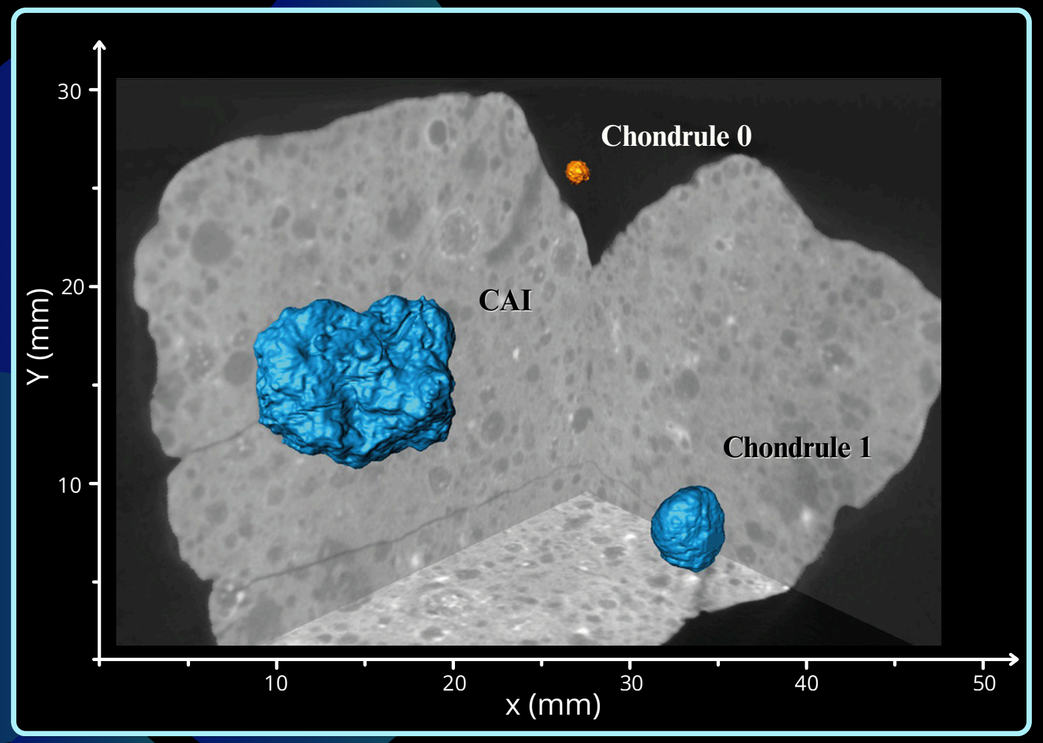
3 chondrules analogs
~20 mm radius



1 calcium aluminium inclusion analog
~50 mm radius

I - Microwave analogy (MWA)

Studied analogs



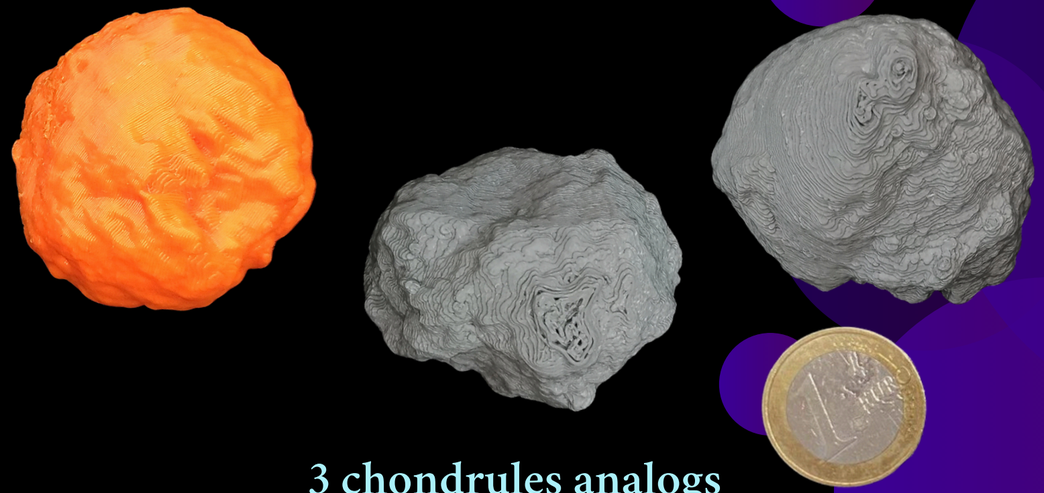
Chondrules and inclusions in a chondritic meteorite
(X ray tomography)

x f

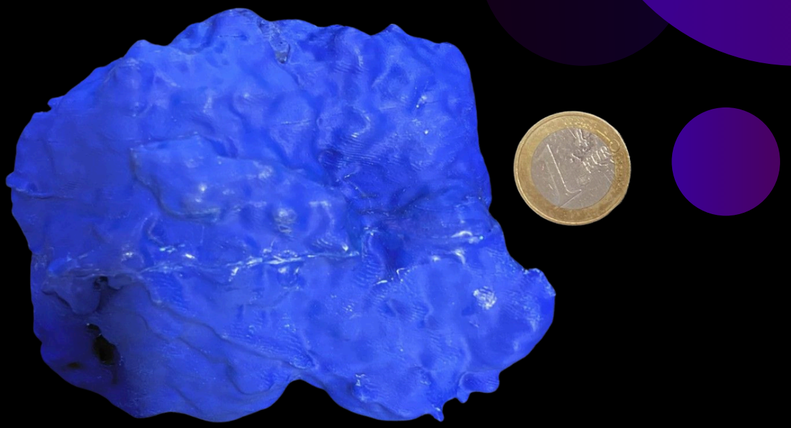
x f

NIR / mm

cm (MWA)



3 chondrules analogs
~20 mm radius



1 calcium aluminium inclusion analog
~50 mm radius

II - Discrete dipole approximation

Numerical simulations

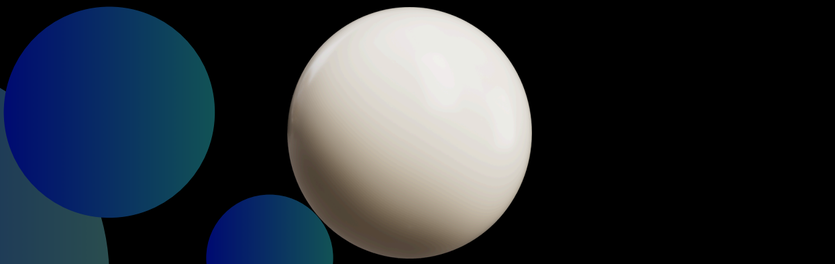
II - Discrete dipole approximation

Using ADDA (M. Yurkin version)

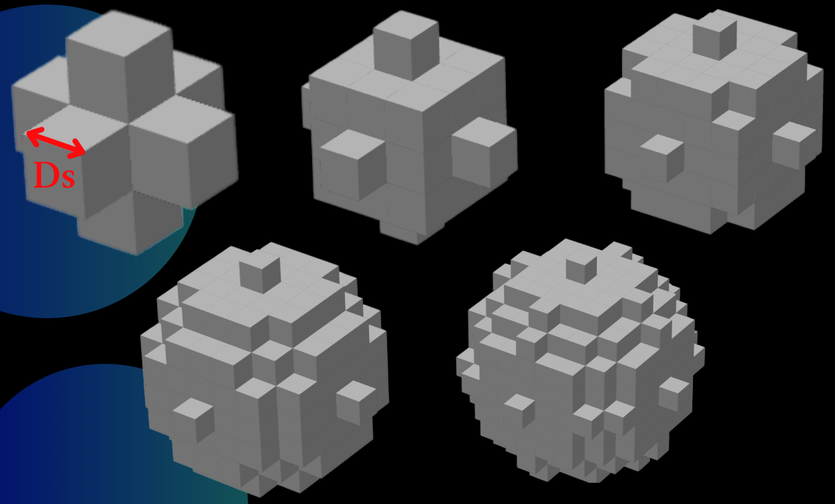
Amsterdam

Purcell + 1973

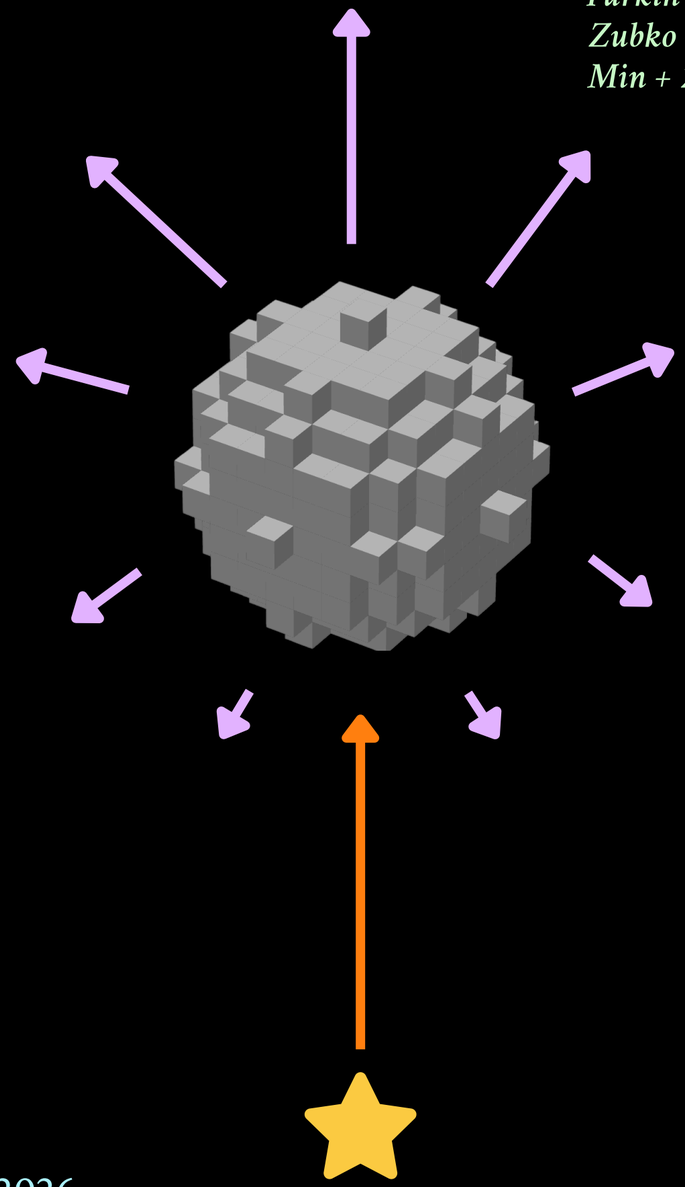
Yurkin + 2007 (a, b) code
Zubko + 2007 (for GRS)
Min + 2018 (aggregates)
...



From a continuous object

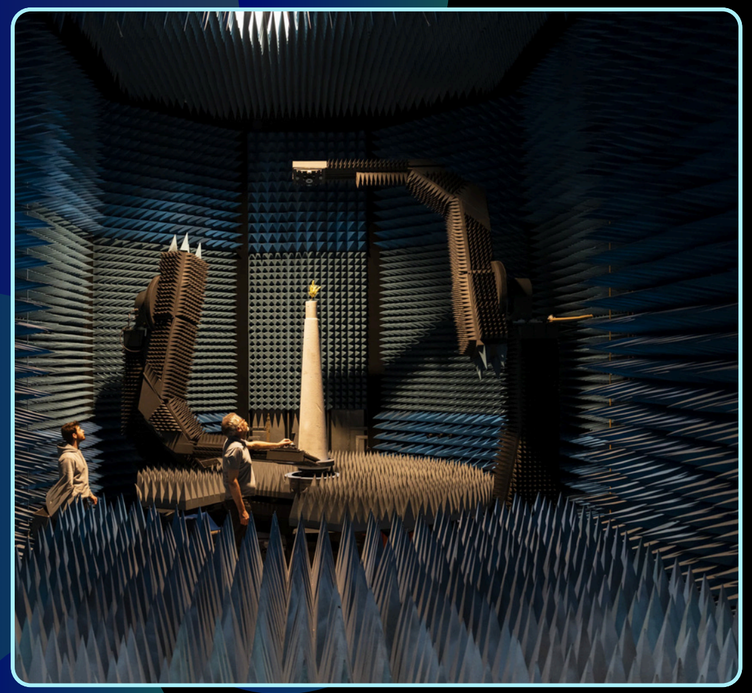


To a discrete volume made of dipoles



Why measurements + simultions

Measurements versus simulation



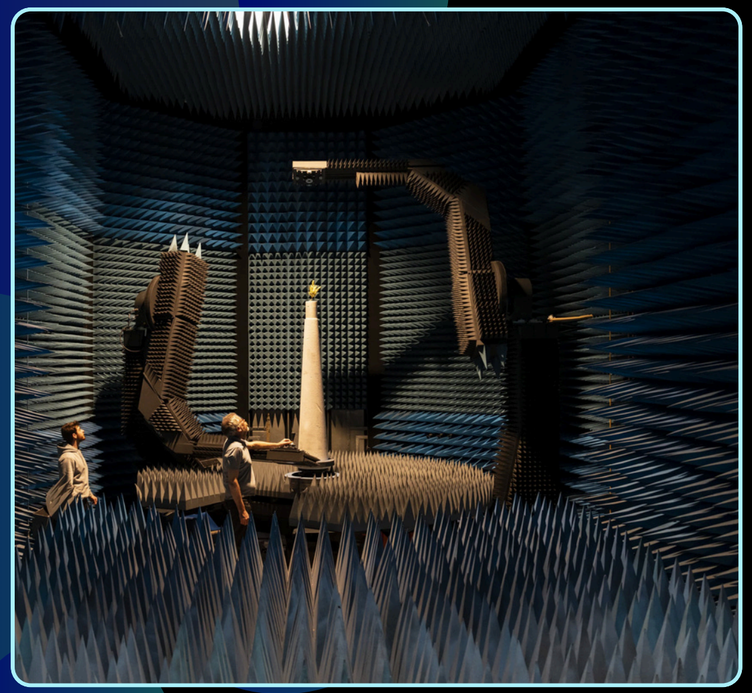
MWA

MWA

- ✅ Duration of one set of measurements does not depend on the material or sample
- ✅ Wide range of refractive index depeding on all the different 3D printing materials
- ❌ scattering angles limited to 150 deg
- ❌ Finding the good materials can be tough

Why measurements + simultions

Measurements versus simulation



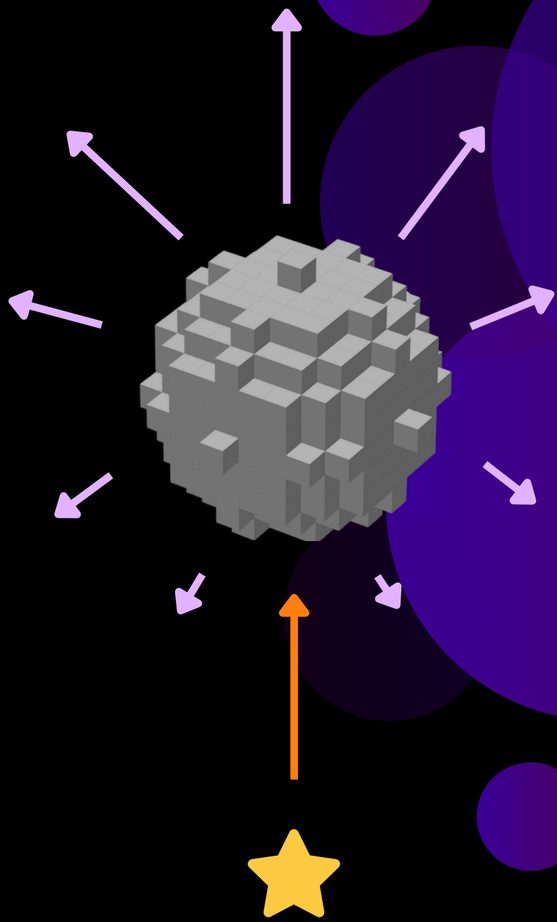
MWA

MWA

- ✅ Duration of one set of measurements does not depend on the material or sample
- ✅ Wide range of refractive index depeding on all the different 3D printing materials
- ❌ scattering angles limited to 150 deg
- ❌ Finding the good materials can be tough

DDA

- ✅ Can run very fast with a low number of dipoles and reach good acuracy
- ✅ Code available online with a doc.
- ✅ Reach angles from 0° to 180° whereas meas. are limited
- ❌ Cannot reproduce the MWA setup (how the emmitor and receptor are placed in 3D)
- ❌ The higher the refractive index, the lower the code



DDA

Results

Main results from the study of chondrules

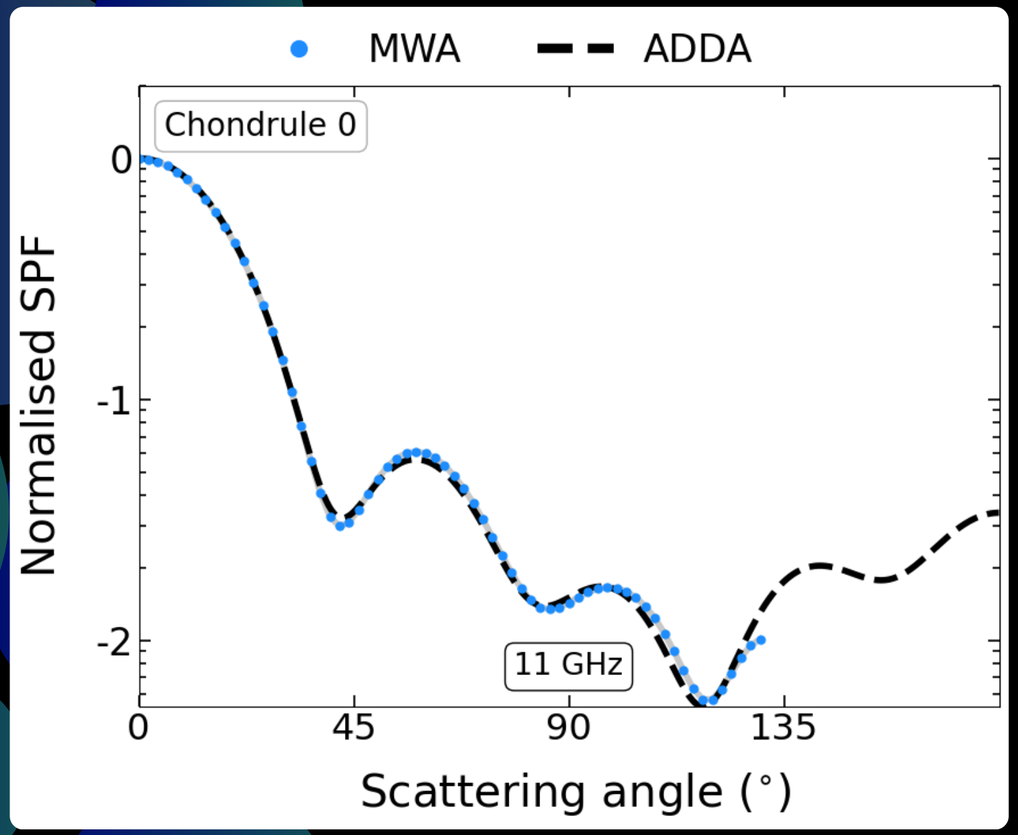
ZERNA et al, 2026, in prep

Result I :

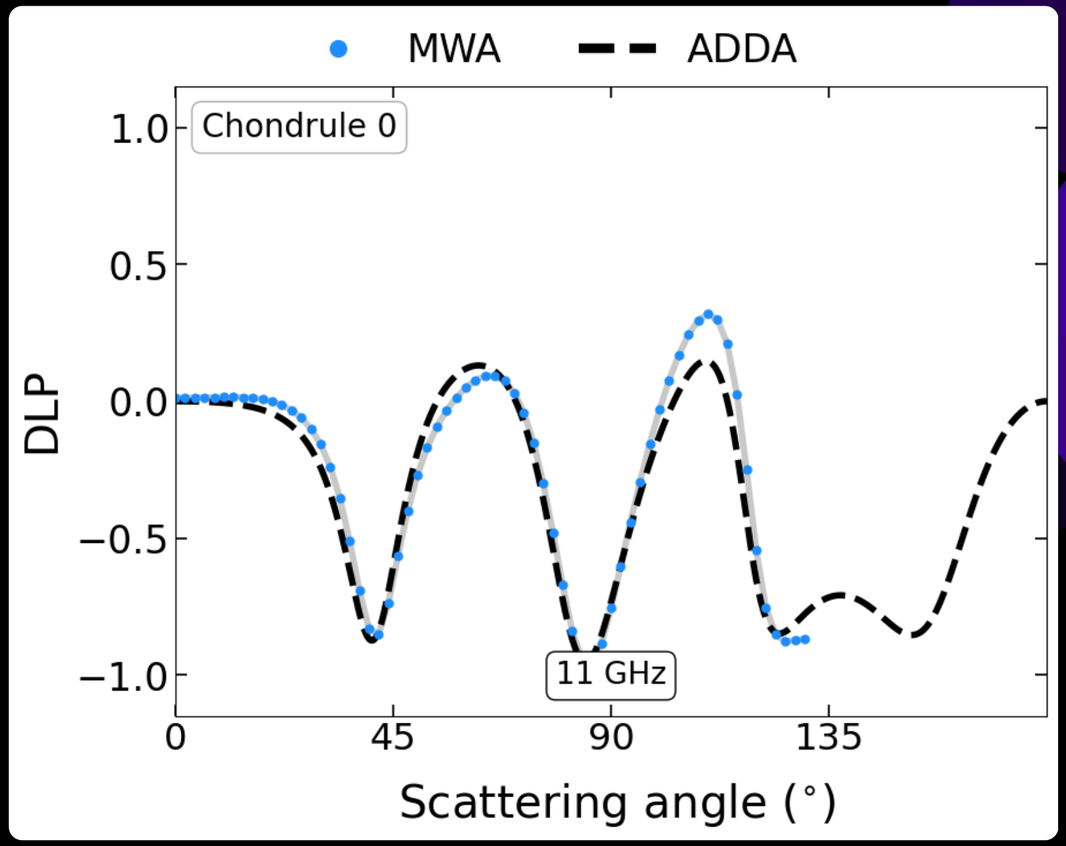
Cross validation of the methods

Astro silicate NIR
m = 1.7 + 0.01 j

Scattering Phase Function (SPF)



Degree of Linear Polarization (DLP)

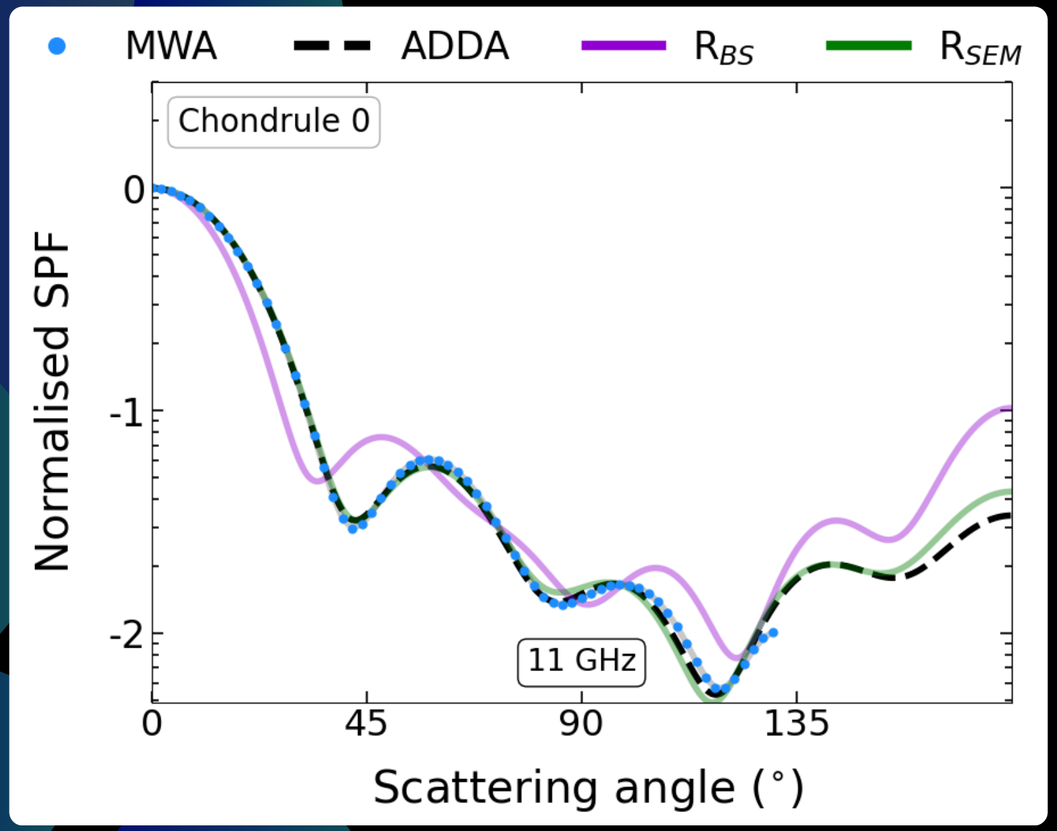


Result II :

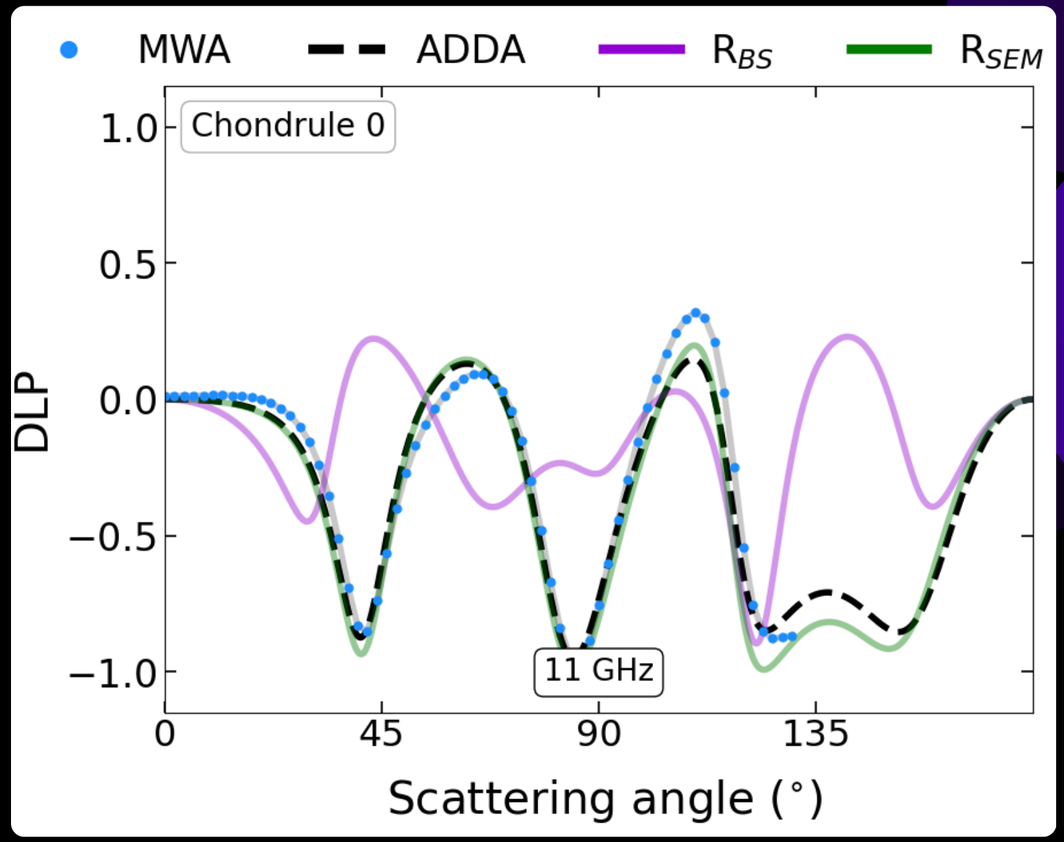
SPF and DLP against Mie theory

Astro silicate NIR
m = 1.7 + 0.01 j

Scattering Phase Function (SPF)



Degree of Linear Polarization (DLP)

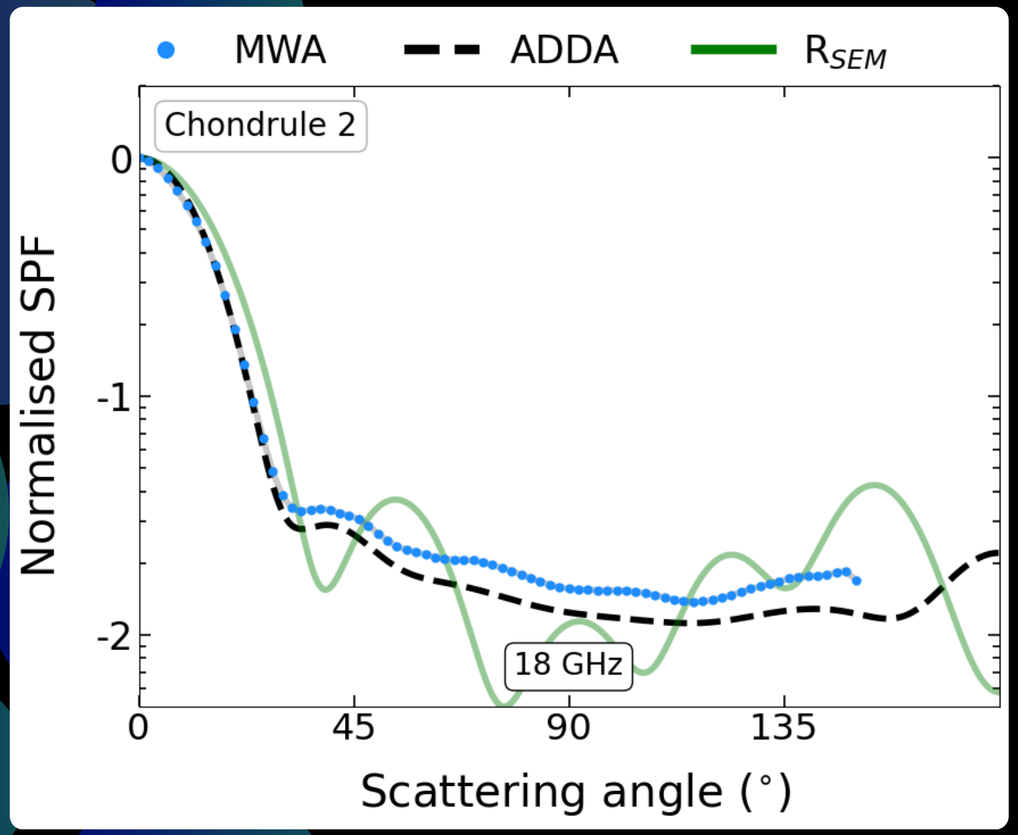


Result I + II (mm range) :

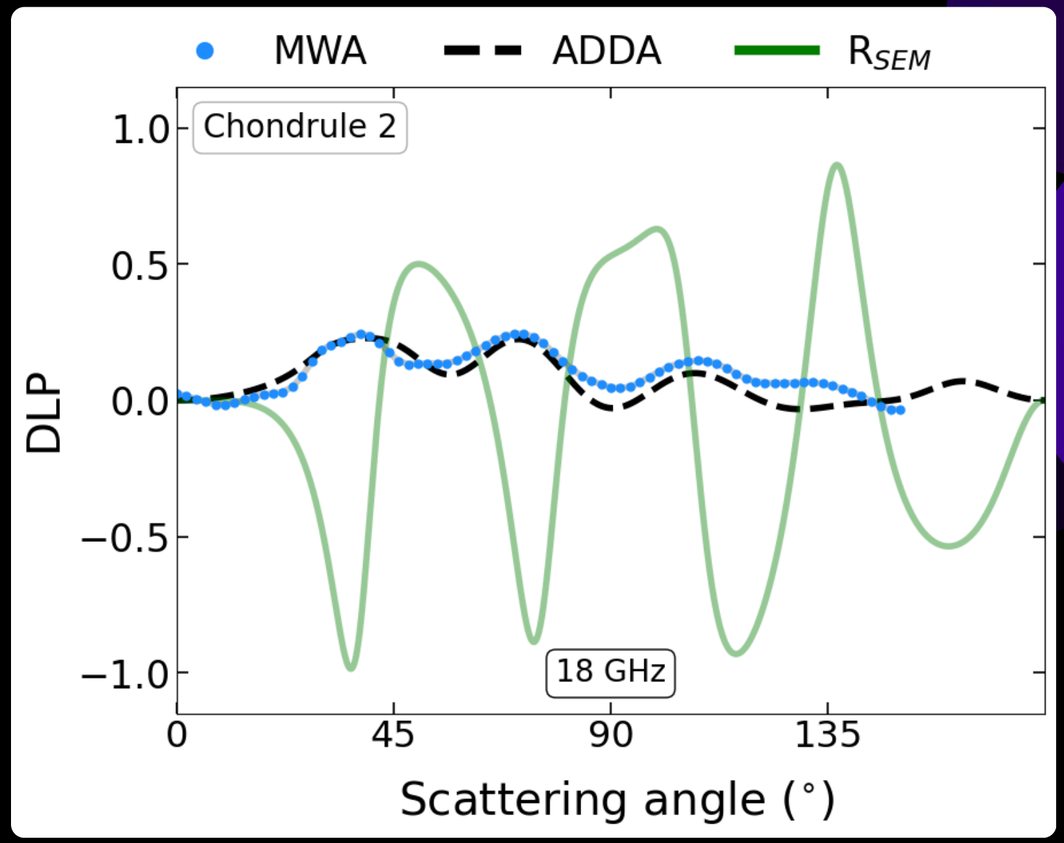
Cross validation of the methods

Astro silicate mm
m = 3.04 + 0.011 j

Scattering Phase Function (SPF)

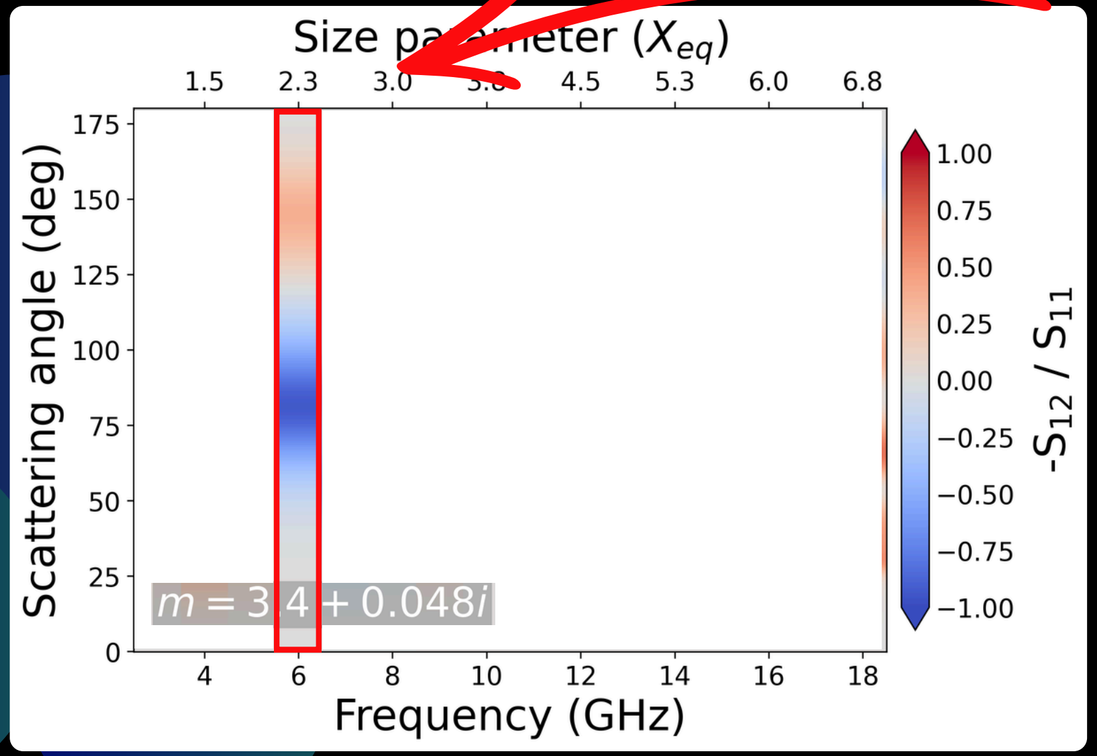


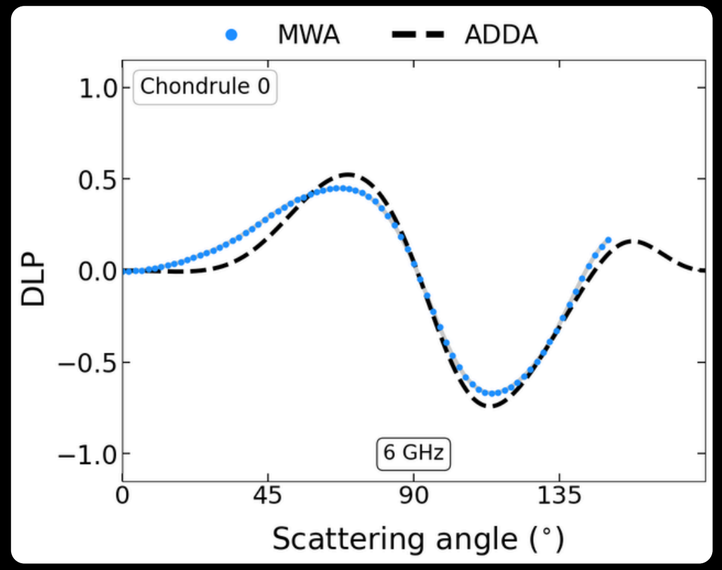
Degree of Linear Polarization (DLP)



Result III :

DLP of chondrules in mm range

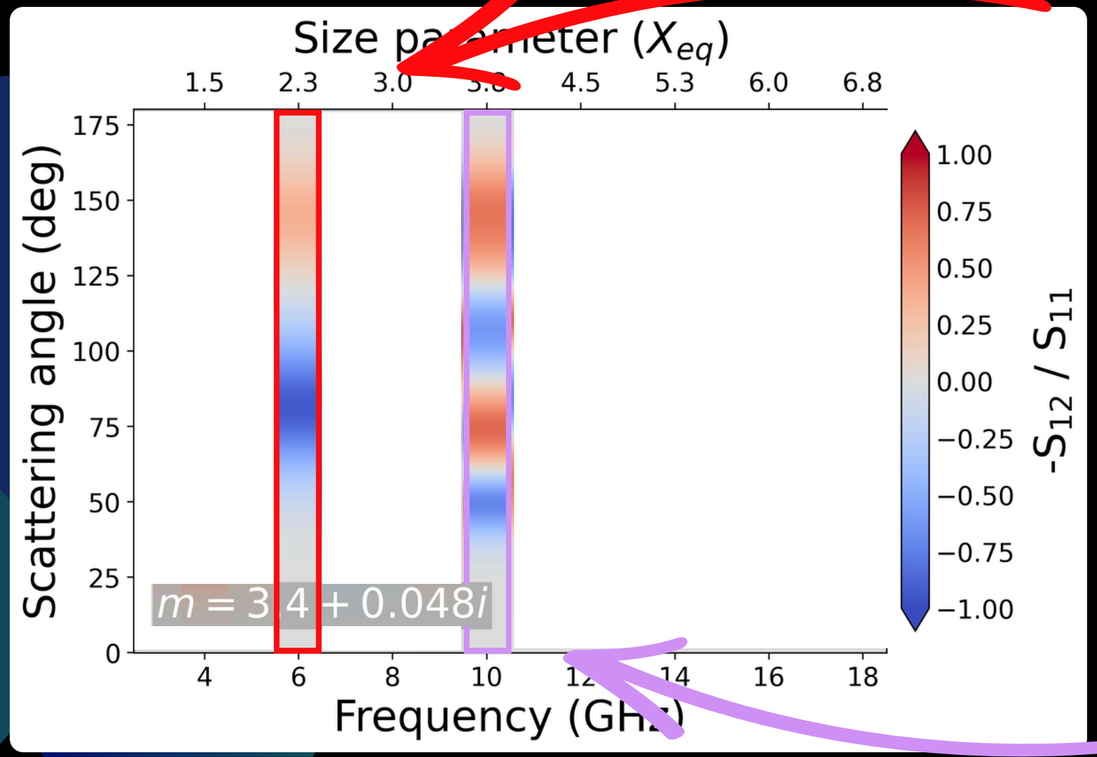


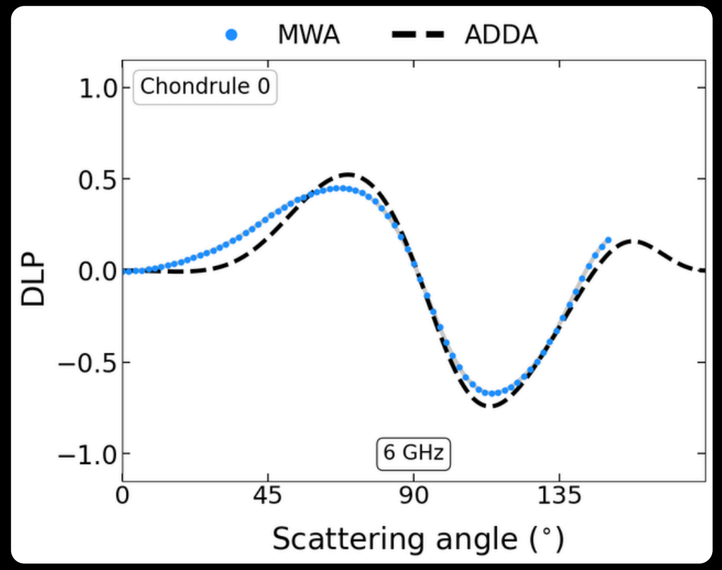


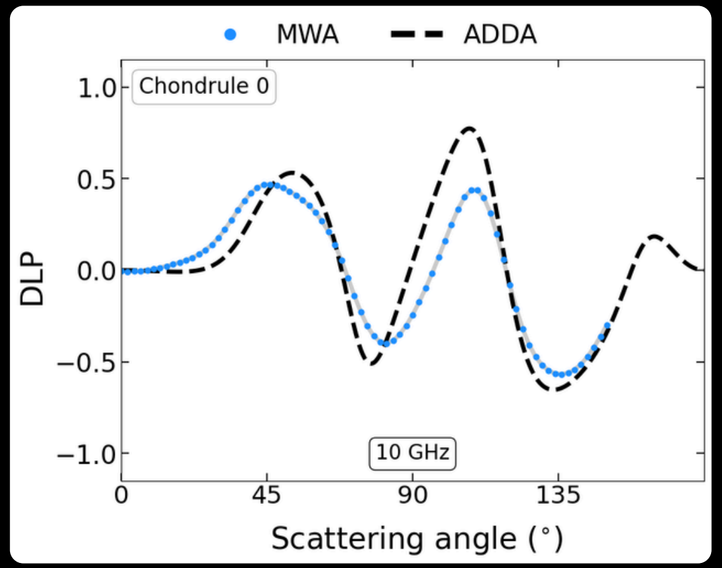
Almost spherical chondrule

Result III :

DLP of chondrules in mm range



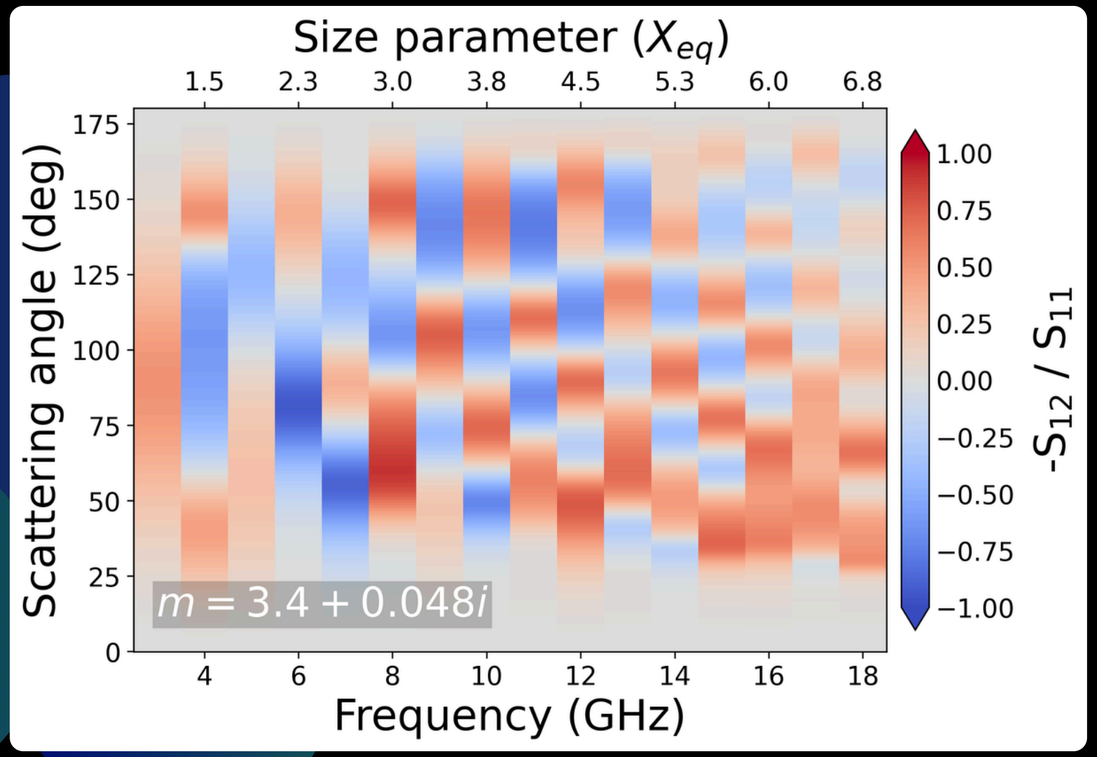




Almost spherical chondrule

Result III :

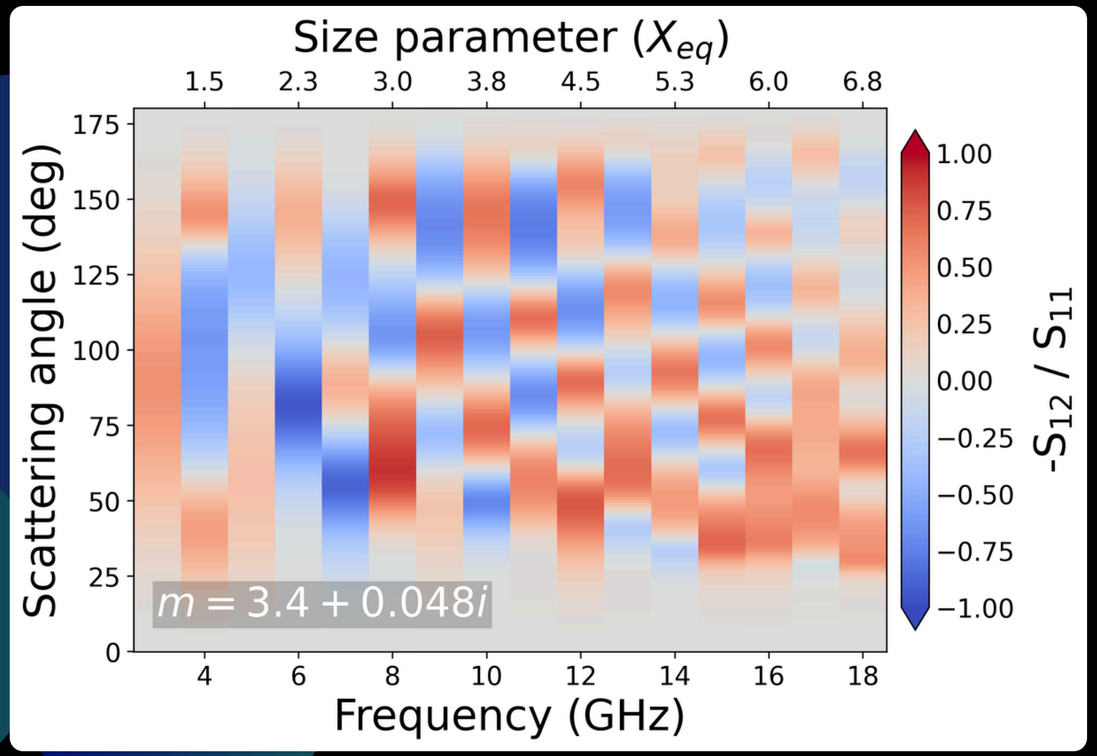
DLP of chondrules in mm range

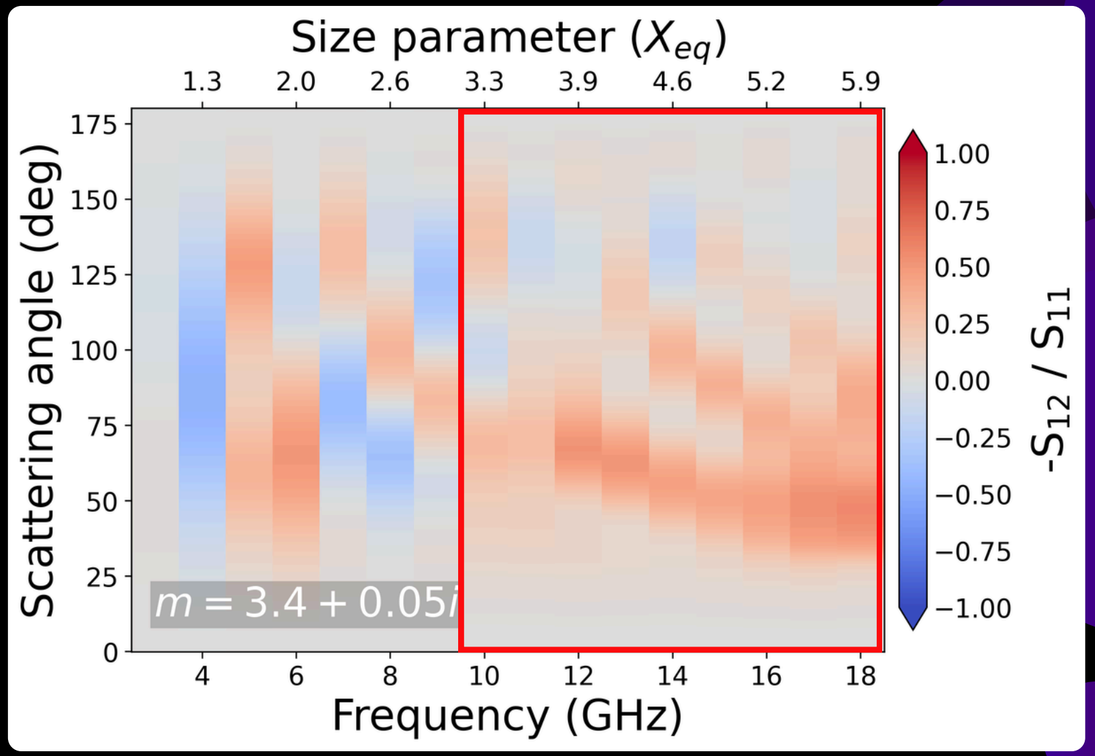


Almost spherical chondrule

Result III :

DLP of chondrules in mm range



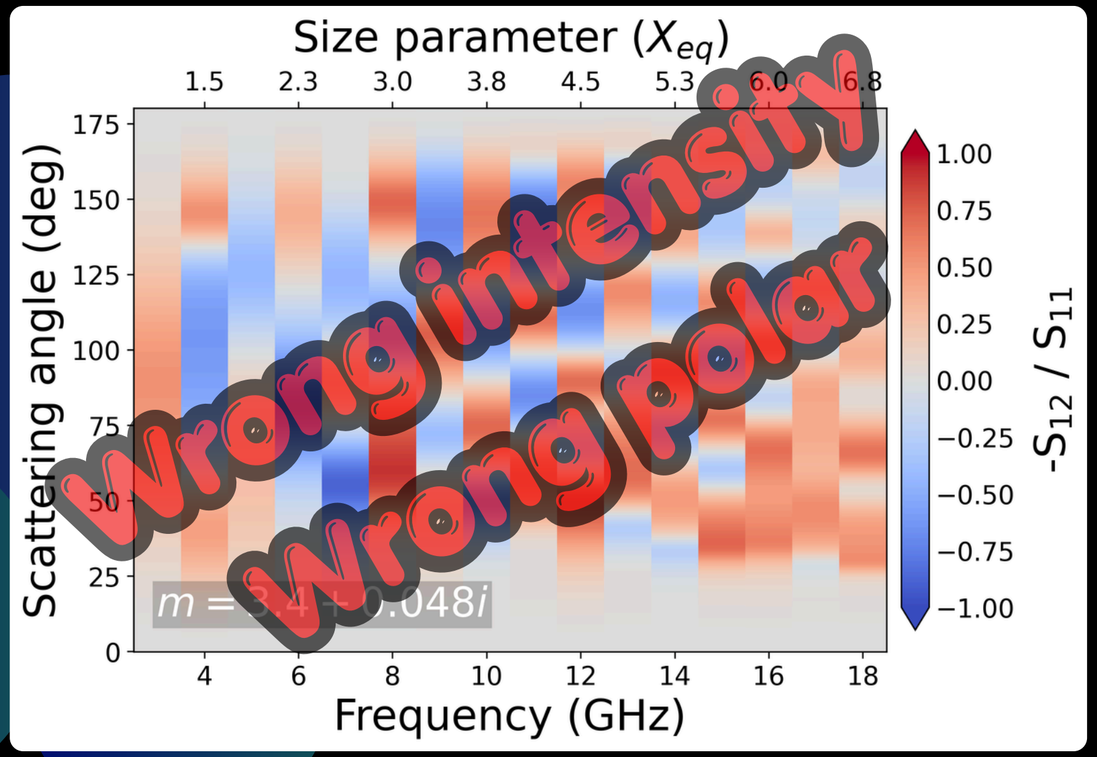


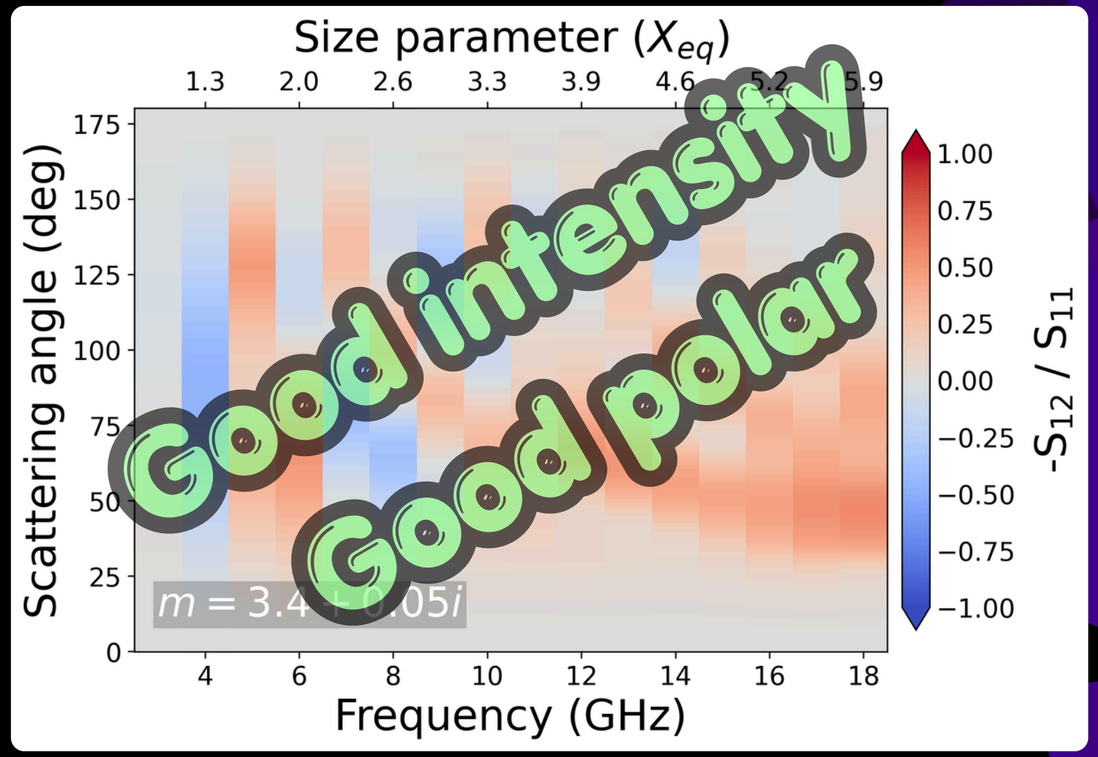
Almost spherical chondrule

Slightly less spherical chondrule

Result III :

DLP of chondrules in mm range





Almost spherical chondrule

Slightly less spherical chondrule

Take away messages

- Cross validation between ADDA and MWA
  - Depending on the studied case, we can chose between one or the other method, and trust it.
- Non spherical chondrules could have the good properties for reproducing ALMA observation at ~1 mm
  - Indeed, in mm range, chondrules have SPF close to Mie theory while DLP can have an interesting behavior.
    → we need to run radiative transfer simu. to test this hypothesis
- We better know how to use ADDA for non spherical analogs + high refractive indices
  - A paper summaryzing everything should be written to help other ADDA users.