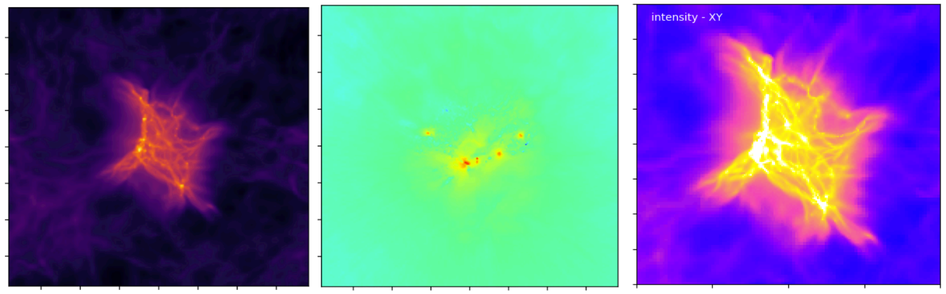
POST-PROCESSING OF NUMERICAL SIMULATIONS

EXPLORING SIGNS OF DUST GROWTH AT BAND 2 THROUGH POLARIZATION



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CONTEXT AND MAIN GOAL

CONTEXT:

ENYGMA: a NOEMA large program within ECOGAL, which aims to do polarimetry at 3mm and characterize dust properties in ~50 Class 0 protostars.

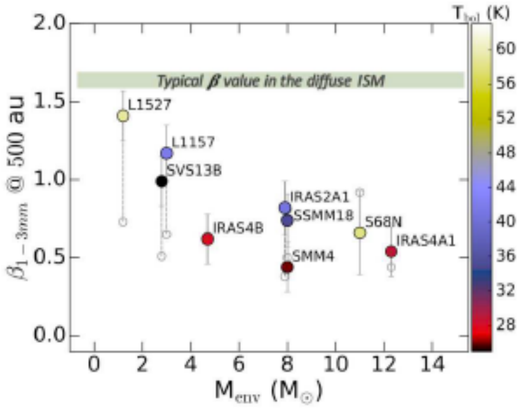
GOAL:

POST-PROCESS of 3-D MHD simulations of cloud collapses to compare polarimetry of ENYGMA sources with synthetic polarimetric maps and constrain dust growth.

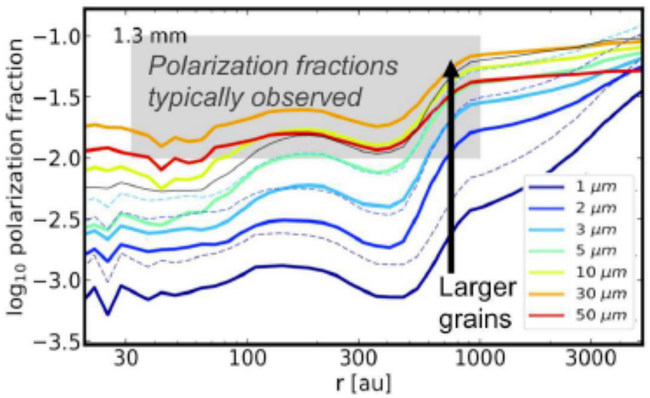
WHY IT MATTERS FOR ALMA BAND 2:

SELF-SCATTERING of larger grains (between ~0.4 cm to ~0.7 cm) is likely to be detected at wavelengths > 3 mm.

Galametz et al. (2019)

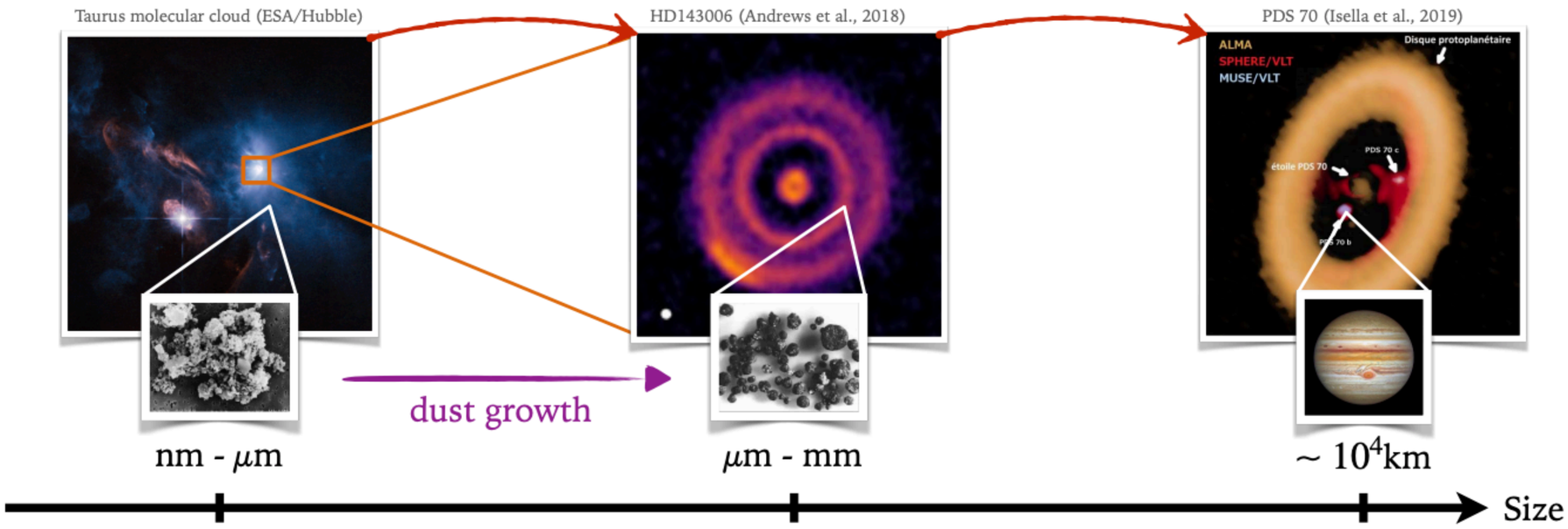


Valdivia et al. (2019)



3D SIMULATIONS WITH DUST DYNAMICS DURING PROTOSTELLAR COLLAPSE

Dust growth, the first step for planet formation



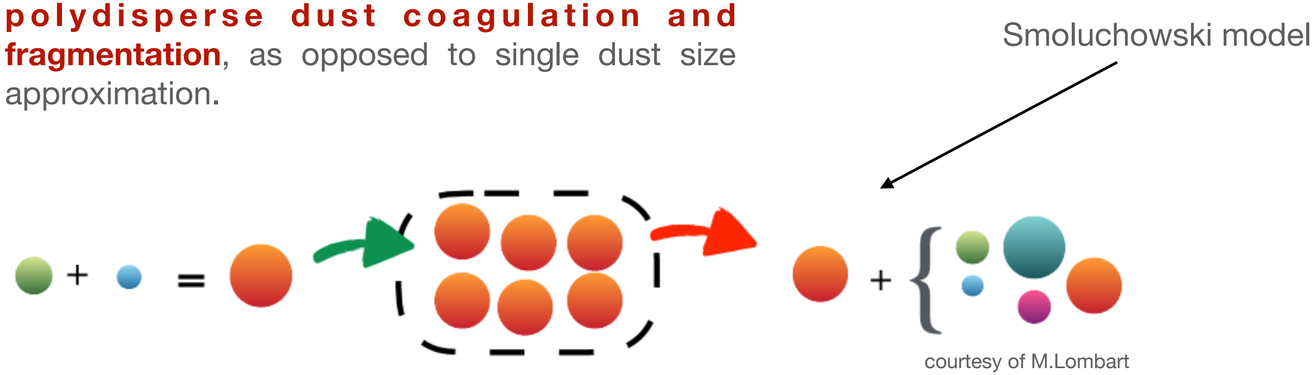
courtesy of M.Lombart

Dust growth is an effective process and should be detected at early stages around YSOs

3D SIMULATIONS WITH DUST DYNAMICS DURING PROTOSTELLAR COLLAPSE

The multi-fluid approach

New models allow for 3D simulations with **polydisperse dust coagulation and fragmentation**, as opposed to single dust size approximation.



courtesy of M.Lombart

Allows for up to **three orders of magnitude** in dust size (1micron to mm-size).

Model is now coupled to the MHD **RAMSES** code. Consist of a mass range **discretization** (lower numerical cost).

E.G.

SHARK (1D)

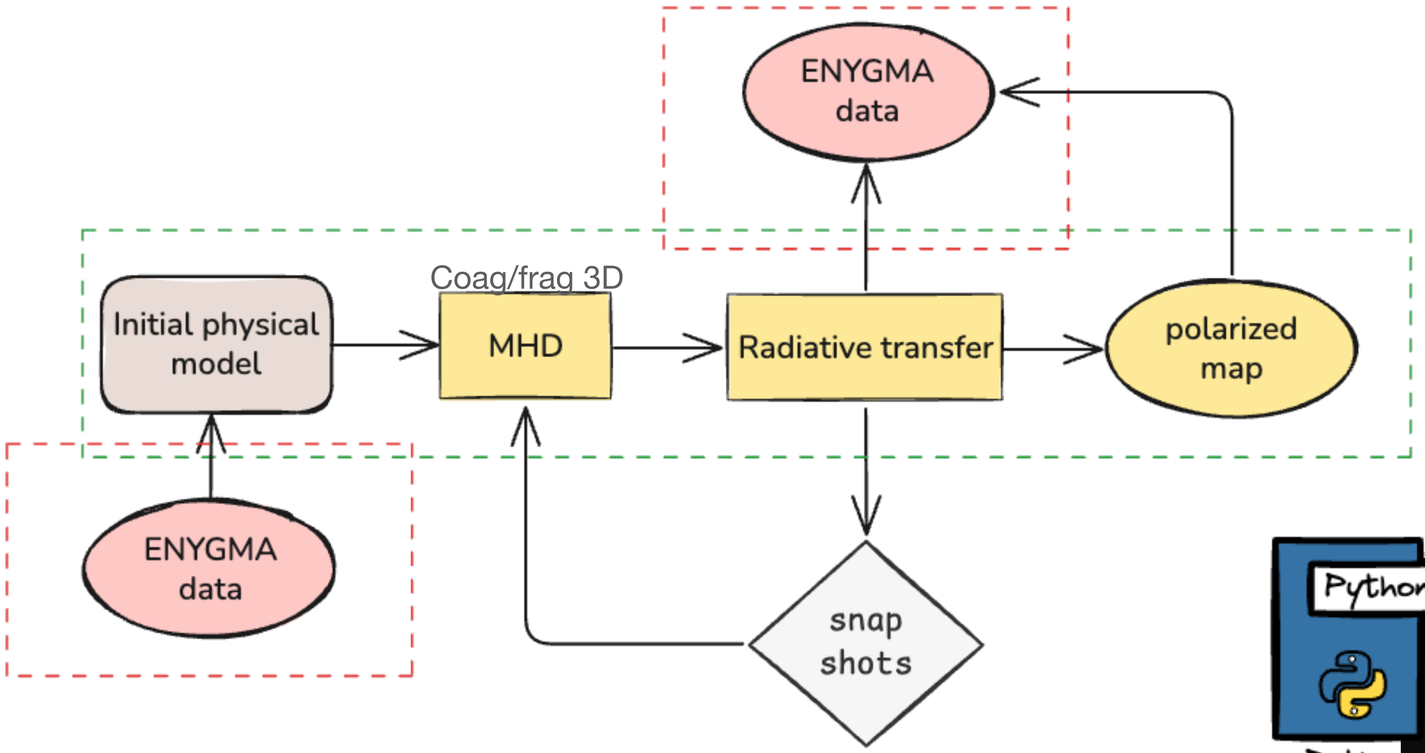
Lebreuilly et al. (2023)

COALA (3D)

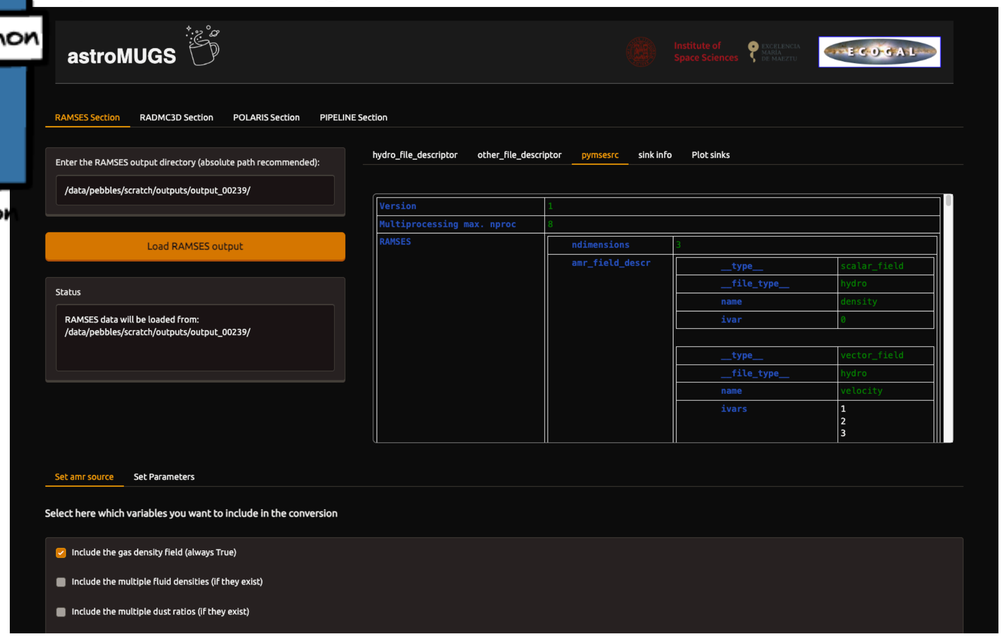
Lombart et al. (2026)

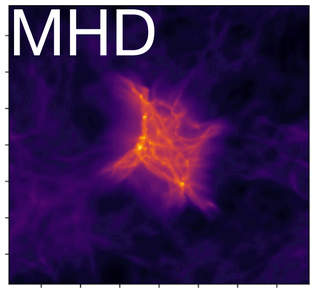
POSTPROCESSING PIPELINE OVERVIEW

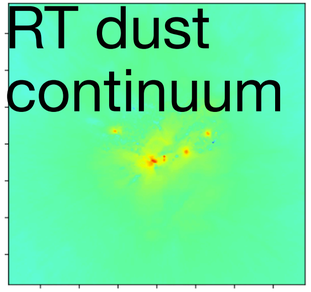
Built for multi-fluid MHD simulations

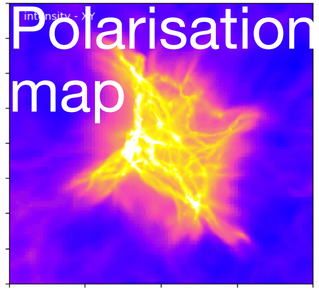


Built as a Graphical User Interface Python package (*I.Han, S,Gavino*)









Multi-grain chemistry

...

Preliminary results

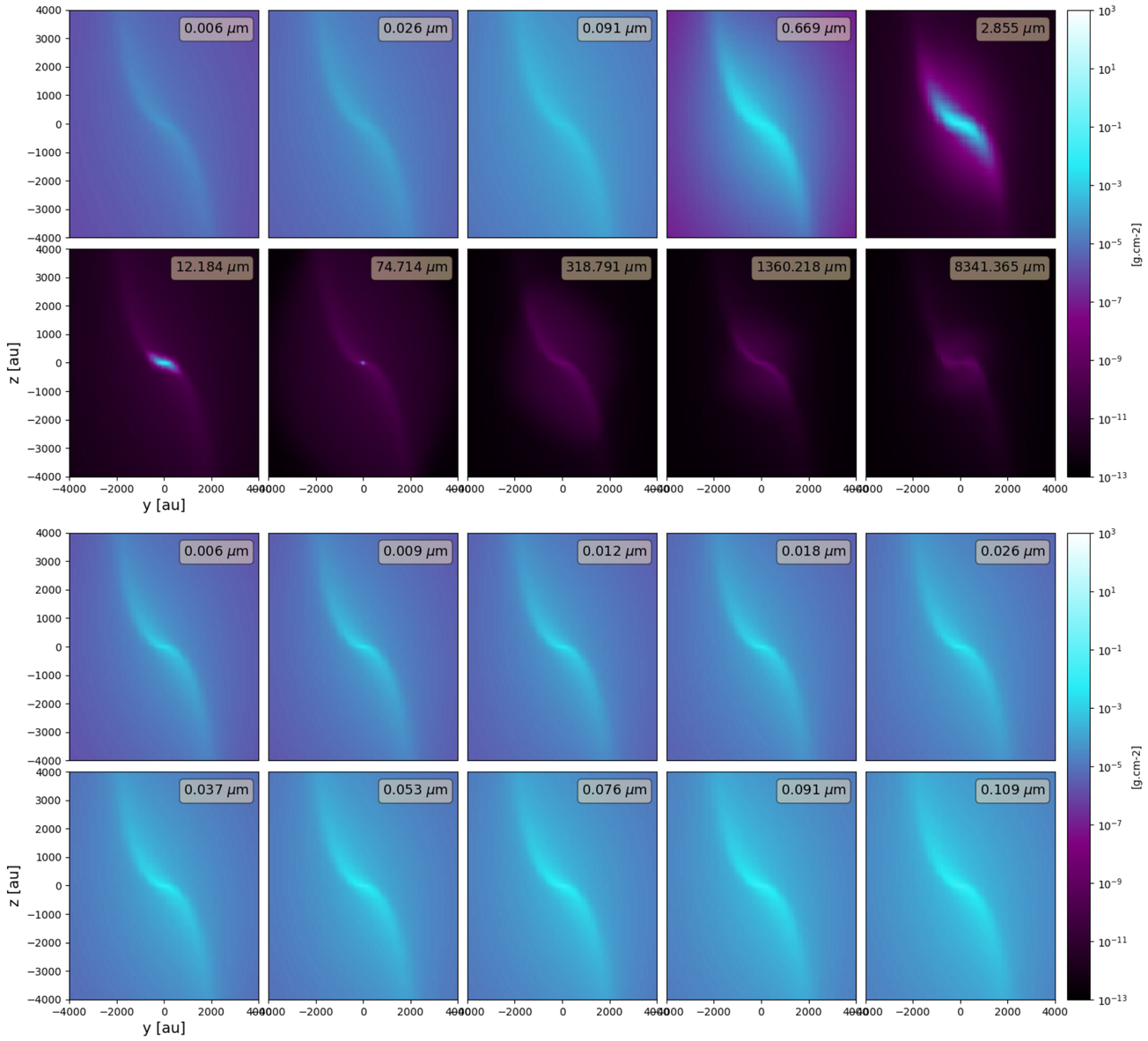
A case of dust growth in a single-core collapse simulation

TWO MODEL CASES

Dust model comparison

Growth case: 40 discretized mass fractions from the multi-fluid simulation itself. Size range from 5nm to 1cm.

No-growth case: 40 discretized mass fractions derived from a typical MRN distribution. Size range from 5nm to 1micron —> no dust growth.



RAMSES simulations by G.Verrier

Goal: Test the effect of dust dynamics (growth) on the synthetic polarization maps

POST-PROCESSING STEPS

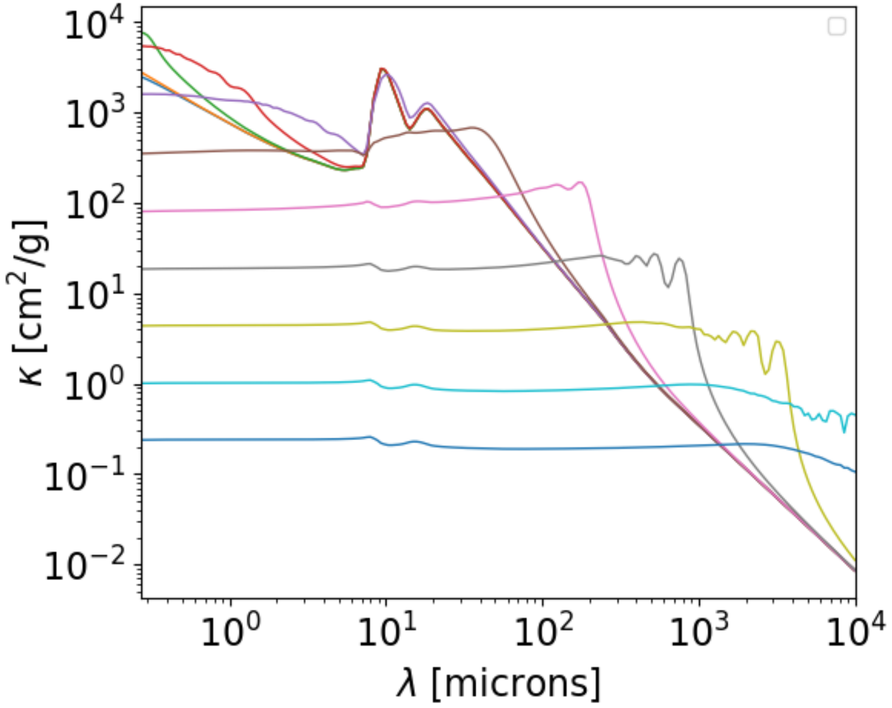
Radiative transfer: consistent opacities

Dust mass from simulations - Sizes between 5 nm to 1 cm

Mass fractions derived from MRN distribution from 5nm to 1microns

Growth (multi-fluid) model

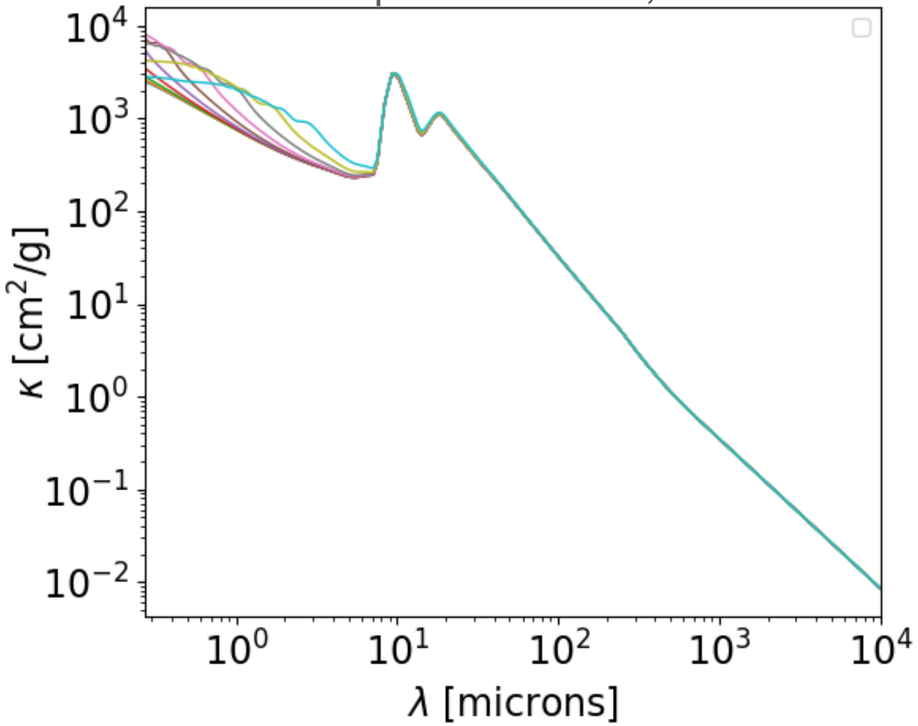
40 dust opacities/sizes, Draine03



Caveat: only spherical grains for now!

No-growth model

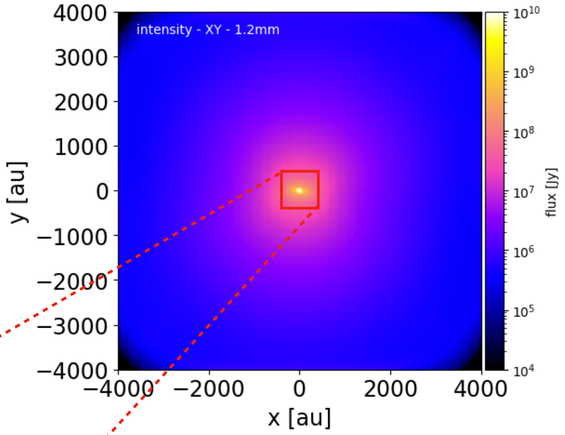
40 dust opacities /sizes, Draine03



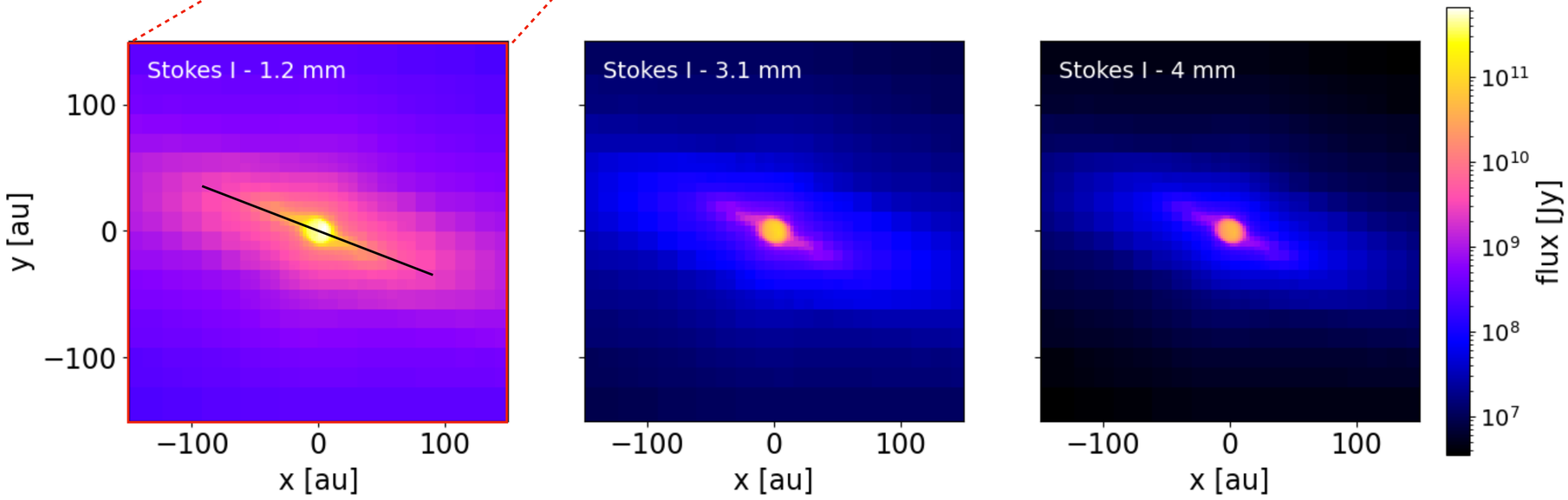
The “Growth” model includes dust sizes whose self-scattering shall be detected at Band 2.

POST-PROCESSING STEPS

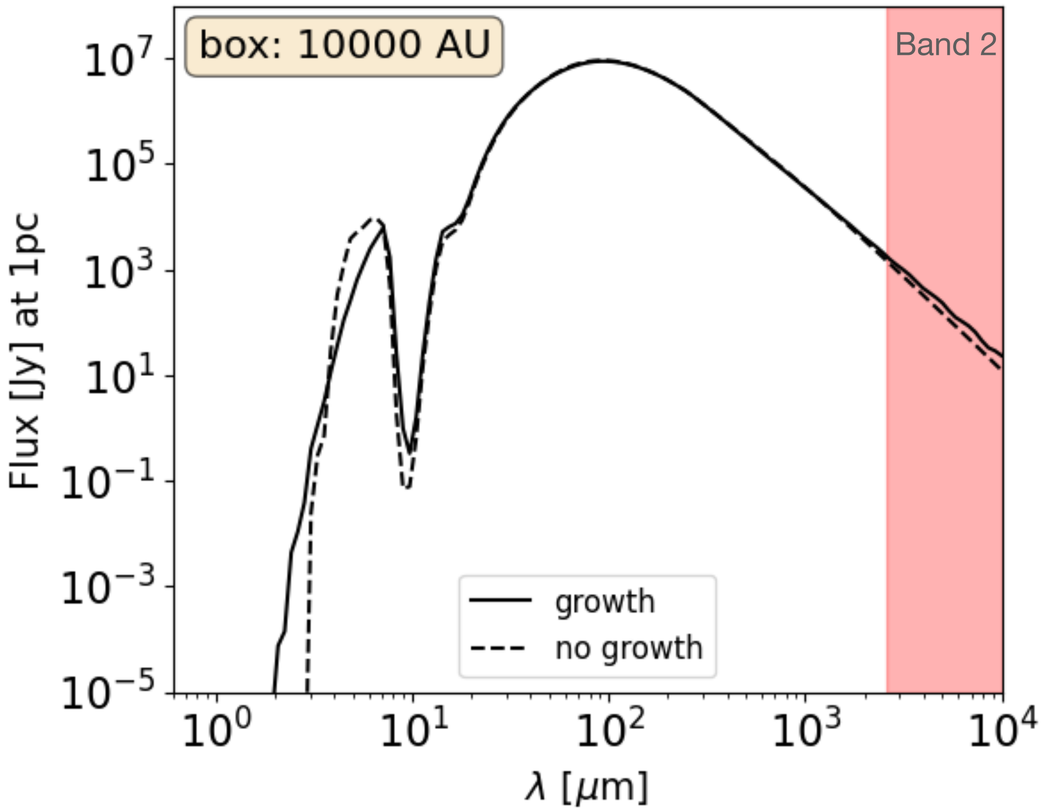
Radiative transfer/Ray-tracing

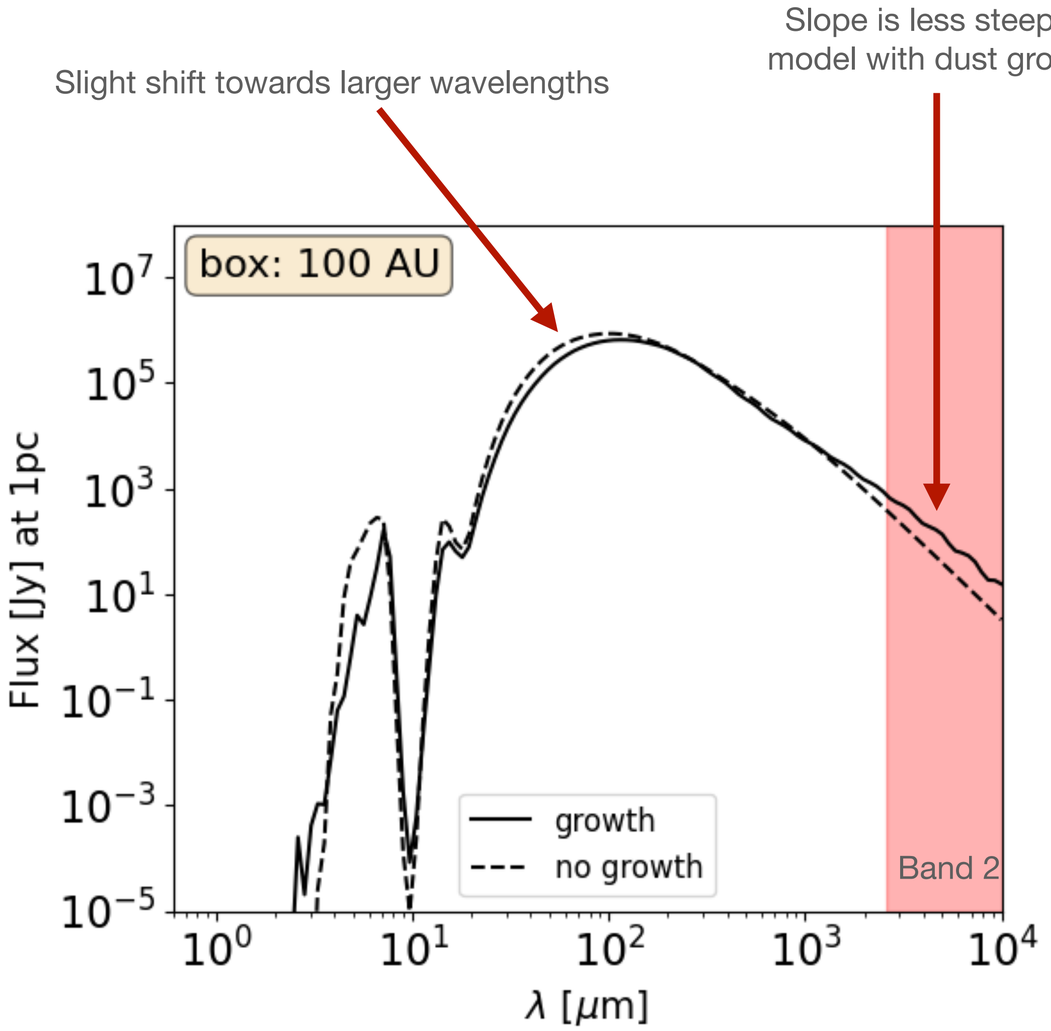


<u>Three lines:</u> 1.2mm - 3.1mm - 4mm



SPECTRAL ENERGY DISTRIBUTION (SEDs)



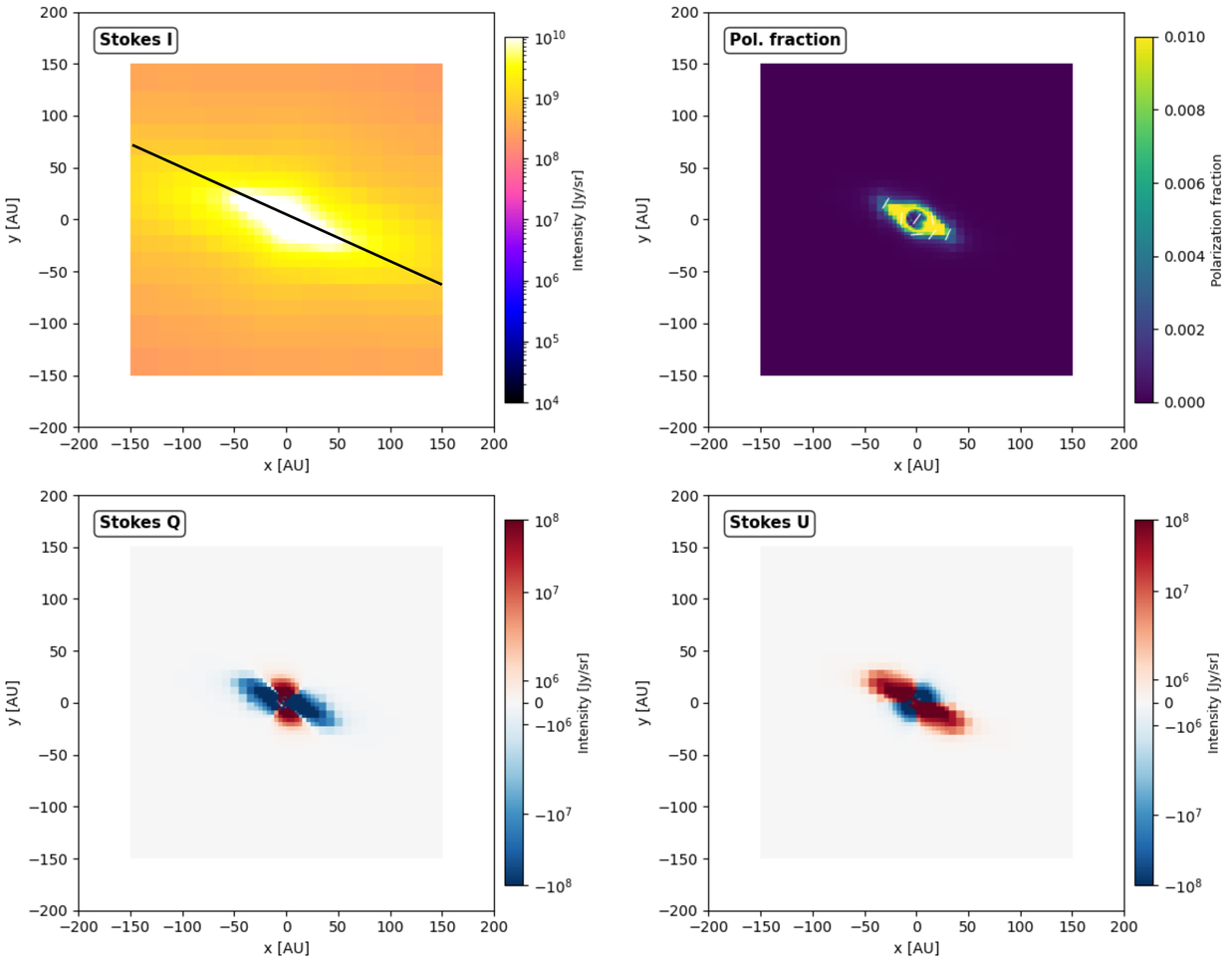


Dust growth implies slight, but measurable changes (in particular in Band 2)

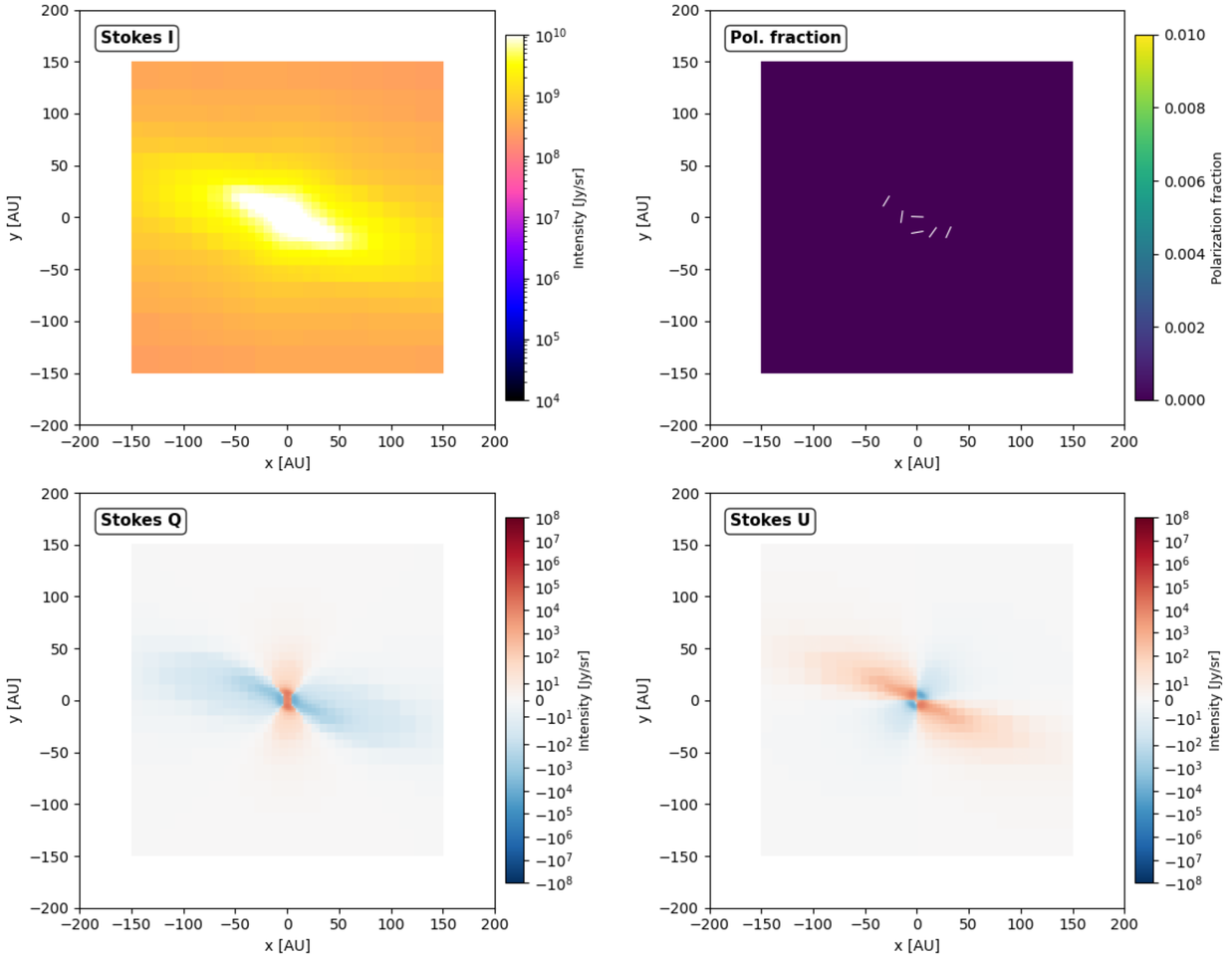
Polarisation maps

Model comparison in Band 6 (**λ = 1.2mm**)

Growth model



No-growth model

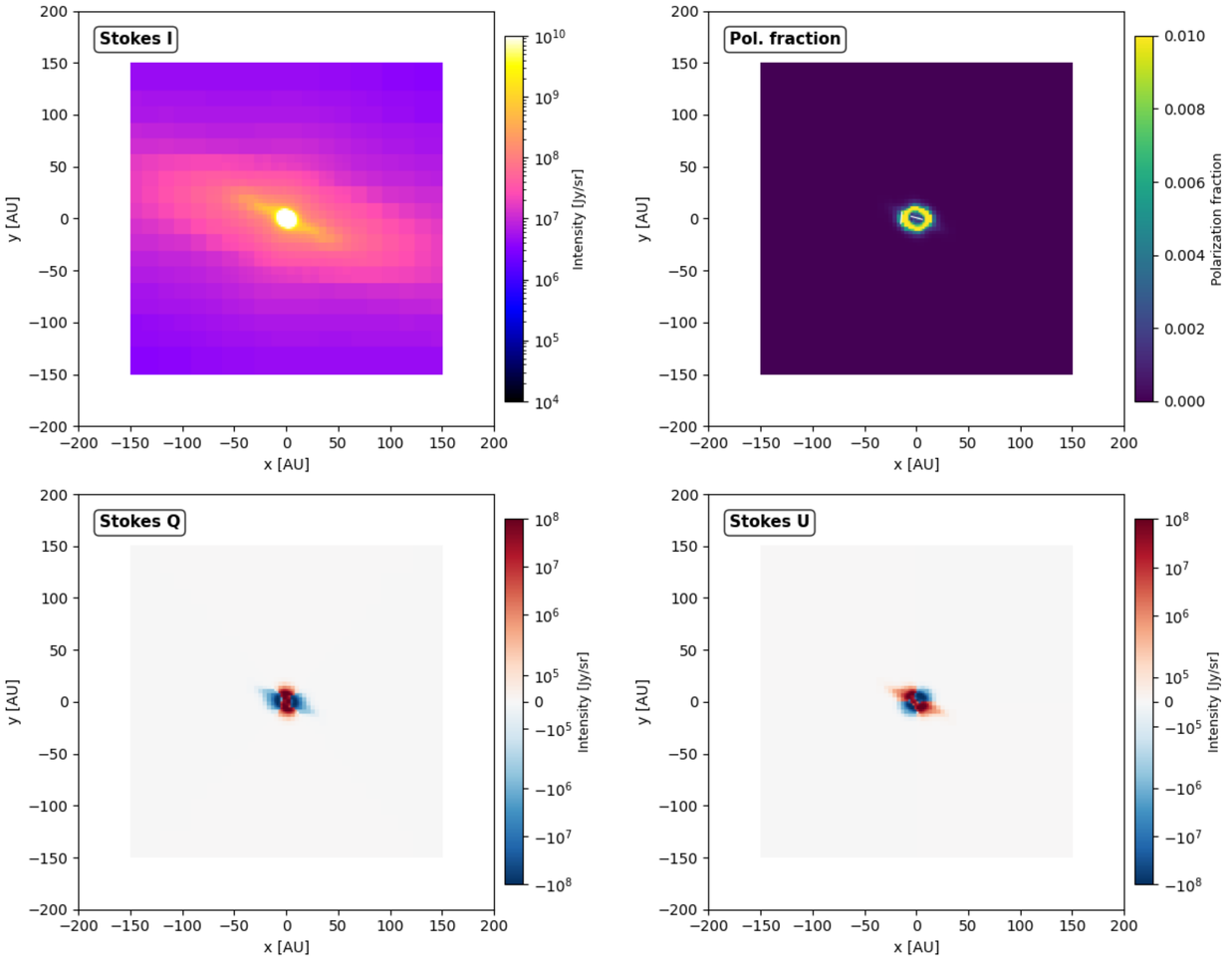


Polarisation maps

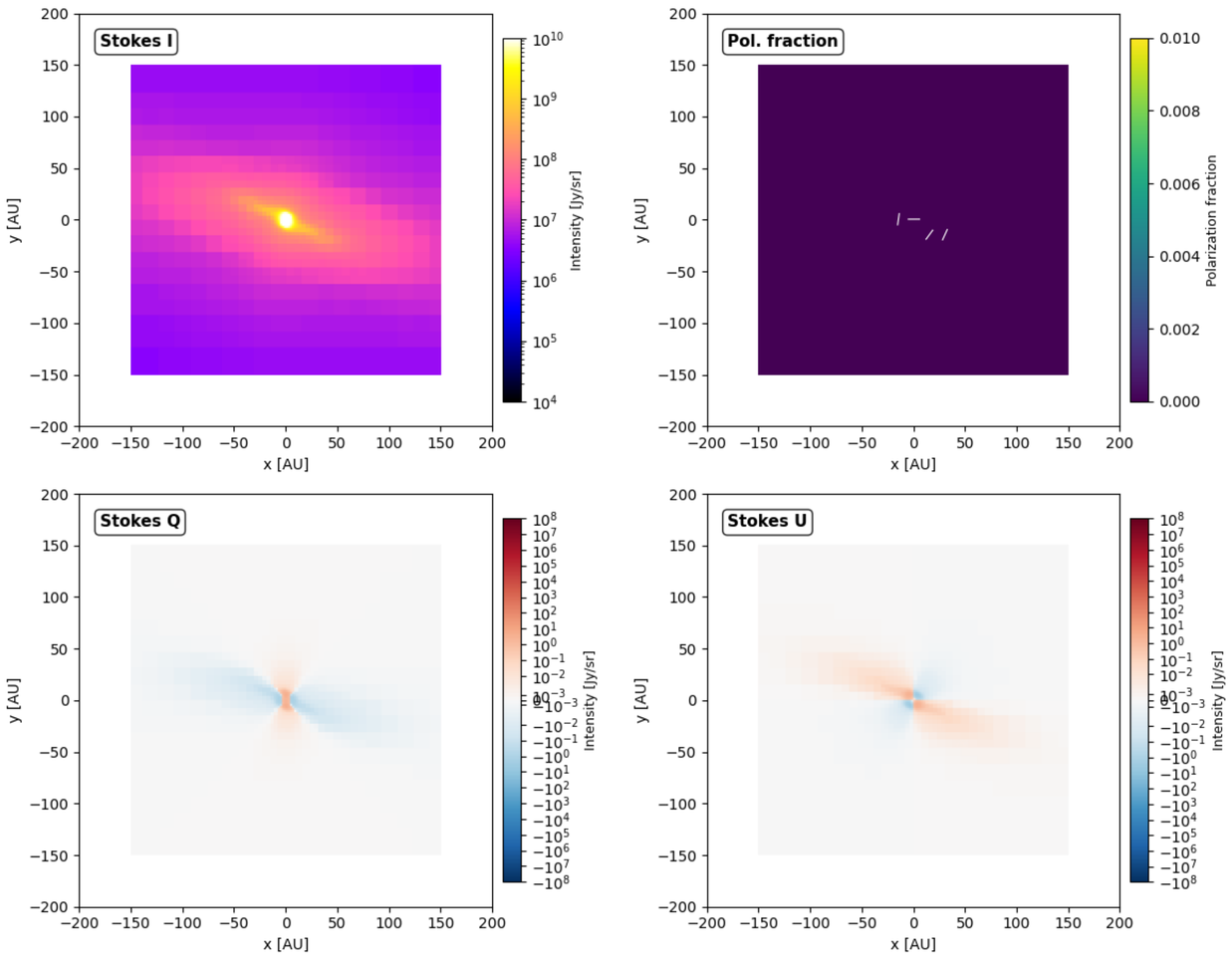
Model comparison in Band 2 (**λ = 4mm**)

Results: suggest growth is measurable through pol. Fraction at band 2.

Growth model



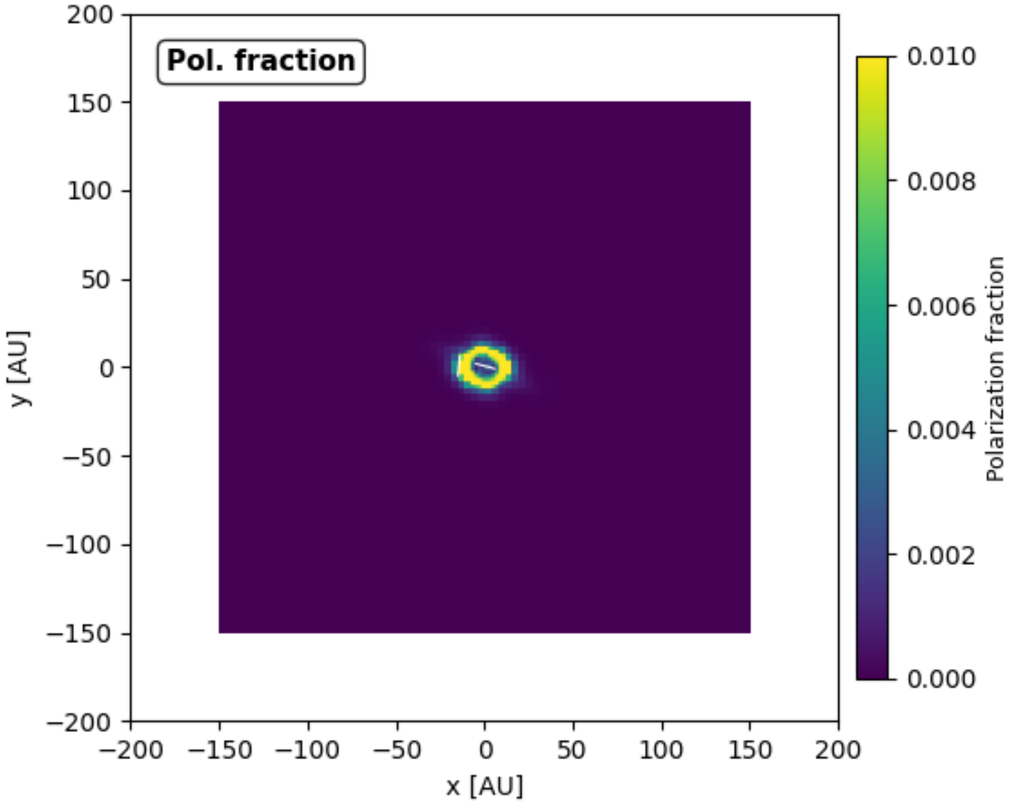
No-growth model



Polarisation maps

Comparison with observed sources

Growth model



Synthetic polarised maps show **abrupt transition** between disk and envelope in polarization fraction at band 2, 3 and 6. Consistent with dust growth at disk scale. Consistent with **ENYGMA** data (previous talks).

Caveat: optical depth effects or actual growth? —> Needs more analysis.

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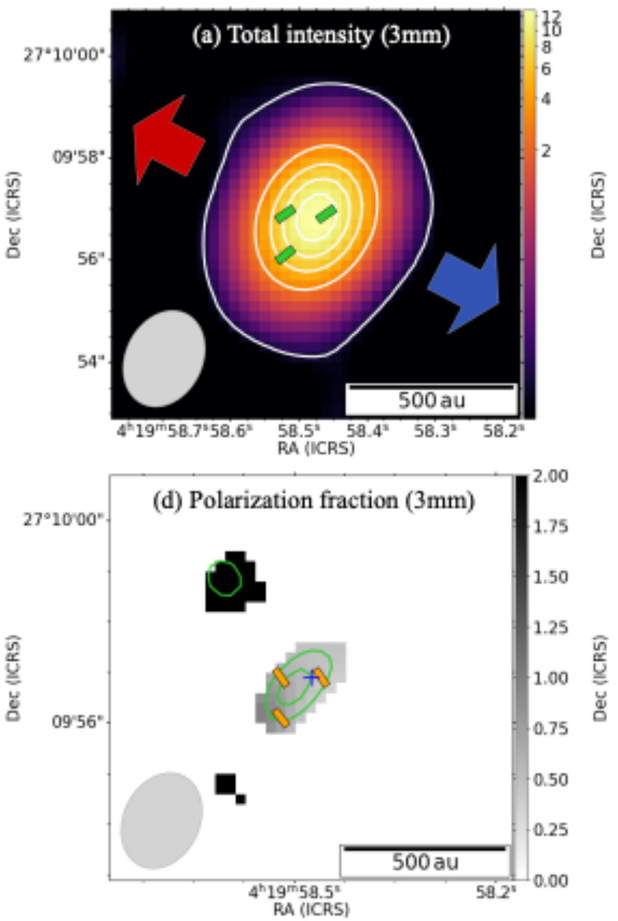

A.Sato et al. (2026)'s ALMA polarimetric observations show transition from envelope (magnetically aligned grains) to self-scattering at disk scale

Key take-away

- Context: ENYGMA, a NOEMA large program within ECOGAL, which aims to map at 3mm magnetic fields and characterize dust properties in ~50 Class 0 protostars.
- New 3-D MHD code (RAMSES) coupled to dust coagulation/ fragmentation models (COALA, *Lombert et al. 2026, G.Verrier et al. 2025*).
- We build a full post-processing pipeline for multi-fluid cases to generate synthetic maps of polarized dust emission and constraint dust growth in ENYGMA sources. First results show polarisation at Band 2, probably self-scattering.
- From preliminary ENYGMA results (previous presentations today), we don't see the collapse of polarisation at 3 mm typically observed.
- Future: further analyses of synthetic observation data, use of more complex dust models (*e.g. M-A Caprine et al. 2025*), RAT modeling, constraint dust growth (sizes > a few 100 microns) at Band 2 wavelengths.