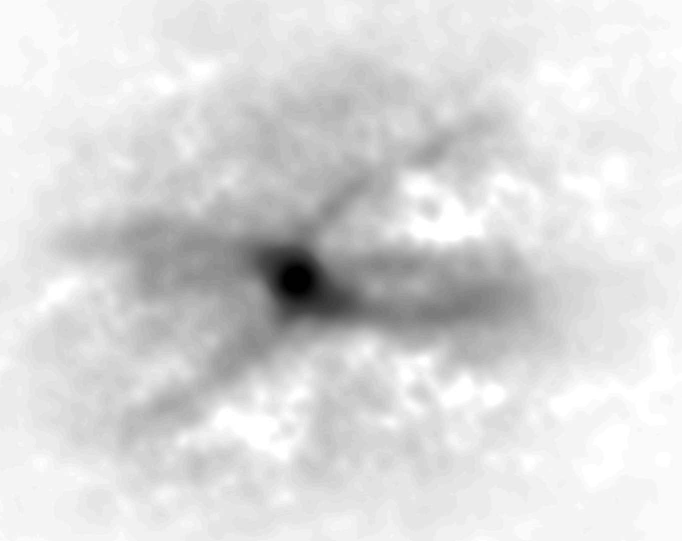
Constraining the Dust Grain Alignment Mechanism(s) Responsible for the (Sub-)millimeter Dust Polarization Observed in Class 0 Protostellar Cores

Our Galactic Ecosystem: Opportunities and Diagnostics in the Infrared and Beyond

Valentin Le Gouellec

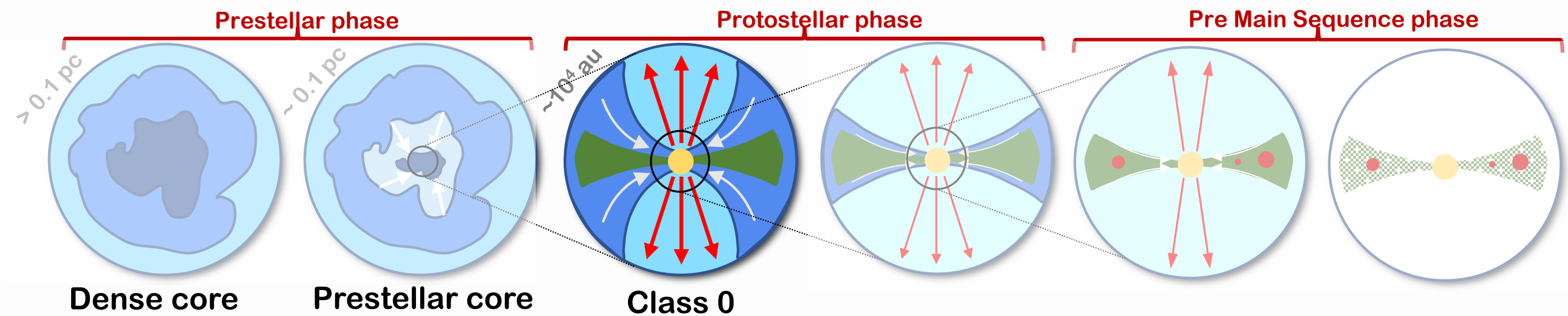
March 2nd 2022



Anaëlle Maury (CEA), Chat Hull(NAOJ), J.M. Girart (ICE-CSIC), V. Guillet (IAS), P. Hennebelle (CEA), M. Gonzalez (CEA), A. Verliat (CEA), R. Mignon-Risse (CEA), V. Valdivia (CEA), M. Galametz (CEA), F. Louvet (CEA), P. Cortes (NRAO), Lars Kristensen (NBI), Antoine Gusdorf (LPENS), L. Tychoniec (ESO),

How do solar-type stars form ?

Lada + 1984, 1987, André + 2000,2002

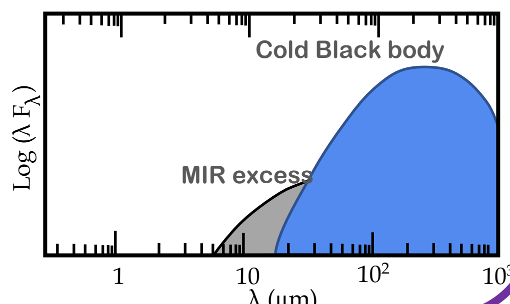


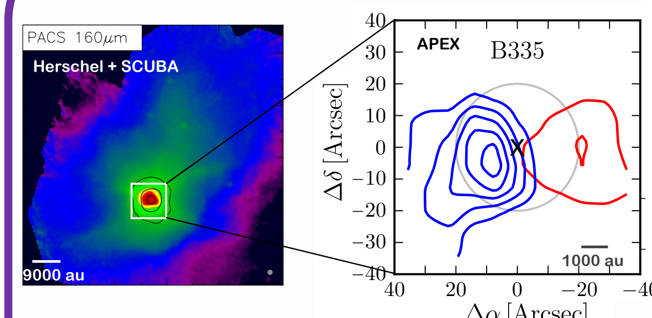
Main **accretion** phase. Material is accreted onto the **protostellar embryo** from the **collapsing envelope.**

Formation of a **circumstellar disk**

Ejection of mater via **bipolar outflows**

Size ~ 10 000 au
Duration ~ 10^4 yrs
$T_{bol} < 70$ K
$M_* << M_{env}$
$M_{acc} \sim 10^{-5} M_{sun} yr^{-1}$

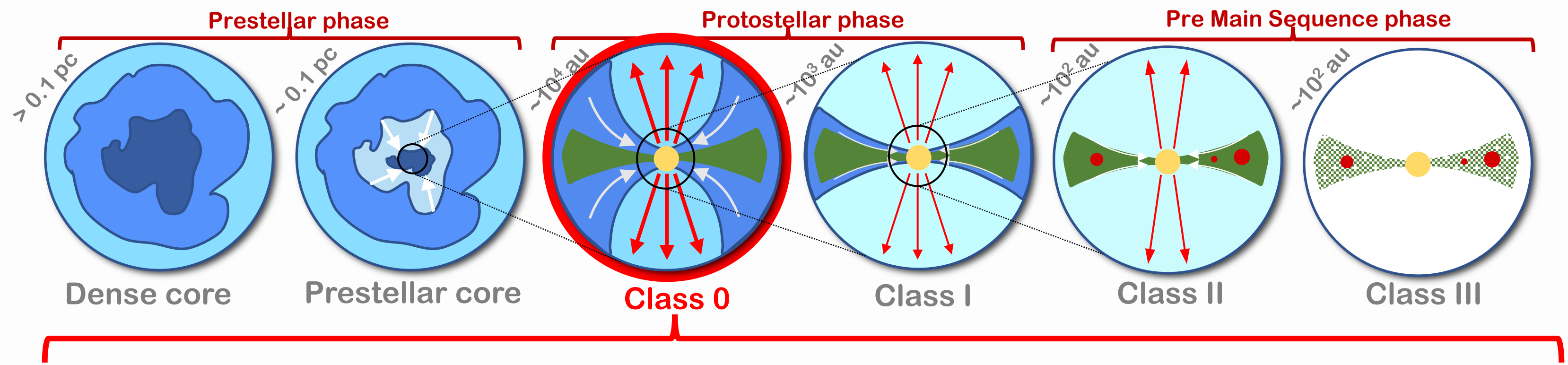




Launhardt + 2013

Yildiz + 2015

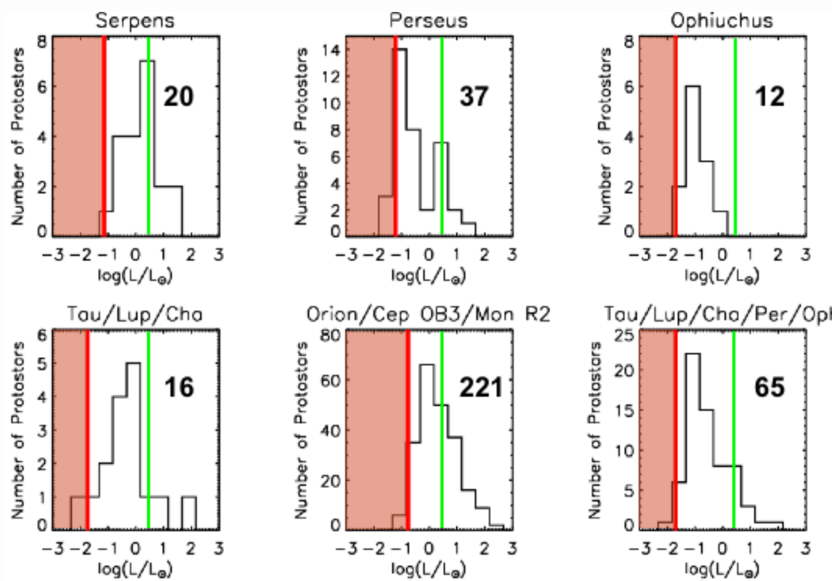
Class 0 protostars: what problems remain?



Evolution of Class 0 : how do the infall and accretion proceed?

How do we reconcile the infall of the envelope with the accretion onto the protostellar embryo ?

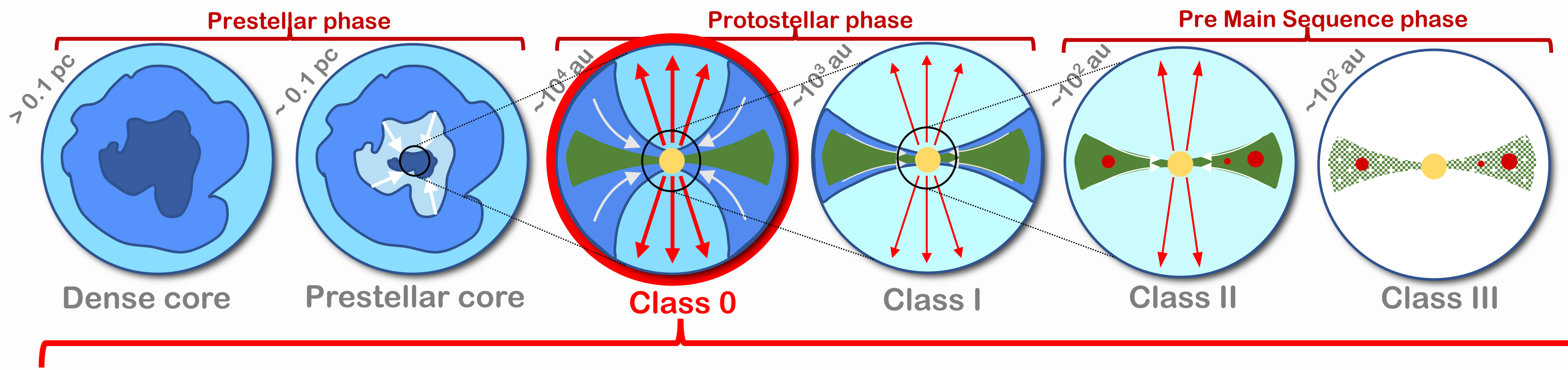
- Episodic accretion events

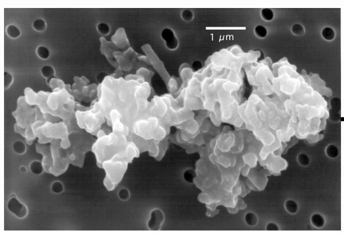


from c2d Spitzer, Kryukova + 2012

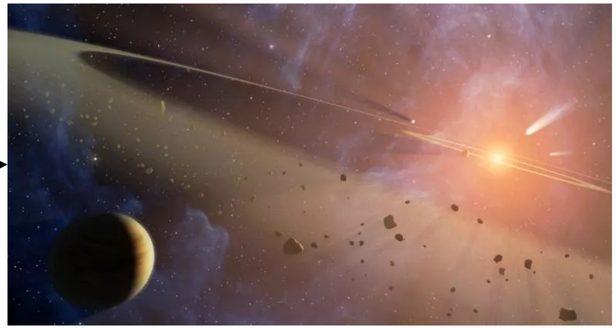
Luminosity of protostars < Expected Mass accretion rate

Class 0 protostars: what problems remain?





Cosmic dust grains



Pebbles and Planetesimals

Observations of their thermal emission in star forming regions to find protostars

1/100 of the gas density

What are the characteristics of the dust populating YSOs?

What is the dust size distribution in the envelope?

How efficient is the dust growth in the Class 0 stage as a function of scales and region of YSOs?

How all those problems are linked to **magnetic fields** and **dust polarization** ?

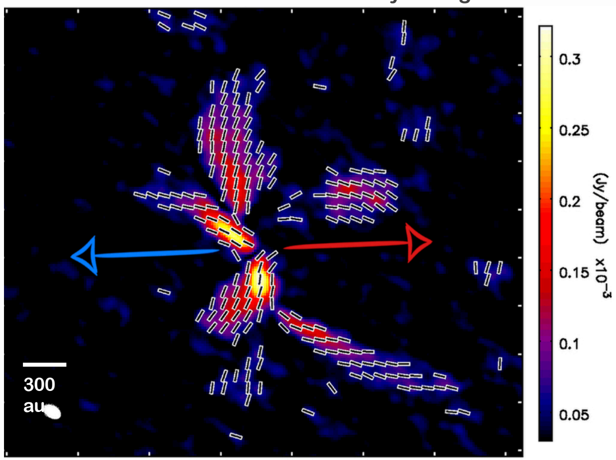
The role of magnetic fields in protostars

500 – 1000 au

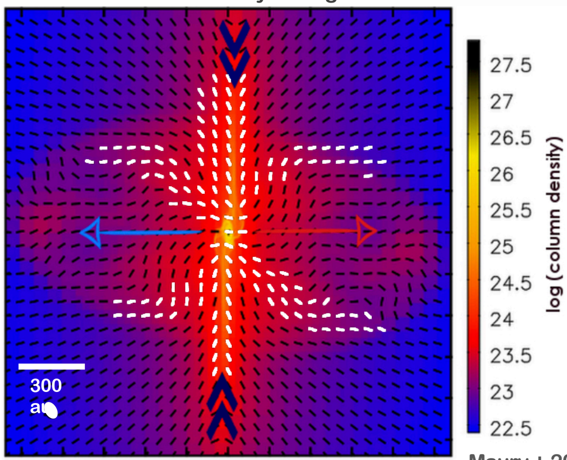
Protostellar envelope

What **ALMA** reveals at below 500 au scale.
B335: a possible magnetically regulated collapse?

ALMA observations: Polarized intensity + magnetic fields



Model: Column density + magnetic fields



Maury + 2018

How efficient is this regulation?

Is magnetic braking influencing for the formation of young disks (their size and mass)?

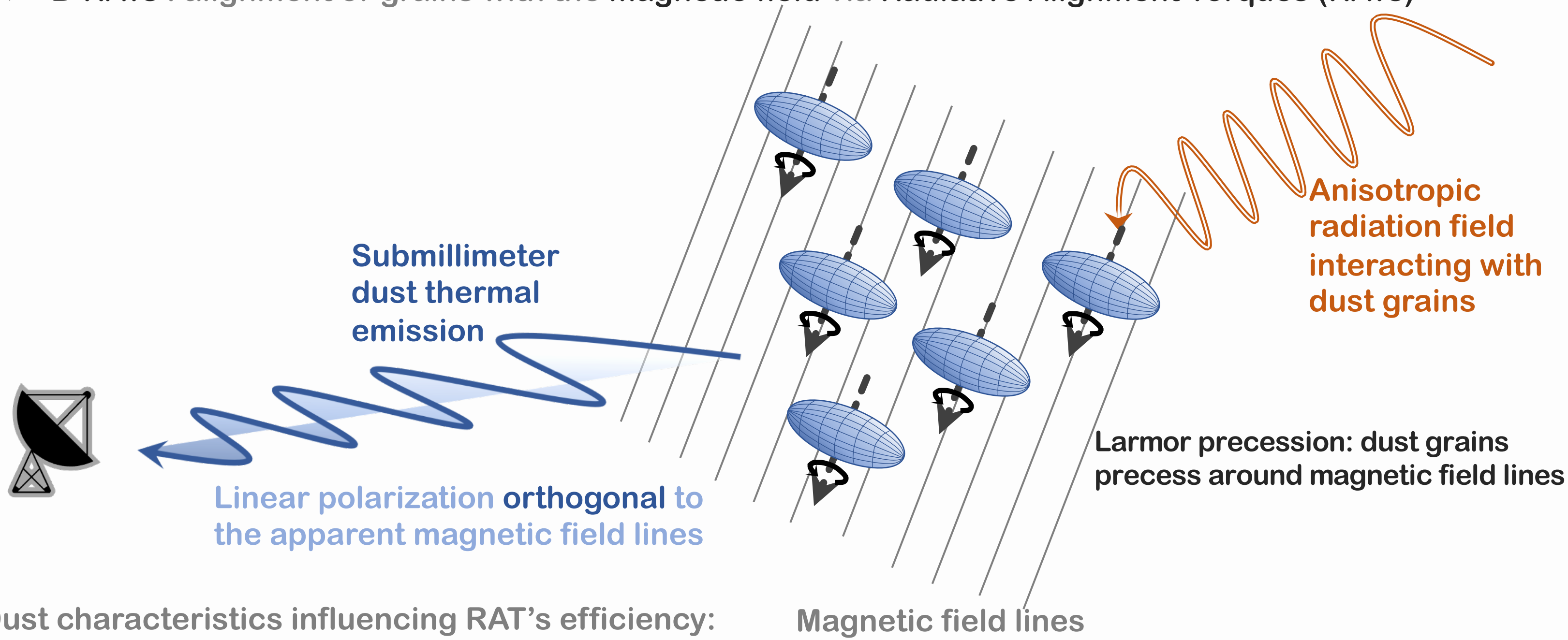
Observational constrains on the **coupling** between **collapsing material** and **magnetic fields:**

- **Ionization** (charged particles, atomic and molecular ions)
- **Dust characteristics**

Dust polarization and grain alignment

What **grain alignment mechanisms**?

- **B-RATs** : alignment of grains with the **magnetic field** via **Radiative Alignment Torques (RATs)**



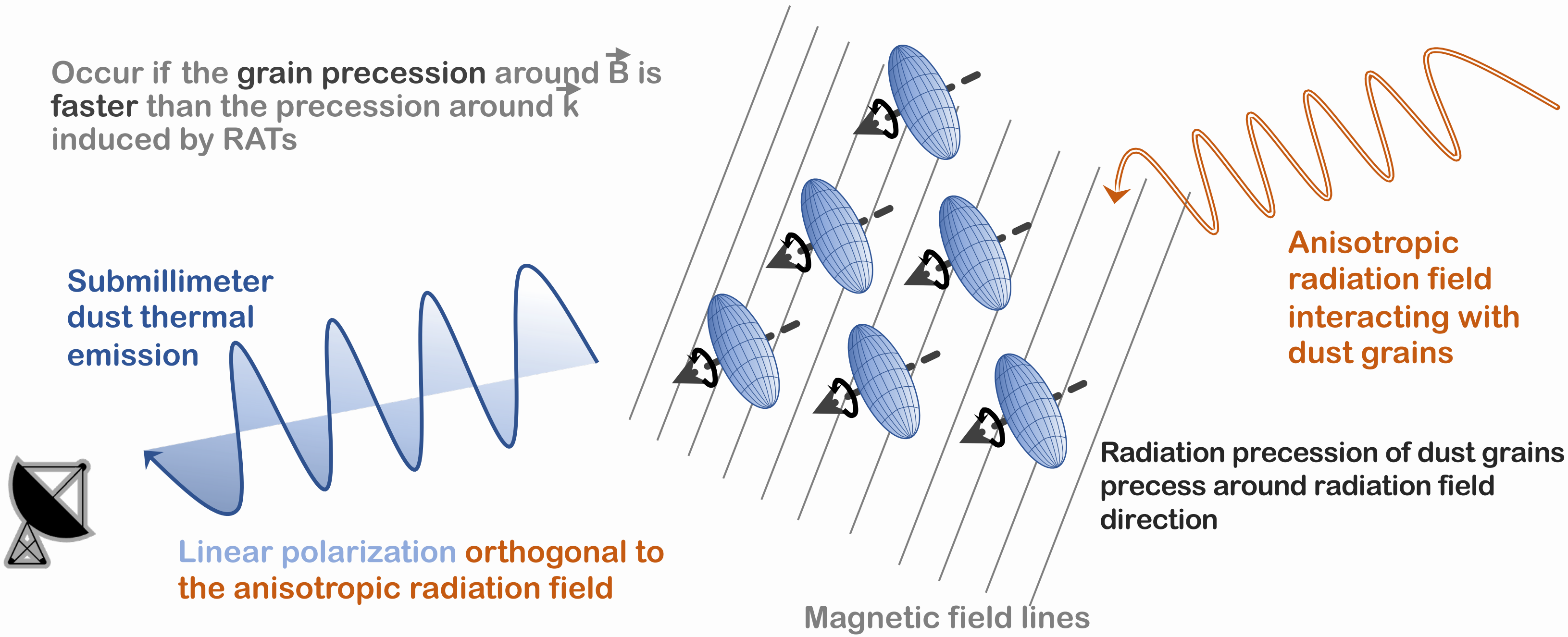
Dust characteristics influencing RAT's efficiency:

- Size
- Shape
- Composition

Dust polarization and grain alignment

What **grain alignment mechanisms?**

- B-RATs : alignment of grains with the magnetic field via Radiative Alignment Torques (RATs)
- **k-RATs :** alignment of grains with the **radiation field** via **Radiative Alignment Torques (RATs)**



Dust polarization and grain alignment

Is the collapse magnetically regulated ?

Which grain's characteristics reproduce the polarization?

Theory of grain alignment mechanisms

Analysis of the observations with respect to grain alignment theories

Le Gouellec + 2019

Class 0 protostars

Implementation of RATs (success and limitations)

Le Gouellec + 2020,
Le Gouellec + 2022 in prep

Dust polarization observations
Molecular line observations

ALMA

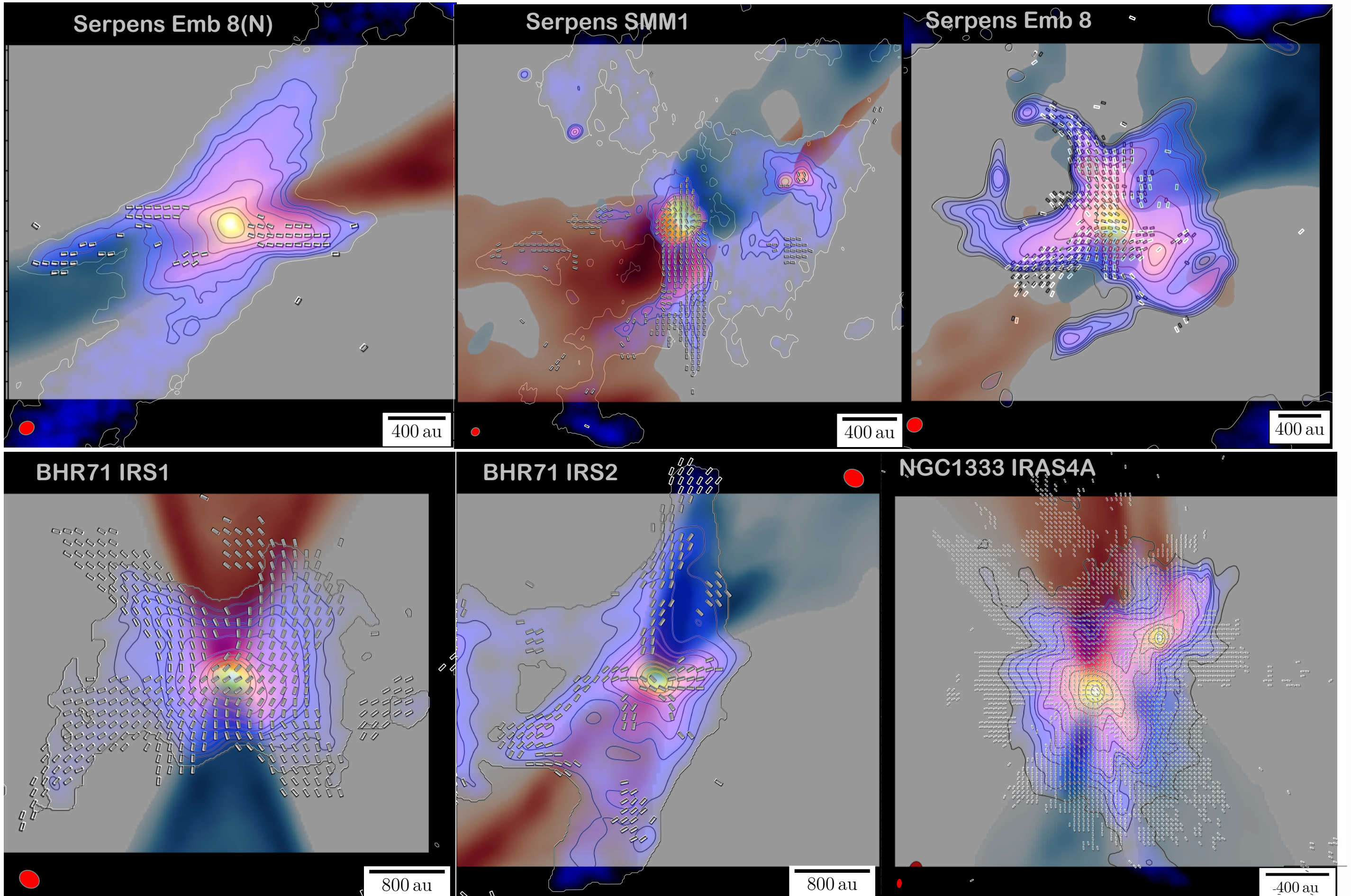
Synthetic observations

MHD simulation :RAMSES
Radiative transfer: POLARIS

Comparing the dust grain alignment efficiency

Le Gouellec + 2020, Le Gouellec + 2022 in prep

ALMA observations of Class 0 protostars



Analysis of the ALMA **dust polarization** observations of **Class 0 protostellar cores**

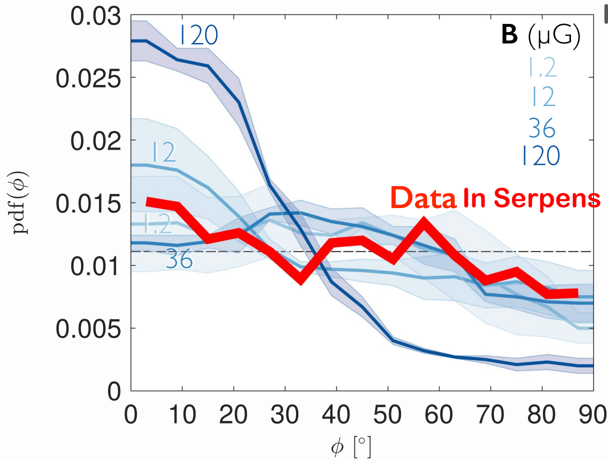
Spatial resolution of 30-200 au

Inside the inner envelope, we will study:

- The morphology of the thermal emission
- The morphology of magnetic fields
- The spatial locations of the polarized emission

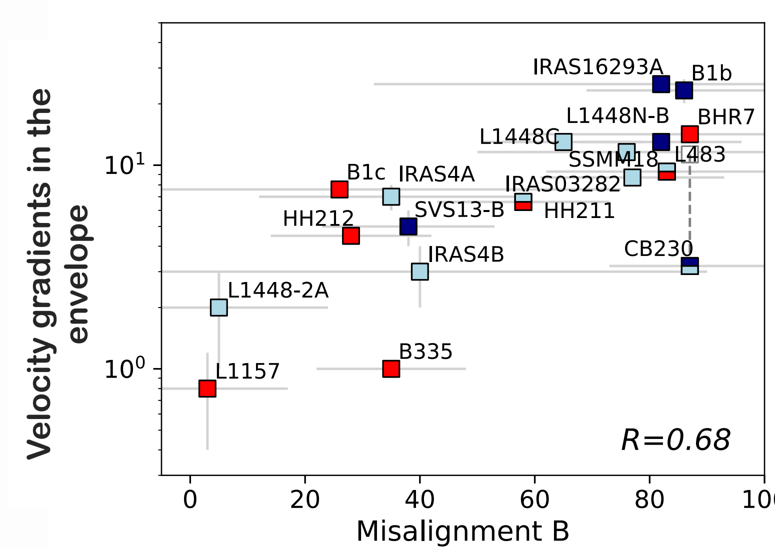
Le Gouellec + 2019, Ko + 2020, Hull + 2020

Magnetic fields in Class 0 protostars



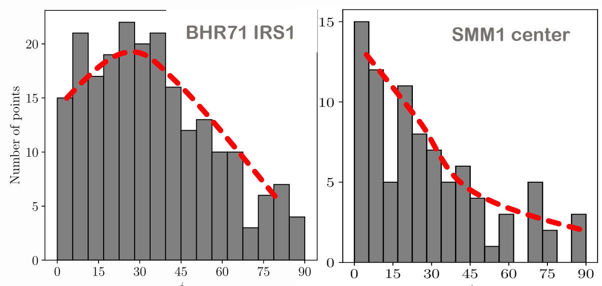
Hull + 2017

Data In Serpens Emb 8 suggest a weak field scenario

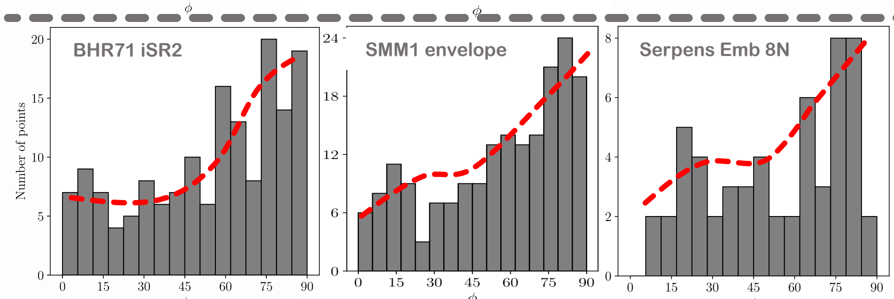


Misalignment between magnetic field and outflow axis

Galametz + 2020, using SMA



B-fields // to density gradients

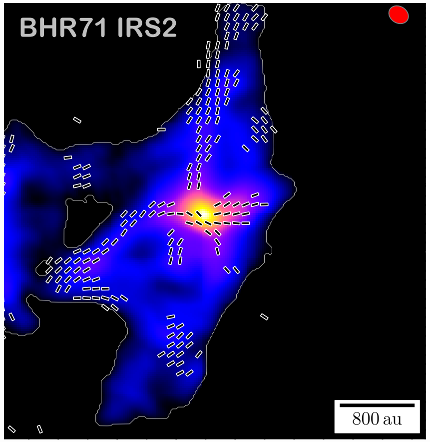


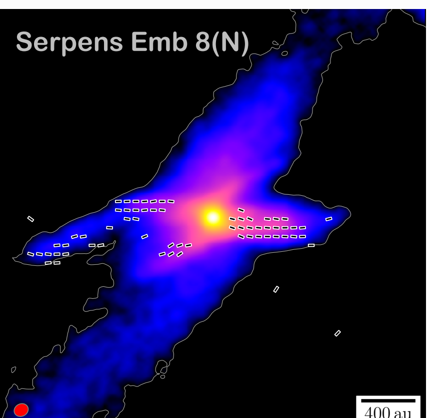
B-fields ⊥ to density gradients

Le Gouellec + 2019, Hull + 2020

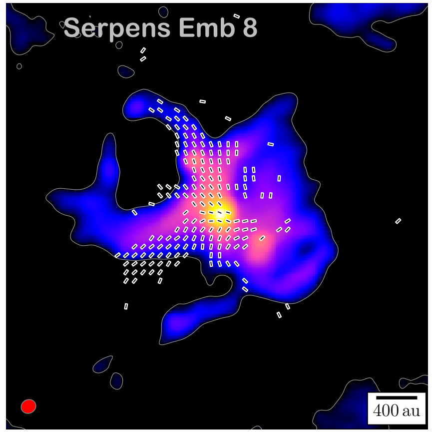
Magnetic fields in Class 0 protostars

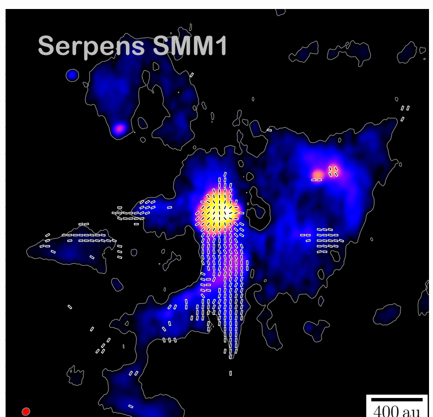
B-field organized along cavity walls



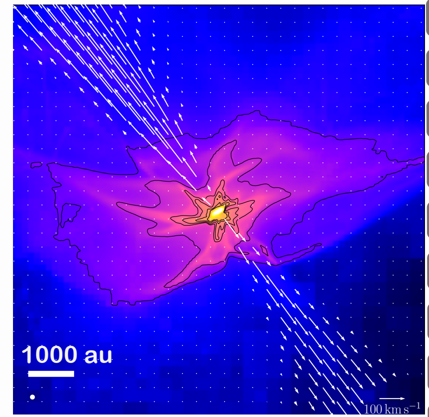


B-field less organized, streamer structures



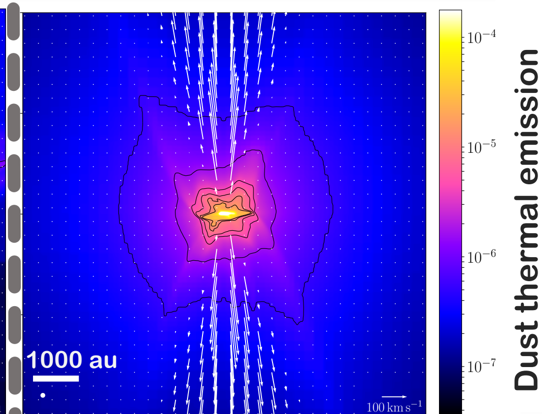


Turbulence Ms = 2
Mass-to-flux ratio: 6

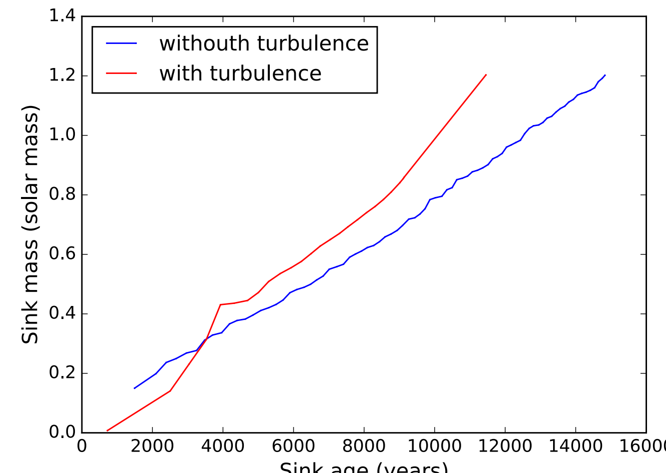


Fragmentation, streamers

No turbulence Ms = 0
Mass-to-flux ratio: 5



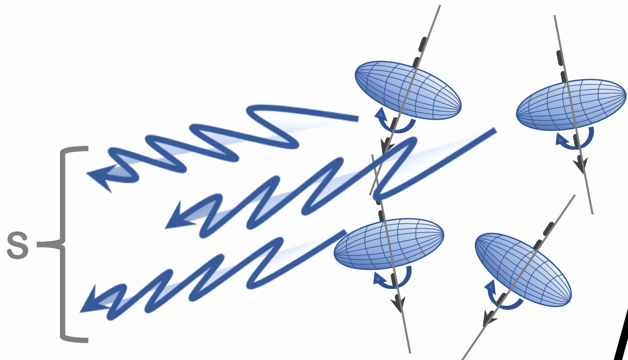
No fragmentation, organized B-field



Magnetic fields in Class 0 protostars

Polarization angle Dispersion function

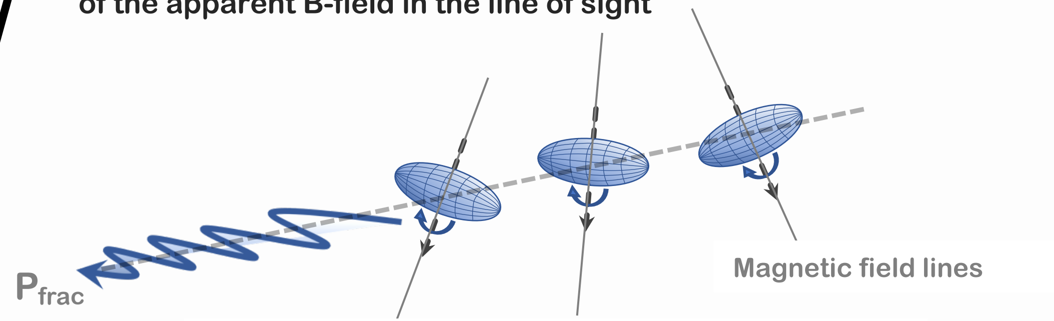
$$S(r,\delta) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}[\Psi(r+\delta_i)-\Psi(r)]^2}$$

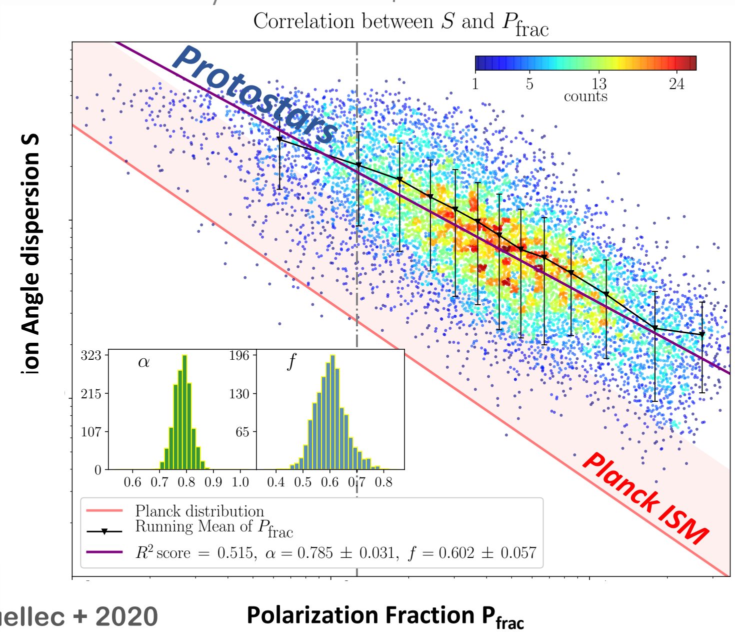


disorganized component of the apparent B-field in the plane of the sky

Polarization fraction

Grain alignment efficiency + disorganized component of the apparent B-field in the line of sight





Le Gouellec + 2020

- ➢ **Correlation between S and P_{frac} in Class 0 protostars. What does it tell us about magnetic field structures?**

See Planck + 2020, King + 2018, 2019, and Sullivan + 2021

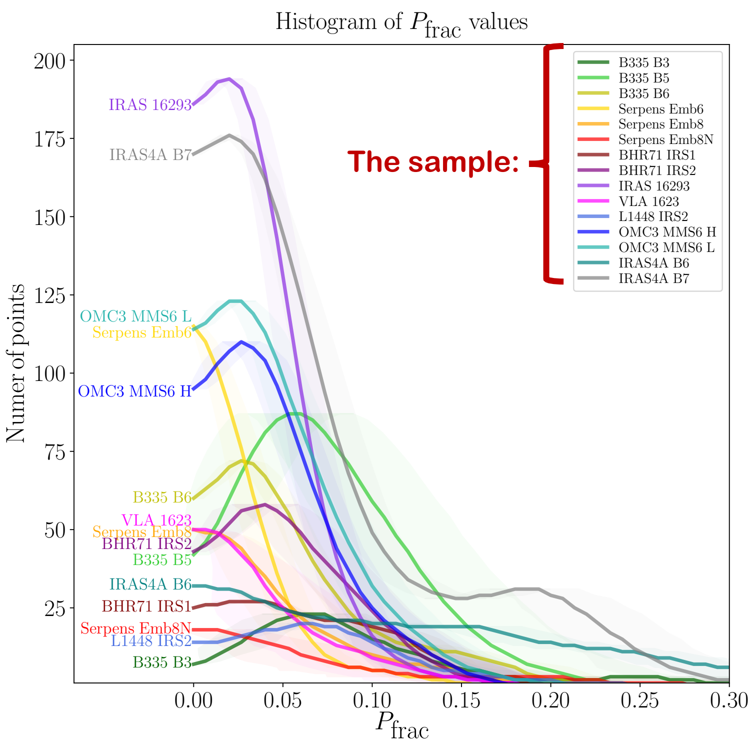
Aligned dust grains in Class 0 protostars

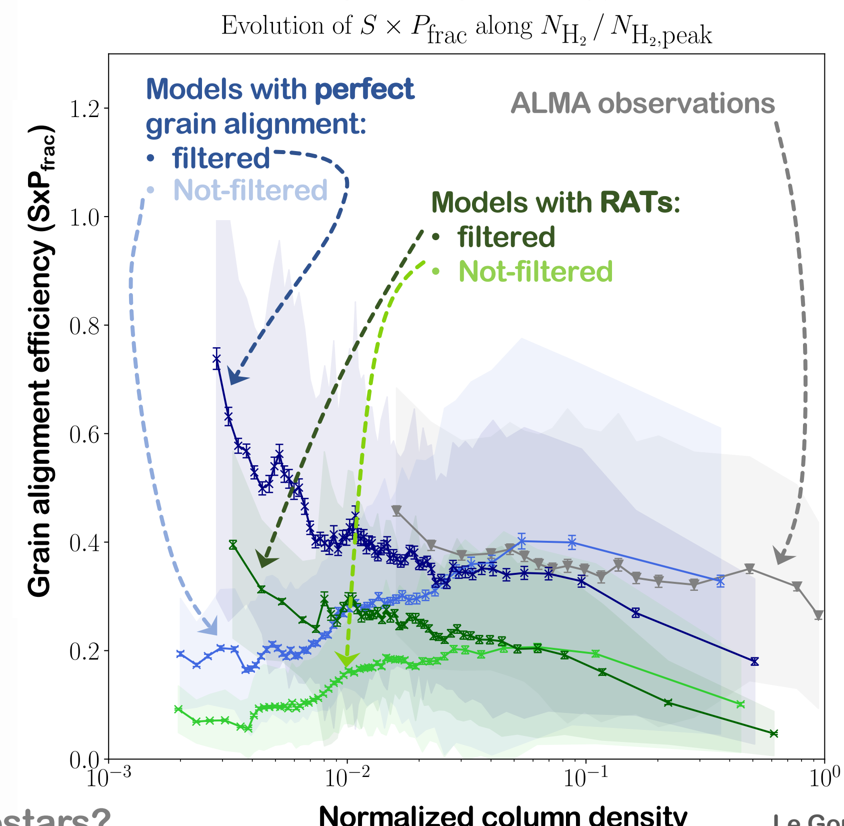
The dependence on the B-field geometry is removed in the product S x P_{frac} which becomes a proxy for the grain alignment efficiency

See Planck collab 2020

RAMSES Non-ideal MHD models → POLARIS Radiative transfers → Artificial interferometric filtering / ALMA observations of YSOs (S x P_{frac})

Different grain alignment hypotheses



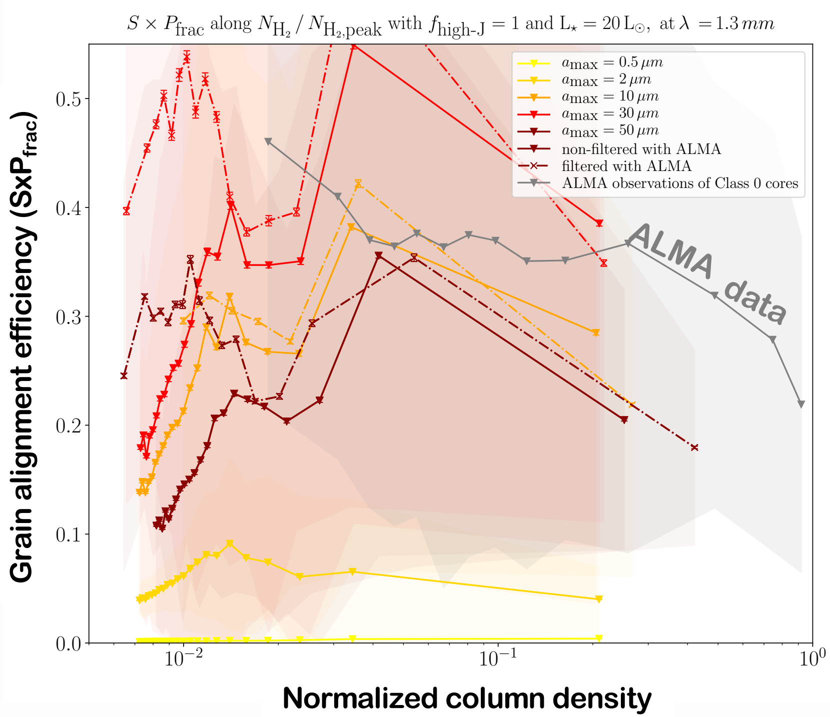


Le Gouellec + 2020

➢ Why is the grain alignment so efficient in protostars?

Aligned dust grains in Class 0 protostars

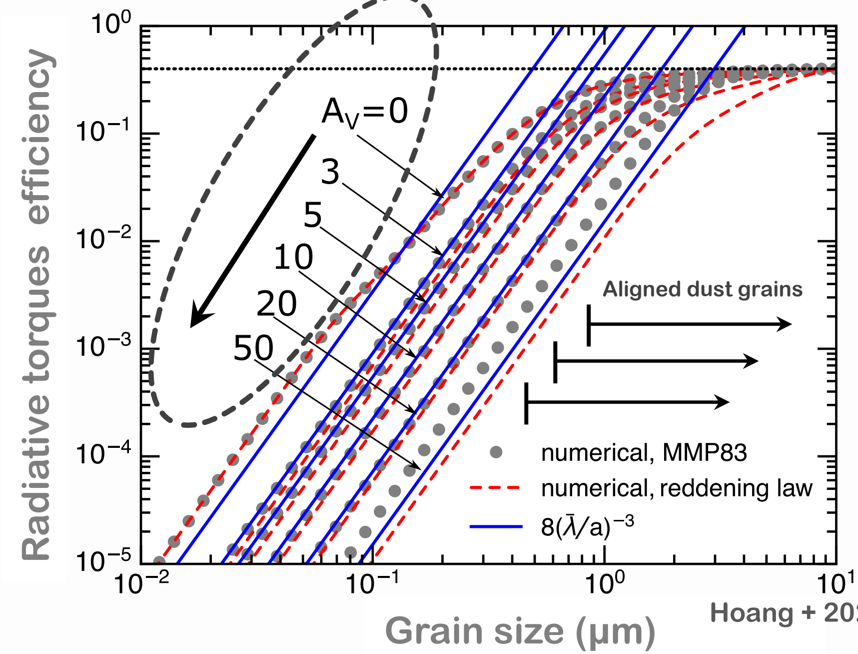
Influence of the different maximum grain sizes on the grain alignment



Increasing extinction A_v

=>

Increasing of the radiation field wavelength



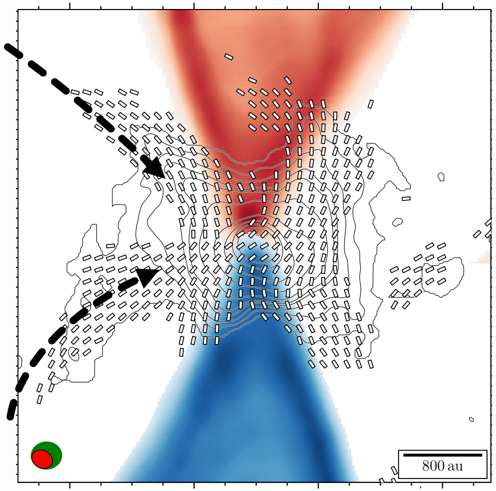
Hoang + 2020

- Only grains larger than ~10 μm could align in the dense outflow cavity walls and streamers we detect
- Suggestive of early grain growth in Class 0 protostars

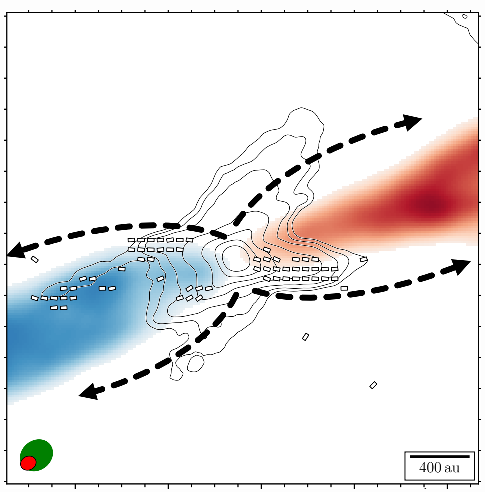
Le Gouellec + 2019, Valdivia + 2019, Hull + 2020
Le Gouellec + 2022 in prep

Aligned dust grains in Class 0 protostars

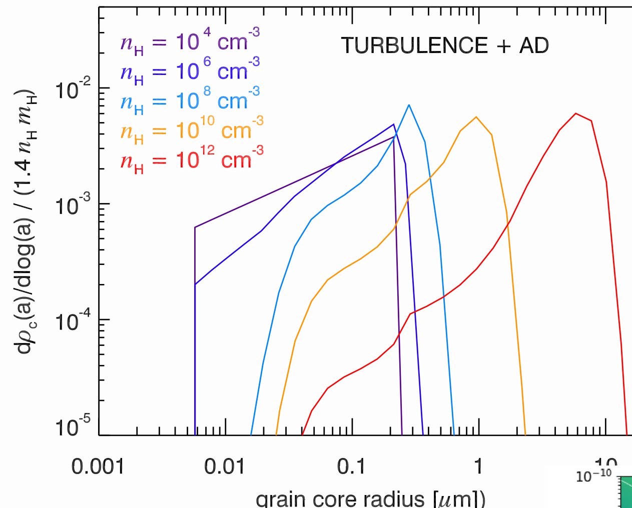
Where do these large grains come from ?



Infalling material ?

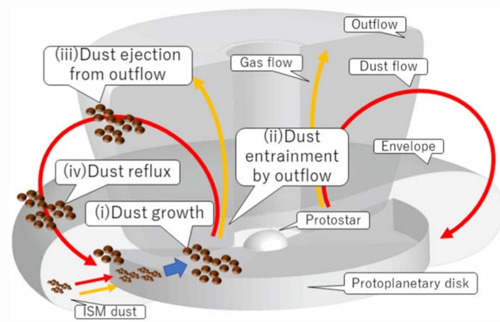


Material entrained by the wind from the dense disk?

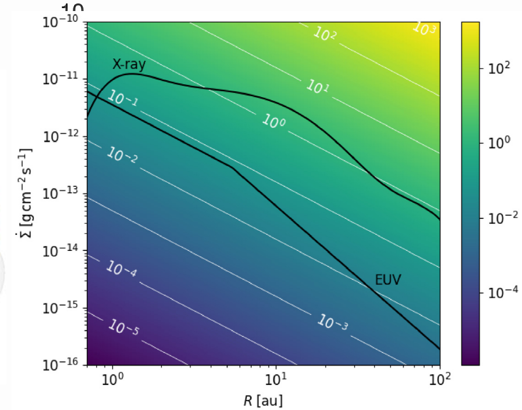


Grains coagulation along collapse, after one free-fall time, with **turbulence and ambipolar drift**

Guillet + 2020



Tsukamoto + 2021



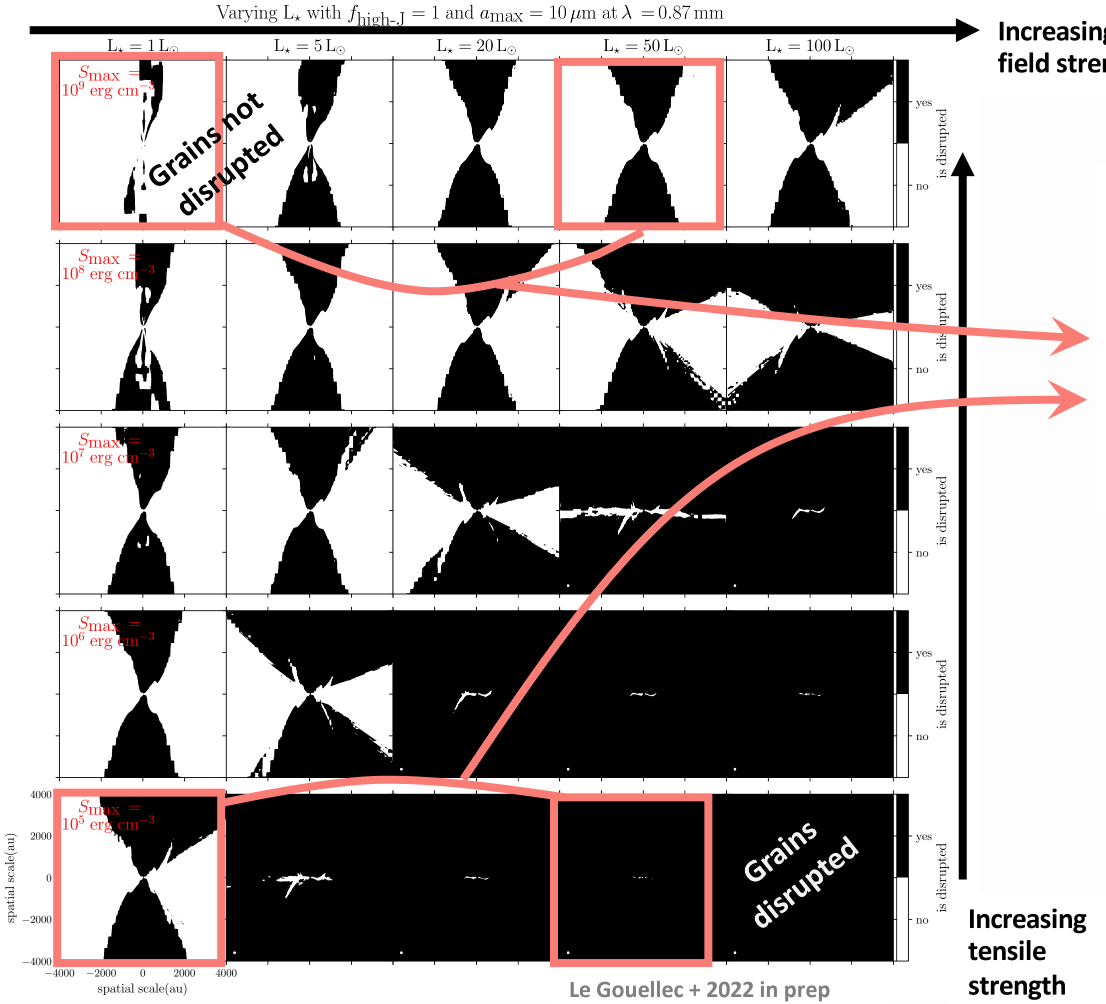
Booth & Clarke 2021

See also Liffman + 2020; Vinkovic & Čemeljić 2021;Hutchison & Clarke 2021

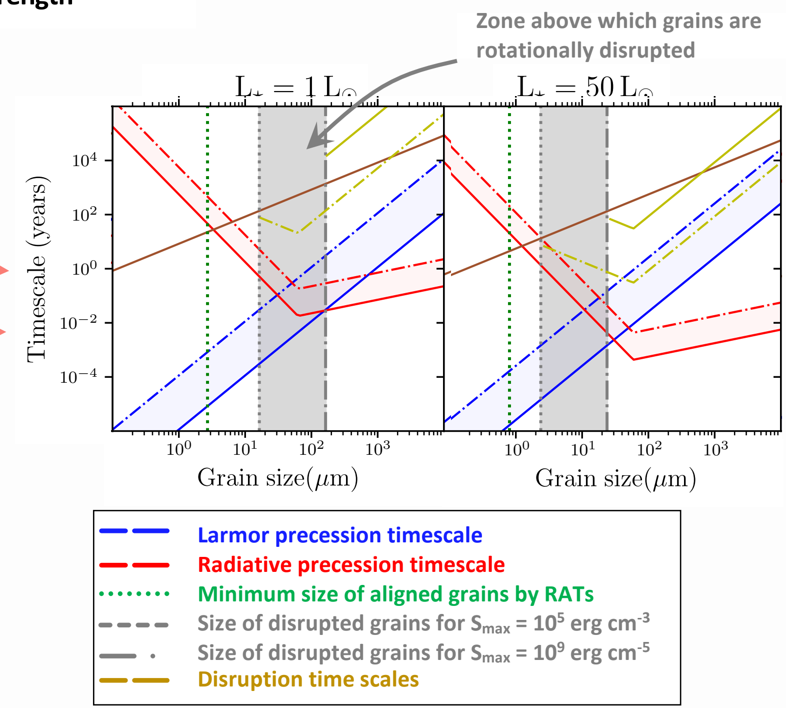
The role played by the radiation field

Do large grains can survive the radiation field or do they get rotationally disrupted?

Hoang + 2020, Tram + 2020, **see Tram's poster**



Le Gouellec + 2022 in prep

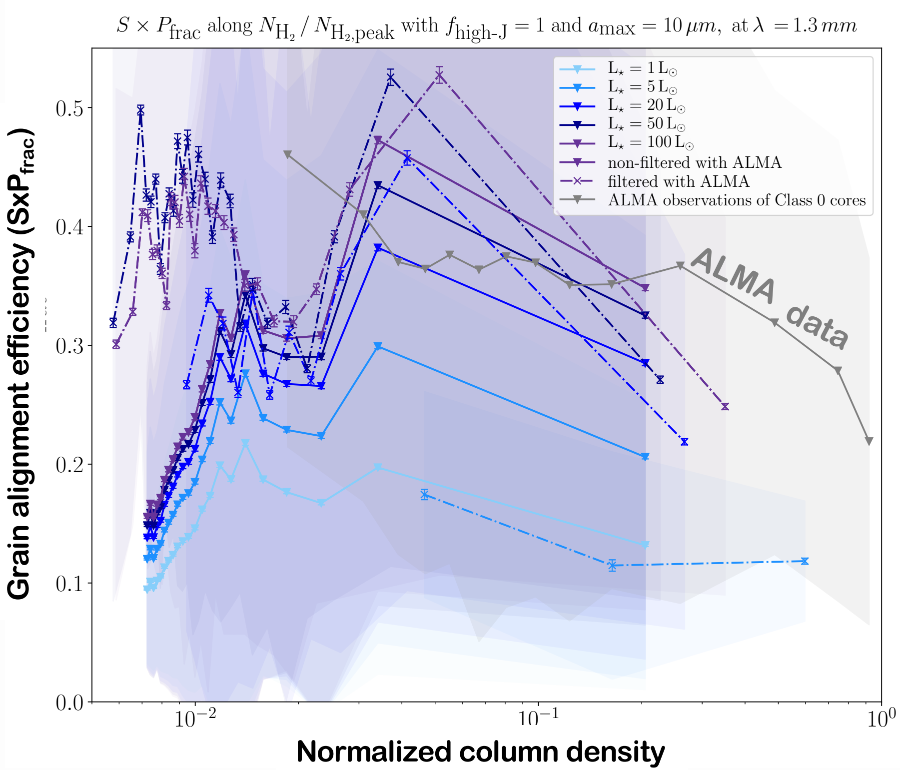


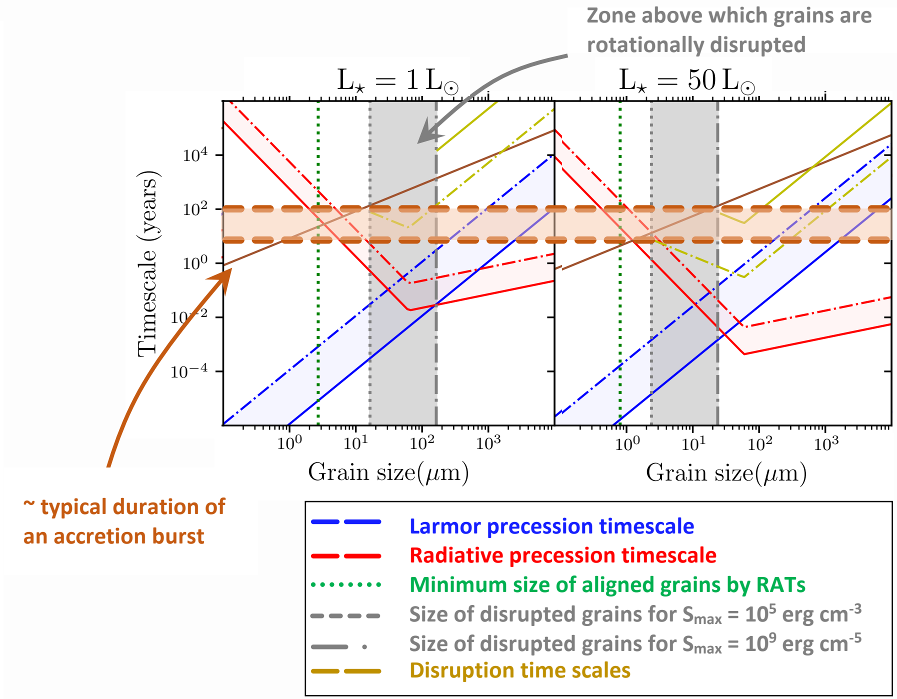
- ➢ Grains are disrupted before aligning with the radiation field via k-RATs
- ➢ What are the consequences on grains of variable accretion/luminosity?

The role played by the radiation field

The accretion luminosity is the main actor responsible for the dust polarization observed in YSOs' envelope

Influence of the radiation field on the grain alignment





- ➢ Dust polarization should increase during an accretion burst
- ➢ Grains can also get rotationally disrupted during an accretion burst

Le Gouellec + 2022 in prep

Global Picture