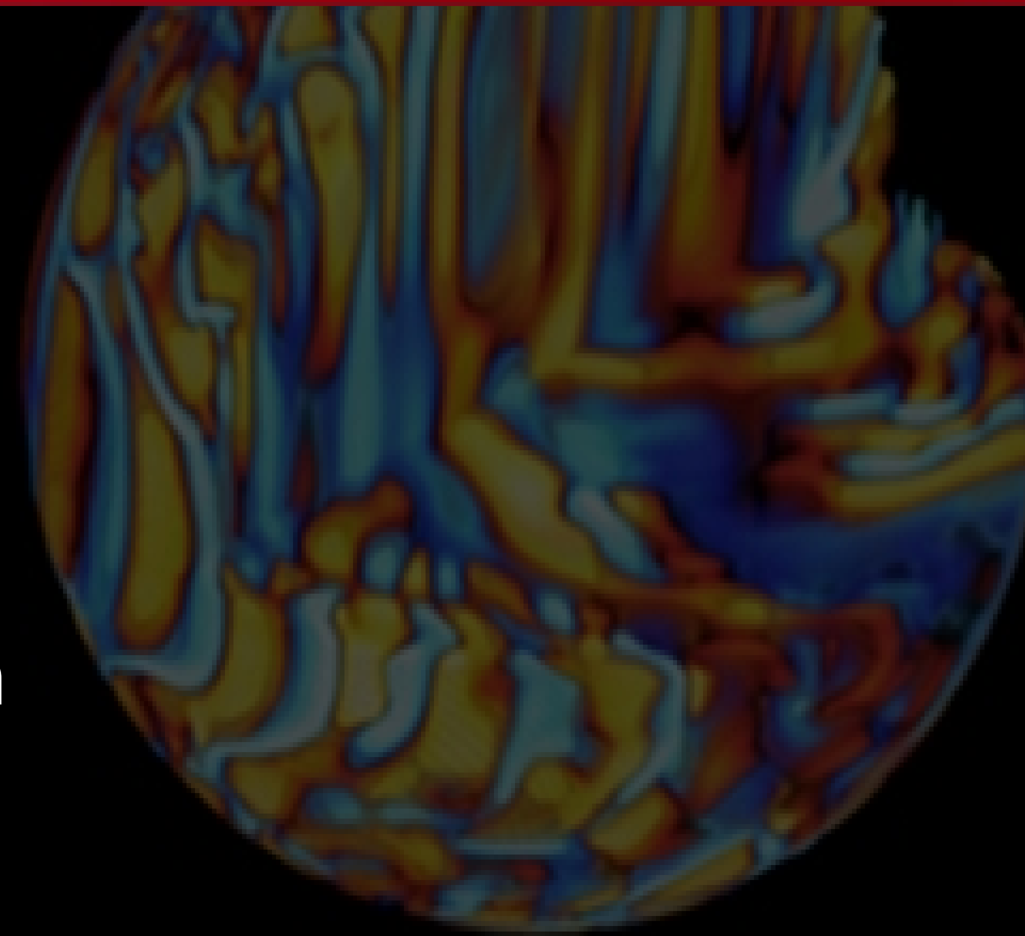


* Constance Emeriau-Viard

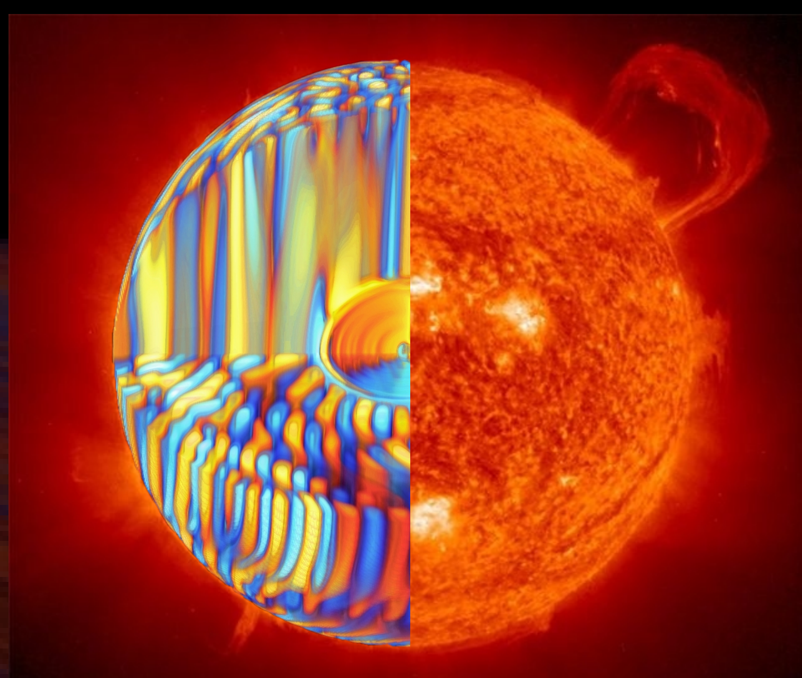
* ENS Cachan - parcours PHYTEM
Master Modélisation et Simulation

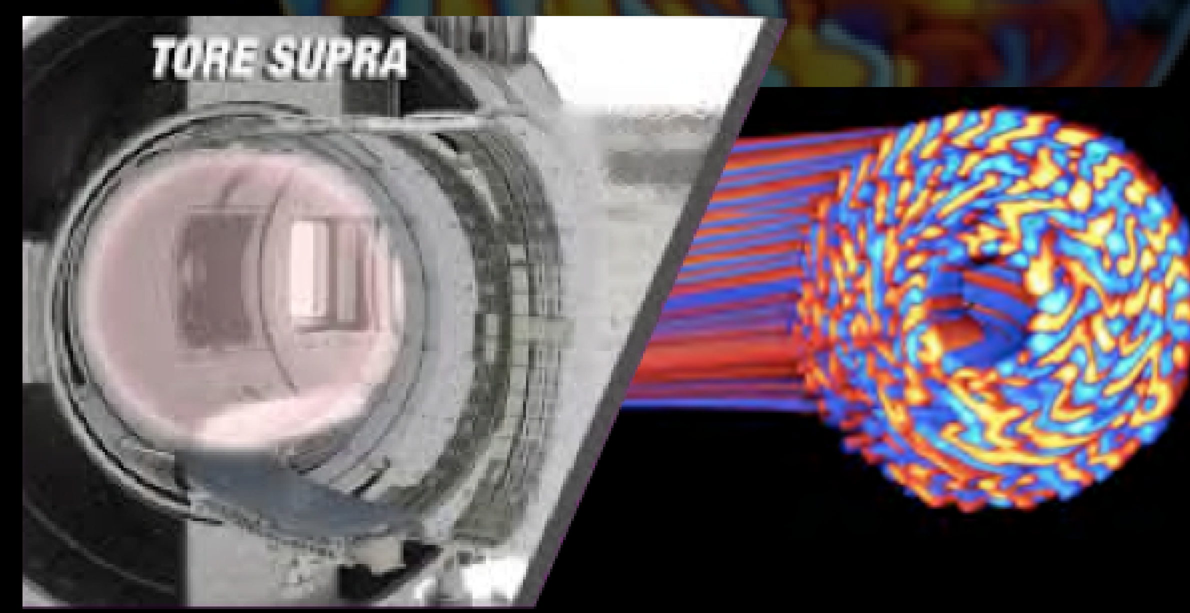
* Phd advisor : Allan Sacha Brun

* Auto-organization of heat and angular momentum
transport in tokamaks and stellar plamas

* Astrophysics and especially stellar physics
Multidisciplinary thesis

Auto-organization of heat and angular momentum transport in tokamaks and stellar plasmas



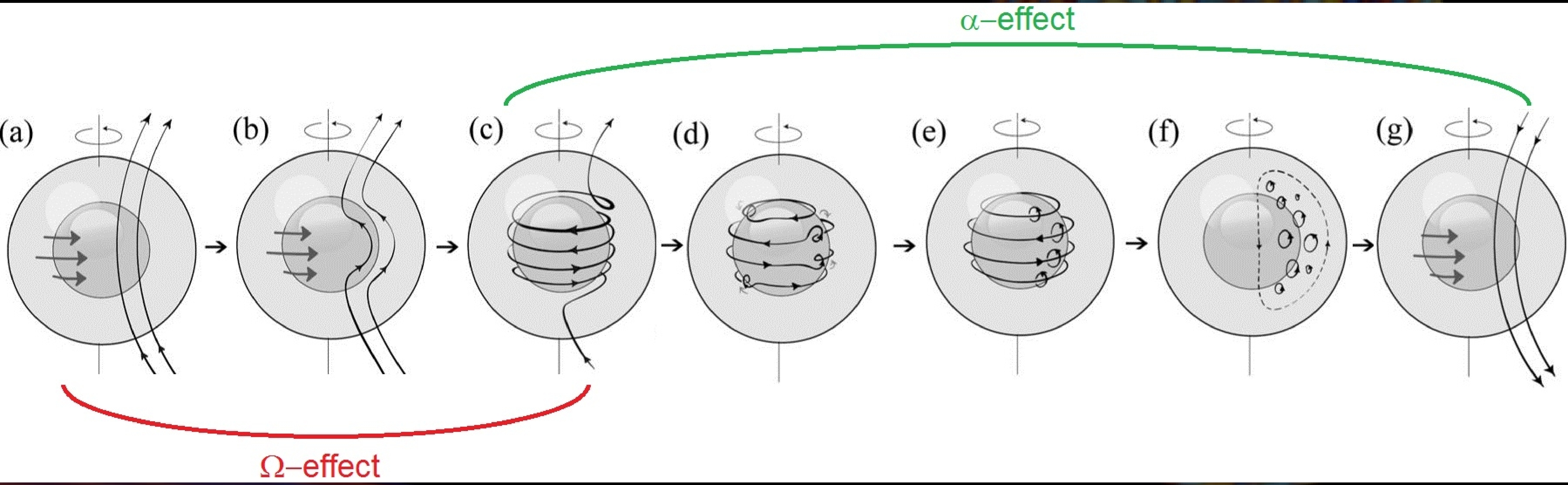


- Stellar physics

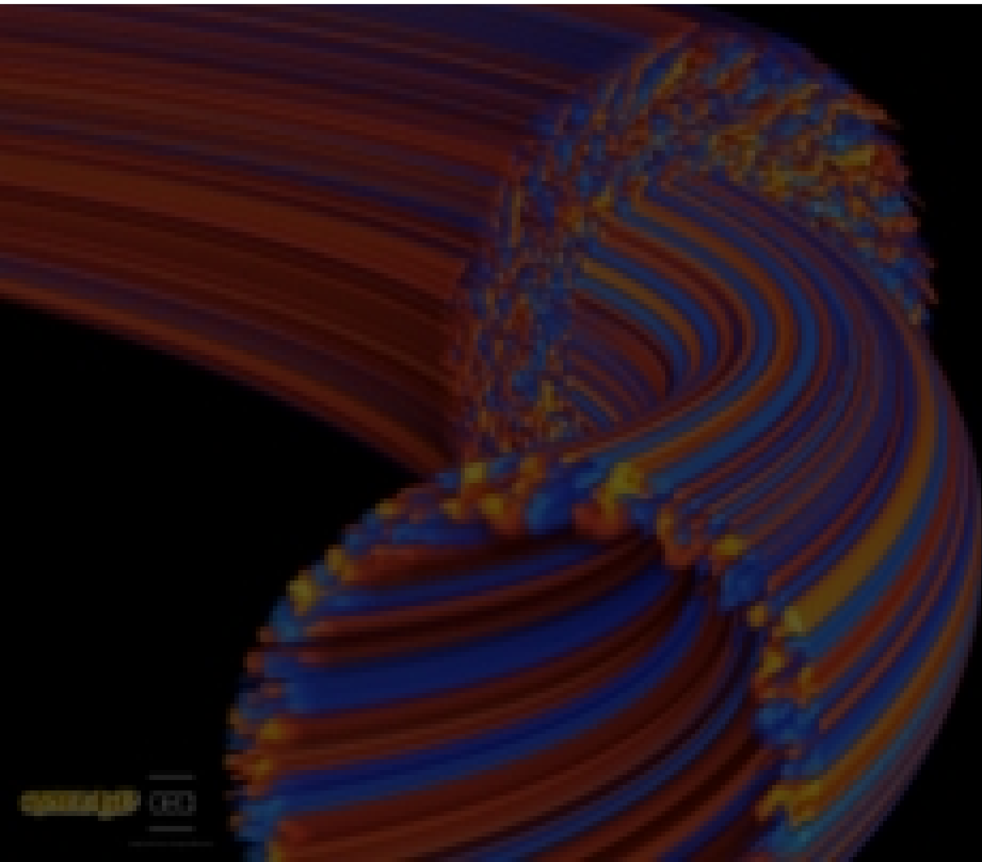
- Tokamaks

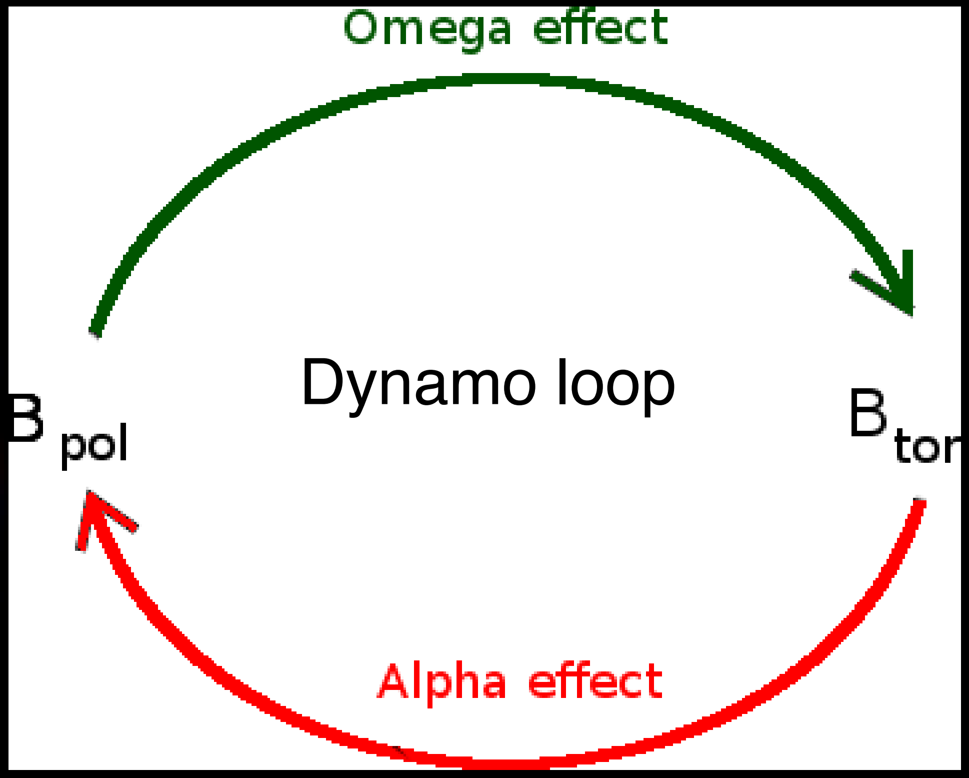
- Plasmas
- Auto-organization

Dynamo



α–effect
(a)
(b)
(c)
(d)
(e)
(f)
(g)
Ω–effect

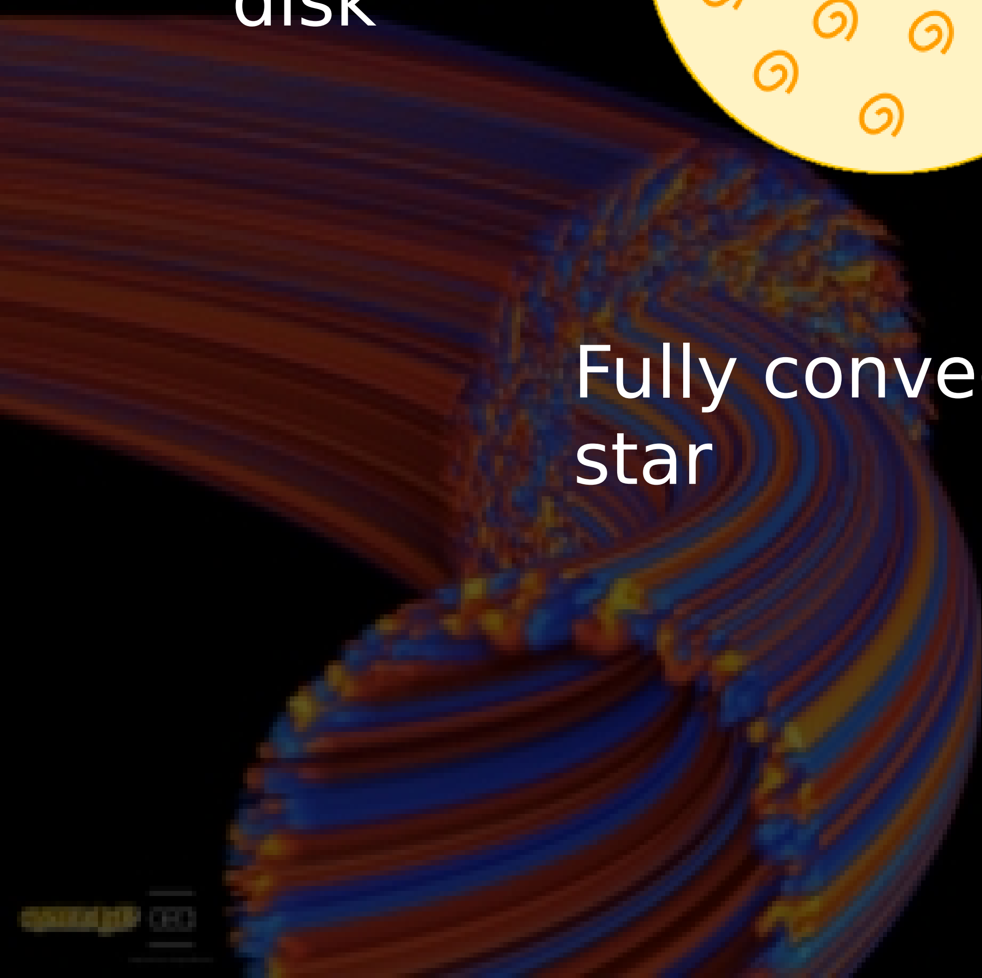




Omega effect
Dynamo loop
B pol
B tor
Alpha effect

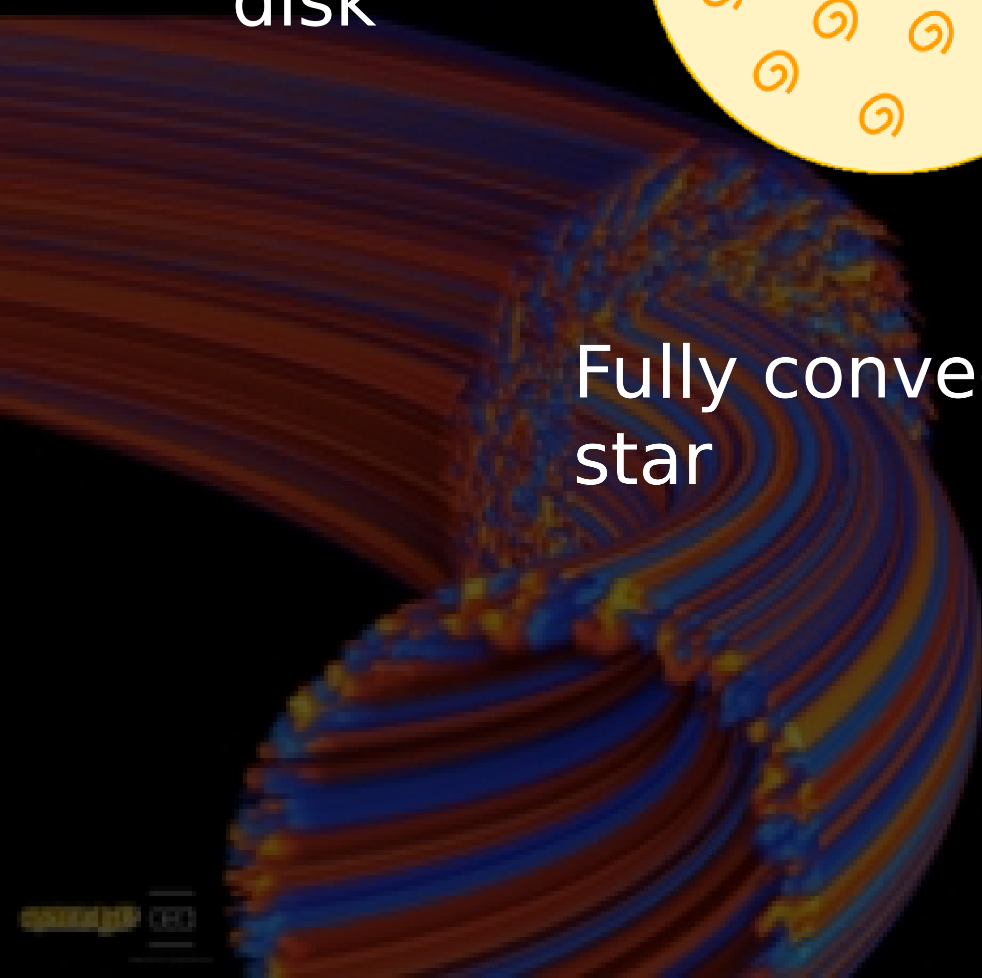
Stellar evolution : Pre main sequence

Protostellar disk

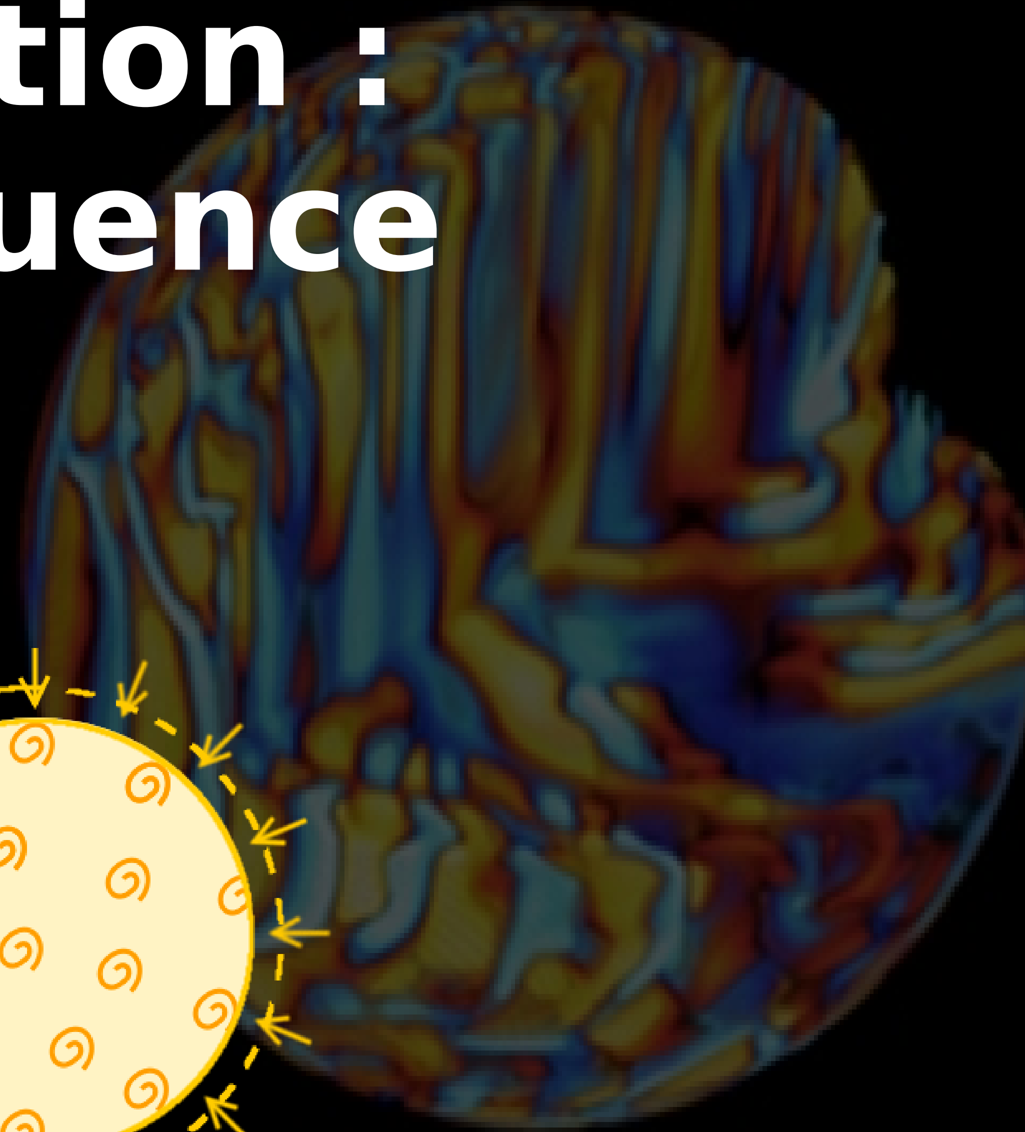


Fully convective star

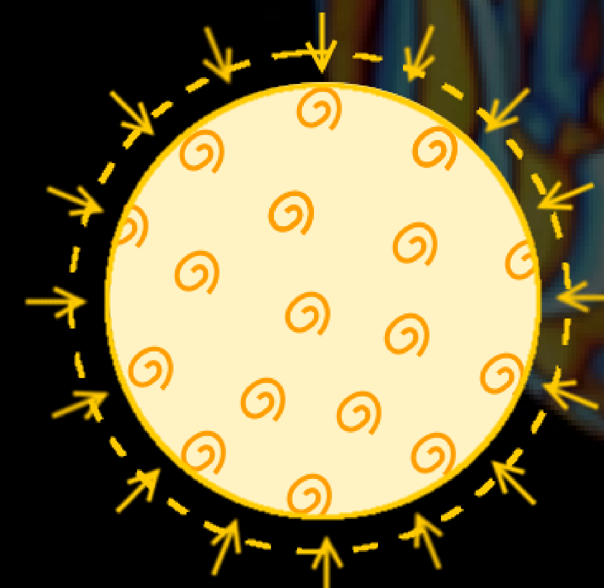
Stellar evolution : Pre main sequence



Protostellar disk



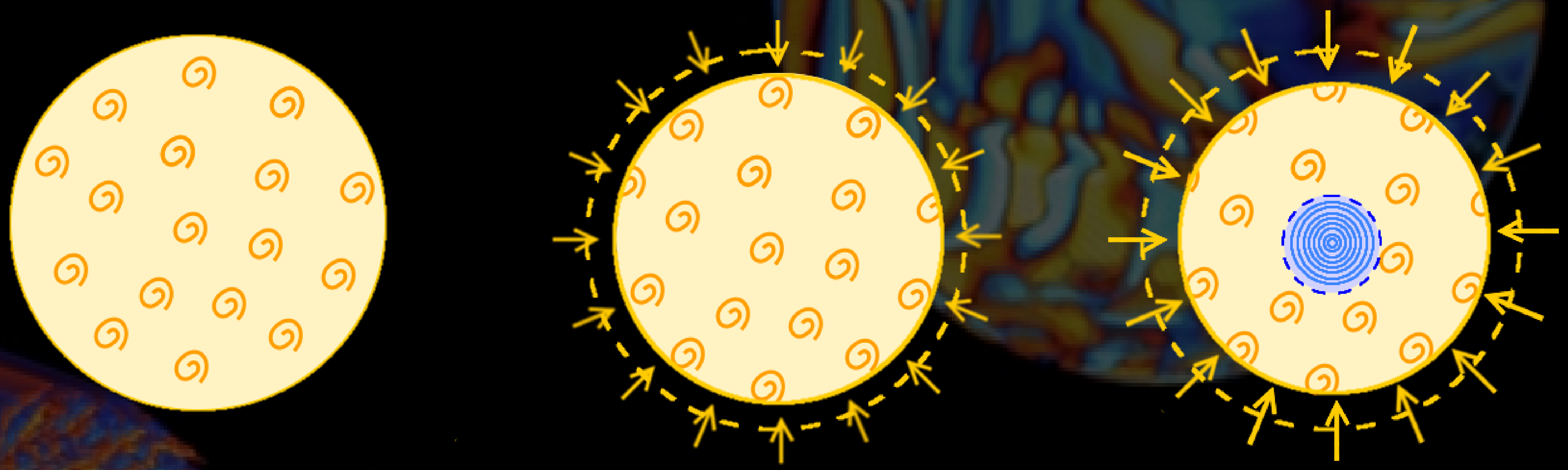
Fully convective star



Increase of $\mathbf{T}$ and ρ in the core

Stellar evolution : Pre main sequence

Protostellar disk



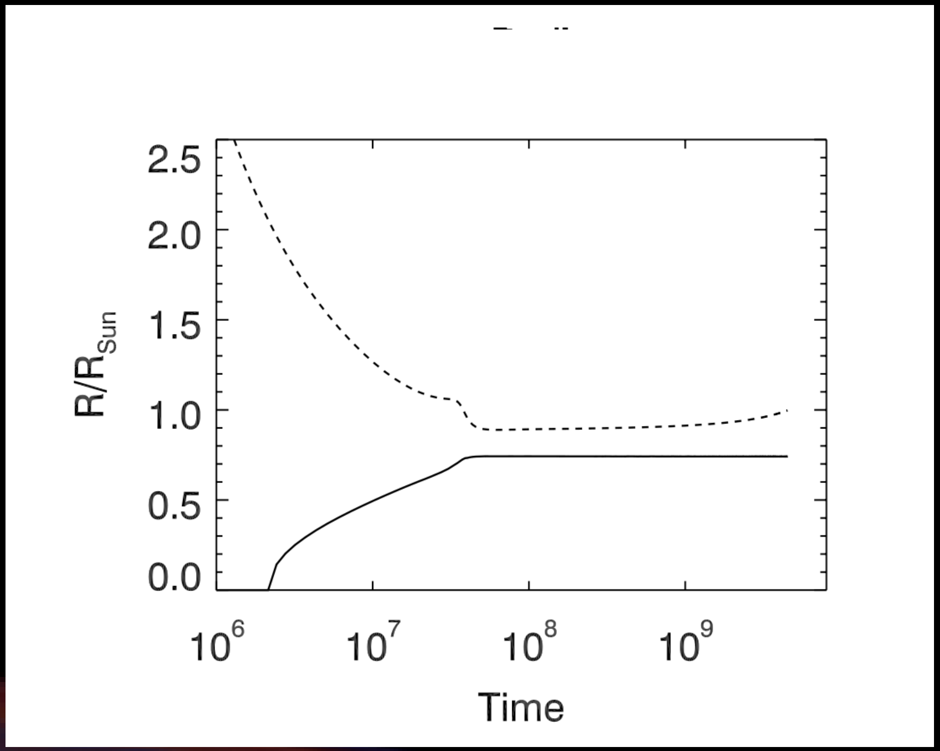
Fully convective star

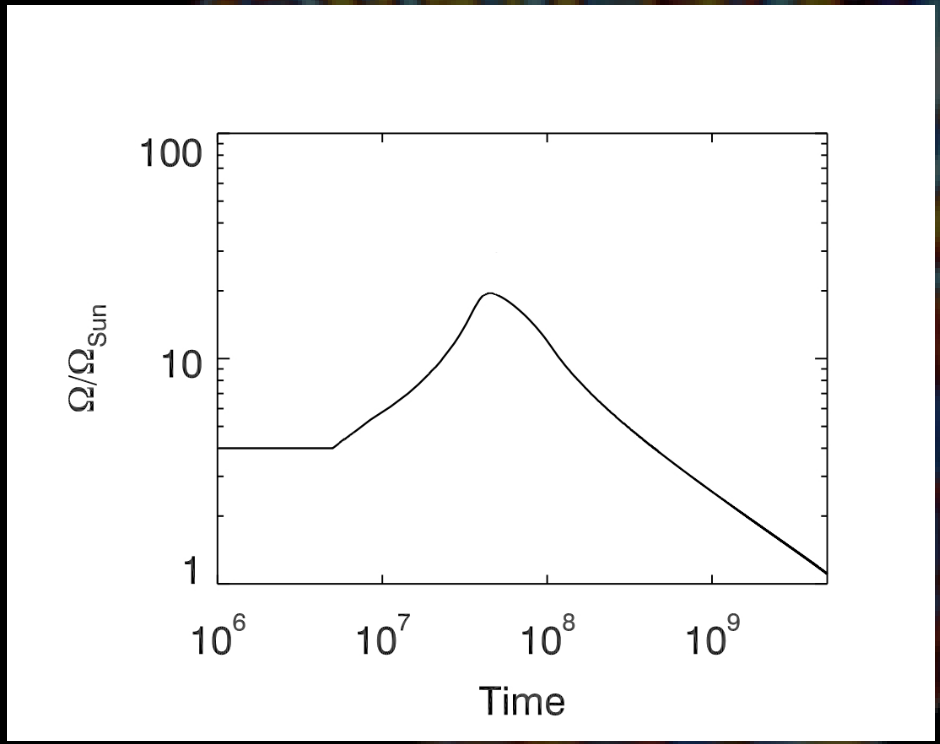
Increase of T and ρ in the core

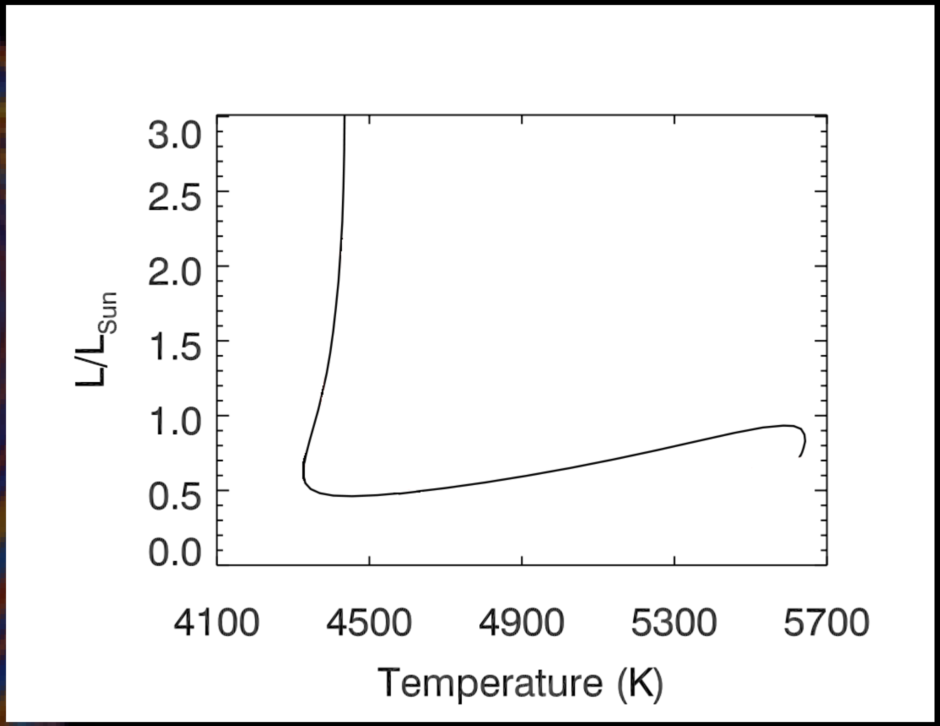
Opacity drops

Radiative core appears and grows

1D secular evolution







Code ASH - 3D models

- Anelastic equations for a conductive plasma in a rotating sphere

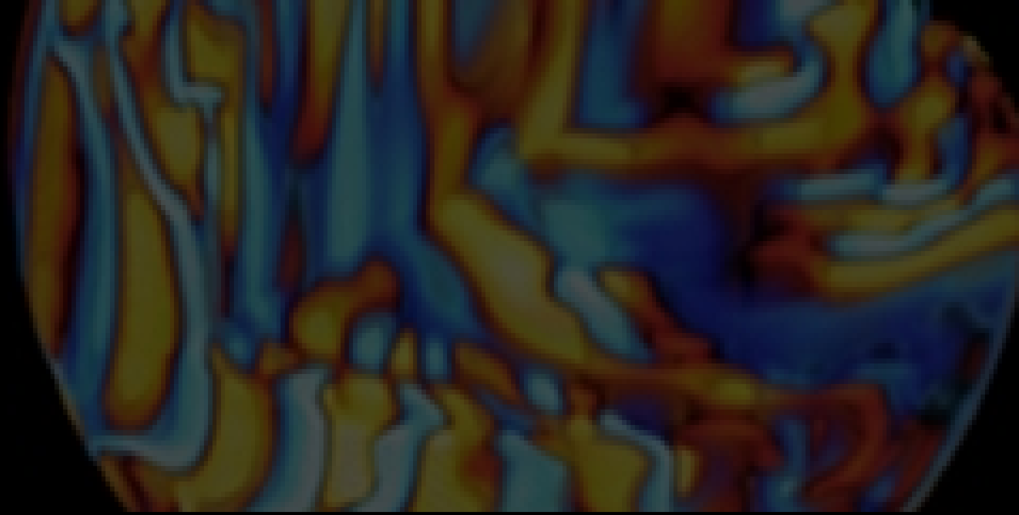
$$\frac{\rho}{\bar{\rho}} = \frac{P}{\bar{P}} - \frac{T}{\bar{T}} = \frac{P}{\gamma \bar{P}} - \frac{S}{c_p}$$

$$\vec{\nabla}.\left(\bar{\rho}\vec{v}\right) = 0$$

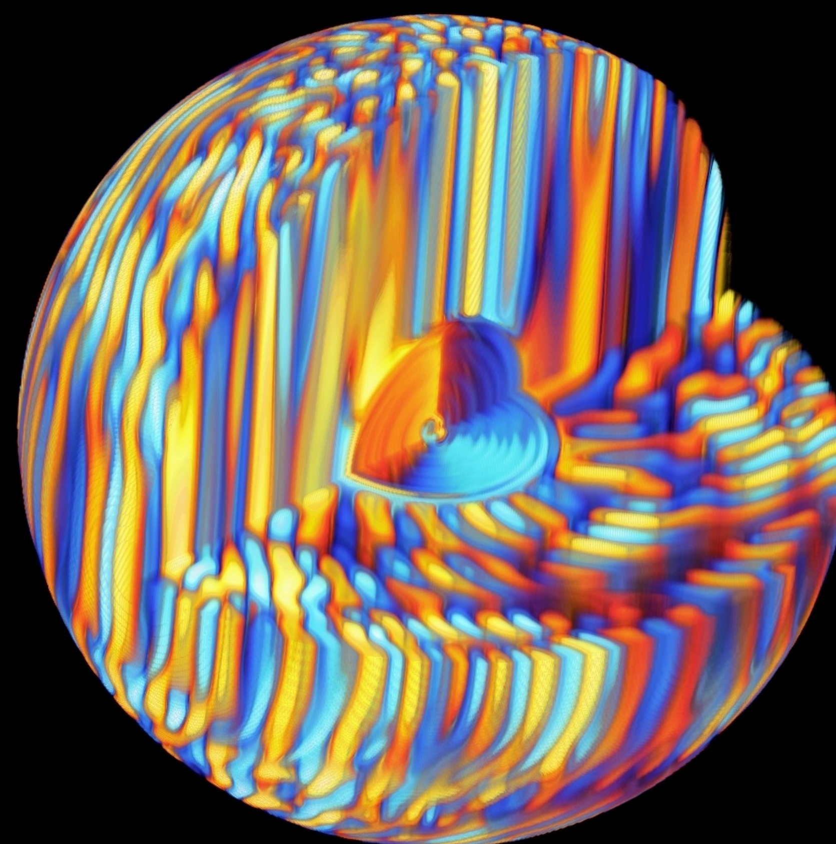
$$\bar{\rho}\left(\frac{\partial \vec{v}}{\partial t} + \left(\vec{v}.\vec{\nabla}\right)\vec{v}\right) = -\bar{\rho}\vec{\nabla}\tilde{\omega} - \bar{\rho}\frac{S}{c_p}\vec{g} - 2\bar{\rho}\vec{\Omega}_0 \times \vec{v} - \vec{\nabla}.\vec{\mathcal{D}}$$

$$\bar{\rho}\bar{T}\frac{\partial S}{\partial t} + \bar{\rho}\bar{T}\vec{v}.\vec{\nabla}\left(S + \bar{S}\right) = \bar{\rho}\epsilon + \vec{\nabla}.\left[\kappa_r \bar{\rho} c_p \vec{\nabla}\left(T + \bar{T}\right) + \kappa\bar{\rho}\bar{T}\vec{\nabla}S + \kappa_0\bar{\rho}\bar{T}\vec{\nabla}\bar{S}\right] + 2\bar{\rho}\nu\left[e_{ij}e_{ij} - 1/3\left(\vec{\nabla}.\vec{v}\right)^2\right]$$

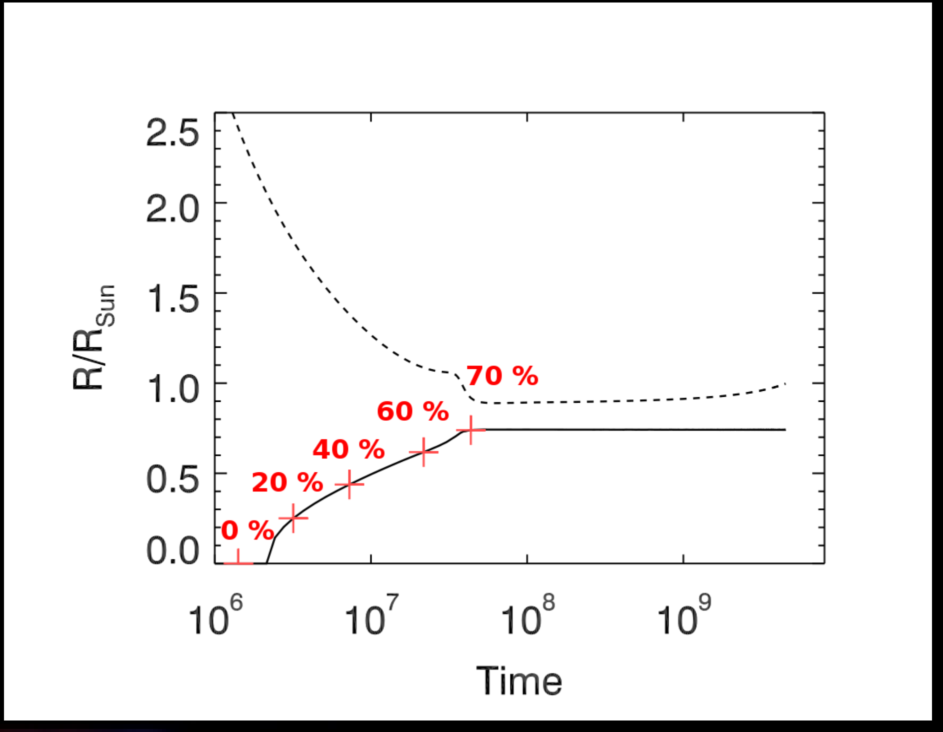
$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times \left(\mathbf{v} \times \mathbf{B}\right) - \nabla \times \left(\eta \nabla \times \mathbf{B}\right)$$

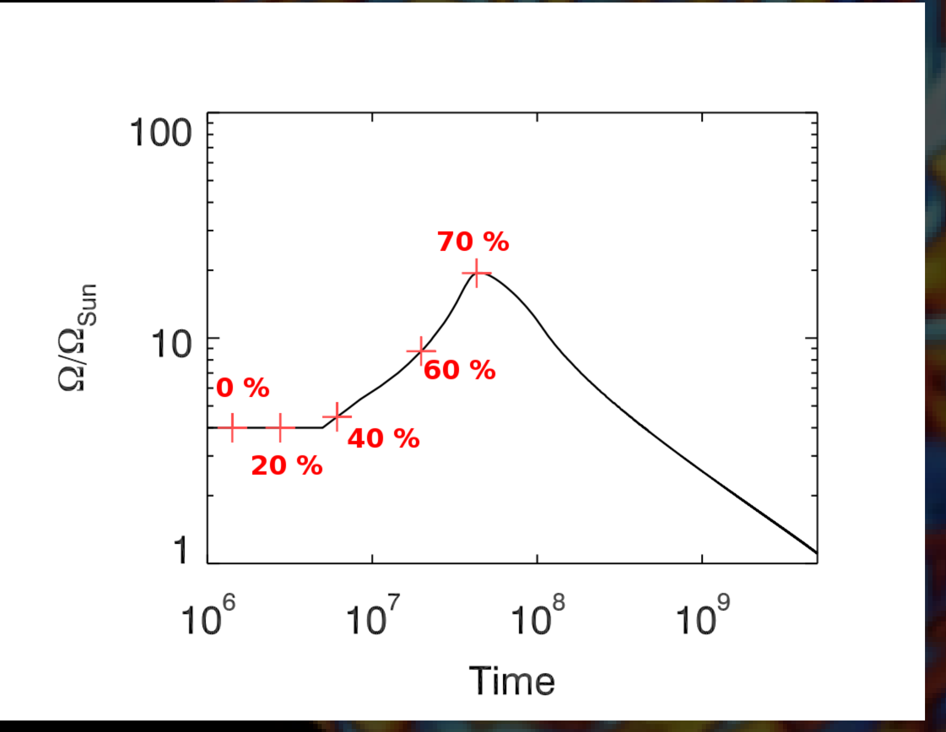


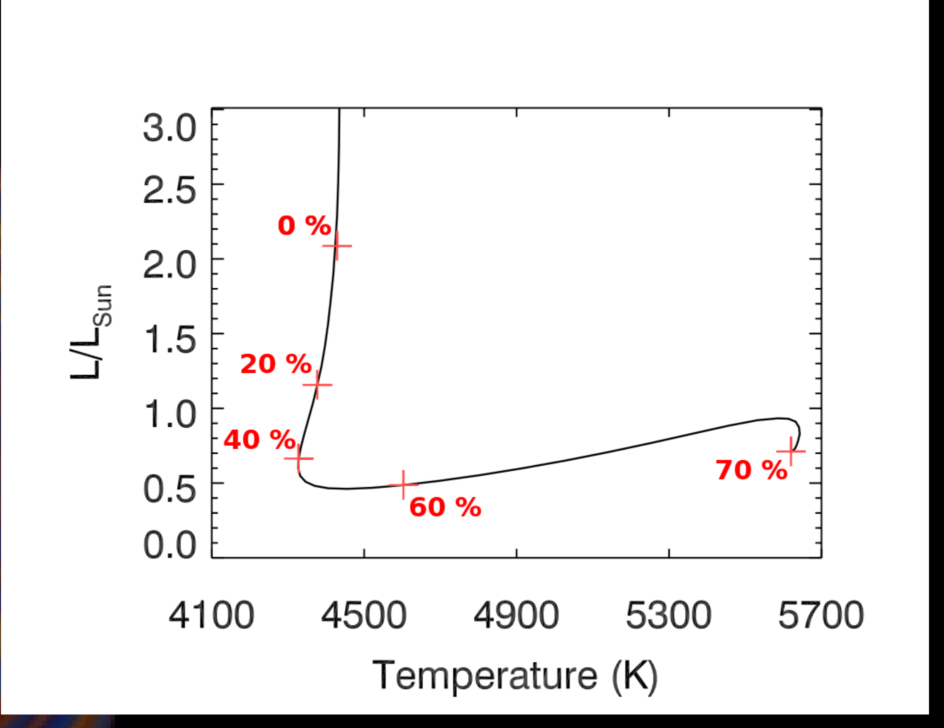
- Geometry : 3D full sphere
- Spherical harmonics : Θ,ϕ (FFT)
- Radiale structure : finite differences (order 4 or 6)



Choice of our ASH models

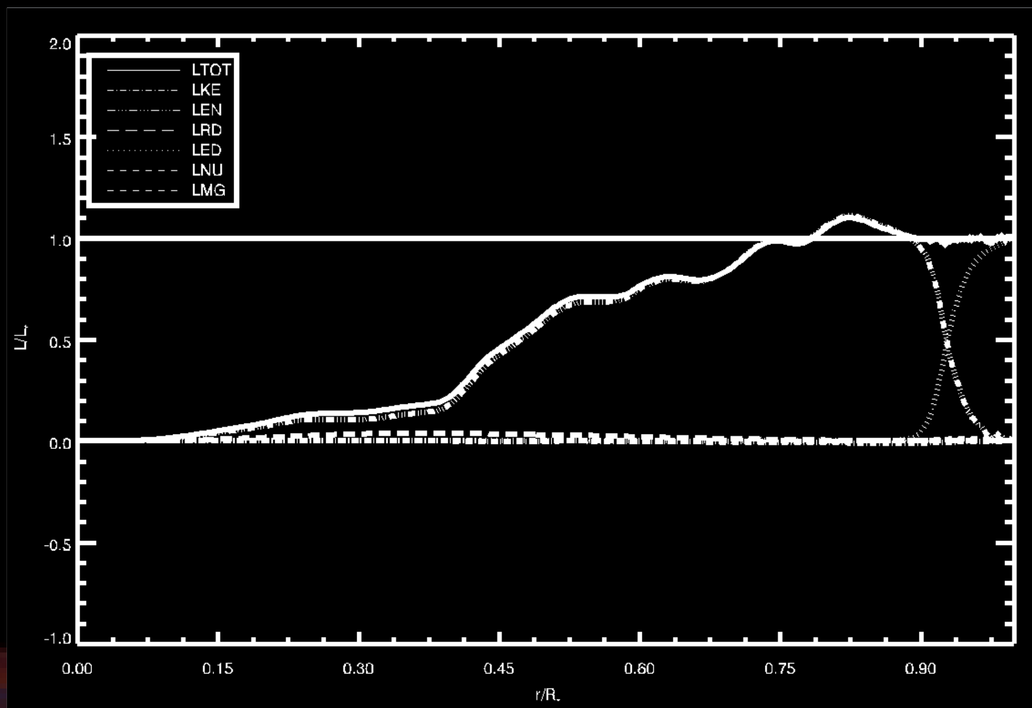




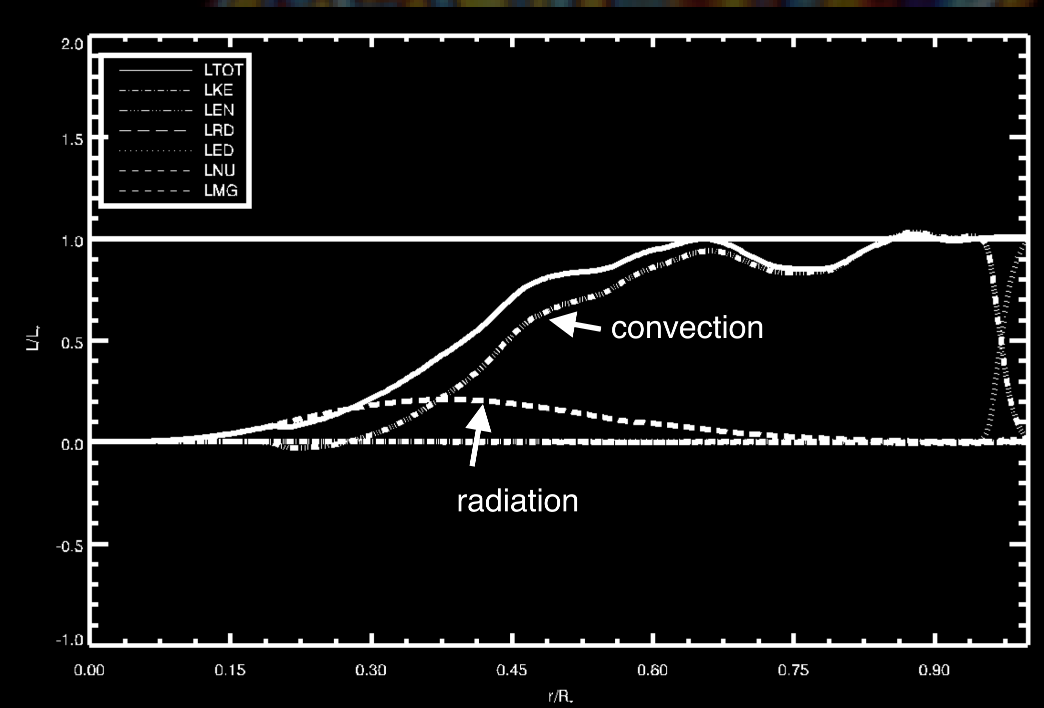


Flux balance

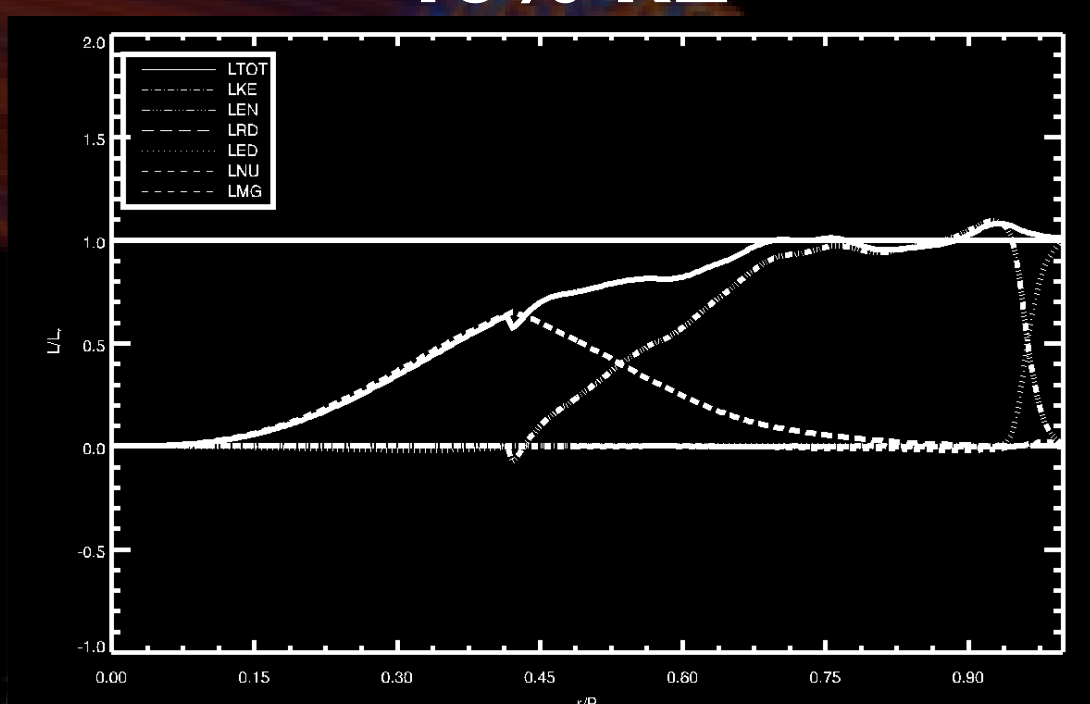
FullConv



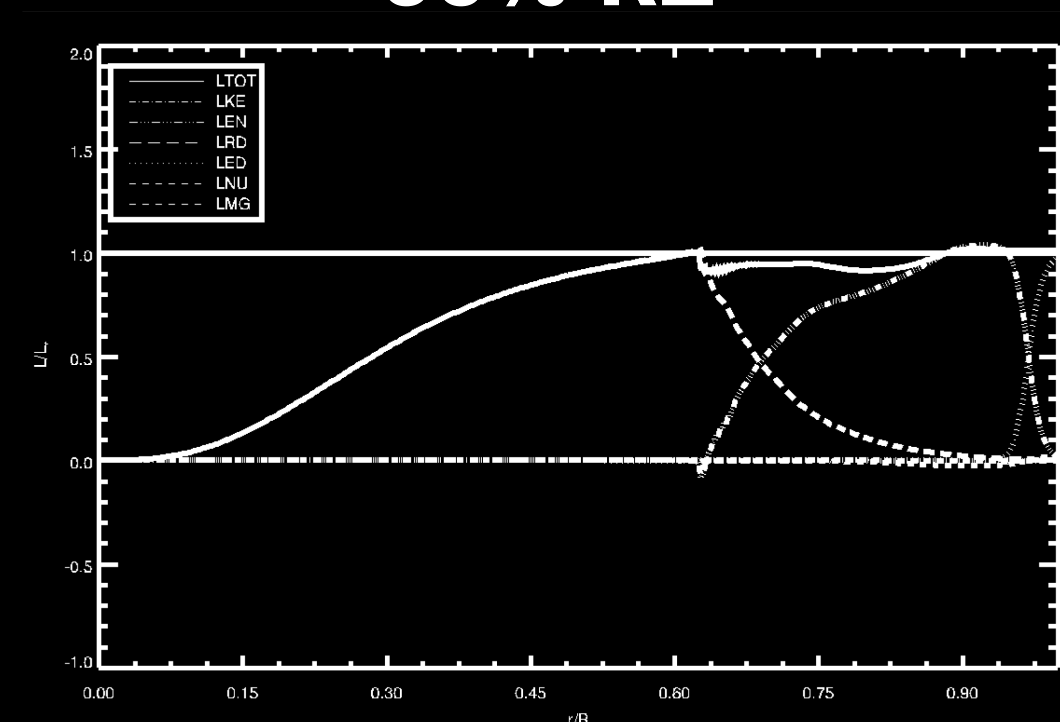
20% RZ



40% RZ



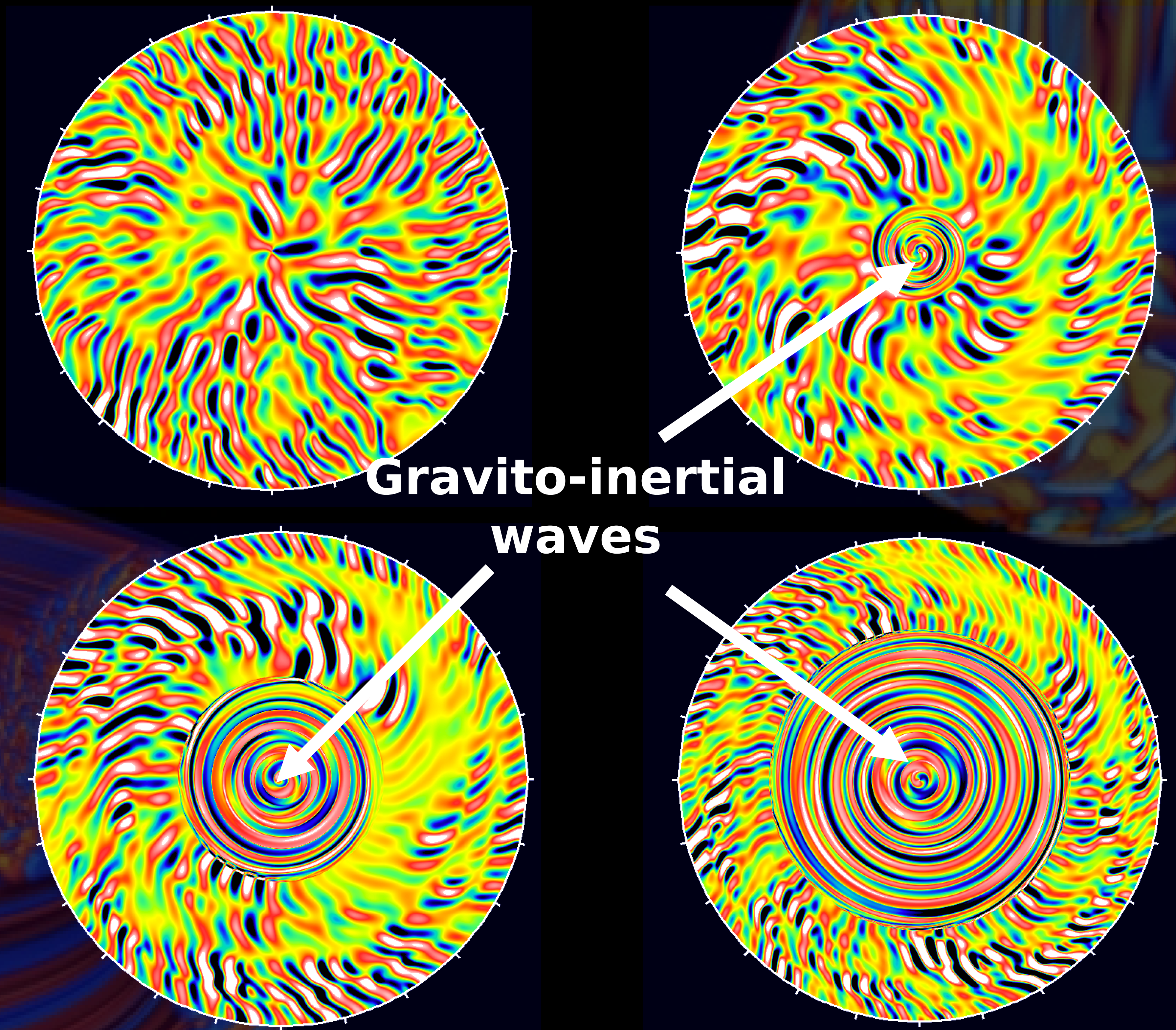
60% RZ



Hydrodynamical models

FullConv

20% RZ

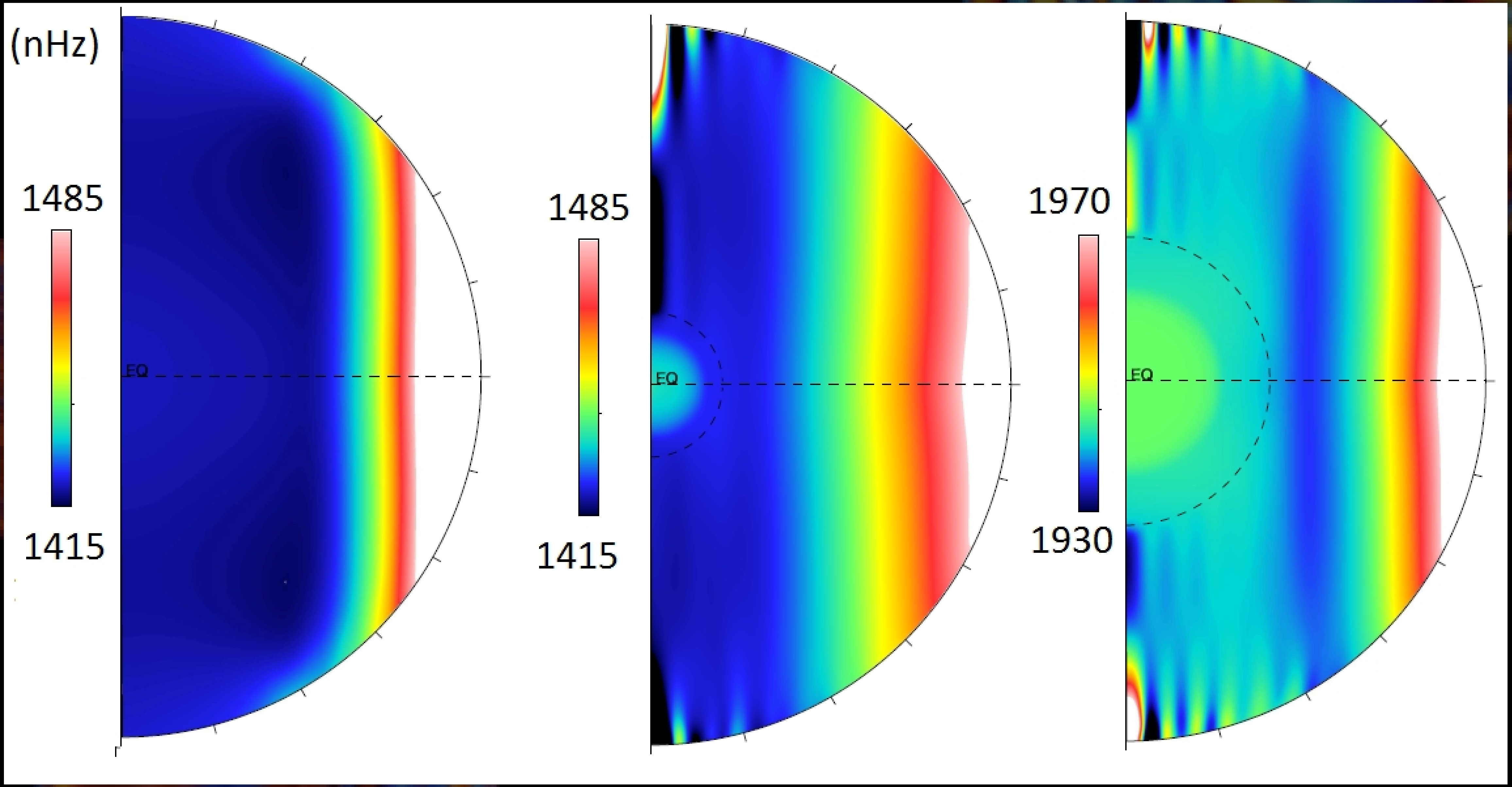


40% RZ

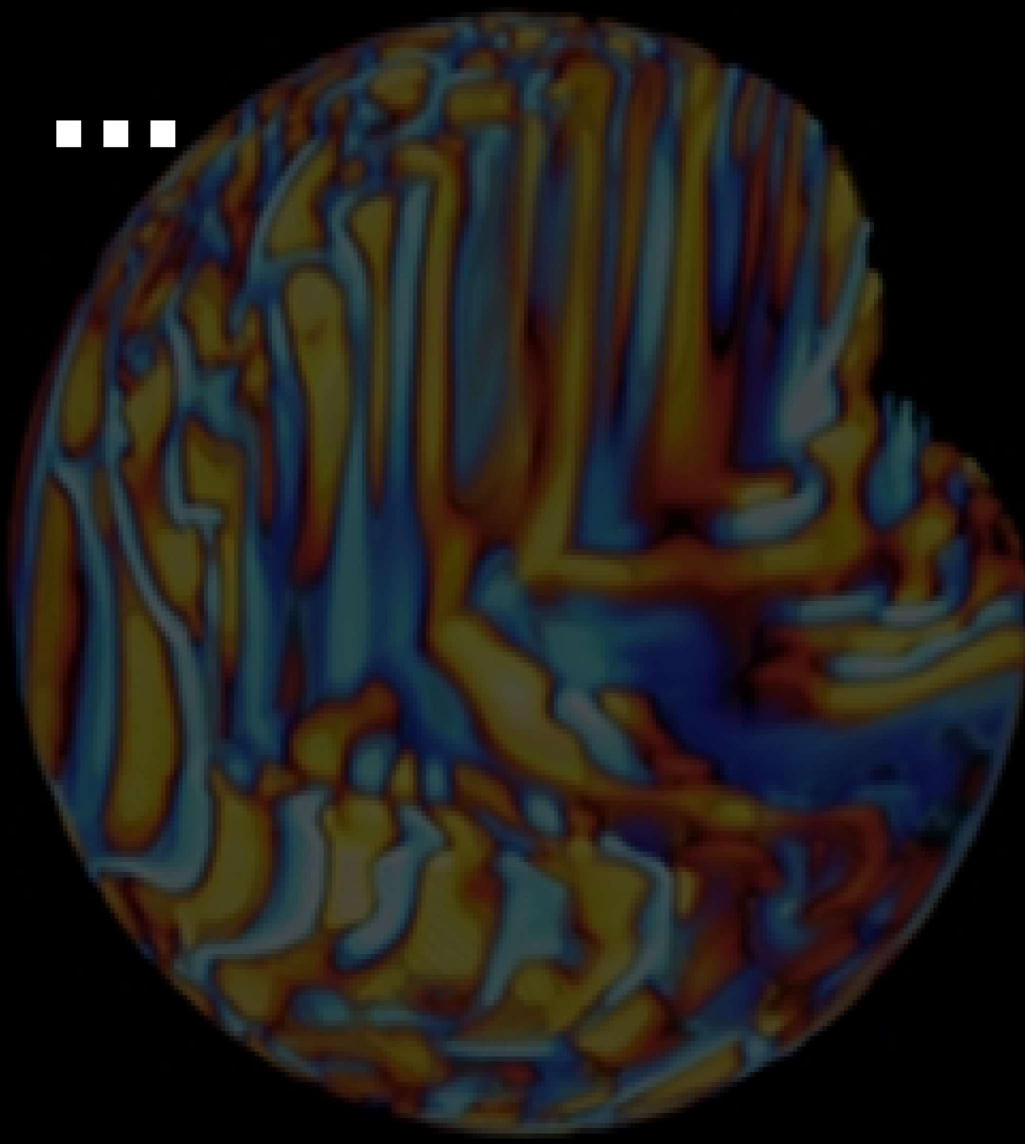
60% RZ

Hydrodynamical models

FullConv	20% RZ	40% RZ
4 Ωsun	4 Ωsun	4.5 Ωsun



How to ...



Seed magnetic field (confined dipole)

↓

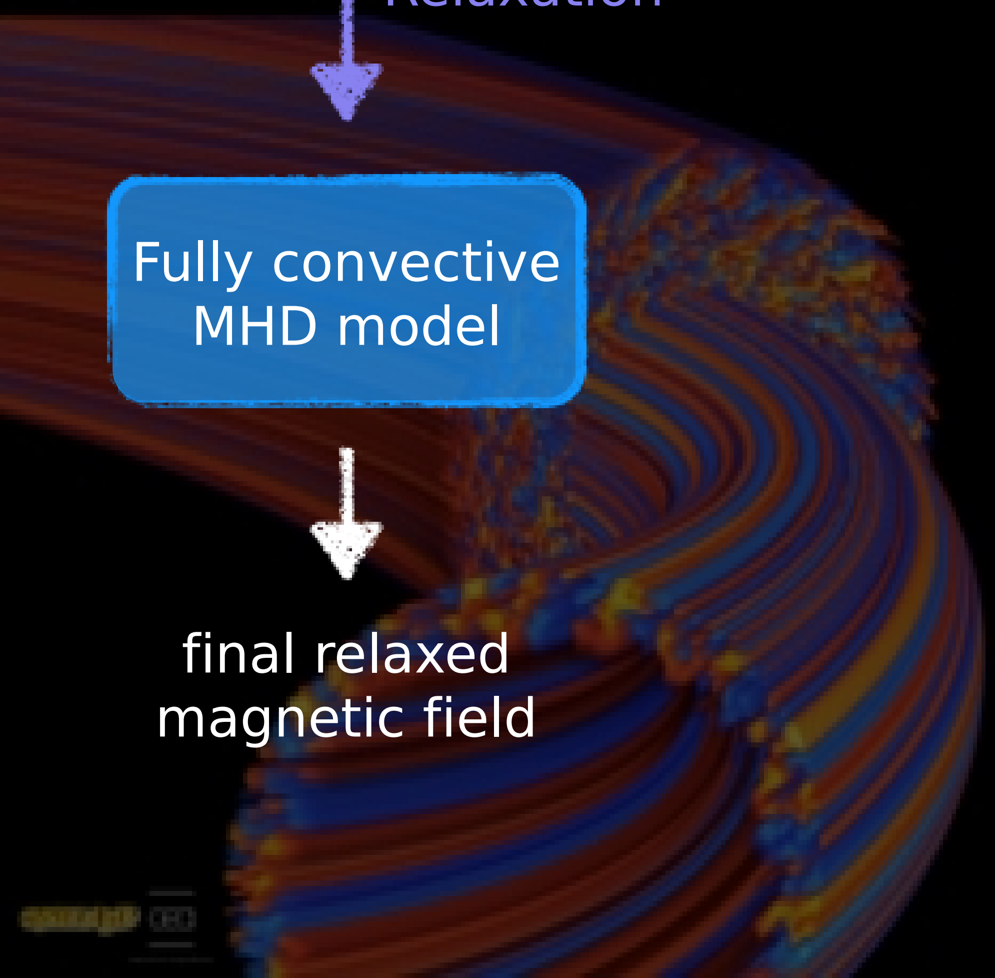
Fully convective hydrodynamical model

↓ Relaxation

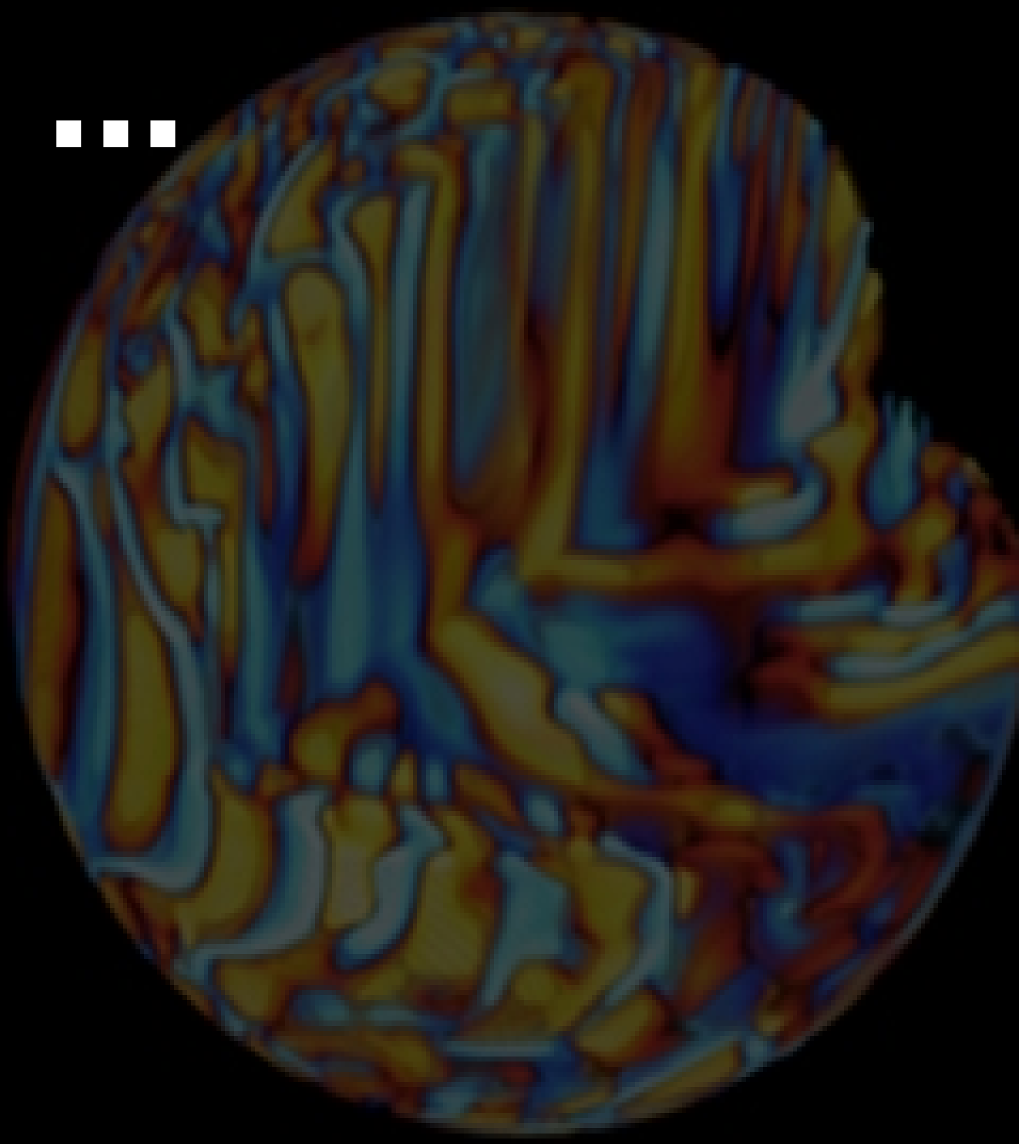
Fully convective MHD model

↓

final relaxed magnetic field



How to ...



Seed magnetic field (confined dipole)

↓

Fully convective hydrodynamical model

↓ Relaxation

Fully convective MHD model

↓

final relaxed magnetic field

→

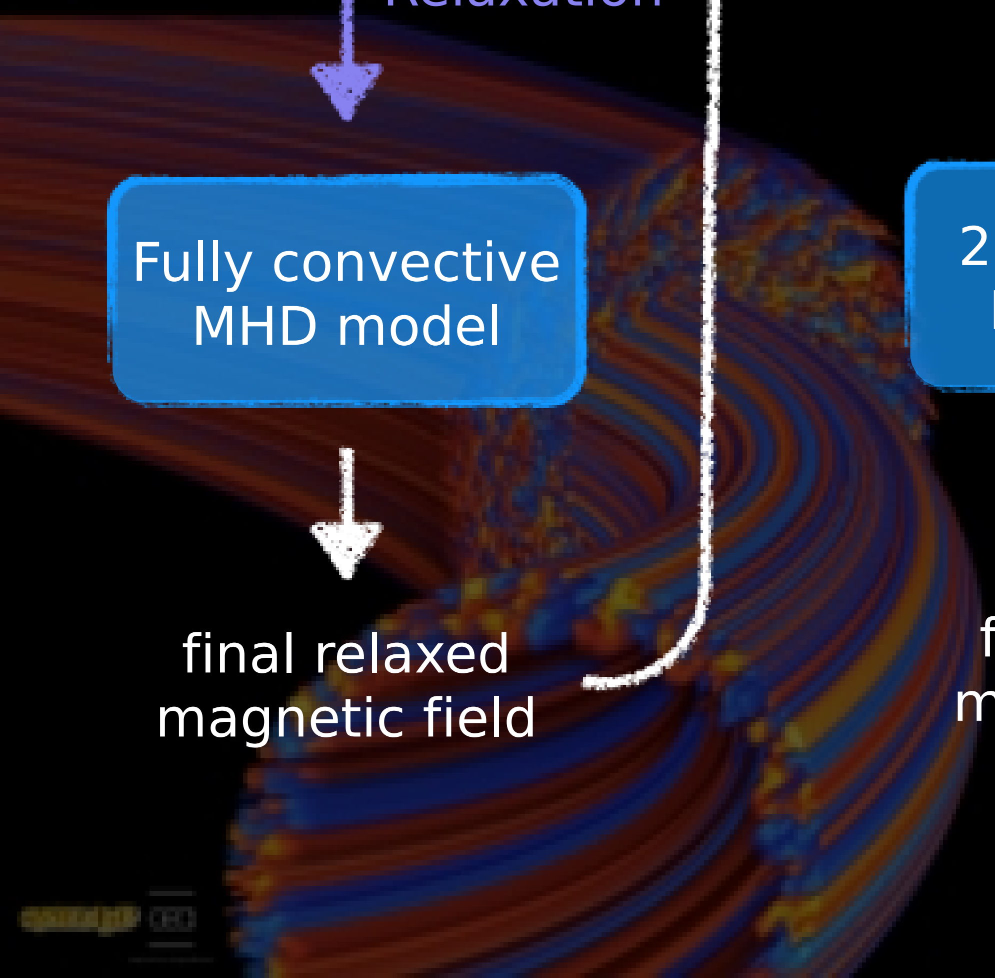
20% radiative hydrodynamical model

↓ Relaxation

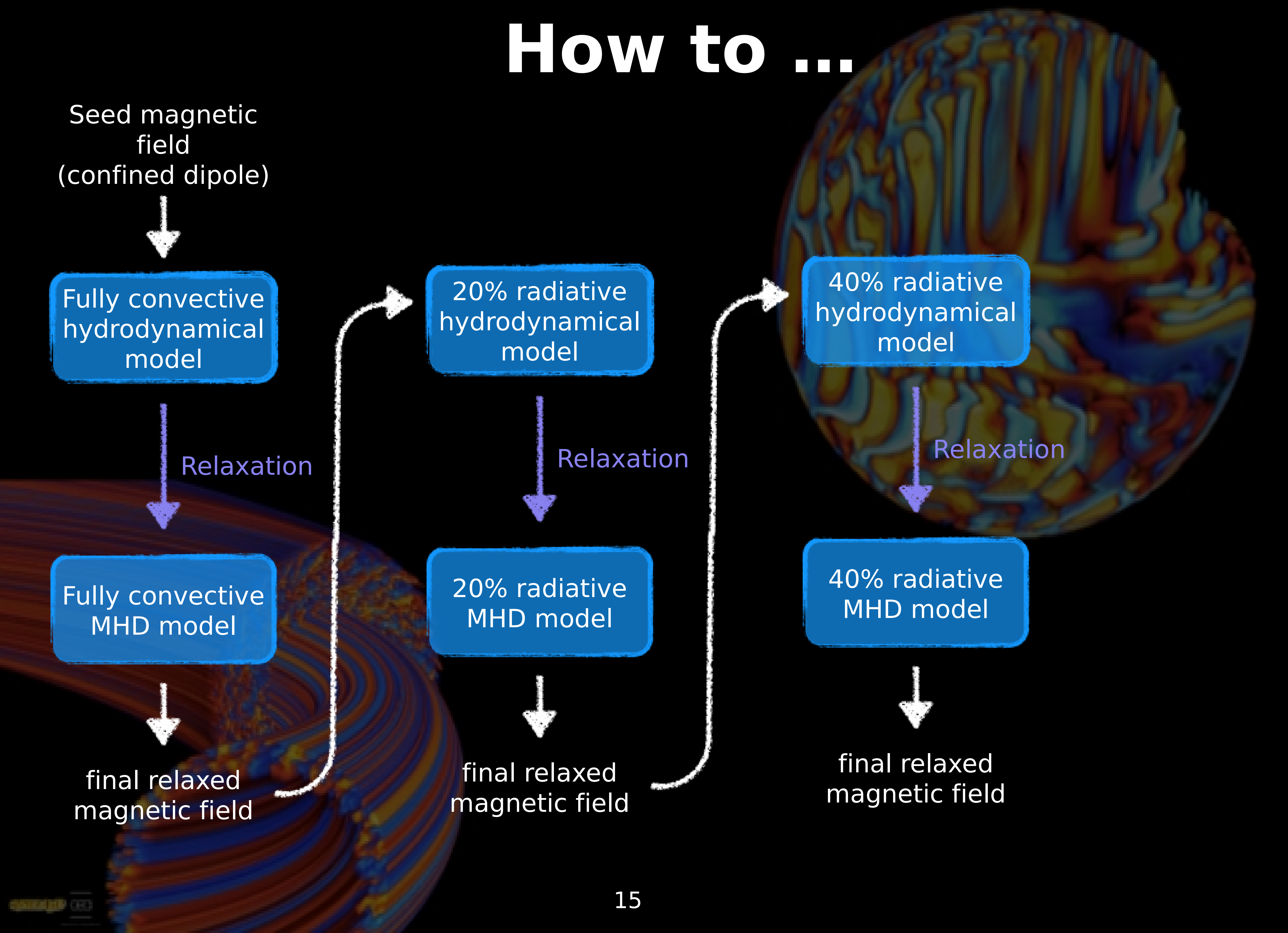
20% radiative MHD model

↓

final relaxed magnetic field



How to ...


Seed magnetic field (confined dipole)
Fully convective hydrodynamical model
Relaxation
Fully convective MHD model
final relaxed magnetic field
20% radiative hydrodynamical model
Relaxation
20% radiative MHD model
final relaxed magnetic field
40% radiative hydrodynamical model
Relaxation
40% radiative MHD model
final relaxed magnetic field

How to ...

Seed magnetic field (confined dipole)

↓

Fully convective hydrodynamical model

↓ Relaxation

Fully convective MHD model

↓

final relaxed magnetic field

→

20% radiative hydrodynamical model

↓ Relaxation

20% radiative MHD model

↓

final relaxed magnetic field

→

40% radiative hydrodynamical model

↓ Relaxation

40% radiative MHD model

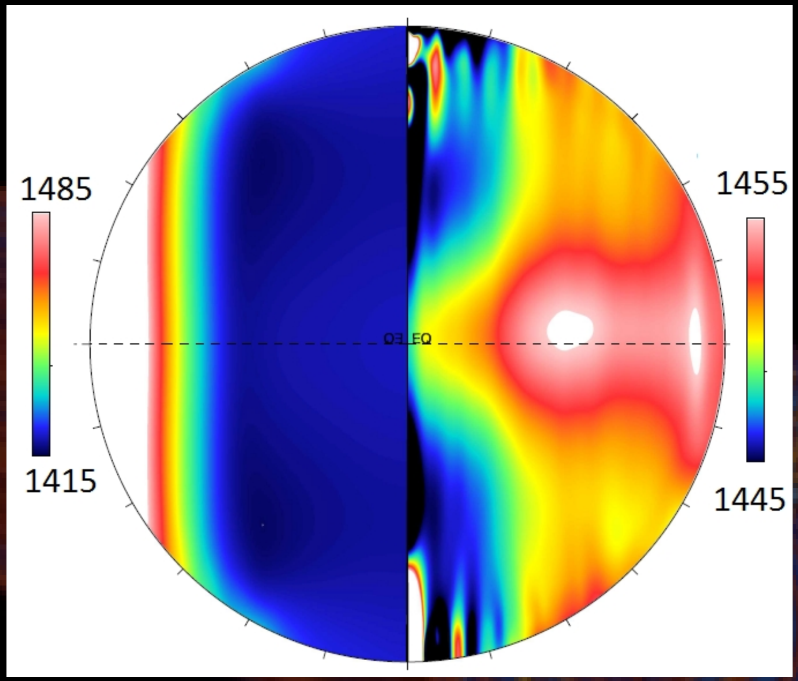
↓

final relaxed magnetic field

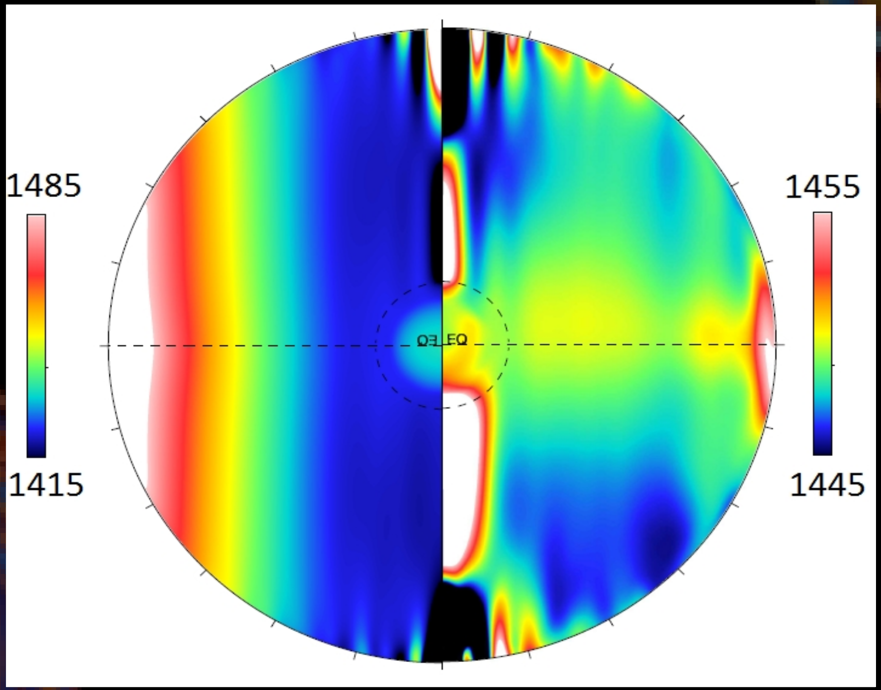
→ ...

HD vs MHD
Differential rotation

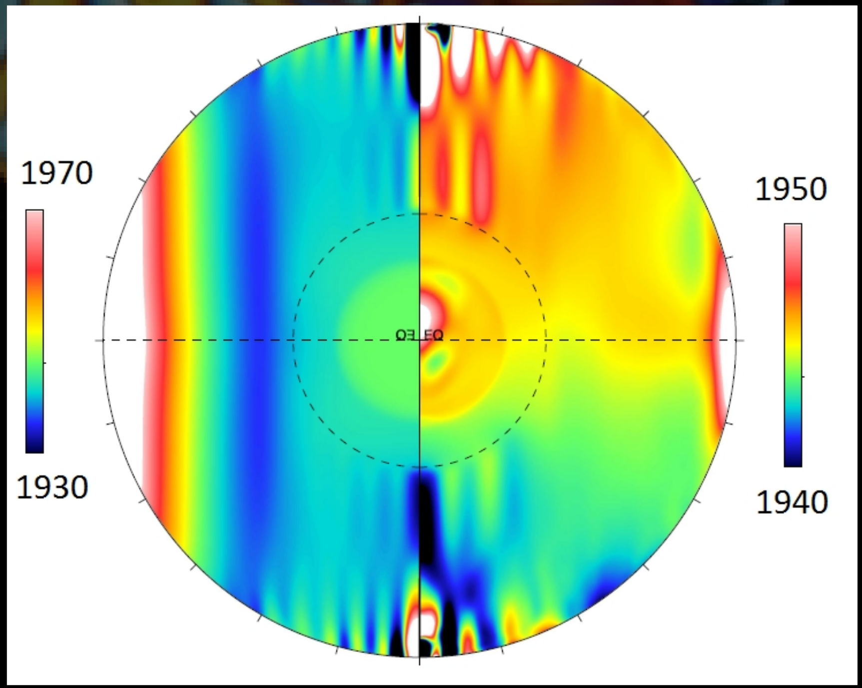
FullConv



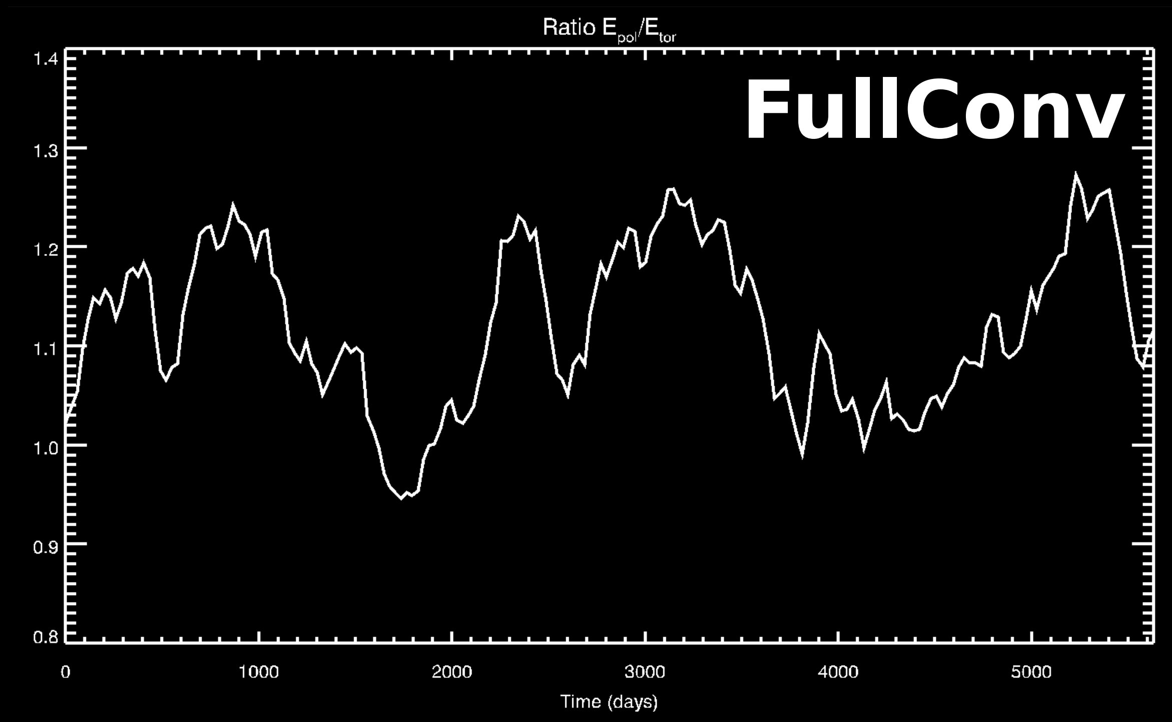
20% RZ

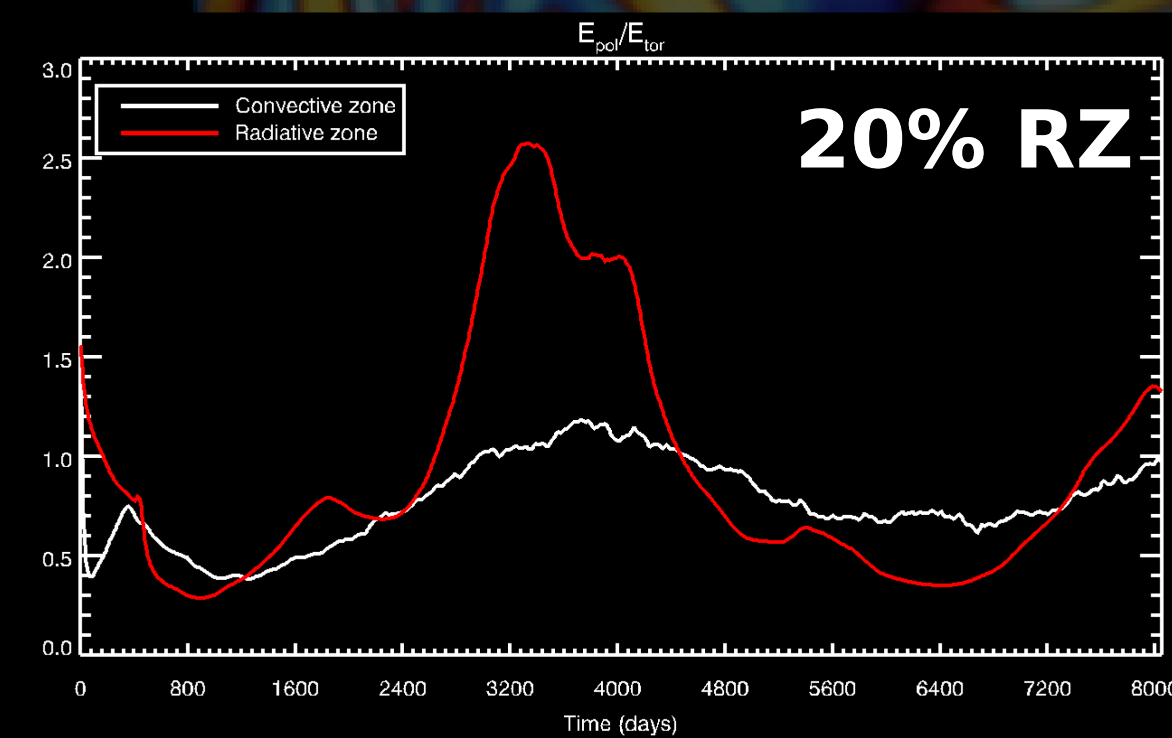


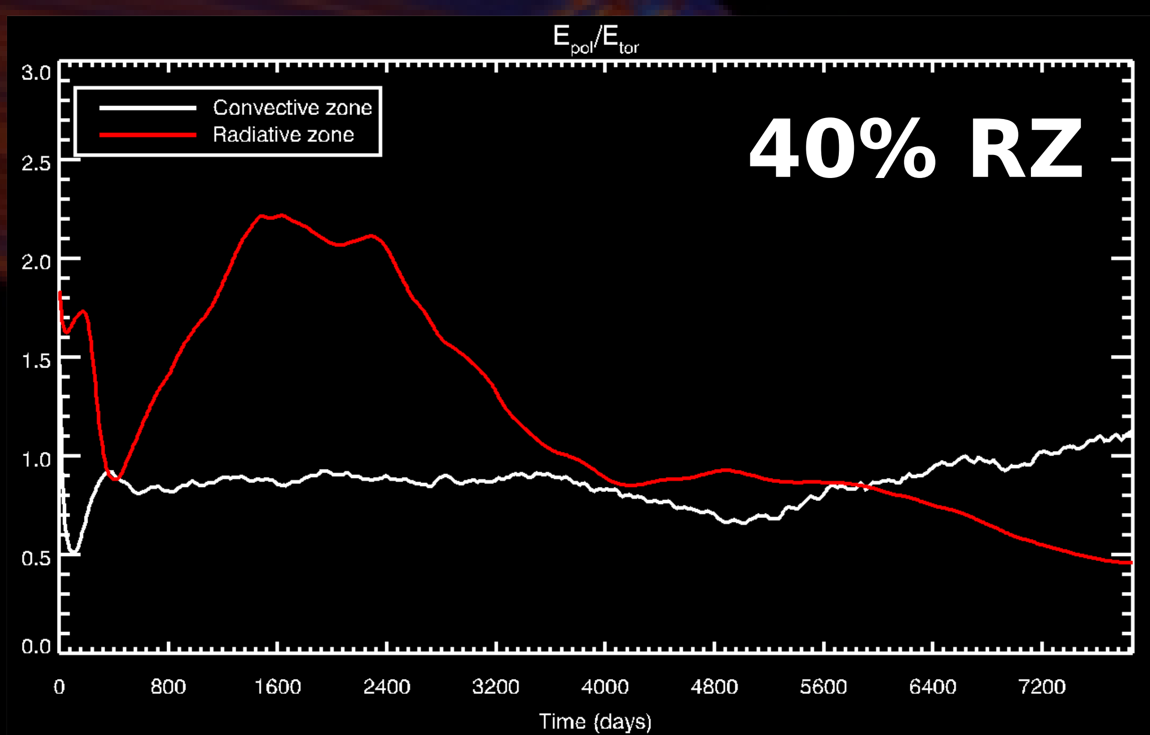
40% RZ



Magnetic energies

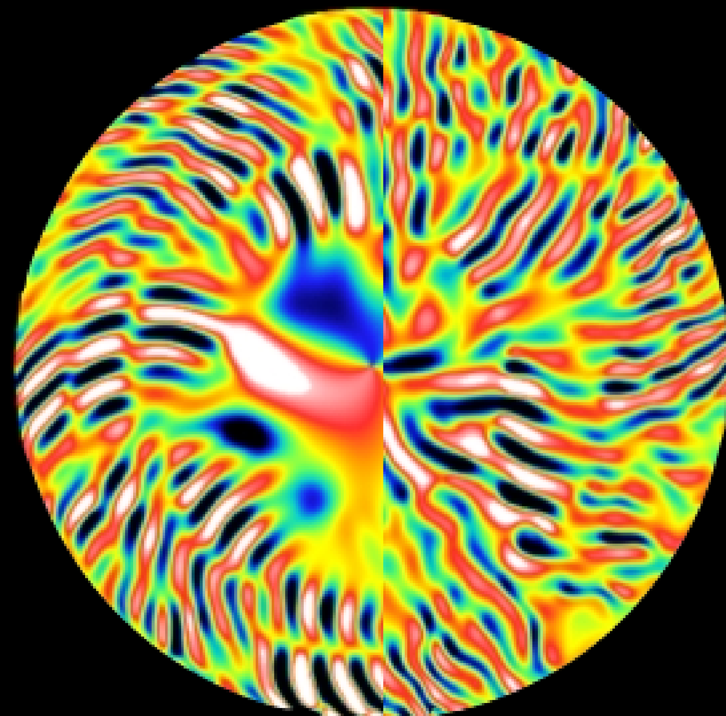




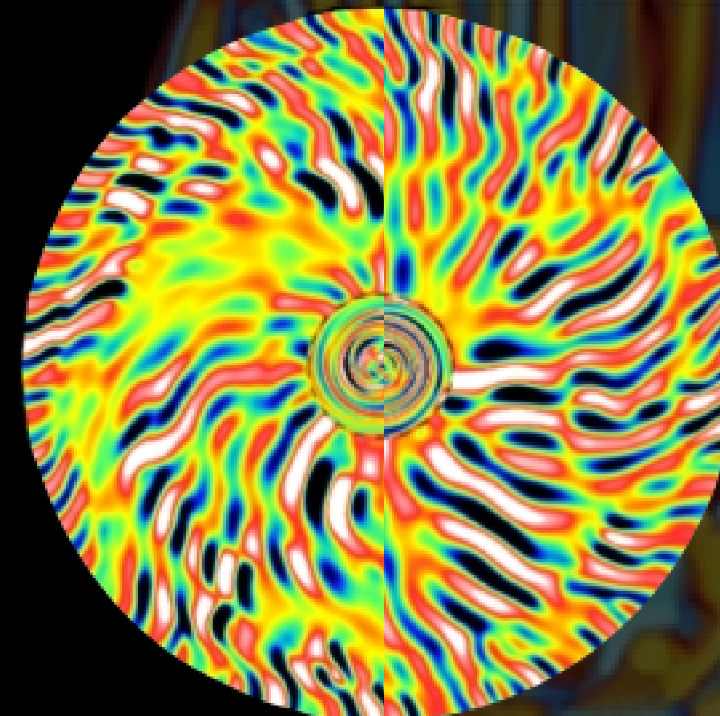


HD vs MHD Convection

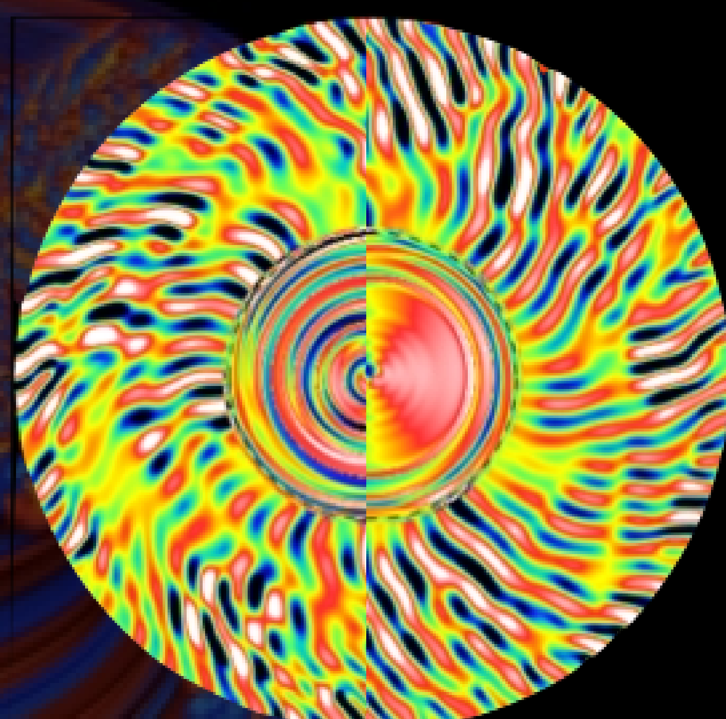
FullConv



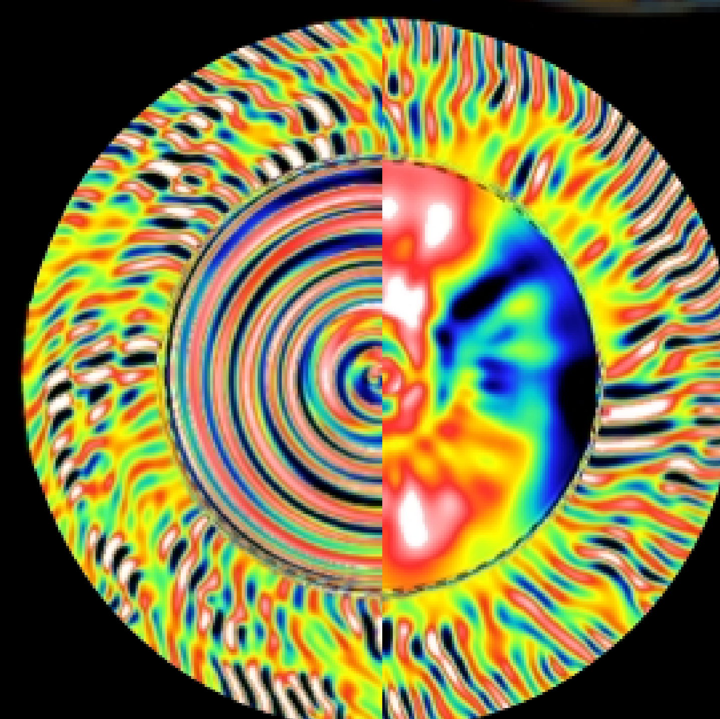
20% RZ



40% RZ

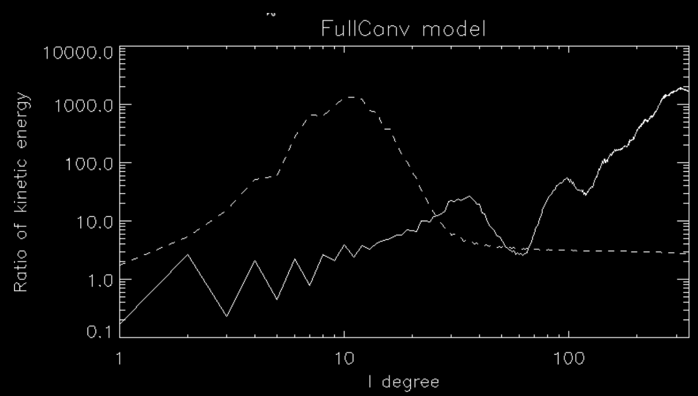


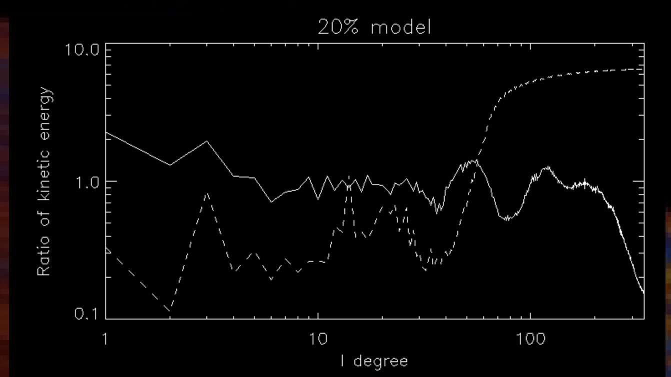
60% RZ

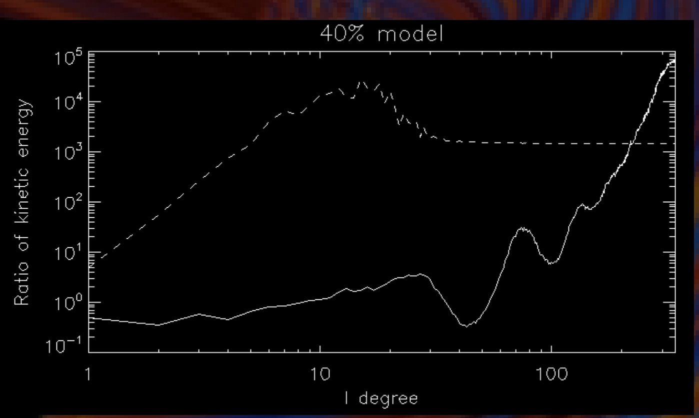


HD vs MHD

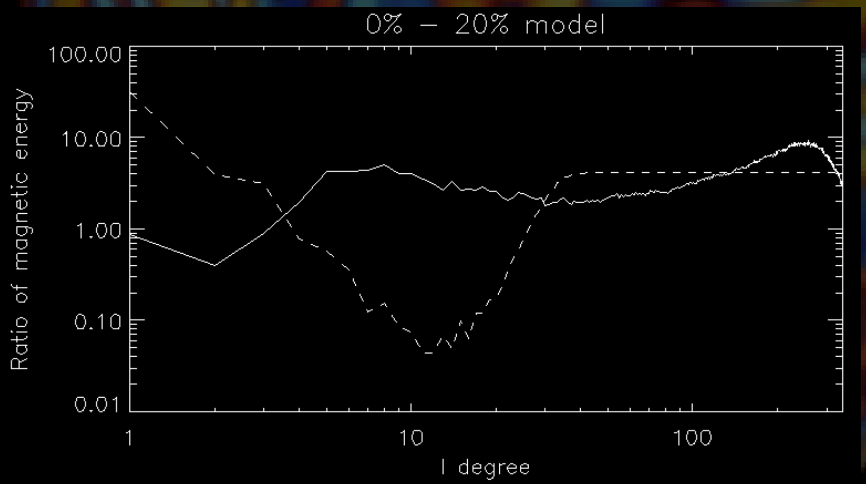
Ratio kinetic energy spectra

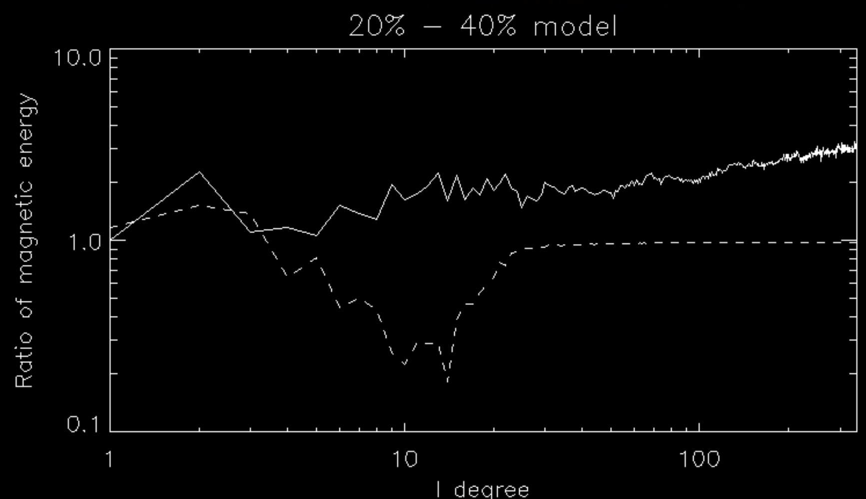




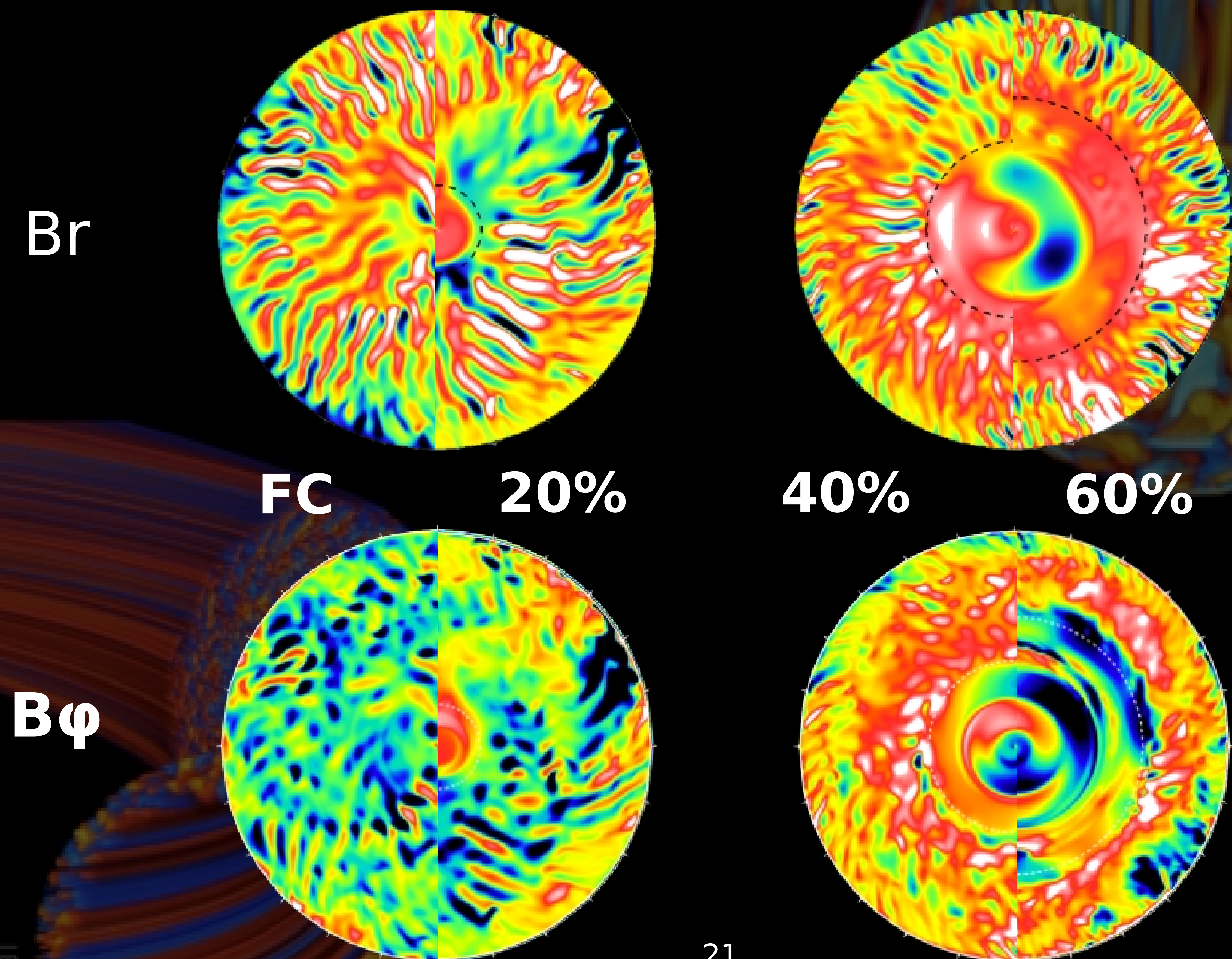


Ratio magnetic energy spectra



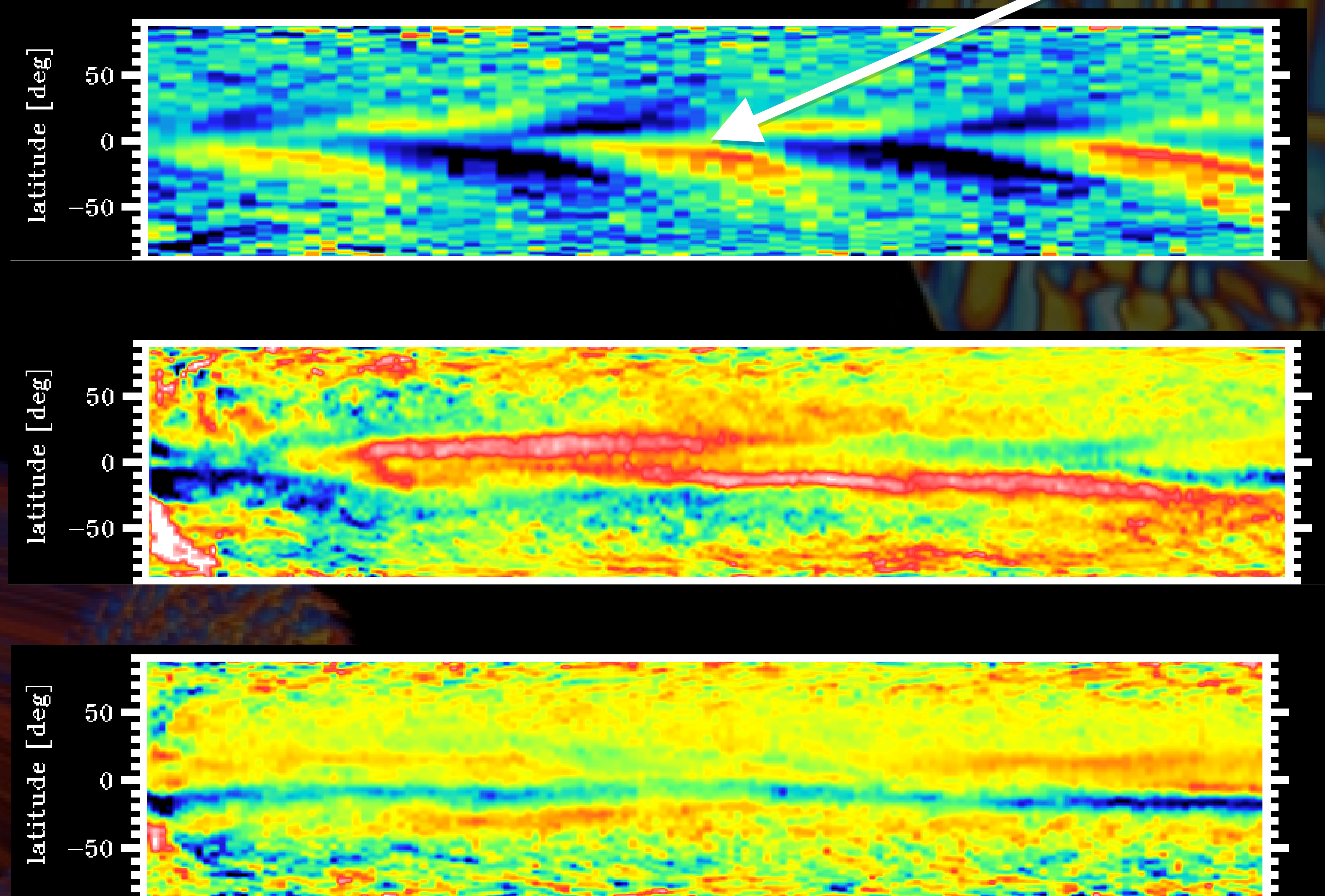


MHD magnetic field



Butterfly diagram

Polarity inversion



FullConv

20%

40%

~8000 days

Conclusion and perspectives

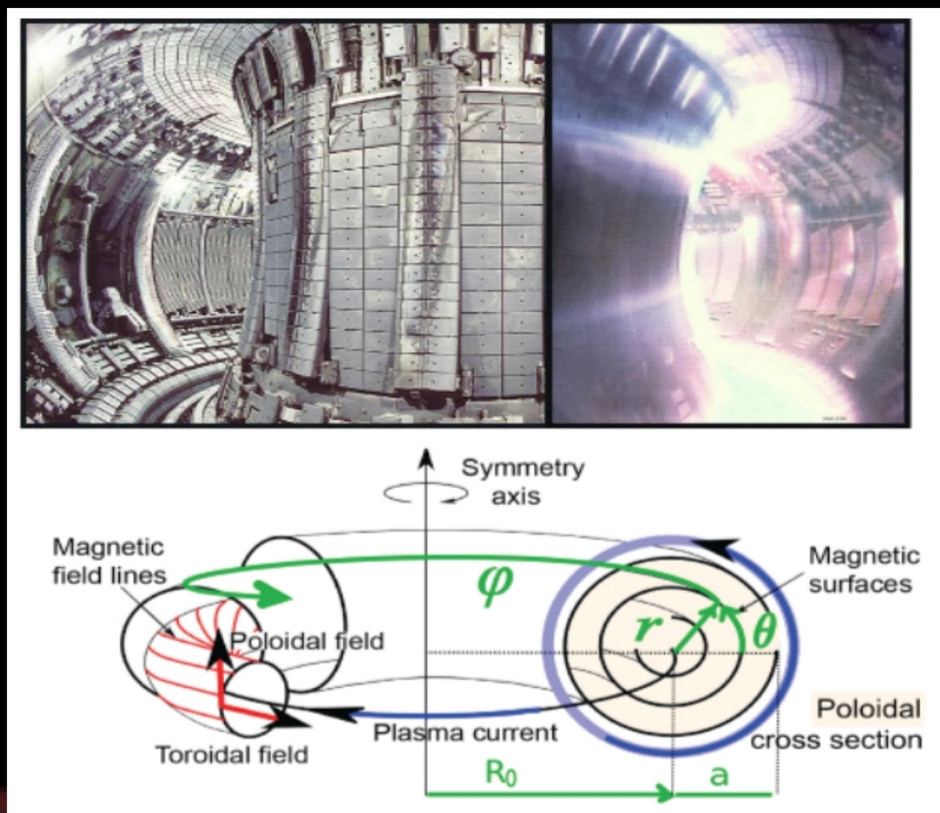
- Complete models with radiative zone at 60% and 70% to finish the PMS study

- Develop analysis of magnetic field dynamo (generation, α-Ω effect, butterfly diagram ...)

- Compute models for the MS study

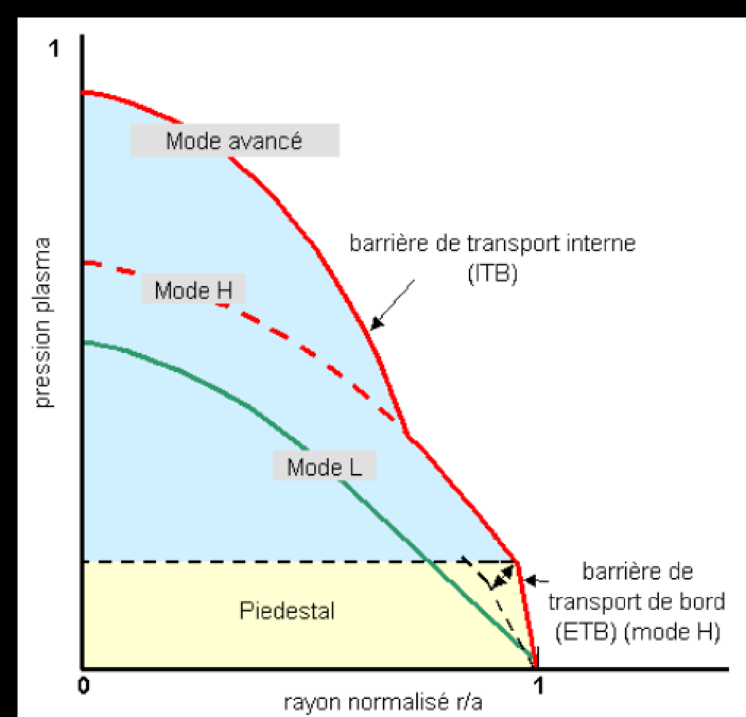
- Poster at the Dynamo workshop at Göttingen (May 2015)
- Poster at the PNST conference at Hendaye (March 2016)
- Talk at the « Simulations numériques en astrophysique » session at SF2A 2016
- « A theoretical picture of the formation of fossil magnetic fields in rotating stars » *to be submitted*
- « Evolution of internal magnetic field in solar-like stars during the PMS » *in preparation*

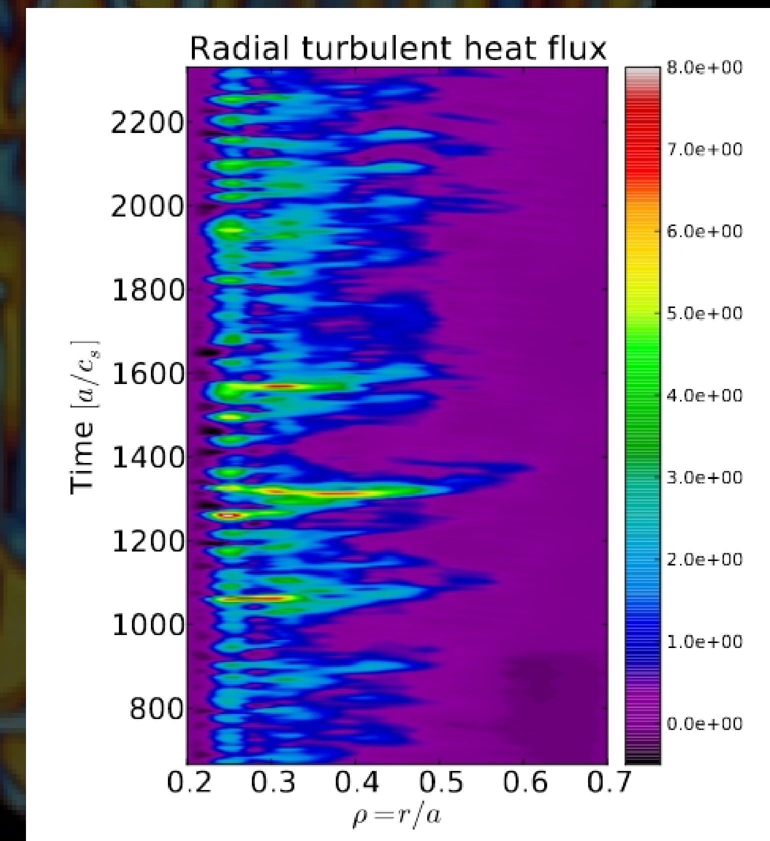
Fusion



Tokamaks :
context and geometry

Transports
in
tokamaks





Spectra analysis
on
avalanches

Fusion and astrophysics

- Pre main sequence evolution VS avalanches
- Transport of heat, entropy and angular momentum
- Multi-scale interaction and spectra analysis

	Astrophysics	Plasma
Used variables	Global energy Magnetic helicity Cross helicity	Entropy
Functions basis	Spherical harmonics	Fourier decomposition

Evolution equations that give coupling terms