The convective origin of hemispherical dynamos: an application to Mars

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EGU General Assembly Vienna

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Crustal magnetization on Mars

- measured by MGS space craft [Acuna et al., SCIENCE (1999)]
- strong dichotomy aligned with crustal thickness anomaly
- remanent magnetic field strength comparable to Earth rocks
- mainly the southern hemisphere is magnetized
- is this the fingerprint of an ancient internal dynamo?

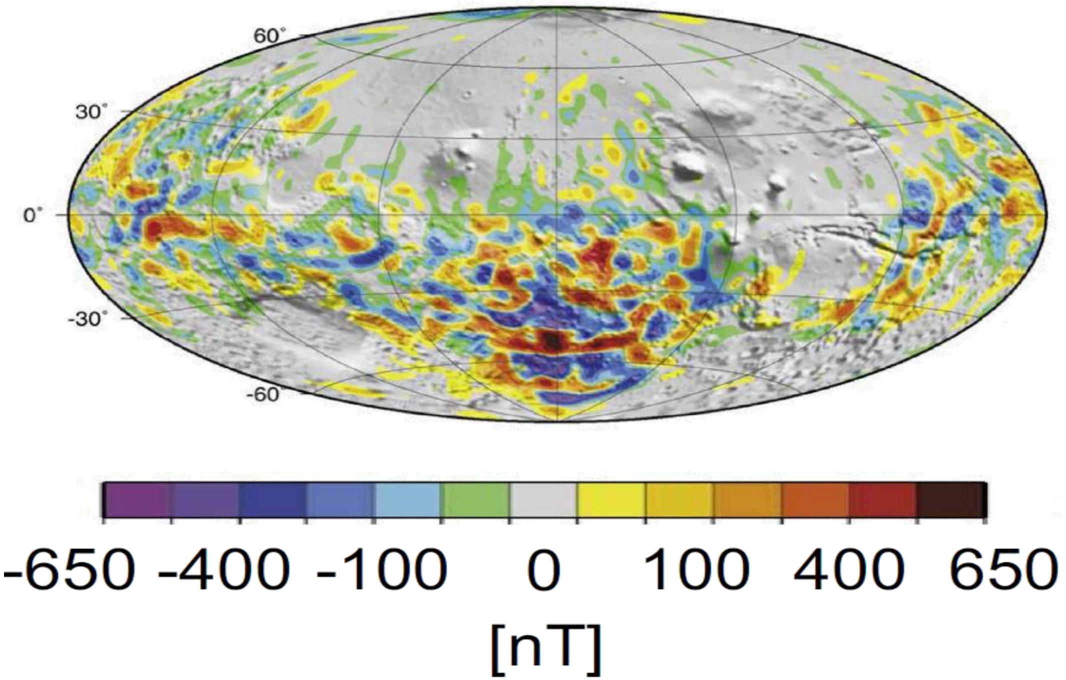
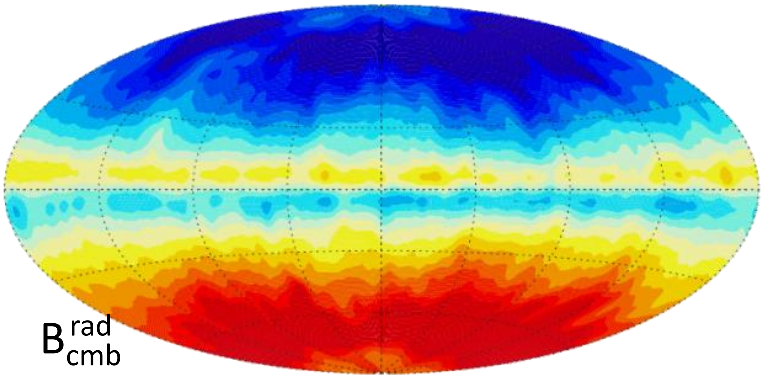


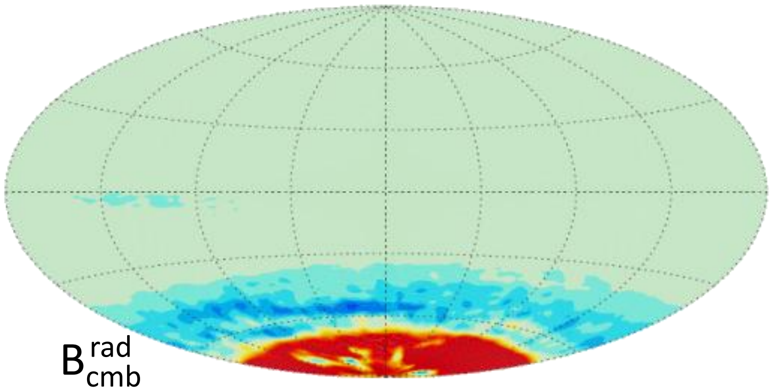
Figure 1: Crustal magnetization map in nT [Langlais et al., JGR (2004)] is mainly localized in the southern hemisphere

Magnetization Models – Ancient Dynamo

dipolar magnetizing field: fully magnetized crust, but partial demagnetization due to resurfacing events like giant impacts, volcanoes or tectonics [Lillis et al, 2008]



hemispherical magnetizing field: crust becomes magnetized just locally, [Stanley et al. Science, 321, 2008] for principal mechanism, [Amit et al., time averages]

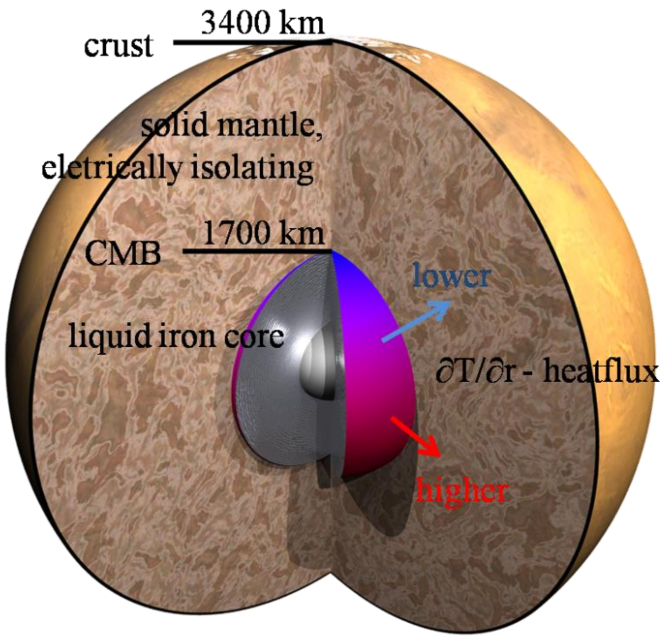


What is special about the Martian Dynamo ?

- fully liquid core, so just thermal convection can drive dynamo [Spohn et al., 2001]
- non-homogeneous cooling from the core mantle boundary (CMB):
  - local heating from giant impacts [Roberts et al., 2009]
  - low-degree mantle convection [Roberts & Zhong, 2006]

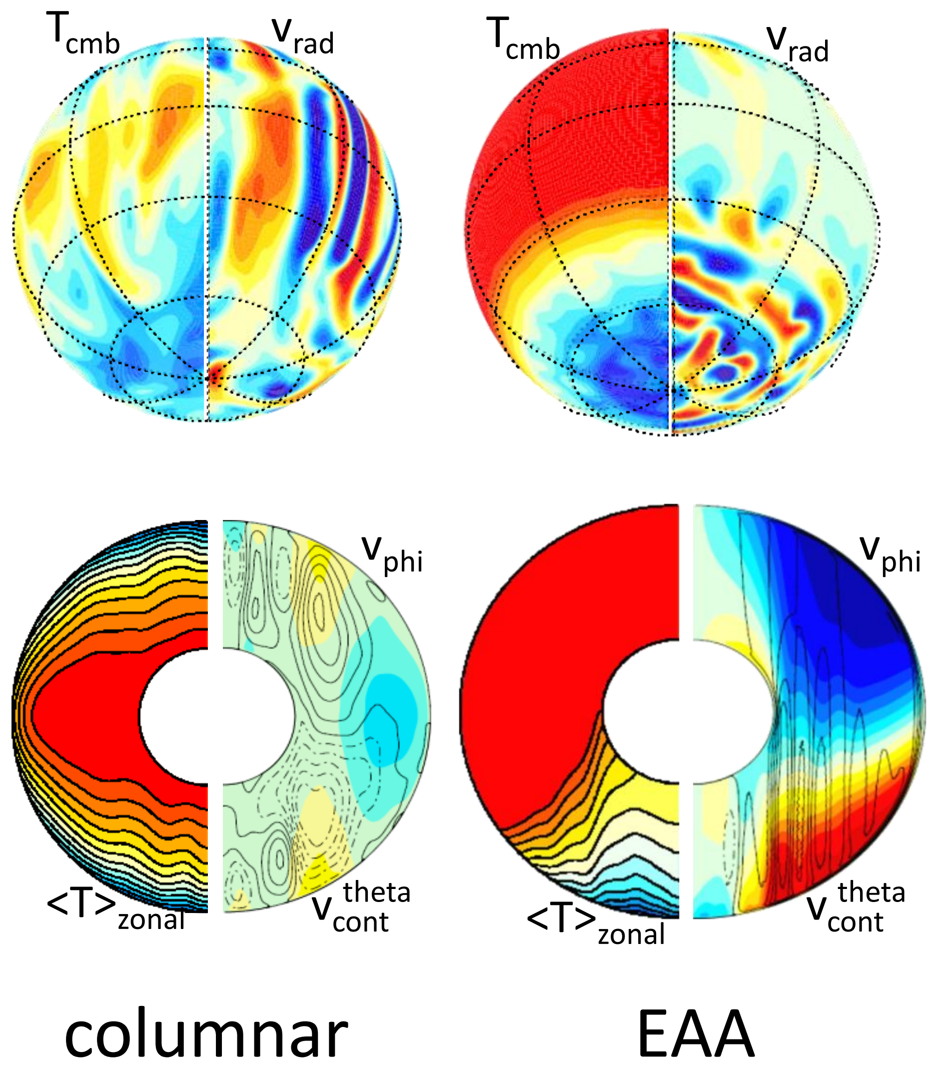
Our Model :

- full 3D numerical dynamo [Wicht, 2002]
- internal heating with a present but passive inner core [Hori et al., 2010]
- sinusoidal (degree-1) perturbation of cmb heat flux with variable orientation and amplitude



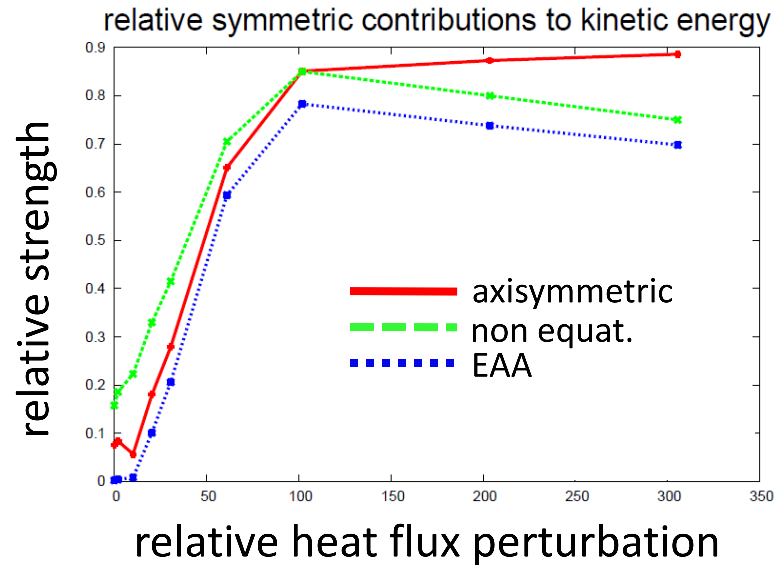
New convective mode

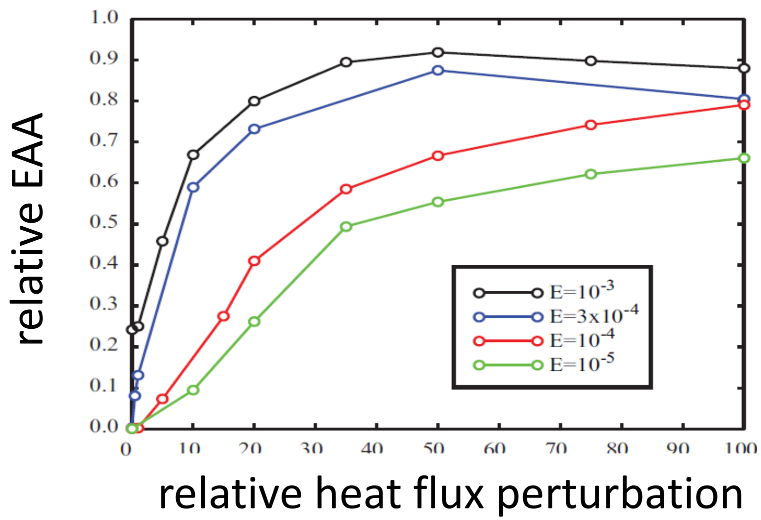
- usually convective columns dominate the motions in rotating fluids which are nonaxisymmetric, but equatorially symmetric
- natural onset of an equatorially antisymmetric and axisymmetric mode of convection (EAA) at higher supercritical Rayleigh numbers (Landeau&Aubert,2011)
- EAA mode consists of:
  - axisymmetric Temp. anomaly
  - weak meridional circulation
  - two strong zonal flow cells

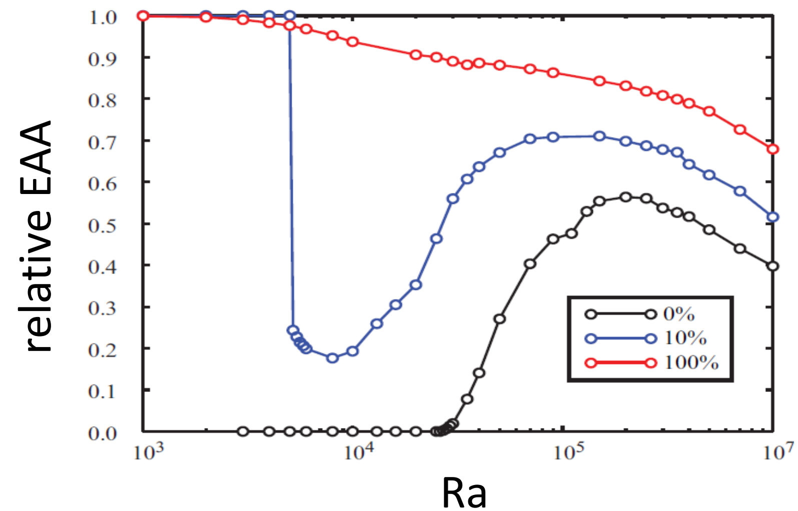


Onset of EAA

- transition from a columnar towards the EAA convection
- amplitude and orientation of cmb heat flux perturbation variable
- from an relative perturbation of 60% the EAA mode dominates the system

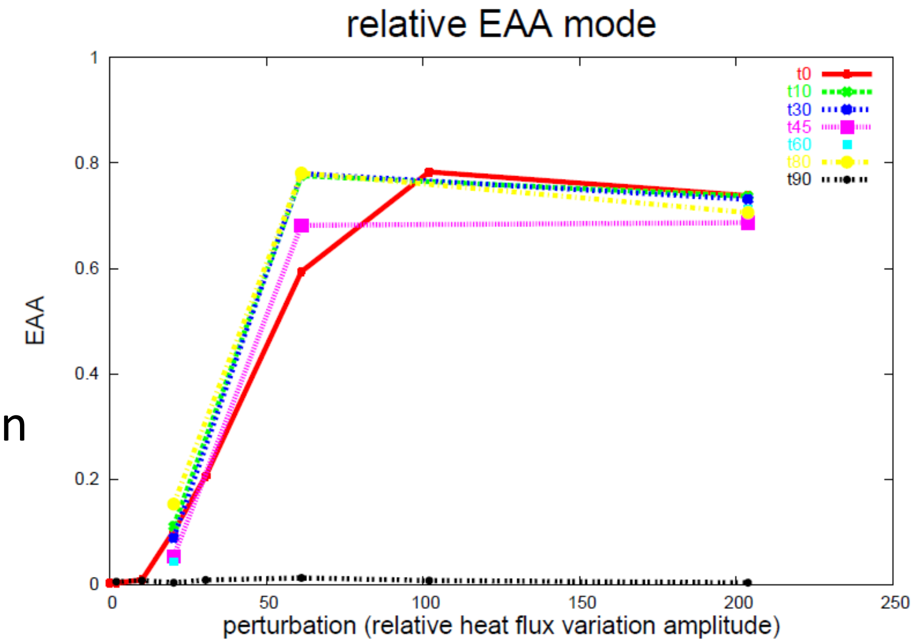


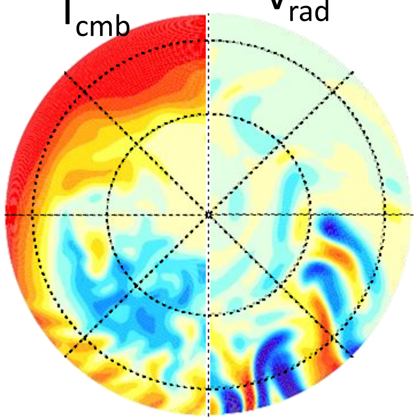


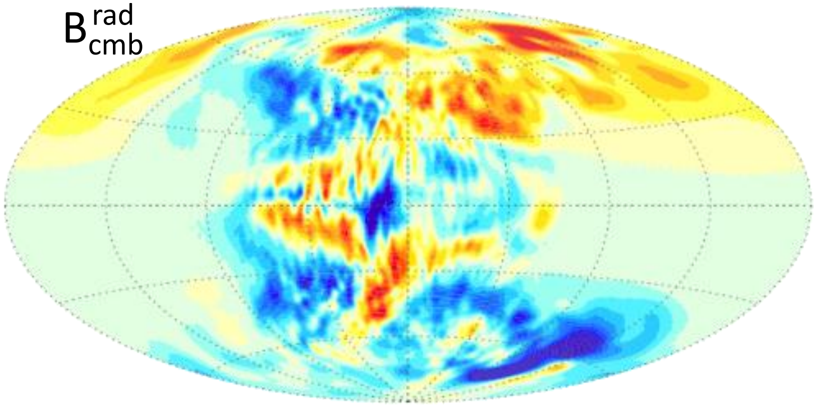


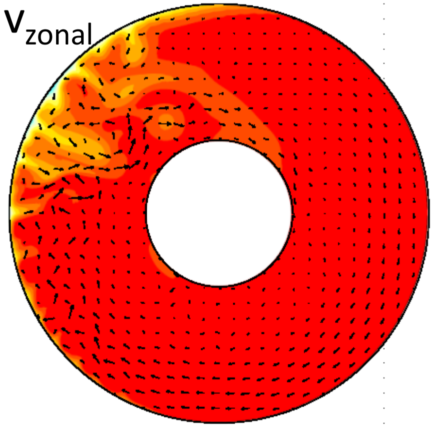
Tilting the perturbation

- effect remains of the perturbation is tilted by angles up to 80 degrees latitude
- from 80 degrees system reorganizes in another forced (not intrinsic) mode
- 90 degree is a special case:



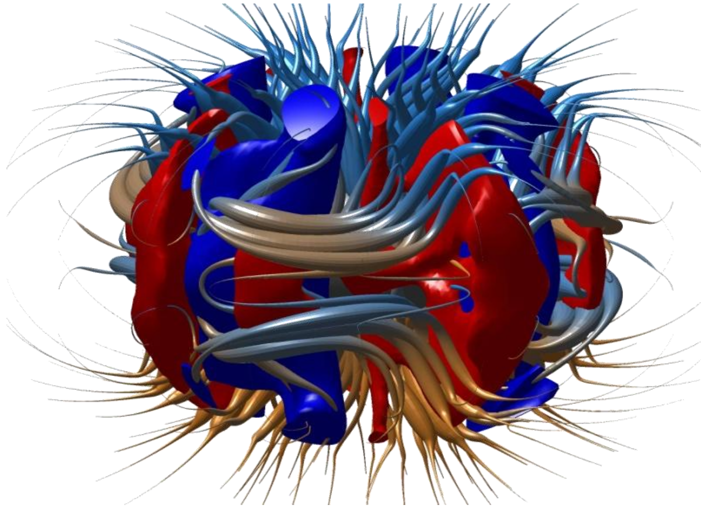


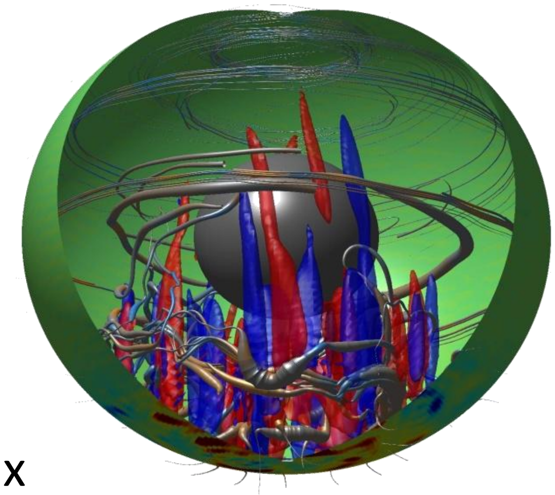




Induction process

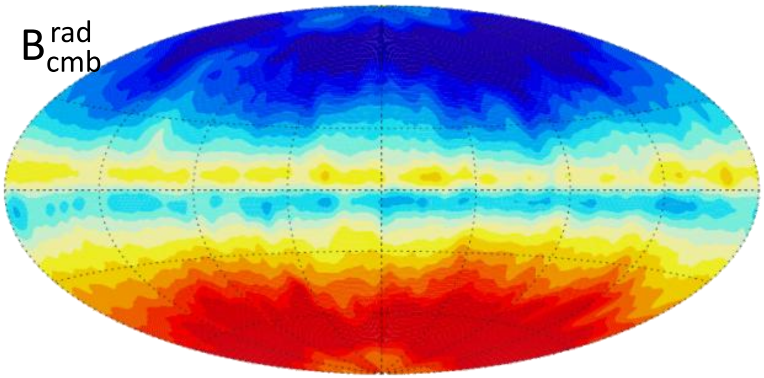
- a columnar dynamo is a first order α^2-dynamo
  - toroidal and poloidal field are created mainly in helical flow in the convective columns
  - usually dipole dominated fields, if convection is not to vigorous
- in EAA convection hemispherical configuration is preferred ($\alpha\omega$-dynamo)
  - if the coloumns are weakened, poloidal and toroidal field contributions are decreasing both simulationeously
  - toroidal field is also produced in the shear layer between the two zonal flow cells (ω-effect)
  - poloidal field is then just induced in the small scale convection (α) in the vicinity of high heat flux



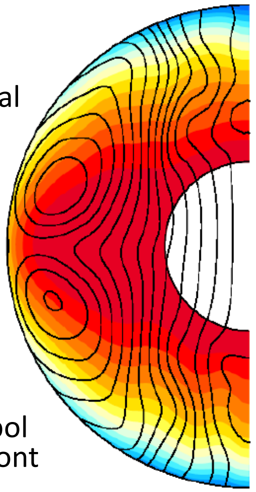


Induction process

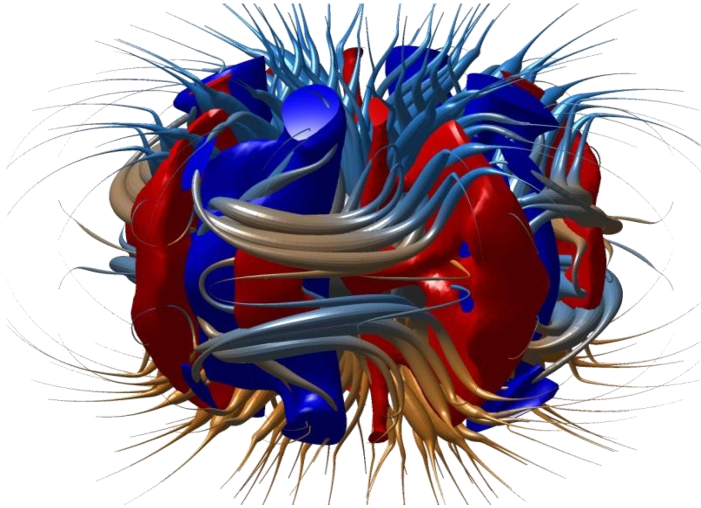
B_{cmb}^{rad}



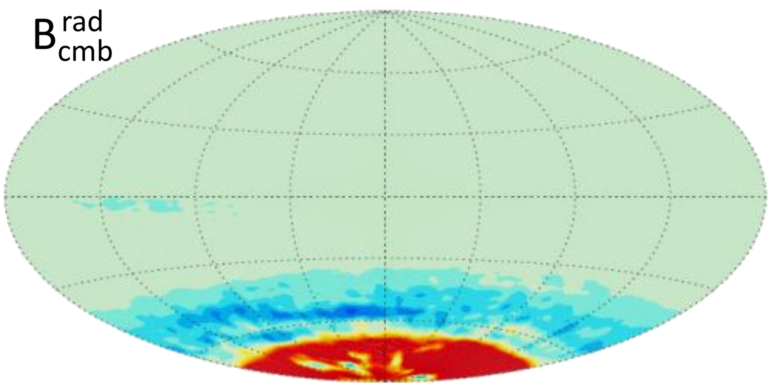
$\langle T \rangle_{zonal}$



B_{cont}^{pol}



B_{cmb}^{rad}



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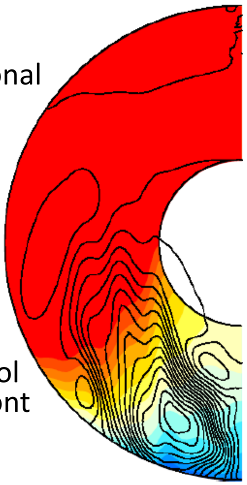

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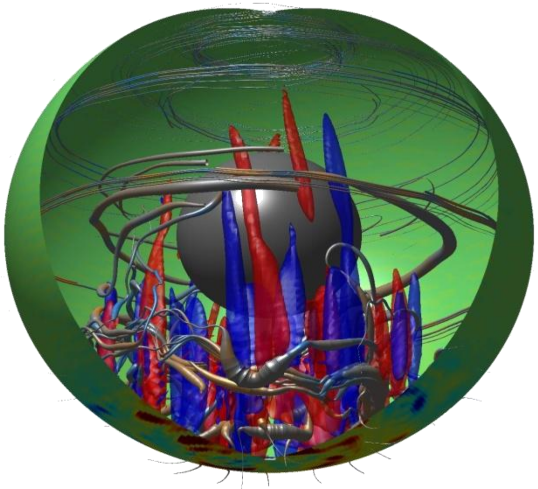
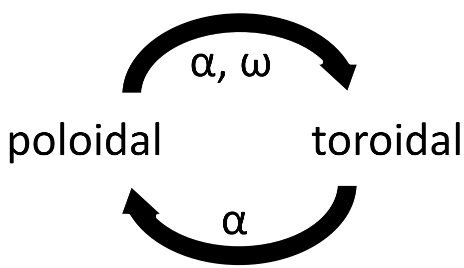
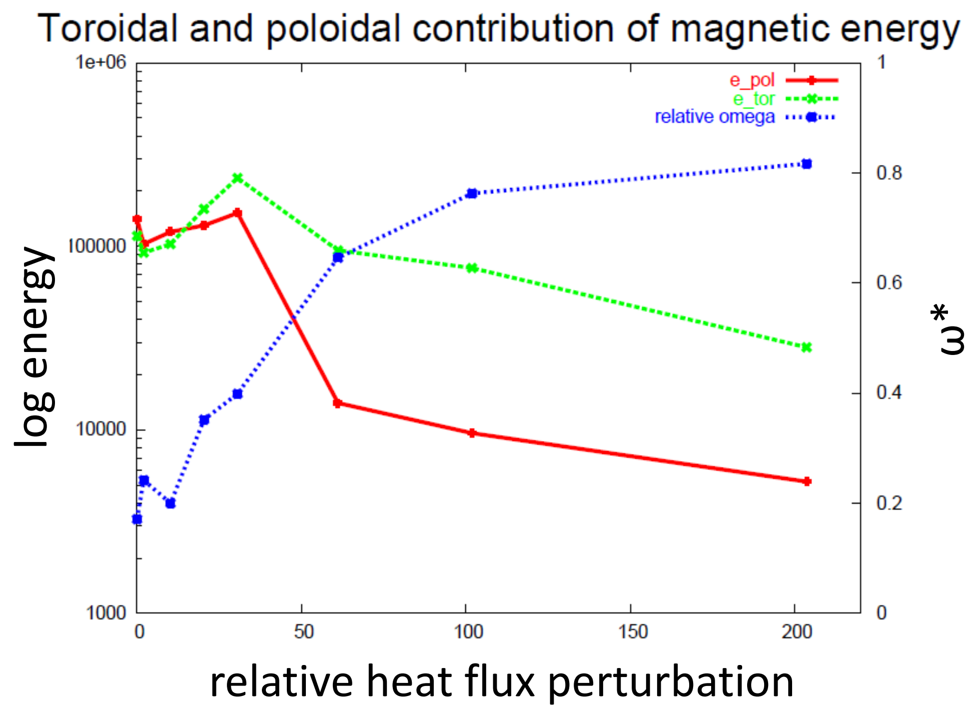


Results - Induction

- relative ω-effect dominates induction process
- poloidal (radial) magnetic energy decreases by an order of magnitude

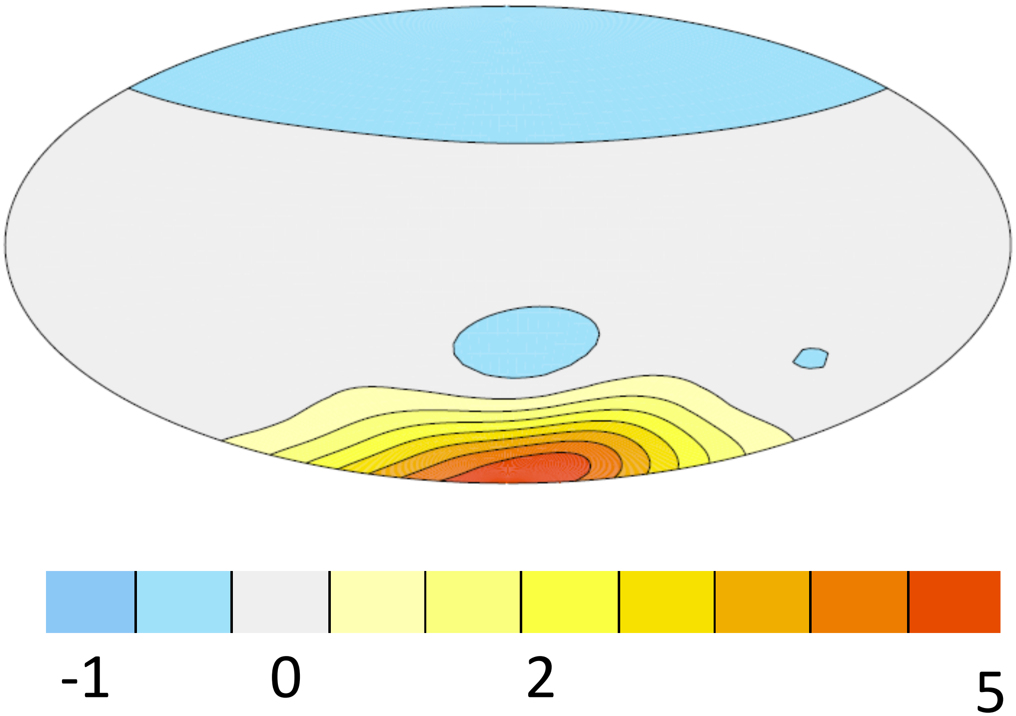
$$\omega^* = \frac{(\vec{B}\cdot\vec{\nabla})u_\phi^{as}}{(\vec{B}\cdot\vec{\nabla})u}$$





Results – surface field

- surface extrapolation for Mars
- field is weak :
  - small scale radial field
  - weak dipole component
  - induction is confined
  - time-average
- then the field is again more dipolar at the surface



Radial magnetic field at the surface of Mars in µT

Conclusion

- new convective mode (equatorially asymmetric, axisymmetric)
- EAA mode can emerge either as an intrinsic mode at higher Ra-Number, or forced with cmb heat flux perturbations
- hemispherical dynamos are a natural consequence of the dynamics in this new mode of convection
- relative ω-effect dominates induction of toroidal field, transition from α^2 to αω-dynamo
- radial magnetic field is weaker in hemispherical case
- **an internal origin of the crustal magnetization dichotomy is plausible**