GdR Dynamo, ICTS-TIFR Bangalore, 8-12 June 2015

The present status of the DRESDYN project

(and some recent theoretical results)

Frank Stefani

with thanks to

Th. Albrecht, G. Gerbeth, A. Giesecke, Th. Gundrum, E. Kaplan,
O. Kirillov, Ch. Steglich, M. Seilmayer, N. Weber, T. Weier (Dresden)
G. Rüdiger, M. Gellert (Potsdam), R. Hollerbach (Leeds),
A. Gailitis (Riga)

HZDR

HELMHOLTZ
ZENTRUM DRESDEN
ROSSENDORF

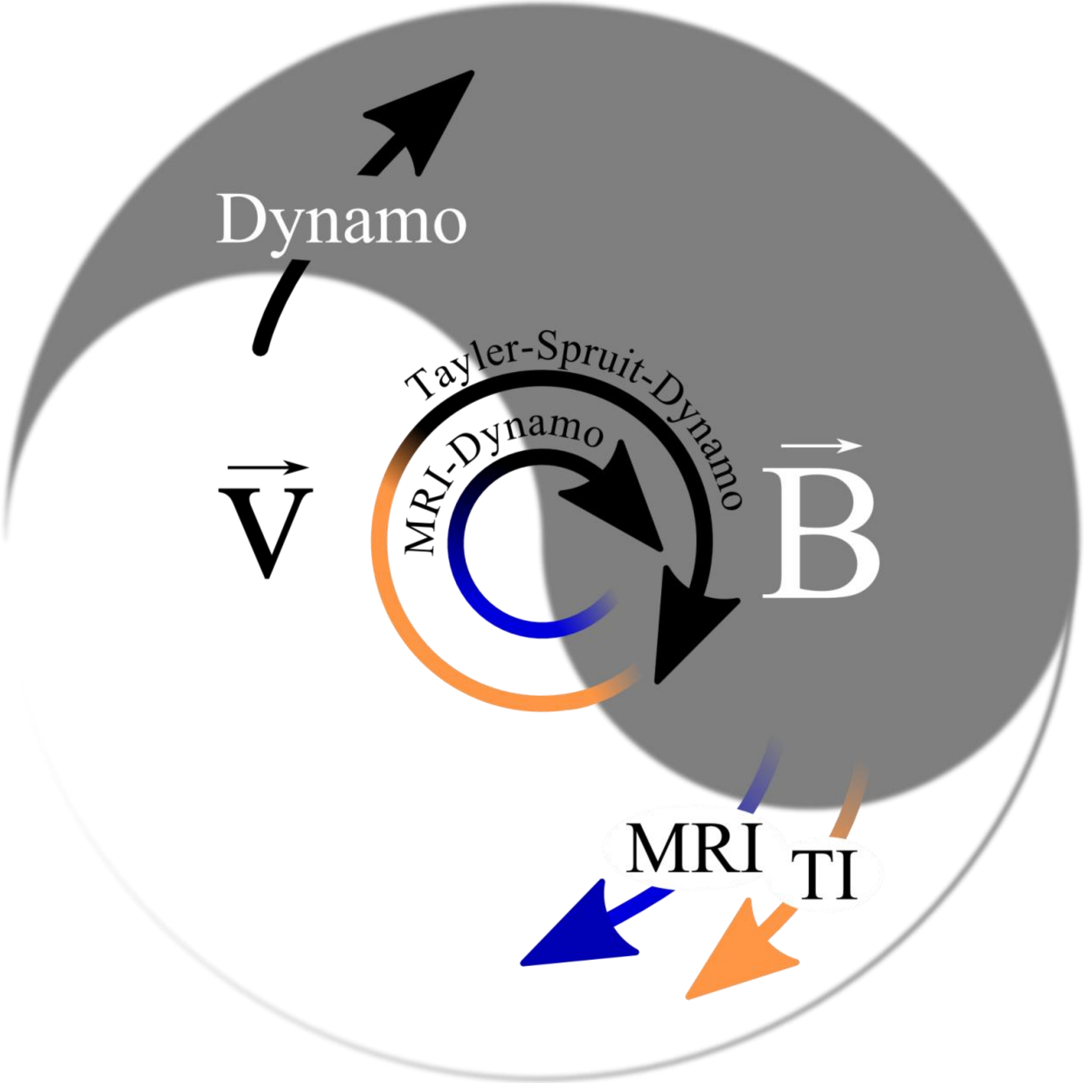
“Anyone who knows anything about astrophysics knows that magnetic fields have nothing to do with it.”

…editor of the *Astrophysical Journal,* rejecting Eugene Parker’s first manuscript (1951)

E. N. Parker: *Reminiscing my sixty year pursuit of the physics of the Sun and the Galaxy.*

Res. Astron. Astrophys. 14 (2014), 1-14

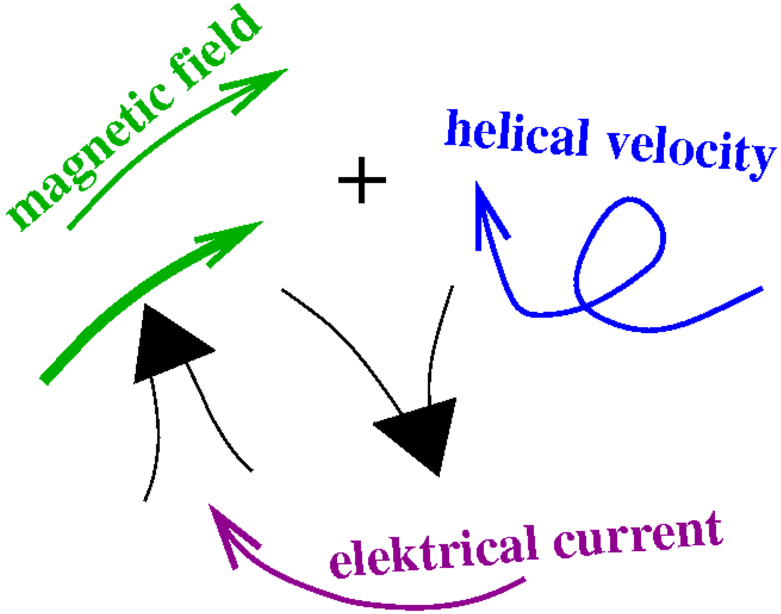
Motivation: The Yin-Yang of cosmical MHD



Motivation

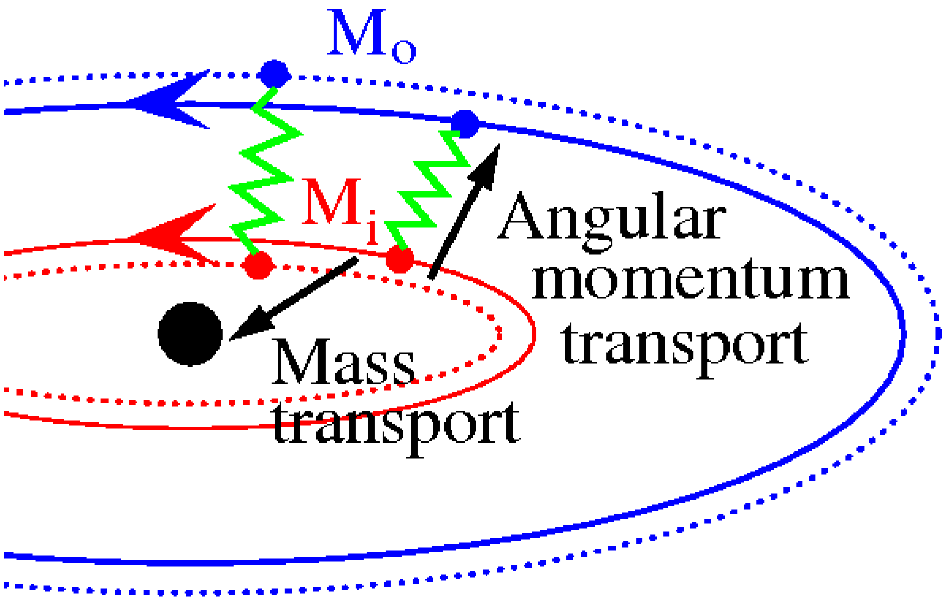
Homogeneous dynamo effect:

Self-excitation of magnetic fields in sufficiently strong, helical flows of conducting fluids



Magnetorotational instability (MRI):

Magnetic fields act like springs and trigger angular momentum transport in accretion disks around protostars and black holes

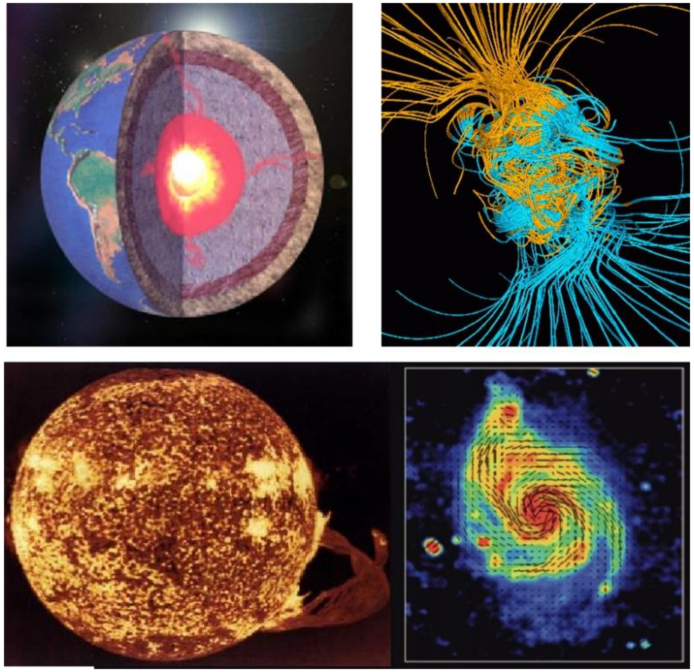


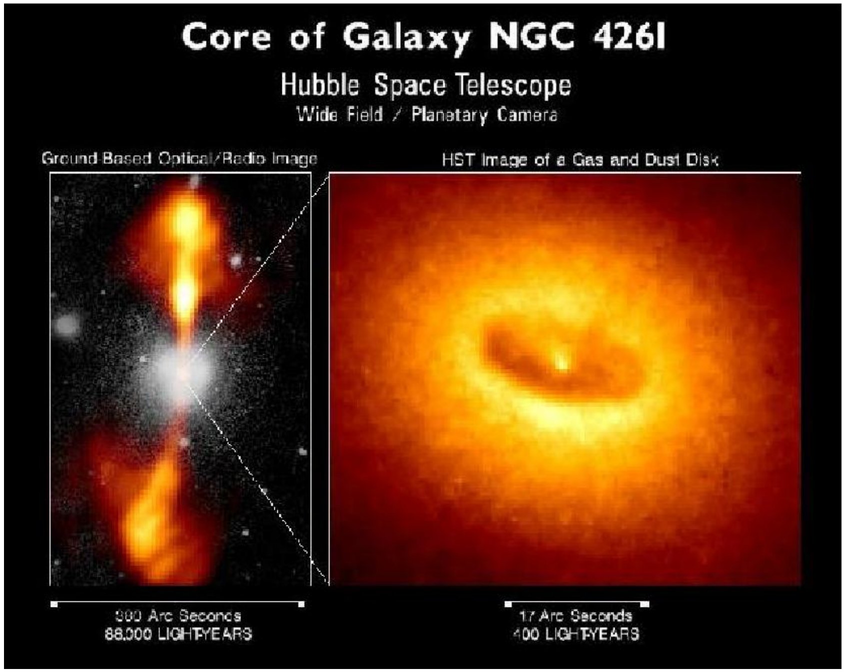
Motivation

Cosmic magnetic fields…

…are produced by the homogeneous dynamo effect

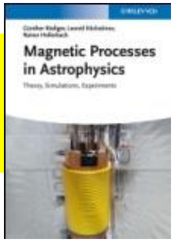
…play a key role in cosmic structure formation by virtue of the magnetorotational instability





Rüdiger, Kitchatinov, Hollerbach:

Magnetic Processes in Astrophysics (2013)



History: From theory to experiment

Experiments on cosmic magnetic fields since 15 years

Dynamo experiments:

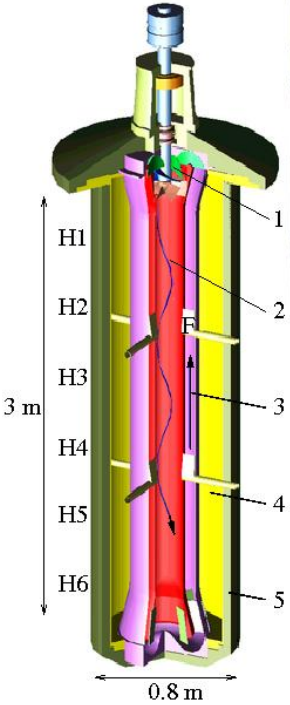
Riga, **Karlsruhe** (1999),
Cadarache (2006),

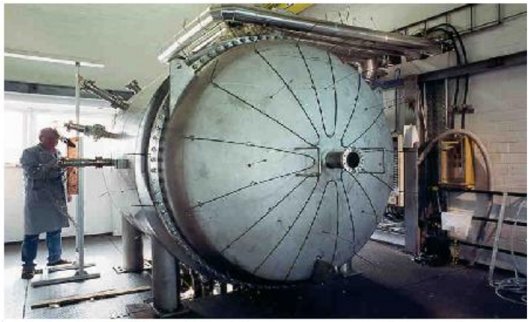
Maryland, Madison, Perm…

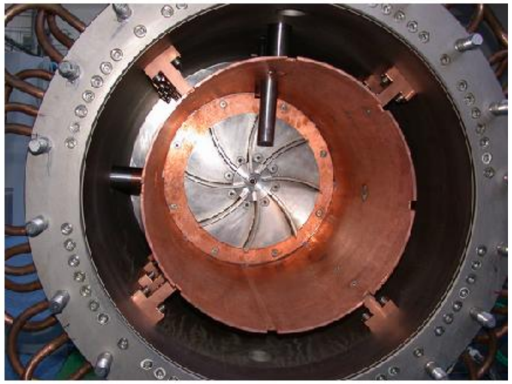
Experiments on the magnetorotational instability (MRI):

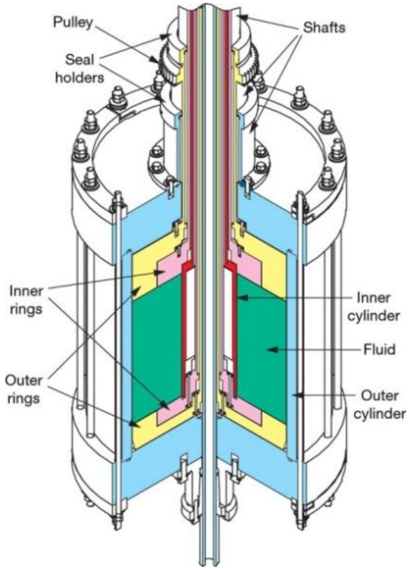
Maryland, Princeton,

Dresden-Rossendorf (2006)









Stefani, Gailitis, Gerbeth: ZAMM 88 (2008), 930

Prospects: DRESDYN

The *DREsden Sodium facility for DYNamo and thermohydraulic studies* is a **platform for geo- and astrophysics experiments** as well as for liquid metal applications in energy related technologies.

- Precession driven dynamo experiment
- Magnetorotational instability (MRI) and Tayler instability (TI)
- Liquid metal batteries (storage of intermittent renewables)
- Measuring techniques (magnetic flow tomography etc...)
- Thermohydraulics of sodium fast reactors

Stefani et al.: Magnetohydrodynamics 48 (2012), 103;
Magnetohydrodynamics (2015), in press, arXiv:1410.8373

DRESDYN: General features

- New building ~500 m^2
- Total sodium inventory: 12 tons
- Large experimental hall for MRI/TI experiment, sodium loop, X-ray lab, liquid metal batteries
- Precession driven dynamo experiment with separate strong basement and containment for Argon flooding

DRESDYN: General features

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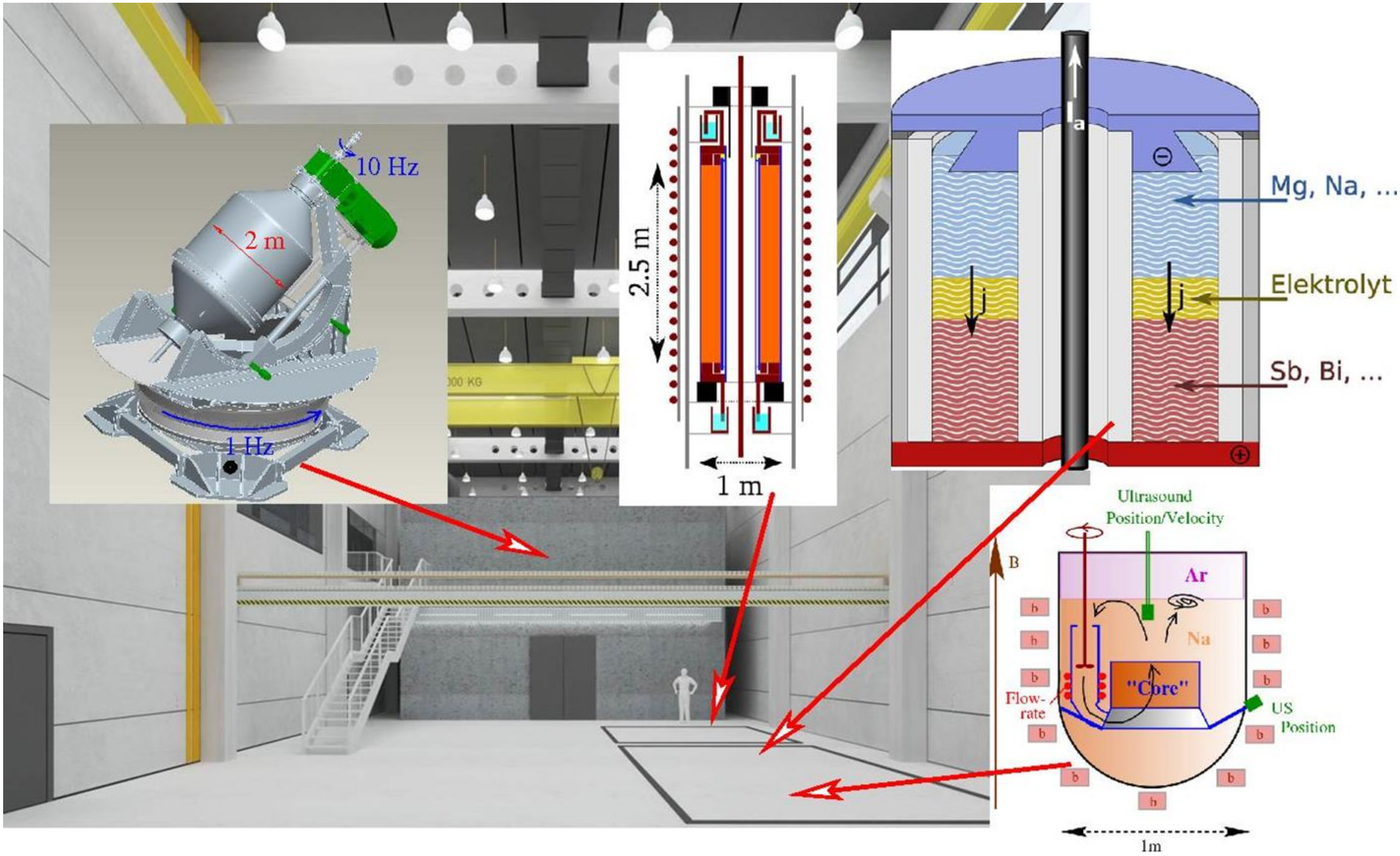
Construction site as of May 2015

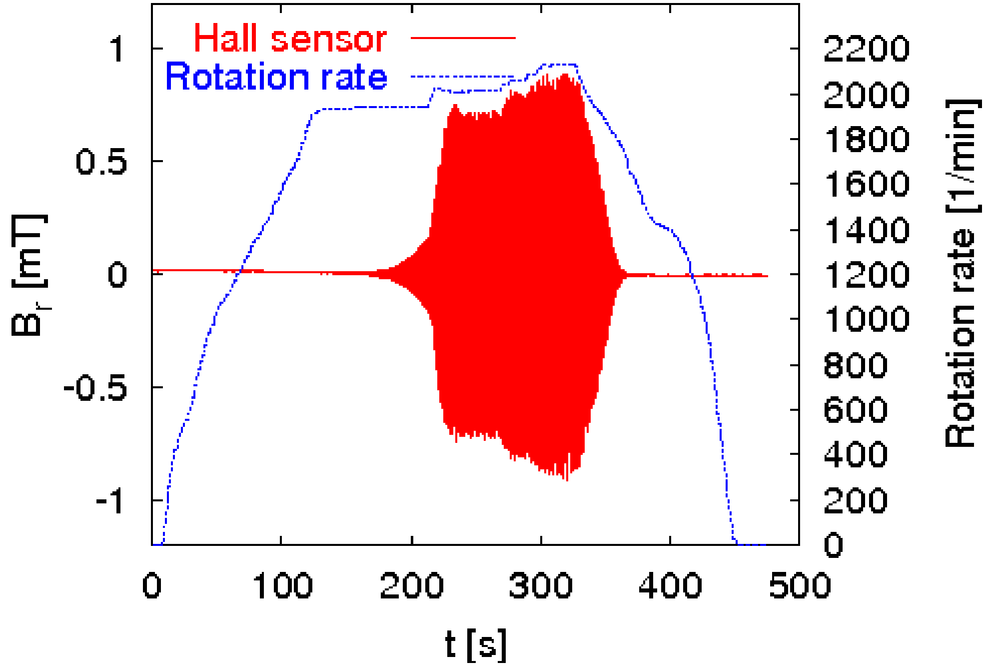
DRESDYN: General scheme

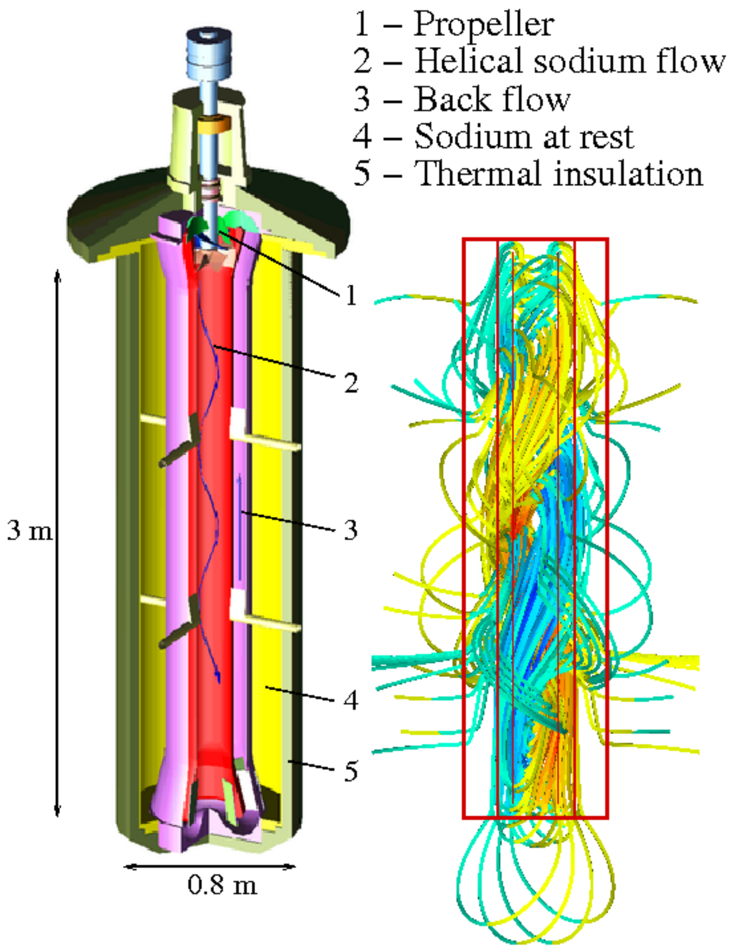


Dynamos

Riga dynamo experiment

First experimental realization of magnetic field self-excitation in a liquid metal flow (11 November 1999)



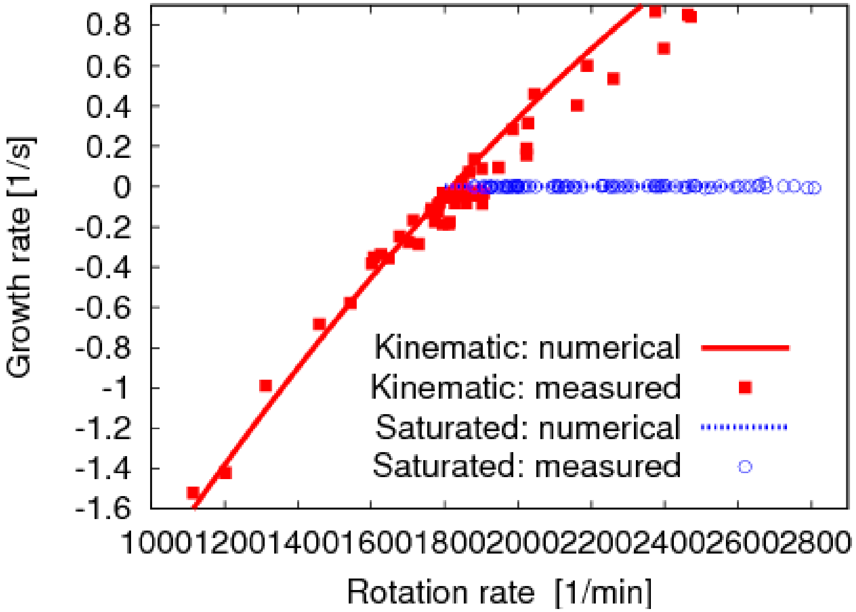


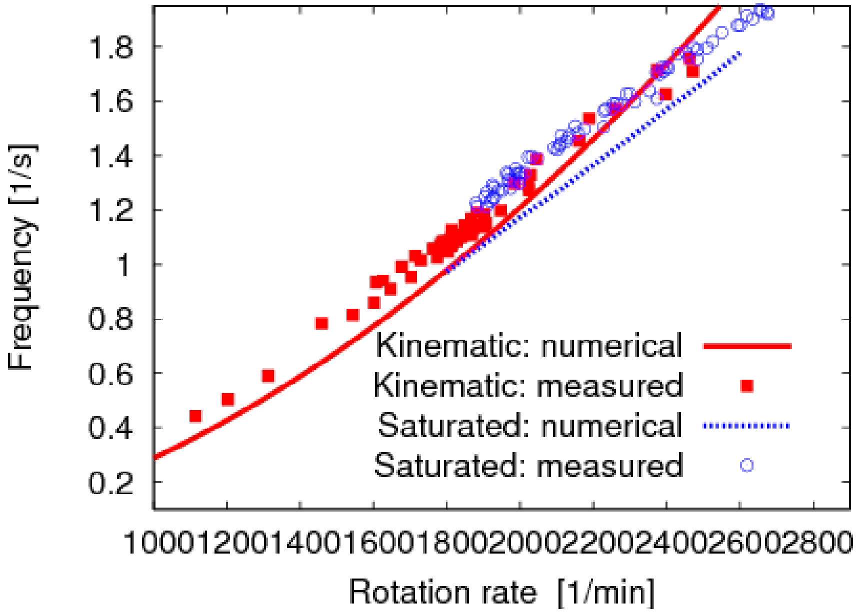
Dynamo module

Simulated eigenfield

Gailitis et al., Phys. Rev. Lett. 84 (2000) 4365; Phys. Rev. Lett. 86 (2001) 3024; Rev. Mod. Phys. 74 (2002) 973 ; Phys. Plasmas 11 (2004) 2838; Compt. Rend. Phys. 9 (2008), 721

Riga dynamo experiment: Growth rates and frequencies



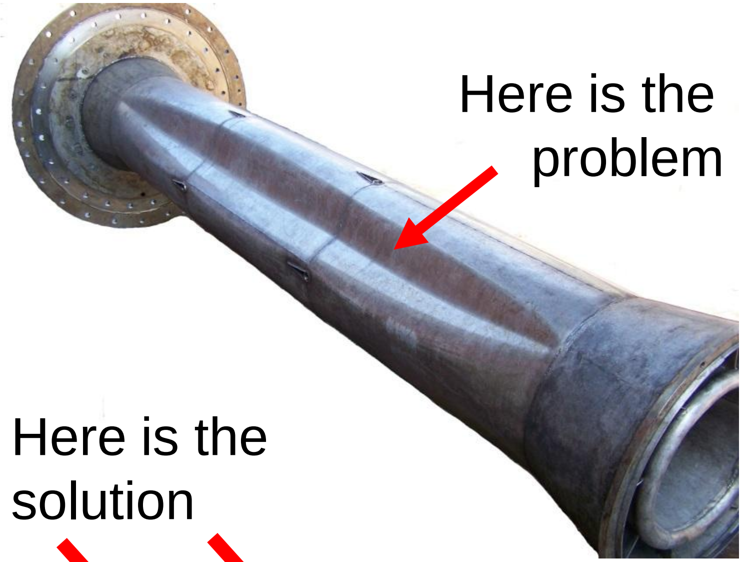


Numerical predictions (with correct vacuum boundary conditions) of the kinematic dynamo were accurate to some 5-10 per cent

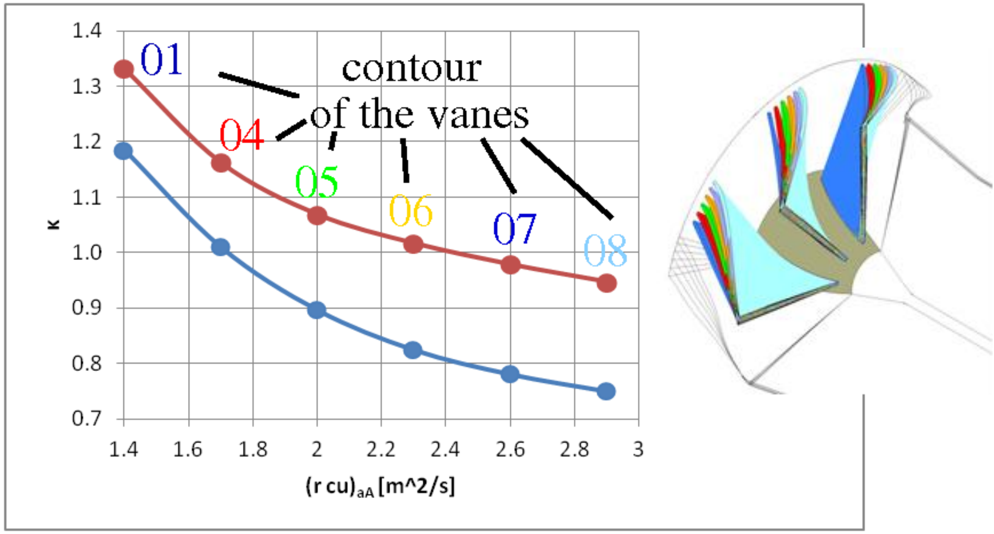
Simplified back-rection model (Lorentz forces acting along streamlines) gives very reasonable field amplitudes and structures in the saturation regime

Gailitis et al., C. R. Physique 9 (2008), 721

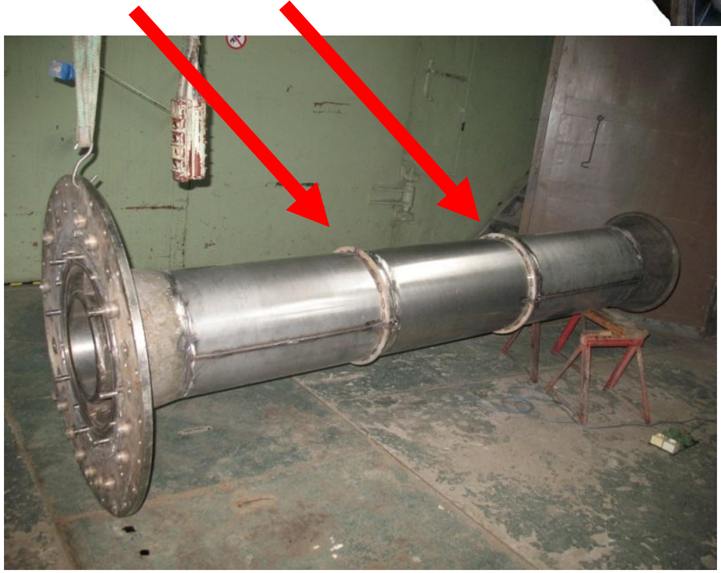
Riga dynamo experiment: Recent problems and new plans



Here is the problem



Here is the solution



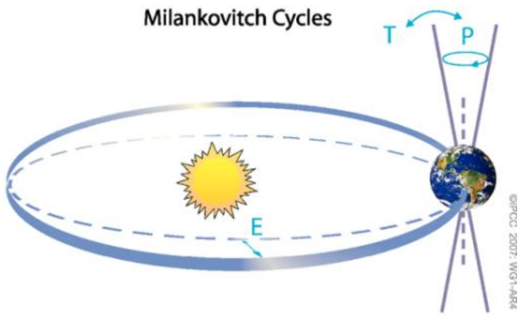
By increasing (i.e., de-optimizing!) the azimuthal velocity, we hope to see interesting saturation effects (period doubling, transition to chaos?)

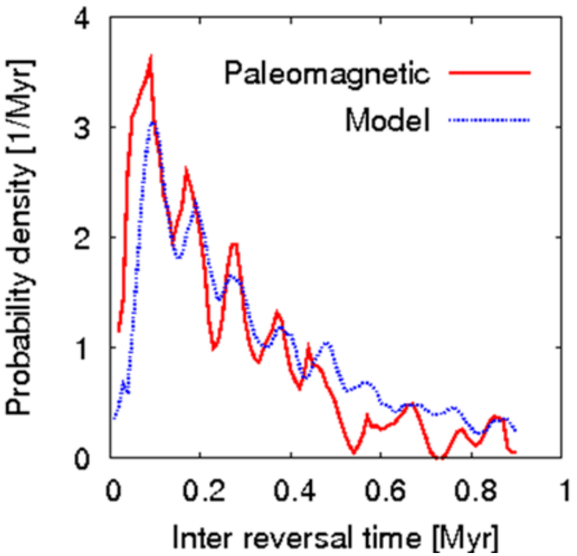
Stefani, Gailitis, Gerbeth:

Astron. Nachr. 332 (2011), 4

Precession driven dynamo: Geo- and astrophysical motivation

Indication for influence of variations of Earth‘s orbit parameters on the geodynamo





Probability density of inter-reversal times shows maxima at multiples of the Milankovic cycle of Earth‘s orbit eccentricity (95 ka) ⟷ climate??

Consolini and De Michelis, Phys. Rev. Lett. 90 (2003), 058503

Recent discussion of the lunar dynamo in terms of precession or impacts

Dwyer et al., Nature 479 (2011), 212; Le Bars et al., Nature 479 (2011), 215

Evidence for ancient core dynamo in asteroid Vesta

Fu et al., Science 338 (2012), 238

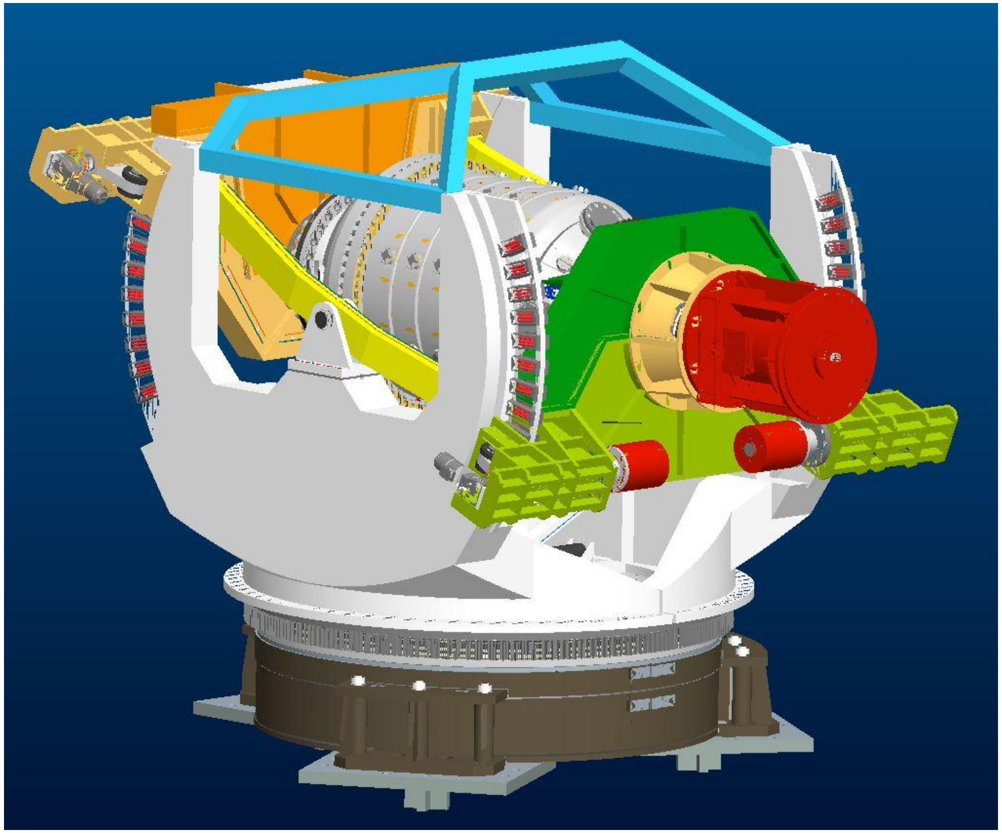
Precession driven dynamo: Planned sodium experiment

Key parameters:

- 2 m diameter, 2 m height, 8 m^3 liquid sodium

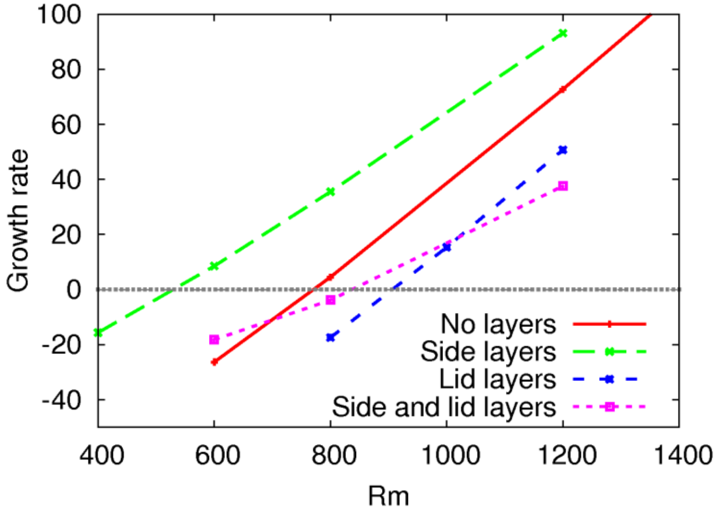
- Cylinder rotation: 10 Hz (will need some 800 kW motor power)
- Turntable rotation: 1 Hz
- Magnetic Reynolds number ~ 700

- Gyroscopic torque onto the basement: 8 MNm !



The role of copper walls

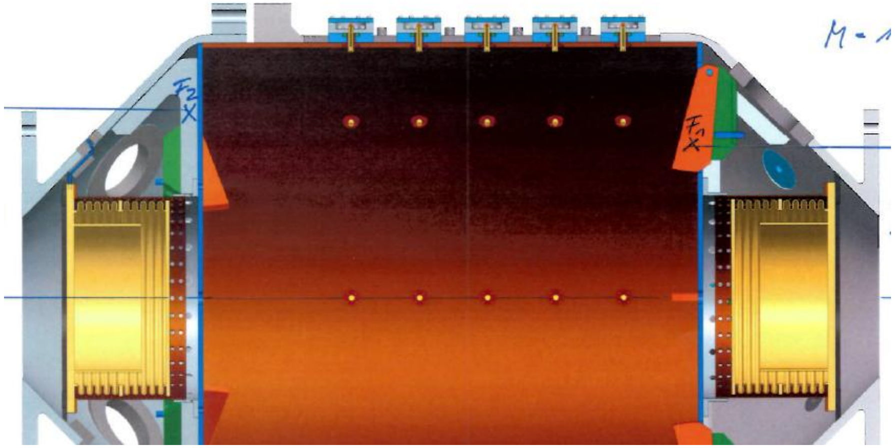
Caroline Nore: Conducting side walls are good for the dynamo, conducting lids are bad (for Pm~1)



Stefani et al., Magnetohydrodynamics (2015), in press, arXiv:1410.8373

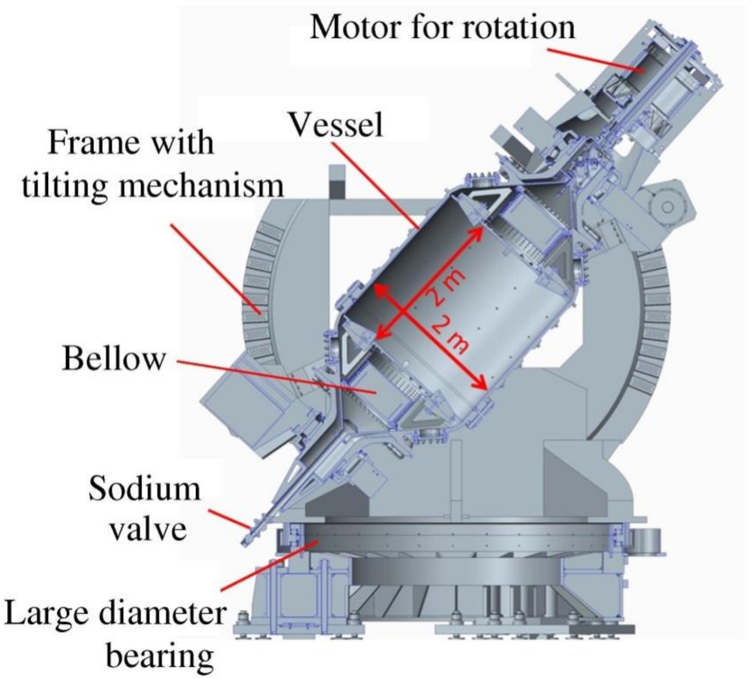
HOWEVER: Recent simulations with lower Pm are less optimistic!

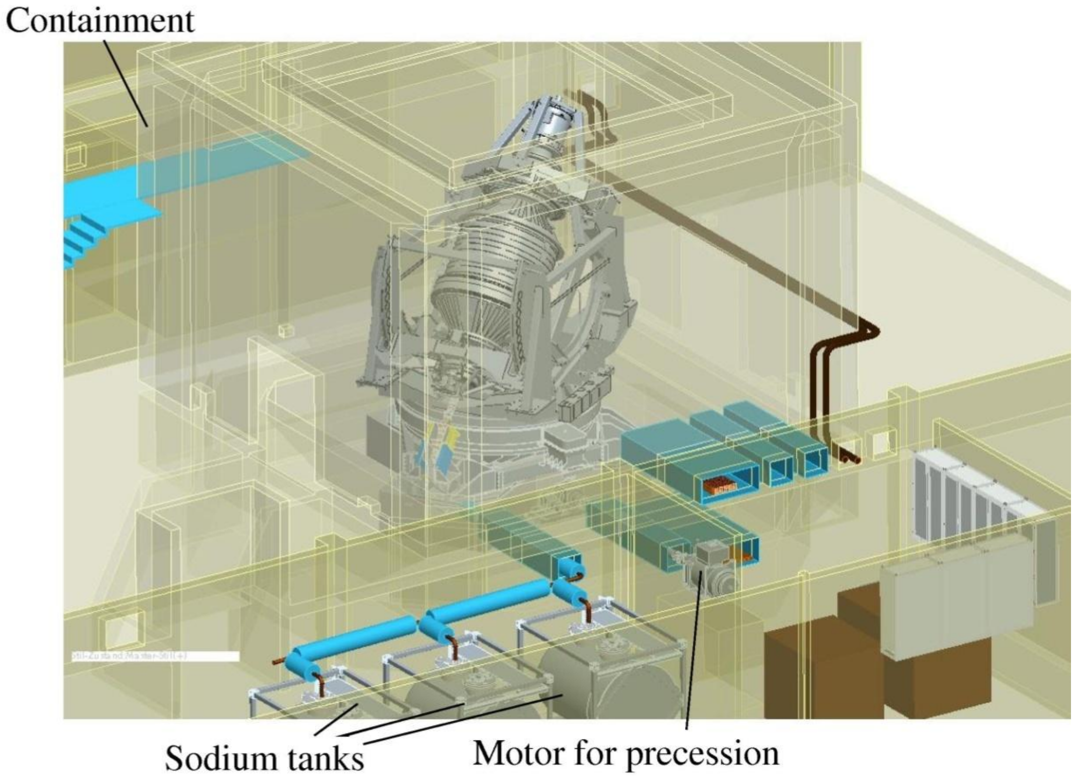
Giesecke et al., Magnetohydrodynamics (2015), in press., arXiv:1411.1195

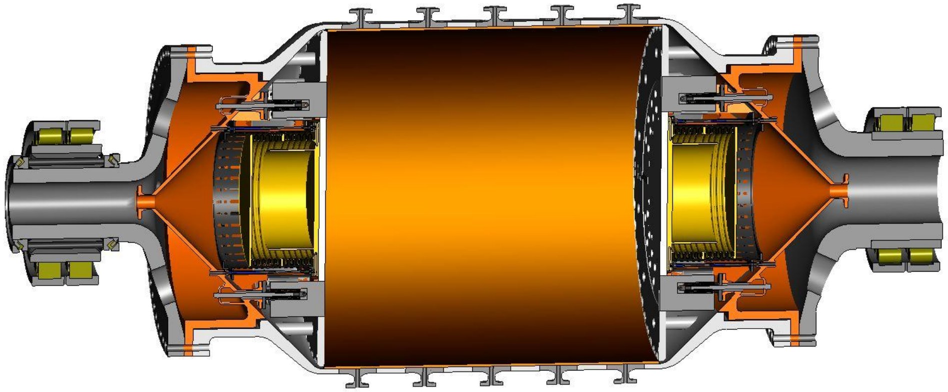


We will start without any copper layer, but with the option to add it later on (by galvanization)

Precession driven dynamo: present state of the design







Central vessel

“Fundamental” problems due to huge gyroscopic torque

April 2013: drilling 7 holes (22 m deep)

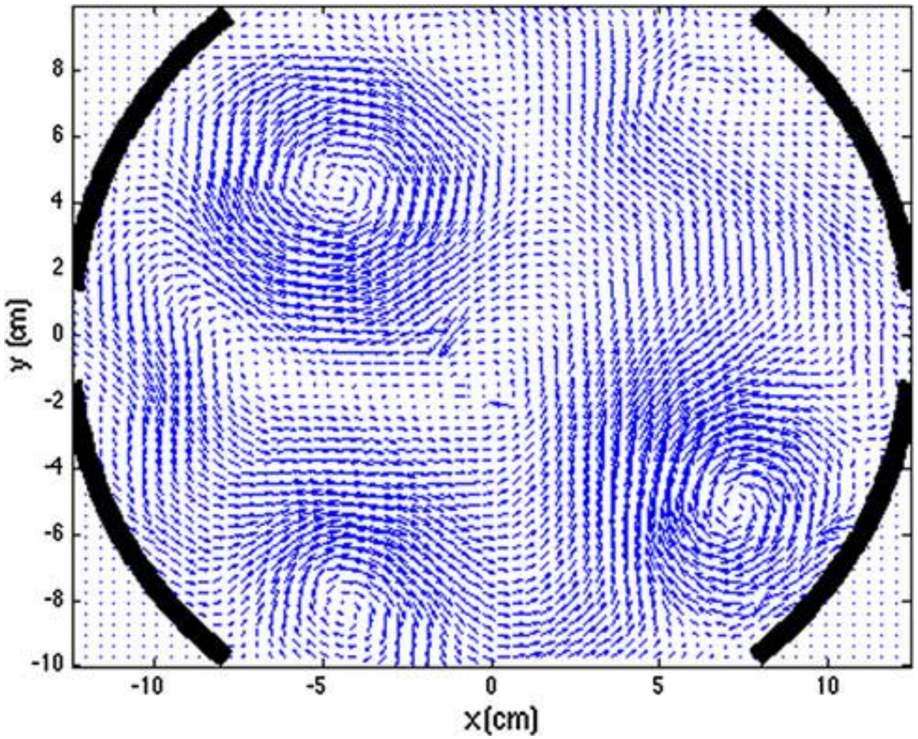
July 2013: Constructing the ferroconcrete basement

May 2015: The tripod for the dynamo within the containment (with stainless steel “wallpaper”)

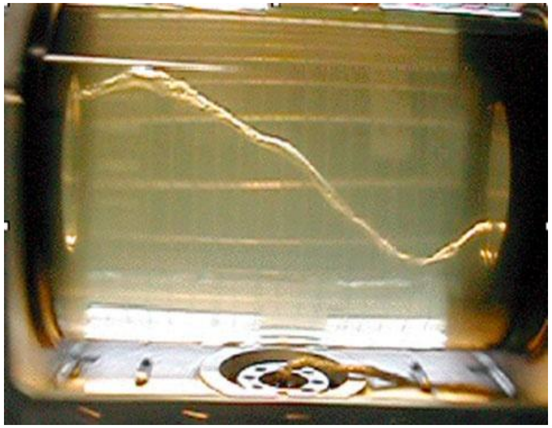
Fluid dynamics of precession: Jacques Léorat’s ATER-Experiment

Three regimes:

- ☐ $\varepsilon < 0.01...0.02$
  ➔ laminar, Kelvin mode with m=1
- $0.01...0.02 < \varepsilon < 0.07...0.1$
  ➔ cyclonic regime
- $0.07...0.1 < \varepsilon$
  ➔ fully turbulent regime



Vortices in the **cyclonic regime**, for h/D=1.17, $\varepsilon = 0.033$, Re=140,000



W. Mouhali et al., Exp. Fluids 53 (2012), 1693

1:6 water mockup at HZDR

$$f_{turntable} = 0 \ldots 1 Hz$$

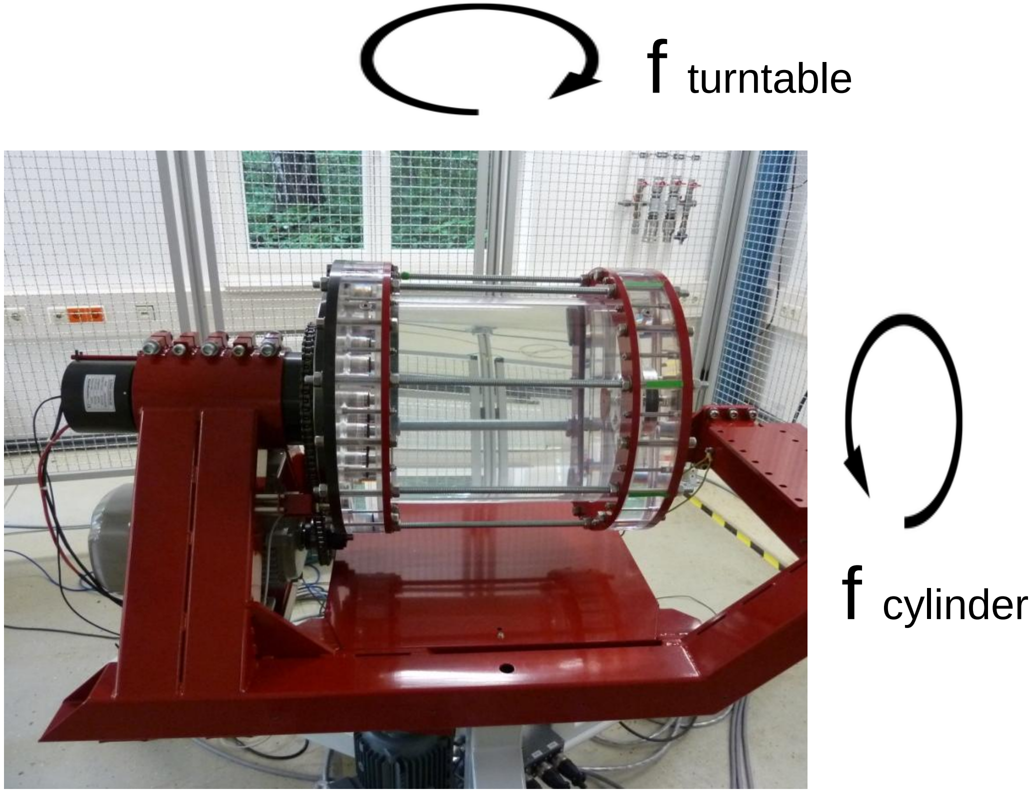
$$f_{cylinder} = 0 \ldots 10 Hz$$

Precession angle

$$\theta = 90 \ldots 60°$$

Precession ratio

$$\varepsilon = \frac{f_{turntable}}{f_{cylinder}}$$

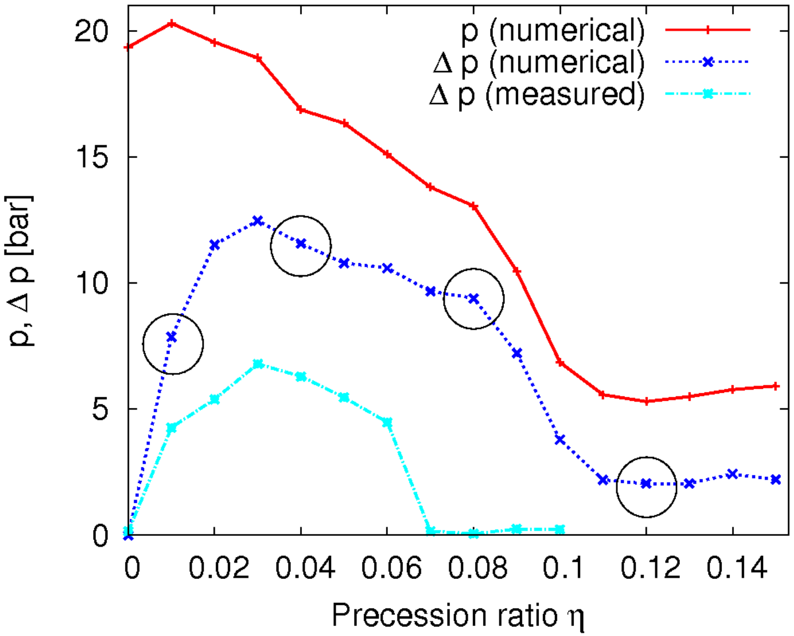


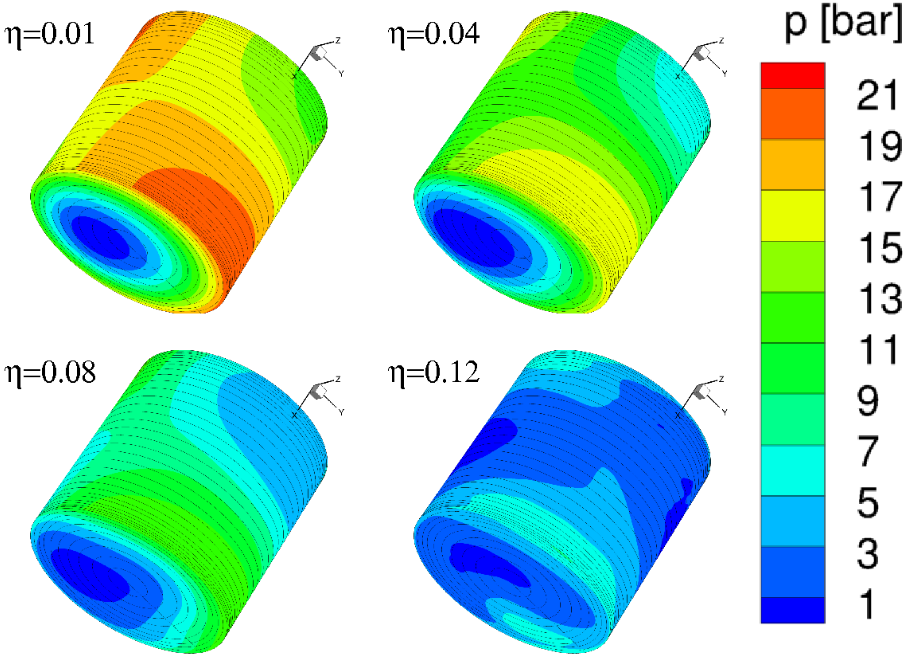
length = diameter = 326 mm

$$\mathrm{Re} \approx 2 \cdot 10^{6}$$

Pressure and pressure variations at the outer rim

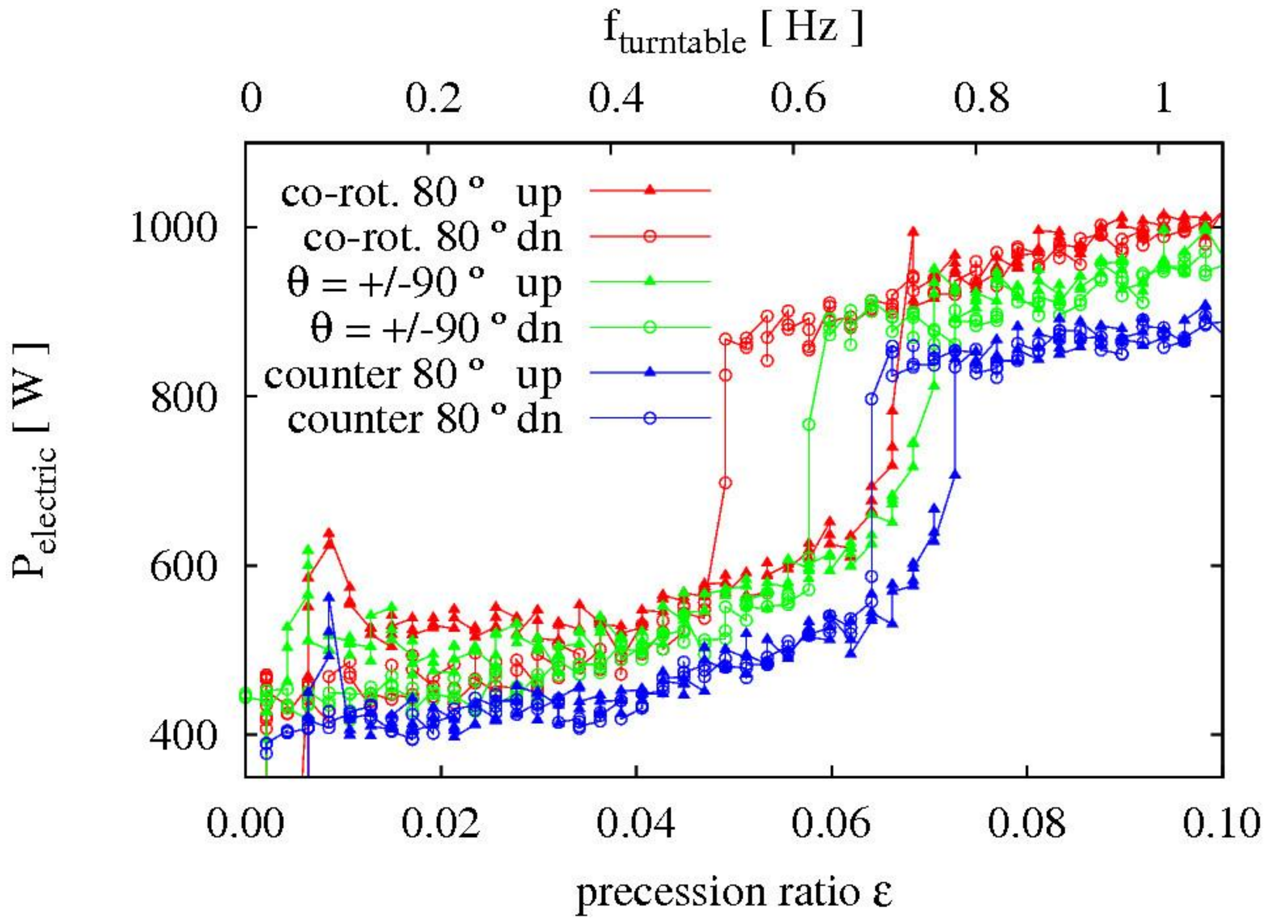
Experimental (at $Re=2x10^6$) and numerical (at $Re=6500$) results, both up-scaled to the large machine





Stefani et al., Magnetohydrodynamics (2015), in press, arXiv:1410.8373

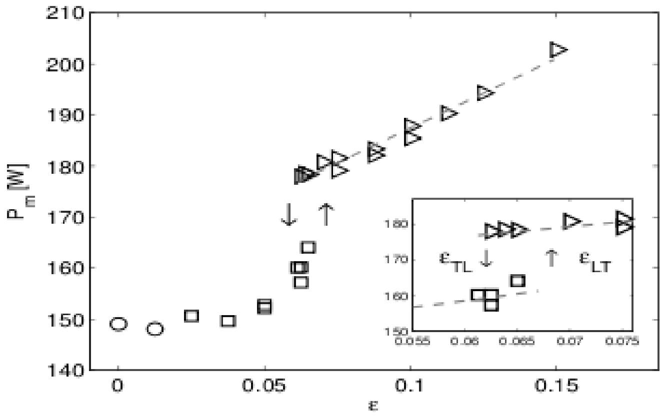
Subcritical transition from laminar to turbulent regime



$f_{cyl.}$ = 10 Hz

- Jump of the power at critical precession ratio with hysteresis effect
- Dependence on angle
- At present: Study of higher m-modes

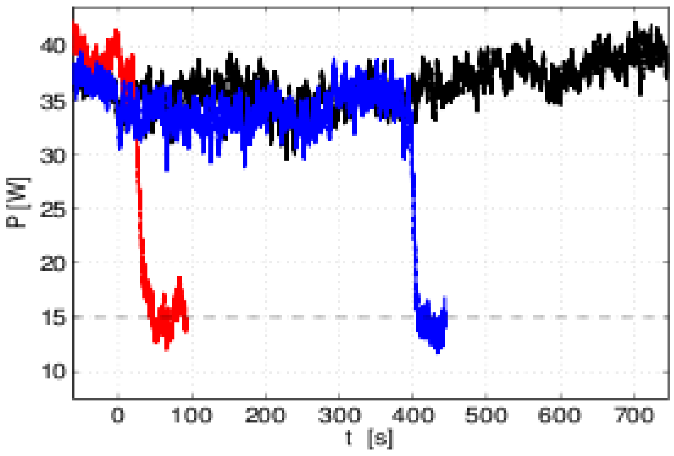
Subcritical transition to turbulence

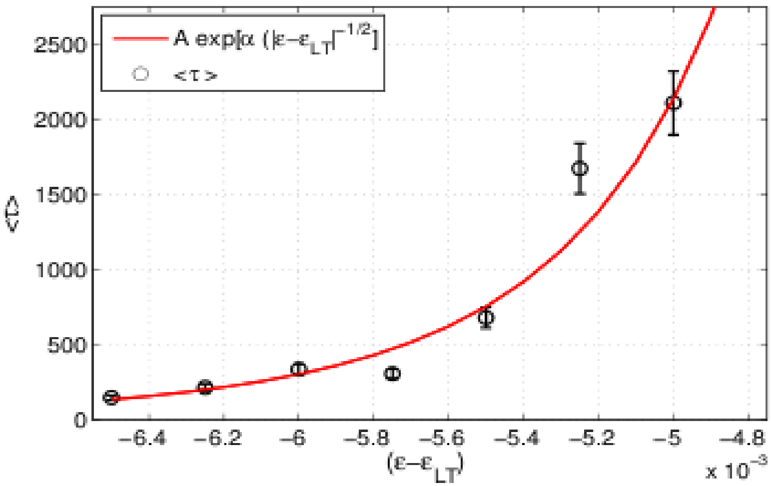


Motor power shows: Hysteresis from laminar to turbulent regime, and back

Turbulence (in the hysteresis) is metastable:

Probably: supertransient behaviour of the mean waiting time: $\langle\tau\rangle = A \exp(\alpha|\varepsilon - \varepsilon_{LT}|^{-1/2})$

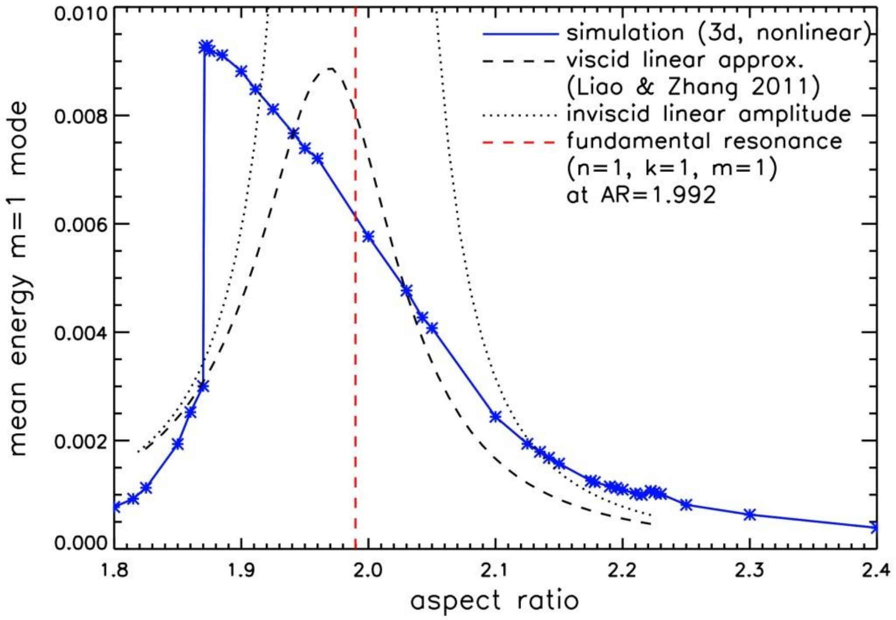




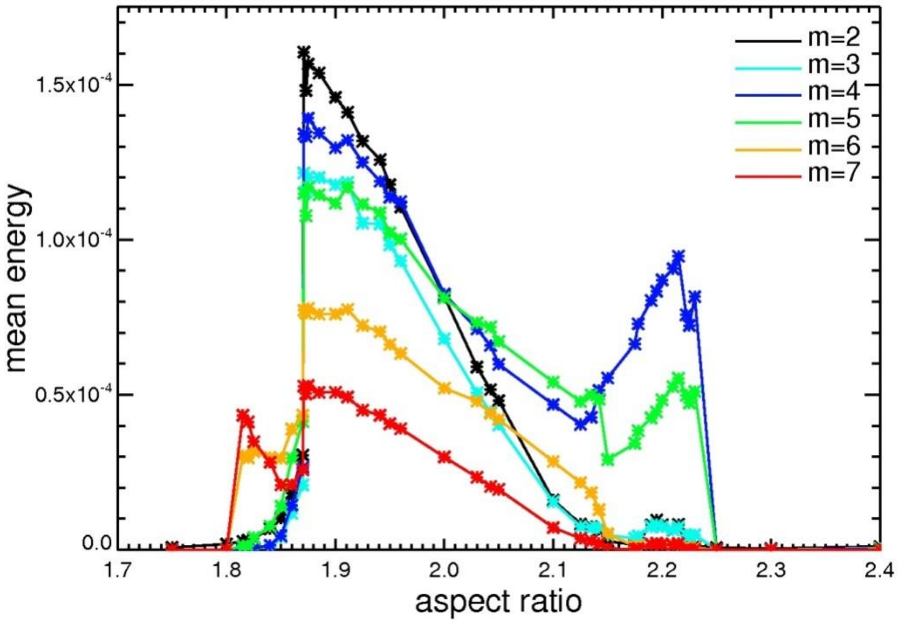
Herault et al., Phys. Fluids, submitted

Numerical simulations of higher m-modes, for Re=6500, ε=0.141

m=1

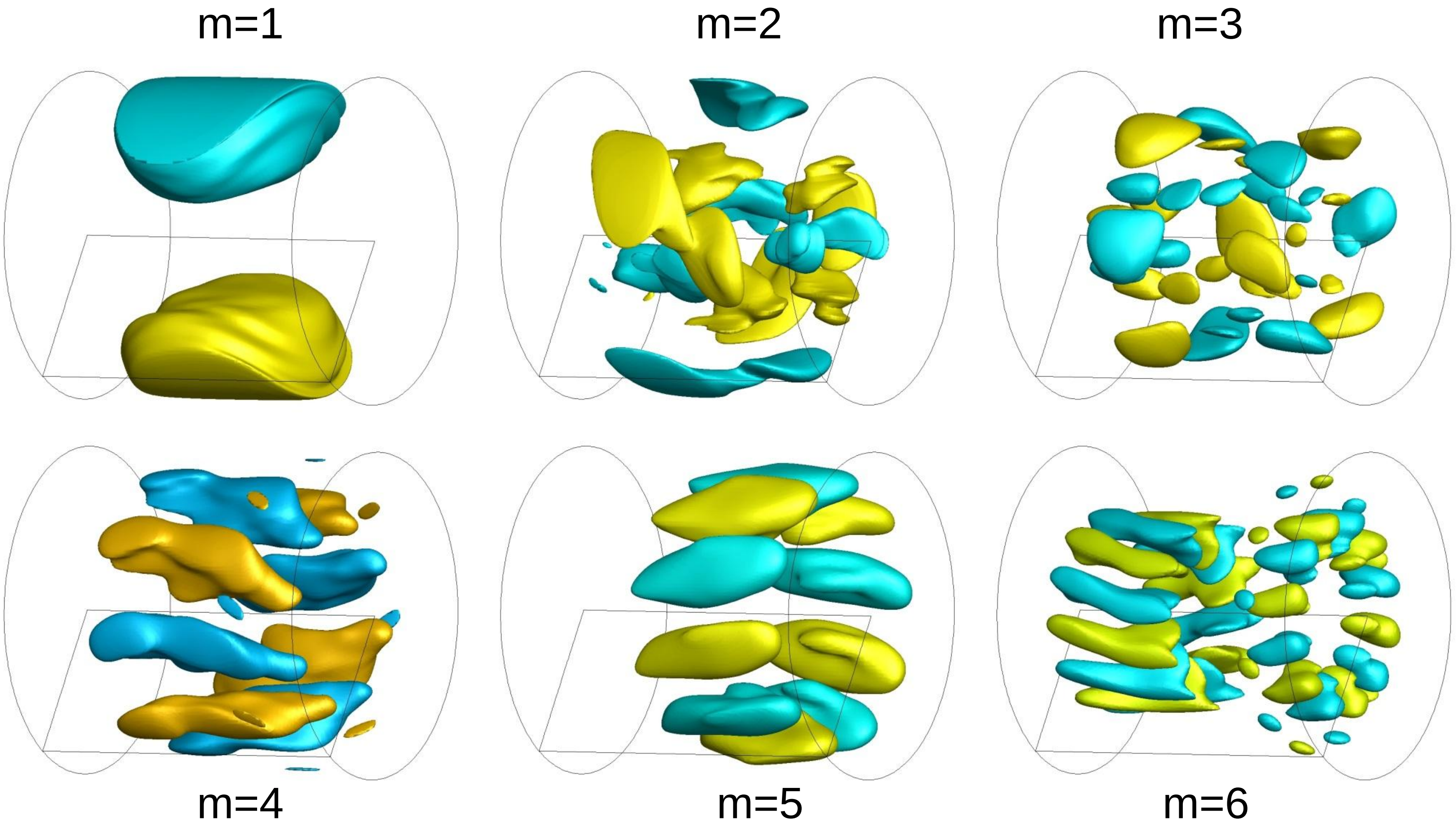


m=2…7



Giesecke et al., in preparation

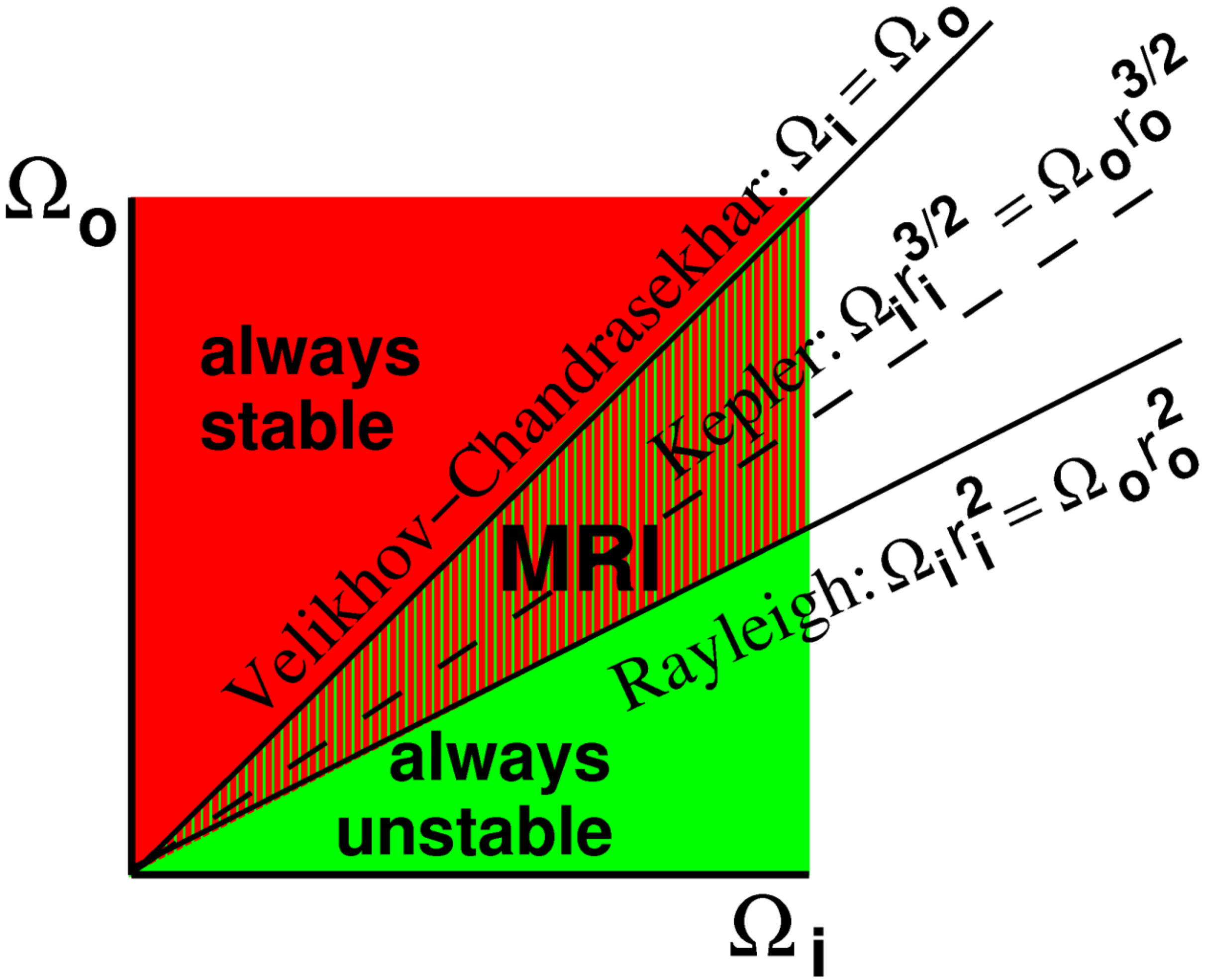
Mode structure, for Re=6500, $\varepsilon=0.141$



(Promising) dynamo simulations, based on these higher m-modes, are in progress

Magnetorotational and Tayler instability

History of MRI: Magnetized Tayler-Couette flow

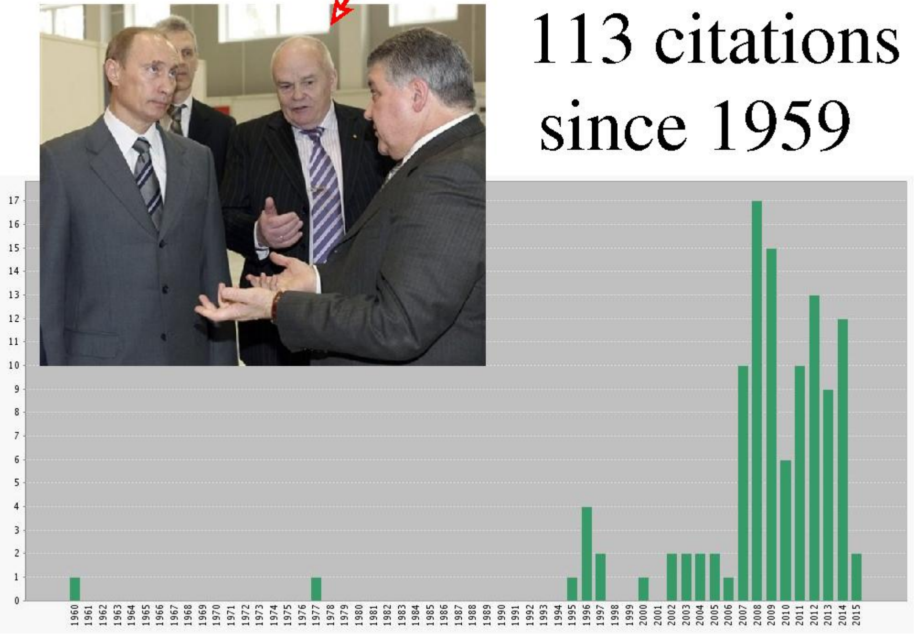


E.P. Velikhov: Sov. Phys. JETP 9 (1959), 995

Citation history of MRI

E.P. Velikhov

113 citations since 1959



S.A. Balbus and J.F. Hawley

2161 citations since 1991

E.P. Velikhov: Sov. Phys. JETP 9 (1959), 995

S.A. Balbus and J.F. Hawley: ApJ 376 (1991), 214

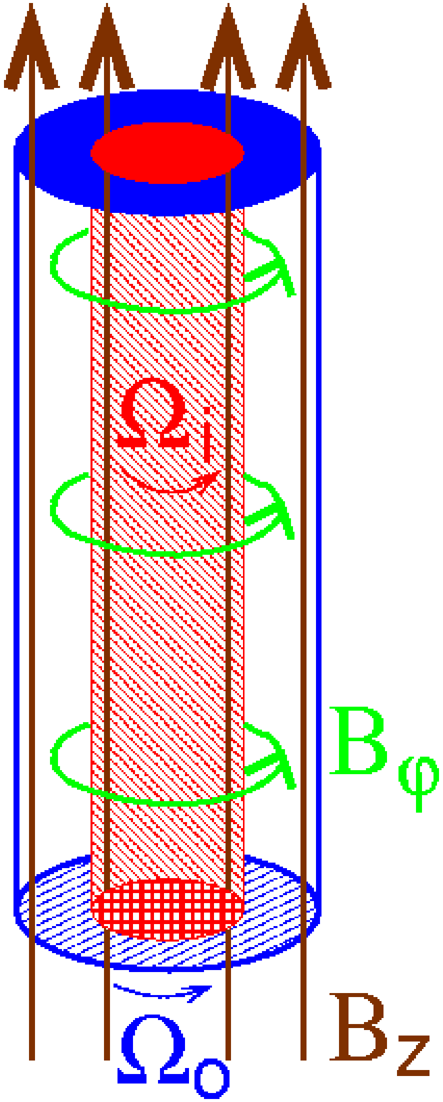
Standard MRI and helical MRI

- Standard MRI (with purely axial field) scales with Lundquist (S) und magnetic Reynolds (Rm)
- Experiments on SMRI with large Rm in Maryland and Princeton
- Helical MRI: B_z replaced by B_z+B_φ: scales with Hartmann (Ha) and Reynolds (Re)

Hollerbach and Rüdiger: Phys. Rev. Lett. 95 (2005), 124501

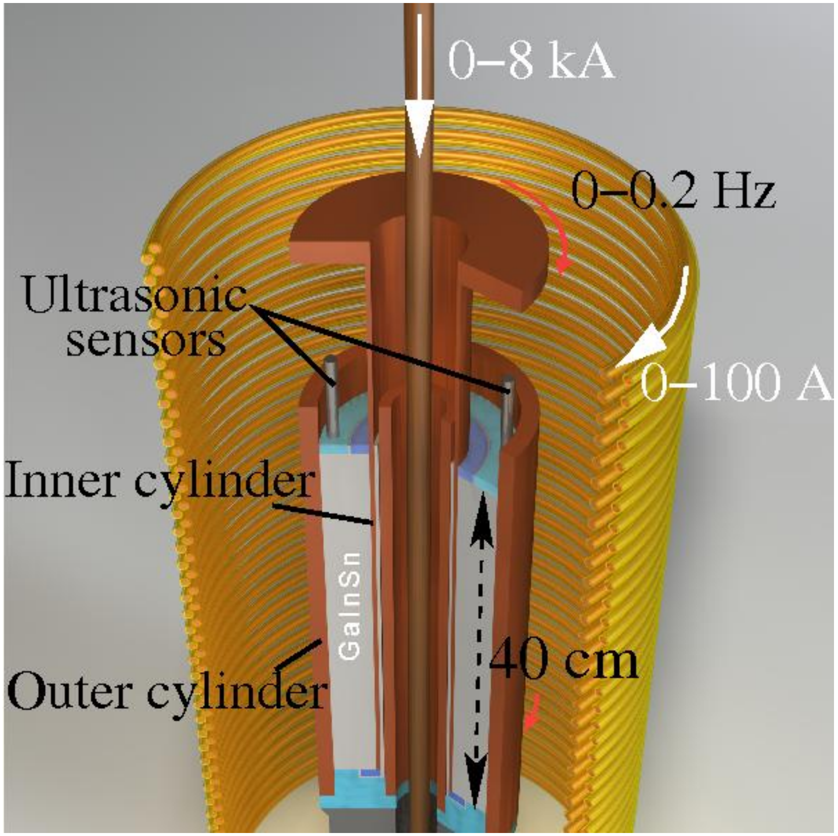
- Re_{crit}: 10^3 instead of 10^6
- Ha_{crit}: 30 instead of 1000

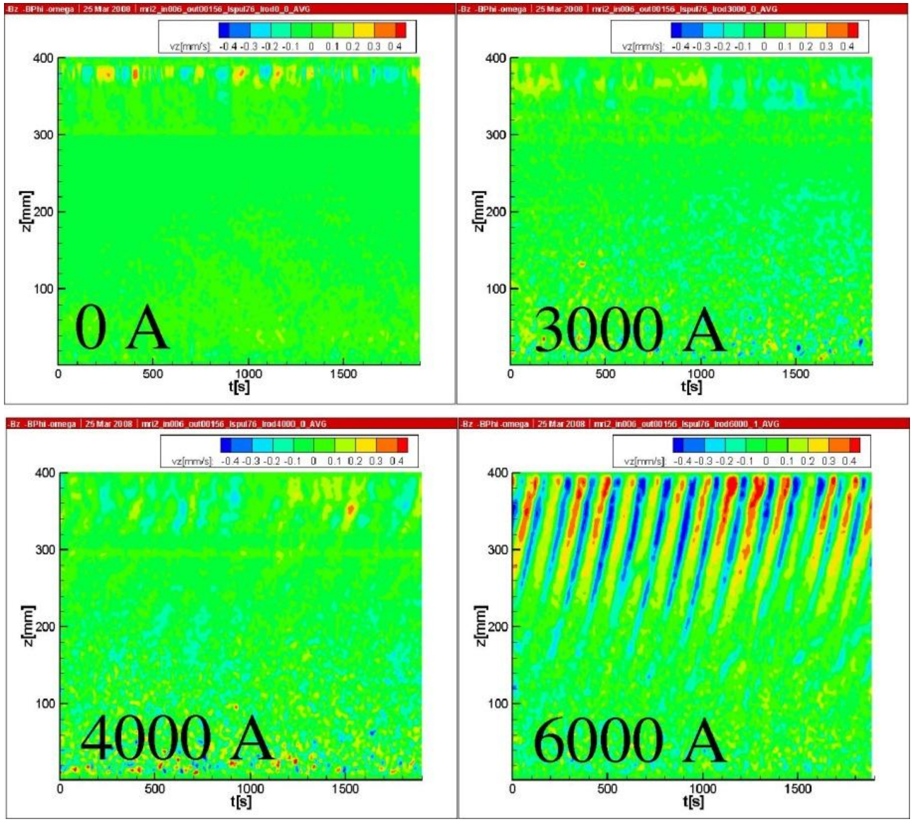
- → Potsdam ROssendorf Magnetic InStability Experiment (PROMISE)
- Drawback: does not work for Kepler (yet)!



Helical magnetorotational instability (HMRI)

2006: First experimental evidence of HMRI at HZDR

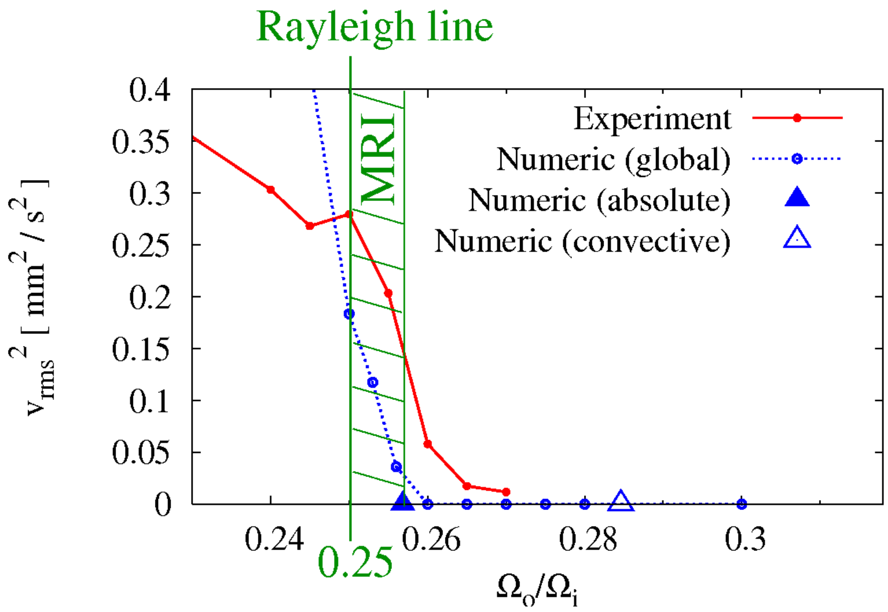


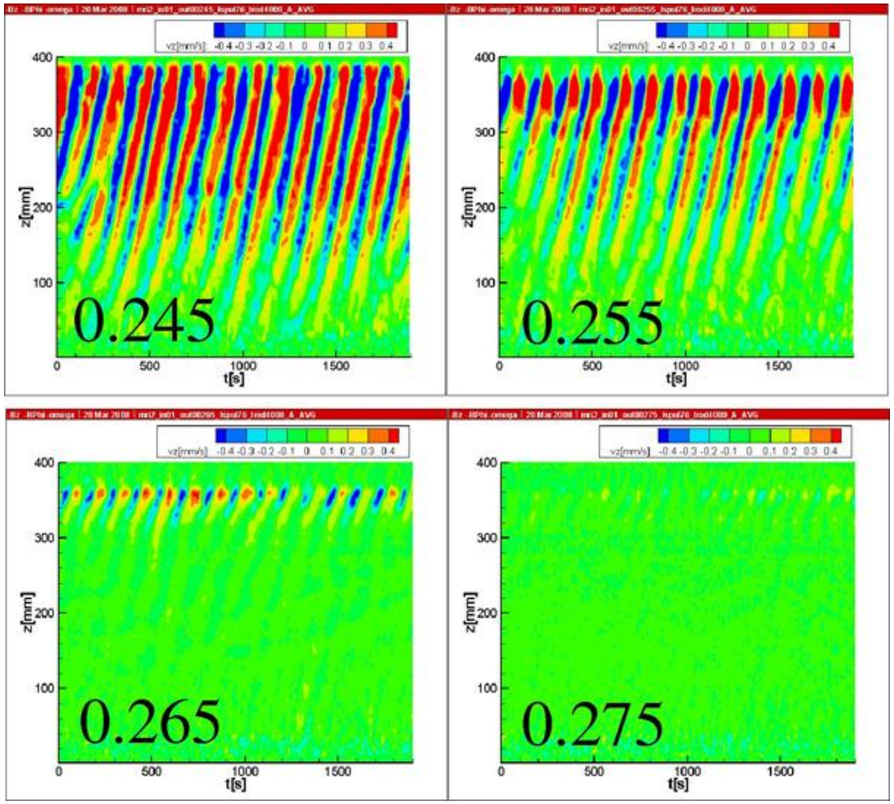


Stefani et al., PRL 97 (2006), 184502; New J. Phys. 9 (2007), 295; Phys. Rev. E 80 (2009), 066303

Helical magnetorotational instability (HMRI)

HMRI extends only slightly beyond the Rayleigh line (this is typical for all inductionless types of MRI)





Yet, it is indeed a global, and not only a convective instability

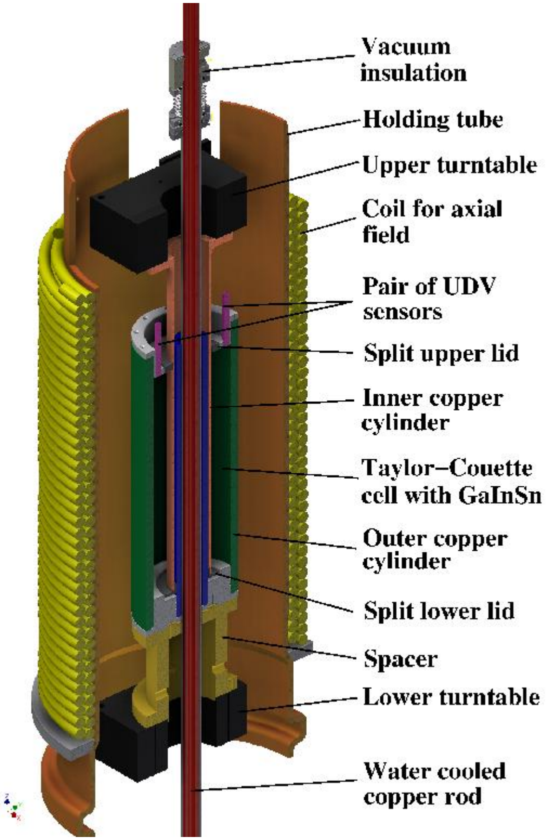
Stefani et al., Phys. Rev. E 80 (2009), 066303

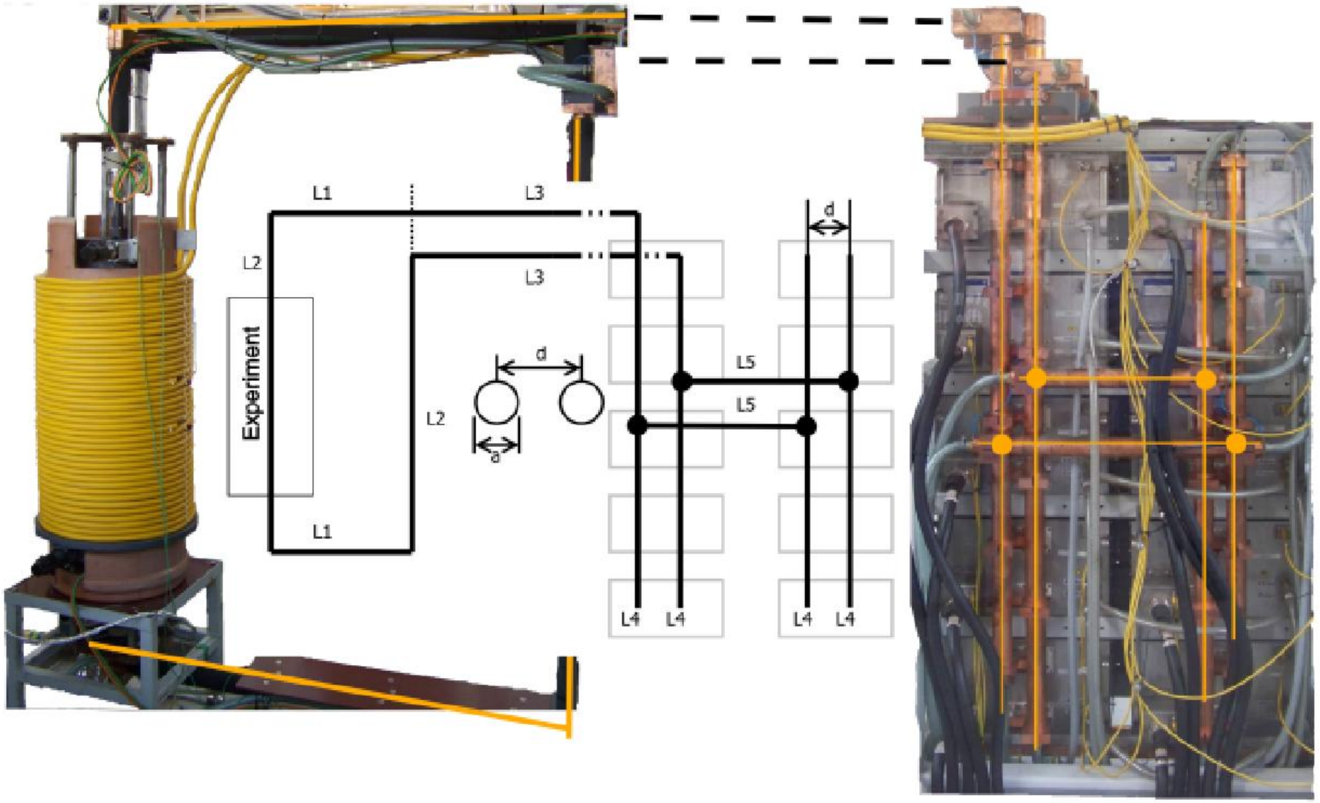
Azimuthal MRI (AMRI): m=1 mode under influence of dominant B_φ

Hollerbach, Teeluck, Rüdiger:

Phys. Rev. Lett. 104 (2010), 044502

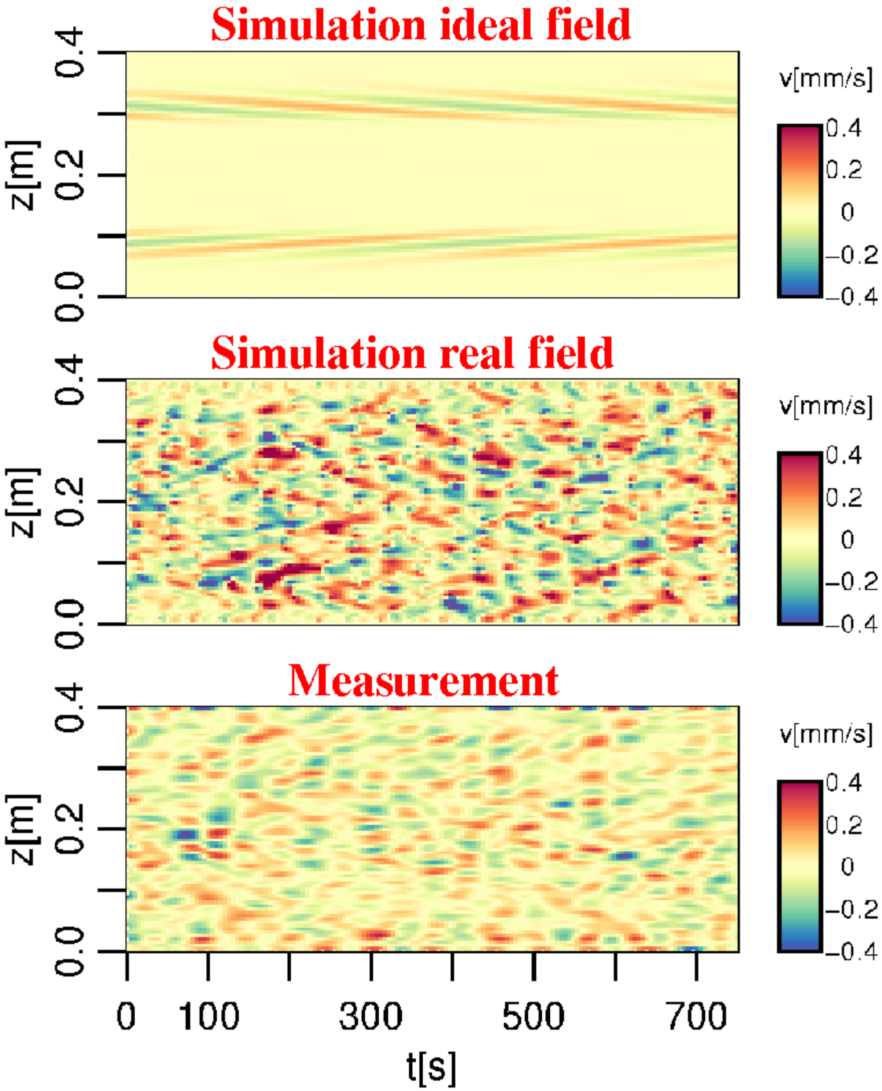
New power supply for 20 kA

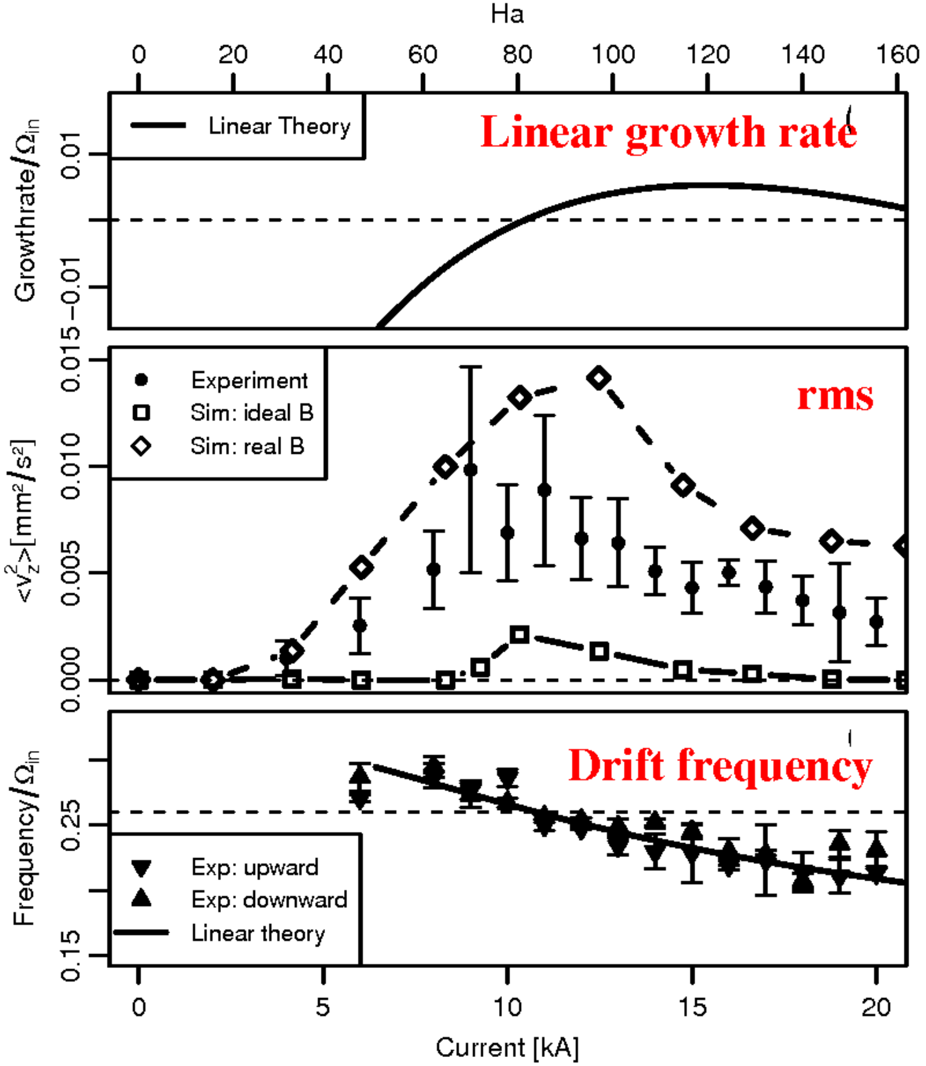




Very important: Numerical simulation of the real geometry, including the slight symmetry breaking of the applied magnetic field

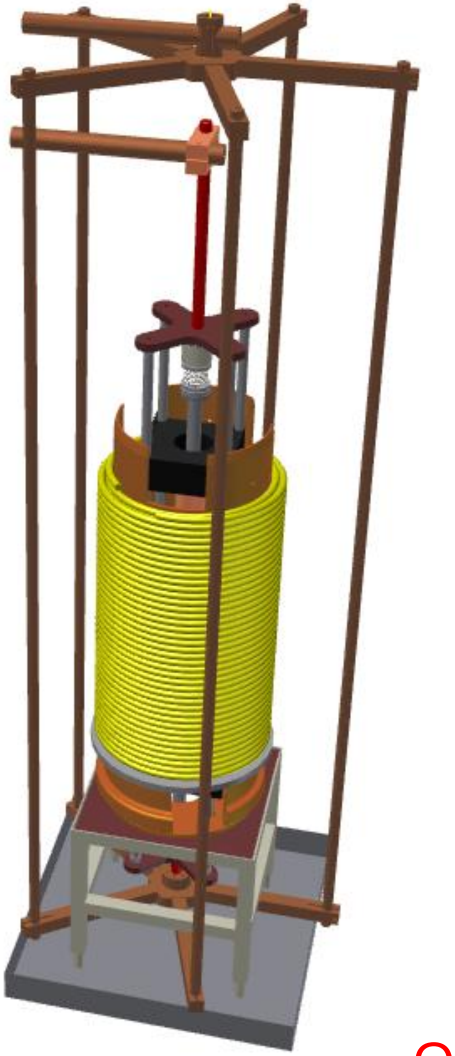
Evidence for AMRI: m=1 mode under influence of (nearly) pure B_φ



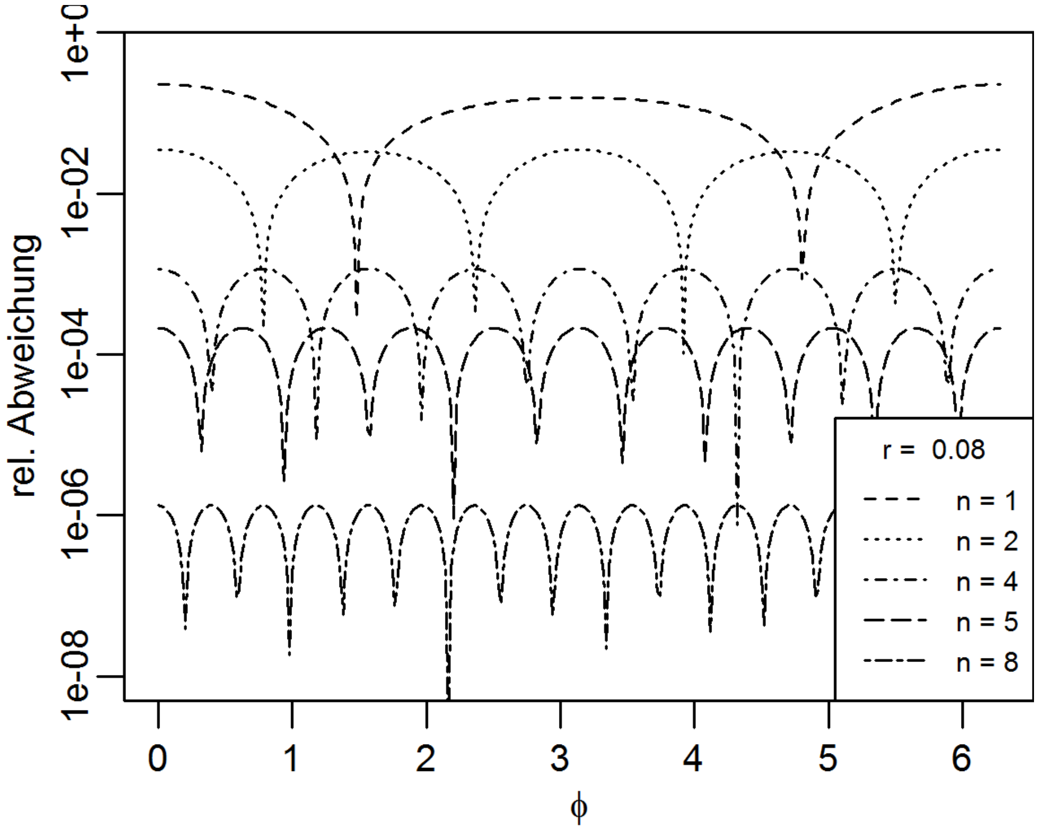


Seilmayer et al., Phys. Rev. Lett. 113 (2014), 024505

Next step for PROMISE: Improve the symmetry



The asymmetry of the field can be strongly decreased by a cage-like structure of the return-current with n wires

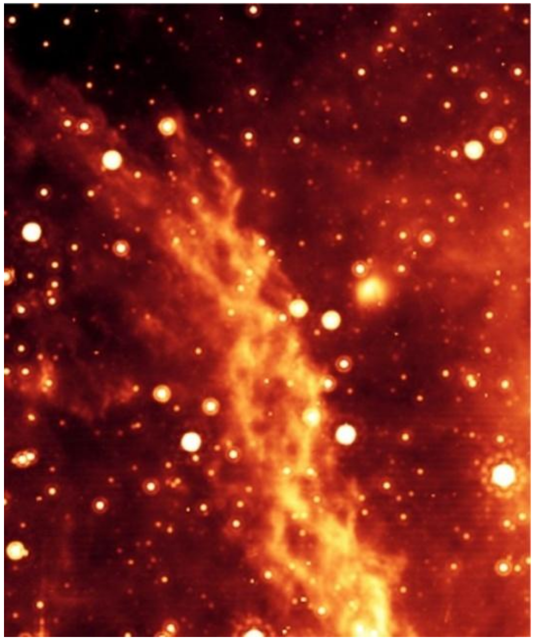


Our choice: n=5

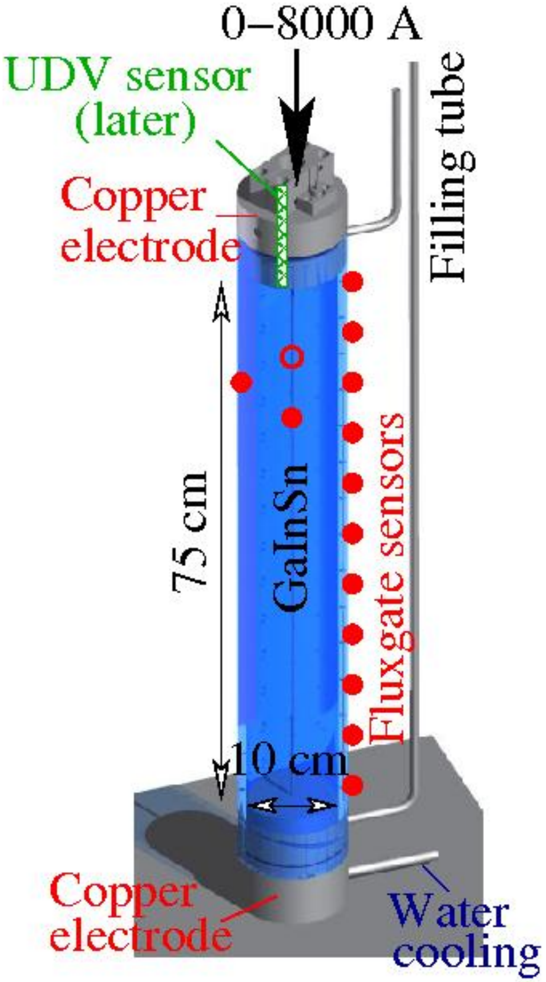
Kink-type Tayler instability (TI)

Astrophysical motivation:

- Alternative mechanism of solar dynamo (Tayler-Spruit dynamo)
- Braking of neutron stars
- Structure formation in cosmic jets

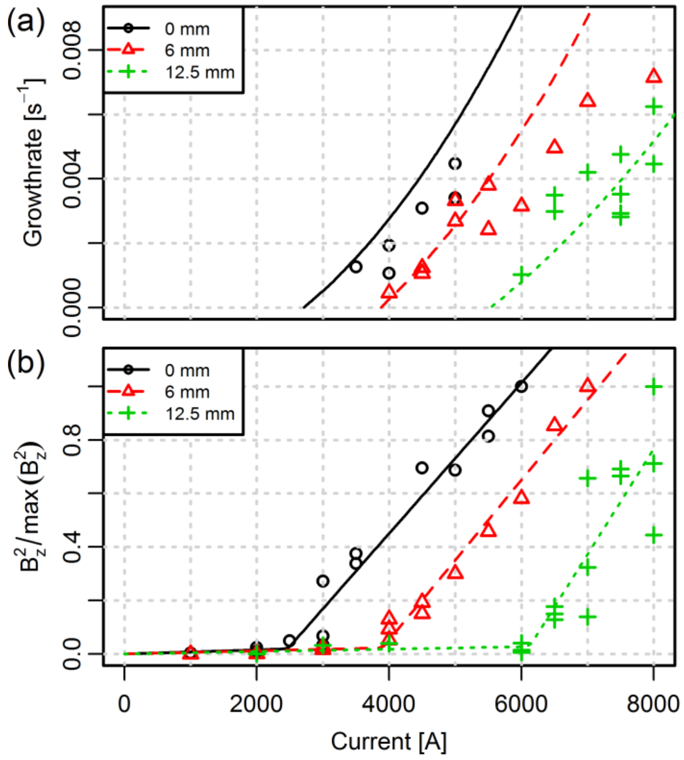


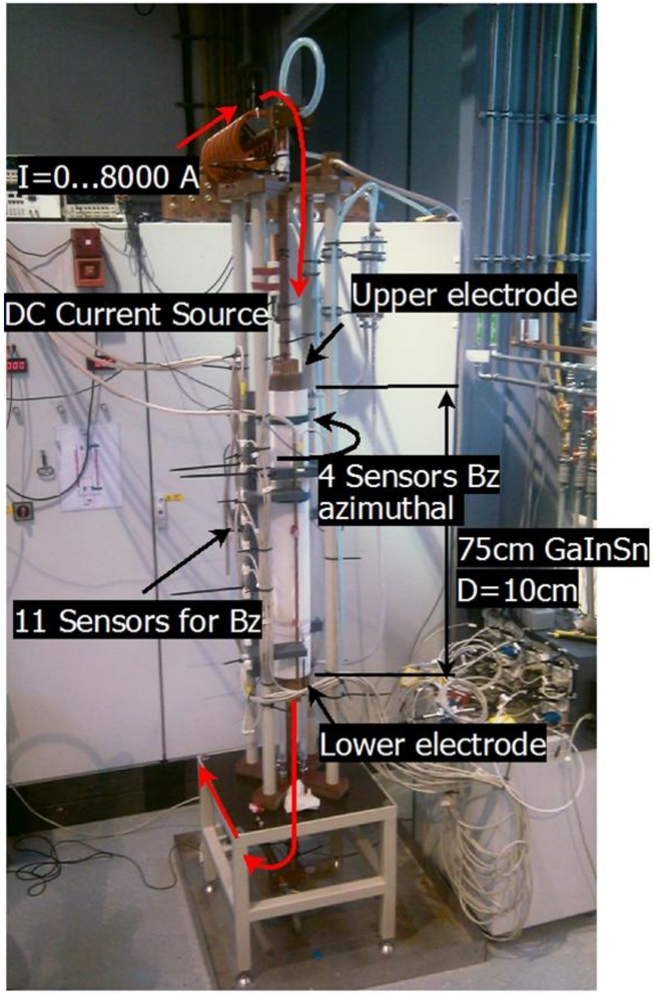
Seilmayer et al.,
Phys. Rev. Lett. 108
(2012), 244501

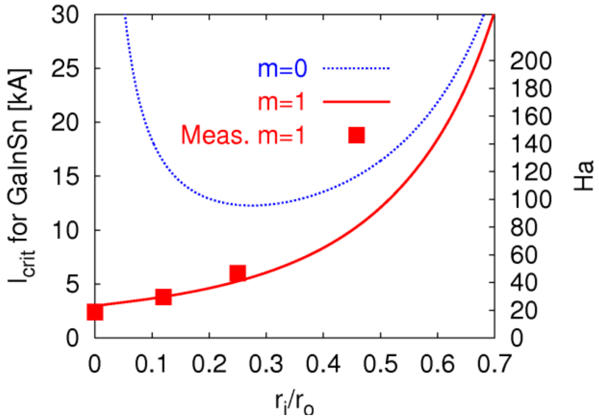


First TI experiment with a liquid metal at HZDR

Results of TI experiment for different r_i, and comparison with numerics

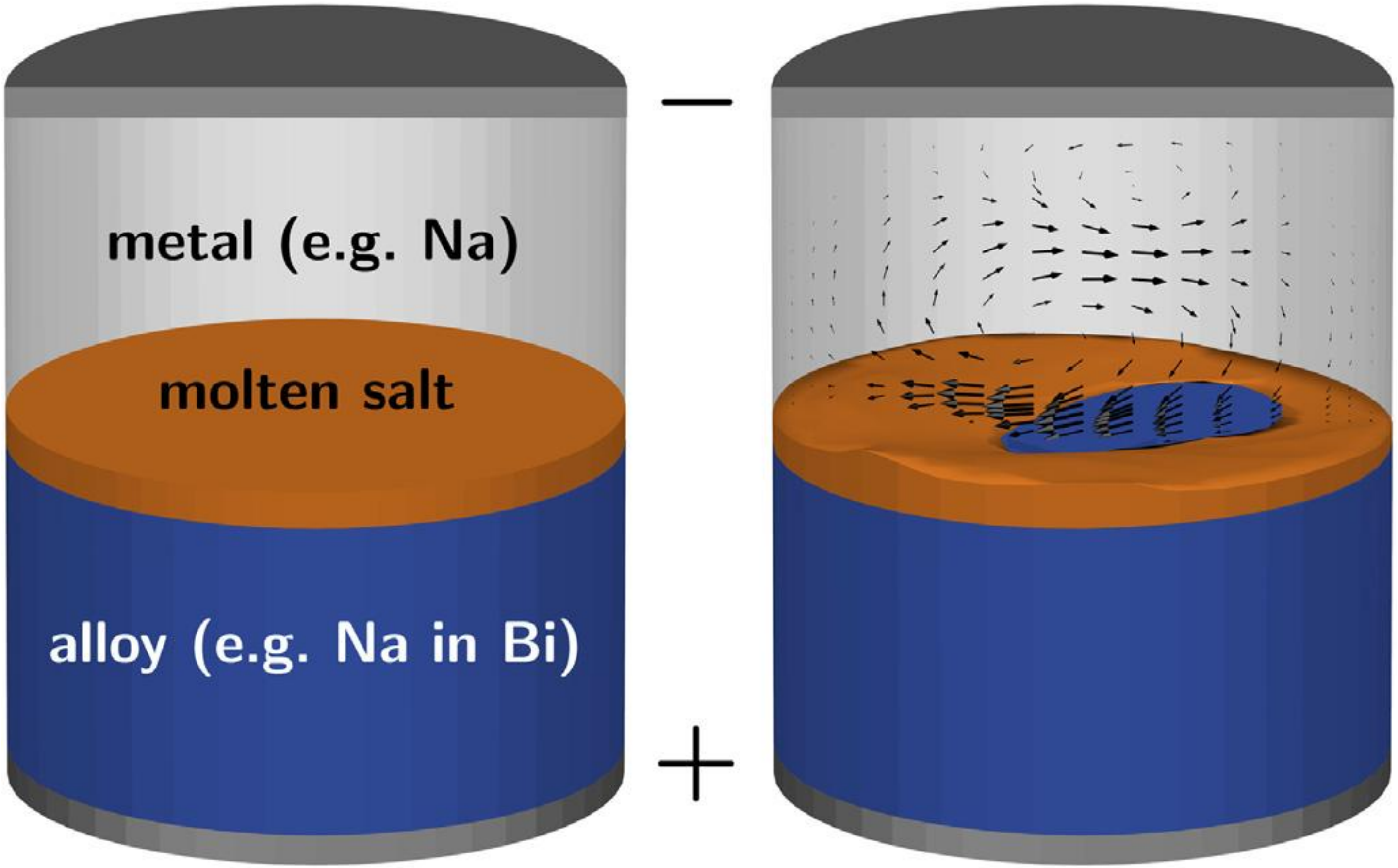






Seilmayer et al., Phys. Rev. Lett. 108 (2012), 244501

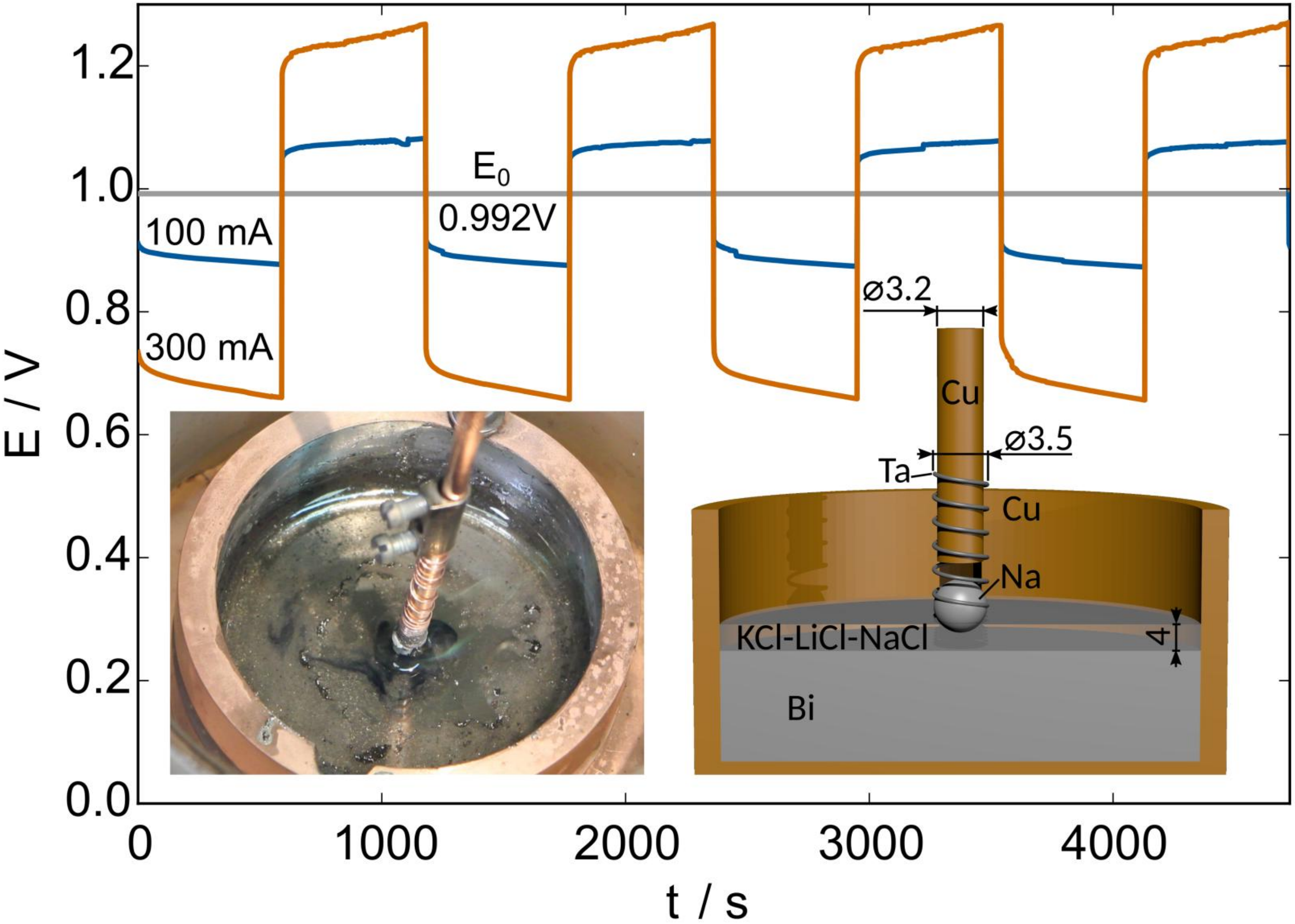
Relevance of Tayler instability for large-scale liquid metal batteries?



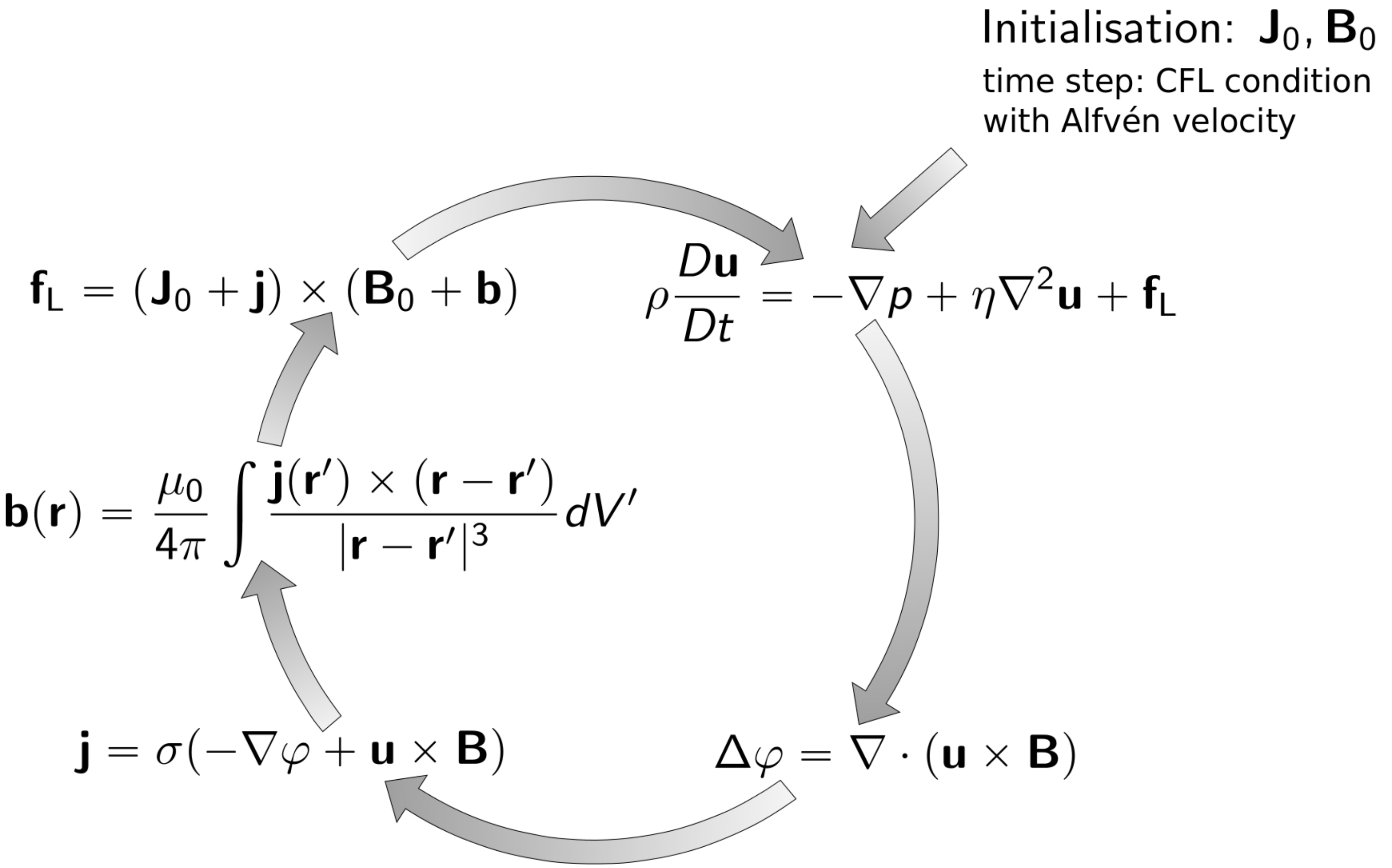
Stefani et al., Energy Conv. Managem. 52 (2011), 2982

Weber et al., J. Power Sources 265 (2014), 166

Our first liquid metal battery



Integro-differential equation code (OpenFoam+Poisson+Biot-Savart)



Initialisation: $\mathbf{J}_0, \mathbf{B}_0$

time step: CFL condition
with Alfvén velocity

$$\rho \frac{D\mathbf{u}}{Dt} = -\nabla p + \eta \nabla^2 \mathbf{u} + \mathbf{f}_\mathrm{L}$$

$$\Delta\varphi = \nabla \cdot (\mathbf{u} \times \mathbf{B})$$

$$\mathbf{j} = \sigma(-\nabla\varphi + \mathbf{u} \times \mathbf{B})$$

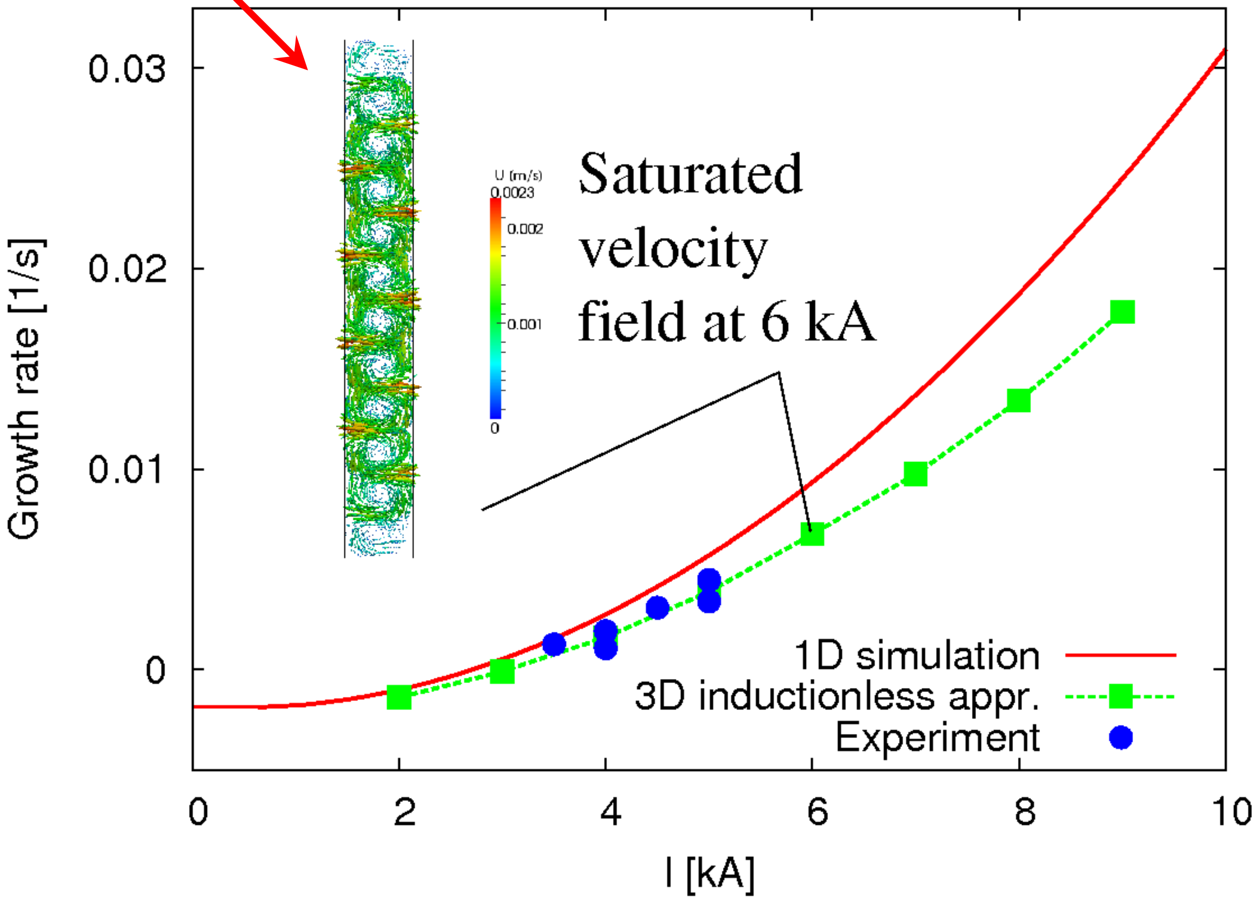
$$\mathbf{b}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int \frac{\mathbf{j}(\mathbf{r}') \times (\mathbf{r} - \mathbf{r}')}{|\mathbf{r} - \mathbf{r}'|^3} dV'$$

$$\mathbf{f}_\mathrm{L} = (\mathbf{J}_0 + \mathbf{j}) \times (\mathbf{B}_0 + \mathbf{b})$$

Weber et al., New J. Phys. 15 (2013), 043034

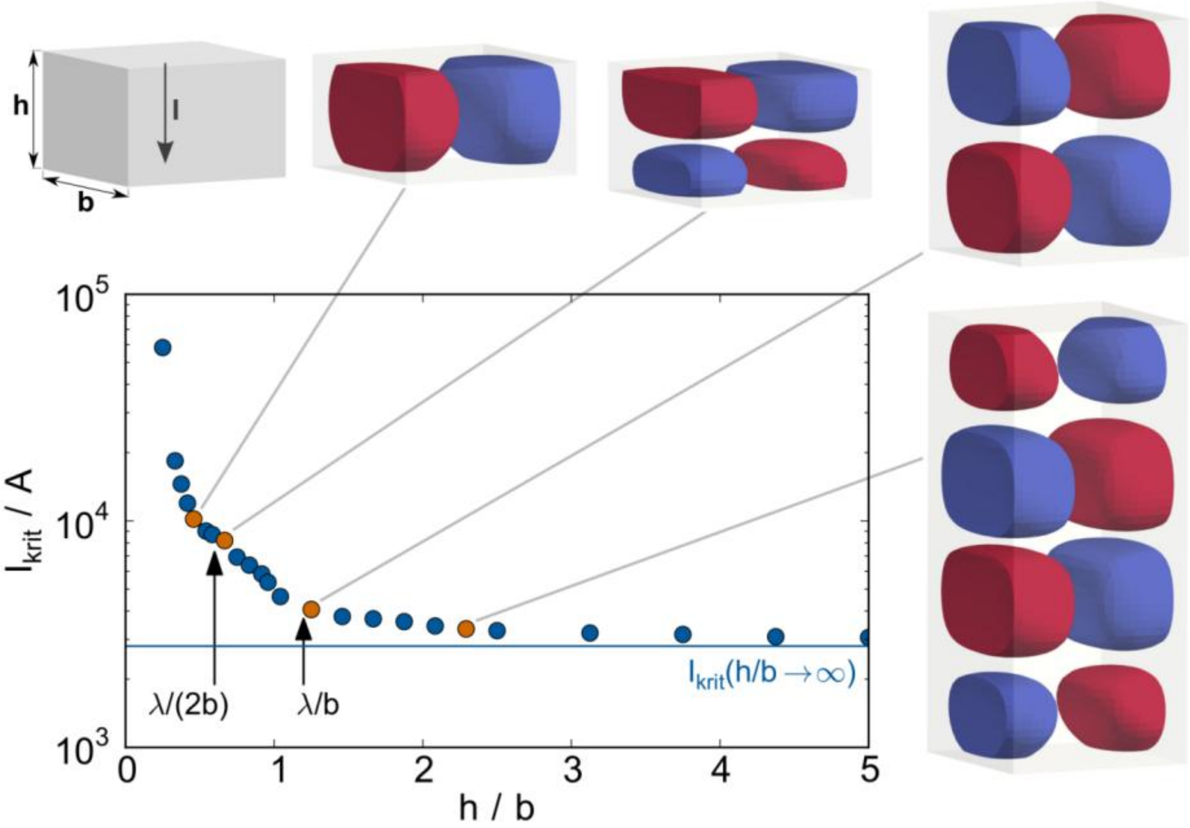
Simulation of the TI experiment with integro-differential equation code

Saturation: Re~Ha^2



Weber et al., New J. Phys. 15 (2013), 043034

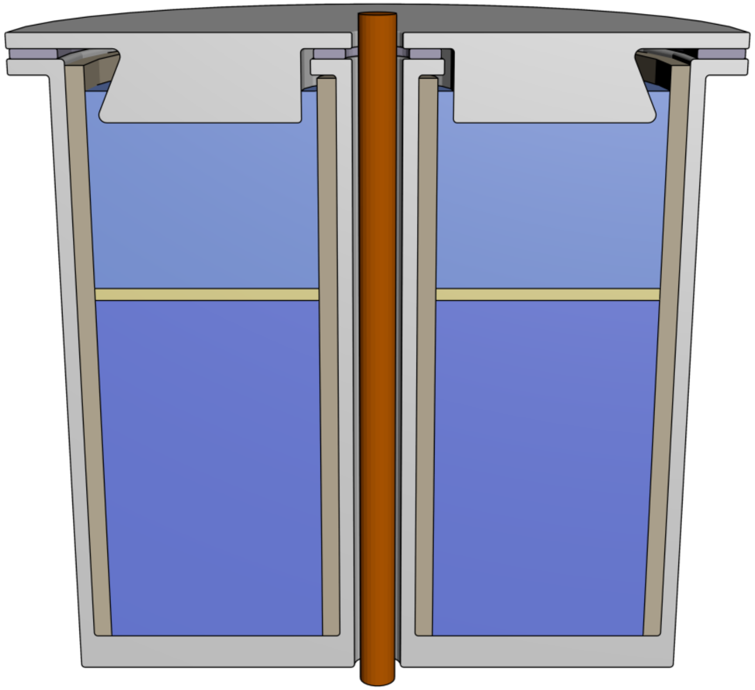
Simulation of TI in a cuboid with at different aspect ratios

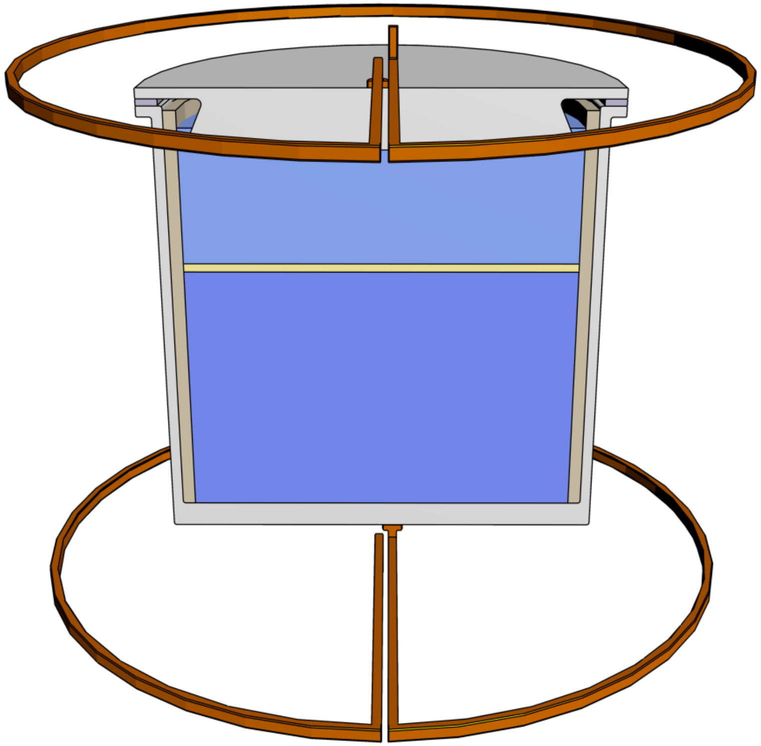


The critical current increases with decreasing aspect ratio. Plateaus appear at full and half wavelength.

Weber et al., New J. Phys. 15 (2013), 043034

Two ways of stabilizing the battery





Return current through the center changes $B_\varphi(r)$

Applying B_z (Kruskal-Shafranov)

Stefani et al., Energy Conv. Managem. 52 (2011), 2982

Weber et al., J. Power Sources 265 (2014), 166

Saturation of TI and helical symmetry breaking

Ideal fluids, or Pm~1: Two mechanisms contribute to saturation (see also Taylor relaxation in reversed field pinches):

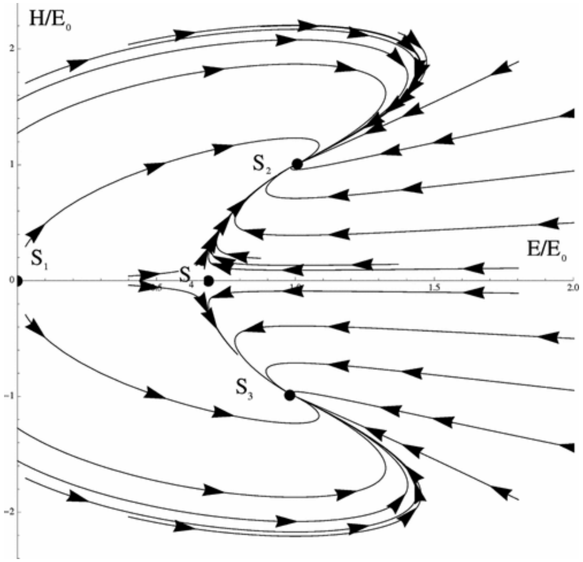
1. Radially dependent β effect → changes $B_\varphi(r)$ (acts like a return current)

2. α effect → produces B_z (stabilizes according to Kruskal-Shafranov)

Bonanno et al., Phys. Rev. E 86 (2012); 016313

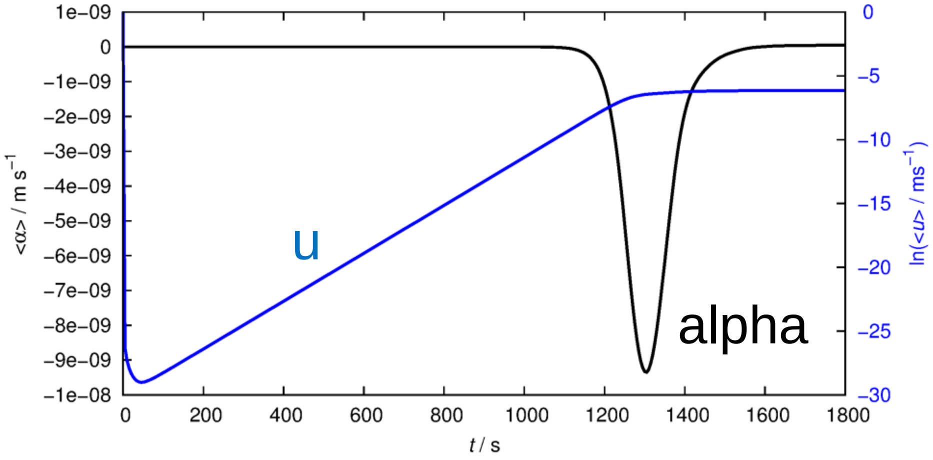
Appropriate Lagrangian leads to:

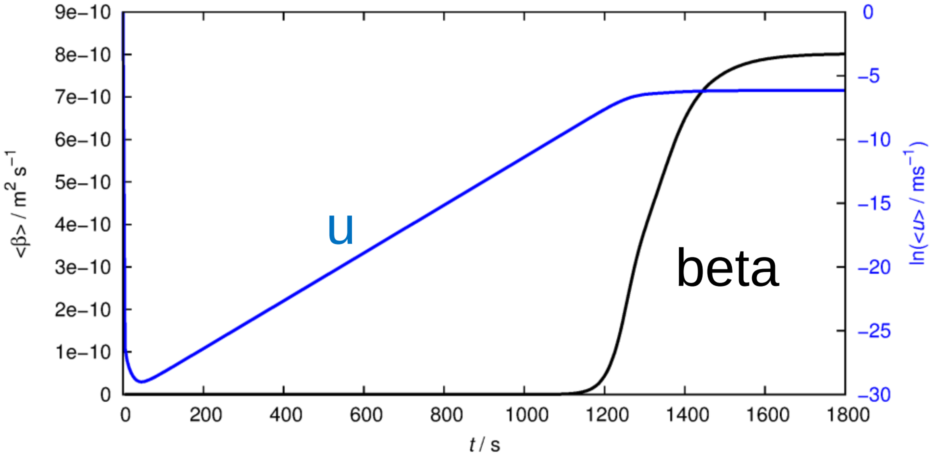
$$\boxed{\begin{aligned}\frac{dE}{dt} &= 2\gamma E - 2(\mu+\mu_*)E^2 - 2(\mu-\mu_*)H^2 \\ \frac{dH}{dt} &= 2\gamma H - 4\mu EH\end{aligned}}$$



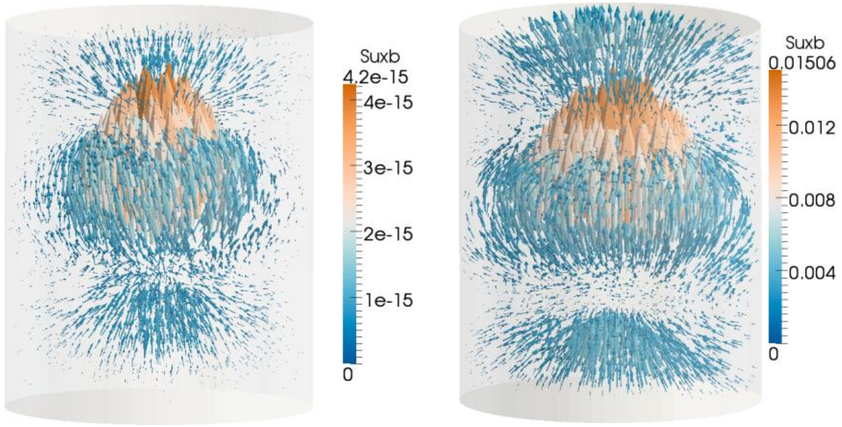
Saturation (and helical symmetry breaking?) at low Pm

At low Pm, neither the β effect nor the α effect are strong enough to change the magnetic base configuration. α effect appears only in the exponential growth phase and disappears in the saturation regime.





Induced current at…



500 s

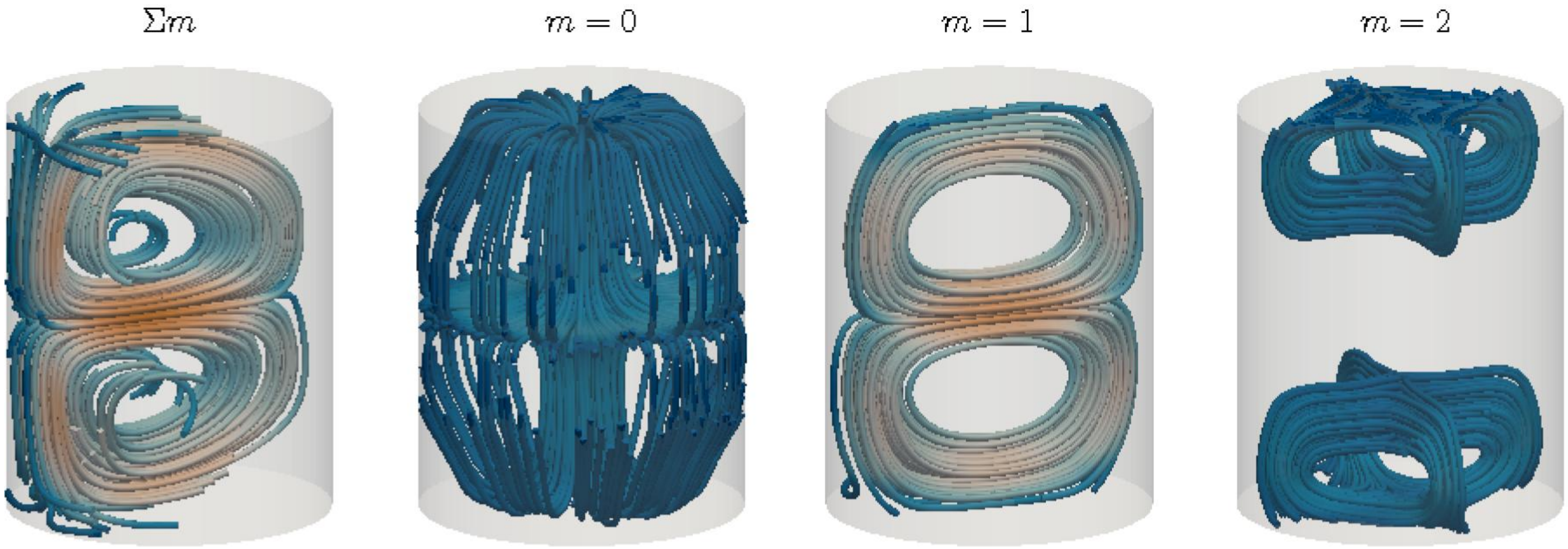
1800 s

Example: h/d=1.25, Ha=55

Weber et al., NJP (subm), arXiv:1504.06120

Saturation (and helical symmetry breaking?) at low Pm

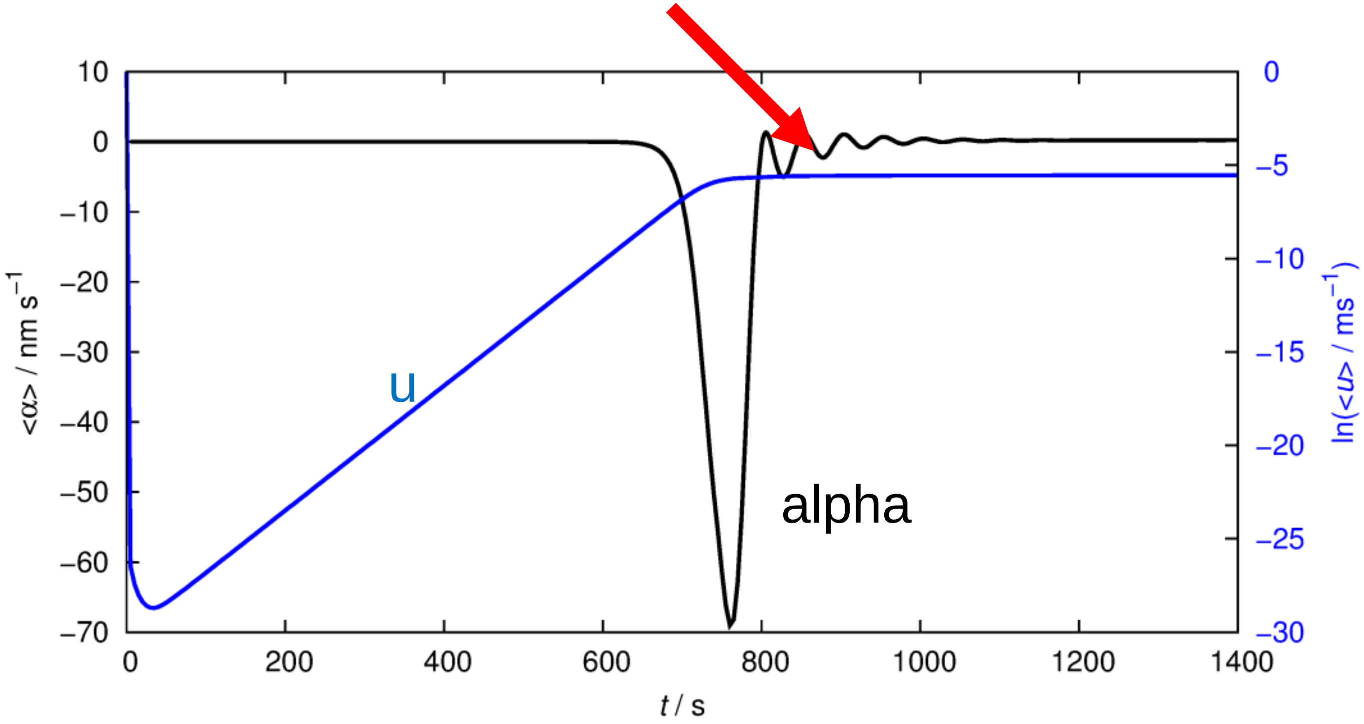
At low Pm, the saturation mechanism relies exclusively on the modification of the hydrodynamic base state (nonlinear appearance of m=0 and m=2 flow contributions)



Weber et al., NJP (subm), arXiv:1504.06120

Saturation (and helical symmetry breaking?) at low Pm

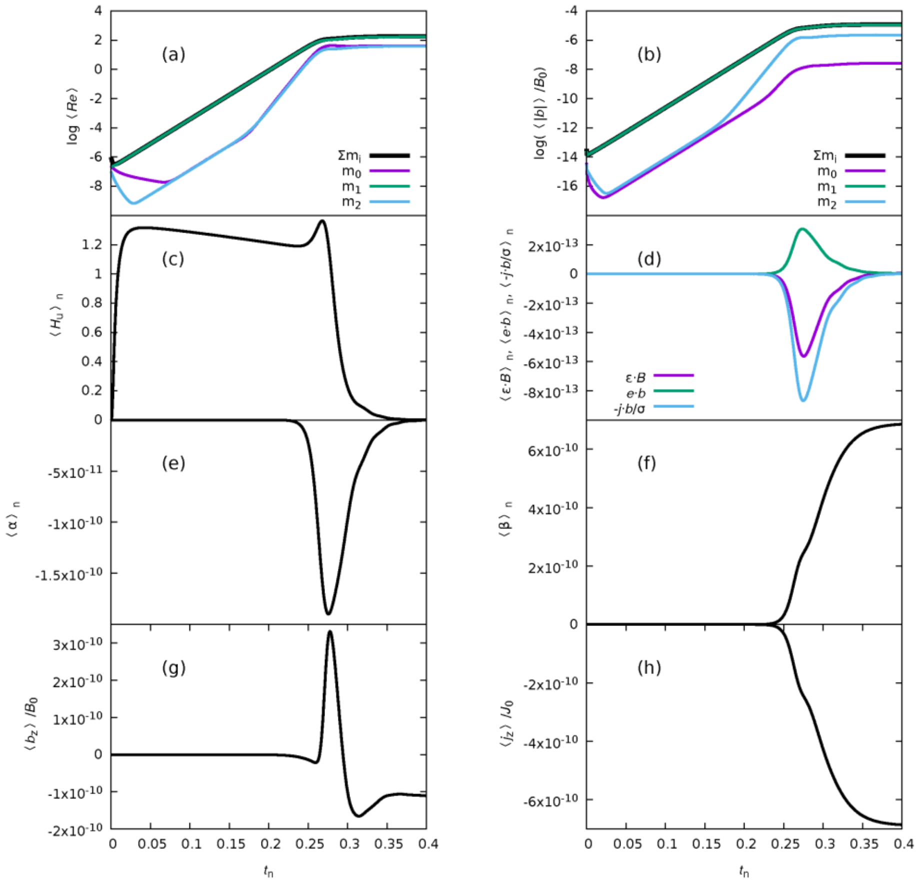
Helicity waves at higher Ha (=70)



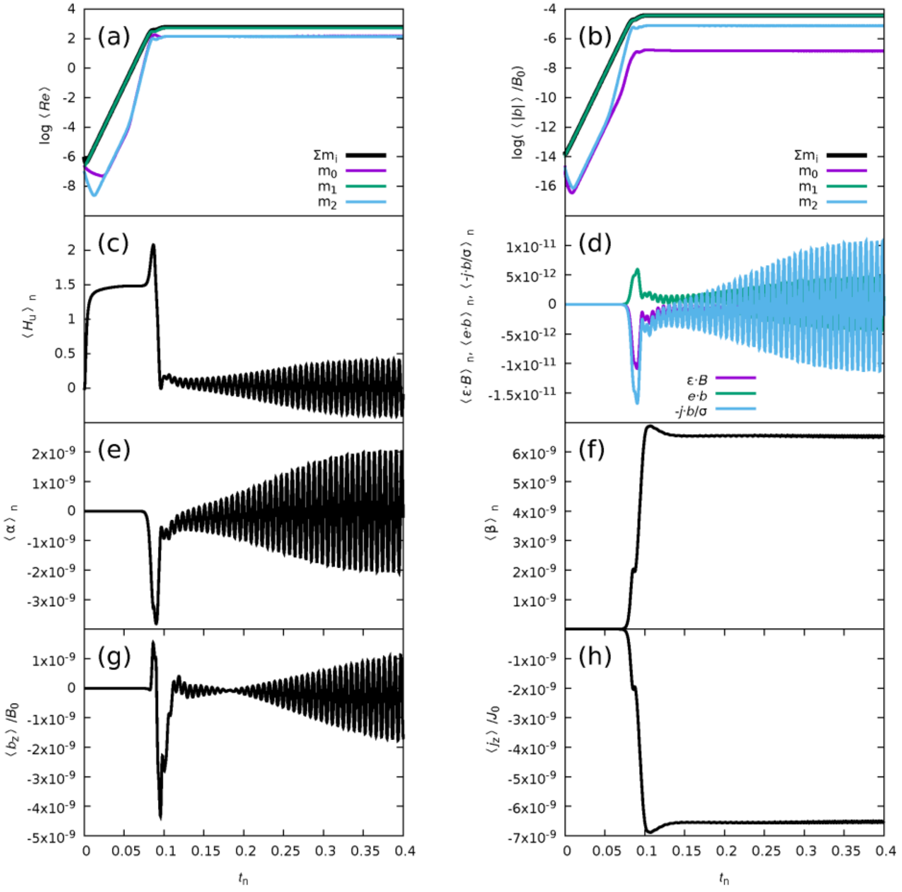
Appearance of stable finite helicity for still higher Ha is unclear (because of breakdown of quasistatic approximation at $S=Pm^{1/2}\ Ha\sim1$)

Weber et al., NJP (subm), arXiv:1504.06120

Saturation and helicity waves at Pm=10^{-6}



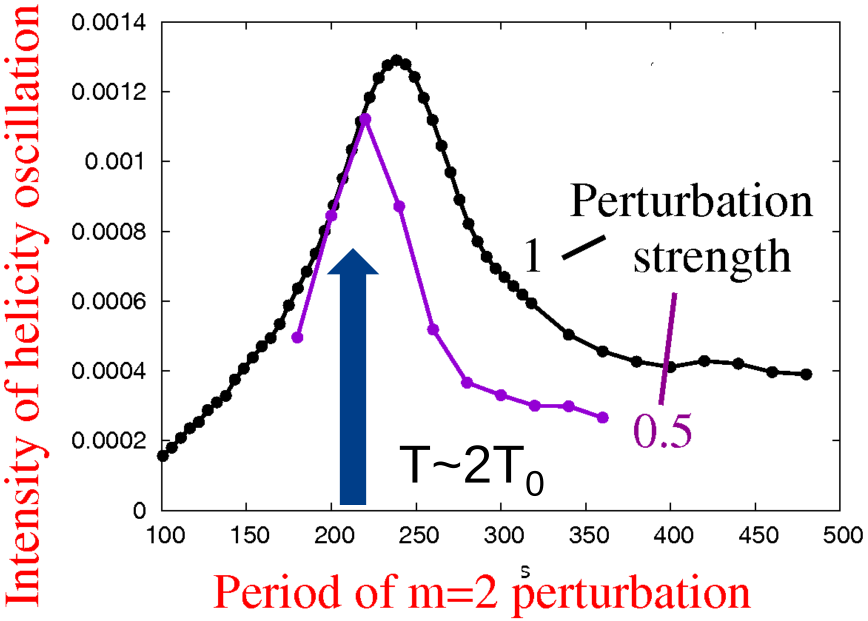
Ha=60

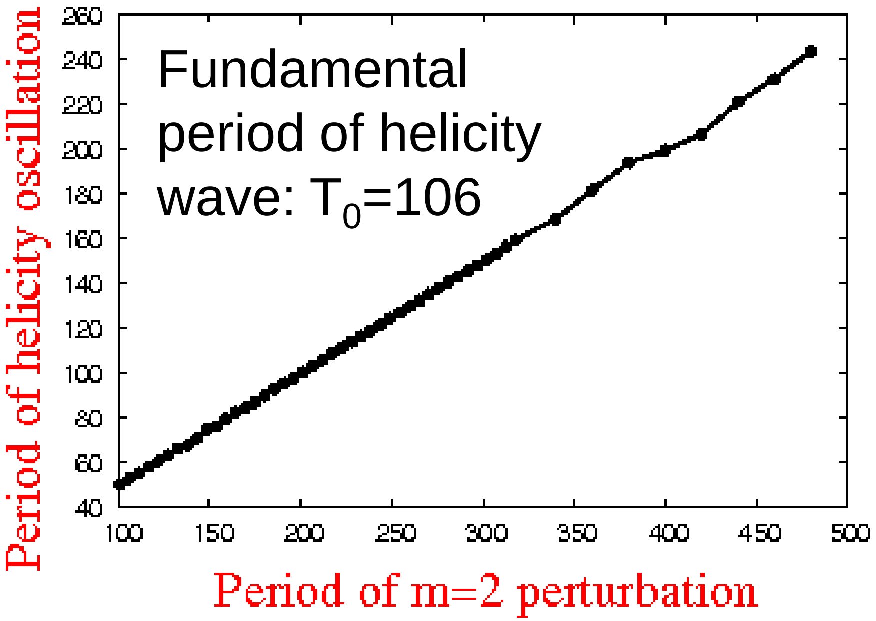


Ha=100

Weber et al., NJP (subm), arXiv:1504.06120

Any chance to synchronise helicity waves with planetary torques?





Main idea: Tayler-Spruit-like dynamo, no problem with Ω-effect, α-effect relies on chiral symmetry breaking, α-oscillation could be triggered and synchronized by planetary torques (emulated here by a m=2 viscosity wave) **with minor energy input**

Speculative example: recurrence of Venus-Earth-Jupiter conjunction after 44.77 years, solar cycle: ~22.4 years

Weber et al., to be published

MRI and TI: Viscous, resistive MHD with azimuthal wavenumber m

Navier-Stokes equation:

$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}\cdot\nabla\mathbf{u} = -\frac{\nabla P}{\rho} + \frac{\mathbf{B}\cdot\nabla\mathbf{B}}{\mu_0\rho} + \nu\nabla^2\mathbf{u}$$

Induction equation:

$$\frac{\partial \mathbf{B}}{\partial t} + \mathbf{u}\cdot\nabla\mathbf{B} = \mathbf{B}\cdot\nabla\mathbf{u} + \eta\nabla^2\mathbf{B}$$

Viscous, resistive, and two Alfvén frequencies for axial and azimuthal field

$$\omega_\nu = \nu|\mathbf{k}|^2, \quad \omega_\eta = \eta|\mathbf{k}|^2, \quad \omega_{A_z} = \frac{k_z B_z^0}{\sqrt{\rho\mu_0}}, \quad \omega_{A_\phi} = \frac{B_\phi^0}{r\sqrt{\rho\mu_0}}$$

Dimensionless: Magnetic Prandtl, Field ratio, Reynolds, Hartmann, n

$$\mathrm{Pm} = \frac{\omega_\nu}{\omega_\eta}, \quad \beta = \alpha\frac{\omega_{A_\phi}}{\omega_{A_z}}, \quad \mathrm{Re} = \alpha\frac{\Omega}{\omega_\nu}, \quad \mathrm{Ha} = \frac{\omega_{A_z}}{\sqrt{\omega_\nu\omega_\eta}}, \quad n = \frac{m}{\alpha}$$

with $\alpha = k_z|\mathbf{k}|^{-1}, |\mathbf{k}|^2 = k_r^2 + k_z^2$

Theory: Short wavelength approximation (WKB):

Hydrodynamic and magnetic Rossby numbers:

$$\boxed{\mathrm{Ro} = \frac{r}{2\Omega}\frac{\partial \Omega}{\partial r}, \qquad \mathrm{Rb} = \frac{r}{2\omega_{A_\phi}}\frac{\partial \omega_{A_\phi}}{\partial r}}$$

Secular equation: $\boxed{p(\lambda) = \det(\mathbf{H} - \lambda \mathbf{E}) = 0}$ with

$$\boxed{\mathbf{H} = \begin{pmatrix} -in\,\mathrm{Re} - 1 & 2\alpha\,\mathrm{Re} & \frac{i\mathrm{Ha}(1+n\beta)}{\sqrt{\mathrm{Pm}}} & -\frac{2\alpha\beta\mathrm{Ha}}{\sqrt{Pm}} \\ -\frac{2\,\mathrm{Re}(1+\mathrm{Ro})}{\alpha} & -in\,\mathrm{Re} - 1 & \frac{2\beta\mathrm{Ha}(1+\mathrm{Rb})}{\alpha\sqrt{\mathrm{Pm}}} & \frac{i\mathrm{Ha}(1+n\beta)}{\sqrt{\mathrm{Pm}}} \\ \frac{i\mathrm{Ha}(1+n\beta)}{\sqrt{\mathrm{Pm}}} & 0 & -in\,\mathrm{Re} - \frac{1}{\mathrm{Pm}} & 0 \\ \frac{-2\beta\mathrm{HaRb}}{\alpha\sqrt{\mathrm{Pm}}} & \frac{i\mathrm{Ha}(1+n\beta)}{\sqrt{\mathrm{Pm}}} & \frac{2\,\mathrm{Re}\,\mathrm{Ro}}{\alpha} & -in\,\mathrm{Re} - \frac{1}{\mathrm{Pm}} \end{pmatrix}}$$

Kirillov and Stefani, Phys. Rev. Lett. 111 (2013), 061103; JFM 760 (2014), 591

Combining MRI and TI: A chance to destabilize Keplerian profiles?

WKB-Analysis of the complete viscous and resistive MRI/TI problem for arbitrary azimuthal modes

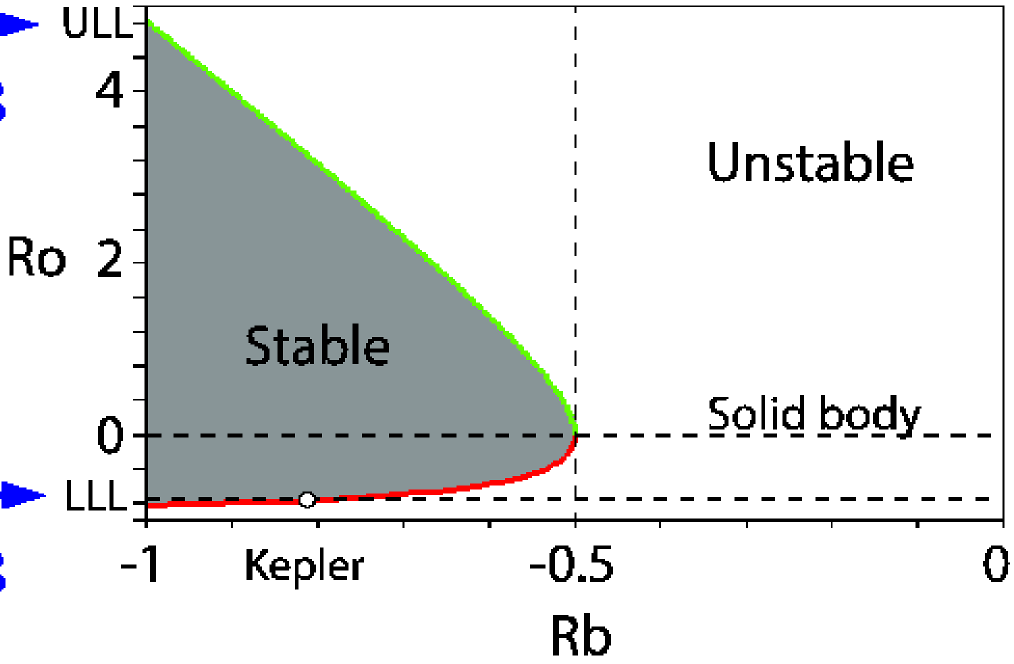
Main results:

$$Rb = -\frac{1}{8}\frac{(Ro+2)^2}{Ro+1}$$

Upper Liu limit: Ro=+4.828

Liu, Goodman, Herron, Ji, Phys. Rev. E 74 (2006), 056302

Lower Liu limit: Ro=–0.828



Steepness of rotation

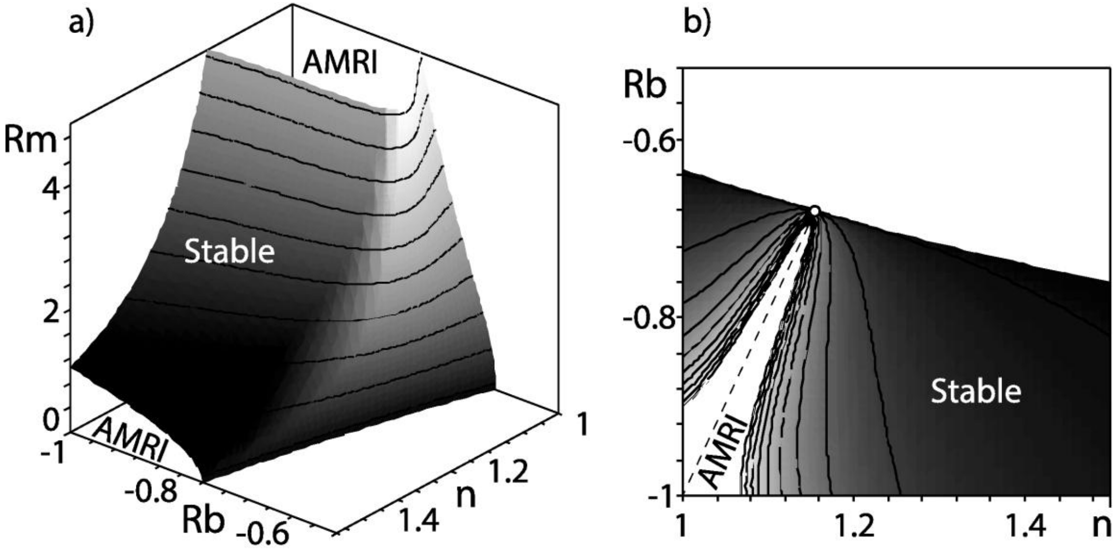
Steepness of azimuthal magnetic field

Kirillov and Stefani, Phys. Rev. Lett. 111 (2013), 061103; Fluid Dyn. Res. 46 (2014), 031403; JFM 760 (2014), 591

Dissipation induced instability of Chandrasekhar‘s equipartition state

Chandrasekhar theorem: An ideal fluid with equal amplitudes of Alfvén velocity and rotation velocity is stable.

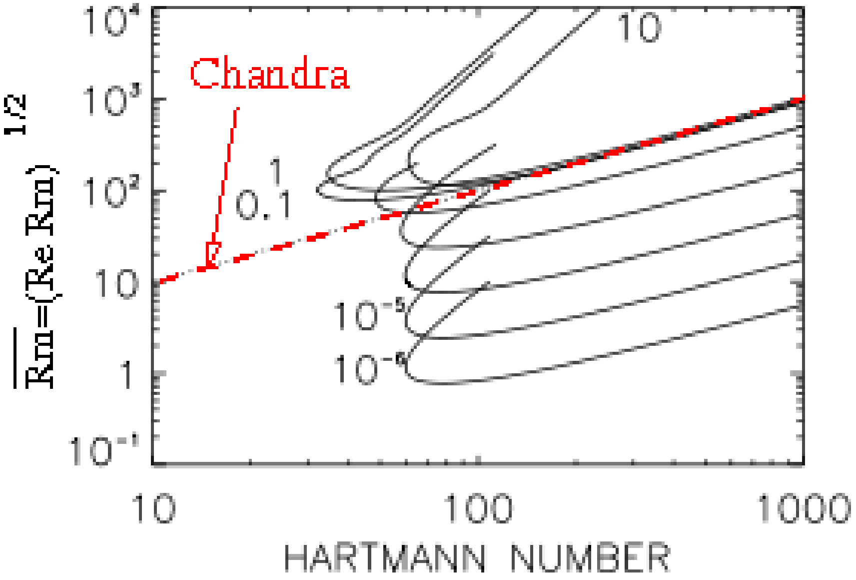
New result: **An infinitesimal small electrical resistivity destabilizes the marginal stable solution.** This a typical example of a dissipation-induced instability

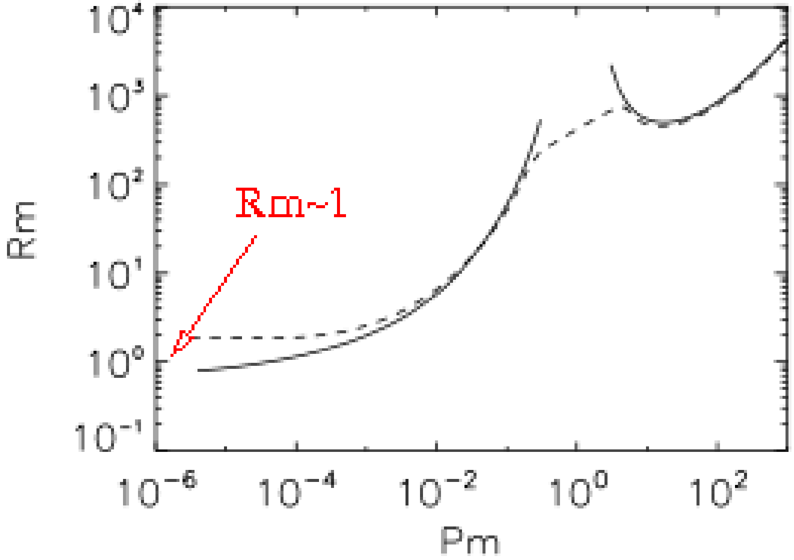


The threshold of instability at Ha^2= Rm Re and Re → ∞ in the (n,Rb,Rm) space. In the limit Rm → ∞ the instability degenerates into a ray (dashed)

Kirillov, Stefani, Fukomoto, JFM 760 (2014), 591

Dissipation induced instability of Chandrasekhar‘s equipartition state





Für all Pm, there is a crossing of the instability curve with the Chandrasekhar line

Any small viscosity or resistivity destabilizes the flow: → Diffusive (dissipation induced) instability

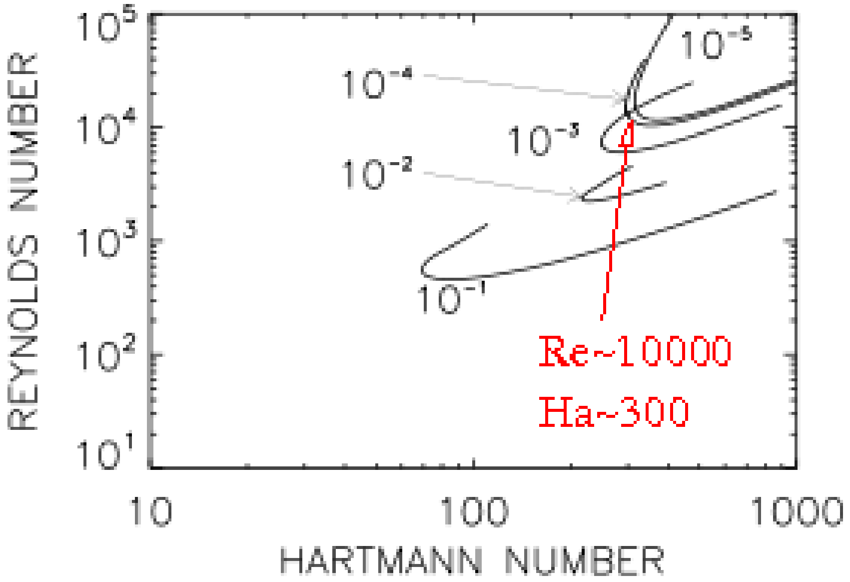
Rüdiger et al: Astrophys. J., submitted; arXiv:1407.1195

A lesson from diffusive instabilities

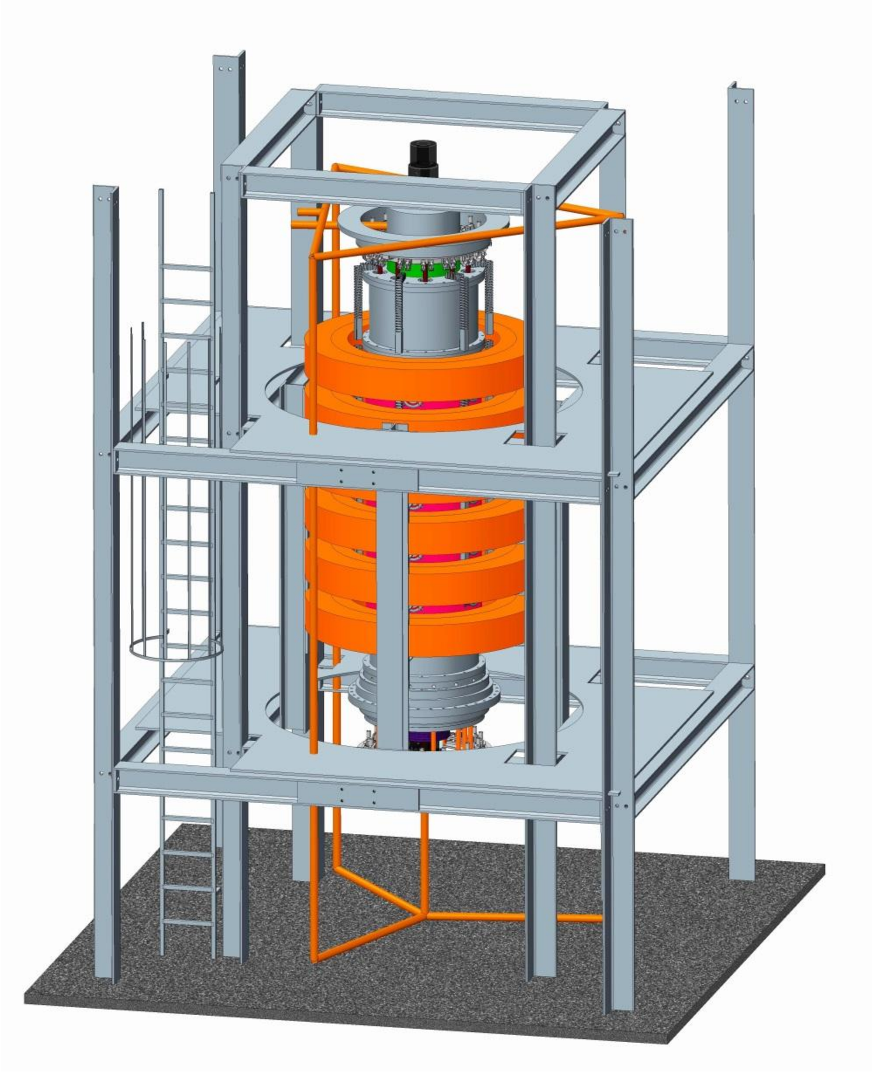
“Much as in the mid-nineteenth century, the point was missed ***that for fluid equations of the Navier-Stokes type the ideal limit with zero dissipation coefficients has essentially nothing to do with the case of small but finite dissipation coefficients”***

D. Montgomery: *Hartmann, Lundquist, and Reynolds: The role of dimensionless numbers in non-linear magnetofluid behavior.* Plasma Phys. Control. Fusion 35 (1993) B105-B113

What is needed to destabilize Kepler with a MRI/TI combination?



Critical Re und Ha fit nicely to the experimental capabilities



Rüdiger et al: Astrophys. J., submitted; arXiv:1407.1195

Combined MRI/TI experiment planned in the framework of DRESDYN

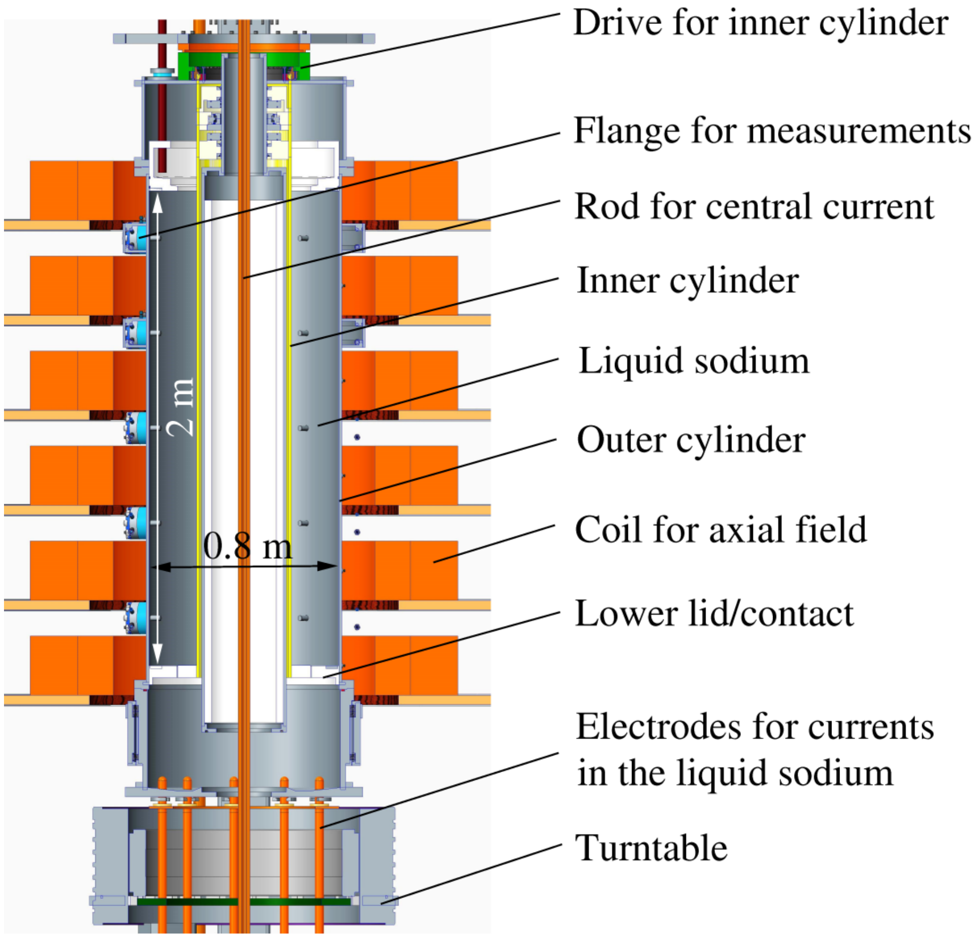
...will (hopefully) allow us to study helical MRI, azimuthal MRI, standard MRI, and their combinations with Tayler instability

- R_{in}=0.2 m
- R_{out}=0.4 m
- H=2 m

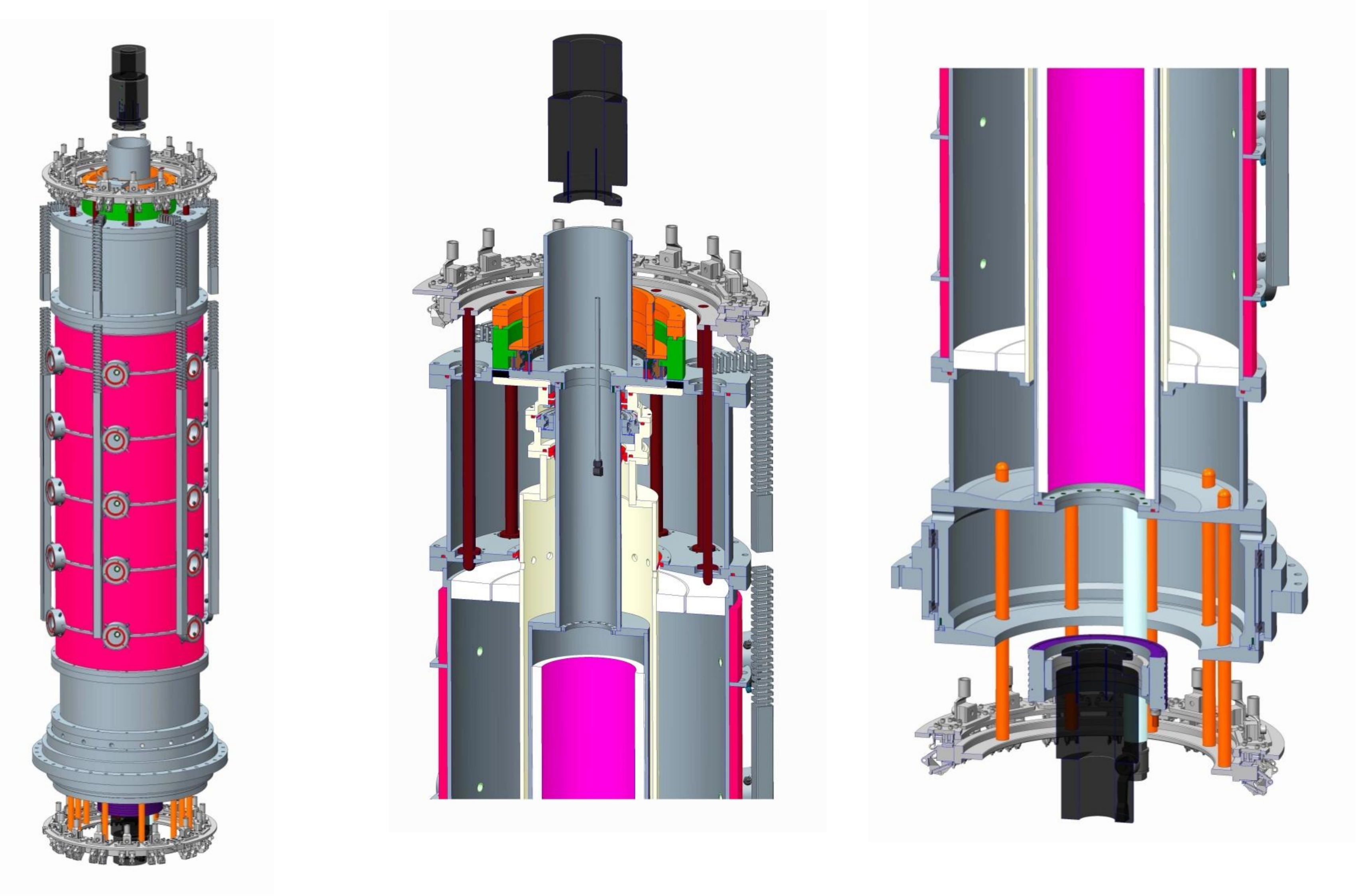
- f_{in}=20 Hz
- f_{out}=6 Hz

- B_z=120 mT
- (will need some 500 kW)

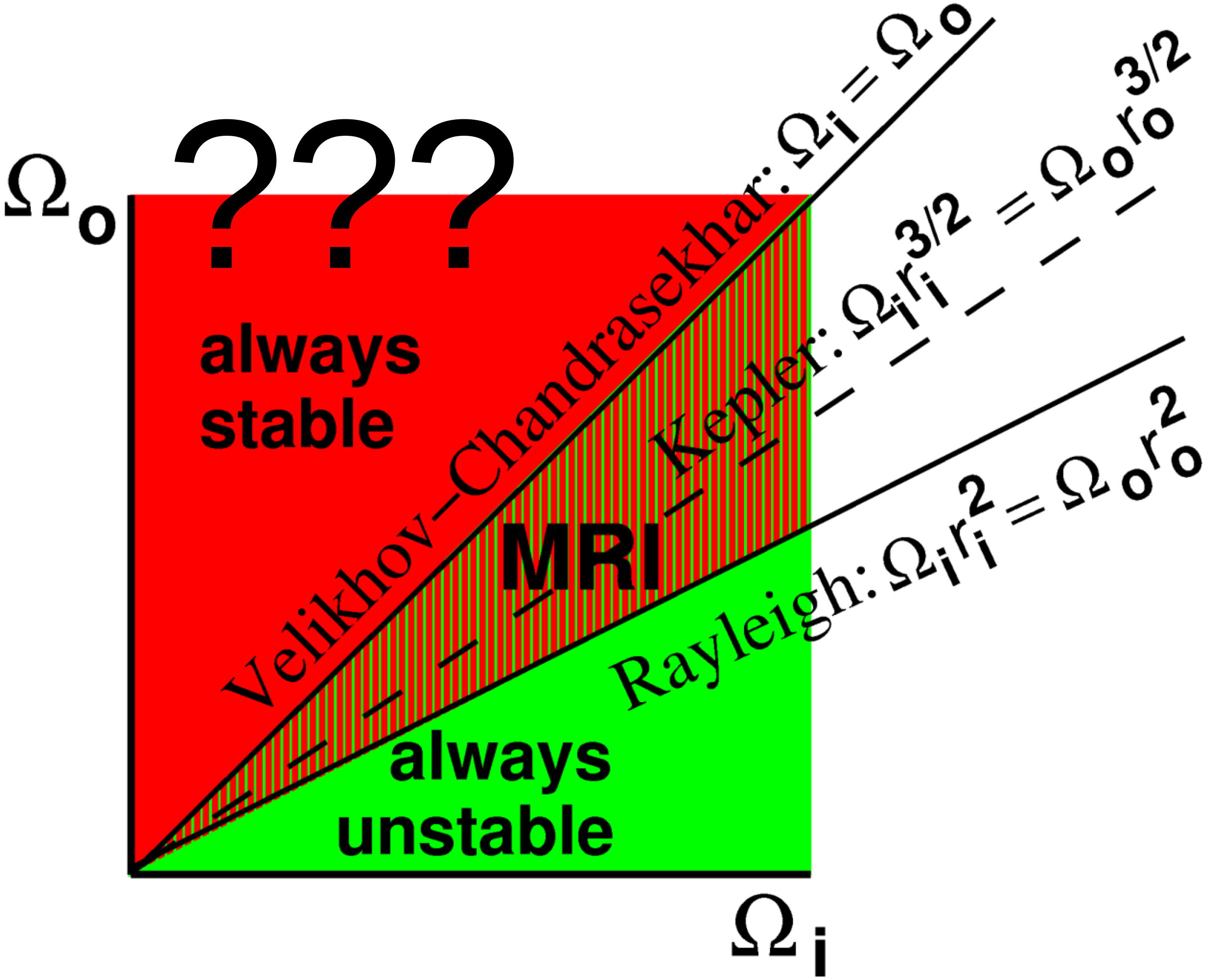
- Rm=40
- Lundquist=8



Combined MRI/TI experiment: some technical details



Can magnetic fields destabilize rotational flows with positive shear?



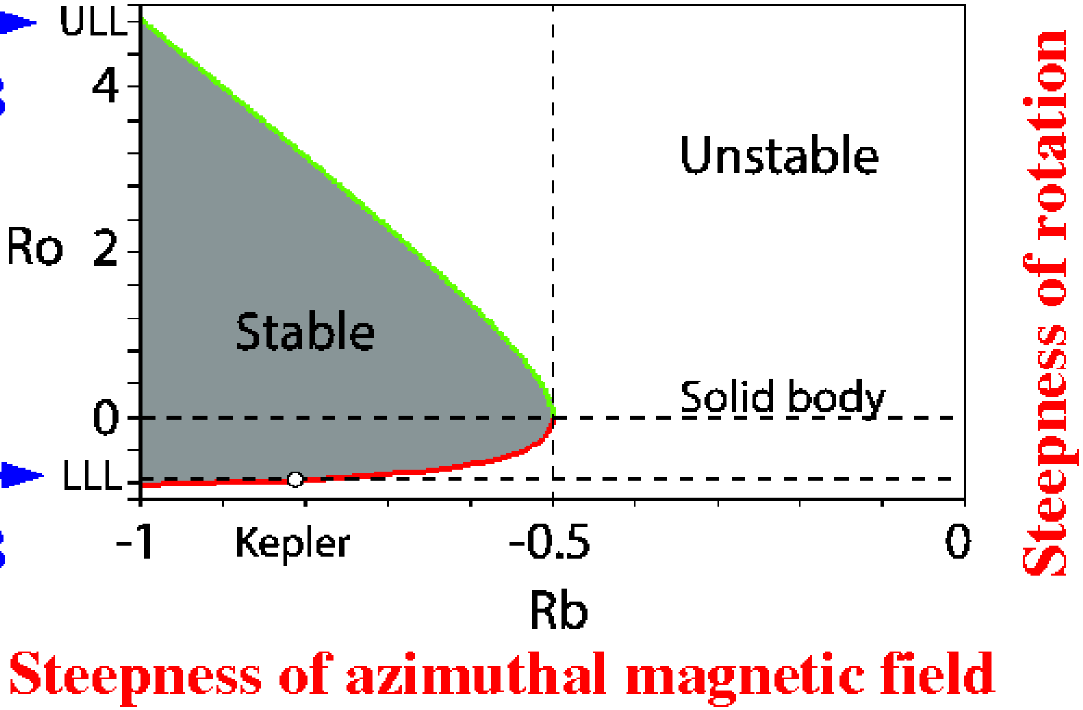
Can magnetic fields destabilize rotational flows with positive shear?

Liu, Goodman, Herron, Ji, Phys. Rev. E 74 (2006), 056302

Upper Liu limit: Ro=+4.828

Liu et al., PRE 2006

Lower Liu limit: Ro=–0.828

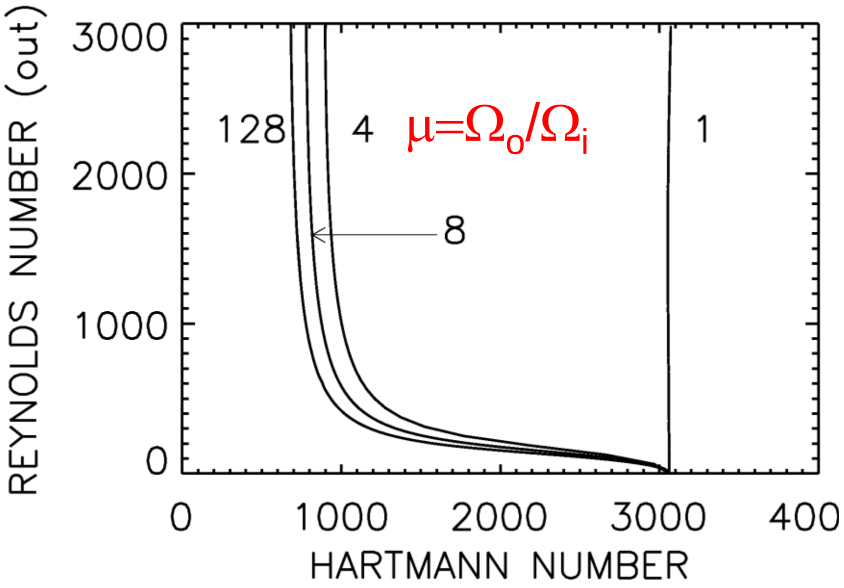


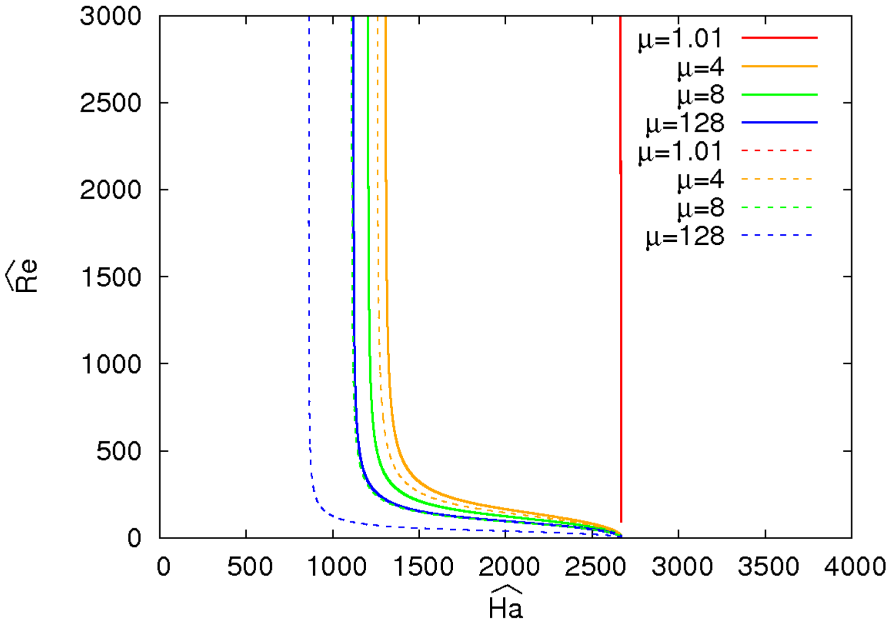
Kirillov and Stefani, Phys. Rev. Lett. 111 (2013), 061103; Fluid Dyn. Res. 46 (2014), 031403; JFM 760 (2014), 591

$$Rb = -\frac{1}{8}\frac{(Ro+2)^2}{Ro+1}$$

A first safe result: Tayler instability is **amplified** by positive shear!

Nearly perfect correspondence of 1D stability code with WKB-Analysis





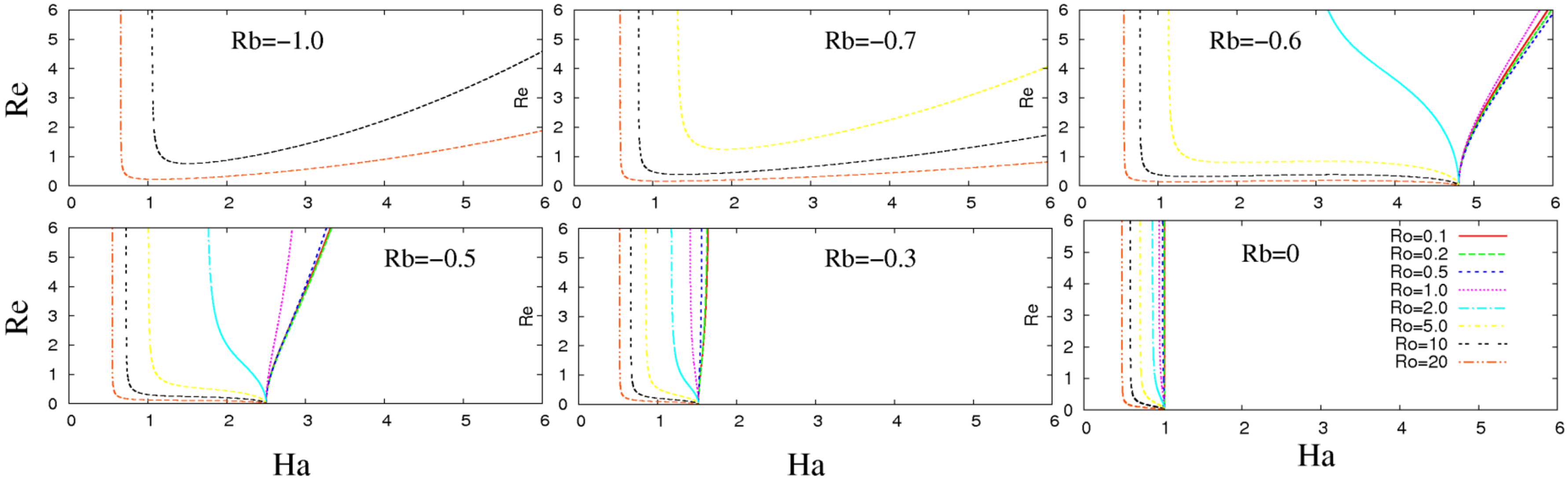
Rüdiger et al., Phys. Fluids (subm.); arXiv:15.05.05320

Stefani and Kirillov, arXiv:1506.00399

Transition between shear-driven and current-driven type for pure B_φ

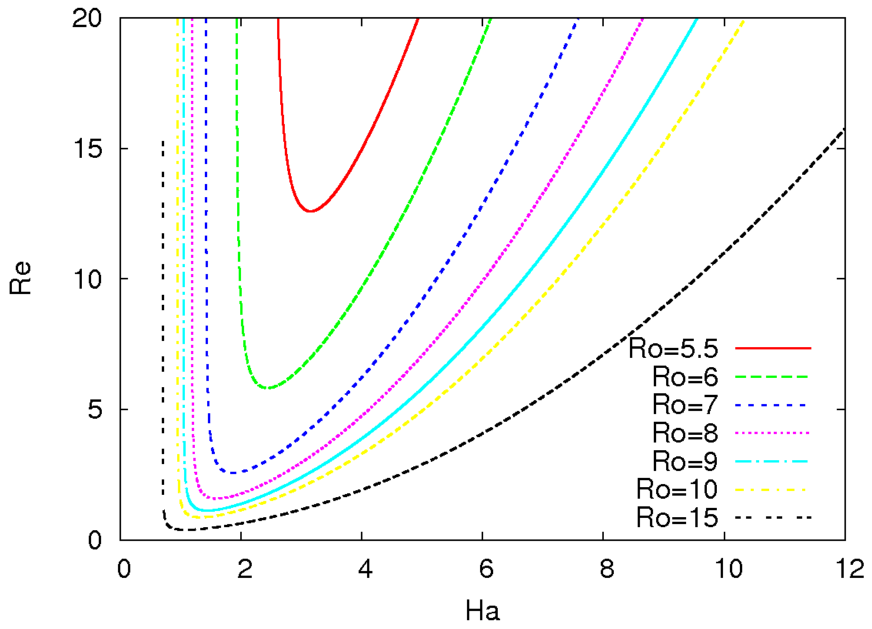
Analytical formula: Kirillov, Stefani, Fukumoto, JFM 760 (2014), 591

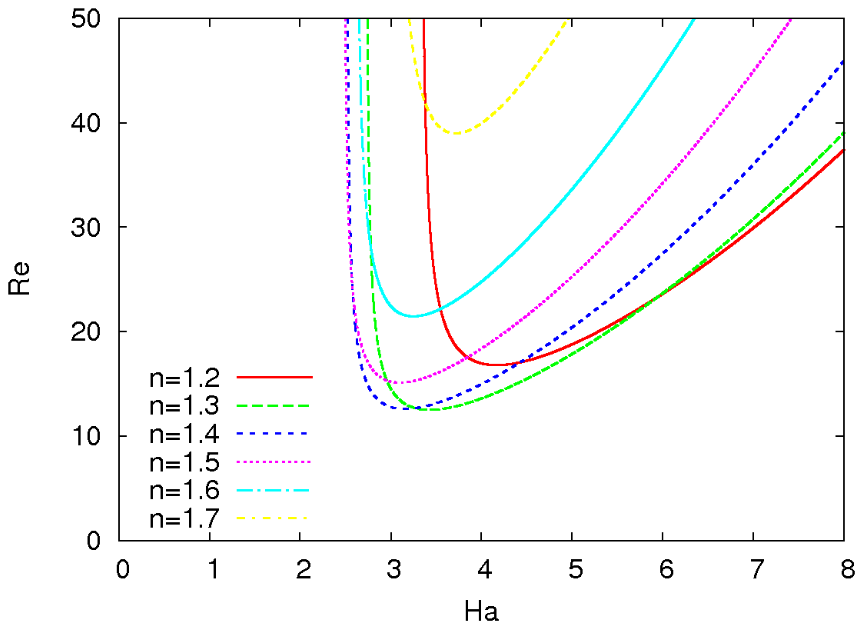
$$Re^2 = \frac{1}{4}\frac{[(1+Ha^2n^2)^2 - 4\,Ha^2Rb(1+Ha^2n^2) - 4Ha^4n^2][1+Ha^2(n^2-2Rb)]^2}{Ha^4Ro^2n^2 - \left[\left(1+Ha^2(n^2-2Rb)\right)^2 - 4Ha^4\,n^2\right][Ro+1]}$$



Stefani and Kirillov, arXiv:1506.00399

Is there a „Super-AMRI“? What about an experiment?





Translation of Ro to μ is crucial! Taylor-Couette-Experiment with small gap is needed (at least r_i/r_o~0.85). Central current ~ 80 kA!
Not yet planned for DRESDYN…

Stefani and Kirillov, arXiv:1506.00399

Thank you…