GeoFlow: On the status of experimental preparation of spherical gap flow experiments with central force field on International Space Station (ISS)

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BTU
Brandenburgische Technische Universität Cottbus

Outline

1. Previous Works
2. Experiment Preparation
   - Experiment Set-up
   - Measurement Techniques
   - Status and Schedule
3. Experiment Operation
   - Experiment Flow Plan
   - Data Downlink
   - Data Analysis
4. Concluding Remarks

Space Shuttle Experiment (1985) and 2nd campaign (1995)

Hart et al. (1986) JFM, **173**, and NASA-TP-1999-209-576:

- Rotating Hemispherical Shells
- Radial and Latitudinal Temperature Gradients, i.e. Equator-to-Pole Temperature Differences
- Gravity modelled by Imposing a Central Electric Field (V_{rms})
- Visualisation applying Schlieren Technique
- Experiments Compared with Three-Dimensional Nonlinear Simulations

Fluid flow analogy . . .

. . . of spherical gap flow model in atmospheric motion and convection in core regions of gasous planets as described in

- Yavorskaya et al. (1984)
  'A simulation of central-symmetry convection in microgravity conditions'
- Hart et al. (1986)
  'Space-laboratory and numerical simulations of thermal convection in a rotating hemispherical shell with radial gravity'

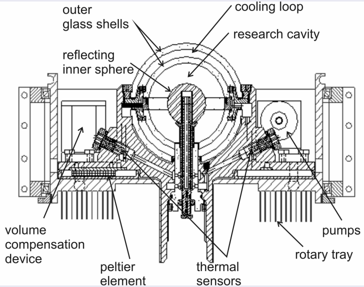
Discussions of Central Force Fields in Geophysical Analogy. . .

. . . in Earth's outer core. Essential character of the flow is captured as described in

- Früh (2005)
  'Using magnetic fluids to simulate convection in a central force field in the laboratory'
- Beltrame et al. (2006)
  'Simulation of convection in a spherical shell under central force field'

Fluid Cell Assembly

Core of Experiment



Science Reference Model

Free Experiment Parameters

Rotation Rate	Ω	$[Hz]$	≤ 2	$\rightarrow$	$Ta \leq 1.3 \times 10^7$
High Voltage	V_{rms}	$[kV]$	$= 10$	$\}$	$Ra_{central} \leq 1.4 \times 10^5$
Temperature Diff.	ΔT	$[K]$	≤ 10		

Experiment Parameters

Geometric Parameters of Research Cavity

Inner Radius	r_i	$[mm]$	13.5
Outer Radius	r_o	$[mm]$	27.0
Gap Width	$r_i - r_o$	$[mm]$	13.5

$$\eta = {}^{r_i}/_{r_o} = 0.5$$
$$\beta = {}^{(r_i - r_o)}/_{r_i} = 1$$

Physical Properties of Working Fluid (Silicone Oil)

Density	$[{}^{g}/_{\mathrm{cm}^3}]$	0.92
Kinematic Viscosity	$[{}^{m^2}/_{\mathrm{s}}]$	5×10^{-6}
Thermal Diffusivity	$[{}^{m^2}/_{\mathrm{s}}]$	7.735×10^{-8}
Thermal Conductivity	$[{}^{W}/_{(\mathrm{K}\times\mathrm{m})}]$	0.116
Cubic Exp. Coeff.	$[{}^{1}/_{\mathrm{K}}]$	108×10^{-5}
Dielectric Constant	ϵ_r	2.7
Thermal Coeff. of ϵ_r	$[{}^{1}/_{\mathrm{K}}]$	1.07×10^{-3}

$$Pr \approx 64$$

Measurement Techniques

Tracer Particles . . .

not suitable due to High Voltage Field

Applicable Techniques

- Wollaston-Shearing-Interferometry (*WSI*)
- Schlieren Technique / Shadowgraphy

Principle of *WSI*

- detects refractive index gradients
- sensitive to density gradients due to temperature differences
- optical path length variations cause interference phenomena

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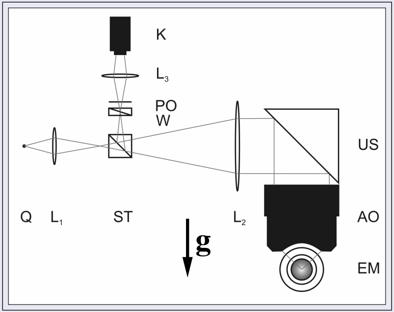
WSI set-up at BTU Laboratory

Sketch



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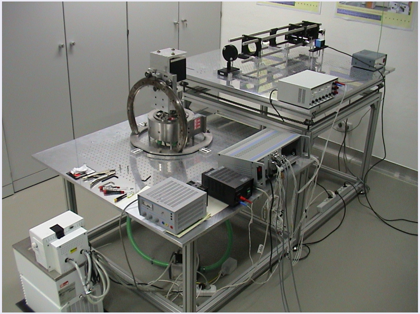
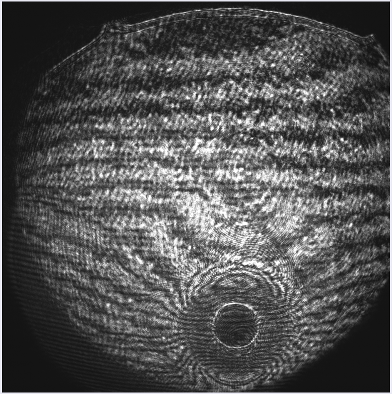


Applying *WSI* in GeoFlow set-up: Non-Rotational Experiments

WSI Image at $\Delta T \approx 8\,K$, $\Omega = 0\,Hz$, $V_{rms} \approx 10\,kV$



Parameters

- $Ra = 4.31 \times 10^6$
- $Ra_{central} = 1.14 \times 10^5$
- $Ta = 0$

Flow pattern

Thermal Blob Convection

Goal of *WSI* Analysis

Information about temperature field (corresponding to flow field) and its time dependent behaviour

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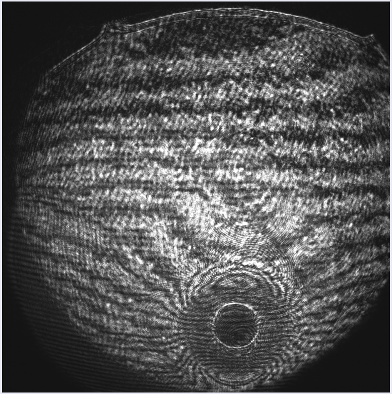

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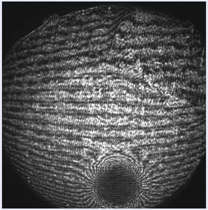
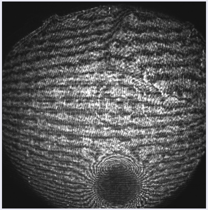
Applying *WSI* in GeoFlow set-up: Rotational Experiments

Natural Convection, $V_{rms} = 0\ kV$, $Ra = 4.31 \times 10^6$

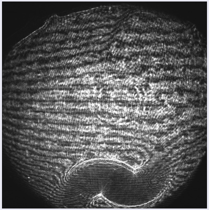
$Ta = 0$



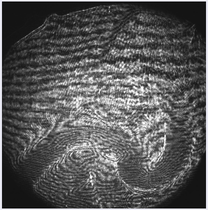
$Ta = 8.6 \times 10^2$



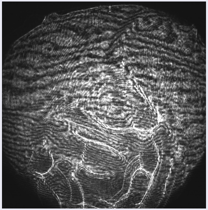
$Ta = 1.3 \times 10^5$



$Ta = 5.4 \times 10^5$



$Ta = 1.1 \times 10^7$



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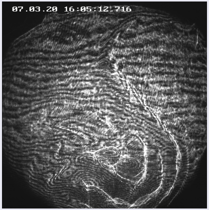
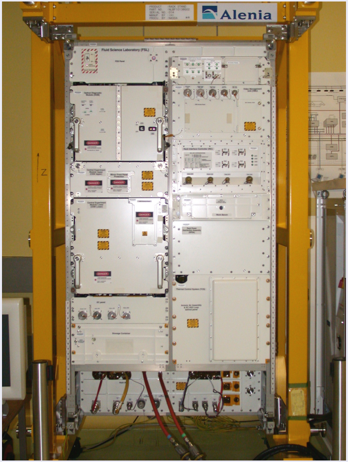
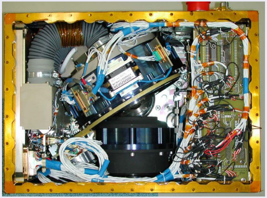


Hardware Environment

Fluid Science Lab



EC



Photos:

Left:

MARS, Napoli, Italy

Right:

Astrium GmbH, Friedrichs-hafen, Germany

Status of Experiment Hardware Preparation

Columbus Arrival at KSC (May 30th, 2006), Photo: ESA

Launch of COF / GeoFlow EC

Scheduled to December 6th, 2007 with NASA Space Shuttle 'Atlantis'

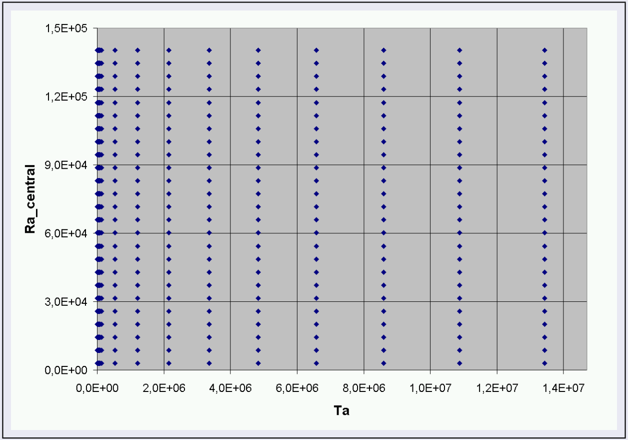
Experiment Flow Plan (Cycle 1)

Analysis of Flow Pattern

by variation of

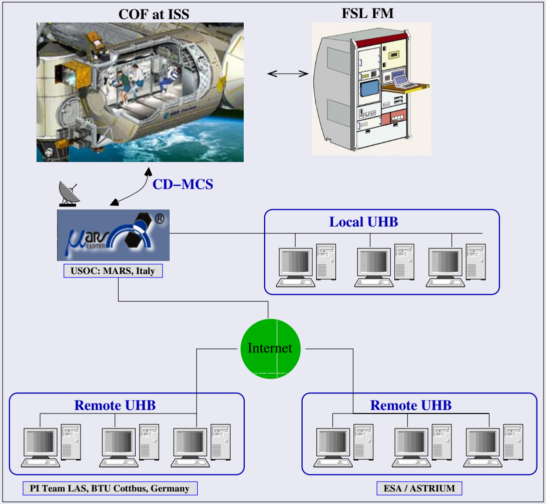
- *Ra* only
- *Ta* and *Ra*

High Resolution Parameter Scan

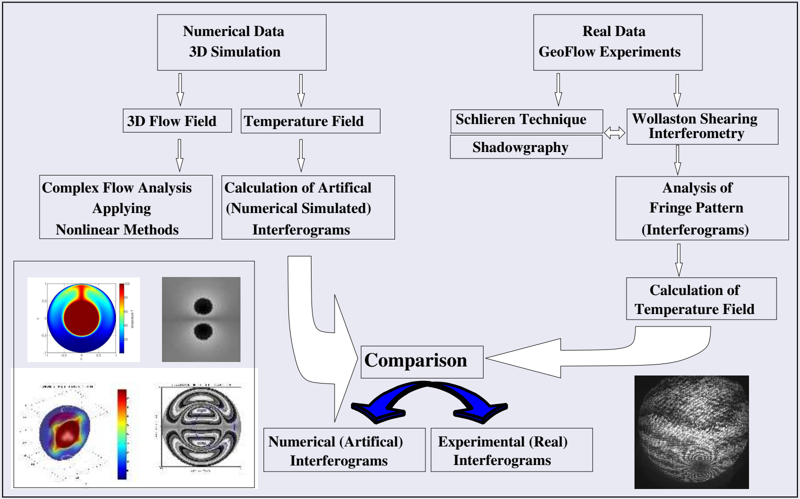


Shared Communication and Data Downlink

Data down link
from ISS to BTU



Numerical and Experimental Data Analysis



Numerically constructed interferogram

- optical path through spherical gap

$$s(T) = \int_{r_i}^{r_o} n(T)\,\mathrm{d}r$$

- phase shift between adjacent rays

$$\Delta s = \int_{r_i}^{r_o} n(T)\,\mathrm{d}r - \int_{r_i}^{r_o} n(T + \Delta T)\,\mathrm{d}r$$

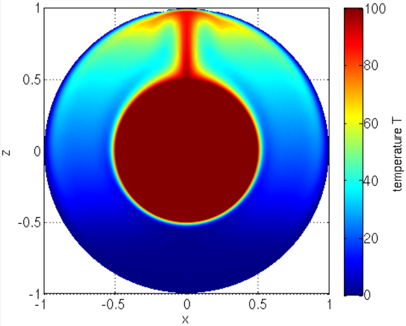
- with linear behaviour $n(T) = aT + b$

$$\frac{\Delta s}{a} = \int_{r_i}^{r_o} T(r, \theta, \phi)\,\mathrm{d}r - \int_{r_i}^{r_o} T(r, \theta + \Delta\theta, \phi)\,\mathrm{d}r$$

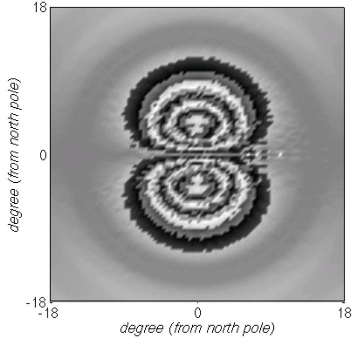
- pattern of bride and dark fringes
  $\Delta s/(\lambda/2) = k_{bride} \pm 2, \pm 4 \ldots$ and $\Delta s/(\lambda/2) = k_{dark} \pm 1, \pm 3 \ldots$

Example of Forward Modelling (3D)

Calculated Temperature Field



Calculated Interferogram

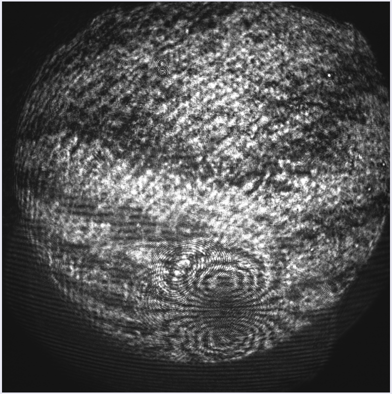


Flow Pattern: Natural Convection (Steady State)

Parameters: $Ra = 8.09 \times 10^6$, $Ta = 0$ $\quad (\Delta T = 15.0\,K,\ \Omega = 0\,Hz)$

Example of Inverse Modelling

Experimental Interferogram



Flow pattern

Natural Convection (Steady State)

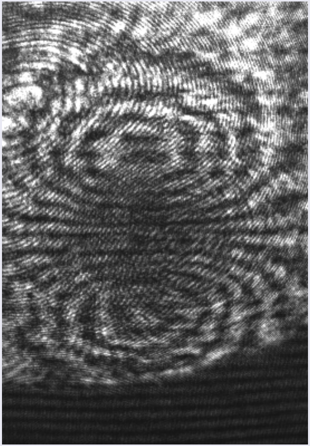
Parameters

$Ra = 2.26 \times 10^6$, $Ta = 0$

$(\Delta T = 4.19\,K\,,\ \Omega = 0\,Hz\,,\ V_{rms} = 0)$

Example of Inverse Modelling

Region of Interest



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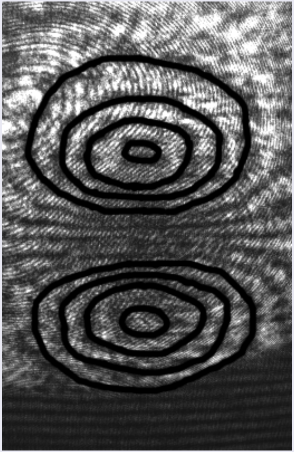
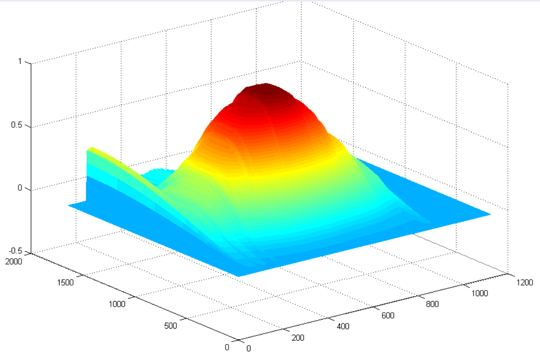


Example of Inverse Modelling

Calculated Integrated Temperature Field



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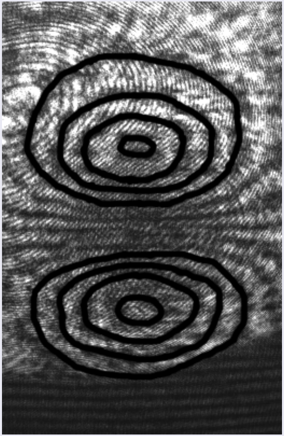

Conclusion and Outlook

Experiment Preparation

- Experiment Hardware ready to go
- Preparative Experiments and Numerics will be finished in autumn 2007

Experiment Operations

- Experiment Flow Plan allows for High Resolution Scan
- Data Downlink and preparative Numerics allow for fast flow pattern analysis

Outlook

2nd flight campaign: *LDV* measurements envisaged