

SIMULATION D'IRM ANGIOGRAPHIQUE PAR EXTENSION DU LOGICIEL JEMRIS



Alexandre FORTIN

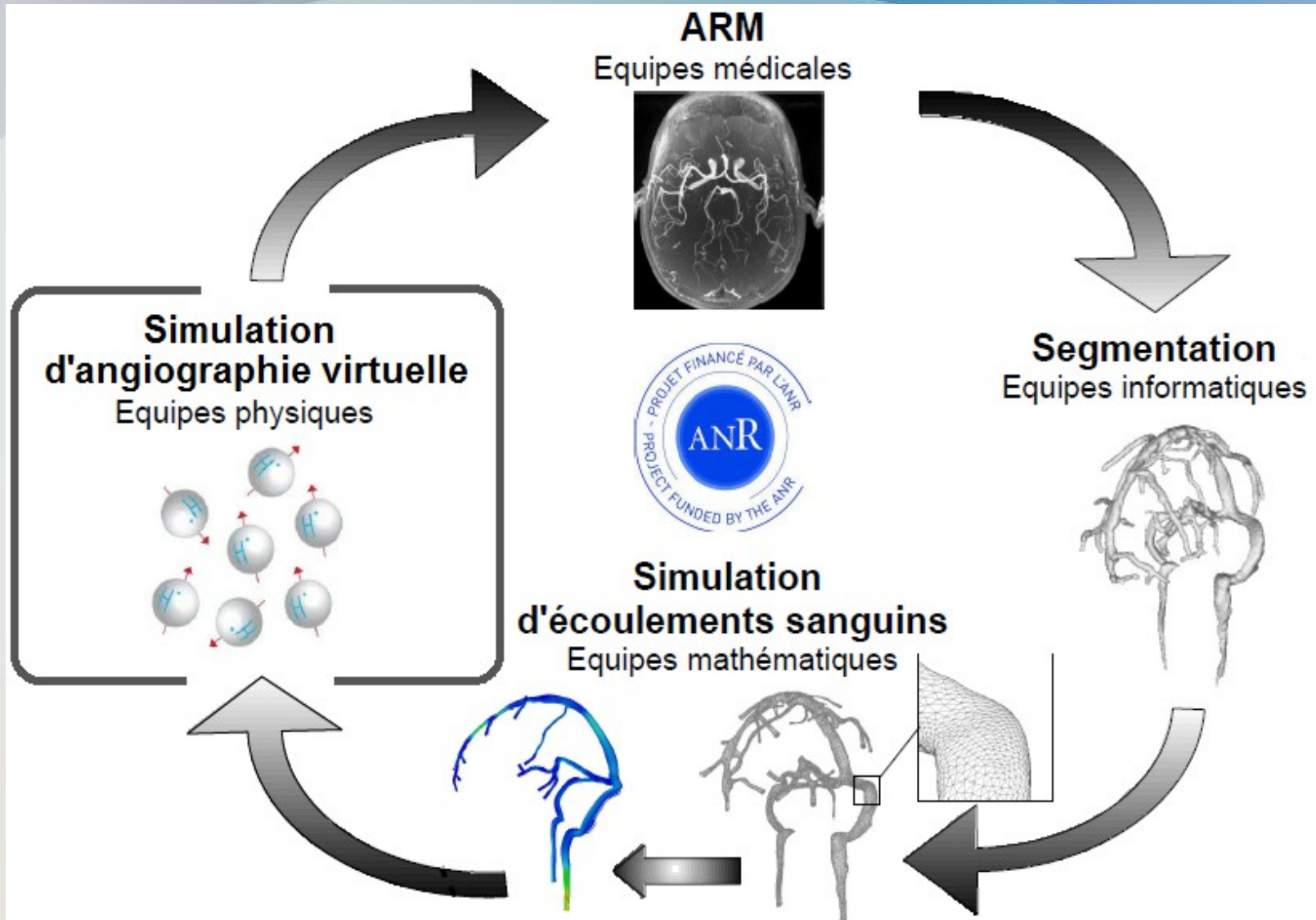
Supervised by Emmanuel DURAND

and Stéphanie SALMON

Laboratoire de Mathématiques de Reims



VIVABRAIN PROJECT



④ PHYSICAL BASIS OF MRI

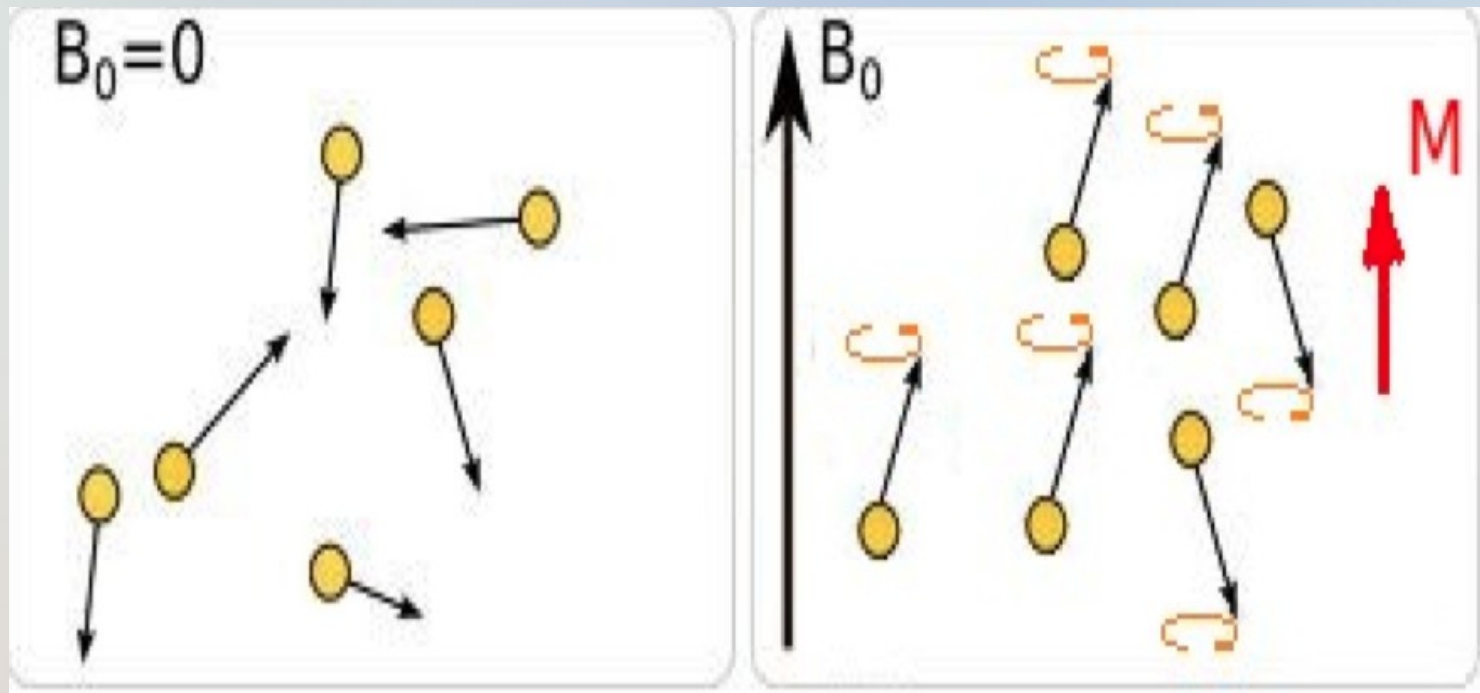
Schematically :

MRI machine = a magnet + radio antennas



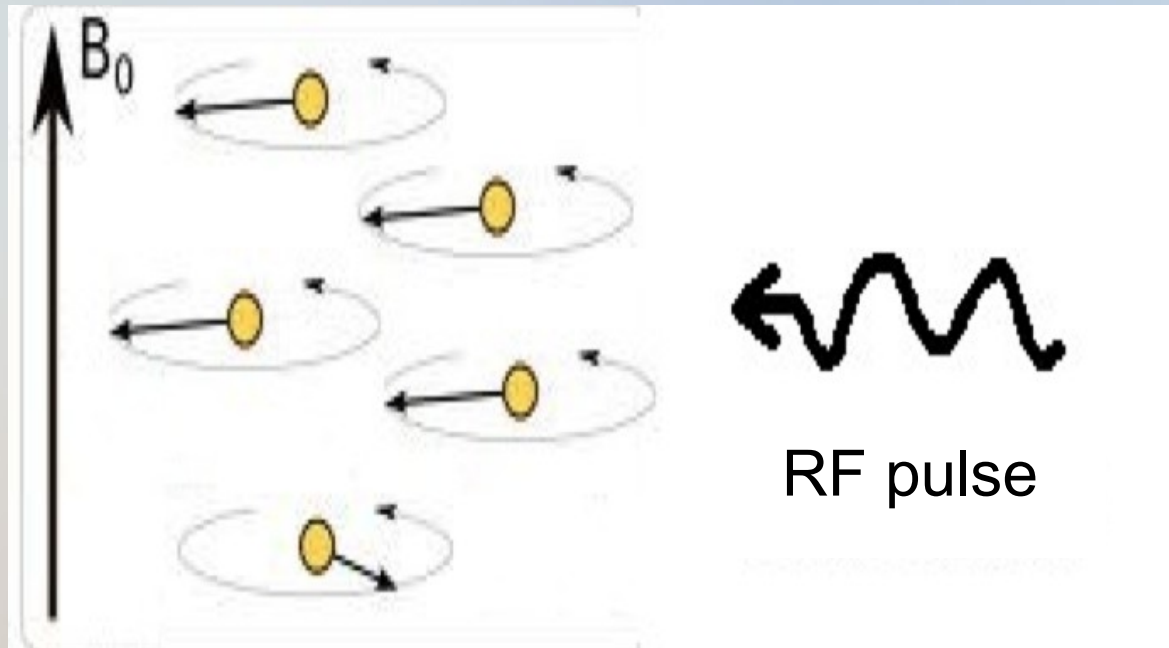
Ⓢ PHYSICAL BASIS OF MRI

A magnet : to generate macroscopic magnetization in tissues



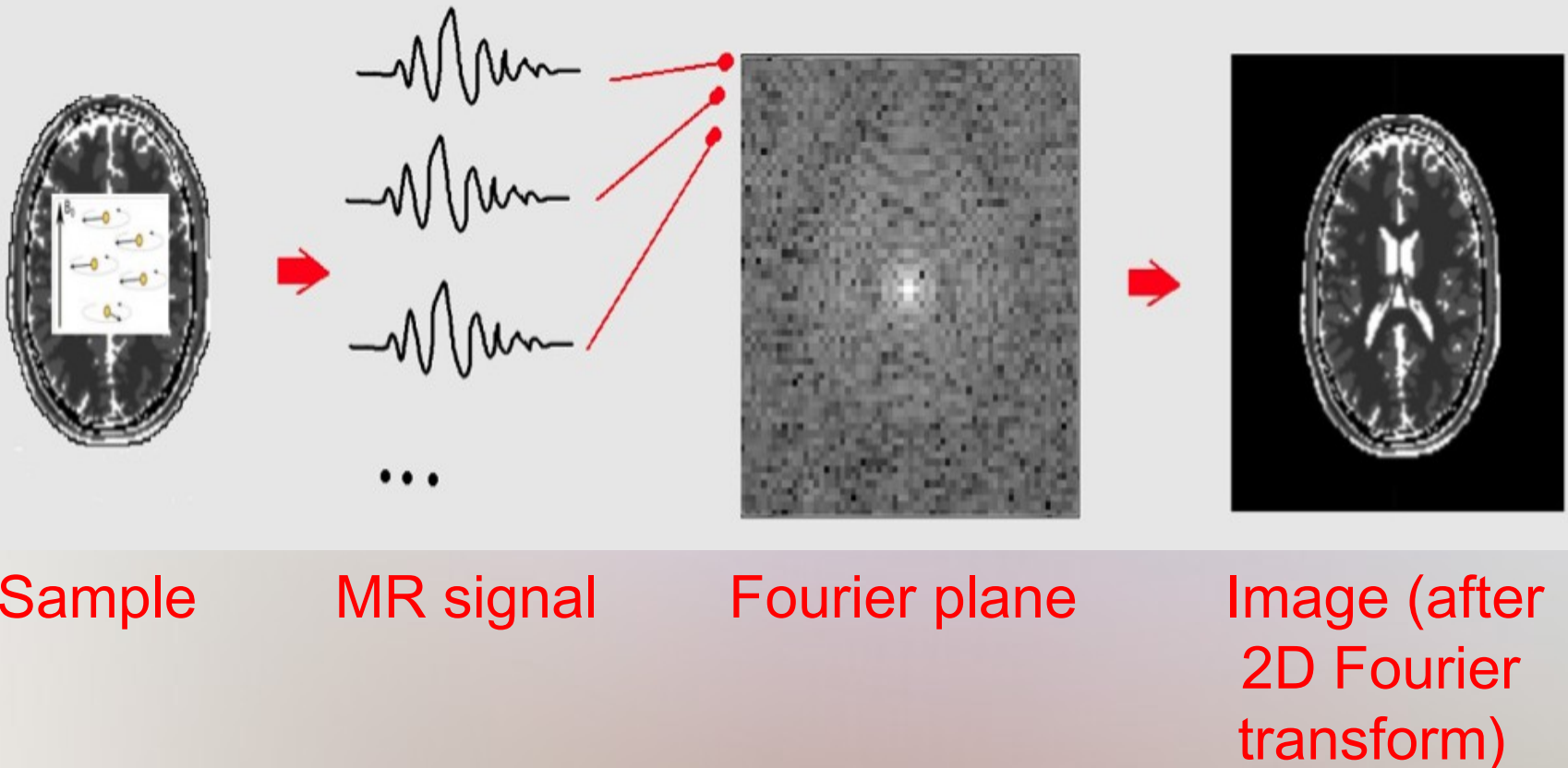
Ⓢ PHYSICAL BASIS OF MRI

Radio antennas : to excite protons with RF pulses and to collect MR signal



④ PHYSICAL BASIS OF MRI

Building image from MR signal



🎮 WHY MRI SIMULATION ?

Motivations :

- ✓ ***Education***, understanding MRI physics
- ✓ *Optimization* of MRI sequences
- ✓ *Validation* of physic models (CFD models for us)
- ✓ *Conducting experiments* difficult in reality
(because of time, ethic, cost...)

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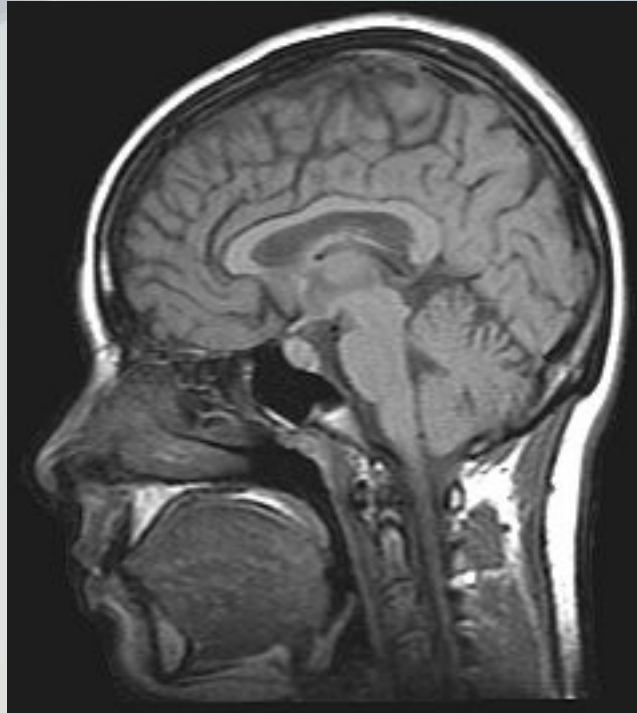
- ✓ ***Education***, understanding MRI physics
- ✓ ***Optimization*** of MRI sequences
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- ✓ ***Conducting experiments*** impossible in vivo
(because of time, ethic, cost...)

🎮 MRI SIMULATORS

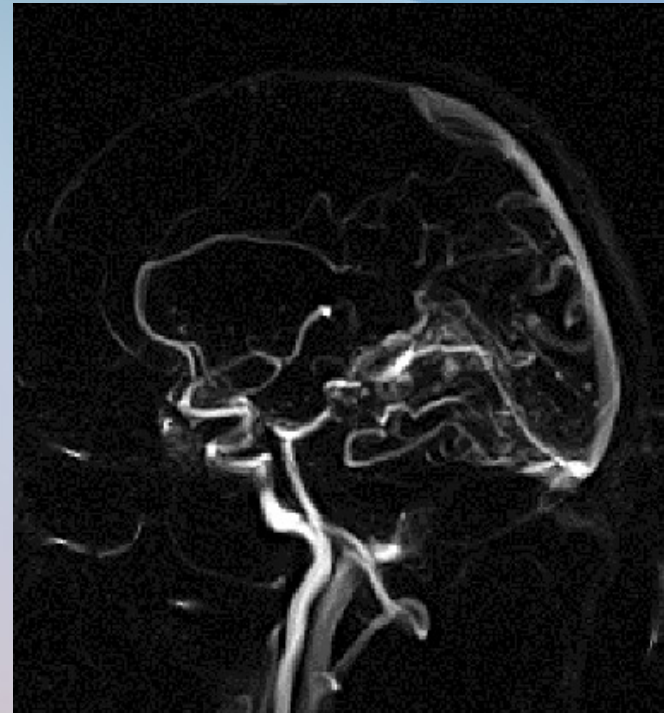
Some advanced MRI simulators (mostly open-source)

JEMRIS, ODIN, SIMRI, POSSUM...

④ POSITION OF THE PROBLEM



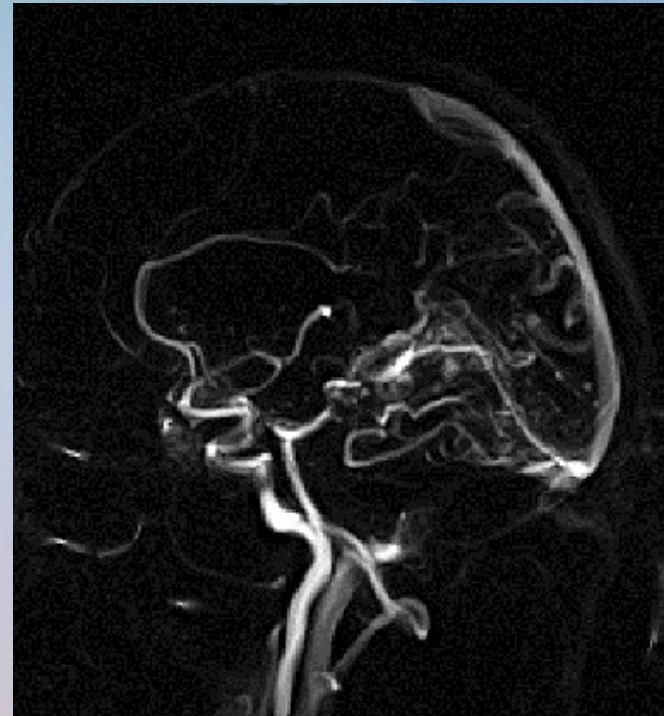
**What simulators can do (static
tissues)**



**What we expect
(angiographic images)**

Ⓜ POSITION OF THE PROBLEM

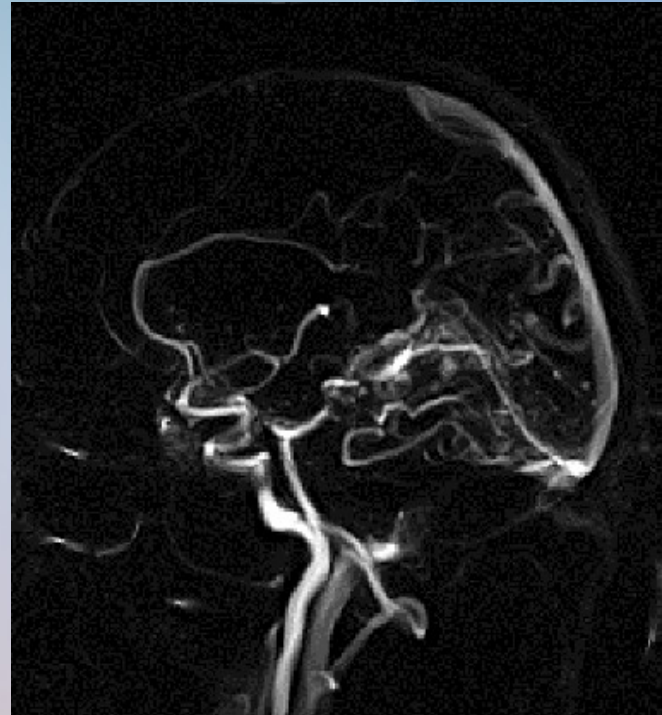
Necessity to simulate ***complex
blood movements***



What we expect
(angiographic images)

Ⓜ POSITION OF THE PROBLEM

Necessity to simulate ***complex blood movements***



What we expect
(angiographic images)



Not implemented
in advanced softwares



FLOW MOTION IN JEMRIS

JEMRIS: Simulation

File Settings

Sequence: epi.xml

Sample: **brain**

T1 x

T2 x

T2* x

M0 x

CS x

slice(s)

{dx,dy} [mm]

__suscept.

ROI [px]

start simu

simulation message dump

```
jemris 2.7 (d69cc4ae)
Model : Bloch , solver = CVODE
Sample : brain , spins = 25841
TxArray : /usr/share/jemris/matlab/uniform.xml
RxArray : /usr/share/jemris/matlab/uniform.xml
Sequence : /usr/local/share/jemris/examples/epi.xml

Simulating |
Simulating |
Simulating | *
Simulating | *
```

increment to store M(t)

concomitant fields [Cmax/B0]

random noise [%]

MotionTrajectory variable

Diffusion Multiply

image space

Phase Encode

Readout (Freq. Enc.)

M0

T1 [msec]

T2 [msec]

Dw [rad/sec]

The screenshot displays the JEMRIS simulation software interface. At the top, the title bar reads 'JEMRIS: Simulation' with standard window controls. Below the title bar is a menu bar with 'File' and 'Settings'. The main window is divided into several sections. On the left, under 'Sequence: epi.xml', there is a 'Sample' dropdown menu set to 'brain'. Below this are input fields for T1, T2, T2*, M0, CS, slice(s), and {dx,dy} [mm], all set to 1, 1, 1, 1, 1, and 1 respectively. There is also a field for '__suscept.' and an 'ROI [px]' field set to 0. A 'start simu' button is located below these fields. In the center-right, a 'simulation message dump' window shows the simulation parameters and a log of the simulation process. To the right of the message dump are several input fields for simulation parameters: 'increment to store M(t)' (0), 'concomitant fields [Cmax/B0]' (0), 'random noise [%]' (0), 'MotionTrajectory variable' (empty), 'Diffusion' (empty), and 'Multiply' (empty). Below these fields is a large 'image space' plot showing a brain slice. To the left of the 'image space' plot are four smaller plots: 'M0', 'T1 [msec]', 'T2 [msec]', and 'Dw [rad/sec]', each showing a brain slice with a color scale. The 'M0' plot has a scale from 0 to 1. The 'T1' plot has a scale from 0 to 2000. The 'T2' plot has a scale from 0 to 300. The 'Dw' plot has a scale from 0 to 1000. The 'image space' plot has a vertical axis labeled 'Phase Encode' and a horizontal axis labeled 'Readout (Freq. Enc.)'.

JEMRIS Version 2.7
Copyright (C) 2006-2013 Tony
Stöcker, Kaveh Vahedipour,
Daniel Pflugfelder

Forschungszentrum
Jülich, Deutschland

④ FLOW MOTION IN JEMRIS

Limit of motions in Jemris

Only *rigid motion* of the *whole sample* (eg to simulate a movement of the patient).



Oscillating sphere (from Stöcker T, Vahedipour K, Pflugfelder D, Shah NJ. High-performance computing MRI simulations.

Magn Reson Med. 2010 Jul;64(1):186-93)

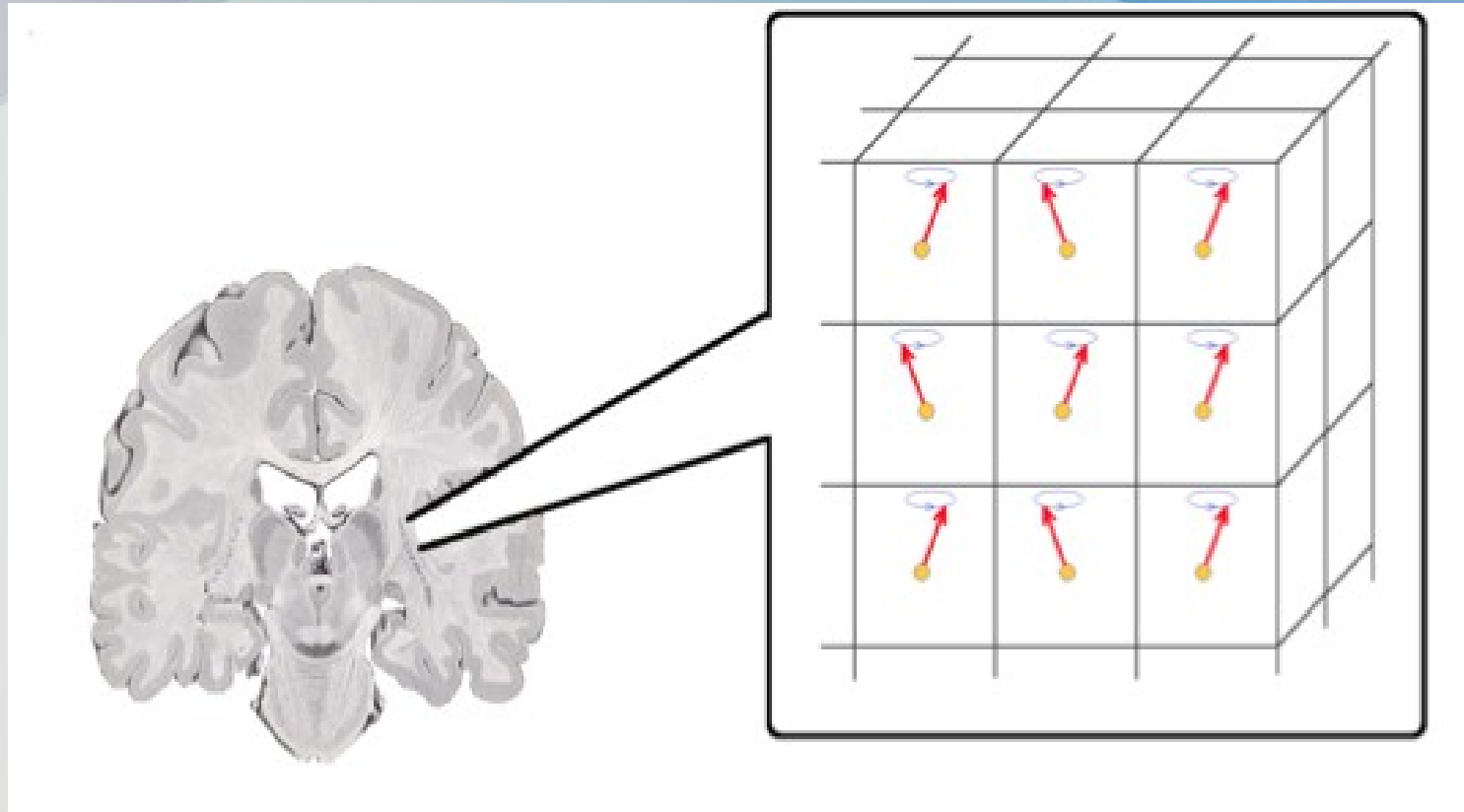
④ HOW TO SIMULATE FLOW MOTION ?

Simulate MRI = Simulate evolution of ***macroscopic magnetization*** of tissues, ie solve an ODE (***Bloch equation***) in every point of the sample.

$$\frac{d \vec{M}}{dt} = \gamma \vec{M} \times \vec{B}$$

(... plus a relaxation term)

④ HOW TO SIMULATE FLOW MOTION ?



Isochromat Summation

⏮ HOW TO SIMULATE FLOW MOTION ?

And for flow motion ?

$$\frac{\partial \vec{M}}{\partial t} + (\vec{V} \cdot \vec{\nabla}) \vec{M} = \gamma \vec{M} \times \vec{B}$$

(... plus relaxation term)

We could express Bloch equation considering **velocity** in each point. But resolution becomes more complex (PDE).

Eulerian approach

⏮ HOW TO SIMULATE FLOW MOTION ?

And for flow motion ?

$$\frac{d \vec{M}}{dt} = \gamma \vec{M} \times \vec{B} \quad (\dots \text{plus relaxation term})$$

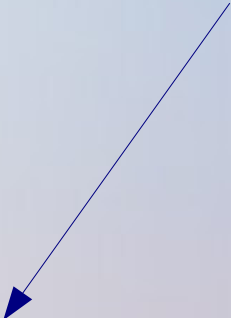
Otherwise, keep the same equation but make evolve **the position** of each flow particle over time.

Lagrangian approach

⏮ HOW TO SIMULATE FLOW MOTION ?

And for flow motion ?

$$\frac{d \vec{M}}{dt} = \gamma \vec{M} \times \vec{B} \quad (\dots \text{ plus relaxation term})$$


$$r = \mathbf{r}_i(t) \Rightarrow \mathbf{B}(t) = B_0 + G(t) \cdot \mathbf{r}_i(t)$$

Lagrangian approach

⏮ HOW TO SIMULATE FLOW MOTION ?

And for flow motion ?

$$\frac{d \vec{M}}{dt} = \gamma \vec{M} \times \vec{B} \quad (\dots \text{plus relaxation term})$$

Advantages : Easy to solve, flexible, possibility to simulate contrast agent injection.

Lagrangian approach

▶ FLOW MOTION IN JEMRIS

Limit of motions in Jemris

One *unique trajectory* can be specified for the *whole sample* in Jemris...

but...

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Only *rigid motion* of the *whole sample* (eg to simulate a movement of the patient).



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▶ FLOW MOTION IN JEMRIS

Limit of motions in Jemris

One *unique trajectory* can be specified for the *whole sample* in Jemris...

but...

Simulating flow motion suppose to know the *individual trajectory of each particle*.

④ FLOW MOTION IN JEMRIS

Limit of motions in Jemris

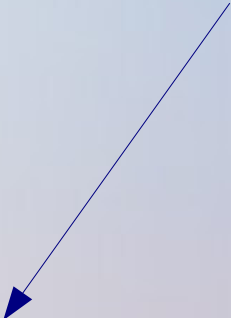
=> Necessity to ***modify Jemris code*** in order to take multiple trajectories as input

Simulating flow motion suppose to know the ***individual trajectory of each particle.***

④ HOW TO SIMULATE FLOW MOTION ?

And for flow motion ?

$$\frac{d \vec{M}}{dt} = \gamma \vec{M} \times \vec{B} \quad (\dots \text{plus relaxation term})$$


$$r = \mathbf{r}_i(t) \Rightarrow \mathbf{B}(t) = B_0 + G(t) \cdot \mathbf{r}_i(t)$$

Lagrangian approach



FIRST RESULTS

Simple test :
4 spins with 4 different
trajectories

JEMRIS: Simulation

File Settings

Sequence:

simulation message dump
empty

Sample: 2D sphere

T1 [ms] 1000
T2 [ms] 100
T2* [ms] 100
M0 1
CS [rad/s] 0
Radius [mm] 50
{dx,dy} [mm] 1

start simu

ROI [px] 0

increment to store M(t) 0
concomitant fields [Gmax/B0] 0
random noise [%] 0
MotionTrajectory variable
Diffusion Multiply

image space

Phase Encode

Readout (Freq. Enc.)

__EPI reordering?
__zoom Image

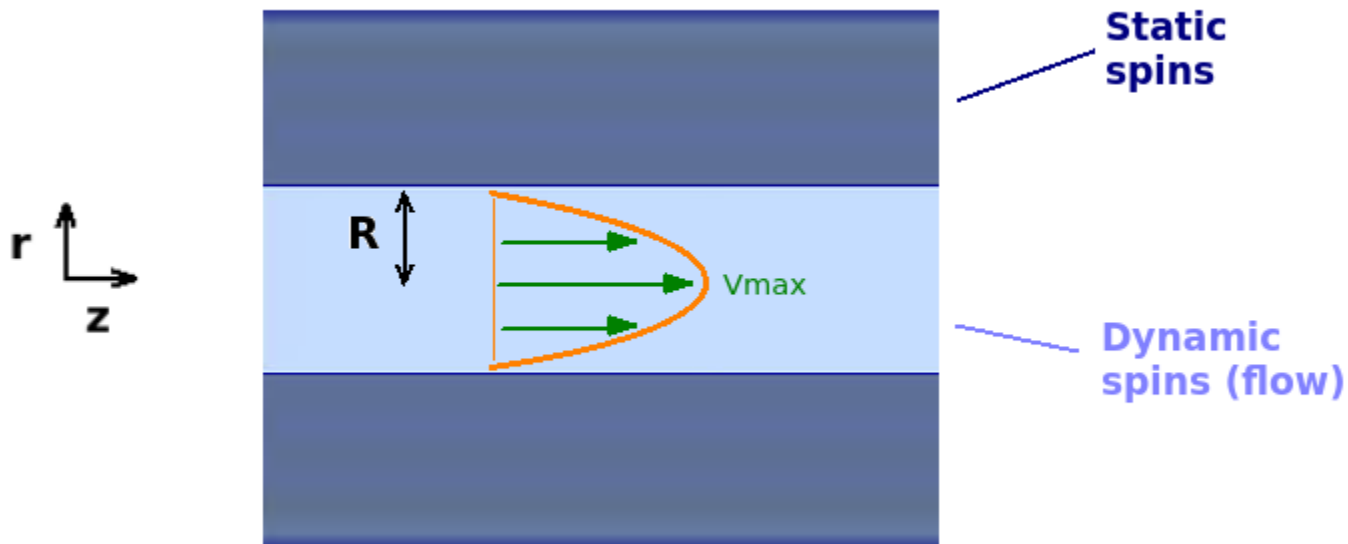
Sample

🎮 FIRST RESULTS

Simulation of phase contrast MRI

Input data : Synthetic trajectories of Poiseuille.

$$z_i(t) = z_i(0) + V_{\max} \cdot \left(1 - \left(r_i/R\right)^2\right) \cdot t$$



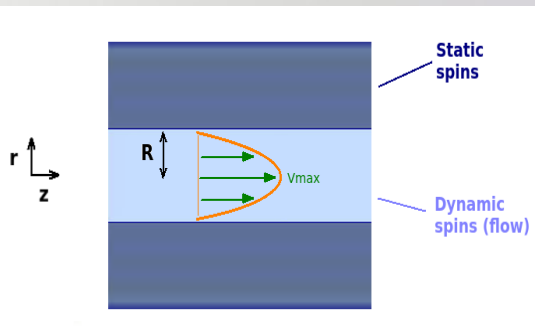
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Trajectories



JEMRIS

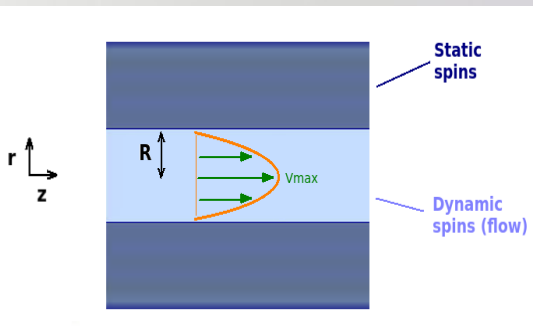
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Trajectories



**MRI sequence
(phase contrast)**



JEMRIS



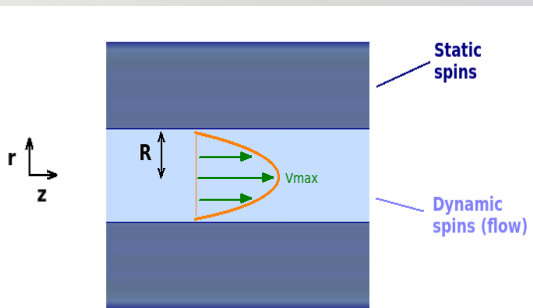
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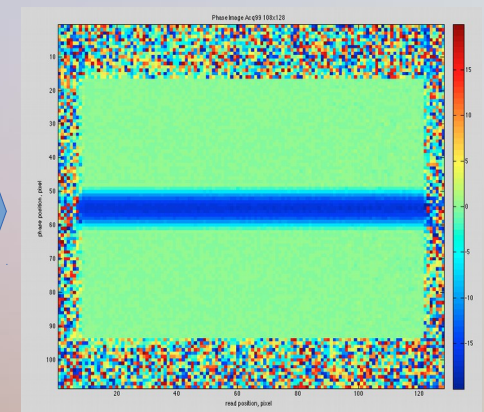
Trajectories



MRI sequence
(phase contrast)

JEMRIS

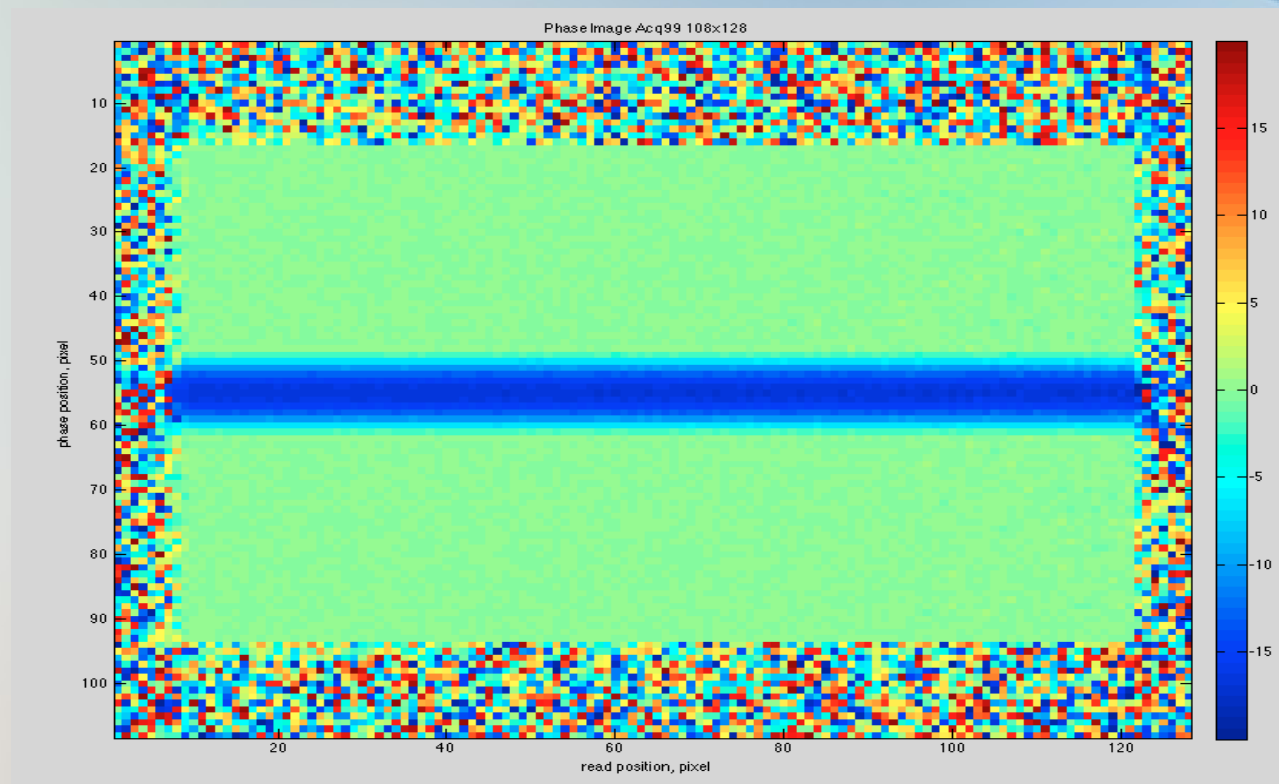
Image





FIRST RESULTS

Simulation of phase contrast MRI



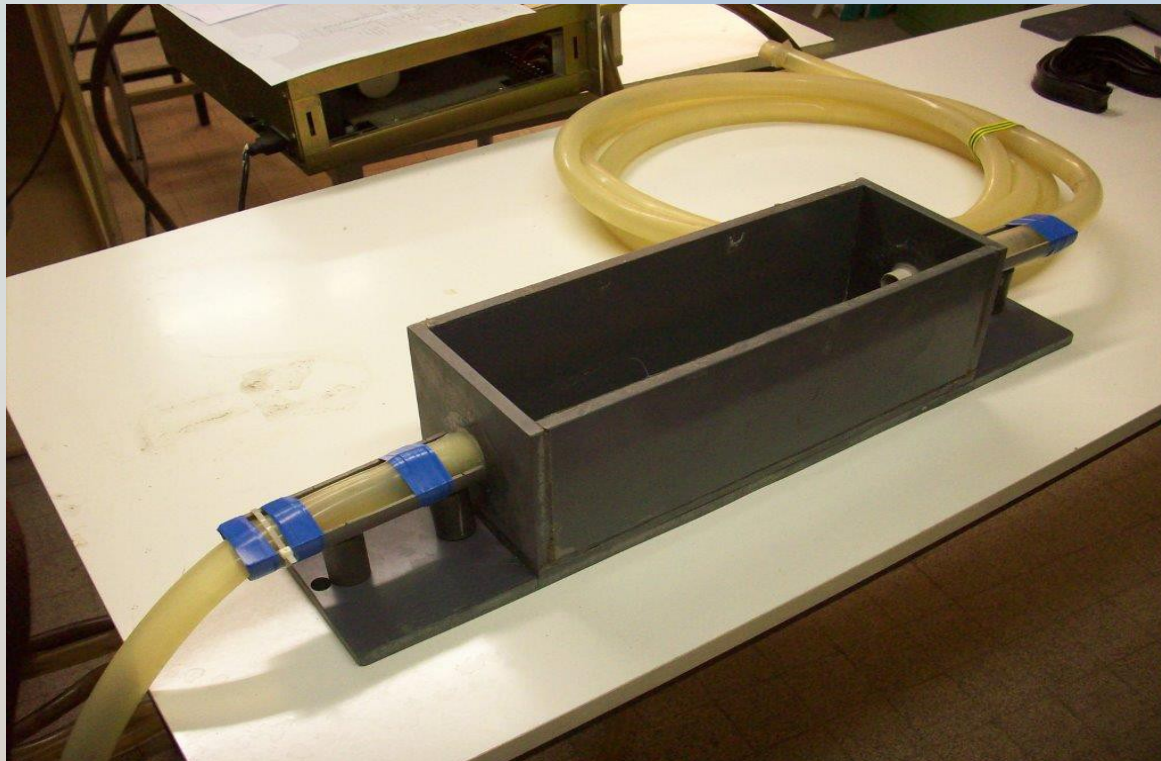
Velocity map



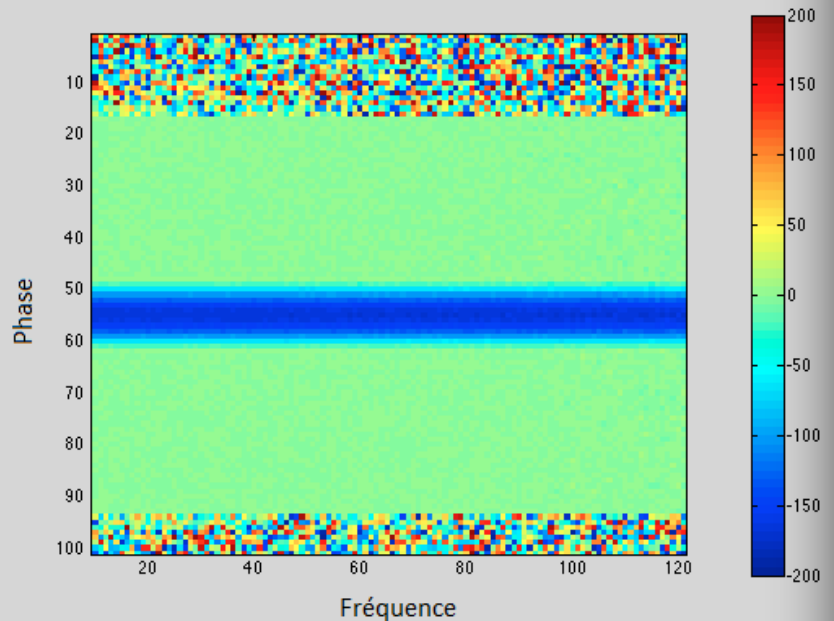
EXPERIENCES

Comparison to experimental images

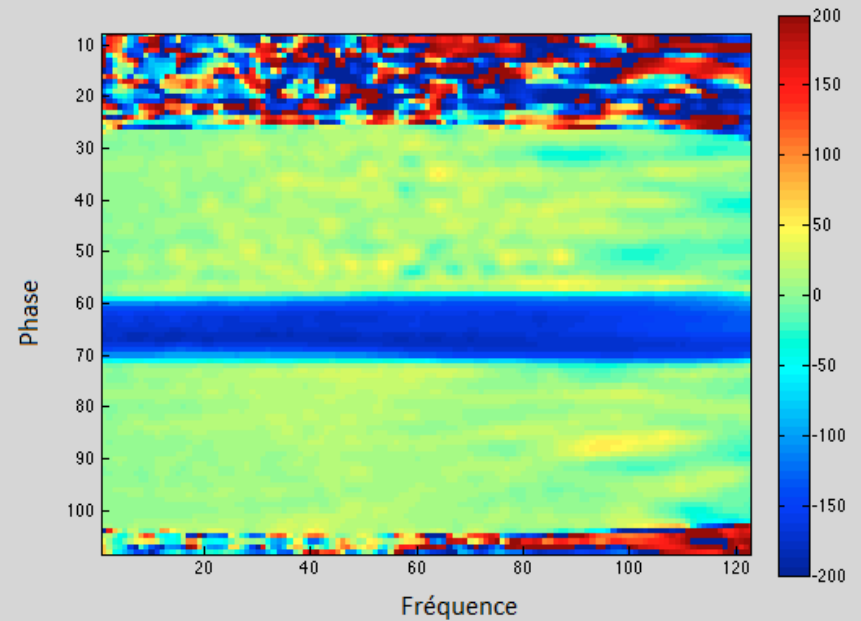
Hydrodynamic pulsed bench.



⏮ COMPARISON

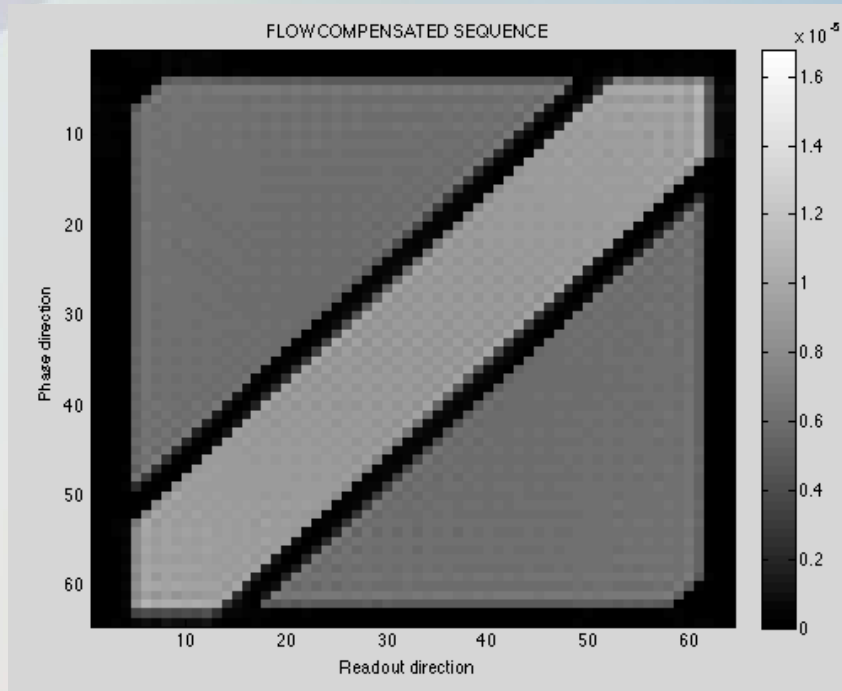


SIMULATION

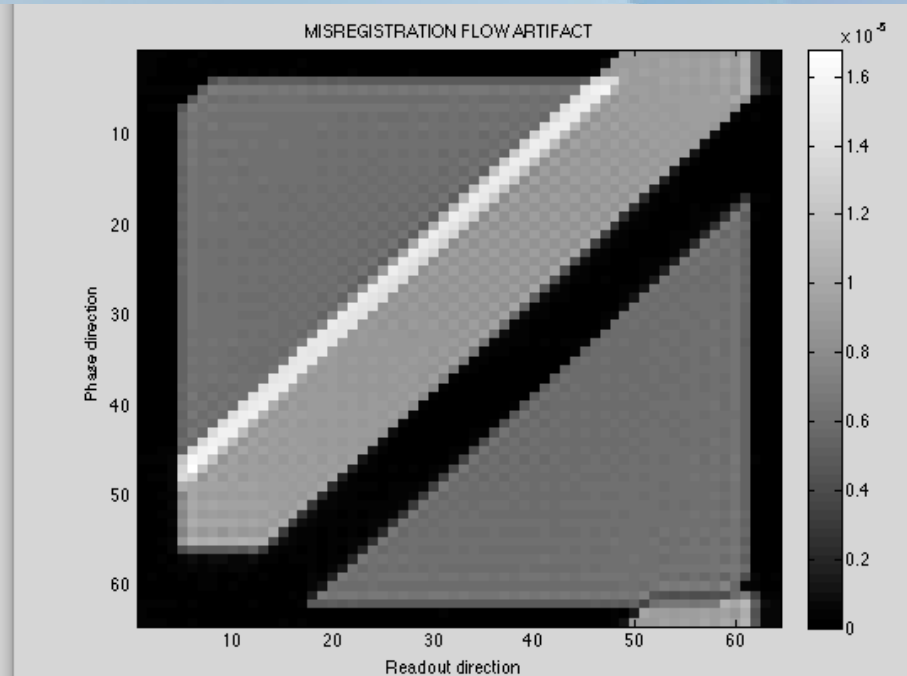


HYDRO BENCH

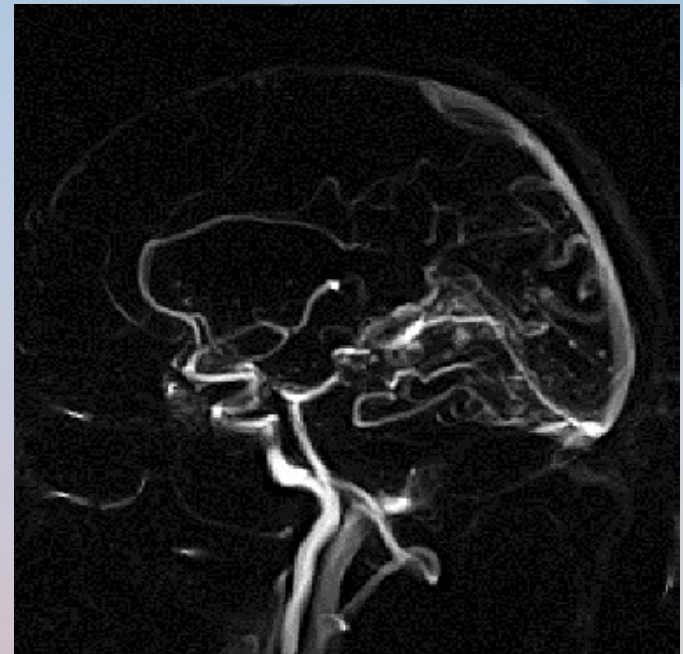
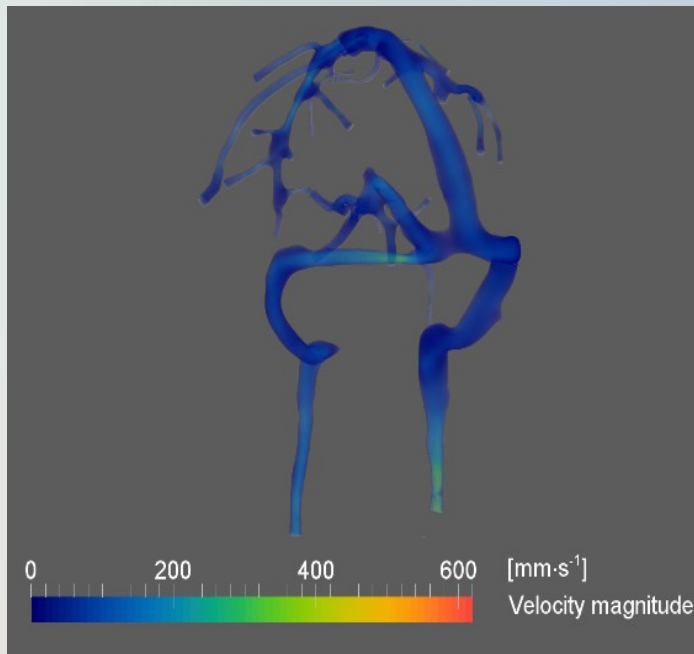
Ⓢ OTHER SIMULATIONS : FLOW ARTIFACTS



« Normal » image with
flow compensation



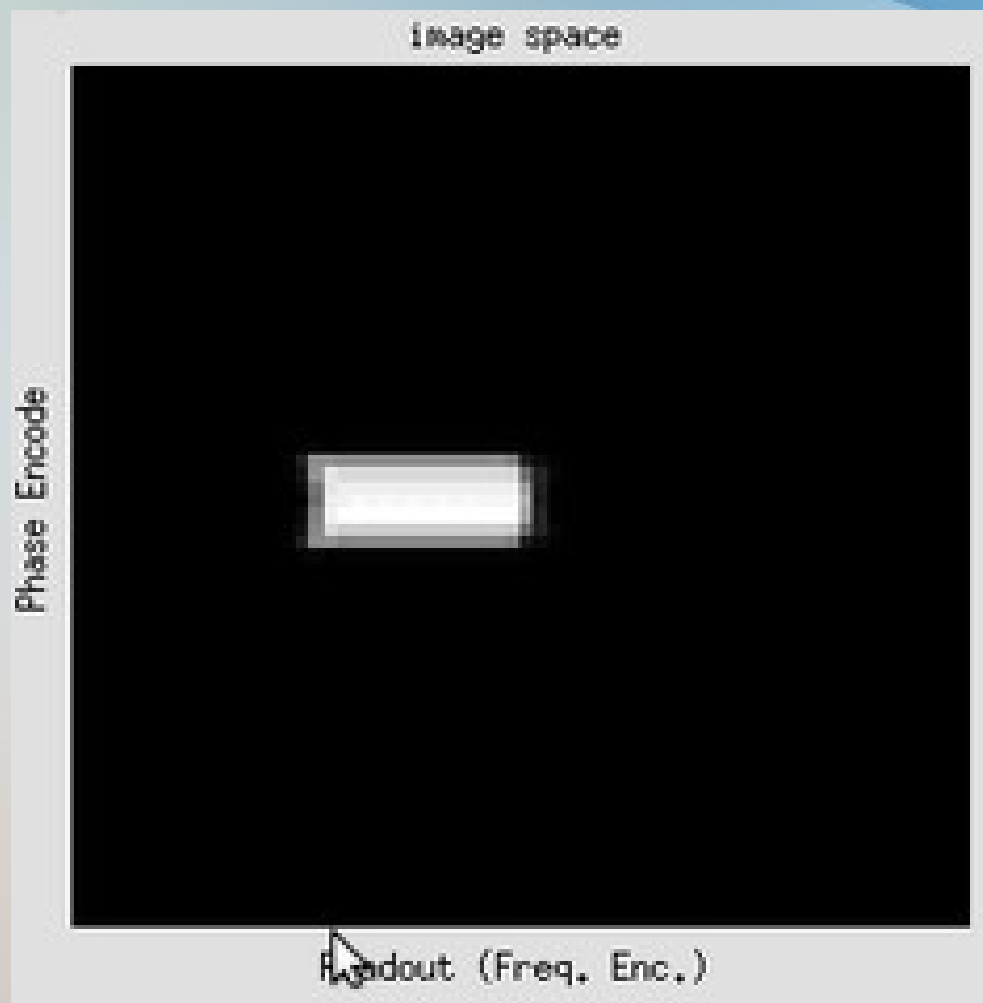
Misregistration artifact with
uncompensated sequence



Simulate images of *cerebral vasculature* with velocities obtained by *Computational Fluid Dynamic* (numerical solving of Navier-Stokes equations)



PROSPECT



- Use Jemris to study errors in PC concerning flow rate and vessels diameter measurement
- Eventually couple this measures with other well-known source of errors, such as concomitant fields or non uniform gradients

THANK YOU !

AND THANKS TO JEMRIS DEVELOPERS...

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Jemris website: <http://www.jemris.org>