SIMULATION D'IRM ANGIOGRAPHIQUE
PAR EXTENSION DU LOGICIEL JEMRIS

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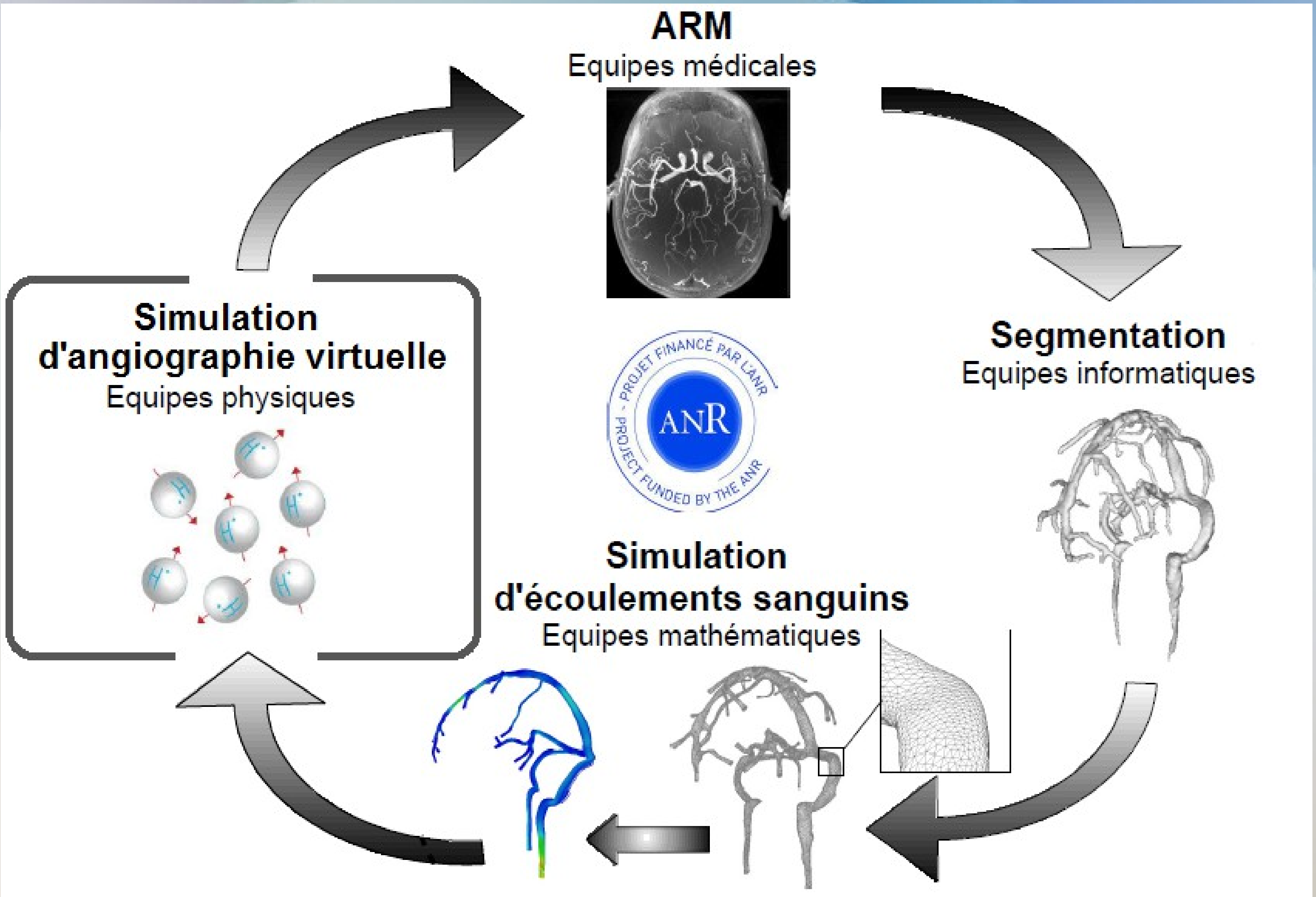
VIVABRAIN PROJECT



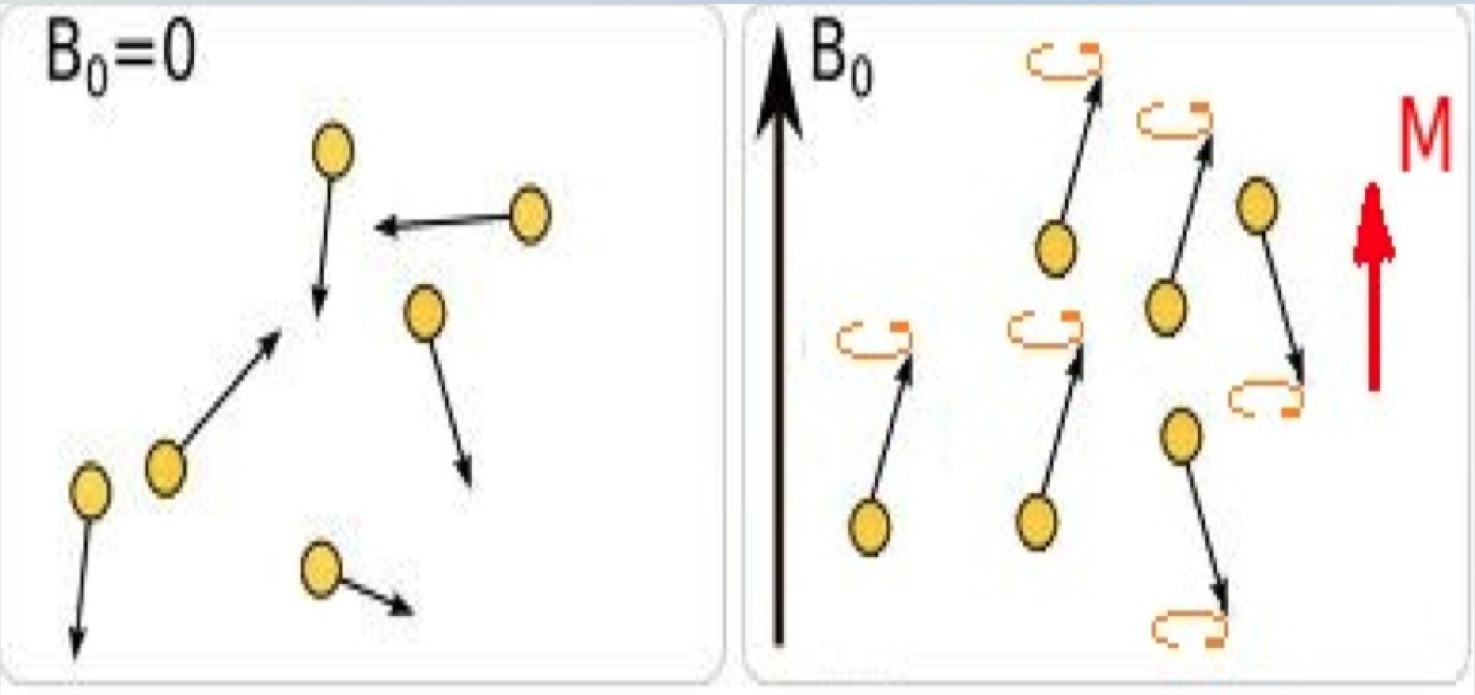
PHYSICAL BASIS OF MRI

Schematically :

MRI machine = a **magnet** + **radio antennas**

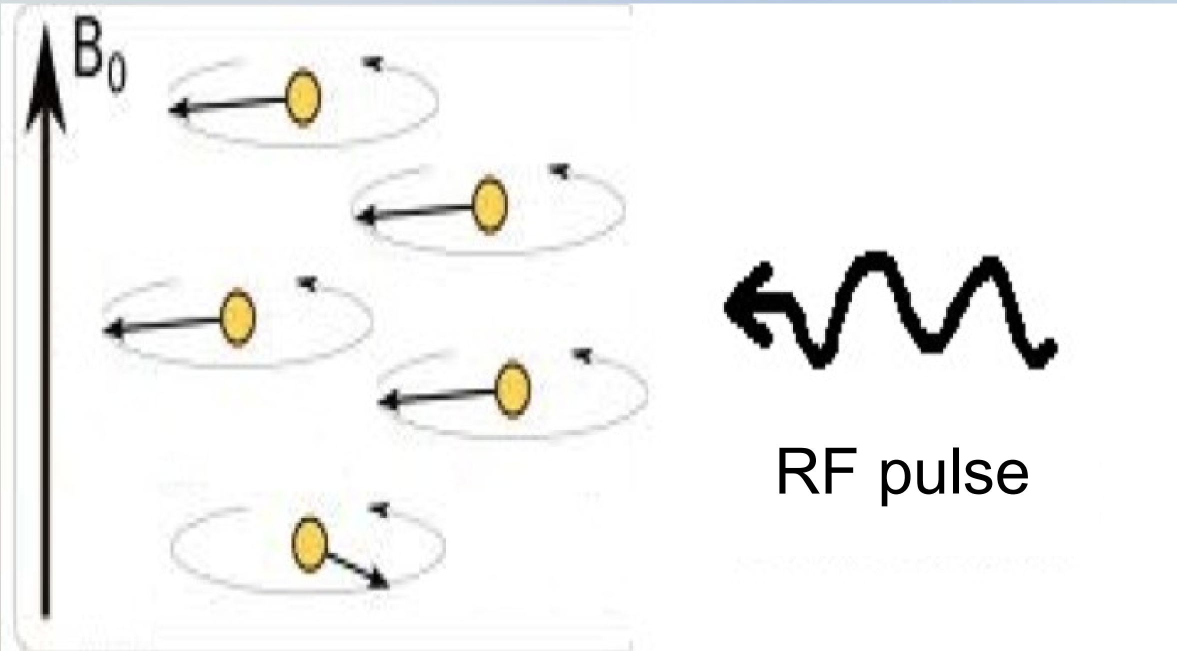
PHYSICAL BASIS OF MRI

 # A magnet : to generate macroscopic magnetization in tissues



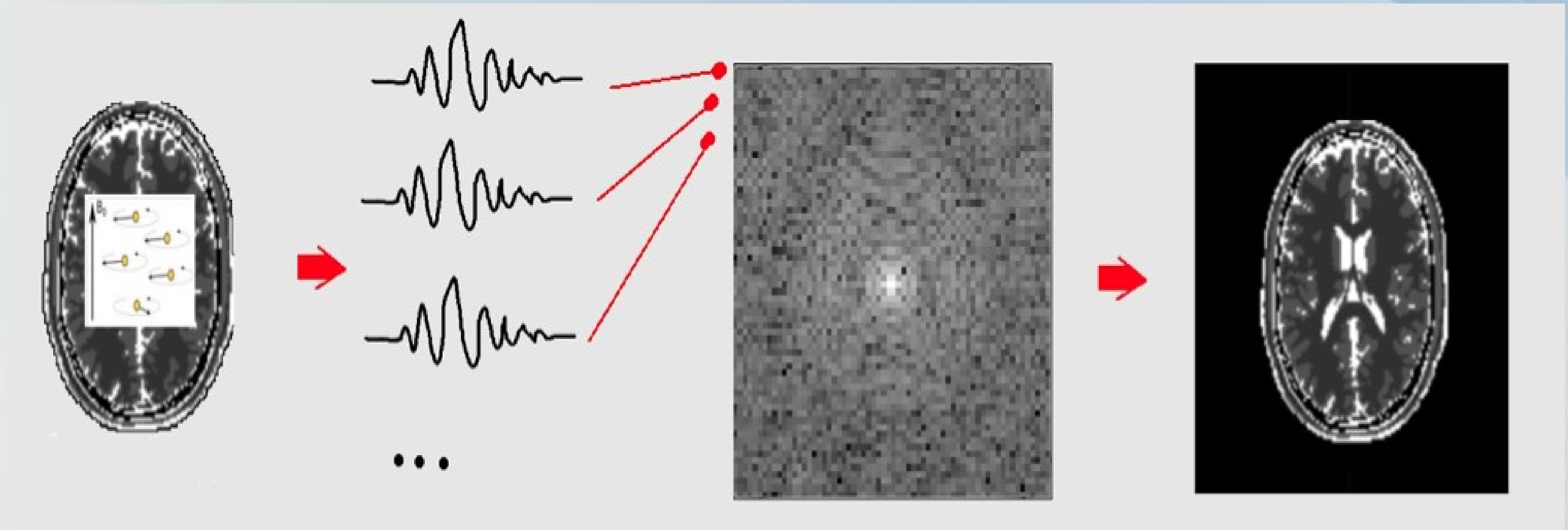
PHYSICAL BASIS OF MRI

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



PHYSICAL BASIS OF MRI

Building image from MR signal



Sample   MR signal   Fourier plane   Image (after 2D Fourier transform)

WHY MRI SIMULATION ?

<u>**Motivations :**</u>

- ✔ ***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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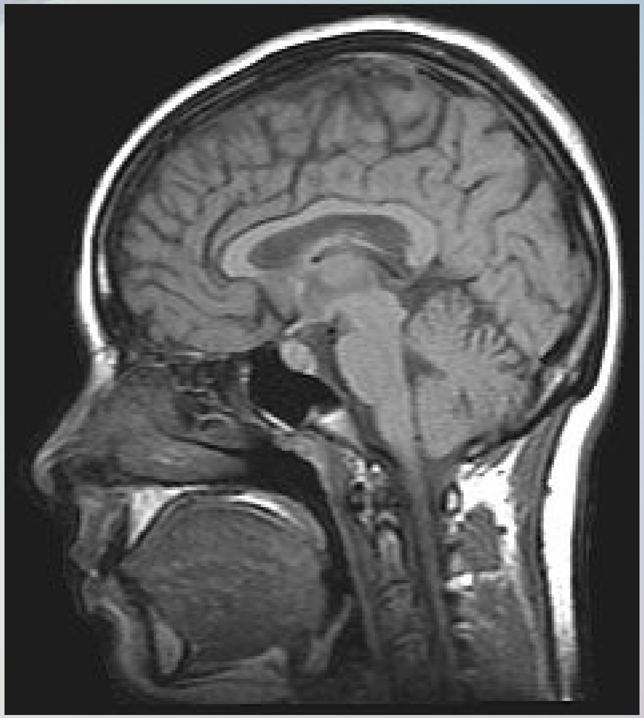
MRI SIMULATORS

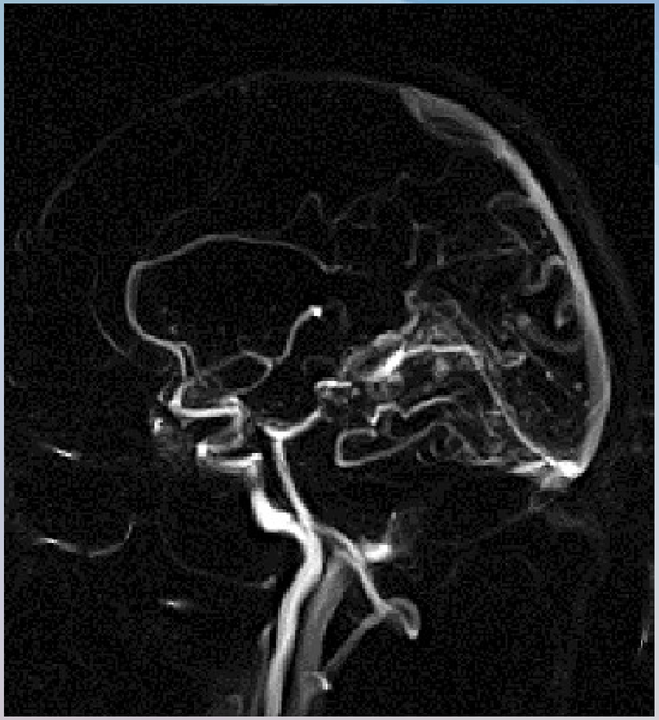
<u>Some advanced MRI simulators</u> (mostly open-source)

JEMRIS, ODIN, SIMRI, POSSUM…

POSITION OF THE PROBLEM



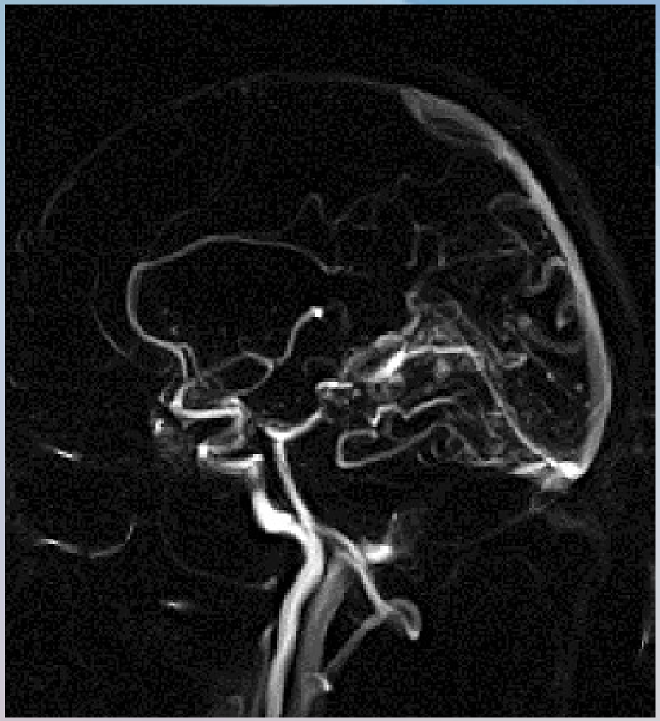
What simulators can do (static tissues)



What we expect (angiographic images)

POSITION OF THE PROBLEM

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



What we expect

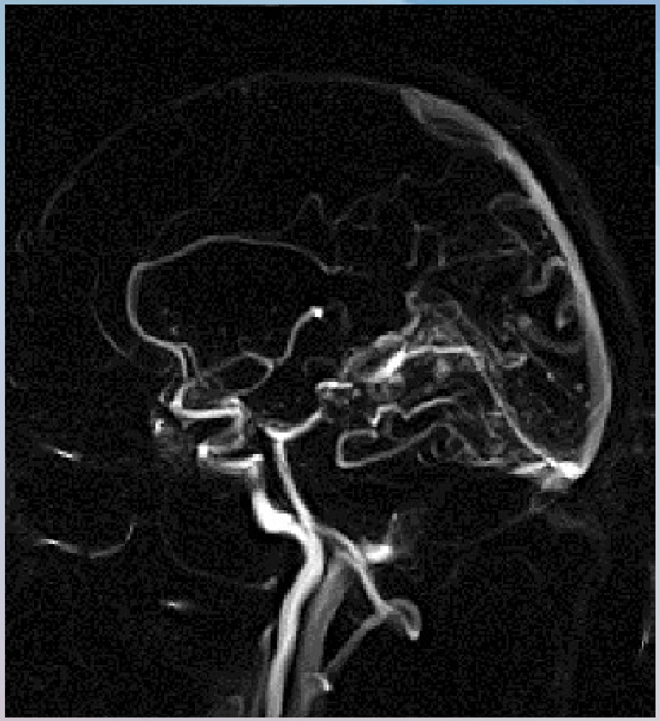
(angiographic images)

POSITION OF THE PROBLEM

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

Not implemented

in advanced softwares



What we expect

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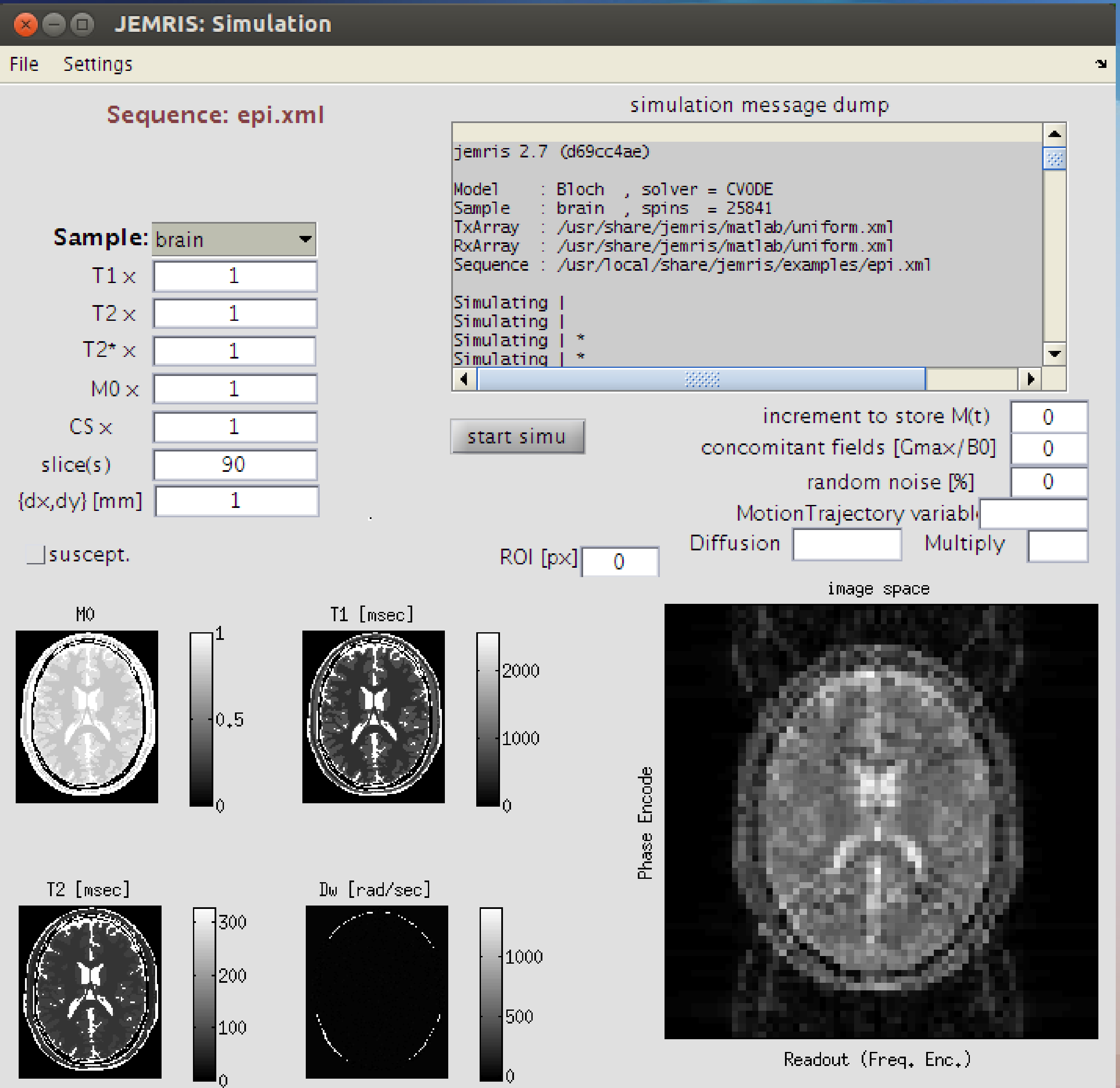
FLOW MOTION IN JEMRIS



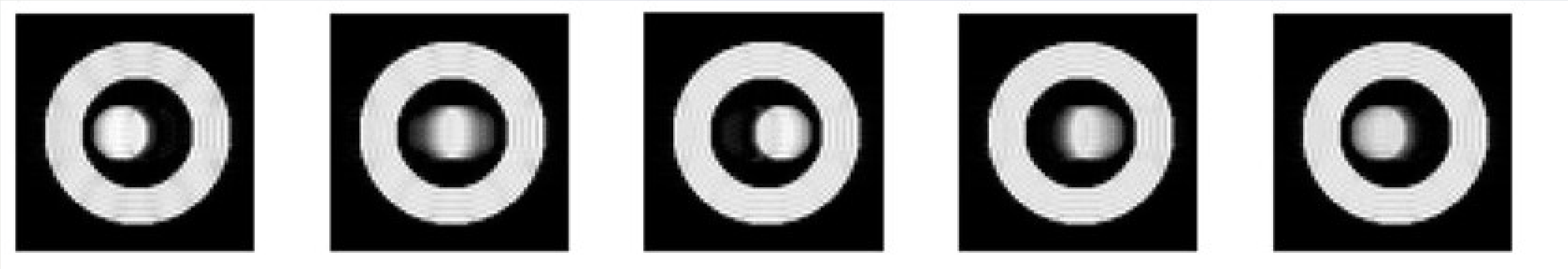
JEMRIS Version 2.7
Copyright (C) 2006-2013 Tony Stöcker, Kaveh Vahedipour, Daniel Pflugfelder

Forschungszentrum Jülich, Deutschland

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)*

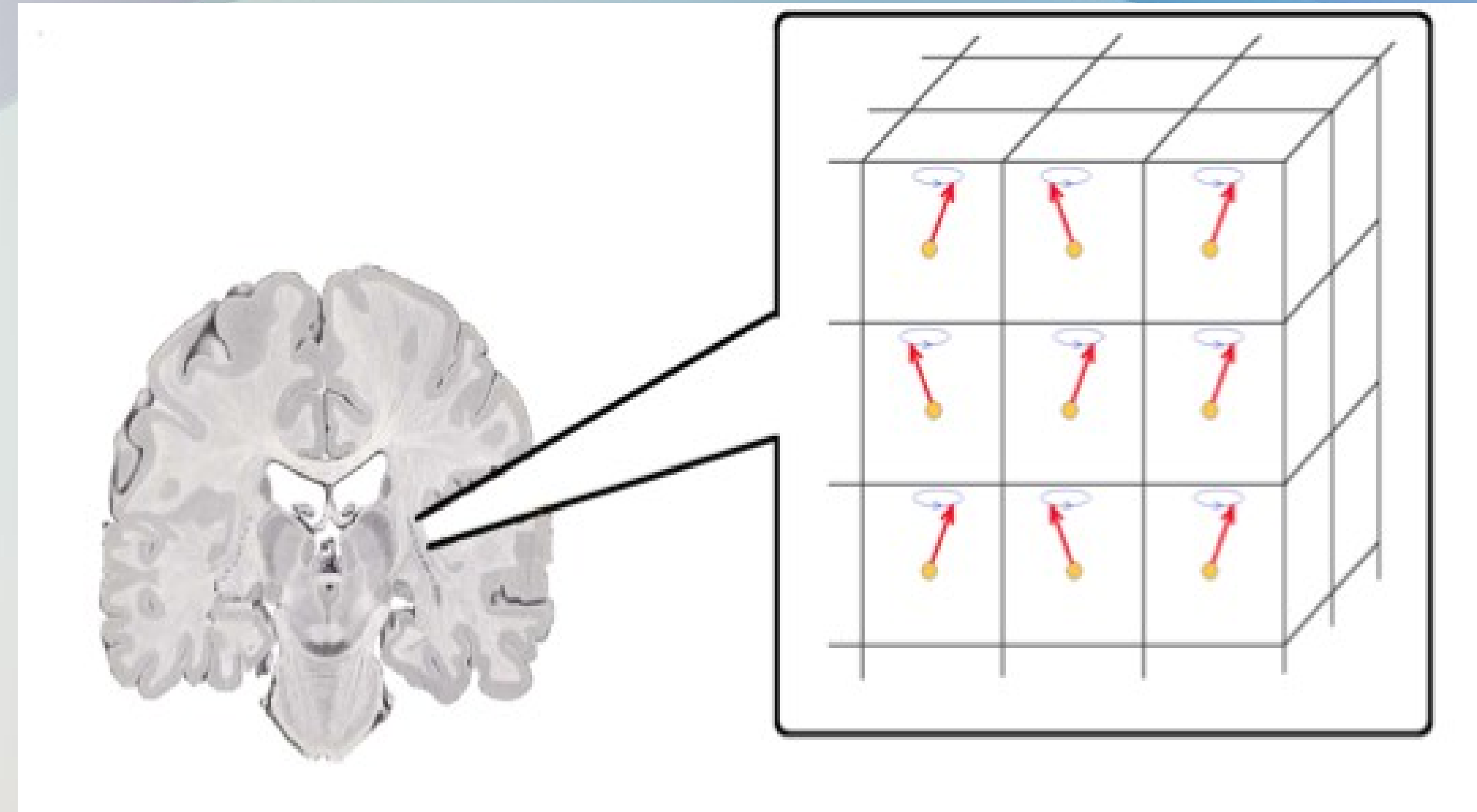
HOW TO SIMULATE FLOW MOTION ?

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

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

(… plus a relaxation term)

HOW TO SIMULATE FLOW MOTION ?



Isochromat Summation

HOW TO SIMULATE FLOW MOTION ?

<u>And for flow motion ?</u>

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

(… 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 ?

<u>And for flow motion ?</u>

$$\frac{d\vec{M}}{dt} = \gamma \vec{M} \, x \, \vec{B}$$ (... 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 ?

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

(... plus relaxation term)

$r = \mathbf{r_i(t)} \Rightarrow B(t) = B_o + G(t).\mathbf{r_i(t)}$

Lagrangian approach

HOW TO SIMULATE FLOW MOTION ?

<u>And for flow motion ?</u>

$$\frac{d\vec{M}}{dt} = \gamma \vec{M} \, x \, \vec{B}$$ (… 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

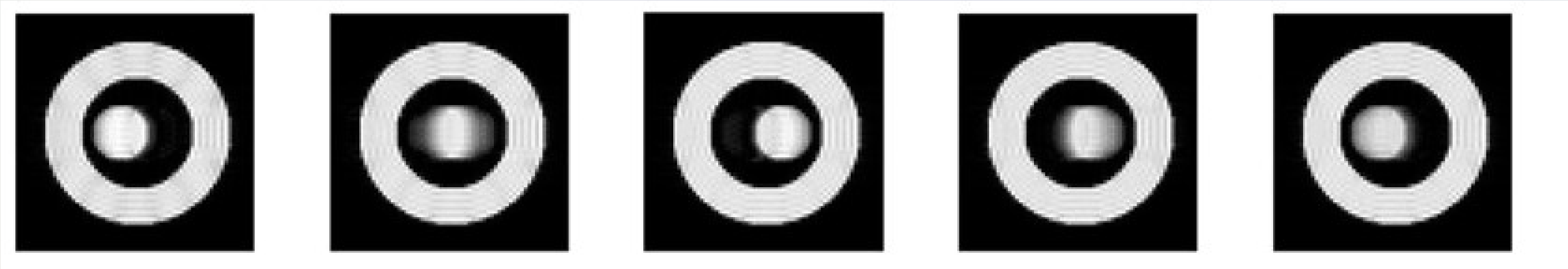
One ***unique trajectory*** can be specified for the ***whole sample*** in Jemris…

but…

FLOW MOTION IN JEMRIS

Limit of motions in Jemris

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



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FLOW MOTION IN JEMRIS

<u>**Limit of motions in Jemris**</u>

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***.

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***.

HOW TO SIMULATE FLOW MOTION ?

And for flow motion ?

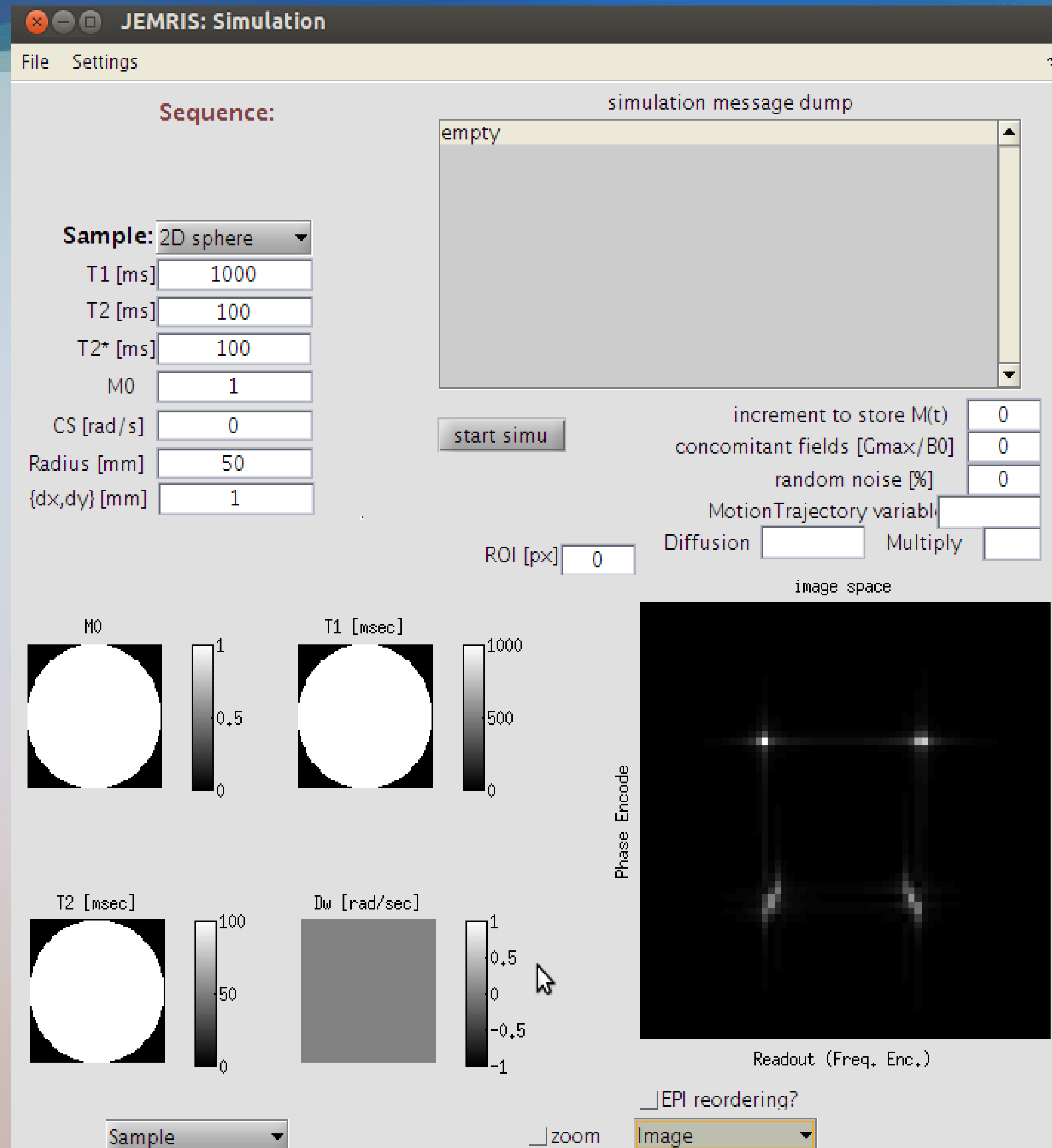
$$\frac{d\vec{M}}{dt} = \gamma \vec{M} \, x \, \vec{B}$$ (... plus relaxation term)

$r = r_i(t) \;\Rightarrow\; B(t) = B_0 + G(t).r_i(t)$

Lagrangian approach

FIRST RESULTS

Simple test :
4 spins with 4 different trajectories

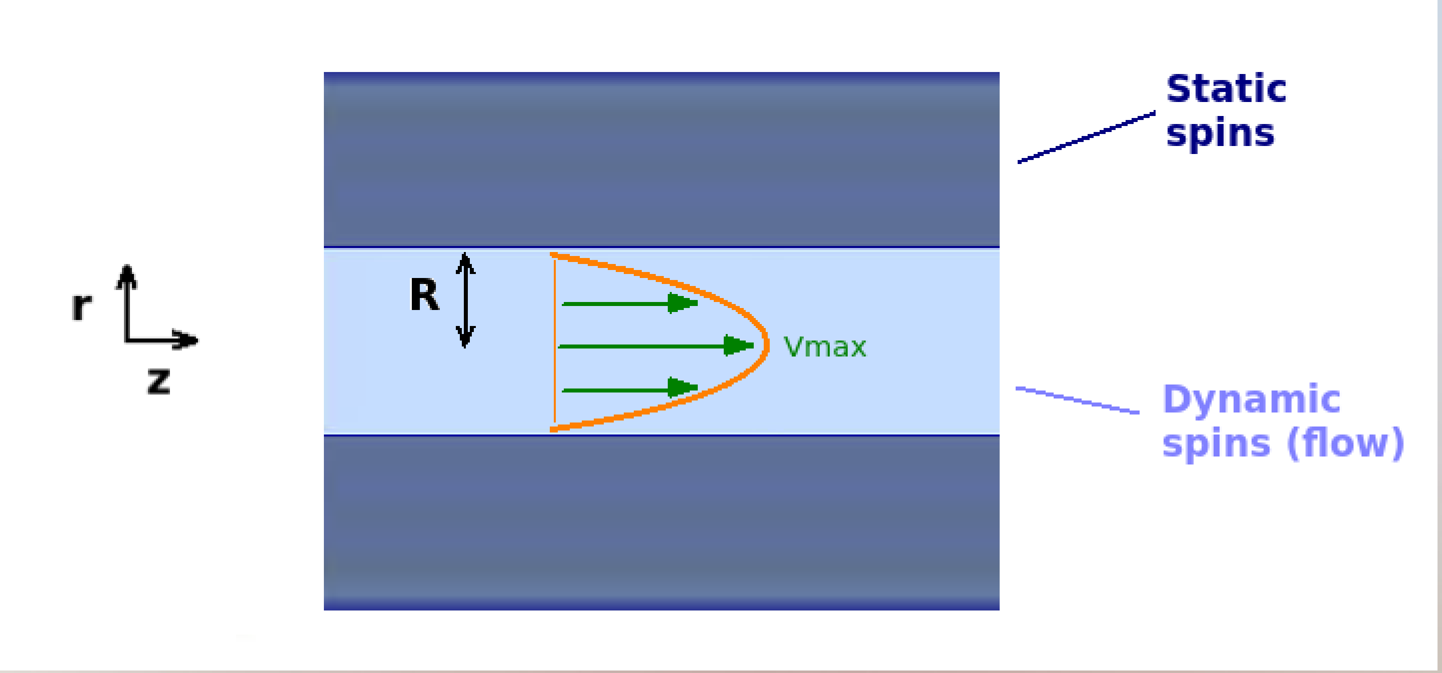


FIRST RESULTS

Simulation of phase contrast MRI

Input data : Synthetic trajectories of Poiseuille.

$$z_i(t) = z_i(0) + Vmax \,.\, (1 - (r_i/R)^2) \,.\, t$$



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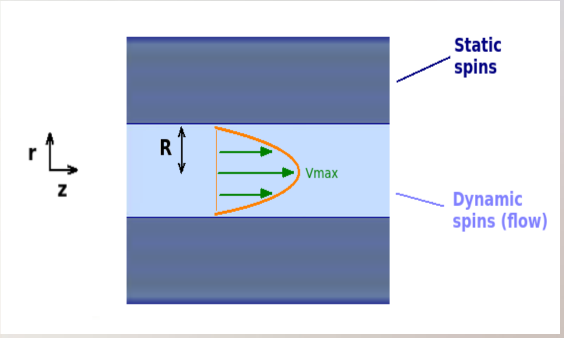
Trajectories



JEMRIS

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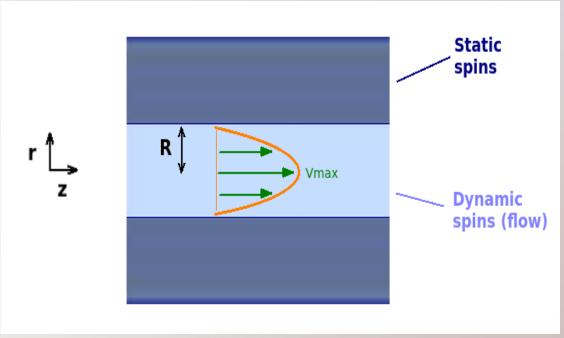
MRI sequence
(phase contrast)

Trajectories



JEMRIS

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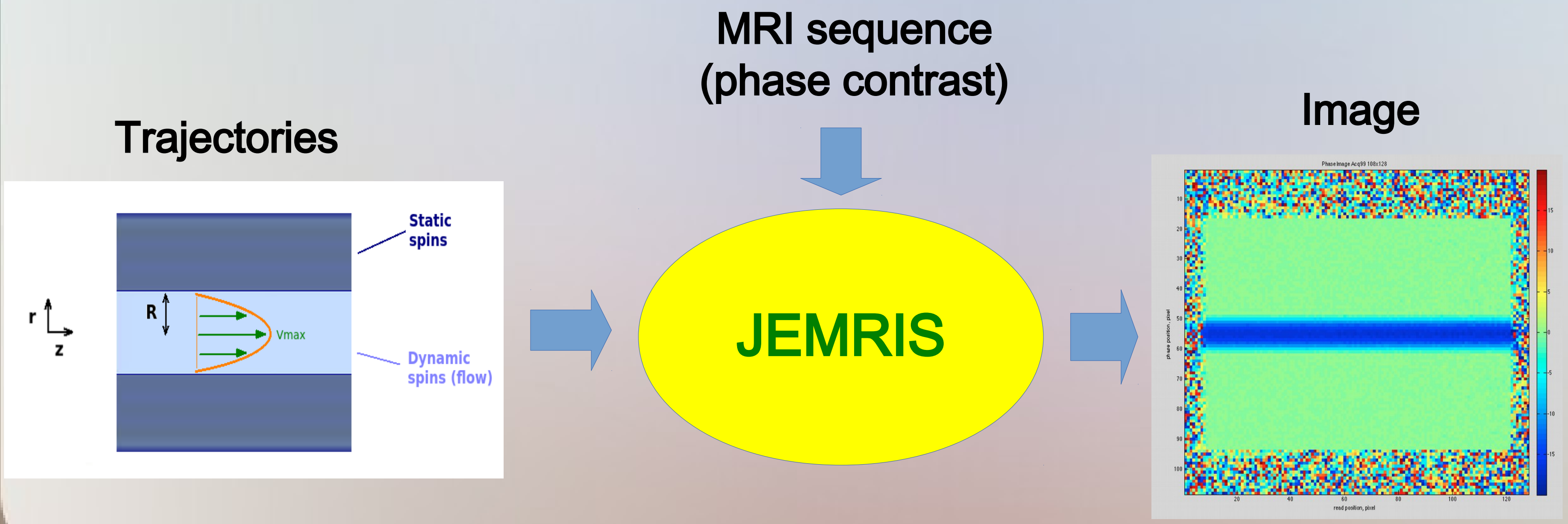

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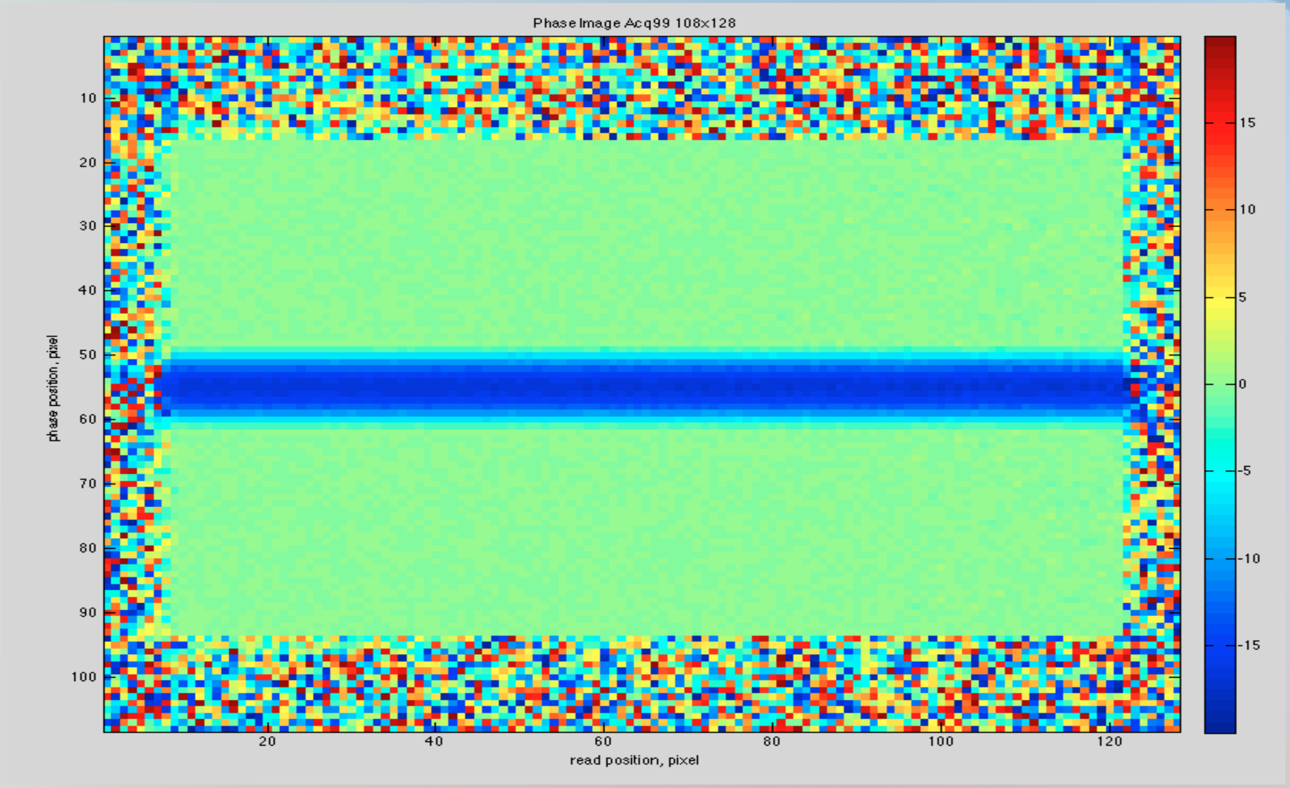
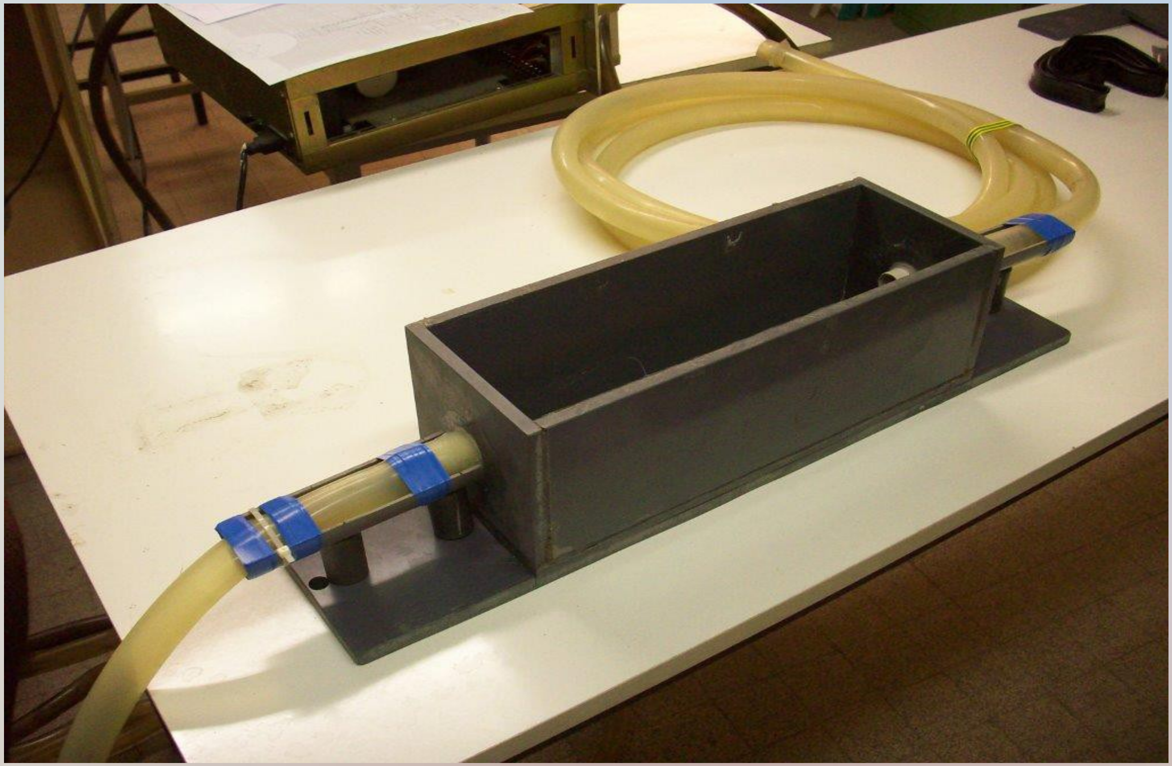


Velocity map

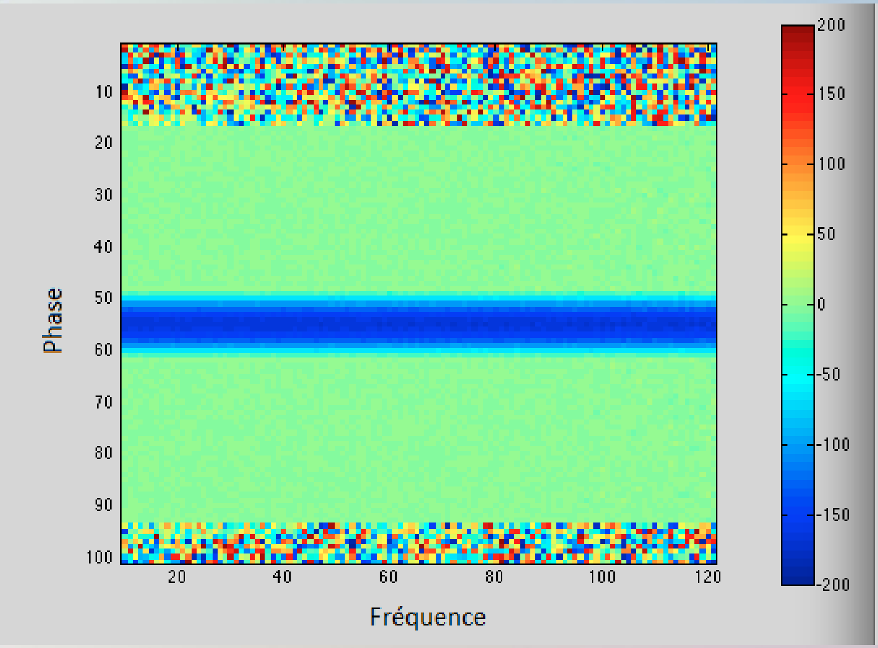
EXPERIENCES

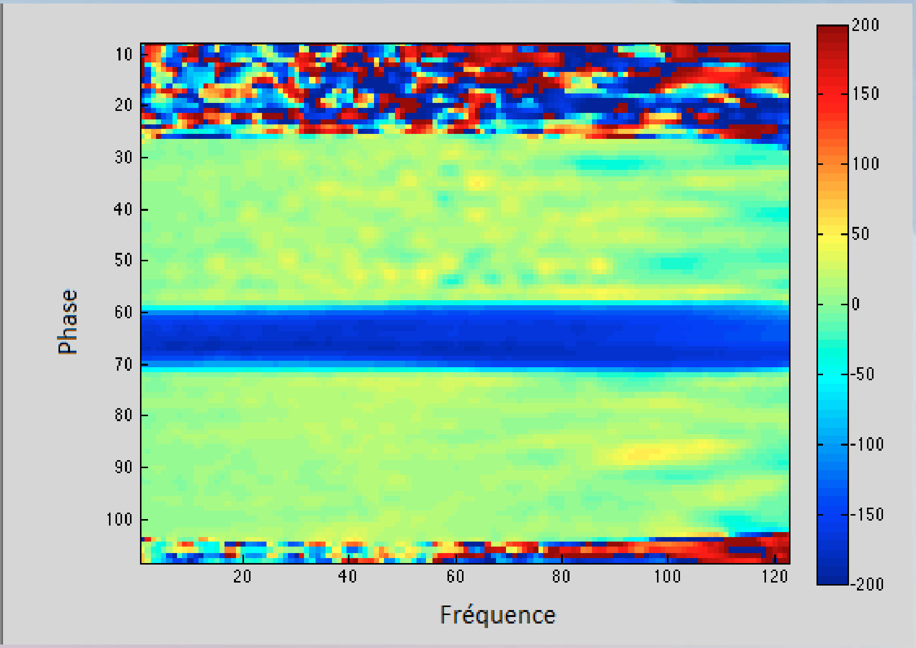
Comparison to experimental images

Hydrodynamic pulsed bench.



COMPARISON

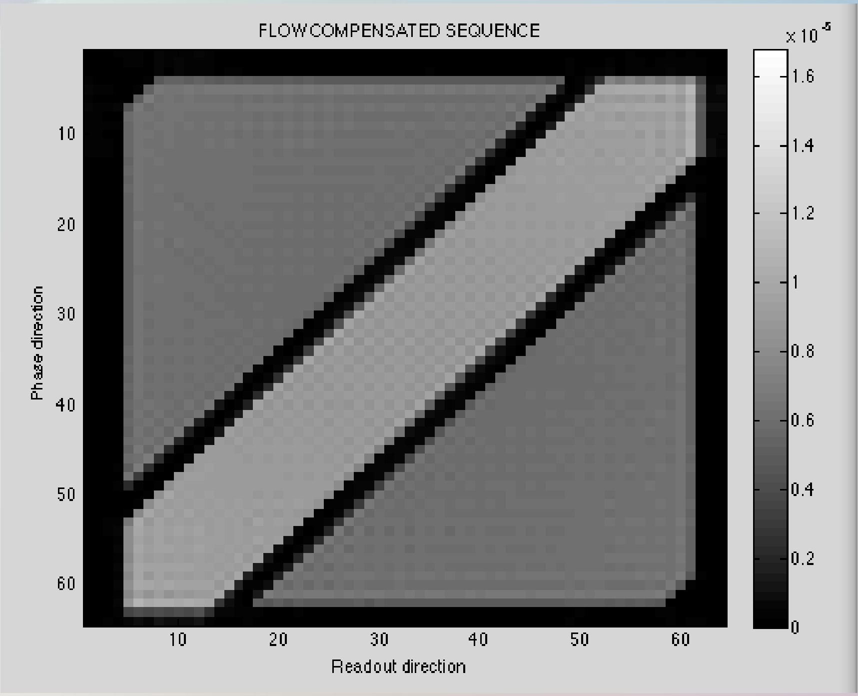




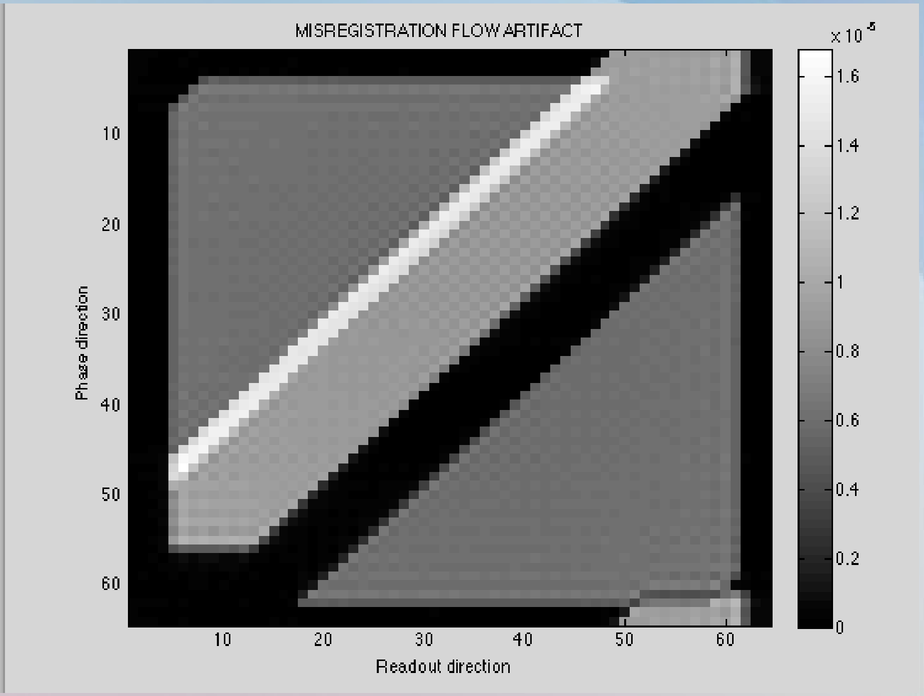
SIMULATION

HYDRO BENCH

OTHER SIMULATIONS : FLOW ARTIFACTS

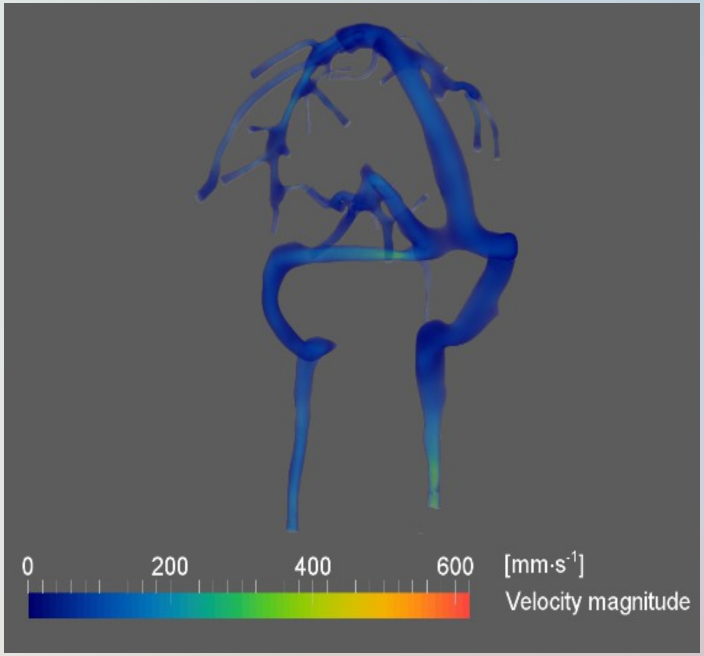


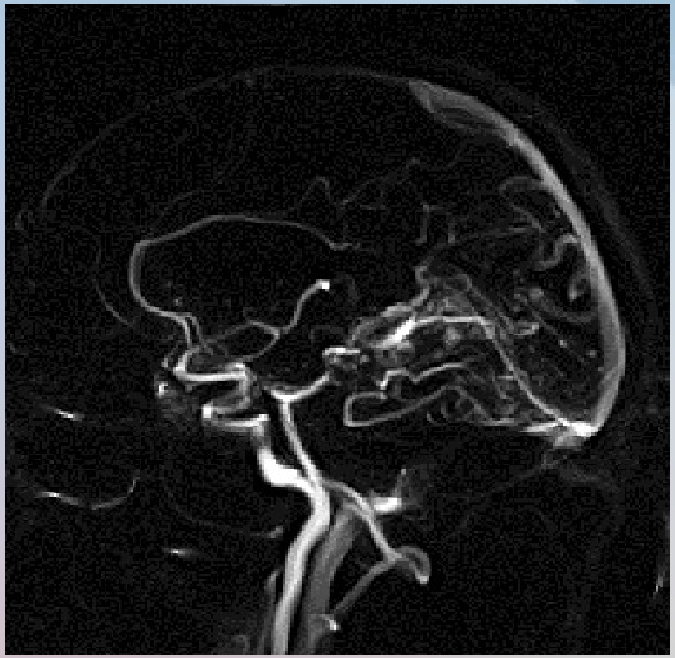
« Normal » image with flow compensation



Misregistration artifact with uncompensated sequence

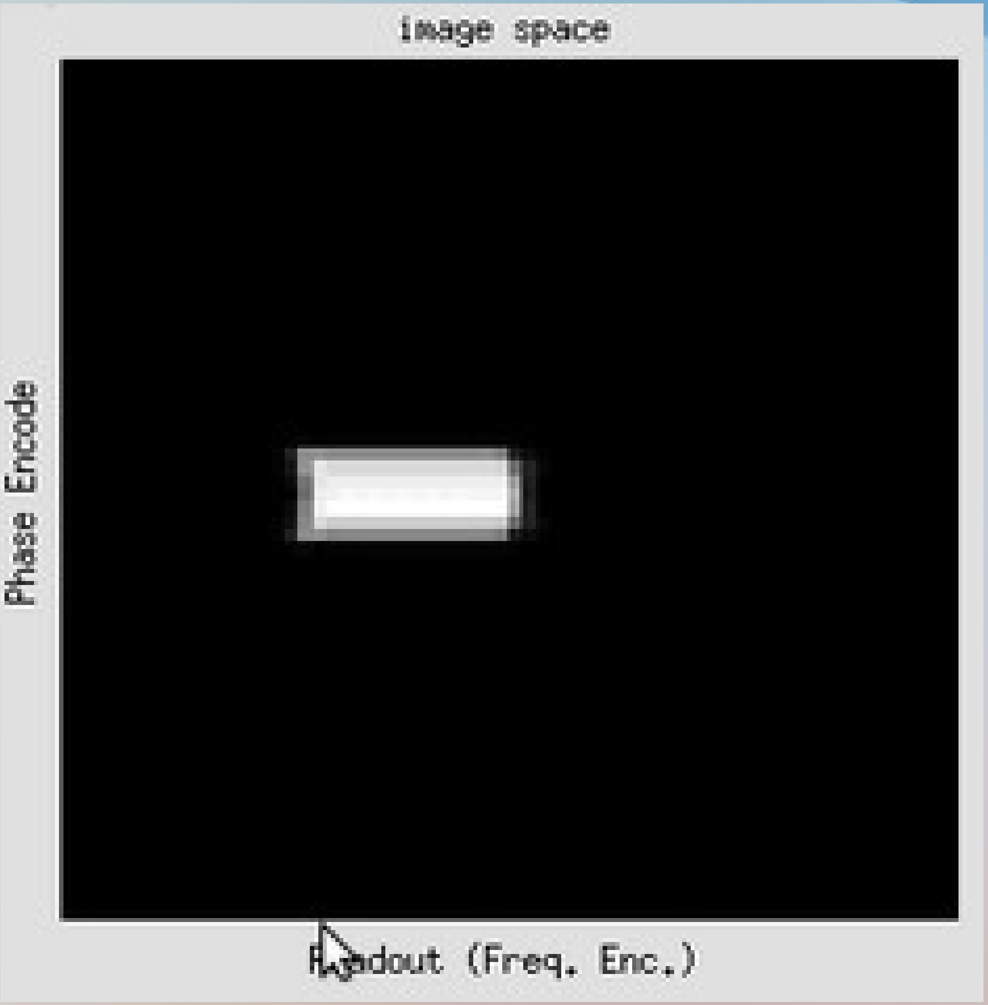
PROSPECT





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

PROSPECT



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

PROSPECT

THANK YOU !

AND THANKS TO JEMRIS DEVELOPERS…

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