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Inria

HEMISFER

Hybrid Eeg-MrI and Simultaneous neuro-FEedback for brain Rehabilitation

HEMISFER Partnership

- Labex team representatives
  - Christian BARILLOT (INSERM Visages U1228, IRISA CNRS 6074)
  - Anatole LECUYER (HYBRID Team, INRIA/IRISA CNRS 6074)
  - Rémi GRIBONVAL (PANAMA Team, INRIA/IRISA CNRS 6074)
  - Isabelle BONAN (PU-PH, INSERM Visages U1228, Rehabilitation Dept. CHU Rennes)
- Collaborator Team representatives
  - Dominique DRAPIER (EA 4712, University of Rennes I, Psychiatric Hospital of Rennes)
  - Maureen CLERC (INRIA ATHENA team, Sophia-Antipolis)

General objectives of HEMISFER

- Make full use of neurofeedback (NF) paradigm for brain self-regulation/stimulation in :
  - rehabilitation (ADHD, Stokes, …)
  - psychiatric disorders (resistant mood disorders, anxiety, schizophrenia, ….)
- Main Challenges:
  - Learn a coupling model associating functional and metabolic information from simultaneous Magnetic Resonance Imaging (fMRI) and Electro-encephalography (EEG)
  - Enhance the NF paradigm from the coupling model

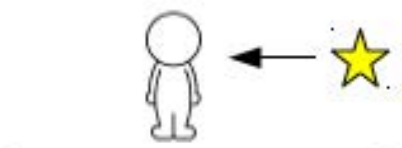
From Imaging Biomarker to therapeutic process

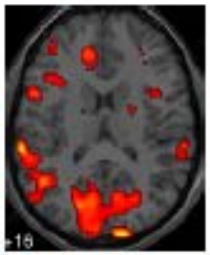
HEMISFER CONTEXT

General consideration about brain function

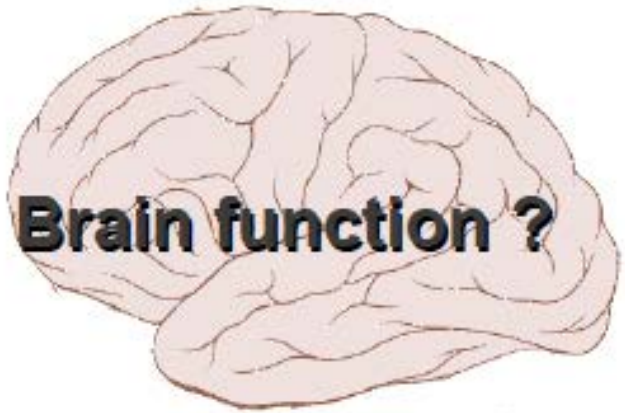
- Two views about brain functions [Raichle 2010]:

Event-related activity



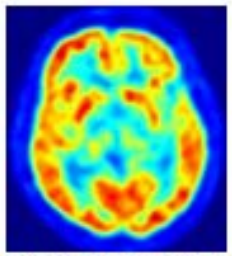


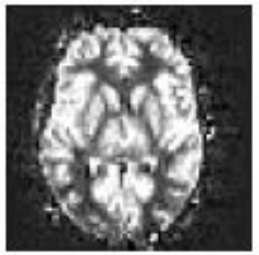
Functional
ASL/fMRI/EEG



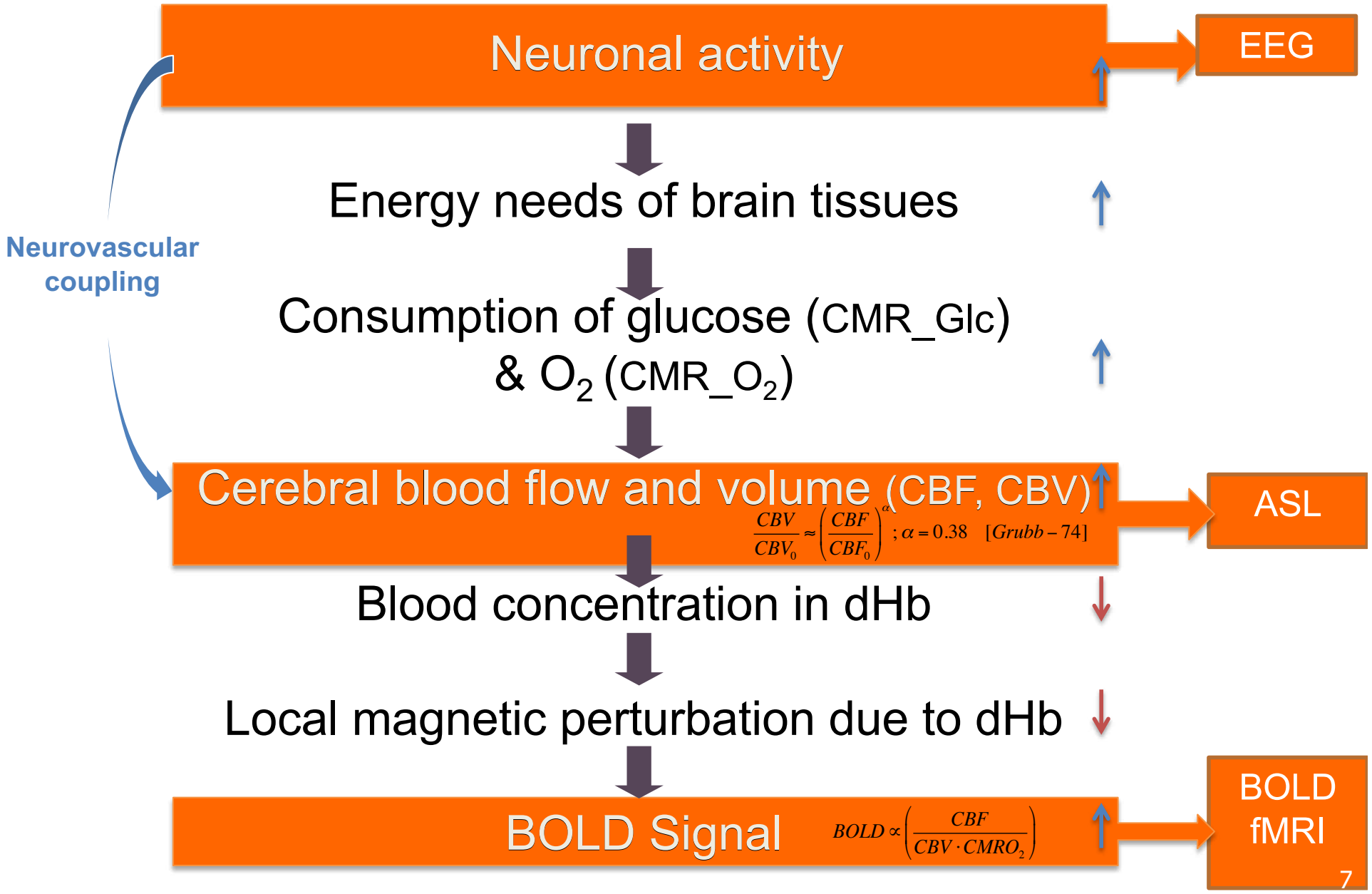
Intrinsic brain function

Basal ASL



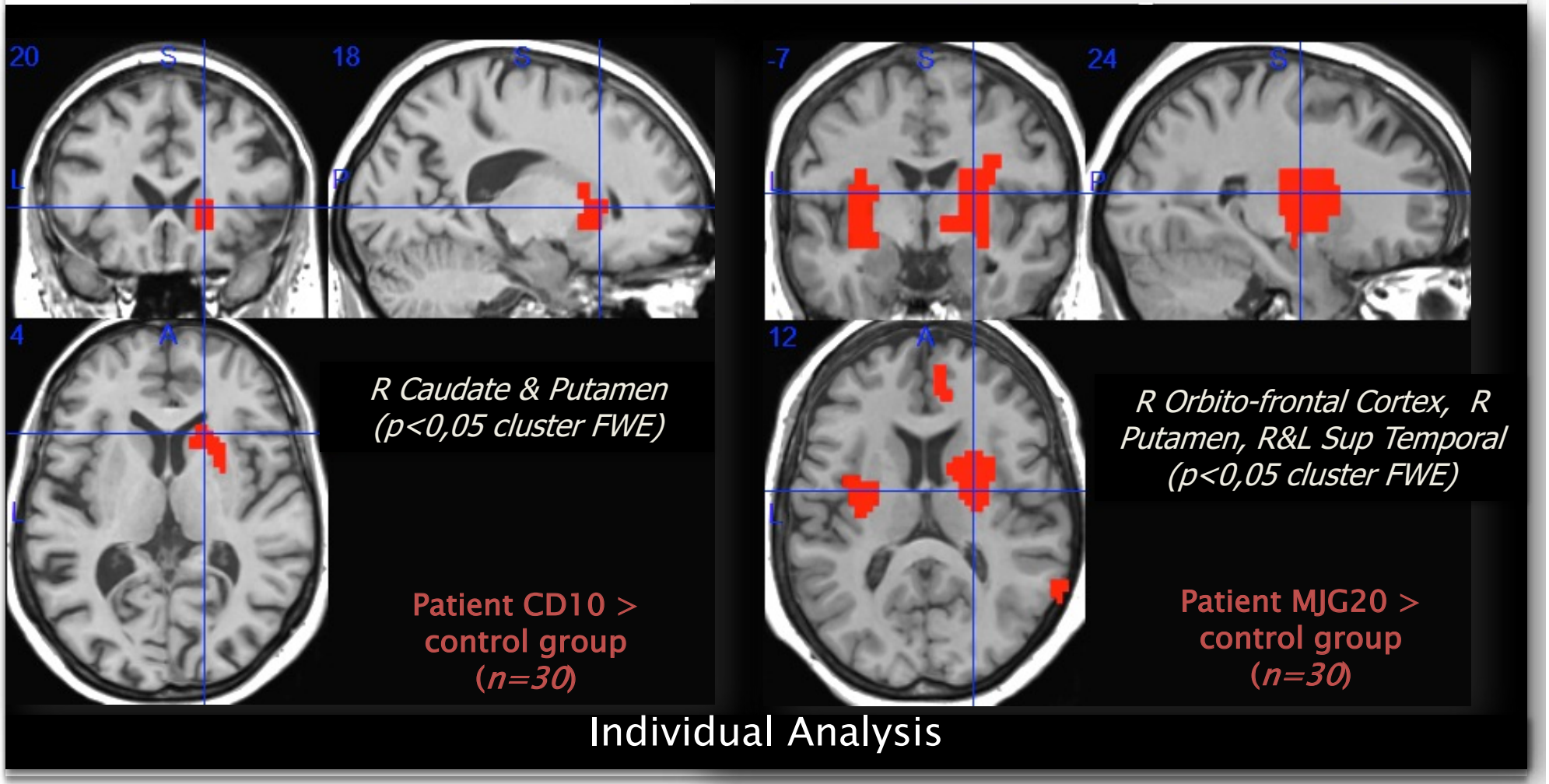


Biophysical parameters for fMRI (ASL and BOLD)



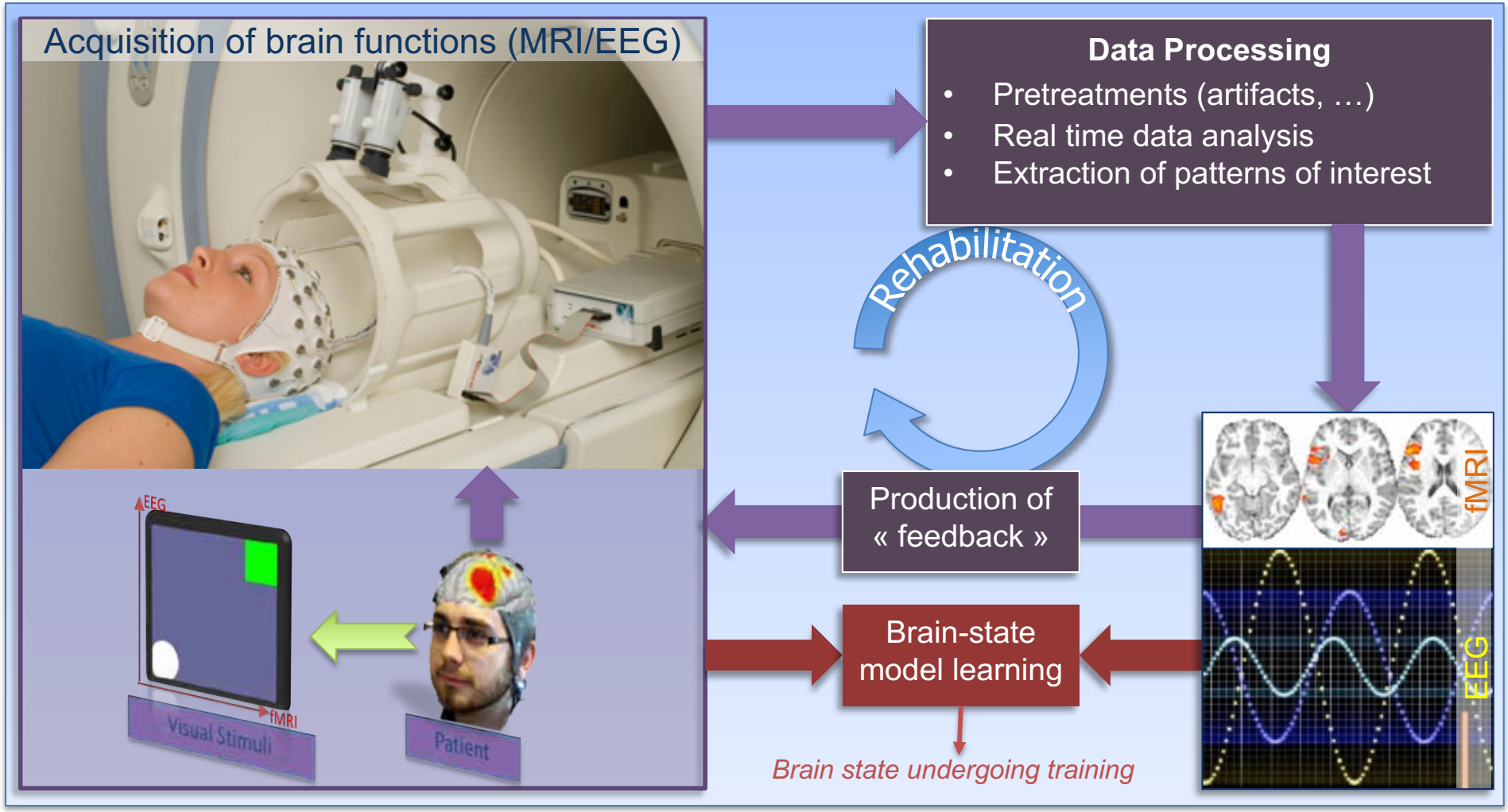
Brain Perfusion as an imaging bio-marker in psychiatry

- Perfusion abnormalities in depressions [1]



[1] Robert G. et al. 2014

From imaging biomarkers to new therapeutic solutions: The HEMISFER Project



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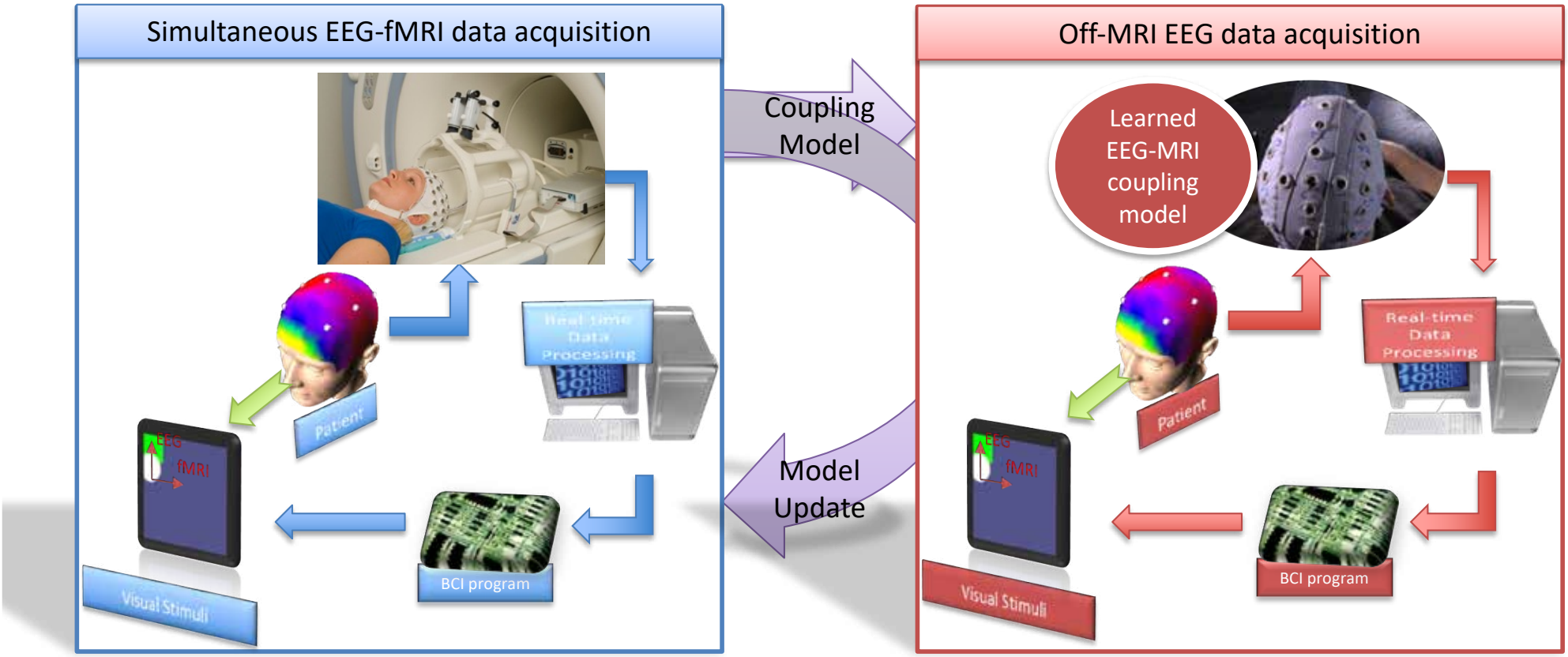
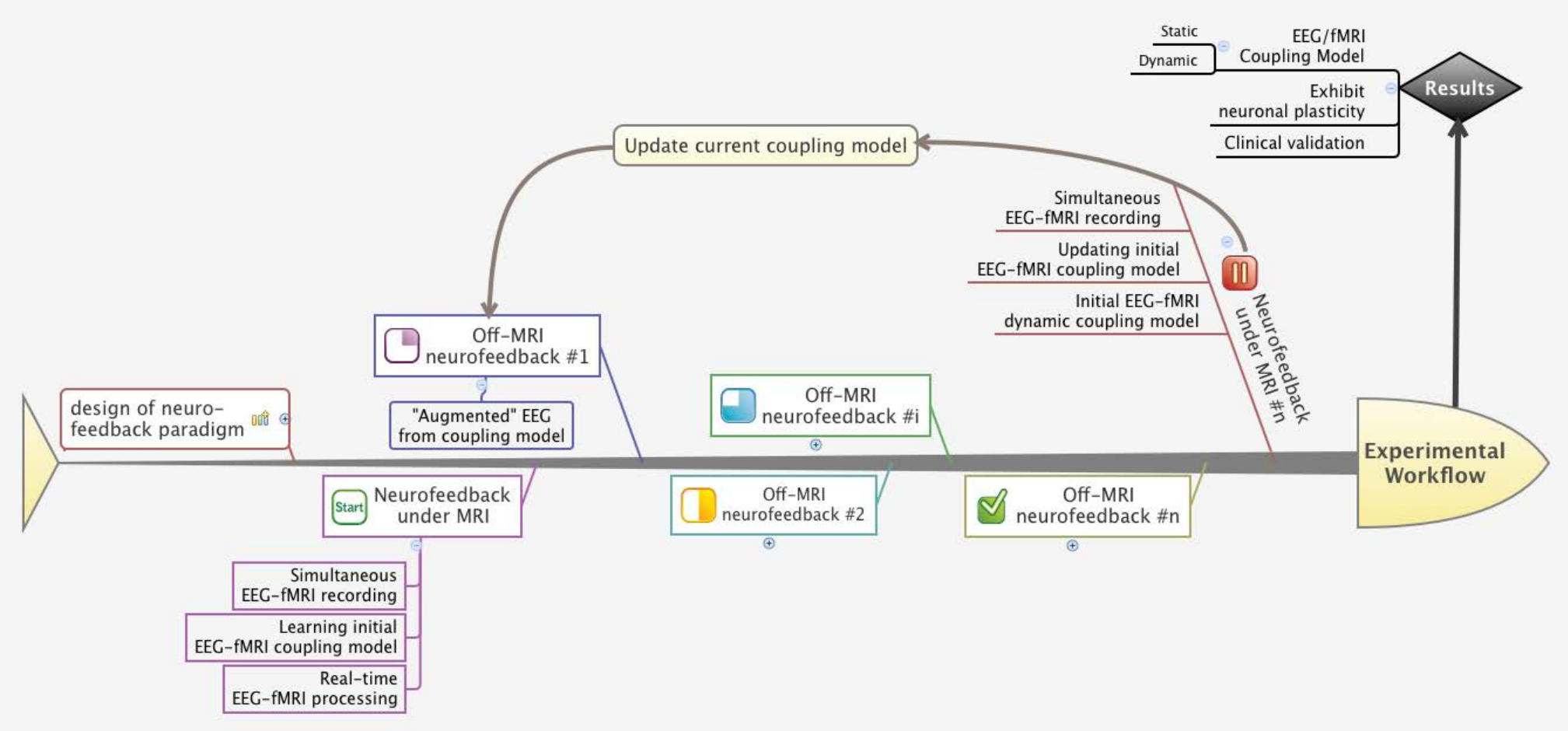
HEMISFER project: From imaging biomarker to image-guided therapy



- Joint project with Visages, PANAMA and HYBRID teams and Univ. Hosp. and Psychiatric Hosp. of Rennes
- Applications: Make full use of neurofeedback (NF) paradigm for brain self-regulation/stimulation in :
  - rehabilitation (ADHD, Stokes, …)
  - psychiatric disorders (resistant mood disorders, anxiety, schizophrenia, ….)

HEMISFER : Experimental scenario

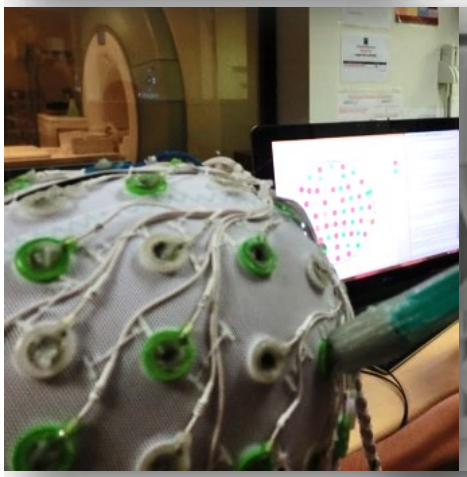


HEMISFER : Major challenges

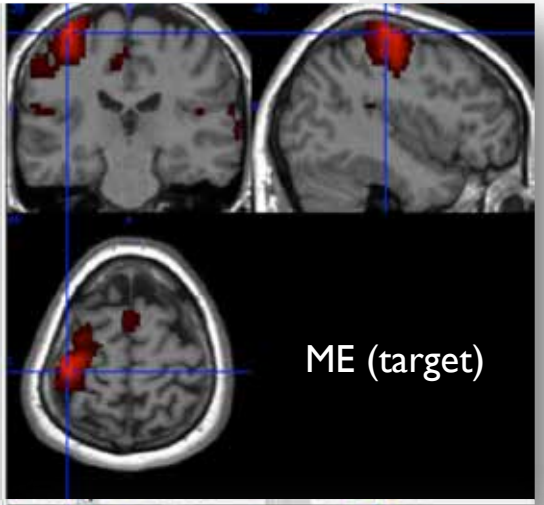
- Develop new neurofeedback paradigms able to profit from simultaneous EEG/fMRI/fASL recordings
  - We expect these novel paradigms to be able to concentrate the brain metabolism on specific regions of the brain
- Learn models at the signal level able to explain the coupling of EEG and fMRI signals under simple and more advanced brain stimuli (e.g. BOLD fMRI, fASL, basal ASL)
  - Learn both the domain in which brain activity is sparse (e.g., dictionary learning), and adjust parametric models of the acquisition processes
  - Achieve super-resolution in the spatial and frequency domain by expressing the problem as a linear inverse problems regularized with the learned coupled model
  - Use brain connectivity models as prior information (*later stage*)
- Use the learned coupling models in order to “enhance” the EEG signal while performing the same stimuli and neurofeedback tasks outside MRI

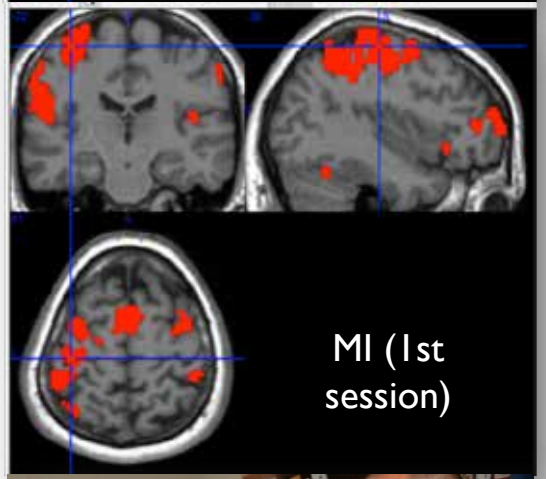
Experimental Environment: The Neurinfo Platform

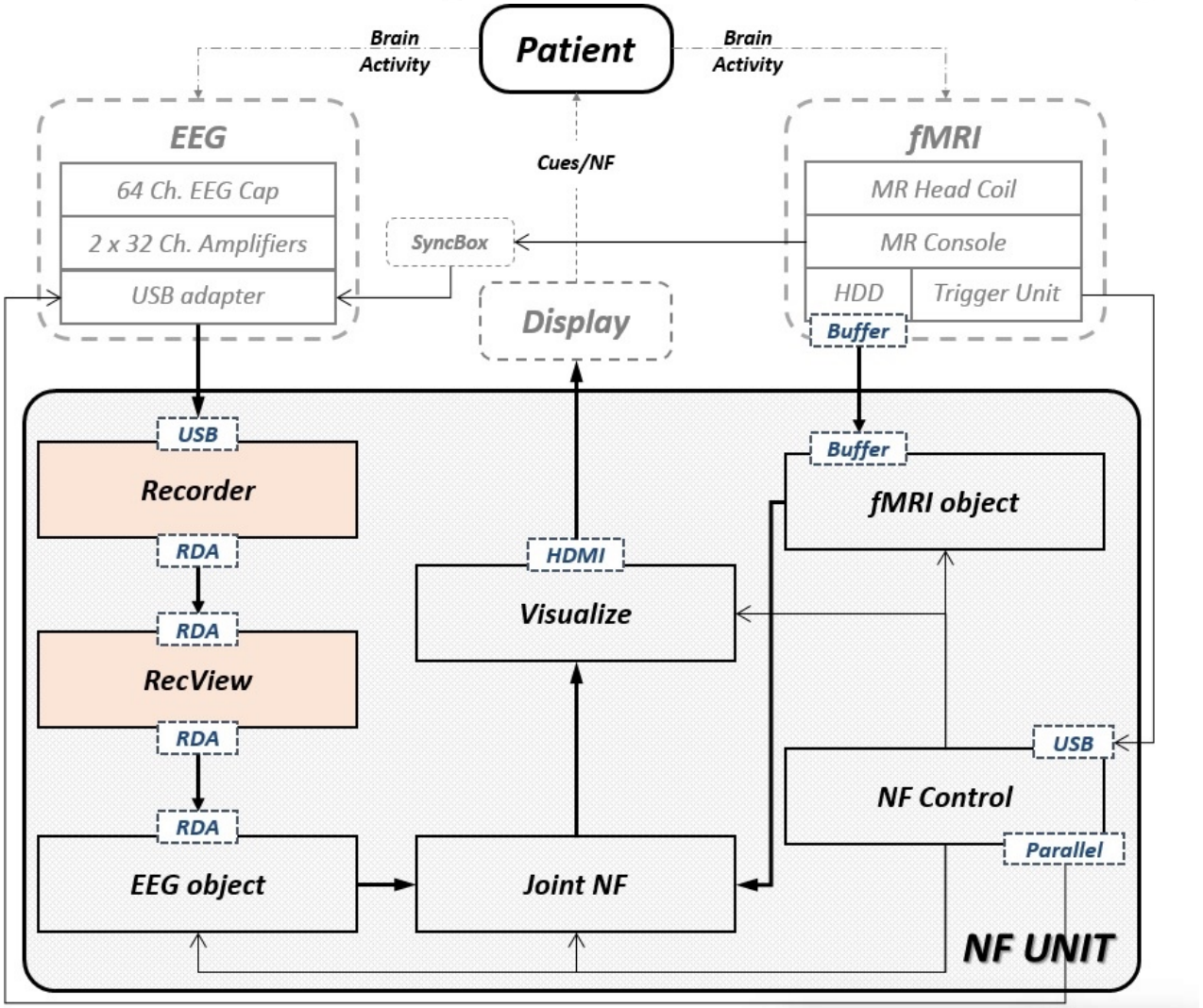
- 3T Verio by SIEMENS ➔ 3T PRISMA:
  - 60 cm Diameters– Length 198cm
  - 10 tons,
  - side positioning
  - Field of View : 50 x 50 x 50 cm
  - Gradients 80mT/m @ 200T/m/s, @400µs
  - 128 independent channels
  - Field homogeneity :
    - <0.1 ppm/h
    - 0,1 ppm (@ 40 cm)
    - 0,045ppm (@ 30 cm)
- MR-EEG BrainProducts 64 channels system



EEG/fMRI Real-Time Processing System Neurofeedback [Patent Mano et al. 2016]







HARDWARE CONFIGURATION

[Mano et al, 2016]: Patent, OHBM 2016

Preliminary study : Safety issues for hybrid EEG/ASL

1465

Accepted to ISMRM 2015 & SFRMBM 2015

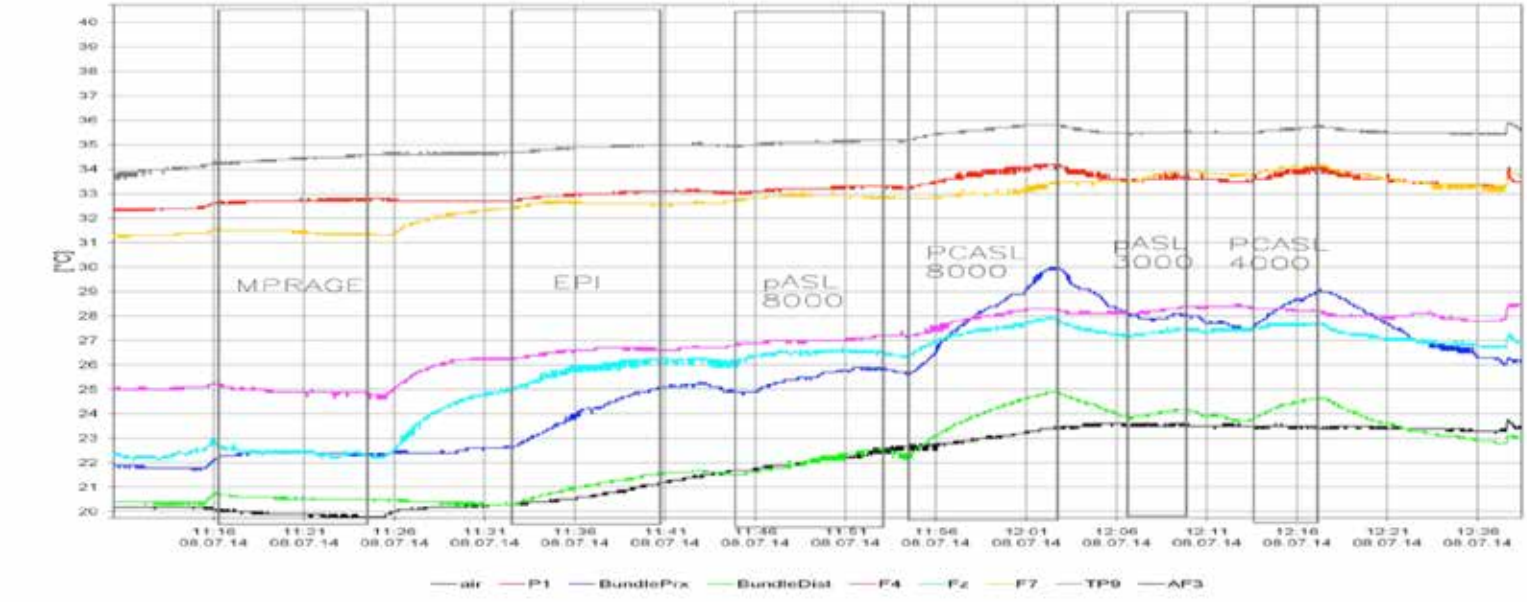
On the feasibility and specificity of simultaneous EEG and ASL MRI at 3T

Elise Bannier[1,2], Marsel Mano[2,3], Robert Stroemer[4], Isabelle Corouge[2], Lorraine Perronnet[2,3], Jussi T. Lindgren[3], Anatole Lecuyer[3], and Christian Barillot[2]

[1]*Radiology, University Hospital of Rennes, Rennes, France,* [2]*Unité VISAGES U746 INSERM-INRIA, IRISA UMR CNRS 6074, University of Rennes, Rennes, France,* [3]*Unité HYBRID INRIA, IRISA UMR CNRS 6074, Rennes, France,* [4]*Brainproducts GmbH, Gilching, Germany*

Start Time	Sequence	Duration (*min*)	TR (*ms*)	Slices	Dynamics	Flip Angle(°)	SAR (*W/kg*)
11:25:19	3D MPRAGE	08:08	1900	176	1	9	0.046
11:33:14	ep2d_bold	08:06	3210	32	150	90	0.046
11:45:50	PASL	08:10	8000	14	61	90 + L/C	0.036
11:55:39	pCASL	08:08	8000	19	60	90 + L/C	0.105
12:08:35	PASL	03:08	3000	14	61	90 + L/C	0.118
12:15:19	pCASL	04:12	4000	19	60	90 + L/C	0.192

Table1: Sequence parameters and SAR Values



Project means

- BCI and rtfMRI (Hybrid, Visages)
  - 2 Phd Students
    - Lorraine Perronnet (Cominabs)
      - With Athena and coll. F. Lotte
      - Started 01-14, Defended 07-17
    - Mathis Fleury (FRM)
      - Started 11-17
- Real-time platform & Software integration (Hybrid, Visages)
  - 2 Research Engineers (PhDs)
    - Marsel Mano (Cominabs)
      - Started 06-14, Ended 09-17
    - Giulia Lioi (Cominabs + FRM)
      - Starded 11-17
- Additional means (self funded)
  - MS/PhD in psychiatry (PI D. Drapier)
  - MS/PhD in Rehabilitation (PI I. Bonan)
- Coupling model between MRI and EEG (Panama, Visages)
  - 4 post-docs (Cominabs)
    - Thomas Oberlin (01/14→ 08/14)
    - Nicolas Raillard (02/15→03/15)
    - Saman Norzade (10/15→03/17)
    - Claire Cury (10/17→…)
- Grants:
  - Comin Labs:
    - Hemisfer (phase I)
    - Hemisfer-Clinical
  - FRM
- Experiments :
  - 100h of MRI experiments
- Additional means (*self funded*)
  - MR-compatible EEG system
  - Computing (GPU, …)
  - Travelling

General Organization

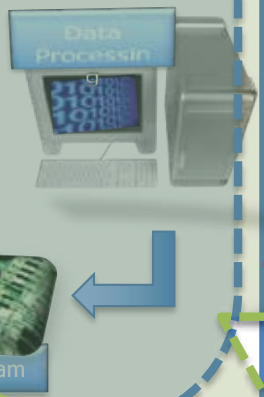
Simultaneous EEG-fMRI data acquisition

Coupling Model

Off-MRI EEG data acquisition

Learned EEG-MRI coupling model

Model Update



Added value of collaboration

- Signal & image processing and machine learning → PANAMA team along with VISAGES and ATHENA teams
- BCI and EEG processing → HYBRID, Visages and ATHENA teams
- Real-time processing of fMRI (BOLD and ASL) → Visages U1228 and Hybrid Teams along with Neurinfo
- Clinical Research → Visages U1228, Hybrid and EA 4712 teams
- Potential industrial collaboration (*long term*):
  - Clinical research: Biotrial
  - BCI and software integration: Mensia Tech.

Hemisfer: Current Summary

- Project actually started on Jan 2014
- Major Originalities:
  - The “theragnostic” concept: translate imaging sensors to therapeutic systems
  - Hemisfer paradigm never addressed before
  - Joint fMRI/EEG for Neurofeedback addressed only very recently by one team in 2014 (*not afterwards*)
  - EEG/fMRI coupling model from machine learning and sparse representation has never been addressed before
- Major opportunities:
  - High integration of the work between the Hemisfer partners (from information processing, brain computer interface to clinical medicine)
  - Two major clinical applications : same generic technology applied to two very different clinical rehabilitation domains
  - Ancillary opportunity: *observe the pathological brain under evolution*
- High efficiency of the collaboration:
  - All dedicated people are shared between at least two teams
  - Effective cross-fertilization between different domains (signal & image processing, VR & Virtual interfaces, medicine)
- Actual outcomes
  - Technological aspects:
    - integration of a new MR-compatible EEG system (Brain Product)
    - Integration of real time processing for the EEG/fMRI system (first in-vivo experiments done) (*one patent is under discussion*)
    - One of the first world-wide study for safety compatibility of simultaneous ASL/EEG recording [*ISMRM & SFRMBM 2015]*

Hemisfer: Current Publications

- Coupling EEG and fMRI
  - Noorzadeh, S., Maurel, P., Oberlin, T., Gribonval, R., Barillot, C., 2017. Multi-modal EEG and fMRI Source Estimation Using Sparse Constraints. MICCAI 2017 - 20th International Conference on Medical Image Computing and Computer Assisted Intervention, Quebec, Canada.
  - Oberlin, T., Barillot, C., Gribonval, R., Maurel, P., 2015. Symmetrical EEG-FMRI Imaging by Sparse Regularization. European Signal and Image Processing Conference - EUSIPCO 2015. IEEE, pp. 1-5.
- Platform
  - [**Patent**] Mano, M., Perronnet, L., Lecuyer, A., Barillot, C., 2016. Hybrid Eeg-MrI and Simultaneous neuro-feedback for brain Rehabilitation. In: Inria (Ed.). CNRS, INRIA, France
  - Mano, M., Lecuyer, A., Bannier, E., Perronnet, L., Noorzadeh, S., Barillot, C., 2017. How to Build a Hybrid Neurofeedback Platform Combining EEG and fMRI. Front Neurosci 11, 140.
  - Mano, M., Bannier, E., Perronnet, L., Lécuyer, A., Barillot, C., 2017. Hybrid EEG and fMRI platform for multi-modal neurofeedback. International Society of Magnetic Resonance in Medicine. ISMRM, Honolulu, United States, p. 4550.
  - Mano, M., Bannier, E., Perronnet, L., Lécuyer, A., Barillot, C., 2016. Design of an Experimental Platform for Hybrid EEG-fMRI Neurofeedback Studies. 22nd Annual Meeting of Human Brain Mapping, Geneva, CH, p. 2078.
- Neurofeedback
  - Perronnet, L., Lecuyer, A., Mano, M., Bannier, E., Lotte, F., Clerc, M., Barillot, C., 2017. Unimodal Versus Bimodal EEG-fMRI Neurofeedback of a Motor Imagery Task. Front Hum Neurosci 11, 193.
  - Perronnet, L., Lécuyer, A., Mano, M., Bannier, E., Lotte, F., Clerc, M., Barillot, C., 2016. Hybrid EEG-fMRI neurofeedback of a motor-imagery task. 22nd Annual Meeting of Human Brain Mapping, Geneva, CH, p. 4133.
  - Perronnet, L., Lécuyer, A., Lotte, F., Clerc, M., Barillot, C., 2016. Brain training with neurofeedback. In: Clerc, M., Bougrain, L., Lotte, F. (Eds.), Brain-Computer Interfaces / Les Interfaces Cerveau-Ordinateur. ISTE-Wiley, pp. 291-309.
  - Perronnet, L., Lécuyer, A., Lotte, F., Clerc, M., Barillot, C., 2016. Entraîner son cerveau avec le neurofeedback. In: Maureen, C., Laurent, B., Fabien, L. (Eds.), Les interfaces cerveau-ordinateur 1. ISTE editions, pp. 277-292.
- Misc.
  - Bannier, E., Mano, M., Robert, S., Corouge, I., Perronnet, L., Lindgren, J., . . . Barillot, C., 2015. On the feasibility and specificity of simultaneous EEG and ASL MRI at 3T. ISMRM, Toronto, Canada.
  - Bannier, E., Mano, M., Robert, S., Corouge, I., Perronnet, L., Lindgren, J., . . . Barillot, C., 2015. Faisabilité et spécificités de l'ASL-EEG simultané à 3T. SFRMBM, Grenoble, France.
- Workshop Neurofeedback and Brain Computer Interfaces (Rennes, Sept. 7th, 2017)