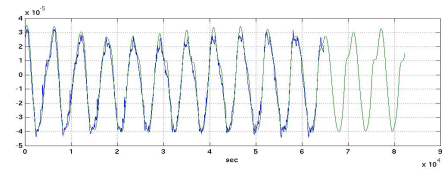
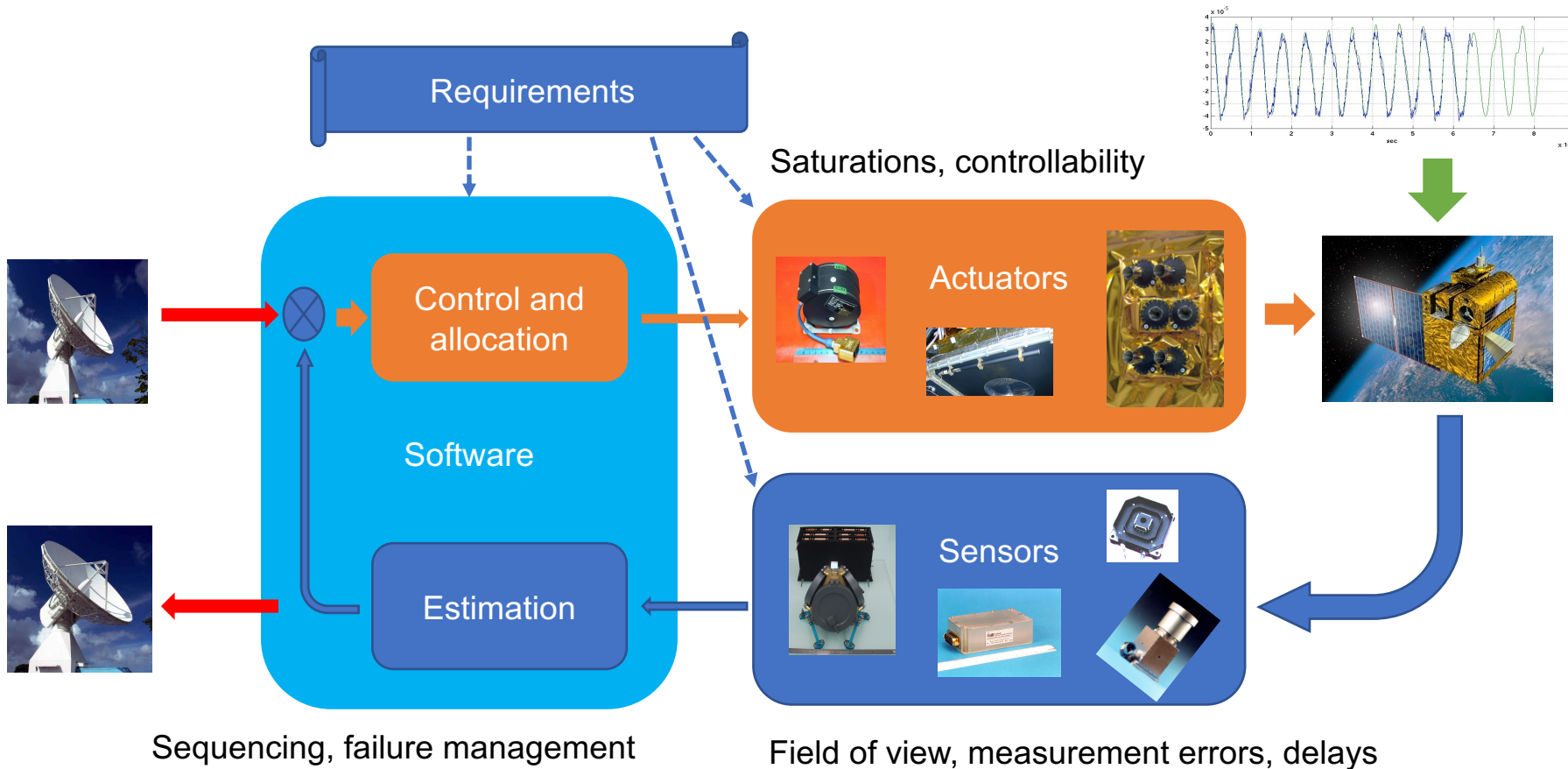




**COMET SCA / GT MOSAR workshop, March 2019**  
**Feedback about robust control and analysis**

**C. Pittet** ([christelle.pittet@cnes.fr](mailto:christelle.pittet@cnes.fr))

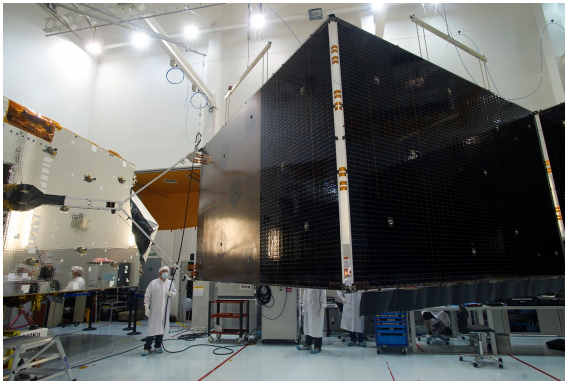
# Research interest : attitude control of satellites



# CNES studies about Robust control started in the 90's

## Flexible modes

- Larger structures with lower frequency flexible modes

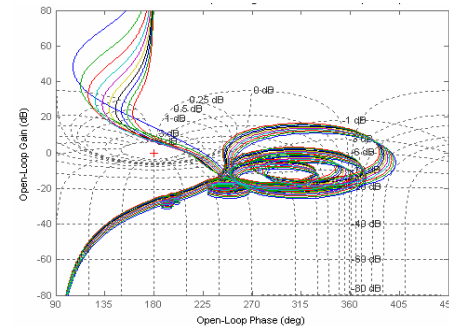


© CNES/GRIMAULT Emmanuel, 2013

- Unmodelled dynamics
- Family of platforms

## MIMO control

- Performance and stability margins



## Multi-objectives requirements

- Time domain
- Frequency domain

SISO PD controller synthesis limited  $\Rightarrow$  find a robust MIMO synthesis technique

# Convex optimization based results



Flexible LTI control

Attitude and active payload control : the  $H_\infty$  revolution, C. Pittet, J. Mignot, F. Viaud, 2017



Input constrained LTI control

Formation flying control for satellites: anti-windup based approach, J. Boada, C. Prieur, S. Tarbouriech, C. Pittet, and C. Charbonnel, 2012



Periodic control

Robust Hinf Performance of Periodic Systems with Memory: New Formulations, Analysis and Design Results, Jean-François Tréguët, Denis Arzelier, Dimitri Peaucelle, Yoshio Ebihara, Christelle Pittet et Alexandre Falcoz, 2012



LPV  
LTV control  
Adaptive (passivity / descriptor)

Linear Parameter Varying Analysis of Switched Controllers for Attitude Control Systems, J-M. Biannic, C. Roos, C. Pittet, 2011

In Flight Results of Adaptive Attitude Control law for a Microsatellite, Pittet, C.1; Luzi, A. R.2; Peaucelle, D.3; Biannic, J-M.2; Mignot, J.1., 2014

Adaptive attitude control of a microsatellite during payload deployment, H. Leduc, D. Peaucelle, C. Pittet, 2017



Adaptive LPV control?

Global stability  
HiFi simulator proven

Difficult to tune  
A posteriori robustness  
In-flight proven

Easier to tune  
A priori robustness  
HiFi simulator proven

4-blocks  $H_\infty/H_2$   
SISO synthesis  
Manual order reduction  
In-flight proven

6DOF synthesis  
not possible  
(numerical issue)

No real performance  
improvement, complex  
implementation

# My feedback about convex optimization

## Pros

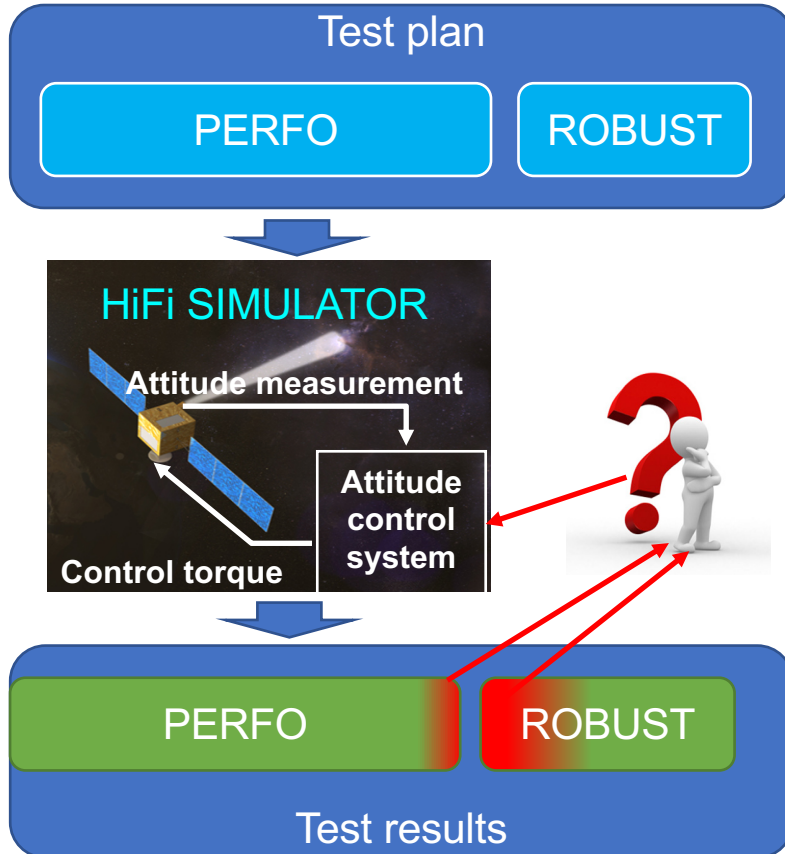
- Computation time (LMIs)
- Global convergence
- Flexible tool
  - Continuous/discrete time
  - Time domain (pole placement)
  - Frequency domain
  - Optimizing
    - Set of initial conditions
    - Uncertainties range
    - Trade-offs performance/stability

## Difficulties

- Full order controller synthesis
- Order reduction may lead to stability /performance degradation
- MIMO weighting functions hard to tune
- Numerical issues
  - Size of decision variables
  - Numerical sensitivity to the way of writing LMIs ( $x'Px < \mu \neq x'(P/\mu)x < 1$ )
  - Expert skills for solver tuning
- Robust controller synthesis often more conservative than **nominal synthesis + robustness analysis**

# Robustness analysis : my expectations ...

## Monte Carlo simulations



## Robustness analysis

- Early in the project
  - Pre-identify robustness and/or performances cases that should be successful and remove them from the test plan
- Focus Monte-Carlo simulations on problematic cases

➔ Save time

# Robustness analysis : ... facing reality

- LFR form not easy to compute
- Real uncertainties difficult to handle
- Fail on flexible modes

DEMETER, a benchmark for robust analysis and control of the attitude of flexible microsatellites , C. Pittet, D. Arzelier, 2006

$\mu/v$  analysis

Computational time and memory issues

Worst case analysis for flexible microsatellite attitude control, Internship, JB Provenzano, 2014

Worst case analysis (genetic algorithms)

SMAC (Back to  $\mu$ -analysis with branch and bound)

$\mu$ -probability

Analytic methods can detect problems but simulation is needed to check

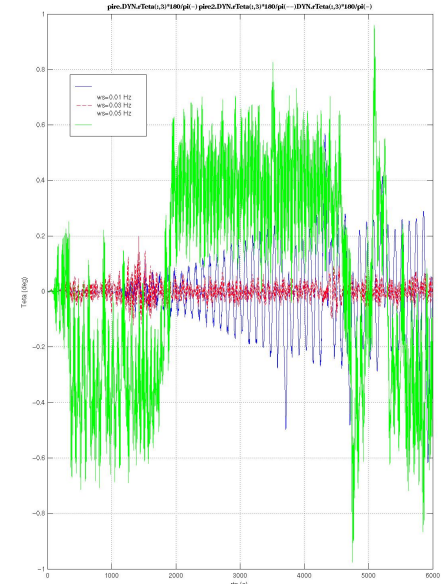
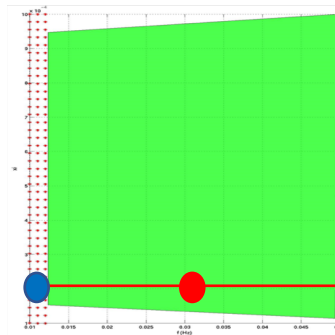
Probabilistic Mu Analysis for System Performances Assessment, A. Falcoz, D. Alazard, C. Pittet, 2017

Computational time issue for 3-axis problem with flexible modes

Quadratic separators

Robust analysis of Demeter benchmark via quadratic separation , D. Peaucelle, A. Bortott, F. Gouaisbaut, D. Arzelier, C. Pittet, 2010

Able to detect non intuitive robustness issues





# My recommendation

