Méthode de séparation de sources
Modèles et algorithmes

Applications en Astrophysique

Introduction au cours

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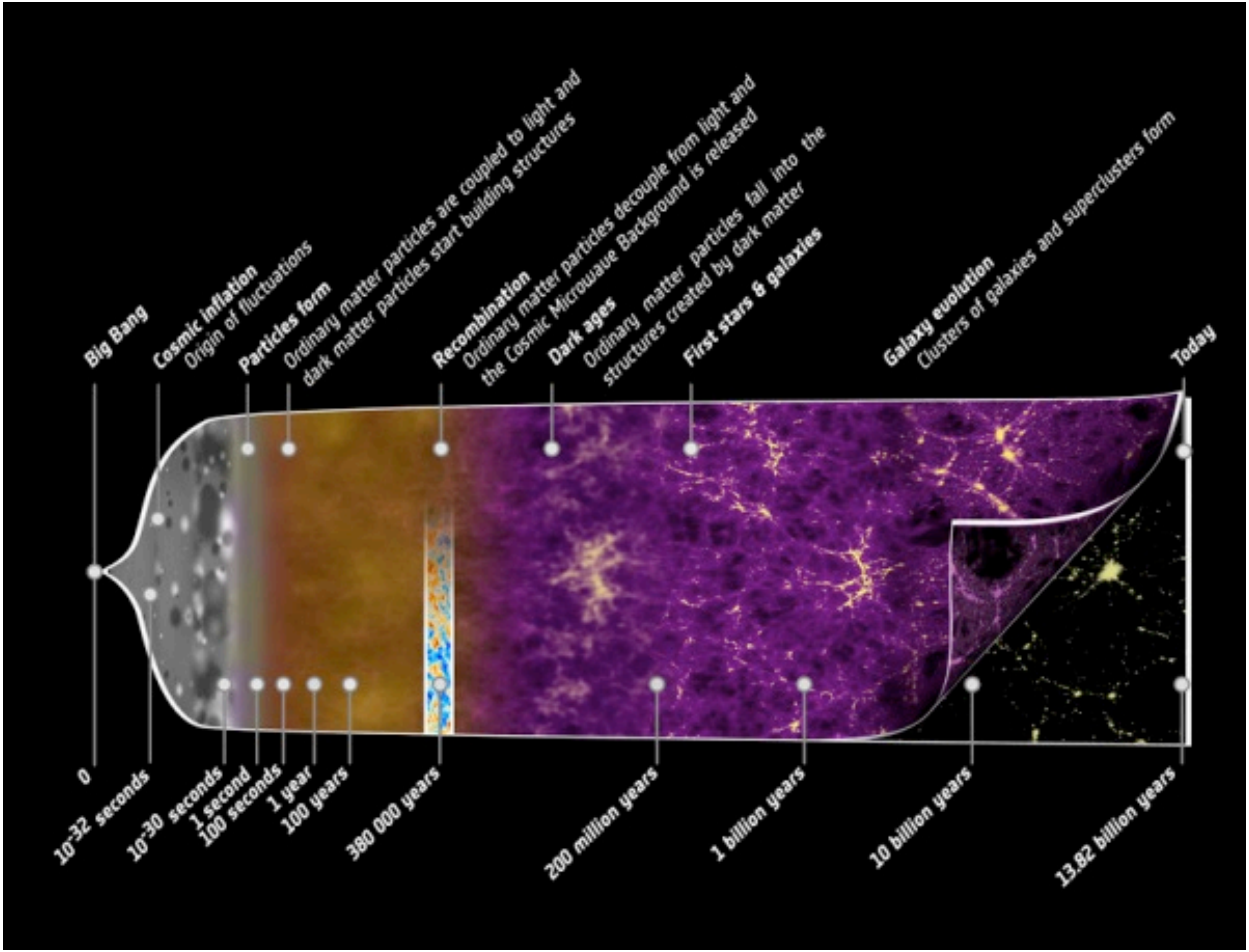
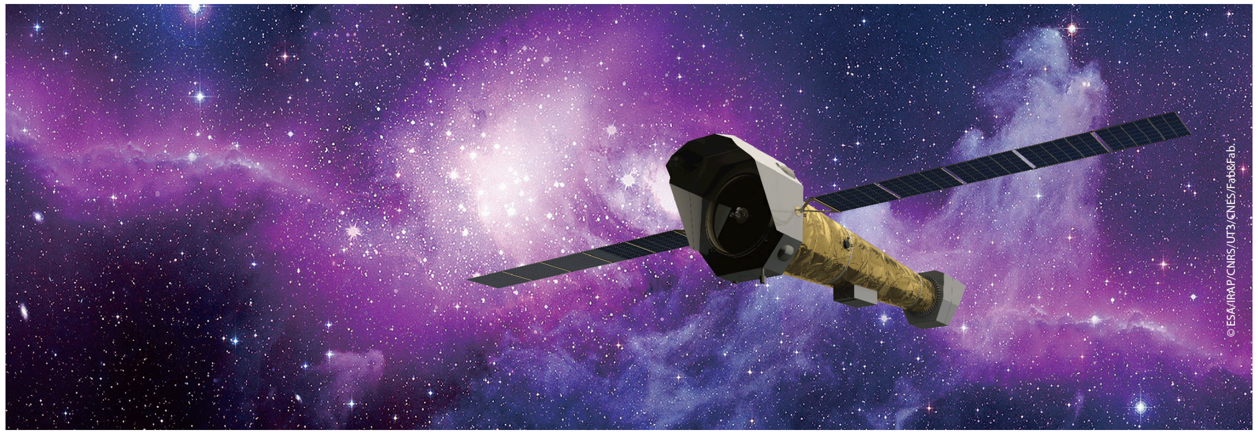
Big questions in astrophysics

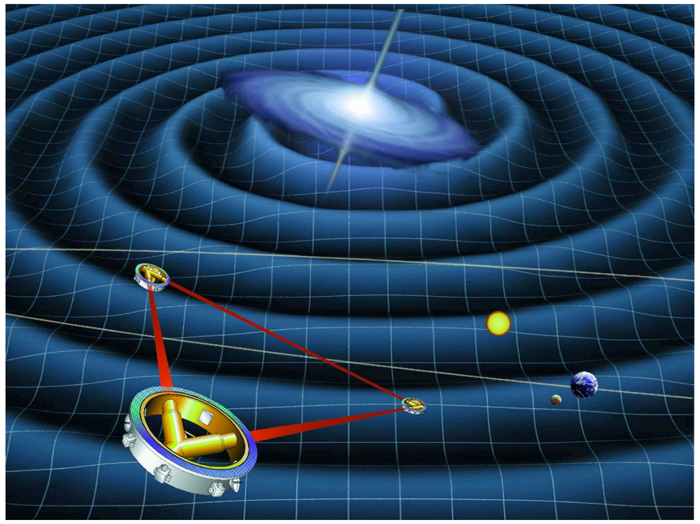


Astrophysique : un déluge de données complexes …

Already started : Square Kilometre Array
(radio-interferometry)
Early evolution of the Universe, its large-scale structures, as well as energetic objects (radio burts, etc)

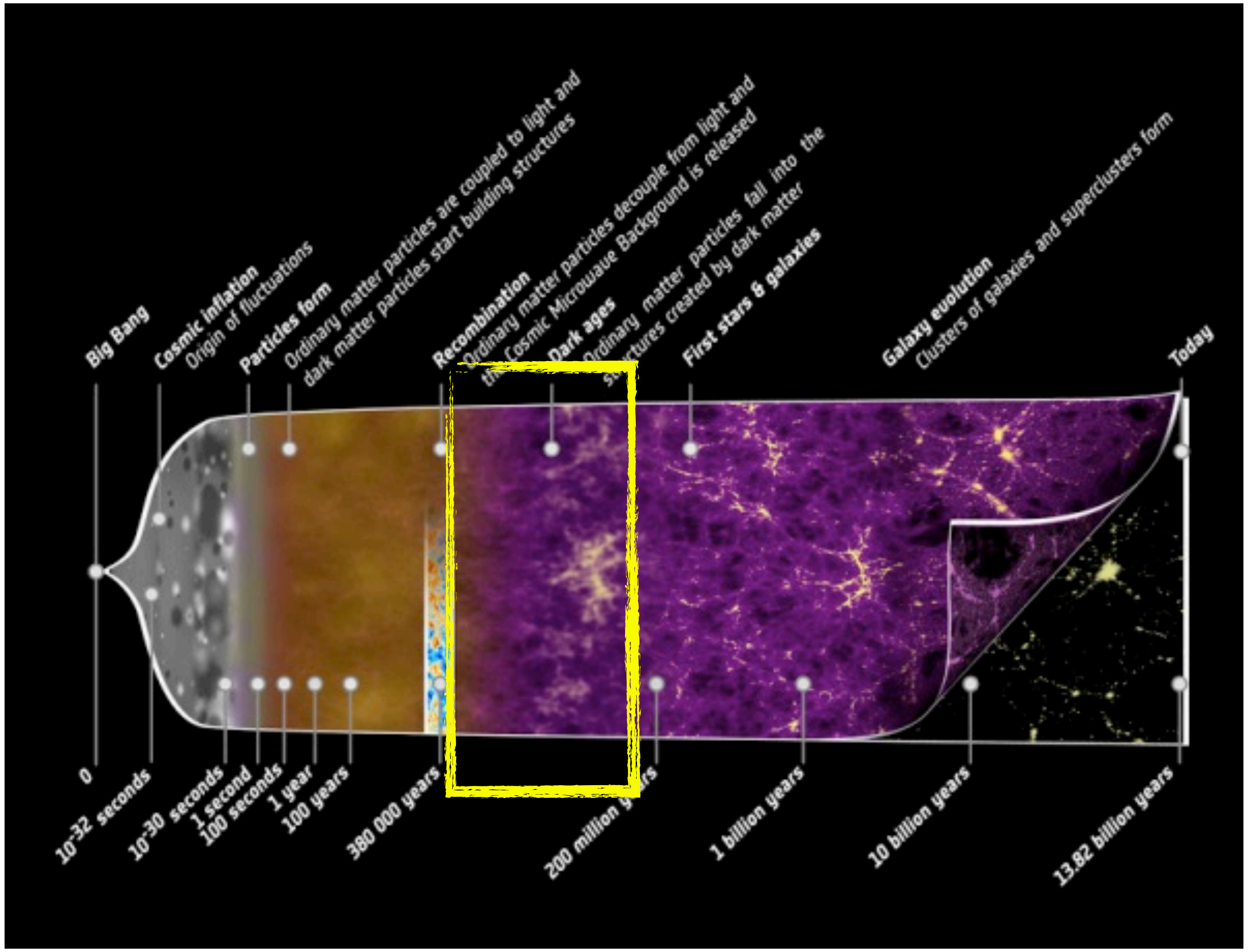


2034 : Athena (X-ray telescope)
Observing highly energetic phenomena in the Universe (supernovae residuals, etc)



2034 : LISA (Space interferometer)
Observing gravitational waves generated by highly massive objects (black holes, neutron stars binaries, etc)

Raise highly challenging data processing issues



Observation through the H1 21 cm line … *redshifted line, which is now at ~2m*

High-resolution images cannot be obtained with single dish antenna

Imaging the dawn of the Universe

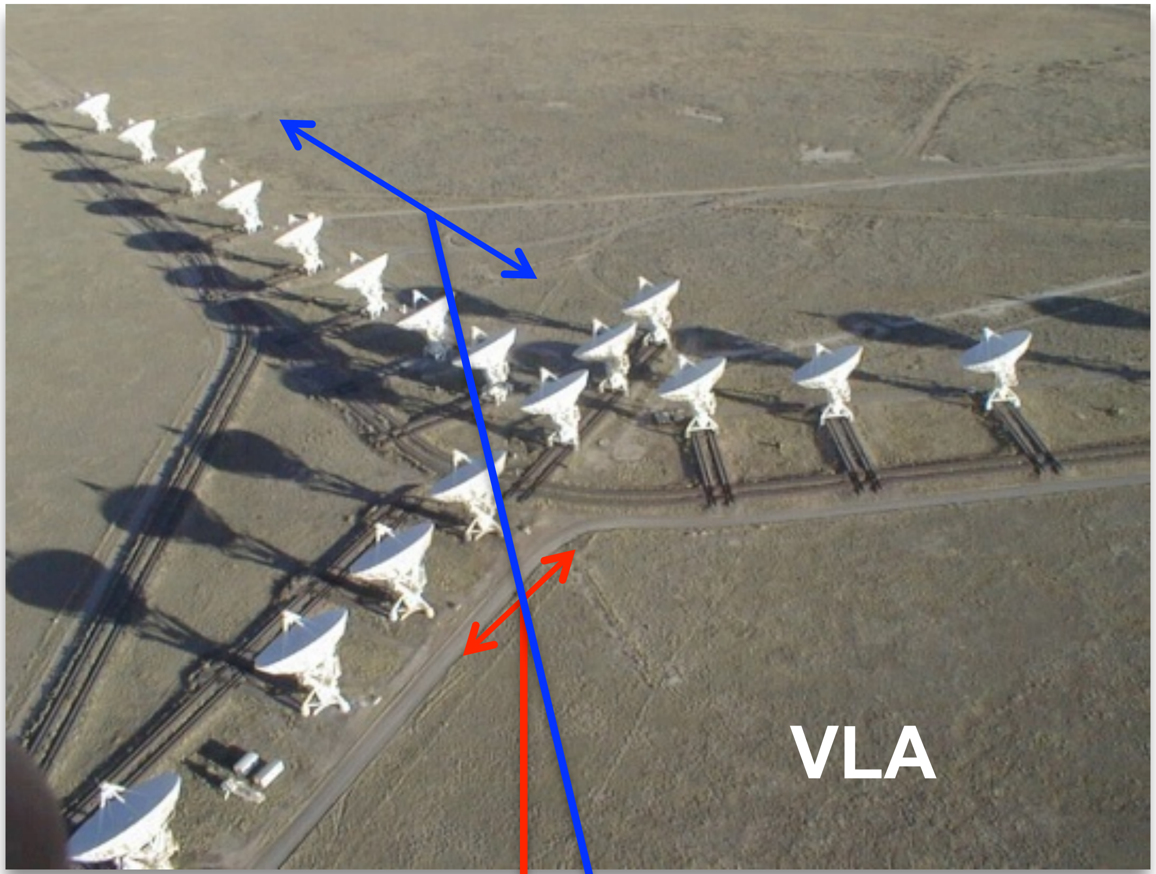
LOFAR

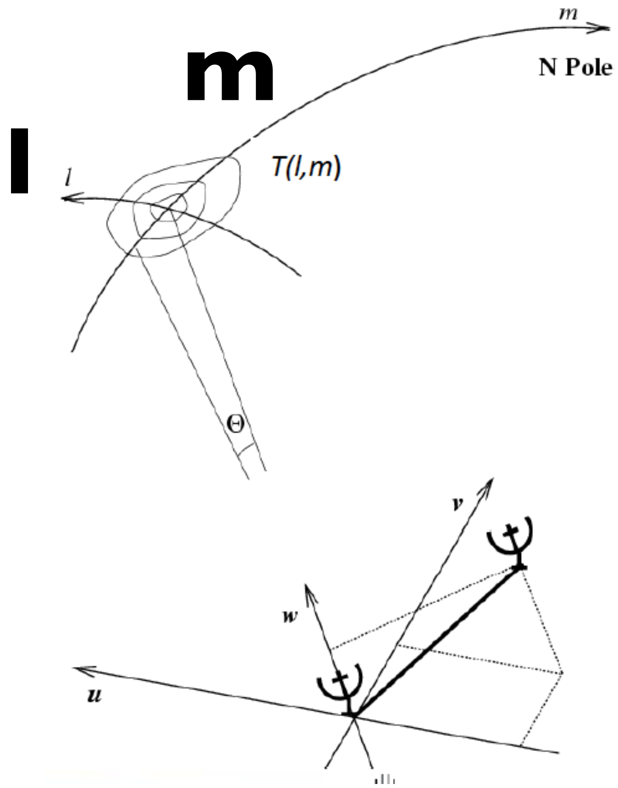
SKA
SQUARE KILOMETRE ARRAY

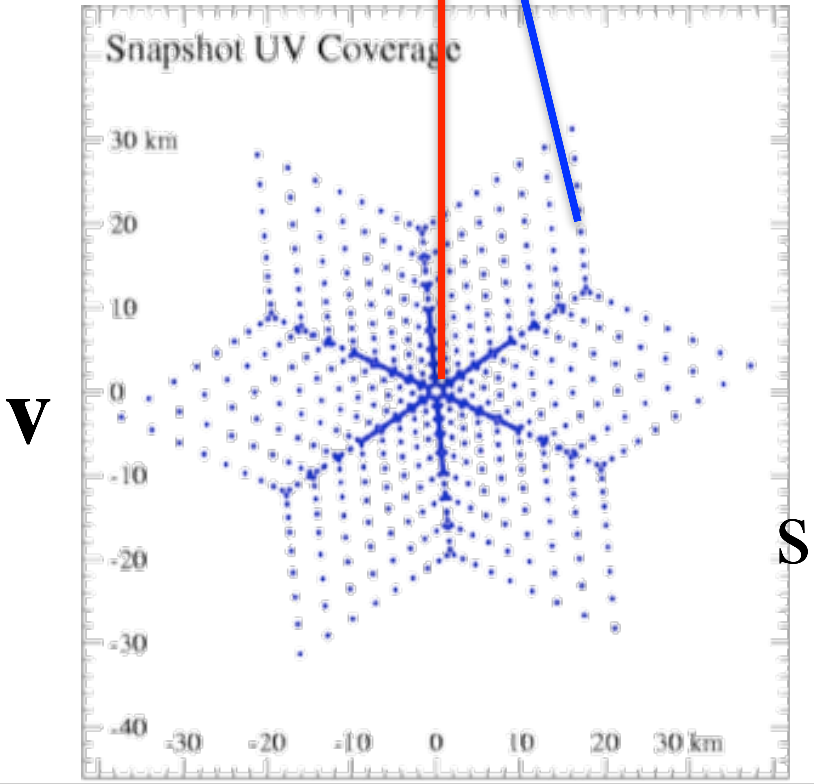
N **antennas/telescopes**

$$\frac{N(N-1)}{2}$$ **independent baselines**

1 projected baseline
= 1 sample in the Fourier « u,v » plane

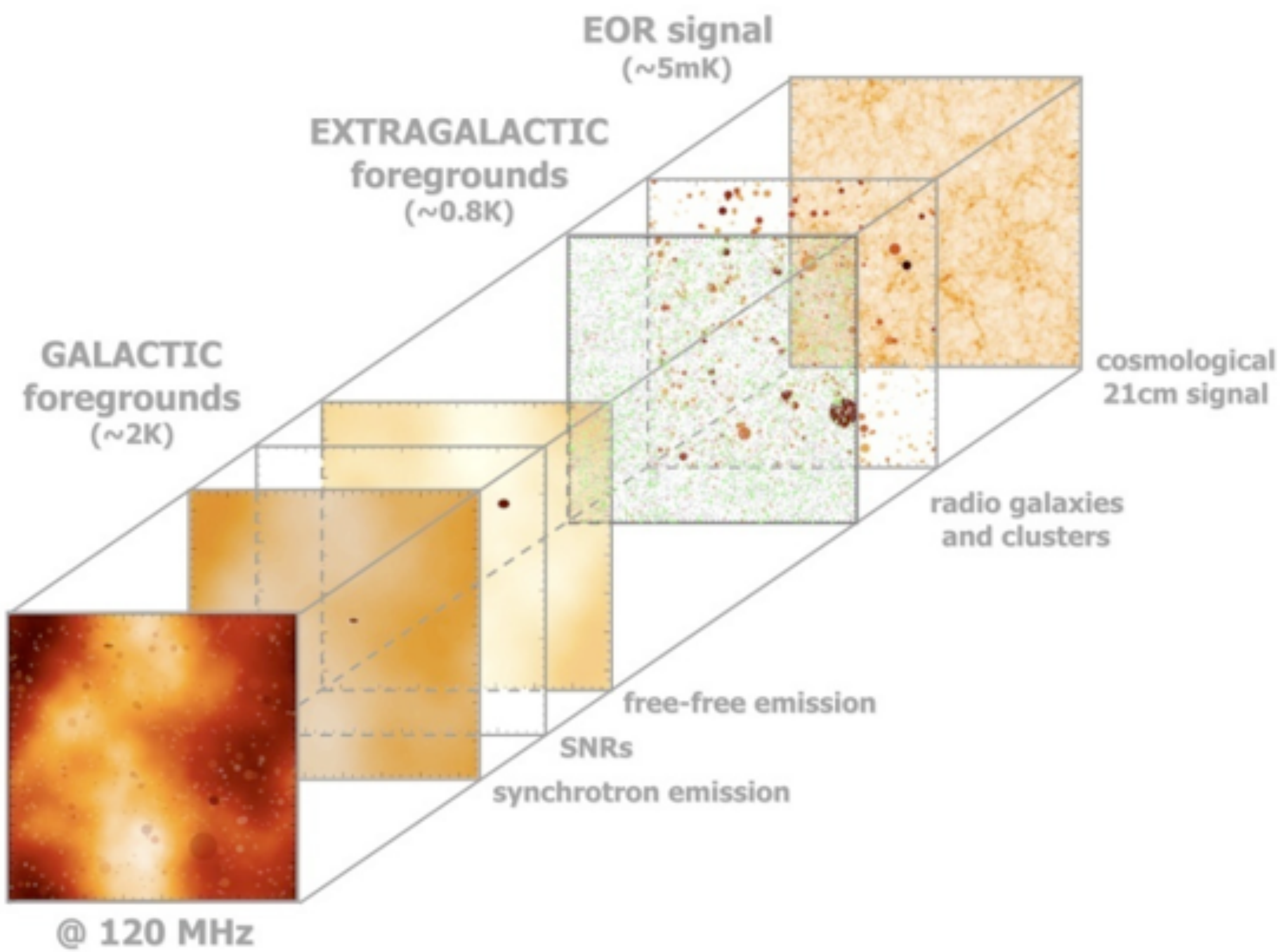






(u,v)
plane
sampling

Imaging the dawn of the Universe



- Multichanel observations
Lofar : 115 - 200 MHz
SKA low : 50 - 200 MHz

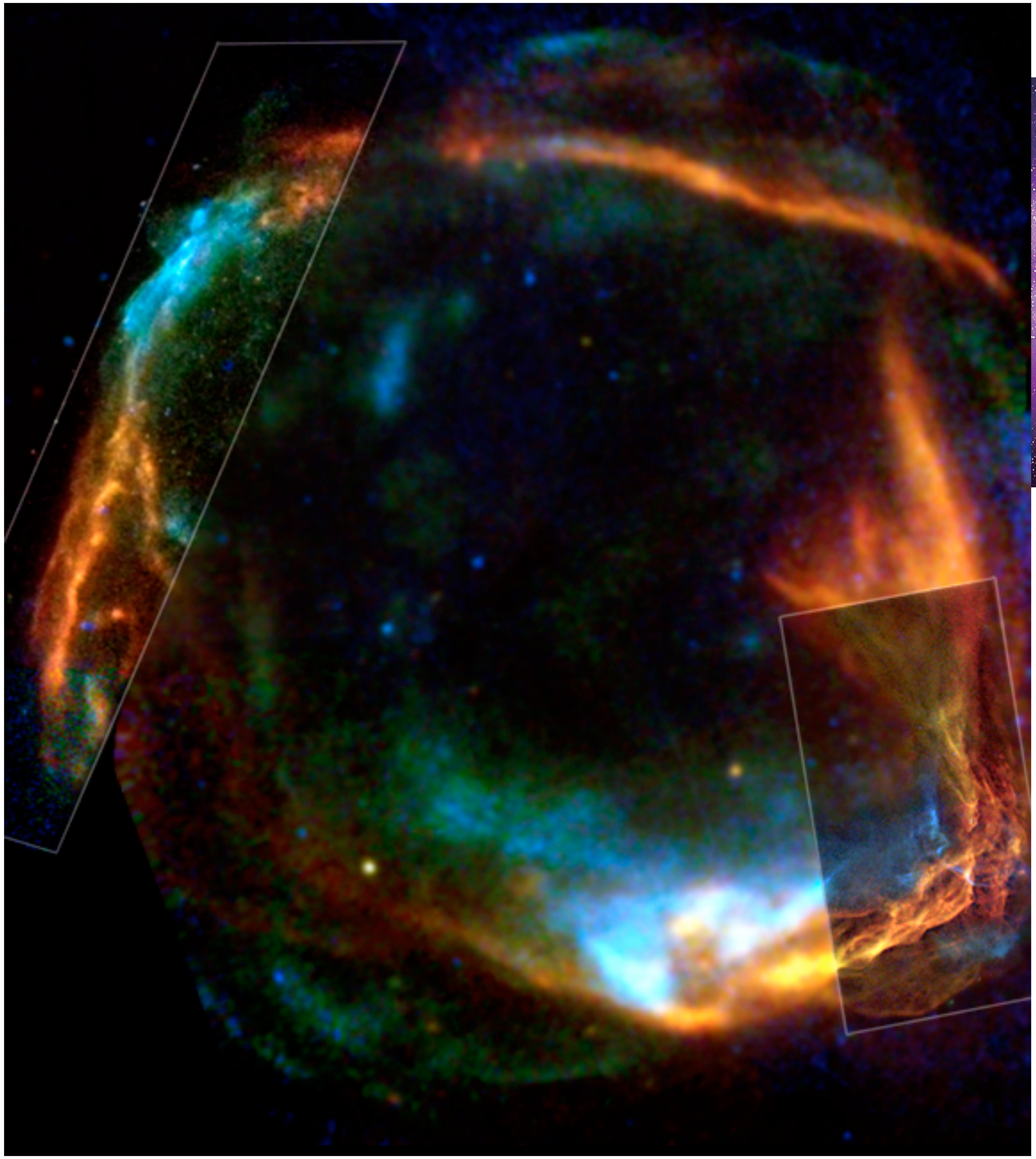
- Mixture of astrophysical components:
Synchrotron, free-free, radio sources

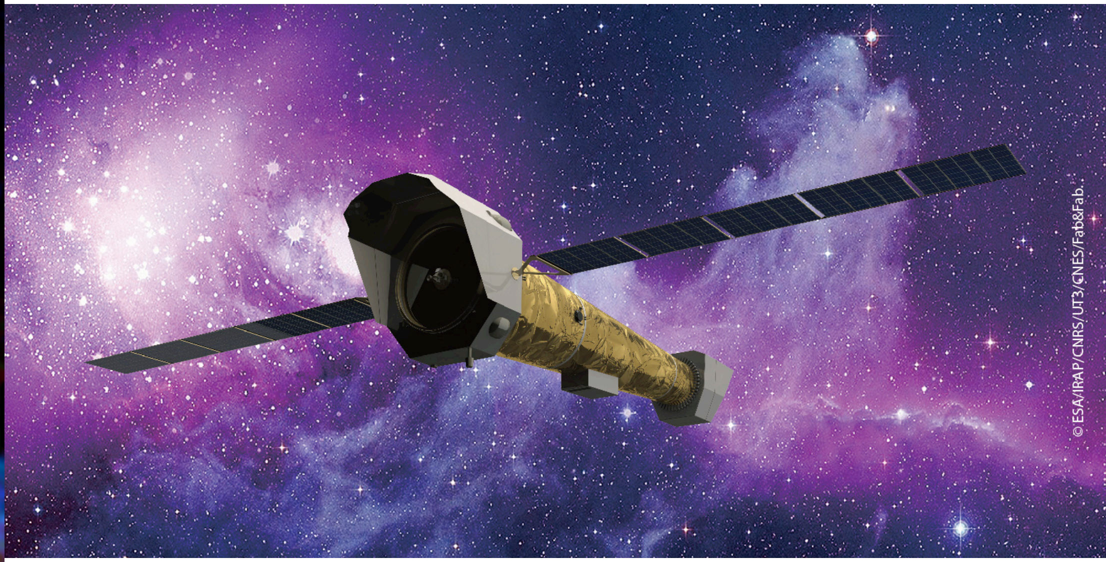
- Very low-level signal

Foregrounds $>$ Noise $>$ EoR signal

$\sim 1 - 10^2$ $\sim 10^{-3}$

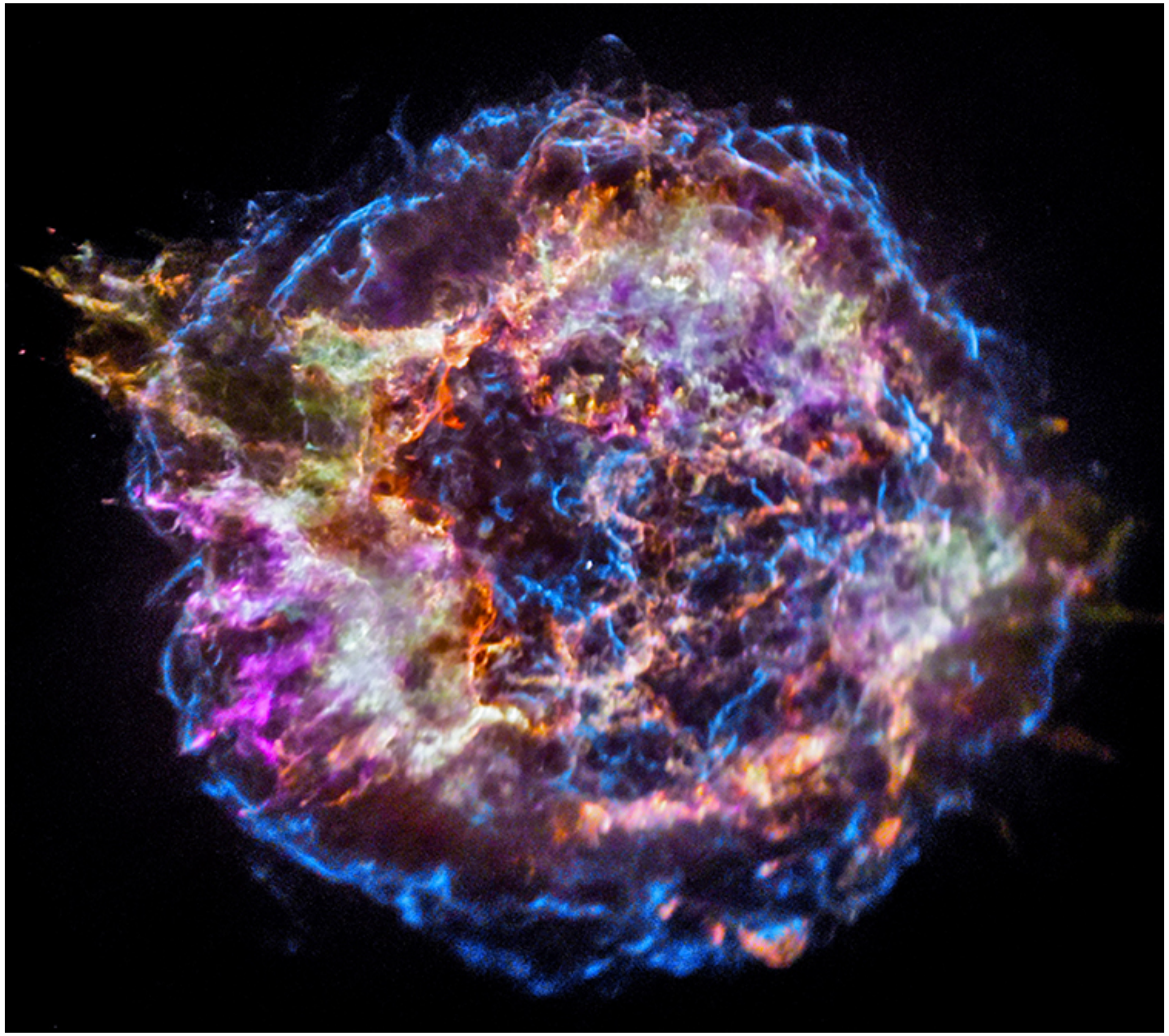
Imaging highly energetic phenomena



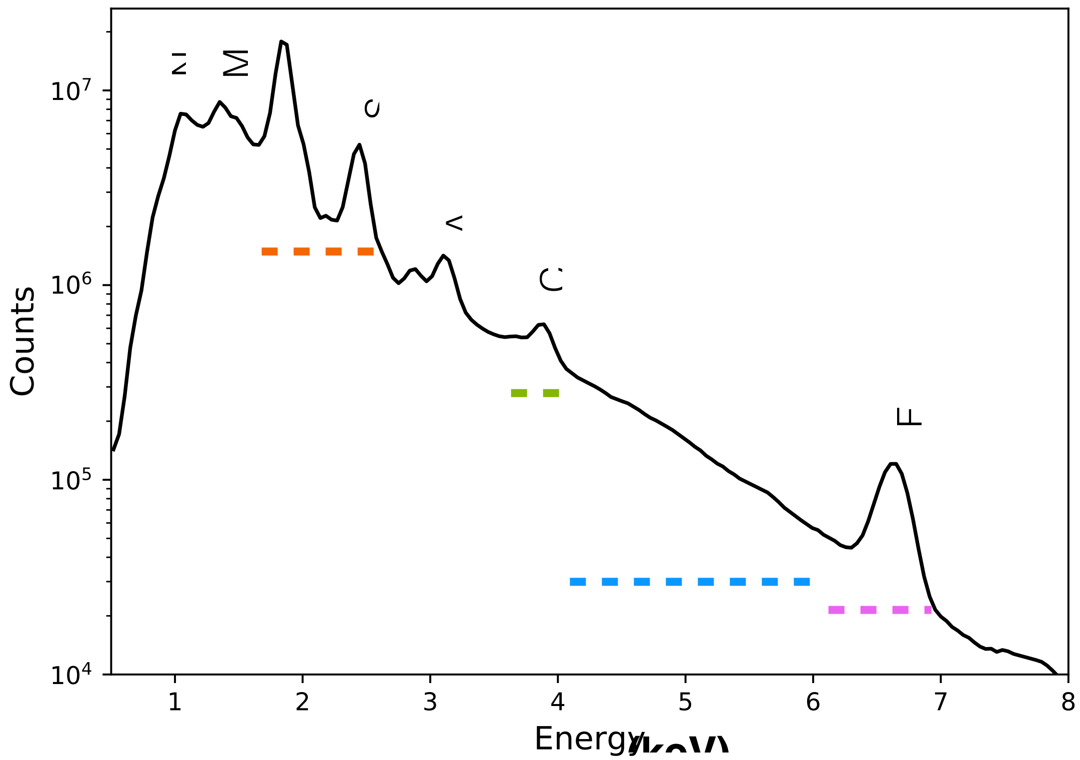


Athena: future European X-ray Space telescope

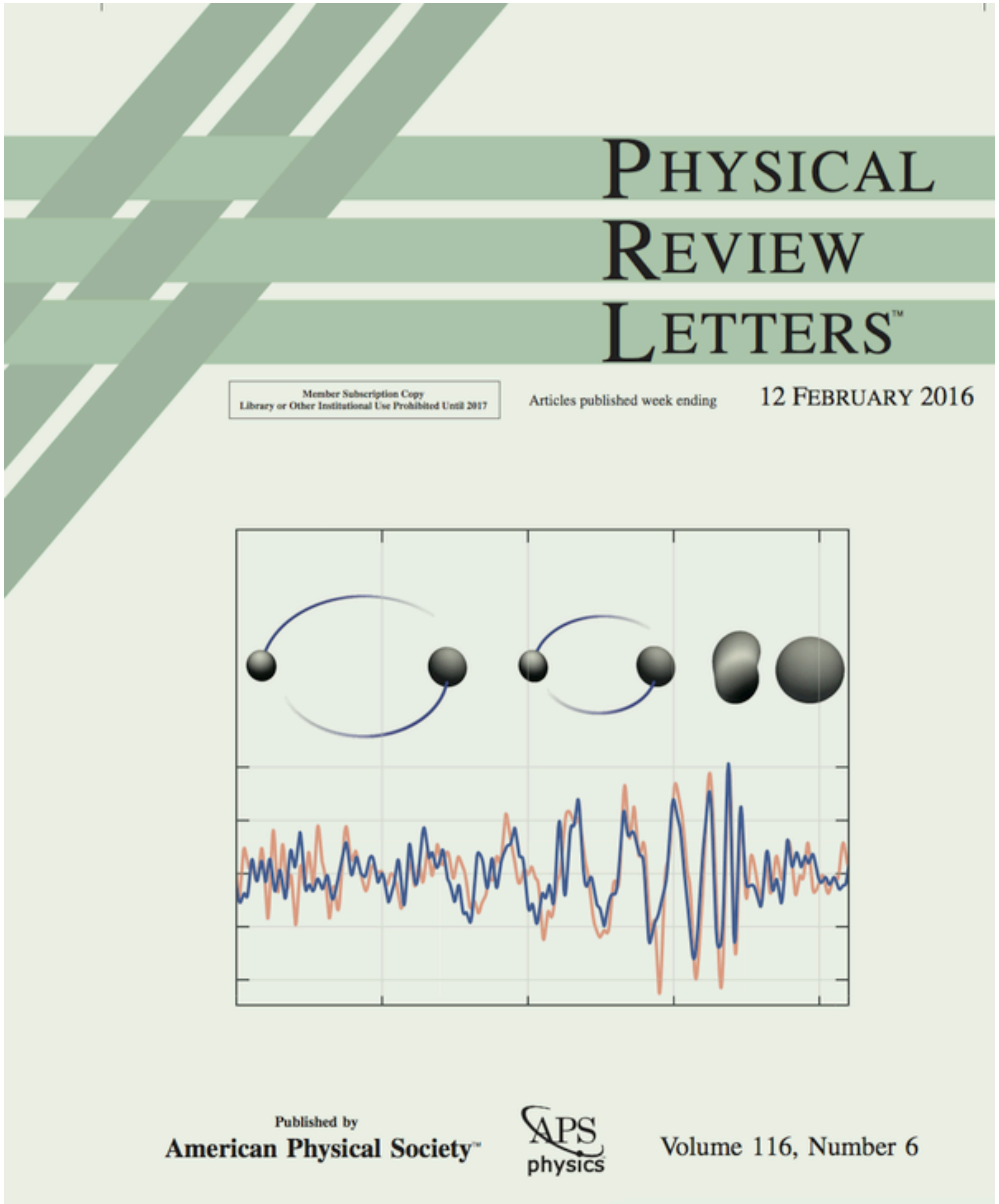
Imaging highly energetic phenomena



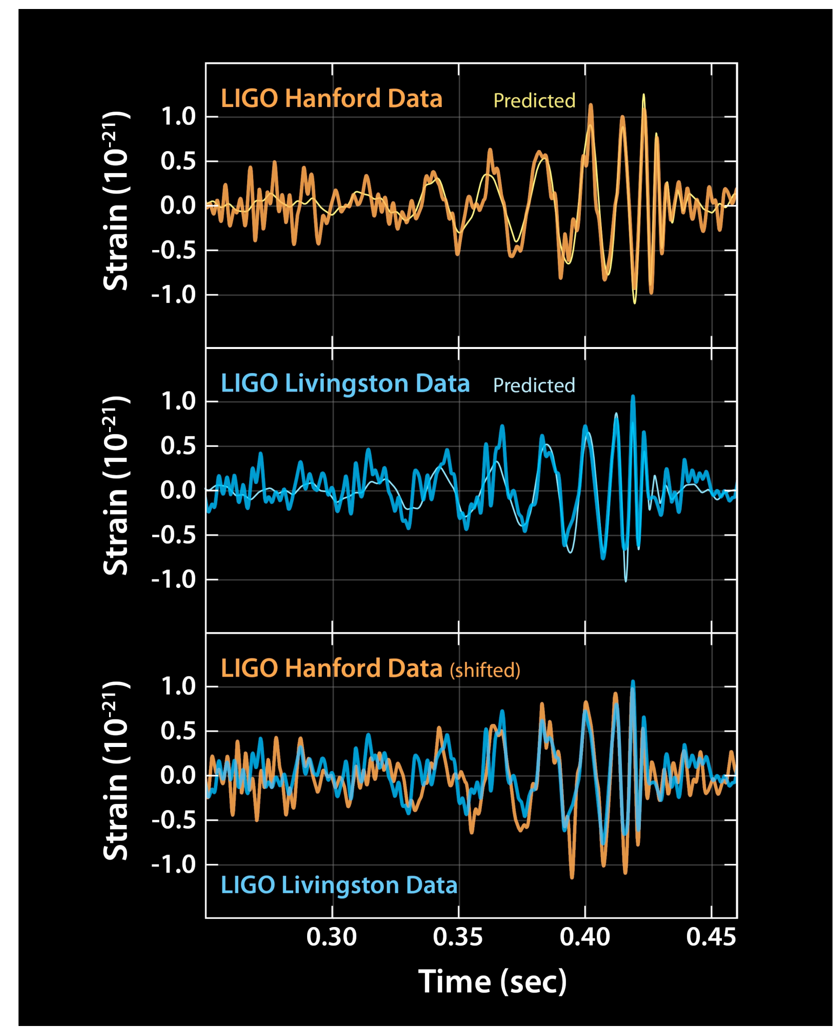
**X-ray images provide
High-spatial/spectral resolution
multispectral
Images of the sky**



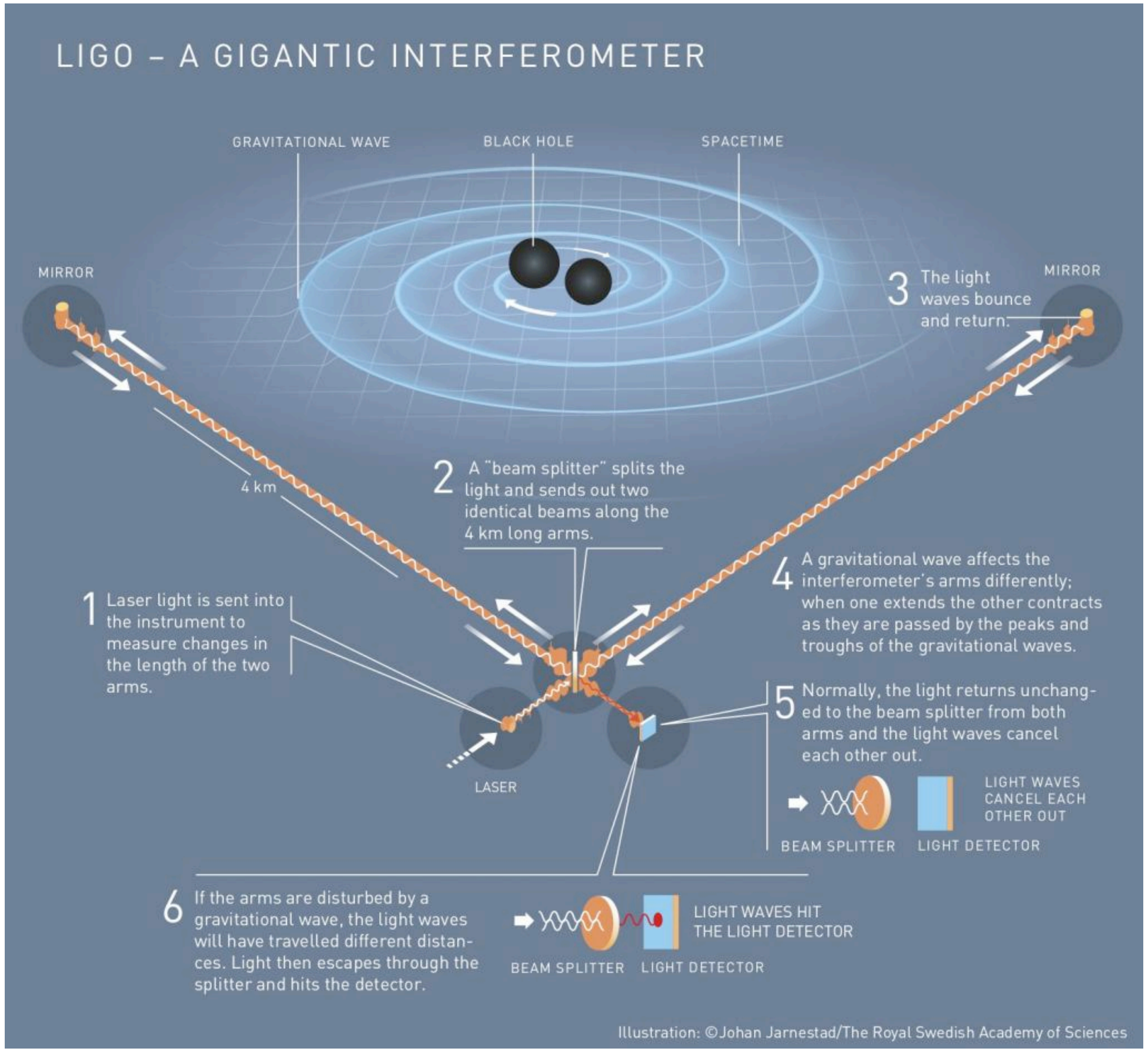
The quest for the gravitational waves



First detection of gravitational waves
Fall 2015



The quest for the gravitational waves

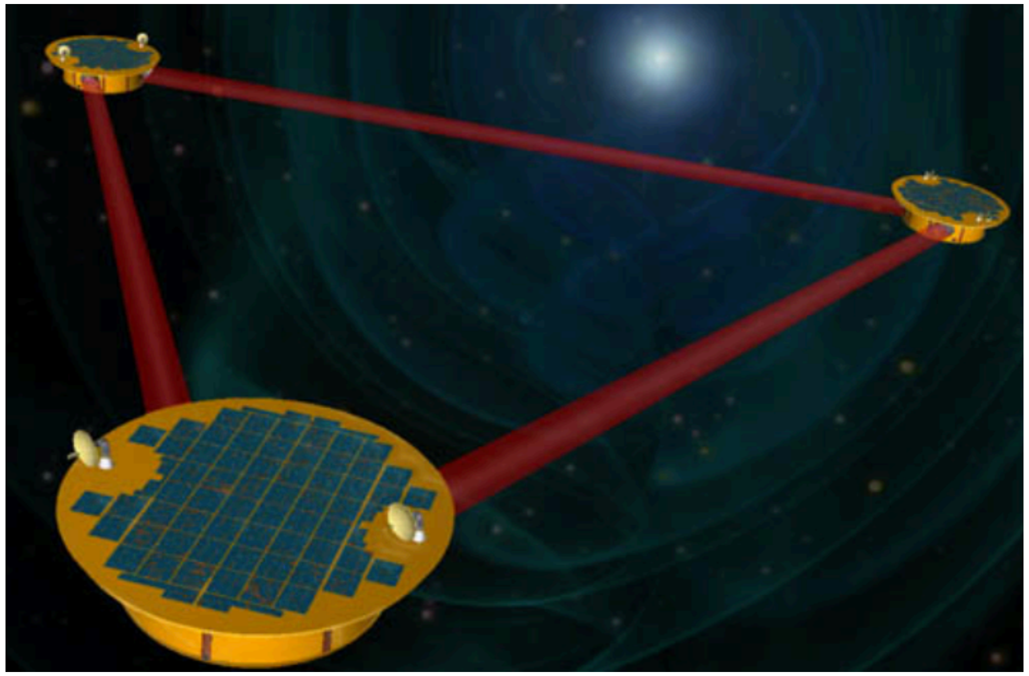


Ground-based: LIGO (US), VIRGO (EU)

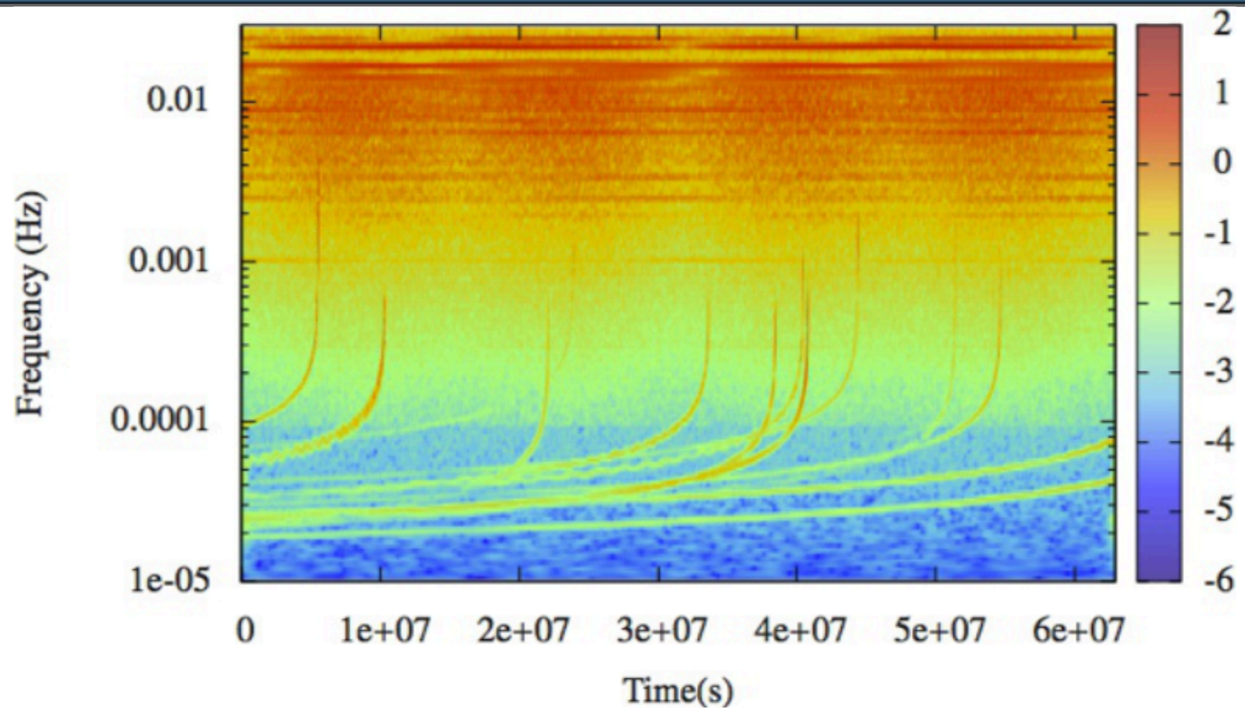
Arms length limited to few kilometres

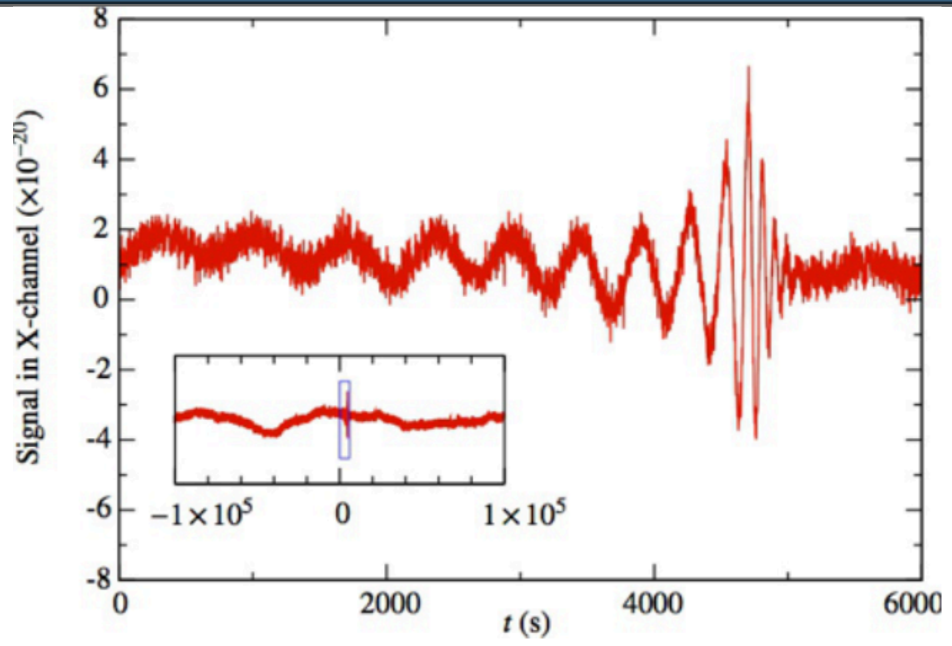
Need to go to space (up to 2.5 million km arms !)

Higher sensitivity, GW at lower frequencies



The quest for the gravitational waves



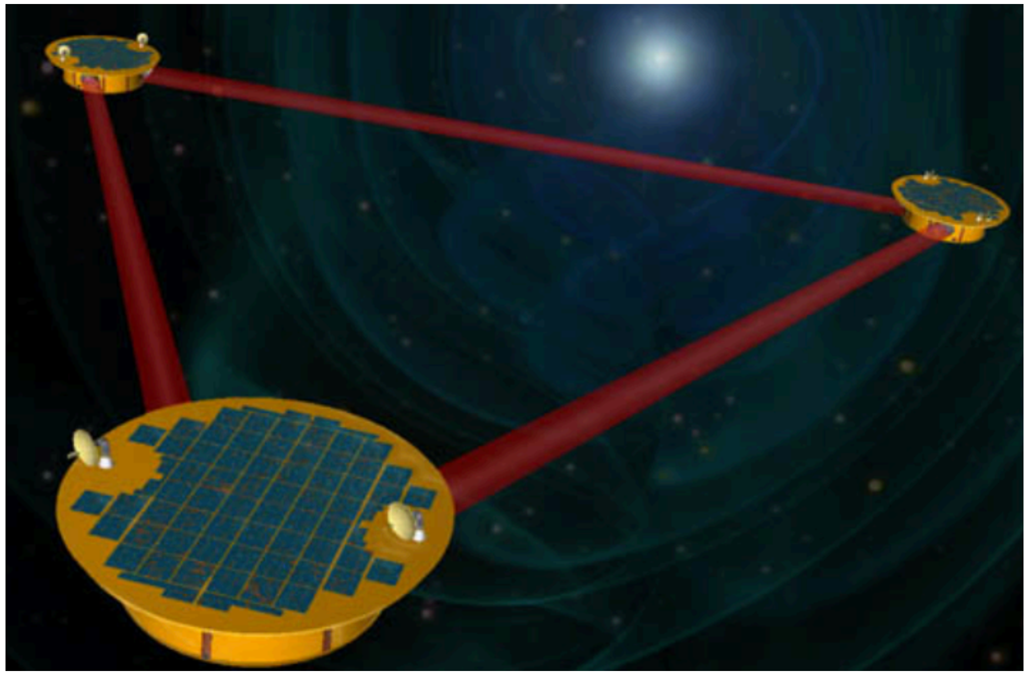


The measurements are composed of 3 time series

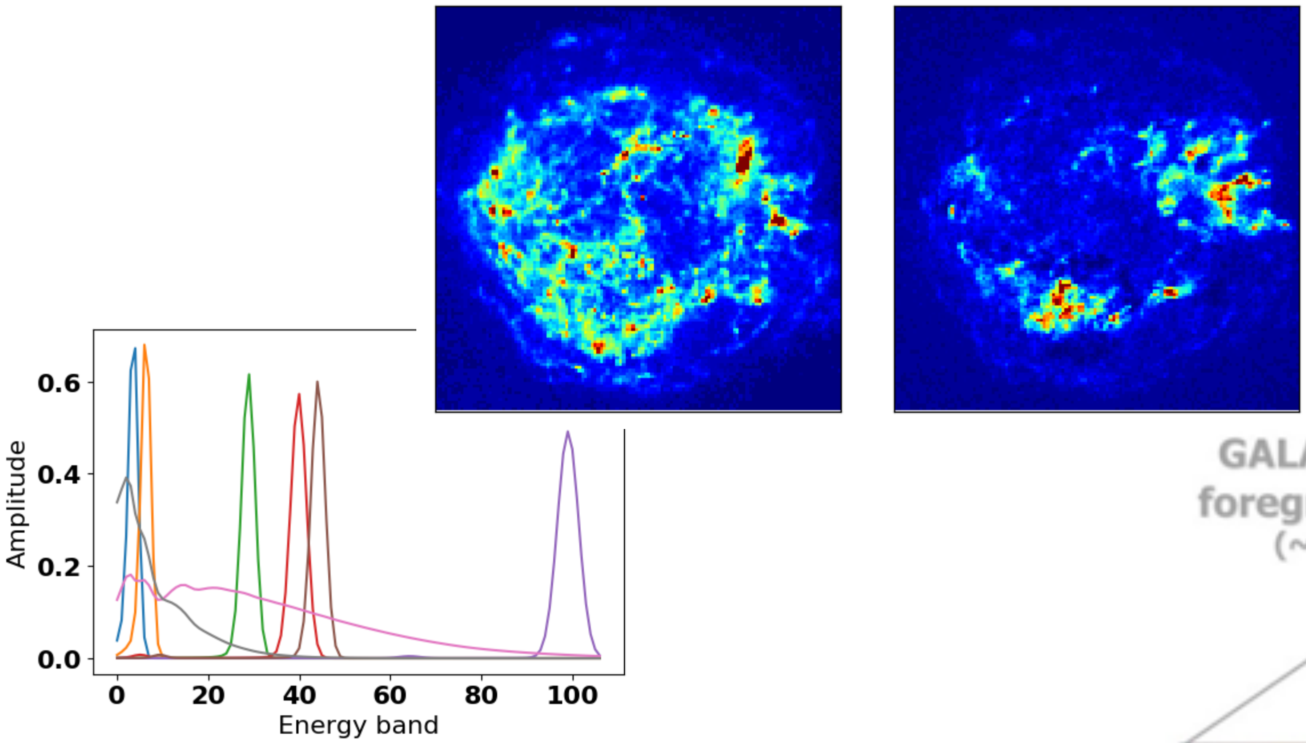
Superimposition of :

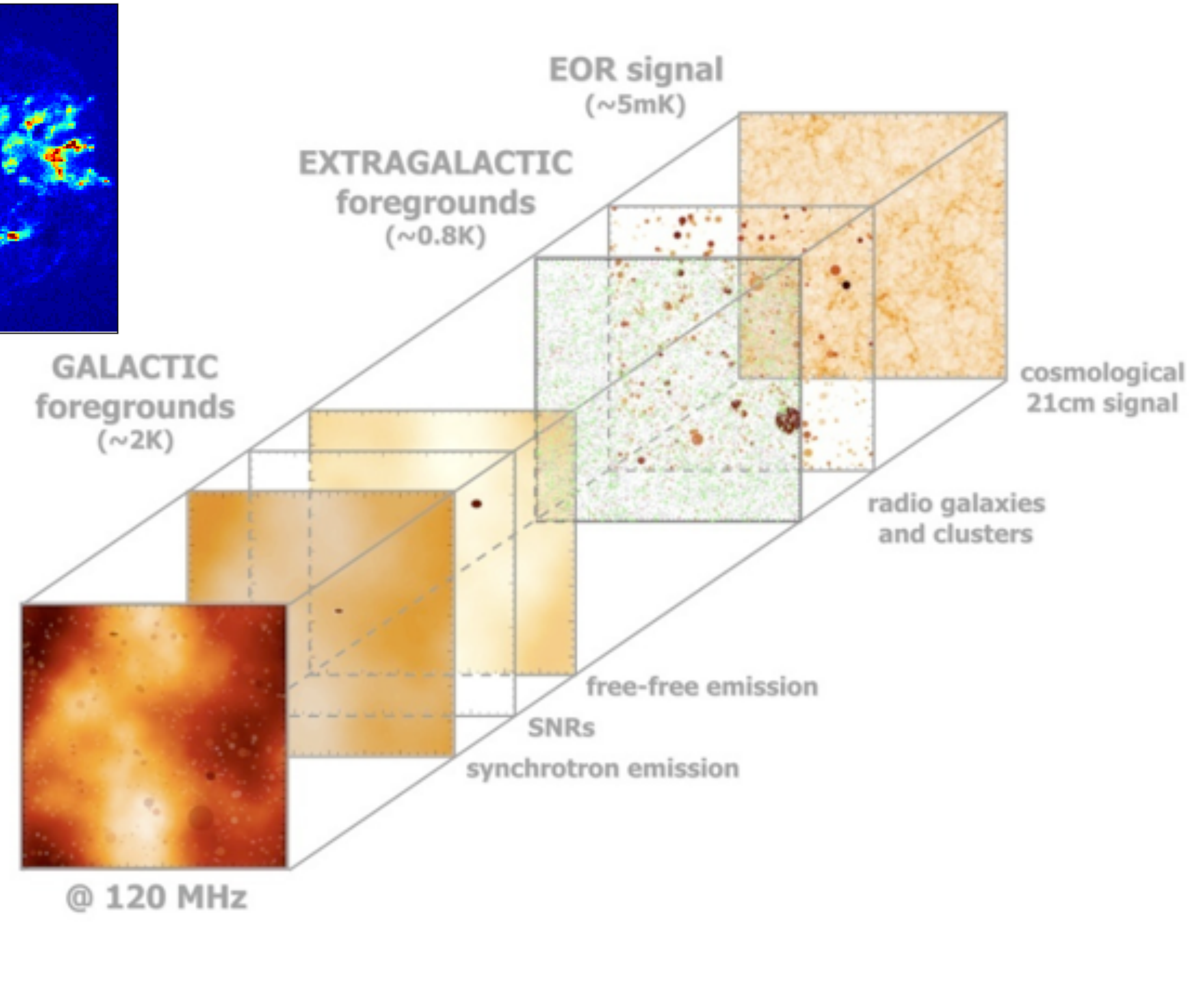
- **> 1000000 Galactic binaries**
- **10 to 100 SMBHB/year**
- **Thousands of Stellar Mass BHB**
- **Hundreds of Extreme Mass Ratio Inspirals**

Most have never been observed



All problems might seem quite different

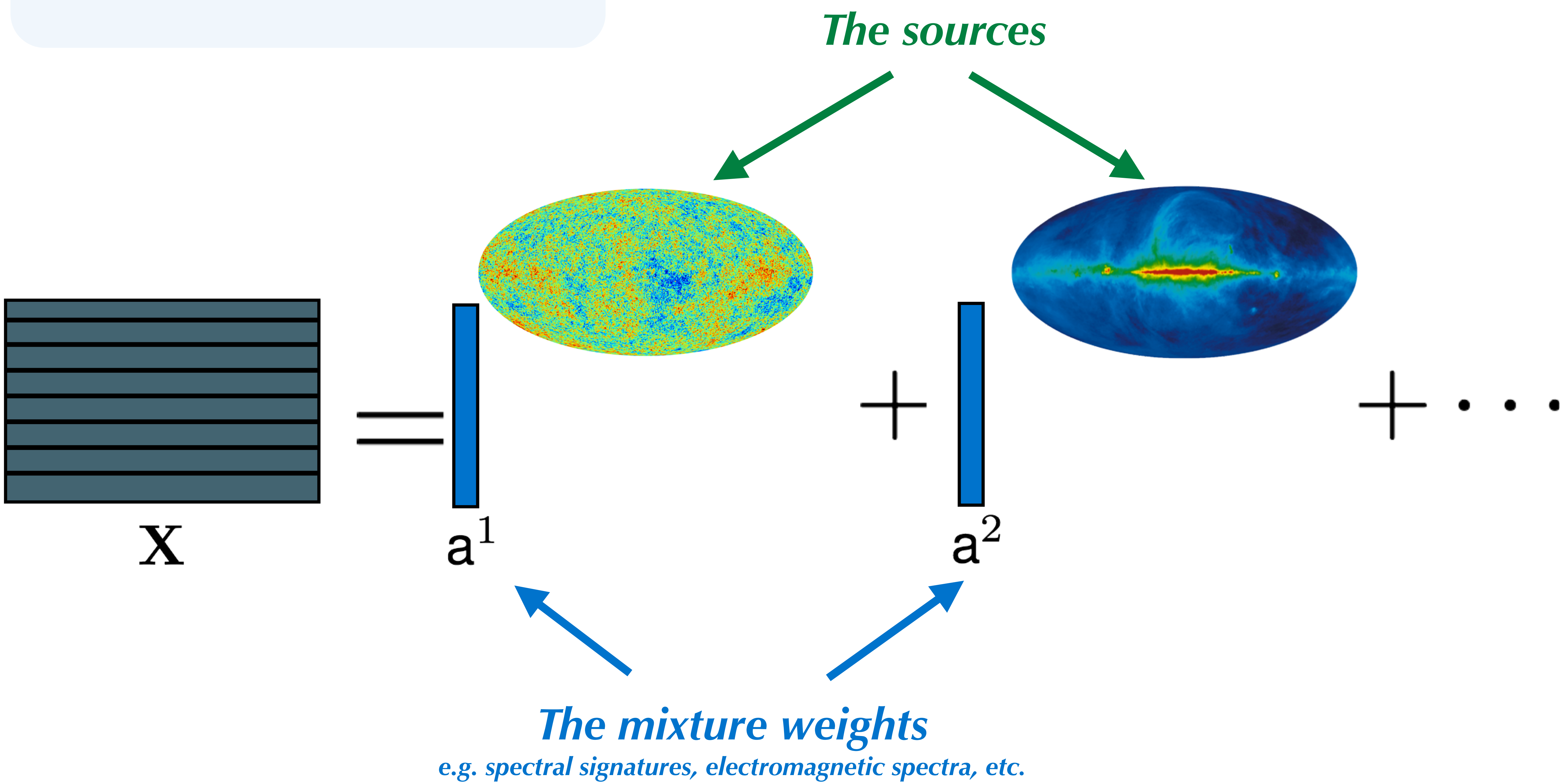




Different scientific fields but …

common problems: mixtures of elementary signals or sources

The linear mixture model



Challenges !

I - What are the models and methods to be used to recover physically meaning information ?

Source separation methods, regularisations, models (linear vs non-linear, etc.)

II - How to efficiently numerically solve BSS problems ?

Dealing with non-convex matrix factorisation problems, fast and efficient algorithms for massive data.

III - Building interpretable methods ?

Machine-learning based BSS, hybrid methods

Menu of the course

An overview:

- Source separation problems are central methods in a large number of applications, beyond astrophysics.

- Overview of the current state-of-the art methods in BSS, with *(real-world)* applications for astrophysical data analysis.

- Focus on methodologies and their practical applications

- This is not an astrophysics course !

Menu of the course

Course #I - Introduction to source separation methods, statistical principles

Statistical principles, independent component analysis and applications

Starting practical work #1

Course #II - Advanced statistical source separation methods

From linear to non-linear models, learning-based methods, limitations

Ending practical work #1

Course #III - Sparse modelling and source separation

Sparse representations and their applications to source separation

Applications in astrophysics

Starting practical work #2

Menu of the course

Course #IV - Algorithms for regularised BSS

Proximal algorithms for non-convex problems

Practical work #2

Course #V - Algorithms for regularised BSS

Proximal algorithms for matrix factorisation and implementations

Practical work #2

Course #VI - Advanced regularised BSS

Learning-based hybrid (plug-and-play) methods interpretability

Applications in astrophysics

Ending practical work #2

Menu of the course

Course #VII - Introduction to NMF

Principles of non-negative matrix factorisation, theory and algorithms

Starting practical work #3

Course #VIII - Advanced NMF methods

Beyond linear models in NMF, applications

Ending practical work #3

Menu of the course

Evaluation :

- Based on the practical works (PW) reports (50 % of the final mark) :

  Some basic questions to be answered with numerical illustration
  Will require basic coding skills (using Python)
  Will lead to coding building blocks for future PW

- Simple "Research" project, final report + oral presentation (50 % of the final mark) :

  Choosing between two different projects, which will be released in february
  Answer to a data analysis challenge in astrophysics
  Make use of the methods introduced during the course
  Will require basic coding skills (using Python)
  More than the numerical results, the proposed reasoning will be mostly important

Questions or comments ?

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Slides, data et solutions of the practical works :

http://jerome-bobin.fr/teaching/master-2-mva/

https://github.com/BSScourse/MVA