Thème : Grandes Structures & Projet : Euclid

Séminaire interne de l'IAP 2022
Jardins de l'Anjou

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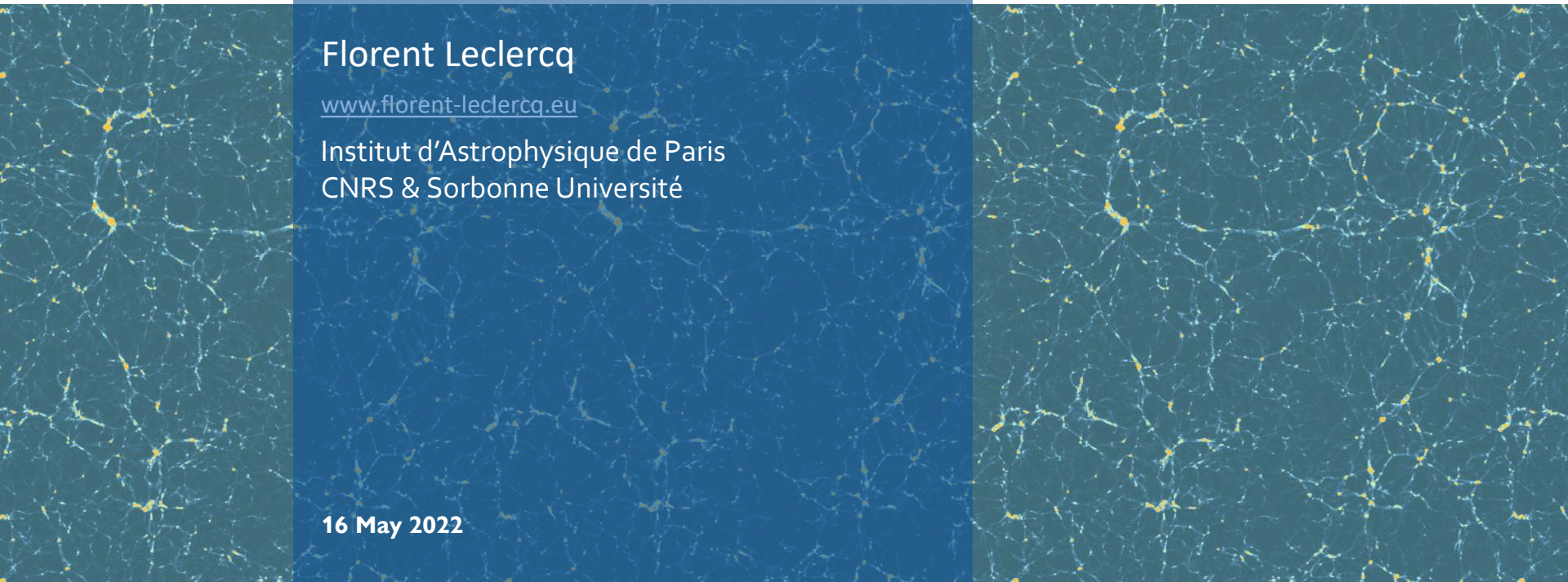
CNRS & Sorbonne Université

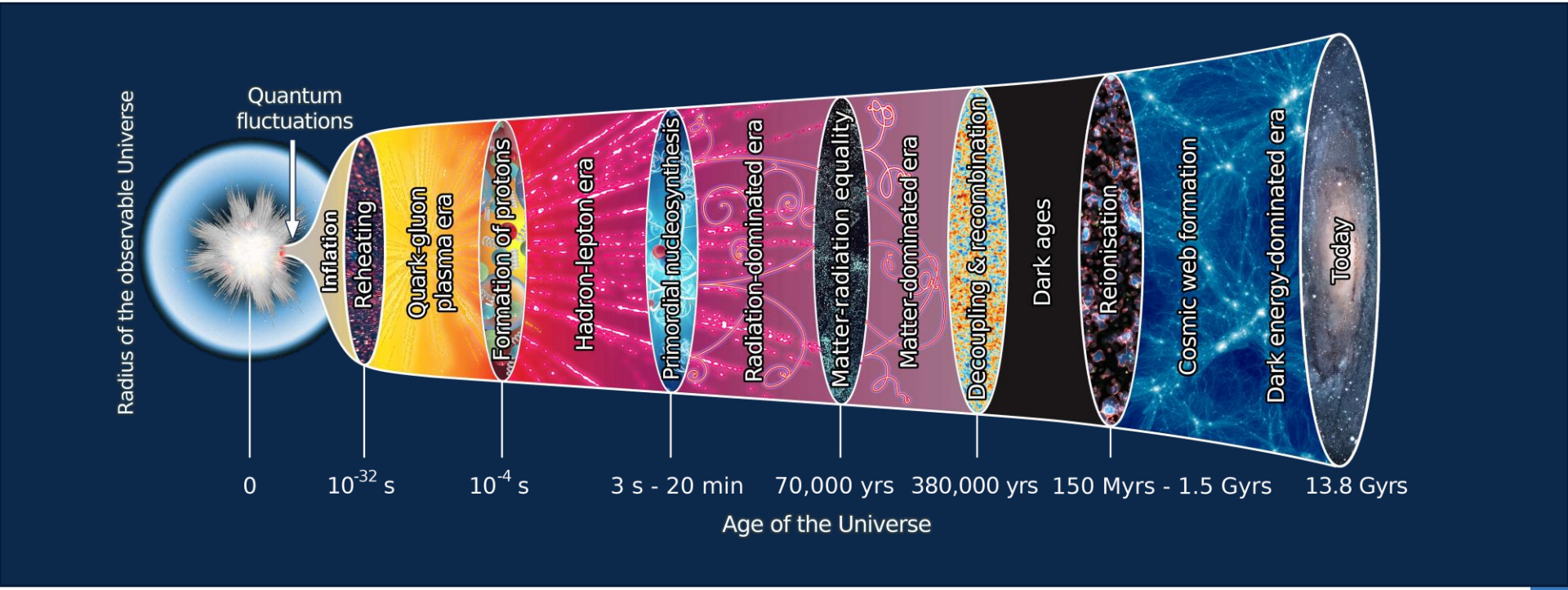
16 May 2022



Thème : Grandes structures

Groupe “Grandes structures et Univers profond”

Our field: physical cosmology



Our (modest!) goal: we want to understand the Universe at the deepest level (origin, evolution, content, and dynamics)

Overview of our interests

Scientific themes

- CMB temperature and polarisation, primordial non-Gaussianity
- Large-scale structure, galaxy formation and evolution, gravitational lensing

Large projects:

- Planck (until 2020), and post-Planck processing [F. Bouchet]
- Euclid [Y. Mellier]
- Simulations [C. Pichon]

But also a rich variety of *smaller projects*.

Scientific methods

- Data science: statistical methods, machine learning, numerical simulations
- High-performance computing (HPC) and high-performance data analysis (HPDA)
- (Semi-)analytical methods, computational geometry
- Pipelines and complex workflows (Planck Data Processing Centre, Terapix, Euclid Science Ground Segment)

Big projects

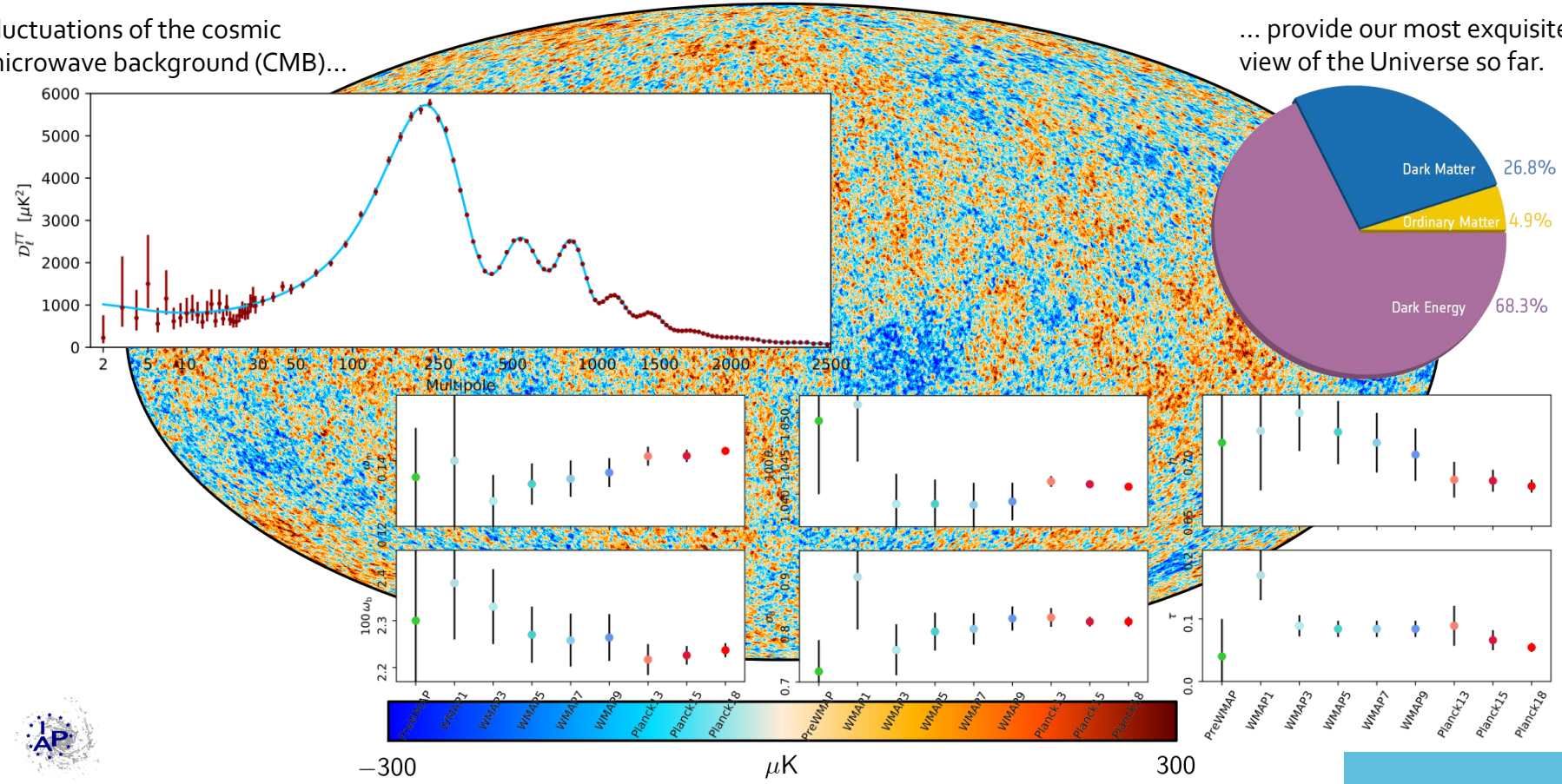
Planck, Euclid, and Simulations

Planck: a milestone in the history of cosmology – successes and legacy

[K. Benabed, F. Bouchet, J.-F. Cardoso, S. Galli, É. Hivon, B. Wandelt + groups]

Fluctuations of the cosmic microwave background (CMB)…

… provide our most exquisite view of the Universe so far.



Planck: a milestone in the history of cosmology – successes and legacy

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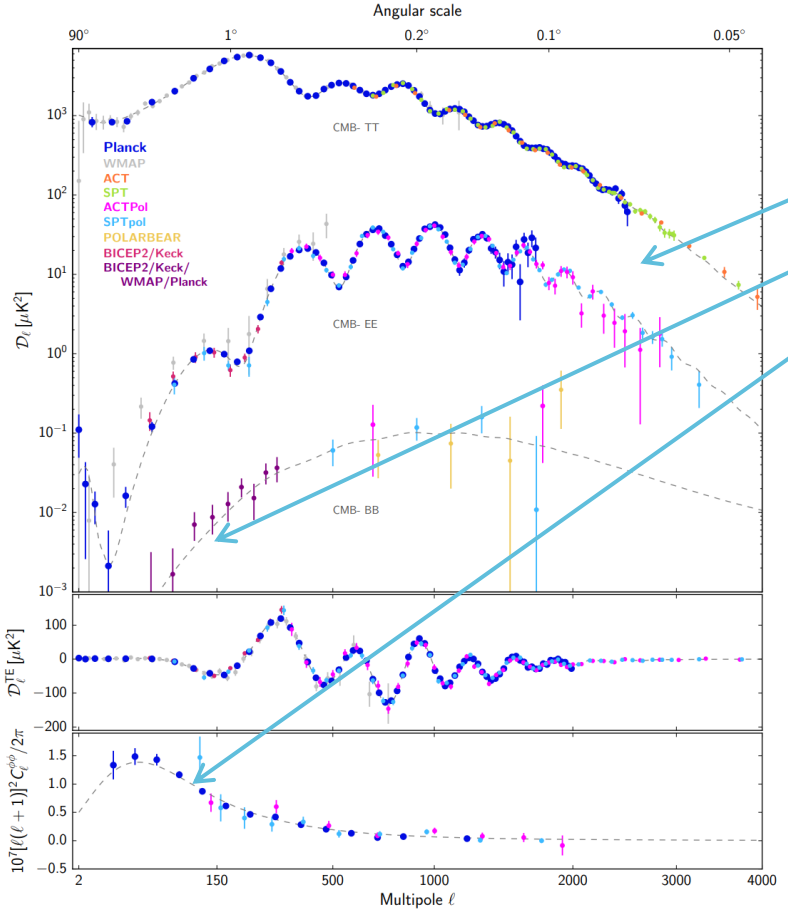
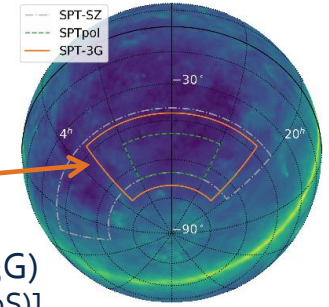


Scientific potential of CMB not exhausted with Planck:

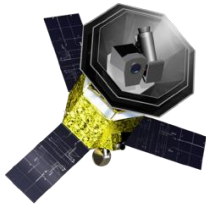
- Neutrino masses at small scales
- B-modes at large scales
- Secondary effects, lensing
- Spectral distortions



Sky observed by SPT-3G

Now at IAP:

- South Pole Telescope (SPT-3G) [S. Galli + group (ERC NEUCosmoS)]
- LiteBIRD satellite [É. Hivon…], CMB-S4 (see Atelier "Cosmologie")



Euclid: the next space mission will map the dark Universe

[K. Benabed, F. Bernardeau, C. Laigle, G. Lavaux, F. Leclercq, H. J. McCracken, Y. Mellier, P. Tisserand + groups (scientific exploitation)]

Goal: understand

- The origin of the Universe's accelerating expansion
- The properties and nature of Dark Energy and Gravity

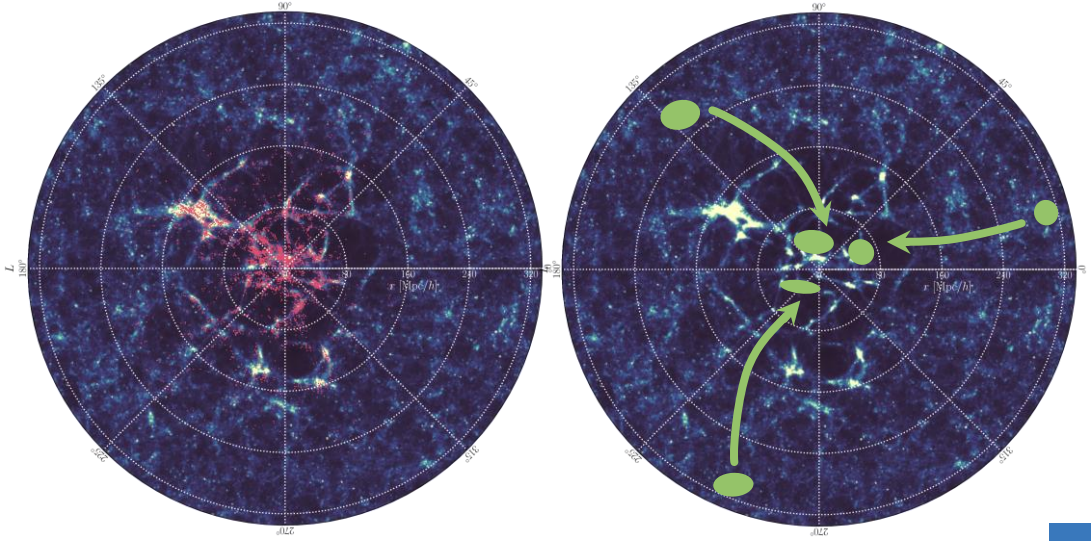
$$w = P/\rho \qquad w(a) = w_0 + w_a(1-a)$$

Probe the effects of Dark Energy, Dark Matter and Gravity by

- Using at least 2 independent but complementary probes
- Tracking their observational signatures on the
  - Geometry of the universe: Weak Lensing, Baryon Acoustic Oscillations
  - Cosmic history of structure formation: Weak Lensing, Redshift-Space Distortions, Clusters of Galaxies
- Controlling systematics to an unprecedented level of accuracy.

1- Galaxy clustering

2- Weak gravitational lensing



(more about the Euclid project in the second part of this presentation)

Simulations: a key ingredient for data-intensive scientific discovery

[K. Benabed, F. Bouchet, S. Colombi, Y. Dubois, J-B. Fouvry, S. Galli, É. Hivon, C. Laigle, G. Lavaux, C. Pichon, B. Wandelt + groups]

- Comparing observations with theory is hard in complex physical systems. Computer simulations are becoming the new way to express theories in order to assess their reliability.
- Historical expertise and leadership in the development of astrophysical simulations at the IAP.
- Transition to exascale computing: compelling science opportunities, but numerous challenges (scalability, massive parallelism, energy requirement, run-time errors).

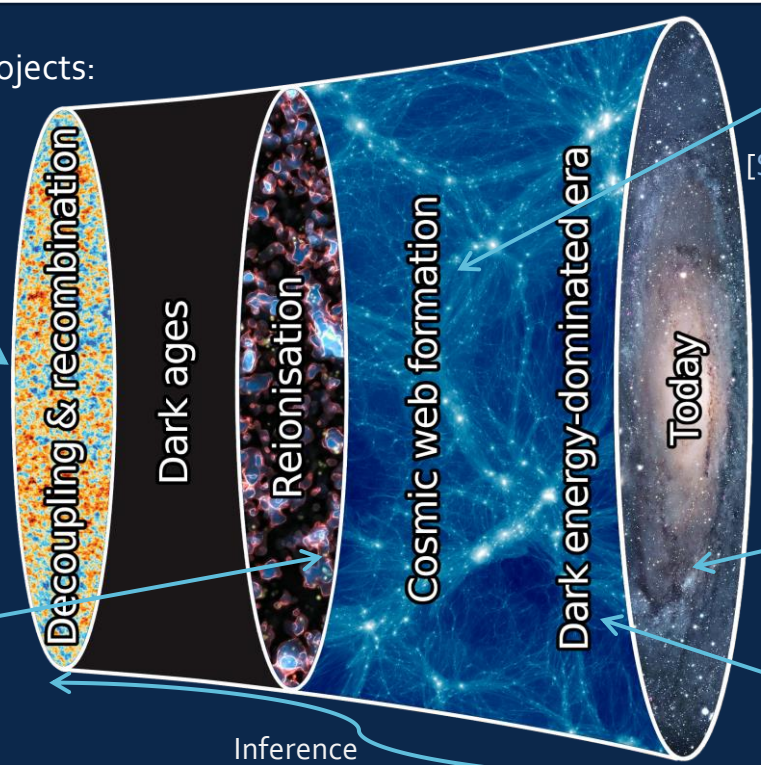
(see the presentation of the Infinity cluster and the Atelier "Numérique")

The Horizon-AGN simulation
[Y. Dubois, C. Pichon, C. Laigle, D. Le Borgne, M. Volonteri, K. Benabed, S. Colombi + collaborators]

Many other interesting questions

Back to the thermal history of the Universe…

A (non-exhaustive) list our other projects:



Primordial non-Gaussianity, Gravitational wave background [K. Benabed, F. Bouchet, S. Galli, G. Lavaux, B. Wandelt…]

Cosmic web and gravitational dynamics of structures [S. Colombi, C. Pichon, J-B. Fouvry…]

Black holes [A. Riazuelo],Stellar astrophysics [P. Tisserand]

Cosmic Dawn, Lyman-α tomography [C. Laigle, H. J. McCracken…]

Strong and weak gravitational lensing [C. Alard, K. Benabed…]

Inference [G. Lavaux, F. Leclercq, B. Wandelt…]

(more opportunities and challenges in the Ateliers "Cosmologie", "Galaxies", and "Hautes Énergies")

Cosmic web and gravitational dynamics of structures

[S. Colombi, J-B. Fouvry, C. Laigle, C.Pichon + groups]

The cosmic web is the largest known structure in nature:

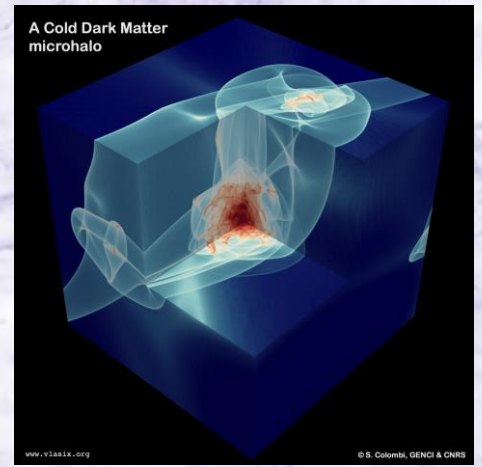
- Anisotropic,
- Multiscale/hierarchical,
- With a complex spatial connectivity.

It gives information on

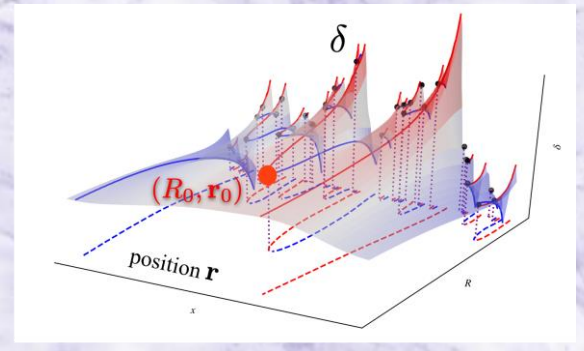
- Galaxy formation and evolution as a function of the environment,
- Dark energy and gravity through its evolution and memory of the initial conditions.

It is studied at the IAP through…

- Numerical simulations,
- (Semi-)analytical methods,
- Computational geometry.



Colombi 2021

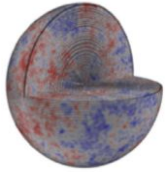


Cadiou, Pichon *et al.* 2020

We can understand a lot about the Universe by starring at initial conditions!

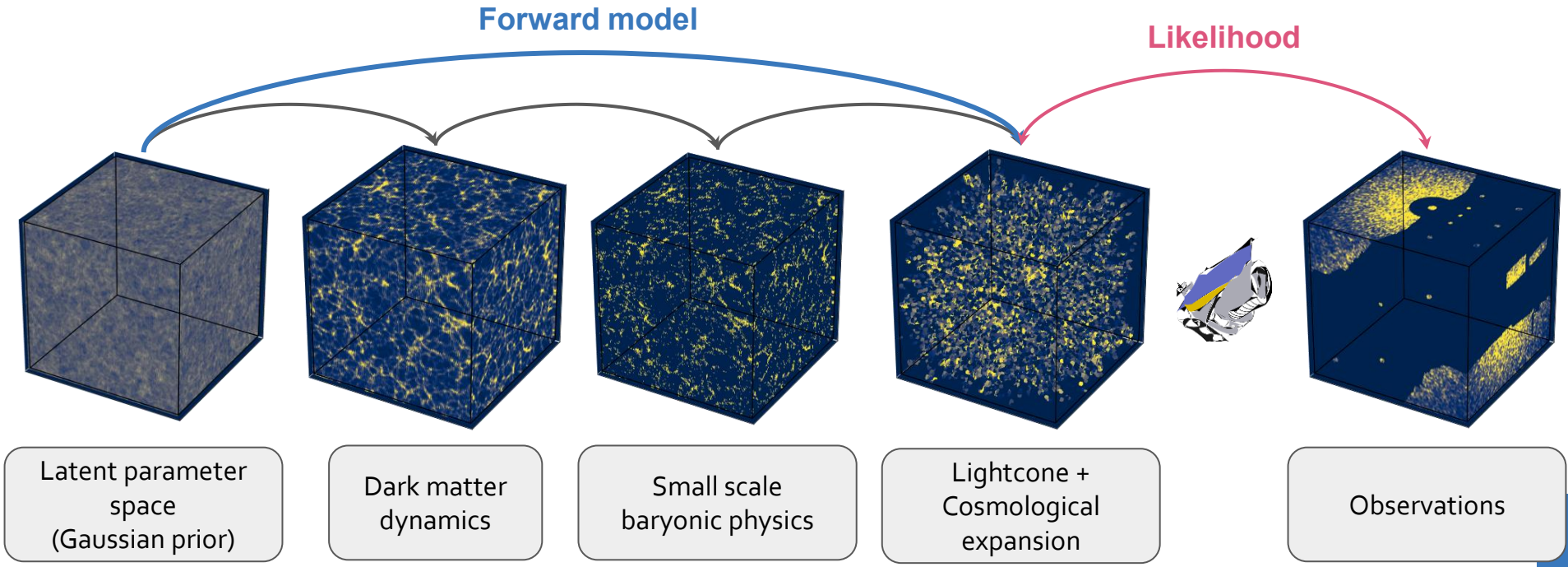
BORG reconstructions

Aquila Consortium



Learning the Universe

[G. Lavaux, F. Leclercq, B. Wandelt + groups]



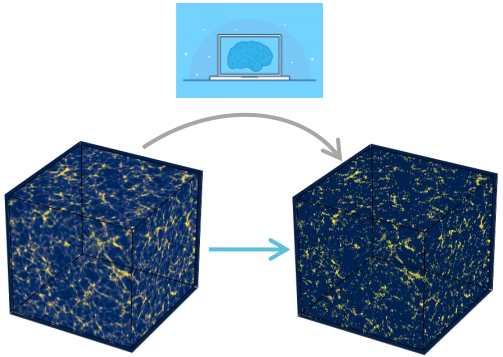
BORG now handles: galaxy clustering, weak lensing, Lyman-α forests, and distance tracers

[Last IAP colloquium organised by K. Benabed, G. Lavaux, H. J. McCracken]

Why machine learning for cosmology?

Speed up & go beyond approximations

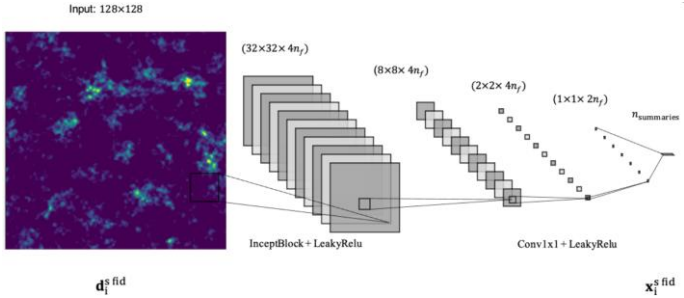
Emulators



Kodi Ramanah *et al.* 2019

Be information optimal

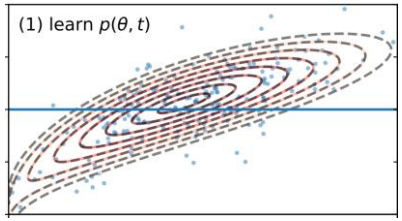
Automatic data compression



Makinen *et al.* 2021

Deal with complex inference problems

Implicit likelihood inference



Alsing *et al.* 2019

(more about high-performance data analysis at the Atelier "Numérique")

The strength and uniqueness of the group: our expertise in data science

Our success is largely based on a methodological expertise:

Bayesian analyses, data mining, processing of large datasets, simulations, modelling…

Can we develop this further now? Some ideas recently discussed in the group:

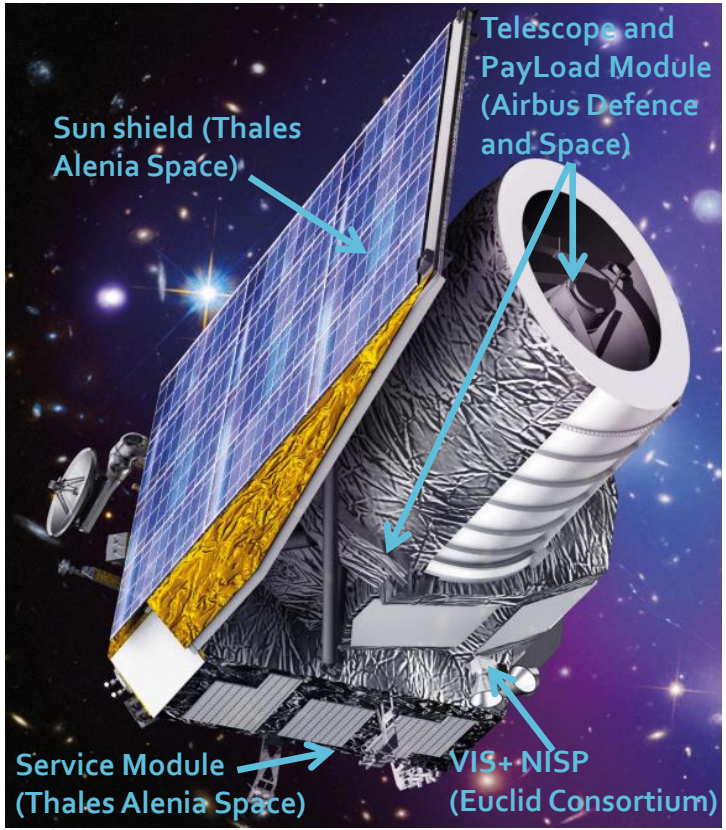
- Give more visibility to this aspect as a group strength and uniqueness?
- Favour interdisciplinarity: collaborations/interactions with other groups/institutions?
- Organise workshops/seminars around data-intensive aspects?
- Look for methodological expertise when hiring?

Future: how do we keep this uniqueness to foster innovation?

(more about these aspects at the Ateliers “Numérique” and “Attractivité”)

Projet : Euclid

The Euclid satellite and its two instruments



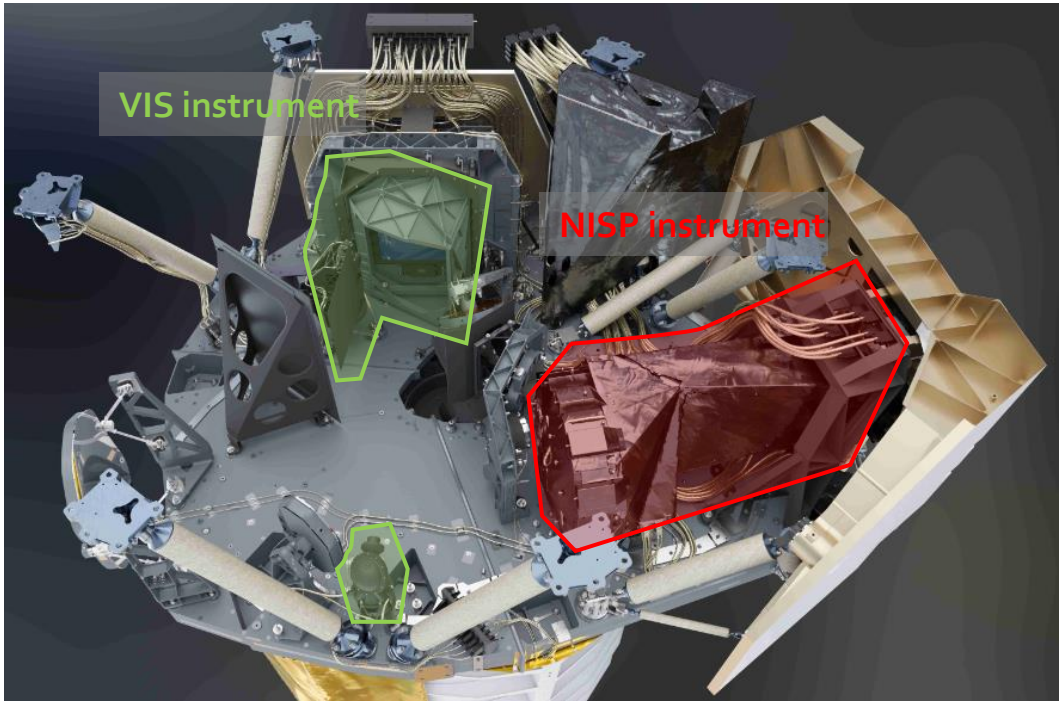
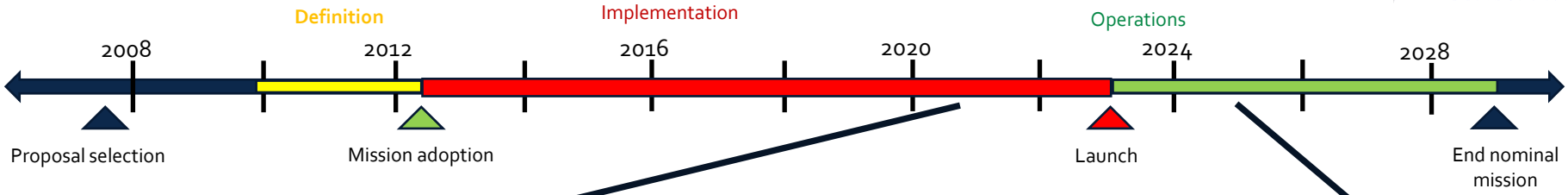
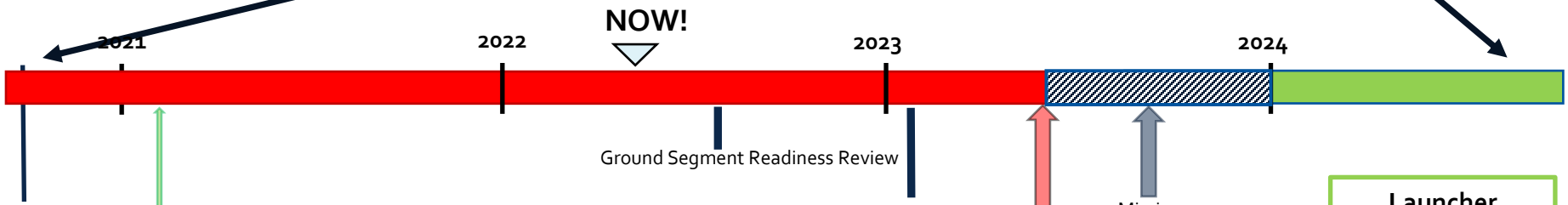


Photo: courtesy ESA/TAS

Mission timeline





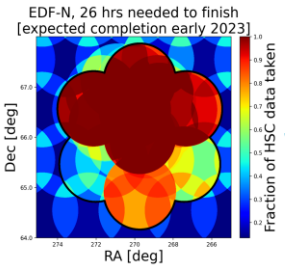
Launcher and launch date To be confirmed

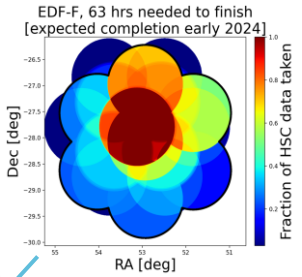
Public data releases:
Q1 (50 deg²) at T0+17 months
DR1 (2500 deg²) at Q1+1 year
DR2 (7000 deg²) at Q1+3 years
DR3 (14000 deg²) at Q1+6 years

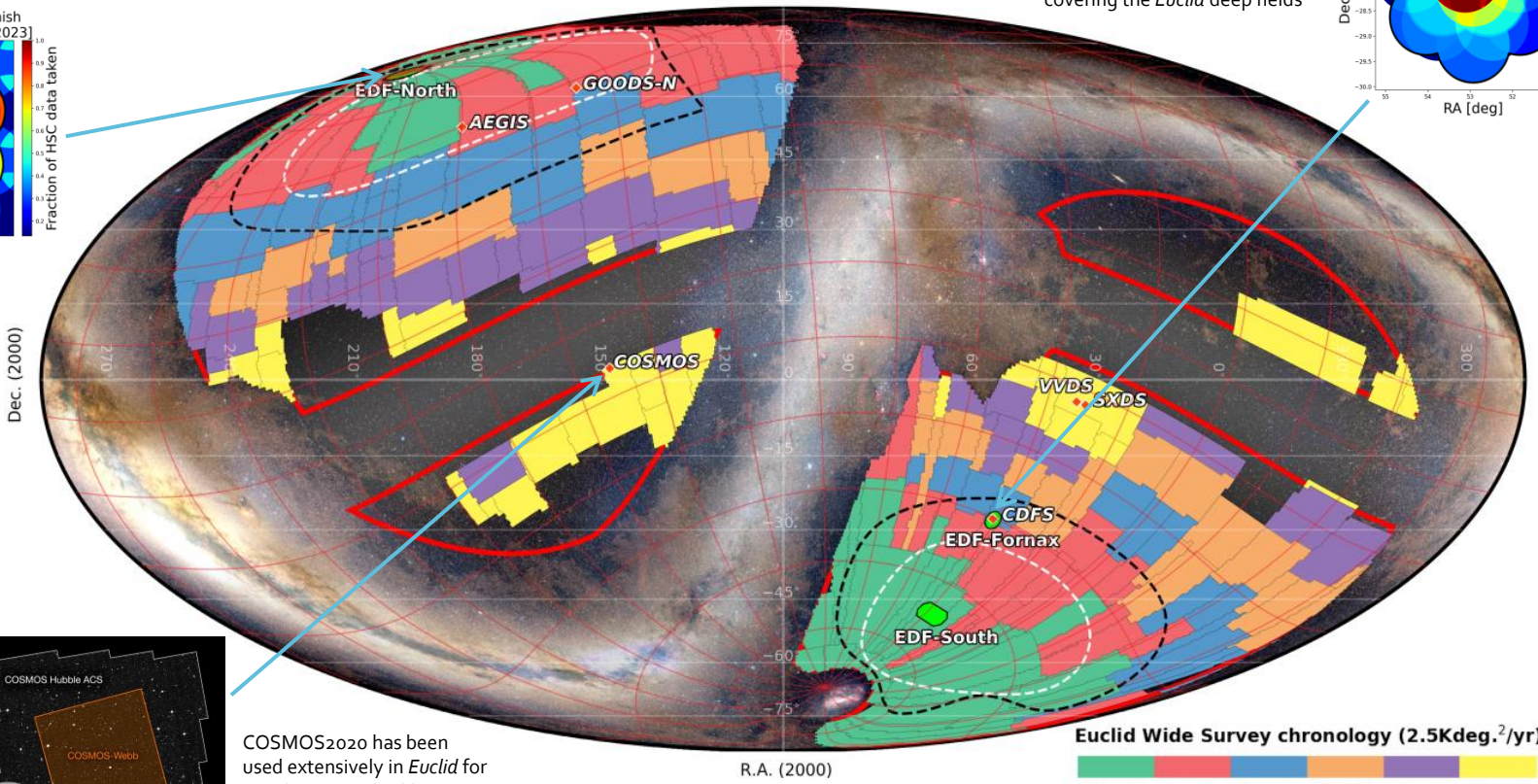
Euclid survey: wide (14 000 deg^2) + 3 deep fields

COSMIC DAWN SURVEY

Euclid pre-launch Key Project covering the *Euclid* deep fields







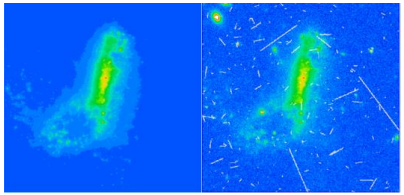
COSMOS2020 has been used extensively in *Euclid* for simulations and calibration.

Cosmos-Webb (JWST): first data arrive Dec 2022.

Euclid Wide Survey chronology (2.5Kdeg.^{2}/yr)

Year1 | Year2 | Year3 | Year4 | Year5 | Year6

Euclid at IAP



Hz-AGN mock galaxy Mock VIS image [C. Laigle]

Science Ground Segment

OU-VIS

Characterisation and correction for instrumental effects present in raw ("LE1") VIS data

[T. Flanet, C. Grenet, O. Hérent, C. Laigle, H. J. McCracken (lead), S. Mottet, K. Nguyen Kim]

OU-SIM

Simulation of Euclid images ("LE2" data products)

[P. Hudelot (co-lead), S. Huot]

- Pipeline for LE1 VIS data [C. Grenet, K. Nguyen Kim]
- OU-LE3: Processing Functions for LE3 data [F. Durret, G. Mamon]
- OU-EXT: External complementary data (Subaru and Subaru/Spitzer) [H. J. McCracken, A. Moneti]

- SPV: Science Performance Validation [F. Bernardeau, M. Delaire, P. Guillard, P. Tisserand]

Science Working Groups

- Core science: Galaxy clustering & weak lensing (GC, WL) [K. Benabed, F. Bernardeau, G. Lavaux, F. Leclercq, B. Wandelt]
- Theory & cosmological simulations (COTH, COSIM) [S. Colombi, C. Deffayet, Y. Dubois, G. Lavaux, G. Mamon, C. Pichon, J-P. Uzan, B. Wandelt]
- Legacy Science:
  - Galaxy Evolution, Local Universe, Primordial Universe (GAEV, LU, PU) [H. Atek, P. Guillard, C. Laigle, V. de Lapparent, G. Mamon, H. J. McCracken, P. Tisserand]
  - Clusters of Galaxies (CG) [F. Durret, G. Mamon]
  - Exoplanets [E. Bachelet, J-P. Beaulieu, A. Cassan]
- Rubin-Euclid derived data products report [G. Lavaux, F. Leclercq, H. J. McCracken, B. Wandelt]

Euclid Consortium (EC) Management & Support

- EC Lead & Deputy EC Lead [Y. Mellier, F. Bernardeau]
- EC Diversity Committee [F. Durret]
- Communication [A. Le Reun, F. Magnard]
- ECL support & tracking support [S. Berquez, T. Havard]

The teams

L'équipe Grandes Structures et Univers Profond

- Head of group since 2021: Karim Benabed
- 19 permanent researchers (6 CNAP, 11 CNRS, 1 SU, 1 émérite): C. Alard, K. Benabed, F. Bouchet, J-F. Cardoso, J. Colin, S. Colombi, Y. Dubois, J-B. Fouvry, S. Galli, É. Hivon, C. Laigle, G. Lavaux, F. Leclercq, H. J. McCracken, Y. Mellier, C. Pichon, A. Riazuelo, P. Tisserand, B. Wandelt
  - But… 2 are leaving for Hautes Énergies
  - And, 2 left the lab in 2021 (S. Codis, R. Gavazzi)
  - But also: +2 in 2019 (J-B. Fouvry, C. Laigle), +1 in 2021 (F. Leclercq)
- 7 ITA and 2 ITRF, most of them in Euclid: M. Delaire, C. Grenet, O. Hérent, P. Hudelot, F. Magnard, A. Moneti, S. Mottet, K. Nguyen Kim, S. Rouberol
- 4 ITA CDD, most of them in Euclid: A. Doussot, T. Flanet, S. Huot, A. Le Reun
- 3 postdocs: F. Guidi, M. Petersen, S. Saga
- 9 PhD students: E. Ayçoberry, C. Boonkongkird, E. Camphuis, N. Chartier, S. Ding, A. Lapel, M. Roule, M. Shuntov, K. Tep
- Major grants: 1 ERC, 2 ANR PI, 1 Simons Foundation grant

Le projet Euclid

- Euclid Consortium Lead: Yannick Mellier
- Deputy Euclid Consortium Lead: Francis Bernardeau (IAP & IPhT)
- Cheffe de projet IAP: Catherine Grenet
- 20 permanent researchers (5 Galaxies, 2 GReCO, 2 Exoplanètes): H. Atek, J-P. Beaulieu, K. Benabed, A. Cassan, S. Colombi, C. Deffayet, Y. Dubois, F. Durret, P. Guillard, C. Laigle, V. de Lapparent, G. Lavaux, F. Leclercq, G. Mamon, H. J. McCracken, Y. Mellier, C. Pichon, P. Tisserand, J-P. Uzan, B. Wandelt
- 7 ITA and 1 ITRF: M. Delaire, C. Grenet, O. Hérent, P. Hudelot, F. Magnard, A. Moneti, S. Mottet, K. Nguyen Kim
- 4 ITA CDD: T. Flanet, T. Havard, S. Huot, A. Le Reun
- 1 postdoc: E. Bachelet
- 1 doctorant: M. Shuntov