



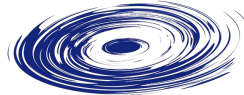
# Analyse de données à l'Observatoire de la Côte d'Azur

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# Laboratoires OCA pour LISA



- Laboratoire ARTEMIS
- Le principal thème de recherche est les ondes gravitationnelles
- Contributions à long terme à Virgo
  - Responsabilité du laser et de l'optique d'entrée
  - Analyse des données
  - L'astronomie multimessager
- Participation à long terme à LISA
  - Contributions majeures pour LISA, dont l'initiative expérimentale française
  - Analyse des données LISA et études scientifiques en cours
- La recherche sur Virgo est également en transition pour Einstein Telescope



## LAGRANGE

- Laboratoire Lagrange
- Très large spectre d'activités de recherche en astrophysique
- Activité scientifique connexe à LISA: physique stellaire, physique galactique, trous noirs supermassifs
- Contributions LISA
  - A. Lamberts actuelles : Binaires galactiques (naines blanches, trous noirs, autres)
  - Expérience pertinente de Gaia, Euclid
  - Large expérience de travail sur les segments sol avec le CNES
  - Expérience similaire et pertinente de grands projets à l'ESO
- Equipe "Signal et Images" : expertise problèmes inverses, IA, analyse Bayésienne
- Intérêt scientifique fort équipe "Galaxies/Cosmo"

=>Coordination scientifique en parallèle de la coordination technique

# Technical resources and experience at OCA

Expected availability of Research Engineers for computation/Ground Segment, over period ~ 2024-2030:

**~0.5 FTE/year (lab. Artemis) + 3 x 0.5 FTE/year (lab. Lagrange)**

+ possible contribution from OCA engineers (expertise in algorithmics and HPC)

## Local technical expertise, applicable to LISA:

- Implication in Ground Segment Sol of ESA/CNES space missions
  - **Euclid**: 0,8 FTE x 10 years
    - Comparison and selection of the scientific prototype codes, over 3 Challenges for the detection and characterisation of galaxy clusters
    - Maturation of prototype codes towards the standards expected for implementation in Ground Segment
    - Deployment of codes in the developpement et production environnements
    - 8 years management of CDD engineer (CNES funding) on Euclid Ground Segment
  - **Gaia** (2 x ~0.9 FTE x 12years) and **Herschel** (4 FTE)
    - Development of the data reduction pipelines
    - Exploitation of Segment Sol data during satellite operation. Internal validation, and successive releases of the GAIA catalogues
- ⇒ The Lagrange engineers implied in these GS projects are those expected to participate in LISA
- ESO interferometric instruments for VLTI: MATISSE, MIDI, AMBER: DRS, and custom data analysis pipelines
- Interactions with nearby industrial through labcoms : TAS-Cannes, ACRI, on topics including Signal Processing and Interferometry
- “Signal & Image” team at Lagrange: AI, inverse problems, Bayesian analysis... (ex. currently applied to SKA)

# Current LISA Data Analysis Research

- Stochastic Gravitational-wave Background (SGWB)
- Spectral separation and estimation: cosmological and astrophysical SGWBs and LISA noise
  - MCMC to estimate all parameters
  - "Spectral separation of the stochastic gravitational-wave background for LISA: Observing both cosmological and astrophysical backgrounds", [G Boileau](#), [N Christensen](#), R Meyer, NJ Cornish, PRD **103**, 103529 (2021).
- Next step, add Milky Way, Lamberts model
  - "Predicting the LISA white dwarf binary population in the Milky Way with cosmological simulations", [A Lamberts](#) et al., MNRAS **490**, 5888 (2019).
  - "Spectral separation of the stochastic gravitational-wave background for LISA in the context of a modulated Galactic foreground ", [G Boileau](#), [A Lamberts](#), [N Christensen](#), NJ Cornish, R Meyer, MNRAS **508**, 803 (2021).

# Current LISA Data Analysis Research

- SGWB - specific cosmological models
- Cosmic strings
  - Developed a detection statistic: Deviance information criterion (DIC), used with MCMC
  - Parameter estimation
  - "Ability of LISA to detect a gravitational-wave background of cosmological origin: The cosmic string case", [G Boileau](#), AC Jenkins, M Sakellariadou, R Meyer, [N Christensen](#), PRD, **105**, 023510 (2022).
- First order phase transitions in the early universe
  - Apply detection statistic DIC and estimate parameters
  - Paper in preparation: [G Boileau](#), [N Christensen](#), Chloe Gowling, M Hindmarsh, R Meyer

# Current LISA Data Analysis Research

- LISA noise studies
  - “Log power spectral density estimation using a smoothness prior with applications to separating LISA instrumental noise and the astrophysical SGWB”, P Maturana-Russel, P Nianqi Tang, JJ Eldridge, N Christensen, R Meyer, To be presented at LISA Symposium
  - "Identifying and addressing nonstationary LISA noise", MC Edwards, P Maturana-Russel, R Meyer, J Gair, N Korsakova, N Christensen, PRD **102**, 084062 (2020).
  - "Figures of merit for a stochastic gravitational-wave background measurement by LISA: implications of LISA Pathfinder noise correlations", G Boileau, N Christensen, R Meyer, arXiv:2204.03867
  - "Formulation of an extended null channel formalism for a triangular gravitational wave interferometer configuration in the case of non-identical and correlated noise", K Janssens, G Boileau, MA Bizouard, N Christensen, T Regimbau, N van Remortel, arXiv:2205.00416

# 3IA Côte d'Azur

- Interdisciplinary Institute for Artificial Intelligence
- <https://3ia.univ-cotedazur.eu>
- 3IA Côte d'Azur is one of the four "Interdisciplinary Institutes for Artificial Intelligence" that were created in France in 2019.
- Led by Université Côte d'Azur, with CNRS, Inria, INSERM, EURECOM, and SKEMA Business School
- Recent meeting (Christenen, Lamberts, Bizouard) with 3IA leadership to initiate research collaboration for GW research with 3IA, especially LISA. Full day workshop in September between OCA and 3IA; many topics, including GWs.

# LISA Data Analysis Research - Next Steps

- SGWB search while identifying individual galactic binaries
  - RJMCMC (PRD **72**, 022001, 2005) or other methods
- EMRIs with AI: Auckland, 3IA Côte d'Azur (advice from N. Korsakova?)
- LISA noise modeling
  - Increase number of noise parameters
  - Include correlations
- Participate in the data challenges



# LISA Data Analysis Goals

- SGWB: cosmological, astrophysical, galaxy, LISA noise
- Global fit
- Galactic binaries
- Galactic waveform generation
- Catalogs?
- Alerts?
- Instrument noise
- Various technical activities

# Active research connections with groups around the world

- Auckland and the New Zealand Astrostatistics and General Relativity Working Group (Meyer et al.)
  - Large grant for LISA, Christensen Co-I
  - <https://www.gravity.ac.nz/>
  - 6 PhDs, 2 postdocs for LISA starting now
  - Long time collaboration of GW data analysis; Christensen and Meyer
  - Overlapping galactic expertise: Lamberts and Eldridge (project on GBs ongoing, to be presented at LISA Symposium)
- Montana State (Cornish et al.)
- Kings College London (Sakellariadou et al.)
- Helsinki Institute of Physics (Hindmarsh et al.)

# Questions

- What are the timelines for the different packages ?
- How to estimate the different required FTEs per package?
- How will the LISA Ground Segment compare with Gaia or Euclid (organisation, architecture, common tools,...) ? Re-using things that work might help a lot...
- How does this work tie in with the LSG ?
- Needs for expertise/hardware in HPC ?