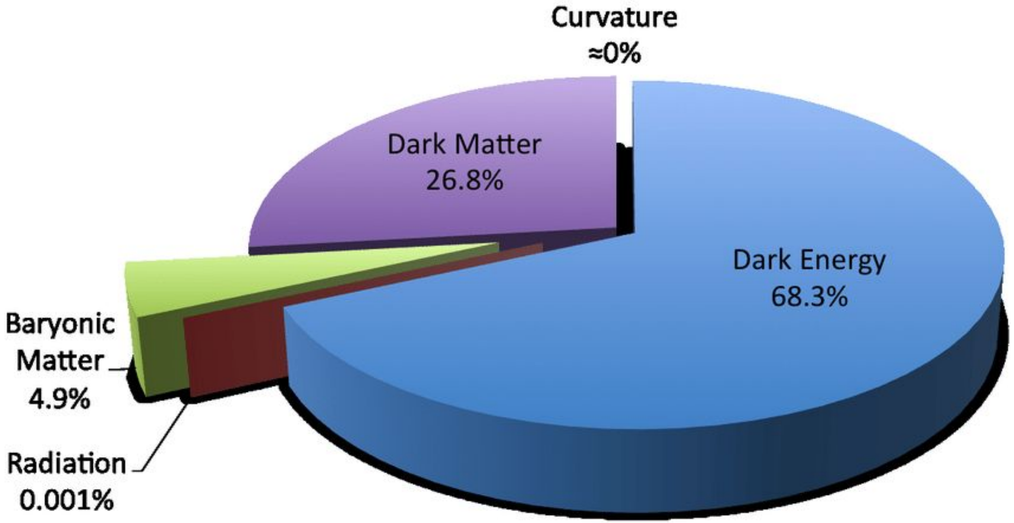
WP3 - Dark matter and dark energy in the universe or the standard model of cosmology

Céline Combet

Thank you to all the contributors: A. Barrau, F. Calore, L. Derome, J. F. Macías-Pérez, D. Maurin, K. Martineau, F. Mayet, L. Perotto, V. Poireau, D. Santos, P. Serpico

WP3: unknown 95% of the energy content of the universe



- Nature and properties of dark matter?
- Nature and properties of dark energy? cosmological constant or not?
- Beyond ΛCDM cosmological model?

Dark matter searches

Complementary approaches

Dark matter

Standard model particles

Direct detection	Indirect detection	Particle colliders	Astro., gravitational probes


Xenon-1T


Fermi


ATLAS


ESA/Hubble, NASA

WP1

Direct detection

WIMP-DM/nucleus:
Xenon-1T, LUX, etc.

Axion-DM/photons:
HAYSTAC, ADMX

Indirect detection

DM annihilation/decay

→ CRs: e+, pbar, dbar (AMS-02)
→ photons: gamma, X, radio (Fermi-LAT, HESS, etc.)
→ neutrinos (IceCube, etc.)

Particle colliders

BSM, new physics

→ LHC: ATLAS, CMS
→ Future leptonic collider?

Astro., gravitational probes

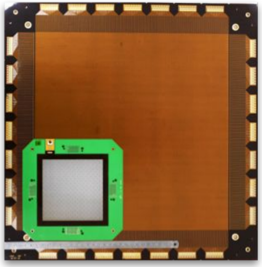
Cold/warm/SIDM?

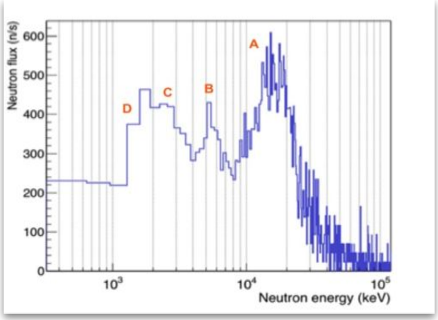
→ abundance of low-mass DM halos.
→ inner DM density, etc.

Direct detection with MIMAC and NEWS-G *[LPSC]*

Directional Detection with MIMAC (the only signature to confirm a WIMP candidate as a particle of our Galactic halo) based on 3D nuclear recoil tracks.

- Enigmass-1 has funded the 35 cm MIMAC-Bi-chamber Low Background prototype
  - Electronic boards and chamber ready. Detectors "quite" ready (03/2021)
  - First commissioning run in June 2021 at LSM
- Many experiments coupling COMIMAC to one MIMAC chamber to study the track lengths and angular resolution of MIMAC
  - Yi Tao, Ph.D thesis (Tsinghua University (China)
- Enigmass-1 has helped to "valorize" one MIMAC chamber as a Fast Neutron Directional Spectrometer (MIMAC-FastN)





NEWS-G (a big sphere (diameter = 1.4 m) to find WIMP or KK-axions event candidates) installed at SNOLAB (November 2020); First Run: January 2021

- Ionization Quenching Factor Measurements with COMIMAC; paper in progress (Cyprien Beaufort et al.)
- SEDINE sphere installed and running at LSM

Indirect detection with AMS-02 *[LPSC, LAPTh, LAPP (until 2019)]*

Data analysis of antimatter CRs
(AMS-02 on ISS since 2011)

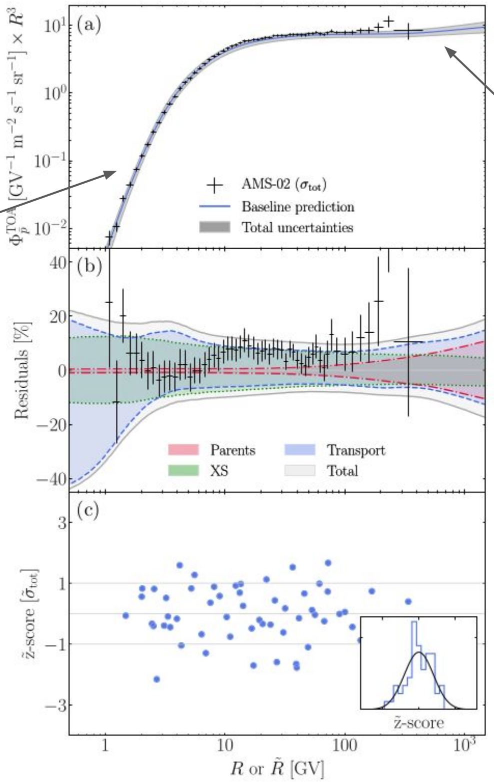
Publications
- e+: Aguilar et al. (2013, 2014, 2019)
- pbar: Aguilar et al. (2019)

→ LAPP involved in e+ and pbar analyses

Future AMS analyses (no date yet)
- Update of e+ and pbar analyses
- Anti-deuterons and anti-nuclei

Involvement of Enigmass labs
- LAPP: till 2019 (left AMS-02 since)
- LPSC: analysis of Z≥1 data (*see WP2*)

Boudaud et al., PRR 2, 023022 (2020)



Comparison model/data (top), residuals and modeling/data uncertainties (middle), score with covariance matrix of uncertainties (bottom)

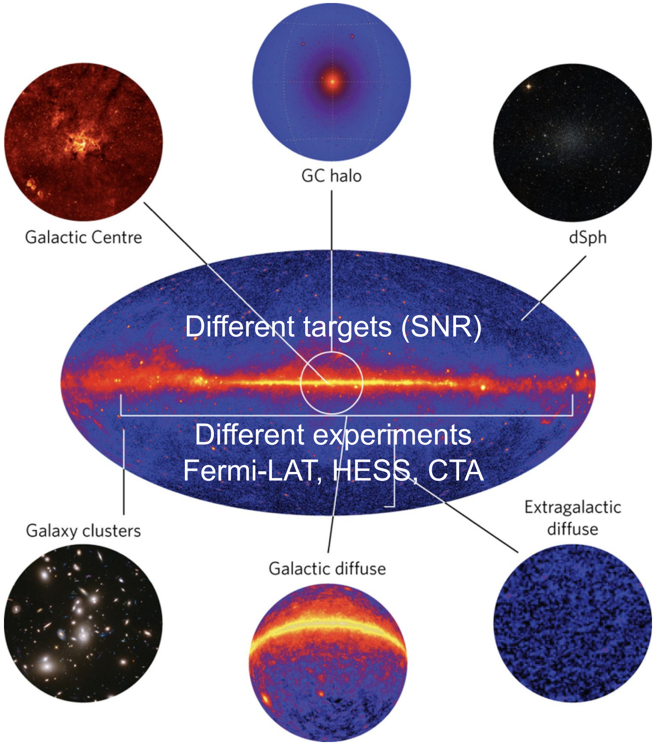
Pheno. for DM indirect detection

Publications
- e+: Boudaud et al. (2015, 2017)
- pbar: Boudaud et al. (2015, 2020)
- dbar: Arakami et al. (2016), von Doetinchem et al. (2020)
- He-bar: Poulin et al. (2019)

Future plans (in progress)
- Update of transport parameters for DM analyses
- Derive DM constraints from pbar (one of the best probe for DM)

Involvement of Enigmass labs
- LAPP: till 2017
- LAPTh and LPSC

Indirect detection with gamma rays *[LAPP, LAPTh, LPSC]*

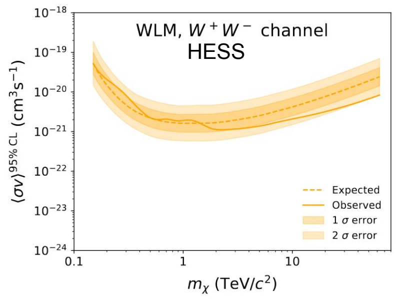


★ **Fermi-LAT Galactic center excess**: characterisation and dark matter interpretation (LAPTh)

★ Constraints on WIMP dark matter with **dwarf spheroidal galaxies (dSph)** observations (LAPTh, Fermi-LAT)

★ HESS (LAPP) put constraints on WIMP DM using:

- dwarf **irregular** galaxies
- **ultra-faint** dSph (PRD 102, 062001, 2020)
- a **combination** of results with 5 major experiments (HESS, MAGIC, VERITAS, HAWC, Fermi-LAT)



★ LAPP/LAPTh plan to participate in the "ESCAPE/EOSC future" TSP (**Test Science Project**) for DM with CTA: **open science** with public data, open tools, reproducibility

★ **Sensitivity predictions** for detection of dark matter signals with CTA (LAPTh, LPSC)

★ Constraints on **alternative dark matter candidates**, e.g. axion-like particles and primordial black holes (LAPTh)

★ Continued development of the **CLUMPY** code (LPSC)

From WIMPy paradigm to gravitational probes *[LAPTh]*

mostly @ LAPTh F. Calore & P. Serpico +

Cristopher Eckner (postdoc ANR), Joanna Berteaud & Joaquim Iguaz (PhD students)

DM as pressureless fluid is a **simple effective** description on many scales & different epochs, but how to interpret it in terms of fundamental dof?

Searches for WIMPs came up empty-handed till now. What's next?

Option I. Keep searching:
- Better characterisation of backgrounds
- new data-driven techniques

Option II. DM interacts (much) less than weakly:
- Use special astro systems as probes, e.g. neutron stars as giant 'direct' DM detectors

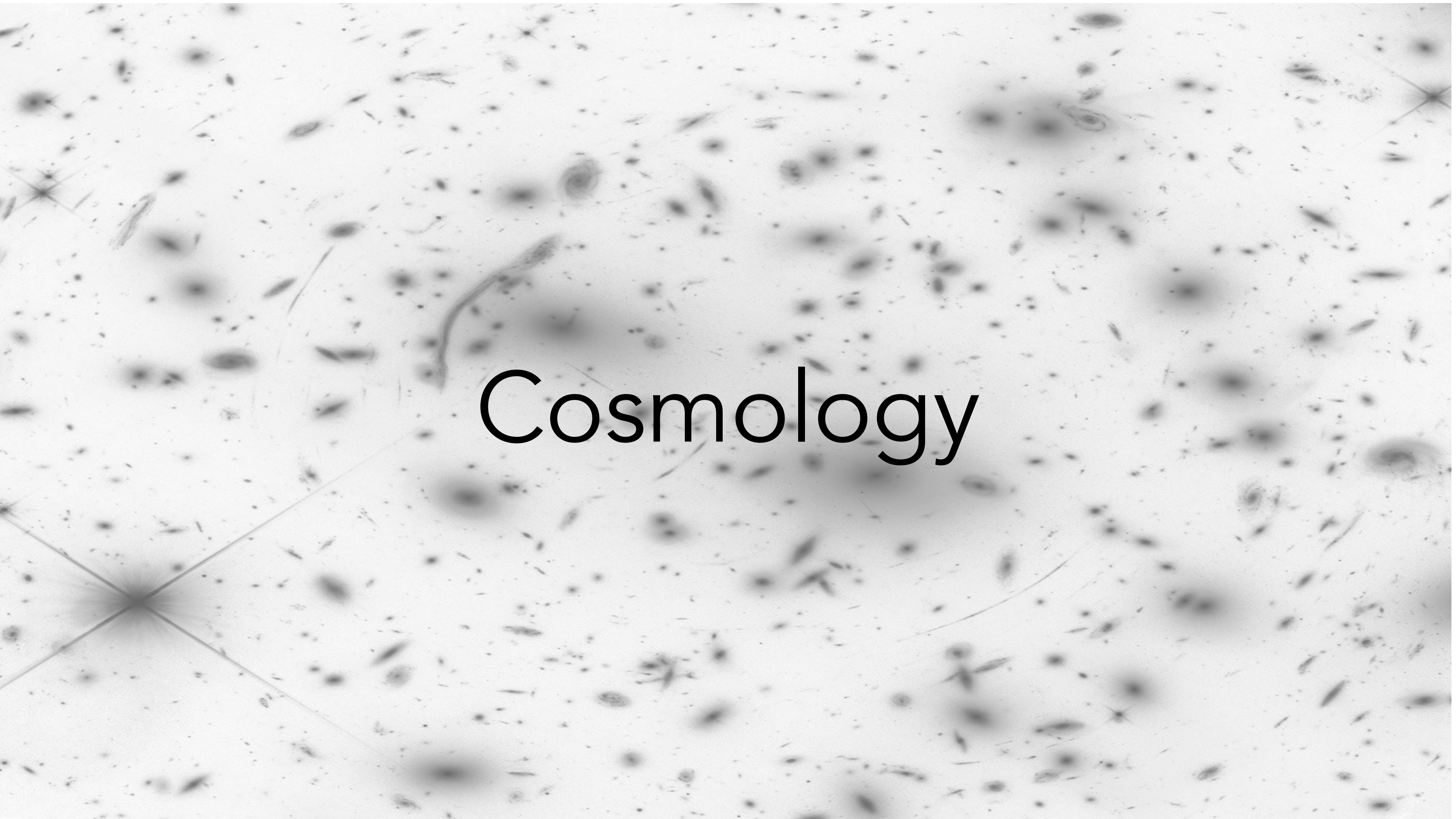
Option III. Test the fluid CDM paradigm to explore 'gravitationally' if/ when it breaks up :
- Effects of DM (possibly inelastic) self-interaction on astrophysics and cosmology
- Effects of granularity at small scales, e.g, due to primordial black holes, and associated gravitational wave production in the early universe.

Enigmass' postdoc

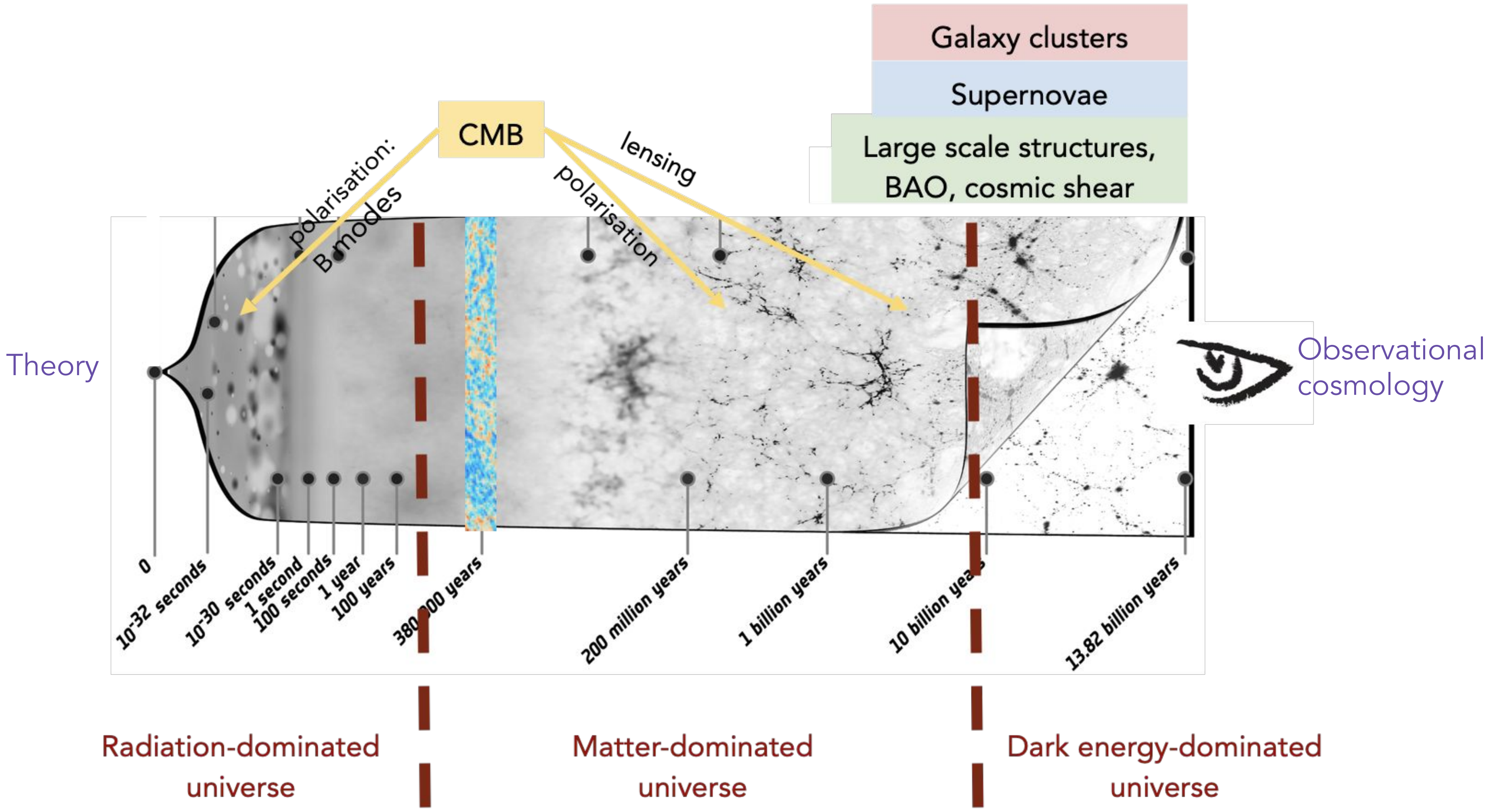
Aniket Joglekar

(from Univ. of California, Irvine)

will work on such aspects



Cosmology


Galaxy clusters
Supernovae
Large scale structures,
BAO, cosmic shear
CMB
polarisation:
B modes
lensing
polarisation
Theory
Observational
cosmology
0
10-32 seconds
10-30 seconds
1 second
100 seconds
1 year
100 years
380 000 years
200 million years
1 billion years
10 billion years
13.82 billion years
Radiation-dominated
universe
Matter-dominated
universe
Dark energy-dominated
universe

Theoretical cosmology *[LPSC]*

Goal: place observational constraints on theories of gravity beyond general relativity (focusing on cosmology and black holes physics), including quantum gravity.

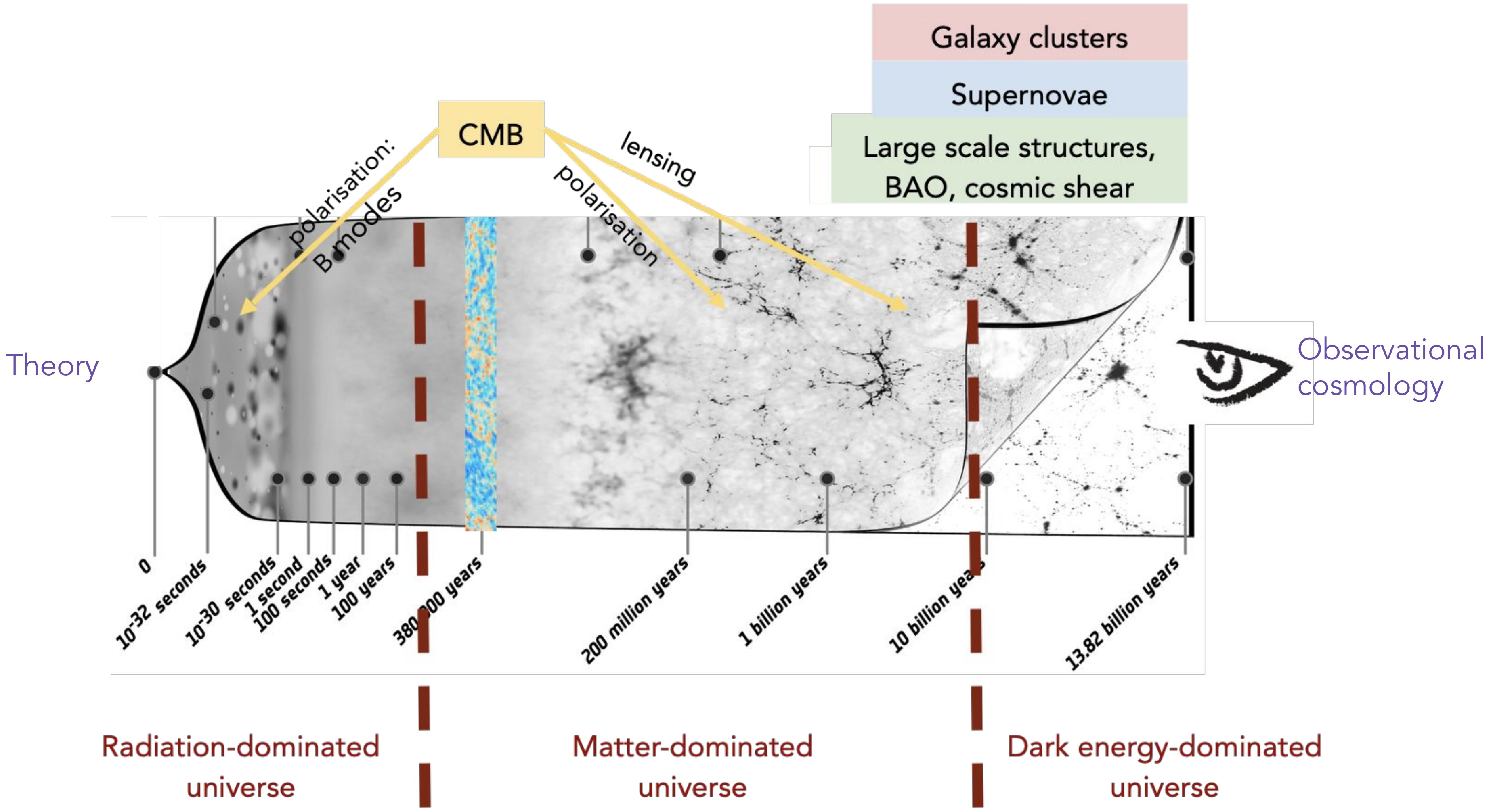
Recent results

- Consistency and observational footprints of a pure general relativistic curvature bounce at the origin of the Universe *[Barrau (2020); Renevey, Barrau, Martineau, et al. (2020]*
- Phenomenology associated with the formation of white hole remnants in non-perturbative quantum gravity *[Barrau, Ferdinand, Martineau, et al. Submitted.]*
- Black hole dark matter produced by trans-planckian scattering *(Barrau, Martineau, Ngono (2019)]*

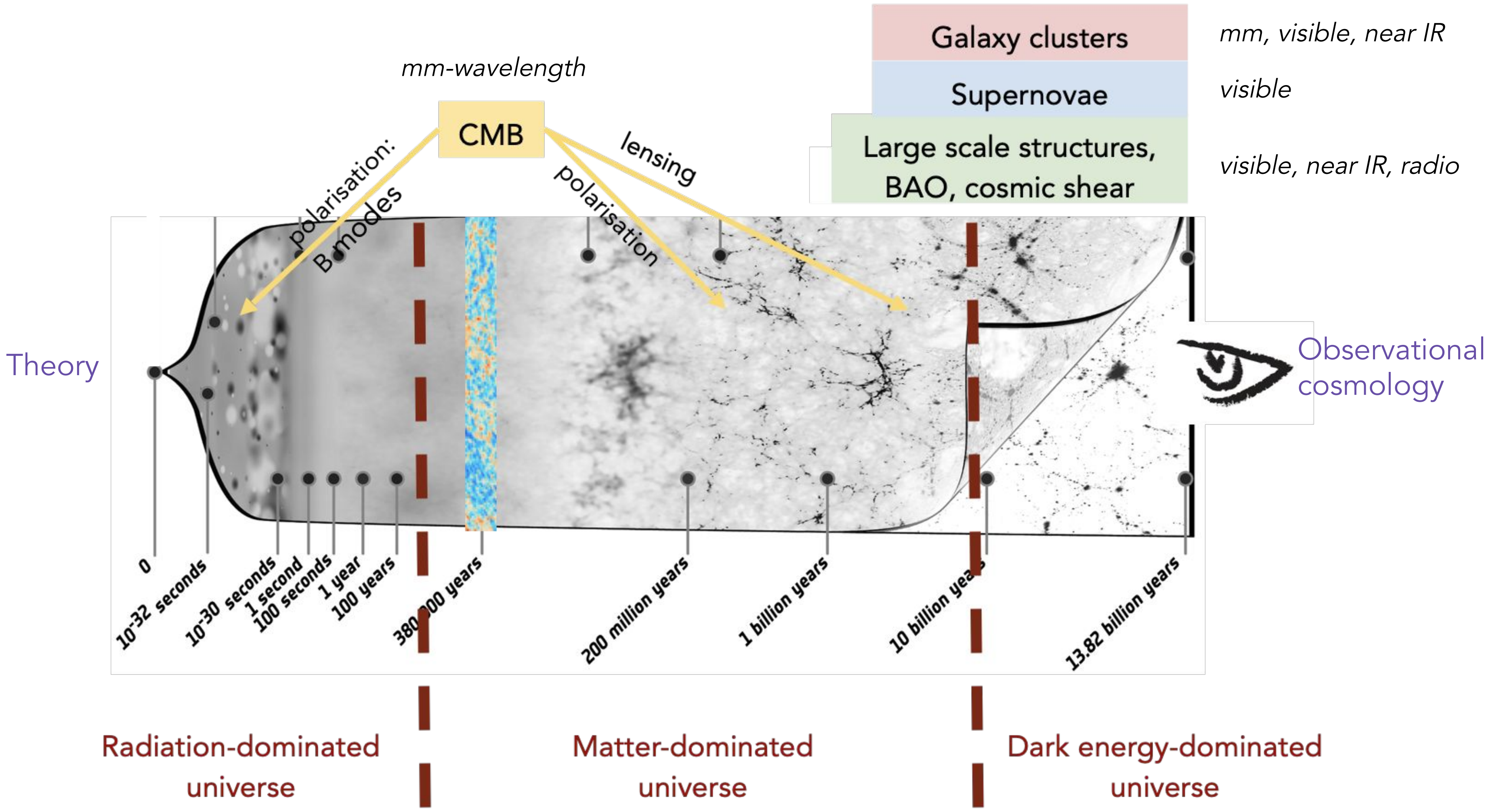
Current works and projects

Constraints from the Vera C. Rubin observatory, Euclid & SKA on the string theory swampland. Preliminary results indicate that the next generation of cosmology experiments might show that the actual behavior of the Universe is in strong tension with string theory (if the de Sitter conjecture holds). Work in progress.

Quantum cosmology : focus on the trans-planckian issue for cosmological perturbations and development of a more generic formalism for the Loop Quantum Cosmology model.



Galaxy clusters
Supernovae
Large scale structures,
BAO, cosmic shear
CMB
polarisation:
B modes
polarisation
lensing
Theory
Observational
cosmology
0
10^{-32} seconds
10^{-30} seconds
1 second
100 seconds
1 year
100 years
380 000 years
200 million years
1 billion years
10 billion years
13.82 billion years
Radiation-dominated
universe
Matter-dominated
universe
Dark energy-dominated
universe



Galaxy clusters
mm, visible, near IR
Supernovae
visible
Large scale structures, BAO, cosmic shear
visible, near IR, radio
mm-wavelength
CMB
polarisation: B modes
polarisation
lensing
Theory
Observational cosmology
0
10-32 seconds
10-30 seconds
1 second
100 seconds
1 year
100 years
380 000 years
200 million years
1 billion years
10 billion years
13.82 billion years
Radiation-dominated universe
Matter-dominated universe
Dark energy-dominated universe

mm-wavelength: the NIKA2 camera *[LPSC]*

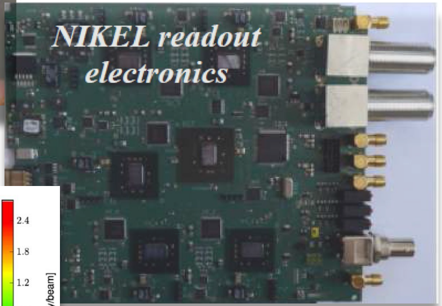
NIKA2

- is a dual band mm camera
- has been built in Grenoble (IN and LPSC)
  - → strong contribution from LPSC
  - → Electronics, computing, SERM and SDI
- is installed at the IRAM 30-m telescope
- founded by ANR (2 projects), Enigmass-1 (PhD, PD)

NIKA2 is an international collaboration lead by Grenoble

→ strong responsibilities at LPSC

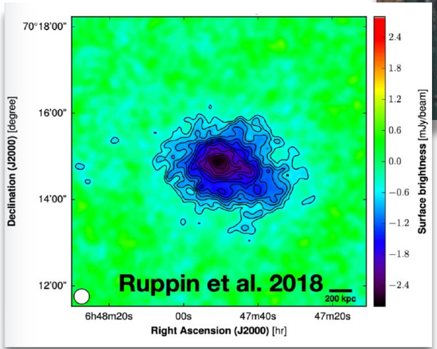
- Project scientist, EB manager and commissioning, SZ Large program leaders (LPSZ)



NIKA2 is an ideal instrument for SZ cluster cosmology

- LPSZ : a follow-up of Planck and ACT clusters
- High-resolution SZ observation

□ → assessing tools used for SZ surveys : scaling relation



More on NIKA2 clusters in Marina's talk

Enigmass postdoc: E. Artis

mm pathfinder/futur: KISS, Concerto, LiteBird *[LPSC]*

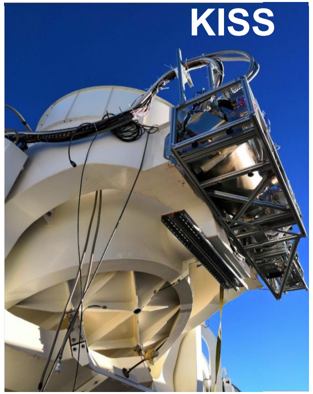
LiteBird: JAXA and ESA satellite experiment for measure CMB polarization anisotropies targeting primordial B-modes. Currently in phase A - instrumental contribution at LPSC so far

KISS / CONCERTO: Low resolution spectroscopy observations at mm wavelengths to map cluster physical properties from spectral CMB distortions. LPSC (with IN) leads KISS and contributes significantly to instrumentation, data analysis and observations.

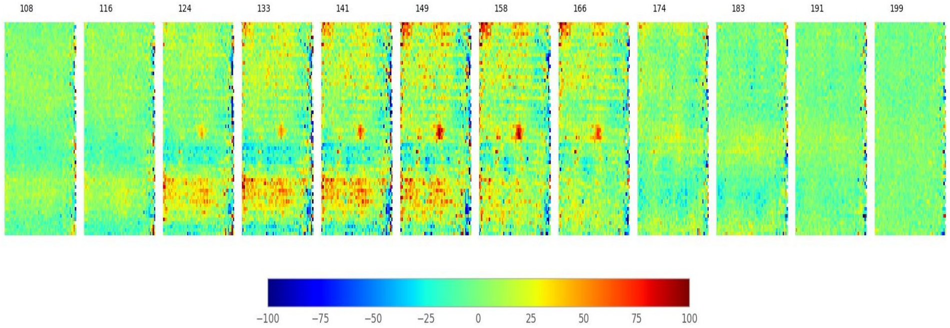
KISS - low redshift clusters
600 KIDs for spectroscopy from 120 to 260GHz
QUIJOTE telescope in Tenerife
Currently in commissioning phase

CONCERTO - high redshift cluster
5000 KIDs for spectroscopy from 120 to 350 GHz
APEX telescope in Atacama
Currently being built, installation in March 2021

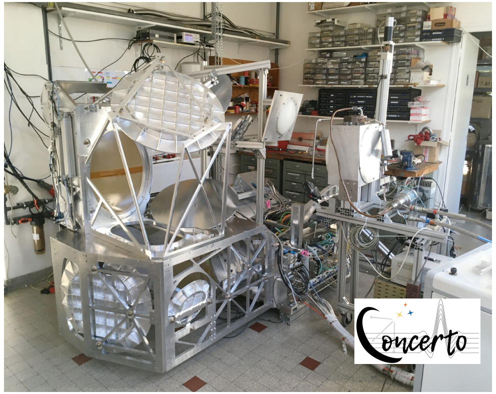
Fasano+2020



Preliminary KISS Jupiter spectra



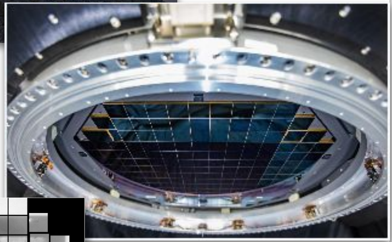
Concerto collaboration 2020

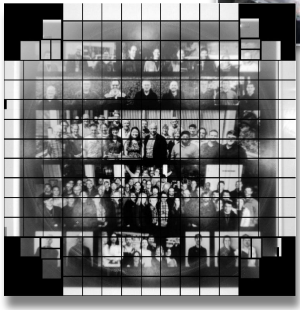


Optical/near IR surveys: 1. LSST *[LAPP, LPSC]*

Vera C. Rubin Observatory

- 8-m class telescope, 6 bands
- 9.2 deg^2 f-o-v, 3.10^9 pixels
- Legacy Survey of Space and Time





Cosmology → WP3

Solar system

Milky Way

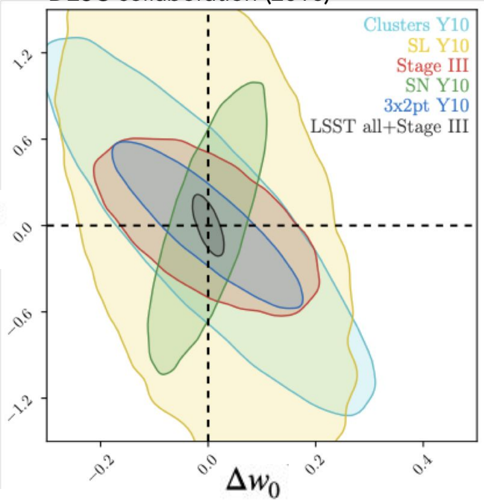
Transients → WP2

Dark Energy Science Collaboration

- Supernovae
- Strong lensing
- LSS, cosmic shear
- Galaxy clusters

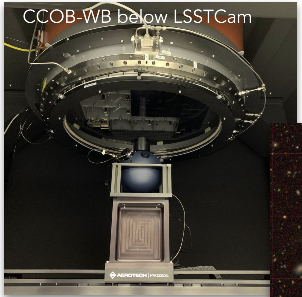
\+ Dark matter

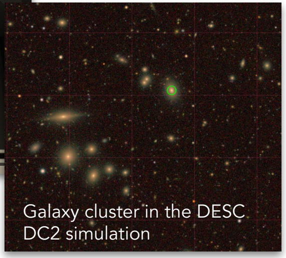
DESC collaboration (2018)



Contribution of Enigmass labs

- Camera [LPSC]: filter loader, CCOB (narrow and wide beam)
- Computing [LAPP]: DM-stack, sim prod., data access, science platform
- DESC service contributions





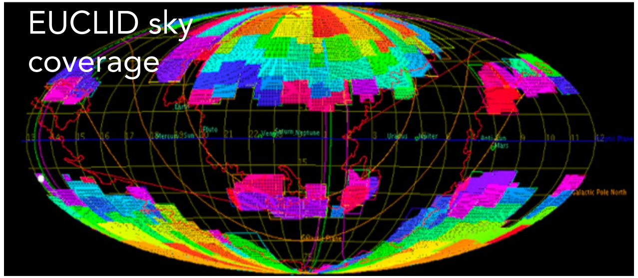
Cluster Cosmology [LAPP + LPSC]:
→ see Marina's talk;
→ Enigmass postdoc: Calum Murray

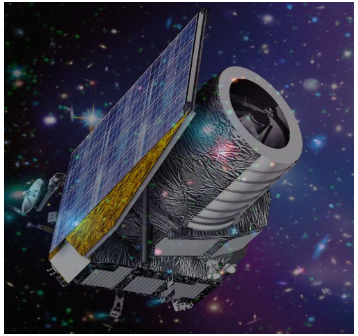
Optical/near IR surveys: 2. Euclid *[LPSC]*

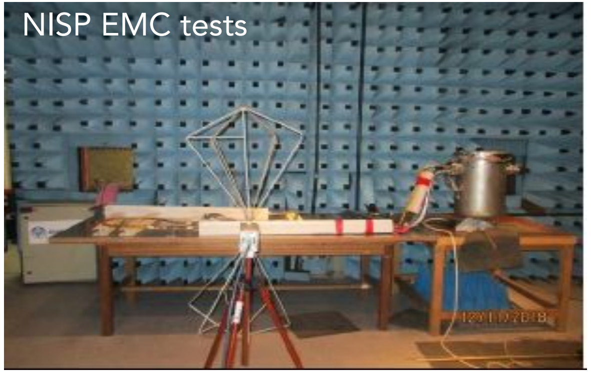
- Medium Class ESA mission - launch 09/2022
- Study nature dark energy and dark matter
- Various cosmological probes:
  - Weak Lensing (WL): cosmic shear
  - Galaxy clustering (BAO)
  - Clusters of galaxies
- Two instruments:
  - VIS: optical single photometer
  - NISP: IR spectro-photometer
- Two surveys:
  - Wide - 15000 deg2
  - Deep - 40 deg2
- Around 2 billion galaxies

Strong contribution from LPSC
- Communication
- Instrumental developments
  - EMC tests of the NISP : c. SDI, SERM and electronic
  - Cosmic rays tests at Grenoble
  - Characterization of the readout noise of the NISP
- Software developments in the SGS
  - Leaders of WP Internal data, sky masks: c. computing group
  - Clusters of galaxies selection function
- Clusters of galaxies SWG (more in Marina's talk)

A. Jiménez Muñoz PhD (3 yr)

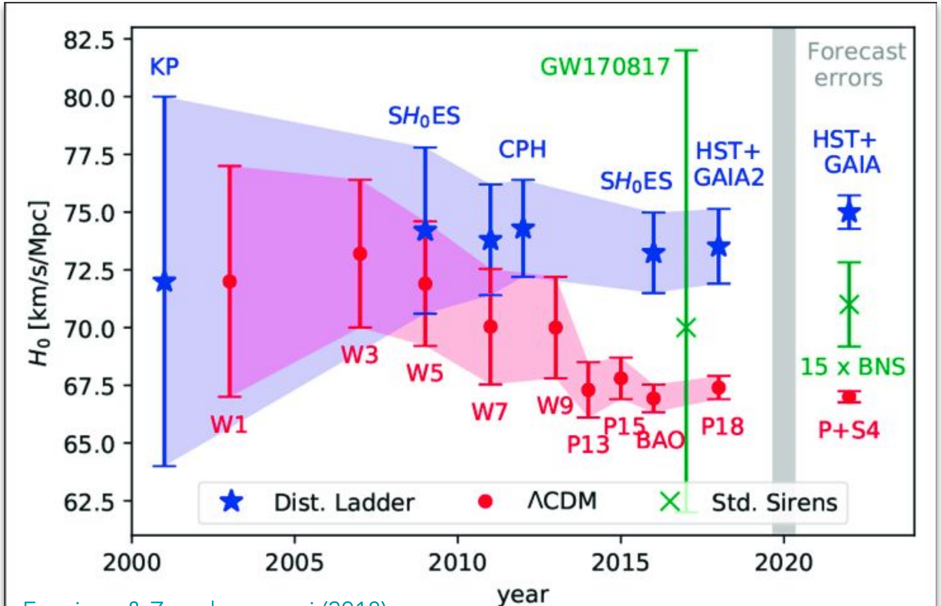






Gravitational waves for cosmology

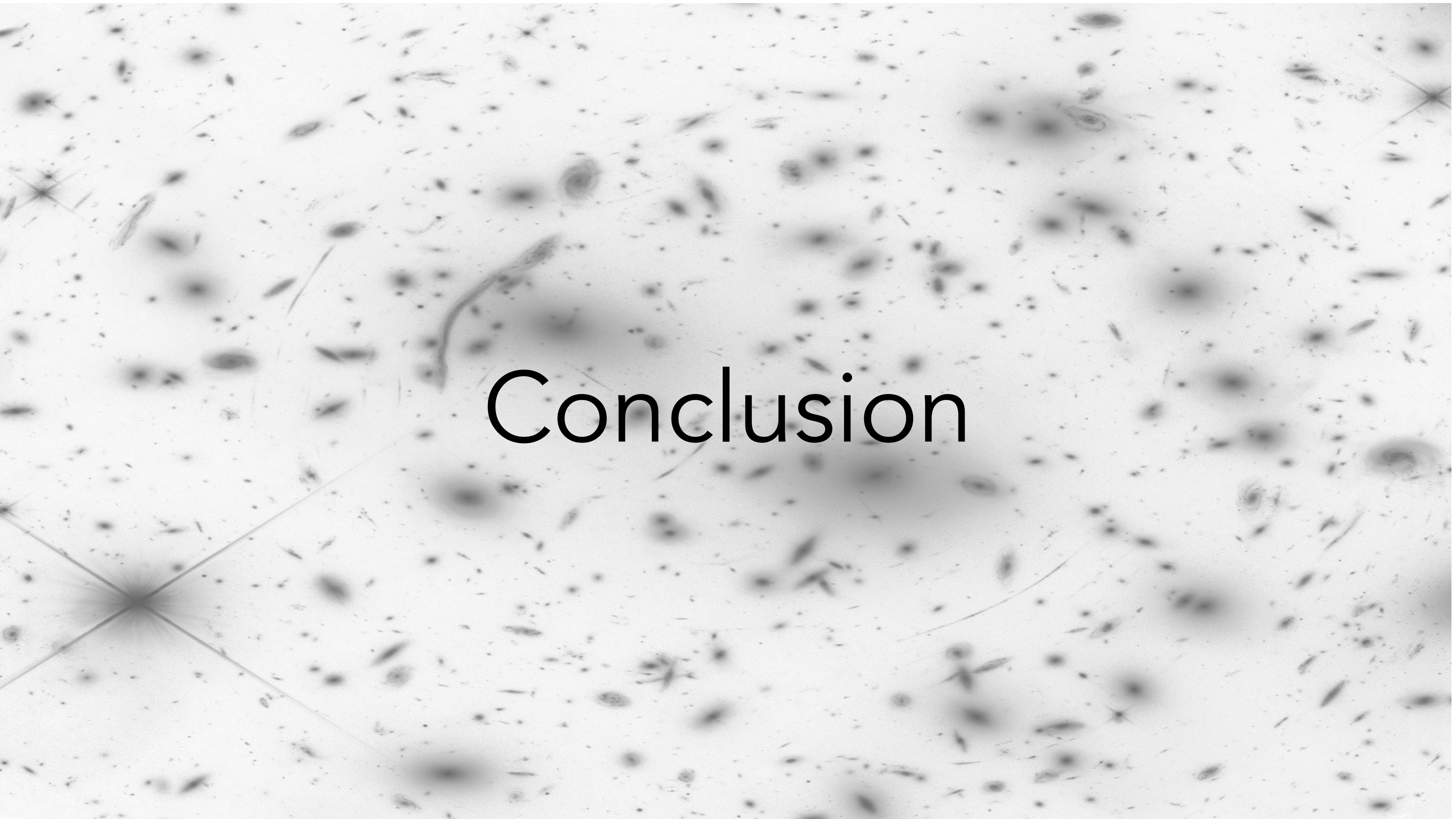
The H0 ~~tension~~ problem



Ezquiaga & Zumalacarregui (2018)

Virgo/LIGO described in WP2 but, GW can be used for cosmology

- Use GW from as standard siren
- Need EM-counterpart to get the redshift (BNS or BHNS)
- Independent measurement the expansion rate of the universe!



Conclusion

WP3 - dark matter, dark energy, cosmological model

- Many activities and projects in Enigmass to tackle the unknown 95% of the universe
  - Important contributions to major projects of the coming decade
  - Development of new experiments, concepts
  - Theoretical and phenomenological work

- Ongoing collaborations between labs and/or team of several topics
  - e.g., indirect DM detection, cluster cosmology

- 2020: Enigmass-funded WP3 postdocs on
  - Astrophysical/gravitational probes of dark matter (A. Joglekar)
  - Cluster cosmology with NIKA2 (E. Artis) and LSST (C. Murray)