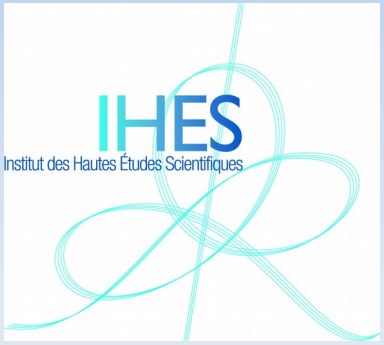
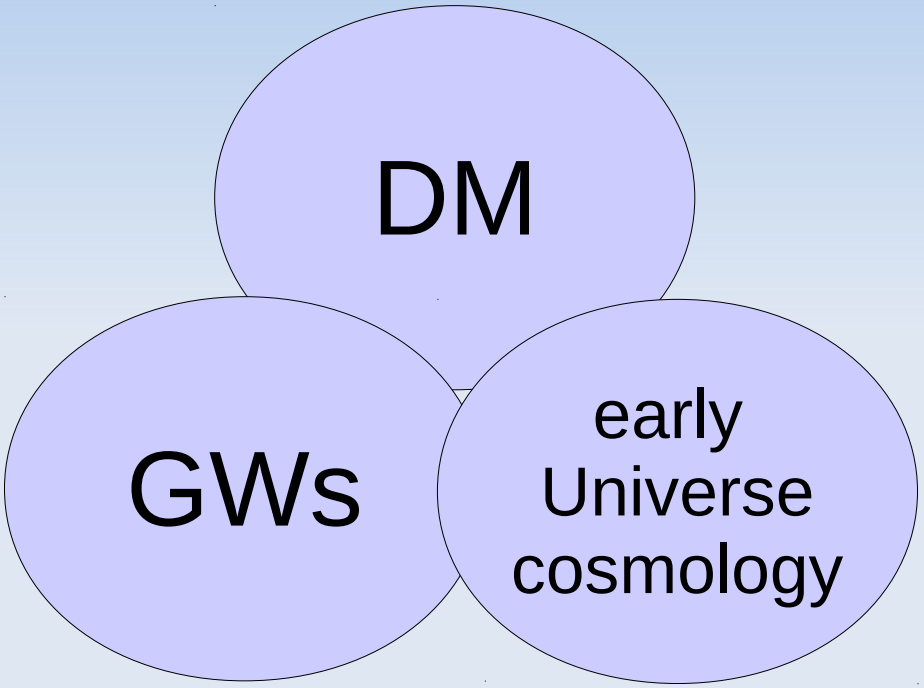
Dark matter, gravity and cosmology

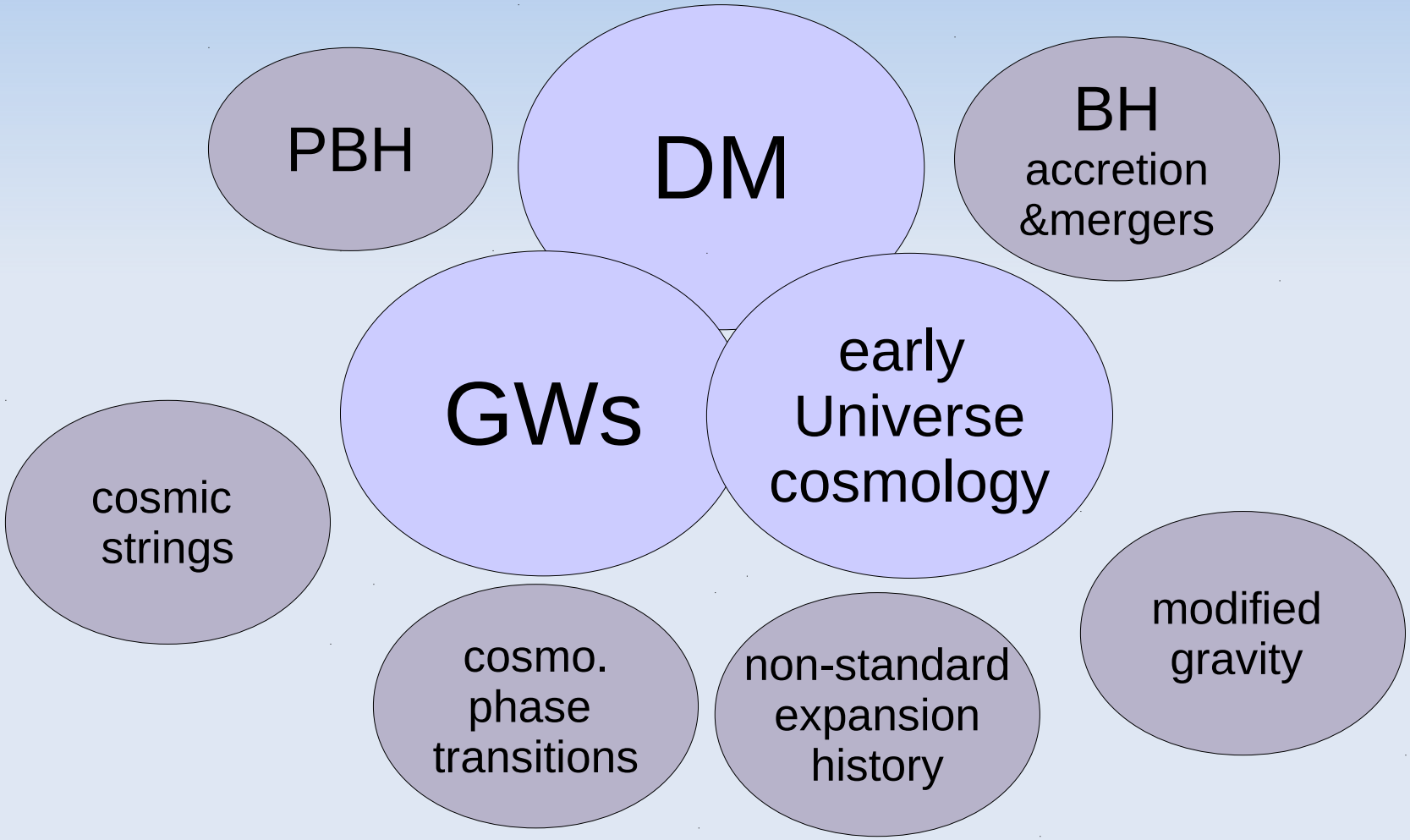


DMLab kickoff meeting
December 10,2021

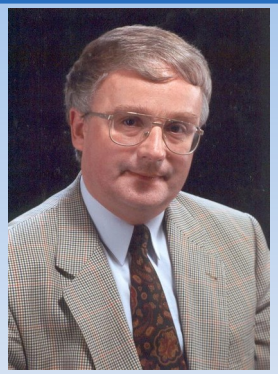
Overview



Overview

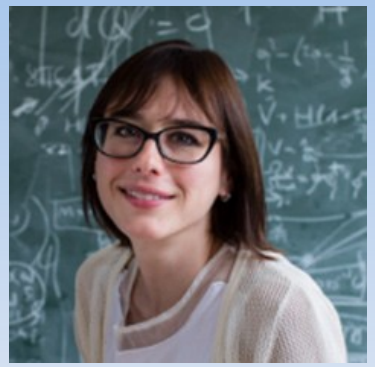

PBH
DM
BH
accretion
&mergers
GWs
early
Universe
cosmology
cosmic
strings
cosmo.
phase
transitions
non-standard
expansion
history
modified
gravity

Project team

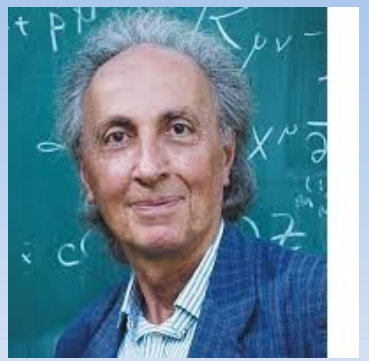


Johannes Blümlein (DESY)

Giacomo Caccipaglia (IP2I)



Chiara Caprini (APC)



Thibault Damour(IHES)

Christophe Grojean (DESY)

Thomas Konstandin (DESY)

Peter Marquard (DESY)

Rafael Porto (DESY)

Filippo Sala (LPTHE)

Gerhard Schäfer (Jena University)

Geraldine Servant (DESY)

Daniele Steer (APC)

Main activities

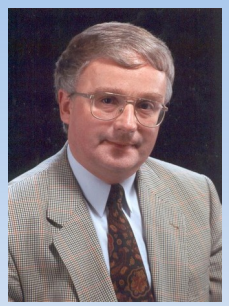
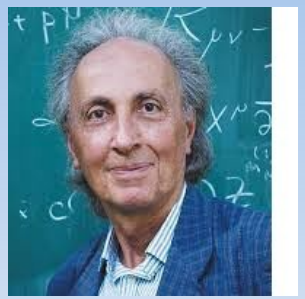
Activities in **Dark matter, gravity and cosmology** can be roughly split into

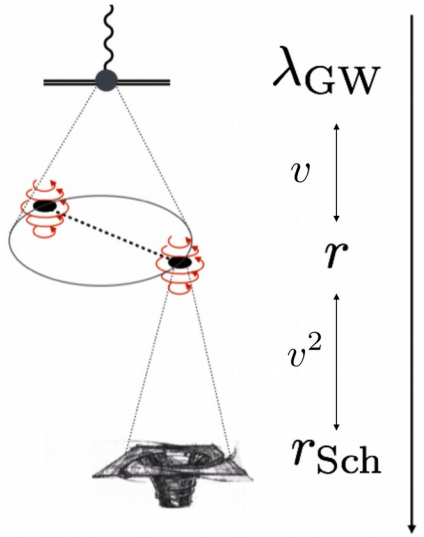
- precision predictions for binary mergers

- involvement GW experiments

- early Universe cosmology: GWs from phase transition, cosmic strings, kination, axions, relaxions, ...

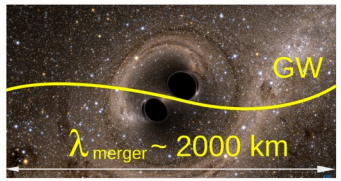
EFT approach to GW physics

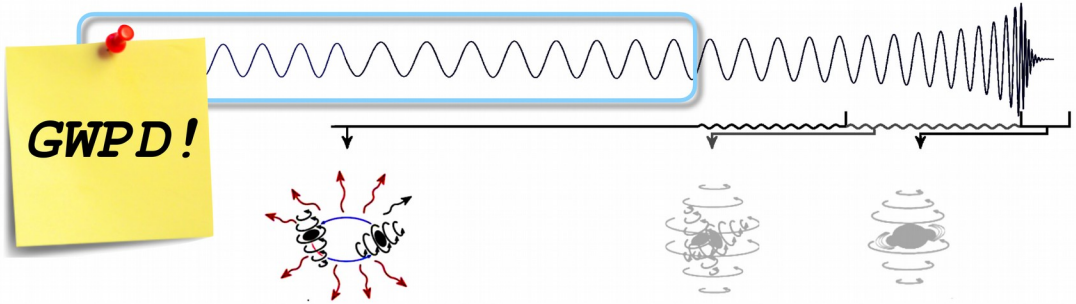



- **Separation of Scales (2-body in GR):**

$$r_{\rm Sch} \ll r \ll \lambda_{\rm GW}$$



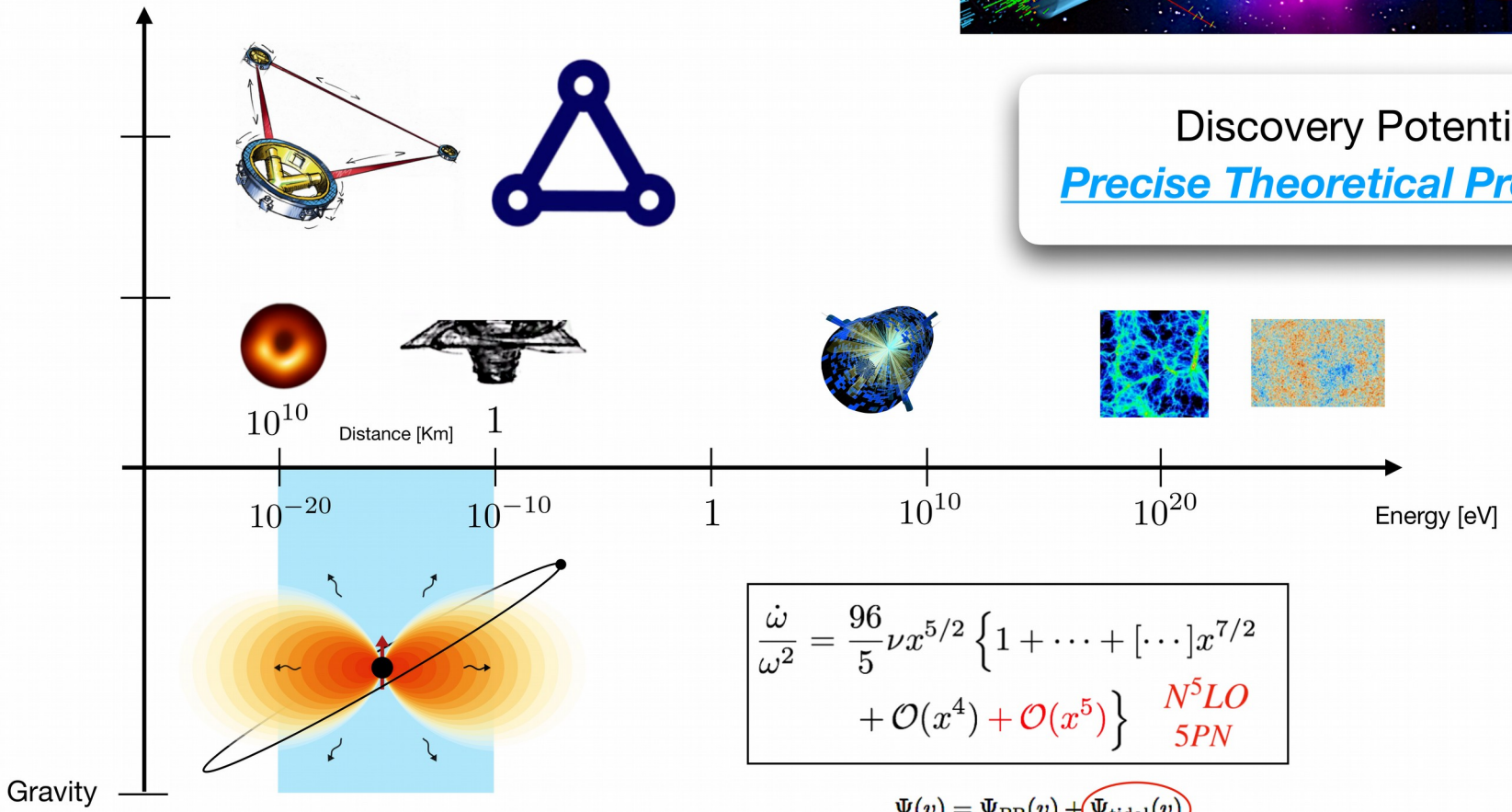
- **Effective Field Theory:**
  One scale at a time
- **Tools from HEP:** Feynman diagrams, regularization/renormalization/RG-flow



The effective field theorist's approach to gravitational dynamics
Rafael A. Porto
Physics Reports
Volume 633, 20 May 2016, Pages 1-104

Precision GW predictions

NEW frontier in particle physics



Discovery Potential =
Precise Theoretical Predictions

$$\frac{\dot{\omega}}{\omega^2} = \frac{96}{5}\nu x^{5/2}\left\{1 + \cdots + [\cdots]x^{7/2} + \mathcal{O}(x^4) + \mathcal{O}(x^5)\right\}$$

N^5LO
$5PN$

$$\Psi(v) = \Psi_{\rm PP}(v) + \Psi_{\rm tidal}(v)$$

'New Physics'
Threshold

'Standard Model'
Background!

Some recent results

5th order results in the Post-Newtonian expansion.

Blümlein, Maiera, Marquard, Schäfer 2021

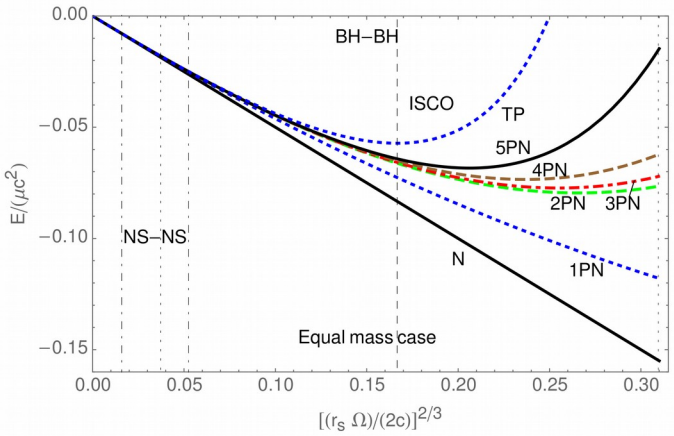


Figure 2: The binding energy in the quasi-circular case for equal masses. Lower full line: Newtonian case (N); Dotted line: 1PN; Dashed line: 2PN; Dash-dotted line: 3PN; Upper dashed line: 4PN; Upper full line: 5PN; Upper dotted line: test particle solution (TP). Dashed vertical line: the innermost stable circular orbit (ISCO) at 5PN. The other vertical lines mark the frequency spectrum for neutron star (NS) and black hole (BH) merging at LIGO.

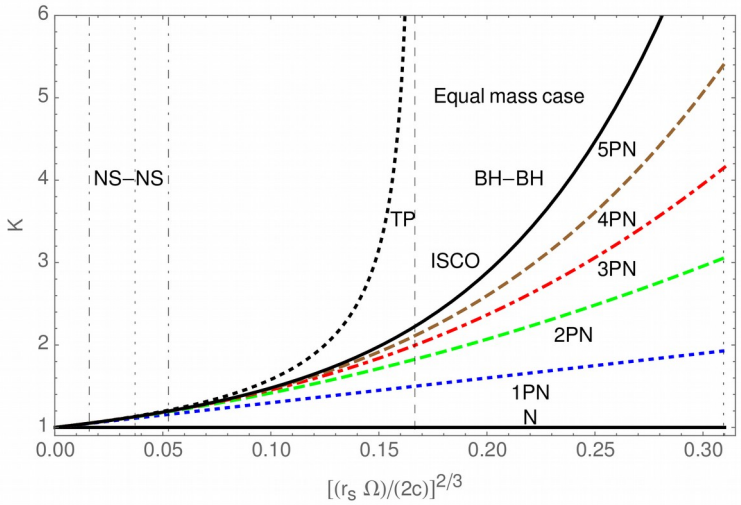
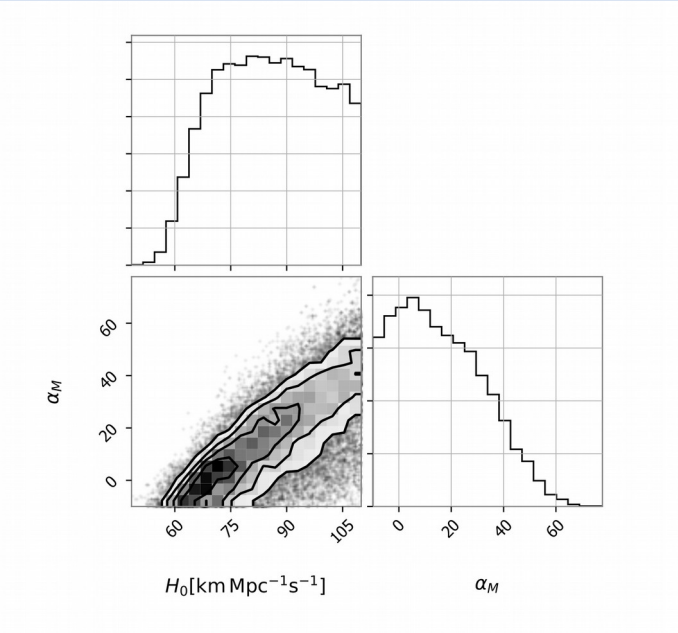


Figure 3: The periastron advance in the circular limit. The labeling of the curves is the same as in Figure 2.

binding energy

periastron advance

GW observations I

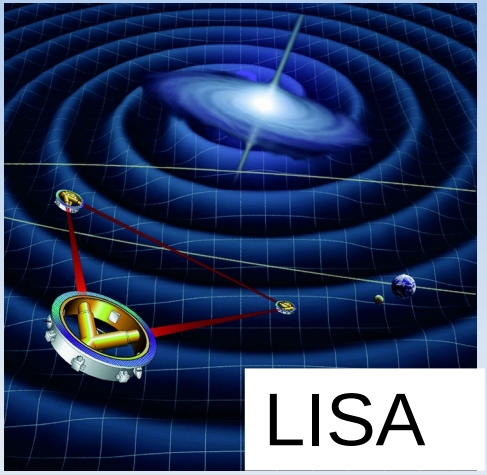


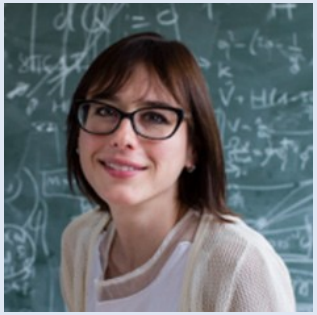
Using GW observations of binary mergers in combination with gamma-ray burst to

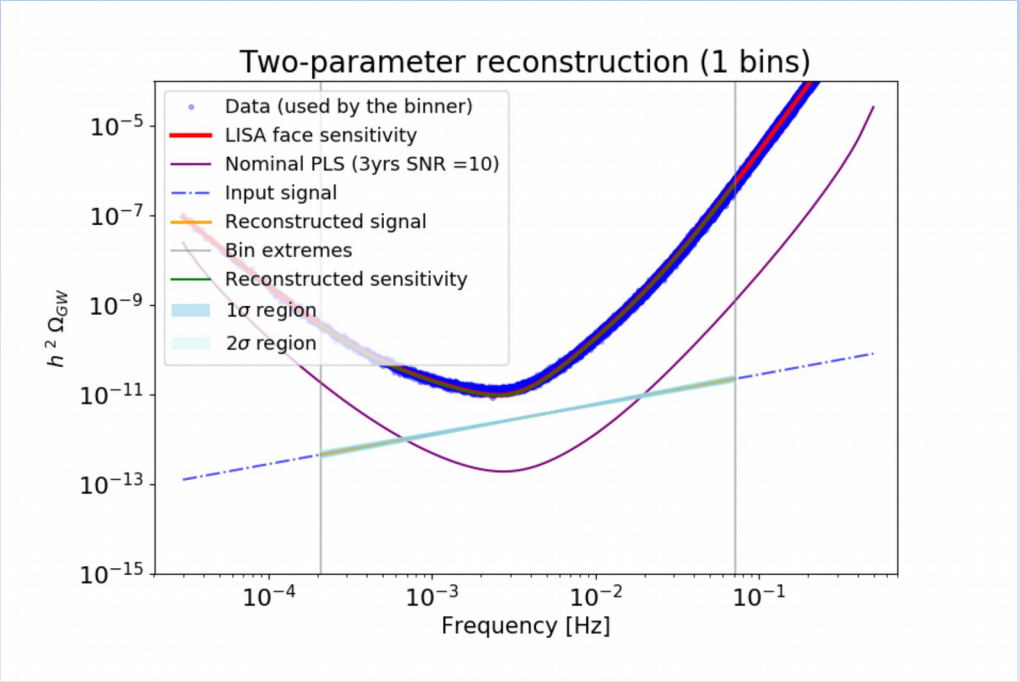
- measure H_0
- test modified gravity
  → DM

Mastrogiovanni, Steer, Barsuglia, 2021

GW observations II







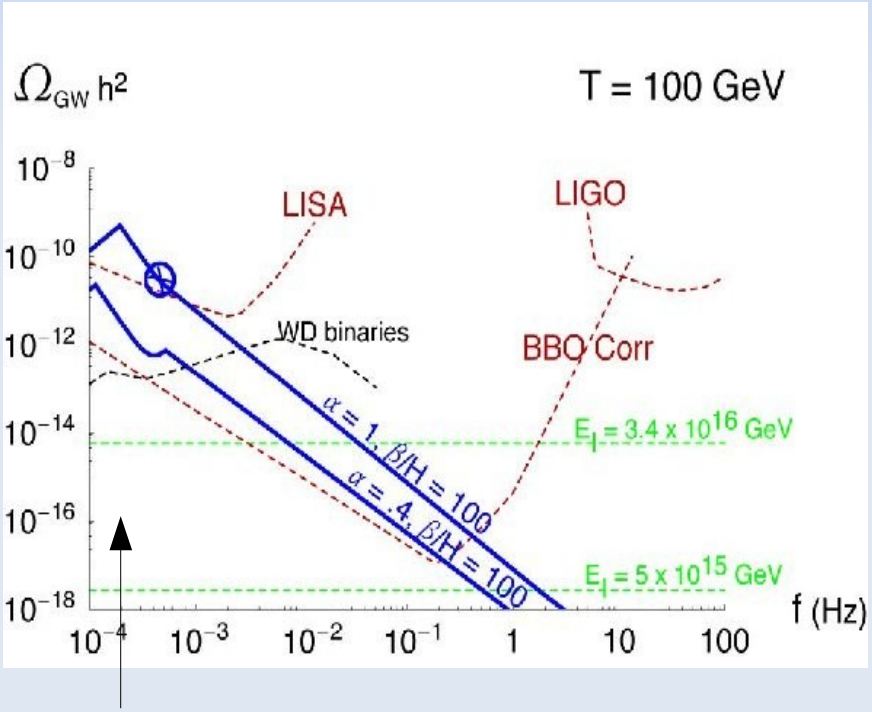
Assess the reach of LISA to detect stochastic backgrounds
- simulate detector response of noise & signal
- likelihood analysis
- reconstruction of noise parameters
- guidance for S/N analysis

Caprini, Figueroa, Flauger, Nardini, Peloso, Pieroni, Ricciardone, Tasinato 2019

GWs from first-order phase transitions

[Grojean&Servant '06]

The produced gravitational waves can be observed with laser interferometers in space (think LISA)

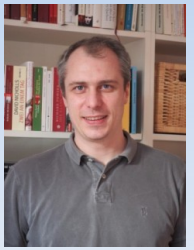


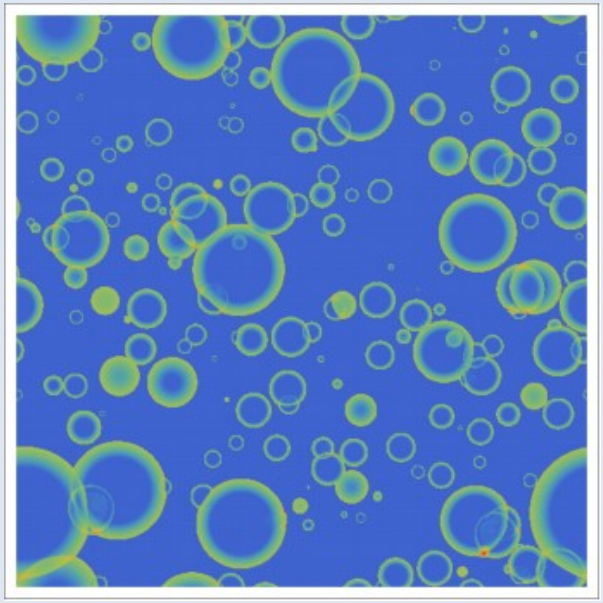
redshifted **Hubble horizon** during a phase transition at T ~ 100 GeV

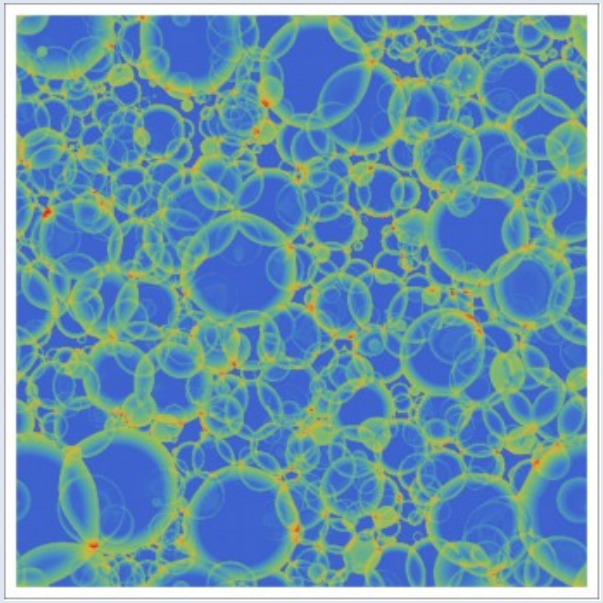
Gravitational waves from first-order phase transitions

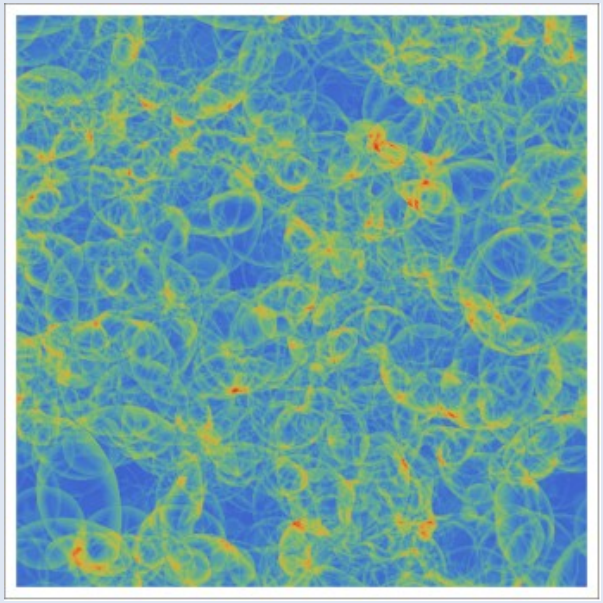
With the observation of binary mergers by LIGO and the tentative hint by **NANOGrav,** also gravitational waves from phase transitions gained more attention.

One recent activity in the cosmo group is to perform **simplified simulations** of the phase transitions to better understand the parametric dependence of the GW spectrum on the model parameters



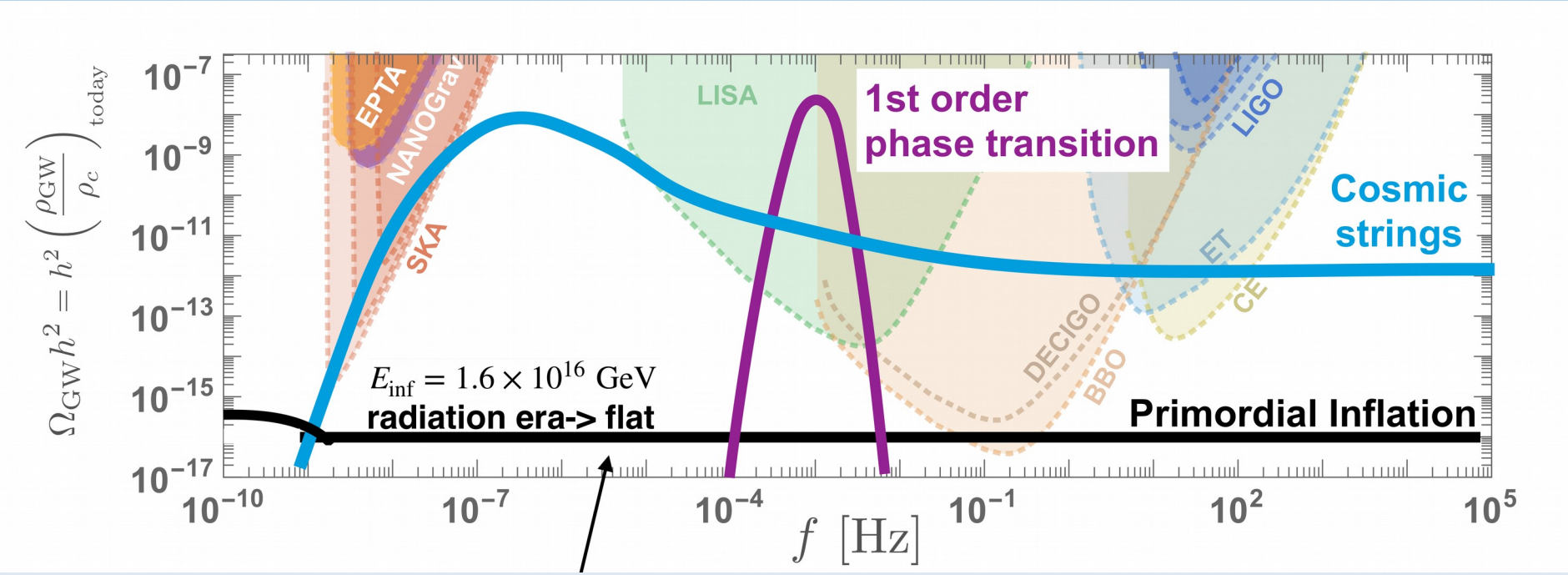






Jinno, TK, Rubira, 2020
Jinno, TK, Rubira, van de Vis, 2021

GW background of primoridal origin

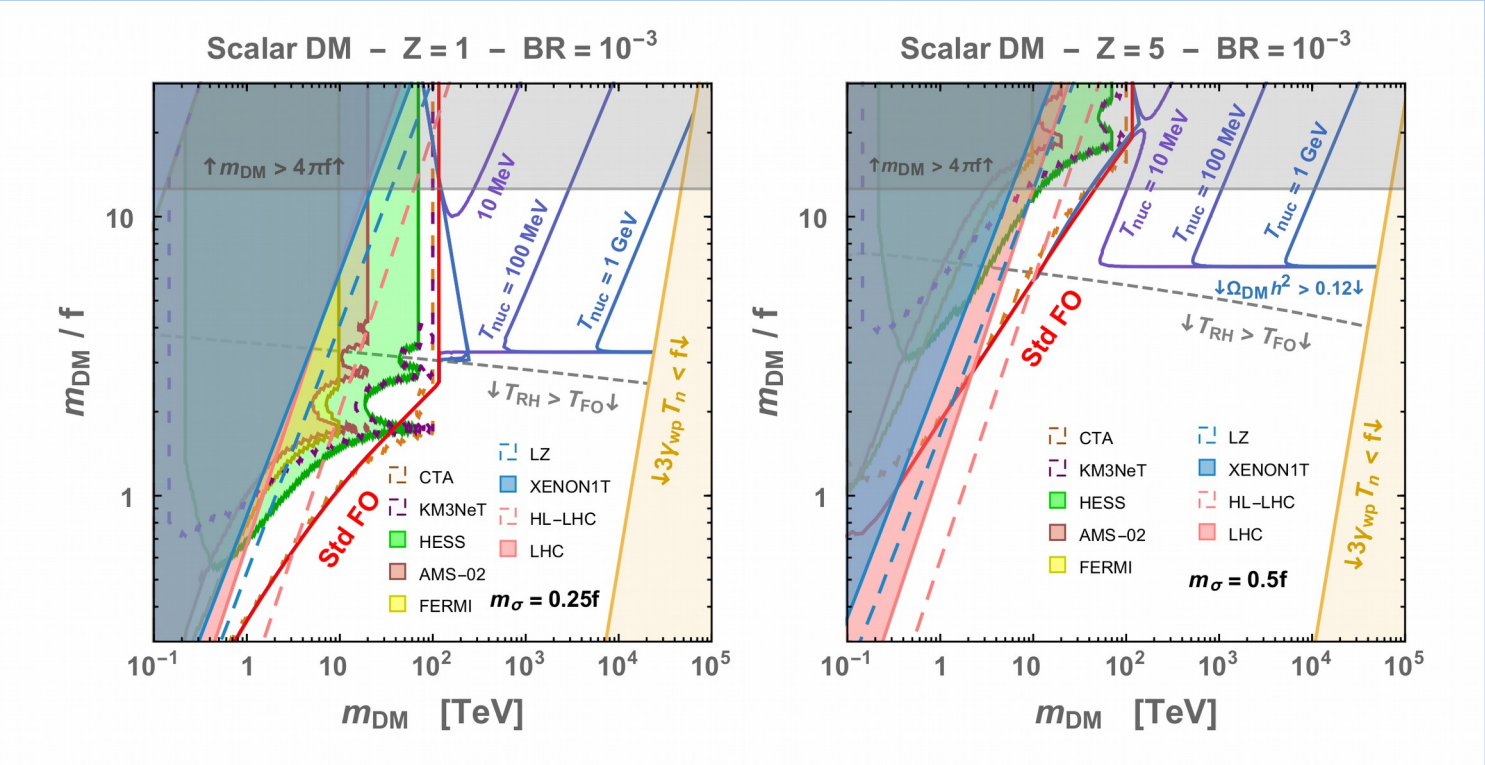


Cosmic strings are another potential source of a GW background

Connection to axions / relaxions / kination / DM

Gouttenoire, Servant, Simakachorn, 2021

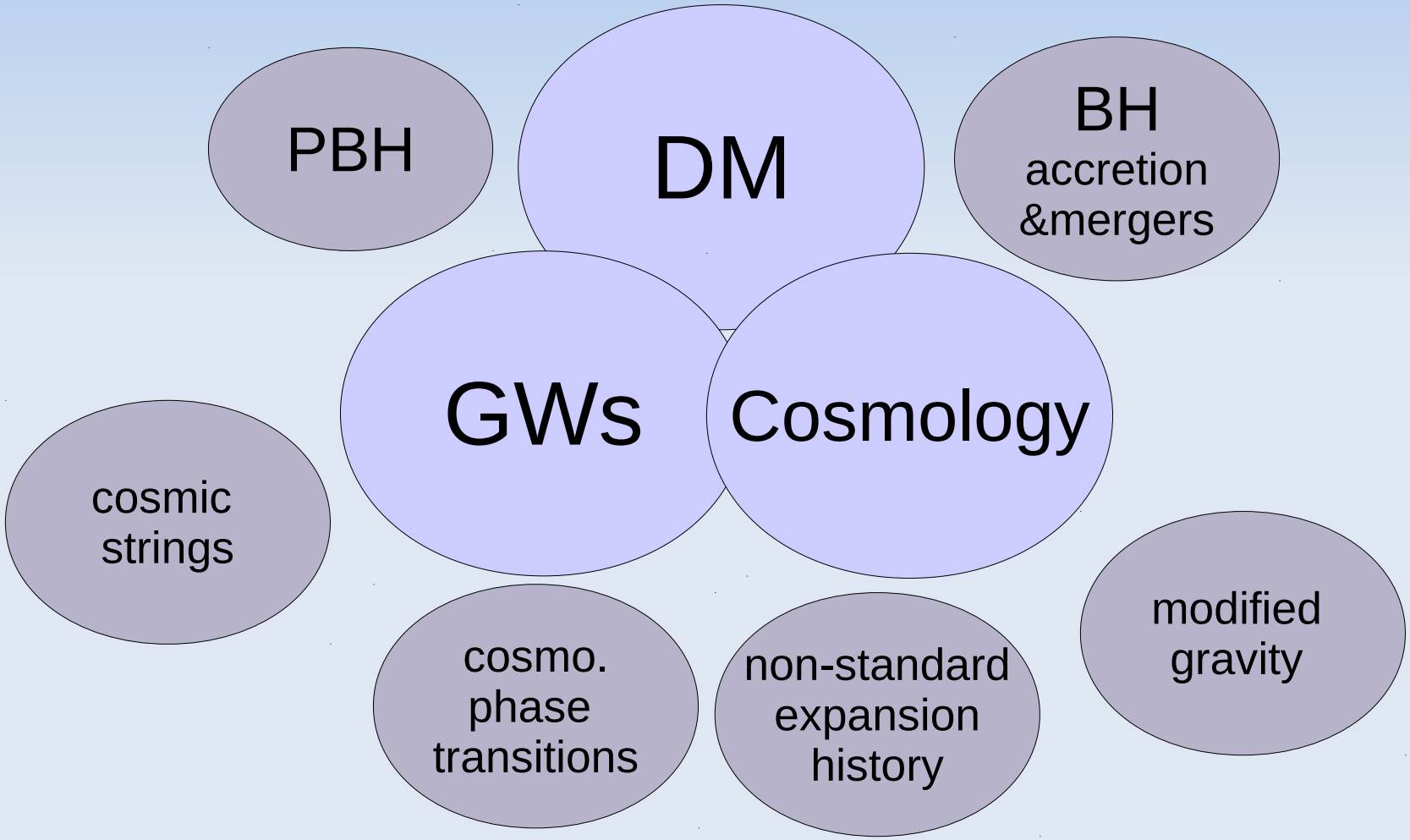
DM as a composite state



Baldes, Gouttenoire, Sala, Servant, 2021

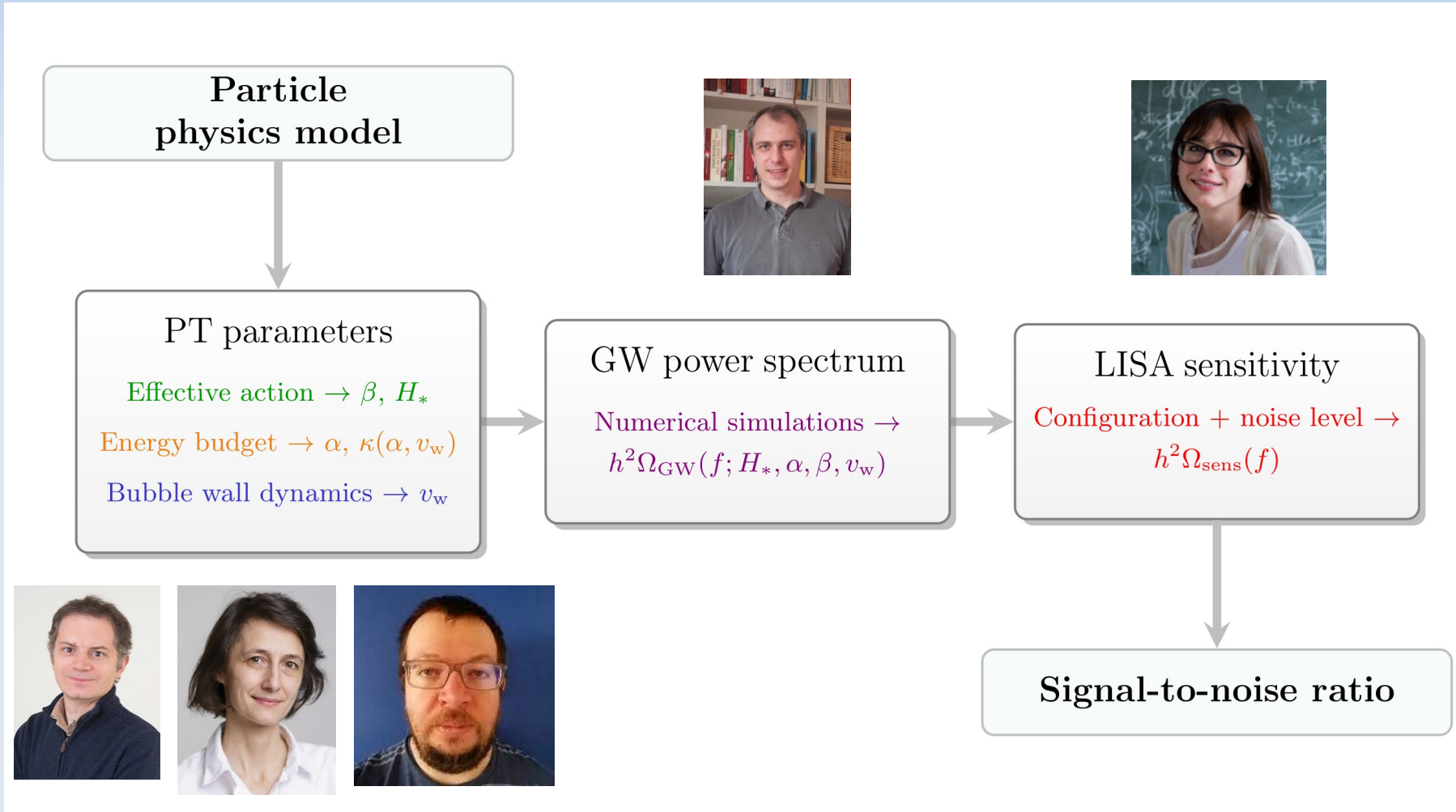
DM could be a composite state.
- highly predictive when the mediator to the SM is the dilaton
- conventional unitarity bounds on DM can be avoided
- GW signal from confinement
- composite Higgs → collider pheno

Future projects



Connection between topics

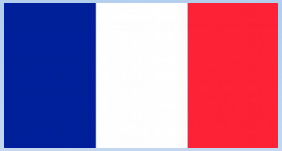
Example: GWs from phase transitions [from LISA Cosmo WG]

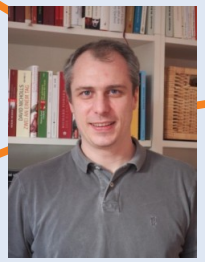


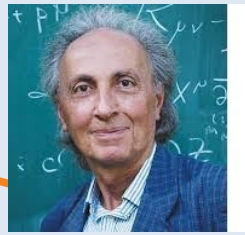
Connection in the team

Early Universe

Late Universe







How DMLab can help

Activities in **Dark matter, gravity and cosmology** can be roughly split into

- precision predictions for binary mergers

- involvement in GW experiments

- early Universe cosmology: GWs from phase transition, cosmic strings, kination, axions, relaxion, ...

DMLab can help to **foster connections** even more.

The team is already quite interconnected – even **across borders and topics**

→ interesting developments often at the interface between topics

→ short term visits likely to be fruitful