

Theory: Particle Cosmology



87th PRC meeting, 21 May 2019

Filippo Sala



People - Staff



- ★ Wilfried Buchmüller (honorary member)
- ★ Valerie Domcke (5yrs)
- ★ Thomas Konstandin
- ★ Rafael Porto* (Zeuthen, but located in Hamburg)
- ★ Andreas Ringwald
- ★ Filippo Sala (5yrs)
- ★ Geraldine Servant
- ★ Alexander Westphal*

*External fundings: 2 ERC consolidator grants

People - Staff



- ★ Wilfried Buchmüller (honorary member)
- ★ Valerie Domcke (5yrs) → Offered 6 year CERN-EPFL staff position
(starting date negotiated to May 2020)
- ★ Thomas Konstandin
- ★ Rafael Porto* (Zeuthen, but located in Hamburg)
- ★ Andreas Ringwald
- ★ Filippo Sala (5yrs) → Ranked 1st in CNRS section02 competition
(starting date etc to be negotiated)
- ★ Geraldine Servant
- ★ Alexander Westphal*

*External fundings: 2 ERC consolidator grants

People - Postdocs/Students/Other



+ more later

- ★ Federico Carta*
- ★ Luca Di Luzio* (arrives Fall 2019)
- ★ Yohei Ema*
- ★ Nayara Fonseca
- ★ Ryusuke Jinno*
- ★ Enrico Morgante
- ★ Kyohei Mukaida*
- ★ Ryosuke Sato
- ★ Yvette Welling*
- ★ Felix Giese
- ★ Yann Gouttenoire
- ★ Jakob Moritz*
- ★ Henrique Rubira
- ★ Peera Simachakorn
- ★ Stefan Sanders
- ★ Prof. Jorge Gamboa (Humboldt visitor Apr-July 2019)

*External fundings (partial or all) - japanese JSPS fellowships, ERC, Marie Curie

External Fundings and Networks

- ★ Excellence Cluster (participation to “Quantum Universe” proposal)
- ★ ERC consolidator grant “Stringflation” (Alexander)
- ★ ERC consolidator grant “LHCtoLISA” (Rafael, Zeuthen but located in Hamburg)
- ★ Cost European Network “Fundamental Connections”
- ★ Invisibles-Plus RISE and Elusives European ITN Network
(Horizon2020 projects, University of Goettingen-DESY node)
- ★ PIER Seed project funding (Filippo&Geraldine)
“Dark Matter at 10 TeV and beyond, a new goal for cosmic-ray experiments”



- ★ Nordic Network of Dark Matter (Thomas, funds Danish Research Council)
- ★ Member of ANTARES collaboration (Filippo, observer status)

Event Organisation (since 2018)

Local

- ★ 6 Apr 2018 - Gravitational Waves: windows of opportunities
- ★ 18-22 Jun 2018 - 14th Patras Axion-WIMP workshop
- ★ 21-23 Aug 2018 - Probing strong-field QED in $e - \gamma$ interactions
- ★ 25-28 Sep 2018 - DESY theory workshop
- ★ 19-20 Mar 2019 - Quantum Universe Kickoff meeting

External

- ★ 14-18 May 2018, **CERN**
Primordial vs Astrophysical origin of Black Holes
- ★ 9-21 July 2018, **Corsica**, Cargese Summer School
- ★ 7-13 April 2019, **Benasque**, Light Scalars Workshop
- ★ 10-21 June 2019, **ICTP Trieste**, Particle Physics summer school
- ★ 7-12 July 2019, **Valencia**, GR22



PARTICLE PHYSICS CHALLENGES.

DESY Theory Workshop
25 - 28 September 2018
Hamburg, Germany

Plenary Talks

| | | | |
|--------------------------|----------------------|--------------------------|------------------------------|
| U. Blumenschein (London) | J. Kopp (Mainz) | M. Pospelov (Perimeter) | L. Tancredi (CERN) |
| M. Craig (Santa Barbara) | F. Maltoni (Louvain) | F. Rademacker (Bristol) | A. Urbano (Trieste) |
| M. Czakon (Aachen) | T. Mannel (Siegen) | M. Schmidt (Boston) | C. Vallée (Marseille & DESY) |
| A. Denner (Würzburg) | F. Moortgat (CERN) | K. Schmidt-Hoberg (DESY) | L. Verde (Barcelona) |
| A. Eichhorn (Heidelberg) | I. Moult (Berkeley) | M. Spannowsky (Durham) | L.-T. Wang (Chicago) |

DESY Heinrich-Hertz Lecture on Physics
George Sterman (Stony Brook University)

Parallel Sessions
Contributions by young researchers are especially encouraged.
Deadline for abstract submission in early July 2018

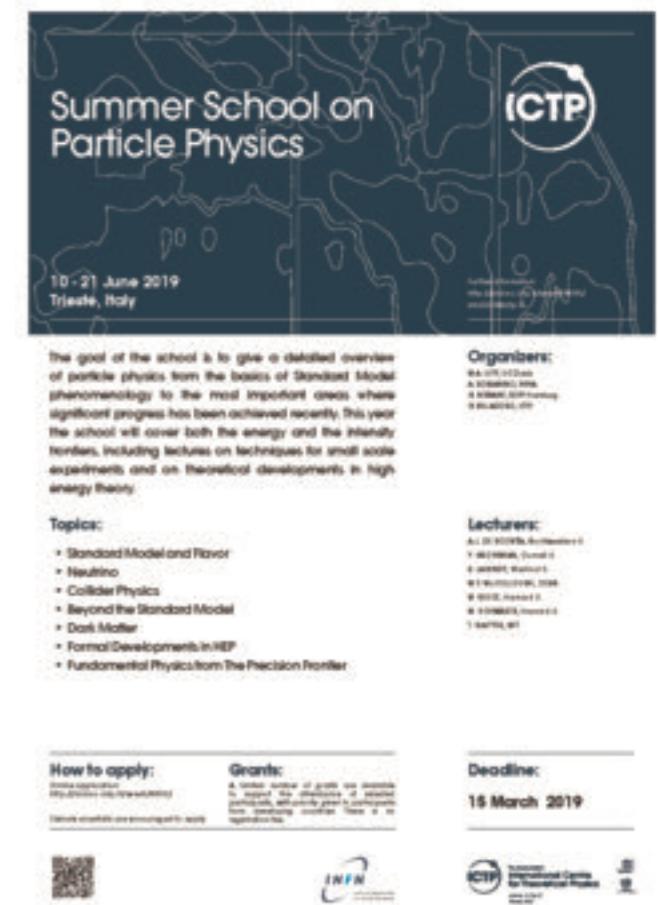
- Strings & Mathematical Physics: O. Schlotterer (Potsdam & Perimeter Inst.), E. Pomoni (DESY)
- Cosmology & Astroparticle Physics: F. Kahlhoefer (Aachen), V. Domcke (DESY)
- Particle Phenomenology: S. Gieseke (Karlsruhe), M. Bauer (Heidelberg)

ORGANIZING COMMITTEE:
R. Kaiser, C. Krause, J. Laiho, J. Leibnitz, M. Krämer (Chair),
A. Kulesza, P. Marquard, G. Montagna-Pick,
S. Schumann, P. Schwaller,
T. Schwick-Mangold, F. Tackmann

<http://th-workshop2018.desy.de>

Accelerators | Photon Science | Particle Physics
Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association





Summer School on Particle Physics

10 - 21 June 2019
Trieste, Italy

The goal of the school is to give a detailed overview of particle physics from the basics of Standard Model phenomenology to the most important areas where significant progress has been achieved recently. This year the school will cover both the energy and the intensity frontier, including lectures on techniques for small scale experiments and on theoretical developments in high energy theory.

Topics:

- Standard Model and Flavor
- Neutrino
- Collider Physics
- Beyond the Standard Model
- Dark Matter
- Formal Developments in HEP
- Fundamental Physics from the Precision Frontier

Organizers:
INFN - Istituto Nazionale di Fisica Nucleare
Scuola Normale Superiore
Istituto Nazionale di Fisica Nucleare

Lecturers:
A. De Simone (Trieste)
Y. Grossman (Cern)
D. Harari (Tel Aviv)
M. Lindner (Heidelberg)
M. Raggi (Trieste)
M. Ricci (Trieste)
F. Sannino (Milan)

Deadline:
15 March 2019

How to apply:
<http://www.ctp.sns.it/summer-school-2019/>

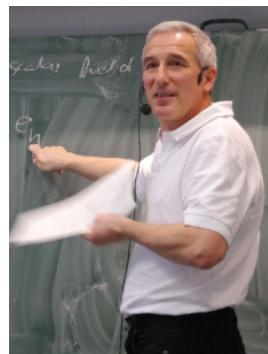
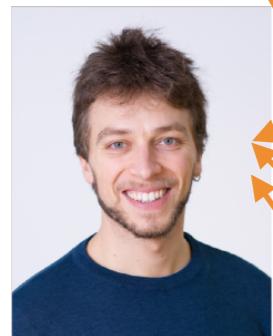
Grants:
A limited number of grants are available to support the participation of selected postgraduate students and early career researchers. There is no registration fee.



Lectures and Teaching (since 2018)

- ★ Summer semester 2018, [Uni. Hamburg](#), Theoretical Cosmology course [Servant+Westphal]
- ★ Summer semester 2018, [DESY](#), “Workshop Seminar” on Flavour Physics, 11 lectures
- ★ June 2018, [Erice](#), “Erice international school of science journalism”, 1 lecture [Servant]
- ★ July 2018, [Mainz](#), “MITP Summer School 2018”, 4 lectures [Domcke]
- ★ July 2018, [Trieste](#), “Jennifer summer school on particle physics and detectors”, 2 lectures [Sala]
- ★ Winter semester 2018, [DESY](#), “Workshop Seminar” on Hot Topics in QFT&String theory, 12 lectures
- ★ Summer semester 2019, [DESY](#), “Workshop Seminar” on Semiclassical objects in QFT, 11 lectures
- ★ Summer semester 2019, [Uni. Hamburg](#), Theoretical Cosmology course [Domcke+Servant]
- ★ August 2019, [Ljubljana](#), Summer School, 2 lectures + 2 tutorings [Sala+Gouttenoire]

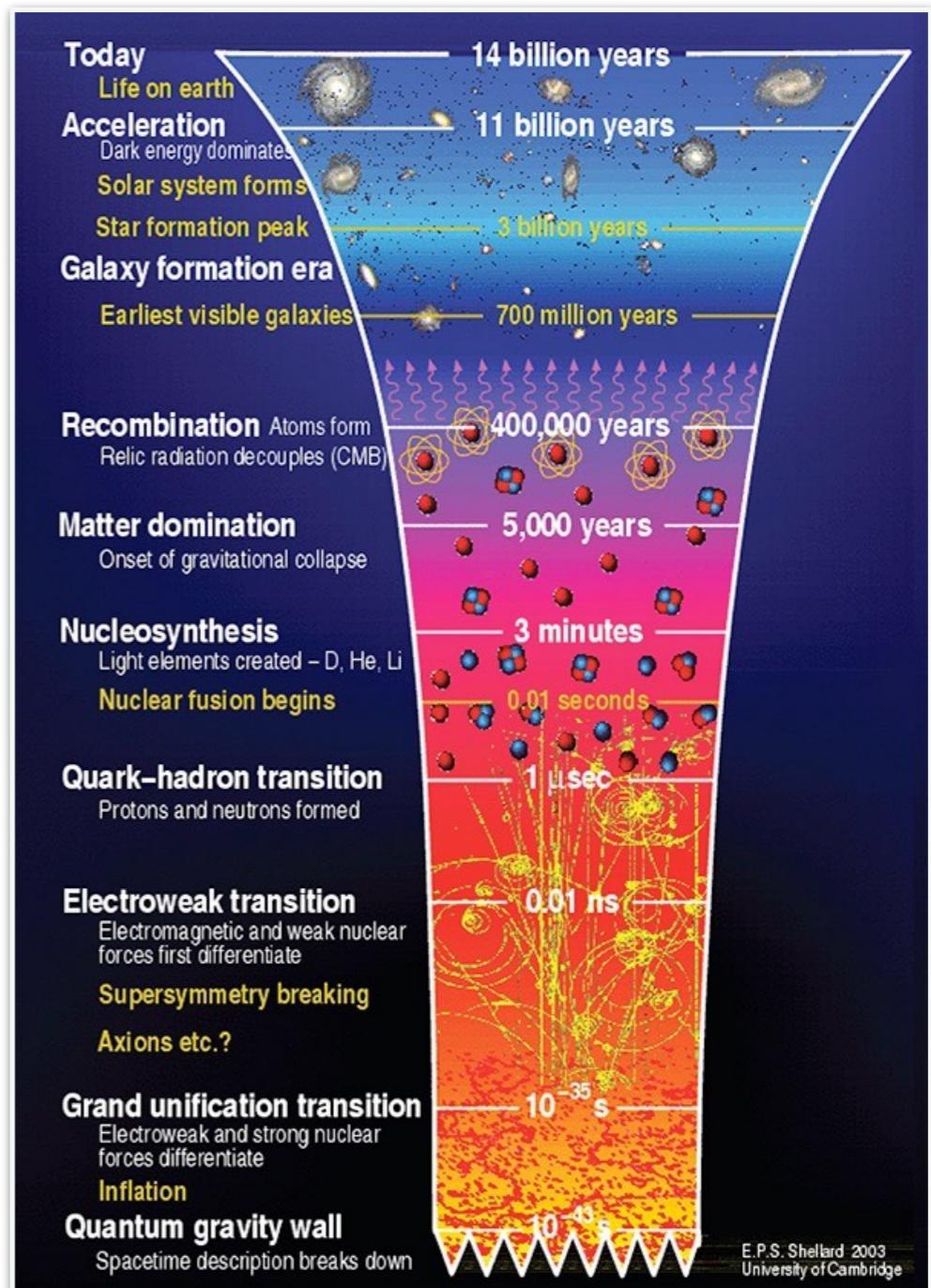
Research: The Big Picture



We work to understand:

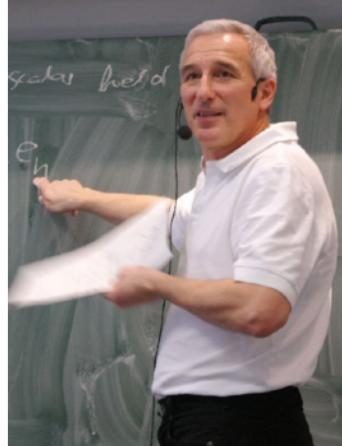
- Dark Matter
- Baryon Asymmetry
- Neutrino Oscillations
- Quantum Gravity
- Inflation
- Dark Energy
- EW symmetry breaking
- Strong CP problem
- Origin of SM flavour
-

Our lab:



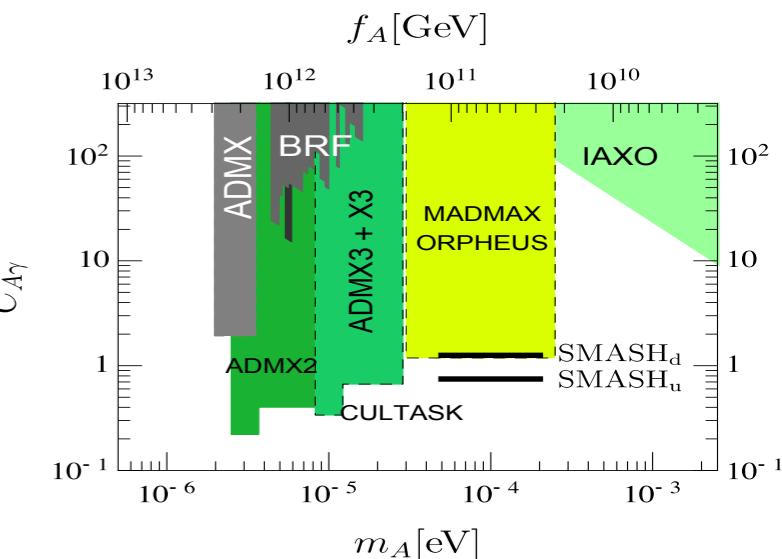
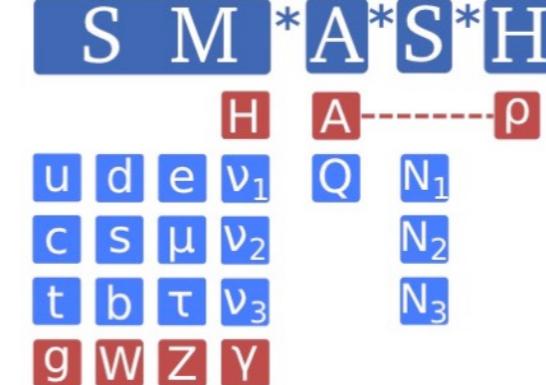
SMASH

Self-contained and consistent description of particle physics and cosmology

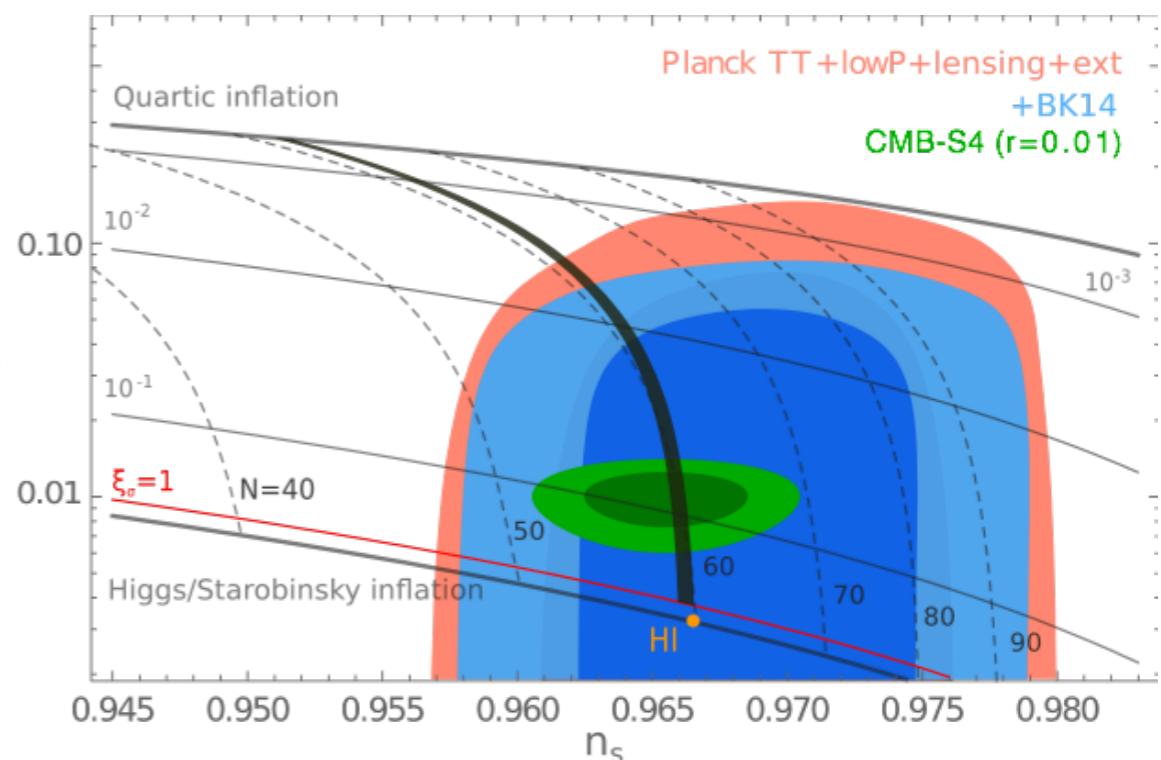


SMASH

- Added to Standard Model (SM) singlet complex scalar field featuring spontaneously broken Peccei-Quinn symmetry, a vector-like quark, and three right-handed singlet (sterile) neutrinos
- Model solves several problems of particle physics and cosmology in one stroke:
 - Inflation (non-minimal chaotic PQ/H field inflation)
 - Baryogenesis (leptogenesis)
 - Dark matter (axion)
 - Strong CP problem (axion)
 - Neutrino masses and mixing (seesaw)

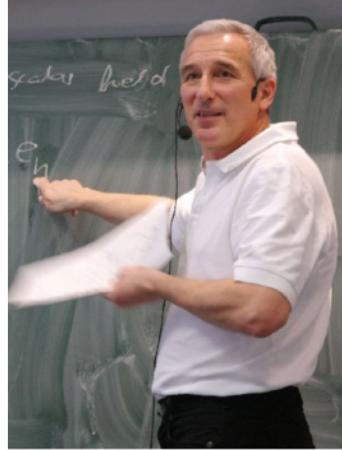


[Ballesteros, Redondo, Ringwald, Tamarit 1608.05414; 1610.01639]



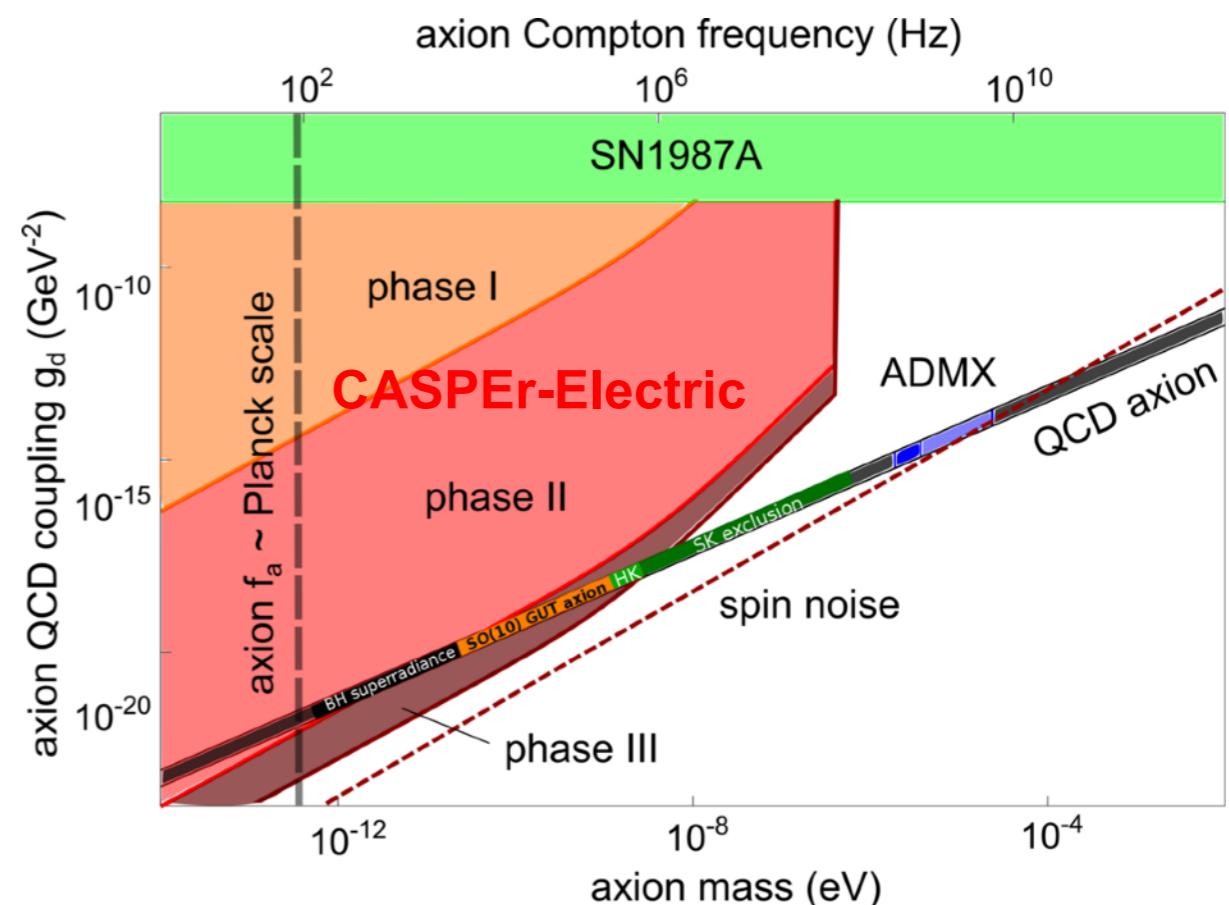
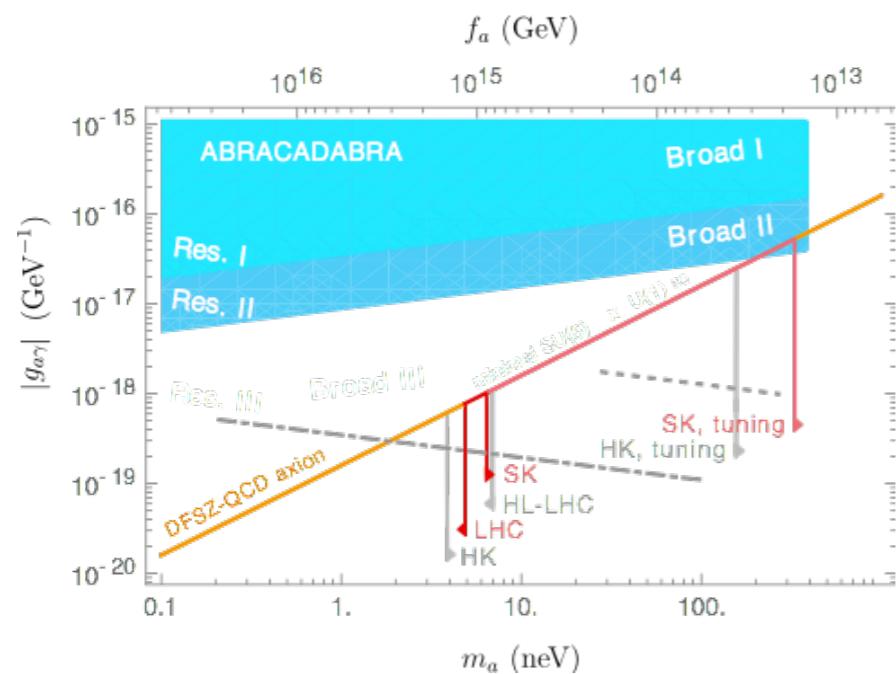
GUT SMASH

Self-contained and consistent description of particle physics and cosmology



Non-SUSY GUT SMASH

- Non-SUSY $\text{SO}(10) \times \text{U}(1)_{\text{PQ}}$ and $\text{SU}(5) \times \text{U}(1)_{\text{PQ}}$ models addressing both neutrino masses and gauge coupling unification predict axion mass in window accessible in axion DM direct detection
- Intriguing possibility that Higgs field required for GUT breaking may be responsible for inflation



[Ernst 18; CASPER prospects from Kimball et al. 17]

[Ernst,Ringwald,Tamarit 1801.04906; Di Luzio,Ringwald,Tamarit 1807.09769]



Flavour-Electroweak symmetry breaking cosmological interplay

- Effect of varying Yukawas on EW phase transition
Baldes, Konstandin, Servant, 1604.04526
- Implementation in Froggatt-Nielsen
Baldes, Konstandin, Servant, 1608.03254
- Natural realisation of Yukawa variation in Randall-Sundrum
Von Harling, Servant, 1612.02447
- Calculation of baryon asymmetry in models of variable Yukawas
Bruggisser, Konstandin, Servant, 1706.08534
- Outcome in composite Higgs models
Bruggisser, VonHarling, Matsedonskyi Servant, 1803.08546 & 1804.07314
- High scale EW phase transition
Baldes, Servant, 1807.08770



Cosmological relaxation of the electroweak scale

- UV completion in Randall-Sundrum type of models

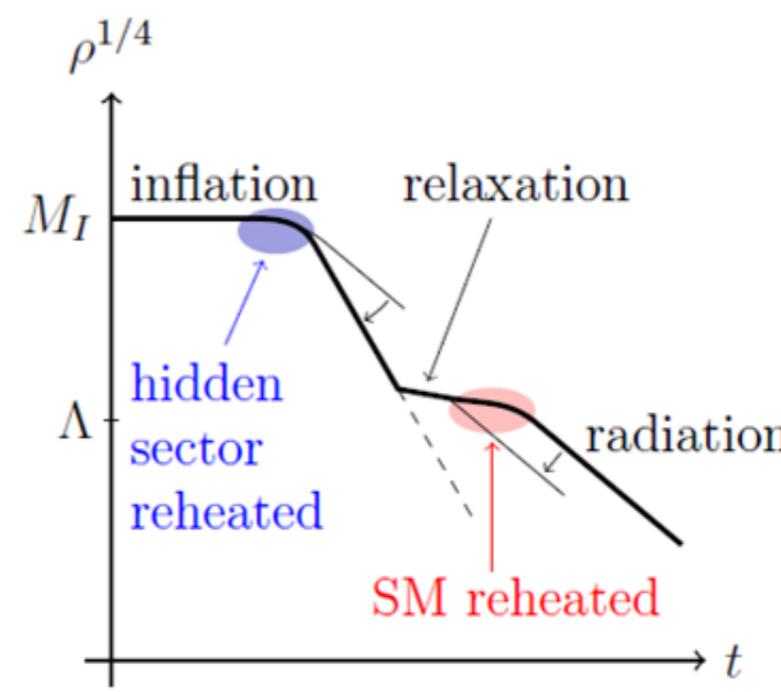
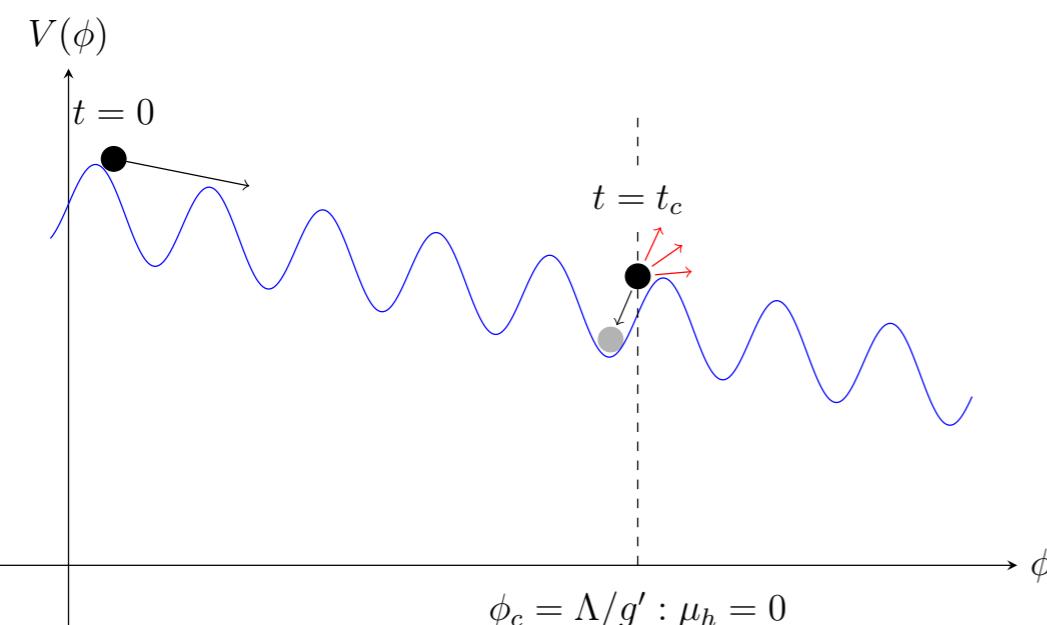
Fonseca, Von Harling, De Lima, Machado, 1712.07635

- Higgs relaxation after inflation

Fonseca, Morgante, Servant, 1805.04543

- Relaxation dark matter

Fonseca, Morgante, 1809.04534



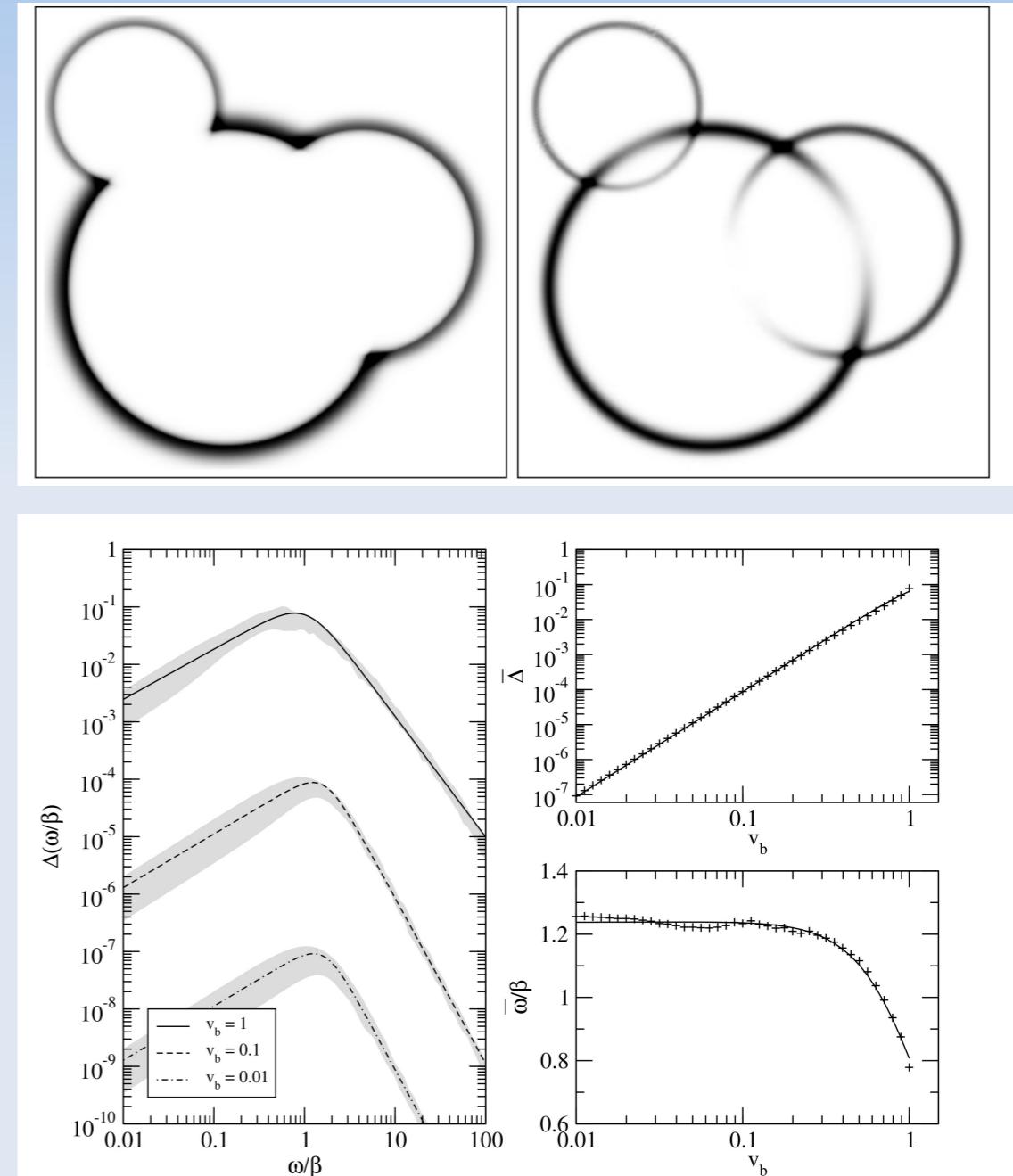


GW spectra from fluid models

Predictions of gravitational waves from cosmological phase transitions often rely on hydrodynamic lattice simulations.

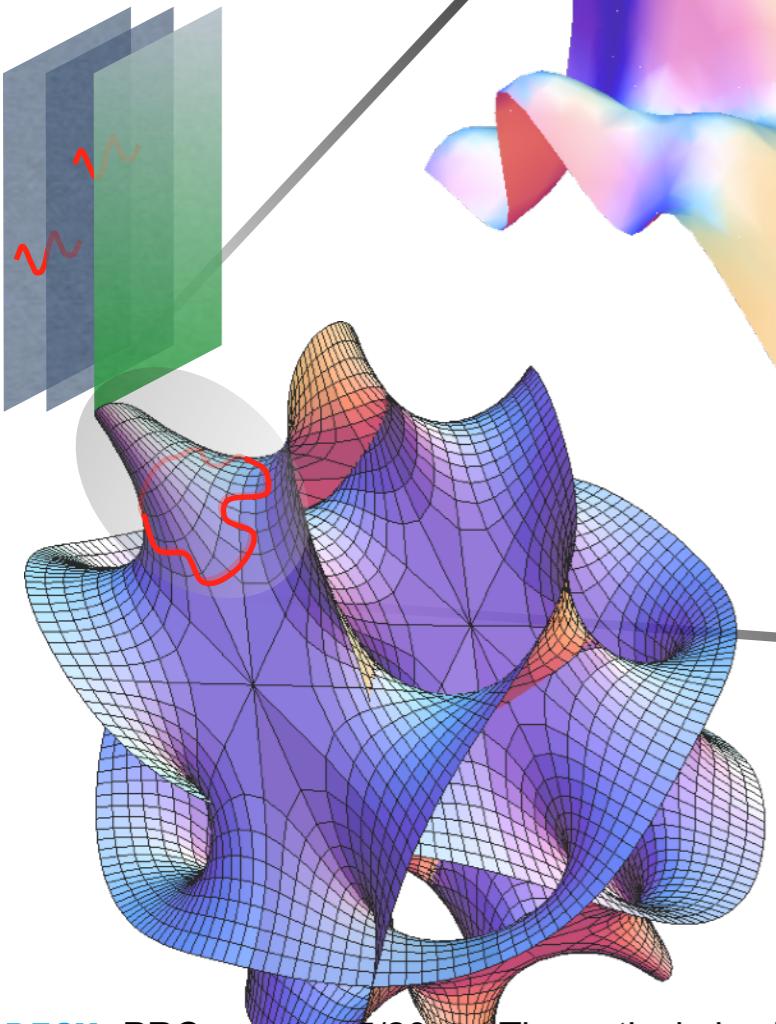
These simulations are limited by grid resolutions and time scales.

Semi-analytic models can assess these regimes. They are based on energy considerations and fluid modelling from the simulations.

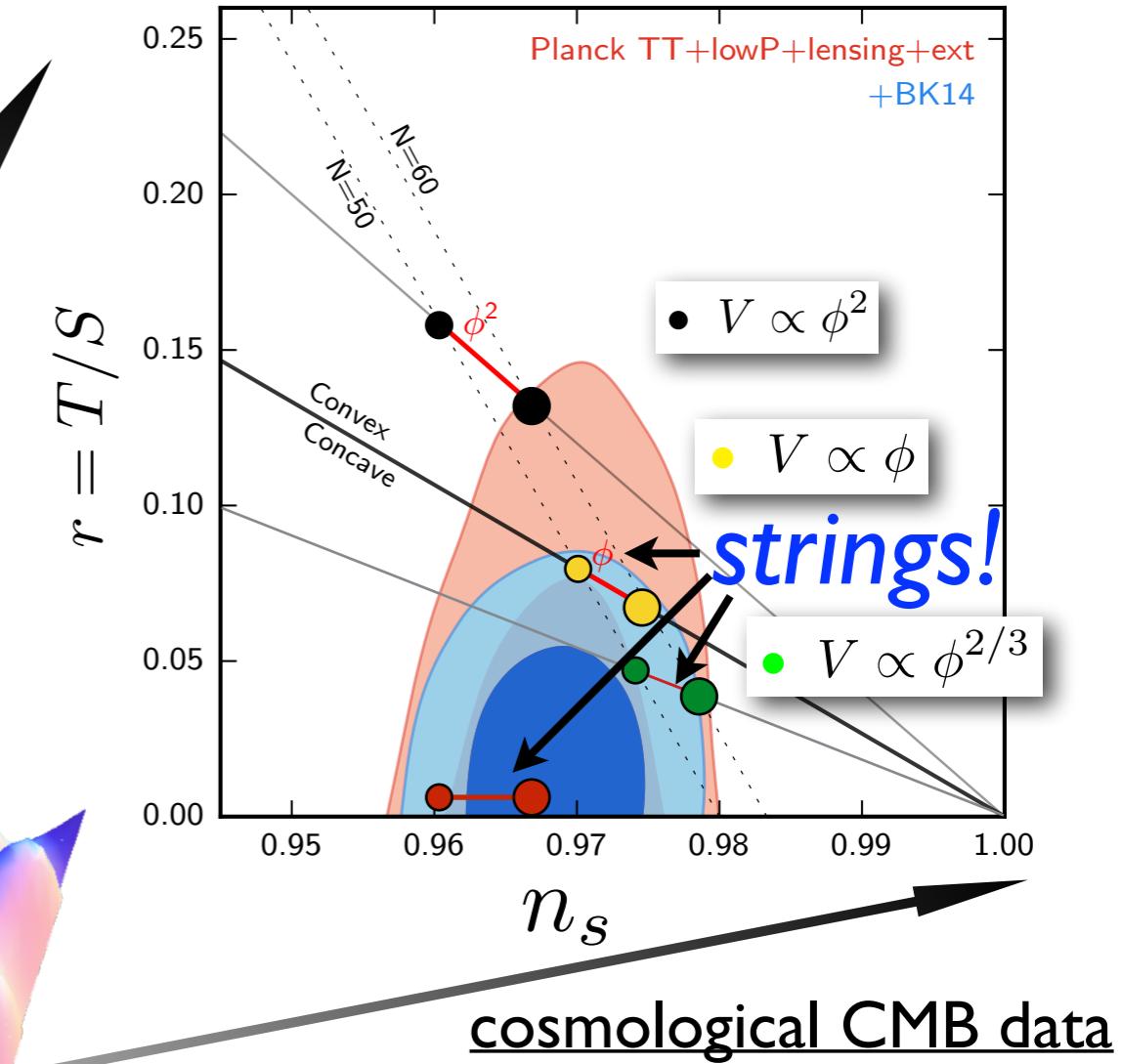
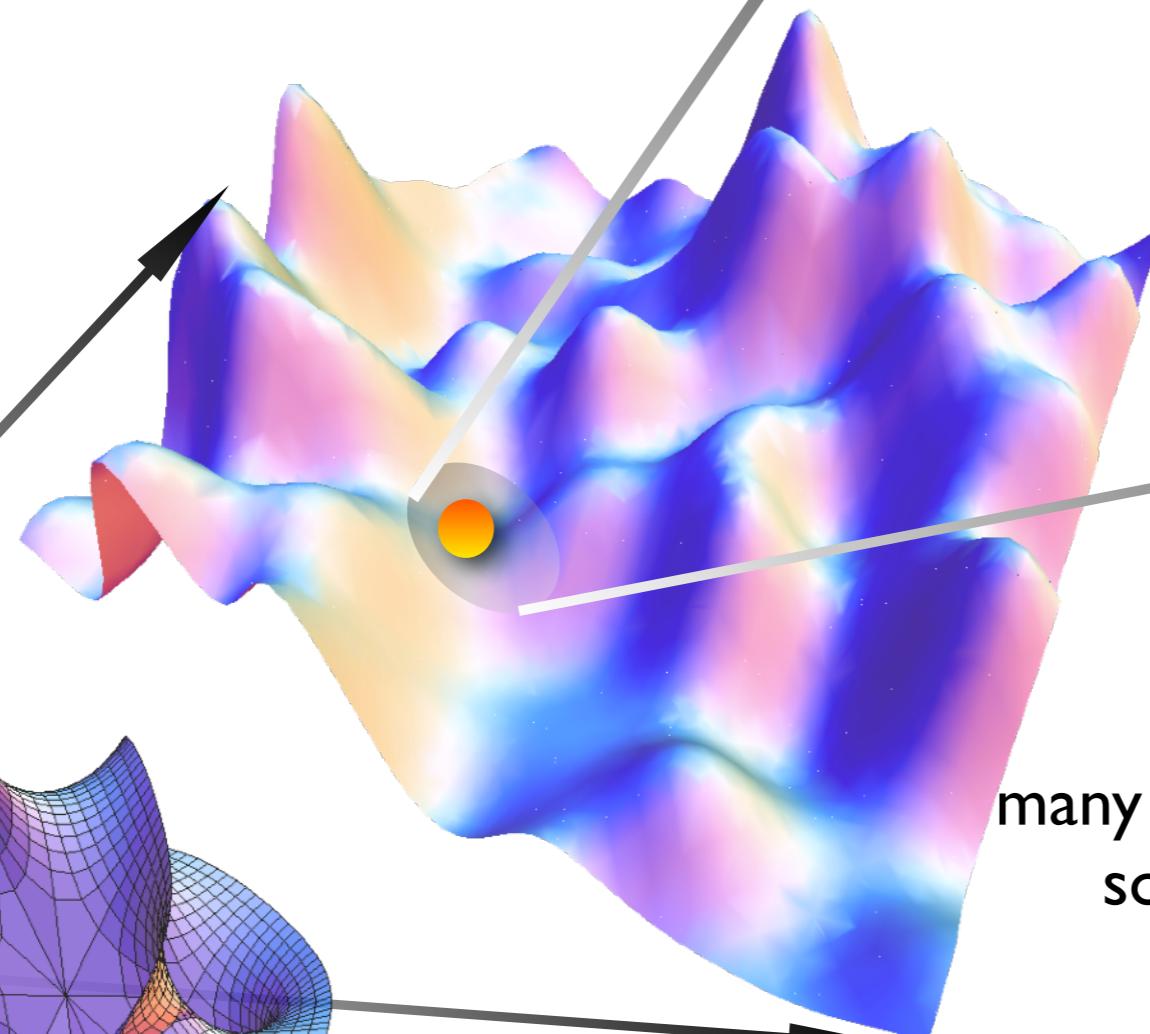


[TK '17]

test string theory with inflation & CMB



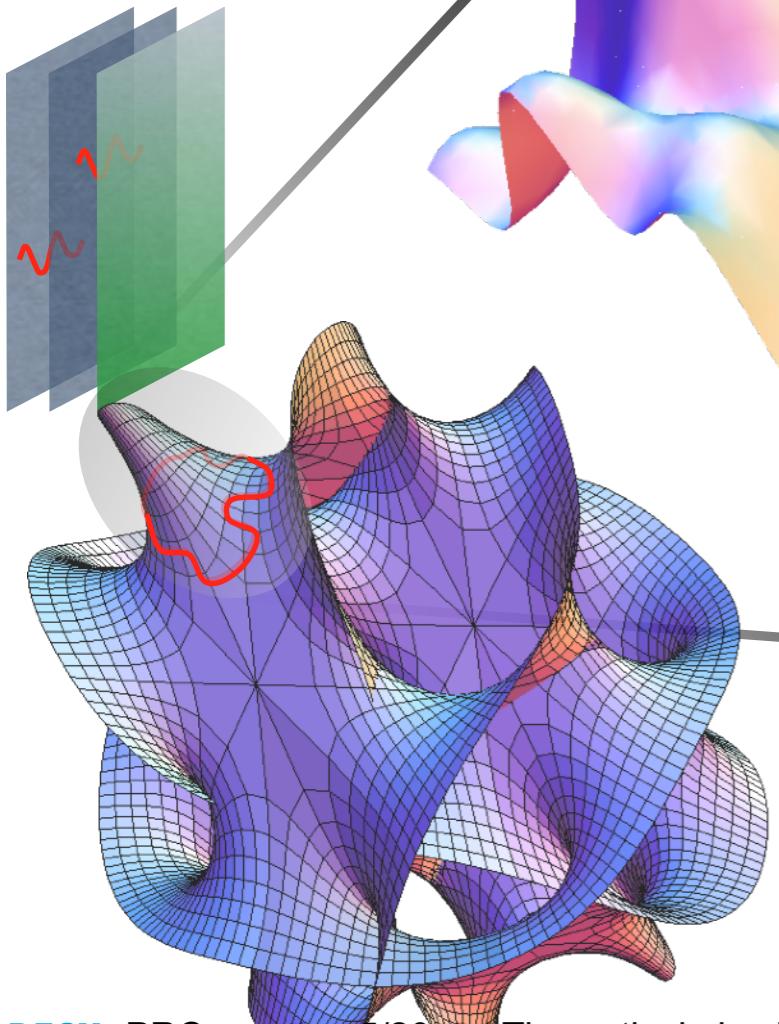
string theory's 6 compact dimensions:
strings, branes & **fluxes**



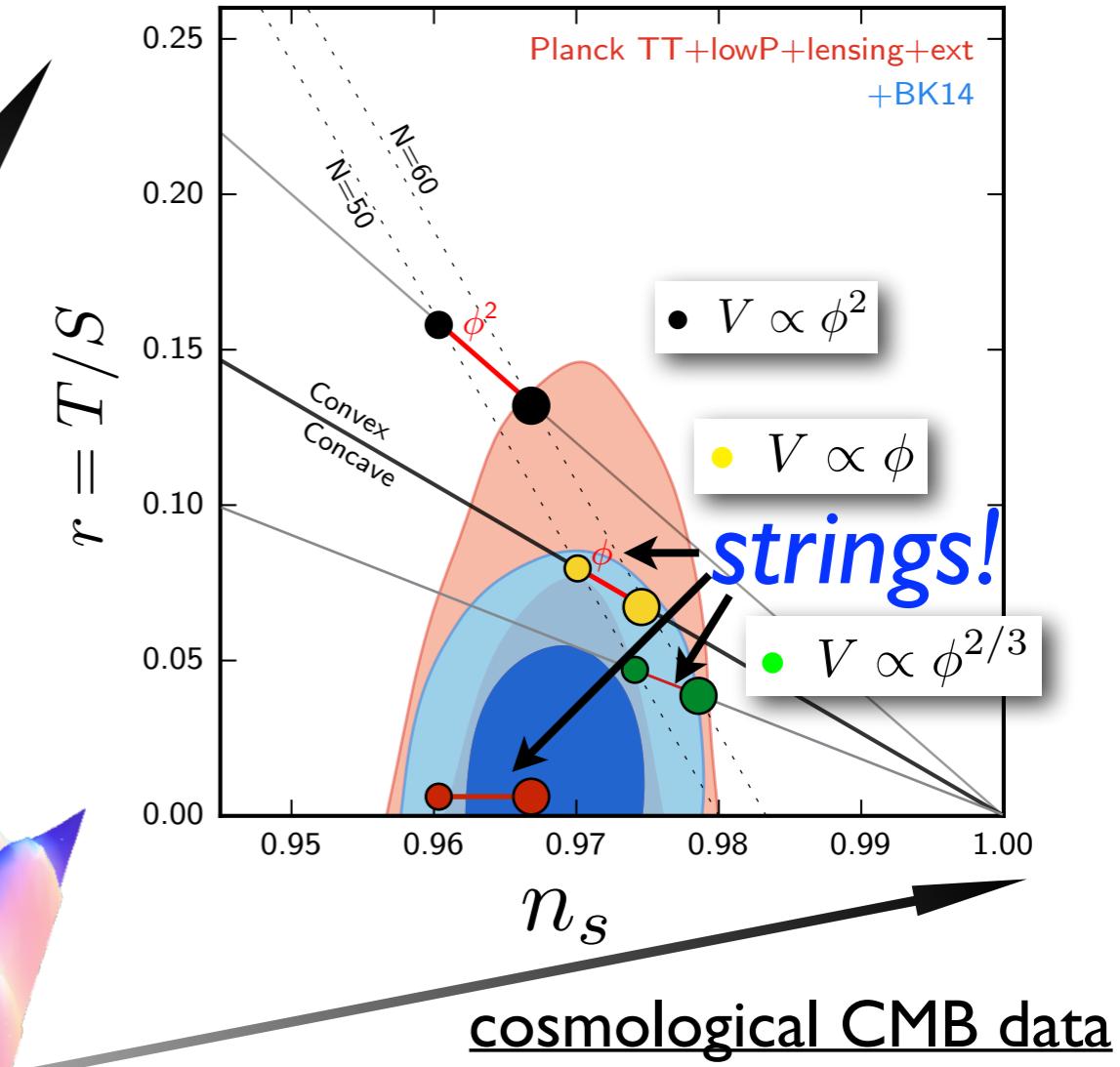
the string theory landscape:
many isolated vacua, connected by tunneling
some mountain slopes drive inflation



test string theory with inflation & CMB



string theory's 6 compact dimensions:
strings , branes & fluxes



**moduli & axions:
light scalars ...**



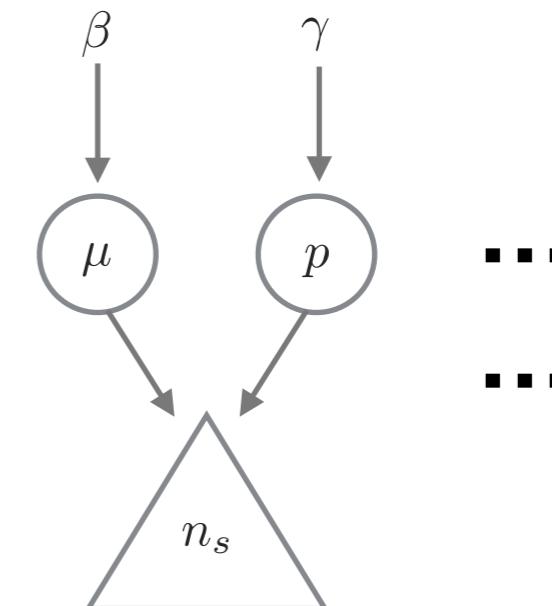
machine learning for axion monodromy inflation

Steps:

1. Identify relevant scales (class of models)
2. Learn the mapping from parameters to observables
3. Study how predictions change according to prior choice

Use numerical methods developed in previous work to generate a large sample assuming

$$\mu \sim \mathcal{U}(0.1, 1) \quad p \sim \mathcal{U}(0.1, 2)$$



$$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 - V_0 \left[\left(1 + \left(\frac{\phi}{\mu} \right)^2 \right)^{p/2} - 1 \right] + \Delta V_{p,np}$$

- Take a random draw of μ and p
- Solve background equations of motion
- Solve equations of motion for the perturbations and compute n_s
- Repeat many times
- Use machine learning to get $n_s(\mu, p)$

machine learning for axion monodromy inflation

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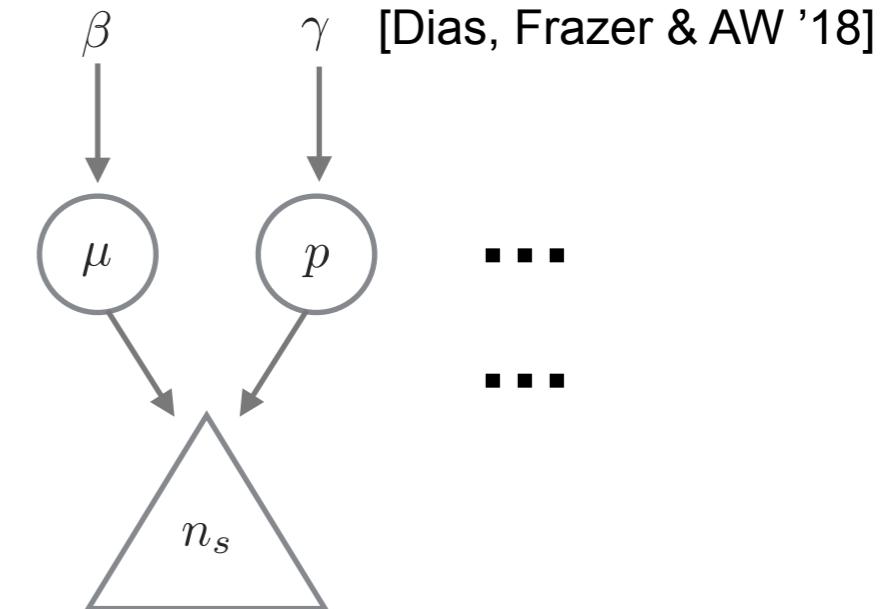
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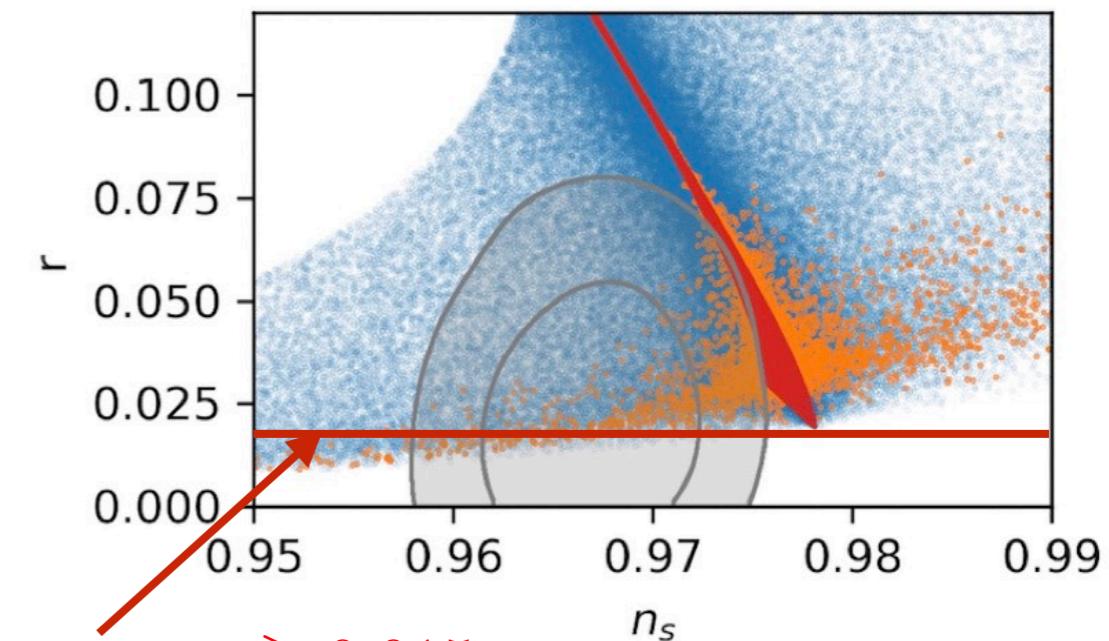
$$\mu \sim \mathcal{U}(0.1, 1) \quad p \sim \mathcal{U}(0.1, 2)$$

$\Delta V_{n,np}$: full model — 12 parameters !

- Take a random draw of μ and p
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$$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 - V_0 \left[\left(1 + \left(\frac{\phi}{\mu} \right)^2 \right)^{p/2} - 1 \right] + \Delta V_{p,np}$$



lower bound $r \gtrsim 0.015$
independent of μ



Particle production during inflation

Slow-roll inflation → very flat scalar potential

Reheating after inflation → coupling to the SM



Inflaton as Pseudo Goldstone Boson with shift-symmetric couplings

$$\phi F_{\mu\nu} \tilde{F}_{\mu\nu}$$

$$(\partial_\mu \phi) \bar{\psi} \gamma^\mu \gamma^5 \psi$$

explosive helical gauge boson production

additional friction modifies dynamics of inflation, see also relaxion models

Strongly enhanced non-gaussian polarized GW spectrum at scales. of LIGO and LISA

chiral fermion production

baryogenesis through spontaneous CPT violation

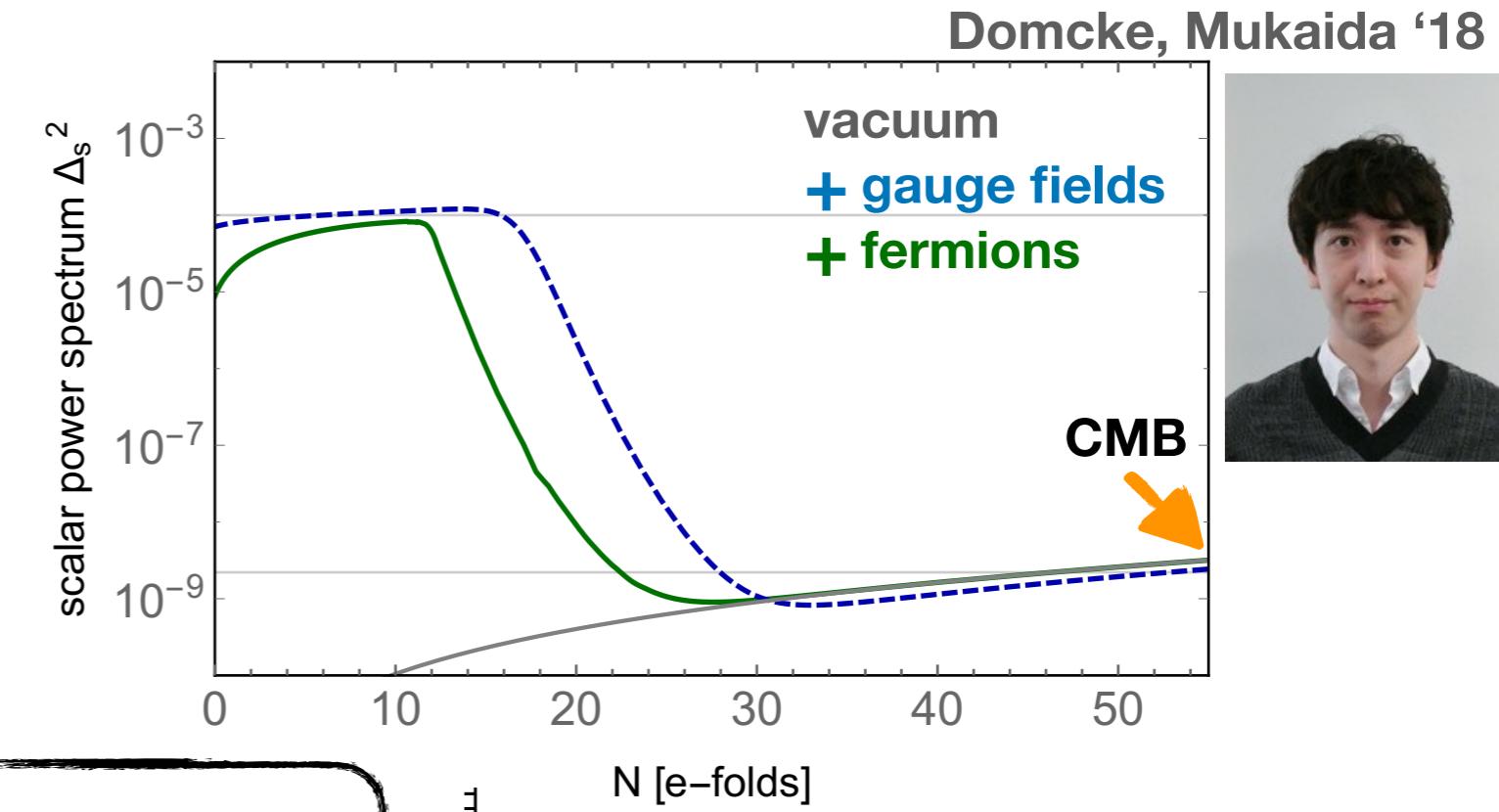
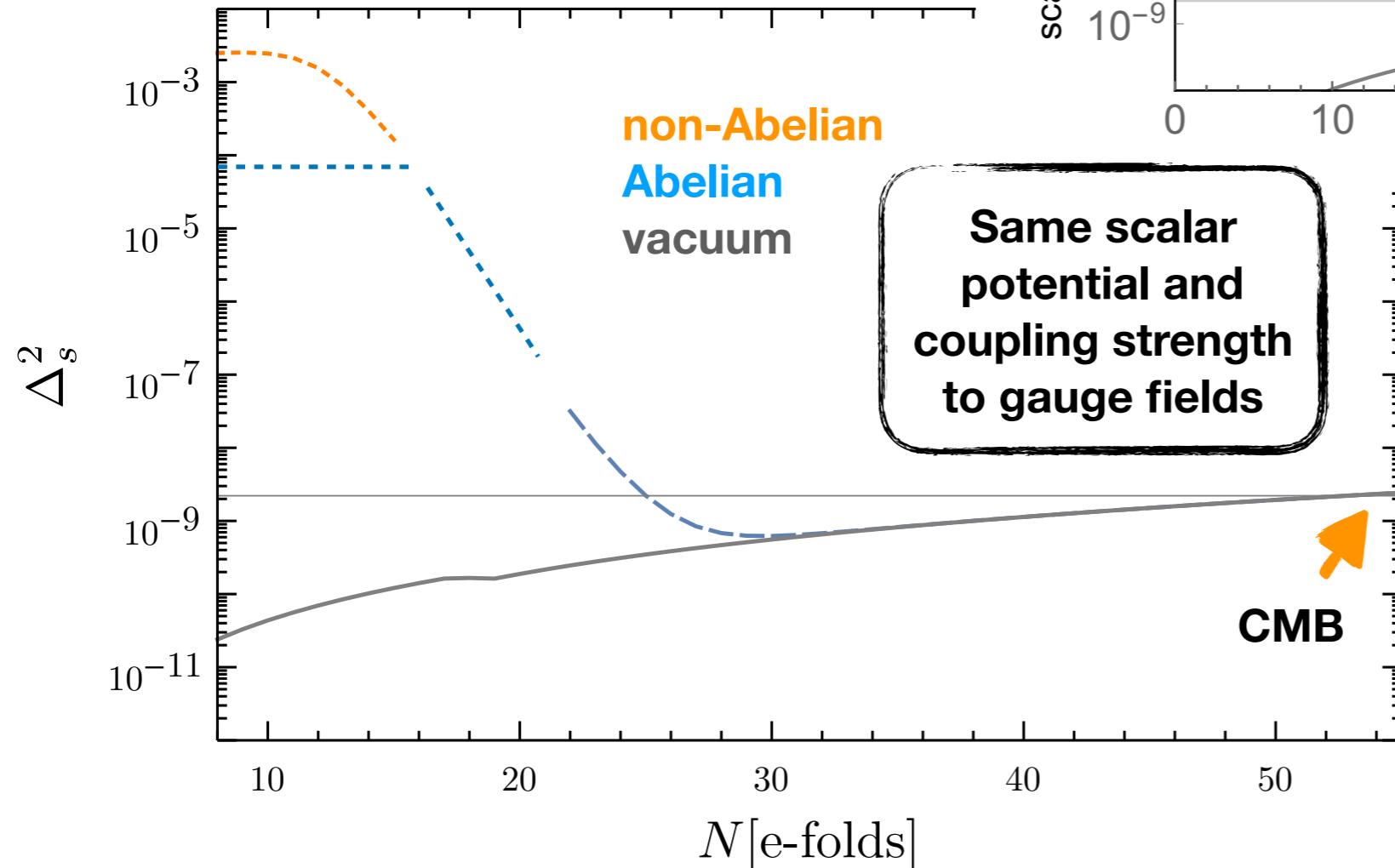
backreaction through induced current modifies gauge boson production



Particle production during inflation

**One example:
Scalar power spectrum
at small scales**

Domcke, Mares, Muia, Pieroni '18

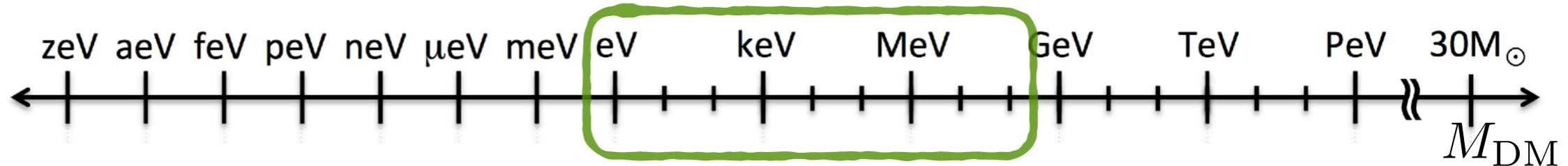


**Different inflaton couplings
can be probed by
observations!**

(PBHs, UCMHs, mu-distortions)

**Similar effects (expected)
in GW spectrum**

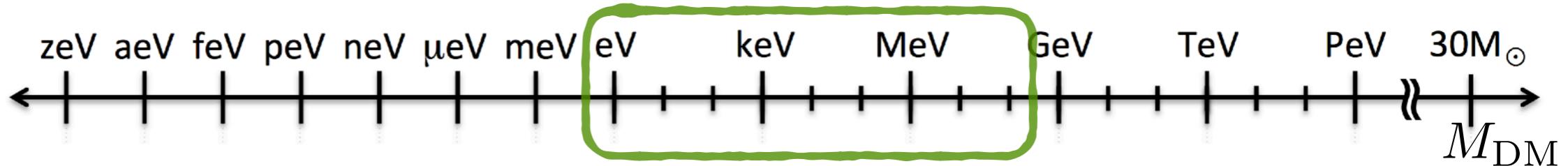
Light Dark Matter at Neutrino Experiments



Experiment $E_{\text{recoil}} \lesssim \text{keV} \longrightarrow$ Standard Detectors not sensitive (Xenon1T,...)

Theory New connections in recent years (w/flav. anomalies, hierarchy problem, ...)

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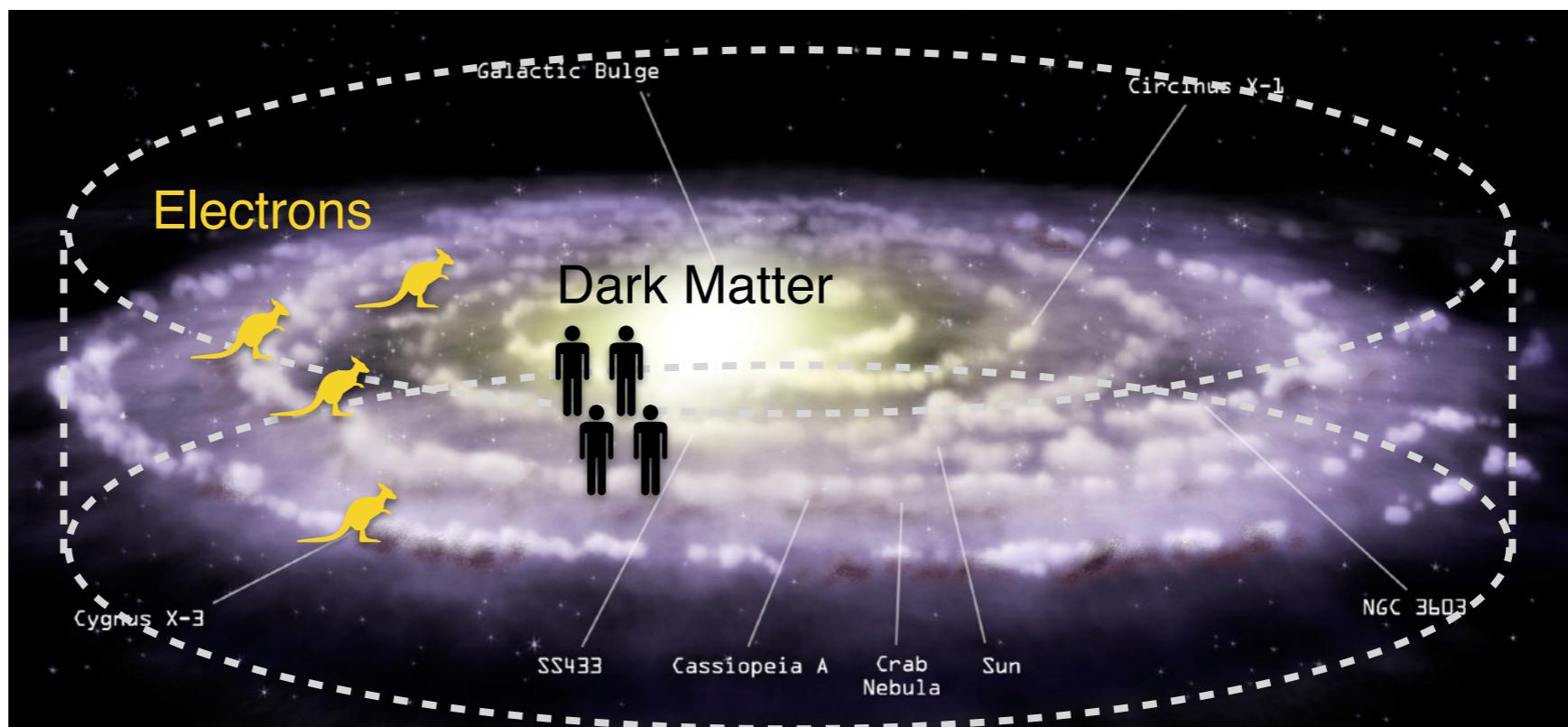


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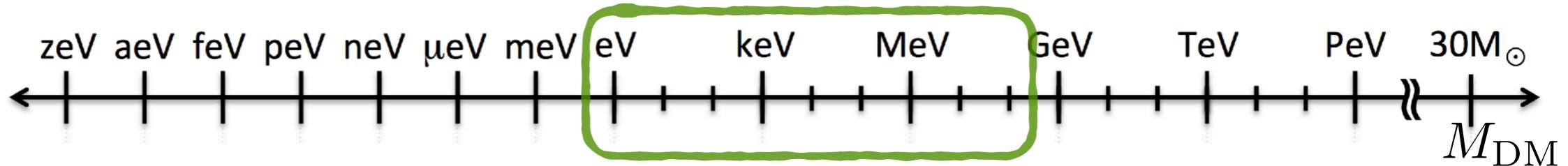
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Ema Sala Sato PRL 122 (2019) no.18:

High-speed DM component unavoidably generated by Cosmic-ray scatterings!



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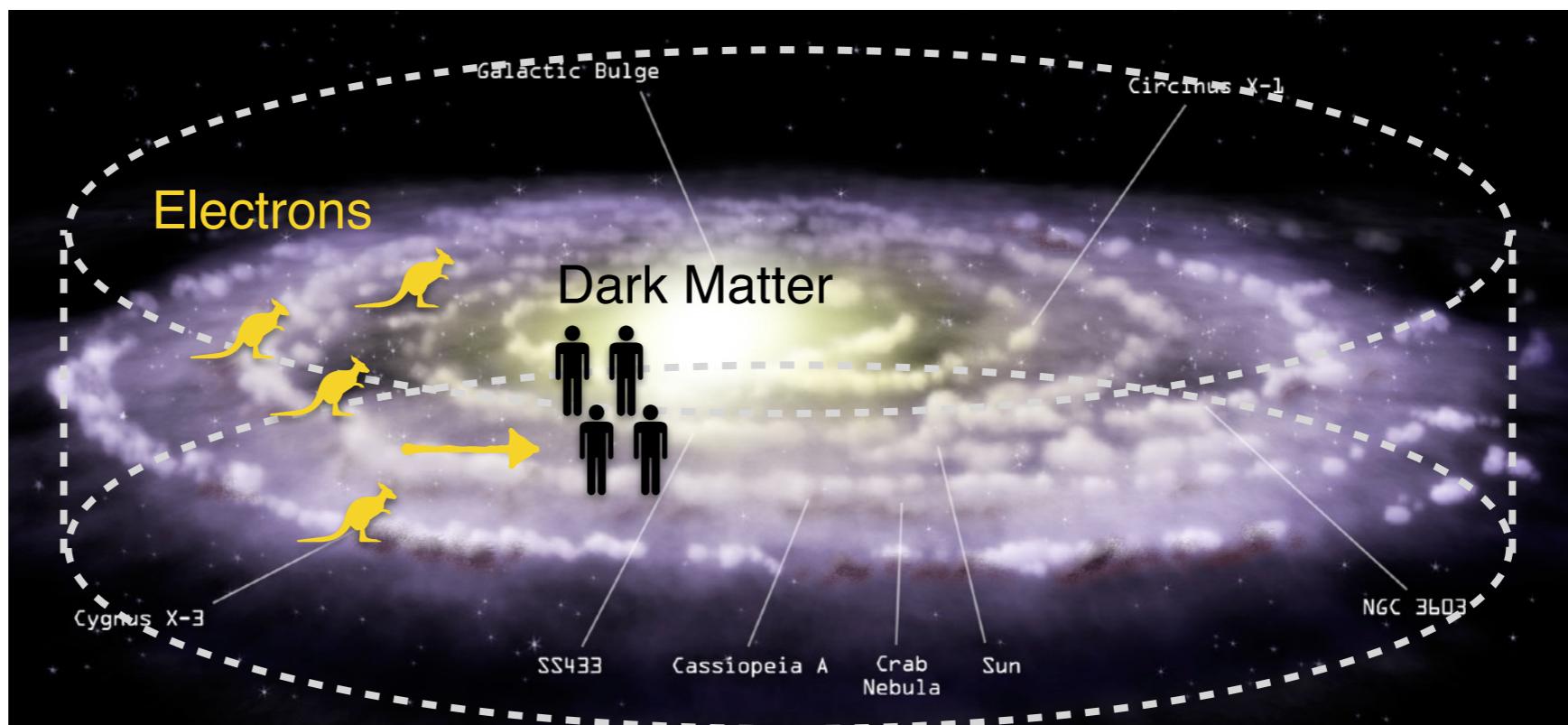


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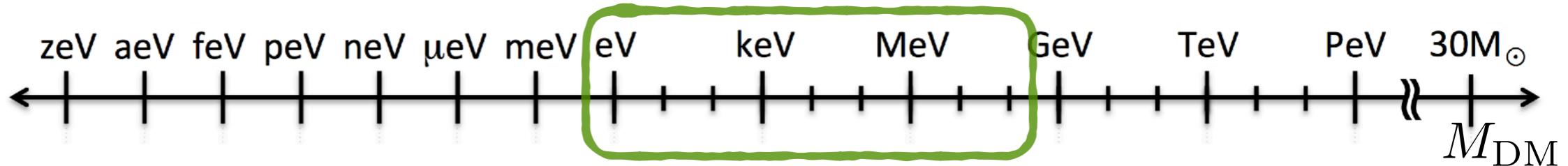
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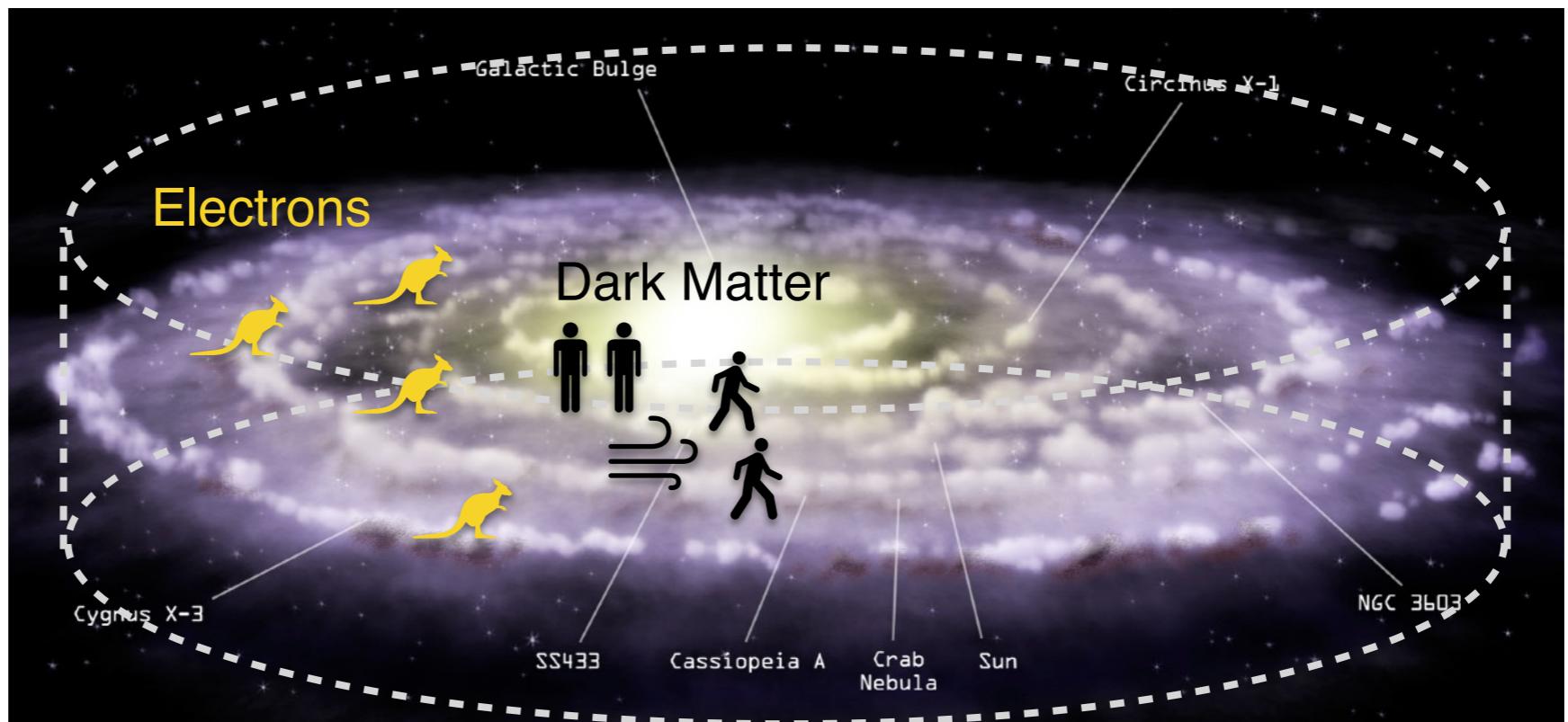


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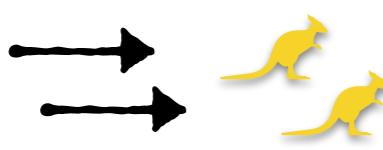
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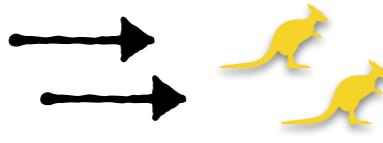


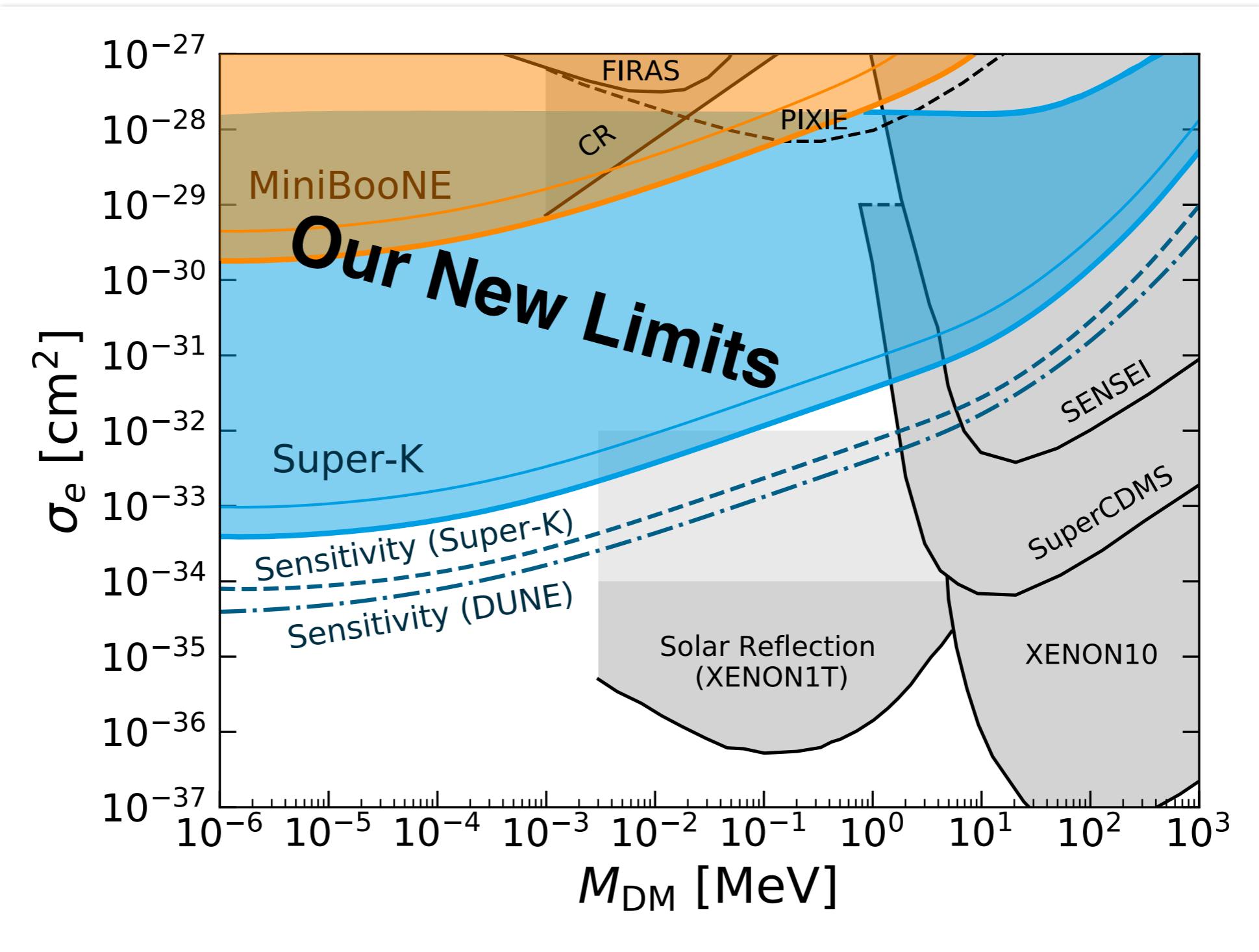
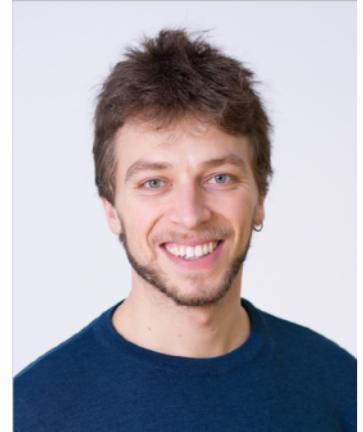
Light Dark Matter at Neutrino Experiments

  Energies > 10 MeV  go to biggest existing detectors!

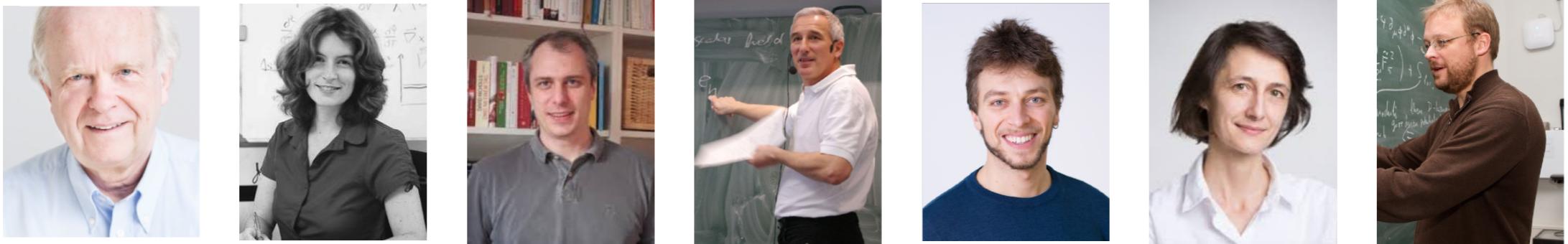


Light Dark Matter at Neutrino Experiments

  Energies > 10 MeV  go to biggest existing detectors!



Cosmo approaches to the Big Picture



We work to understand:

- ★ Dark Matter
- ★ Baryon Asymmetry
- ★ Neutrino Oscillations
- ★ Quantum Gravity
- ★ Inflation
- ★ Dark Energy
- ★ EW symmetry breaking
- ★ Strong CP problem
- ★ Origin of SM flavour
- ★ ...

