Theory programme 2014 – 19

- **Nuclear Structure for Weak and Astrophysical Processes**
  Markus Kortelainen, Jyväskylä
- **QCD and Strongly Interacting Gauge Theory**
  Tuomas Lappi, Jyväskylä
- **Domain Wall Dynamics in Ferromagnets**
  Lasse Laurson, Aalto→Tampere
- **Cosmology of the Early and Late Universe**
  Syksy Räsänen, Helsinki
- **High Energy Phenomenology in the LHC era**
  Aleksi Vuorinen, Helsinki

Euclid

Hannu Kurki-Suonio, Helsinki

New theory projects 2020 – 22 – 25

- **QCD and Strongly Interacting Gauge Theory** (continuation until 2022)
  Tuomas Lappi, Jyväskylä
  - Heavy-ion collisions, partonic structure, thermalization

- **High Energy Phenomenology in the LHC era** (continuation until 2022)
  Aleksi Vuorinen, Helsinki
  - BSM physics, gauge/gravity dualities, dense QCD matter

- **Theoretical cosmology**
  Sami Nurmi, Jyväskylä
  - Quantum origins, inflation, large-scale structure, dark matter,

- **Designer topological matter**
  Teemu Ojanen, Tampere
  - Amorphous topological matter, Weyl semimetals

- *Project leaders chosen from 27 applications*
- *Continue main HIP research areas*

Nature of theory projects

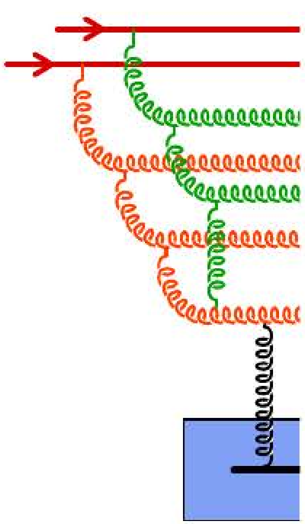
- **Scientific quality**

- **Compatible with HIP and member university research interests**
  - Large community of researchers in BSM, pheno, QCD, cosmology → projects

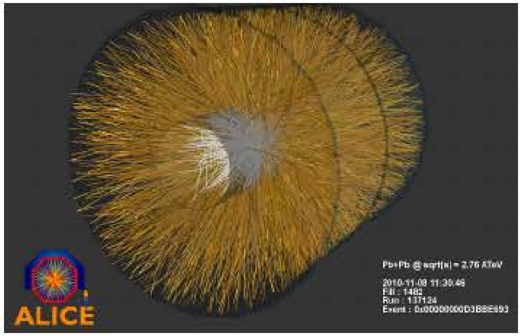
- **Career stage of the researcher** (”junior faculty”)

QCD and strongly interacting gauge theory

Overall unifying factor:
Phenomenology of strong interaction physics at collider experiments



1. Partonic structure of hadrons and nuclei: nuclear PDF's, small-x physics
2. Initial conditions and hydrodynamics for heavy ion collisions



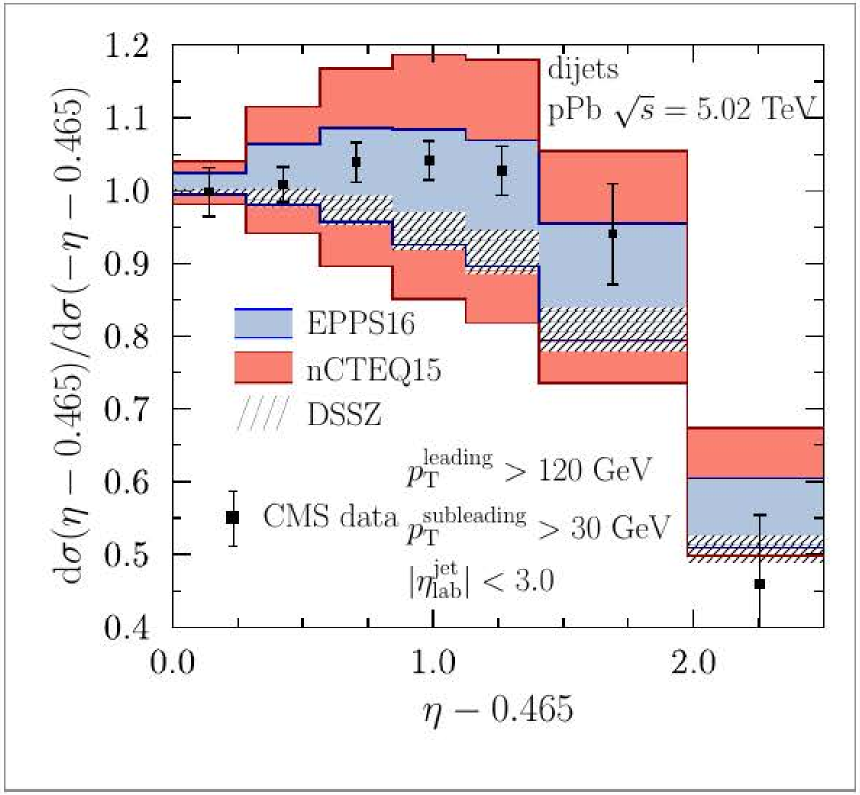
Nuclear parton distributions

Previous Jyväskylä nuclear PDF set EPS09 ∼900 citations.

New release in Dec 2016: EPPS16

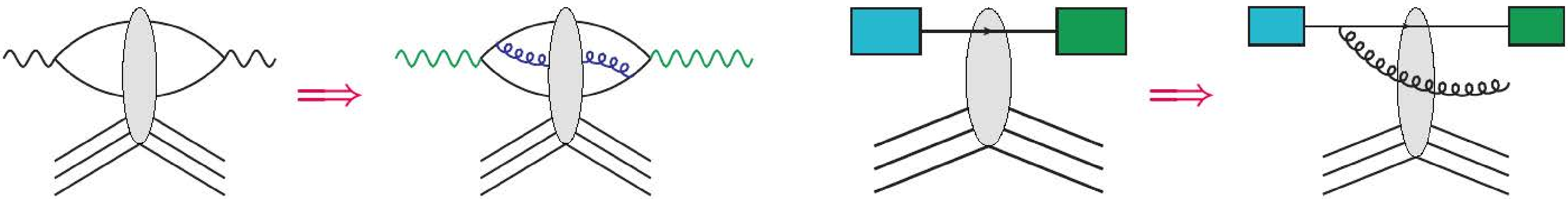
K. J. Eskola, P. Paakkinen, H. Paukkunen and C. A. Salgado, Eur. Phys. J. C **77** (2017) 163

- Current standard nPDF
- First to include LHC data



NLO calculations in CGC

"Dilute-dense" collisions in gluon saturation limit of high energy QCD: moving towards NLO phenomenology



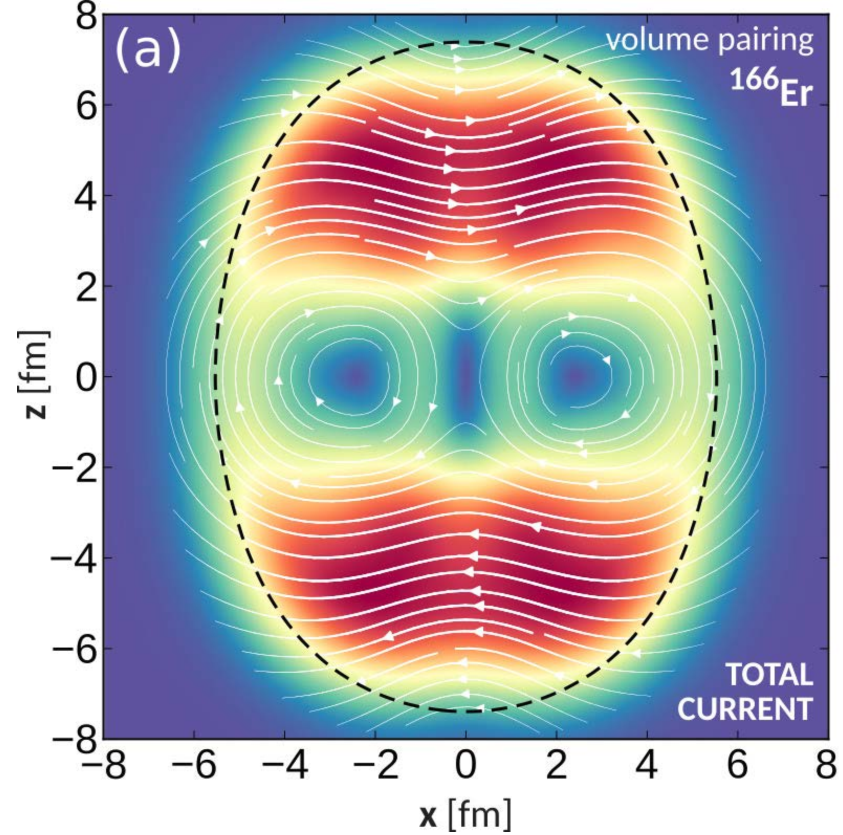
- 1st numerical solution of NLO BK equation: T. L. and H. Mäntysaari, Phys. Rev. D **91** (2015) 074016 ; Phys. Rev. D **93** (2016) 094004
- NLO single inclusive particle production in forward pA: factorization, treatment of running coupling: B. Ducloué, T. L. and Y. Zhu: Phys. Rev. D **93** (2016) 114016; Phys. Rev. D **95** (2017) 114007 ; Phys. Rev. D **97** (2018) 054020 (with E. Iancu et al)
- NLO DIS cross section: B. Ducloué, H. Hänninen, T. L. and Y. Zhu, Phys. Rev. D **96** (2017) 094017; H. Hänninen, T. L. and R. Paatelainen, Annals Phys. **393** (2018) 358

Nuclear structure in weak and astrophysical processes

Nuclear density functional theory, numerical simulations

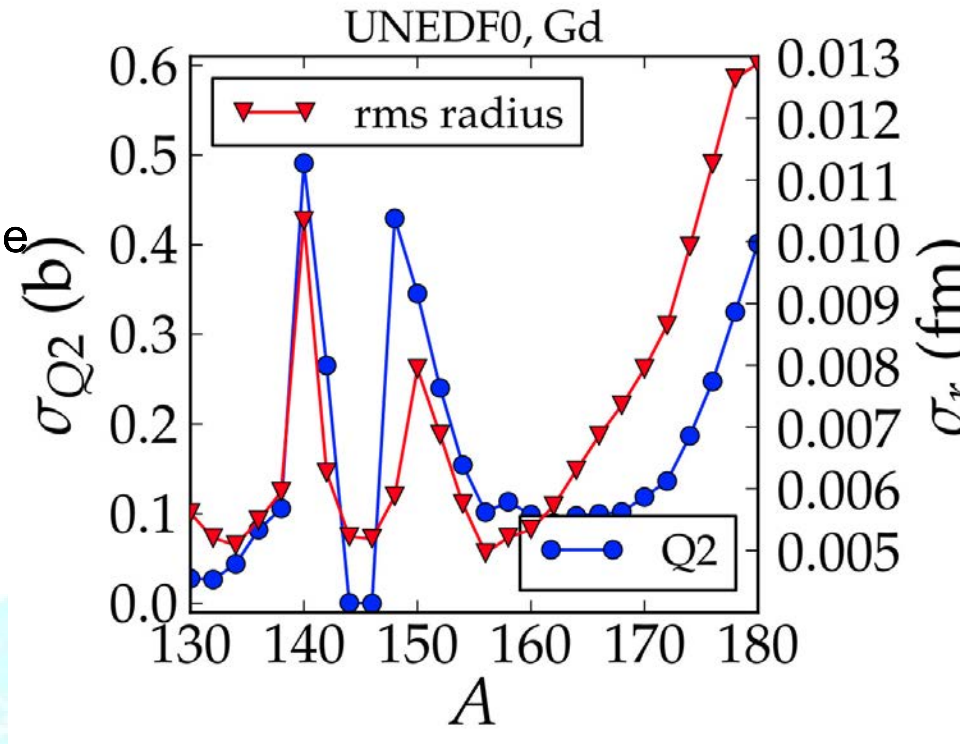
Isospin-symmetry breaking nuclear forces

Thouless-Valatin moment of inertia from linear response theory →
Superfluid flow in ^{166}Er



Correlating nuclear octupole moment and Schiff Moment

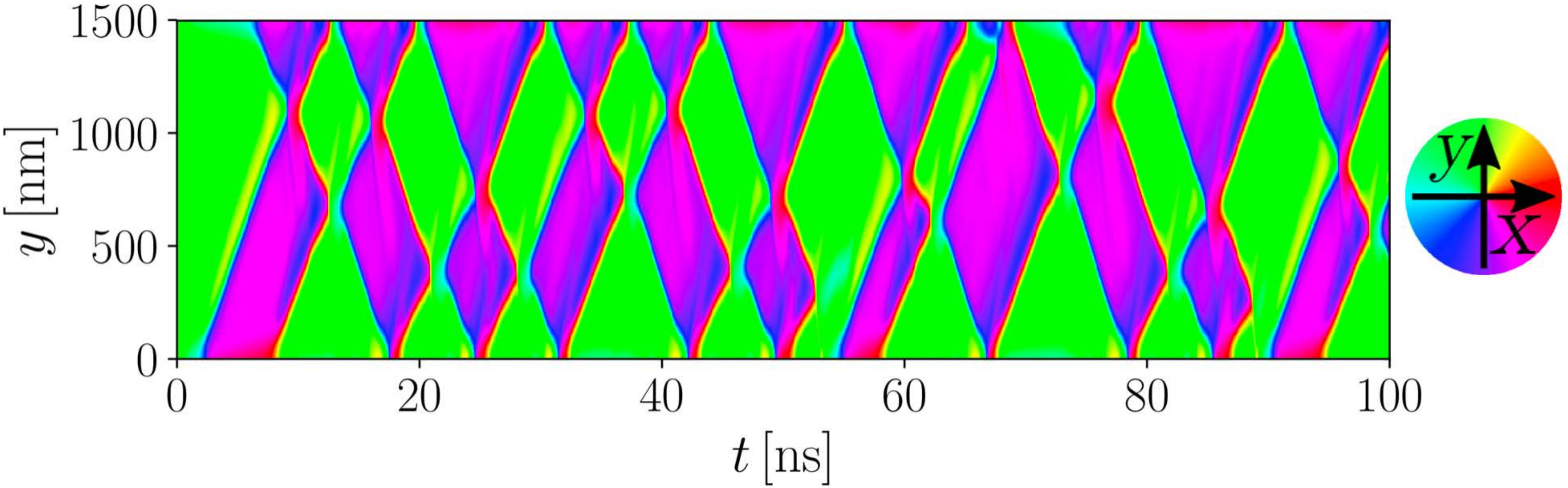
Energy density functional (EDF) method: Proton rms radius and intrinsic quadrupole Moment in Gd isotopes →



Domain wall dynamics (project leader: Lasse Laursen)

- Moving ferromagnetic domain walls in low-dimensional wires and strips

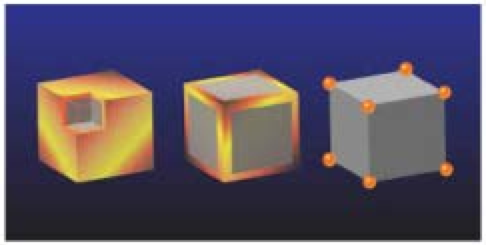
Time evolution of internal domain wall magnetization corresponding to one of the Bloch line excitation modes responsible for the multistep nature of the Walker breakdown for long domain walls.

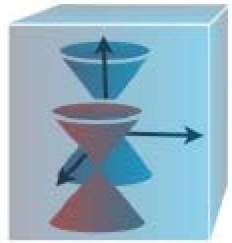


Designer topological matter (Teemu Ojanen, Tampere)

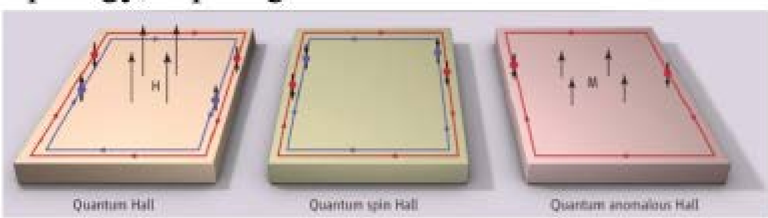
1.Crystalline systems

“Elemental”



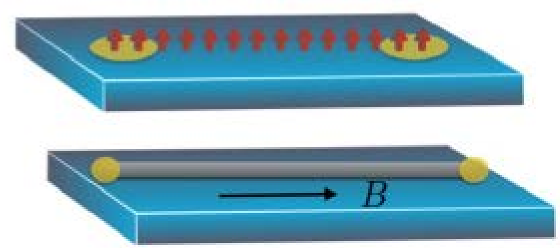


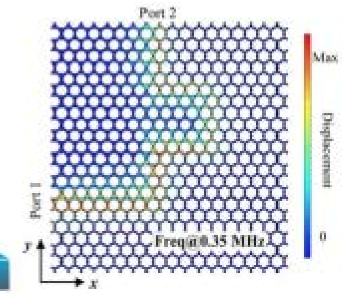
3d topological insulators, crystalline&higher order topology, topological semimetals



2d topological insulators and superconductors

“Man-made”



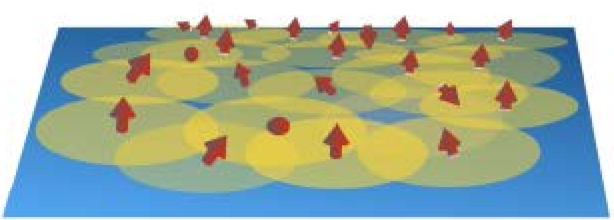


Majorana wires

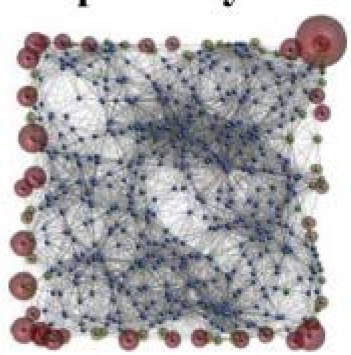
Topological heterostructures

Topological metamaterials: mechanical, optical, electromagnetic, Josephson etc

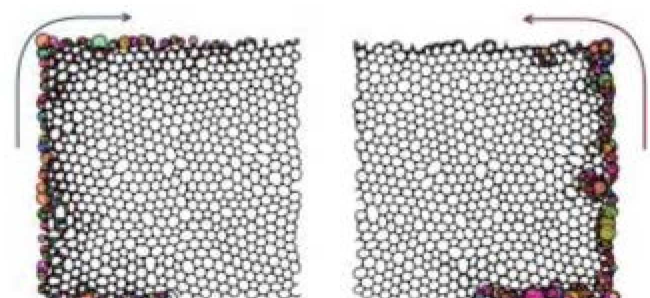
2. Amorphous systems



Amorphous topological superconductivity through random dopants
T.O. et al., Nature Comm. 2018



Amorphous topology and quantized transport
Agarwala&Shenoy, PRL 2017



Amorphous gyroscopic metamaterial
Mitchell et al., Nat. Phys. 2018

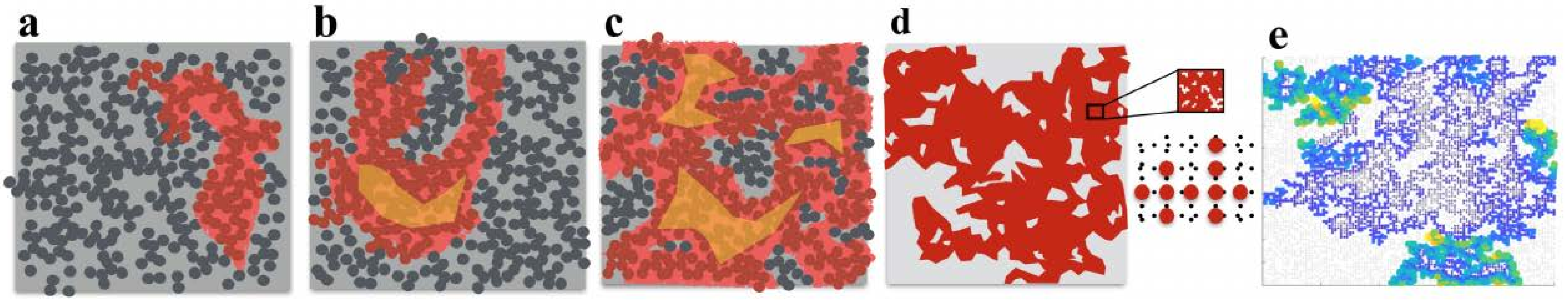


Figure 2: *Topological phase transition in 2d systems with continuous and discrete random geometry.*

High-energy phenomenology (Aleksi Vuorinen)

Prospects for indirect detection of frozen-in dark matter

Matti Heikinheimo,[1,2,*] Tommi Tenkanen,[3,†] and Kimmo Tuominen[1,2,‡]

[1] *Department of Physics, University of Helsinki*
P.O. Box 64, FI-00014, Helsinki, Finland

A cancellation mechanism for dark matter–nucleon interaction

Christian Gross[1], Oleg Lebedev[1], Takashi Toma[2]

[1] *Department of Physics and Helsinki Institute of Physics, Gustaf Hällströmin katu 2, FI-00014 Helsinki, Finland*
[2] *Physik-Department T30d, Technische Universität München, James-Franck-Straße, D-85748 Garching, Germany*

Vacuum Stability and Perturbativity of SU(3) Scalars

Matti Heikinheimo,[a] Kristjan Kannike,[b] Florian Lyonnet,[c] Martti Raidal,[b] Kimm Tuominen,[a] and Hardi Veermäe[b]

[a] *Helsinki Institute of Physics and Department of Physics, University of Helsinki P.O. FI-00014, Helsinki, Finland*
[b] *National Institute of Chemical Physics and Biophysics, Rävala 10, 10143 Tallinn, Eston*
[c] *Department of Physics, Southern Methodist University, 3215 Daniel Ave., Dallas, Texas*
E-mail: matti.heikinheimo@helsinki.fi, kristjan.kannike@cern.ch,

Cool quark matter

Aleksi Kurkela[1] and Aleksi Vuorinen[2]

[1] *Theoretical Physics Department, CERN, Geneva, Switzerland and Faculty of Science and Technology, University of Stavanger, 4036 Stavanger, Norway*
[2] *Department of Physics and Helsinki Institute of Physics,*

Electroweak phase transition and dimensional reduction of the Two-Higgs-Doublet Model

Tyler Gorda,[a] Andreas Helset,[b] Lauri Niemi,[a] Tuomas V.I. Tenkanen[a] and David J. Weir.[a]

[a] *Department of Physics and Helsinki Institute of Physics, P.O. Box 64, FI-00014 University of Helsinki, Finland*
[b] *Niels Bohr International Academy and Discovery Centre, Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen, Denmark*
E-mail: tyler.gorda@helsinki.fi, ahelset@nbi.ku.dk, lauri.b.niemi@helsinki.fi, tuomas.tenkanen@helsinki.fi, david.weir@helsinki.fi

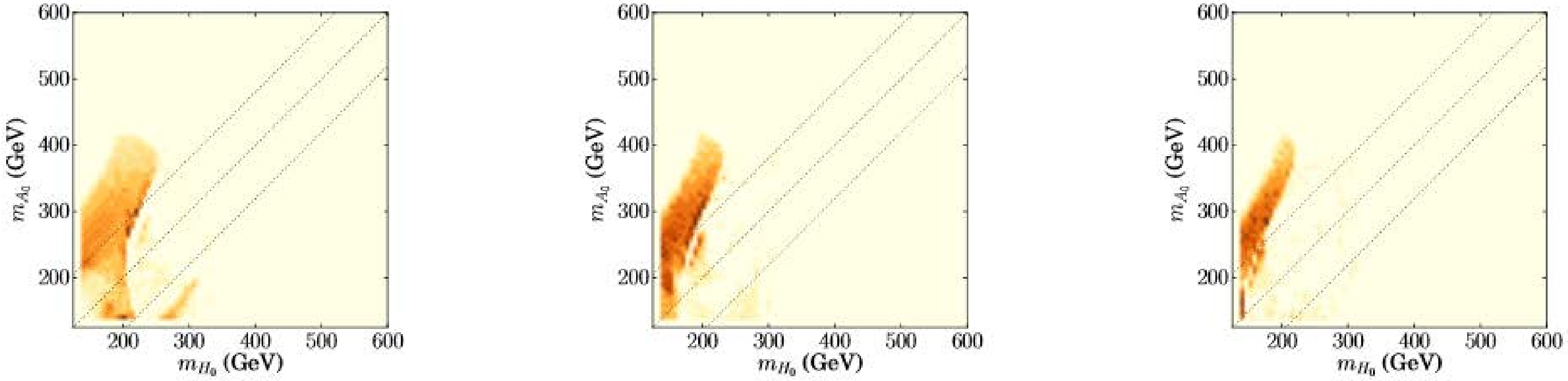
On the validity of perturbative studies of the electroweak phase transition in the Two Higgs Doublet model

Kimmo Kainulainen,[a] Venus Keus,[b] Lauri Niemi,[b] Kari Rummukainen,[b] Tuomas V.I. Tenkanen[c] and Ville Vaskonen[d]

[a] *Department of Physics, University of Jyväskylä, P.O. Box 35, FI-40014 University of Jyväskylä, Finland*
[b] *Department of Physics and Helsinki Institute of Physics, P.O. Box 64, FI-00014 University of Helsinki, Finland*
[c] *Albert Einstein Center for Fundamental Physics, Institute for Theoretical Physics, University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland*
[d] *Physics Department, King's College London, London WC2R 2LS, United Kingdom*

Example 1: EW transition in BSM models

- No signs of new physics at the LHC Complementary cosmol. tests of BSM models increasingly important
- Extended Higgs sector may provide Dark Matter & strengthen EWPT GWs, possibly baryogenesis
- Extensive program: Use dimensional reduction + 3d lattice simulations to study EWPT in BSM models Parameter spaces scanned for promising regions



Brauner, Tenkanen, Tranberg, AV, Weir, 1609.06230, JHEP 1703 (2017)
Andersen, Gorda, Helset, Niemi, Tenkanen, Tranberg, AV, Weir, 1711.09849, PRL 121 (2018)

Dense holographic QCD

Universiteit Utrecht
Järvinen

Chesler
Loeb

Pantelidou

Universidad de Oviedo
Hoyos

Faedo
Mateos

Henriksson
Jokela
Remes
Tarrio
Vuorinen

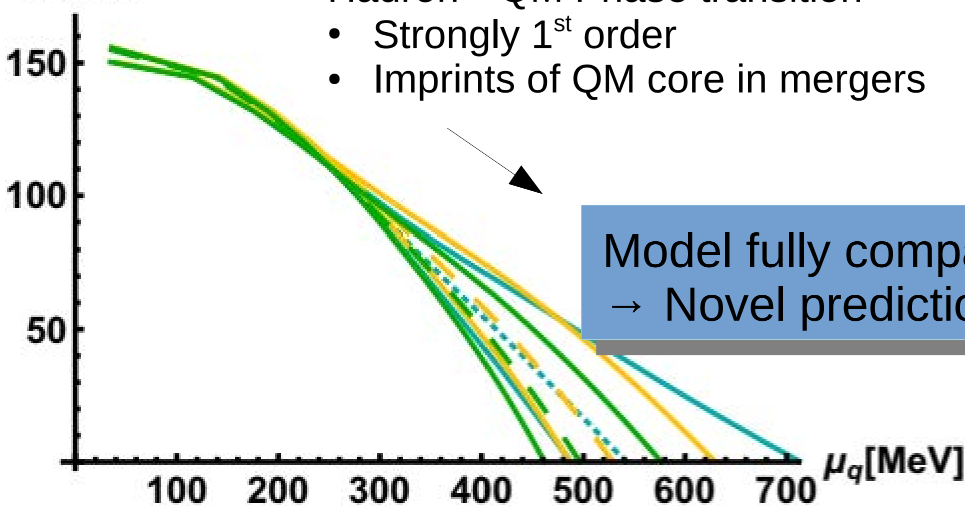
Unpaired quark matter

3-flavor quark matter model

- Captures QCD physics
- Fit to lattice QCD @ μ=0
- Extrapolate to μ≠0

Hadron→QM Phase transition

- Strongly 1st order
- Imprints of QM core in mergers

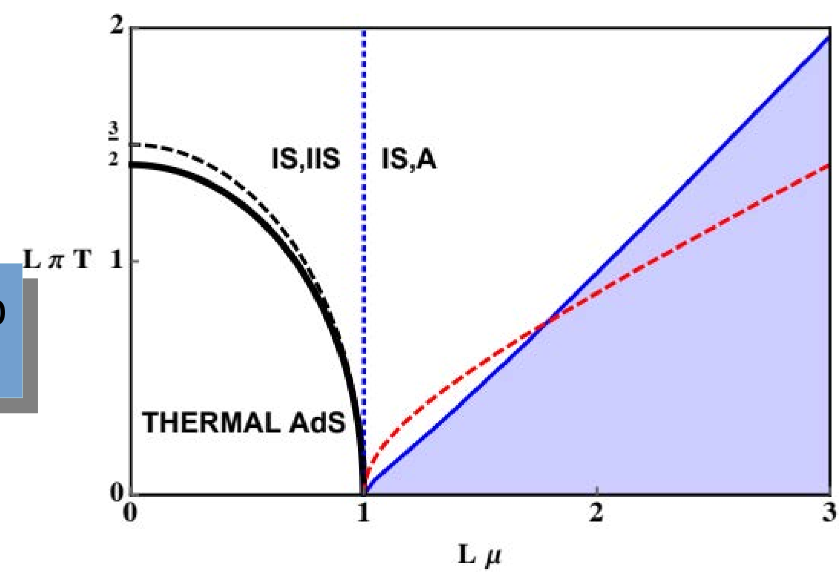


Model fully compatible w/ astro
→ Novel predictions

Color superconducting phases

Novel phase predicted in supersymmetric models at strong coupling

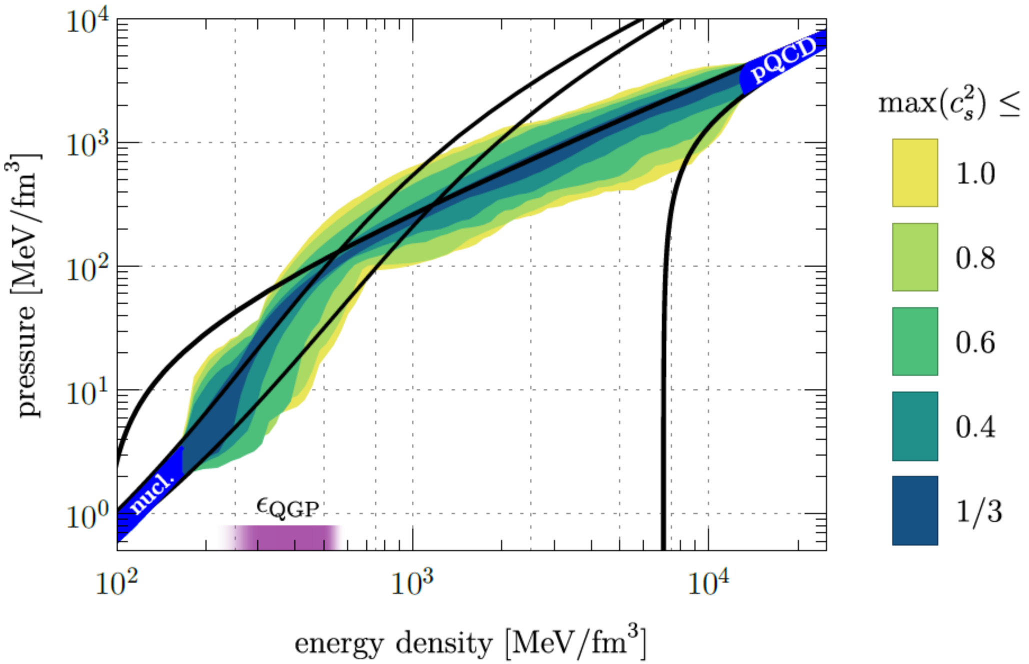
- SU(Nc) → SU(Nc-n)xU(n)
- Gauge invariant treatment
- Compatible with weak coupling expectations

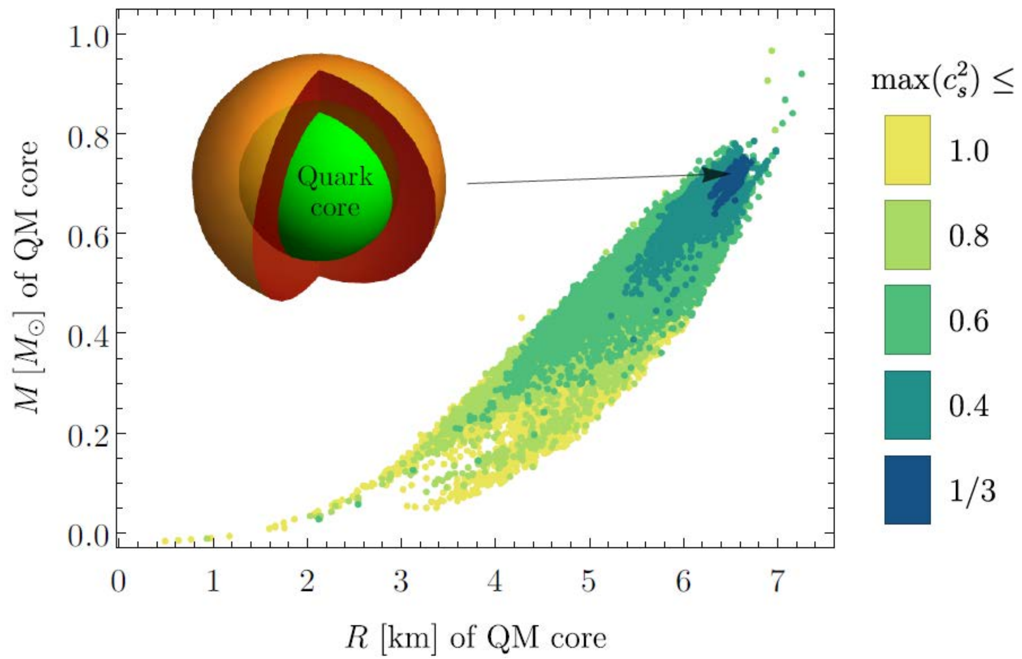


E. Annala, T. Gorda, A. Kurkela, J. Nättilä, **A. Vuorinen**: “Quark-matter cores in neutron stars”, 1903.09121 (under review in Nature Physics)

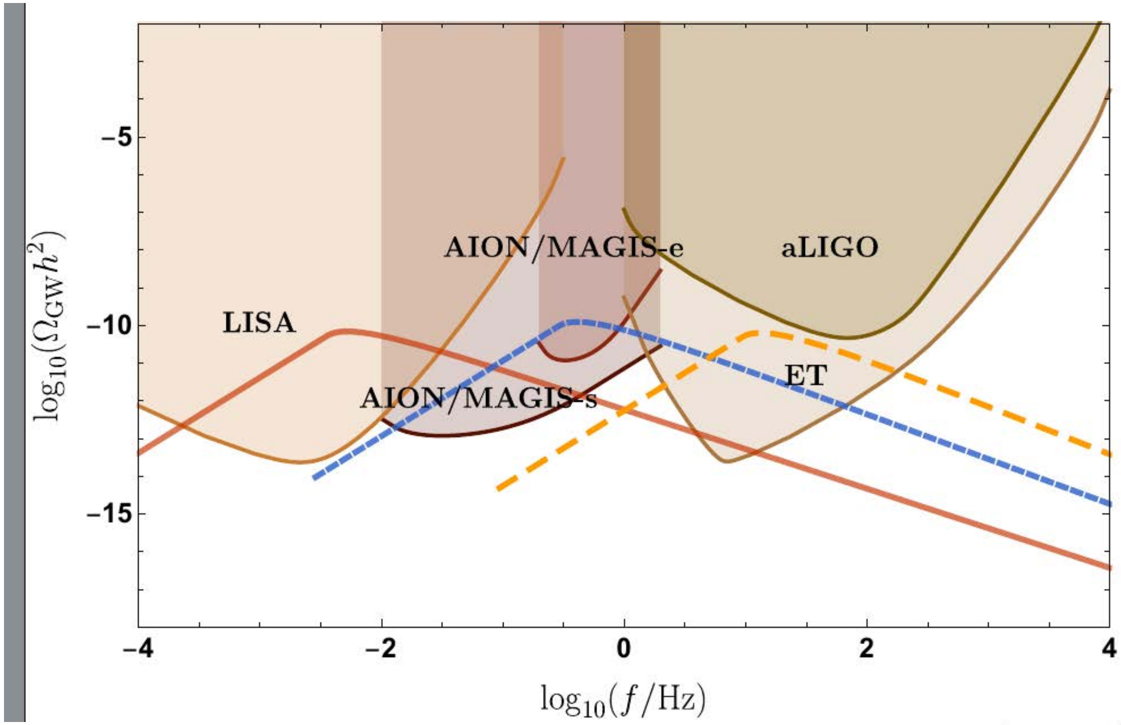
Model-independent constraints for the existence of quark-matter cores inside NSs: presence of deconfined matter inside the most massive stable stars almost inevitable

Observational input from LIGO GW measurements crucial in reaching the conclusion: field in rapid development





Cosmology (leader: Syksy Räsänen, HU)

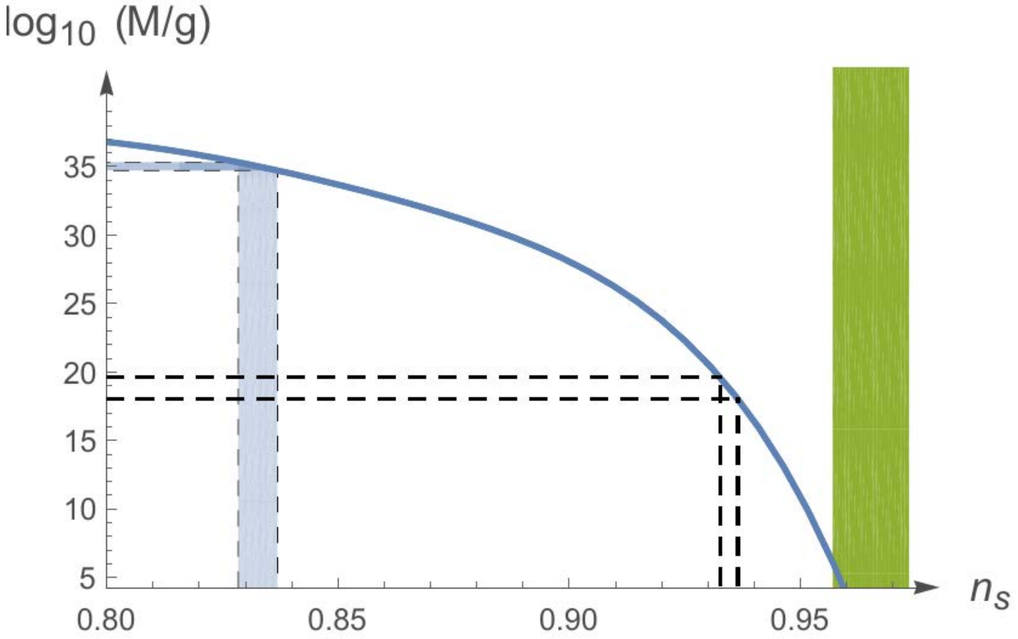


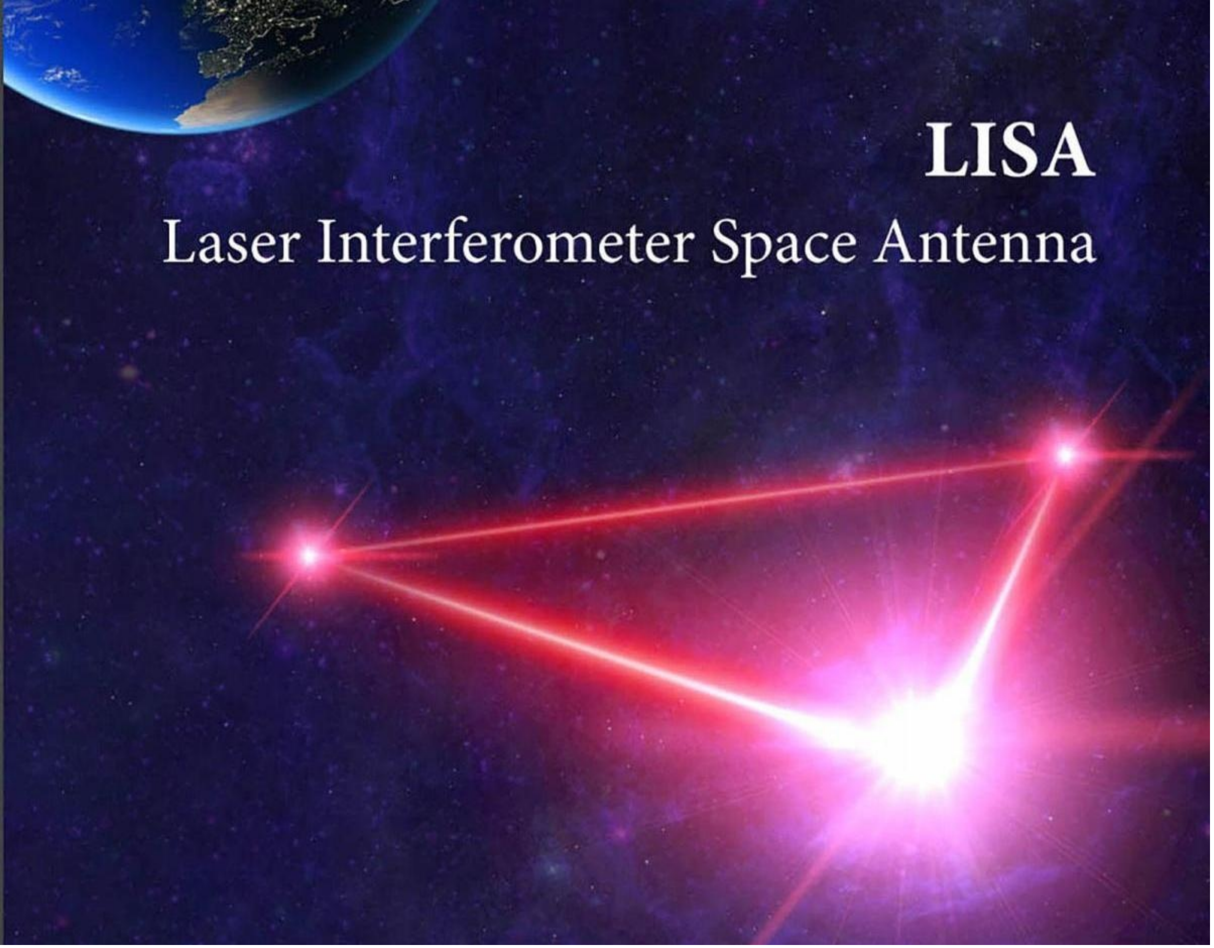
Gravitational waves from cosmic strings generated during quintessential inflation

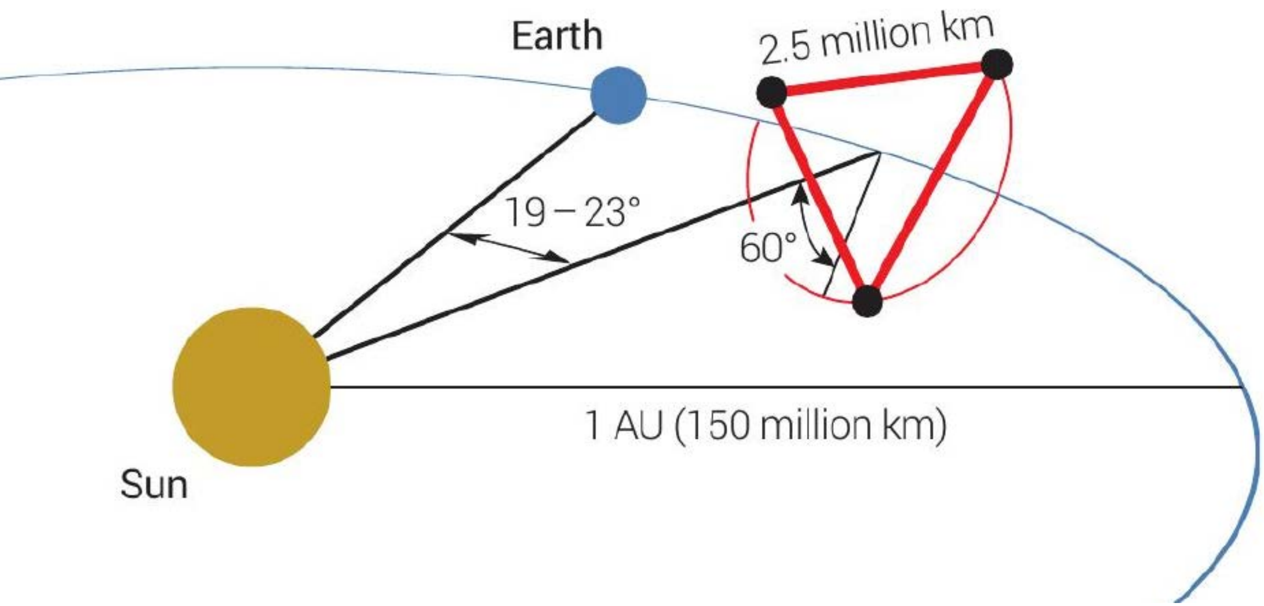
Bettoni et al

CMB spectral index from primordial Black holes created during Higgs inflation

Räsänen and Tomberg







Gravitational wave observatory in space

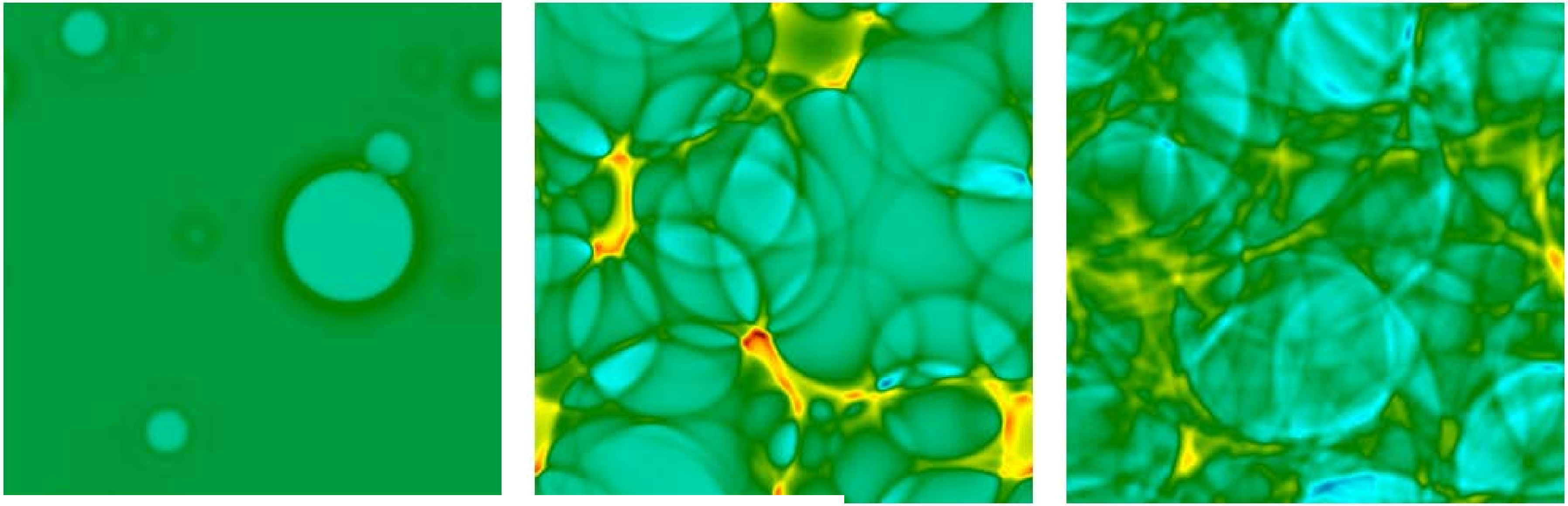
ESA ”L3” science mission
Projected launch 2034

- Astronomy: galactic black holes, compact binaries
- cosmology

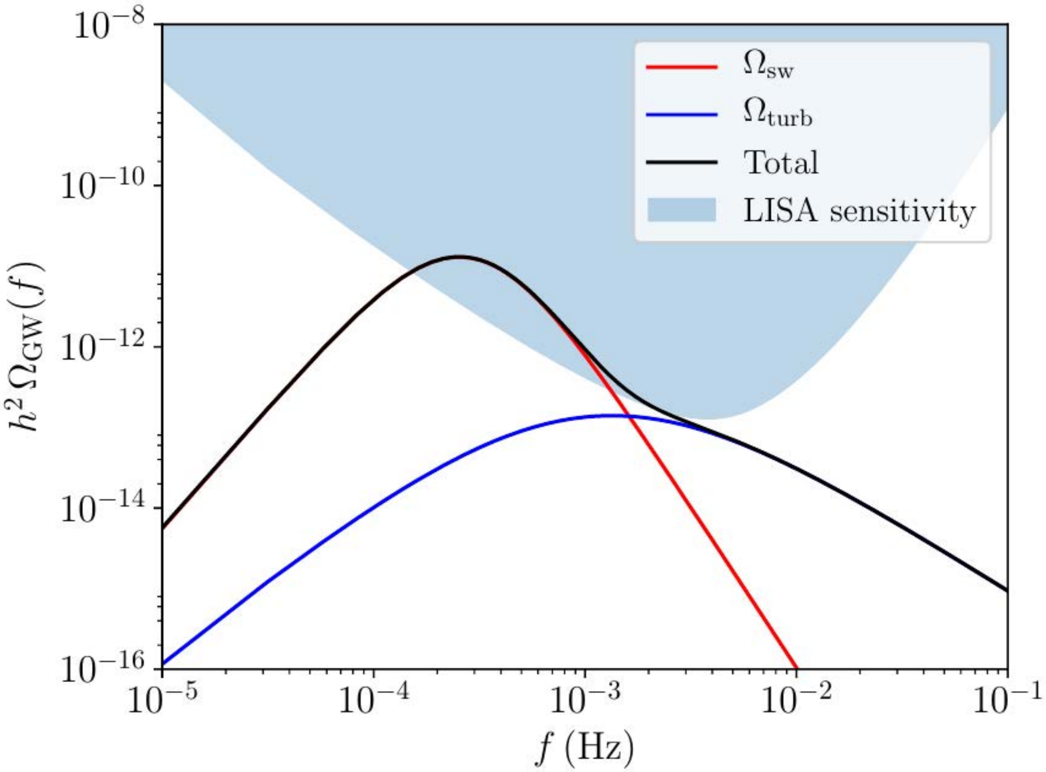
Helsinki has ~ 9 LISA consortium members in cosmology and astrophysics

Helsinki PROFI TT professorship in gravitational waves: David Weir

Gravitational waves through 1st order phase transitions in the early universe?



Hindmarsh et al.

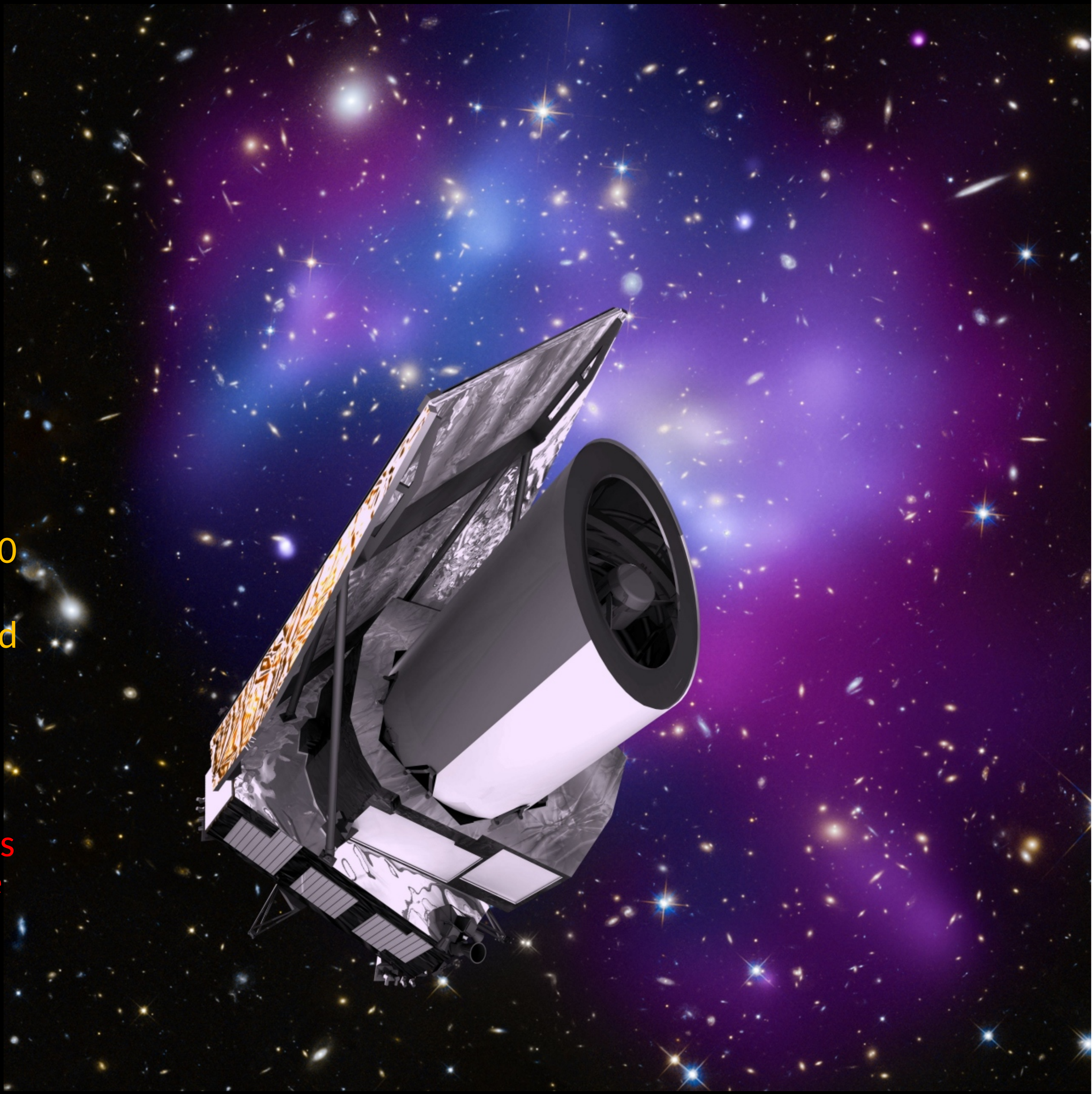


Gravitational wave signal →
Sign of BSM physics!

Euclid

European Space Agency (ESA) cosmology mission

- Wide-field space telescope
- To map 3D distribution of galaxies and dark matter
- (Dark matter from grav. lensing)
- Over 1/3 of sky and the last 10 billion years
- To measure expansion law and growth of structure
- To constrain dark energy and modified gravity
- To help theorists solve the mystery of dark energy: why is the expansion of the universe accelarating
- Launch 2022
- 6 years of observations



Finnish contribution

- Finland is one of the 16 member countries
- Univ. Helsinki, Turku, Jyväskylä, Aalto, (Oulu?)
- HIP, CSC, FINCA
- SDC-FI, one of the 9 Euclid data centers
  - National FIRI infrastructure
  - Located in CSC Kajaani data center
- Agreed data-analysis contributions
  - Euclid data simulation
  - ”Level-3” software: statistical measures of galaxy distribution (2-point and 3-point correlation functions and their power spectra
- 28 consortium members from Finland (16 from Helsinki, 3 from Aalto)
- Participation in Scientific Working Groups on
  - Theory (cosmological and gravity), Cosmology simulations, Weak gravitational lensing, CMB cross correlation, Galaxy clustering, Clusters of galaxies, Supernovae and transient objects, Galaxy/AGN evolution, Local universe, Solar system objects

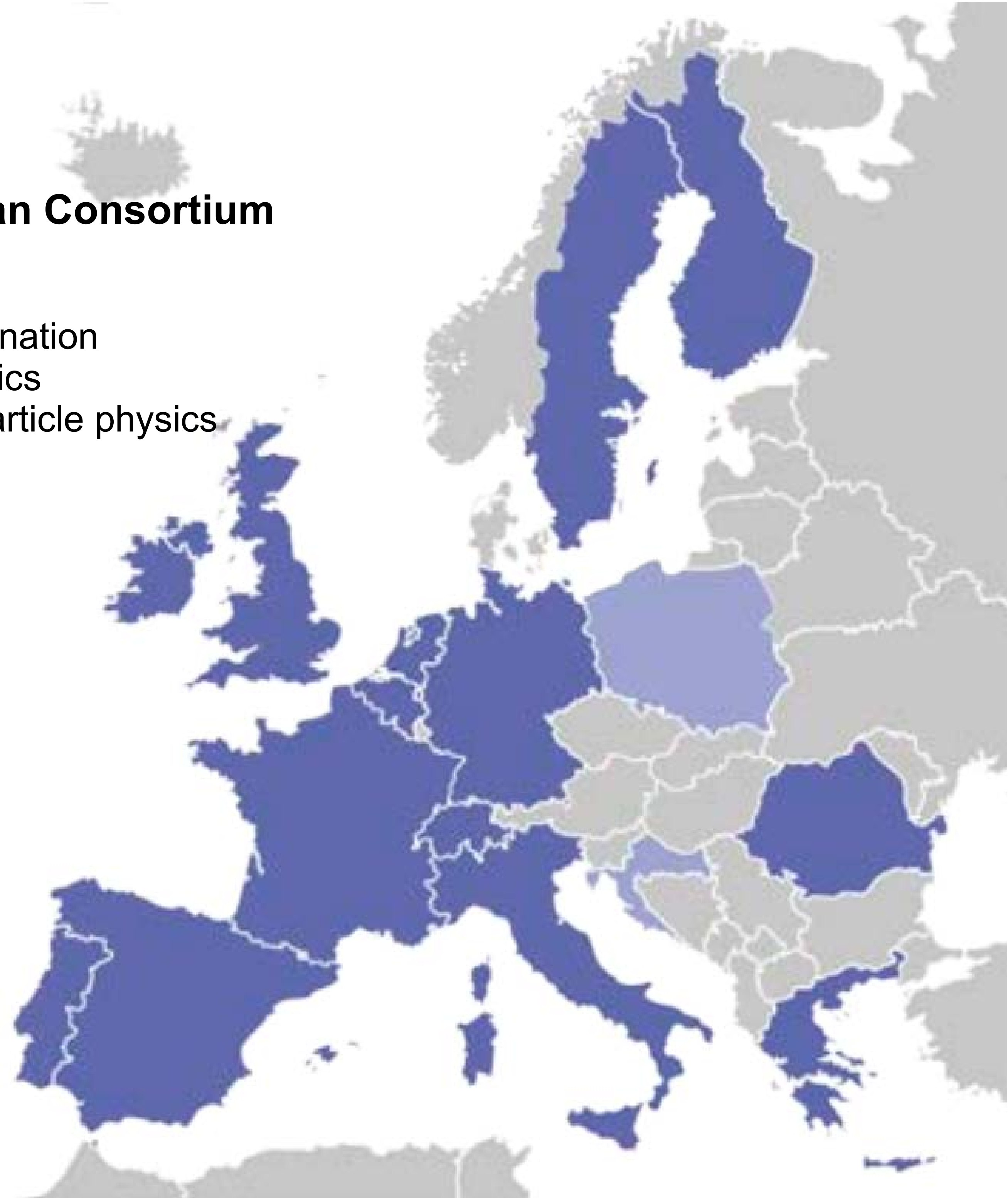
APPEC

AstroParticlePhysics European Consortium

- Discussion forum for the coordination of European Astroparticle Physics
- Roadmap for European astroparticle physics

- Experiments:
  - Gamma rays
  - Cosmic rays
  - Gravitational waves
  - Dark matter
  - Neutrinos

- Astroparticle theory



Extract of the HIP strategy draft for theory:

High-energy physics and cosmology are closely connected, which is particularly reflected in theoretical research. Finland has long traditions in theoretical high-energy physics and cosmology. The links between theory and particle physics experiments are closest in particle physics phenomenology. The research in this area concentrates on BSM phenomenology, both for collider experiments (at LHC or at future collider experiments) and for cosmology (implications of BSM physics scenarios for cosmology). The research in cosmology includes also inflation and structure formation. Particle theory and phenomenology on QCD is studied especially in the context of heavy ion physics.

HIP theory program welcomes proposals connected to the experimental activities of the Institute.