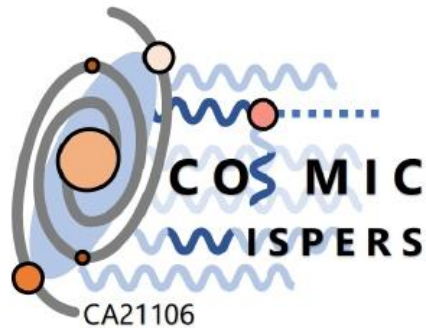


# WG1: WISPs Model Building

Michele Cicoli

Bologna Univ. and INFN

1st General Meeting COSMIC WISPers, 7 Sept 2023



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ALMA MATER STUDIORUM  
UNIVERSITÀ DI BOLOGNA

# WG1: Main goal

## Tasks:

- Coordinate **theory advances** and promote **knowledge exchange**
- Give **theoretical guidance** to experiments
- Determine nature, number, masses and couplings of **WISPs** with applications to particle physics, cosmology and astrophysics via **2** complementary approaches:

1) **Bottom-up**: indication of **WISP** models promising for pheno

UV scenarios compatible with observations



phenomenology in low-energy effective field theory

2) **Top-down**: restrict **WISP** models from UV consistency (string theory)

UV complete model building



UV constraints on WISP properties

# WG1: Organisation

- Leader: Michele Cicoli (Bologna) [michele.cicoli@unibo.it](mailto:michele.cicoli@unibo.it)
- Co-leader: Ilaria Brivio (Bologna) [ilaria.brivio@unibo.it](mailto:ilaria.brivio@unibo.it)

From 18 Sept 2023 Ilaria will be Chair of new COST action COMETA

→ **New** co-leader: Sophie Renner (Glasgow) [sophie.renner@glasgow.ac.uk](mailto:sophie.renner@glasgow.ac.uk)

- Google group “CosmicWISPers WG1”:  
<https://groups.google.com/g/cosmicwispers-wg1/>
- 78 members so far
- mailing list: [cosmicwispers-wg1@googlegroups.com](mailto:cosmicwispers-wg1@googlegroups.com)

# WG1: Activities during year 1

- Contributions to **organisation**:

- i) Kick-off Meeting, 23-24 Feb 2023, Frascati
- ii) 1<sup>st</sup> General Meeting, 5-8 Sep 2023, Bari
- iii) 1<sup>st</sup> Training School, 11-14 Sep 2023, Lecce

→ “Axion theory and production in the early universe”

Lecturer: Kiwoon Choi (IBS, Daejeon), Trainer: Nicole Righi (King’s College, London)

- **Dissemination** talk:

“Ultra-light axions in string cosmology”

Michele Cicoli, String Phenomenology 2023, 3-7 July 2023, IBS, Daejeon

- **Outreach** talk:

“String theory multiverse”

Michele Cicoli, European night of researches 2023, 27 Sep 2023, Bologna

- Monthly WG1 **meetings**:

- i) Online via Zoom

- ii) Mondays at 2pm CET → next one: 16 Oct 2023

- iii) Duration: 1.5 hours: 3 20 minute talks by WG1 members + 30 minute discussion

- iv) Present personal research activity and get to know each other

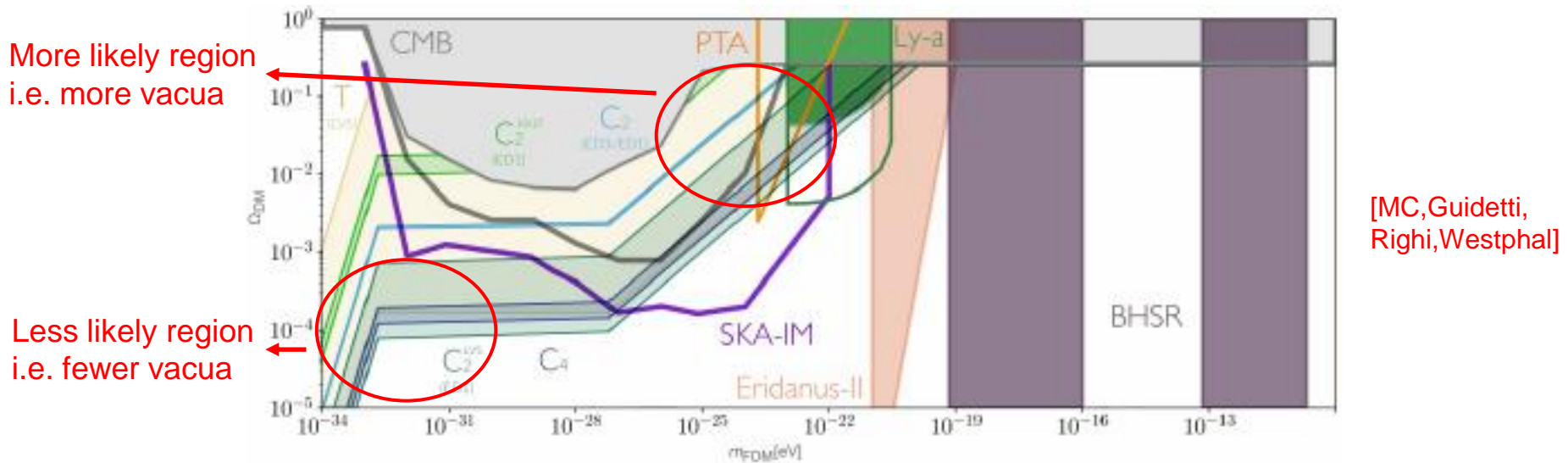
- **STSM**: Matteo Licheri from Bologna to Cambridge

# WG1: Future activities

- Contributions to **organisation** of meetings and training schools
- **Dissemination** talks at major conferences and **outreach** activities
- Monthly WG1 **meetings**:
  - i) Same format for year **2** to finish to get to know each other in WG1
  - ii) From year **3**: topical discussions, invitation of external speakers, recent papers...
- More **STSM**: please apply!
- In year **3**: organise a **3-day WG1 workshop** in person (in Bologna?)  
focused on a specific topic: axions? hidden photons? dark sector physics?
- Deliverables:
  - i) **talks** at major conferences and workshops
  - ii) **publications** on top refereed journals
  - iii) contribution to the writing up of **scientific reports**
  - iv) increase **interactions with other WGs**
    - predictions from UV motivated classes of models superimposed on exclusion plots
- Suggestions!

# Road to UV predictions

- Dream: UV-motivated predictions superimposed on exclusion plots for WG2, 3 and 4
- Is it doable with a **landscape** of 4D solutions from string theory?
  - Yes** but just for classes of motivated models with probability of each point in a band

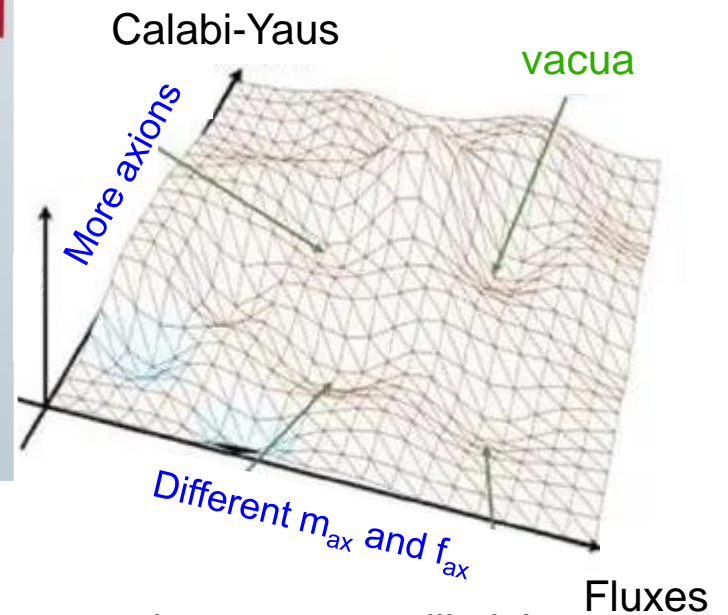
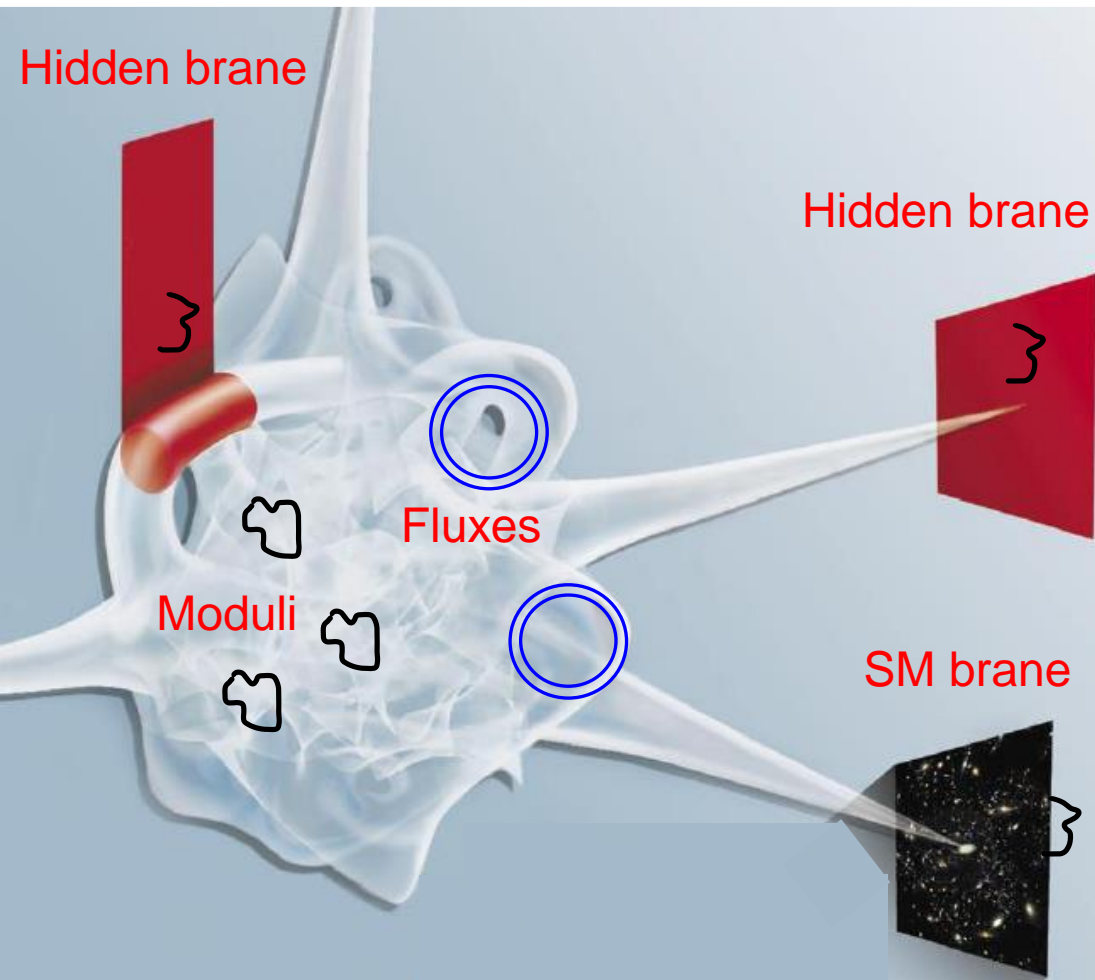


- Better to search for **scenarios** more than models  
**generic** stringy signatures (especially if they are not motivated from **QFT** viewpoint):
  - O(100)** ultra-light **axions** with **gravitational** couplings  
 applications: fuzzy dark matter, dark radiation, stellar cooling, quintessence, early dark energy...
  - Non-standard cosmological histories with **early matter domination** or **kinetic domination**  
 applications: dilution effects on dark matter, baryogenesis, GWs, dark radiation, growth of pert...

# String compactifications

- String theory lives in 10D and needs SUSY for consistency
- Compactification:  $X_{10D} = M_{4D} \times Y_{6D}$
- 4D EFT for  $E \ll M_{KK} = \text{Vol}(Y_{6D})^{-1/6}$
- Geometrical and topological properties of  $Y_{6D}$  determine 4D physics
- N=1 SUSY in 4D if  $Y_{6D}$  is a Calabi-Yau manifold  $\longrightarrow$  chiral theory  $\longrightarrow$  realistic!
- $Y_{6D}$  can be deformed in size and shape
  - i) maths: deformations parametrised by moduli
  - ii) 4D physics: moduli  $\phi$  are new scalar particles with gravitational couplings and axionic partners
- Only 1 free parameter: string length  $\longrightarrow$  all properties of EFT are  $\phi$ -dependent  
 $g_{YM}(\phi), Y_{ijk}(\phi), M_{SUSY}(\phi), m_{ax}(\phi), m_{\phi}(\phi), H_{inf}(\phi), \Lambda(\phi), \dots$
- Need to know  $\phi$  to make predictions
  - $\longrightarrow$  moduli stabilisation: develop  $V(\phi)$  to fix  $\langle\phi\rangle$  at minimum
- $V(\phi)$  sourced by background fluxes = non-zero VEVs of anti-symmetric forms
- 2 choices:
  - i) Calabi-Yau topology gives number of moduli and axions
  - ii) VEV of fluxes determines  $\langle\phi\rangle$   $\longrightarrow$  landscape of string vacua  $\sim 10^{500}$

# 4D string models



Different fluxes can also yield same  $m_{ax}$  and  $f_{ax}$   $\longrightarrow$  some values are more likely!



# Different vacua but common features

- Questions with no answer without UV completion  $\longrightarrow$  need UV physics for consistency
- Vacuum-independent mechanisms:
  - 1: What is the origin of QCD axion shift symmetry? higher dimensional gauge symmetry
  - 2: What dynamics breaks  $U(1)_{PQ}$  spontaneously and sets  $f_a$ ? non-linear realisation in EFT
  - 3: Is  $f_a$  related to some scale  $M_p$ ,  $M_s$ ,  $M_{kk}$ ,  $M_{GUT}$ ,  $M_{soft}$ ?  $M_{kk}$  for bulk and  $M_s$  for local cycles
  - 4: What breaks  $U(1)_{PQ}$  explicitly and sets  $m_a$ ? stringy instantons/gaugino condensation
  - 5: Is  $m_a$  generated by QCD instantons or other effects? QCD instantons if EFT is under control
  - 6: What solves the axion quality problem? perturbative shift symm + control over EFT
- Vacuum-dependent issues:
  - 1: How is the axion produced in the early universe? Misalignment/moduli decay
  - 2: How many ALPs can arise? CY-dependent issue
  - 3: What is the parameter space of  $f_a$  and  $m_a$  for ALPs? determined by fluxes
  - 4: What can be the role of ALPs in phenomenology?  
Inflation? Dark matter? Dark radiation? Quintessence? Astrophysical signals? .....
  - 5: How are ALP  $f_a$  and  $m_a$  statistically distributed in the string landscape?
  - 6: Are there UV correlations among ALP  $f_a$  and  $m_a$  and different physics?  
like supersymmetry breaking, inflation, dark matter, dark radiation, etc...
  - 7: What are the properties of hidden photons with kinetic mixing with ordinary photons?
  - 8: Can we build from string theory fully consistent WISP models?  
instead of just string-inspired scenarios
  - 9: Can we study WISPs in non-perturbative limits? Interesting for pheno?