Towards Simultaneous Global Fits of Particle Physics and Cosmology

Janina Renk
Oskar-Klein Centre, Stockholm University

on behalf of the GAMBIT collaboration
Inflation $\rightarrow$ primordial power spectrum

* scales not realistic
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Big Bang Nucleosynthesis $\rightarrow$ light element abundances

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Decoupling → CMB

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Decoupling $\rightarrow$ CMB

Structure formation $\rightarrow$ BAO scale

$\rightarrow$ gravitational lensing

$\rightarrow$ recession velocities of SNe Ia

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Standard Model of Cosmology

- 68% Dark Energy
- 27% Dark Matter
- 5% "Ordinary" Matter

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Dark Matter?  Dark Energy?
“Ordinary” Matter?

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Galaxies $\rightarrow$ indirect detection

Dark Matter? Dark Energy? "Ordinary" Matter?

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Dark Matter?  \ Cybernetics  \ “Ordinary”  \ Matter?

Ground-based:
  → direct detection
  → particle collider
  → neutrino experiments

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Dark Matter?

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HOW TO TACKLE THIS?

- Tool(s) to compute cosmological predictions/observables
- Tool(s) to compute cosmological likelihoods
- Tool(s) to compute DM relic density abundance & cross-sections
- Tool(s) to compute direct & indirect detection likelihoods
- Tool(s) to compute <prediction> / <likelihood> for ...
HOW TO TACKLE THIS?

- Tool(s) to compute cosmological predictions/observables
  .. for different BSM models

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- Combine all of the above in a consistent way
- Keep track of all models & model-dependent assumptions
- Perform parameter scans with sensible sampling algorithms
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Does something like this exist already?

=> YES, GAMBIT!!
GAMBIT: The Global And Modular BSM Inference Tool

- Extensive model database – not just SUSY
- Extensive observable/data libraries
- Many statistical and scanning options (Bayesian & frequentist)
- Fast LHC likelihood calculator
- Massively parallel
- Fully open-source

Members of:
ATLAS, Belle-II, CLIC, CMS, CTA, Fermi-LAT, DARWIN, IceCube, LHCb, SHiP, XENON

Authors of:
DarkSUSY, DDCalc, Diver, FlexibleSUSY, gamlike, GM2Calc, IsaTols, nulike, PolyChord, Rivet, SoftSUSY, SuperISO, SUSY-AI, WIMPSim

Recent collaborators:
Peter Athron, Csaba Balázs, Ankit Beniwal, Sanjay Bloor, Torsten Bringmann, Andy Buckley, José Elie El Camargo-Molina, Marcin Chrząszcz, Jonathan Cornell, Matthias Danninger, Joakim Edsjö, Ben Farmer, Andrew Fowlie, Tomás E. Gonzalo, Will Handley, Sebastian Hoof, Selim Hotinli, Felix Kahlhoefer, Anders Kvellestad, Julia Harz, Paul Jackson, Farvah Mahmoudi, Greg Martinez, Are Raklev, Janina Renk, Chris Rogan, Roberto Ruiz de Austri, Pat Scott, Patrick Stöcker, Aaron Vincent, Christoph Weniger, Martin White, Yang Zhang

40+ participants in 11 experiments and 14 major theory codes
**FACT SHEET**

**CosmoBit:**
- Inflation: MultiModeCode (*Price*, 14)
- BBN: AlterBBN (*Arbey*, 18)
- Boltzmann solver: CLASS (*Blas*, 11)
  - + exo_class (*Stöcker*, 18) [+ hi_class (*Bellini*, 19)]
- Likelihoods: MontePython (*Brinckmann*, 18)

*all links work! (except this one)*
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DarkBit:
Relic abundance: WIMPs [DarkSUSY (Bringmann+, ’18) micrOMEGAS (Belanger+, ’18)],
  Axions (Hoof+, ’18), your_Lagrangian [GUM (Bloor+, ’20)]
Direct detection: Xenon, LUX, PICO, ...
  [DDCalc (Athron+, ’19)]
Indirect detection: Fermi-LAT data [gamLike (Bringmann+, ’17)]
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**NeutrinoBit:**
- **Oscillations:** NuFit *(Esteban+, `18)*
- **Direct detection:** DELPHI, ATLAS, CMS, NuTeV, ...
- **Indirect searches:** Lepton Flav Violation & Universality, Nu-less double β decay

**SpecBit:**
- **Phase Transitions:** Vevacious++ *(Camargo-Molina+, `13)*

**ScannerBit:**
- **Scanners:** GreAT *(Putze+, `14)*, MultiNest *(Feroz+, `13)*, Polychord *(Handley+, `15)*, T-Walk *(Christen+, `10)*, Diver + PostProcessor *(Martinez+, `17)*

02.09.2019

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EXAMPLE: ALPs

keV-scale Axion-Like Particles

→ Mass range \( 1 \text{ keV} \lesssim m_a \lesssim 1 \text{ MeV} \)

→ Interactions with SM via effective coupling to photons

\[ \mathcal{L} = \frac{g_{a\gamma\gamma}}{4} a F_{\mu\nu} \tilde{F}_{\mu\nu} \]
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- Production via Primakoff process

\[ f \gamma \rightarrow f a \]

- Abundance given by

\[ Y_a = \frac{n_a}{s} \propto g_{a\gamma\gamma}^2 M_{\text{Pl}} (T_R - m_e) \]

- Decay to photons with lifetime

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\( \rightarrow \) ALP is subcomponent of DM

\( \rightarrow \) Agnostic about origin of \( n_a \)

\( \rightarrow \) Model parameters:

\[ \left\{ m_a, g_{a\gamma\gamma}, \xi = \frac{n_a m_a}{\rho_{\text{cdm}}} \right\} \]
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BBN

CMB

Structure formation

Observable signatures

Heat up $\gamma$ w.r.t. $\nu \rightarrow \Delta N_{\text{eff}}$

Spectral distortions

ALP decay time

$t < t_{\text{rec}}$

Galaxies & stars

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$X$- and $\gamma$-rays

Stellar evolution $\rightarrow$ horizontal branch

ALP burst of type II SNe (SN1987A)
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Credit to Patrick Stöcker (RWTH Aachen) for scans & plots

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More about GAMBiT ..

→ Recent results:
  - right-handed neutrinos \( (1908.02302) \) → Tomas Gonzalo‘s talk
  - Axions & ALPs \( (1810.07192) \)
  - EW-MSSM \( (1809.02097) \) → Pat Scott‘s talk
  - Higgs portal DM \( (1808.10465) \) → Ankit Beniwal‘s talk

→ Code publicly available: gambit.hepforge.org

→ Talk to one of us @TeVPA (Peter Athron, Csaba Balazs, Ankit Beniwal, Sanjay Bloor, Torsten Bringmann, Tomas Gonzalo, Andre Scaffidi, Pat Scott, Wei Su, Aaron Vincent, Martin White or me)
CONCLUSION

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Simultaneous Global Fits of Particle Physics and Cosmology!

=> GAMBIT can help!

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Backup Slides
Electromagnetic constraints on ALPs
When will CosmoBit be released?
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