COSMIC "COLLIDERS":

HIGH ENERGY PHYSICS WITH FIRST ORDER PHASE TRANSITIONS

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BIBHUSHAN SHAKYA

FUNDAMENTAL PHYSICS AND GRAVITATIONAL WAVE DETECTORS WORKSHOP

POLLICA PHYSICS CENTRE

DESY.

ABOUT ME

Currently: Junior Staff Scientist
in Theory (Cosmo) group at DESY

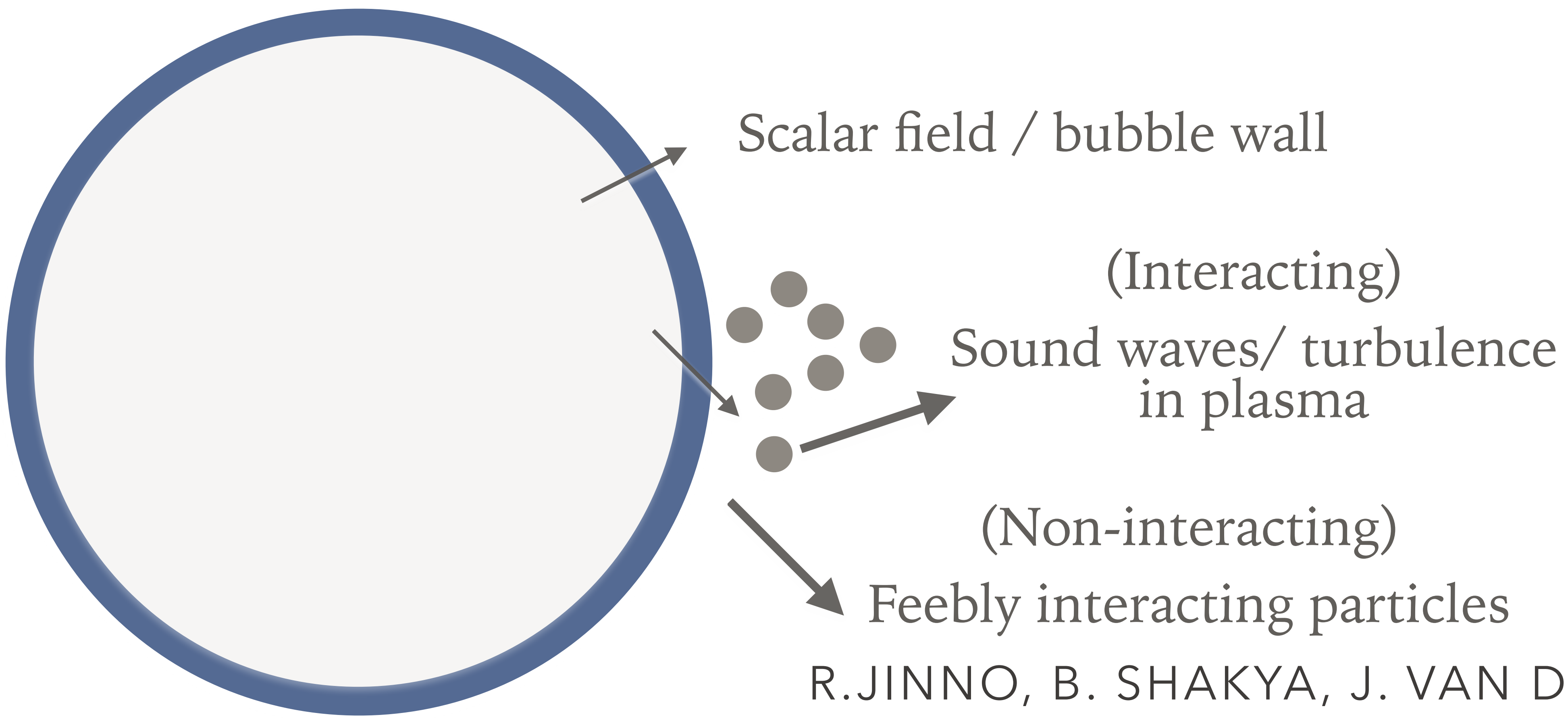
Previously:
Undergraduate @ Stanford University
Ph.D. @ Cornell University
Postdocs at U. Michigan, U.Cincinnati/UC Santa Cruz, CERN

Research Background / Interests:

Broadly high energy phenomenology: dark matter, hidden sectors, connections with neutrinos, Higgs dynamics in the early Universe, gravitational wave phenomena from the early Universe

FIRST ORDER PHASE TRANSITIONS

One of the most promising+widely studied cosmological source of gravitational waves



R.JINNO, B. SHAKYA, J. VAN DE VIS, 2211.06405

In the runaway case, bubble collisions also act as high energy colliders that reach energy scales possibly far higher than any temperature or energy ever reached in our cosmic history

$$E_{\rm wall} = \gamma_{\rm max}/l_{w0} \sim M_{Pl}/(\beta/H)$$

UNDERSTANDING THE PHYSICS OF BUBBLE COLLISIONS

Use the **effective action formalism**:

Watkins+Widrow Nucl.Phys.B 374 (1992)
Konstandin+Servant *1104.4793 [hep-ph]*
Falkowski+No 1211.5615 [hep-ph]

Probability of particle production:

imaginary part of the effective action of the background field

$$\mathcal{P} = 2\,\mathrm{Im}\,(\,\Gamma[\phi\,]\,)$$

……..

Decompose background field excitation into **Fourier modes**

Each mode can be interpreted as **off-shell field quanta with given four-momentum** that can decay

2 point 1PI Green function.

Imaginary part gives **decay probability**

$$\frac{N}{A} = 2\int \frac{dp_z\, d\omega}{(2\pi)^2}\, |\tilde{\phi}(p_z,\omega)|^2\, \mathrm{Im}[\tilde{\Gamma}^{(2)}(\omega^2 - p_z^2)]$$

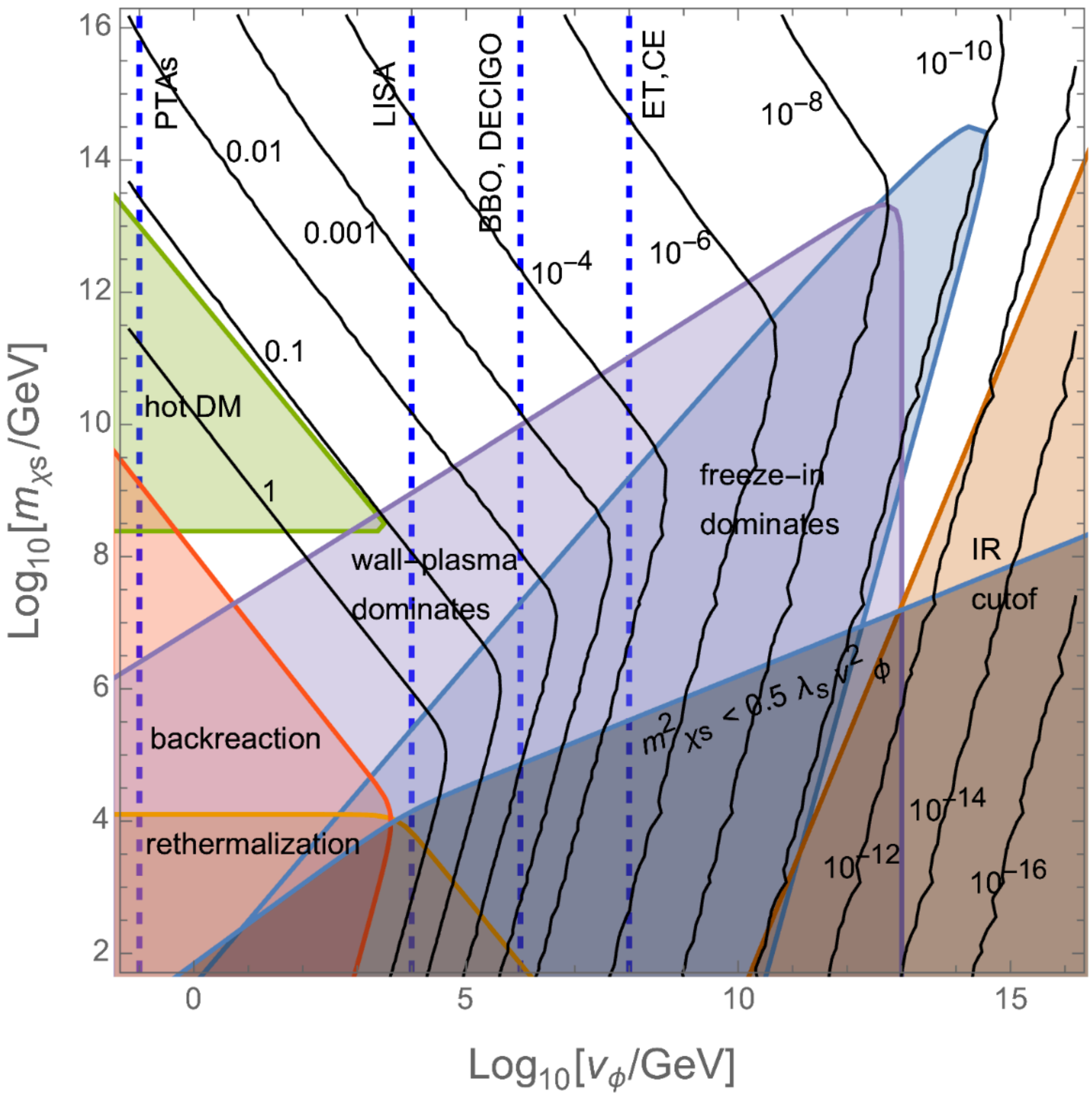
Efficiency **at high p falls as ~1/p^4 power law,** independent of the details of the collision

B. SHAKYA, 2308.16224

H. MANSOUR, B. SHAKYA, 2308.13070

NONTHERMAL DARK MATTER PRODUCTION

G. GIUDICE, H.M.LEE, A.POMAROL, B.SHAKYA, 2403.03252



This plot: scalar dark matter

$$\frac{\lambda_s}{4}\phi^2\chi_s^2$$

Contours:

Size of coupling needed to produce the correct dark matter relic density

Vertical dashed lines:

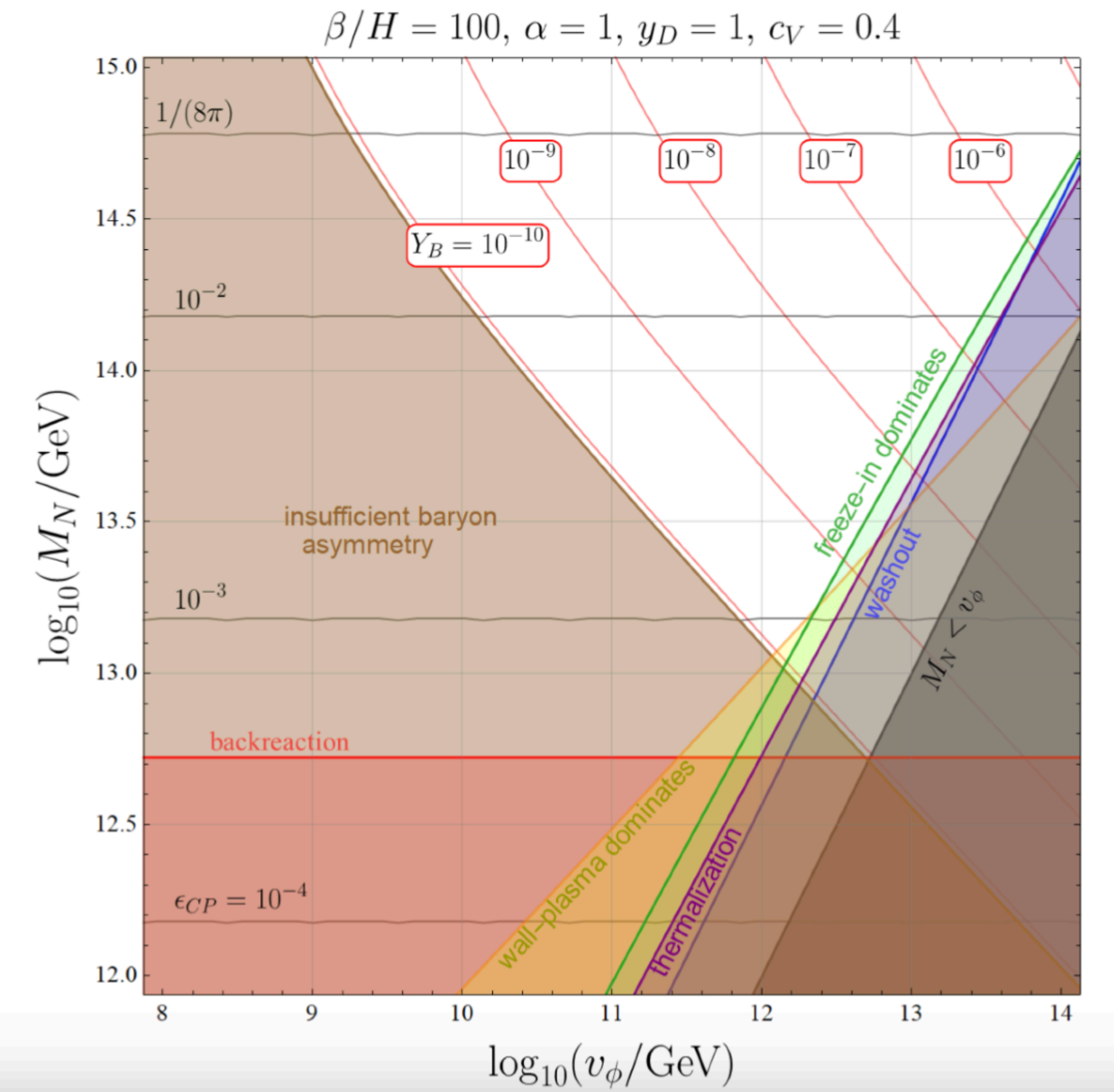
Scale corresponding to peak sensitivity of various GW experiments

LEPTOGENESIS

CATALDI, SHAKYA, 2407.16747

The simplest extension: couple N to FOPT field, mirroring the same interaction

$$\mathcal{L} \supset y_D\,\phi\,\chi\,N + y_\nu\,L\,H\,N + M_N N N$$



Field excitation decays to RHNs

$$\phi^* \to \chi N$$

Inverse "decays" absent/ inefficient: no washout!

Contours:

amount of baryon asymmetry

NEXT STEPS

- Efficient production of (heavy) particles from bubble collisions provide **a new source of gravitation waves**, possibly with distinct features

Work in progress w/ Kentaro Kasai, Marc Kamionkowski, Keisuke Inamoto

- Production of heavy particles in **specific BSM setups**, with **interesting phenomenological consequences**

- **Improvements to the formalism** for calculating particle production from bubble collisions