My Research Programs @ IPM

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Opening remarks

- Research in basic science is a universal and collaborative venture.
- Physics progresses through collective work of many in the course of years.
- It yields a picture, narrative of how our universe works, through a (rigorous) mathematical modeling and development of physical theories.
- There is a division of work among physicist in this endeavor.
- In HEPCo, one can recognize different work: experiment/observation, data analysis, phenomenology, model building and theory.

- Persistence is the key in advancement of science.
- Researchers hence follow specific lines of research.
- Within a given line of research they *devise* **research programs**.
- Research programs in practice are carried out through **research projects**.
- Results of research projects are **reported** through papers written and published in scientific journals as well as in scientific seminars, conferences and workshops.

Plan of the talk

- My Lines of Research in the last 10 years
- My Research Program along the lines of research
- Current and ongoing research projects
- My picture of the field

▶ My Lines of Research in the last 10 years

(I) Black Hole Physics

- Black hole are generic solutions to Einstein GR (and other modified gravity theories).

- The very salient feature of black holes is presence of the horizon that cuts the spacetime into two causally disconnected parts.

- They show peculiar features that are unveiled when one considers other areas of physics, especially thermodynamics and stat. mech. and quantum theory, in presence of black holes.

- Understanding and formulating these peculiar features has been an ongoing line of research of many theoretical physicists in the last 50 years.

- There are also growing number of observations involving black holes, especially in the last decade.

- So, there is a growing research field that studies black hole in conjunction with various observations.

- My field of research is, nonetheless, on more theoretical semi-classical aspects of black holes.

(II) Late Universe Cosmology

- Cosmology concerns reconstructing history of evolution of the Universe.

- Efforts of last 40-50 years have lead to a story-line which is sold as a coherent narrative; it has been dubbed Standard Model of Cosmology.

- Current picture is that ΛCDM model describes cosmic evolution (since after inflation).

- ΛCDM is a remarkably simple model, it has 2 parameters in the background and 4 parameters associated with perturbations/large cosmological structures.

- The 2 background parameters of ΛCDM are H_0 and Ω_m.

- They may be directly measured from low-redshift $z < 0.3$ cosmological data in a cosmological model independent way (using cosmographic expansion of Hubble diagram):

- H_0 is local Hubble expansion rate and Ω_m is related to acceleration of the expansion of the universe.

- They may also be determined through higher redshift cosmological data within ΛCDM model.

- These two ways may lead to different values, cosmological tensions.

- Cosmological observations are advancing very fast.

- Their precision is growing and we expect to receive a good wealth of data in (near) future.

- As we gather more data the resolution of our picture of cosmology also improves.

- Cracks in the Standard Model of Cosmology is the most natural expectation.

- We may need to rewrite the cosmic history.....

(III) Testing Cosmological Principle

- Our current cosmic picture is based on the Cosmological Principle, the assumption that universe at "cosmic scales" is (statistically) homogeneous and isotropic.

- With the cosmological data it is prudent to verify all assumptions, especially the Cosmological Principle, **CP**.

- Necessity of exploring (establishing/refuting) **CP** observationally was on the agenda of cosmologists before 1980s.

- However, there was not enough quality cosmological data until last 10 years to explore **CP**.

- CMB observations starting from mid-1990s prompted upgrading the **CP** to a "principle", and off the main agenda of observational cosmologists and model builders.

- Theoretically inflation and Wald's cosmic no-hair theorem, and of course, simplicity of model building within FLRW setup were instrumental to establish the status of **CP**.

- Nonetheless there are growing observational hints that **CP** can and should be critically scrutinized and tested.

My Research Programs

- My research programs has been focused on exploring specific ideas and viewpoints about the 3 lines of research mentioned above.

- Research programs are developed and pushed within extensive and continued scientific discussions.

- Collaboration, especially international collaboration, is the corner-stone of my scientific programs.

- My scientific programs, while start with certain observational or theoretical questions and motivations, are gradually developed and improved as they are carried out.

(I) Semiclassical aspects of black holes

- My main focus in the last 10 years has been on semiclassical aspects of black holes.

- My central idea has been

  Black hole thermodynamics and information problem are defined and to be addressed within semiclassical gravity setting.

- I think a fully-fledged *Quantum Gravity* (QGr), is not needed.

- Our ideas have been shaped and sharpened in the course of carrying out this program.

- Semiclassical gravity should of course be defined.

- The main feature of black holes is existence of horizons that are boundaries of spacetime as viewed by a good class of observers.

- Therefore, gravity in spacetimes with boundaries is the main theoretical framework one should fully develop in this context.

- This uncovers and formulates boundary degrees of freedom.

- In our picture semiclassical gravity means

  quantized boundary theory with classical bulk.

- I have been pushing this research program along the ideas outlined, with a good team of researchers, in the last 10 years or so.

- This team included/includes

  Daniel Grumiller (TUW) and his team of postdocs and PhD students, especially Celine Zwikel.

  Geoffrey Compere and Glenn Barnich (ULB) and their team of postdocs and students

  Hossein Yavartanoo (BIMSA), Arjun Bagchi and Pujian Mao

  My own students and postdocs at IPM including
  Ali Seraj, Kamal Hajian, Saeedeh Sadeghian, Mohammad Vahidinia, Hamid Afshar, Hamid Safari, Vahid Hosseinzadeh, Erfan Esmaeili, Hamed Adami, Vahid Taghiloo, Ali Parvizi, Ida Rasulian.

- We have, so far and in the last 10 years or so, published over 40 research papers in the related areas with this group.

- A full list of papers may be found on the arXiv and/or Inspire hep databases.

- We have had MANY presentations in various seminars, workshops and conferences around the globe.

- We have published three essays that received honorable mention in Contest of Essays on Gravity.

- Our work has been funded nationally ad well as internationally.

My current research projects on BH physics

- We are now working on several projects related to

  Physics @ Null Boundaries

  with Hamed Adami, Mahdi Golshani (my new PhD student from IASBS), Ali Parvizi (our former postdoc at IPM), Vahid Taghiloo, Mohammad Vahidinia.

- With Aritra Banerjee, Arjun Bagchi, Sudipta Dutta, Daniel Grumiller and Ida Rasulian
  we are pushing few projects on formulating

  Null Strings or Branes

  with the motivation of using them for identifying black hole microstates and addressing information problem.

(II) Cosmological Tensions and their implications

- Along with many others in the last 5-6 years, I have tried to understand cosmological tensions, Planck ΛCDM. H_0 and S_8 tensions, better and what they imply for cosmological models.

- My central idea has been the question

What do tensions tell us about cosmological models, in particular for Planck ΛCDM before jumping onto specific models.

- Through a thorough analysis of various low redshift $z \lesssim 5$ cosmological datasets, we have come to the conclusion that
  - These tensions, in particular, H_0 tension, is most likely physical (not due to systematics or stat. fluke);
  - pressureless matter, specifically Ω_m in Planck ΛCDM, is as questionable as the Dark Energy sector.

- Two of our central ideas have been that
  - consistency of any model requires its parameters, like H_0 and Ω_m, when specified through fitting the model to data, *should remain constant up to errors*;
  - The first step toward resolving a tension is to specify what is the redshift/scale associated with the tension.

- In the last 5-6 years and in developing the ideas outlined above and pushing this research program I have enjoyed collaborating with a good team of researchers, in particular Eoin O. Colgain.

- My other collaborators include

  Anjan A. Sen and his team of postdocs and PhD students, in particular Ruchika.

  Roya Mohayaei (IAP), Misao Sasaki, Chethan Krishnan, Lavinia Heisenberg

  Tao Yang, Lu Yin and Aritra Banerjee

  Mohammad Malekjani (Hamedan), Saeed PourOjaghi

  Maria Dainotti, Dejan Stojkovic

  and many others not name here.

- We have, so far and in the last 5-6 years or so, published over 15 research papers in the related areas with this group.

- A full list of papers may be found on the arXiv and/or Inspire hep databases.

- We have had MANY presentations in various seminars, workshops and conferences around the globe.

- In particular, I was involved in writing SNOWMASS2023 report on Tensions in Cosmology.

- Our work has been funded nationally ad well as internationally.

My ongoing projects on cosmological tensions

- We are now working on several projects related to

  Localizing Cosmological Tensions

  Vetting ΛCDM through Studying evolution of cosmological model parameters

  with Eoin O. Colgain and Ozgur Akarsu, Maria Dainotti, Saeed PourOjaghi, Dejan Stojkovic, Anjan A. Sen, and ....

- In a new publication we have explored the new DESI 2024 data.

(III) Contesting Cosmological Principle

- Various low redshift $z \lesssim 5$ cosmological data have been pointing to possible signatures of anisotropy at cosmological scales.

- Bulk flows (Brent Tully et al, CF4 collaboration) have also been found to extend to $\sim 300 - 400$Mpc ($z \sim 0.1$). What expected to be in the Hubble flow regime less than 10 years ago.

- There are hints for breakdown of homogeneity (Giant Arcs).

- My central questions have been

Exploring cosmological data for evidence for anisotropy;

Formulating beyond FLRW frameworks.

- In the last 5-6 years we have explored the questions above. I have enjoyed collaborating with a good team of researchers.

- My collaborators include

  – Observational side

  Eoin O. Colgain, Roya Mohayaei (IAP), Chethan Krishnan, Tao Yang,

  and many others with whom we wrote an extensive review article, marking all hints and traces of **CP** violation (till August 2022).

  – Theoretical side

  Chethan Krishnan, Ranjini Mondol, Ehsan Ebrahimian, Alireza Allahyari

  we have been developing the Dipole Cosmology framework.

- We have, so far and in the last 5-6 years or so, published 7-8 research papers in the related areas with this group.

- A full list of papers may be found on the arXiv and/or Inspire hep databases.

- We have had MANY presentations in various seminars, workshops and conferences around the globe.

- In particular, I was involved in organizing a workshop in 2021 in APCTP on Cosmology beyond FLRW.

- Our work has been funded nationally ad well as internationally.

My ongoing projects on Cosmology beyond CP

- We are now working on projects developing further different aspects of Dipole Cosmology

- I am leading a team of experts in writing an extensive review article on theoretical aspects of violation of CP.

You are cordially invited to take part in my research programs.

Thank You
For Your Attention