What is the mysterious dark energy that is accelerating our Universe today?

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Republic of South Africa
Province boundary*
Province capital**
*Province boundaries are subject to change under provisions of the South African Constitution.
**The KwaZulu/Natal provincial legislature has not yet chosen its provincial capital.
Press reports indicate that the capital will be either Pietermaritzburg or Ulundi.
Final province capitals are to be determined.
0 100 200 Kilometers
0 100 200 Miles
BOTSWANA
ZIMBABWE
NAMIBIA
MOZAM-BIQUE
SWAZILAND
LESOTHO
NORTHERN TRANSVAAL
NORTH-WEST
GAUTENG
EASTERN TRANSVAAL
ORANGE FREE STATE
KWAZULU / NATAL
NORTHERN CAPE
EASTERN CAPE
WESTERN CAPE
Maun
Bulawayo
Masvingo
Plumtree
Francistown
Ghanzi
Rio Save
Messina
Chicualacuala
Limpopo
Pietersburg
Gaborone
Nylstroom
Chokwe
Lobatse
Rustenburg
Pretoria
Witbank
Nelspruit
Xai-Xai
Mmabatho
Maputo
Johannesburg
Mbabane
Vereeniging
Keetmanshoop
Vryburg
Klerksdorp
Vaal
Standerton
Kroonstad
Golela
Sishen
Bethlehem
Upington
Ladysmith
Ulundi**
Orange
Kimberley
Richards Bay
Bloemfontein
Maseru
Okiep
Pietermaritzburg**
Mafeteng
Durban
De Aar
Kokstad
Port Shepstone
Calvinia
Victoria West
Middelburg
Umtata
South Atlantic Ocean
Vanrhynsdorp
Queenstown
Indian Ocean
Beaufort West
Bisho
Saldanha
East London
Worcester
Cape Town
Port Elizabeth
Mosselbaai
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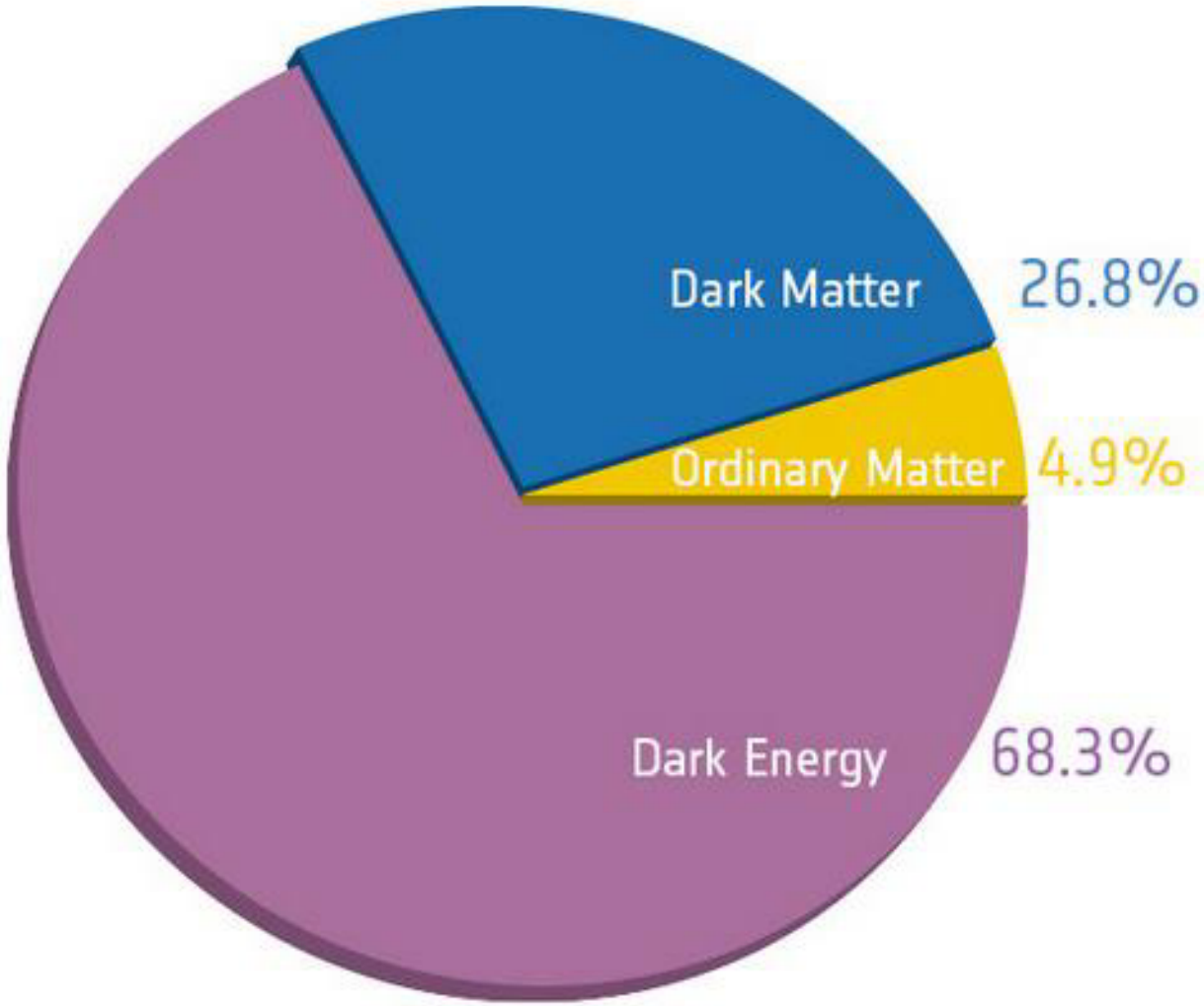
Introduction

This project aims to address the following two questions that were raised in the BRICS Astronomy Framework for Scientific Cooperation 2017-2020 document, viz.,

- "What is the mysterious dark energy that is accelerating our Universe today?
- Is it possible that there is no dark energy, but instead Einsteins theory breaks down on the largest scales?"

A major discovery made in 1998 by two independent teams studying distant supernovae was the accelerated expansion of the universe [1], for which two Nobel prizes have been awarded. This accelerated expansion was later confirmed by several other independent observations.


Dark Matter
26.8%
Ordinary Matter
4.9%
Dark Energy
68.3%

The most widely accepted explanation for this expansion is some mysterious, as yet unknown form of matter, dubbed dark energy (DE). There is no shortage of models for DE, such as [2]:

- ΛCDM model (most popular, $p/\rho = \omega = -1$)
- quintessence ($\omega > -1$)
- phantom DE ($\omega < -1$)
- anthropic principle
- tuning mechanisms (field which cancels Λ)
- holographic principle (choose ρ from a principle)
- quintom DE (time varying ω which crosses -1)
- alternative theories of gravity (do we have right theory of gravity)

One of the questions that this investigation aims to address is the form of this dark energy, if it actually exists.

Anthropic principle - interesting idea.

- Not possible to derive every parameter from first principles, e.g., temperature of earth.
- Other planets have different surface temperatures. why?
- "Natural explanation" - there are intelligent beings on earth who can ask such questions.
- Earth is thus special
- Temp must fit human beings
- This kind of argument called anthropic principle
- Cosmology - different Λ's is different parts of universe
- Existence of humans sensitive to Λ
- We are typical observers, and observed universe is typical in multiverse

DE problem - most important problem in theoretical cosmology today. Despite the fact that the Lambda CDM model fits current astronomical observations well, there are some problems which are difficult to explain, such as:

- the fine tuning problem - Λ is 120 orders of magnitude different from vacuum energy
- the coincidence problem - why is dark energy and dark matter of the same order today
- Despite good agreement with data, some "tensions"
- the initial big-bang singularity
- Einstein's GR needs to be modified on large scales

Questions to be addressed:

- Does any modified gravity theory provide a better explanation and fit in better with the observations?
- Carry out a systematic study of modified gravity theories to see if they could fit the observations better
- Some indications that a dynamic Λ provides a better fit to observations than a constant Lambda [3]. In some theories, a dynamic Λ arises naturally
- Variable equation of state - can it provide framework for all stages of evolution of universe?

It is also possible that there is no dark energy of the kind envisaged above, but that the accelerated expansion of the universe could be explained in other ways, e.g.,

- A very promising idea is that of the universe being filled with an imperfect fluid, which gives rise to accelerated expansion at late times [4]. Can avoid initial singularity, solve entropy problem, mimic Λ, varying EOS
- Inhomogeneous cosmological models can also explain the accelerated expansion without requiring dark energy [5].

We envisage studying these ideas to see if indeed the expansion of the universe can be explained better.

Partners:

- Russia: Professor Sergey Chervon, Ulyanovsk State Pedagogical University, Ulyanovsk, Russia; Prof Igor Fomin, Bauman State Technical University, Moscow, Russia
- India: Professor Rishi Kumar Tiwari, Pt. S.N.S. University, Shahdol, India; Professor Bikash Chandra Paul, North Bengal University, Siliguri, India; Dr Vijay Singh, Delhi, India (currently postdoc)
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- Professor Sunil Maharaj, UKZN, Durban, South Africa

Conclusion

- ΛCDM model has some difficulties
- Solution to Λ problem still open
- Origin of DE not known for sure
- Motivation for different form for DE
- Different approaches
- Use EOS to look for deviations using observations
- Different theory/model which can explain DE, as well as Λ problem, initial singularity, entropy problem, etc
- Better observations will no doubt help narrow the range of possibilities
- No of pages on DE: 4536 (web of science)

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4. G Acquaviva & A Beesham Phys. Rev. D 90 (2014) 023503 Nonlinear bulk viscosity and the stability of accelerated expansion in FRW spacetime.
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