SANT GADGE BABA AMRAVATI UNIVERSITY, AMRAVATI
DEAPRTMENT OF MATHEMATICS

MAJOR RESEARCH PROJECT
[F.No. 41-770/2012 (SR) dated 17/07/2012]

Title of the Research Project : Cosmological Models of the Universe in Theories of Gravitation

University Grants Commission New Delhi sanctioned **Major Research Project** [Rs.10,45,800/- (Rupees : Ten lakh fourty five thousand eight hundred only) entitled as "**Cosmological Models of the Universe in Theories of Gravitation**" vide UGC letter **No. F.41-770/2012 (SR) dated 17/07/2012** to Dr. Kishor S. Adhav for the period 2012-2015 under the scheme of "UGC support for the Major Research Project in Mathematics to University/College Teachers".

Principal Investigator :		**Dr. K. S. Adhav** (Prof & Head , Deaprtment of Mathematics, Sant Gadge Baba Amravati University, Amravati)
Co- Investigator	:	i) **Dr. D. R. K. Reddy** (Ex.Head & Prof., Deaprtment of Applied Mathematics, Andhra University, Visakhapatnam)
		ii) **Dr. S. D. Katore** (Prof , Deaprtment of Mathematics, Sant Gadge Baba Amravati University, Amravati)
Project Fellow	:	**Mr. Samadhan L. Munde** (Research Associate, Deaprtment of Mathematics, Sant Gadge Baba Amravati University, Amravati)

The Major Research Project was started wef 01-07-2012 under the 12th plan guidelines of UGC and completed on 30-06-2015 [extended upto 31-12-2015]. The Major Research Project completely finilised & submitted on 24/06/2016 to University Grants Commission, New Delhi.

The Final Report / Executive Summary of Major Research Project is as follows

Final Report of
Major Research Project
[F. No. 41-770/2012 (SR) dated 17/07/2012]

Title : Cosmological Models of the Universe in Theories of Gravitation.

Submitted by: Dr K S Adhav (Principal Investigator)
Professor and Head
Department of Mathematics
Sant Gadge Baba Amravati University
AMRAVATI (444602)
MAHARASTRA

Final Report of Major Research Project
entitled "Cosmological Models of the Universe in
Theories of Gravitation".

Submitted by:Dr K S Adhav(Principal Investigator)
          Professor and Head
          Department of Mathematics
          Sant Gadge Baba Amravati University
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(I) Introduction
(II) Review of Research and Development in the Subject
(III) Methodology
(IV) Observations and Final Results:

a) Manpower trained
b) Ph. D. Awarded
c) Publication of results
d) Other Impact, if any:

(i) Eleven (11) research students are registered;

(ii)Ten (10) students awarded Ph.D. degree;

(iii)Twenty (20) research papers are published in International Journals ;

(iv)One (01) International Conference ICGR-2015 was organised and
Very Good impact has been developed on research students during
tenure (01/07/2012 to 31/12/2015) of the MRP .

(I) Introduction : Origin of Research Problem: Origin of present problem

lies in the study of mathematical models in cosmology. Cosmology is a separate branch of science which deals with large scale structure of the universe. This universe consists of stars, galaxies, groups of galaxies, milky ways and that which we cannot see with our naked eyes. The main research in cosmology centers round the study of the mathematical models of our universe. This study is important because we live in this universe and hence one would like to know the shape of the universe and the fate of the universe.

In recent years, there has been lot of interest in formulating mathematical models of cosmology and in studying the physical properties of the universe. Several researchers have investigated cosmological models of the universe in Einstein and other new theories of gravitation with the aim of finding / disclosing secretes of the universe. However, the work done so far in this direction is not complete and there is lot of scope to unravel the mysteries of the universe through the construction of mathematical models.

To incorporate certain physical principles which are lacking in Einstein's theory of gravitation , several new theories of gravitation have been formulated by Lyra (1951), Brans-Dicke (1961), Nordtvedt(1970) , Rosen(1973) , Barber(1982) , Saez-Ballester(1985). The subject of investigation of structure formation of the universe through the mathematical models is still an interesting problem in these days.

Even in this modern time, it is still a challenging problem to know the exact physical situation at very early stages of formation of universe. At the very early stage of evolution of universe due to phase transitions and subsequent symmetry breaking, topologically stable defects such as strings, domain walls, monopoles have been found. Construction of mathematical models of universe with above topological defects forms the origin of the main subject of investigation in Einstein's theory and other new theories of gravitation.

Interdisciplinary Relevance: The topic of investigation under consideration has direct relevance to Mathematics, Physics and Astrophysics. To construct mathematical models, symmetries on the space-times like spherical symmetry, plane symmetry and axial or cylindrical symmetry have to be introduced. Using these symmetries, mathematical models can be derived. In this formation of mathematical models non-linear differential equations play a vital role .Mathematical modeling through differential equations is the subject matter of almost relevance to the present day scenario.

The relevance to Physics lies in the study of physical properties like the matter content in the universe , singularities of the universe etc and to decide the shape of the present day universe, the dark matter of the universe and the ultimate fate of the universe. This study has relevance to every human being living in this universe. Since mathematical models without physical relevance will not help to study large scale structure of the universe, one has to go into the physical details of the investigations.

Also, in the present age of fast computers, one can use computer software to perform, even minute calculations, to determine the physical structure like galaxy formation of the universe.

This study has also astrophysical relevance because the cosmic strings, domain walls and monopoles play a vital role in galaxy formation and structure of the universe which forms a part of Astrophysical study.

(II) Review of Research and Development in the Subject :

International Status: In recent years there has been lot of research going on throughout the world in this particular area. Cosmological models with cosmic strings , domain walls and monopoles as sources have been investigated by most of other researchers in the world. Many prominent research workers have investigated about origin , evolution and shape of the universe using general theory of relativity and other alternative theories of gravitation. The most significant amongst them are Lyra (1951) , Brans and Dicke (1961) , Hoyle & Narlikar(1964) , Nordtvedt (1970) , N Rosen (1973) , Kibble (1976) , Stachel (1980) , Barber (1982) , Letelier (1983) , Vilenkin (1983) , Saez and Ballester (1985) and Goetz (1990) etc. , Also, Stephen Hawking is even today continuously engaged in exploring the present day universe. These cosmological models of universe have international status. **The 10-billion dollar " Big Bang" experiment known as "Large Hadron Collider "(LHC) is established to unearth the secrets of cosmos at CERN in Geneva. This experiment will recreate post-Big Bang conditions , which scientists theorize(mathematically) , was the creation of the universe 14 billion years ago. This experiment at CERN , creating a record for the energy of particle conditions , will allow researchers to examine the nature of matter and the origin of stars and planets. The extra energy in Geneva is expected to reveal even more about the unanswered questions of particle physics , such as the existence of antimatter and the search for the Higgs boson , a hypothetical particle that scientists theories gives mass to other objects and creatures in the universe. Thus, the proposed work has international status.**

National Status : Mukharjee (1993) , Karade *et al* (1996,97, 99, 2001,03 , 05,07) , Mohanty *et al*(1997,99,2002,04,06, 08) , Reddy *et al* (1982, 84 , 89, 90,95, 2000,02, 03, 04, 05, 06, 07 , 08, 09) , Khadekar *et al* (1999,2000,01,03,05,07,08) Rahman andMukharjee (2003,05,08) ,Adhav and Karade (1996,97,2000), Adhav and Reddy (2002,04,06,07,08,09) , Adhav *et al* (2004,05,06,07 08,09), Katore *et al* (2002,03,05,07,08) , Mete (2002, 03 ,05 ,07 08) , Ghate (2003,04 05,07), Ugale (2006,07,08) , Nimkar (2005,06,07,08,09) , Rane (2007,08,09,10) have discussed extensively the cosmic strings, domain walls in general relativity and in alternative theories of gravitation. In spite of the fact that there is continuous work being done by all researchers to determine the cosmological models of the universe . still a lot of work is yet to be done in this field.

Significance of the Study: In view of the 10-billion dollar " **Big Bang**" experiment known as **"Large Hadron Collider "(LIIC)** which is established to unearth the secrets of cosmos at **CERN** in **Geneva** , this subject has wide scope for its further research. The scientific and technological benefits will definitely emerge out. It is a matter relating to scientific and technical advancement of knowledge also.

Objectives: The objectives of project "Cosmological Models of the Universe in Theories of Gravitation " are

a) To construct different cosmological models of universe using different theories of gravitation and different combinations of matter.

b) To study physical and kinematical properties of these models of universe.

c) To compare these models of universe with actual universe.

d) To compare our findings [drawn by mathematical calculations] with the actual findings [drawn with the help of Hubble Telescopes].

e) To publish final conclusions/results in international journals.

(III) Methodology: In the present work, we have taken up the construction

of the cosmological [mathematical] models of the universe in the framework of the above new theories of gravitation. It is well known that the structure of the universe is determined by the underlying geometry of the universe. If one works out the field equations of the any one new theory of gravitation for any one relevant space-time , we get ,a set of highly non-linear differential equations. In many cases , the number of

unknowns present in these highly non-linear differential equations is greater than the number of differential equations. In such cases , to obtain a determinate solution , we have to consider /assume one or two physical conditions/ relations between metric potentials . After solving these field equations , we get its solutions . Using these solutions. we have constructed cosmological models of the universe in these theories of gravitation which will help to determine the structure of the universe by studying its physical and kinematical properties.

Year wise Plan of work and targets to be achieved :

First Year : We have appointed ONE PROJECT FELLOW . In the first year of the project work , the team was engaged in the field work / literature collection , acquisition of more relevant books and journals which are necessary for carrying out the project work without hindrance. During first year . most of the literature was collected by team by means of **visiting all relevant research centers through out India.**

Second Year : In the second year of project , the entire team has taken up the study of the specific problems mentioned in the proposed research work. We also studied the various mathematical new techniques and methodologies which will be necessary for successful completion of the proposed research work. The team visited other centers in India to learn these new techniques from the relevant experts in this field.

Third Year : In the third year . the project team has been exposed to the core problems in the proposed research work and was busy throughout the year in obtaining the desired results and establishing the relevance to the physical problems. Also the entire team was concentrating on the piling up the results and writing them out to publish in the standard national and international journals of repute. Team has attended and participated in relevant Seminars / Conferences / Workshops to project their findings during project work in a systematic way.

Details of collaboration, if any, intended : We have collaborated with local

research workers at the Government Vidarbha Institute of Science and Humanities , Amravati .

We also worked with the researchers at

(a)Government Institute of Science , NAGPUR .

(b) Department of Mathematics, S R T M Nagpur University, NAGPUR.

(c) Department of Applied Mathematics, Andhra University, WALTAIR (VISAKAPATTANAM) A.P.

We have visited some of the research centers in India like

(a) Harish Chandra Research Institute , ALLAHABAD

(b) IUCAA , Pune University, PUNE

(c) Einstein Foundation International , NAGPUR

(d)Bhabha Atomic Research Center, Trombay, MUMBAI

(e)Institute of Physics, BHUVANESHWAR

(f)Institute of Mathematical Sciences, CHENNAI

(g)Tata Institute of Fundamental Research, MUMBAI

(h)Jawaharlal Nehru Center for Advanced Scientific Research, BANGLORE

(i)Physical Research Laboratory , AHAMADABAD

(j)Space Physics Laboratory ,THIRUANANTPURAM

(k)Indian Institute of Astrophysics, BANGLORE

And other such advanced research centers in India.

(IV) Observations and Final Results:

a) Manpower trained : The following research students were enrolled for Ph.D. work.

Sr.No.	Name of student	Title of Ph.D. Topic	Registered on date
1	Ku. M. S. Desale	Study of higher dimensional cosmological models in creation field cosmology	15-07-2010
2	Miss. S. M. Borikar	Study of two fluid cosmological models ingeteral theory of relativity	15-07-2010
3	Shri. R. P. Wankhade	Study of cosmological models with dark energy	15.1.2011
4	Shri. I. D. Pawade	Dynamics of cosmological models of the universe in theories of gravitation	15.7.2011
5	Shri. S. L. Munde	Study of cosmological models in $f(R)$ theory of gravity	15.1.2012
6	Shri. H. G. Ajmire	Study of cosmological models of universe with a special form of deceleration parameter	15.7.2012
7	Mrs. M. A. Purandare	study of cosmological models of universe with quadratic equation of state	15.1.2013
8	Ku. S. M. Kuber	Study of cosmological models of universe with polytropic equation of state	15.7.2013
9	Shri. S. M. Gawande	Study of cosmological models of universe with hybrid expansion law	15.1.2014
10	Shri. V. D. Bokey	Study of holographic dark energy cosmological model of universe	15.7.2014
11	Shri. Dineshkumar Joshi	Study of cosmological models of universe with dark matter and dark energy in $f(R)$ theory of gravity	15.7.2014

b) Ph. D. Awarded : The following students have been awarded Ph.D. degree.

Sr.No.	Name of student	Title of Ph.D. Thesis	Ph.D. awarded on date
1	Shri. A. S. Bansod	Study of cosmological models in creation field cosmology	16-05-2013
2	Ku. M. S. Desale	Study of higher dimensional cosmological models in creation field cosmology	28-04-2014
3	Ku. R. B.Raut	Study of LRS Bianchi type cosmological models in creation field cosmology	28-04-2014
4	Shri. R. P. Wankhade	Study of cosmological models with dark energy	15.05.2014
5	Ku.S.M.Borikar	Study of two fluid cosmological models in general theory of relativity	17.06.2014
6	Mrs. R.G. Deshmukh	Study of dark energy cosmological model in alternative the ories of gravitation	20.06.2014
7	Shri. I. D. Pawade	Dynamics of cosmological models of the universe in theories of gravitation	22.11.2014
8	Shri. S. L. Munde	Study of cosmological models in $f(R)$ theory of gravity	05.06.2015
9	Shri. H. G. Aimire	Study of cosmological models of universe with a special form of deceleration parameter	02.11.2015
10	Ku.G.B.Tayade	Study of accelerating anisotropic cosmological models of universe	02.11.2015

c) Publication of results : The following Research papers have been published.

Sr. No.	Title of Paper	Name of the Journal and Vol. No., Year, Page No.
1	Dynamics of Kantowski-Sachs universe with magnetized anisotropic Dark Energy	Astrophysics &Space Science Journal no. 10509 , Springer Netherlands.Vol.337, No.1, pp.393-400,Jan 2012
2	Kaluza-Klein Universe with Linearly Varying Deceleration Parameter.	Bulgarian Journal of Physics. Vol.39, No.3, pp.207-214, Sept 2012.
3	Kaluza-Klein Interacting Cosmic Fluids Cosmological Model.	Journal of Theoretical and Applied Physics. Vol.06, No.33, 22Nov2012
4	Early Decelerating & Late Time Accelerating Anisotropic Cosmological Models with Dynamical Equation of State Parameter.	Astrophysics &Space Science (NETHERLANDS) Journal no. 10509 , Springer Netherlands. Vol. 345, No.2 ,pp. 405-413, May 2013.
5	Bianchi Type-III Universe with Anisotropic Dark Energy and Special Form of Deceleration Parameter.	International Journal of Innovative Research in Science. Engineering & Technology . Vol.2, No.5. , pp.1656-1665,May 2013

6	Bianchi Type-II, VIII & IX Universe filled with Wet Dark Fluid in $f(R,T)$ Theory of Gravity.	International Journal of Theoretical and Marhematical Physics. Vol.3, No.5, pp.139-146,July 2013.
7	LRS Bianchi Type-I Cosmological Model with Anisotropic Dark Energy and Special Form of Deceleration Parameter.	Journal of Modern Physics, Scientific Research Publishing Inc., P. O. BOX 54821, Irvine CA 92619-4821, USA. Vol.4. No.8, Aug.2013.
8	Magnetized Bianchi Type-III Cosmological Model with Linear Equation of State	International Journal of Mathematical Archive (IJMA).Vol.4, No.8, pp.86-91, Aug 2013.
9	Bianchi Type-VIII Universe with Linear Equation of State.	International Journal of Science &Technology. NETHERLAND, Journal No. 10773 . Springer US.Vol.3. No.10, Oct 2013.
10	Bianchi Type-VI_0 Universe with Anisotropic Dark Energy in Lyra Geometry.	American Journal of Mathematics and Mathematical Sciences. Vol.2, No.2, pp.91-99,July-Dec, 2013.
11	Vacuum Solutions of Bianchi Type-I and V Models in $f(R)$ Gravity with a Special Form of Deceleration Parameter	*International Journal of Science and Advanced Technology* , Vol.4 No 3 March 2014
12	Bianchi Type-II Universe with Linear Equation of State.	Central European Journal of Physics. **ITALY** Vol.12. No.8, pp.597-602, June. 2014.
13	Oscillating Universe: Big Bang to Big Crunch with Linear Equation of State.	The African Review of Physics, **ITALY**. Vol.9, No.3, pp.17-20,June 2014.
14	Bianchi Type-III Cosmological Model with Linear Equation of State.	Bulgarian Journal of Physics.**BULGARIA**. Vol.41, No 3, pp.187-193,June 2014
15	Magnetized Anisotropic Dark Energy Bianchi Type III Cosmological Models in Brans-Dicke Theory of Gravitation.	International Journal of Advanced Applied Physics Research. Vol.1. No.2, pp. 30-38. Dec. 2014.
16	Kantowski-Sachs Cosmological Model with Quark and Strange Quark Matter in $f(R)$ Theory of Gravitation.	Open Physics. **ITALY** Vol.13, No.1, pp.88-93, Jan, 2015.
17	Anisotropic Cosmological Models in $f(R)$ Gravity with Quark & Strange Quark Matter and Special Form of Deceleration Parameter.	The African Review of Physics, **ITALY**. 04 Feb. 2015.
18	Plane Symmetric Cosmological Model with Quadratic Equation of State	Bulgarian Journal of Physics.**BULGARIA**. Vol.42, No.1, pp.20-28, April 2015
19	Bianchi Type-I Cosmological Model with Quadratic Equation of state.	Astrophys Space Sci (2015) 357:20
20	Interacting Dark Matter and Holographic Dark Energy in Bianchi Type-V Universe.	Astrophysics & Space Science (NETHERLANDS) Vol.359, No.1, pp.24, Sept, 2015.

d) Other Impact, if any:

(a) Eleven (11) research students are registered;

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(d) One (01) International Conference ICGR-2015 was organised and Very

Good impact has been developed on research students during tenure (01/07/2012

to 31/12/2015) of the MRP .

Name and Signatures:
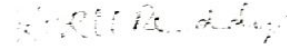
(a) Principal Investigator:

(Dr K S Adhav)

Dr. K. S. ADHAV
Principal Investigator
U.G.C.(Major Research Project)
2012 - 2013

(b) Co- Investigators: (i)

(Dr D R K Reddy)

(ii)

(Dr S D Katore)

(c) Registrar (Signature with Seal):

(Dr Ajay Deshmukh)

Date : 24 / 06 / 2016.
Place : Amravati