# Constraints on alternative theories of gravity

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**Abstract**

One could call 2006 as the year of cosmology since in the year two US scientists were awarded by the Nobel prize for their studies of Cosmic Microwave Background (CMB) spectrum and anisotropy. Studies of CMB anisotropy done with the Soviet spacecraft Prognoz-9 by the Relikt-1 team are reminded. Problems of modern cosmology are outlined. We discuss conformal cosmology parameters from supernovae data in brief. Two approaches to solve the basic problems of cosmology, such as dark matter and dark energy, are discussed, the first (standard) possibility is to introduce new particles, fields etc, the second possibility is to try to change a gravity law to fit observational data. We discuss advantages and disadvantages of the second choice.

## 1 Introduction

For a scientific community 2005 was the World year of physics due to publications of the famous Einstein's papers and the birth of modern (contemporary) physics in 1905; 2006 was remarkable for a physical community (it was the year of astrophysics and cosmology) since in 2006 the Nobel prize for CMB studies was presented to J. Mather and G. Smoot, moreover J. Mather and the COBE (COsmic Background Explorer) team was awarded by the Peter Gruber prize on cosmology in the same year at the General Assembly of the International Astronomical Union in Prague. No doubt, 2007 will be recognized as the very important year for astrophysical (or probably for scientific in general) community since a number of of discoveries were done even at present date. For Russian space science 2007 is the jubilee year since the first artificial satellite (Sputnik) was launched fifty years ago on October 4, 1957.

## 2 CMB anisotropy studies, Relikt-1 & COBE

Cosmic microwave background (CMB) existence was predicted in the framework of the the so called Big Bang cosmological model, however, first estimates CMB temperature $T_{CMB} \sim 50^0$ K were rather rough since it was assumed that the age of the Universe is about 2–3$\times 10^9$ years (because of the Hubble constant estimate was very high $H = 500\ km/(s \cdot Mpc)$ due to errors in distance measurements at the time), but later Gamow re-estimated the temperature $T_{CMB} \sim 6^0$ K. The CMB radiation was discovered by A. Penzias and R. Wilson [1] in an unexpected way (and they awarded by the Nobel prize for the discovery in 1978).

In 1983, in the Soviet Union the Relikt-1 experiment was conducted aboard the Prognoz-9 spacecraft in order to investigate CMB radiation from space for the first time in history. As many other Prognoz missions, the scientific payload was prepared by the Space Research Institute of the Soviet Academy of Sciences. Dr. Igor Strukov was the principal investigator. The spacecraft Prognoz-9, had an 8 mm band radiometer with an extremely high sensitivity of 35 $\mu K$ per second and it was launched into a high apogee orbit with a 400,000 km semi-axis. The high orbit was a great advantage of the mission since it allows to reduce of geomagnetic field impact on measurements. A disadvantage of the experiment was that the observations were conducted only in one spectral band, therefore, it was a freedom for a theoretical interpretation of the results, in contrast, multi-band measurements provide very small room for alternative explanations of anisotropy. The radiometer scanned the entire celestial sphere for six months. Computer facilities (and therefore, data analyzing) were relatively slow in the time. Preliminary analysis of anisotropy studies indicate upper limits on anisotropy [3], but in this case even the negative results (upper limits) were extremely important to evaluate a sensitivity to design detectors for next missions (including COBE).

In 1986, at the Space Research Institute it was decided to prepare a next generation of space experiments to study the anisotropy of CMB, and start to develop the Relikt-2 project. The sensitivity of the detectors was planned to be in 20 times better than the Relikt-1 sensitivity. The Libris satellite was scheduled to carry the Relikt-2 payload and the spacecraft was planned to be located near the Lagrangian point $L_2$ (in the Sun – Earth system).Originally, it was a plan to launch the Libris spacecraft in 1993–1994, however, the project has not been realized, basically due to a lack of funds. To prepare Relikt-2, the team members re-analyzed Relikt-1 data and finally in beginning of 1991 they discovered signatures of the quadrupole anisotropy, but I. Strukov required to check the conclusions again and again. The discovery of anisotropy by the Relikt-1 spacecraft was first reported officially in January 1992 at the Moscow astrophysical seminar and the Relikt-1 team submitted papers in Soviet Astronomy Letters [4] and Monthly Notices of Royal Astronomical Society [5] (soon after the papers were published). Relikt-1 results are described in an adequate way at the at the official NASA web-site http://lambda.gsfc.nasa.gov/product/relikt/ "... The Relikt Experiment Prognoz 9, launched on 1 July 1983 into a high-apogee (700,000 km) orbit, included the Relikt-1 experiment to investigate the anisotropy of the CMB at 37 GHz, using a Dicke-type modulation radiometer. During 1983 and 1984 some 15 million individual measurements were made (with 10% near the galactic plane providing some 5000 measurements per point). The entire sky was observed in 6 months. The angular resolution was 5.5 degrees, with a temperature resolution of 0.6 mK. The galactic microwave flux was measured and the CMB dipole observed. A quadrupole moment was found between 17 and 95 microKelvin rms, with 90% confidence level. A map of most of the sky at 37 GHz is available..." (also, references [4, 5], given at the NASA web-site).

The Nobel Prize in Physics for 2006 was awarded to John Mather and George Smoot. The Royal Swedish Academy of Sciences had issued the Press Release, dated on 3 October 2006, on The Nobel Prize in Physics 2006. The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2006 jointly to John C. Mather (NASA Goddard Space Flight Center, Greenbelt, MD, USA), and George F. Smoot (University of California, Berkeley, CA, USA) "for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation". Really, J. Mather was the project scientist of the COBE mission and was responsible for measurements of CMB spectrum (he was the PI of the Far InfraRed Absolute Spectrometer (FIRAS) experiment) and measurements of CMB spectrum were rather successful. G. Smoot did a great contribution into measurements of the dipole anisotropy [2] and the quadrupole one [6], since he was PI of the differential microwave radiometer (DMR) aboard the COBE satellite and found the quadrupole anisotropy with these facilities, but both anisotropies were discovered earlier by other people.

The discovery of anisotropy by the Relikt-1 spacecraft was first reported officially in January 1992 at the Moscow astrophysical seminar. The Relikt-1 team submitted their paper in Soviet Astronomy Letters and Monthly Notices of Royal Astronomical Society on January 19, 1992 and on February 3, 1992, respectively.

On April 21, 1992, G. Smoot (the head of DMR experiment aboard the COBE mission) and his co-authors submitted a paper in Astrophysical Journal (Letters) [6]. On April 22, 1992, Smoot reported at a press conference about the discovery of the CMB anisotropy with the COBE satellite. After that mass media reported this results as the main science success. In 1992, COBE results about discovery of the CMB anisotropy were reported elsewhere. However, no doubt, the COBE collaboration knew results of the Relikt-1 team and even quoted their upper limit on the quadrupole anisotropy published at the paper [3]. However, summarizing, one could say that since papers of the Relikt-1 team were submitted on January 19, 1992 and February 3, 1992 in Soviet Astronomy and Monthly Notices of Royal Astronomy Society respectively, but the COBE paper was submitted on April 21, 1992, one would conclude that the discovery one quadrupole anisotropy was done by the Relikt-1 team and published in papers [4,5].

## 3 Standard Cosmology vs. f(R) gravity

The standard cosmological model has problems to understand an origin of Dark Matter (DM) and dark energy (DE). Another approach was proposed and it was based on an assumption that gravity is different from standard general relativity it can be described by a modified Lagrangian (however, there are tensions with Solar system constraints). The model was successful to explain an acceleration of the Universe, but it has problems to fit Solar system data. Recently, it has been proposed a generalization of the approach in the framework of higher order theories of gravity – also referred to as $f(R)$ (or fourth order) theories – a modification of the gravity action with the form [7,8]

$$\mathcal{A} = \int d^4x\sqrt{-g}[f(R) + \mathcal{L}_m], \tag{1}$$

where $f(R)$ is a generic function of the Ricci scalar curvature and $\mathcal{L}_m$ is the standard matter Lagrangian. For example, if $f(R) = R + 2\Lambda$ the theory coincides with General Relativity (GR) with the $\Lambda$ term. In particular, it was considered a power law function $f(R)$ theories of the form $f(R) = f_0R^n$. As a result, in the weak field limit, the gravitational potential is found to be

$$\Phi(r) = -\frac{Gm}{2r}\left[1 + \left(\frac{r}{r_c}\right)^\beta\right], \tag{2}$$

where

$$\beta = \frac{12n^2 - 7n - 1 - \sqrt{36n^4 + 12n^3 - 83n^2 + 50n + 1}}{6n^2 - 4n + 2}. \tag{3}$$

Fourth order gravity theories were very successful to explain standard cosmological data such as SNe Ia fits, an acceleration of the Universe, rotation curves for galaxies [7] and it was suggested that the standard general relativity plus DM and DE may be distinguished from $R^n$ approaches with gravitational microlensing [8], but Solar system data (planetary orbital periods, in particular) put severe constraints on parameters of the the theories [9].

## 4 Conclusions

In conclusion we note that, unfortunately, even well-informed Russian (and other) authors did not cite Relikt-1 results in papers on cosmology, where the COBE anisotropy result was quoted as the only experiment discovered the phenomenon. It means the Nobel prize winner (1978) P. L. Kapitza wrote quite correctly about this kind of problems in 1946: "... Our main national defect is an underestimation of our powers and overestimation of foreign ones. So, an extra modesty is much more defective than an extra self-confidence... Very often a cause of unused innovations is that usually we underestimate our own discoveries and overestimate foreign ones..."

Solar system constraints put severe constraints on parameters of alternative theories of gravity [9].

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