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50 лет космической эры: реальные и виртуальные исследования неба

21-25 ноября 2011 г., Ереван, Армения

Труды конференции

Conference of young scientists of CIS countries

50 years of cosmic era: real and virtual studies of the sky

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Распределение темной материи в скоплении галактик Abell 1689

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Резюме. Мы представляем результаты обработки Чандра наблюдений скопления галактик Эйбелл 1689, очень горячего скопления (kT = 10.04 кеВ) с красным смещениям z = 0.1832, мы получили распределения для температуры, плотности и массы газа и тёмной материи в скоплении для радиального распределения по отношению к радиусу $R_{200.}$ Этот радиус соответствует контрасту плотности δ ~ 200 к критической плотности Вселенной, отнесённой на определённое красное смещение. Распределение тёмной материи хорошо описывается с помощью НФВ - модели. Предположив гидростатическое равновесия и сферическую симметрию, мы использовали наблюдаемое распределения температуры и численное моднлирования для профиля плотности газа, чтобы получить распределения массы в скоплении (M_{200} = $(9.36\pm1.21)\cdot10^{14}$ $M_☼$). Распределения газа сосредоточено в центре скопления, в первую очередь, как результат распределения тёмной материи. Отношения масс рентгеновского газа к полной массе увеличивается с увеличениям радиуса к ~ 0.2. Также мы использовали метод де-проэкции данных для более точной оценки масс.

Ключевые слова: методы: симуляции N-тел – галактики: рентгеновские скопления галактик – космология: тёмная материя

The dark matter distribution in the Abell 1689 galaxy cluster

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Abstract. We present the results of our processing of Chandra observations of Abell 1689, a very hot (kT = 10.04 keV) galaxy cluster at z = 0.1832. We reconstructed the temperature, density, and mass profiles of the gas and dark matter over the radial range up to R_{200}. This radius corresponds to a density contrast δ ~ 200 to the critical density of the Universe at the redshift of the cluster. The dark matter distribution is well described by the NFW model. Assuming hydrostatic equilibrium and spherical symmetry, we use the observed temperature profile and numerical simulations for the gas density profile to produce the total mass distribution of the cluster (M_{200} = $(9.36\pm1.21)\cdot10^{14}$ $M_☼$). The gas distribution is peaked in the center, primarily because of the cusp in the dark matter distribution. The X-ray gas content to the total mass ratio rises with increasing radius to ~0.2. To estimate the masses more precisely, we used the method of deprojection of the data.

Keywords: methods: N-body simulations - galaxies: X-ray galaxy cluster - cosmology: dark matter

1. Introduction

About 20% of the matter in the Universe is the so called dark matter, and emission directly from this matter has not been detected at any wavelength. However, the presence of this matter is inferred from different observations which have shown that the galaxy clusters contain dark matter and intracluster gas.

X-ray clusters have a very high luminosity due to the high temperature ($10^{7–8}$ K) of intracluster medium (ICM). In rich clusters, most of the luminous mass (~ 20% of the total cluster mass) emits from this hot medium. Observations of this hot intracluster medium permit a sensitive determination of the properties of dark-matter structure, which can then be compared to the results of numerical simulations.

Measuring the mass distribution of a galaxy cluster is central to a number of methods for constraining cosmological parameters. Potential estimates include the baryonic density Ω_b, the dark matter distribution etc.

In this paper, we describe our data analysis of the Chandra observations of Abell 1689. The spectral analysis and radial temperature profiles are described in Section 2. In Section 3, we give the modeling of the mass distribution and describe the DSDEPROJ method of spectrum deprojection [9, 10]. In Section 4, we discuss the ICM characteristics and the hydrostatic equilibrium within the R_{200} radius (a radius within which the mean cluster mass density is 200 times the cosmic critical density), such as the total cluster mass (M_{200}) and the fraction of dark matter within R_{200}.

We use H_0 =73 km s^{-1} Mpc^{-1}, assuming a flat universe with Ω_m=0.27. Errors are given at the 90% confidence level.

2. Observation and data analysis

A1689 is the richest of the Abell clusters, one of only nine that have a richness of four or higher (A665 is the only cluster of richness five). It is at a redshift of z ~ 0.18, with a virial radius of R_{200} = 1.15 Mpc (or 1.13 h^{-1} Mpc [7]) and hence about 10 arcmin. The entire core of the cluster fits within the single Chandra ACIS chip [1]. A1689 has a variety of published redshift estimates, ranging from 0.183 [11] to 0.203 [5].

In our work, we have chosen the redshift z = 0.1832 (http://ned.ipac.caltech.edu). In 2006, Halkola et al. [6] estimated the velocity dispersion σ ~ 1500 km s^{-1} for this cluster, placing the galaxy in the upper ~ 1% of cluster members for the low-z estimate. Abell 1689 is a regular galaxy cluster (Fig. 1) with the diameter of ~13 arcmin. The X-ray emission from the ICM is peaked in the center (RA: 13:11:29.455; DEC: –01:20:28.14, 2000.0).

The data sets analyzed in this paper are those that were examined in [3,4]. We used the CIAO software package and Chandra archive data from HEASARC (http://heasarc.gsfc.nasa.gov). The observation was conducted in March 2006 with the ACIS-I detector (the exposure time was 77 ks).

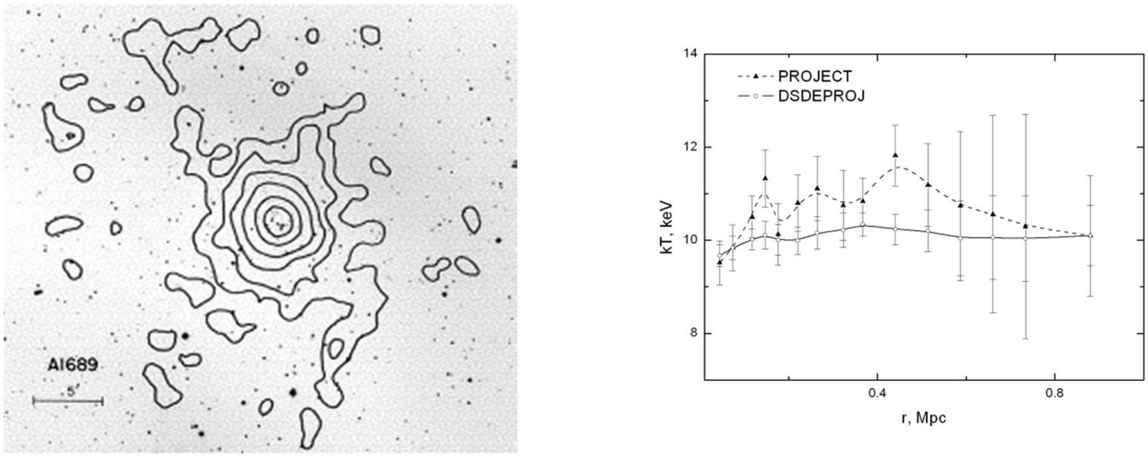

Figure 1: Left: The image of Abell 1689 taken from DSS.
Right: The radial temperature profiles of A1689.

We have obtained the image of A1689, split into annuli with 4000 (±50) in each ring, and removed point sources. For the spectral analysis, we extracted spectra from each ring. The same procedure was applied to the spectra from the background event files with the same size of ring for foreground. To analyze the spectra, we fit them in Xspec version 12.6 [2]. The energy range 0.5–7.0 keV was used during fitting, and the spectra were grouped to have at least 50 counts per spectral bin. For fitting, we used the MEKAL thermal spectral models.

The results from fitting the cluster data using the model in Xspec can be misleading. Because we obtained different parameters from projection image, it is needed to obtain these parameters from 3D images. For this aim, we used the DSDEPROJ method [10]. The routine takes spectra extracted from annuli in a sector, and their blank-sky background equivalents. From each spectrum, we subtract the respective blank-sky background spectrum.

3. Modeling

3.1. The modeling of surface brightness profile

We used numerical simulations and the Navarro–Frenk–White (NFW) density profile of dark matter [8] for reconstruction of the dark matter distribution. Our model assumes that the cluster is spherically symmetric and that the gas is in hydrostatic equilibrium with the cluster potential. The NFW density profile has the following form:

$$\rho(r) = \frac{\rho_0}{(\frac{r}{r_s})(1+\frac{r}{r_s})^2},$$

where ρ_0 is the characteristic density of dark matter; r_s is the core radius of dark matter halo. A massive dark matter halo is characterized by a gravitational potential field that determines the shape of the hot gas halo.

For estimating the total mass, we used the usual approach, namely to model the (deprojected) gas temperature, T(r), and density, ρ(r), separately and combine them to infer the mass profile under the assumption of hydrostatic equilibrium (HSE), via the following equation:

$$M(<r) = -\left(\frac{kT(r)r}{G}\mu m_p\right)\left(\frac{dln\rho}{dlnr}+\frac{dlnT}{dlnr}\right),$$

where μ is the mean molecular weight of the gas and m_p is the proton mass.

3.2. The deprojection technique

Direct Spectral Deprojection (DSDEPROJ) is a model-independent approach, assuming only spherical symmetry, which solves some of the issues inherent to model-dependent deprojection routines for X-ray spectra [9, 10]. DSDEPROJ starts with spectra extracted from a series of concentric annuli in a sector of the X-ray cluster image and subtracts off suitable blank-sky background spectra. Assuming spherical symmetry and using appropriate volume scaling factors, DSDEPROJ subtracts projected spectra from each successive annulus to produce a set of deprojected spectra.

4. Discussion

From the X-ray observational data for A1689, we got the normalization parameter of the best-fit MEKAL model norm MEKAL, which was fitted by $norm_{sim}$ values from simulations. Therefore we were able to obtain the field of hot gas density. We reconstructed the parameters of dark matter distribution by fitting the observational X-ray data with our modeling results. For two parameters, ρ_0 and r_s, we determined the cluster potential and the distribution of hot gas. It helped us to build the emission-measure profiles and then compare them to the observed ones (see Fig. 2). We have checked by a χ^2 test that our model corresponds to the data at the significance level of 90%. We used two free parameters, ρ_0 and r_s, for reconstruction of the density and mass (see Fig. 3) distributions for dark matter and intracluster gas.

We have obtained the total mass $M_{200} = (9.36 \pm 1.21)\ 10^{14}\ M_{\odot}$. Also, we have estimated the fraction of gas and dark matter in the total mass of Abell 1689; for gas, it is ~0.1 and for dark matter, ~0.9. Note that the total mass is the sum of the dark-matter and gas masses; we did not take into account the mass of galaxies in the cluster.

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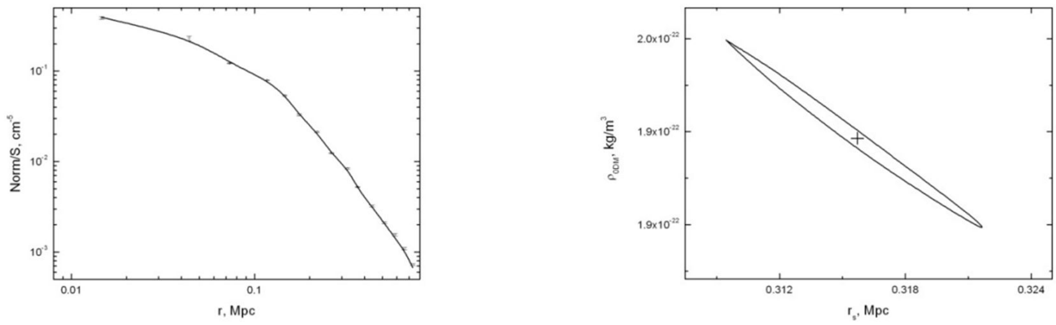

Figure 2: Left: The surface brightness profile of Abell 1689.
Right: The distributions of r_s and ρ_0 at the 90% confidence level.

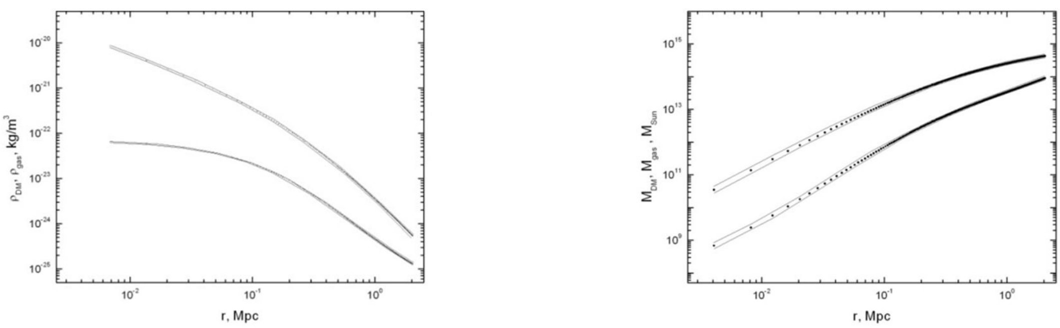

Figure 3: Left: The density profiles of the dark matter and hot gas in Abell 1689.
Right: The distributions of mass for dark matter and gas.

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