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Constraints on the population of Galactic objects in the JWST UNCOVER survey catalogue

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Abstract. The paper assesses the potential galactic nature of small distant objects (also known as “little red dots”) in the SUPER galaxy catalogue of the James Webb Space Telescope (JWST) UNCOVER survey. The estimate is based on the assumption that these objects could be brown dwarfs or similar objects with temperatures of a few hundred degrees — if the radiation from the low-temperature bodies was interpreted as the photometric redshift of a typical galaxy. The hypothetical number density of these objects in our galaxy is calculated, such as to match the observed number of “little red dots” in the survey. The physical possibility of having this number density in our Galaxy is discarded as contradictory to the dynamical constraints based on the halo mass of our Galaxy estimated elsewhere.

Keywords: cosmology: observations; galaxies: distances and redshifts

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1 Introduction

The first published catalogue of objects discovered in the deep-field images from the James Webb Space Telescope (JWST) contains more than 65,000 objects with photometric redshifts up to $z \approx 20$ and about 400 objects with reliably determined spectral redshifts up to $z = 7$ (Bezanson et al. 2022; Weaver et al. 2024). Most of these objects are identified in the catalogue as galaxies, with their angular radii θ. This allows us to perform a cosmological test by plotting a diagram which relates galaxy angular sizes with redshifts (the θ–z test).

The left panel of Fig. 1 presents a θ–z diagram for all 65,000 objects from the catalogue. In this plot, there are noticeable moments, particularly the presence of a large family of objects with small angular radii. These are seen as a uniform stripe of very small objects at the bottom of the diagram. Sometimes they are called "little red dots", as many of them are highly redshifted. Since they cover the entire redshift range, it raises the question about the nature of these objects: could some of them be part of our Galaxy? For example, they could be brown-dwarf stars with their low surface temperatures. Without a clear certainty about their nature, performing the θ–z test will be improper.

The authors of the catalogue (Weaver et al. 2024) note that objects fainter than $m = 25^m$ require additional scrutiny, so we are examining the question above. When extracting a sample of relatively bright objects with $m < 25^m$, the resulting catalogue is significantly smaller, consisting of approximately 5500 objects with photometric- and around 300 objects with spectroscopic redshifts. The θ–z diagram for this small sample is shown in the right panel of Fig. 1. The nature of the remaining $60,000$ small faint objects with their photometric redshifts $0 \lesssim z_{\text{phot}} \lesssim 20$ remains a matter of debate. We can approach this issue as follows.

If the spectral energy distribution of such an object has a maximum at, say, $\lambda = 0.5\,\mu$m, then it might be a low-temperature nearby object — a brown dwarf with $1.25\,\mathrm{R}_{♃}$ (in Jupiter-radius units). Then its temperature will be equivalent to a certain photometric "pseudo-redshift" – z_{pseudo}. The temperatures corresponding to pseudo-redshifts $0 < z_{\text{pseudo}} < 20$ vary from $\sim$ 200K to $\sim$ 2000K, and the luminosity varies from $\sim 10^{-6} L_{\odot}$ to $\sim 10^{-2} L_{\odot}$ (assuming the blackbody spectral-energy distribution of the object).

Given the sensitivity limit of the JWST, it is possible to determine the maximum distance at which a brown dwarf could be detected. Thus, the number of objects from the UNCOVER catalogue provides an estimate of their hypothetical number density within the Milky Way and its halo.

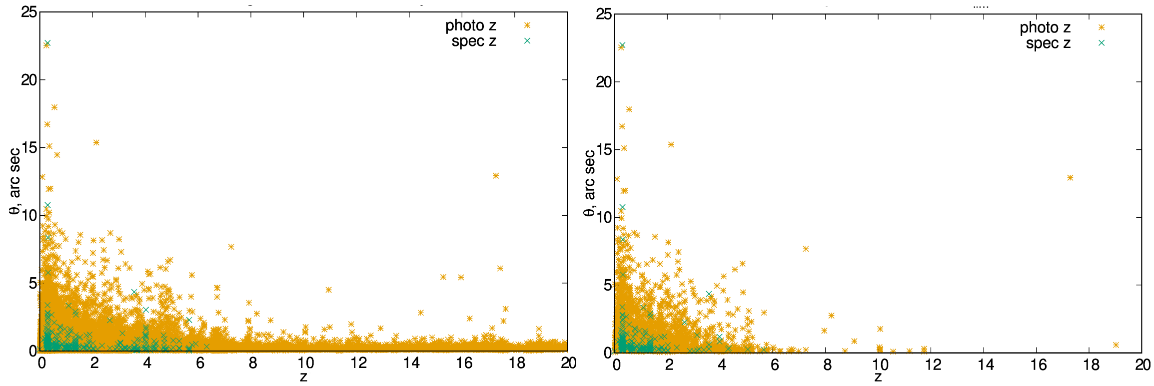

Fig. 1. Left panel: θ–z chart, for all JWST UNCOVER catalogue objects identified in this catalogue as galaxies. Right panel: the same chart, but for the objects brighter than 25^m. Yellow colour indicates the objects with photometric redshifts, and the green dots correspond to the objects with spectroscopic redshifts.

2 Assessment of a number density of possible brown dwarfs by their $z_{\rm pseudo}$ values

Only objects with photometric redshifts were selected from the UNCOVER catalogue for this assessment. The entire range of $0 \lesssim z_{\rm phot} \lesssim 20$ was broken down into 50 equal redshift bins. In each redshift bin, the number $\mathit{\Delta} N$ of the catalogue objects was counted. For the center of each bin, the blackbody temperature T and the brown-dwarf luminosity corresponding to this temperature were calculated. These luminosities are converted into absolute magnitudes (taking $M_\odot = 4.7^m$ and $L_\odot = 3.827 \cdot 10^{26}\,{\rm W}$). Next, the limiting distance $D_{\rm lim}$ at which this object can be seen was calculated using the JWST aperture. The calculation was performed for two options: (1) using all objects from the catalogue, assuming the object's apparent magnitude limit $m_{\rm lim} = 30^m$, and (2) using only objects brighter than $m_{\rm lim} = 25^m$.

Based on the obtained value of $D_{\rm lim}$, the number density of objects corresponding to the selected redshift bin was calculated. In each redshift bin, the number of objects is equal to $\mathit{\Delta} N$. The calculation refers to the limiting distance $D_{\rm lim}$ (the radius of a sphere), while the catalogue's deep field size of 49 square arcminutes (Weaver et al. 2024) was extrapolated to the entire sphere. Graphs of the number of the observed objects and the number densities of brown dwarfs matching the given number $\mathit{\Delta} N$ for each bin are shown in Fig. 2. It should be noted that with the approach used, the observational selection effect is excluded, since the selection of objects with the same temperature (a slice of the bin on $z_{\rm pseudo}$ gives a complete volume sample — i.e. a sample of objects with a given luminosity, whose number density is calculated in a sphere in which all of the objects are visible, while outside of this sphere they are not visible.

Summing up the number density values for all bins, we obtain the total number density of brown dwarfs that would be required to obtain the same observed number of objects that are included in the catalogue. In the case (1) of using all objects from the catalogue, the total number density is equal to $5.42 \cdot 10^{23}$ pc^{-3}. In the case (2), when sampling only objects up to 25^m, the total number density obtained is equal to $8.14 \cdot 10^{23}$ pc^{-3}. If we take a value of 1% $M_\odot$ as the lower estimate of the brown dwarf mass, then, with the 16 kpk-radius of our Galaxy, we can extrapolate the resulting number density to the whole Milky Way and obtain a value equal to $\sim 5 \cdot 10^3\,\mathrm{pc}^{-3}$. Thus, this number density leads to an estimate of the contribution of the brown dwarfs to the mass of all objects in the Galaxy, equal to $\sim 10^{15}\,M_\odot$. This is about 10^3 times larger than the observational estimates based on the Milky Way's halo-mass dynamics (Watkins et al. 2019; Ou et al. 2024).

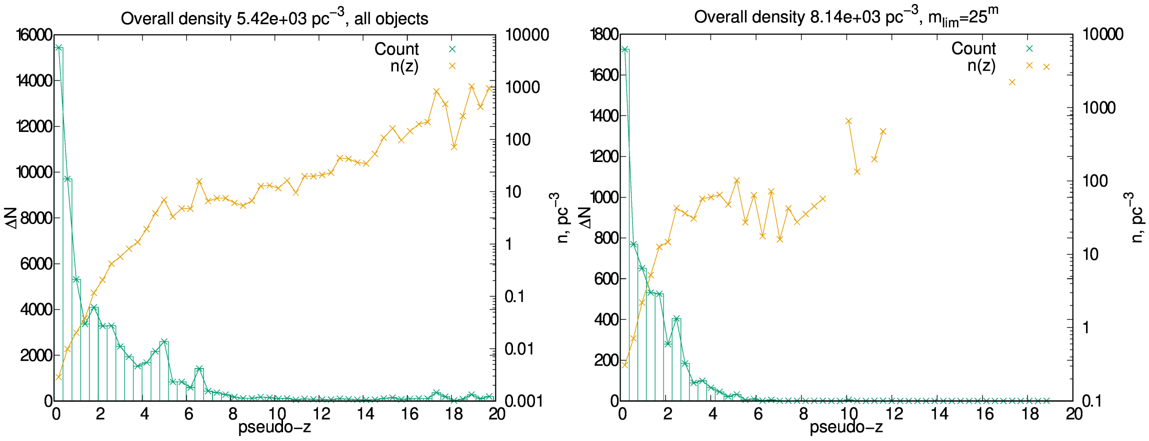

Fig. 2. An estimate of the brown dwarfs number densities from the JWST UNCOVER catalogue in redshift bins of z_{pseudo} corresponding to effective temperatures) of all catalogue objects (left panel) and of a sample limited to $m > 25^m$ (right panel).

In accordance with this estimate, it can be concluded that the proportion of brown dwarfs among the faint objects of the JWST UNCOVER catalogue cannot be larger than 0.1%. Otherwise, it will be in conflict with the dynamical properties of the Milky Way deduced from observational data. Therefore, it is most likely that 99.9% of the faint objects with small angular sizes in the UNCOVER catalogue are extragalactic and that the photometric estimates of their redshifts are not pseudo-redshifts but approximately correspond to the real redshifts of these objects.

Indirect evidence favouring the extragalactic nature of the disputed objects consists in the fact that the obtained estimates of number densities for the total number of objects and for the objects with $m < 25^m$ turned out to be of the same order. In this context, the "little red dot" objects are viewed as part of the group of objects accurately classified as galaxies in the UNCOVER catalogue. However, at the moment, it is premature to assert with 100% certainty that all of these objects are of extragalactic nature.

In principle, it is possible to carry out similar estimates for objects of other types (for example, diffuse nebulae), which have the same low temperatures as brown dwarfs, but which are larger. It is understandable that, as the radius R of an object increases, while the temperature is maintained, the brightness increases as R^2, and, therefore, the maximal distance from which the object is seen also increases as R^2. That is, the number density will fall as R^{-6}. For example, dust clouds with radii of $\sim 10\,\mathrm{R}_{♃}$ can be used to achieve "reasonable" number densities. Due to their lower density, these objects, unlike brown dwarfs, will not make a "catastrophic" contribution to the total mass of the Galaxy. Note, however, that the number density of hypothetical "brown dwarfs" (Fig. 2) exhibits growth at large z_{pseudo}, which should not be the case if these objects indeed were brown dwarfs: there should be a number density peak for the temperatures $\sim$ 300–500K ($z_{\mathrm{pseudo}} \sim$ 6–10). On the other hand, this growth does not contradict to the possible dusty nature of the objects, if their number density increases with a decrease in temperature, including a decrease below the available JWST wavelength sensitivity limit ($z_{\mathrm{pseudo}} = 20$, $T \sim 100K$). We think that further assessment of these issue is required.

3 Angular-size vs. redshift test

Considering the concerns about the nature of the "little red dots," we conducted the angular-size — redshift test for them. In each redshift bin, the average angular size and its dispersion were calculated. The results are shown in Fig. 3, his figure presents the theoretical predictions of the ΛCDM model and of the toy model based on Zwicky's tired light (TL) hypothesis — the latter being taken as an example of a cosmological model based on a static spacetime metric.

The results of this test show a strong disagreement with the ΛCDM predictions and some agreement with the TL model, which may indicate that either the discussed objects are not galaxies, or that the increase in the linear size of galaxies due to evolution precisely compensates for the geometrical changes with time of the coordinate reference frame predicted by the expanding-universe model. These test results align with the findings of other works, including our previous review (Lovyagin et al. 2022).

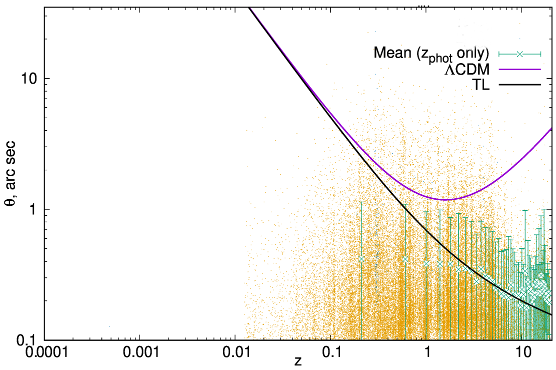

Fig. 3. The angular size — redshift relation (θ–z) for all of the objects with photometric redshifts from the JWST UNCOVER catalogue.

The combination of the recently identified issues regarding the age of the Universe and the challenges in explaining the formation of high-redshift galaxies within the standard cosmological model may suggest a potential need for a reassessment of the model.

4 Conclusions

A study of faint objects with small angular dimensions ("little red dots") from the JWST UNCOVER catalogue showed that only a negligible fraction of these objects (0.1%) can belong to the population of brown-dwarfs in the Milky Way and/or its halo. It is most likely that the majority of these objects are real distant galaxies.

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