Challenges to the Big Bang

Journal Club

9 May 2023

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Evidence for the Big Bang

1) Expanding space,
    - Redshift-Distance relation.
2) Primordial abundance of elements,
    - Big Bang Nucleosynthesis: H, He, Li
3) Cosmic Microwave Background/Temperature
    - Large Scale Isotropy
    - Small scale structure
    - 3 degree prediction
    - Period of re-ionization at z = 1100
4) Strong gravitational lensing
    - H_0 from quad SN = H_0 from expansion

Challenges to ΛCDM (from Eric Lerner):

1) Size of galaxies as a function of distance
2) Surface brightness of galaxies
3) Dynamical mass vs Luminous mass
4) Galaxy rotation curves as a function of radius
5) Existence of Super Massive Black Holes
6) Elliptical galaxy formation
7) Chemical evolution of quasars

Challenges to ΛCDM (from Eric Lerner):

1) Apparent size of galaxies as a function of distance

Objects of a given size, D, should have an apparent size that scales with distance like 1/R until a redshift of about 1.25.

Beyond that point, the apparent size increases because the universe was much smaller then.

The ΛCDM cosmology makes assumptions about the way galaxies grow in size over the age of the universe, through a combination of star formation and mergers.

Lerner assumes no growth (static universe) and no apparent size increase with distance.

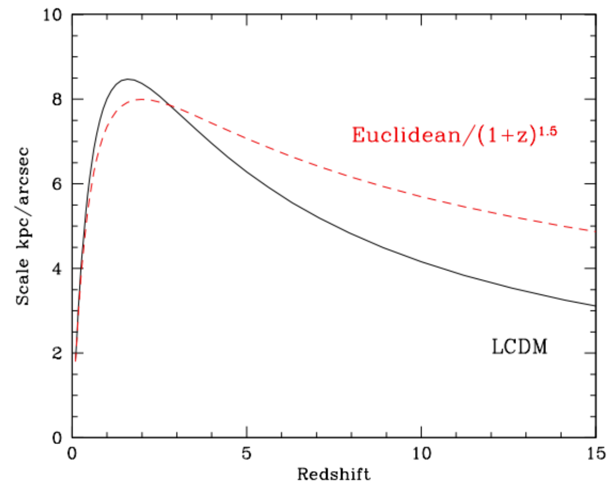

Fig. 3 Scale factor in kpc per arcsec versus redshift, as predicted by LCDM cosmology (solid line), compared to the Euclidean values divided by $(1+z)^{1.5}$ (red dashed line). This is not an attempt to fit the LCDM curve which cannot be parameterized as a simple function of (1+z). Rather, this is meant to show that when galaxies are investigated within LCDM, a size evolution approximately proportional to this factor is expected.

Challenges to ΛCDM (from Eric Lerner):

1) Size of galaxies as a function of distance

Morphologies of ~190,000 Galaxies at z = 0–10 Revealed with *HST* Legacy Data. III. Continuum Profile and Size Evolution of Lyα Emitters

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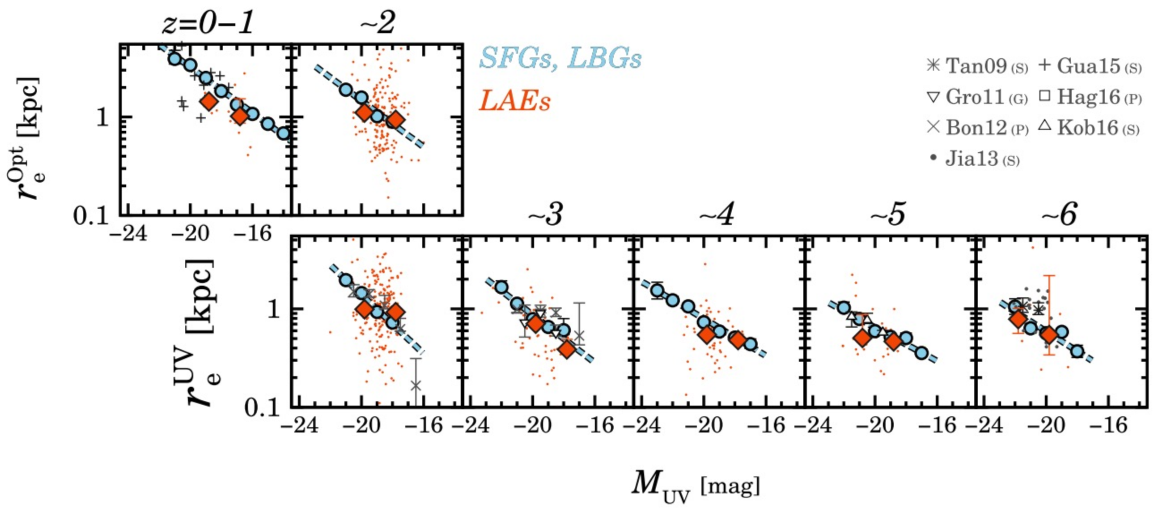

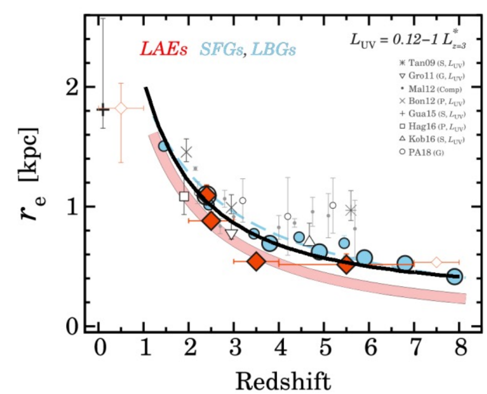

Figure 8. Relation between effective radius, r_e, and UV magnitude, M_{UV}. The top and bottom panels represent r_e^{Opt} and r_e^{UV}, respectively. The redshifts are labeled at the top of the panels. The red filled diamonds and dots indicate the representative and individual r_e measurements for the LAEs. The cyan filled circles represent the SFGs and LBGs (Paper I). The cyan dashed lines denote the best-fit power-law functions of $r_e \propto L_{UV}^{\alpha}$ for the r_e–M_{UV} relations. The gray symbols present LAEs in the literature (gray asterisks: Taniguchi et al. 2009; gray open inverted triangles: Gronwall et al. 2011; gray x-marks: Bond et al. 2012; gray dots: Jiang et al. 2013; gray crosses: Guaita et al. 2015; gray open squares: Hagen et al. 2016; gray open triangles: Kobayashi et al. 2016). The measurement technique is noted in the parenthesis of the legend (S: `SExtractor`; G: `GALFIT`; P: `PHOT`; see also Table 2). The data points are slightly shifted along the x-axis for clarity. The error bars of some data points are smaller than the size of symbols.

Challenges to ΛCDM (from Eric Lerner):

1) Dynamical mass vs Luminous mass

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Constraints on the evolutionary mechanisms of massive galaxies since $z \sim 1$ from their velocity dispersions

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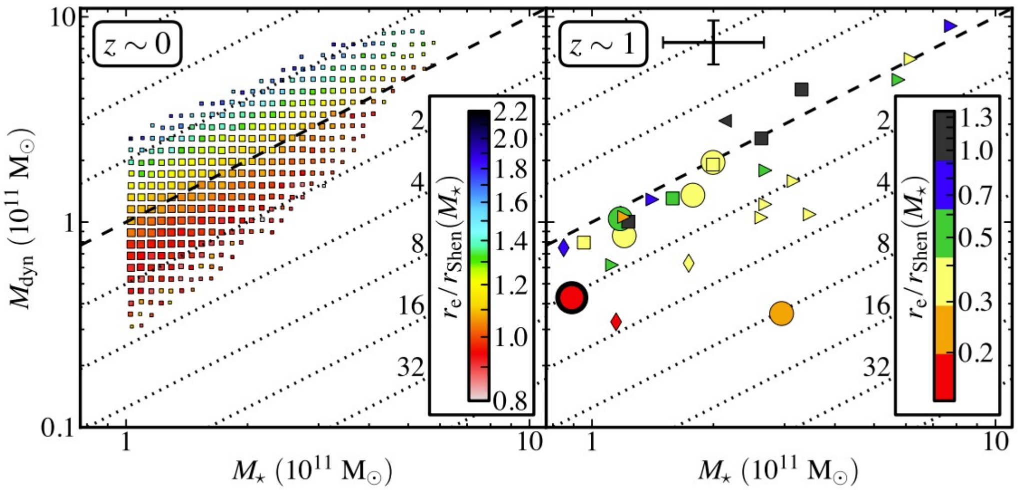

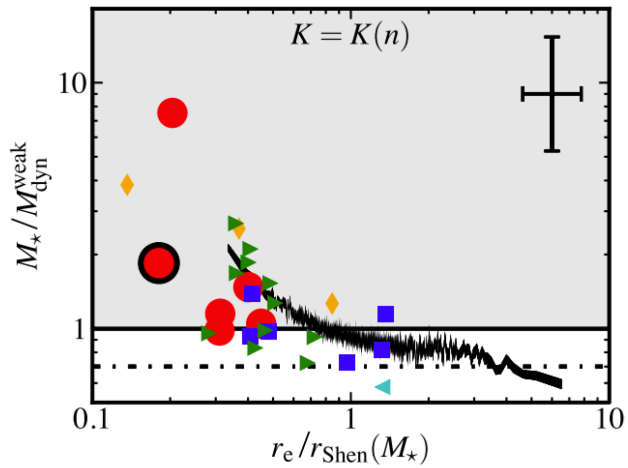

Figure 3. Stellar versus dynamical masses for the two redshift samples. Dashed line shows the identity relationship ($M_\star = M_{\rm dyn}$). Dotted lines below/above the dashed line indicate how many times (in powers of 2) the stellar mass is greater/smaller than dynamical mass (i.e. $M_\star = 2^i M_{\rm dyn}$ where i is an integer). Left-hand panel shows the $z \sim 0$ sample. For this sample, the data have been binned depending on their dynamical and stellar masses. The size of each symbol in the left-hand panel scales with the number of galaxies in each bin. For clarity, bins with fewer than 10 galaxies have been omitted. In the right-hand panel, which contains galaxies with $z \sim 1$, symbol shapes as in Fig. 2. In both panels, the colour of each symbol represents the compactness indicator $r_e/r_{\rm Shen}(M_\star)$, defined as the r_e offset from the stellar mass–size distribution of ETGs in the nearby Universe. The error bar cross on the top of the right-hand panel represents the mean errors of our six compact galaxies at $z \sim 1$.

Challenges to ΛCDM (from Eric Lerner):

1) Galaxy rotation curves as a function of radius

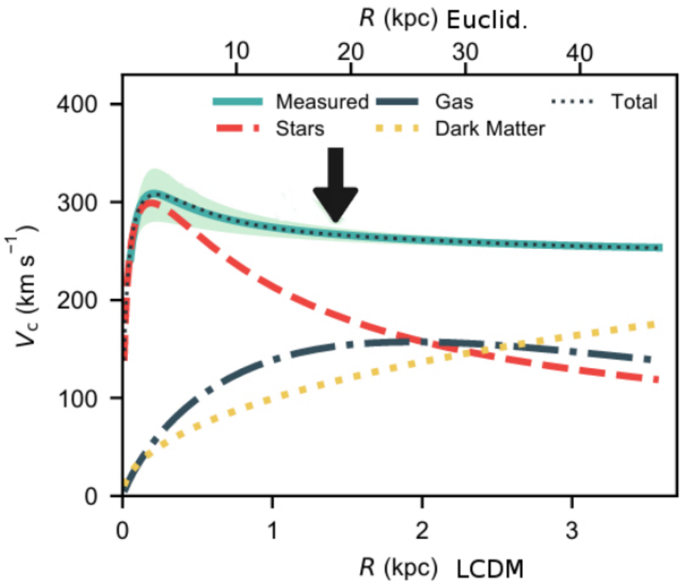

Fig. 5 The rotation curve of the galaxy SPT0418-47 at $z = 4.2$ (green curve), as reported by [27], with the typical description in terms of stars, gas, and dark matter. Note the very small computed size of the galaxy in LCDM (lower scale), compared to the Euclidean model (upper scale). The flattening of the rotation curve at large radii is evident. The arrow show the radius where the curve flattens out, according to [27]. When quantities are evaluated in the Euclidean framework, at this position the acceleration v^2/r is consistent with a_0.

A dynamically cold disk galaxy in the early Universe

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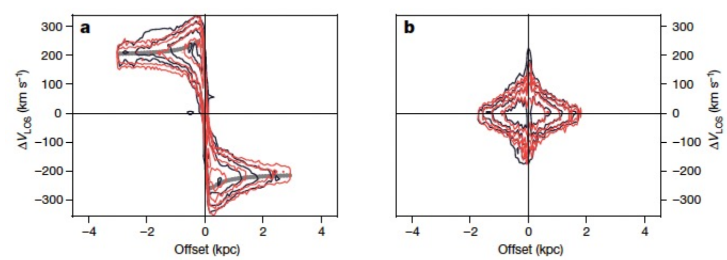
The extreme astrophysical processes and conditions that characterize the early Universe are expected to result in young galaxies that are dynamically different from those observed today[1–5]. This is because the strong effects associated with galaxy mergers and supernova explosions would lead to most young star-forming galaxies being dynamically hot, chaotic and strongly unstable[1,2]. Here we report the presence of a dynamically cold, but highly star-forming, rotating disk in a galaxy at redshift[6] $z = 4.2$, when the Universe was just 1.4 billion years old. Galaxy SPT–S J041839–4751.9 is strongly gravitationally lensed by a foreground galaxy at $z = 0.263$, and it is a typical dusty starburst, with global star-forming[7] and dust properties[8] that are in agreement with current numerical simulations[9] and observations[10]. Interferometric imaging at a spatial resolution of about 60 parsecs reveals a ratio of rotational to random motions of 9.7 ± 0.4, which is at least four times larger than that expected from any galaxy evolution model at this epoch[1–5] but similar to the ratios of spiral galaxies in the local Universe[11]. We derive a rotation curve with the typical shape of nearby massive spiral galaxies, which demonstrates that at least some young galaxies are dynamically akin to those observed in the local Universe, and only weakly affected by extreme physical processes.



Challenges to ΛCDM (from Eric Lerner):

1) Existence of Super Massive Black Holes

9.3.1. How do BHs grow so quickly at high redshifts? The highest-redshift quasar (z = 7.085) known already had $M_\bullet \sim (2.0^{+1.5}_{-0.7}) \times 10^9\, M_\odot$ only 770 million years after the Big Bang (Mortlock et al. 2011). The BH mass is based on the quasar's luminosity and on its MgII λ 2,798-Å line width. It is uncertain. But this is only the latest and most extreme of a growing number of known giant BHs at early times whose rapid growth, within the (somewhat squishy) constraint of the Eddington limit, is difficult to understand. The best bet is that these BHs get a head start on radiatively efficient growth by merging many small seed BHs, possibly Population III remnants. The point worth making is this: Such objects are so rare that any attempt to find a "natural" explanation is probably wrong. If the suggested process that makes these objects is not extremely unusual, it is probably the wrong process. This subject is reviewed by Volonteri (2010).

Challenges to ΛCDM (from Eric Lerner):

1) Existence of Super Massive Black Holes

9.3.2. Why do we not see many BH binaries near galaxy centers? BH binaries formed in galaxy mergers shrink in separation by several processes. At moderate separations, the tendency toward energy equipartition causes binaries to fling stars away, thereby—we believe—excavating cores. At small separations, they emit gravitational radiation. In between, there can be a bottleneck at separations of ~1 pc where decay processes are slow. This "final parsec problem" is discussed or reviewed by Begelman, Blandford & Rees (1980); Yu (2002); Milosavljević & Merritt (2003); Makino & Funato (2004), and Merritt & Milosavljević (2005). The subject is complicated; we have neither the space nor the expertise to review it. Komossa (2006) reviews the observations. The bottom line is that BH binaries with separations ~1 pc are surprisingly rare, especially in big classical bulges and ellipticals. Additional decay processes are discussed in the above papers. We bring this subject up because it leads to interesting expectations, as follows.

Challenges to ΛCDM (from Eric Lerner):

1) Existence of Super Massive Black Holes

9.3.3. Why do we not see BHs that are not at galaxy centers? If a second merger supplies a third BH to a BH binary, the resulting three-BH interactions generally fling all BHs away from the center. Even if the most massive BHs make a binary that ejects the third BH, the binary recoils. This leads to expectations that we have not observed: Where are the BH-less bulges and ellipticals? And where are the free-flying BHs and their very compact cloaks of stars?