ΛCDM problems

A survey

Beyond ΛCDM: Problems, solutions, and the road ahead

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https://arxiv.org/pdf/1512.05356

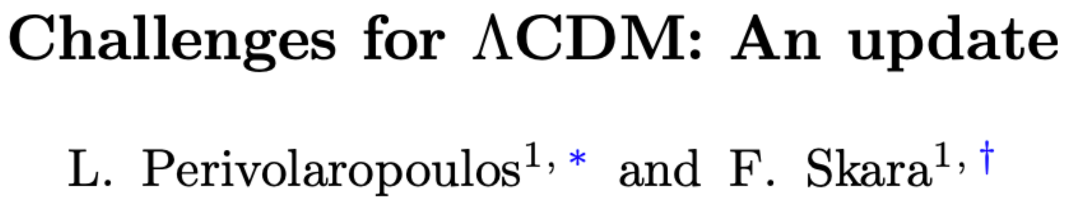
Abstract

Despite its continued observational successes, there is a persistent (and growing) interest in extending cosmology beyond the standard model, ΛCDM. This is motivated by a range of apparently serious theoretical issues, involving such questions as the cosmological constant problem, the particle nature of dark matter, the validity of general relativity on large scales, the existence of anomalies in the CMB and on small scales, and the predictivity and testability of the inflationary paradigm. In this paper, we summarize the current status of ΛCDM as a physical theory, and review investigations into possible alternatives along a number of different lines, with a particular focus on highlighting the most promising directions. While the fundamental problems are proving reluctant to yield, the study of alternative cosmologies has led to considerable progress, with much more to come if hopes about forthcoming high-precision observations and new theoretical ideas are fulfilled.

exotic components

theoretical issues

anomalies



Challenges for ΛCDM: An update

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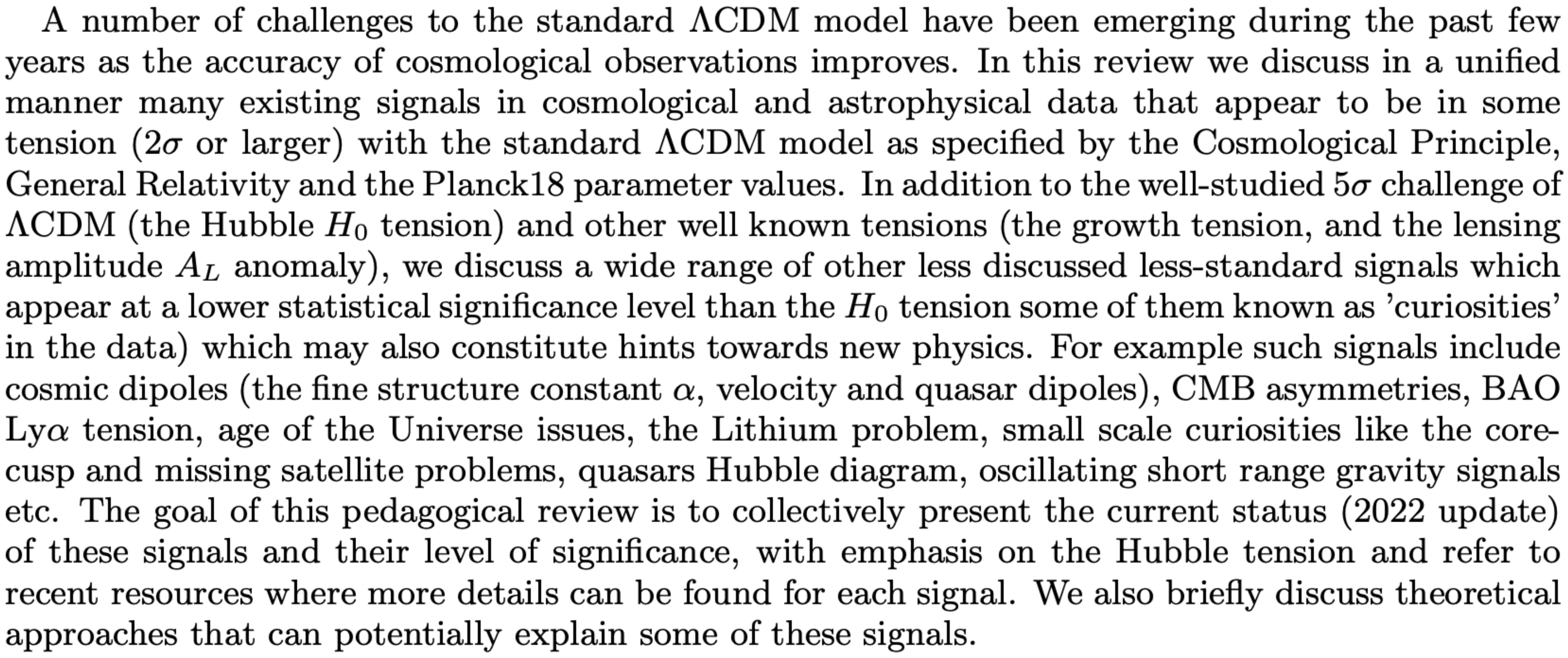
https://arxiv.org/pdf/2105.05208



A number of challenges to the standard ΛCDM model have been emerging during the past few years as the accuracy of cosmological observations improves. In this review we discuss in a unified manner many existing signals in cosmological and astrophysical data that appear to be in some tension (2σ or larger) with the standard ΛCDM model as specified by the Cosmological Principle, General Relativity and the Planck18 parameter values. In addition to the well-studied 5σ challenge of ΛCDM (the Hubble H_0 tension) and other well known tensions (the growth tension, and the lensing amplitude A_L anomaly), we discuss a wide range of other less discussed less-standard signals which appear at a lower statistical significance level than the H_0 tension some of them known as 'curiosities' in the data) which may also constitute hints towards new physics. For example such signals include cosmic dipoles (the fine structure constant α, velocity and quasar dipoles), CMB asymmetries, BAO Lyα tension, age of the Universe issues, the Lithium problem, small scale curiosities like the core-cusp and missing satellite problems, quasars Hubble diagram, oscillating short range gravity signals etc. The goal of this pedagogical review is to collectively present the current status (2022 update) of these signals and their level of significance, with emphasis on the Hubble tension and refer to recent resources where more details can be found for each signal. We also briefly discuss theoretical approaches that can potentially explain some of these signals.

exotic components

theoretical issues

anomalies

tensions

1. What are the biggest problems or shortcomings of the ΛCDM scenario?

a) Nothing is wrong with ΛCDM

b) The cosmological constant problem

c) The coincidence problem

d) Dark matter

e) The big bang singularity

f) Inflation

g) ΛCDM will remain the best-fit model to the data
while not being understood theoretically

h) It cannot explain small-scale structure

i) Baryonic effects are too difficult to model

j) Cosmic variance

01:00

1. What are the biggest problems or shortcomings of the ΛCDM scenario?

a) Nothing is wrong with ΛCDM	5%
b) The cosmological constant problem	66%
c) The coincidence problem	13%
d) Dark matter	21%
e) The big bang singularity	10%
f) Inflation	21%
g) ΛCDM will remain the best-fit model to the data while not being understood theoretically	48%
h) It cannot explain small-scale structure	23%
i) Baryonic effects are too difficult to model	18%
j) Cosmic variance	2%

2. The cosmological constant problem will be solved by...

a) a dark energy theory

b) a modified gravity theory

c) better understanding of particle physics

d) realising it is not a problem

3. Dark energy will turn out to be...

a) a new scalar field

b) indistiguishable from a cosmological constant

c) related to dark matter

d) a modification to GR

e) something completely different

01:00

2. The cosmological constant problem will be solved by...

a) a dark energy theory	18%
b) a modified gravity theory	28%
c) better understanding of particle physics	46%
d) realising it is not a problem	20%

3. Dark energy will turn out to be...

a) a new scalar field	15%
b) indistiguishable from a cosmological constant	48%
c) related to dark matter	12%
d) a modification to GR	26%
e) something completely different	33%

4. Dark matter. We will...

a) never know what dark matter is

b) show that dark matter is not a particle

c) show that dark matter is modified gravity

d) discover the dark matter particle

5. Baryonic physics will...

a) be completely understood through simulations

b) be reasonably understood, enough to unbias the estimators

c) remain difficult to simulate, but it has negligible effects

d) remain difficult to simulate and continue to be an important bias

01:00

4. Dark matter. We will...

a) never know what dark matter is	10%
b) show that dark matter is not a particle	13%
c) show that dark matter is modified gravity	18%
d) discover the dark matter particle	56%

5. Baryonic physics will...

a) be completely understood through simulations	3%
b) be reasonably understood, enough to unbias the estimators	33%
c) remain difficult to simulate, but it has negligible effects	7%
d) remain difficult to simulate and continue to be an important bias	56%

6. Anomalies

a) will overturn ΛCDM

b) will remain and must be addressed

c) will go away

d) new anomalies will be found

7. Observational progress will...

a) speed up

b) slow down due to computational challenges

c) slow down due to lack of theoretical progress

d) slow down due to difficult systematics

01:00

6. Anomalies

a) will overturn ΛCDM	7%
b) will remain and must be addressed	67%
c) will go away	20%
d) new anomalies will be found	84%

7. Observational progress will...

a) speed up	20%
b) slow down due to computational challenges	15%
c) slow down due to lack of theoretical progress	44%
d) slow down due to difficult systematics	49%

8. Next generation experiments will make discoveries that will...

a) confirm ΛCDM to higher precision

b) lead to additions to ΛCDM

c) lead to large modifications to ΛCDM

d) overturn ΛCDM

01:00

8. Next generation experiments will make discoveries that will...

a) confirm ΛCDM to higher precision	39%
b) lead to additions to ΛCDM	39%
c) lead to large modifications to ΛCDM	31%
d) overturn ΛCDM	10%