The SDSS *Renaissance*: The End of the ‘Dark Age’ in Cosmology

Sloan Digital Sky Survey

23 January 2015

Sloan Foundation
2.5-m Telescope
Apache Point, NM

Image credit: Reidar Hahn, *Fermilab Visual Media Services*

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☞ IMPORTANT!

On 6 January 2015, two new SDSS Data Releases (DR11 & DR12) were issued simultaneously (see press release). This slide deck references DR10 data; *these two new releases have no effect on any of the science presented herein.*

A Revolutionary New View of Sloan Digital Sky Survey (SDSS) Astrophysical Data

• a scientific thesis in content presented in a convenient, informative and advantageous graphical form •

Complementary *ApJ* & *Phys. Rev. D* submissions are in preparation.

www.astro.uni-bonn.de

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Pavel Kroupa

I thank Profs. Pavel Kroupa & Hans Fahr for their support of this research at the Institute and for their productive critical comments, which led to the creation of this presentation.

Hans Fahr

Click photos for additional information.

This instructional annotation applies to all slides.

Why this substantial HD* slide deck?

Purpose

This substantial slide deck is not designed or intended to be a live presentation. In support of pending conventional journal articles, it provides important new information for critical peer review in a way that is impossible to achieve with such articles. For example, one may dynamically compare similar graphs by toggling between subsequent slides, thus easily perceiving their differences.

Audience

These slides are suitable for a wide audience, from professional physicists and astronomers to science journalists and university students in various disciplines. Mathematics anticipates a diverse *technical* audience with no unusual expertise beyond the typical university-level training of all physical scientists and engineers.

Internet-enabled

Photos and literature references are hyperlinked to relevant Internet resources.

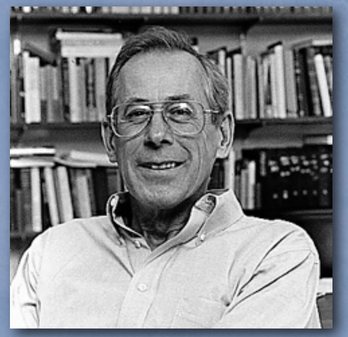
* Native resolution: 1920 × 1080 pixels

Physical cosmology is the attempt to make sense of the large-scale nature of the material world around us, by the methods of the natural sciences. It is to be hoped that those who love physical science will take pleasure in cosmology as an example of the art. ...

Behind physics is the more ancient and honorable tradition of attempts to understand where the world came from, where it is going and why.

– P. J. E. Peebles,

Albert Einstein Professor of Science, Emeritus, Princeton University



James Peebles

This instructional annotation applies to all slides.

Click the reference for additional information.

Source: P. J. E. Peebles, *Principles of Physical Cosmology*. Princeton: Princeton University Press, 1993, p. 3.

MOTIVATION

"The consequences of overclaiming the significance of certain theories are profound — the scientific method is at stake (see go.nature.com/hh7mm6). To state that a theory is so good that its existence supplants the need for data and testing in our opinion risks misleading students and the public as to how science should be done and could open the door for pseudoscientists to claim that their ideas meet similar requirements.

What to do about it? Physicists, philosophers and other scientists should hammer out a new narrative for the scientific method that can deal with the scope of modern physics. In our view, the issue boils down to clarifying one question: what potential observational or experimental evidence is there that would persuade you that the theory is wrong and lead you to abandoning it? If there is none, it is not a scientific theory.

Such a case must be made in formal philosophical terms. A conference should be convened next year [2015] to take the first steps. People from both sides of the testability debate must be involved.

In the meantime, journal editors and publishers could assign speculative work to other research categories — such as mathematical rather than physical cosmology — according to its potential testability. And the domination of some physics departments and institutes by such activities could be rethought[1,2].

The imprimatur of science should be awarded only to a theory that is testable. Only then can we defend science from attack."

– George Ellis & Joe Silk, "Defend the integrity of physics," *Nature* **516**, 331 (16 December 2014).

George Ellis

Joe Silk

1. Woit, P. *Not Even Wrong* (Cape, 2006).
2. Smolin, L. *The Trouble with Physics* (Penguin, 2006).

MOTIVATION

A SIMPLE idea underpins science: “trust, but verify”. Results should always be subject to challenge from experiment. That simple but powerful idea has generated a vast body of knowledge. Since its birth in the 17th century, modern science has changed the world beyond recognition, and overwhelmingly for the better.

But success can breed complacency. Modern scientists are doing too much trusting and not enough verifying—to the detriment of the whole of science, and of humanity.

Too many of the findings that fill the academic ether are the result of shoddy experiments or poor analysis (see article).

–Eds., “How Science goes wrong,” *The Economist* (19 October 2013)

“Theoretical physics is a developing subject and new physics may offer a variety of new cosmological applications. Finally, observations and theoretical understanding are always limited, hence even a quite credible world model has its limitations, too (in current cosmology 99.5% of the needed mass has unknown nature). These emphasize the importance of crucial observational tests as the only safe way to decide between alternative cosmological ideas.”

– Yurij Baryshev, “Paradoxes of cosmological physics in the beginning of the 21st century,” 30th Int’l Workshop on High Energy Physics, Protvino; arXiv:1501.01919 [physics.gen-ph] (4 January 2015).

MOTIVATION

The following seven slides are a preview of what this presentation is about...

Color denotes datapoint density.

The SDSS is the most important achievement in the history of astronomy.

Sloan Digital Sky Survey ☀ www.sdss.org

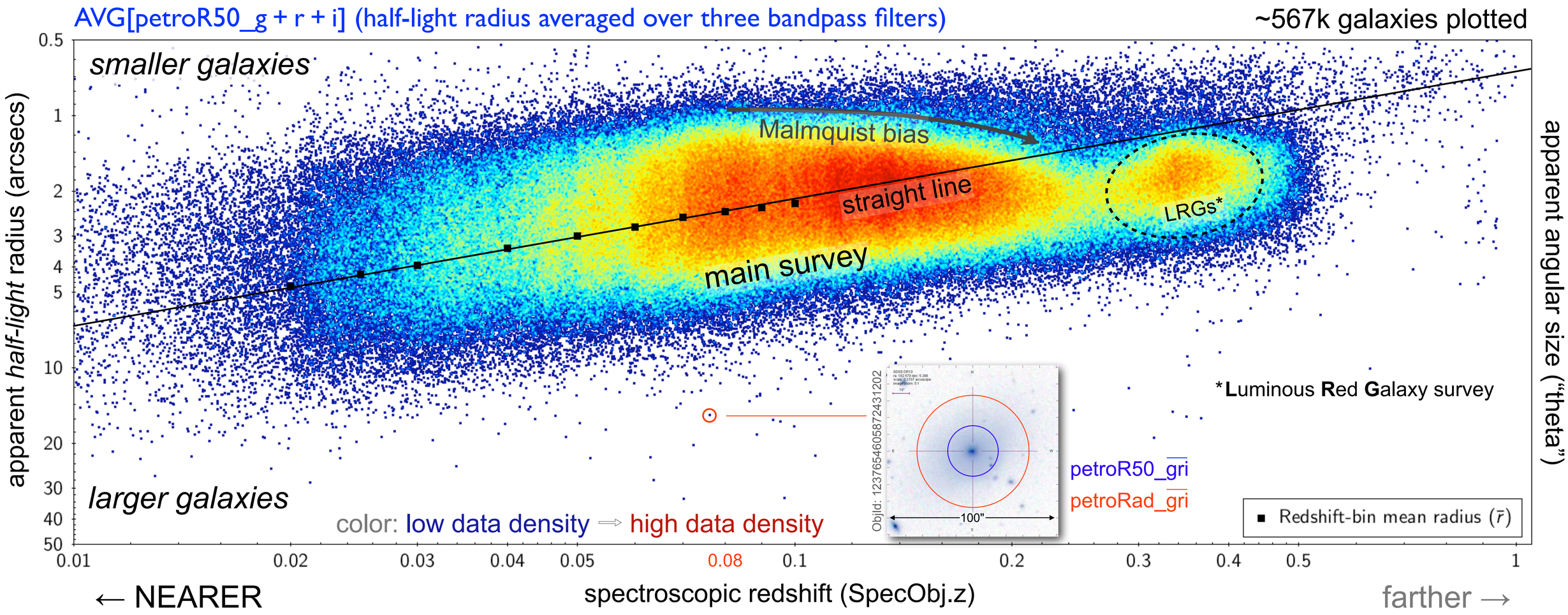
EARNEST ADVISORY

Cognitive dissonance is the mental stress experienced by an individual who is confronted by new information that conflicts with existing beliefs or ideas. People with weak constitutions are motivated to avoid information that is likely to increase it.

Because "it is the scientist's duty to attempt to disprove his conjectures" (K. Popper), a fundamental characteristic of a competent professional scientist is the ability to deal with this stress, just as an aviator must occasionally deal with the stress of a major malfunction (e.g., Hudson River emergency landing on 3 March 2010 by Capt. C. "Sully" Sullenberger). As this new information can potentially induce *extreme stress*, professional counseling is recommended for those affected.

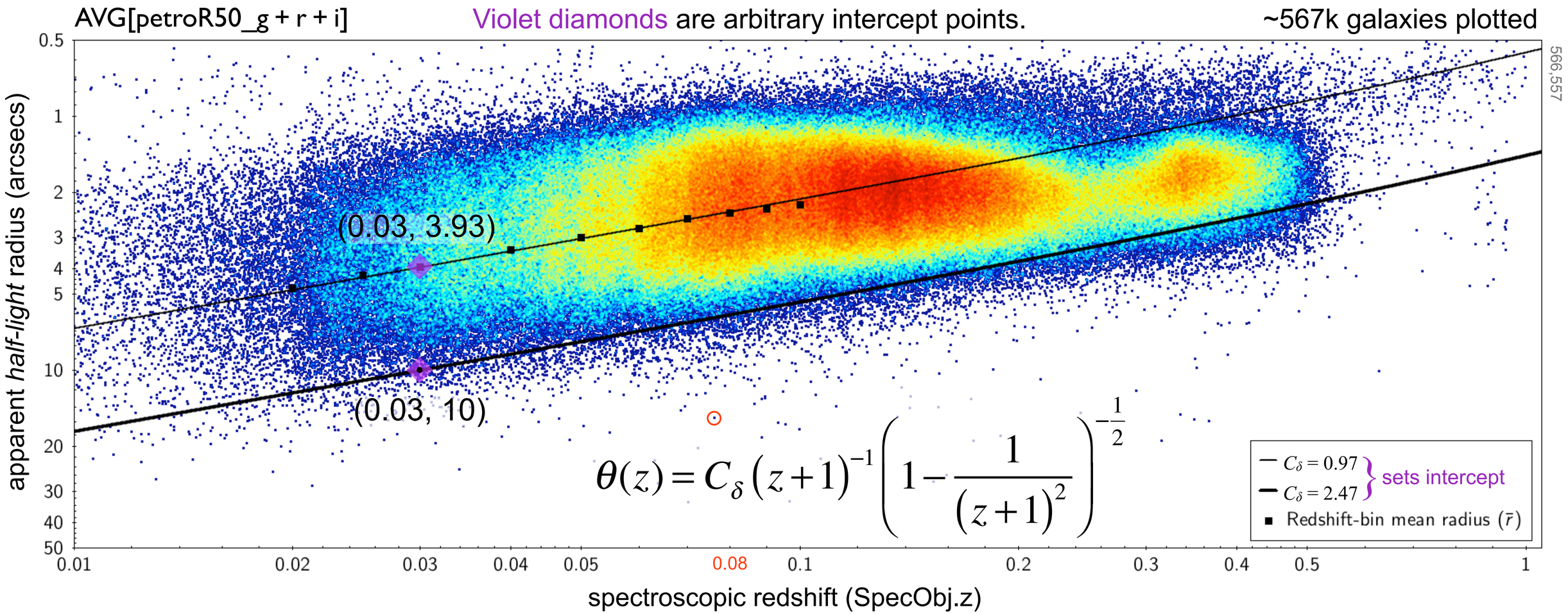
MOTIVATION

SDSS measurements of apparent angular galaxy size ("theta") versus spectroscopic redshift (z)



This empirical "theta-z" graph constitutes over 2.2 million (~567k × 4) distinct high-quality empirical measurements. The statistical nature of the data is intuitively obvious; the redshift-bin mean radius measurements [▪] represent a class of galaxies that are expected to be of approximately the same intrinsic size, yielding a cosmic "standard rod."

Predictive standard-rod curves according to the new theta-z formula shown [log-log plot]



This revolutionary predictive function clearly corresponds to the SDSS data *using no free parameters*. It is just one of several correlated *a priori** predictive formulas that all demonstrate similar predictive power in light of SDSS data.

* (derived from first principles)

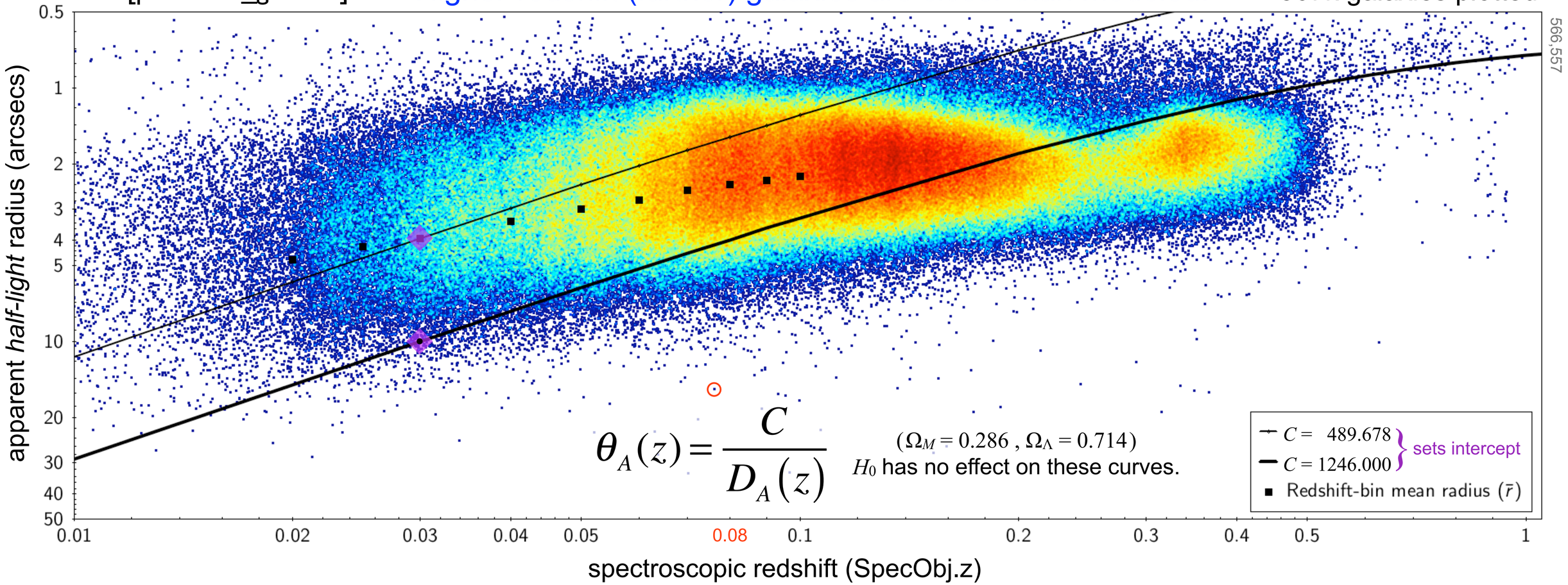
LCDM concordance cosmological model standard-rod curves (for comparison)

"**L**ambda **C**old **D**ark **M**atter"

AVG[petroR50_g + r + i]

Higher-redshift (farther) galaxies are closer than modeled.

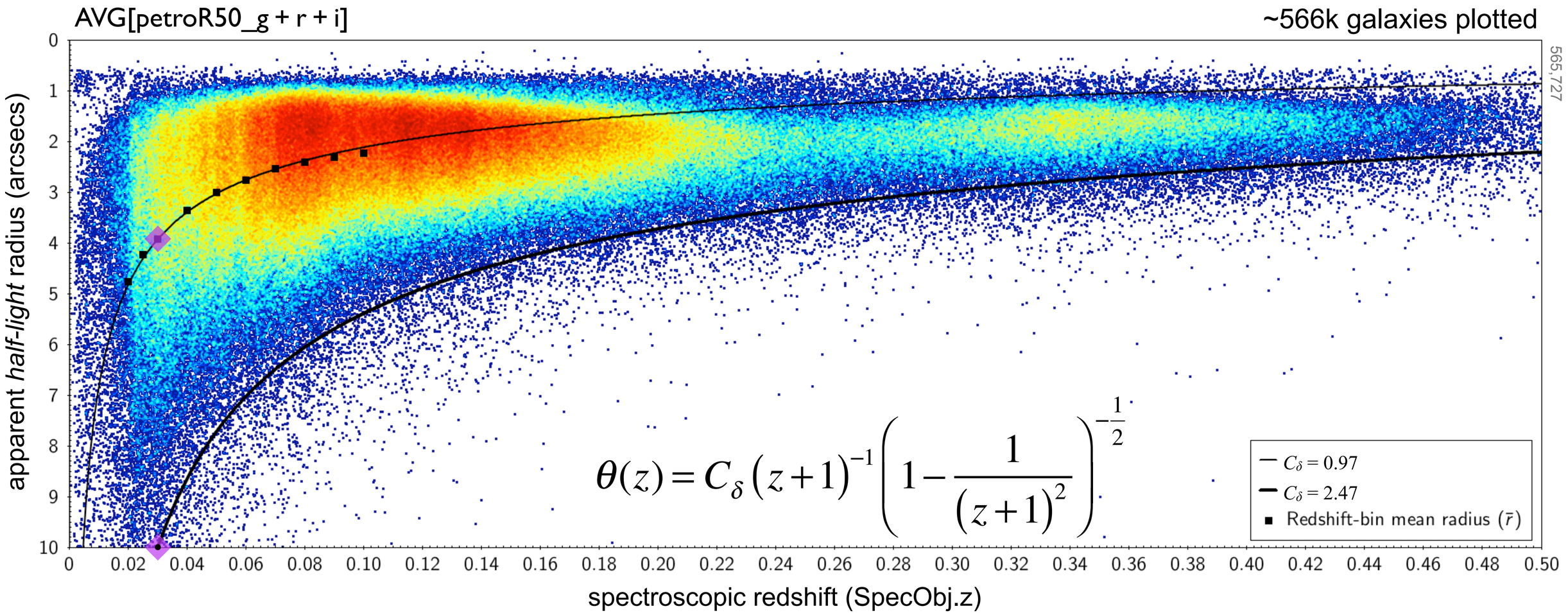
~567k galaxies plotted



This canonical function does not correspond to the empirical data, which implies that the prediction is incorrect. This single confrontation of theory with empirical evidence puts the standard cosmological model in jeopardy.

MOTIVATION

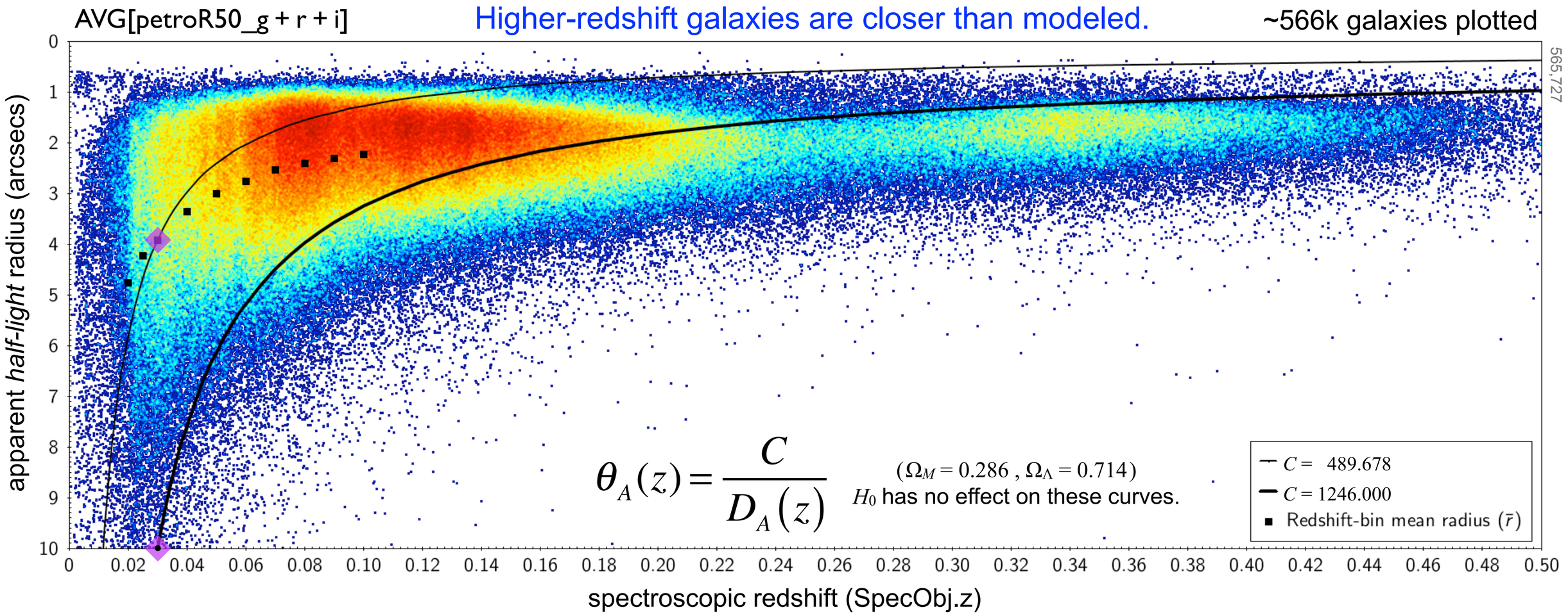
The identical data, intercepts, and *new predictive-formula* curves plotted with linear axes
$(0 \leq z \leq 0.5)$ & $(0 \leq r \leq 10 \text{ arcsecs})$



This revolutionary *a priori* predictive function clearly corresponds to the SDSS data *using no free parameters*.
This function rests on first principles; it is based on a subtle amendment to the general theory of relativity.

MOTIVATION

LCDM concordance cosmological model standard-rod curves (for comparison)



By itself, this graph is insufficient evidence to falsify the standard cosmological model, which requires the verification, *independent corroborating evidence* and superior predictive theory that are also provided herein.

MOTIVATION

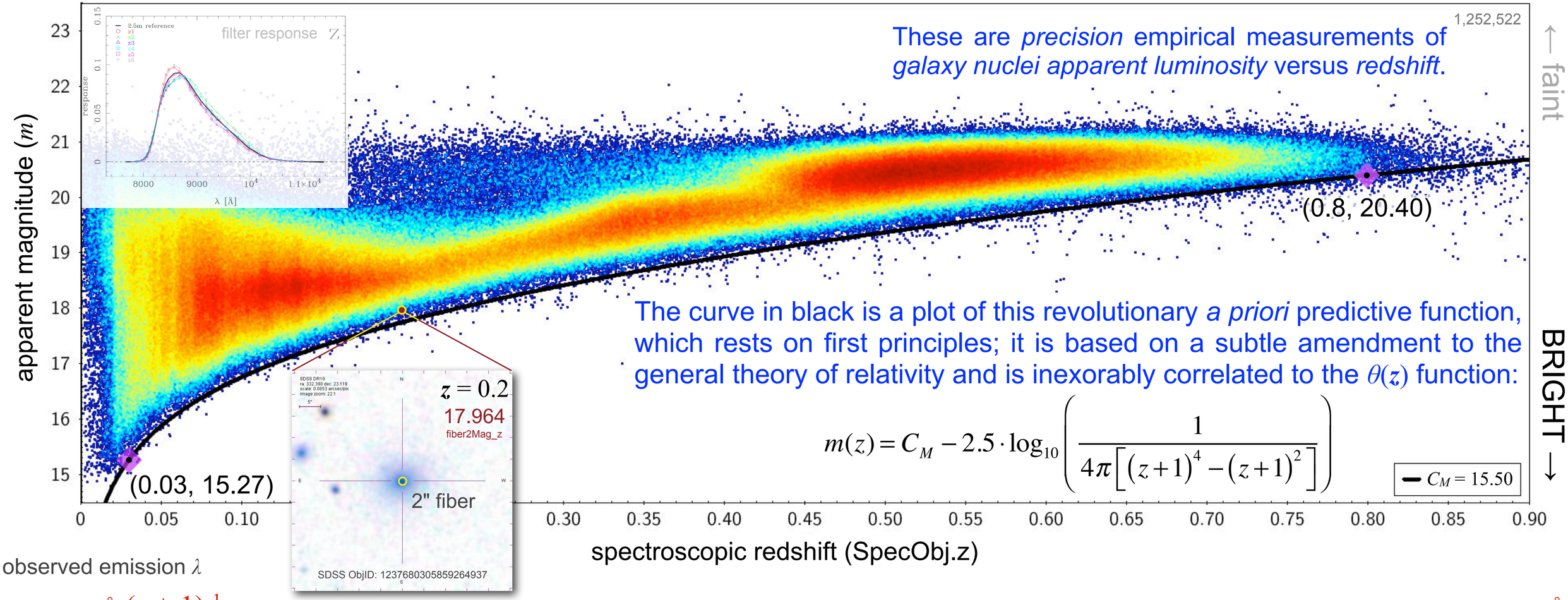
z′-band
$\lambda_{eff} \sim 0.89\ \mu m$

The '*brightest*'† *galactic nuclei* (no QSO* are selected), as measured in the infrared ($\lambda_{eff} \sim 8900$ Å) by optic fibers, constitute the baseline of this dataset.

† excluding outliers * **Q**uasi-**S**tellar **O**bjects

PhotoObj.fiber2Mag_z (<1% error)

~1.25M galaxies plotted



observed emission λ

λ_{min} 8200 Å $(z+1)^{-1} \approx$	6825	6300	5850	5475	5125	4825	4550	4325 Å
λ_{max} 9700 Å $(z+1)^{-1} \approx$	8075	7450	6925	6475	6075	5700	5400	5100 Å

SDSS filter response curve from Mamoru Doi et al. (2010); arXiv:1002.3701 [astro-ph.IM].

MOTIVATION

z′-band

$\lambda_{eff} \sim 0.89$ μm

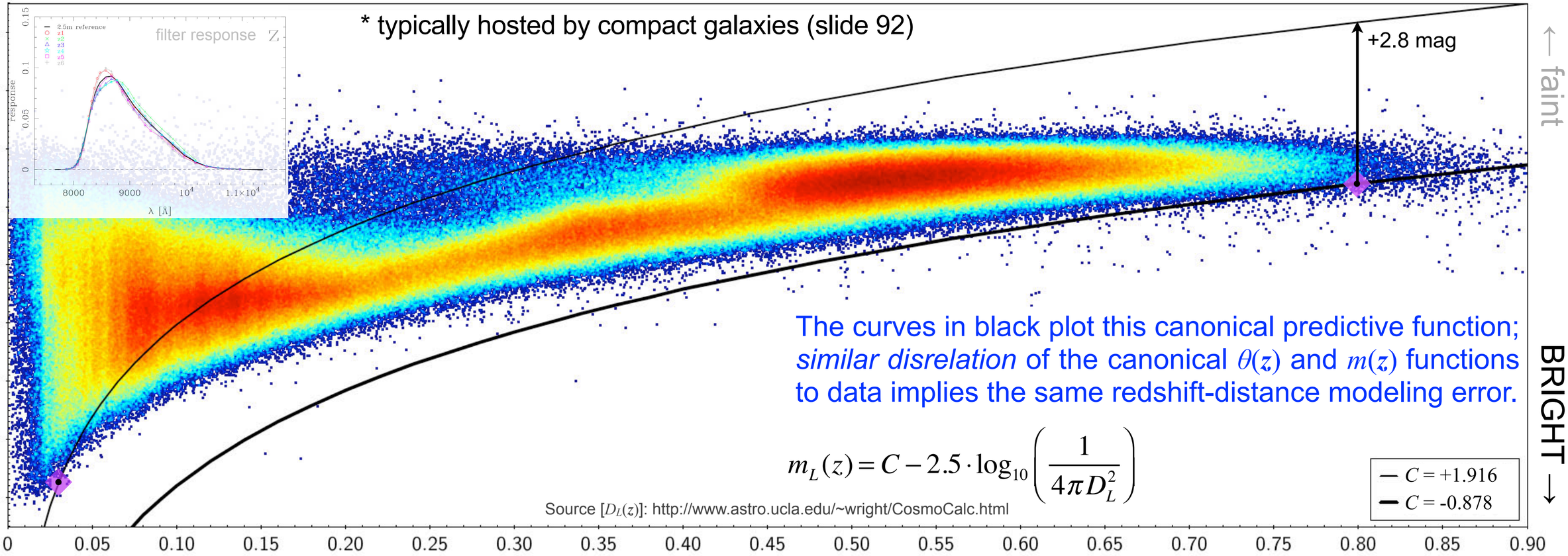
The relationship of the tiny SDSS optic fibers to the class of *compact* '*brightest*' galactic nuclei* is such that only very minor perspective corrections are required.

PhotoObj.fiber2Mag_z (<1% error)

Farther galaxies are closer than modeled.

~1.25M galaxies plotted

* typically hosted by compact galaxies (slide 92)



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SDSS filter response curve from Mamoru Doi et al. (2010); arXiv:1002.3701 [astro-ph.IM].

MOTIVATION

Rhetorical question: Is it scientifically reasonable to suppose that the observed relationships between the new *a priori* $\theta(z)$ and $m(z)$ predictions and the SDSS data are simply 'accidental'?*

"And where science gets *tough*, tough in the sense that you can be mistaken, even if you passionately believe something, is that a good scientific theory makes predictions and those predictions can be tested."[1]

– Lee Smolin, *Perimeter Institute for Theoretical Physics*

Lee Smolin

The pursuit of science requires sophisticated intellectual *and* emotional thinking; curiosity and inspiration in response to scientific criticism are the hallmark of a professional scientist. Fear, anger and other inappropriate defensive behavior may occur as instinctive responses to *tough* scientific challenges that have been emotionally misinterpreted as a personal attack. Intellectual discipline and professional ethics ought to override any such irrational responses, which include the choice to ignore or suppress criticism at the expense of scientific integrity.

1. Online Lecture: *The Nature of Space and Time* (1:05:50 / 1:28:25)
Note: The word "wrong" (verbatim) has been changed to "mistaken."

* Disciplined scientific thinking does not allow for the naïve idea that "anything is possible."

The tool implementing the mediation between theory and practice, between thought and observation, is mathematics. Mathematics builds the connecting bridges and is constantly enhancing their capabilities. Therefore it happens that our entire contemporary culture, in so far as it rests on intellectual penetration and utilization of nature, finds its foundations in mathematics.

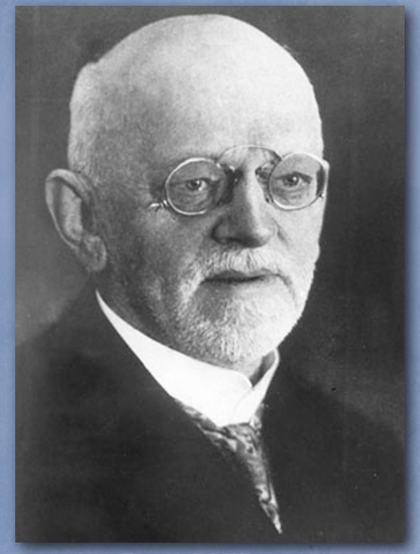
…

For us there is no ignorance, especially not, in my opinion, for the natural sciences.

Instead of this silly ignorance, on the contrary let our fate be:

"We must know, we will know."

– David Hilbert, *Preeminent 20th-century mathematician (1862–1943)*



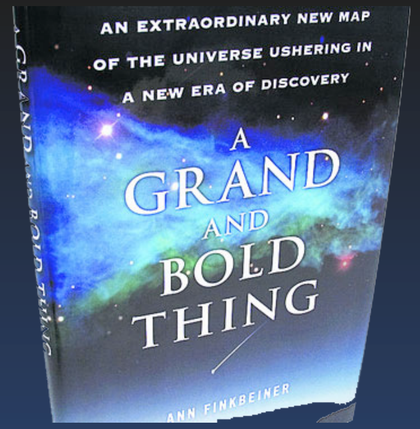
David Hilbert

Source: *Translation of an address given by David Hilbert in Königsberg*, Fall 1930; translation by Amelia and Joe Ball.

MOTIVATION

Both the mathematical physics and supporting empirical evidence presented in this document are definitive. The physics demonstrates remarkable predictive power enhanced by elegant formulas that contain no free parameters and rest exclusively on the basic principles underlying the general theory of relativity. The validity of the SDSS empirical data is ensured by its statistical nature.

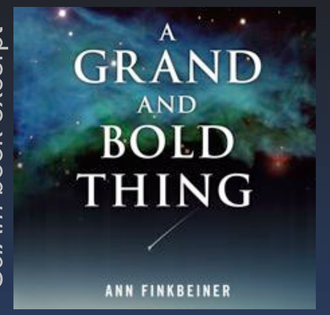
The foregoing graphs make it clear that the standard cosmological model is under terminal threat. Furthermore, it will be made obvious that purported 'precision measurements' supporting the Lambda-CDM consensus cosmological model were either model-driven or perhaps simply manufactured to conform with this ruling paradigm. Appeal to these reported measurements, which include Type Ia supernovae (SNe Ia) data and cosmic microwave background (CMB) data, in cursory rebuttal of the foregoing graphs has no scientific merit; this repudiation of the consensus model demands thoroughly-informed criticism.



Builders of the Sloan Digital Sky Survey

"The builders of the SDSS are those individuals whose contributions to project infrastructure make the exciting SDSS science possible. Specifically, these are the individuals who have contributed two years or more of effort to the infrastructure of the project writing pipeline software, building hardware, or through leadership and fundraising."

SciAm book excerpt



Click name for homepage or best reference.

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Source: http://classic.sdss.org/members/builders.html (April 2014)

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Tycho Brahe*
(1546 – 1601)

James Edward Gunn,

the person most responsible for enabling these new discoveries.

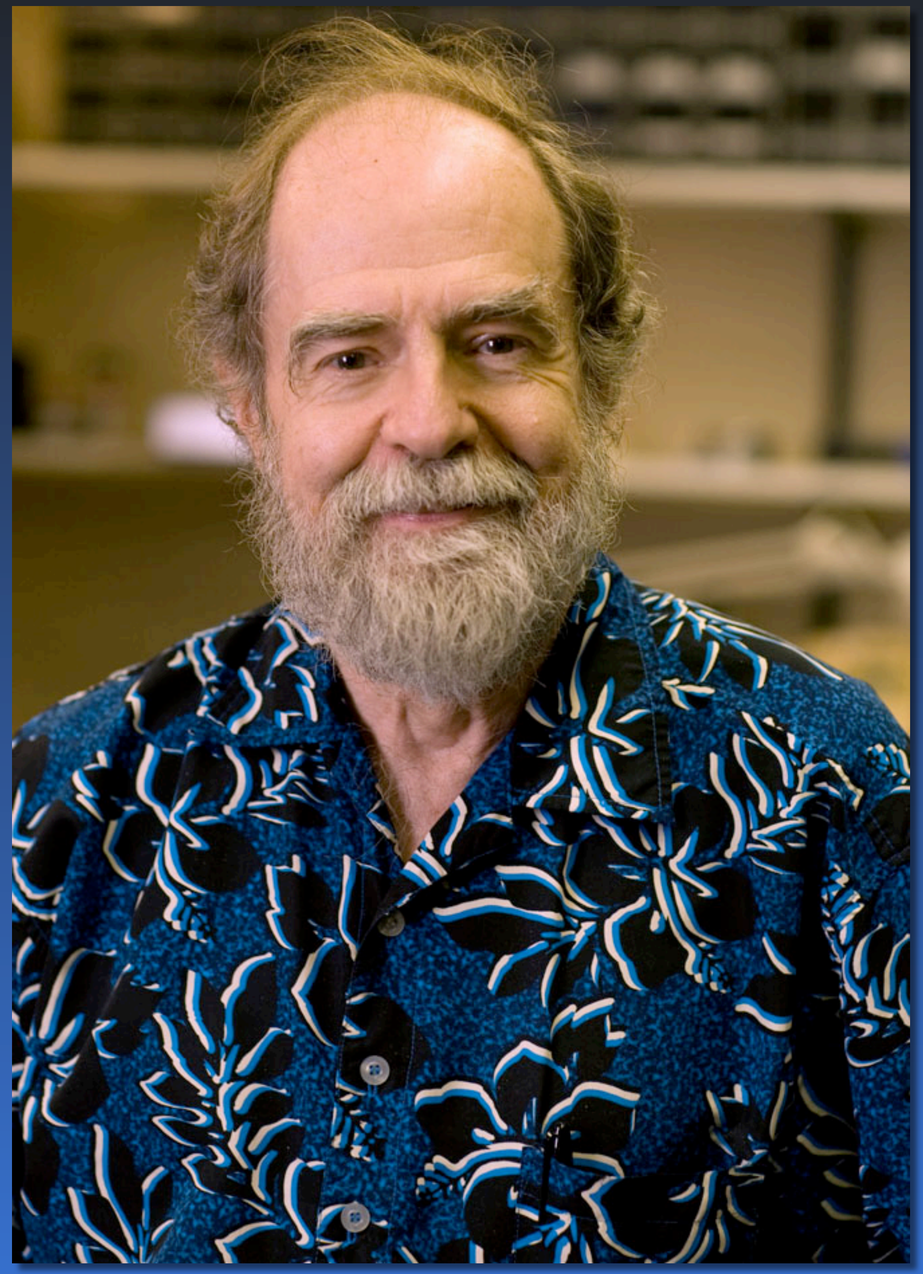

Photo 2009 by Brian Wilson • brianwilsonphotographer.com •

"In 1987 Gunn proposed putting an array of CCDs on a 2.5m-telescope and using it for both images and spectra, scanning the entire visible sky in about five years and building an enormous data archive which could be used for far more than his main interest, determining the three-dimensional structure of the universe of galaxies. This ultimately became the Sloan Digital Sky Survey, and Gunn devoted a large portion of his career to building it and making it work."

Source: http://www.phys-astro.sonoma.edu/brucemedalists/Gunn/index.html

- Recipient of the 2009 U.S. National Medal of Science
- Recipient of the Catherine Wolfe Bruce Medal Gold Award
- Recipient of the Gold Medal of the Royal Astronomical Society
- Eugene Higgins Professor of Astronomy at Princeton University

JAMES E. GUNN ET AL., "THE 2.5 m TELESCOPE OF THE SLOAN DIGITAL SKY SURVEY," THE ASTRONOMICAL JOURNAL, 131:2332-2359, 2006 April

* Tycho Brahe's accurate astronomical data allowed Johannes Kepler to discover that the planets moved in elliptical orbits, which led to Isaac Newton's universal law of gravitation. James Gunn's work proves to be of a similar nature.

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* * *