Covering the Cosmology Frontier:

Particle Astrophysics and Cosmology in the Review of Particle Physics

Director's review of the LBNL Physics Division
2013 May 8

Don Groom for PDG

On a single page, RPP 1986 included a table of *Astrophysical Constants*, including

$$40 \text{ km s}^{-1}\text{Mpc}^{-1} < H_0 < 100 \text{ km s}^{-1}\text{Mpc}^{-1}$$

$$\Lambda < 3 \times 10^{-52} \text{ m}^{-2}$$

$$\text{age of Universe} = 15 \pm 5 \text{ Gyr}$$

Planck 2013	67.3
	1.09
	13.82

. . . and a review: *Big Bang Cosmology*, by Keith Olive and Serge Rudaz

Unlike Kolb and Turner, Olive and Rudaz included Λ !

"Let me be clear:"© For almost 30 years, at least 90% of the credit for astrophysics in RPP must go to Keith Olive.

We anticipated progress: RPP 1996 included Chris Hogan's *The Hubble Constant*

In 1996 key rungs in the distance ladder were not available, especially the distance to the Large Magellanic Cloud.

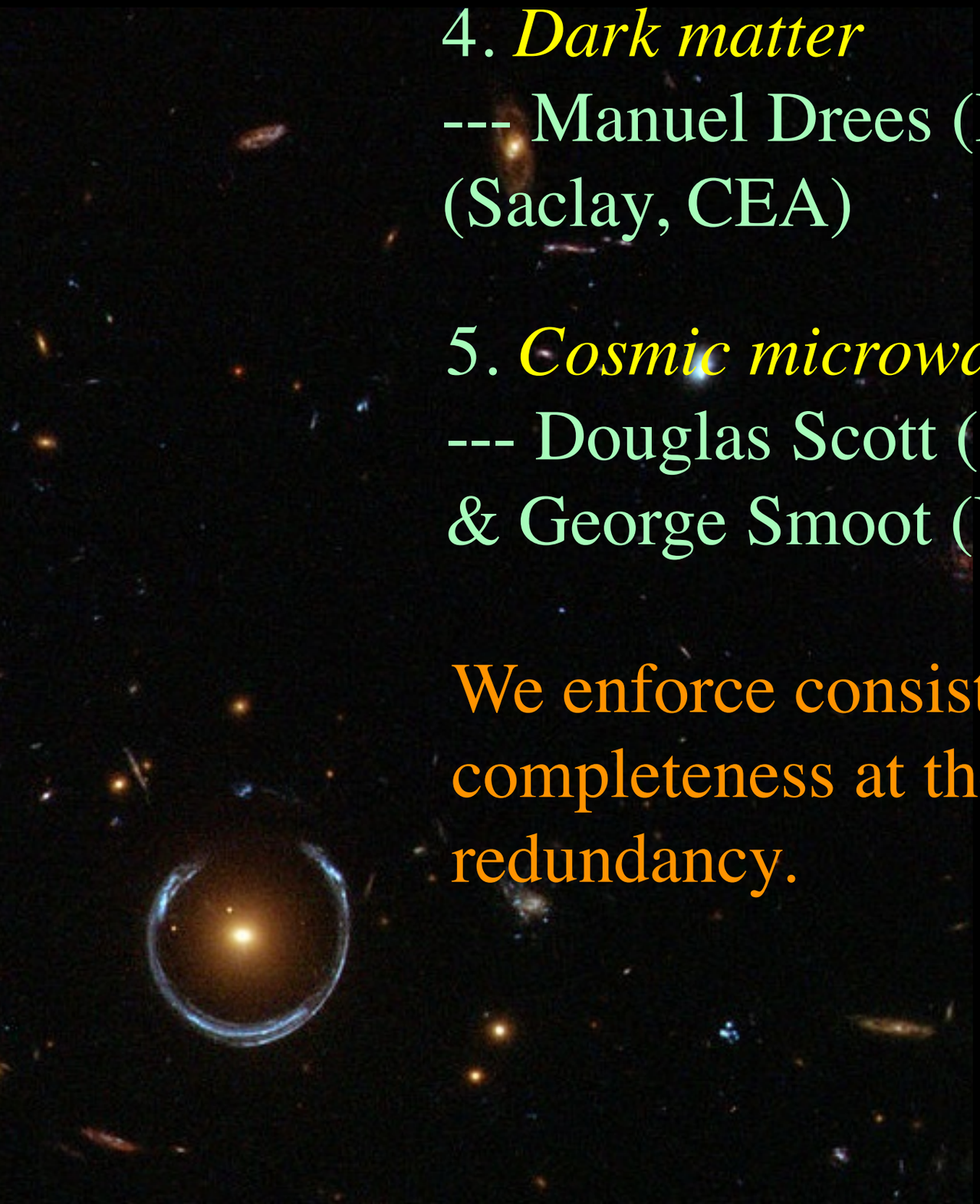
Frustratingly, at that time the distribution of LMC distance measurements had *two peaks*.

The staggering pace of discoveries in cosmology meant rapid changes in RPP coverage. Five core reviews were introduced in 1996:

1. *Big Bang Cosmology*
--- Keith Olive (Minnesota) & John Peacock (Edinburgh)
(This serves as a "motherboard" for the others:)

2. *Big-bang nucleosynthesis*
--- Brian Fields (Illinois) & Subir Sarkar (Oxford)
(To be joined by Paolo Molaro in RPP2014)

3. *The cosmological parameters (nee Hubble Constant)* --- Ofer Lahev (U College London) & Andrew Liddle (Sussex)



4. *Dark matter*

--- Manuel Drees (Bonn) & Gilles Gerbier (Saclay, CEA)

5. *Cosmic microwave background*

--- Douglas Scott (British Columbia) & George Smoot (UCB/LBNL)

We enforce consistency as well as completeness at the expense of some redundancy.

In 2014 a new review will be added to this group:

6. *Dark energy*

--- David Weinberg (Ohio), Martin White (Berkeley, LBNL), and Michael Mortonson (LBNL)

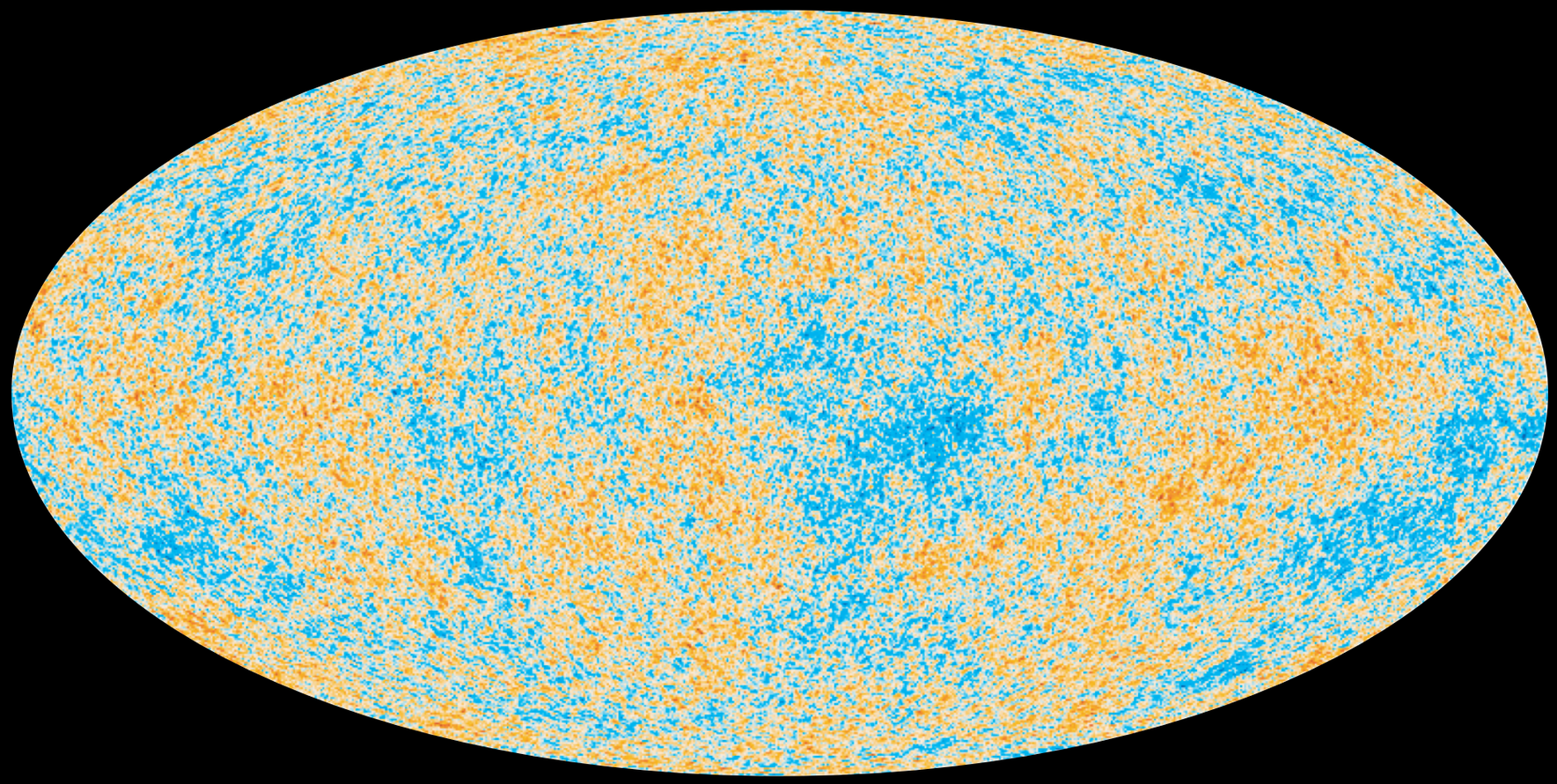
The core group is bracketed by two closely related reviews:

0. *Experimental tests of general relativity*
--- Thibault Damour

7. *Cosmic rays*
--- Jim Matthews and Jim Beatty
(to be joined by Scott Wakely in RPP2014)

and there is a two-page *Table of astrophysical constants and parameters*: top half units, Solar System, and Galaxy; bottom half cosmology with values from the Reviews

After Vernal Equinox 2013 the sky looked different:



Only minor parameter updates, but only the concordance model 6-parameter ΛCDM is needed.

As in HEP, *nothing* (so far) beyond the Standard Model!

PDG breakout May 8

SUM OF THE NEUTRINO MASSES, m_{tot}

(Defined in the above note), of effectively stable neutrinos (i.e., those with mean lives greater than or equal to the age of the universe). These papers assumed Dirac neutrinos. When necessary, we have generalized the results reported so they apply to m_{tot}. For other limits, see SZALAY 76, VYSOTSKY 77, BERNSTEIN 81, FREESE 84, SCHRAMM 84, and COWSIK 85.

VALUE (eV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 0.81	95	[57] SAITO	11	COSM	SDSS
< 0.44	95	[58] HANNESTAD	10	COSM	
< 0.6	95	[59] SEKIGUCHI	10	COSM	
< 0.28	95	[60] THOMAS	10	COSM	
< 1.1		[61] ICHIKI	09	COSM	
< 1.3	95	[62] KOMATSU	09	COSM	WMAP
< 1.2		[63] TERENO	09	COSM	
< 0.33		[64] VIKHLININ	09	COSM	
< 0.28		[65] BERNARDIS	08	COSM	
< 0.17–2.3		[66] FOGLI	07	COSM	
< 0.42	95	[67] KRISTIANSEN	07	COSM	
< 0.63–2.2		[68] ZUNCKEL	07	COSM	
< 0.24	95	[69] CIRELLI	06	COSM	
< 0.62	95	[70] HANNESTAD	06	COSM	
< 1.2		[71] SANCHEZ	06	COSM	
< 0.17	95	[69] SELJAK	06	COSM	
< 2.0	95	[72] ICHIKAWA	05	COSM	
< 0.75		[73] BARGER	04	COSM	
< 1.0		[74] CROTTY	04	COSM	
< 0.7		[75] SPERGEL	03	COSM	WMAP
< 0.9		[76] LEWIS	02	COSM	
< 4.2		[77] WANG	02	COSM	CMB
< 2.7		[78] FUKUGITA	00	COSM	
< 5.5		[79] CROFT	99	ASTR	Ly α power spec
<180		SZALAY	74	COSM	
<132		COWSIK	72	COSM	
<280		MARX	72	COSM	
<400		GERSHTEIN	66	COSM	

The main astrophysics visibility in the Full Listings are limits on sum of neutrino masses . . .

Planck 2013 + HighL + WMAP + BAO:

$$\sum m_\nu < 0.23 \text{ eV}$$

(or 6 other results, ranging up to < 0.98 eV, depending on data combinations)

+ many footnotes about caveats, priors, etc.

Limits from Astrophysics and Cosmology

Number of Light ν Types

("light" means < about 1 MeV). See also OLIVE 81. For a review of limits based on Nucleosynthesis, Supernovae, and also on terrestial experiments, see DENEGRI 90. Also see "Big-Bang Nucleosynthesis" in this *Review*.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 4.08	95	MANGANO	11		BBN
$0.9 < N_\nu < 8.2$		[3] ICHIKAWA	07	COSM	
$3 < N_\nu < 7$	95	[4] CIRELLI	06	COSM	
$2.7 < N_\nu < 4.6$	95	[5] HANNESTAD	06	COSM	
$3.6 < N_\nu < 7.4$	95	[4] SELJAK	06	COSM	
< 4.4		[6] CYBURT	05	COSM	
< 3.3		[7] BARGER	03C	COSM	
$1.4 < N_\nu < 6.8$		[8] CROTTY	03	COSM	
$1.9 < N_\nu < 6.6$		[8] PIERPAOLI	03	COSM	
$2 < N_\nu < 4$		LISI	99		BBN
< 4.3		OLIVE	99		BBN
< 4.9		COPI	97		Cosmology
< 3.6		HATA	97B		High D/H quasar abs.
< 4.0		OLIVE	97		BBN; high ^{4}He and ^{7}Li
< 4.7		CARDALL	96B	COSM	High D/H quasar abs.
< 3.9		FIELDS	96	COSM	BBN; high ^{4}He and ^{7}Li
< 4.5		KERNAN	96	COSM	High D/H quasar abs.
< 3.6		OLIVE	95		BBN; ≥ 3 massless ν
< 3.3		WALKER	91		Cosmology
< 3.4		OLIVE	90		Cosmology
< 4		YANG	84		Cosmology
< 4		YANG	79		Cosmology
< 7		STEIGMAN	77		Cosmology
		PEEBLES	71		Cosmology
<16		[9] SHVARTSMAN	69		Cosmology
		HOYLE	64		Cosmology

. . . and the number of light neutrino types

Planck 2013 + HighL + WMAP + BAO: $N_{\rm eff} = 3.30 \pm 0.27$

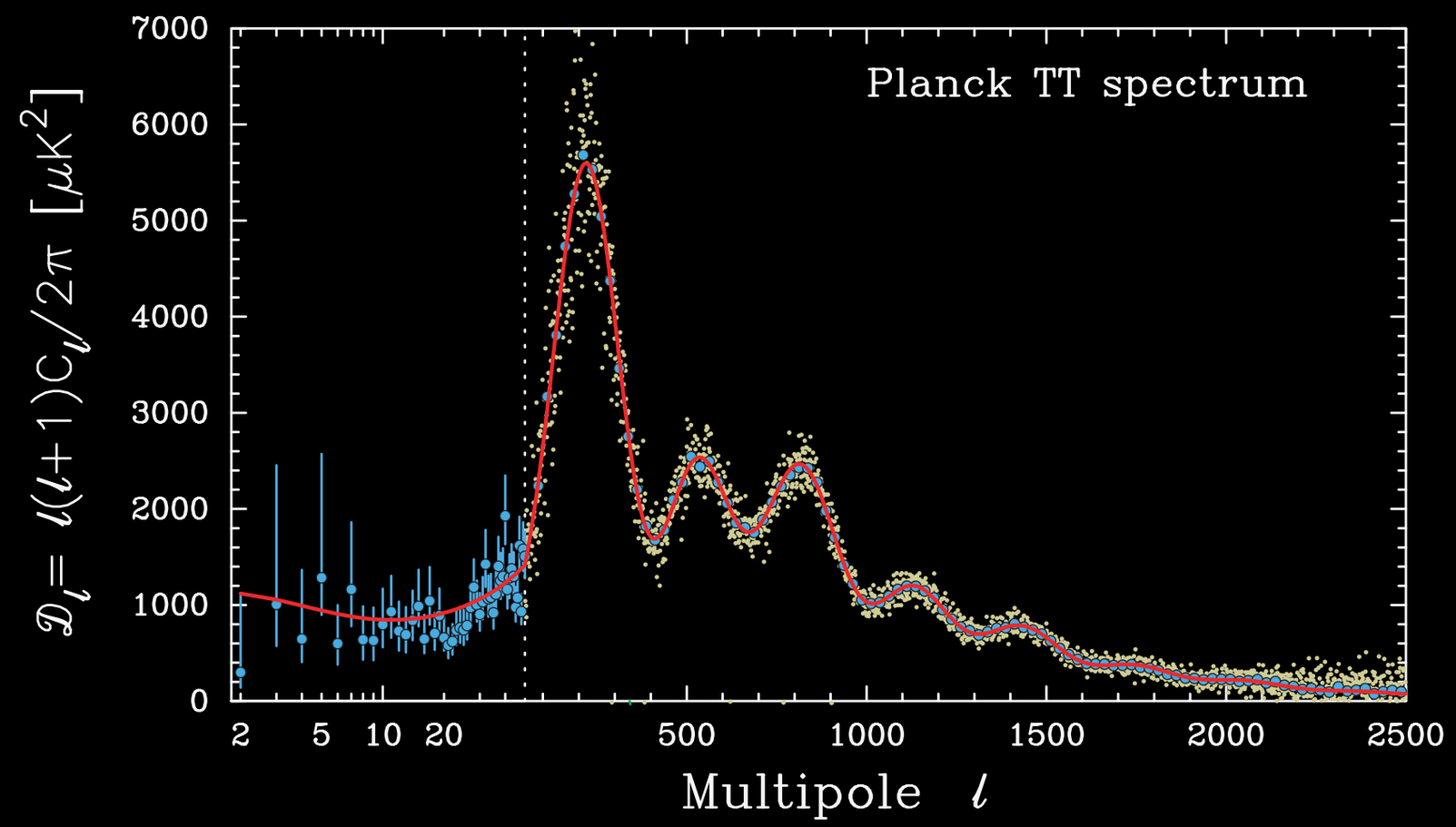
(At last the astrophysicists got it right: SM expects 3.046 "due to non-instantaneous decoupling corrections")

+ many footnotes about caveats, priors, etc.

Conclusions:

Precision cosmology is providing torrents of detail

Stand by for a vastly improved astroparticle treatment in RPP2014



Extra slides from here on

PDG particle data group

Director's review of the LBNL Physics Division 7-8 May 2013

PDG breakout May 8

BERKELEY LAB

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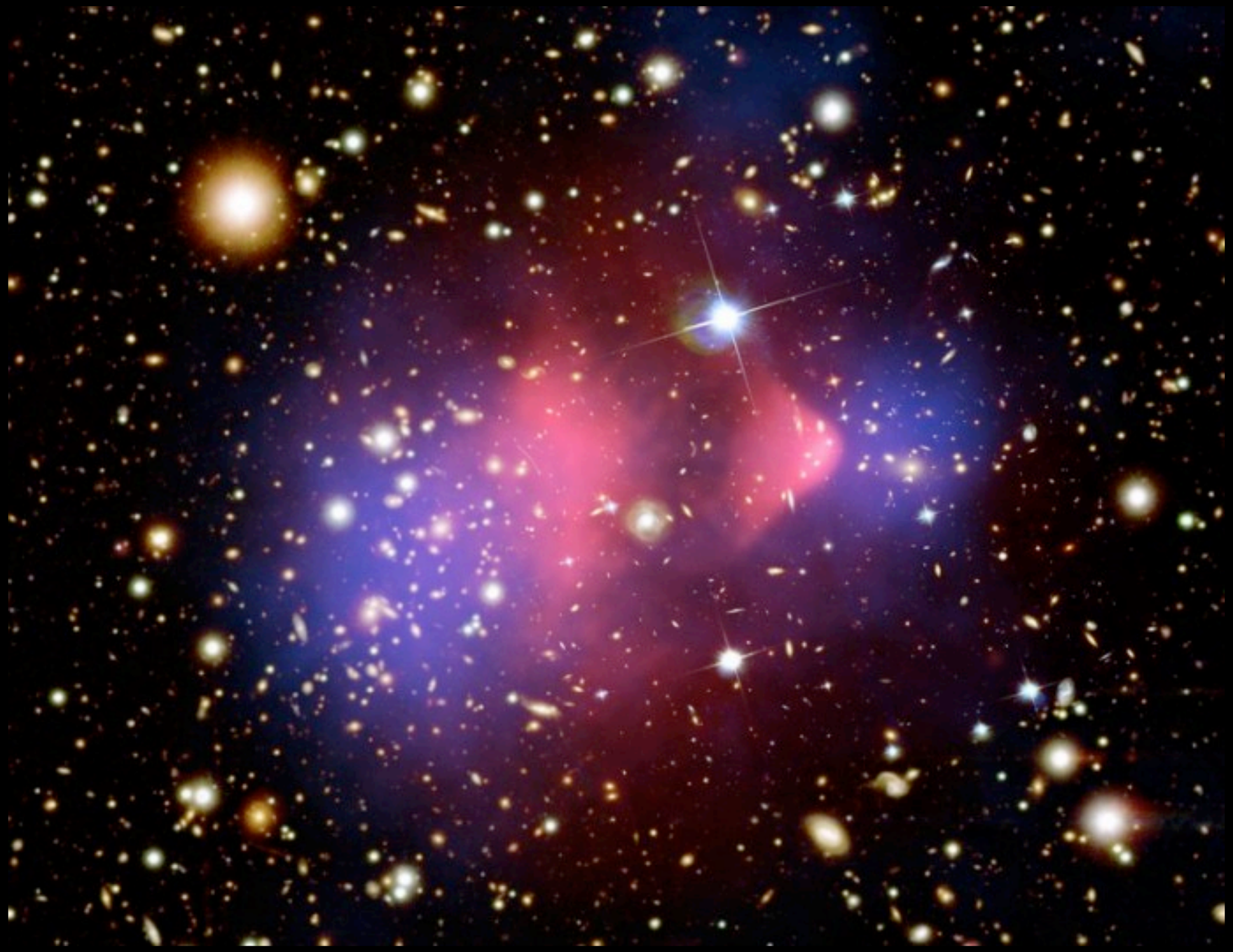

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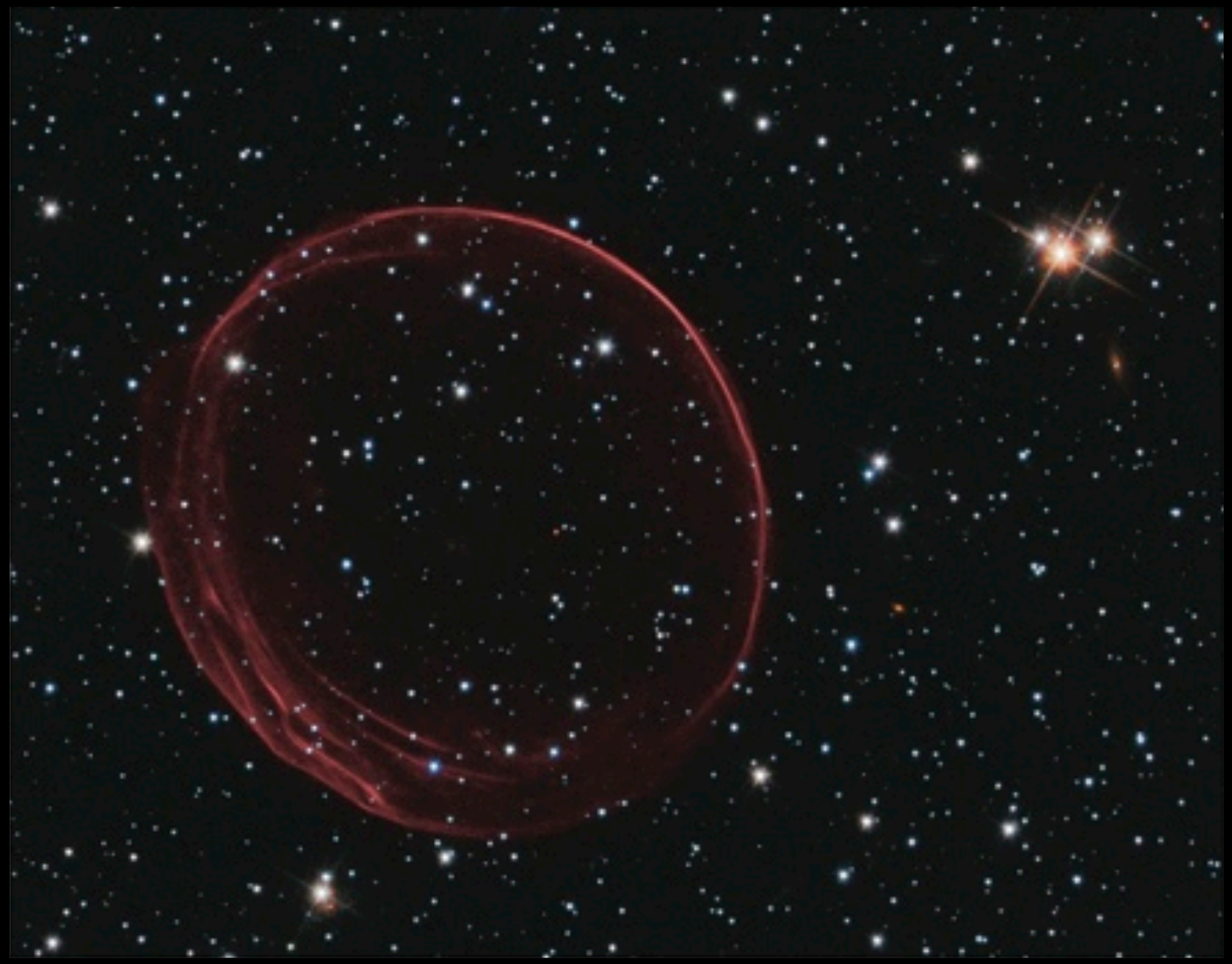
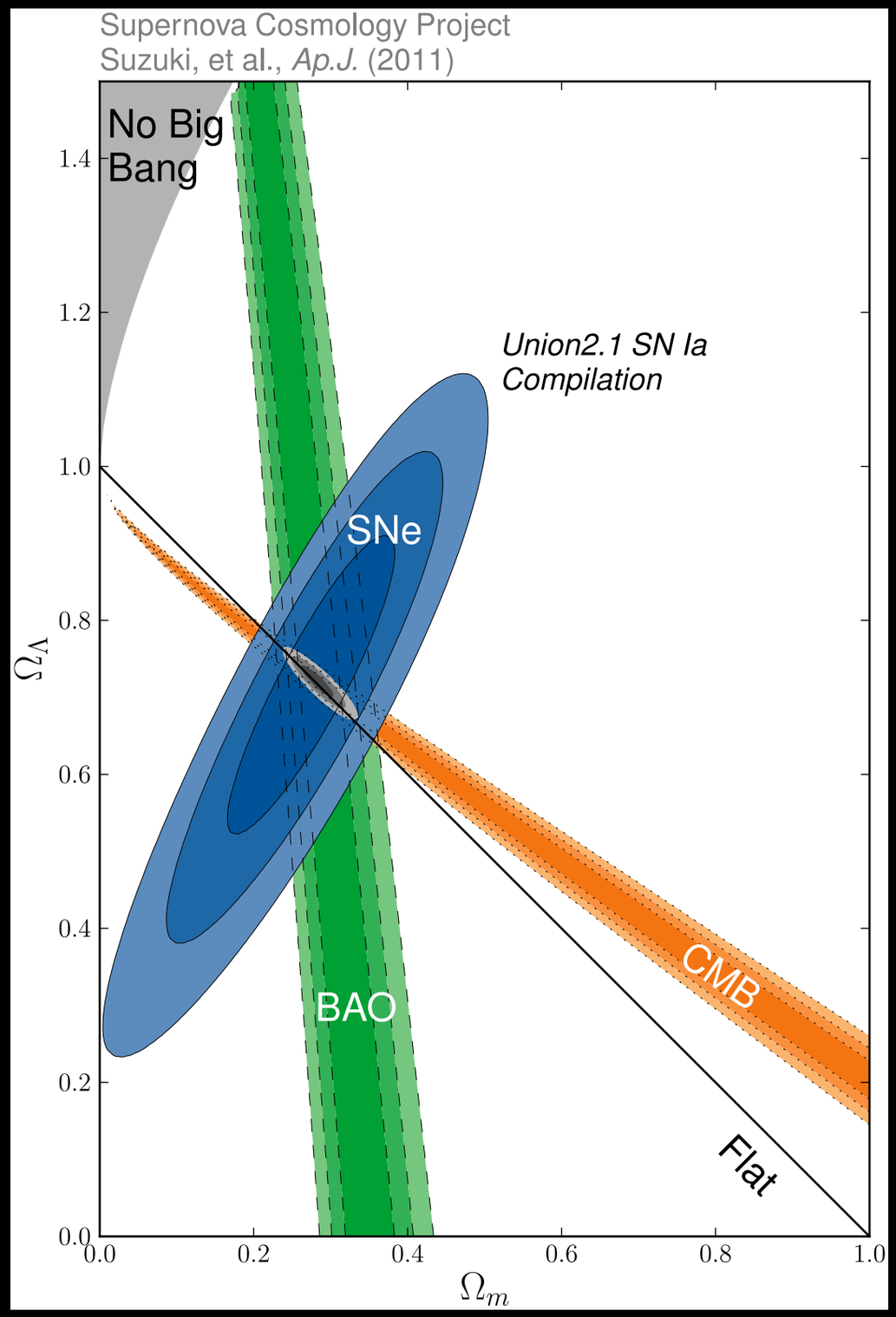
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