Phenomenology of Dark Matter

Felix Kling

Course Announcement

Phenomenology of Dark Matter

by Dr. Felix Kling (DESY, Hamburg)

Course description: Astronomical observations have shown that the known forms of matter, such as stars or gas clouds, make up only a small fraction of the matter content of the universe. Instead, about 85% of the universe's matter is made of a new form of matter, called dark matter, that does not emit light and whose presence could only be inferred through its gravitational impact. The existence of dark matter provides clear evidence that the Standard Model of particle physics is incomplete. Therefore, understanding the particle nature of dark matter is one of the most important questions in ongoing particle physics research. This lecture will provide an introduction to dark matter, reviewing the evidence for its existence, providing an overview on the landscape of proposed dark matter model and production paradigms, and present strategies to search for particle dark matter.

- Review of cosmology and evidence for Dark Matter
- Weakly Interacting Massive Particle Dark Matter and Thermal Freezout
- Axions and Ultralight Dark Matter
- Laboratory Searches for Dark Matter

Prerequisites: Basic knowledge in Quantum Field Theory, Particle Physics and the Standard Model.

Organization:

Where? Sala Prof. Jayme Tiomno (3056), DFMA, IFUSP

When? 18/02-18/03, Tuesdays and Thursdays, **2pm-4pm**.

References:

- **An Introduction to Particle Dark Matter**. Book by Stefano Profumo. World Scientific (2017). ISBN: 9781786340009.
- **TASI lectures on dark matter models and direct detection**. Lecture notes by Tongyan Lin. Available under https://arxiv.org/abs/1904.07915
- **Yet Another Introduction to Dark Matter**. Lecture notes by Martin Bauer and Tilman Plehn. Available under https://arxiv.org/abs/1705.01987
- **TASI Lectures on the Strong CP Problem and Axions**. Lecture notes by Anson Hook. Available under https://arxiv.org/abs/1812.02669
- **Cosmology of axion dark matter**. Topical Review by Ciaran A. J. O'Hare. Available at arxiv.org/abs/2403.17697

You can get credit points for this lecture

Grade will be based on homework and final project.

Contact Email:
felix.kling@desy.de

Lecture Dates and Outline

FEBRUARY						
S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	

MARCH						
S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

18. & 20. Feb: evidence and overview

26. & 27. Feb: thermal freeze-out DM

3.-7. Mar: carnival week

11. & 13. March: axion DM

18. & 20. March: Project Presentations

Final Project

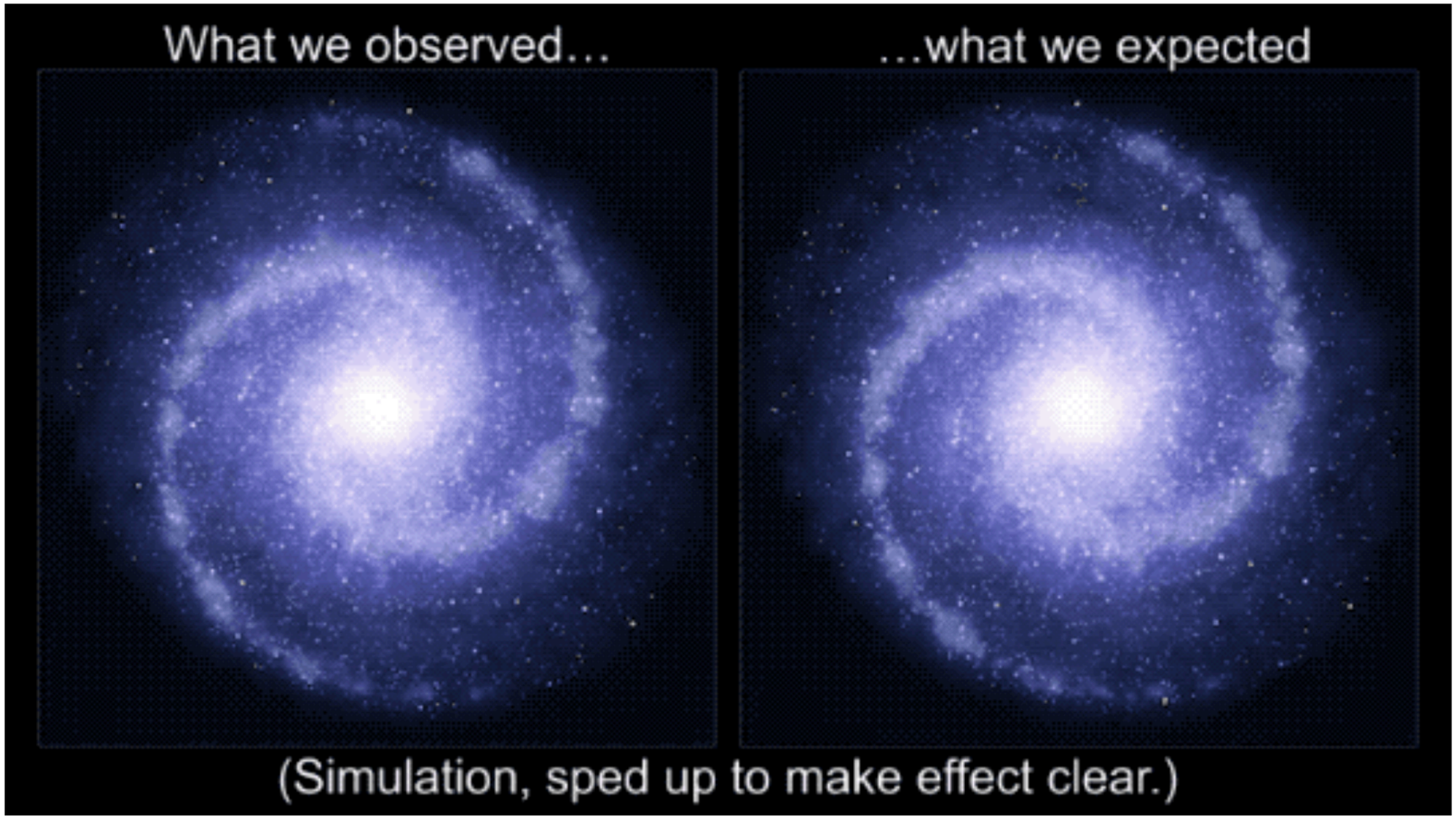
Idea is to have ~6 groups that each give a ~20min presentation on a DM related topic of their choice.

<u>Topics</u>

- primordial black holes
- sterile neutrino DM
- DM in SUSY
- direct direction
- indirect detection
- accelerator searches

Goal: decide groups/topic by Thursday.

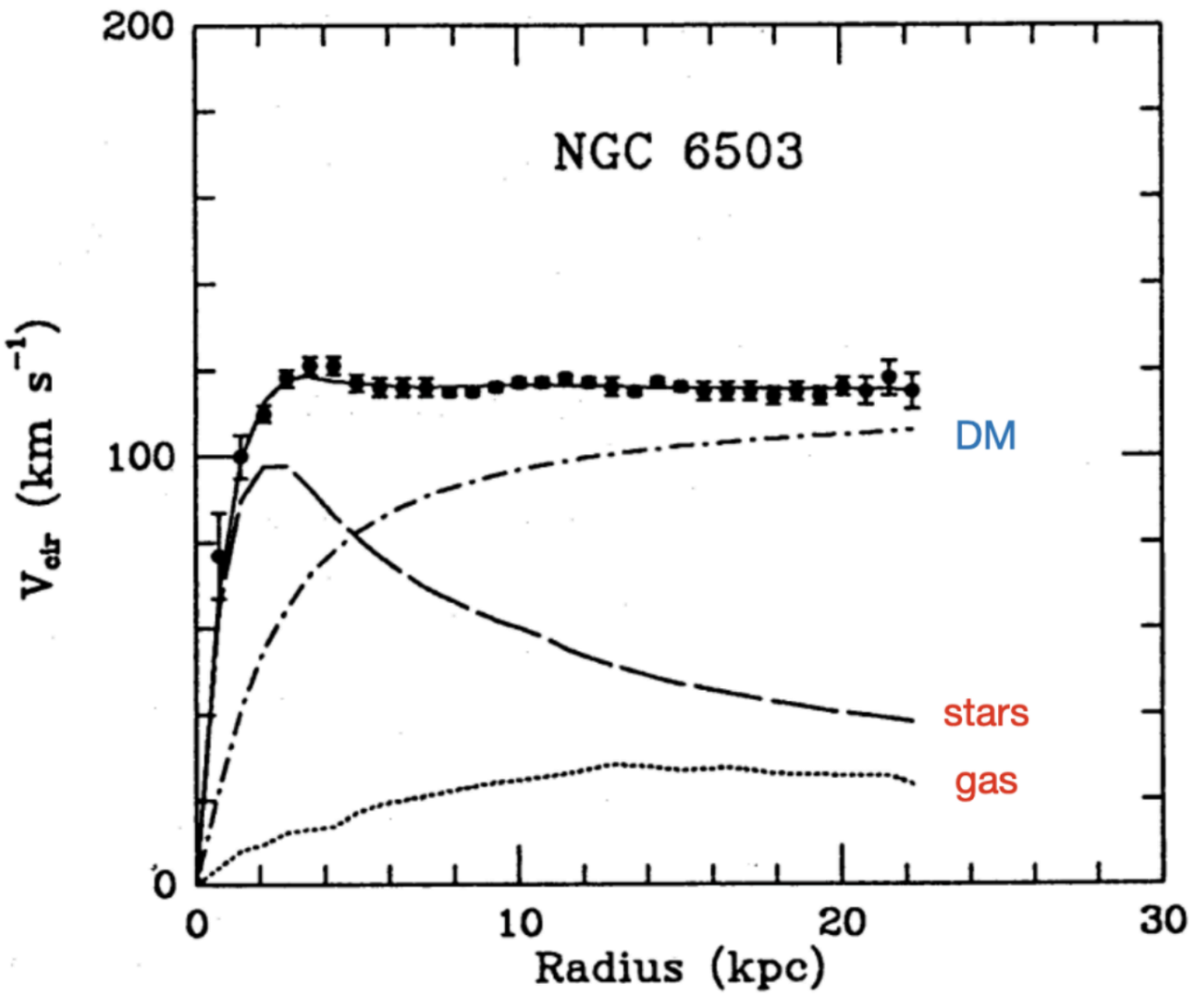
Rotation Curves



Source: NASA

https://commons.wikimedia.org/wiki/File:Galaxy_rotation_under_the_influence_of_dark_matter.ogv

Rotation Curves



Begeman et al 1991

The circular velocity at the radial position *R* is

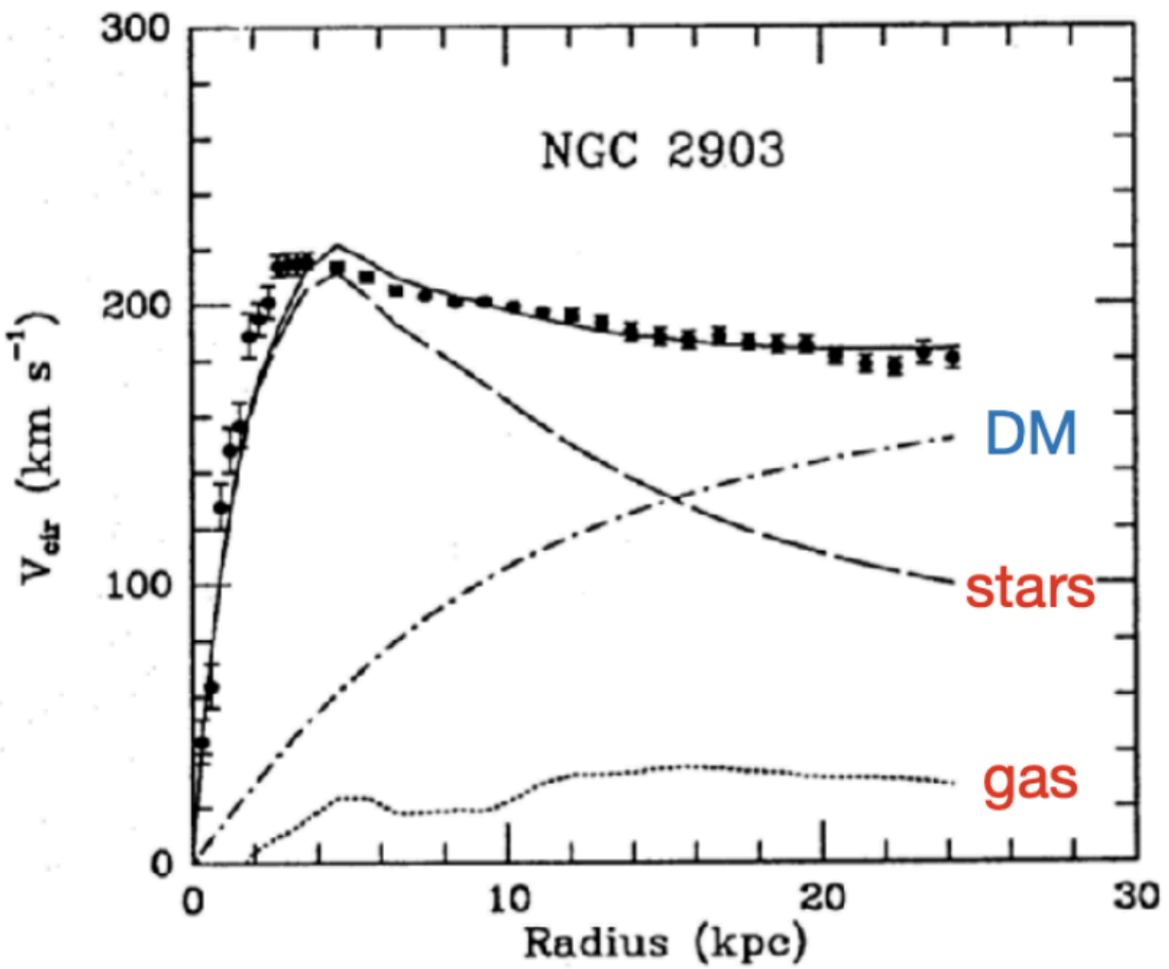
$$v_c(R) = \sqrt{\frac{GM(R)}{R}}$$

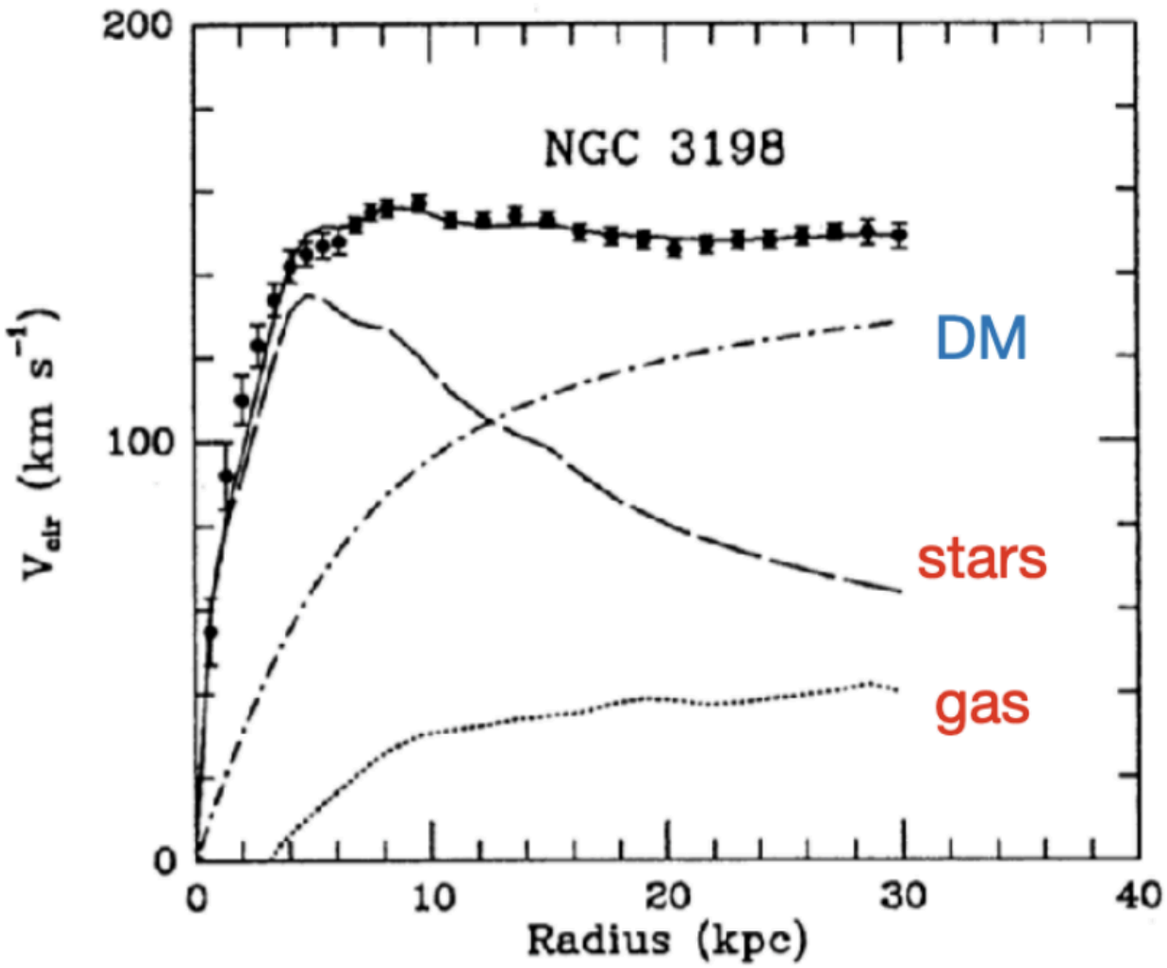
If *R > size of system*

the circular velocity is expected to scale

$$v_c(R) \propto 1/R^{1/2}$$

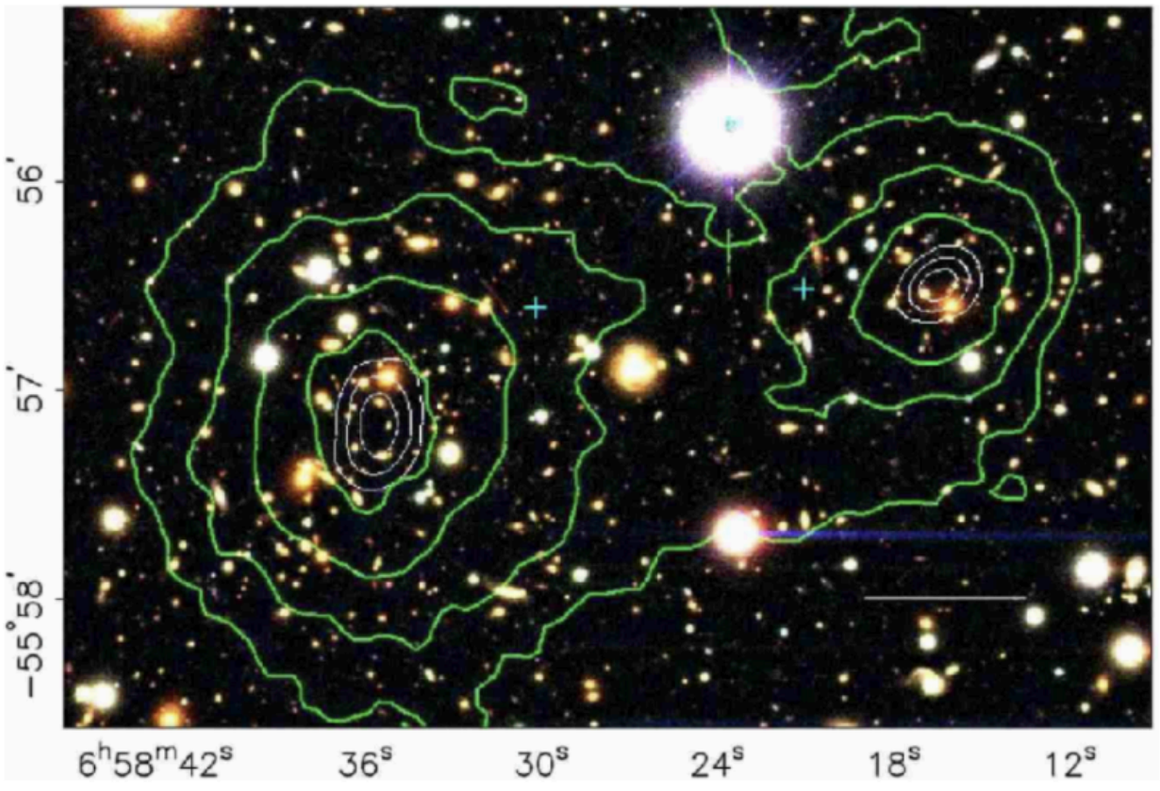
Rotation Curves

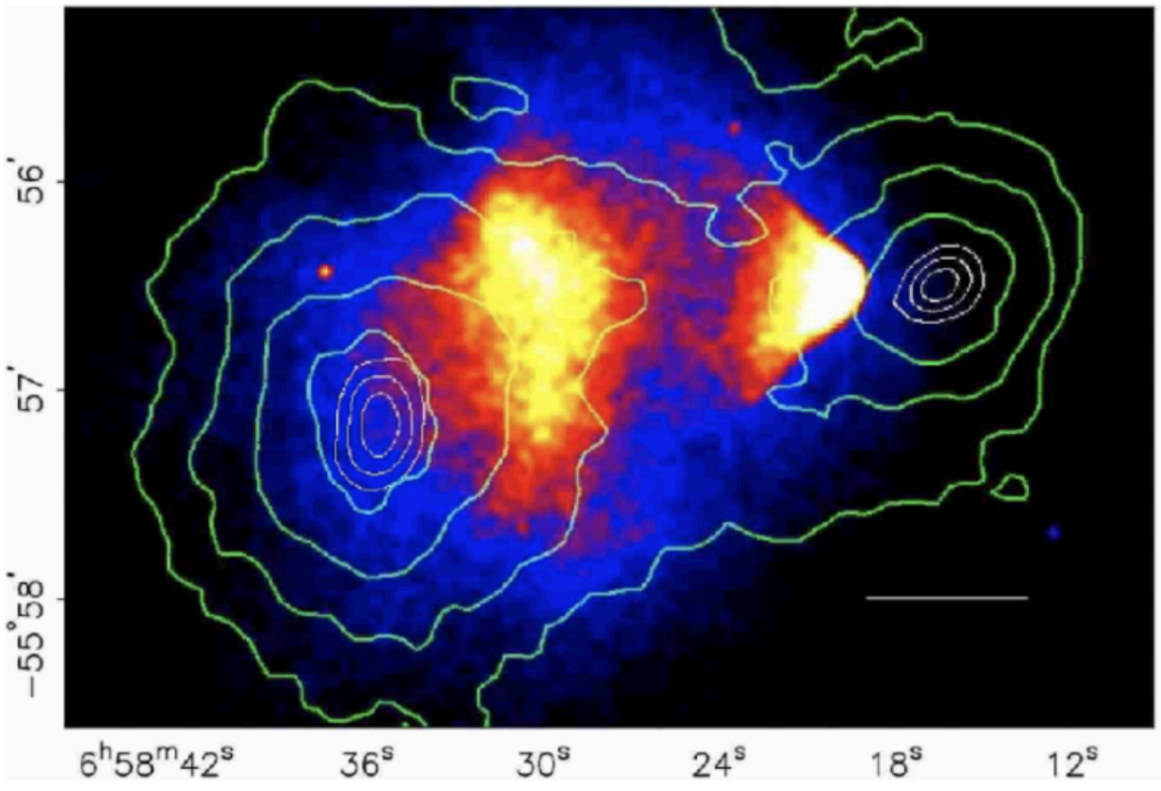




Begeman et al 1991

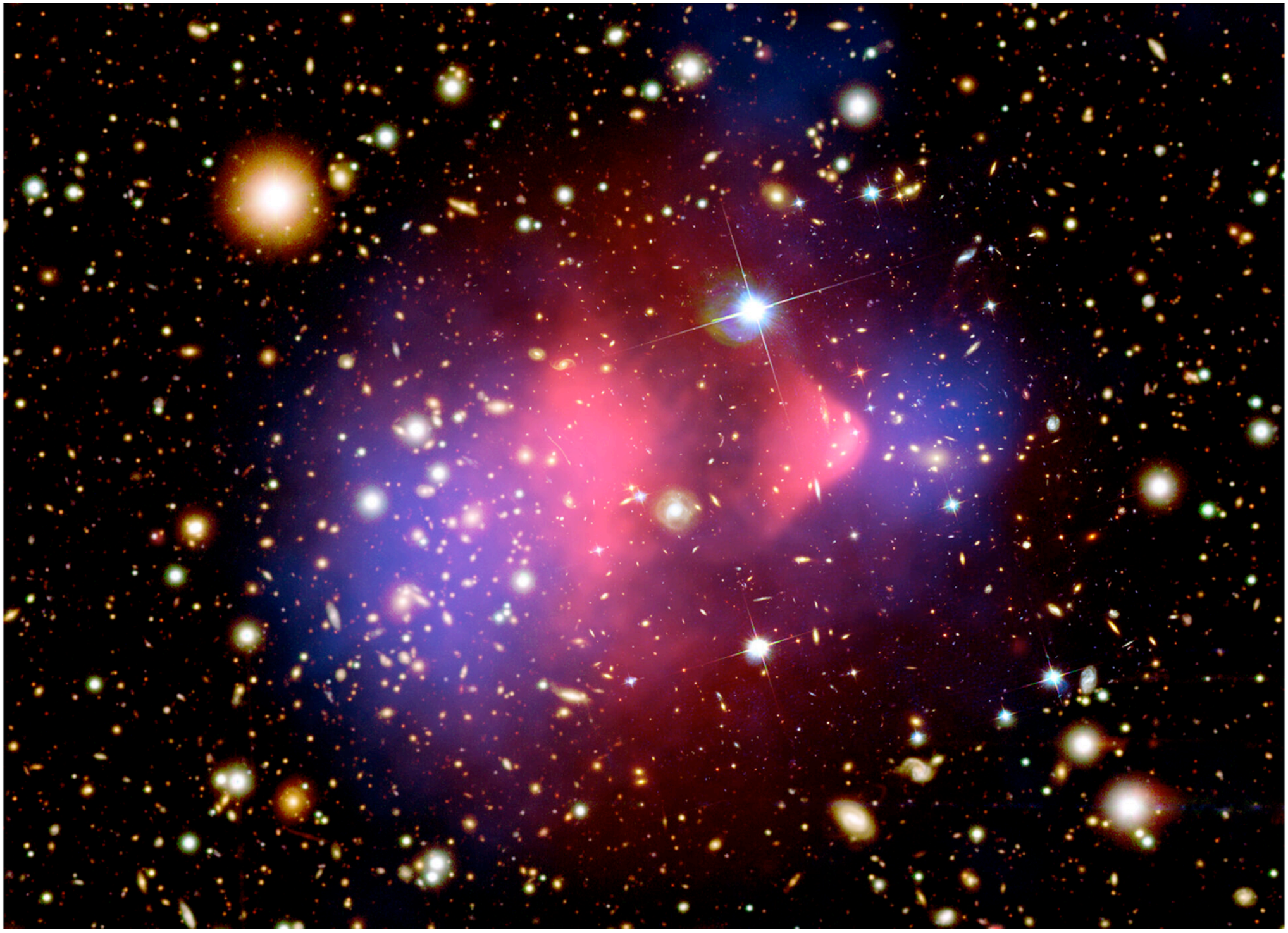
Bullet Cluster



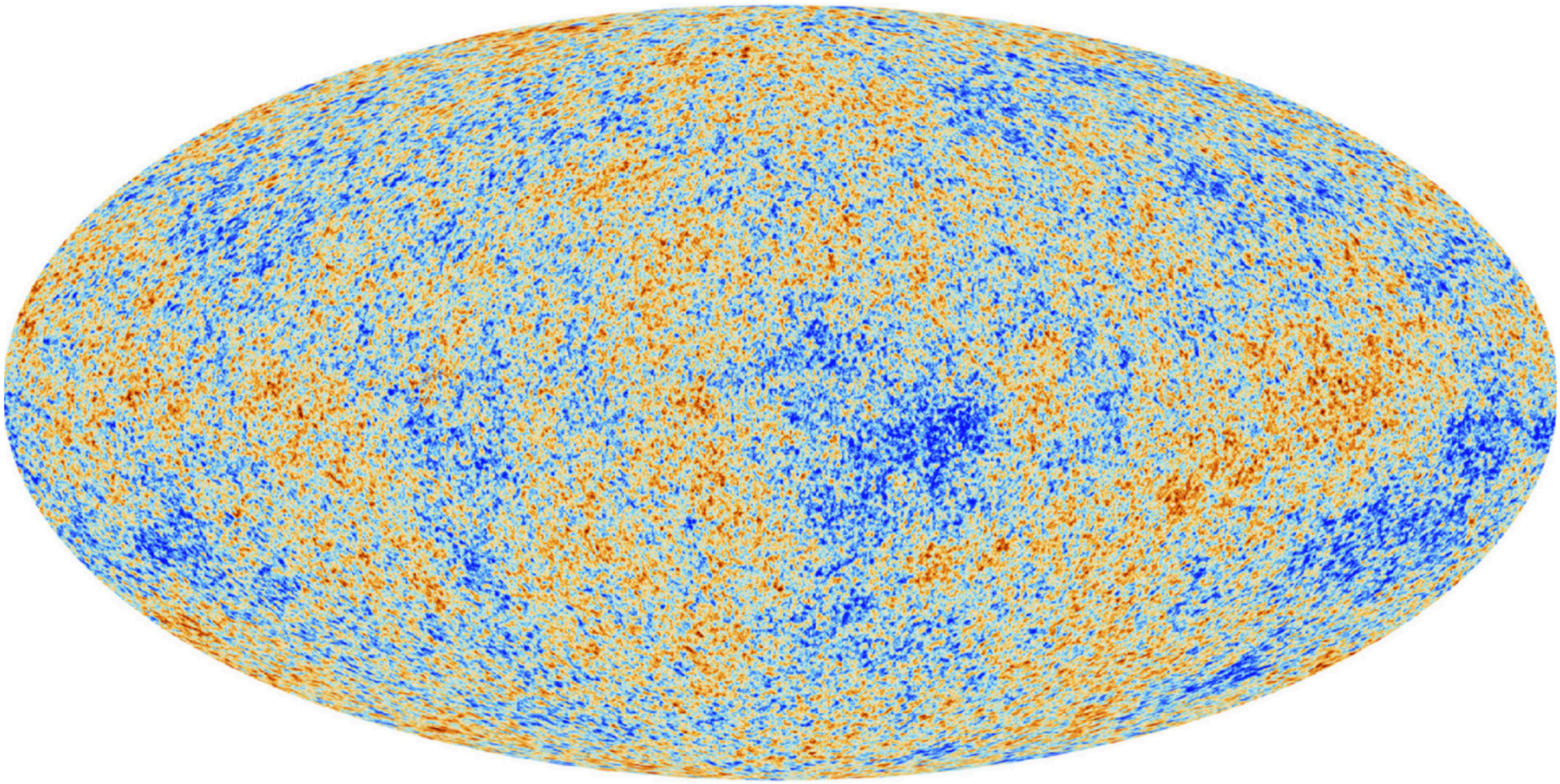


[Clowe et al 2006]

Bullet Cluster



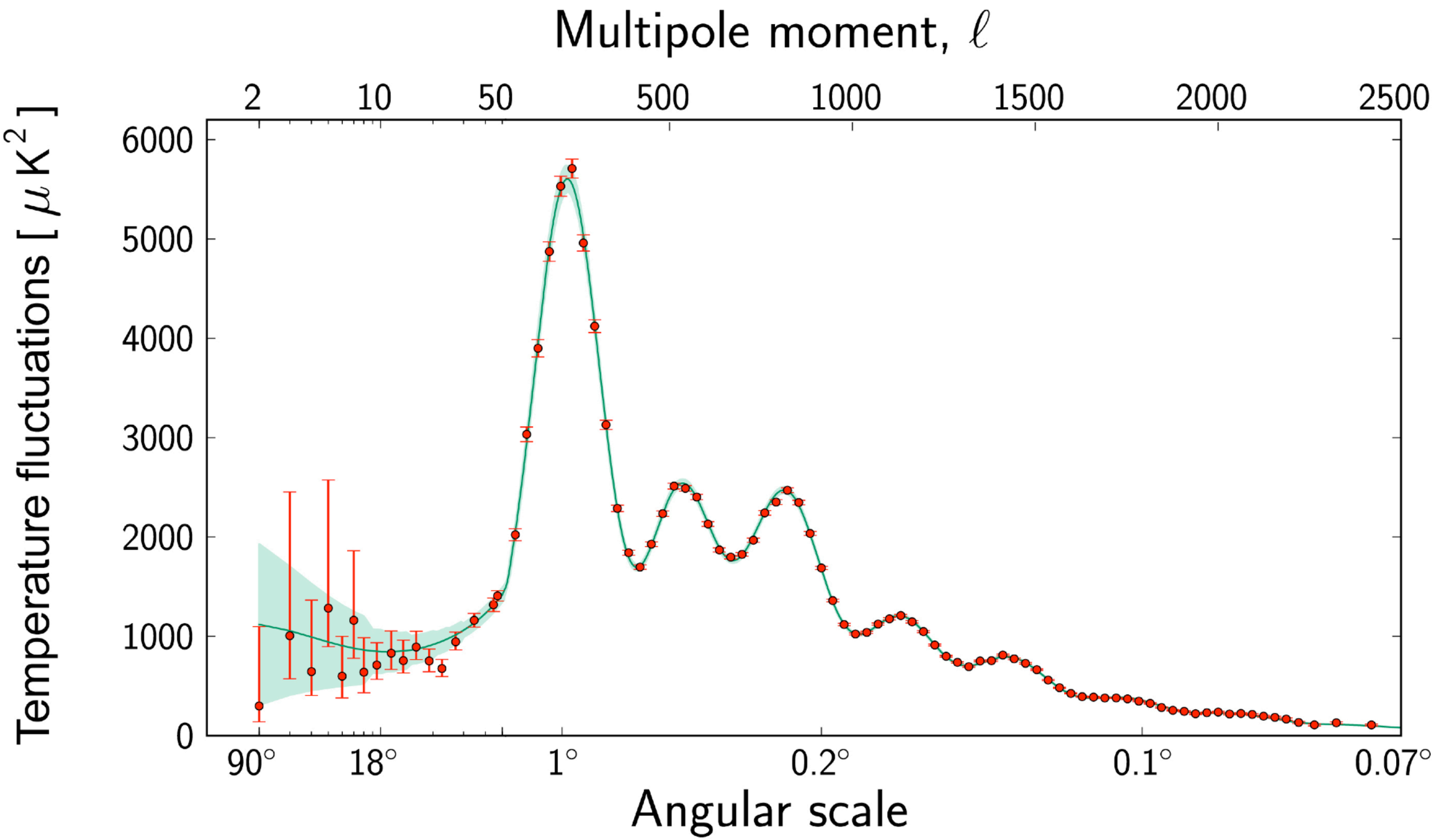
CMB



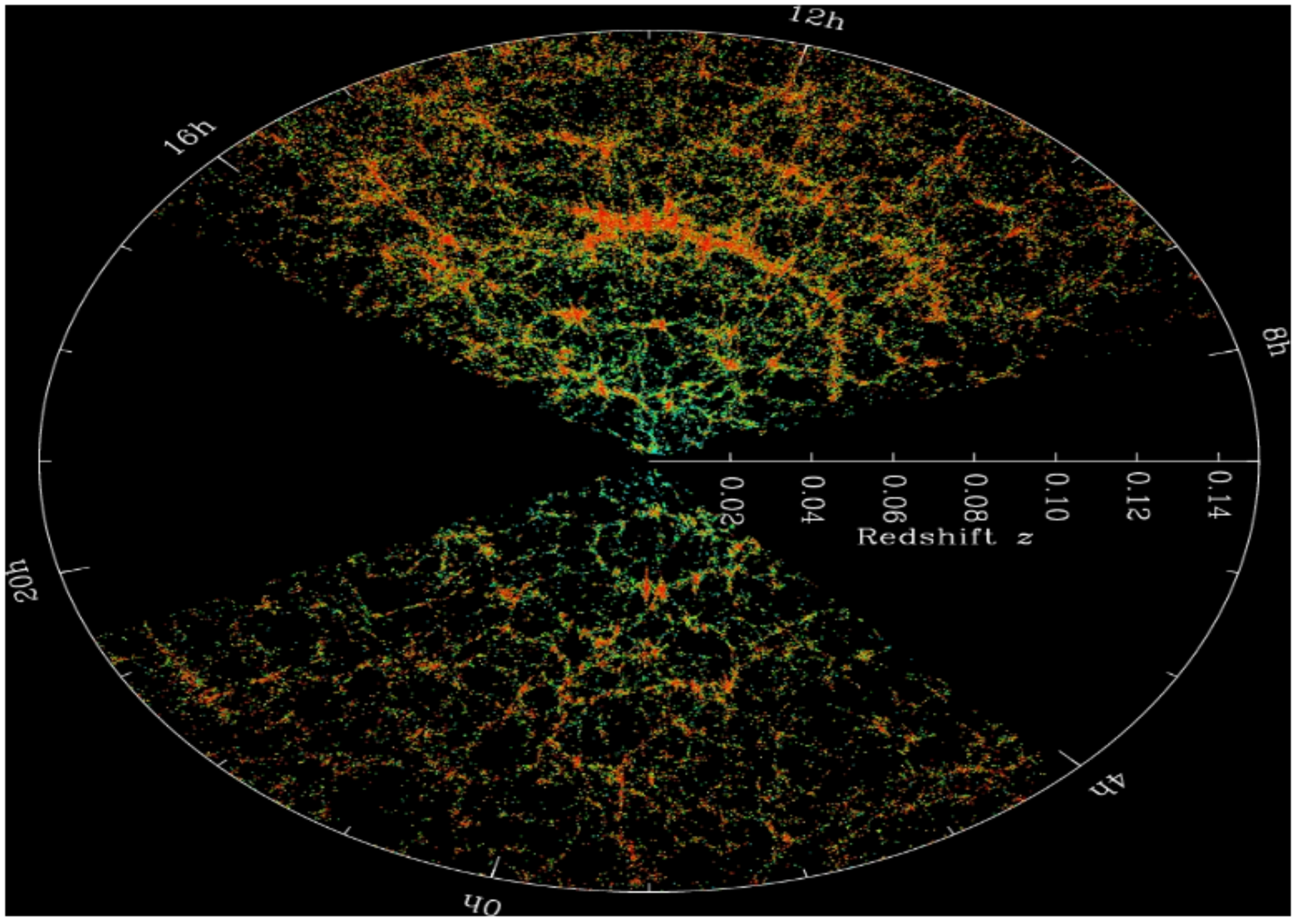
Credit: ESA and the Planck Collaboration

https://chrisnorth.github.io/planckapps/Simulator/#

CMB

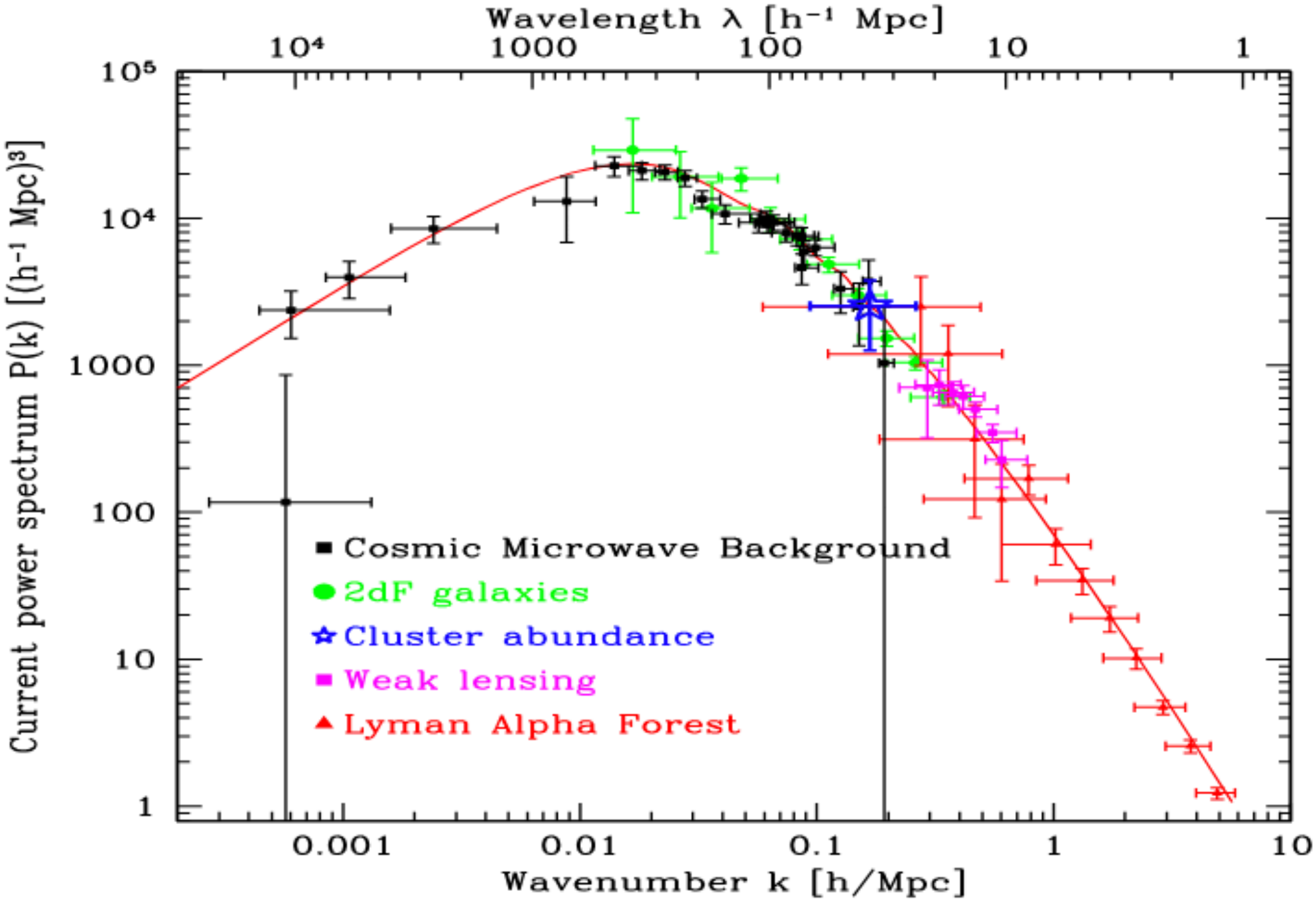

Multipole moment, ℓ
2
10
50
500
1000
1500
2000
2500
Temperature fluctuations [μ K^2]
6000
5000
4000
3000
2000
1000
0
90°
18°
1°
0.2°
0.1°
0.07°
Angular scale

Large Scale Structure



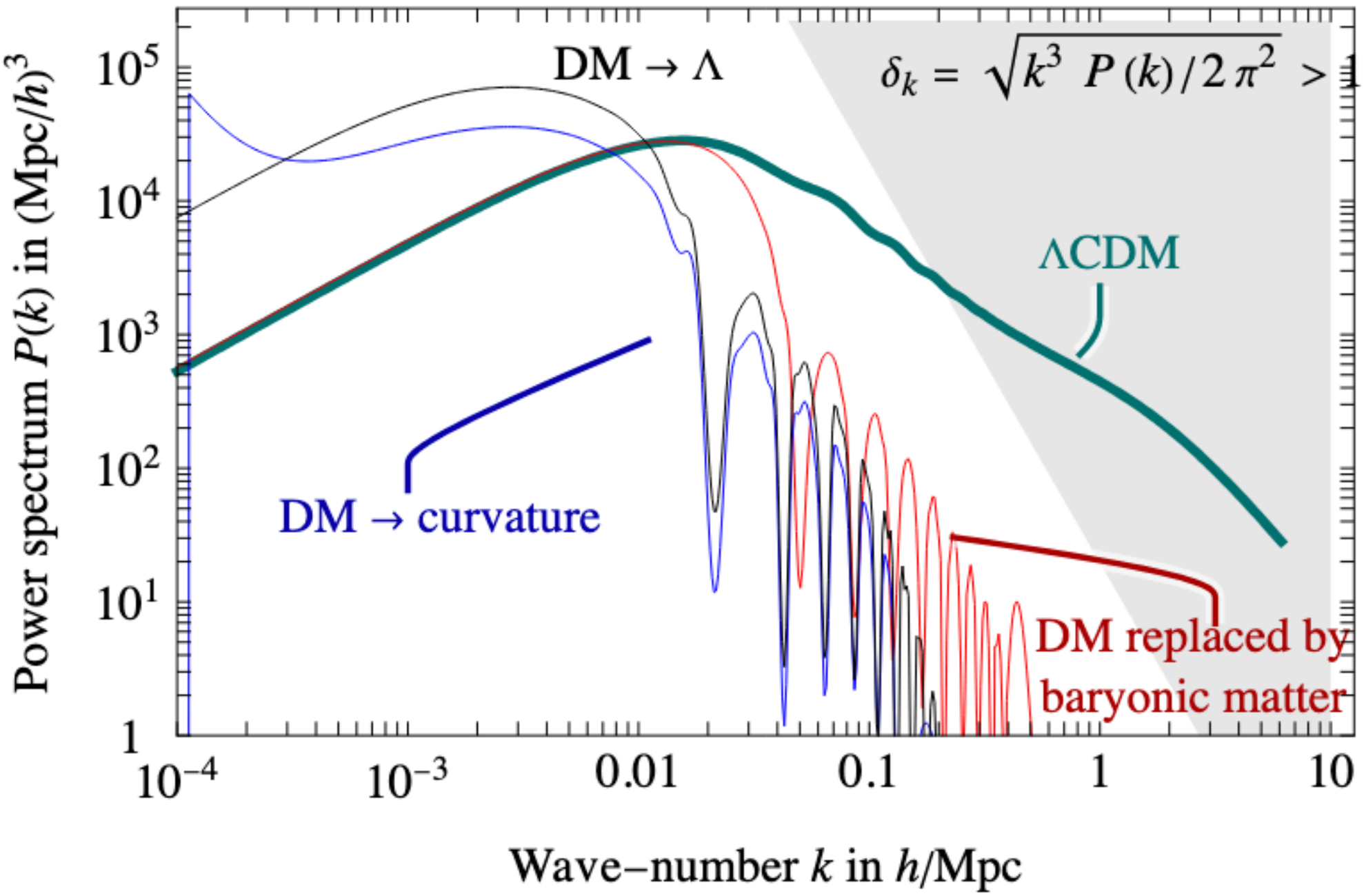
https://arxiv.org/pdf/2406.01705

Large Scale Structure



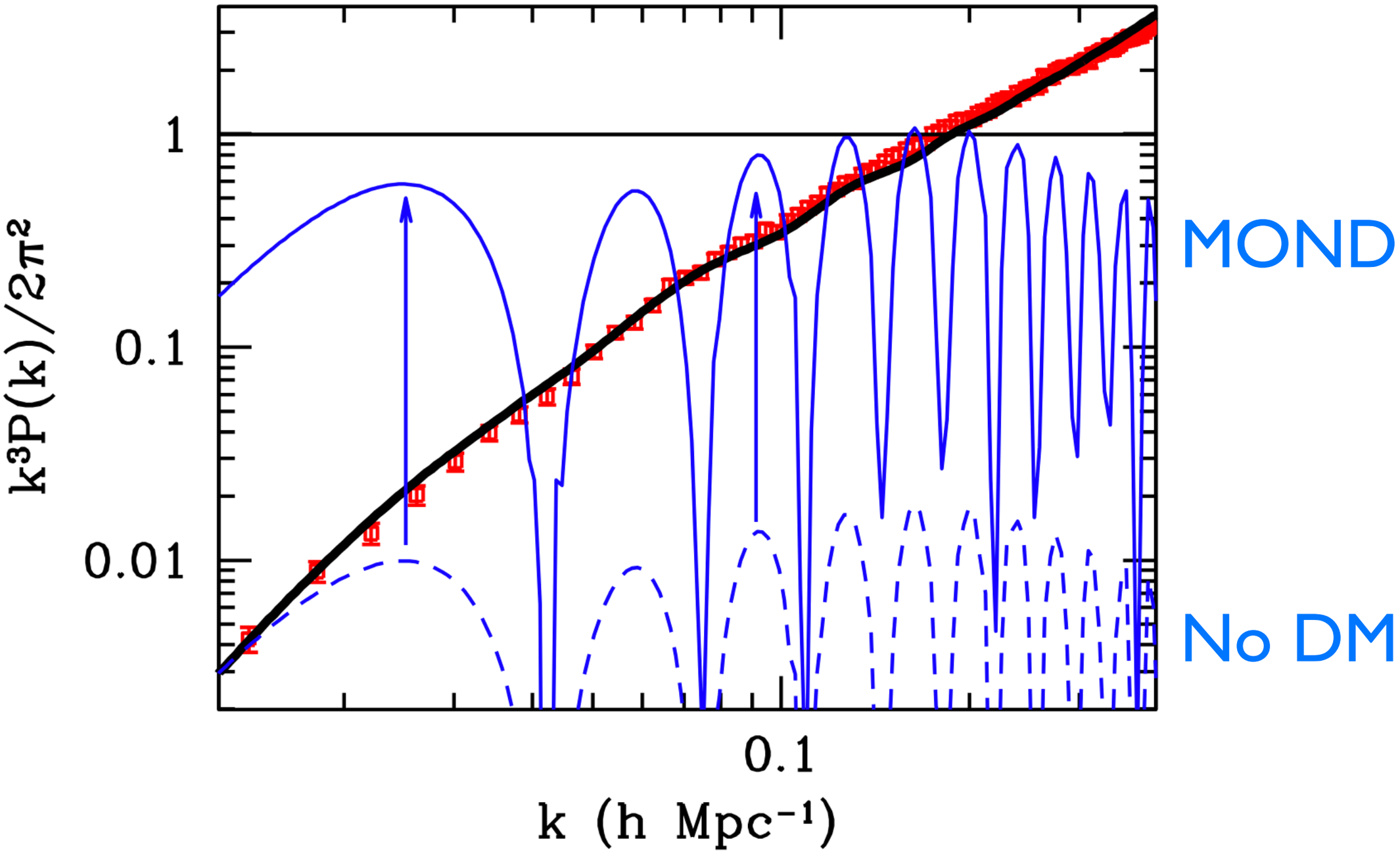
https://arxiv.org/pdf/2406.01705

Large Scale Structure



https://arxiv.org/pdf/2406.01705

Large Scale Structure



https://arxiv.org/abs/1112.1320