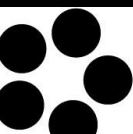


What is the Dark Matter?

William Shepherd

Niels Bohr International Academy

Johannes Gutenberg University Mainz



DET FRIE FORSKNINGSRÅD
DANISH COUNCIL FOR
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Outline

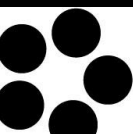
- Evidence for the existence of dark matter
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Is There Dark Matter?

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IN PHOTOGRAPHY

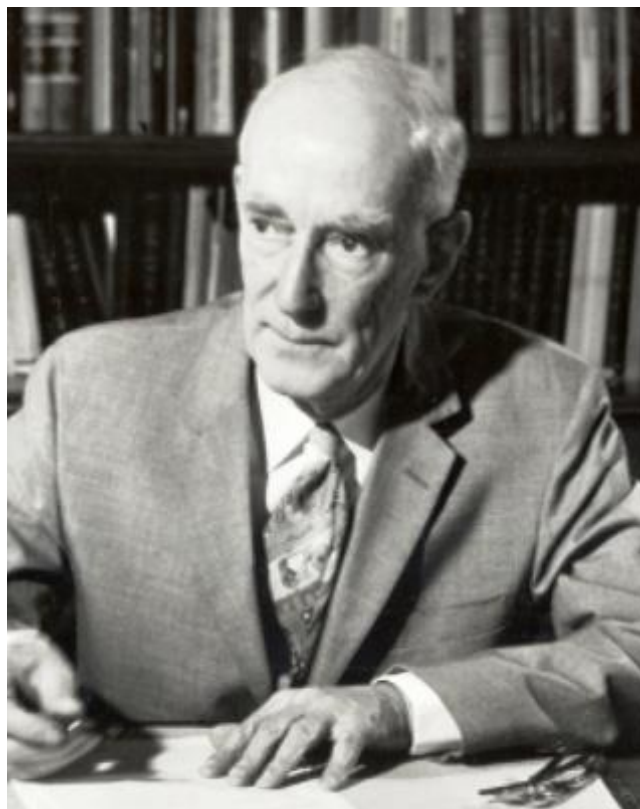
UNLEASH



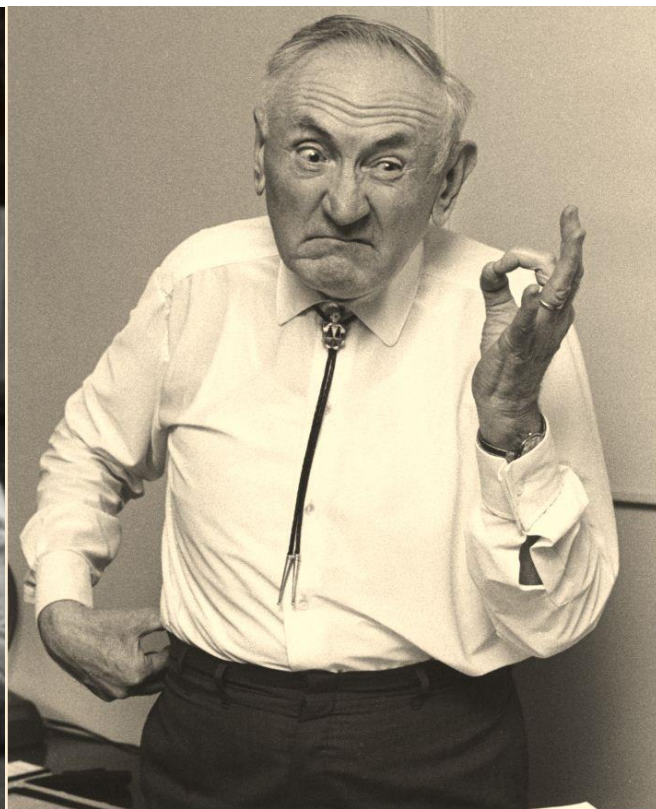
Fathers of Dark Matter



Jacobus Kapteyn



Jan Oort



Fritz Zwicky



Galactic Rotation Curves

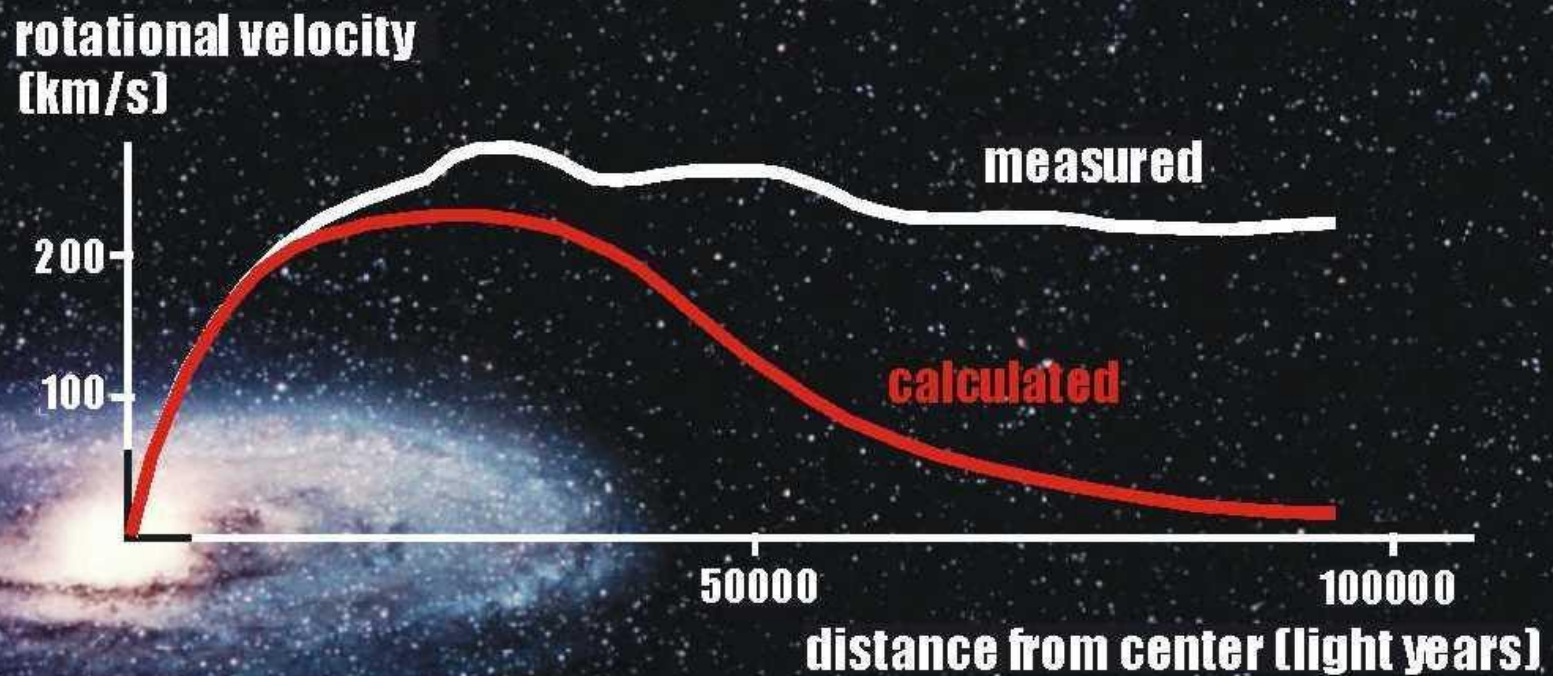


Horace Babcock



Vera Rubin and Kent Ford

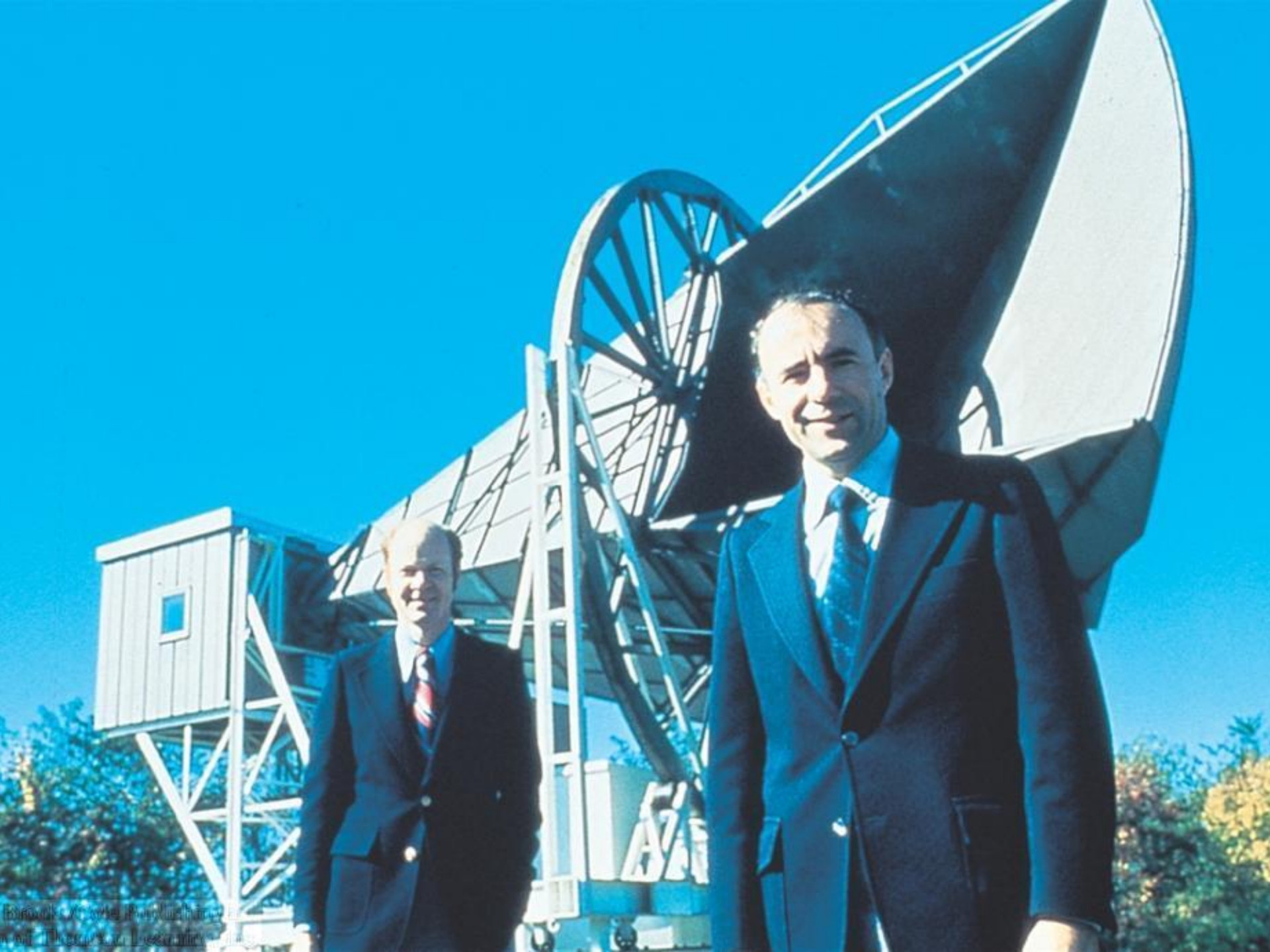
Rotation Curve of Andromeda



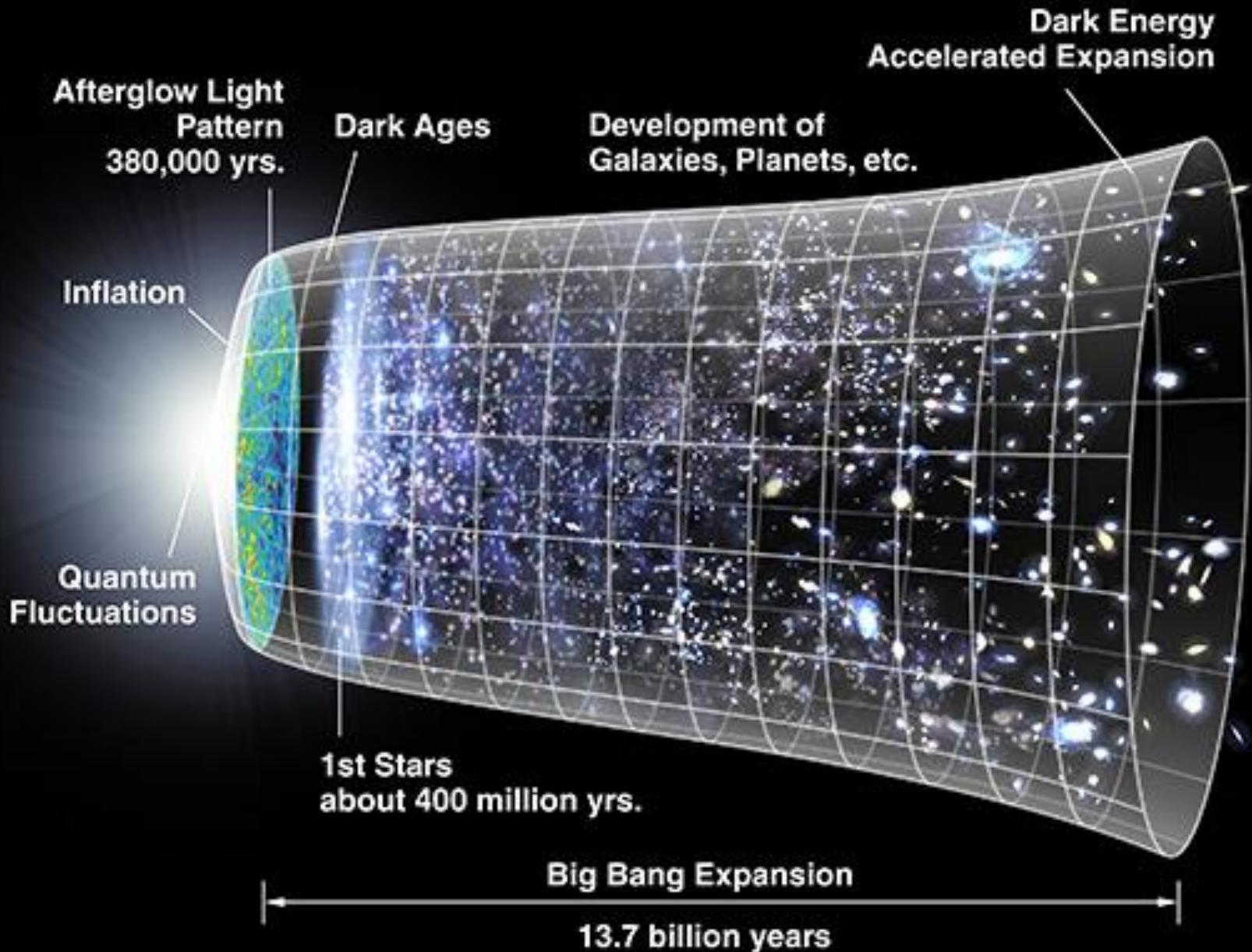
Cosmological Evidence

A man in a black tuxedo and white shirt with a bow tie is seated at a dark, modern-looking desk. He is looking down at his hands, which are resting on the desk. On the desk, from left to right, there is a clear glass bottle, a small glass, a microphone on a stand, and a white rotary telephone. The background is a blurred outdoor setting with green grass and trees. The overall tone is serious and formal.

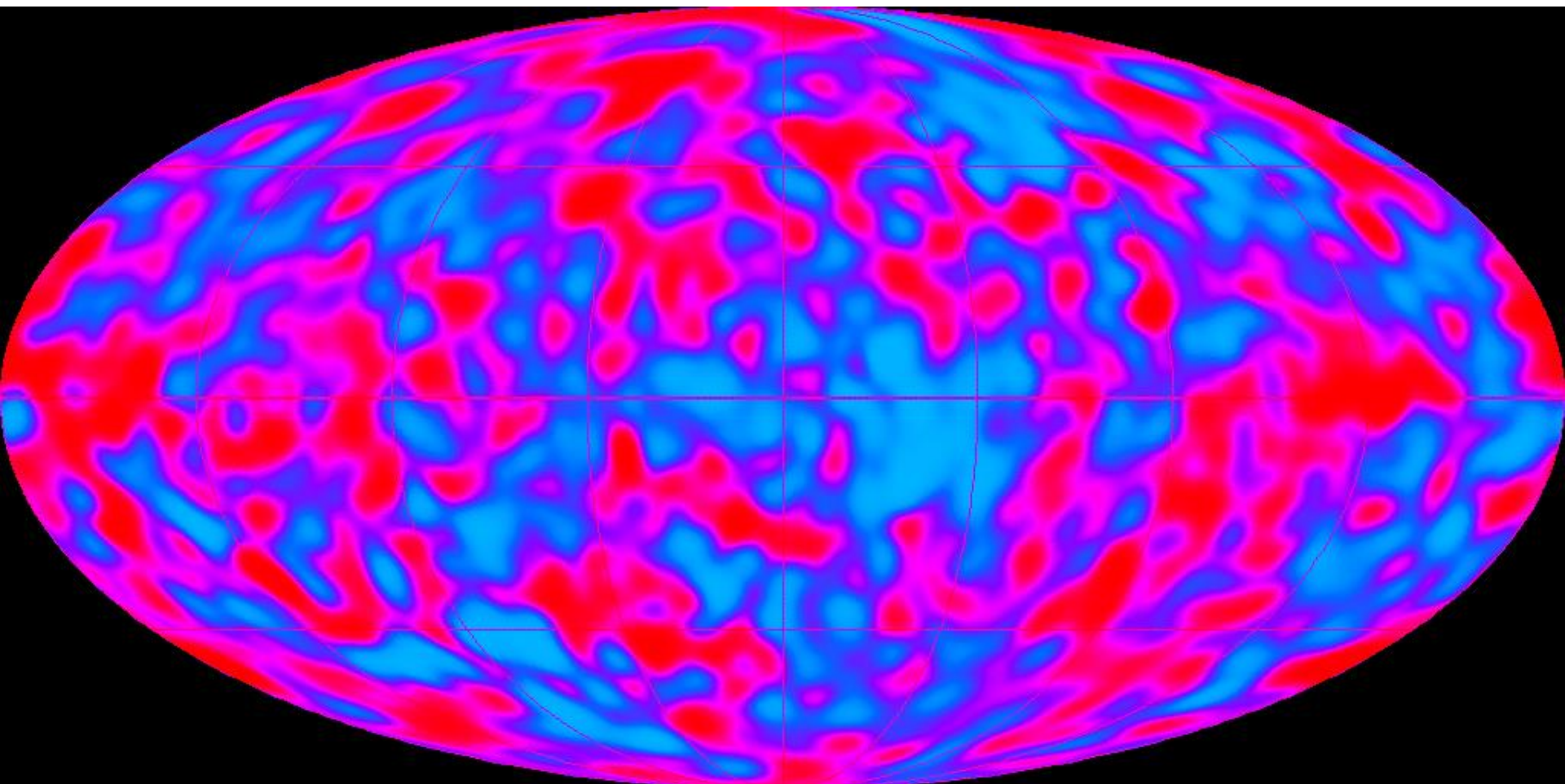
And now for something completely different



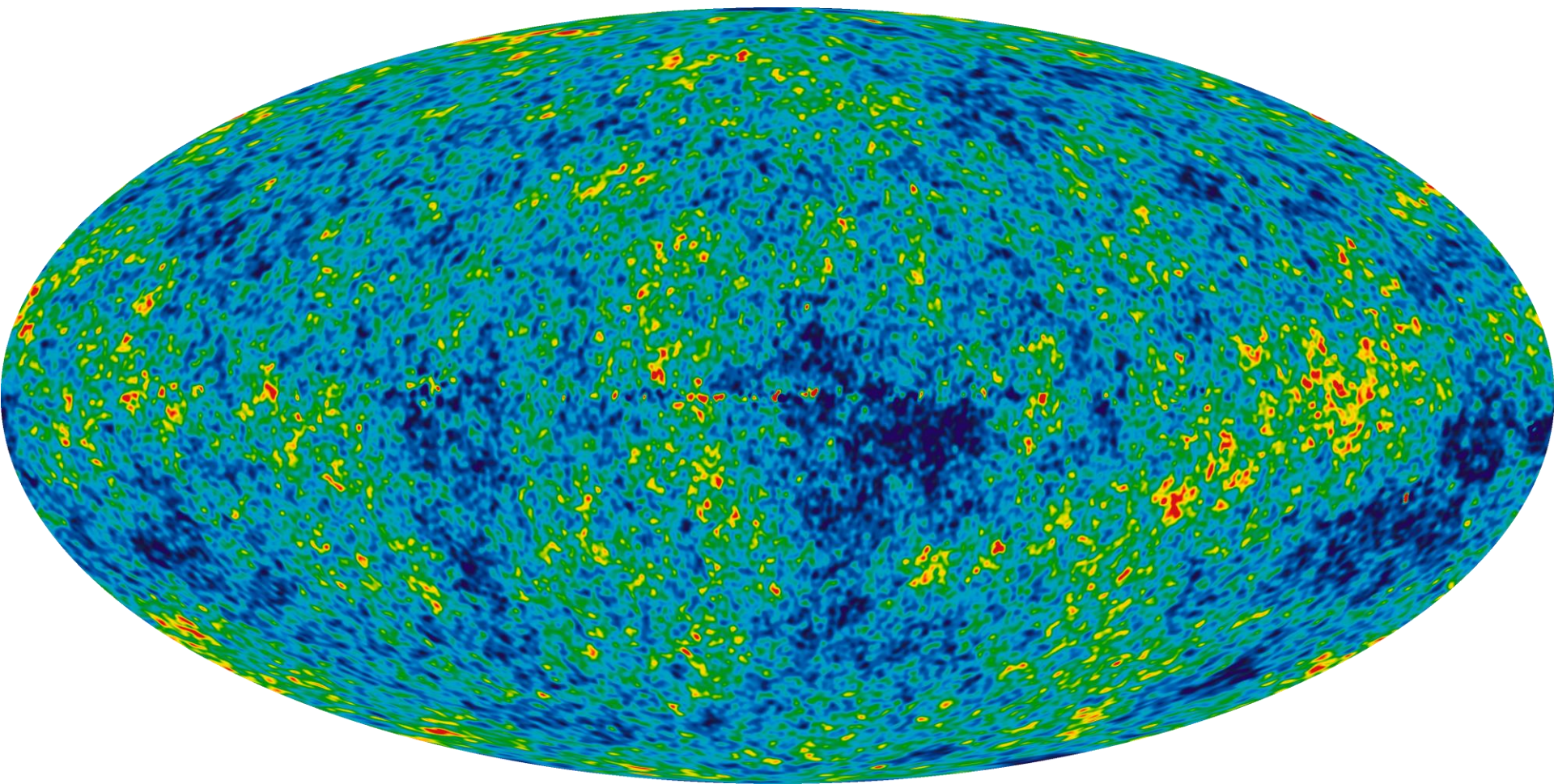
History of the Universe



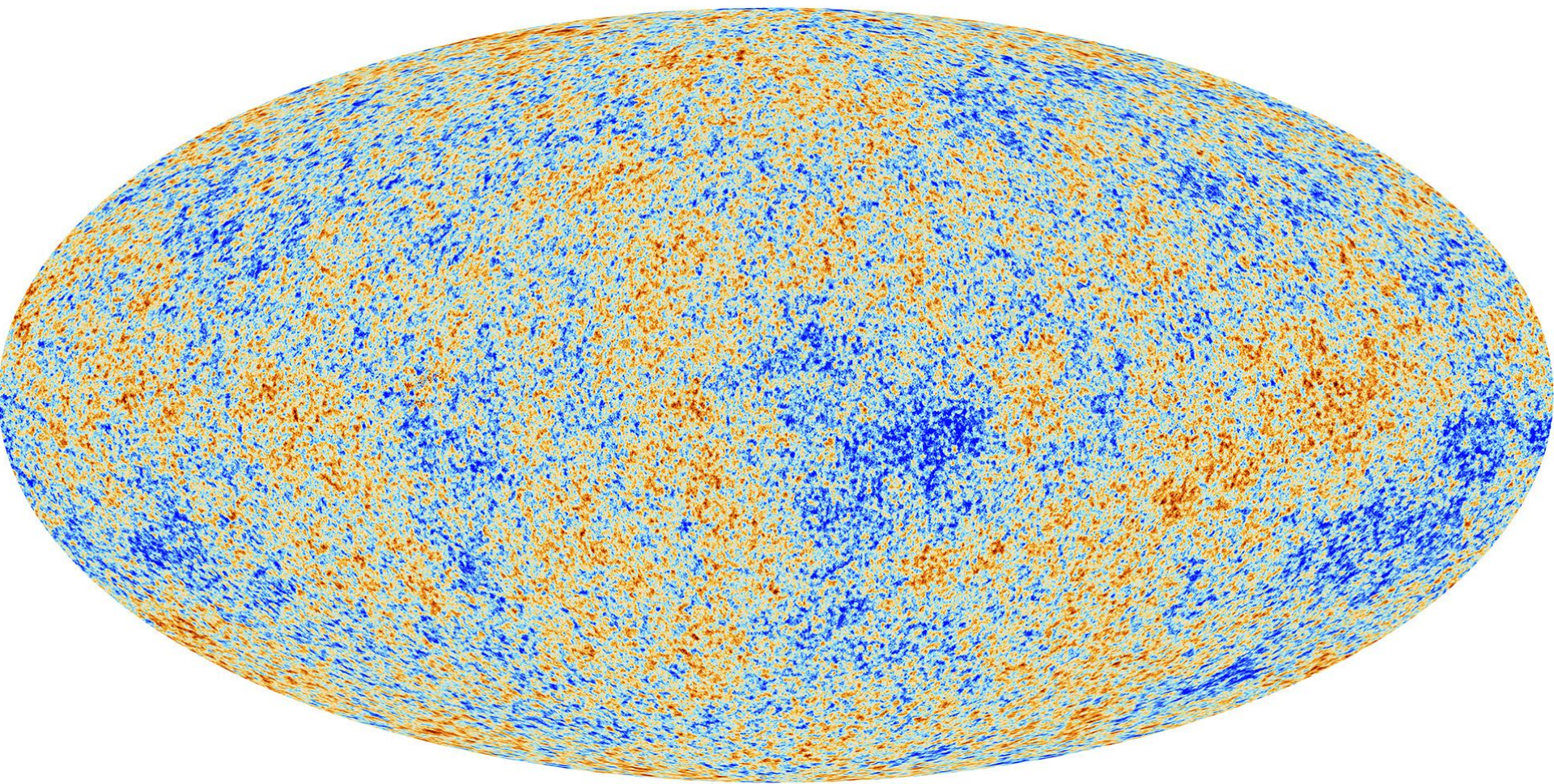
COBE



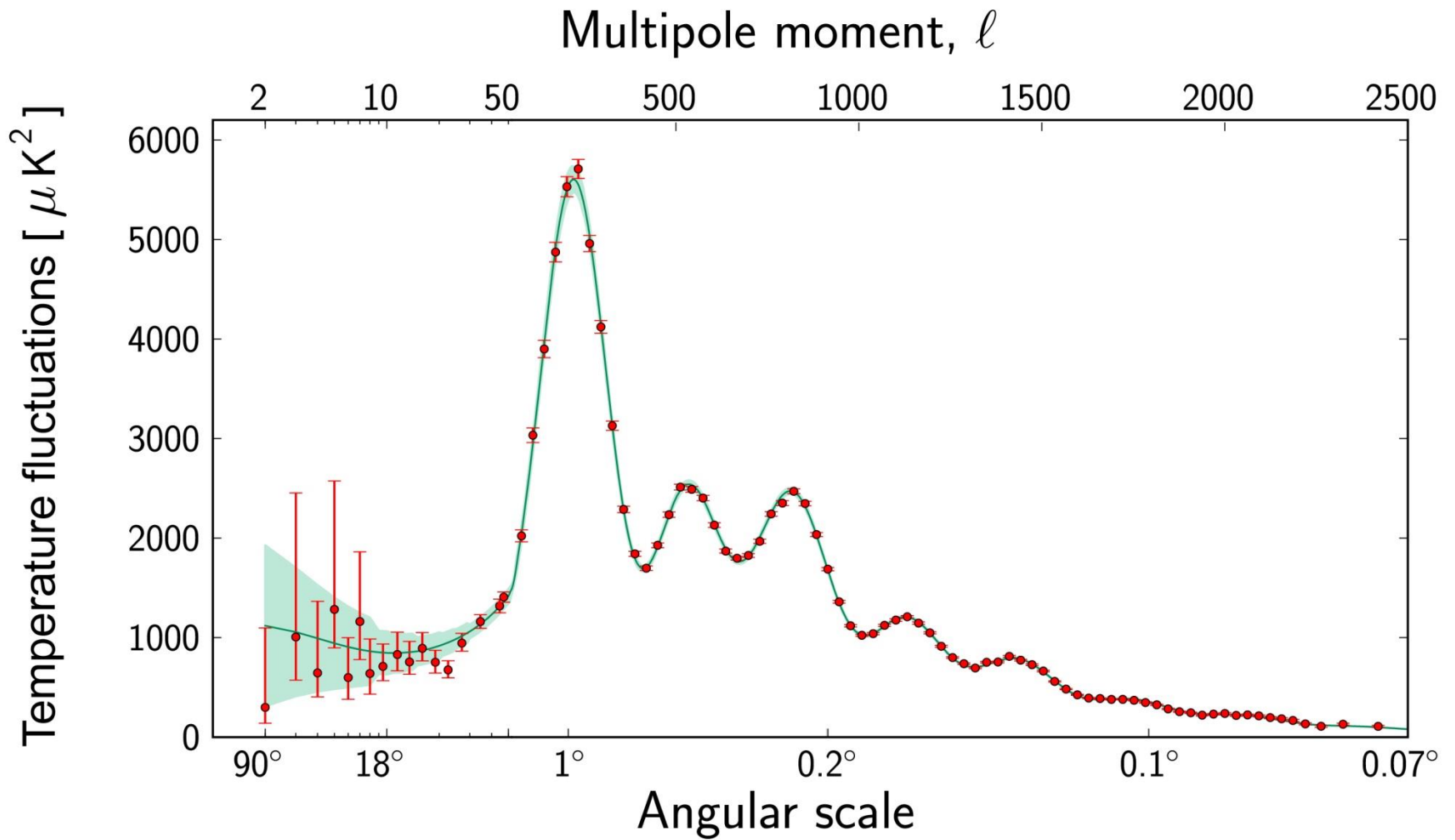
WMAP



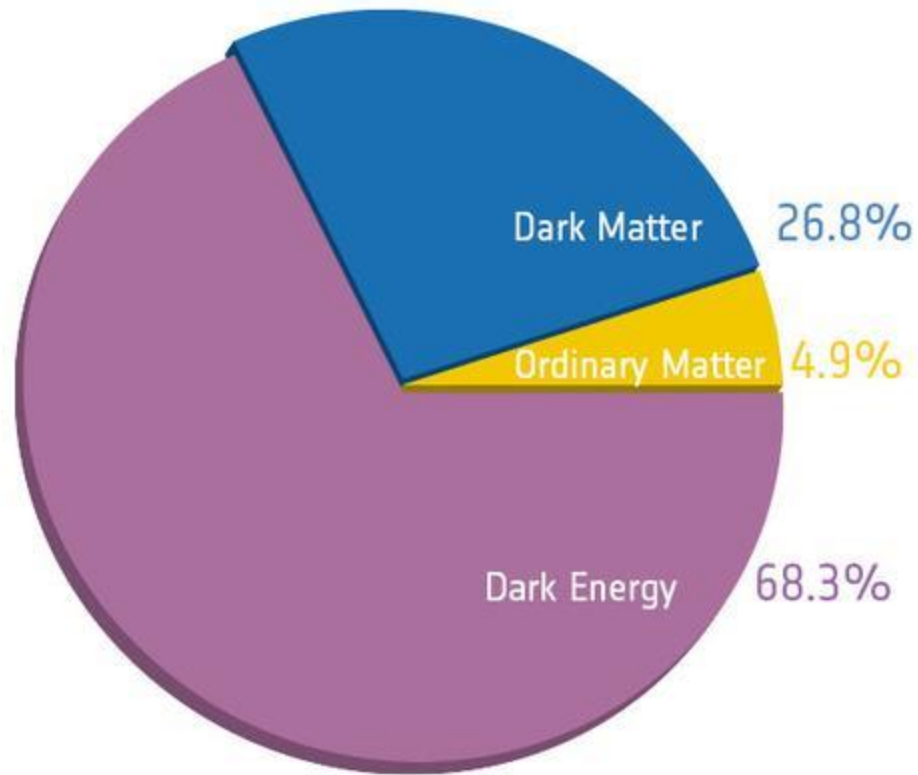
Planck



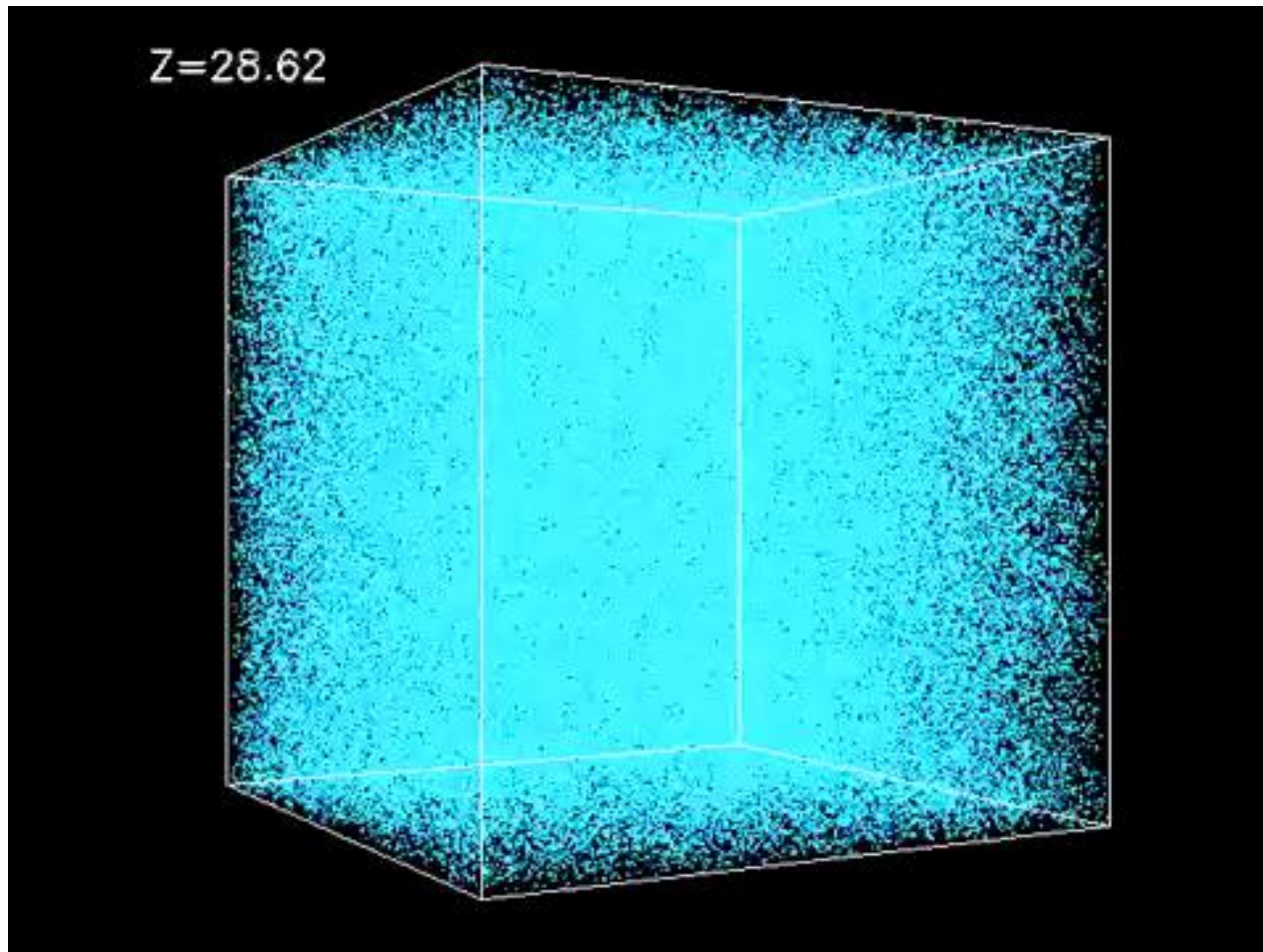
Planck

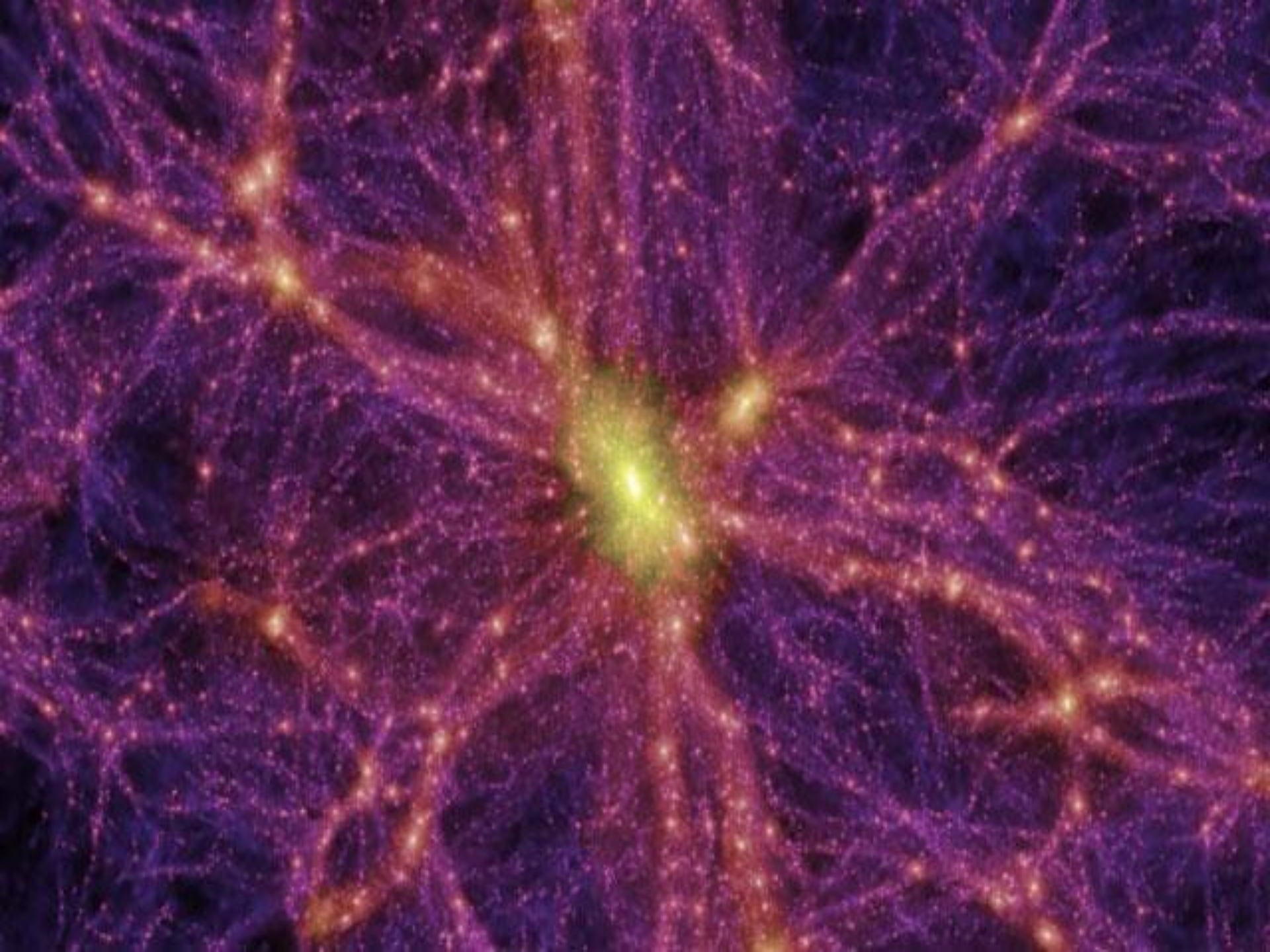


Universal Recipe

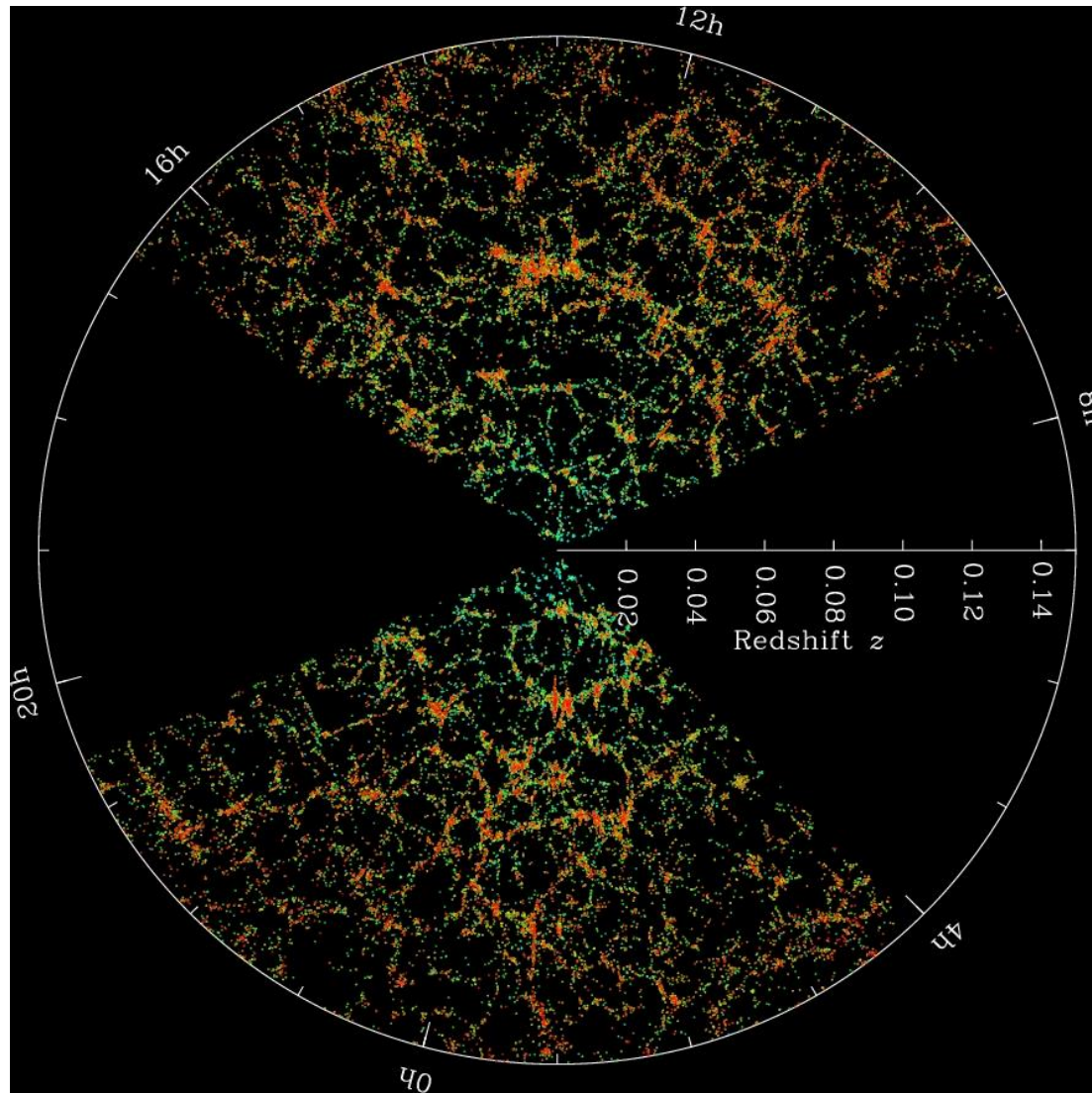


Structure Formation





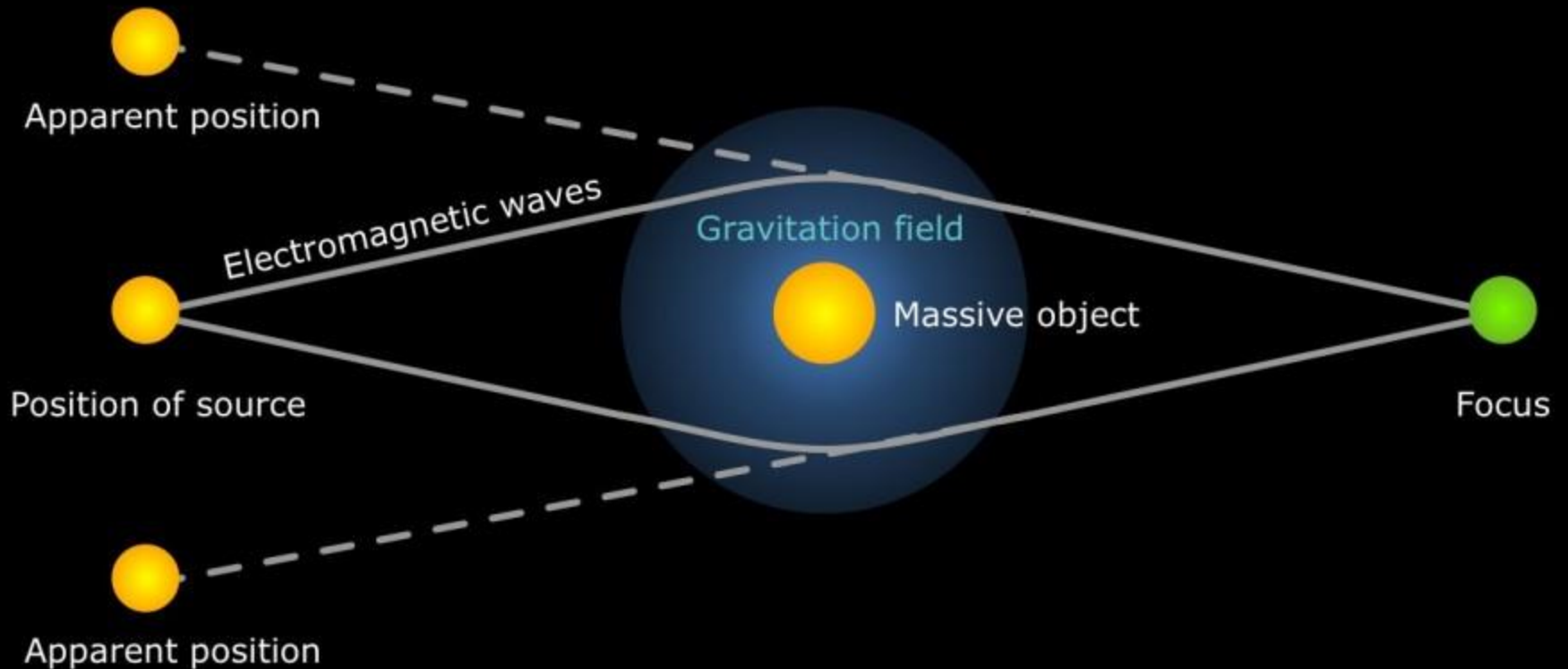
Actual Observations (SDSS)

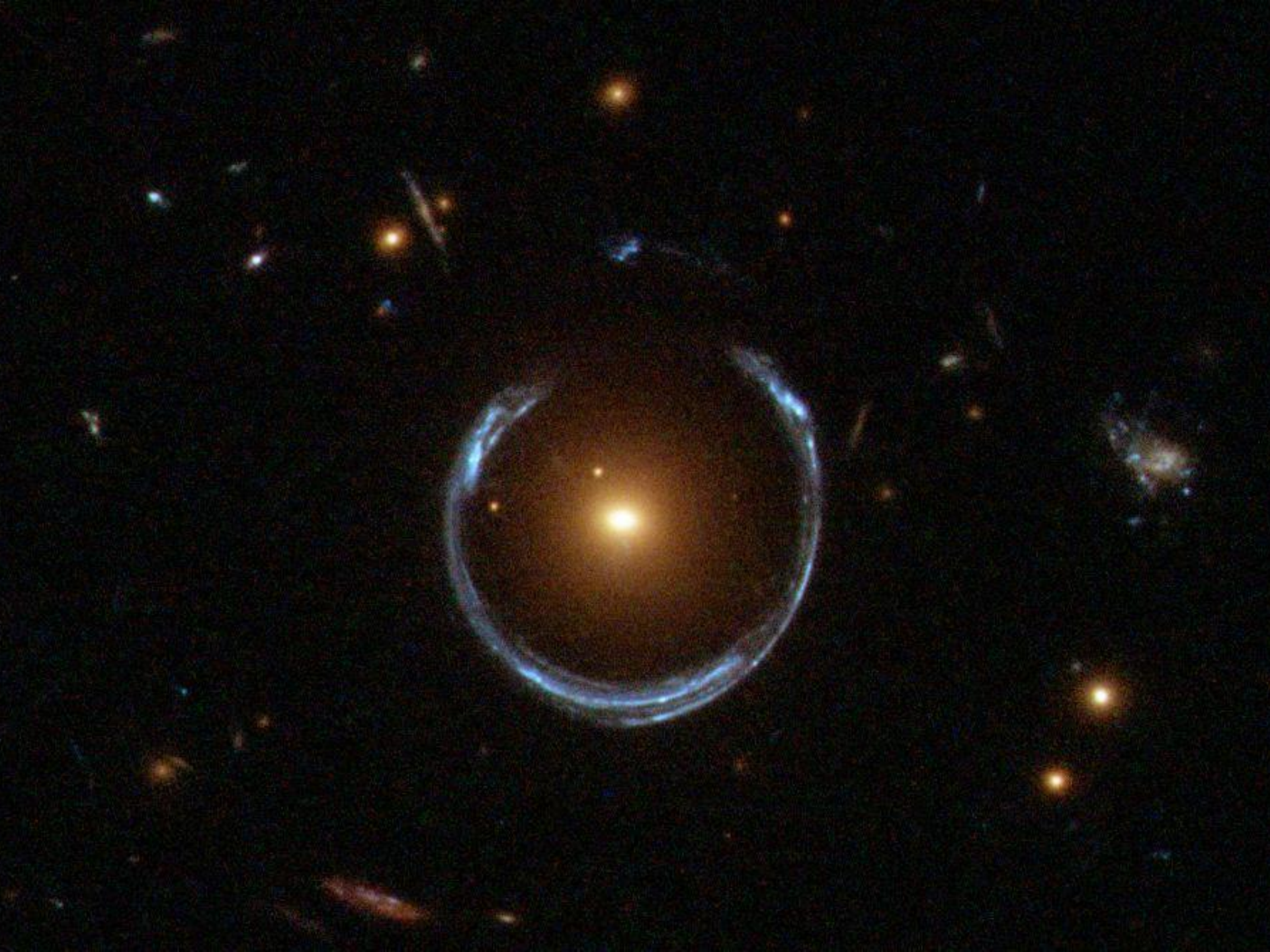


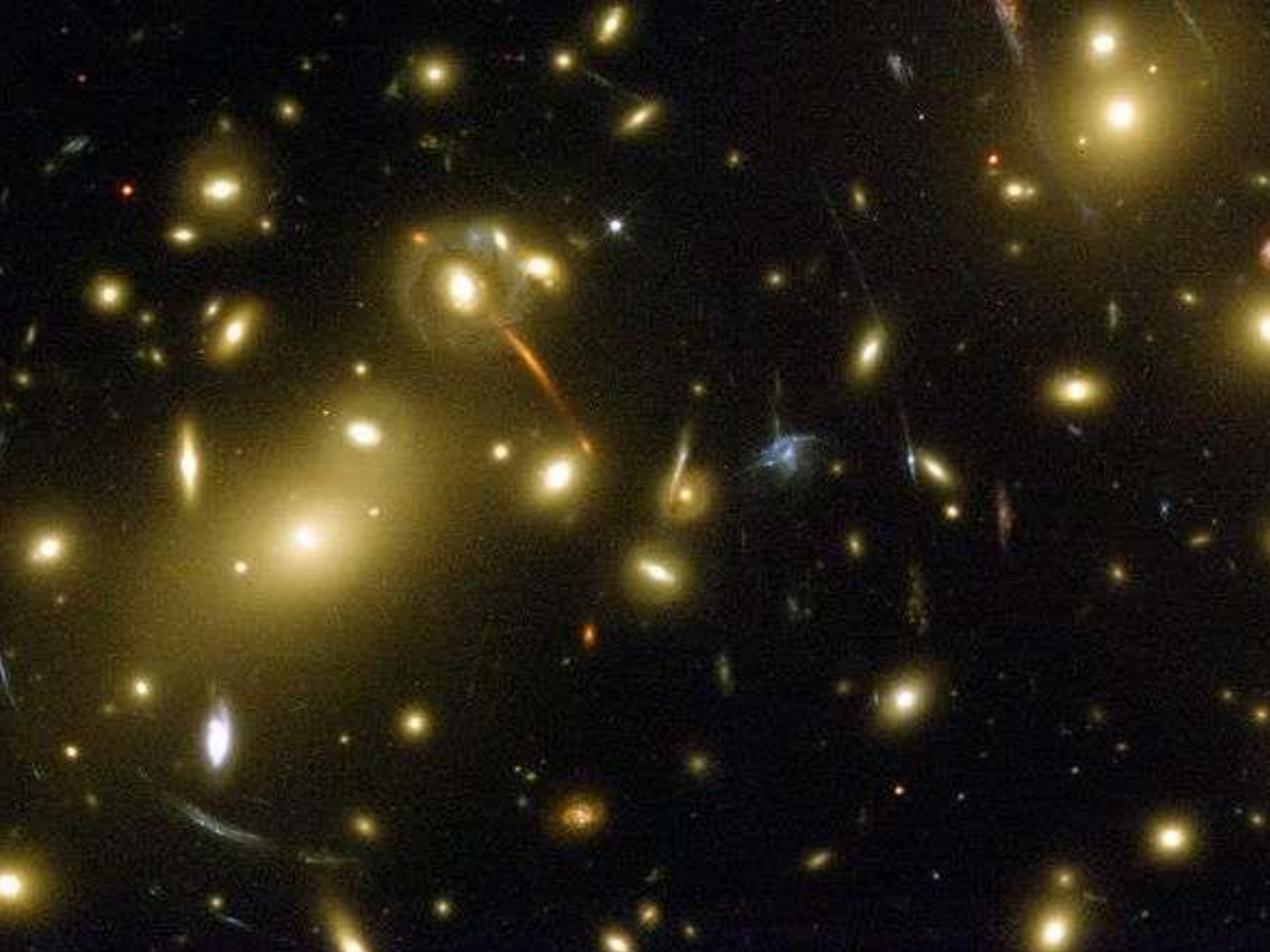
Gravitational Lensing



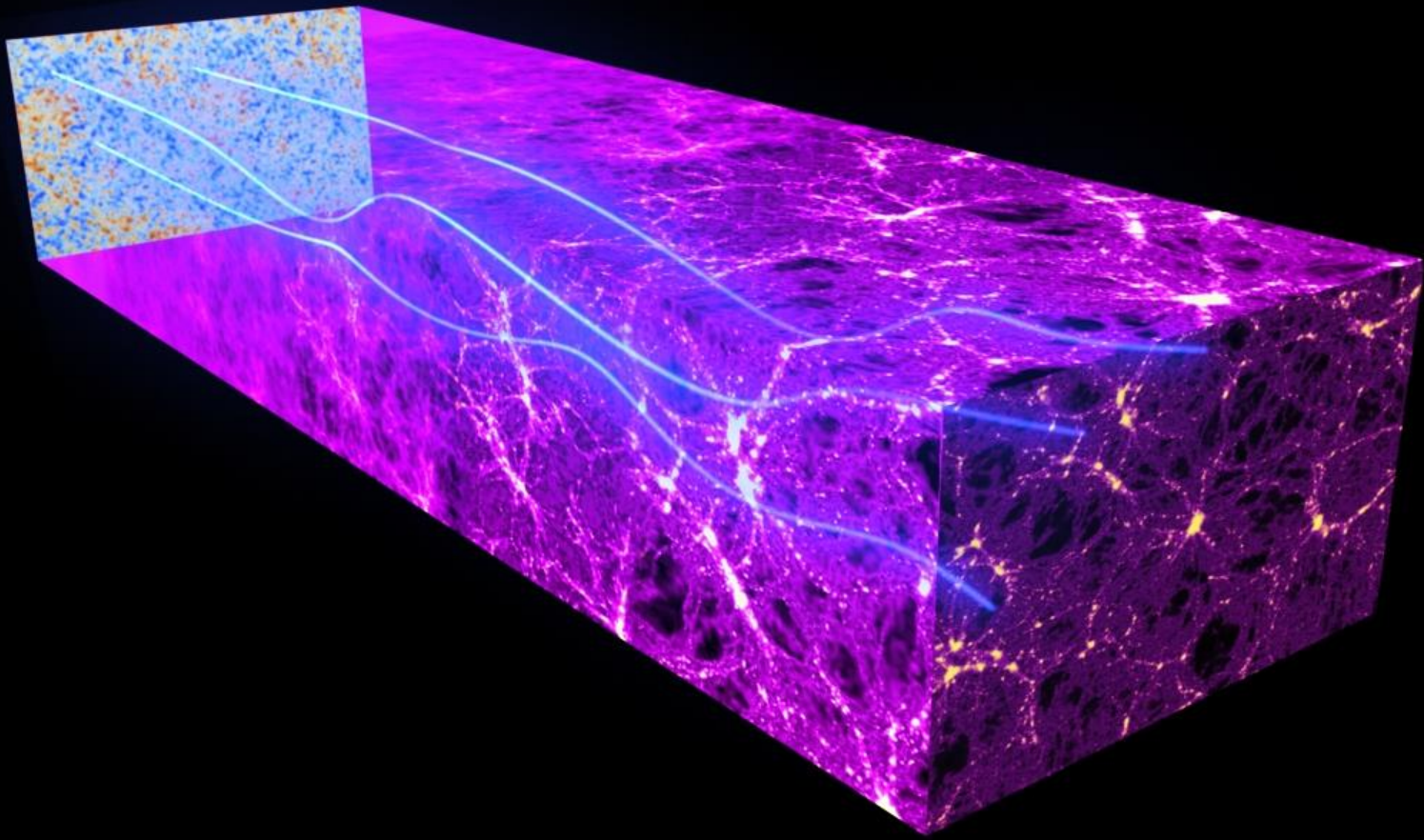
Gravitational Lensing



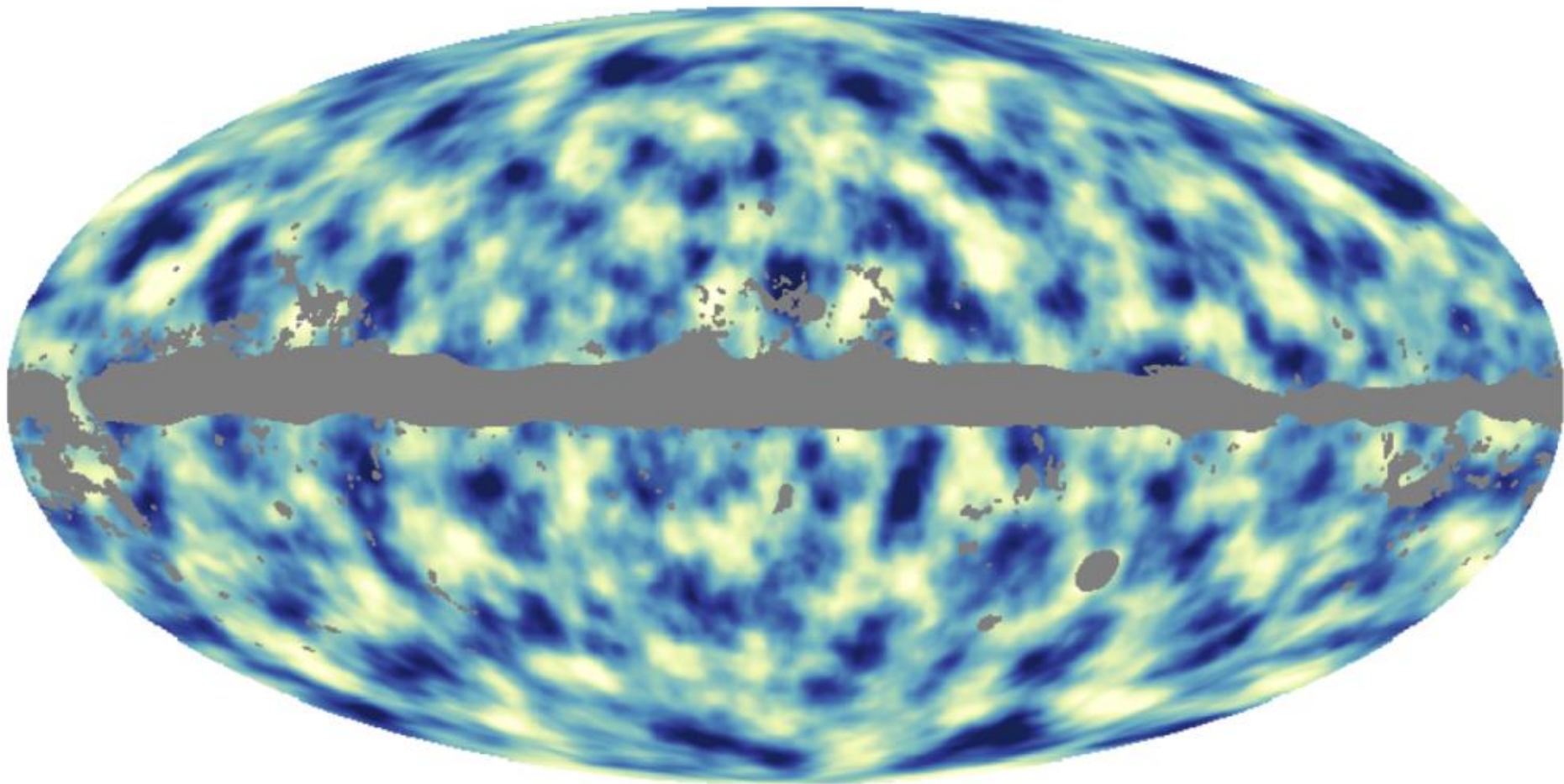


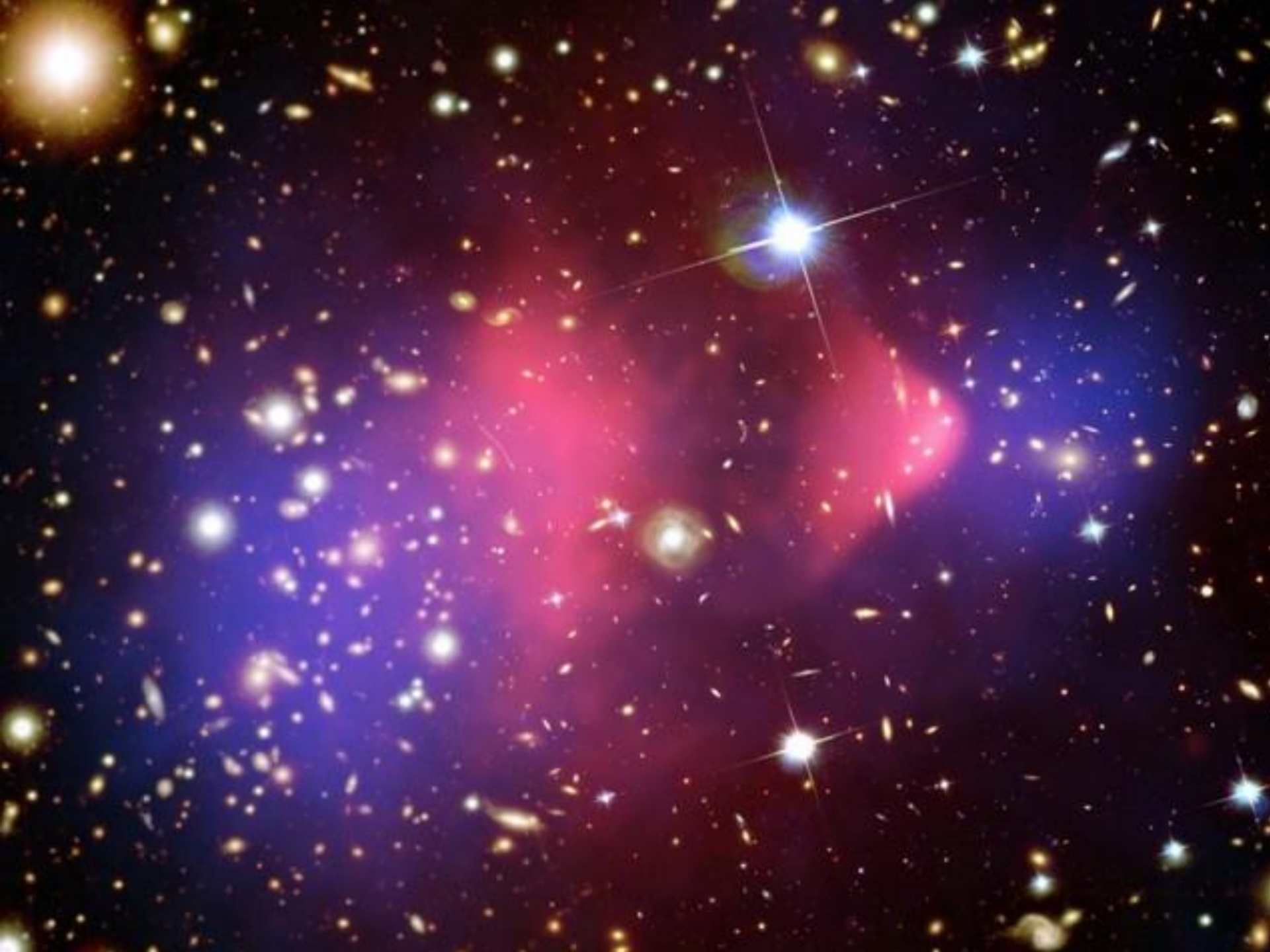


Lensing the CMB



Planck Lensing Map





Evidence for Dark Matter

- Dynamics of visible matter
 - Need extra gravity to explain why things haven't flown apart already
- Cosmology and structure formation
 - Without dark matter, we don't make seeds for galaxies and clusters fast enough for them to be here now
- Gravitational Lensing
 - We can actually map the mass of structures in the universe, and see that the mass doesn't always line up with the ordinary matter.

Intermission

Outline

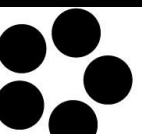
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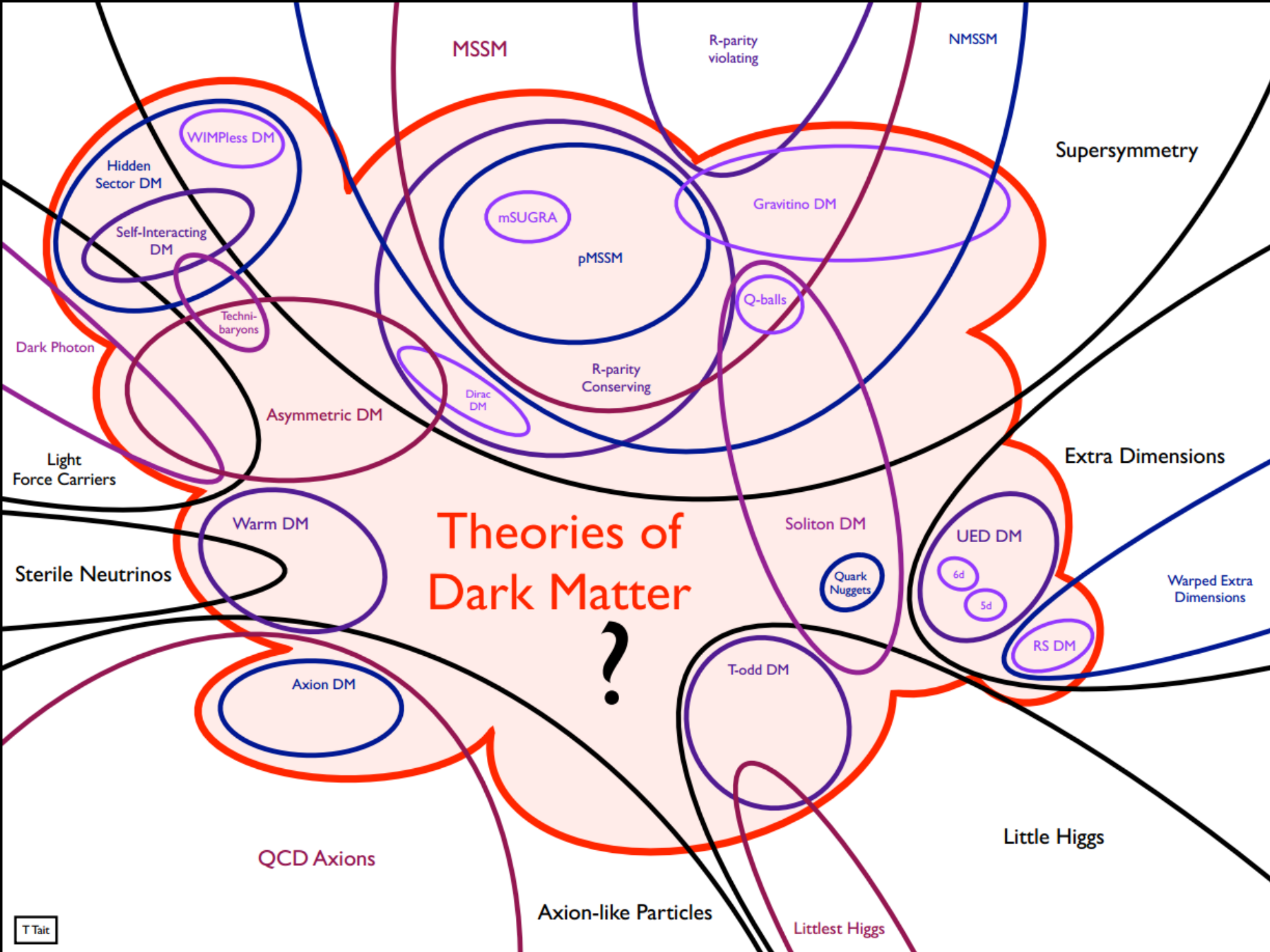


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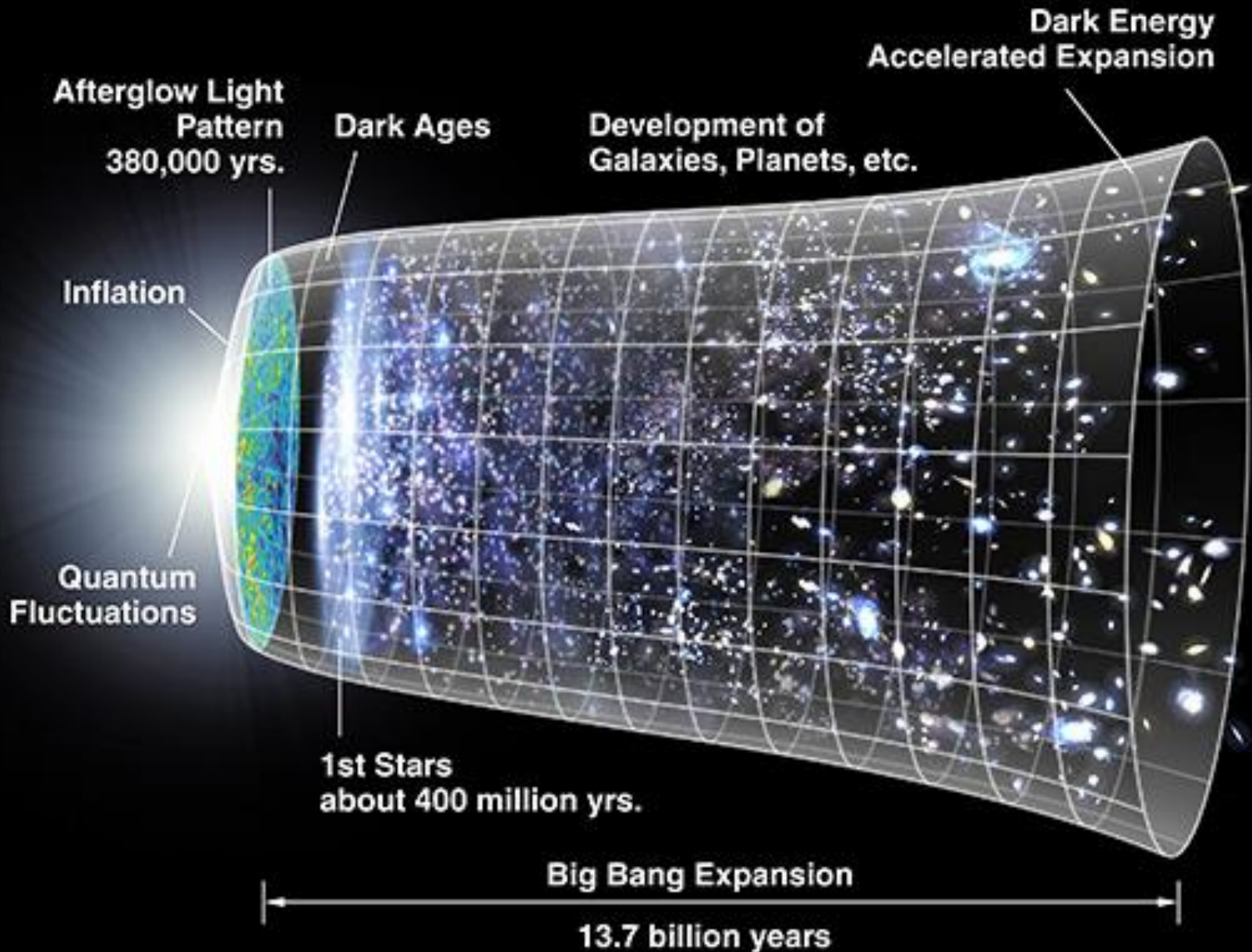
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Theories of Dark Matter

- While others exist, there are two big classes of dark matter models: WIMPs and FIMPs.
- WIMP: Weakly Interacting Massive Particle
 - Expected to be much heavier than a proton
 - Expected to interact with some regularity
- FIMP: Feebly Interacting Massive Particle
 - Expected to be much lighter than anything known
 - Expected to interact with extreme rarity

History of the Universe

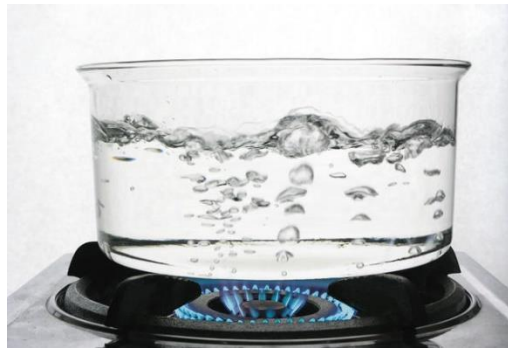


Dark Matter Production

- WIMPs: interact often, so make a lot
 - Also destroy a lot
 - Rate of destruction sets amount left over
 - This process is called freeze out
- FIMPs: interact very rarely
 - So we don't make many
 - Almost never destroy them
 - Just the right amount made while the universe is hot
 - Freeze in

Freeze out

- As universe cools, DM is destroyed
- Bubbles = DM particles
 - Can only go away by finding each other
- When the universe is cold compared to the DM mass scale, all the DM should be gone, except...



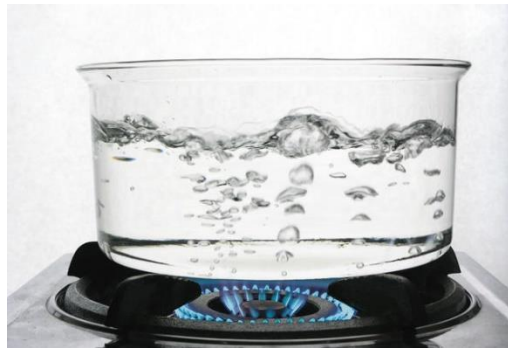
Freeze out

- As the universe cools, it also expands
 - Eventually, particles so far apart they can't find each other anymore



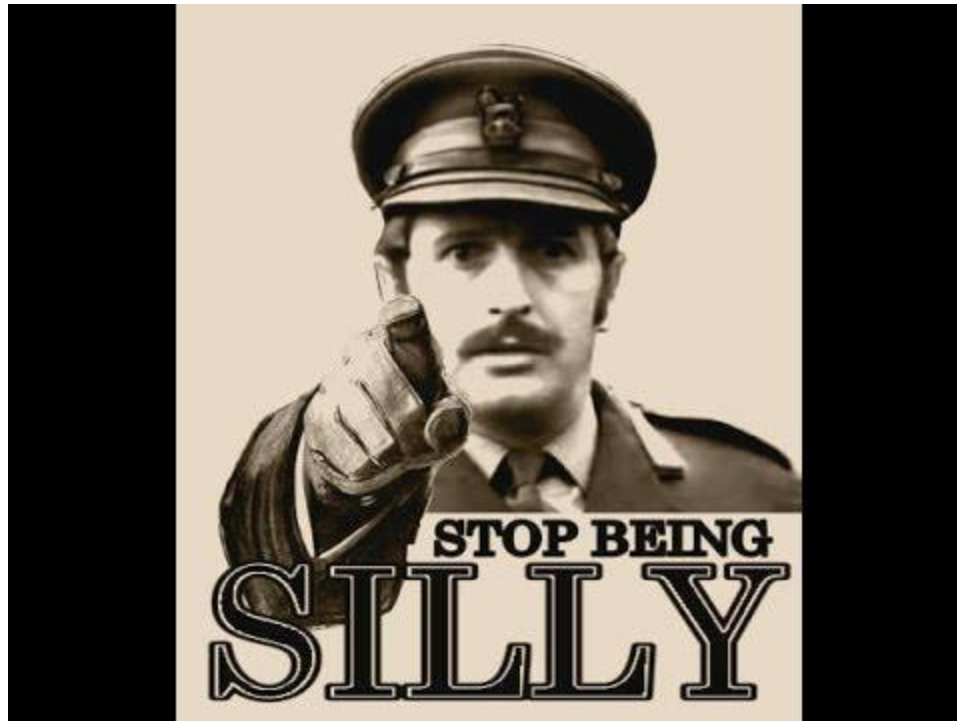
Freeze in

- Every so often, a particle gets produced
 - More often when the universe is hotter
- This is like the rare occasions where the pot spits water outside itself from a bubble
- As the pot is turned down, it happens more and more rarely



Theories are all well and good...

But sooner or later someone comes along and wants to know the truth about the universe.

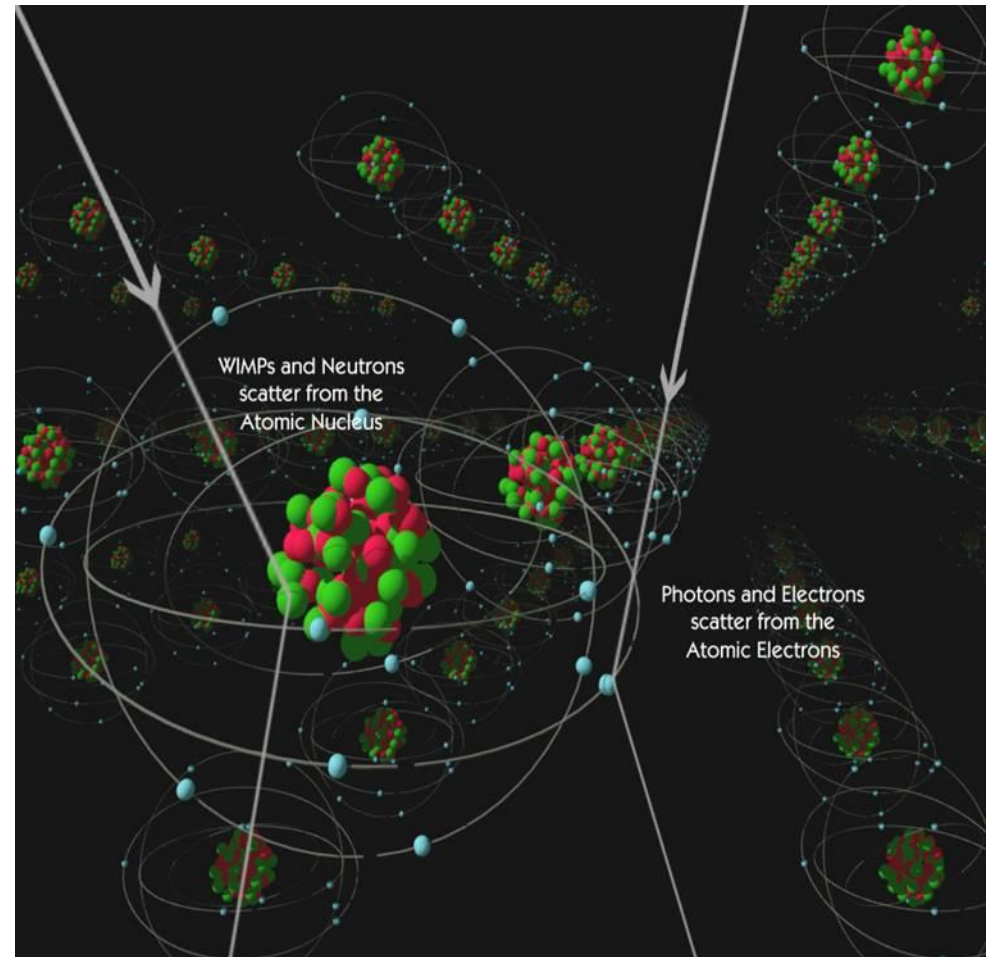


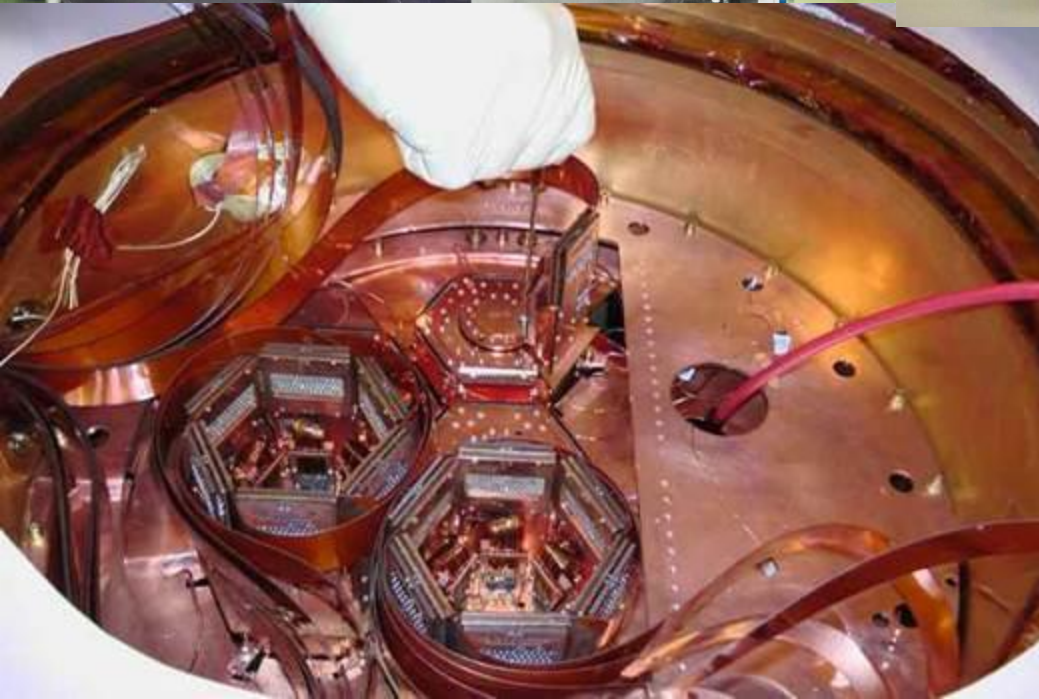
How can we measure the dark matter?

- Three things to try...
 - Detect some interacting with us
 - Detect the results of interactions somewhere else in the neighborhood
 - Make some for ourselves
- Different techniques needed for WIMPs and FIMPs in each of these attempts
- A lot of effort going into all these fronts

WIMP Direct Detection

- Simple, just watch for a WIMP to bounce off something
 - Doesn't leave much energy behind
 - Other things bounce too
- Characterize the bounce as well as possible
- Bury it deep in a mine
- Calibrate very carefully





FIMP Direct Detection

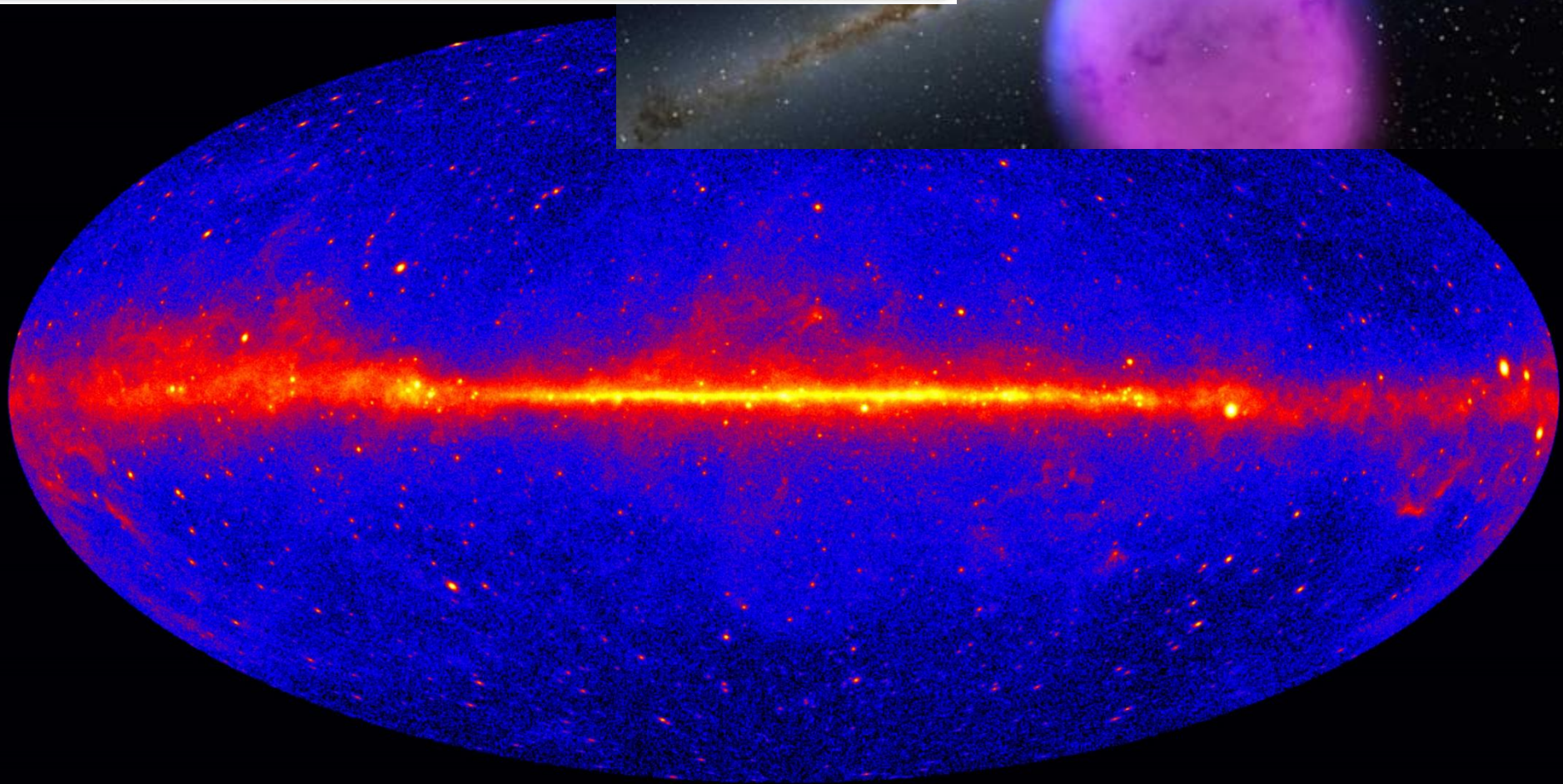
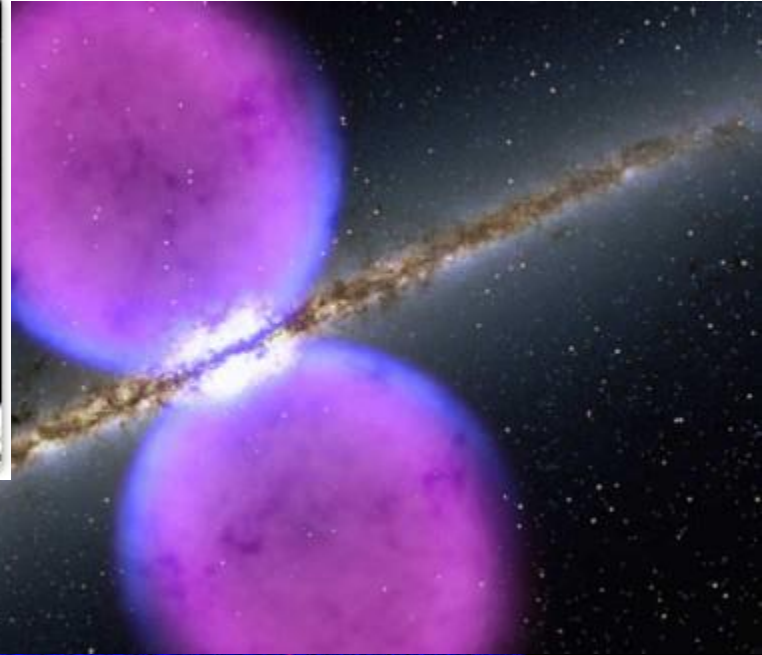
- FIMPs are so light that they can only convert into photons, nothing else is light enough
- The best way to make this happen is to have them experience a strong magnetic field
- The photon this creates is still very low energy and difficult to detect
- Need to be able to tune the frequency we're looking for just like you tune a radio

ADMX



WIMP Indirect Detection

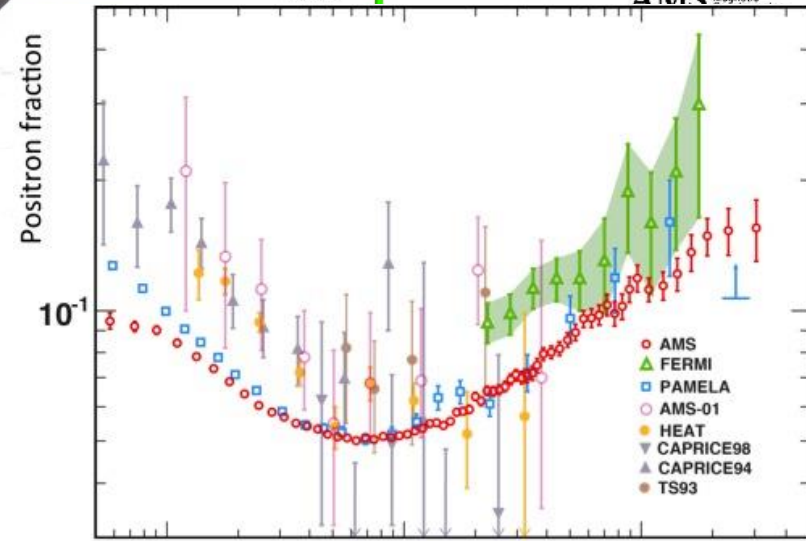
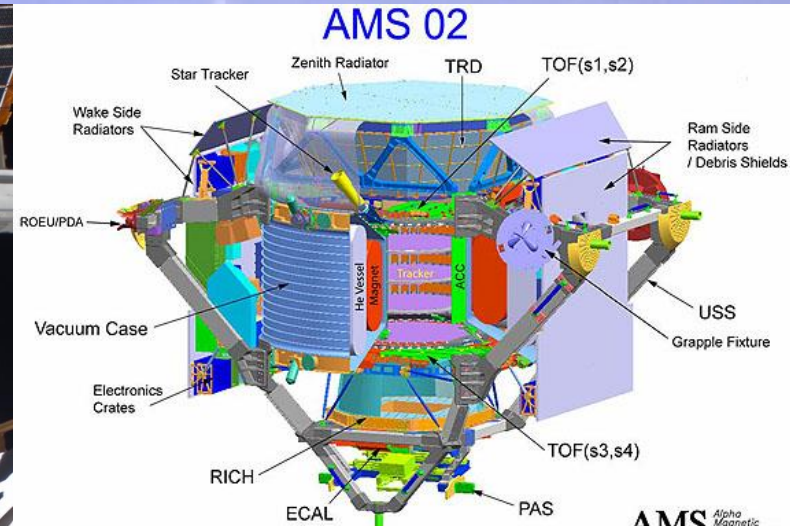
- The next technique is to look for the results of DM interactions in the sky
- For WIMPs, this means the results of ongoing (rare) annihilations, producing normal stuff
 - Many different things can be produced, but a few are easier to see than others
- I'll focus on searching in gamma rays (very energetic photons) and antimatter





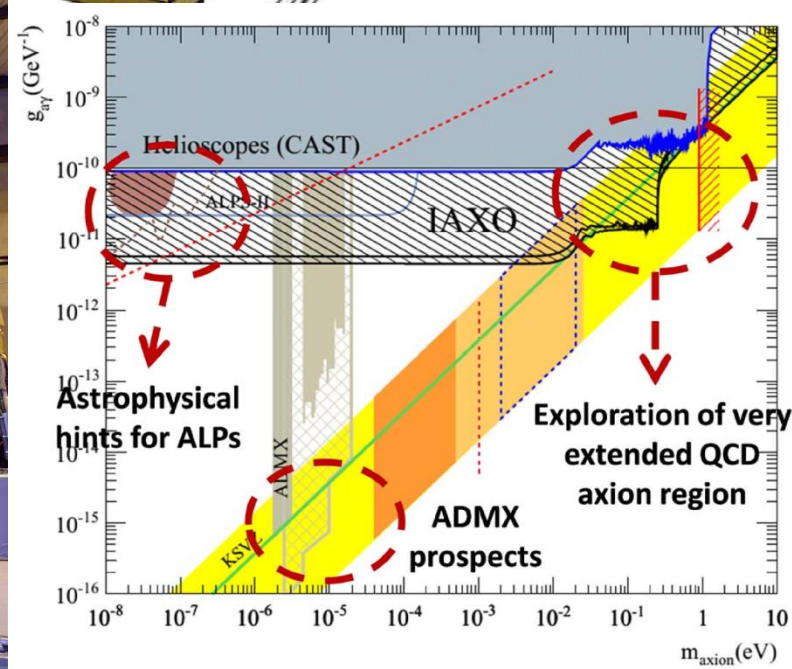
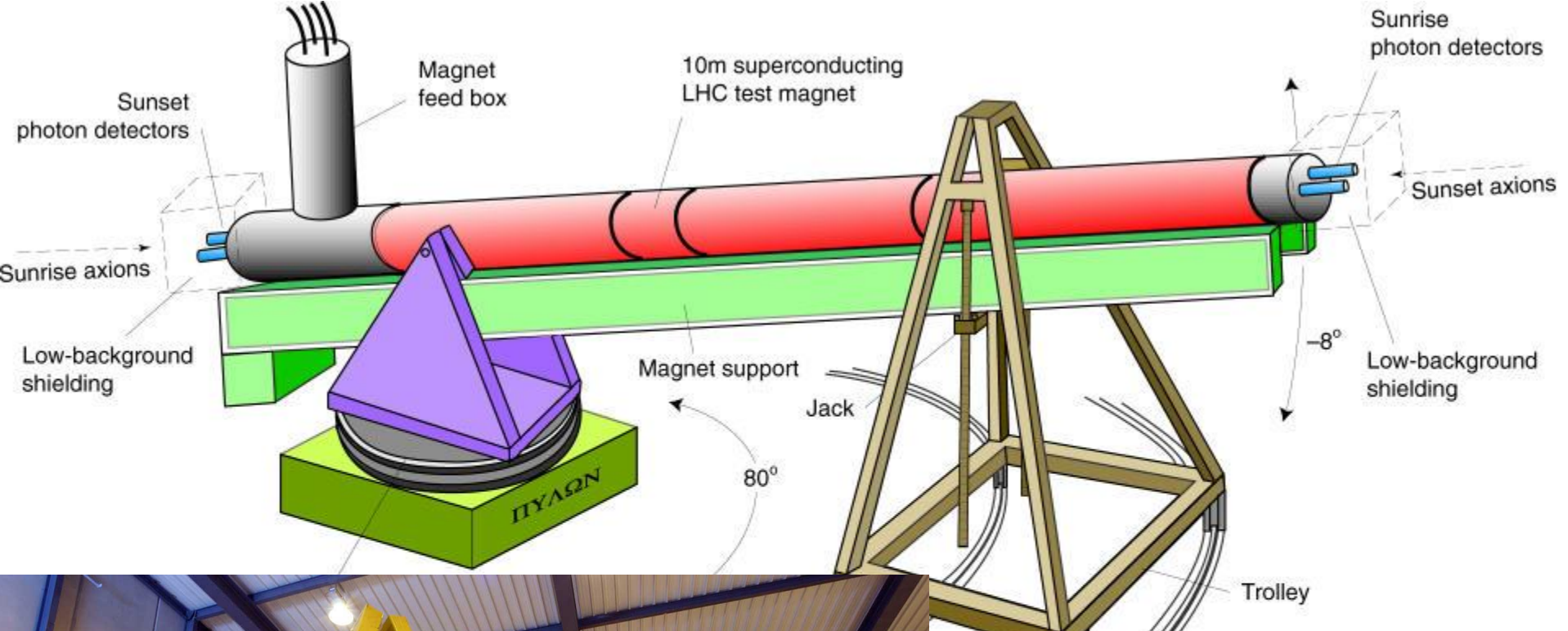
AMS-02

The Alpha Magnetic Spectrometer Experiment



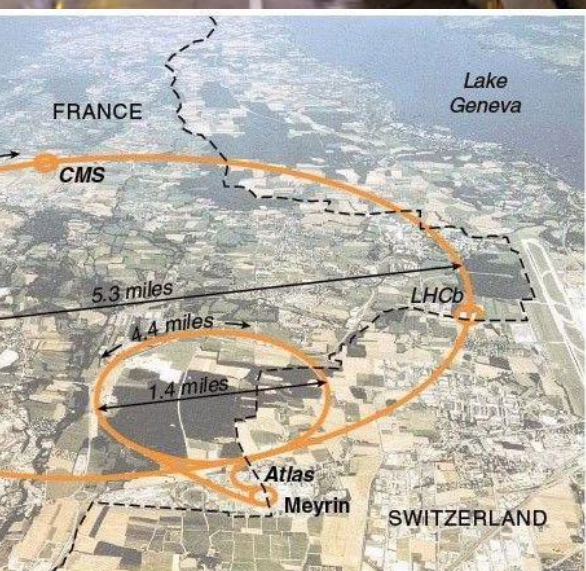
FIMP Indirect Detection

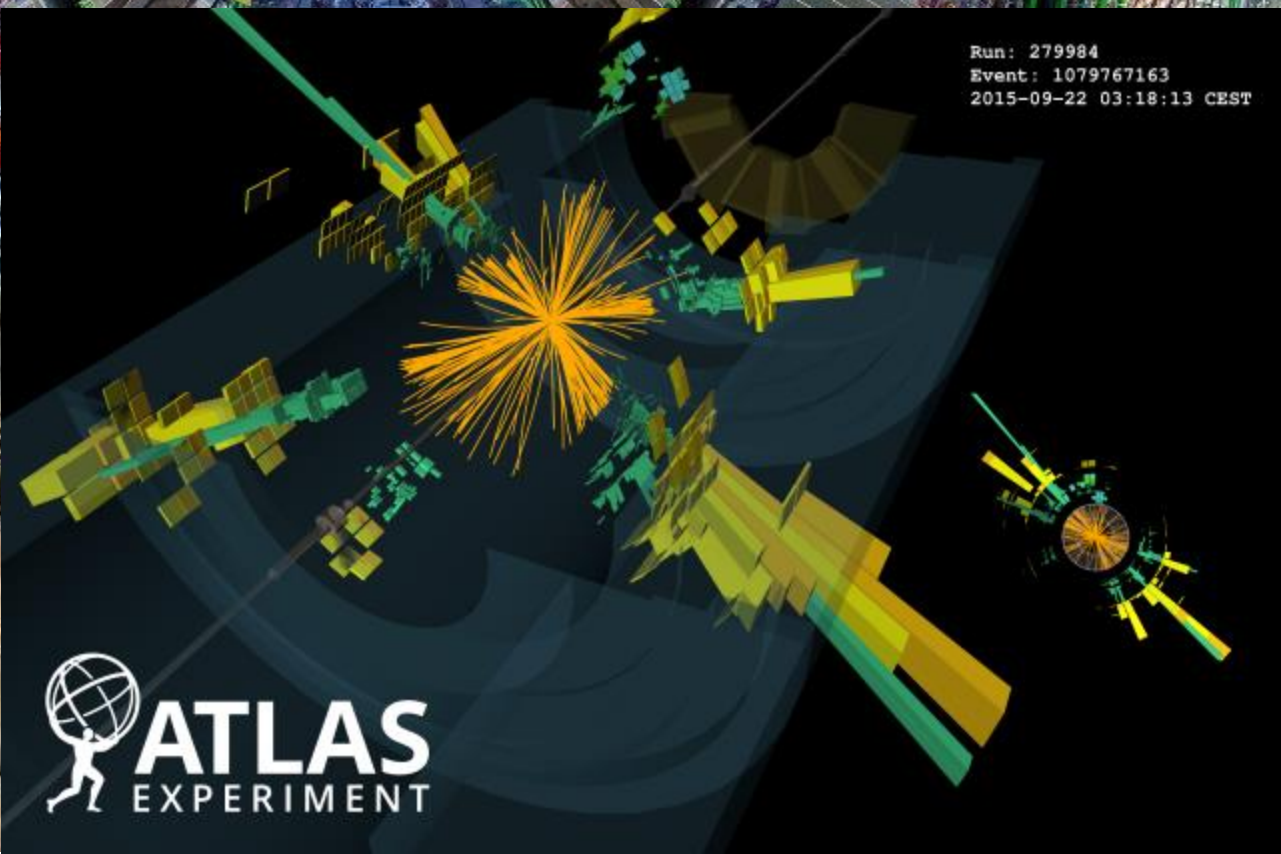
- The detection technology for FIMPs is, as usual, rather different
- The photons generated by FIMP decays are so low energy that they can't be reliably detected
- Instead, we look for ongoing FIMP production somewhere hot and dense
- The sun is a perfect candidate for this



WIMP Production

- WIMP production is driven by Einstein's famous relation, $E = mc^2$
 - If we put in enough energy, there's a chance that we can make something more massive that's going slower than what we put in
 - This is actually the principle that searches for new physics at colliders has been running on forever
- WIMPs are a decent target for this, because their interactions are not so tiny



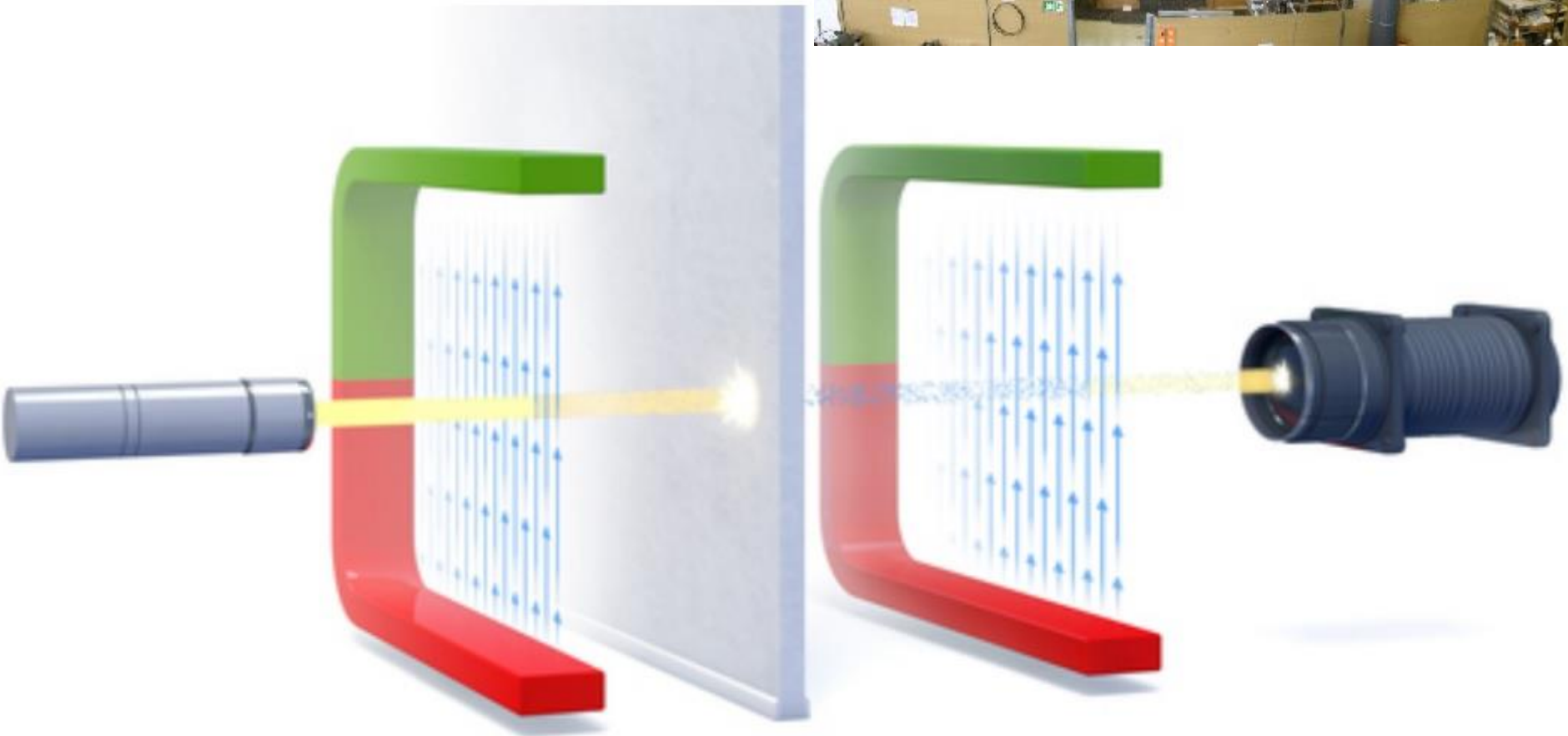


 **ATLAS**
EXPERIMENT

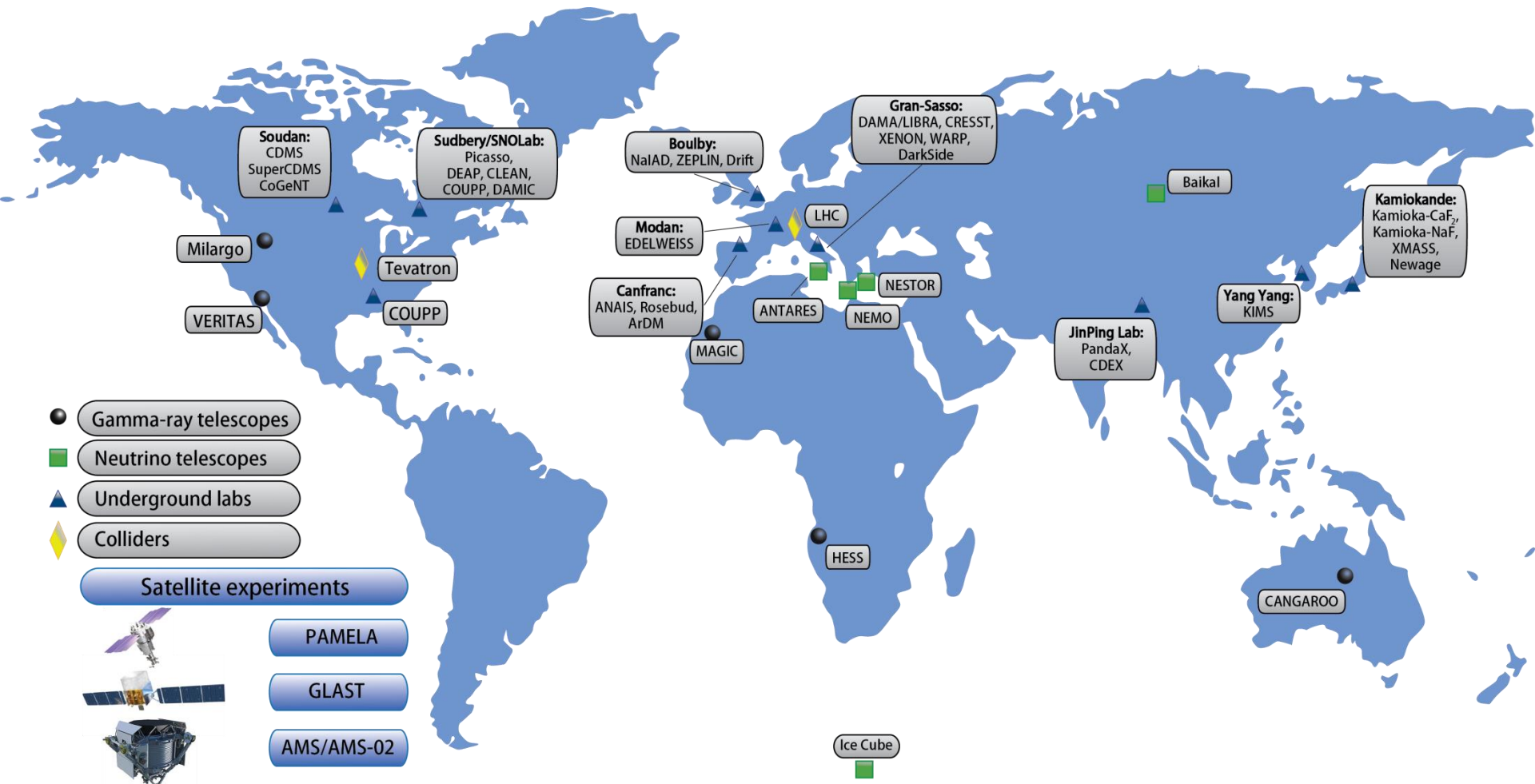
FIMP Production

- FIMPs couple to two photons
 - One can come from a magnetic field
- Producing a FIMP from a photon is rare
 - We want a strong light source for many chances
- Once made, we need to detect it
 - Convert it back to a photon
 - Need to stop the light from overwhelming our detector though

Light shining through walls



Dark Matter Experiments



**THE END
OF THE FILM**

