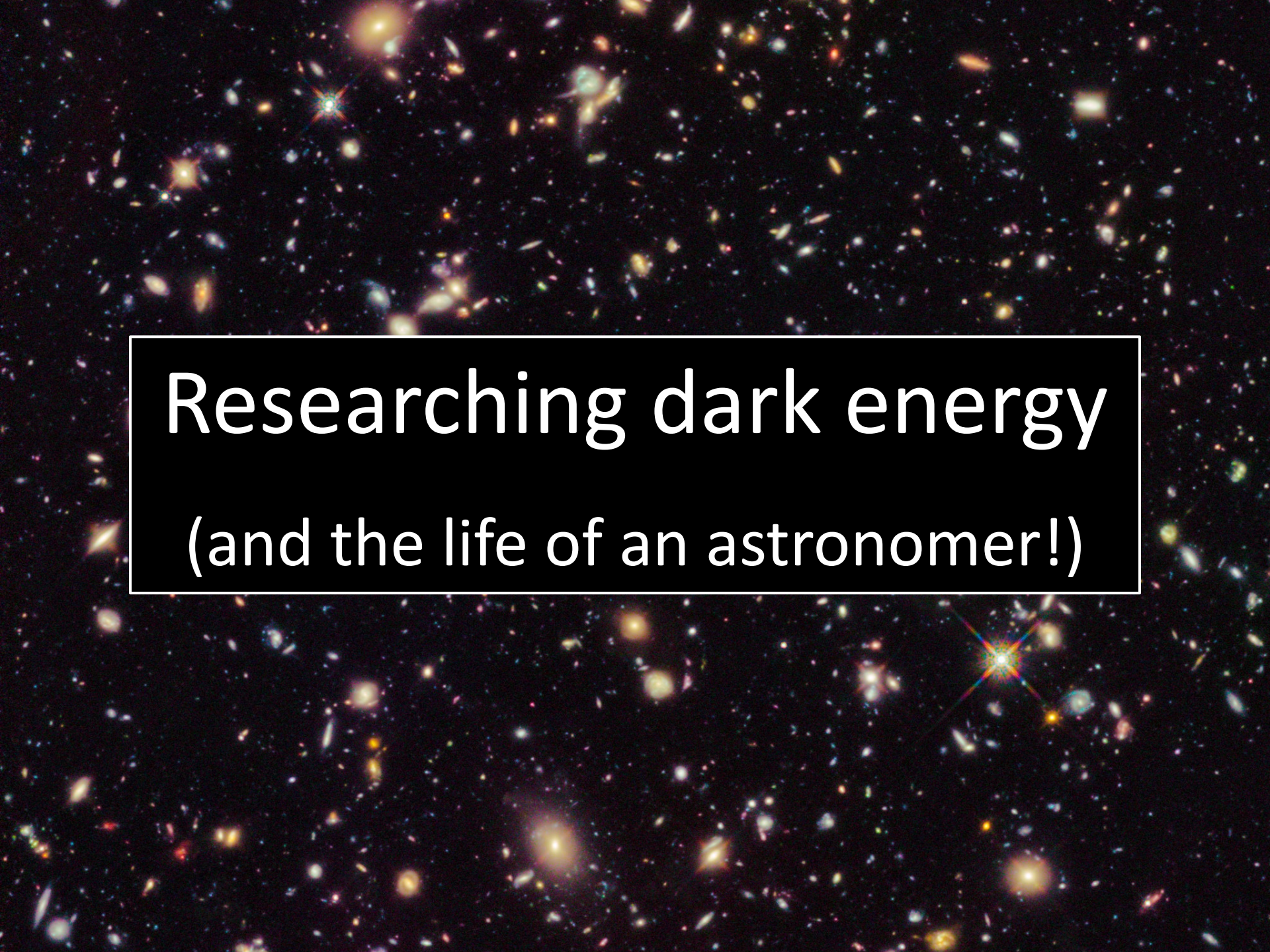

Researching dark energy
(and the life of an astronomer!)

I’m an astronomy researcher!

We are scientists who study planets, stars, galaxies … and the Universe as a whole!

We gather data on the Universe … using the best technologies!

We process and analyse data using computer codes, maths, statistics

We use these results to improve our theory of how the Universe formed and evolved

A bit about me!

Where am I from?

I come from Sheffield, a town in the north of England …

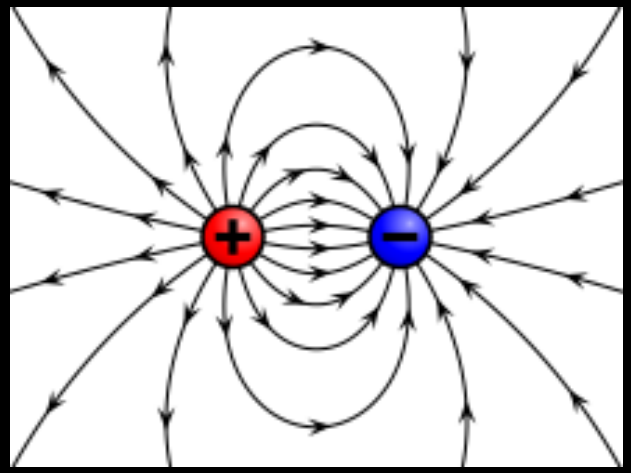
A bit about me!

My first memory of being interested in astronomy was in 1986 when I saw…

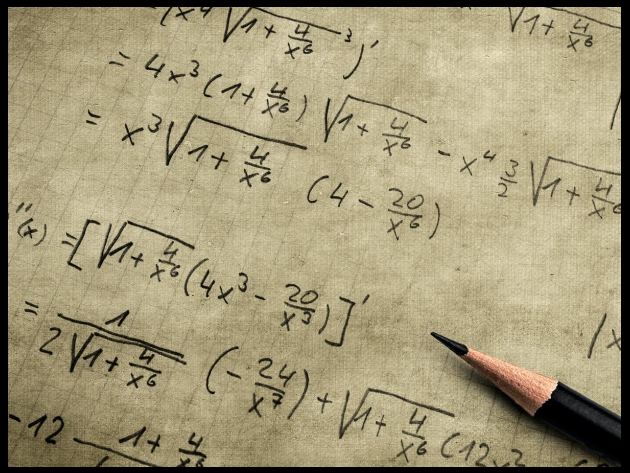
Put 28 July, 2061 in your diaries!

What I liked to study …

Physics



Maths



History

I got the chance to go to University and chose to study physics

I didn’t know anything about research!

I got interested in astronomy!

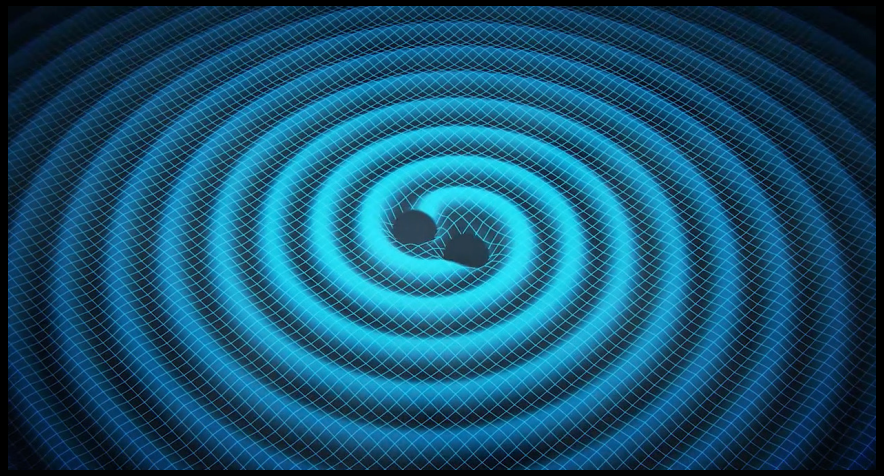
In 1996 I had a very lucky opportunity to visit …

After my degree I started PhD research in astronomy

I realized the Universe is the greatest physics laboratory of them all!

Why research is fun …?

Discovering things which no-one has seen before



Creative process

Team work

Challenging yourself

My research field of cosmology aims to build a physical model of the contents and history of the Universe …

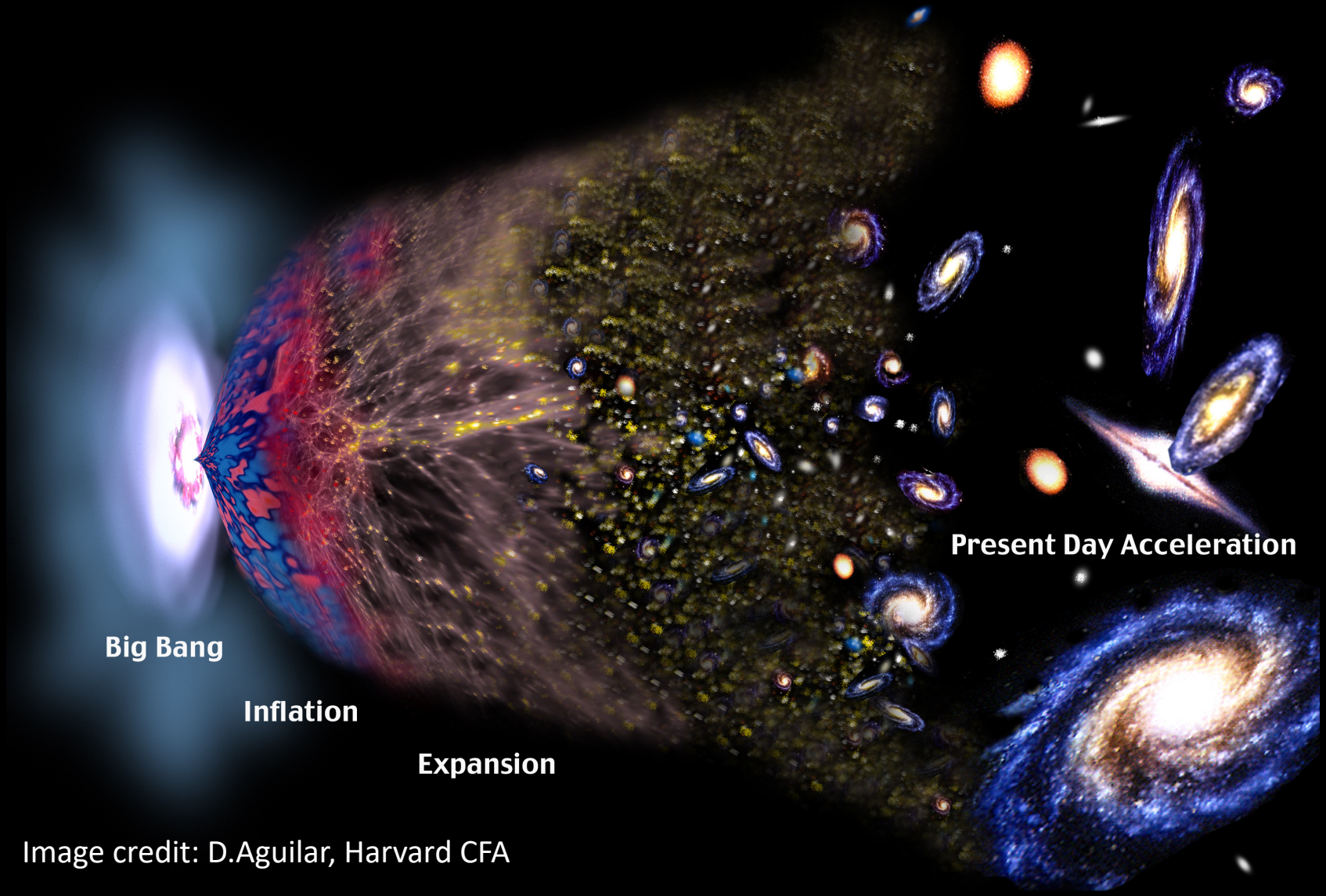
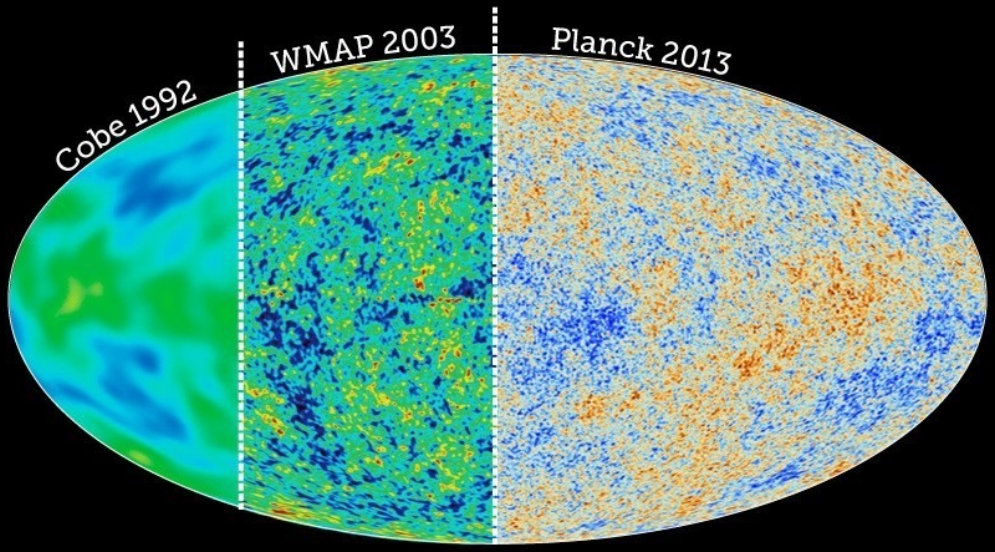
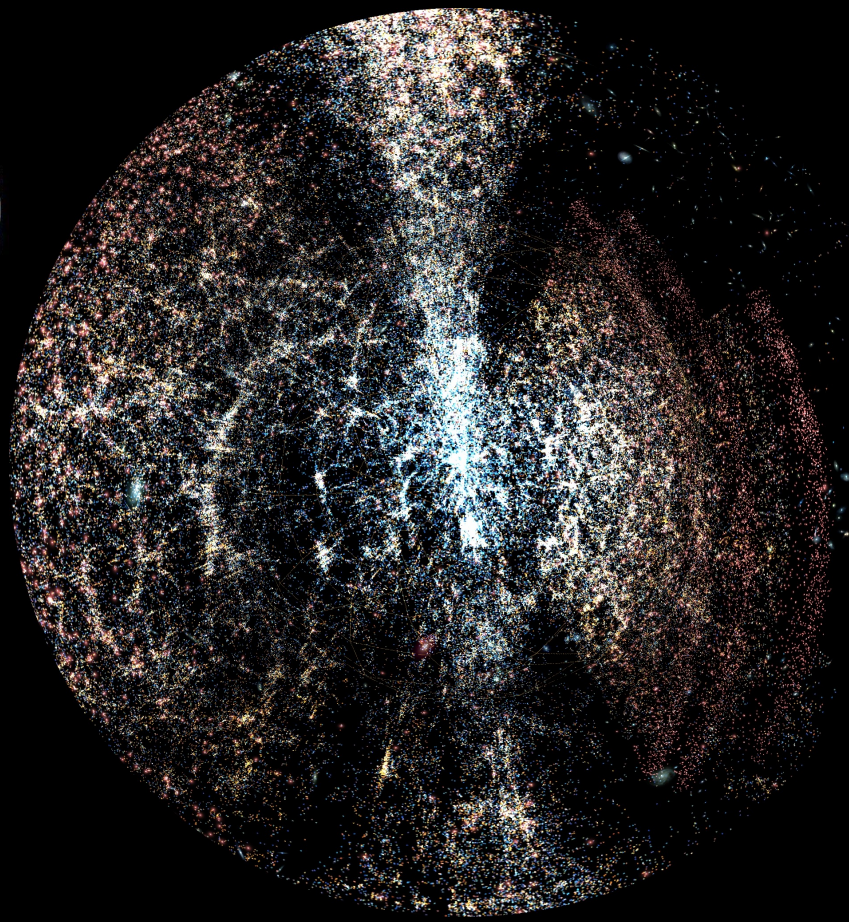


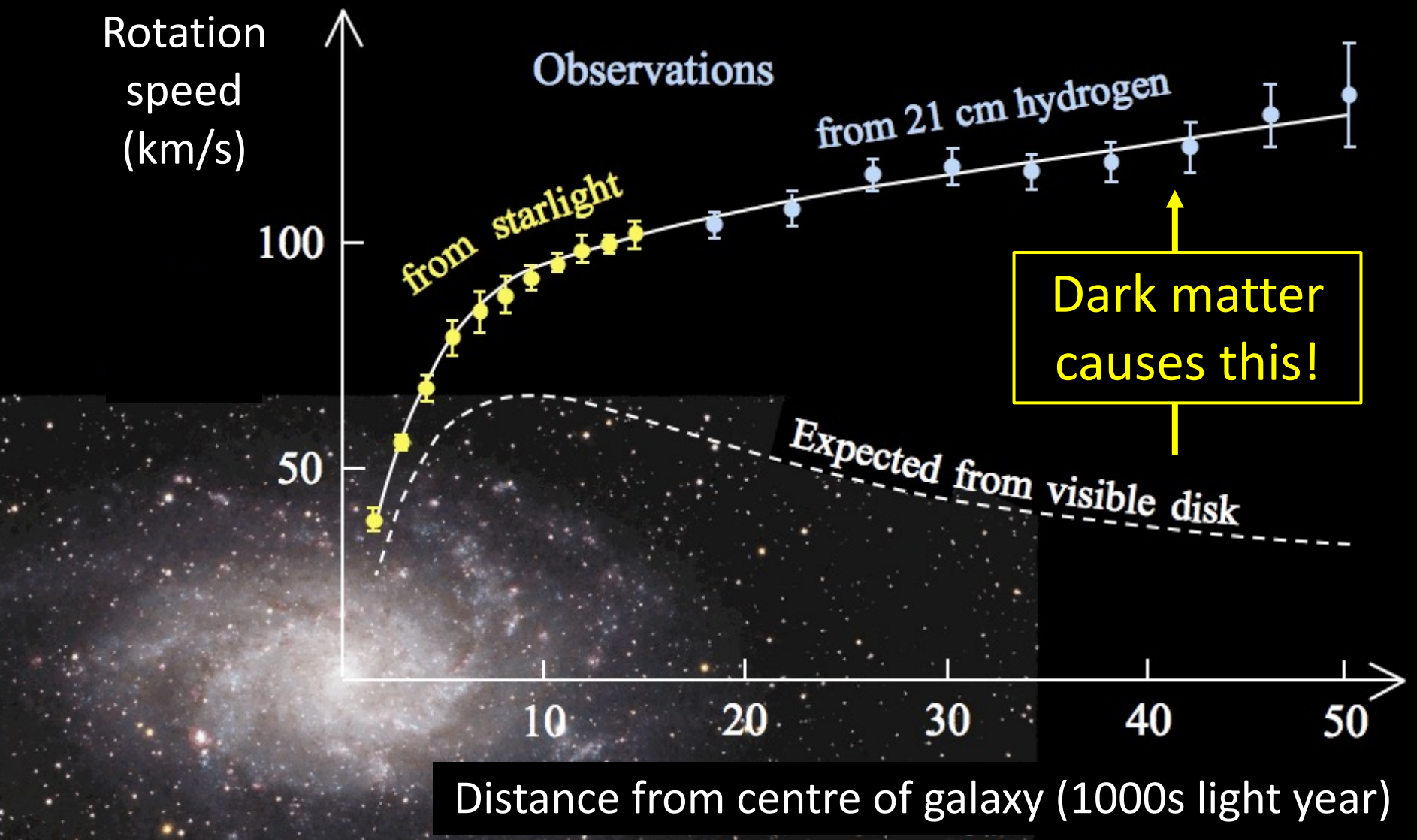
Image credit: D.Aguilar, Harvard CFA

… and has been transformed by a remarkable growth in data over the past 2 decades!





We have learned galaxies are full of invisible dark matter …



… but the most startling discovery is that the cosmic expansion seems to be accelerating!

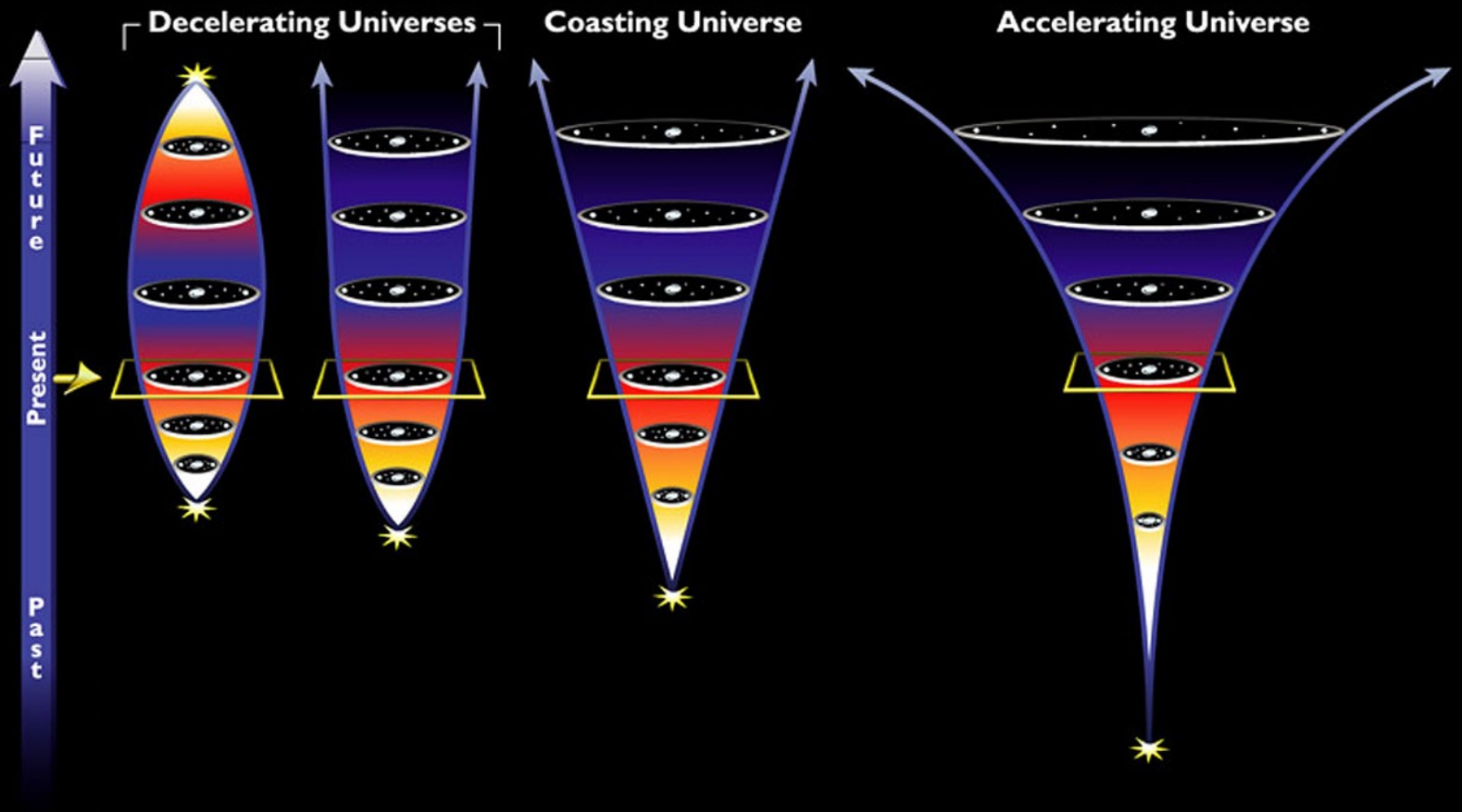
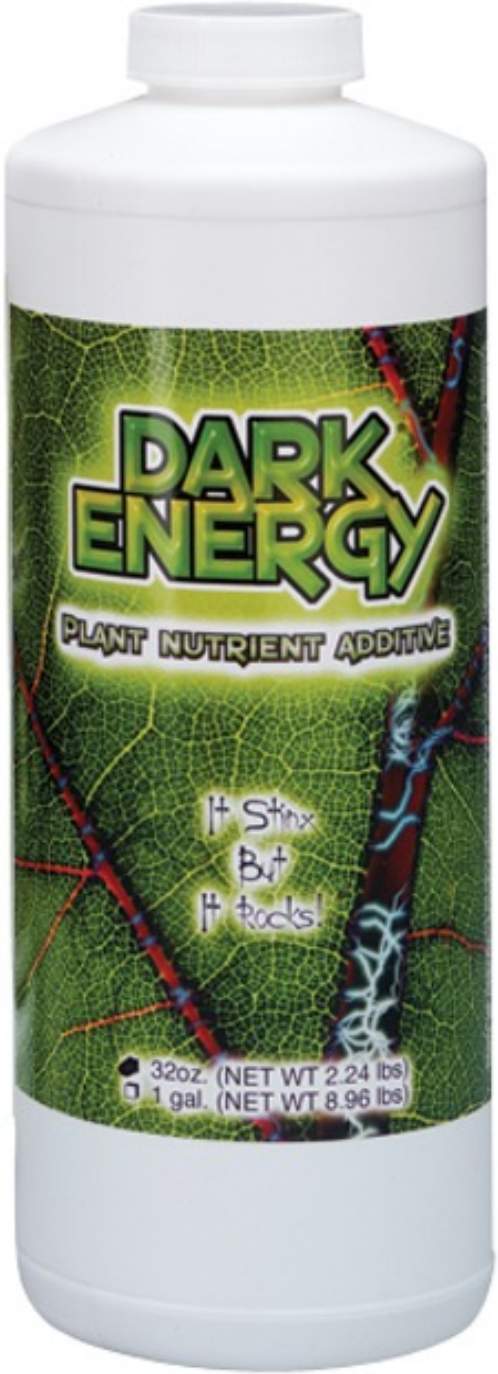
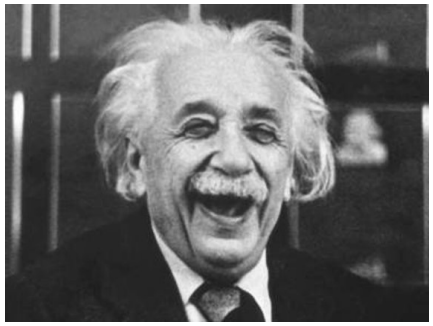


Image credit: The Cosmic Perspective

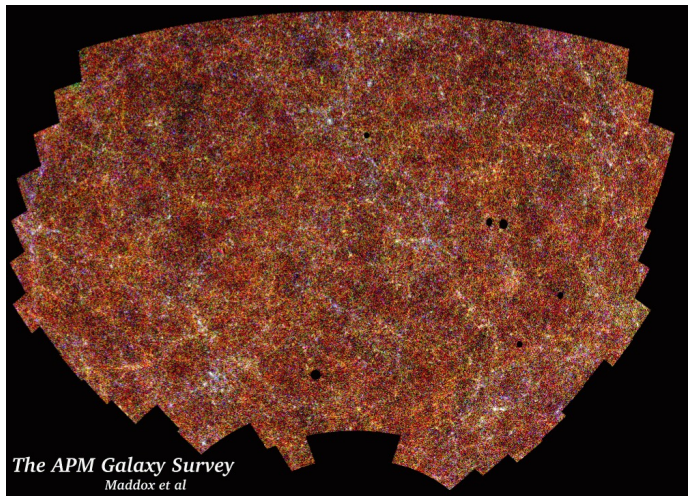
This is the “dark energy problem”: the attempt to understand the physics of cosmic acceleration, and its implications

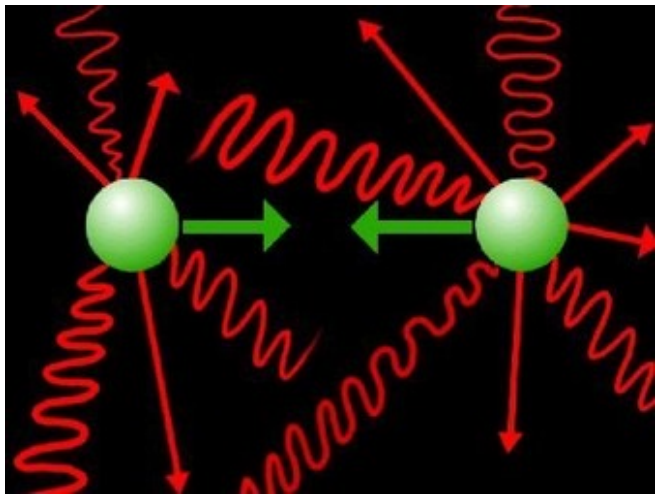


The dark energy problem



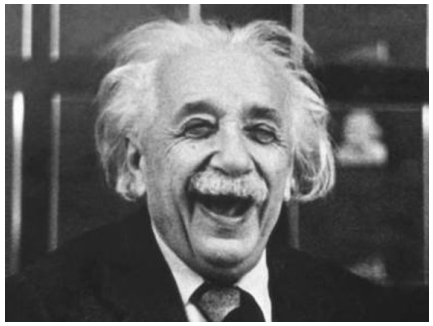
$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$





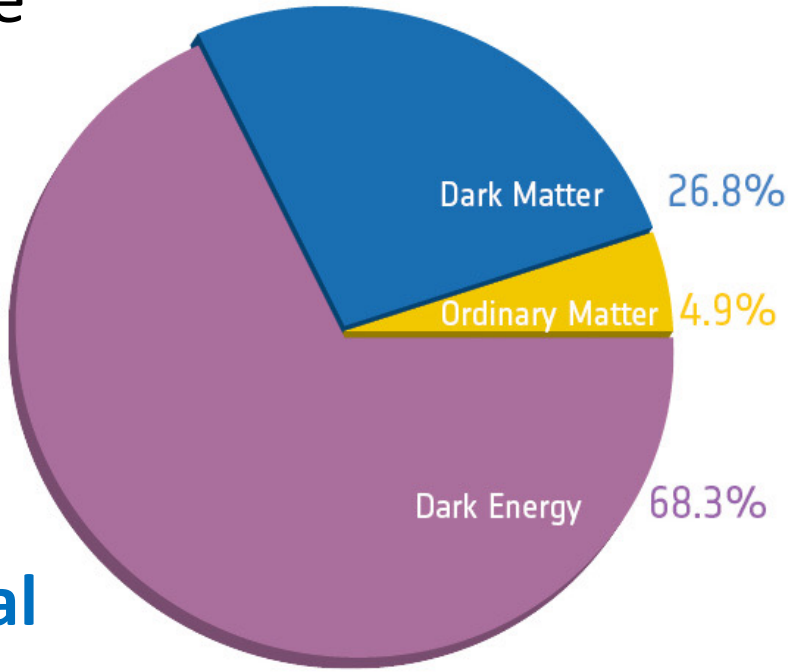
- The accelerating cosmic expansion cannot be produced by applying **General Relativity** to a **homogeneous and isotropic** Universe containing **matter and radiation**

The dark energy problem



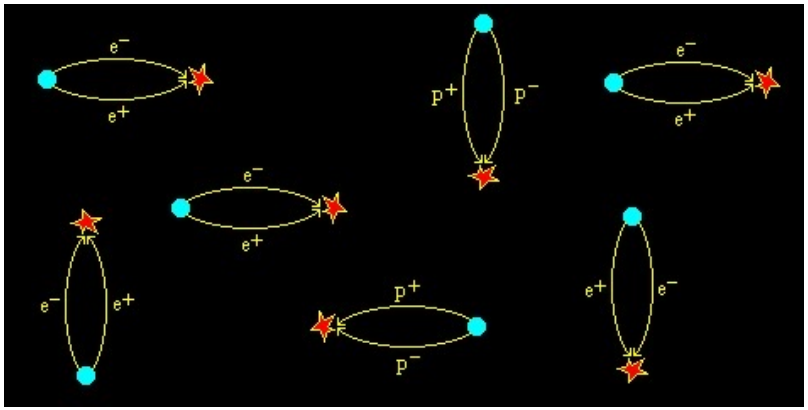
$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} - \Lambda g_{\mu\nu}$$

- Accelerating expansion can be produced by adding a **cosmological constant** term
- A wide range of data is consistent with a Universe where the current energy density is **~70% cosmological constant and ~30% matter**



Why is this a problem?

$$\Lambda_{\text{obs}} \sim (10^{-30}\, M_{\text{Planck}})^4$$



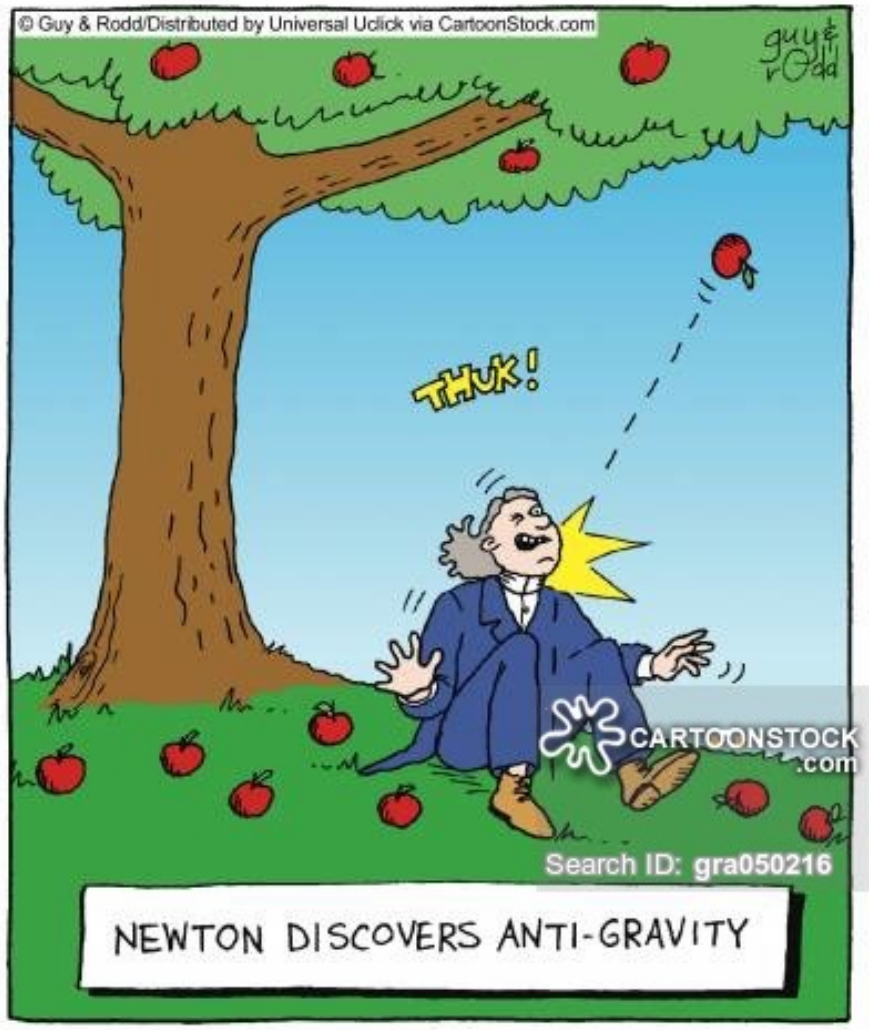
- In physics we seek a microscopic explanation of what the terms in an equation mean
- Unfortunately, this energy scale is **many tens of orders of magnitude lower** than expected from quantum mechanical processes involving standard particles
- **Is the cosmological constant a sign of new physics?**

Other explanations?

Let's seek another solution!

- *"Accelerating cosmic expansion cannot be produced applying GR to a homogeneous/isotropic Universe containing matter and radiation"*
- Modify gravitational physics? [e.g. Einstein-Hilbert action]
- Allow for effects of inhomogeneity? [very hard!]
- Add extra "source"? [e.g. dynamical scalar field]

What does it mean to “modify gravity”?



- Add some kind of “fifth force” [to the four we already have]
- But we have extremely accurate laboratory and solar system tests of General Relativity!
- Add a “screening mechanism” which allows the fifth force to vary with environment

Cosmological observations

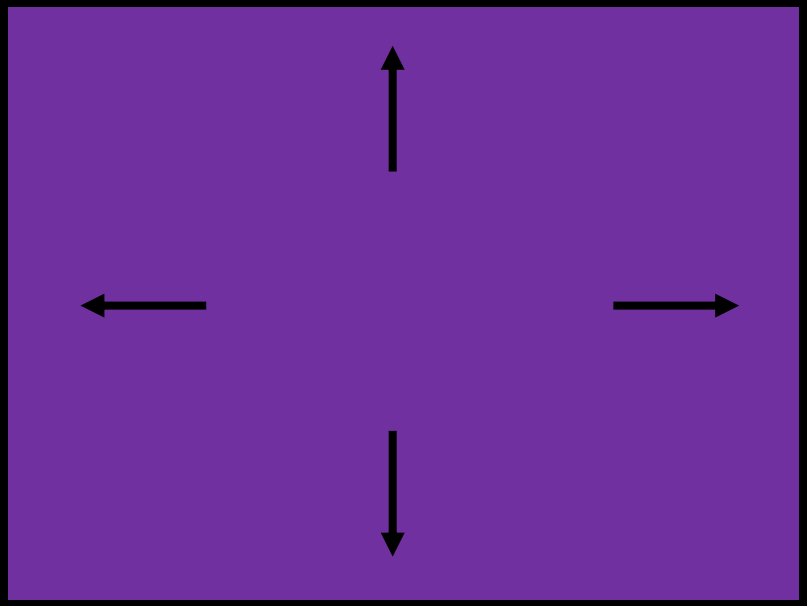
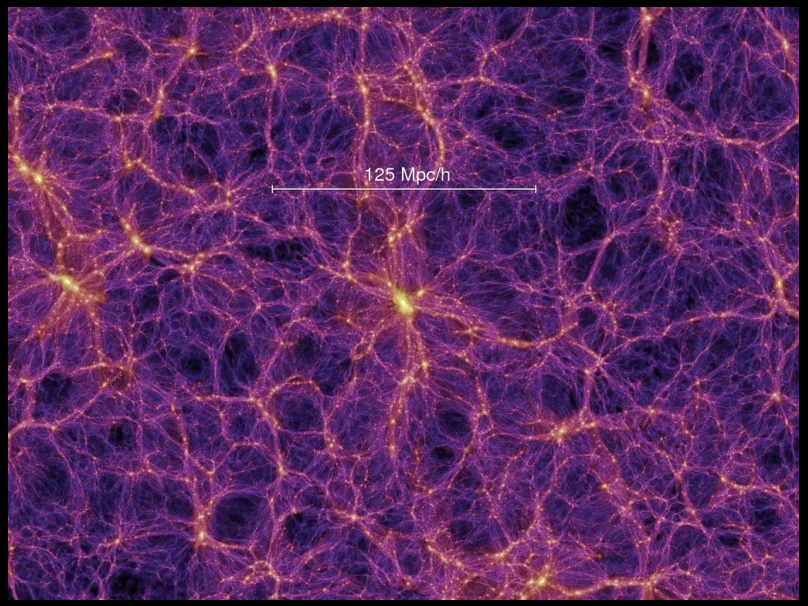


Image credit: Millennium simulation



Homogeneous expansion of the Universe

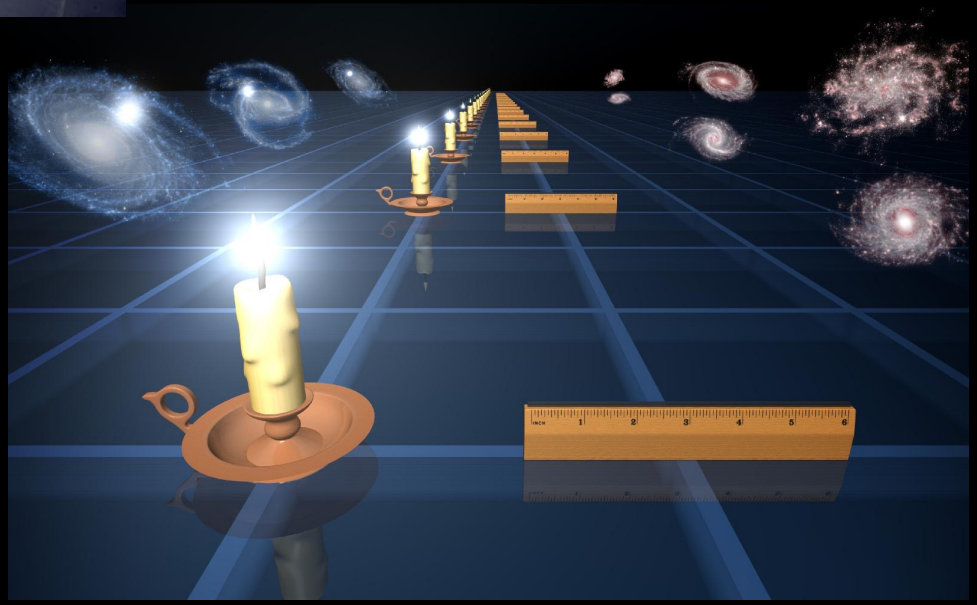
Growth of perturbations within the expanding background

Cosmological observations

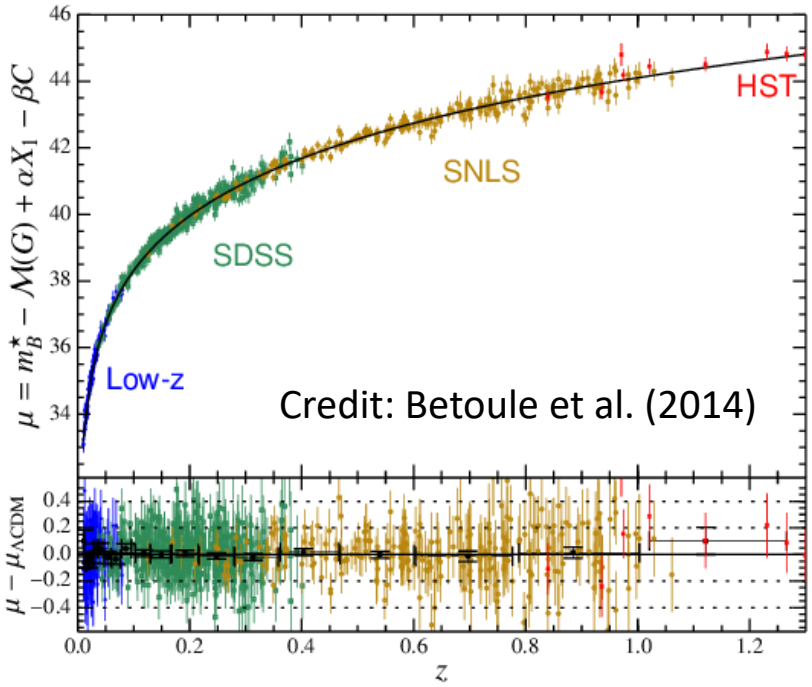
To do the first, we need to measure distances …

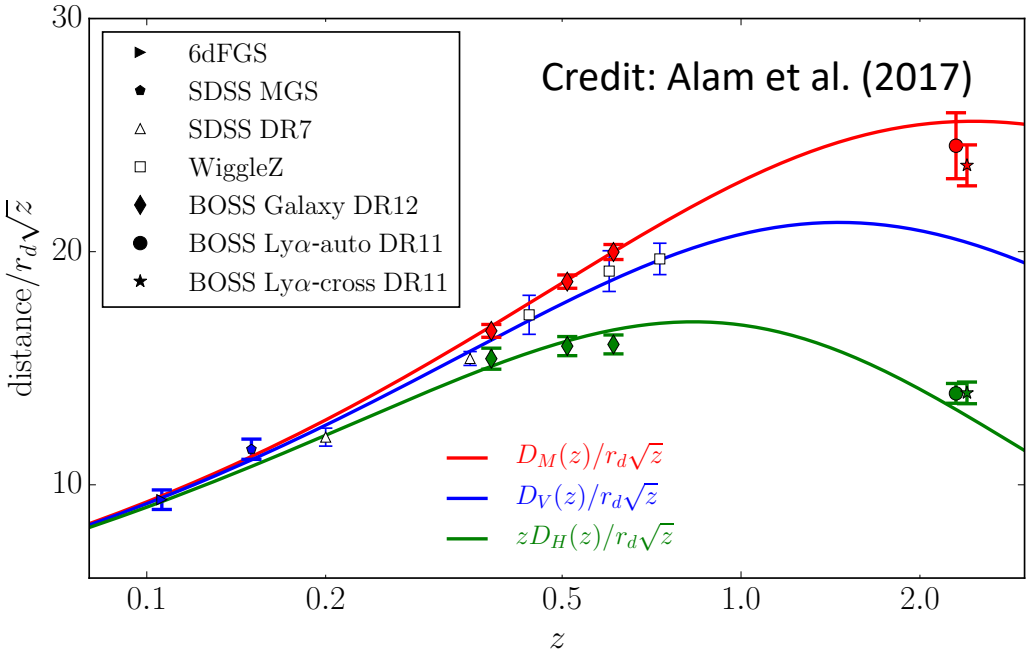
We can tell the distance of cars from the observed separation of the headlights and their brightness

In astronomy we do this with standard candles and standard rulers!



Cosmological observations





- The **cosmic expansion history** has been measured with ~1% accuracy using supernovae and baryon acoustic oscillations
- The **cosmic growth history** has not yet been measured as accurately, but is crucial for distinguishing physics

Measuring cosmic structure

- There are a rich variety of observable signatures of the clumpy Universe …
- Clustering of galaxies
- Velocities of objects
- Gravitational lensing
- Abundance/properties of objects

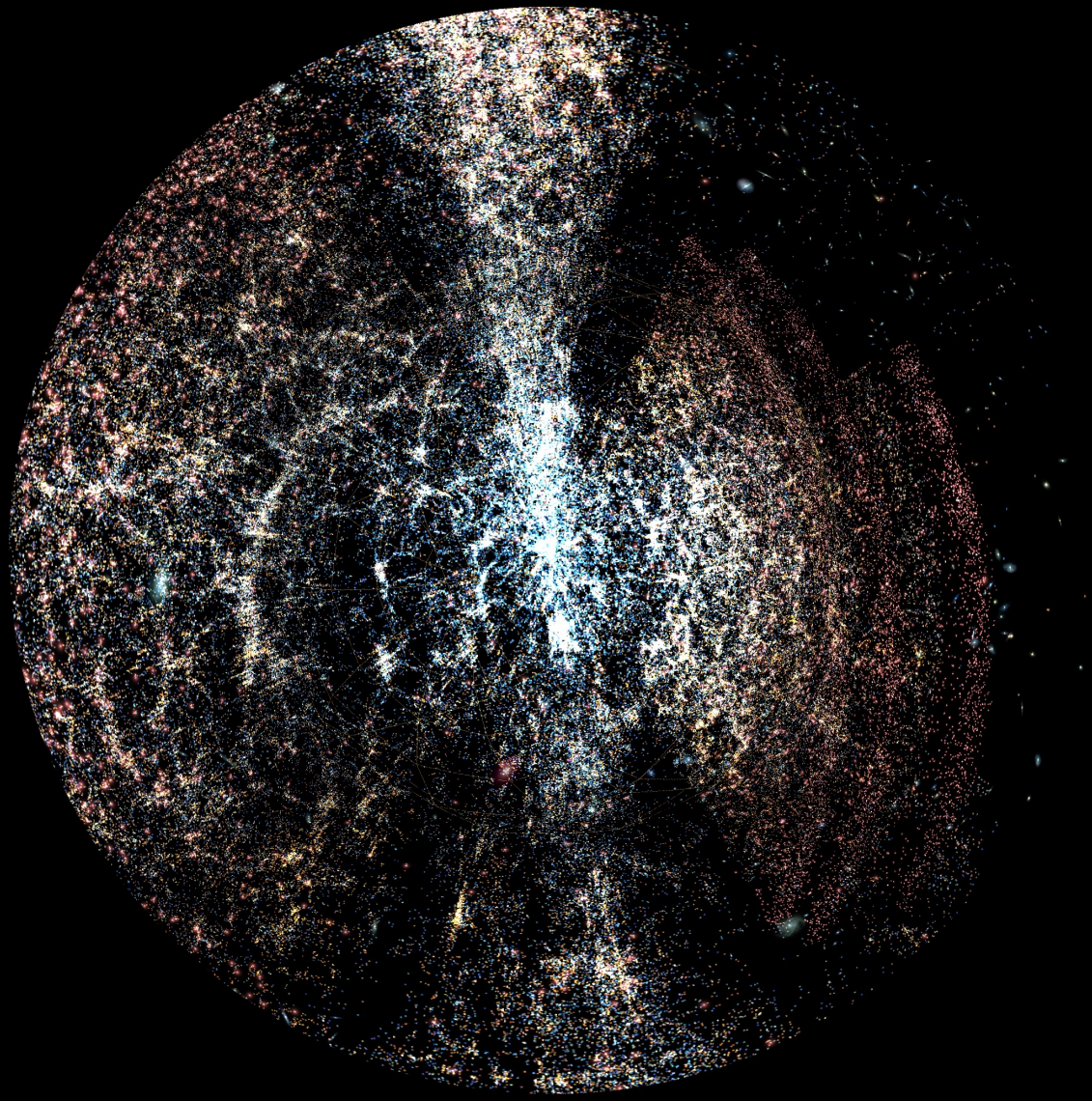
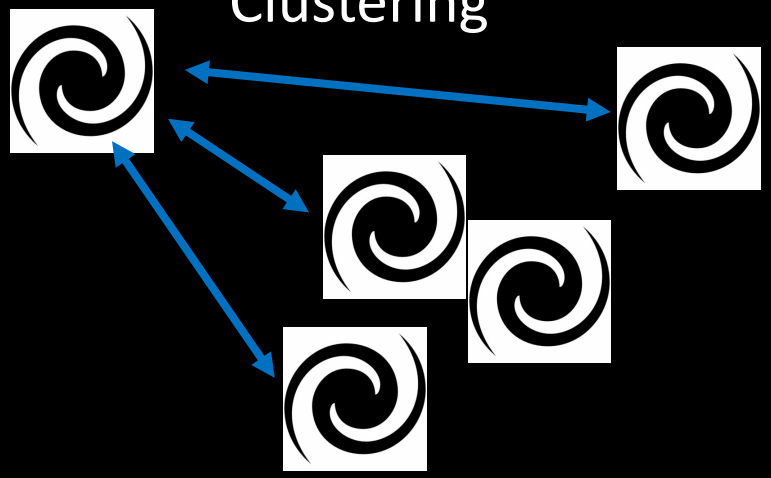


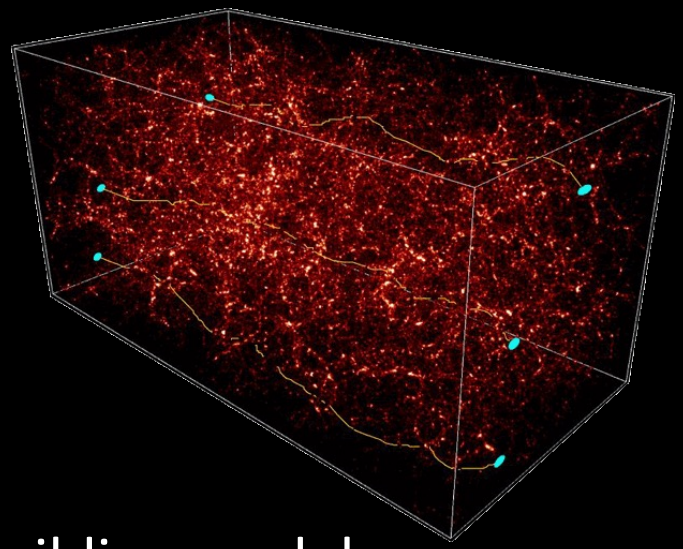
Image credit: Sloan Digital Sky Survey

Measuring cosmic structure

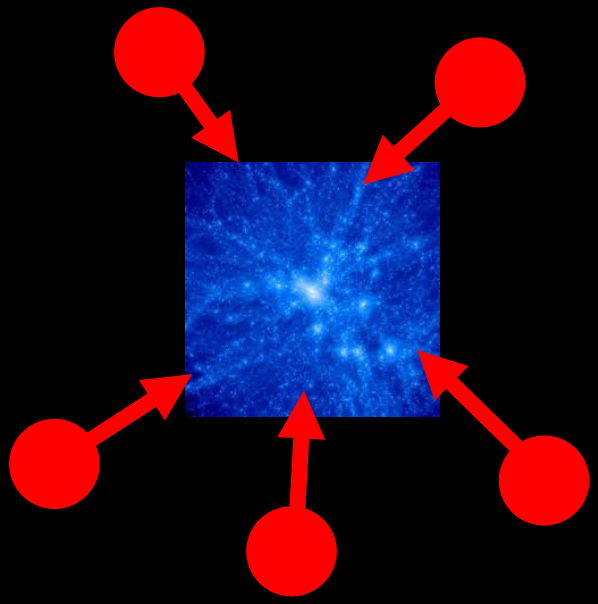
Clustering



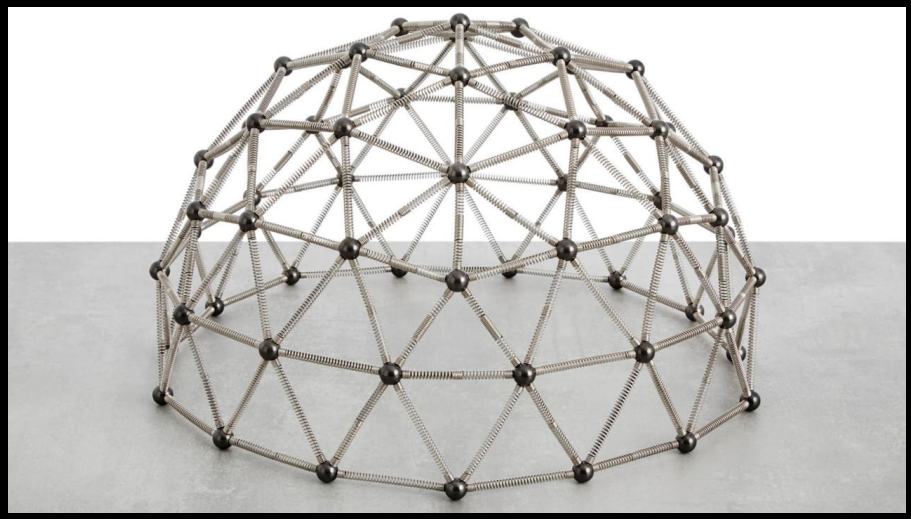
Gravitational lensing



Galaxy velocities

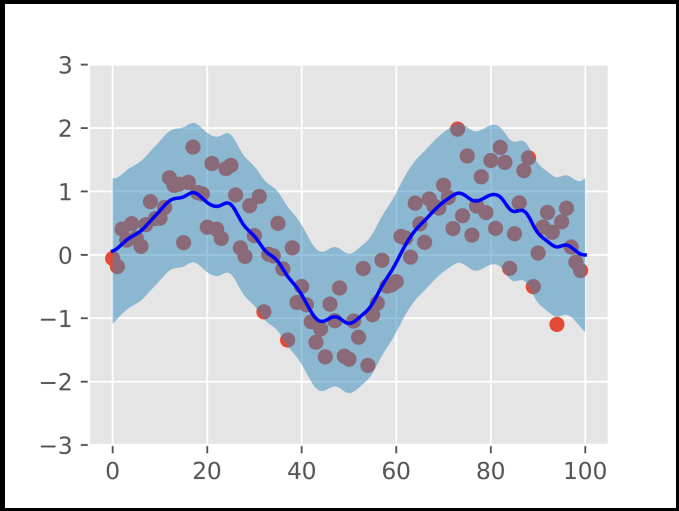


Building models



Research skills

Data science skills



Computing skills

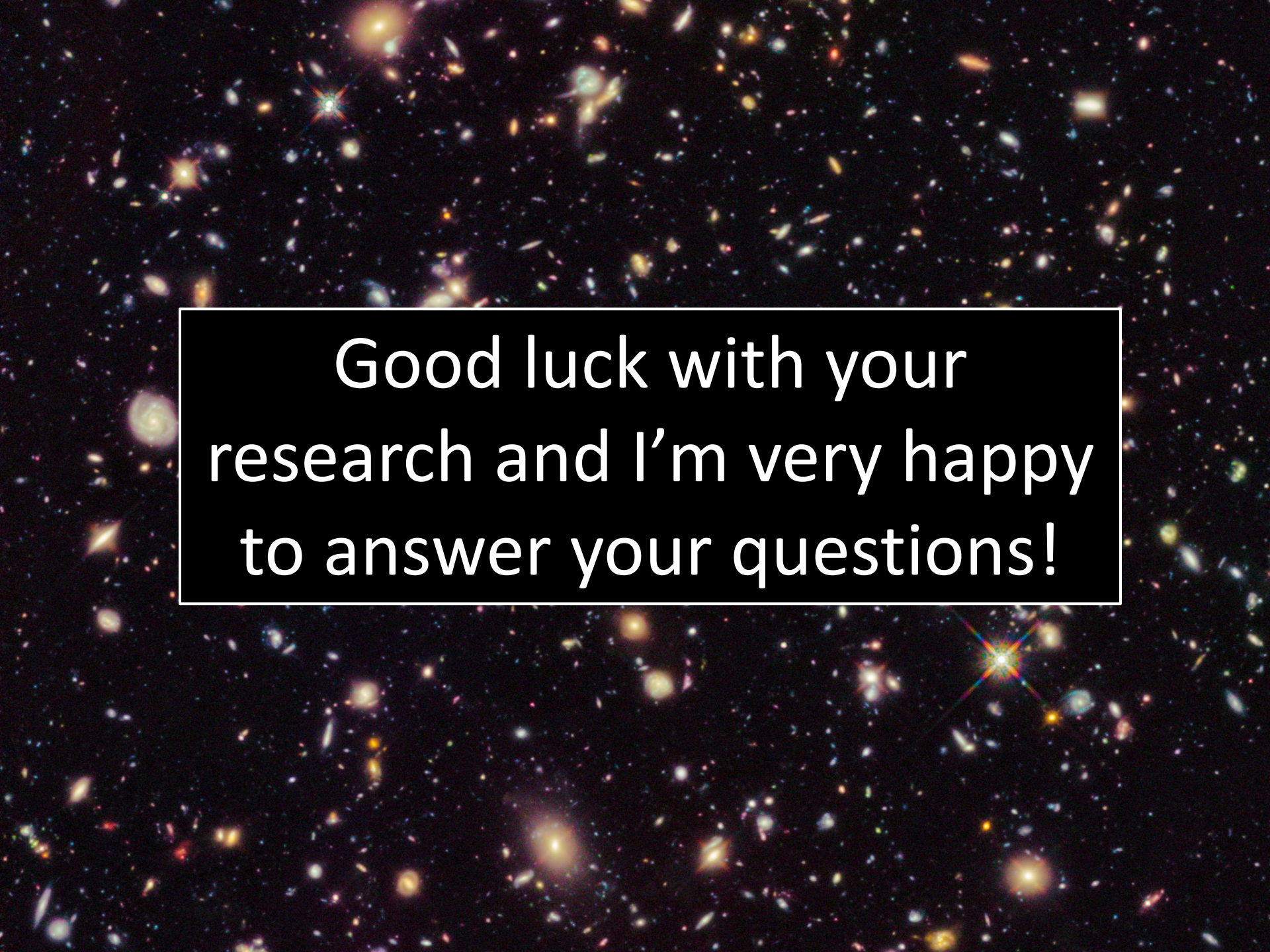
```
for i in people.data.users:
    response = client.api.statuses.user_timeline.get(screen_name=i.scre
    print 'Got', len(response.data), 'tweets from', i.screen_name
    if len(response.data) != 0:
        ltdate = response.data[0]['created_at']
        ltdate2 = datetime.strptime(ltdate,'%a %b %d %H:%M:%S +0000 %Y'
        today = datetime.now()
        howlong = (today-ltdate2).days
        if howlong < daywindow:
            print i.screen_name, 'has tweeted in the past' , daywindow,
            totaltweets += len(response.data)
            for j in response.data:
                if j.entities.urls:
                    for k in j.entities.urls:
                        newurl = k['expanded_url']
                        urlset.add((newurl, j.user.screen_name))
        else:
            print i.screen_name, 'has not tweeted in the past', daywind
```

Communication skills

Challenging yourself

Opportunities for research at Swinburne

Activity	Unit code	When?
R&D Project 1	NPS10002	Summer after 1st/2nd year
R&D Project 2	NPS20006	Winter of 2nd/3rd year
Grand Challenge	NPS30003	3rd year
Vacation Projects	-	Summer after 2nd/3rd year
Honours	NPS40009	4th year undergraduate
PhD	DR-SCI	3.5-4 year program


Good luck with your research and I’m very happy to answer your questions!