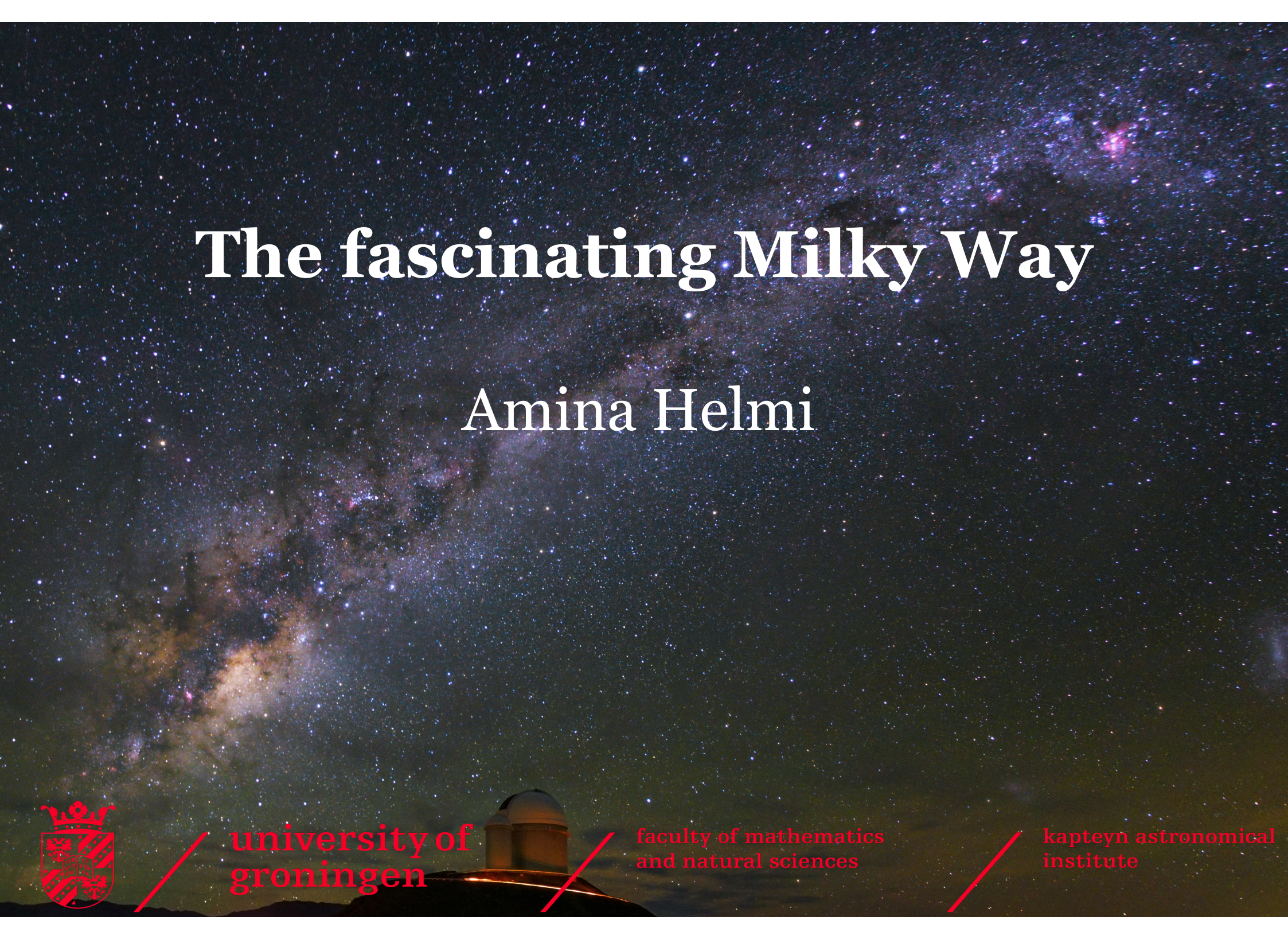
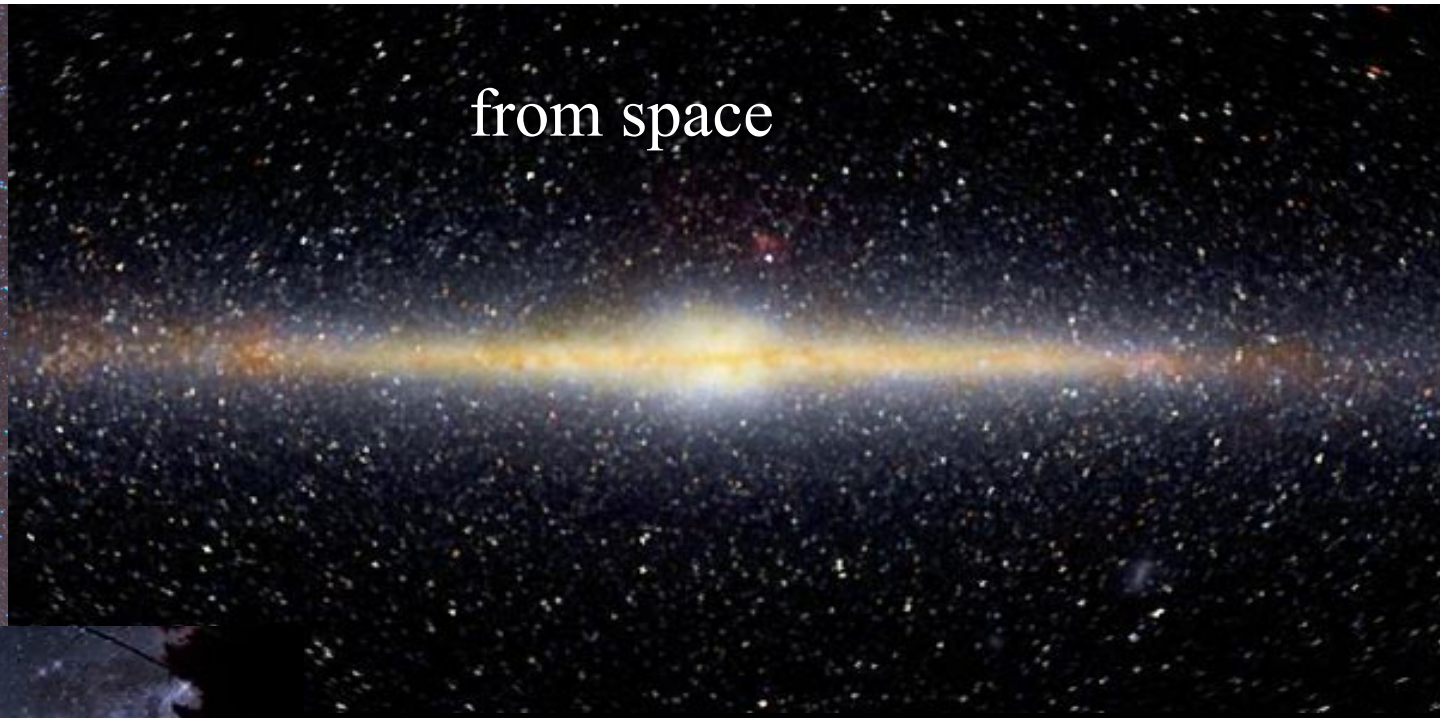
The fascinating Milky Way

Amina Helmi



university of groningen
faculty of mathematics and natural sciences
kapteyn astronomical institute

Canary Islands



from space

Argentina

Netherlands

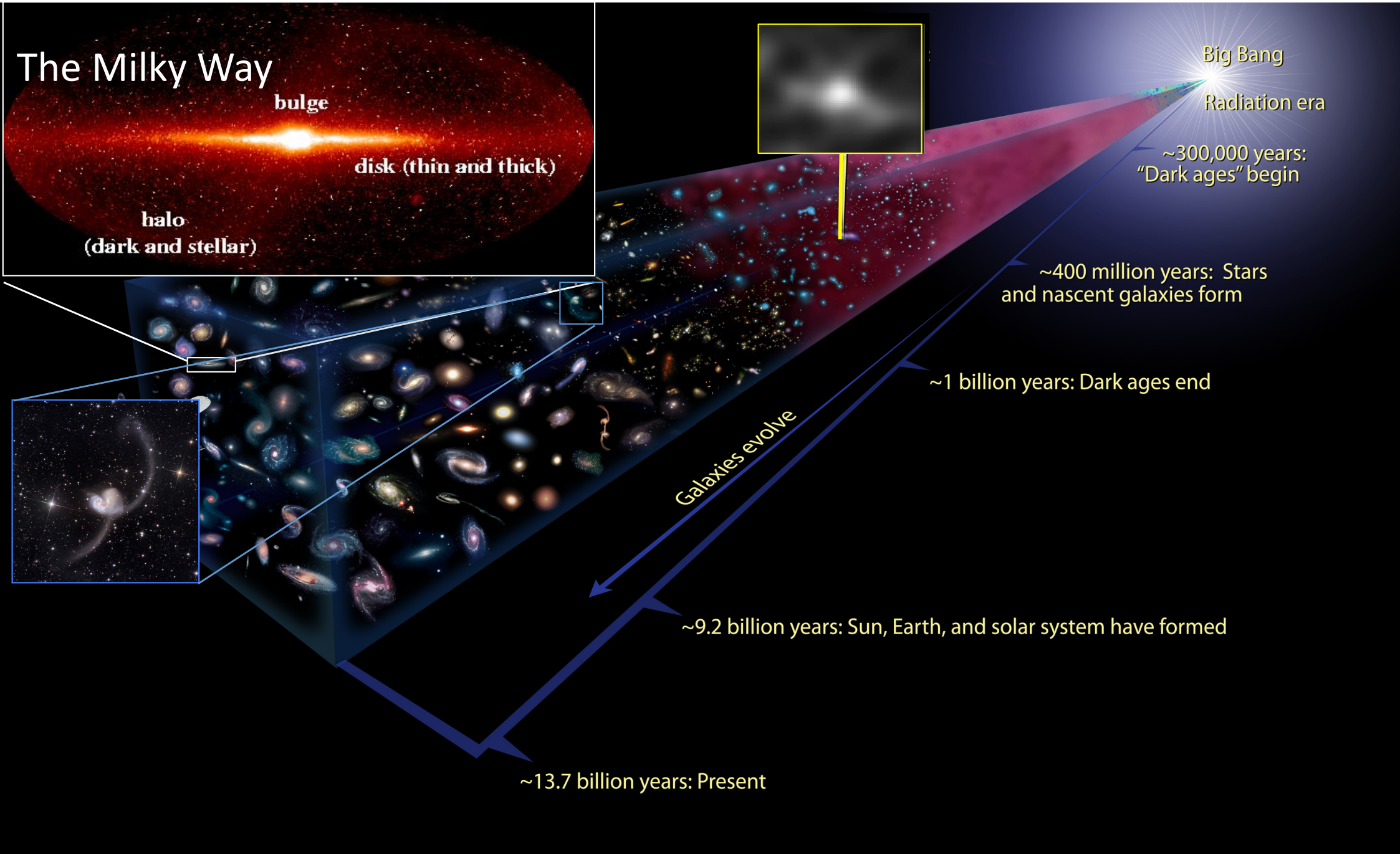
Our Galaxy is one of many, and rather typical

- A disk like 2/3 of galaxies in the Universe
- Characteristic size and brightness

It can be used to understand

- how (all) galaxies form
- physical processes in the history of the Universe
- what is the Universe made of

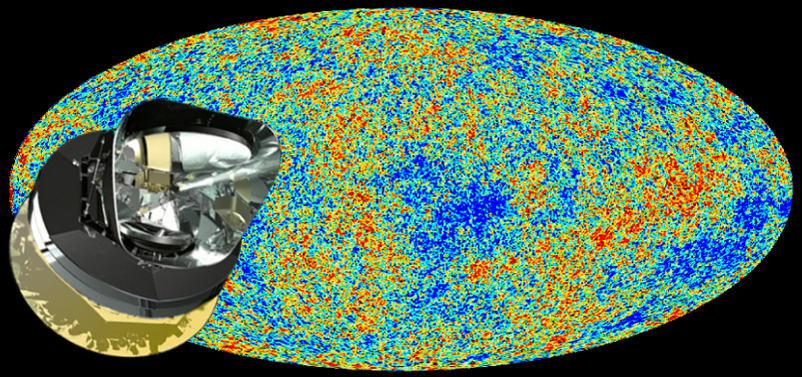
What is the history of our home in the Universe?



We can study the Milky Way and its fossil record with extraordinary detail

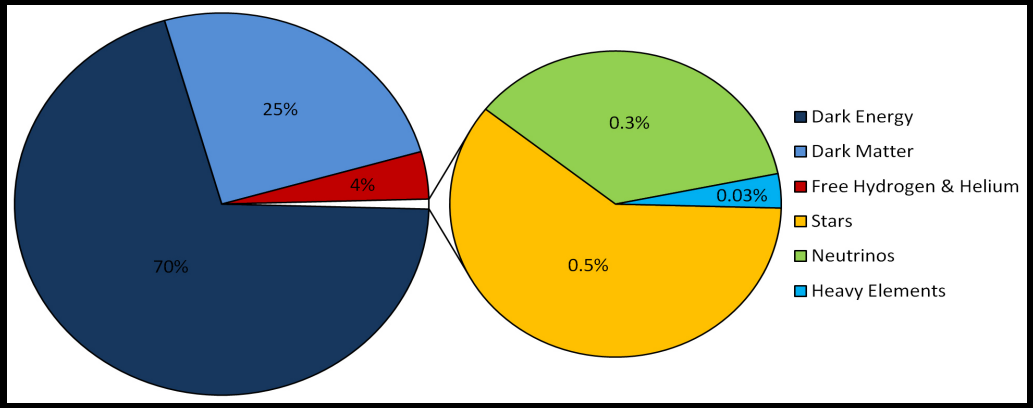
(impossible for other galaxies in the Universe)

The cosmological concordance model



- Big bang and inflation:
  - expanding Universe, density fluctuations seeds of structure we see today

- Constituents of the Universe:
  - Dark energy: dominates the large-scales of the Universe
  - Dark matter: dominates dynamics of galaxies' outskirts
  - Gas and stars: what we "see"



- Galaxies
  - inside vast dark matter halos
  - grow from small to large

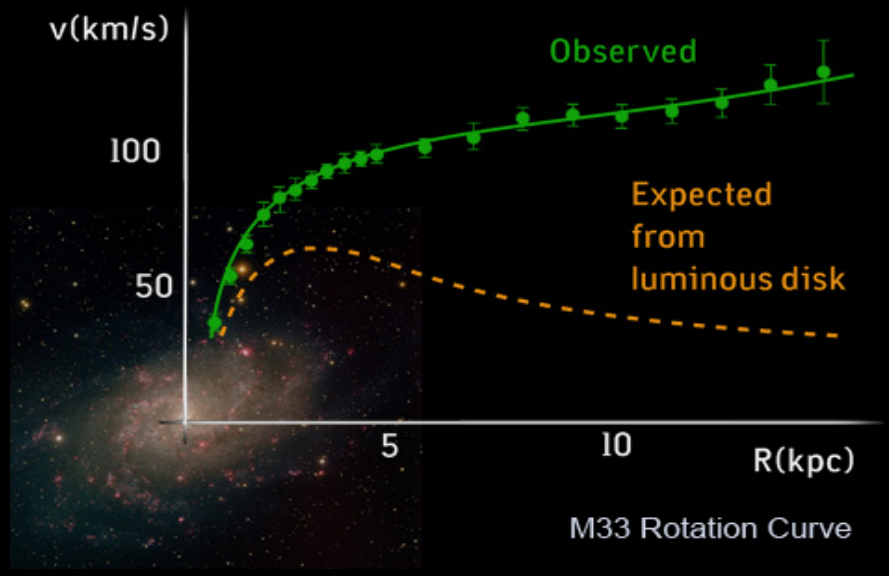
Dark-matter: most of the mass in a galaxy

- Observational evidence:
  - the motions of gas and stars

  related to mass present inside trajectory:

  $V^2 \approx M/r$

  There is more mass than can be accounted for by the stars and gas



  - could imply that Newton's law of gravity is not correct

- In the cosmological concordance model
  - Elementary particles (yet to be directly detected in laboratory)

Hierarchical model of galaxy formation

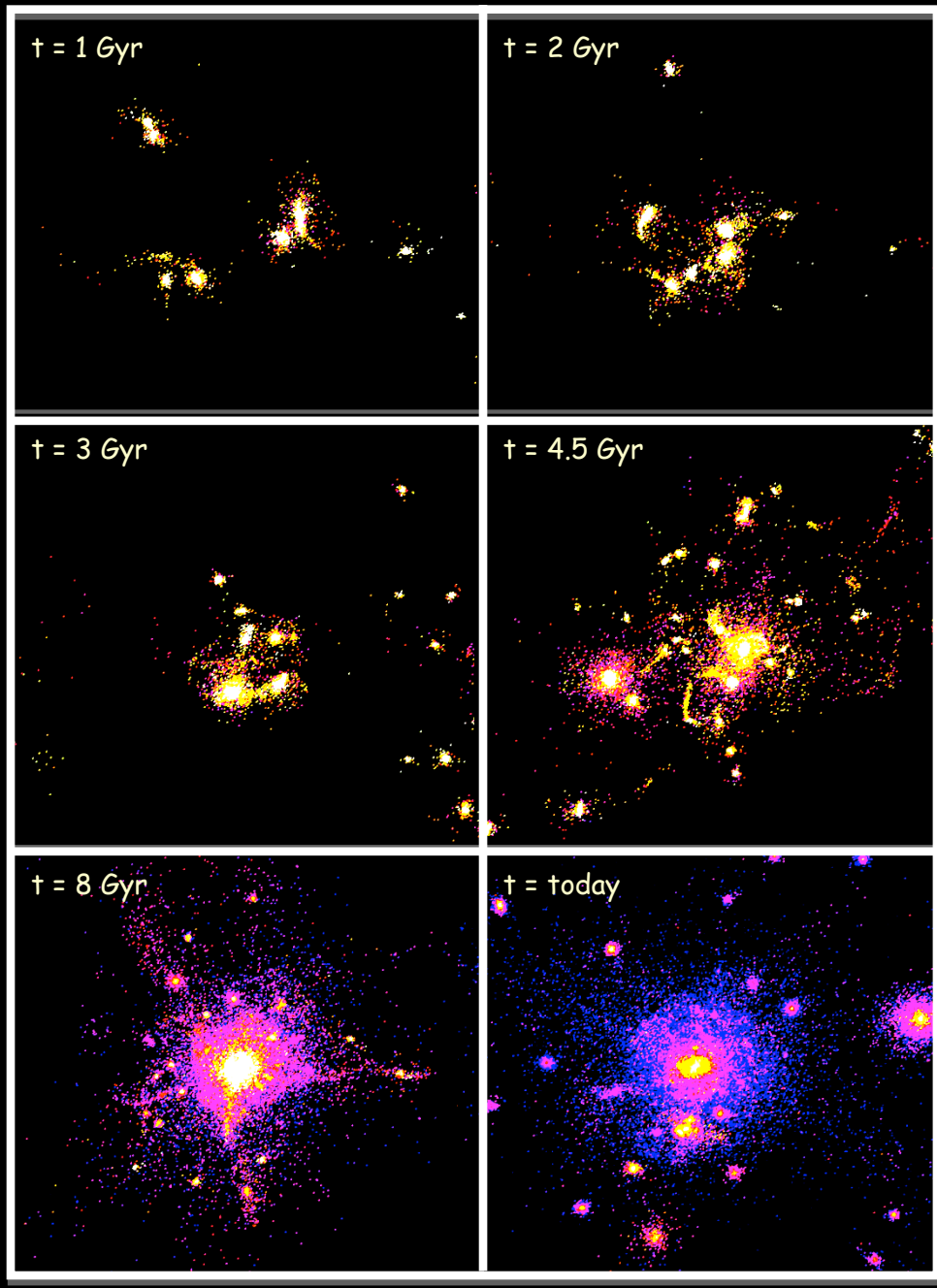
- Stellar and dark halos of large galaxies expected to form via mergers of smaller galaxies

- Encounters and mergers more frequent in the past, as Universe was smaller

- Chances of being "acquired" by a larger system were bigger

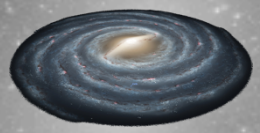
Testing the hierarchical paradigm. I

- One of the main characteristics of model: mergers
- Were mergers important for Milky Way?
  - How often and when did they happen?
  - Can we find the signatures of this process?
  - How do we find the accreted stars?
  - What do they tell us about the building blocks? What were their properties?



Testing the hierarchical paradigm. II

Is this "picture" correct?



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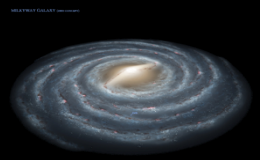

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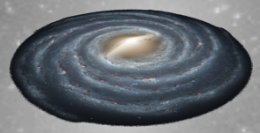
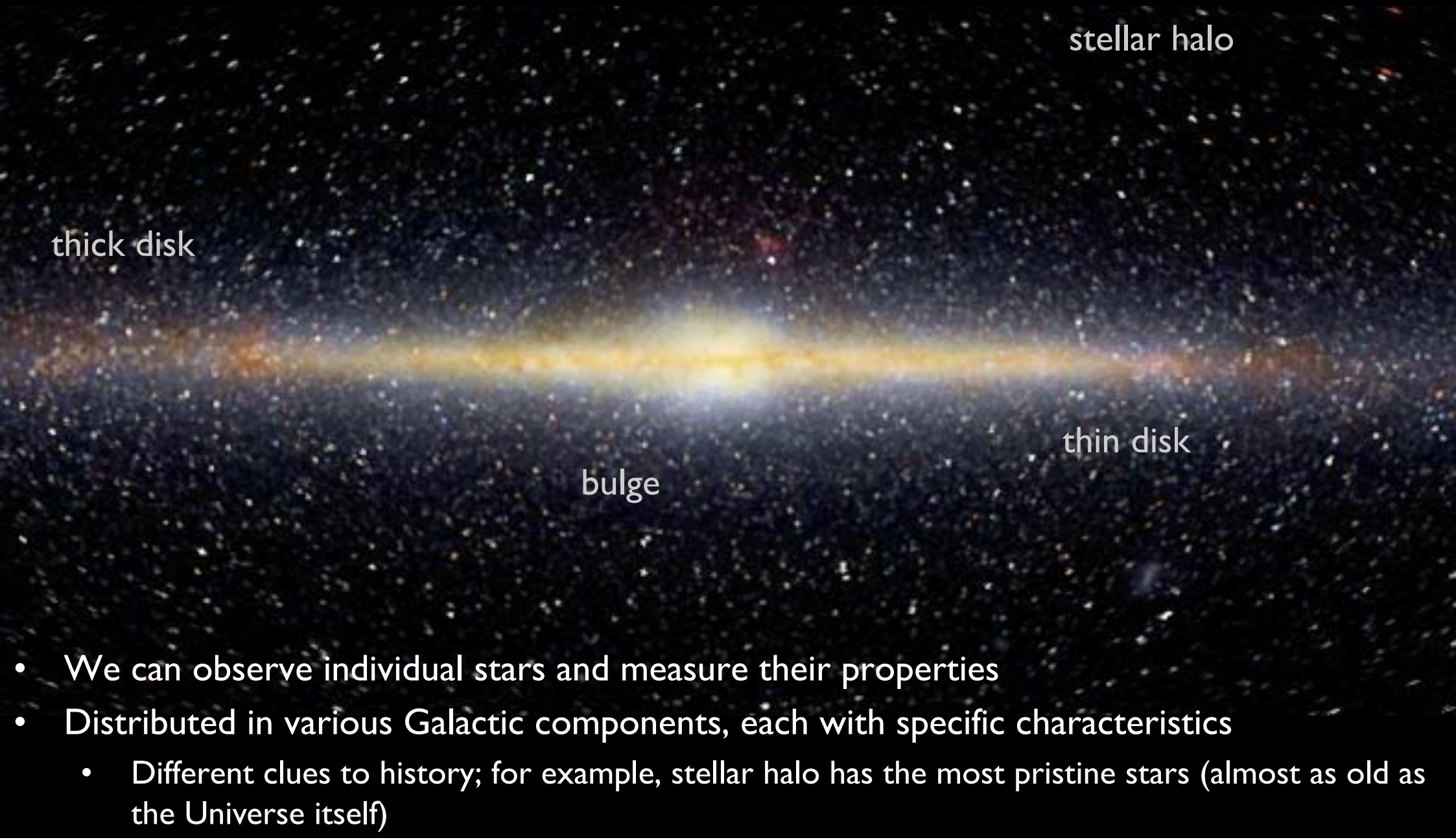


- Are galaxies like the Milky Way embedded in dark matter halos like those predicted by the cosmological model?
- How much dark matter is there?
  - how is it distributed?
  - what is the dark matter?

The Milky Way is a Rosetta stone



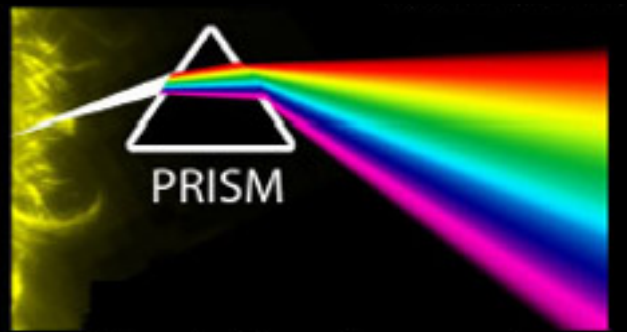
- We can observe individual stars and measure their properties
- Distributed in various Galactic components, each with specific characteristics
  - Different clues to history; for example, stellar halo has the most pristine stars (almost as old as the Universe itself)

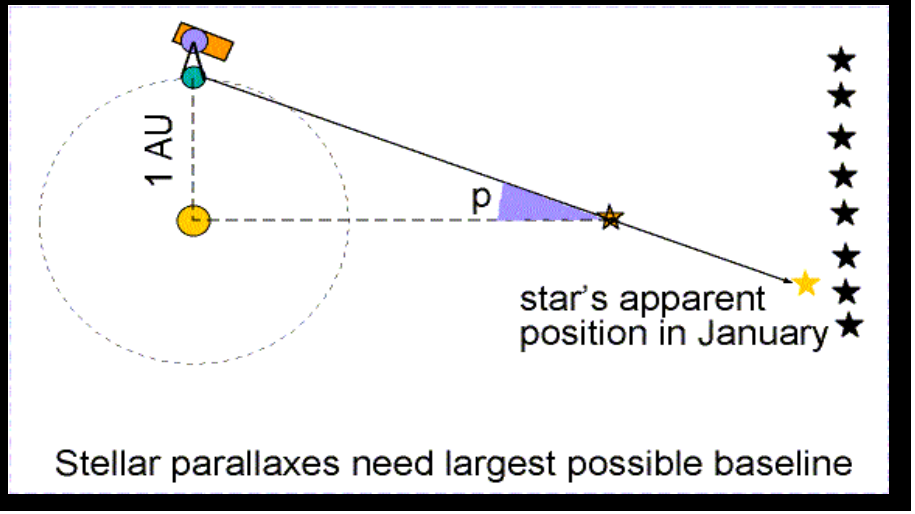
Mapping the Galactic fossil record

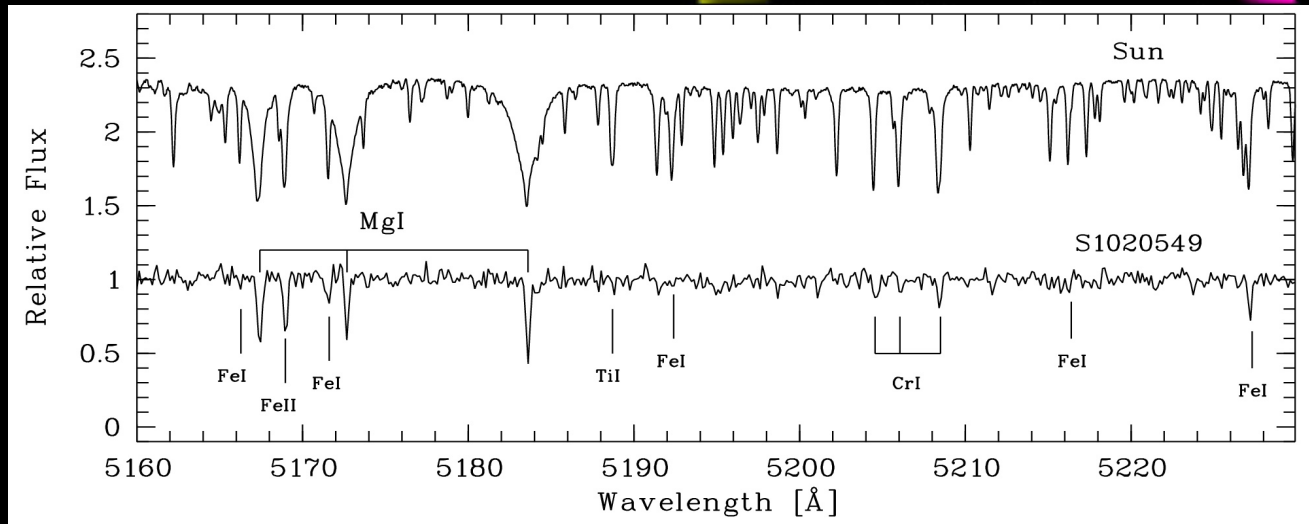
- Position and velocities information:
  - trajectories, origin and gravitational field (today and in the past)
    - *from* parallax (distance), proper motions, radial velocities (Doppler shift in spectra)

- Chemical abundances:
  - conditions of the medium (gas clouds) at time of formation
    - *from* spectra (chemical elements present as absorption lines)

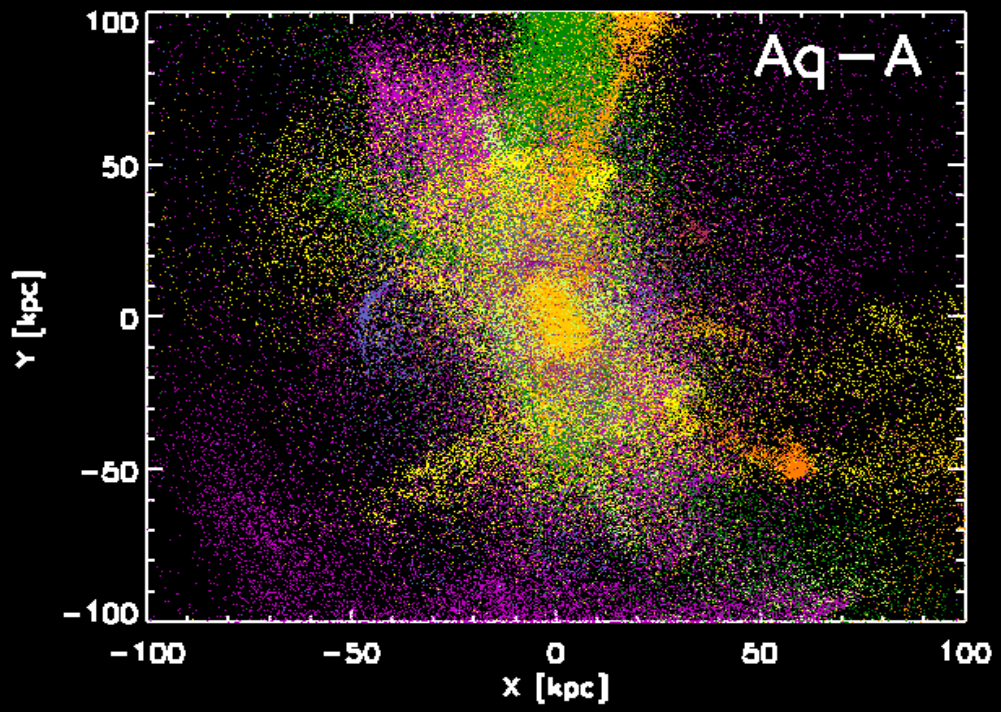
- Ages:
    - *from* spectra of decaying elements; from temperature and luminosity

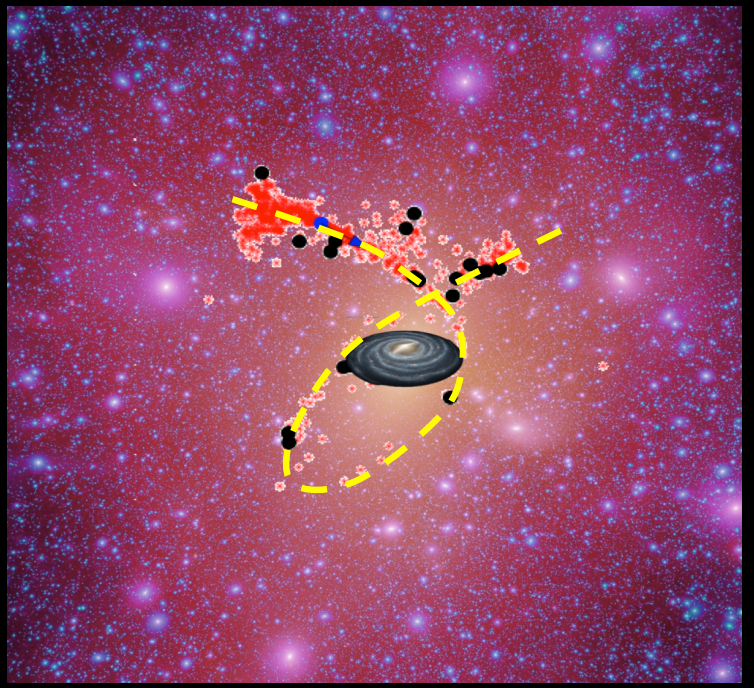






Stellar halo: treasure trove



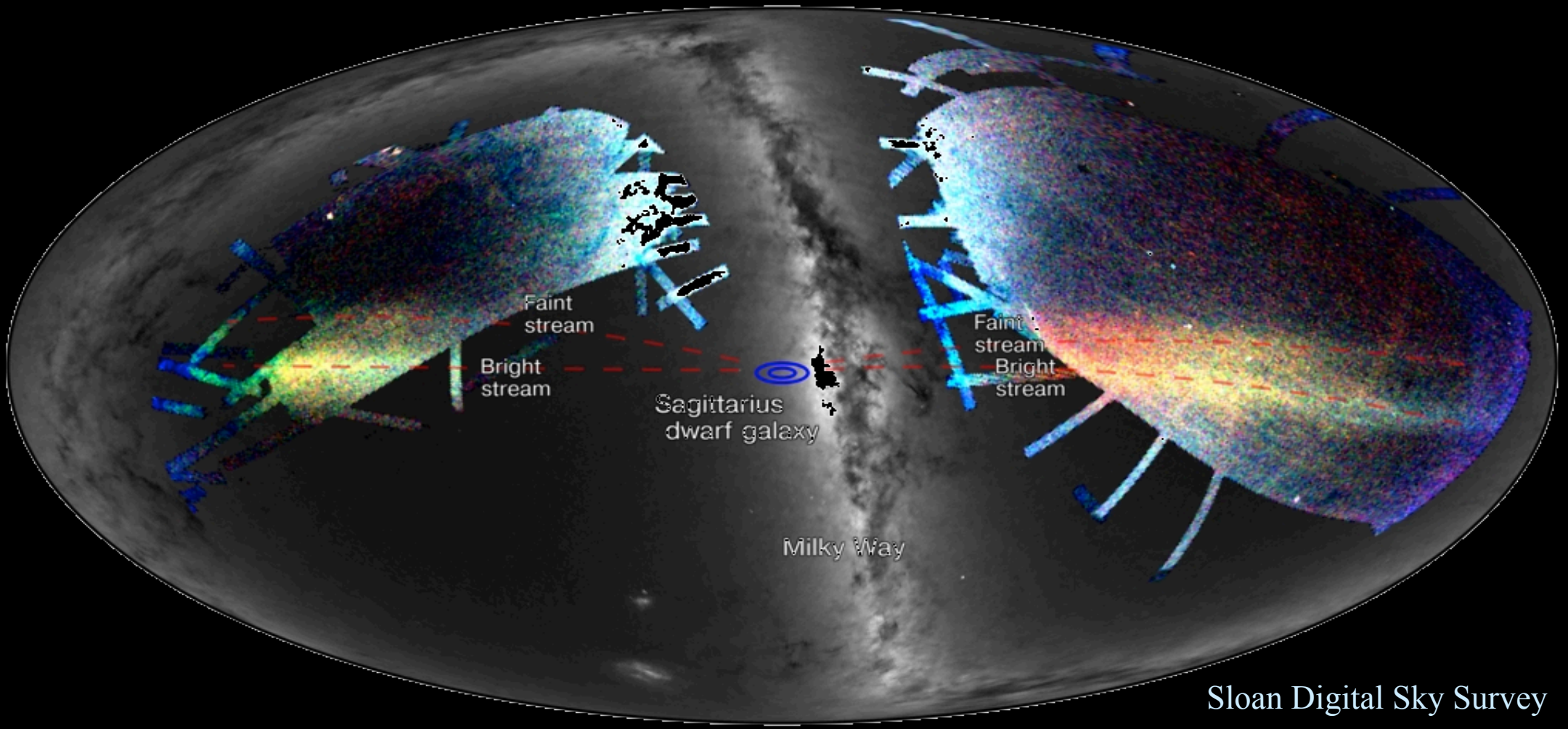


- The superposition of disrupted galaxies/debris leads naturally to a stellar halo
  - precious component for merger signatures: *Substructures and tidal streams*

- Many streams located in outskirts of galaxies
  - good probes of dark halos
  - stars in streams "nearly" delineate an orbit: mapping force field

Distant stellar halo: first spectacular results

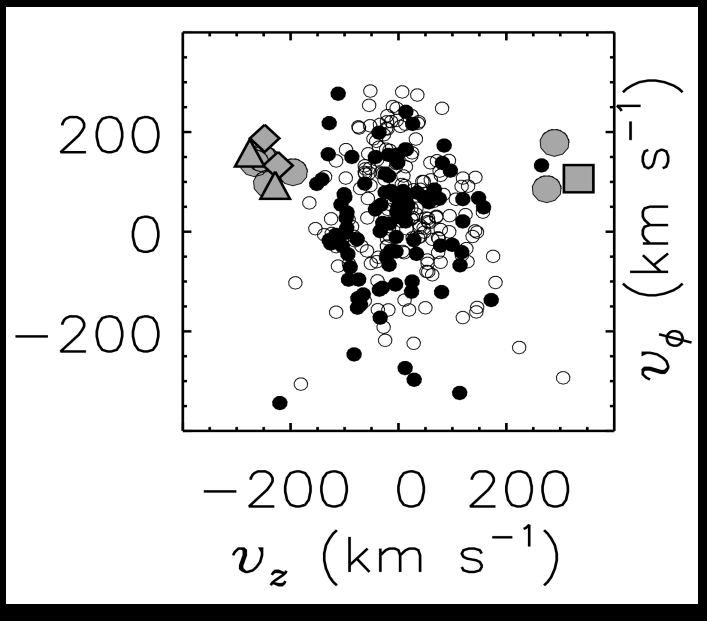
- Only 1/4 of the sky mapped
- Lots of substructure discovered: streams/clouds
- Still only qualitative understanding



Nearby halo

- Memory of origin
  - Retained in the motions
  - 100s of streams should cross Sun's vicinity
  - So far.. two streams near the Sun from a galaxy disrupted very early on

Velocity space

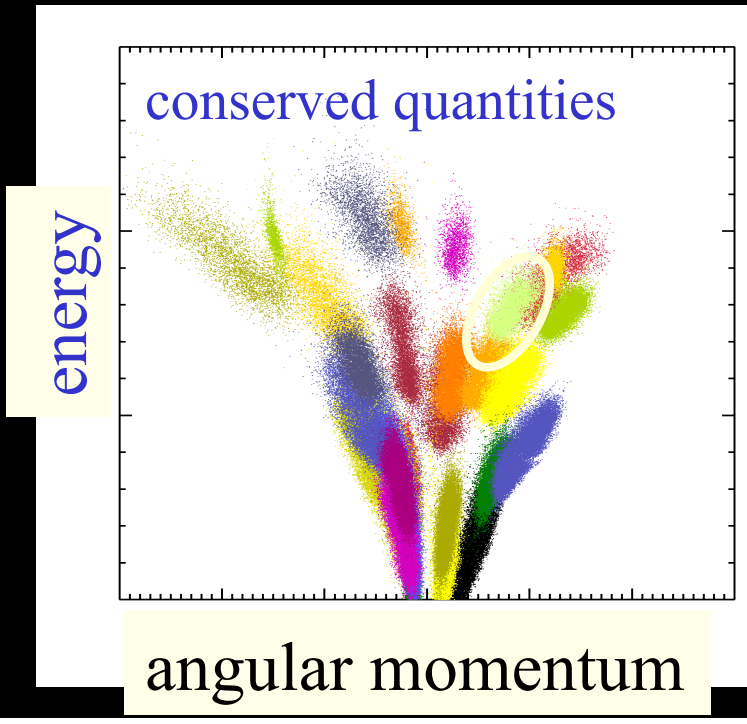


Helmi et al. 1999

Many more hiding…

How to find these?

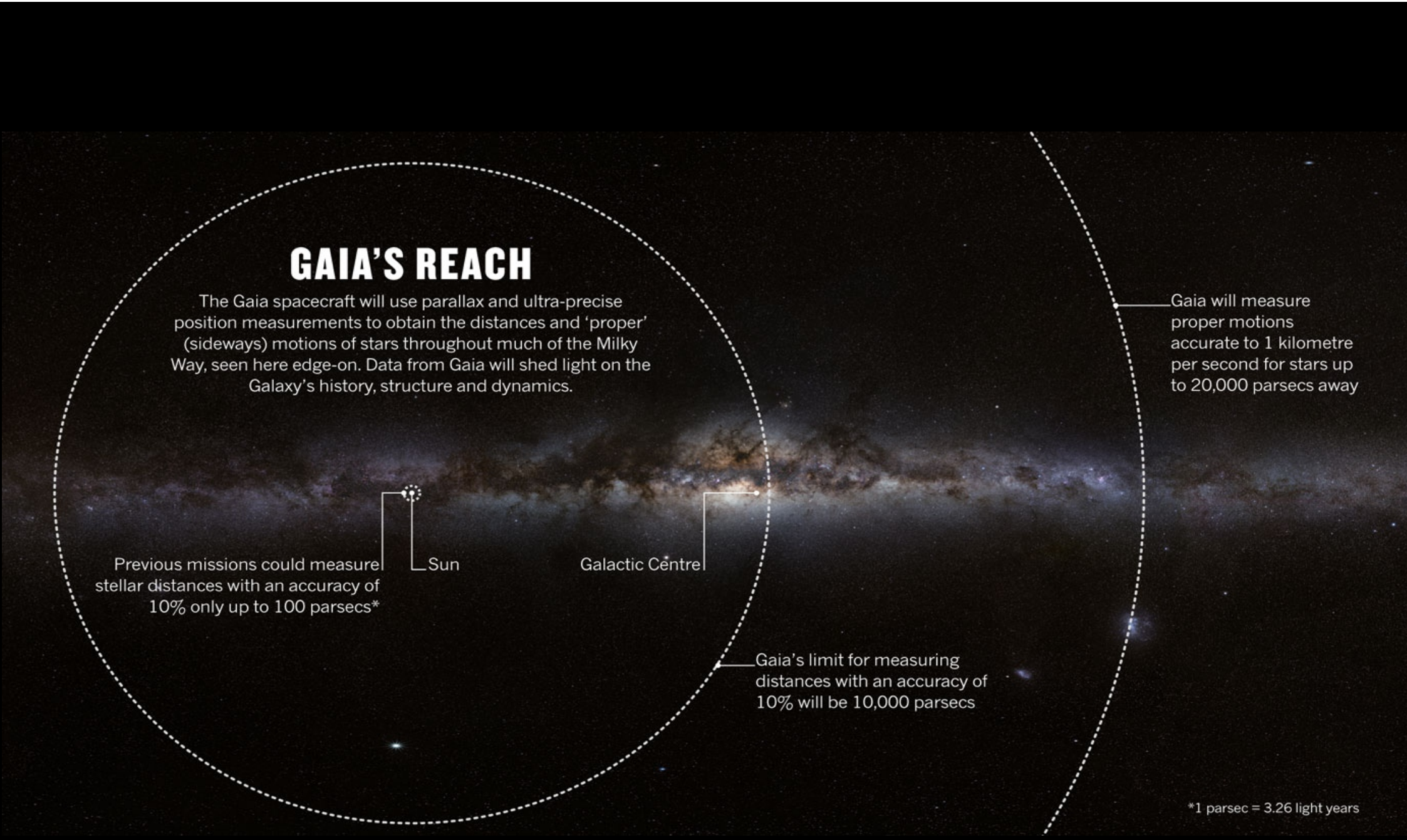
- Clustering in conserved quantities
- A good dataset



The revolution: Gaia

- Launched in Dec. 2013 by the European Space Agency (*a cornerstone mission*)
- It will measure the location in space and motions of 1 billion (1,000,000,000) stars in the Milky Way; also their astrophysical properties
- Discovery space will increase by huge amount
  - Impact on understanding of stars, their evolution, planets, General Relativity, nearly discovery of every field of Astrophysics …
  - Formation history and dynamics of the Milky Way

A completely new view of the Milky Way

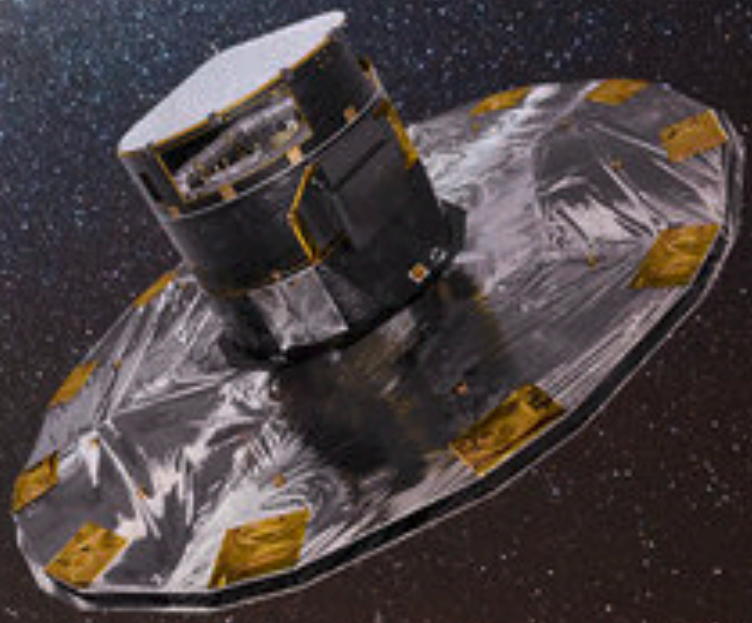

GAIA'S REACH
The Gaia spacecraft will use parallax and ultra-precise position measurements to obtain the distances and 'proper' (sideways) motions of stars throughout much of the Milky Way, seen here edge-on. Data from Gaia will shed light on the Galaxy's history, structure and dynamics.
Gaia will measure proper motions accurate to 1 kilometre per second for stars up to 20,000 parsecs away
Previous missions could measure stellar distances with an accuracy of 10% only up to 100 parsecs*
Sun
Galactic Centre
Gaia's limit for measuring distances with an accuracy of 10% will be 10,000 parsecs
*1 parsec = 3.26 light years

How the satellite mission works: Inside Gaia's billion pixel camera

https://www.youtube.com/watch?v=bbfb8VhH7L0#action=share

Next steps: exploitation of the Gaia data

- Lead the Gaia revolution
  - Discovery of hundreds of streams
  - Characterization of the building blocks of the stellar halo of our Galaxy
  - History of the Milky Way from the earliest times (using fossils from the infant Universe)
  - Mass distribution and nature of dark matter
  - Milky Way to provide new constraints on galaxy evolution and the cosmological model
- Many challenges
  - "Big Data" analysis
  - Computing power; smart software
  - Astrophysical understanding
  - Development of new instrumentation for follow-up



A fascinating and exciting time but we need more …

A good team!

Very international: 12 different nationalities

Gender balance: 50/50

Fascination for the Universe is gender-free

- Children (independently of gender) fascinated by breathtaking images of Universe
- But look around you
  - The higher up the university hierarchy the lower the fraction of women (striking in NL)

- <u>Choice of a career in science appears to be affected by environment</u>
  - nurturing/fostering or hindering/censoring innate abilities
  - role models missing; not related to economic welfare (possibility to work part-time)
    - in NL 23% *vs* 77% female/male working population, but of all full professors only 10% are women
  - Competence and Confidence are both important for success

- <u>Biases prevent fully profiting from the brainpower and skills of talented woman</u>
  - Society needs both men and women; the same is true for the scientific enterprise
  - Many different strategies on different levels (primary/secondary schools; university level such as Rosalind Franklin Fellowship program at RuG)
  - Example: *blind auditions* changed male-dominated in 1970s to gender-balanced orchestras today
  - Awareness

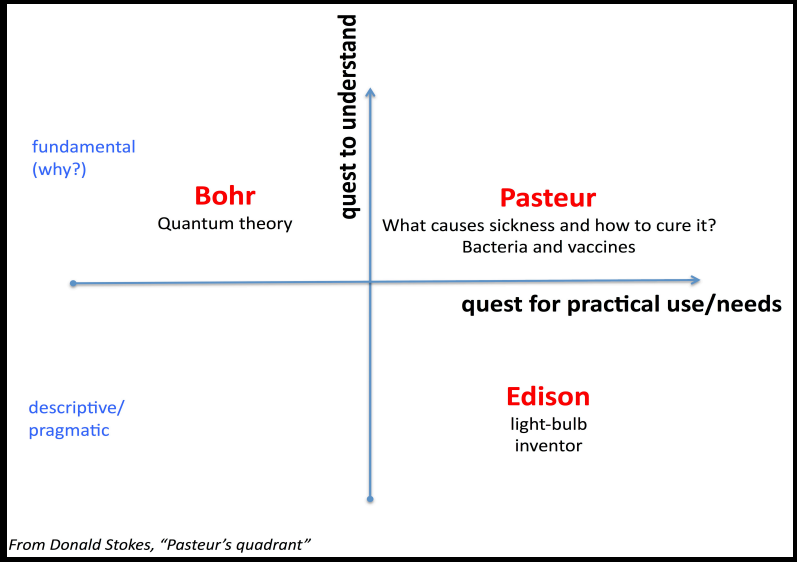
Fascination by science

- Humans: search for truths and knowledge, innate curiosity, capacity to ponder and wonder at the beauty of Nature

- Today's society/ funding climate:
  - Immediate return for investment, but *"Good things take time"*
  - Measuring impact of research with monetary indicators too restrictive
  - How to measure impact of Bohr's research at his time? How much value does a PhD degree /A critical and analytic thinker add to society?
  - Economy is to serve humans, and not the other way around

The importance of outreach:
http://nos.nl/video/152428-kijkje-in-het-heelal.html

- Substantial investment and intellectual freedom to pursue fundamental scientific research
  - True innovation
  - *All aspects that define a high quality of human life*



From Donald Stokes, "Pasteur's quadrant"


The fascinating Milky Way
to be continued...
university of groningen
faculty of mathematics and natural sciences
kapteyn astronomical institute