What do galaxies and shadow puppets have in common?

Understanding the Formation and Evolution of Galaxies

THE UNIVERSITY OF SYDNEY

ASTRO 3D
ARC CENTRE OF EXCELLENCE FOR ALL SKY ASTROPHYSICS IN 3D

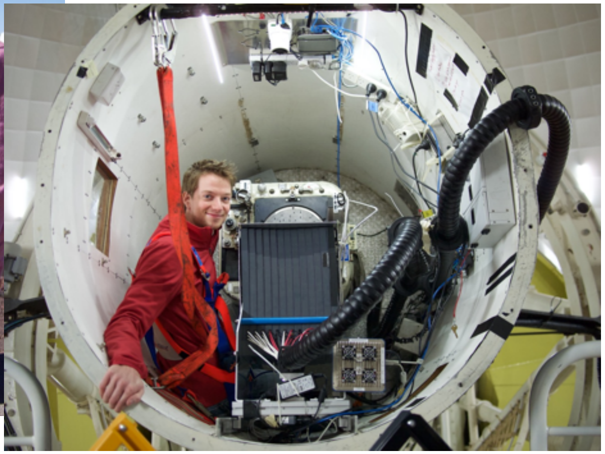
sami galaxy survey

CCE lecture series 2019
Quarks to the Cosmos
Thursday 31 October 2019

Jesse van de Sande Sydney Institute for Astronomy

Who am I?

- PhD 2010-2014 from Leiden Observatory, The Netherlands
- Postdoctoral Researcher at Sydney Institute for Astronomy 2015-Present
- Observational Astronomer working with the SAMI Galaxy Survey

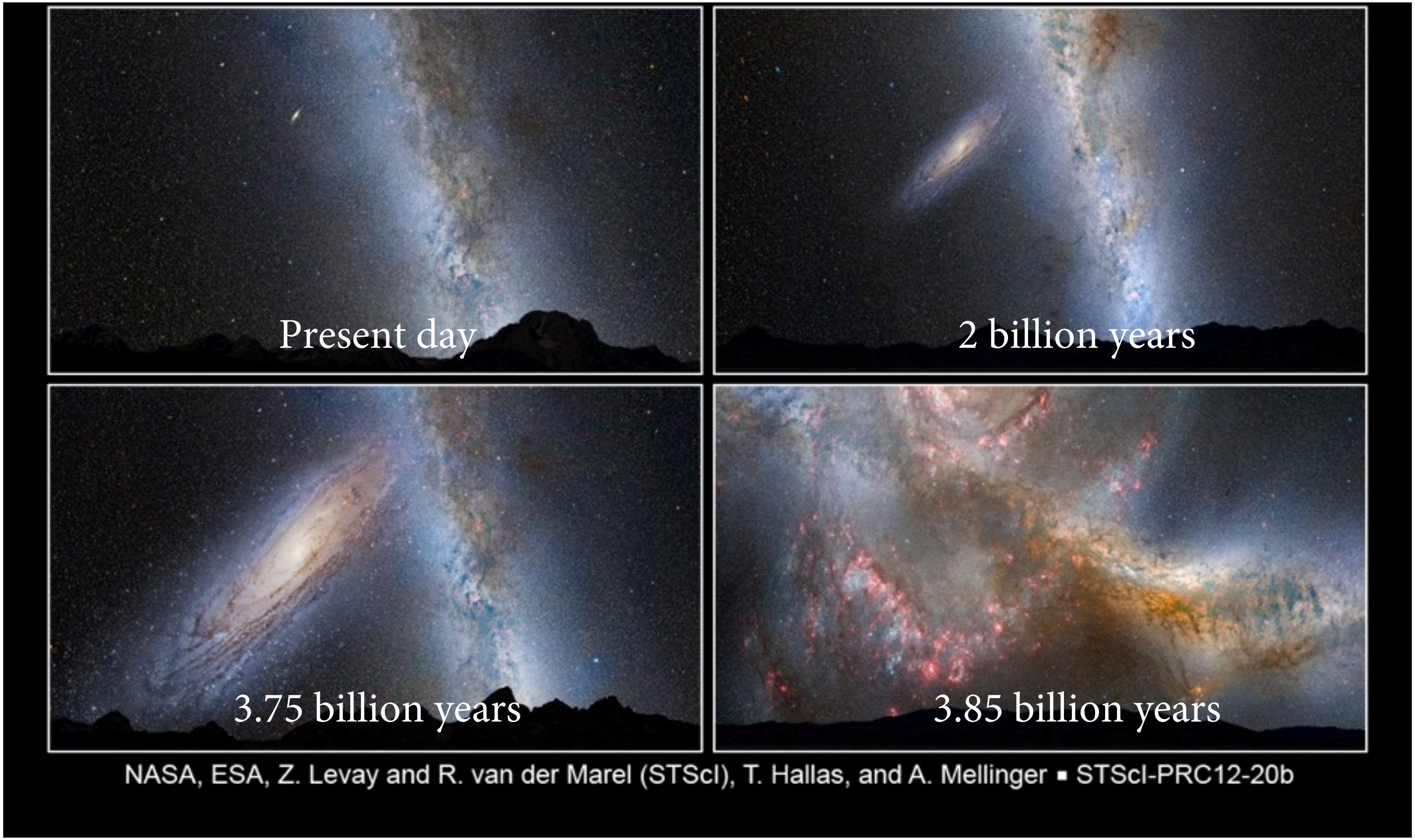


The Big Questions

The Big Questions

- Is our Milky Way unique?
- How did the Milky Way form?
- Is the Milky Way the final product of evolution, or will it evolve further?

Our Milky Way is on a collision course with the Andromeda Galaxy



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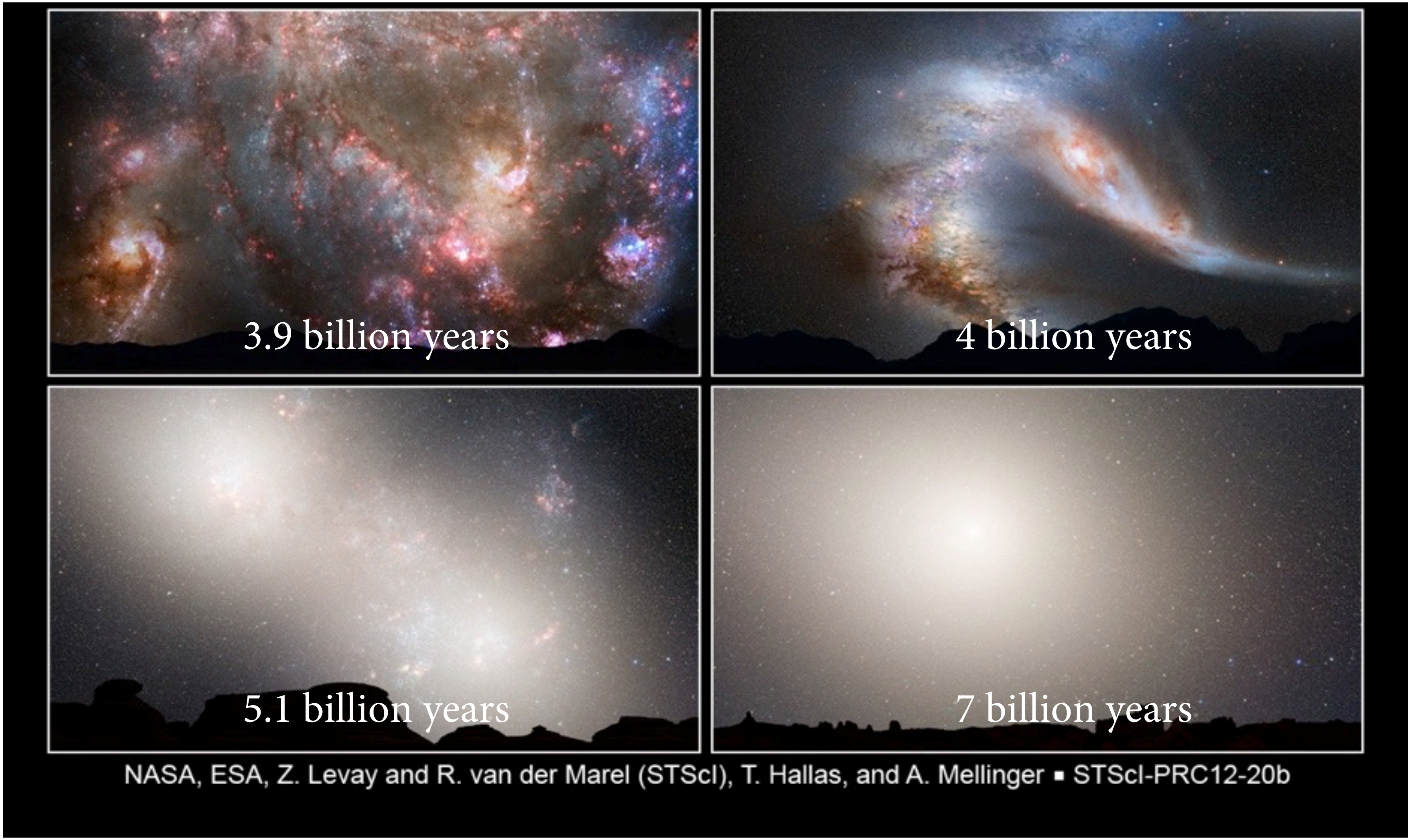
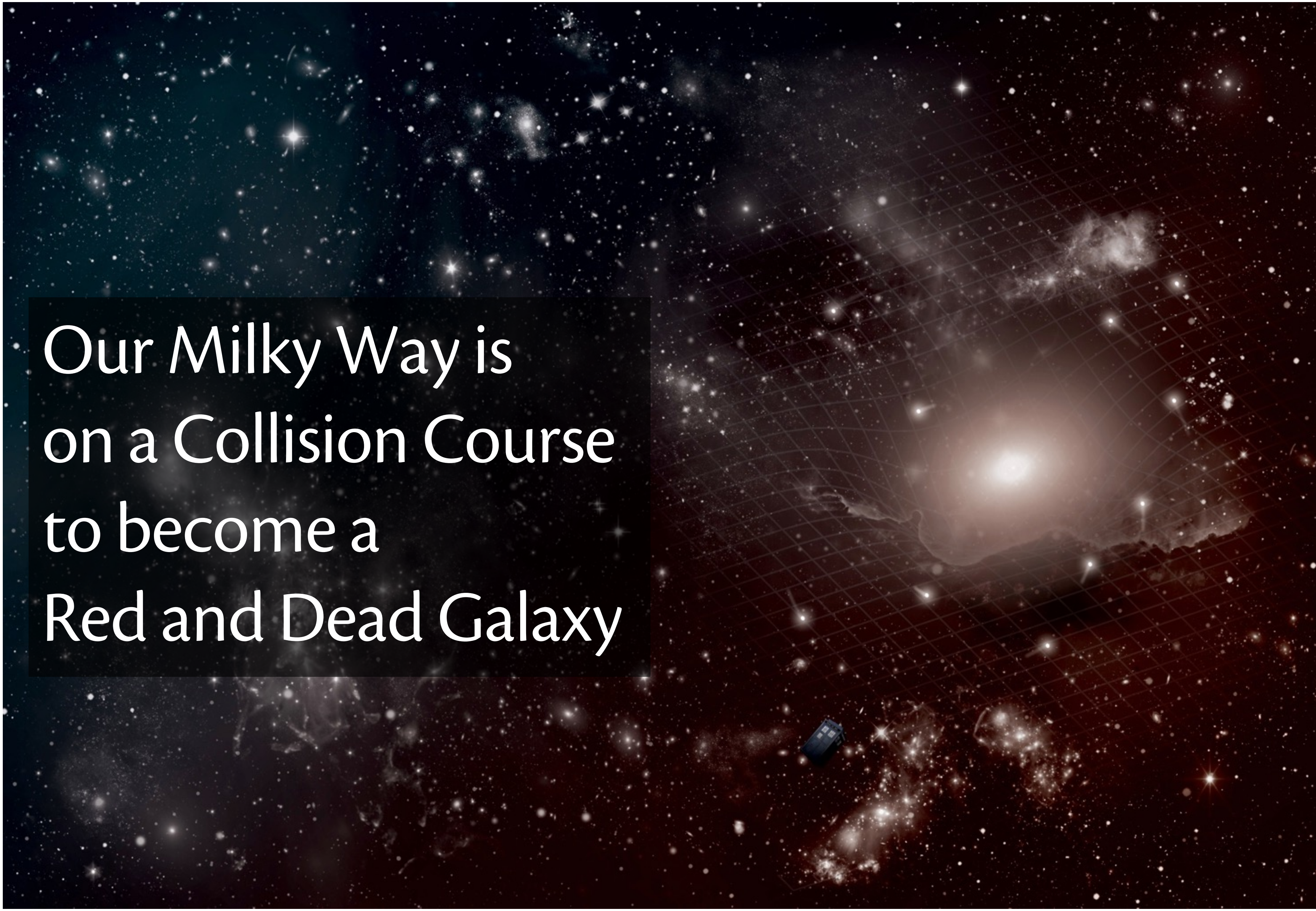
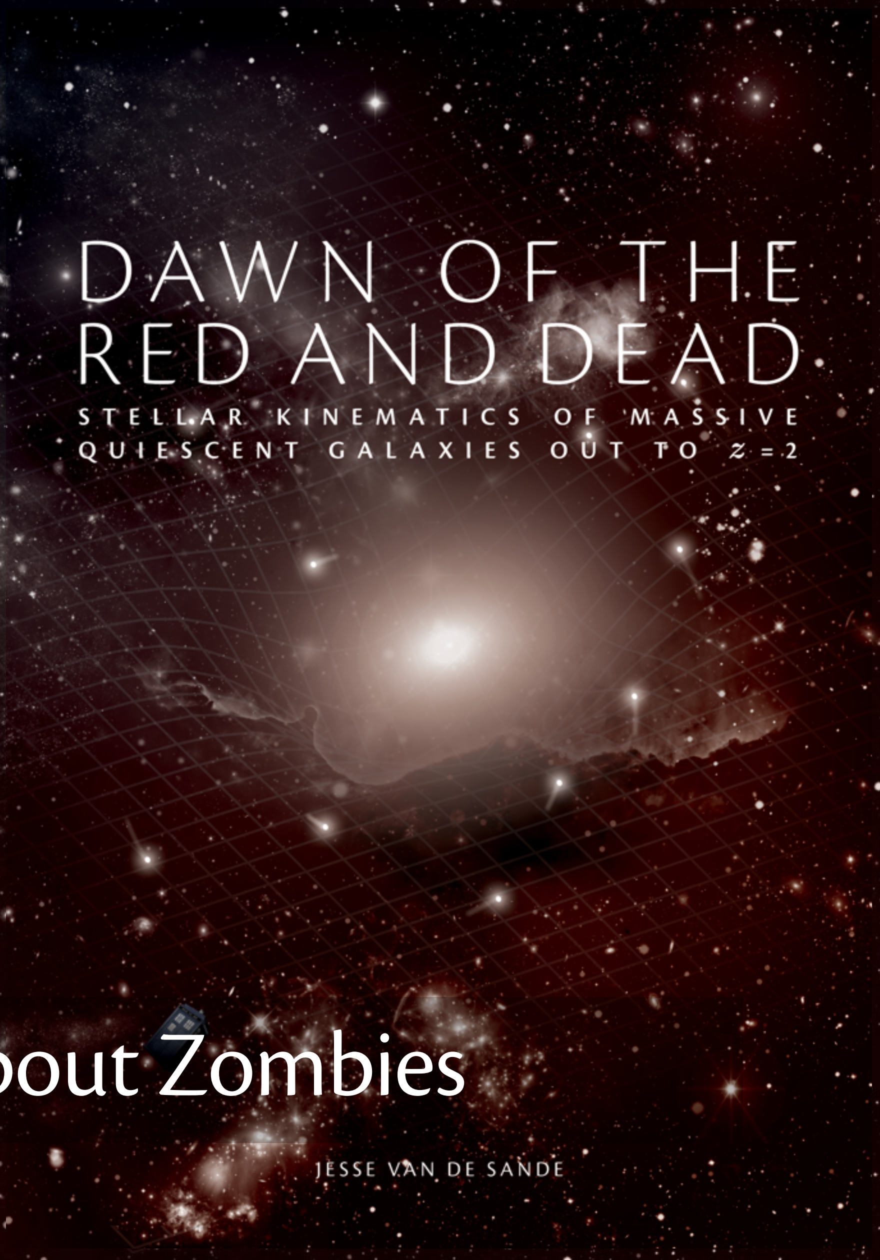



Our Milky Way is
on a Collision Course
to become a
Red and Dead Galaxy

What does this movie
have in common with my PhD Thesis?



They are both about Zombies

Today's talk

Galaxies in the present-day Universe

Galaxies at high-redshift: dawn of the red and dead

WHAT DO GALAXIES AND SHADOW PUPPETS HAVE IN COMMON?

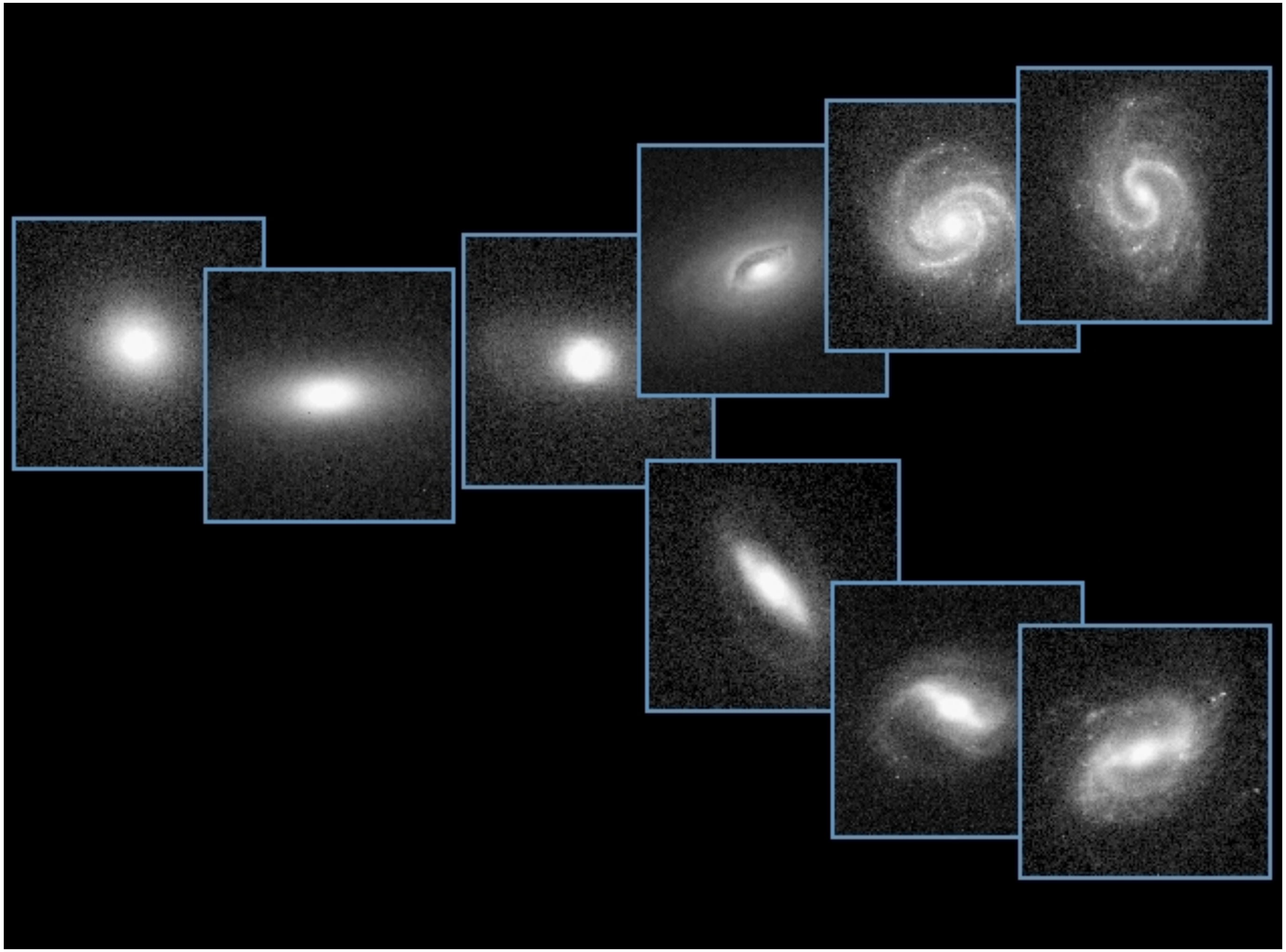
Galaxies in the present-day Universe

Galaxies at high-redshift: dawn of the red and dead

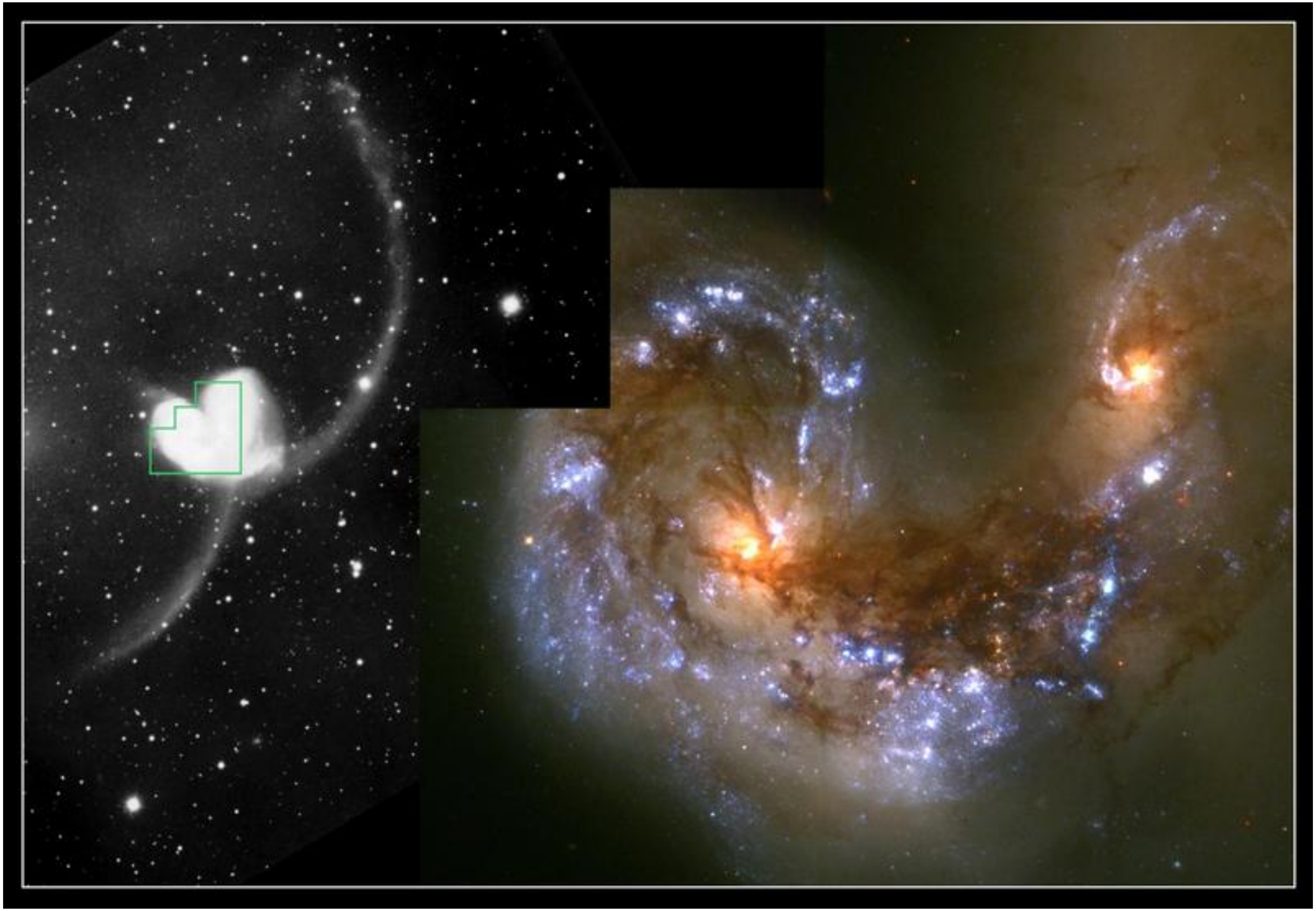
WHAT DO GALAXIES AND SHADOW PUPPETS HAVE IN COMMON?

Hubble's Tuning Fork:

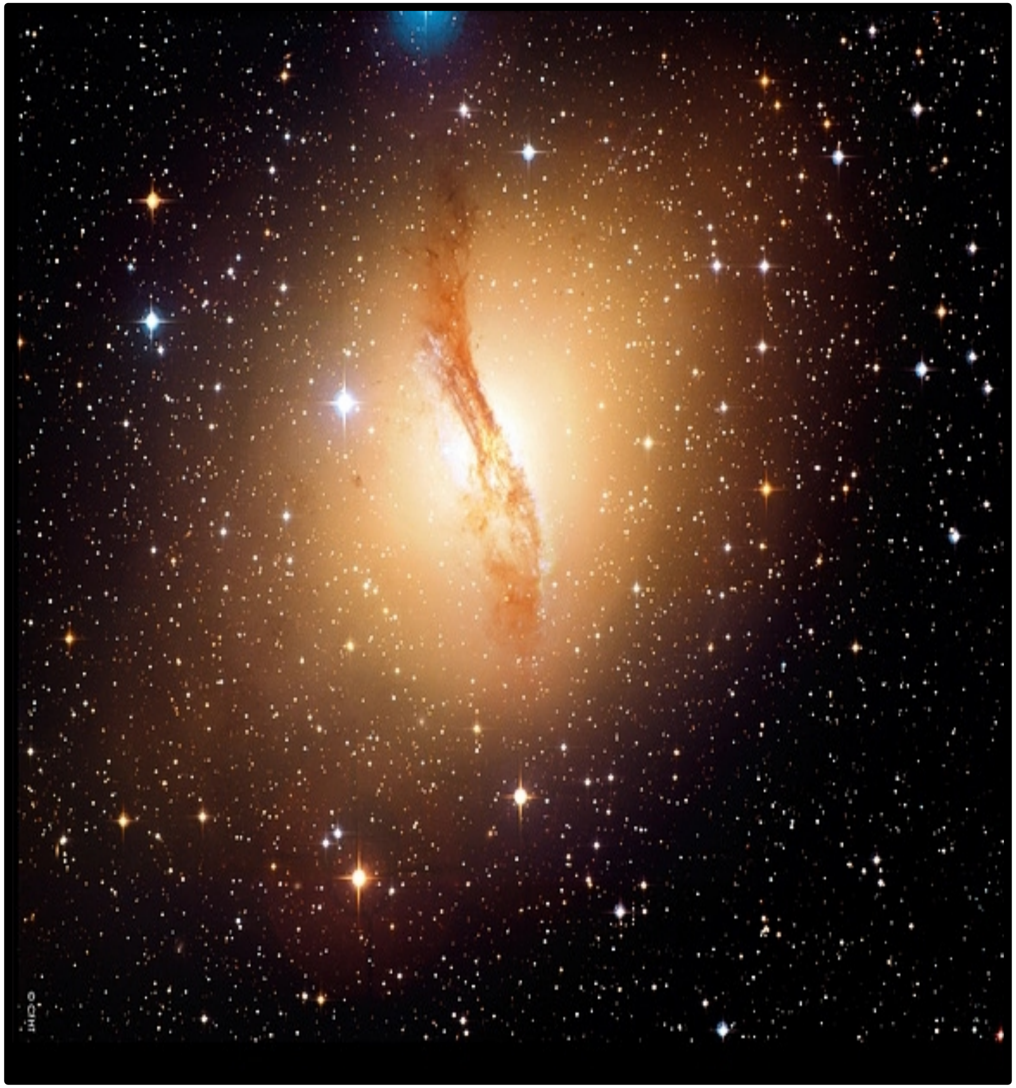
Is the diversity of galaxies in the present day universe the result of 14 billion years of galaxy evolution?



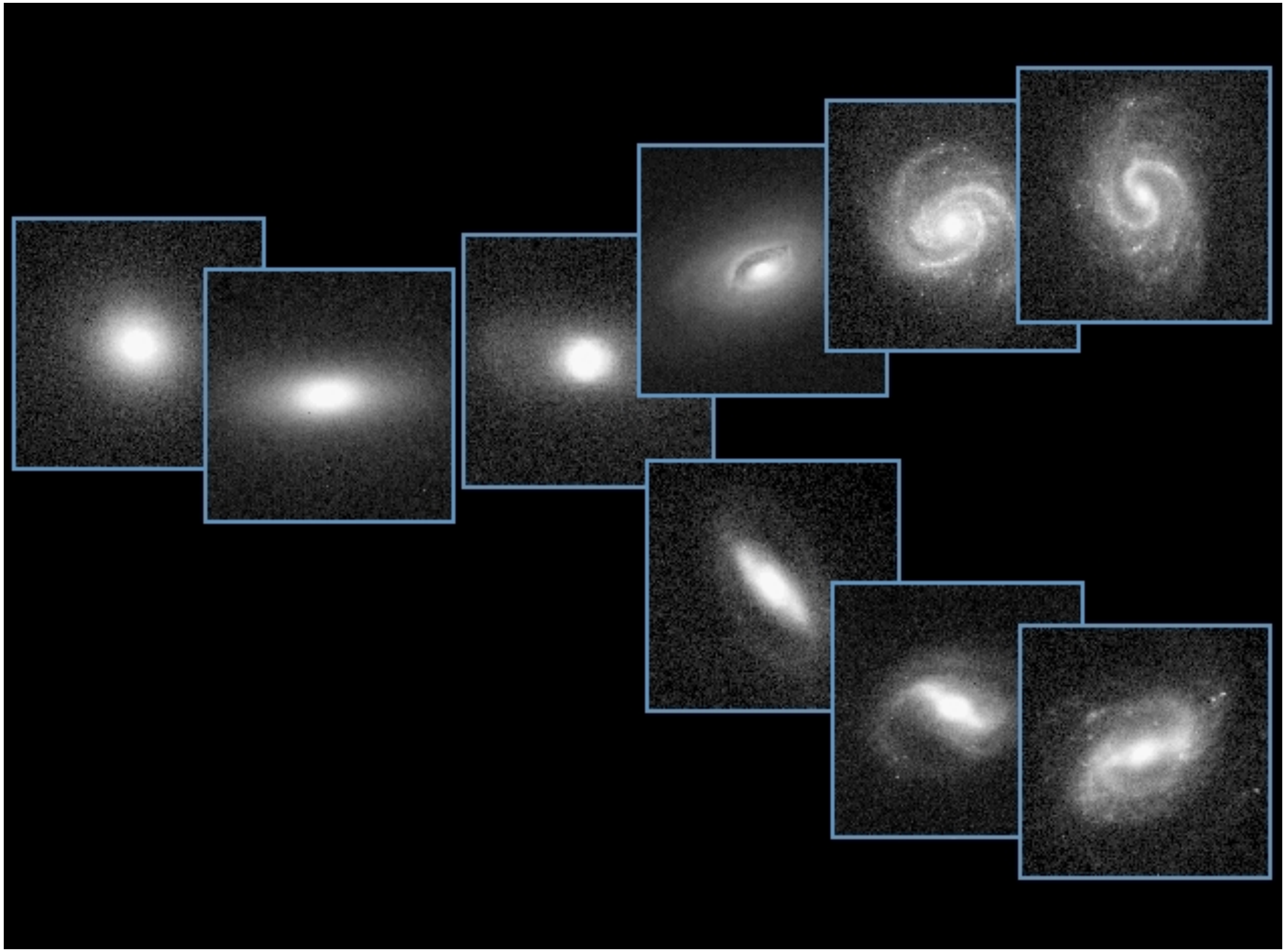
Galaxies Caught in the Act

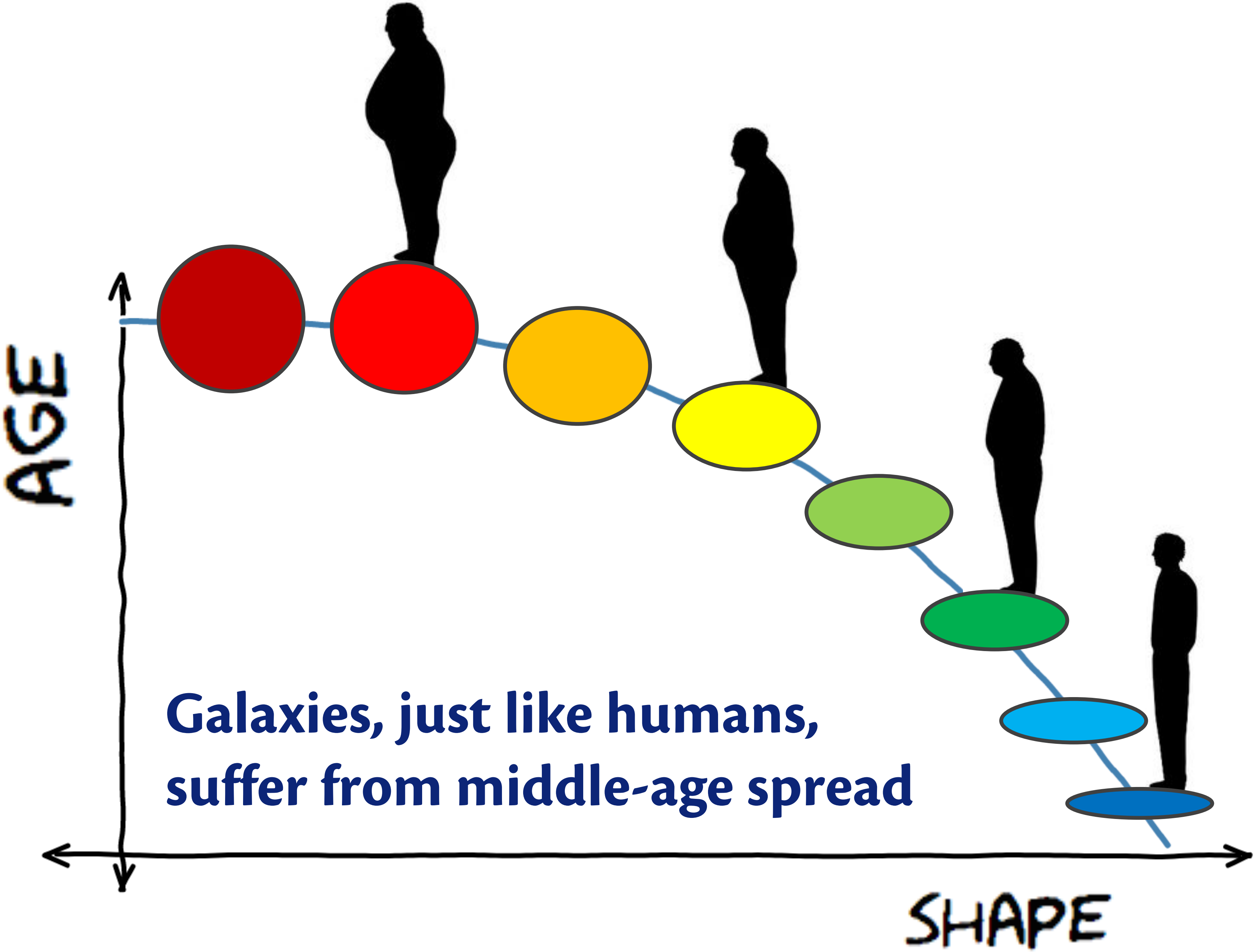


Merger Remnants



Hubble's Tuning Fork:
Intrinsic shape related to formation history





Galaxies, just like humans, suffer from middle-age spread

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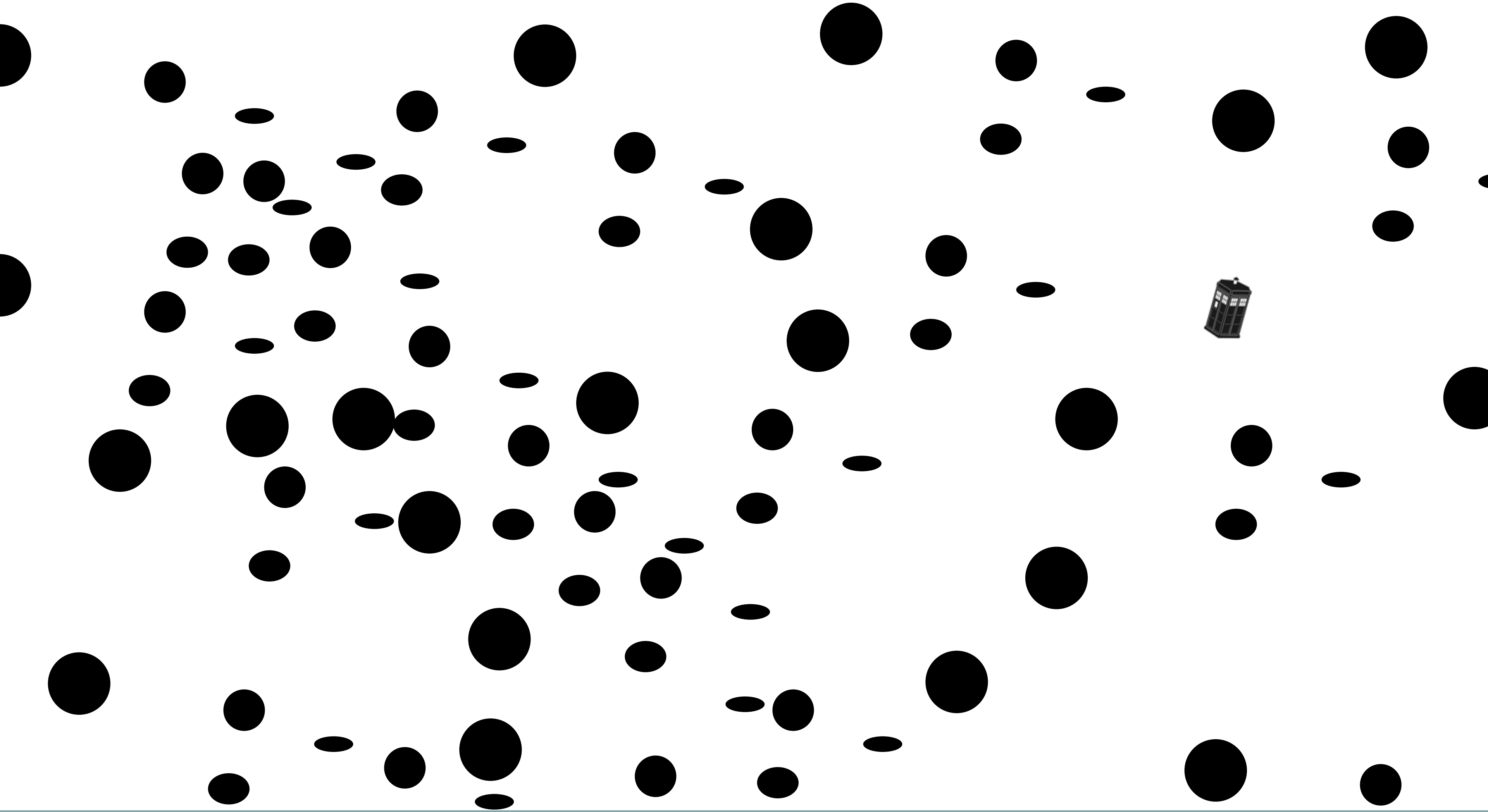
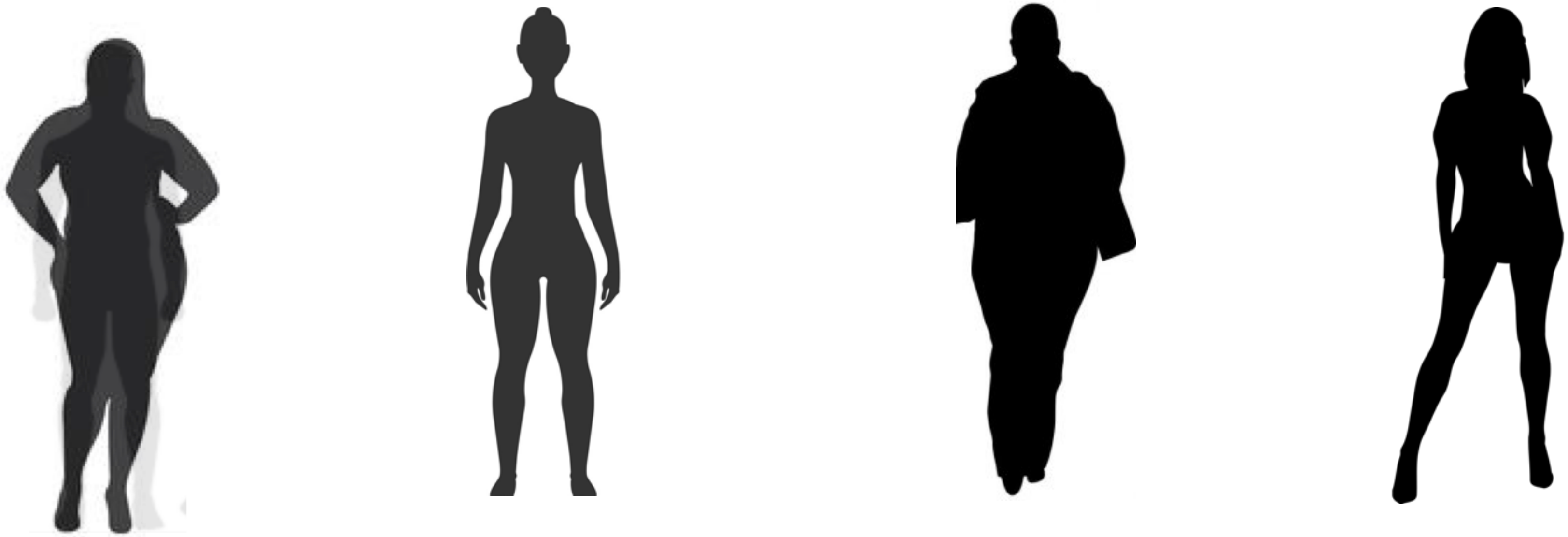
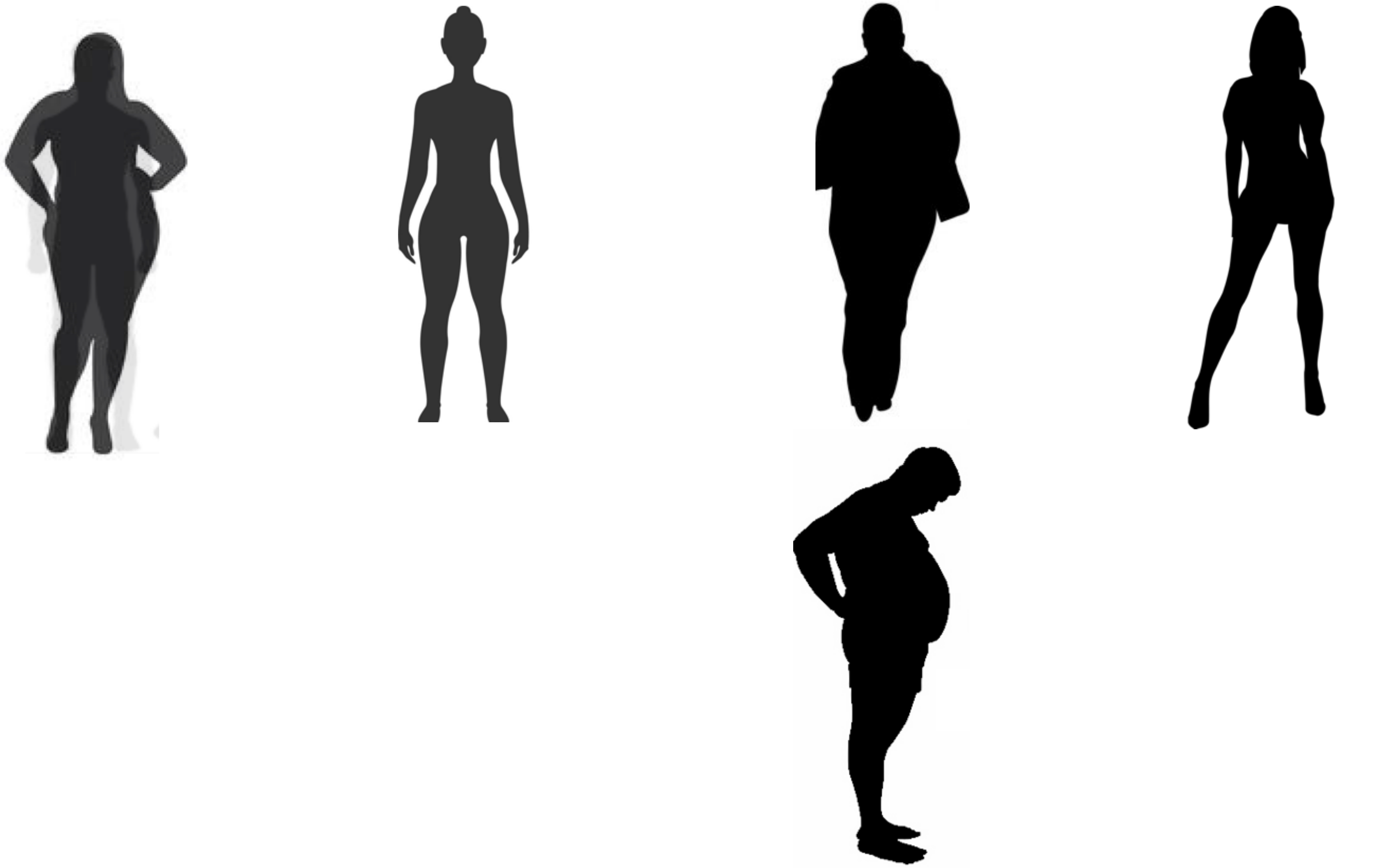


How do we derive the intrinsic shape of galaxies?



Projection makes everything harder



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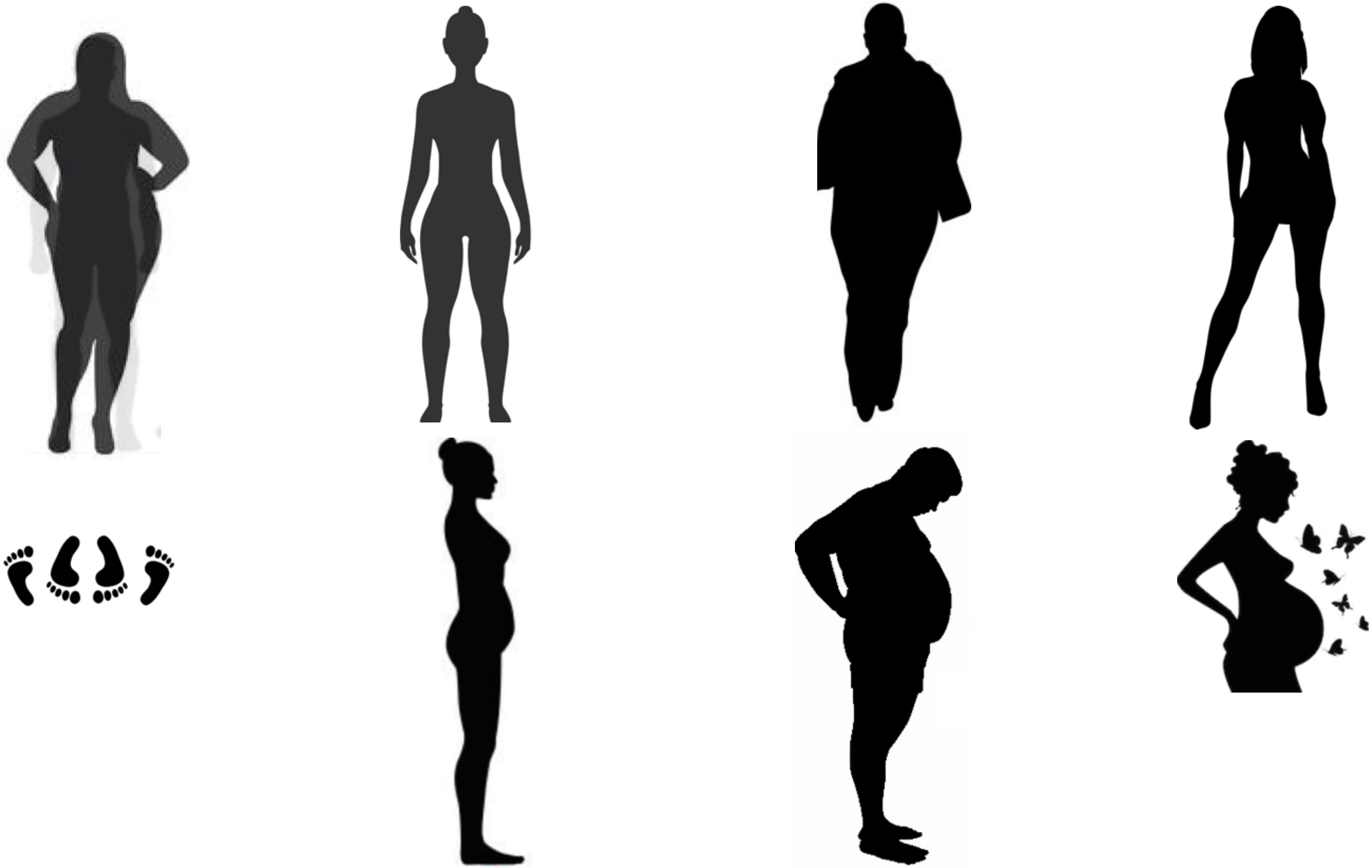

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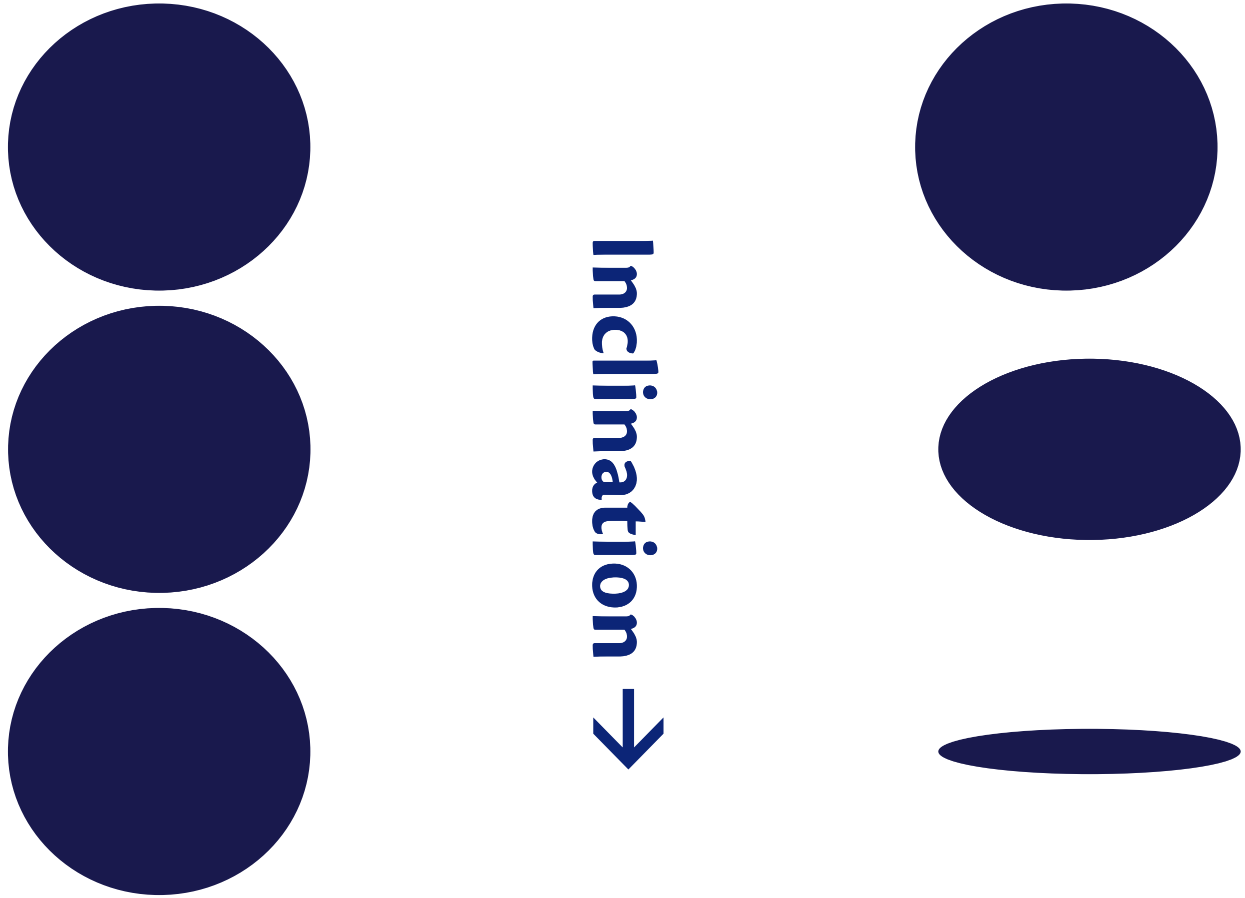
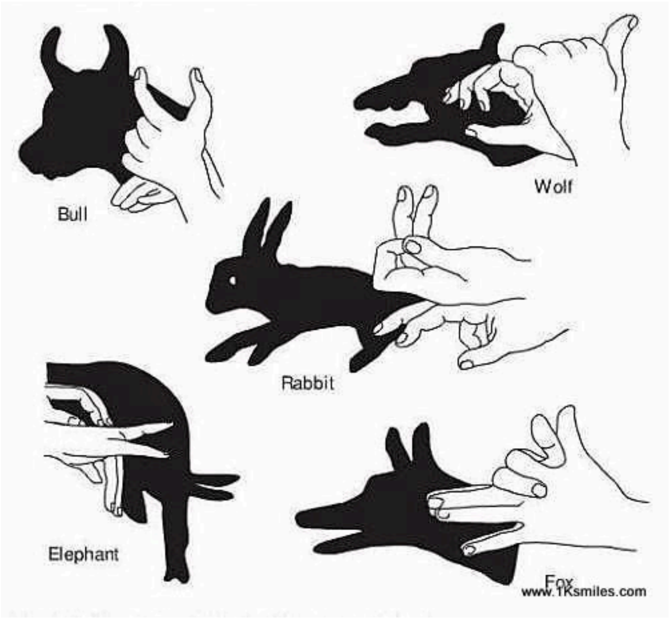


Projection makes everything harder

What do galaxies and shadow puppets have in common?



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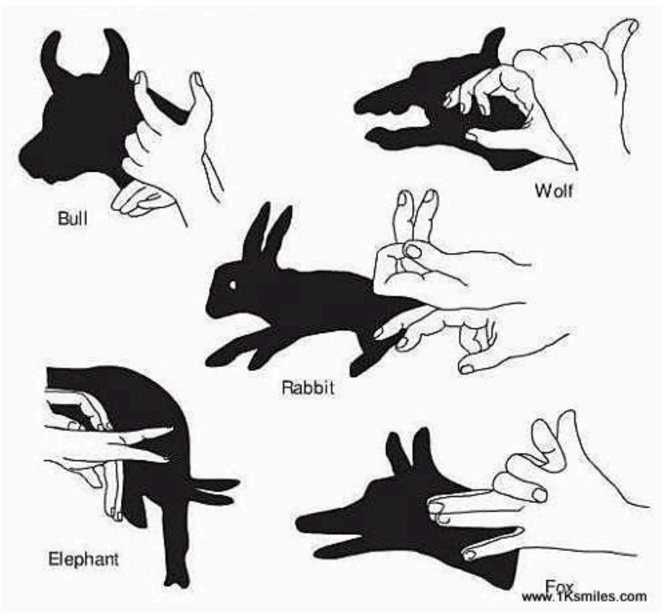
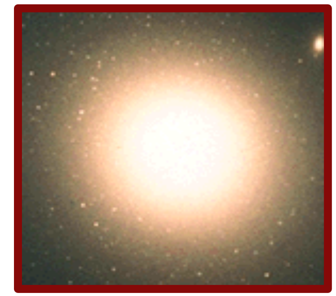




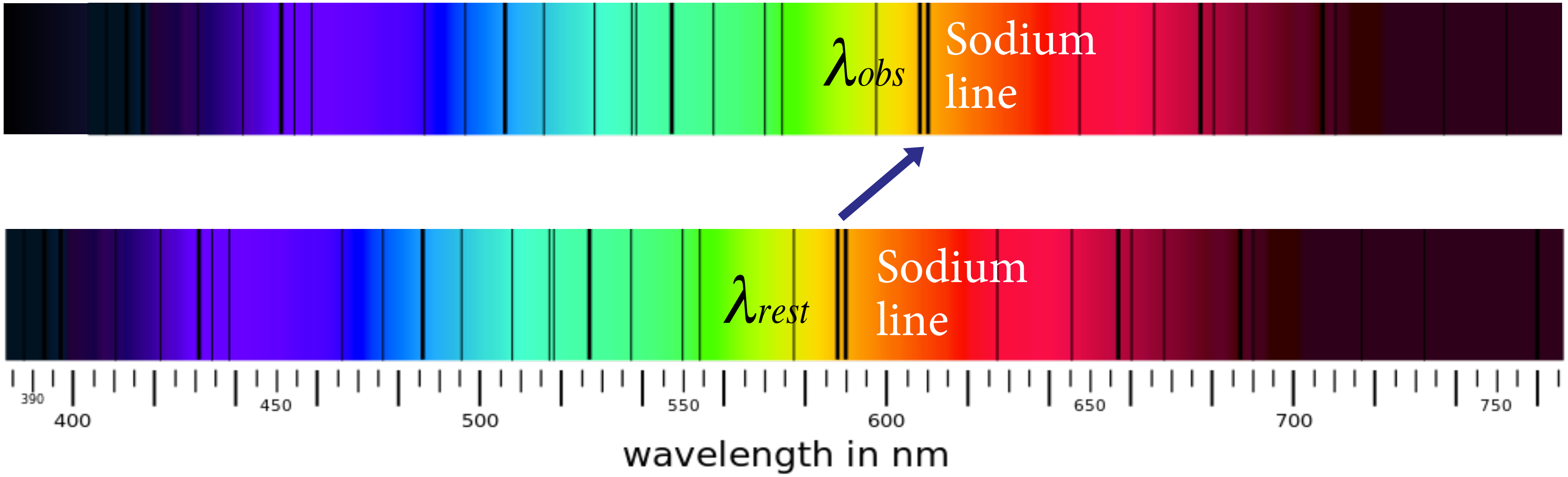
To derive the intrinsic shape, you need extra information: galaxy rotation

Spectroscopy can reveal galaxies' 3rd dimension

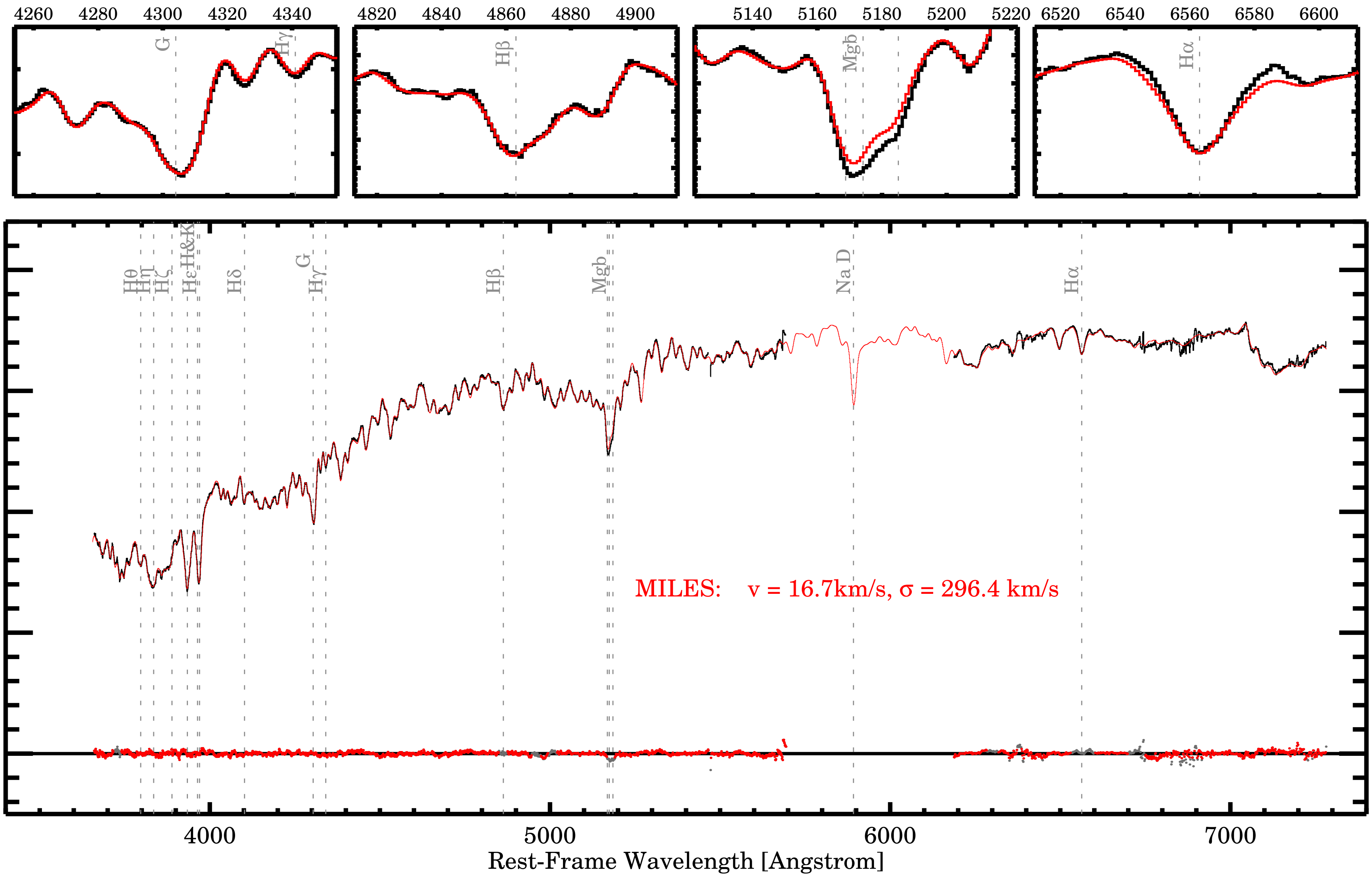
How do we measure a velocity?

- Doppler effect causes a *blueshift* or *redshift* of the spectrum

- Blueshift: stars moving towards you
- Redshift: stars moving away from you

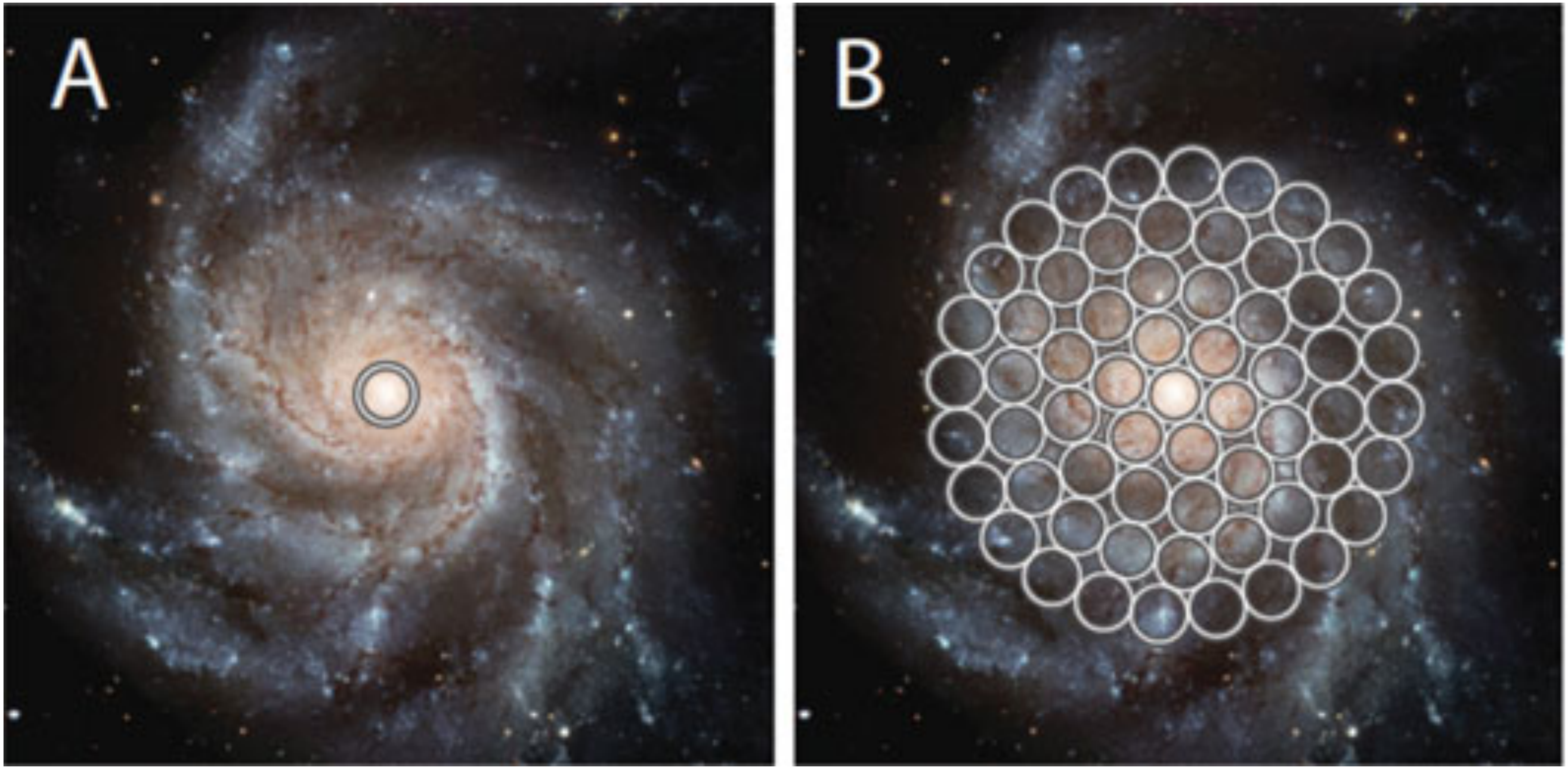


Galaxy spectra: absorption lines reveal velocity



Single fibre only reveal systemic velocity

Many fibres per galaxy can reveal rotation!



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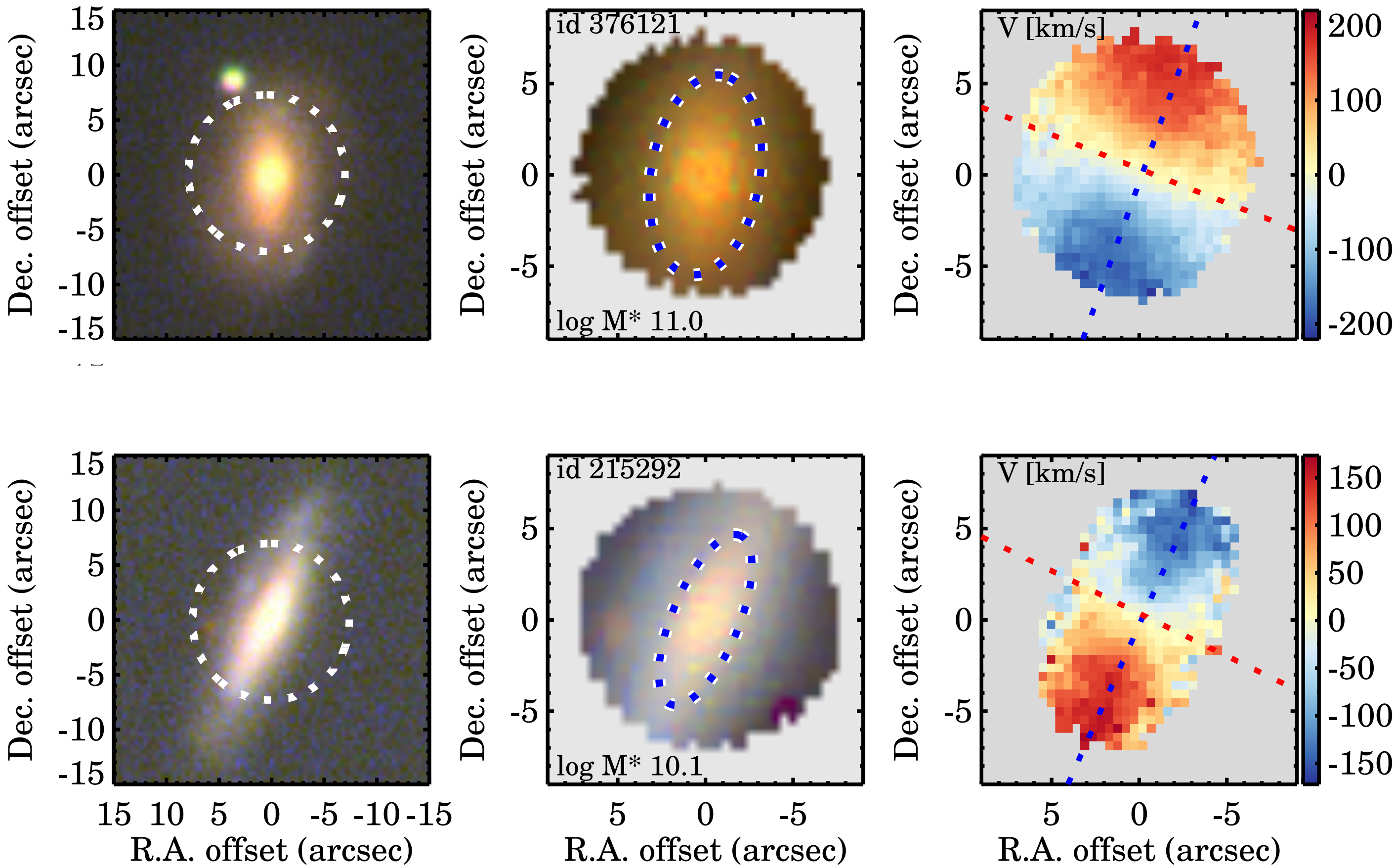
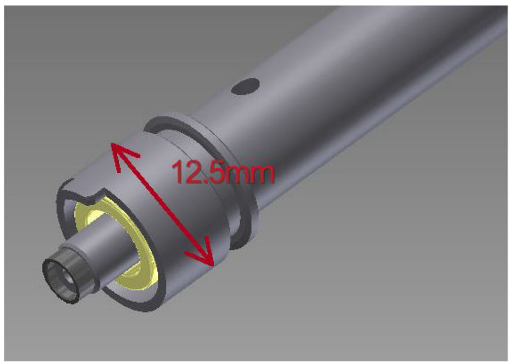
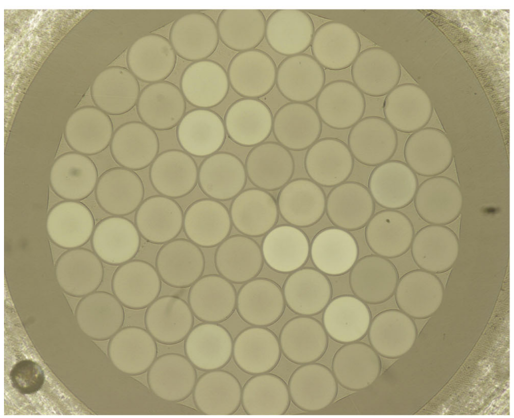
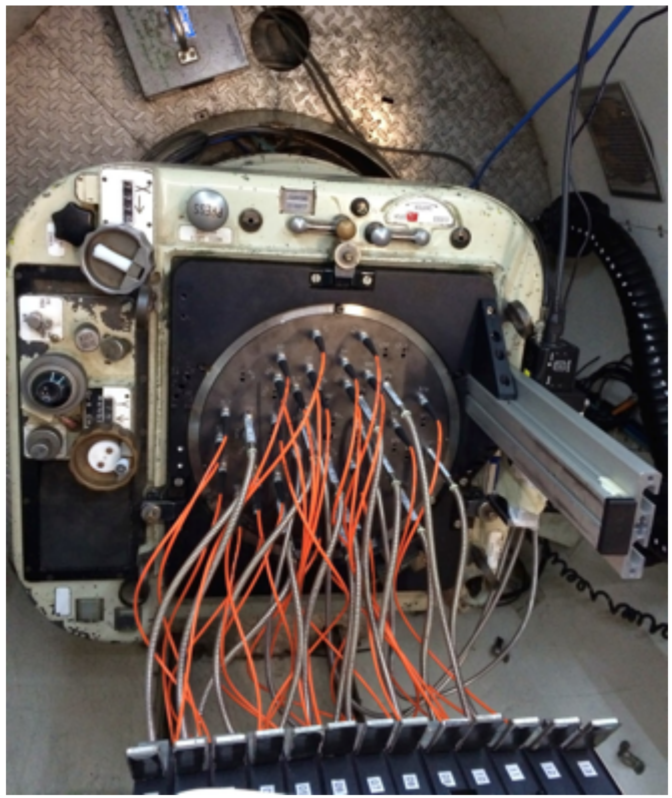


IFS Survey of ~3000 galaxies

- Total of ~200 nights on the 3.9m Anglo Australian Telescope







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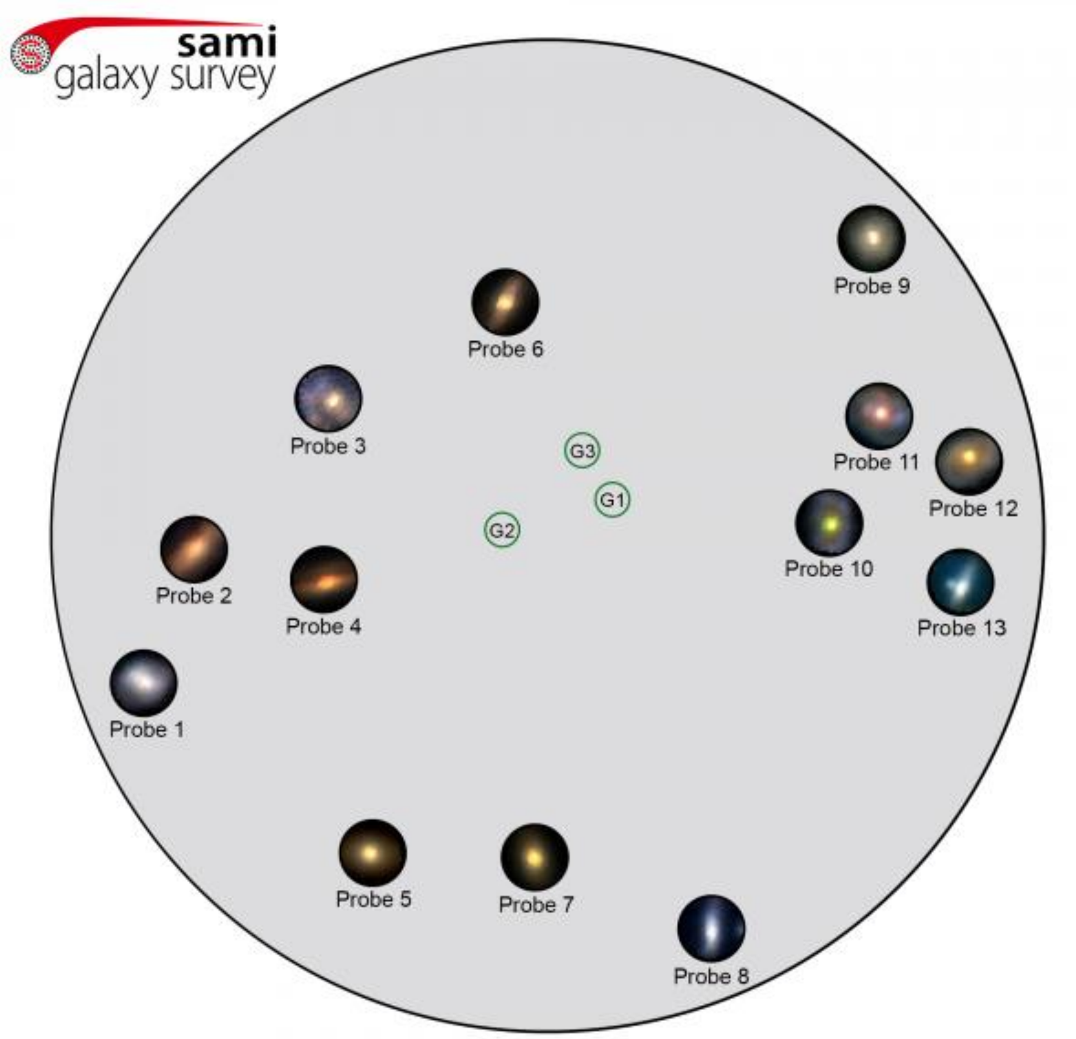

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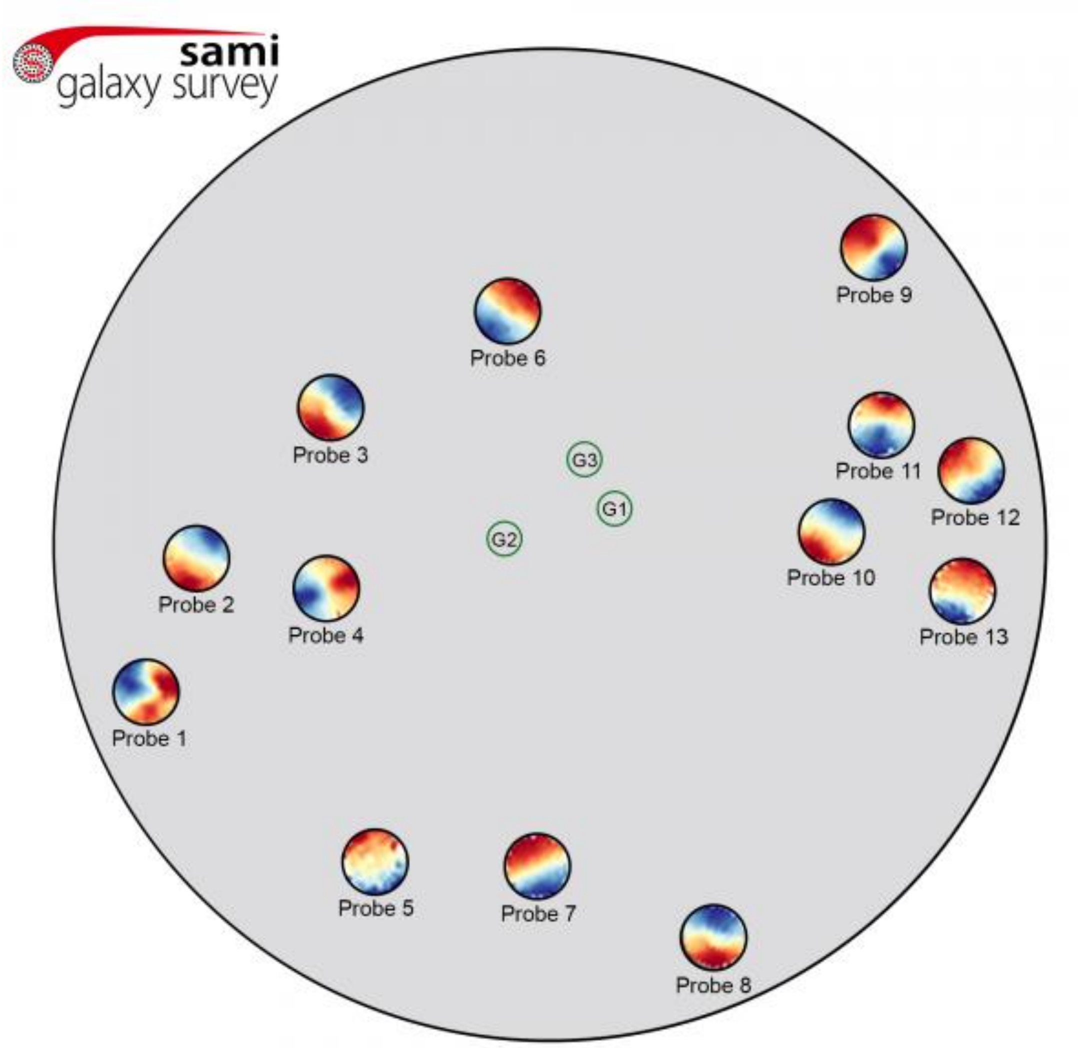
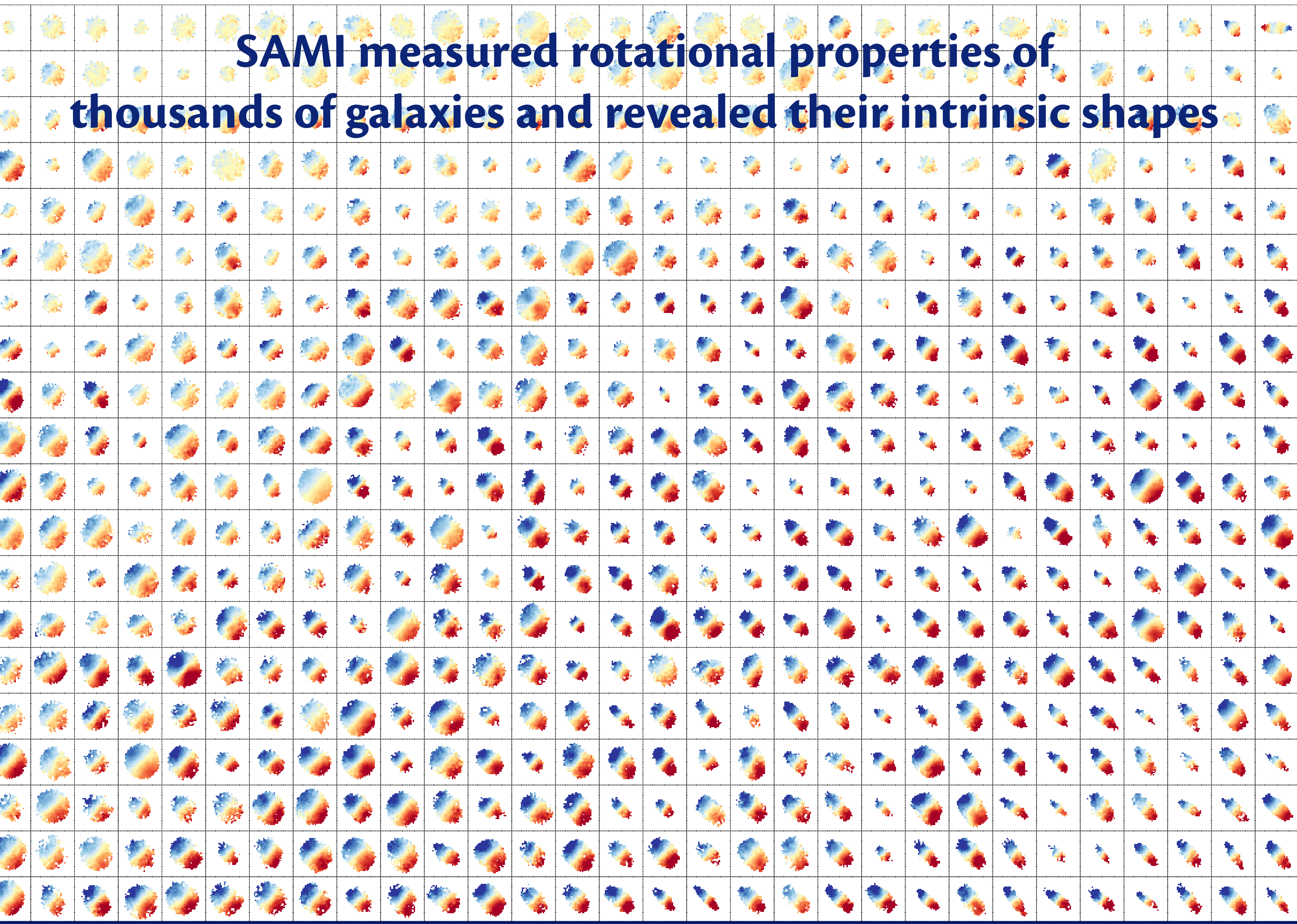


SAMI measured rotational properties of thousands of galaxies and revealed their intrinsic shapes



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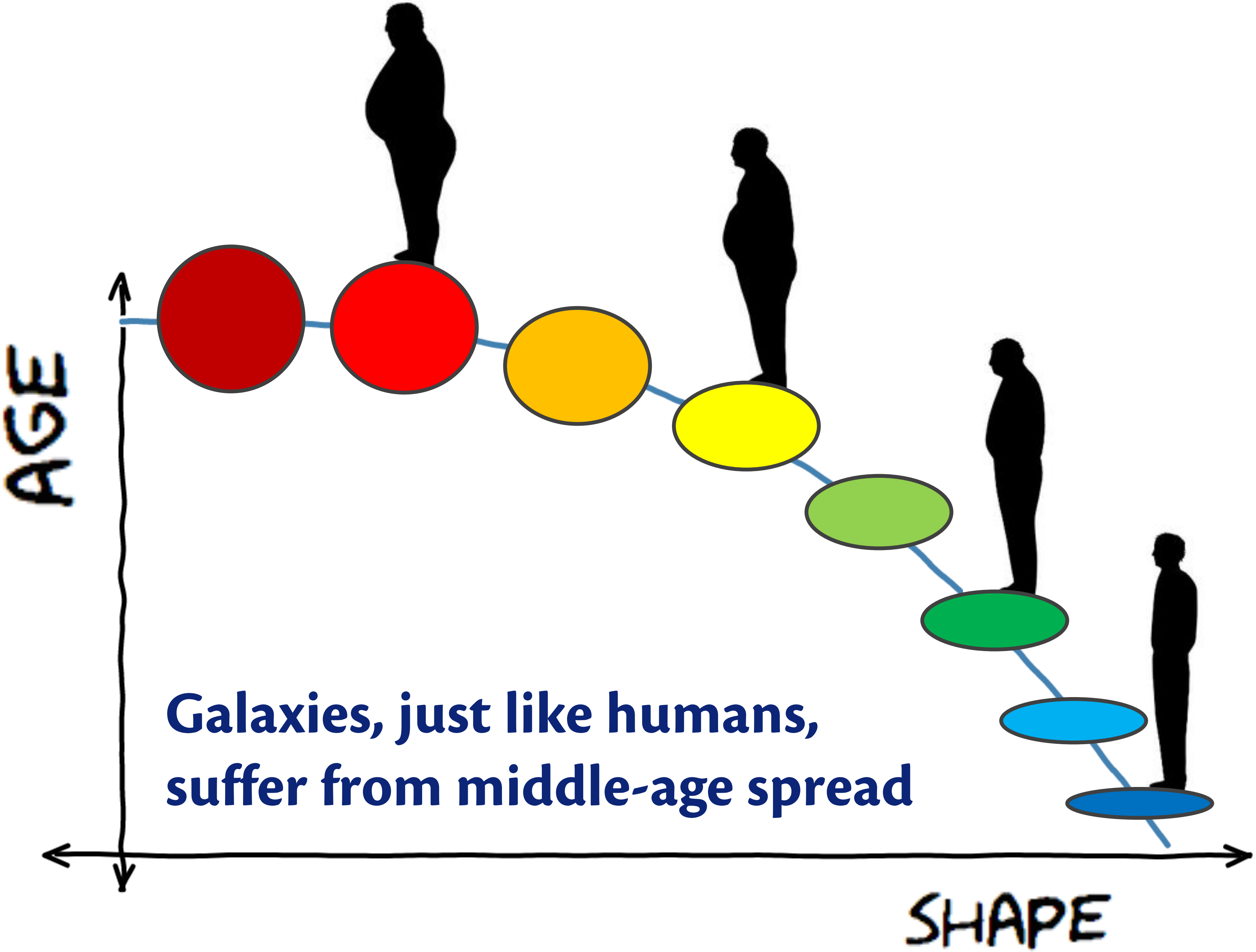


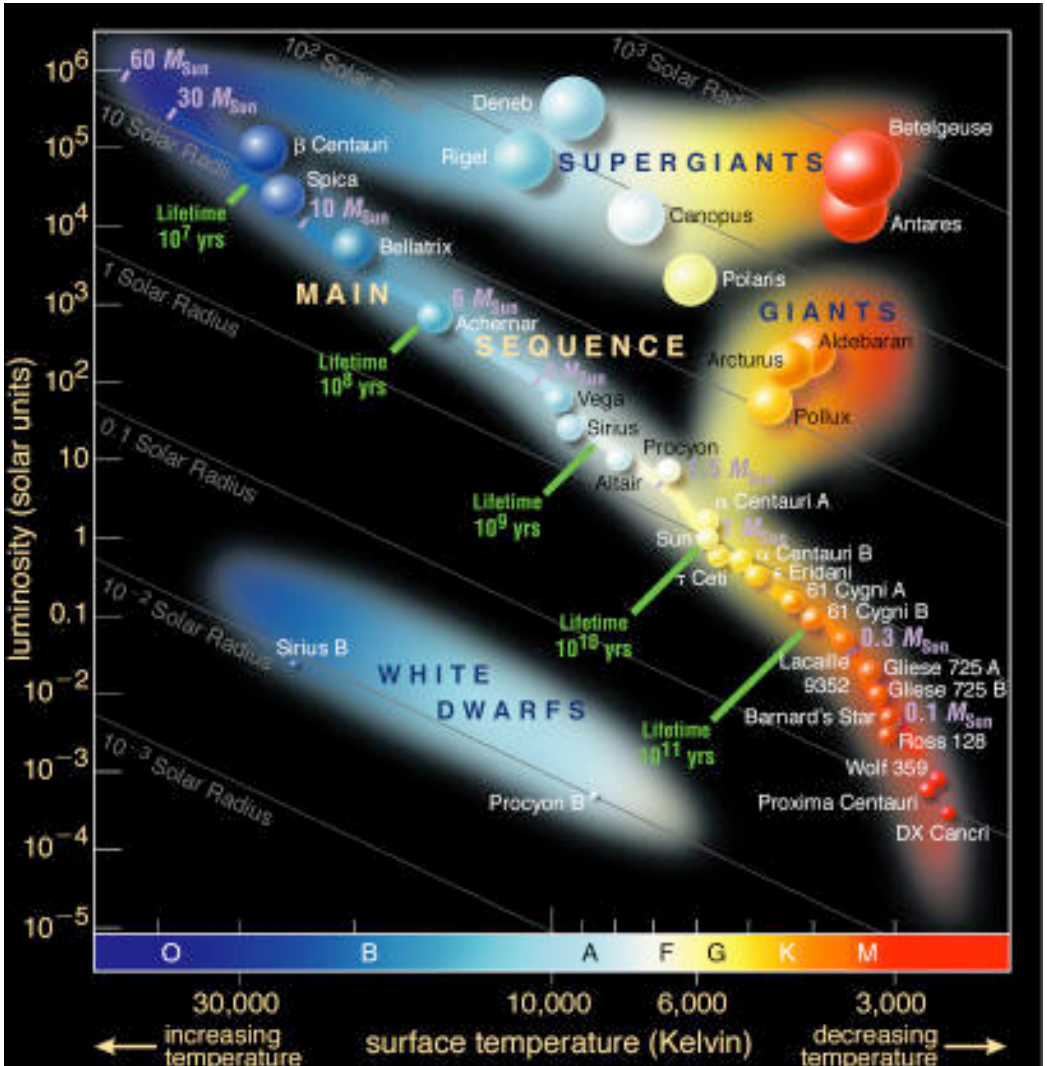
Galaxies, just like humans, suffer from middle-age spread

Why measuring the age of galaxies is hard

Analogy: imagine dendrology (study of wooded plants) from space :

- How many trees are there in a forest?
- Is the forest young, or extremely old?
- What is the ratio of oak vs. pine trees?
- How many young trees versus old versus dead?

A detailed understanding of stellar evolution is crucial for understanding galaxies



Hertzsprung-Russell diagram

- colour = age

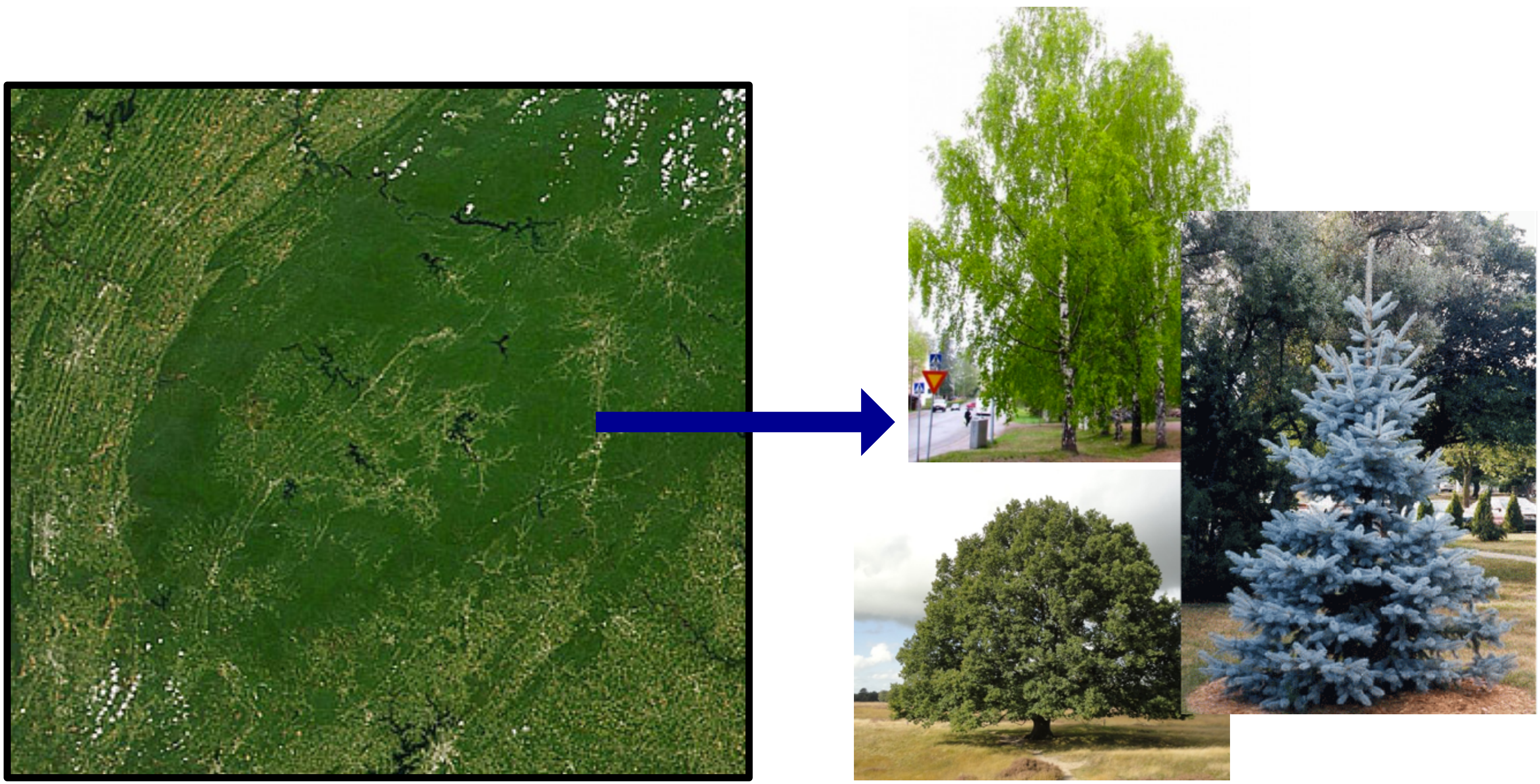
  blue=young
  red = old

- colour = mass

  blue = heavy
  red = light

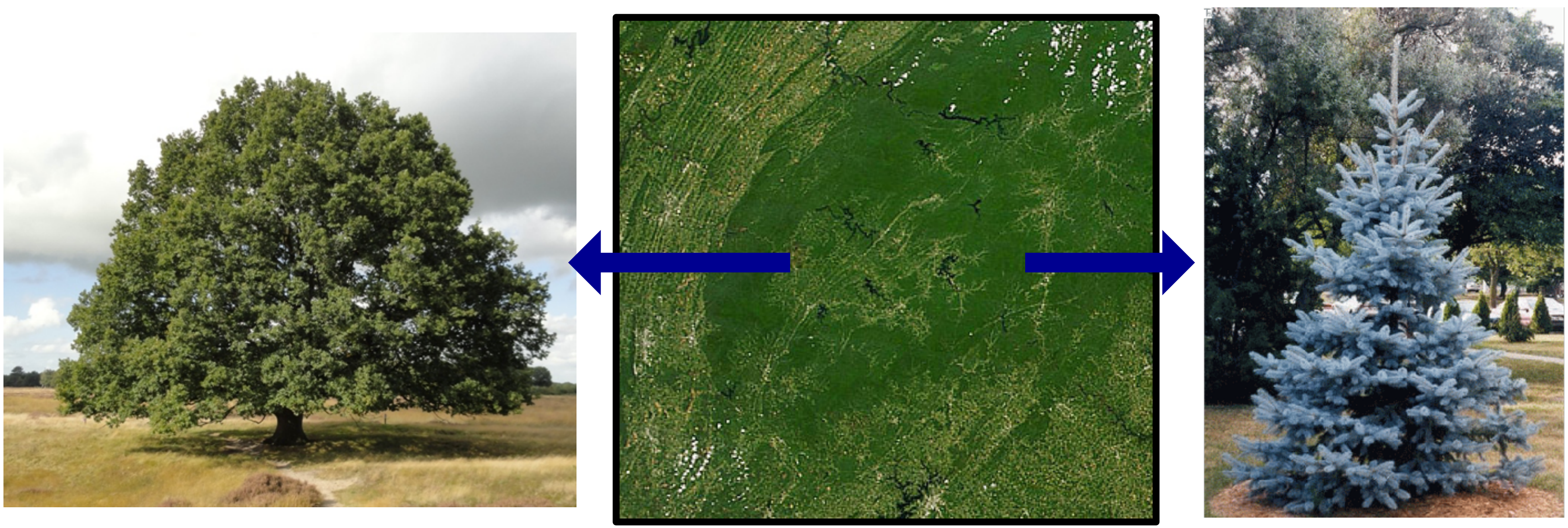
Analogy

- The colour of the leafs tell you which trees are in a forest



Analogy

- Pine trees grows faster than oaks
- An oak of 10 meters high
  is much heavier than
  a pine tree of 10 meter



Is it really that simple?

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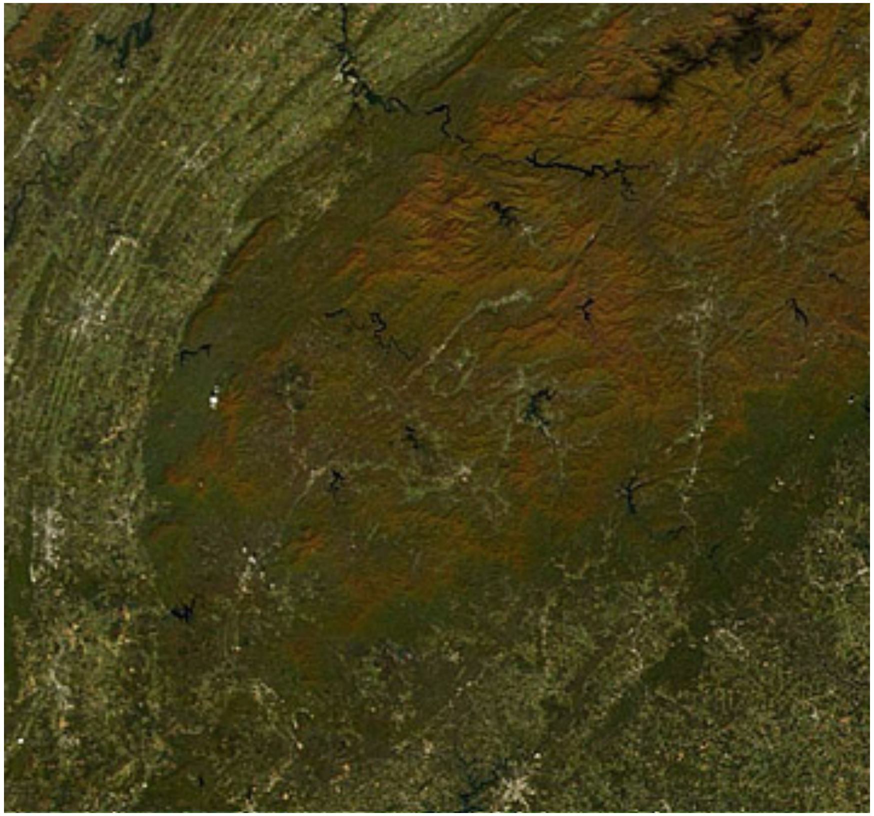

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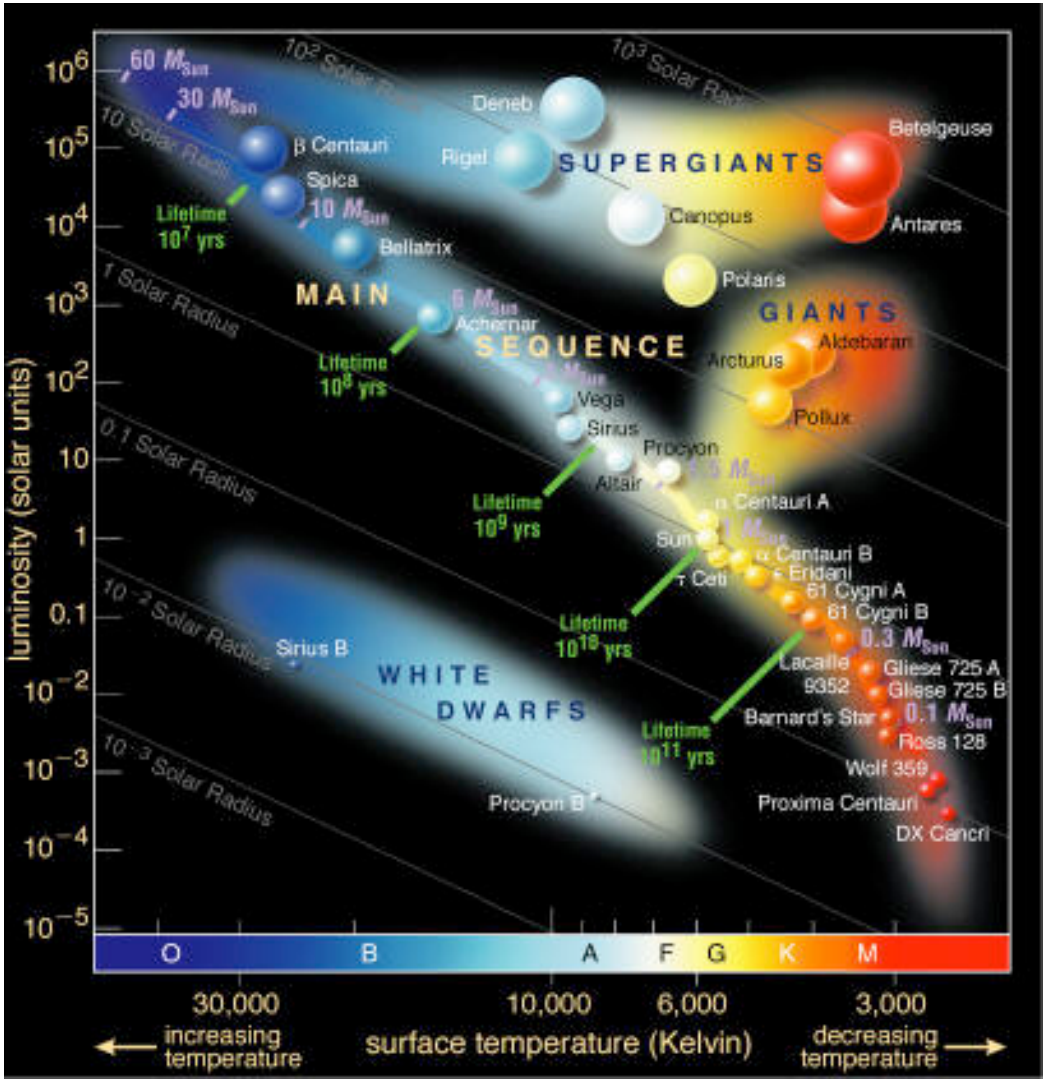

Hertzsprung-Russell diagram

- colour = age

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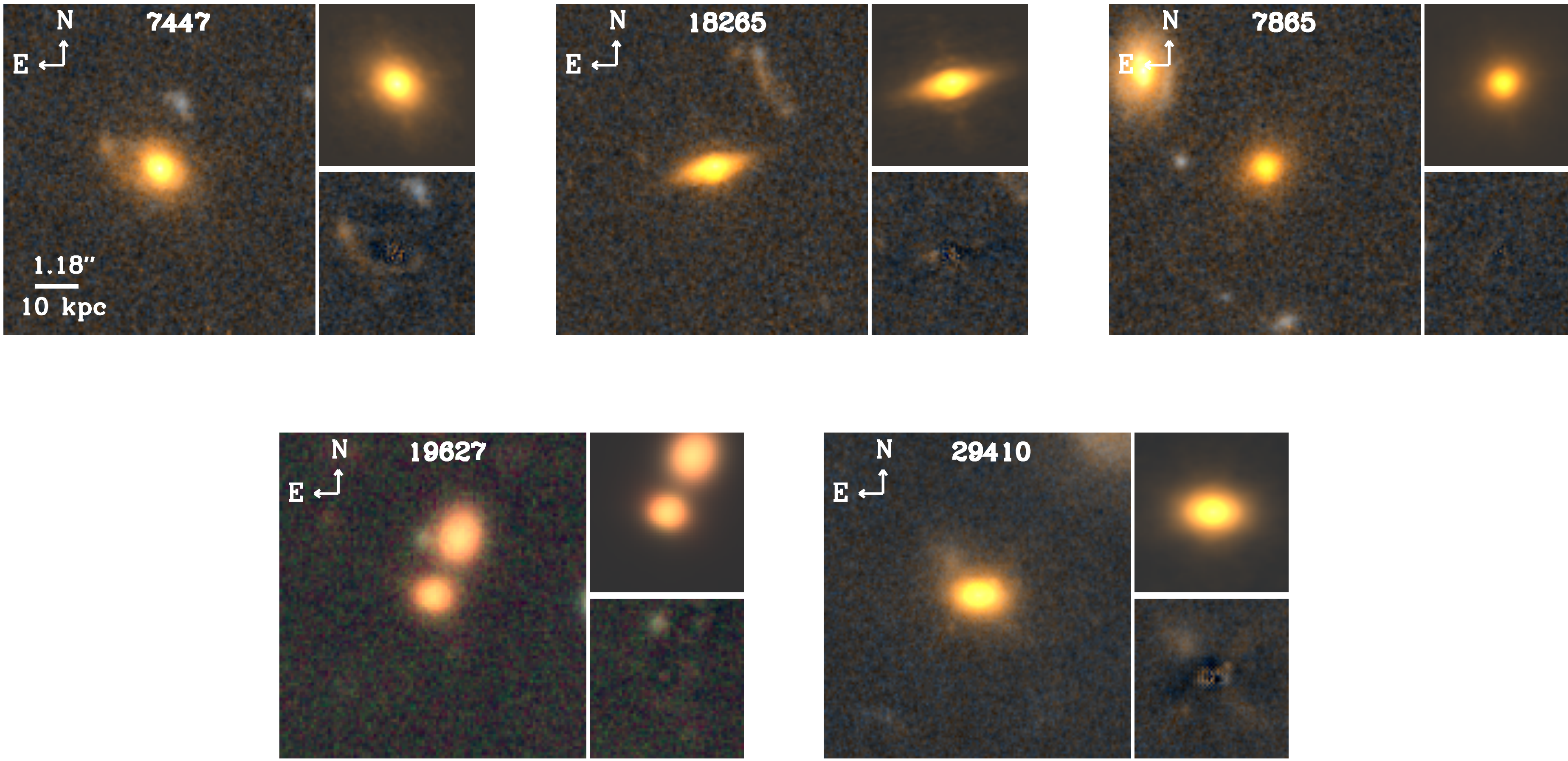
- colour = mass

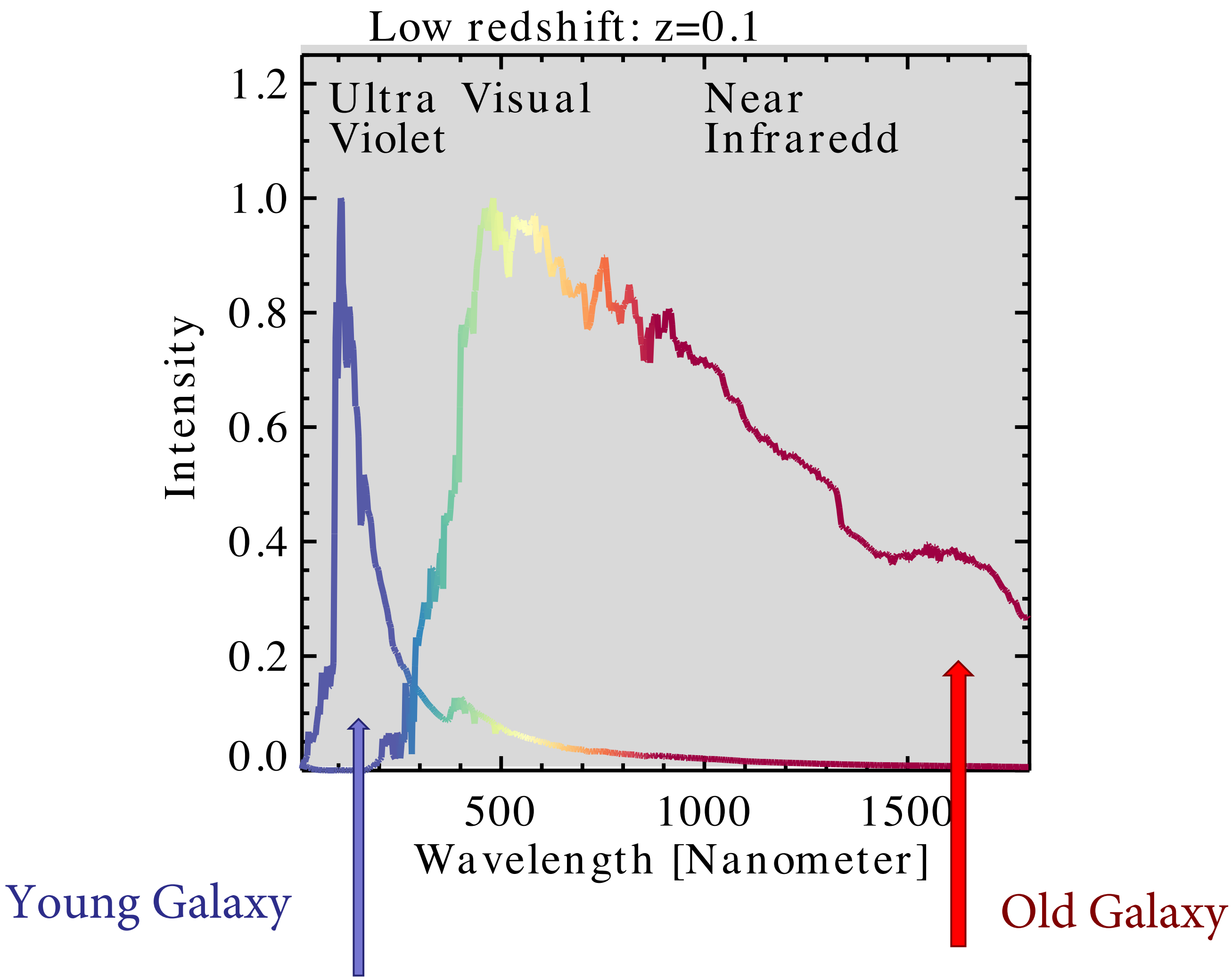
  blue = heavy
  red = light

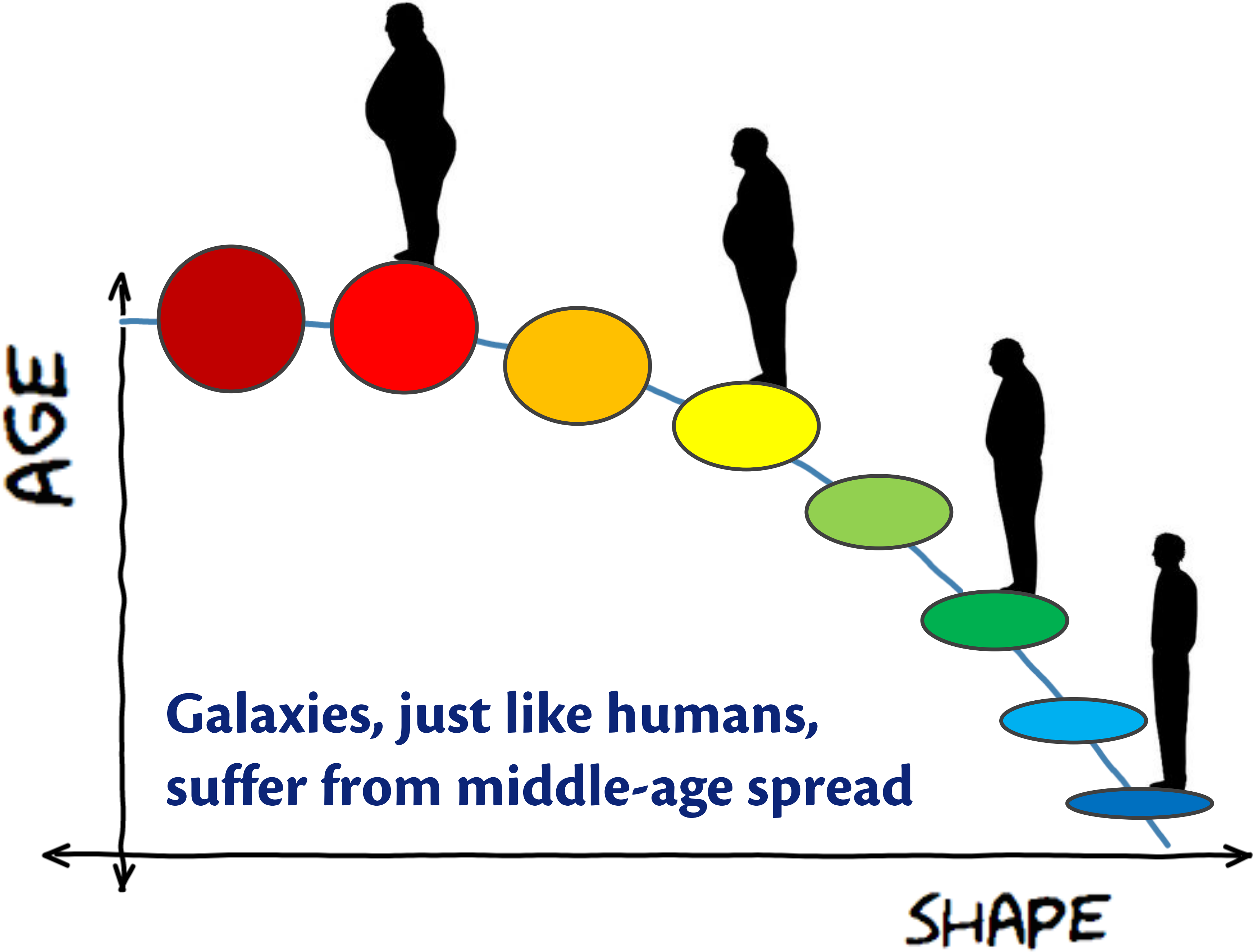
It could be relatively simple for this galaxy?

Is it really that simple for these galaxies?



Spectroscopy also reveals galaxy age!




AGE
Galaxies, just like humans,
suffer from middle-age spread
SHAPE

Galaxies in the present-day Universe

Galaxies at high-redshift: dawn of the red and dead

WHAT DO GALAXIES AND SHADOW PUPPETS HAVE IN COMMON?

Hubble's Law

- Galaxies that are farther away,
  are moving away from us at a faster rate

- Relation between velocity and distance:
  $v = H_0 * D$
  H_0 is the Hubbleconstant expressed in km s^{-1} Mpc^{-1}
  D is the distance to the Earth in Megaparsec
  v is the velocity (in km s^{-1}) of the galaxy moving away.

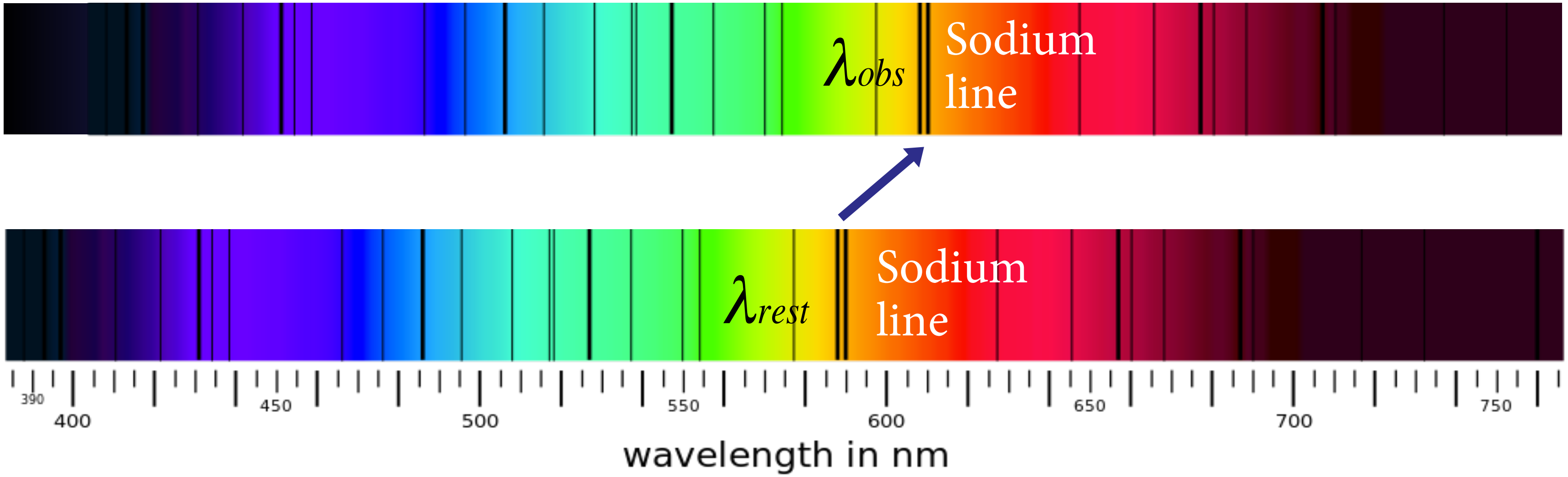
- Georges Lemaître formulated this law in 1927
  (two years before Edwin Hubble)

How do we measure a velocity to get a distance

- Cosmological Redshift due to expansion of the Universe:

$$1 + z = \frac{\lambda_{obs}}{\lambda_{rest}}$$

- Further away = higher redshift = further back in time



By studying galaxies at different redshift we can directly witness galaxy evolution:

At z=10 the universe was ~ 0.5 Gyr old
At z=3 the universe was ~ 2.1 Gyr old
At z=2 the universe was ~ 3.3 Gyr old
At z=1 the universe was ~ 5.9 Gyr old
At z=0 the universe was ~13.7 Gyr old

- Galaxies become rapidly fainter with increasing redshift:

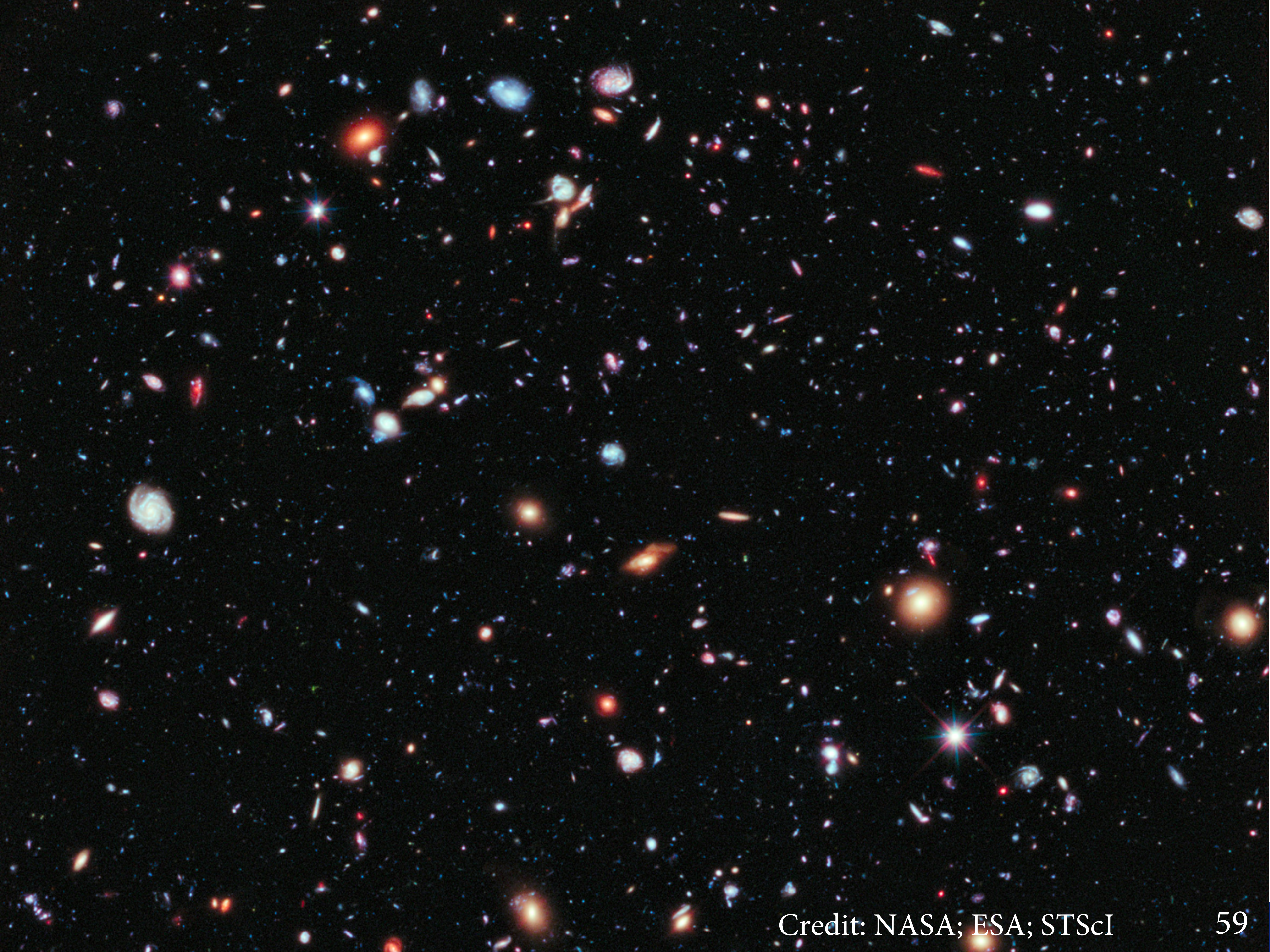
$$S \sim (1 + z)^{-4}$$

- Galaxies are smaller (in angular size)

- Harder to detect as the light moves into the NIR

Hubble Space Telescope

- High Angular Resolution
- Ideal for taking extremely sharp images.
- Can take images in visual and near infrared



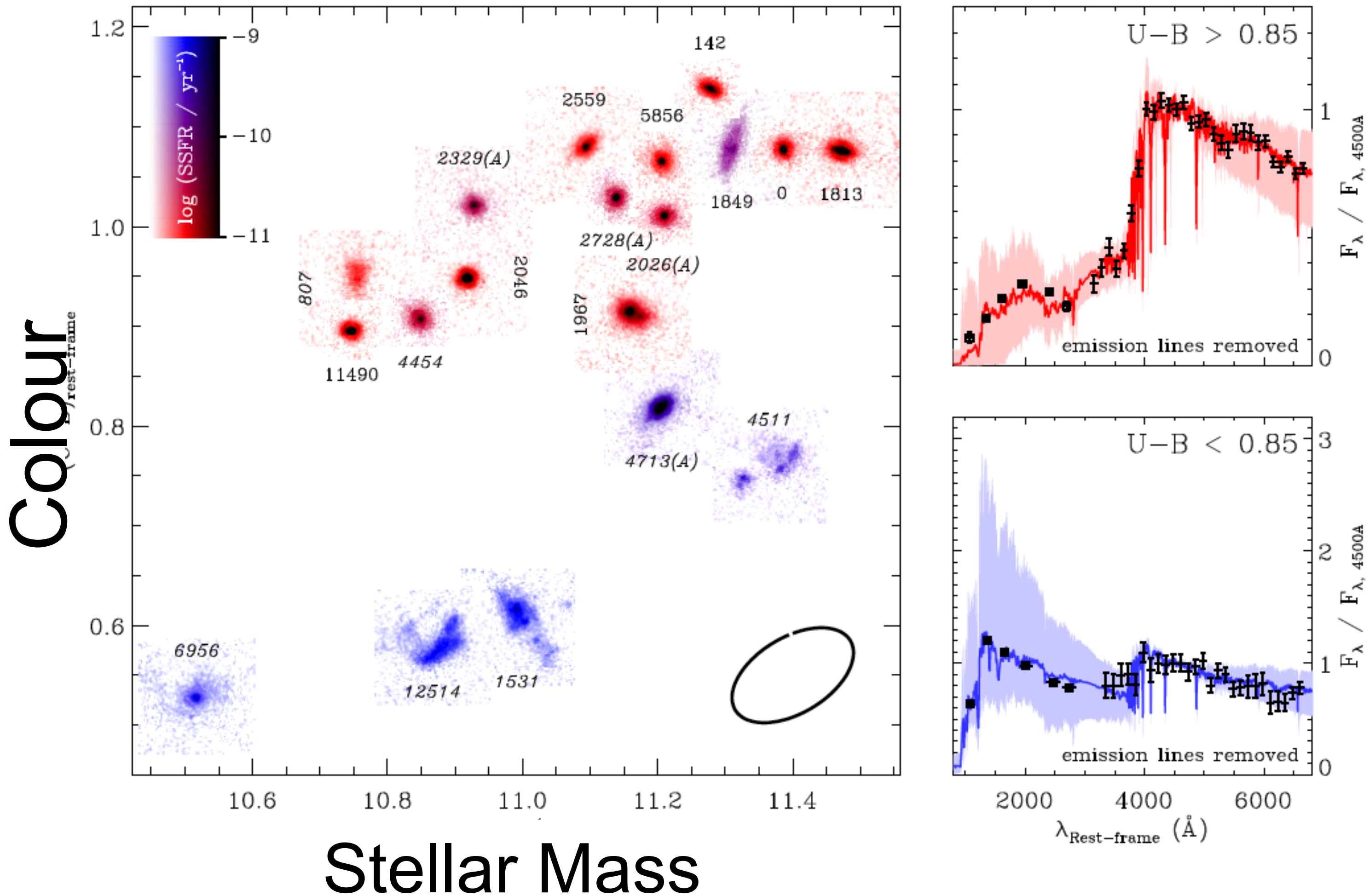
Credit: NASA; ESA; STScI

The Hubble eXtreme Deep Field

- “The XDF is the deepest image of the sky ever obtained and reveals the faintest and most distant galaxies ever seen.”
- Total exposure time of 2 million seconds (~50 days continuous observing)
- 2000 images stacked together taken with two cameras on board HST
- 5500 Galaxies visible from redshift z~0.1 to z~10

Dawn of the Red and Dead

- The first Red and Dead galaxies existed 3 billions years after the big bang.



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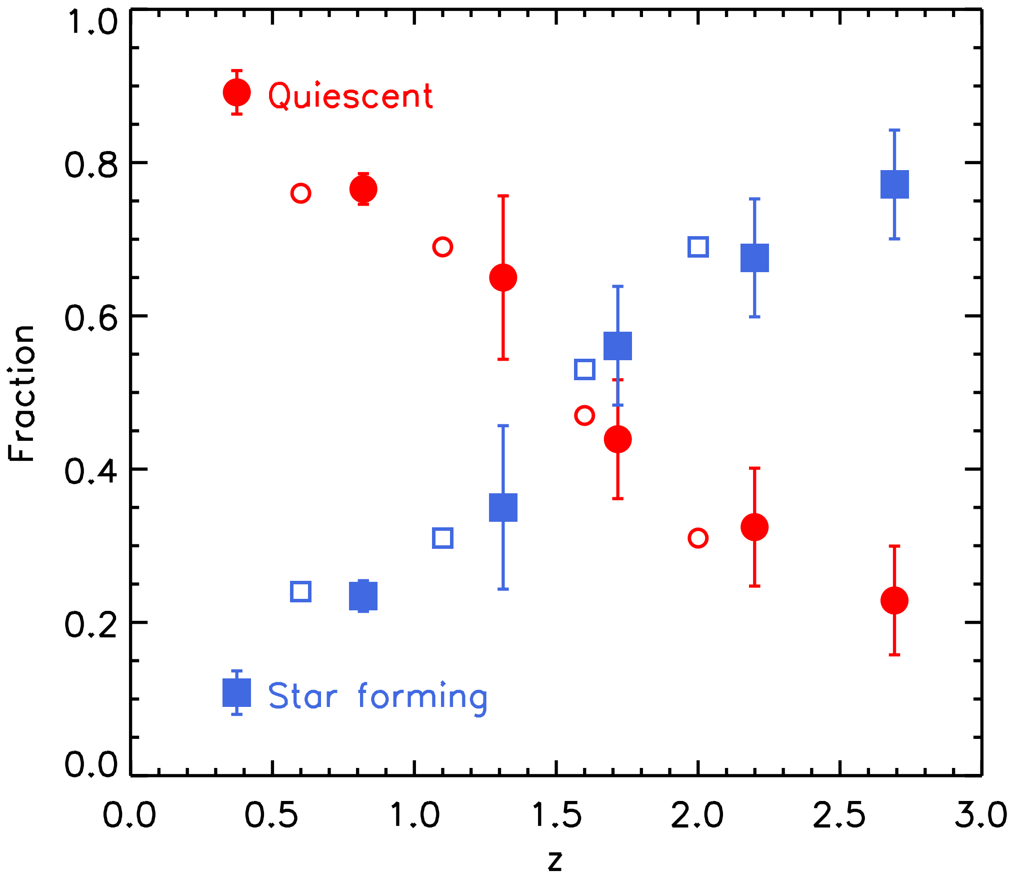
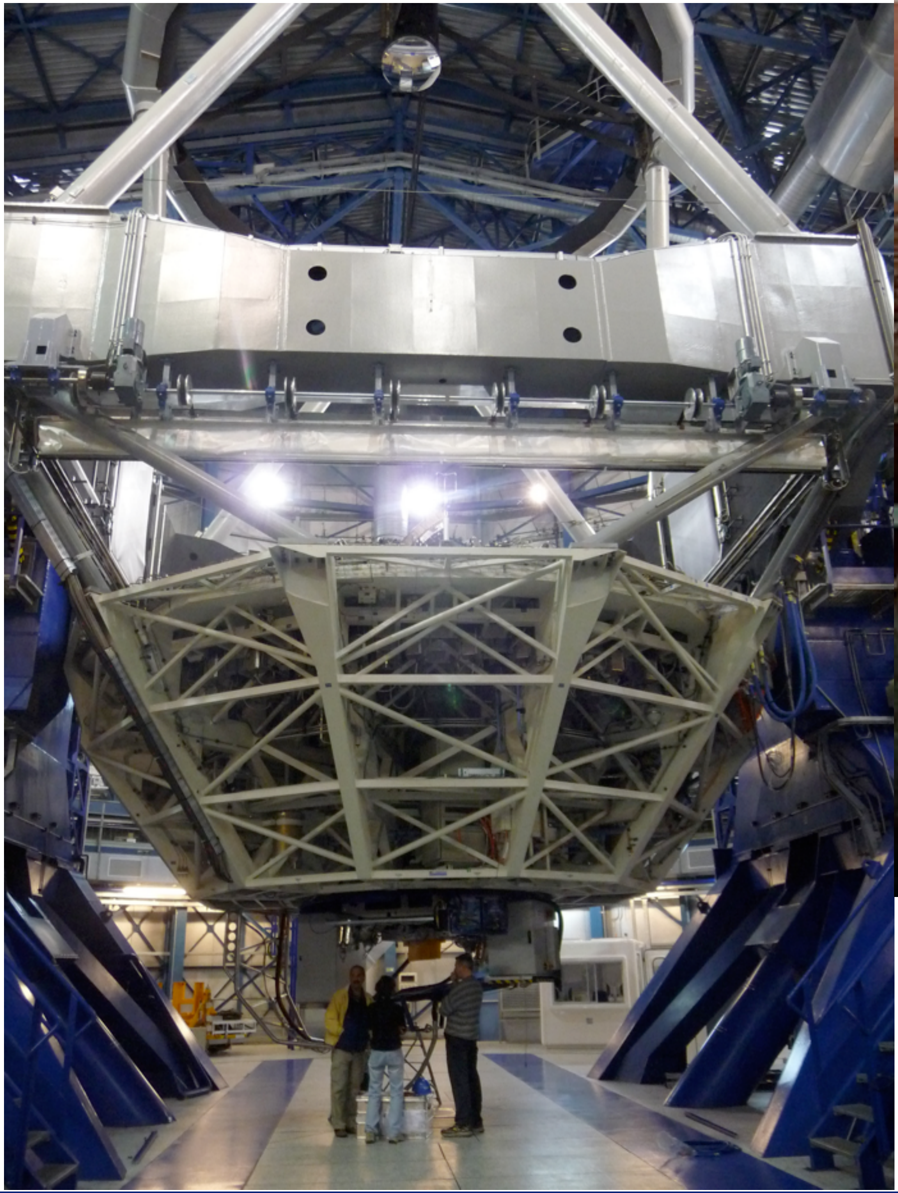


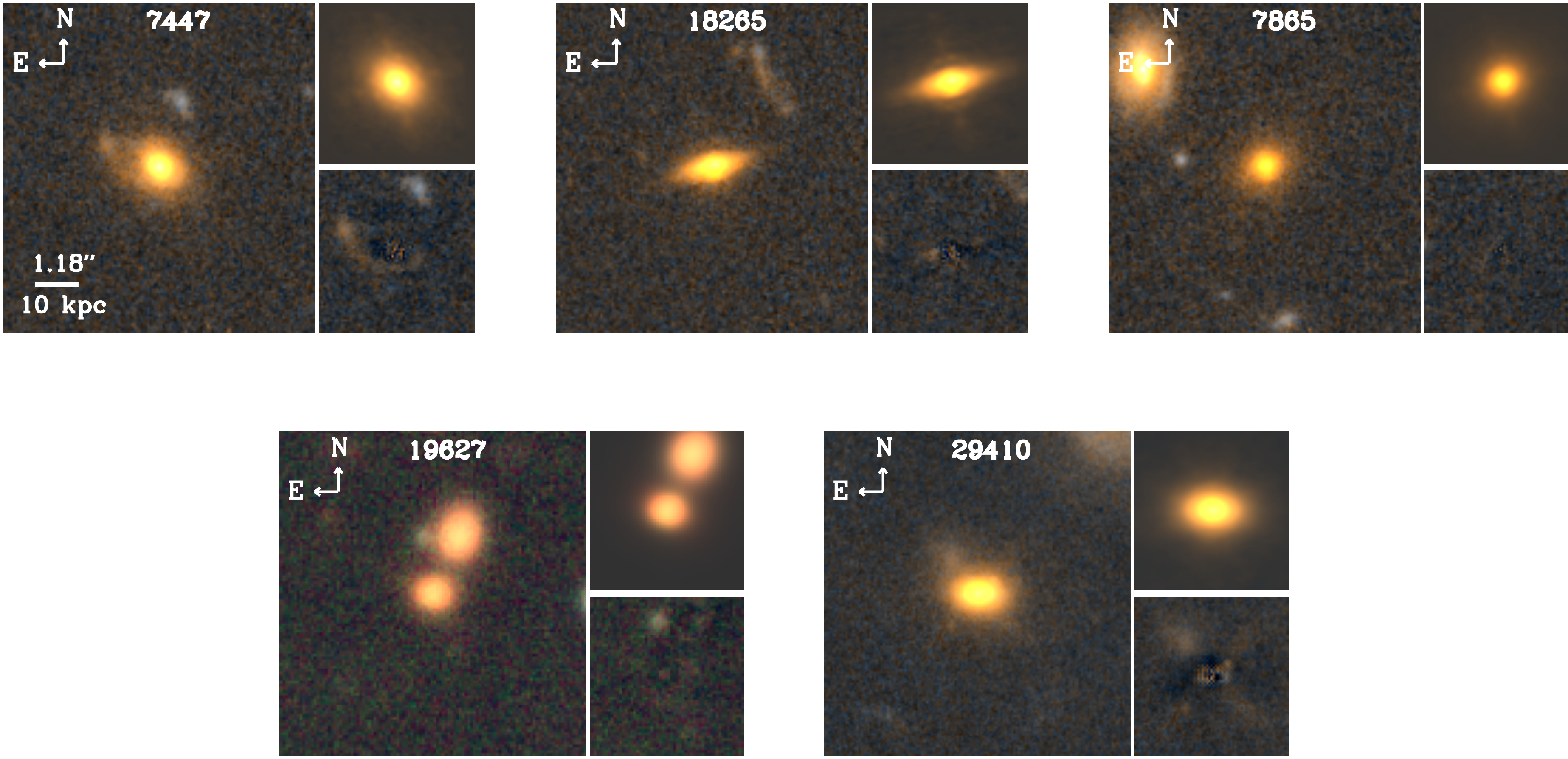
Patel et al. 2013

Very Large Telescopes

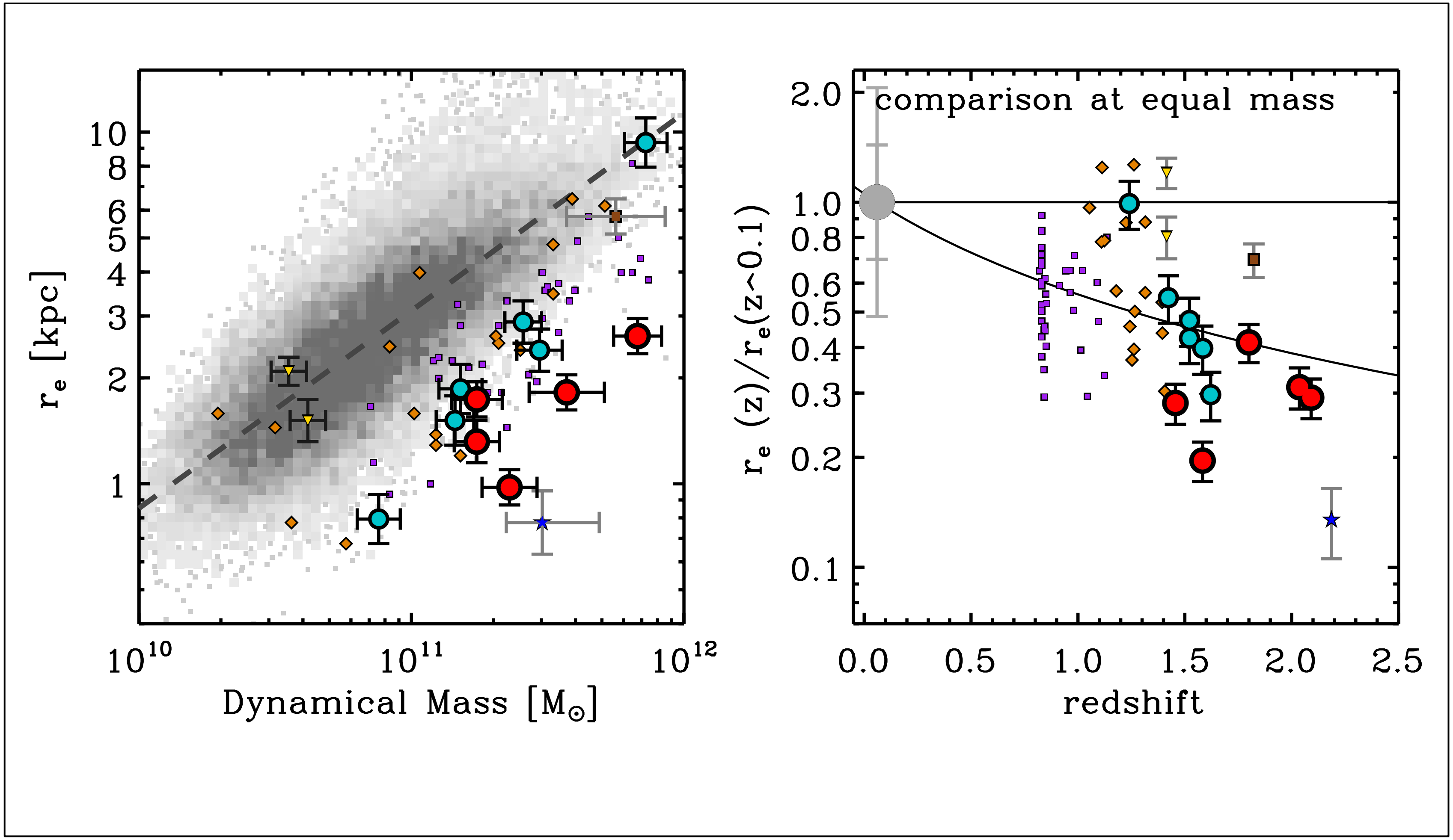


+ X-Shooter

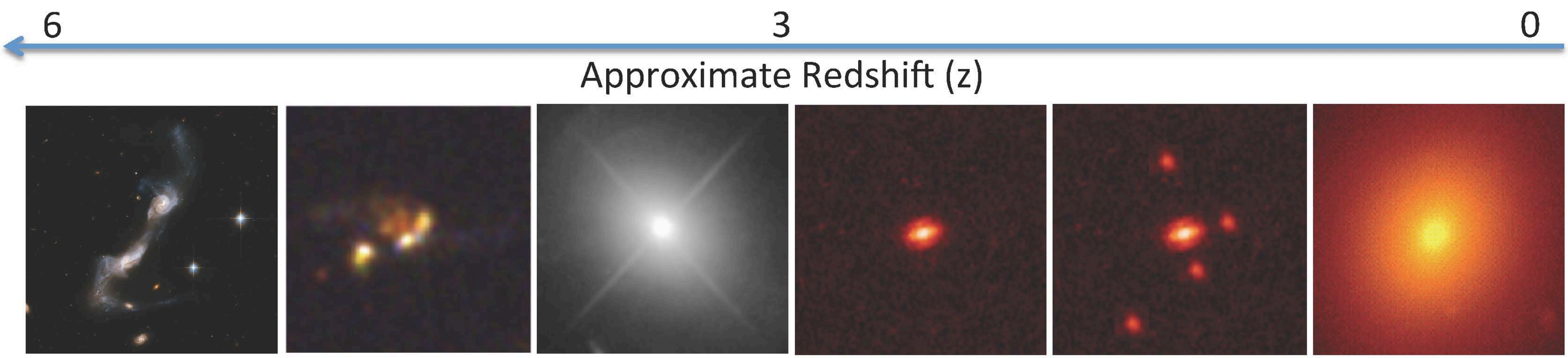
Deep N-IR Spectroscopy of 5 high-redshift galaxies



Red and Dead Galaxies in the early Universe are much more compact than expected!



Complete Picture



Major Gas-Rich Merger

Dusty Nuclear Starburst (SMG)

QSO/AGN (Quenching)

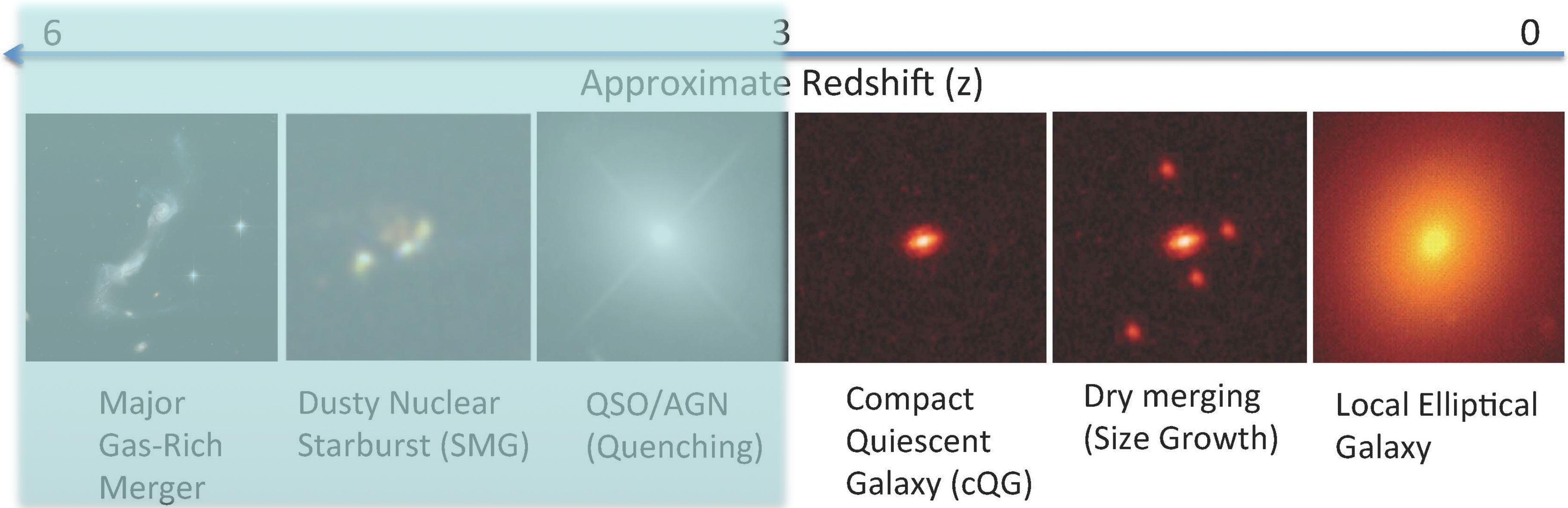
Compact Quiescent Galaxy (cQG)

Dry merging (Size Growth)

Local Elliptical Galaxy

Toft et al. 2014

Complete Picture?



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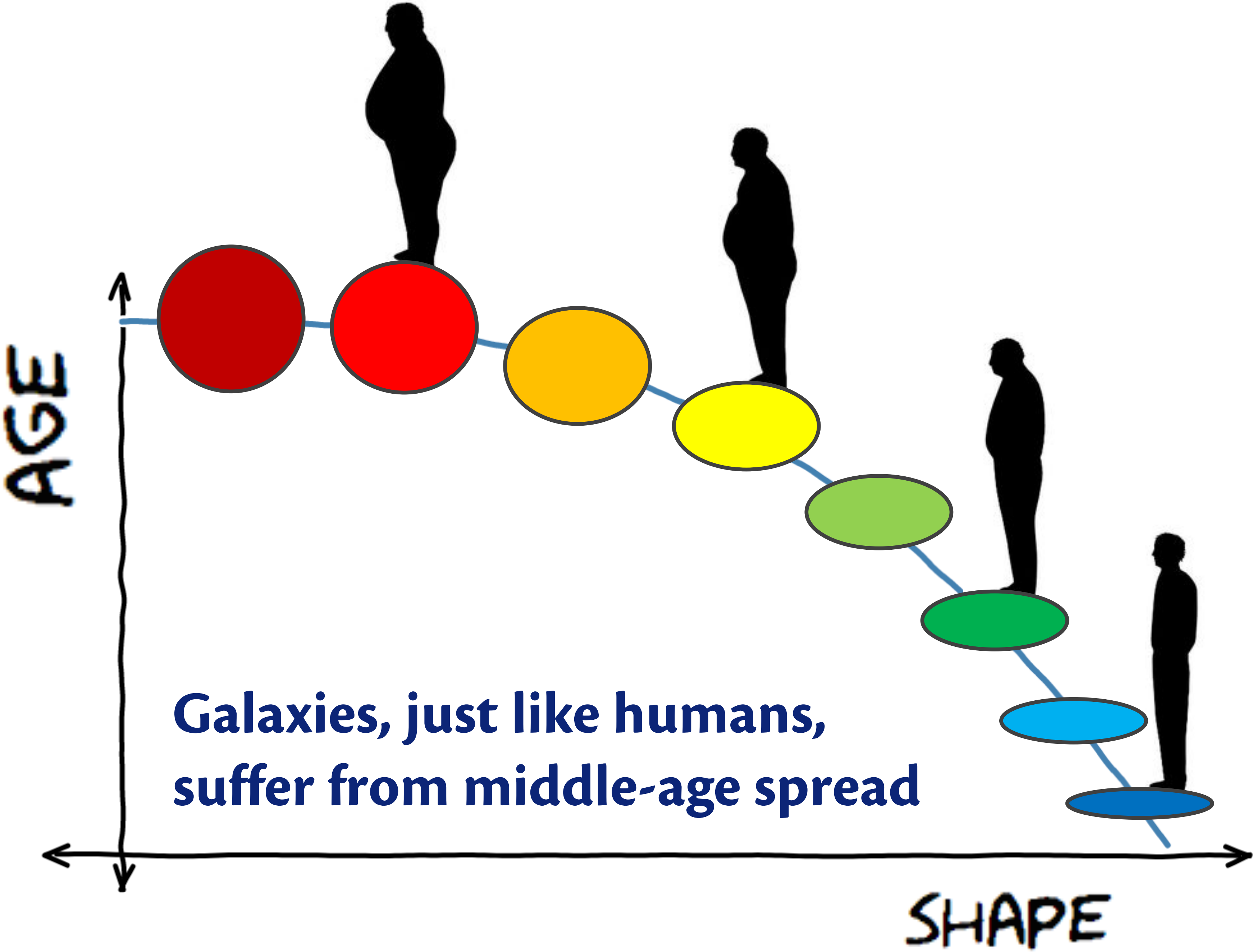

Galaxies, just like humans, suffer from middle-age spread

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Red and Dead galaxies already existed 3 billion years after big bang

Galaxies evolve through merging

Our Milky Way is on a Collision Course to become a Red and Dead Galaxy

Late-Type galaxies: lots of star formation and young stars in disc, old bulge

Early-type galaxies : massive, large, filled with old stars (Red and Dead).