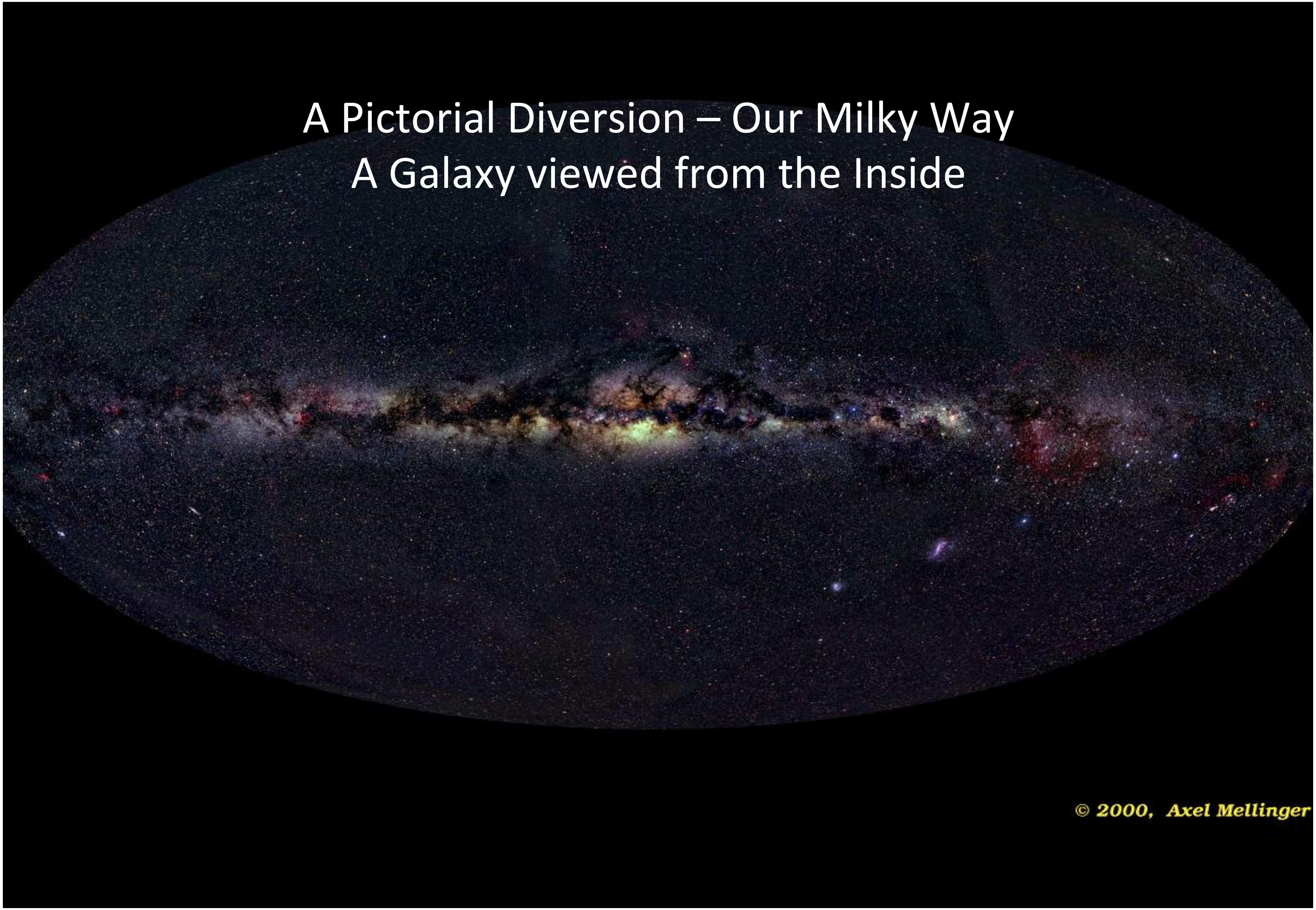
PHYS2160 – Astronomy

- This course will cover much of basic astronomy, and will be presented by two lecturers
- Chris Tinney (Weeks 1-6) will cover “Part I” – our Galaxy (the Milky Way), other galaxies (spiral, elliptical, active and starburst galaxies, and quasars), the cosmic distance scale and the size and age of the Universe.
- Sarah Martell (Weeks 7-12) will cover “Part II” – Galaxies at High Redshift and their Evolution (galaxy number counts, cluster and field galaxy evolution; redshift surveys; gravitational lensing), Cosmology (Models and observations; the Big Bang; Inflation and Grand-Unified Theories; galaxy formation; the cosmic microwave background; dark matter models; cold dark matter scenario).
- Lectures
  - Tuesday, 11am, Old Main Building 151
  - Wednesday, 1pm, Old Main Building 150
- Website (for Part I)
  - http://www.phys.unsw.edu.au/~cgt/PHYS2160_-_Part_1
- Website at School of Physcs
  - https://www.physics.unsw.edu.au/courses/phys2160-astronomy
- Assessment
  - 1 assignments worth 15% of final mark
  - In-session exam (during Thursday lecture of Week 6) worth 35% of final mark

PHYS2160 – Astronomy

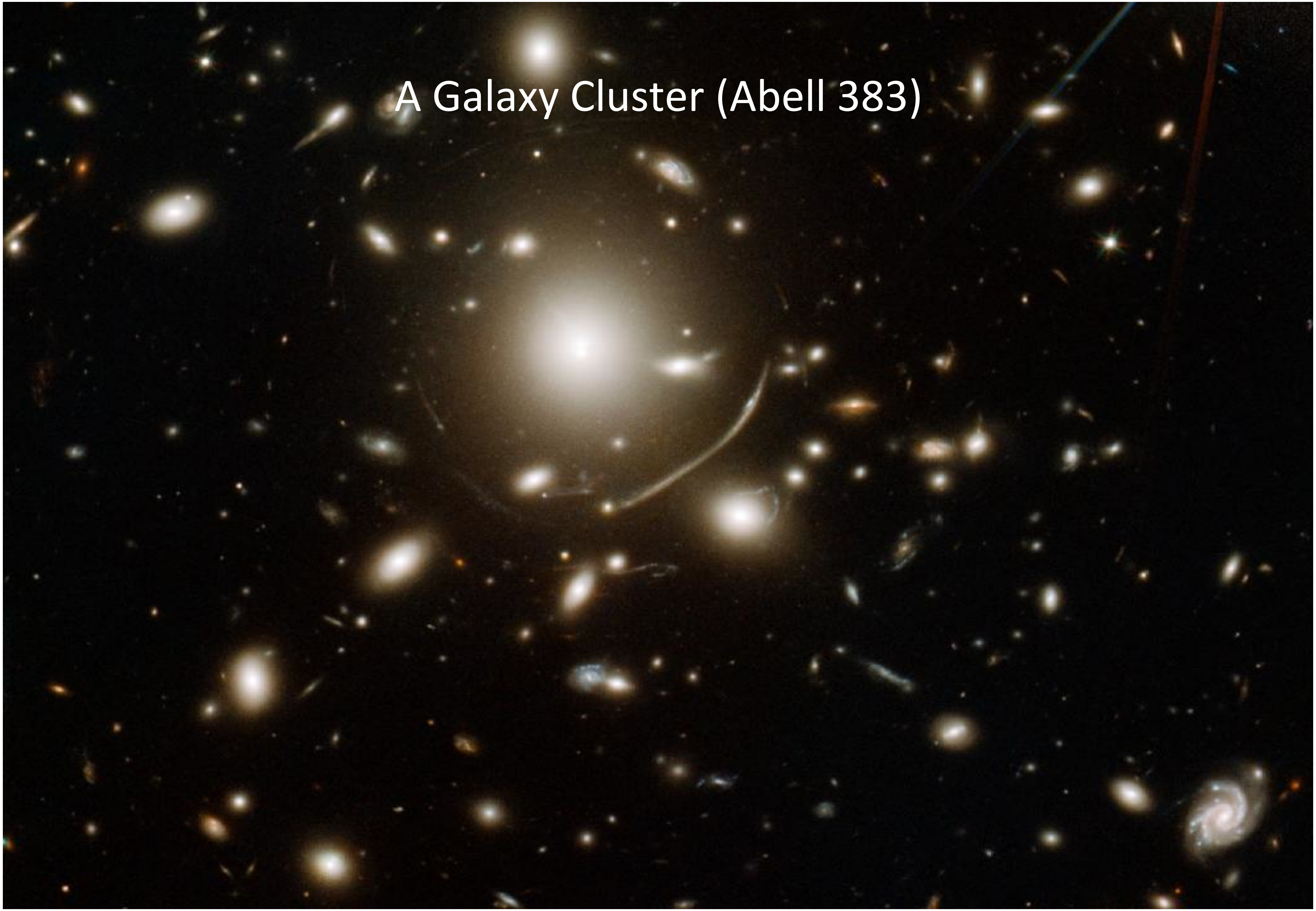
- By the end of this course you should have a better understanding of
  - how our Milky Way galaxy works;
  - how the stars and gas and dust are distributed in it;
  - how spiral galaxies are generally different from elliptical galaxies;
  - how studies of the distribution of galaxies throughout the universe, and searches for the most distant galaxies and quasars tell us about how the universe formed and how galaxies evolve;
  - how measuring the distances to galaxies with ever more precision has told us both how old the universe is, how big it is and how much stuff it has in it – including the fact that the stuff you and I are made from makes up only ~4% of the Universe with the rest being a combination of dark matter and dark energy.

A Pictorial Diversion – Our Milky Way
A Galaxy viewed from the Inside

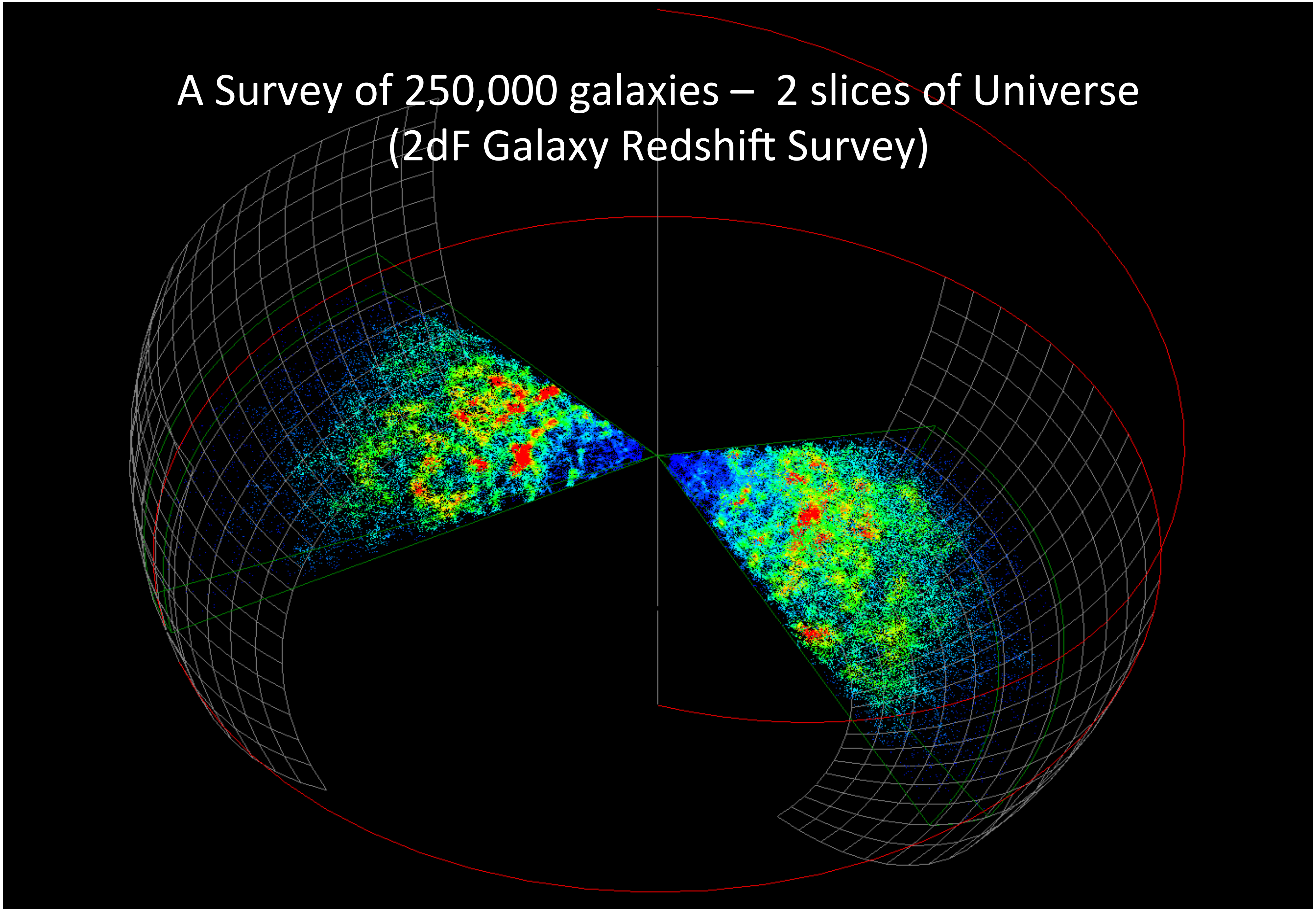


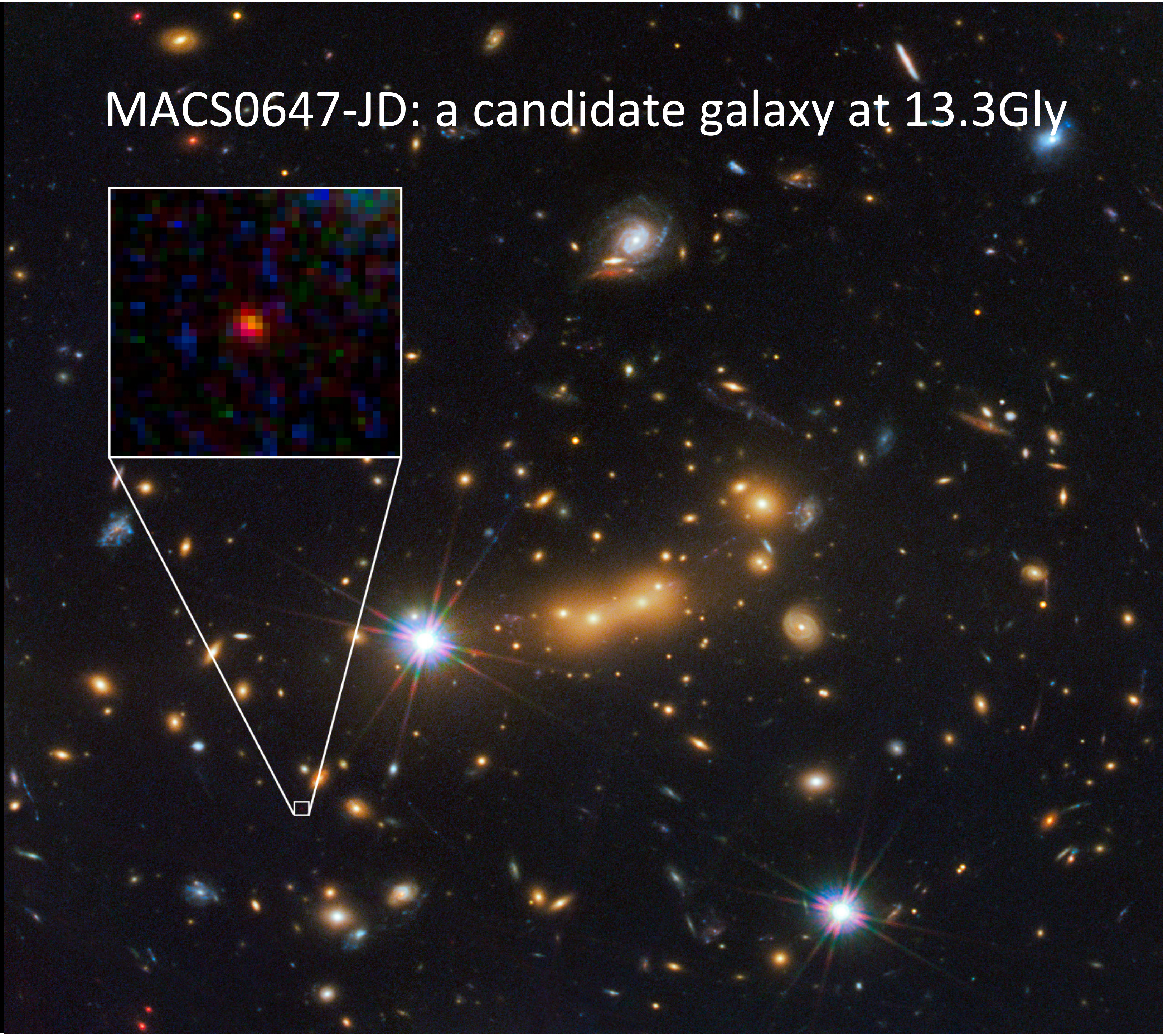

A very similar galaxy (Andromeda) viewed extrnally

A Galaxy Cluster (Abell 383)

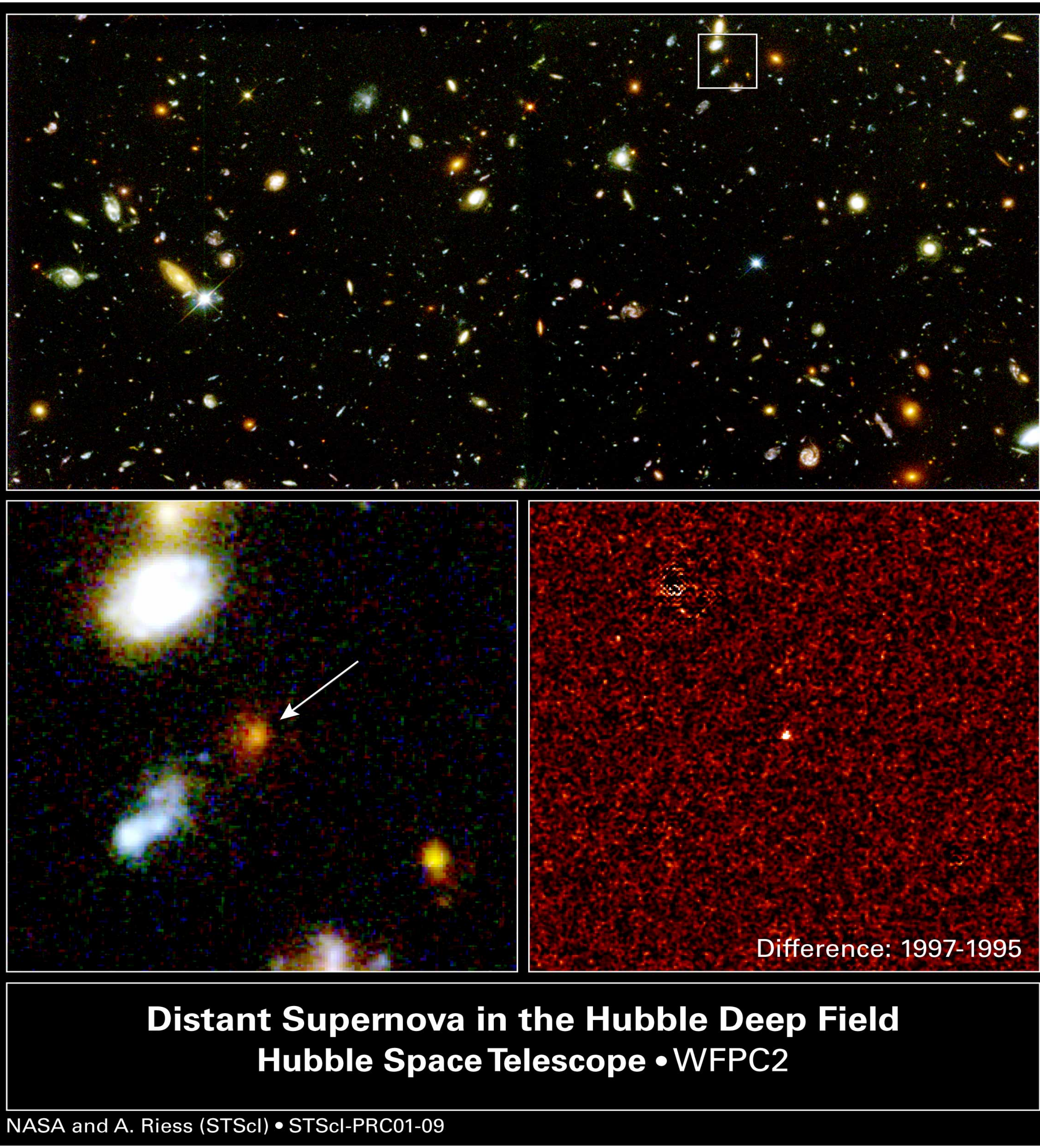


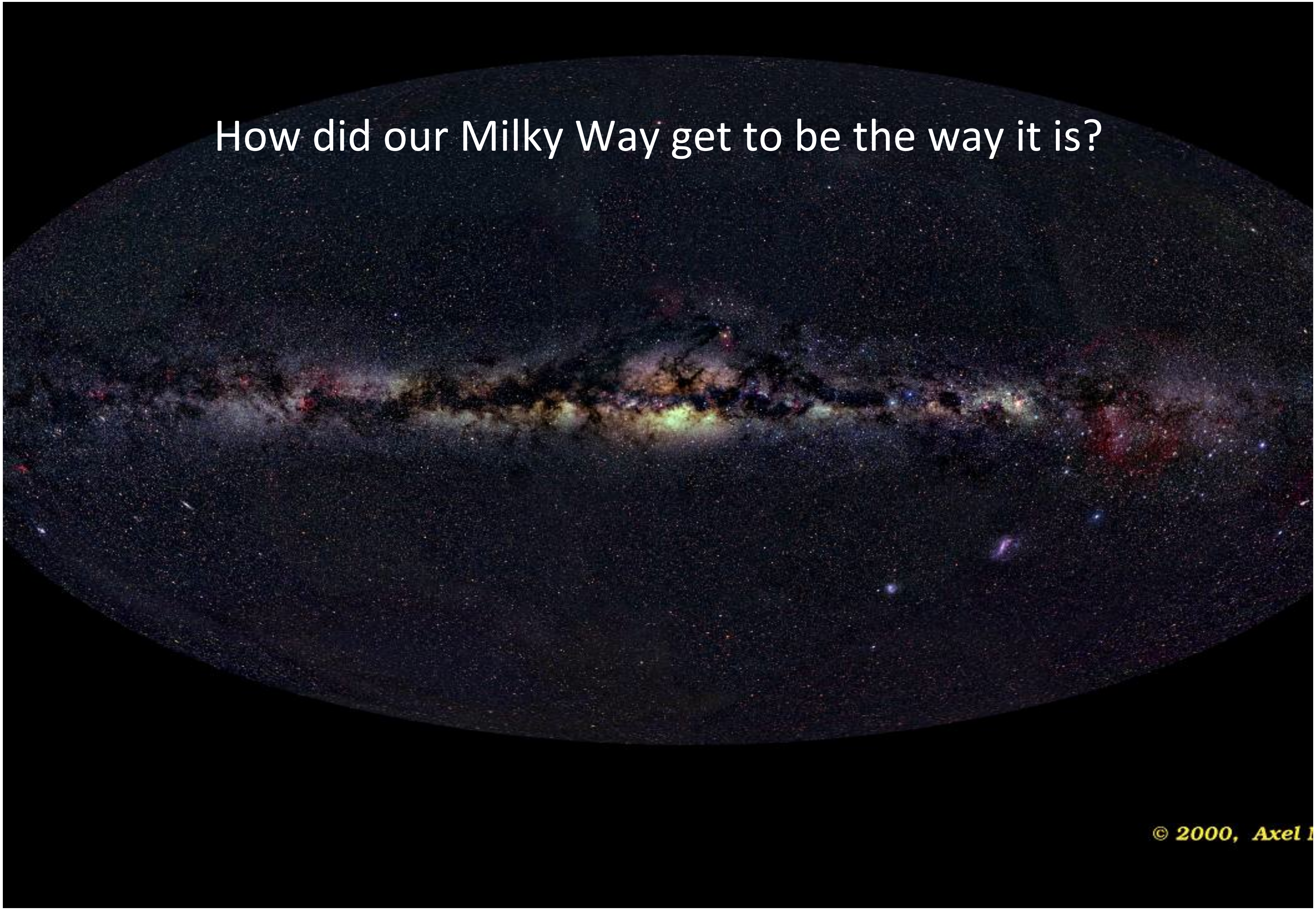
A Survey of 250,000 galaxies – 2 slices of Universe
(2dF Galaxy Redshift Survey)




MACS0647-JD: a candidate galaxy at 13.3Gly

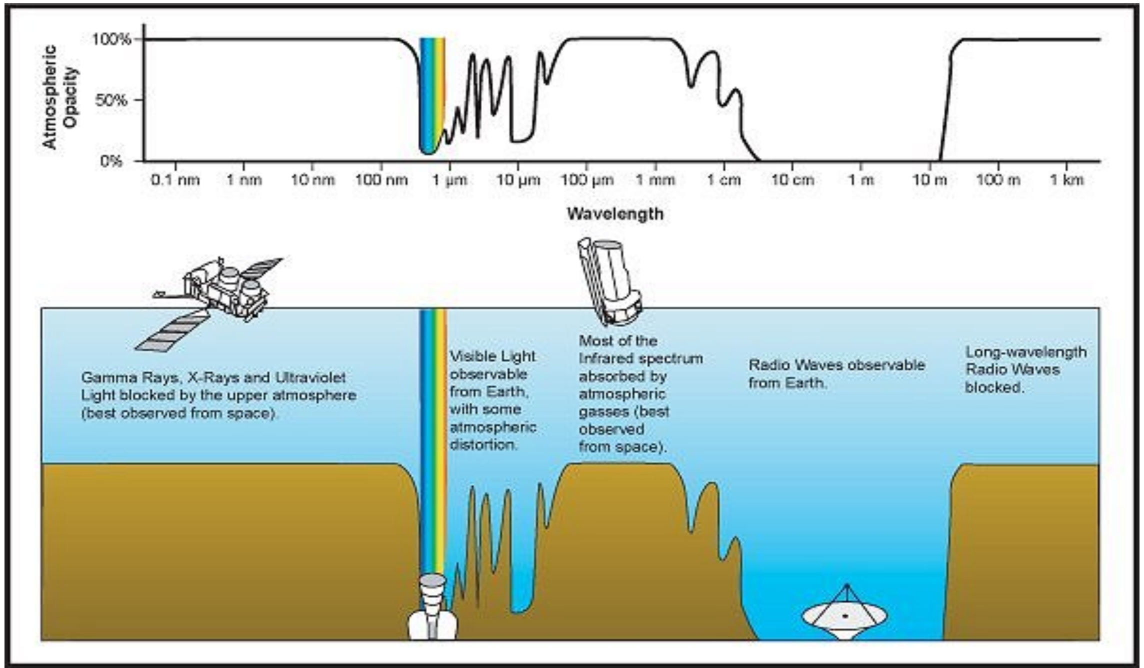
SN1997ff
z~1.7 or 10Gly –
one the of Sne that
revealed Dark Energy




How did our Milky Way get to be the way it is?
© 2000, Axel

PHYS2160 – Lecture 1 – Our Galaxy: Fundamentals

Electromagnetic radiation (i.e. photons) provides pretty much all the information astronomers can access about the Universe beyond our Solar System.



coolcosmos.ipac.caltech.edu

From the ground, there are limited regions of this spectrum that we can access

UV/Optical-to-Mid-infrared (300nm – 15um)

Radio – (1mm – 10m)

Everything else has to be done from space

PHYS2160 – Lecture 1 – Our Galaxy: Fundamentals

Define some quantities

Apparent brightness, or flux, *f* is the total energy received per unit time per unit collecting area integrated over a given energy range

Common units for *f* are the

Janky (Jy) = 10^{-26} W m^{-2} Hz^{-1} (common in radio astronomy) or

erg cm^{-2} s^{-1} (an optical astronomy flux scale.)

In optical astronomy we more commonly use the logarithmic “magnitude” system, where the flux ratio f_1/f_2 between two objects related to the magnitude difference between m_1 and m_2 as follows:

$$m_1 - m_2 = -2.5 \log10 (f_1/f_2)$$

Beware the minus sign! *Larger* magnitudes means *fainter* objects.

This system is admitted to be a historical hangover – arising from the fact our eye registers light on a logarithmic scale. However it has some useful features

f ratio factor of 10 => 2.5 mag, *f* ratio factor of 2 => 0.753 mag

f ratio factor of 10% => 0.1 mag, *f* ratio factor of 1% => 0.01 mag

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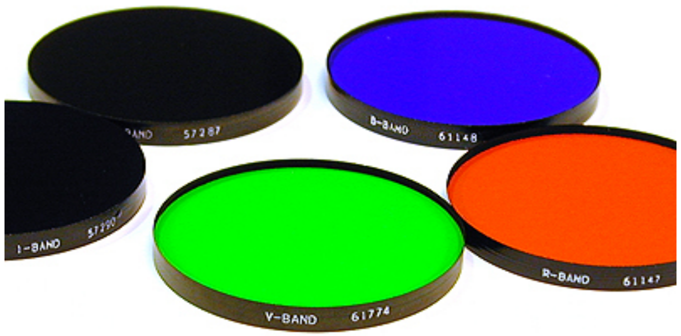
The previous flux and magnitude definitions referred to energy "integrated over a given energy range". What does that mean?

Usually, it means you have done your observations through a standardised filter, chosen to cover useful wavelength ranges, and defined your "zero point" using a standard A0 star – Vega.

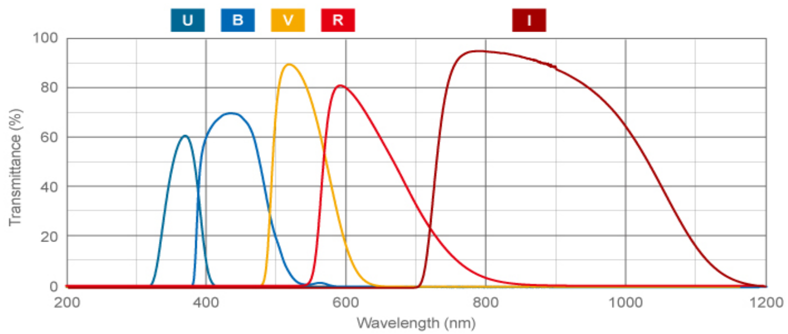
For each filter, there will be a flux F_0 that corresponds to zero magnitude in that filter.

Band[1]	$\Delta\lambda$ μm	λ_{eff} A0	F_0 Janskys
U	0.325–0.395	0.366	1,181
B	0.39–0.49	0.44	4,520
V	0.50–0.59	0.542	3,711
R	0.565–0.725	0.638	3,180
I	0.73–0.88	0.787	2,460
J_{CIT}	1.16–1.35	1.22	1,568
H_{CIT}	1.49–1.80	1.63	1,076
K_S	2.00–2.30	2.15	650
K_{CIT}	2.02–2.43	2.19	674
L_{CIT}	3.24–3.73	3.45	281
L′	3.52–4.12	3.80	235
M	4.5–5.05	4.75	154

Table adapted from Reid & Hawley (2005, p20, above) summarising filter band-passes and zero-point fluxes for some common filters. Figure below.



Example optical filters



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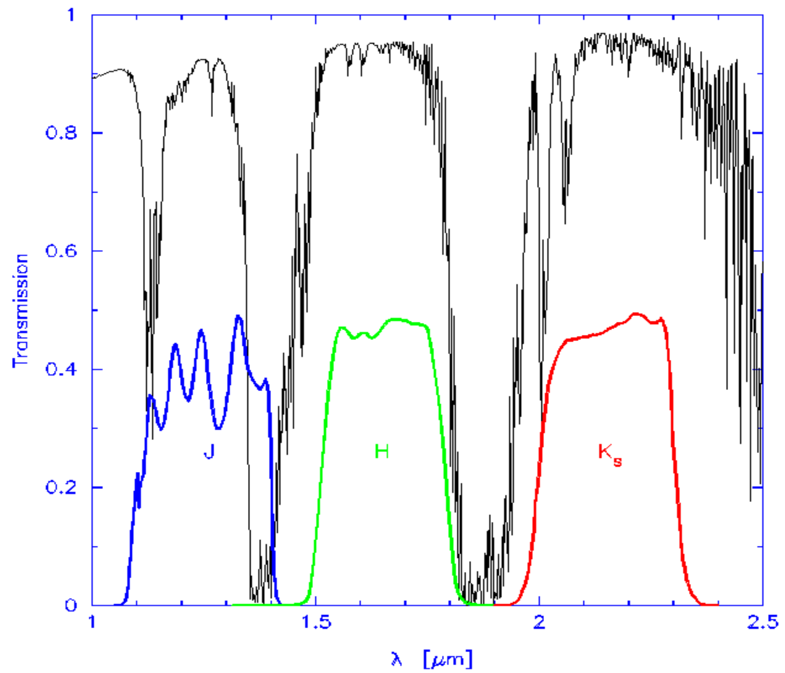
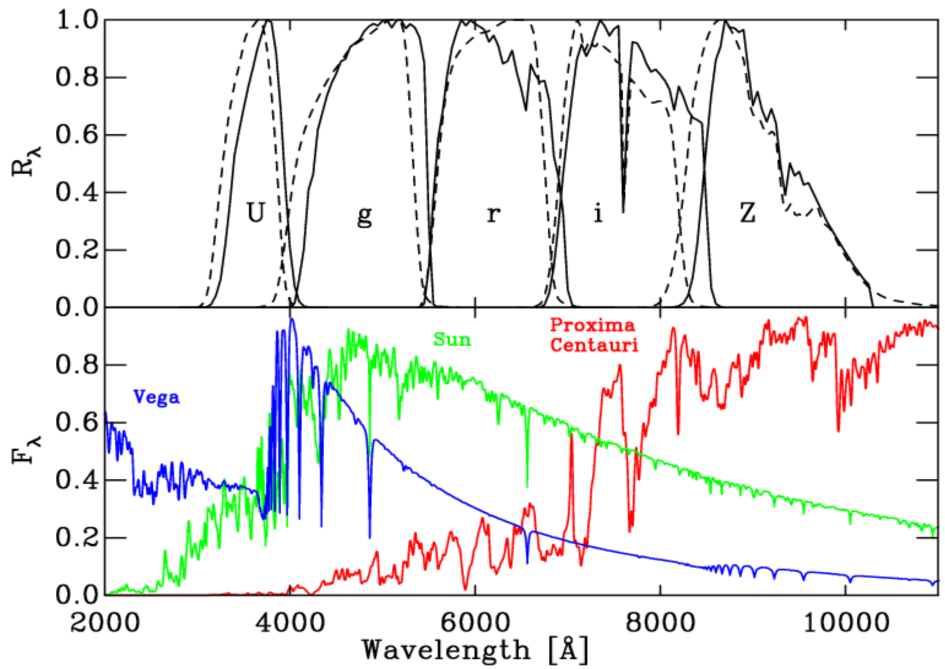
"Useful" here can mean either that it's a wavelength range that sits in a gap in the atmospheric transmission (e.g. in the infrared), or because it probes useful quantities in the stars in question



Near-infrared filters (colours) tuned to match gaps in sky transmission (black line)



Vega 9600K Sun 5800K Prox Cen 3000K

UgriZ optical filter system (black solid) showing how they probe spectral differences for different types of stars (Bell et al. 2012, arXiv:1206.2361)

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More quantities

Luminosity (L) and flux (*f*) in a given band-pass are related by distance (d)

$$L = f \,.\, 4\pi d^2$$

If you integrate the total flux from an object over all wavelengths, you get the *bolometric luminosity* L_{bol}, meaured in units with dimensions of energy per unit time (e.g. erg s^{-1}, J s^{-1}, or W)

We also define the magnitude version of luminosity the *absolute magnitude* M, which is the magnitude a star would have if it were at a standard distance, chosen to be 10 parsecs (10pc).

1pc = 3.26 light years = 3.086×10^{16}m

…. we'll come back to why this unit of the parsec is what it is later.

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More quantities

From the previous equation defining the magnitude scale, this gives us

$$m - M = 2.5 \log[(L/10^2) / (L/d^2)] = 5 \log d - 5$$

This difference m-M is known as the *distance modulus*.

Some examples – in the V (or “visual”) passband the Sun has $m_\odot = -26.78$, $M_\odot = 4.82$.

The Sun’s total (or bolometric) luminosity is

$L_{bol} = 3.86 \times 10^{33}$ erg s^{-1},

$m_{bol\odot} = -26.85$, $M_{bol\odot} = 4.75$.

Some easily observed objects in the sky

m(Venus) = -4.4, m(Sirius) = -1.4, m(alpha Cen) = -0.27

The faintest objects currently detected are at ~30^{th} mag in the Hubble Space Telescope Ultra-Deep Field … 10^{12} times fainter than alpha Cen.

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Why the parsec? The *only* fundamental distance measure in astronomy is trigonometric parallax. It is used to define our fundamental unit of distance – the parsec

For the *very* small angle π

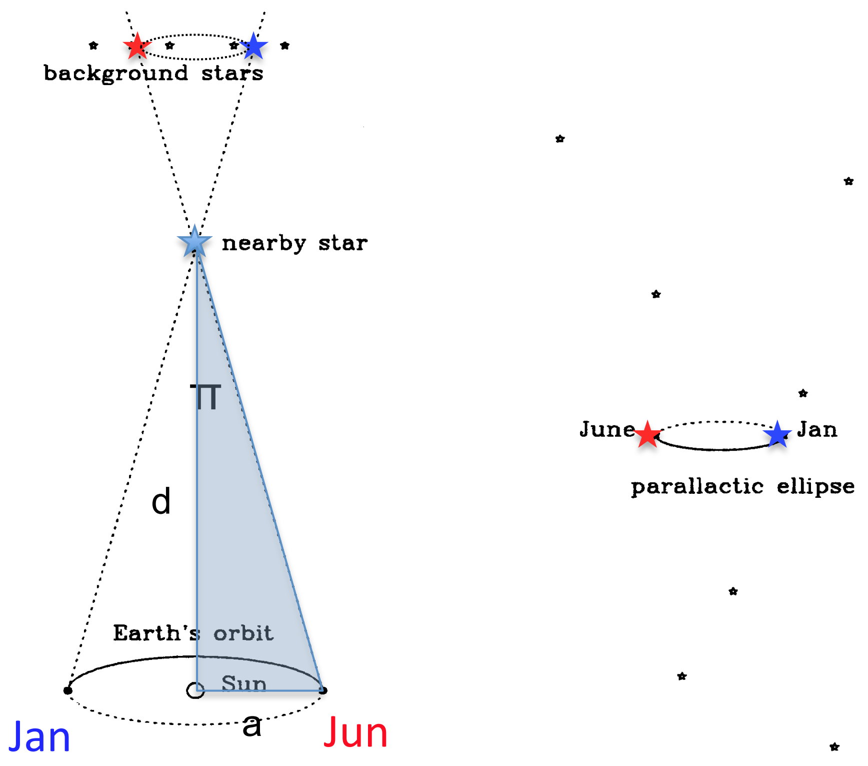
$\pi = \mathrm{Tan}(\pi) = a/d$

For scale – the nearest star to the Sun as a parallax π of 0.75”

[cf. 1degree(°) = 60 arcminutes(’)
= 3600 arcseconds (“)]

We define our basic distance unit, the parsec (pc), as the distance at which an object has a parallax of 1”.

Current limits for parallax measurement are about 0.001” (or 1 milliarcsecond or 1mas)



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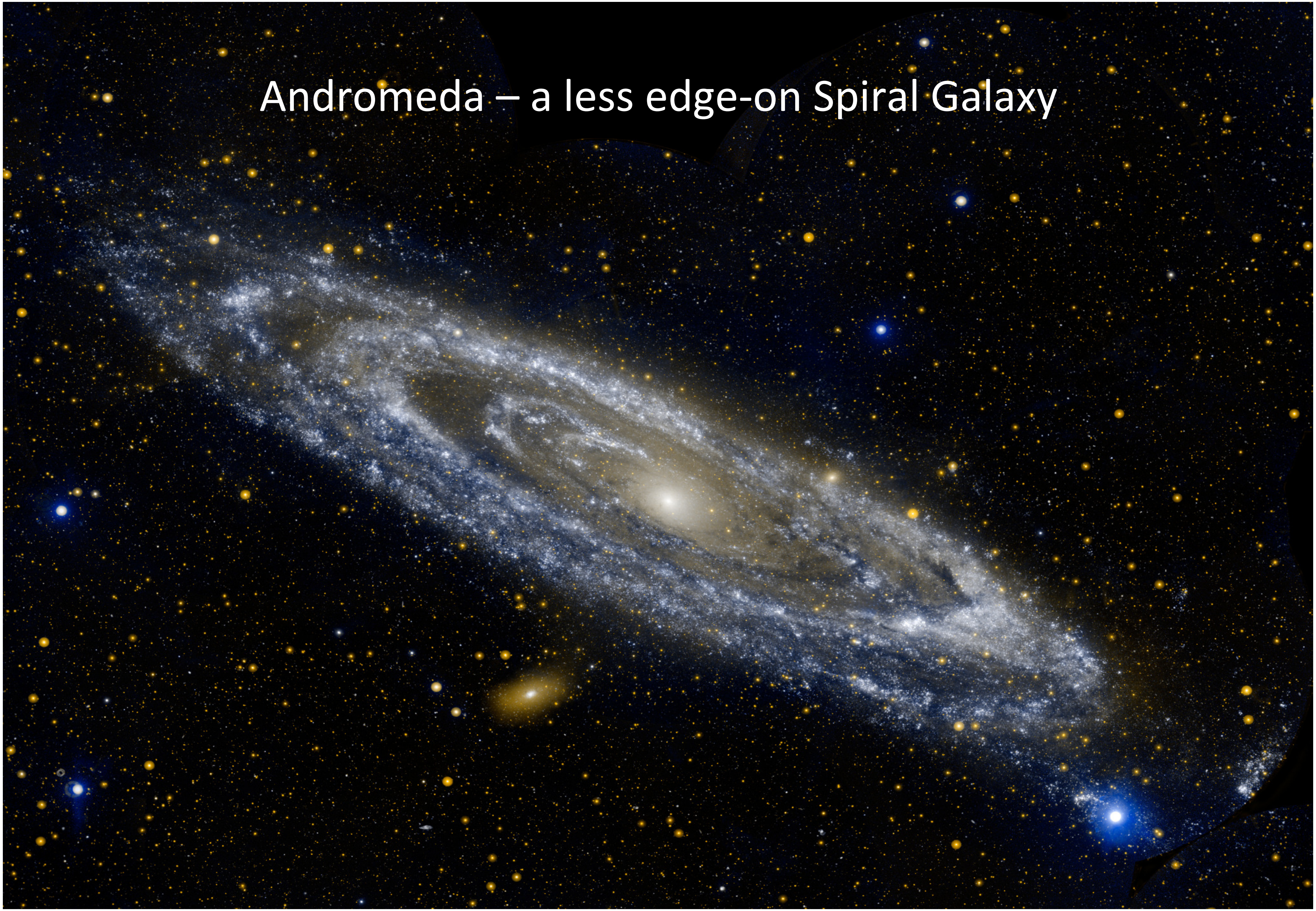
Our Galaxy

When we look up at the night sky, its hard to get a global picture of what the Galaxy looks like … because we are viewing it from the inside.


Our Galaxy
Similar view – but higher in the sky – of the central part of our Galaxy


An external edge-on Spiral Galaxy


Andromeda – a less edge-on Spiral Galaxy

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How (from our position inside the Galaxy) did we work out the Galaxy has this shape?

Early astronomers counted stars in different directions on the sky and concluded that they were the same in all directions, so we must lie in the centre of the visible Universe.

William Herschel (1738-1822) built some of the world's first truly large large telescopes, and used them to make two critical discoveries. First - that there are a great many "fuzzy patches" called nebulae, many of which we know today as "galaxies". And second, he recognised that we live in a huge collection of stars – the Milky Way.

Herschel tried to measure the approximate distance to as many stars as possible, using the rough approximation that all stars are equally bright. Although we know that assumption to be wrong, it did allow him to estimate the approximate distances to several hundred stars. Most of those stars are located in a circular band around the sky, suggesting that we are located in a disk of stars, with the plane of the disk aligned with the hazy Milky Way. His measurements suggested that the thickness of the disk was about one-tenth its diameter.

An impressive result for someone using just eyes as a detector!

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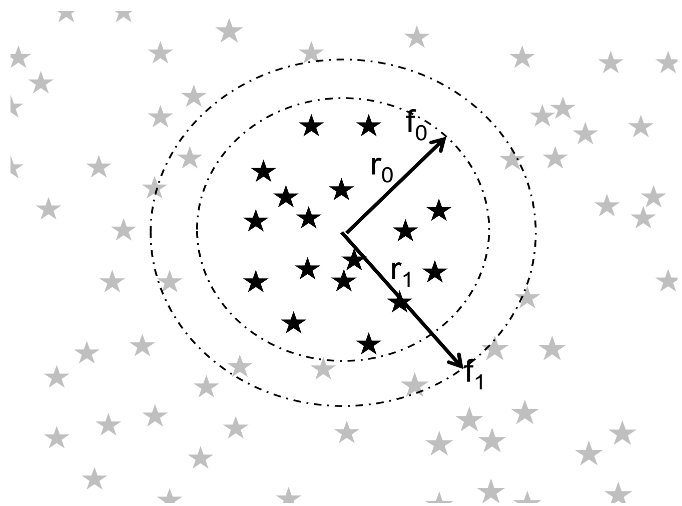
Indeed you can make quite a bit of progress even when you don't know the distances to stars.

If you assume all stars have the same luminosity and are uniformly distributed, then its easy to see that you expect the number of stars brighter than a given flux to scale as that flux limit to the power -3/2.

Imagine observing all the stars out to the distance limit r_0 set by a limiting flux f_0. The number of stars in that sphere of space will be $N_0 = 4/3\pi\ \rho\ r_0^3$, where ρ is the space density of stars. If the flux limit is halved (to see fainter and more distant stars) then the distance limit for detection becomes $r_1 = \sqrt{2}\, r_0$, so the volume (and so the number of stars N_1 at flux limit $f_1=f_0/2$) increases by $(f_1/f_0)^{3/2}$



Actual star count experiments (e.g. work by Kapteyn starting in 1906 by counting numbers of stars as a function of brightness) do not see this – star counts grow much more slowly than the 3/2th power, telling us that the universe is not uniformly filled with stars. And indeed the 'thinning' out is also not uniform, confirming the idea that the Galaxy is a flattened disk.

(Actual stars are not all the same brightness … but this doesn't matter in this case. Why? See next page)

But where does the Sun lie in this disk? At the centre? At the edge?

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Let $n(L)$ be the number density of stars with luminosity L. Assume $n(L)$ is spatially uniform. The observed brightness is

$$f_o = \frac{L}{4\pi r_o^2}$$

The number of stars with luminosity L with apparent brightness $f > f_o$ is

$$N_L(f > f_o) = n(L)\frac{4}{3}\pi r_o^3$$

Substitute for r_o from the first equation above, to get

$$N_L(f > f_o) = n(L)\frac{L^{3/2}}{3(4\pi)^{1/2}} f_0^{-3/2}$$

The *total* number of stars with $f > f_o$ is then

$$\begin{aligned} N(f > f_o) &= \int_0^\infty N_L(f > f_o)dL \\ &= f_0^{-3/2}\int_0^\infty \frac{n(L)L^{3/2}}{3(4\pi)^{1/2}}dL \\ &= Af_o^{-3/2} \end{aligned}$$

Thus, if we see 1000 stars down to a limiting brightness f_o, we should see $1000 \times 4^{3/2}$ down to $f_o/4 = 8000$ stars.

Tutorial exercise to reproduce, understand and explain this.

But where does the Sun lie in this disk? At the centre? At the edge?

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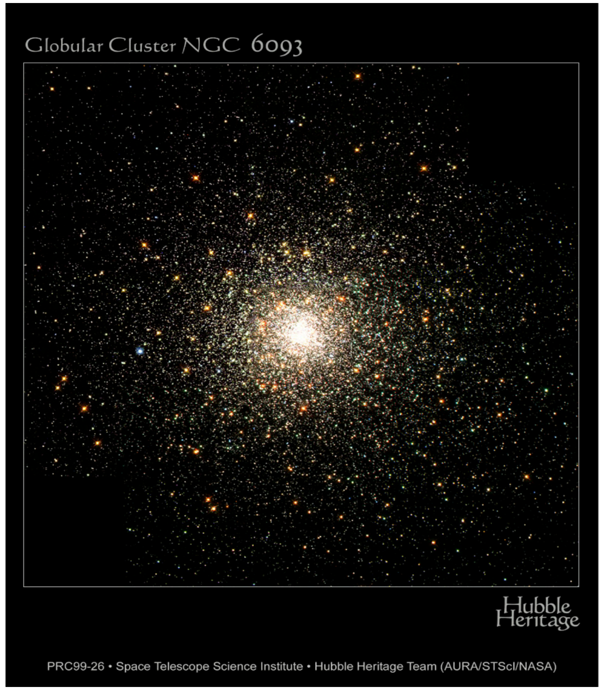


Globular Clusters

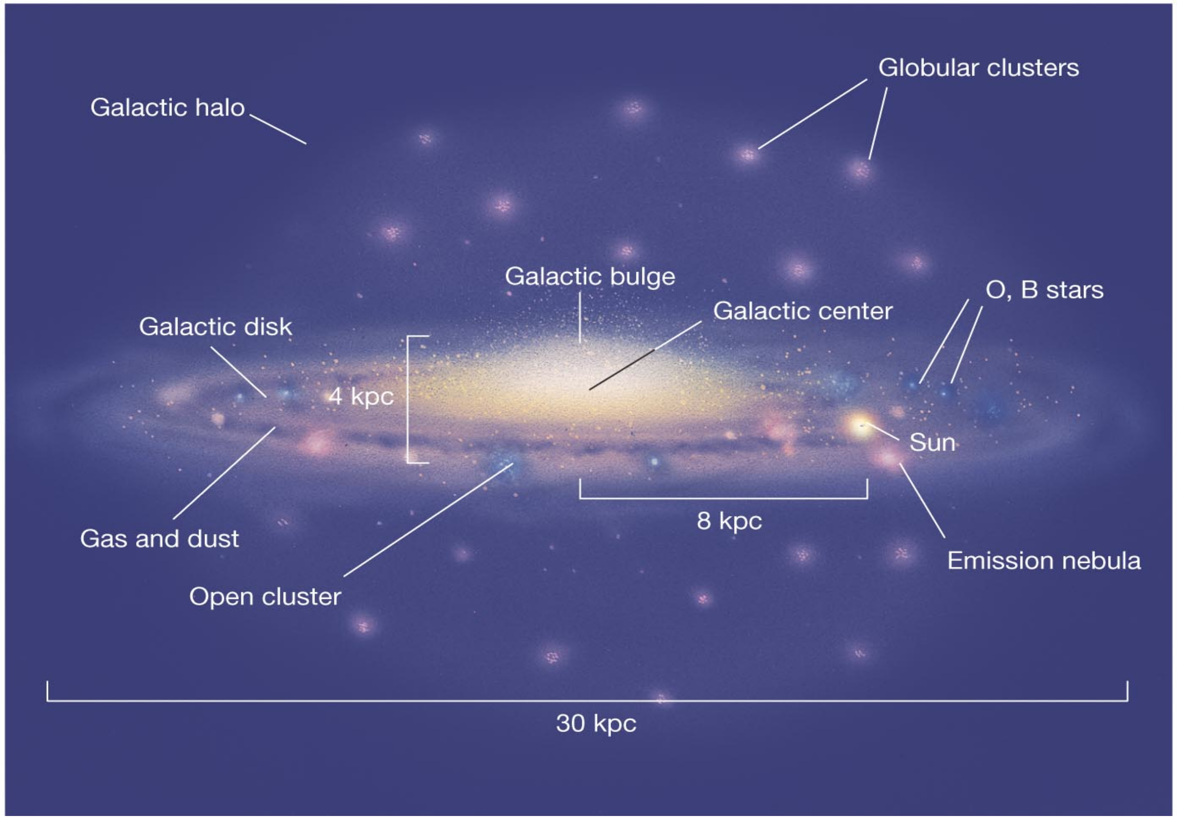
- Spherical agglomerations of 10^5-10^6 stars
- Among the first nebulae seen by Herschel.
- Around 200 associated with Galaxy
- Lie at great distances from the Sun, so can be seen even when they reside on the other side of the Galaxy.

You can estimate distances to them using a variety of techniques (assuming same size, comparing magnitudes of certain types of *variable stars*). From 1914 onwards Shapley studied globular clusters and found them to be highly asymmetric relative to the position of the Sun. He therefore used them to define a position for the Galactic Centre, which has the Sun far from the centre of the Galaxy.

The reason Shapley & Kapteyn got such different answers is that star counts can not probe to the centre of the Galaxy. *Extinction* by clouds of dust along the plane of the Galaxy obscures the Galactic Centre, and means star counts just can't probe the whole Galaxy's structure.

Globular clusters reveal the Sun lies ~8kpc from the Galactic Centre (8.3±0.3kpc is a recent determination by Gillessen et al. 2009, ApJ, 692, 1075)

The Slightly-less Schematic Milky Way Galaxy



Disk – stars (young and middle-aged like Sun), gas, dust

Central Bulge – stars (but largely hidden from view in the MW).

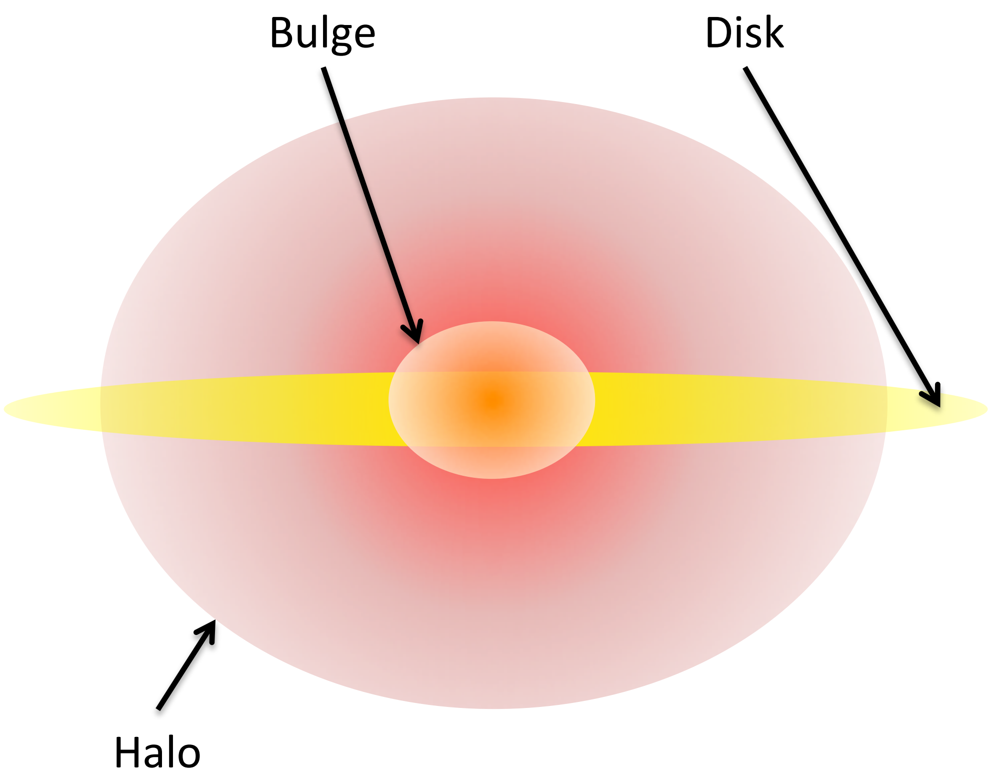
Halo – globular clusters and old stars (which are asymmetric relative to the Sun)

The Sun orbits at 8kpc with velocity 220 km s^{-1}.

Galactic 'year' ~230 Myr.

Mass of Galaxy ~ $6 \times 10^{11} M_{\odot}$.

The Schematic Milky Way Galaxy



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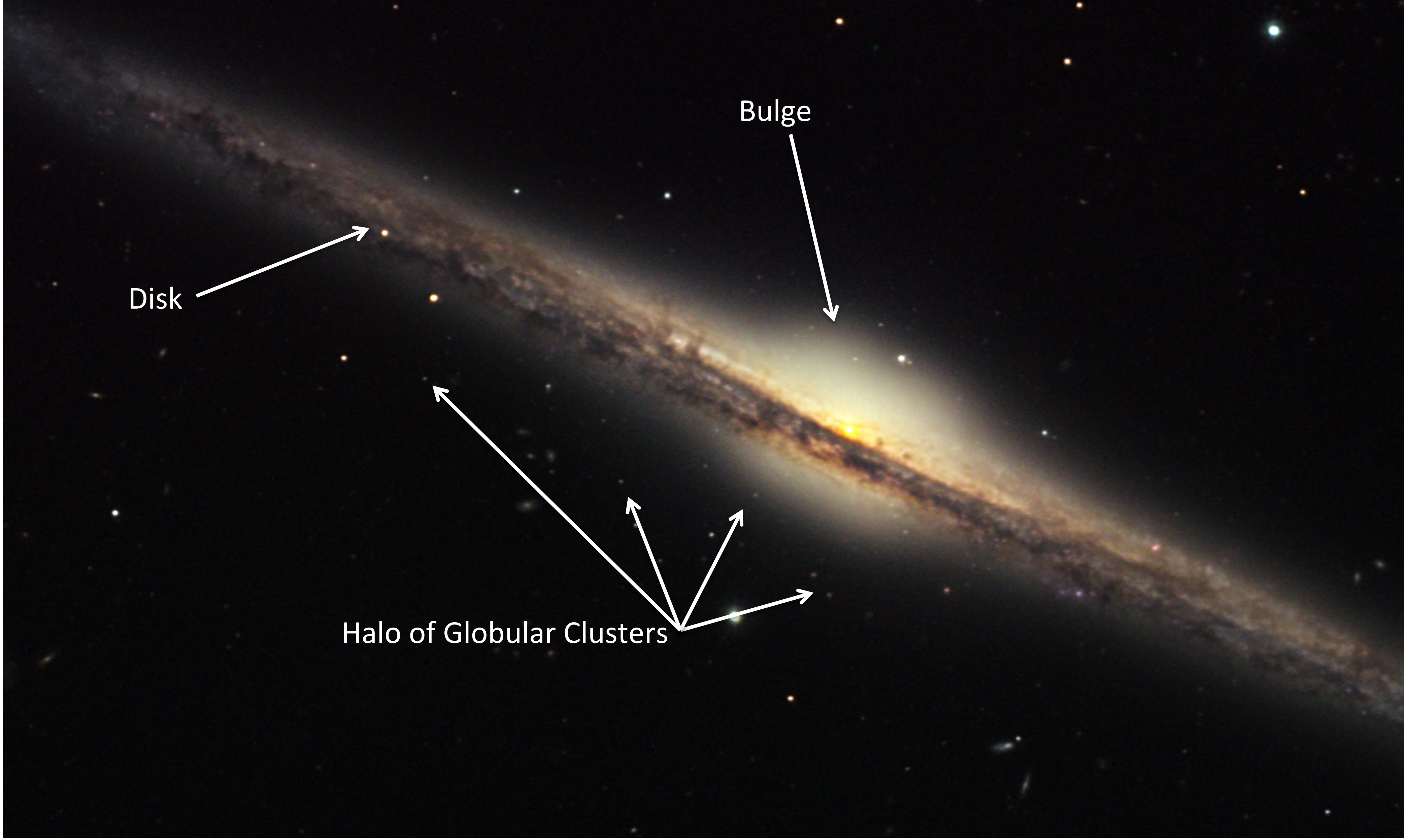
Same in an external edge-on Spiral Galaxy



Are you interested in contributing to the improvement of teaching in Physics? Ensuring that the opinions of students are heard?
Become a course representative.

What's a course representative?

- A student who acts as a liaison between the students in a course and the School of Physics Teaching Committee. This may include meeting with the Committee to provide general feedback; or passing on student problems or complaints.
- We would like one representative from every undergraduate physics course.

How to nominate:

- Send an email with your name, student number and course code to Sue Hagon s.hagon@unsw.edu.au by Sunday 2 August. If more than one student nominates in a course, we will organize a vote.

UNSW Science Student Research Expo

http://www.science.unsw.edu.au/svrs

View this email in your browser

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Student Research Expo

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Summer Vacation Research Scholarships

The Faculty of Science at UNSW offers a number of highly competitive summer research scholarships to currently enrolled undergraduate students who are considering to continue their studies at postgraduate research level in the future.

This Scheme will enable students to gain valuable research experience. Students will be supervised by our international team of academics at state of the art research facilities at UNSW or through our industrial partners.

PHYS2160 – Lecture 1 – Our Galaxy: Fundamentals

- References
  - Reid, I.N. & Hawley, S. "New Light on Dark Stars", Springer, 2005
- Bibliography
  - Shu, F. The Physical Universe, Chapter 12, p255-258 (can be found on google books)
  - Reid, I.N. & Hawley, S. "New Light on Dark Stars", Springer, 2005, Chapter 1-1.2, 1.3.2, 1.5-1.5.1

Useful constants, units, and formulae:

Gravitational constant	G	=	6.67	×	10^{-11}	N m^2 kg^{-2}
Speed of light	c	=	3.00	×	10^{8}	m s^{-1}
Planck constant	h	=	6.626	×	10^{-34}	J s
Boltzmann constant	k	=	1.38	×	10^{-23}	J K^{-1}
Stefan-Boltzmann constant	σ	=	5.67	×	10^{-8}	W m^{-2} K^{-4}
Mass of the hydrogen atom	m_H	=	1.67	×	10^{-27}	kg

Solar mass	$M_\odot$	=	1.99	×	10^{30}	kg
Solar radius	$R_\odot$	=	6.96	×	10^{8}	m
Earth mass	$M_\oplus$	=	5.98	×	10^{24}	kg
Equatorial radius of Earth	$R_\oplus$	=	6.378	×	10^{6}	m
Mass of moon	M_{moon}	=	7.3	×	10^{22}	kg
Astronomical unit	AU	=	1.496	×	10^{11}	m
Parsec	pc	=	3.086	×	10^{16}	m
Hubble's constant	H_0	=	70			km s^{-1} Mpc^{-1}

Distance modulus	$m - M$	=	$5 \log d - 5$ (d in pc)
Apparent magnitude	$m_2 - m_1$	=	$2.5 \log \frac{f_1}{f_2}$
For small recession velocities	v/c	=	$\Delta\lambda/\lambda$
Definition of redshift	$(1+z)$	=	$\lambda_{obs}/\lambda_{rest}$
Energy and frequency	E	=	$h\nu$
Frequency and wavelength	c	=	$\nu\lambda$