Galaxy Formation and Evolution

Lecture 5:
Survey Astronomy

Course contents

1. Historical introduction
2. Challenges and recent advances
3. Galaxy formation in theory
4. Spectral synthesis and star formation indicators
5. The fossil record for local galaxies
6. Survey astronomy
7. The Madau Diagram and Lyman Break galaxies
8. Studying galaxy evolution in the IR/sub-mm
9. The evolution of early-type galaxies
10. Morphological evolution and spiral galaxies
11. AGN discovery and observed properties
12. AGN unification and energy sources
13. Black hole growth and formation
14. The triggering of AGN
15. AGN feedback and outflows
16. The link between star formation and AGN activity
17. The far frontier and outstanding challenges
18. The future of the Universe

By the end of this lecture:

You should have an understanding of:

- why we conduct extragalactic surveys;
- the different survey strategies, and why we use them;
- how survey fields are selected for observations;
- the multi-wavelength aspect of surveys;
- the pros and cons of survey science;
- some of the key results from extragalactic surveys.

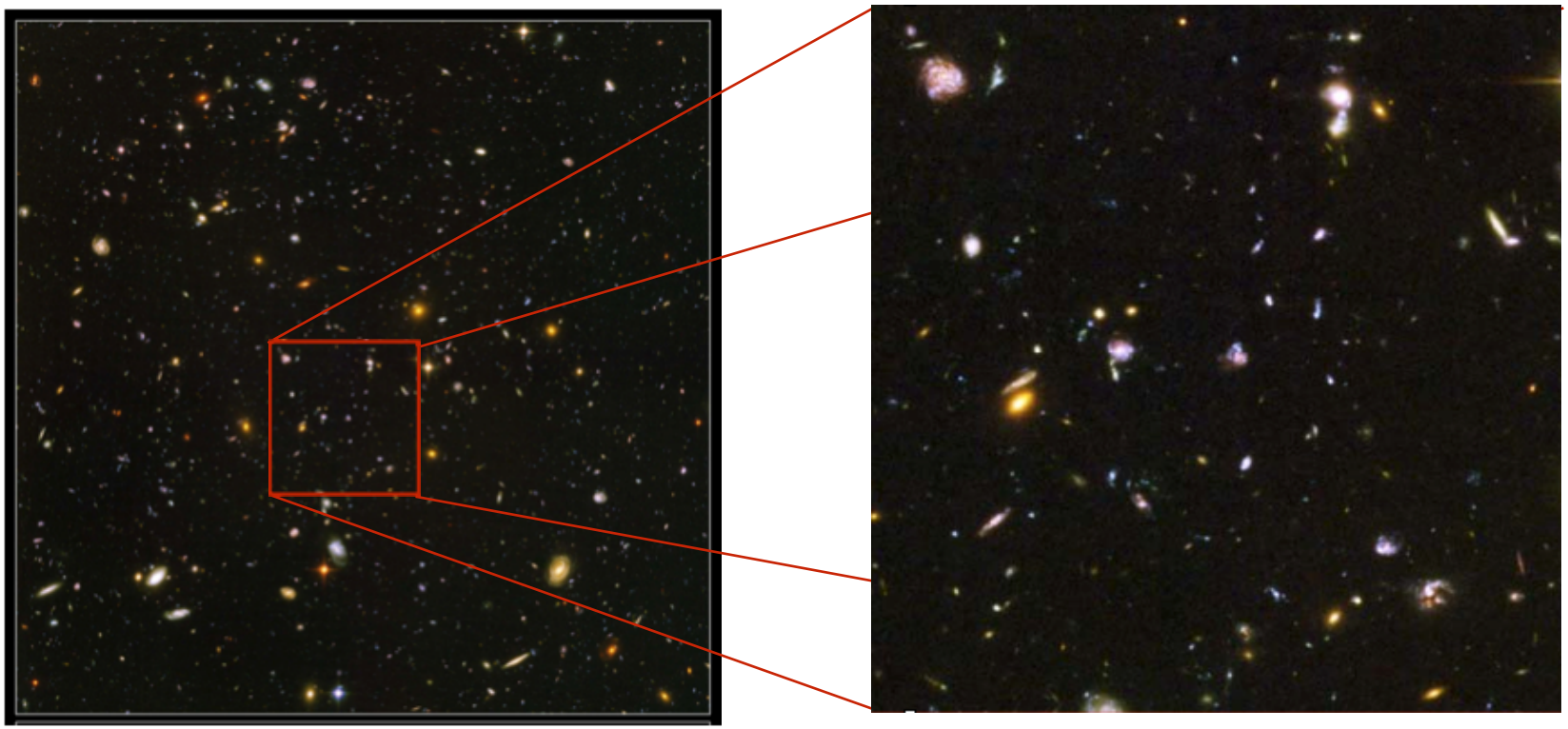
Extragalactic Surveys

What are they?

- Any sample of galaxies that meet some selection criteria.

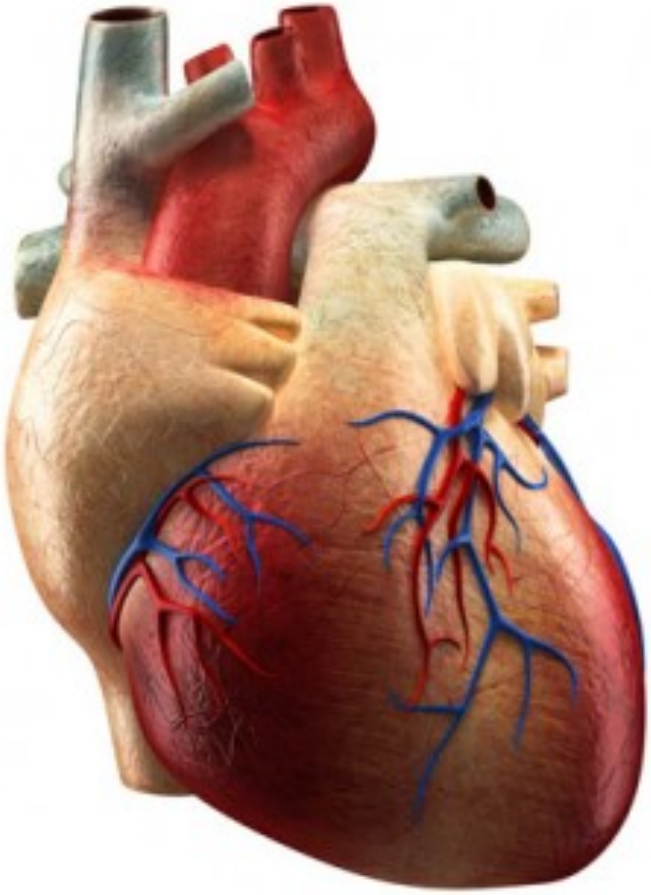
For the purposes of this lecture, selection criteria:

- Detected in a contiguous field of the sky.

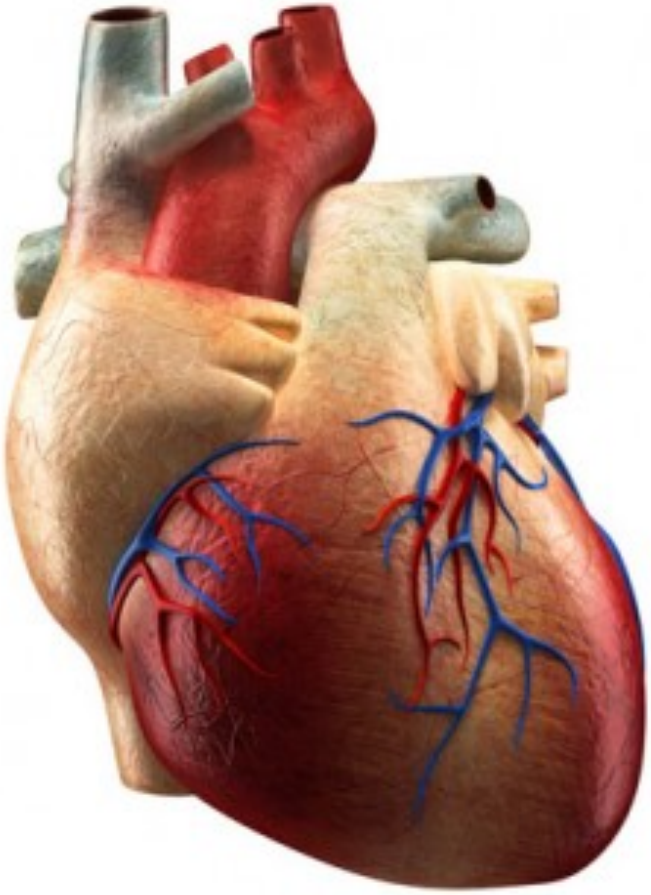


The Hubble Ultra Deep Field

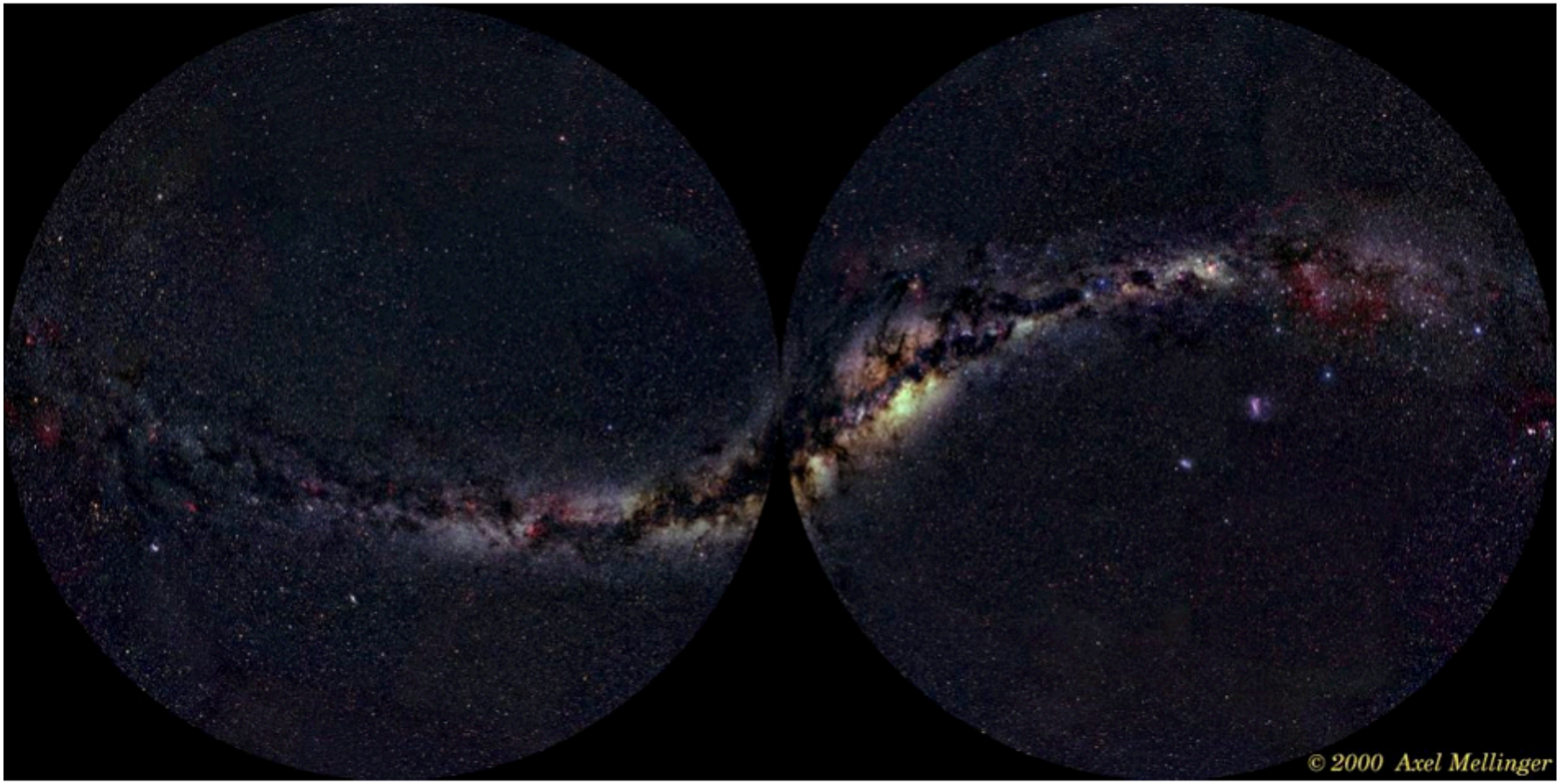
Survey Philosophy



Survey Philosophy



Survey Strategies



Ideally, we'd survey the whole sky to very "deep" levels.
But, impractical and inefficient use of telescope time.

Survey Strategies

Copernican Principle tells us:
"the Universe is the same in all directions"
➡Only need to survey patches of sky to get representative samples.

Q: But, how large an area do we need to survey, and to what "depth" (or sensitivity)??

A: That depends on your science goals.

Survey Strategies

Analogy: Pebbles on a beach

Big, “rare” pebbles → Luminous, rare galaxies

Small, “common” pebbles → Fainter, more common galaxies

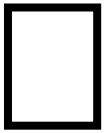
Survey Strategies

Copernican Principle tells us:
"the Universe is the same in all directions"
➡Only need to survey patches of sky to get representative samples.

Science goals dictate size and depth of patch.

Large area:
Good for:
- rare, extreme galaxies.
- sampling large-scale structure.

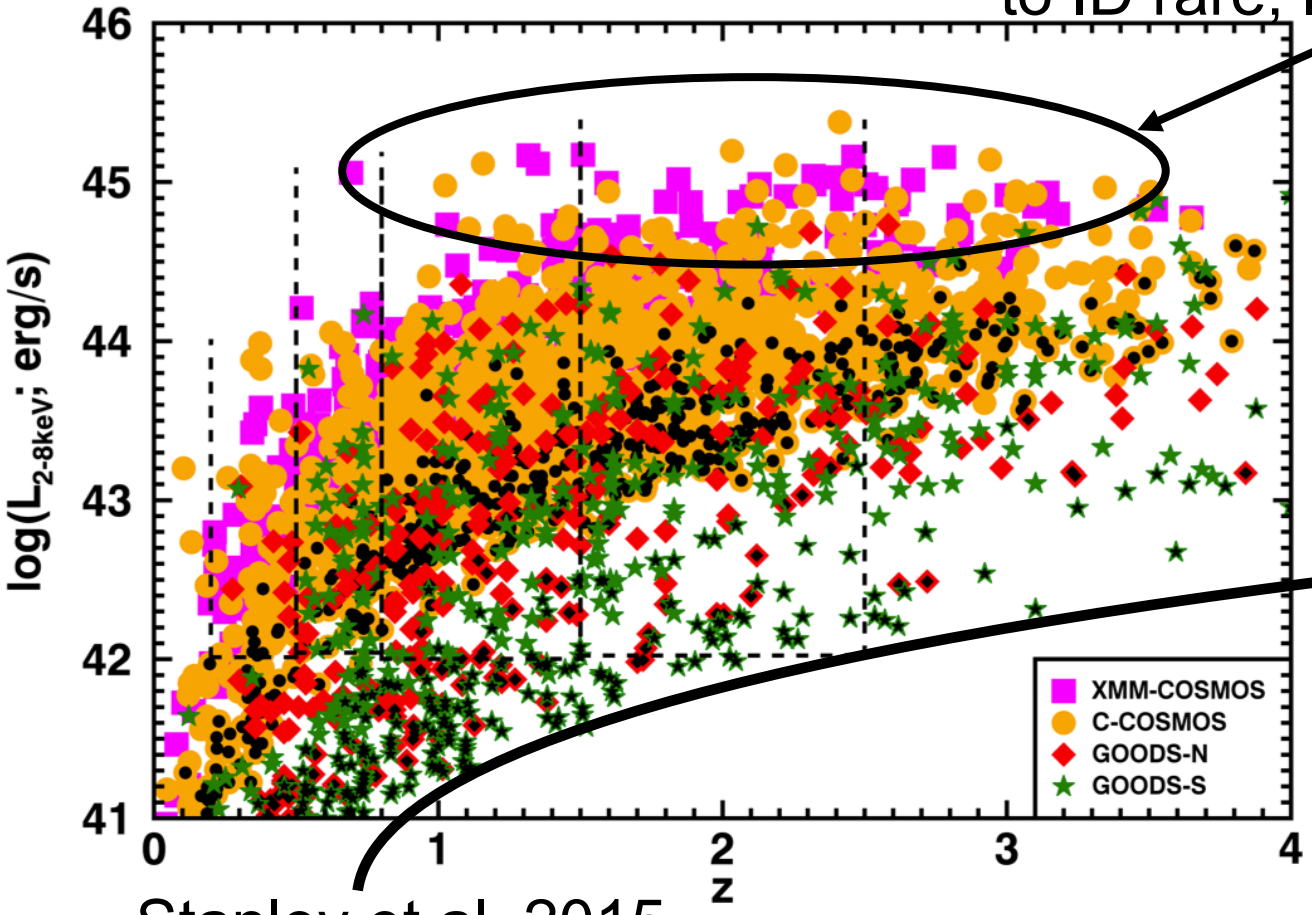
Less good for:
- common, fainter galaxies

Small area: 
Good for:
- common, fainter galaxies.

Less good for:
- large-scale structure
- rare, extreme galaxies

Survey Strategies

Need wide area surveys to sample large enough volumes to ID rare, luminous galaxies.

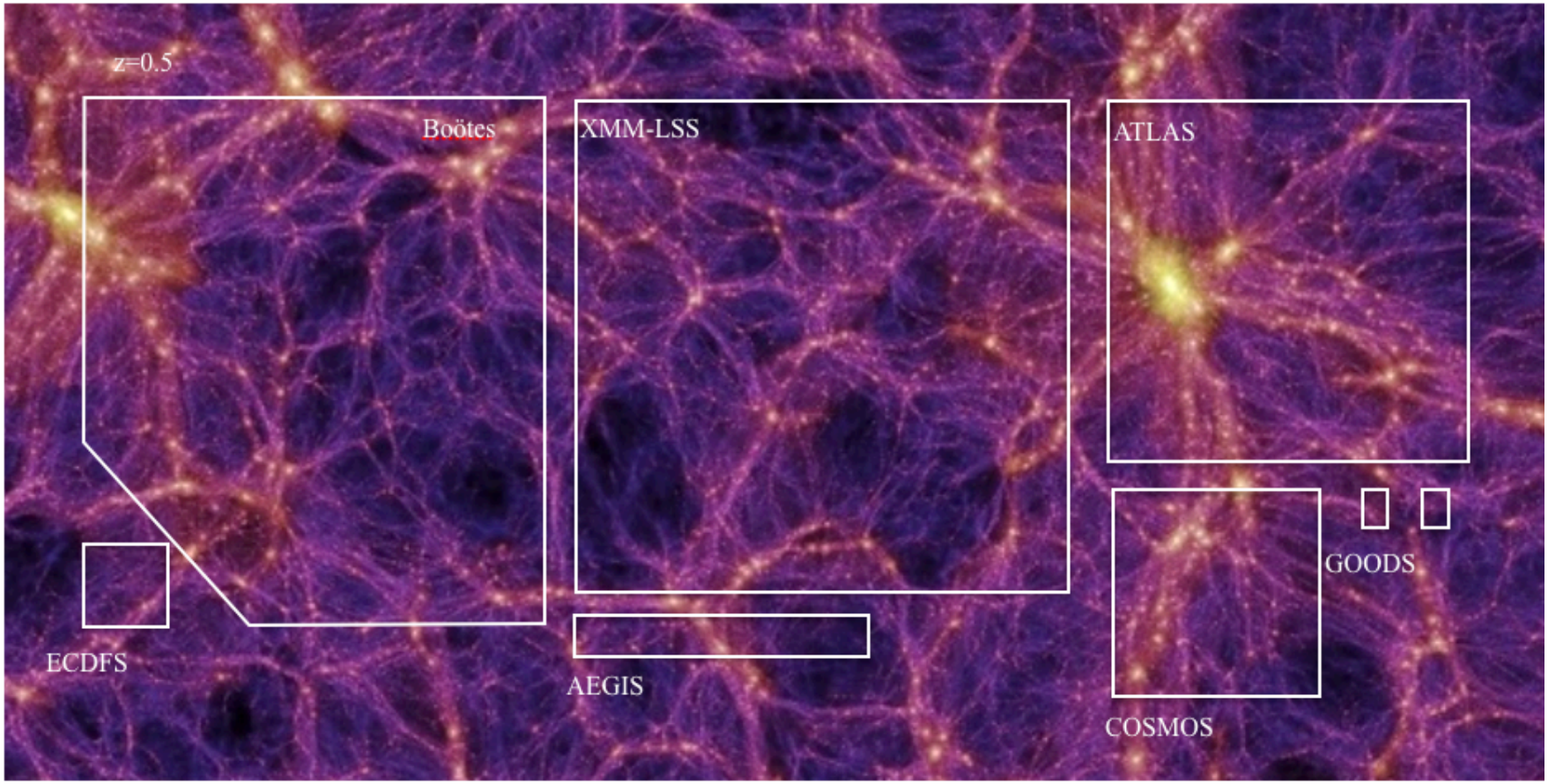


Need deep surveys to survey common, but fainter galaxies.

Stanley et al. 2015

Survey Strategies

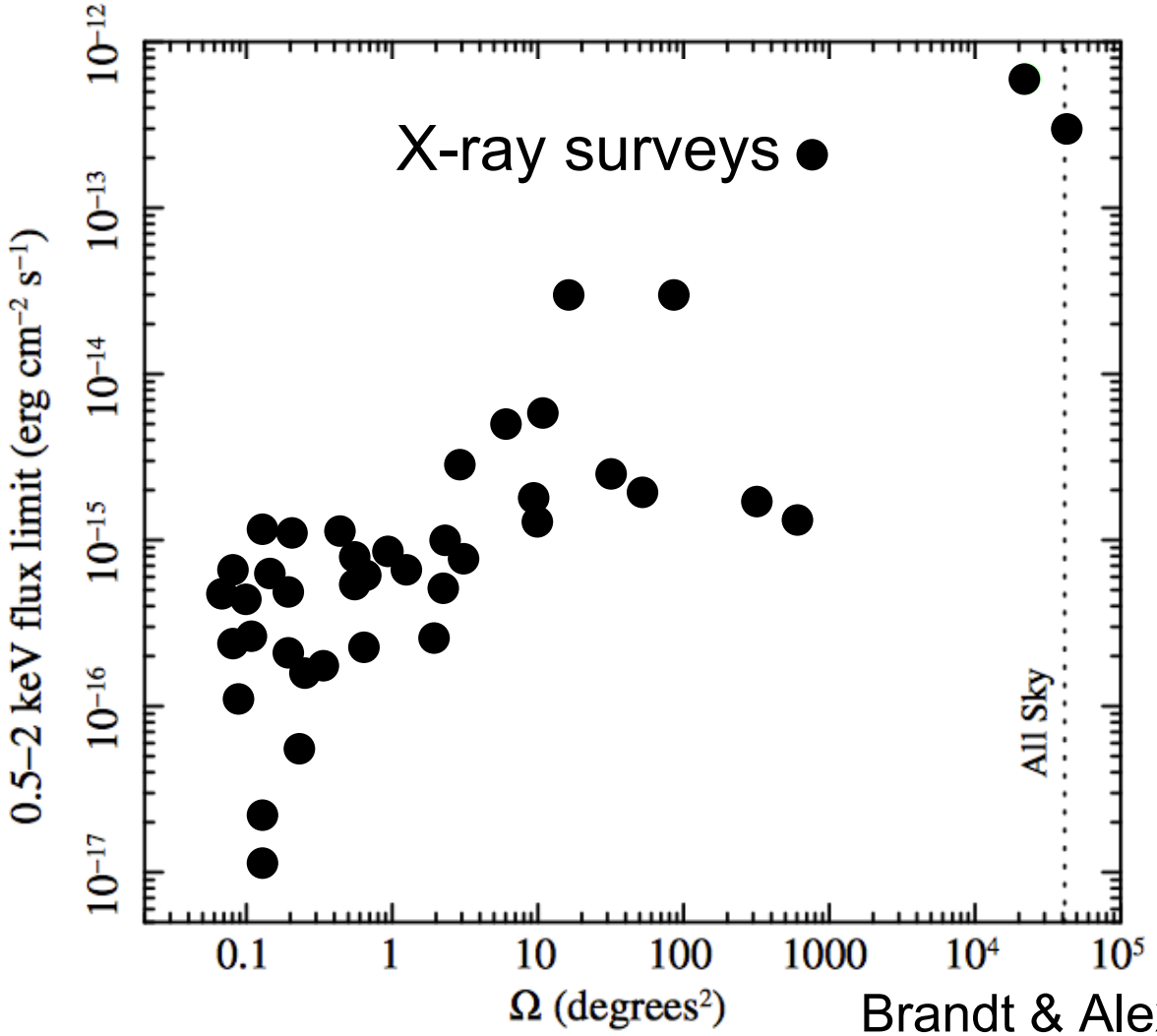
Sampling the large-scale structure with different-sized surveys



Note: Placed side-by-side for comparison - they're not really placed next to each other.

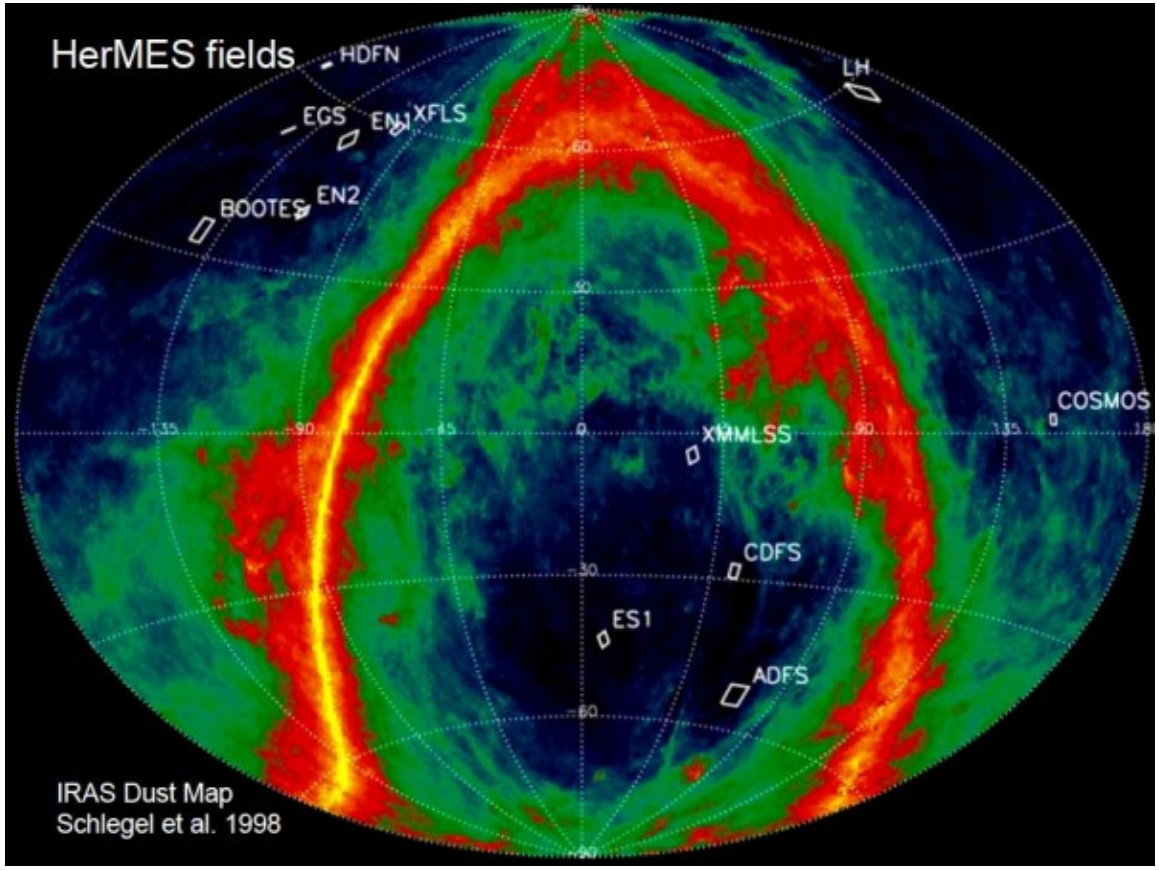
Survey Strategies

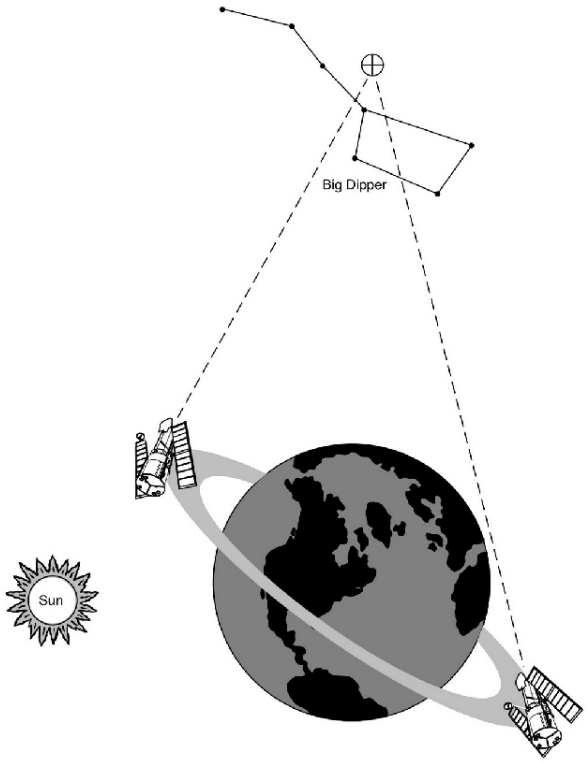
There are now many different extragalactic surveys spanning the area-depth plane.



Brandt & Alexander 2015

Where to survey?

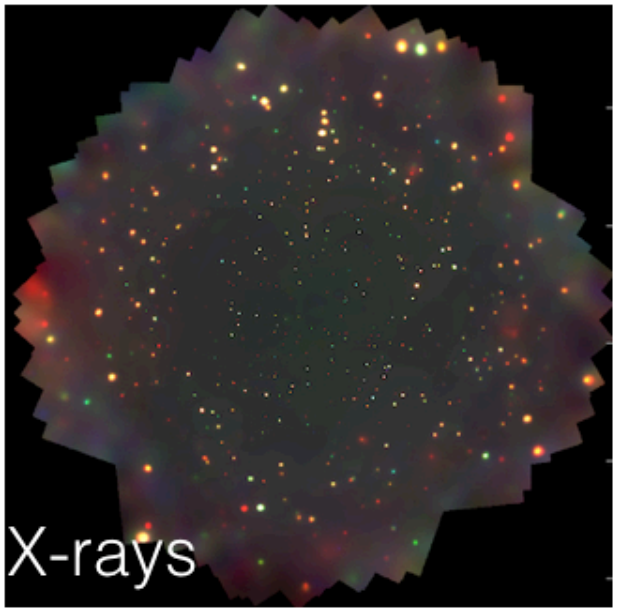


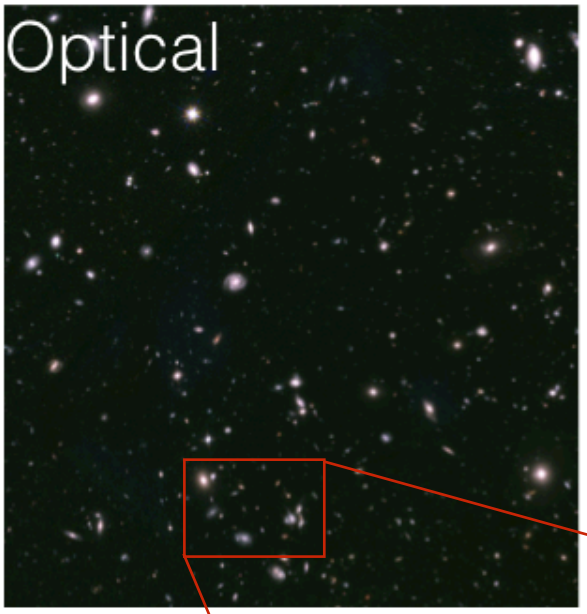


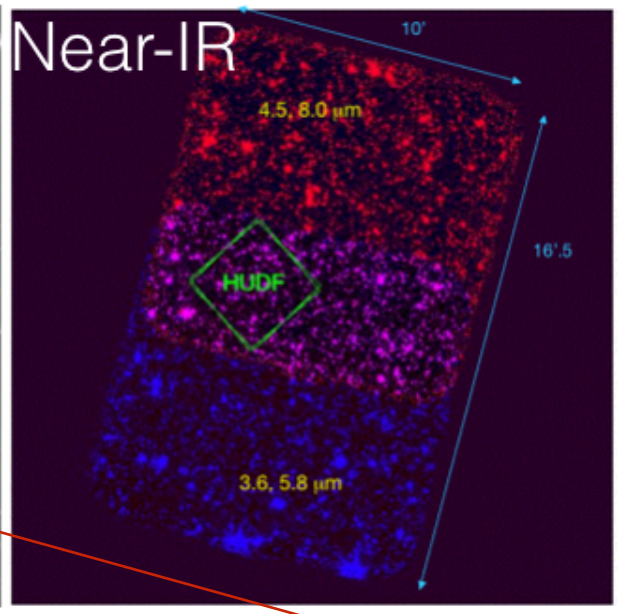
For extragalactic surveys, we need to look outside the Milky Way.

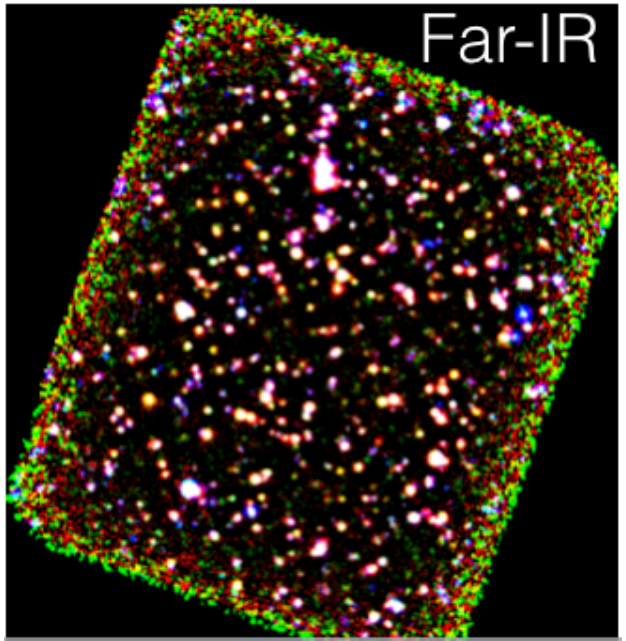
Also, should consider telescope location.

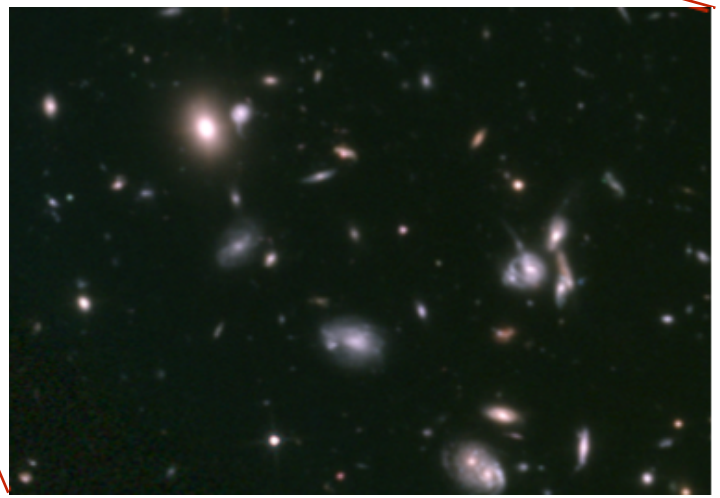
Multi-wavelength surveys



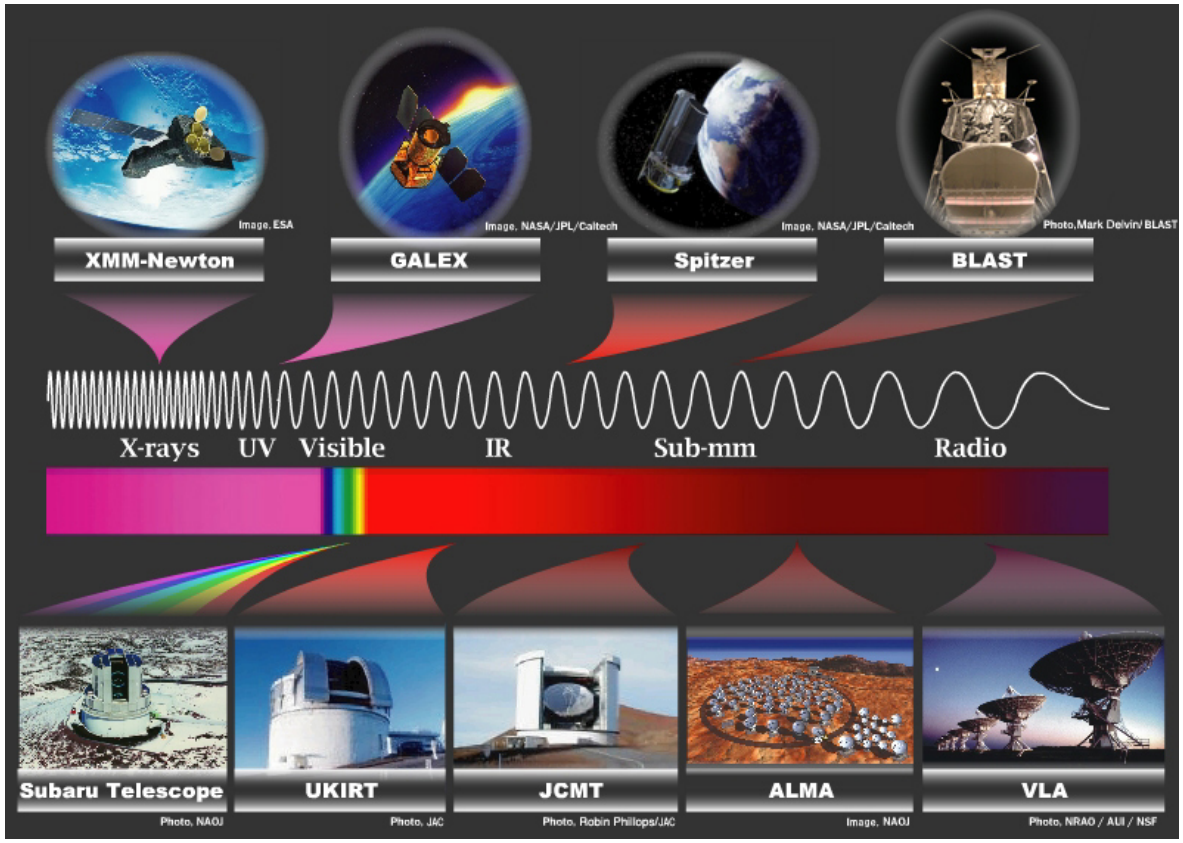








Multi-wavelength surveys



To maximise science output, extragalactic fields are observed at many different wavelengths.

Different wavelengths tell us about different physical properties/processes.

Multi-wavelength surveys

X-rays:

UV:

Optical:

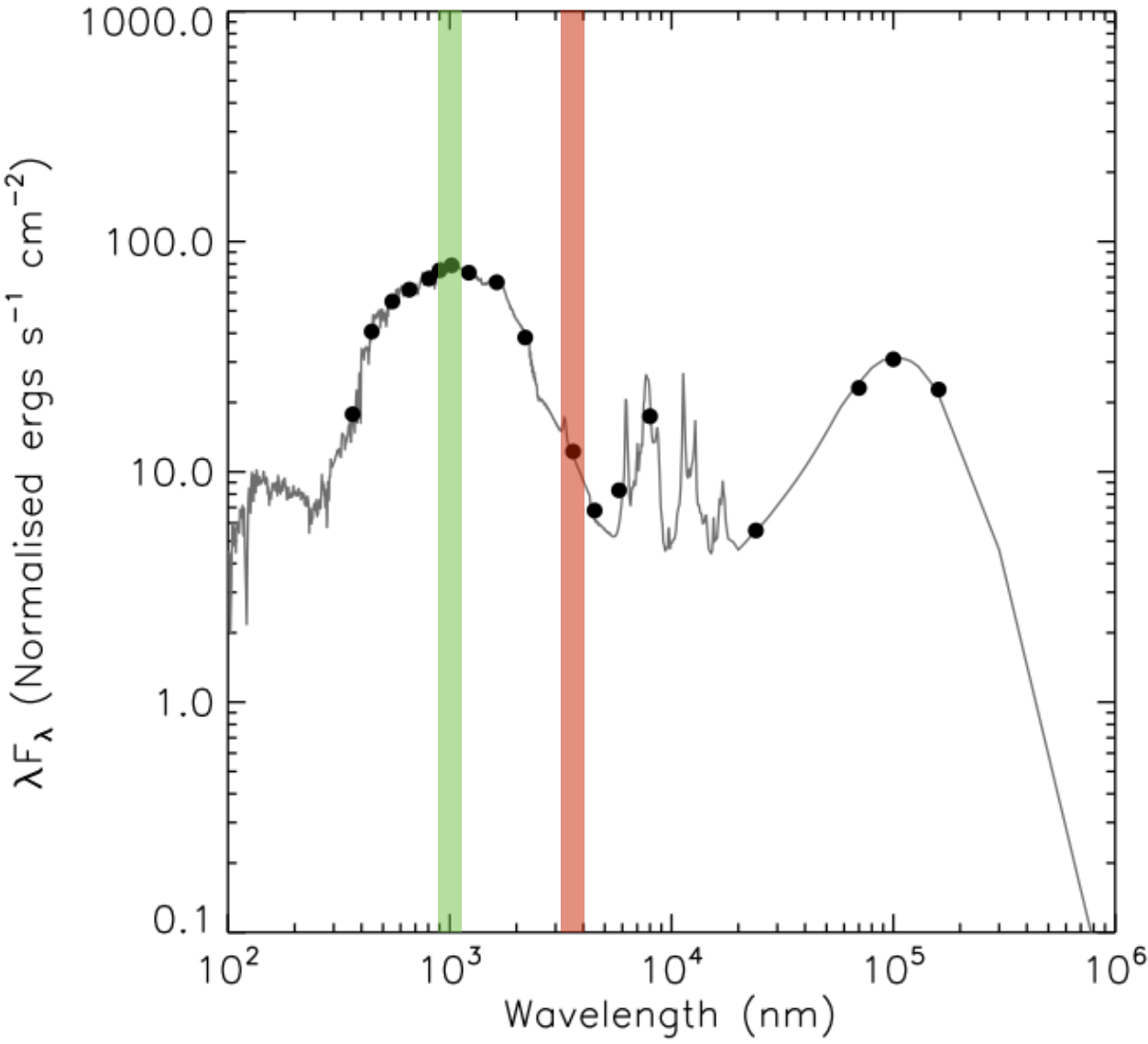
Near-IR:

Mid-IR:

Far-IR:

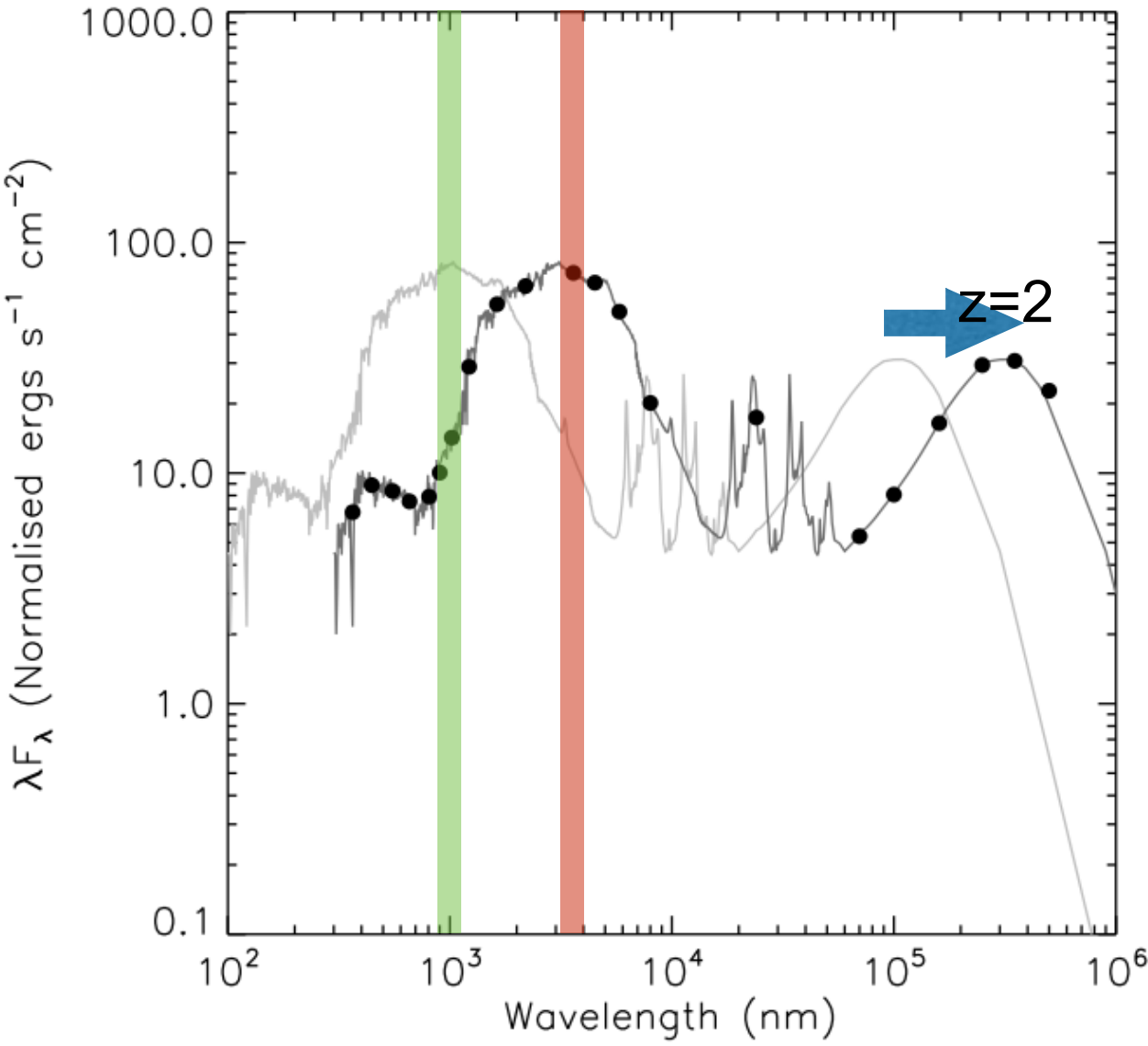
Sub-mm:

Radio:



Multi-wavelength surveys

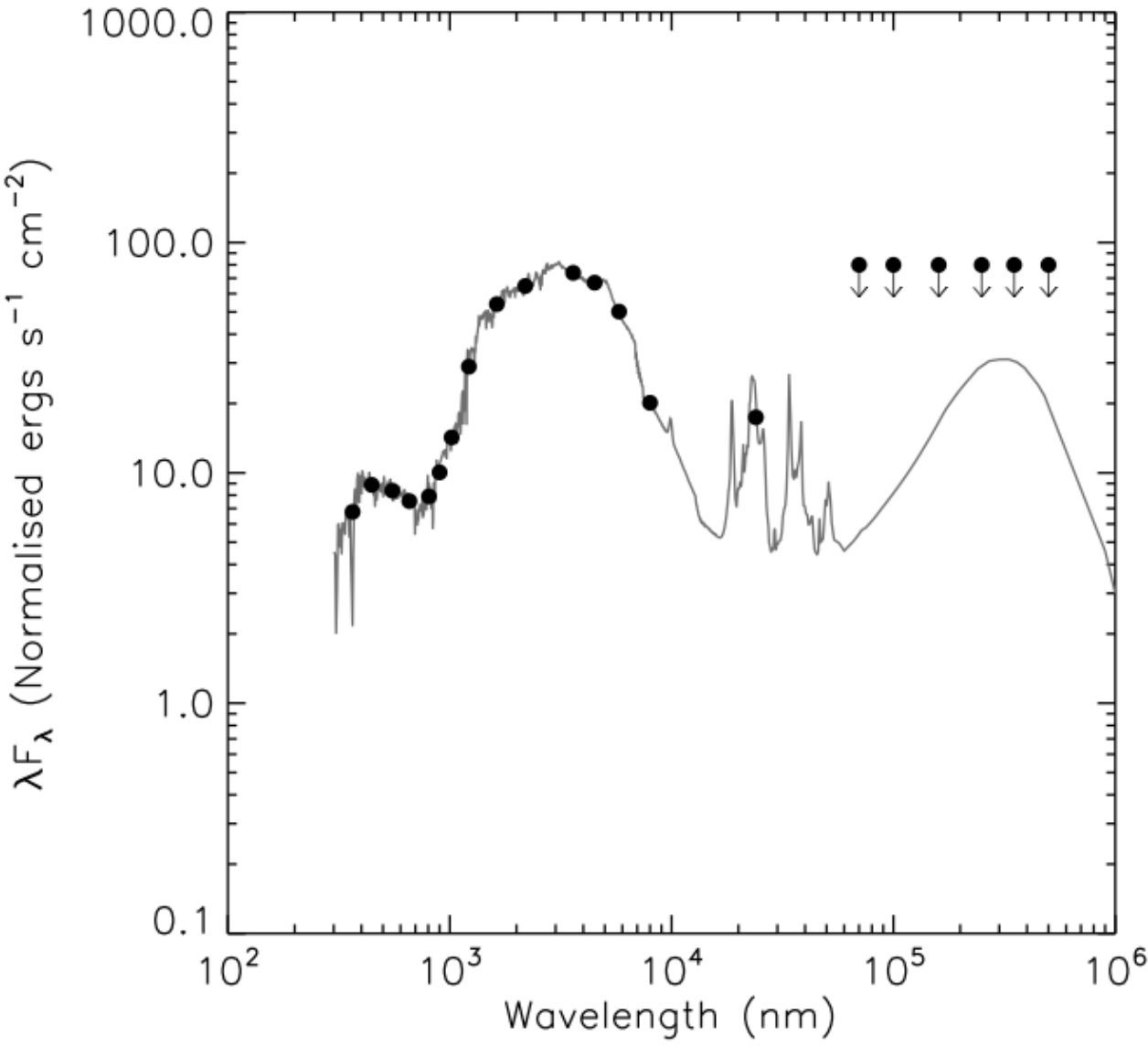
k-correction:
The other benefit of a multi-wavelength approach is that it overcomes the problem of different parts of the spectrum shifting ou of observed wavelength range.



Multi-wavelength surveys

Astronomers try to match the sensitivity of their surveys, but sometimes this is impossible. Thus, we need to be careful to overcome biases introduced by flux limits.

For example, we may only detect the most strongly star-forming galaxies in one survey.



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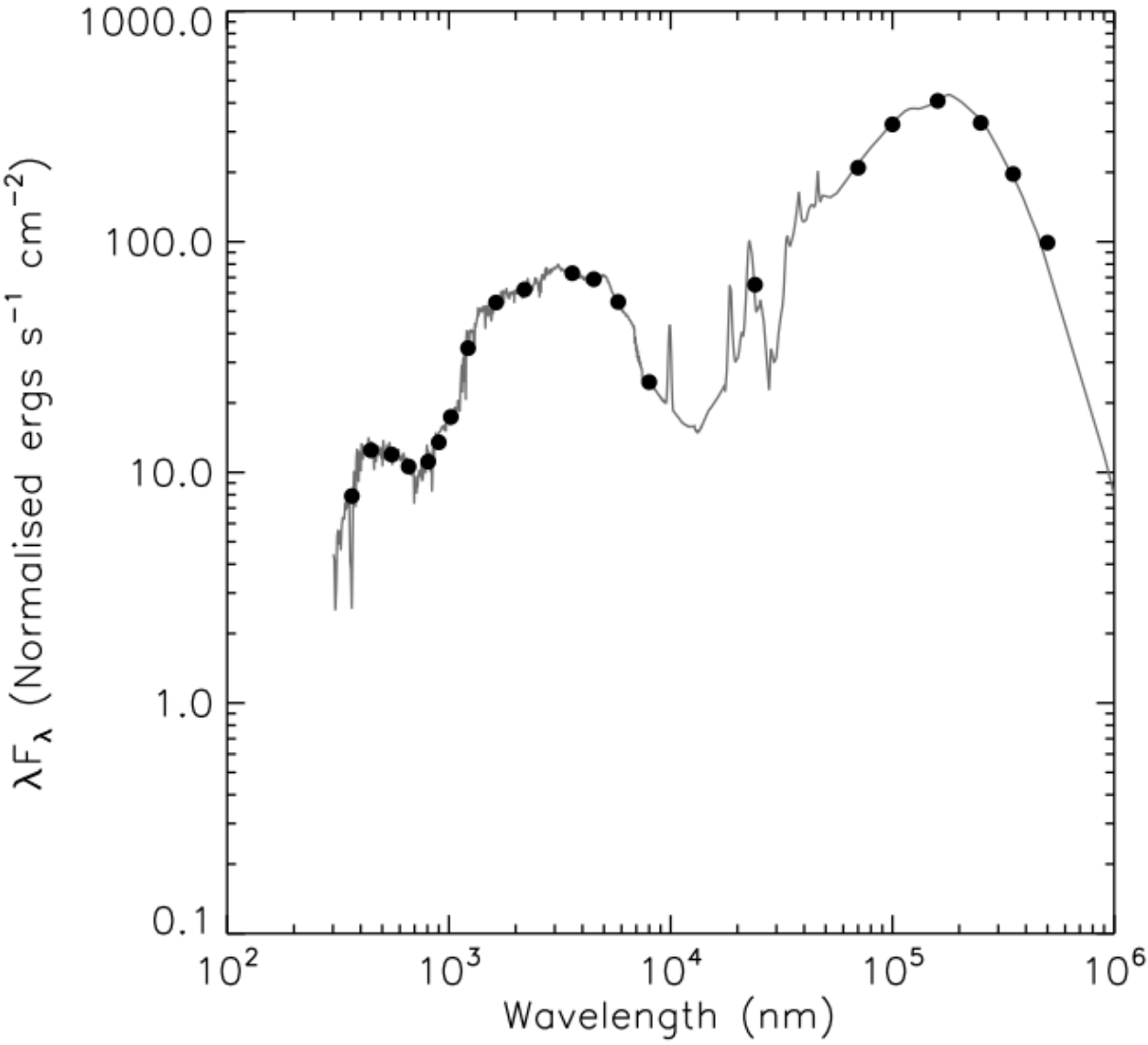
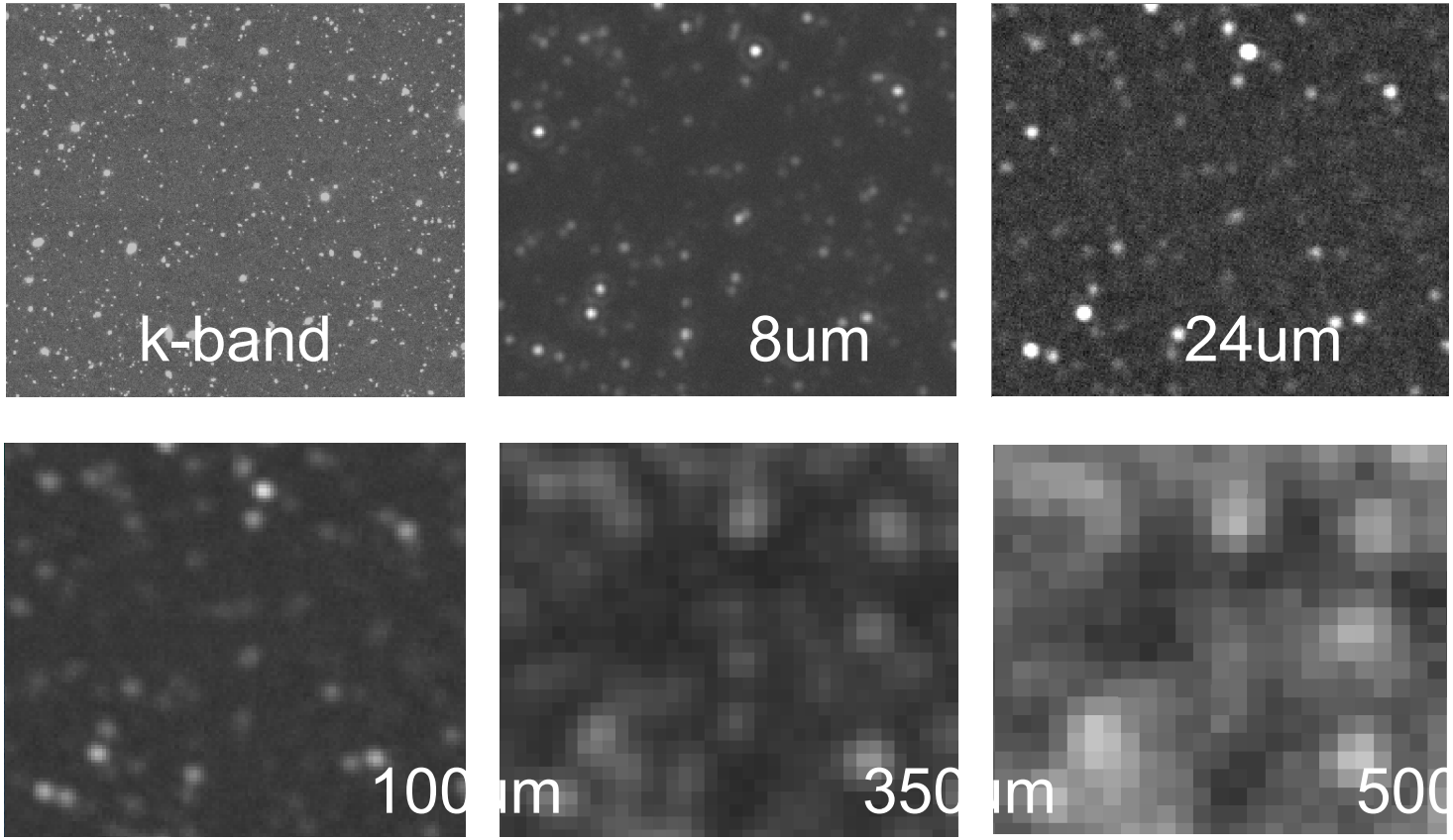


Multi-wavelength surveys

As well as different sensitivity limits, different surveys also have different resolutions, making it difficult to associate sources in different wavelengths.



Pros and Cons

Pros:

- Samples of galaxies unbiased by pre-selection.
- Multi-wavelength data.
- Source for more detailed follow-up targets.
- Deepest provide the most sensitive view of the Universe.

Cons:

- Not devoid of biases - e.g., biased toward brightest.
- Difficulties matching between wavelengths.
- Lacks detail of “targetted” astronomy.
- Susceptible to cosmic variance - especially the smallest, deepest fields.

Spectroscopic Surveys

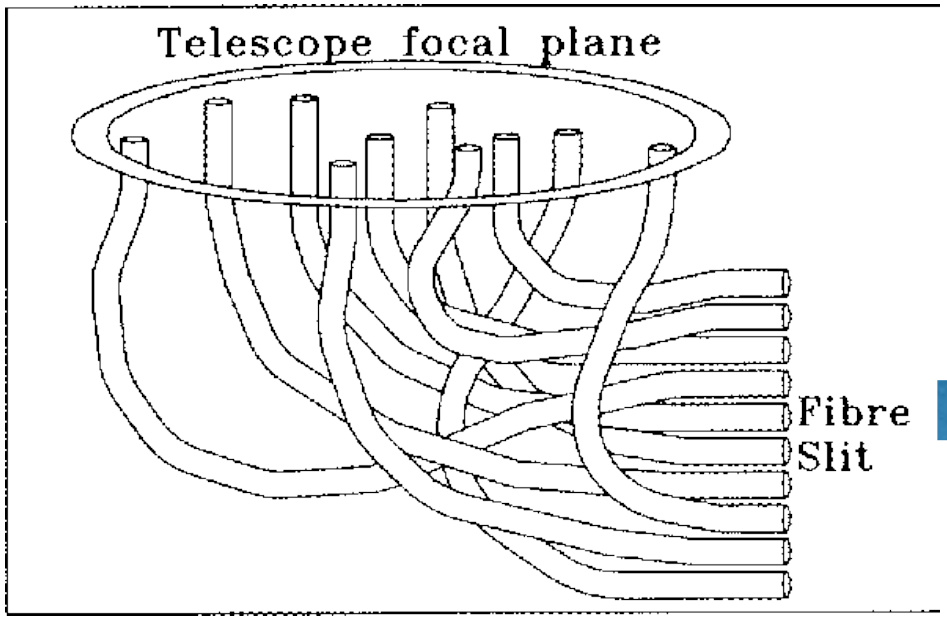
- Most surveys are “photometric” - i.e., imaging the sky in a certain waveband/frequency (radio)/energy (X-rays).
- But, photometric surveys have their limitations:

  Imprecise photometric redshifts

  No kinematic information

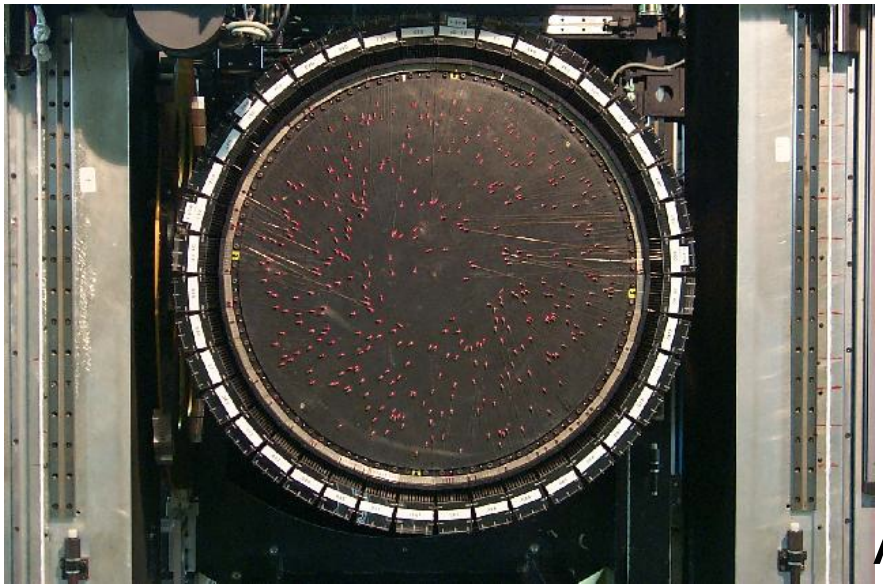
  Little/no information on gas physics
- Recently, we’ve seen the rise of spectroscopic surveys.
- Most famous is the SDSS, but now most large telescopes now have “multiplexing” capabilities.
- Allows them to take many spectra (up to 1000s) at the same time.
- But, targets must be pre-selected from photometry.

Spectroscopic Surveys



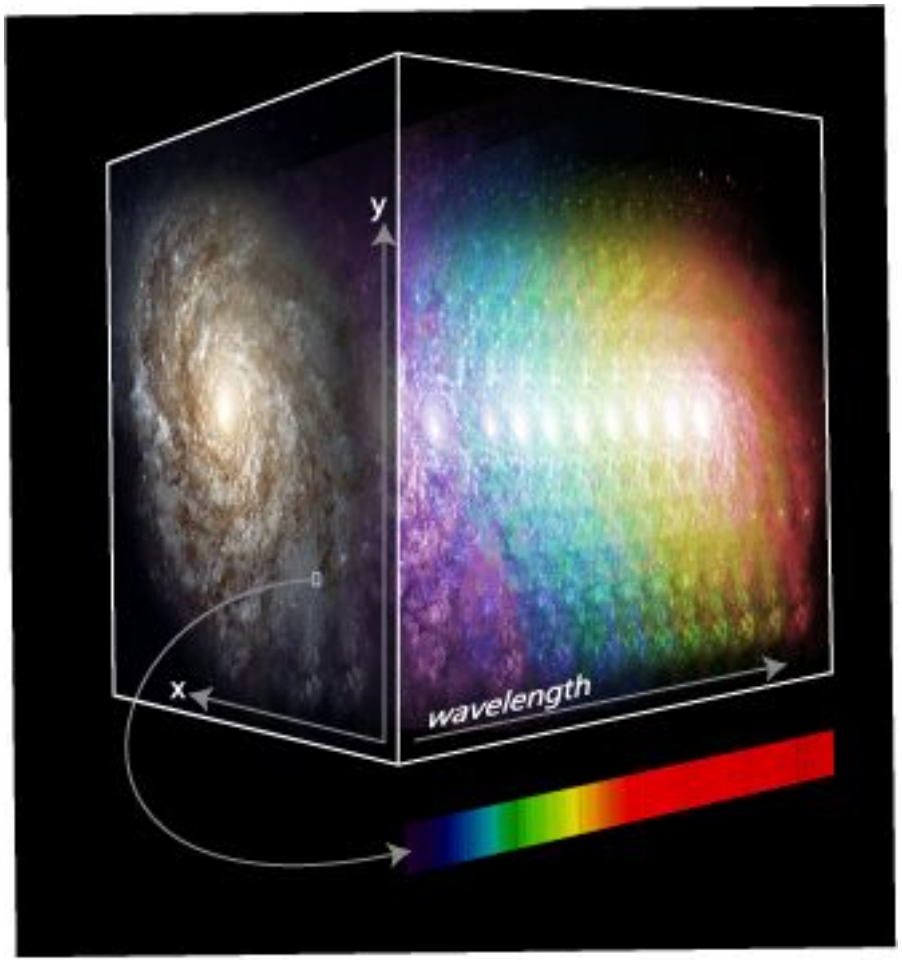
Grating (spectrograph)

CCD (detector)



Anglo-Australian Telescope

Spectroscopic Surveys



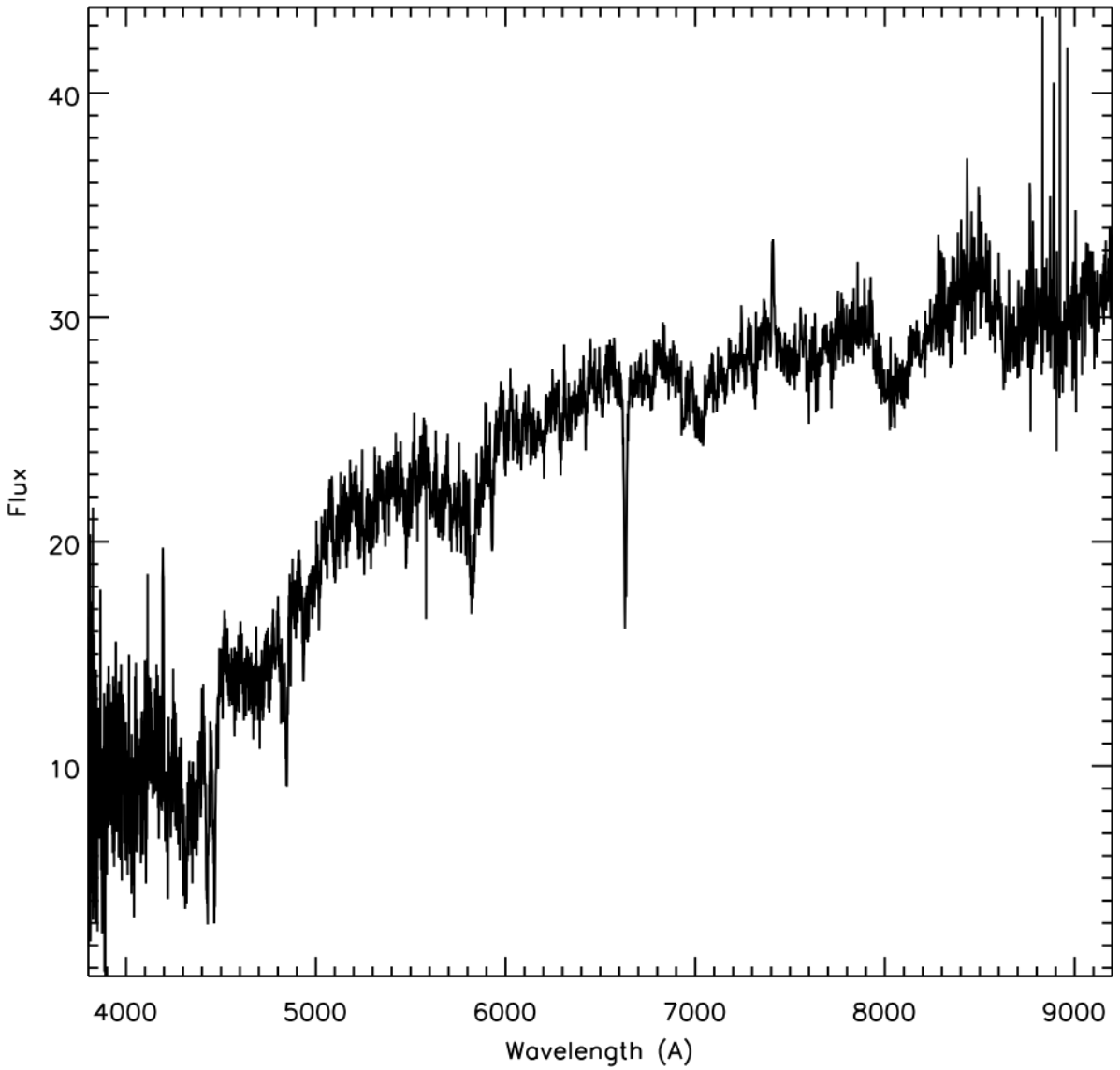
Integral Field Units take a spectrum at every position in the field of view (FOV).

Until recently, limited by small FOV (few arcsec).

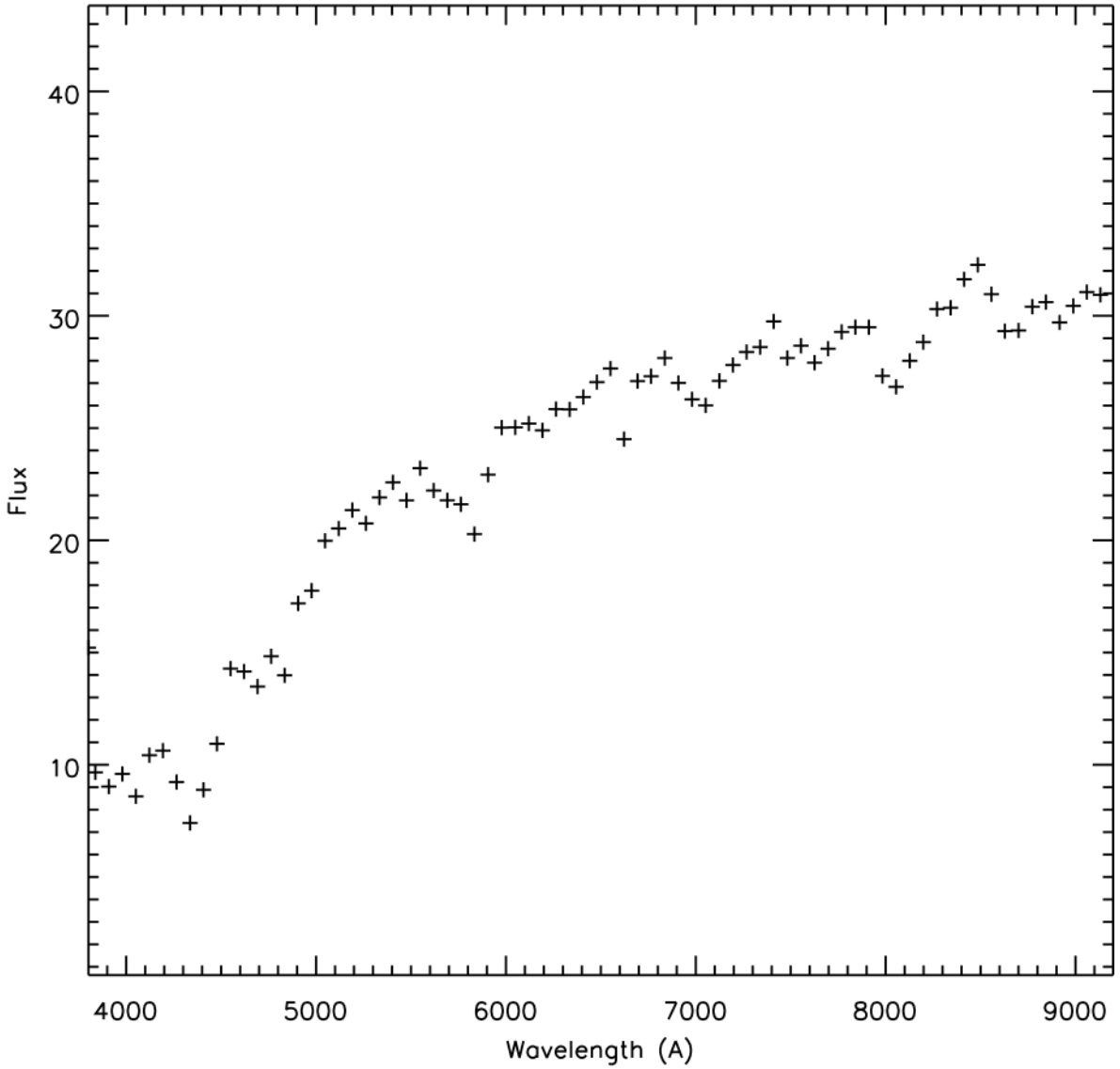
MUSE, on the VLT, has a FOV of 1 arcminute (comparable that of Hubble)

Opens up the possibility of “complete” spectroscopic surveys.

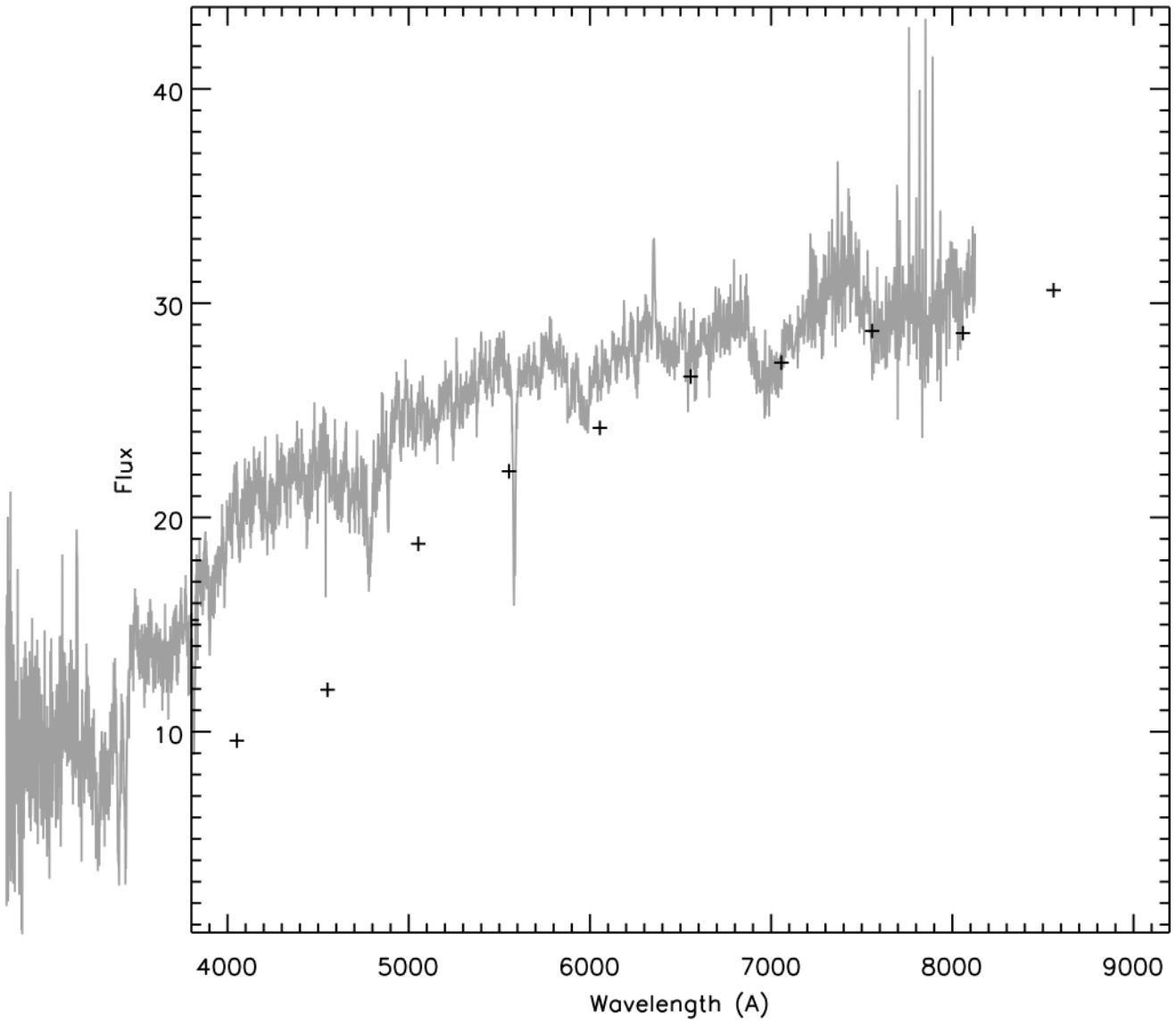
Photometric redshifts



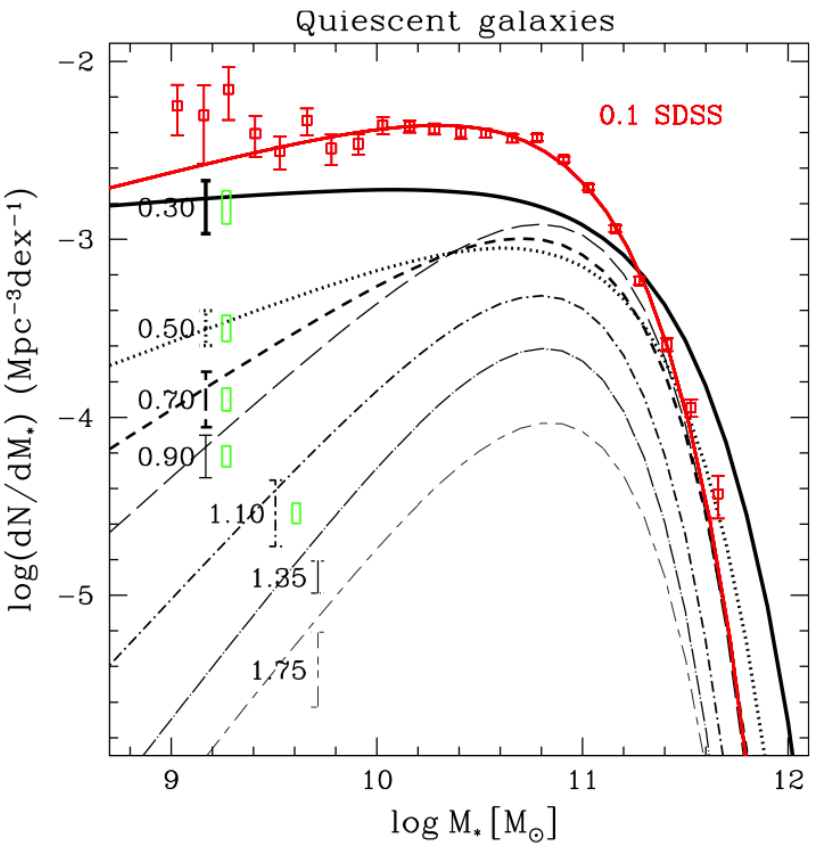
Photometric redshifts



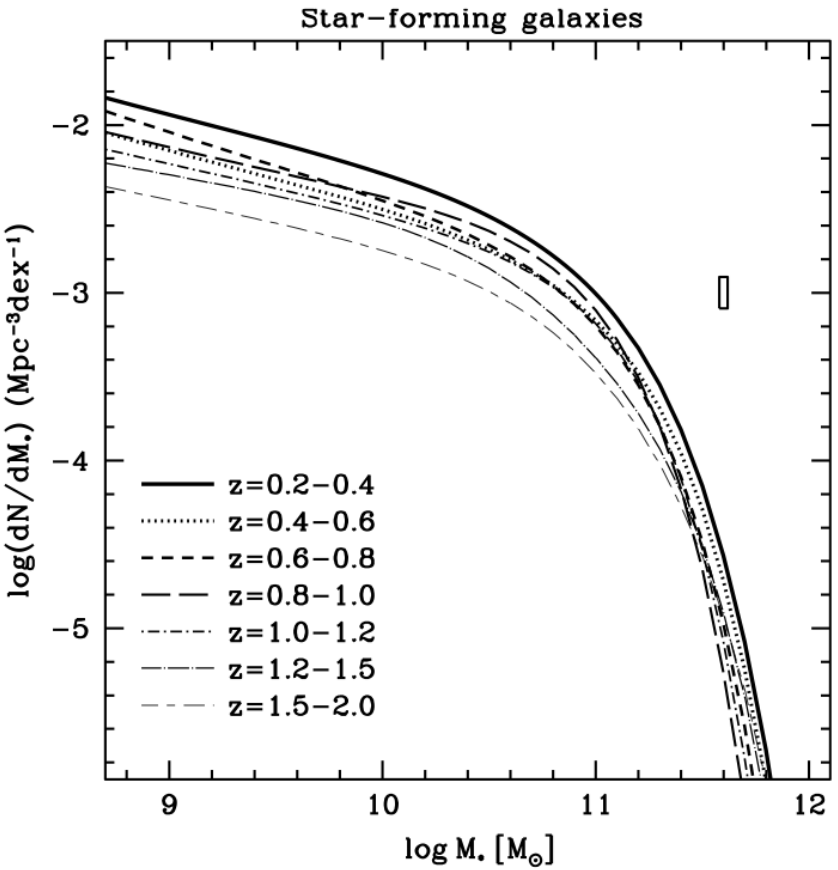
Photometric redshifts



Some Key Science Results



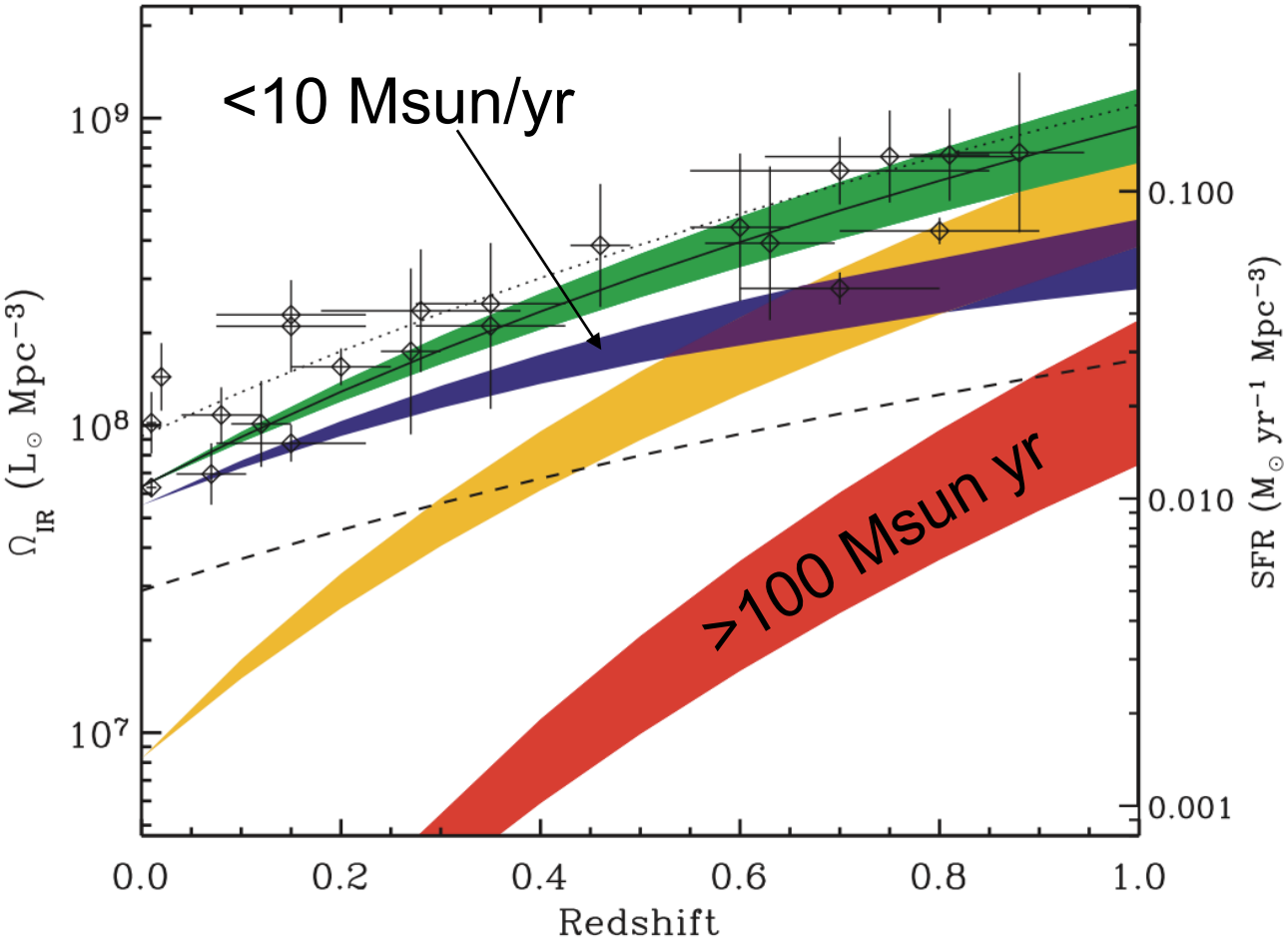
Evolution of the galaxy mass function.
Downsizing: “Big galaxies formed first”.



Ilbert et al. 2010

Some Key Science Results

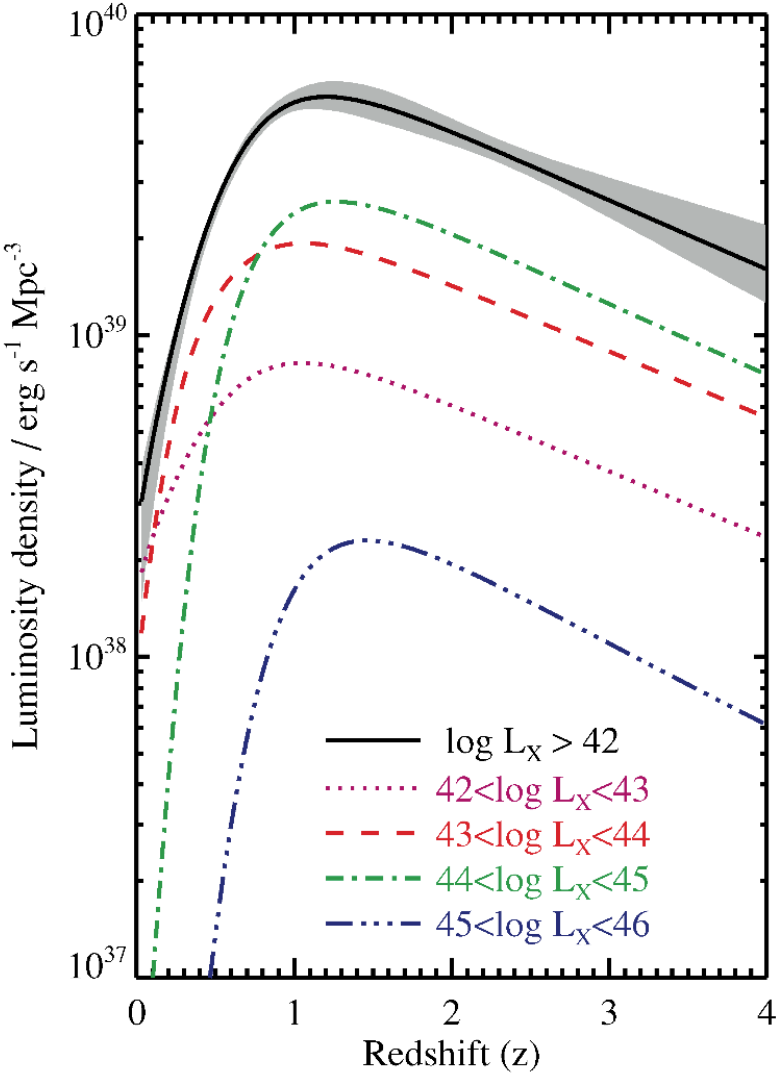
Star-formation rate history of the Universe



On average, galaxies formed stars more rapidly in the early Universe.

Some Key Science Results

Black Hole accretion history

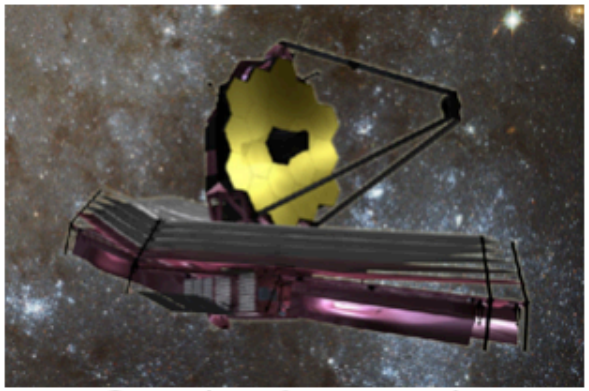


On average, black holes grew more rapidly in the early Universe.

BH “downsizing”: The most rapidly growing BHs dominated growth budget in the early Universe.

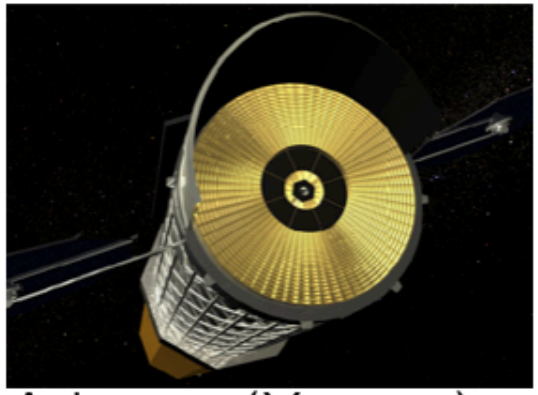
The Future

Survey astronomy is now factored-in as a major aspect to all significant, new observing facilities.

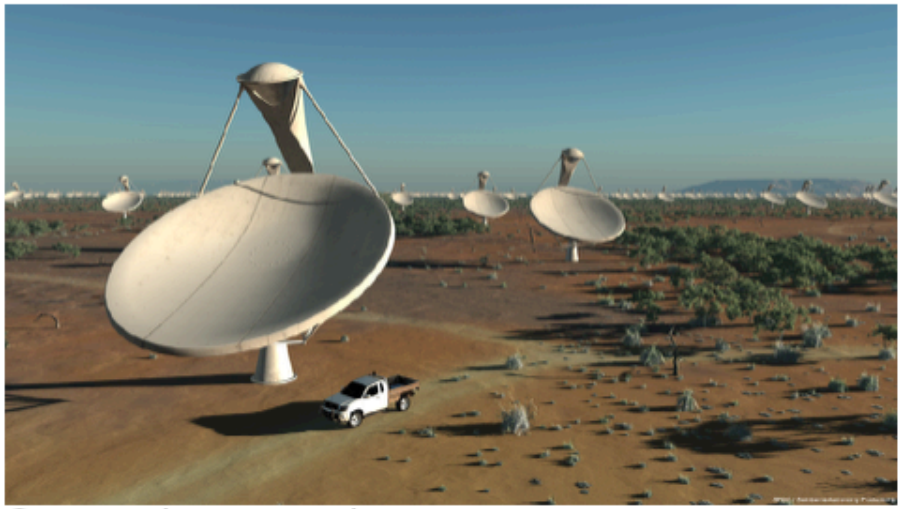


JWST (Infrared)

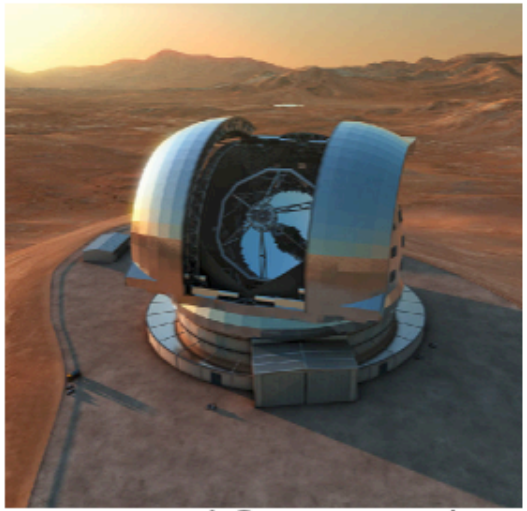
LSST (Optical)



Athena (X-rays)



SKA (Radio)



E-ELT (Optical/Near-IR)

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