Seminar III: The most distant galaxies

General instructions

This document provides preparation instructions for third of the three seminars forming part of the examination for the course *Physics of Galaxies* in 2017. The topic of this seminar is *The most distant galaxies*.

Galaxies are being detected at ever-increasing redshifts, and as of 2017, a number of photometric galaxy candidates have been claimed at $z \approx 10$–12, i.e. at about 300-500 Myr after the Big Bang. So far, only one such object has been confirmed through spectroscopy (at $z \approx 11.1$), but the race to detect even more of these primordial galaxies is on.

The point of this exercise is to:

- Practice reading technical research papers (as opposed to popular articles, review papers or textbooks). As a professional astronomer, most of the stuff you will read is likely to be of this variety.
- Practice critical thinking (for this purpose, speculative and controversial seminar topics have deliberately been chosen).
- Practice creativity. The answers you need may not be in the suggested literature – or in *any* publication for that matter. You may simply have to come up with a solution on your own.
- Practice information retrieval (learning not to waste time reading off-topic papers is an invaluable skill).
- Practice analyzing observational data
- Practice presenting material in front of others

In preparing for the seminar, you should try to:

- Develop some insight into the field of high-redshift galaxies by studying the relevant literature. In doing so, the seminar questions listed below may serve as guidance as to what you should focus on.
- Prepare to explain and discuss various concepts and recent results relevant to this field in front of the class. The use of computer, whiteboard or projector is highly encouraged.
- Analyze the enclosed data set on one potential redshift-breaking galaxy and prepare to present your findings to the class (using e.g. computer screen, blackboard, projector or printouts).

You are perfectly welcome to collaborate with your classmates when preparing for the seminar, but once there – everyone is on their own. This means that you are not supposed to rely on the calculation, notes, printouts etc. of others.

Suggested reading

A couple of good places to start are:

- Oesch, P. et al. 2016, ApJ, 819, 129 (arXiv:1603.00461)
- Zitrin et al. 2015, ApJ, 810 L12 (arXiv:1507.02679)
- Bouwens, R. et al. 2011, Nature 469, 504 (arXiv:0912.4263[1])

Please note that these papers represent the *minimum* reading required for the seminar. It is highly recommended that you study other articles as well. When looking for relevant papers, you may find the following keywords useful:

- Lyman-alpha emitter
- Extreme emission-line galaxies
- OIII emitters
- Population III galaxies

The recommended article databases are:

- `http://adsabs.harvard.edu/abstract_service.html` (to get published versions of papers)
- `http://arxiv.org` (preprints, some of which are too strange to ever get published)

Seminar questions

Here are a few examples (i.e. not a complete list) of questions that may come up during the seminar:

- Why is the study of high-redshift ($z > 6$, let's say) galaxies considered important?
- What methods are commonly used to determine the redshifts of these objects?
- What emission lines are available for spectroscopic redshift estimates of galaxies at $z > 6$?
- Why do spectroscopic follow-up observations of $z > 6$ galaxies often fail?
- Are all $z > 6$ galaxy candidates likely to be at $z > 6$?
- What are AB magnitudes?

Case study: An extreme high-redshift galaxy candidate

You are PhD students working within an international collaboration that is conducting an imaging survey for high-redshift galaxies in blank fields using the Hubble Space Telescope (HST). Your team has proprietary access to photmetric data in HST bands F105W(Y), F125W(J) and F160W(H). Based on these data, a number of interesting $z > 6$ galaxy candidates have been selected for follow-up spectroscopy using a ground-based near-infrared spectrograph, in hope of getting spectroscopic redshifts for some of these objects.

Suddenly, there is a stir within the collaboration. The Italian group that was responsible for reducing the spectroscopic data is claiming the detection of a Lyα emitter at a record-breaking

[1] In this case, it's better to get the paper from arXiv, since this version contains some additional appendices

redshift[2]. If this is indeed the case, you now need to act quickly, since competition is fierce and there is a rumour going around that a Japanese collaboration may also have detected Lyα emission at a similar redshift. The Italians have just sent an email to everybody wihtin your collaboration, saying that they would like to get a paper submitted to Nature by the end of this week(!). However, the British group that processed the photometry are cautious, as the Italians have gotten everybody worked up over nothing before. To put this putative detection on a more robust footing, the Brits have traded data with another team and gotten access to HST imaging data of the interesting candidate in two additional filters: F555W(V) and F814W(I). It's at this point that your your supervisor, Professor Angela Shapiro-Jensen, a renowned expert on the modelling and interpretation of high-redshift galaxies, is called in for a second opinion on the reliability of the detection. Unfortunately, Angela is scheduled to give an important keynote talk at a conference, and doesn't have time to even look at the data until next week. So, she leaves it in the capable hands of her PhD students, namely *you*.

Your task is to analyze the data at hand, say as much possible about the likely nature of this candidate high-redshift galaxy, and come up with a recommendation on whether or not it's a good idea to go ahead with that Nature paper. Professor Shapiro-Jensen also want to know what sort of follow-up observations one could consider doing to gain further insight into the nature of this object.

The available data on the high-redshift galaxy candidate are presented in Figures 1–2 and Table 1. Figure 1 contain thumbnail images (3 arcsec $\times$ 3 arcsec) in the five filters for which you have data. The corresponding broadband fluxes (in AB magnitudes) are presented in Table 1. The near-infrared spectrum that has gotten the Italians so excited is shown in Fig. 2.

The following questions may provide some guidance on what to focus on when analyzing the data:

- What is the likely redshift of this object? How robust is this estimate?
- Do the optical images corroborate the claim that this object has a record-breaking redshift?
- Are there alternative explanations for the properties of this object?
- What future observations or investigations would you propose to get additional clues about the nature of this object?
- Is this Nature-worthy material or not?

Erik Zackrisson, March 2017

[2] As in "the highest redshift ever detected for a Lyα emitter" – it remains unclear if the the redshift is actually higher than that of the Oesch et al. (2016) object, for which the spectroscopic redshift was based on the detection of a continuum break

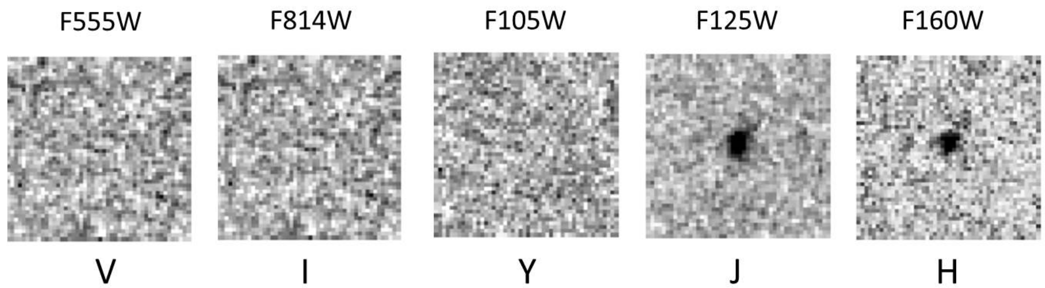

Figure 1: Thumbnail images (3 arcsec × 3 arcsec) in various broadband Hubble Space Telescope images of the high-redshift galaxy candidate (clearly detected in the J and H bands).

Table 1: The photometric broadband fluxes (in AB magnitudes) derived from the images in Fig. 1. Upper limits indicate non-detections at the 2σ limit. The 2σ detection limits in the F125W and F160W bands are very similar to that of the F105W band.

m_{555}	> 28.2
m_{814}	> 28.0
m_{105}	> 28.4
m_{125}	27.0 ± 0.2
m_{160}	27.5 ± 0.2

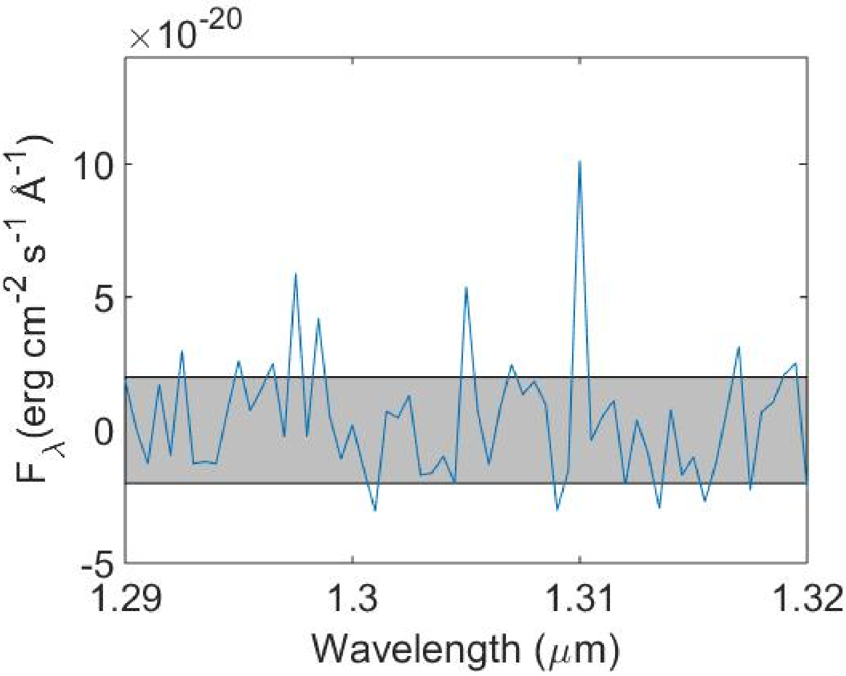

Figure 2: The near-infrared spectrum (at 5 Å resolution) of the high-redshift galaxy candidate. The 1σ uncertainty on the flux is indicated by the gray region. The data supposedly shows an emission feature at $\lambda \approx 1.31$ μm (13100 Å), detected at the ≈ 4–5σ level.