Observers' Forum

Ancient Light

Imaging a quasar without a telescope

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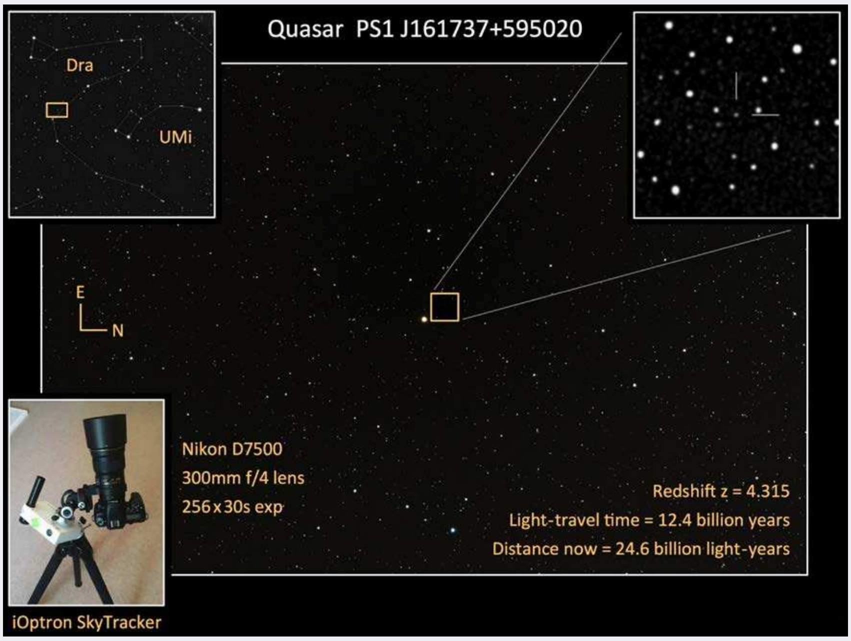

The bottom left inset shows the camera and 300mm telephoto lens on a star tracker (the white box). The rectangle in the top left inset shows the field of view of the lens in the constellation of Draco. The main image is a two-hour exposure (256×30s exposures) that shows the fifth-magnitude star AT Dra at the centre. Zooming in to the area near the centre, the top right inset shows the quasar identified by the two grey lines. At a distance of 25 billion light-years, the quasar is barely one pixel in the image. *Steven Barrett*

During the pandemic of 2020 I recalled Stephen Hawking's words 'Remember to look up at the stars and not down at your feet' and set myself a lockdown challenge – not just to look up, but to look up as far as possible. What is the most distant object that I can photograph with my camera without using a telescope?

I looked up a research paper cataloguing quasars (very distant galaxies that emit a huge amount of energy) and picked the most distant one that is high in the sky as seen from the UK during the summer months.[1] Having identified the target quasar,[2] the first opportunity to try to image it came on July 20. My camera equipment comprises a Nikon D7500 digital SLR camera with a 300mm *f*/4 telephoto lens – the set-up that I use for normal daylight photography, not 'customised' or 'modified' in any way for astrophotography. I set up the camera on a small star tracker that rotates it at one revolution per day to follow the stars, as shown in the bottom left inset of the figure. The quasar is located in the constellation of Draco (top left inset) which is high in the sky during the darkest part of the night in the UK spring/summer.

Not knowing how long an exposure was necessary, I exposed for as long as the short summer night allowed. Rather than take a single very long exposure, I took a continuous series of shorter 30-second exposures over a period of about an hour either side of midnight. After discarding images spoiled by passing clouds, the remaining exposures were added together to produce an image that was equivalent to taking a single two-hour-long exposure. This final image, the result of 256 exposures, is shown in the main panel of the figure. The top right inset of the figure shows the quasar identified by two grey lines.

Having shown that it is possible to capture the light from this quasar using a digital SLR camera, the big question is: just how far away is it? If the quasar is a tiny dot, even in a large telescope, how can its distance be determined? We have to remind ourselves that the distance to the quasar cannot be measured directly. The length of time that the light has been travelling to reach us also cannot be measured. The key to determining distances on cosmological scales is the one thing that can be measured – the spectrum, from which we can calculate the redshift that results when an object is receding from us. Schindler *et al.* (2019; ref. 1) determined that this quasar has a redshift of $z = 4.3$.

Determining the distance is complicated by the fact that the Universe is expanding at a rate that changes with time. This means that we can only calculate the distance to a remote object if we have some understanding of how the Universe is expanding, and in particular how it has expanded over the interval between the time when the light left the object (perhaps billions of years ago) up to the time when it arrived here on Earth (now). The so-called concordance model of the Universe is based on the currently accepted 'best guess' of the parameters that determine the way it expands and evolves.[3] Using these parameters it is possible to convert measurements of redshift into distances. For our quasar with a redshift of $z = 4.3$ we find that (i) it was about 5 billion light-years away when the light was emitted; (ii) the light from it has been travelling for over 12 billion years; and (iii) while the light was travelling the Universe continued to expand and so the quasar is now about 25 billion light-years away. The light-travel time, also known as the look-back time, of over 12 billion years is absolutely mind-boggling. Bearing in mind that no telescope, no matter how powerful, can look back further than 13.8 billion years (the age of the Universe), it is remarkable to realise that a camera can 'see' light that has been travelling for 90% of the age of the Universe.

A quick back-of-the-envelope calculation using the distances quoted leads to a very interesting conclusion. The distance to the quasar increased by 20 billion light-years during the light-travel time of 12 billion years, so that corresponds to the quasar receding from us at a speed that is faster than the speed of light. At first sight this seems wrong, but actually this does not contradict any laws of physics. The quasar is not moving through space at this speed, but the Universe is expanding at this rate and the quasar is 'along for the ride'. A more detailed calculation tells us that when the light was emitted, the quasar was receding from us at a little more than twice the speed of light.

When looking at the image, I think about the incredible journey that the ancient light has taken to form it, with the narrative as seen from the perspective of the light...

The light was emitted by the quasar 1.4 billion years after the Universe was created in the Big Bang. It had already been travelling for nearly 8 billion years when the Sun and the Earth were born. The light continued on its journey through the void for another 4.5 billion years. Life evolved on Earth. The light travelled on. Dinosaurs came and went. The light travelled on. In the last million years of its journey it arrived at the edge of our Milky Way galaxy, crossed a few spiral arms, and entered the Solar System. In its last few hours it finally arrived at Earth, travelled through the atmosphere in a fraction of a second, hurtled towards England, dodged a few clouds, entered the lens and hit the camera sensor. Just a pixel in the image... but what a journey!

1 J-T. Schindler *et al.*, 'Extremely Luminous Quasar Survey in the Pan-STARRS 1 Footprint (PS-ELQS)', *Astrophys. J. Suppl. S.*, **243**, 5 (2019): **bit.ly/395xQOq**
2 Quasar PS1 J161737+595020, magnitude 17.4, redshift $z = 4.315$
3 Matter density = 0.3, dark energy density = 0.7, Hubble constant H_0 = 70km/s/Mpc

More details on the observation and its interpretation are at: **www.liverpool.ac.uk/~sdb/Astro/Ancient-Light-JBAA.pdf**