Student Projects for Fall 2017

Physics & Astronomy 308 – Observational Astronomy

September 18, 2017

Consider choosing a project from one of these categories. You will need to narrow the topic and be specific about your work. These are to give you a broad sense of what subjects are possible. While we will discuss these possibilities and answer questions about them in class, if you have one or more of your own that's a welcome addition.

Extragalactic

The largest aperture we have available is 0.7 m in Australia. While it is a dark sky site, this is an order of magnitude smaller than the largest ground based telescopes currently in operation. Thus, it can "see" to about 1/10 the distance these very large telescopes can explore. On the other hand, it has a wide field of view and is optically fast. Possibilities would be

- Deep exposure to look for low surface brightness intergalactic gas in a cluster, or in interacting galaxies
- Detect a Cepheid variable in M31 or M33, two nearby Local Group galaxies,
- Follow a supernova decay (given an opportune discovery)
- Image and model gravitational lensing

Magellanic Clouds

The Large (LMC) and Small (SMC) Magellanic Clouds are visible from our Australian observatory. The SMC (200,000 ly) transits over the south celestial pole at midnight local time during October, and the LMC follows later that night. Both contain clusters and nebula which are observable, as are the individual brighter stars. Since both are over 5 degrees in extent on the sky, studies would concentrate on some component. An informative one would be to look for Cepheid variables, the classic observation that supports the cosmic distance ladder.

Globular star clusters

There are over 100 visible, and the two largest are Omega Centauri and 47 Tucanae that are seen from the southern hemisphere. In the north we have M15 and M2 well placed and visible now through hours after midnight, and M13 and M92 immediately after sunset. Each one has a unique structure, age, and population. Use a color-magnitude or color-color diagrams to find ages and populations, RR Lyrae stars to find distances, luminosity profiles to find gravitation potential distribution.

Open star clusters

This is a good season for open star clusters with the northern Milky Way overhead at midnight in North America. From Australia, clusters in the Magellanic Clouds are observable this fall later at night, while those in the heart of the Milky Way toward Sagittarius are overhead at sunset in early October.

The key issue with star clusters is that all of the stars should have similar age, and thus their color-color and color-magnitude distributions should trace how stars of different mass age. Most well-known star clusters (the Messier and Caldwell lists, as well as the majority of NGC clusters) are very observable with our telescopes. The nearer ones will have detectable red dwarf stars on the main sequence, unlike globular clusters which are more distant, and typically much older, where detection of even solar-like stars is problematic. The angular size of all but a few clusters is small enough to capture in one pointing. The exceptions would be the Pleiades, Hyades, and Double Cluster in the northern sky, where either multiple pointings or study of a part of the cluster would be appropriate.

Astrophysics of a planetary nebulae and supernova remnants

Planetary nebulae are the gaseous remnants of an ejected outer stellar envelop from an evolved aging star. They are typically small, subtending angles of a few arcminutes, though some are large and very low surface brightness. Usually there will be a central star that's observable too. The most famous example, th e Ring Nebula M57, is visible at sunset in the northern sky now, but there are others at any time of night or season. For our telescopes the difficult is that the detail is often just at the limit of resolution, and the surface brightness is low enough to challenge sky brightness from Moore. We have darker sky at Mt. Lemmon and Mt. Kent, and both are possible instruments. We have a selection of interference filters that will isolate hydrogen alpha, ionized oxygen and sulfur emission. These filter observations can be used to determine ionization and temperature in the gas.

Eta Carinae, and its Homunculus Nebula, is not a planetary nebula but a remnant of an unusual activity in a star which is expected to become a supernova. It is observable from the southern hemisphere. Unfortunately, it is an object for their fall sky, that is spring for us. The Crab Nebula, M1, is a supernova remant that is observable from northern observatories now. It is very well studied, but shows interesting time-dependent properties, polarization (due to synchrotron emission of electrons trapped in magnetic fields), and filaments of hydrogen to explore. The central pulsar is observable. It is too faint for us to time-resolve its pulses however.

Astrophysics of a star-forming nebula

Associated with some star clusters or famously some dramatic nebulae like M42 n Orion we can observe the gas and shock waves where stars are being born. The Orion Nebula is ideal of course, and rises late at night now. It would be observable for several hours at the end of the semester. These "H II" regions (ionized hydrogen) trace spiral arms of galaxies, and some are detectable in M31 and M33 but not well-resolved. Several good ones are in the direction of the Milky Way center and could be observed from Australia if done soon. They are too low in the sky after 11 PM local time and that gets progressively earlier in the night as the season goes on.

Measurements possible include the images in hydrogen, oxygen, and sulfur, dust and extinction, and shock waves. There is an opportunity for detailed physical modeling based on knowledge of the radiation from the exciting stars. One could also look for exoplanet transits and short term variability by staring a the embedded stars for several hours. This type of study has not been done with high precision on most clusters and nebula, since it is usually used for validating suspect exoplanet candidates that are discovered with patrol cameras that cannot resolve individual stars in denser clusters or when there is background gas emission.

Proper motion of nearby stars

A few nearer stars have large enough proper motion that images taken now will show them in significantly different positions than they are in archival images, for example in the digital sky survey. Possibilities include using data we have on hand for Proxima Centauri, and looking at others. Most of these will also have good parallaxes from Hipparcos or Gaia, so a proper motion can be connected with a space velocity transverse to the line of sight. With radial velocities from spectroscopic measurements in the literature, proper motion thus connects the star to space motions and to membership in the various populations in the Milky Way. Proxima Centauri is not well placed in the southern sky now, nor is Groombridge 1830, a nearby northern sky star. Most of the other largest proper motion stars are in the southern sky, but 61 Cygni is visible now in the north.

Pulsating variable stars

RR Lyrae stars are the classic pulsators and there are hundreds known. Another type, called "δ-Scuti" variable are turning up in large numbers in exoplanet followup measurements. These are Cepheid-like, typically spectral type e F, with may periods and sometimes exhibiting several interacting modes of oscillation on periods from several minutes to several hours. Ones that are measurable for us are fainter than magnitude 8, brighter than magnitude 14. Possibilities include studying oscillations in one that is previously studied to see how it has changed, or in making a more detailed observation and analysis of one previously unstudied but turned up in the exoplanet work of our observatories.

Stellar rotation and activity

Because stars with magnetic fields have spots, and occasional flares associated with changes in the fields, it is possible to find the rotation of stars from the variation of the light over a period, and to identify magnetic activity through the presence of flares. Some stars are well known to produce large flares: Proxima Centauri in the south is one, and DG Canum Venaticorum in the north is another. DG CVn produced one of the largest flares ever seen and produced a burst of gamma radiation that was detected by monitoring satellites in 2014. Both are unfortunately best seen in the spring or summer. An interesting study would be to seek out another star of similar type observable now, monitor it for flares, and hopefully detect one in progress with frequency enough data to see the onset of the event. One possibility is II Pegasi, which is visible at sunset and later for several hours.

Eclipsing binary stars

The eclipsing binaries or "EB's" are a mainstay of routine time-dependent astronomical photometry. By analysis of the light variation or "light curve" we find the relative sizes and brightnesses of the stars, their limb darkening, and the geometry of their orbits. Aided with spectroscopic determination of velocity, we have the masses of the stars, and detailed analysis of the light curve may also yield information about gas and dust shared by the stars, and features on their surfaces. Thousands of them are known and cataloged, and we are discovering hundreds more in the exoplanet search work because they can mimic a transiting planet.

Most recently, 2MASS J05321554+6246281, a magnitude 13.3 red (M?) star, turned out to be an eclipsing binary. We have only a little partial information about its eclipses, but enough to seek out new measurements which would include eclipse light curves in different filters, and a search for the secondary eclipse if indeed we have seen the primary eclipse in the first detection. The interesting thing about this star is that it is quite cool, and the eclipse is about 15% of its light, suggesting that it could have a companion that is even smaller. The star is placed well for observing now, but the period of the orbit that is known is 13.17 days. There is only one eclipse, on 11-21-2017, that allows a full 6-hour long eclipse to be seen . There are partial eclipses with the next visible ingress on 9-29 at 6 AM.

If the object is of sufficient interest by the time of the 11-21 eclipse, we could enlist help of other observers in eastern North America to help overcome the significant probability it would be clouded out here.

There are of course other possibilities, and many new ones turn up often, or well-known ones are always instructive to revisit.

Exoplanet candidate validation and discovery

We are currently supporting validation of exoplanet candidates found the by the (Kilodegree Extremely Little Telescope) KELT project. There are candidates to look at every night, and occasionally one of them turns out to be a previously unknown planet. Usually they lead us to find eclipsing binary stars or δ-Scuti stars or something anomalous. A good project could be to participate in this search, take one or more data sets, and do the analysis on it to see what it can show. Some of the star fields include hundreds of stars that can be searched for variability of the hours it takes to acquire data. We do find serendipitously other stars of interest in the course of this work too.

The KELT target list includes other targets of interest to members of the team, and they would welcome measurements of those as well.

Exoplanet transit timing

With several thousand known transiting exoplanets, most are not very well followed because the majority of them were found with the NASA Kepler spacecraft which studied primarily faint stars in a spatially limited region of the sky and had incomplete ground-based followup. There are now 20 KELT exoplanets which are precisely validated from the ground and for which are are many measurements of the transits with high precision. The same is true for other surveys as well, leading to two tasks for following known planets. One is to re-measure one transit several years after discovery. This gives a longer timebase, and allows a better determination of the ephemeris so the planet will not be lost. The other is to make many measurements of the transit of an exoplanet and to look for statistically significant changes in the timing that may be attributed to unseen companions. This transit timing variation or TTV method is proven to find planets that do not transit, but requires exceptional sensitivity and precision, plus persistence. An interesting project would be to pick up on one planet for which we do have a lot of data, and to see if you can acquire new data that is sufficiently precise to contribute to a TTV study. While there would not be enough time this fall to do more than a few transits of any one known planet, it would contribute to a larger scientific effort or be a small project that could continue after the semester.

Satellites of currently visible planets

This fall the giant planets Jupiter and Saturn are just about out of reach. Saturn is visible for a few hours before sunset, from both hemispheres but better from the south. Jupiter is in the Sun's glare all semester. However both Uranus and Neptune are visible and they have satellite systems that are easily seen and measured. Colors and variations in satellite brightness would reveal composition and rotation, and while this sort of work has been done before, it is educational to see what can be found. Of course the orbital periods and sizes give the masses of the host planets. We are limited to about 18th magnitude, making the faintest satellites of the outer planets out of reach.

Comets progressive changes

There are always new comets to follow. Most are far from spectacular, put simply tracking one or more and measure the light curve as well and the spatial distribution of the tail can be revealing. At this time we do not know of a comet that will be a showpiece or unusual enough to warrant "must see" attention.

Tracking nearby asteroids

Near-Earth asteroids show up often with little prior notice, and may be observed rapidly moving across the sky. Others are bright enough to be well known and often studied for rotation light curves. Measurements can give the orbit of the asteroid, and the light curve may be connected to a model to discern something about its shape and distribution of material. Given recent ESA and NASA missions, this type of work has become more an object for unmanned exploration and close up imaging. The exception are the NEO's, which represent a hazard.

This fall, we know that asteroid 2012 TC4 will make a close approach on October 12, 2017. There is an observing campaign organized for it

2012tc4.astro.umd.edu

Moon high resolution imaging, polarization, colors

Small telescopes are remarkably good at recording detail on the Moon (and giant planets) because their aperture is comparable to size of density fluctuations in Earth's atmosphere. As a result, the images have low order error that may be corrected, and often enough to be useful, have no serious image error at all in very short exposures. The angular resolution that is achievable is diffraction limited for the telescope aperture, and is the simplest example of adaptive optics to obtain angular resolution better the time-averaged seeing profile.

On the Moon the imaging can be spectacular, and there is some science to do as well. Lunar light is polarized and the degree of polarization depends on the illumination angle. Imaging and determining the polarization state of the light can reveal the distribution of various minerals and ejecta on the Moon that is not obvious in white light and gray-scale imaging. Similarly, very subtle color differences are affected by changing illumination and various mineral and terrain types. High quality imaging, especially looking at rarely seen regions that roll into view at favorable moments of libration, are at the least interesting. While new information on the Moon may not come from this, insight into how these effects would be manifested if we see other planets would be a desirable outcome.

Instrumentation: seeing profile, resolution, photometry errors

A specific thorough measurement of the seeing profile produced by our telescopes would be a good productive study, tied to atmospheric turbulence, optical physics, and data analysis. An unresolved question is what are the photometry errors introduced by turbulence and seeing when we make very high precision measurements. There is known theory that has not be tested with the current precision technology.

Instrumentation: photometry filter calibration

The standard photometric filter set is that used by the Sloan Digital Sky Survey, employing bands known as g', r', i', and z'. Historically, there is a large body of work existing with data taken in the Johnson-Cousins filter system known as U, B, V, R, and I. The translation between them depends on the object being measured because these are broad-band filters that integrate the light of what is roughly a thermal blackbody source. Also, what is detected depends on the sensor's response as well. A careful study of the calibration of the filter sets against one another using known stars, and testing for absolute (rather than relative) photometry in a cluster that has recent high quality measurements would be useful for new work that has to compare to existing data, or to data taken elsewhere.

Instrumentation: limiting magnitudes

An often asked question is "How far can you see?", or to put it into astronomical terms, what is the limiting magnitude of the instrumentation we have available. In principle this is a straightforward acquisition of deep exposures with different telescopes, the identification of known stars, and the measurement of the sky brightness as well as the brightness of stars on the images. The sky brightness will vary with the Moon too, and probably with other conditions such as airglow and (close to Louisville) atmospheric moisture. We expect significant differences between sites, and even between instruments with comparably sized optics because of the condition of the mirror coatings, the filters, and the quantum efficiency of the detectors.