Stars and Galaxies

Observational Techniques Homework Set 4

1) a) Explain why X-ray telescopes have very long focal lengths [1 mark]

b) One of the instruments onboard the NuStar X-ray Observatory has a detector with 32×32 pixels and a field of view of 400×400 arcseconds. If each pixel is $625 \times 625\,\mu$m in size, calculate the plate scale (in arcsec / mm) and hence the focal length of the telescope. [2 marks]

2) The star, Vega, is observed with a stellar interferometer (operating at 700 nm), and it is found that the fringes disappear when the telescopes are 55 meters apart. The measured flux on Earth from Vega is $3.92 \times 10^{-8}\,\mathrm{W}\,/\,\mathrm{m}^2$ and it displays a parallax of 130 mill-arcseconds.

a) What is the stars angular size on the sky (in milli-arcseconds)? [1 mark]

b) What is its distance (in parsecs)? [1 mark]

c) What are Vega's diameter, luminosity and effective temperature? Where does Vega lie on a Hertzsprung-Russel diagram, and hence what type of star is it? [2 marks]

The stephan-boltman constant is $\sigma = 5.669 \times 10^{-8}\,\mathrm{W\,m^2\,K^4}$.

3) Researchers are often asked to peer review proposals. Below are three (shortened) science cases that were submitted to an 8-meter telescope. You have two tasks:

a) Rank them scientifically. If you could only give one of these observing time, which one would you suggest is carried out? [state your reasons] [1 mark]

b) Each of these proposals request one full night of observing time. You have three nights to give out, but the weather forcast is such that:

– night one will be excellent conditions (no cloud, very stable atmosphere);

– night two will be average conditions (some thin cloud at times, some low-level wind and so less stable atmosphere)

– night three will be patchy cloud and poor seeing (lots of turbulent atmosphere).

Which proposal should be given which night to maximise scientific return? [2 marks]

Proposal 1: How do massive stars form?

Massive stars ($M > 10\,M_\odot$) dominate the cycle of star-formation in their host galaxies, from the large amounts of ionizing radiation they emit, to the kinetic energy they pump back into the interstellar medium through their winds and supernova explosions. However, it is still unknown how such stars form. Massive stars are intrinsically rare, and much of the formation process happens on very short timescales ($<10^5$ years) while the proto-star is still heavily embedded in its dust cloud and hence difficult to observe. In addition, classical theory suggests that radiation pressure from the protostar inhibits further accretion once the stellar mass reaches $10\,M_\odot$.

One options for their formation is that massive stars may form through a mechanism similar to that of lower mass stars, whereby matter is accreted from a circumstellar disk, with the outward radiative force preferentially escaping via the poles. Some numerical simulations have succeeded in creating stars with masses $>10\,M_\odot$ this way (e.g. Yorke & Sonnhalter 2002, ApJ 569, 846; Krumholz et al. 2009, Science, 323, 754). The observational evidence to support this scenario however is limited. Large-scale bi-polar outflows have been observed to originate from heavily embedded objects (Beuther et al. 2002, A&A 383, 892); and anecdotal studies have found evidence of accretion disks in individual massive protostars (Patel et al. 2005, Nature 437, 109; Beltran et al. 2006, Nature 443, 427).

To measure the morphology of young, massive stars in formation we propose adaptive optics assisted observations with the NIFS integral field spectrograph on the 8-meter Gemini Telescope. These observations aim to spatially resolve the proto-star and its immediate environment on small ($<0.05''$) scales. These observations are designed to search for a rotationally-flattened 'torus', search for a bipolar winds and test whether they are aligned perpendicular to the disks. We have selected 10 stars that have luminosities ranging from (1-6) $\times\,10^4\,L_\odot$, and hence cover a predicted mass range of ~ 10–$20\,M_\odot$. This program will be the first step creating a firm statistical footing for the accretion-disk-plus-bipolar-jet formation scenario for massive stars over a range of stellar masses.

Proposal 2: The formation of Lenticular Galaxies

Lenticular, or S0, galaxies make up $\sim 25\%$ of the galaxy population in the local Universe (e.g. Dressler, 1980, ApJ, 236, 351), so understanding how they form must constitute a significant element of any explanation of galaxy evolution. Their location at the crossroads between ellipticals and spirals in Hubble's tuning-fork diagram underlines their importance in attempts to develop a unified understanding of galaxy evolution, but also means that it is not even clear to which of these classes of galaxy they are more closely related. One option is that S0's represent a transitional phase between spiral- and elliptical- galaxies If the transformation simply involves a spiral galaxy losing its gas content and fading into an S0, then clearly S0s and spirals are closely related. However, it is also possible that mergers can cause such a transformation: while equal-mass mergers between spirals create elliptical galaxies, more minor mergers can heat the original disk of a spiral and trigger a brief burst of star formation, using up the residual gas and leaving an S0. In such a merger scenario, the mechanism for creating an S0 is much more closely related to that for the formation of ellipticals.

Clues to which mechanism is responsible can be found in the "archaeological record" that can be extracted from spectral observations of nearby S0 galaxies. For example, the present-day stellar dynamics should reflect the system's origins, with the gentle gas stripping of a spiral resulting in stellar dynamics very similar to the progenitor spiral, while the merger process will heat the stars, resulting in kinematics more dominated by random motions, akin to an elliptical. In addition, the absorption line strengths can be interpreted through stellar population synthesis to learn about the metallicity and star formation histories of these systems. These dynamical and stellar properties can be compared to see if a consistent picture can be constructed for the formation of each system.

Here, we propose to measure the spectral properties of 20 S0 galaxies in the Virgo cluster. We will definitively tie down how closely S0 galaxies are linked evolutionarily to spirals, and to ascertain the degree to which this relationship depends on mass.

Proposal 3: The proper motion of a magnetar

Magnetars are young neutron stars, with extremely strong magnetic fields (B>10^{14} Gauss), whose extotic properties offer a window in to the extreme physics underying the final stages of stellar evolution. They are identified by periods of prolific bursting activity in the X-rays, with bursts lasting 10–100 milliseconds. Timing studies of their X-ray persistent emission have revealed coherent periodic modulations, interpreted as being due to the neutron star rotation. These periods range between 2–12 seconds, much slower than in the majority of pulsars with comparable ages.

Here we propose observations to constrain the properties of SGR 0501+4516 – one of the nearest magnetars by direct measurement of its proper motion using the NIRI camera on the Gemini telescope. The location of SGR 0501+4516 is close to a supernovae remnant, and it's age of ∼8000–20 000 years, and offset from the centre of this remnant (∼80 arcmin) suggests a proper motion in the range of 0.2–0.4″ per year if the two are related (i.e. was the magnetar the progenitor star that was ejected when the supernovae occured?). We already have two epochs of imaging, obtained ∼7 months apart, which provide evidence of proper motion at the 2σ level, with a direction consistent with the centre of the supernovae remnant. Here, we propose a further epoch of imaging which will have a baseline of 18 months to cleanly confirm or reject these results, and provide the first proper motion measurement for a magnetar.

Finally, a proper motion measure would also constrain the neutron star tangential kick velocity, which in itself depends crucially on the processes underlying core collapse. The measured offset from this star already suggests that this may be very high (> 1100 km/s).