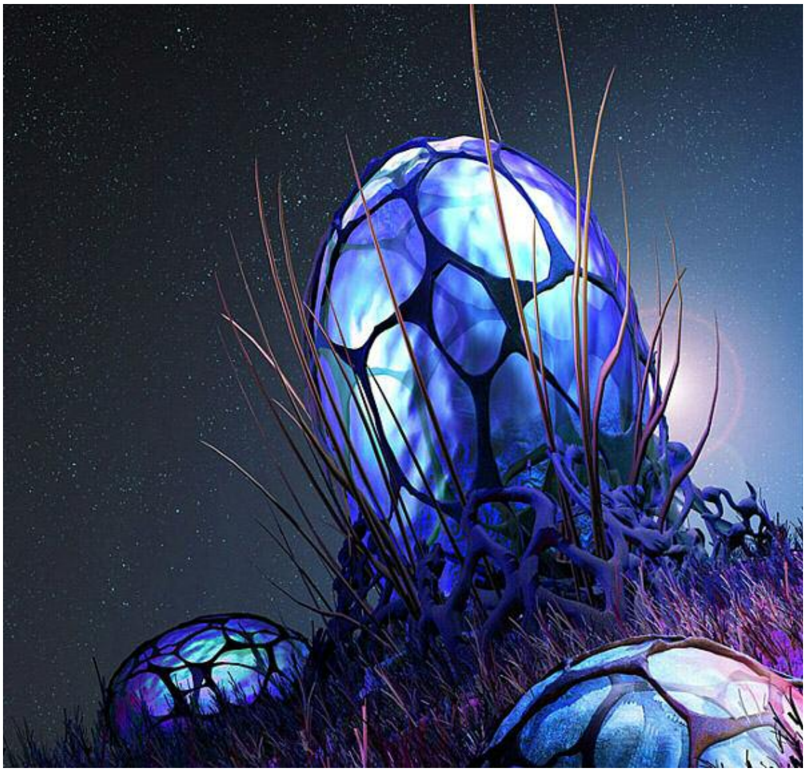
Exotic photo-synthesis in binary star systems

We don't normally think of extra-terrestrial plant life, but it could be just this that we first detect on another planet, thanks to the traces left in the atmosphere by exotic photosynthesis. What would this plant life look like if illuminated by a light different from that of the Sun?



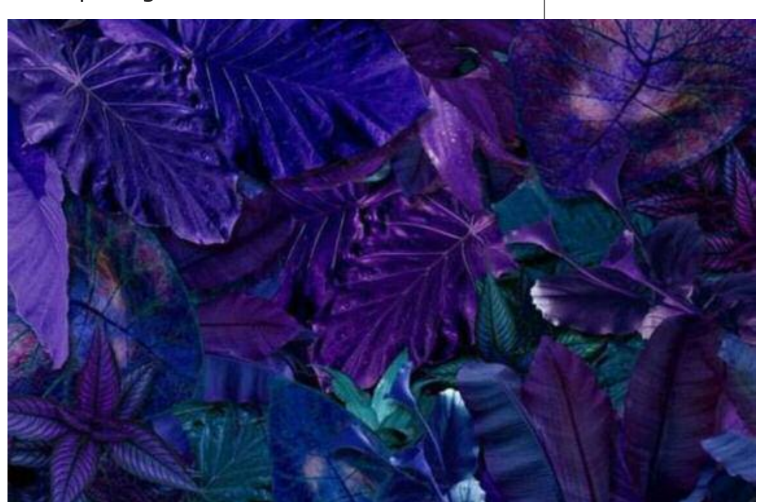
In the images on this page we see some representations of what plant life, illuminated by a star other than the Sun (especially red dwarfs), might look like.

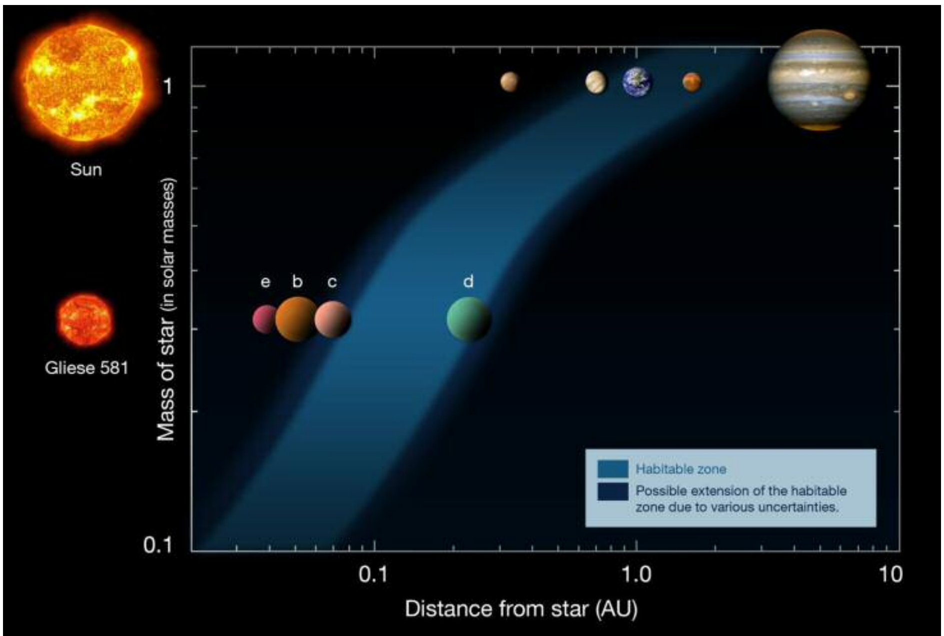
The question of whether there is life on other worlds is an ancient one, dating at least as far back as the Atomist philosophers, who put forward the idea that there were other worlds in other parts of the Universe, populated with "races of different men and animals" – Lucretius. These ideas have persisted over the centuries, but it is only in recent years, with the birth of the field of astrobiology, that we are able to scientifically test these ideas.

Astrobiology is the study of life in the Universe, both on and beyond our own planet. While we have not yet found life elsewhere, we do have the ability to detect it if it is there; the difficult part is knowing where to look in the vastness of the cosmos.

The best chance of successfully detecting extraterrestrial life would come from looking for life resembling that on Earth – life as we know it. On Earth, photosynthesis (the conversion of sunlight into chemical energy) is the basis for the majority of life. It is the energy source for plants and, hence, animals higher up the food chain. This makes sense as the Sun is the most abundant, long-lived, easily exploitable source of energy available and it is likely that, if life developed on other planets, it would choose to use that planet's star as a primary energy source.

Extraterrestrial oxygenic photosynthetic life is of particular interest, because, if it is present on a large enough scale, it will produce tell-tale signatures of atmospheric oxygen and ozone, which would be detectable remotely from Earth. These signatures, along with the presence of liquid water, would produce a compelling case for the existence of life





Comparison between the habitable zones of the Sun and Gliese 581, a red dwarf with planets in a favourable position (although, for other reasons, not particularly suitable for life).

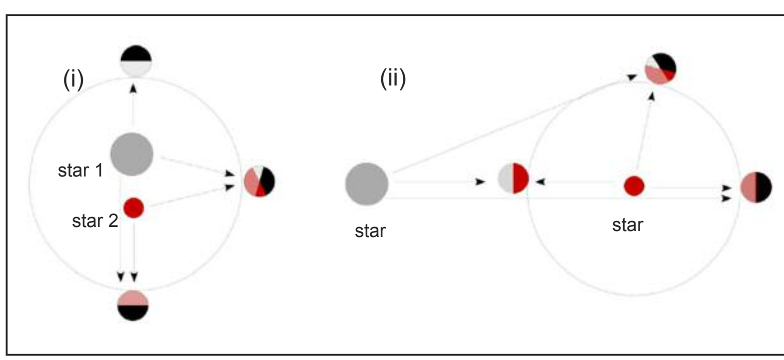
on a planet. Research has already been carried out that speculates on the nature of plant life on extrasolar planets with host stars of different types to our Sun (see for example work by Nancy Kiang or John Raven). However, approximately half of the star systems in the galaxy are composed of two or more stars, which leads to the question of how life might evolve differently when presented with two (or more) energy sources, especially if those energy sources were two very different types of star.

It was once thought that it would be difficult for planets to exist in binary or multiple star systems as it was thought that the gravitational pull of many stars would prevent a planet following a stable orbit. However, it is possible for stable orbits to form in binary systems. If the stars are close together, a planet could orbit both stars as if they were a single star ((i) in the diagram below), or if the stars are further apart, a planet could orbit one of the two stars ((ii) in the diagram below).

Many extrasolar planets have now been found in such systems, most notably two planets with masses less than 10 times the mass of Earth: 55 Cnc e (an 8.3 Earth-mass planet found in a binary star system consisting of a G star and an M star) and GJ 667C b (a 5.7 Earth-mass planet found in a trinary system consisting of an M star and two K stars).

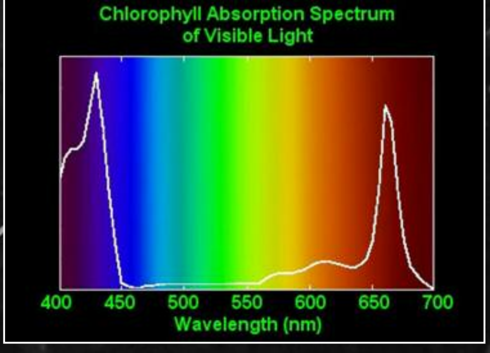
My investigation focused on the influence of G type (Sun-like) stars and M type (red dwarf) stars on the characteristics of photosynthetic life on an Earth-analogue planet within the continuously habitable zone in which a planet could retain liquid water on its surface over the geological timescales necessary for life to evolve in binary and three-star systems.

G and M type stars were chosen because the former are known to host a number



Planetary orbits in (i) close binary and (ii) wide binary systems. The shaded regions on the planet represent the area illuminated by each star at different points in the orbit.

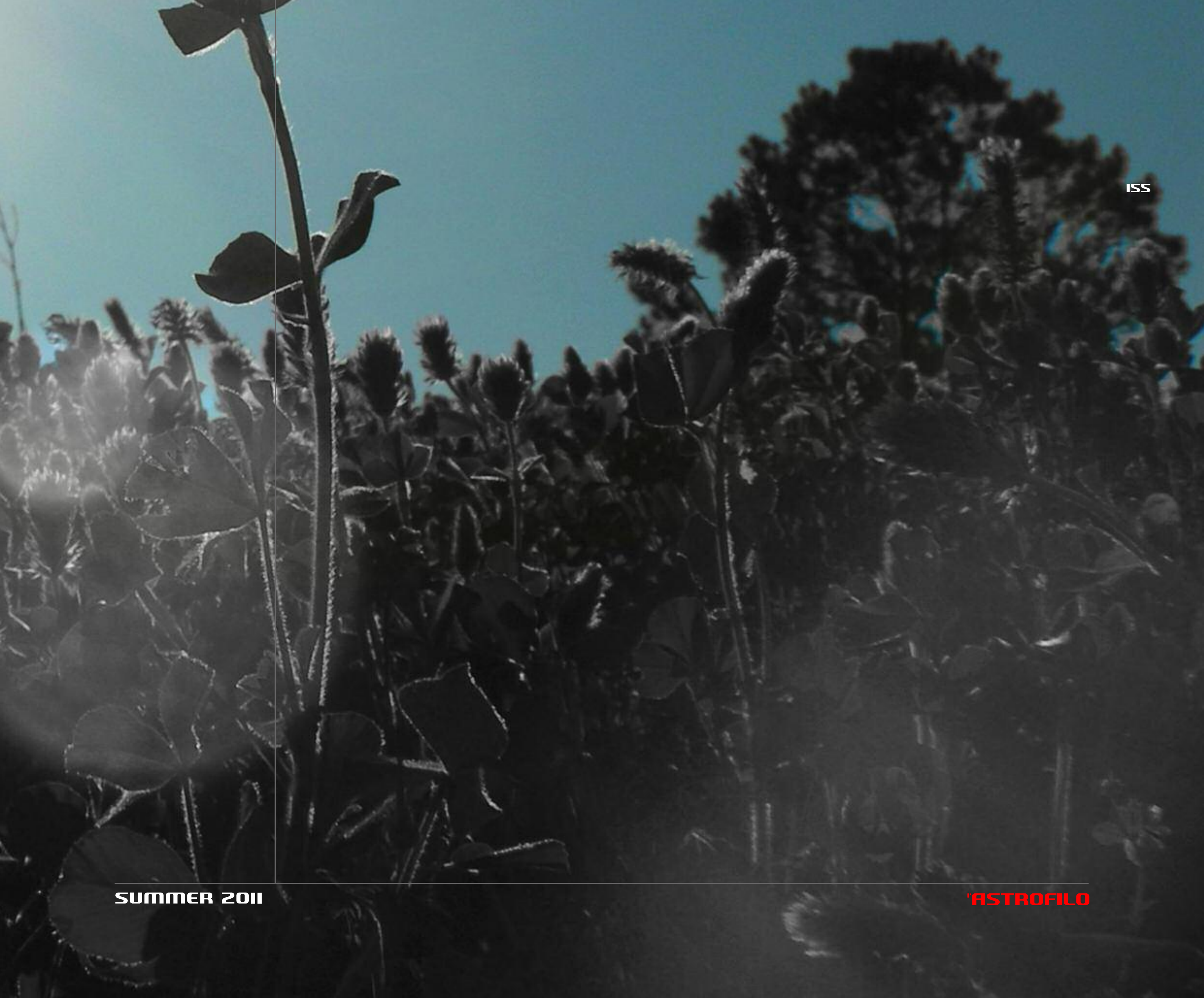
of extrasolar planets and the latter are the most abundant stars in the galaxy. Furthermore, approximately 57% of G stars are found in multiple systems and, though only 25-30% of M stars are found in multiple systems, there are so many M stars in the galaxy that 25-30% is still a very large number.
A survey carried out by Duquennoy and Mayor suggests that M and G stars occur together in multiple systems fairly frequently.
Combinations of M and G stars in close-binaries, wide-binaries and three-star systems consisting of two close stars and a third, more distant star (essentially a combination of the first two cases) were investigated.
The peak photon flux (the wavelength of the most numerous photons emitted) from each of the stars in each scenario was modelled. On Earth, the wavelength range used by photosynthesis is centred on the wavelength just below that of maximum photon flux from the Sun (approximately half way between the two peaks in the diagram below); hence, knowing the maximum photon flux from



stars allows assumptions to be made about the reaction centre wavelength used in photosynthesis.

For G stars, the peak photon flux occurs at a wavelength of approximately 643 nm and for M stars it occurs at 991 nm. It was necessary to measure the photon flux densities at these wavelengths for each star as a sufficient number of photons per unit area per second would need to be arriving on the surface of a planet in order to drive photosynthesis.

The simulations suggest that planets in multi-star systems may host exotic forms of the more familiar plants we see on Earth. A planet orbiting close to an M star with a more distant G star companion would have a photosynthetic light regime dominated by infrared radiation. There would be an adequate infrared photon flux density to compensate for the theoretical need for a greater quantity of photons required for oxygenic photosynthesis reactions to occur at these long wavelengths. In such infrared-dominated radiation environments, vegetation may have more photosynthetic pigments in order to make use of



a fuller range of wavelengths, giving them a darker appearance.

How might photosynthetic life adapt to the presence of two different radiation environments? Would it use G star radiation, M star radiation, or a combination of both?

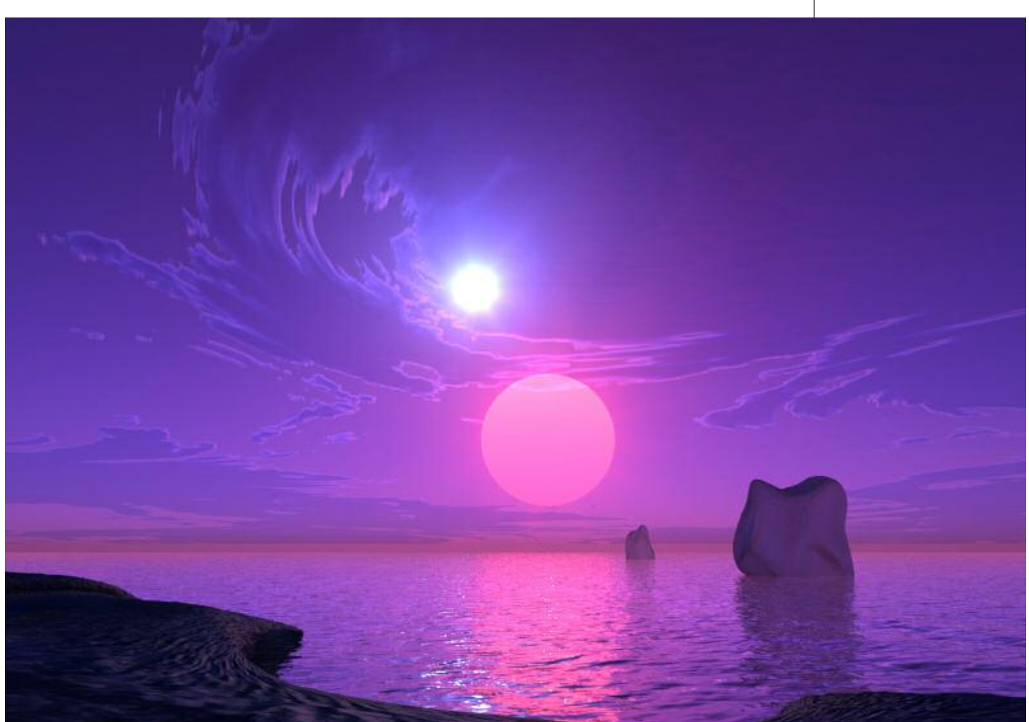
For the example of an M and G star in a close binary arrangement, a habitable planet would be approximately 1 AU from the barycentre. At this distance the photon flux density from the M star would be much lower than that from the G star, suggesting that G star radiation would be preferred, although there may be some environments on such a habitable planet that make using infrared photons preferable, perhaps due to the light attenuation properties of a certain habitat.

The case for photosynthetic organisms adapted to use both forms of radiation is harder to make.

It would be complicated and expensive in terms of energetic investments to house both of these systems in a single organism.

The possibilities become more interesting for the wide binary M-G star scenarios. The primary star's radiation always has a greater magnitude than that of the distant secondary star; however, there are periods where a portion of the planet would be illuminated only by light from the less photosynthetically favourable secondary star. When the G star is the planet-hosting star, the M star is too distant to make any useful contribution to a habitable planet's photosynthetically active radiation. However, if the M star hosts a planet, some organisms may evolve to exploit the low photon flux density from the distant G star, as G-star-only illumination can persist in

Some further examples of what alien plant life may look like (based on terrestrial species).



A red dwarf and a more distant solar-type star set close in the sky of a distant Earth-like planet.

A three-star system as seen form the surface of the moon of an extra-solar planet.

some regions on the planet's surface for a significant portion of its orbit.

On Earth specialists tend to be more successful than generalists when there is a large range of resources available in a habitat. The changing radiation regimen in M-G binary systems raises the possibility of spectral niche variation, with different organisms in the same habitat adapted to use radiation from different stars at different times in the planet's orbit. Evolving a mechanism to exploit both types of radiation available in a habitat, switching between the two in response to the changing environment may be a too costly a strategy to be favourable. It is more likely that two distinct categories of organism would evolve under these conditions; each adapted to make use of one form of radiation or the other, perhaps entering a dormant state when the necessary radiation conditions are absent.

Similar arguments would apply to three-star systems.

There are a number of different arrangements of multiple star systems in which Earth-like planets can be classed as habitable; each providing unique environments and a variety of possibilities for oxygenic photosynthetic life.

These results suggest that binary and multiple star systems are plausible targets in the search for extrasolar oxygenic photosynthesis.

Jack O'Malley-James began his academic life in physics, then he moved on to biology before settling into the astronomy department in St. Andrews to put the two skill sets together to the task of astrobiology. He his now coming to the end of the first year of a PhD investigating how biosignatures on extrasolar Earth-analogue planets evolve over the main-sequence lifetime of their host stars.