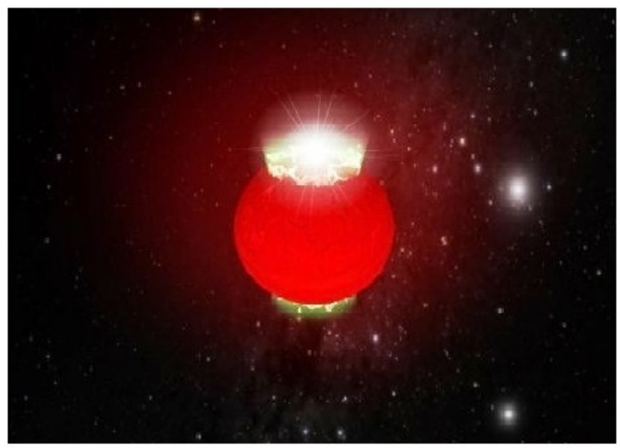
Enhancing Our Understanding of Ultracool Dwarfs with Arecibo Observatory

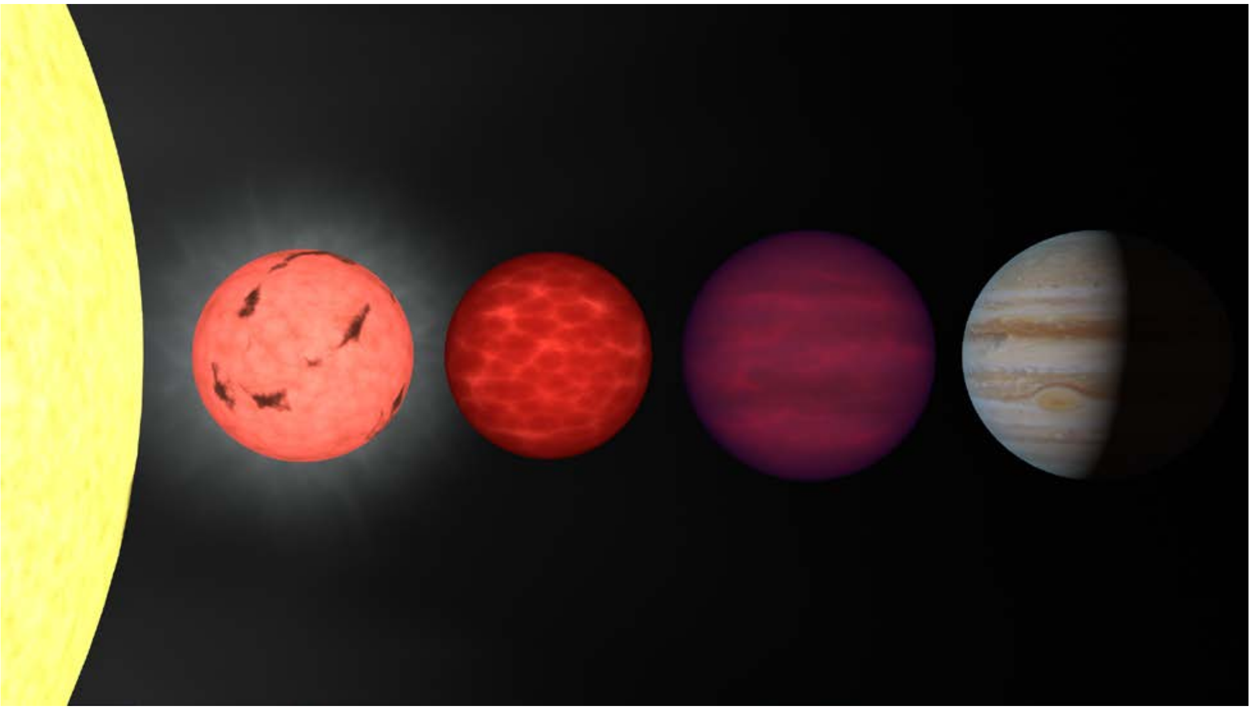
Arecibo Observatory has recently been involved in searches for bursts of radio emission from ultracool dwarfs, which bridge the stellar and planet regimes in terms of their physical properties. In the Solar System, the Earth, Jupiter, and Saturn have all been shown to have detectable radio emission emanating from their magnetic poles. This radiation is emitted by charged particles from the solar wind spiraling along planetary magnetic field lines. They are responsible for the appearance of aurorae in the upper atmospheres of these planets. Similarly, stars of various types, including the Sun, exhibit activity such as starspots, flares, and prominences that have accompanying radio emission components. Understanding the radiation mechanisms involved in these phenomena allows us to study the magnetic fields and magnetospheres of very low mass stars and brown dwarfs, commonly called ultracool dwarfs (UCDs), providing insights into the physics of these fascinating objects.

At left, Arecibo University at dusk (Cornell University). At right, an artist's impression of flaring emission from a brown dwarf (Gregg Hallinan, California Institute of Technology).

The study of radio emission from UCDs is important because:

- Radio emission provides a unique means to study magnetic fields of these objects.
- Understanding the properties of UCD radio emission allows for an assessment of how the internal and magnetospheric physics, as well as activity of substellar objects evolves from low mass stars, through brown dwarfs, to planets.
- Measurements of the magnetic fields of brown dwarfs and extrasolar planets give insight into the internal structure and processes that generate them.
- The detection and characterization of radio emission from cool brown dwarfs informs attempts to discover radio emission from extrasolar planets.
- **The detection of magnetic fields around extrasolar planets would help to assess the likelihood of life elsewhere in the Milky Way. The terrestrial magnetic field protects life here on Earth from harmful interactions with charged particles from the Sun, and similar fields would likely be necessary to shield life elsewhere.**



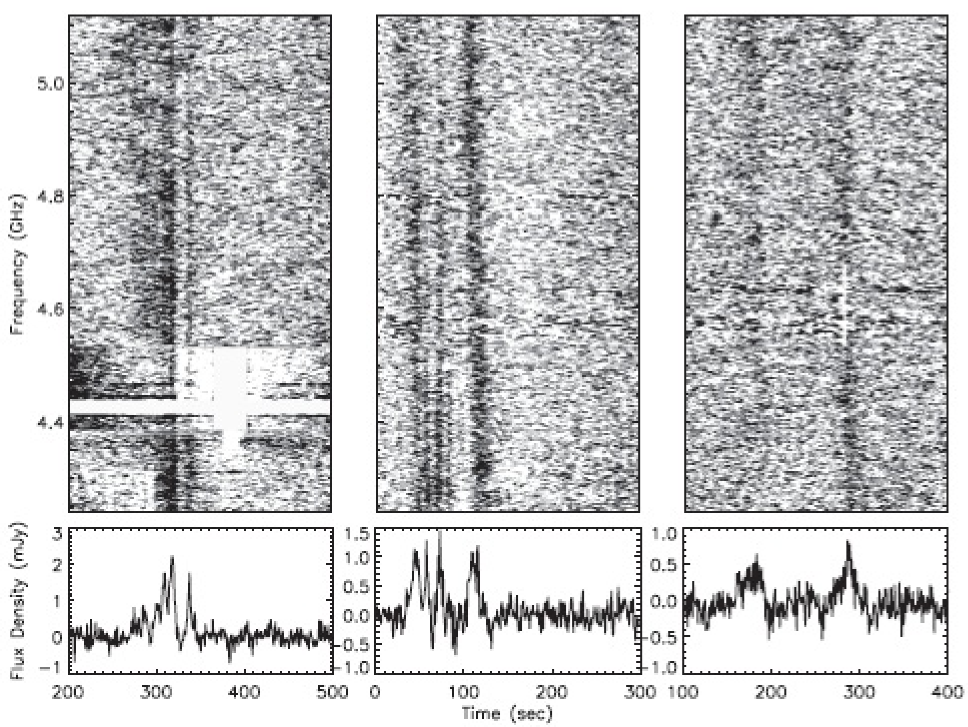
An artist's impression of the relative sizes and colors of the Sun, a red dwarf (M-dwarf), a hotter brown dwarf (L-dwarf), a cool brown dwarf (T-dwarf) similar to J1047+21, and the planet Jupiter. Credit: NASA/IPAC/R. Hurt (SSC).

High quality data provided by the Arecibo radio telescope allow scientists to determine a variety of properties of the UCDs, such as:

- Magnetic field strength and geometry
  - Can be determined by relating the frequency of maximum emission to the cyclotron frequency. The properties of the field can be inferred from the short-term and long-term temporal behavior of the observed emission.
- Radio emission mechanism
  - Can be identified by combining knowledge of the source's brightness temperature and the polarization fraction of the radio emission. A low brightness temperature and polarization fraction are indicative of gyrosynchrotron radiation, while large values for both quantities indicate electron cyclotron maser instability as the emission mechanism.
- Size of the radio-emitting region
  - There are several ways to estimate this. For example, by measuring the time scale of the shortest temporal variations, and invoking the light travel time argument, one can derive an upper limit to the size of the emitting region. Another possibility is to infer the source size from measurements of the magnetic field strength, and frequency drift rate of radio bursts, assuming the field geometry and velocity of the emitting plasma along the field lines.
- Rotational period of the object
  - Can be measured, if the observed radio bursts are periodic.

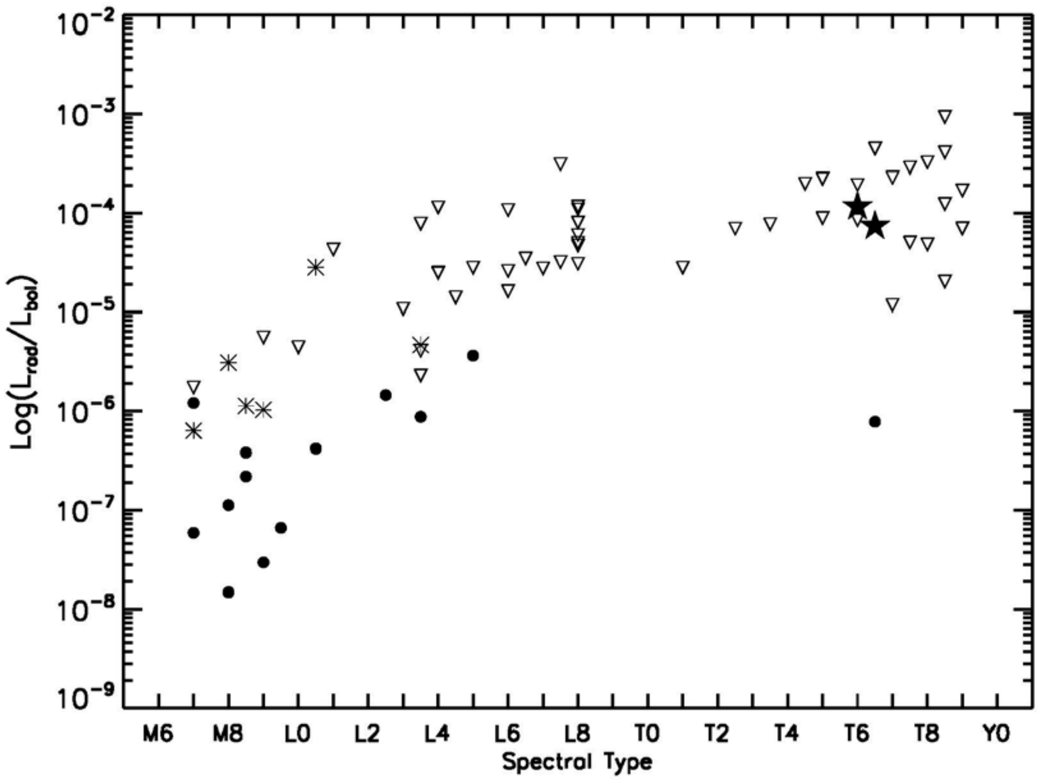
- Whether the radio emission originates from persistent active regions, like starspots, or from temporary plasma cavities, such as for terrestrial radio emission
    - Can be inferred from high time resolution observations, and long-term monitoring of the source
    - Precision timing of the periodic flares can also be used to detect differential rotation of the star
- Whether the magnetic field is stable over a long time period
    - Can be determined by long-term monitoring of the source.
- Whether the object is in a binary system
    - This can be determined from timing measurements of objects that exhibit a periodic radio emission.
- Plasma motion along the line of sight
    - Indicated by the frequency drift observed in time-frequency spectrograms.
- Electron density of the plasma giving rise to the emission
    - Computed from the observed frequency of maximum emission, assuming that it has to be higher than the local plasma frequency.

Observations with the Arecibo radio telescope have already helped pushing the existing limits in this course of scientific inquiry by discovering the coolest known radio star, J1047+21, a T6.5 brown dwarf with an inferred temperature of approximately 900K.



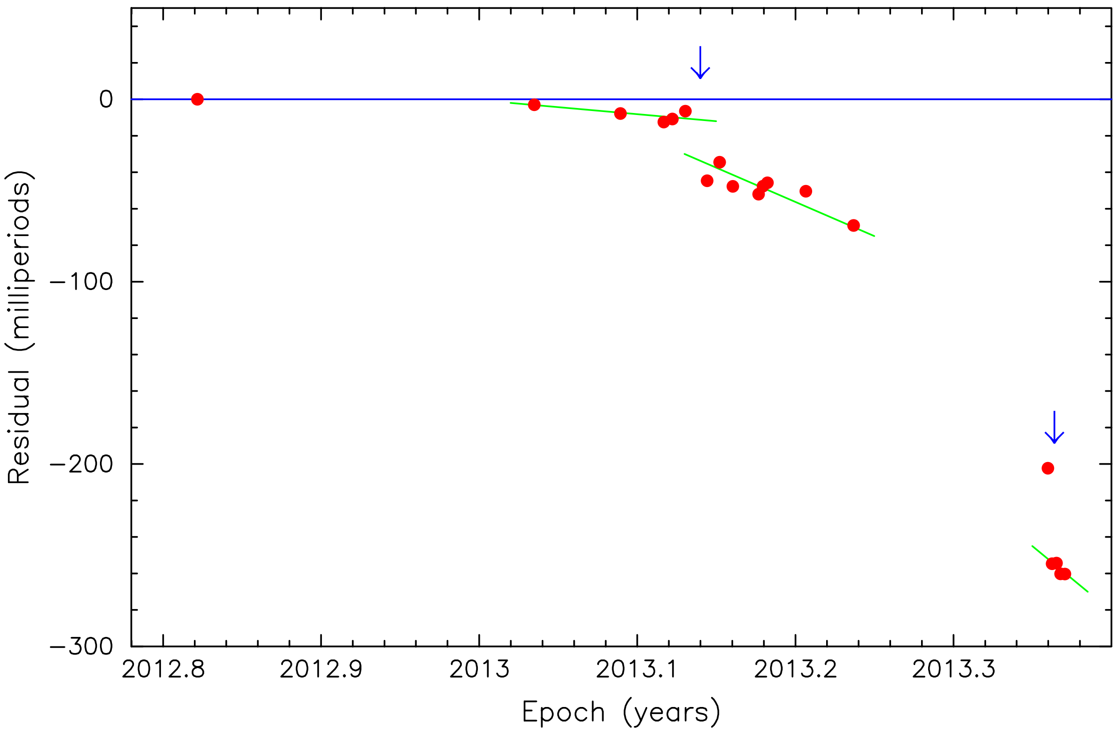
Time-frequency spectrograms and time series of Stokes V fluxes for three burst events from J1047+21, the coolest known brown dwarf for which radio emission has been detected. For the spectrograms, darker colors represent larger flux densities of right-handed circular polarization. In the first spectrogram, the white regions near 4.4 GHz and 380 s are artifacts from radio frequency interference (RFI) removal. The spectrograms have been smoothed and binned to a resolution of 6 s and 2 MHz in time and frequency, respectively. The time series have been integrated over the entire 1 GHz bandpass and binned at 0.9s time resolution (Route, M. & Wolszczan, A., *ApJ*, **747**, L22 (2012)).

Radio surveys of ultracool dwarfs conducted at Arecibo have expanded the number of dwarfs surveyed for radio activity by 13%, and have detected 22% of the known or suspected radio flaring brown dwarfs.



A diagram of the logarithm of the ratio of the radio luminosity to the bolometric luminosity versus spectral type for ultracool dwarfs. Asterisks denote the radio flares detected prior to the Arecibo radio survey of ultracool dwarfs. Inverted triangles depict the upper limits of radio emission from various sources surveyed at Arecibo. Filled stars denote the locations of the radio flaring brown dwarf 1047+21 (T6.5) (Route, M. & Wolszczan, A., *ApJ*, **747**, L22 (2012)), and another T-dwarf recently detected at Arecibo (Route & Wolszczan, in preparation).

High time resolution data from Arecibo over a long temporal baseline have led to the very possible detection of differential rotation in an ultracool dwarf.



Phase residuals from the best fit of a fixed-period model to the arrival times of radio flares from the M9 UCD, TVLM 513, observed with the Arecibo radio telescope at 5 GHz. The flare arrival times become progressively earlier compared to the predicted ones, because of the shortening of the apparent rotation period of the UCD. The two consecutive phase jumps marked with arrows are readily apparent. Green, sloping lines indicate the increasing rate of shortening of the period after each jump. This flare behavior can be explained in terms of a combined effect of the active region's latitudinal migration and the UCD's differential rotation, just as in the case of the sunspot migration and the differential rotation of the Sun (Wolszczan, A. & Route, M. *ApJ*, **788**, 23 (2014)).

For detection and detailed study of the UCDs, Arecibo is important because:

- Its large collecting area provides exquisite signal sensitivity needed to reliably detect and characterize weak, polarized radio flares with typical fluxes in the 0.5 - 5 mJy range.
- The MOCK spectrometer allows for the determination of full polarization of incoming signals at high frequency resolution, providing over 1 GHz of simultaneous frequency coverage. The exquisite temporal resolution of the spectrometer allows for a native time resolution of 0.2 ms, with excellent signal to noise ratios obtained for temporal integrations of 0.1 s or greater. Dynamic spectra measured this way are of unique quality and contain a wealth of information concerning the physical characteristics of the emitting body.