Astro2020 Science White Paper

Secular Transient Radio Sources

Thematic Areas: ☐ Planetary Systems ☐ Star and Planet Formation
☐Formation and Evolution of Compact Objects ☐ Cosmology and Fundamental Physics
X Stars and Stellar Evolution ☐Resolved Stellar Populations and their Environments
X Galaxy Evolution ☐Multi-Messenger Astronomy and Astrophysics

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Abstract (optional):

The discovery and subsequent study of slow (days to years) "secular radio transients" are reviewed in this White Paper via consideration of a number of representative examples. These are chosen to include both Galactic and extragalactic instances, and include both spectral-line and continuum transients. The major contributions by large single-dish telescopes such as the GBT at the Green Bank Observatory and the Arecibo 305-m telescope are highlighted. The important contributions that these large-aperture instruments have made to high-resolution follow-up studies using VLBI networks such as the HSA, EVN and the Global Array are also illustrated. Keeping these telescopes at the cutting-edge via adequate support and state-of-the-art instrumentation is vital to their contributing to these important endeavors.

Secular Transient Radio Sources

1. Introduction

Large single-dish radio telescopes such as the Green Bank Telescope (GBT) and the Arecibo 305-m telescope have demonstrated their preeminent position in the study of fast (millisecond) transient radio emitters such as Fast Radio Bursts (FRBs) and Rotating RAdio Transients (RRATs), However, they have also contributed greatly to the discovery and study of slower, secular transient events, both Galactic and extragalactic. This they have done both in their own right, and as the major photon-collecting elements in very long-baseline interferometer arrays such as the High Sensitivity Array (HSA) and the European VLBI Network (EVN). With their utility in these roles expected to continue for the foreseeable future, this document presents a selection of their achievements in the field of “slow transient” research, and mentions their likely future contribution to this given current technical and support developments.

2. Radio Transients Associated with AGN: Tidal Disruption Events

In recent years a number of transient radio sources have been localized within the nuclear regions of galaxies, these often being associated with jet formation. A likely cause is either (a) the infall of a gas cloud on to the central super-massive black hole (SMBH) of the galaxy (e.g. Park et al., 2015, A&A, 576, L16), or (b) a "tidal disruption event" (TDE) caused by a star passing within the "tidal radius" of the SMBH and being torn asunder, with part of its material being ingested by the BH, and the remainder being ejected as a high velocity jet (Rees, 1988, Nature, 333, 523; Zauderer et al., 2011, Nature, 476, 425; Bower et al., 2013, ApJ, 763, 84). As of August 2018, "the Open TDE Catalog" run by CfA contained 87 entries of "TDEs and possible TDEs" (https://tde.space/). The evolution of an outburst's morphology and the associated line and continuum light curves can provide detailed tests for many of the models proposed for TDEs.

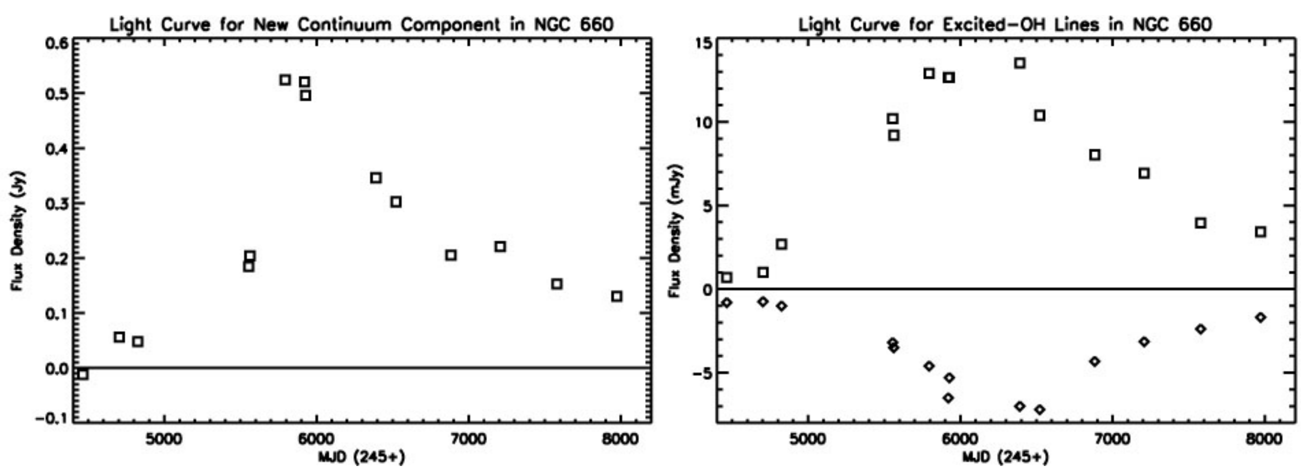

Fig 1: (Left) The 4.7-GHz light curve of the NGC660 transient continuum component. (Right) The light curves of NGC660's transient excited-OH molecular lines. The data at the top (squares) represent the mean peak intensities of the strongest emission components at 4750- and 4765~MHz, while the data at the bottom (diamonds) show the mean peak intensities of the two 4660-MHz absorption components.

While most TDEs have been seen to evolve on a timescale of less than one year for all wavelength ranges, and been found in quiescent, post-starburst galaxies, presumably representing the destruction of low-mass stars, a number of long-lasting transients associated with AGNs have been recently monitored that likely represent high-mass TDEs. These longer-lasting events have evolved over time scales of at least a decade. For example, the transient in the Luminous Infra-Red Galaxy, NGC 660 was discovered at Arecibo in 2008 and has been monitored by that single-dish telescope both via its radio continuum emission, and its strong, variable molecular lines, particularly of the excited 4.7-GHz transitions of excited-OH (see Fig. 1). HSA VLBI observations (including the GBT and Arecibo) show the presence of a helically-precessing, single-sided, and hence relativistic, jet centered on the weak compact nucleus of the galaxy, with strong diametrically-opposed hotspot pairs. These hotspots display associated excited-OH megamaser emission and absorption (Fig. 2). NGC 660's nucleus being a region of extremely high opacity, this bright, local transient event was only seen at radio wavelengths.

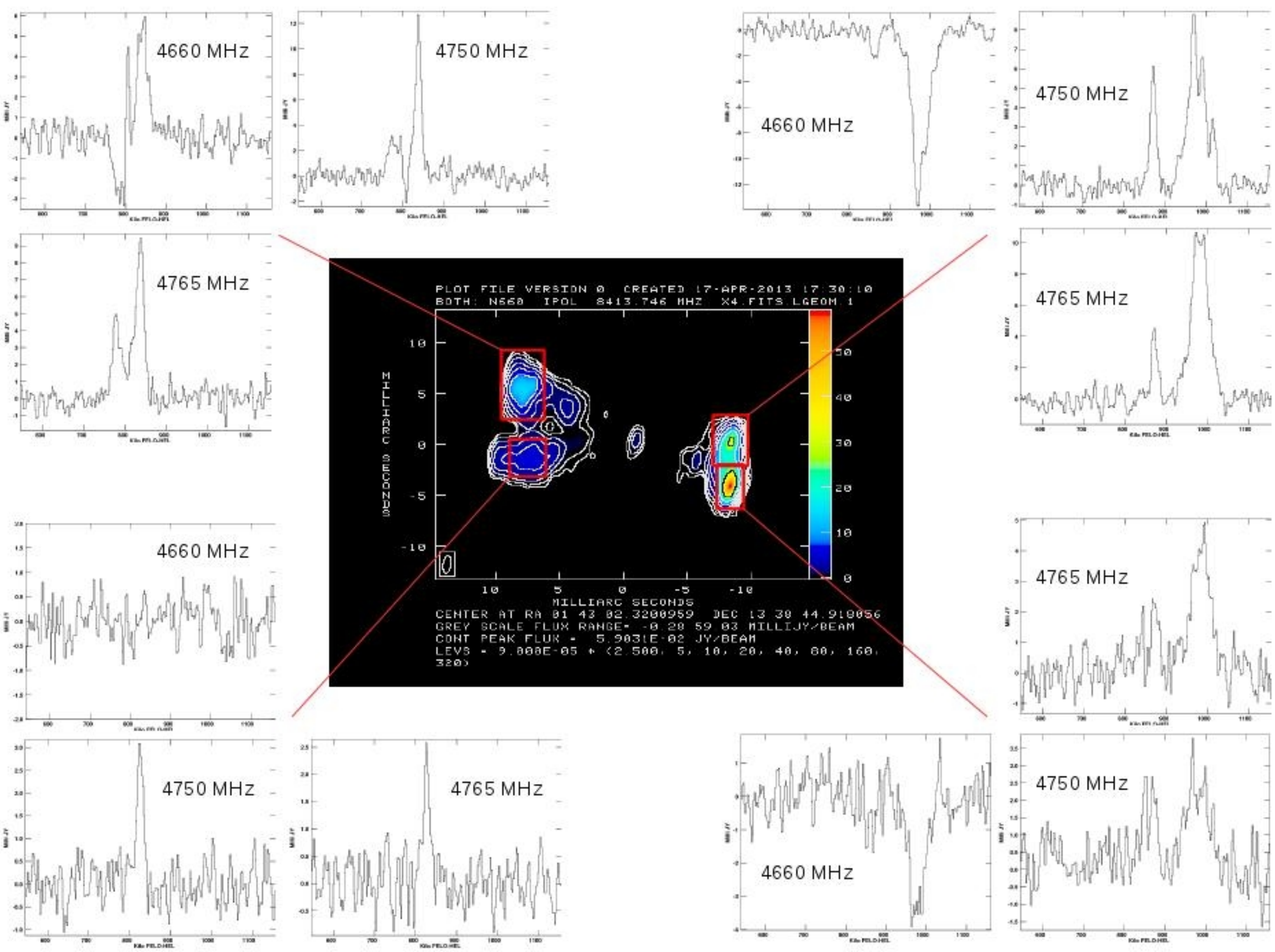

Fig 2: (Center) The HSA continuum images of NGC~660 at 8.4~GHz, (HPBW = 1.6 × 0.7 milliarcsec at P.A. = --5.9 deg. (Surround) The integrated 4.7-GHz excited-OH lines from the regions of the 4 “hotspots'” seen in the continuum image.

Similarly, a transient source was discovered in 2005 by Mattila et al. (2018, Science, 361, 482) in the western nucleus of the merging galaxy pair, Arp 299. While bright in the infrared and radio, this transient was not luminous at optical or X-ray wavelengths. They interpret this as a TDE with much of its emission re-radiated at infrared wavelengths by dust. VLBI observations (EVN, VLBA and Green Bank) resolve an expanding and decelerating jet, probing the jet formation and evolution around the associated SMBH. A further likely TDE lasting for over a decade was recently discovered in the soft X-ray range within a dwarf starburst galaxy by Lin et al. (2017, Nature Astronomy, 1, 33).

Radio Supernovae

Core-collapse supernovae (i.e. SNe of Types Ib, Ic and II) produce strong, rapidly-evolving, transient radio sources which provide unique information on the detailed dynamics of the events, e.g. the circumstellar media (and hence pre-outburst mass loss), the parameters and configurations of magnetic fields in the developing remnant shells, and on outburst asymmetries. As even in nearby galaxies the angular diameters of radio SNe are tiny, the high resolution of VLBI is needed to study these transient sources. Moreover, their relative faintness, with surface brightnesses that fall rapidly with decreasing flux density and increasing angular diameter, decrees that the largest possible telescopes participate in the VLBI arrays used. All these points are well illustrated by a study of SN1993J which exploded in the nearby galaxy, M81 (distance = 3.6 ± 0.3 Mpc). Bietenholz et al. (2003, ApJ, 597, 374) produced a sequence of 31 images covering from 50 days to ~9 yr after shock breakout allowing a remarkable study of the evolution of the expanding radio shell. A number of these images are shown in Fig 3. Attention is drawn to the the second and third images down in the right-hand column which were the only ones in that column to benefit from the presence of the GBT. Their superior quality is notable.

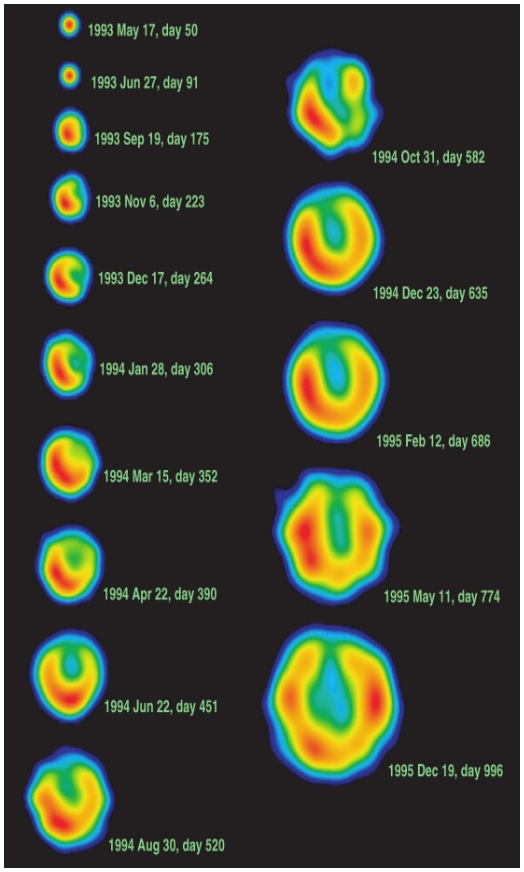

Fig. 3: VLBI Images of SN1993J at 8.4 GHz in false color. The brightness scale runs from 16% to 100% of peak brightness in each image.

Galactic Maser Transients

A transient molecular maser is illustrated in Fig. 4. This was discovered by Strack et al. (2019, ApJ, submitted) in the 4765-MHz satellite transition lines of the $^2\Pi_{1/2}$ J=½ state of the excited OH molecule in the pre-planetary nebula, CRL 618 (the Westbrook Nebula), and is the first detection of 4765-MHz OH in a late-type stellar object. It was detected strongly by two separate groups in May and October 2008, but had vanished in follow-up observations in 2015 and 2017 (Fig. 4). Despite its strong detection in 2008, it was not seen in other other transitions of OH from the 1.6 GHz main lines up to the excited lines at 8.6 GHz.

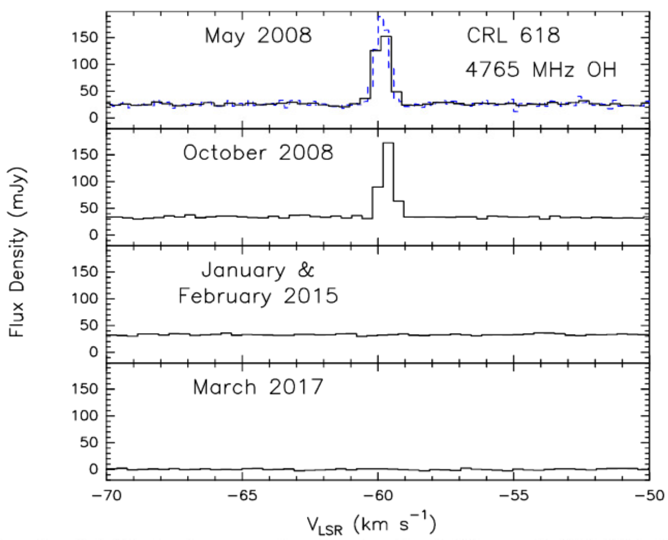

Fig. 4: The 4765 MHz excited-OH maser in CRL 618 detected in 2008, but not seen in 2015 and 2017. The dashed line in the top panel shows higher resolution data, smoothed to the resolution of the other spectra as shown by the solid line.

Transient emission is also found on occasions associated with OH/IR stars. A good example was documented by Lewis (2005, BAAS, 37, 1335) for the low-mass OH/IR star, IRAS 19479+2111, whose 1612-MHz main-line OH maser emission suddenly flared by a factor of over 100 having previously faded into invisibility for over a deacade despite a likely pulsation period of about one year. Lewis interpreted this to indicate a strong modulation in the mass-loss rate from this star, accompanied by dust formation.

A further example of transient maser emission resulted from spectra taken with the Arecibo 305-m telescope for a students' "Hands-on" experiment for the 2013 NAIC-NRAO "Single-Dish Summer School". This project looked for the 4.7 GHz excited-OH lines, (plus the 4.829 GHz H 2 CO line, and the H(110)α hydrogen recombination line) from six HII regions, detecting OH lines from five of the targets. Fig. 5 shows the resultant spectra for the compact HII region, W49N at 4660 MHz, and compares it with a spectrum of the same line acquired with the 76-m Jodrell Bank Lovell telescope acquired in 1989 (Cohen et al., 1991, MNRAS, 250, 611). While both the 1989 and 2013 spectra clearly show broad "quasi-thermal" emission, in 2013 the 4660-MHz transition shows two strong, very narrow, maser emission lines that were not present in the earlier spectrum. These are only the eighth

4660-MHz maser emission lines yet seen from an HII region. It is to be mentioned that while the 4750-MHz main line had not changed over the intervening 24 years, strong 4765-MHz maser lines were seen in 1989 that had completely changed their radial velocities and intensities in the interim.

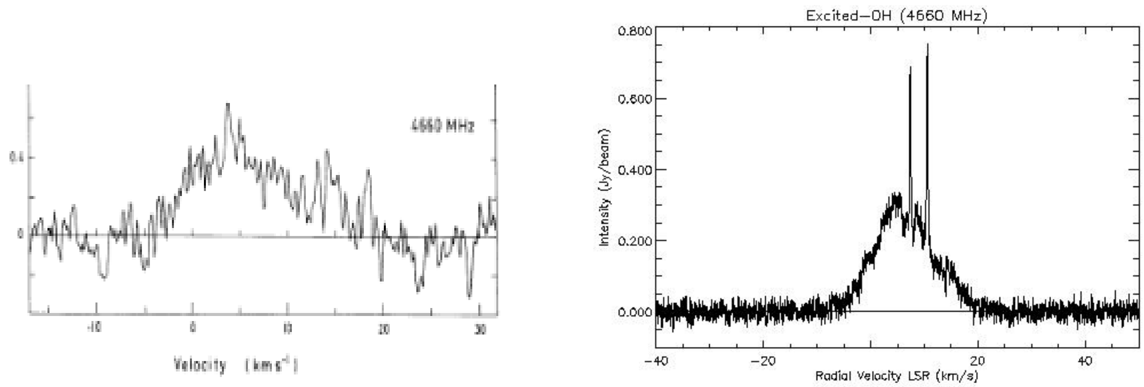

Fig. 5: (Left) The Jodrell Bank spectrum of the 4660-MHz excited-OH line from the compact HII region W49N acquired in 1989. (Right) The Arecibo spectrum of the same excited-OH line taken in 2013. The x-axes are LSR radial velocities in kms^{-1}, while the y-axes are intensities in Jy/beam.

The Discovery and Study of Secular Transients

While studies of radio supernovae (and novae) are usually triggered by (the increasing number of) high-sensitivity all-sky optical surveys, it is notable that many of the other events highlighted above resulted from serendipitous discoveries from observations made with large single-dish radio telescopes, such those at Green Bank and Arecibo. Once discovered, these secular transients are also very efficiently monitored by these same large aperture telescopes. Clearly both the monitoring of the light curves of these phenomena and follow-up VLBI studies benefit greatly from retention of state-of-the-art instrumentation on these major single-dish telescopes.

In practice, secular transients are rarely strong, and for the most sensitive, highest resolution studies with interferometer arrays in the radio regime, participation of the largest single dishes in the VLBI networks employed, (e.g. the HSA, EVN and Global Arrays), is often crucial.