Radio continuum observations of the Serpens and W40 star-forming regions

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Introduction

The Serpens molecular cloud belongs to a larger complex of local dark molecular clouds called the Aquila Rift. The region of $\sim 6'$ centered on the Serpens reflection nebulosity, known as the Serpens cloud core, is populated by more than ~ 300 objects found in many different evolutionary stages. At a angular distance of $\sim 3°$ to the south of the center of the Serpens core is located the star forming region known as W40. A cluster of near-IR sources is detected in TwoMicron All Sky Survey (2MASS) images within its central $5'$. This cluster has also been observed at radio and X-ray wavelengths. 20 compact sources in the central portion of the cluster have been detected at 3.5 cm. The X-ray observations reveal approximately 200 sources, the majority of which are thought to be low-mass YSOs. Very close to W40 in projection on the plane of the sky is located an embedded cluster of IR sources referred to as Serpens South. This cluster was reported by Gutermuth et al. (2008) from *Spitzer* observations of the Aquila rift region. They identified 54 Class I and flat-spectrum protostars and 37 Class II YSOs within a $14' \times 10'$ region.

Large numbers of visible YSOs and embedded infrared sources in star-forming regions are strong radio sources. Very little has been done, however, on the characterization of the Serpens, Serpens South and W40 regions at radio wavelengths. Radio continuum observations are relevant because they provide insights into thermal and non-thermal emission in YSOs, stellar coronal activity of YSOs, and magnetic fields.

In the present contribution we report on new sensitive and high angular resolution radio observations of the Serpens star-forming region. The observations cover large fields of view of the Serpens molecular cloud, the Serpens South cluster and the W40 region.

Observations

The Serpens molecular cloud, the W40 region and the Serpens South cluster were observed with the Karl G. Jansky Very Large Array (VLA) in its A configuration. Two frequency sub-bands, each 1 GHz wide, and centered at 4.5 and 7.5 GHz, respectively, were recorded simultaneously.

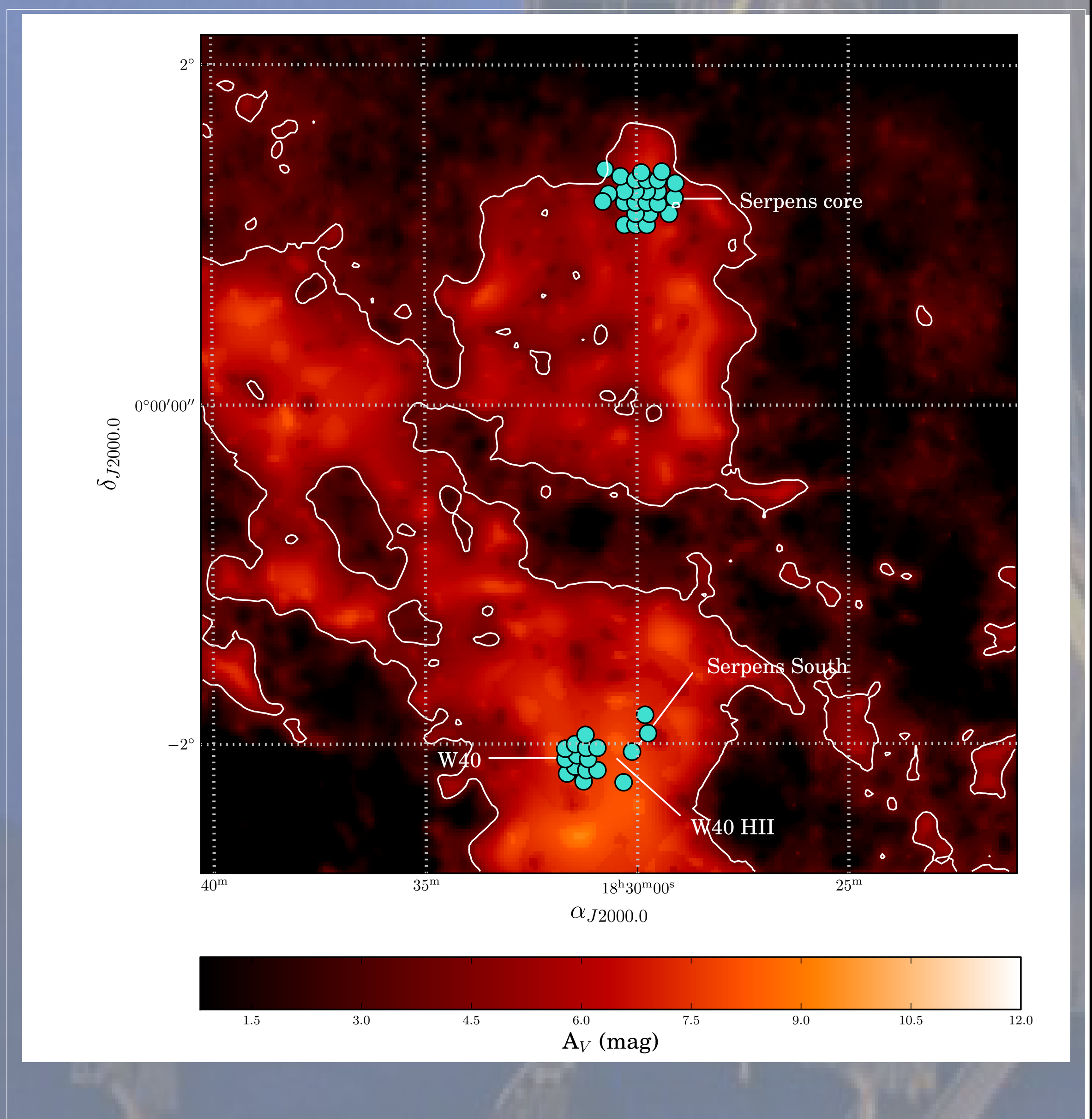

Figure 1: Extinction map of the Serpens star-forming region obtained as a part of the COMPLETE project based on the STScI Digitized Sky Survey data (Cambrésy 1999).

The Serpens molecular cloud and the Serpens South cluster were observed in the same observing sessions on three different epochs (June 17, July 19, and September 12, 2011). The W40 region was, on the other hand, only observed on two epochs (June 17 and July 16, 2011). This dual frequency, multi-epoch strategy was chosen to enable the characterization of the spectral index and variability of the detected sources, and help in the identification of the emission mechanisms (thermal vs. non-thermal).

A total of 25 VLA pointings were used to map an area of ~900 (530) square arcminutes at 4.5 (7.5) GHz of the Serpens molecular cloud. The covered area of the W40 region using 13 pointings was ~415 (280) square arcminutes at 4.5 (7.5) GHz. Additionally, 4 pointings were used for the Serpens South cluster, covering in this case an area of ~290 (110) square arcminutes at 4.5 (7.5) GHz. The standard flux calibrator 3C 286 was first observed for 10 minutes. We subsequently spent one minute on the phase calibrator J1804+0101 followed by a series of three target pointings, spending three minutes on each. This phase calibrator/target sequence was repeated until all target fields were observed.

Mosaics for the Serpens Molecular cloud and the W40 region were constructed. To produce images with improved sensitivity, the three or two epochs (in Serpens and W40 respectively) were combined.

Results

The identification of the radio sources was done using the images corresponding to the concatenation of all of the epochs. We detected 92 sources in the Serpens molecular cloud, 41 in the W40 region and 8 in the Serpens South cluster, giving a total of 141 detections. An estimation of the radio spectral index of each source was obtained from the fluxes measured in each sub-band (at 4.5 and 7.5 GHz). The level of variability of the sources was estimated by comparing the fluxes measured at the three or two epochs.

	Flux properties				Spectral
VLA Name	$f_{4.5}$ (mJy)	Var. (%)	$f_{7.5}$ (mJy)	Var. (%)	Index
J182951.04+011533.8	0.610	41.5	0.584	45.7	-0.09
J182951.17+011640.4	0.089	>50.7	0.075	>29.3	-0.35
J182951.17+010529.7	0.085	–	<0.04	–	<-1.71

Note: This table is available in its entirety in Ortiz-León et al. (in prep.). A portion is shown here for guidance regarding its form and content.

VLA source positions were compared with source positions from X-ray, optical, near- and mid-infrared catalogs. VLA sources were considered to have a counterpart at another wavelength when the positional coincidences were better than the combined uncertainties of the two datasets. The search was done in SIMBAD, and accessed all the major catalogs. Out of 141 VLA sources, only 33 had previously been detected at radio wavelengths, while the other 108 are new radio detections. On the other hand, we found a total of 56 counterparts at X-ray, near- and mid-infrared wavelengths, some of which have known radio counterparts. In total, the number of sources that were previously known (at any frequency) is 72, while 69 of the sources in our sample are reported here for the first time. 23 of the 72 sources with counterparts are classified in the literature as YSOs and are listed in the following table.

VLA Name	Spectral type	SED classification	Var.	α	X-ray	Ref.
J182933.07+011716.3	G2.5	Class III	Y	P	Y	1, 2
J182956.96+011247.6	M3.0	Class II	Y	P	Y	1, 2
J182957.89+011246.0	K1.0	Class II	Y	F	Y	1, 2

Notes: Var. = Y when the source variability is higher than 50% in at least one frequency; N when it is lower. α refers to the spectral index, and is given as P (for positive) when it ishigher than 0.2; F (for flat) when it is between –0.2 and +0.2, and N (for negative) when is is lower than –0.2. X-ray = Y when there is a X-ray flux reported in literature, N when it is not. 1= Giardino et al. (2007); 2 = Winston et al. (2010). This table is available in its entirety in Ortiz-León et al. (in prep.).

It is worth a mention that out of the 81 sources unclassified in the Serpens molecular cloud, 24 have a positive spectral index or exhibit high variability (both characteristics of young stars), and they can account for a small population of YSOs in that region.

Discussion

We analyze the radio properties of the YSOs detected in our observations. The variability at both frequencies increases, on average, with the evolutionary status, i.e., the younger sources seem to be less variable than their more evolved counterparts. The presence of high variability in the older YSOs (Class III sources) points to non-thermal radio emission, probably powered by the gyrosynchrotron mechanism.

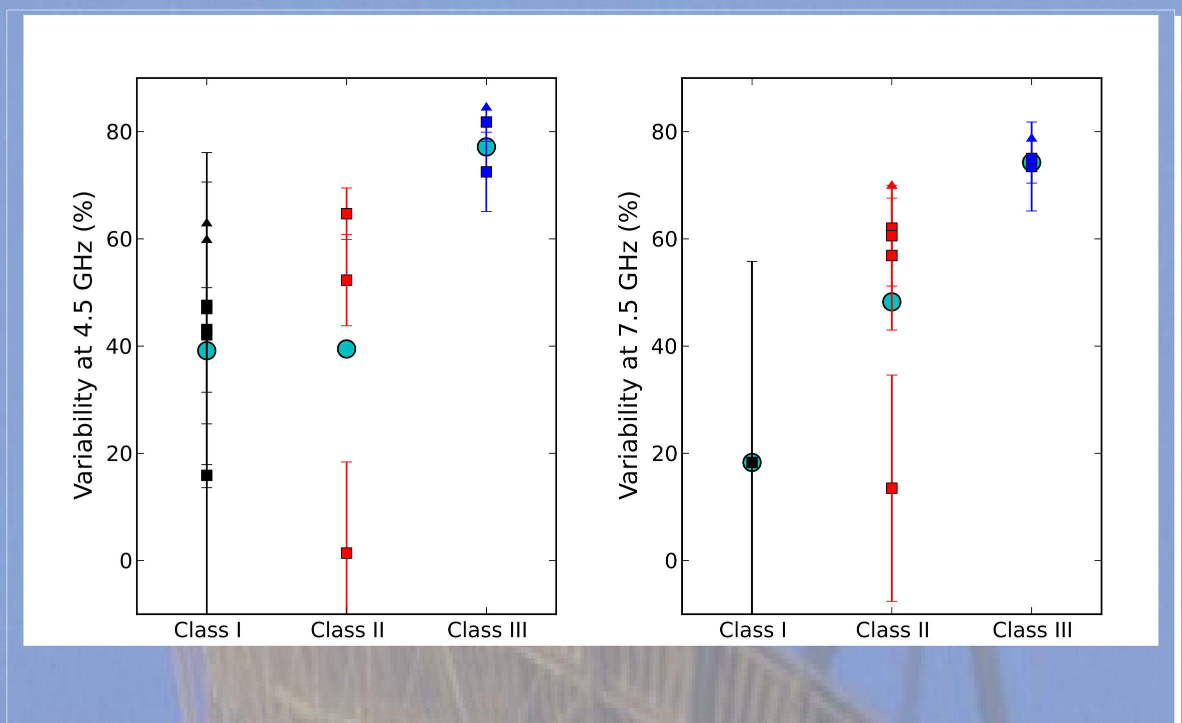

Figure 2: Variability as a function of the evolutionary status.

We study the Güdel-Benz relation for the YSOs with X-ray counterparts in our sample. For our analysis, we assume that the Serpens molecular cloud and the W40 region are part of the same molecular clouds complex and are at the same distance of 415 pc. We found that our sample of YSOs detected simultaneously at radio and X-ray obeys the relation $\log L_X \leq \log L_R + 15.5$, as in the case of coronal active stars (main-sequence and evolved giants).

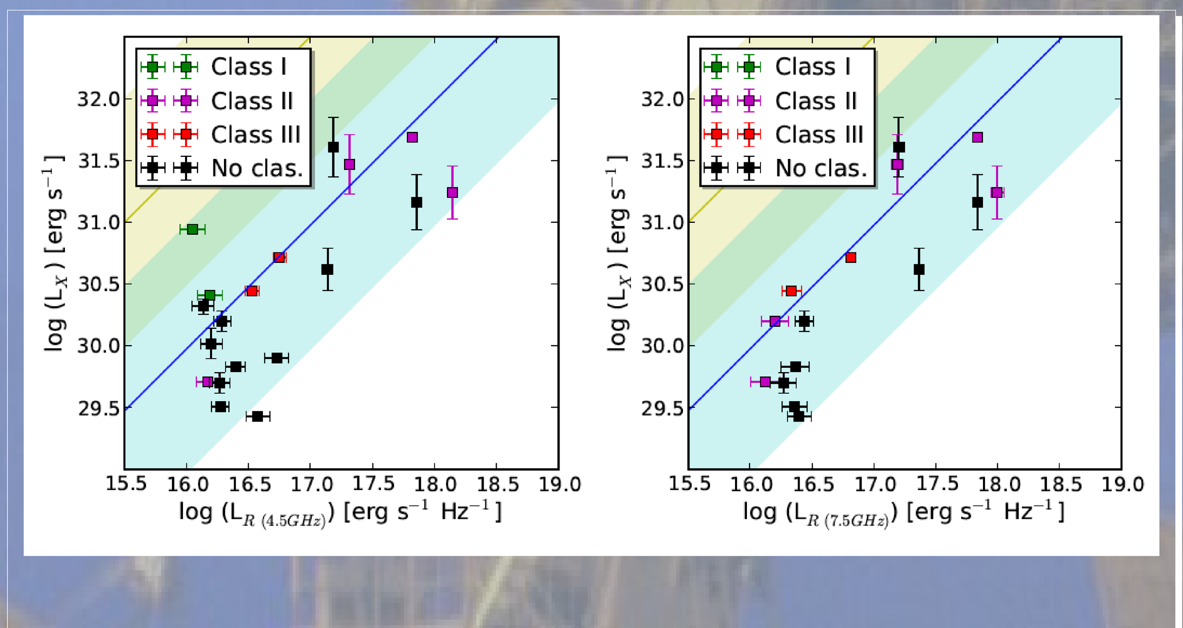

Figure 3: X-ray luminosity as a function of radio luminosity for the YSO detected in Serpens and W40. The yellow line corresponds to the relation $L_X/L_R = \kappa \cdot 10^{15.5\pm1}$, with $\kappa = 1$, and the blue one to the same relation but with $\kappa = 0.03$.

Acknowledgments

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