Study of the γ-ray source 1AGL J2022+4032 in the Cygnus Region*

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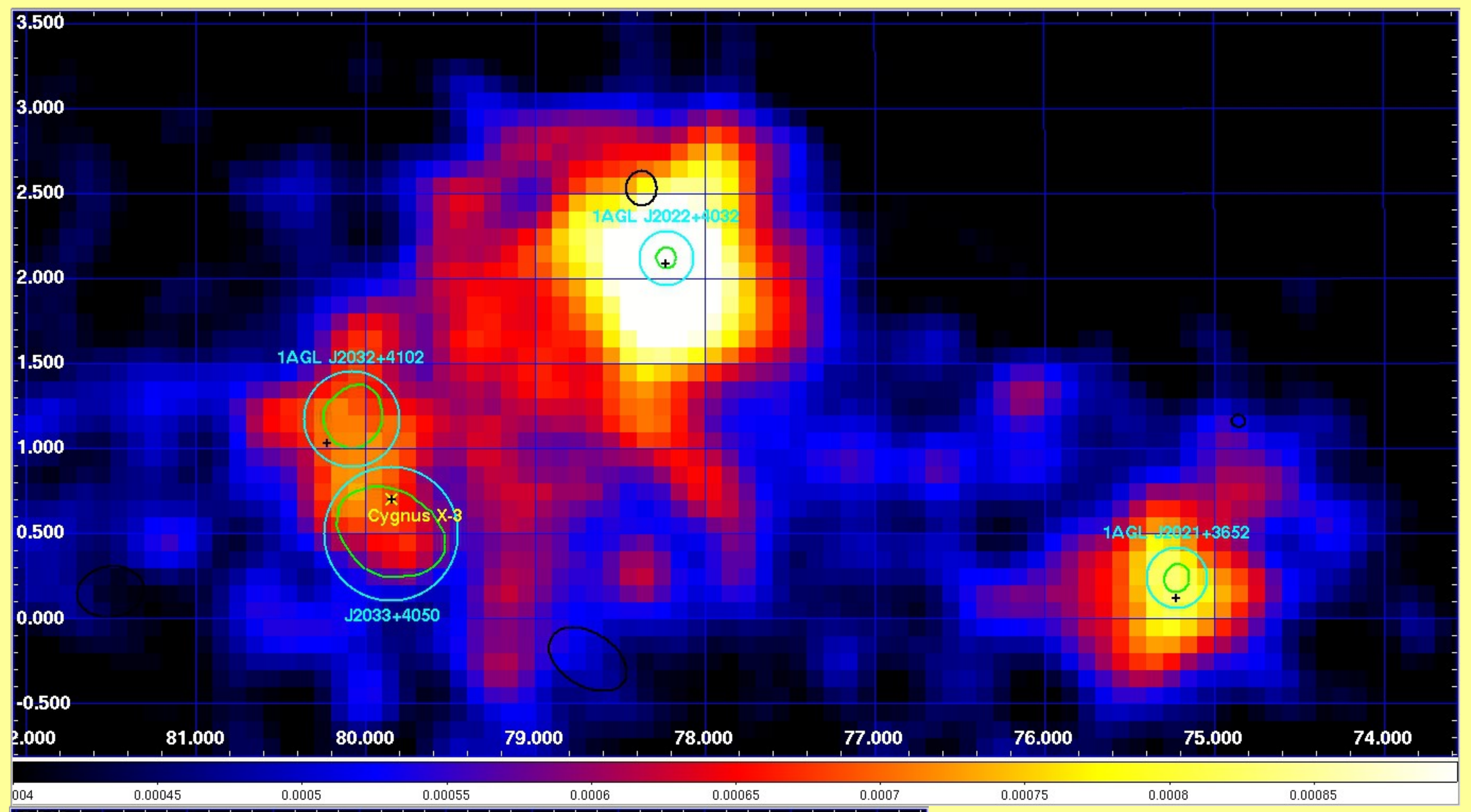
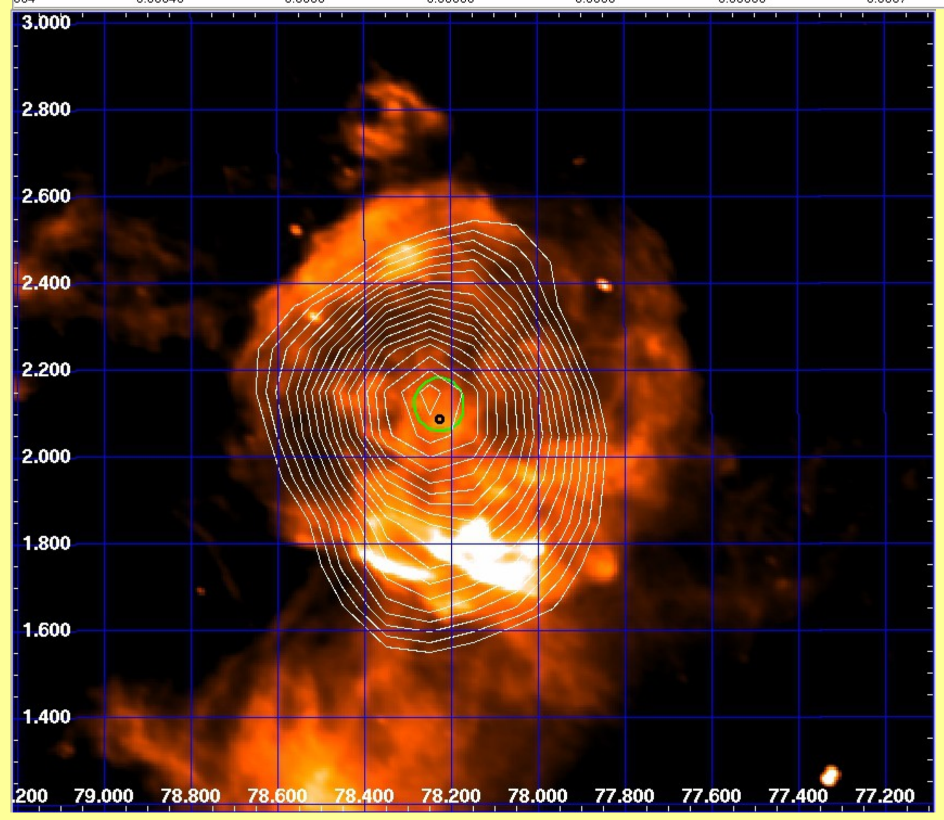
Abstract:

1AGL J2022+4032, coincident with the interior of Gamma Cygni (SNR G78.2+2.1) in the Cygnus Region, has been identified by *Fermi* as a γ-ray pulsar, LAT PSR J2021+4026. Long-term observations of 1AGL J2022+4032 with the *AGILE* γ-ray telescope and detailed simulations to estimate the probability of the apparent observed variability show that the flux variability of 1AGL J2022+4032 appears to be greater than the level predicted for a constant flux from statistical and systematic effects. The γ-ray emission may be due to the superposition of two or more point sources, some of which may be variable. A nearby X-ray quiet microquasar contributing to the flux of 1AGL J2022+4032 may be more likely than a background blazar or intrinsic variability of LAT PSR J2021+4026.

Cygnus Region in galactic coordinates, γ-ray intensity map for E > 100 MeV. AGILE-GRID data (November 2007 - August 2009). Green contours: AGILE-GRID 95% confidence level; Cyan contours: AGILE-GRID statistical + systematic error; Black contours: Fermi-LAT (1-year catalog), statistical error only, crosses shown for contours too small to be visible. Green contours have been calculated with a multi-source likelihood analysis, using four persistent sources.

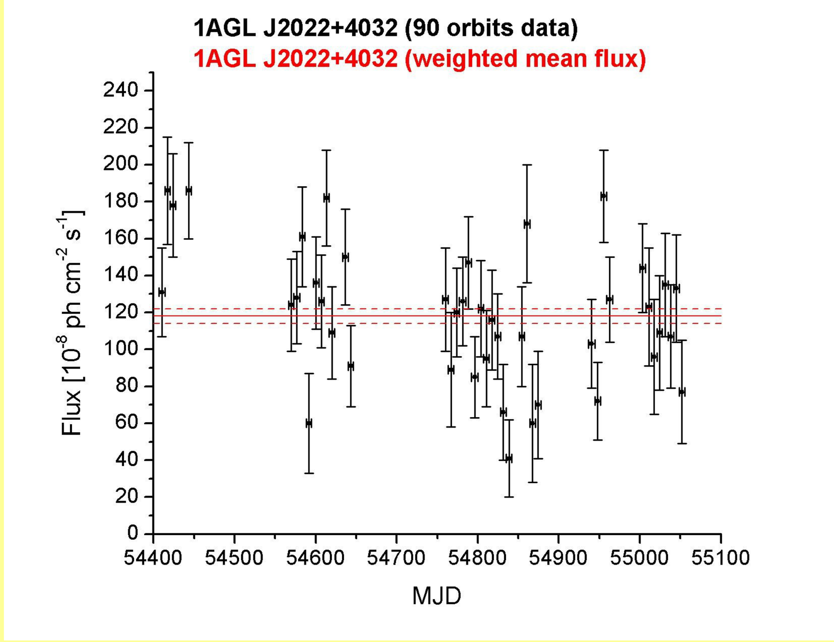




SNR Gamma Cygni (G78.2+2.1) in galactic coordinates. DRAO Radio telescope, 21.1 cm. White contour: AGILE-GRID intensity; Green contour: AGILE-GRID 95% confidence level for E > 100 MeV; Black circle: LAT PSR J2021+4026.

Observations and Data Analysis:

AGILE has been in orbit since April 2007 and has observed the Cygnus region numerous times, beginning in November 2007. We used these observations to characterize the γ-ray variability of the sources in the Cygnus region using the following procedure. First, we performed multi-source likelihood analysis on the deep-integration AGILE-GRID data. This analysis revealed γ-ray emission from four point sources, whose average fluxes and positions are shown in Table 1. Fermi source 1FGL J2020.0+4049 was not detected in either energy range due to the combination of its proximity to 1AGL J2022+4032 and its low flux.



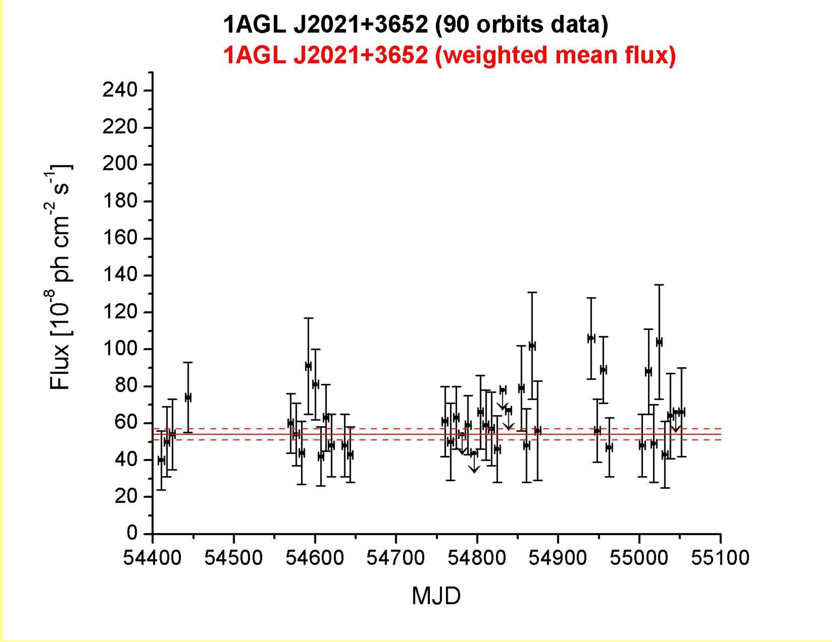


Table 1. γ-ray sources in the Cygnus Region.

Name	Position	√TS	Flux[a]
1AGL J2021+3652, $E \geq 100$ MeV	(l, b) = (75.22, 0.24) ± 0.08° (stat) ± 0.10° (syst)	25.02	60 ± 3 (stat) ± 10% (syst)
1AGL J2022+4032, $E \geq 100$ MeV	(l, b) = (78.23, 2.12) ± 0.06° (stat) ± 0.10° (syst)	39.64	131 ± 4 (stat) ± 10% (syst)
1AGL J2032+4102, $E \geq 100$ MeV	(l, b) = (80.08, 1.18) ± 0.18° (stat) ± 0.10° (syst)	10.82	37 ± 4 (stat) ± 10% (syst)
J2033+4050[b], $E \geq 100$ MeV	(l, b) = (79.84, 0.50) ± 0.29° (stat) ± 0.10° (syst)	5.17	14 ± 3 (stat) ± 10% (syst)
1AGL J2021+3652, $E \geq 400$ MeV	(l, b) = (75.16, 0.23) ± 0.07° (stat) ± 0.10° (syst)	23.07	17 ± 1 (stat) ± 10% (syst)
1AGL J2022+4032, $E \geq 400$ MeV	(l, b) = (78.21, 2.12) ± 0.05° (stat) ± 0.10° (syst)	33.80	33 ± 1 (stat) ± 10% (syst)
1AGL J2032+4102, $E \geq 400$ MeV	(l, b) = (80.05, 0.98) ± 0.14° (stat) ± 0.10° (syst)	10.59	9 ± 1 (stat) ± 10% (syst)

Notes. [a] γ-ray fluxes in units of 10^{-8} photons cm^{-2} s^{-1}. [b] Positionally consistent with Cygnus X-3.

Table 2. Variability analysis with and without 10% systematic errors on fluxes.

Name	Syst. errors	$\chi^2(N_{df} = 41)$	P_{var}	V	V_F	P_{V_F}	$\delta F/F$
1AGL J2022+4032, $E \geq 100$ MeV	yes	66.84	99.34%	2.18	63.26	0.014	0.20
	no	82.45	99.99%	3.88			
1AGL J2021+3652, $E \geq 100$ MeV	yes	40.28	49.76%	0.30	40.03	0.51	0.11
	no	44.47	67.24%	0.48			
1AGL J2022+4032, $E \geq 400$ MeV	yes	48.10	79.27%	0.68	46.07	0.27	0.10
	no	54.46	92.23%	1.11			
1AGL J2021+3652, $E \geq 400$ MeV	yes	34.05	22.95%	0.11	32.77	0.82	—
	no	36.50	32.94%	0.17			

Next, we divided the observations from November 2007 to August 2009 into 42 discrete fixed-length time intervals of ~ 6 days (~90 orbits) each, analyzing the AGILE γ-ray flux from the position of 1AGL J2022+4032, (l, b)=(78.23,2.12), for E > 100 MeV and E > 400 MeV, while keeping its position fixed and all nearby sources fixed in flux and position. We performed the same analysis on the nearby γ-ray source 1AGL J2021+3652, 3.5° away from 1AGL J2022+4032, which Halpern et al (2008) identified as PSR J2021+365, in order to account for the effects of systematic errors. The figure above shows the light curves of the two sources. The red line indicates the weighted mean of the 42 individual fluxes, from which the χ^2 was calculated: (118 ± 4) × 10^{-8} photons cm^{-2} s^{-1} for 1AGL J2022+4032, and (54 ± 3) × 10^{-8} photons cm^{-2} s^{-1} for 1AGL J2021+3652.

Results

We used the method developed by McLaughlin et al. (1996) to test the γ-ray flux variability of 1AGL J2022+4032 with respect to 1AGL J2021+3652. A similar analysis for all the 1AGL sources is in preparation (Verrecchia et al. 2011). The weighted mean flux is calculated from the fluxes in each 6-day time interval and their corresponding errors, from which the χ^2 is derived. Q is the probability that an intrinsically non-variable source (i.e. with constant flux) would produce by random chance a measured value of χ^2 greater than or equal to the χ^2 observed, and the variability index V is defined as V = - log Q. A source can be classified as nonvariable if V < 0.5, uncertain if 0.5 ≤ V < 1, or variable if V ≥ 1. The value V=1 corresponds to a probability of variability P_{var} = 1-Q of 90%. Table 2 shows the value of V for 1AGL J2022+4032 and 1AGL J2021+3652 for E ≥ 100 MeV and E ≥ 400 MeV. For 1AGL J2022+4032 we find V=2.18 when systematic effects are included (V=3.88 for statistical only). For 1AGL J2021+3652 the corresponding values are V=0.30 (V=0.48).As a cross-check, we also calculated a complementary variability index, V_F, according to the formula used in the Fermi catalogs (Abdo et al. 2009a, b). This index is a simple χ^2 where the weights include the systematic error, f_{rel} which in our case is 10%, and the number of degrees of freedom is 41. We find evidence for variability for E ≥ 100 MeV in the emission from 1AGL J2022+4032 even allowing for systematic errors on the level of 10%. Any systematic effects that would influence the measurement of the flux should also have affected the nearby source 1AGL J2021+3652, for which no corresponding variability is found. However, 1AGL J2021+3652 is only half as bright as 1AGL J2022+4032. Similarly, although we found no evidence for variability in the flux of 1AGL J2022+4032 for E ≥ 400 MeV when systematic errors are taken into account,the average flux is only a quarter that of E ≥ 100 MeV. In both cases, the same intrinsic variability might be rendered undetectable because of reduced photon statistics.