Historical Scientific Highlights and Impressions from 15 Years of MAGIC Operation

MAGIC

LS I +61 303

H10 Taburiente (La Palma)

26 - 29 June 2018

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EXCELENCIA MARÍA DE MAEZTU

IEEC

LS I+ 61 303: A luminous star

LS I +61 280	2 32 18.38 +61 27 52.7 M 4046- 080-1				11.6	OB-		Tycho-2 coords wrong
LS I +61 281	2 32 34.54 +61 32 19.2 T 4046- 492-1				11.0	OB		
LS I +61 282	2 32 36.27 +61 28 25.6 T 4046- 118-1		+60	501	9.6	OB		
LS I +61 283	2 32 40.84 +61 27 59.7 T 4046- 850-1				11.4	OB		crowded
LS I +61 284	2 32 42.54 +61 27 21.6 T 4046- 44-1	15558	+60	502	8.0	OBe		Wrn of 10" pair
LS I +61 285	2 32 43.90 +61 27 20.3 T 4046- 44-2				10.7	OB		Ern of 10" pair
LS I +61 286	2 32 49.42 +61 22 42.1 T 4046- 606-1	15570	+60	504	8.2	OB+		
LS I +61 287	2 32 55.24 +61 38 56.9 T 4046-1124-1				10.9	OB-		
LS I +61 288	2 32 58.99 +61 22 23.5 M 4046-1332				11.7	OB		
LS I +61 289	2 33 01.15 +61 26 21.5 T 4046-1002-1		+60	505	10.1	A2II		
LS I +61 290	2 33 04.69 +61 28 21.0 T 4046-1204-1				11.6	OB-		
LS I +61 291	2 33 11.44 +61 27 03.1 T 4046- 78-1		+60	506a	11.2	OB		Srn of 25" pair
LS I +61 292	2 33 11.88 +61 27 28.1 T 4046- 814-1		+60	506b	11.6	OB		Nrn of 25" pair
LS I +61 293	2 33 20.59 +61 31 18.2 T 4046-1192-1	15629	+60	507	8.5	OB+e		
LS I +61 294	2 33 43.01 +61 26 12.2 T 4046-1352-1				11.0	OB-		SWrn of 11" pair
LS I +61 295	2 33 47.83 +62 05 58.1 T 4050-1778-1				12.2	OB-		
LS I +61 296	2 34 02.53 +61 23 10.9 T 4046- 228-1		+60	513	9.4	OB		SErn of 38" opt pair
LS I +61 297	2 34 15.01 +61 24 40.3 T 4046- 280-1				11.2	OB-		
LS I +61 298	2 34 32.41 +61 47 15.2 T 4047- 219-1				11.0	OB-		Nrn of 7" pair
LS I +61 299	2 35 05.27 +61 28 09.9 T 4047-1604-1				11.1	OB-		
LS I +61 300	2 37 32.42 +61 50 31.8 T 4047- 590-1		+61	441	9.5	OB-		
LS I +61 301	2 39 00.17 +61 14 15.7 T 4047- 410-1		+60	529	11.3	OB		
LS I +61 302	2 39 18.05 +61 19 25.1 T 4047- 899-1				10.7	OB-		
LS I +61 303	2 40 31.67 +61 13 45.5 T 4047-1917-1				10.7	OB+		faint comp 12" SE
LS I +61 304	2 40 44.95 +61 16 56.0 T 4047-1157-1	16429	+60	541	7.9	OBe	r	Nrn of 7" pair
LS I +61 305	2 40 46.15 +61 17 48.5 T 4047- 751-1		+60	542	10.5	OB-		
LS I +61 306	2 40 51.09 +61 15 45.5 T 4047-1467-1				11.6	OB-		
LS I +61 307	2 42 43.16 +61 15 57.6 T 4047- 846-1				11.5	OBe		H-alpha em strong
LS I +61 308	2 43 20.58 +62 08 19.8 T 4051- 755-1		+61	468	9.9	OBe		
LS I +61 309	2 43 30.98 +62 03 33.9 T 4051-2721-1				11.5	OB+		Nrn of 16" pair
LS I +61 310	2 44 07.31 +61 20 09.9 T 4047- 183-1				11.5	OB-		
LS I +61 311	2 45 38.42 +61 36 32.3 T 4047-2112-1				11.2	OB		
LS I +61 312	2 46 06.43 +61 54 23.8 T 4051-2483-1				11.5	OBe		
LS I +61 313	2 50 13.63 +62 05 30.8 T 4051-3077-1		+61	487	9.9	OB+e		
LS I +61 314	2 52 42.82 +61 37 28.3 T 4048- 673-1				11.4	OB		
LS I +61 315	2 53 39.16 +61 43 48.3 T 4048- 477-1				10.0	OB-		
LS I +61 316	2 57 04.13 +61 24 57.7 T 4048-1072-1		+60	594	9.3	OBe		
LS I +61 317	2 59 09.23 +62 11 26.2 T 4052-1454-1				12.2	OB-		
LS I +61 318	2 59 47.37 +61 17 23.8 T 4048- 102-1	18352	+60	608	6.8	OB-		
LS I +61 319	3 00 30.02 +61 23 47.8 T 4048- 394-1		+60	609	10.6	OB-		
LS I +61 320	3 02 59.87 +61 41 38.3 T 4048- 371-2				11.4	OB		NErn of 17" pair
LS I +61 321	3 08 28.19 +61 24 23.3 T 4048- 270-1		+60	628	10.2	OB-		
LS I +61 322	3 24 14.19 +61 32 18.9 T 4049- 693-1	20798	+61	570	8.4	OB		SErn of 6" pair
LS I +61 323	3 25 09.19 +62 05 34.0 T 4053-1489-1		+61	571	10.0	OB-	r	Nrn of 5" pair
LS I +61 324	3 40 19.97 +61 50 38.4 T 4062- 888-1		+61	623	9.0	OBe		emission strong

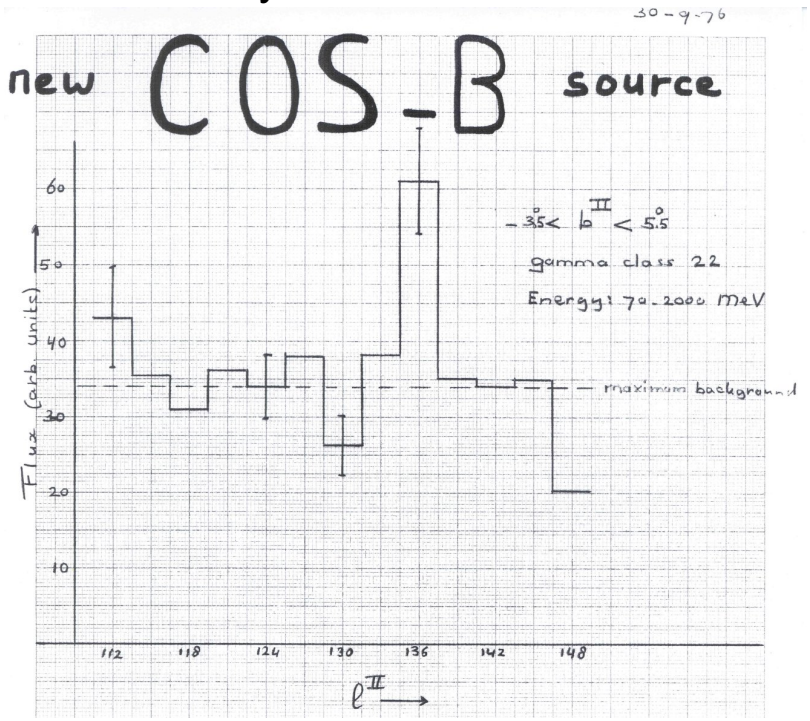
Luminous stars in the Northern Milky Way. Part I.

Hardorp, J.; Rohlfs, K.; Slettebak, A.; Stock, J.

Hamburger Sternw., Warner & Swasey Obs., 1 (1959)

Historical association with a γ-ray source

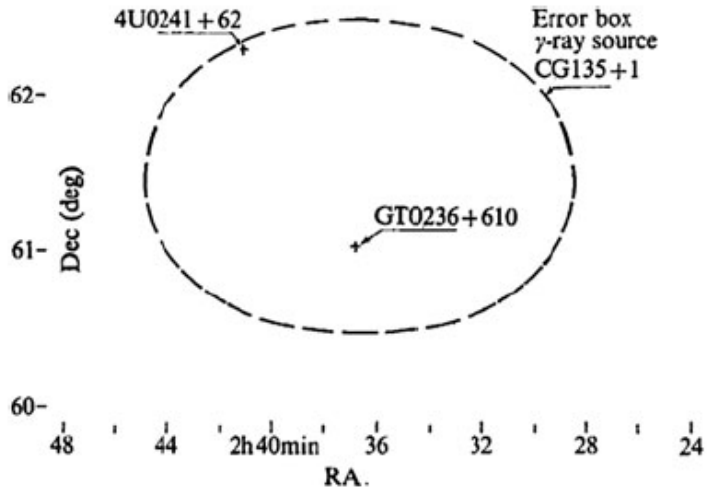
Cosmic Ray Satellite B



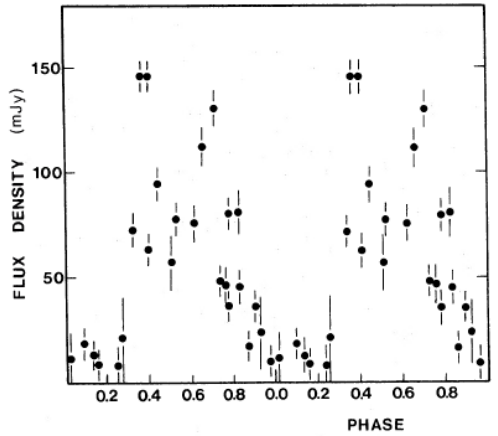
The radio emitting X-ray binary LS I+61 303, since its discovery as a variable radio source, has been proposed to be associated with the γ-ray source 2CG 135+01 (= 3EG J0241+6103)
(Gregory & Taylor 1978, Nature 272, 704)

First high-energy (> 100 MeV) COS-B gamma-ray source: CG/2CG 135+01

Hermsen et al. 1977, Nature 269, 494

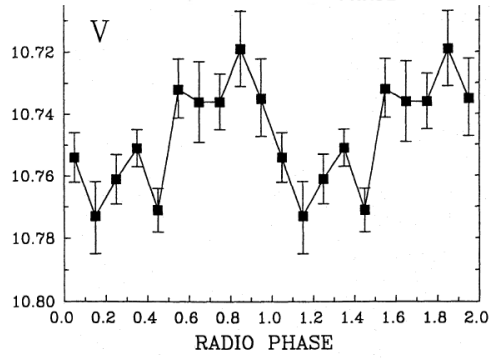


Multiwavelength study: 26.5 d periodicity



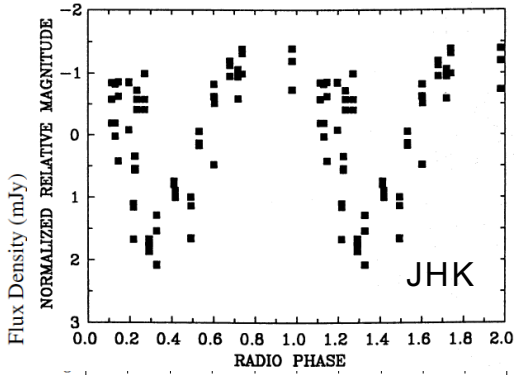
Radio (P=26.496 d)

Taylor & Gregory 1982, ApJ 255, 210;
Gregory 2002, ApJ 575, 427



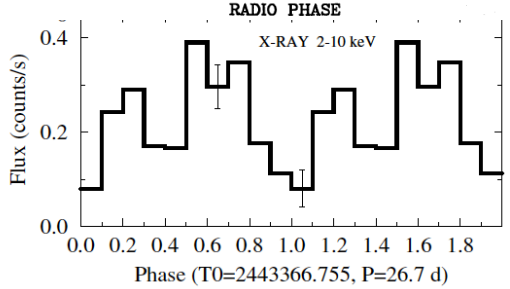
Optical

Mendelson & Mazeh 1989,
MNRAS 239, 733



IR

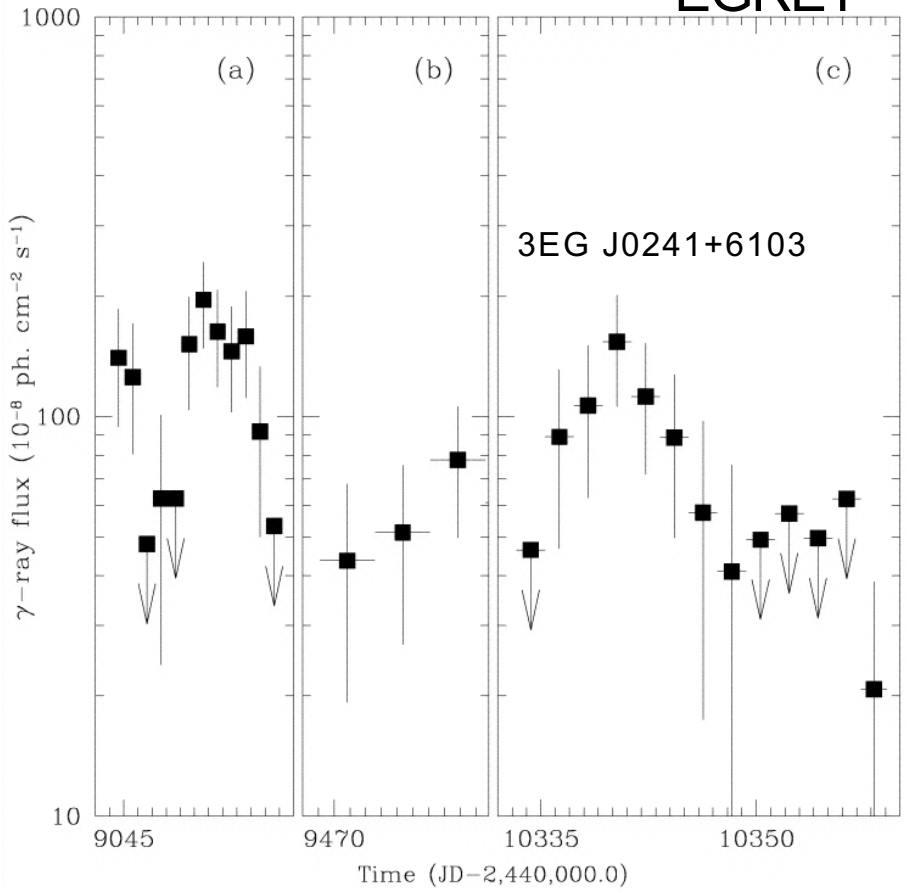
Paredes et al. 1994
A&A 288, 519



X-rays

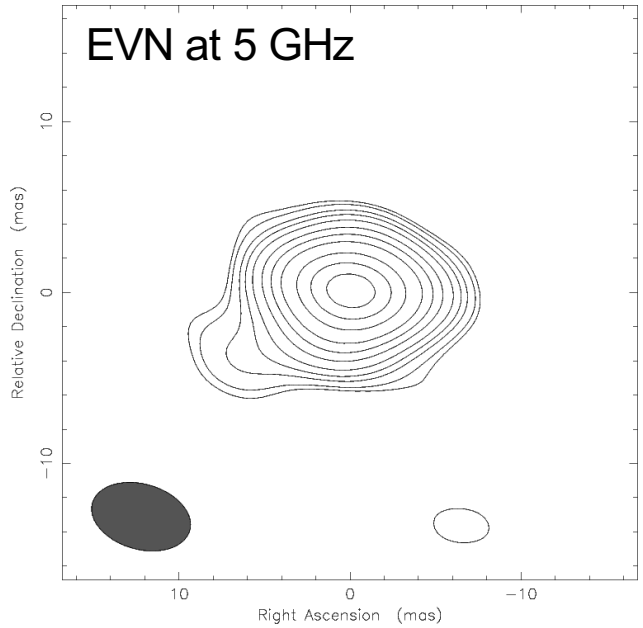
Paredes et al. 1997
A&A 320, L25

EGRET



Tavani et al. 1998, ApJ 497, L89
(see also :Strickman et al 1998, ApJ 497, 419)
Kniffen et al 1997, ApJ 486, 126)

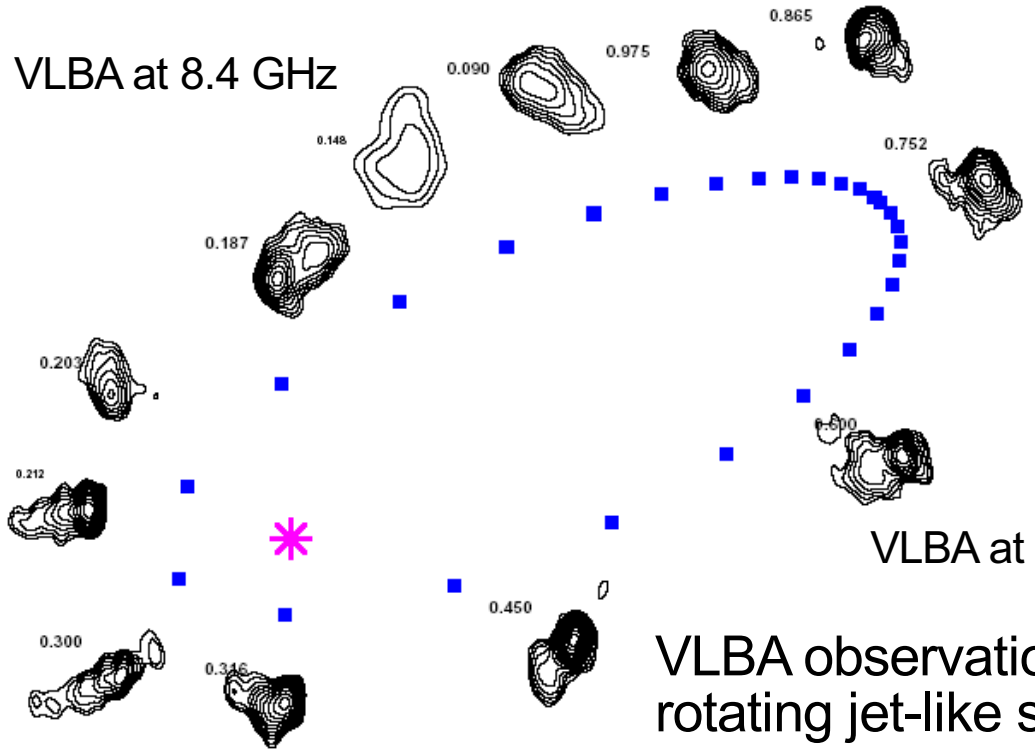
Microquasar or non-accreting pulsar?



Resolved radio emission pointed towards the **microquasar** scenario (Massi et al. 2001 A&A 376, 217)

Accretion onto a compact object (NS or BH) embedded in mass outflow of the B-star

Taylor & Gregory 1982, ApJ 255, 210;
Taylor et al. 1992, ApJ 395, 268



VLBA at 8.4 GHz

VLBA observations show a rotating jet-like structure

(Dhawan et al. 2006, VI Microquasars Workshop, Como)

Non-accreting **young pulsar** in orbit around a mass-losing B star

Maraschi & Treves 1981, MNRAS 194,1
Dubus 2006, A&A 456, 801

MAGIC enter in action

2004 *γ-ray emission from microquasars: A numerical model for LSI +61°303*
(Bosch-Ramon & Paredes 2004, A&A 425, 1069)

UB-IFAE (Manel, Juan, Núria Sidró) meetings

First draft of the proposal

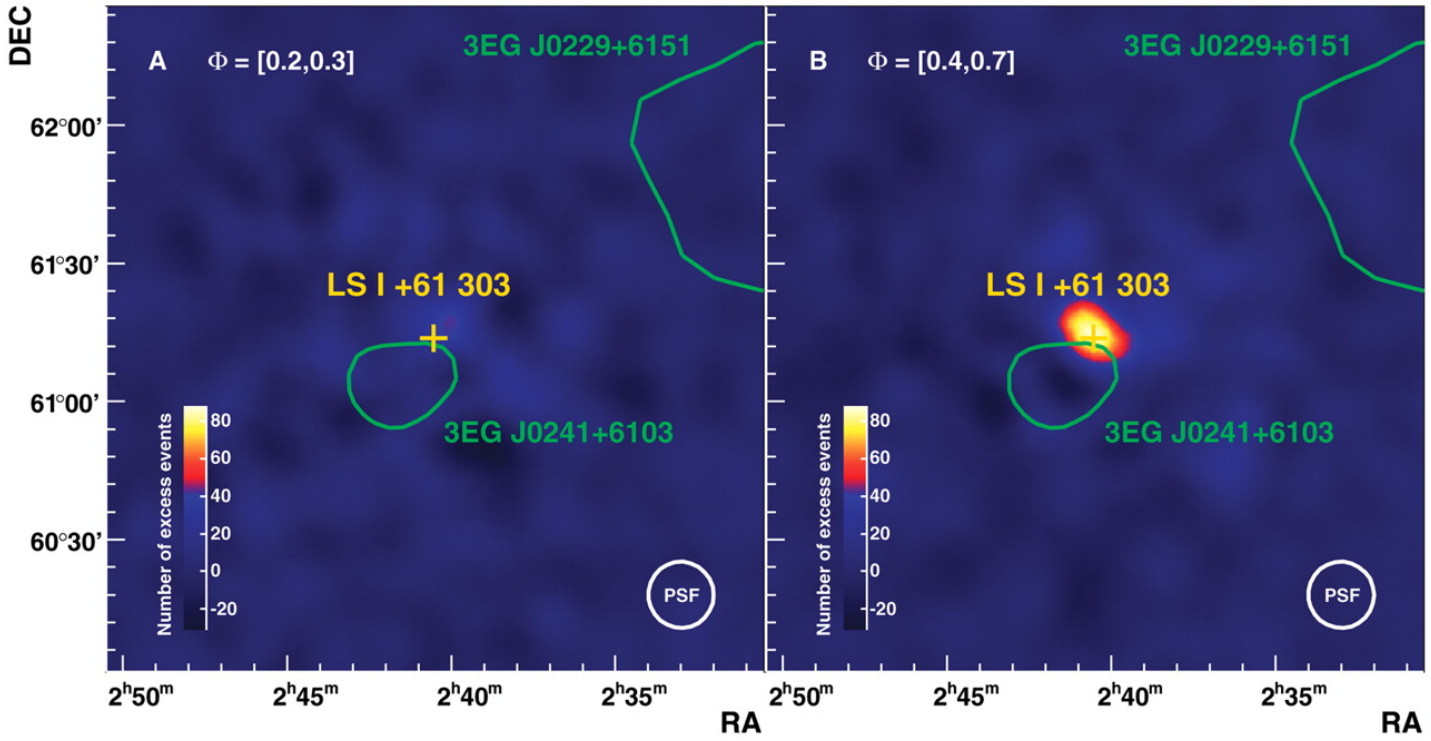
2005
Feb

SEARCH FOR VERY HIGH-ENERGY γ-RAYS IN THE MICROQUASAR LSI +61°303

Principal Investigators: N.Sidro[1], W.Bednarek[2]
Co-Investigators: J.Cortina[1], J.Rico[1], P.Jacon[2], D.Sobczynska[2]
Guest Investigators: J.M.Paredes[3], V.Bosch-Ramon[3], G.Romero[4], D.Torres[5]

LS I +61 303 was observed during 54 hours (after standard quality selection, discarding bad-weather data) between October 2005 and March 2006

MAGIC detection of LS I +61 303



REPORTS

Variable Very-High-Energy Gamma-Ray Emission from the Microquasar LS I +61 303

J. Albert,[1] E. Aliu,[2] H. Anderhub,[3] P. Antoranz,[4] A. Armada,[2] M. Asensio,[4] C. Baixeras,[5] J. A. Barrio,[4] M. Bartelt,[6] H. Bartko,[7] D. Bastieri,[8] S. R. Bavikadi,[9] W. Bednarek,[10] K. Berger,[1] C. Bigongiari,[8] A. Biland,[3] E. Bisesi,[9] R. K. Bock,[7] P. Bordas,[11] V. Bosch-Ramon,[11] T. Bretz,[1] I. Britvitch,[3] M. Camara,[4] E. Carmona,[7] A. Chilingarian,[12] S. Ciprini,[13] J. A. Coarasa,[7] S. Commichau,[3] J. L. Contreras,[4] J. Cortina,[2] V. Curtef,[6] V. Danielyan,[12] F. Dazzi,[8] A. De Angelis,[9] R. de los Reyes,[4] B. De Lotto,[9] E. Domingo-Santamaría,[2] D. Dorner,[1] M. Doro,[8] M. Errando,[2] M. Fagiolini,[14] D. Ferenc,[15] E. Fernández,[2] R. Firpo,[2] J. Flix,[2] M. V. Fonseca,[4] L. Font,[5] M. Fuchs,[7] N. Galante,[14] M. Garczarczyk,[7] M. Gaug,[8] M. Giller,[10] F. Goebel,[7] D. Hakobyan,[12] M. Hayashida,[7] T. Hengstebeck,[16] D. Höhne,[1] J. Hose,[7] C. C. Hsu,[7] P. G. Isar,[7] P. Jacon,[10] O. Kalekin,[16] R. Kosyra,[7] D. Kranich,[3,15] M. Laatiaoui,[7] A. Laille,[15] T. Lenisa,[9] P. Liebing,[7] E. Lindfors,[13] S. Lombardi,[8] F. Longo,[17] J. López,[2] M. López,[4] E. Lorenz,[3,7] F. Lucarelli,[4] P. Majumdar,[7] G. Maneva,[18] K. Mannheim,[1] O. Mansutti,[9] M. Mariotti,[8] M. Martínez,[2] K. Mase,[7] D. Mazin,[7] C. Merck,[7] M. Meucci,[14] M. Meyer,[1] J. M. Miranda,[4] R. Mirzoyan,[7] S. Mizobuchi,[7] A. Moralejo,[2] K. Nilsson,[13] E. Oña-Wilhelmi,[2] R. Orduña,[5] N. Otte,[7] I. Oya,[4] D. Paneque,[7] R. Paoletti,[14] J. M. Paredes,[11] M. Pasanen,[13] D. Pascoli,[8] F. Pauss,[3] N. Pavel,[16*] R. Pegna,[14] M. Persic,[19] L. Peruzzo,[8] A. Piccioli,[14] M. Poller,[1] G. Pooley,[20] E. Prandini,[8] A. Raymers,[12] W. Rhode,[6] M. Ribó,[11] J. Rico,[2†] B. Riegel,[1] M. Rissi,[3] A. Robert,[5] G. E. Romero,[21,22] S. Rügamer,[1] A. Saggion,[8] A. Sánchez,[5] P. Sartori,[8] V. Scalzotto,[8] V. Scapin,[8] R. Schmitt,[1] T. Schweizer,[16] M. Shayduk,[16] K. Shinozaki,[7] S. N. Shore,[23] N. Sidro,[2†] A. Sillanpää,[13] D. Sobczynska,[10] A. Stamerra,[14] L. S. Stark,[3] L. Takalo,[13] P. Temnikov,[18] D. Tescaro,[2] M. Teshima,[7] N. Tonello,[7] A. Torres,[5] D. F. Torres,[2,24] N. Turini,[14] H. Vankov,[18] V. Vitale,[9] R. M. Wagner,[7] T. Wibig,[10] W. Wittek,[7] R. Zanin,[8] J. Zapatero[5]

rapidly precessing radio-emitting structures at angular extensions of 0.01 to 0.05 arc sec has been interpreted as unambiguous evidence of the microquasar nature of LS I +61 303 (*16*, *17*).

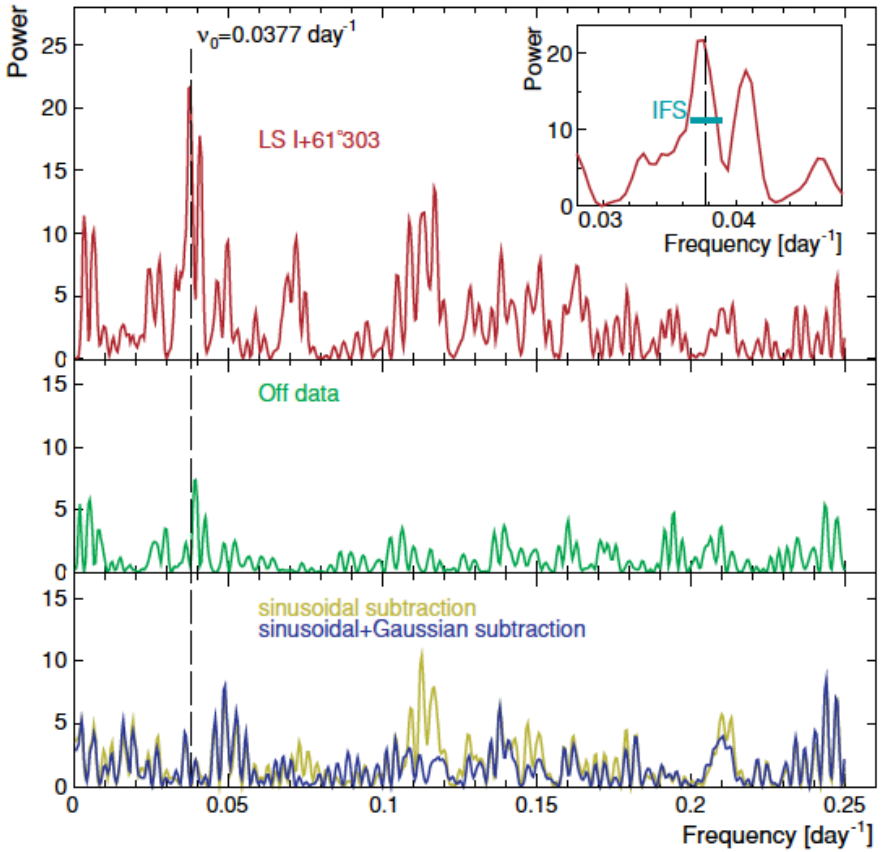
The gamma-ray source 3EG J0241+6103 (also known as 2CG 135+01) was discovered by Cosmic Ray Satellite B (COS-B) at energies above 100 MeV (*18*). Despite its large uncertainty (~1°) in position, the source was proposed to be the high-energy counterpart of the 26.5-day periodic radio outburst source GT 0236+610, which turned out to be the early-type star LS I +61 303 (*11*). The large uncertainty of the position of 3EG J0241+6103 did not allow unambiguous association with LS I +61 303. The GeV gamma-ray emission from this EGRET source is clearly variable (*19*). Even though the GeV data remain scarce in this regime, an increased emission has been suggested for the periastron passage (*20*) and was firmly reported around phase 0.5 (*6*), coincident with the x-ray outbursts.

MAGIC, located on La Palma, Canary Islands (Spain), is an imaging air Cherenkov telescope (IACT). This kind of instrument images the Cherenkov light produced in the particle cascade initiated by a gamma ray in the atmosphere. MAGIC (*21*, *22*) includes several innovative techniques and technologies in its design and is currently the largest single-dish telescope (diameter 17 m) in this energy band. It is equipped with a 576-pixel photomultiplier

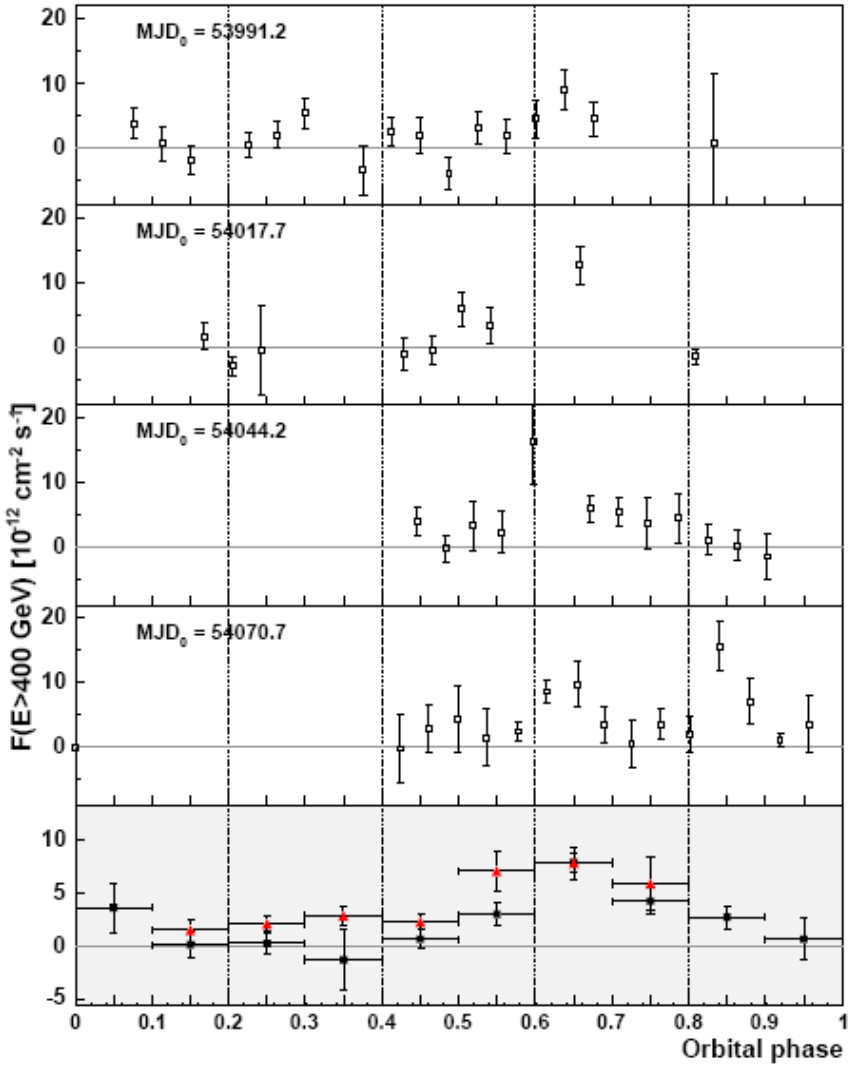
Albert et al. 2006, Sci 312, 1771

357 citations

Periodic (26.5d) VHE γ -ray emission from LS I +61 303



Albert et al. 2009, ApJ 693, 303

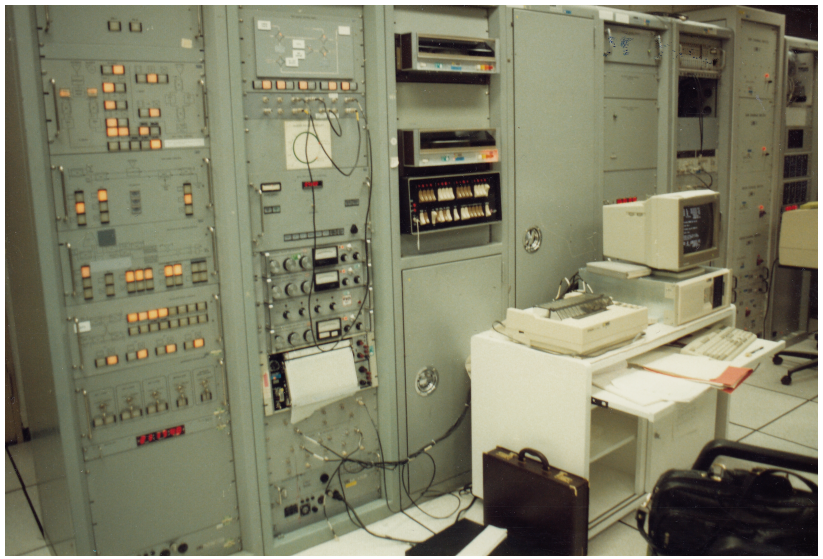


MAGIC

4.4 yr periodicity in radio

Data observació	13 cm flux (mJy)	3.6 cm flux (mJy)	Fase	Polarització circular
207/82	< 47	< 17	0.31	-
269/84	-	< 24	0.23	-
357/84	-	28 ± 6	0.54	+0.21 ± 0.22
110/86	-	45 ± 3	0.81	-0.08 ± 0.06
110/86	-	42 ± 3	0.81	-0.08 ± 0.07
160/86	-	107 ± 4	0.69	-0.01 ± 0.03
160/86	-	109 ± 5	0.69	-0.11 ± 0.04
161/86	-	103 ± 22	0.72	+0.06 ± 0.15
162/86	-	92 ± 5	0.77	+0.01 ± 0.05

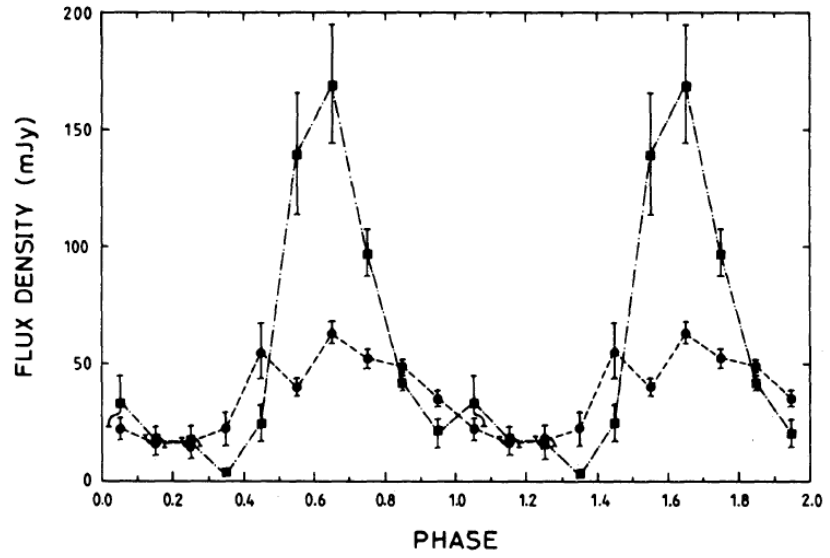
Flux màxim (mJy)	Data mes-any	Freqüència GHz	Referència
300	8-77	5	Taylor i Gregory, 1982
140	2-78	10	Taylor i Gregory, 1982
150	8-78	5	Taylor i Gregory, 1982
100	8-79	5	Taylor i Gregory, 1982
40	6-80	10	Taylor i Gregory, 1982
60	8-80	5	Taylor i Gregory, 1982
300	8-81	5	Taylor i Gregory, 1984
250	8-81	10	Taylor i Gregory, 1984
200	11-81	10.7	Coe et al., 1983



A ~4 yr modulation of the peak of the radio LC was suggested in 1987 Paredes 1987, PhD Thesis

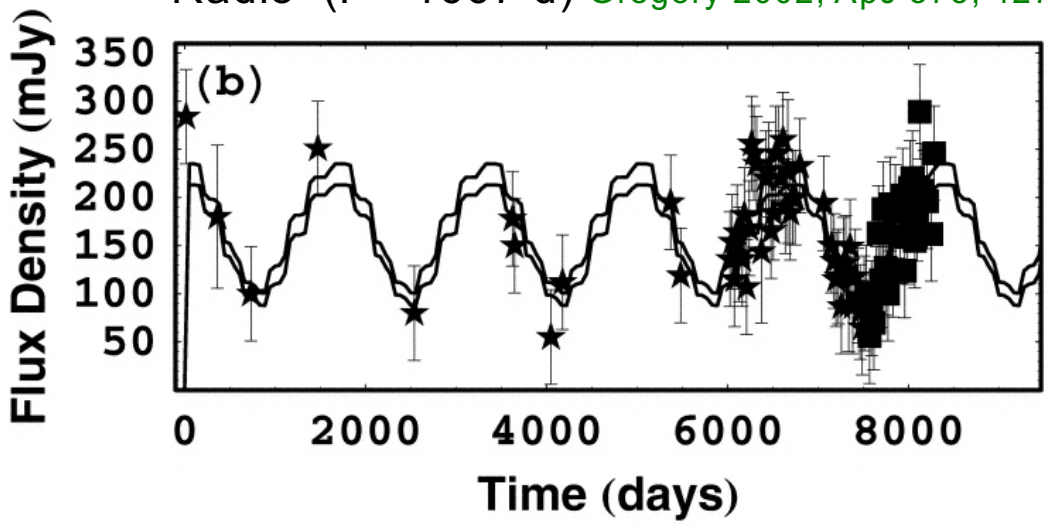
4.4 yr periodicity in radio and at VHE

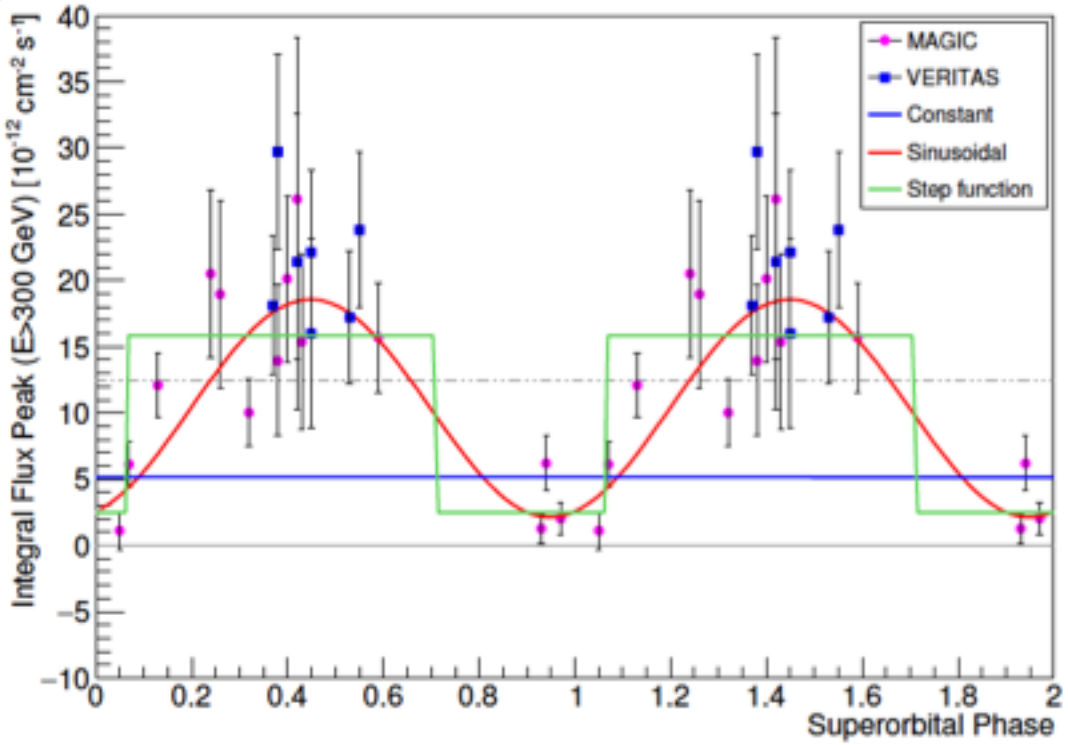
Paredes et al. 1990, A&A 232, 377



Radio (P= 1667 d) Gregory 2002, ApJ 575, 427

Gregory 2002, ApJ 575, 427





Super-orbital variability of LS I +61 303 at TeV energies

Ahnen et al. 2016, A&A, 591, A76

Impressions from 13 years of MAGIC

2004
First contacts UB-IFAE (M. Martínez, J. Cortina, N. Sidró)
First draft of LS I +61 303 MAGIC proposal

Feb 2005
Proposal of LS I +61 303: Guest Investigators

Exciting days
Good relationship with (MAGIC) IFAE people and others
Very good feelings

Feb 2006
MAGIC meeting in Munich.
Joined the Collaboration

Very happy
Unique opportunity to work with VHE data
MAGIC people seemed friendly, extremely excited with the project and eager to do things

Next years

Confirmation of the initial perception and discovery that in MAGIC there are:
Excellent persons
Good scientists
Collaborative and motivate people
and
Open and friendly Collaboration

M. Ribó J.M. Paredes V. Bosch-Ramon

HAPPY BIRTHDAY AND GOOD LUCK

Daniel López / IAC