Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Universidad de La Laguna

VHE binary systems with MAGIC+LST and a brief introduction to SII

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Sexten School - Advances in Modeling High Energy Astrophysical Sources

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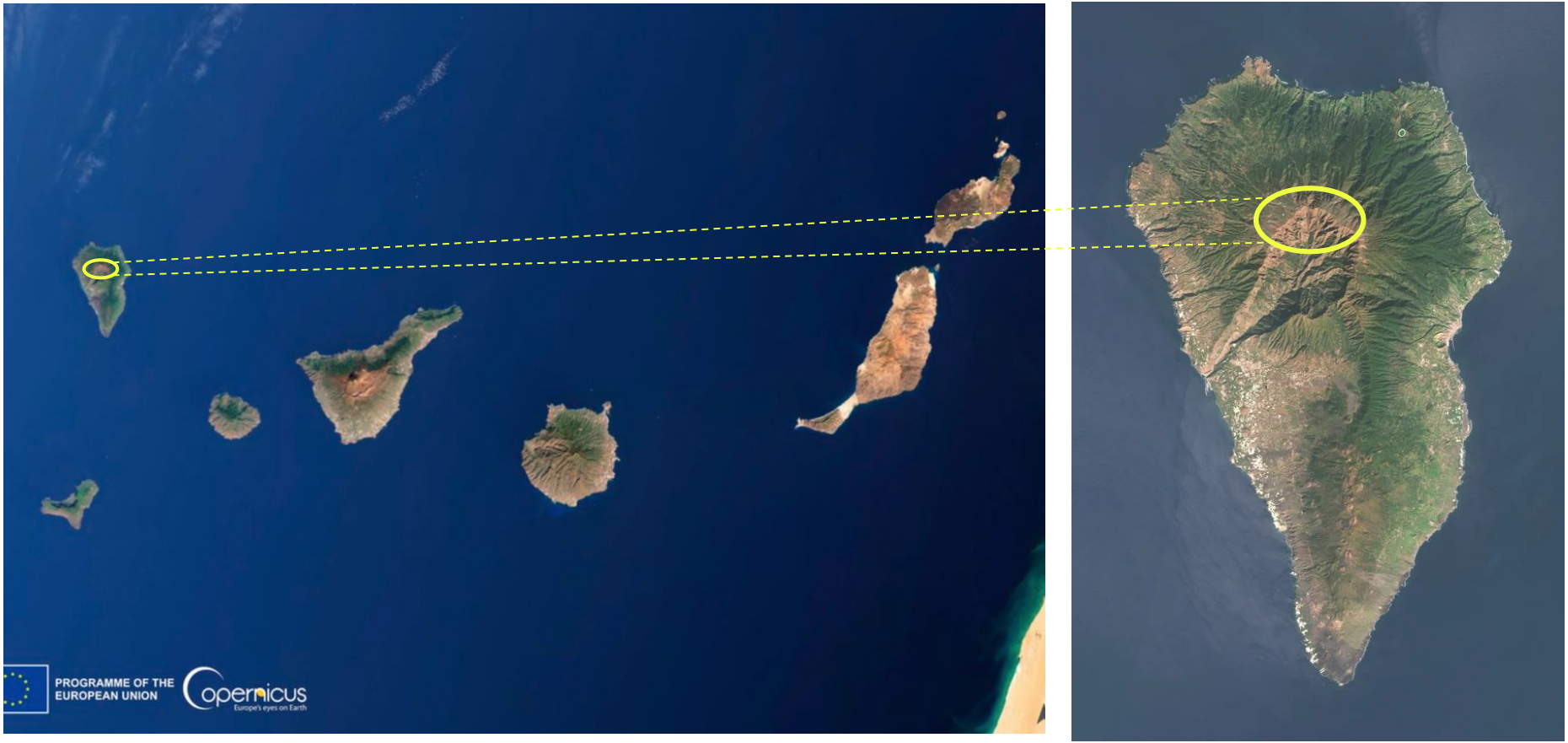
GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

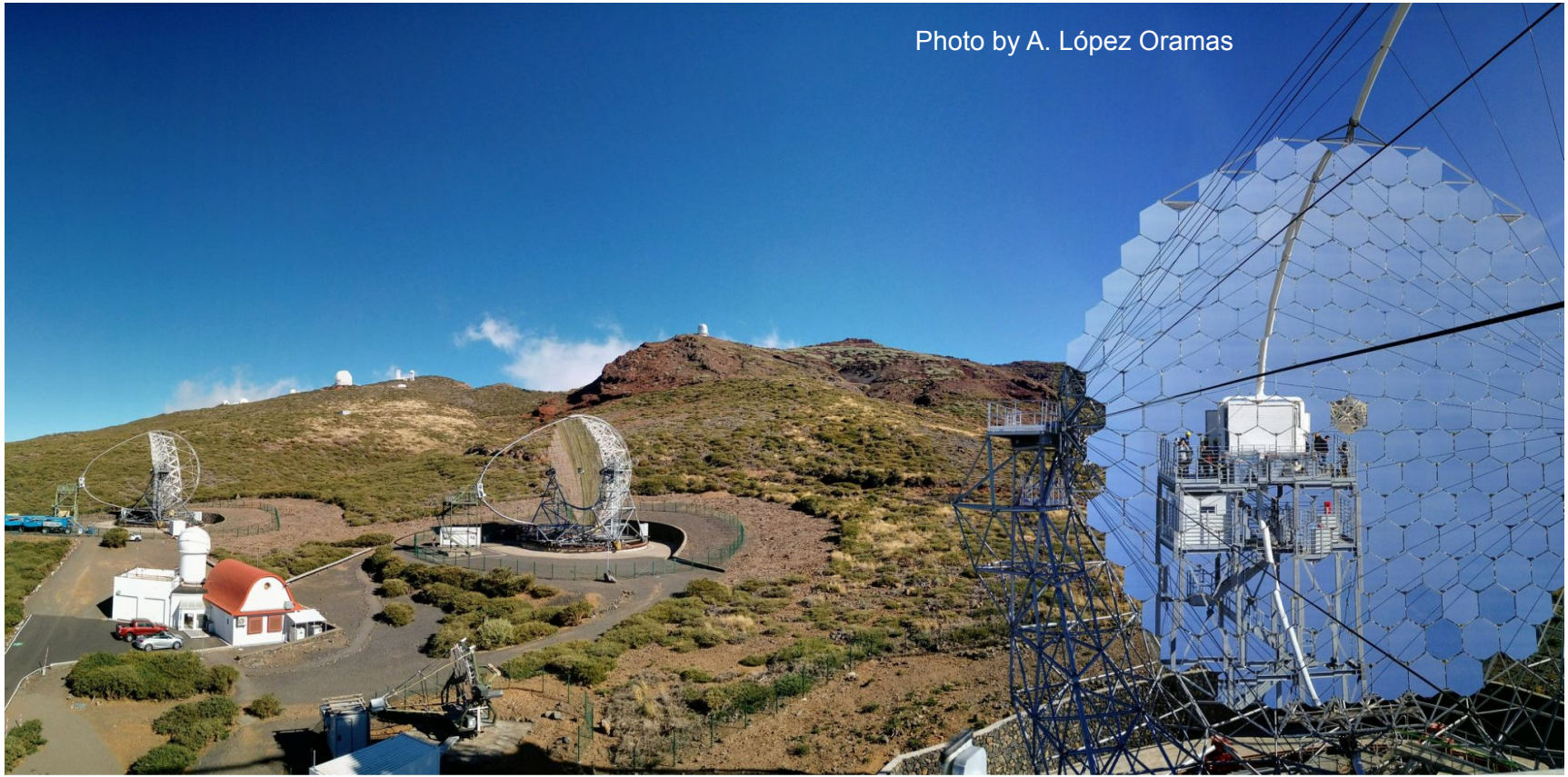
AGENCIA ESTATAL DE INVESTIGACIÓN

Cofinanciado por la Unión Europea

The site: Observatorio Roque de los Muchachos (ORM) in La Palma



MAGIC and LST-1 at ORM



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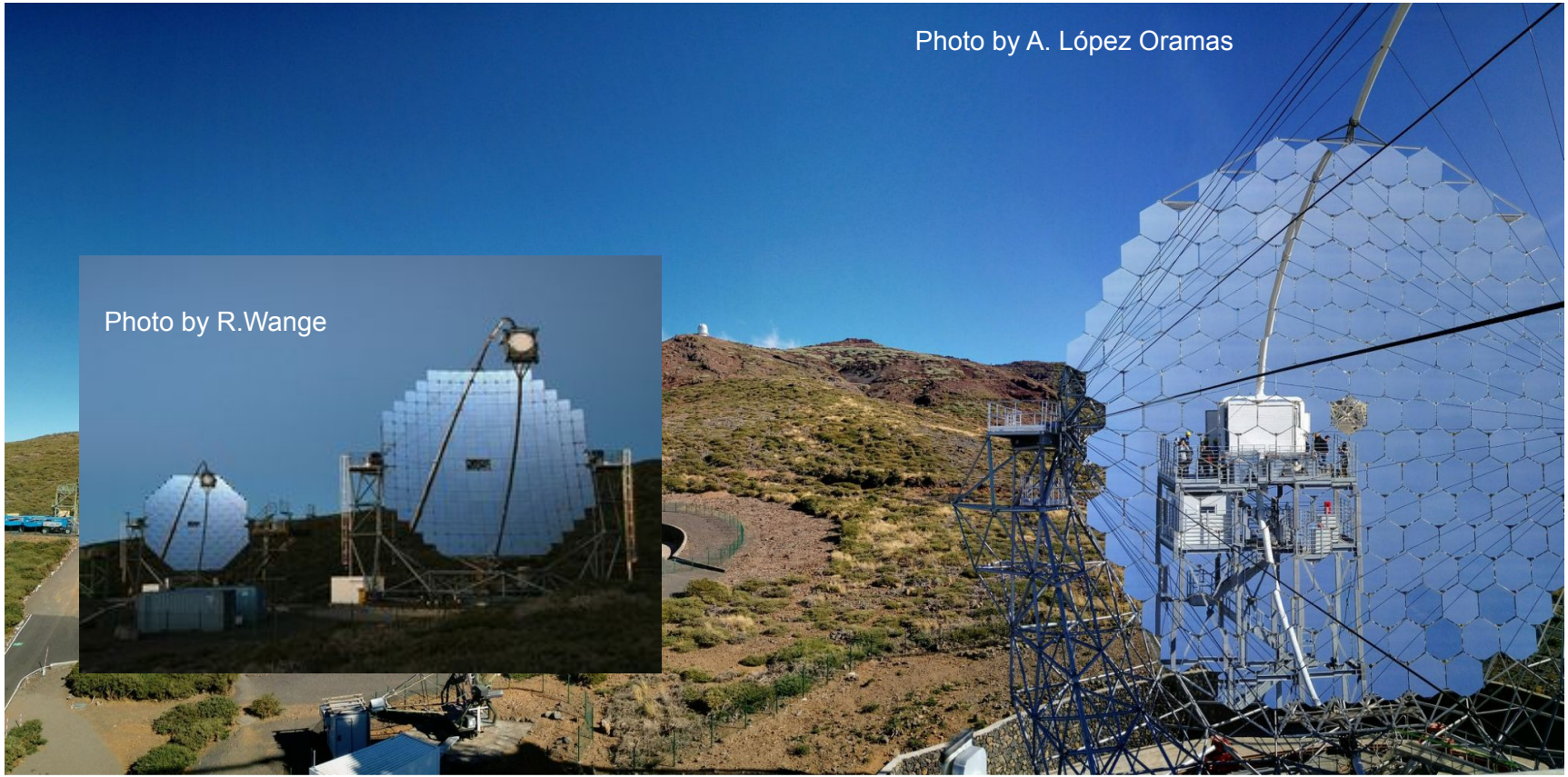
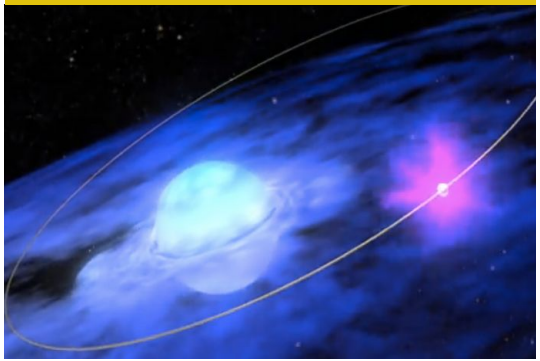
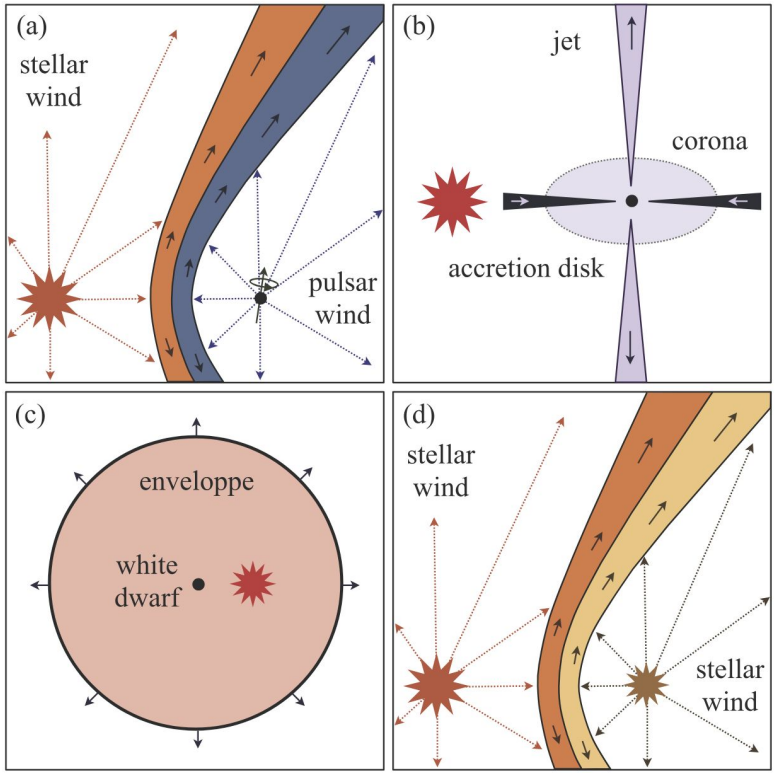


VHE (>100 GeV) binary emitters

Non-accreting pulsars



Microquasars



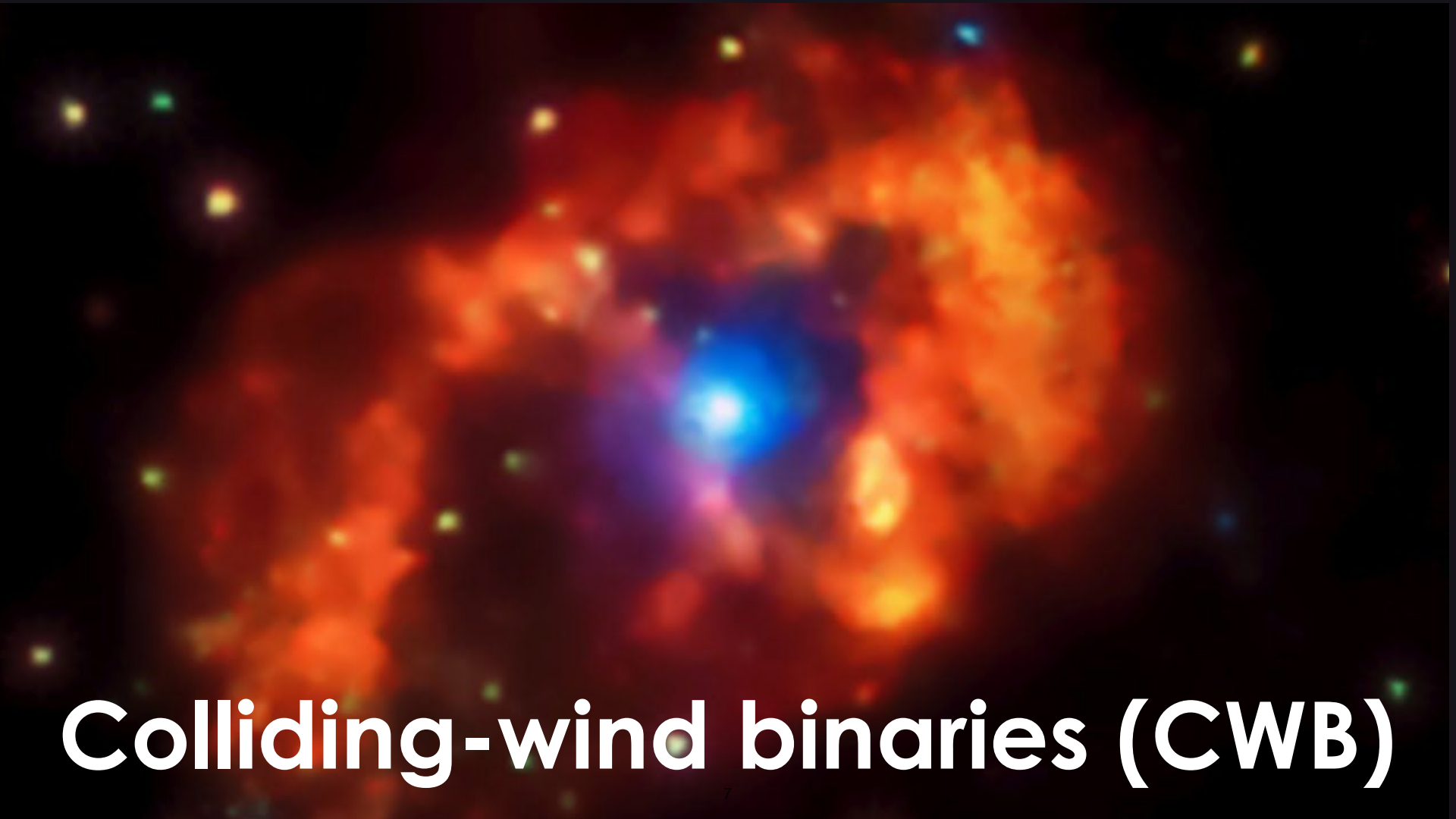
Novae

Colliding Wind Binaries

Dubus 2015

Gamma-loud binaries at VHE: state-of-the-art

	System	Star spectral type	Compact object	Porb [days]	HE emission	VHE emission	UHE emission
Gamma-ray binaries (non-accreting pulsars)	PSR B1259-63	O9.5Ve	48ms pulsar	1236.72	yes	yes	-
	LS 5039	O	pulsar?	3.91	yes	yes	yes (> 25 TeV)
	LS I +61 303	Be	pulsar	26.49	yes	yes	yes
	HESS J0632+057	Be	-	315.50	yes	yes	-
	FGL J1018.6-5856	O	-	16.58	yes	yes	-
	LMC P-3	O	-	10.20	yes	yes	-
	HESS J1832-093	O	-	82	yes	yes	-
	PSR J2032+4127	Be	143 ms pulsar	50 years	yes	yes	-
Microquasars	SS 433	A	BH	13.08	yes	yes	yes
	V4641 Sgr	B9III	BH	2.80	no	yes	yes
	GRS1915+105	K-M III	BH	33.85	no	yes	yes
	MAXI J1820+070	K	BH	0.69	no	yes	yes
	Cyg X-1	O9.7Iab	BH	5.60	yes	hint (4.0 σ)	hint (4.0 σ)
CWB	eta Carinae	LBV	O/B star	5.5 years	yes	yes	-
Novae	RS Ophiuchi	red giant	white dwarf	454	yes	yes	-

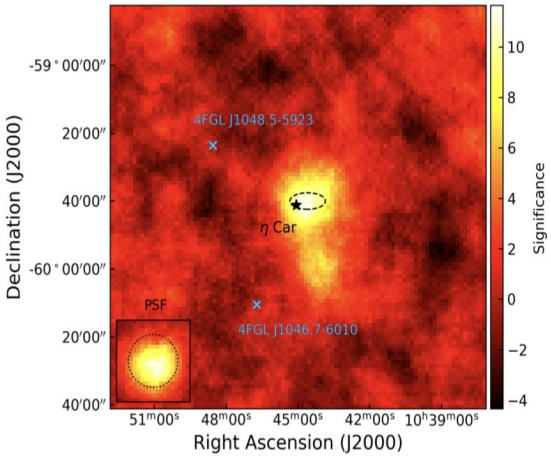


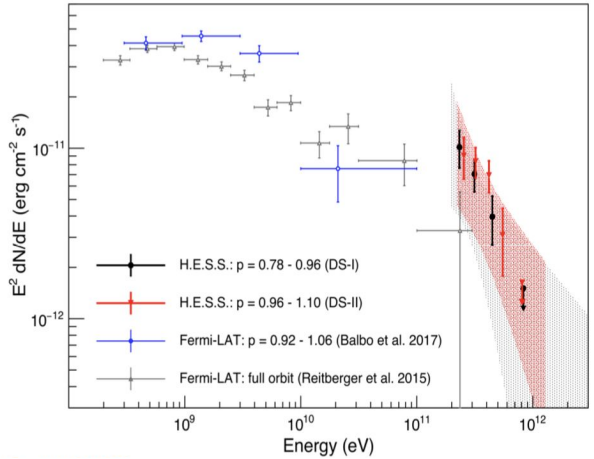
Colliding-wind binaries (CWB)

Eta Carinae, first CWB at VHE

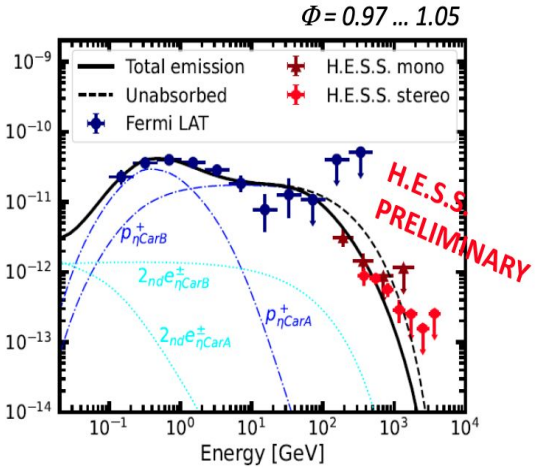
- **Luminous Blue Variable** ~100 $M_\odot$ + **O- or B-type** ~30 $M_\odot$
  - eccentric orbit (e ~ 0.9) with a ~5.5 yr period (**last periastron passage**: February 2020)
  - high mass-loss rates
- **VHE emission** detected during **periastron passage** (H.E.S.S. Coll 2020)
  - **2020 passage**: detected at energies 0.14 TeV **up to above 1 TeV** (Steinmassl PoSICRC 2023)
  - **Hadronic scenario**

2014



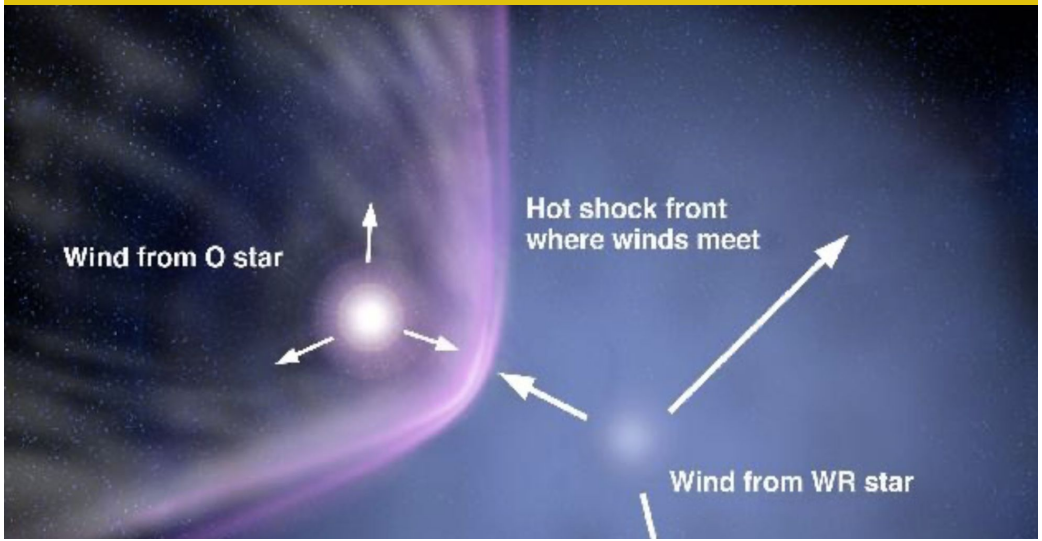


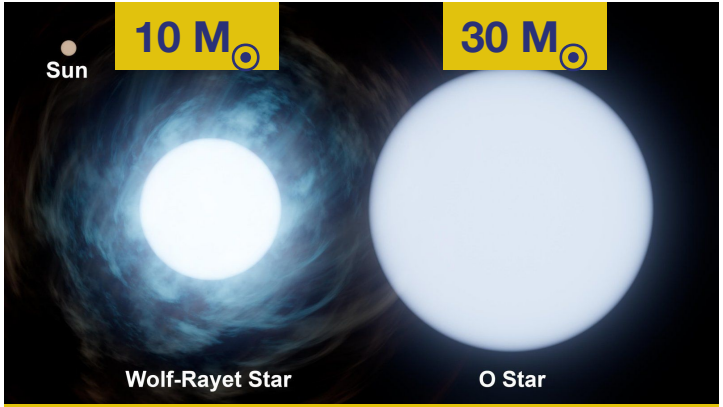
2020



WR 140, a CWB in the northern hemisphere

Objective: first CWB in the northern hemisphere and second CWB after Eta Carinae at VHE





period 7.9 yr, e ~ 0.9

Simbad
Other ID: HD193793
RA (J2000): 20 20 27.98
DEC (J2000): +43 51 16.28
distance (pc): 1810

Spectral type(s): WC7 + O5

Multiplicity:
Confirmed binary system
Period(s): 7.9 yr
Orbital solution: yes
Ref: Marchenko et al.(2003), Fahed et al.(2011)

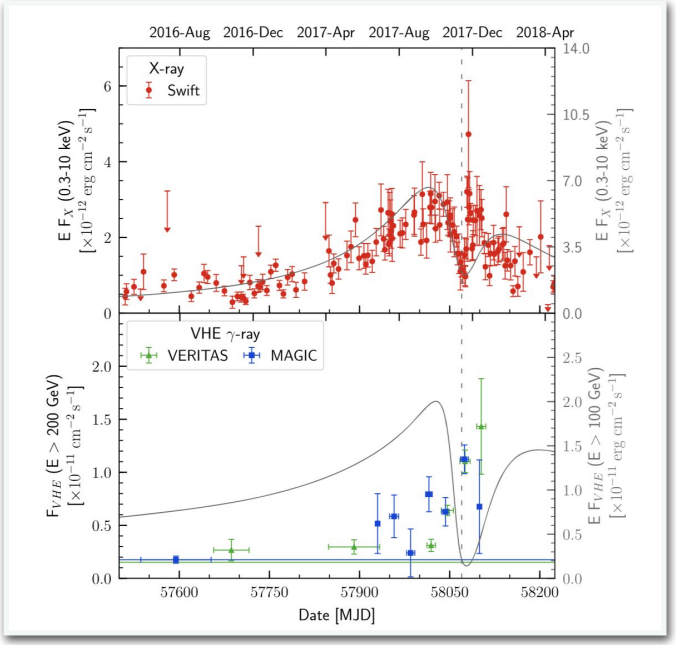
WR 140 MAGIC+LST-1 campaign

Critical configurations of WR 140 in 2024-25

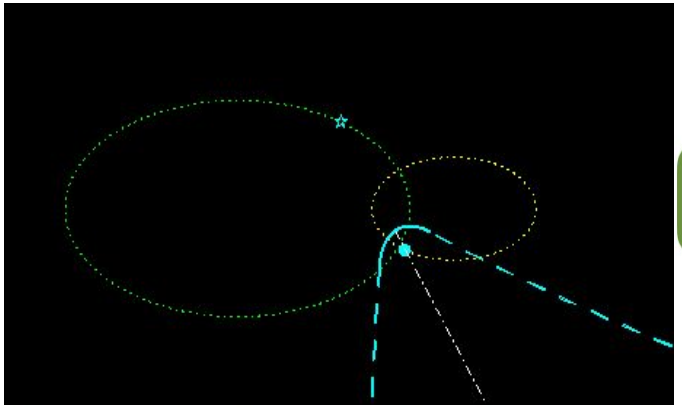
Orbital phenomenon	*f*	r/a	P.A.	pos	ψ	MJD	Year	Date
conjunction: WC star behind	223	0.56	84	E	30	60506	2024.54	July 15
quadrature	313	0.12	354	N	90	60626	2024.86	Nov 12
periastron passage	0	0.10	327	NW	129	60637	2024.89	Nov 23
conjunction: O star behind	42	0.12	263	W	150	60645	2024.91	Dec 1
quadrature	133	0.51	174	S	90	60751	2025.21	Mar 17

- **Start** of the monitorization in June 2024
- **Increasing cadence** after each orbital phenomenon
- **Quadrature not visible** due to Moon brightness
- **Not visible** anymore **after second conjunction**

PSRJ2032 (Abeysekara et al. 2018)



First gamma-ray campaign for WR140



From WR140 orbit

1st conjunction

Periastron passage

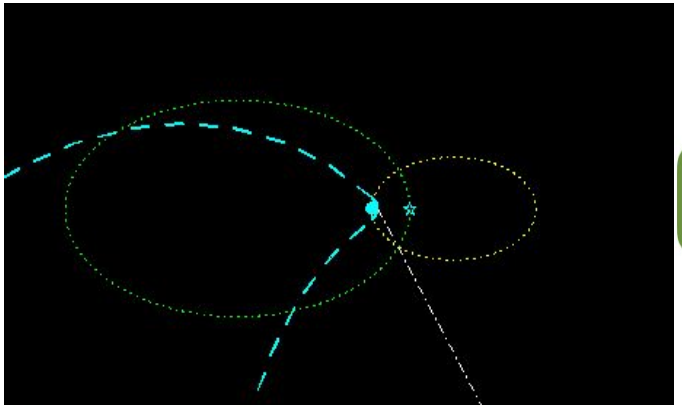
2nd conjunction

Jun | Jul | Aug | Sep | Oct | Nov | Dec

0.94 | 0.95 | 0.96 | 0.97 | 0.98 | 0.99 | 1.0

Orbital phase

First gamma-ray campaign for WR140



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Orbital phase

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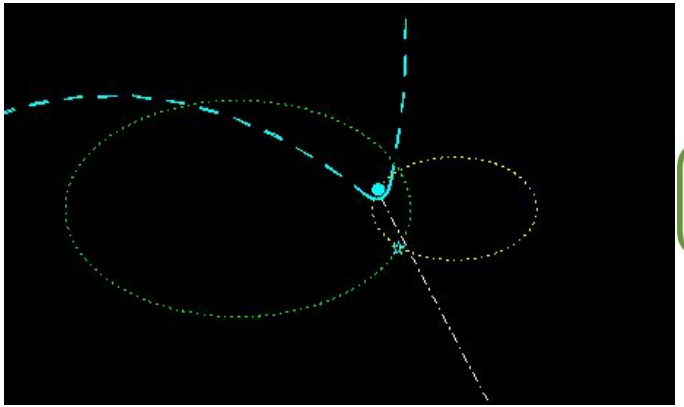


From WR140 orbit

1st conjunction

Periastron passage

2nd conjunction

Jun | Jul | Aug | Sep | Oct | Nov | Dec

0.94 | 0.95 | 0.96 | 0.97 | 0.98 | 0.99 | 1.0

Orbital phase

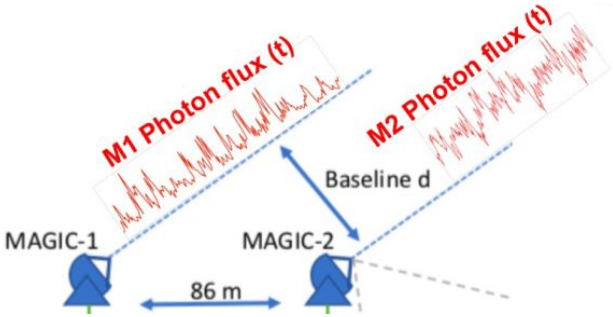
VHE binary emitters. Take home message

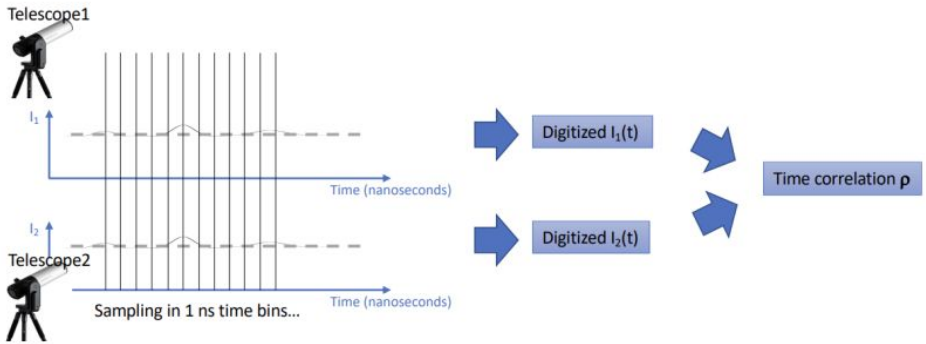
- Few gamma-ray binaries with variable emission at VHE
- Most detected ones had short orbital periods (~days).
    - CWB several years: Eta Carinae ~5.5 years and WR140 ~8 years
- Designing the **observational campaigns** is crucial part of the work
- Combination with Fermi-LAT for long-time integrated campaigns:
    - Fermi-LAT detected Eta Carinae in 2009 at HE (from 100 MeV to 100 GeV) with ~1 year data and VHE after integrating data over 3 periastron passages
- More information: VHE Galactic sources Seminar by A. López Oramas


Stellar Intensity
Interferometry (SII)

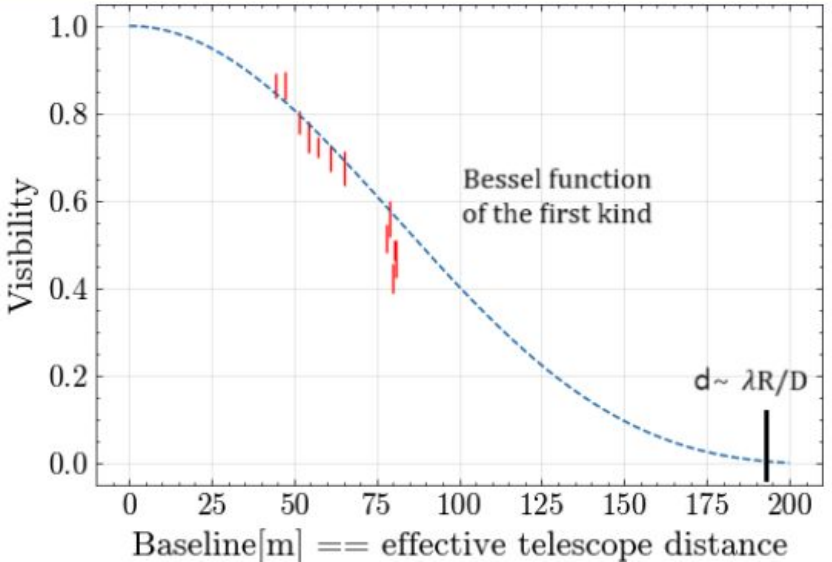
Intensity Interferometry: time correlation of detected photons

- **Van Cittert–Zernike theorem**: if you **measure** spatial coherence of the light waves it tells you information about the Fourier transform of the source's brightness.

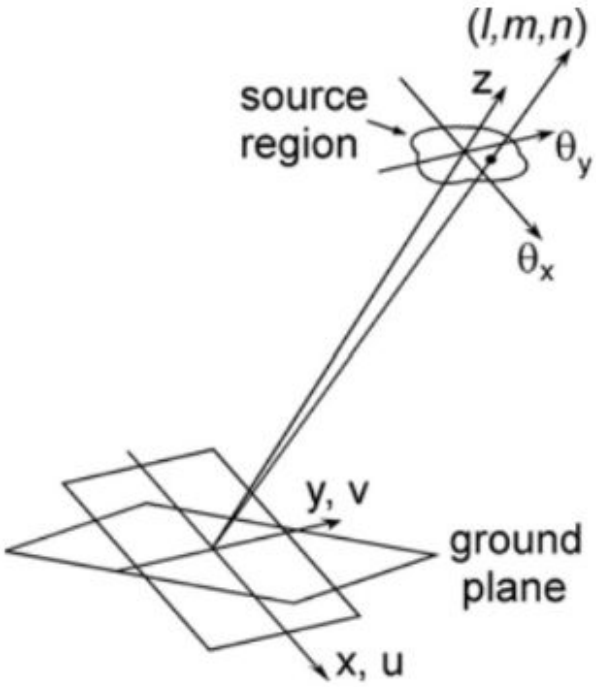


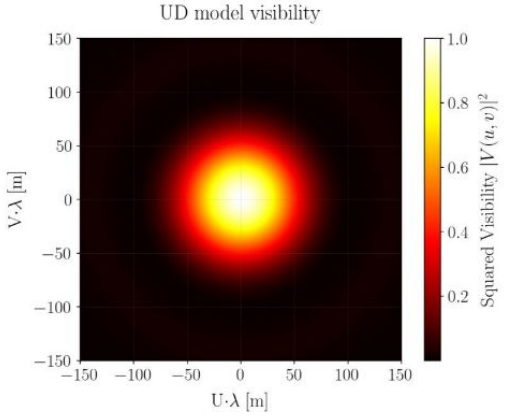


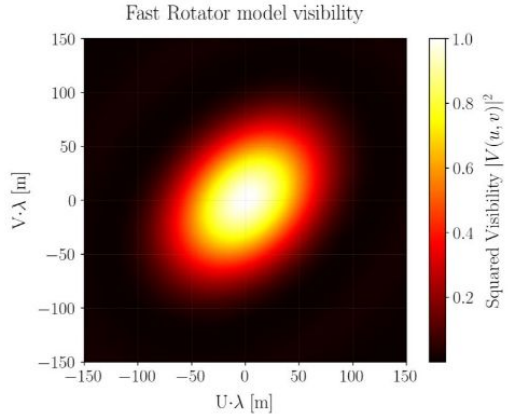
- SII is not limited by the moonlight and changing from gamma-ray to SII mode is very fast in both MAGIC and LST

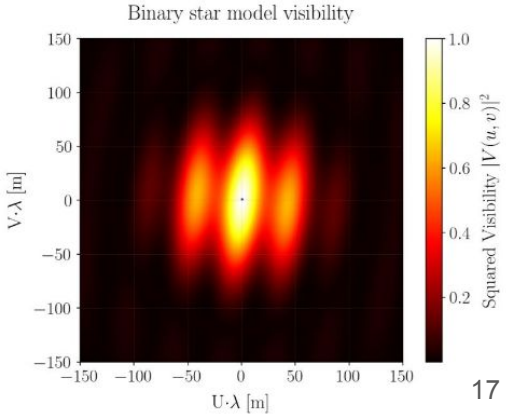


The UV plane


(l,m,n)
z
source
region
θy
θx
y, v
ground
plane
x, u

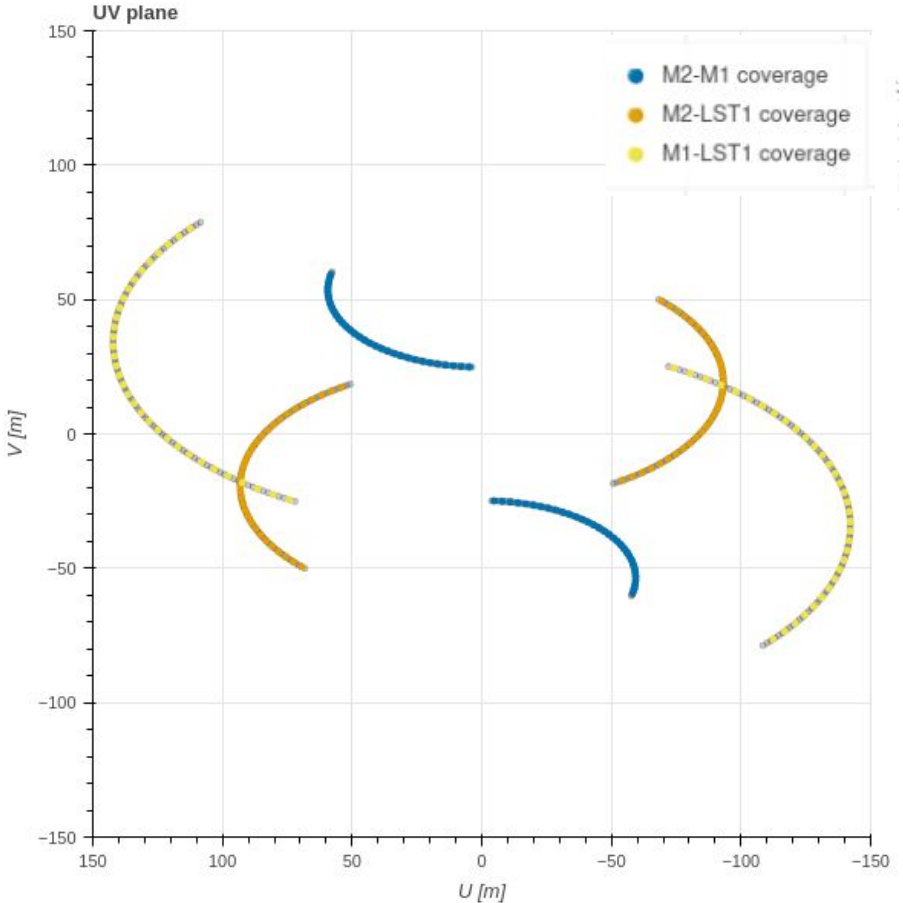

UD model visibility
V·λ [m]
U·λ [m]
Squared Visibility $|V(u,v)|^2$


Fast Rotator model visibility
V·λ [m]
U·λ [m]
Squared Visibility $|V(u,v)|^2$


Binary star model visibility
V·λ [m]
U·λ [m]
Squared Visibility $|V(u,v)|^2$

MAGIC+LST Stellar Intensity Interferometer

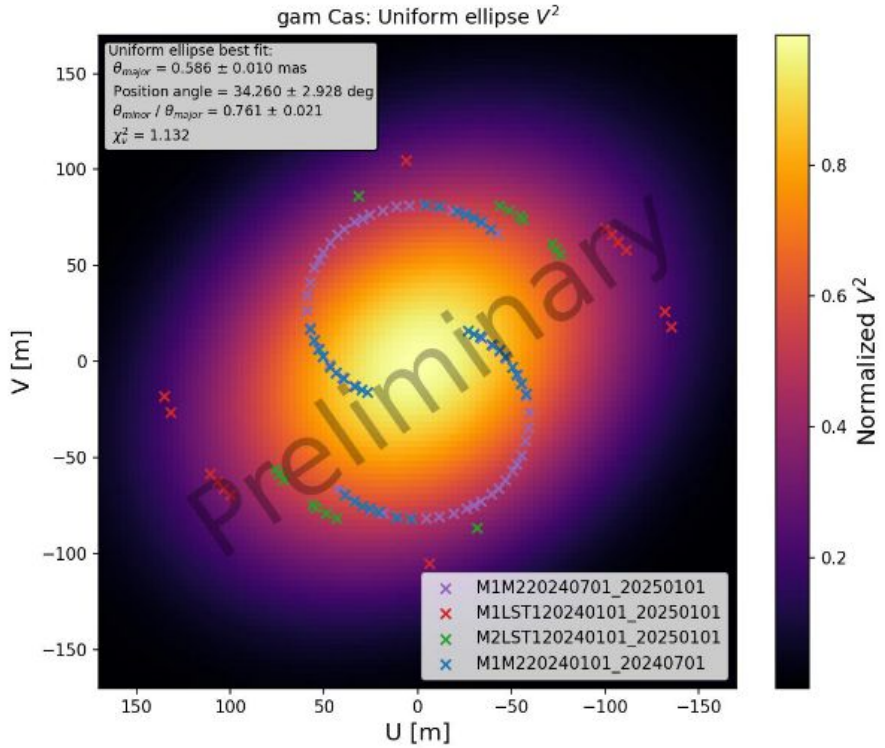
- 3 pairs available
- 15 pairs combining MAGIC with the 4 LSTs



Fast rotators with MAGIC+LST SI Interferometer

- Some results already presented by A. Cifuentes last week at EAS in the Symposium “The future of visible/infrared High-Angular Resolution Astronomy in Europe”

- It shows the importance of having several pairs of telescopes in terms of UV plane coverage

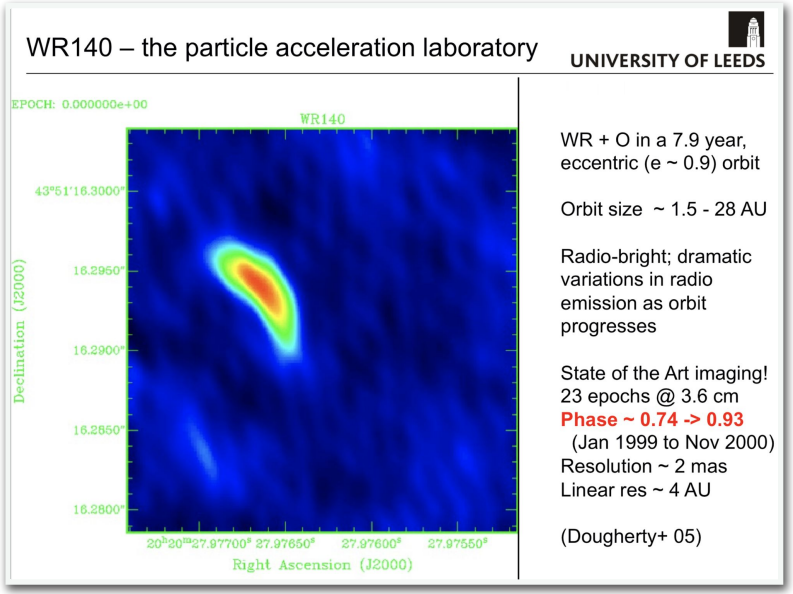


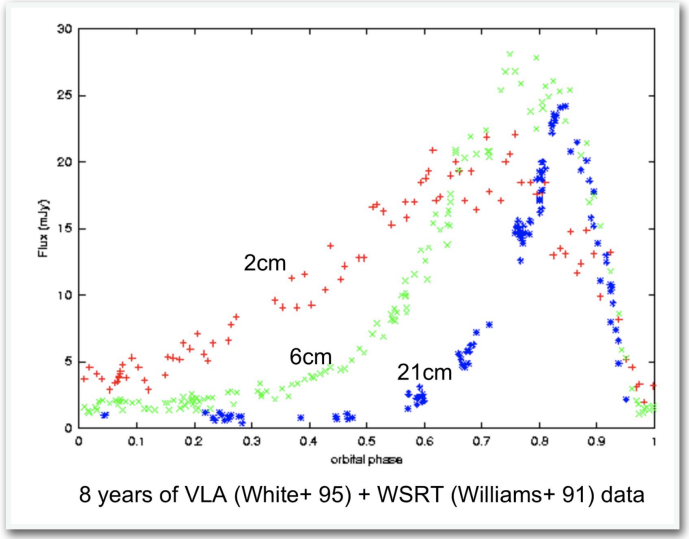
SII. Take home message

- IACTs are great instruments that have relaunched this technique
- Different science scenarios
  - Fast rotators
  - Resolving binary systems
  - Asteroseismology
- SII observations do not interfere with gamma-ray observations
- With more telescopes (more pairs) and technical upgrades, much more science to be done.
- More information: SII Seminar by J. Cortina and MAGIC Stellar Intensity Interferometer Performance paper.

Backup

WR140: Radio campaign

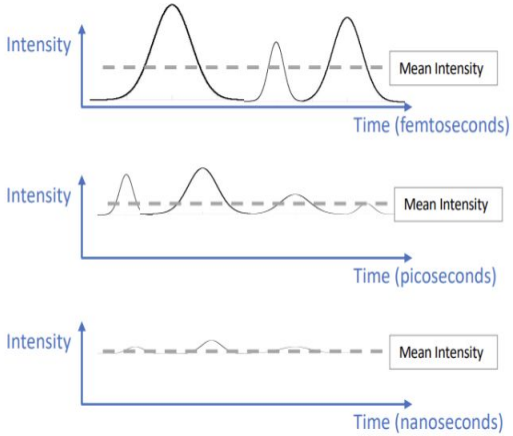




Pittard (VGGRS 2010)

SII: coherence region

d, spatial coherence length, follows:
$d \sim \lambda \cdot R/D$
R: distance to the source
D: physical diameter of the source



Always some modulation but relative amplitude get smaller and smaller with time scale