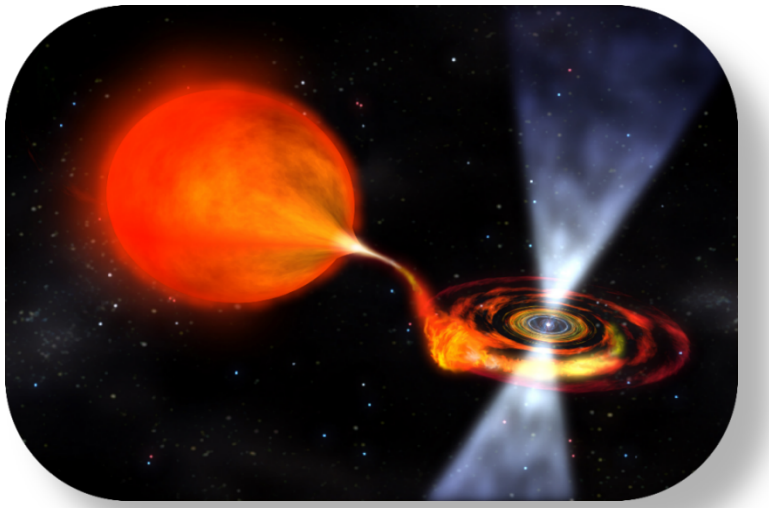
SiFAP2@TNG: a look inside fast periodic and transient phenomena at sub-μs time scales



Filippo Ambrosino [INAF OA Roma]

filippo.ambrosino@inaf.it

Collaborators: Alessandro Papitto, Piergiorgio Casella, Gianluca Israel, Arianna Miraval Zanon, Luigi Stella (INAF/OAR)
Adriano Ghedina, Massimo Cecconi, Manuel Gonzalez, Ennio Poretti (INAF/Fundacion Galileo Galilei)
Franco Meddi (Sapienza Univ. di Roma), Franco Leone (Univ. di Catania), Sergio Campana, Paolo D'Avanzo (INAF/OAB)

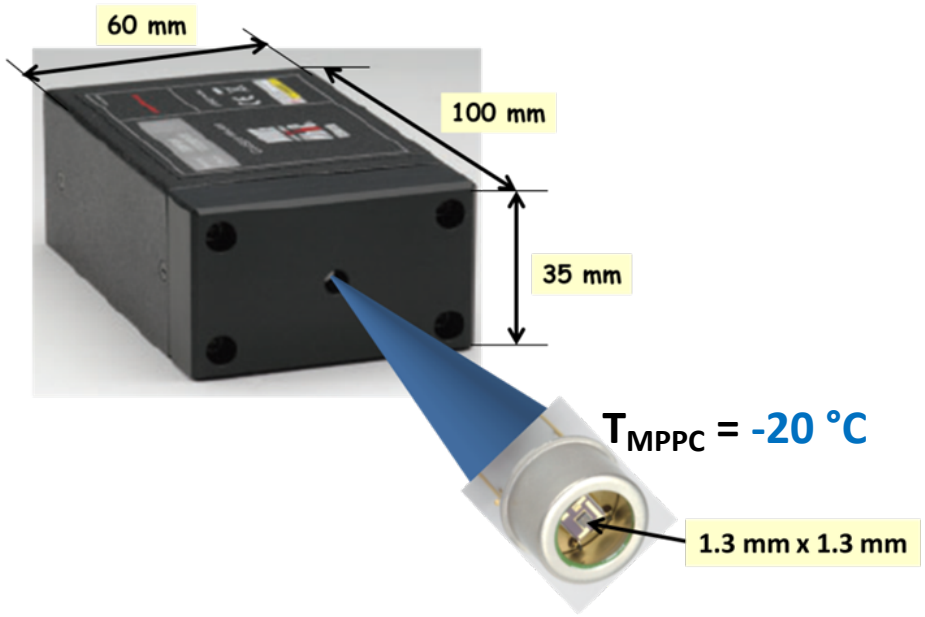
TNG 25° anniversary – La Palma – October 20, 2021

Silicon Photo Multiplier Multi-Pixel Photon Counter

SiPM = MPPC

HAMAMATSU

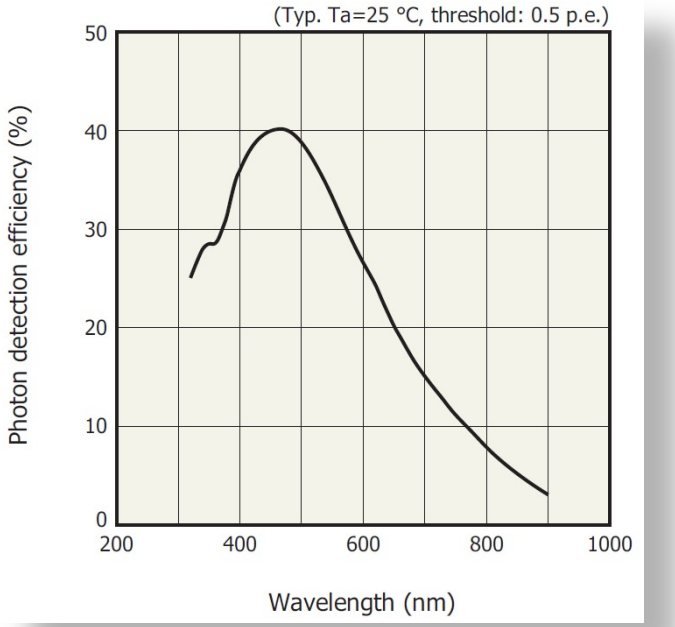
HAMAMATSU PHOTONICS K.K., Solid State Division
1126-1, Ichino-cho, Higashi-ku, Hamamatsu City, 435-8558, Japan
Telephone: (81)53-434-3311, Fax: (81)53-434-5184
www.hamamatsu.com

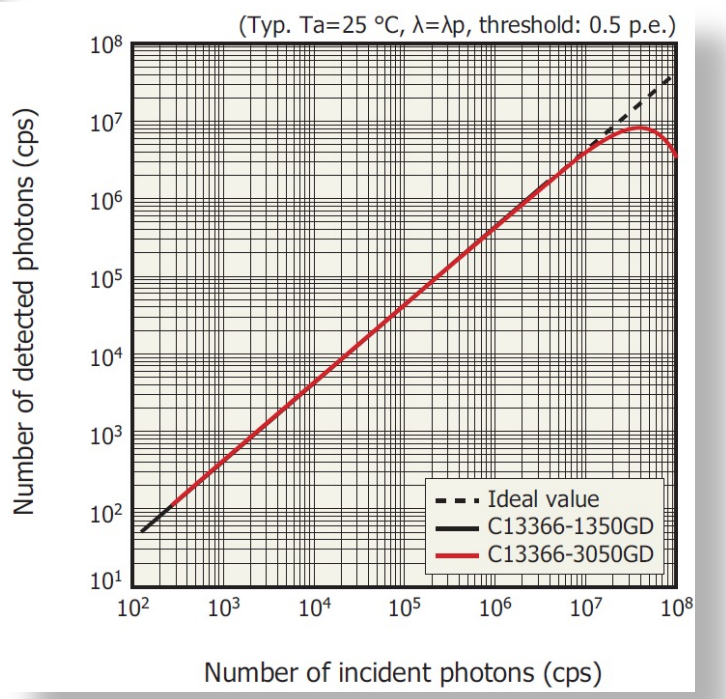


Single photon counting capability!!!

Rise time ~ 2-5 ns

Dark count rate ~ 2.0 kcps

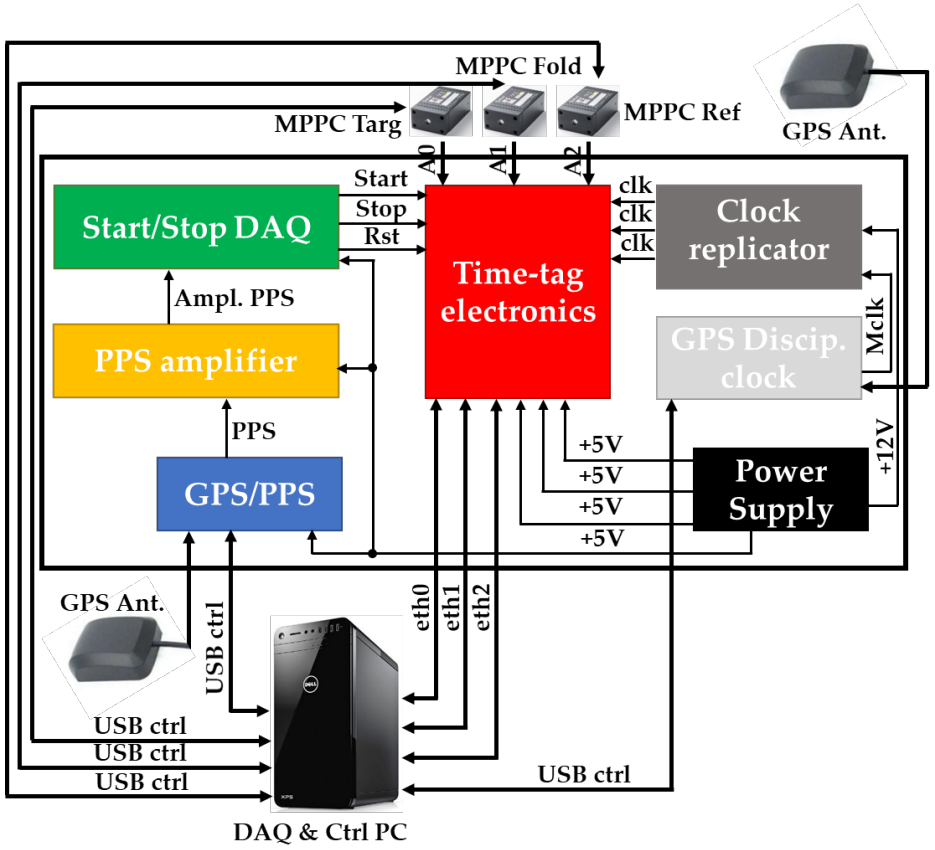




Time resolution: **8 ns**

Relative time accuracy: **10^{-6}**

Absolute time accuracy < **60 μs!**



Desktop PC chassis size

Developed at Sapienza University of Rome

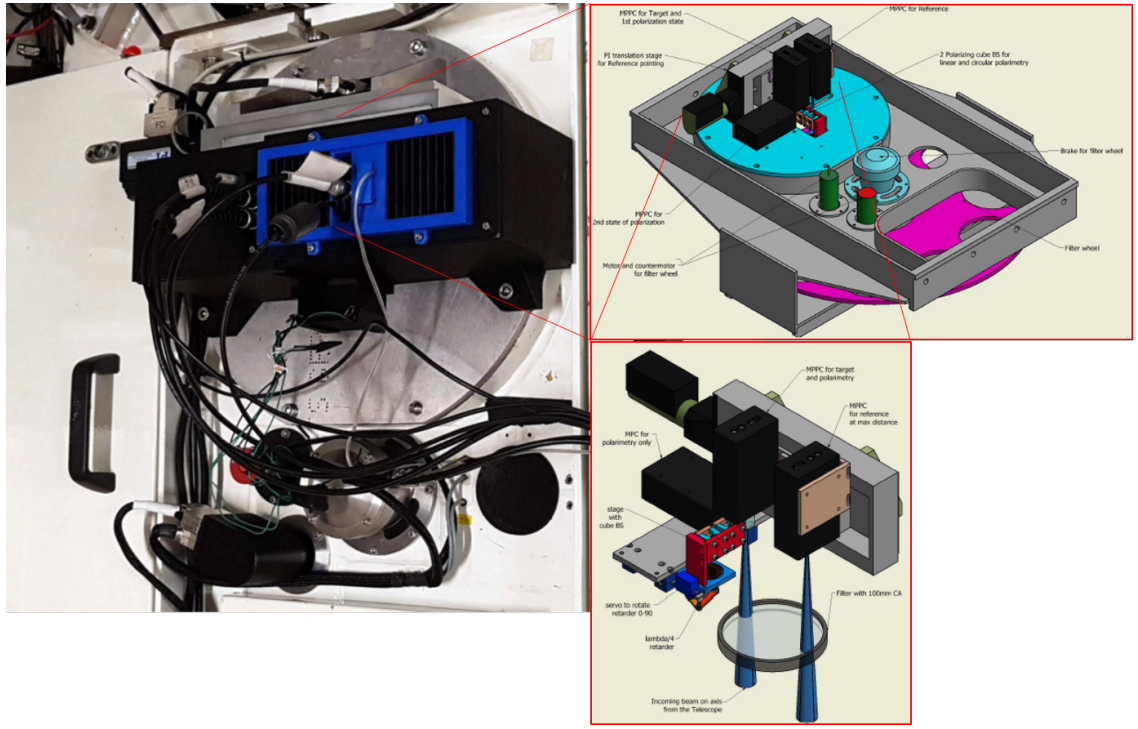
2011-2014 - Mounted at 152 cm Loiano telescope

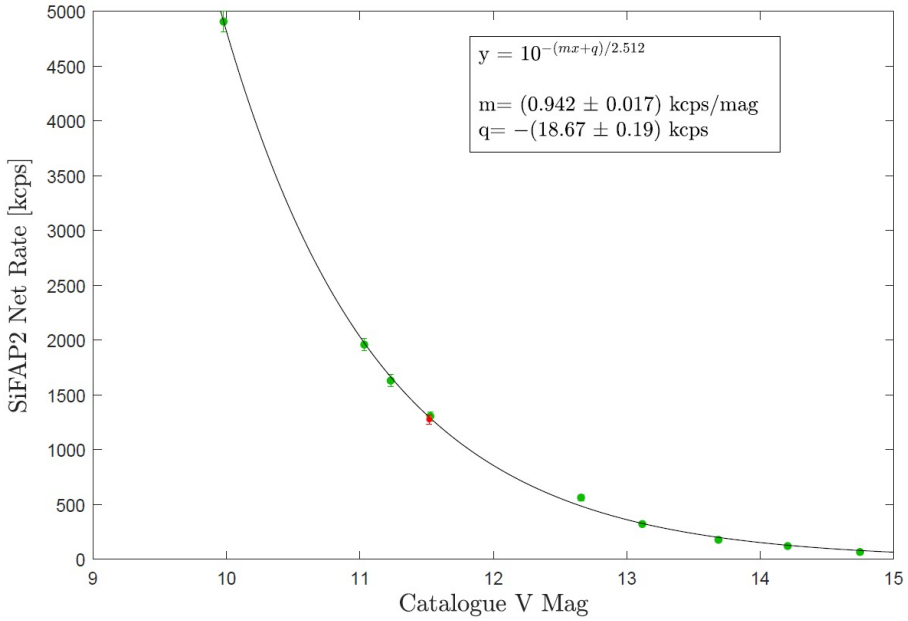
2014.5 - Successfully tested at TNG

Meddi et al., 2012; Ambrosino et al., 2013, 2014, 2016

SiFAP2@TNG

Nasmyth A focus





Versatile mechanical system

- SiFAP2 permanently mounted
- Fast response for transient events

Observing modes

- BVR/ugriz fast photometry
- Linear polarimetry
- Circular polarimetry

http://www.tng.iac.es/instruments/sifap2/

Ghedina et al. 2018

Internal testing call in 2019 - 2 dedicated runs

Call for proposals AOT43 (Apr - Sep 2021)

Highest number of proposals (8 out of 19)

54 hours approved and scheduled, 10 hr lost (bad weather)

Binary millisecond radio pulsars

FRBs

Cataclysmic Variables & X-ray transients

Blazars

Asteroidal and lunar occultations

Call for proposals AOT 44 (Oct – Mar 2022)

37 hr approved and scheduled

SiFAP2 in the context

Instrument	Detector	Group	Time res. [s]	Mode
SiFAP2	SiPM	INAF Rome/FGG	8e-9	Fast Timing/Polarimetry
Aqueye+/Iqueye	SPAD	INAF Padua	1e-10	Fast Timing
UltraCam	CCD	Sheffield/Warwick	5e-3	3-band Imaging
UltraSpec	eMCCD	Sheffield/Warwick	1e-3	Spectroscopy
GASP	eMCCD	Galway	6e-4	Polarimetry
Optima	APD	MPE	1e-9	Fast Timing/Polarimetry
Arcons	MKID	UCSB	2e-8	Imaging
Circe	HAWAII-2RG	IAC/Florida	1e-3	Photometry/Polarimetry
HiperCam	CCD	Sheffield/IAC	6e-4	5-band Imaging

Optical millisecond pulsars, a challenge to the paradigm

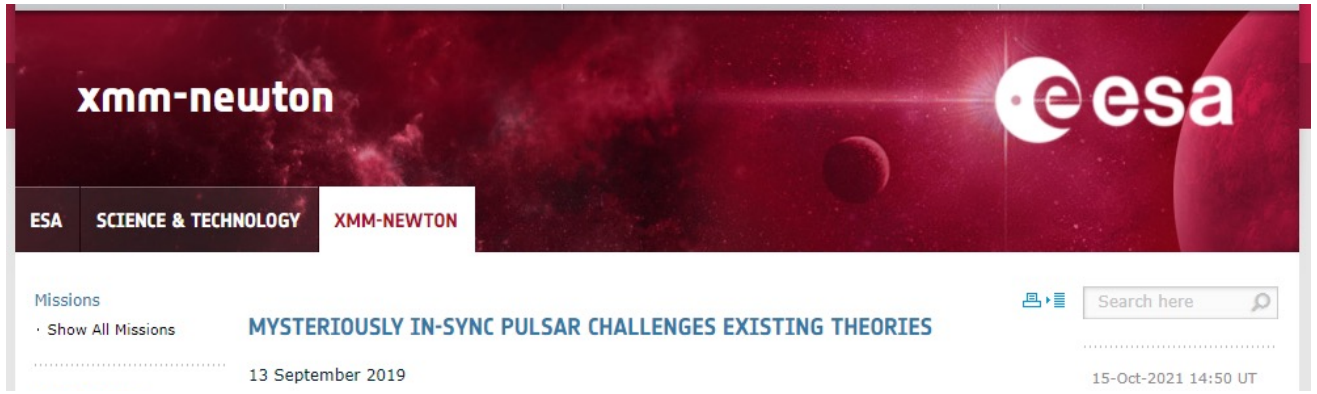
nature astronomy

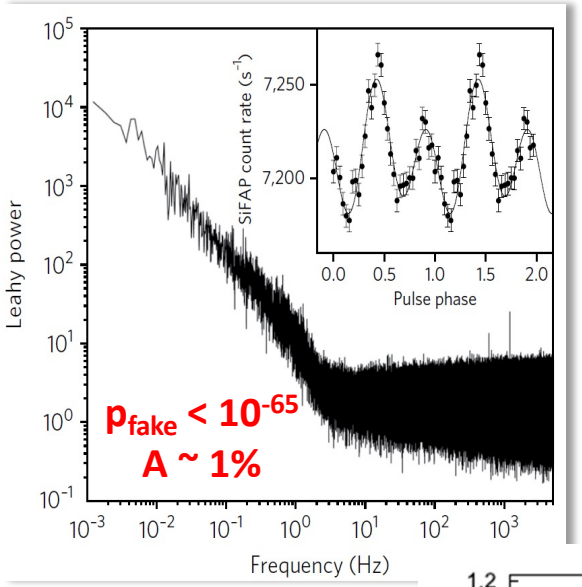
LETTERS

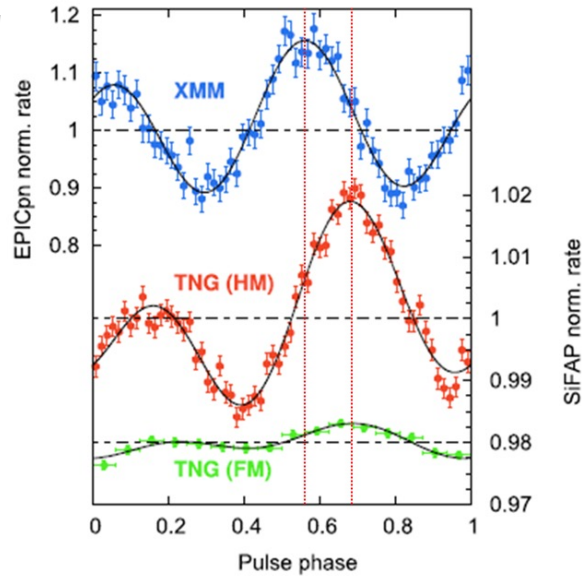
DOI: 10.1038/s41550-017-0266-2

Optical pulsations from a transitional millisecond pulsar

F. Ambrosino[1,2], A. Papitto[3]*, L. Stella[3], F. Meddi[1], P. Cretaro[4], L. Burderi[5], T. Di Salvo[6], G. L. Israel[3], A. Ghedina[7], L. Di Fabrizio[7] and L. Riverol[7]







Ambrosino, Papitto et al. 2017, Nature Astronomy

Papitto et al. 2019, ApJ

Optical/UV millisecond pulsars, unveiling a new class of sources

nature astronomy

LETTERS

https://doi.org/10.1038/s41550-021-01308-0

Check for updates

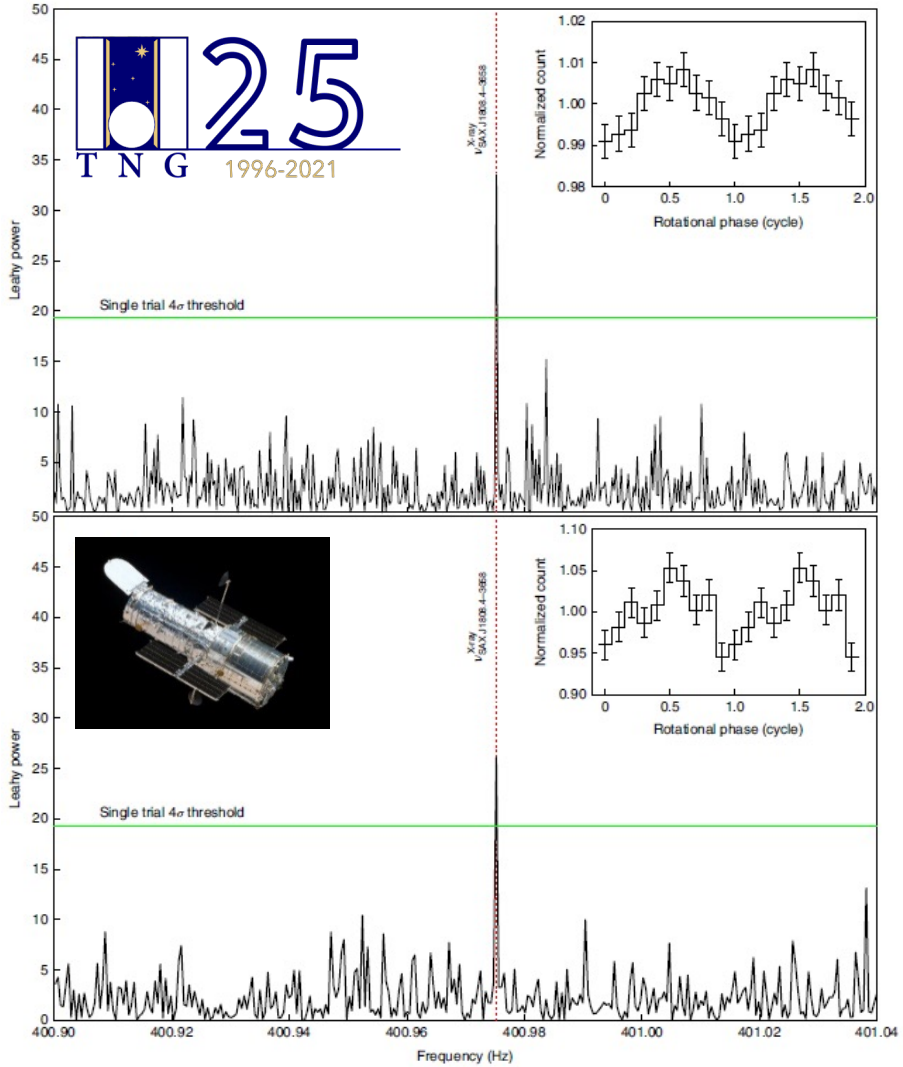
Optical and ultraviolet pulsed emission from an accreting millisecond pulsar

F. Ambrosino[1,2,3,22] ✉, A. Miraval Zanon[4,5,22] ✉, A. Papitto[1], F. Coti Zelati[5,6,7], S. Campana[5], P. D'Avanzo[5], L. Stella[1], T. Di Salvo[8], L. Burderi[9], P. Casella[1], A. Sanna[9], D. de Martino[10], M. Cadelano[11,12], A. Ghedina[13], F. Leone[14], F. Meddi[3], P. Cretaro[15], M. C. Baglio[5,16], E. Poretti[5,13], R. P. Mignani[17,18], D. F. Torres[6,7,19], G. L. Israel[1], M. Cecconi[13], D. M. Russell[16], M. D. Gonzalez Gomez[13], A. L. Riverol Rodriguez[13], H. Perez Ventura[13], M. Hernandez Diaz[13], J. J. San Juan[13], D. M. Bramich[16] and F. Lewis[20,21]

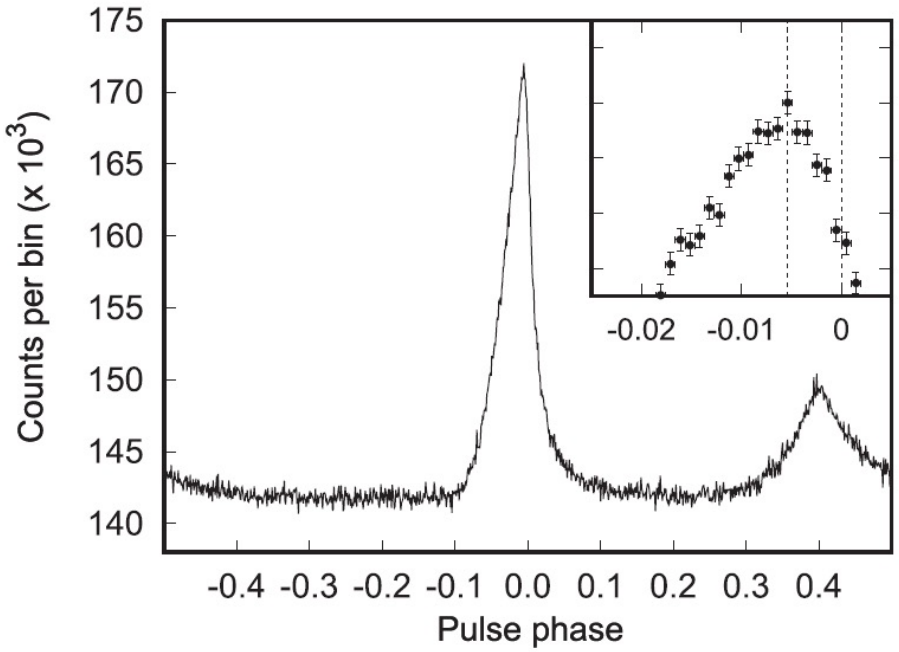
1 hour-long TNG/HST campaign

Ambrosino, Miraval Zanon et al. 2021, Nature Astr.

Future: search for optical pulses from candidate steady gravitational wave sources (e.g. Sco X-1)

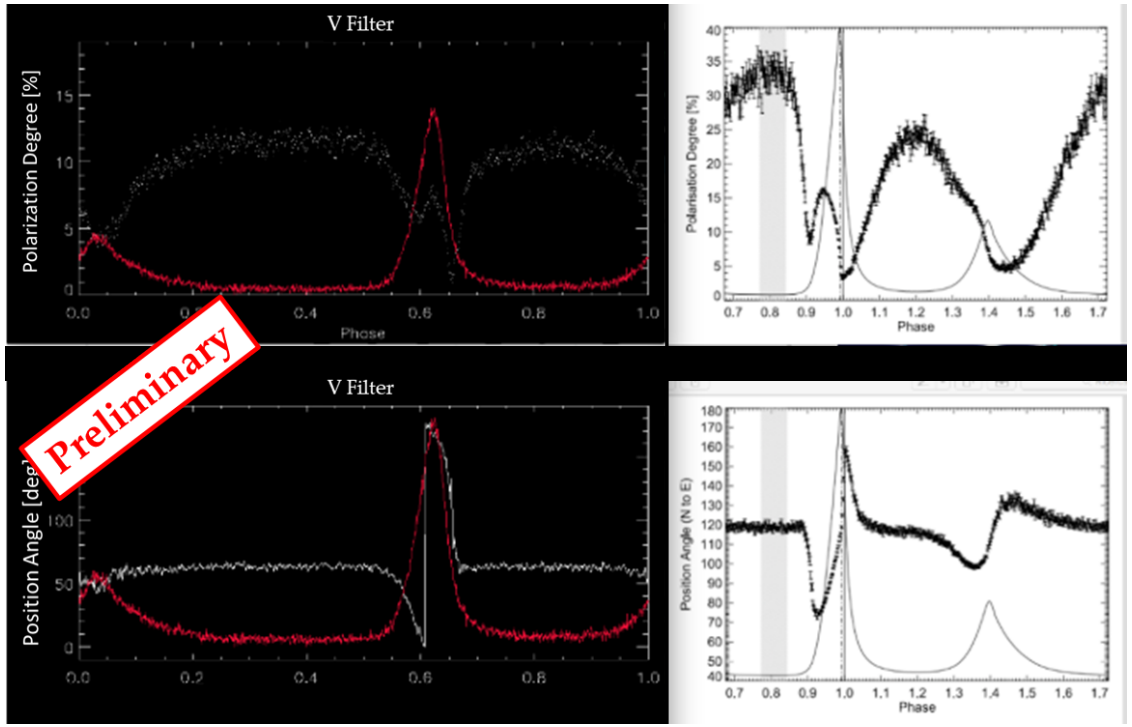


The Crab pulsar, absolute timing & linear polarization



Optical lag radio pulse by
$\delta\tau^{Crab}$ = (181 ± 62) μs
compatible with existing measures
Papitto+ 2019

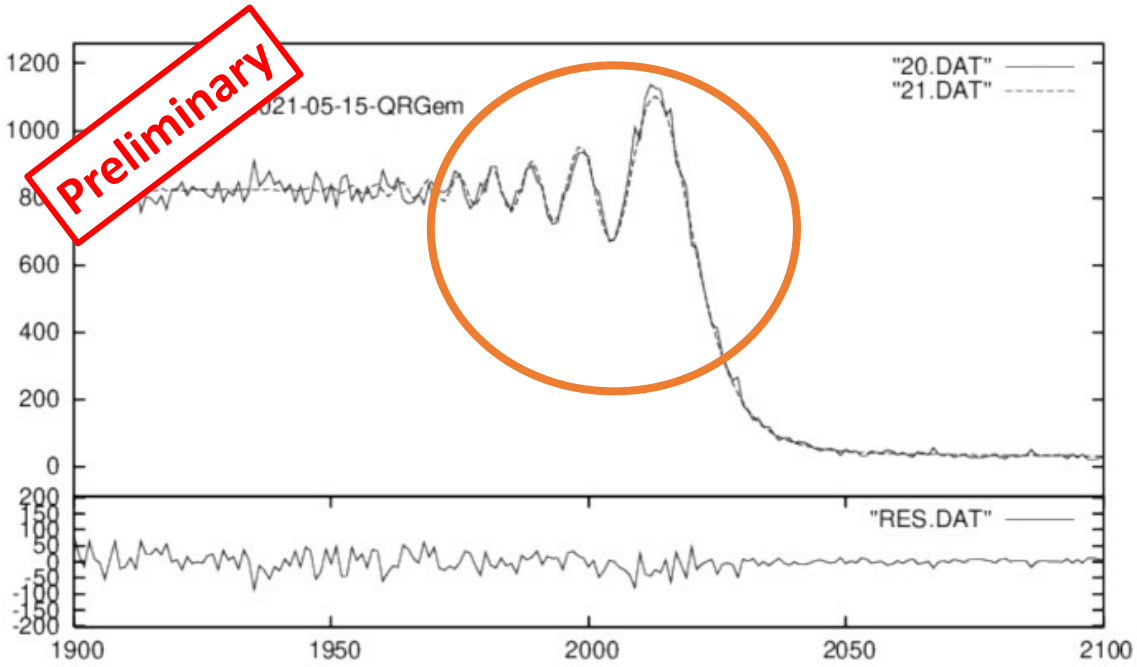
Courtesy of F. Leone (Leone+ 2022 in prep.)



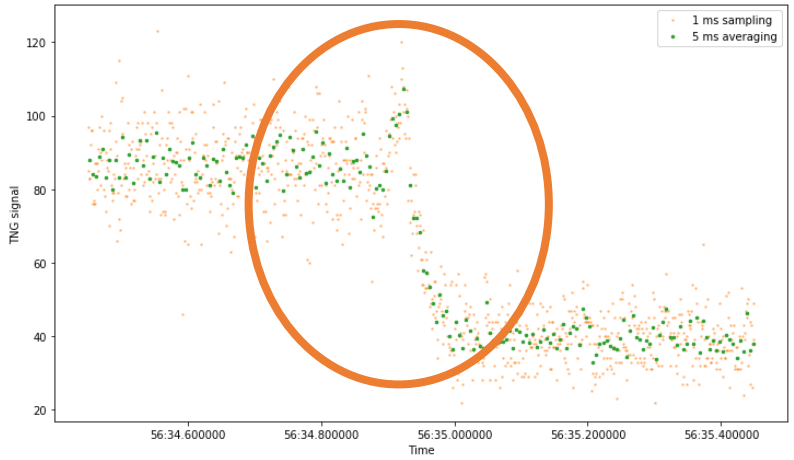
Polarization degree up to 15%
& swings of the polarization angle
Compatible with OPTIMA & GASP results

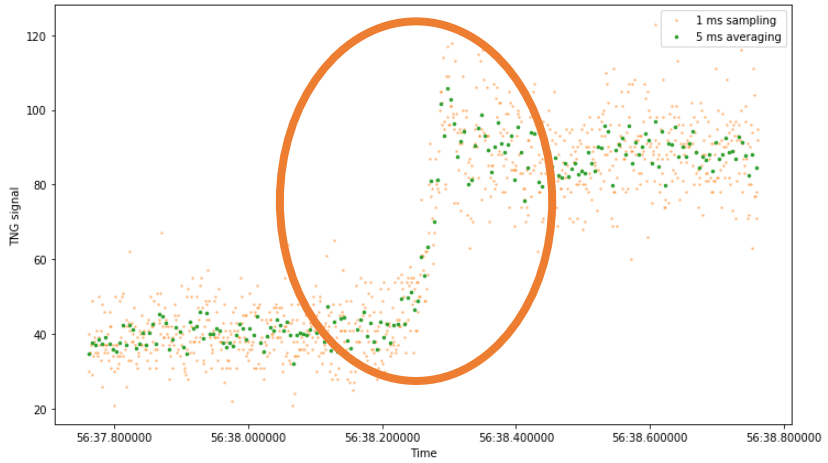
Lunar & asteroidal stellar occulations

Diffraction fringes measure star angular diameters



QR Gem: V = 7.65, long-period variable star occulted by the Moon
Courtesy of A. Richichi



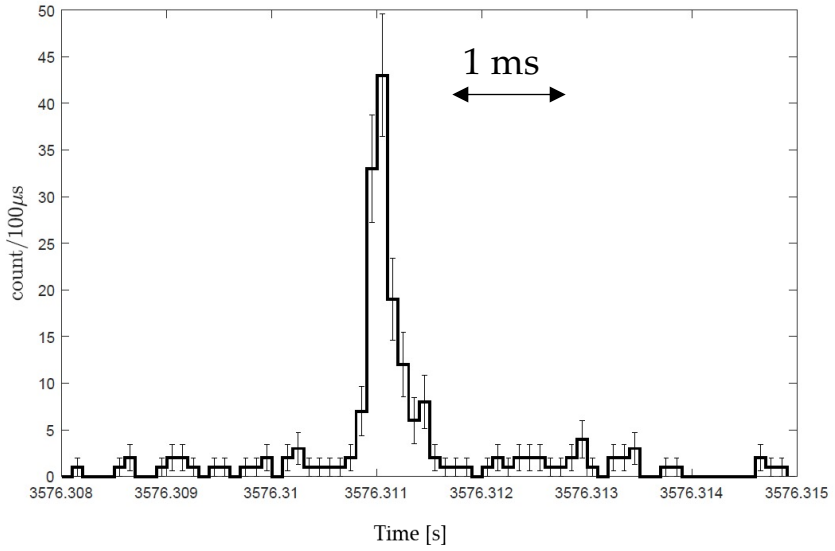


UCAC4 340-082004: V = 11.7
occulted by Lameia asteroid
Courtesyof T. Hassan

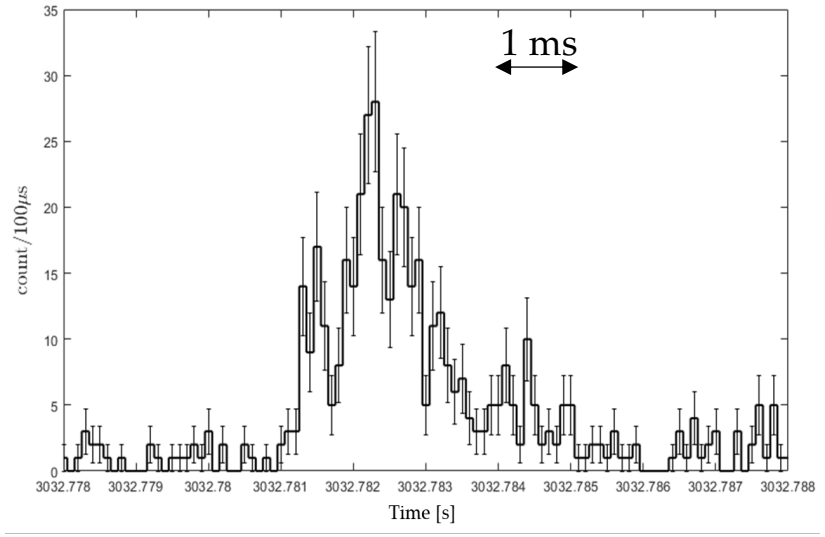
Fast optical bursts

Preliminary

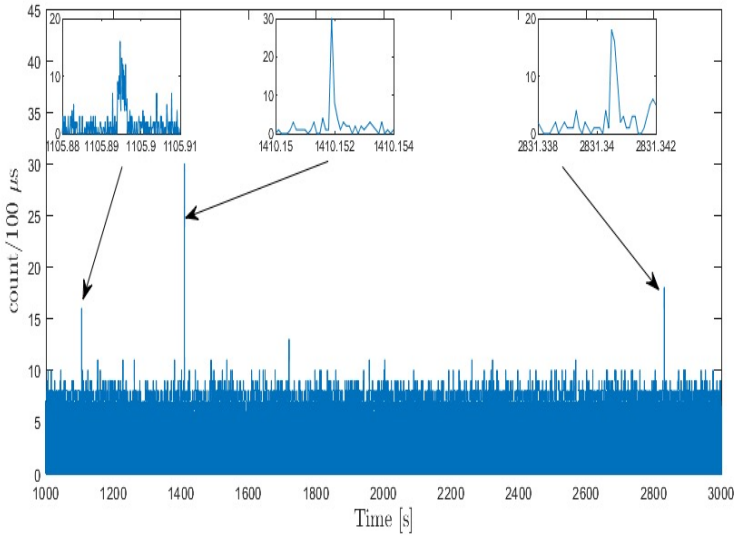
Fast Radio Bursts



Magnetars



Pulsars



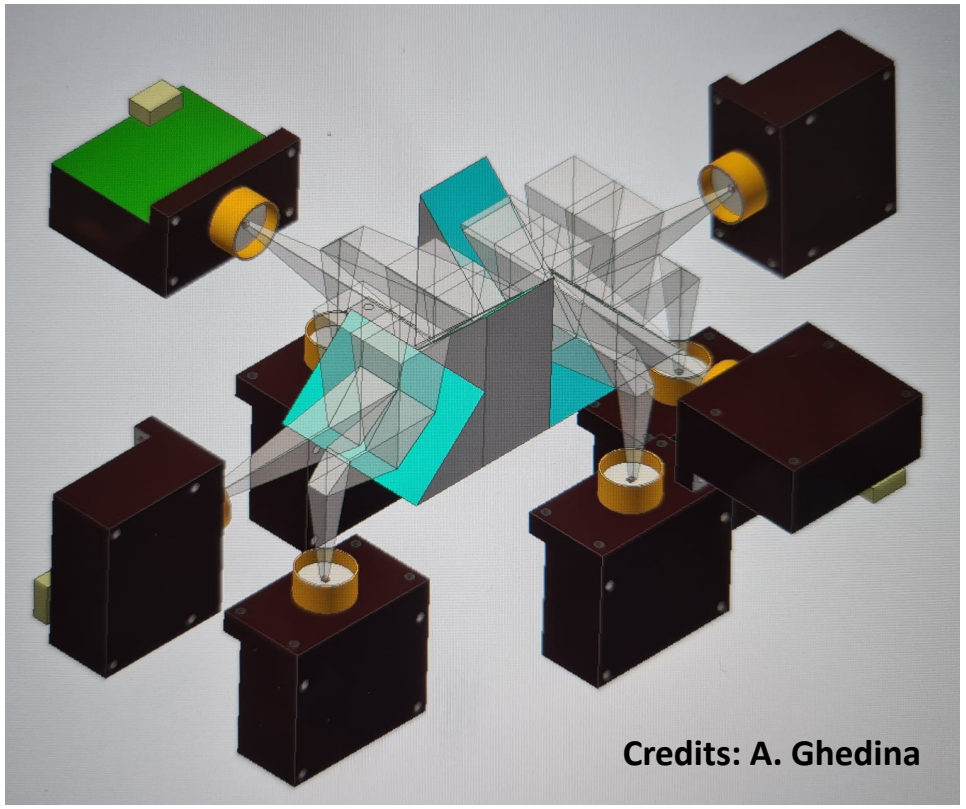
One burst per hour in a 7 x 7 arcsec^2 FoV >> meteor/fireballs expected rate

Atmospheric flashes? Space debris? Satellites?

Multiwavelength campaigns & more burst statistics needed

No bursts simultaneous to Sardinia Radio Telescope repeating FRB detection – Pilia+ 2020

The future - Fast optical polatimetry & photometry



Nasmyth B focus

8 x MPPC detectors & new optical design

POLARIMETRY

Simultaneous measurement of the 4 Stokes parameters

Better estimate of the instrumental polarization

Simultaneous multiwavelength observations with new generation satellites (IXPE, eXTP)

PHOTOMETRY

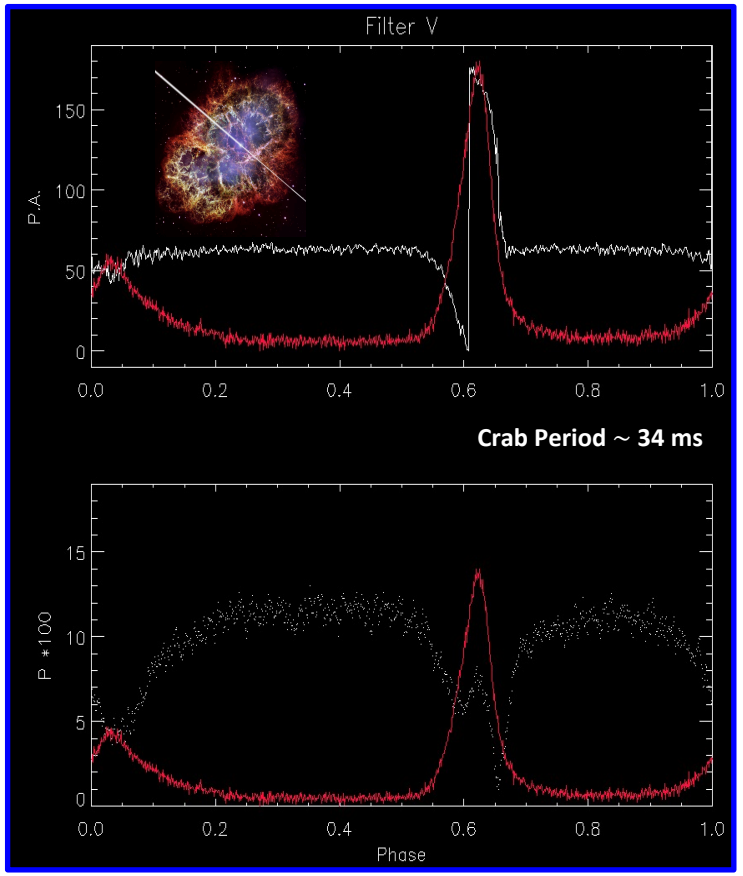
Possibility to perform UBVRI/ugriz photometry with simultaneous sky background

Saturation point increased and dead time reduced (factor 4) ➔ Observation of brighter sources

The X-ray polarimetric window re-opens (IXPE launch in Dec 2021)

SiFAP2 development (eP-SiFAP) to exploit synergies with IXPE through High-time resolution simultaneous MWL polarimetric observations

In collaboration with: P. Soffitta, S. Fabiani, A. Di Marco, E. Costa



The SiFAP2/TNG growing team

Instrumental development – PI: F. Ambrosino

Sensors - F. Ambrosino, F. Meddi, A. Ghedina, M. Cecconi

Photometry - A. Ghedina, F. Ambrosino

Polarimetry - F. Leone, M. Cecconi, L. Di Fabrizio

Mechanics - A. Ghedina, L. Riverol

Electronics - F. Ambrosino, M. Gonzalez, M. Hernandez, H. Perez Ventura

Control/DAQ software - F. Ambrosino, P. Cretaro, M. Gonzalez

Science – PI: A. Papitto

MSP - A. Papitto, F. Ambrosino, A. Miraval Zanon, L. Stella, F. Coti Zelati; S. Campana, P. D'Avanzo, A. Sanna, A. Riggio, L. Burderi; T. Di Salvo, R. Iaria, D. De Martino

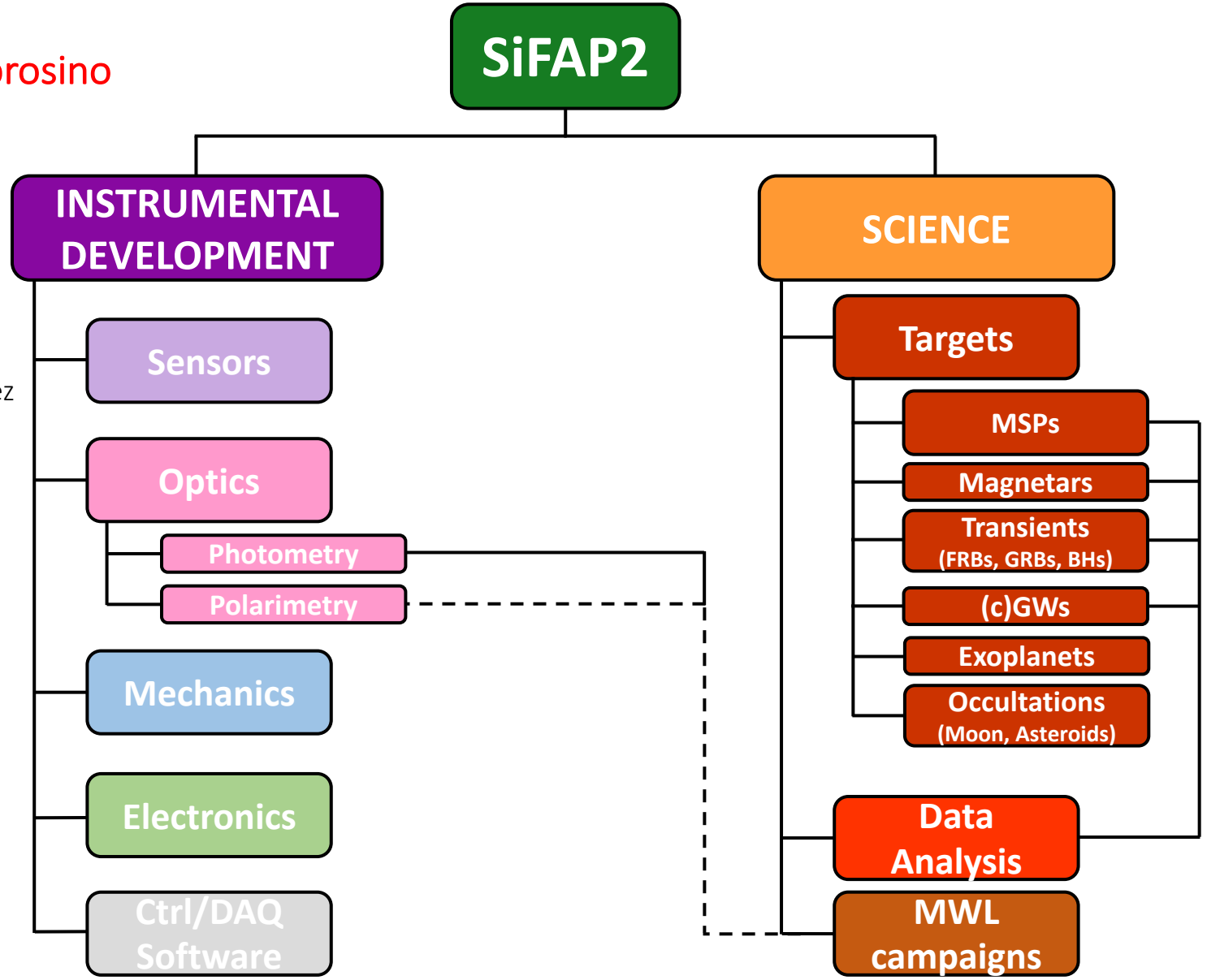
Magnetars - G.L. Israel, A. Papitto, F. Ambrosino; N. Rea, F. Coti Zelati, A. Borghese

Transients - P. Casella, A. Papitto, F. Ambrosino; M. Pilia, A. Possenti, M. Burgay

Exoplanets - F. Borsa, E. Poretti; F. Ambrosino; A. Ghedina, M. Cecconi

Occultations - A. Richichi, T. Hassan; F. Ambrosino, A. Papitto; A. Ghedina, M. Cecconi

(c)GWs: A. Papitto, P. Astone; F. Ambrosino, L. Stella; P. Leaci, C. Palomba, S. Dall'Osso



SiFAP2/TNG collaborating MWL facilities

- **Radio:** Sardinia Radio Telescope, Parkes, ATCA, LOFAR, MeerKAT, SKA, VLA, FAST, GMRT
- **near-infrared:** REM, GTC
- **Optical:** Copernicus/Aqueye+, VLT, NTT, WHT, SALT, TESS
- **UV:** Hubble Space Telescope
- **X-rays:** XMM Newton, Swift, NuSTAR, NICER, INTEGRAL, Chandra, HXMT, **IXPE**
- **gamma-rays:** Fermi, AGILE (space); MAGIC, **ASTRI**/CTA (ground)

SiFAP2@TNG

Low-cost instrumentation (**disruptive technology**) with very **high scientific impact**

Synergy between **commercial** and **custom** electronics (MPPC sensors, DAQ electronic chains)

First detection ever of optical pulsations from a transitional ms pulsar (i.e. PSR J1023+0038)

First detection ever of optical/UV pulsations from an accreting ms pulsar (i.e. SAX J1808.4-3658)

First detection of both lunar and asteroidal occultations

Upper limit on FRB magnitude

Optimized mechanical interface @TNG

Possibility to perform both classical photometry and polarimetry

7 scientific papers (2 Nature Astronomy), 3+ in preparation & 3 technical papers

A new window on fast variable optical emission has opened & much more awaits be done with an improved instrument

SiFAP2 technological improvements

Increase **temporal & photometric** accuracy

New **polarimetric unit** (eP-SiFAP) for simultaneous measurements of the 4 Stokes parameters

Extend SiFAP2 capability also to **NIR region** (0.9 – 2.6 μm, JHK bands)

SiFAP2 as **PI instrument** at TNG (control interface under development)

Funds:

TNG funds & manpower (TNG staff)
proposed (PRIN, MUR, EU ERC funding scheme)