High Energy and Time Resolution Astrophysics

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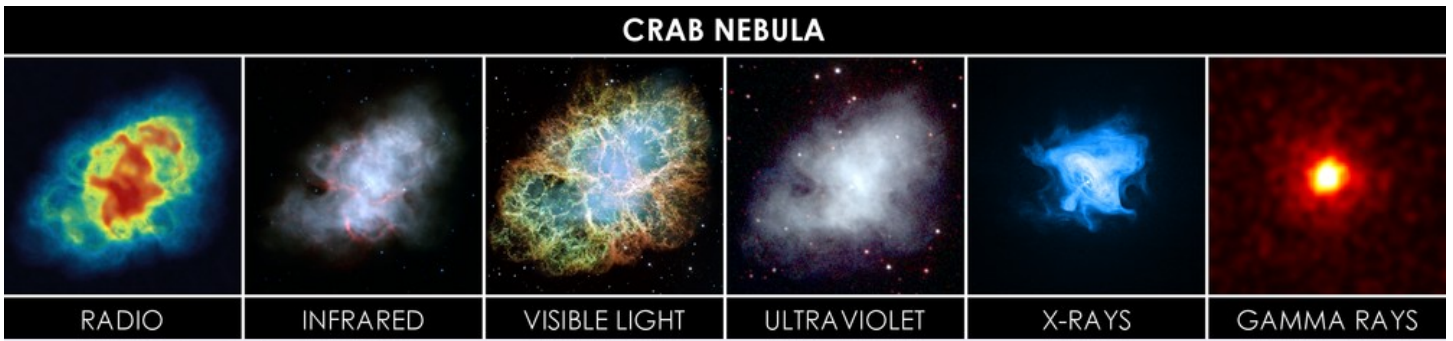
For the ASTRI Collboration

and

the AQUEYE+IQUEYE Collaboration
http://web.oapd.inaf.it/zampieri/aqueye-iqueye/index.html

INAF-OAPd days – Padova – Jun 17-18, 2019

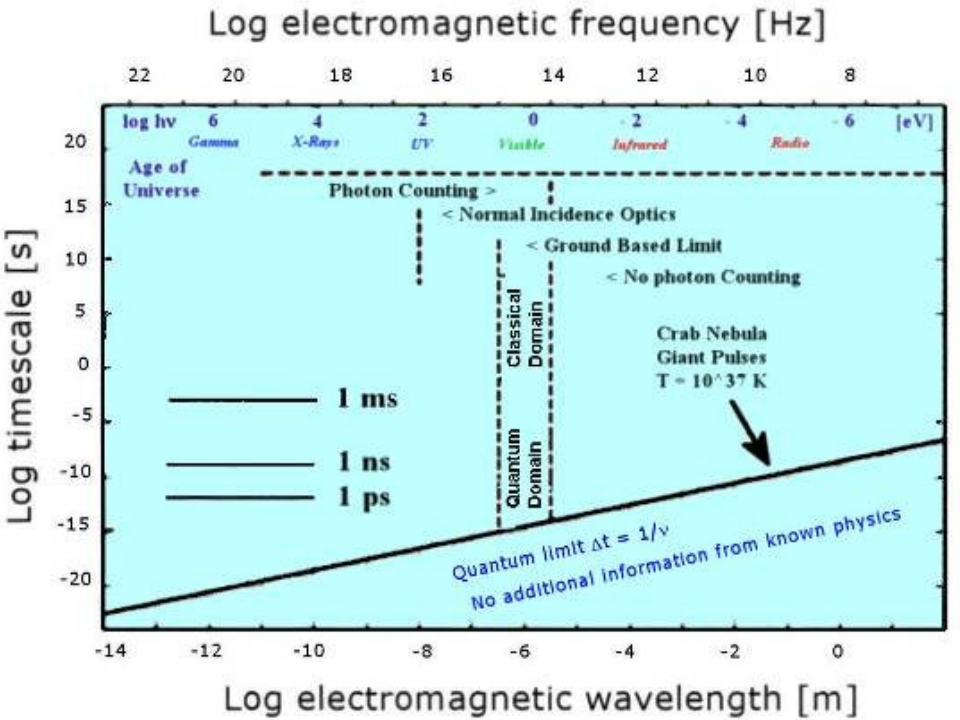
Astrophysics across wavelength



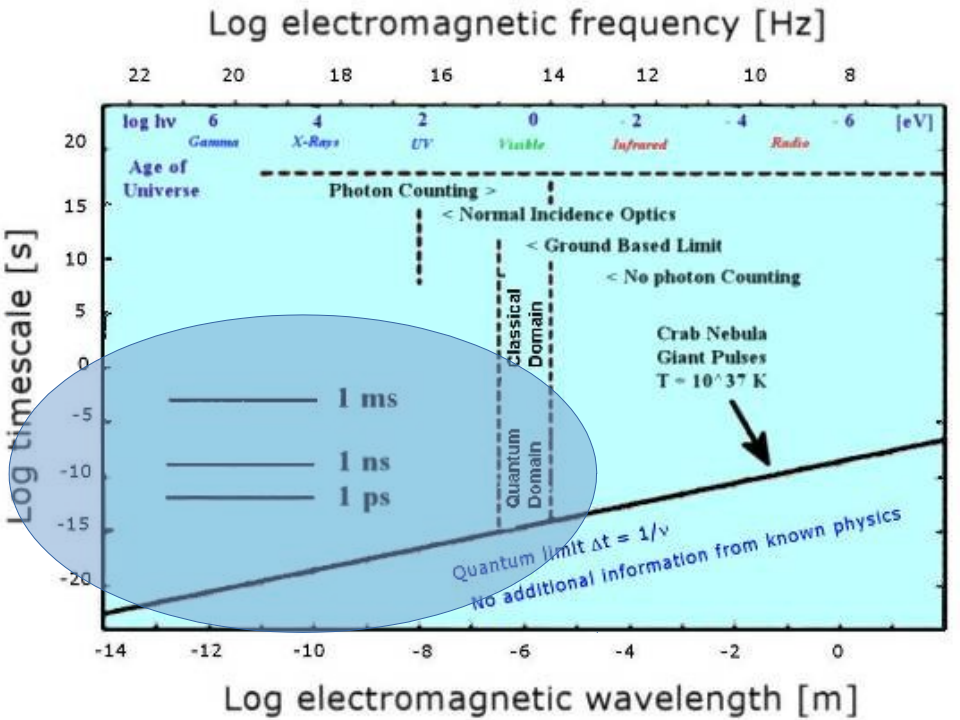
The crab nebula in radio, infrared, visible, ultraviolet, x-ray and gamma-ray wavelengths.

Sources: Radio: NRAO/AUI and M. Bietenholz, J.M. Uson, T.J. Cornwell; Infrared: NASA/JPL-Caltech/R. Gehrz (University of Minnesota); Visible: NASA, ESA, J. Hester and A.Loll (Arizona State University); Ultraviolet: NASA/Swift/E. Hoversten, PSU, X-ray: NASA/CXC/SAO/F. Seward et al.; Gamma: NASA/DOE/Fermi LAT/R. Buehler

Astrophysics across wavelength and time



Astrophysics across wavelength and time



High energy and time resolution Astrophysics deals mainly with:

neutron stars (pulsars)
stellar black holes

in different environments (isolated, in binary systems, embedded in their nebulae/remnants)

ASTRI (Astrophysics with Italian Replicating Technology Mirrors): Observing the sky at the highest energies

The ASTRI Project

ASTRI (Astrophysics with Italian Replicating Technology Mirrors) started as a **MIUR flagship project** approved in 2010 to support the development of technologies within the **CTA** project for *observing the sky at the highest energies*

The first result of the ASTRI project was the construction of a prototype Cherenkov telescope (4m) in Schwarzschild-Couder optical configuration, presently operating at Serra La Nave (INAF-Catania)

The next phase of the project foresees INAF involved in the construction of an array of 9 units in Tenerife

ASTRI in OAPd

Science and Technology
Enrico Giro, Ulisse Munari, Claudio Pernechele, Luca Zampieri

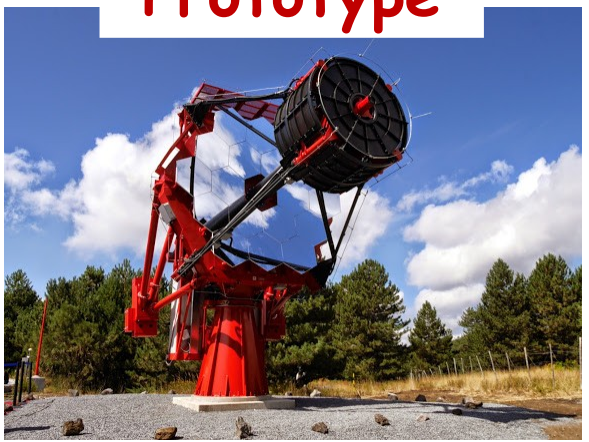
Outreach
Caterina Boccato, Serena Pastore

Technical support
Luigi Lessio, Giancarlo Farisato, Aldo Frigo

Postdoc and PhD students
Cornelia Arcaro, Aleksandr Burtovoi, Elisa Prandini, Federico Di Giacomo, Michele Fiori

ASTRI: The prototype Horn D'Arturo, the Mini-array and CTAO

Prototype

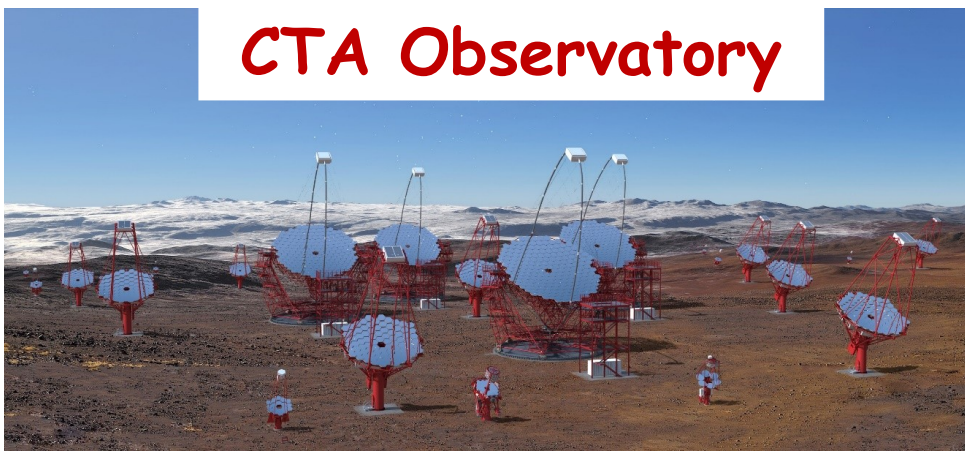


ASTRI SST-2M telescope - Demonstrator to validate the novel technology for Cherenkov telescopes

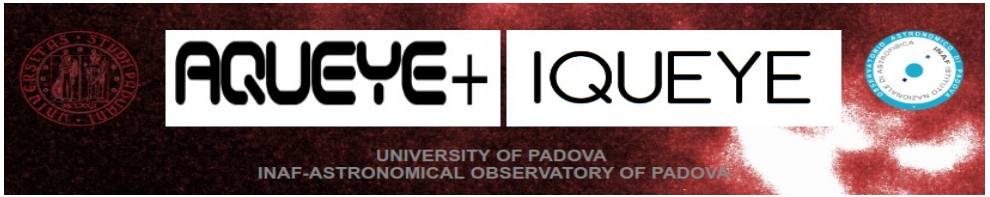
Mini-Array

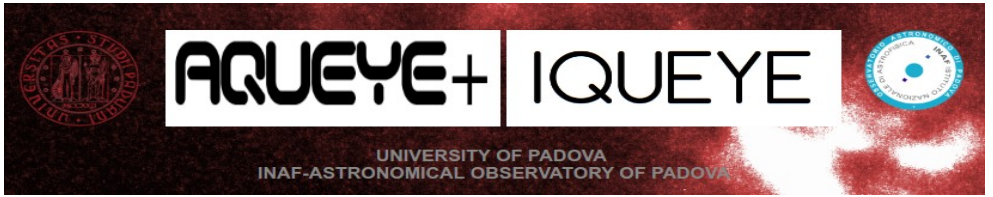
Array of 9 ASTRI SST-2M - Astrophysical observations at ~100 TeV, testing activity for CTAO, experimenting optical imaging via intensity interferometry

CTA Observatory



Full CTA South site array





The AQUEYE+IQUEYE project: Observing the sky at the shortest timescales

The AQUEYE+IQUEYE team

Coordination, scientific utilization
Luca Zampieri, Giampiero Naletto, Cesare Barbieri

Instrument design, realization, technological development
Giampiero Naletto, Luca Zampieri, Cesare Barbieri

Instrument software and hardware
Luca Zampieri, Mauro Barbieri

Optomechanical interfacing with telescopes
Luigi Lessio (AQUEYE+), *Gabriele Umbriaco* (IQUEYE)

Technical operations
Venerio Chiomento, Giancarlo Farisato, Aldo Frigo, Giorgio Martorana, Mauro Rebeschini, Luciano Traverso, Robertino Bau', Giovanni Costa

Operational support and assistance with observations
Paolo Ochner, Alessandro Siviero

Technical support
Maurizio D'Alessandro, Marco Fiaschi (MFC Elettronica, Padova)

Postdocs and students
Aleksandr Burtovoi, Michele Fiori, Alessia Spolon

Undergraduate student
Michele Scalco

The project goals

Performing optical and multi-wavelength High Time Resolution Astrophysics with *sub-ms time resolution*

Measuring the entropy of light through the *statistics of the photon arrival times*

AQUEYE+IQUEYE web page:

https://web.oapd.inaf.it/zampieri/aqueye-iqueye/index.html

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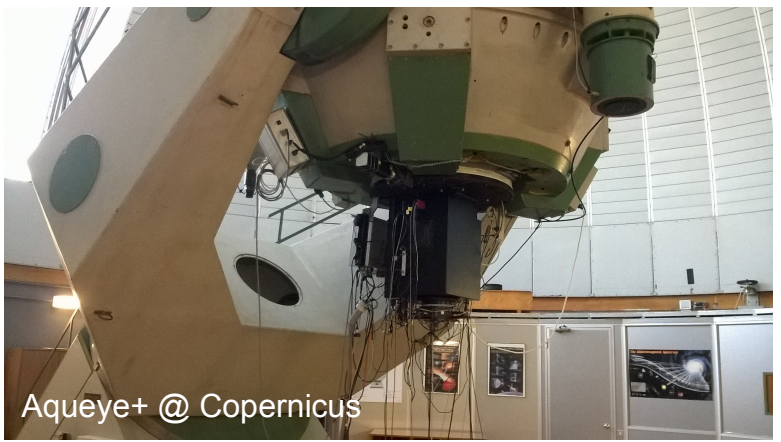
Aqueye+ and IFI+Iqueye

Aqueye+ and IFI+Iqueye *are non-imaging instruments for very fast optical photometry*
(Barbieri et al. 2009; Naletto et al. 2009, 2013; Zampieri et al. 2015, 2019)

http://web.oapd.inaf.it/zampieri/aqueye-iqueye/index.html

- Field of view: few arcsec
- Optical design: entrance pupil split with a pyramidal mirror
- Detectors: SPADs with <50 ps time resolution
- Acquisition system: Sub-ns time tagging accuracy wrt UTC
- Iqueye Fiber Interface (IFI) provides an efficient optical fiber coupling of Iqueye with the telescope


Aqueye+ @ Copernicus

Grants

- MIUR ASTRI flagship project and PRIN (9 M€)
- MISE “Astronomia Industriale” (10 M€)
- ASTRI International partners: Universidade de Sao Paulo – Brazil (1.8 M€), North Western University – South Africa (300 k€)
- MIUR CTAO funds (50 M€)
- PRIN INAF 2016 “ASTRI/CTA Data Challenge” (PI: P. Caraveo, 680 k€)
  OAPd (total: 92 k€) responsible for two work packages:
  Multiwavelength Identification (Coordinator: L. Zampieri)
  Communication, Public and Industrial Outreach (Coordinator: C. Boccato)
- ASI/INAF grants (2017-2019) on high energy and time resolution observations (n. I/037/12/0, n. 2017-14-H.O): 321 k€ (total OAPd: 34 k€)

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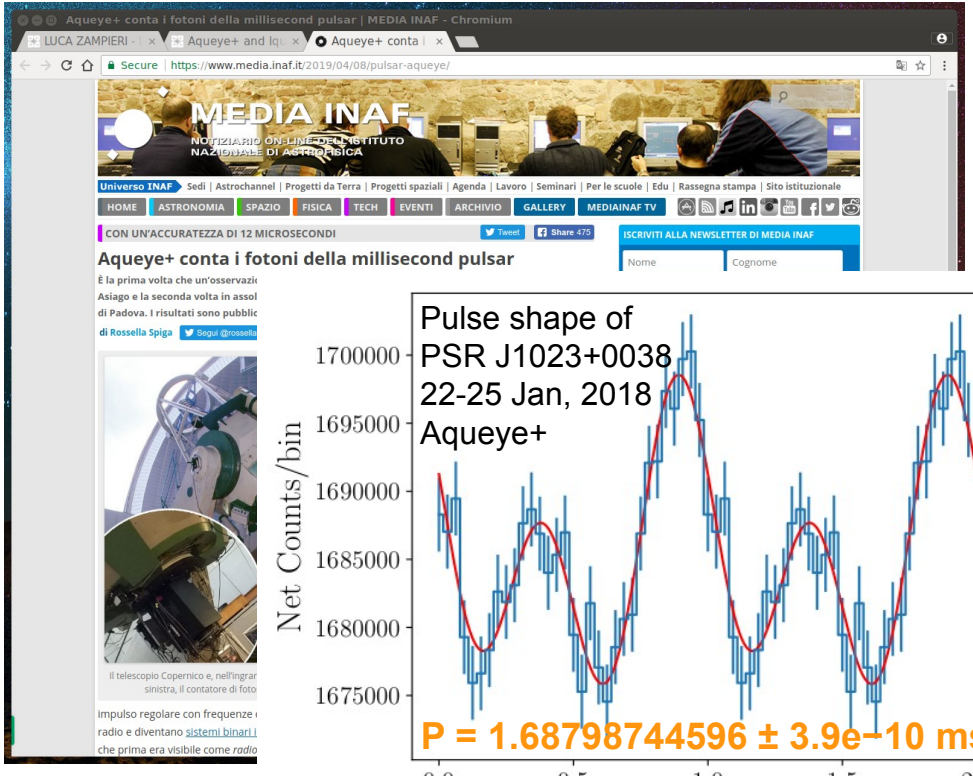
Highlights: PSR J1023+0038

*We report the first detection of **millisecond optical pulsations** from PSR J1023+0038 with Aqueye+@Copernicus in Asiago (Zampieri et al. 2019, MNRAS Letters, 485, L109)*

This is an independent detection of ms optical pulsations after that obtained with SiFAP at TNG (Ambrosino et al. 2017)

Best absolute optical time accuracy (10 microseconds wrt UTC) achieved to date

https://www.media.inaf.it/2019/04/08/pulsar-aqueye/



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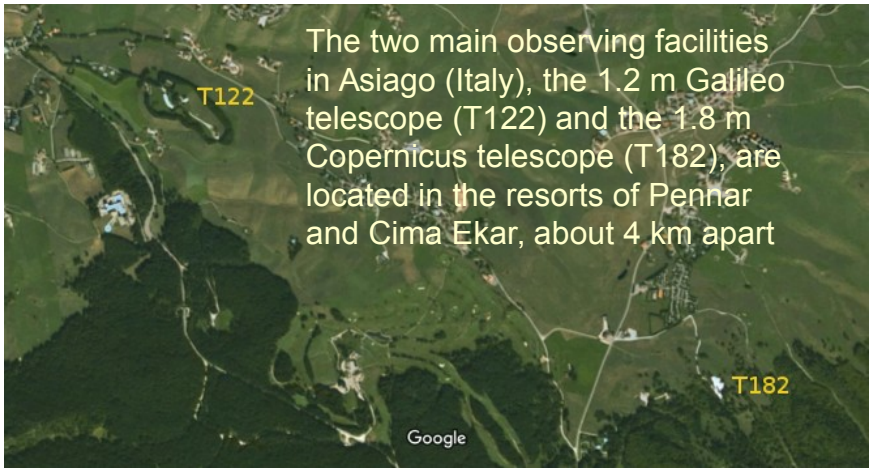
Highlights: The Asiago stellar intensity interferometry experiment

Asiago SII preparatory experiment on a km baseline
(Zampieri et al. 2016, Naletto et al. 2016)

- Telescopes equipped with **Aqueye+ and Iqueye**

- *Interferometer has a variable baseline* because its projected component parallel to the wavefront changes with time

  ~ 3885 m with a significant E-W component
  ~ 1000 m for a source at small elevation at E or W



The two main observing facilities in Asiago (Italy), the 1.2 m Galileo telescope (T122) and the 1.8 m Copernicus telescope (T182), are located in the resorts of Pennar and Cima Ekar, about 4 km apart

- Post-processing analysis in photon counting mode: Data is acquired and correlation on photon arrival times is then performed in post-processing

Main goals

- **Performing the first measurements of the correlation function on a star counting coincidences in post-processing**
- **Validating the feasibility of this type of measurements on a km baseline**

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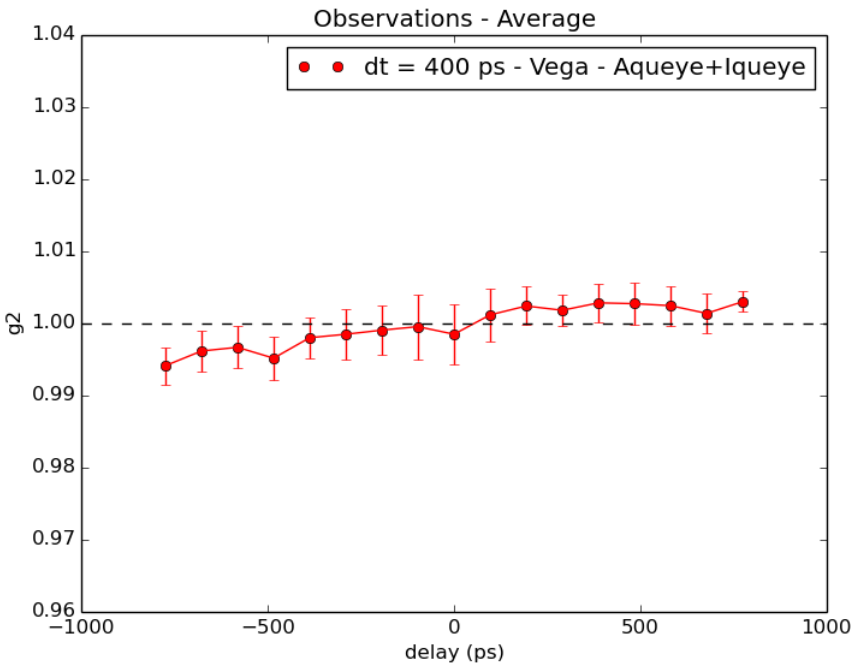
Highlights: The Asiago stellar intensity interferometry experiment

NEW preliminary result: Measurement of g2 in post-processing on a ~4 km baseline



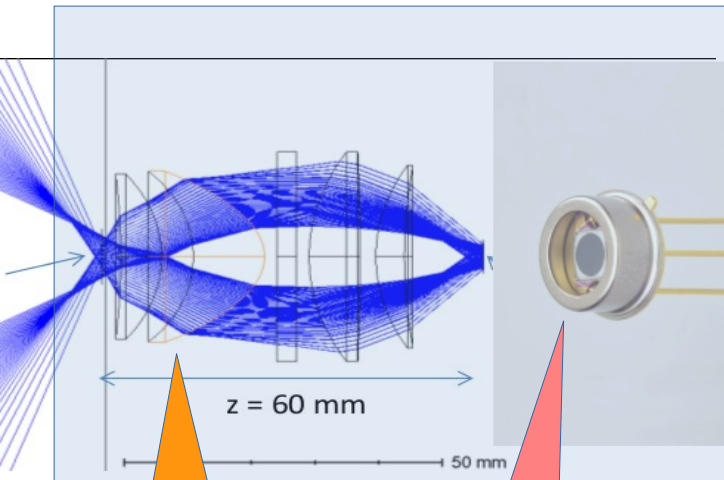
Simultaneous observation of Vega (A0V, V=0) with Aqueye+ and IFI+Iqueye

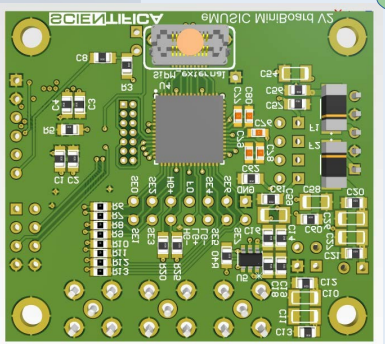
Aug 2017 – 0.5 hours
Narrow band filter: 510.3 nm, 0.3 nm FWHM
Geometric average of count rates: 0.7 Mcounts/s

First measurement of g2 (discrete degree of coherence) on a ~4 km baseline, counting coincidences in post-processing

Result shows lack of correlation (g2=1), as expected for Vega on this baseline

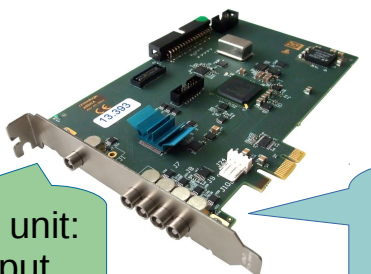
Photon Detection module for Intensity Inteferometry (PDMII) for the ASTRI telescope and camera





Amplifier: Analog output

To acquisition electronics: Analog output



Time tagger unit: Digital output

To acquisition electronics: Digital output

Focal plane optics

SiPM detector (cooled)

Front-end board for SiPM readout (USB controlled)

White rabbit node for time distribution provides reference signal for the time tagger unit

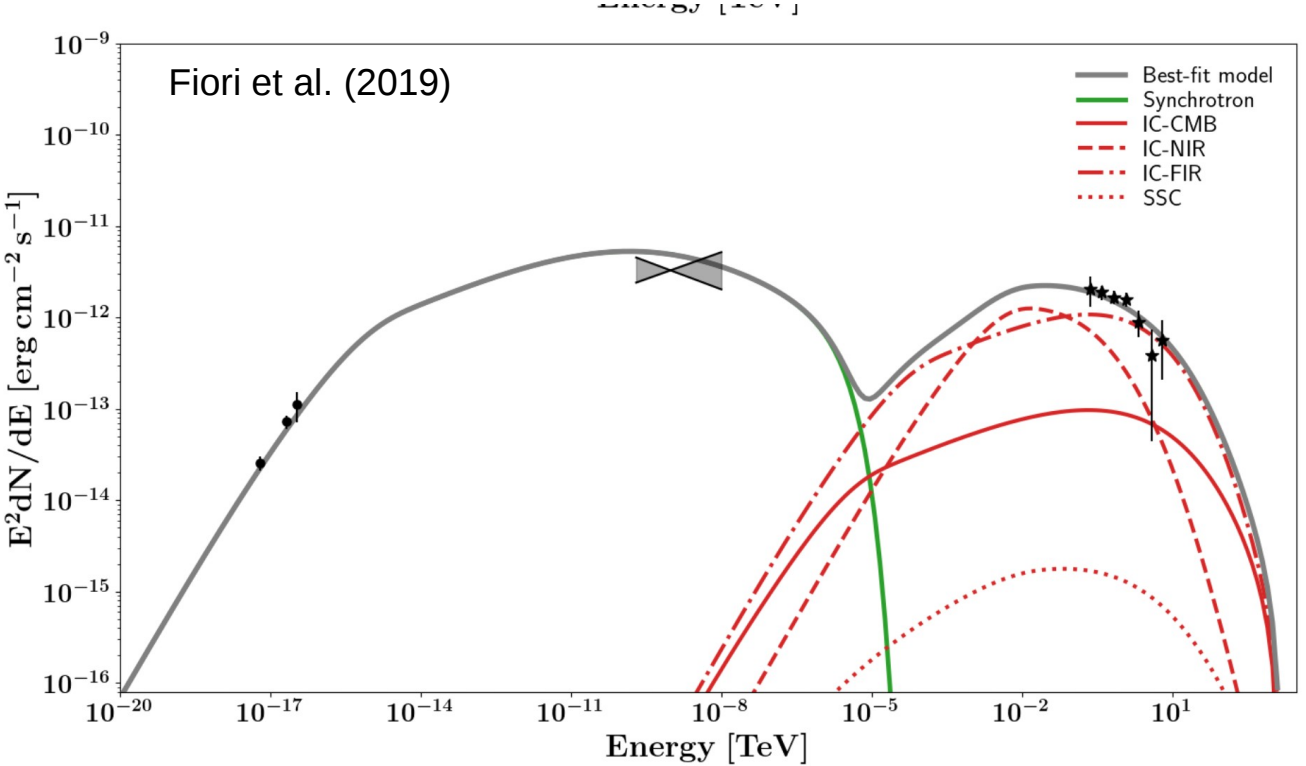
Pulsars and Pulsar Wind Nebulae at Very High Energies: Highlights

Simulations, testing and modelling activities for ASTRI and CTA (Burtovoi et al. 2016, 2017; Fiori et al. 2019)

Multiwavelength spectrum of the Pulsar Wind Nebula (PWN) G0.9+0.1

Different spectral models and cut-off energies are distinguishable

The parameters of the PWN are well constrained



Some items for discussion

- **ASTRI started its activity in 2011 before the birth of the multimessenger, multiwavelength and rapid variability era (gravitational waves, neutrinos, gamma rays, fast transients)**
- **Aiming to be competitive in this new and promising field requires a scientific and instrumental know-how extending beyond what optical imaging and spectroscopy entail**
- **Time is ripe for INAF for: demonstrating the feasibility of an array of SST-2M, obtaining the first important astrophysical results in the TeV band and experimenting optical high time resolution astrophysics with the Cherenkov Telescopes**
- **Given the know-how grown up within OAPd in these years and the potential synergies with UniPD and INFN, OAPd should not miss this outstanding opportunity to be in the game as primary actor**