VERITAS Observations of Fast Radio Bursts

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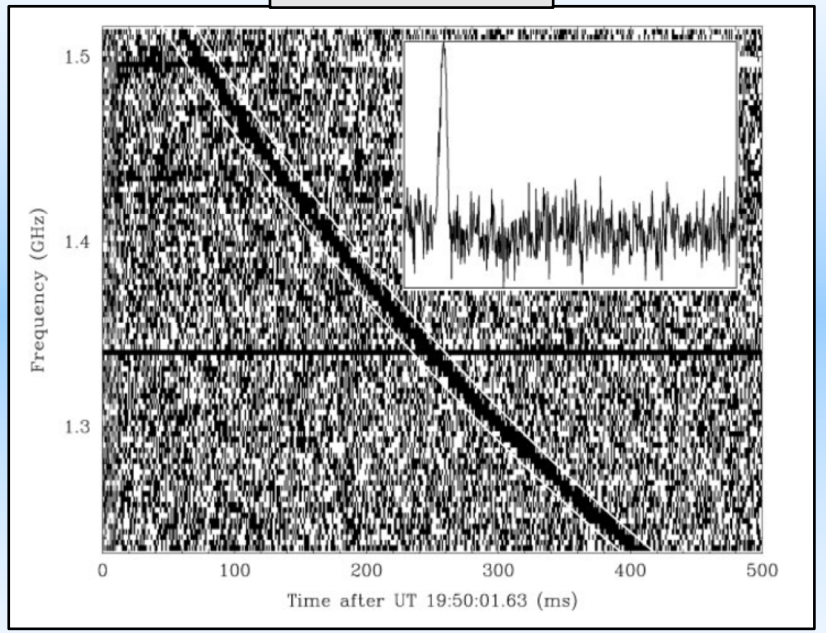
Fast Radio Bursts: Motivation

- Fast radio bursts are bright, millisecond duration radio pulses of extragalactic origin.
- Less than 100 burst locations have been published.
- Two have been observed to repeat.
- FRB121102 *may* be associated with a young magnetar.
- Generally, their origins are still unknown.

The Lorimer Burst

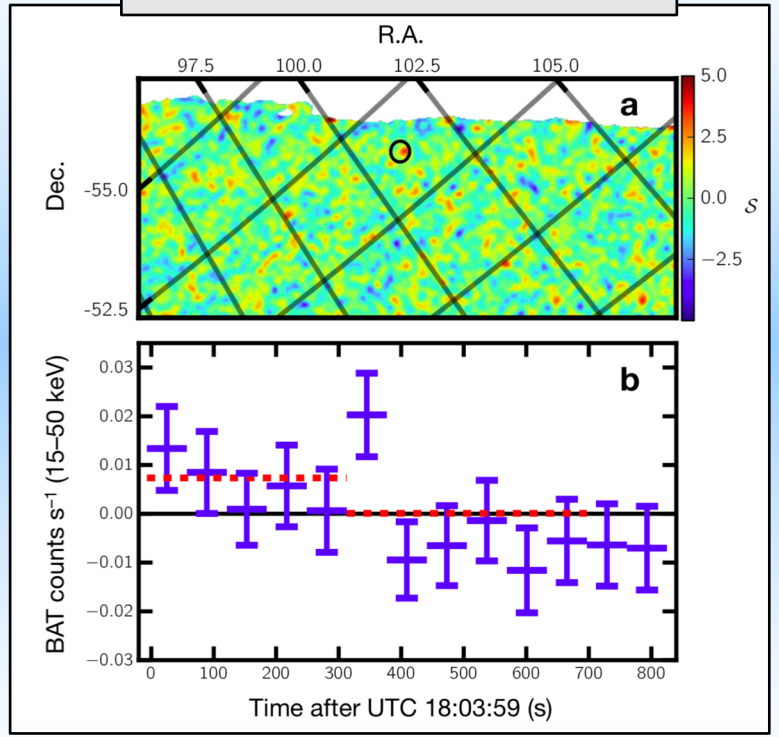


Lorimer, D.R. et al., Science, 318, 777 (2007).

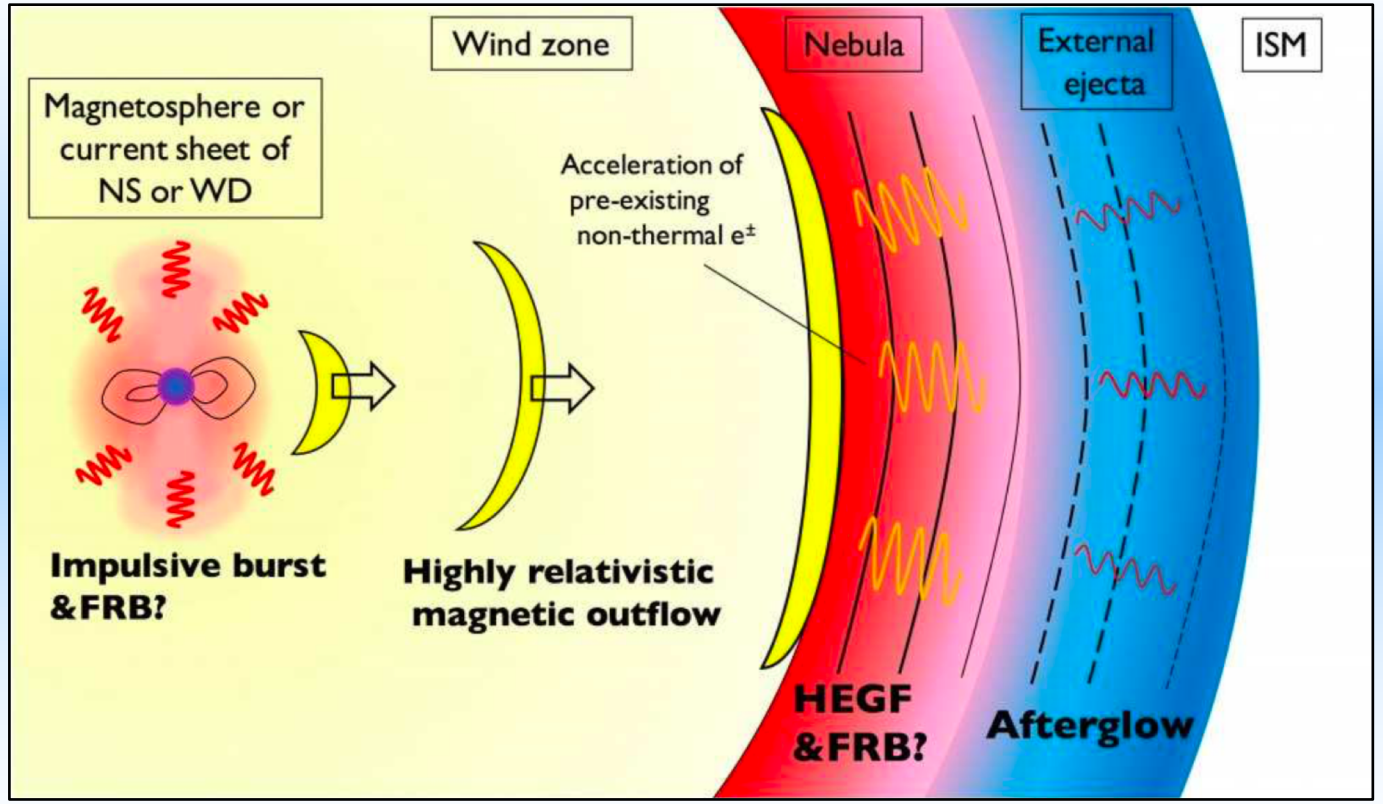
Fast Radio Bursts: Motivation

- Various emission models predict prompt optical and/or high energy counterparts.
- 3.2σ hint of a 400s-long transient in Swift/BAT, coincident with FRB 131104.
- The detection of any counterpart would
  - Strongly constrain the possible origin scenarios.
  - Estimate the energy budget.
  - Provide a new tool for cosmology/ fundamental physics tests.

Swift-BAT observations of FRB131104



DeLaunay, J. J., et al. 2016, ApJL, 832, L1

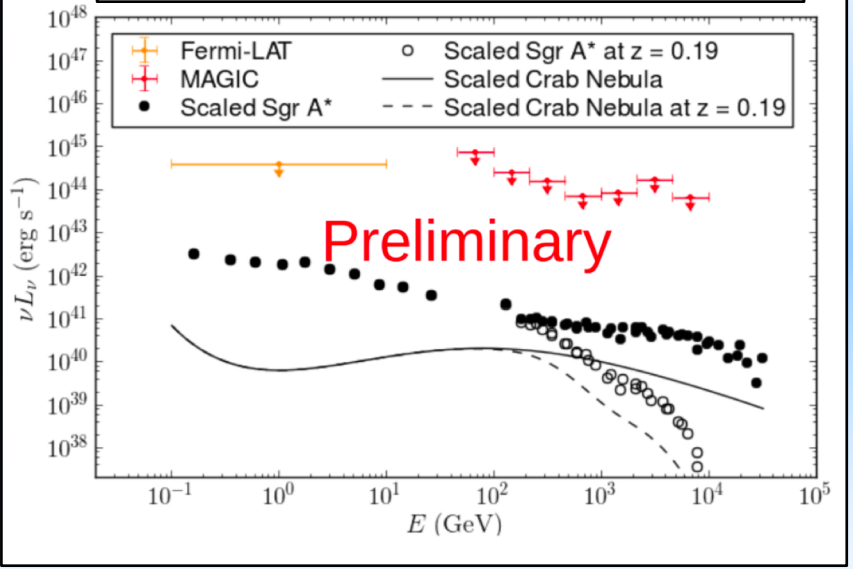


Murase, K. et al., 2016: HEGF = High-Energy Gamma-ray Flash

Fast Radio Bursts: Motivation

- IACTs have huge effective area, and zero background for ms transients.
- They can search in both optical and gamma-ray wavebands – but where and when to look?
- Searches by HESS, MAGIC, LAT, GBM, IceCube…
- MAGIC sampled 5 Arecibo-detected FRBs during their observations of FRB121102.

MAGIC limits to steady emission from FRB121102



J. Hoang, et al., ICRC 2019
MAGIC Collaboration , MNRAS, 481, 2479, 2018.

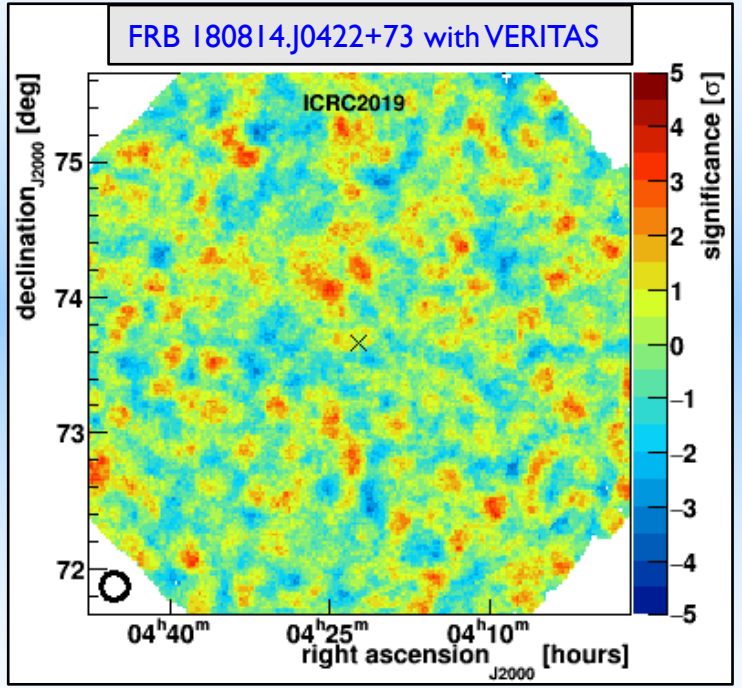
VERITAS

VERITAS

Method 1: Observe the repeaters with VERITAS

- FRB 121102 and FRB 180814.J0422+73 have both been observed with VERITAS (for 12.7 and 8.2 hours).
- No evidence for steady emission.
- New limits for FRB 180814.J0422+73:
  - 9.2×10^{-13} ph cm^{-2} s^{-1} >300 GeV for *soft* cuts
  - 6.3×10^{-13} ph cm^{-2} s^{-1} >500 GeV for *moderate* cuts

(95% confidence. E^{-2} power law assumed, 46° elevation)

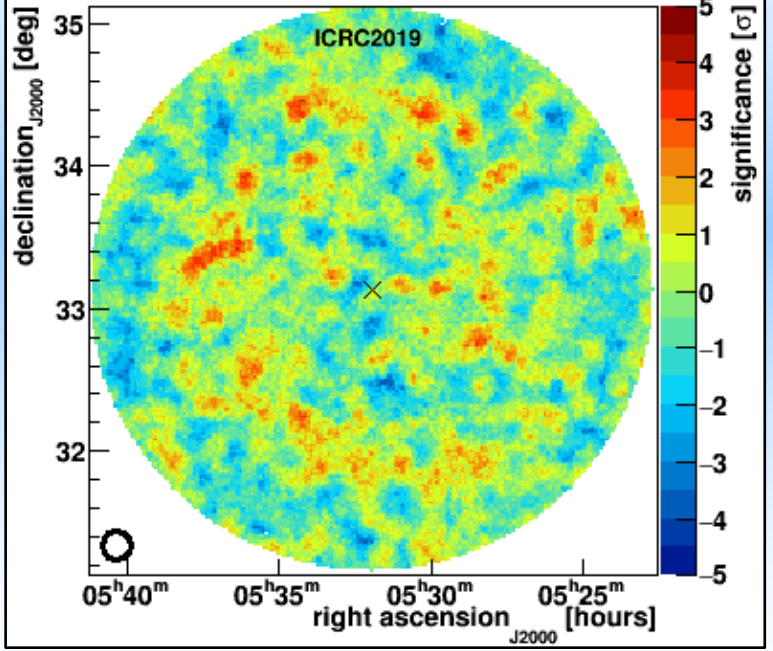


Method 2: Observe the repeaters, in coincidence with radio telescopes

- FRB 180814.J0422+73 VERITAS observations were timed to overlap with the CHIME radio telescope.
- No CHIME bursts have been reported during the VERITAS exposures.

- 115 minutes of VERITAS observations of FRB 121102 were taken in coincidence with Greenbank Telescope.
  - 25 November 2017 (MJD 58082)
  - 15 radio bursts were seen (*in prep*).
- 95% UL ***during*** these 115 minutes
  - 5.3×10^{-13} ph cm^{-2} s^{-1} >200 GeV for *soft* cuts
  - 1.9×10^{-12} ph cm^{-2} s^{-1} >300 GeV for *moderate* cuts

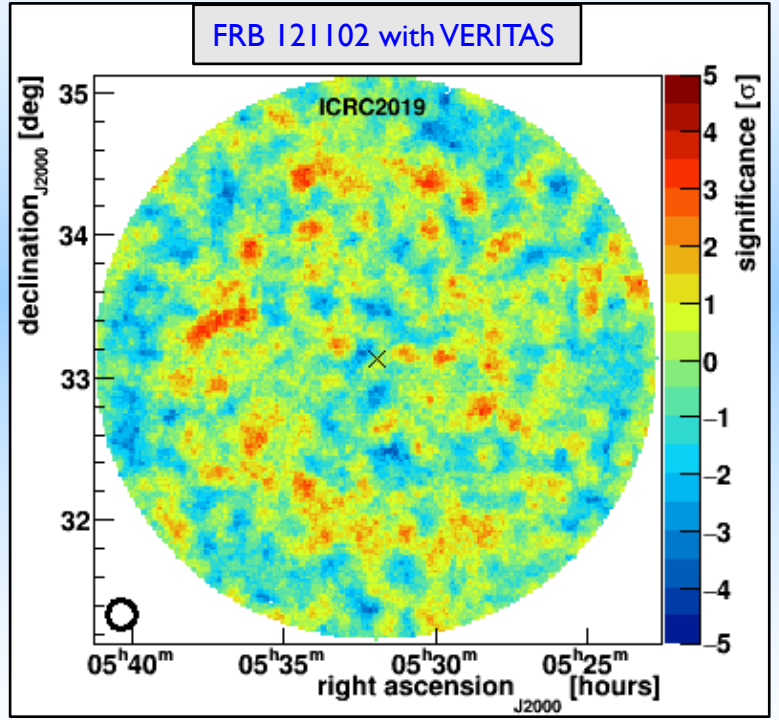
FRB 121102 with VERITAS



Method 3: Search for gamma-ray emission coincident with radio bursts

- FRBs have typical durations of a few ms.
  - Apply barycentric correction (TEMPO2).
  - Apply *soft* gamma-ray cuts.
  - Search a 10ms window around the burst times.
- Background = 9×10^{-5} events in 10ms ≅ 0!
- 95% confidence upper limit = 3.6 events.
  - 5.6×10^{-7} ph cm^{-2} s^{-1} >200 GeV for each burst.
  - 3.7×10^{-8} ph cm^{-2} s^{-1} >200 GeV for all 15 bursts.

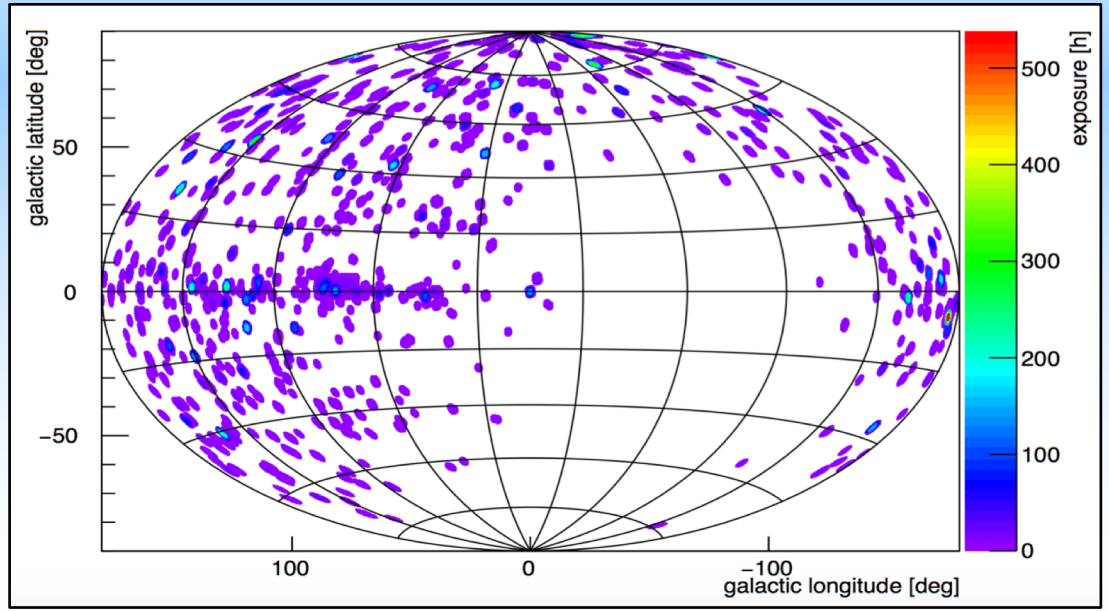
- Future analysis will explore (while accounting for trials)
  - A range of burst window durations.
  - Multiple event selections.
  - Delayed/precursor emission.



What about non-repeating bursts?

- An archival ms burst search analysis is underway.
  - VERITAS field of view = 9.6 square degrees.
  - Estimated all-sky FRB rate is typically ~1000/day.
  - Implies ~1/observing night occurs in the VERITAS field of view.
- But coincident radio identification is still much more powerful…

Exposure map of the VERITAS archive

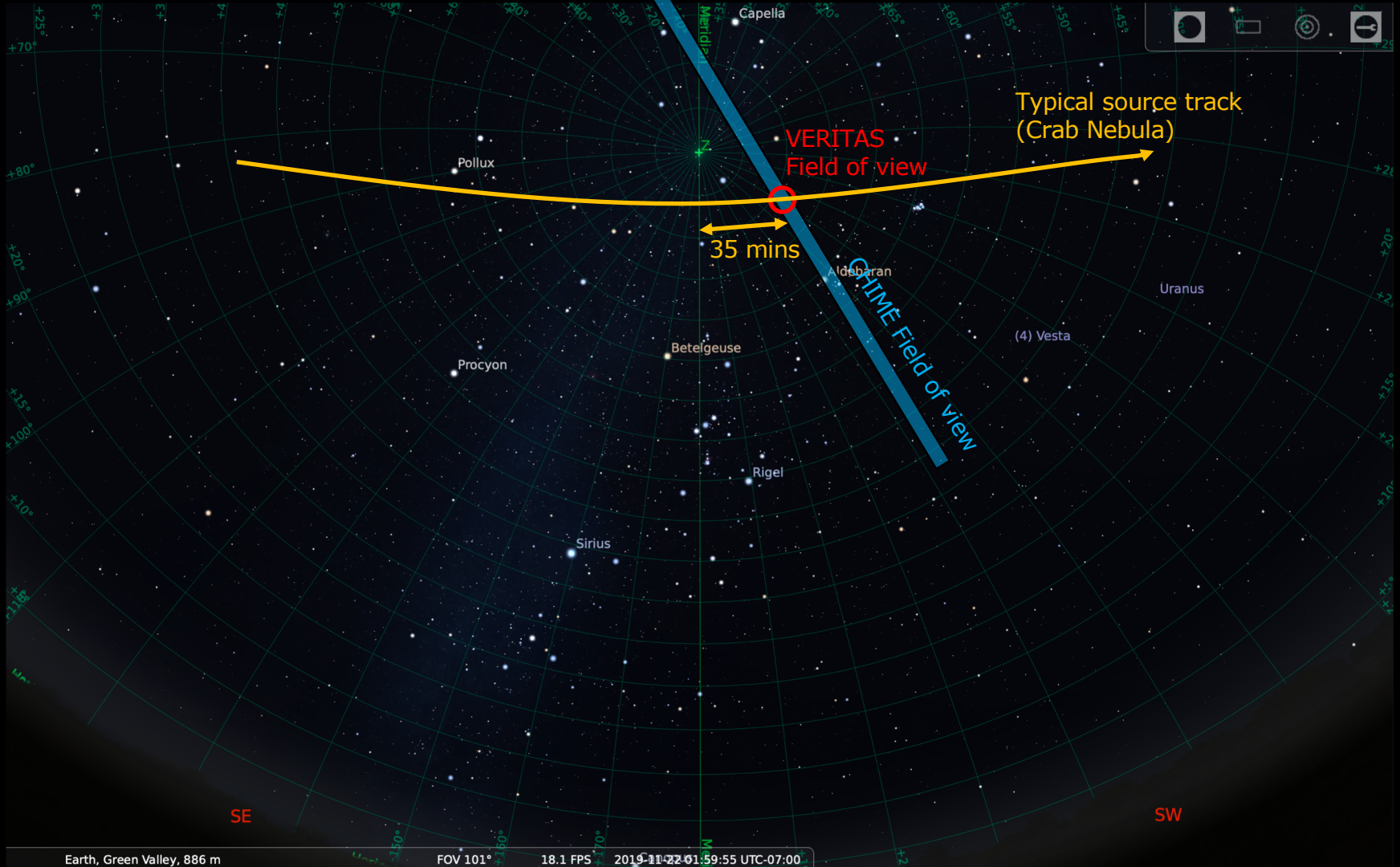



CHIME


MAGIC II


VERITAS


H.E.S.S. II


Capella
Meridian
Typical source track
(Crab Nebula)
VERITAS
Field of view
Pollux
35 mins
Aldebaran
Uranus
(4) Vesta
Betelgeuse
Procyon
CHIME Field of view
Rigel
Sirius
SE
SW
Earth, Green Valley, 886 m
FOV 101°
18.1 FPS
2019-11-22 01:59:55 UTC-07:00

Which ones to look at?

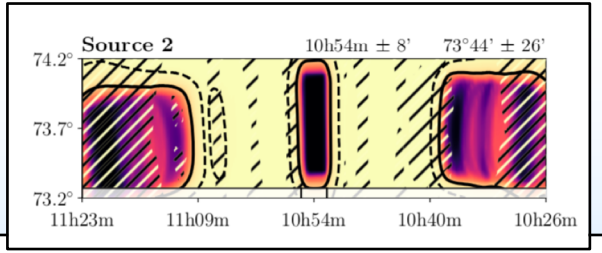


Table 1. Properties of Eight New CHIME/FRB Repeating Sources

Source	Name[a]	R.A.[b] (J2000)	Dec.[b] (J2000)	l^c (deg)	b^c (deg)	DM[d] (pc cm^{-3})	DM^e_{NE2001} (pc cm^{-3})	DM^e_{YMW16} (pc cm^{-3})	N_{bursts}	Exposure[f]	Completeness[g] (Jy ms)
1	180916.J0158+65	1h58m±7′	+65°44′±11′	129.7	3.7	349.2(3)	200	330	10		4.2
2	181030.J1054+73	*10h54m±8′*	*+73°44′±26′*	133.4	40.9	103.5(3)		32	2	27±14 / 19±11	... / 17
3	181128.J0456+63	*4h56m±11′*	*+63°23′±12′*	146.6	12.4	450.5(3)	110	150	2	16±10	4.0
4	181119.J12+65	12h42m±3′	+65°08′±9′	124.5	52.0	364.05(9)	34	26	3	19±9	2.6
		12h30m±6′	+65°06′±12′								
5	190116.J1249+27	12h49m±8′	+27°09′±14′				20	20	2	8±5	5.7
6	181017.J1705+68	*17h05m±12′*	*+68°17′±12′*	99.2	34.8	1281.6(4)	43	37	2	20±11	5.6
7	190209.J0937+77	*9h37m±8′*	*+77°40′±16′*	134.2	34.8	425.0(3)	46	39	2	34±19 / 28±18	3.8 / ...
8	190222.J2052+69	20h52m±10′	+69°50′±11′	104.9	15.9	460.6(2)	87	100	2	20±10	5.4

Many bursts

Close

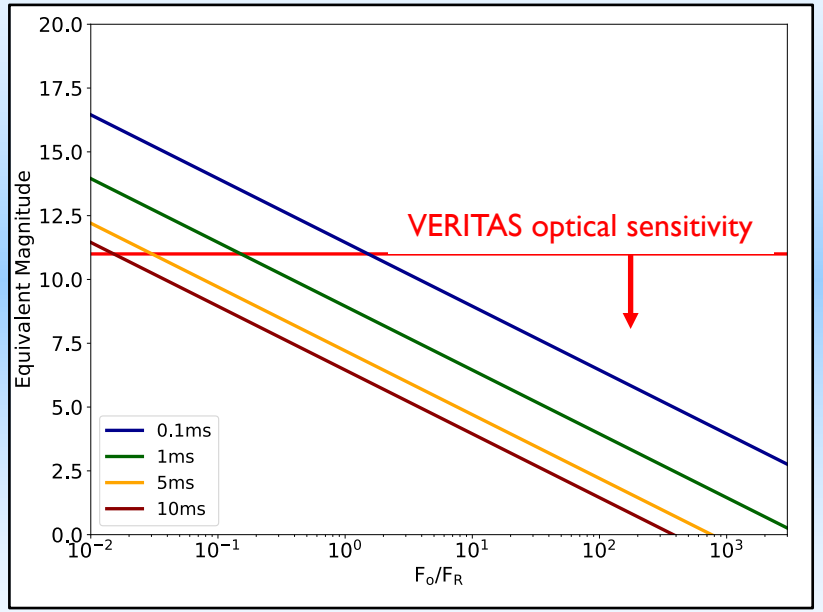
High elevation

- FRB121102 (well-studied, very well located, +33° declination)
- FRB 180814.J0422+73 (well located).
- 30 hours of observations in progress

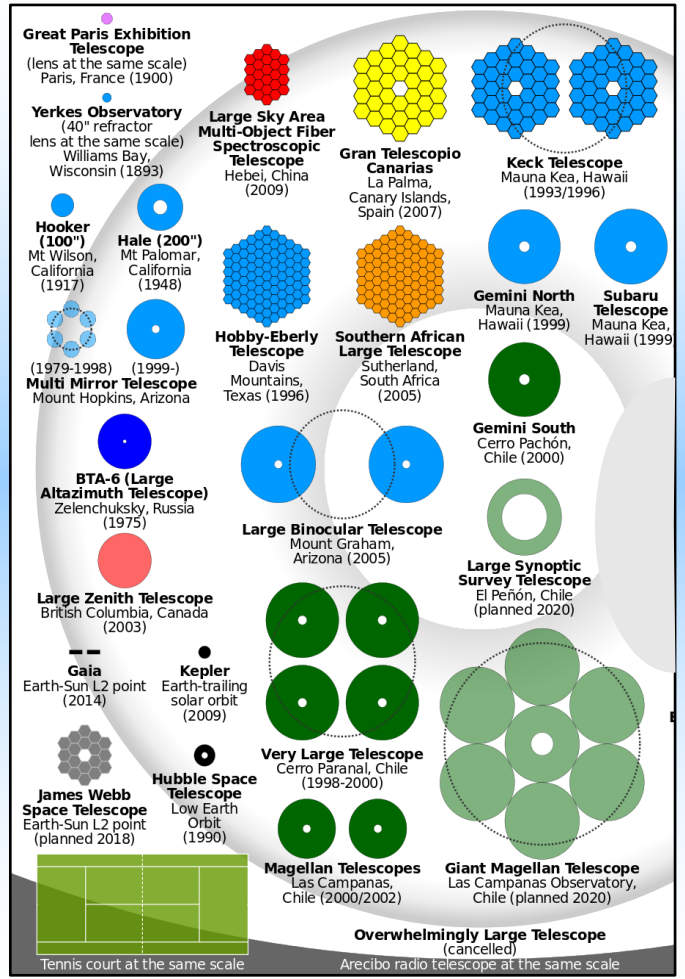
Searching for rapid optical transients associated with FRBs

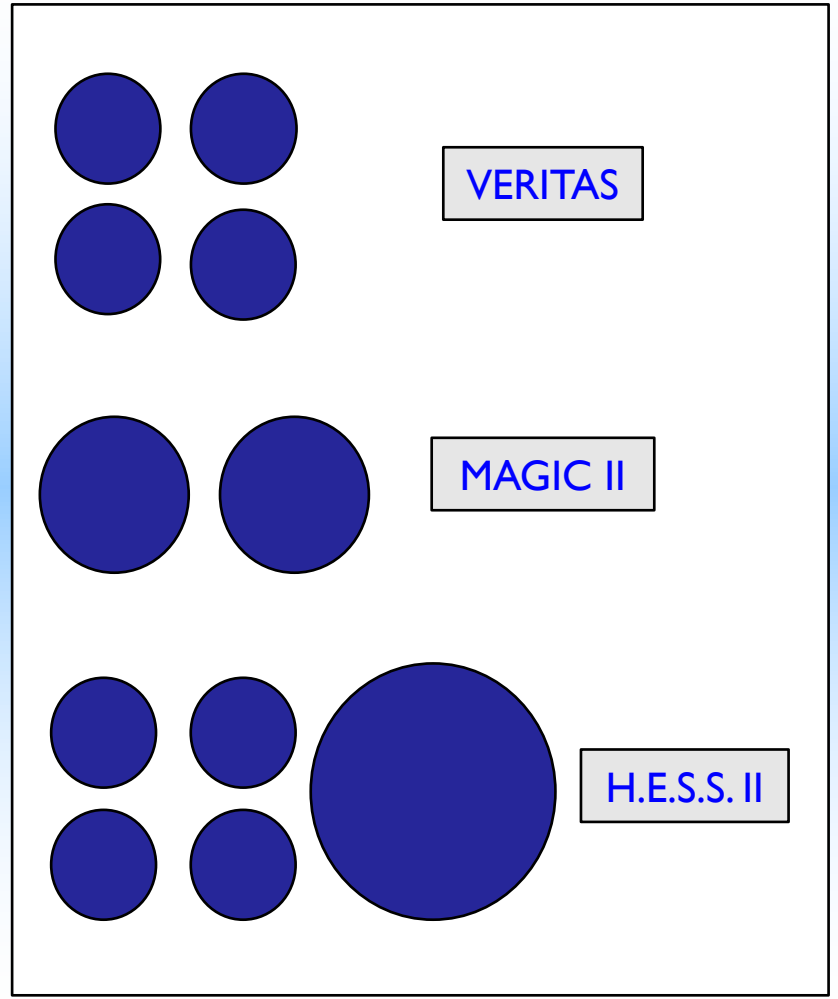
- IACTs are the largest optical telescopes in the world, great for high-speed optical photometry.
- VERITAS has a 14-bit, kHz-sampling DC-voltage recorder on between 2 and 16 photomultiplier tube channels on all four telescopes.

- System under commissioning during observations of FRB121102, when 15 bursts occurred.
  - Only 1 telescope, no accurate timestamping.
- Preliminary analysis suggests observations are consistent with only background events (meteors).

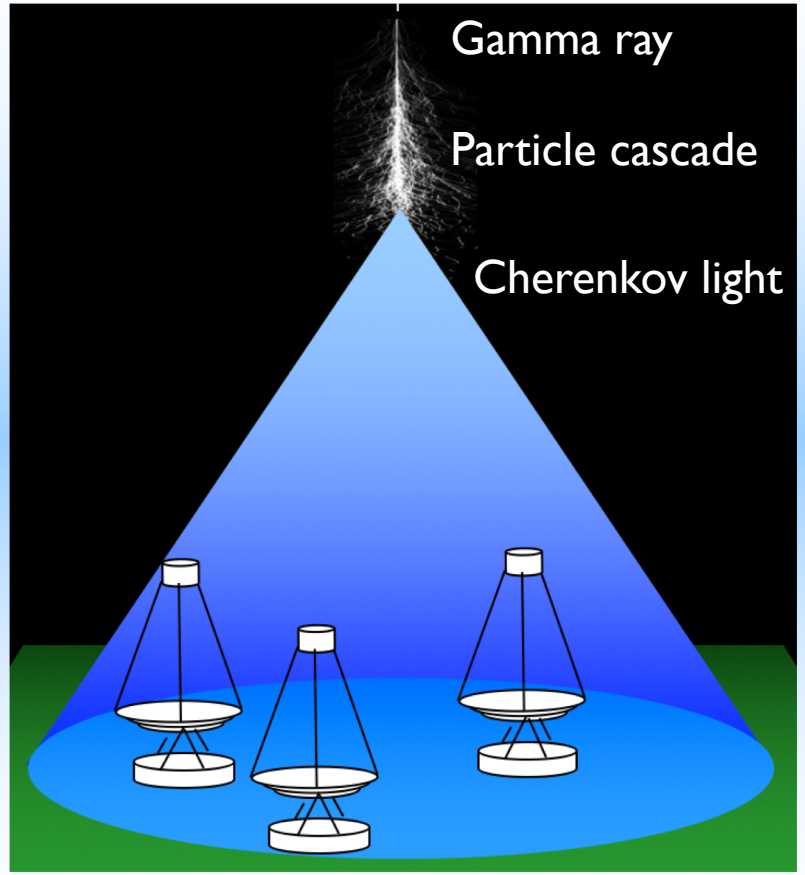


After Lyutikov & Lorimer, 2016

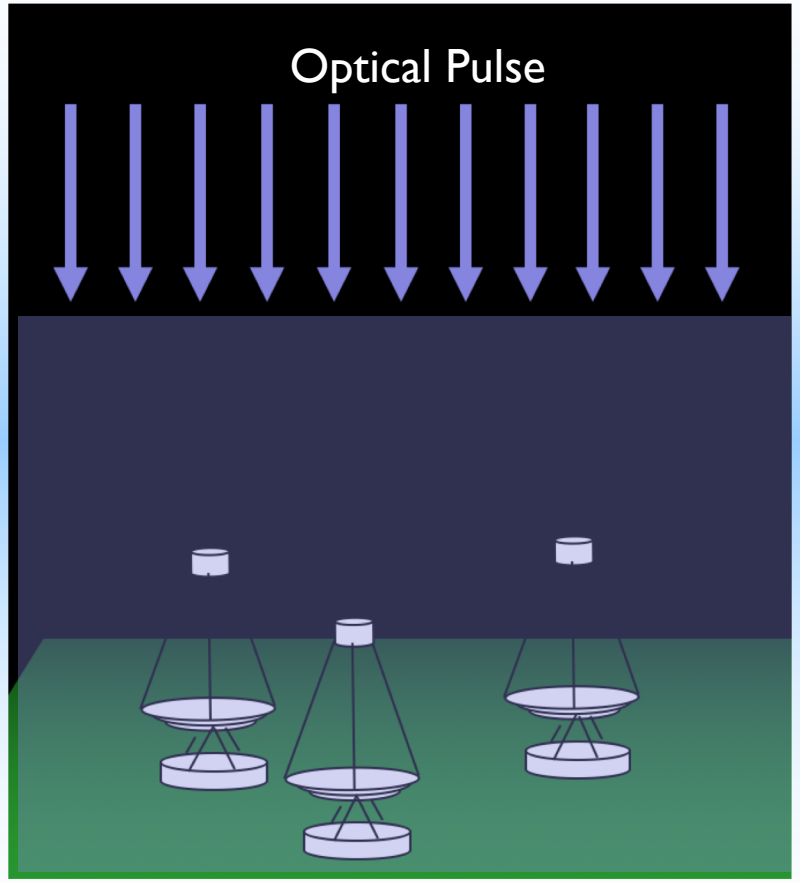

Great Paris Exhibition Telescope
(lens at the same scale)
Paris, France (1900)
Yerkes Observatory
(40" refractor lens at the same scale)
Williams Bay, Wisconsin (1893)
Hooker (100")
Mt Wilson, California (1917)
Hale (200")
Mt Palomar, California (1948)
(1979-1998)
(1999-)
Multi Mirror Telescope
Mount Hopkins, Arizona
BTA-6 (Large Altazimuth Telescope)
Zelenchuksky, Russia (1975)
Large Zenith Telescope
British Columbia, Canada (2003)
Gaia
Earth-Sun L2 point (2014)
Kepler
Earth-trailing solar orbit (2009)
James Webb Space Telescope
Earth-Sun L2 point (planned 2018)
Hubble Space Telescope
Low Earth Orbit (1990)
Large Sky Area Multi-Object Fiber Spectroscopic Telescope
Hebei, China (2009)
Gran Telescopio Canarias
La Palma, Canary Islands, Spain (2007)
Keck Telescope
Mauna Kea, Hawaii (1993/1996)
Hobby-Eberly Telescope
Davis Mountains, Texas (1996)
Southern African Large Telescope
Sutherland, South Africa (2005)
Gemini North
Mauna Kea, Hawaii (1999)
Subaru Telescope
Mauna Kea, Hawaii (1999
Gemini South
Cerro Pachón, Chile (2000)
Large Binocular Telescope
Mount Graham, Arizona (2005)
Large Synoptic Survey Telescope
El Peñón, Chile (planned 2020)
Very Large Telescope
Cerro Paranal, Chile (1998-2000)
Magellan Telescopes
Las Campanas, Chile (2000/2002)
Giant Magellan Telescope
Las Campanas Observatory, Chile (planned 2020)
Overwhelmingly Large Telescope
(cancelled)
Tennis court at the same scale
Arecibo radio telescope at the same scale


VERITAS
MAGIC II
H.E.S.S. II

Gamma-ray Astronomy



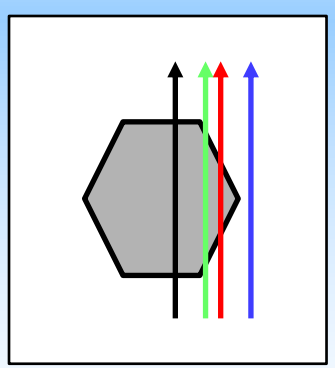
Optical FRB counterpart

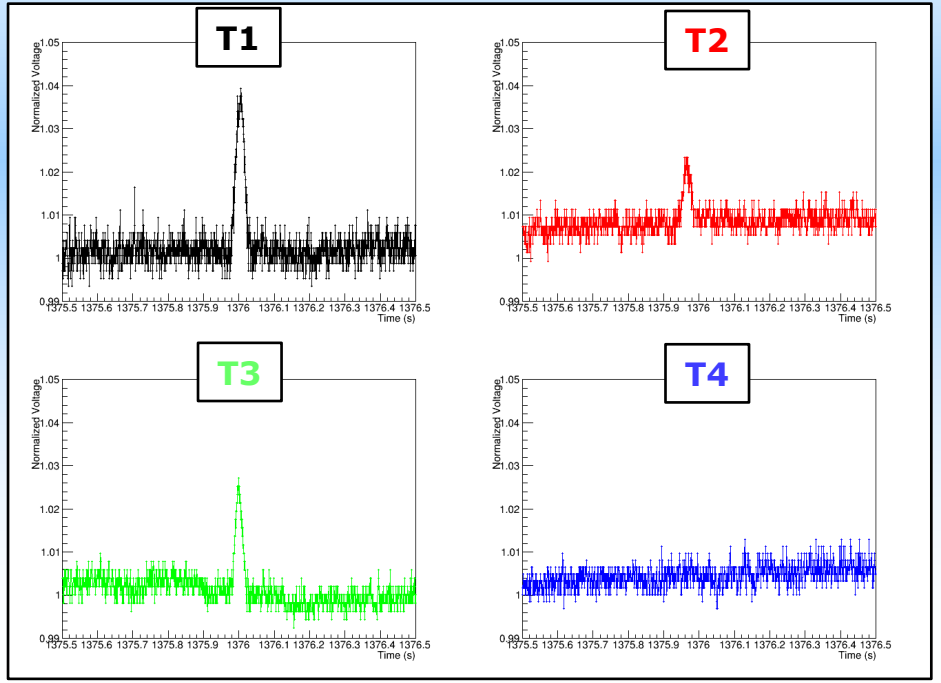


Optical Searches: 4-telescope parallax helps

- Meteors produce a high background of ms optical transients.
- The light is emitted locally (~80km altitude).
- 100m telescope baseline results in noticeable parallax (0.07°)
- This can be used to greatly reduce the local meteoric background for future searches

A meteor with parallax seen by VERITAS





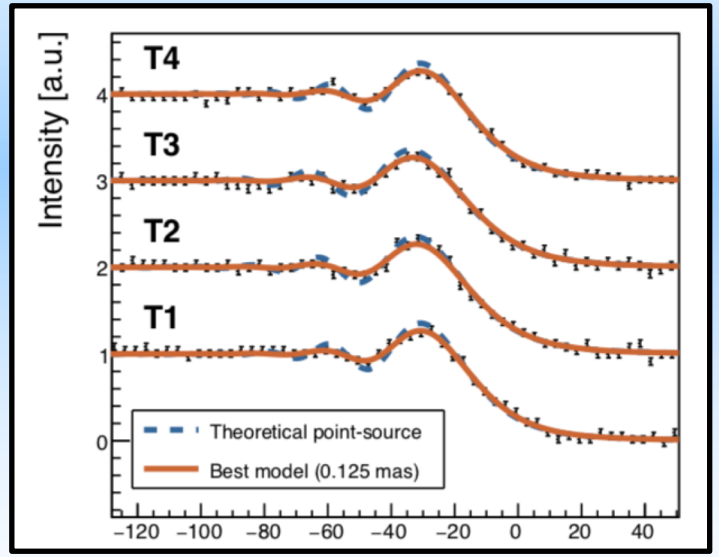
Summary

- VERITAS has observed the two known repeating fast radio bursts.
- No evidence for steady high-energy emission is found.
- Overlapping observations for 15 Greenbank Telescope radio bursts were recorded from FRB 121102.
- No gamma-ray like events are observed within 10ms of the radio burst times.
- These are the strongest limits on high energy emission from FRBs.
- No optical counterparts of ms duration were seen.
- Future prospects for archival analyses, overlapping observations with CHIME and background-suppressed optical searches are very promising.

BACKUP

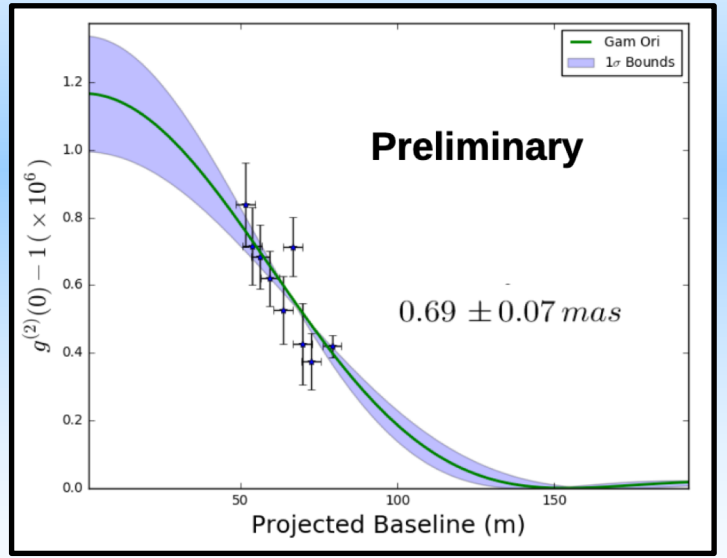
Optical Applications: Recent news

The diffraction pattern of an asteroid occultation shadow used to measure the smallest stellar diameters (0.1 mas)



The VERITAS Collaboration, Nature Astronomy, 2019

Stellar Intensity Interferometry with light buckets successfully implemented for the first time since Hanbury Brown and Twiss.



N. Matthews for the VERITAS Collaboration. April APS meeting, Denver, 2019

- Optical sources at infinity have the following characteristics:
  - They all appear in the same place in the telescope cameras.
  - They all have the same intensity.
  - They are point-like – they have the same morphology as the optical PSF.
- For a pre-defined target – the images appear at the location of the source.