LASA and the WFBT: Two Concepts for All-Sky Transient Telescopes

Ryan Lynch
Green Bank Observatory

On Behalf of Duncan Lorimer, Maura McLaughlin, Kevin Bandura (WVU) and Steve Ellingson (Virginia Tech)
SETI Success

- Spatial Resolution
- Field-of-view
- Bandwidth
- Sensitivity/Depth
- Polarisation
- Frequency Resolution
- Temporal Resolution
- Data Processing, AI & Signal recognition

?
SETI Success

Spatial Resolution

Field-of-view

Commensal Science Partners

Bandwidth

Sensitivity/Depth

Polarisation

Data Processing, AI & Signal recognition

Temporal Resolution

Frequency Resolution
Taking full advantage of multi-messenger (MM) astronomy requires 24/7 full-sky coverage

FRBs offer a rich MM discovery space for wide-field telescopes

LASA and the WFBT are cost-effective concepts for all-sky telescopes with commensal science opportunities
Taking full advantage of multi-messenger (MM) astronomy requires 24/7 full-sky coverage

FRBs offer a rich MM discovery space for wide-field telescopes

LASA and the WFBT are cost-effective concepts for all-sky telescopes with commensal science opportunities
70 EM + 3 GW observatories
> 450 publications
Both GW and EM observatories needed for precise localization

24/7 all-sky coverage and rapid data sharing and response time were essential

Andersson, 2013, CQG, 30, 193002
Taking full advantage of multi-messenger (MM) astronomy requires 24/7 full-sky coverage.

FRBs offer a rich MM discovery space for wide-field telescopes.

LASA and the WFBT are cost-effective concepts for all-sky telescopes with commensal science opportunities.
Fast Radio Bursts

- Extra-galactic, ms-duration radio flashes
- 51 FRBs discovered to-date (http://frbcat.org)
- Only one FRB known to repeat
  - Only source with precision localization, host galaxy identification
FRB 121102: only repeating FRB to-date

Discovered by Arecibo PALFA survey

Rules out cataclysmic source for (at least some) FRBs

Complex morphology may point to plasma lensing

Spitler et al., 2016, Nature, 531, 202
- Precise VLA/EVN localization
  - Host at z=0.2
- Bursts 100% polarized
- Highest Faraday RM
  - RM not constant
- Parallels with Galactic center magnetar?
Physical source of FRBs remains mysterious

> Building evidence for a connection to young, energetic compact objects…but no smoking gun

Cannot rule out multiple populations

Still a relatively small population, but this is changing….
Discovery rate is increasing rapidly

- Need $T \times \Omega$

- Telescopes like ASKAP, CHIME, DSA-2000 are poised to discover and localize 100s-1000s of FRBs

- Prediction: in the next decade we will know population statistics and start using FRBs for cosmology
- CHIME FoV $\sim 150 \text{ deg}^2$ @ 600 MHz
- ASKAP FoV $\sim 30 \text{ deg}^2$ @ 1.4 GHz
  - Fly’s-eye mode leads to increases of several
  - Already found 23 FRBs
- But neither offers all-sky coverage
24/7 all-sky telescope network needed to maximize MM astronomy with FRBs

Will need to be...
- Globally distributed
- Easily to deploy / maintain
- Cost-effective at scale
- Ideally homogeneous

Cast a shallow but wide net
- Catch brightest (closest) sources for detailed follow-up
Taking full advantage of multi-messenger (MM) astronomy requires 24/7 full-sky coverage.

FRBs offer a rich MM discovery space for wide-field telescopes.

LASA and the WFBT are cost-effective concepts for all-sky telescopes with commensal science opportunities.
L-Band Array of Small Arrays

- Array of tiles, each with 256 dipoles
  - Each tile can form 16 beams pointable w/in 30 deg of zenith
  - Each beam covers \( \sim 30 \text{ deg}^2 \) @ 1.45 GHz
- 100 MHz band tunable w/in 1.2 - 1.7 GHz
- Up to 10 tiles chained to form “supertiles”
  - Supertiles spaced over several km for localization
Dipoles grouped into “quads”

Output of each quad summed before beamforming

Significant cost savings

10 tiles per supertile
Backend consists of beamformer and search-engine

Down-converted and sampled 12-bit @ 250 Msps

GPS-disciplined chip-scale atomic clock for time and frequency standard
LASA-30 would consist of 3 supertiles.

- Spaced over 3-4 km
- ~0.2 arcmin localization
- Expect several FRBs per month

Additional tiles can be added to increase sensitivity or more stations for sky-coverage.
• Backend spectrometer and search-engine based on GBTrans
  ▶ Successfully deployed on GBO 20-m telescope

• Real-time dedispersion and transient search on compute nodes

• Would also include pulsar observing modes
Wide Field Burst Telescope

- 64-element quad-ridge horn array
  - Sparser packing, fewer elements than EMBRACE
  - 64 beams per station covering $\sim 300 \text{ deg}^2$ @ 1 GHz
- 0.4 – 1.2 GHz
- Dual polarization
- Arcsecond localization by correlating stations
- $\sim$few FRBs/month expected with first phase prototype
- 8-m x 8-m stations
- Room-temp LNAs
  - Proto-type based non Minicircuits SAV-541 transistor has been tested
- RFOF to electronics rooms
  - Based on CHIME technology
▶ Correlator based on ICE-system design
  ▶ Already tested as part of CHIME
▶ 8-bit @ 1.25 Gsps ADCs
▶ 16 compute nodes for correlation, beamforming, averaging, and real-time searching
ICE enables large array of interconnected FPGAs for signal processing/networking

- Built around custom motherboard and backplane connecting 16 FPGAs per crate
- Each motherboard connects to 2 FMC daughter boards for specific applications
- Custom software for automatic configuration, M&C

- Single low-noise clock and absolute time tagging
- Easily adaptable for VLBI
- Highly scalable and cost effective
- Robust, easy to maintain
- Complex voltage for 1024 channels sent through corner-turn to 16 compute nodes
  - 625 Gpbs total data rate
- GPU-cluster will act as X-engine and perform real-time transient search using “Bonsai” code-base used in CHIME
WFBT designed to be scalable

- More horns $\rightarrow$ higher sensitivity
- More baselines $\rightarrow$ better localization, cleaner beam
- More stations $\rightarrow$ cover more sky

Currently seeking funding for prototype to be deployed at Green Bank Observatory
Commensal Science

- FRB pipelines designed for broad-band, dispersed, impulsive signals
  - Repeating FRB demonstrating need for searches of band-limited signals (see Zhang et al., 2018, arXiv:1809.03043)

- Parallel pipelines could be implemented for different signal types / commensal science
  - e.g. SETI, monitoring ISM effects in bright MSPs (important for GW detection using pulsars)
Taking full advantage of multi-messenger (MM) astronomy requires 24/7 full-sky coverage

FRBs offer a rich MM discovery space for wide-field telescopes

LASA and the WFBT are cost-effective concepts for all-sky telescopes with commensal science opportunities

Thanks!