Radio Searches of Fermi Unassociated γ-Ray Sources

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Fermi Gamma-Ray Space Telescope

Credit: Nasa Spacecraft Icons

- Launched 06-2008
 - Mission: 5-10 years
 - Elapsed: 13.4 years
- Two primary instruments
 - LAT Directional "telescope"
 - GBM Burst monitoring
- Main data product: TOAs



Okay but What Does It Really See?





Teamwork Makes the Dreamwork

- We can provide support from radio
 - Less crowded than other wavelengths
- We're good at finding pulsars and AGN
 - And the other stuff
- We use the VLA

A Lot of Looking

- About 10 years of radio follow-up on unassociated fields
- Lots of interesting stuff in there, see:
 - Bruzewski et al 2020
- Cool recent bonus:
 - VLASS



VLASS

- Largest and deepest survey with Modern VLA
- We made an Epoch 1 quicklook catalog
 - Data: cv.nrao.edu/F357/
 - o arXiv: 2102.07397
- Our catalog corrects for systematic error in positions
 - Based on crossmatching with GAIA



Some Example Results

- For each unassociated field:
 - Find interior sources
 - PyBDSF
 - Network via distance
 - Assemble into catalog
 - Make cool plots
 - Analyze spectrum
- Find some interesting sources, generate interest follow-up







Spectrum Speculating

- Can get spectral index fairly easily
- Compactness from total/peak flux
- Start classifying
 - Steep and compact could be PSR
 - Flat and compact could be AGN

• etc...



Continuation...

- VLASS was great
- What if we add more surveys?
 - North + South
 - Multiple frequencies
 - Bigger number =
 better science
- 100 MHz to 20 GHz





Roughly Summed Coverage



And that's... in prep 2021



Appearances

1

2



Going back, empty?

- Some fields we've looked at and found **NOTHING**
 - What is making gamma-rays then?
 - Maybe pulsars
 - Scattered by dust
 - Target at low frequency
 - Our efforts so far:
 - 3 projects
 - ~260 hours
 - ∼120 fields

Deep Fields

- Select "pulsar-like" fields we perform dedicated deep observations
- Accurate fluxes and spectral indices
- Can find sources that might be pulsars...
- Needs lots of processing power



Pilot Success: Cannonball

- Empty field result
 - PSR + PWN + SNR
 - Initial values:
 - 2 kpc
 - ~1100 km/s
 - ~115 ms
- Ongoing follow-ups:
 - Bow shock with
 CHANDRA + VLA
 - Parallax with VLBA



Zoom and Enhance

- Preliminary results:
 - Not quite as fast
 - Initial distance looks pretty good
 - ~600 km/s
- Still waiting on more data to better constrain





corner.corner()





In Summary



identify know large use source parameter radio time highproperty low pulsar fermi analysis observation find 8. Questions? model year follow field observe lat telescope

Description	Identified		Associated	
	Designator	Number	Designator	Number
Pulsar, identified by pulsations	PSR	231		
Pulsar, no pulsations seen in LAT yet		122.	psr	10
Pulsar wind nebula	PWN	12	pwn	6
Supernova remnant	SNR	24	snr	16
Supernova remnant / Pulsar wind nebula	SPP	0	spp	92
Globular cluster	GLC	0	glc	30
Star-forming region	SFR	3	sfr	0
High-mass binary	HMB	5	hmb	3
Low-mass binary	LMB	1	lmb	1
Binary	BIN	1	bin	0
Nova	NOV	1	nov	0
BL Lac type of blazar	BLL	22	ы	1080
FSRQ type of blazar	FSRQ	42	fsrq	639
Radio galaxy	RDG	6	rdg	32
Non-blazar active galaxy	AGN	1	agn	16
Steep spectrum radio quasar	SSRQ	0	ssrq	2
Compact Steep Spectrum radio source	CSS	0	CSS	5
Blazar candidate of uncertain type	BCU	3	bcu	1152
Narrow line Seyfert 1	NLSY1	3	nlsy1	5
Seyfert galaxy	SEY	0	sey	1
Starburst galaxy	SBG	0	sbg	7
Normal galaxy (or part)	GAL	2	gal	2
Unknown	UNK	0	unk	118
Total		357		3217
Unassociated				1525

NOTE—The designation 'spp' indicates potential association with SNR or PWN. Designations shown in capital letters are firm identifications; lower case letters indicate associations.

Bonus Slide: Source Breakdown





Bonus Slide: VLASS-GAIA Offsets