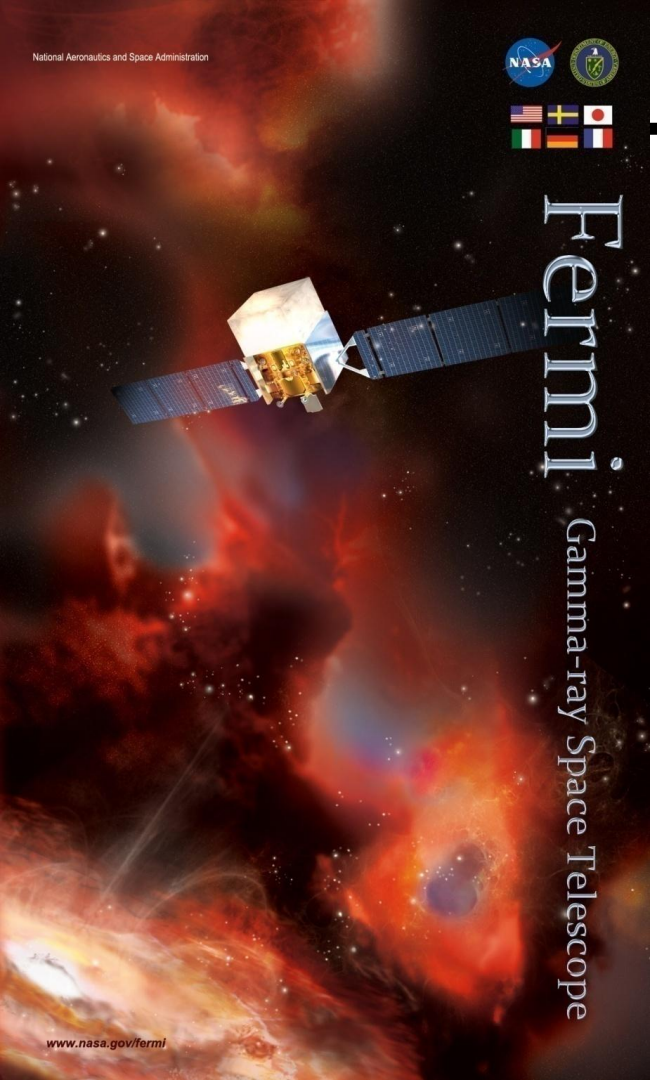

Fermi Gamma-ray Space Telescope

Systematic search for gamma-ray periodicity in Fermi-LAT AGN

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with Alberto Domínguez et al. on behalf of the Fermi-LAT Collaboration, Jorge Otero, Juan Abel Barrio

P. Peñil, The Astrophysical Journal, 2020, Volume 896, N. 2, 34

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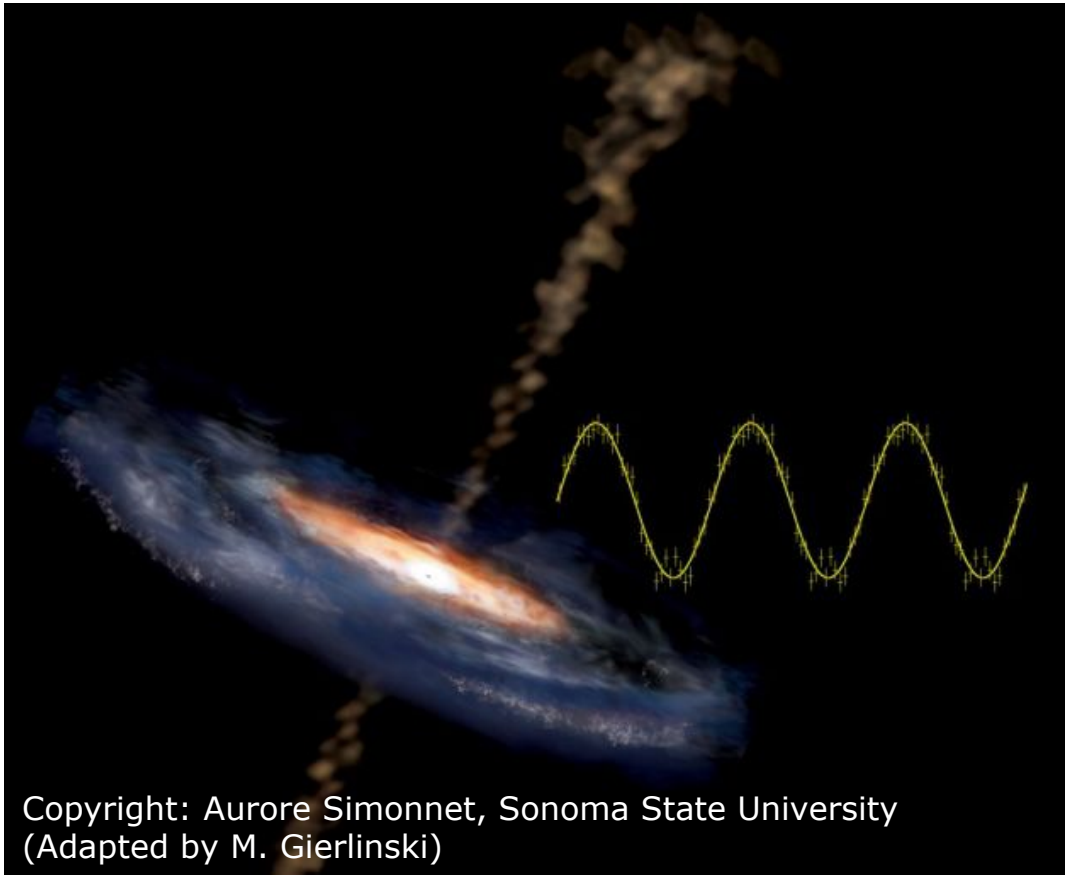
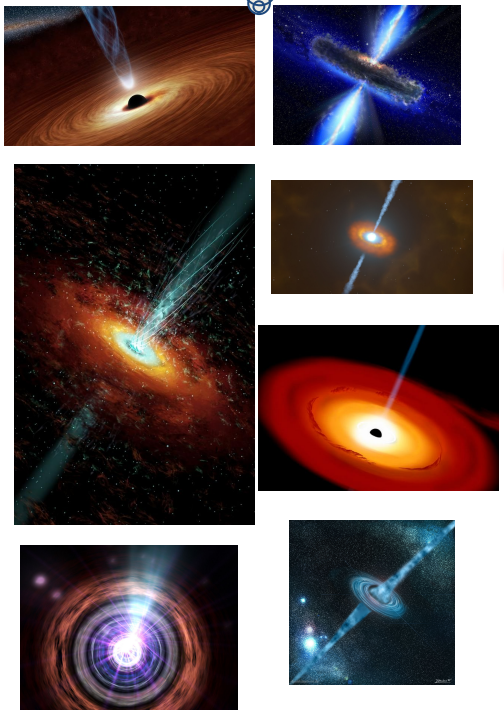
Introduction



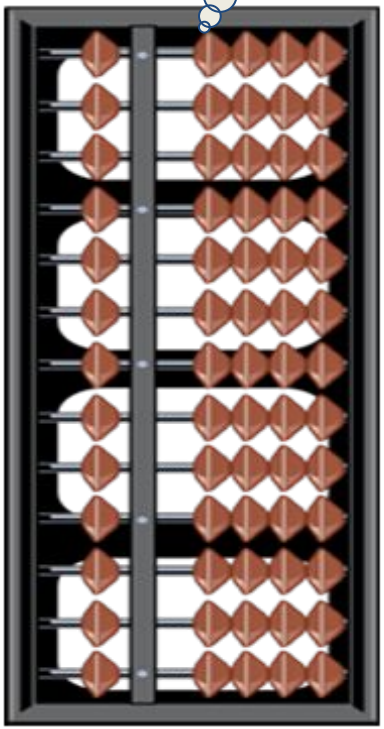
- AGN: variability in the overall electromagnetic spectrum
- Pattern → **Periodicity**
- Different strategies in the literature:
  - one object by means of a few (two) analysis algorithms
  - cross-correlation with other data of different wavelength

Methodology

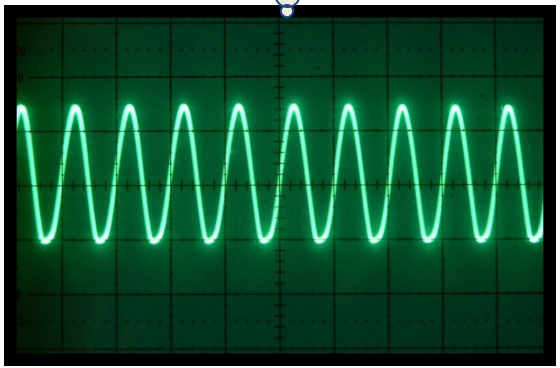
GAMMA-RAY SOURCES



SYSTEMATIC SEARCH



LONG-TERM (≈ YEARS) PERIODICITY?



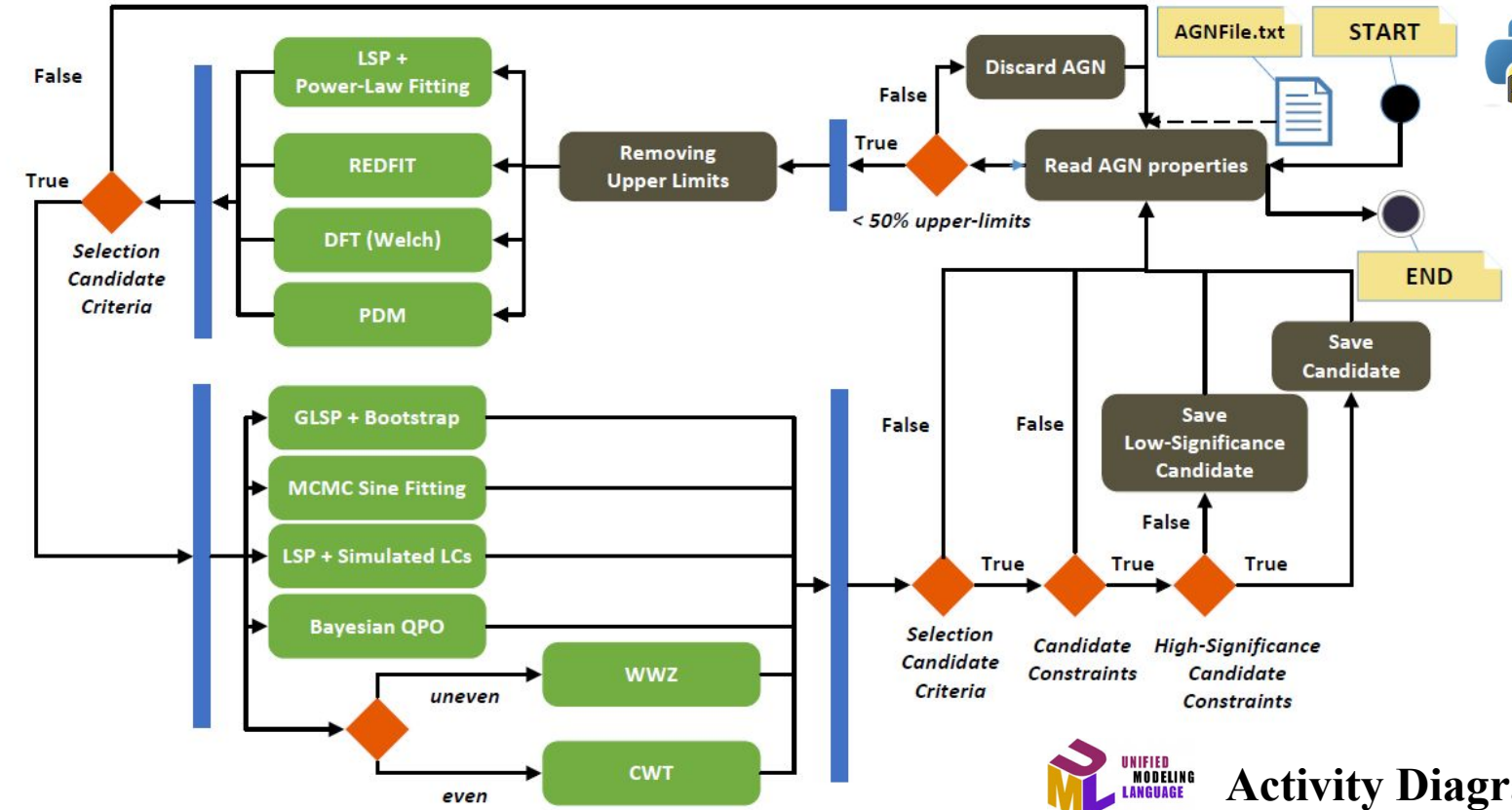
Data sample

- ~ 2300 AGN (3FGL+2FHL+3FHL catalogs)
- Telescope time: 21st August 2008 - 7th September 2017
- Light-curve monthly binned: 28 days, E > 1 GeV
  - *Fermi*-LAT ScienceTools package: version **v11r05p3**
  - **P8R2 SOURCE V6** instrument response functions,
  - **fermipy** software package
- Cuts:
  - zenith angle cut of $\Theta < 90^{o}$
  - solar flares and γ-ray bursts excluded
- For each source:
  - 10^{o} x 10^{o} region
  - Integral Energy Flux above 1 GeV
  - Energy Flux Upper limits for TS<4 ≈ 2σ

Periodicity Detection Methods

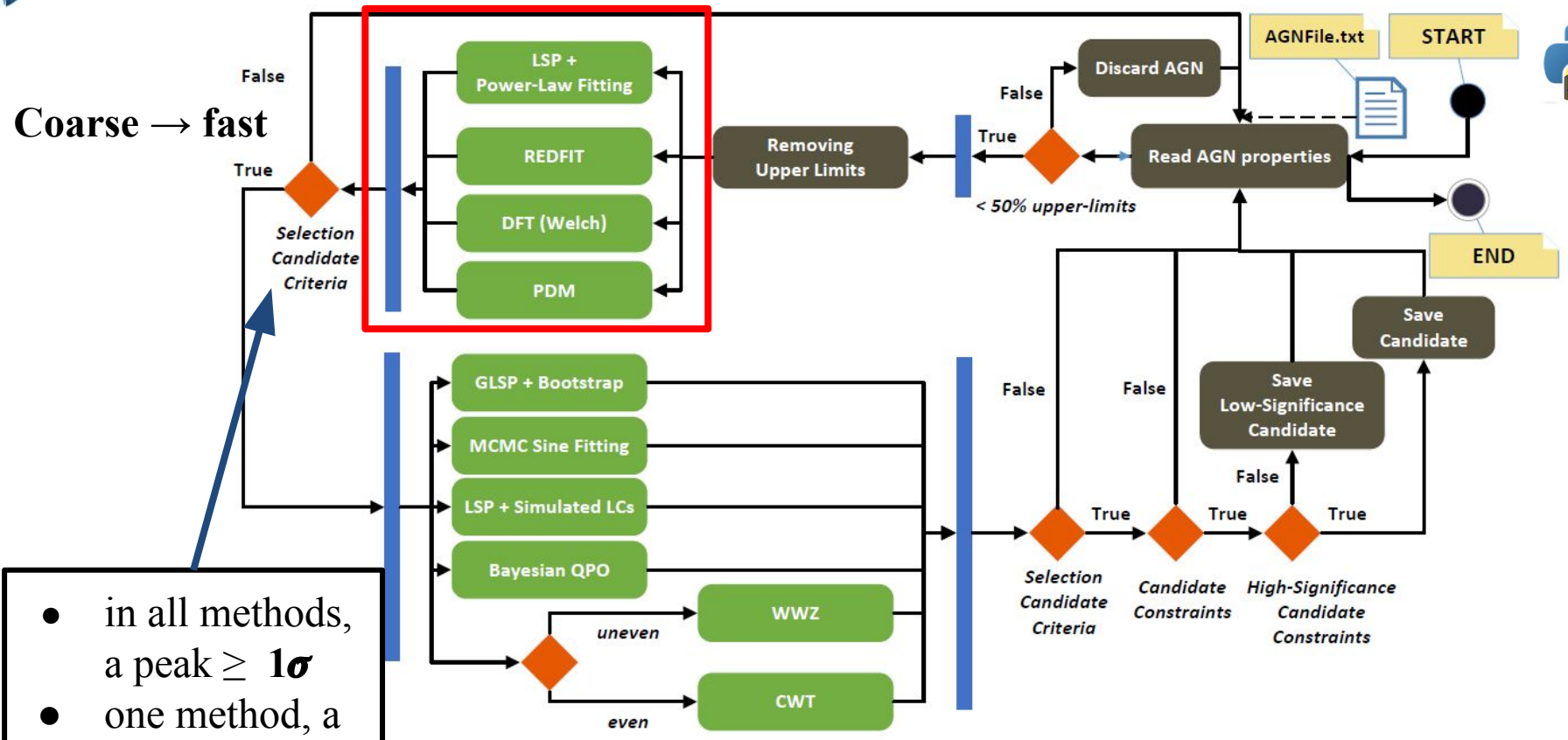
- All of them have advantages and disadvantages VanderPlas J., 2018 Goyal, A., et al. 2017
- Potential results comparison
- Organize the methods according to computational requirements

Periodicity-Search Pipeline



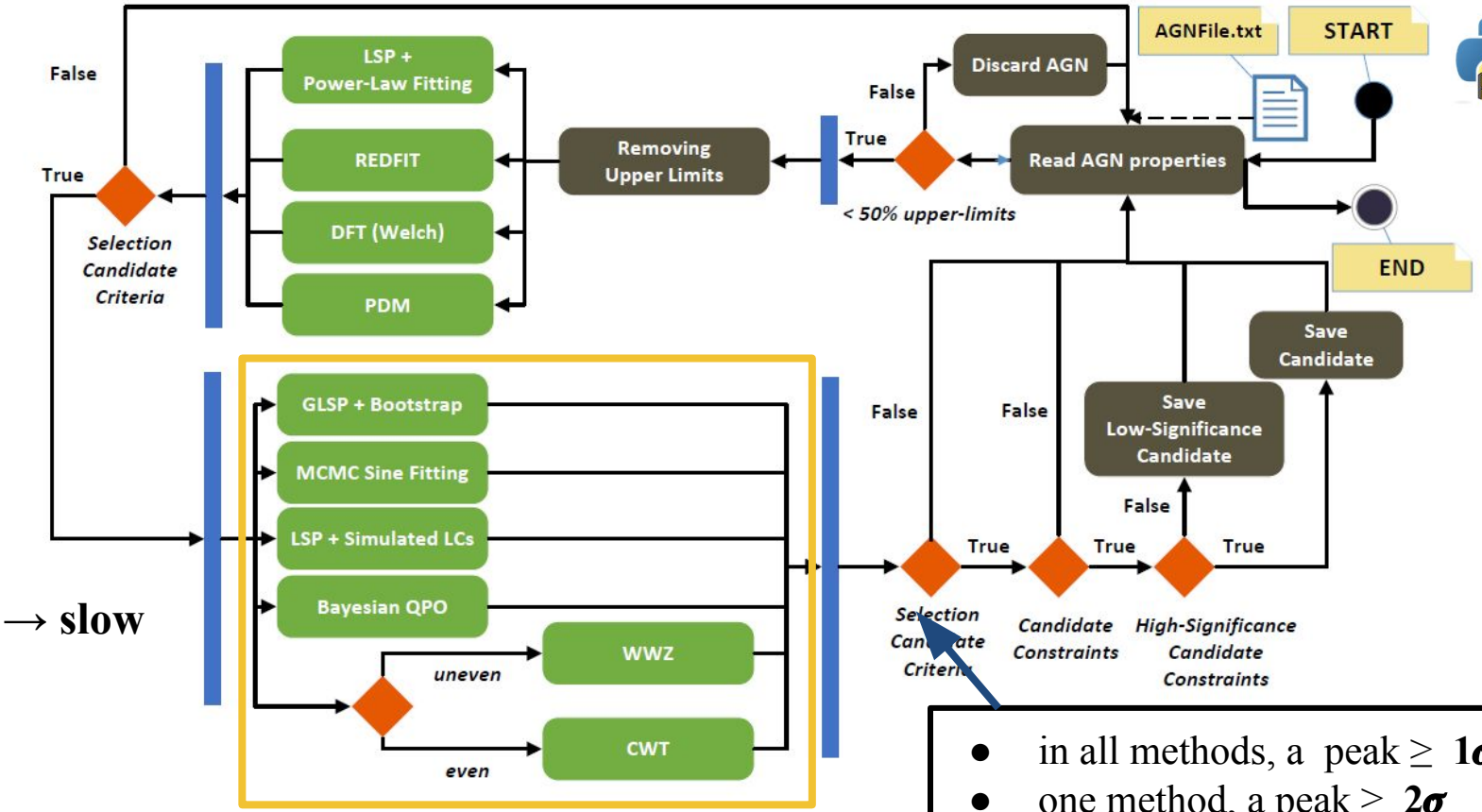
Activity Diagram (UML)

Periodicity-Search Pipeline



- in all methods, a peak ≥ **1σ**
- one method, a peak ≥ **2σ**

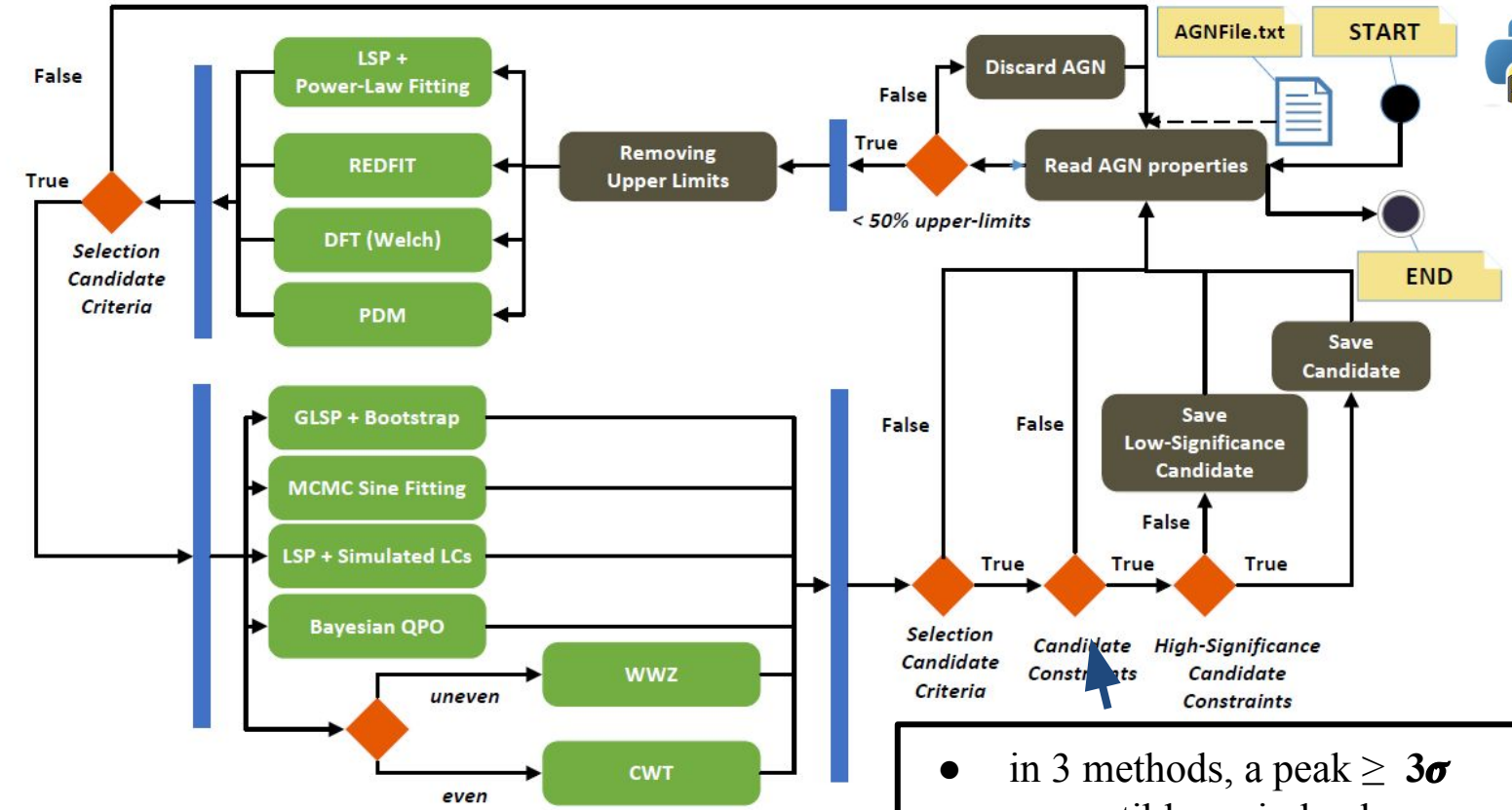
Periodicity-Search Pipeline



Refined → slow

- in all methods, a peak ≥ **1σ**
- one method, a peak ≥ **2σ**

Periodicity-Search Pipeline



- in 3 methods, a peak $\geq$ **3σ**
- compatible period value
- 1 exception

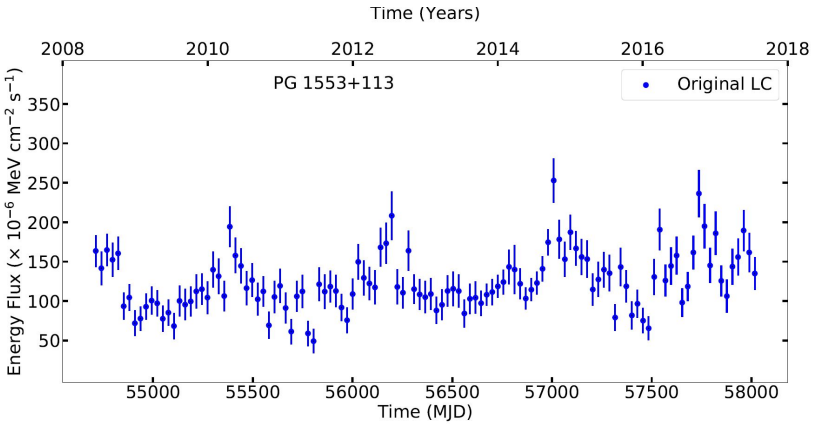
Results (I): Candidates

- 4 methods derive the same period at $\geq 4\sigma$

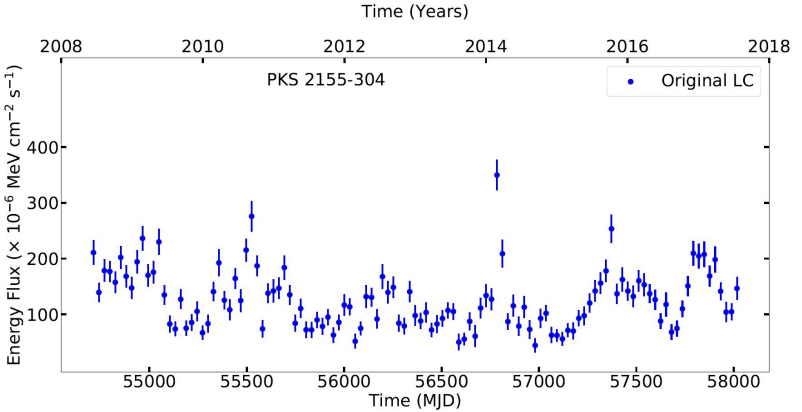
Name	RAJ2000	DecJ2000	Type	Redshift	Association Name
3FGL J0043.8+3425	10.96782	34.42687	fsrq	0.966	GB6 J0043+3426
3FGL J0210.7−5101	32.68952	−51.01695	fsrq	1.003	PKS 0208−512
3FGL J0211.2+1051	32.81532	10.85811	bll	0.2	MG1 J021114+1051
3FGL J0521.7+2113	80.44379	21.21369	bll	0.108	TXS 0518+211
3FGL J0811.3+0146	122.86418	1.77344	bll	1.148	OJ 014
3FGL J1146.8+3958	176.73987	39.96861	fsrq	1.089	S4 1144+40
3FGL J1248.2+5820	192.07728	58.34622	bll	–	PG 1246+586
3FGL J1454.5+5124	238.93169	11.18768	bll	–	TXS 1452+516
3FGL J1555.7+1111*	238.93169	11.18768	bll		PG 1553+113
3FGL J2158.8−3013*	329.71409	−30.22556	bll	0.116	PKS 2155−304
3FGL J2258.0−2759	344.50485	−27.97588	fsrq	0.926	PKS 2255−282

Results (I): Candidates in the Literature

- PG 1553+113:
  - Ackermann, M., et al. 2015, (T=2.2 yr)
  - Tavani M., et al. 2018, (T=2.2 yr)
  - Sandrinelli A., et al., 2018, (T=2.2 yr)
  - **This work:** T = 2.2 ± 0.1 yr ($>4\sigma$)



- PKS 2155-304:
  - Sandrinelli A., et al., 2018 (T=1.73 yr)
  - Zhang P.-F., et al., 2017 (T=1.76 yr)
  - **This work:** T = 1.7 ± 0.1 yr ($>3.5\sigma$)



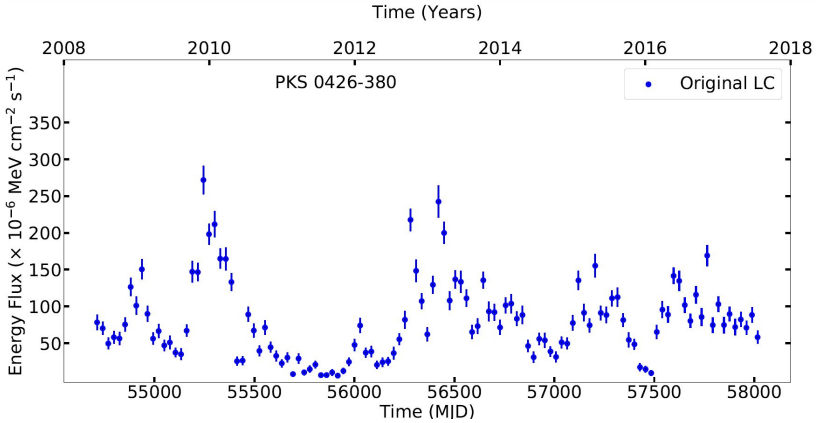
Results (II): Low-Significance Candidates

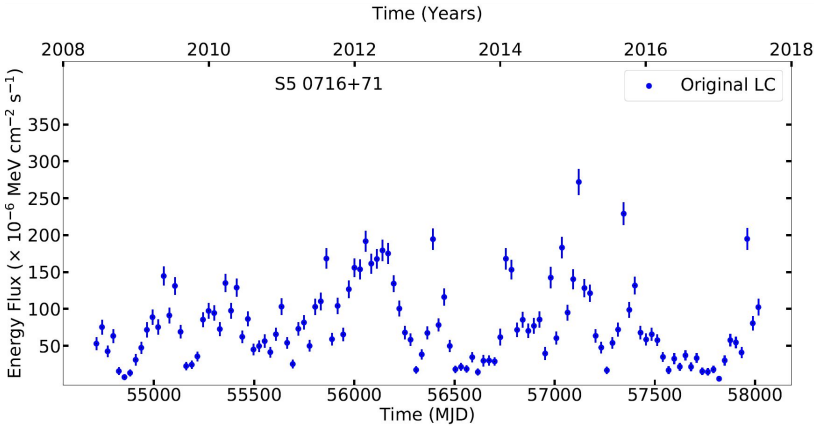
- 3 methods derive the same period at $\geq 4\sigma$

Name	RAJ2000	DecJ2000	Type	Redshift	Association Name
3FGL J0102.8+5825	15.71134	58.41576	fsrq	0.644	TXS 0059+581
3FGL J0252.8−2218	43.20377	−22.32386	fsrq	1.419	PKS 0250−225
3FGL J0303.4−2407*	45.86259	−24.12074	bll	0.266	PKS 0301−243
3FGL J0428.6−3756*	67.17261	−37.94081	bll	1.11	PKS 0426−380
3FGL J0449.4−4350	72.36042	−43.83719	bll	0.205	PKS 0447−439
3FGL J0457.0−2324	74.26096	−23.41384	fsrq	1.003	PKS 0454−234
3FGL J0501.2−0157	75.30886	−1.98359	fsrq	2.291	S3 0458−02
3FGL J0721.9+7120*	110.48882	71.34127	bll	0.127	S5 0716+71
3FGL J0818.2+4223	124.56174	42.38367	bll	0.530	S4 0814+42
3FGL J1303.0+2435	195.75454	24.56873	bll	0.993	MG2 J130304+2434
3FGL J1649.4+5238	252.35208	52.58336	bll	–	87GB 164812.2+524023
3FGL J1903.2+5541	285.80851	55.67557	bll	–	TXS 1902+556
3FGL J2056.2−4714	314.06768	−47.23386	fsrq	1.489	PKS 2052−47

Results (II): L-Significance Candidates in the Literature

- PKS 0301-243:
  - Zhang P.-F., et al., 2017 (T=2.1 yr)
  - **This work:** T = 2.0 ± 0.1 yr (≈3σ)
- PKS 0426-380:
  - Zhang P.-F., et al., 2017 (T=3.3 yr)
  - **This work:** T = 3.2 ± 0.1 yr (≈3σ)
- S5 0716+71:
  - Prokhorov D. A., Moraghan A., 2017 (T=0.9 yr)
  - Sandrinelli et al., 2017 (T=0.9 yr)
  - **This work:** T = 2.7 ± 0.1 yr ($>$2.5σ)





Other calculations

- False-Periodicity Detection Rate:
  - ~ 1 false detection
- 5σ exposure estimation:
  - range 2-5 extra years
- The impact of upper limits in LCs:
  - significance: 10%-40%
  - period: 5%-30%

Name	#of Cycles to Reach 5σ	#Extra Years of LAT Observation
GB6 J0043+3426	≈2.8	≈6
TXS 0059+581	X	X
PKS 0208−512	≈1.6	≈4
MG1 J021114+1051	≈2	≈4
PKS 0250−225	≈3	≈3
PKS 0301−243	≈3.6	≈7
PKS 0426−380	≈2	≈6
PKS 0447−439	≈2	≈5
PKS 0454−234	≈1.4	≈4
S3 0458-02	X	X
TXS 0518+211	≈1.4	≈4
S5 0716+71	X	X
S4 0814+42	≈2	≈4.4
OJ 014	≈2.9	≈12
S4 1144+40	≈1.9	≈ 7
PG 1246+586	≈2.2	≈4
MG2 J130304+2434	X	X
TXS 1452+516	≈1.4	≈3
PG 1553+113	≈ 1	≈2
87GB 164812.2+524023	≈ 1.4	≈4
TXS 1902+556	X	X
PKS 2052−47	≈ 2.8	≈5
PKS 2155−304	≈ 2	≈4
PKS 2255−282	≈ 1.8	≈ 2.5

Future Work

- Update γ-ray LAT light curves from September 2017 forward
- Improve the periodicity-search pipeline:
  - Autoregressive Models: ARIMA, ARFIMA, CARIMA, CARFIMA
- Expand the periodicity investigation to other wavelengths:
  - cross-correlation
  - analysis of possible emission mechanisms

Summary

- Systematic search of gamma-ray periodicity ~ 2300 *Fermi*-LAT AGN studied over 9 years of data.

- 11 gamma-ray periodicity candidates (4 methods at > 4σ)
  - 9 new candidates
  - 2 previously reported in the literature

- 13 low-significance candidates (3 methods at > 4σ)
  - 10 new candidates
  - 3 previously reported in the literature

- On-going research