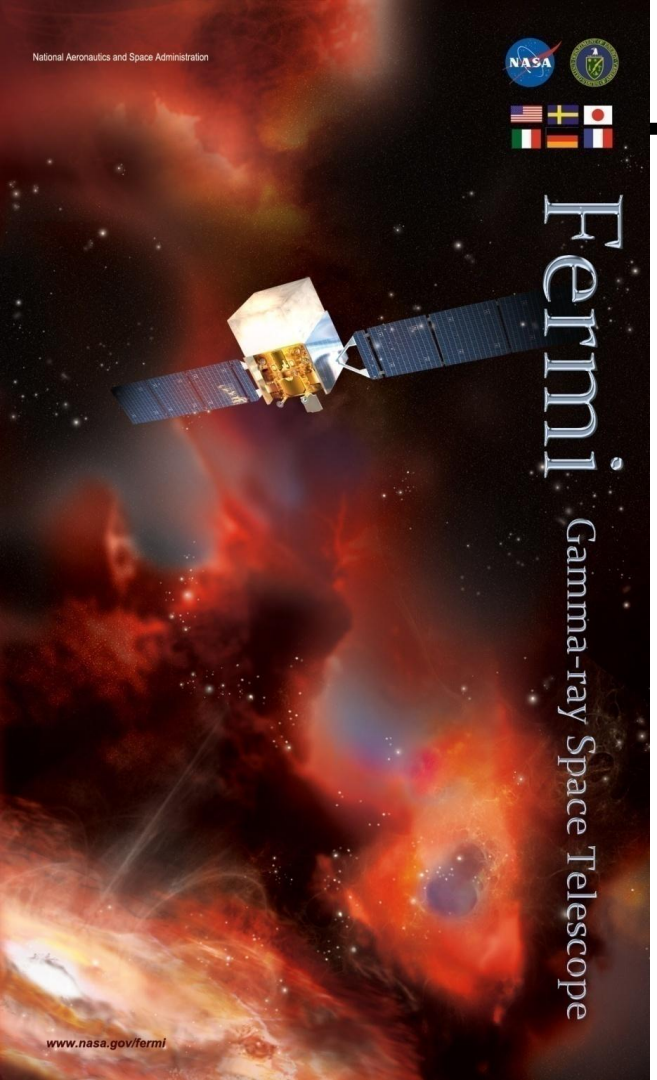

Systematic search for gamma-ray periodicity in *Fermi*-LAT AGNs

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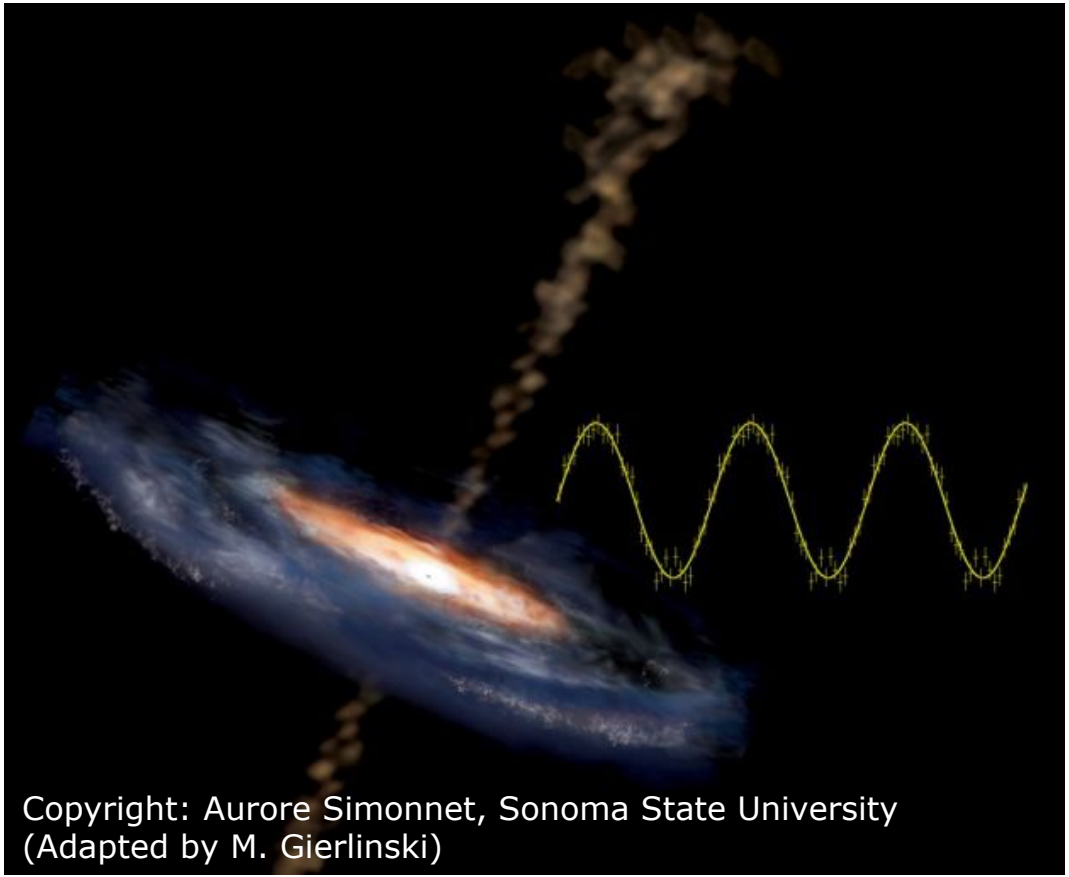
with Jorge Otero, Juan Abel Barrio

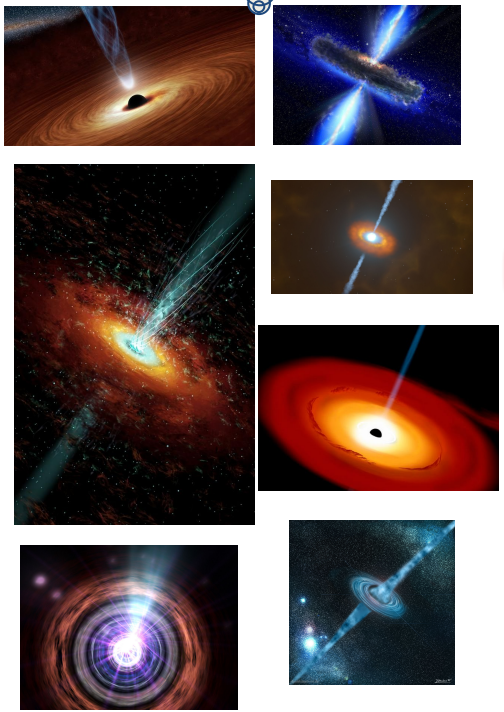
Introduction



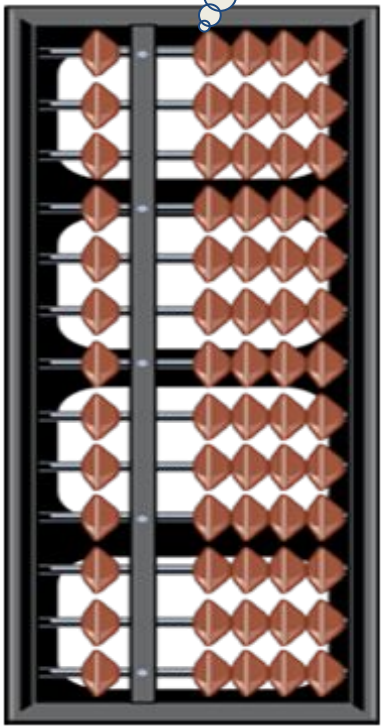
- AGN high-energy emission variability
- Pattern → **Periodicity**
- Different strategies:
  - one object by means of a few (two) analysis algorithms
  - cross-correlation with other data of different wavelength

Methodology

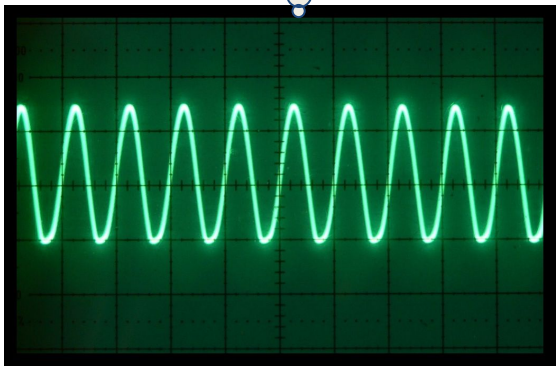
GAMMA-RAY SOURCES



SYSTEMATIC SEARCH

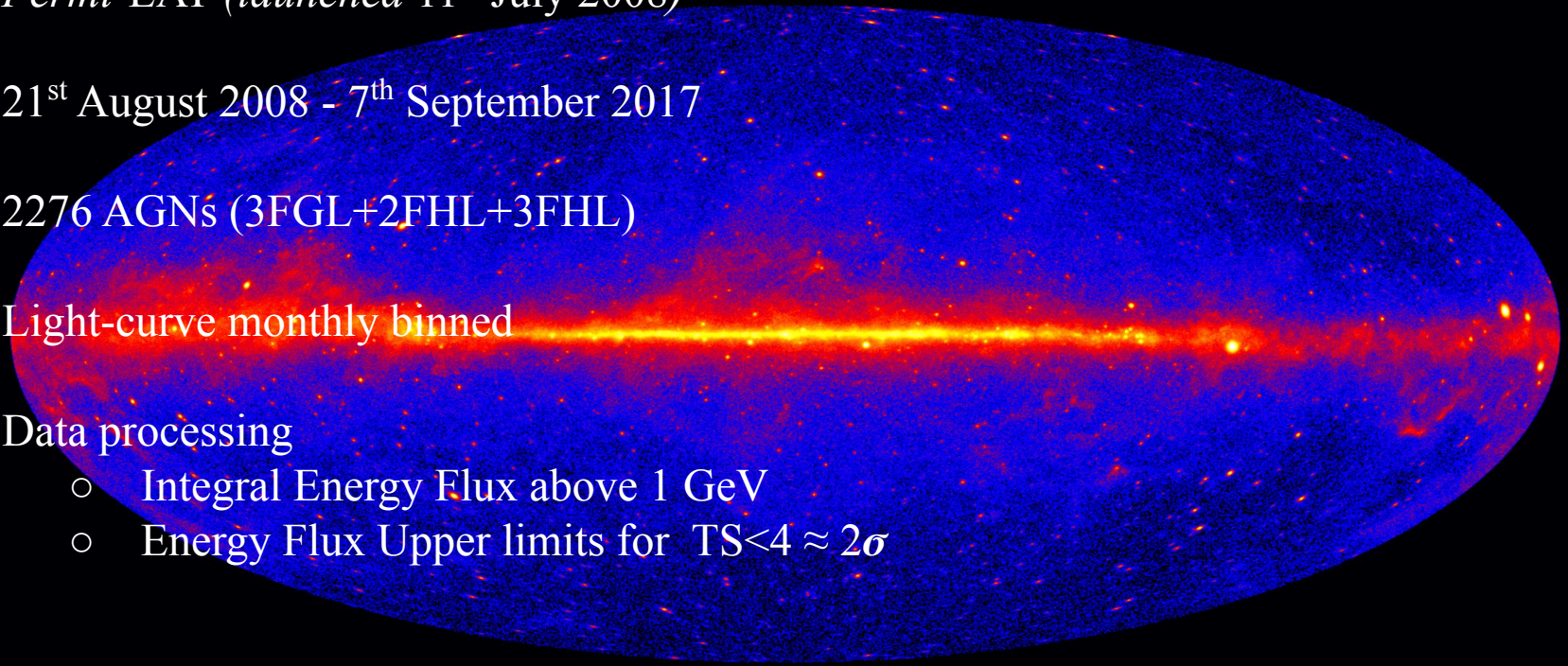


LONG-TERM PREDICTION?



Data sample

- *Fermi*-LAT *(launched* 11th July 2008*)*
- 21st August 2008 - 7th September 2017
- 2276 AGNs (3FGL+2FHL+3FHL)
- Light-curve monthly binned
- Data processing
  - Integral Energy Flux above 1 GeV
  - Energy Flux Upper limits for TS<4 ≈ 2σ



Periodicity Detection Methods

- **Lomb-Scargle**
  - **Power-Law Fitting**
    - Vaughan, 2005
  - **Bootstrap**
    - astroML
  - **Simulated-LCs**
    - Emmanoulopoulus, 2013
    - Connolly, 2015

Periodicity Detection Methods

Phase Dispersion Minimization

PyAstronomy

Fisher' Method of Randomization

Linnell Nemec, A. F. and Nemec, J. M. 1985

REDFIT

Schulz and Mudelsee, 2002

Periodicity Detection Methods

Wavelets

- **CWT**
  - pycwt
- **WWZ**
  - Pyleoclim

Welch's Method (DFT)

- SciPy

Fisher' Method of Randomization

- Linnell Nemec, A. F. and Nemec, J. M. 1985

Periodicity Detection Methods

Fit to a Sinusoidal Function

- emcee
- $O + A*\sin(t/T + \theta)$

Bayesian QPO

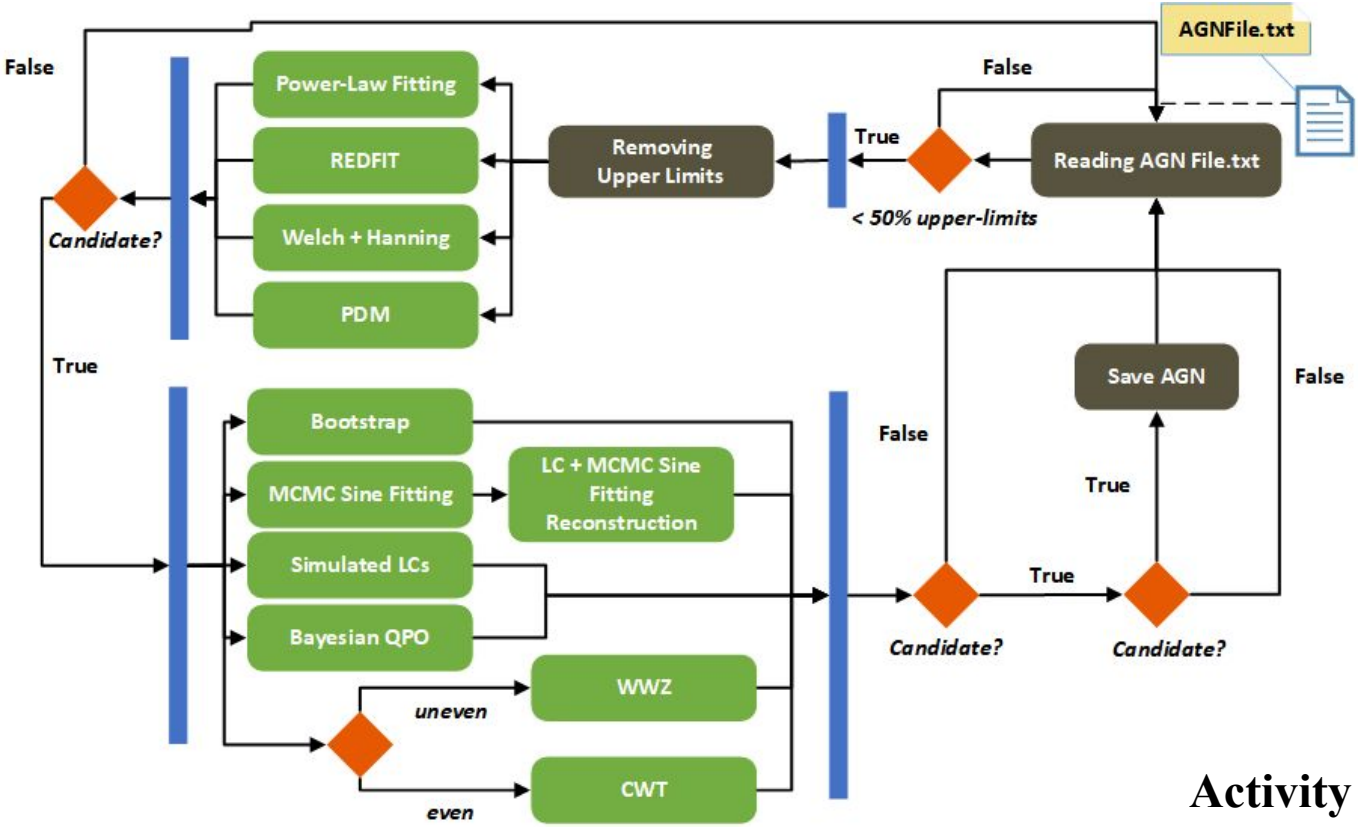
- Huppenkothen, 2013
- Red Noise

Periodicity Detection Methods

- All of them have drawbacks and advantages
  VanderPlas J., 2018
  Goyal, A., et al. 2017

- Potential results comparison

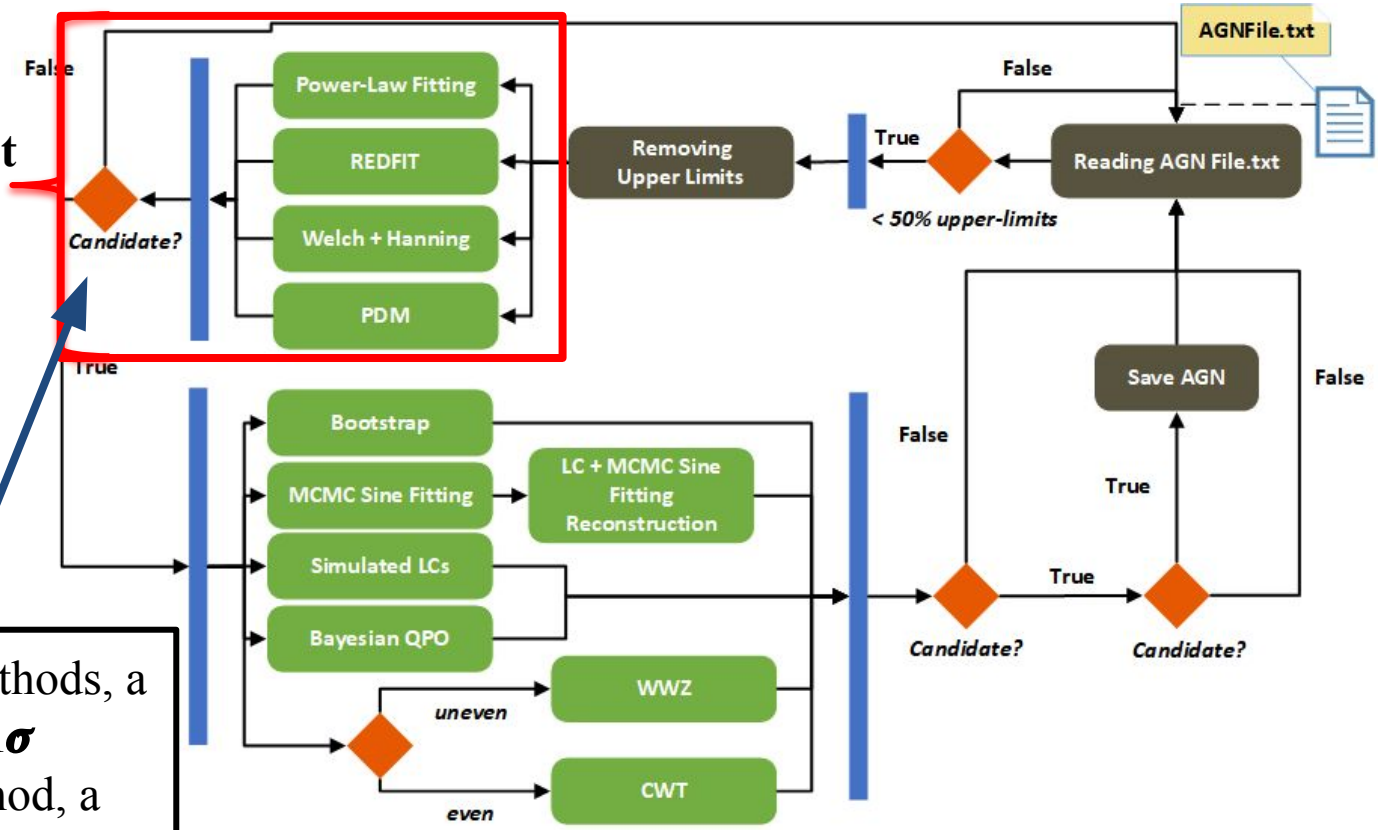
Periodicity-Search Flow



Activity Diagram (UML)

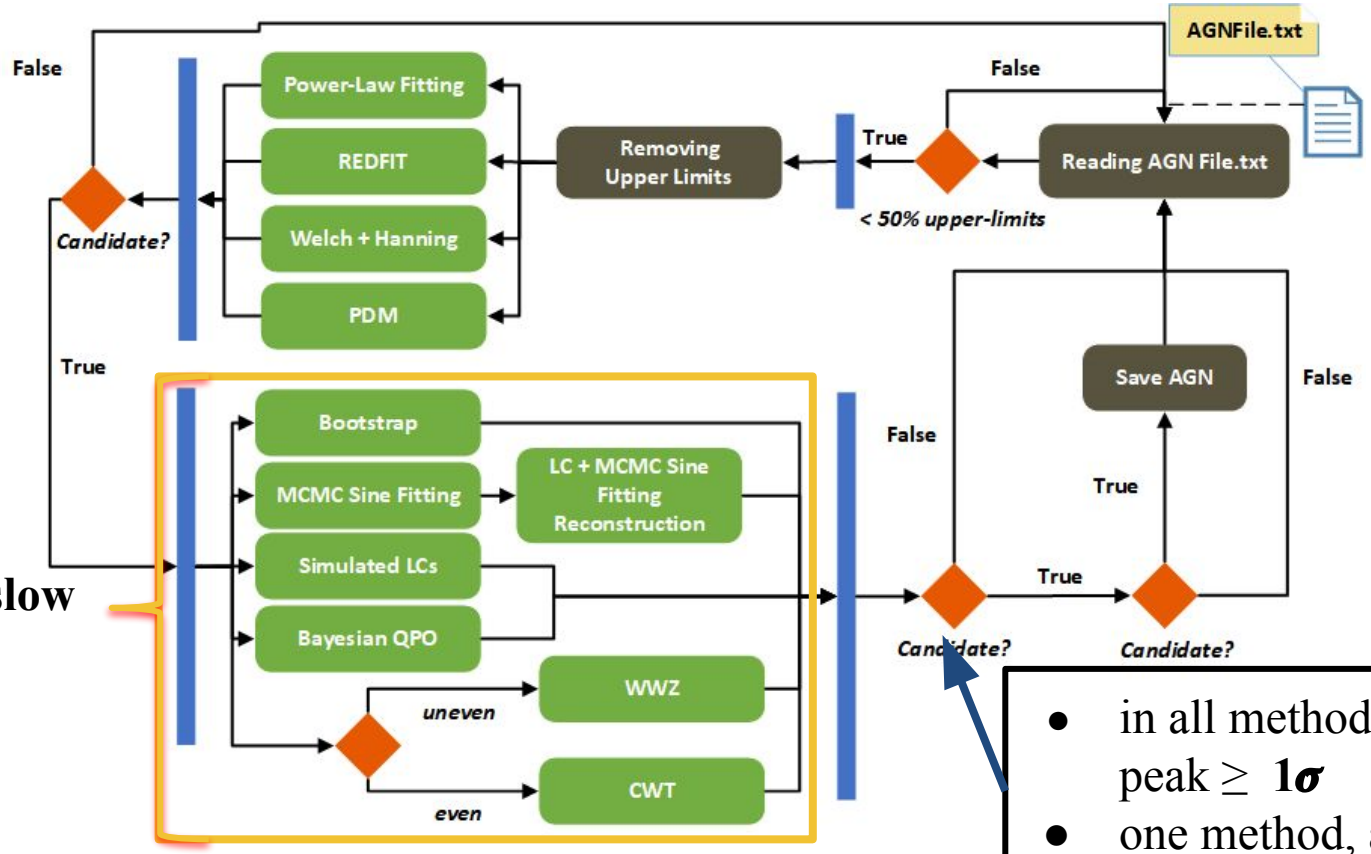
Periodicity-Search Flow

Coarse → fast



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

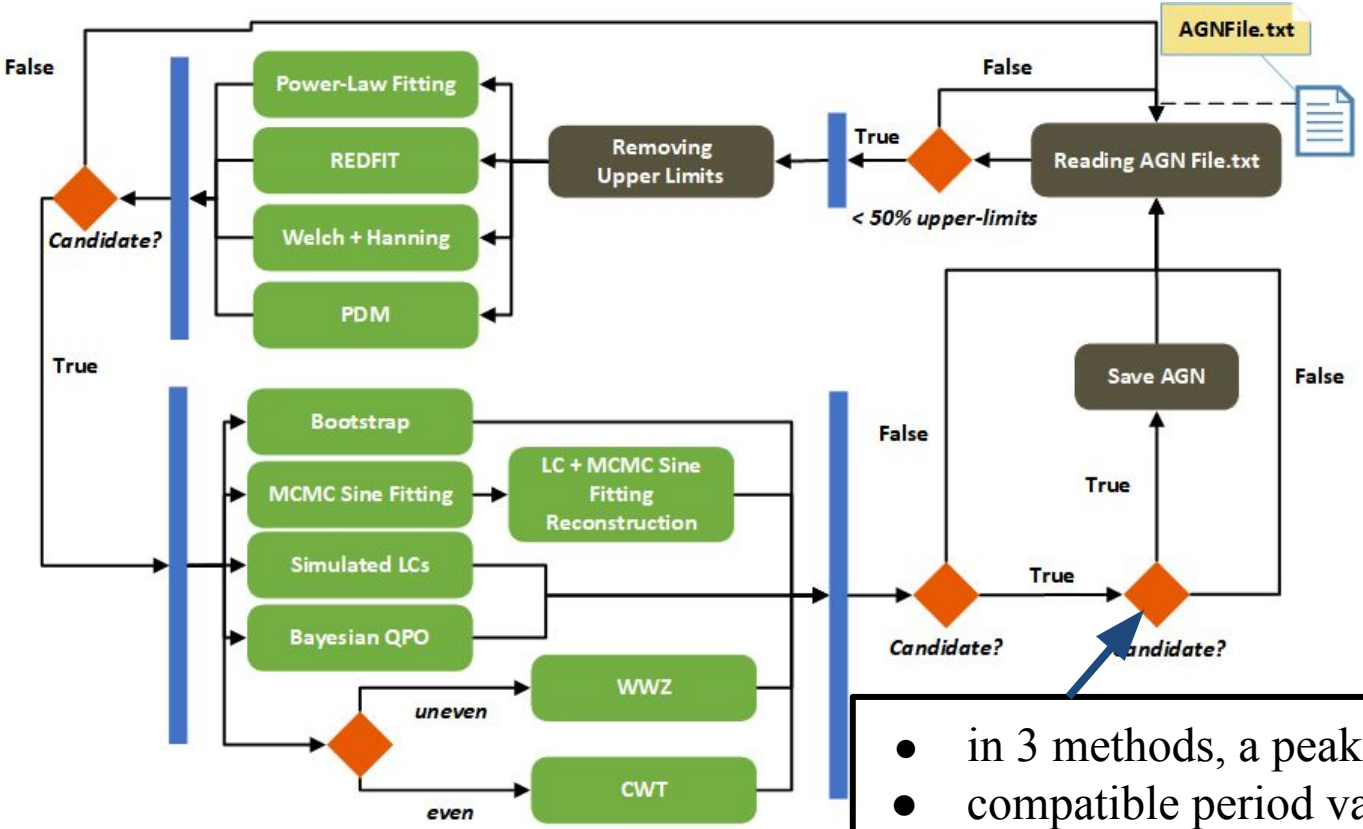
Periodicity-Search Flow



Refined → slow

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

Periodicity-Search Flow



- in 3 methods, a peak ≥ **3σ**
- compatible period value
- 1 exception

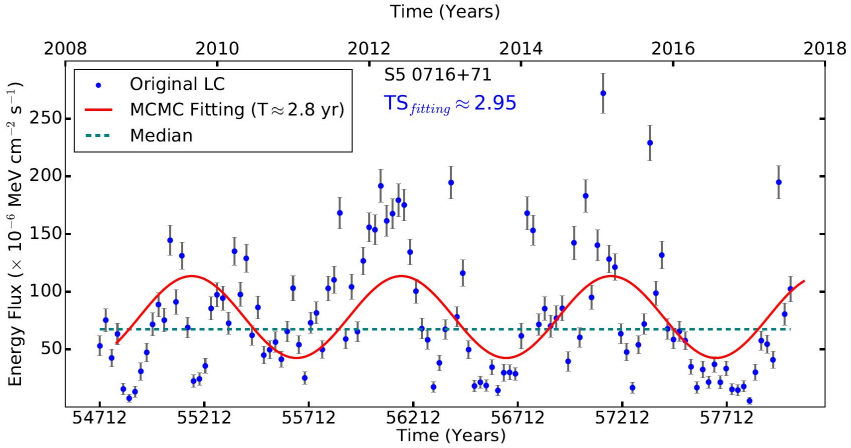
Candidates

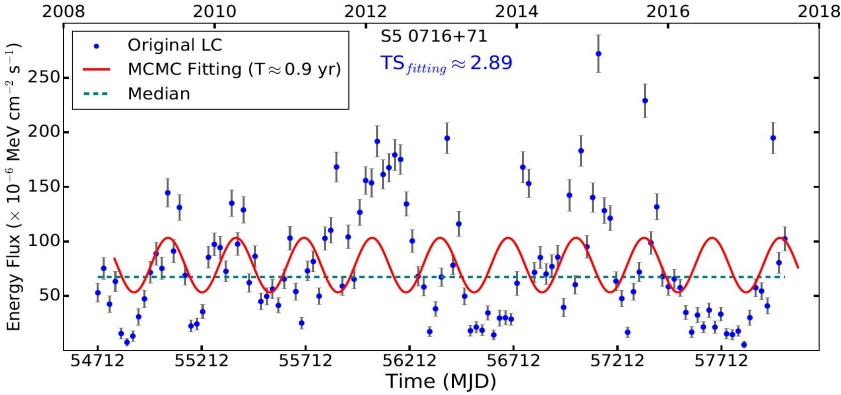
- 23 AGNs as candidates to have periodic gamma-ray emission:
  - 5 previously reported
  - 18 new candidates

GB6 J0043+3426	PKS 0454-234	3FGL J1303.0+2435
3FGL J0102.8+5825	3FGL J0501.2-0157	3FGL J1454.5+5124
3FGL J0210.7-5101	TXS 0518+211	PG 1553+113
MG1 J021114+1051	TXS 0603+476	3FGL J1649.4+5238
3FGL J0252.8-2218	S5 0716+71	3FGL J2056.2-4714
PKS 0301-243	OJ 014	PKS 2155-304
PKS 0426-380	3FGL J1146.8+3958	3FGL J2258.0-2759
PKS 0447-439	3FGL J1248.2+5820	

Candidates already in the literature

- PKS 0301-243:
  - Zhang P.-F., et al., 2017, T=2.1 yr
  - **This work:** T = 2.1 ± 0.1 yr (≈3σ)
- PKS 0426-380:
  - Zhang P.-F., et al., 2017, T=3.35 yr
  - **This work:** T = 3.2 ± 0.1 yr (≈3σ)
- S5 0716+71:
  - Prokhorov D. A., Moraghan A., 2017, T= 0.9 yr
  - Sandrinelli A., et al., 2017, T= 0.9 yr
  - Li, H. Z. et al. 2018, T= 0.9 yr
  - **This work:** T = 2.8 ± 0.1 yr (>2.5σ)





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 ($>3\sigma$)

New Candidates

AGN	Period (yr)	AGN	Period (yr)
GB6 J0043+3426	$2.1^{+0.1}_{-0.4}$ ($\approx 4\sigma$)	TXS 0603+476	$1.3^{+1.8}_{-0.3}$ ($>3\sigma$)
3FGL J0102.8+5825	$2.2^{+1.5}_{-0.1}$ ($\approx 3\sigma$)	OJ 014	4.6 ± 0.2 ($>3.5\sigma$)
3FGL J0210.7-5101	2.7 ± 0.1 ($>3\sigma$)	3FGL J1146.8+3958	3.5 ± 0.1 ($>3\sigma$)
MG1 J021114+1051	1.8 ± 0.1 ($>3.5\sigma$)	PG 1246+586	$2.2^{+2.6}_{-0.1}$ ($>3\sigma$)
3FGL J0252.8-2218	1.2 ± 0.1 ($>2.5\sigma$)	3FGL J1303.0+2435	$2.1^{+0.1}_{-0.7}$ ($>2.5\sigma$)
PKS 0447-439	2.1 ± 0.1 ($\approx 3\sigma$)	3FGL J1454.5+5124	2.2 ± 0.1 ($>3.5\sigma$)
PKS 0454-234	2.3 ± 0.1 ($>2.5\sigma$)	3FGL J1649.4+5238	2.8 ± 0.1 ($>2.5\sigma$)
3FGL J0501.2-0157	1.8 ± 0.1 ($>2.5\sigma$)	3FGL J2056.2-4714	$1.7^{+0.1}_{-0.4}$ ($>2.5\sigma$)
TXS 0518+211	2.9 ± 0.1 ($>3\sigma$)	3FGL J2258.0-2759	1.3 ± 0.1 ($\approx 4\sigma$)

New Candidates: Uncertainties

AGN	Period (yr)	AGN	Period (yr)
GB6 J0043+3426	$2.1^{+0.1}_{-0.4}$ ($\approx 4\sigma$)	TXS 0603+476	$1.3^{+1.8}_{-0.3}$ ($>3\sigma$)
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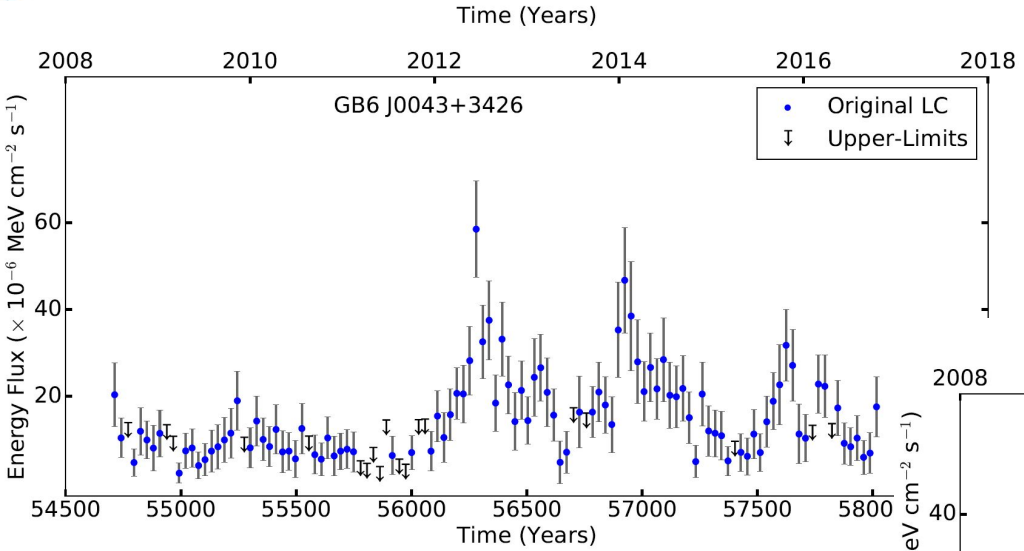
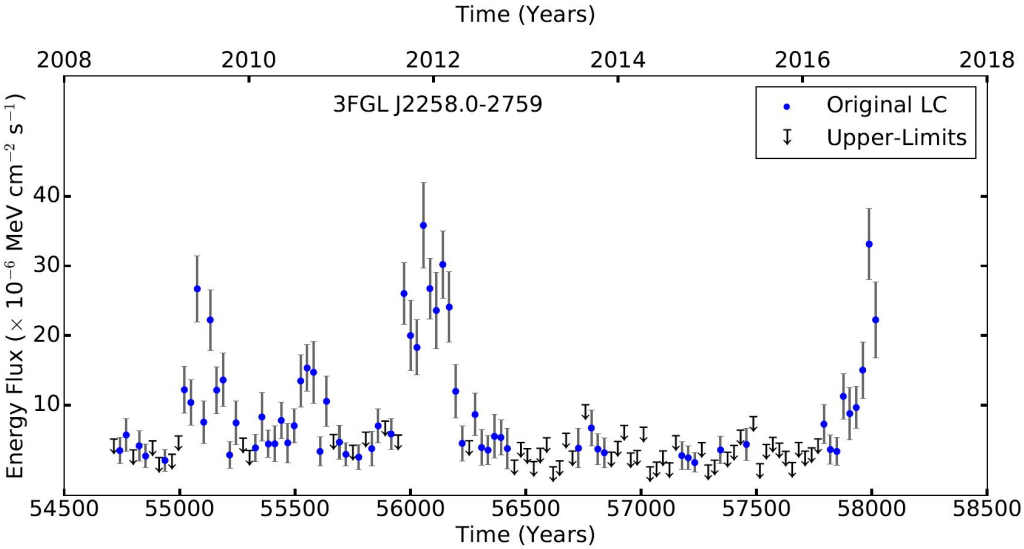
3FGL J0252.8-2218	1.2 ± 0.1 ($>2.5\sigma$)	3FGL J1303.0+2435	$2.1^{+0.1}_{-0.7}$ ($>2.5\sigma$)
PKS 0447-439	2.1 ± 0.1 ($\approx 3\sigma$)	3FGL J1454.5+5124	2.2 ± 0.1 ($>3.5\sigma$)
PKS 0454-234	2.3 ± 0.1 ($>2.5\sigma$)	3FGL J1649.4+5238	2.8 ± 0.1 ($>2.5\sigma$)
3FGL J0501.2-0157	1.8 ± 0.1 ($>2.5\sigma$)	3FGL J2056.2-4714	$1.7^{+0.1}_{-0.4}$ ($>2.5\sigma$)
TXS 0518+211	2.9 ± 0.1 ($>3\sigma$)	3FGL J2258.0-2759	1.3 ± 0.1 ($\approx 4\sigma$)

New Candidates: Uncertainties

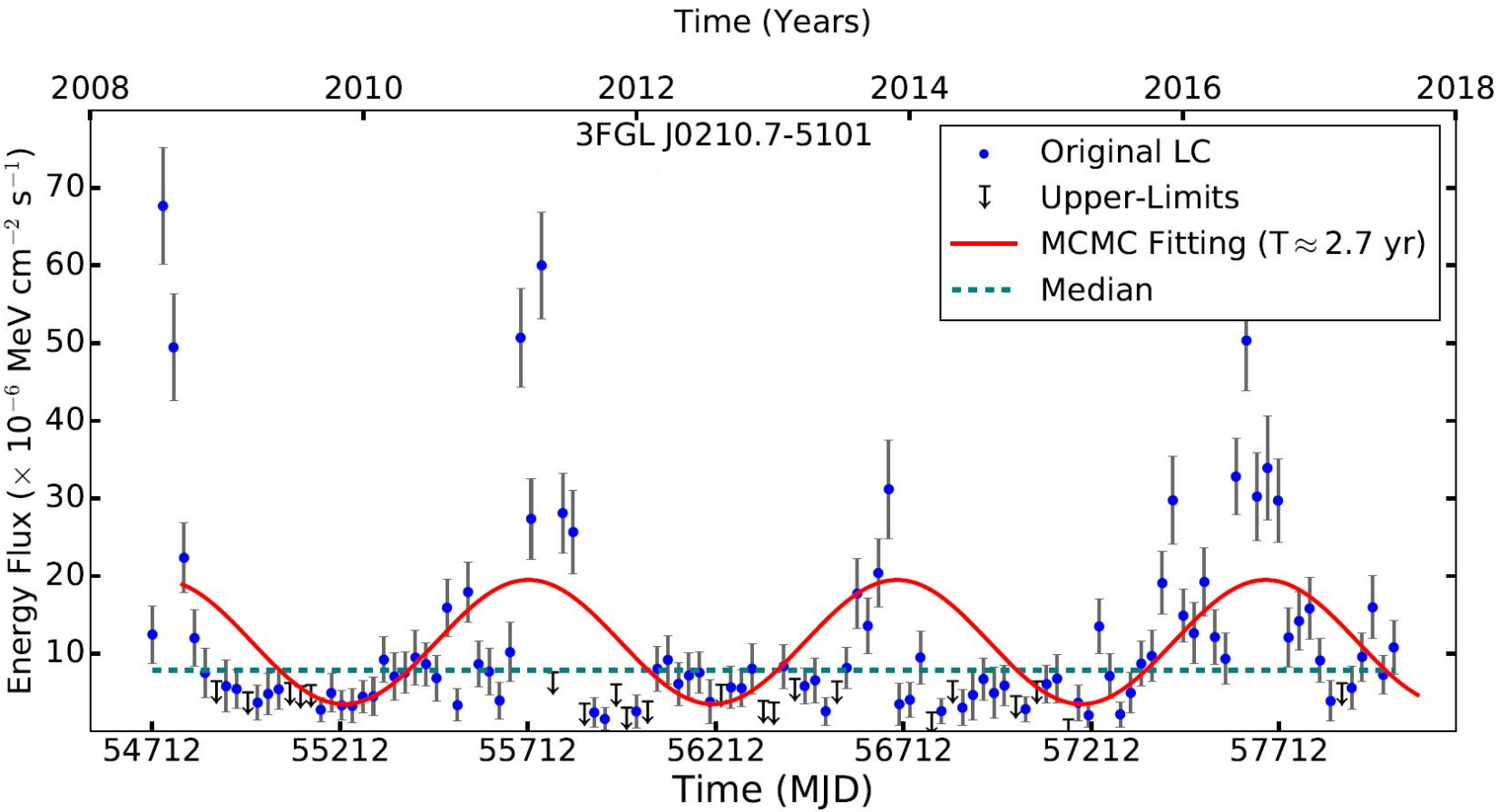


Asymmetric LCs

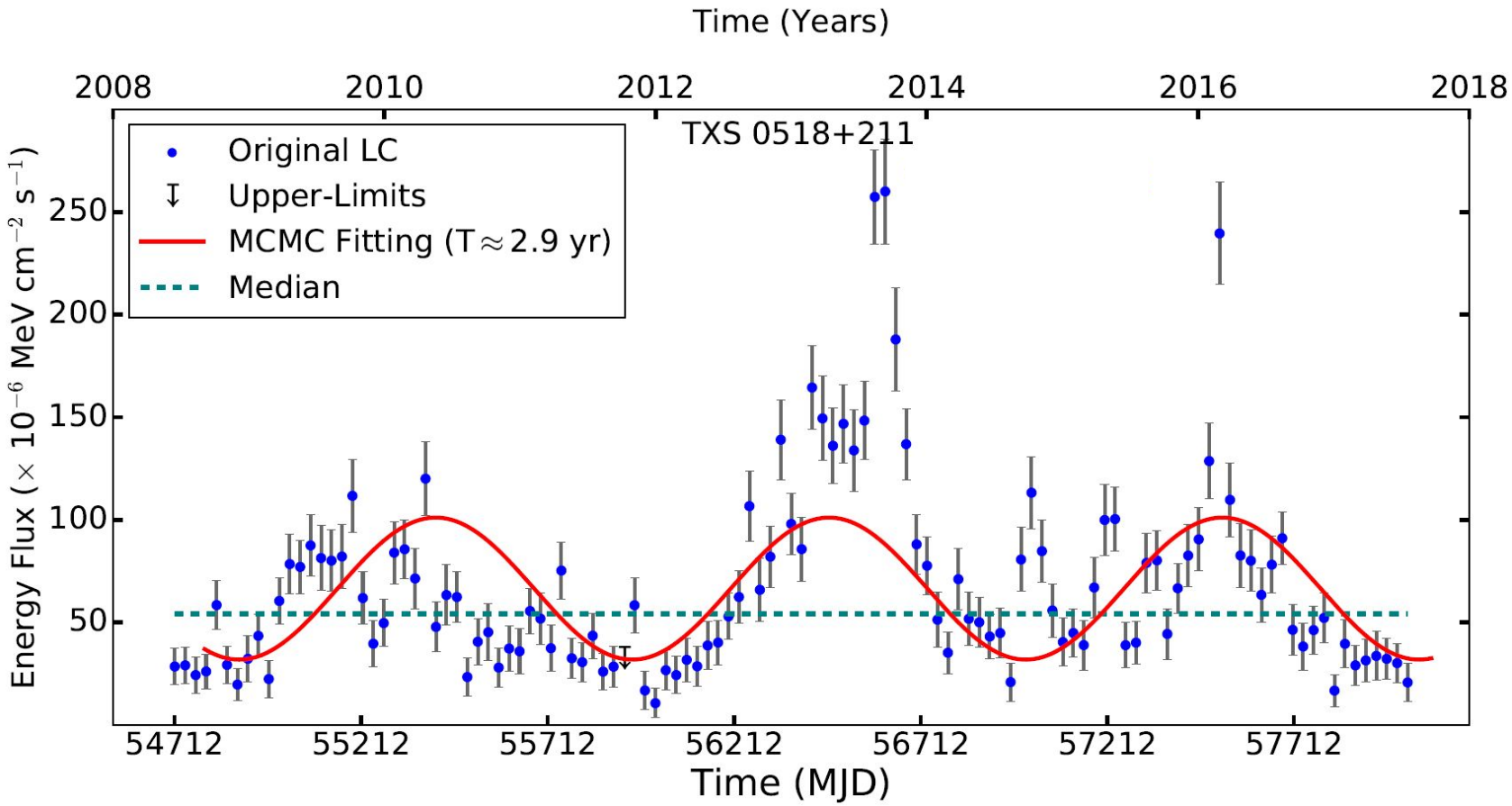
Gaps in LCs



Best New Candidates: 3FGL J0210.7-5101



Best New Candidates: TXS 0518+211



Summary and Conclusions

- Systematic search of gamma-ray periodicity in 2276 *Fermi*-LAT AGNs studied over a period of 9 years

- 23 gamma-ray periodicity candidates
  - 18 new candidates such as 3FGL J0210.7-5101 and TXS 0518+211
  - Only 5 previously reported in the literature

- On-going:
  - Fake Periodicity Detection Rate
  - Multi-Wavelength study
  - Extend time range