

# X-ray and gamma-ray observations of the mode-changing gamma-ray pulsar PSR J2021+4026

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for the Fermi LAT Collaboration

Tuesday, 10 September 2024

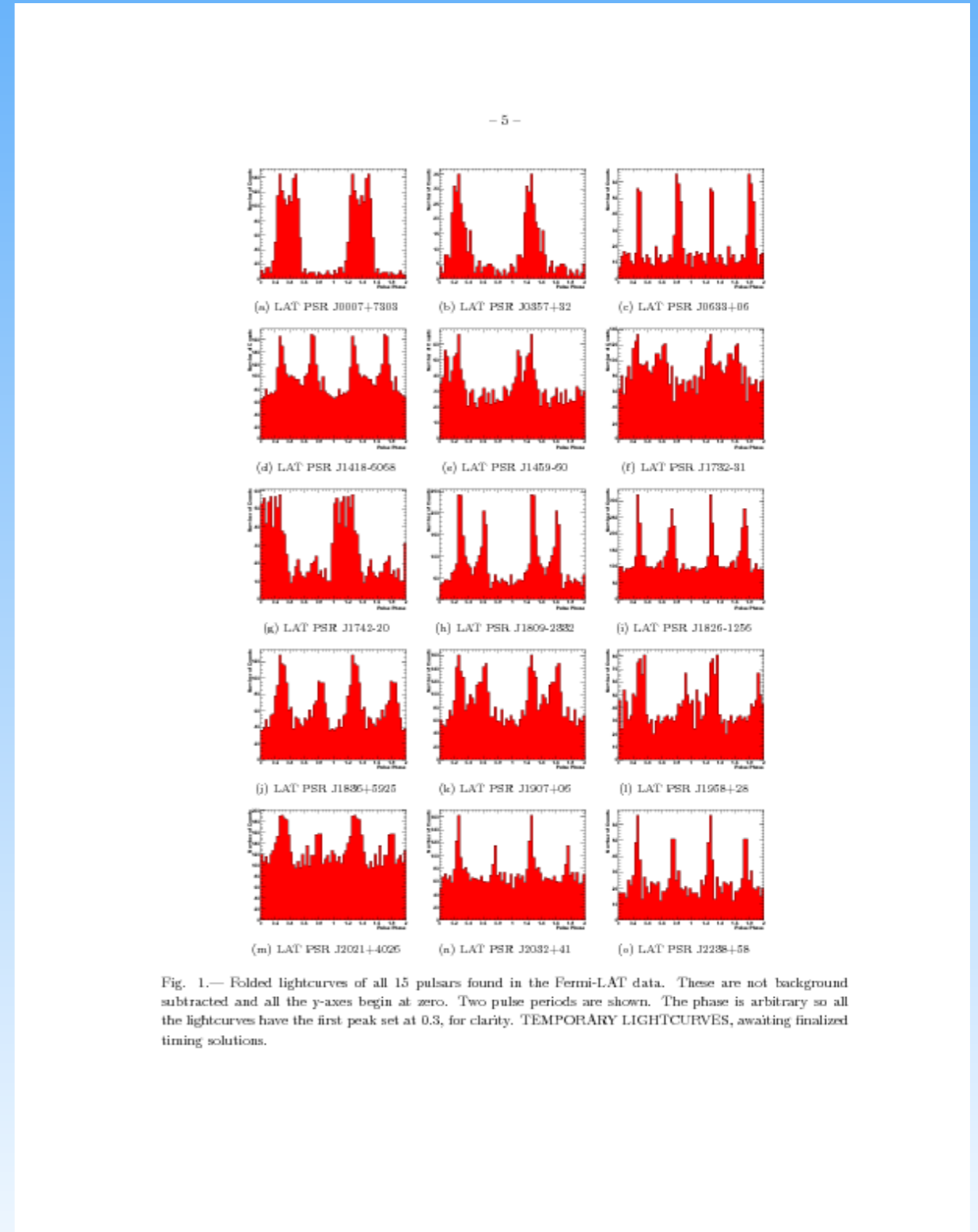


UNIVERSITY OF CALIFORNIA  
**SANTA CRUZ**

# PSR J2021+4026: an early blind search pulsar

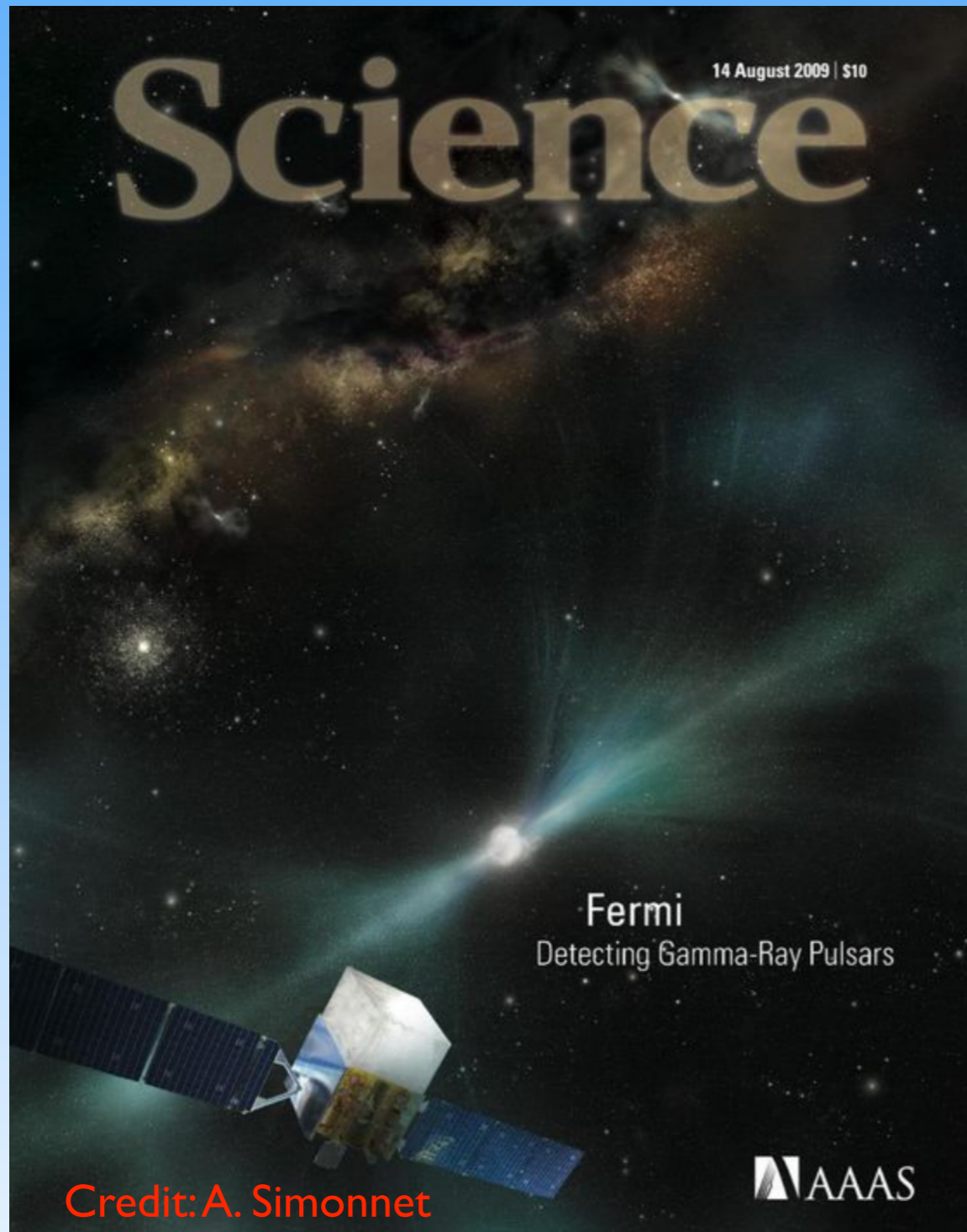


Abdo et al. 2009





# PSR J2021+4026: an early blind search pulsar



Abdo et al. 2009

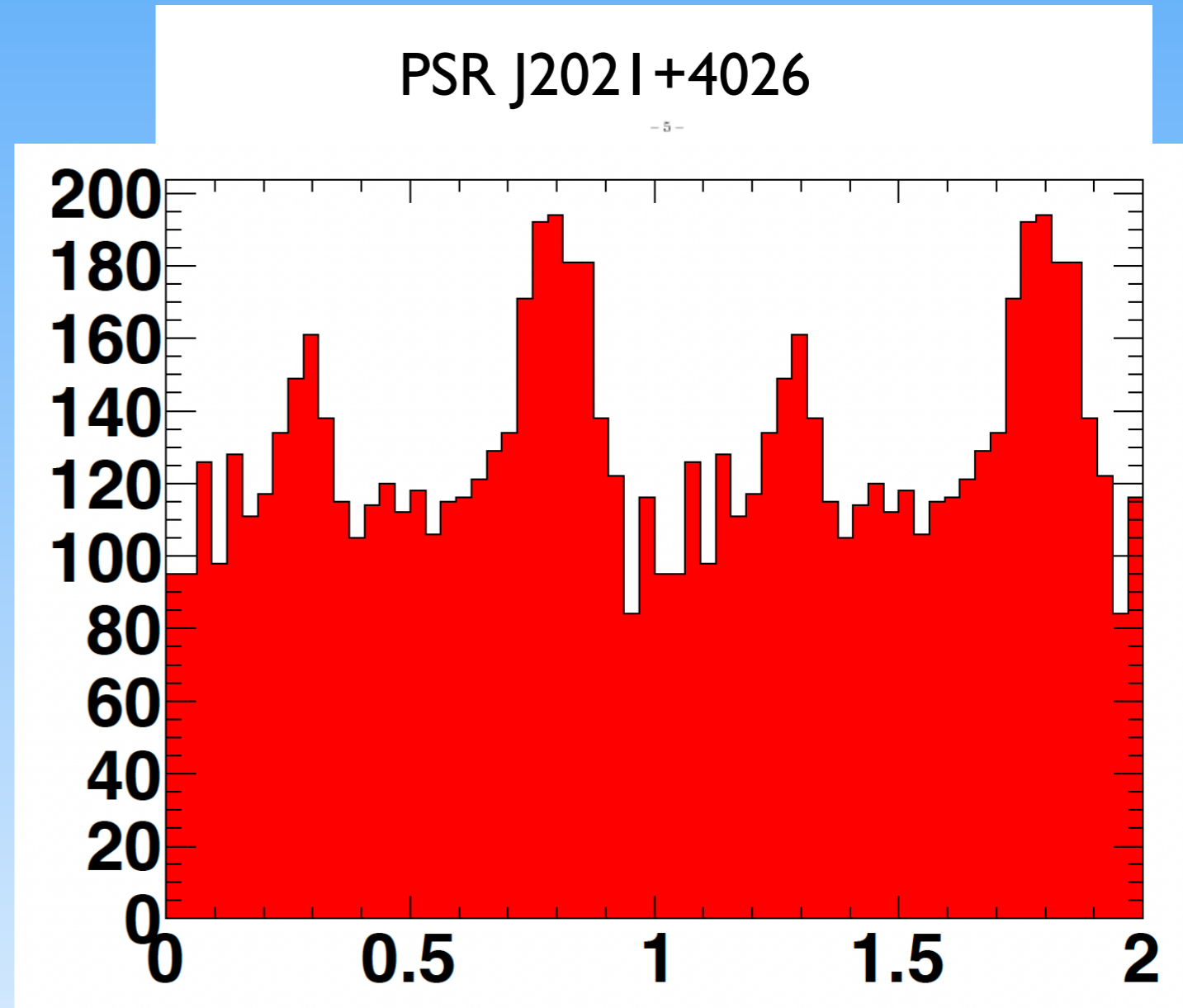
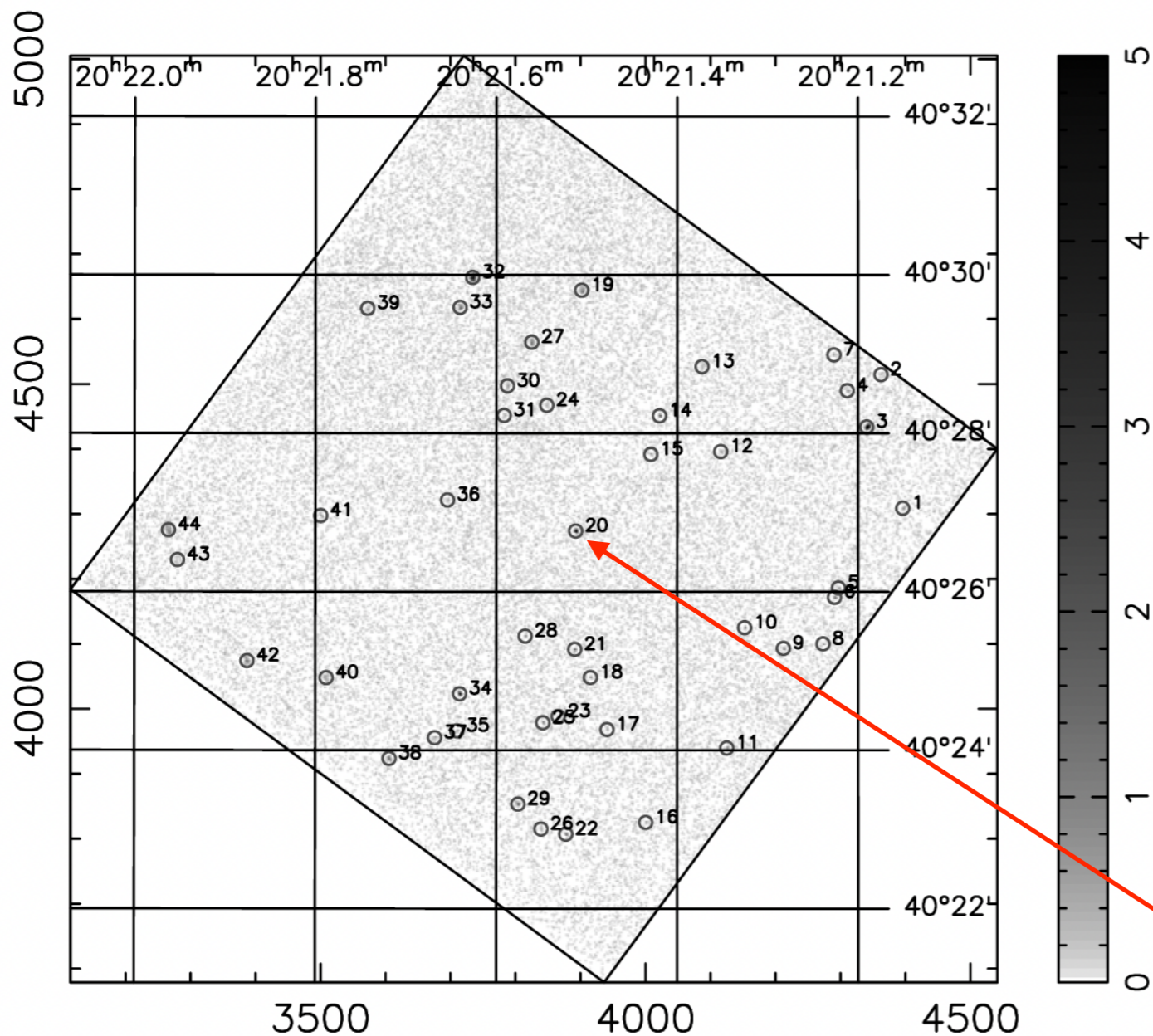


Fig. 1.— Folded lightcurves of all 15 pulsars found in the Fermi-LAT data. These are not background subtracted and all the y-axes begin at zero. Two pulse periods are shown. The phase is arbitrary so all the lightcurves have the first peak set at 0.3, for clarity. TEMPORARY LIGHTCURVES, awaiting finalized timing solutions.



## THE IDENTIFICATION OF THE X-RAY COUNTERPART TO PSR J2021+4026

MARTIN C. WEISSKOPF<sup>1</sup>, ROGER W. ROMANI<sup>2</sup>, MASSIMILIANO RAZZANO<sup>3,4,5</sup>, ANDREA BELFIORE<sup>4,6,7</sup>, PABLO SAZ PARKINSON<sup>4</sup>, PAUL S. RAY<sup>8</sup>, MATTHEW KERR<sup>9</sup>, ALICE HARDING<sup>10</sup>, DOUGLAS A. SWARTZ<sup>11</sup>, ALBERTO CARRAMIÑANA<sup>12</sup>, MARCUS ZIEGLER<sup>4</sup>, WERNER BECKER<sup>13</sup>, ANDREA DE LUCA<sup>6,14,15</sup>, MICHAEL DORMODY<sup>4</sup>, DAVID J. THOMPSON<sup>16</sup>, GOTTFRIED KANBACH<sup>13</sup>, RONALD F. ELSNER<sup>1</sup>, STEPHEN L. O'DELL<sup>1</sup>, AND ALLYN F. TENNANT<sup>1</sup>



**X-ray source dominated by thermal (not power law) emission.**  
**One of 44 sources detected in a 2010, 56 ks *Chandra* observation.**

R.A. 20<sup>h</sup>21<sup>m</sup>30<sup>s</sup>.733, decl. +40°26'46''.04 (J2000)

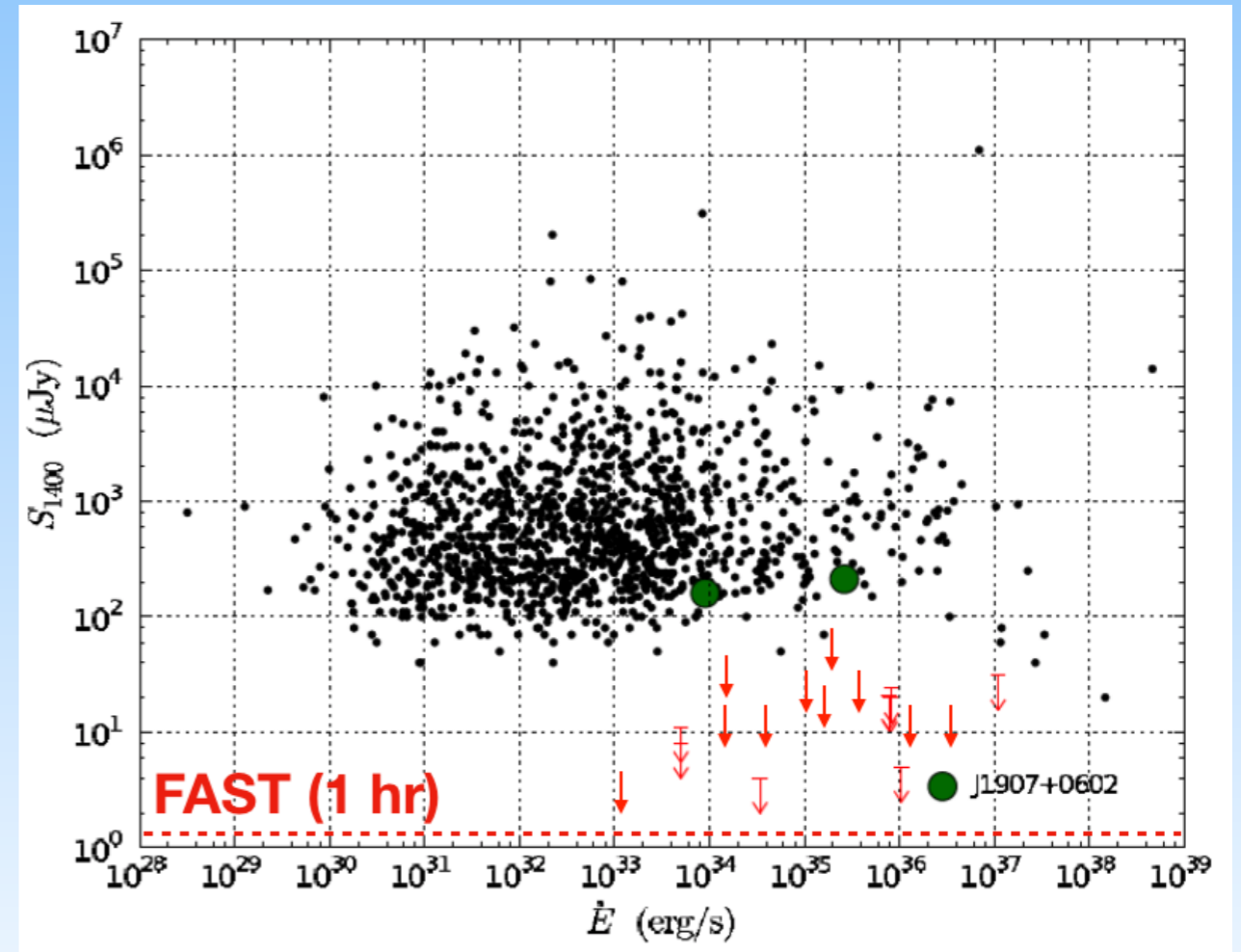
**56 ks *Chandra* observation (ObsID 11235, 2010 August 27)**



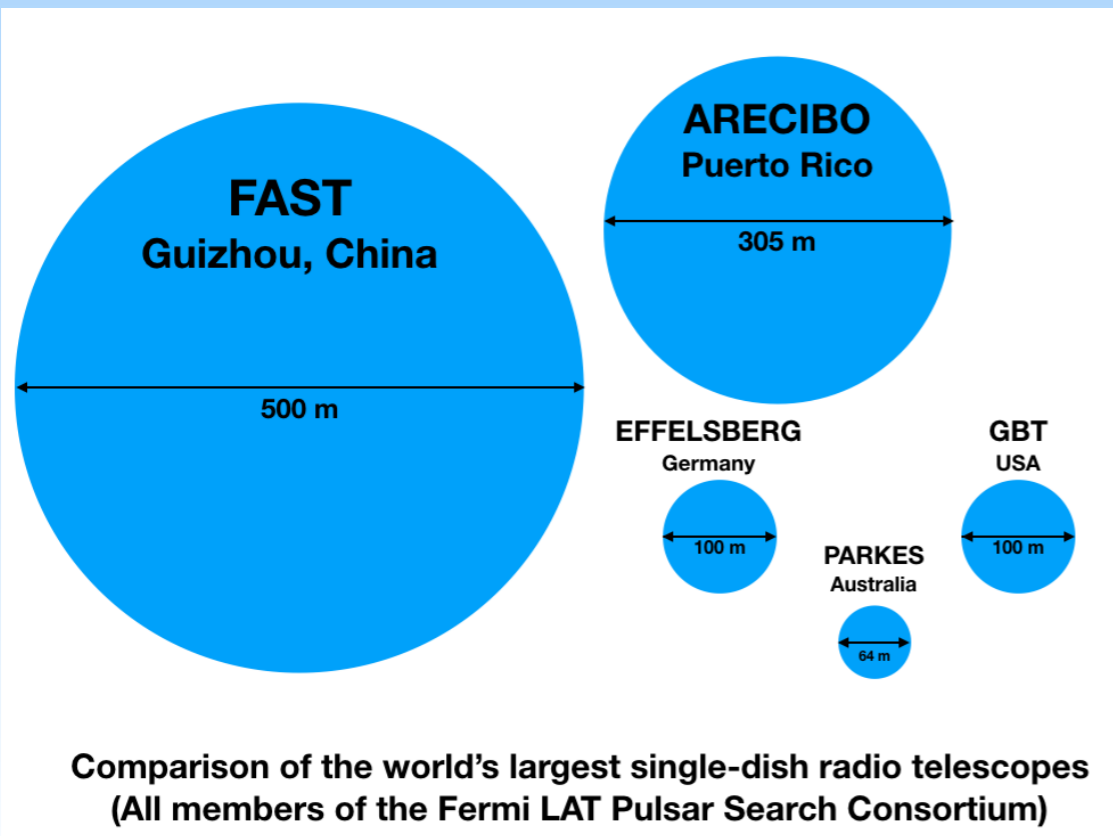
# Radio follow-up observations



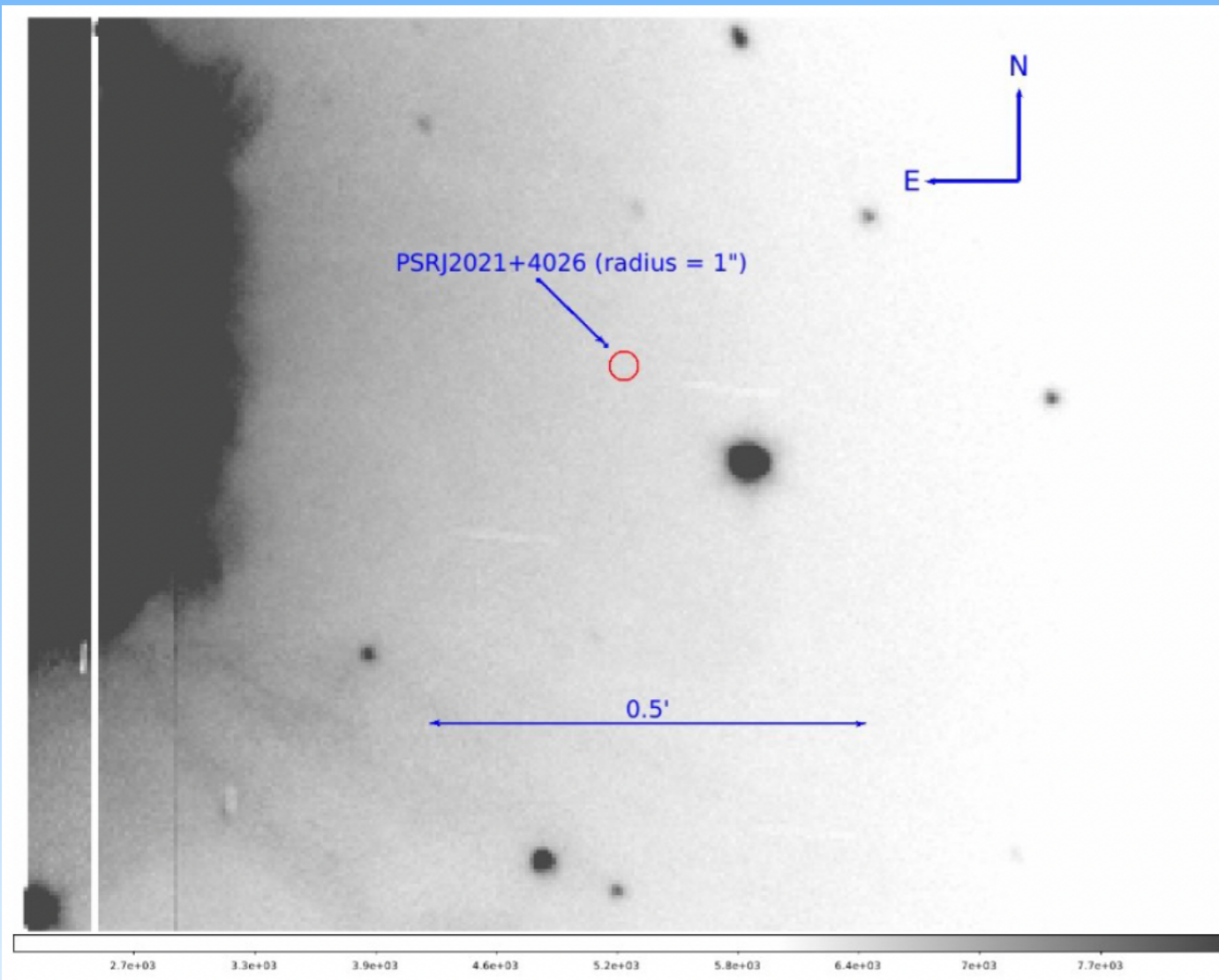
The Pulsar Search Consortium (PSC) was set up to search for radio pulsars in LAT sources/pulsars (Ray et al. 2012)



Adapted from Saz Parkinson et al. 2010



# Search for optical counterpart

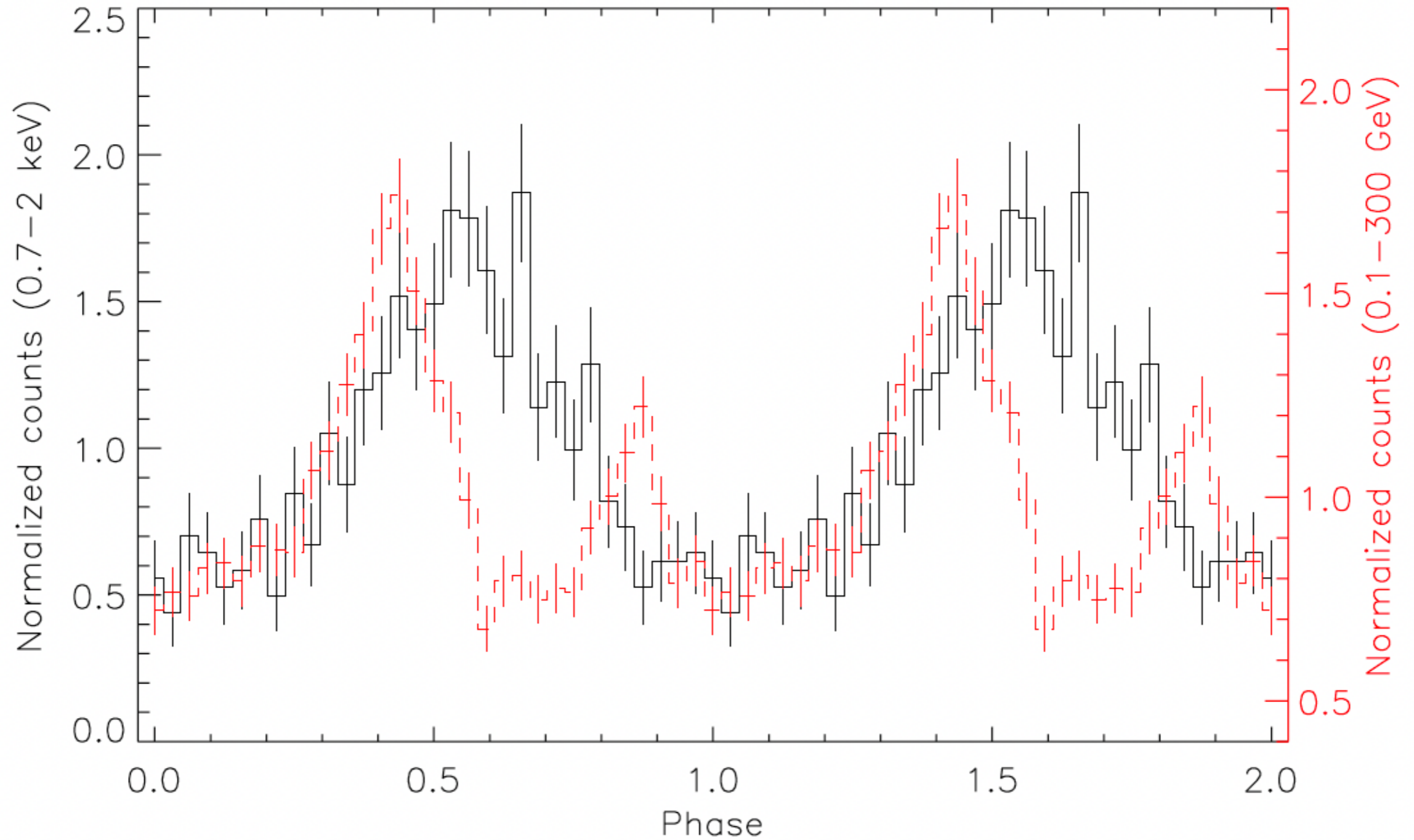


Credit: R. P. Mignani

- Observed with Gran Telescopio Canarias (GTC) @ La Palma
- OSIRIS camera with  $7'.8 \times 7'.8$  FoV and  $0''.25$  pixels.
- $3\sigma$  optical upper limits from RMS background
  - $r' = 25.3$
  - $g' = 26.1$



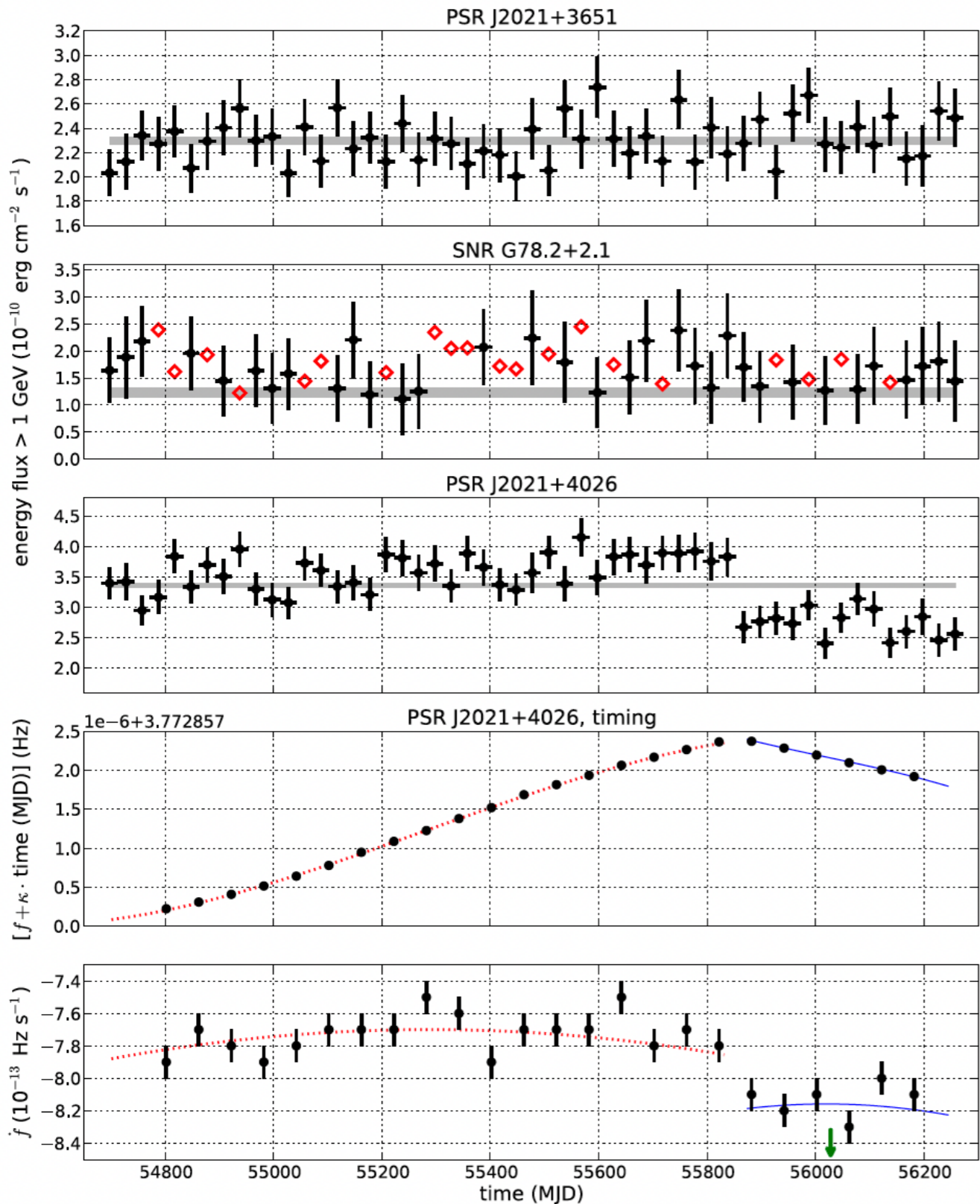
# X-ray pulsations



*~133 ks XMM-Newton Observation, 2012, April 11 (Obs. ID: 0670590101)*

**Lin et al. 2013**

# Variability in PSR J2021+4026!

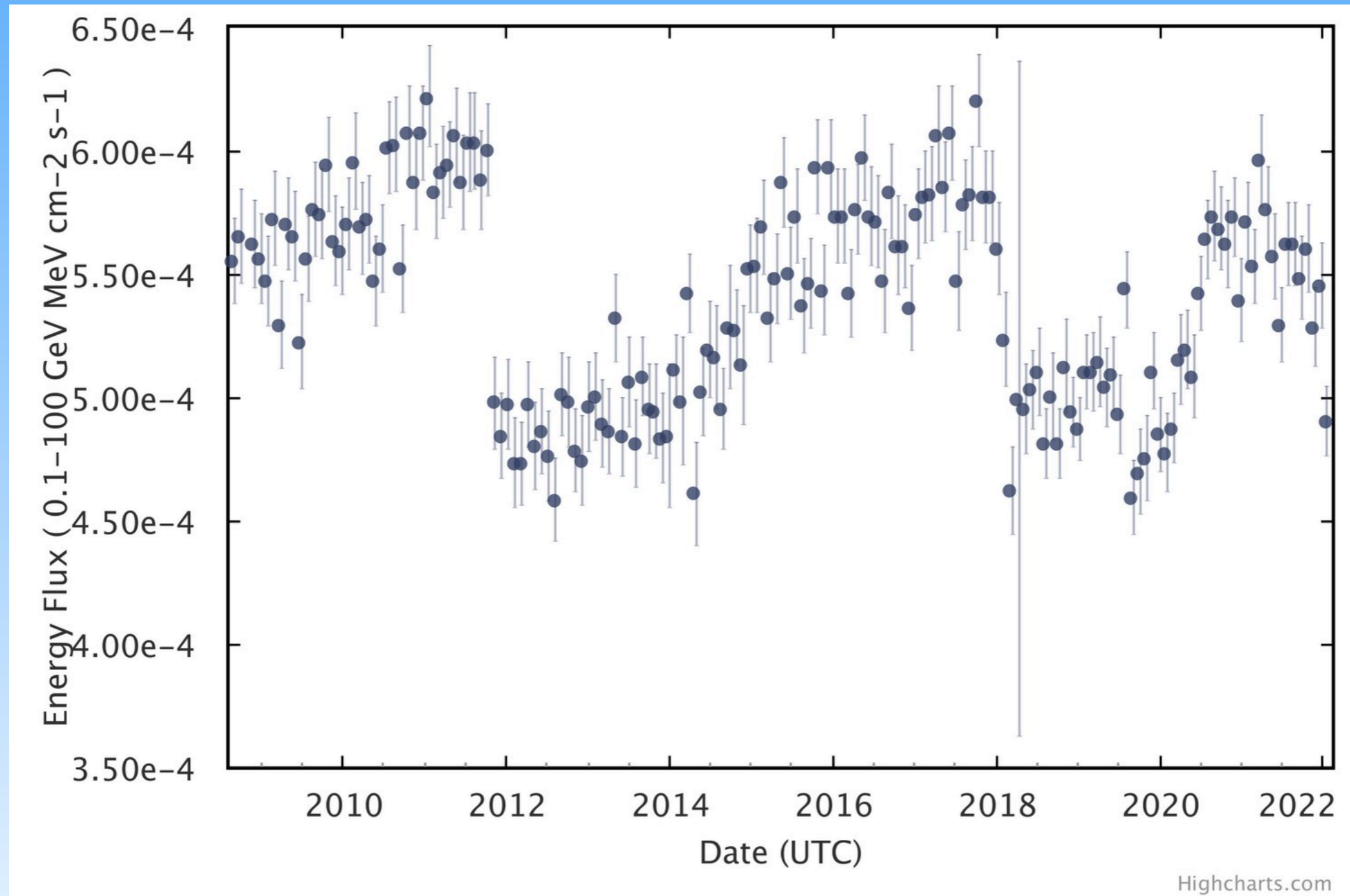


- Flux decrease ( $\sim 20\%$ ) around October 2011
- Frequency spin down rate increase ( $\sim 5\%$ )
- Changes in pulse profile observed

The first *variable* gamma-ray pulsar seen by Fermi LAT

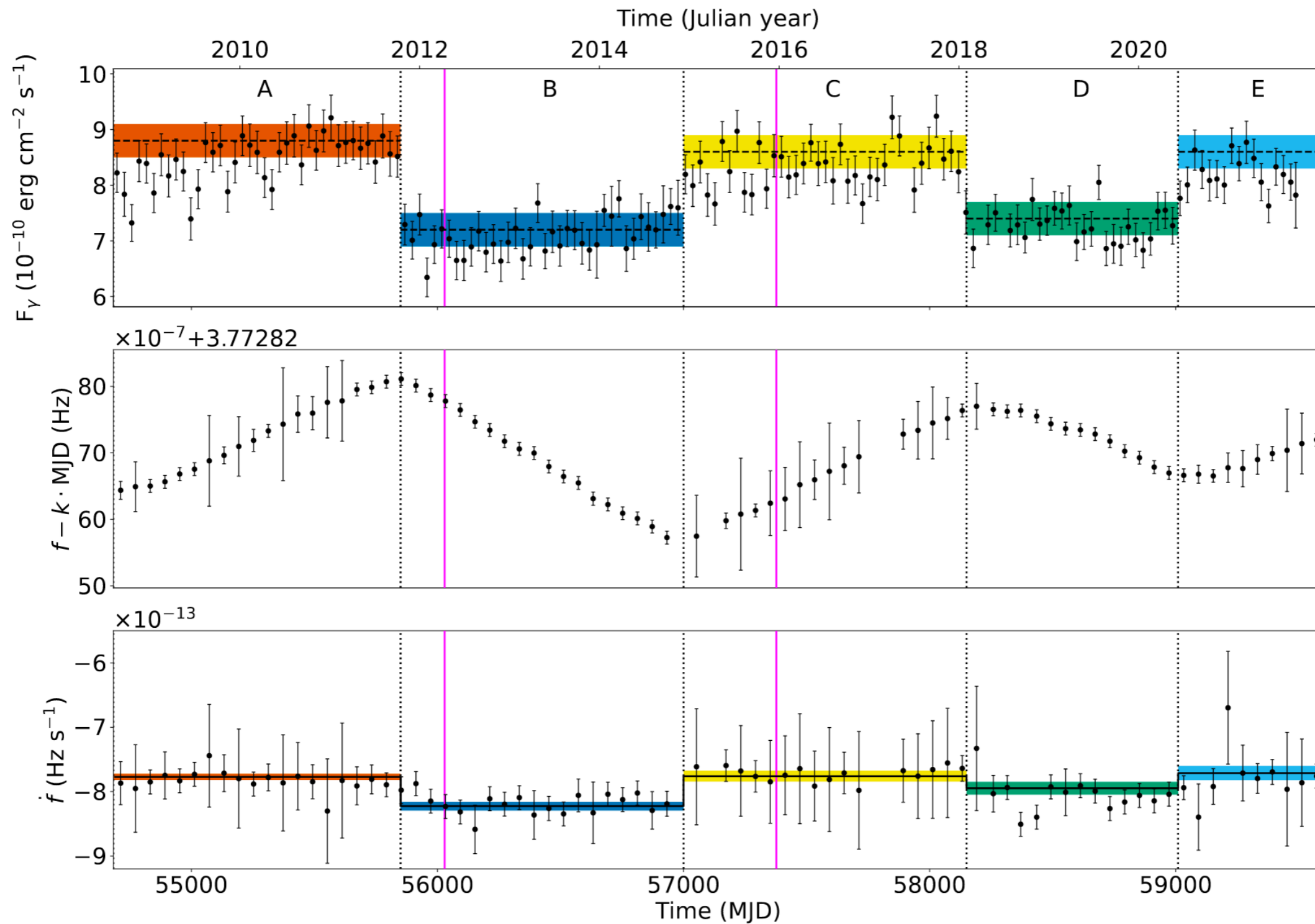


# Variability in PSR J2021+4026



<https://fermi.gsfc.nasa.gov/ssc/data/access/lat/LightCurveRepository/>

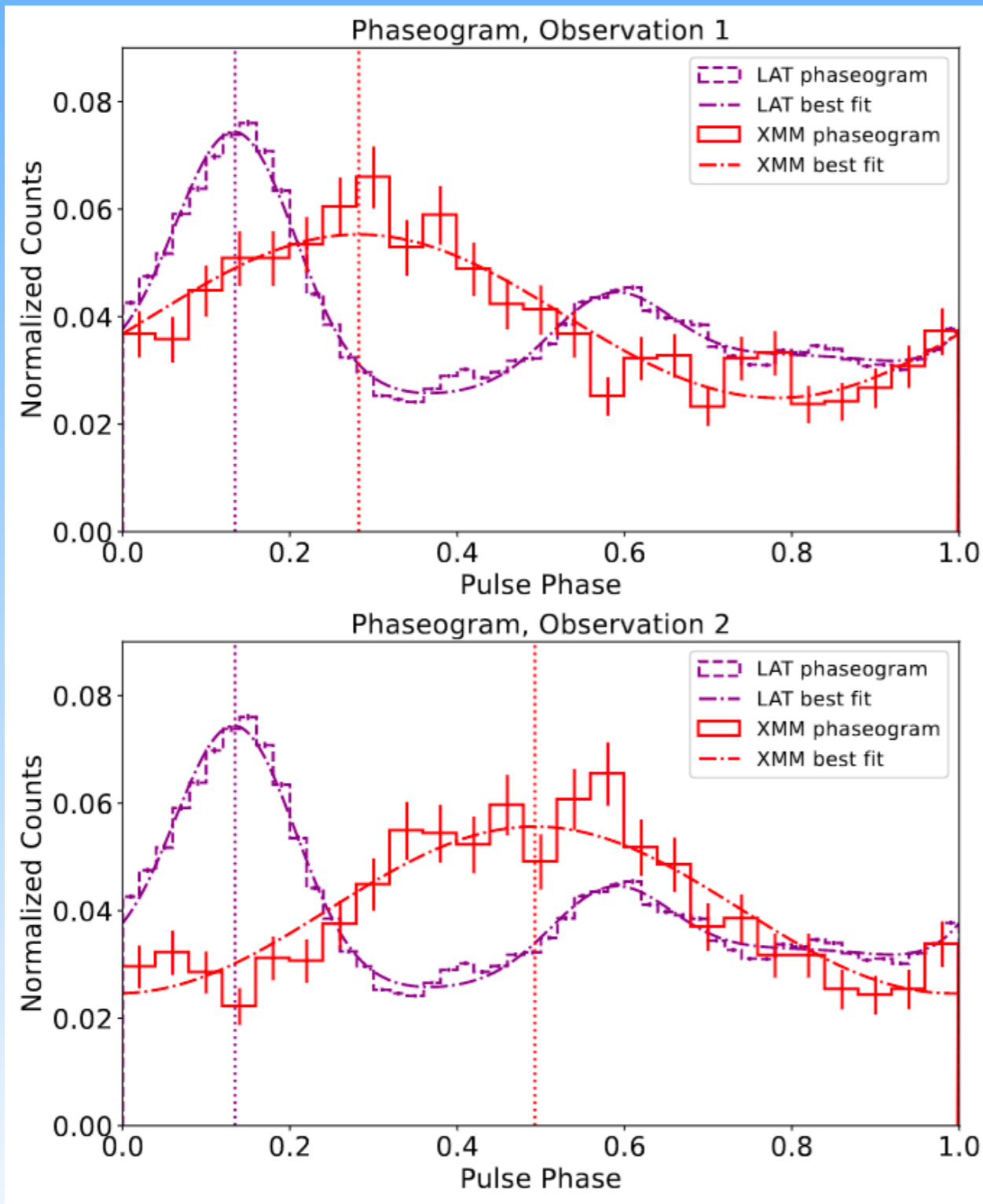
# PSR J2021+4026



Fiori et al. 2024



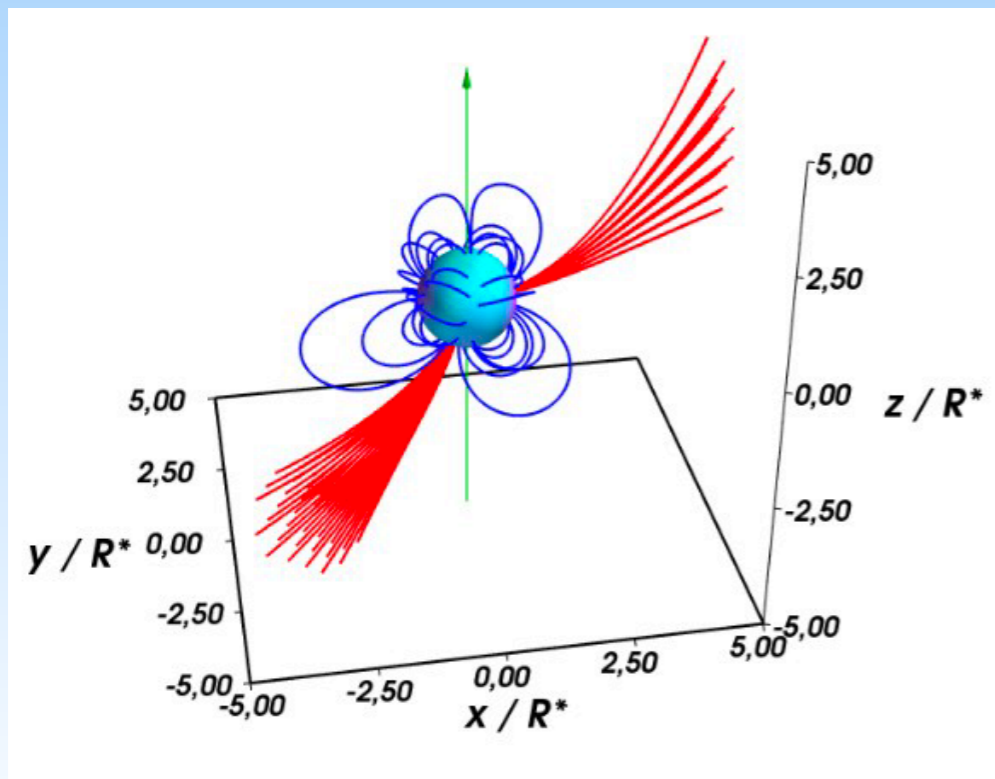
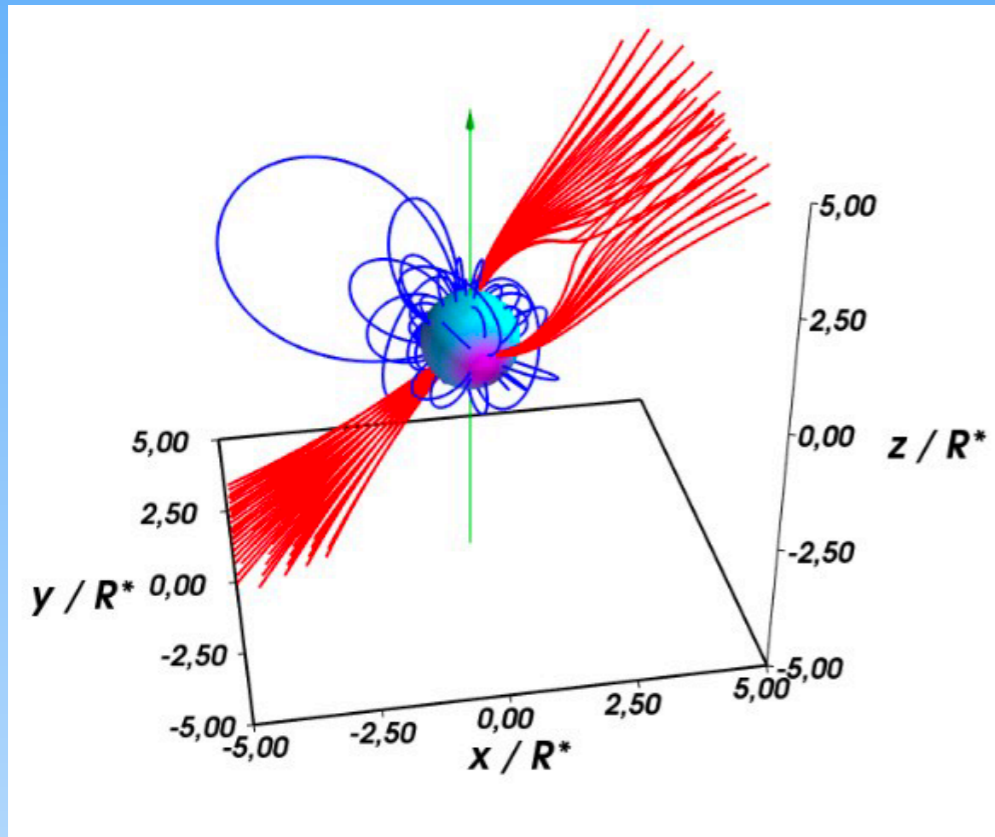
# Gamma-ray/X-ray pulse shifts



- 12 Years of data
- 100 MeV to 300 GeV
- Full mission timing analysis
- XMM Observation 1 and 2 roughly equal length (~130 ks) separated by 3.7 yr

Razzano et al. 2023

# Possible interpretation (toy model)



Credit: A. Harding

- X-ray emission consistent with heated polar cap
- Phase shift could be related to a change in the connection of the dipole field with the inner quadrupole field component close to neutron star surface.
- Mode changes could affect the accelerating electric field
- Repeating nature of mode changes suggests a periodic reconfiguration of the magnetosphere



# NICER

(Neutron Star Interior  
Composition Explorer)

**Launched:** 3 June 2017,  
on a SpaceX Falcon 9



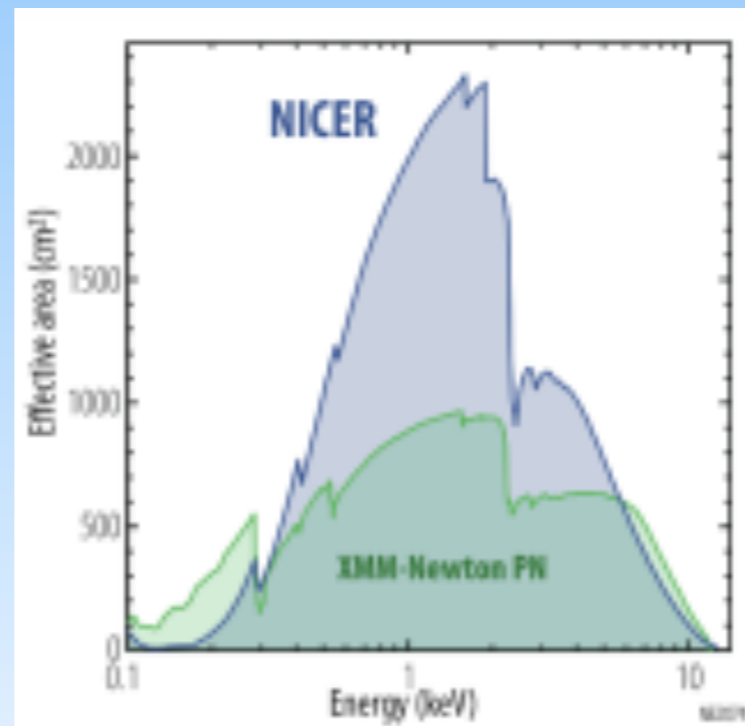
Energy Range

0.2 - 12 KeV

Time Resolution

<300 ns

Effective Area



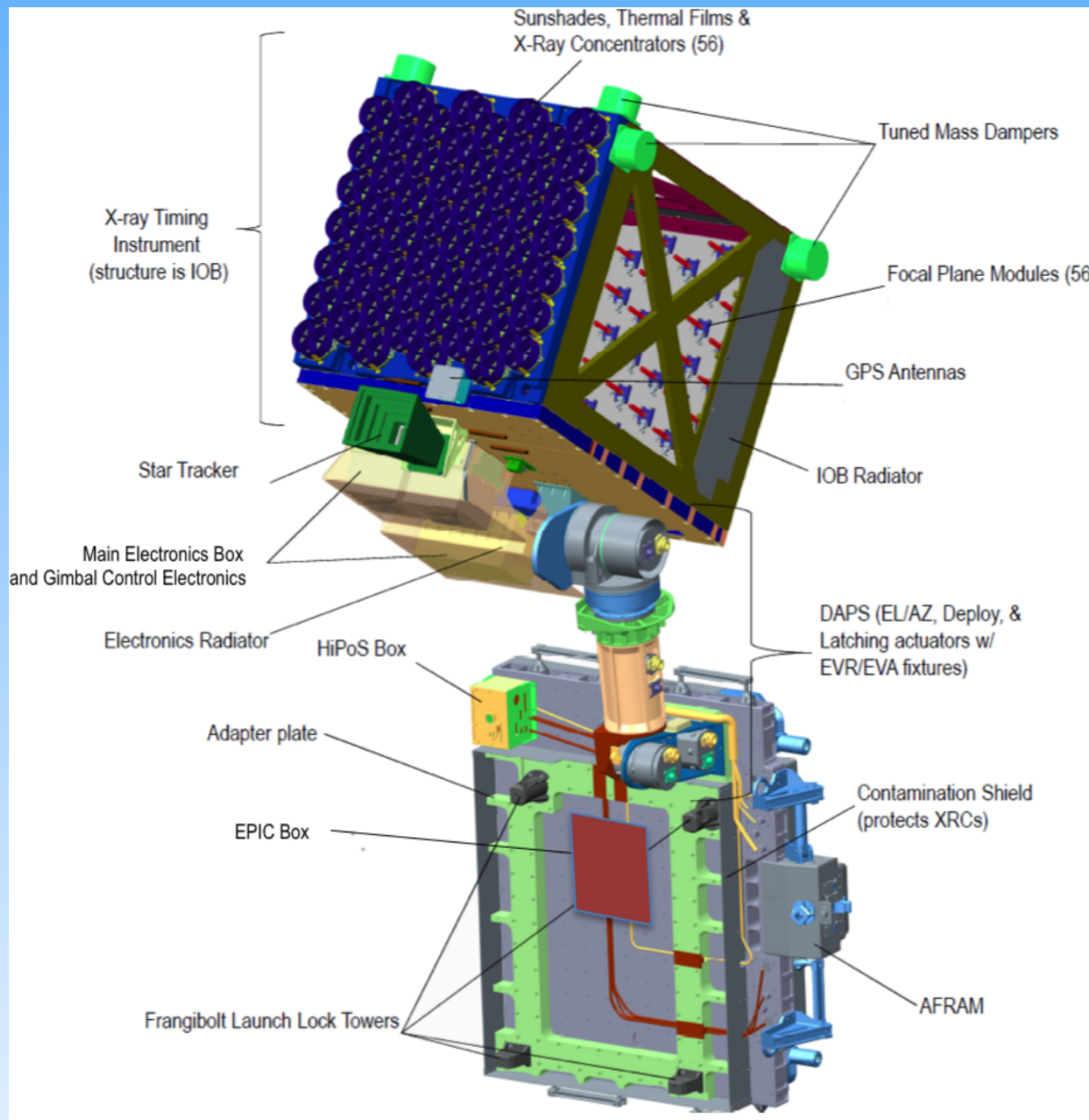
FOV

30 arcmin<sup>2</sup>

Pointed

56 X-ray “concentrator” telescopes  
with Silicon-drift detectors

# NICER Monitoring Observations



Credit: NASA

<https://heasarc.gsfc.nasa.gov/docs/nicer/>

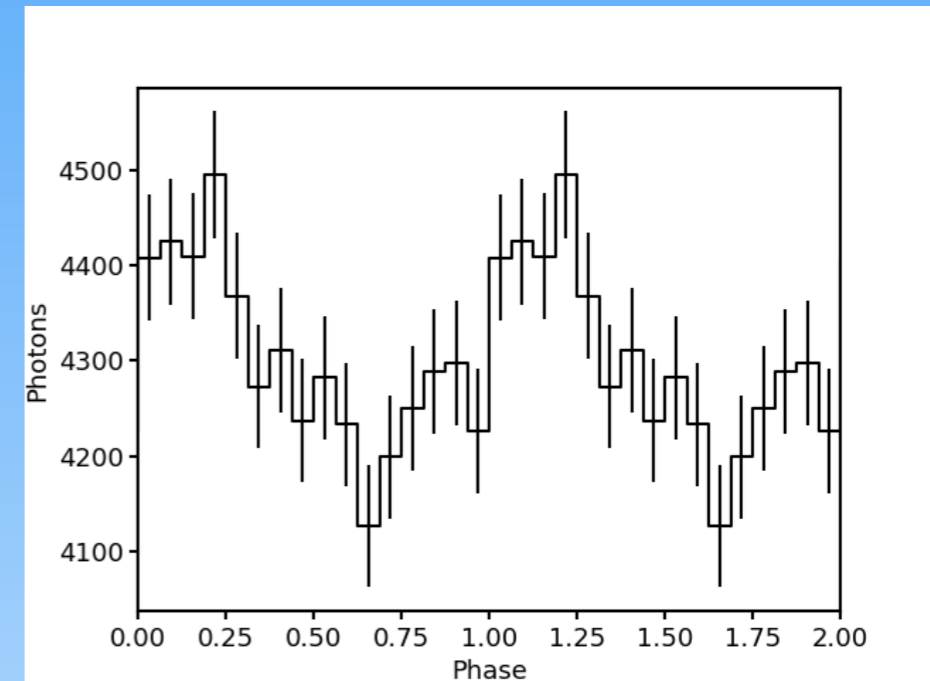


Table 1. NICER observations of PSR J2021+4026

ObsID	Date	Exposure (ks)	ObsID	Date	Exposure (ks)
1033350101	2018-12-21 00:44	5.581	2606010703	2019-09-06 13:27	5.164
1033350102	2018-12-22 01:28	4.648	2606010704	2019-09-07 03:12	1.323
1033350103	2018-12-26 22:46	1.105	2606010705	2019-09-17 13:48	.192
1033350104	2018-12-27 03:28	11.590	2606010801	2019-10-06 05:12	6.034
1033350105	2018-12-28 02:37	5.494	2606010802	2019-10-06 23:46	2.025
1033350106	2018-12-29 08:09	9.847	2606010803	2019-10-08 17:30	.981
1033350107	2018-12-30 00:56	16.058	2606010804	2019-10-09 02:47	7.321
1033350108	2018-12-31 03:24	11.581	2606010805	2019-10-10 00:27	6.200
1033350109	2019-01-04 10:36	.568	2606010806	2019-10-20 03:23	1.065
1033350110	2019-01-05 06:54	5.297	2606010807	2019-10-21 21:09	.289
1033350111	2019-01-06 13:32	9.651	2606010808	2019-10-22 00:22	4.648
1033350112	2019-01-07 01:54	23.078	2606010901	2019-11-08 00:15	9.377
1033350113	2019-01-07 23:38	17.269	2606010902	2019-11-25 18:02	.218
2606010101	2019-03-12 14:36	6.483	2606010903	2019-11-26 18:44	.355
2606010902	2019-11-25 18:02	.218	2606010904	2019-11-27 02:22	.299
2606010201	2019-04-09 00:11	10.454	2606011101	2020-01-03 10:43	3.022
2606010401	2019-06-05 09:36	7.973	2606010905	2020-01-04 22:21	.523
2606010402	2019-06-06 01:07	2.877	2606010906	2020-01-05 00:00	1.537
2606010501	2019-07-10 22:30	.949	2606011201	2020-02-01 12:28	1.879
2606010502	2019-07-11 00:03	10.065	2606010102	2019-03-13 02:55	1.856
2606010601	2019-08-05 12:49	4.700	2606011003	2020-02-16 16:19	.837
2606010602	2019-08-07 00:23	5.240	2606011004	2020-02-17 04:39	.697
2606010701	2019-08-27 13:09	4.358	2606011007	2020-02-29 07:58	3.414
2606010702	2019-08-28 00:17	3.182	2606011008	2020-03-01 07:11	2.527
			2606011009	2020-03-02 00:13	1.277

N3 intern Pranav Shankar project  
<https://n3.sonoma.edu/>



# Summary

- PSR J2021+4026, in the Gamma-Cygni SNR, discovered in early blind searches of Fermi LAT data is one of the brightest, most energetic *radio-quiet* gamma-ray pulsars.
- It exhibits quasi-periodic mode-changing episodes every 3-4 years, making it the first *variable* gamma-ray pulsar, unique among the overall gamma-ray pulsar population.
- X-ray pulsations of PSR J2021+4026 enable the joint study of this unique system and show hints of possible magnetospheric effects related to the mode-changing episodes, leading to shifts in the gamma-to-X-ray phase.