Progress on Pulsar Tools Development

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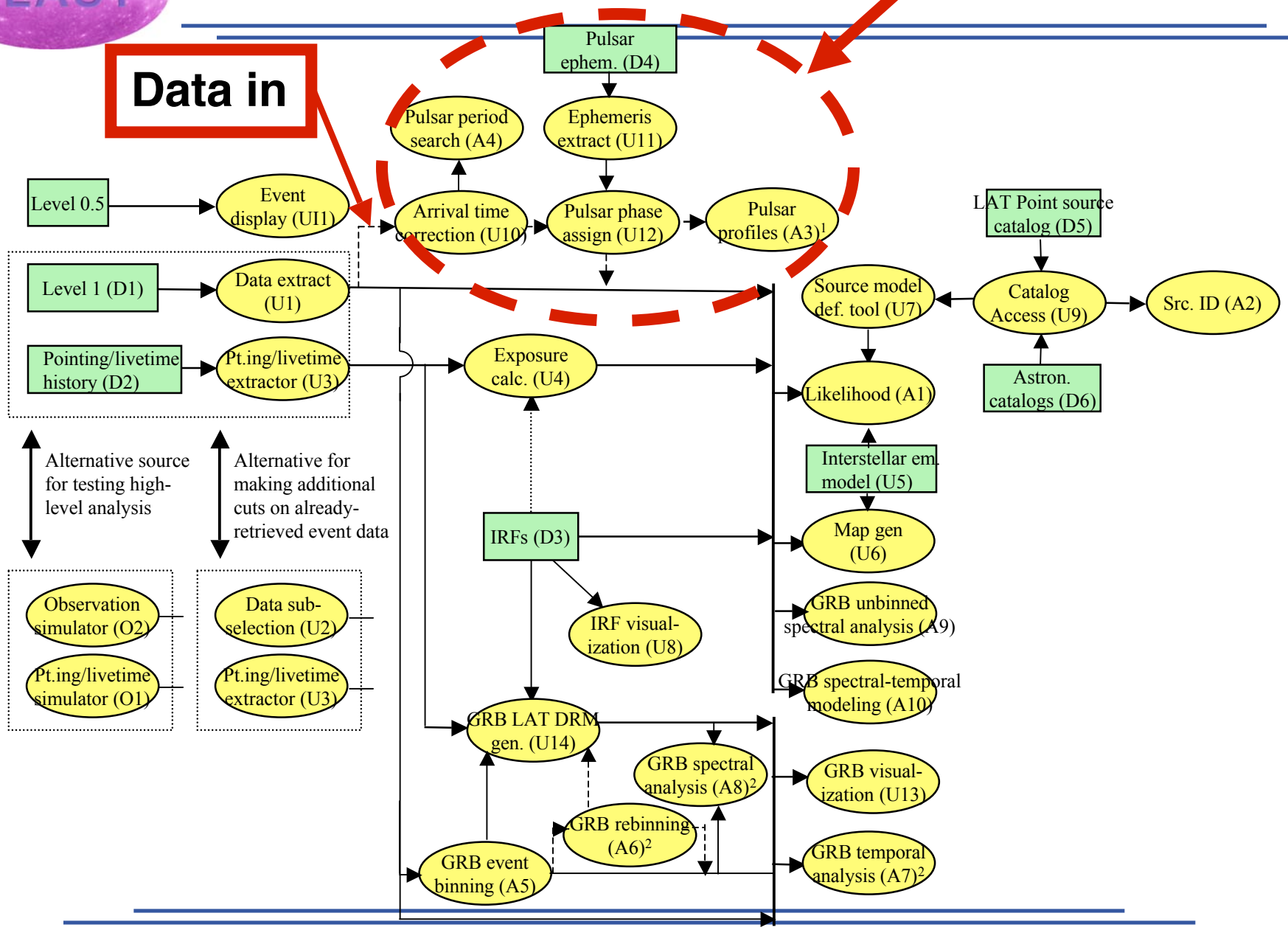
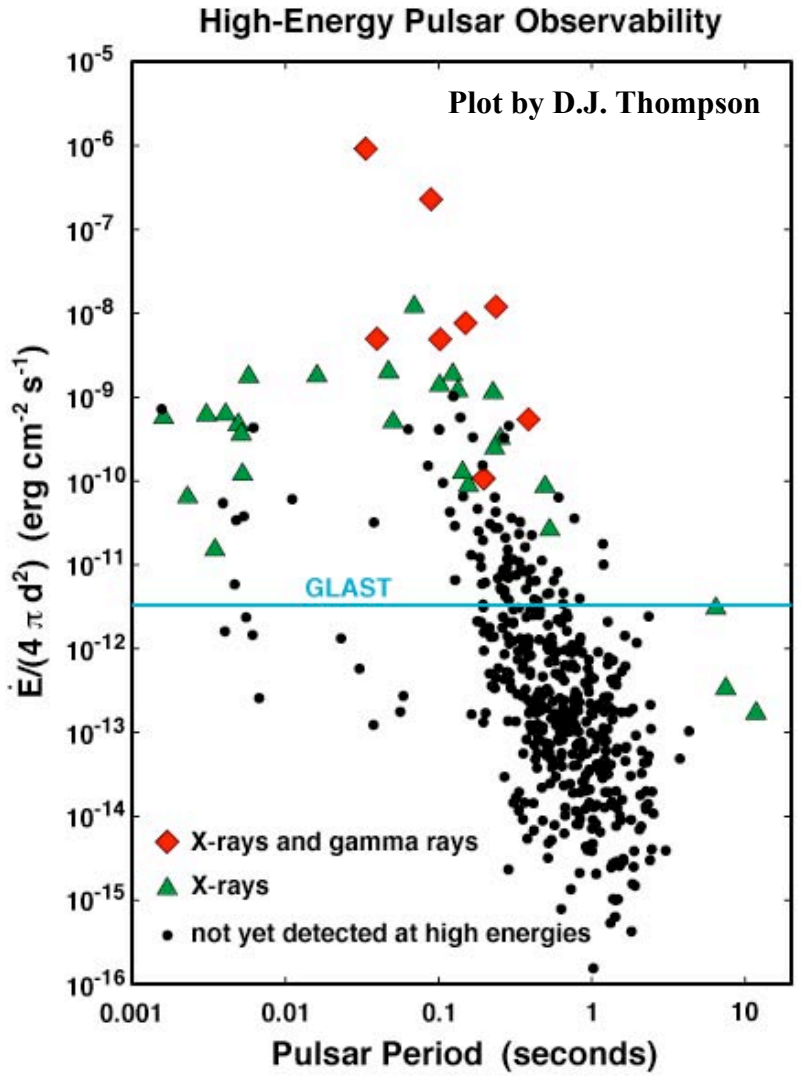
http://glast.gsfc.nasa.gov/ssc/dev/psr_tools/

Pulsar Tools



Pulsars for GLAST LAT

- Pulsars are point sources
- GLAST expected to detect pulsations from 50-100 pulsars
  - 10-50% are predicted to be radio quiet like Geminga
  - Most need 1 year exposure for detection
- Sparse data
  - One photon per 500 pulses (Crab 30 MeV – 300 GeV)
- Scanning with large FOV
  - All sources get some exposure every day throughout a year
  - Large number of short observations
  - ⇒ Both good and bad news for pulsar timing



Typical Pulsar Analysis

1. Download data and screen events
   - For maximum pulse-detection sensitivity, select only events within a small region, typically size of a couple of PSFs
2. Correct event times – barycentric correction
   - To cancel Doppler effect resulting from the orbital motions of the Earth and the spacecraft
3. Find pulsar ephemeris at the time of observation
   - Case 1: Use a radio ephemeris as is
   - Case 2: Scan pulse frequencies around extrapolation of radio ephemeris
   - Case 3: Search for pulsations if no radio ephemeris is available
4. Calculate pulse phase for each photon
5. Use pulse phases in your analysis
   - Pulse shape (or pulse profile)
   - Phase-resolved spectrum
   - Phase-resolved image

What Pulsar Tools Are Needed?

- **Barycentric corrector**
  - Photon arrival time converter (U10)
- **Pulsar ephemeris "finder"**
  - Case 1: use a radio ephemeris as is
    - Pulsar ephemerides database (D4)
    - Pulsar ephemeris extractor (U11)
  - Case 2: scan around a radio ephemeris
    - Pulsar profile & periodicity tests (A3)
  - Case 3: search for pulsations
    - Pulsar period search (A4)
- **Pulse phase calculator**
  - Pulsar phase assignment (U12)

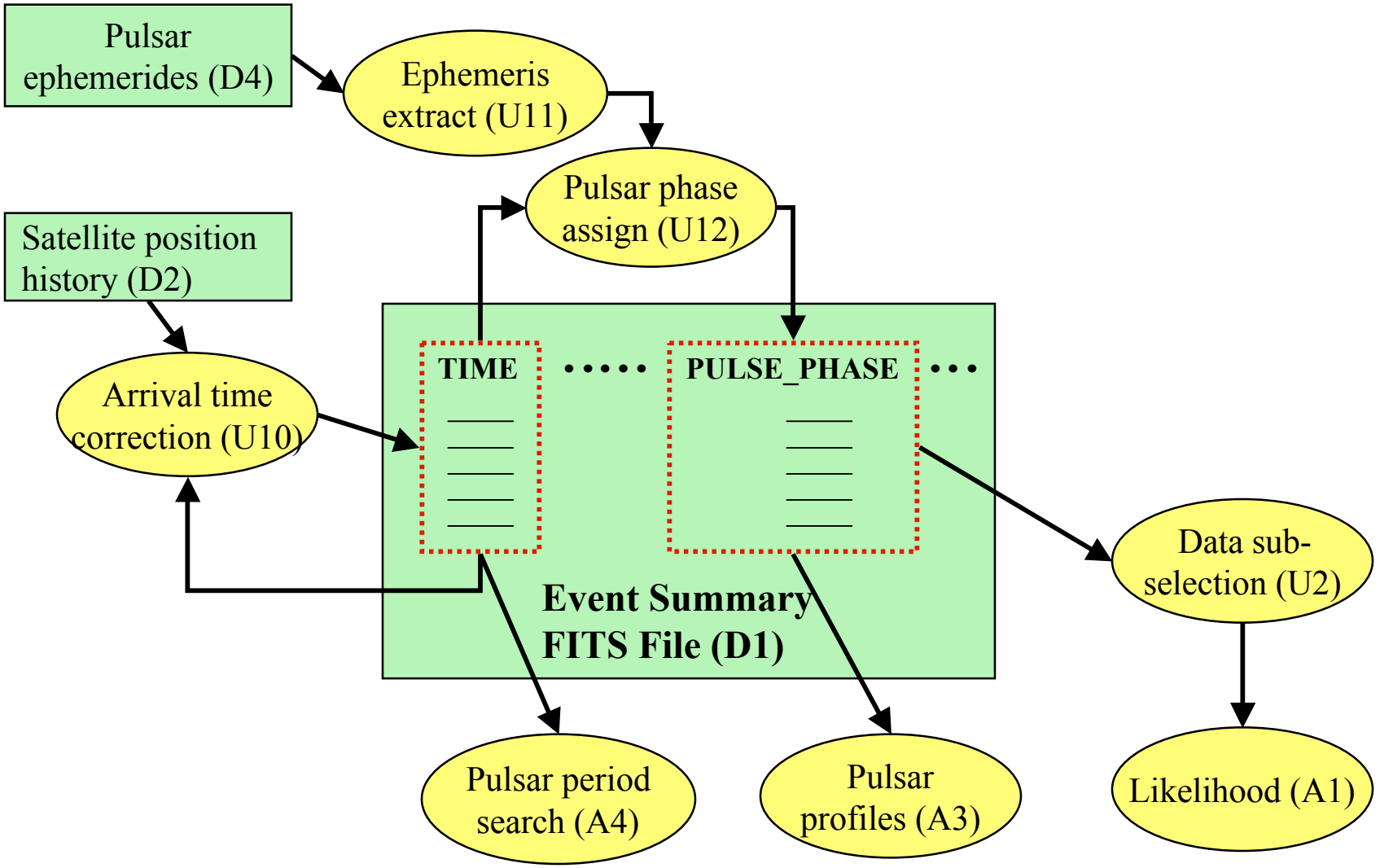
Algorithms

- **Periodicity tests**
  - Chi-squared test (Leahy et al. 1983, ApJ 266, 160; Vaughan et al. 1994, ApJ 435, 362)
  - Zn^2 test (Buccheri et al. 1983, A&A 128, 245)
  - Rayleigh test (equivalent to Zn^2 test for n = 1)
  - H test (De Jager et al. 1989, A&A 221, 180)
  - Bayesian approach (Gregory and Loredo 1992, ApJ 398, 146; Gregory and Loredo 1996, ApJ 473, 1059)
- **Period search**
  - Discrete Fourier transforms (Ransom 2002, AJ 124, 1788)
  - Lomb-Scargle periodogram (Lomb 1976, Ap&SS 39, 447; Scargle 1982, ApJ 263, 835; Press & Rybicki 1989, ApJ 338, 277)

Pulsar Tools Components

- Pulsar ephemerides database (D4)
  - List of pulsar timing solution maintained during the mission for potential LAT sources.
  - Downloadable as a FITS file.
- Pulsar ephemeris extractor (U11)
  - Basic front end to the pulsar ephemerides database
- Photon arrival time converter (U10)
  - Converts photon arrival times in a photon list to those at the solar system barycenter.
- Pulsar phase assignment (U12)
  - Assigns pulse phase to each photon in a photon list
- Pulsar profile & periodicity tests (A3)
  - Epoch-folds photon arrival times at trial pulse frequencies and estimate significance of pulsation at each frequency
- Pulsar period search (A4)
  - Searches for periodic emission from a point source

Pulsar Tools In Action



Current Status of Development

	Design	Existing counterparts	Implementation	Testing
Ephemrides database	Defined in detail	Identified	Examples available	To be used in DC2
Ephemeris extractor	Rough design	None	Later	Not yet
Arrival time converter	Algorithms identified	Identified	Complete	In progress
Phase assignment	Algorithms identified	Identified	Limited features	Partially done
Pulse profile & period scan	Algorithms identified	Identified	Start soon	Not yet
Period search	Algorithms identified	Identified	Later	Not yet

Data Challenge 2

- Almost ready for Data Challenge 2
  - Pulsar ephemerides database (D4)
  - Photon arrival time converter (U10)
  - Pulsar phase assignment (U12) – limited features
- To be ready by Data Challenge 2
  - Pulsar profile & periodicity tests (A3) – limited features
  - Pulsar period search (A4) – re-use of FTOOLS counterparts
- Major tasks beyond Data Challenge 2
  - Pulsar ephemerides database
    - Database ingest (D4)
    - Extractor tool (U11)
  - Pulsar phase assignment (U12) – full features
  - Pulsar profile & periodicity tests (A3) – full features
  - Pulsar period search (A4) – polish user interface?

Backup Slides

Pulsar Ephemerides Database (D4, U11)

- Full definition of D4 FITS file complete.
  - Similar to the CGRO catalog, with some improvements
- Examples of D4 FITS file available.
  - Contents based on the CGRO catalog.
  - To be used in Data Challenge 2.
- Action items:
  - Discuss on ephemerides data ingest with the pulsar IDS.
  - Implement extractor tools (U11).
  - Resolve minor issues/concerns on FITS definition.

Photon Arrival Time Converter (U10)

- Existing counterparts identified.
  - FAXBARY seems to be “re-usable” for GLAST.
  - FAXBARY: FTOOLS originally developed for XTE, now available for other missions such as Swift.
- FAXBARY modified to adopt to GLAST data.
  - Currently under test.
  - To be used in Data Challenge 2.
- Action items:
  - Complete initial test.
  - Deliver to the LAT team as a part of the HEADAS package.

Pulsar Phase Assignment (U12)

- **Basic functionality implemented and tested.**
  - **Single set of frequency ephemeris can be given.**
  - **Probably already good enough for Data Challenge 2.**
  - **Multiple ephemerides from database (D4) under development.**
  - **To be used in Data Challenge 2.**
- **Action items:**
  - **Implement application of multiple ephemerides to a single GLAST data file.**

Pulsar Profile & Periodicity Tests (A3)

- **Suggested algorithms for periodicity test.**
  - **Chi-squared test (Leahy et al. 1983, ApJ 266, 160; Vaughan et al. 1994, ApJ 435, 362)**
  - **Zn^2 test (Buccheri et al. 1983, A&A 128, 245)**
  - **Rayleigh test (equivalent to Zn^2 test for n = 1)**
  - **H test (De Jager et al. 1989, A&A 221, 180)**
  - **Bayesian approach (Gregory and Loredo 1992, ApJ 398, 146; Gregory and Loredo 1996, ApJ 473, 1059)**
- **Existing counterparts identified.**
  - **Some FTOOLS are usable for GLAST w/o modification.**
  - **To be used in Data Challenge 2.**
- **Action items:**
  - **Test existing tools with GLAST data format.**
  - **Identify periodicity tests to be implemented.**
  - **Implement identified tests in C++ or w/ Python wrapper.**

Pulsar Period Search (A4)

- Suggested algorithms for period search.
  - Discrete Fourier transforms (Ransom 2002, AJ 124, 1788)
  - Lomb-Scargle periodogram (Lomb 1976, Ap&SS 39, 447; Scargle 1982, ApJ 263, 835; Press & Rybicki 1989, ApJ 338, 277)
- Existing counterparts identified.
  - "powspec" (XRONOS) calculates power spectrum density
  - "perdgrm" (FTOOLS) computes Lomb-Scargle periodogram
- Action items:
  - Test existing tools with GLAST data format.
  - Implement Python wrapper if needed.