IGR J18245-2452 or the swinging pulsar: the Holy Grail of millisecond pulsars research
Pulsar emission mechanisms

**Rotationally powered: EM energy produced from rotational kinetic energy**

- Spin down

**Accretion powered: X-ray emitted by accreting material**

- Generally spin-up, but also spin-down

- Possible reduction of B-field
Rotationally powered evolution

Accretion powered evolution

Recycled pulsars

• Accretion of material brings angular momentum and spins-up the pulsar.
The accretion phase

Kulkarni & Romanova (2013)

Figure 1. Left panel: A 3D view of the funnel flow from the disc to a magnetized star, where the dipole moment $\mu$ is tilted by $\Theta = 20^\circ$ about the rotational axis. One of the density levels is shown in green; sample field lines are shown in red. Right panel: the energy flux distribution on the
Propeller accretion

- For lower accretion rate, pressure of matter lowers and collimated outflow of matter and angular momentum appears.
- Centrifugally driven at the inner boundary of accretion disc.
- Matter is partly accreted and partly expelled
- Neutron Star spins down efficiently

Romanova et al. (2005)
Propeller phase - spin down

- Simulation of ~1 Gyr accretion spin-up
- Pulsar evolution driven by accretion rate
- Strong spin down during propeller phase, but decoupling from equilibrium reduces braking and produces a millisecond pulsars.
- Roche Lobe decoupling is thought to be a “short” phase.

Tauris (2012)
- **Red backs**: radio pulsars eclipsing at certain phases due to ablated material from a non degenerate companion.
- Probably objects turning from (propeller) accretion to rotation powered emission.
- **Black widows**: radio emission ablates companion.
IGR J18245-2452

IGR J18245-2452: a new hard X-ray transient discovered by INTEGRAL

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on 29 Mar 2013; 11:18 UT
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Subjects: X-ray, Gamma Ray, Request for Observations, Black Hole, Neutron Star, Transient

Referred to by ATel #: 4927, 4929, 4934, 4959, 4960, 4961, 4964, 4981, 5003

During the observations of the Galactic Center performed on 2013 March 28 from 2:56 to 17:38 (UTC), the hard X-ray imager IBIS on-board INTEGRAL detected a new transient source, dubbed IGR J18245-2452, at:
RA=276.1383
DEC=-24.8793
with an associated uncertainty of 1.4 arcmin (all uncertainties

- We triggered Swift, XMM-Newton, Chandra, INTEGRAL, ATCA follow-up observations
- Others have looked into the HST archive

- Discovered during the quick-look of INTEGRAL data
- Located in the globular cluster M 28
It is the 15\textsuperscript{th} accreting millisecond pulsar

Papi\'o et al. (Nature 501, 517-520, 2013)

Flicker noise

30 ks + 70 ks XMM-Newton TOOs

11 hours
• Only one detected during the Swift/XRT monitoring.
• Burst oscillation at 3.9 ms, phase locked with spin modulation
• It is an accreting millisecond pulsar!
Table 1: Spin and orbital parameters of IGR J18245–2452 and PSR J1824–2452I.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>IGR J18245–2452</th>
<th>PSR J1824–2452I</th>
</tr>
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<tbody>
<tr>
<td>Right Ascension (J2000)</td>
<td>$18^h 24^m 32.53(4)^s$</td>
<td></td>
</tr>
<tr>
<td>Declination (J2000)</td>
<td>$-24^\circ 52' 08.6(6)''$</td>
<td></td>
</tr>
<tr>
<td>Reference epoch (MJD)</td>
<td>56386.0</td>
<td></td>
</tr>
<tr>
<td>Spin period (ms)</td>
<td>3.931852641(2)</td>
<td>3.93185(1)</td>
</tr>
<tr>
<td>Spin period derivative</td>
<td>$&lt; 2 \times 10^{-17}$</td>
<td></td>
</tr>
<tr>
<td>RMS of pulse time delays (ms)</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Orbital period (hr)</td>
<td>11.025781(2)</td>
<td>11.0258(2)</td>
</tr>
<tr>
<td>Projected semi-major axis (lt-s)</td>
<td>0.76591(1)</td>
<td>0.7658(1)</td>
</tr>
<tr>
<td>Epoch of zero mean anomaly (MJD)</td>
<td>56395.216889(5)</td>
<td></td>
</tr>
<tr>
<td>Eccentricity</td>
<td>$\leq 1 \times 10^{-4}$</td>
<td></td>
</tr>
<tr>
<td>Pulsar mass function ($M_\odot$)</td>
<td>$2.2831(1) \times 10^{-3}$</td>
<td>$2.282(1) \times 10^{-3}$</td>
</tr>
<tr>
<td>Minimum companion mass ($M_\odot$)</td>
<td>0.174(3)</td>
<td>0.17(1)</td>
</tr>
<tr>
<td>Median companion mass ($M_\odot$)</td>
<td>0.204(3)</td>
<td>0.20(1)</td>
</tr>
</tbody>
</table>

- **PSR J1023+0038** showed radio emission and evidence for a dormant accretion disc.
- **SAX J1808.4-3658** showed indirect signs of radio activation during X-ray quiescence.

Red back: Radio signal is weak and characterized by irregular “eclipses”, due to intra-binary plasma.

Papitto+ (2013)
Radio loud again!

The transient low-mass X-ray binary IGR J18245-2452 is again active as a radio pulsar

ATel #5069; A. Papitto (IEEC-CSIC), J. W. T. Hessels (ASTRON/UvA), M. Burgay (INAF-OAC), S. Ransom (NRAO), N. Rea (IEEC-CSIC), A. Possenti (INAF-OAC), I. Stairs (UBC), C. Ferrigno (ISDC/U. Geneva), E. Bozzo (ISDC/U. Geneva) on behalf of a larger collaboration

on 17 May 2013, 01:20 UT

- Only ONE day after the last X-ray detection!
The first crucial point

- The first pulsar swinging from rotational powered X-ray to accretion powered X-ray emission

- Swings are as short as a few days!

- What about the X-ray accretion powered emission?
XMM-Newton light curve

- Very interesting variability, unique among AMSP.
- Episodes of enhanced hardness at low flux.
- No orbital dependency.

Hard 3.5-10 keV
Soft 0.5-3.5 keV

Ferrigno + (in prep.)
Two branches

- **Blue**: higher flux, limited Hardness variation
- **Magenta**: lower flux, swings of hardness, what are they?
Two accretion states

Higher state

Lower state

TWO log-normal distributions
Black-body and hard Compton tail
Low pulsed fraction and two harmonics
Broad Iron line and Comptonization spectrum
Sinusoidal profile with high pulsed fraction
Hardness dependency

- From black-body and Comptonization to partially covered power-law
- Ejection?
ATCA radio GHz variability

- Optically thick variable radio free-free emission, signature of outflows, not jets.
- Quasi contemporary X-ray Swift monitoring is consistent with low source state.
Interpretation

- Low state: propeller accretion and ejection episodes
- High state: variable accretion along field lines

Mixing is still present
Conclusions

• The first system swinging from radio to accretion and vice versa in time scales of days.
• Fast transitions, a benchmark for theory.

• Peculiar bimodal variability interpreted as the switch from “pure” accretion to “propeller” accretion with outflows/jets. Estimate of B-field consistent with other MSPs.
• Paucity of thermonuclear bursts.
• Why is IGR J18245-2452 so peculiar?
Prospectives

• Discovery of important transients relies on quick data transmission and prompt analysis.
• INTEGRAL is unique for faint hard transients (\(<\sim 20 \text{ mCrab}\)) in crowded regions of the sky.
• A monitoring facility and telescopes with high throughput are a winning combination to study X-ray sources.
• New project like LOFT, combining wide field monitor and large detectors will boost our knowledge on these systems.

• LOFT is one of the four M3 mission candidates selected by ESA in 2011 to compete for a launch opportunity in \(\sim 2020\).
  • Payload:
    – Large Area Detector (LAD) Area \(~12 \text{ m}^2\) - 200 eV spectral resolution in 2-80 keV band
    – Wide Field Monitor (WFM) 2 sr FOV - arcmin localization - 2-80 keV band -80 cm\(^2\) area