Intermediate-mass black holes & Gaia science alerts’ unique potential

Peter Jonker (SRON & RU)
Thomas Wevers (RU & SRON)
Francesca Onori (SRON & RU)
Marianne Heida (SRON & RU)

Netherlands Institute for Space Research

European Research Council

Do IMBHs exist?

Let me summarize facts about intermediate-mass black holes.

That was pretty accurate!
Occupation fraction depends on the nature of the seed BH
Ultra-luminous X-ray sources

Cartwheel galaxy

HST
(Credit: NASA/STScI)

Chandra
(Credit: NASA/CXC/A.Wolter & G.Trinchieri et al.)
ULXs: BH-red supergiant binaries?

Imaging survey: 4m class telescopes WHT
Spectroscopic follow-up: VLT, Keck, Gemini
ULXs: BH-red supergiant binaries

ULX in NGC253

VLT/X-shooter

2MASS $K_s$

ESO ISAAC $K_s$

Heida, Torres, Jonker, et al. 2015
ULXs: BH-red supergiant binaries

$V_{\text{radial}} = 66 \pm 6 \text{ km/s}$
ULXs: BH-red supergiant binaries

Heida, Torres, Jonker et al. 2015
ULXs: BH-red supergiant binaries
ULXs: BH-red supergiant binaries

- Prob. for bound orbit
- Prob. $V_{\text{sys}} > 60$ km/s

$V_{\text{sys}}$ [km/s] vs. $M_{\text{BH}}$ [$M_\odot$]

Fractional probability

Heida, Torres, Jonker et al. 2015
Candidate IMBHs
hyper-luminous X-ray sources
$L_x \geq 3 \times 10^{40}$ erg/s


N10 Cartwheel; Wolter et al. 2006
M82X-1; Kaaret et al. 2001
other IMBH candidates:
Mezcua et al. 2015; NGC2276
NGC5252; Kim et al. 2015
HLX2

$L_{x,\text{peak}} = 2 \times 10^{41} \text{ erg s}^{-1}$

IMBHs & tidal disruption events?
Tidal disruption events; X-ray

Komossa 2015

XMM: e.g. Esquej+08; Maksym+10, 13, 14; Saxton+14; Feng+15; Lin+11, 15
Tidal disruption events; optical

Figure 3
Spectral energy distribution. SED of PS1-10jh during near simultaneous GALEX ultraviolet and PS1 optical observations (with the host galaxy flux removed) at two epochs (rest-frame days -19 to -17 and 242 to 247 from the peak of the flare). Flux densities have been corrected for Galactic extinction of $E(B-V) = 0.013$ mag. The ultraviolet-optical SED from -19 to 247 rest-frames days from the peak is fitted with a $2.9 \times 10^{-4} K$ blackbody. Orange solid lines show blackbodies with this temperature scaled to the NUV flux densities for the respective epochs. Open symbols show the GALEX and PS1 flux densities corrected for an internal extinction of $E(B-V) = 0.08$ mag, and dotted blue line shows the $5.5 \times 10^{-4} K$ blackbody fitted to the de-reddened flux densities for the respective epochs. The upper limit from the Chandra observation on 2011 May 22.96 UT assuming a spectrum with a photon index of $\Gamma = 2$, typical of an AGN, is plotted with that thick black line. The X-ray flux density expected from an unobscured AGN with a comparable NUV flux is plotted for comparison with a thick grey line. Also shown are the $u$, $g$, and $r$ band flux densities measured from aperture photometry with the Liverpool Telescope on 2011 Sep 24 UT, after subtracting the host galaxy flux measured by SDSS. Errors, 1σ.

Supplementary Information is linked to the online version of the paper at www.nature.com/nature.

Gezari et al. 2012
Tidal disruption events & IMBHs

Y-axis ($r_{\text{tidal}}$ in km)

- $10 \, M_{\odot}$ MS star
- $1 \, M_{\odot}$ MS star
- $0.1 \, M_{\odot}$ MS star
- $1 \, M_{\odot}$ WD
- Schwarzschild radius

X-axis ($M_{\text{BH}}$ in $M_{\odot}$)
# Tidal disruption of a WD by an IMBH

## WD–BH encounter

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>masses (sol.)</td>
<td>0.2 (WD) &amp; 1000 (BH)</td>
</tr>
<tr>
<td>in. separation</td>
<td>50 (in 1.0E9 cm)</td>
</tr>
<tr>
<td>hydrodynamics</td>
<td>SPH (4 030 000 particles)</td>
</tr>
<tr>
<td>EOS, gravity</td>
<td>Helmholtz, N</td>
</tr>
<tr>
<td>nucl. burning</td>
<td>red. QSE-network (Hix 98)</td>
</tr>
<tr>
<td>simul. time</td>
<td>5.4 min</td>
</tr>
<tr>
<td>color coded</td>
<td>column density</td>
</tr>
<tr>
<td>penet. factor</td>
<td>12</td>
</tr>
</tbody>
</table>

* coding, simulation, visualisation: S. Rosswog

---

Rosswog, Ramirez-Ruiz, Hix 2009
Nuclear (?) event

Data courtesy Lukasz Wyrzykowski
Tidal disruption events & IMBHs

 Alerts for Gaia-detected galaxies: $\Delta m < -0.3$, $G < 20$

 Nadia’s talk yesterday

Figure courtesy Sjoert van Velzen
Tidal disruption events & IMBHs

I. Approach

II. Compression & Burning

III. Decompression of Ejecta

IV. Circularization

V. Disk & Jet Production

VI. Radiation from Unbound Ejecta

MacLeod et al. (2015)
Nuclear Type \( \sim \) Ia

MacLeod et al. 15

a.o. Luminet & Pichon 89; Rosswog et al. 08 & 09
Nuclear Type \( \sim \) Ia

MacLeod et al. 15
Nuclear Type $\sim$ Ia

MacLeod et al. 15

Wavelength [Angstroms]
Are there WD TDEs?
Detection of a fast X-ray transient

\[ F_{\text{peak}} (0.5-10 \text{ keV}) = 2 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1} \]

Precursors to the transient

$\sim 4000 \text{ s}$

$\sim 4000 \text{ s}$

$\text{0.1-7 keV rate; counts s}^{-1}$

WD orbits IMBH

Macleod et al. 2014 (and refs therein)
More fast X-ray flashes:

More fast X-ray flashes:

Counts (0.3-7 keV)

reported in ATEL #6541: Luo et al. 2014
Conclusion:

Capitalize on Gaia strengths: fast, virtually simultaneous spectroscopy & diffraction limited imaging

Gaia-discovered tidal disruption events will be a great tool to search for intermediate-mass black holes

OGLE found some peculiar (nuclear) Type Ia’s what are they?

Second the call for a “watch list”