Bright nuclear transients
- what are they?

June 2012                     Andy Lawrence               ESAC TDE conference

with Suvi Gezari, Martin Elvis, Martin Ward, Tim Heckman and

the Harvard and Belfast transient pipeline teams
(especially Stephen Smartt, Ken Smith, Darryl Wright)
the PS1 project team
the PS1 transients WG

Monday, 25 June 12
PanSTARRS-1 3π survey

- 1.8m / 7 sq.deg / g r i z y
- 30,000 sq.deg, 2 month cadence, g=22-ish

- Pipeline in Maui
- Transient pipelines in Harvard and Belfast

- 3 year survey started Jan 2011
- ~3500 "good" transients so far
- ~150 confirmed SNe

- ~tens of good nuclear candidates? TDEs?
Programme

- bright transients triggered by 3Pi vs SDSS difference
- choose those
  - coinciding with SDSS object=galaxy
  - with distance <0.5"
- follow up on Liverpool Telescope at $u\ g\ r$
  - weekly at first then monthly
  - simple 2arcsec photometry for now
- 49 targets followed since October 2011
- typically
  \[
  \begin{align*}
  g(\text{gal}) & = 21-22 & z_{\text{phot}} \sim 0.2-0.3\text{ish} \\
  g(\text{transient}) & = 19-20
  \end{align*}
  \]
colours

three colour groups
colours

three colour groups

blue objects
typical of quasar colours
colours

three colour groups

blue objects
typical of
quasar colours

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colours

three colour groups

some ultra-blue objects much bluer than normal quasars

blue objects typical of quasar colours
combined light curves

red = fast
(t$_{1/2}$ ~ month)
most blue = slow
(t$_{1/2}$ ~ 1-3 years)
some seen rising

Much slower than predicted for TDEs

PS1-10jh stands out as different

open symbols = spectral type
circle=AGN
square=SN
<table>
<thead>
<tr>
<th>OBJECT</th>
<th>light curve</th>
<th>type</th>
<th>redshift</th>
<th>galaxy mag</th>
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<tr>
<td>090119</td>
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<td>z=0.11</td>
<td>g=21.50</td>
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<tr>
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<td>g=20.62</td>
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<tr>
<td>160928</td>
<td>rise and fall</td>
<td>TDE</td>
<td>z=0.17</td>
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<td>OR</td>
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<td></td>
<td>z=0.996</td>
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Spectra collected and analysed by the Belfast team

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## spectral summary

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Proposal: most of the blue transients are background AGN amplified by **stellar microlensing** in the foreground galaxy

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Lensed Quasars:
• differential flickering in multiple components (Irwin et al 1989)
• massive galaxy $\rightarrow$ strong macrolensing
  significant lensing optical depth
  continual low level amplification

PS1 transients:
• smaller galaxy $\rightarrow$ little macrolensing
  small optical depth
  rare high amplification single star events

• AGN not seen before event
• Seyfert-like rather than quasar ($L \sim 10^{43-44}$ erg/s)
Meusinger et al 2010 show that a flaring object in M31 is actually at z=2 background quasar.

They discuss two possibilities:

- microlensing by a star in M31
- tidal disruption of a star in the quasar
z=0.17 HeII explanation

different... but BLR should not be amplified (see later)

z=0.97 MgII+CIII explanation

... but $z_{\text{host}} = z_{\text{HeII}}$

optical light curve can be modelled by microlensing ...

... but BLR should not be amplified (see later)

TDE still preferred model for this unusual object
fits to more typical transient

Fit parameters
base level $F_0$
impact param. $u_{\text{min}} = \theta_{\text{min}}/\theta_E$
crossing time $t_E$

note $t_{1/2} \approx 2 u_{\text{min}} t_E$
and amp $\approx 1/u_{\text{min}}$

t_{1/2} reasonably measured
but $F_0$ poorly known

$\Rightarrow$ range of possible $t_E/u_{\text{min}}$ values

Model with $F_0$ 1 mag below galaxy:

$u_{\text{min}} = 0.033$, $A = 30$
$t_E = 11,289$ days $= 31$ years

but small $u_{\text{min}}$ events
less likely
does this make sense?

we observe:

• AGN at z~1
• hosts at z~0.3
• amplification ~30
• rise/decay timescales 1-3 years ==> $t_E \sim 30-100$ years
• ~100 in outburst at any one time

how does this compare to what we might expect?
most AGN at $z=1-3$
all at the same $D_A$ ...

maximum lensing area per $dz$ shell at $z\sim0.27$

....consistent with observed hosts

but more distant AGN are fainter - so most of what we see will be $z\sim1$

Use typical $z_s=1$ $z_l=0.25$ $z_{ls}=0.6$ which for a solar mass lens gives

$$\theta_E = 2.91\mu\text{as} \left(\frac{M}{M_{\odot}}\right)^{1/2}$$
event timescale

at lens plane $\theta_E$ corresponds to

$$r_E = 3.48 \times 10^{14} \text{m} \left(\frac{M}{M_\odot}\right)^{1/2} = 2326 \text{AU} = 0.011 \text{pc}$$

Relative motion mostly due to relative galaxy motions - use 300 km/s

$$t_E = \frac{r_E}{v} = 36.8 \text{ years} \left(\frac{M}{M_\odot}\right)^{1/2} \left(\frac{v}{300}\right)^{-1}$$

Observed timescale depends on amplification / impact parameter:

$$t_{1/2} = 893 \text{ days} \left(\frac{M}{M_\odot}\right)^{1/2} \left(\frac{v}{300}\right)^{-1} \left(\frac{u_{\text{min}}}{0.033}\right)$$
event rate

for Milky Way like gal at $z_l=0.25$:

covering factor at $\theta_E$ is $f \sim 0.1$
covering factor at $u=0.033$ is $f \sim 10^{-4}$
so repeat timescale is

$$t_{rpt} \sim 6000 \text{ years } (M/M_\odot)^{1/2} \left(\frac{v}{300}\right)^{-1} \left(\frac{u_{min}}{0.033}\right)^{-1}$$

Outburst duty cycle $\sim 6 \times 10^{-4}$
Surface density of distant AGN $\sim 1\ \text{arcmin}^{-2}$

$\Rightarrow$ 0.03% of foreground galaxies have a background AGN
and 0.06% are in outburst at any one time

Number of $g=22$ish galaxies $\sim 10^8$

$\Rightarrow$ expect 20 to be currently in outburst ...
resolution effects

Scale to $M_{BH}=10^8$; accretion disc ~10 $R_S$; BLR ~1000 $R_S$

At $z=1$ $D_A=1650$ Mpc

$\theta_{disc} = 12R_{10}M_8$ nas \hspace{1cm} c.f. \hspace{1cm} $\theta_{lens} = 291 \left(\frac{u_{min}}{0.1}\right)$ nas

\[\begin{array}{ccc}
A=10 & \hspace{1cm} A=100 \\
\text{lens 291 nas} & \hspace{1cm} \text{lens 29nas} \\
\text{disc 12nas} & \hspace{1cm} \text{pt srce} & \hspace{1cm} \text{significant resoln effects} \\
\text{BLR 1200 nas} & \hspace{1cm} \text{amplified less} & \hspace{1cm} \text{amplified very little}
\end{array}\]
what we can learn from microlensing events

accretion disc structure $A(\lambda)$
BLR size and geometry rise vs decay
cosmological geometry distbn of lens redshifts
separating microlensing and TDEs?

ultra blues?  
blue but fast?  

Could also be high amplification lensing events

Optical spectra

need \( z_{\text{em}} = z_{\text{absn}} \)

what is the signature of a TDE?
- \( T=10^5 \) K?
- broad lines?
- coronal lines?
- no lines?
- jet?
host mags

hosts consistent with normal gals \( z \sim 0.3 \)ish
In general
red = fast (month)
blue = slow (year)
colour vs decay rate

in general
red=fast (month)
blue=slow (year)

PS1-10jh
PanSTARRS-1

- 1.8m telescope on Hawaii with FOV 7 sq.deg
- Imaging in $g r i z y$
- Medium Deep Survey: 12 fields, 3 night cadence, $g=25$-ish
- 3Pi Survey: 30,000 sq.deg, 2 month cadence, $g=22$-ish
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QC reduces by factor $10^3$
light curve fit to PS1-10jh

Microlens probably ruled out in this case
- but what about the more common slow blue transients?

simple microlens model

but NUV non-detection at earlier epochs suggest amplification $\sim 350$

much rarer and should strong colour effects and negligible BLR amplification (see later)