# The extremes of AGN variability


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<th>Intro: variability in classical Seyferts: absorption &amp; reflection</th>
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<td>Deep X-ray low-flux states in (NL)S1 galaxies <em>(factor 10)</em></td>
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<td>AGN at the highest amplitudes: giant drops &amp; outbursts <em>(&gt;factor 100)</em></td>
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| “Changing-look” AGN: multi-λ view of extreme Sy-type changes |
| Blazars/SMBBHs: OJ 287 *(periodicity)* |
| The highest amplitudes today *(factor > 1000)*: TDE flares from *quiescent* galaxies |
The extremes of AGN variability


- Intro: variability in classical Seyferts: absorption & reflection
- Deep X-ray low-flux states in (NL)S1 galaxies (*factor 10*)
- AGN at the highest amplitudes: giant drops & outbursts (*factor 100*)

- “Changing-look” AGN: multi-λ view of extreme Sy-type changes
- Blazars/SMBBHs: OJ 287 (*periodicity*)
- The highest amplitudes today (*factor > 1000*): TDE flares from quiescent galaxies

Extreme flux and spectral states: -- can reveal the nature of the inner accretion disk, -- the physics of matter under strong gravity, -- offer a way of measuring BH spin, -- provide insight on the material expelled by the SMBH incl. strong outflows, feedback; -- route to discovery of rare new transients, TDEs, changing-look AGN, SMBBHs, ...
absorption & reflection in AGN

[recent reviews: Turner & Miller 09, Brenneman 13, Reynolds 14, Fabian 15]
deep X-ray low-flux states: the NLS1 Mrk 335

- nearby, highly variable NLS1 galaxy
- has traditionally been a bright X-ray source
- deep X-ray low-state (factor >10 drop) seen with Swift in 2007
- triggered follow-ups, and ongoing monitoring
- since then: - deep low-state in 2013: XMM, Suzaku & NuStar follow-ups
  - bright flare in 2014: another NuStar follow-up
  - rapid UV decline in 2015/16: HST & XMM-RGS follow-up

[Grupe,Komossa,Gallo+ 07, 08, 12; Longinotti+ 13, Gallo+ 13, Parker+ 14, Komossa+ 14, Gallo+ 15, Wilkins+ 15, Longinotti+ 16-- prep]
deep X-ray low-flux states: the NLS1 Mrk 335

depth low-state (NuSTAR/Suzaku)

[Grupe, Komossa, Gallo +07, 08, 12; Longinotti +13, Gallo +13, Parker +14, Komossa +14, Gallo +15, Wilkins +15]
deep X-ray low-flux states: the NLS1 Mrk 335

deep low-state (NuSTAR/Suzaku)

deep low-state scenarios:
(1) reflection-dominated spectrum: low coronal height, above inner disk → strong light bending and blurring
best-fit models require: most of the reflection originates from within a few $r_g$ & high spin
((+ additional warm absorption))
(2) partial covering absorption, unobscured at high-state, strongly absorbed at low-state (cf $\sim 0.95$, log $N$ $\sim 23.3$)

[Grupe,Komossa,Gallo+ 07, 08, 12; Longinotti+ 13, Gallo+ 13, Parker+ 14, Komossa+ 14, Gallo+ 15, Wilkins+ 15]
deep X-ray low-flux states: the NLS1 Mrk 335

flare state (NuSTAR):

in reflection scenario, still requires compact X-ray source few $r_g$ above disk; however, reflection fraction is very small

→ ejection of vertically collimated X-ray corona (at mildly relativistic speed, so emi beamed away from disk) ?

→ related to the ejection of radio-jet component ?

[Grupe,Komossa,Gallo+ 07, 08, 12; Longinotti+ 13, Gallo+ 13, Parker+ 14, Komossa+ 14, Gallo+ 15, Wilkins+ 15]
deep X-ray low-flux states: the NLS1 Mrk 335

independent evidence for (some) absorption:

(1) **XMM-RGS**: 3-component WA, \( N_H = 3 \times 10^{21} - 6 \times 10^{22} \text{ cm}^{-2} \), \( v \sim 5000 \text{ km/s} \)

(2) **HST**: new CIV absorption, \( v \sim v_x \)

**latest UV low-state**: quasi-simultaneous XMM & HST-COS observations triggered.
analysis ongoing \( \rightarrow \) test abs. scenarios & measure WA properties

other deep low-flux states with triggered follow-ups: e.g., PG0844+349, Mrk 1048, 1H0707-495, .......

these do not come with significant optical broad line variability
highest-amplitude AGN variability & transience: huge flares & dips

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<thead>
<tr>
<th>galaxy</th>
<th>X-ray amplitude</th>
<th>notes</th>
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<tr>
<td>1E1615</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>WPVS007</td>
<td>400</td>
<td>drop</td>
</tr>
<tr>
<td>IC3599</td>
<td>100</td>
<td>flare, emi-line response</td>
</tr>
<tr>
<td>PHL1092</td>
<td>260</td>
<td>temp. drop</td>
</tr>
<tr>
<td>GSN069</td>
<td>240</td>
<td>flare</td>
</tr>
<tr>
<td>XMMJ061927-6553</td>
<td>140</td>
<td>flare</td>
</tr>
<tr>
<td>Mrk 590</td>
<td>100 (UV)</td>
<td>accretion event? Sy-type change</td>
</tr>
</tbody>
</table>

[e.g., Piro+ 90, Grupe + 95a,b, 12, 15, Miniutti+ 09, 12, 14, Komossa+ 14, Saxton+ 14, Denney+ 14]
the AGN that ‘disappeared’: WPVS007

• unique, giant-amplitude drop in its X-ray emission (factor ~400), never seen in any other AGN.

• its optical spectrum is that of a NLS1 (z=0.028); little/no changes from 1993-2012

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- **FUSE** UV (vs earlier *HST*) then revealed launch of BAL flow, $v_{\text{max}} \sim 6000$ km/s and FWHM = 3400 km/s unusual for such a low-mass AGN; most BAL sources are massive quasars

[Grupé+ 95, Grupe + 07, 08, 13, Leighly+09, 15]
WPVS007

has remained X-ray faint ever since the 90s, except occasional rapid flaring:

highly variable UV

recent strong change in UV, into very low state: triggered HST observation

[Grupe + 95, 07, 08, 13, Komossa+ 14, Leighly+09, 15]
• overall UV decline & 2015 occultation event
• photometry (Swift) consistent with change in reddening
• deep, highly variable CIV absorption (HST) anti-correlated with reddening

→ l.o.s. grazes edge of clumpy, dusty torus
  - clumps produce occultation event(s)
  - else: view through wind launched from edge of torus, $r \sim 0.1$-1pc

why this unique behavior of WPVS007?
shorter timescales in this low-mass AGN, $M_{\text{BH}} \sim 4 \times 10^6 M_{\odot}$

[Grupe + 07, 08, 13, Leighly+09, 15, Cooper+16-prep]
The X-ray transient Sy1.9 galaxy IC 3599

- luminous X-ray outburst (RASS)
- 'classical' opt AGN before & after, z=0.02 (based on: narrow lines, radio, MIR spec)
- accompanied by variable broad H & forbidden (Fe) lines

photoion. modelling: variable lines consistent with CLR – origin

[Brandt+ 95, Grupe+ 95, Komossa & Bade 99]
IC 3599 did it again

- second flare discovered by Swift, ~20yr after first one
- with similar amplitude (~factor 100)
- preceded by opt high-state ~ 1yr earlier (Catalina survey)
- now back to X-ray low-state (our latest Swift data point is from July 2016)

[Komossa+14, Grupe, Komossa, Saxton 15]
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- repeat TDE ?
  - boosted rate (Chen+ 09, Komossa & Merritt 08, Li+ 15), but no merger, & early recoil too unlikely
  - repeat tidal stripping: (Campana +15)
  - binary star disruption: (Mandel & Levin 2015), then don’t expect a 3rd peak
- SMBBH ?: a la OJ287 (Valtonen+ 14), or stream feeding from disk with inner gap (Tanaka+ 13)
- highly variable AGN: perhaps a disc (LE) instability, as ‘seen’ in Gal BH binary GRS1915 (many uncertainties, but most likely scenario, since a long-lasting AGN)

[Komossa+14, Grupe, Komossa, Saxton 15]
changing-look AGN: now you see it, now you don’t
HE1136-2304

• discovered in high-state in XMM-slew → XMM, NuSTAR, Swift & SALT quasi-sim. within 3d

• change of Sy1.9 into Sy1 (Δt =11yr)

• high amplitude of X-ray increase (x 30) accompanied by strong broad-line increase (x >4)

→ unlikely changes in large-scale extinction/torus

→ change in accretion rate?
  - either BLR sees more photons
  - or cloud-formation conditions change (Nicastro+00, Elitzur+14)

[Parker, Komossa, Kollatschny et al. 16]
semi-periodic variability: SMBBH candidate OJ287

- BBH model: burst interval ~ orbital period, ~ 12 yrs
- double-peak structure: secondary in precessing orbit impacts warped, thick disk twice

- orbital parameters of Valtonen et al.:
  \[ M_1 = 1.8 \times 10^{10} \, M_{\text{sun}} \]
  \[ M_2 = 1.4 \times 10^8 \, M_{\text{sun}} \]
  \[ e = 0.7, \, a = 9300 \, \text{AU} \]

- tentative evidence for orbital shrinkage due to emission of GWs (\(DT_{GW} = 0.01\) yr/period)

[e.g. Silanpää et al. 88, 96, Lehto & Valtonen 96, Katz 97, Sundelius+ 97, Villata+ 98, Pietilä+ 98, Liu & Wu 02, Valtonen+ 97,06, 07,10, 12.....]
candidate SMBBH OJ 287: already after (or, towards) the next maximum?

- strong optical flare Dec.5, 2015
- already the next „decadal“ maximum? \(\rightarrow\) then strong orbital (forward) precession required
- meanwhile, even brighter optical peak was seen; broad ongoing flare
- \(\rightarrow\) multi-\(\lambda\) monitoring continues

[Valtonen+ 15, 16, Komossa+ 15, Zola+ 16]

[e.g., ATEL #8372, #8374, #8378, #8382, #8411, #8667, 2015, #8667, 2016]
summary

- ongoing monitoring programs (Swift) to search for AGN in extreme flux & spectral states
- (rapid) follow-ups at multiple wavebands (e.g., XMM, Suzaku, NuSTAR; HST, optical ground-based telescopes, Effelsberg, ....)

extremes of (X-ray) variability provide us with important insights on accretion physics; nature of the inner disk, relativistic effects; properties & location of absorbers and outflows; discovery of rare/new transients

• **factor ~10 - 20 var:** deep X-ray low (+high) states, absorption vs. reflection scenarios; no strong optical broad-line changes (best-observed case: Mrk 335)

• **factor ~30 - >100 var:** highest-amplitude outbursts and drops in AGN; some require extreme effects
  -- WPVS007: unique in dramatic X-ray & BAL variability in nearby, low-mass NLS1 galaxy
  -- IC3599: unique 2\textsuperscript{nd}, high--amplitude outburst (factor 100), from disk instability?
  -- HE1136: new changing-look AGN, with Sy-type change; driven by change in acc rate?

• **quasi-periodic bursts:** multi-wavelength follow-ups of SMBBH candidate OJ 287: before or after next ‘decadal’ maximum?; ongoing radio monitoring to distinguish sev. SMBBH scenrs

future: - growing importance of *triggered* observations, to catch the extreme states
  - higher sensitivity & *resolution* in X-rays, to break degeneracy of absorption/reflection
  - multi-wavelength approach (incl. HST)
  - dedicated searches for new outbursting AGN & TDEs in transient surveys & rapid f-ups