Narrow-Line Seyfert 1 galaxies

Stefanie Komossa, MPE Garching

- mini-review: NLS1 galaxies - models, open questions
- NLS1s & the $M_{\text{BH}} - \sigma$ relation
- radio-loud NLS1s
**Intro: Narrow-Line Seyfert 1 galaxies**

- **defi**: via optical spectral properties

  \[ \text{FWHM}_{\text{H}_\beta} < 2000 \text{ km/s} \]
  \[ [\text{O III}]/\text{H}_\beta < 3 \]
  \[ \text{FeII}/\text{H}_\beta > 0.5 \]

  [e.g., Osterbrock & Pogge 85, Goodrich 89, Veron-Cetty & 01]

- **NLS1s at „extreme end“ of correlations („EV1“) between line/contini properties of AGN:**

  - small FWHM\text{H}_\beta
  - strong FeII/H\beta
  - weak [O III]/H\beta
  - strong C IV blueshifts, H\beta asym.
  - sometimes: steep X-spectra

    some samples show Γ\_x-FWHM\_H\_\beta corr., others not at all

  [review by Marziani, Dultzin-Hacyan, Sulentic 2006]

  [e.g., Boroson & Green 92, Sulentic & 00; Gaskell 85, Osterbrock & Pogge 85, Pounds & 95, Wang & 96, Boller et al. 96, Grupe & 97, Brandt & 97, Lawrence & 97, Laor & 97, Leighly 99, Wei & 99, Wills & 00, Veron & 01, Marziani & 01, 03, Williams & 02,04, Puchnarewicz & 02, Zheng et al. 02, Boroson 02, Richards & 02, Shemmer & Netzer 02, Sulentic & 02, 03, Xu & 03, 07a,b, Grupe 01, 04, Bachev & 04, Netzer & 04, Fields & 04, Zhou 06]
Intro: Narrow-Line Seyfert 1 galaxies

**models:** what drives the *correlations*??
- high Eddington-scaled *accretion rate* and/or
- low *BH mass*
- *density* of outflowing wind → Dawei’s talk
- *orientation*
- young *age*
- different *host galaxies*
- different NLR/BLR (abundances), ionized absorption

[e.g., Osterbrock & Pogge 85, Boroson & Green 92, Pounds & 95, Wang & 96, Boller et al. 96, Laor 97, Lawrence & 97, Czemy & 97, Goodrich 99, Peterson & 00, Mathur 00, 01, Komossa & Meerschweinchen 00, Hayashida 00, Wills & 00, Marziani & 01, 03, Komossa & Mathur 01, Boroson 02, Shemmer & Netzer 02, Nagao & al 02, Sulentic & 00, 02, 03, Kawaguchi 03, Wang & Netzer 03, Grupe 01, 04, Grupe & Mathur 04, Botte et al. 04, 05, Collin & Kawaguchi 04, Bian & Zhao 04, Wamer & 04, Fields & 04, Done & 04, Gallo & 05, Tanaka & 05, Xu & 03, 07a,b, Wang & Zhang 06, Collin & 06, Ryan & 07, Watson & 07, ......]
The original idea that $L/L_{\text{edd}}$ drives EV1: disk $\rightarrow$ acc. torus, X-rays lead to copious FeII, weak [OIII] from partially shielding the NLR; independent evidence from X-ray obs. (soft spectra; if softness is interpreted as soft excess).

Almost all estimates of $L/L_{\text{edd}}$ are based on BH masses from R-L relation, and fixed bolometric correction.

Recent obs.:  
- NLS1s, have, on average, higher $L/L_{\text{edd}}$ than BLS1s (but not as high as some hi-z quasars)  
- Soft X-ray selected NLS1s have higher $L/L_{\text{edd}}$ than optically selected NLS1s.

[e.g., Boroson & Green 92, Pounds & 95, Boller & 96, Czemy & 97, Sulentic & 00, Boroson 02, Williams & 04, Xu & 03, Wang & Netzer 03, Grupe 04, Collin & Kawaguchi 04, Warner & 04, Greene & Ho 05, Collin & 06, Watson & 07; and many more]
almost all studies find NLS1s are, on a v e. , of lower mass than BLS1s (except: Ryan et al. 07)

methods:

- **reverberation mapping:** only few NLS1s
  - NGC 4051: $\sim 10^6 \ M_{\text{sun}}$
  - 6 NLS1 consistent with $R_{BLR} - L_{\text{opt}}$ relation
- application of Mass-Radius relation of BLS1
  - e.g., $M_{\text{NLS1}} \sim 10^{5.5-7.5} \ M_{\text{sun}}$, while $M_{\text{BLS1}} \sim 10^{7-9}$ (soft-X AGN of G04)
- X-ray variability & spectra
- few from $L_{\text{bulge,B}}, \sigma^*, L_{\text{bulge,IR}}$

major uncertainty: correction for orientation effects, applicability to NLS1s of M-R relation of BLS1s

[e.g., Peterson 00, Hayashida 00, Boroson 03, Shrader & Titarchuk 03, Grupe 04, Bian & Zhao 04, Botte & 04, McHardy & 06, Ryan & 07, and MANY others]
original idea: are NLS1s evolutionary young, re-juvenated? \( \Rightarrow \) good chance to watch BHs grow, obs. `formation' of \( M_{BH} - \sigma_* \)

recent results: NLS1s are

- **OFF/OFF?** \( M_{BH} - \sigma_{[OIII]} \)
- **ON/OFF?** \( M_{BH} - \sigma_* \)
- **ON** \( M_{BH} - L_{bulge,B} \)
- **far OFF** \( M_{BH} - L_{bulge,IR} \)
- **break-down of** \( M_{BH} - L_{bulge,IR} \)

[Mathur et al. 01, Wang & Lu 01, Wandel 02, Grpu Mathur 04, Bian & Zhao 04, Botte & 04, 05, Barth & Mathur & Grupe 05a,b, Greene & Ho 05, Zhou & 07, Watson & 07, Komossa & Xu 07]
**host galaxies of NLS1s**

**idea:** if NLS1s are young and/or rapidly growing their BHs, their host galaxies may show evidence for this.

**observations:** NLS1s (as compared to BLS1s/non-actives) show

- no excess companions
- no evidence for recent mergers
- a high fraction of bars; & nuclear dust-spirals & stellar rings
- redder bulges

**interpretation:** no merger-induced accretion, but likely secular processes: bar-induced BH fuelling

[Krongold & 00, Crenshaw & 03, Deo & 07, Ohta & 07, Ryan & 07]
idea: face-on view of flat BLR; if uncorrected all BH masses would be severely underpredicted

results: orientation difficult to measure; general ´feeling´: inclination is not the primary driver, but it does play some role

arguments against orientation:
• [O III] is isotropic
• scattering/polarization properties of NLS1s

indications that orientation plays a secondary role:
• C IV asymmetries
• subtle differences in Hβ line profile ($\sigma_{\text{line}}$)
• theoret. attempts to ´unify´ AGN-subclasses

[e.g., Osterbrock & Pogge 85, Lawrence & 97, Puchnarewicz & 92, Marziani & 01, Richards & 02, Collin & Kawaguchi 04, Zhang & Wang 06, Collin & 06; contra: BG92, Boroson 02, Smith & 05]
ULIRGs: share strong FeII, weak [OIII] trends. **High-z QSOs:** share super-solar metallicities, high \( L/L_{\text{edd}} \)

**BAL quasars:** NLS1-ness and BAL-ness at same end of EV1 (but opposite end of EV2 - diff. \( L \))

**radio-sources:** NLS1-ness and (steep-spectrum) RLness at opposite ends of EV1 – based on optical properties; but so far almost no radio studies of NLS1s at all

[\text{e.g., Zheng & 02, Mathur 00; Boroson & Green 92, Lawrence & 99, Sulentic et al. 00, 03, Brandt & Gallagher 00, Boroson 02}]
radio-loud NLS1s, RL-RQ bimodality

- almost no previous radio studies of (radio-loud) NLS1s
- radio-properties & fraction of radio-louds allow us to
  - test NLS1 models
  (orientation $\rightarrow$ BH masses, disk-jet models, ... FeII formation)

- re-address: what causes the `RL-RQ bimodality´ of AGN?

  \[ R = \frac{f_{5\text{GHz}}}{f_{4400\text{Å}}} \]

- re-address: what makes an object radio-loud?

[prev. NLS1 sample radio studies: Ulvestad & 95, Stepanian & 03, Greene & 06;
bimodality: e.g., Kellermann et al. 89, Ivezic & 02, Sulentic & 03; but see Cirasuolo & 03,
White & 00; cause of RL-ness: Blandford 00, Wilson & Colbert 95, Laor 00, Ye & Wang 05, Best et al. 05, Metcalf & Magliochetti 05, Sikora et al. 06, Capetti et al. 06, ...]
search for radio-loud NLS1s

- cross-correlation of the catalogue of quasars and AGN [VQC, Veron-Cetty et al. 2003] with radio and \( m_B \) catalogues

\[
\begin{array}{l}
\text{radio} \\
\text{VQC} \\
\text{PKS (4.85 GHz)} \\
\text{PMN, 87 GB (2.7 GHz)} \\
\text{NVSS, FIRST (1.4 GHz)} \\
\text{SUMSS (0.8 GHz)} \\
\text{WENSS (0.3 GHz)} \\
\text{USNO-A,B} \\
\text{GSC2.2} \\
\end{array}
\]

\[ \log R > 1 \]

[Matcher: Adorf et al. 05] developed within the German Astrophysical Virtual Observatory, http://www.g-vo.org
radio-loud NLS1s: statistics & radio prop

- **128** NLQSOs in VQC
- 90% within NVSS survey area,
- among these, **7% are radio-loud (R >10)**
  only 2.5% exceed R = 100
  (for comp.: ~15% radio-louds among opt.-sel. BLQSOs; 20% RLs among BLQSOs in VQC & 14% with R>100)
- most radio-loud NLQSOs are
  - compact,
  - steep spectrum sources,
  - not variable

[R = f_{5GHz} / f_{4400A}]

[K. et al. 06]
radio-loud NLS1s: X-ray variability & spectroscopy

**Variable:** some sources highly variable

\[ \Gamma_{sx} = -2 \ldots -3.5 \]

\[ L_{sx} \sim 10^{44} - 46 \text{ erg/s} \]

X-ray data used for \( L/L_{\text{Edd}} \) estimates:

\[ 10 L_x/L_{\text{Edd}} = 0.2 - 6 \]
radio-loud NLS1s: optical spectroscopy

examples:

- SDSSJ1721+5654
  2nd-most RL

- RXJ1629+4007
  blazar?

- RXJ23149+2243
  dbl-pkd [OIII]

FWHM_{H\beta,dir} = 960 - 2030 \text{ km/s}, \frac{FeII}{H\beta} = 0.5 - 3.2, \frac{[OIII]}{H\beta} = 0.05-3

→ do RL-NLS1s differ in opt. prop. ? ; BH mass estimates.
radio-loud NLS1s: results

• **FeII-[OIII]-FWHM$_{H\beta}$ correlations:**
  - radio-louds cover ~whole FeII-[OIII] range of NLS1s, except they avoid lowest FeII/H$_\beta$ values *)
  - extend known radio-loud objects to those with small FWHM$_{H\beta}$

*) confirmed for larger sample of 30 veryRL NLS1s; in prep.
radio-loud NLS1s: results

- **black hole masses**: at upper end of NLS1 distribution; in a prev. rarely populated regime of the `Laor diagram´

*estimated from $L_\lambda(5100\text{A})$ and $\text{FWHM}_{H\beta}$ [Kaspi & 05]

[Laor 00, Lacy et al. 01; larger coverage: Woo & Urry 02, McLure & Jarvis 04, Metcalf & Magliocchetti 06 ]
radio-loud NLS1s: models

- models to explain RLness of NLS1s:
  - radio-emi AGN related at all? → SB
  - intrinsically RQ, but beamed?
  - truly RL

- why are RL NLAGN more rare than RL BLAGN?
- and is the mechanism for RLness the same in NLAGN and BLAGN?
radio-loud NLS1s: models

- **starburst contribution?**
- **radio powers** $P$ are all in RL regime
  - **IRAS - radio corr.**: $P$ factor $\approx 10^{-120}$ above expected SB contrib.

- **relativistic beaming?** $\rightarrow$ pole-on view
  - most are steep spectrum sources, with radio spectral indices $\alpha_r < -0.5$; beaming not expected
    - exceptions: SDSS0948+0022, RXJ 16290+4007: $\alpha_r = 0.6, 0.4$
  - X-ray spectra of beamed sources typically much flatter

\[ \Sigma: \text{no SBs expected to dom.} / \text{beaming cannot be excluded, but no pos. evidence for it, with 2-3 except.} \]
radio-loud NLS1s: models to explain lower frequency of RLs among NLS1s

- **BH mass**: corr. with RLness much debated. RL-NLS1s tend to be at the high-mass end of NLS1s
- **spin/age**: spin-jet coupling e.g. via Blandford-Znajek mechanism. If NLS1-BHs still growing, and if spin increases `with age`, then, the few RLs should be more evolved than average population. Indeed, they are closer than other NLS1s to the $M_{BH} - \sigma$ relation of AGN. If NLS1 phen. short-lived: not enough time to grow ext. jets/lobes
- **accretion mode**: in Gal. X-binnaries in soft/high-state (&AGN), radio emi. quenched for high Edd. acc. rates [e.g., Maccarone & 03, Greene & 06] → mechanism which suppresses radio-emi for high $L/L_{Edd}$ also responsible for low RL-fraction in NLS1s? But among the RLs, no preference for low $L/L_{Edd}$ ($10 L_x/L_{Edd} = 0.2 - 6$)
**radio-loud NLS1s: models to explain lower frequency of RLs among NLS1s**

- **host galaxies:**
  - central brightness profile (powerlaw vs core galaxies) is linked to RL-ness (only `cores` are radio-loud) \( \rightarrow \) merger histories, **BBHs**, determine RLness [Capetti & Balmaverde 06].
  - If NLS1s are young (and/or mostly spirals with pl bulge)*, they have less often merged, so are less often r-loud. Then, the few radio-loud ones might have had a major merger recently, and host BBHs.
  - This would explain that a # of RL NLS1s shows dual properties: **NLS1 - \( \gamma \) blazar**

* not much known about host gals. of NLQSOs
radio-loud NLS1s: follow-up studies first results from a larger sample

NLS1 - blazar composite:
2MASX0324+32 at z = 0.06,
- highly variably in X with all missions (RXTE, ROSAT, SWIFT,..)
- possible TeV detection
- flat radio-spec. & variable in the radio-band
- but optical NLS1 spectr.
- in one-armed spiral
- high Edd. acc. rate (measured, and typical of NLS1s) conflicts HBL blazar models

[Zhou & 07]
radio-loud NLS1s: 
follow-up studies; started or in prep.

- **larger samples**, based on SDSS: low-L NLS1s; radio-loudness etc. in dependence of FWHM; SEDs
- interesting/extreme **individual objects**
- **optical imaging**: host galaxy types
- **radio imaging**: how compact are the sources? 
  at diff. ν: spectral indices, steepness
  - **monitoring**: variability, beaming?
- **X-rays**: spectra, absorption, rapid(?) variability
- **theory**: jet-disk models, dep. on acc. rate, and on merger history
Summary

- significant increase in # of known radio-loud NLS1s
- fraction of RL NLS1s (7%) < RL BLAGN, almost none with R>100 \(\rightarrow\) VRL-NLS1s do exist, but are rare
- radio: most sources are compact, of steep spectrum, and not variable; \(R\) of all det. sources covers > 4 orders of mag.
- opt-X prop. similar to RQ NLS1s (but high Fe II/\(H\beta\)), radio properties extend the range of RLness to small FWHM\(_{H\beta}\)
- BH masses in prev. rarely populated regime of \(M_{BH}-R\) diagram
- mech.: no pos. evidence for beaming in most sources, accretion mode, age, spin, (BBHs in) host gal ??
- future: larger samples, multi-\(\lambda\) imaging & spectroscopy \(\rightarrow\) new light on RLness & NLS1 models, on BH properties (masses, spins) and environ. (acc. rate) and/or galaxy merging histories