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Narrow-Line Seyfert 1 galaxies

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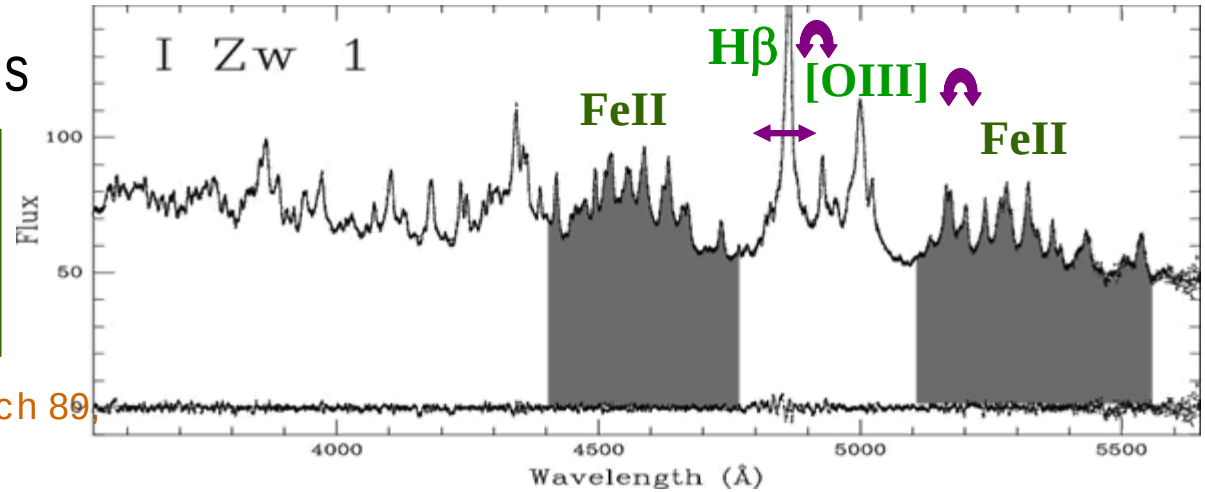
- **mini-review:**
  NLS1 galaxies – models, open questions
- **NLS1s & the $M_{BH} - \sigma$ relation**
- **radio-loud NLS1s**

Intro: Narrow-Line Seyfert 1 galaxies

- **<u>defi</u>:** via optical spectral properties

$FWHM_{H\beta}$ < 2000 km/s
[OIII]/Hβ < 3
FeII/Hβ > 0.5

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



- **NLS1s at „extreme end“ of correlations (`EV1´) between line/conti properties of AGN:**
  - small $FWHM_{H\beta}$
  - strong FeII/Hβ
  - weak [OIII/Hβ]
  - strong CIV blueshifts, Hβ 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, Czerny & 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, Warner & 04, Fields & 04, Done & 04, Gallo & 05, Tanaka & 05, Xu & 03, 07a,b, Wang & Zhang 06, Collin & 06, Ryan & 07, Watson & 07, ...]

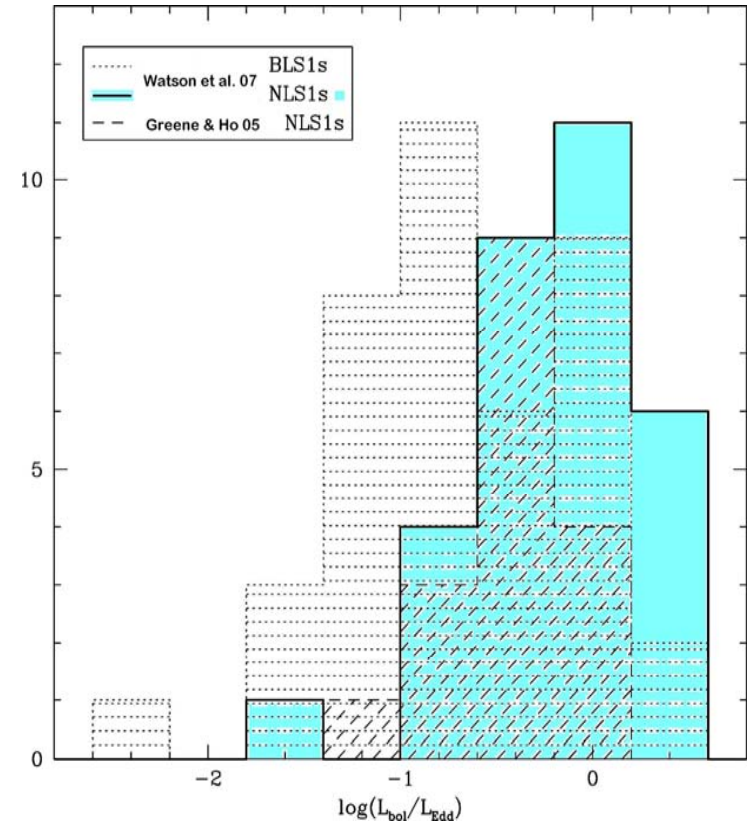
NLS1s as high L/L_{edd} accretors

original idea that L/L_{edd} drives EV1: disk → 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_{edd} are based on BH masses from *R-L* relation, and fixed bolometric correction

recent obs.:

- NLS1s, have, on average, higher L/L_{edd} than BLS1s (but not as high as some hi-z quasars)
- soft X-ray selected NLS1s have higher L/L_{edd} than optically selected NLS1s



[e.g., Boroson & Green 92, Pounds & 95, Boller & 96, Czerny & 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]

BH masses of NLS1s

almost all studies find NLS1s are, on ave., of lower mass than BLS1s (except: Ryan et al. 07)

methods:

- **reverberation mapping:** only few NLS1s
  NGC 4051: $\sim 10^6$ M_{sun}
  6 NLS1 consistent with $R_{BLR} - L_{opt}$ relation
- **application of Mass-Radius relation of BLS1** ←
  e.g., $M_{NLS1} \sim 10^{5.5-7.5}$ M_{sun} , while $M_{BLS1} \sim 10^{7-9}$ (soft-X AGN ofGr04)
- **X-ray variability & spectra**
- few from $L_{bulge,B}$, σ_* , $L_{bulge,IR}$

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]

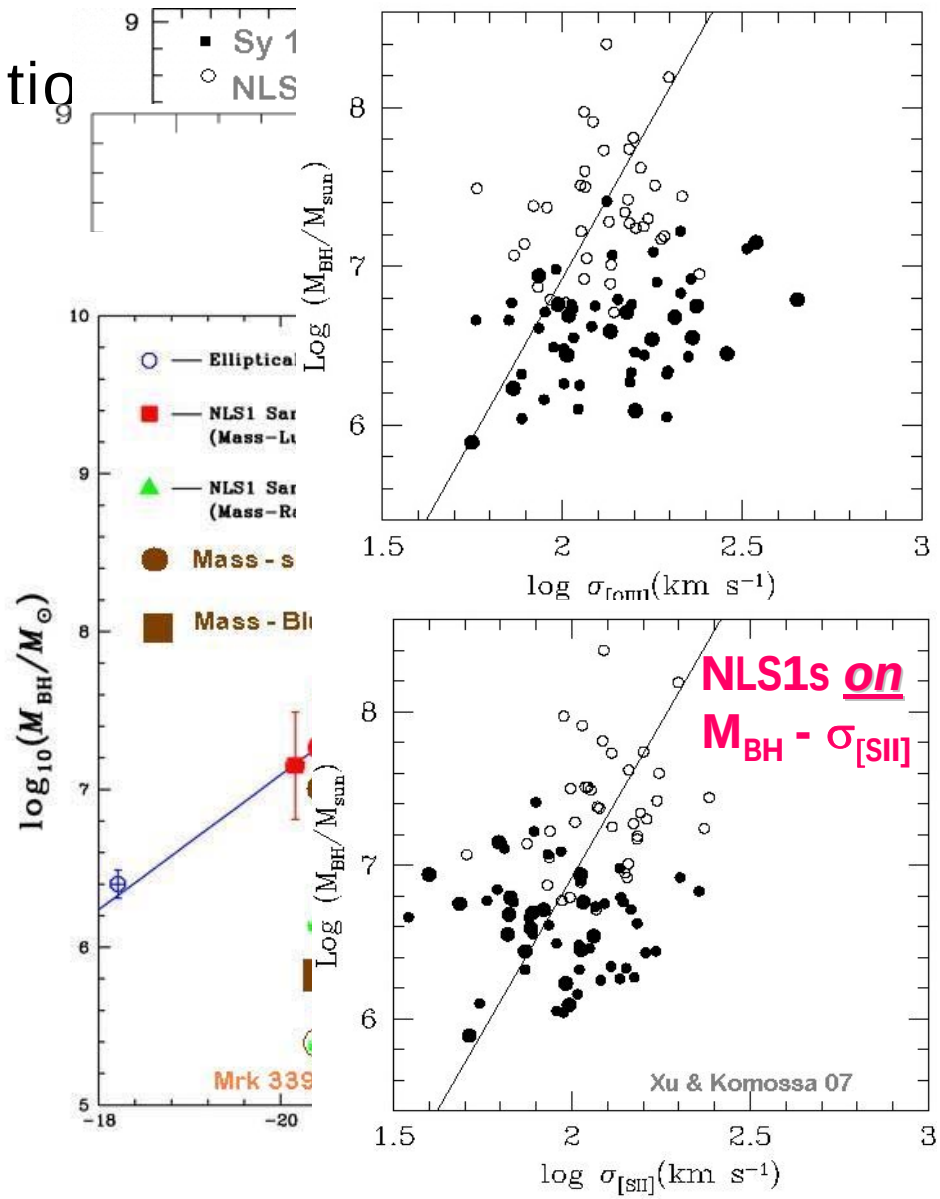
NLS1s on the $M_{BH} - \sigma_{[OIII]}, \sigma_*, L_{bulge,B,IR}$ planes

original idea: are NLS1s evolutio
young, re-juvenated ? → g
chance to watch BHs grow
obs.`formation´ of $M_{BH} - \sigma_*$

recent results: NLS1s are
OFF/ON? $M_{BH} - \sigma_{[OIII]}$
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, Grup
Mathur 04, Bian & Zhao 04, Botte & 04, 05, Barth &
Mathur & Grupe 05a,b, Greene & Ho 05, Zhou & C
07, Watson & 07, Komossa & Xu 07]



host galaxies of NLS1s

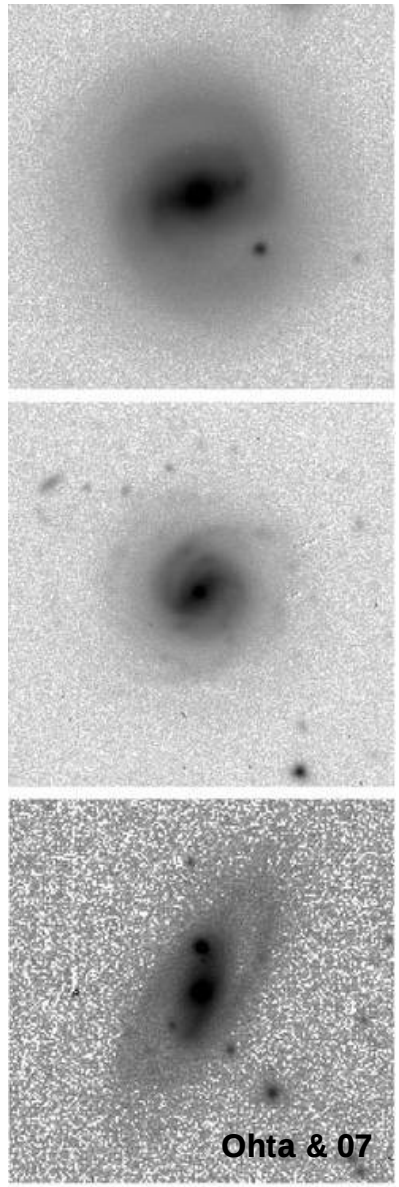
idea: if NLS1s are young and/or rapidly growing their BHs, their host galaxies may show evidence for this

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]



inclination of NLS1s

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:

- [OIII] is isotropic
- scattering/polarization properties of NLS1s

indications that orientation plays a secondary role:

- CIV asymmetries
- subtle differences in Hβ line profile (σ_{line})
- theoret. attempts to ´unify´ AGN-subclasses

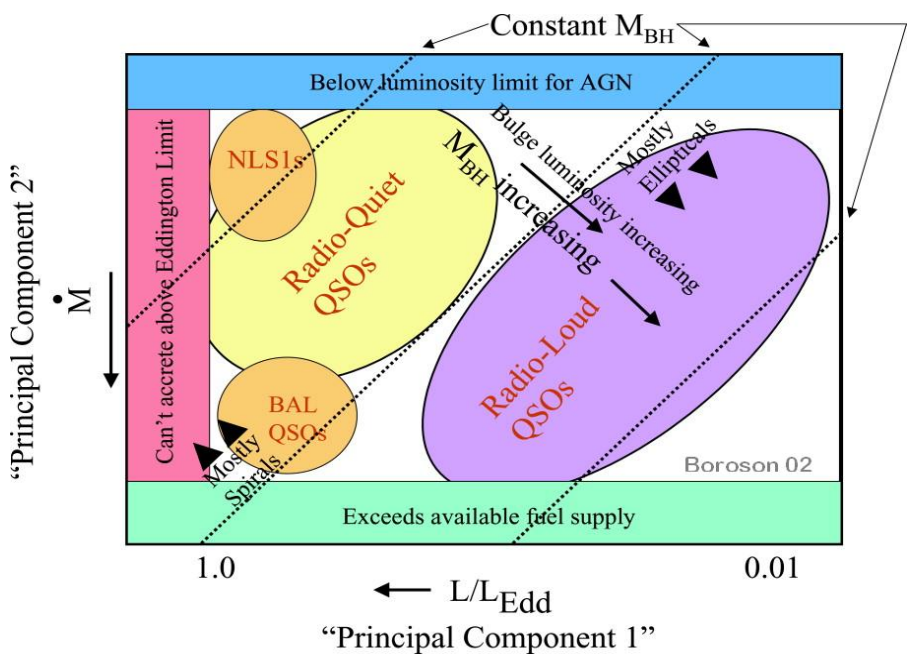
[e.g., Osterbrock & Pogge 85, Lawrence & 97, Puchnarewicz & 92, Marziani & 01, Richards & 02, Collin & Kawaguchi 04, Zhang & Wang 06, Collin & 06; contra: BG92, Boroson 02, Smith & 05]

NLS1s: links with other types of sources

ULIRGs: share strong FeII, weak [OIII] trends. **High-z QSOs:** share super-solar metallicities, high L/L_{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



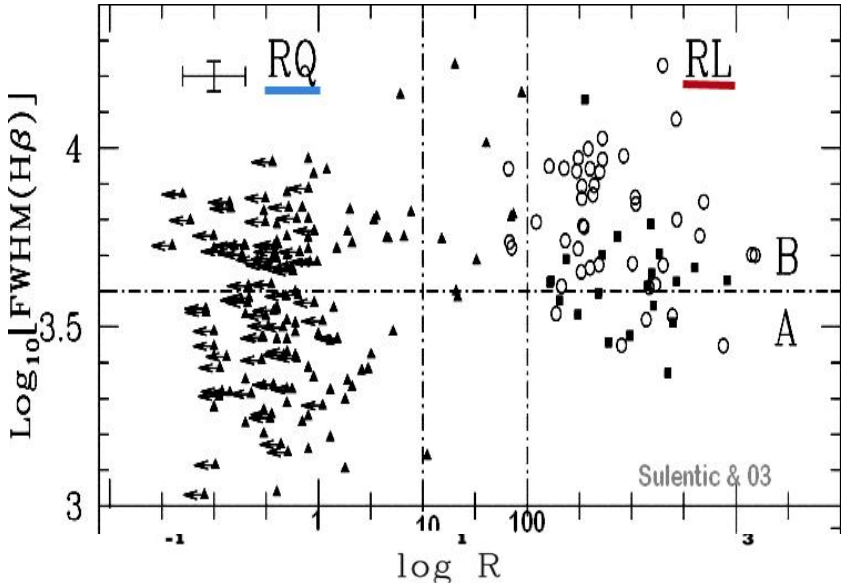
[e.g., Zheng & 02, Mathur 00; Boroson & Green 92, Lawrence & 99, Sulentic et al. 00, 03, Brandt & Gallagher 00, Boroson 02]

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 → BH masses, disk-jet models, ... FeII formation)
  - **re-address: what causes the `RL-RQ bimodality´ of AGN ?**

$$R = f_{5GHz} / f_{4400A}$$

  - **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

catalogues:

VQC

radio

PKS (4.85 GHz)
PMN, 87 GB (2.7 GHz)
NVSS, FIRST (1.4 GHz)
SUMSS (0.8 GHz)
WENSS (0.3 GHz)

[Wright & Otrupcek 90, Griffith & 94, Gregory & Condon 90, Condon & 98, White & 97, Mauch & 03, de Bruyn & 98; Monet & 03]

m_B

USNO-A,B
GSC2.2

RL →
log R > 1

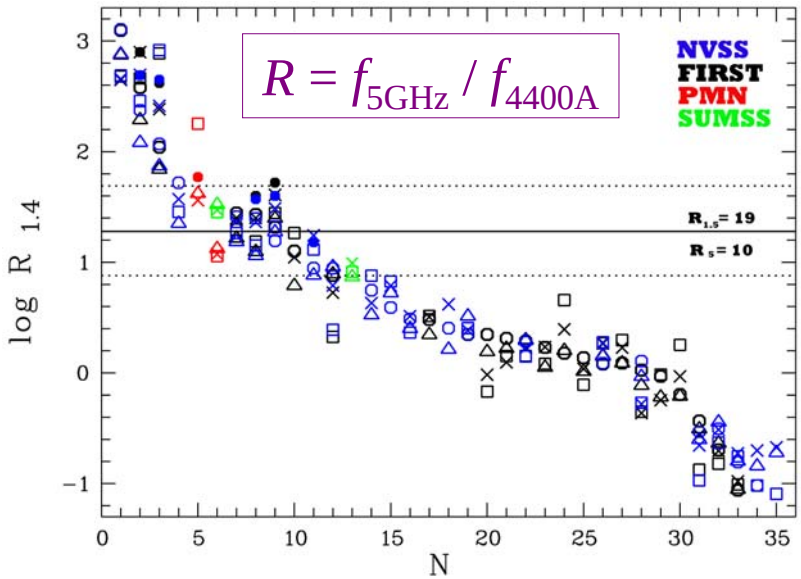
opt
X, IR

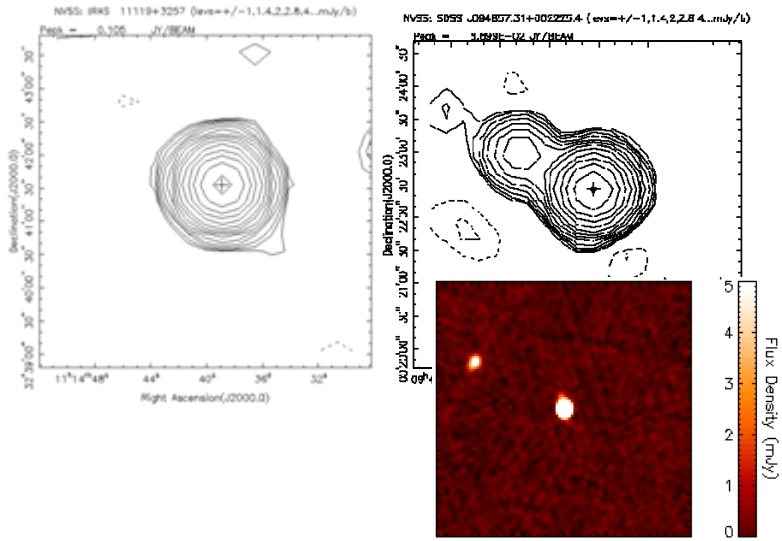
SDSS & new spec.
ROSAT, IRAS

Matcher: [Adorf et al. 05] **developed within the *German Astrophysical Virtual Observatory*, http://www.g-vo.org**

radio-loud NLS1s: statistics & radio prop

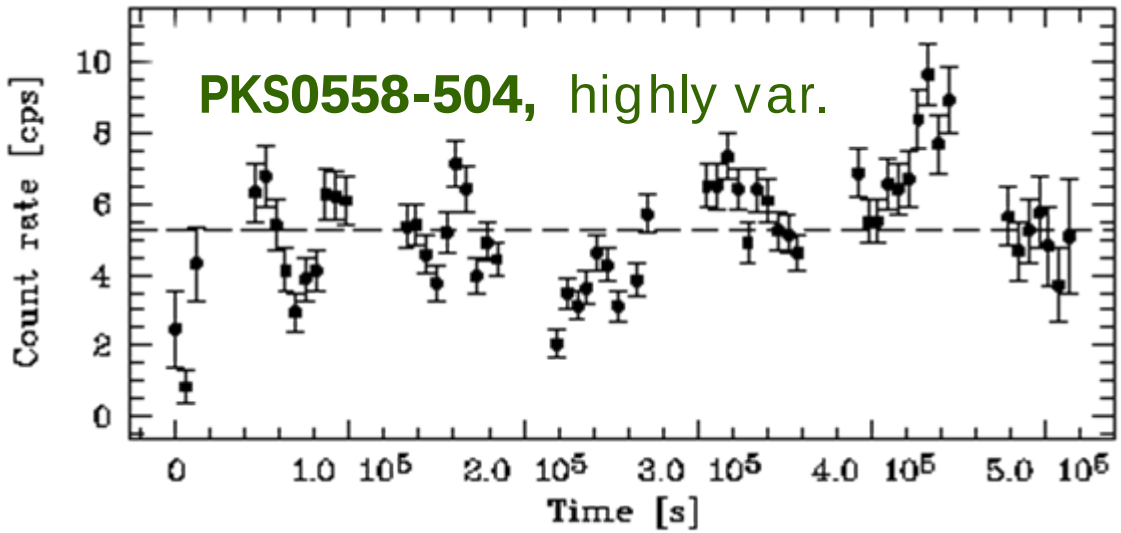
- **128** *NL*QSOs in *VQC*
- 90% within NVSS survey area,
- among these,
  7% are radio-loud (*R* >10)
  only 2.5% exceed *R* = 100
  (for comp.: ~15% radio-louds among opt.-sel. *BL*QSOs; 20% RLs among BLQSOs in *VQC* & 14% with R>100)
- **most radio-loud NLQSOs are**
  - compact,
  - steep spectrum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

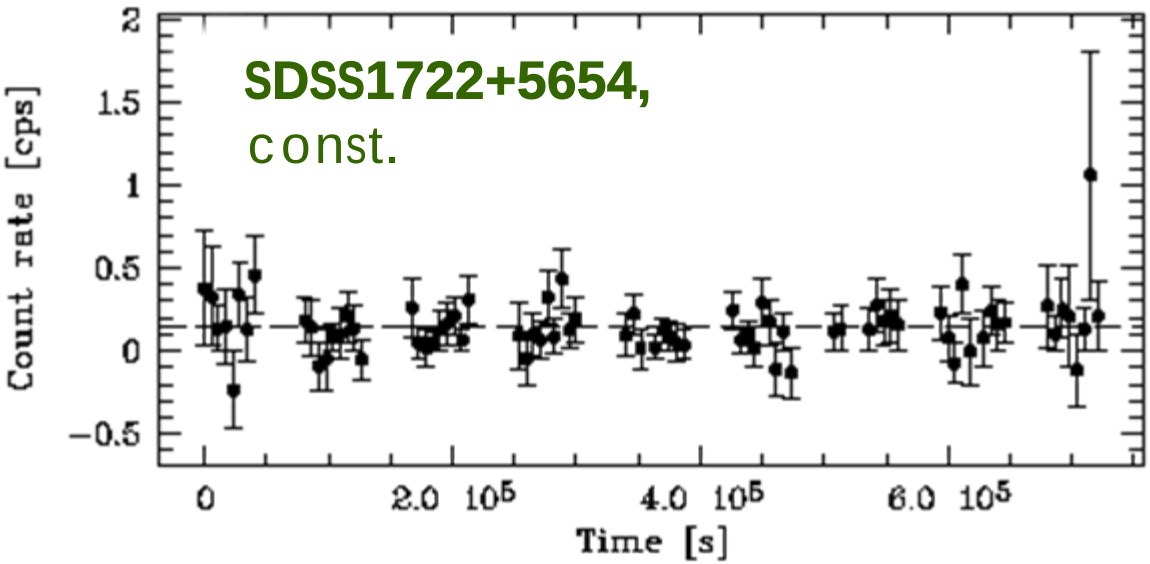




[K. et al. 06]

radio-loud NLS1s: X-ray variability & spectroscopy





var.: some sources highly variable

Γ_{sx} **= -2 ... -3.5**

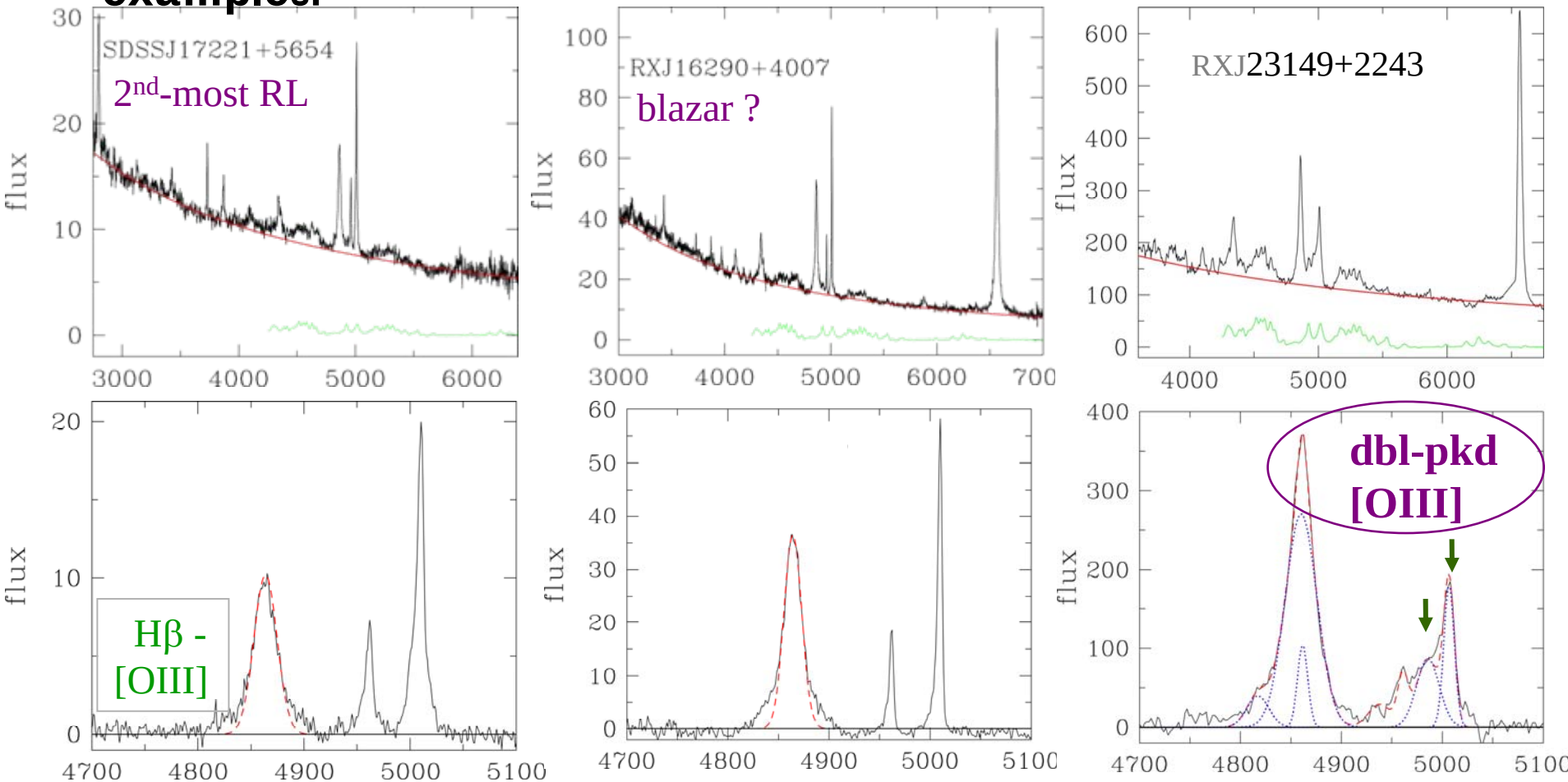
$L_{sx} \sim 10^{44-46}$ **erg/s**

X-ray data used for L/L_{Edd} estimates:

$10\, L_x/L_{Edd} = \mathbf{0.2 - 6}$

radio-loud NLS1s: optical spectroscopy

examples:



SBS1517

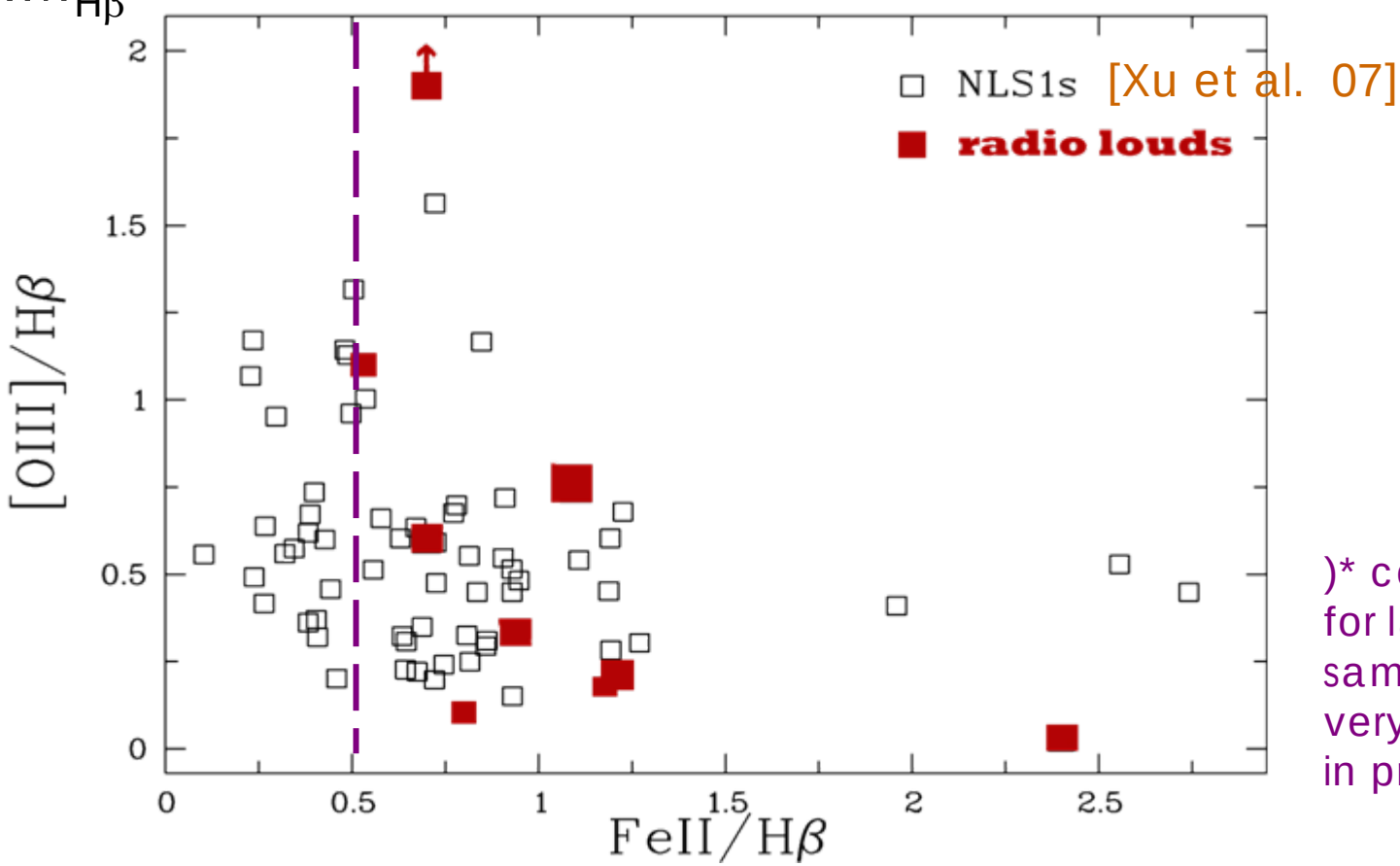
FWHM$_{H\beta,dir}$= 960 – 2030 km/s, **FeII/Hβ** =0.5 – 3.2, **[OIII]/Hβ** = 0.05-3

→ do RL-NLS1s differ in opt. prop. ? ; BH mass estimates.

radio-loud NLS1s: results

- **FeII-[OIII]-FWHM$_{H\beta}$ correlations:**

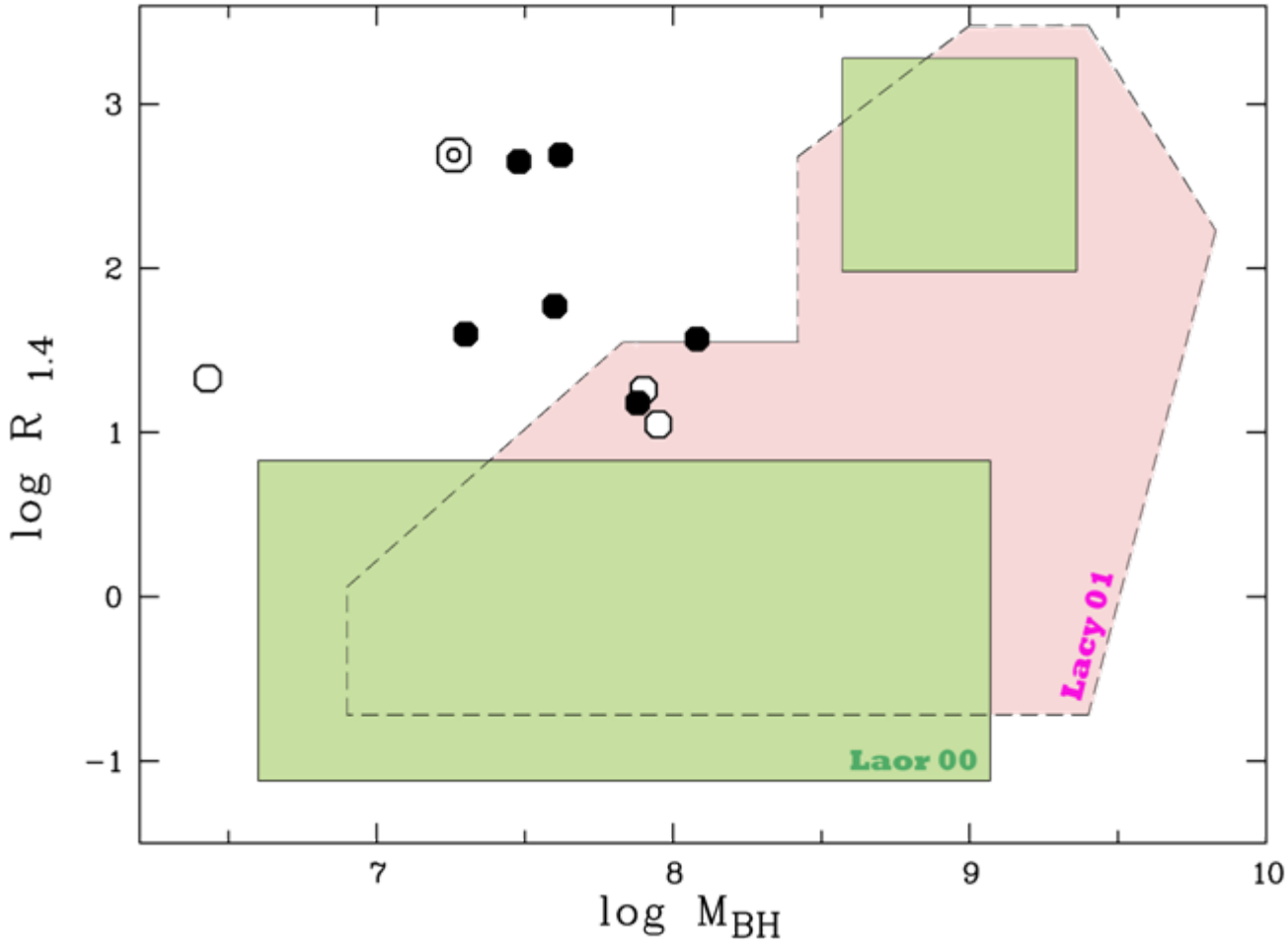
- radio-louds cover ~whole FeII-[OIII] range of *NLS*1s, except they avoid lowest FeII/Hβ values)*
- extend known radio-loud objects to those with small FWHM$_{H\beta}$



)* 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´



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

*estimated from L_λ(5100A) and $FWHM_{H\beta}$ [Kaspi & 05]

radio-loud NLS1s: models

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

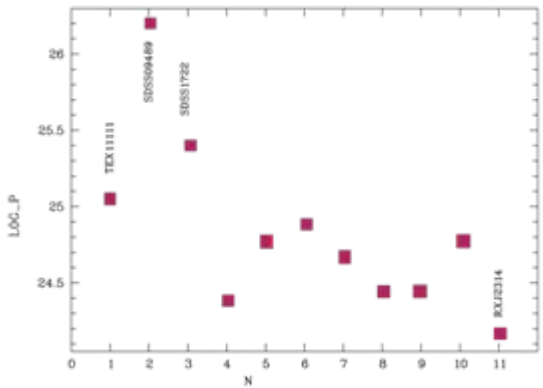
- **why are RL NLAGN more rare than RL BLAGN ?,**
- **and is the mechanism for RLness the same in NLAGN and BLAGN ?**

radio-loud NLS1s: models

- **<u>starburst contribution</u> ?**

- **radio powers** *P* are all in RL regime

- ***IRAS* – radio corr.:** *P* factor ~**10-120** above expected SB contrib.



- **<u>relativistic beaming</u>** ? → pole-on view

  - most are steep spectrum sources, with radio spectral indices α_r **<** -0.5; beaming not expected

    exceptions: SDSS0948+0022, RXJ16290+4007: α_r=0.6, 0.4

  - X-ray spectra of beamed sources typically much flatter

Σ: no SBs expected to dom. / 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 gow ext. jets/lobes

- **accretion mode**: in Gal. X-binaries 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

- **<u>host galaxies</u>:**

- central brightness profile (powerlaw vs core galaxies) is linked to RL-ness (only `cores` are radio-loud) → 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 - γblazar**

}* not much known about host gals. of NLQSOs

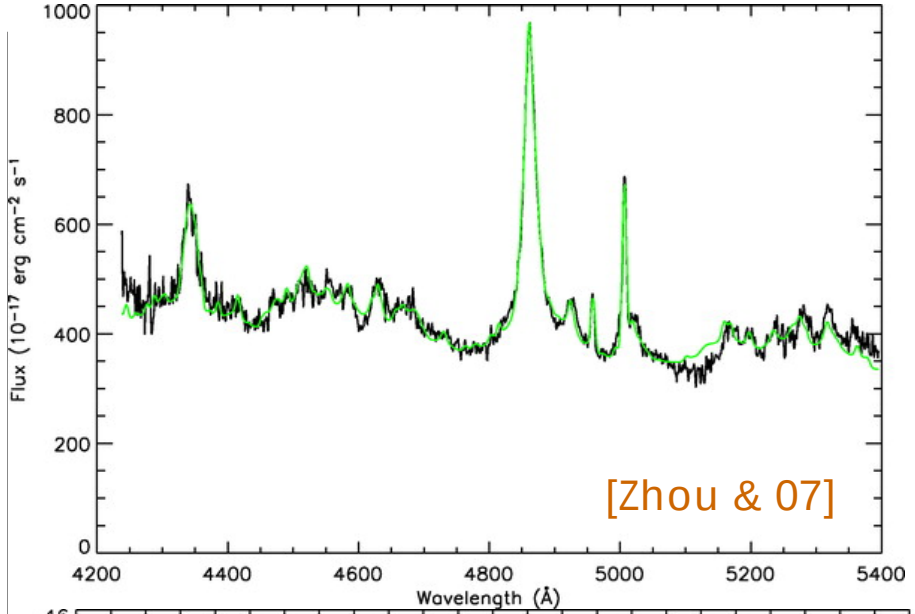
radio-loud NLS1s: follow-up studies first results from a larger sample

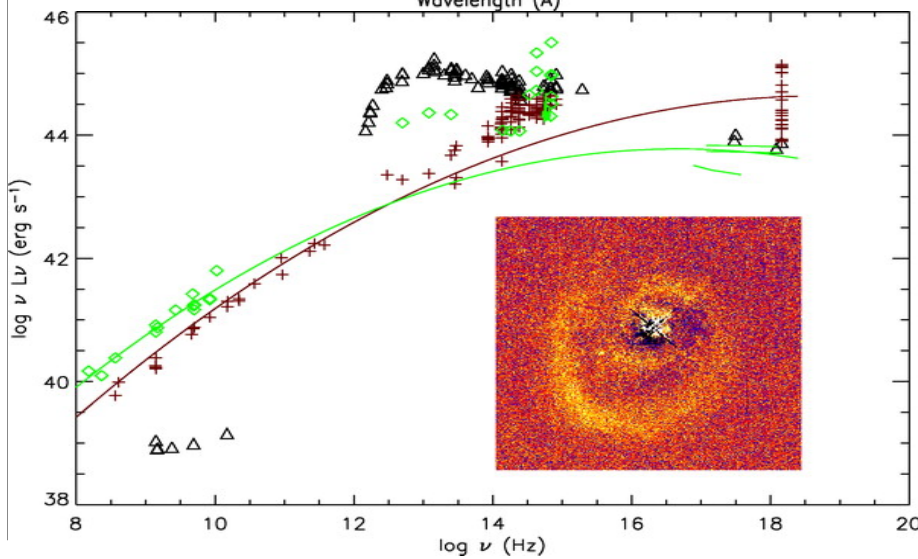
NLS1 – blazar composite:

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





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

[20006a, *ApJ* 639; 2006b, *AJ* 132; 2007 *ApJL* i.press]

- **significant increase in # of known radio-loud NLS1s**
- **fraction of RL NLS1s (7%) < RL BLAGN, almost none with R>100 → 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 FeII/Hβ), 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-λ imaging & spectroscopy **→ new light on RLness & NLS1 models, on BH properties (masses, spins) and environ. (acc.rate) and/or galaxy merging histories**