Gravitational Lens Mapping of the Narrow Line Region in Quasars

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1. Introduction

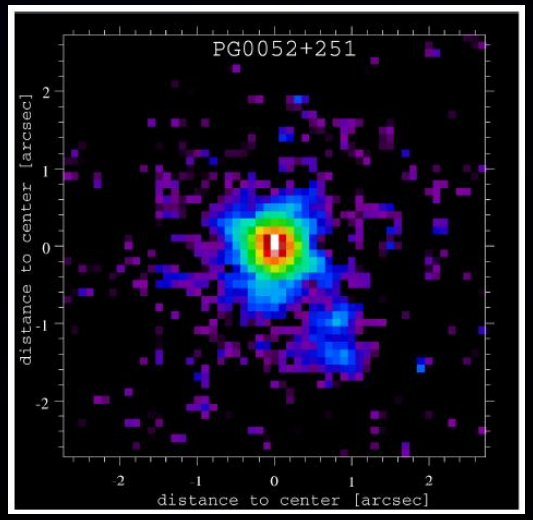
Narrow Line Region (NLR)

Spatially extended, line emitting region
← AGN unified scheme (Antonucci 1993)

In an optically thin regime, balance of
"Ionizing photons" VS "Recombining atoms"

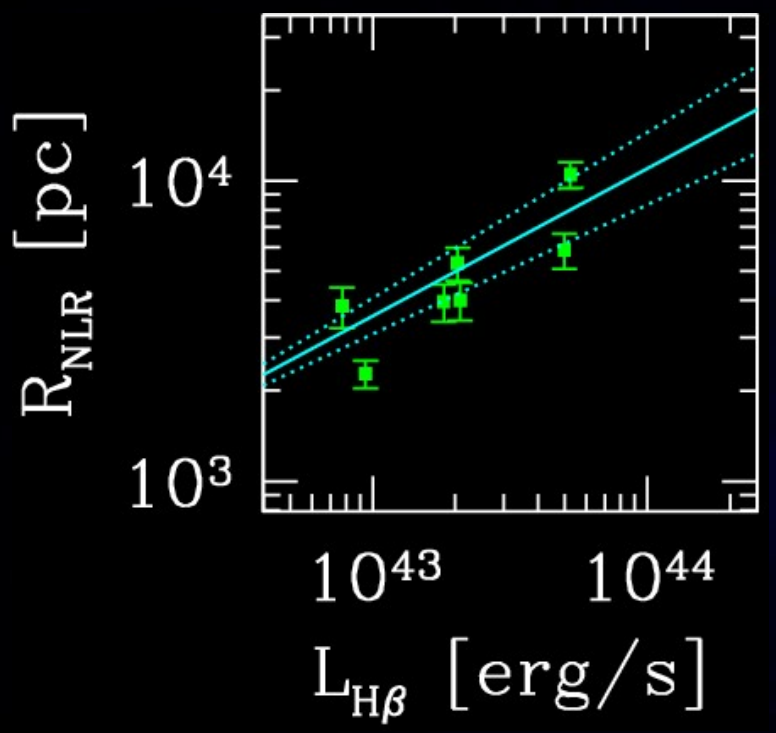
- Source luminosity ($\propto L$)
- Volume of ionized gas ($\propto 4\pi R^2 c$)

$\Rightarrow R \propto L^{1/2}$



NLR (HST, narrow band)
Bennert et al. (2002)

Size-Luminosity Relation; Quasars



$\Rightarrow R \propto L^{0.67\pm0.15}$ (solid line)

sample: quasars at "z < 0.4"

$\rightarrow R \propto L^{0.52\pm0.06}$

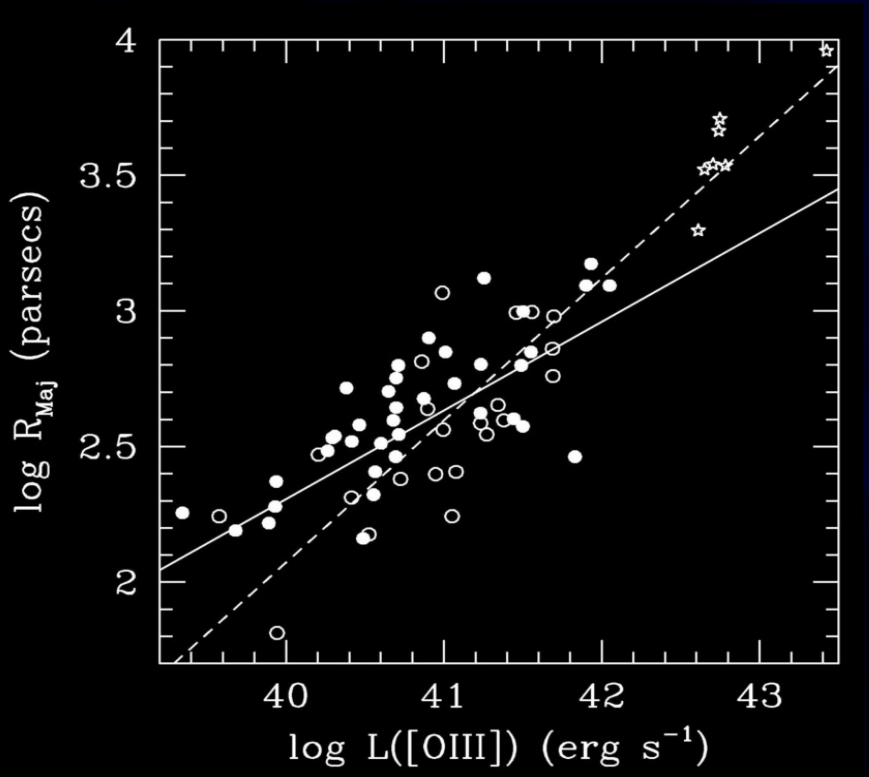
sample including Seyfert 2

consistent with simple model (Bennert et al. 2002)

$\Rightarrow$ the relation may change at some stage

Size-Luminosity Relation; Seyferts

Positive correlation betweem size of NLR ([OIII]) and AGN luminosity (Hβ etc.) via narrow band imaging



⇒ $R \propto L^{0.33\pm0.04}$ (solid)

inconsistent with simple estimation (Schmidt et al. 2003)

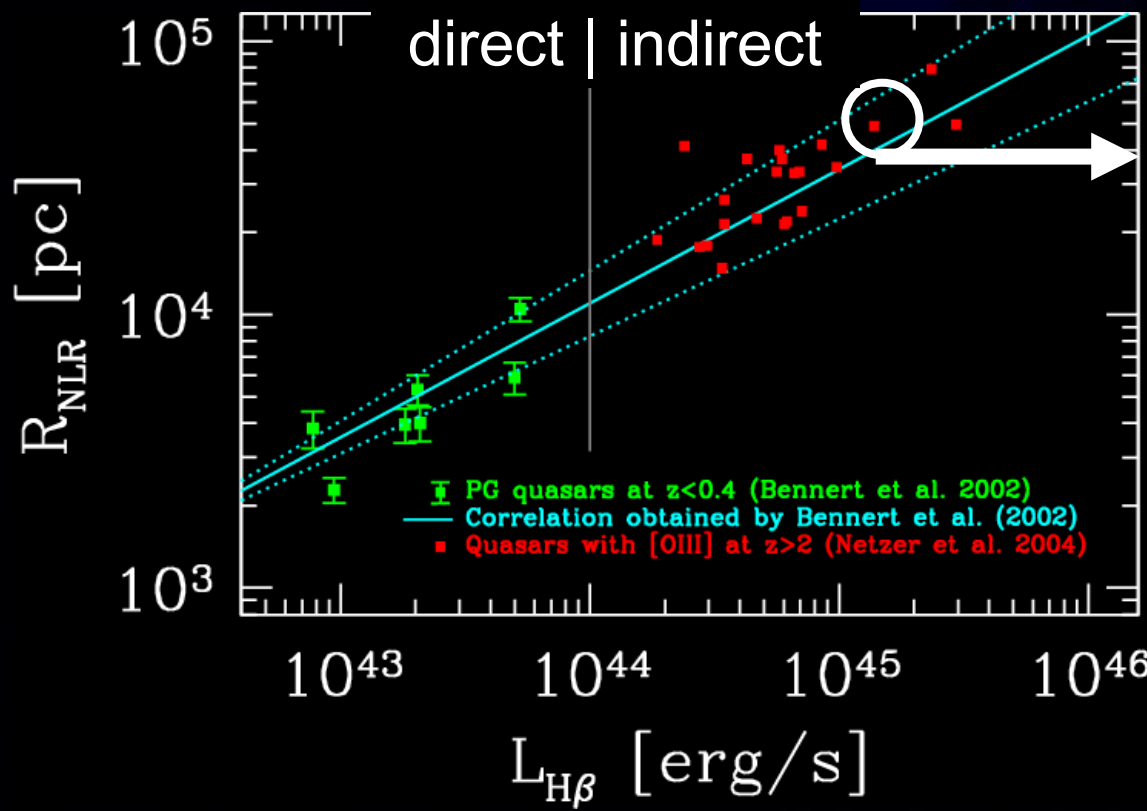
○: Type 1 Seyfert

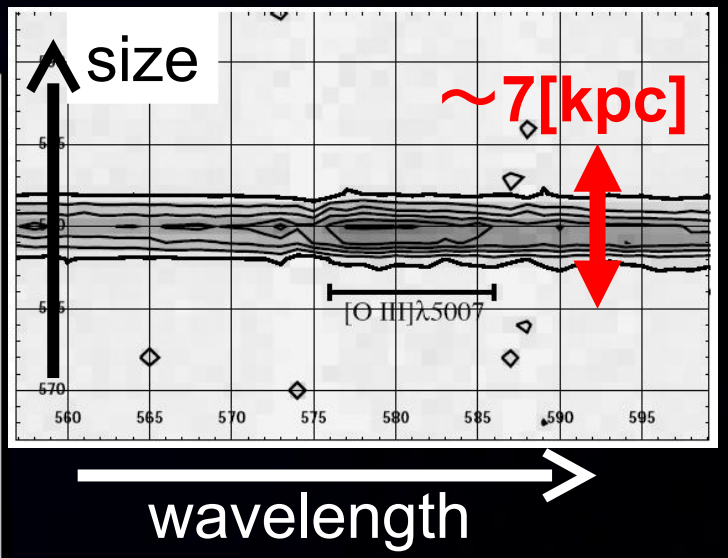
●: Type 2 Seyfert

The Relation at High z/$L_{H\beta}$(1)

NIR slit spectroscopy ([OIII] & Hβ at z>2)

→ R_{NLR} : R_{NLR} – $L_{[OIII]}$ relation at low-z (Netzer et al. 2004)

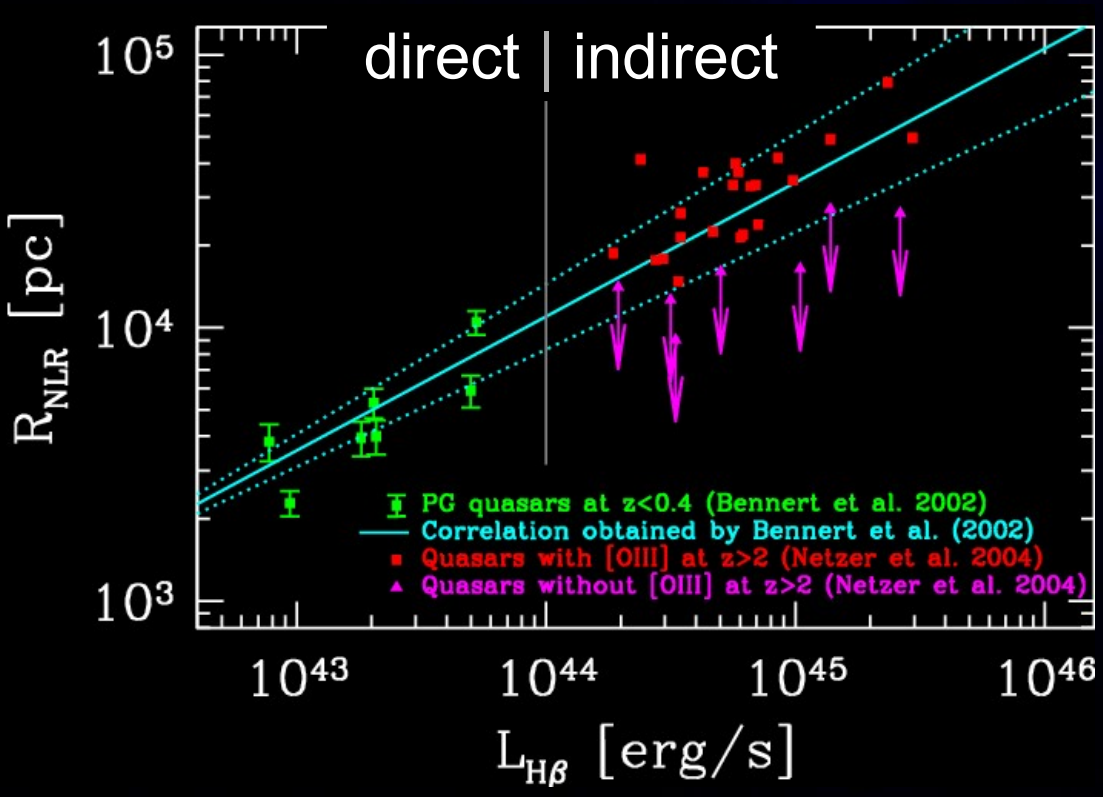




The relation breaks down at large $L_{H\beta}$

The Relation at High z/$L_{H\beta}$(2)

[OIII] emission line is not clearly detected
→ upper limit on R_{NLR} : R_{NLR} – $L_{[OIII]}$ relation
(Netzer et al. 2004)



No/faint NLR in these quasars?

At least, 2 types
- strong [OIII]
- weak or w/o [OIII]

The Relation at High z/$L_{H\beta}$(3)

Direct measurement of R_{NLR}
at high-L and/or high-z is required

- Essential difficulty :

  small apparent size (distant objects)
  e.g., 0.1 [arcsec] ～ 1 [kpc] at z～2
  ⇒ natural “magnifying glass” is required

- Technical difficulty :

  redshifted emission line(s)
  e.g., almost no proper NB filter for imaging
  ⇒ 3D (IFU) spectroscopy is necessary

2. Idea

Basic Idea: size dependence

[original image]

lensing

[lensed image]

larger source

Basic idea: model dependence

[original image]

lensing

[lensed image]

shallower density slope

Basic Idea: measurement

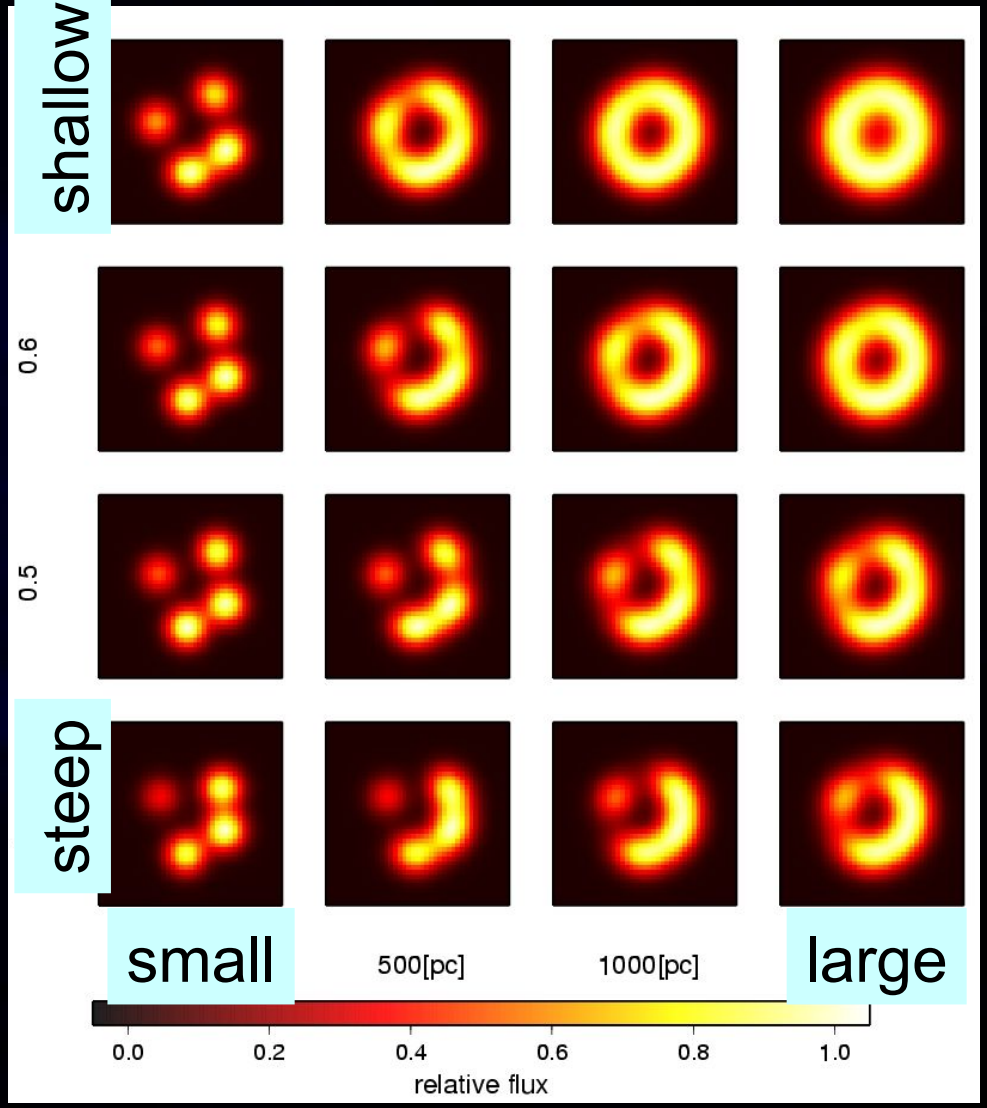
NLR size & lens model

Idea and application
(to Huchra's lens)

see Yonehara (2006)

Sampling rate: 0.1”

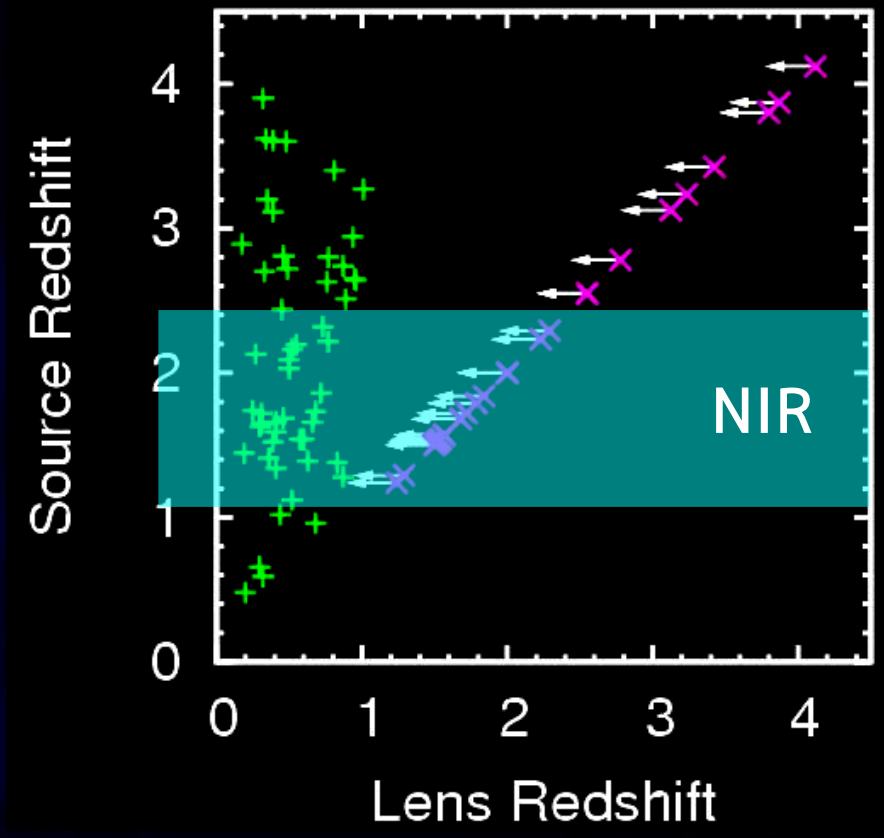
Seeing size: 0.7”



Observation of lens quasar (1)

Possible targets for direct measurement

- source redshift
  - mostly, z > 1
- target emission line
  - [OIII] & Hβ ～ 500nm at rest
  - IFS at NIR



Observation of a lens quasar (2)

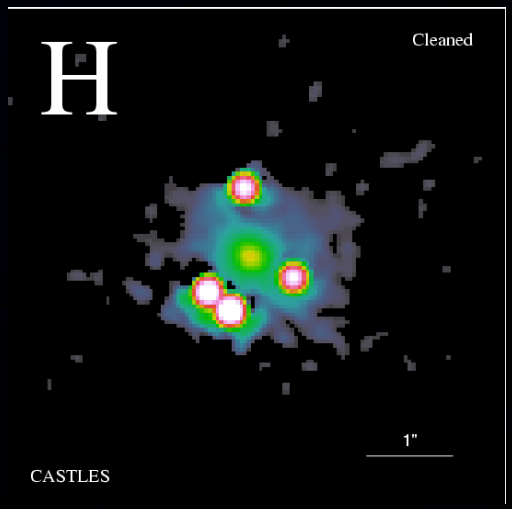
Observation:

VLT(UT4)-SINFONI

- service mode (IFS, w/o-AO)
- FOV = 8”(1pix = 0.125”)
- WFI 2026-4536
- H+K grating, 600[s]x10[OB]

WFI 2026-4536
quad. lens at z=2.23

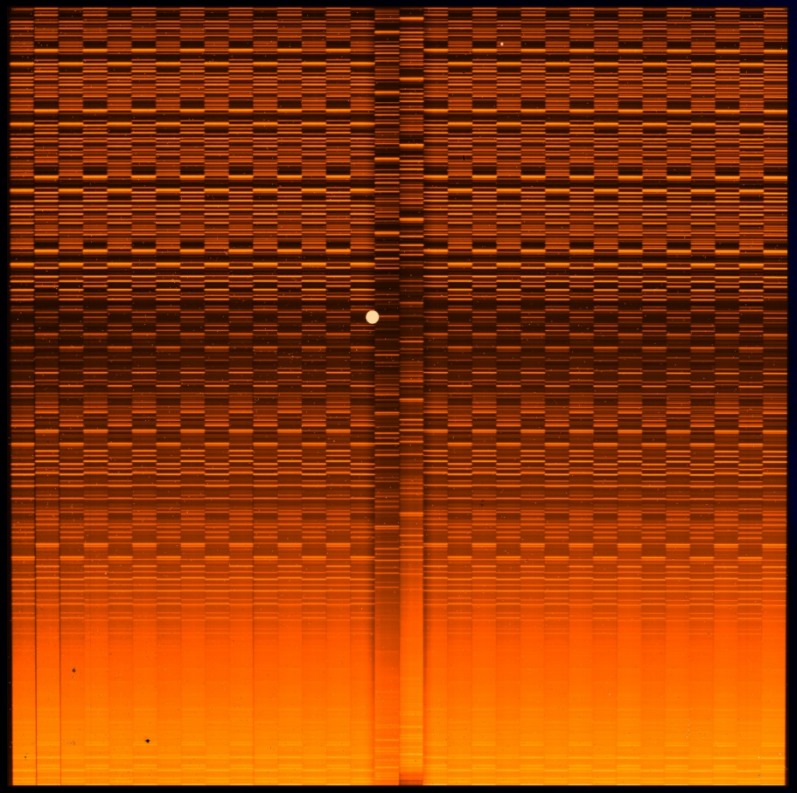
HST (CASTLEs)

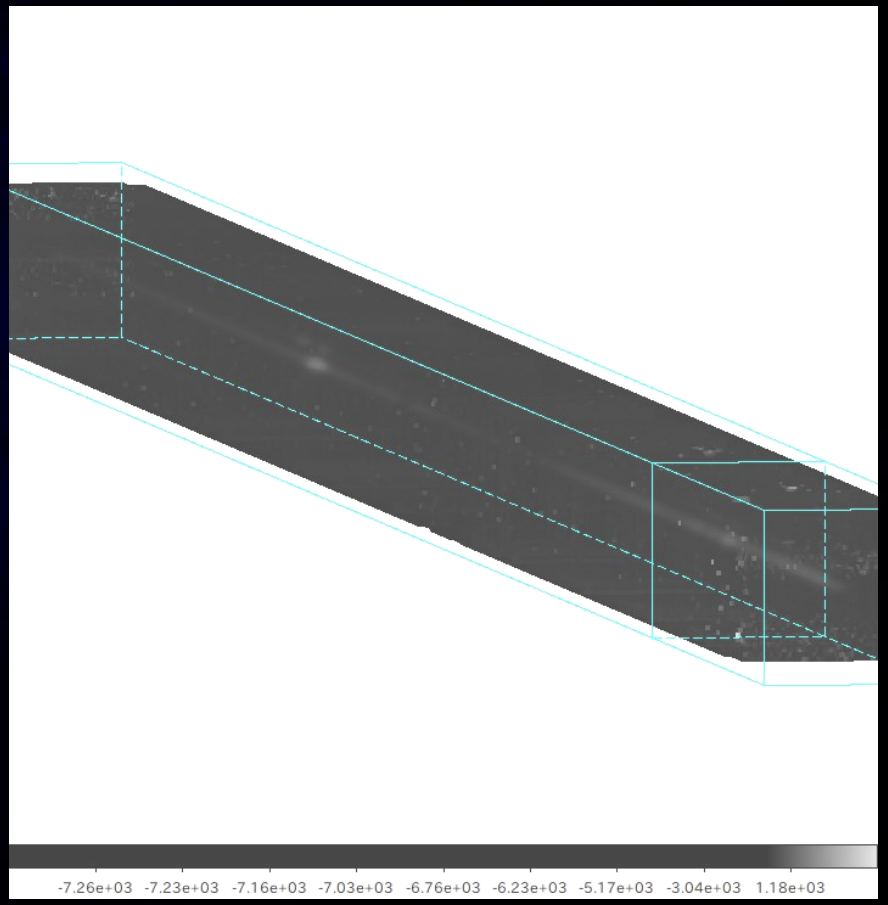


3. Result

Data analysis (1)

Mostly done by standard pipelines
⇒ “data cube” for WFI 2026-4536

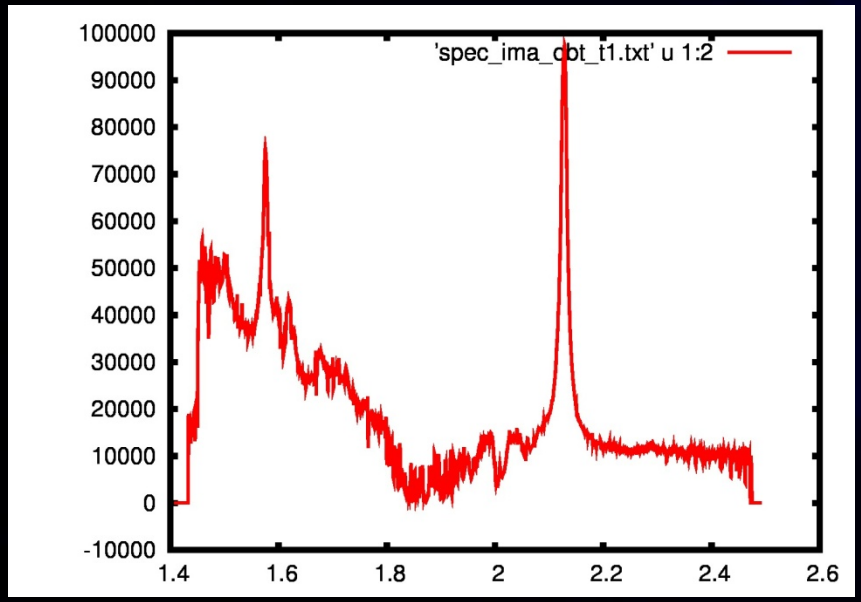




Data analysis (2)

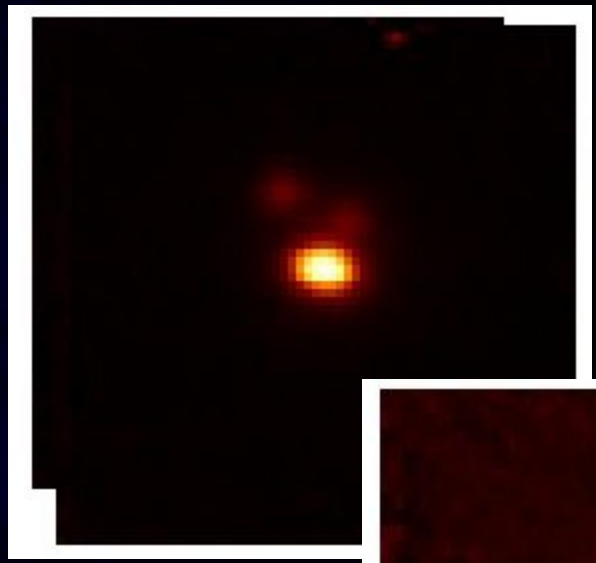
"Combined" spectrum

Image "cuts" (continuum, BLR, NLR etc.)

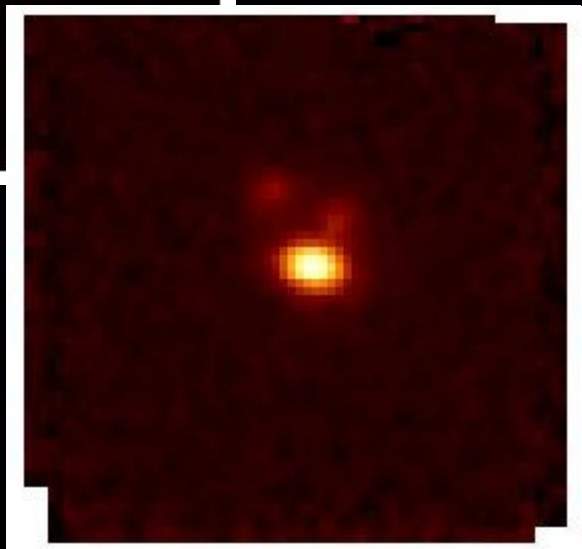


Hβ Hα

[OIII]

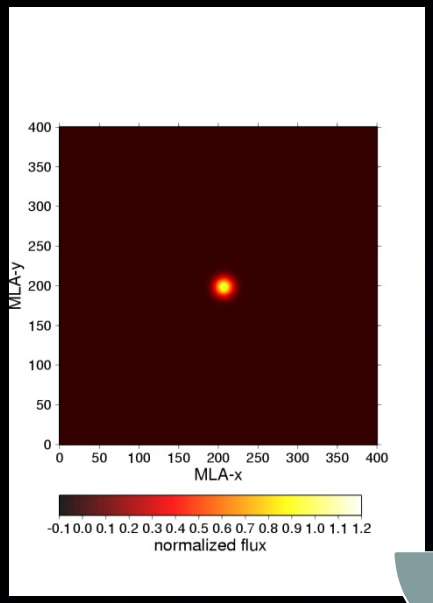


continuum

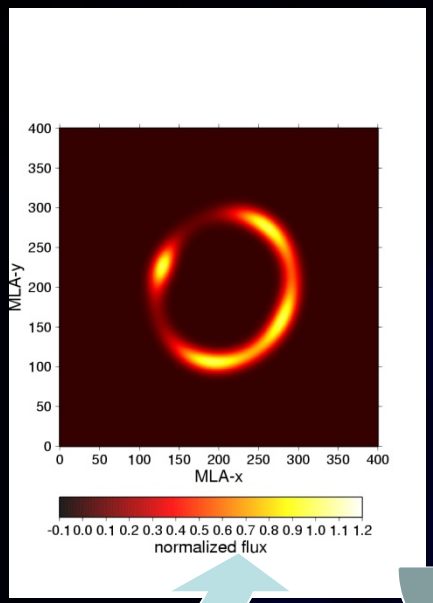


NLR, [OIII]

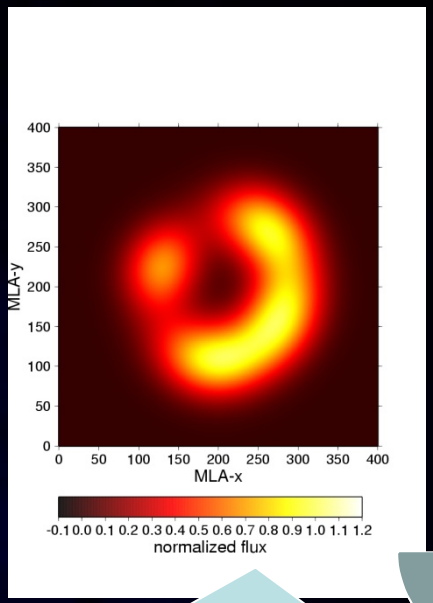
Model fitting (1)



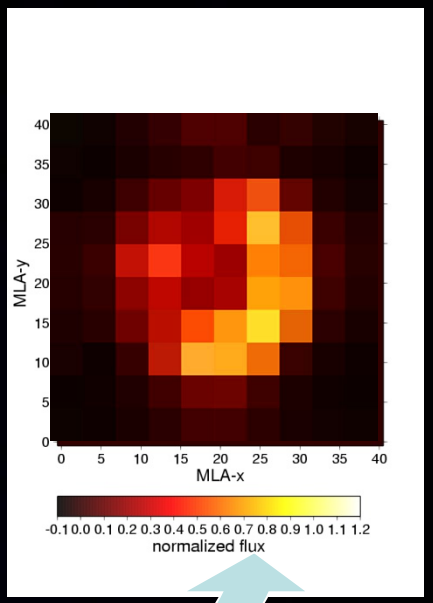
unlensed source (NLR)



lensing by a model



seeing effect



finite sampling

compare model image with observed image

→ the best fit parameters (χ^2-fitting)

Model fitting (2)

- Lens model :
  - (simple) elliptical potential model
  - various density slope (by fitting HST images)

potential $$\varphi(\vec{\theta}) = \alpha_E^{2-2\lambda}\left[(1-e)\theta_x^2 + (1+e)\theta_y^2\right]^{\lambda}$$

- NLR model :
  - circular source
  - Gaussian emissivity profile ($\sigma \rightarrow$ size)

Model fitting (3)

- PSF model :
  - reference is Hβ line wing (BLR, compact)
  - fitting for each OB with elliptical Gaussian

    → reduced $\chi^2 \sim 1$
- Cube co-addition :
  - create model for each OB (NLR images) for a given lens model, NLR size, and PSF
  - co-add model OB, compare with data

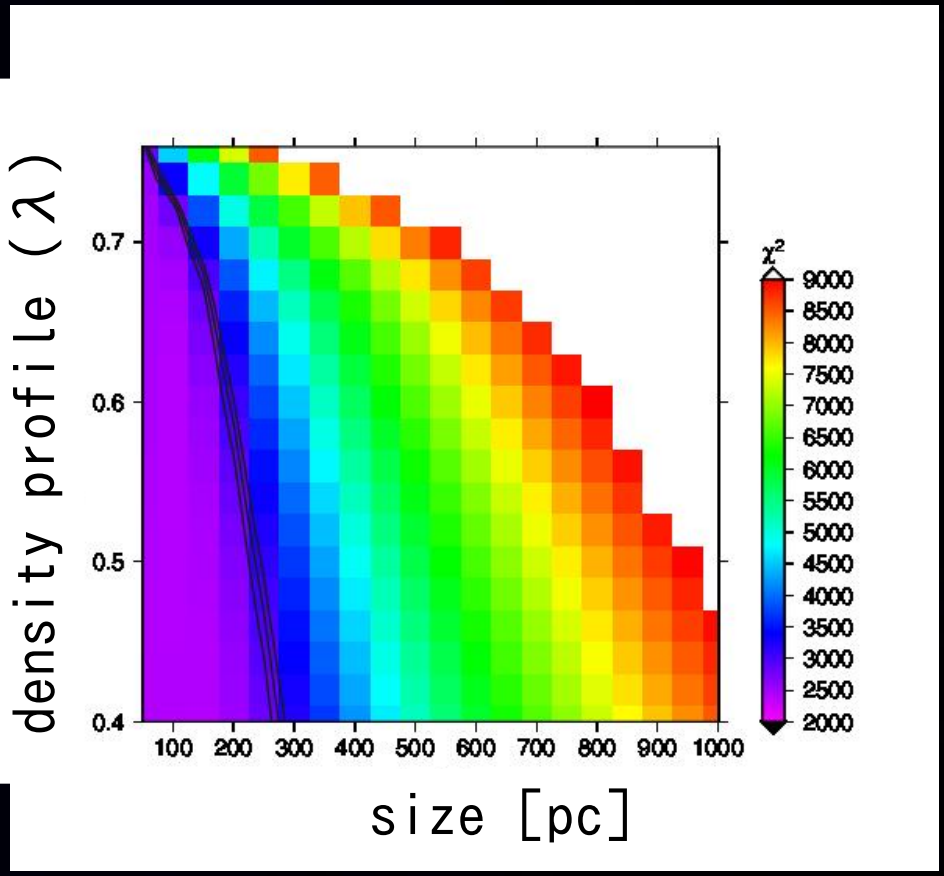
→ grid search for lens model and NLR size

Result: lens model and NLR

- Best fit model
  - NLR size : point like
  - density slope : λ ～0.6

- 1-σ confidence via Δχ^2
  - NLR size < 250 [pc]
  - no constraint on λ

    (0.3-0.75 is acceptable

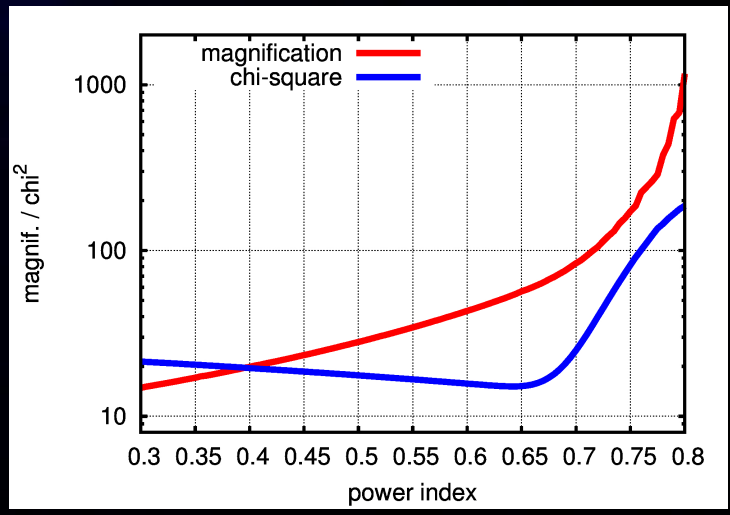


1. Introduction

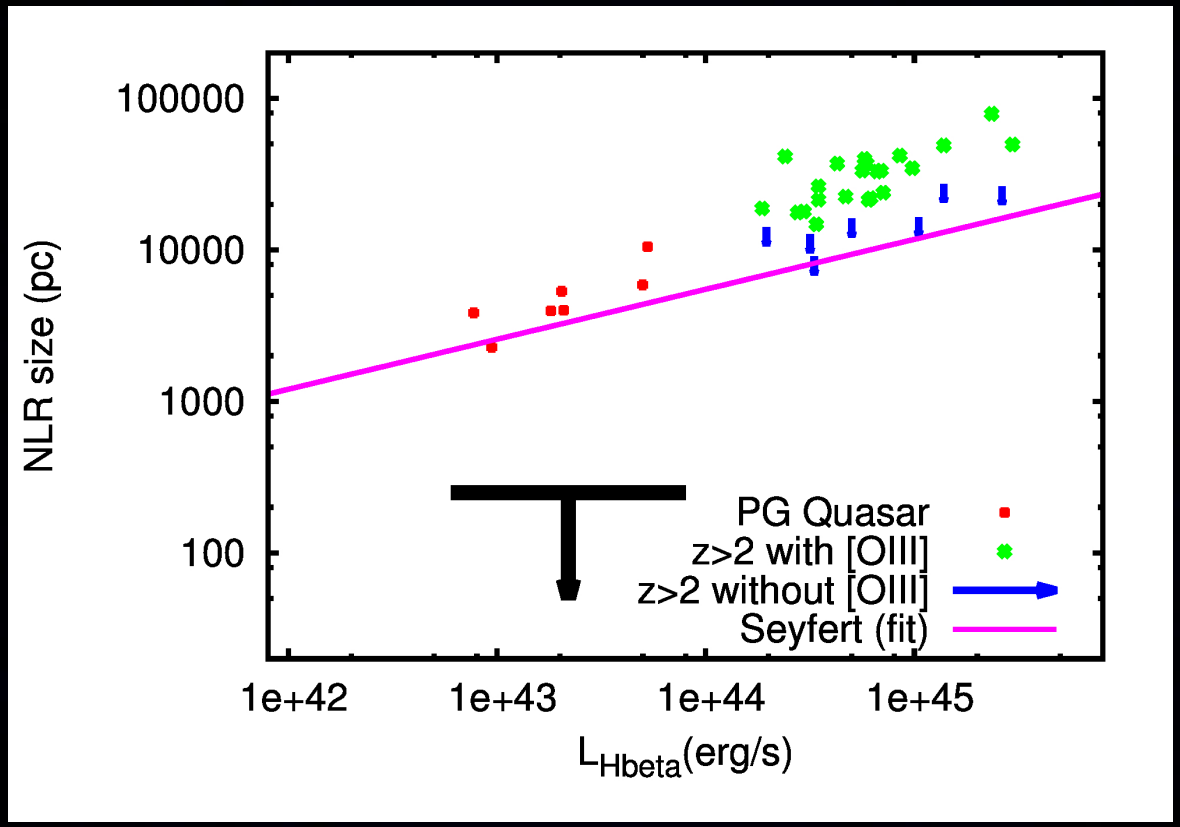
Result: quasar (Hβ) luminosity

- Hβ flux estimate via standard star
  → 3.2 x 10^{-14} [erg/s/cm^2]
- D_A (z=2.23) from standard cosmology
  → 5.5 x 10^{28} [cm]
- Magnified by 15 ～ 200

- L_{Hβ}
  - 6.0 x 10^{42} [erg/s] (lower)
  - 8.0 x 10^{43} [erg/s] (upper)



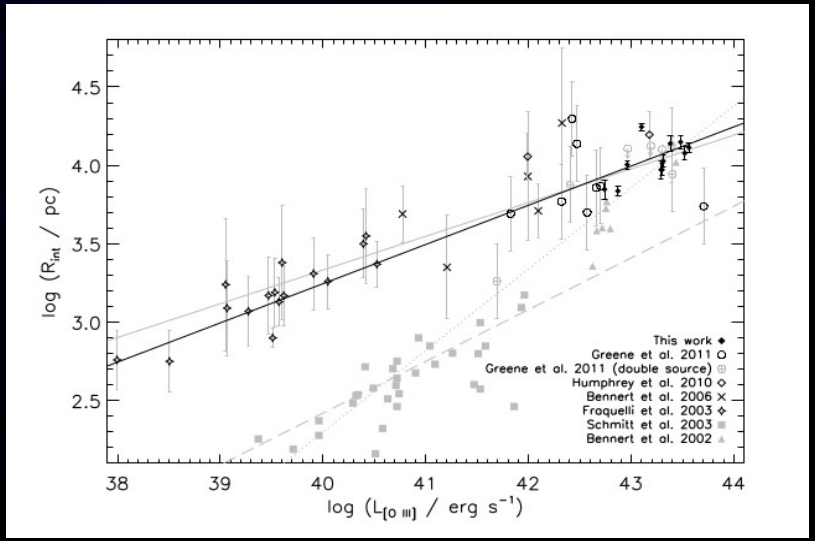
Results : size-luminosity relation



NLR size is far below the size expected from previously known size-luminosity relation

Future works

- Still high χ^2 value
  - Elliptical (elongated) source?
- Other lens quasars
- Other targets
  - Type-2 (viewing angle)
  - Radio-loud (mechanism)



Liu et al. (2013)