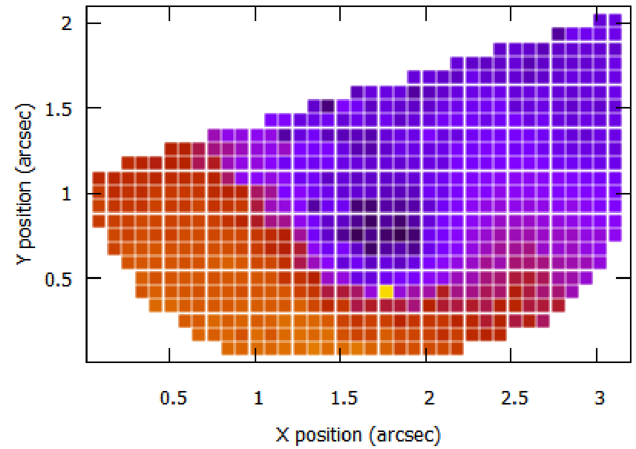
Some aspects of super-Eddington accreting AGNs -- Feedback Process and Illumination --

Toshihiro KAWAGUCHI (Onomichi City U., Japan)

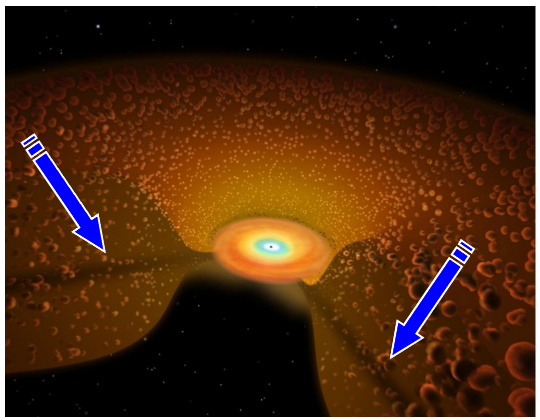
21--23 Oct, 2018（Slim Discs Workshop）

< Topics >

1. Fast, Dense, 100s-pc scale Outflow in super-Eddington AGN.
   Seems insufficient for feedback to host galaxy.



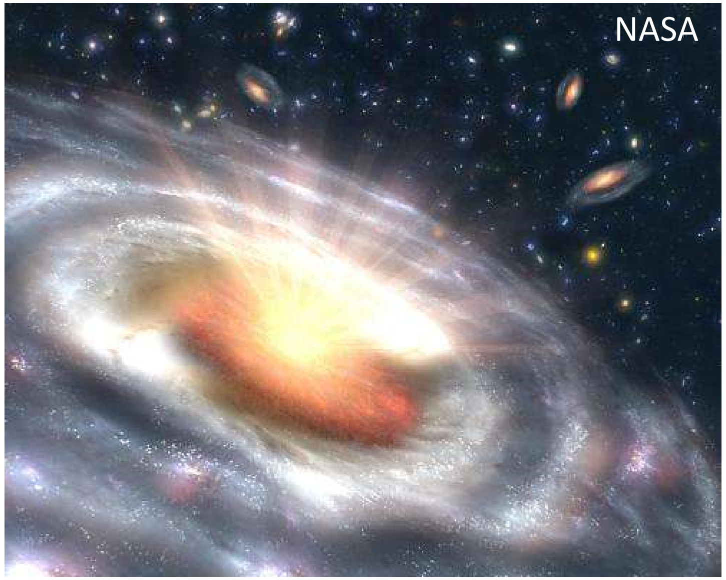
2. Large geometrical thickness of slim discs reduces Torus emission.
   "Dust-free quasars" may have non-illuminated tori.



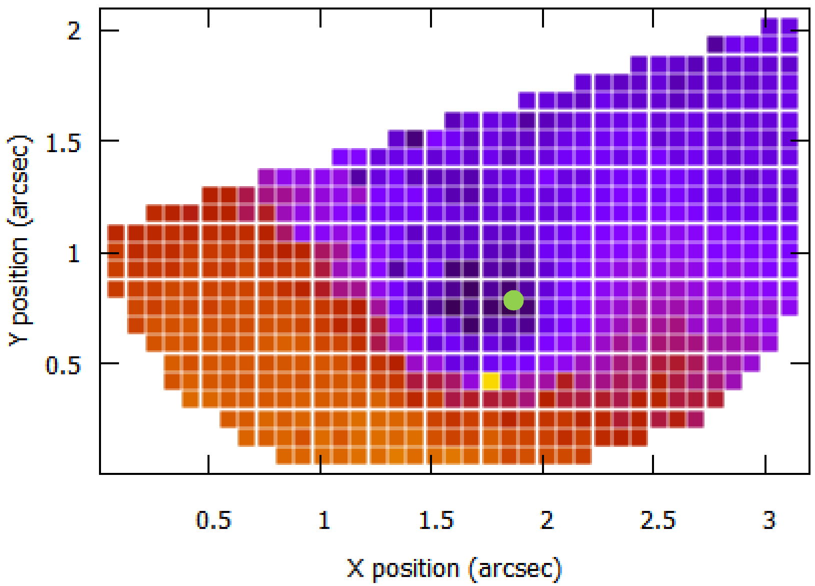
A 100-pc Scale, Fast and Dense Outflow in a Super-Eddington Accreting Active Galactic Nucleus

< Key questions >

* Is there really quasar-mode feedback?
* Is it powerful enough to quench star formation?



Velocity Field around Black Hole



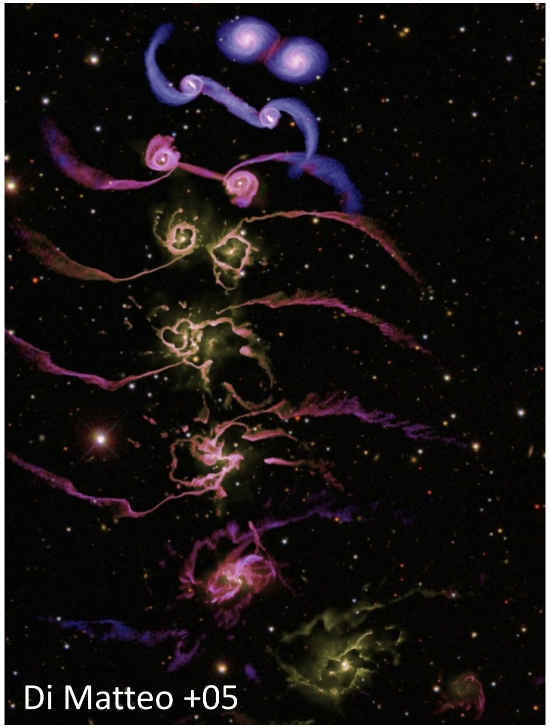
3.1” ~ 2.2kpc

(Kawaguchi + 2018)

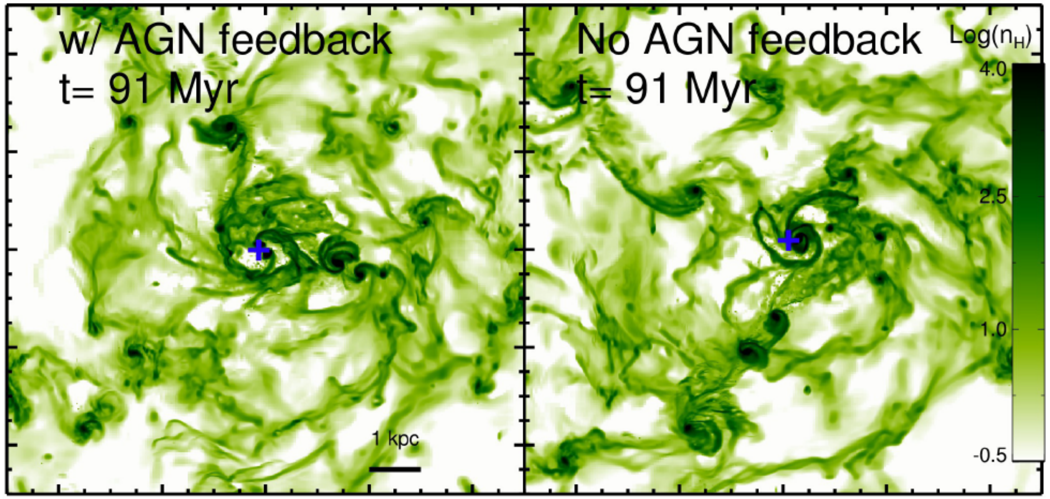
AGN outflows regulate black hole and galaxy evolution?

Yes: Silk & Rees 98; Fabian 99; King 03;
Schawinski +07; Wylezalek +16, ...

Di Matteo +05:
Galaxies collide,
Gas inflow towards
galactic center(s),
AGN onset,
Quasar-mode feedback,
Quenching gas inflow



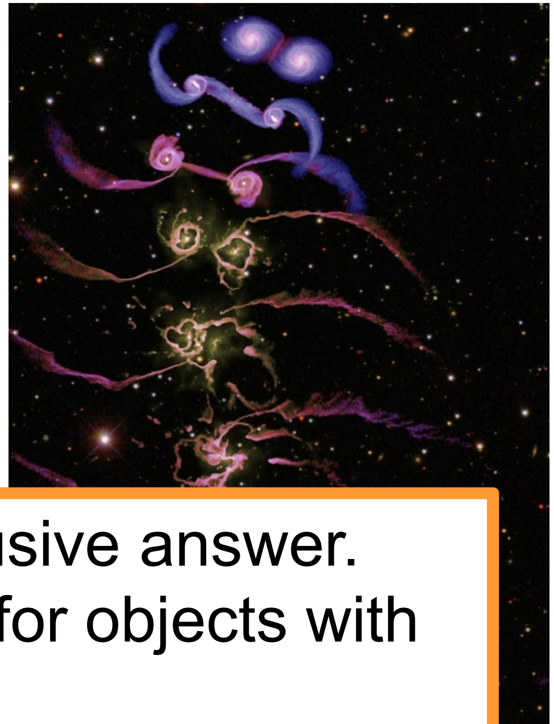
No: Balmaverde +16; Kakkad +16;
Carniani +16;
Villar-Martin +16;
Mahoro +17 ...



Gabor +14

AGN outflows regulate black hole and galaxy evolution?

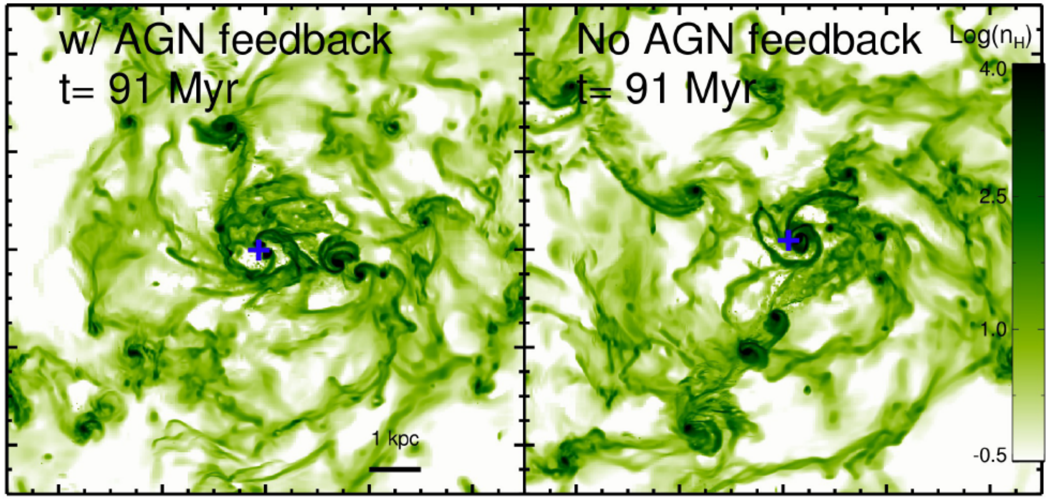
Yes: Silk & Rees 98; Fabian 99; King 03;
Schawinski +07; Wylezalek +16, ...



Di Matteo +05:
Galaxies collide,
Gas inflow towards

「Is there really AGN feedback?」 No conclusive answer.
→ Observations with high-spatial resolution for objects with galactic-scale outflow

No: Balmaverde +16; Kakkad +16;
Carniani +16;
Villar-Martin +16;
Mahoro +17 ...



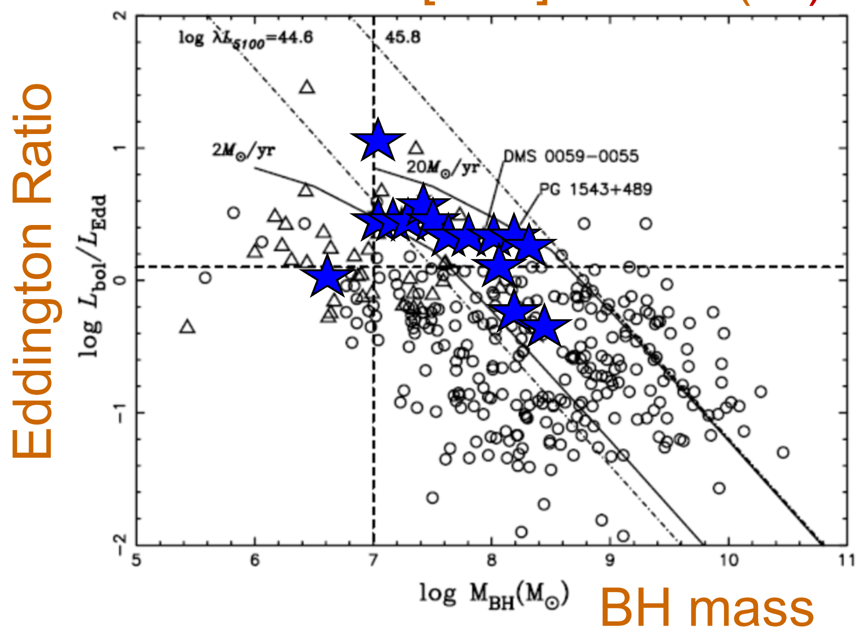
Gabor +14

Our targets: AGNs with [O III] blueshifts (>= 300km/s)

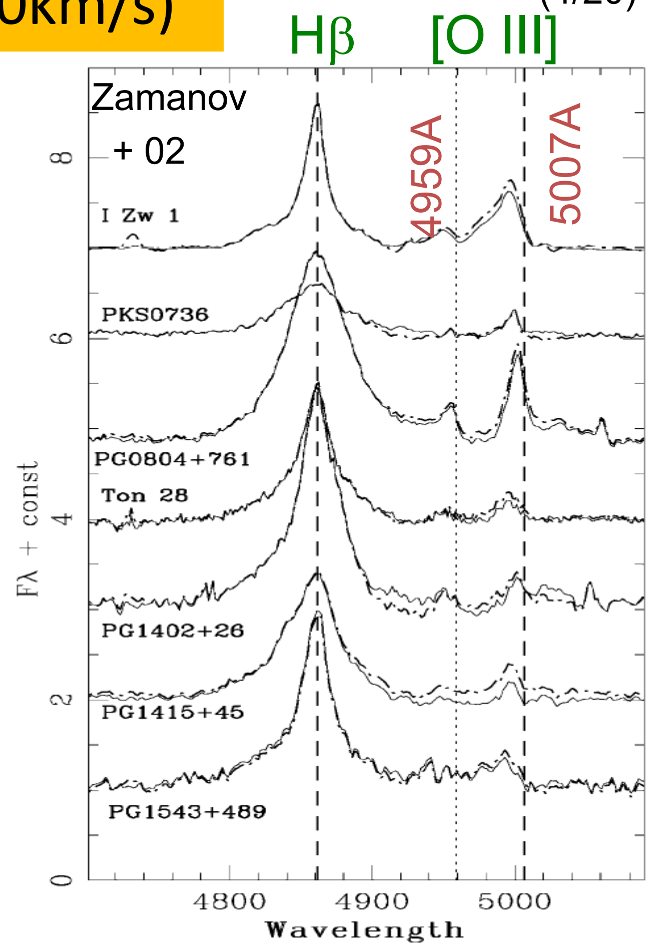
* Outflow in narrow line region (Radio-quiet = not jet-driven)

* Outflows occur when accretion rates onto central BHs are large (super-Eddingoton), e.g., Narrow-line Seyfert 1 galaxies.

AGNs with [O III] outflow(★)



Aoki, Kawaguchi, Ohta 05



Galactic-scale fast outflow (AGN feedback site?) associated with rapid BH growth (Kawaguchi 03; +04)

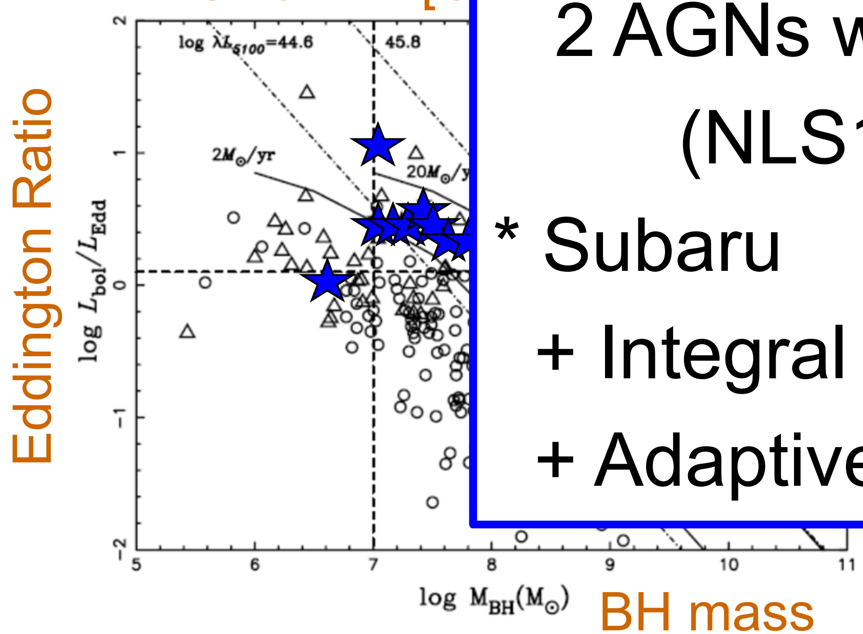
→ Laboratory for BH-galaxy coevolution

Our targets: AGNs with [O III] blueshifts (>= 300km/s)

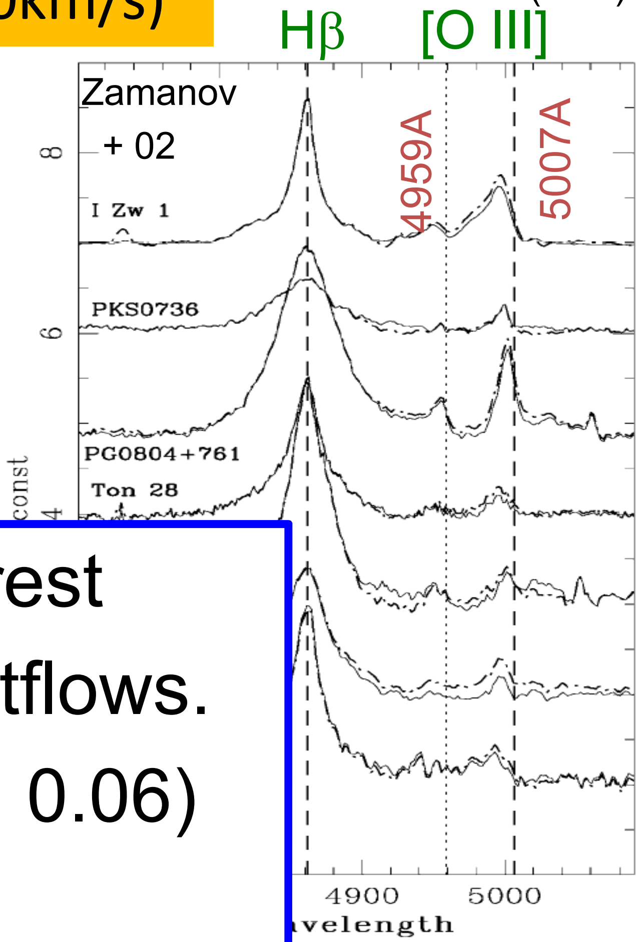
* Outflow in narrow line region
  (Radio-quiet = not jet-driven)

* Outflows occur when accretion rates onto central BHs are large (super-Eddingoton), e.g., Narrow-line Seyfert 1 galaxies.

AGNs with [O



Aoki, Kawaguchi, Ohta 05



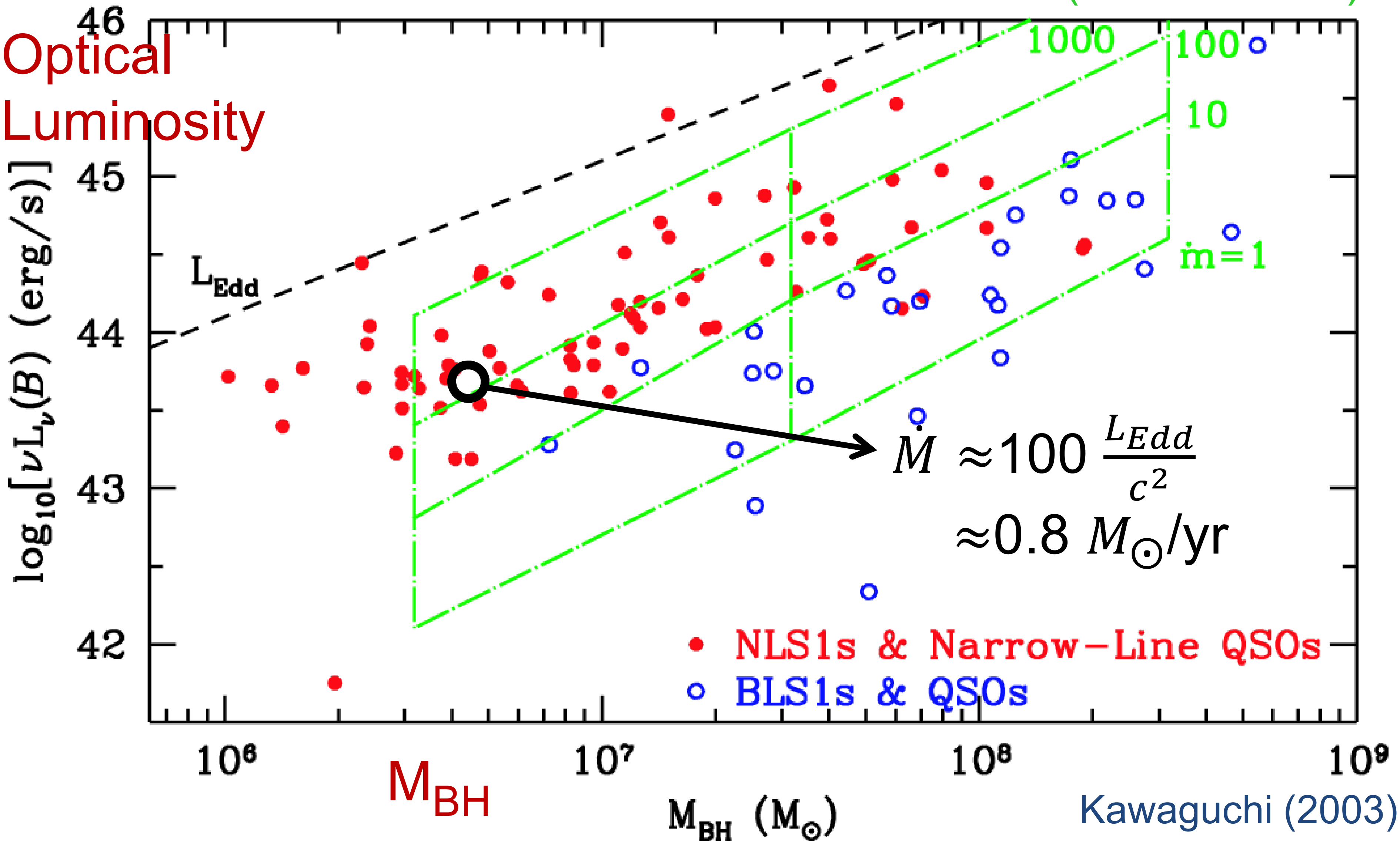
* We observed the nearest 2 AGNs with [O III] outflows.
  (NLS1s at z=0.04, 0.06)
* Subaru
  + Integral Field Spectroscopy
  + Adaptive Optics

GN feedback
BH growth
guchi 03; +04)

→ Laboratory for BH-galaxy coevolution

IRAS04576 along with other AGNs

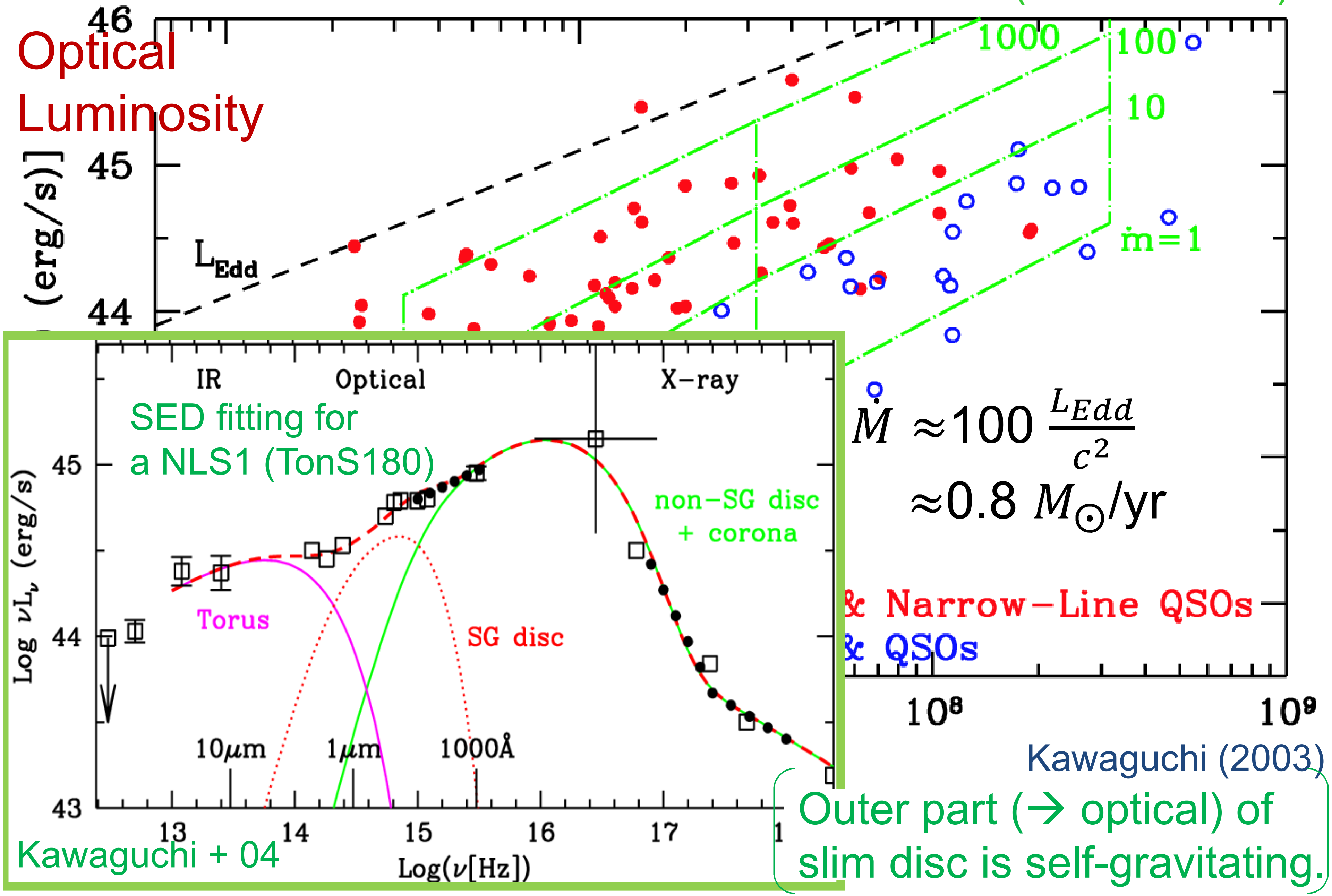
Green lines: Disc model (thin and slim)



Kawaguchi (2003)

IRAS04576 along with other AGNs

Green lines: Disc model (thin and slim)



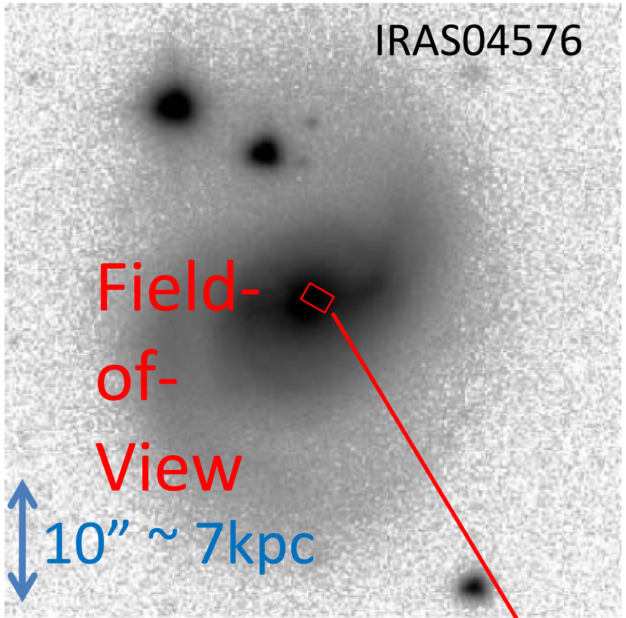
$$\dot{M} \approx 100 \frac{L_{Edd}}{c^2} \approx 0.8\ M_\odot/\text{yr}$$

Kawaguchi (2003)

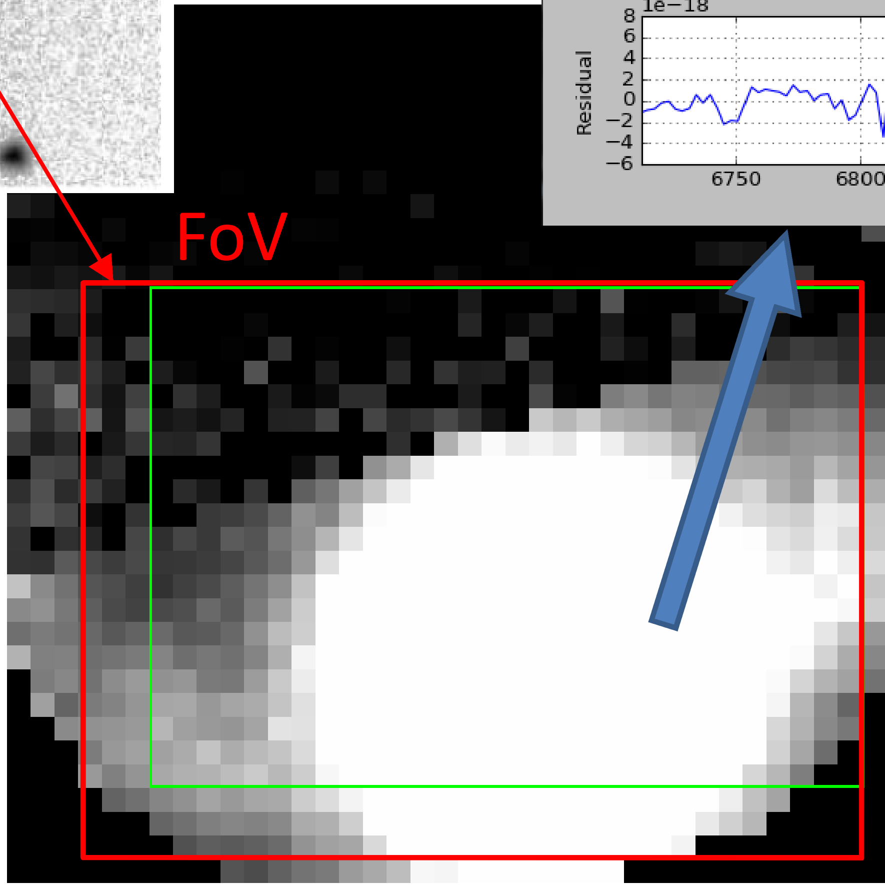
Outer part (→ optical) of slim disc is self-gravitating.

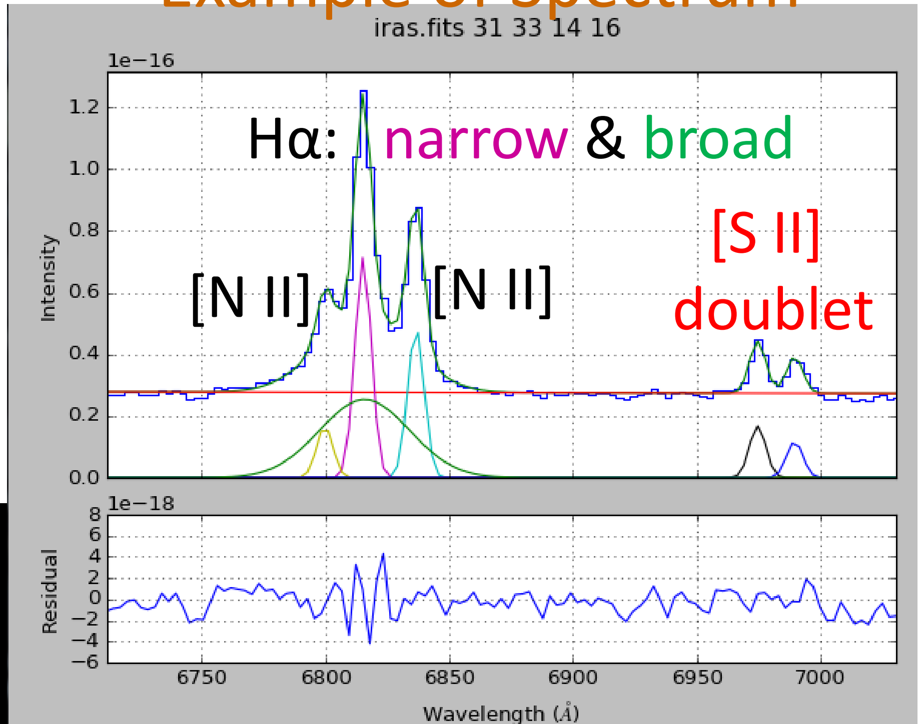
Data analysis for IRAS 04576

Example of Spectrum



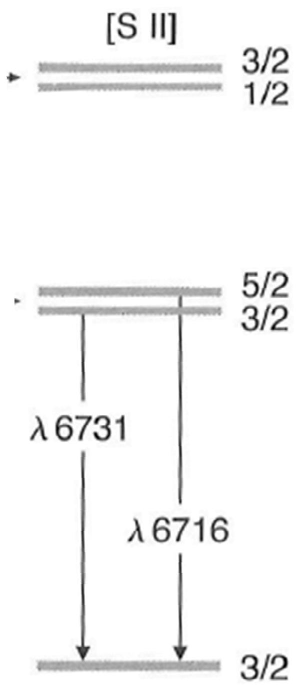
Ohta, Aoki, Kawaguchi, Kiuchi 2007





Integral Field Spectroscopy = Spectrum at each position

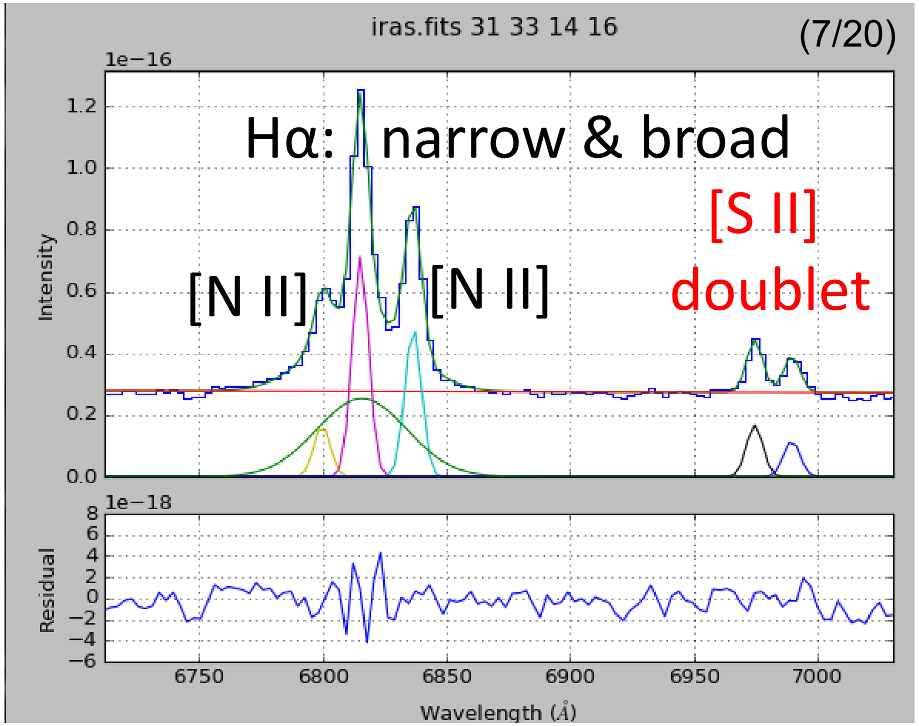
Density-sensitive [S II] emission lines (6716, 6731 Å)

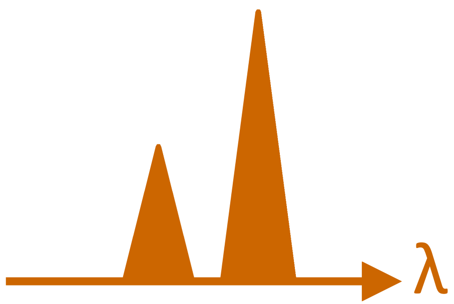


Density-sensitive [S II] emission lines

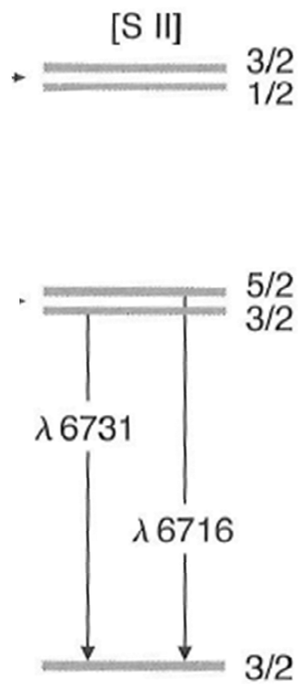
High density
→ Collisions
→ Lower level, then emit
→ longer wavelength, stronger

(Osterbrock & Ferland 06)



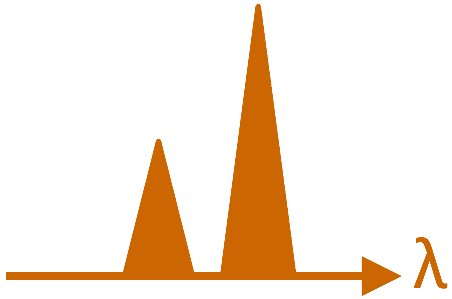


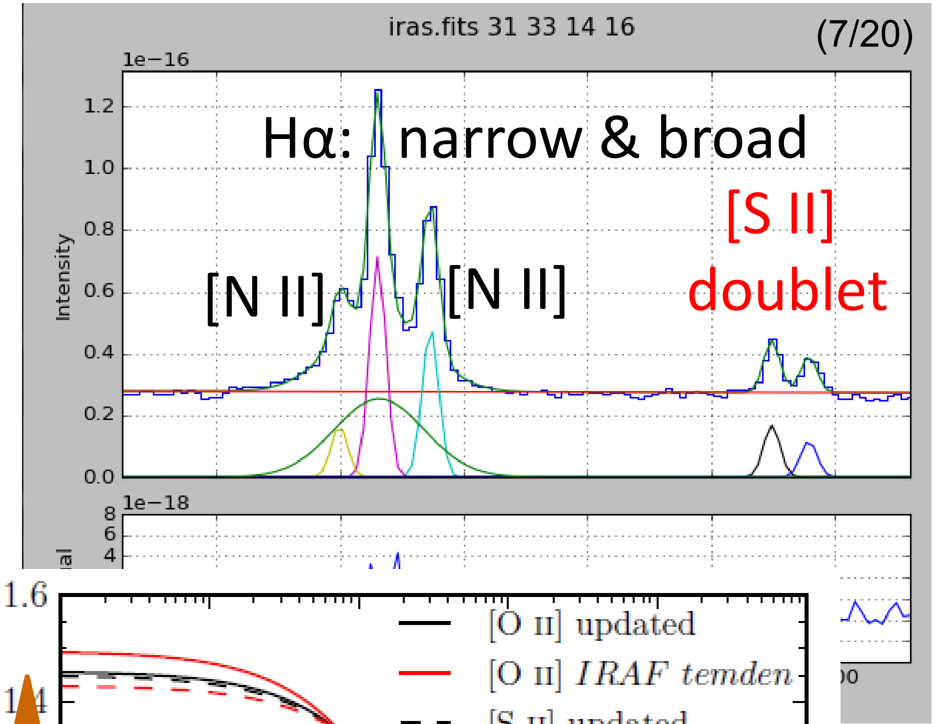
Density-sensitive [S II] emission lines

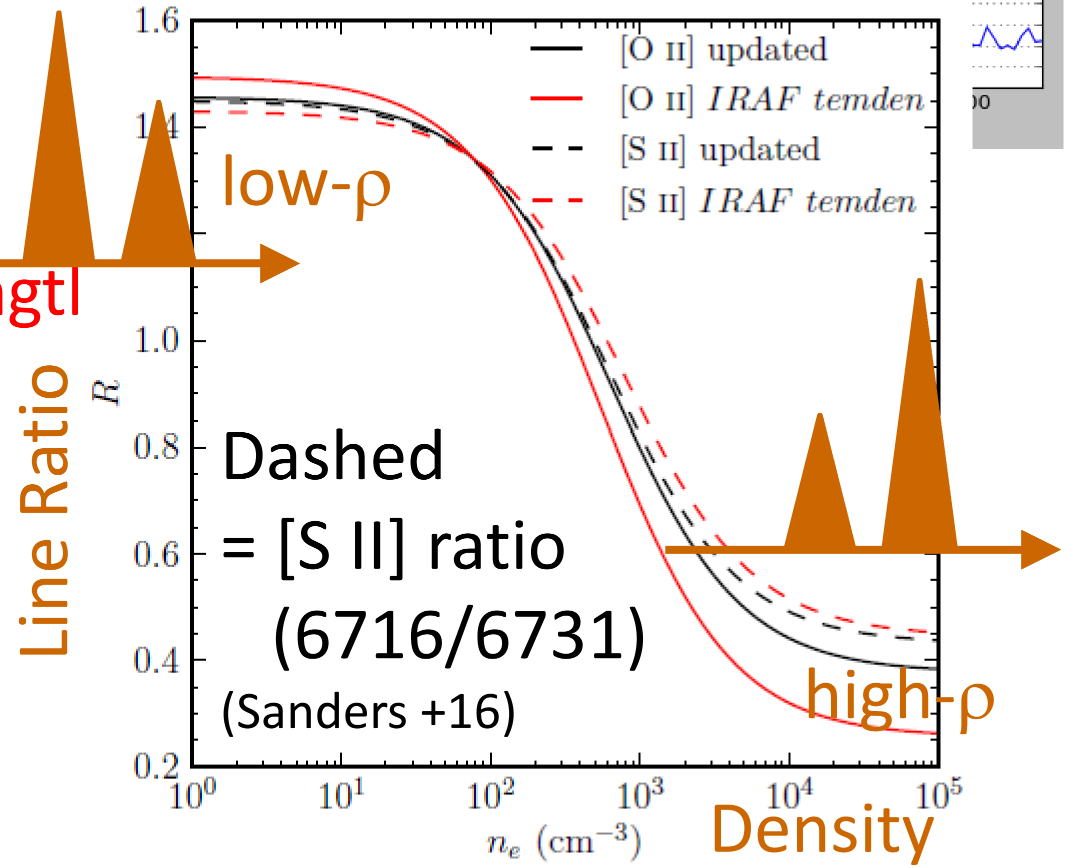


High density
→ Collisions
→ Lower level, then emit
→ longer wavelength stronger

(Osterbrock & Ferland 06)





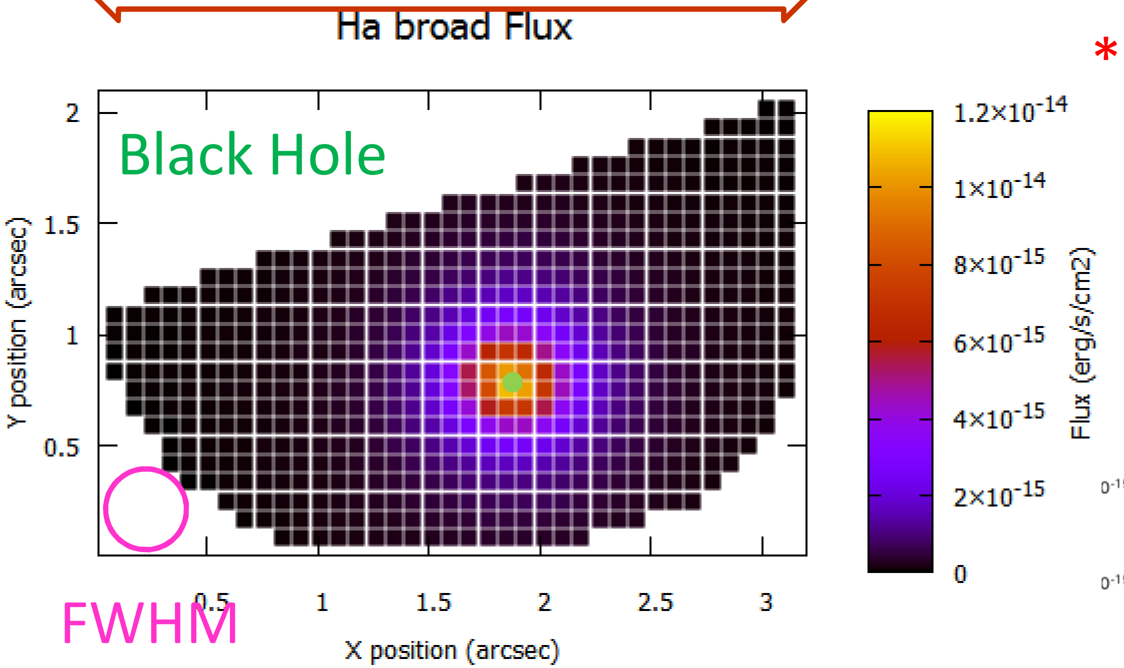


Flux Map of Hα Broad Emission Line: PSF

(Actual size of Broad-line-region ~ 0.01pc << 1pixel)

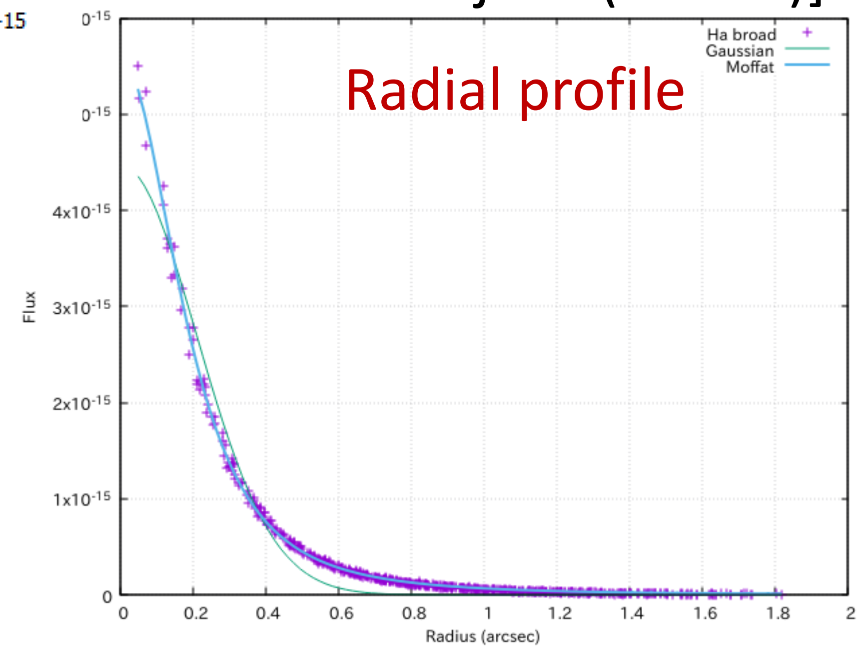
Spectral fit for 615 lenslets

3.1” ~ 2.2kpc



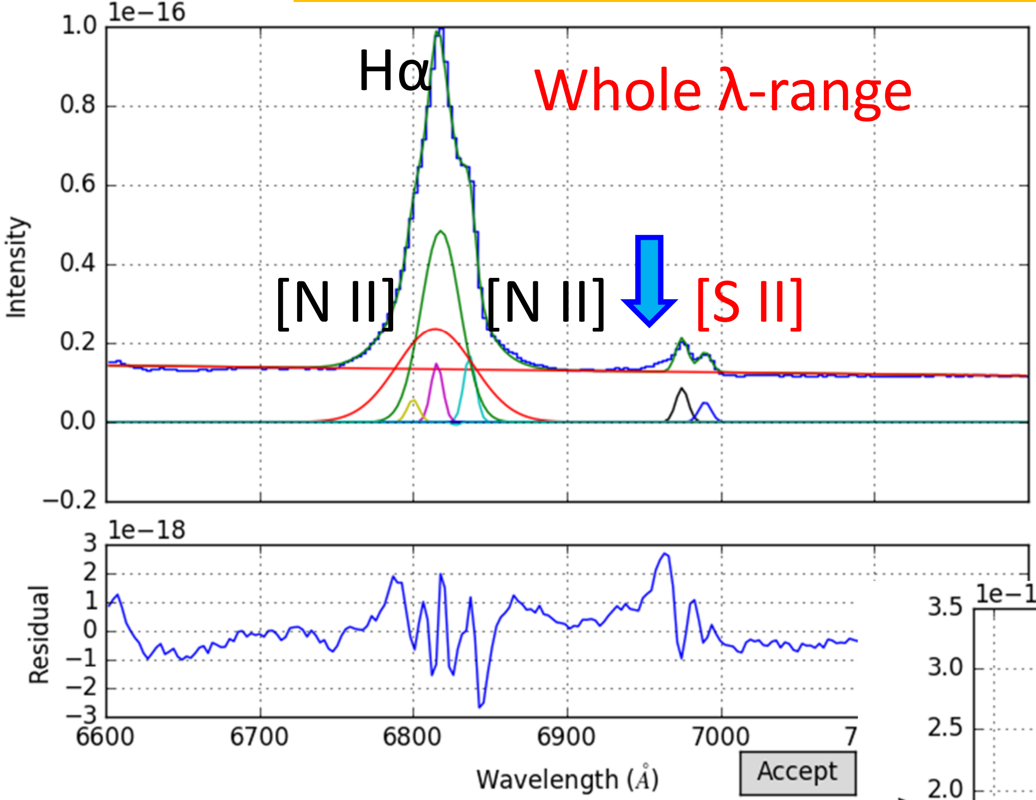
* Round shape of PSF

* FWHM ~ 0.37” [Better FWHM for another object (~0.2”?)]



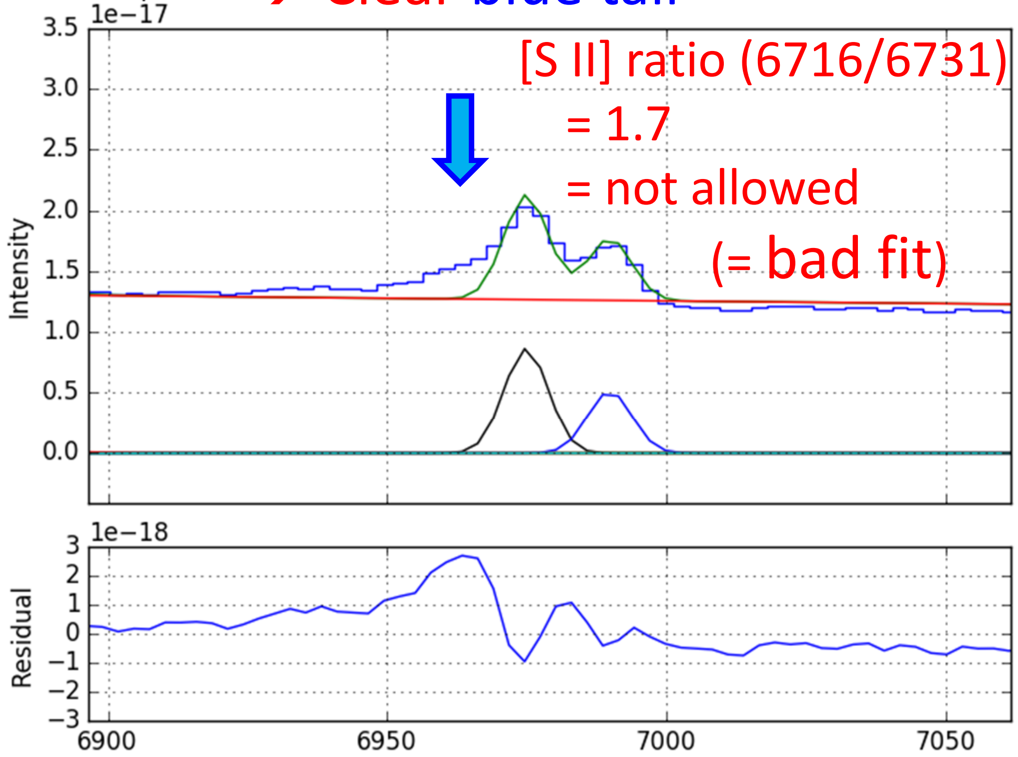
1 lenslet (0.084”) = 60pc

Blue tails of [S II] lines in many lenselets

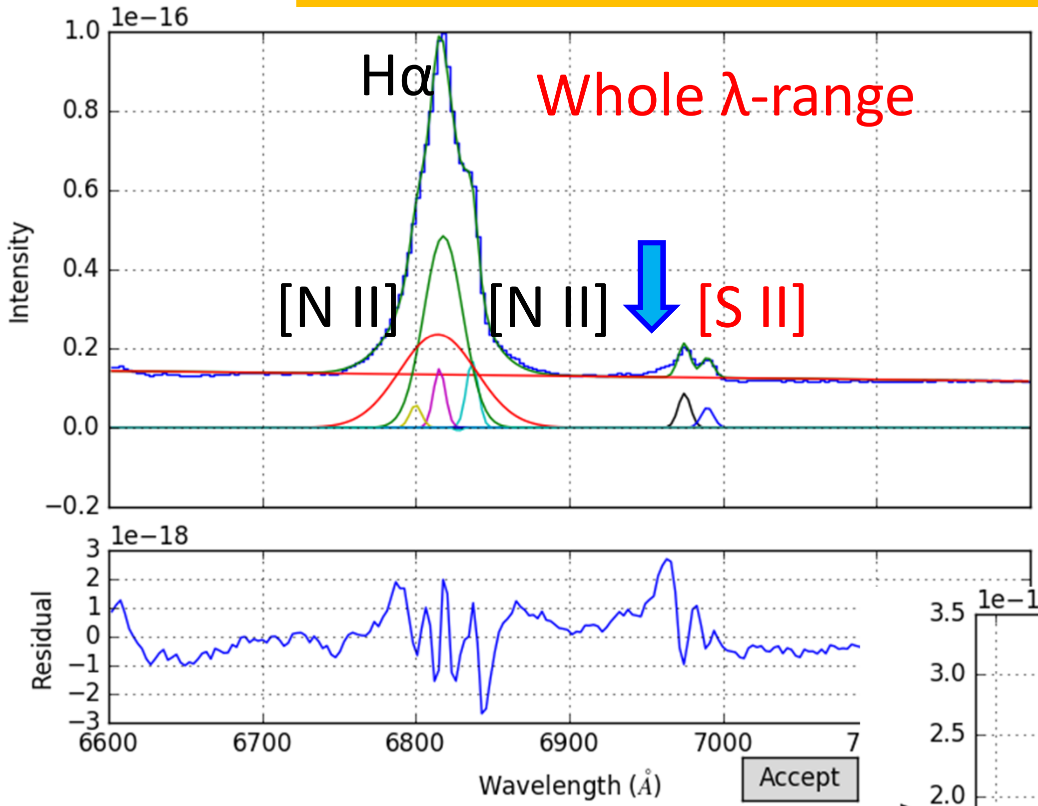


1-component Fit

Close-up View around [S II] :
→ Clear blue tail

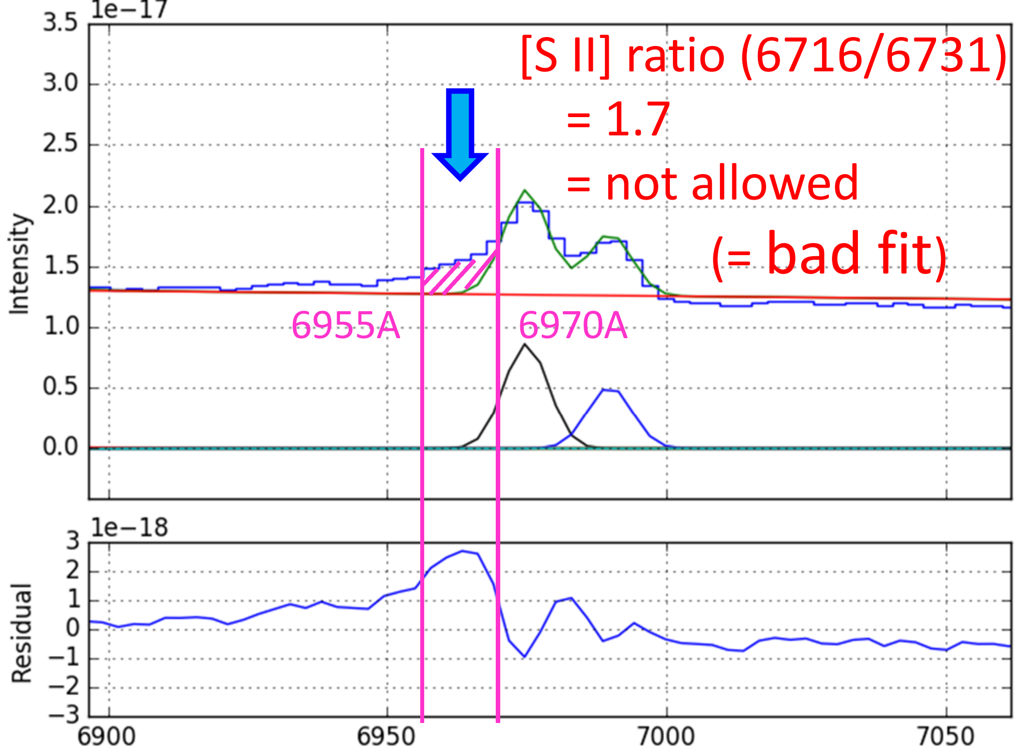


Blue tails of [S II] lines in many lenselets



1-component Fit

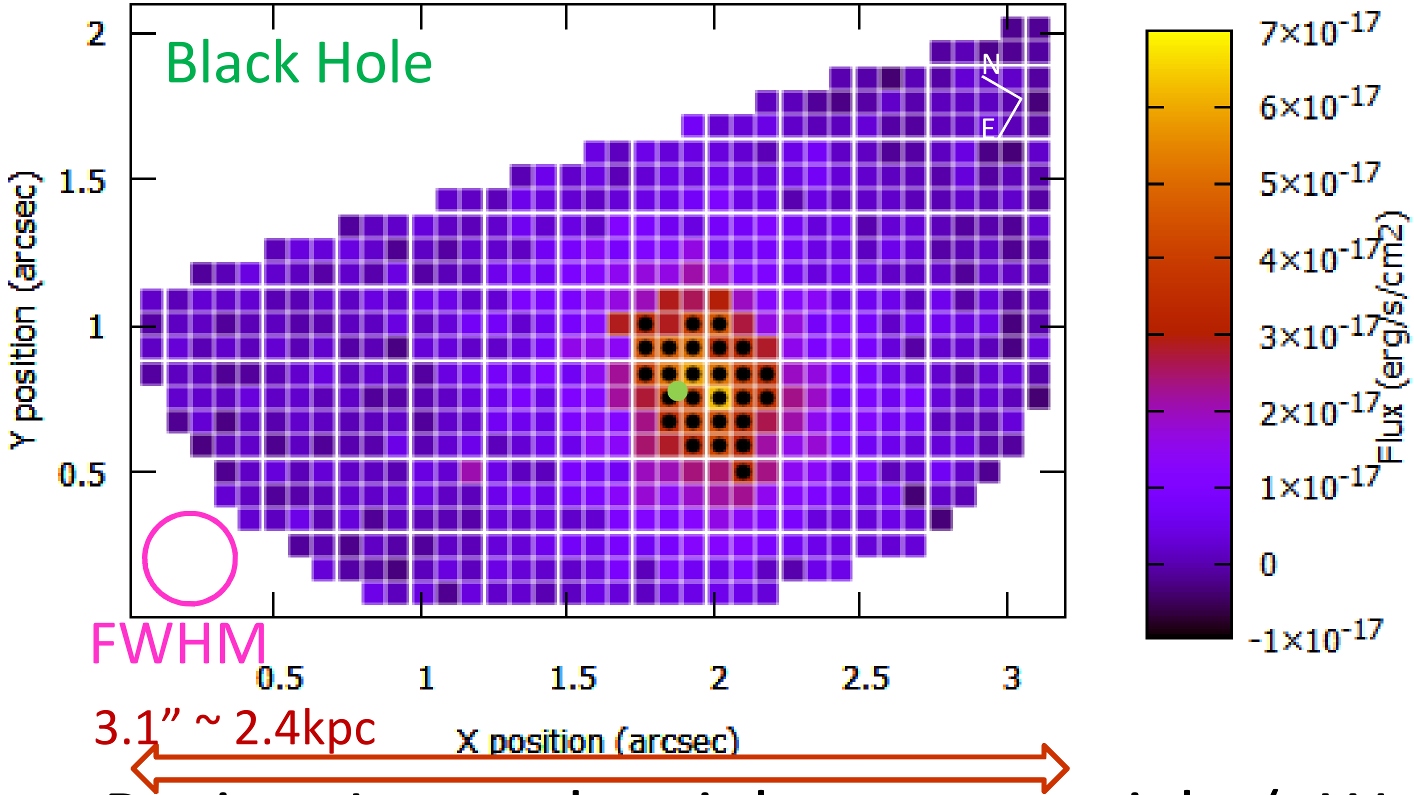
Close-up View around [S II] :
→ Clear blue tail



Identifying the outflowing region
→ Excess flux (data - model)
in 6955-6970 Å map

Excess Flux Map at 6955-6970 Å

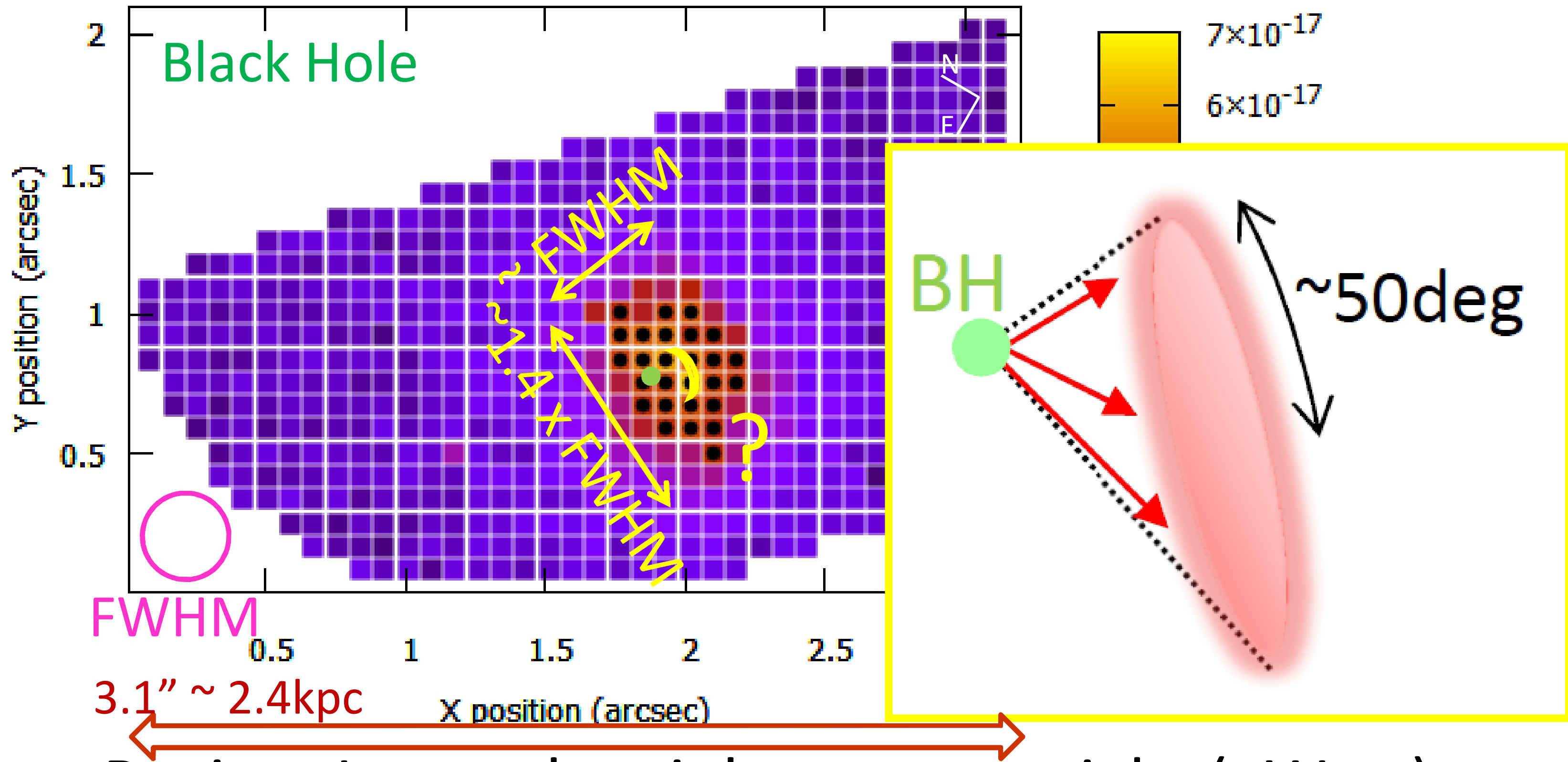
(● = excess flux >= 3 x 10^-17 [erg/s/cm^2] = peak / 2)



- Outflow Region: Located mainly at upper-right (~West)
- 100s pc -scale outflow

Excess Flux Map at 6955-6970 Å

(● = excess flux >= 3 x 10^-17 [erg/s/cm^2] = peak / 2)

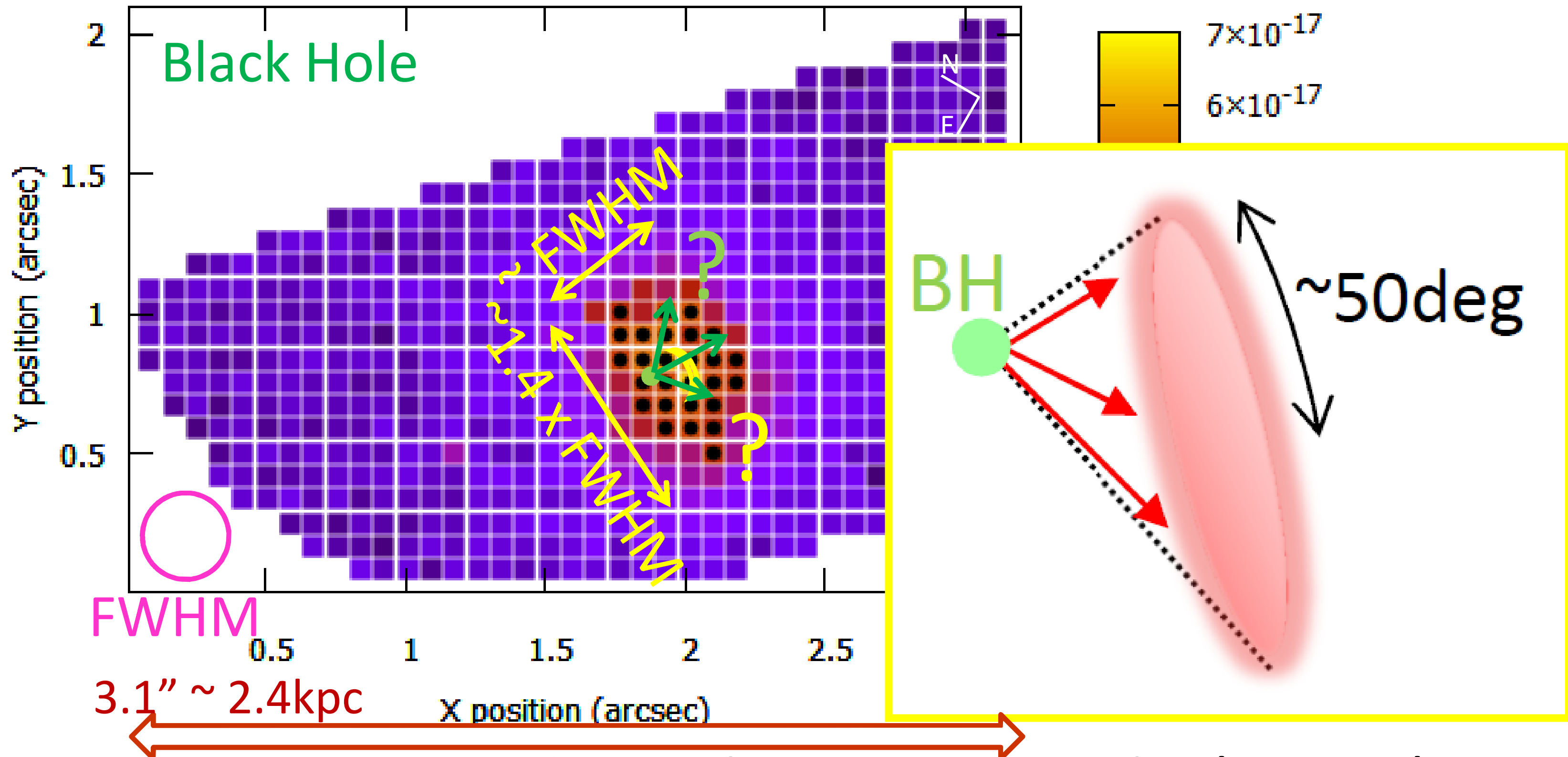


* Outflow Region: Located mainly at upper-right (~West)
* 100s pc -scale outflow
* Offset from BH: disfavors pole-on view of outflow ?
* Half opening angle of outflow ~ 50 deg ? (not jet like)

Large angle favors AGN feedback hypothesis?

Excess Flux Map at 6955-6970 Å

(● = excess flux >= 3 x 10^-17 [erg/s/cm^2] = peak / 2)



* Outflow Region: Located mainly at upper-right (~West)

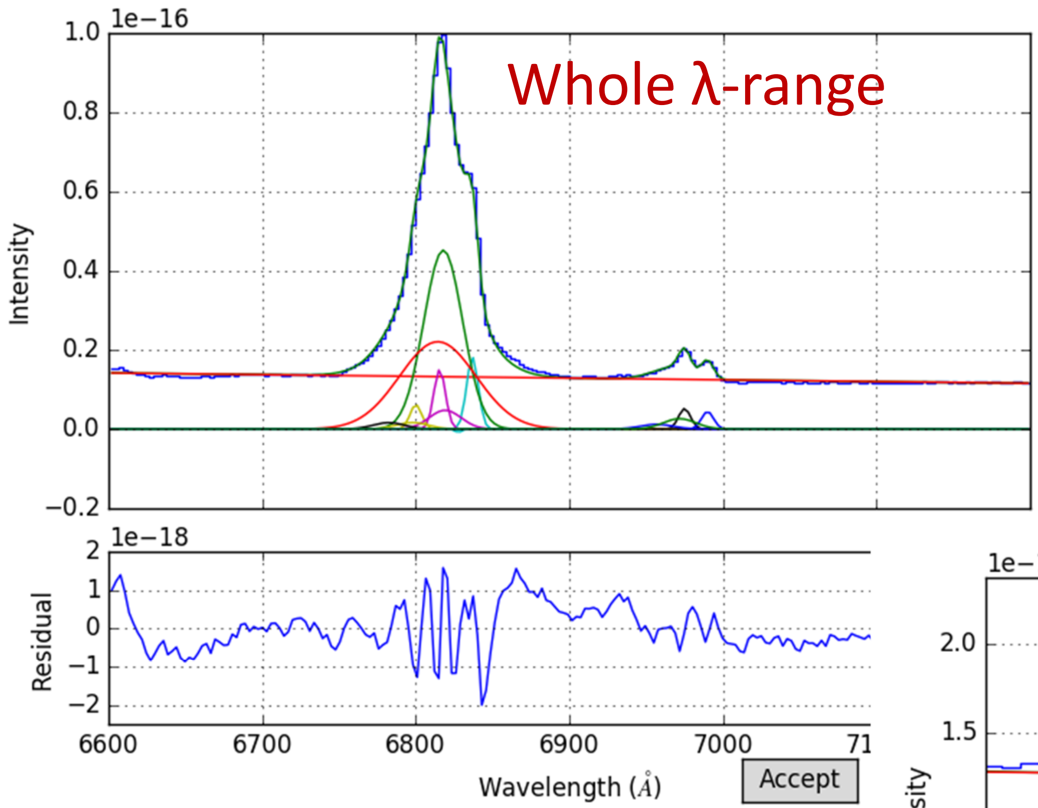
* 100s pc -scale outflow

* Offset from BH: disfavors pole-on view of outflow ?

* Half opening angle of outflow ~ 50 deg ? (not jet like)

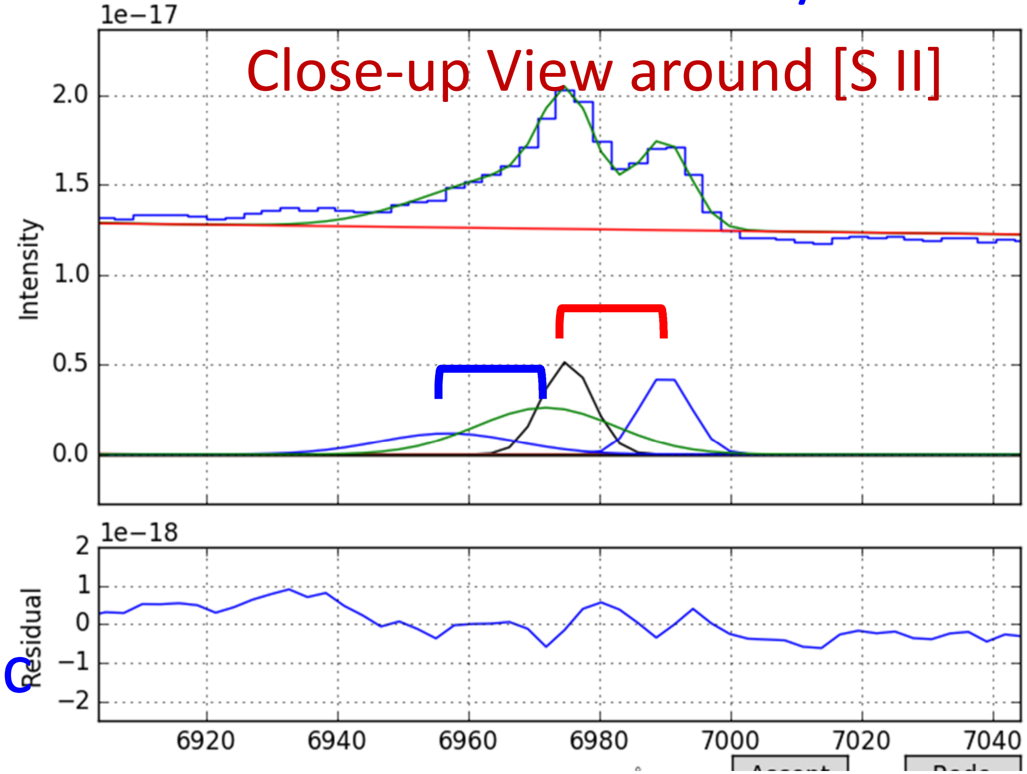
Large angle favors AGN feedback hypothesis?

Velocity and density of the outflowing gas



2-component Fit

* 860km/s blueshift
* FWHM = 1000km/s



--- [S II] 6716/6731 ratio ---

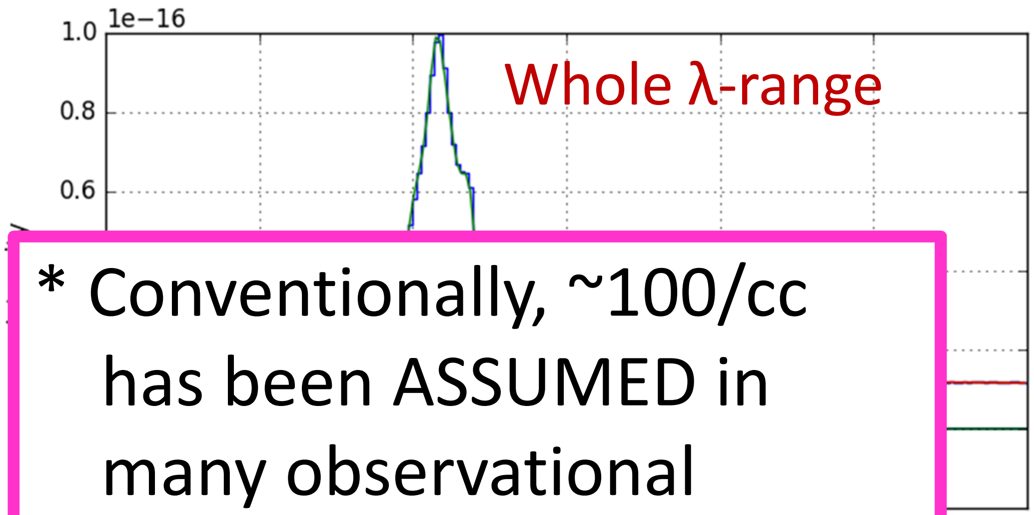
Stronger component:

1.17 → n ~ 300/cc

Outflowing component:

0.43±0.21 → n >3000/cc

Velocity and density of the outflowing gas

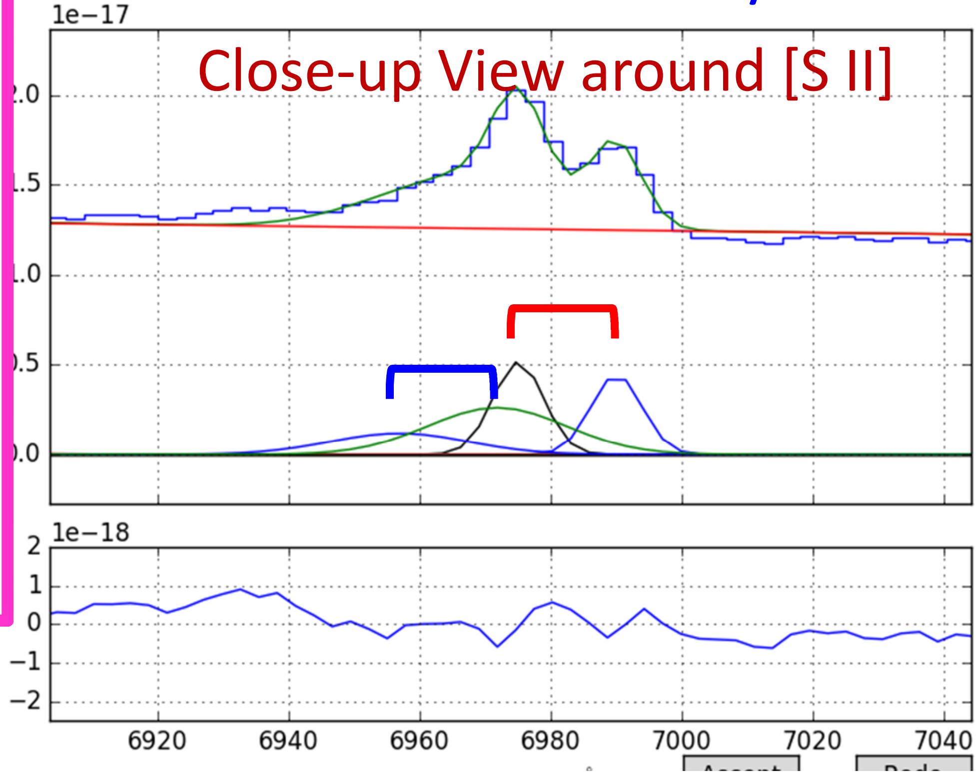


2-component Fit

* Conventionally, ~100/cc has been ASSUMED in many observational studies of AGN outflows:
* Gas mass ∝ density^{-1} ($L_{H_\alpha} \propto n_H n_e V \propto M_{gas} n$)
* Overestimation of the Outflow rate, Kinetic energy injection rate, etc.

0.43±0.21 → n >3000/cc

* 860km/s blueshift
* FWHM = 1000km/s

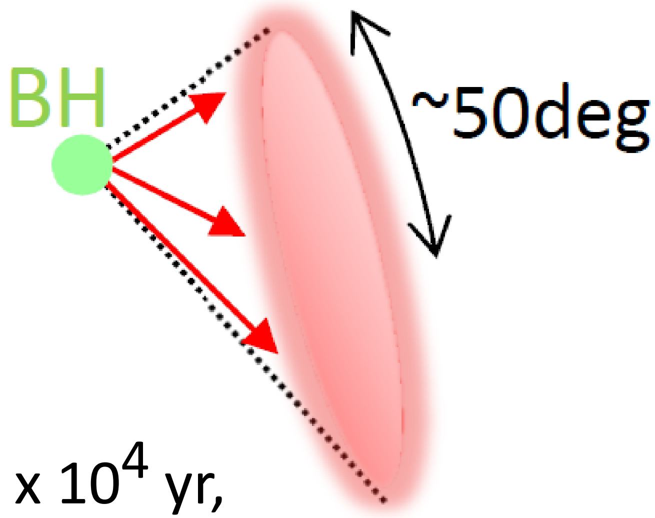


Quantities of the Outflow

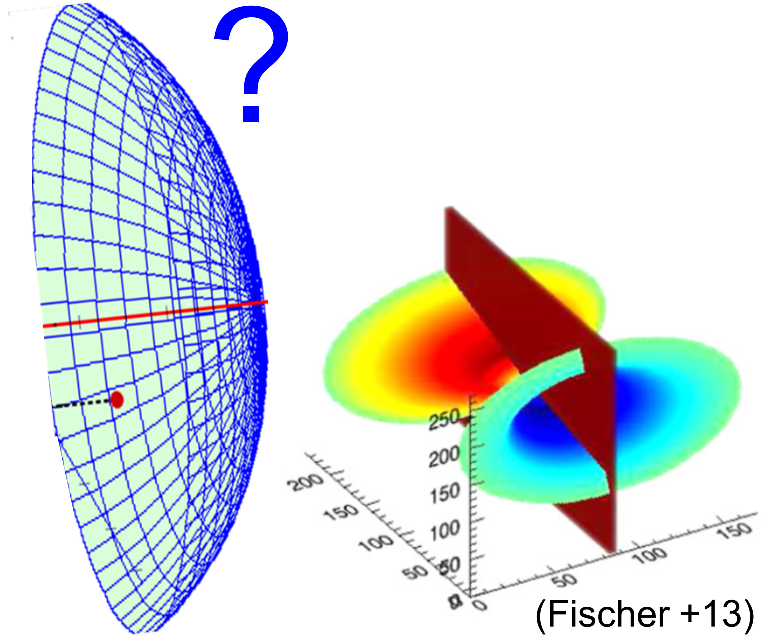
* Ionized gas mass (← Hα luminosity, density) ~ < 1.6 x 10^4 M_{sun}

Size of outflowing region ≈ Point Spread Function

⇒ Deconvolution-like estimation (large uncertainty) :



Launched for 2 x 10^4 yr,
10^5 yr ago?



(Fischer +13)

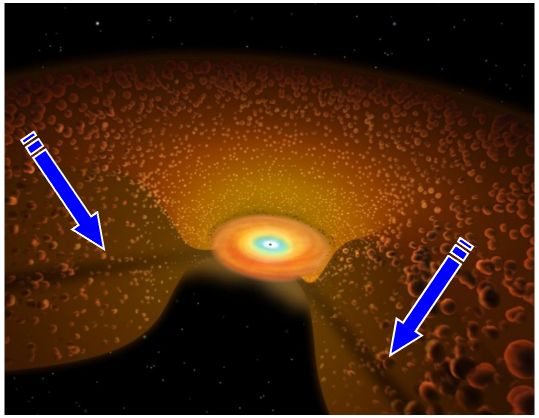
* Gas outflow rate (0.7 M_{sun}/yr) ~ 90% of (sup-Edd) accretion rate:
* Kinetic energy injection rate ~< 0.07 % of Bolometric luminosity :
Insufficient for governing host galaxy?

< Topics >

1. Fast, Dense, 100s-pc scale Outflow in super-Eddington AGN.

* Testing "AGN feedback to host galaxy" hypothesis
* AO + Optical IFU capability of Subaru
  → Density-sensitive [S II] emission lines
* Seems insufficient for feedback to host galaxy.

2. Large geometrical thickness of slim discs reduces Torus emission.
"Dust-free quasars" may have non-illuminated tori.



Various Models for AGN Tori

(Ibar & Lira 2007)

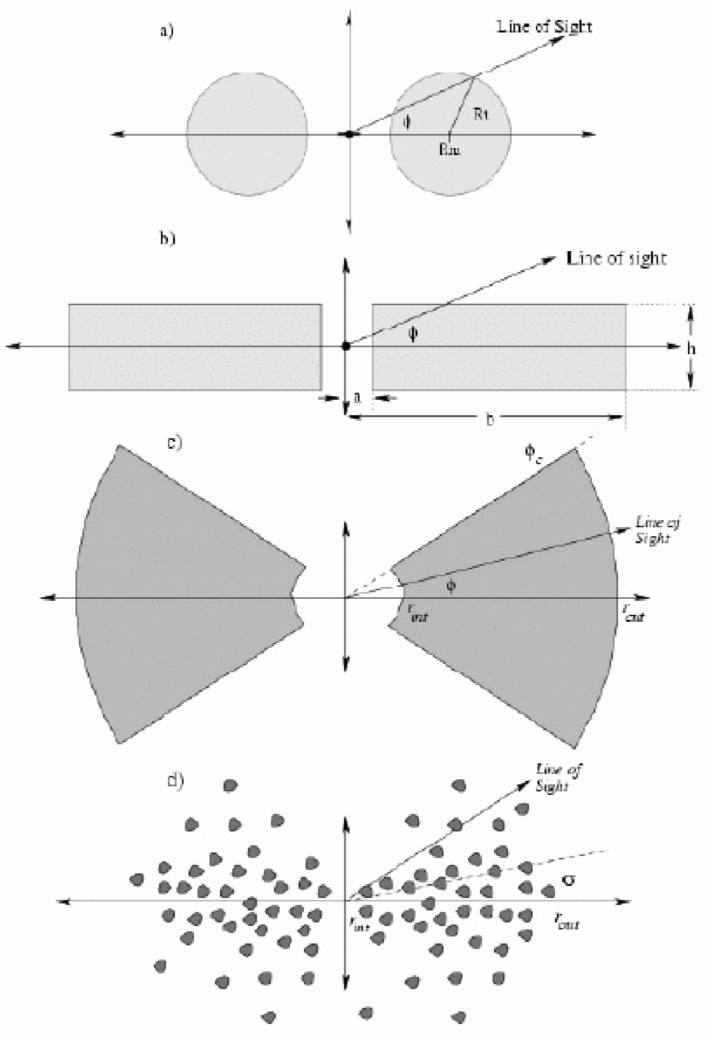
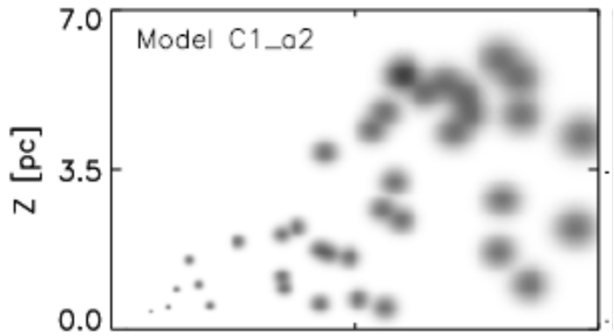
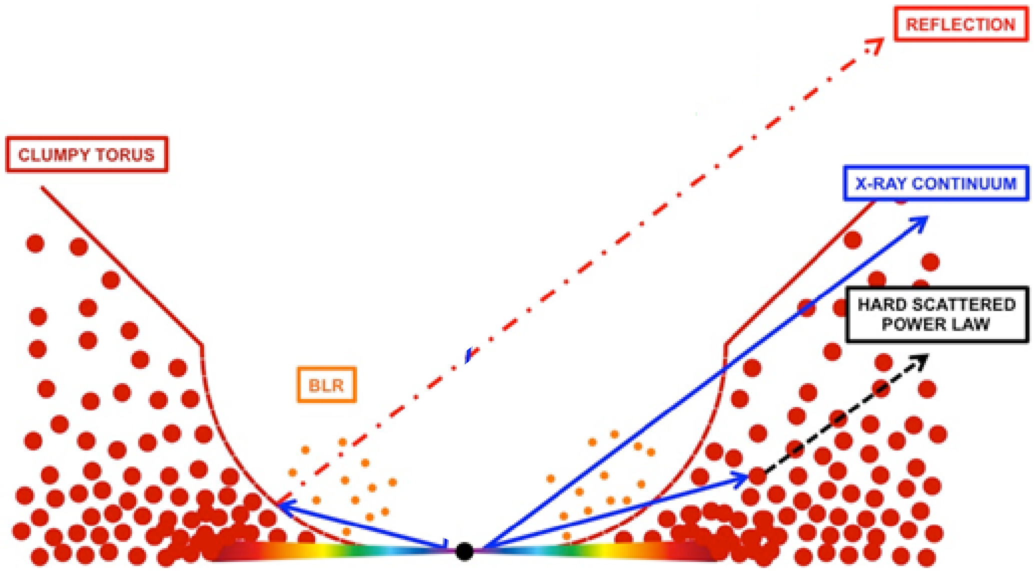


Fig. 1. Geometrical matter density distributions assumed for the torus models. Figures **a)**, **b) c)** and **d)** are based on the previous work by Treister et al. (2004), Pier & Krolik (1992), Granato & Danese (1994) and Nenkova et al. (2002), respectively.

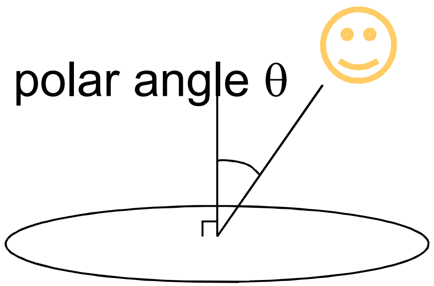
(Dullemond & van Bemmel 05)





(Miniutti + 14)

What determines the shape of the torus innermost region
Anisotropy of disk emission (even if infinitesimally thin)



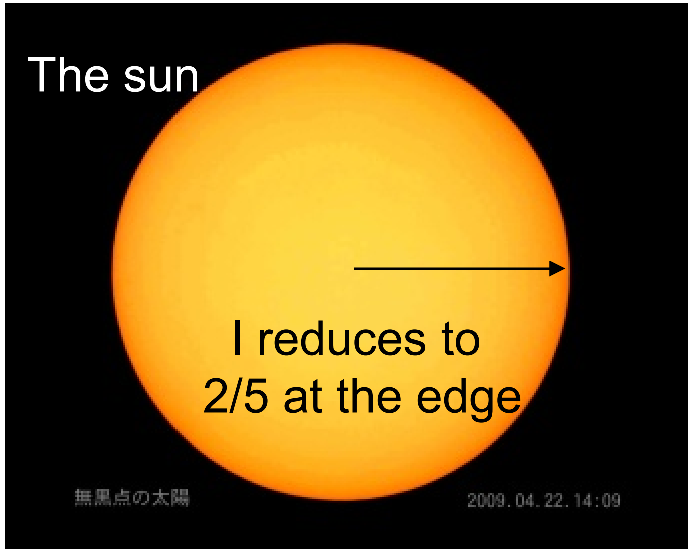
Flux toward the polar angle $\theta \propto \cos\theta\,(1 + 2\cos\theta)$

projection of the surface area

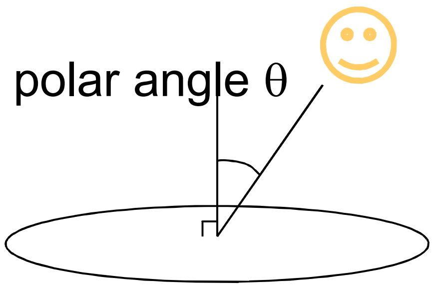
$$\text{Flux} = \int I \cos\theta \, d\Omega$$

Limb darkening effect

(1.5 rather than 2 if absorption exceeds election scattering)

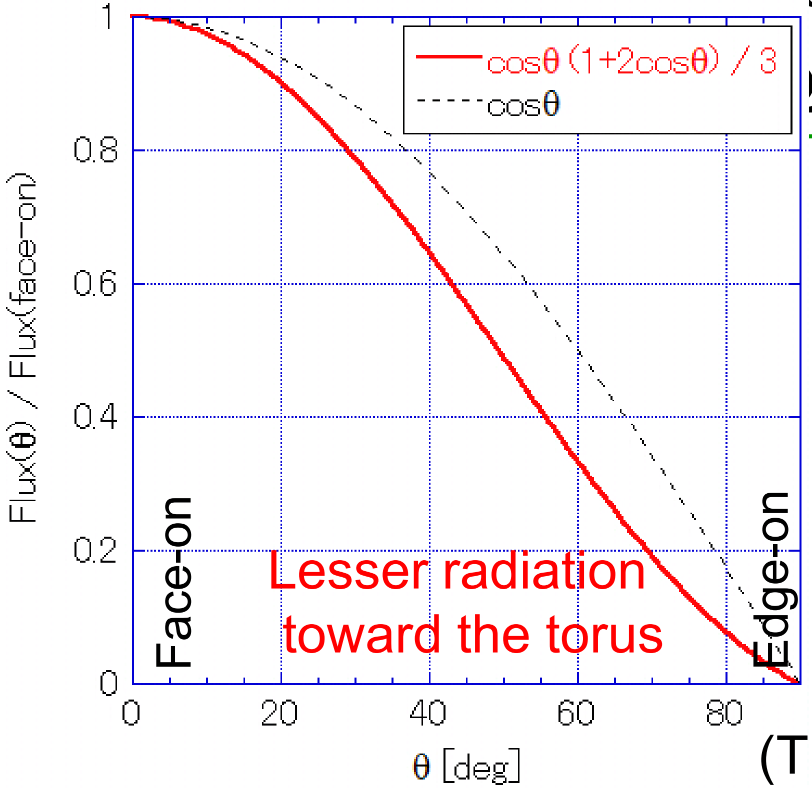


What determines the shape of the torus innermost region
Anisotropy of disk emission (even if infinitesimally thin)



Flux toward the polar angle θ $\propto \cos\theta\,(1 + 2\cos\theta)$

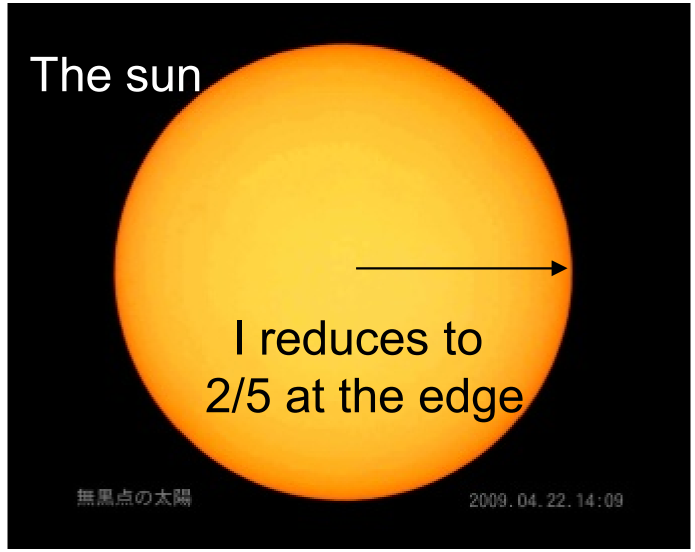
projection of the surface area



(TK & Mori 11)

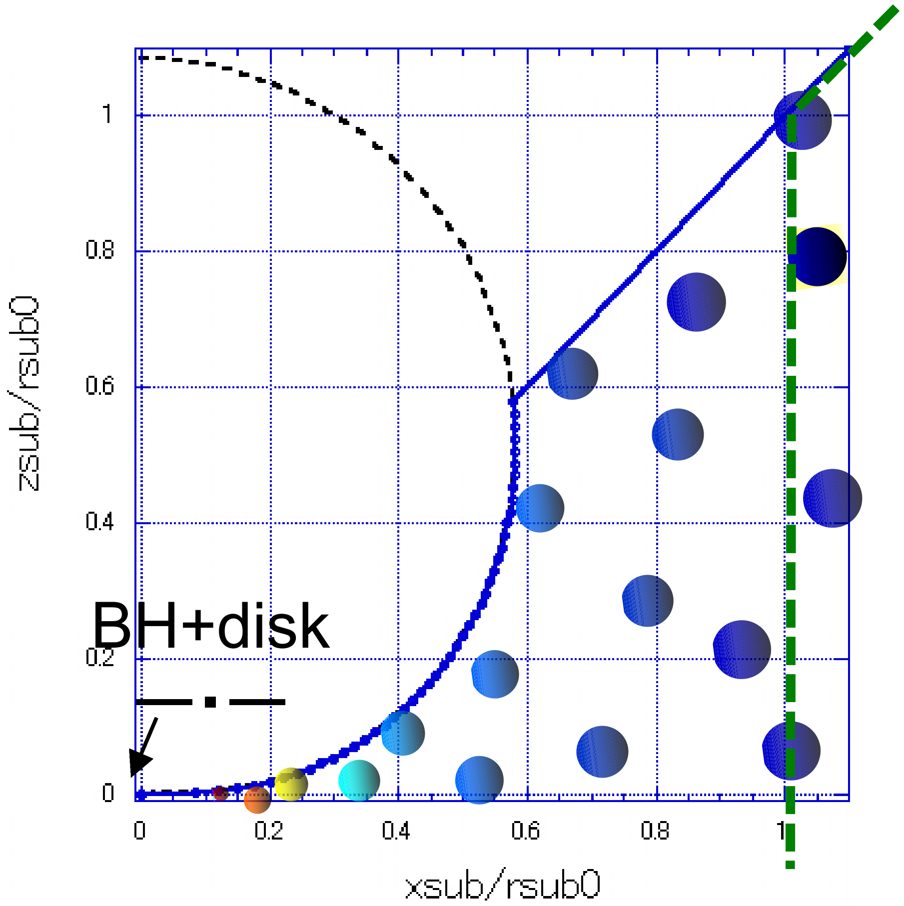
Limb darkening effect

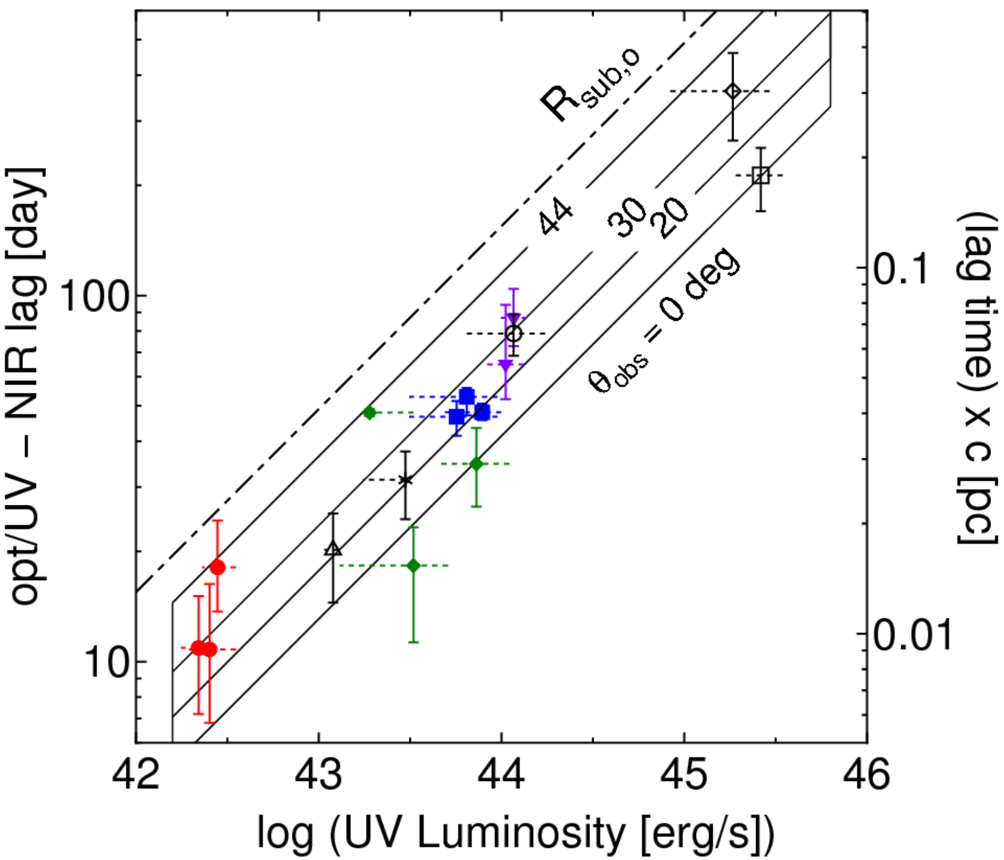
(1.5 rather than 2 if absorption exceeds election scattering)



Innermost structure and NIR reverberation of AGN tori

(Kawaguchi+ 2010, 11, 12)





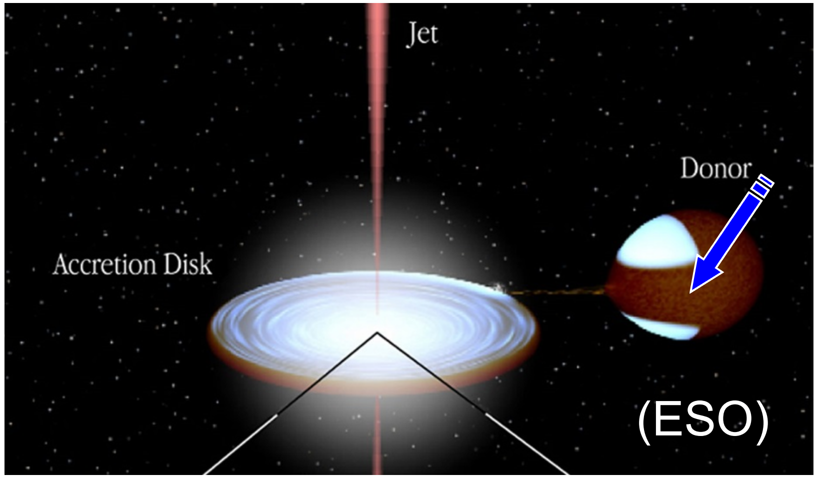
(1) closer to the BH.
(2) concave/hollow

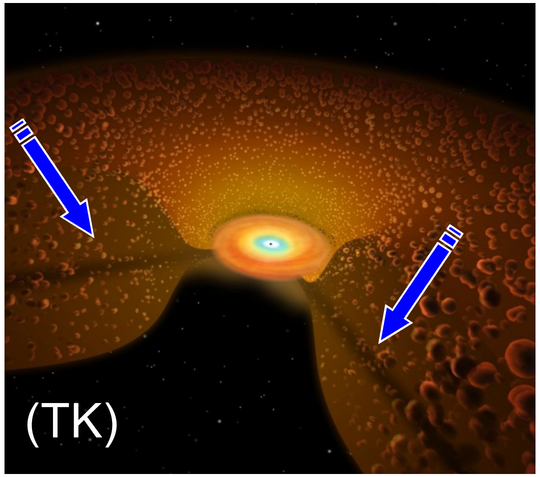
It explains the observed time lag.

Accretion rate dependency:

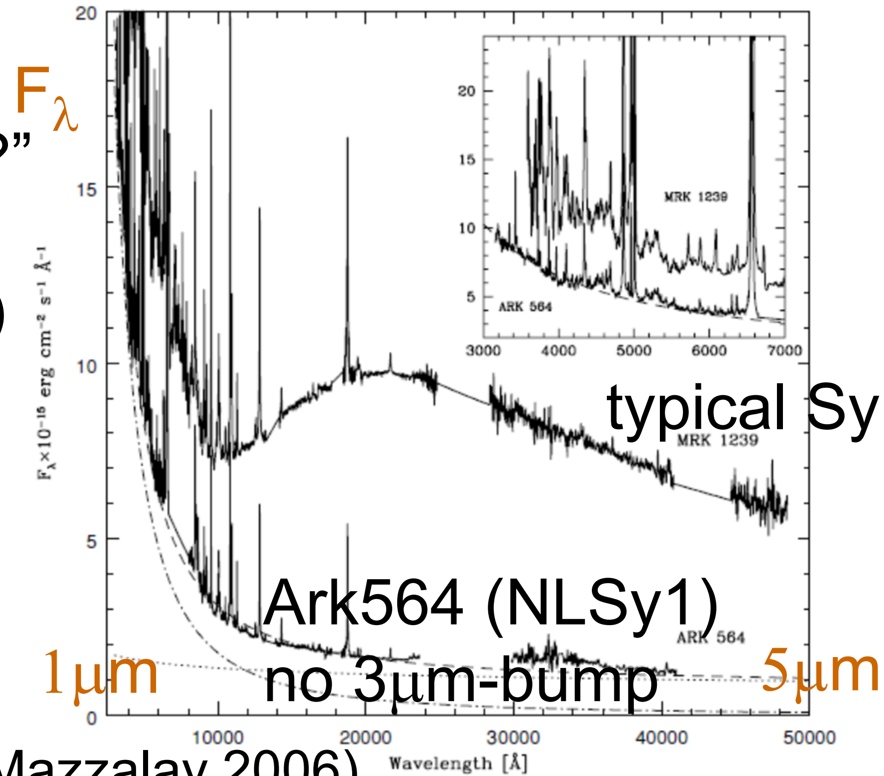
Shade of disk (disk self-occultation)

(Fukue 00, Madau88)





NIR Spectra



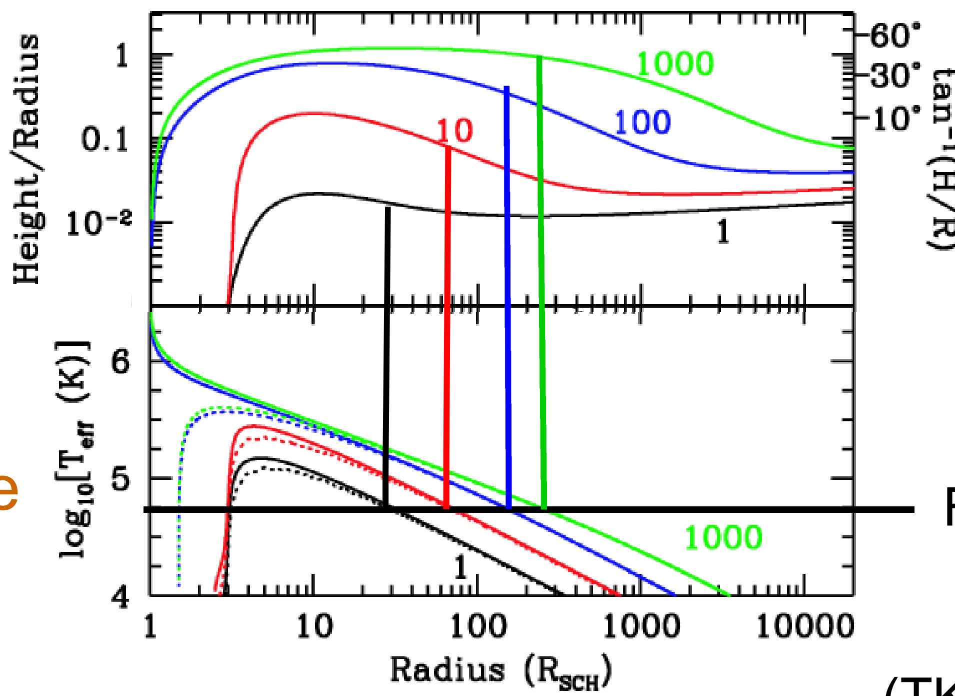
- "Super-Eddington AGNs (NLS1, NLQ) show weak NIR?"
  TonS180(TK+04), Ark564,
  Jiang+10 ("dust-free quasars")
  (cf. Hao+2010)
- High accretion rate
  ⇒ Geometrically thick disk
  ⇒ Huge disk shade

(Rodriguez-Ardila & Mazzalay 2006)

Disk thickness at FUV emitting region

$\dot{M}/(L_{Edd}/c^2)$ = 1, 10, 100, 1000 ← Super-Eddington

1, 10: Sub-Eddington accretion (standard accretion disk)



disk thickness (H/r)

disk temperature

angular thickness (=90° − θ_{max})

1°, 4°: shade negligible

17°

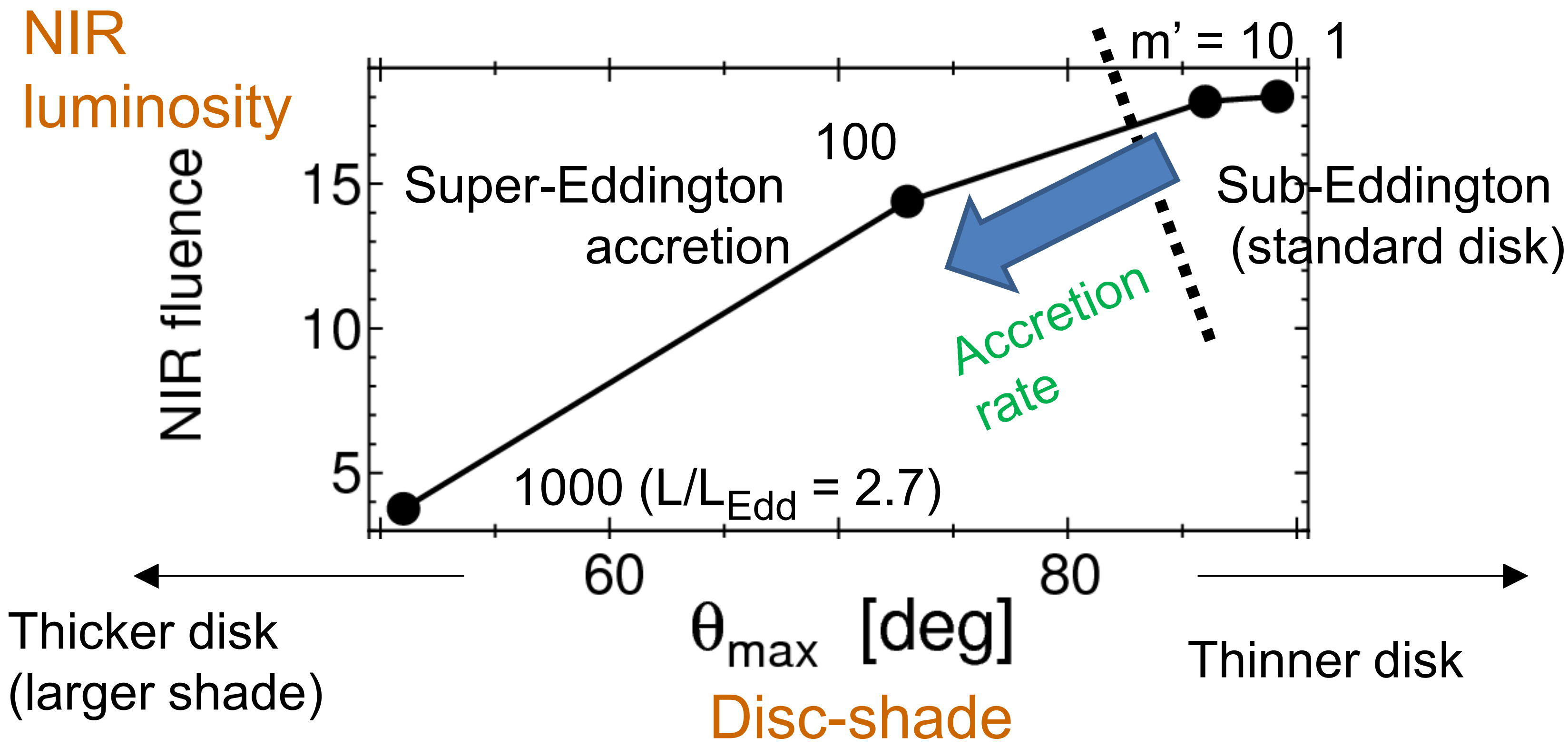
39° huge shade

FUV emission (~4-5 10^4 K)

(TK 2003)

distance from BH (r_{Sch})

4. Disk thickness (accretion rate) dependency



When the accretion rate becomes super-Eddington, large shade of the disk (less illumination to torus) reduces the NIR emission.

➔ * "Dust-free quasars" may have non-illuminated (dusty) tori.
* Rest-NIR selection tends to miss super-Eddington accretors.

< Topics >

Summary

1. Fast, Dense, 100s-pc scale Outflow in super-Eddington AGN.

* Testing "AGN feedback to host galaxy" hypothesis
* AO + Optical IFU capability of Subaru
  → Density-sensitive [S II] emission lines
* Seems insufficient for feedback to host galaxy.

2. Large geometrical thickness of slim discs reduces Torus emission.

"Dust-free quasars" may have non-illuminated (dusty) tori.