高ガス降着率活動銀河核からのガス噴出の面分光による研究

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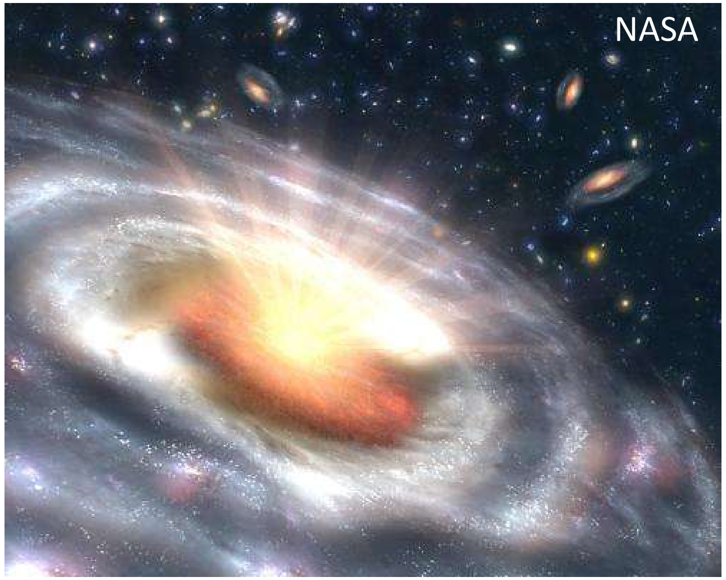
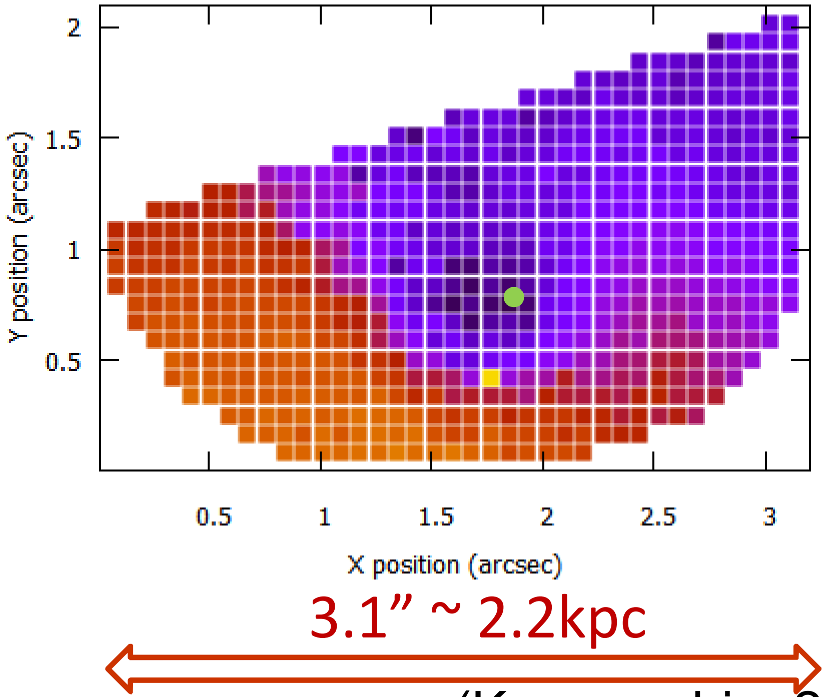
< Key questions >

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



Velocity Field around Black Hole



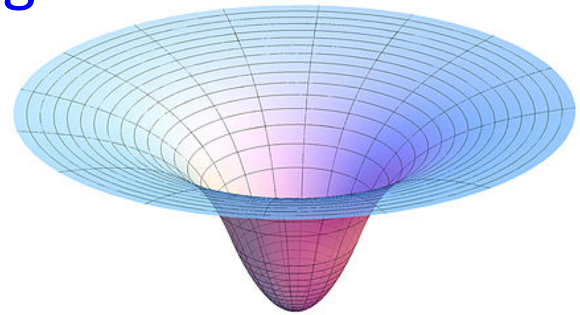
(Kawaguchi + 2018)

銀河中心の巨大ブラックホールと母銀河

* 銀河のガス･星の運動エネルギー E_{gal}

$\sim M_{gal} v^2$

$(v \sim 300 km/s)$



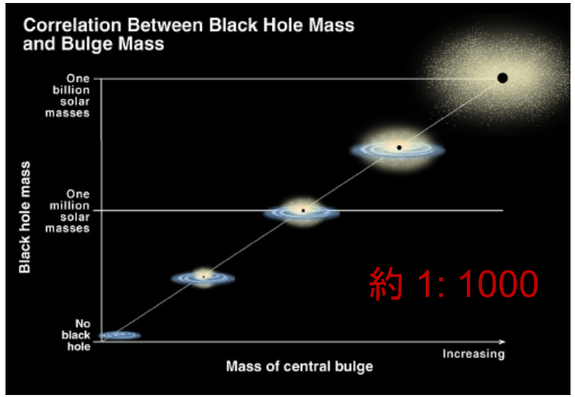
* 銀河中心ブラックホールへガスが落ちることで光るエネルギー E_{BH}

$\sim 0.1 \, M_{BH} c^2$

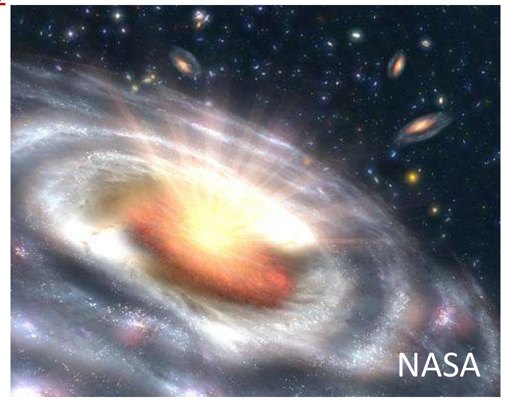
$\sim 0.1 \, (M_{gal}/1000) \, (1000 \, v)^2$

$\sim 100 \, E_{gal}$

銀河中心ブラックホール質量



銀河(バルジ)質量

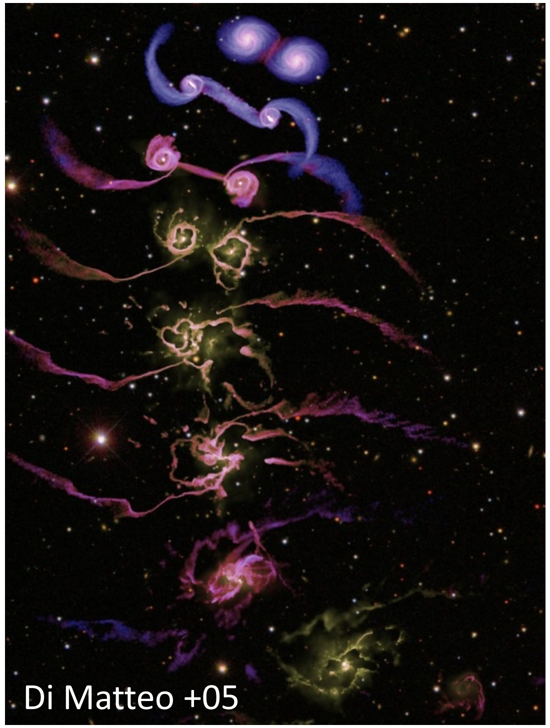


ほんの一部が銀河に与えられると母銀河の進化を支配

AGN outflows regulate black hole and galaxy evolution?

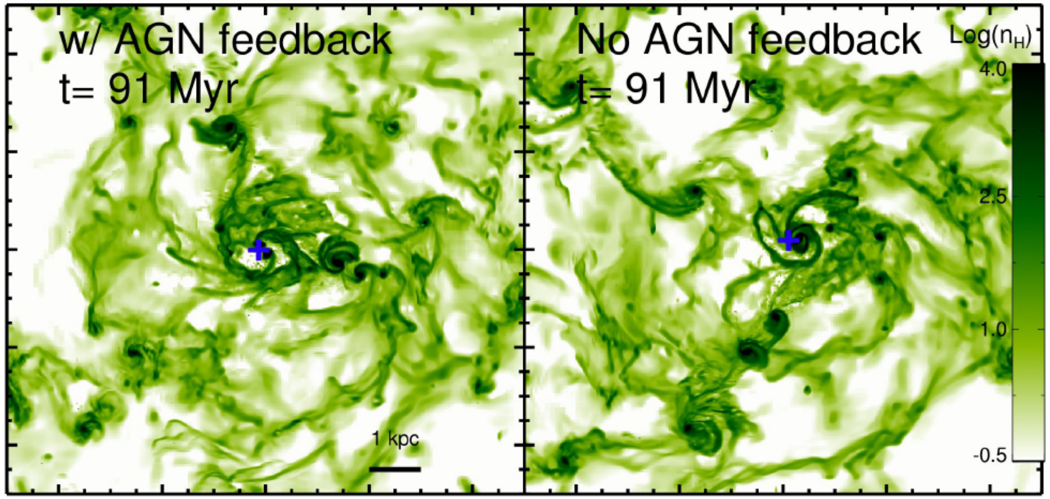
Yes: Silk & Rees 98; Fabian 99; King 03;
Schawinski +07; Wylezalek +16, ...

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



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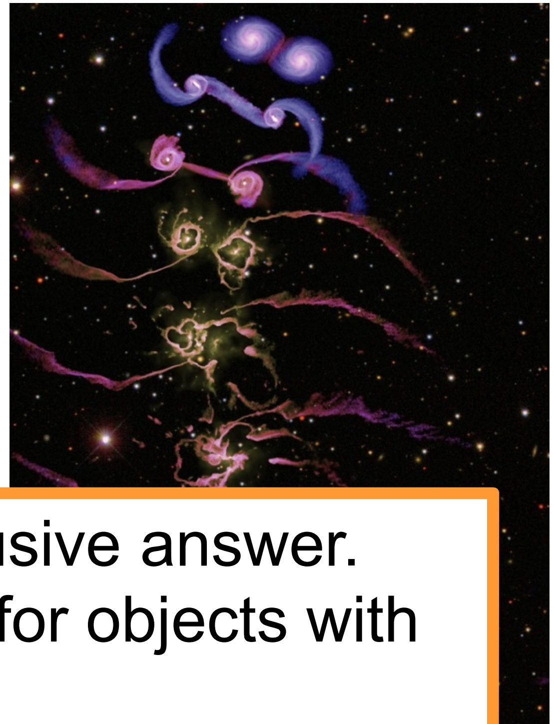
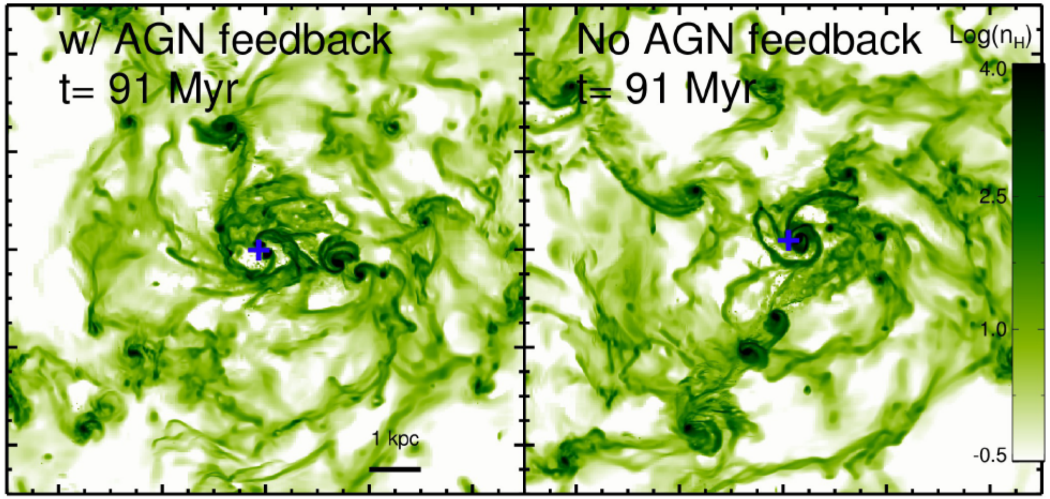


「Is there really AGN feedback?」 No conclusive answer.
→ Observations with high-spatial resolution for objects with galactic-scale outflow

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



Gabor +14

AGN feedbackは存在するか？ (1/4)

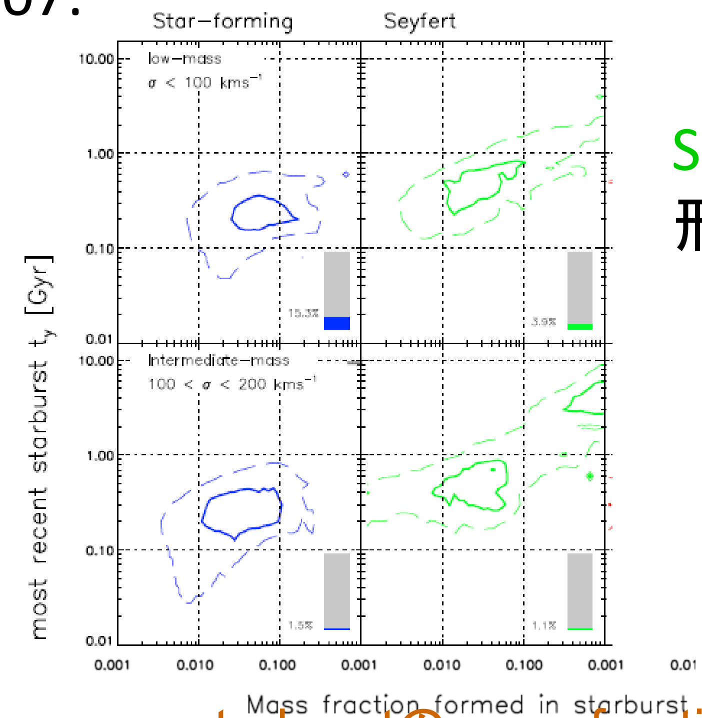
-- Quasar/Seyfert による母銀河での星形成活動へのNegative feedback --

『＋』肯定的な結果・論調の研究例: (2頁)

* Silk & Rees 98; Fabian 99; King 03: Energy/Momemtum (wind,rad pressure)

* Schawinski +07:

一番最近のstarburstからの年



starburstのmass fraction

Seyfert host galaxyの典型的星形成史 v.s. 星形成銀河

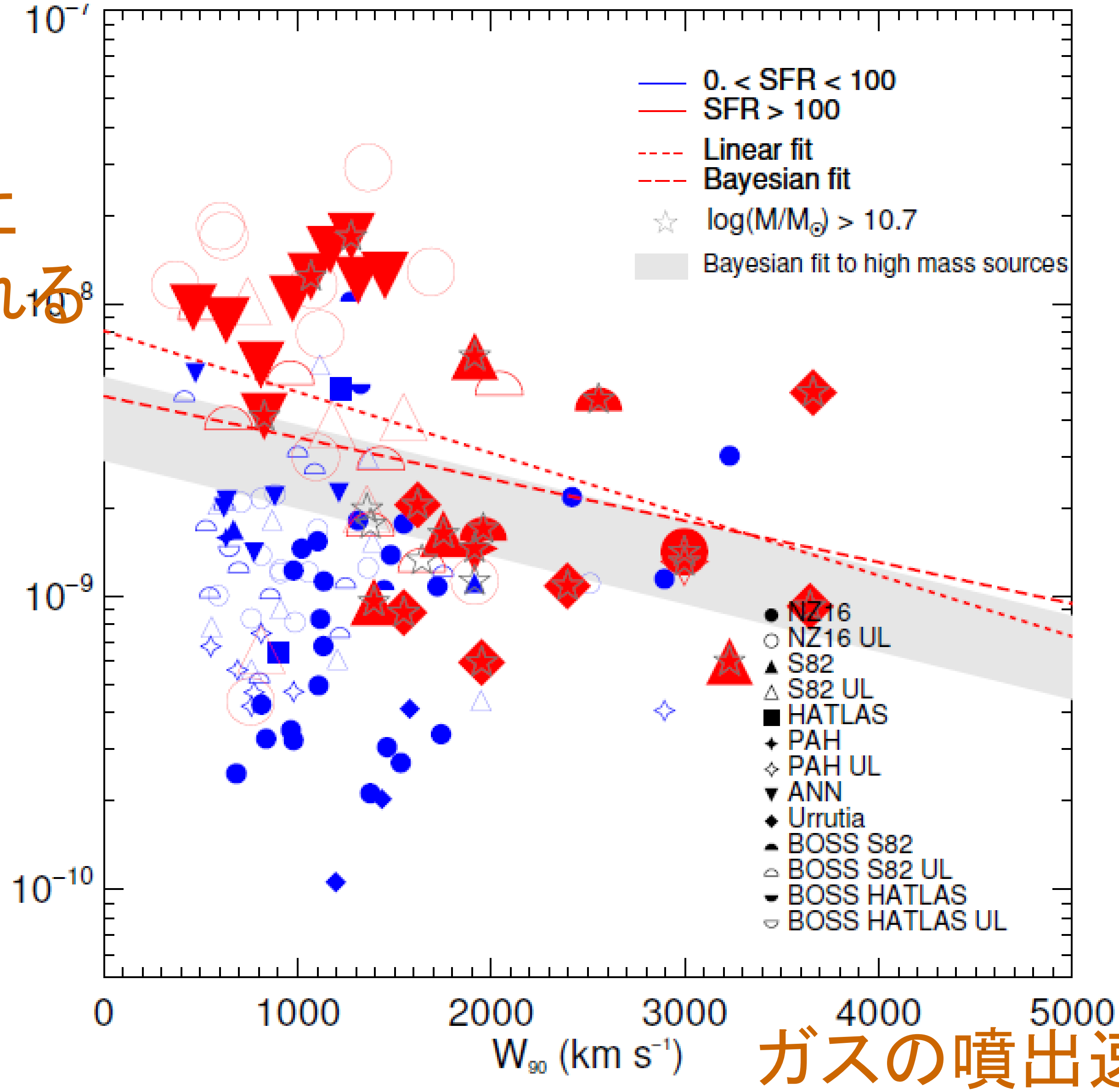
AGNによるQuenching of star formation を示唆

* モデルで使用される、bolometric 光度に対するwind powerの大きさの例

Lwind ~ 5% of Lbol (Di Matteo +05), 0.5 % (Hopkins + Elvis 10)

銀河中心からのガス噴出速度が速いほど、星形成は起こりにくい

星間ガス
から新たに
星が作られる
速さ



ガスの噴出速度

(Wylezalek +16)

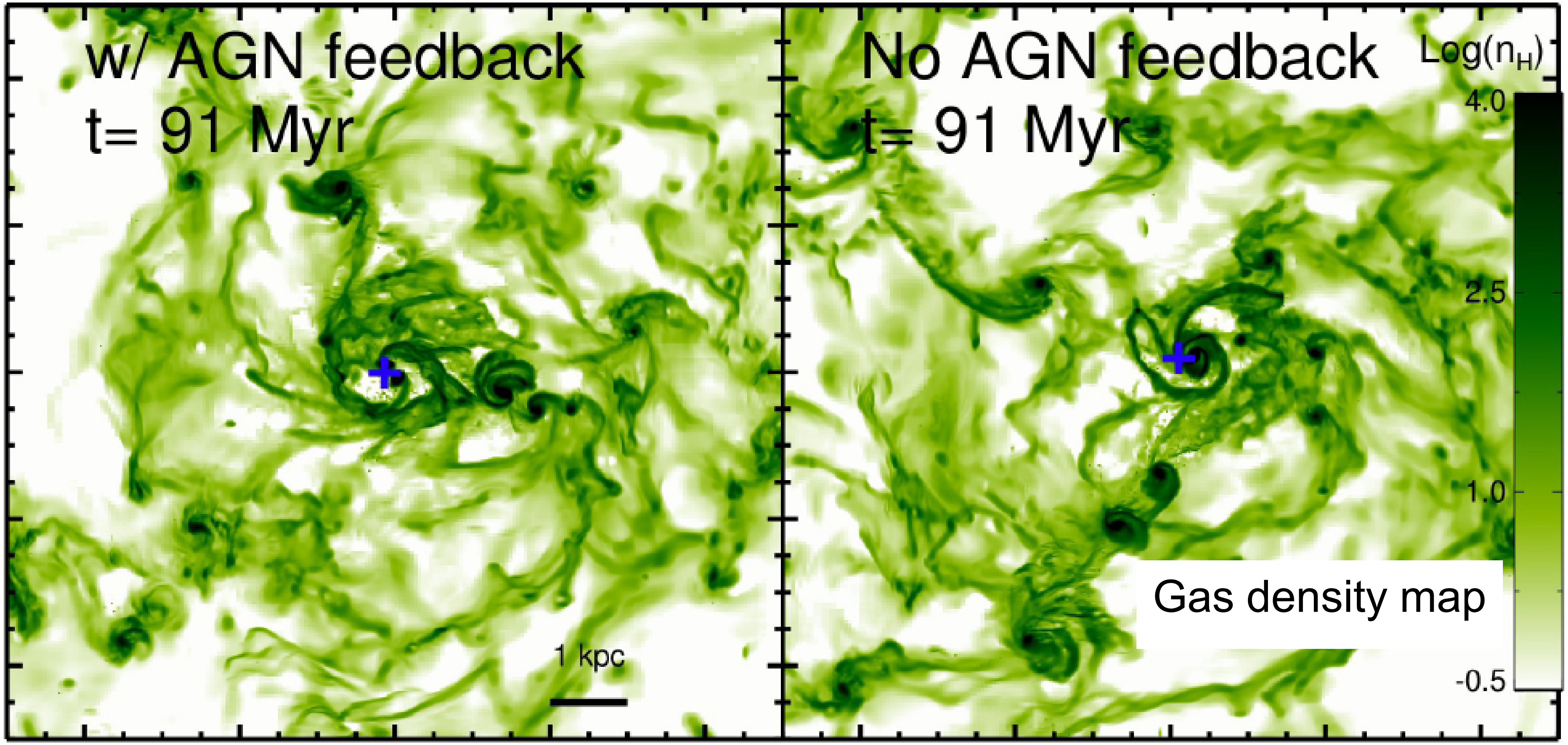
AGN feedbackは存在するか？ (3/4)

-- Quasar/Seyfert による母銀河での星形成活動へのNegative feedback --

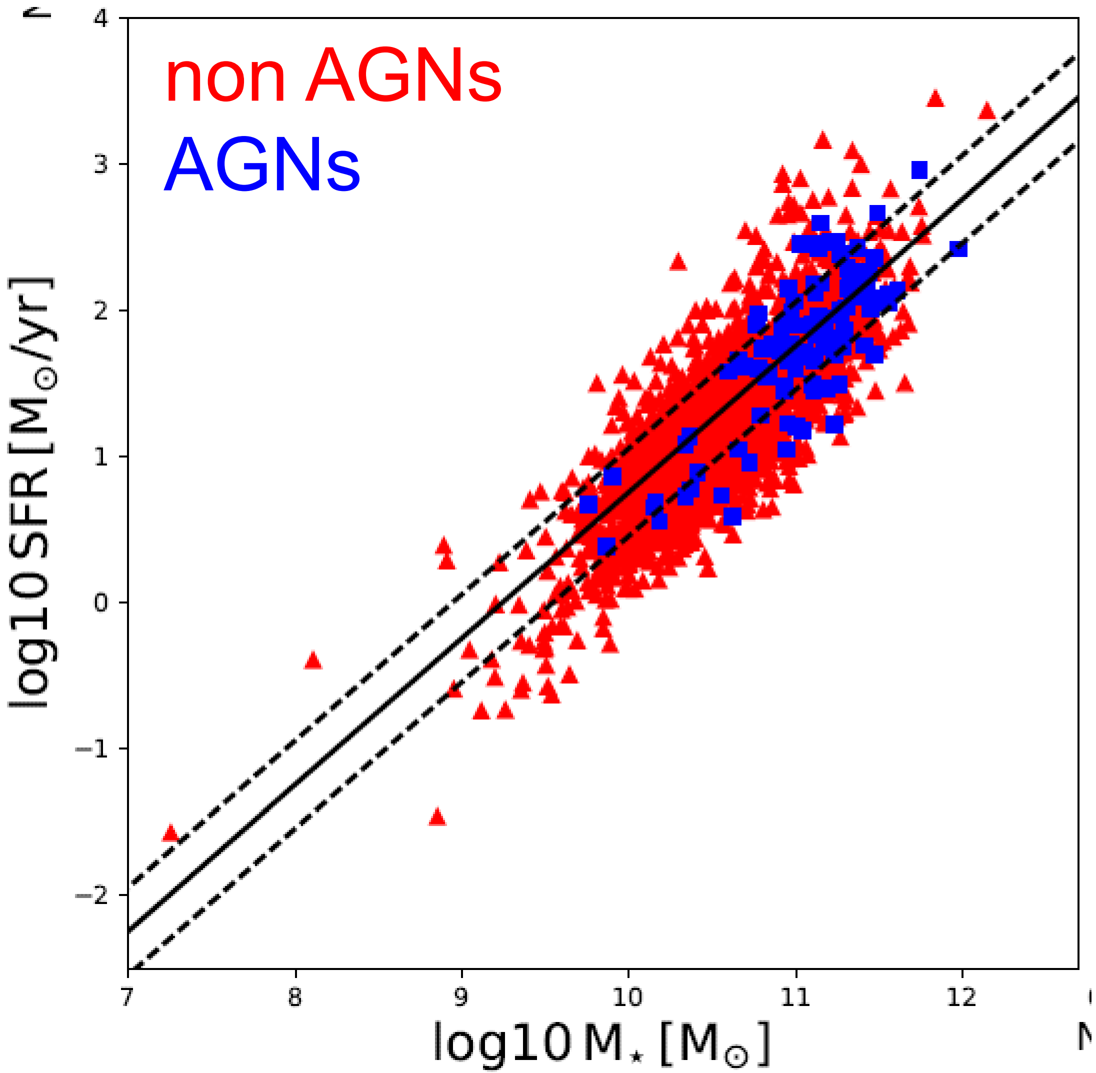
『一』否定的な結果・論調の研究例: (2頁)

* Gabor + 14: Hydrodynamical simulation: Lwind = 15% of Lbol

→ Little impact on starforming galaxy disc



銀河の星形成諸量は銀河中心のブラックホールの活動性にあまりよらない



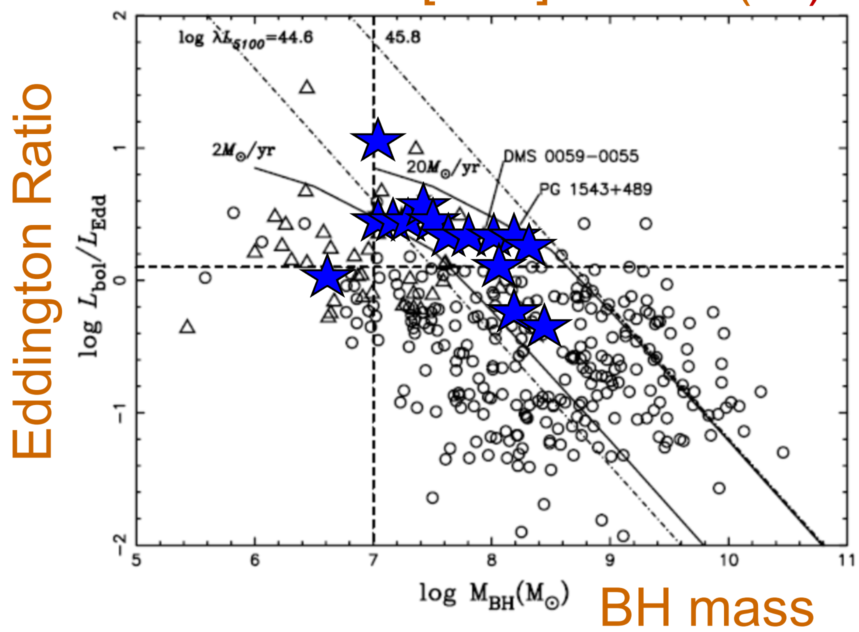
(Mahoro +17)

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

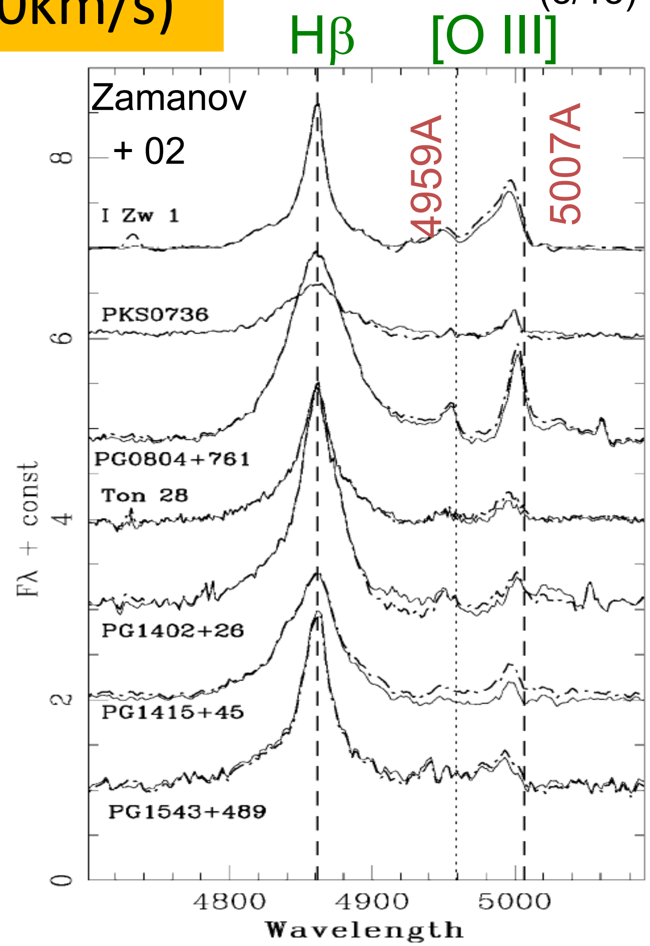
* Outflow in narrow line region
  (Radio-quiet = not jet-driven)

* 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)
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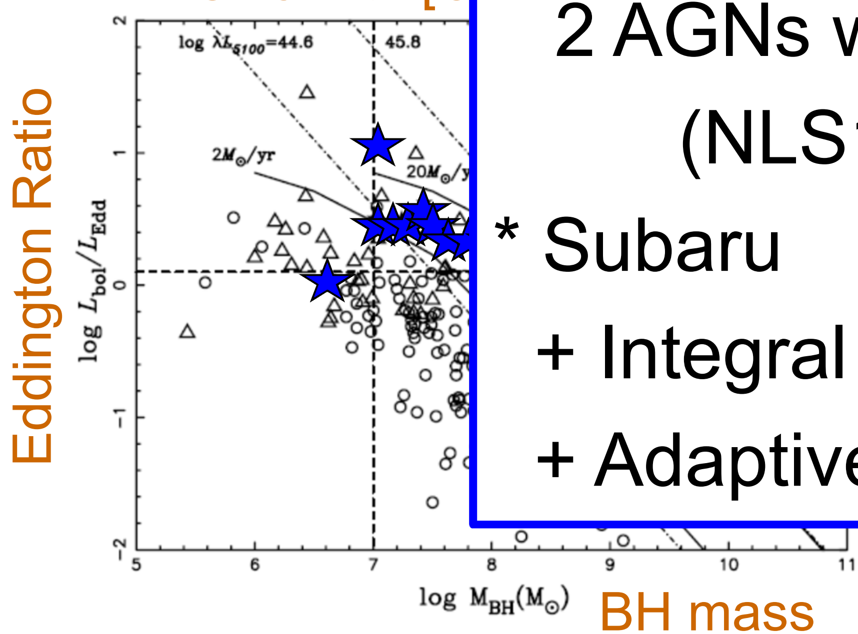
AGNs with [O



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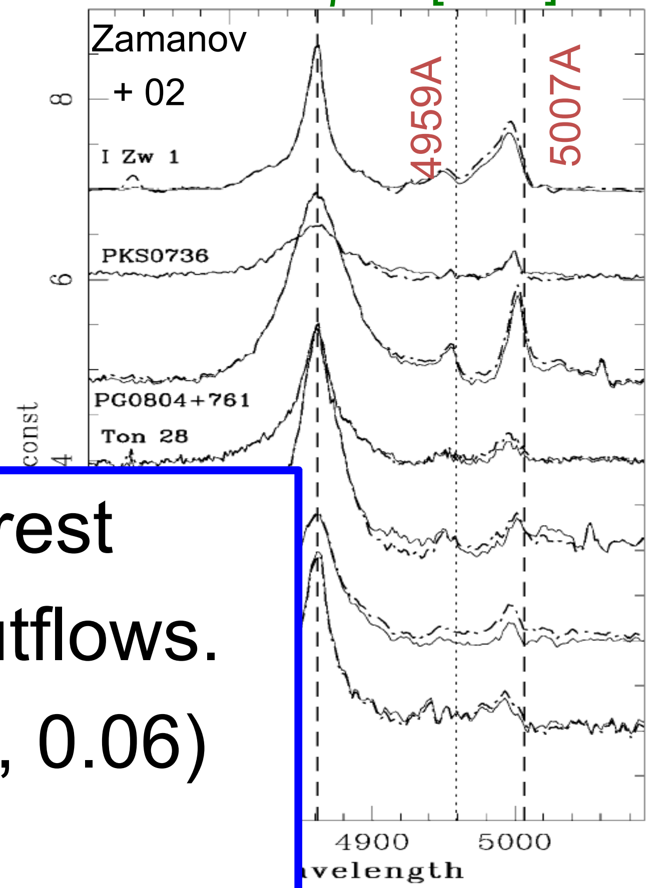


* We observed the nearest 2 AGNs with [O III] outflows. (NLS1s at z=0.04, 0.06)
* Subaru
  + Integral Field Spectroscopy
  + Adaptive Optics

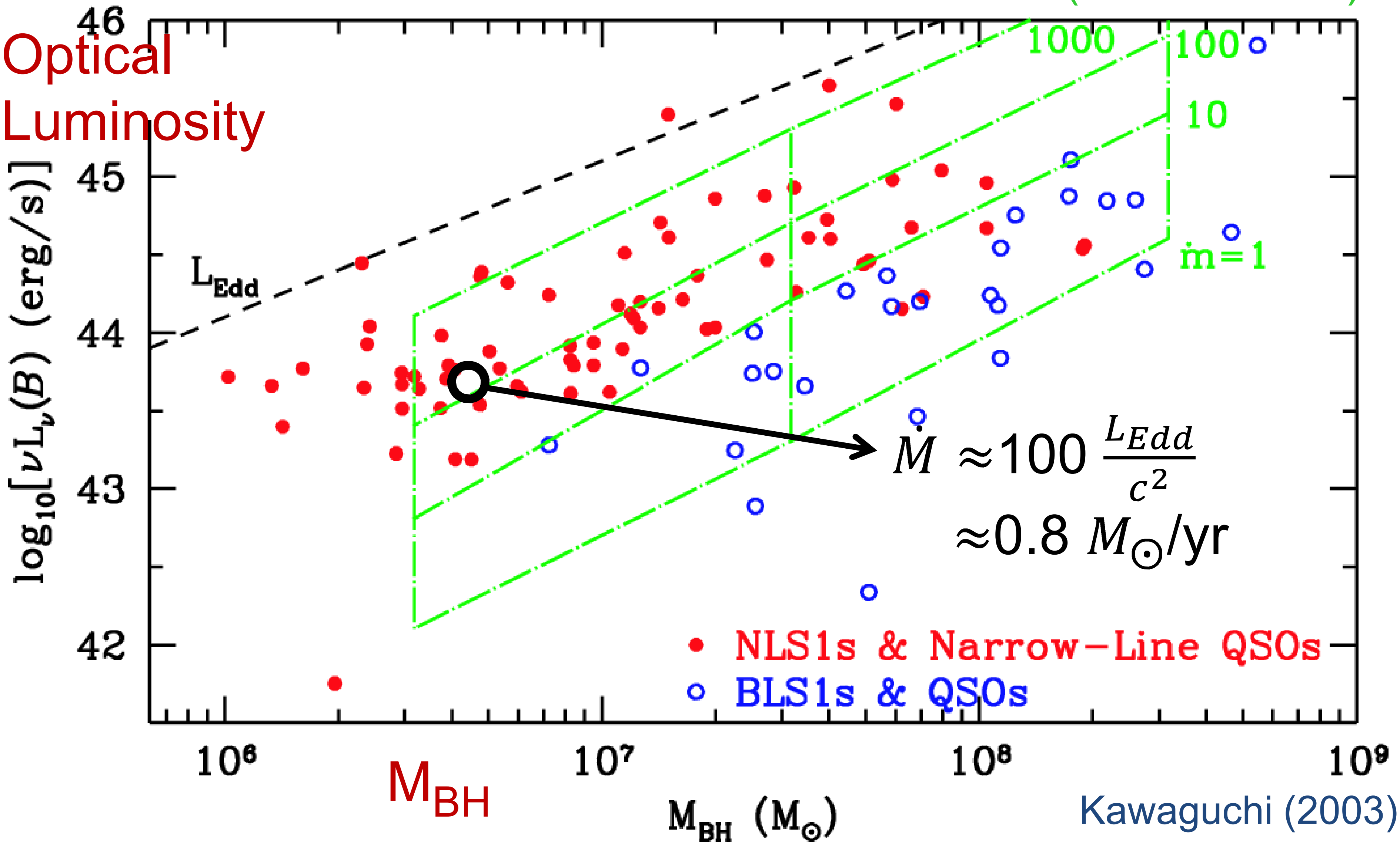
AGN feedback

BH growth

guchi 03; +04)

→ Laboratory for BH-galaxy coevolution

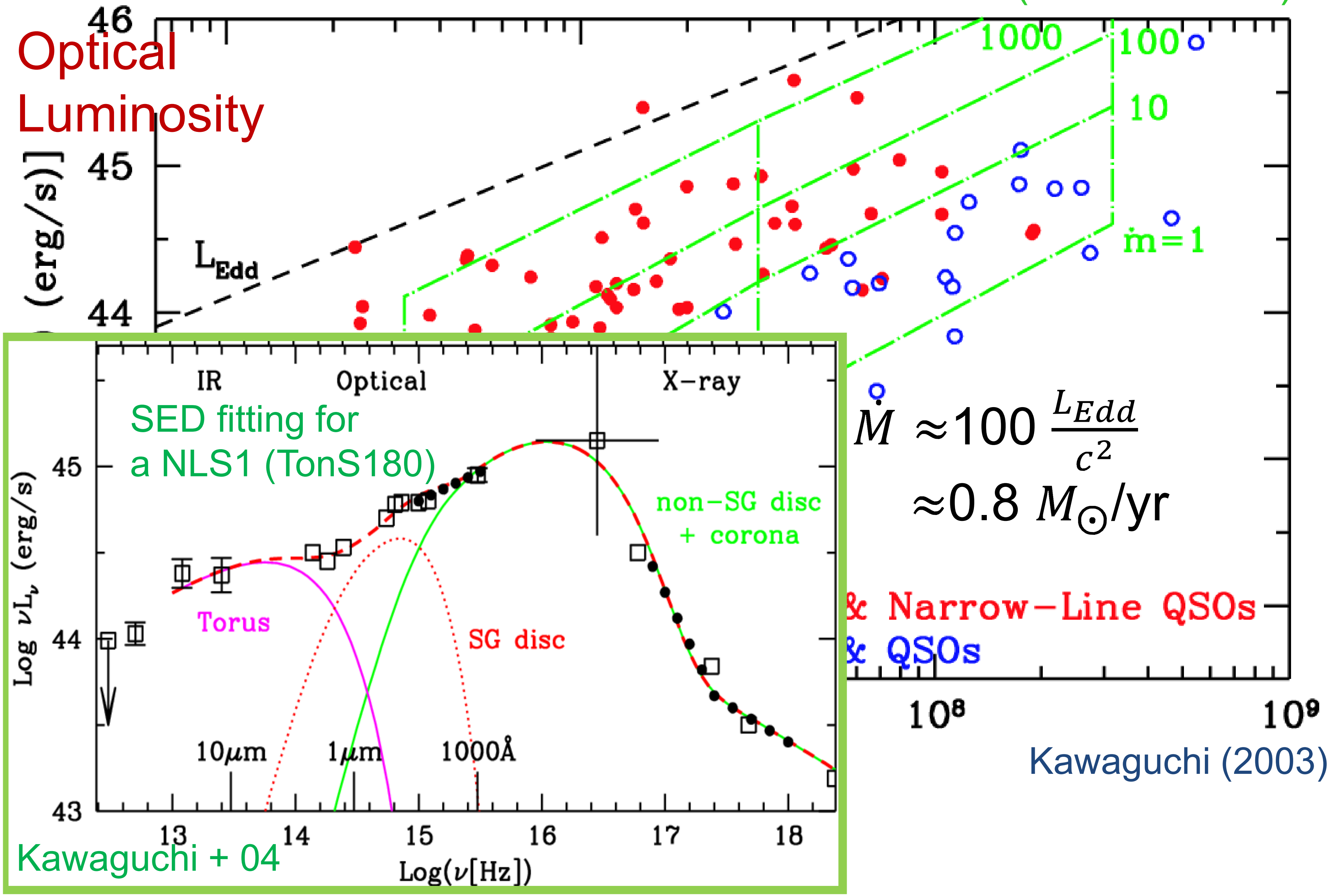
IRAS04576 along with other AGNs



Kawaguchi (2003)

IRAS04576 along with other AGNs

Green lines: Disc model (thin and slim)



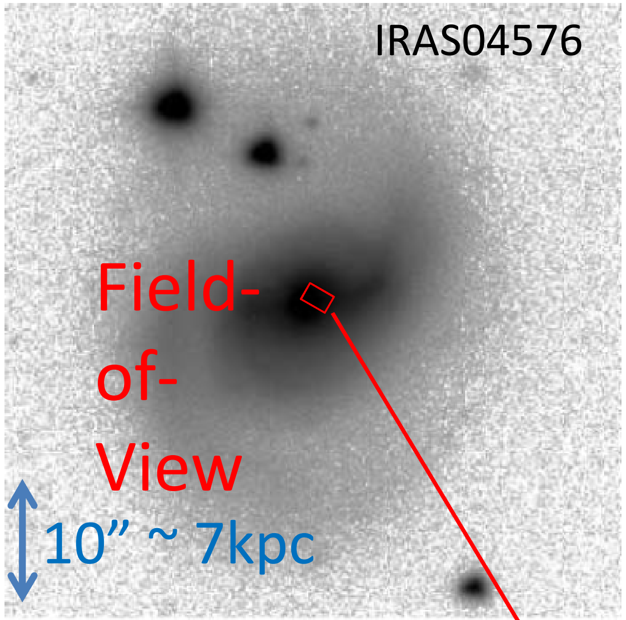
$$\dot{M} \approx 100 \frac{L_{Edd}}{c^2}$$

$$\approx 0.8\ M_{\odot}/\mathrm{yr}$$

Kawaguchi (2003)

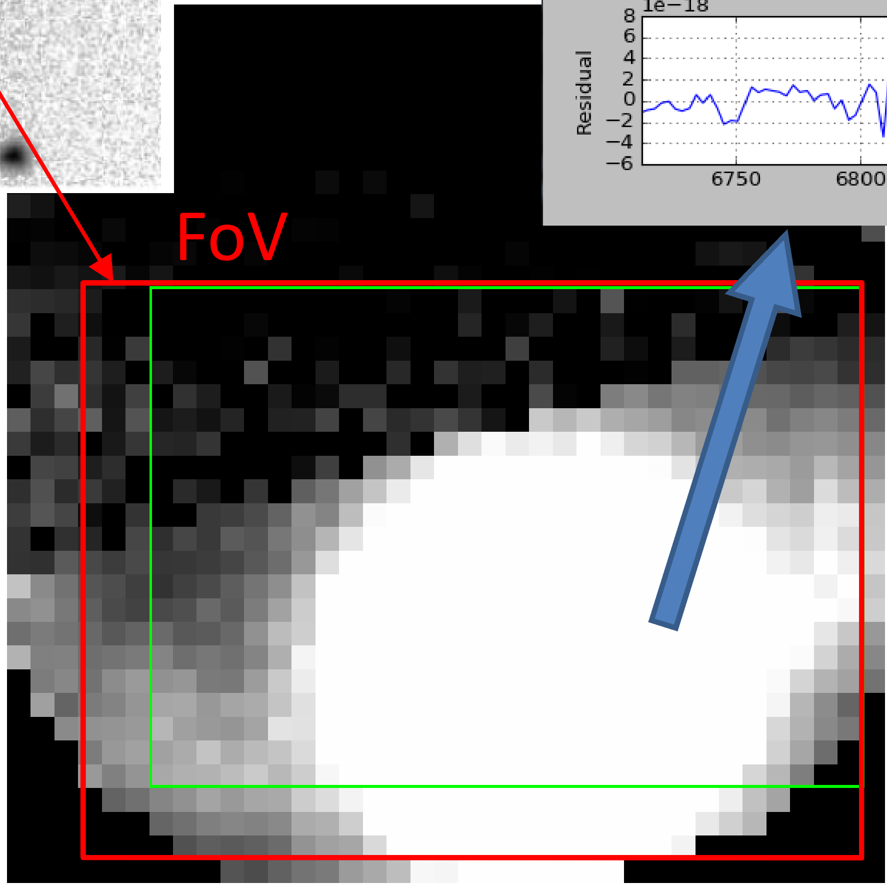
Kawaguchi + 04

Data analysis for IRAS 04576

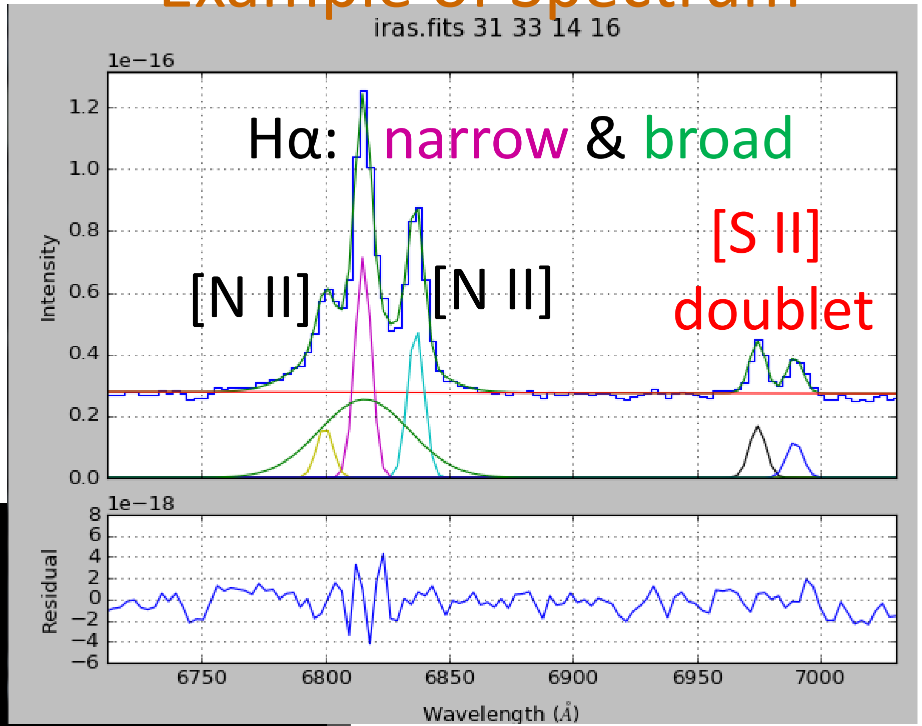


Ohta, Aoki, Kawaguchi, Kiuchi 2007

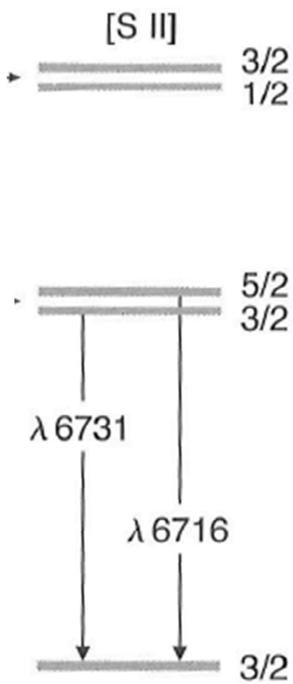
Integral Field Spectroscopy = Spectrum at each position



Example of Spectrum



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



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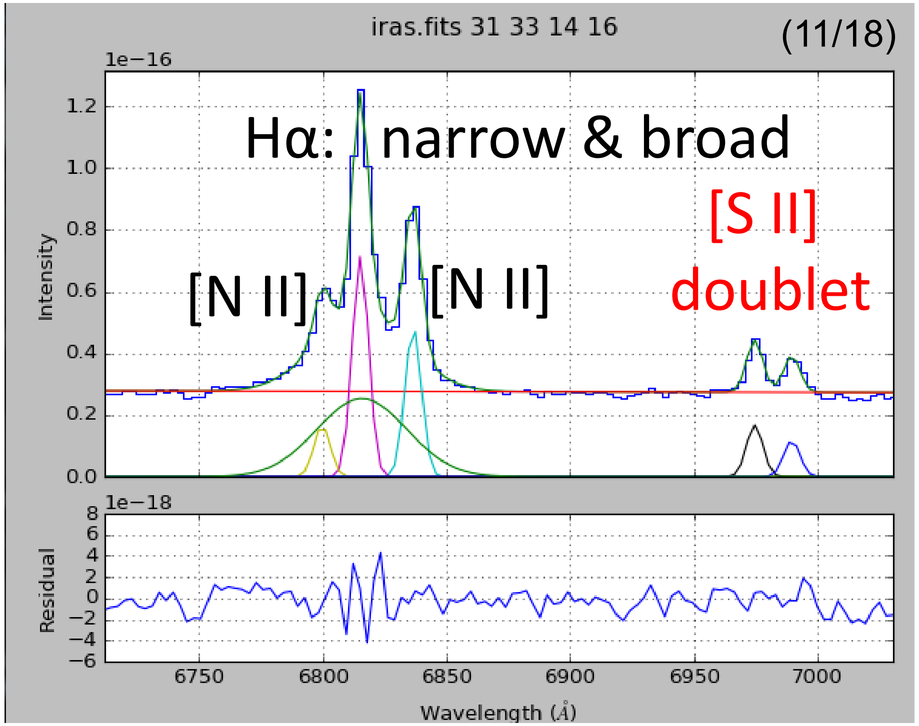
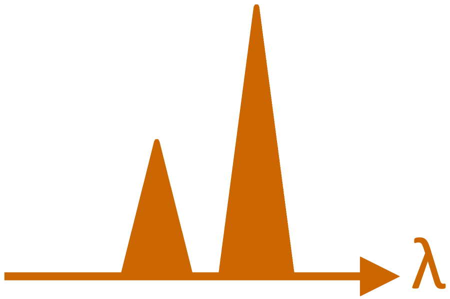


High density
→ Collisions
→ Lower level, then emit
→ longer wavelength, stronger

(Osterbrock & Ferland 06)



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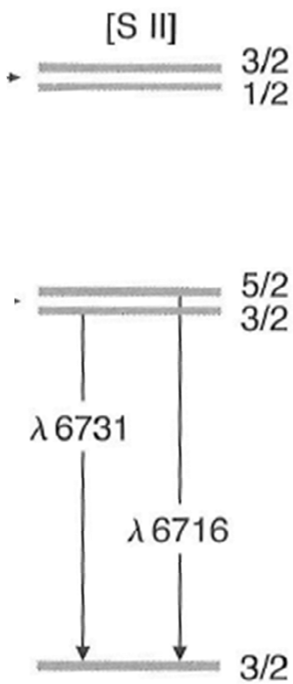

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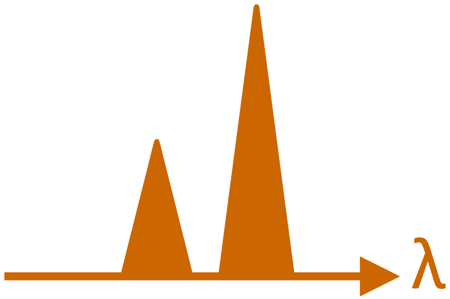
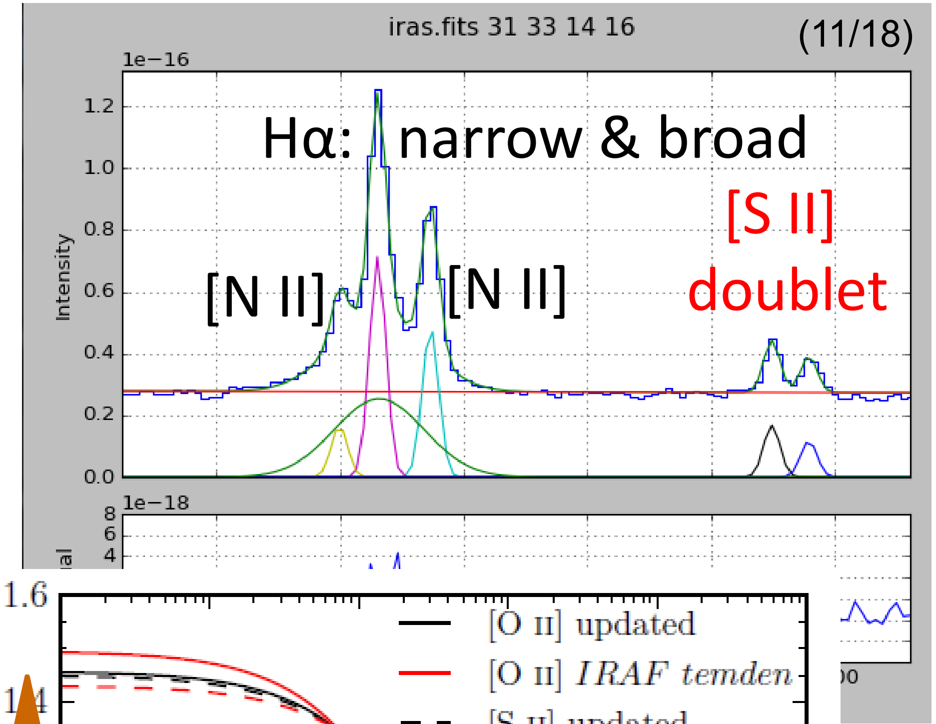
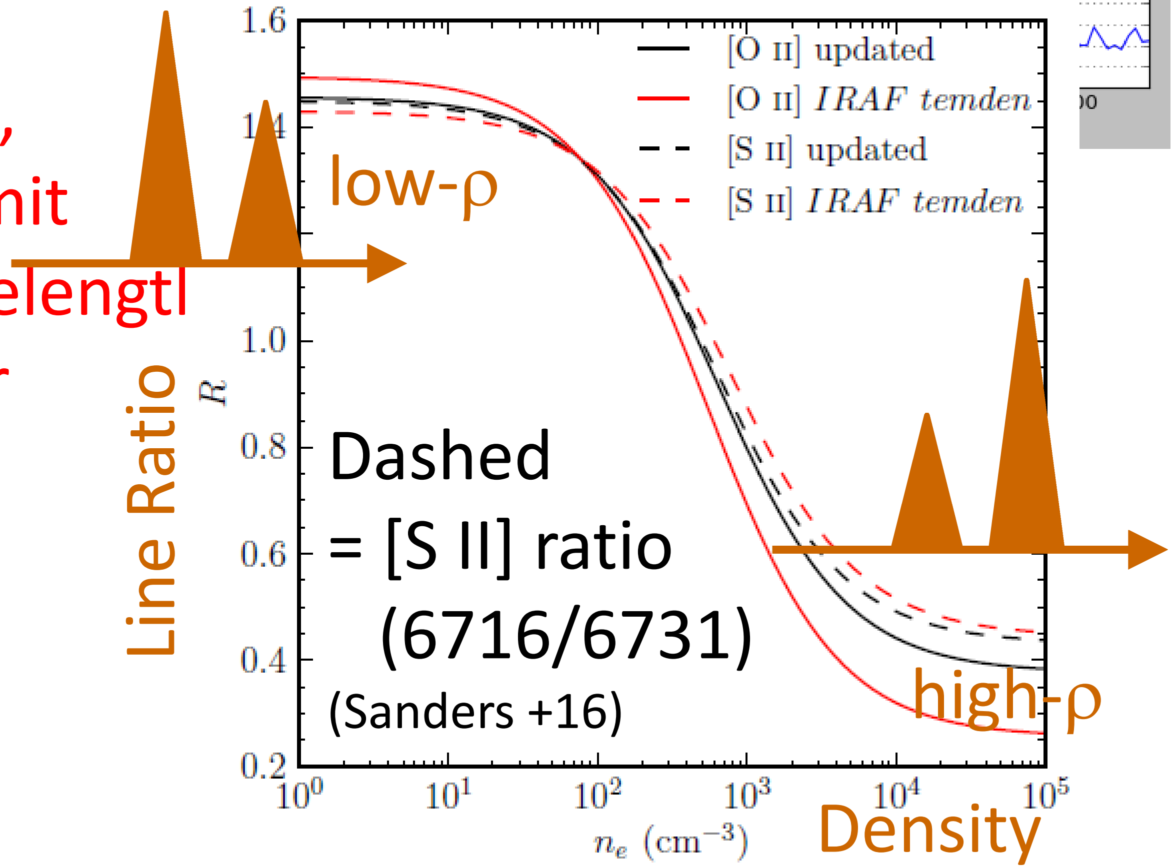
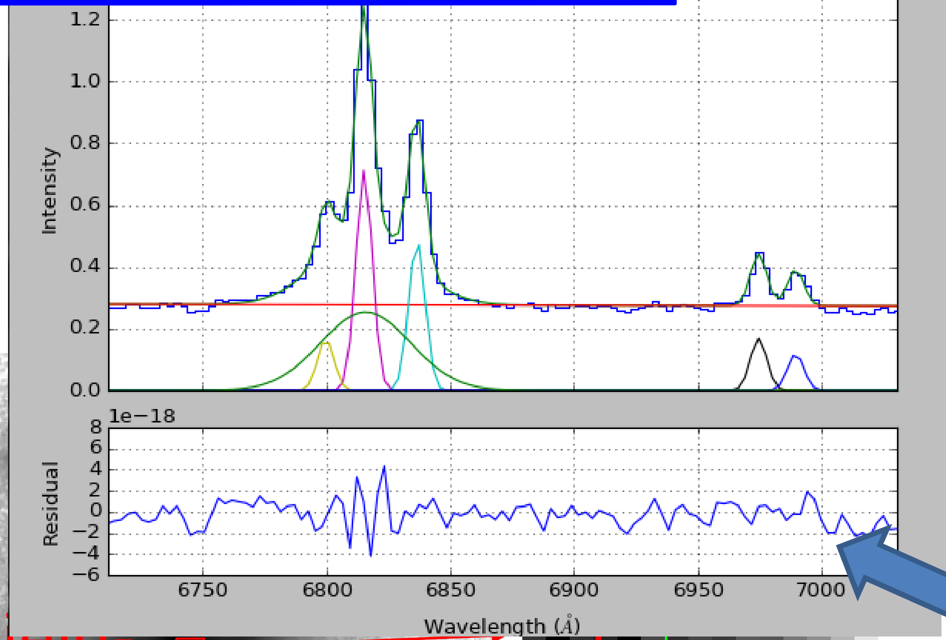
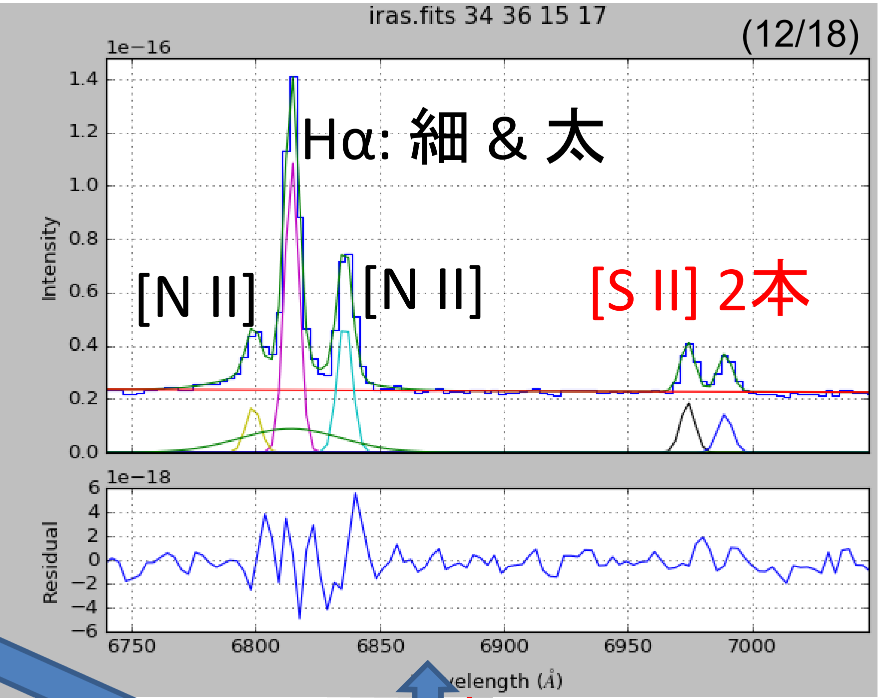


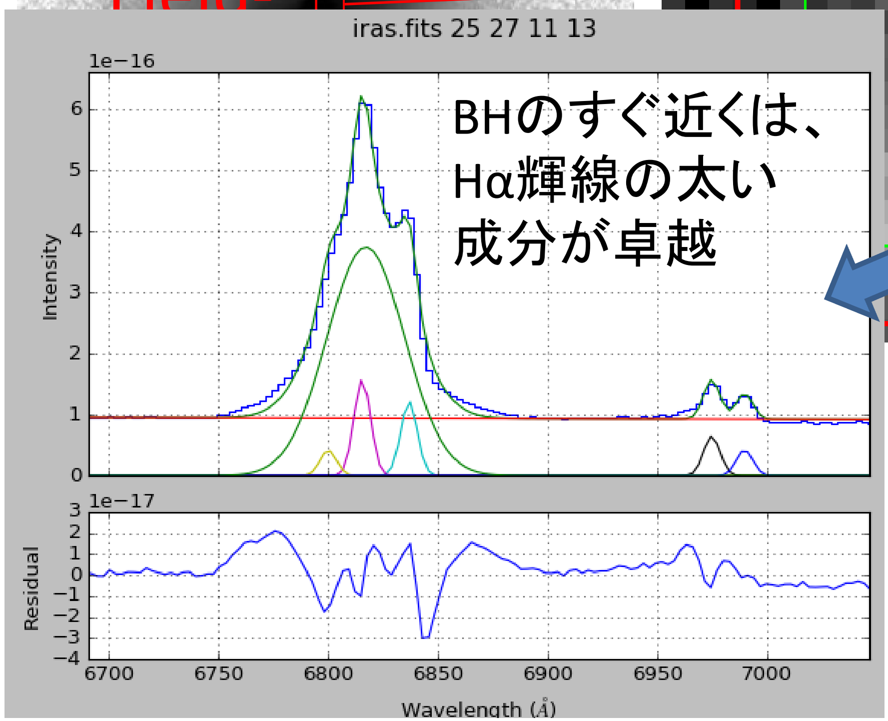




面分光 = 各位置のスペクトル取得







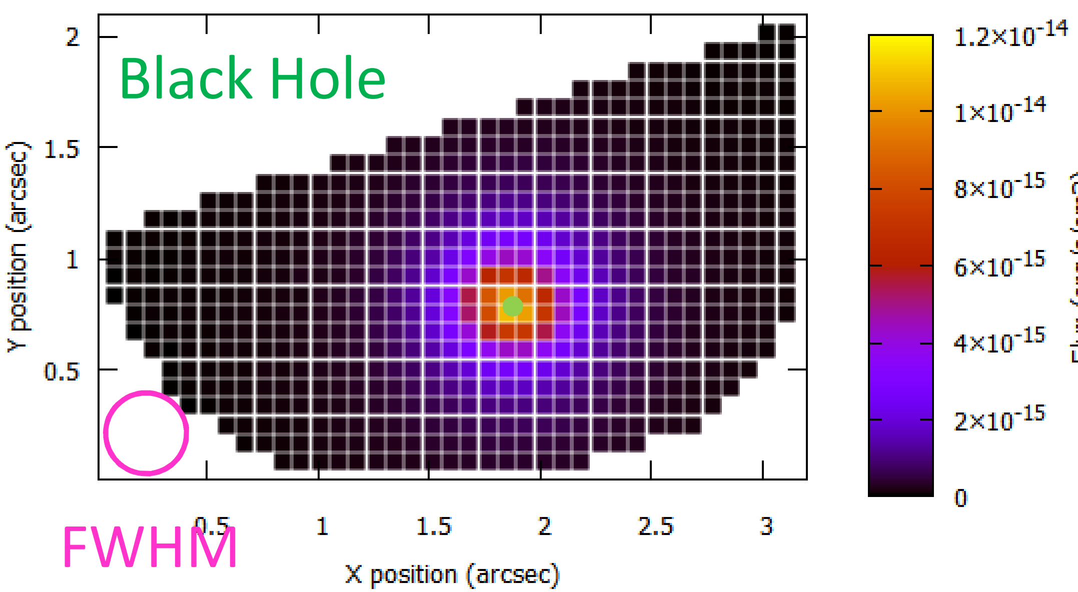
Hα輝線の太い成分が空間的に拡がって
観えるのは、大気のゆらぎのせい
（補償光学で極力小さくしてもこれだけ残る）
広輝線領域(BLR)の実際の大きさ(~0.01pc)は
1pixel(60pc)よりずっと小

Flux Map of Hα Broad Emission Line: PSF

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

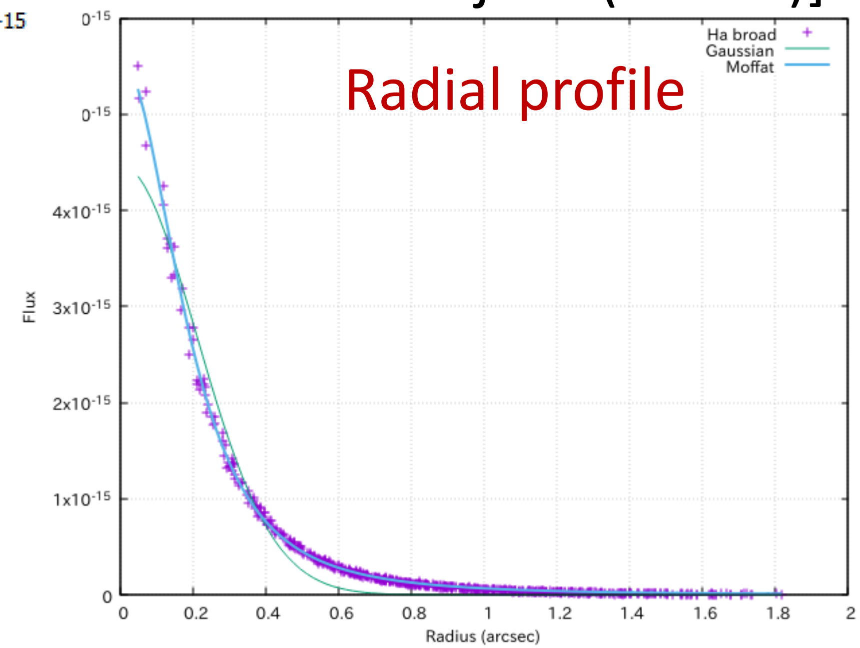
Spectral fit for 615 lenslets

3.1” ~ 2.2kpc



* Round shape of PSF

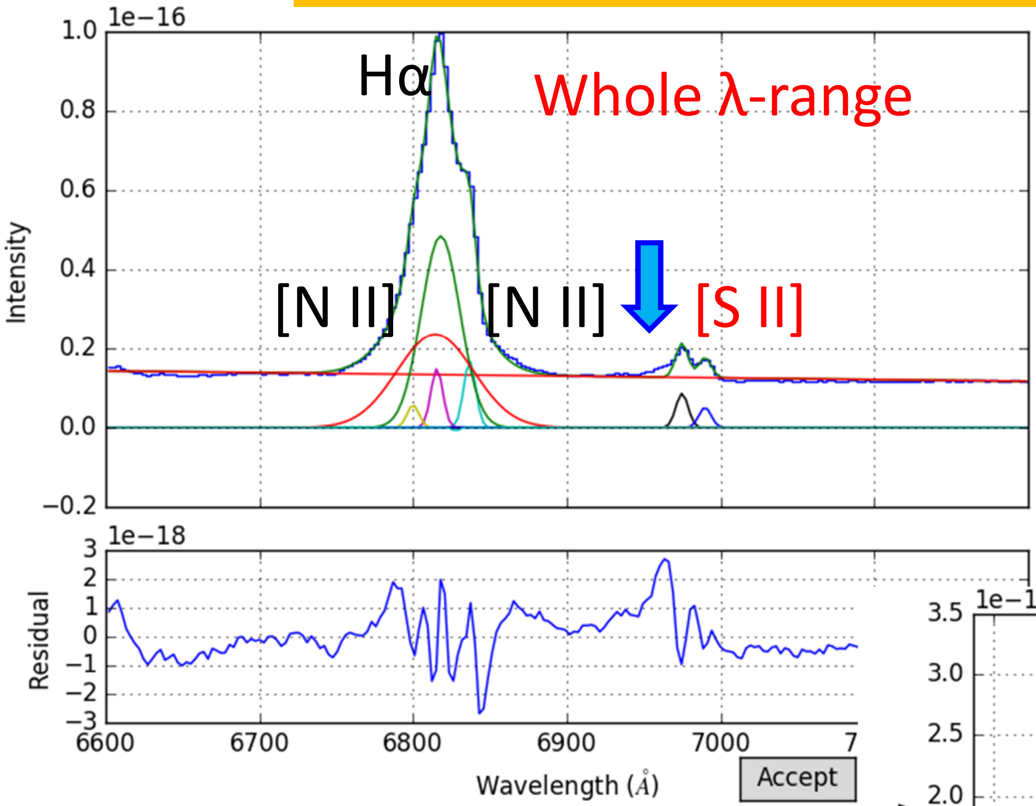
* FWHM ~ 0.37”
[Better FWHM for another object (~0.2”?)]



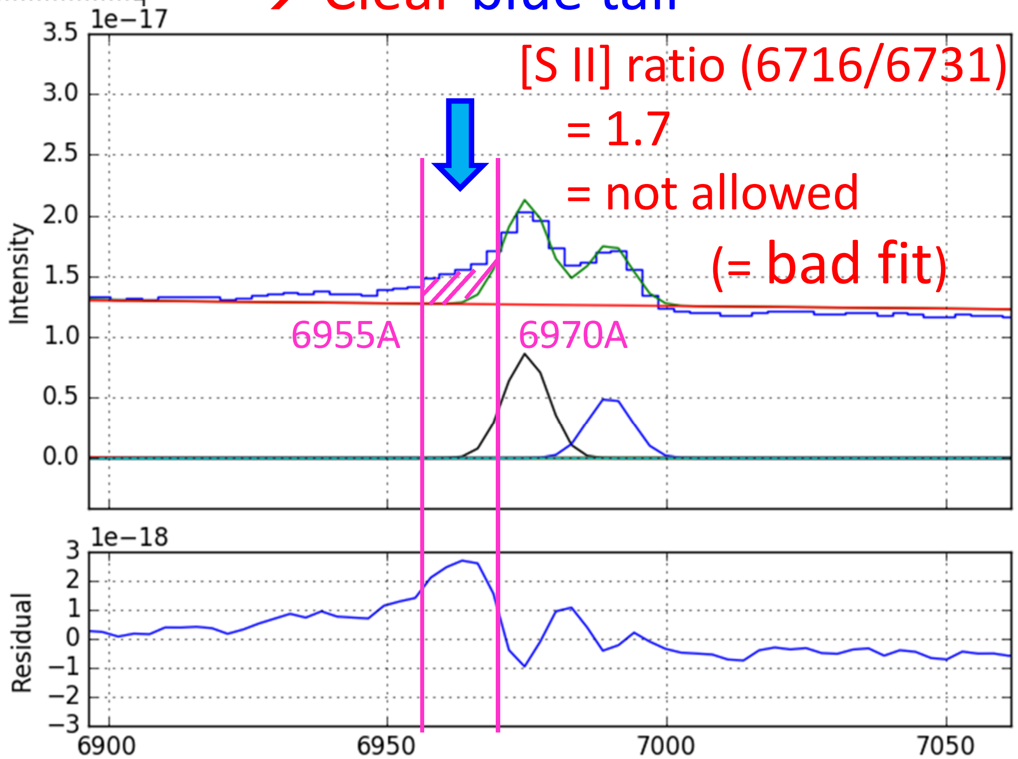
1 lenslet (0.084”) = 60pc

Blue tails of [S II] lines in many lenselets

1-component Fit



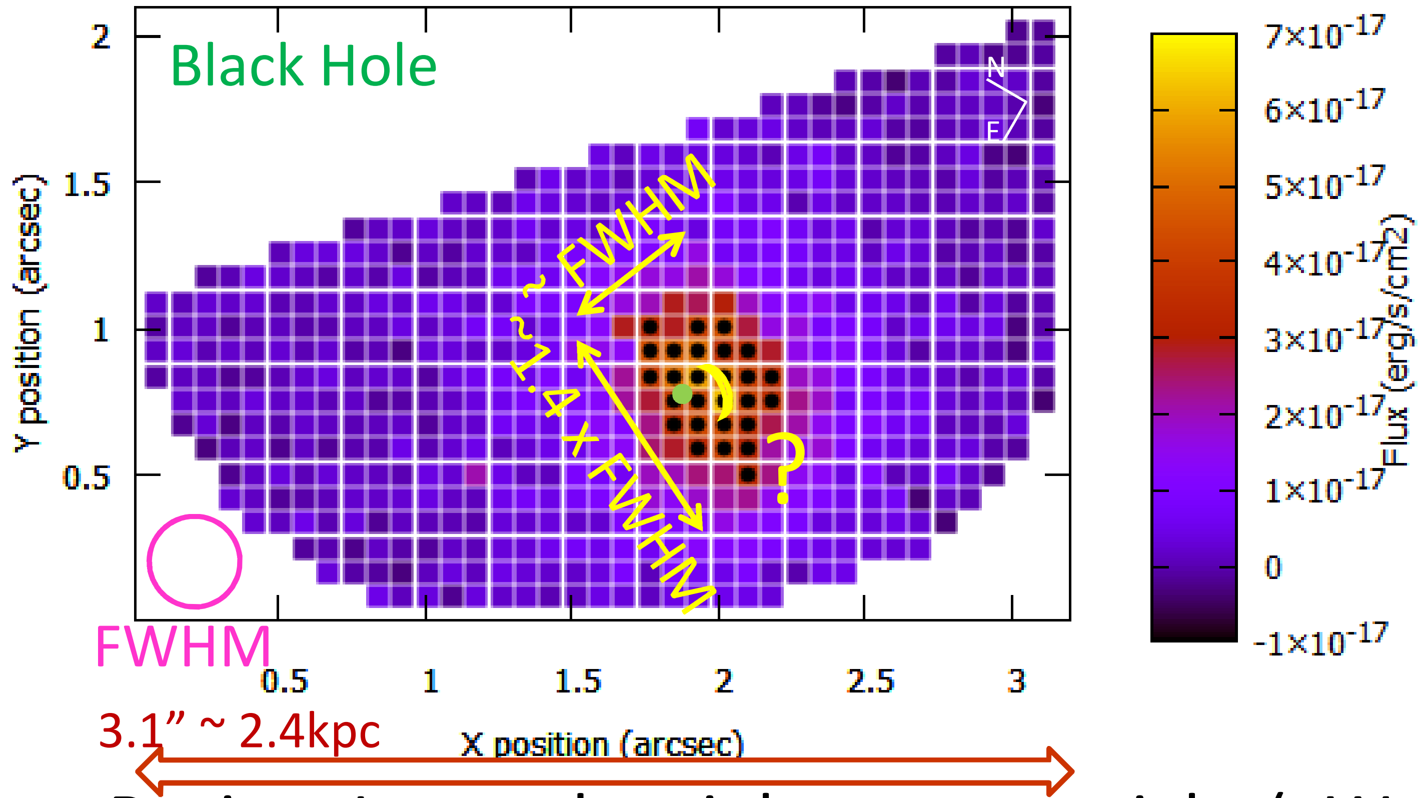
Close-up View around [S II] :
→ Clear blue tail



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

Excess Flux Map at 6955-6970 Å

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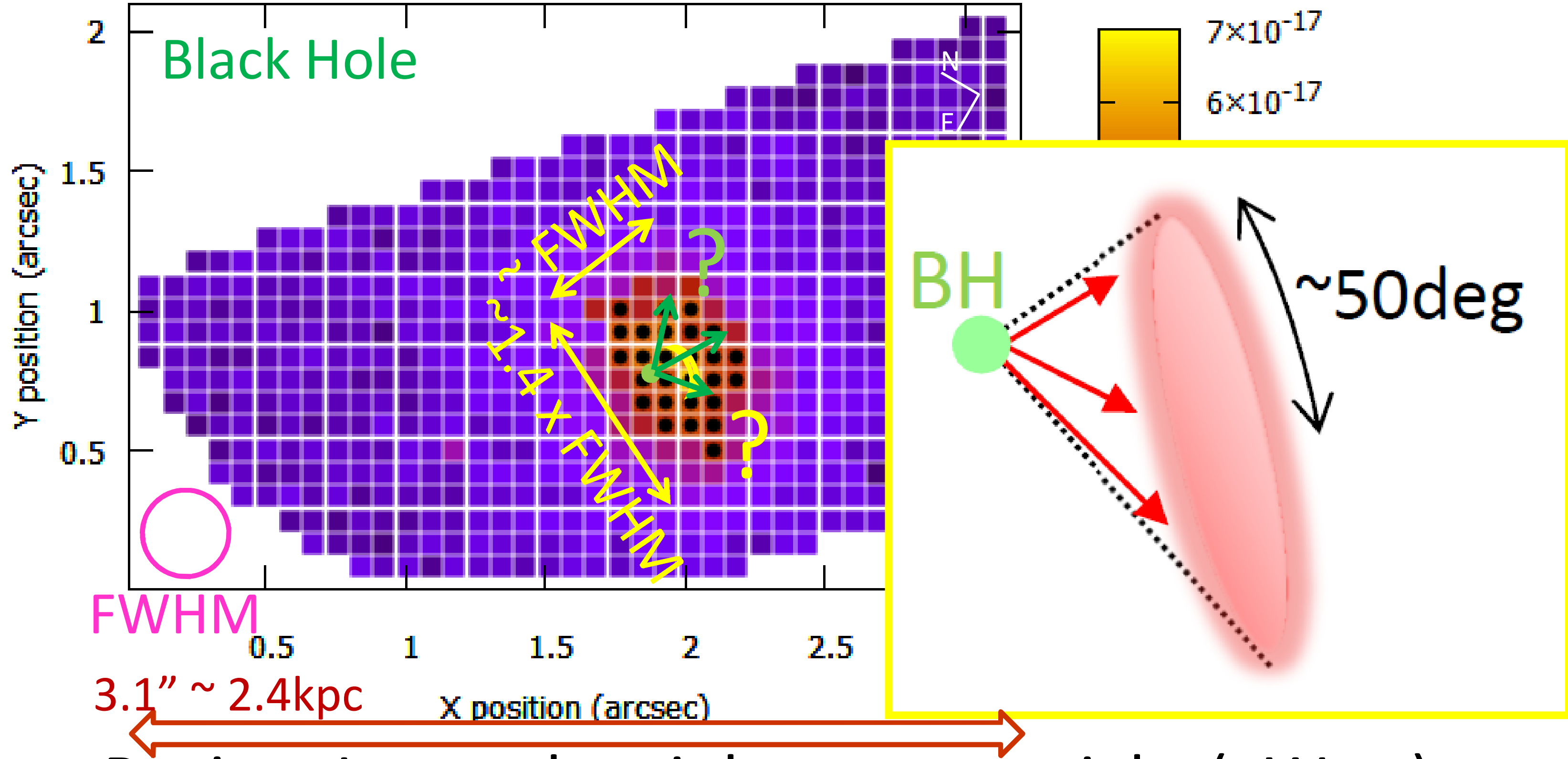


* Outflow Region: Located mainly at upper-right (~West)

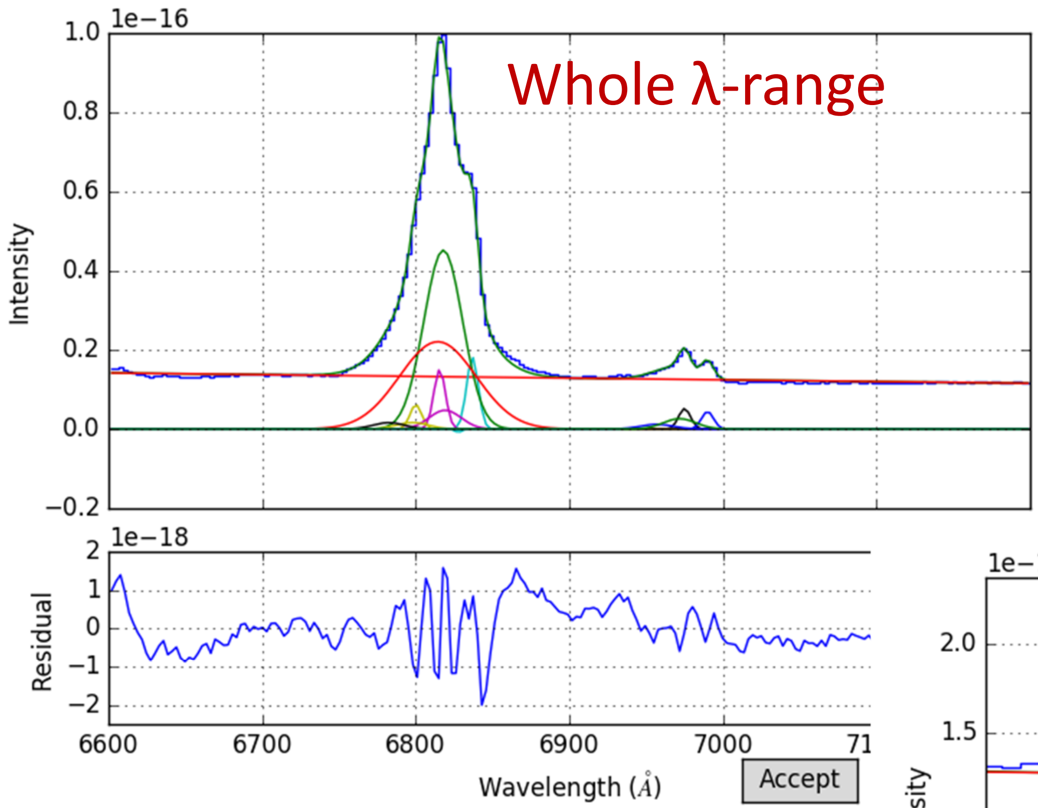
* 100s pc -scale outflow

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

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

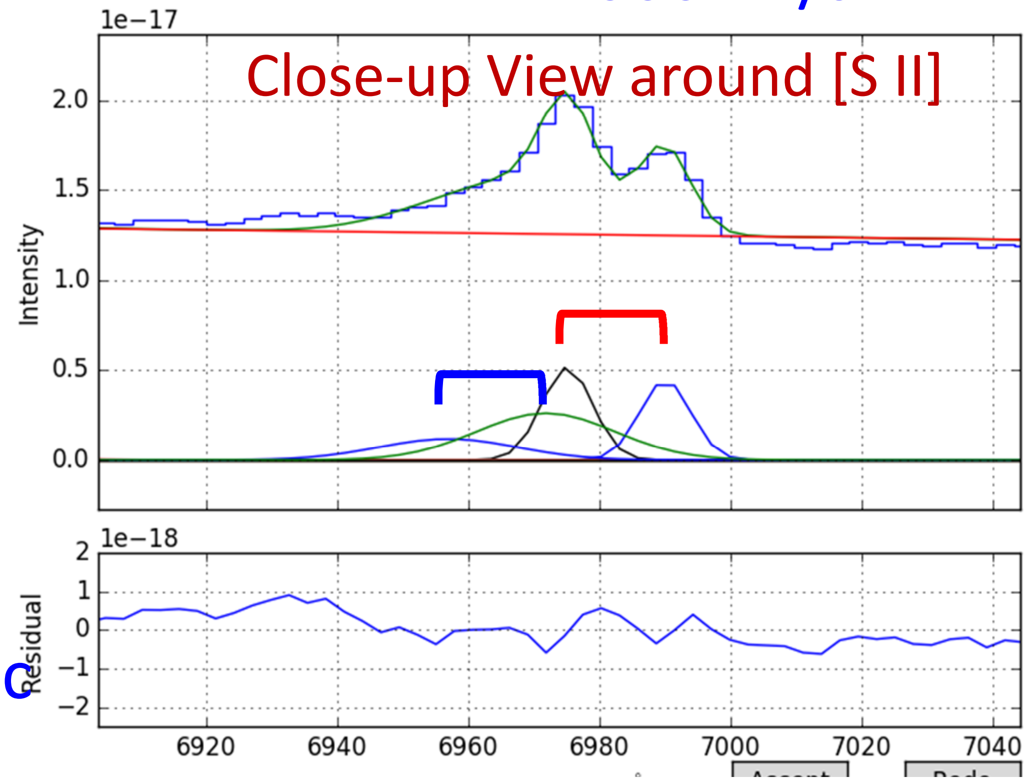
Large angle favors AGN feedback hypothesis?

Velocity and density of the outflowing gas



2-component Fit

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



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

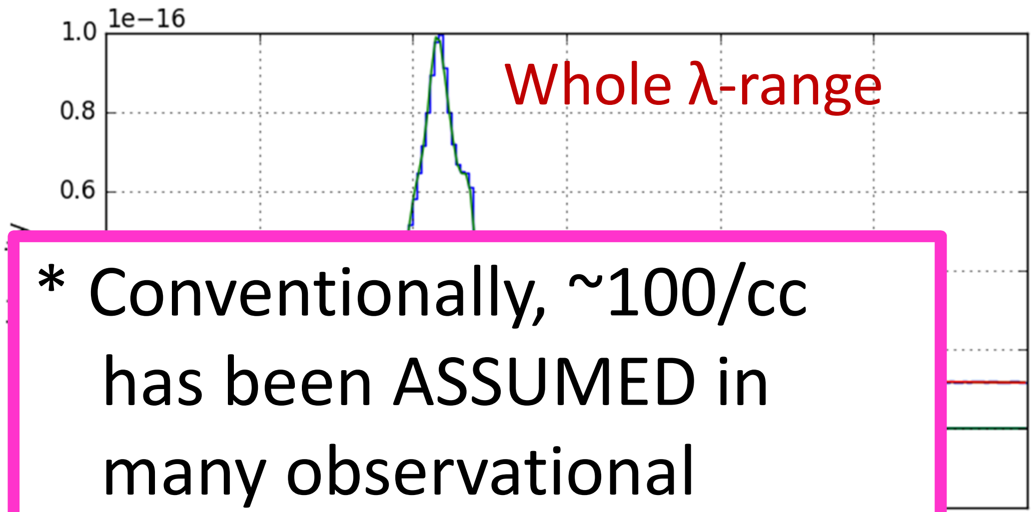
Stronger component:

1.17 → n ~ 300/cc

Outflowing component:

0.43±0.21 → n >3000/cc

Velocity and density of the outflowing gas



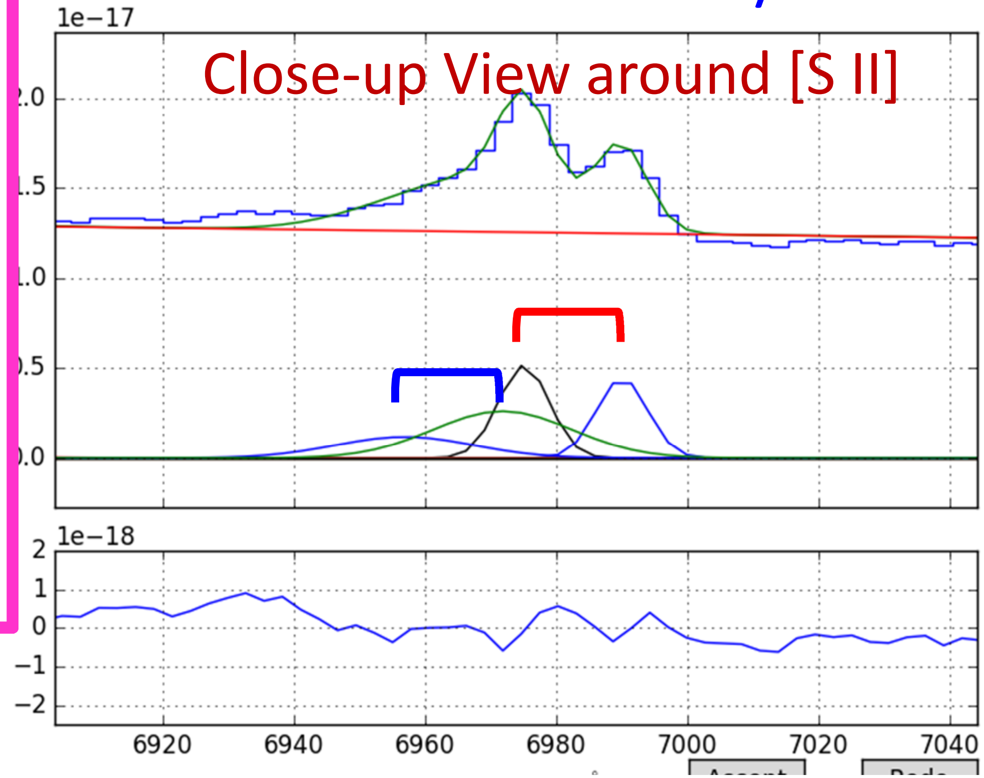
* Conventionally, ~100/cc has been ASSUMED in many observational studies of AGN outflows:
* Gas mass ∝ density^{-1}
($L_{H_\alpha} \propto n_H n_e V \propto M_{gas} n$)

* Overestimation of the Outflow rate, Kinetic energy injection rate, etc.

0.43±0.21 → n >3000/cc

2-component Fit

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

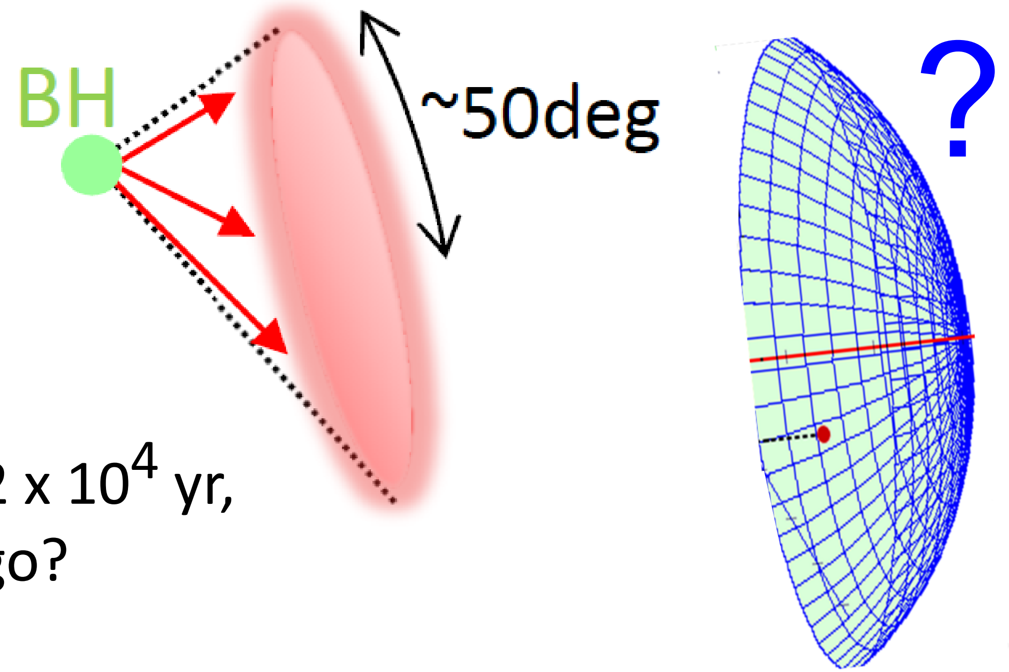


Quantities of the Outflow

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

Size of outflowing region ≈ Point Spread Function

⇒ Deconvolution-like estimation (large uncertainty) :



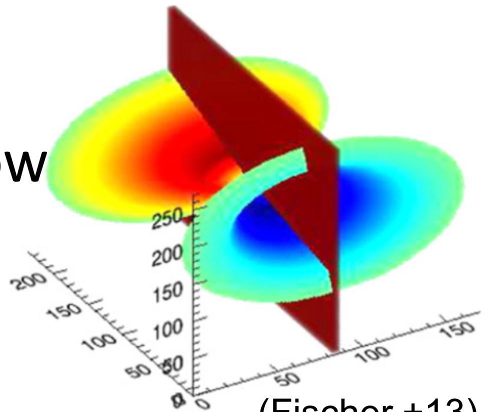
Launched for 2 x 10^4 yr,
10^5 yr ago?

* 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?

Summary & Future Steps

* Testing "AGN feedback to host galaxy" hypothesis
* AO + Optical IFU capability of Subaru
  → Density-sensitive [S II] emission lines observable
* ~ 100s pc scale structures in velocity, gas density, ionization source
* Fast, Dense, Broad-angle, Offset Outflow
  (~ 900km/s, > 3000/cc, not jet-like)
* Seems insufficient for feedback to host galaxy

* Next:
  * Better spatial resolution IFU at NIR; Gemini/NIFS, JWST/NIRSpec
    Now that we obtained the density of outflow gas
  * VLT/MUSE narrow-field mode (optical AO IFU);
    [O III] (= strong) observable
  * ALMA: interplay between ionized/molecular outflow
  * Modeling geometry & kinematics



(Fischer +13)