Black Hole Mass Measurements with Adaptive Optic Assisted 3D-Spectroscopy

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Courtesy ESO

OUTLINES

- INTRODUCTION: Supermassive Black Holes and Galaxy's evolution
- Principal methods used to measure M_{BH} in nearby and far galaxies
- The potentiality of 3D Spectroscopy: SINFONI at the VLT
- Our sample and VERY PRELIMINARY RESULTS
- Conclusions

INTRODUCTION

- Presence of Supermassive Black Holes (SBH) ($M_{BH} = 10^6$-$10^{10} M_{\odot}$) in the most luminous nuclear regions of nearby galaxies *(Ferrarese & Ford 2005)*

- BH Mass measurements, mostly in elliptical galaxies, revelead straight correlations between M_{BH} and several structural host galaxy's parameters:

➔ M_{BH} / L_{sph} *(Kormendy & Richstone 1995, Marconi e*

➔ M_{BH} / σ_* *(Ferrarese & Merrit 2000, Tremaine et al. 2*

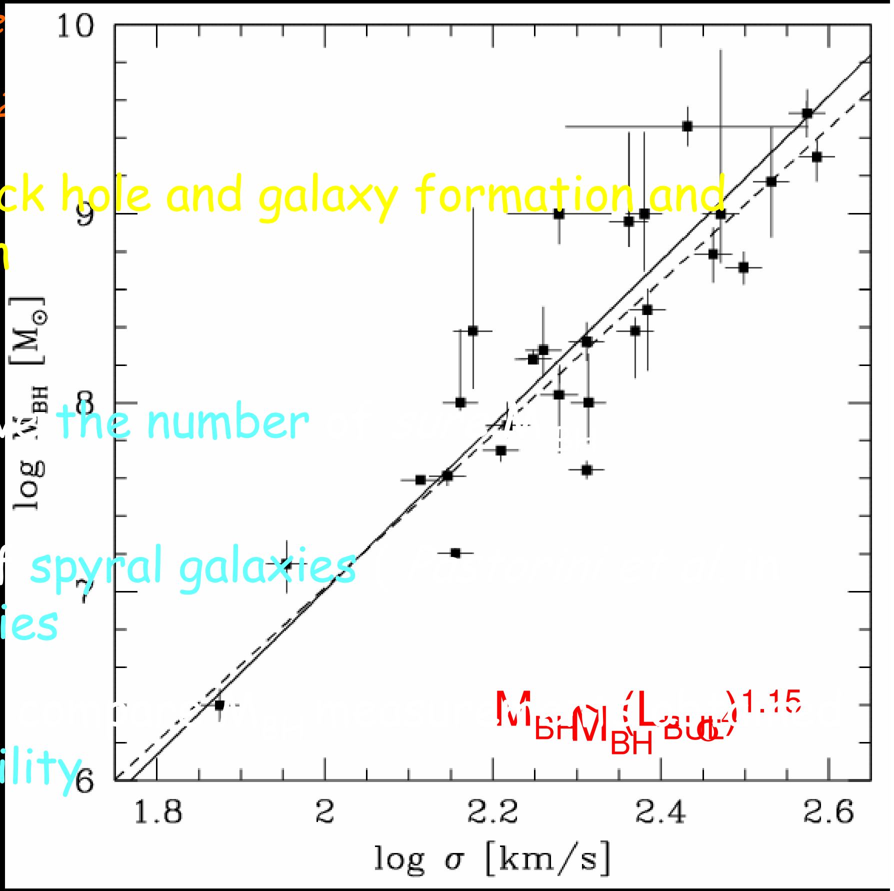
Thight link between growth onto the black hole and galaxy formation and evolution

Principal targets:

- Correlations not yet well defined ➔ Improv the number measurements (actually very small))

- Extend these estimates also to the class of spyral galaxies preparation) and to the class of Active Galaxies

- Need to measure M_{BH} at all redshift and to with different methods to check their reliability



M_{BH} MEASUREMENTS METHODS

Principal Problem: the high spatial resolution required to resolve BH's sphere of influence (usually << 1")

Direct methods: currently avalaible only for nearby galaxies (< 100 Mpc):

$\Phi(r) = -G^*(M_{\star}(r) + M_{BH})/r$

- ➔ Stellar Dynamics
- ➔ Gas Kinematics

Indirect methods: Assumption: broad emission lines are produced in the Broad Line Region (BLR) by gravitationaly bounded gas orbiting with Keplerian velocities (Virialized BLR)

$M_{BH} = f^* R_{BLR} {}^* \sigma^2 {}^* G^{-1}$

f = geometrical factor about the BLR structure

σ = line's FWHM

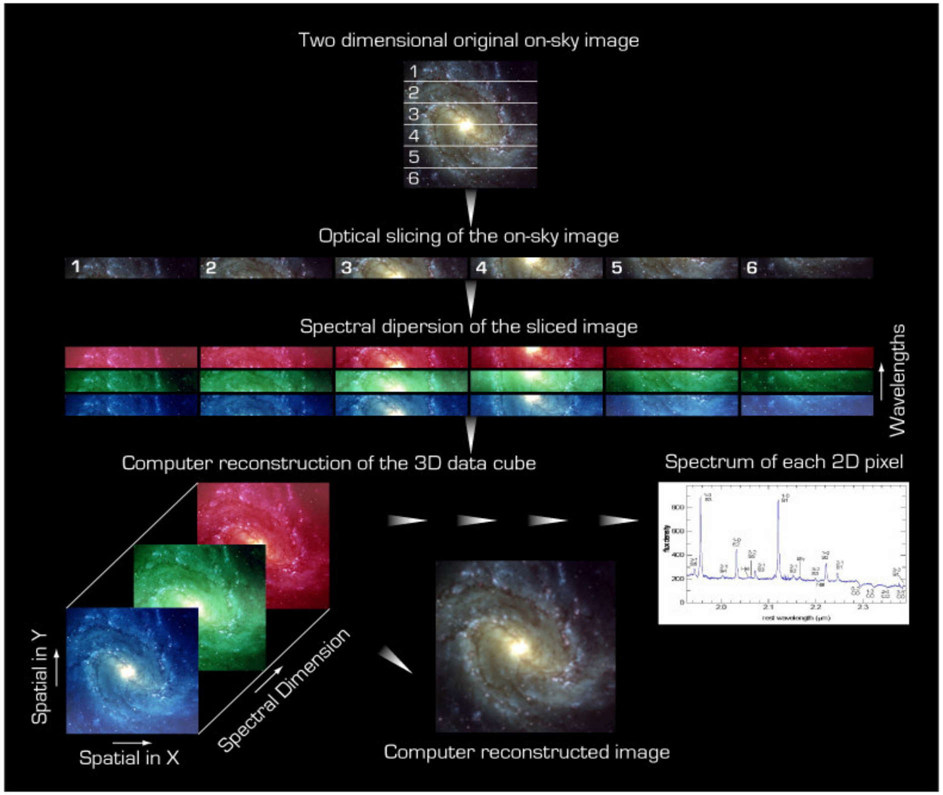
Radius of Broad Line Region (R_{BLR})

➔ Time delay between continuum and broad line variation (Reverberation Mapping)

➔ Correlation between R_{BLR} and $L_{5100Å}$ *(Kaspi at al.2000)*

SINFONI (Integral field spectrograph (SPIFFI) for near-IR (1.05 – 2.45 μm) + Adaptive Optics module (MACAO)).

Images Slicers: the only IFU which preserves completly the spatial information



The Principle of Integrated Field Spectroscopy (IFS)

Courtesy ESO

ESO PR Photo 24/04 (24 August 2004)

Field of view divided in 32 *slices:*

Slice's width	F.O.V. on the sky	Each Pixel
250 mas	8'' x 8''	125 x 250 mas
100 mas	3'' x 3''	50 x 100 mas
25 mas	0.8'' x 0.8''	12.5 x 25 mas

For each slice 64 pixels ➔ 32 x 64 spectra of observed region in the sky

Spectral	Resolution:
J	2000
H	3000
K	4000
H+K	1500

$M_{threshold}$ ~ 17-18 (J,H,K)

We used SINFONI to directly measure M_{BH} in a sample of Seyfert 1 galaxies for which there are avalaible Reverberation Mapping M_{BH} estimates.

$$\Delta\theta_k = 1.22\,\frac{\lambda_k}{D} \approx 0.06''$$

$$\left(\Delta\theta_k(\mathrm{HST}) \approx 0.2''\right)$$

- ➔ K Band Spectra (~1h ; R ~ 4000) : both Gas and Stellar Methods.
- ➔ Spectra obtained with and without Adaptive Optics

Targets:

➔ Comparison of M_{BH} estimates obtained with different methods

➔ Analisys of M_{BH}- host galaxy correlations: are they the same as normal galaxies? What informations about galaxy's evolution ?

➔ Analisys of Broad Line Region's structure

OUR SAMPLE:

Object	D (Mpc)	z	M (R)	$\log(M_{BH}/M_{\odot})$
3C 273	564	0.158	12.3	8.9
Fairall9	190	0.047	13.9	8.4
NGC 4593	38	0.009	14.0	6.7
Akn120	133	0.033	14.0	8.2
3C120	133	0.033	14.3	7.7

Peterson et al. 2004

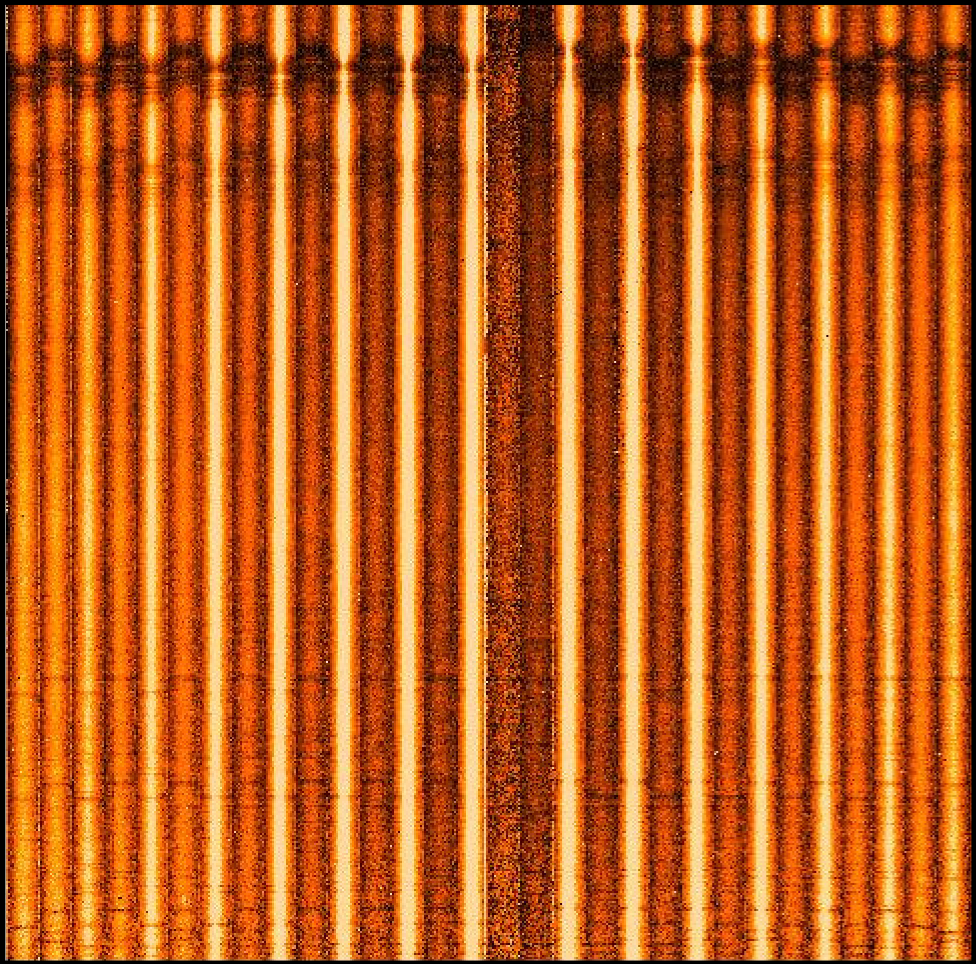
Principal Emission Lines:

P_{α}	18756Å
H2	19576Å
[SiVI]	19635Å
H2	21218Å
Br_{γ}	21665Å
[Ca VIII]	23213Å

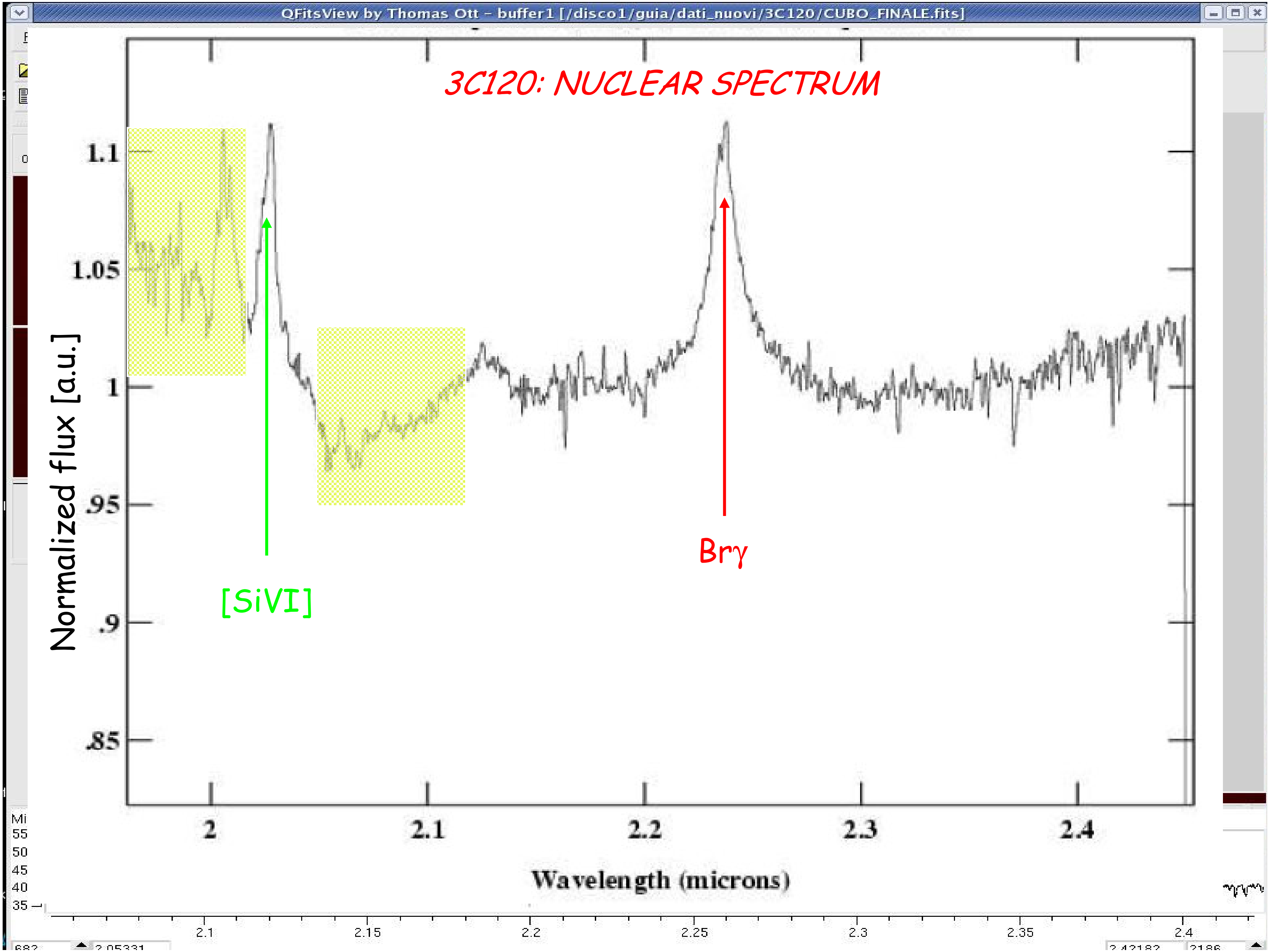
STAR TEMPLATE :

Object	M (V)	M(K)	Spectral Type
HD 60874	11.1	10.5	A0III
HD 288378	10.7	9.1	G0III
HD 293050	10.8	7.9	K0III
[R78b] 245	12.9	7.1	M4III

PSF (AO) ~ 0.15″ – 0.18″
PSF (no AO) ~ 1.1″ – 1.2″

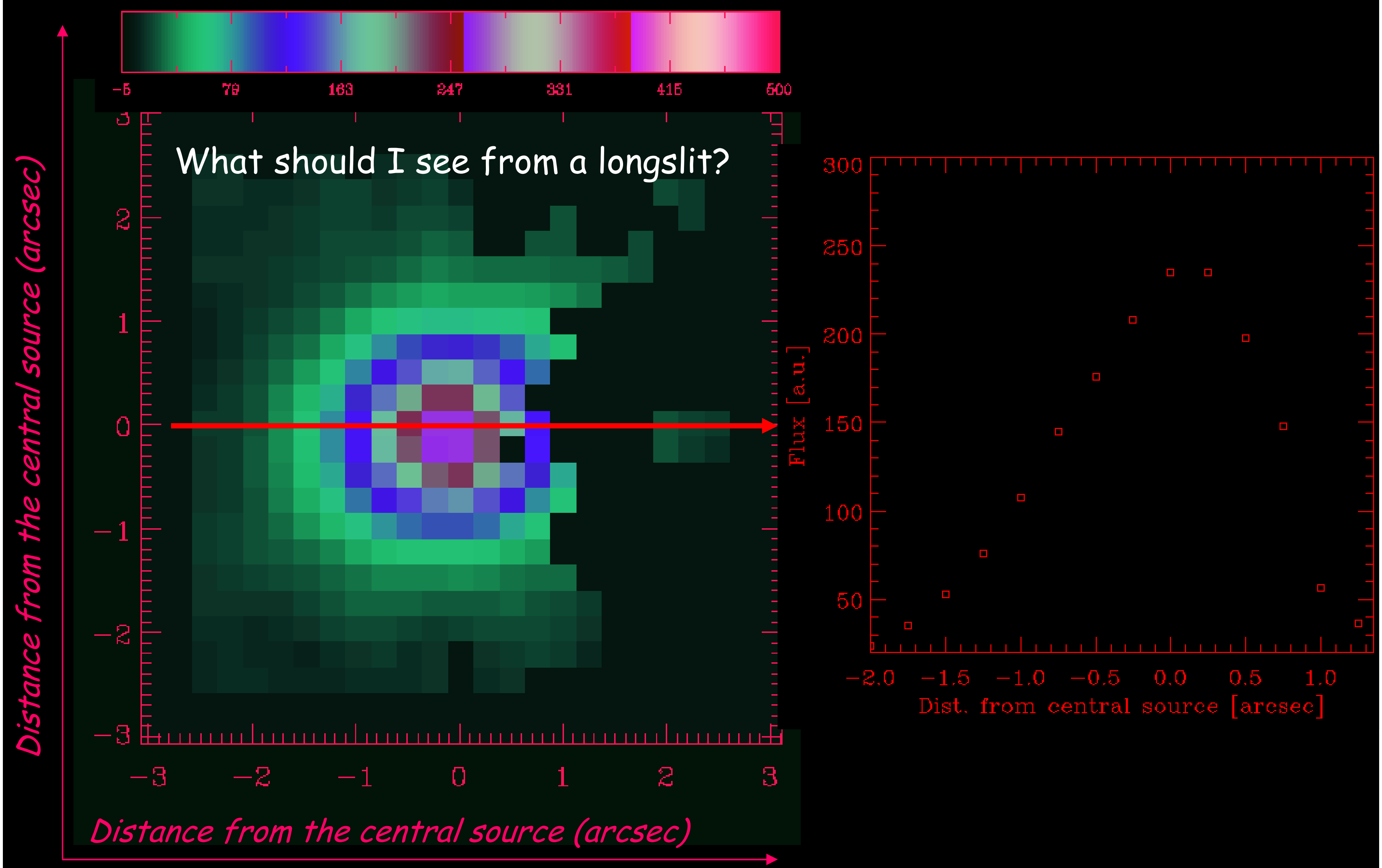


FIRST REDUCTED ON-OFF COUPLE
FOR 3C120

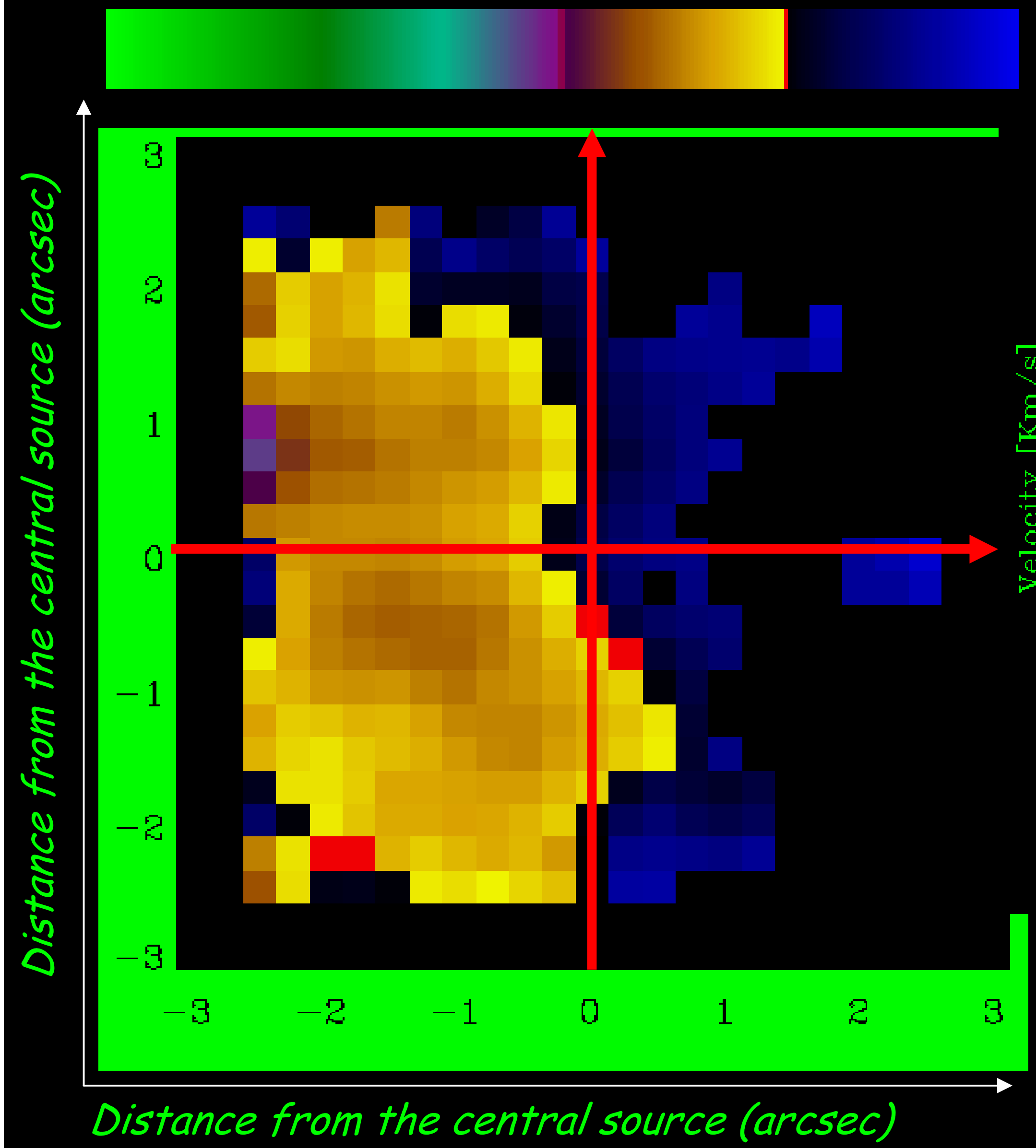


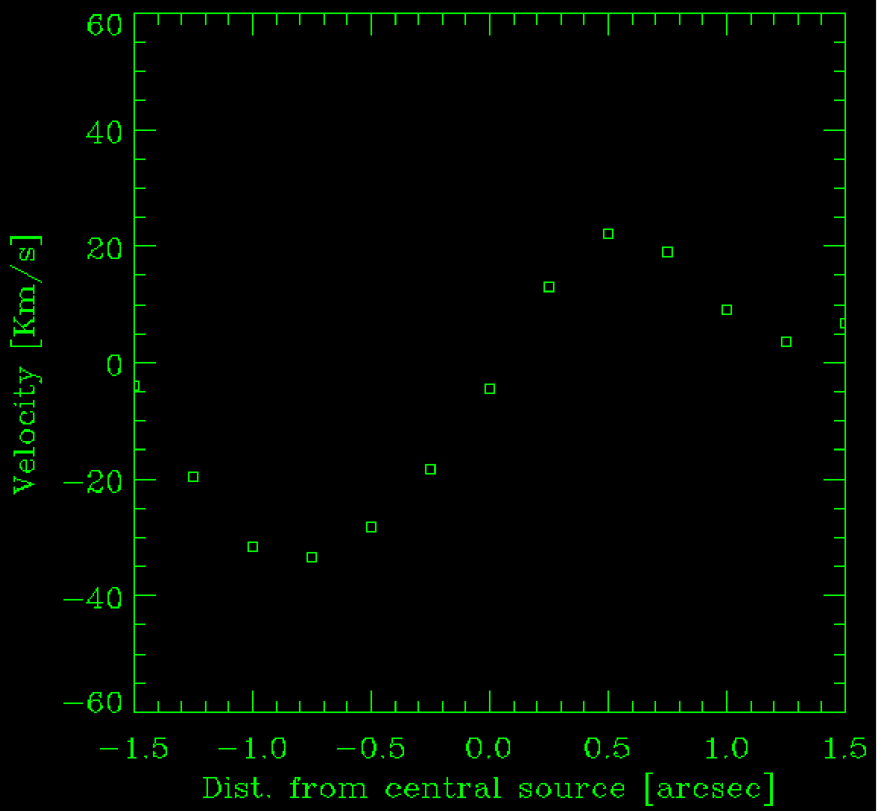
QFitsView by Thomas Ott – buffer1 [/disco1/guia/dati_nuovi/3C120/CUBO_FINALE.fits]
3C120: NUCLEAR SPECTRUM
Normalized flux [a.u.]
Wavelength (microns)
[SiVI]
Brγ
1.1
1.05
1
.95
.9
.85
2
2.1
2.2
2.3
2.4

Flux's Map for H2 (2.12 μm) in NGC 4593 without AO

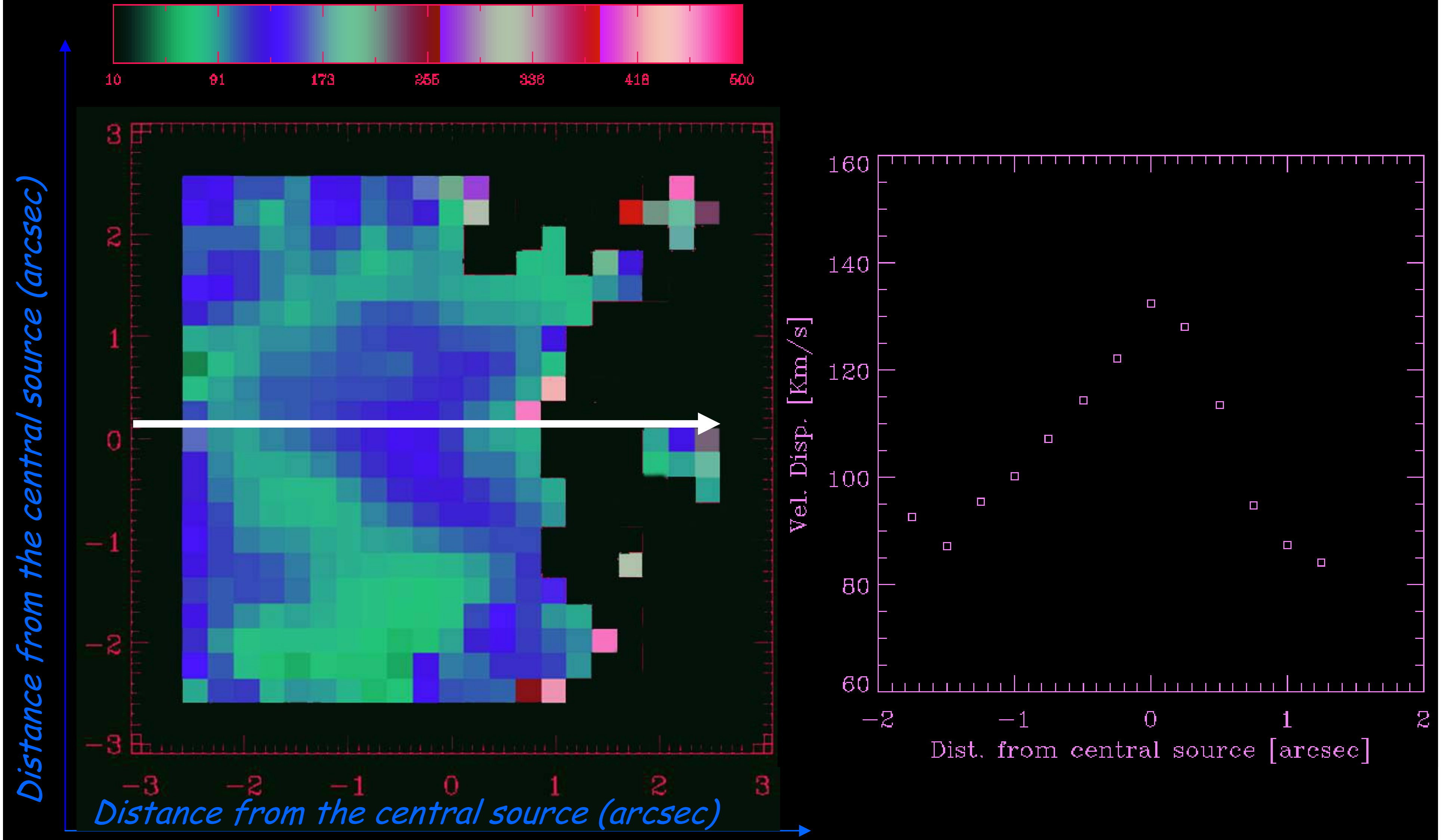


Velocity's Map for H2 in NGC 4593





Velocity Dispersion(σ) Map for H2 in NGC 4593



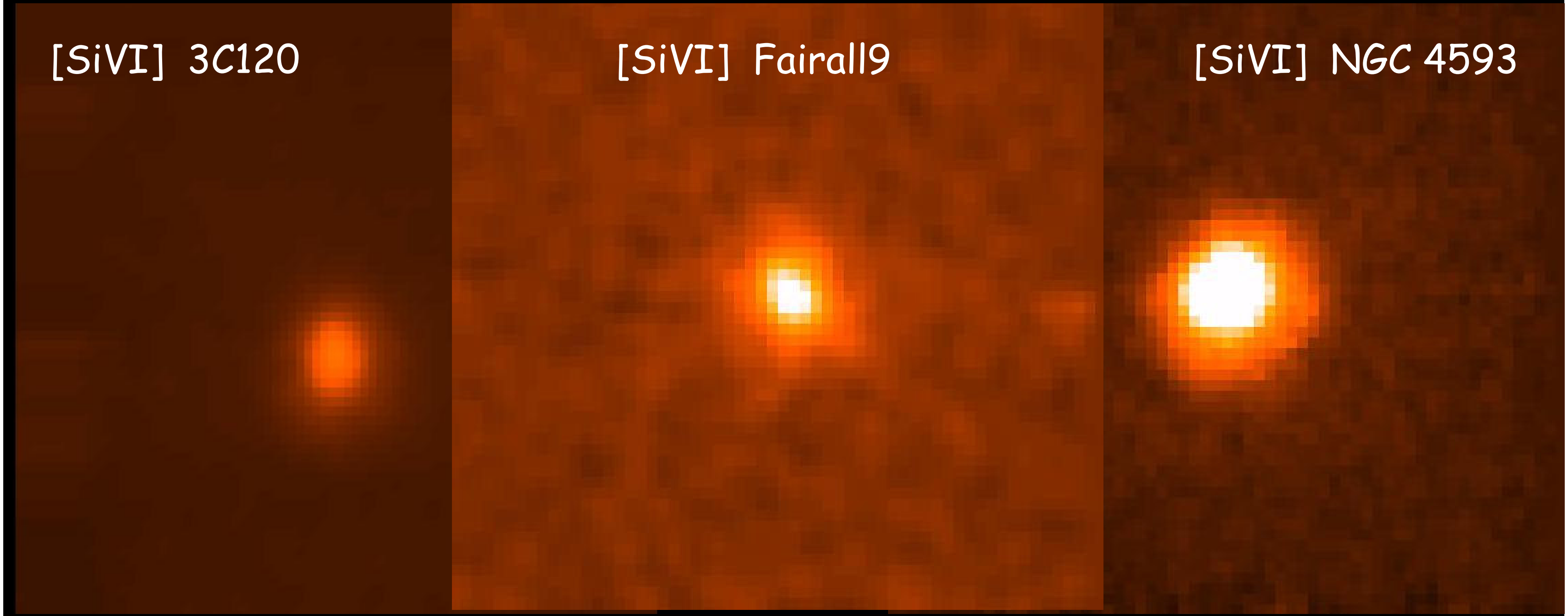
Preliminary Results about [SiVI]

[SiVI] revealed in each object with very large nuclear widths:

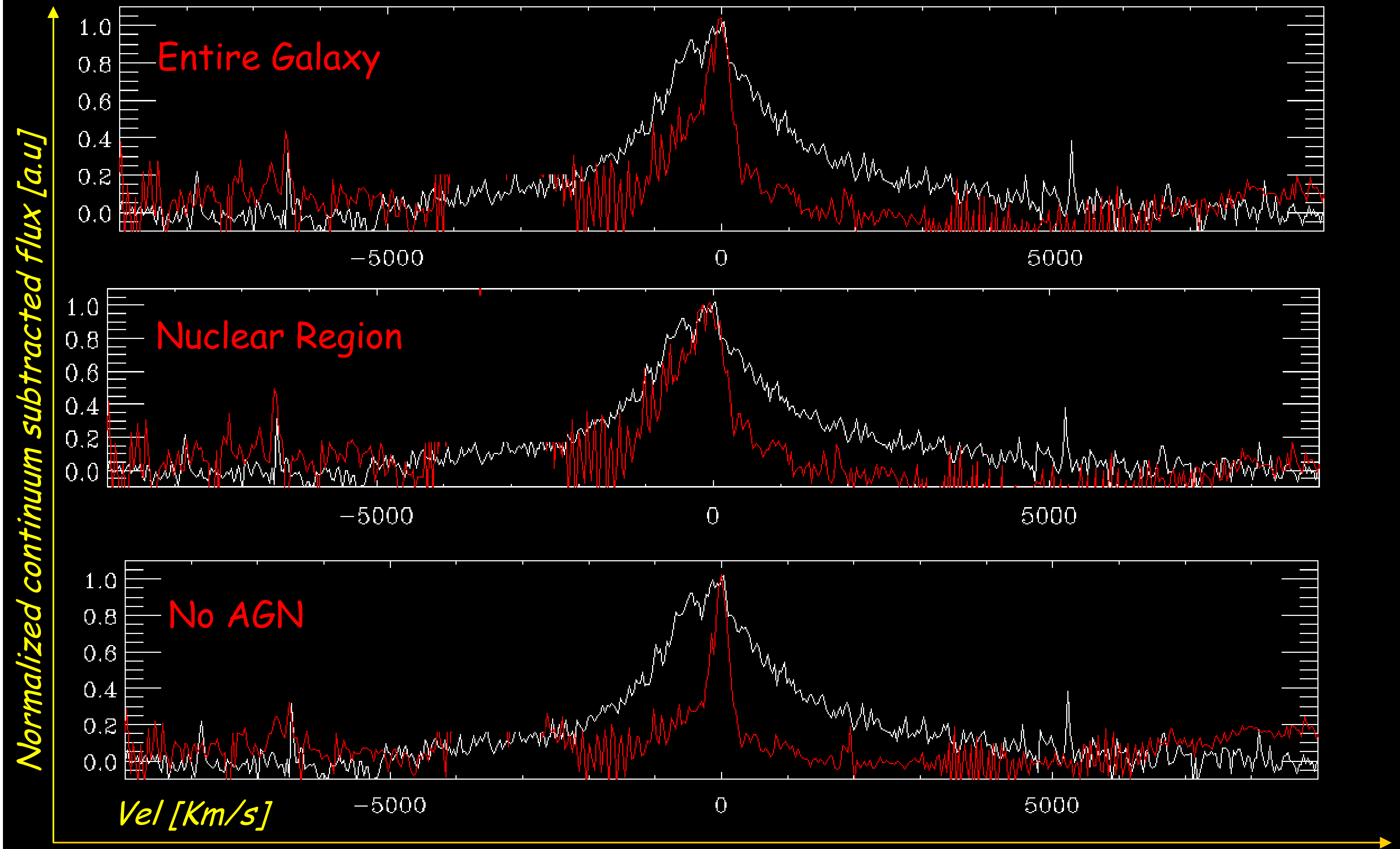
$FWHM_{[SiVI]} \sim 1000\text{-}1300$ Km/s
$FWHM_{Br\gamma} \sim 3000\text{-}8000$ Km/s

It comes from an intermediate region between the NLR and the BLR

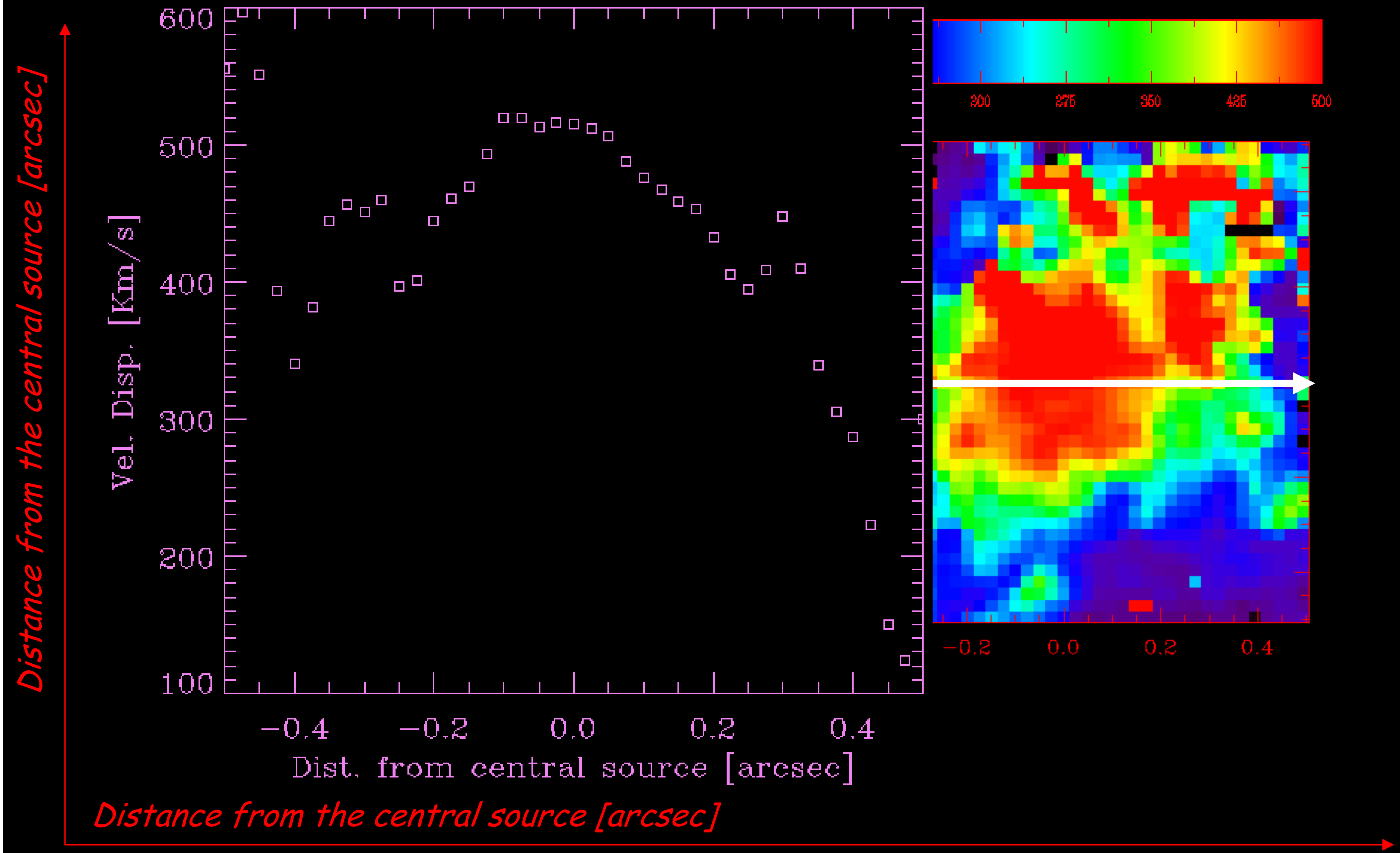
Line's Images



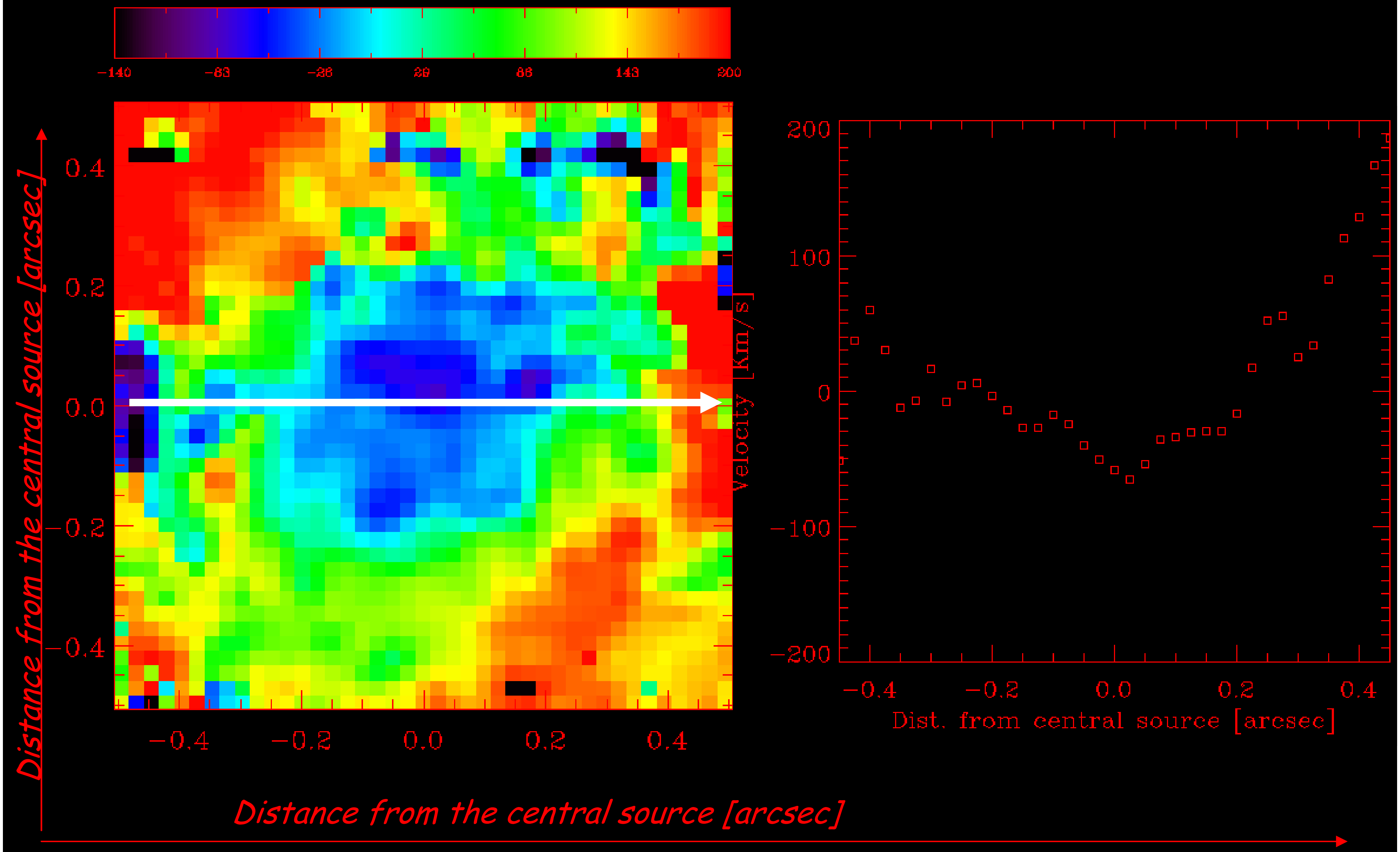
Velocity comparison between nuclear Brγ and [SiVI] extracted from different regions for 3C120 (with AO)



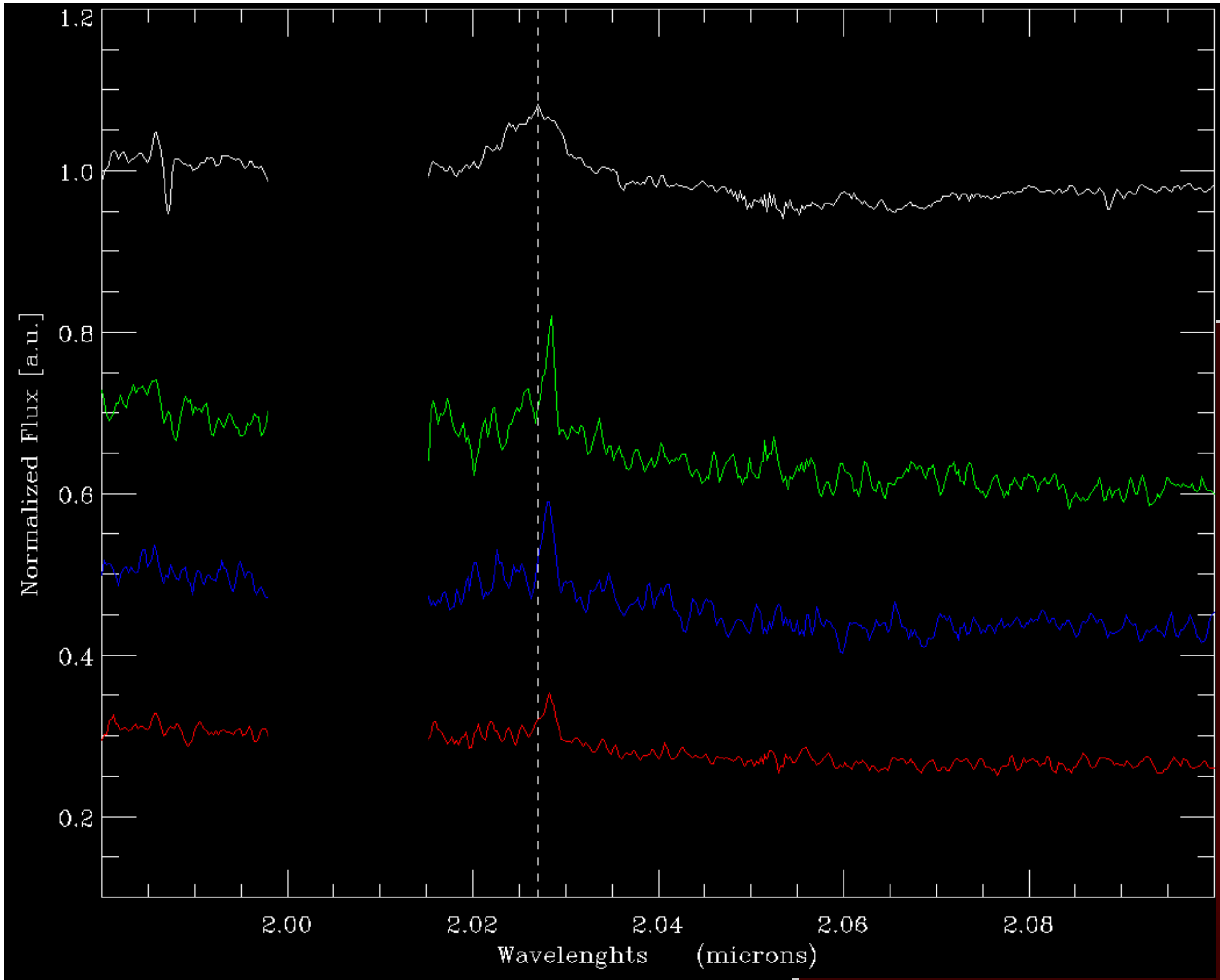
3C120 [SiVi]'s Maps, with Adaptive Optics

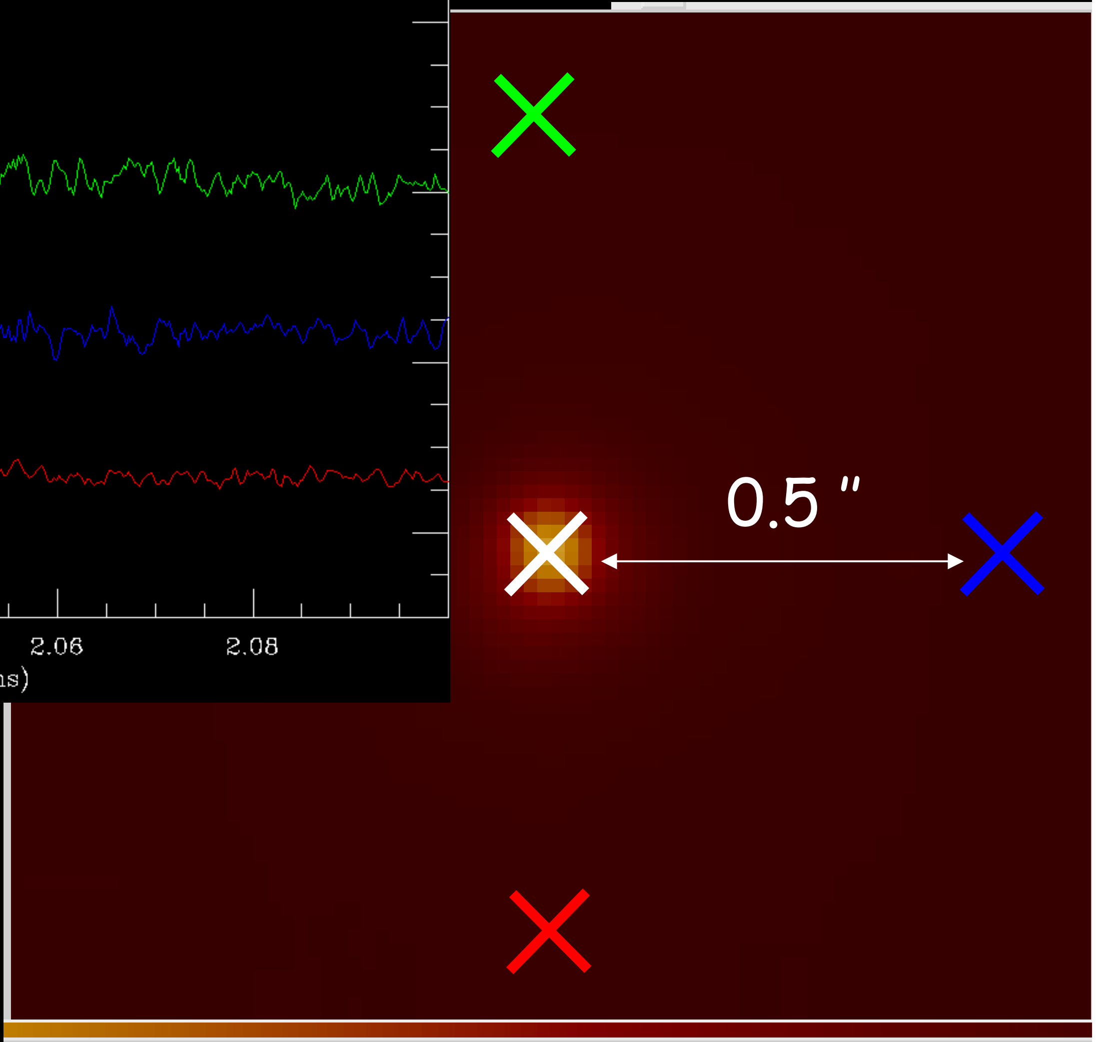


[SiVI] Velocity Map



Red-Shift of [SiVI] peak with the distance from the AGN





0.5 " ~ 300 pc

A POSSIBLE EXPLANATION

The [SiVI] has 2 components:

1) A Nuclear one, spatially unresolved, with r < 0.08 "~ 50 pc with FWHM ~ 1100 Km/s (for comparison FWHM $_{Br\gamma}$ ~ 3000 Km/s)

2) An Extended one, on scale r ~ 0.5" ~ 300 pc with FWHM ~ 400 Km/s

The nuclear component comes from a separate region (CLR) between the BLR and the NLR, the extended component comes from the NLR

The [SiVI] on large scale follows galaxy's rotation, at the galaxy systemic velocity

Nuclear [SiVI], more intense than the extended component, is blueshifted, maybe accelerated by an outflow (wind caused by evaporated material from the torus *(e.g. Rodriguez-Ardila et al. 2002)*).

The large-scale component likely participates to the galaxy's rotation,but we are not able to see the velocity gradient because it's hidden by the more intense nuclear component.

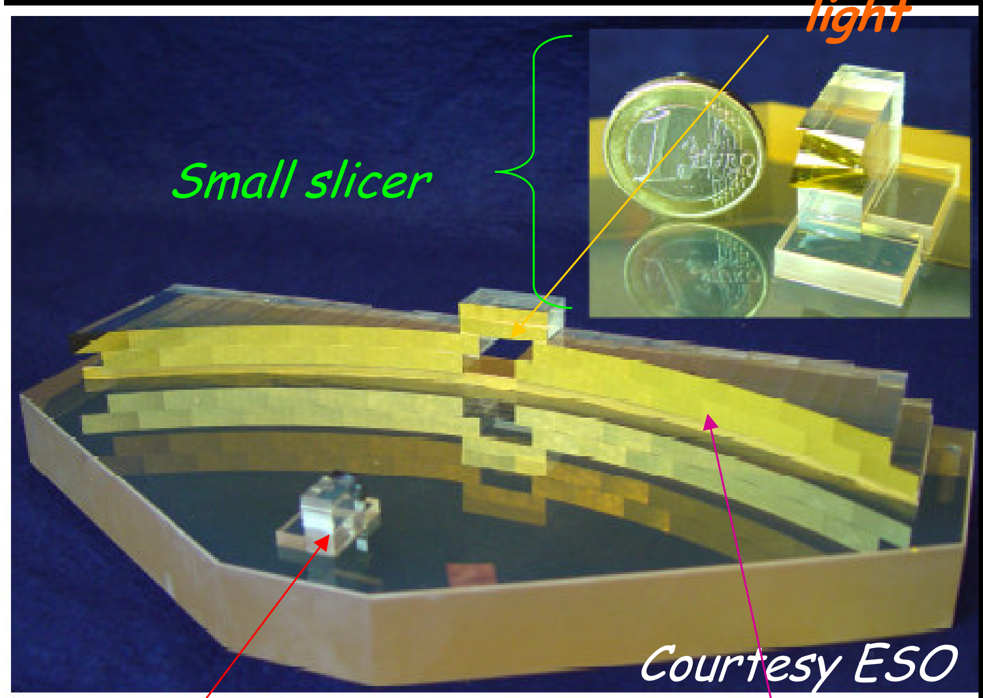
CONCLUSIONS: advantages of using AO assisted 3D Spectroscopy:

- Very high number of spectra acquired simultaneously
- Very high spatial resolution
- Possibility to do both Imaging and Spectroscopy

PRELIMINARY RESULTS:

- Evidence of disk rotation from H_2 (NGC 4593)
- Need an interpretation for the strange [SiVI] kinematics -outflows ?! (3C120)
- Check the spectra reduction
- Obtain Gas and Stellar Kinematics for BH mass measurements

SINFONI'S CHARACTERISTIC PARAMETERS



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Spiffi image slicer : the light enters through the hole in the big slicer. The image is sliced by a stack of 32 small mirrors which redirect the light towards the 32 mirrors of the big slicer. The last one re-arrenges the slitlets into a 31 cm long pseudo-slit.

Spectral Resolution:

J	2000
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AGN's position along the dispersion axis