Star formation in the central 30 pc of NGC 1068

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Estallidos de formación estelar #2

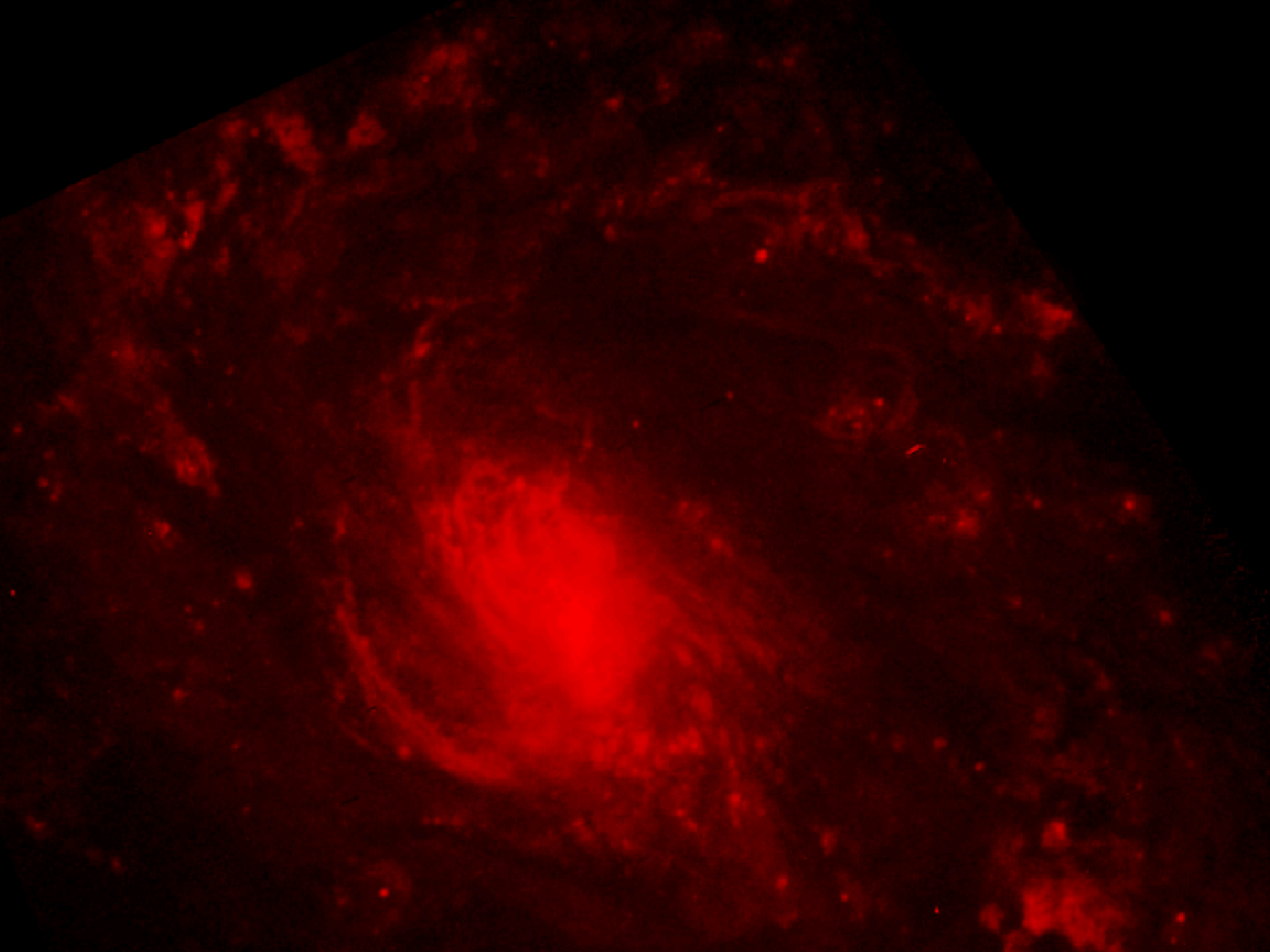
Granada, January 26th , 2004

NGC 1068: the present paradigm

- NGC 1068 is the prototype of Seyfert 2 galaxy, within the scenario of the unified model proposed by Antonucci and Miller:
  - A central accreting black hole with $M \sim 8\acute{}10^6\ M_\odot$ is surrounded by a very dense torus *(log n(HI) > 10^{24} cm^{-2}),* with diameter of few pc *(< 1 pc).*
  - The light originated around the black hole is completely absorbed by the torus, but is illuminating the regions above and below the torus.

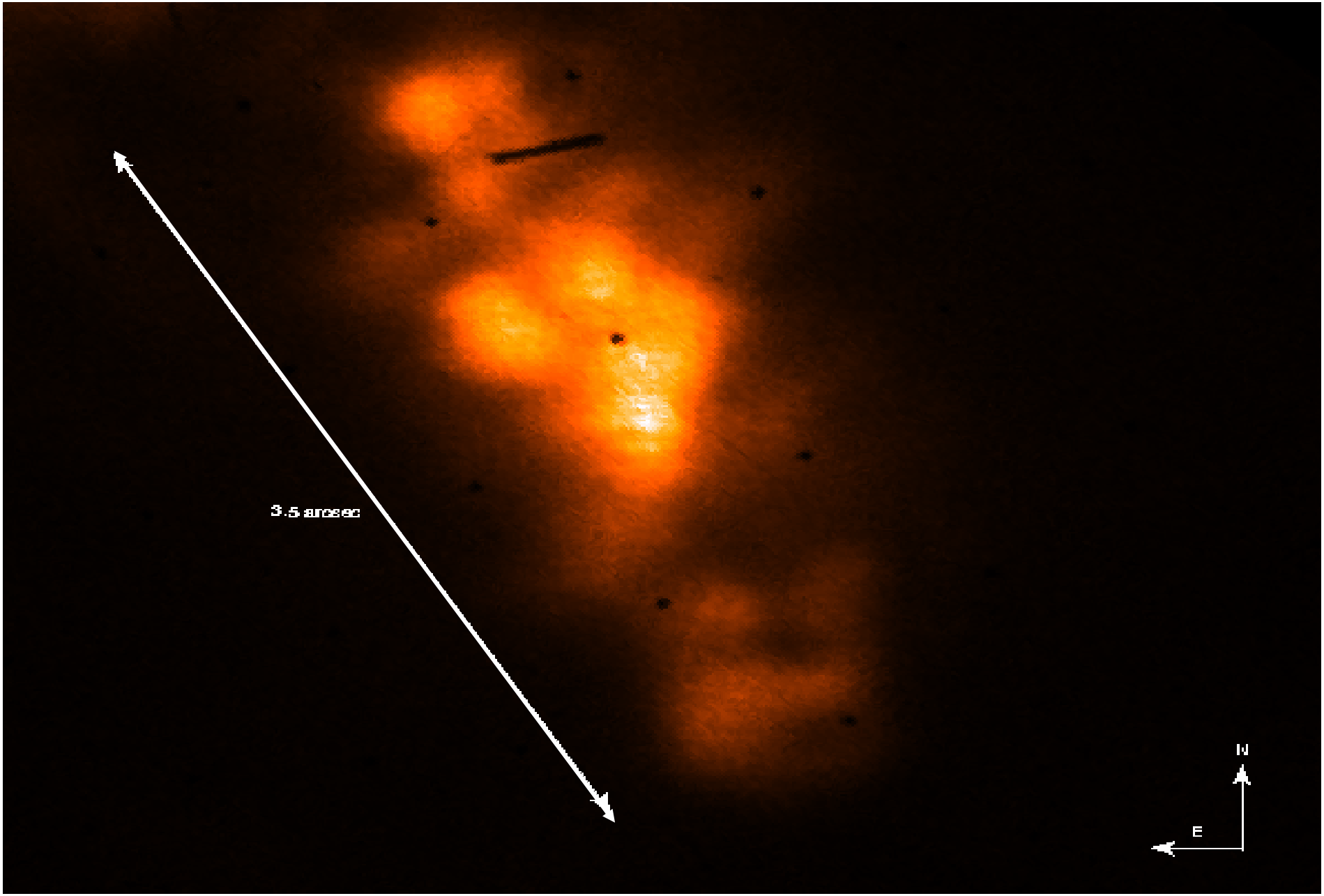
NGC 1068: the present paradigm

- The gas above and below the torus is completely ionized. The free electrons actuate as a *gray* reflector, reemitting the nuclear emission to our line of sight *(typical scale <100 pc).*
  - The broad emission lines originated close to the accretion disk are also reflected by this ionized gas
- The expected efficiency of the reflector is small: *around 1-10%*
- Massive star formation is taking place around the nucleus at distances above *1 kpc (= 15")*



NGC 1068: the observations

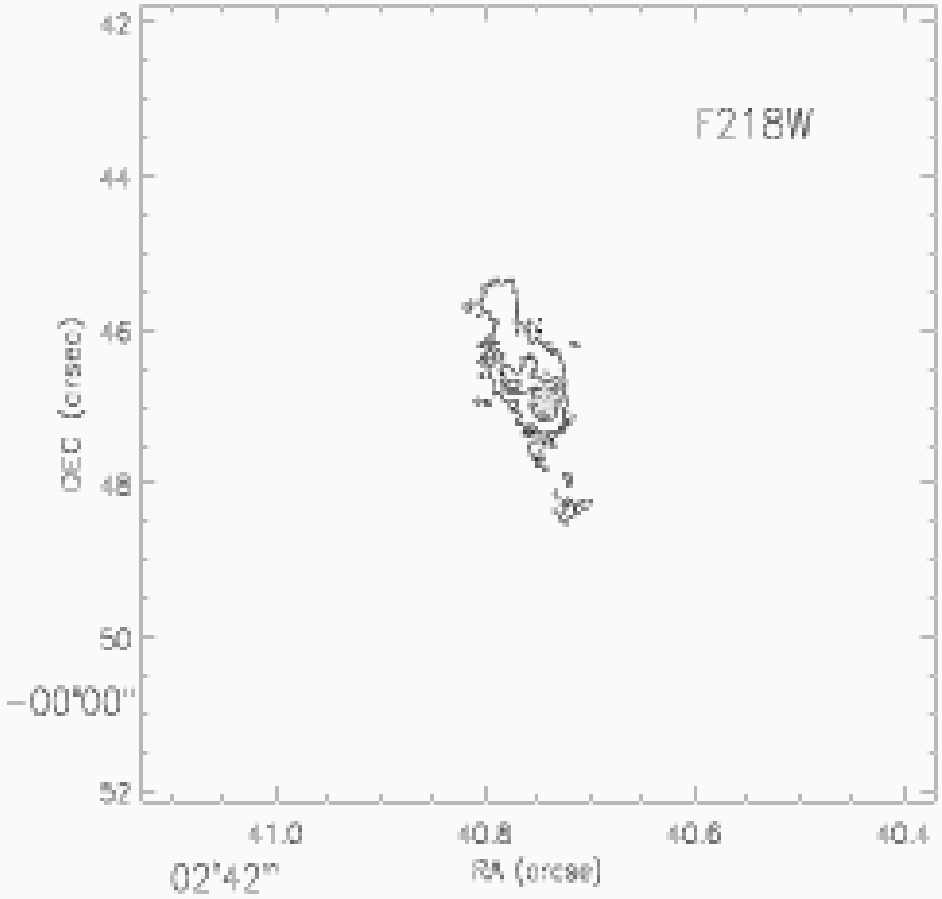
– There is a very small region *(diameter < 0.3” = 22 pc)* emitting most of the energy originated around the nucleus of NGC 1068.

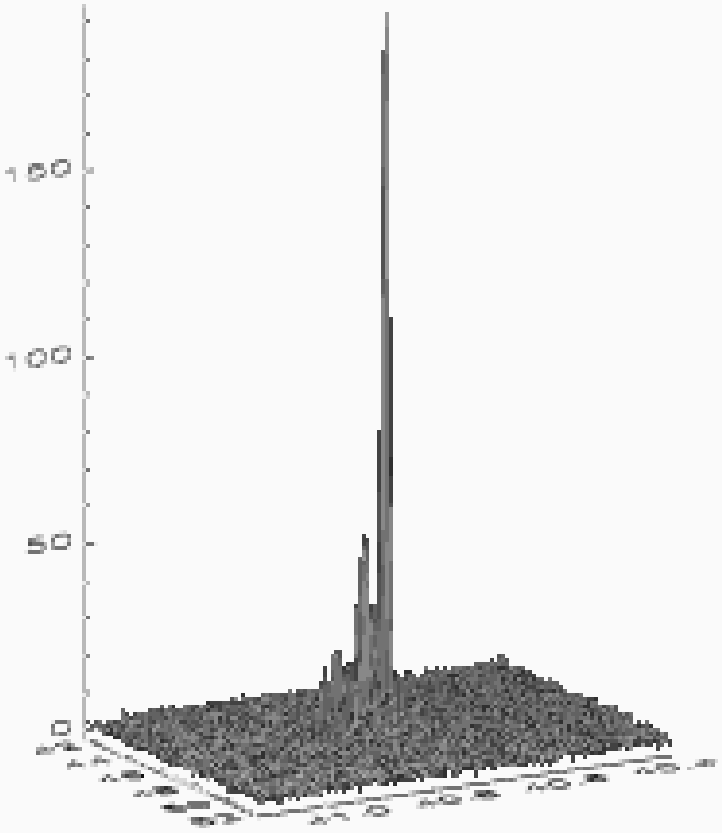

3.5 arcsec
N
E

NGC 1068: the observations

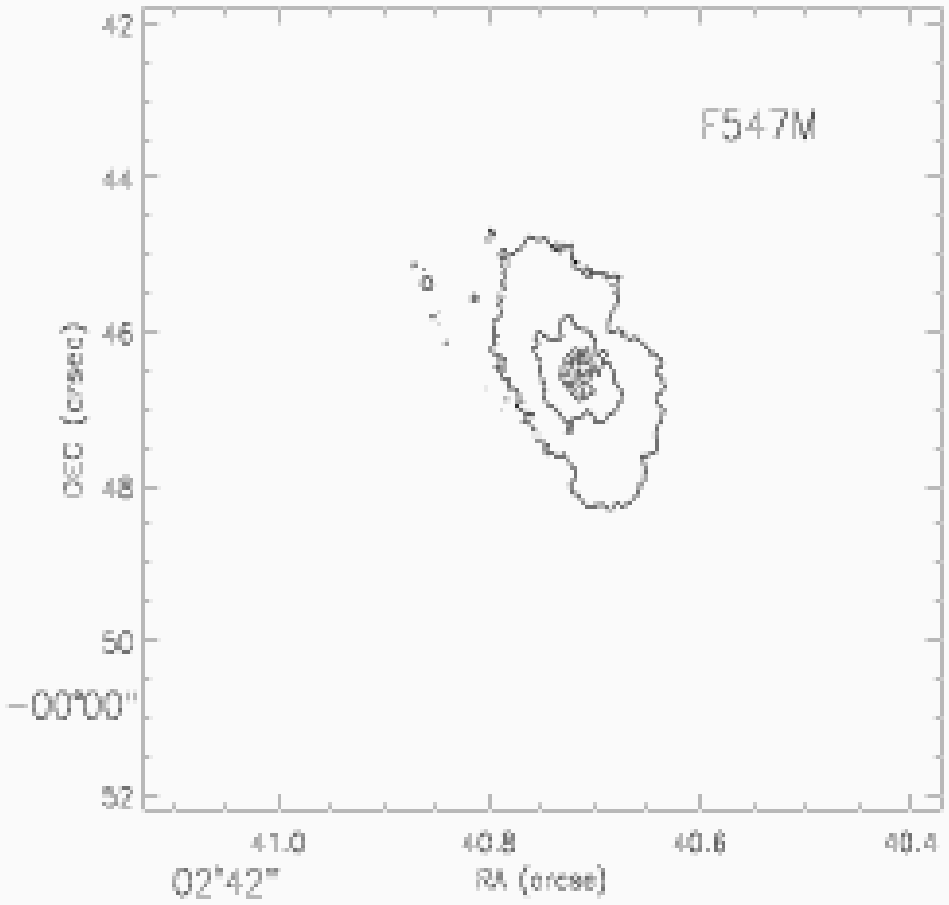
– This region is very prominent at all wavelengths

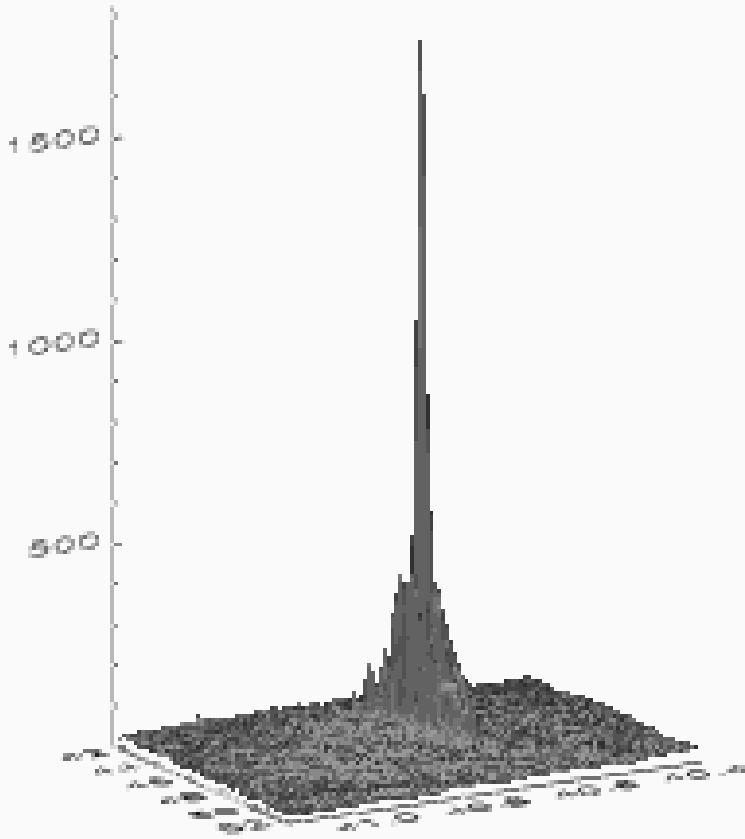
NGC 1068: the observations



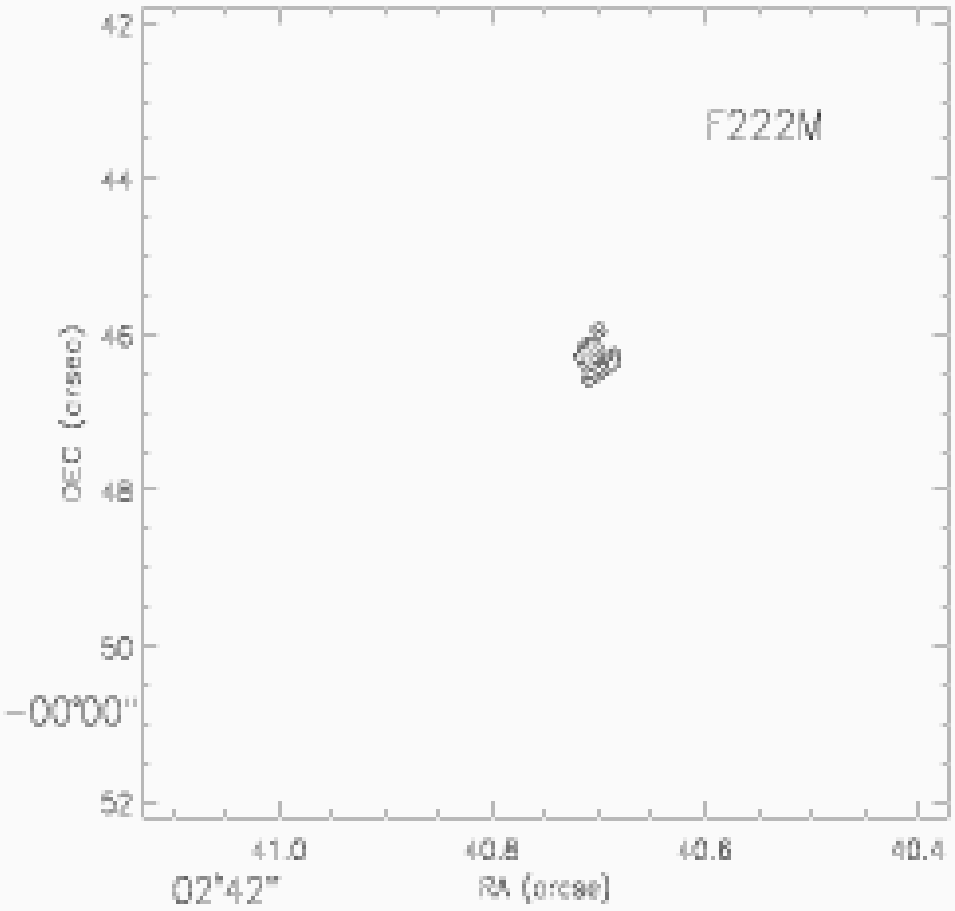


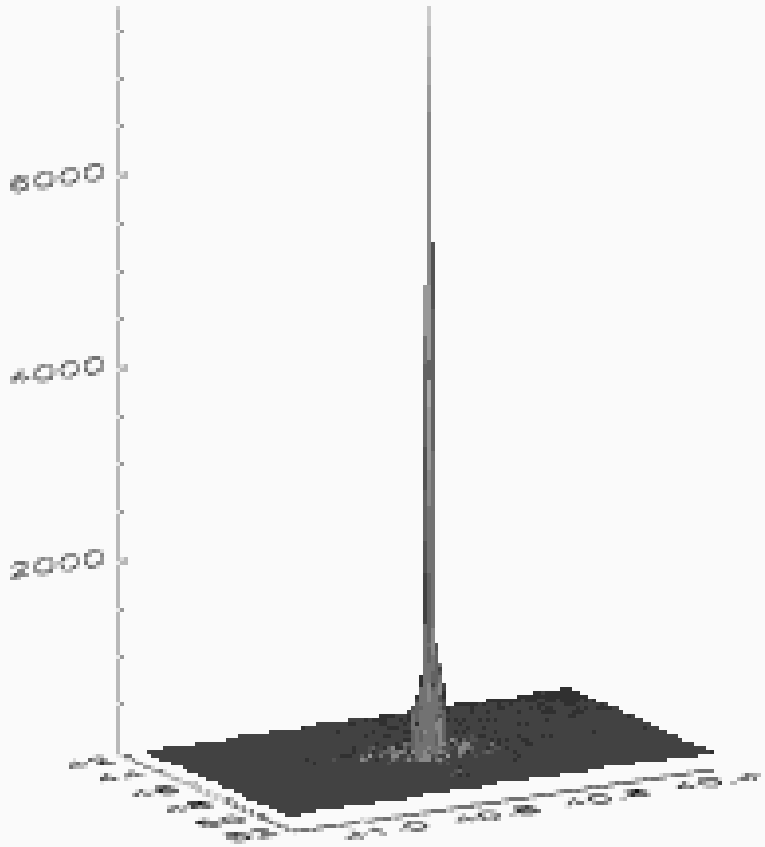
NGC 1068: the observations





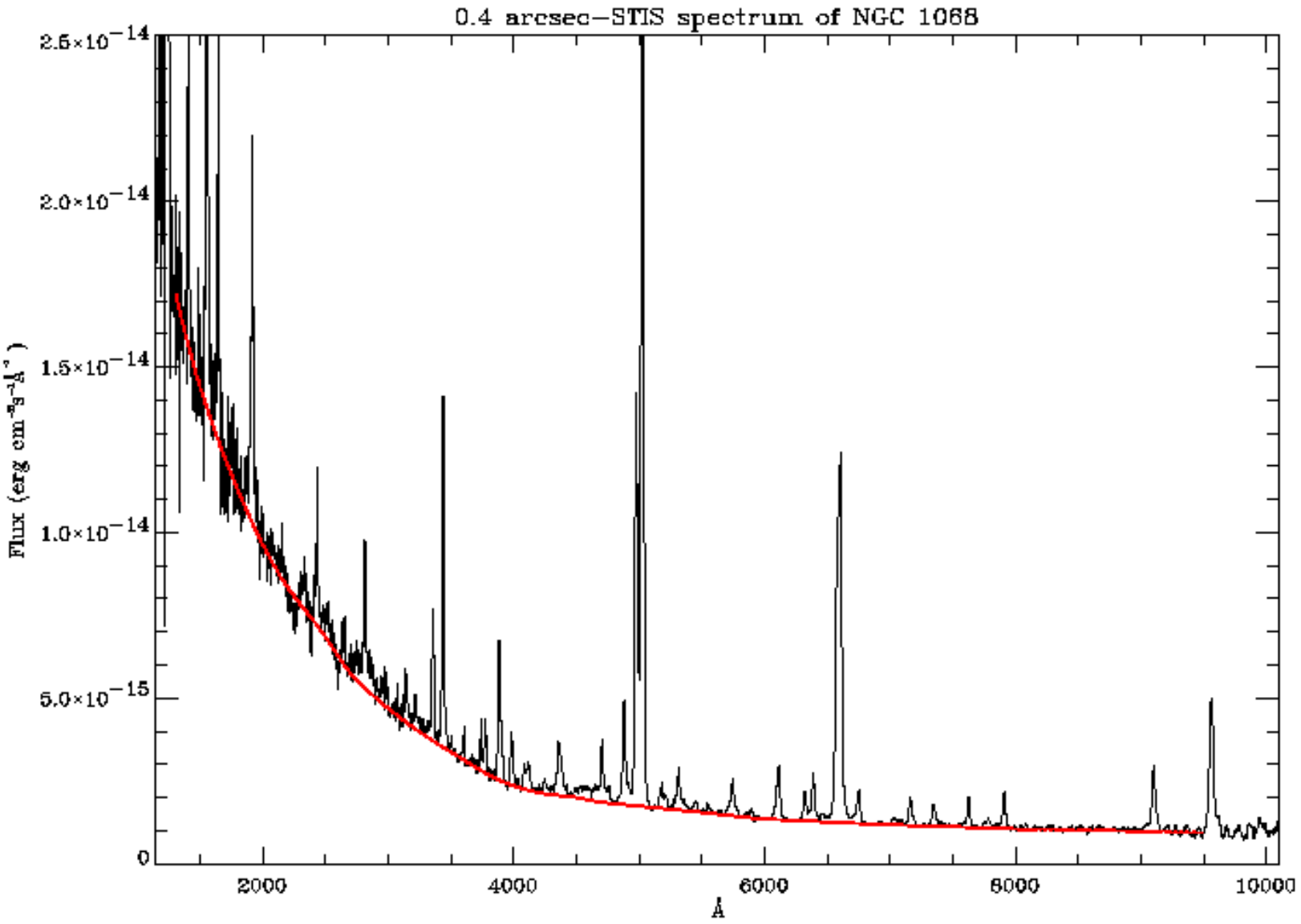
NGC 1068: the observations

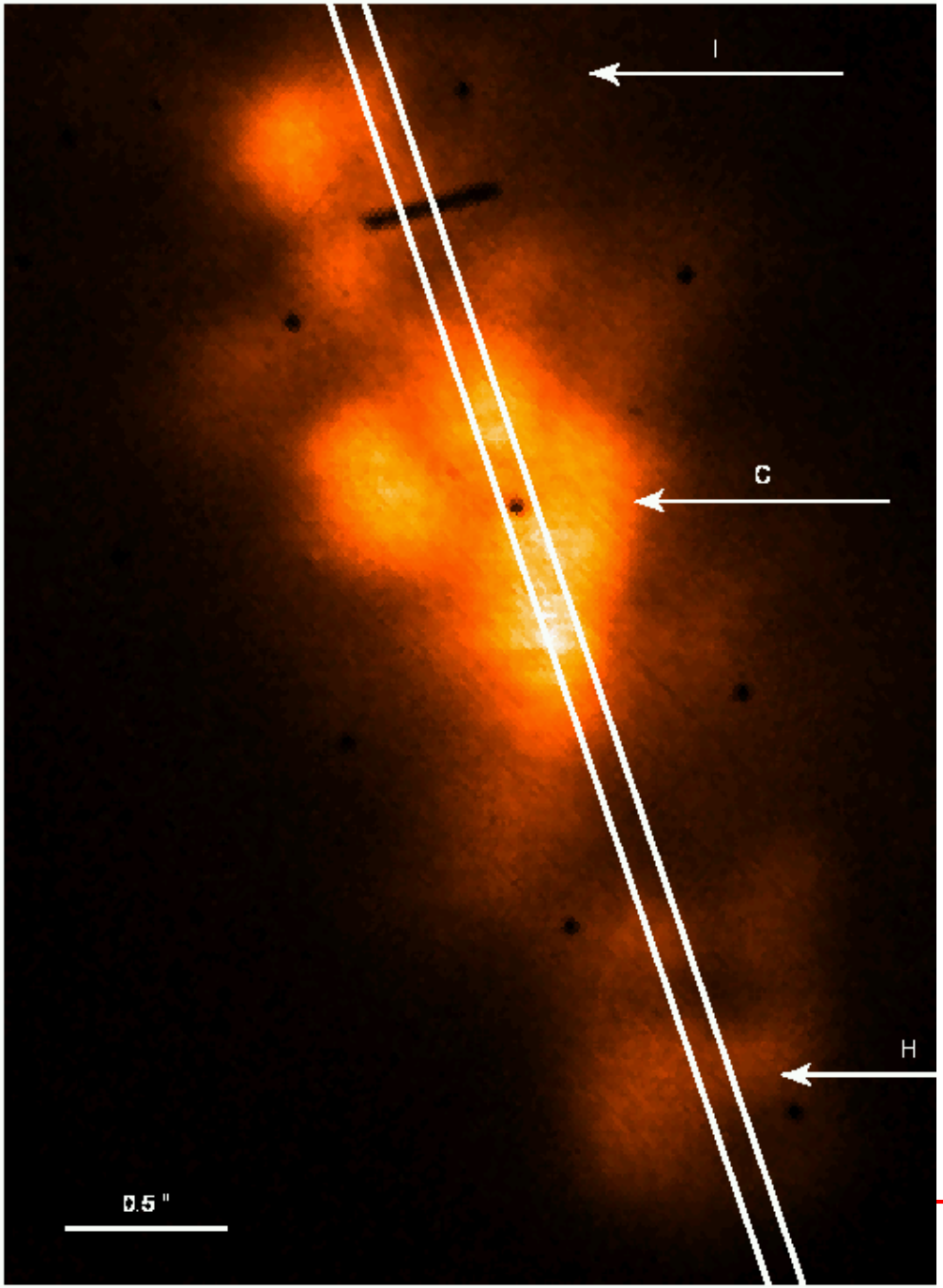


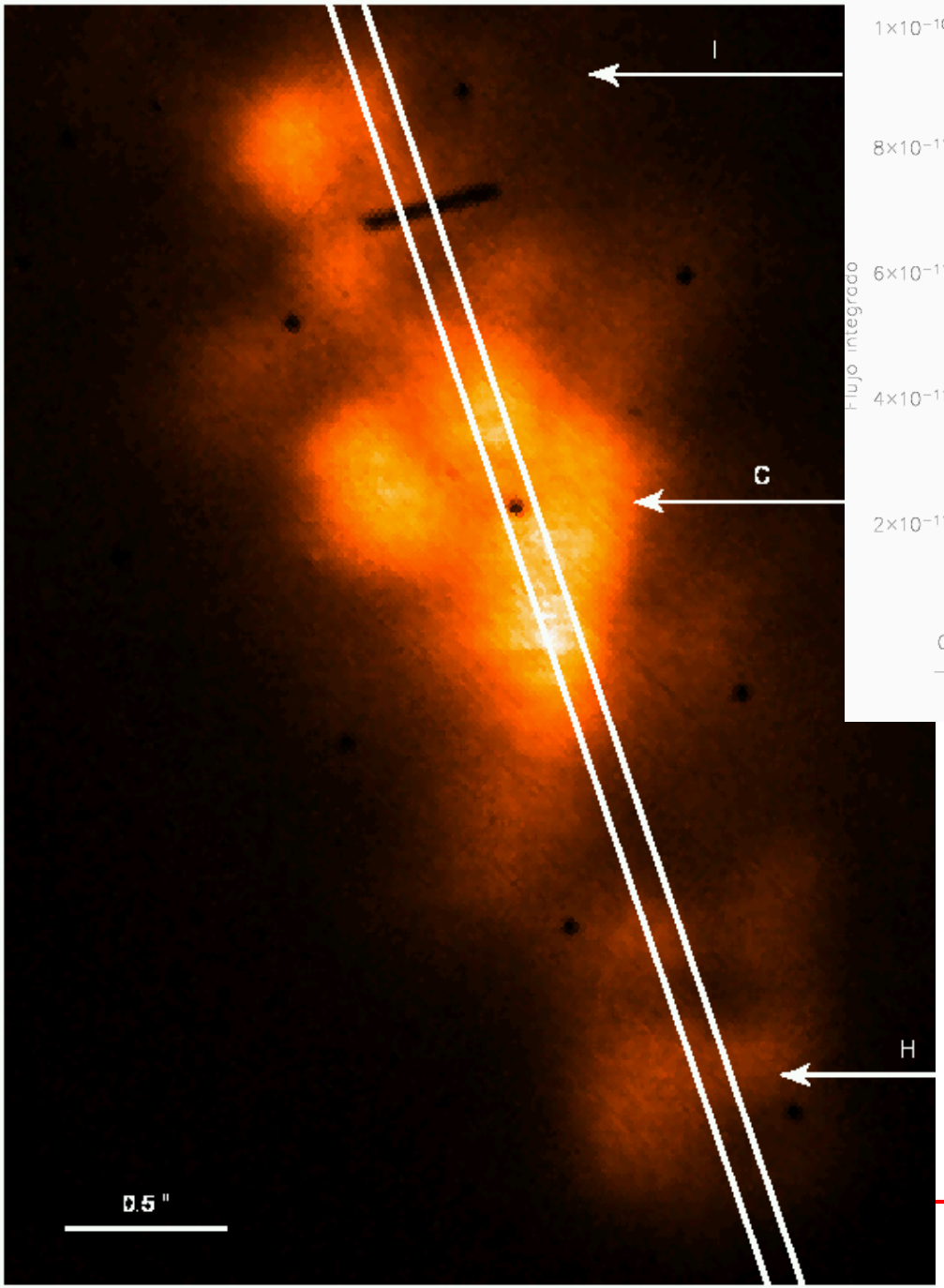


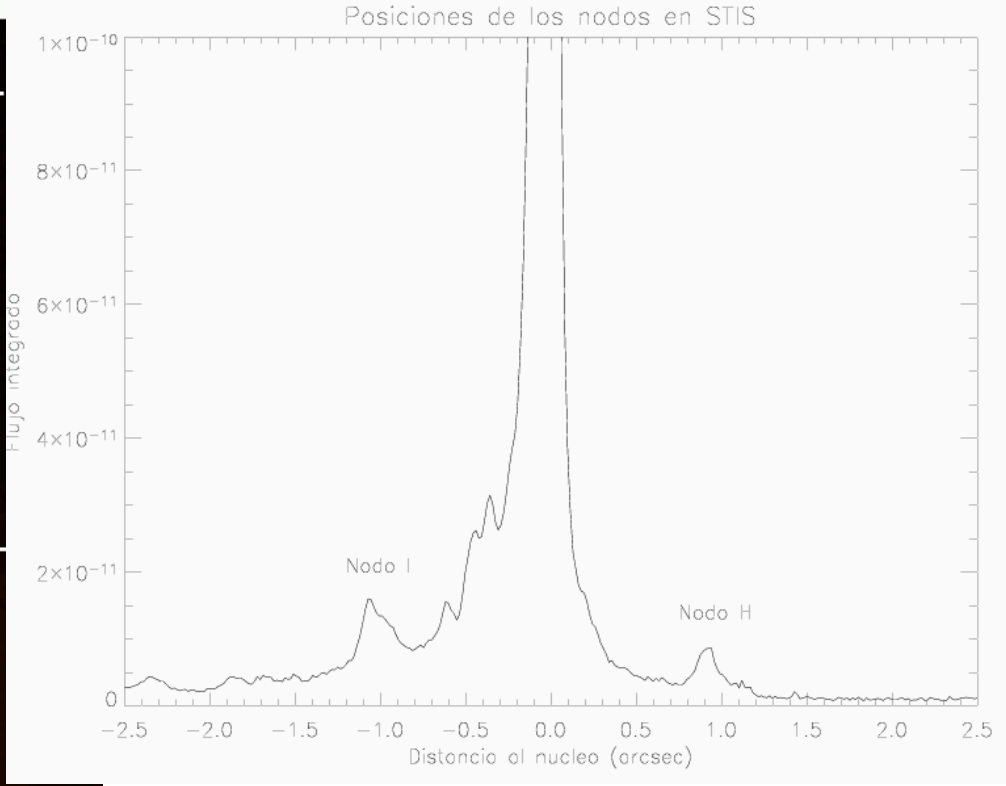
NGC 1068: the observations

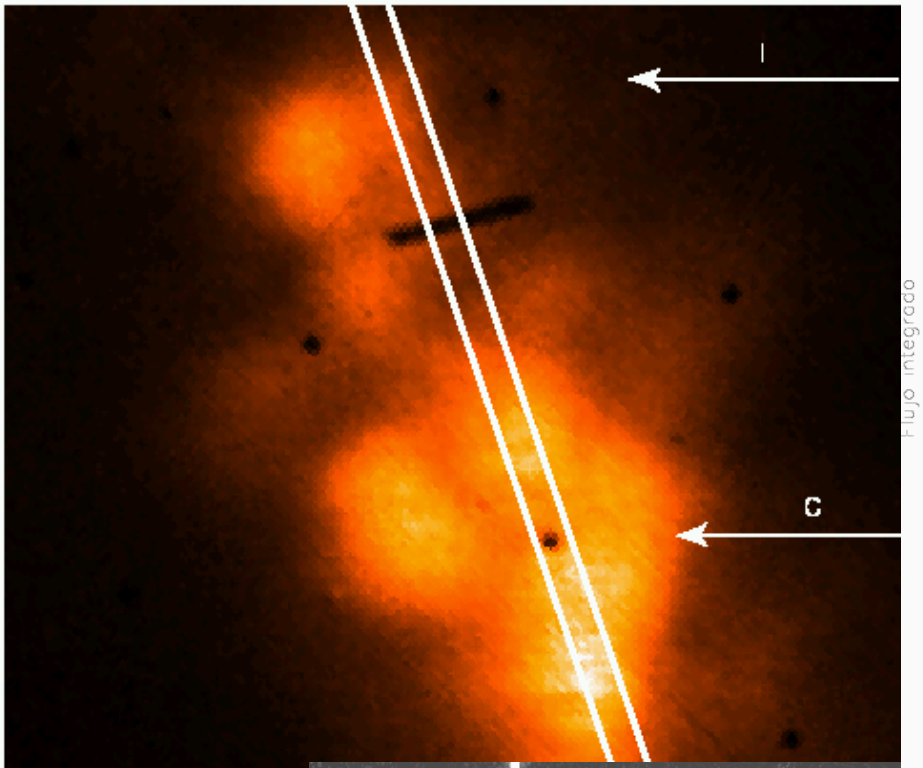
– Long slit HST-STIS spectroscopy shows a very blue continuum with very intense emission lines

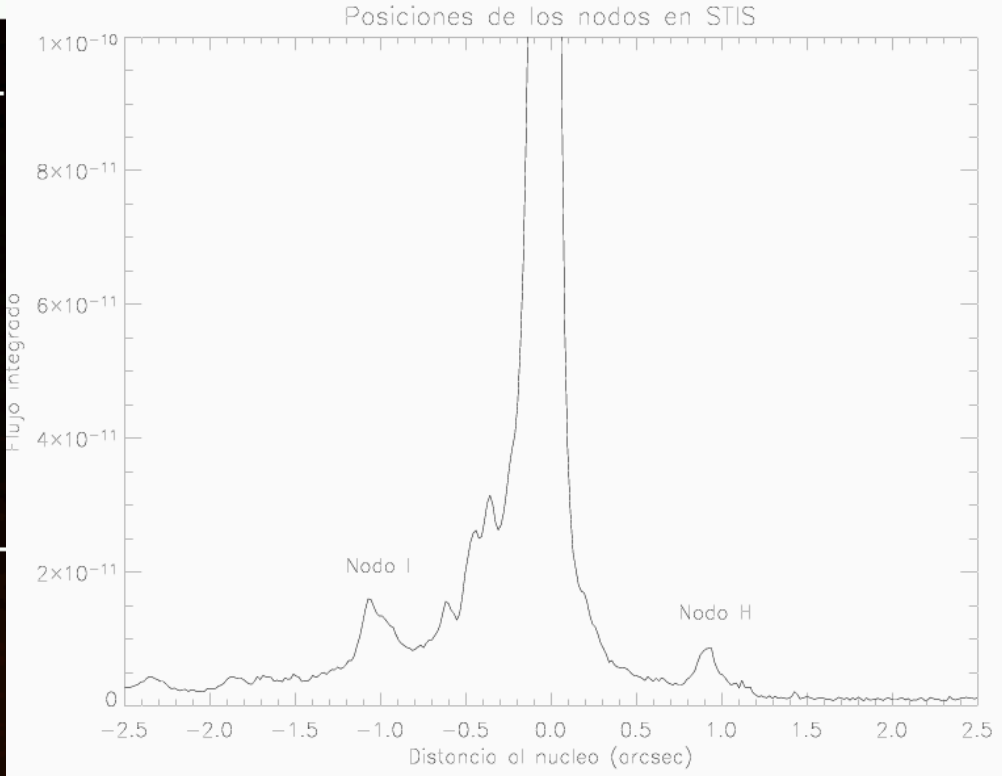

0.4 arcsec–STIS spectrum of NGC 1068
2.5×10^-14
2.0×10^-14
1.5×10^-14
1.0×10^-14
5.0×10^-15
0
Flux (erg cm^-2 s^-1 Å^-1)
2000
4000
6000
8000
10000
Å

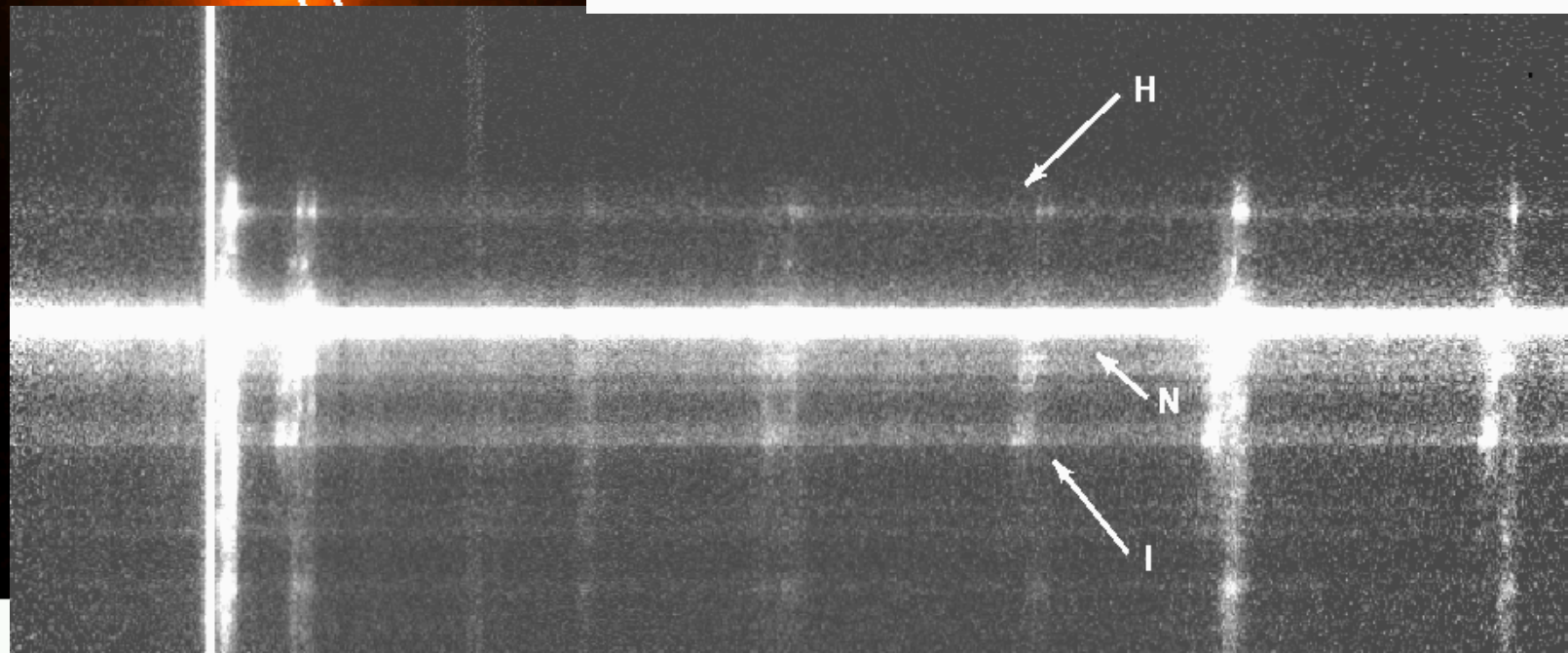

I
C
H
0.5 "

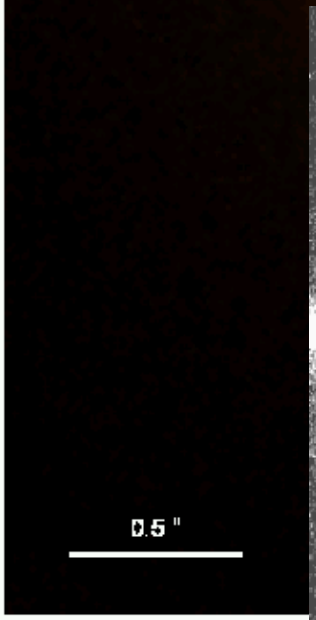

I
C
H
0.5 "


Posiciones de los nodos en STIS
Flujo integrado
1×10⁻¹⁰
8×10⁻¹¹
6×10⁻¹¹
4×10⁻¹¹
2×10⁻¹¹
0
Nodo I
Nodo H
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
Distancia al nucleo (arcsec)


I
C


Posiciones de los nodos en STIS
1×10⁻¹⁰
8×10⁻¹¹
6×10⁻¹¹
4×10⁻¹¹
2×10⁻¹¹
0
Flujo integrado
Nodo I
Nodo H
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
Distancia al nucleo (arcsec)


H
N
I


0.5 "

NGC 1068: the observations

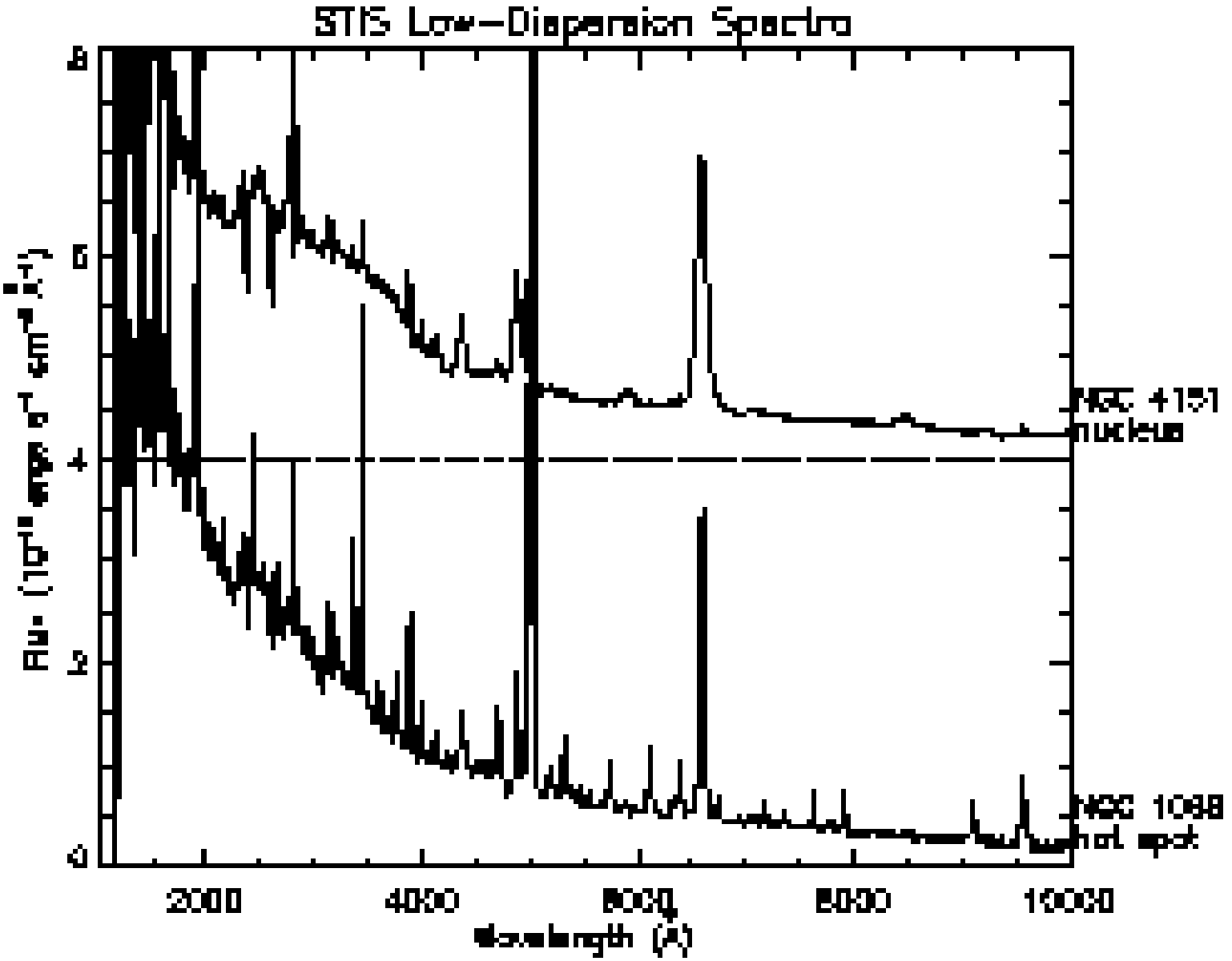
– Present interpretation assumes this knot to be the main reflector reemitting the nuclear, Seyfert 1 like emission.

The continuum should follow a power law with $\alpha \sim -0.5$.

NGC 1068: A different view

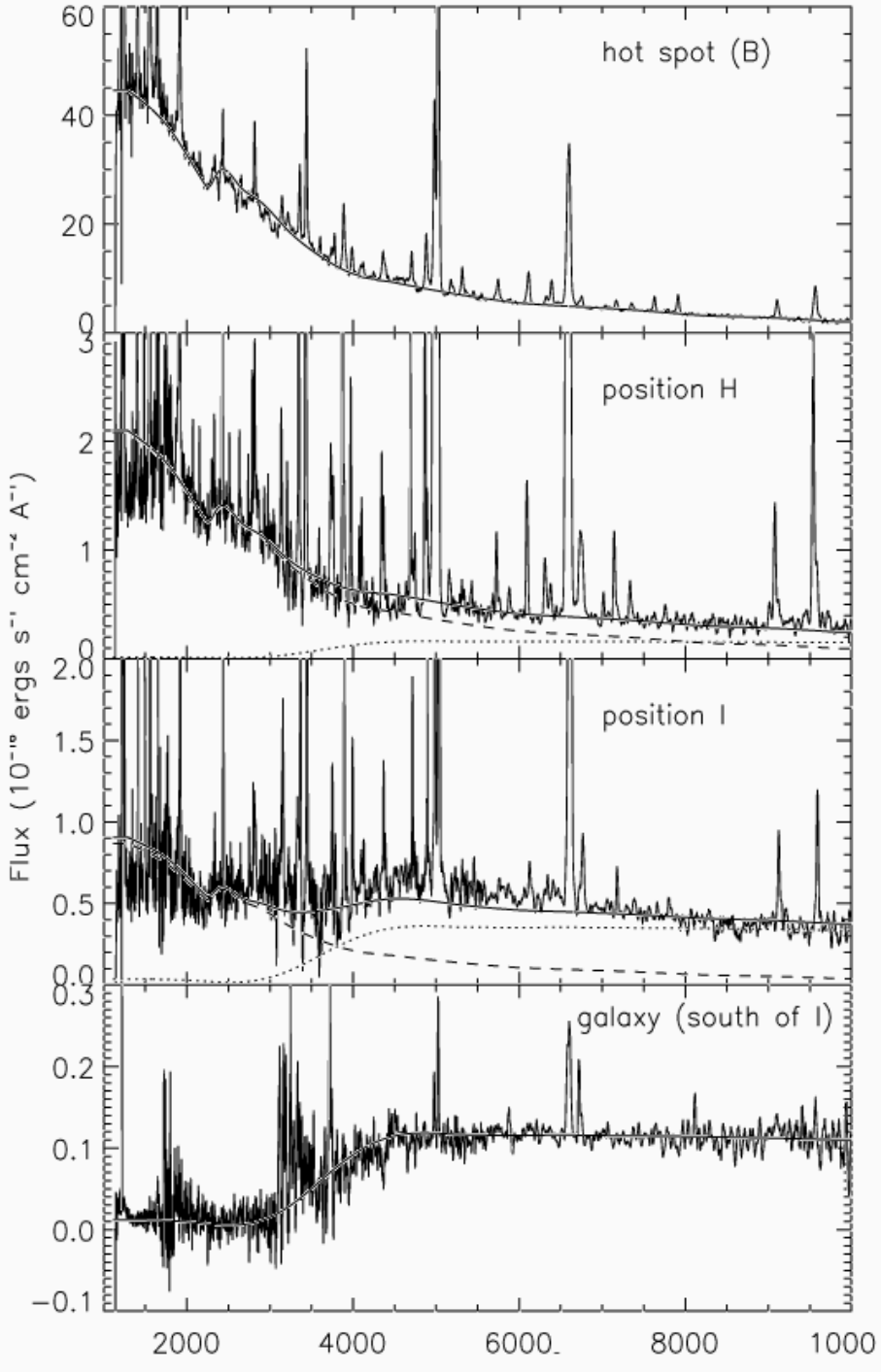
- The polarized emission amounts to only between 15% (UV) and 5% (V) of the total emission.
  - *The non polarized emission does not show the typical properties of Seyfert 1 galaxies, like broad emission lines, and therefore has a different origin than the polarized light!*

- The claimed small bump at around 2000 Å disappears when the continuum is corrected from absorption.


STIS Low-Dispersion Spectra
NGC 4151
nucleus
NGC 1068
2000
4000
6000
8000
10000

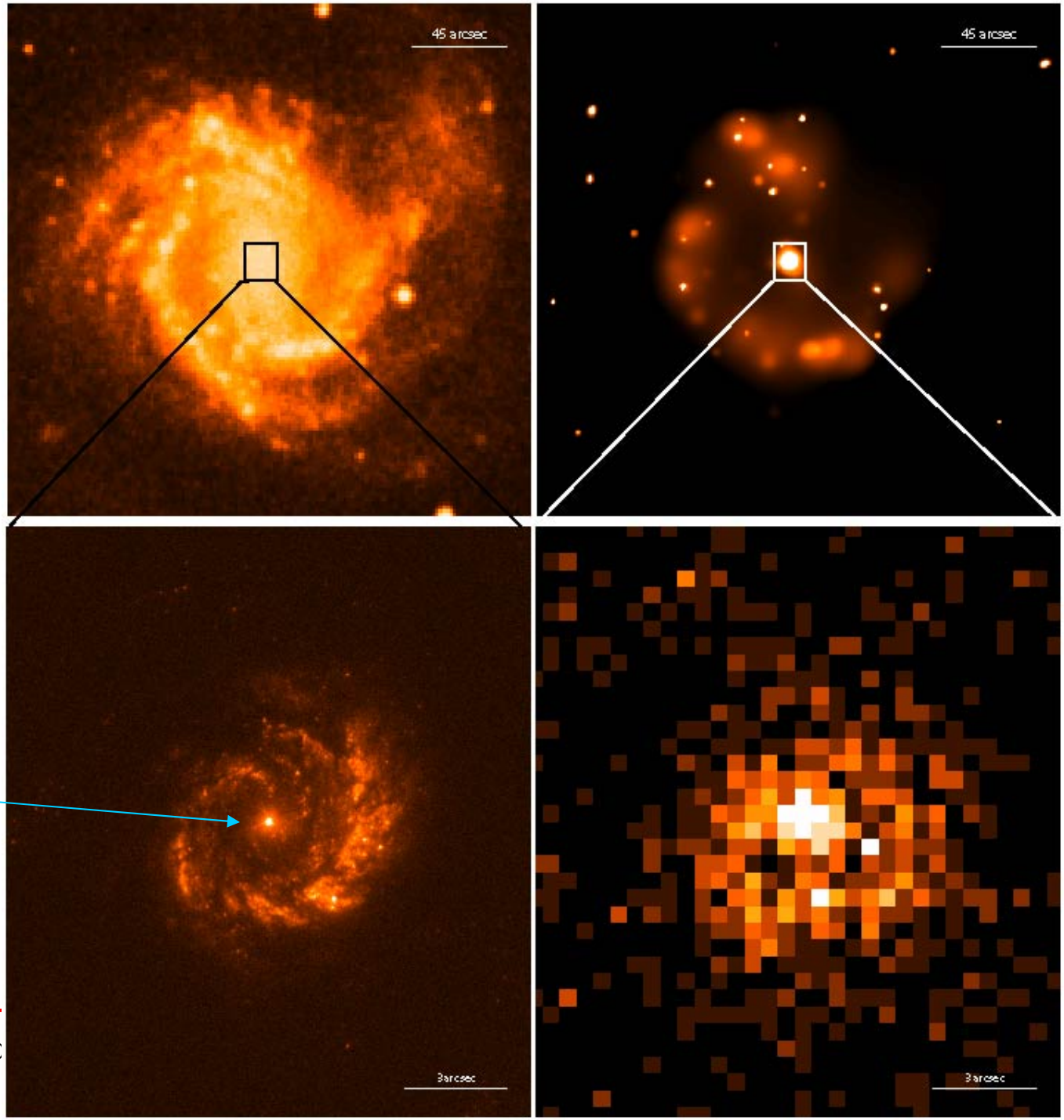
NGC 1068: A different view

- The continuum from 1200 to 10000 Å ressembles a stellar energy distribution


hot spot (B)
position H
position I
galaxy (south of I)
Flux (10⁻¹⁶ ergs s⁻¹ cm⁻² A⁻¹)
60
40
20
0
3
2
1
0
2.0
1.5
1.0
0.5
0.0
0.3
0.2
0.1
0.0
−0.1
2000
4000
6000
8000
1000

NGC 1068: A different view

- We know from other objects (like NGC 4303), that an intense burst of star formation can co-exist with an active nucleus in regions < 3 pc.



The nuclear region covers less than 3 pc

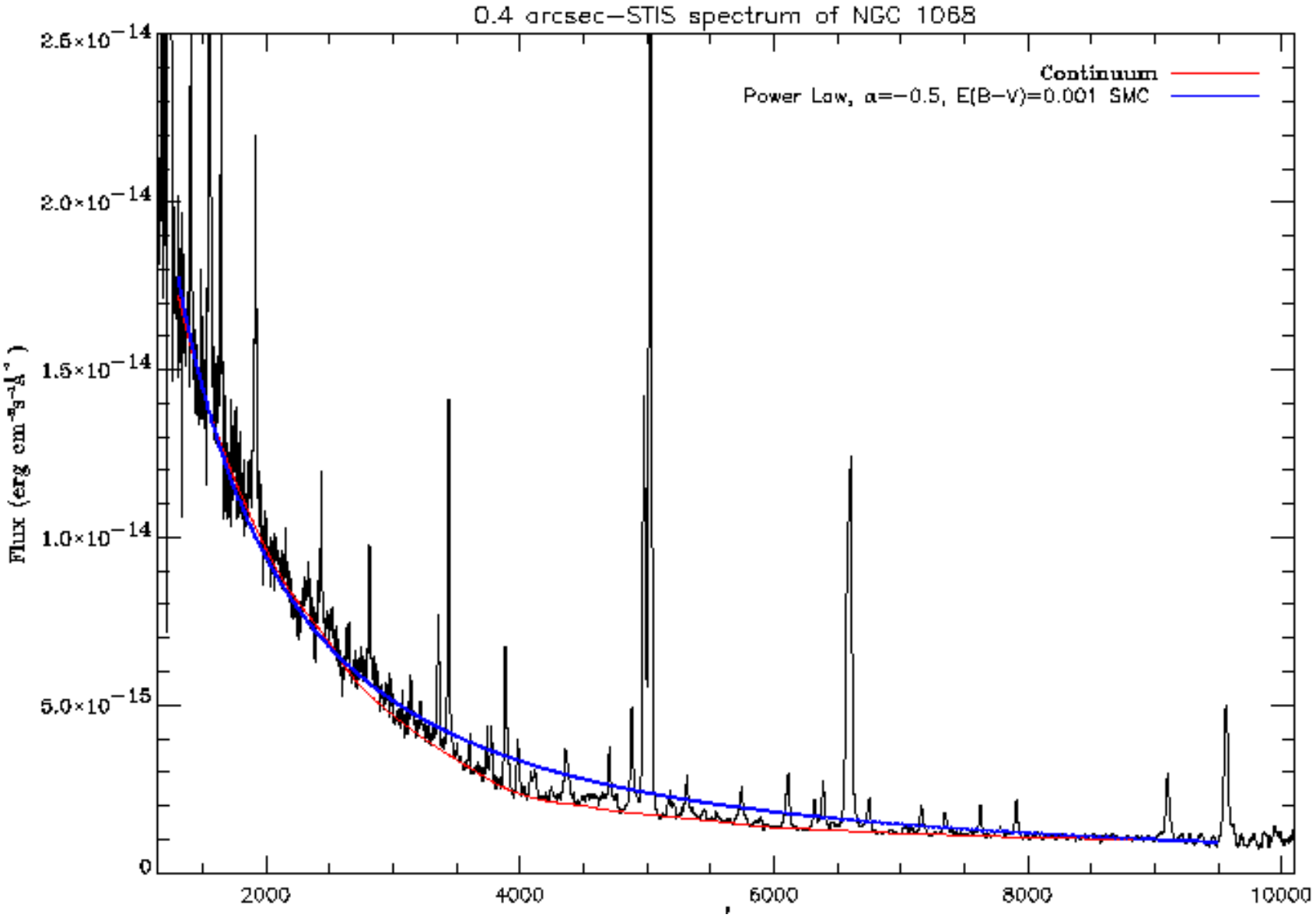
NGC 1068: A different view

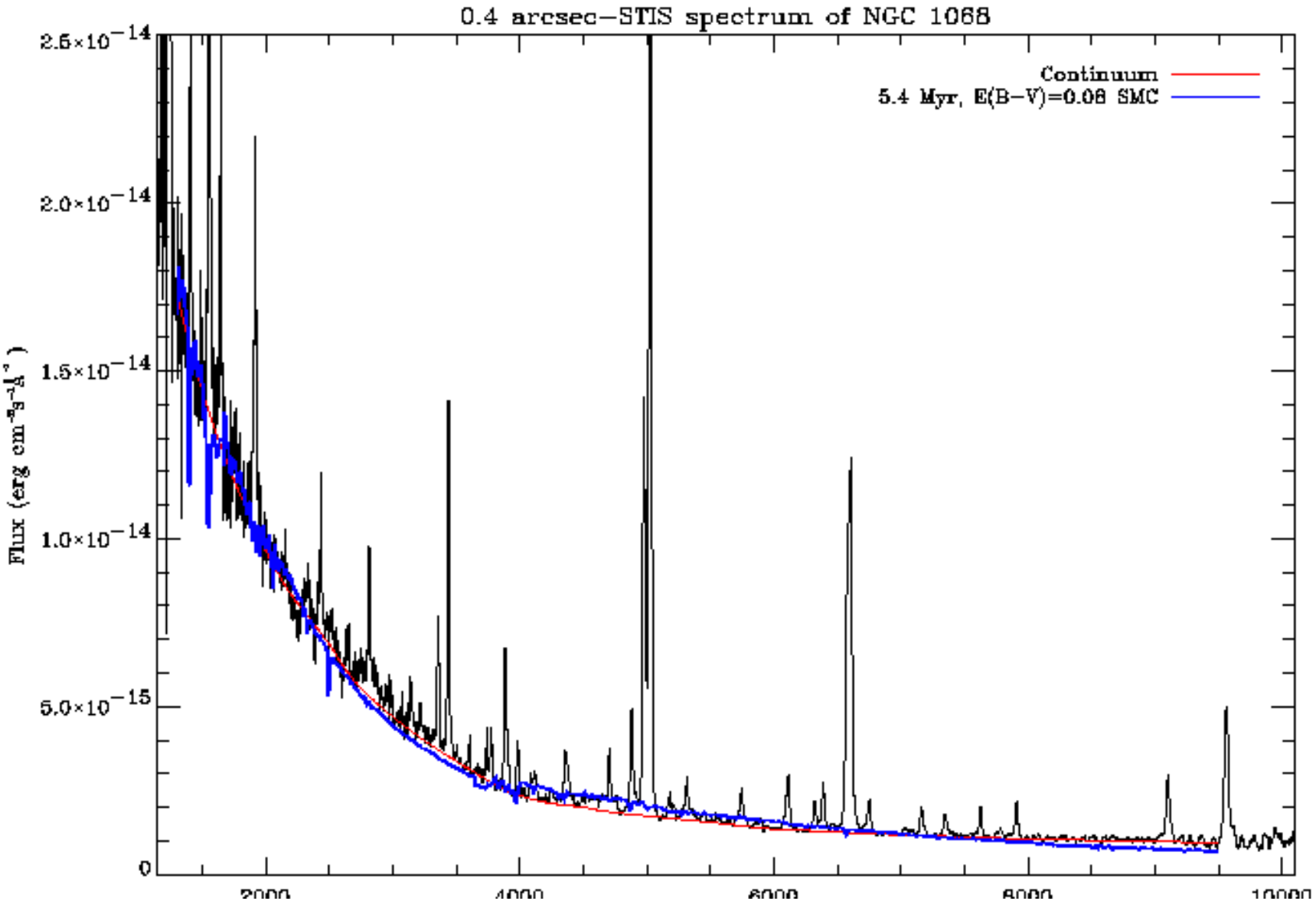
- Strategy: we have considered that the central emission could be dominated, or at least contributed, by a massive starburst.
  - *Since the torus blocks completely the UV emission, the starburst should be more prominent in this wavelength range.*

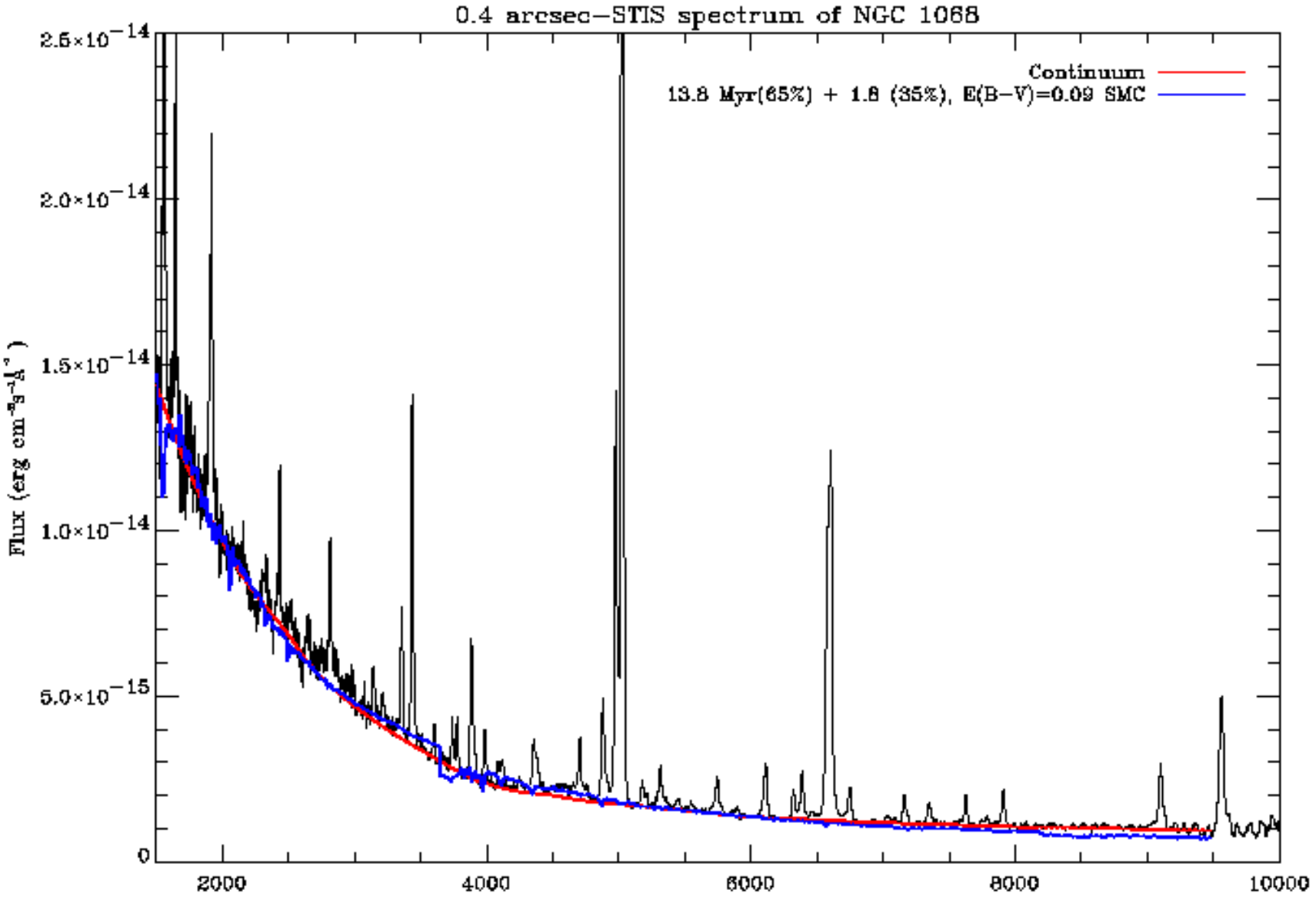
- Once the properties of the starburst are constrained, we have extrapolated its contributions to different energy ranges.

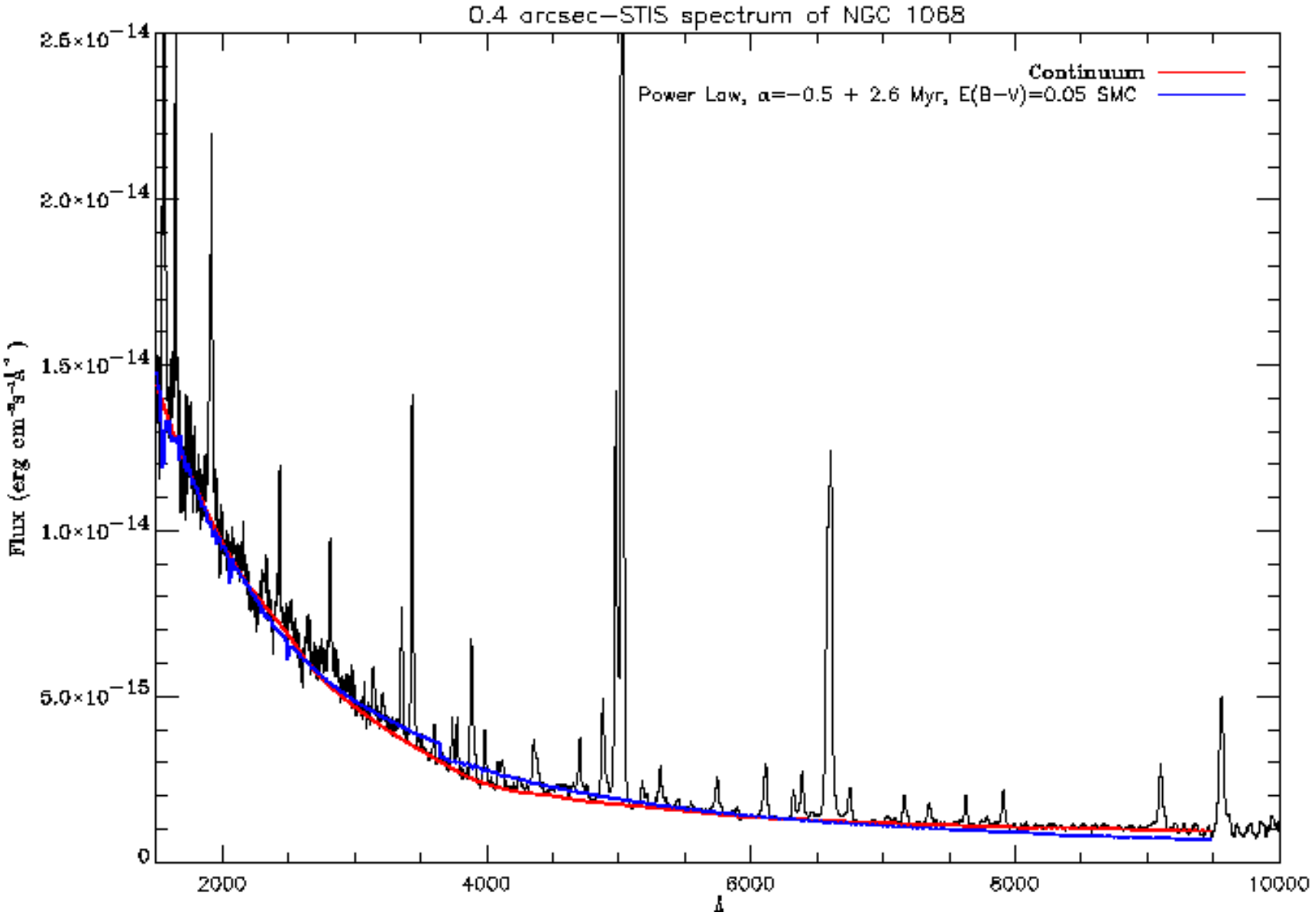
NGC 1068: A different view

- Results:
  - A stellar population reproduces better the UV - optical continuum than a power law.


0.4 arcsec—STIS spectrum of NGC 1068
Continuum
Power Law, α=−0.5, E(B−V)=0.001 SMC
Flux (erg cm⁻²s⁻¹Å⁻¹)
2.5×10⁻¹⁴
2.0×10⁻¹⁴
1.5×10⁻¹⁴
1.0×10⁻¹⁴
5.0×10⁻¹⁵
0
2000
4000
6000
8000
10000


0.4 arcsec−STIS spectrum of NGC 1068
Continuum
5.4 Myr, E(B−V)=0.06 SMC
Flux (erg cm⁻²s⁻¹Å⁻¹)
2.5×10⁻¹⁴
2.0×10⁻¹⁴
1.5×10⁻¹⁴
1.0×10⁻¹⁴
5.0×10⁻¹⁵
0
2000
4000
6000
8000
10000


0.4 arcsec−STIS spectrum of NGC 1068
Continuum
13.8 Myr(65%) + 1.8 (35%), E(B−V)=0.09 SMC
Flux (erg cm⁻²s⁻¹Å⁻¹)
2.5×10⁻¹⁴
2.0×10⁻¹⁴
1.5×10⁻¹⁴
1.0×10⁻¹⁴
5.0×10⁻¹⁵
0
2000
4000
6000
8000
10000


0.4 arcsec—STIS spectrum of NGC 1068
Continuum
Power Law, α=−0.5 + 2.6 Myr, E(B−V)=0.05 SMC
Flux (erg cm⁻²s⁻¹Å⁻¹)
λ
2.5×10⁻¹⁴
2.0×10⁻¹⁴
1.5×10⁻¹⁴
1.0×10⁻¹⁴
5.0×10⁻¹⁵
0
2000
4000
6000
8000
10000

NGC 1068: A different view

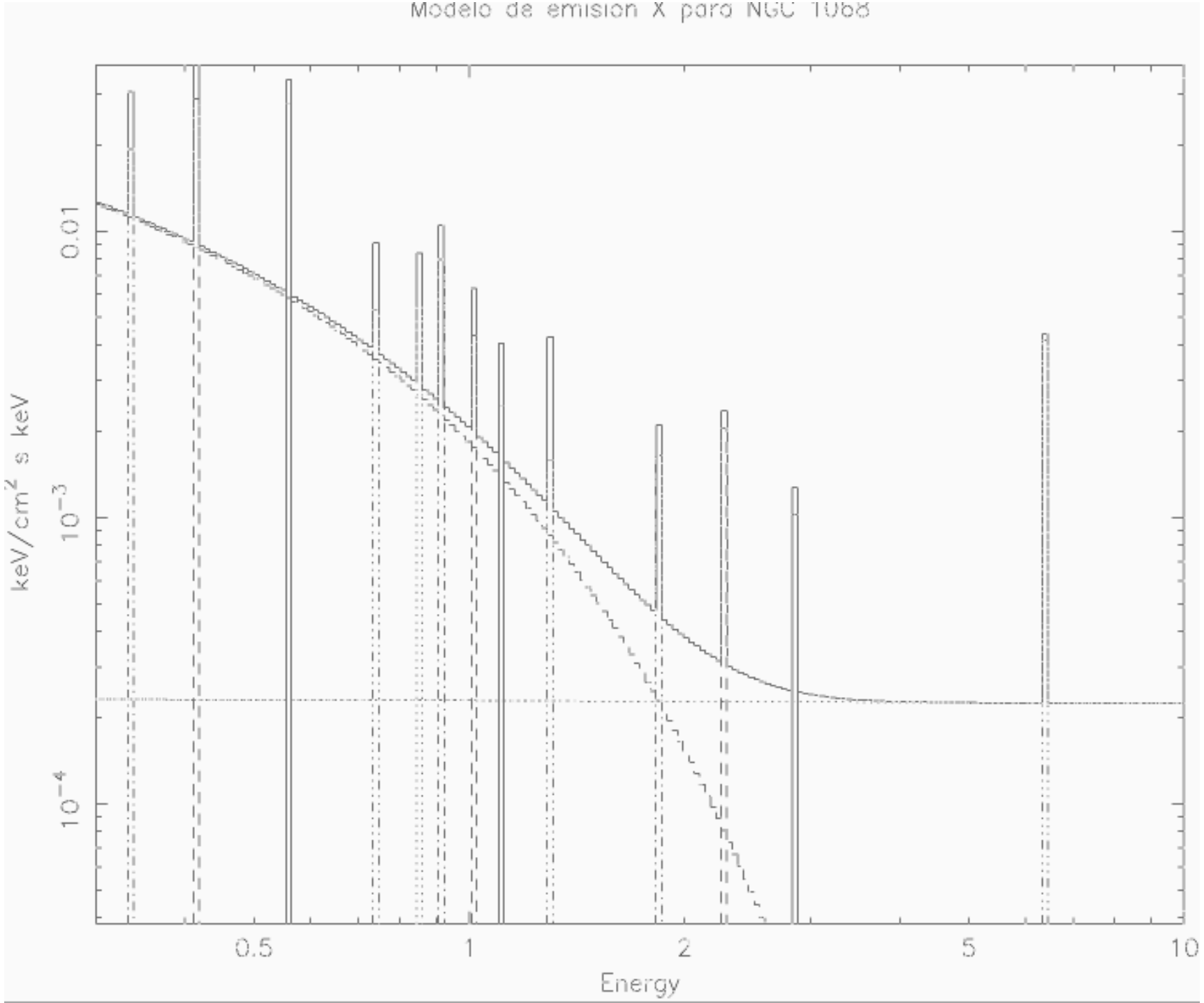
- Results:
  - The mass in stars has to be ~ 2×10^6 $M_\odot$. (Salpeter IMF between 2 and 120 $M_\odot$)
  - The log(LHα) produced by this population (40.7) is significantly smaller than the value measured within 5” (42.3), 1/40.

    As expected, the active nucleus dominates the ionization of the gas above and below the torus.

NGC 1068: A different view

- Results:
  - The starburst contributes to a significant fraction of the soft X-rays, but the hard X-ray range (above 3 keV), is dominated by reflection from the active nucleus

The X-ray emission shows 2 components: thermal gas emission and a power law.


Modelo de emisión X para NGC 1068
keV/cm^2 s keV
0.01
10^{-3}
10^{-4}
0.5
1
2
5
10
Energy

NGC 1068: A different view

	$L_{0.07-2.4}$	L_{2-10}
Total	$\mathbf{1.1´10^{42}}$	$\mathbf{2.4´10^{41}}$
Power law	5.3×10^{40}	1.8×10^{41}
Thermal	8.9×10^{41}	6.2×10^{39}
CMHK model	$\mathit{3.1´10^{41}}$	$\mathit{5.3´10^{39}}$

NGC 1068: A different view

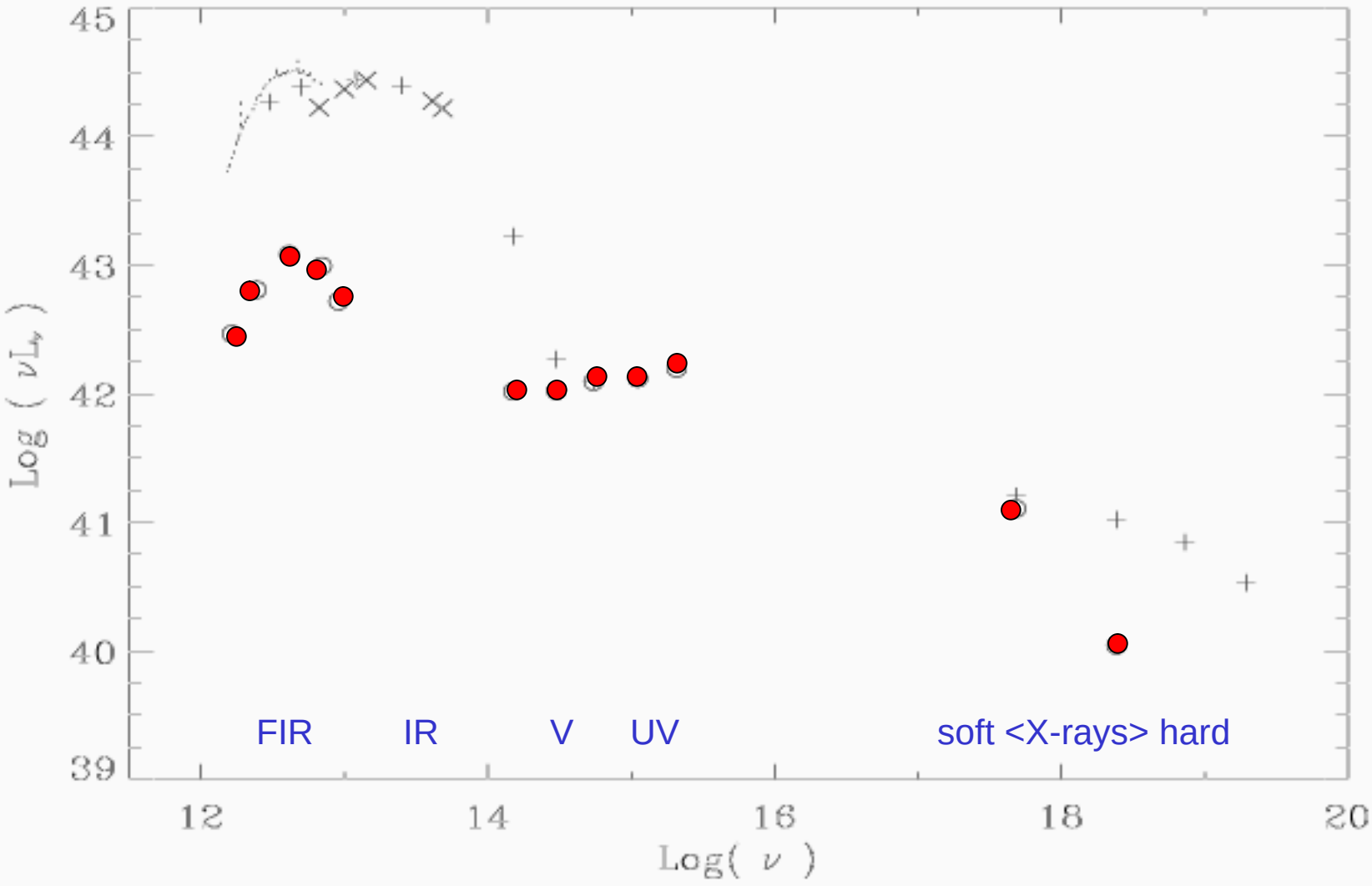
	$L_{0.07-2.4}$	L_{2-10}
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Thermal	8.9×10^{41}	6.2×10^{39}
CMHK model	$3.1 \acute{} 10^{41}$	$5.3 \acute{} 10^{39}$

The starburst can contribute to 35- 85% of the thermal X ray emission in the nucleus of NGC 1068.

NGC 1068: A different view

- Results:
  - The Far Infrared emission associated to the starburst is around a factor 10 lower than the observed one:

    The FIR range is dominated by the internal parts of the torus, which are being heated directly by the black hole and the accretion disk.


45
44
43
42
41
40
39
Log (νL_ν)
12
14
16
18
20
Log(ν)
FIR
IR
V
UV
soft <X-rays> hard

NGC 1068: A different view

- Conclusions:
  - A massive starburst might be contributing to most V-UV-soft X-ray emission of the *hot spot* within the central 22 pc of NGC 1068.
  - The hard X-ray range is mostly nuclear radiation reflected by the ionized gas above and below the torus.
  - This gas is ionized by the high-energy photons emitted by the active source. The contribution from the starburst is negligible globally.

NGC 1068: A different view

- Conclusions:
  - The IR-FIR range is dominated by thermal emission of the blocking material from the torus.
    Most of the energy emitted by the active source is absorbed and reemitted at FIR energies by the torus .
  - Active sources and starbursts might co-exist within relatively small volumes (3-20 pc) in most Seyfert 2 galaxies.

NGC 1068: A different view

Proposed scenario

- *A massive molecular cloud falls to the nucleus of a galaxy from time to time.*
- *The shape of the cloud is distorted in the vicinity of the nucleus, getting a torus-like form.*
- *The internal layers of the molecular cloud are accreted into the central black hole, feeding the active nucleus.*
- *The external layers of the cloud are disturbed, triggering star formation episodes.*
- *The observational properties will depend on the ratio between the internal accretion rate and the external star-forming rate (together with the geometry).*
- *When the molecular cloud is consumed, the nucleus become dormant. The process starts again when a new cloud falls to the nuclear region.*