Narrow Line Region

General Properties

Reminder: Narrow Line Region (Osterbrock, 1989, 1991):

- Line widths 200–700 km s^{-1}
- Allowed lines from H I, He I, He II
- Forbidden lines: strongest: [O III] $\lambda\lambda$4959, 5007, [N II] $\lambda\lambda$6548, 6583
- Studies for Sy 1 problematic as narrow and broad lines blend
- Gas diagnostics from [O III] $\lambda\lambda$ 5007/4959 and 4363 and [S II λ6716/λ6731 ratios: $T \sim 15000$ K and $n_\mathrm{e} \sim 3 \times 10^3$ cm^{-3}, possible density gradient is observed
- NLR mass from Hβ emissivity and assuming spherical symmetry: $L_{\mathrm{H}\beta} = 2 \times 10^8\, L_\odot \Longrightarrow M \sim 7 \times 10^5 (10^4/N_\mathrm{e}) M_\odot$ and $R \sim 20 f^{-1/3} (10^4/N_\mathrm{e})^{2/3}$ pc, i.e., 90 pc with an estimated filling factor of $f = 10^{-2}$.

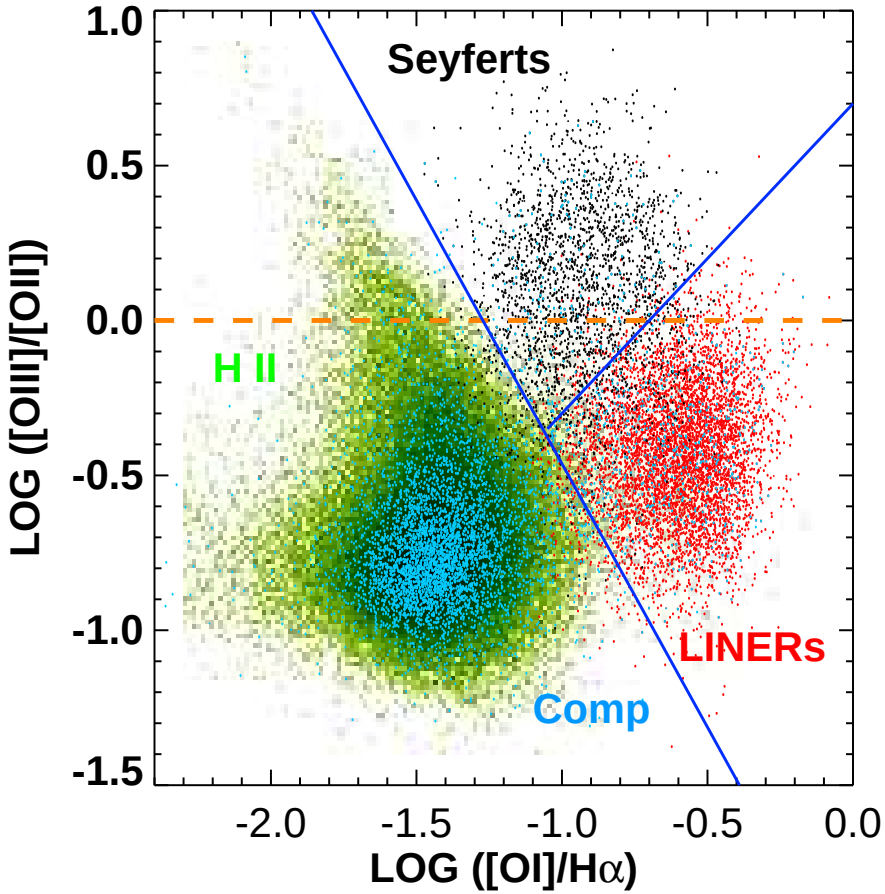
NLR Modeling

Models of the NLR aim to

- Determine flux of lines
- Reproduce line ratios and equivalent widths of narrow lines
- provide estimates for the line width

See talk by B. Groves at Xian AGN meeting for details:
`http://agn06.ihep.ac.cn/`

Nature of the NLR



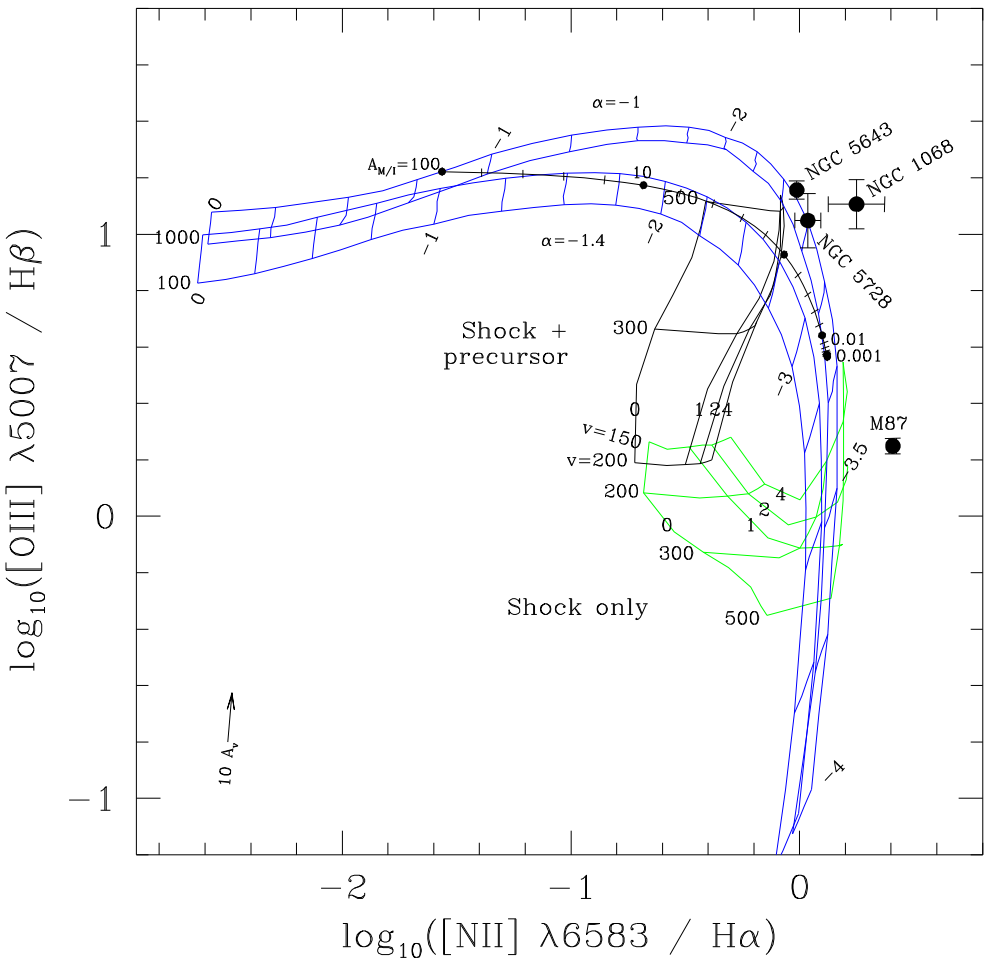
(Kewley et al., 2006)

Reminder: Line ratios are used to define the different types of Seyfert galaxies.

(Kewley et al., 2006;

Baldwin, Phillips & Terlevich, 1981)

Nature of the NLR



(Allen et al., 1999, Fig. 1)

Photoionization models can reproduce ratios of strong observed lines such as [O III 5007]/Hβ ratio and absolute luminosity of these lines.

BUT: Strengths of high and low ionization stages cannot be reproduced simultaneously!

$\Longrightarrow$ rules out the simplest photoionization models!

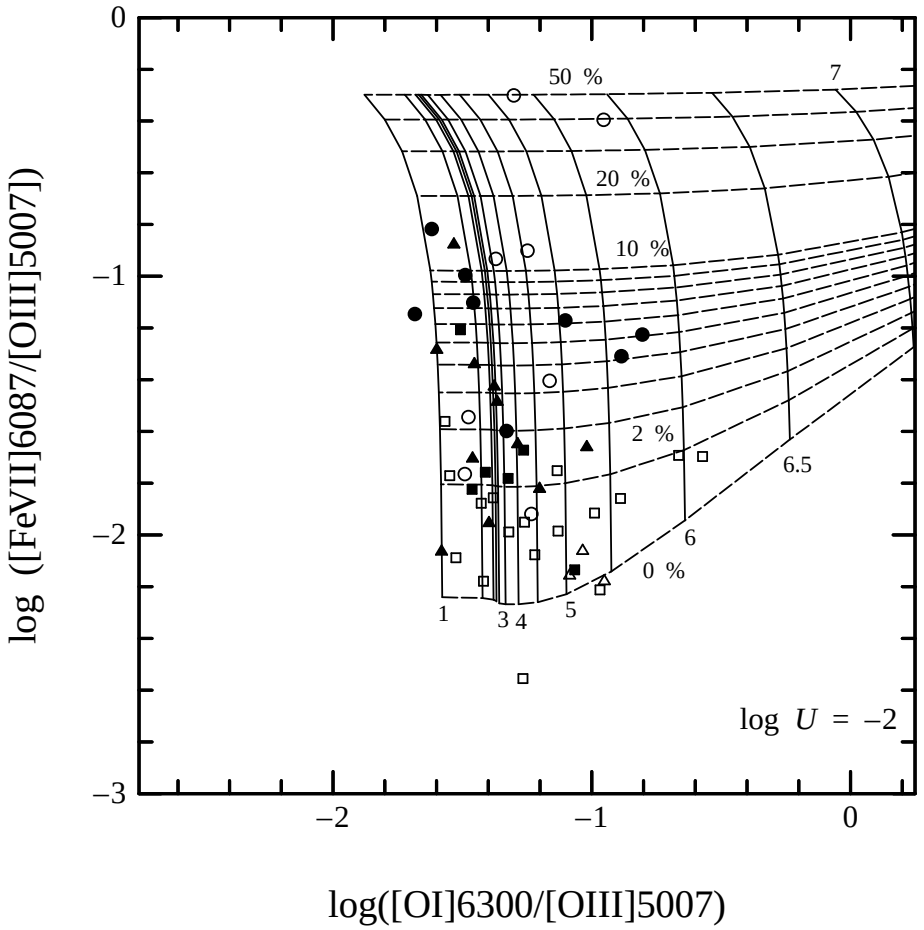
Potential solution: shock ionization (Allen et al., 1999, and therein)!

Photons produced after a shock (where $T \sim 10^6$ K) can ionize pre-shock gas

$\Longrightarrow$ combination of collisional ionization and photoionization.

Shock possibly related to jet/radio outflow.

Nature of the NLR



(Murayama & Taniguchi, 1998, Fig. 2)

Alternative explanation of unusual line ratios: two and multiple zone NLR models.

Triggered, e.g., by too strong Fe line emission

For example: High ionization nuclear emission region (HINER) models (Murayama & Taniguchi, 1998): 10% of NLR emission from high density ($n_e \sim 10^9\,\mathrm{cm}^{-3}$) photoionized region within torus which is responsible for emission from high ionized species.

Similar models have also been proposed, e.g, by Komossa & Schulz (1997) and by many other authors.

Problem: Too many free parameters $\Longrightarrow$ Search for physical constraints!

E.g., matter bounded vs. ionization bounded clouds, locally optimally emitting clouds,. . .

Imaging of the NLR

Line diagnostics: size of NLR: $\sim$90 pc or larger.

$\Longrightarrow$ for the nearest AGN imaging is possible

(e.g., Circinus galaxy: $d = 4$ Mpc $\longrightarrow 1'' = 19$ pc.

Imaging of NLR possible either using integral field spectroscopy or narrow-band filters.

Often used: narrow-band Hα and [O III] filters.

Results (see, e.g., Pogge 1988):

- ionization cones,
- stratified ionization structure in many AGN.

$\Longrightarrow$ Extended Narrow Line Region (ENLR).

In the following: two typical examples: NGC 1068 (=M77) and Circinus galaxy.

Similar studies have been performed for $\gtrsim$ 30 nearby AGN.

NGC 1068 (M77), NOAO 20″

Francois and Shelley Pelletier/Adam Block/NOAO/AURA/NSF

NGC 1068, II

NGC 1068 (M77) (Bill Arnett)

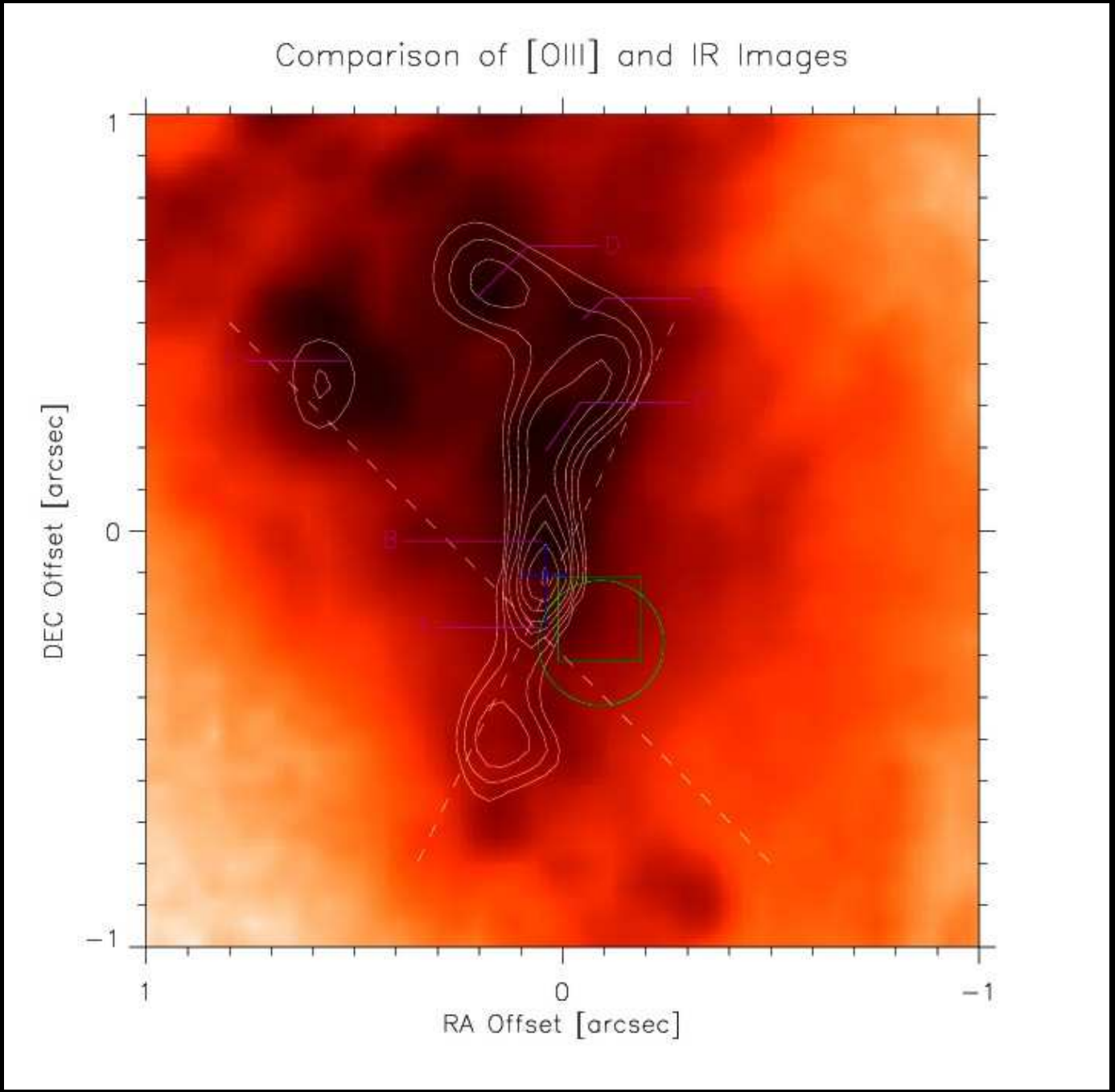
NGC 1068 (M77): Seyfert 2 nucleus at $z = 0.003$ ($d \sim 15$ Mpc), one of the best studied galaxies in the sky.

NGC 1068, III

NGC 1068 (M77) core with HST in O III

NGC 1068 (M77): Seyfert 2 nucleus at $z = 0.003$ ($d \sim 15$ Mpc), one of the best studied galaxies in the sky.

Pogge (1988): Extended ionizing radiation cone from the nucleus of NGC 1068, along the direction of the radio jet.

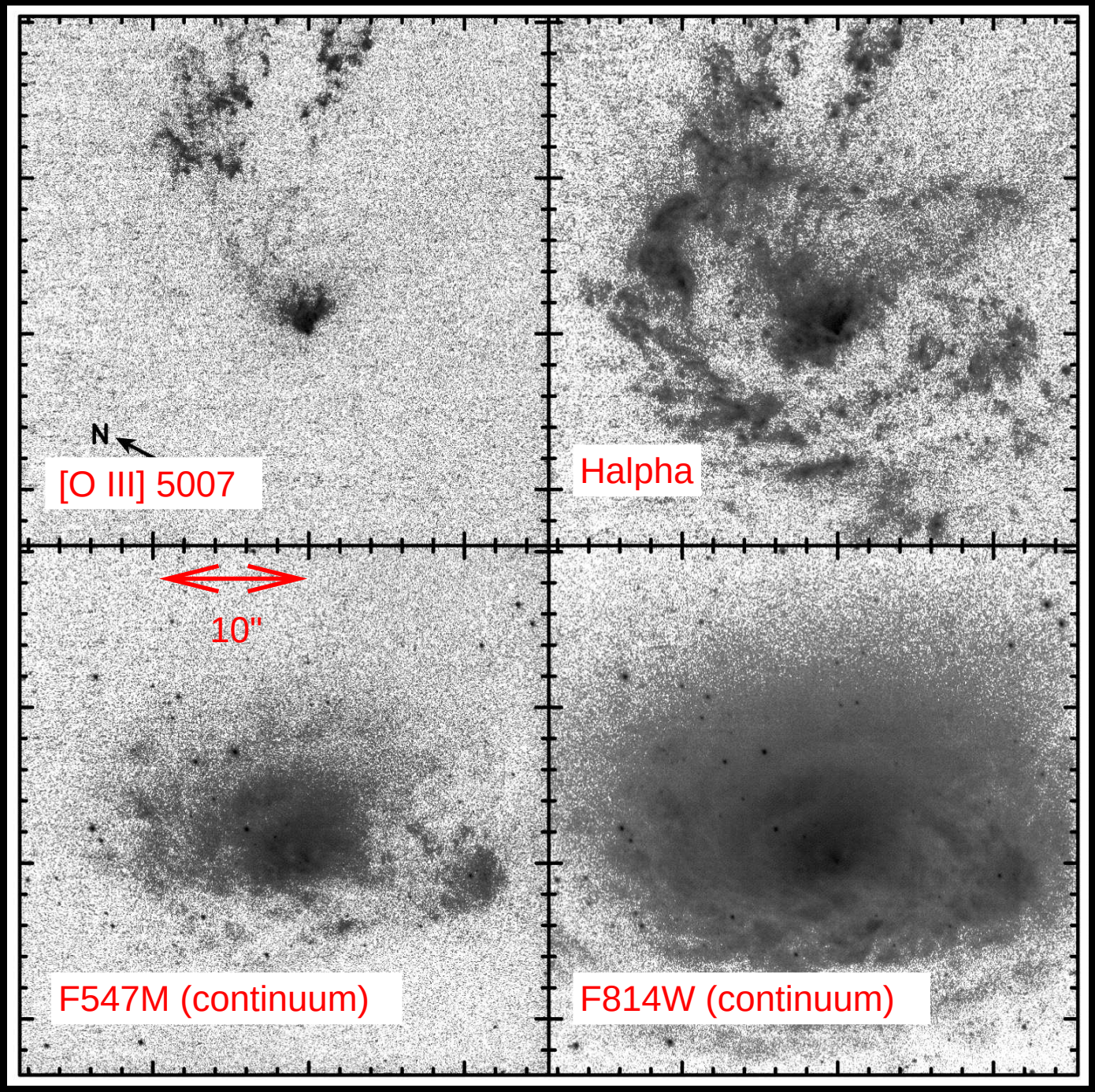


M. Camenzind

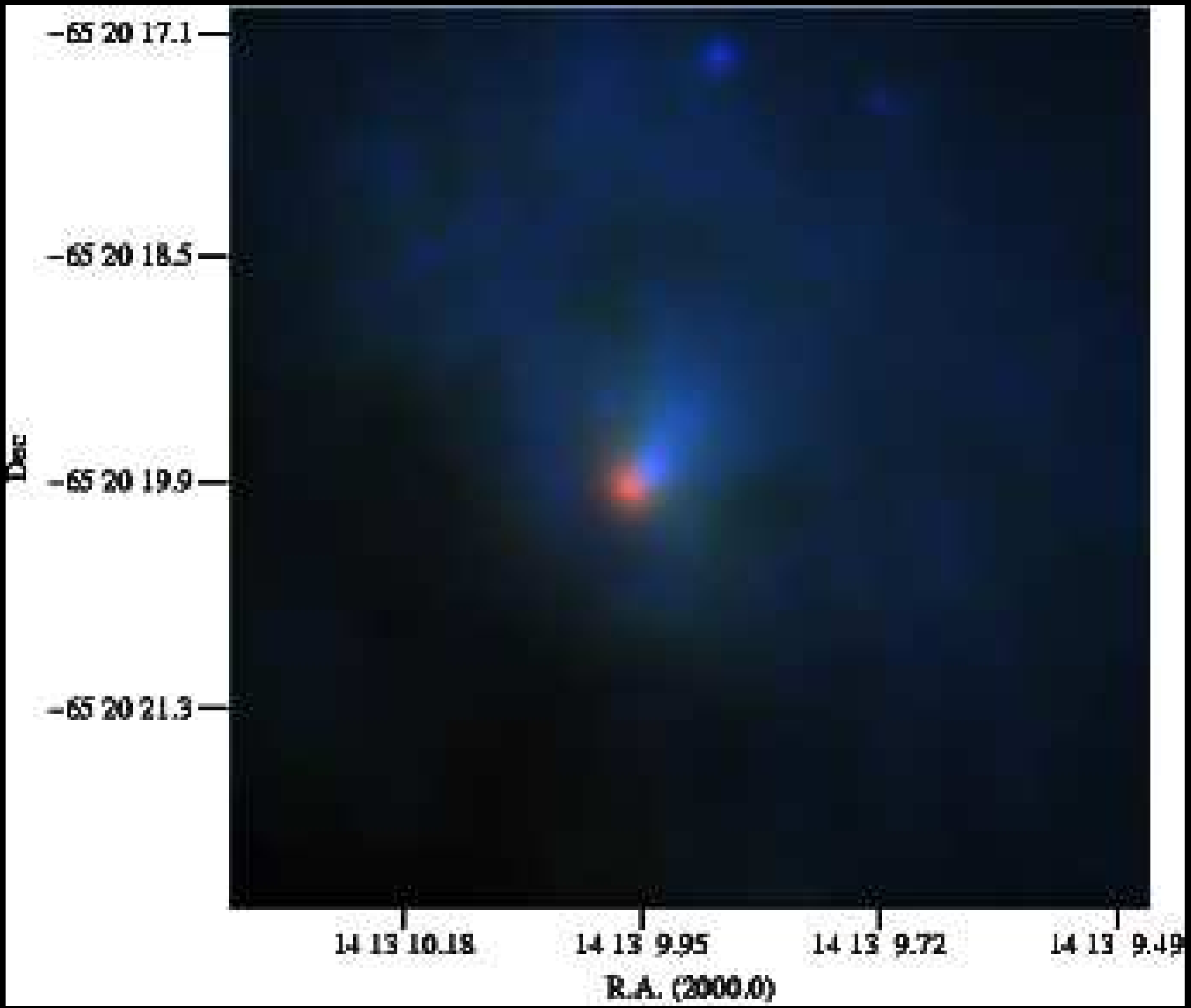
NGC 1068: Funnel in IR overlaid to O III image: Highly structured NLR!

Circinus galaxy:

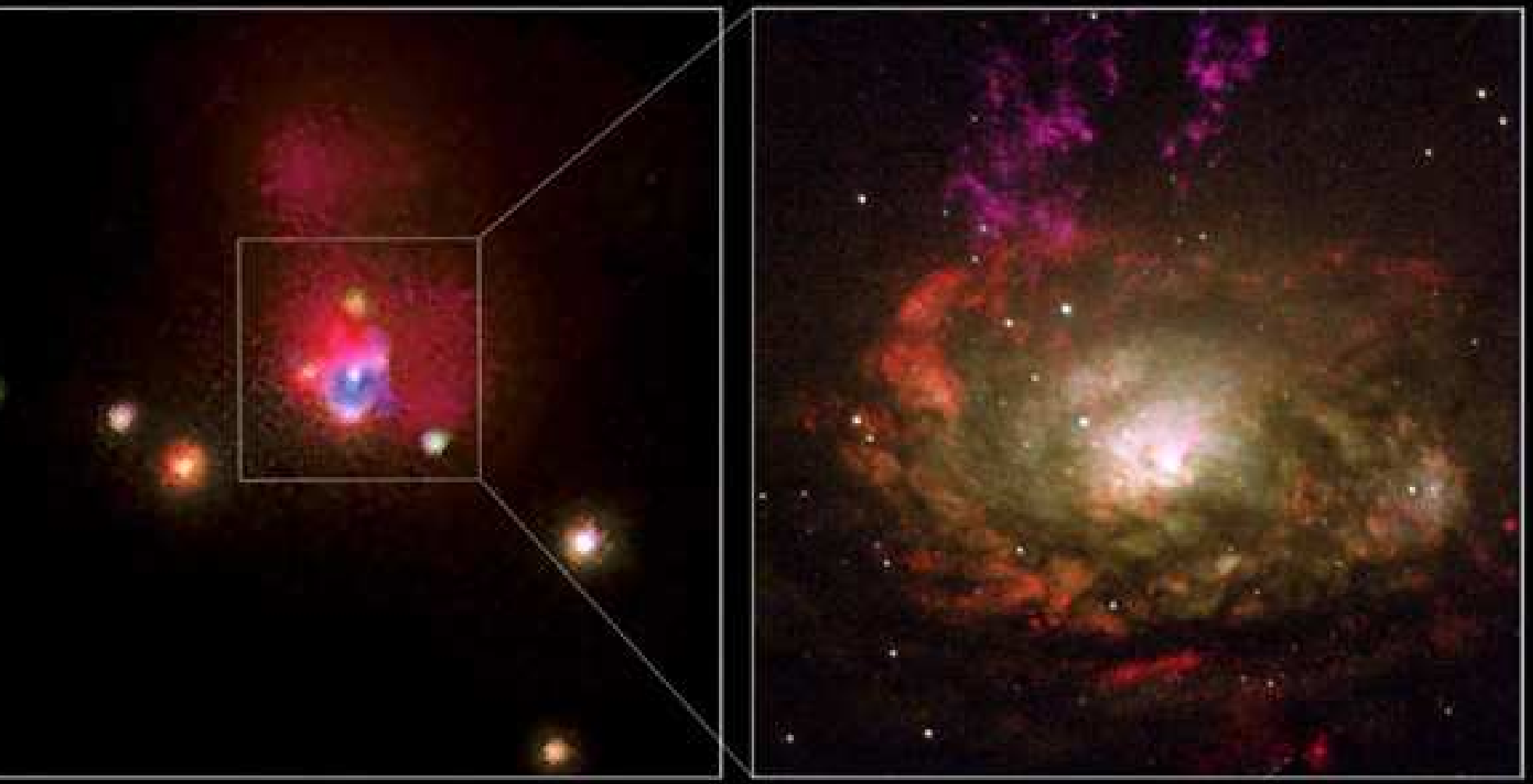
- $d \sim 4$ Mpc ($1'' \sim 19$ pc)
- 2nd nearest AGN on southern hemisphere after Cen A
- SAb galaxy
- Seyfert 2 nucleus



(HST Wilson et al., 2000, Fig. 2)



(HST and VLT (IR) Prieto et al., 2004, Fig. 2)



X-rays (*Chandra*) Optical (HST)

rcinus galaxy: Alignment between hard X-ray emitting gas and optical ionization cone.

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