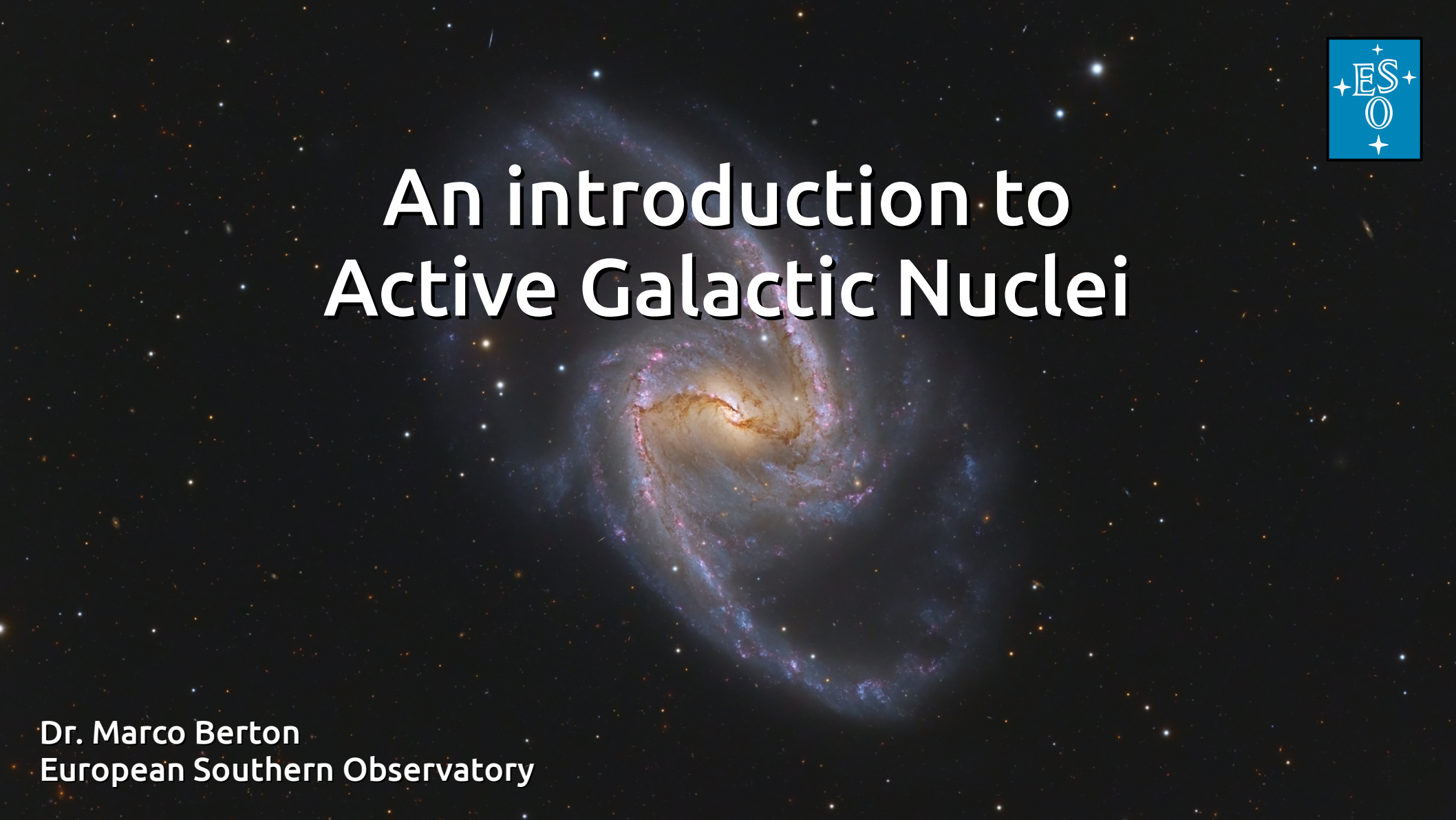
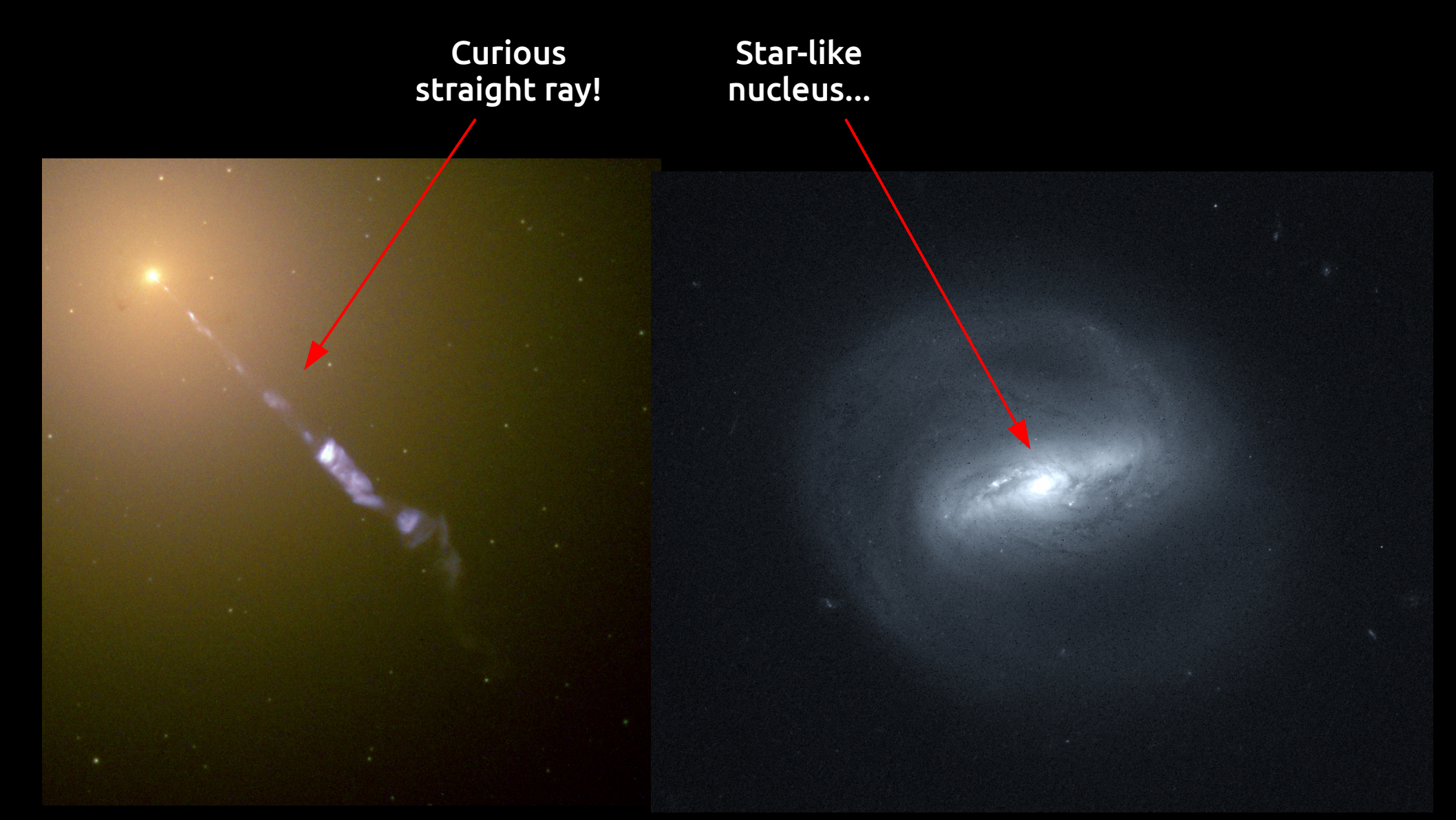


An introduction to Active Galactic Nuclei

Dr. Marco Berton
European Southern Observatory


Curious
straight ray!
Star-like
nucleus...

Seyfert, 1943

TABLE 3

INTENSITIES OF EMISSION LINES IN SIX EXTRAGALACTIC NEBULAE

Atom	λ	NGC 1068	NGC 1275	NGC 3516	NGC 4051	NGC 4151			NGC 7469		NGC 7027*
						Core	Wing	Core+Wing	Core	Core+Wing	
[O II]	3726.2	80:	140:	.....	.....	100:	.....	25:	48:	15:	8
[O II]	3729.7										4
[Ne III]	3869	65:†	35:	.....	P	65:	.....	15:	.....	.....	40
H ζ	3889.1	5:	.....	.....	.....	.....	.....	.....	.....	.....	7
[Ne III]	3968	25:†	20:	.....	.....	25:	.....	5:	.....	.....	15
H ε	3970.1										8
[S II]	4068.5	20	50	.....	.....	25	.....	5	.....	.....	5
[S II]	4076.5										2
H δ	4101.8	20	10:	25	.....	20	20	20	.....	35:	12
H γ	4340.5	40	50	40‡	40	35	30	35	.....	60:‡	20
[O III]	4363.2	35	40	.....	20	75	.....	18	.....	.....	10
C IV[Fe III]	4658.6	.....	.....	.....	.....	5	.....	1	.....	.....	0.9
He II	4685.8	40	.....	.....	25	25	.....	5	.....	.....	40
[A IV]	4711.4	.....	.....	.....	.....	10	.....	2	.....	.....	3
[A IV]	4740.3	.....	.....	.....	.....	10	.....	2	.....	.....	7
H β	4861.3	100§	100	100	100	100	100	100	100	100	100
[O III]	4959.5	400§	80	15	55	375	.....	90	125	35	430
[O III]	5007.6	1200§	270	40	190	1150	.....	275	300	80	1190
[Fe VII]	5158.3	5	.....	.....	.....	P‖	.....	P	.....	.....	2
[N I]	5199.2	25	.....	.....	.....	15	.....	5	.....	.....	3
[Fe VII]	5276.1	5:	.....	.....	.....	P:	.....	P:	.....	.....	1.5±
	5670.5	.....	.....	.....	.....	P	.....	P	.....	.....	.....
[Fe VII]	5720.9	10	.....	.....	.....	20	.....	5	.....	.....	4
[N II]	5755.0	10	.....	.....	.....	.....	.....	.....	.....	.....	20
He I	5875.6	15:	.....	.....	.....	30	.....	5	.....	.....	35
[Fe VII] [Ca V]	6085.7	30	.....	.....	.....	35	.....	10	.....	.....	5
[O I]	6300.2	85	100	.....	30	150	.....	35	.....	.....	40
[S III]	6310.2										15
[O I]	6363.9	30	40	.....	20	50	.....	10	.....	.....	20
[N II]	6548.4				25:	100		25	.....	.....	90
H α	6562.8	1000¶	700	600	600	400	375	400	.....	.....	420
[N II]	6583.9				50:	200		50	.....	.....	190
[S II]	6717.3	140	210	.....	40:	180	.....	40	.....	.....	8
[S II]	6731.5										15

* The intensities in the planetary nebula NGC 7027 (included for comparison) are from the paper by A. B. Wyse, *Ap. J.*, **95**, 356, 1942.

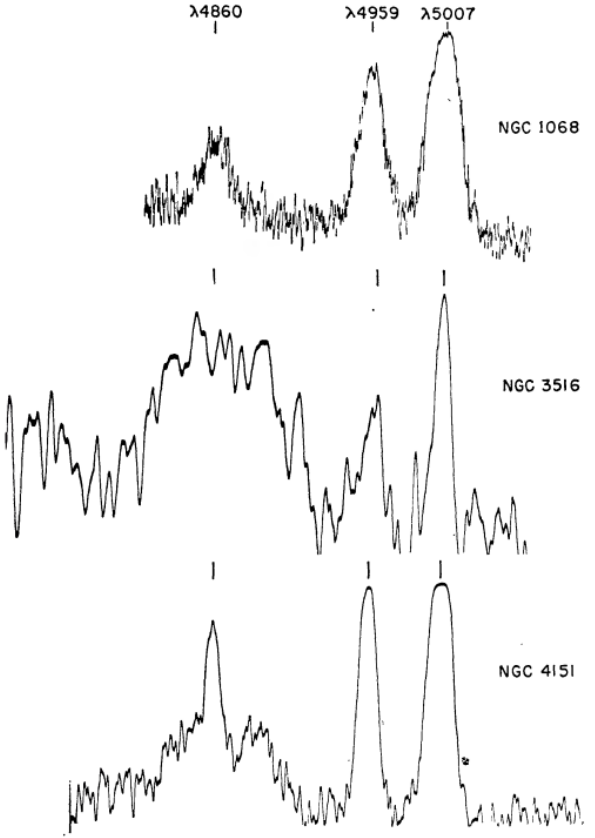
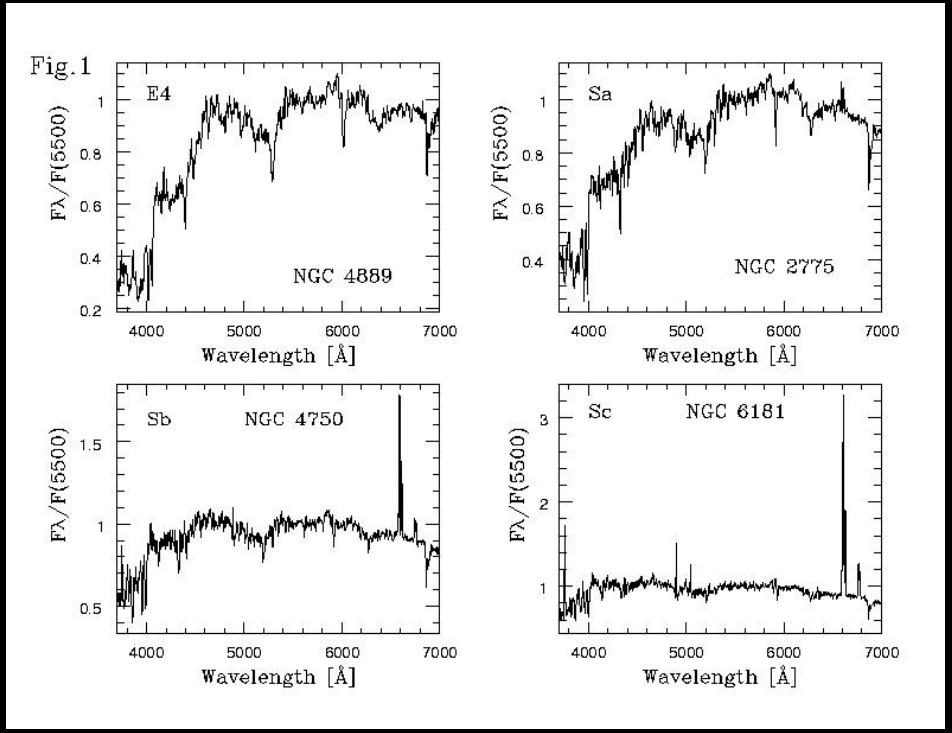


FIG. 1.—Microphotometer tracings of the emission lines λλ 4860 (*Hβ*), 4959 and 5007 [*O* III] in the nebulae NGC 1068, 3516, and 4151.

The spectra of Seyfert galaxies are very different from those of normal galaxies.



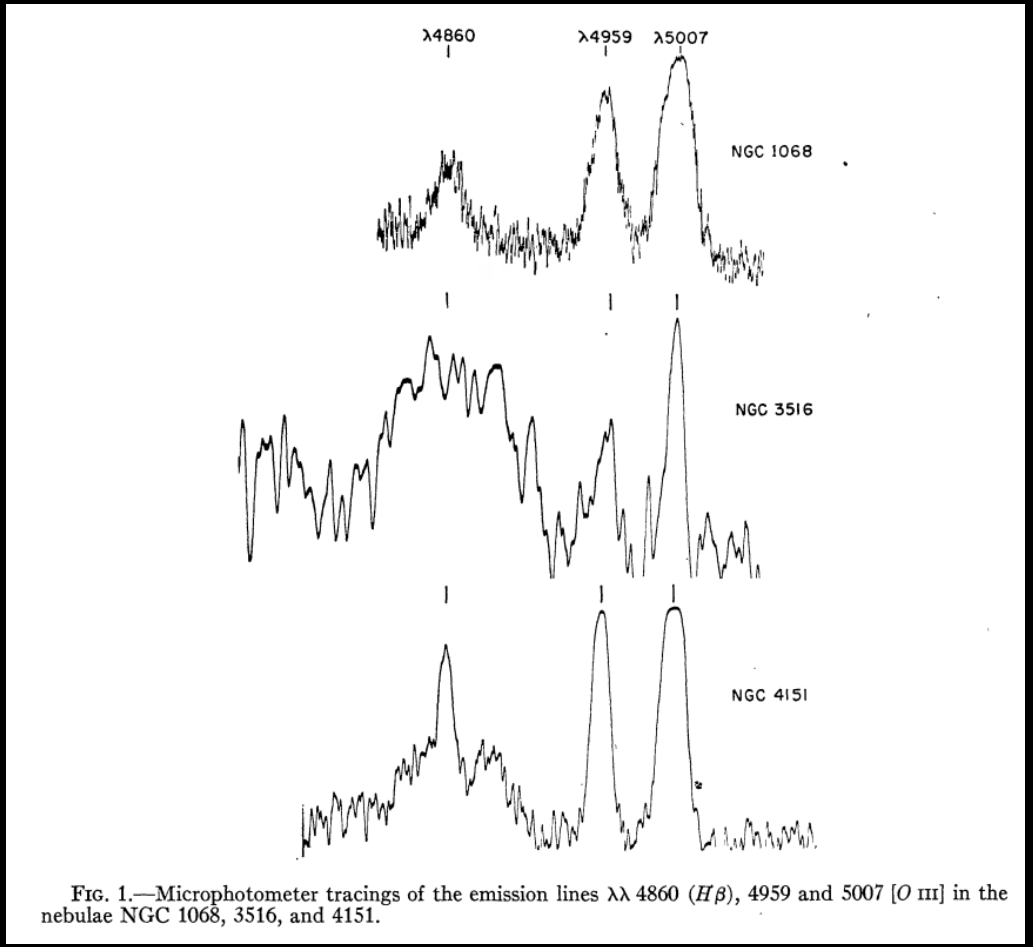


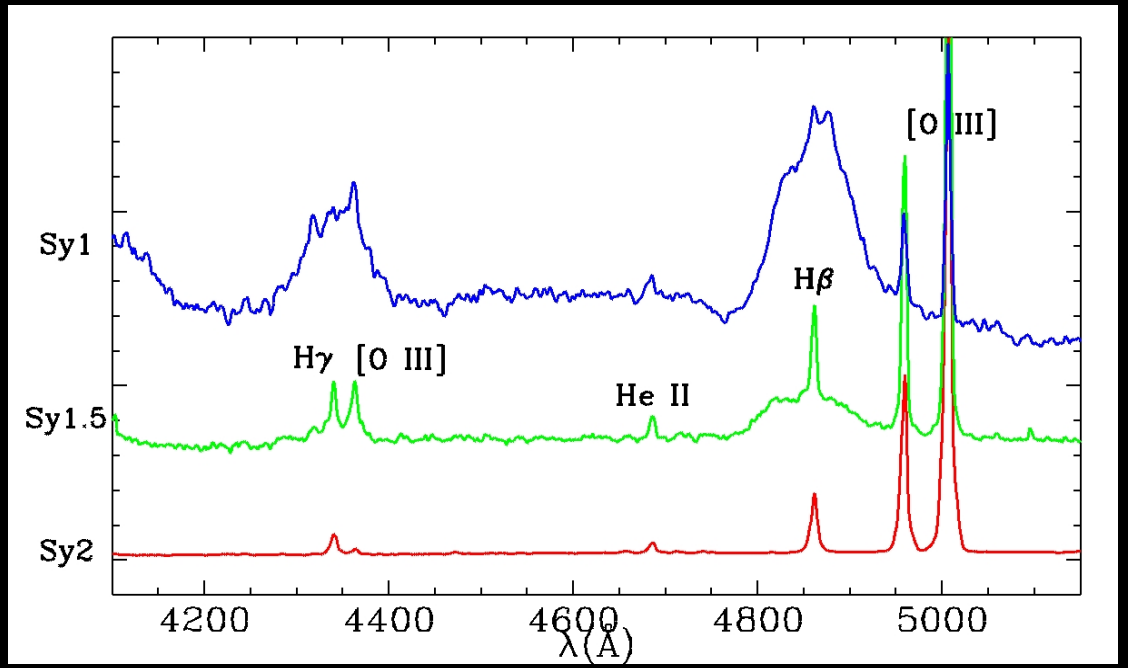
FIG. 1.—Microphotometer tracings of the emission lines λλ 4860 ($H\beta$), 4959 and 5007 [O III] in the nebulae NGC 1068, 3516, and 4151.

Seyfert galaxies are classified in 2+1 groups (Khachikian & Weedman 1974)

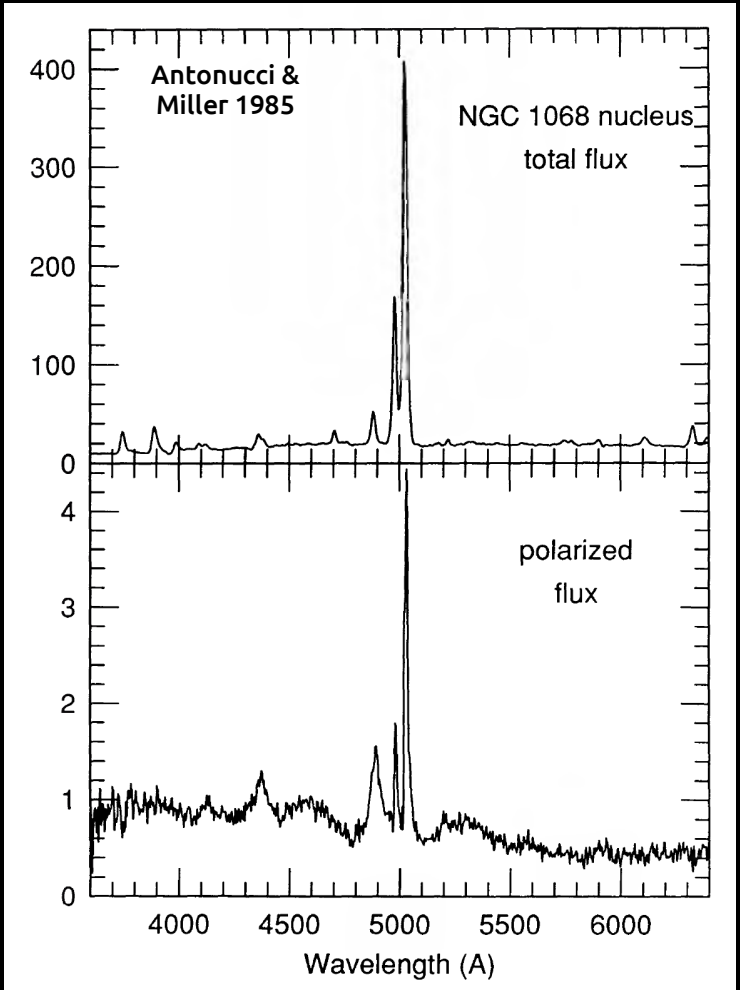
Seyfert 1:
- Broad permitted lines
- Narrow forbidden lines
- Weak or absent absorption lines

Seyfert 2:
- Narrow permitted lines
- Narrow forbidden lines
- More prominent absorption lines

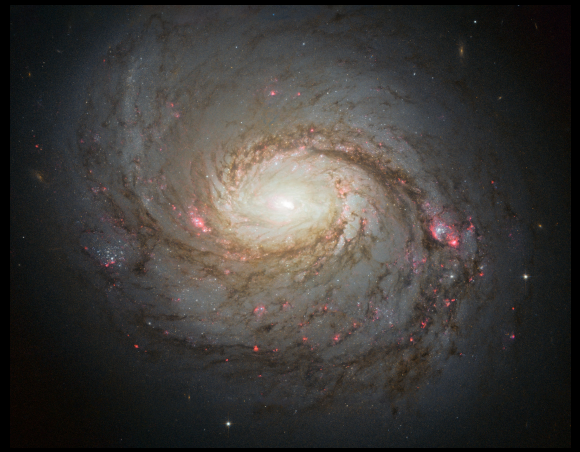
Intermediate types:
- Hybrid permitted lines
- Narrow forbidden lines
- Variable absorption



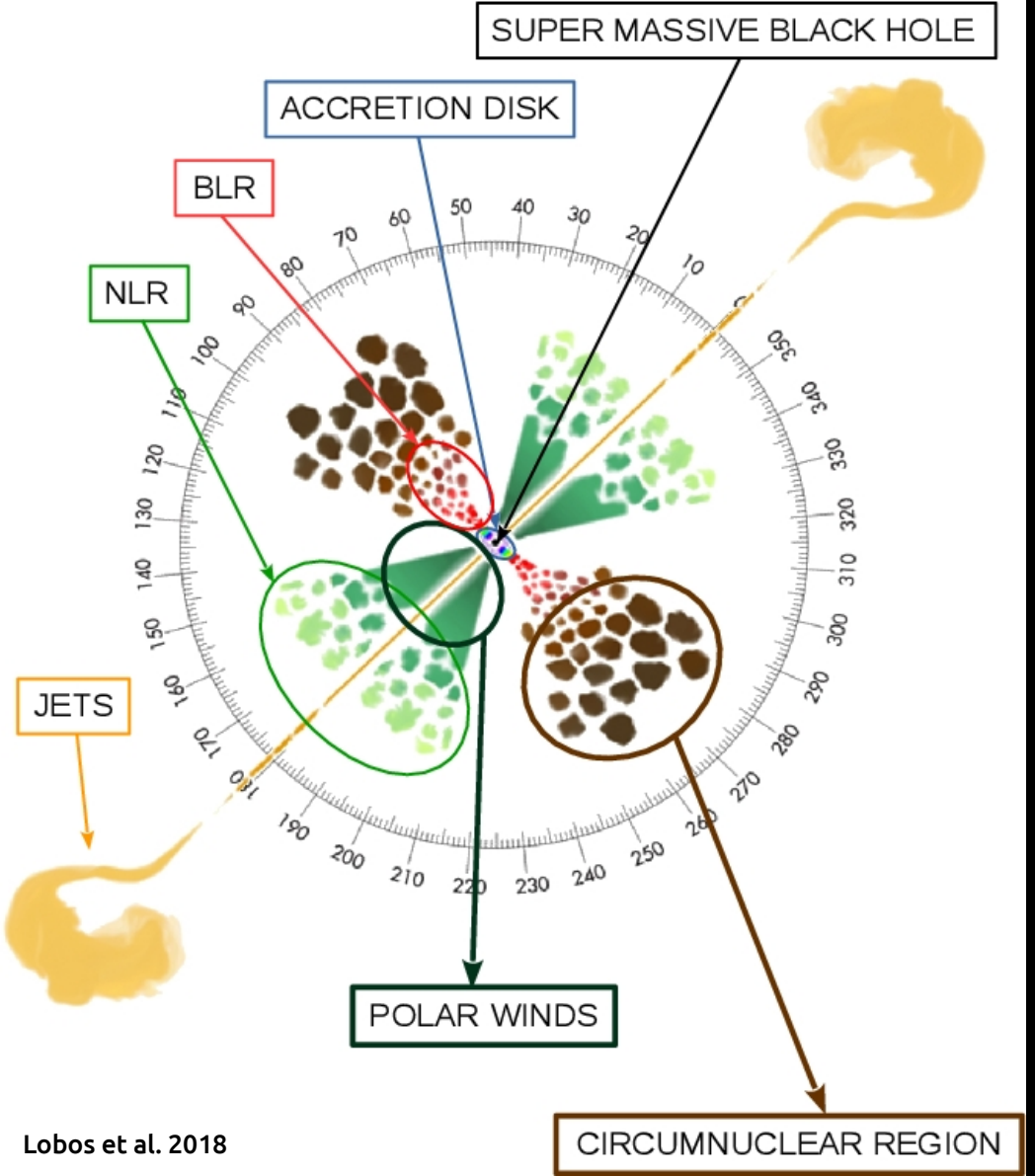
AGN unification

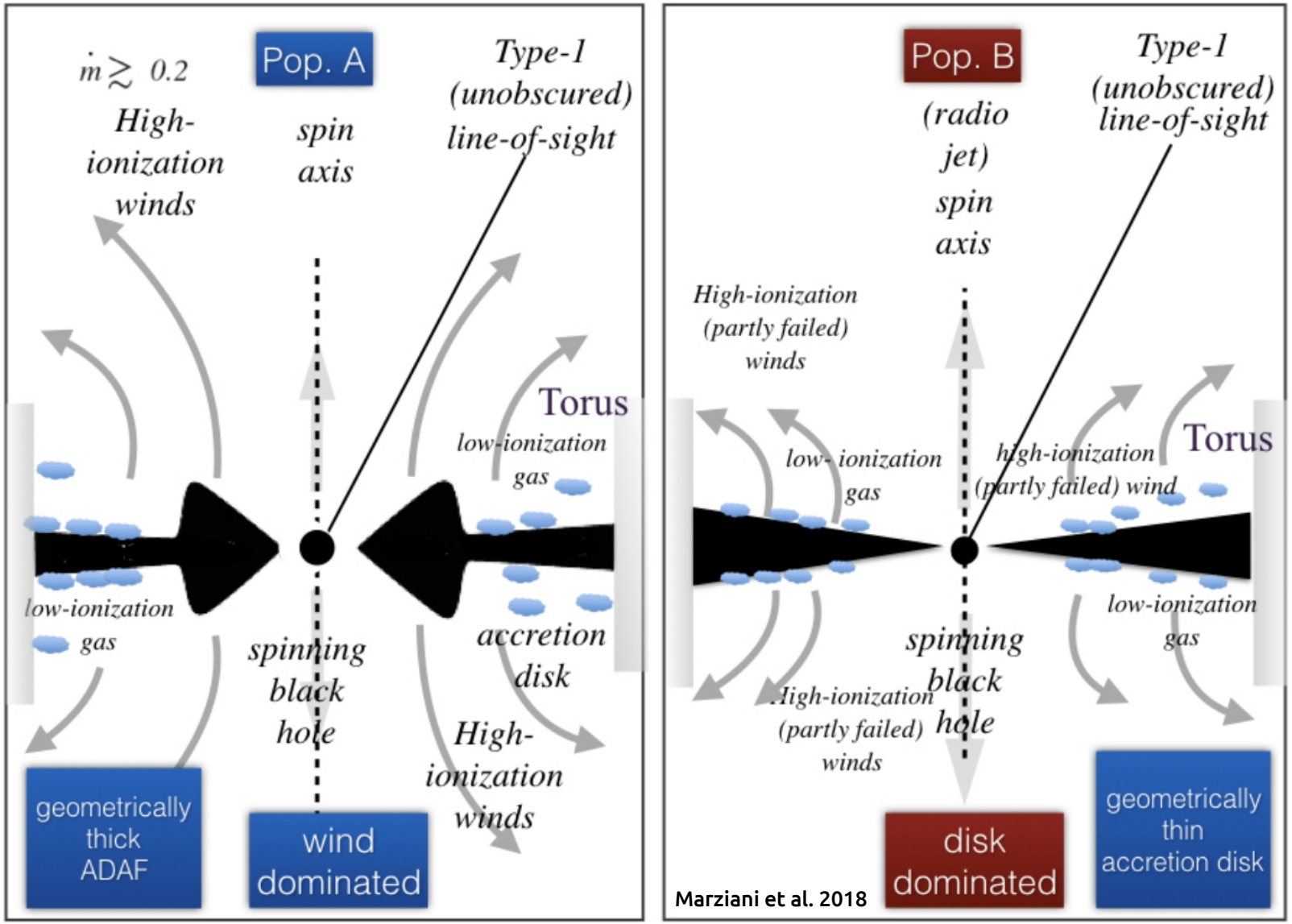


Proposed by Antonucci & Miller (1985), and later confirmed by Miller, Goodrich & Mathews (1991), on NGC 1068, one of the original Seyferts (also known as M77).



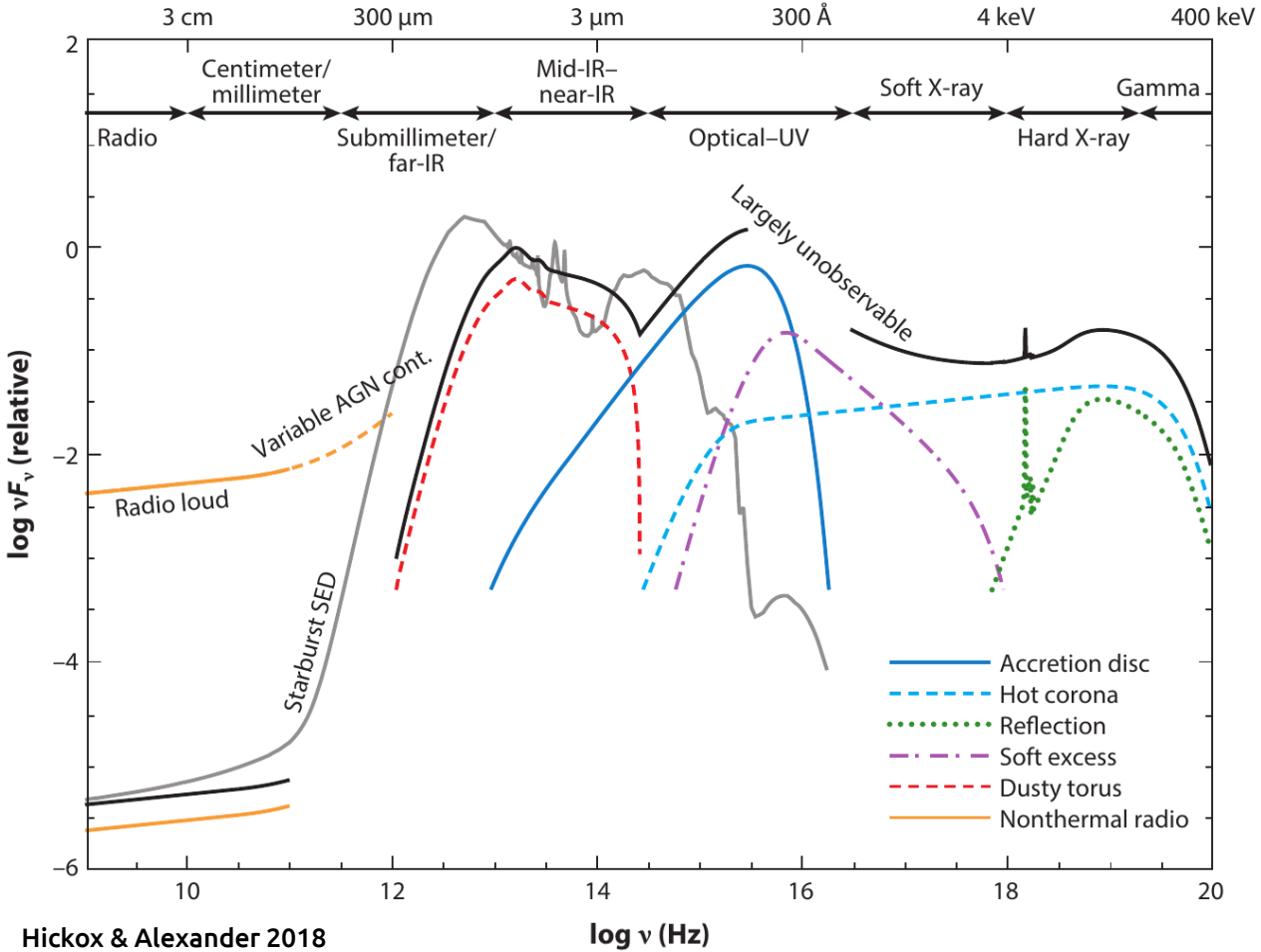
Type 1 and 2 AGN appear as different only due to their orientation with respect to our line of sight (Antonucci 1993).


SUPER MASSIVE BLACK HOLE
ACCRETION DISK
BLR
NLR
JETS
POLAR WINDS
CIRCUMNUCLEAR REGION
Lobos et al. 2018



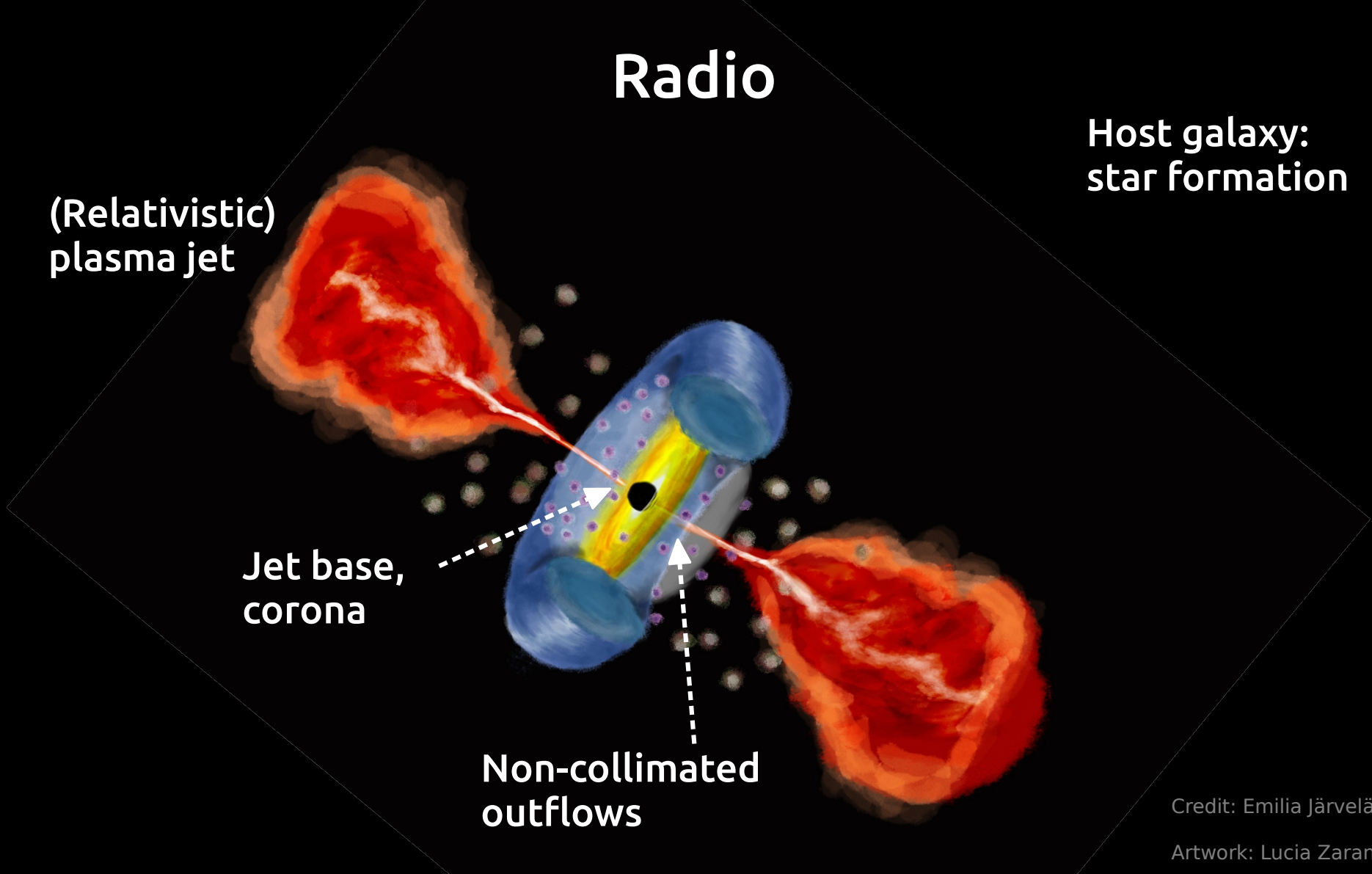
Marziani et al. 2018

Multiwavelength properties



Hickox & Alexander 2018

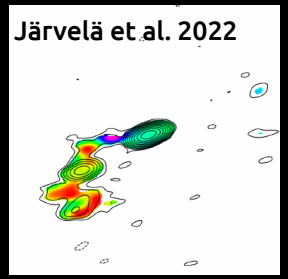
Radio



Credit: Emilia Järvelä

Artwork: Lucia Zarantonello

A 0th-order classification



An AGN shows radio emission

Jetted

High power

Low i

Flat-spectrum radio quasar

High i

High-excitation radio galaxy

Low power

Low i

BL Lacertae objects

High i

Low-excitation radio galaxy

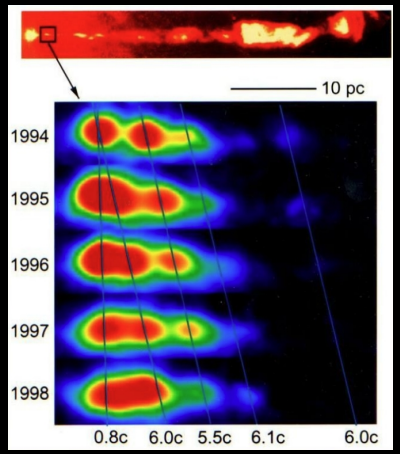
Non jetted

Corona

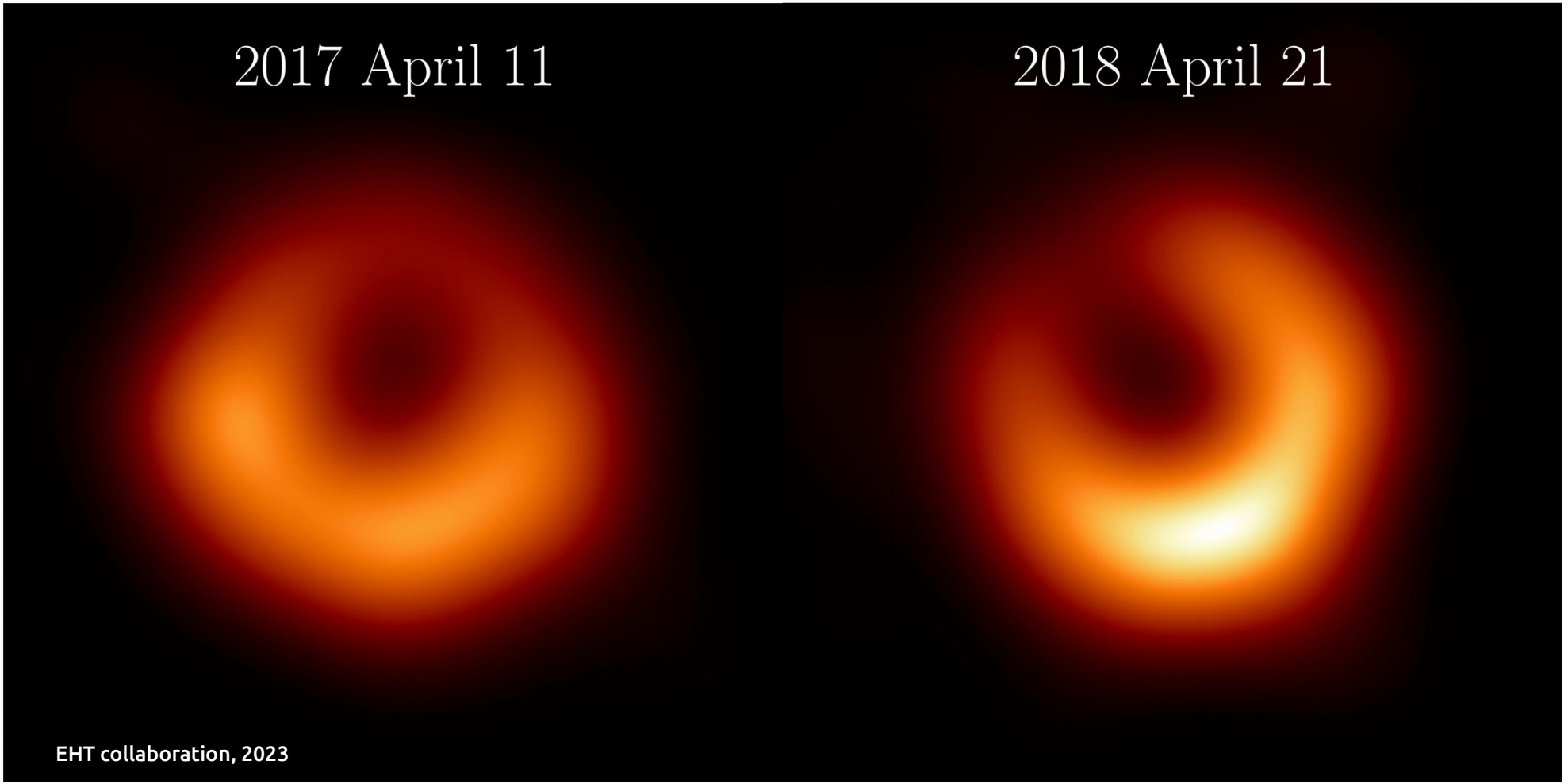
Outflow

Star formation

FSRQ + BL Lac = blazar

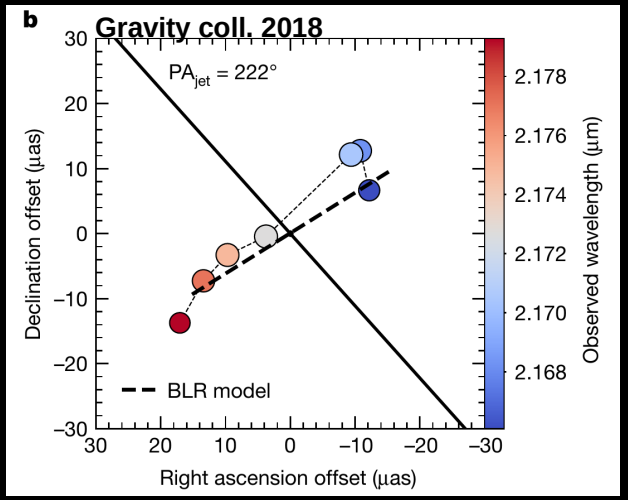


Millimetric

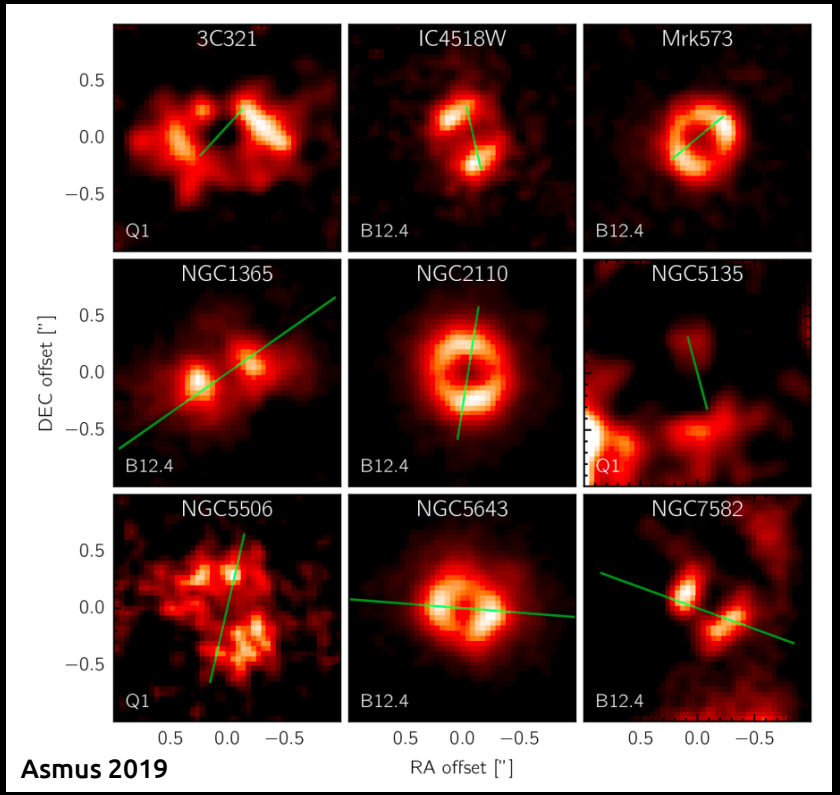


Infrared (low-z)

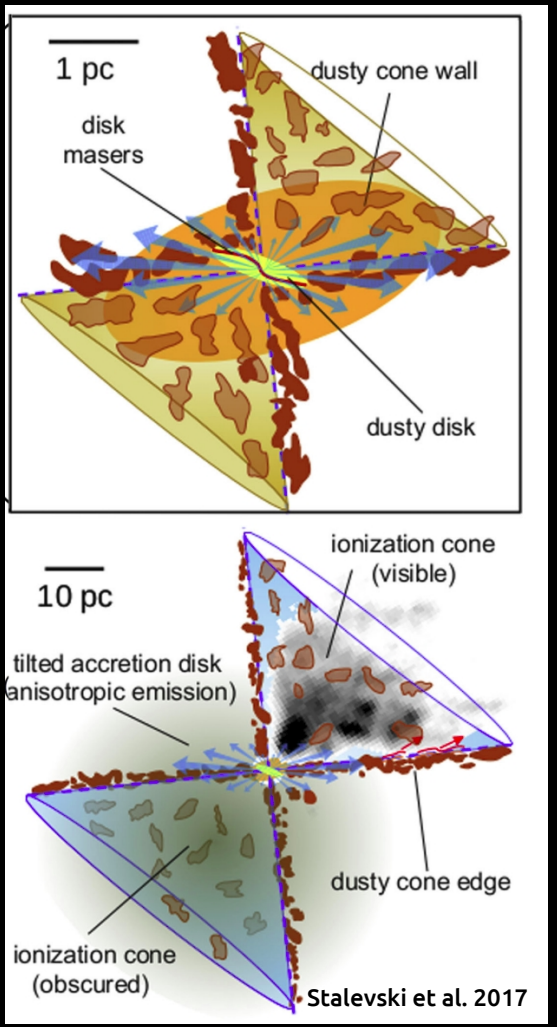
The dust dominates the emission at high spatial resolution.



Interferometry (VLTI) sees the innermost structure of AGN



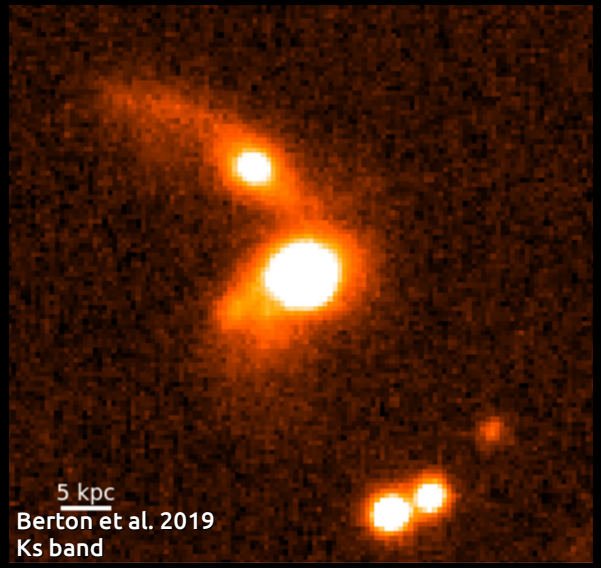
Asmus 2019

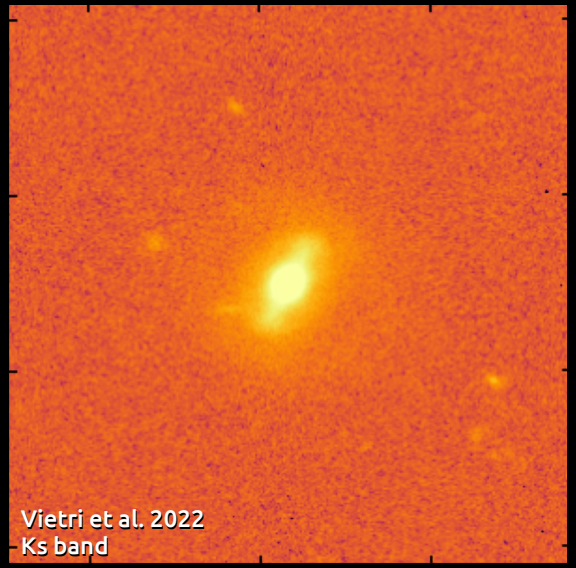


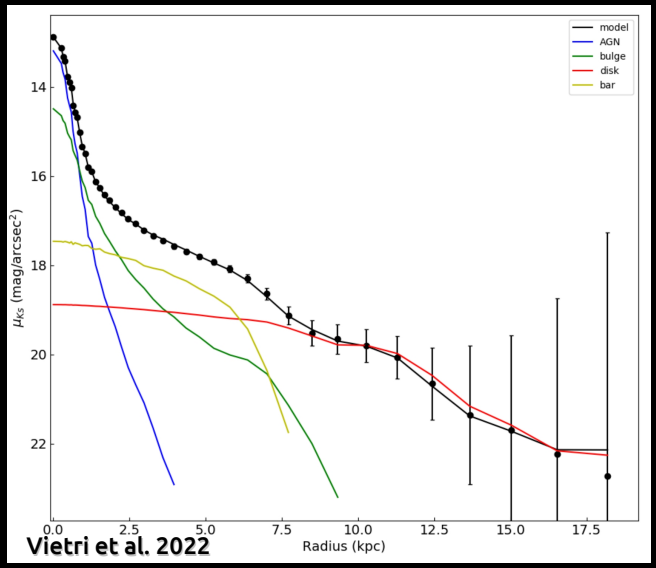
Stalevski et al. 2017

Infrared (low-z)

The host galaxy is brighter than the AGN at low spatial resolution







Optical

Black hole mass:
we assume that the gas is virialized

$$M_{BH} = f\frac{R_{BLR}v^2}{G}$$

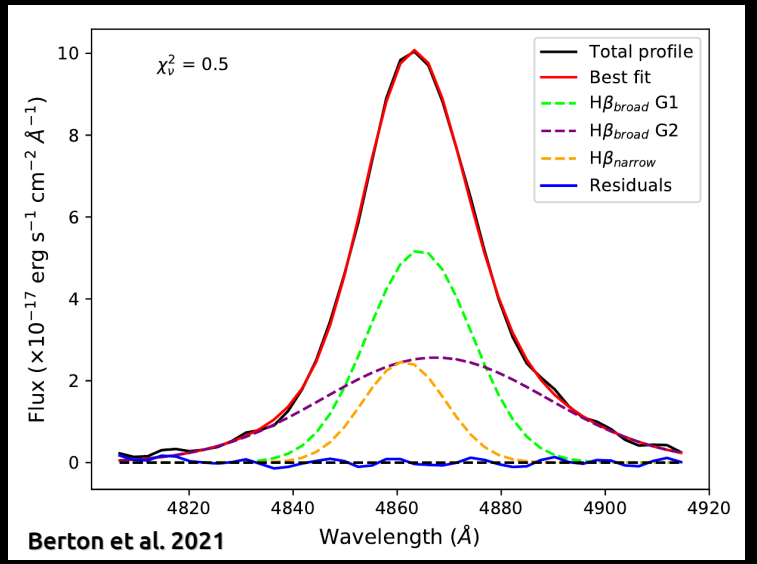
Velocity from the FHWM or the second-order moment of Hβ broad; radius from scaling relations:

$$\log\left(\frac{R_{BLR}}{\text{l.d.}}\right) = (1.53\pm0.03)+(0.53\pm0.03)\log\left(\frac{\lambda L_\lambda(5100)}{10^{44}\text{erg s}^{-1}}\right)$$

f is an unknown factor that depends on the gas geometry and inclination.

Eddington ratio:

$$\epsilon = \frac{L_{bol}}{L_{Edd}} = \frac{L_{bol}}{1.3\times10^{38}\,M_{BH}/M_\odot}$$



Optical

Broad lines parametrized using FWHM/σ parameter, with

$$\sigma^2_{H\beta} = \frac{\int \lambda^2 F(\lambda) \mathrm{d}\lambda}{\int F(\lambda) \mathrm{d}\lambda} - \left(\frac{\int \lambda F(\lambda) \mathrm{d}\lambda}{\int F(\lambda) \mathrm{d}\lambda} \right)^2$$

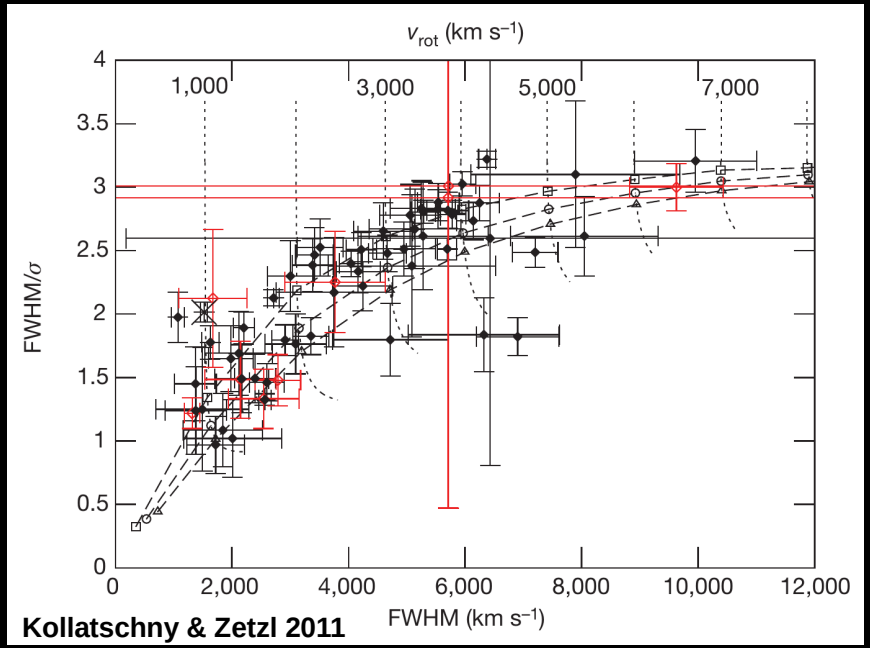
Gaussian ~ 2.355
Rectangular ~ 3.46
Lorentzian → 0

Different line profiles correspond to different BLR geometry. In general:

$$v_{keplerian} > v_{turbulent} \gtrsim v_{inflow}$$

For low FWHM:

$$v_{keplerian} \sim v_{turbulent}$$

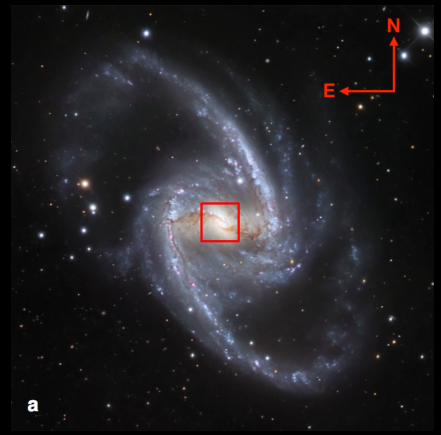


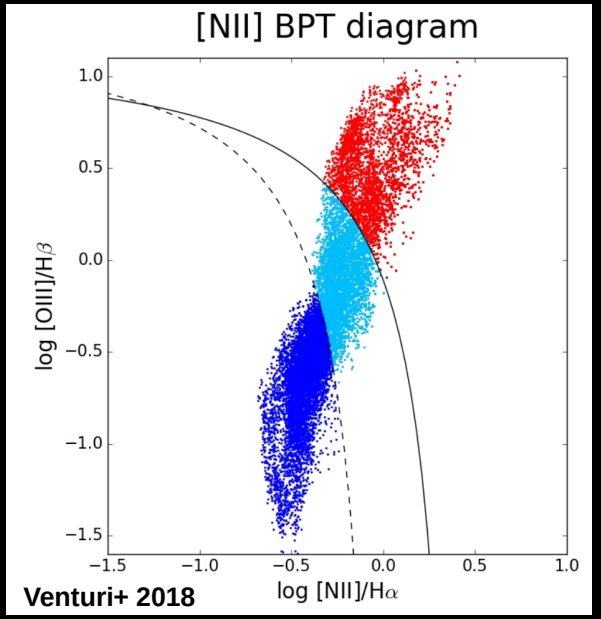
Kollatschny & Zetzl 2011

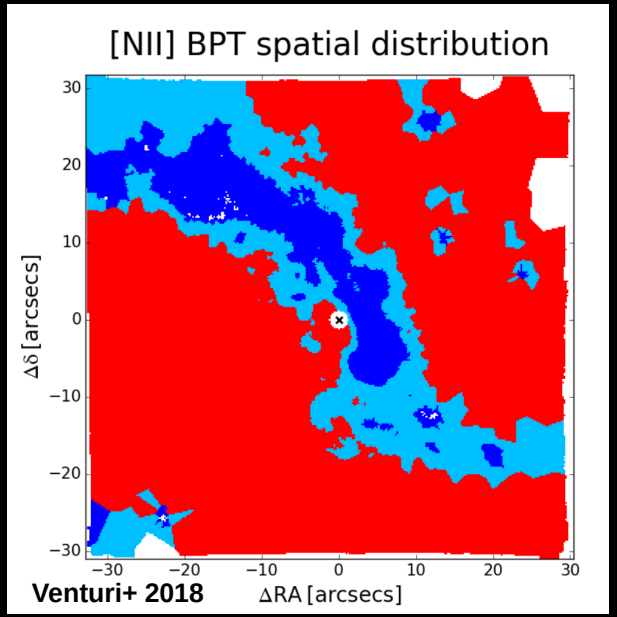
Optical

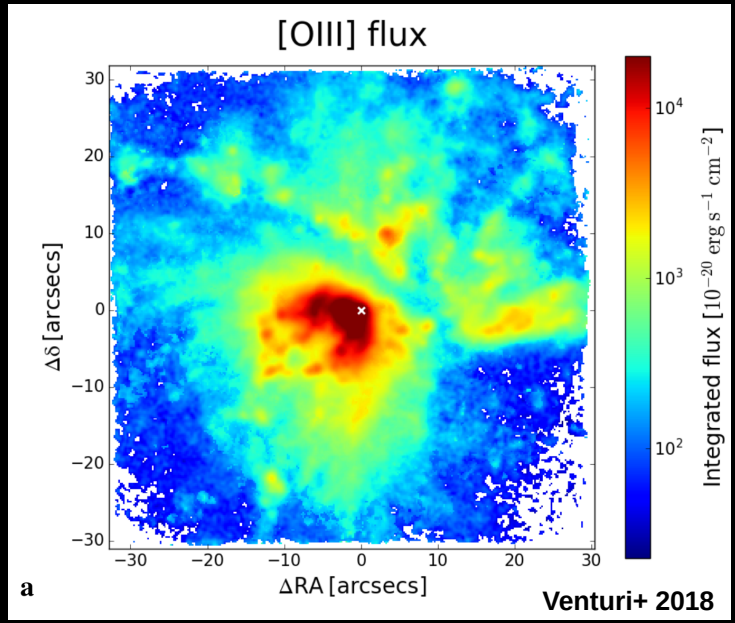
Different regions of the same galaxy can be ionized by different mechanisms

Ionized gas traces the light produced by the AGN









Optical

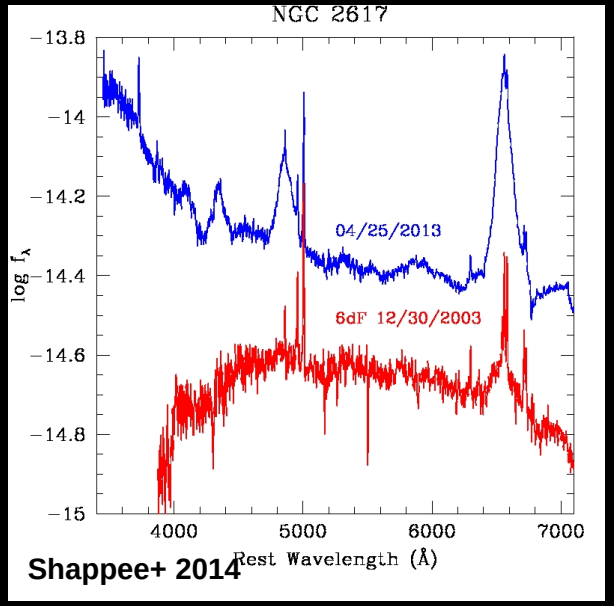
Changing-look AGN

The classification can change with time *on a human timescale*

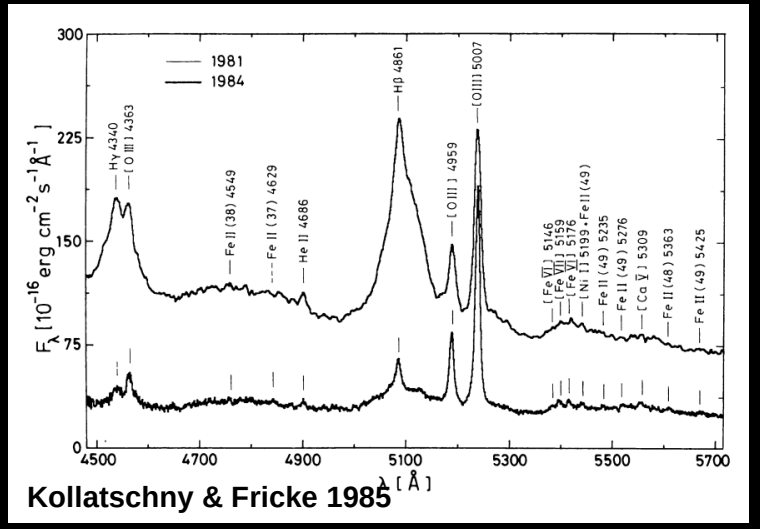
Both type 1 → type 2 and type 2 → type 1, but also switch-on and off.

Possible causes:

- Dust extinction
- Ionizing continuum
- Supernovae
- Tidal disruption events

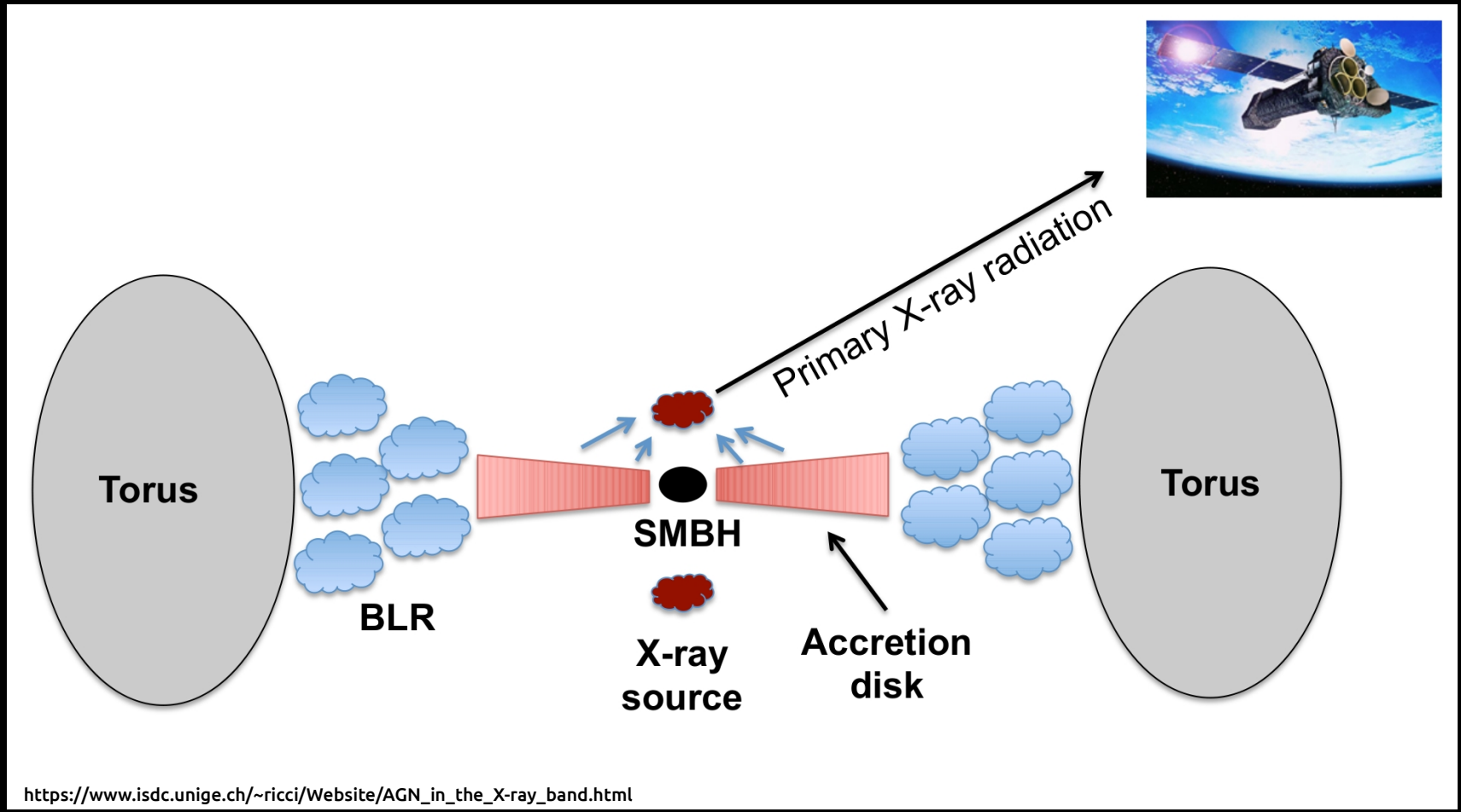


Shappee+ 2014



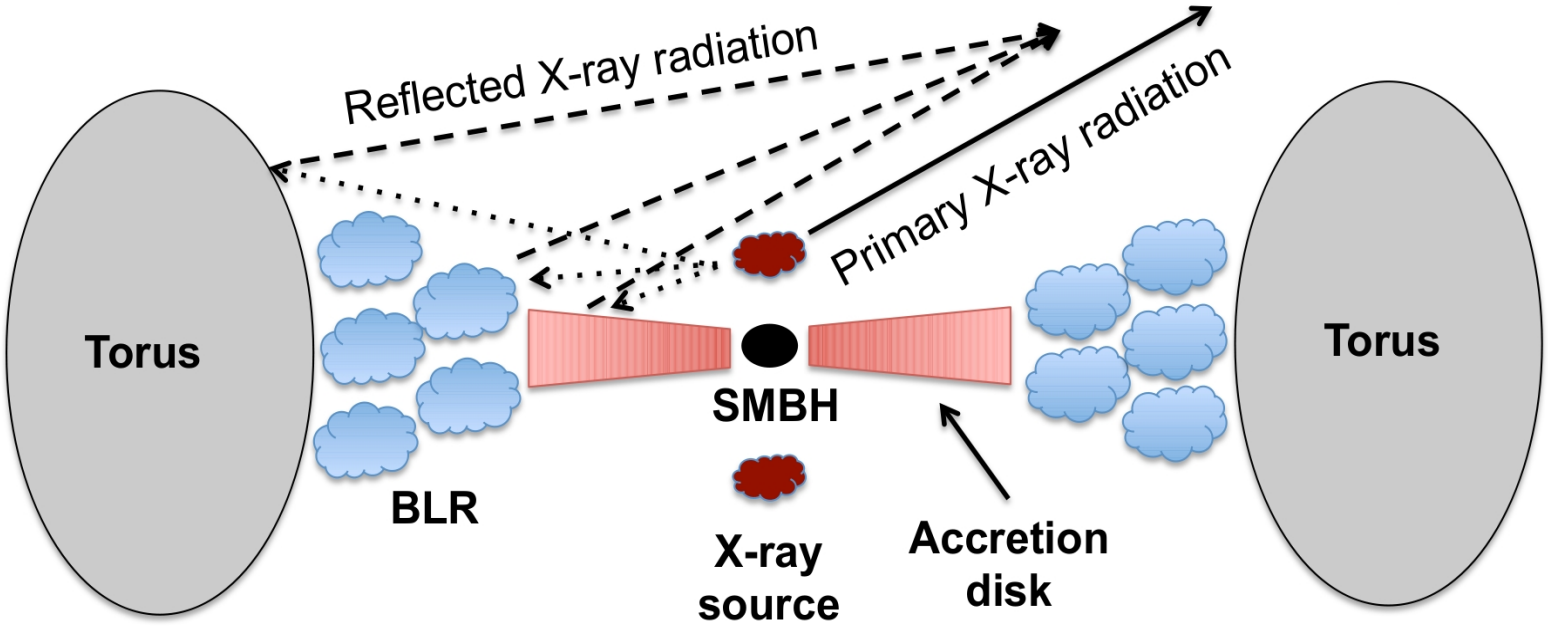
Kollatschny & Fricke 1985

X-rays



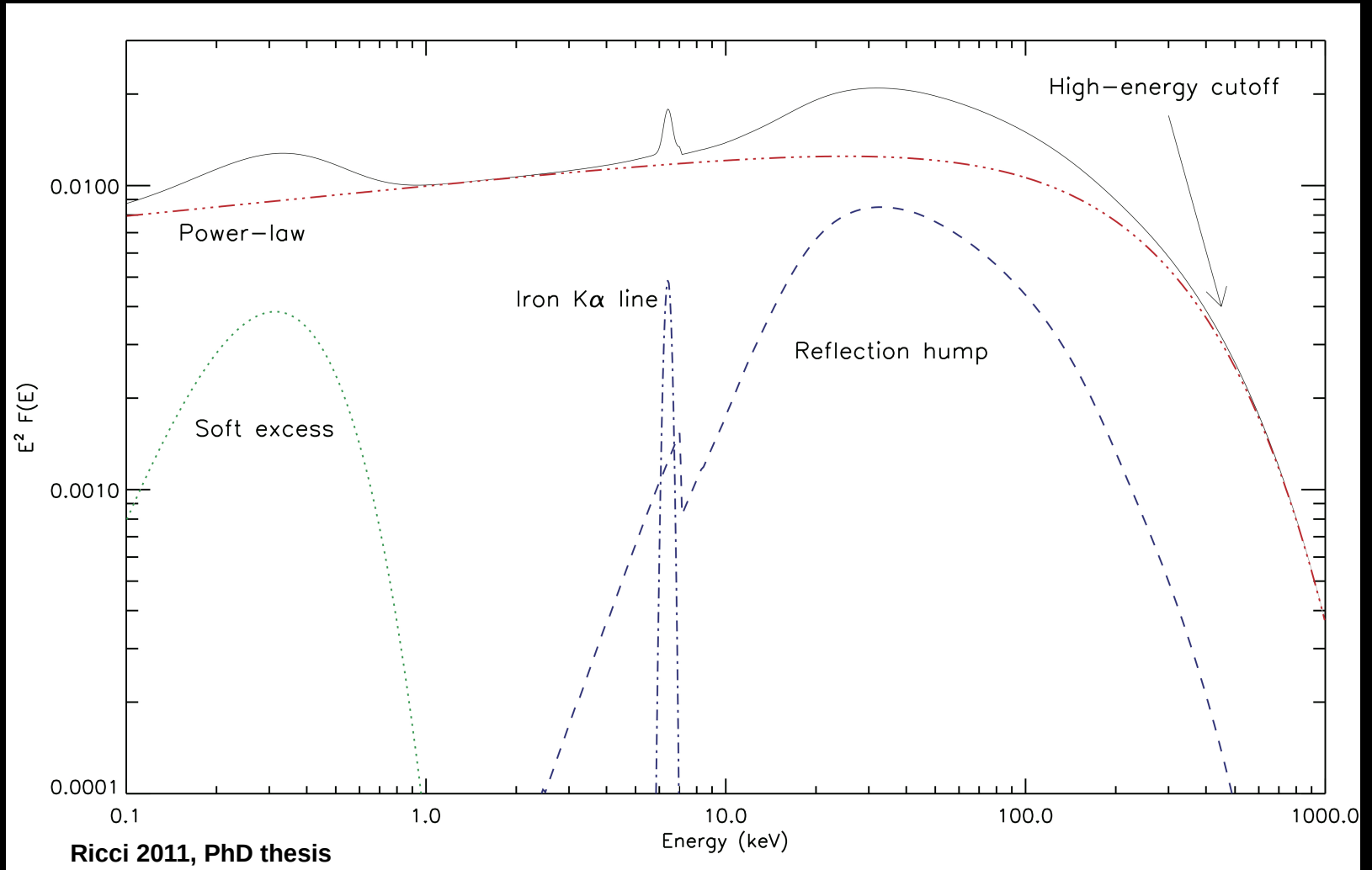
https://www.isdc.unige.ch/~ricci/Website/AGN_in_the_X-ray_band.html

X-rays



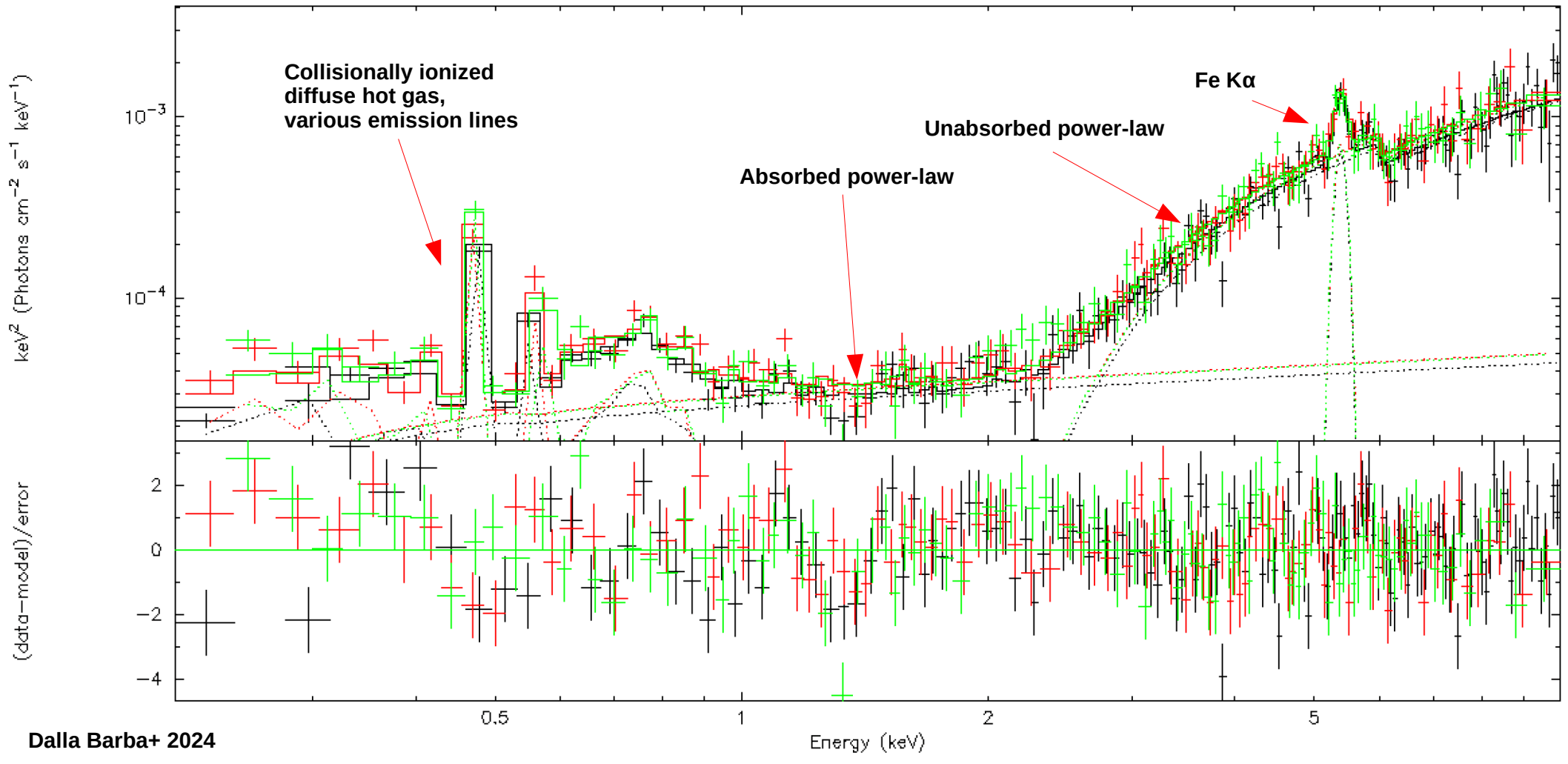
https://www.isdc.unige.ch/~ricci/Website/AGN_in_the_X-ray_band.html

X-rays

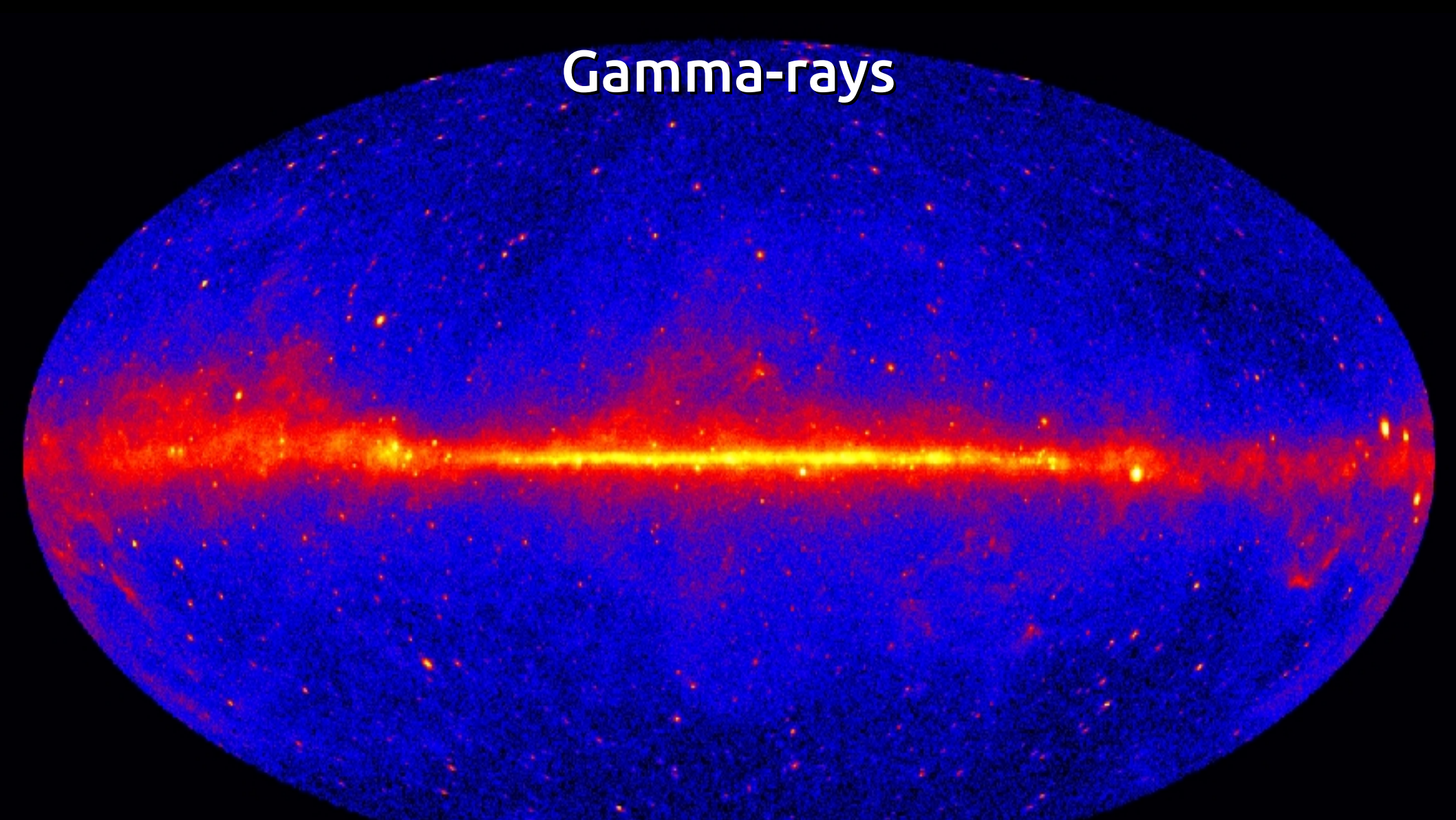


Ricci 2011, PhD thesis

X-rays

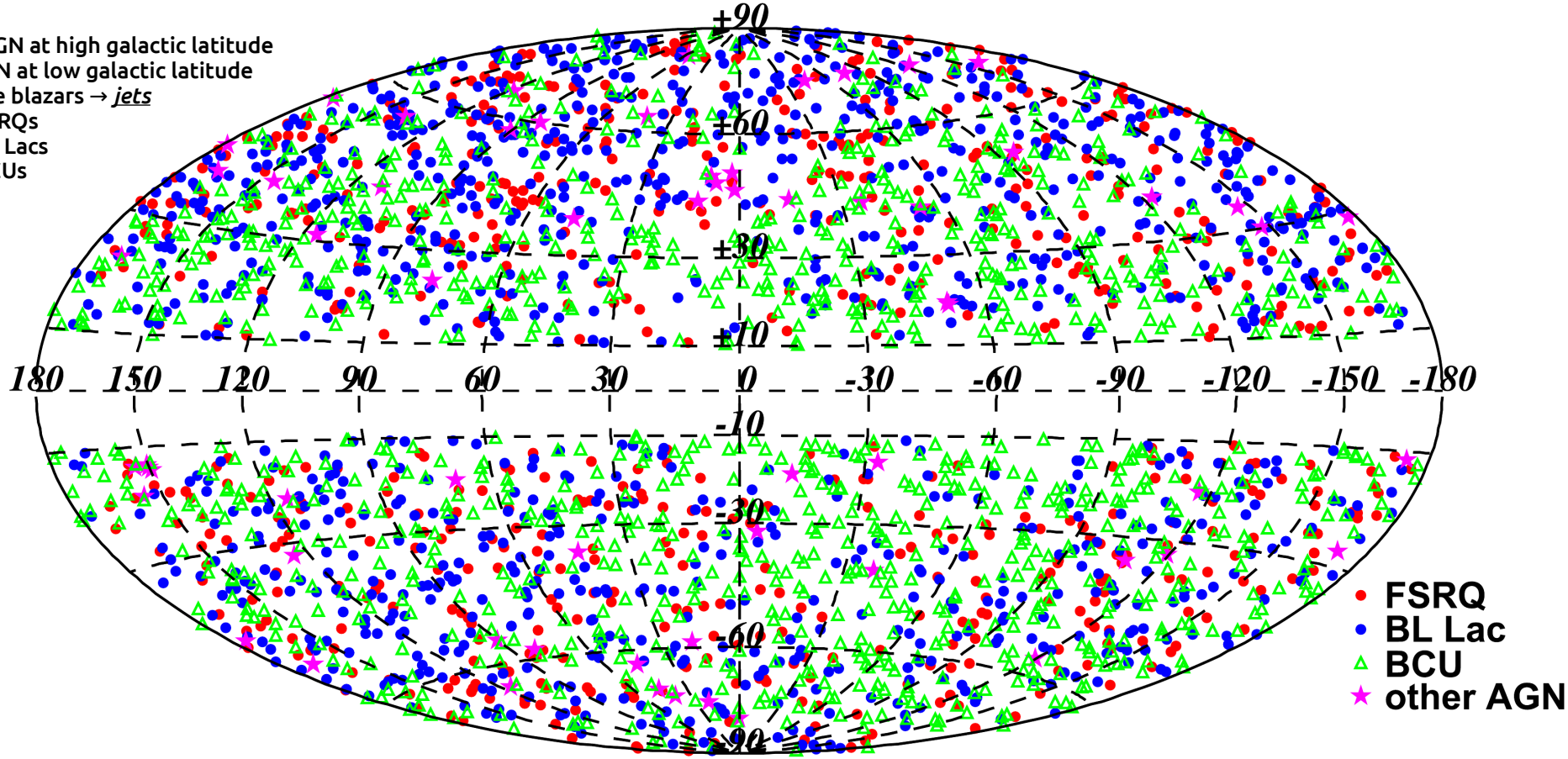


Dalla Barba+ 2024


Gamma-rays

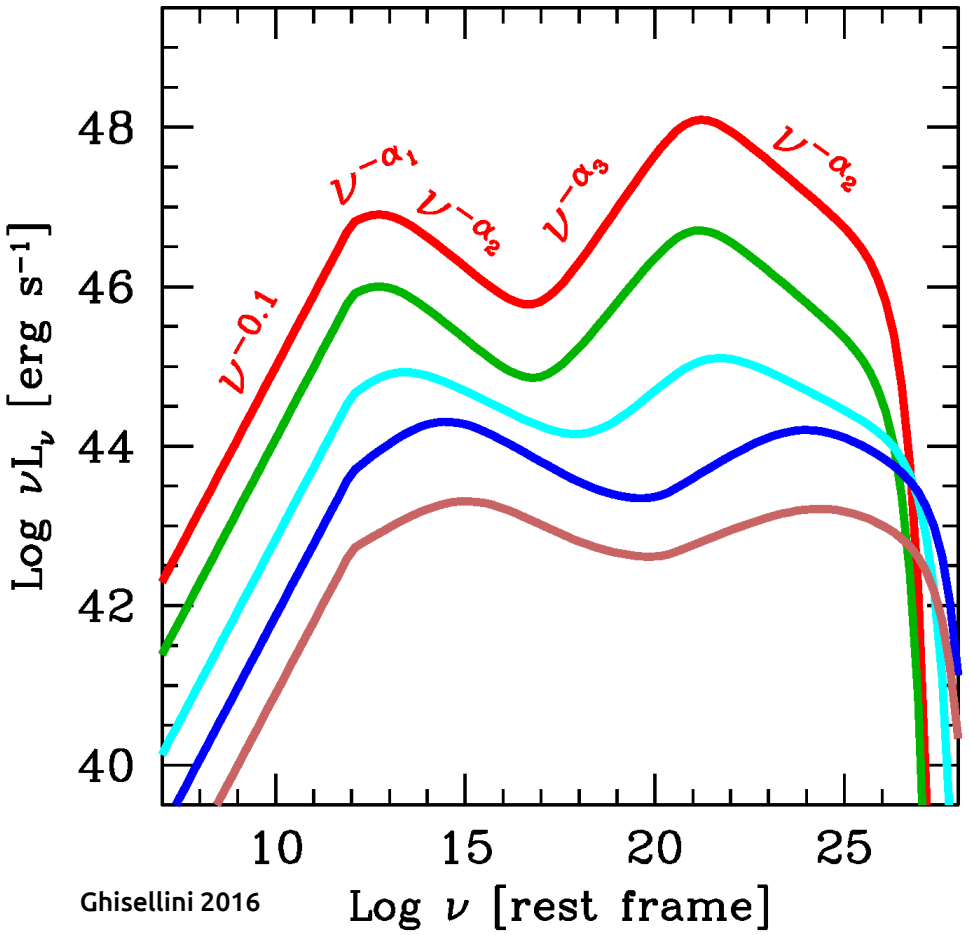
Gamma-rays

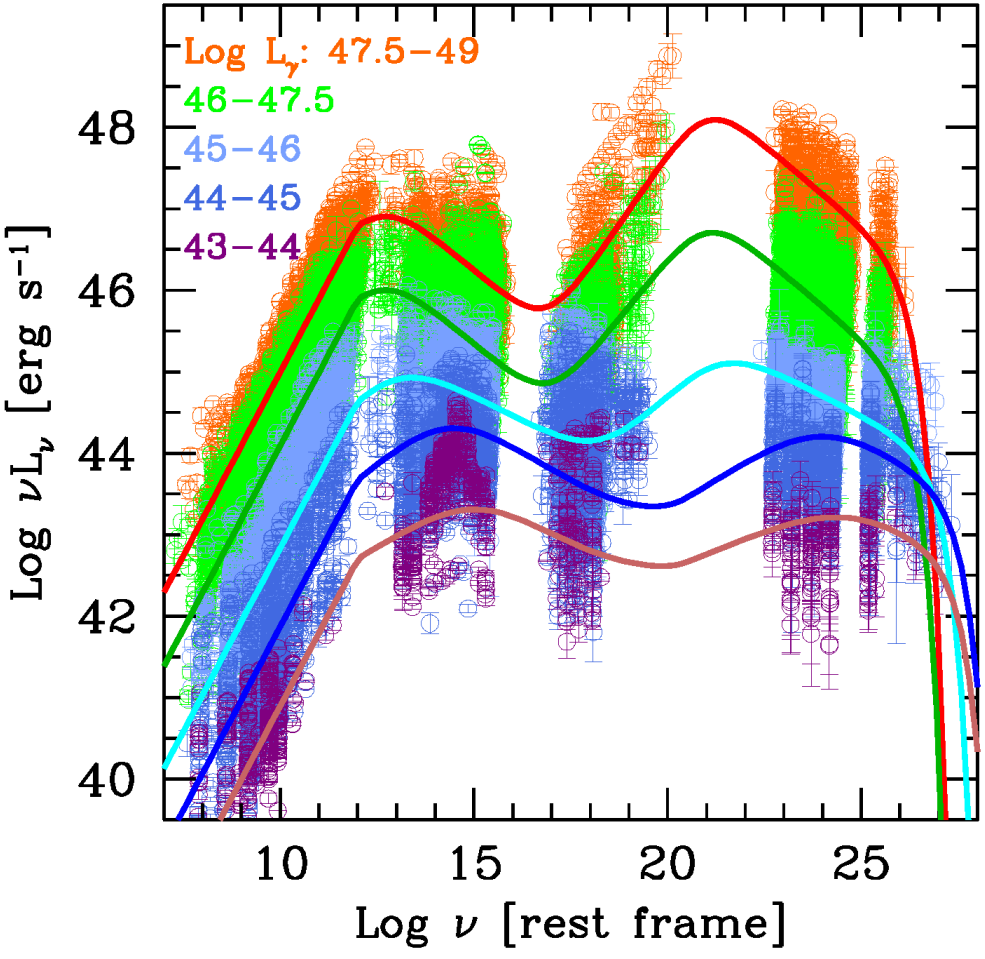
2863 AGN at high galactic latitude
344 AGN at low galactic latitude
98% are blazars → *jets*
24% FSRQs
38% BL Lacs
38% BCUs



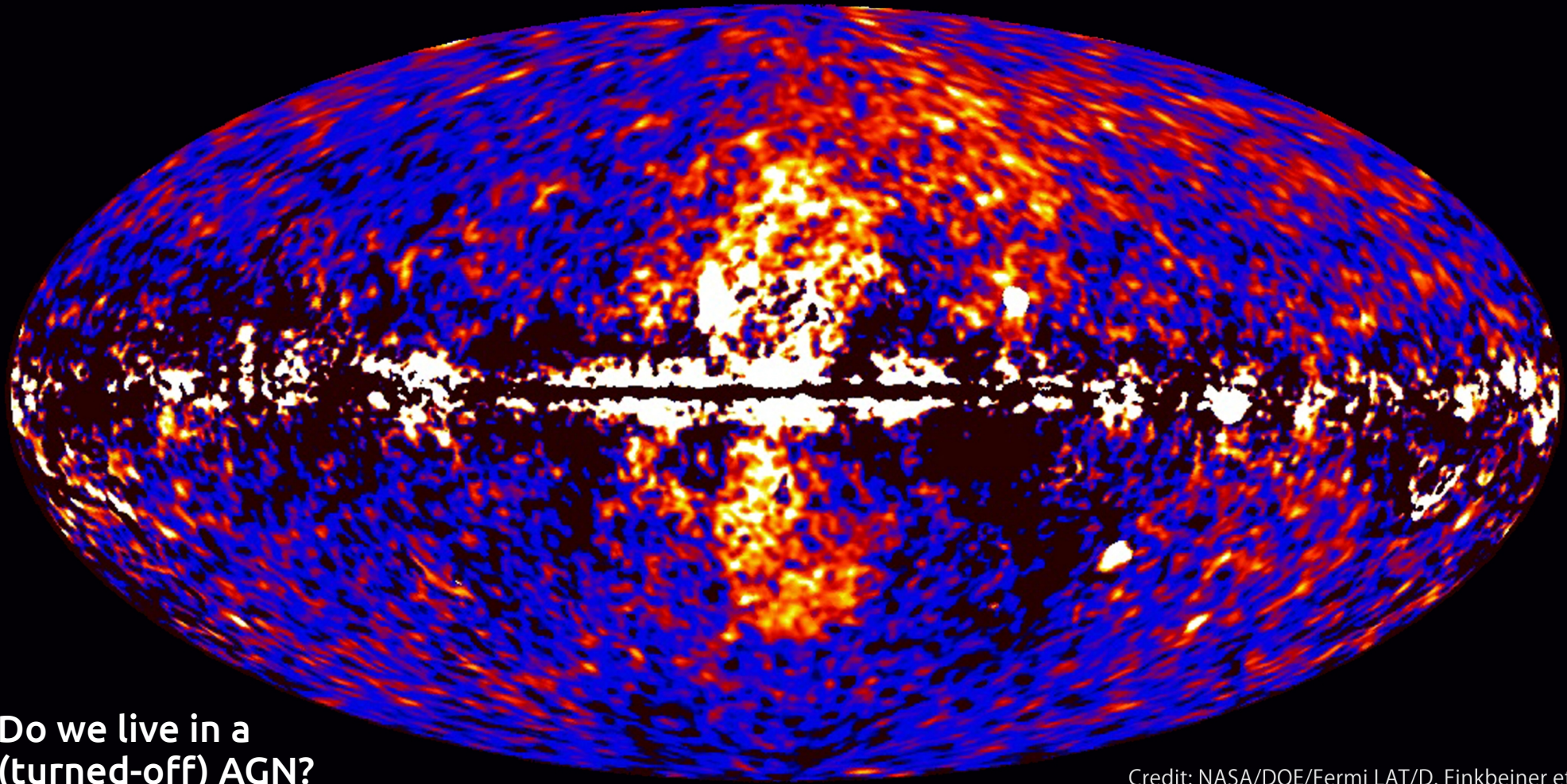
Ajello+ 2020

Gamma-rays


$\nu^{-0.1}$
$\nu^{-\alpha_1}$
$\nu^{-\alpha_2}$
$\nu^{-\alpha_3}$
$\nu^{-\alpha_4}$
Log νL_ν [erg s^{-1}]
Log ν [rest frame]
Ghisellini 2016


Log L_γ: 47.5–49
46–47.5
45–46
44–45
43–44
Log νL_ν [erg s^{-1}]
Log ν [rest frame]

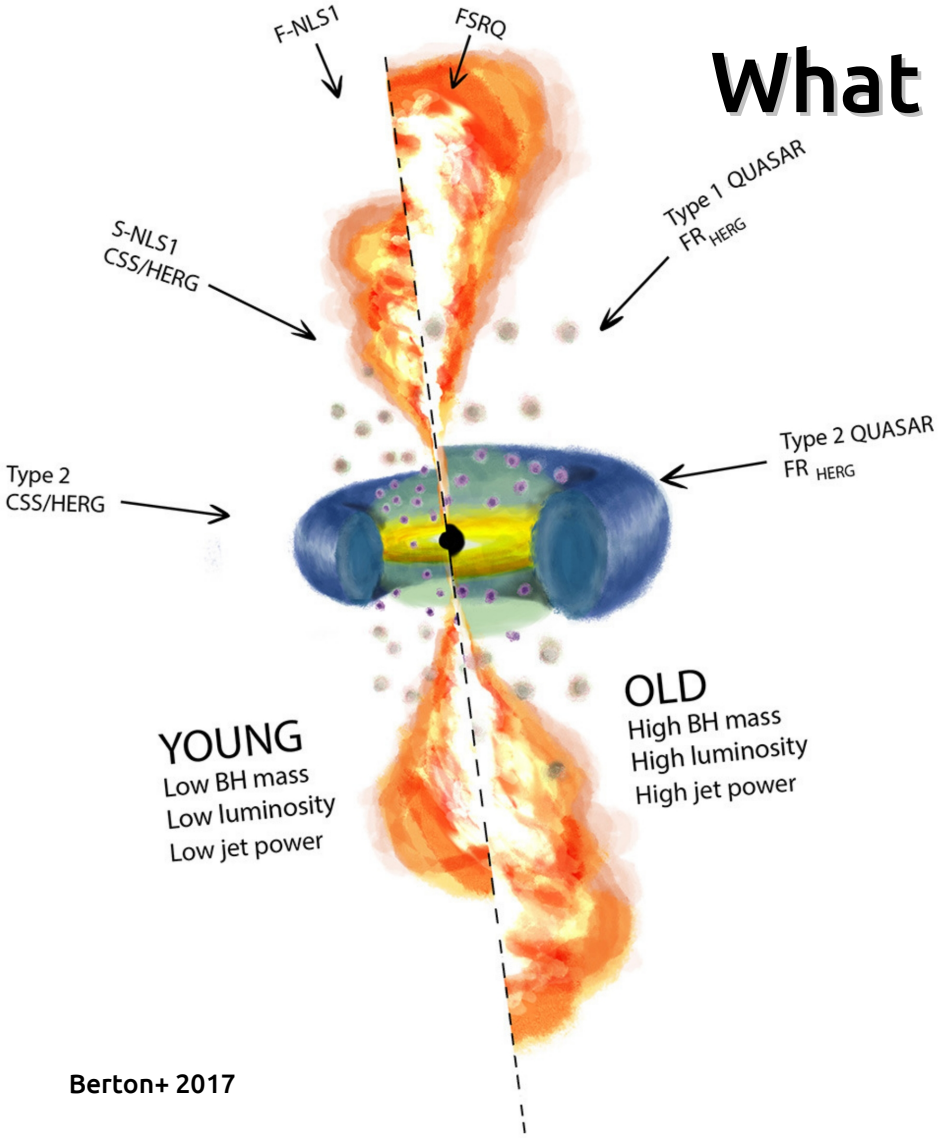
Fermi data reveal giant gamma-ray bubbles



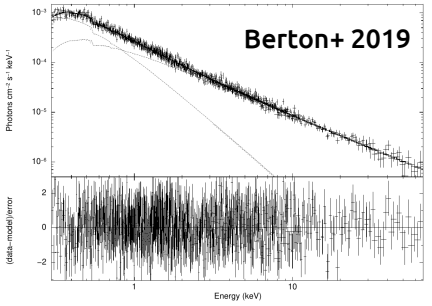
Do we live in a (turned-off) AGN?

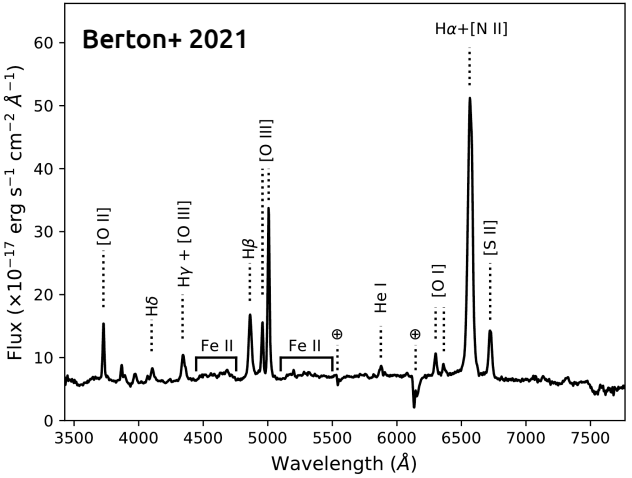
Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.

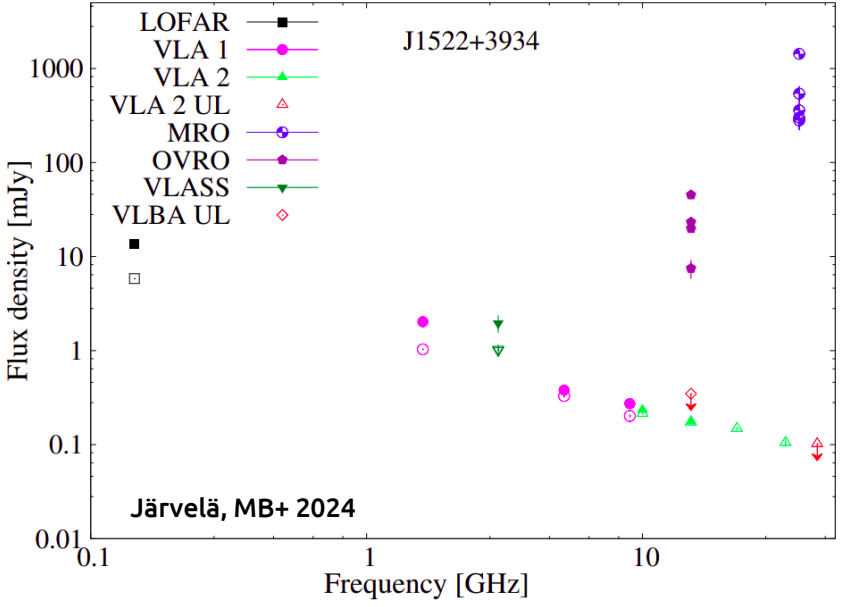
What about me?



Berton+ 2017







Thank you!

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