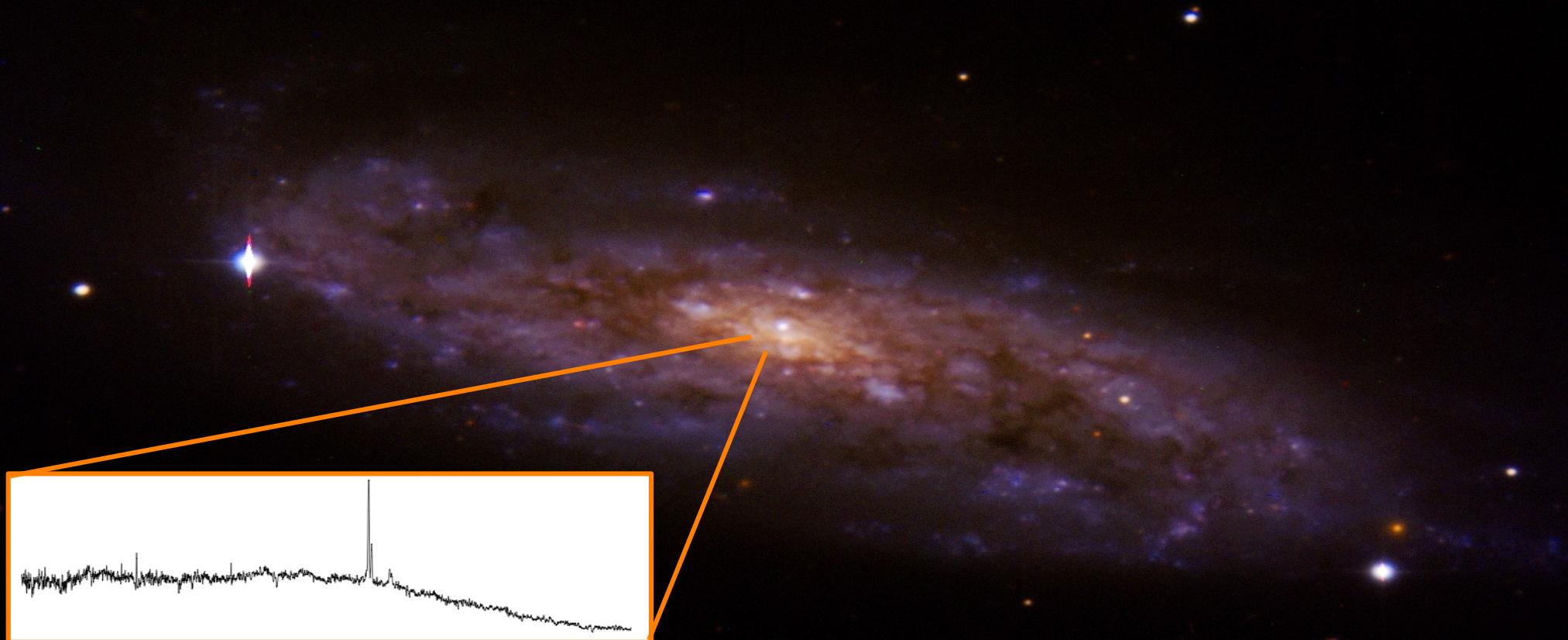




# Characterizing (Nearby and Far) Galaxies with Optical Imaging and Spectroscopy

@EFOSC2/NTT



*Johanna Hartke  
&  
Chiara Mazzucchelli*

La Silla Summer School 2020 - ESO Vitacura



A dark, star-filled background featuring a prominent spiral galaxy in the center. The galaxy has a bright, yellowish core and a winding, blue-tinted spiral arm that curves towards the bottom right. Numerous small, distant stars are scattered across the dark void.

Who are we?

# Chiara Mazzucchelli

## What am I doing now?

I am a 2<sup>nd</sup> year ESO Fellow with duties at Paranal. I support UT1 and UT2 & the instrument KMOS

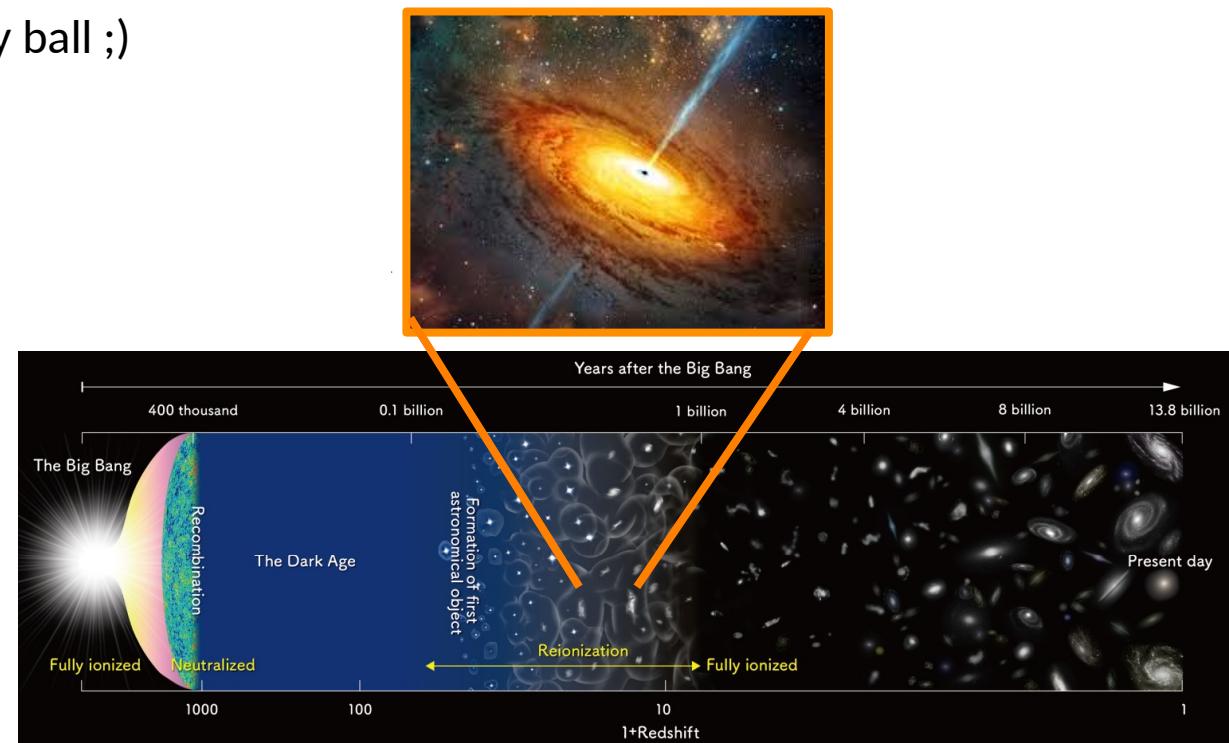
## Where am I from?

I come from a little village in the North of Italy, I got my degree in Milano, and my PhD from the Max Planck Institute in Heidelberg (Germany)

## What am I interested into?

I work on Quasars in the Early Universe (~1 Gyr after the Big Bang; redshift~6-7). I study their black holes, host galaxies and their galactic large scale environment.

I also love coffee, travelling and volley ball ;)

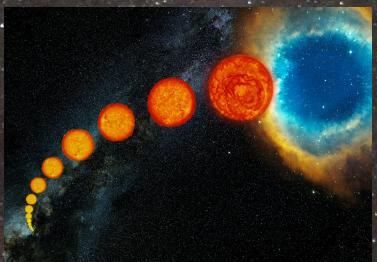
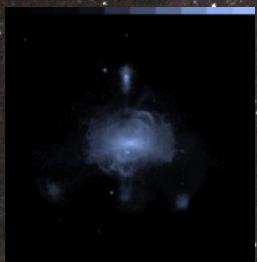


## Johanna Hartke

Currently a 2<sup>nd</sup> year fellow with duties on Paranal (UT3 and UT4) and focus on MUSE.

PhD from Ludwig-Maximilians Universität München/ESO Garching on Galaxies in Group and Cluster Environments.

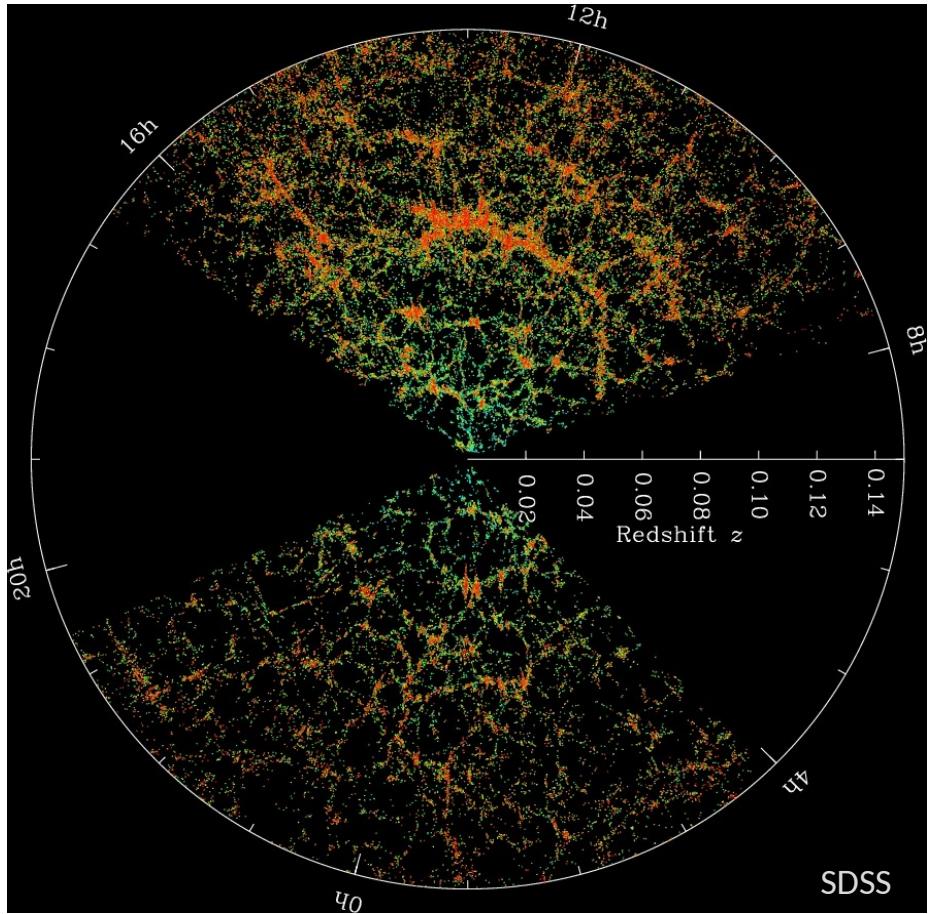
Interested in the build-up of galaxy halos and other diffuse light around galaxies using discrete tracers.



Originally from northern Germany.  
Like classical singing, water sports,  
photography and the beach.

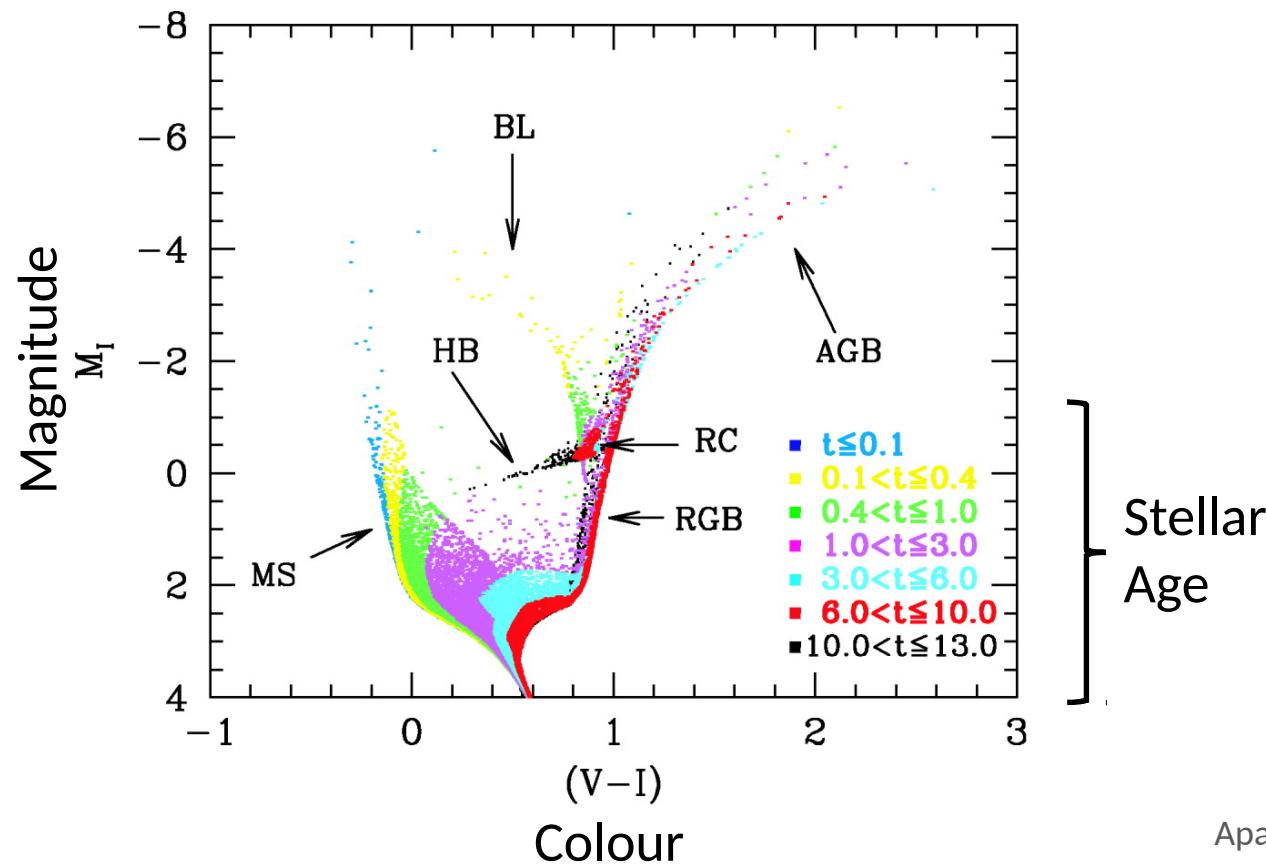
# Project 1a : Photometry





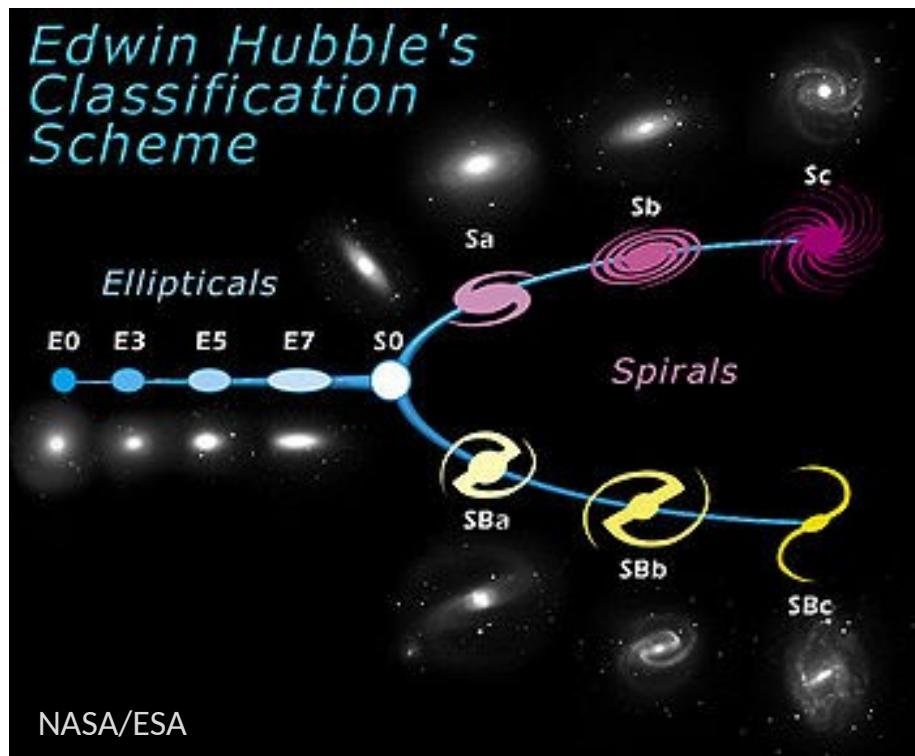
# Galaxies: the building blocks of the Universe

# Galaxies and their stellar populations



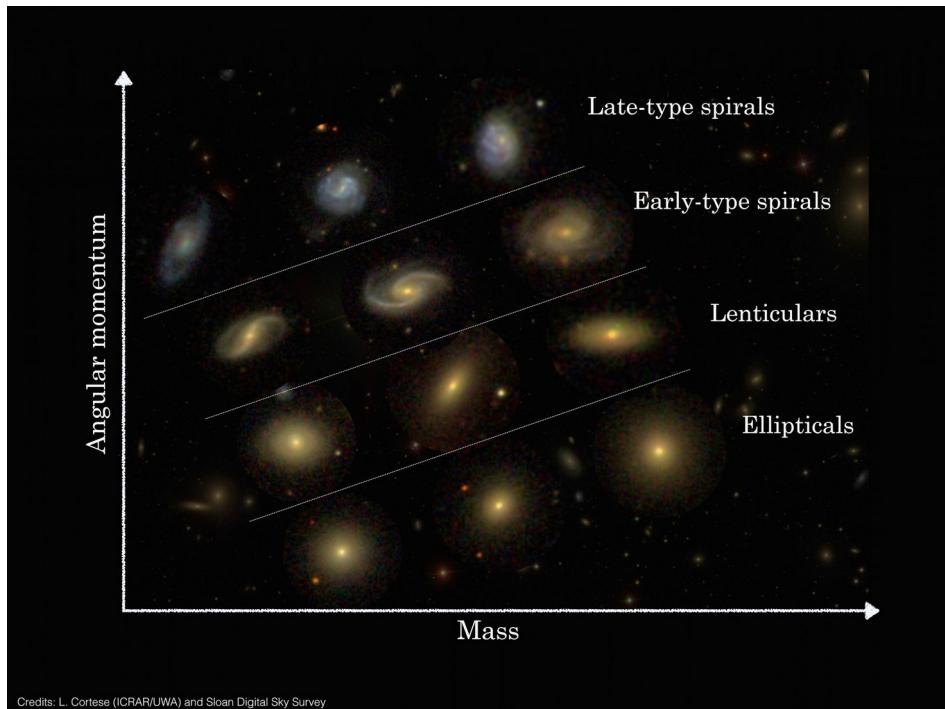
Aparicio & Gallart (2004)

# Galaxy shapes - morphology



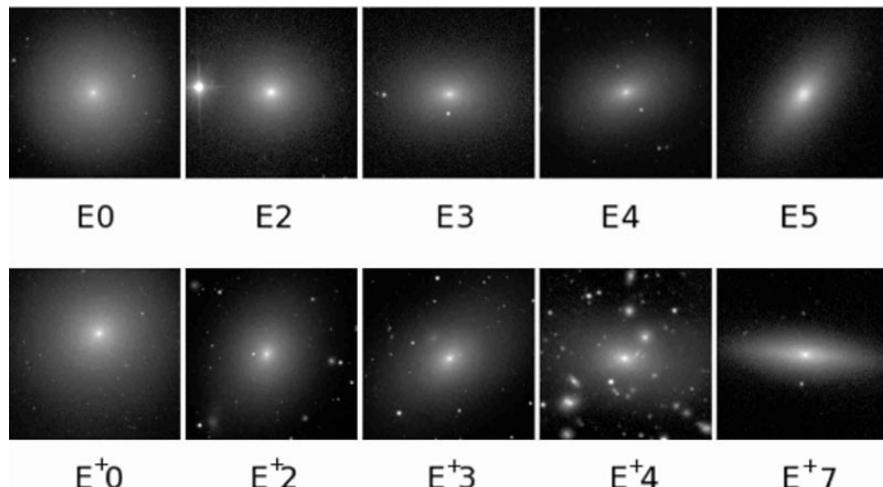
- Large morphological bins
- Good when comparing distant and nearby galaxies
- Does not accurately represent disk dynamics

# Galaxy shapes - morphology



- Large morphological bins
- Good when comparing distant and nearby galaxies
- Does not accurately represent disk dynamics
- Classification based on dynamical properties

# Elliptical and spheroidal galaxies



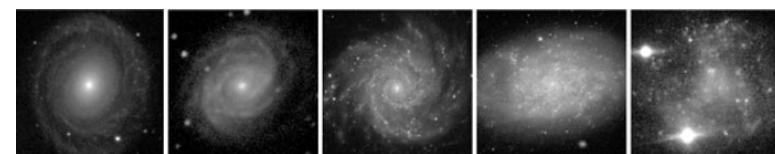
Buta (2011)

- Massive
- Mostly built-up by old stars: "red and dead"
- No significant structural details: "featureless"
- Varying degrees of elongation

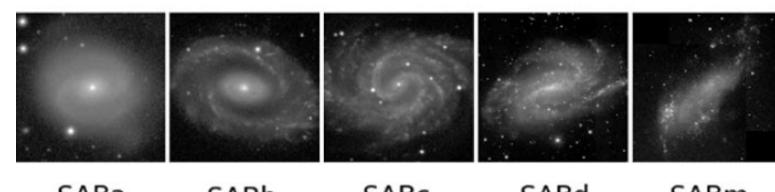
# Spiral galaxies

- Disk of stars in spiral pattern (young stars)
- Central bulge (old stars)
- From Sa to Sc:
  - Contribution of bulge decreases
  - Fraction of gas increases
  - More young stars
  - Less tight spiral arms
- Viewing angle is crucial

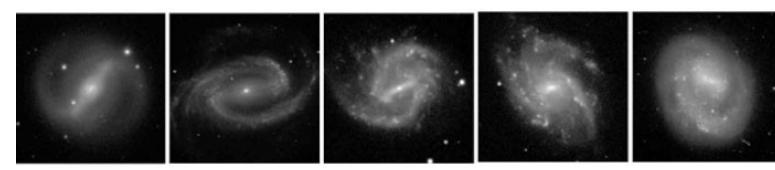
Buta (2011)



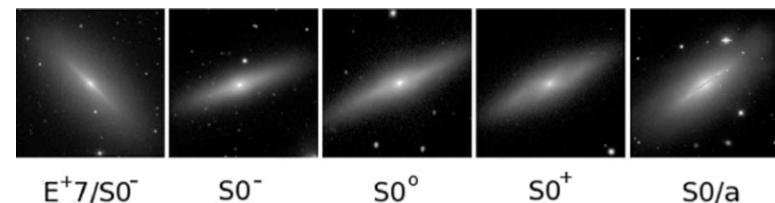
SAA SAb SAC SAd SAM



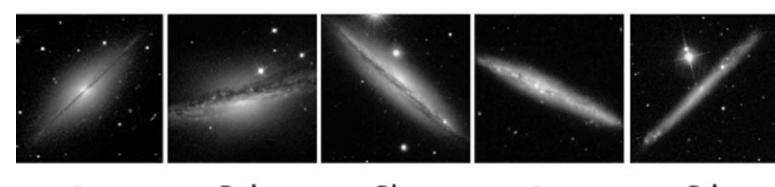
SABA SABb SABC SABd SABm



SBa SBb SBc SBd SBm



E<sup>+</sup>7/S0<sup>-</sup> S0<sup>-</sup> S0<sup>°</sup> S0<sup>+</sup> S0/a



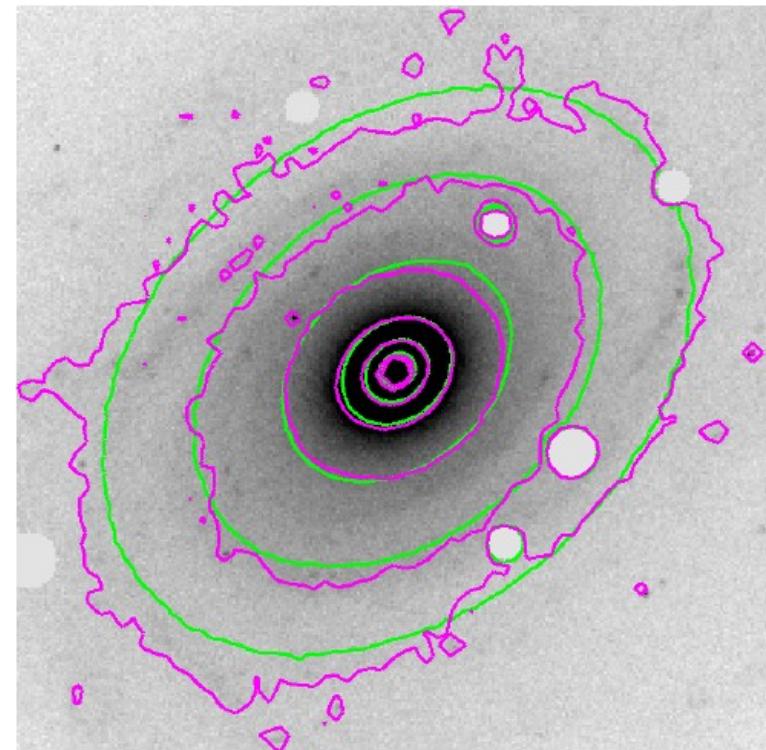
Sa Sab Sb Sc Sd

Edge-on

Face-on

# Measuring surface brightness

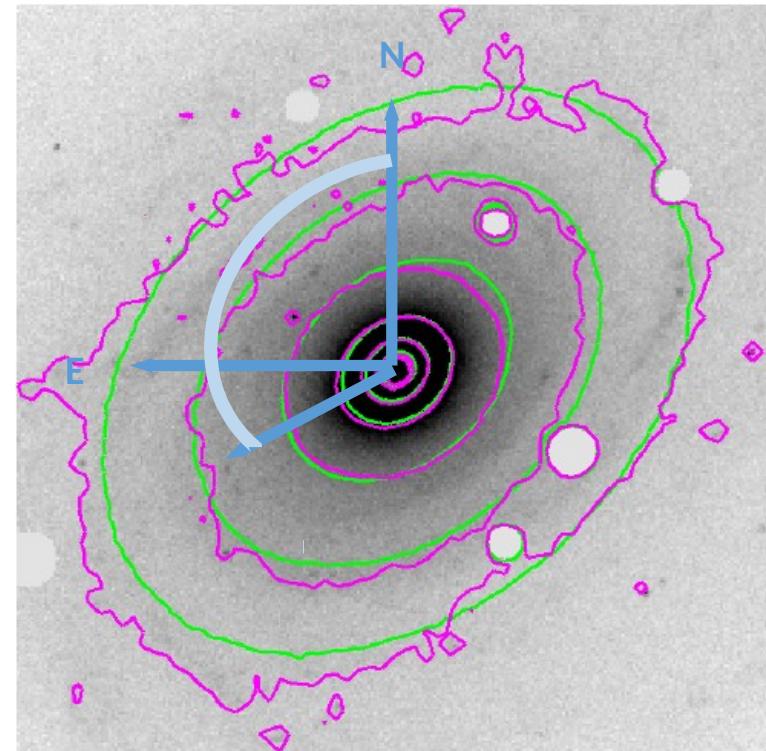
- $S = \text{mag} + 2.5 \log_{10} \text{area}$
- Units: [mag/arcsec<sup>2</sup>]
- Independent of distance :
  - Flux decreases as  $1/d^2$
  - Area subtended by 1 arcsec<sup>2</sup> increases as  $d^2$
  - Until cosmological dimming becomes significant (as  $(1+z)^{-4}$ )
- Isophote: curve of points with equal surface brightness



Isophotes of the Ks-band image of NGC 322  
(Gentile+2015)

# Isophote geometry

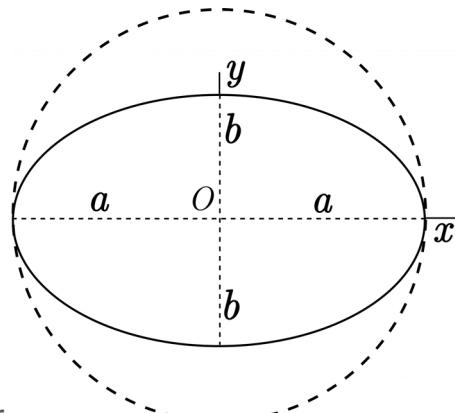
- Position angle (PA)
  - Measured from the North celestial pole in the direction of right ascension



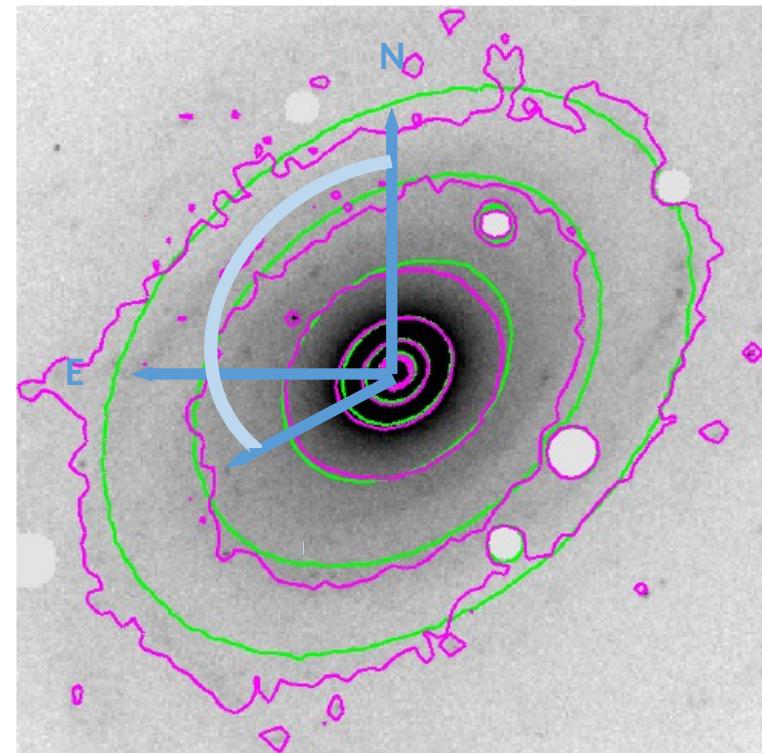
Isophotes of the Ks-band image of NGC 322  
(Gentile+2015)

# Isophote geometry

- Position angle (PA)
  - Measured from the North celestial pole in the direction of right ascension
- Ellipticity  $e = 1 - b/a$

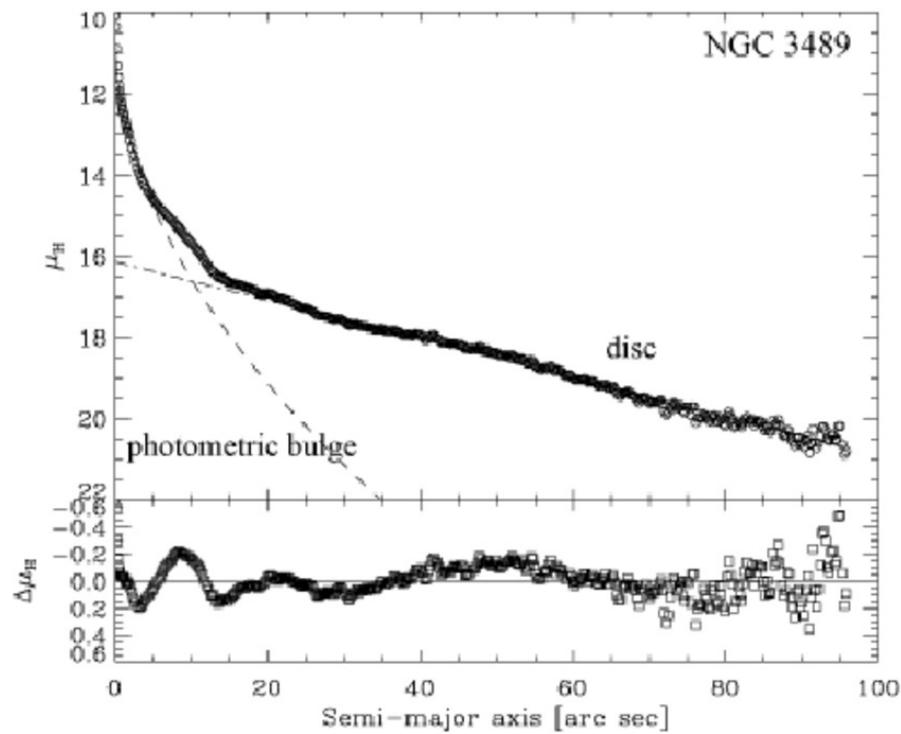


P. Mercator



Isophotes of the Ks-band image of NGC 322  
(Gentile+2015)

# Identifying galaxy components from surface photometry



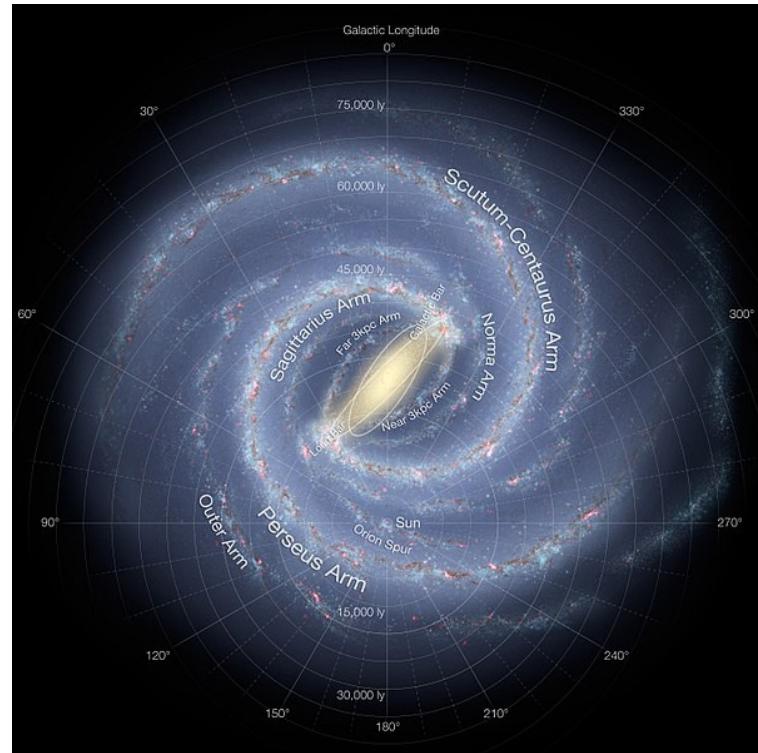
Bulge-disk decomposition of NGC 3489  
(Nowak+2009)



Credit: BUDDA (D. Gadotti)

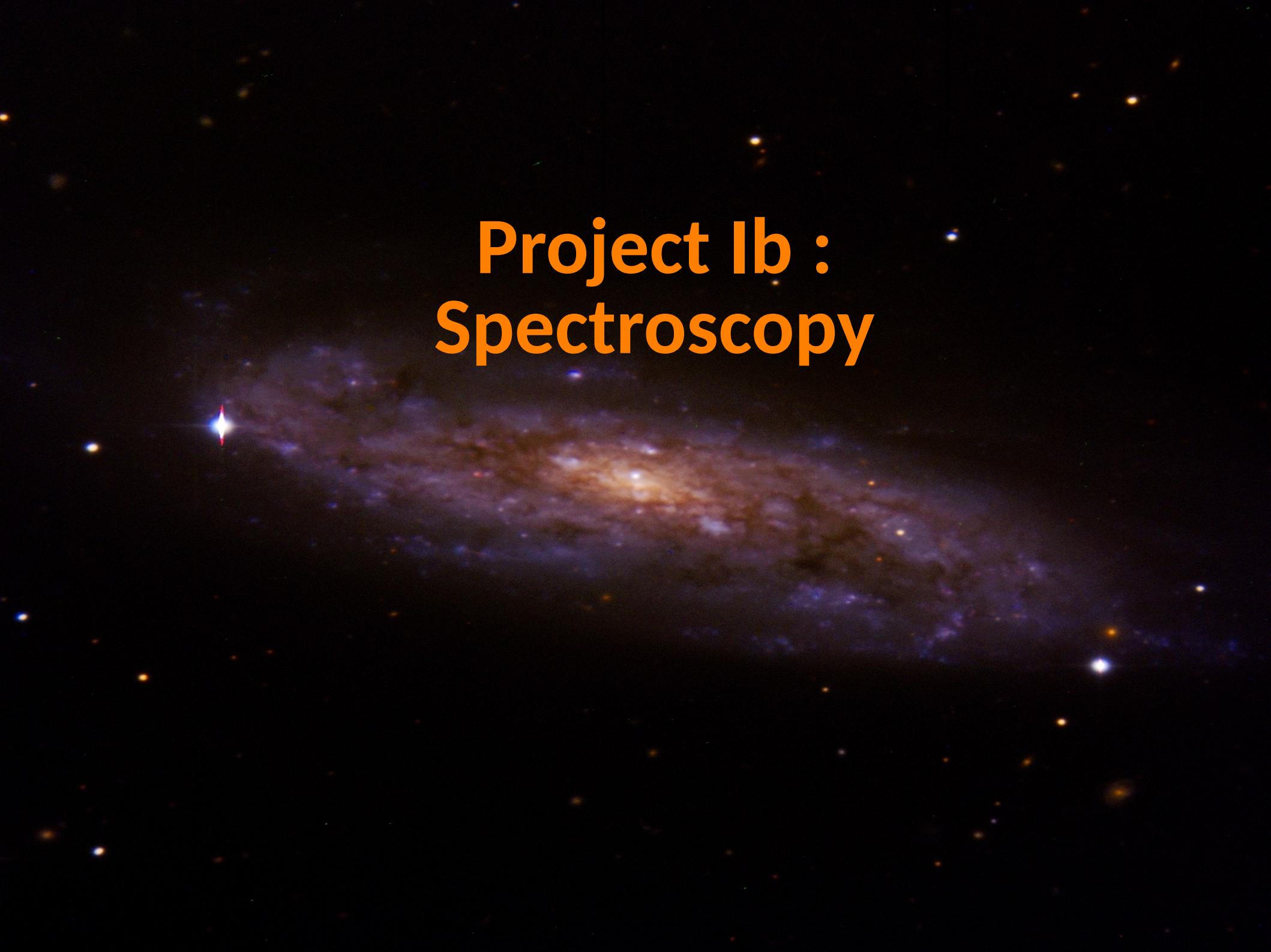
# Goals of this project

- Obtain photometry of nearby (and not so nearby – see project 1b) spiral and elliptical galaxies in different filters
- Create colour images
- Measure surface-brightness and colour profiles as function of radius
- Make inferences about galaxies' evolutionary past



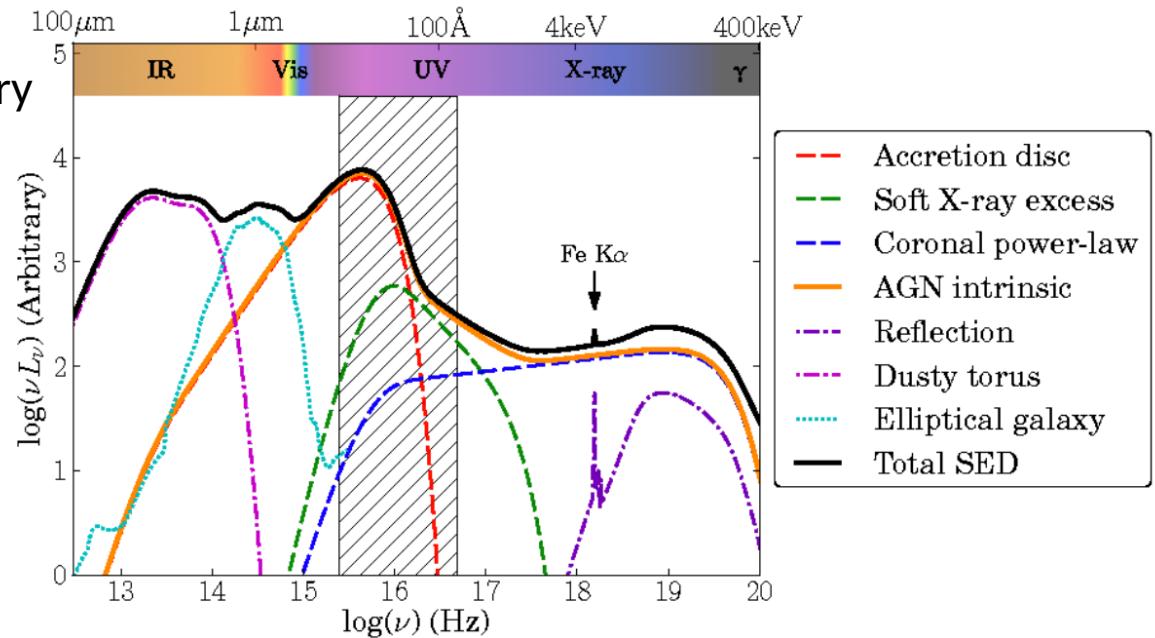
NASA/JPL/ESO/R. Hurt

# Project Ib : Spectroscopy



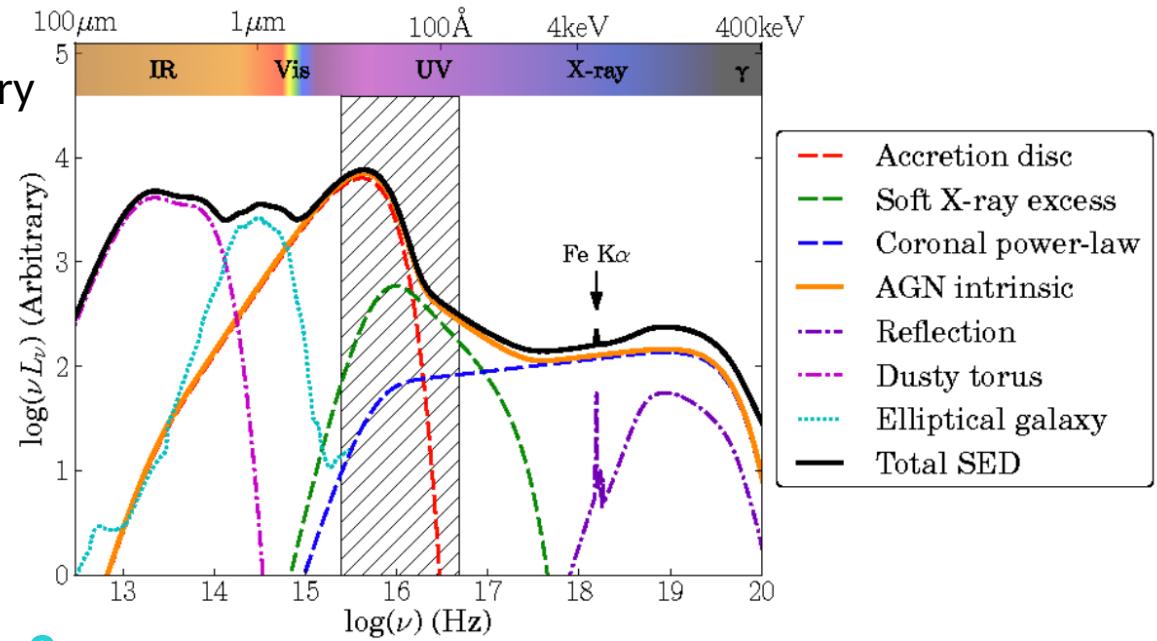
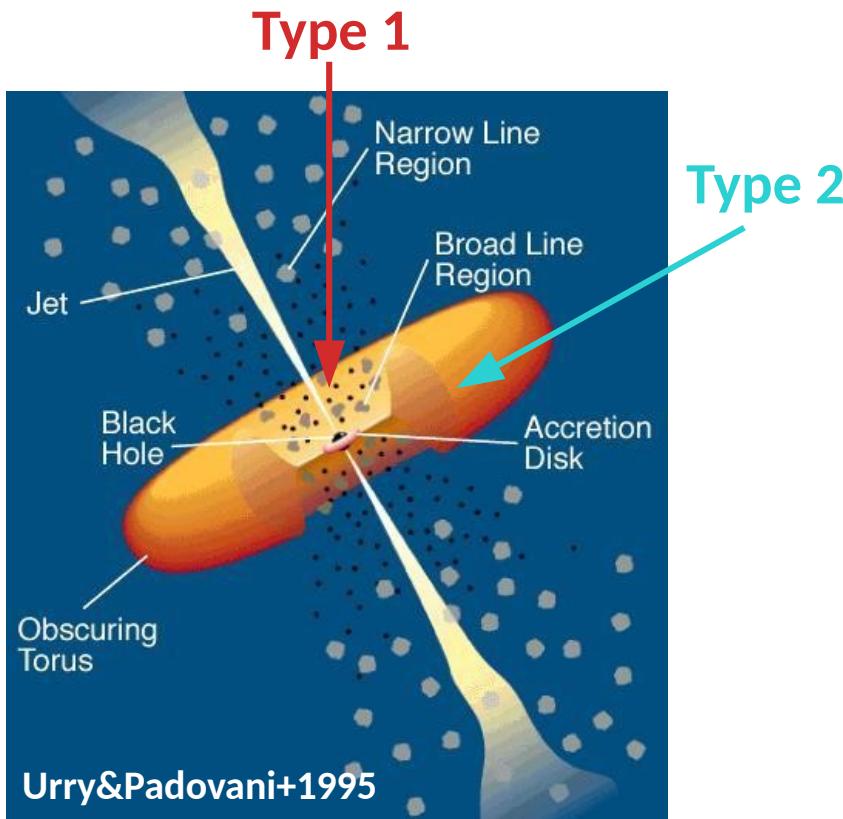
# Active Galactic Nuclei – One word many flavours

- AGN emit in a **large range of wavelength** reflecting **several physical processes** at very **different spatial scales**
- AGN has wild **classification** depending on SED/Luminosity properties (LINERs, Seyfert, QSOs...)



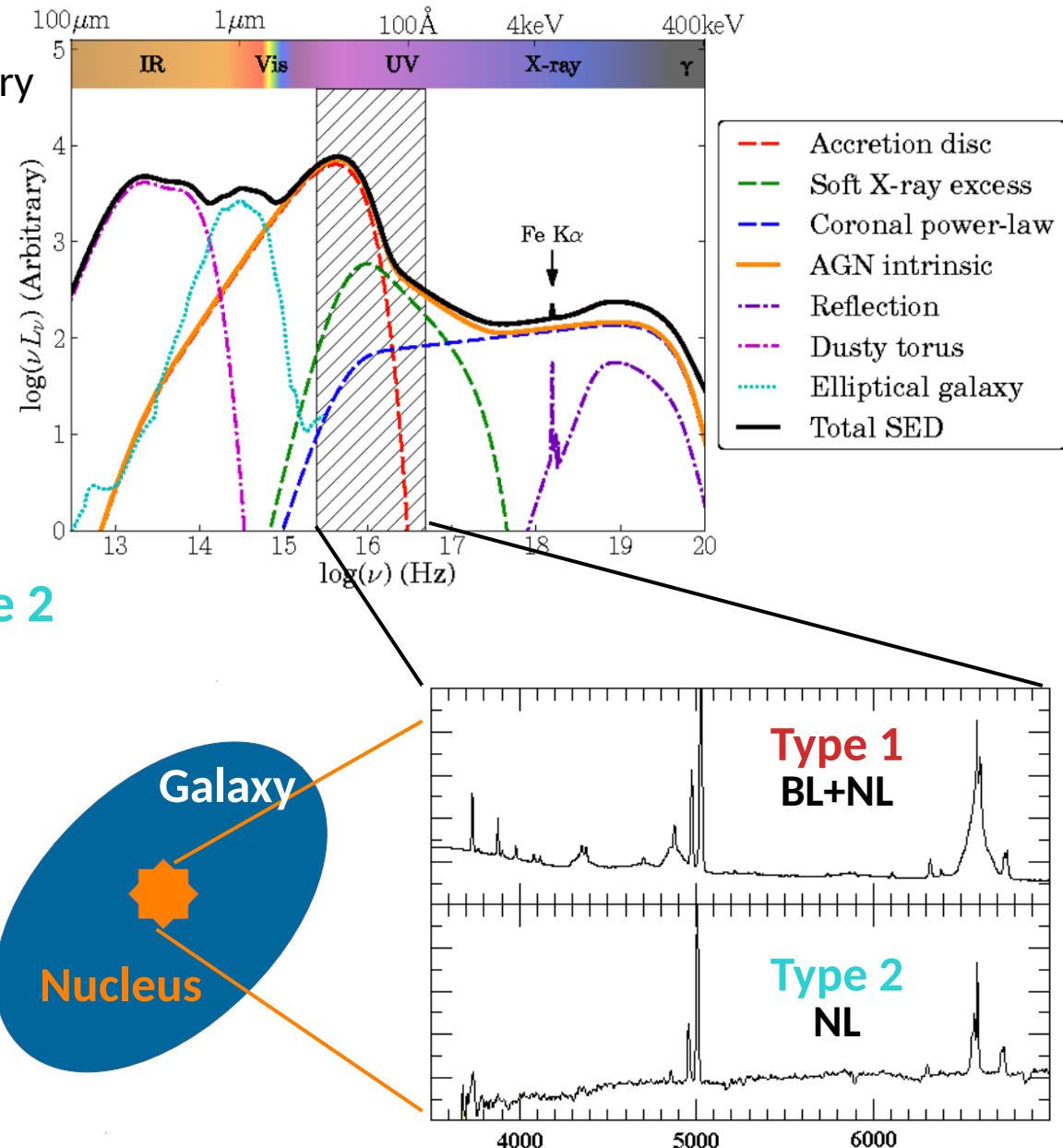
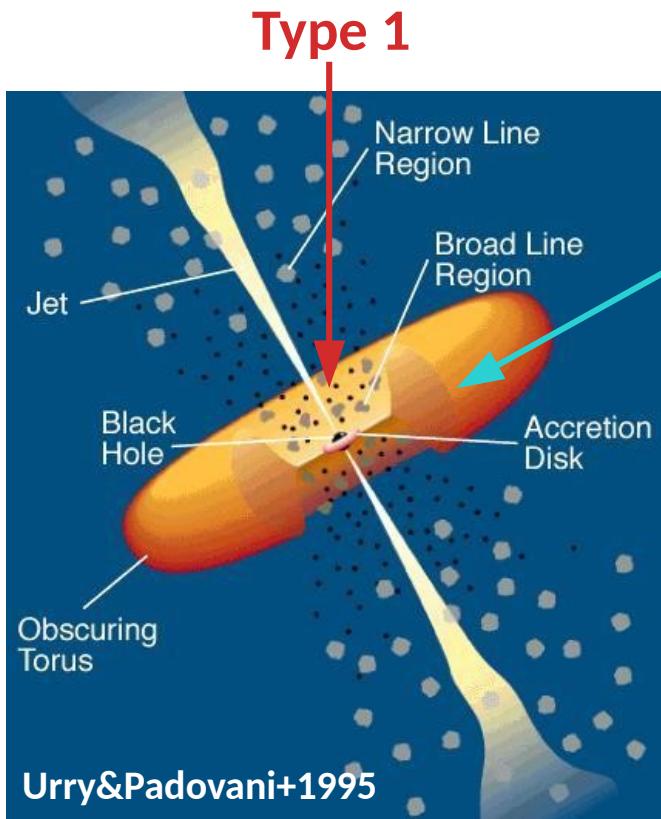
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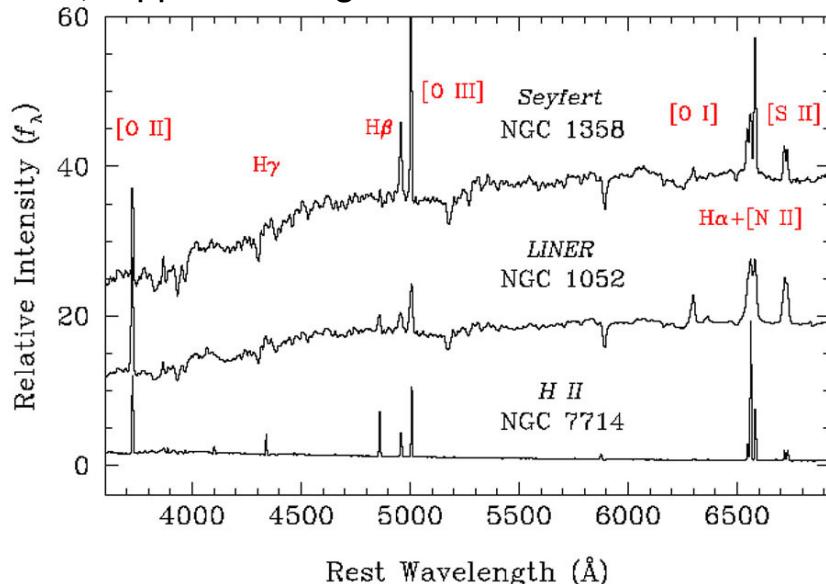
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# Galaxies Nuclear Activity – Emission Lines as Diagnostics I

Ho, Filippenko & Sargent+1993



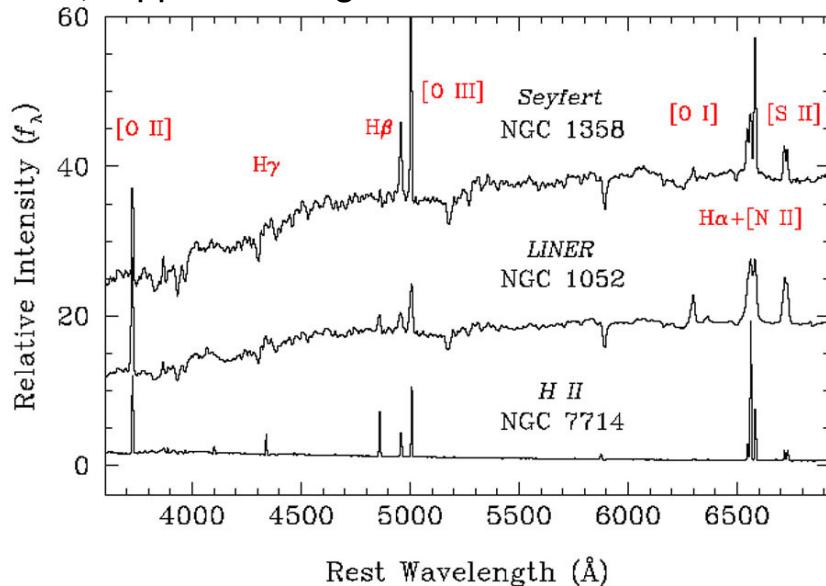
- The **relative strength** of key **emission lines** depends on the different **ionization mechanism** dominant in the galactic nucleus

H $\alpha$   $\lambda$ 6564      H $\beta$   $\lambda$ 4862      [NIII]  $\lambda$ 6584      [OIII]  $\lambda$ 5007  
[SII]  $\lambda$ 6717,6731      [OI]  $\lambda$ 6300  
H $\gamma$   $\lambda$ 4342      [OII]  $\lambda$ 3727

**HII → Star Formation / AGN → Hard nuclear radiation**  
**H $\alpha$ , H $\beta$ , H $\gamma$**       **[NIII], [OIII], [SII] ...**

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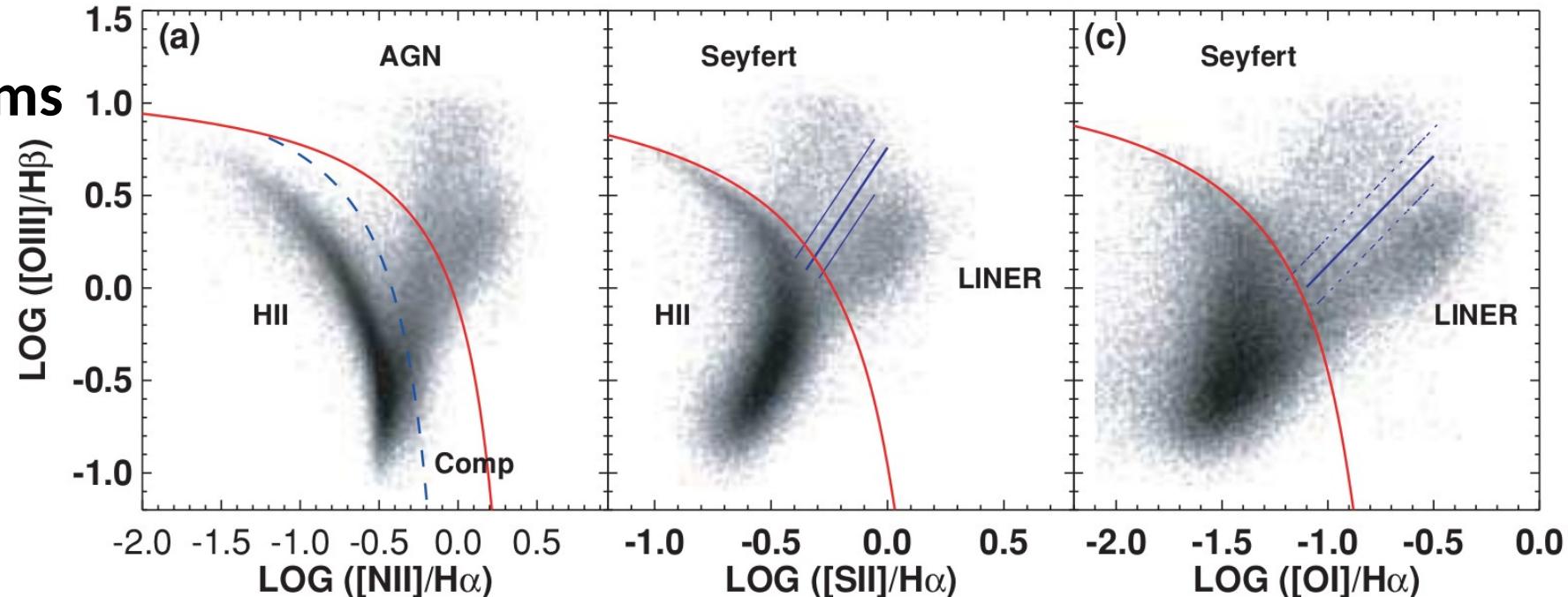


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$\text{H}\alpha \lambda 6564$        $\text{H}\beta \lambda 4862$        $[\text{NII}] \lambda 6584$        $[\text{OIII}] \lambda 5007$   
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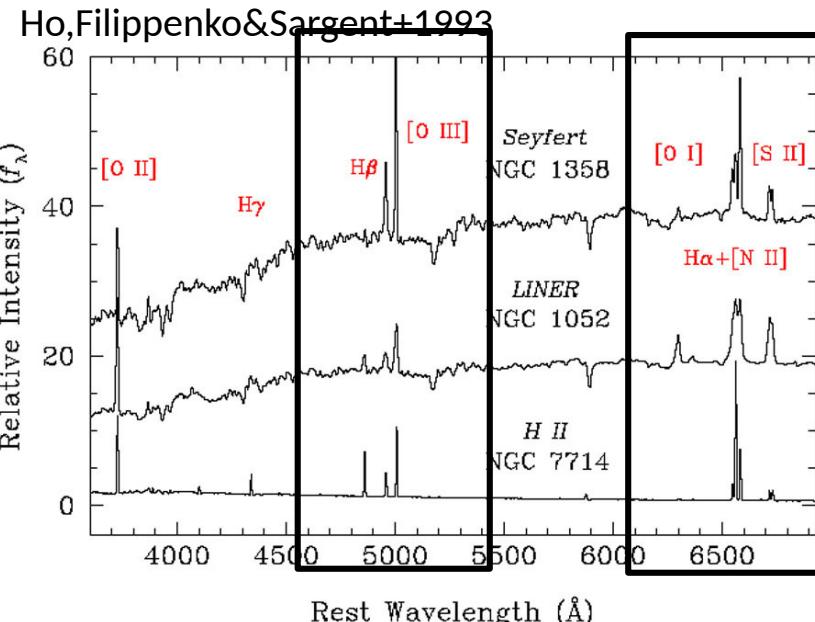
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**[H $\alpha$ , H $\beta$ , H $\gamma$ ]      [NII], [OIII], [SII] ...**

## BPT Diagrams



Baldwin, Phillips & Telervich+1981; Veilleux & Osterbrock+1987; Kewley+2001, 2003, 2006, 2013a,b

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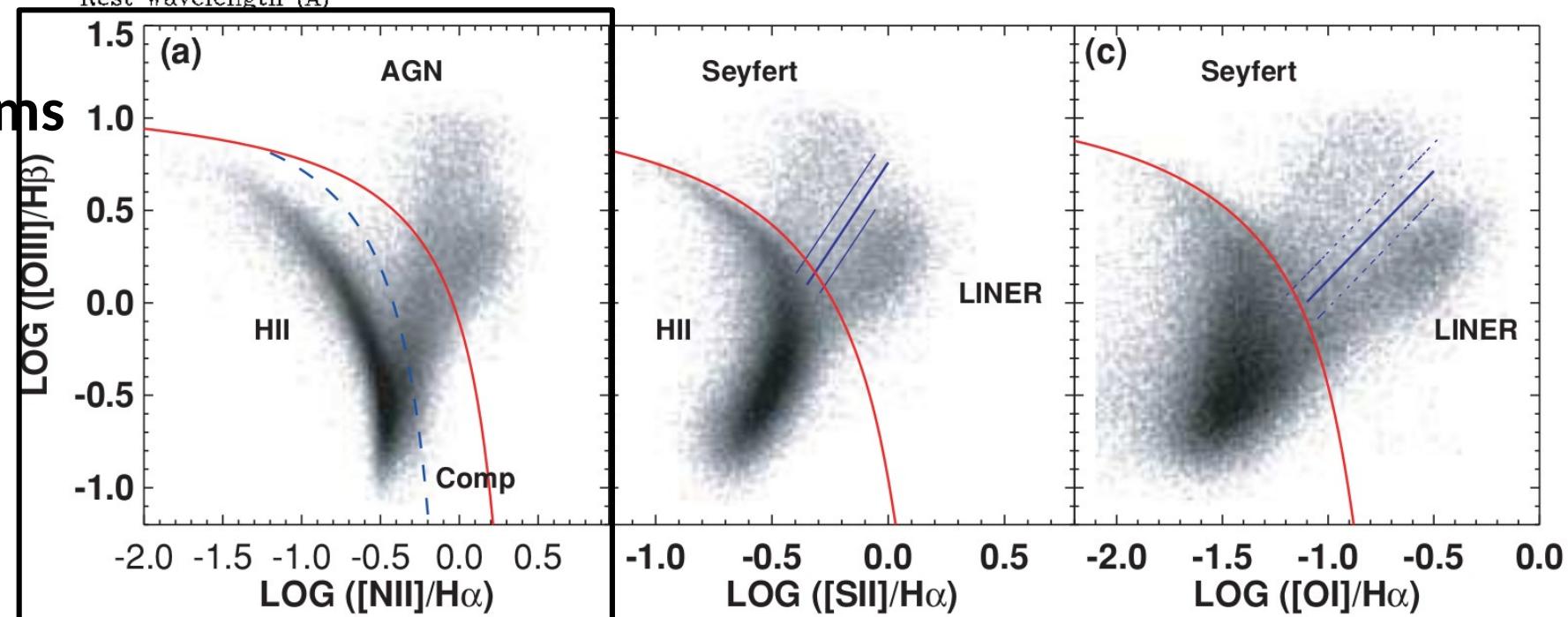


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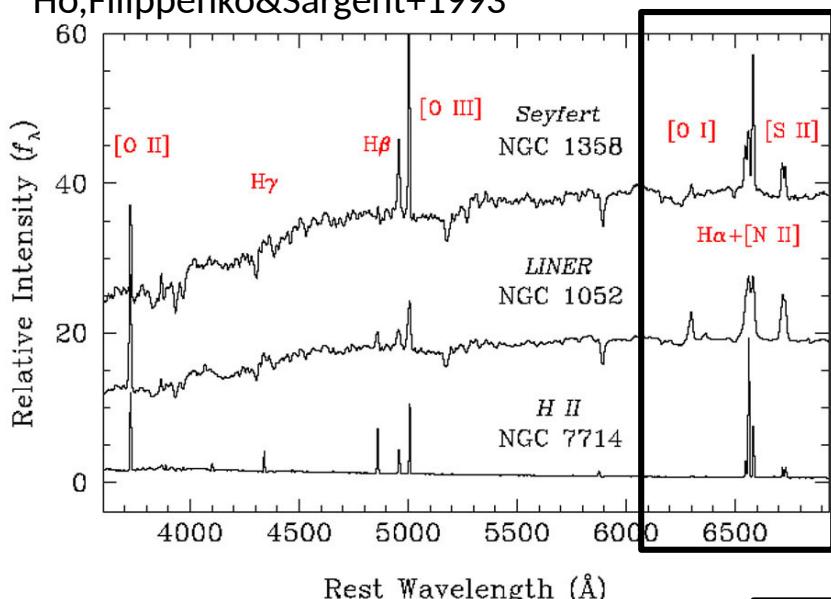
**HII → Star Formation / AGN → Hard nuclear radiation**  
**H $\alpha$ , H $\beta$ , H $\gamma$**       **[NIII], [OIII], [SII] ...**

BPT  
Diagrams



# Galaxies Nuclear Activity – Emission Lines as Diagnostics II

Ho, Filippenko & Sargent+1993



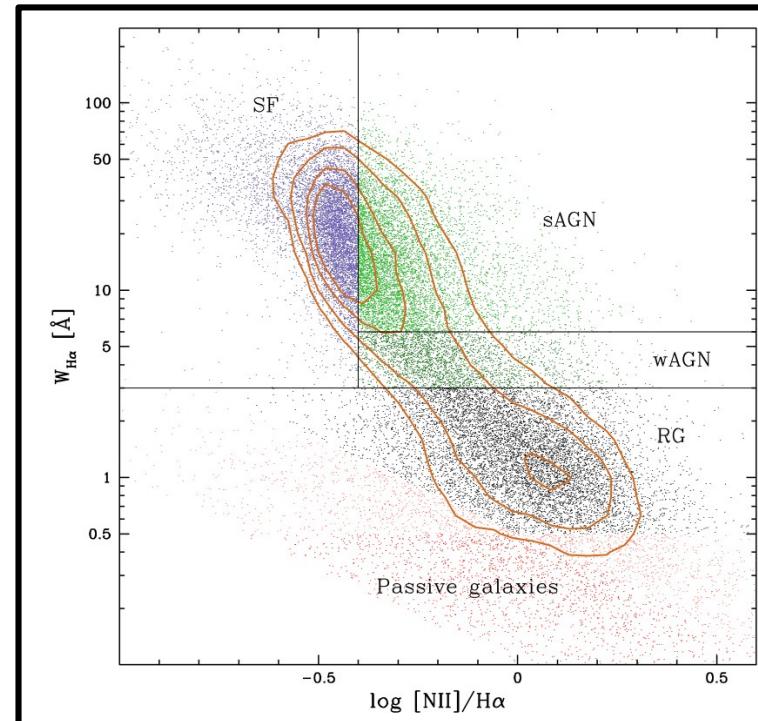
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 **$\text{H}\alpha, \text{H}\beta, \text{H}\gamma$**        **$[\text{NII}], [\text{OIII}], [\text{SII}] \dots$**

## WHAN Diagram

- Useful to classify galaxies when  $\text{H}\beta$  and/or  $[\text{OIII}]$  are not available
- It disentangles weak AGN and Retired galaxies (RG), e.g. that stopped actively forming stars and are ionized by hot low mass evolved stars.



Cid Fernandes+2010, 2011;  
Gavazzi+2011, 2013

# Galaxies Distances – Emission Lines as “Diagnostics” III

- One can determine the distance of galaxies through their **redshift**, i.e. the shift of their spectra towards longer wavelengths

$$z = c \frac{\lambda_{oss} - \lambda_{teo}}{\lambda_{teo}}$$

- Given the **Hubble Law**:

$$z = \frac{H_0}{c} r$$

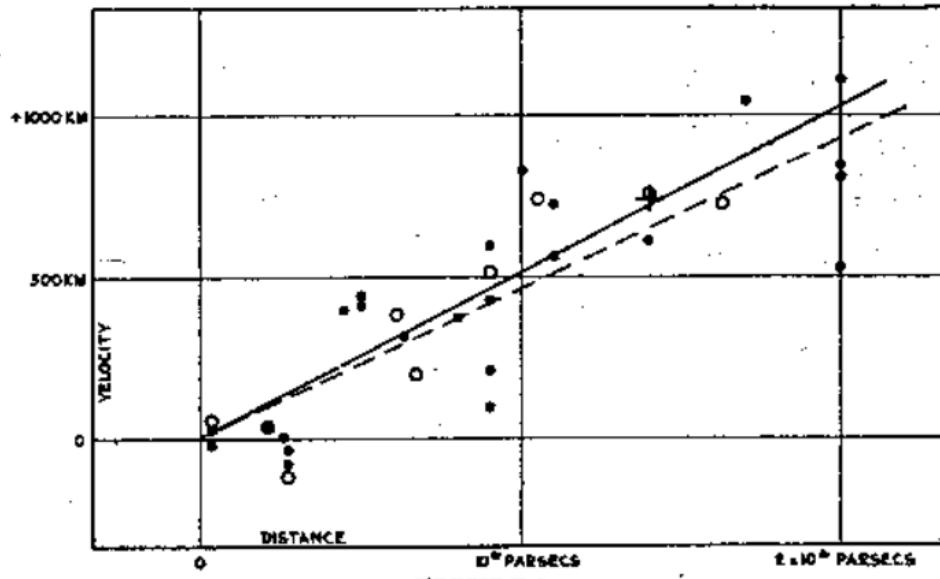
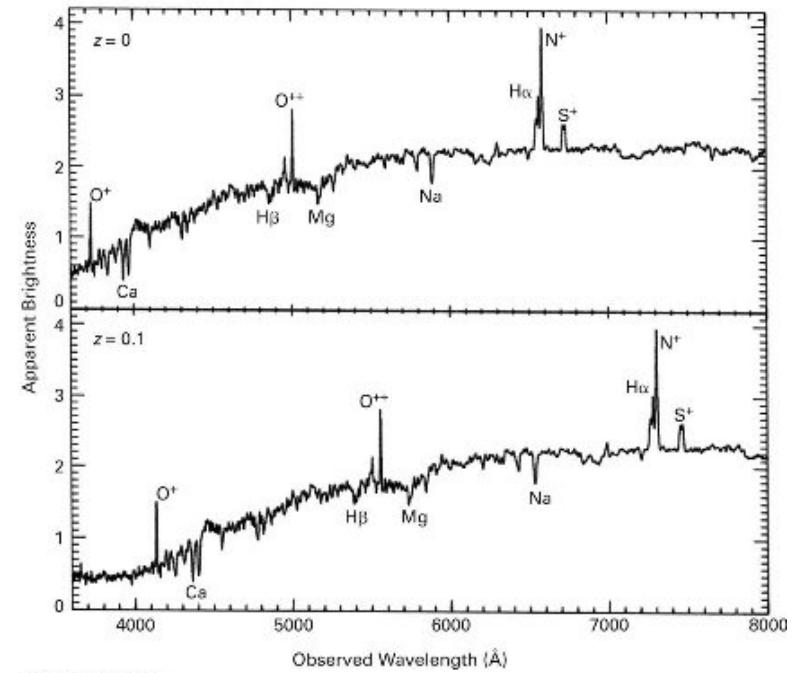


FIGURE 1

Hubble+1929



A. Frigoletto and K. J. Holay

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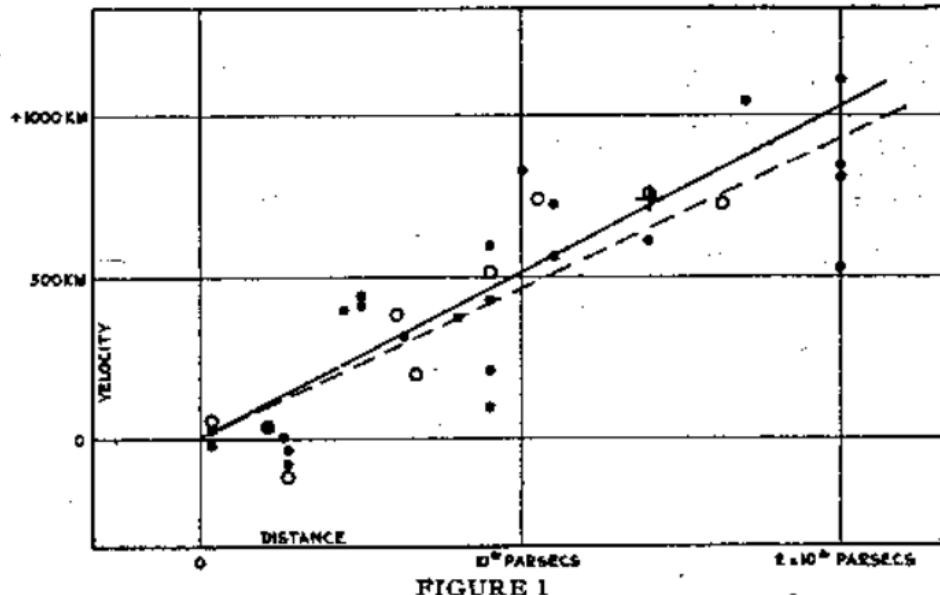
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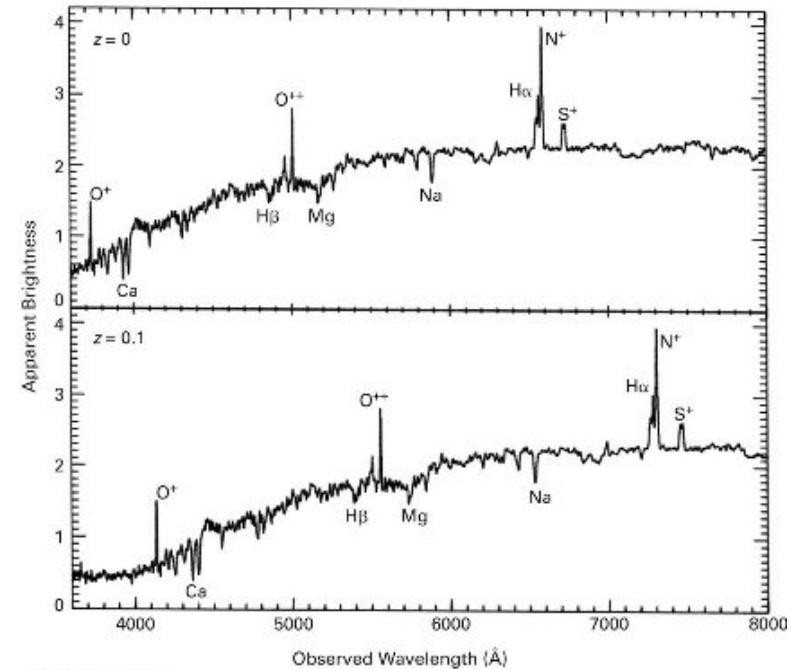
- Given the **Hubble Law**:

$$z = \frac{H_0}{c} r \quad \boxed{\text{Distance}}$$

Derived from peaks of emission lines

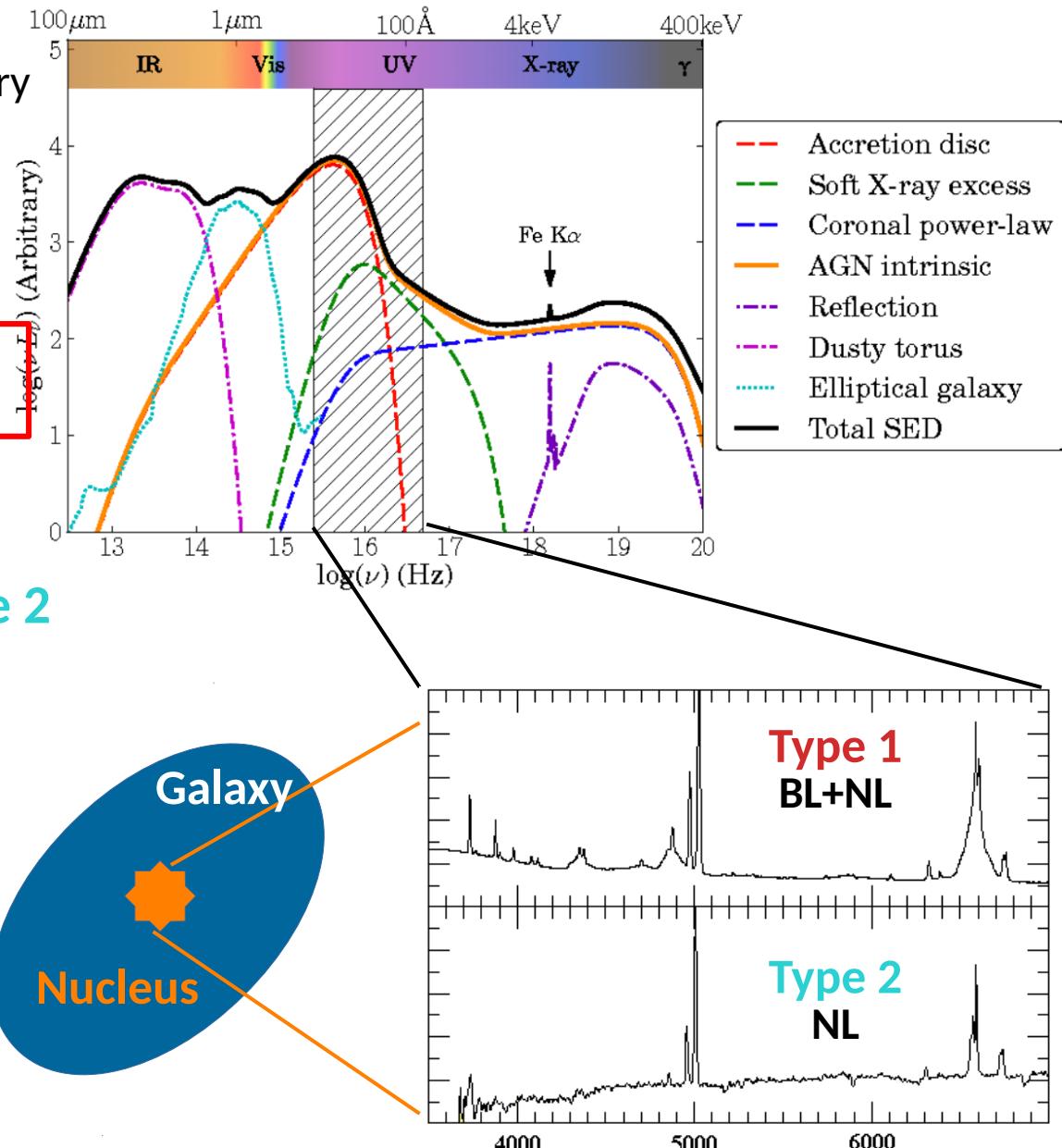
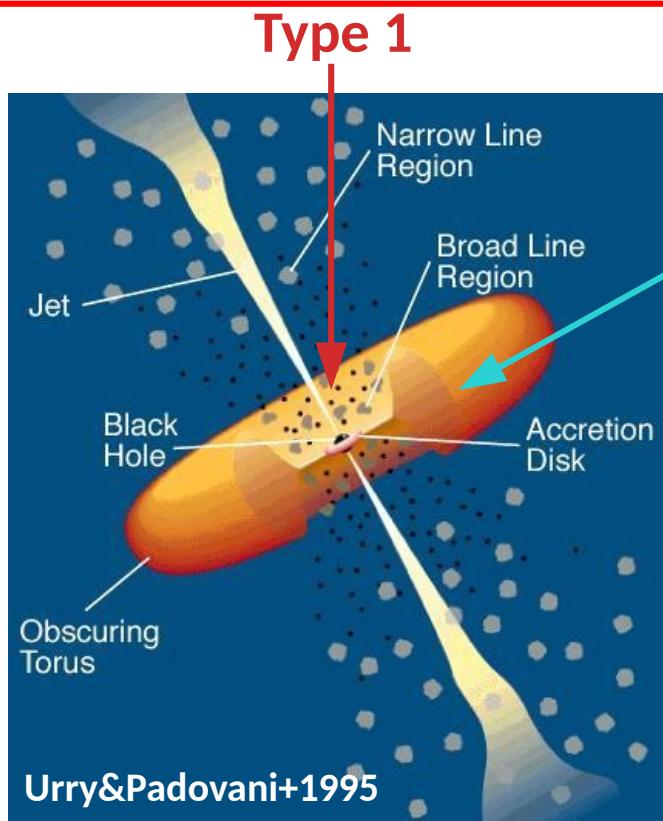


Hubble+1929

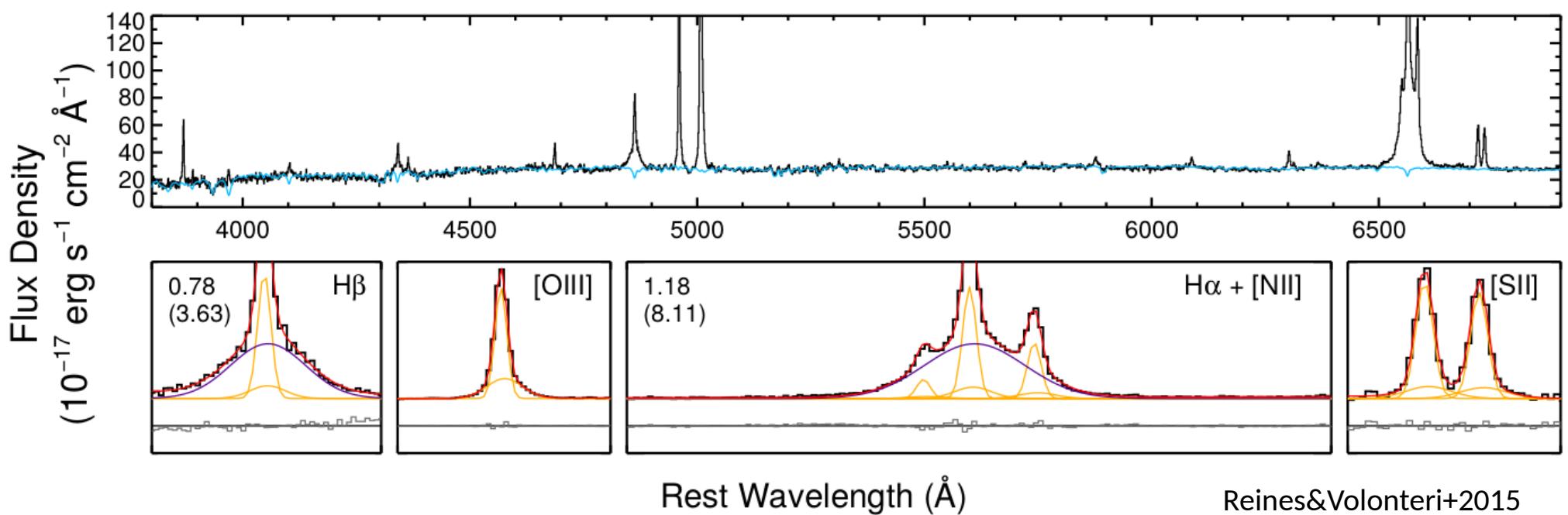


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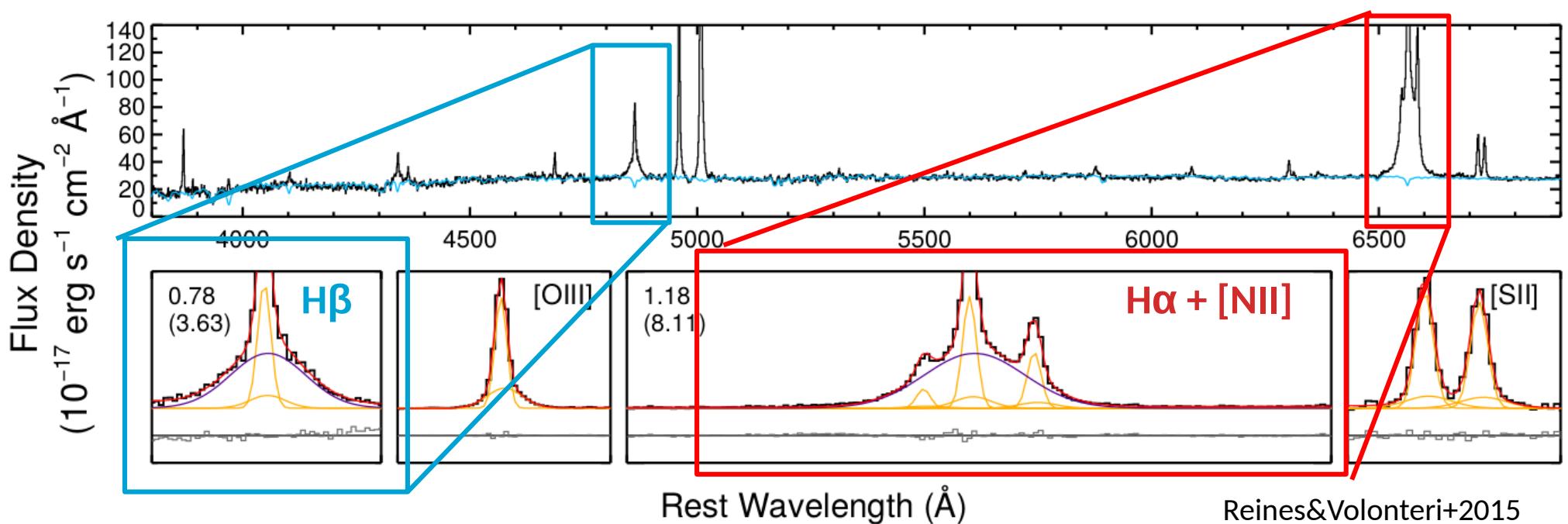


# How to Weight a Black Hole from Broad Emission Lines



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- One can consider the  $\text{H}\beta$  and  $\text{H}\alpha$  broad emission lines (Vestergaard&Peterson+2006, Vestergaard&Osmer+2009, Shen&Liu+2012, ...)



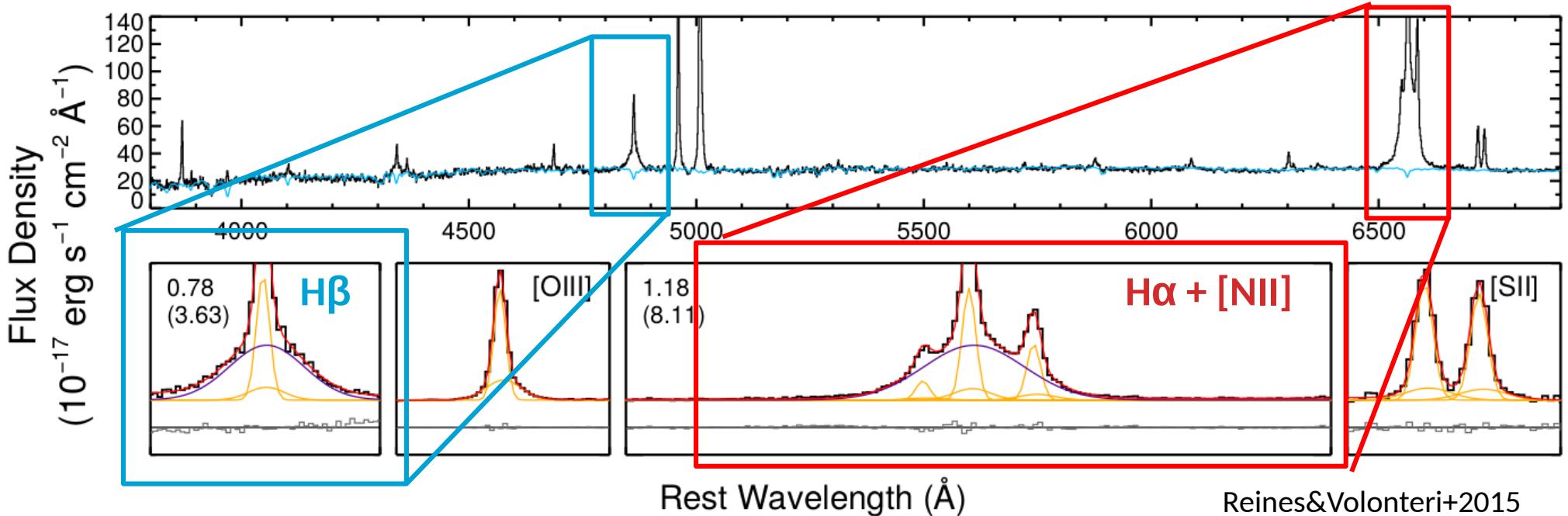
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- One can consider the  $\text{H}\beta$  and  $\text{H}\alpha$  broad emission lines (Vestergaard&Peterson+2006, Vestergaard&Osmer+2009, Shen&Liu+2012, ...)
- One can assume the **virial theorem**:  $M_{\text{BH}} \sim \frac{R_{\text{BLR}} v_{\text{BLR}}^2}{G}$
- The Radius –  $R_{\text{BLR}}$  – is proportional to the Luminosity of the line –  $L$  – and the velocity –  $v_{\text{BLR}}$  – is proportional to the full width at half maximum of the line – FWHM (Kaspi+2000, Bentz+2006, Peterson+2004; Onken+2004, Decarli+2012, ....)

$$\log \left( \frac{M_{\text{BH,vir}}}{M_{\odot}} \right) = a + b \log \left( \frac{L}{10^{44} \text{ erg s}^{-1}} \right) + c \log \left( \frac{\text{FWHM}}{\text{km s}^{-1}} \right)$$

$a, b, c$  depends on the chosen line

Shen&Liu+2012



# This Project : Long Slit Spectroscopy with EFOSC2

- We will obtain the **nuclear spectrum** of 12 bright galaxies with **optical long slit spectroscopy (LSS)** with **EFOSC2** at the NTT

	A	B	C	D	E	F	G
1	Name	Ra	Dec	Band	Mag	expTime	grism
2	UGCA 050	03:03:50.52	-25:16:20.496	V	14.18	60 x 2	G#4
3	NGC 3265	10:31:06.768	28:47:47.976	I	12.80	30 x 2	G#4
4	GSF 016	03:51:33.2208	-46:35:46.896	I	15.04	120 x 3	G#4
5	ESO 482- G 005	03:33:02.112	-24:07:59.16	B	14.32	30 x 2	G#4
6	NGC 1464	03:51:24.50592	-15:24:08.1612	I	14.16	30 x 2	G#4
7	NGC 4262	12:19:30.582	14:52:39.7812	V	12.70	20 x 2	G#4
8	MRK 0841	15:04:01.0	10:26:16.0	R	13.70	60 x 2 / 60 x 2	G#20 & G#18
9	SDSSJ083148.8	08:31:49.00	04:49:41.90	r	15.4	120 x 2	G#17
10	SDSSJ091702.3	09:17:02.00	-00:44:18.00	r	16.65	300 x 2	G#16
11	UGC 04416	08:27:17.00	22:52:39.00	I	11.49	10 x 2	G#4
12	NGC 2608	08:35:17.00	28:28:24.00	I	10.88	10 x 2	G#4
13	NGC 6017	15:57:15.00	05:59:54.00	z	14.01	30 x 2	G#4

- Different Grisms to cover different emission lines
- Filter wheel=free and slit width of 1"
- Science exposures + calibrations (bias/flats/arcs and standard stars)

## Aim / Measurements

- Redshifts, i.e. the distances, from the peaks of strong emission lines
- Characterize the ionization mechanism in the nucleus via the ELs H $\beta$ , [OIII], H $\alpha$ , [NII]
- Calculate the mass of the black holes of bright type 2 AGN in the sample, via the FWHM and luminosity of their H $\alpha$  and H $\beta$  lines.

# Summary of the Project

We will characterize a sample of galaxies with:

- Distance (Redshift) [Ib]
- Color [Ia]
- Nuclear Activity [Ib]
- (Black Hole Mass & Accretion Rate) [Ib]
- Morphology [Ia]
  - Surface Brightness Profile
  - (Bulge/Disk Ratio)

And Have Fun :)