Ryan Hickox & Dave Alexander, 2018, ARA&A, 56, 625

Obscured active galactic nuclei (AGN).

Resources/other reviews:

Shields 1999 – Historical review in PASP

Alexander & Hickox 2012 – New Astronomy Reviews on BH growth

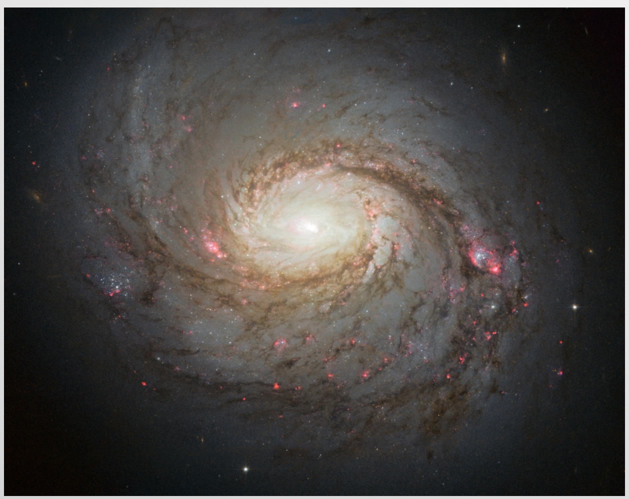
Heckman & Best 2014 – ARA&A on galaxy-BH co-evolution

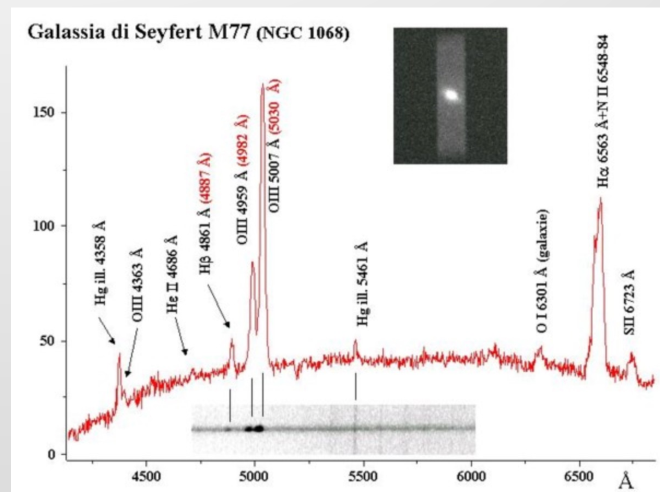
Netzer 2015 – ARA&A article on the unified model of AGN

Padovani 2017 – Frontiers in Astronomy and Space Science general AGN review

Historical overview

- 1908 – Edward Fath notices strong emission lines from H, Ne and O in the nuclear spectrum of NGC 1068.
- 1917 - Vesto Slipher obtains a high quality spectrum of NGC 1068 and notices that the lines are unusually broad.





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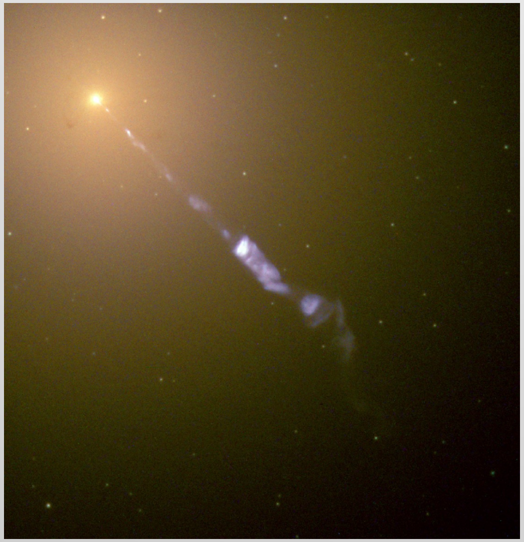

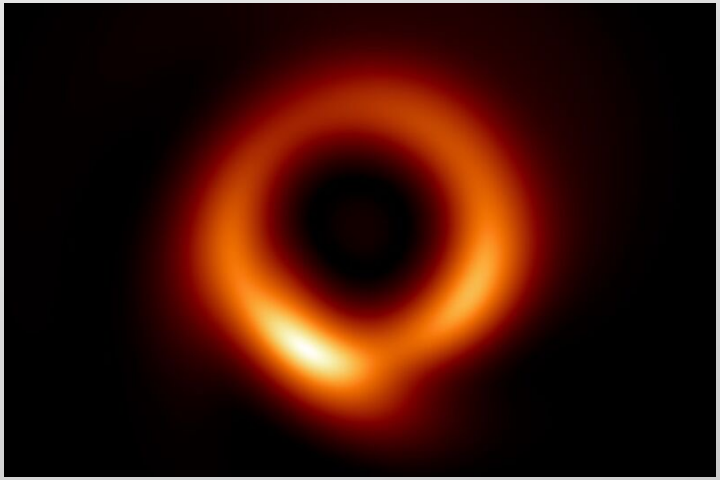

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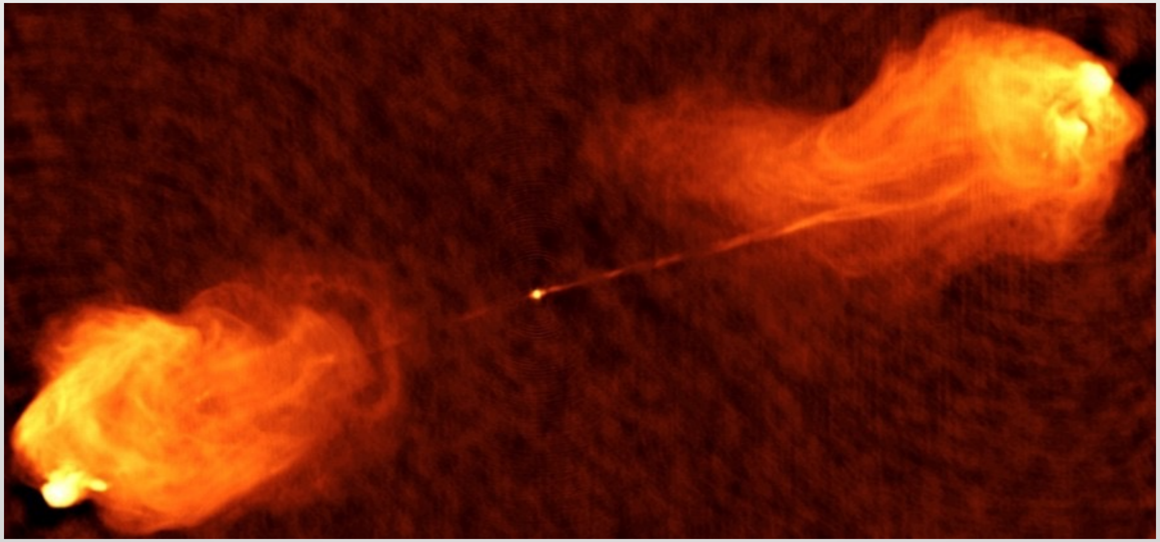
- 1924-1929 – General realization that galaxies are extra-galactic.
- 1926 – Edwin Hubble obtains nuclear spectra of NGC 4051 and NGC 4151, again noting their distinct characteristics.
- 1943 – Landmark work by Carl Seyfert showing that some galaxies show broad emission lines and that these tend to be very luminous. -> “Seyfert galaxies”

Historical overview

- 1939 - Radio astronomy is revolutionized by war efforts and played a major role in the study of AGN. Grote Reber discovers the radio source Cygnus A.
- 1954 - Walter Baade and Rudolph Minkowski find the optical counterpart to Cygnus A and determine a redshift of z=0.057.



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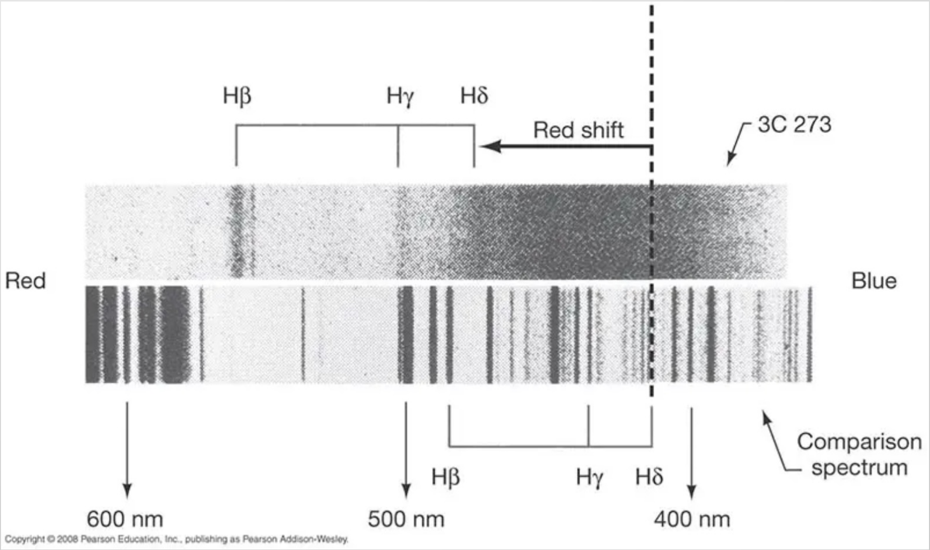
- 1963 - Maarten Schmidt obtains a redshift of z=0.158 for 3C273. Many of the 3C radio sources appear point-like on photographic plates leading to the term "quasi-stellar radio sources" or "quasars" for short. Rapid variability of many of these sources implied very compact sizes.



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- 1964 – Zeldovich and Salpeter (in separate papers) speculate that quasars are fuelled by black hole accretion.

For a more complete and detailed history of the field, see the review by Shields (1999).

AGN essential ingredients:

1. Supermassive black hole
2. Accretion
3. + dust for obscured AGN

In this lecture we will take these ingredients one by one and then finish by discussing how to find AGN.

The discovery of widespread black hole presence (and implication of galaxy co-evolution)

The theoretical idea of a black hole dates to the late 18th century when, in 1784, British astronomer and clergyman John Mitchell proposed a body so large that not even light could escape. But observational measurements were slow to come.

TABLE 1
Census of Supermassive Black Holes (2001 March)

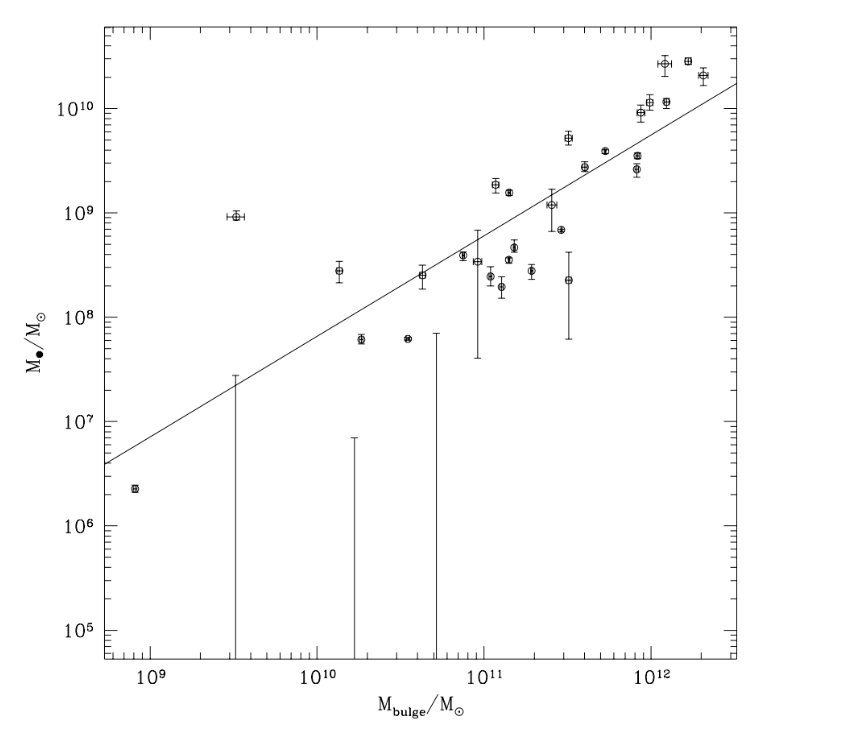
Galaxy	Type	$M_{B,\mathrm{bulge}}$	$M_\bullet$ (M_{low}, M_{high}) ($M_\odot$)	σ_e (km/s)	D (Mpc)	r_{cusp} (arcsec)	Reference
Galaxy	Sbc	−17.65	2.6 (2.4 – 2.8) e6	75	0.008	51.40	See notes
M 31	Sb	−19.00	4.5 (2.0 – 8.5) e7	160	0.76	2.06	Dressler + 1988; Kormendy 1988a
M 32	E2	−15.83	3.9 (3.1 – 4.7) e6	75	0.81	0.76	Tonry 1984, 1987
M 81	Sb	−18.16	6.8 (5.5 – 7.5) e7	143	3.9	0.76	Bower + 2001b
NGC 821	E4	−20.41	3.9 (2.4 – 5.6) e7	209	24.1	0.03	Gebhardt + 2001
NGC 1023	S0	−18.40	4.4 (3.8 – 5.0) e7	205	11.4	0.08	Bower + 2001a
NGC 2778	E2	−18.59	1.3 (0.5 – 2.9) e7	175	22.9	0.02	Gebhardt + 2001
NGC 3115	S0	−20.21	1.0 (0.4 – 2.0) e9	230	9.7	1.73	Kormendy + 1992
NGC 3377	E5	−19.05	1.1 (0.6 – 2.5) e8	145	11.2	0.42	Kormendy + 1998
NGC 3379	E1	−19.94	1.0 (0.5 – 1.6) e8	206	10.6	0.20	Gebhardt + 2000a
NGC 3384	S0	−18.99	1.4 (1.0 – 1.9) e7	143	11.6	0.05	Gebhardt + 2001
NGC 3608	E2	−19.86	1.1 (0.8 – 2.5) e8	182	23.0	0.13	Gebhardt + 2001
NGC 4291	E2	−19.63	1.9 (0.8 – 3.2) e8	242	26.2	0.11	Gebhardt + 2001
NGC 4342	S0	−17.04	3.0 (2.0 – 4.7) e8	225	15.3	0.34	Cretton + 1999a
NGC 4473	E5	−19.89	0.8 (0.4 – 1.8) e8	190	15.7	0.13	Gebhardt + 2001
NGC 4486B	E1	−16.77	5.0 (0.2 – 9.9) e8	185	16.1	0.81	Kormendy + 1997
NGC 4564	E3	−18.92	5.7 (4.0 – 7.0) e7	162	15.0	0.13	Gebhardt + 2001
NGC 4594	Sa	−21.35	1.0 (0.3 – 2.0) e9	240	9.8	1.58	Kormendy + 1988b
NGC 4649	E1	−21.30	2.0 (1.0 – 2.5) e9	375	16.8	0.75	Gebhardt + 2001
NGC 4697	E4	−20.24	1.7 (1.4 – 1.9) e8	177	11.7	0.41	Gebhardt + 2001
NGC 4742	E4	−18.94	1.4 (0.9 – 1.8) e7	90	15.5	0.10	Kaiser + 2001
NGC 5845	E	−18.72	2.9 (0.2 – 4.6) e8	234	25.9	0.18	Gebhardt + 2001
NGC 7457	S0	−17.69	3.6 (2.5 – 4.5) e6	67	13.2	0.05	Gebhardt + 2001
NGC 2787	SB0	−17.28	4.1 (3.6 – 4.5) e7	185	7.5	0.14	Sarzi + 2001
NGC 3245	S0	−19.65	2.1 (1.6 – 2.6) e8	205	20.9	0.21	Barth + 2001
NGC 4261	E2	−21.09	5.2 (4.1 – 6.2) e8	315	31.6	0.15	Ferrarese + 1996
NGC 4374	E1	−21.36	4.3 (2.6 – 7.5) e8	296	18.4	0.24	Bower + 1998
NGC 4459	SA0	−19.15	7.0 (5.7 – 8.3) e7	167	16.1	0.14	Sarzi + 2001
M 87	E0	−21.53	3.0 (2.0 – 4.0) e9	375	16.1	1.18	Harms + 1994
NGC 4596	SB0	−19.48	0.8 (0.5 – 1.2) e8	136	16.8	0.22	Sarzi + 2001
NGC 5128	S0	−20.80	2.4 (0.7 – 6.0) e8	150	4.2	2.26	Marconi + 2001
NGC 6251	E2	−21.81	6.0 (2.0 – 8.0) e8	290	106	0.06	Ferrarese + 1999
NGC 7052	E4	−21.31	3.3 (2.0 – 5.6) e8	266	58.7	0.07	van der Marel + 1998
IC 1459	E3	−21.39	2.0 (1.2 – 5.7) e8	323	29.2	0.06	Verdoes Kleijn + 2001
NGC 1068	Sb	−18.82	1.7 (1.0 – 3.0) e7	151	15	0.04	Greenhill + 1996
NGC 4258	Sbc	−17.19	4.0 (3.9 – 4.1) e7	120	7.2	0.36	Miyoshi + 1995
NGC 4945	Scd	−15.14	1.4 (0.9 – 2.1) e6		3.7		Greenhill + 1997

HST made a huge impact in the study/measurement of black holes, thanks to its spatial resolution.

Census in 2001 in a review by Kormendy & Gebhardt still only lists ~35 objects with measurements.

The discovery of widespread black hole presence (and implication of galaxy co-evolution)

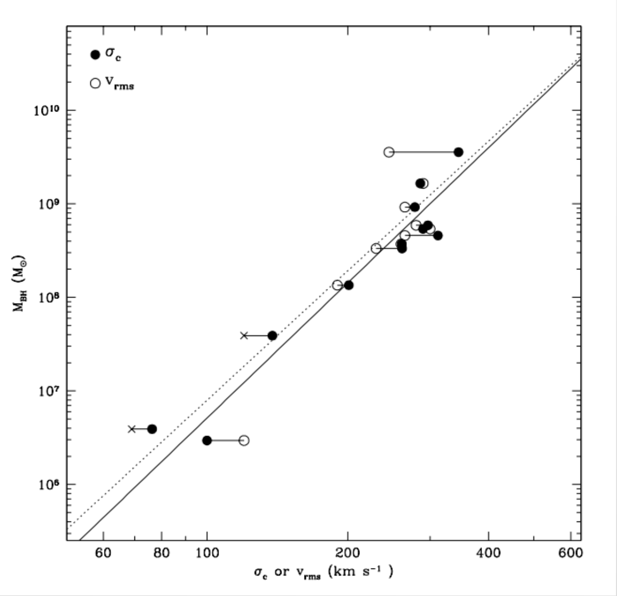
Magorrian et al. (1998) produced one of the first statistical studies of “The demography of massive dark objects in galaxy centres” -> $M_{BH} - M_{bulge}$ (or sometimes ($M_{BH} - L_{bulge}$)) was termed “the Magorrian relation”.



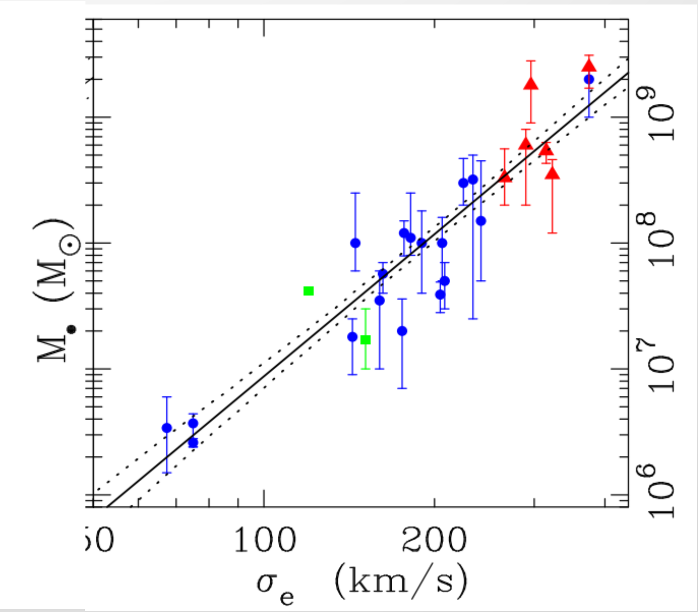
Magorrian et al. (1998)

The discovery of widespread black hole presence (and implication of galaxy co-evolution)

At the 2000 AAS meeting Laura Ferrarese and Karl Gebhardt separately presented the correlation between M_{BH} and the galaxy's central velocity dispersion (σ). M-sigma relation.



Ferrarese & Merritt (2000)

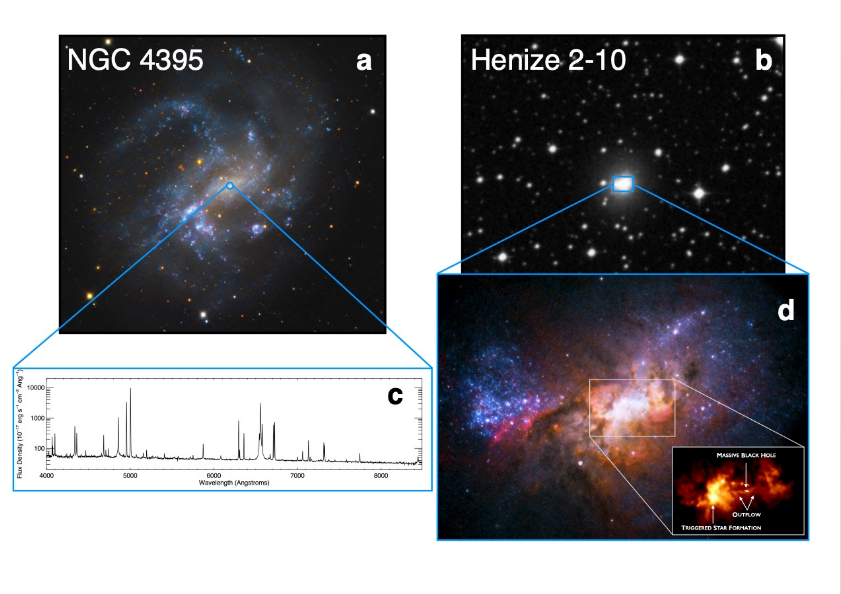


Gebhardt et al. (2000)

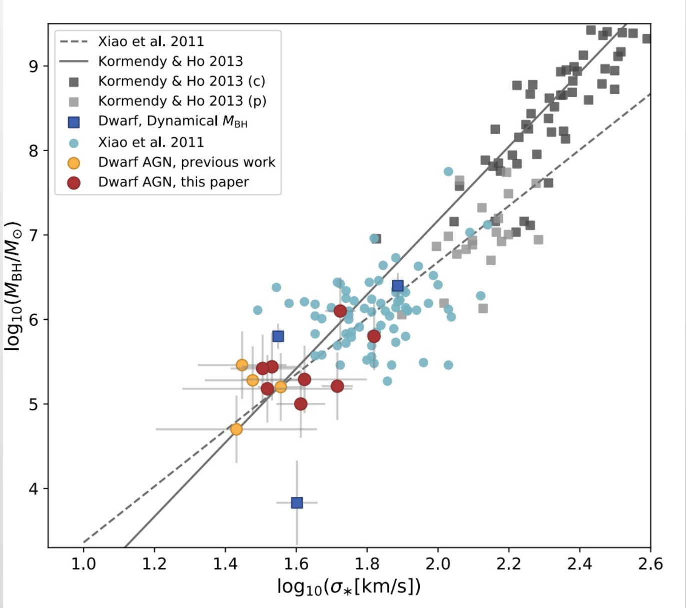
See ARA&A review by Kormendy & Ho (2013) for more on galaxy-black hole co-evolution.

The discovery of widespread black hole presence (and implication of galaxy co-evolution)

Presence of black holes now confirmed even in dwarf galaxies, selected in a range of ways from optical, to radio and mid-IR. The implication for this lecture is that the potential engine to make an AGN is widely present.



Reines (2022)



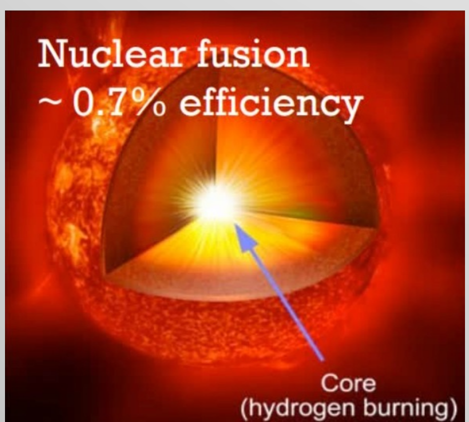
Baldassare et al (2020)

For more on black holes in dwarf galaxies see review by Amy Reines (2022) in Nature Astronomy.

The accretion process

AGN are very efficient at converting mass to energy: $\epsilon \sim$ 0.05 – 0.4 (0.1. is a commonly assumed value).

$$\dot{m}_{\rm BH} = 0.15\left(\frac{\epsilon}{0.1}\right)\left(\frac{L_{\rm bol}}{10^{45}\ {\rm ergs}^{-1}}\right) {\rm M}_{\odot}\ {\rm yr}^{-1}$$



1 solar mass/year (equivalent to mass of the moon/s) is enough to outshine an entire galaxy (yields L_{bol} = 7 x 10^{44} erg/s).

The Eddington luminosity (and rate)

Sir Arthur Stanley Eddington (1882-1944)

Journalist: "Sir Arthur, it is said that only three people in the world understand relativity!"

Eddington: "Yes I've heard that. I am trying to work out who the third person is..."

The Eddington luminosity (and rate)

The Eddington luminosity (AKA Eddington limit) is the theoretical (with some assumptions) maximum luminosity an object can have and still maintain hydrostatic equilibrium (i.e. not blow itself up/expel matter). For a spherically symmetric system:

$$L_{Edd} = \frac{4\pi G M_{BH} m_p c}{\sigma_T}$$

Where σ_T is the electron cross section (assumes opacity is just coming from ionized hydrogen).

The Eddington rate is the accretion rate required to achieve the Eddington luminosity. The Eddington rate and luminosity are related by:

$$\dot{M}_{Edd} = \frac{L_{Edd}}{\epsilon\, c^2}$$

Other "accretion" terms you might hear

Eddington ratio is $\lambda = L_{bol}/L_{Edd}$

Sub-Eddington accretion: Accretion below the Eddington limit.

Super-Eddington accretion: Accretion above the Eddington limit. Can happen, for example, if system is not spherically symmetric or if $\epsilon \ll 0.1$.

Bondi accretion: a spherically symmetric approximation for accretion (often used in simulations since we can't actually resolve/don't understand the details of the accretion).

Advection dominated accretion flow (ADAF)

Radiatively inefficient accretion flow (RIAF)

} Accretion that happens in a geometrically thick disk, but is radiatively inefficient (no strong emission lines), optically thin, occurring for very low accretion rates

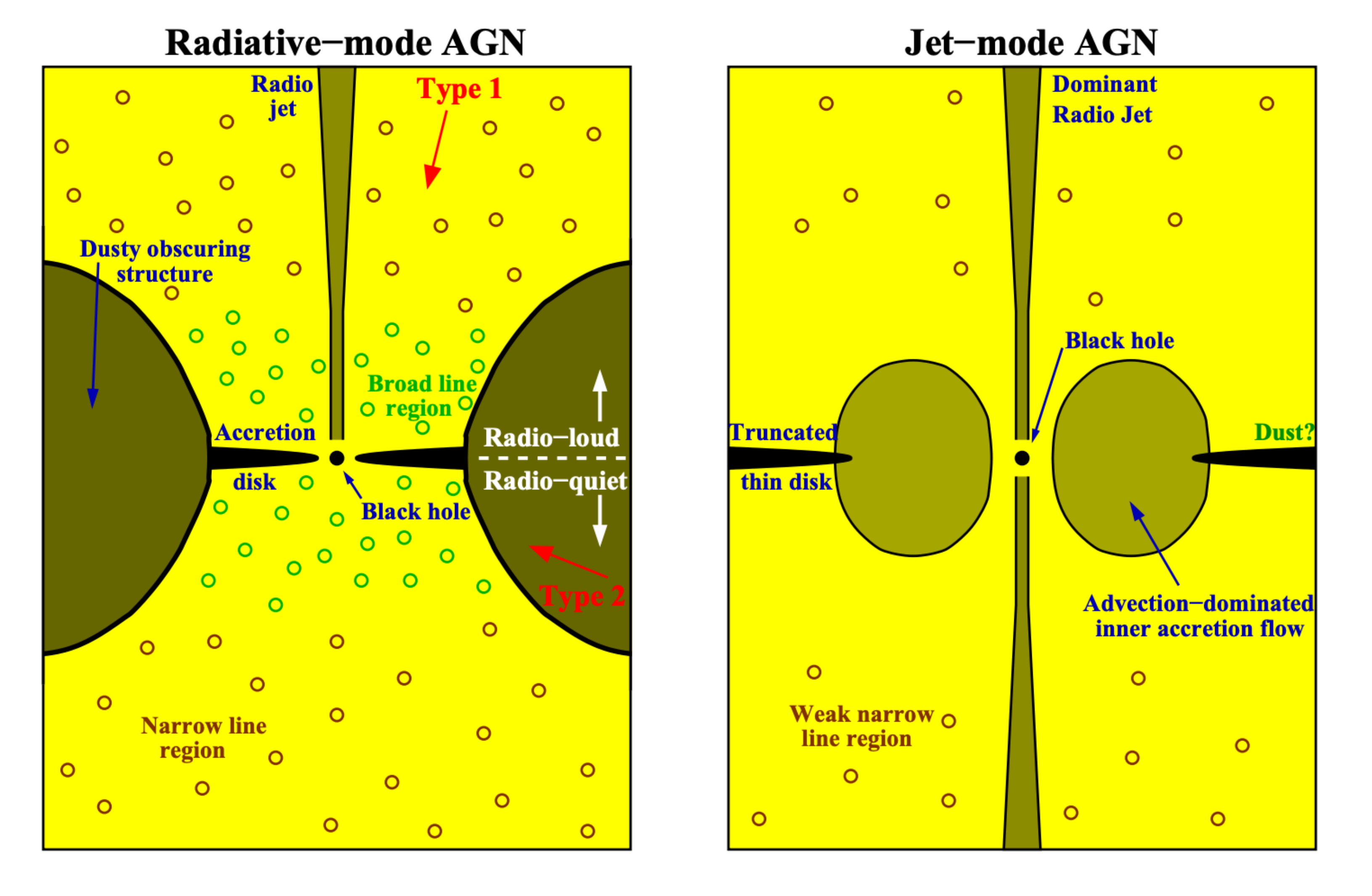
Two AGN fuelling modes

1) High excitation
= radiative mode
= quasar mode
= thermal mode

- Identified in optical, IR etc; *may* have radio jets.
- High accretion rates (1-10% Eddington)

2) Low excitation
= radio mode
= jet mode
= kinetic mode

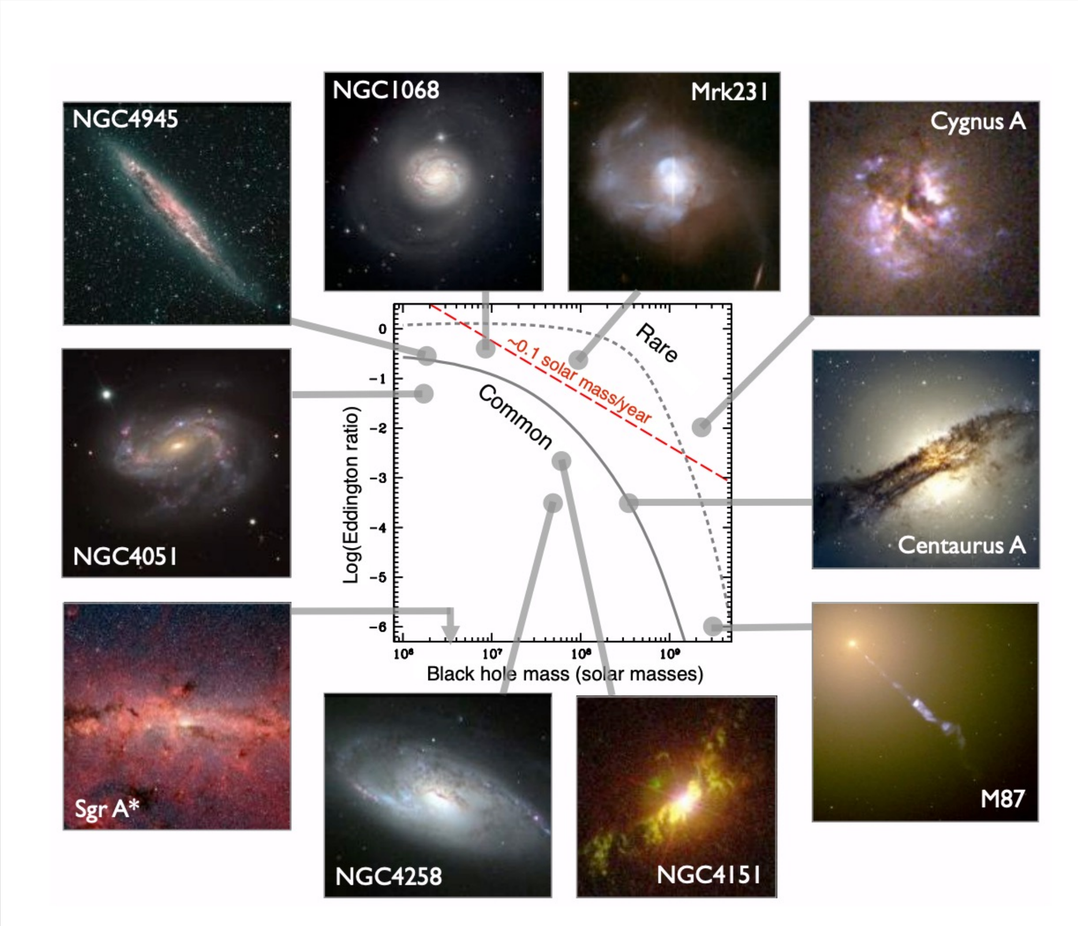
- Characterized through radio emission.
- Low accretion rates (<<1% Eddington)



Heckman & Best (2014)

The accretion process

AGN within 300 Mpc (plus Sag A* whose accretion rate is 10^{-8} Eddington).

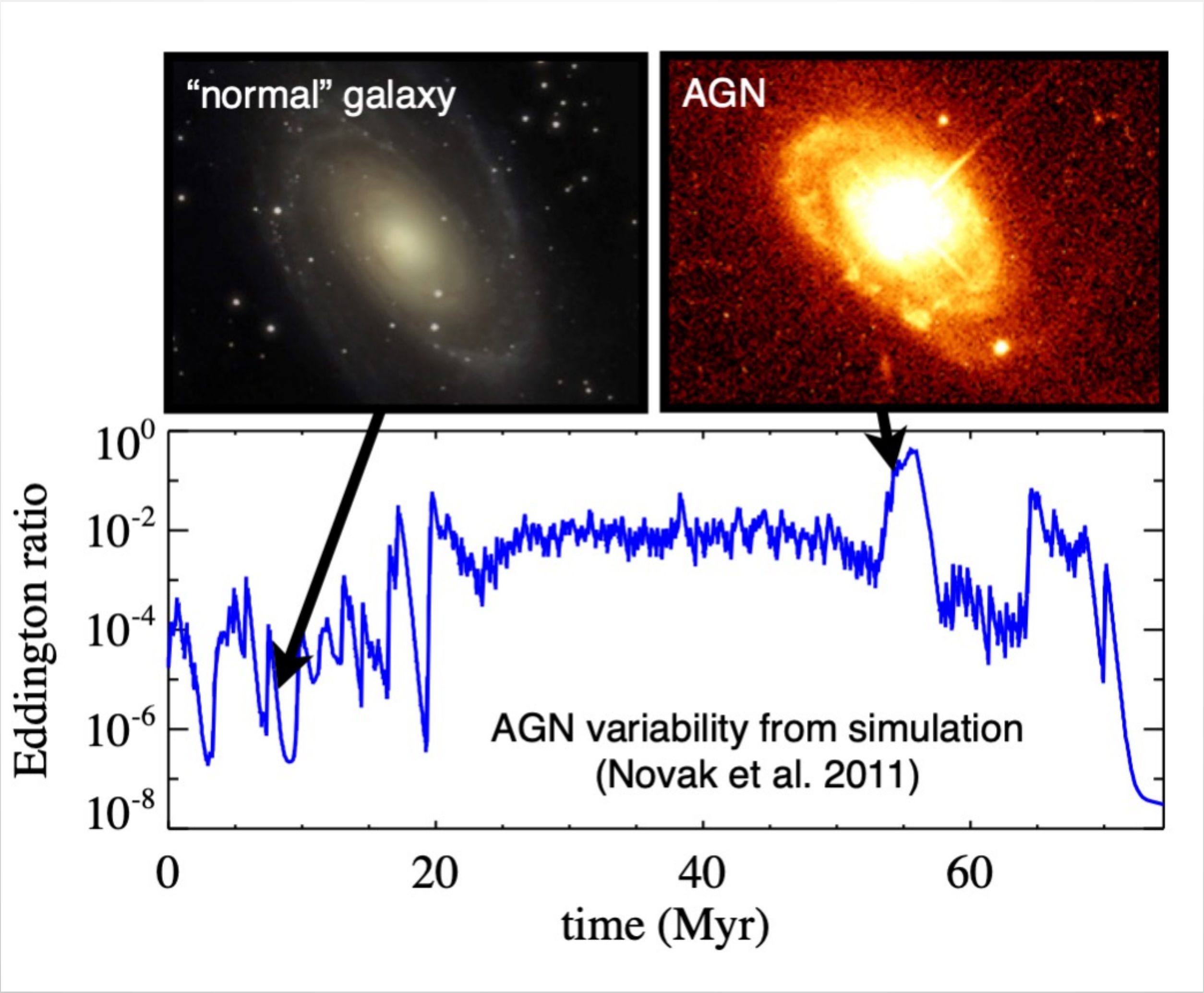


Alexander & Hickox (2012)

It is rare to find a massive black hole accreting close to Eddington, because this implies a very high mass accretion rate (not so hard for low mass BHs to accrete close to their Eddington rate).

The accretion process

The accretion process is very stochastic – has made it hard to connect the accretion rate with other galactic processes (e.g. star formation rate).

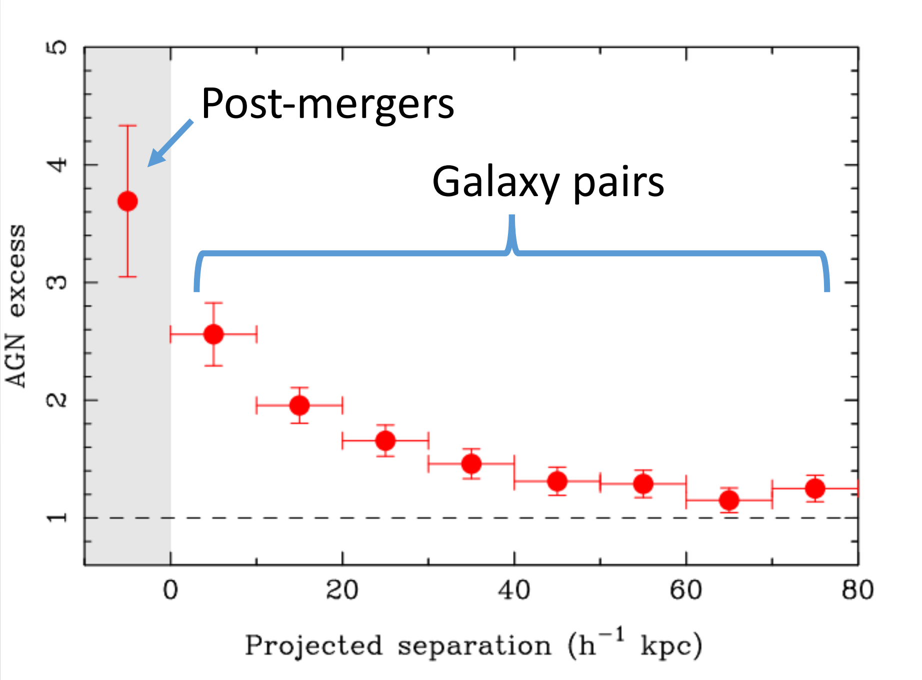


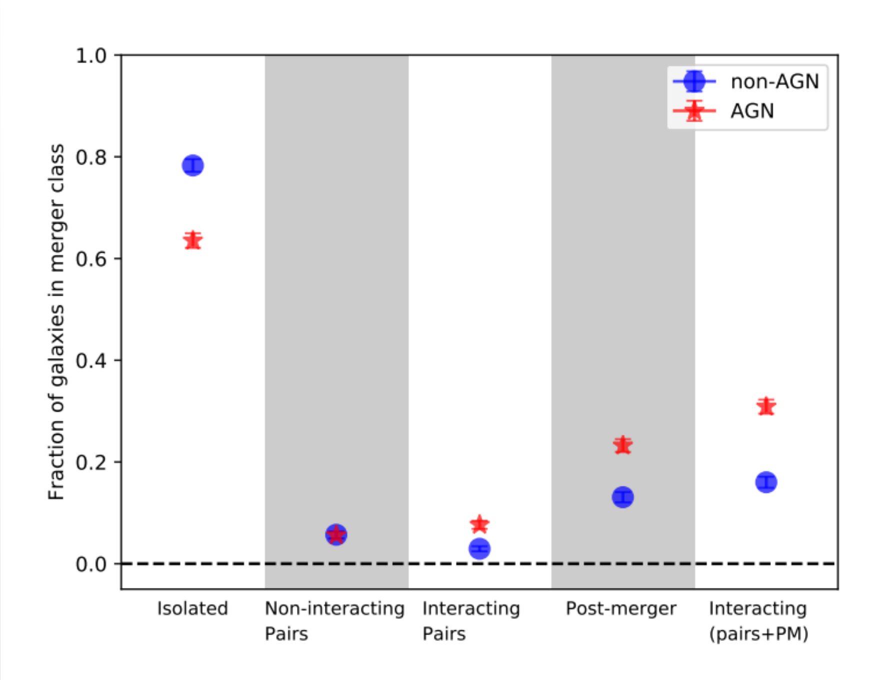
The accretion process – how does gas get to the BH?

Gas has to lose ~99.9% of its angular momentum in order to get from ~10 kpc down to 10 pc (where it starts to be under the influence of the black hole). Large scale torques required on kpc-scales.

Galaxy bars and mergers represent effective mechanisms for this. Mergers are clearly linked to AGN accretion; the role of bars remains more controversial. 3-body interactions need to solve the “final parsec problem”.

The accretion process – how does gas get to the BH?



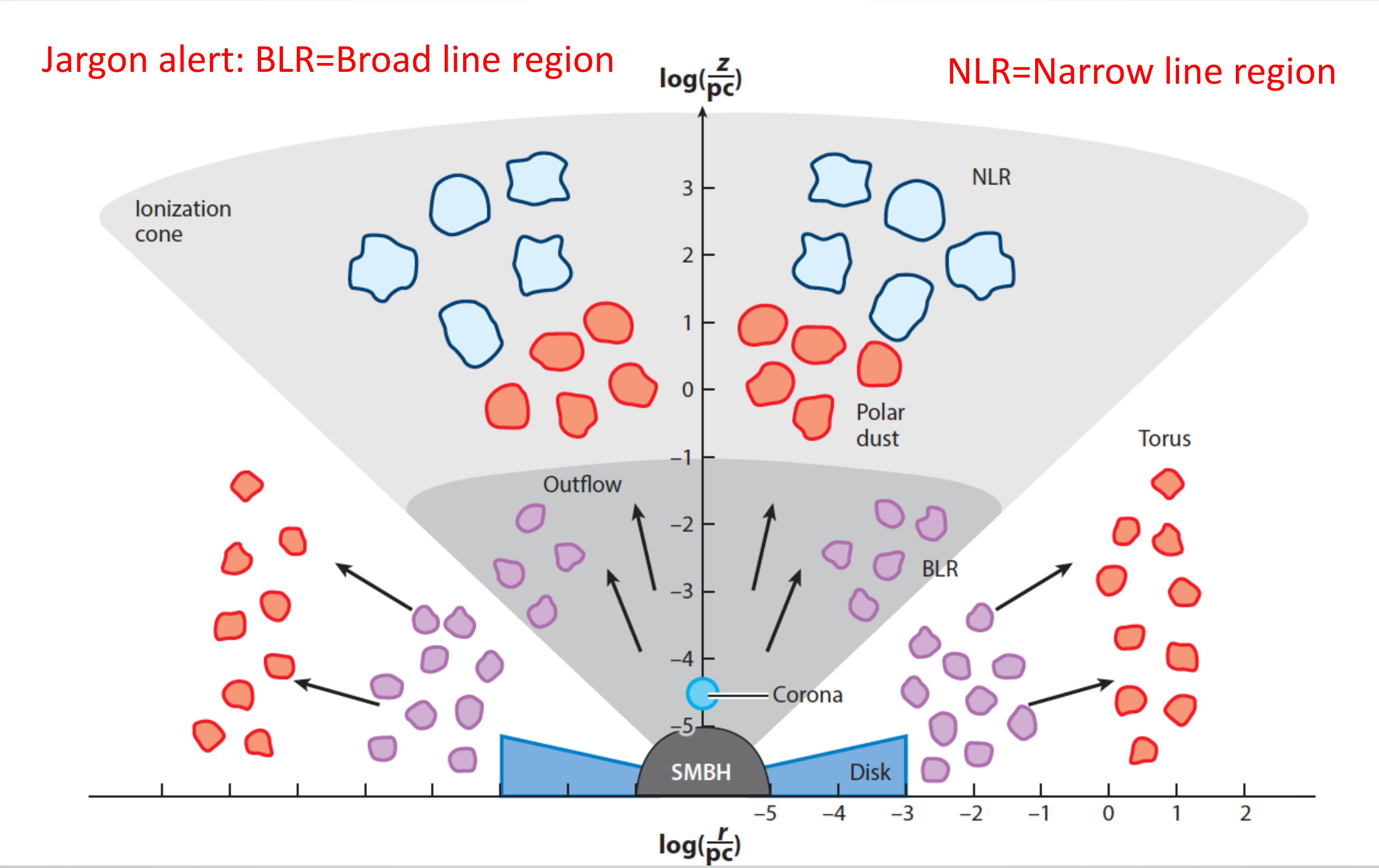


Ellison et al. (2013) found the frequency of AGN increased as galaxies progressed along the merger sequence.

But not all AGN have merger features. Ellison et al. (2019) found that only ~ 1/3 of optical AGN have features of a recent merger.

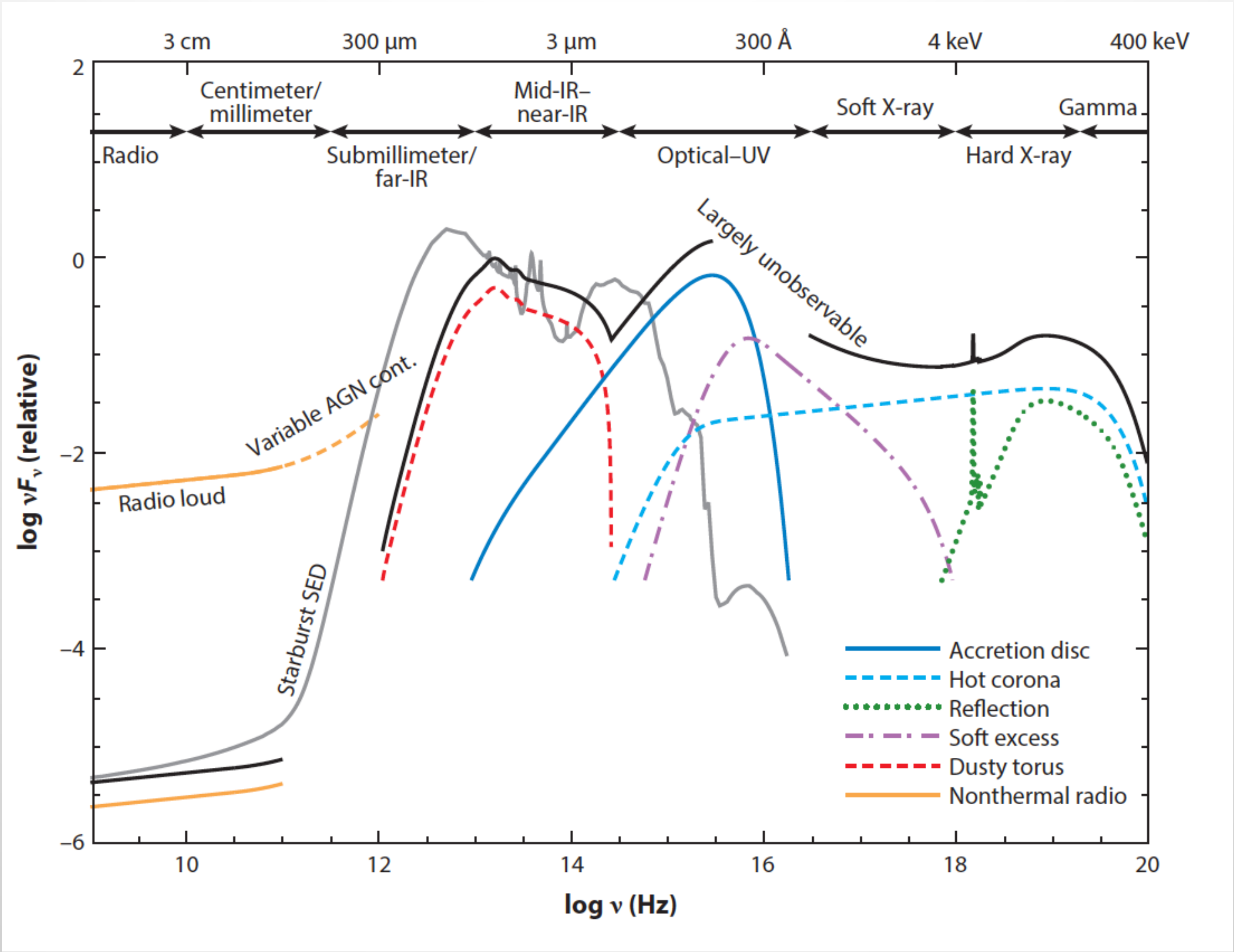
Schematic representation of an AGN

(and why some AGN are obscured)



Hickox & Alexander 2018

AGN Spectral energy distribution (SED)



Harrison (2014)

Table 1 The AGN zoo: list of AGN classes.

Class/Acronym	Meaning	Main properties/reference
Quasar	Quasi-stellar radio source (originally)	Radio detection no longer required
Sey1	Seyfert 1	FWHM $\gtrsim 1,000$ km s^{-1}
Sey2	Seyfert 2	FWHM $\lesssim 1,000$ km s^{-1}
QSO	Quasi-stellar object	Quasar-like, non-radio source
QSO2	Quasi-stellar object 2	High power Sey2
RQ AGN	Radio-quiet AGN	see ref. 1
RL AGN	Radio-loud AGN	see ref. 1
Jetted AGN		with strong relativistic jets; see ref. 1
Non-jetted AGN		without strong relativistic jets; see ref. 1
Type 1		Sey1 and quasars
Type 2		Sey2 and QSO2
FR I	Fanaroff-Riley class I radio source	radio core-brightened (ref. 2)
FR II	Fanaroff-Riley class II radio source	radio edge-brightened (ref. 2)
BL Lac	BL Lacertae object	see ref. 3
Blazar	BL Lac and quasar	BL Lacs and FSRQs
BAL	Broad absorption line (quasar)	ref. 4
BLO	Broad-line object	FWHM $\gtrsim 1,000$ km s^{-1}
BLAGN	Broad-line AGN	FWHM $\gtrsim 1,000$ km s^{-1}
BLRG	Broad-line radio galaxy	RL Sey1
CDQ	Core-dominated quasar	RL AGN, $f_{\rm core} \ge f_{\rm ext}$ (same as FSRQ)
CSS	Compact steep spectrum radio source	core dominated, $\alpha_r > 0.5$
CT	Compton-thick	$N_{\rm H} \ge 1.5 \times 10^{24}$ cm^{-2}
FR 0	Fanaroff-Riley class 0 radio source	ref. 5
FSRQ	Flat-spectrum radio quasar	RL AGN, $\alpha_r \le 0.5$
GPS	Gigahertz-peaked radio source	see ref. 6
HBL/HSP	High-energy cutoff BL Lac/blazar	$\nu_{\rm synch\ peak} \ge 10^{15}$ Hz (ref. 7)
HEG	High-excitation galaxy	ref. 8
HPQ	High polarization quasar	$P_{\rm opt} \ge 3\%$ (same as FSRQ)
Jet-mode		$L_{\rm kin} \gg L_{\rm rad}$ (same as LERG); see ref. 9
IBL/ISP	Intermediate-energy cutoff BL Lac/blazar	$10^{14} \le \nu_{\rm synch\ peak} \le 10^{15}$ Hz (ref. 7)
LINER	Low-ionization nuclear emission-line regions	see ref. 9
LLAGN	Low-luminosity AGN	see ref. 10
LBL/LSP	Low-energy cutoff BL Lac/blazar	$\nu_{\rm synch\ peak} < 10^{14}$ Hz (ref. 7)
LDQ	Lobe-dominated quasar	RL AGN, $f_{\rm core} < f_{\rm ext}$
LEG	Low-excitation galaxy	ref. 8
LPQ	Low polarization quasar	$P_{\rm opt} < 3\%$
NLAGN	Narrow-line AGN	FWHM $\lesssim 1,000$ km s^{-1}
NLRG	Narrow-line radio galaxy	RL Sey2
NLS1	Narrow-line Seyfert 1	ref. 11
OVV	Optically violently variable (quasar)	(same as FSRQ)
Population A		ref. 12
Population B		ref. 12
Radiative-mode		Seyferts and quasars; see ref. 9
RBL	Radio-selected BL Lac	BL Lac selected in the radio band
Sey1.5	Seyfert 1.5	ref. 13
Sey1.8	Seyfert 1.8	ref. 13
Sey1.9	Seyfert 1.9	ref. 13
SSRQ	Steep-spectrum radio quasar	RL AGN, $\alpha_r > 0.5$
USS	Ultra-steep spectrum source	RL AGN, $\alpha_r > 1.0$
XBL	X-ray-selected BL Lac	BL Lac selected in the X-ray band
XBONG	X-ray bright optically normal galaxy	AGN only in the X-ray band/weak lined AGN

The many "faces" of AGN has led to a complicated classification system.

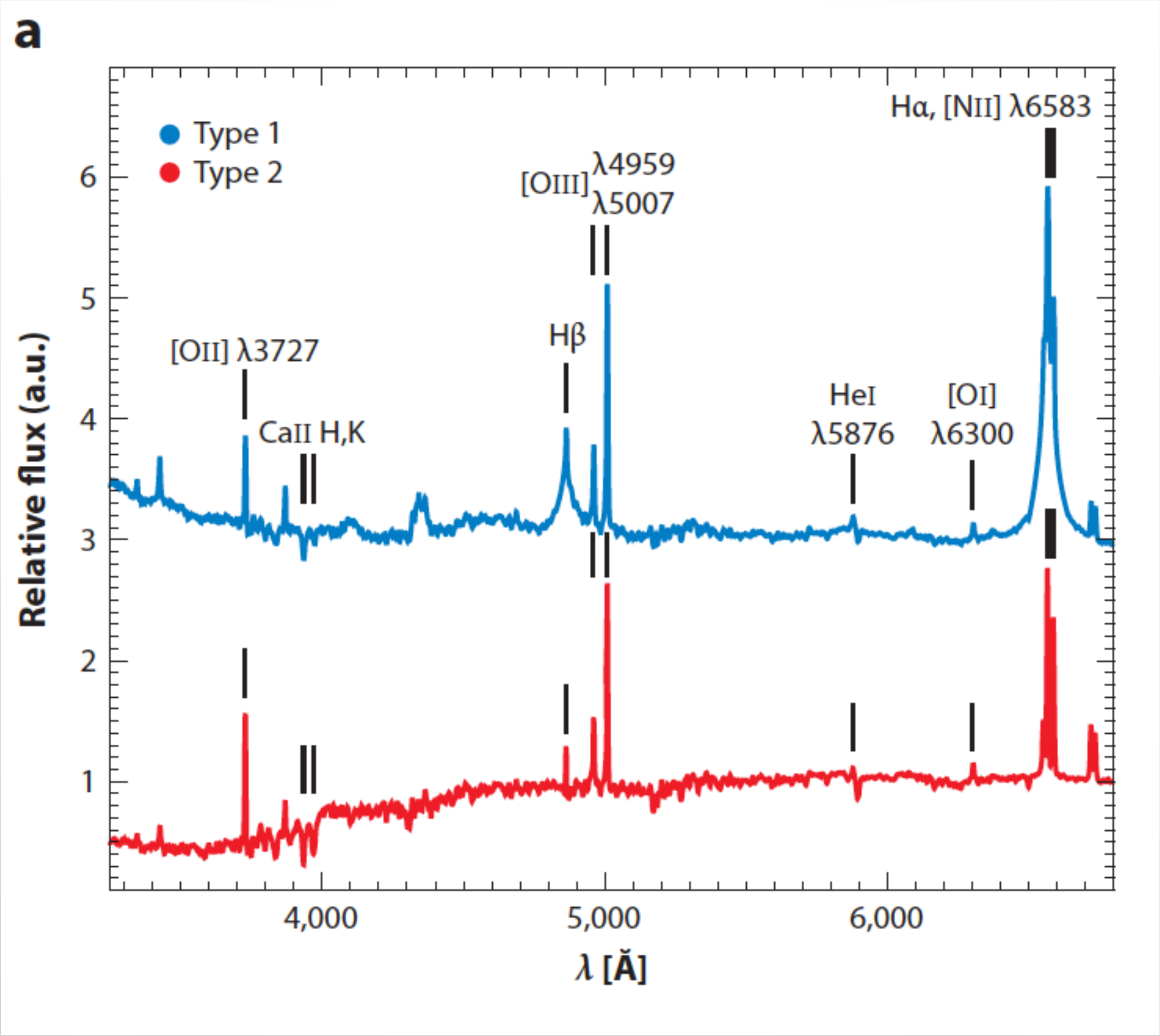
The AGN zoo – as reviewed by Padovani et al. (2017). A confusing menagerie!!

Seyferts and QSOs are the most commonly studied of the AGN classes, corresponding to high and low luminosities:

Seyfert: $10^{42} < L_{bol} < 10^{45}$ erg/s
QSO: $L_{bol} > 10^{45}$ erg/s

Type 1 and 2 depend on velocity width (probing the BLR and NLR). Broad lines have widths 1000 – 10,000 km/s.

Obscured or not: Broad vs. narrow line AGN



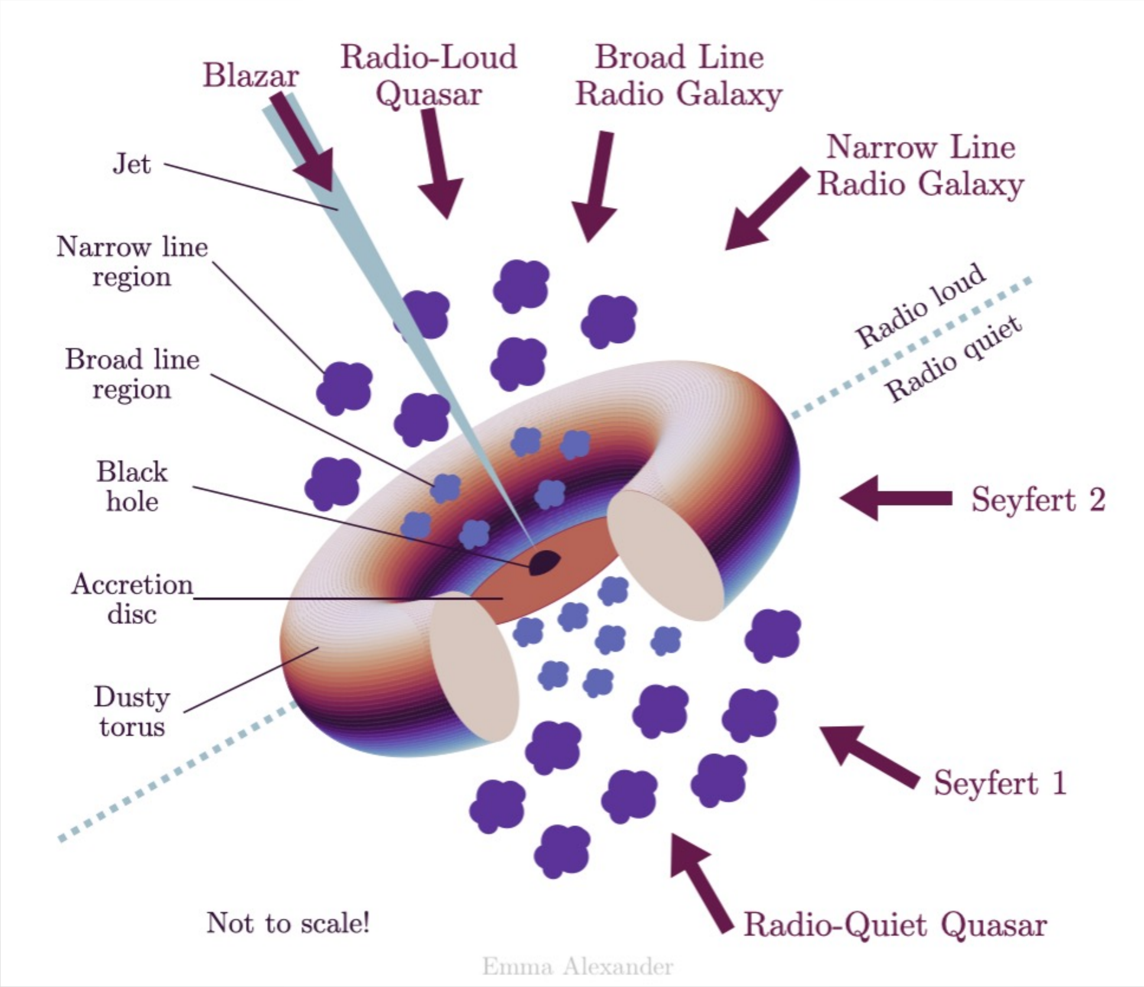
Hickox et al. (2017)

Wikipedia's summary!

Features of different types of galaxies

Galaxy type	Active nuclei	Emission lines		X-rays	Excess of		Strong radio	Jets	Variable	Radio loud
		Narrow	Broad		UV	Far-IR				
Normal (non-AGN)	no	weak	no	weak	no	no	no	no	no	no
LINER	unknown	weak	weak	weak	no	no	no	no	no	no
Seyfert I	yes	yes	yes	some	some	yes	few	no	yes	no
Seyfert II	yes	yes	no	some	some	yes	few	no	yes	no
Quasar	yes	yes	yes	some	yes	yes	some	some	yes	some
Blazar	yes	no	some	yes	yes	no	yes	yes	yes	yes
BL Lac	yes	no	no/faint	yes	yes	no	yes	yes	yes	yes
OVV	yes	no	stronger than BL Lac	yes	yes	no	yes	yes	yes	yes
Radio galaxy	yes	some	some	some	some	yes	yes	yes	yes	yes

The Unified Model



The unified model is the idea that all the AGN flavours are actually the same object, just viewed from different angles. Classic references: Antonucci 1993; Urry & Padovani 1995. Still debated.

Definition of obscured AGN: Defined by N(H)

Classic definition of obscured AGN is that the BLR is not seen, corresponds to $5 < A_V < 10$ mag (recall extinction curves from Salim & Narayanan review).

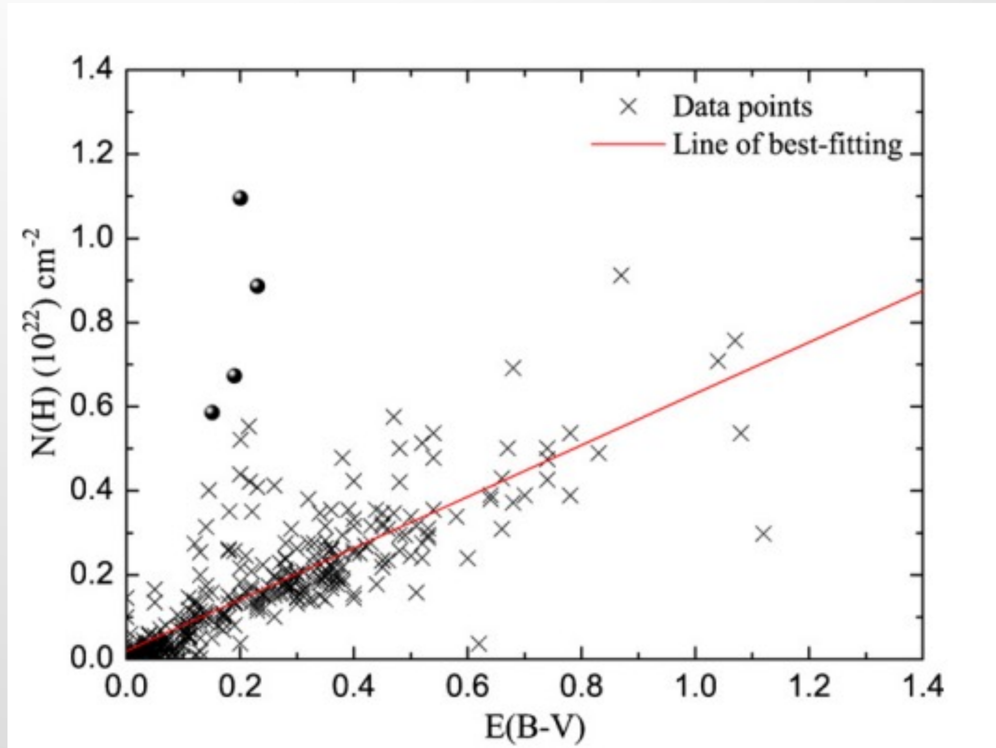
Can express extinction as:

$$R_V = \frac{A_V}{E(B-V)}$$

Where $E(B\text{-}V) = A_B - A_V$.

For typical Milky Way dust, $R_V \sim 3.1$. For 5 mags of optical extinction: $E(B\text{-}V) = 1.6$

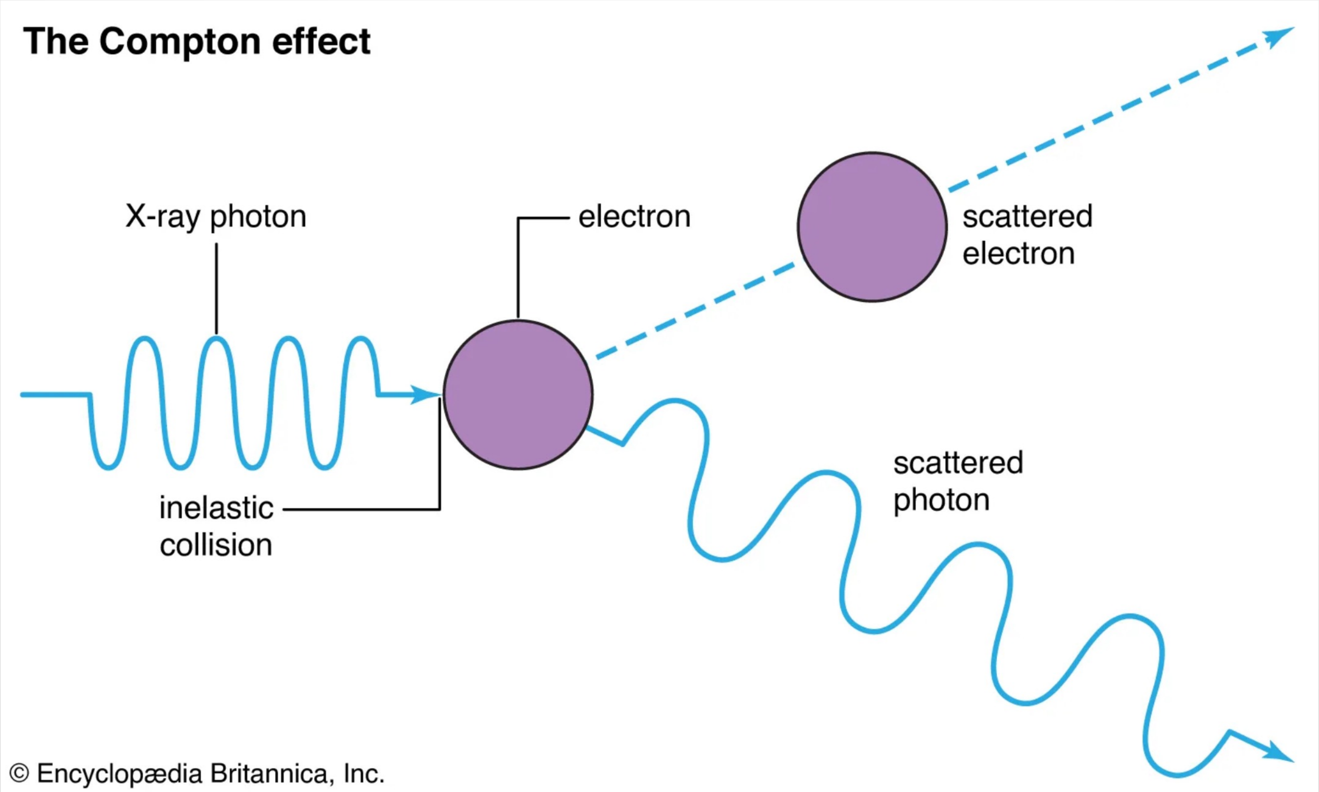
Dust tracks gas. 5 mags of optical extinction corresponds to $> 10^{22}$ cm^{-2} of gas!!



Gas to extinction law for MW: Gudennavar et al. (2012)

The most obscured AGN: Compton thick

If N(H) > 10^{24} cm^{-2} even the hard X-rays become obscured. So-called Compton thick AGN are important as they are needed to balance the energy budget of the X-ray background. But much fewer are detected than required.



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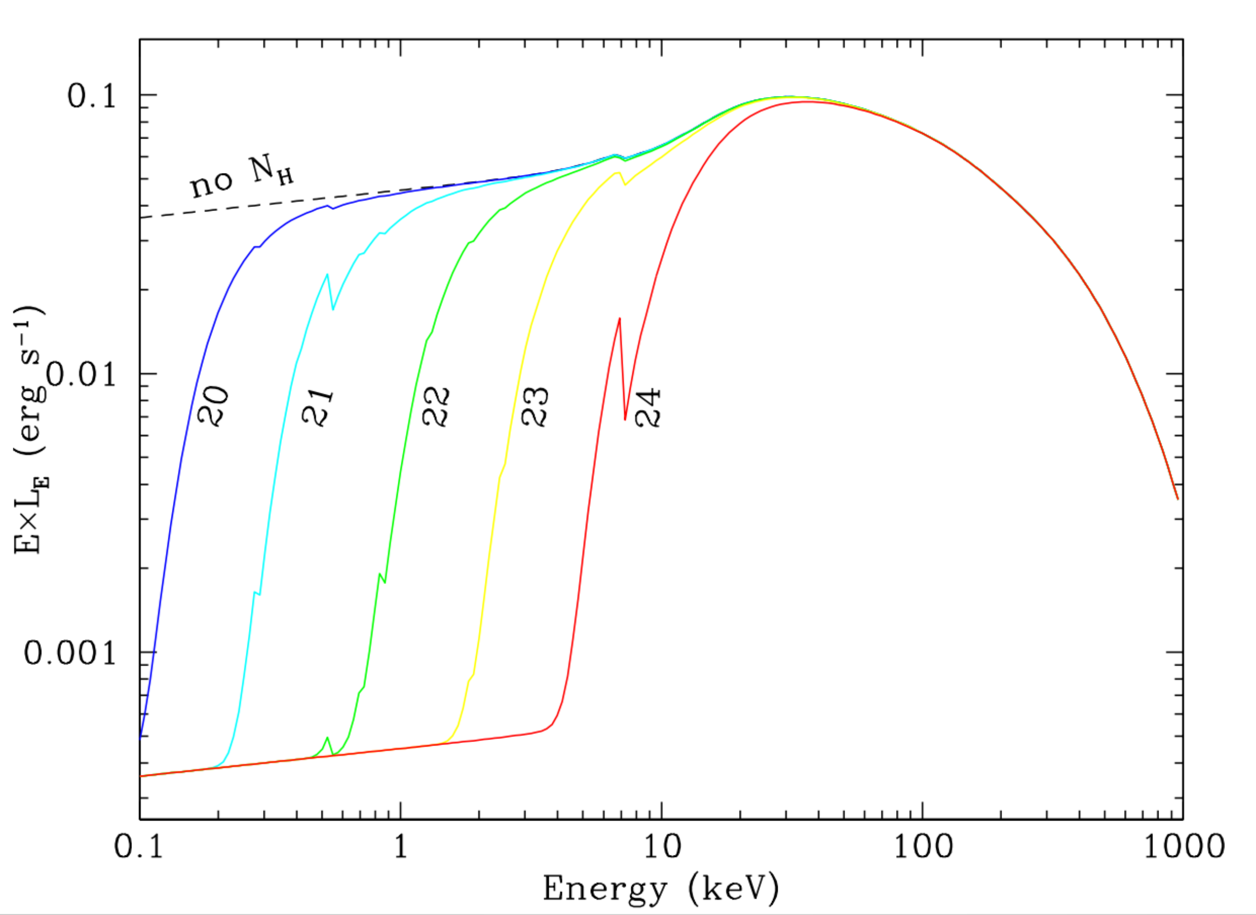

Treister & Urry (2012)

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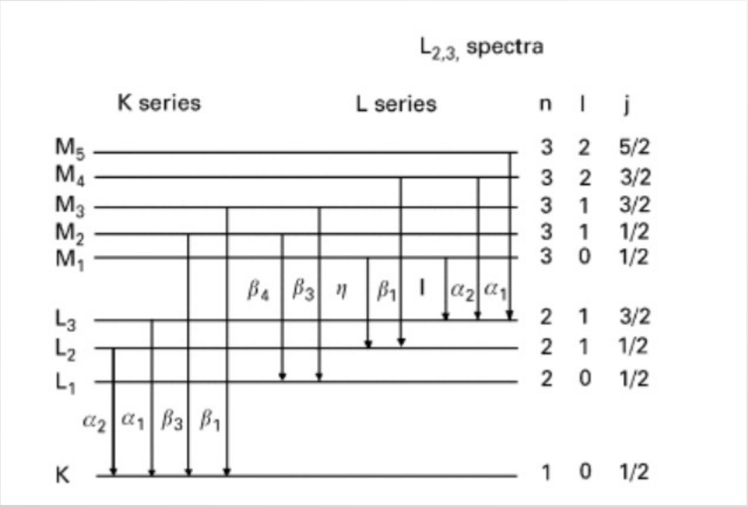
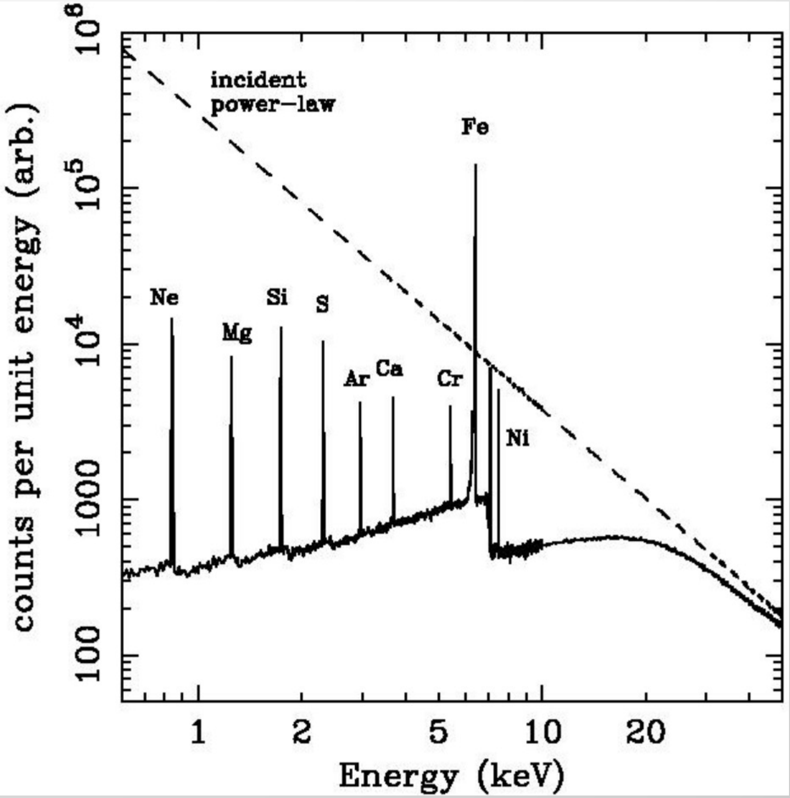
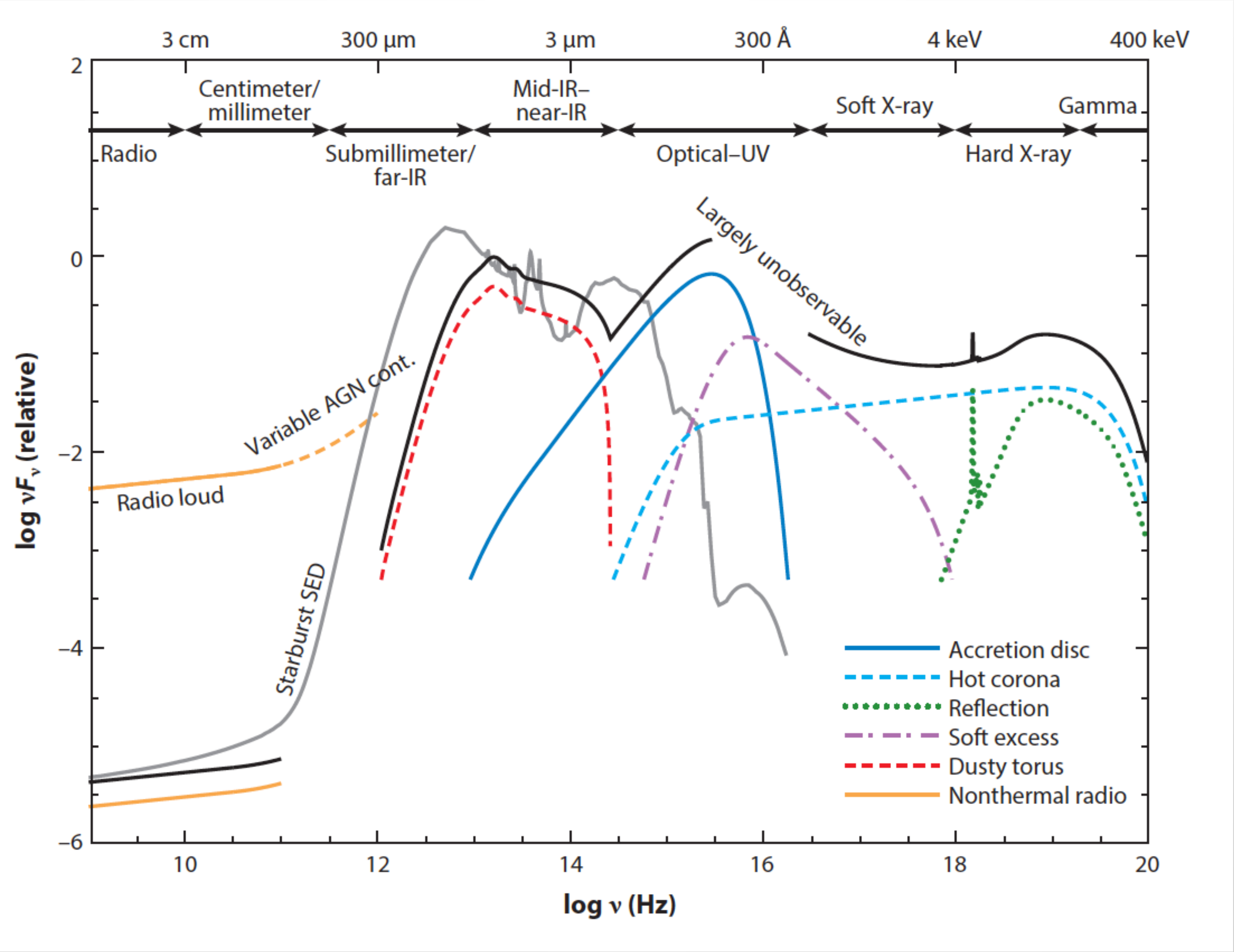




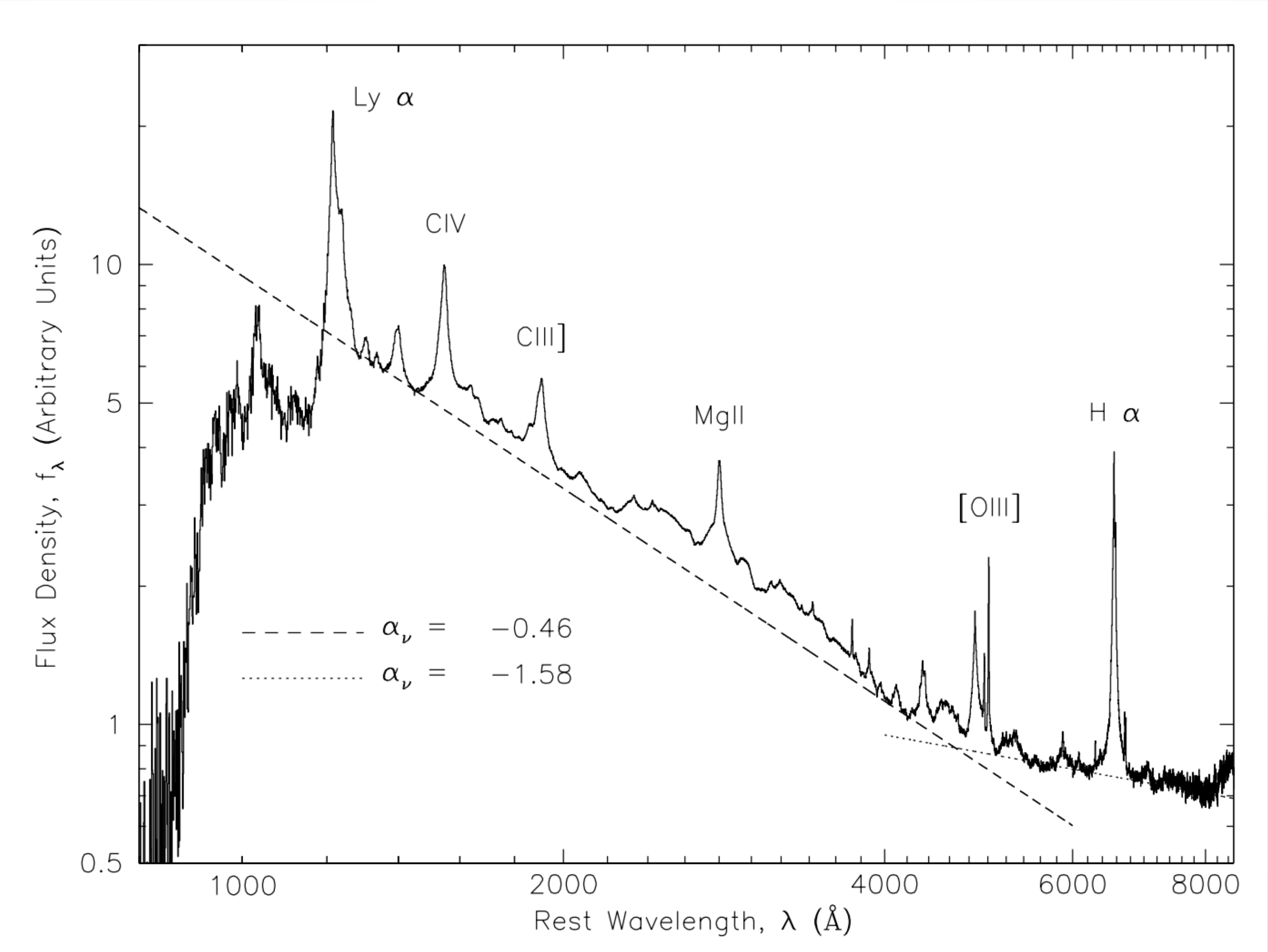
Compton thick AGN are characterized by strong Fe K alpha (inner shell) emission at 6.4 eV linked to reflection. Other lines are weaker.

Finding AGN – a multi-wavelength endeavour



Harrison (2014)

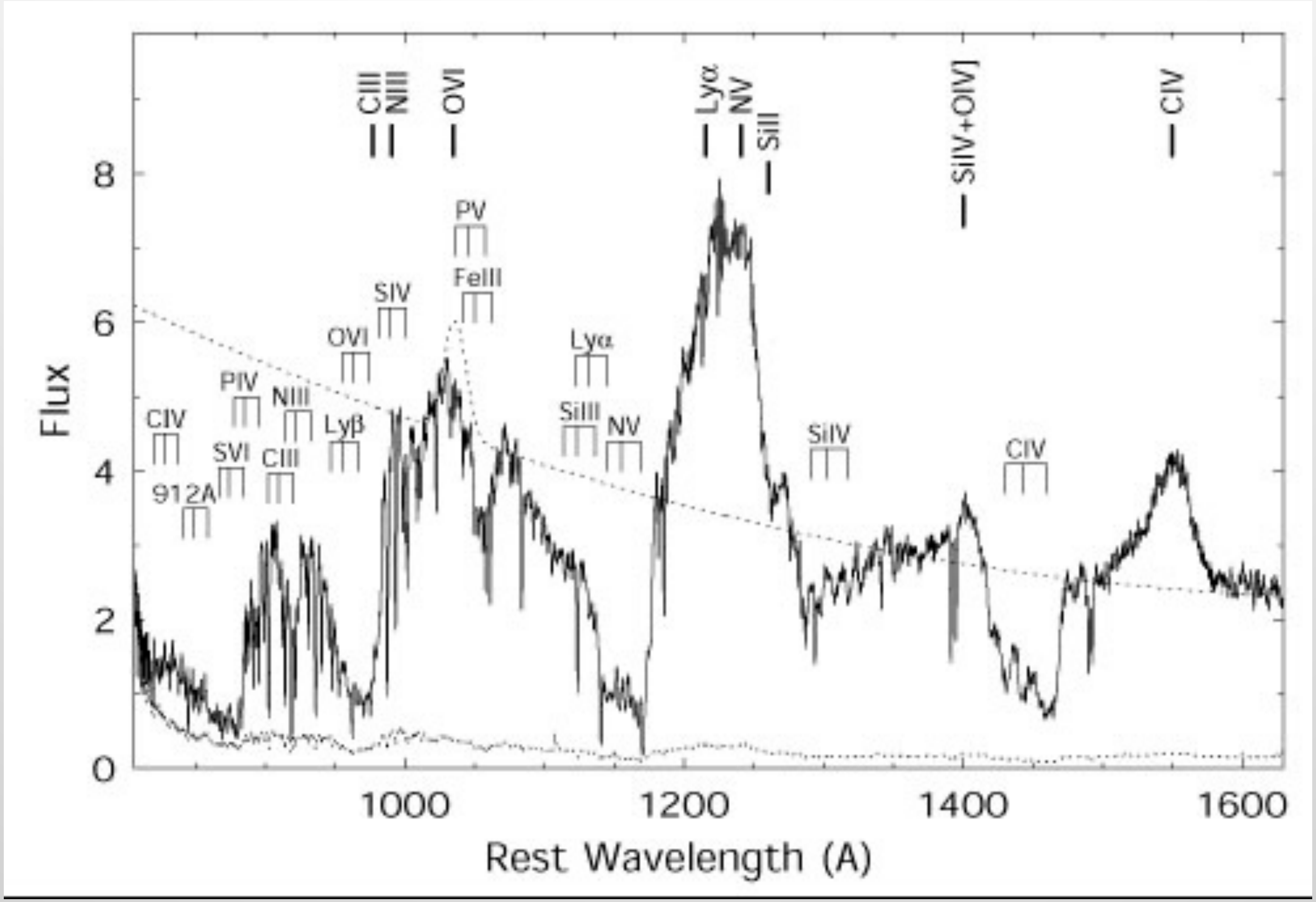
Finding AGN – in the UV/optical



Vanden Berk et al. (2001)

Broad emission lines are a give-away. Composite quasar spectrum from SDSS. Note also the blue power law continuum. Redshift depends on which emission line you use!

Finding AGN – in the UV/optical



Hamann (1998)

Broad absorption lines also sometimes present (BAL QSO) in about 10% of QSOs. Indicative of strong outflows.

Finding AGN – in the UV/optical

High luminosity quasars are easy to spot, but what about lower luminosity AGN?

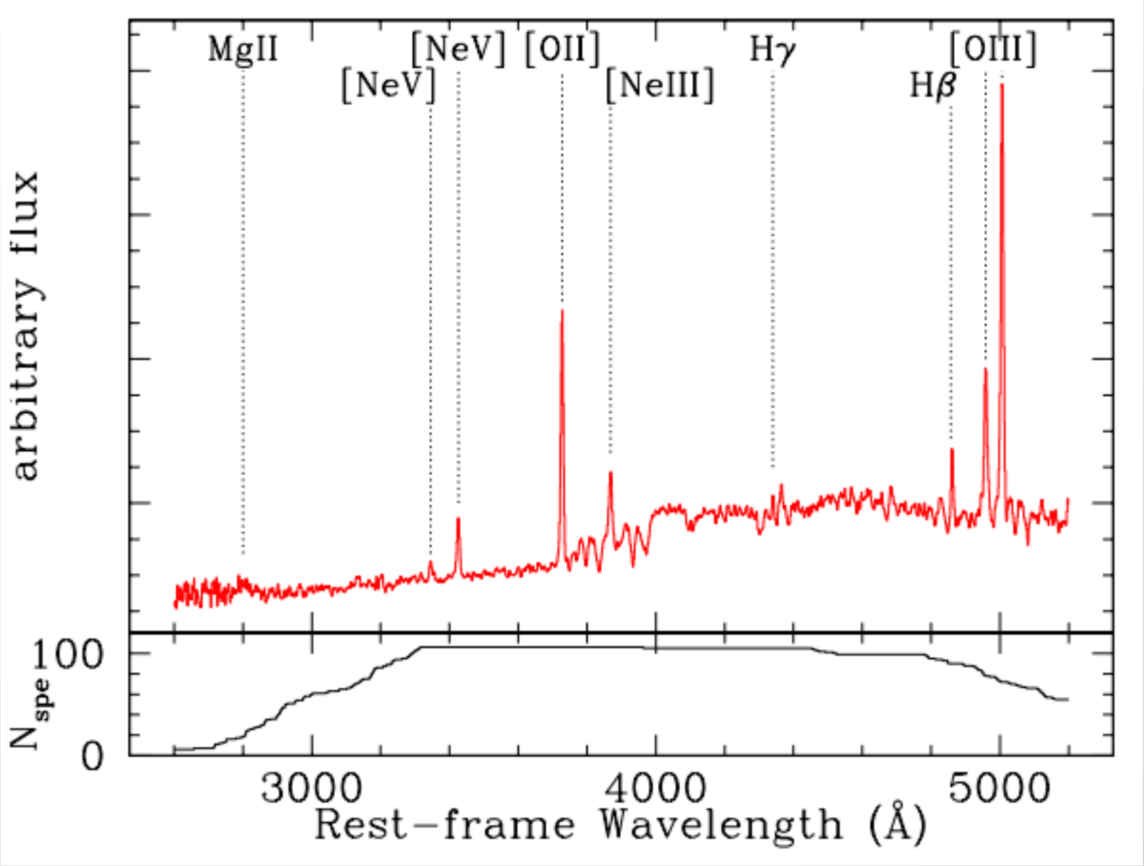
Single high ionization lines indicate AGN, e.g. [NeV] 3426.

Pros:

- Unambiguous signature

Cons:

- Wavelength is a challenge at low z
- Line can be weak (spectrum above is a composite).



Mignoli et al. (2013)

Ratios of strong lines in optical, e.g. BPT diagram

Jargon alert: BPT = Baldwin, Phillips & Terlevich

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CLASSIFICATION PARAMETERS FOR THE EMISSION-LINE SPECTRA OF EXTRAGALACTIC OBJECTS

J. A. BALDWIN AND M. M. PHILLIPS
Cerro Tololo Inter-American Observatory,* Casilla 603, La Serena, Chile

AND

ROBERTO TERLEVICH
Institute of Astronomy, Madingley Road, Cambridge, England CB3 0HA

Received 1980 August 21

An investigation is made of the merits of various emission-line intensity ratios for classifying the spectra of extragalactic objects. It is shown empirically that several combinations of easily-measured lines can be used to separate objects into one of four categories according to the principal excitation mechanism: normal H II regions, planetary nebulae, objects photoionized by a power-law continuum, and objects excited by shock-wave heating. A two-dimensional quantitative classification scheme is suggested.

Key words: H II region—Seyfert galaxies—quasars—spectral classification

Baldwin, Phillips & Terlevich 1981

Ratios of strong lines in optical, e.g. BPT diagram

Jargon alert: BPT = Baldwin, Phillips & Terlevich

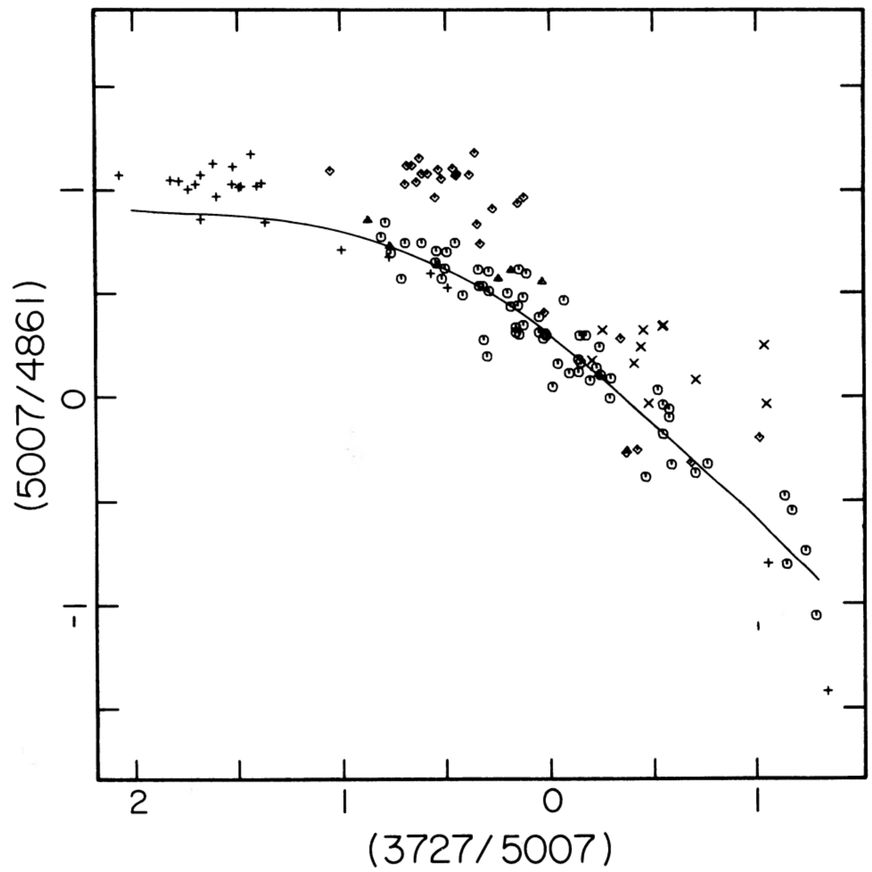
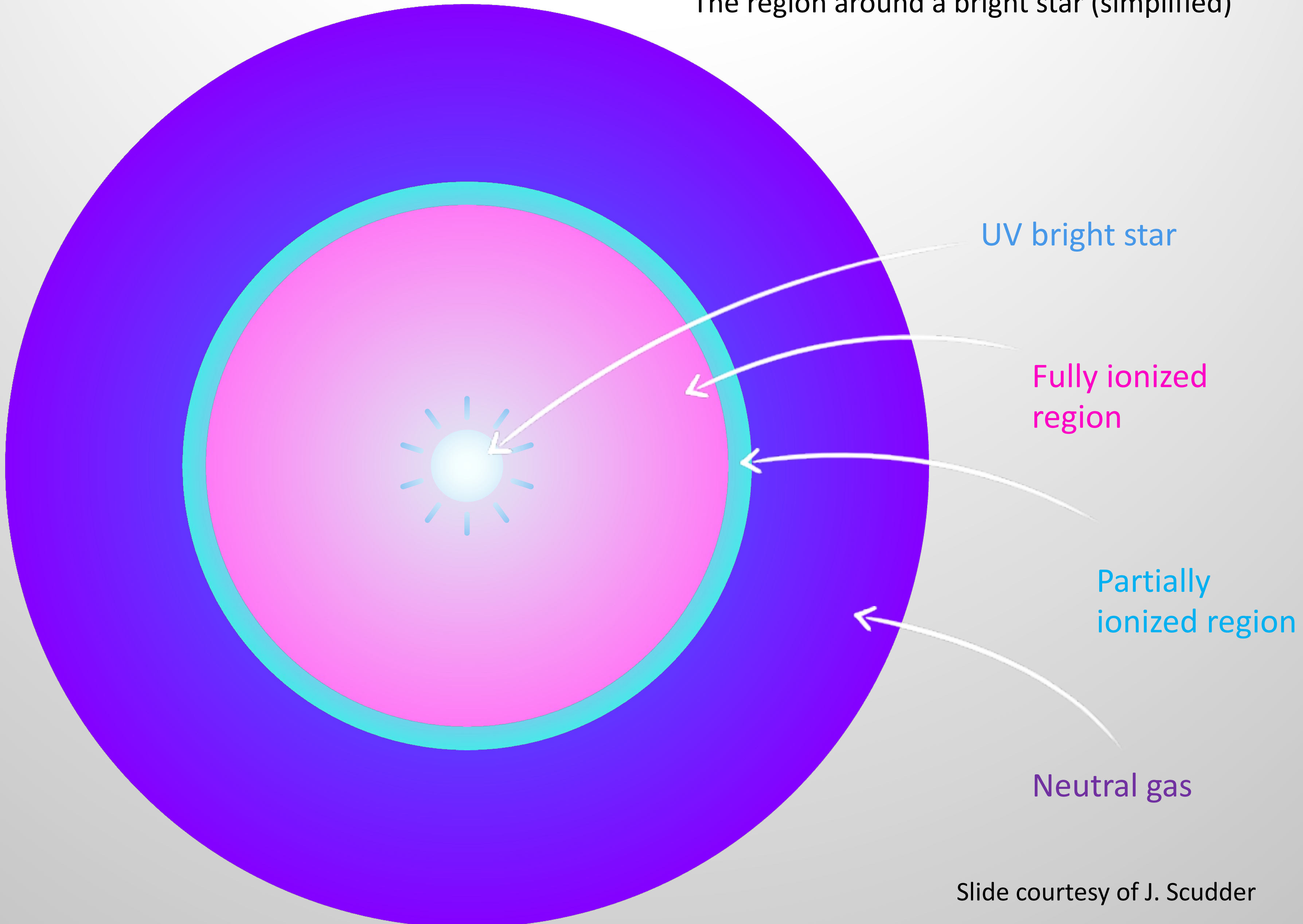


FIG. 2—The same as Figure 1, with the addition of objects photoionized by power laws (shown as diamonds), and shock-heated galaxies (shown as "x"s).

Baldwin, Phillips & Terlevich 1981

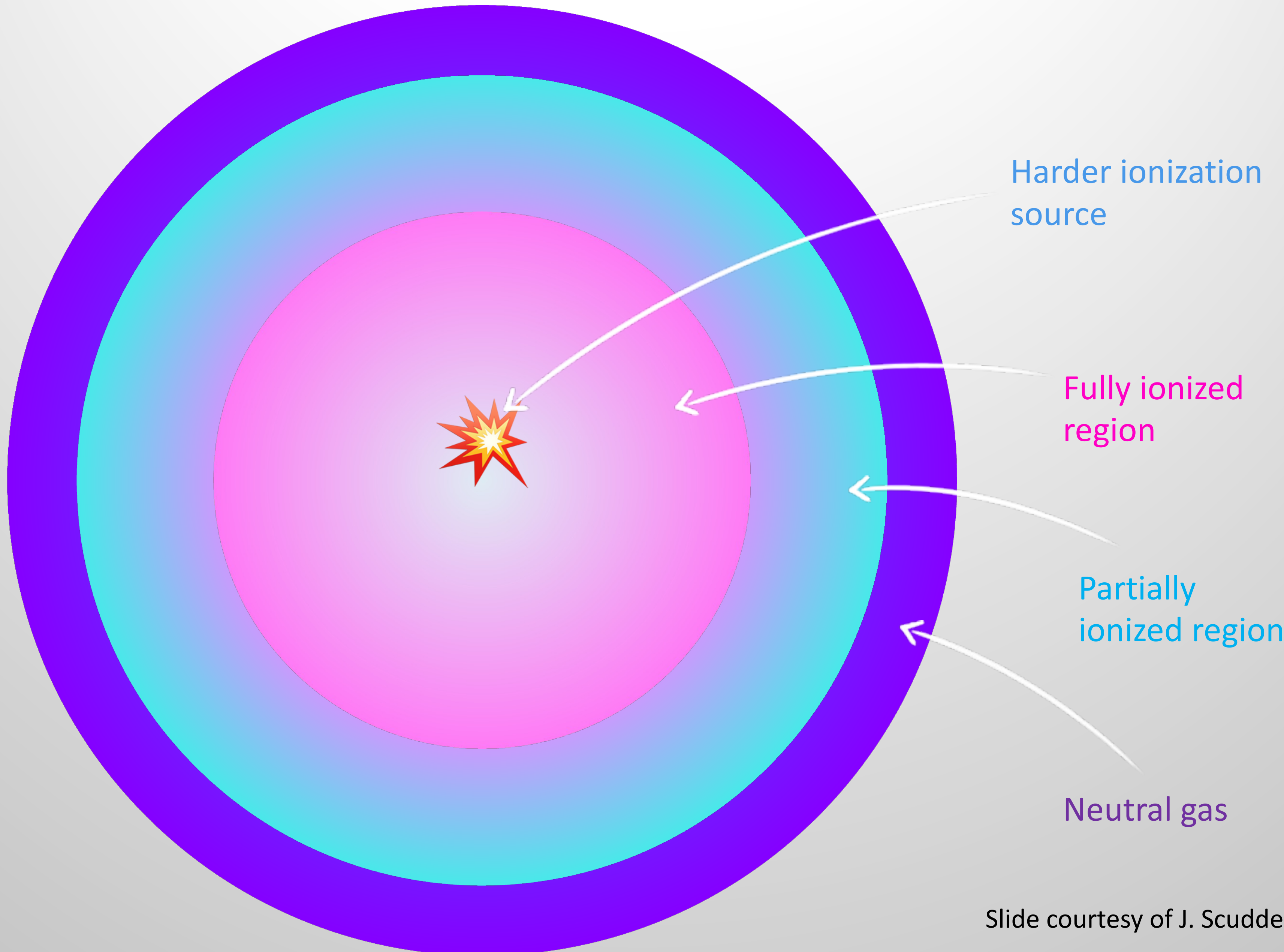
Strömgren spheres

The region around a bright star (simplified)



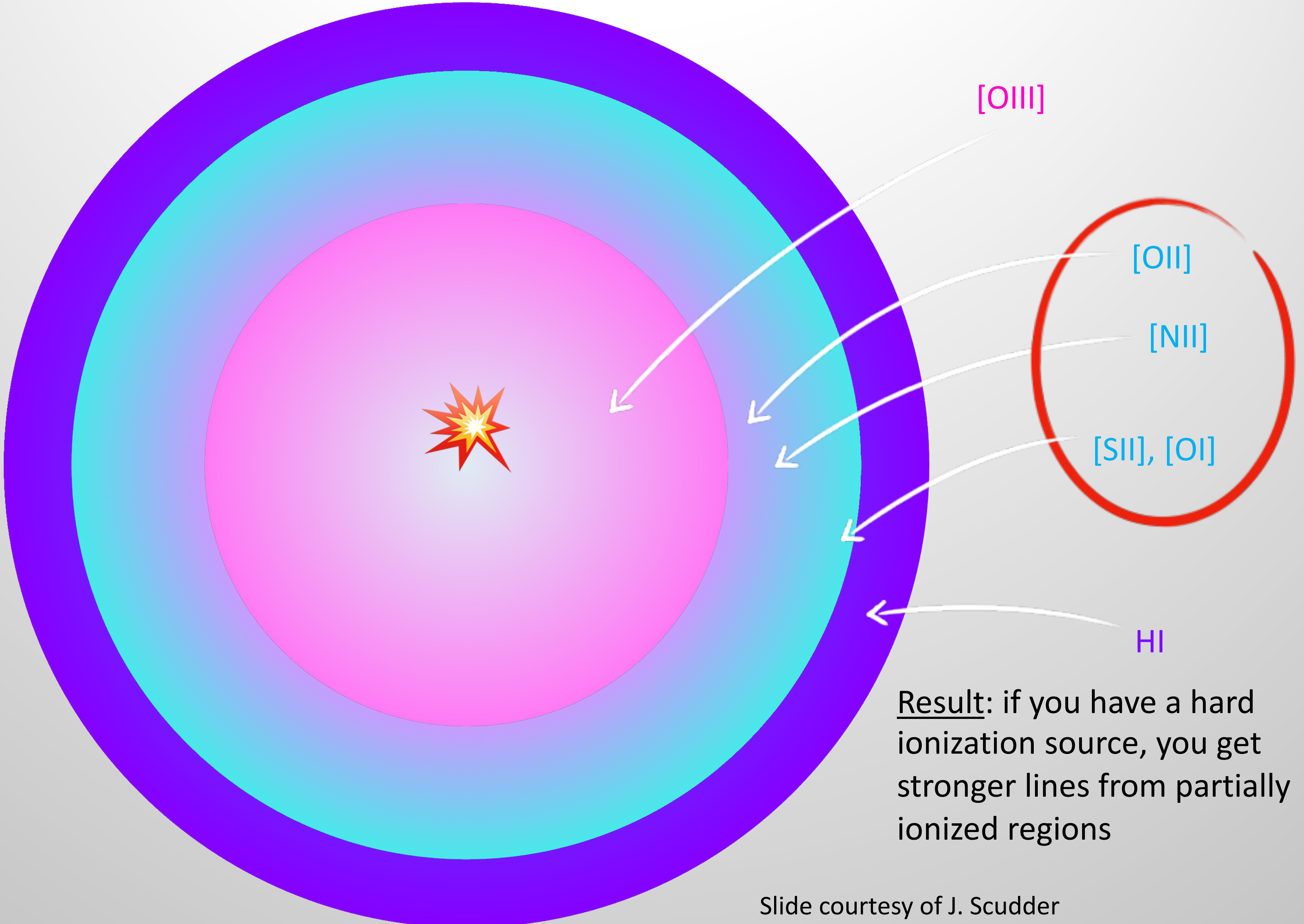
Slide courtesy of J. Scudder

Ionization structure changes if the source does



Slide courtesy of J. Scudder

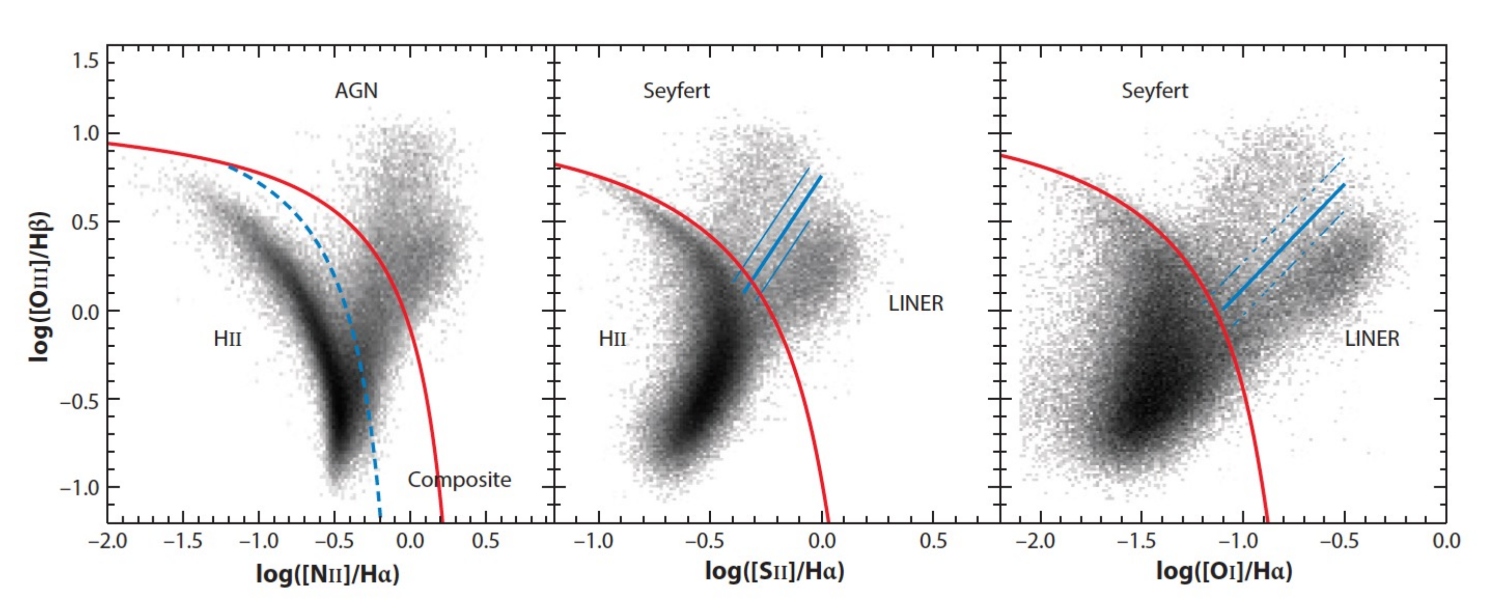
Different emission lines are produced in different zones



Result: if you have a hard ionization source, you get stronger lines from partially ionized regions

Slide courtesy of J. Scudder

Ratios of strong lines in optical, e.g. BPT diagram



Kewley et al. (2006)

Jargon alert: Kewley/Kauffmann lines

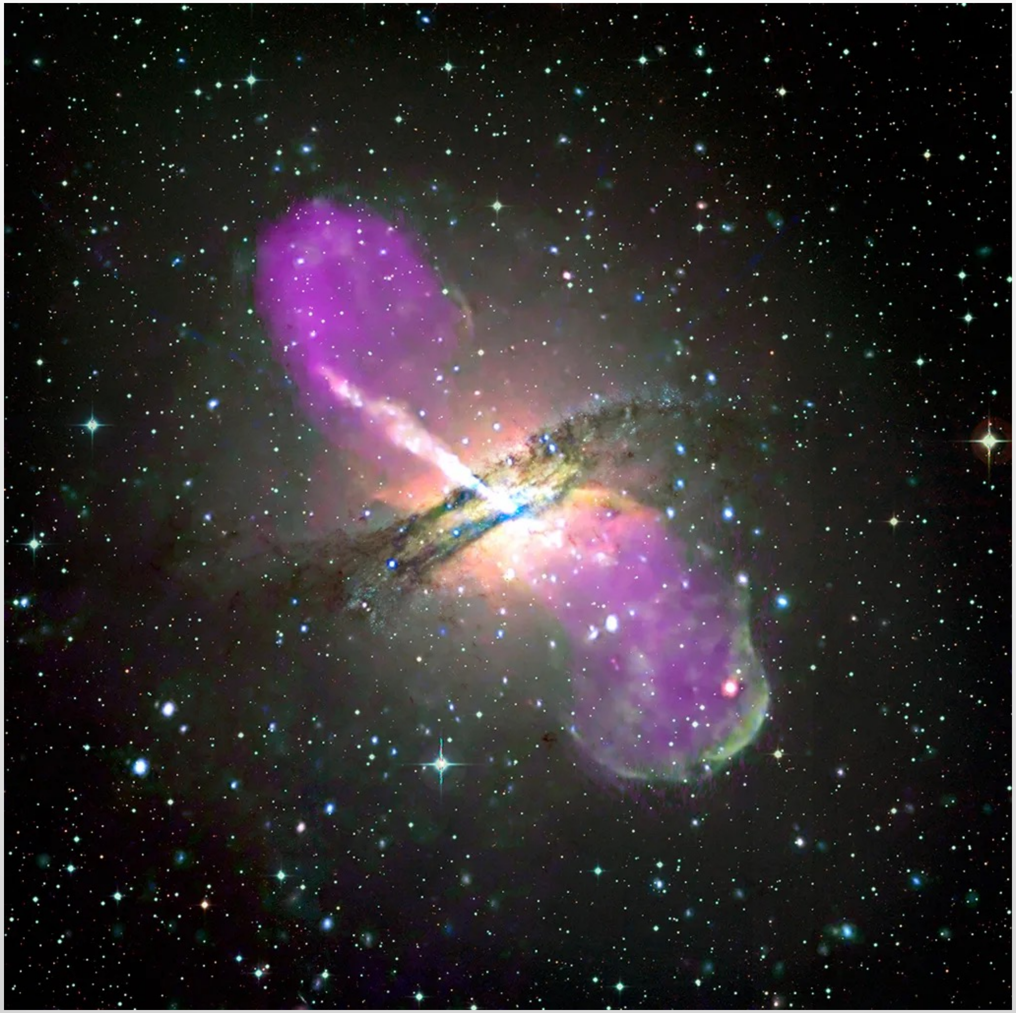
Pros:

- Easily measured for large samples (e.g SDSS) from the ground
- Easy-to-implement (i.e. just measure line fluxes)
- Careful choice of line ratios avoids concern of extinction corrections

Cons:

- Where to draw the line? Dependence on many factors.
- Demarcation lines likely to differ at high z
- Obscuration by dust in host galaxy
- Dilution by star formation (will miss low luminosity AGN)

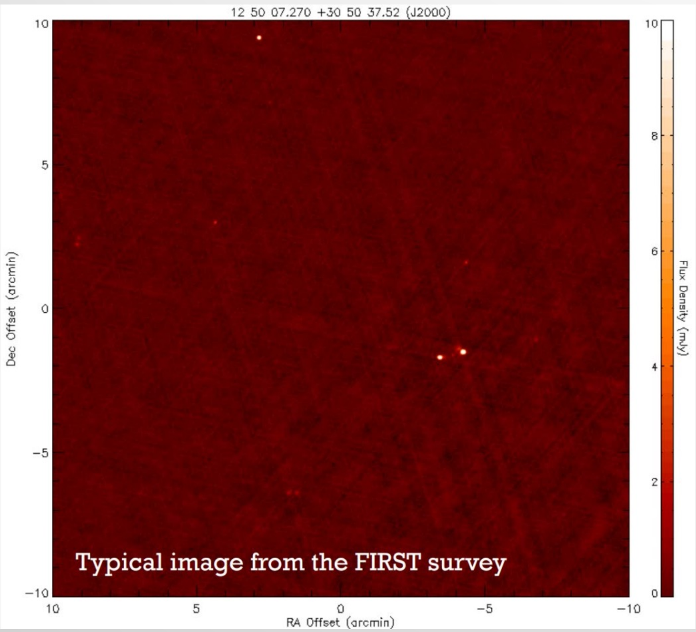
Finding AGN – in the radio

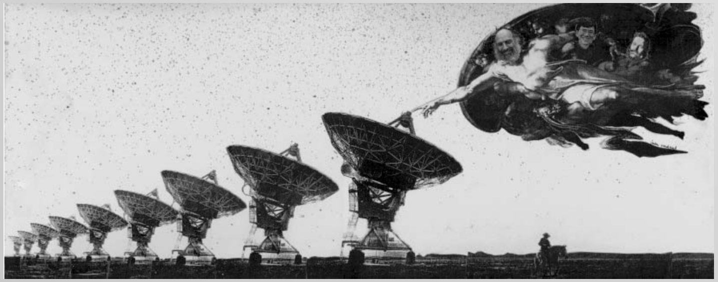


Radio emission comes from jets. Centaurus A (NGC 5128) is one of the closest radio galaxies.

Finding AGN – in the radio

Many of the first QSOs were found in the radio (e.g. 3C survey). The Faint Images of the Radio Sky at Twenty Centimetres (FIRST) survey, done with the VLA was a major contemporary survey finding AGN.





Very modest FIRST architects Becker, Helfand & White.

Radio sources often further divided into HERGs (high excitation radio sources) and LERGs (low excitation radio sources), depending on whether or not they show strong optical emission lines.

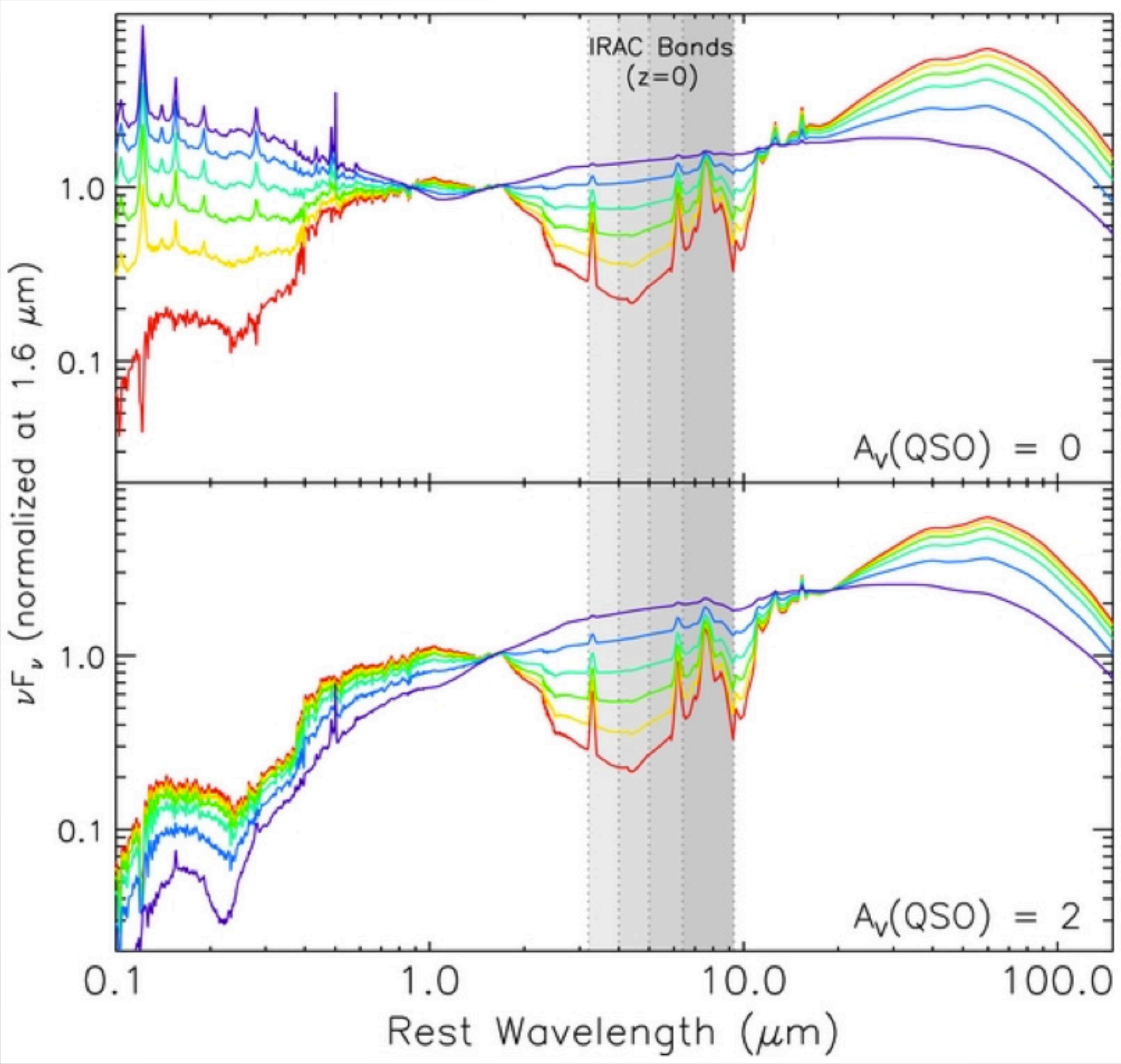
Pros:

- Easy implementation – just find bright point sources.
- Easily done from the ground ("cheap")
- Large modern radio surveys quite sensitive.
- Little contamination from stars
- Positional accuracy generally good for optical follow-up

Cons

- Needs optical follow-up for redshift
- Only about 10% of AGN are radio loud

Finding AGN – in the infra-red



AGN are bright in the mid-IR due to thermal dust emission from torus.

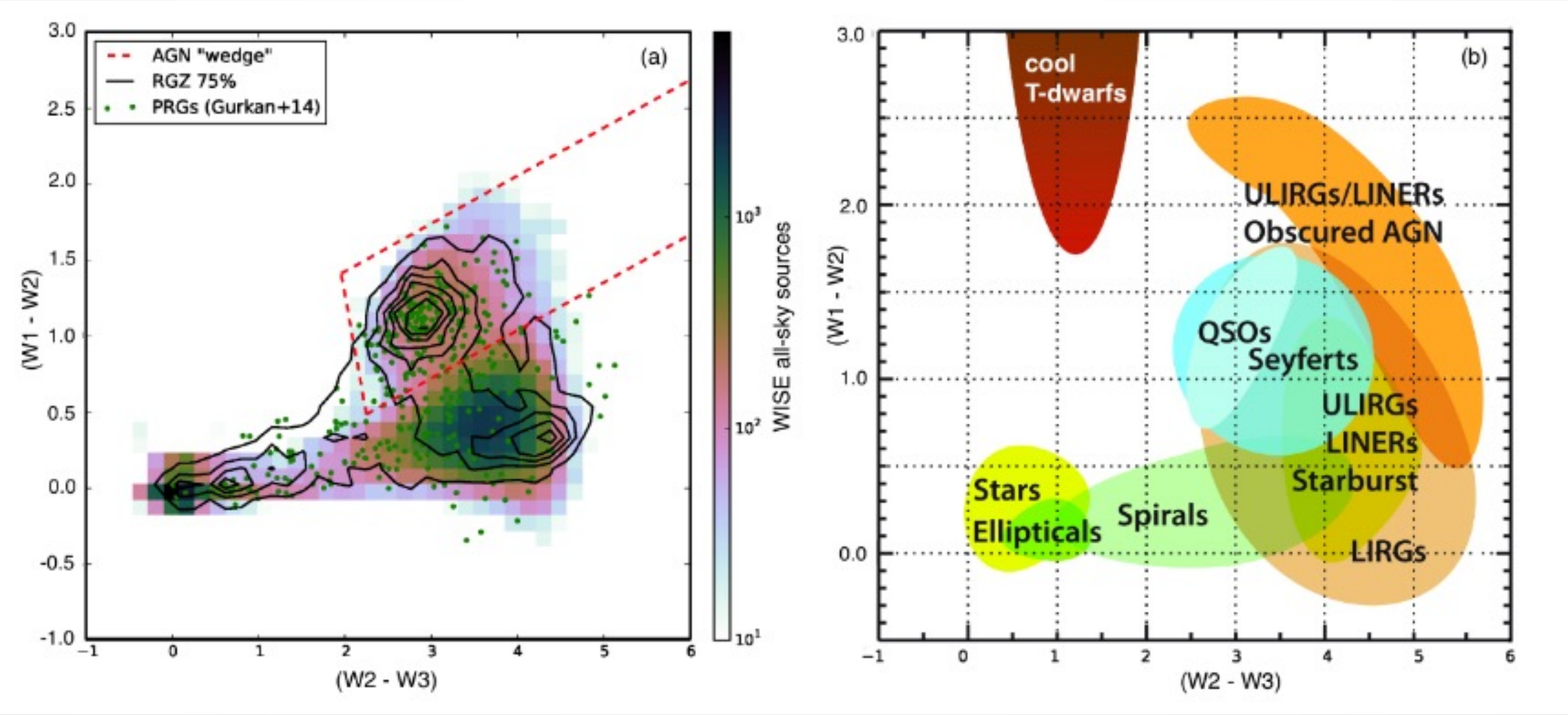
f_{AGN} = 0% (pure SF galaxy)

f_{AGN} = 95% (AGN dominated)

Note that mid-IR colours little affected by dust. Unlike optical photometry, both obscured and unobscured AGN selected with mid-IR

Donley et al. (2012)

The WISE All Sky Survey is a powerful tool for AGN identification



Pros:

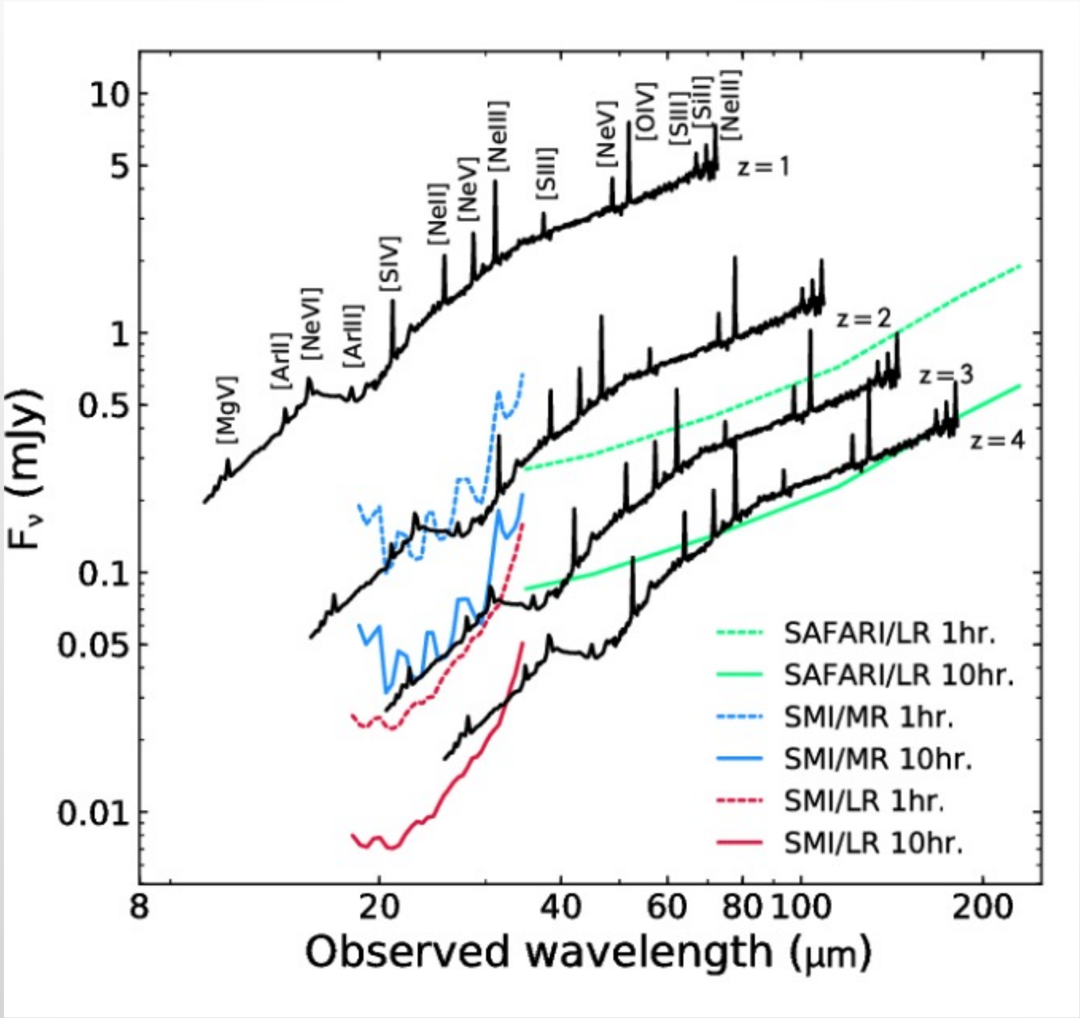
- Measuring colours is easy
- Select obscured and unobscured AGN
- Photometry is cheap
- WISE All sky survey gives large samples

Cons:

- AGN must be bolometrically dominant
- High z SF galaxies can have same colours as AGN, causing contamination

Jargon alert: W1=3.4 microns, W2=4.6 microns, W3=12 microns

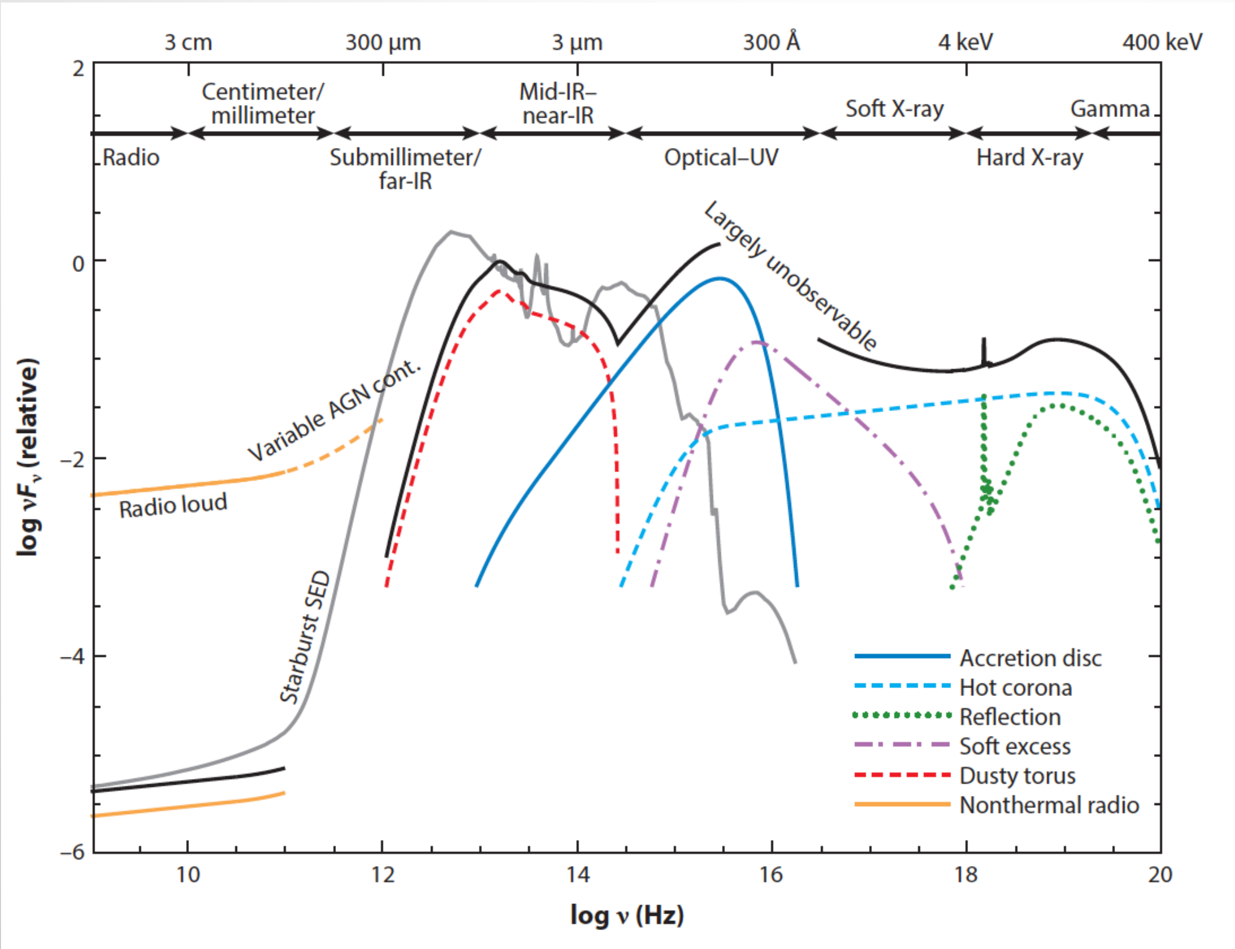
Lower luminosity AGN can be found through single line emission



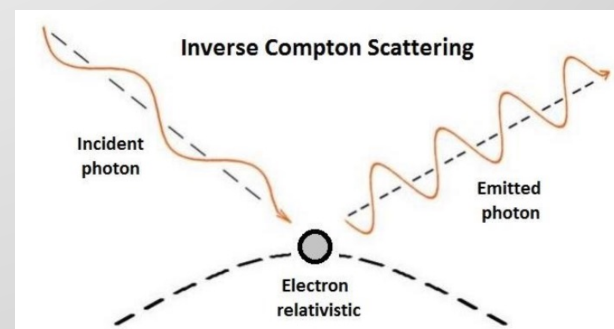
Spinoglio et al (2017)

Currently, mid-IR spectroscopy is very challenging – JWST will be game changer!

Finding AGN – in the X-ray



X-rays don't come from the accretion disk itself, but from the corona. The X-ray emission is generated by inverse Compton scattering of photons from the accretion disk.



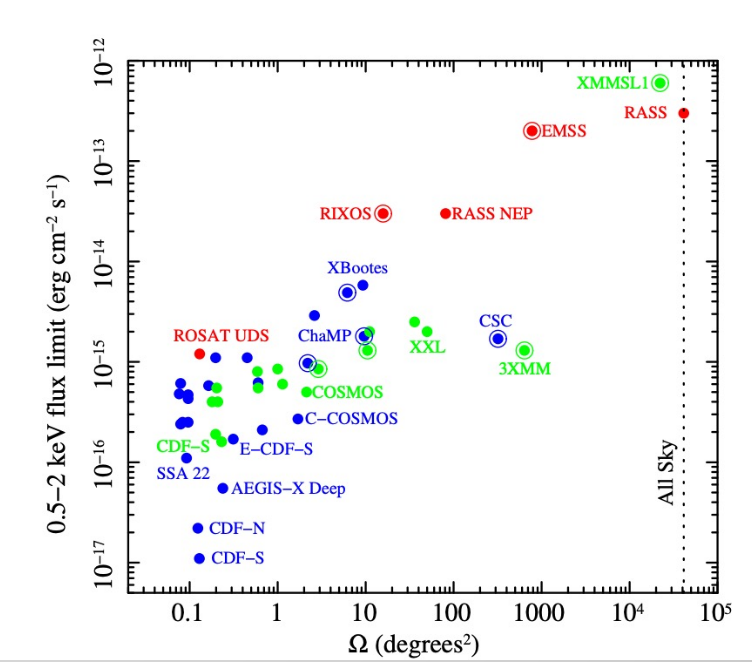
Finding AGN – in the X-ray

Pros:

- X-ray emission expected to be fairly universal.
- Selection is very simple: Point source with L_x (0.5-10 keV) > 10^{42} erg/s
- Relatively little contamination from stars
- Hard X-rays unaffected by obscuration for NH < 10^{24} cm^{-2}

Cons:

- Requires space based observations.
- Lower luminosity AGN need to be distinguished from host galaxy sources (e.g. X-ray binaries)
- No all sky surveys deep enough to generate large samples (but eROSITA is coming!).
- Figuring out obscuration (N(H)) requires spectral fitting, which is costly.
- Low luminosity obscured AGN very weak in soft X-rays – easily missed.



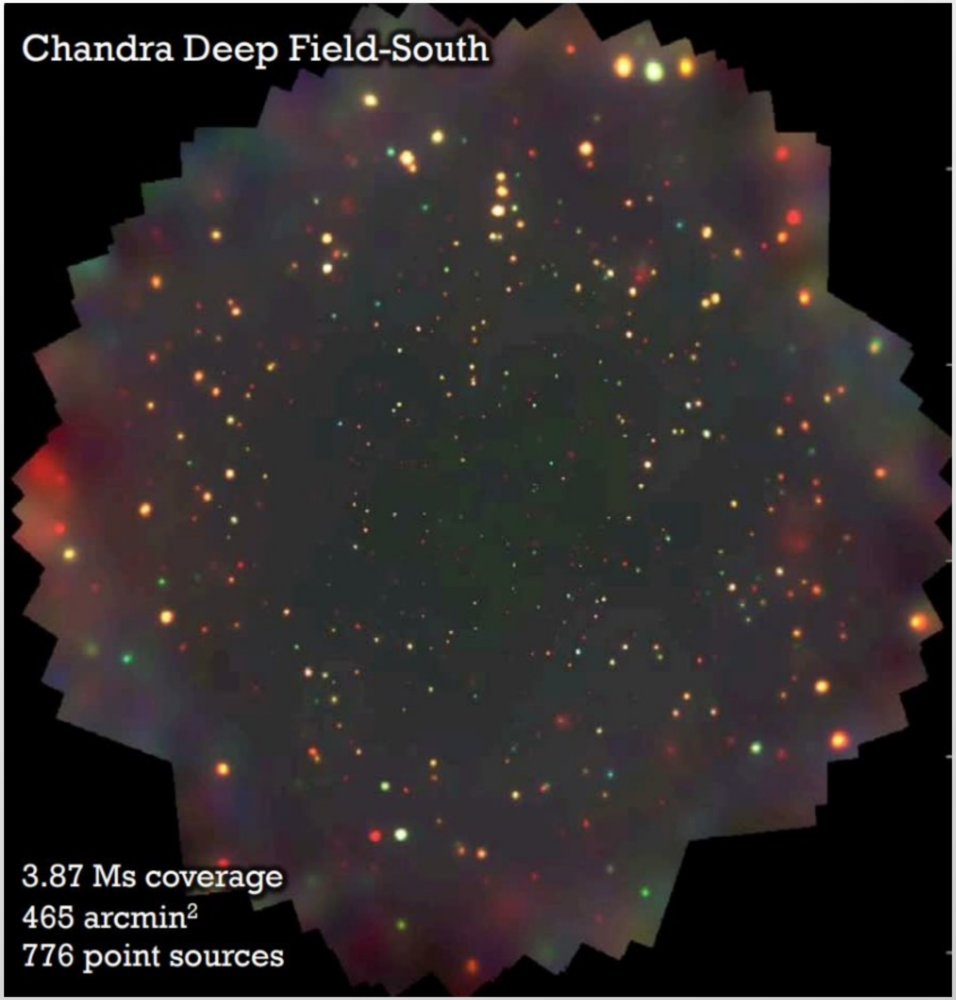
Review on X-ray AGN surveys by Brandt & Alexander (2015)

Finding AGN – in the X-ray

Chandra (NASA) and XMM-Newton (ESA) have been workhorse telescopes in the 0.05 – 15 keV range.

NuSTAR works in the hard X-rays (3-79 keV) and has been particularly vital in identifying Compton thick AGN that are invisible in the soft X-rays.

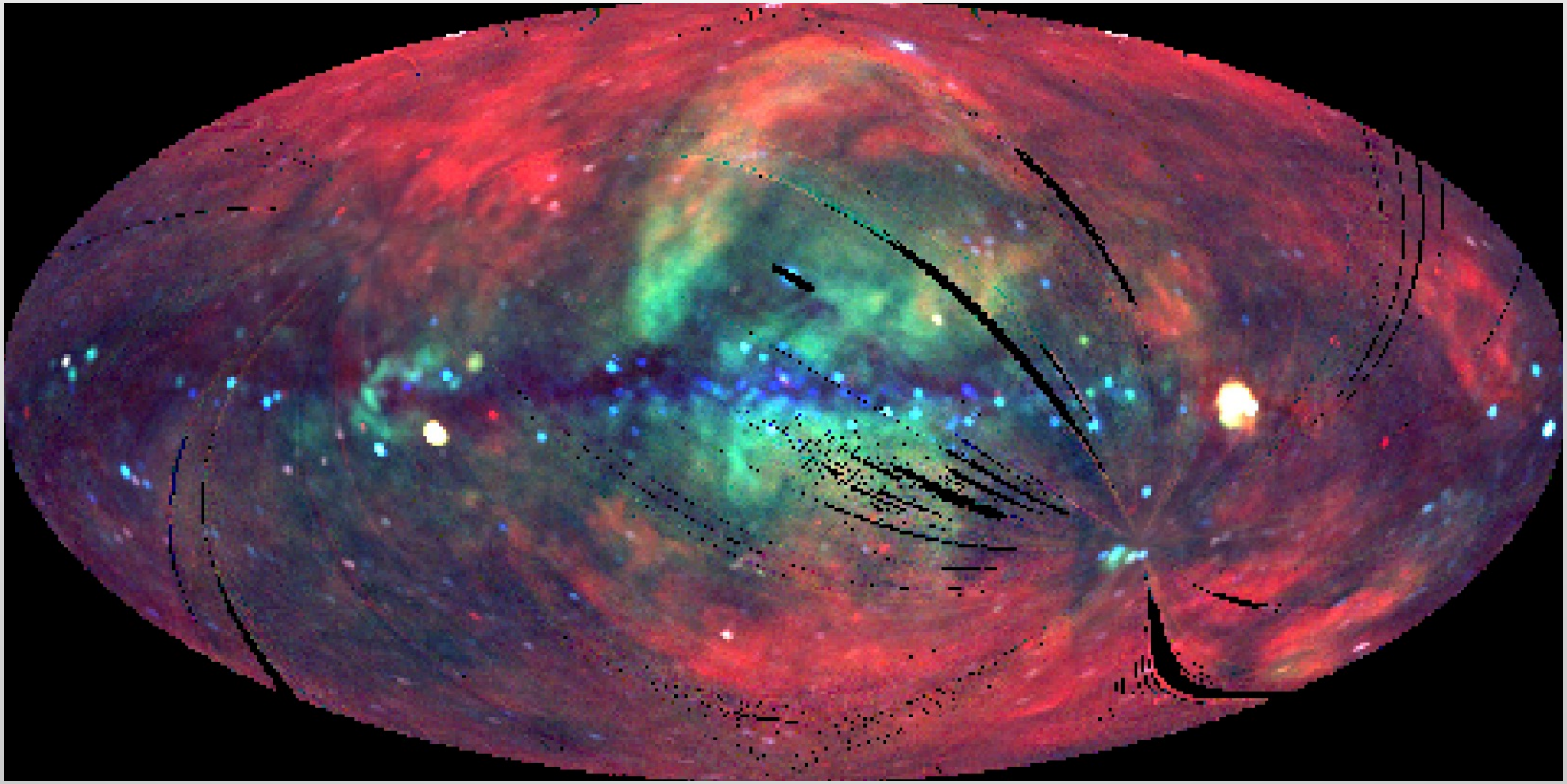
None of these designed as all sky/survey instruments.



Xue et al. (2011)

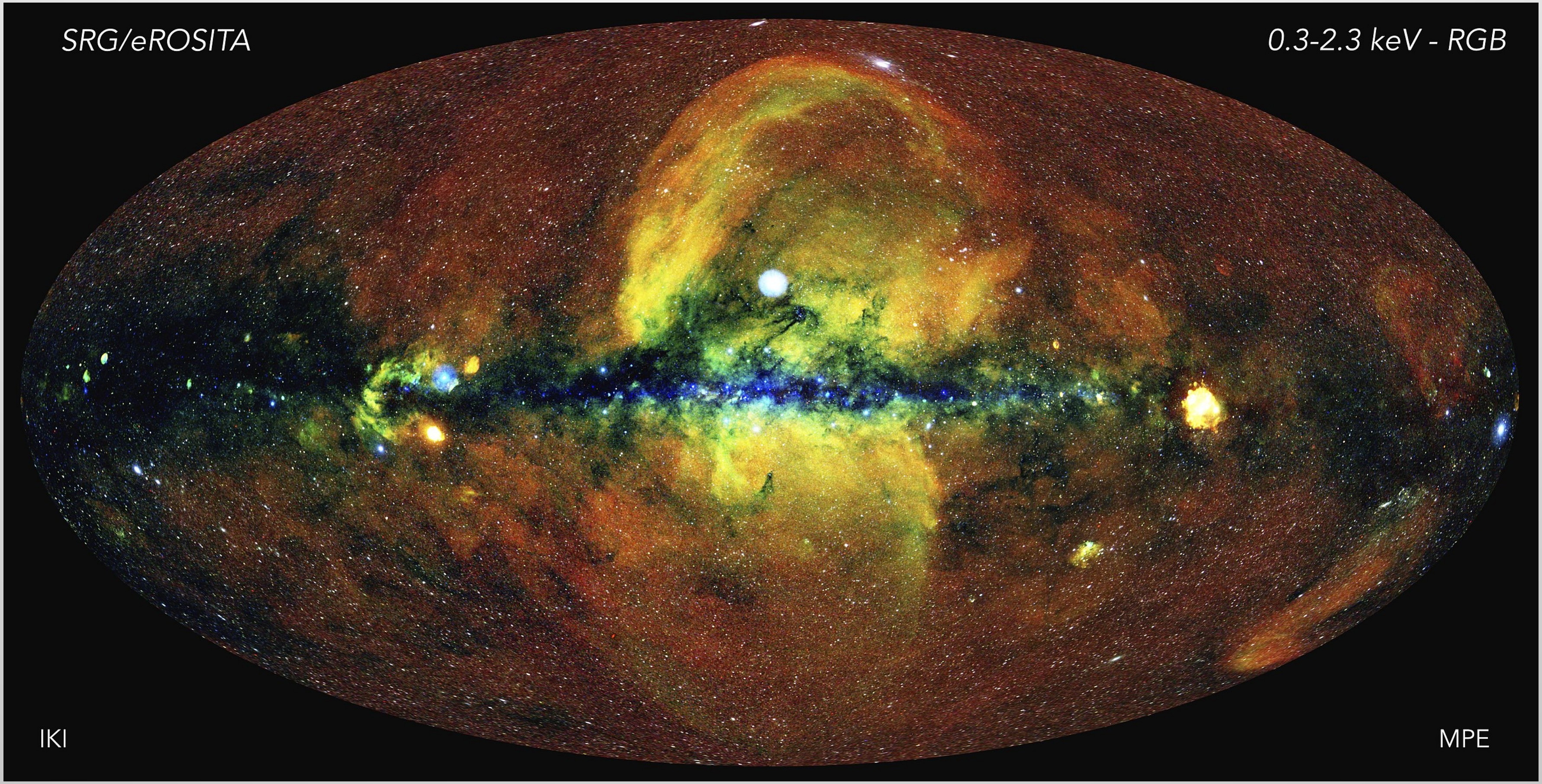
Finding AGN – in the X-ray

ROSAT (1990-91) conducted the first all sky X-ray survey, but was very shallow (and hence incomplete). Detected ~60,000 sources.

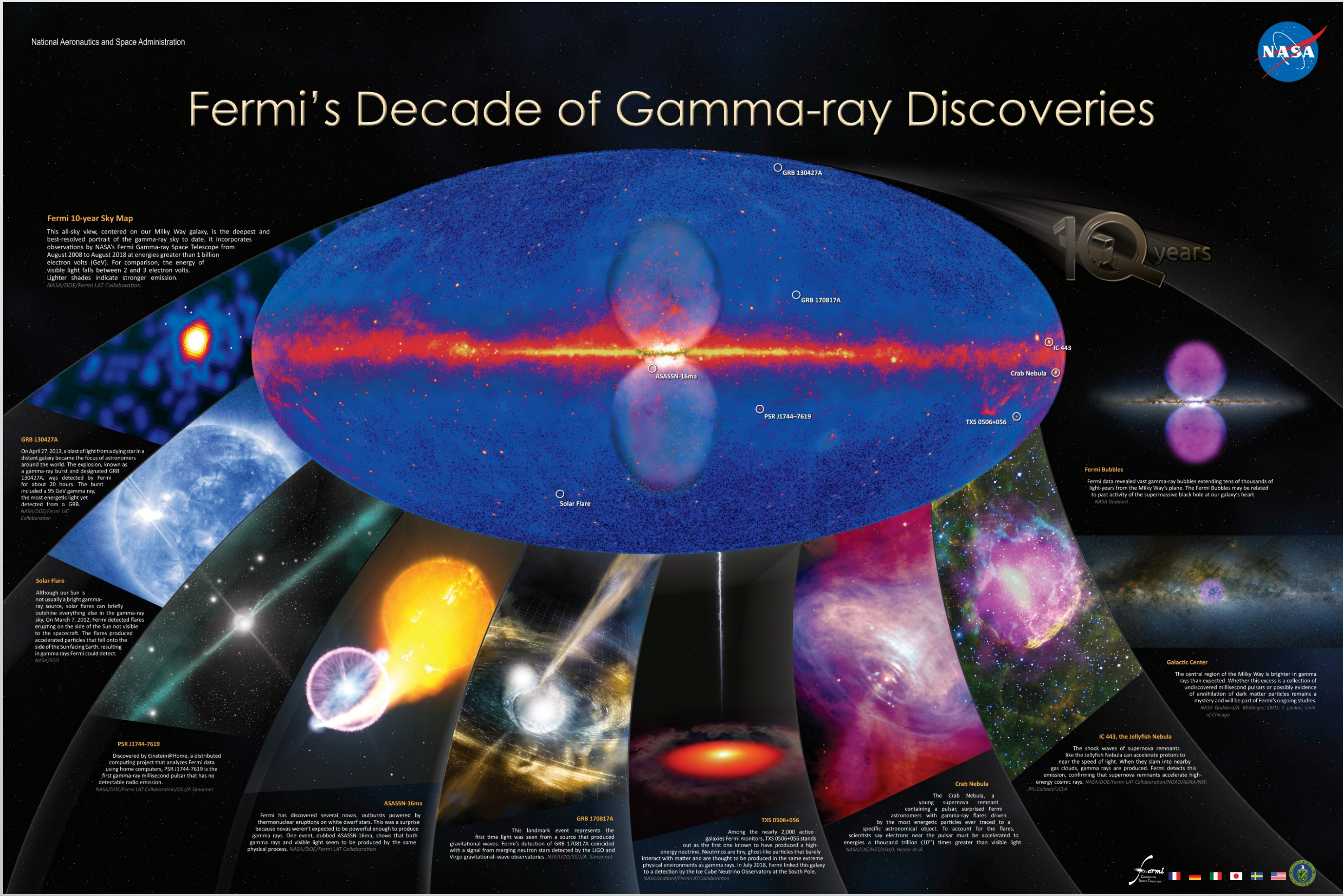


Finding AGN – in the X-ray

eROSITA was launched in 2019 as a joint German-Russian collaboration that will eventually be 25 times more sensitive than ROSAT. The first data release revealed huge X-ray bubbles around the Milky Way.



Finding AGN – in the gamma-ray



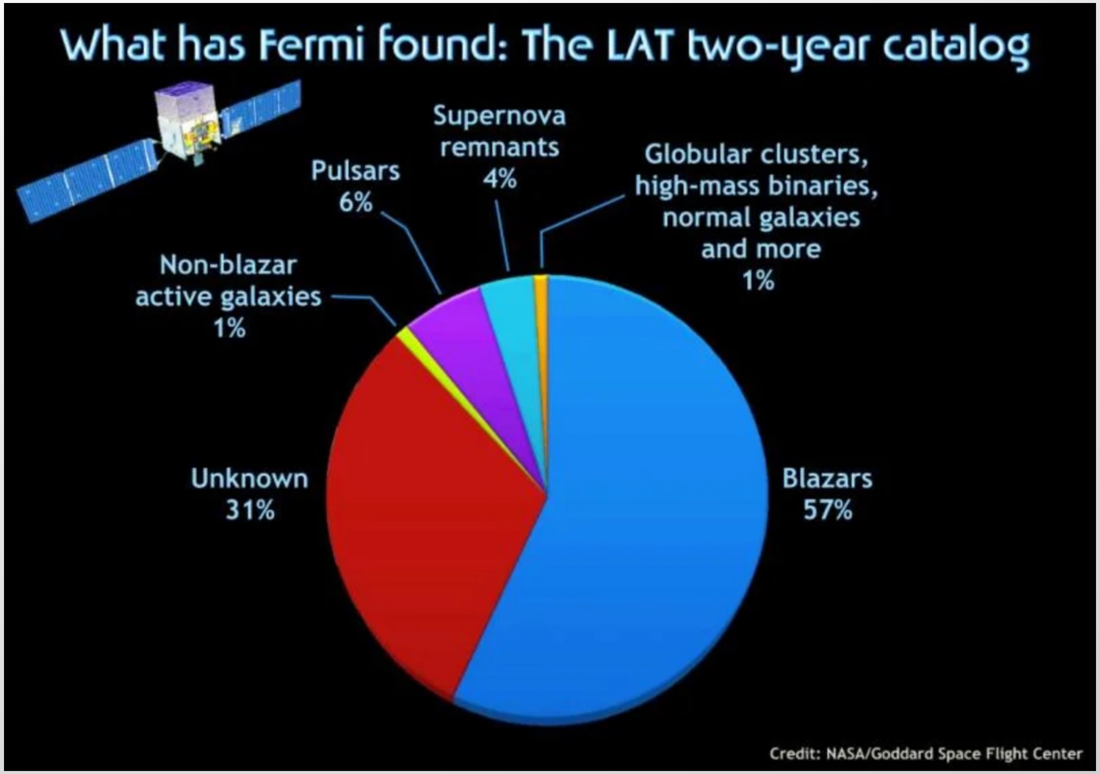
Finding AGN – in the gamma-ray

Pros:

- Relatively little contamination from other sources.

Cons:

- Must be done from space.
- Poor spatial accuracy (makes optical redshift follow-up a challenge)
- Gamma ray detections mostly find blazars, i.e. down the barrel of the jet, so samples are incomplete



Summary

- Black holes exist in essentially all massive galaxies (and likely many dwarfs). This means that the engine for the AGN is omnipresent.

- The central supermassive black hole's mass correlates with galaxy properties – understanding BH growth via accretion (i.e. AGN) is thus an important topic in the field of galaxy evolution.

- AGN accretion is relatively efficient (don't need a high rate to be luminous) and can be triggered by a variety of mechanisms, including mergers.

- There is a confusing menagerie of classifications! One broad distinction is between obscured and unobscured AGN. The Unified Model proposes that all classes can be reconciled by viewing angle

- Observing AGN is a multi-wavelength endeavour. Various issues in identification include "outshining" and obscuration. A full census likely requires many complementary approaches.