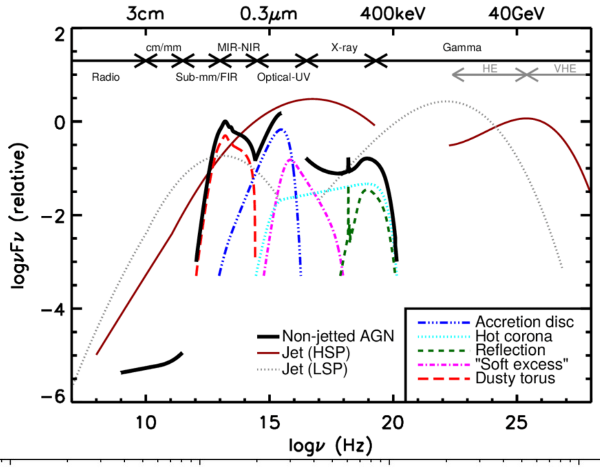
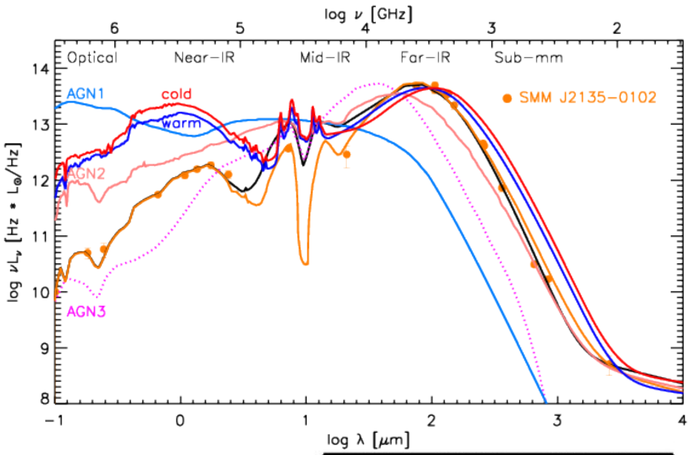
AGN SED & BH-galaxy Co-evolution

Astrophysics X-ray Lab course 2021/2022

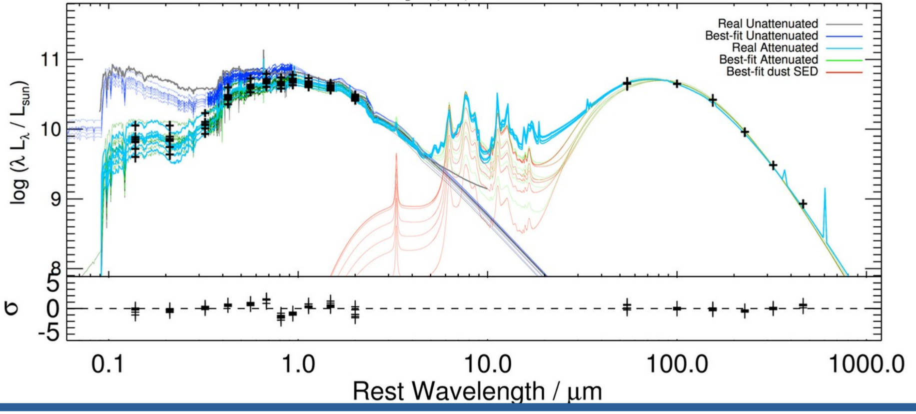
SED: Spectral Energy Distribution

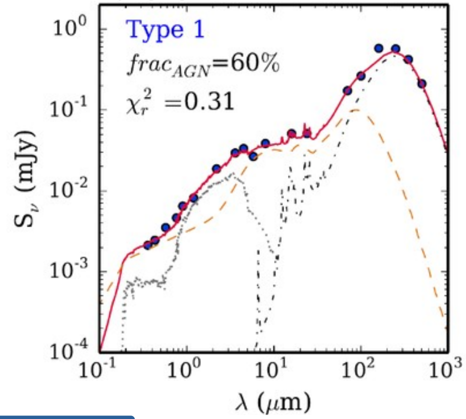
- Overall shape of the AGN emission
- ~ low resolution spectrum





- F_ν → (erg/s/cm^2/Hz), (Jy)
- νF_ν → (erg/s/cm^2), (Jy·Hz)
- F_λ → (erg/s/cm^2/um)
- λF_λ → (erg/s/cm^2)





1 Jy = 10^{-23} erg/s/cm^2/Hz

1 Hz = 4.1357 ·10^{-18} keV

Units conversion tool: https://heasarc.gsfc.nasa.gov/cgi-bin/Tools/energyconv/energyConv.pl

Usuful conversion tables

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Energy Unit Conversion

TO → FROM↓	λ(Å)	$\lambda(\mu m)$	λ(cm)	ν(Hz)	E(keV)	WN(cm^{-1})	E(erg)
λ(Å)	1	$10^{-4}\lambda$	$10^{-8}\lambda$	$3.00\times10^{18}/\lambda$	$12.4/\lambda$	$10^{8}/\lambda$	$1.99\times10^{-8}/\lambda$
$\lambda(\mu m)$	$10^{4}\lambda$	1	$10^{-4}\lambda$	$3.00\times10^{14}/\lambda$	$1.24\times10^{-3}/\lambda$	$10^{4}/\lambda$	$1.99\times10^{-12}/\lambda$
λ(cm)	$10^{8}\lambda$	$10^{4}\lambda$	1	$3.00\times10^{10}/\lambda$	$1.24\times10^{-7}/\lambda$	$1/\lambda$	$1.99\times10^{-16}/\lambda$
ν(Hz)	$3.00\times10^{18}/\nu$	$3.00\times10^{14}/\nu$	$3.00\times10^{10}/\nu$	1	$4.14\times10^{-18}\nu$	$3.34\times10^{-11}\nu$	$6.63\times10^{-27}\nu$
E(keV)	$12.4/E$	$1.24\times10^{-3}/E$	$1.24\times10^{-7}/E$	$2.42\times10^{17}E$	1	$8.07\times10^{6}E$	$1.60\times10^{-9}E$
WN(cm^{-1})	$10^{8}/WN$	$10^{4}/WN$	$1/WN$	$3.00\times10^{10}WN$	$1.24\times10^{-7}WN$	1	$1.99\times10^{-16}WN$
E(erg)	$1.99\times10^{-8}/E$	$1.99\times10^{-12}/E$	$1.99\times10^{-16}/E$	$1.51\times10^{26}E$	$6.24\times10^{8}E$	$5.03\times10^{15}E$	1

Usuful conversion tables

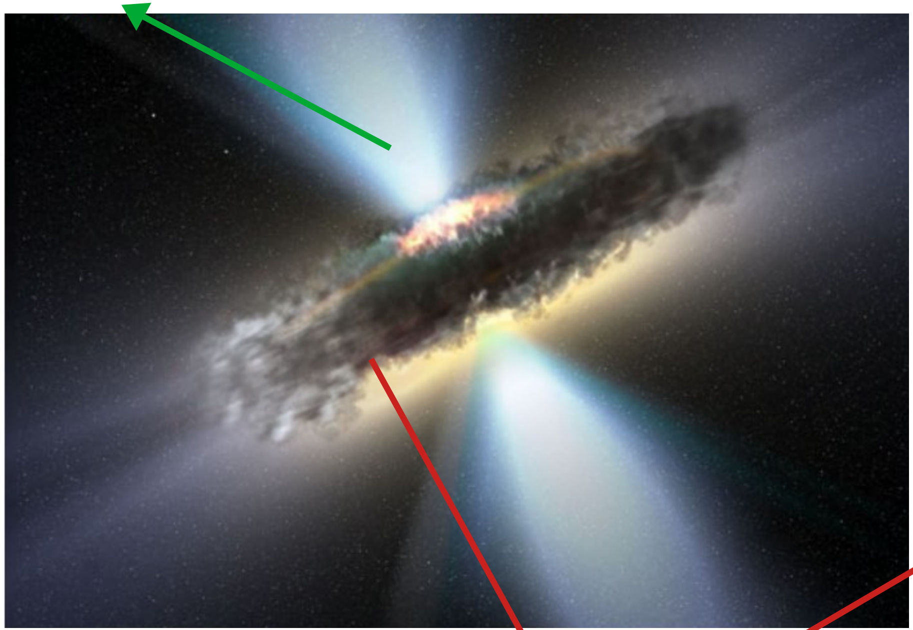
Flux Density Conversion (E in keV; λ in Å)

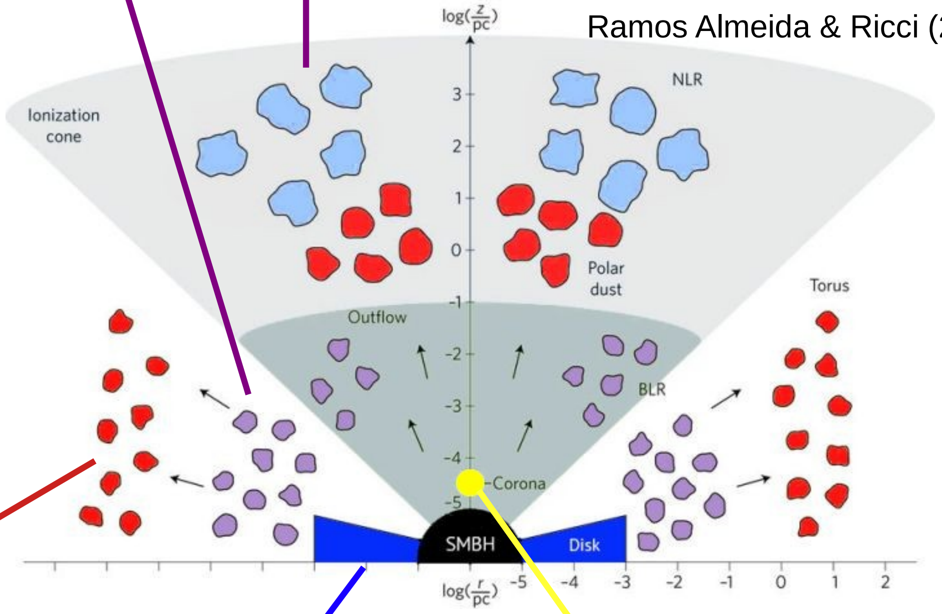
TO → FROM ↓	S_ν(Jy)	$f_E\ \left(\frac{\text{photons}}{\text{cm}^2\,\text{s keV}}\right)$	$f_\lambda\ \left(\frac{\text{photons}}{\text{cm}^2\,\text{s Å}}\right)$	$F_\lambda\ \left(\frac{\text{ergs}}{\text{cm}^2\,\text{s Å}}\right)$	$F_\nu\ \left(\frac{\text{ergs}}{\text{cm}^2\,\text{s Hz}}\right)$
S_ν(Jy)	S_ν(Jy)	$1.51 \times 10^3 S_\nu/E$	$1.51 \times 10^3 S_\nu/\lambda$	$3.00 \times 10^{-5} S_\nu/\lambda^2$	$10^{-23} S_\nu$
$f_E\ \left(\frac{\text{photons}}{\text{cm}^2\,\text{s keV}}\right)$	$6.63 \times 10^{-4} E f_E$	f_E	$8.07 \times 10^{-2} E^2 f_E$	$1.29 \times 10^{-10} E^3 f_E$	$6.63 \times 10^{-27} E f_E$
$f_\lambda\ \left(\frac{\text{photons}}{\text{cm}^2\,\text{s Å}}\right)$	$6.63 \times 10^{-4} \lambda f_\lambda$	$8.07 \times 10^{-2} \lambda^2 f_\lambda$	f_λ	$1.99 \times 10^{-8} f_\lambda/\lambda$	$6.63 \times 10^{-27} \lambda f_\lambda$
$F_\lambda\ \left(\frac{\text{ergs}}{\text{cm}^2\,\text{s Å}}\right)$	$3.34 \times 10^4 \lambda^2 F_\lambda$	$4.06 \times 10^6 \lambda^3 F_\lambda$	$5.03 \times 10^7 \lambda F_\lambda$	F_λ	$3.34 \times 10^{-19} \lambda^2 F_\lambda$
$F_\nu\ \left(\frac{\text{ergs}}{\text{cm}^2\,\text{s Hz}}\right)$	$10^{23} F_\nu$	$1.51 \times 10^{26} F_\nu/E$	$1.51 \times 10^{26} F_\nu/\lambda$	$3.00 \times 10^{18} F_\nu/\lambda^2$	F_ν

AGN structure

RADIO from jet

UV-to-IR broad & narrow lines





Ramos Almeida & Ricci (2017)

INFRARED from torus

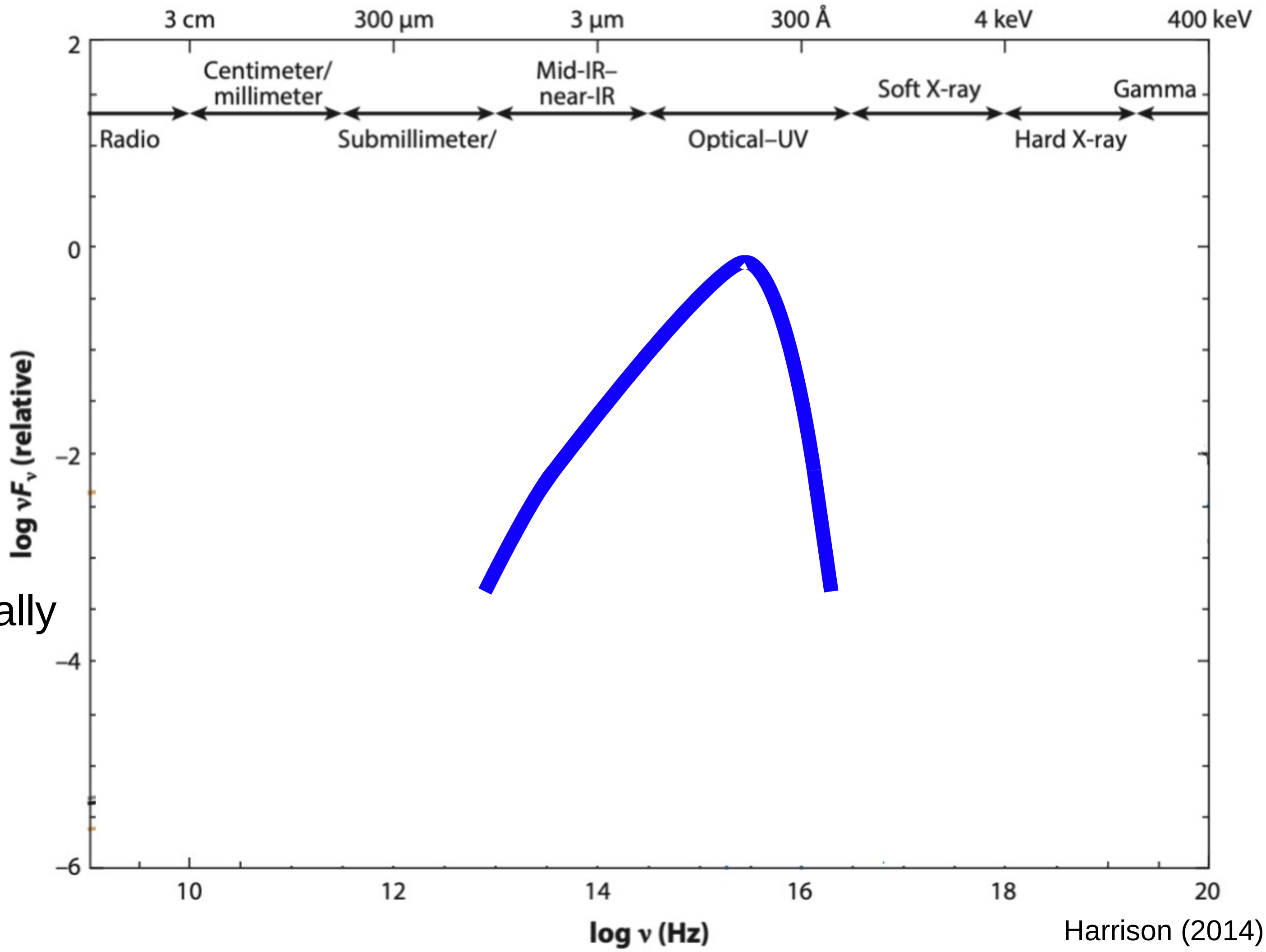
OPTICAL/UV from disk

X-RAY from corona/ base of the jet

AGN SED

- **Accretion disk**

- Big Blue Bump
- **Black Body** (if Sakura & Sunayev disk, i.e. geometrically thin and optically thick)
- $T_{BB} = 2 \cdot 10^5$ K
- peaks UV

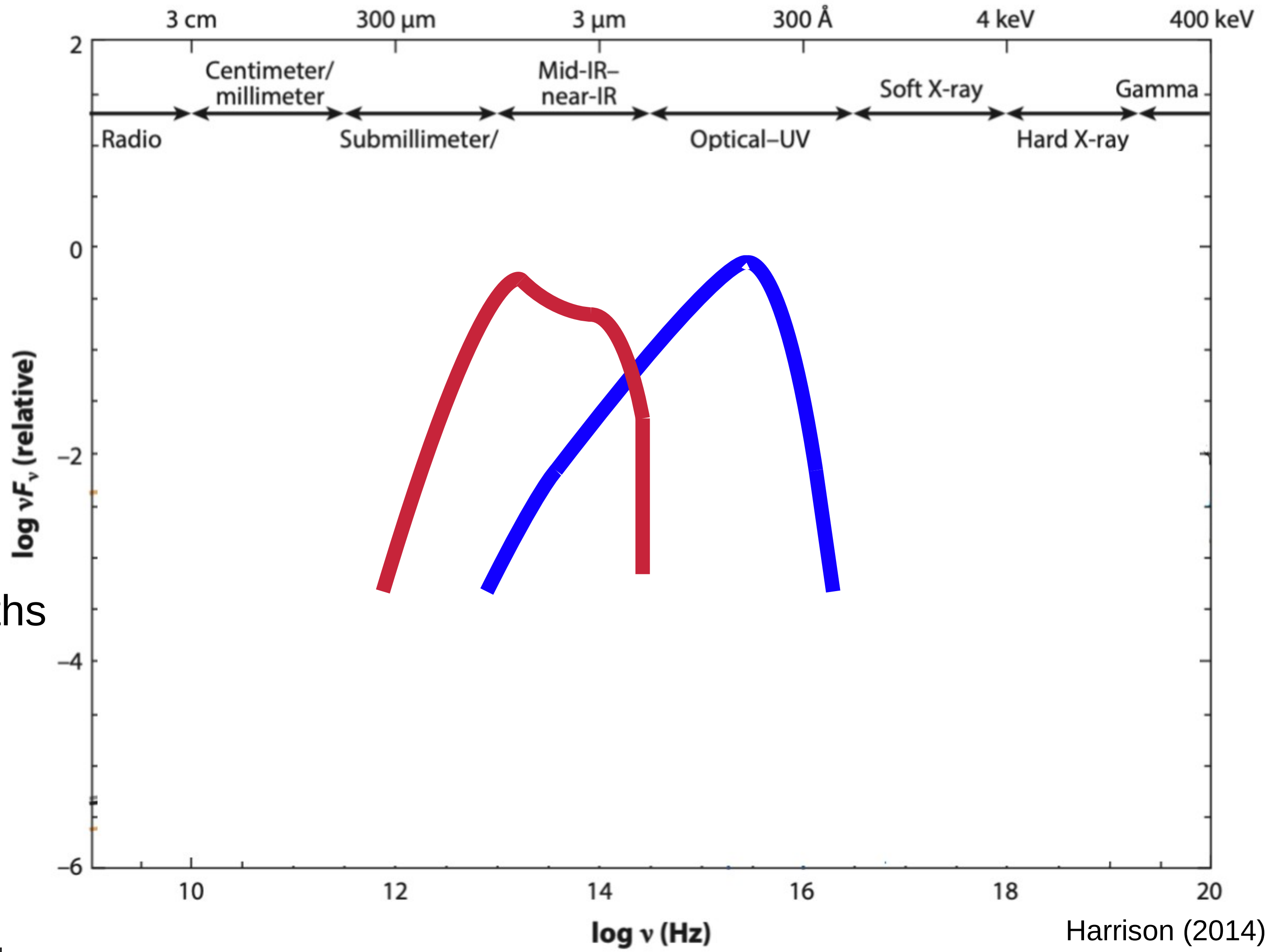


Harrison (2014)

AGN SED

- Accretion disk
- **Dusty torus**

- dust absorbs UV & optical radiations
- re-emits in mid-IR wavelengths
- peaks at λ = 20 -- 50 μm
- Simplest model: multiple temperature black body

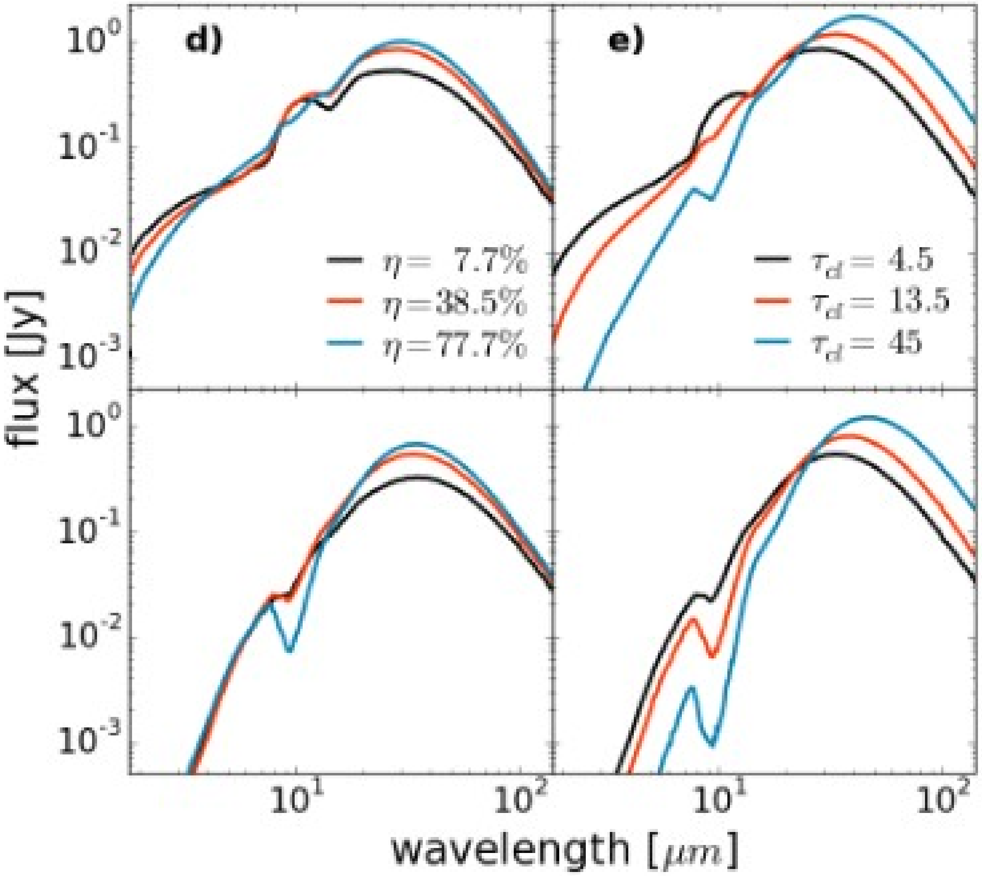


Harrison (2014)

Torus & 10μm silicate feature

9.7μm (≈10μm) **silicate** (Si-O) feature is easily recognizable in torus SED

- In **emission** for **type 1** AGN
- In **absorption** for **type 2** AGN with enough N_H
- Its absorption depth correlates (more or less) with the AGN obscuration (Georgantopoulos+12, Xu+20)
- Does the dust in the host-galaxy contribute to the 10μm absorption? (Goulding+12)



Face on

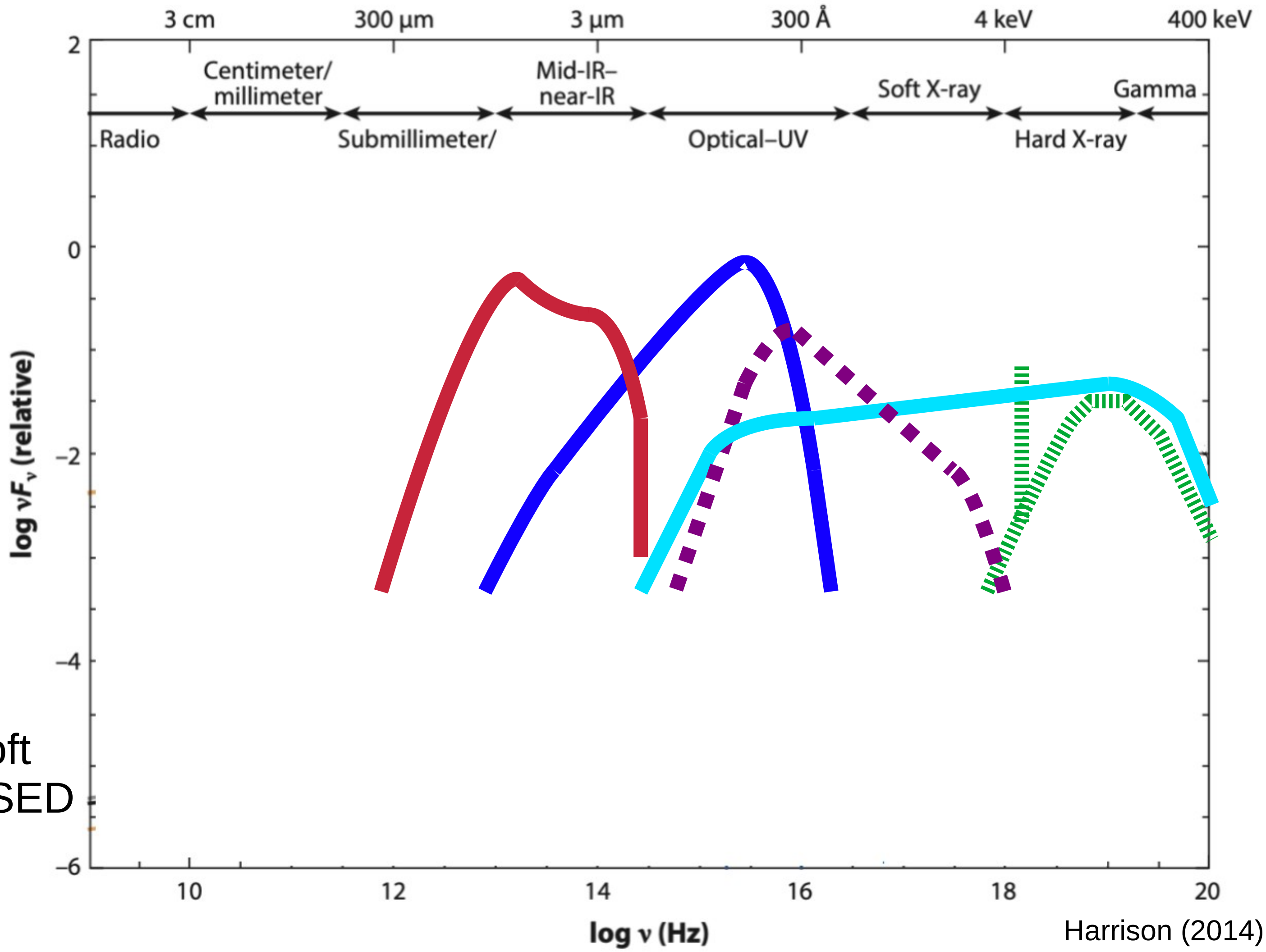
Edge on

Siebenmorgen+15

AGN SED

- Accretion disk
- Dusty torus
- **Hot corona**
- **Reflection component**
- **Soft excess**

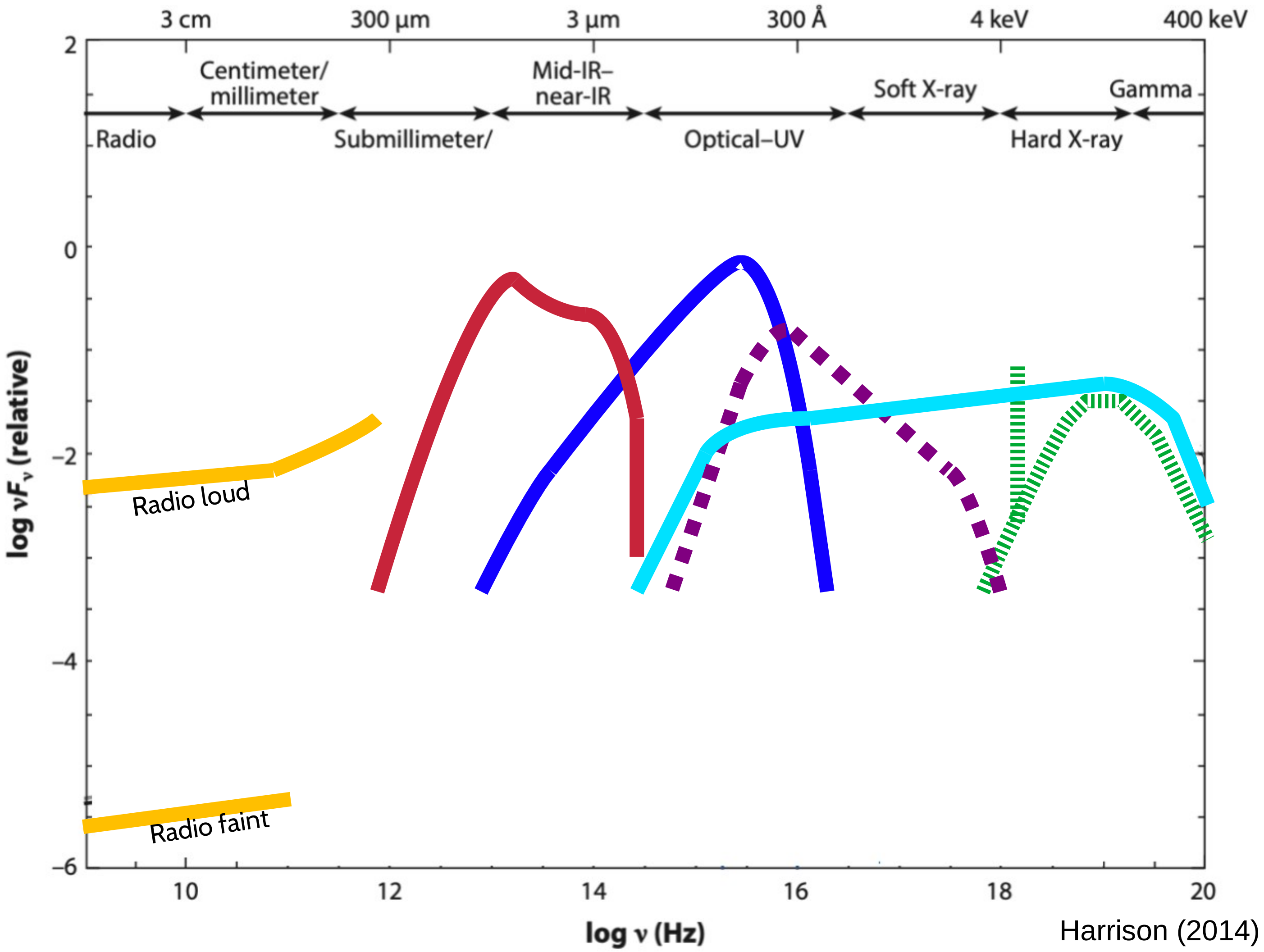
- Hot corona ↔ Power law
- Trace innermost region
- Hot corona + Reflection + Soft excess = Third bump of the SED



Harrison (2014)

AGN SED

- Accretion disk
- Dusty torus
- Hot corona
- Reflection component
- Soft excess
- **Radiojet**



Harrison (2014)

AGN SED

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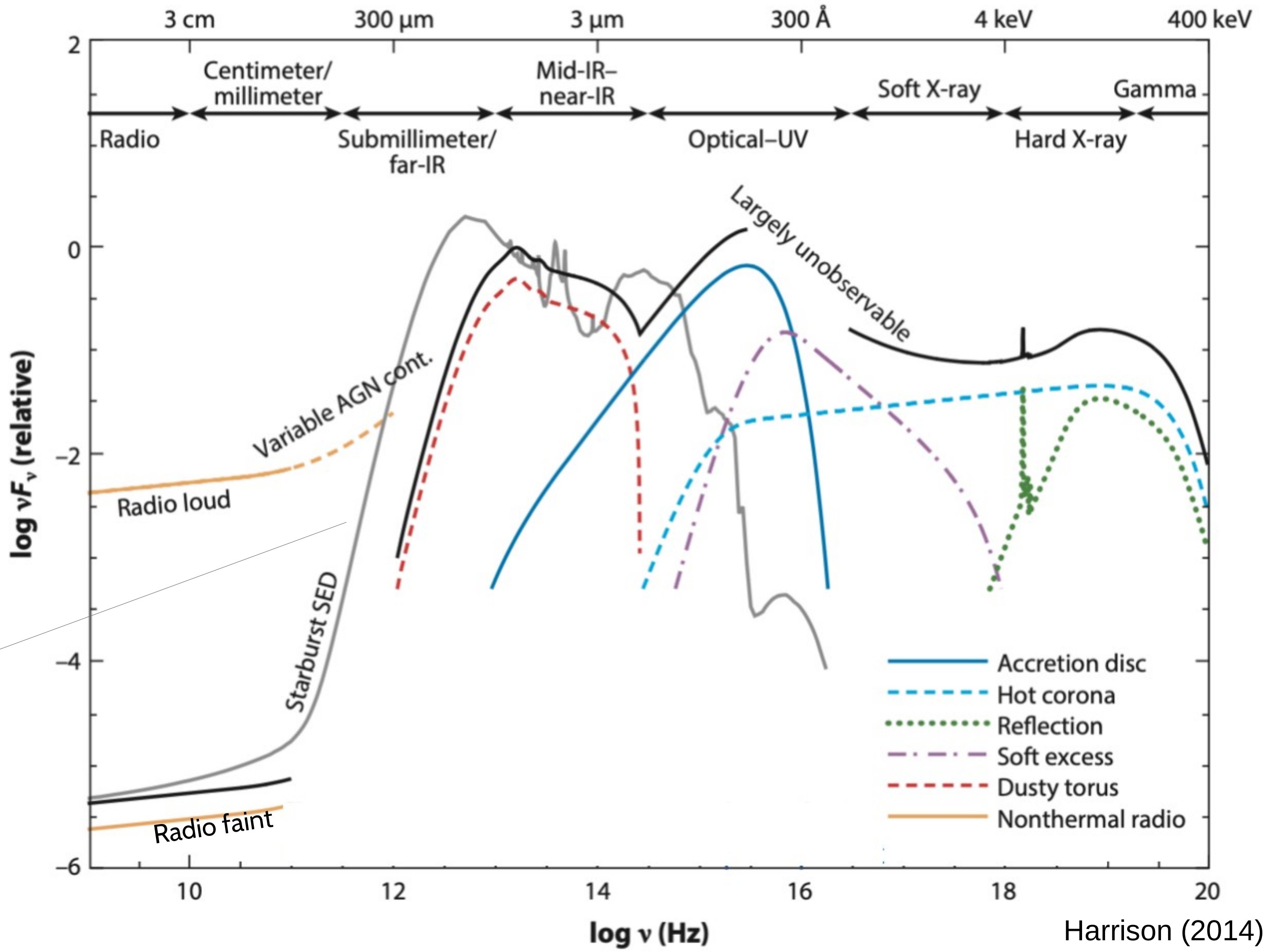
- Radiojet

Host galaxy emission



Harrison (2014)

Type 1 vs Type 2 AGN SED

f_{AGN} = AGN fraction = $L_{IR,AGN}$ / $L_{IR,gal}$

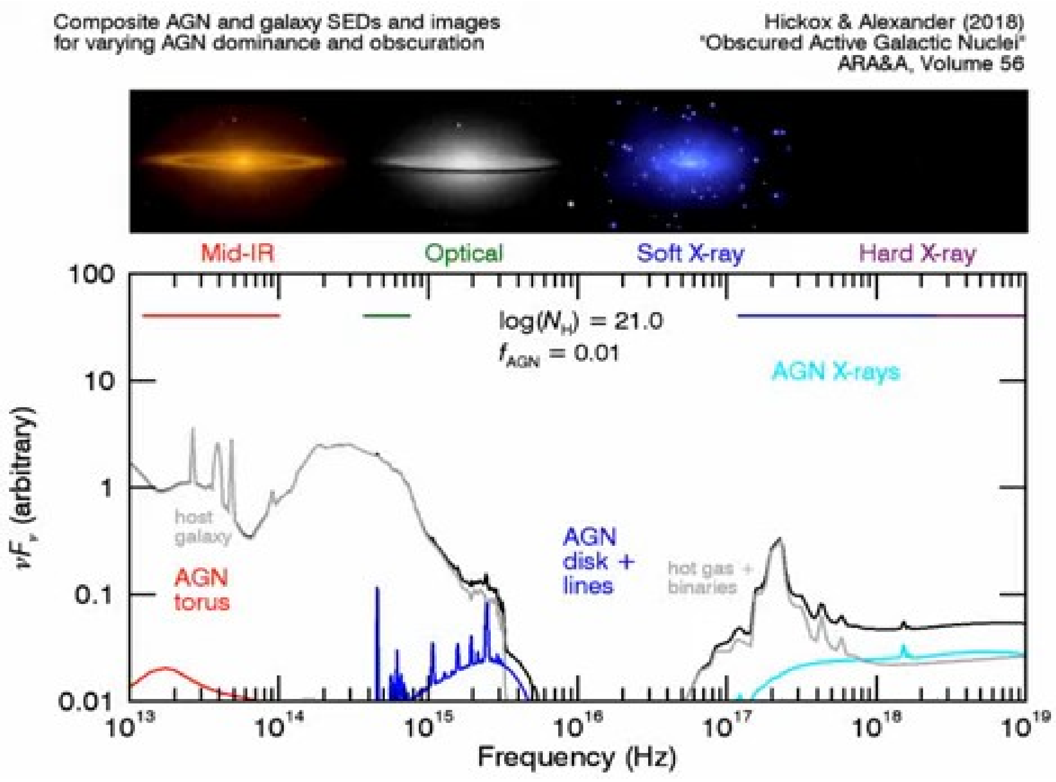
- In the IR-UV range low luminosity AGN are completely dominated by the emission of their host-galaxy
- In the X-ray band AGN dominates:
  - Soft-X may suffer from obscuration
  - In hard-X no obscuration

N_H = Hydrogen equivalent column density [cm^{-2}]

$N_H < 10^{22}$ cm^{-2} : unobscured AGN (type 1)

$N_H > 10^{22}$ cm^{-2} : obscured AGN (type 2)

$N_H > 10^{24}$ cm^{-2} : Compton Thick AGN (CT)



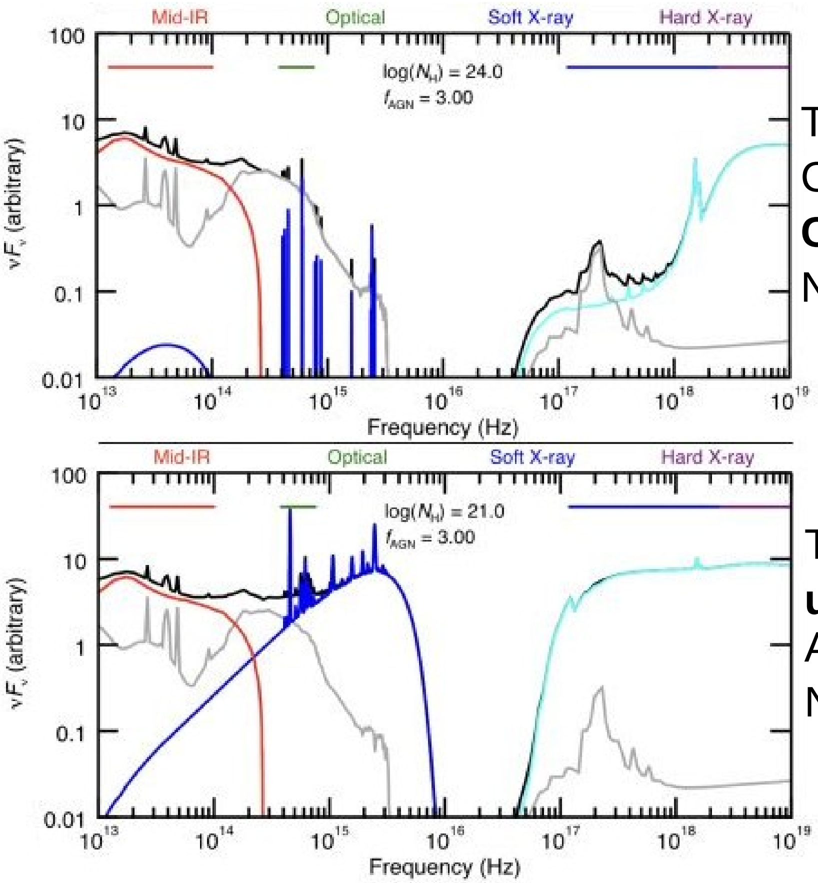
Type 1 vs Type 2 AGN SED

Hickox & Alexander (2018)

- **Type 1 AGN**: 3 component SED
- **Type 2 AGN**:
  - lacks Big Blue Bump
  - only Narrow lines in optical-UV
  - IR torus emission unaffected
  - Hard X-ray emission unaffected
  - Soft-X more and more absorbed as N_H grows

    → N_H ↗ $HR=F_{Hard}/F_{soft}$ ↗
  - Most obscured AGN impossible to detect in optical, difficult in Soft-X

Obscuration ⟶

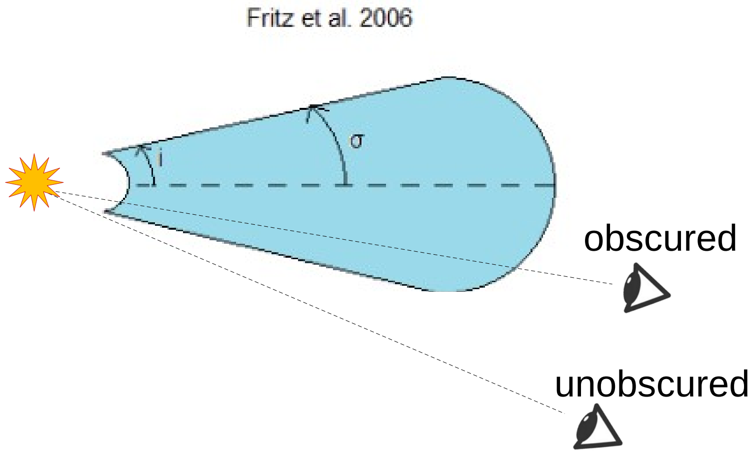


Type 2 Compton Tick **CT-AGN** $N_H>10^{24}$ cm^{-2}

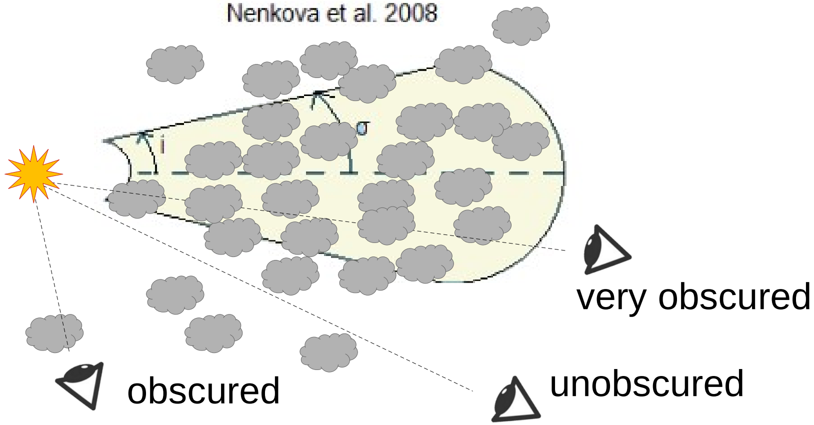
Type 1 **unobscured** AGN $N_H<10^{22}$ cm^{-2}

Torus models

Smooth torus



Clumpy torus



- Continuous distribution of dust
- Source obscured if *los* intercepts the torus → **obscuration** is **linked to torus geometry**
- Dust temperature is a function of the distance from the nucleus

- The **probability of direct viewing** the AGN decreases away from the axis, but it is **always finite**
- Different dust temperatures co-exist at the same distance from the nucleus, and the same temperature can occur at different distances
- With time, cloud movements can change the source obscuration

More torus models...

Hydromagnetic disk wind

Emmering+92, Elitzur+08

- Outflow of clouds embedded in a hydromagnetic disk wind
- The **torus is** merely **a region in the wind** which happens to provide the required toroidal obscuration because the clouds there are dusty and optically thick
- The torus clouds are just a continuation of the BLR clouds. No discontinuity between BLR and torus
- R_D = sublimation radius (no dust for $r < R_D$)
  - $r < R_D$: dustless clouds → Broad line emission
  - $r > R_D$: dust in the clouds shields from ionizing radiations (no line emission), molecule and dust absorb UV/optical and re-emit in the mid-IR

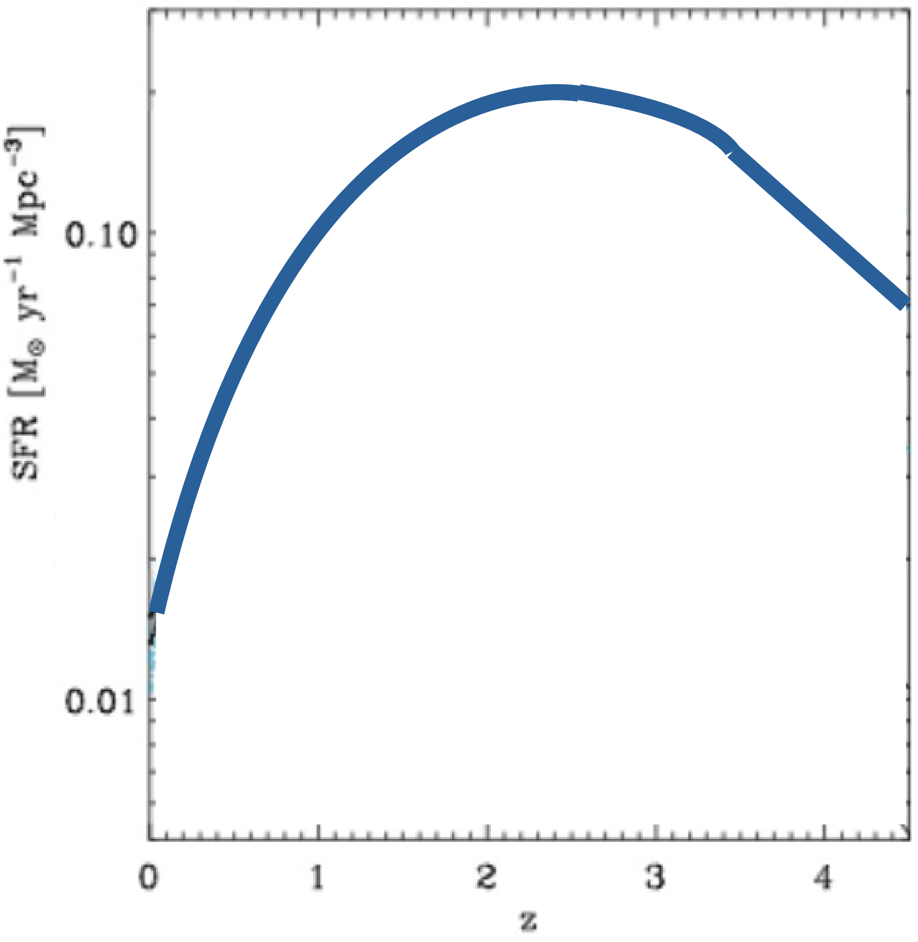
AGN-galaxy co-evolution

"The evolution of the universe can be likened to a display of fireworks that has just ended: some few red wisps, ashes, and smoke. Standing on a well-chilled cinder, we see the fading of the suns and try to recall the vanished brilliance of the origin of the worlds."

Lemaître (1931)

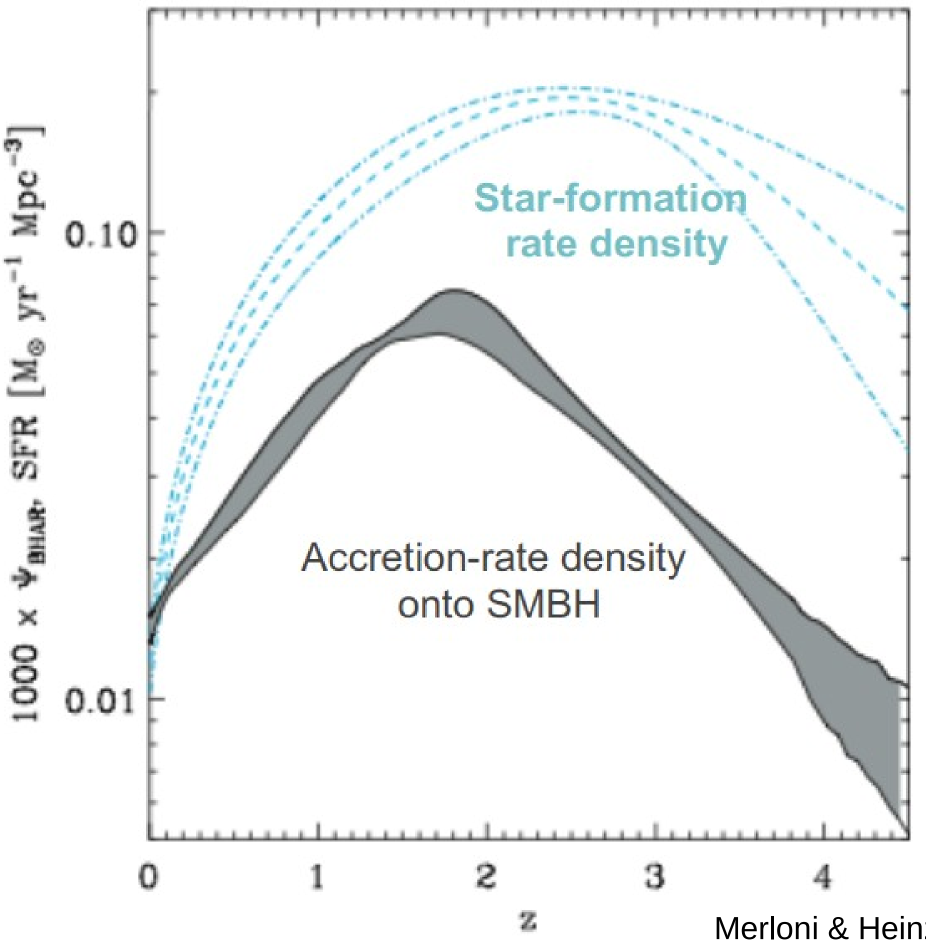
SFR density

- **SFR** as function of redshift **peaks at z ~ 2**, the so called ‘COSMIC NOON’ (Madau98, Merloni & Heinz 08,...)



BH accretion rate density

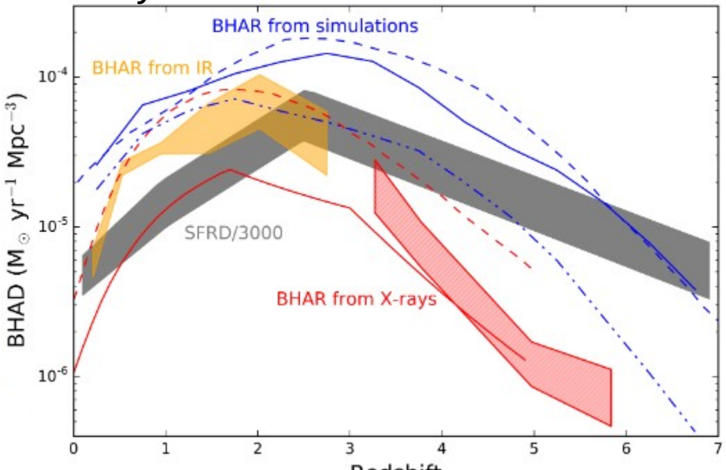
- **SFR** as function of redshift **peaks at z ~ 2**, the so called ‘COSMIC NOON’ (Madau98, Merloni & Heinz 08,…)
- **BH accretion rate density** (BHARD,BHAD) has a very **similar trend**
- Most of the BH growth at 1<z<3



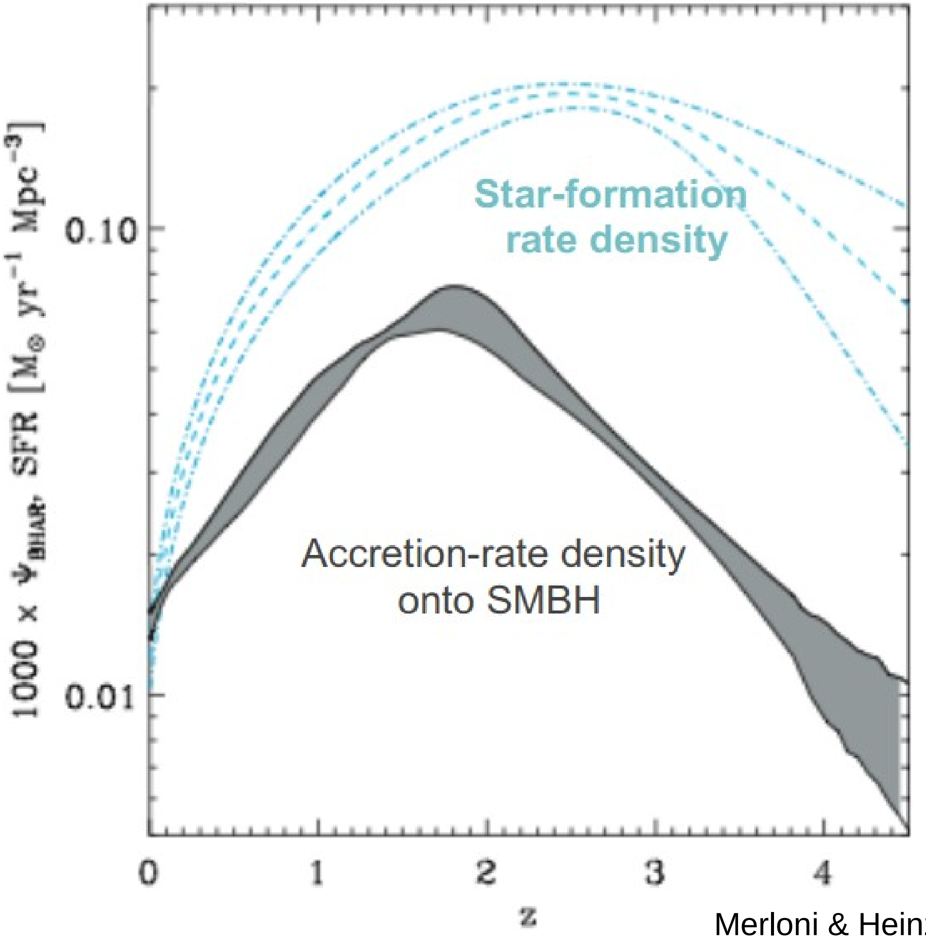
Merloni & Heinz 2008

BH accretion rate density

- **SFR** as function of redshift **peaks at z ~ 2**, the so called 'COSMIC NOON' (Madau98, Merloni & Heinz 08,…)
- **BH accretion rate density** (BHARD,BHAD) has a very **similar trend**
- Most of the BH growth at 1<z<3
- BHAD from X-ray misses very obscured AGN
- BHAD from IR only for z<3



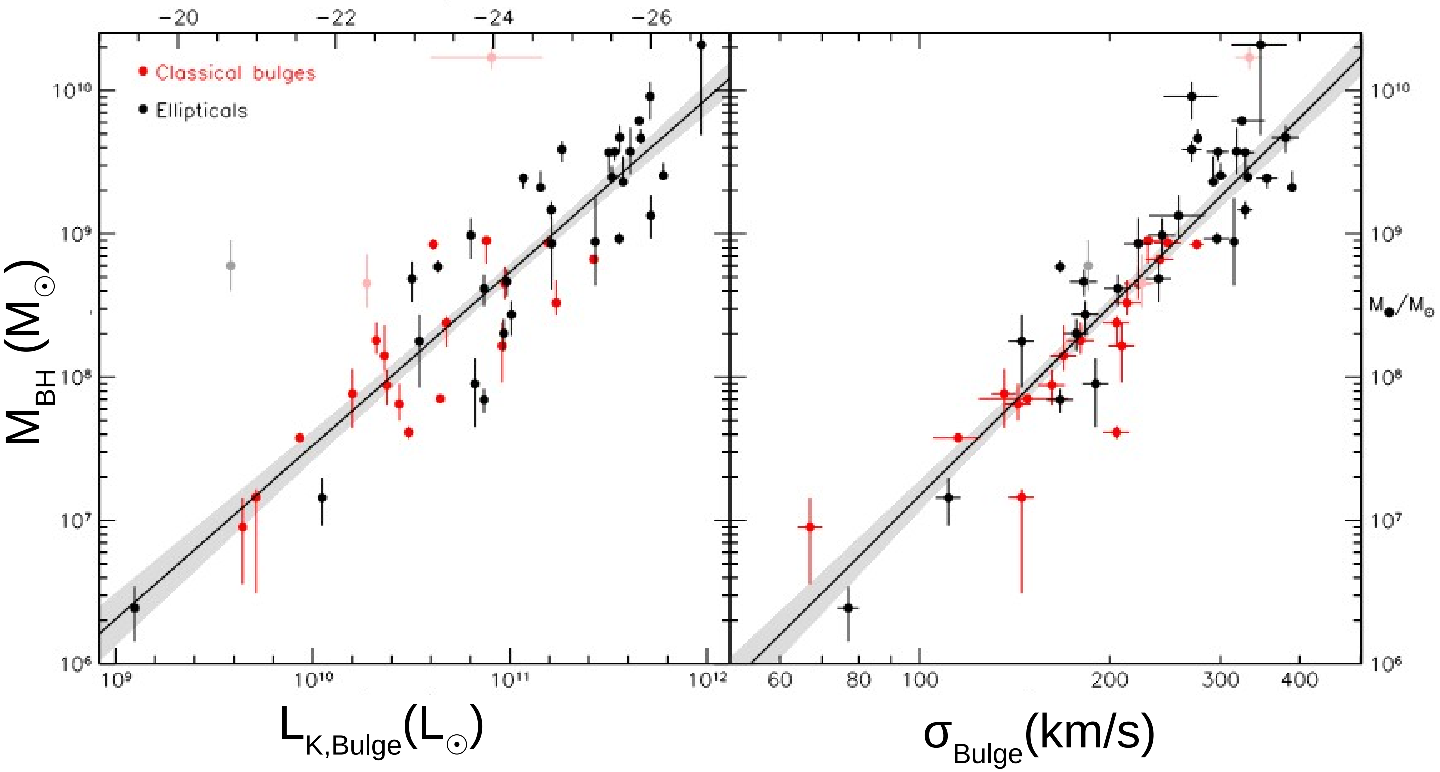
Vito+18



Merloni & Heinz 2008

BH galaxy scaling relations

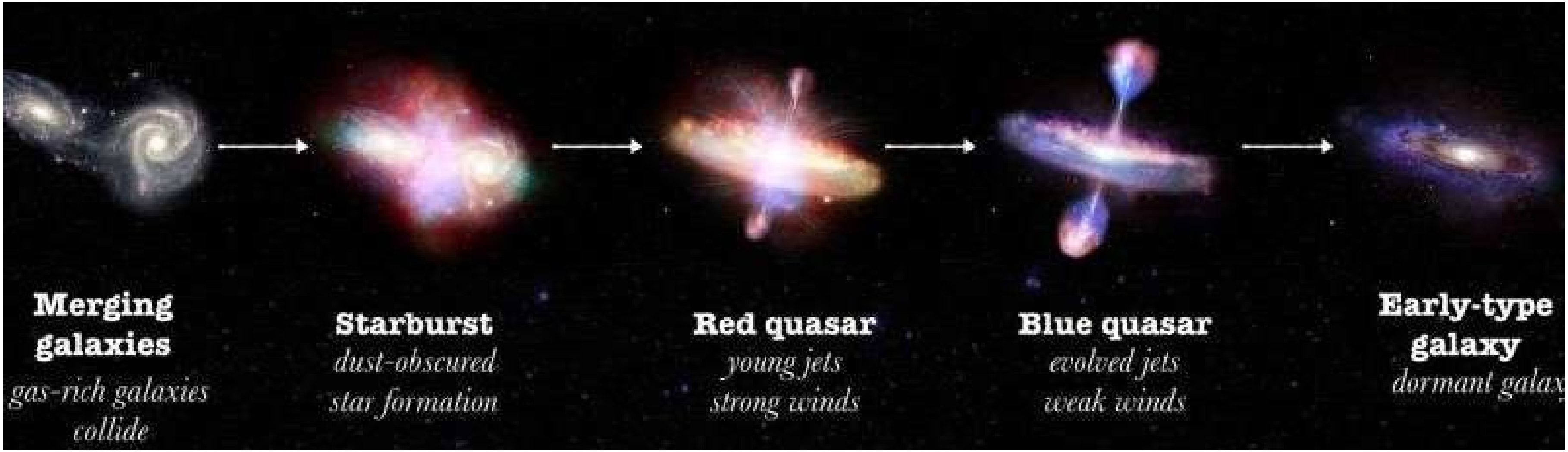
- **Scaling relations** between:
  - $\mathbf{M_{BH}} – \mathbf{M_{bulge}}$ – L_{bulge} (Kormendy & Richstone 1995)
  - $\mathbf{M_{BH}} – \boldsymbol{\sigma_{bulge}}$ (Ferrarese & Merritt 2000)
- σ_{bulge} measured well outside the BH gravitational sphere of influence
- **Coincidence ?**
- Results of coeval growth and **common evolution?**



Kormendy & Ho 2013

BH-galaxy co-evolution paradigm

BH-galaxy co-evolution paradigm



Klindt+19

- Normal gas-rich galaxies
- **Wet merger**
- Merger disrupts gas equilibrium and triggers SF

- Very high SFR
- **SF enshrouded** by high quantity of gas and dust
- SMG/ULIRG

- Fraction of the gas is funneled into the SMBH
- **triggers AGN**
- AGN hidden by gas and dust → **type 2 AGN**

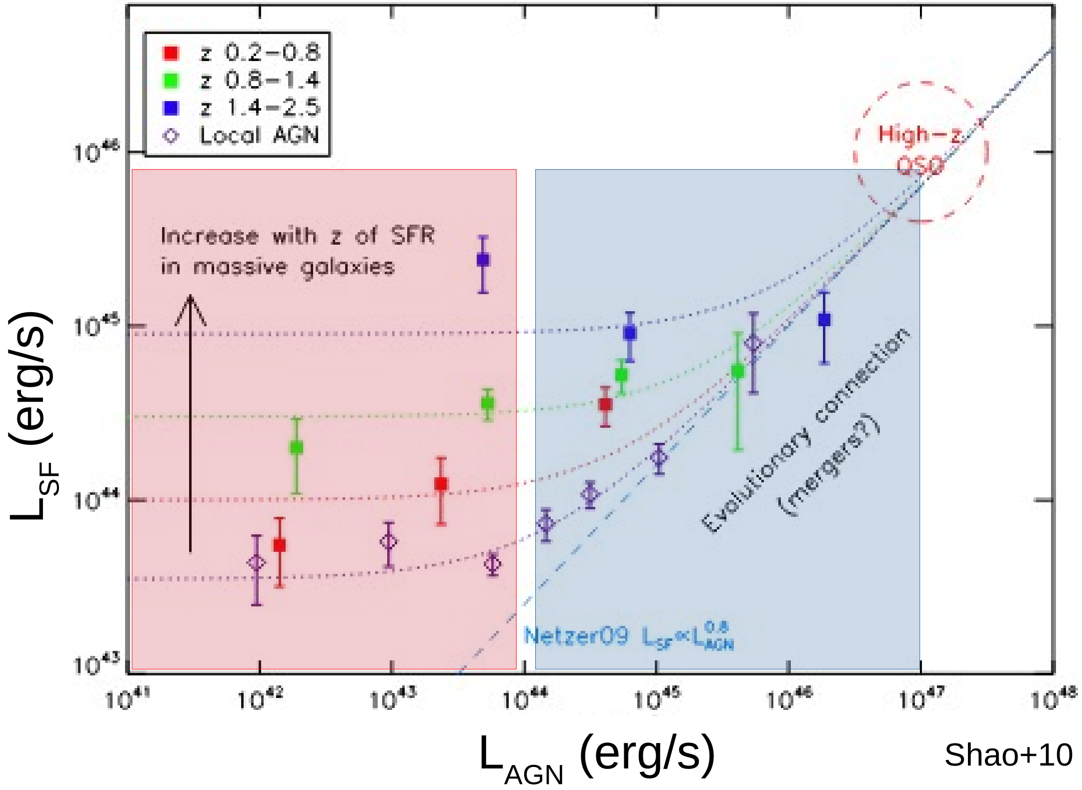
- Gas is consumed by SF and expelled by **SF and AGN feedback**
- SF decreases / stops
- AGN now free from obscuring dust → **type 1 AGN**

- No more gas to accrete → AGN dies
- **Normal** gas-poor **galaxy**
- SF and AGN **can be triggered again** by another wet merger

Two paths of AGN-galaxy co-evolution

Low luminosity AGN (90%):
SF luminosity independent from AGN luminosity → secular, non merger driven SF

High luminosity AGN (10%):
SF luminosity correlates with AGN luminosity → rapid burst of activity

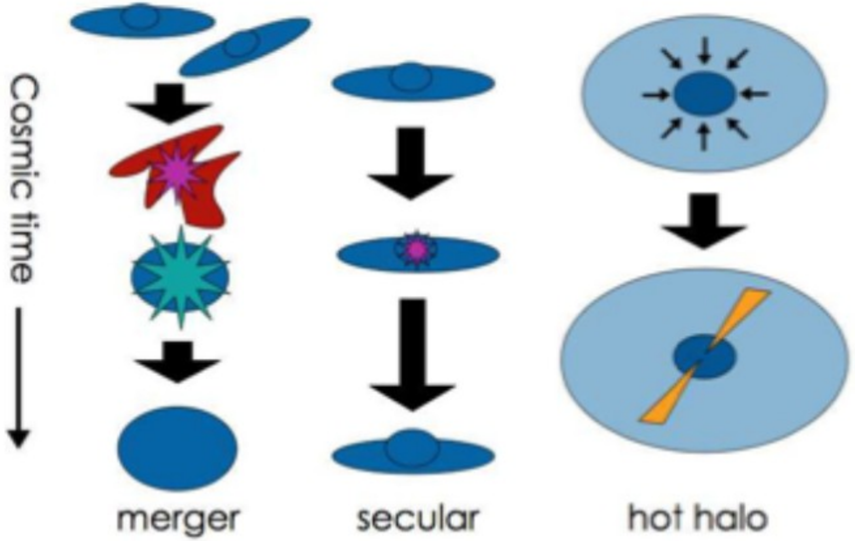


Shao+10

Merger driven accretion - Secular accretion

Merger driven

- High-luminosity AGN
- SF correlates with AGN luminosity
- More common at high *z*?



Secular accretion

- Low-luminosity AGN
- SF independent from AGN luminosity
- Disk instabilities, bars, or minor mergers ?