

Active Galactic Nuclei and Supermassive Black Holes

Main topics

- Recap on emission processes
- AGN physics and classification, AGN evolution, obscuration
- The BH paradigm and accretion discs
- The first AGN in the Universe
- The role of feedback in shaping galaxies (AGN-galaxy coevolution context...)

What you may expect from the course

- Far from being complete, impossible to cover all the active galaxies-related issues (from 64 hr last year to 48 hr currently)
- Overview of emission mechanisms and current understanding of AGN physics
- Census of AGN population and their properties up to high redshift: some answers, but many open questions
- Books vs. papers (review + Arxiv): the way to proceed to have a proper view of what's going on in astrophysics

Basic rule: you have a question, you try and find the way (method: data, simulations, theory) to possibly answer that question

READING/BIBLIOGRAPHY

- H. Bradt: "*Astrophysics Processes: The Physics Of Astronomical Phenomena*", Cambridge University Press
- G. B. Rybicky, A. P. Lightman: "*Radiative Processes in Astrophysics*", Wiley
- G. Ghisellini: "*Radiative processes in high energy astrophysics*", Springer, Lecture Notes in Physics 873
- B. M. Peterson: "*An introduction to Active Galactic Nuclei*", Cambridge University Press
- Frank J., King A. & Raine D.: "*Accretion Power in Astrophysics*", Cambridge University Press
- F. D. Seward, P. A. Charles: "*Exploring the X-ray Universe*", Cambridge University Press
- H. Netzer: "*The Physics and Evolution of Active Galactic Nuclei*", Cambridge University Press
- V. Beckmann, C. Shrader: "*Active Galactic Nuclei*", Wiley-VCH
- Haardt F., Gorini V., Moschella U., Treves A., Colpi M.: "*Astrophysical Black Holes*", Springer, Lecture Notes in Physics, 905
- Falanga M., Belloni T., Casella P., Gilfanov M., Jonker P., King A.: "*The Physics of Accretion onto Black Holes*", Springer, Space Sciences Series of ISSI

+ literature articles (<https://arxiv.org>)

Active Galaxies: program (part I)

- ✓ Introduction to the course.
- ✓ Brief historical perspective on AGN.
- ✓ Pills on on radiative transfer and on thermal and non-thermal processes.
- ✓ AGN classification and unification model.
- ✓ Insights into AGN innermost regions via X-ray observations.
- ✓ Jetted vs. not-jetted AGN. Emission processes, observational features, spectral energy distributions, and blazar sequence. Prospects for the Cerenkov Telescope Array.
- ✓ On the nature of obscuration in AGN: torus vs. host galaxy. Photometric and spectroscopic selection techniques of obscured AGN.
- ✓ The black hole paradigm. Radiatively efficient (Shakura-Sunyaev) accretion discs vs. ADAF solutions. Slim discs and their potential application to growing BHs.
- ✓ A close look at the innermost regions of AGN: EHT and GRAVITY results.
- ✓ The Galactic Center: SgrA* and its accretion history up the recent flares. The Galactic Plane: Fermi bubbles and X-ray chimneys.

Active Galaxies: program (part II)

- ✓ AGN-galaxy co-evolution models at high redshift vs. AGN unification model. Formation and evolution of AGN. X-ray surveys and the cosmic X-ray background. The Soltan argument.
- ✓ The realm of high-redshift AGN and theories on seed black holes.
- ✓ BH masses from reverberation studies and scaling relations.
- ✓ Feedback (radiative/mechanic) from AGN. The impact of winds and outflows on small and large scales in setting the M-sigma relation. Recent multi-wavelength studies.
- ✓ The role of mergers in triggering nuclear activity. The quest for dual/binary AGN in the era of gravitational waves.
- ✓ What we don't know (yet).

Some pills on what we will/may
discuss during the course

The beginning

Fath E.A., 1909

UNIVERSITY OF CALIFORNIA PUBLICATIONS
ASTRONOMY

LICK OBSERVATORY BULLETIN

NUMBER 149

THE SPECTRA OF SOME SPIRAL NEBULAE AND GLOBULAR
STAR CLUSTERS.*

Strong emission lines in galaxies – mid '40: K. Seyfert's work

Pills on emission processes

Emission mechanisms in a nutshell

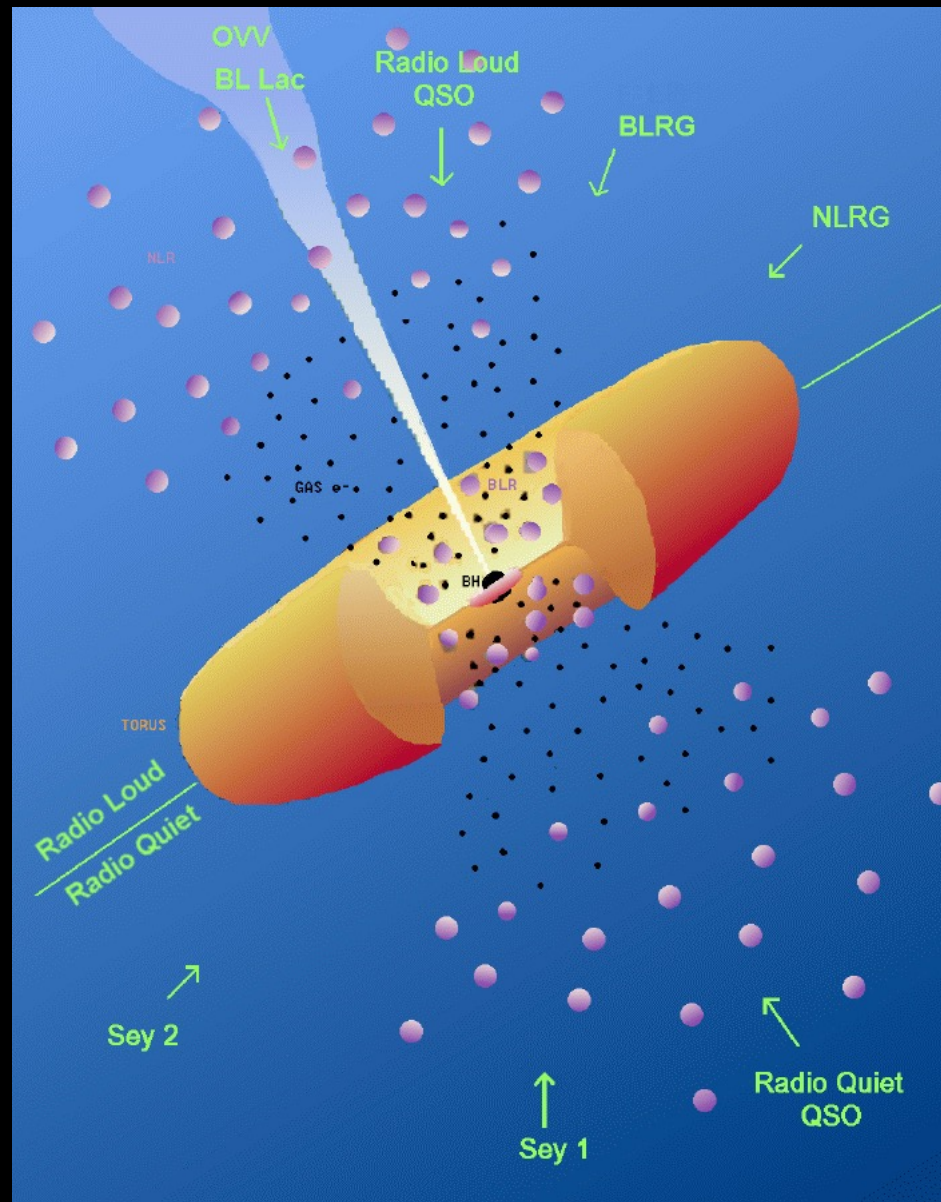
- Blackbody
- Bremsstrahlung
- Synchrotron
- Scattering processes (Thomson/Compton/Inverse Compton)
- Examples in the high-energy field
- Einstein coefficients
- Emission- and absorption-line processes
- Collisional/ionization equilibrium

Much more on emission mechanisms in Prof. D. Dallacasa's course (for LT in Astronomy)

Unification model of AGN

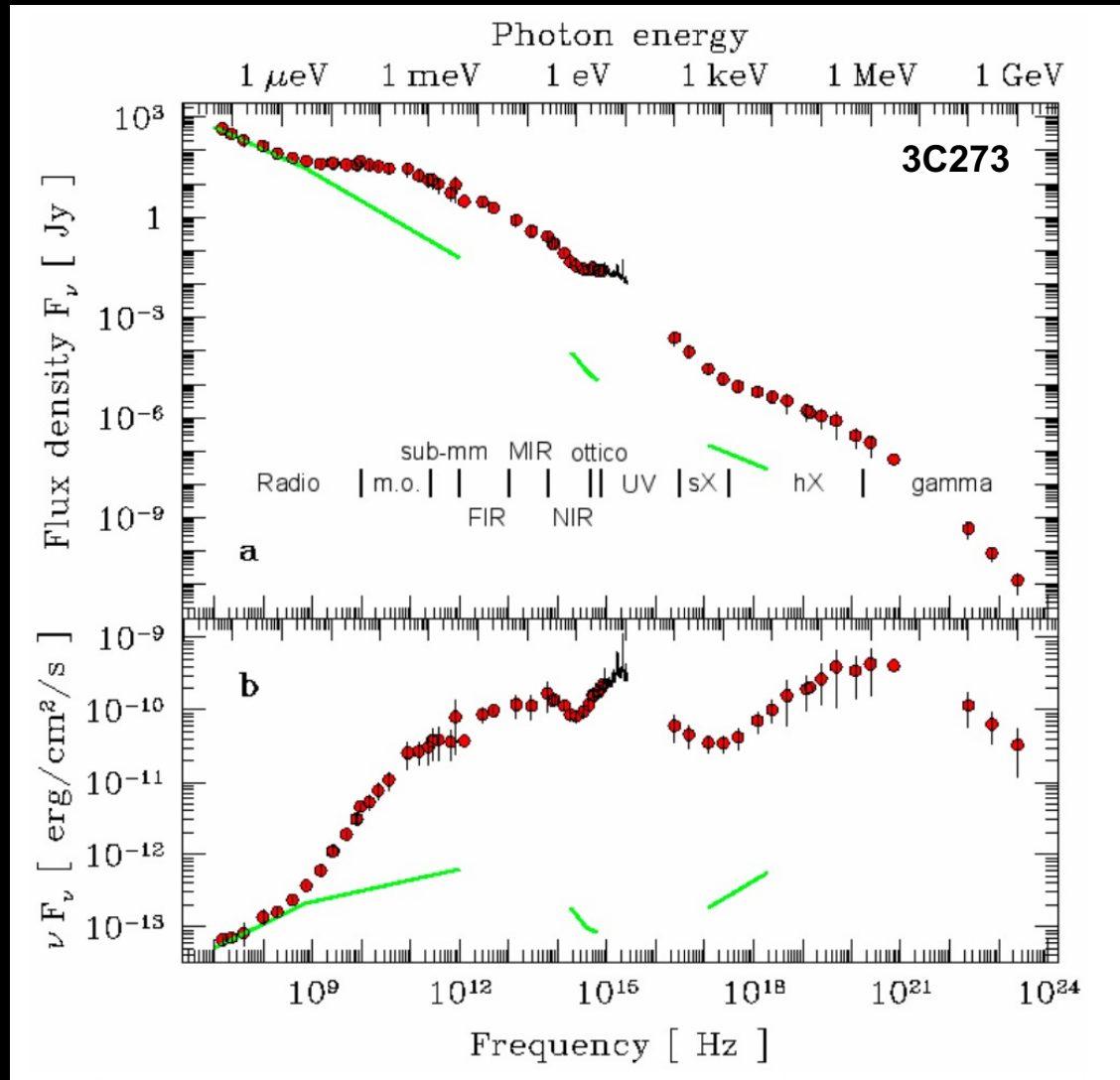
Same engine,
different
observational
properties
depending on the
line of sight

Is the Unified
Model the end of
the story?

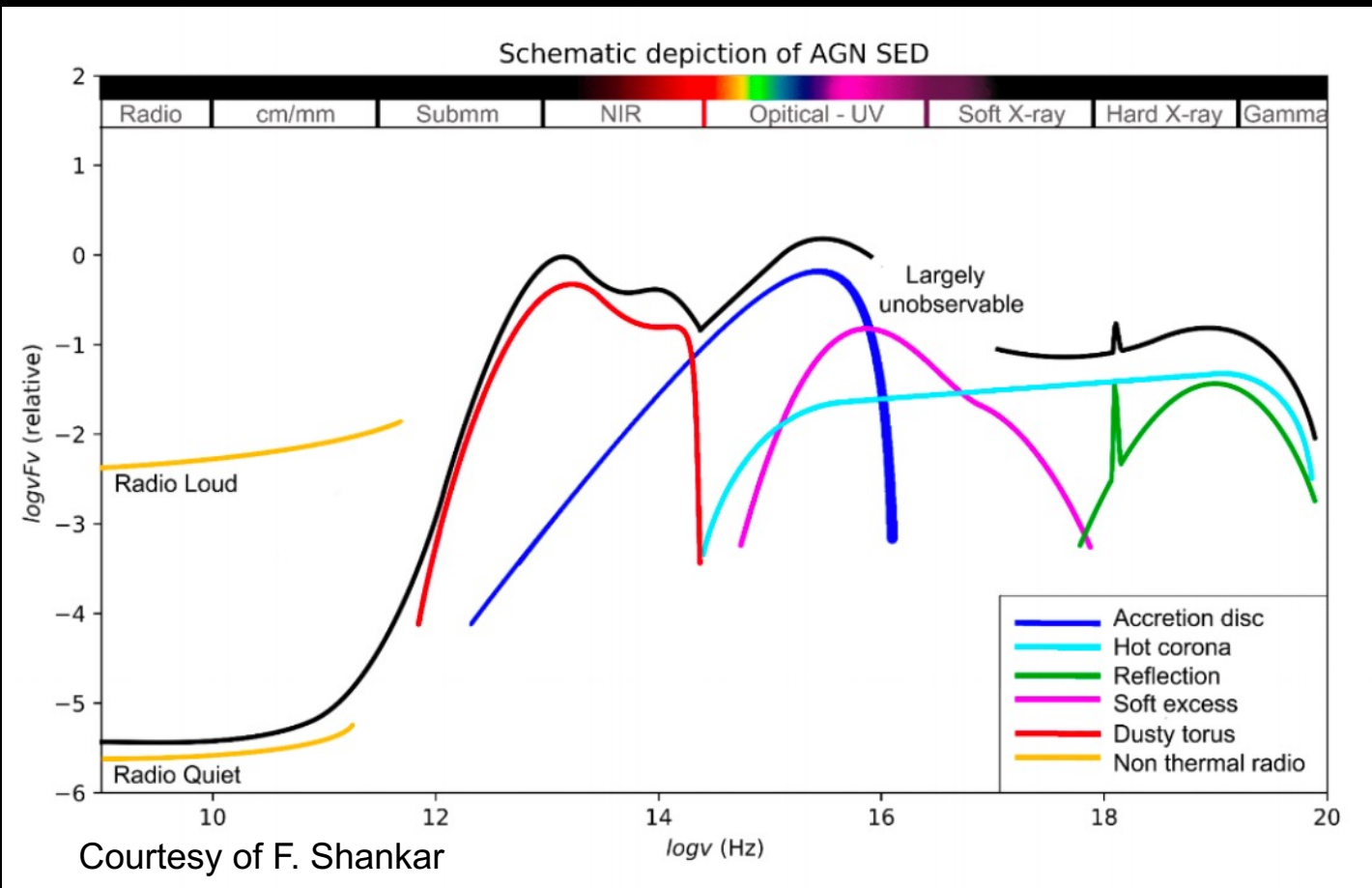


adapted from Urry
& Padovani 1995

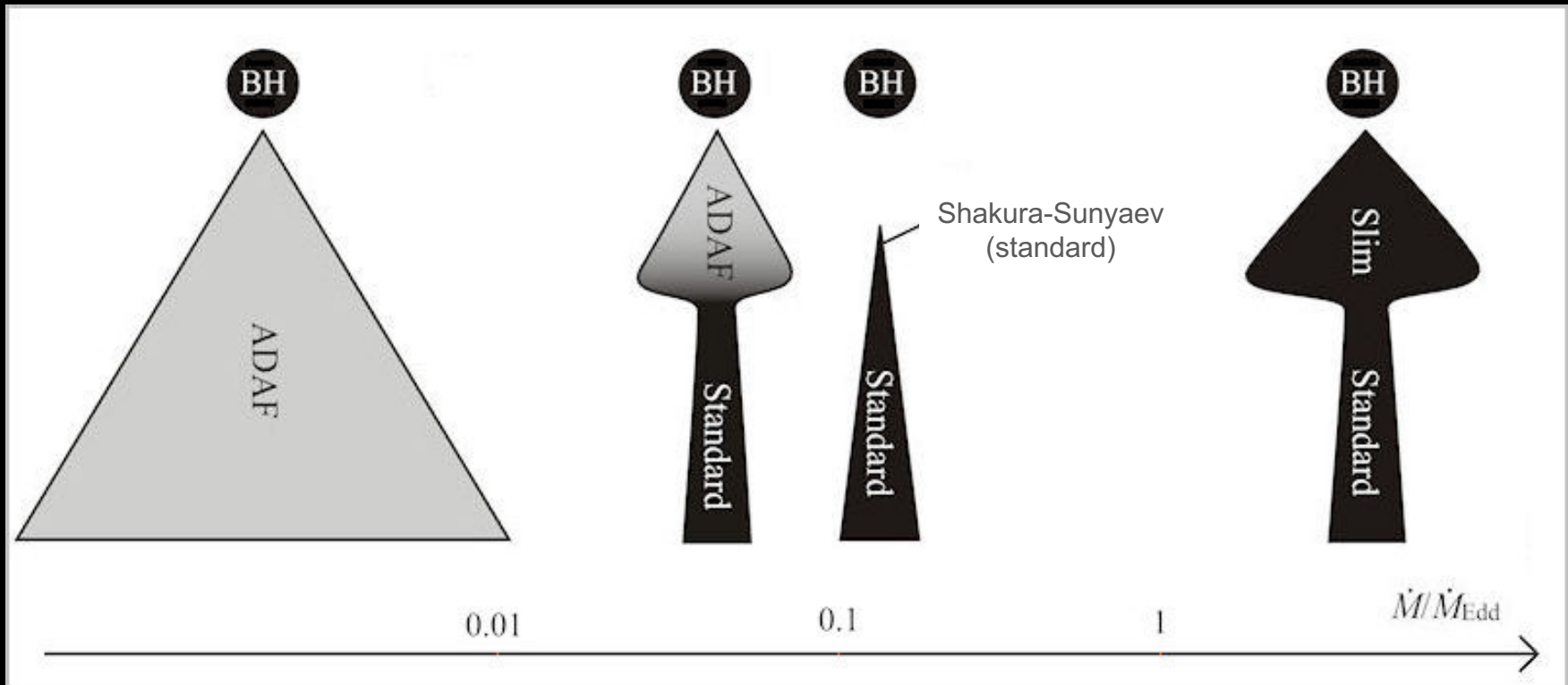
Active galaxies as broad-band emitters



Active galaxies as broad-band emitters

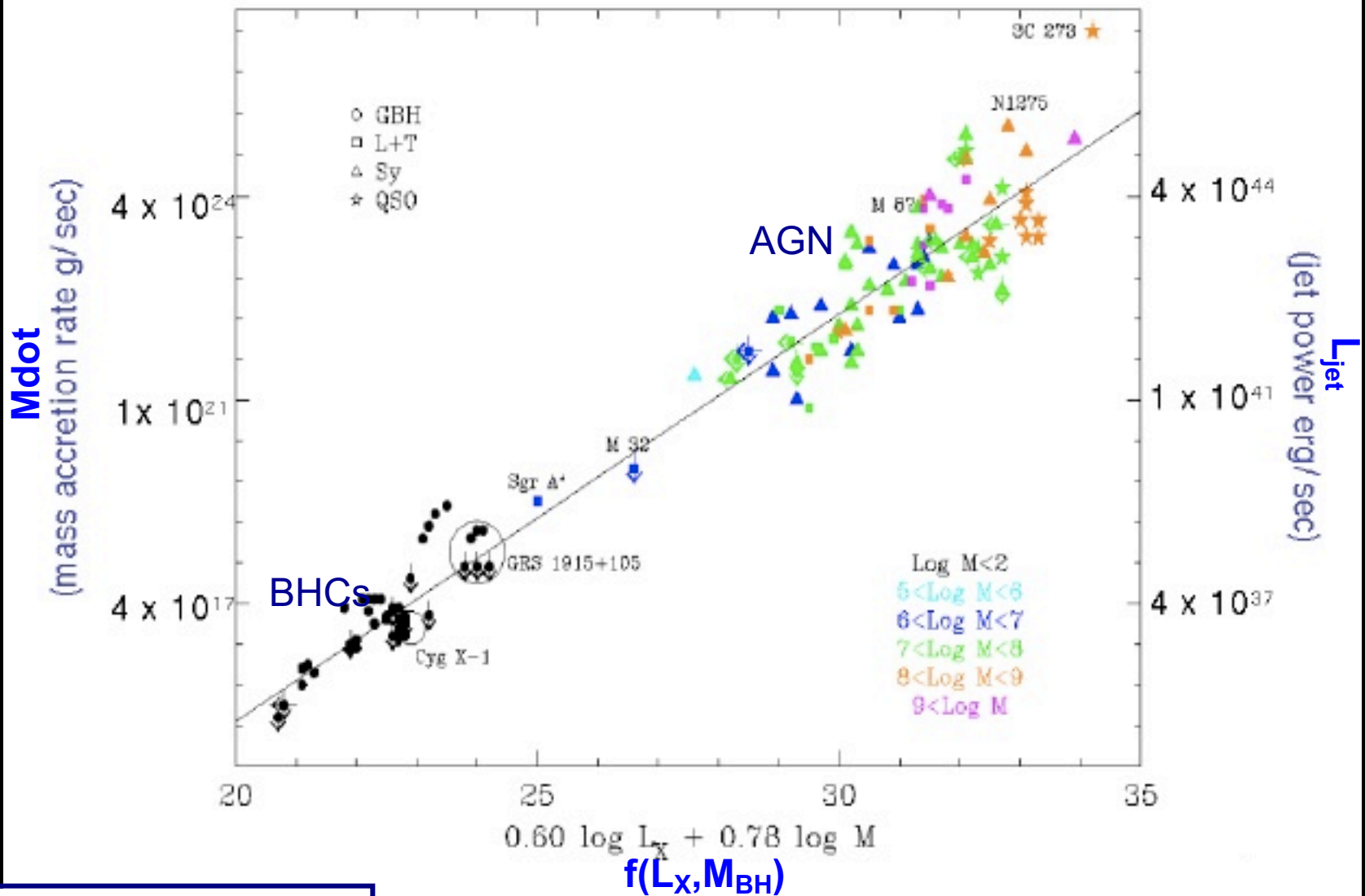


Accretion (disc types)



Efficient vs. inefficient accretion
Close connection with X-ray binaries spectral states?

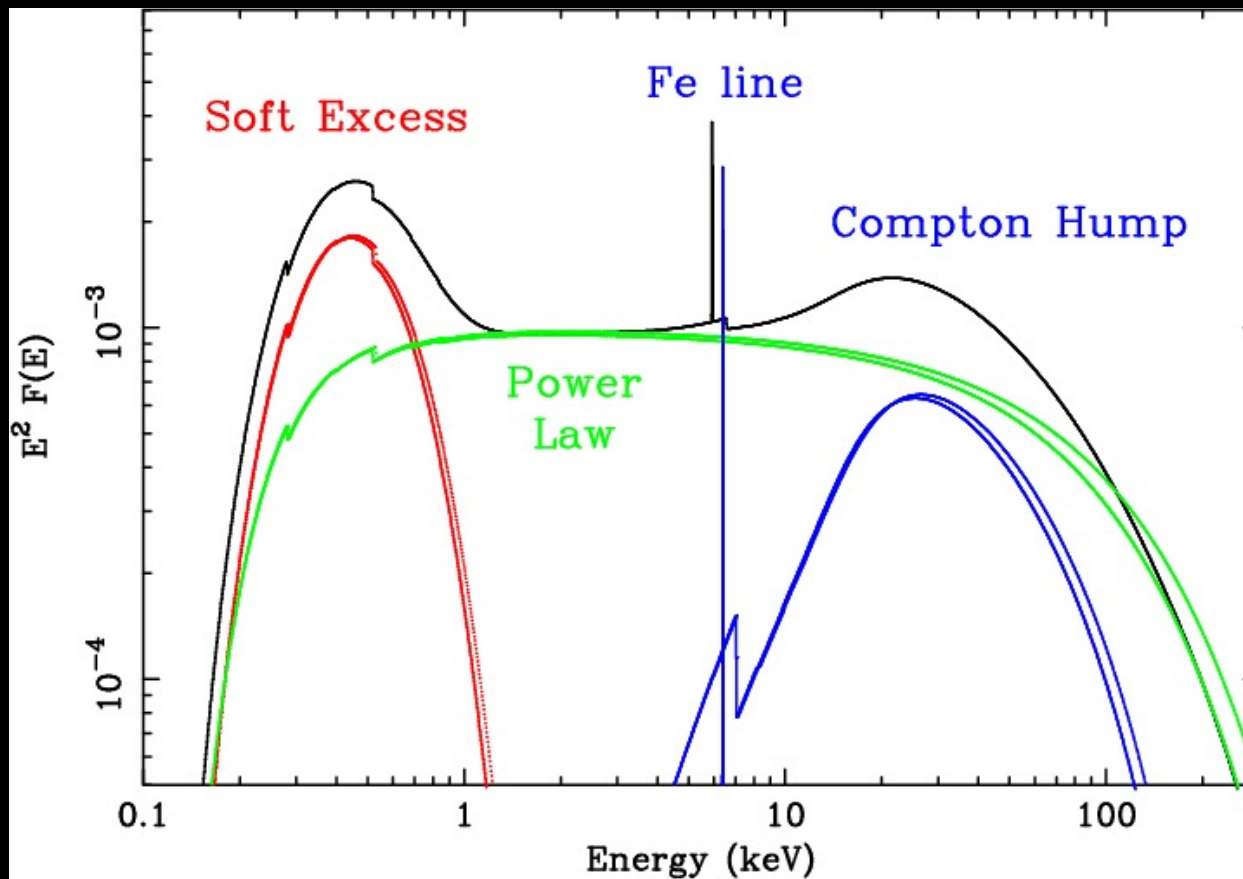
A fundamental plane for accretion



$$L_{\text{radio}} \propto L_X^{0.60} M^{0.78}$$

from Merloni et al. 2003 – Here L_{jet} instead of L_{radio}
 see also Yuan et al. 2009 and Gutelkin et al. 2019

The X-ray view of an AGN



X-rays as a probe
of the innermost
region of AGN

Insights on
accretion
processes (flow,
both inflow and
and outflow) and
feeding of the BH

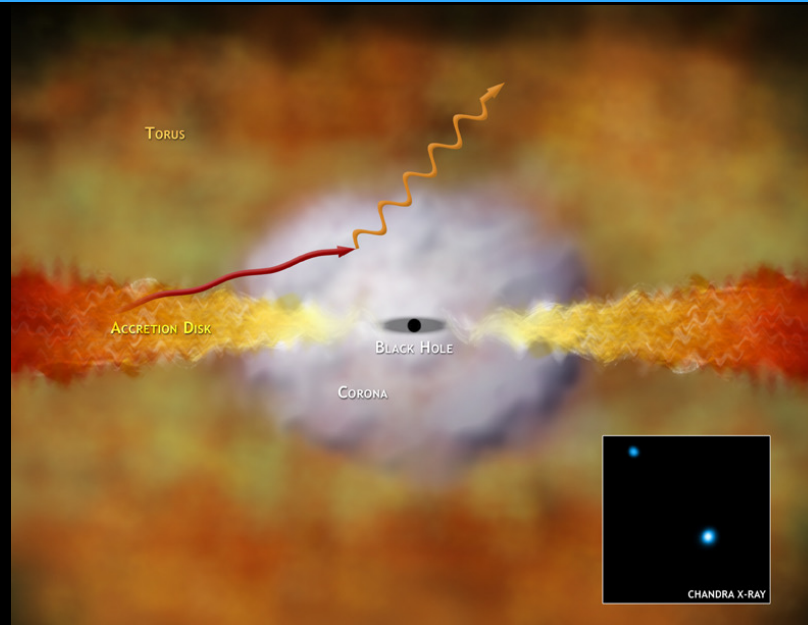
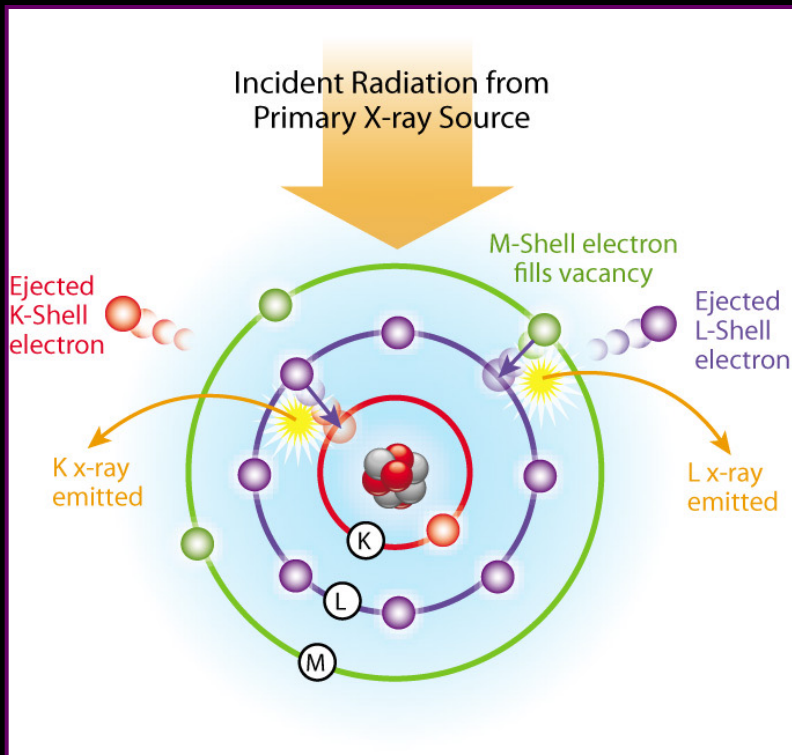
Soft excess (Black body? Reflection? Complex absorption?)

Power-law Component (Thermal Comptonization)

Reflection component (Fluorescence Lines + Compton hump)

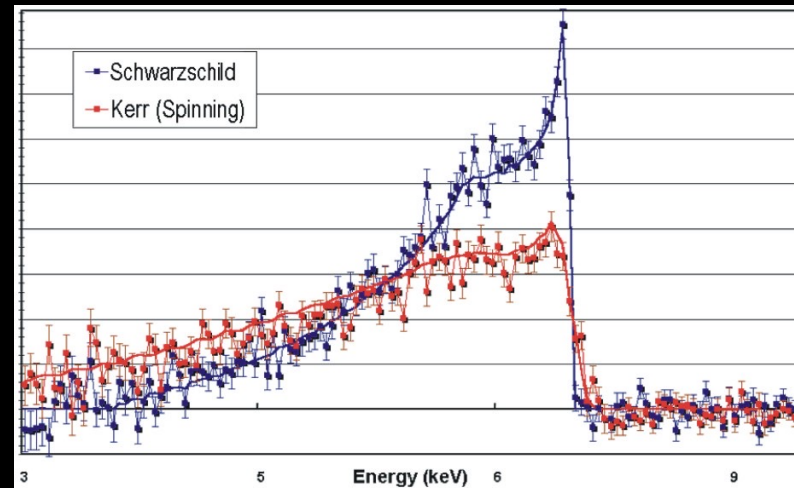
Warm absorber (~50% local Seyfert galaxies)

Probing the innermost regions of an AGN

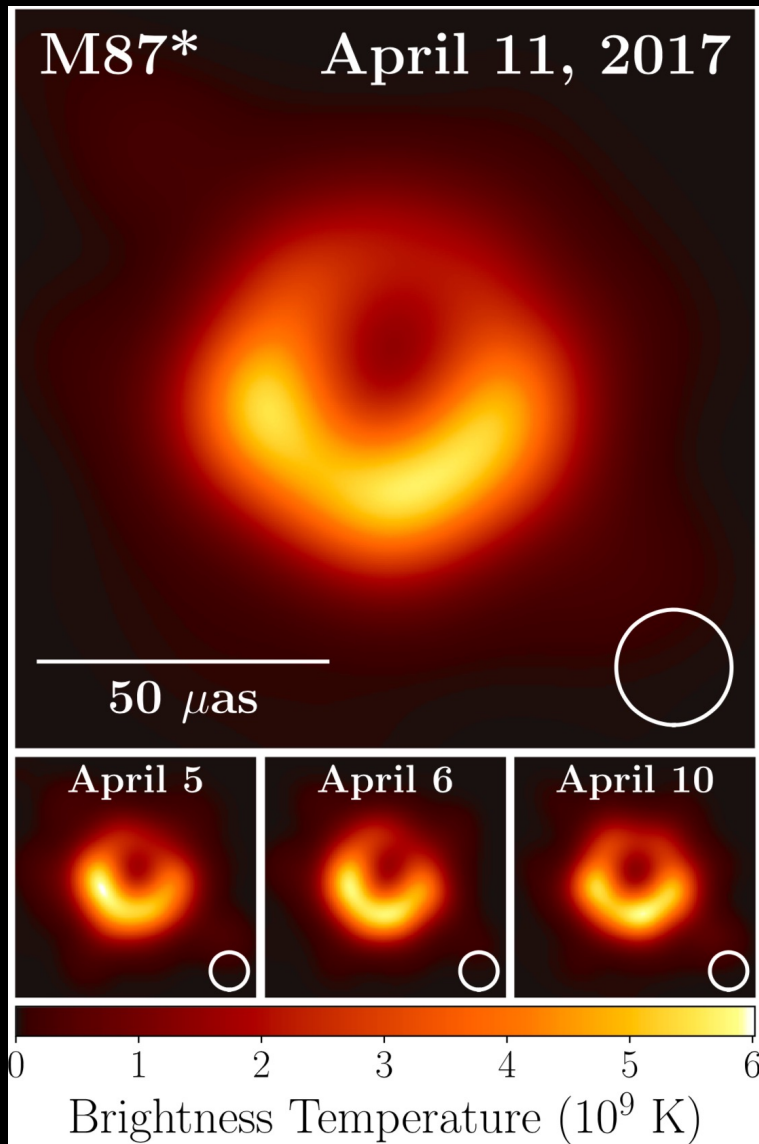


Fluorescence emission vs. Auger

Iron line emission probing the innermost regions of compact objects (AGN, binaries, ...)



New facilities, down to tens of micro-arcsec scales

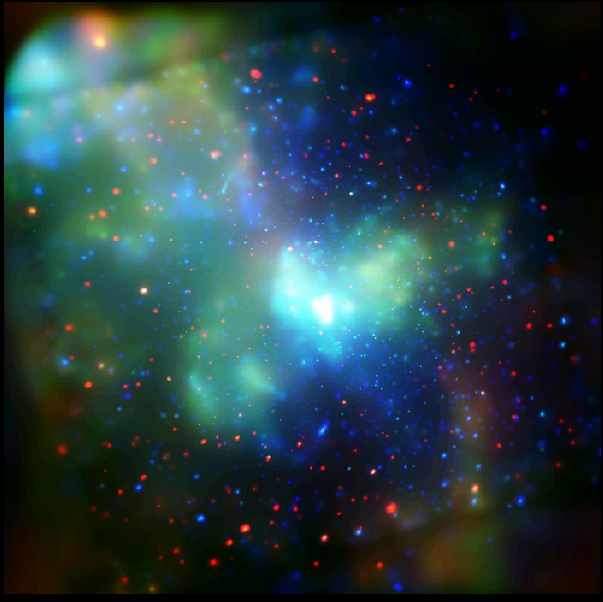


Event Horizon Telescope (EHT)
observational campaign: 5-10 April, 2017
Average of three different imaging methods

- ❑ Shadow of the Kerr BH as predicted by General Relativity
- ❑ Asymmetrical bright emission resolved into a ring (crescent) with diameter of $42 \pm 3 \mu\text{as}$. Asymmetry due to relativistic beaming from a plasma rotating at $v \sim c$ around and very close to the BH

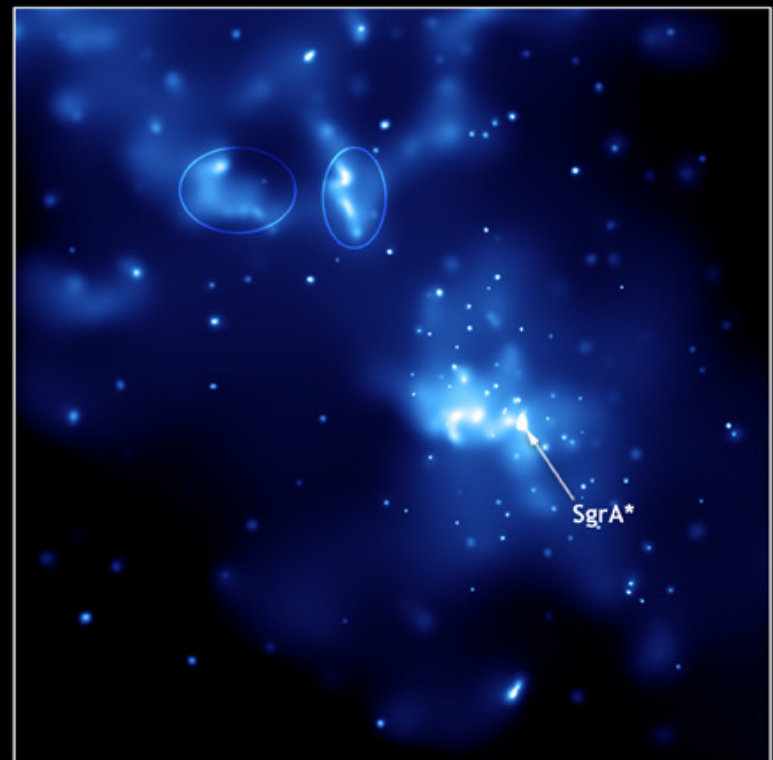
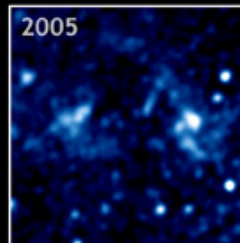
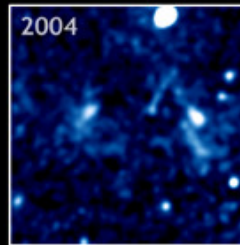
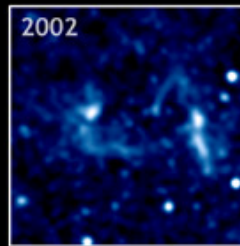
The fascinating world of the Galactic Center

The Galactic Center

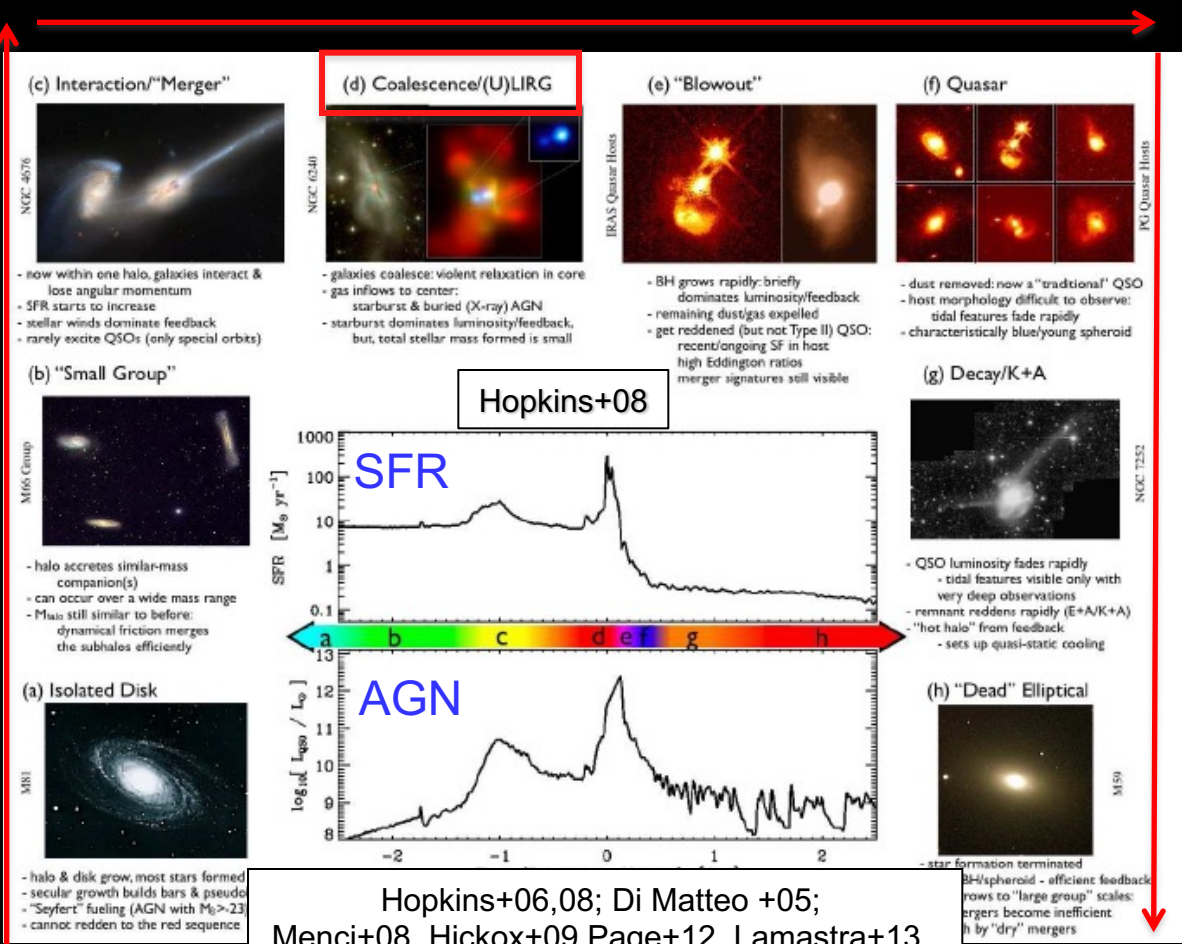


Several million-second exposure
in the Galactic Center and
Galactic Plane region

'Light Echoes' from past SgrA*
activity



The BH-galaxy (co)-evolutionary model



mergers

SF/obscured accretion

"clean" accretion (QSO)

transition (green valley) object

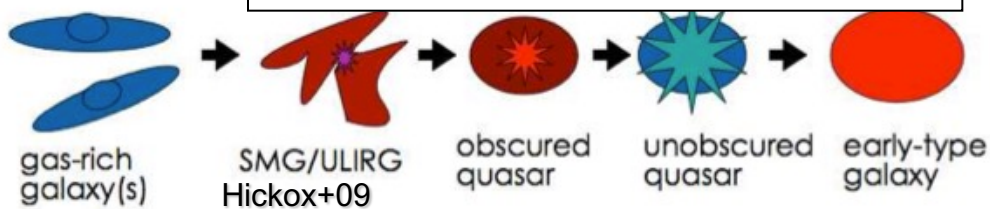
passive red galaxy

SF	Galaxy Morph.	AGN L/LEDD	AGN Obsc.
Strong	Disturbed	High	High
Moderate	Coalescing	Lower	Lower
Low	Relaxed	Lower	No

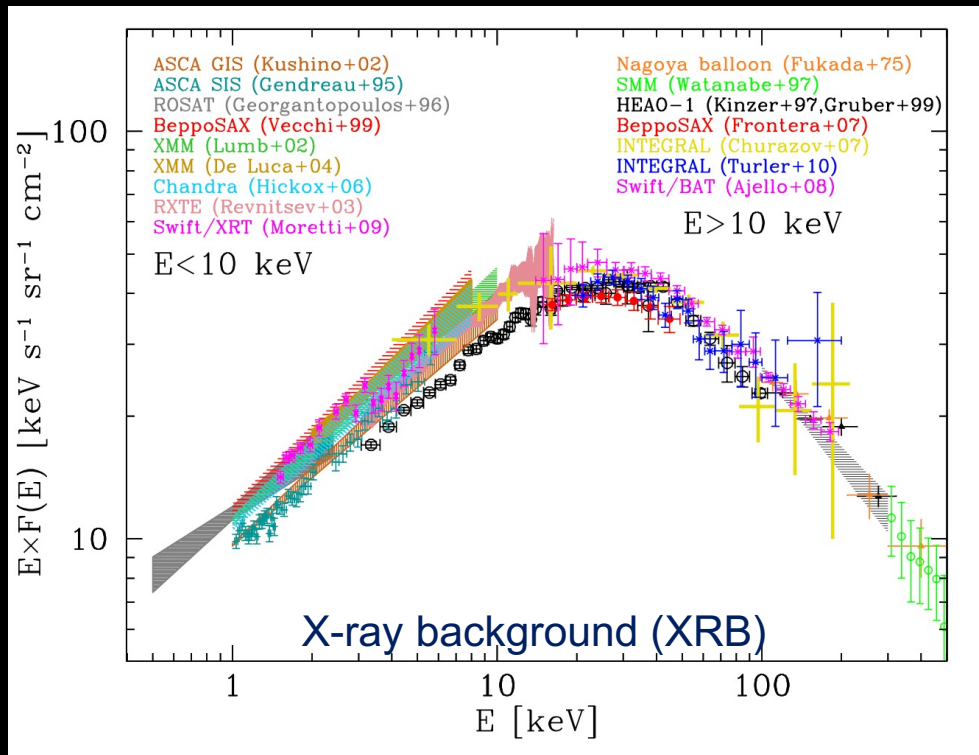
AGN feedback is likely the key to control

the evolutionary sequence

Hold mainly (only?) for *luminous* AGN, while secular ("smooth") accretion via cold gas flows and minor mergers is more likely for lower luminosity Seyferts



The census of AGN and their cosmic evolution

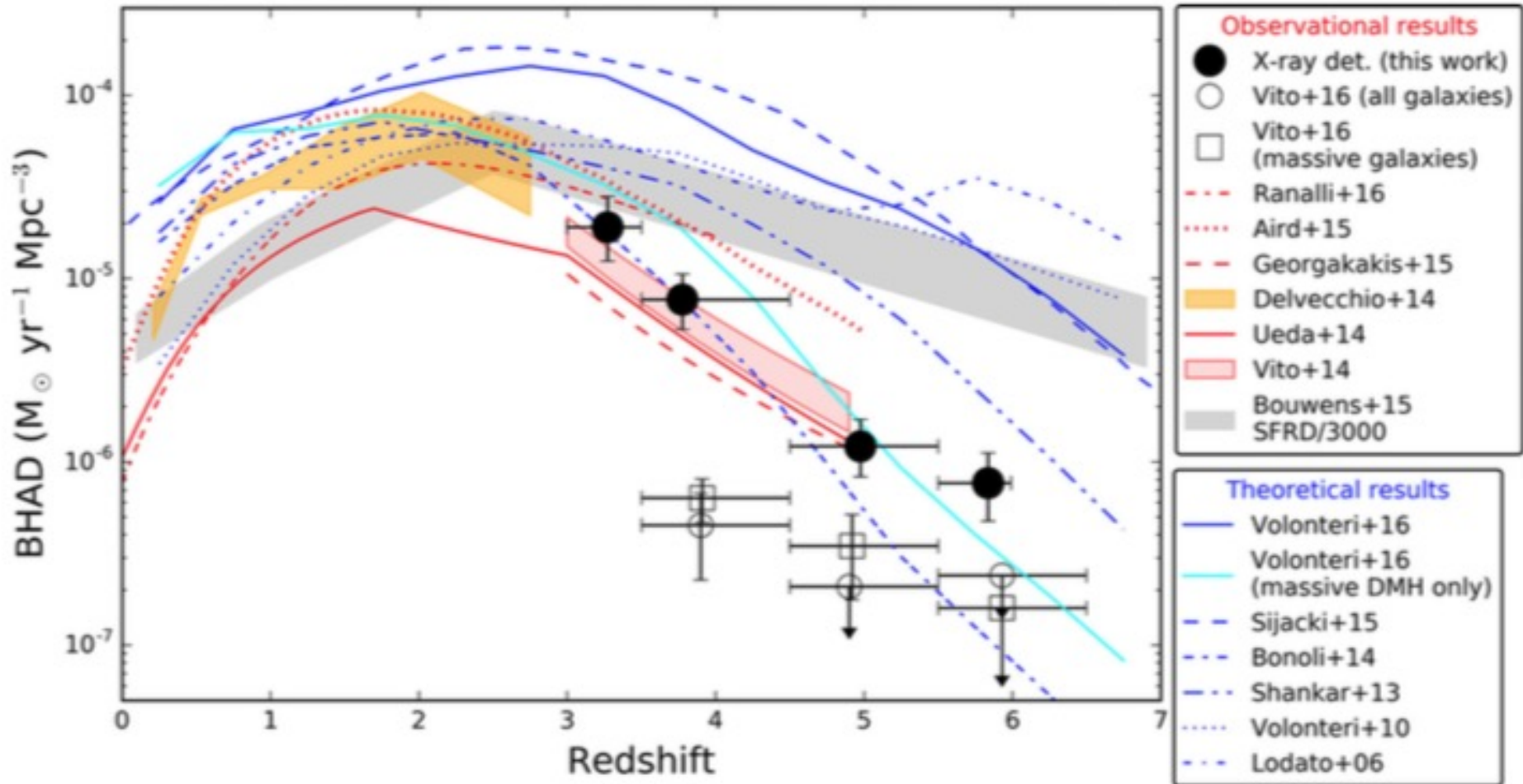


Gilli (2013)

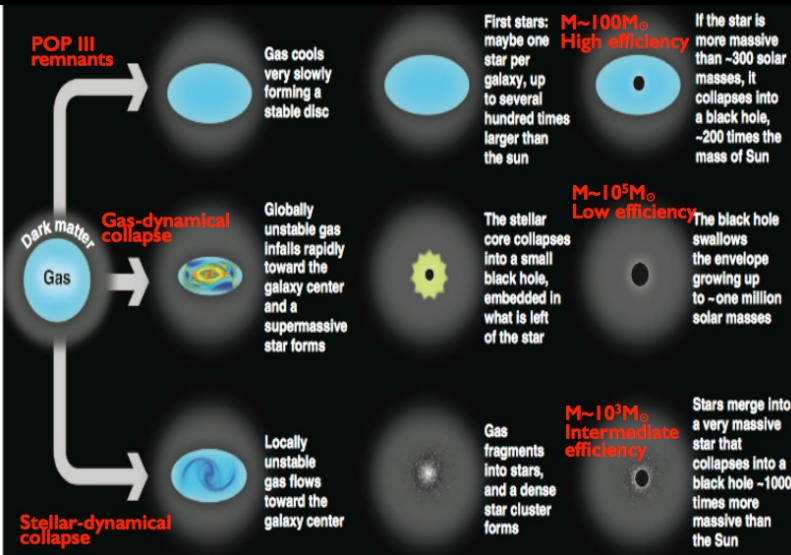
X-ray surveys as a cosmological tool

Population studies to have an almost complete (and possibly unbiased) census of all AGN facets (i.e., including obscured AGN and high-redshift AGN)

The BH accretion rate density (vs. SFRD)



The realm of high-redshift Universe



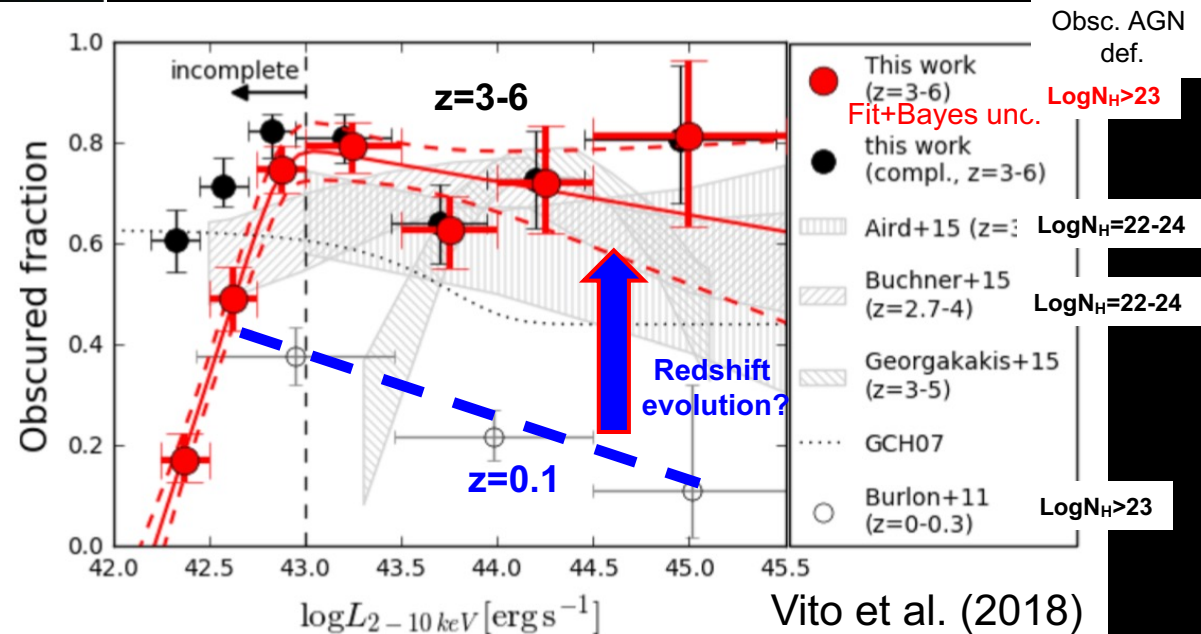
How do SMBH form and accrete at high redshift?

Are we able to get an unbiased view and census of the AGN in the Universe?

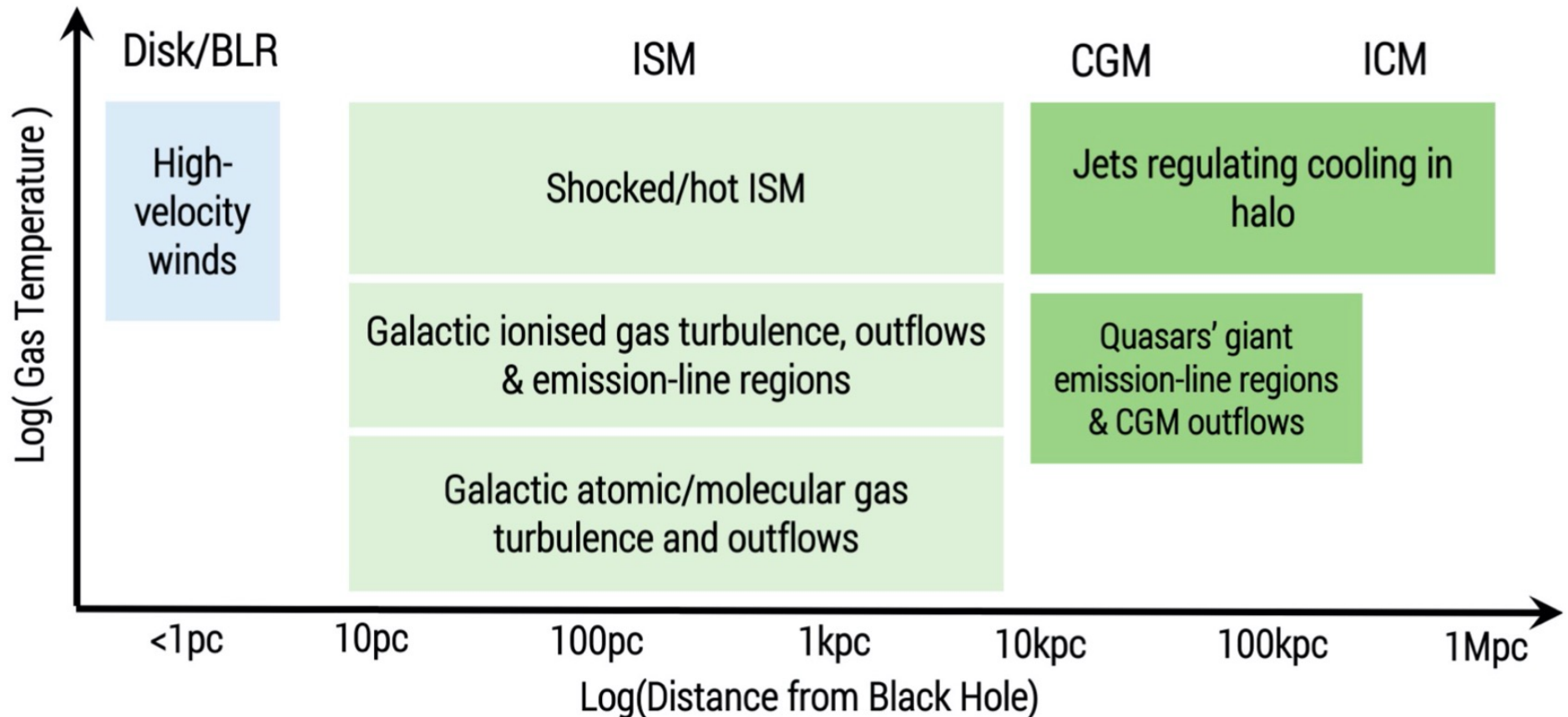
What are next-generation facilities?

CDF-S (7Ms) + CDF-N (2Ms) analysis

Volonteri et al. (2010)



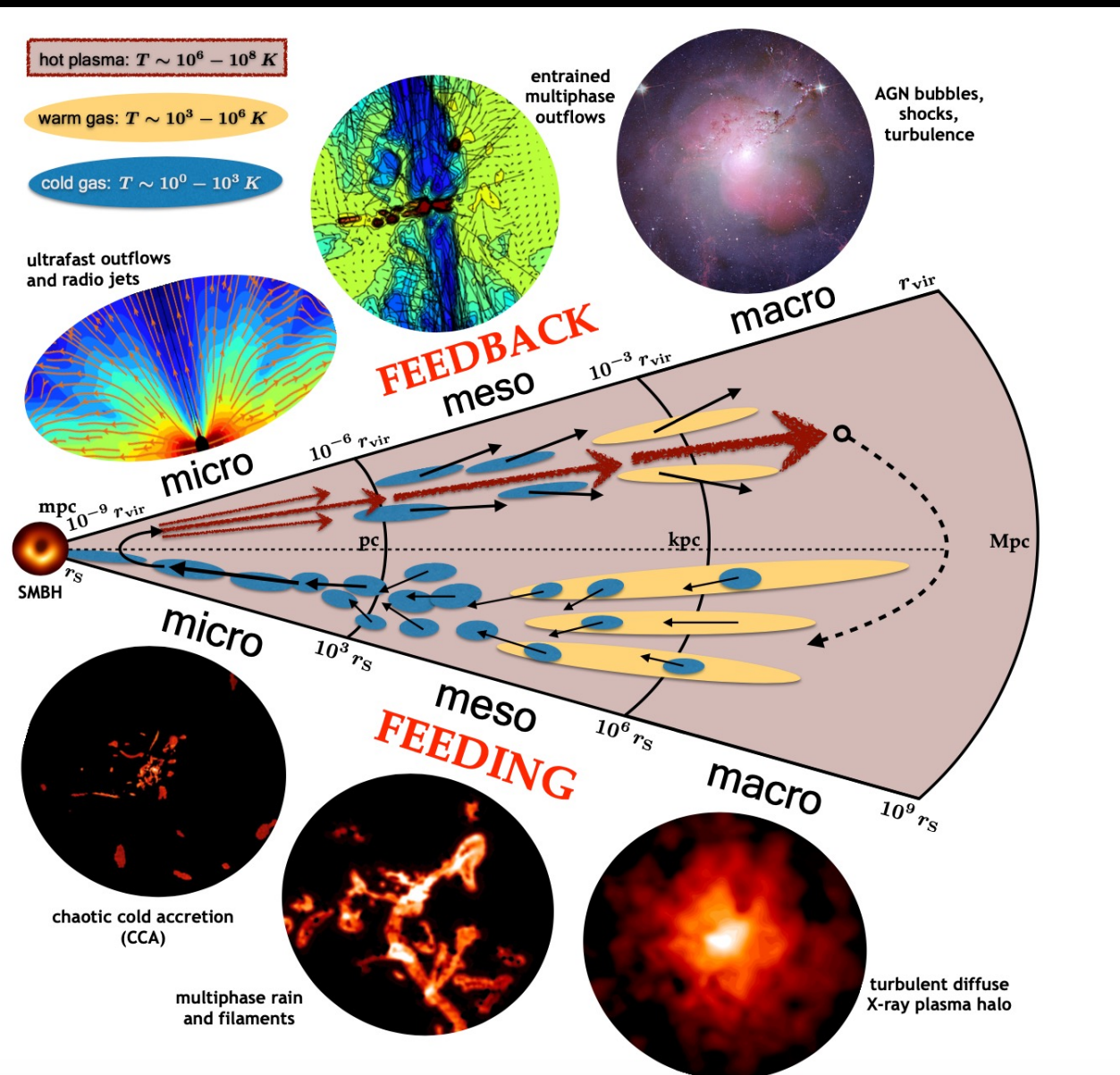
AGN feedback



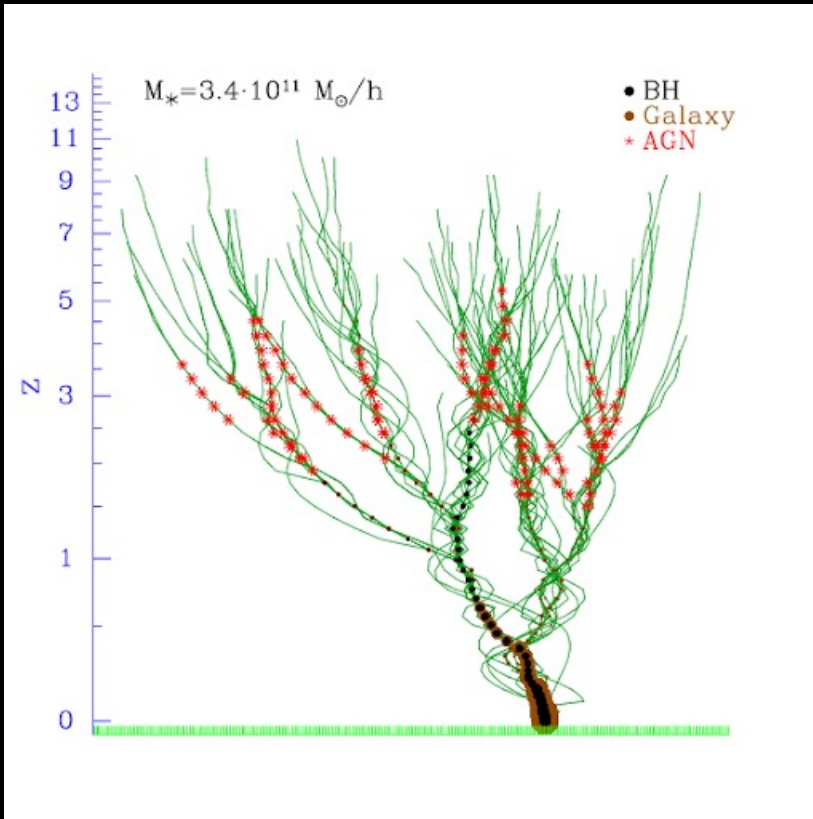
Harrison et al. (2020)

Possible impact of accretion-related (i.e., AGN) activity on very large scales → feedback on the host galaxy

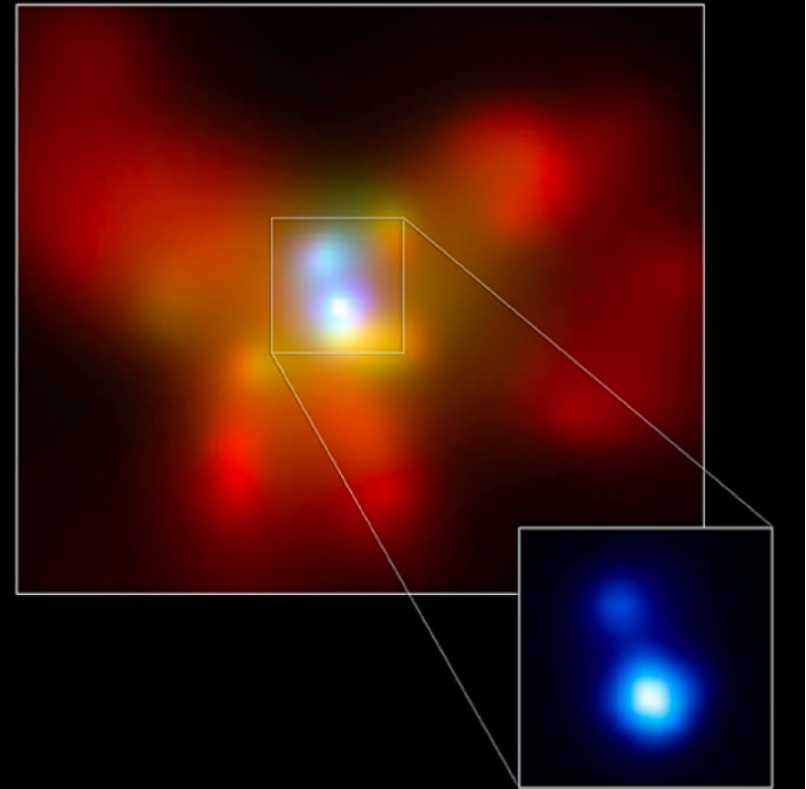
AGN feedback



Triggering AGN accretion, and the role of dual AGN



Courtesy of F. Marulli

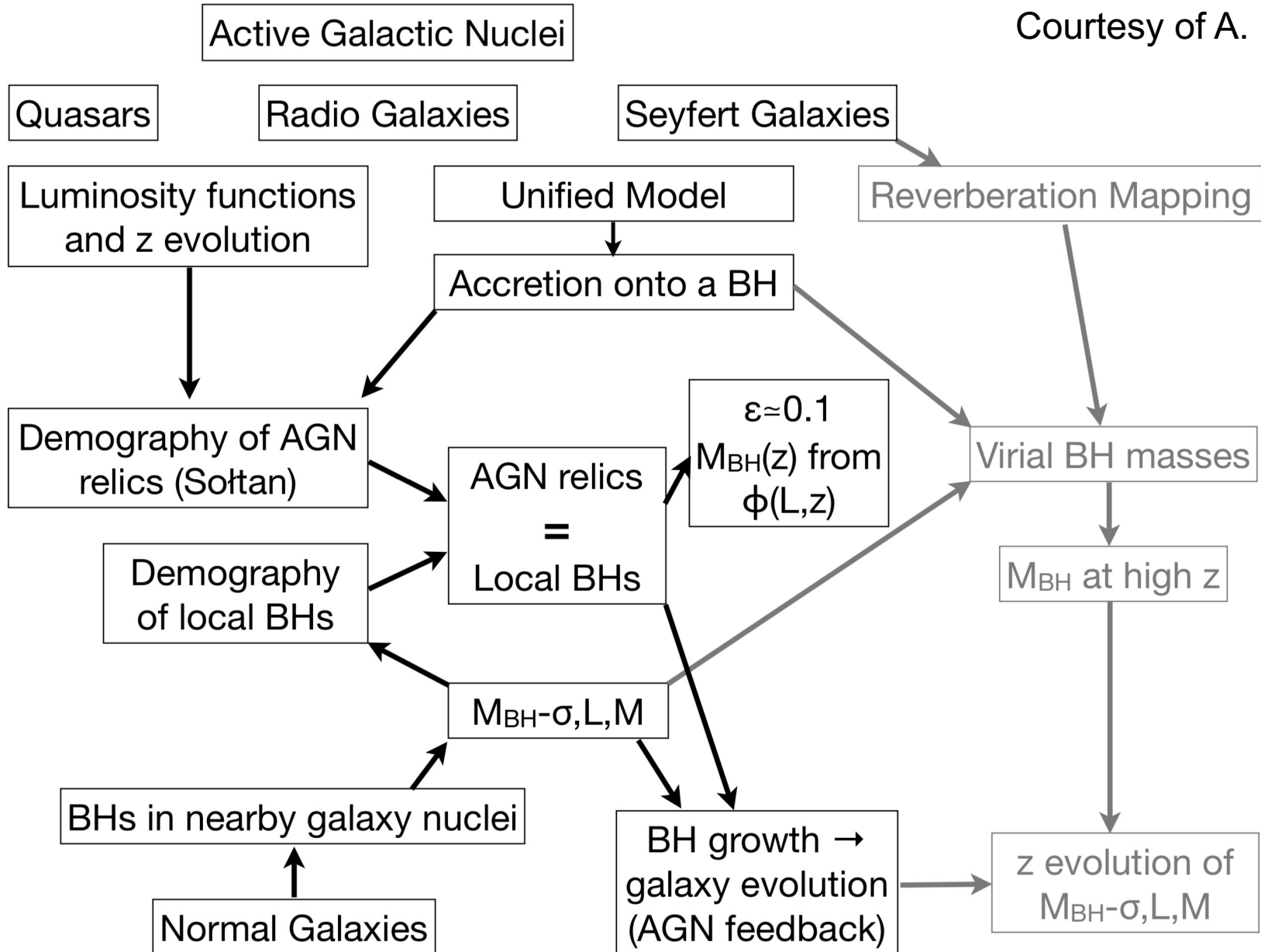


Komossa et al. (2003)

Mergers \rightarrow enhanced accretion (and obscuration), gravitational waves

The variegated AGN-galaxy context

Courtesy of A. Marconi





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Check latest news for info/change of dates/exams/etc

Latest news

Orario lezioni frontali X-ray lab 29-30 ottobre, Sala Seminari IV piano OAS
Published on: October 19 2018

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Office hours

Tuesday and Thursday, 17-18

- Oral examination (one topic at your choice, then questions on all course)
- Books + specialistic papers + slides (as a “guideline”) + <https://arxiv.org>

Slides available on Virtual Learning Environment

and at http://www.bo.astro.it/~vignali/Active_Galaxies/AA2021-22