The feeding cycle of massive black holes

Marta Volonteri
Institut d’Astrophysique de Paris

S. Cielo, Y. Dubois, A. Negri, G. Wafflard-Fernandez (IAP)
M. Habouzit (Simons Foundation)
A. Reines (NOAO)
J. Prieto (Universidad de Chile)
M. Tremmel (University of Washington)
A. Wagner (Tsukuba University)
Massive black holes in galaxies

Massive black holes are routinely detected in nearby galaxies.

Black hole masses correlate with galaxy properties.

This suggests that their growth/evolution are intimately connected.
Galaxies

mass: $10^9$-$10^{12}$ solar masses

\[ R_{\text{halo}} \sim \frac{GM_{\text{halo}}}{\sigma^2} \quad \text{MEGAPARSEC} \]

\[ R_{\text{bulge}} \sim \frac{GM_{\text{bulge}}}{\sigma^2} \quad \text{KILOPARSEC} \]

1 parsec = 3.26 light years = $3 \times 10^{18}$ cm
\[ \sigma \sim 50-400 \text{ km/s for most galaxies} \]

Massive Black Holes

mass: $10^5$-$10^9$ solar masses

\[ R_{\text{bondi}} \sim \frac{GM_{\text{BH}}}{c_s^2} \quad \text{PARSEC} \]

\[ R_{\text{inf}} \sim \frac{GM_{\text{BH}}}{\sigma^2} \quad \text{PARSEC} \]

\[ R_{\text{sch}} = \frac{2GM_{\text{BH}}}{c^2} \quad \text{MICROPARSEC} \]

\[ c_s \sim 10-100 \text{ km/s for most galaxies} \]
\[ c = 3 \times 10^5 \text{ km/s} \]
Active black holes

They are as luminous as galaxies:
$L \sim 10^{11} - 10^{13} \, L_{\odot}$

Size of the emitting region is $10^6$ times smaller than a galaxy \( \sim \) size of solar system

Powered by accreting black holes with masses of millions to billions of $M_{\odot}$
Many massive BHs are quiescent. We have an example in the center of the Milky Way.

The typical luminosity of Sgr A*, is $\sim 10^{34}$ erg/s.

Not much more than the Sun (4$\times 10^{33}$ erg/s).
The feeding/feedback cycle

*Feeding:* the galaxy feeds the black hole through gas inflows

*Black hole feedback:* the kinetic and radiative output from active black holes

A black hole grows by accreting gas and becomes *active*

An *active* black hole launches winds or jets that interact with the gas of the galaxy, modulating gas accretion onto the black hole

If gas is prevented from going back to the black hole, the *active* black hole goes back to *quiescence*
Complex interaction between black hole feeding, feedback, star formation
Complex interaction between black hole feeding, feedback, star formation

Negri & Volonteri 2017
The feeding/feedback cycle in small galaxies

**Feeding**: the galaxy feeds the black hole through gas inflows

**Black hole feedback**: the kinetic and radiative output from active black holes

**Stellar feedback**: radiation from stars and supernova explosions also inject energy and momentum
The feeding/feedback cycle in small galaxies

Small galaxies: $v_{\text{esc}} \sim (M_{\text{gal}}/R_{\text{gal}})^{1/2} \sim \sigma \sim 100 \text{ km/s}$

Supernova-driven winds $v_{\text{SN}} \sim 200-300 \text{ km/s}$

Supernova feedback is sufficient to energize the gas and suppress black hole accretion (Dubois+14)

Also suppress/regulate star formation, ça va sans dire.
SETH, Ramses Cosmological Zoom, ~5pc resolution, Dubois, MV+14
The feeding/feedback cycle in small galaxies

$M_{\text{BH}} \ (M_{\odot})$

$M_{\star, \text{Galaxy}} \ (M_{\odot})$

$z=0 \ BHs$ and AGN 
(Reines & Volonteri 2015)

10 Mpc
cosmological volume,
$\sim80$pc resolution

Habouzit, MV, Dubois 2017
The feeding/feedback cycle

Complex interaction between black hole feeding, feedback, star formation, stellar feedback

In massive galaxies AGN feedback regulates its own feeding (and star formation)

In low-mass galaxies supernova feedback regulates black hole feeding (and star formation)

Supernova and AGN feedback enhance each other