Multiphase Fountains with Black Hole Pumps
Cold gas couples to black holes via both feedback & feeding
Pushing hot gas with jets is easy.

It’s about $2,000 an ounce.
Perseus / NGC 1275
Chandra 1.4 Msec (!)

100 kpc

Fabian+11
Pushing warm gas with jets and bubbles is somewhat easy.
Perseus / NGC 1275
Chandra 1.4 Msec (!)

Fabian+11
Increasing Lifetime of Thermal Instabilities
Multiphase cooling “rain” when

\[ t_{\text{cool}} < 10 \ t_{\text{dyn}} \]

(maybe)

(roughly; there’s large scatter)

Gaspari+12, 13, 15
McCourt+12
Sharma+12
Voit+15, 16
McNamara+16
X-ray + Halpha

15 kpc

Fabian+ and many others
See Becky Canning’s awesome work on Perseus
FUV continuum (young stars), radio contours

Tremblay+15
Pushing cold gas around is hard
Work I’m ripping off…

Gaspari+12,13,14,16
McCourt+12
Sharma+12
Li+14
Voit+15, 16
McNamara+16

…building on decades of work by many (including Paul, Christine, Bill, Becky… )
Fountain Plumes (?)

*HST ACS/SBC FUV continuum (Tremblay+15)*
Observations by Li et al.

R: $\text{H}\alpha$

G: FUV

B: X-ray

-$20 \text{ kpc}$

-$10 \text{ kpc}$

$5 \text{ M}_{\text{sol}} / \text{yr}$

$28 \text{ M}_{\text{sol}} / \text{yr}$

$2.9 \text{ Gyr}$

-$15 \text{ kpc}$

$138 \text{ M}_{\text{sol}} / \text{yr}$

$85 \text{ M}_{\text{sol}} / \text{yr}$

$2.17 \text{ Gyr}$

-$10 \text{ kpc}$

$15 \text{ kpc}$

$1.69 \text{ Gyr}$

$5 \text{ M}_{\text{sol}} / \text{yr}$

$2.9 \text{ Gyr}$

-$1 \text{ kpc}$

$1 \text{ kpc}$

$0.47 \text{ M}_{\text{sol}} / \text{yr}$

$4.82 \text{ Gyr}$

Observation vs. Simulation

Tremblay+15, Li+14, + Max’s talk
We’ve been observing these with ALMA

*HST ACS/SBC FUV continuum (Tremblay+15)*
The ALMA TAC has approved these…

HST ACS/SBC FUV continuum (Tremblay+15)
ALMA shows molecular gas being dragged upward by bubbling
PKS 0745-191

HST FUV

ALMA CO(2-1)

Tremblay+15

1.5 billion

1.3 billion

2 billion

6 kpc

Russell+16
CO(3-2) in 2A 0335: Vantyghem+16
ALMA CO(2-1) and HST Ly-alpha contours. 7.5 kpc (5'').

Radio contours and Tremblay+16a,b.
The Fountain’s “Plume”
CO(2-1) channel maps

Structure over 700 km/s, clearly aligned with jet

Tremblay+16b
Cold “mist” may redirect jet

Tremblay+16b
Cold “mist” stirred by the jet

Tremblay+16b
Jet deflection site

- Absorption on nucleus
- Jet kink / impact site
- Jet region
- Position / velocity slit orientation
- Position (kpc)
- Position (arcsec)
- Velocity (km s\(^{-1}\))
- Northern knot
- Tremblay+16b
The Fountain’s “Drain”
Cold clouds close to the black hole, and falling closer toward it.

Tremblay+16a

See also: Larry David’s 2014 paper
40 pc diameter,
subtending 0.025”

$10^{5-6} \text{ M}_\text{Sol}$ each

$N_H \sim 10^{22} - 10^{24} \text{ cm}^{-2}$, blanking 20% of continuum signal

Low $L$, (nearly) radial orbit

$<100 \text{ pc from BH, short ($\sim 10^6 \text{ yr}$) crossing time, substantial mass flux}$
If we’re right, you might see a change in the absorption features over a short (1 year) timescale

...a “movie” of chaotic cold accretion*?

(*see Max’s talk next)
Cold gas couples to black holes via both feedback & feeding
See Max’s talk for a much better explanation.
Shameless plug:

www.cars-survey.org
15 kpc from the galaxy’s nucleus
VLT / FORS U+V band
Rejkuba+
~2 kpc

MUSE H-alpha
Santoro+14
Hamer+15
biconcoidal outflow
Mrk 1044 (z=0.016)  

CARS Chandra Cycle 17 Target

R: Hα
G: [O III]
B: [N II]

CARS MUSE Data

HST/WFC3

3 kpc (8")

Powell+ in prep
Tremblay+ in prep
HE 0227-0931 ($z = 0.017$)

R: Hα
G: [O III]
B: Cont.

MUSE IFU

R: Hα
G: [O III]
B: [N II]

Apparent Expansion Direction

20″ (8 kpc)

Powell+ in prep
Tremblay+ in prep
Mrk 1018’s second return to the shadows

McElroy+16
Husemann+16
Thanks, Belinda! :)

Chandra DDT

HST / COS DDT

McElroy+16
Husemann+16
Partners in crime

Yuan Li
Keren Sharon
Joel Bregman
Francoise Combes
Philippe Salome
Andy Fabian
Raymond Oonk
Chris O’Dea
Stefi Baum

Alastair Edge
Brian McNamara
Megan Donahue
Mike McDonald
Mark Voit
Tracy Clarke
Alice Quillen
Helen Russell
Tim Davis
Max Gaspari

Malcolm Bremer
Louise Edwards
Daisuke Nagai
Mike Wise
Anaelle Maury
Jeremy Sanders
Roberto Galvan-Madrid
Marco Chiaberge
Bernd Husemann
Meg Urry

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