Star Formation amid Kinetic Black Hole Feedback

Yale

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A two billion solar mass “fountain” of molecular gas and young stars pumped by a black hole
Perseus / NGC 1275
*Chandra* 1.4 Msec (!)
Perseus / NGC 1275
Chandra 1.4 Msec (!)

100 kpc

Fabian, Sanders+12
See also Zhuraleva+14, out yesterday
Perseus / NGC 1275
*Chandra* 1.4 Msec (!)

Fabian, Sanders+12
NGC 1275
HST H-alpha

Fabian+
Conselice+
Hatch+
& many, many others
Mechanical AGN feedback is not a "switch" that shuts off star formation.
The “entropy floor” is both porous & variable. Stars form even amid feedback.
Years of great work on Hydra A, e.g. Wise+, Simionescu+, McNamara+, McDonald+, Hamer+13
Stars can survive the propagation of a jet

FUV continuum with radio contours
Abell 2597

Kinetic AGN Feedback does not exclusively Quench Star Formation

Jet-triggered star formation?

Figures adapted from Tremblay et al. 2012a, 2013
The cool core cluster Abell 2597 (z=0.08)

*Chandra* 120 ksec
X-ray cavity network within inner 100 kpc

X-ray unsharp mask

Tremblay+12a,b
X-ray unsharp mask

100 kpc
X-ray unsharp mask with radio contours
X-ray with optical host galaxy isophotes
HST R-band
H-alpha contours

Tremblay+12a,b
HST FUV continuum
8.4 GHz radio contours
FUV cont. unsharp mask

HST far-ultraviolet continuum
Cold X-ray filament entrained?

Tremblay+12a,b
Oonk+10
Taylor+99
ALMA CO(2-1)

Mean spectrum (mJy/beam)

Velocity (km/sec)
peak CO(2-1) flux
20.2 ± 0.18 mJy

~2 x 10^9 M_☉ of cold H_2
(assuming Galactic X_CO)
A star forming molecular balloon inflated by a jet
Approaching side of the molecular bubble

\[ \sim -500 \text{ km/sec} \]
Approaching side of the molecular bubble

\[ \sim -350 \text{ km/sec} \]
Approaching side of the molecular bubble

\[ \sim -200 \text{ km/sec} \]
Approaching side of the molecular bubble

\[ \sim -150 \text{ km/sec} \]
Approaching side of the molecular bubble

\~-80 \text{ km/sec}
Receding side

$\sim +500 \text{ km/sec}$
Receding side

~+300 km/sec
Receding side

\(~+100\ \text{km/sec}\)
Molecular balloons painted with young stars?

“Jet-triggered” star formation?
Symmetric velocity structures
Approaching and receding sides of the outflow
of molecular gas entrained in jet-driven outflow.
Ballistic molecular “rain” falling back from the fountain plume
Southern Filaments @ +100 km/sec
Slow rain down filaments?
Slow rain down filaments?
Slow rain down filaments?
Slow rain down filaments?
Slow rain down filaments?
Slow drizzle down the filaments
Infalling clouds at...

+250 km/sec
+275 km/sec
+375 km/sec
Could the infalling clouds be in the galaxy outskirts?

Unlikely.
Pressure balance & virial arguments:

Clouds must attenuate continuum signal with sufficiently large column while

(1) respecting pressure balance
(2) respecting observational constraints (FWHM)
Virial & FWHM give rough mass for infalling clouds

$10^6 - 10^7 \, M_\odot$ each into innermost 300 pc of galaxy
Mechanical jet-driven feedback

acts on

and can be powered by

the cold molecular ISM
SUMMARY

*Chandra* sees the rain cloud,

ALMA sees the puddle.