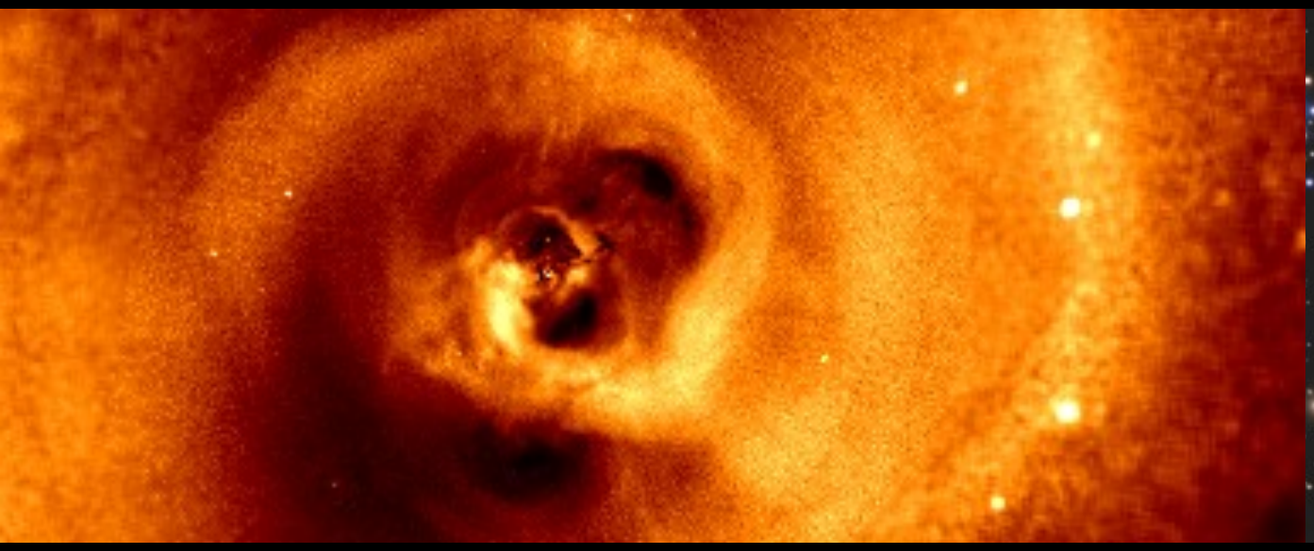


Star Formation amid Kinetic Black Hole Feedback

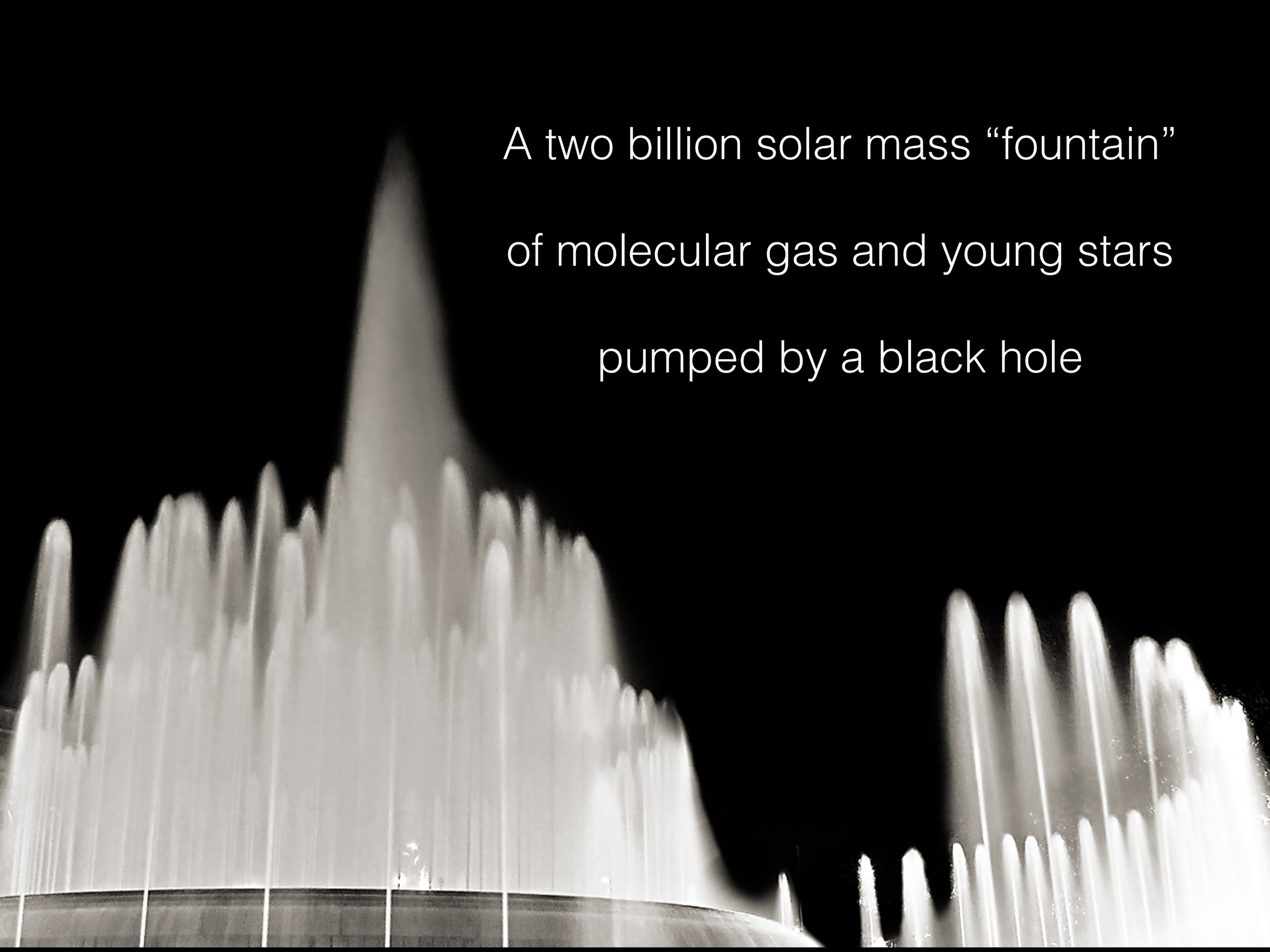
Yale NASA

Grant Tremblay
Einstein Fellow @ Yale University

A two billion solar mass “fountain”

of molecular gas and young stars

pumped by a black hole



Perseus / NGC 1275
Chandra 1.4 Msec (!)

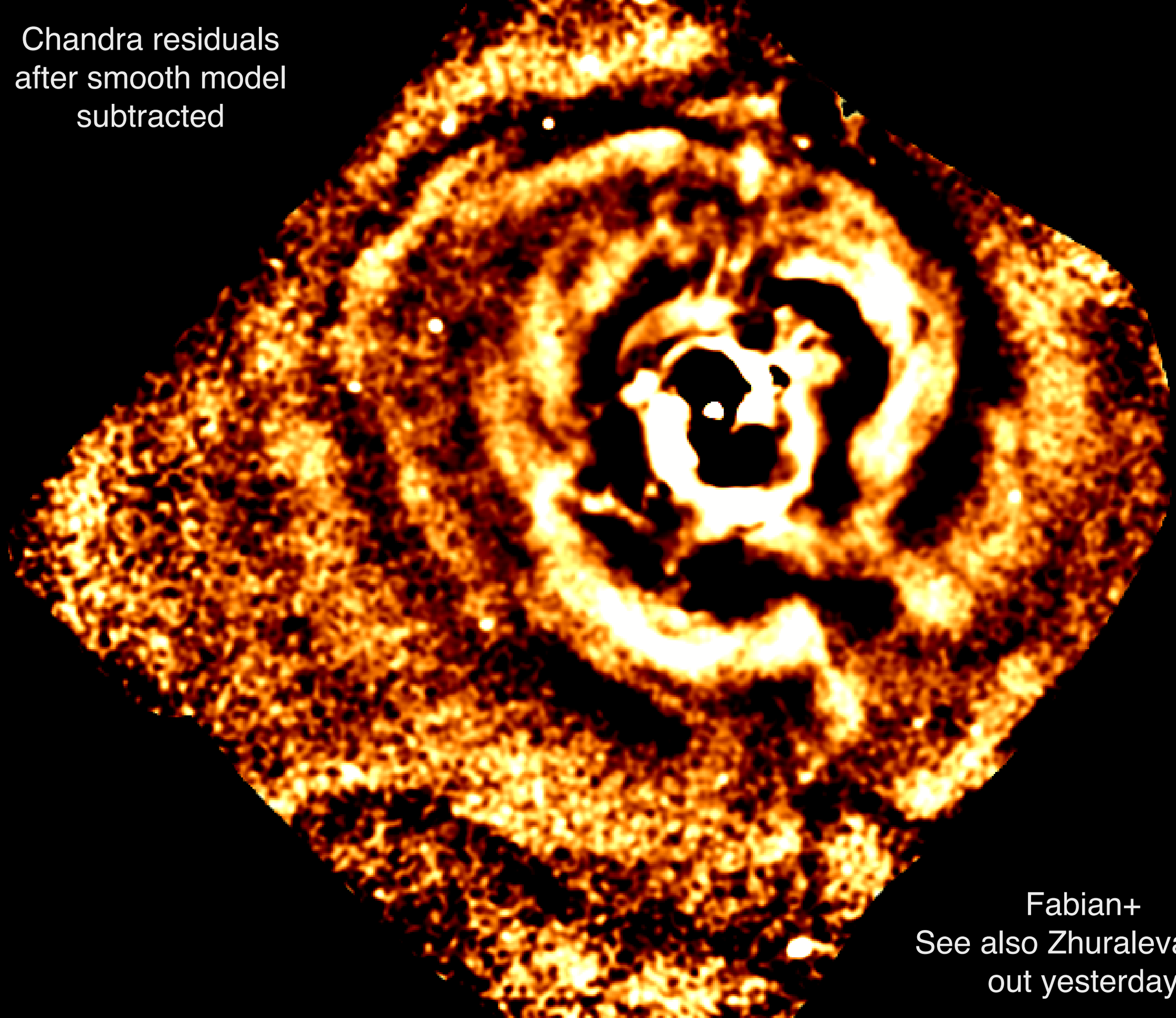
Fabian, Sanders+12

Perseus / NGC 1275
Chandra 1.4 Msec (!)

100 kpc

Fabian, Sanders+12

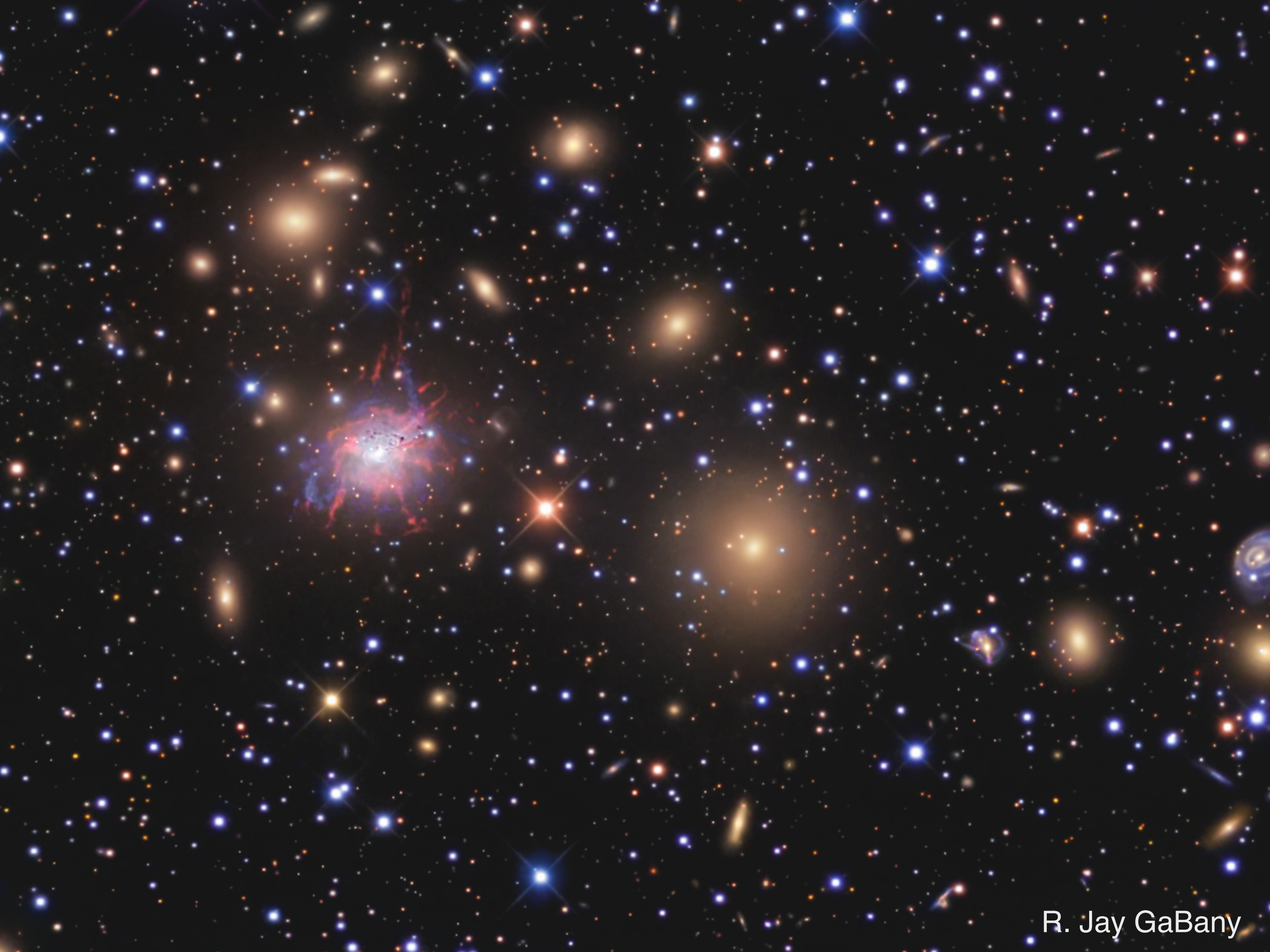
Chandra residuals
after smooth model
subtracted

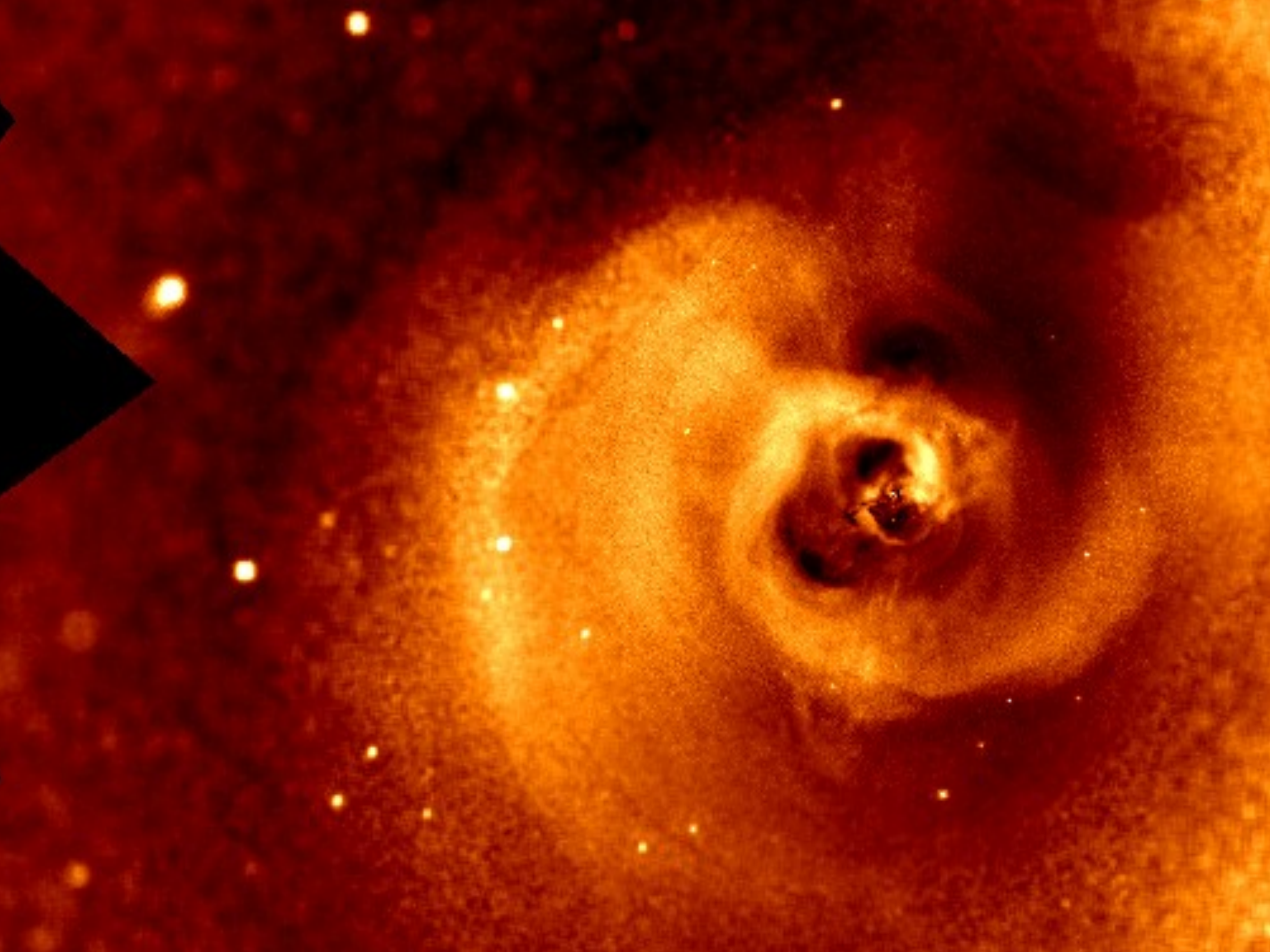


Fabian+
See also Zhuraleva+14,
out yesterday

Perseus / NGC 1275
Chandra 1.4 Msec (!)

Fabian, Sanders+12


R. Jay GaBany



NGC 1275
HST H-alpha

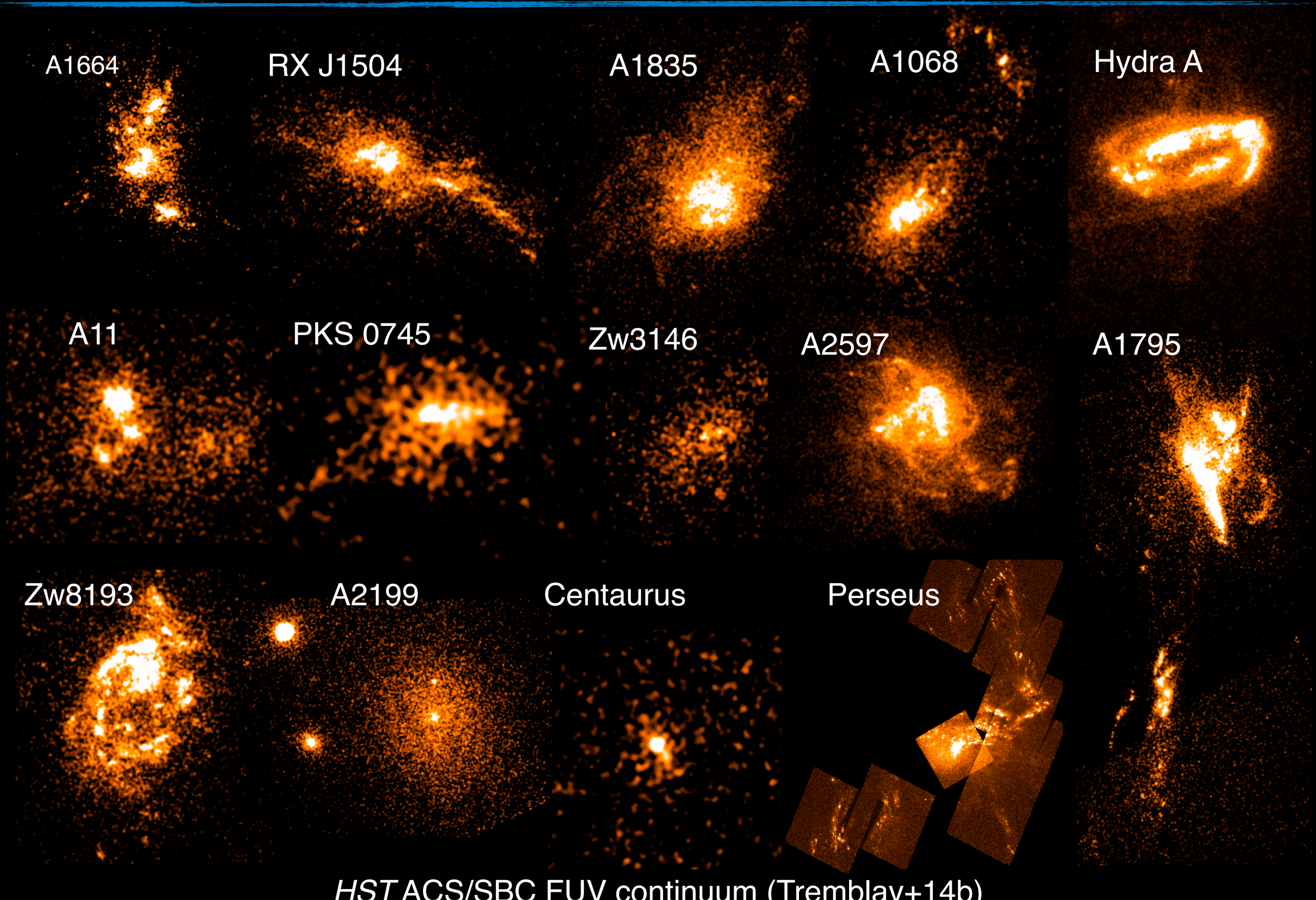
Fabian+
Conselice+
Hatch+
& many, many others

Mechanical AGN feedback

is not

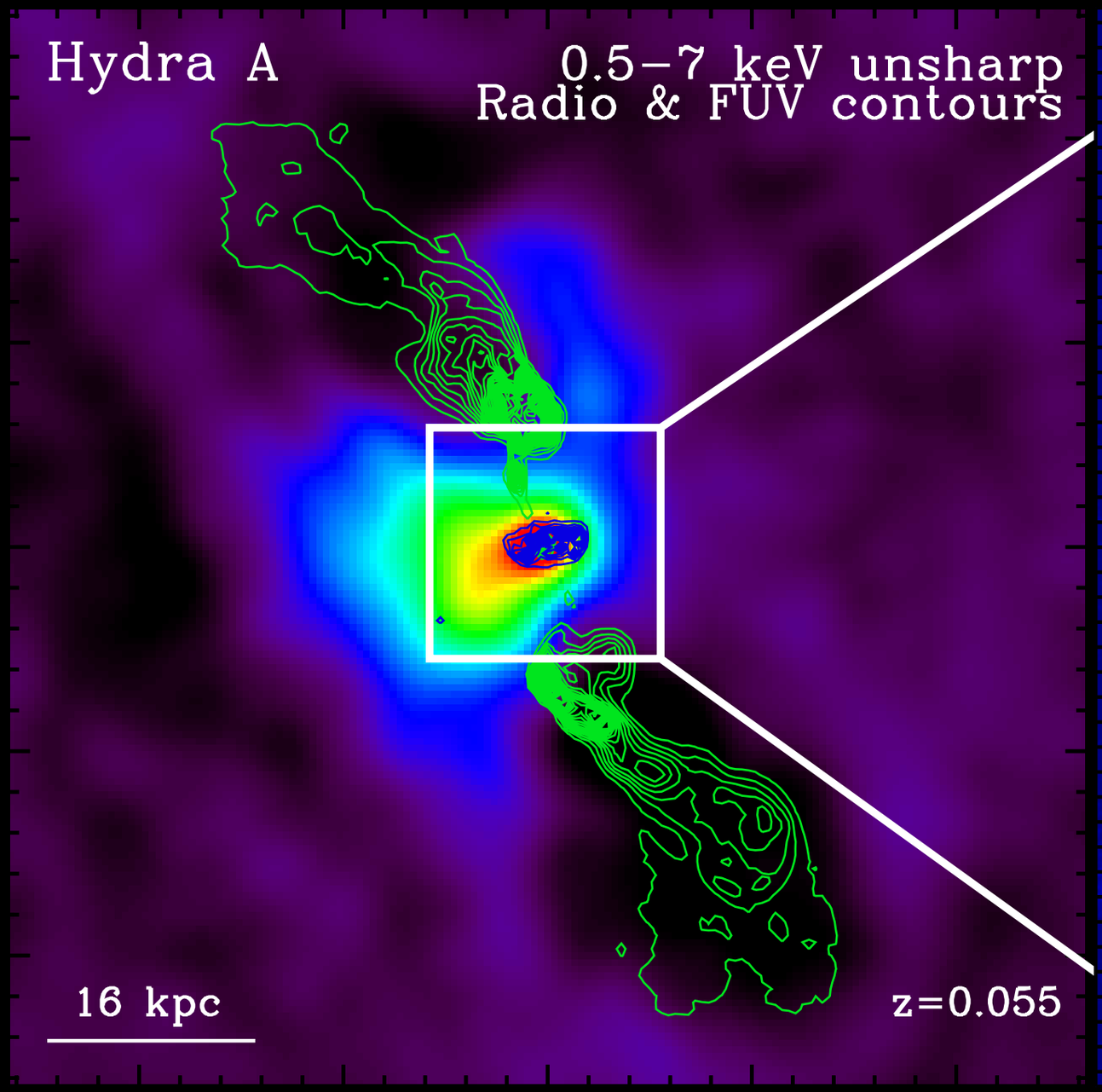
a “switch” that shuts off star formation

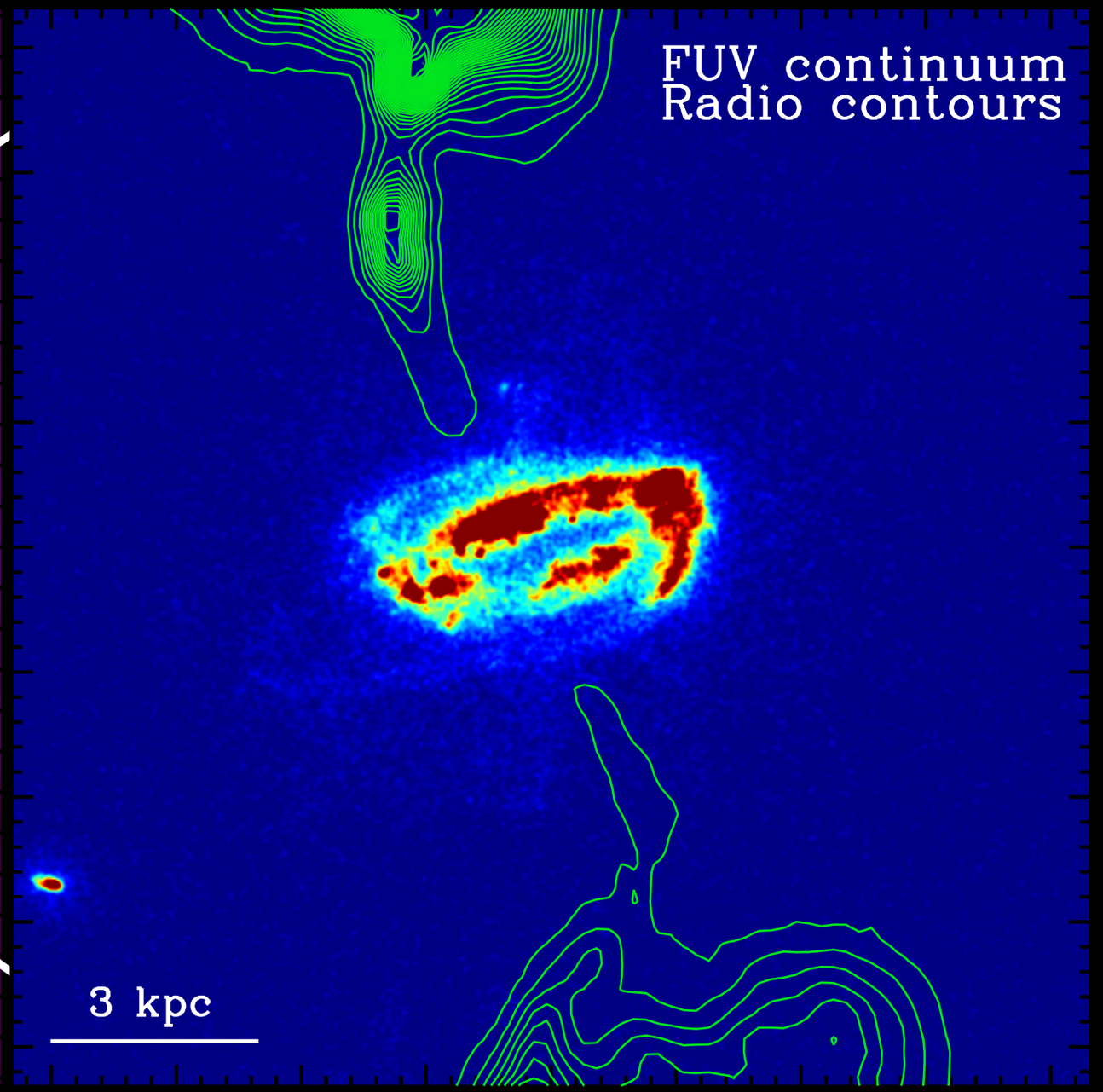
The “entropy floor” is both porous & variable. Stars form even amid feedback.



HST ACS/SBC FUV continuum (Tremblay+14b)

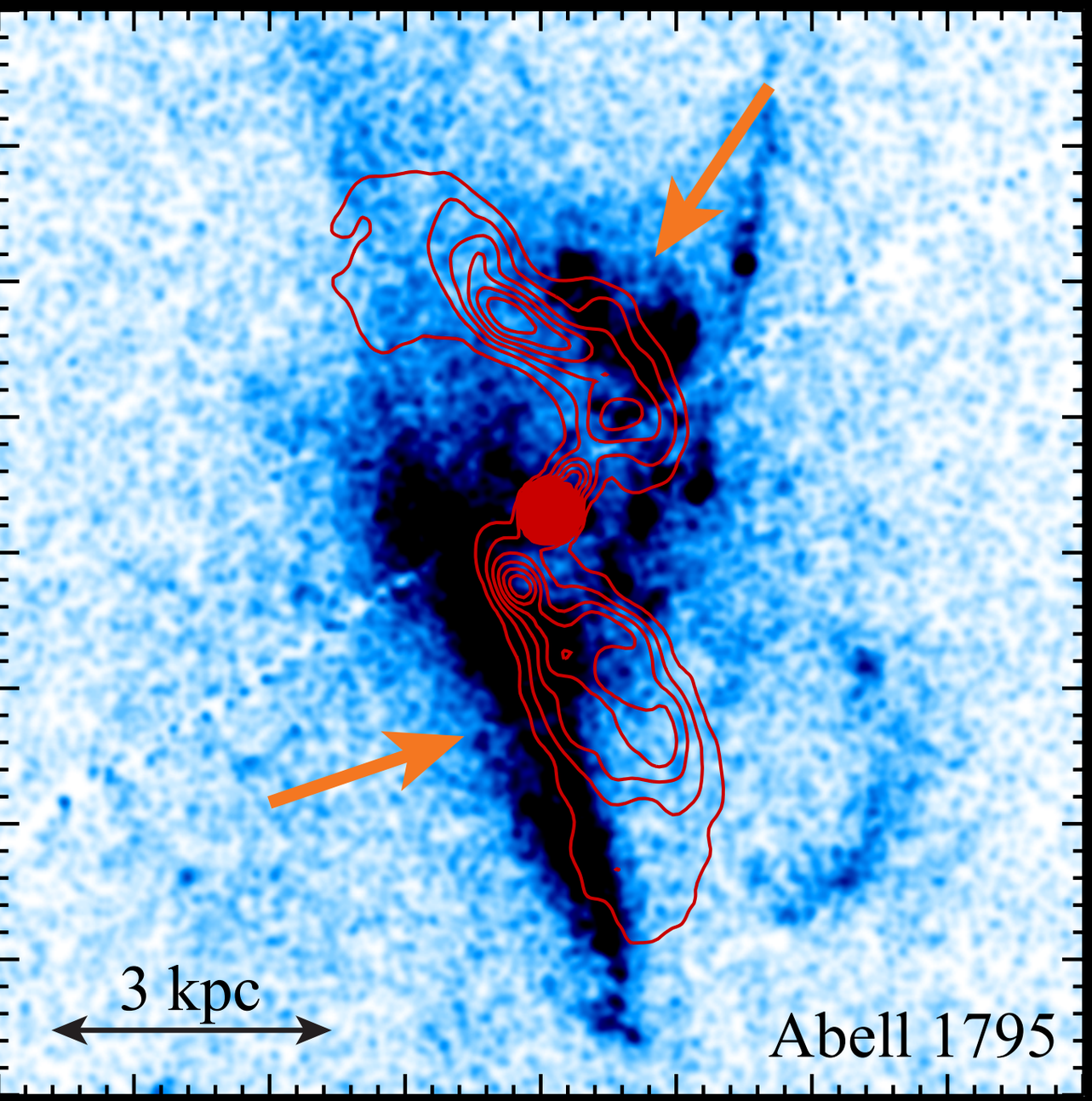
Tremblay+14b

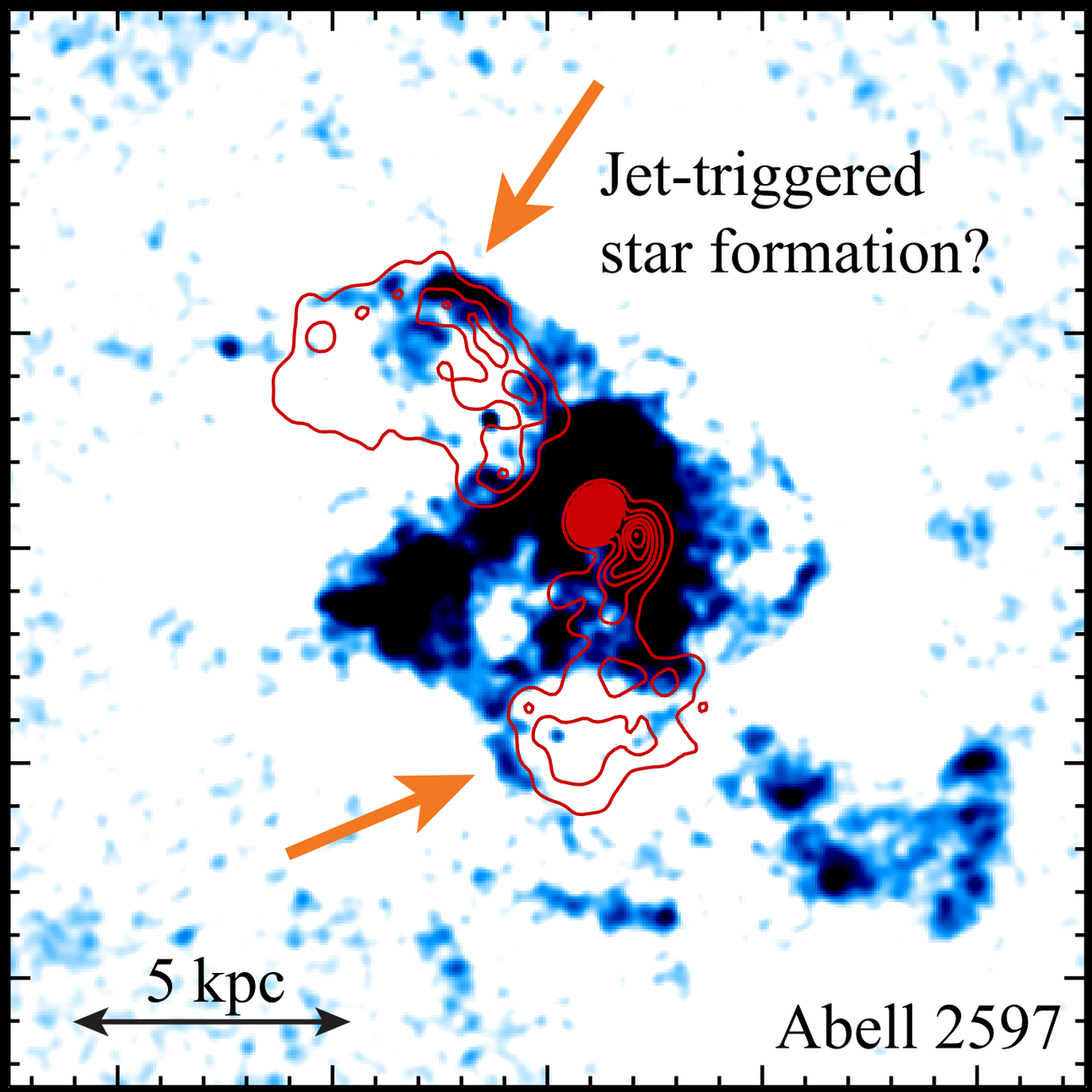




Years of great work on Hydra A, e.g.
Wise+, Simionescu+, McNamara+, McDonald+, Hamer+13

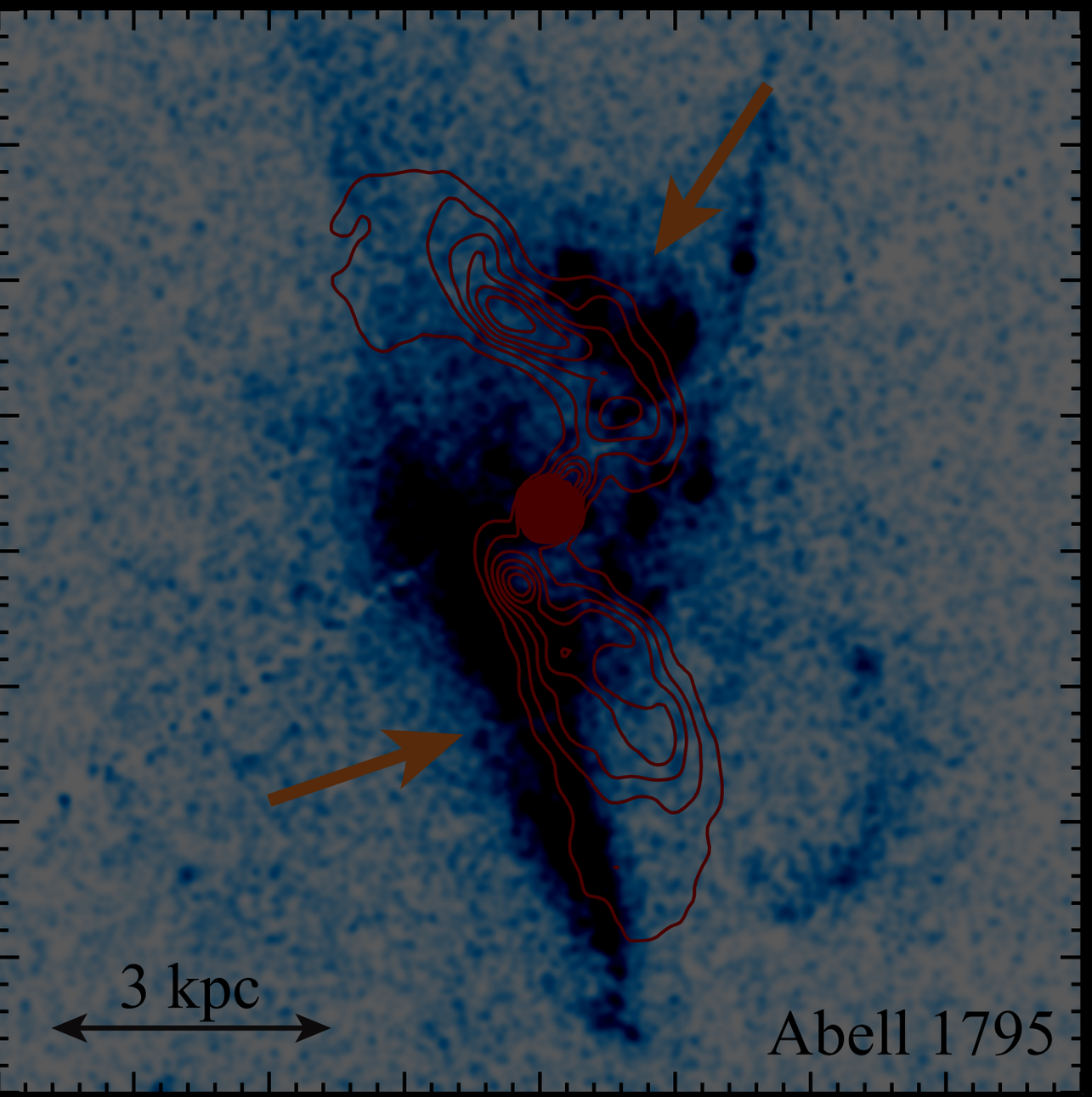
Stars can survive the propagation of a jet

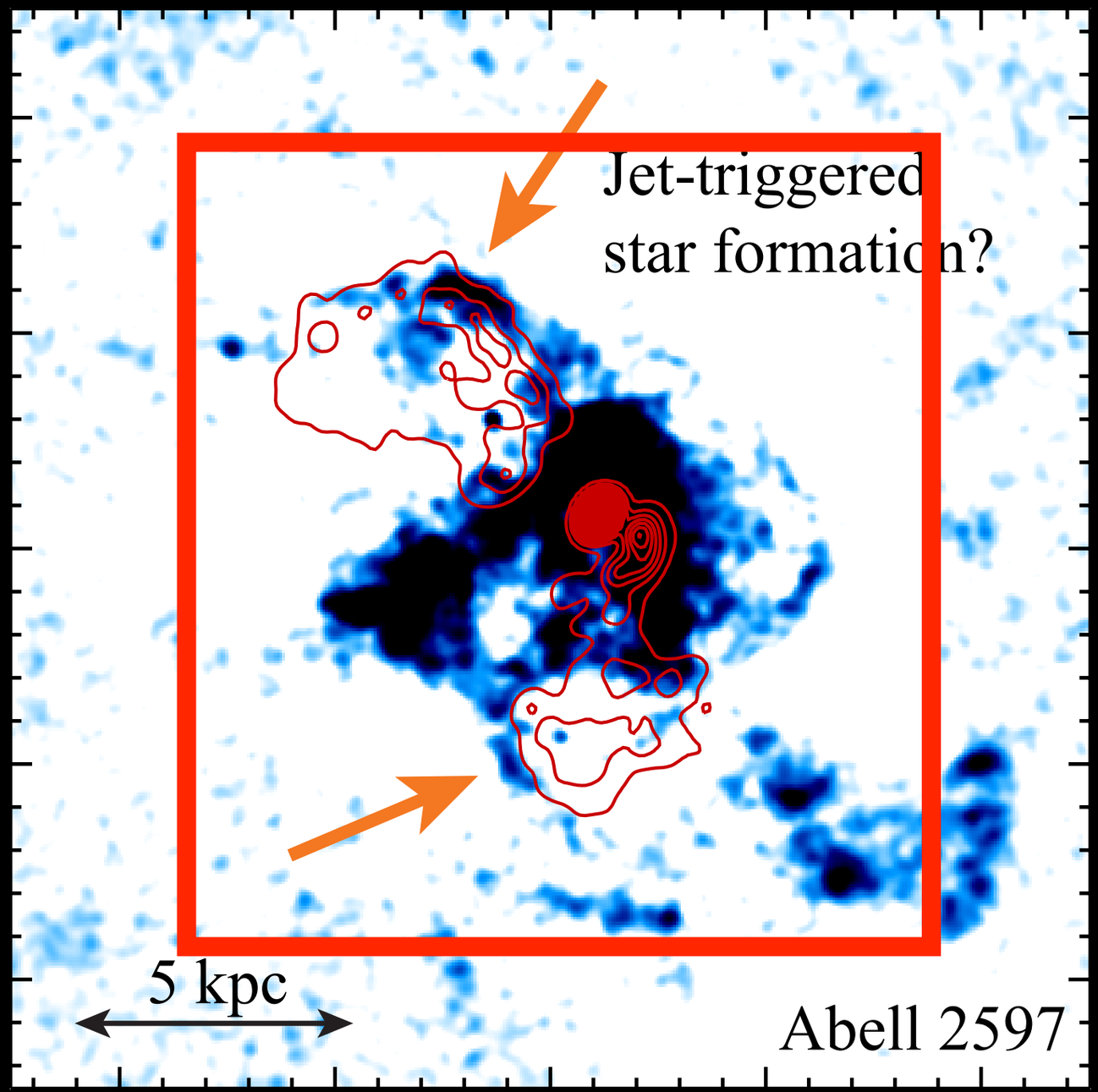




FUV continuum with radio contours

Abell 2597


3 kpc
Abell 1795

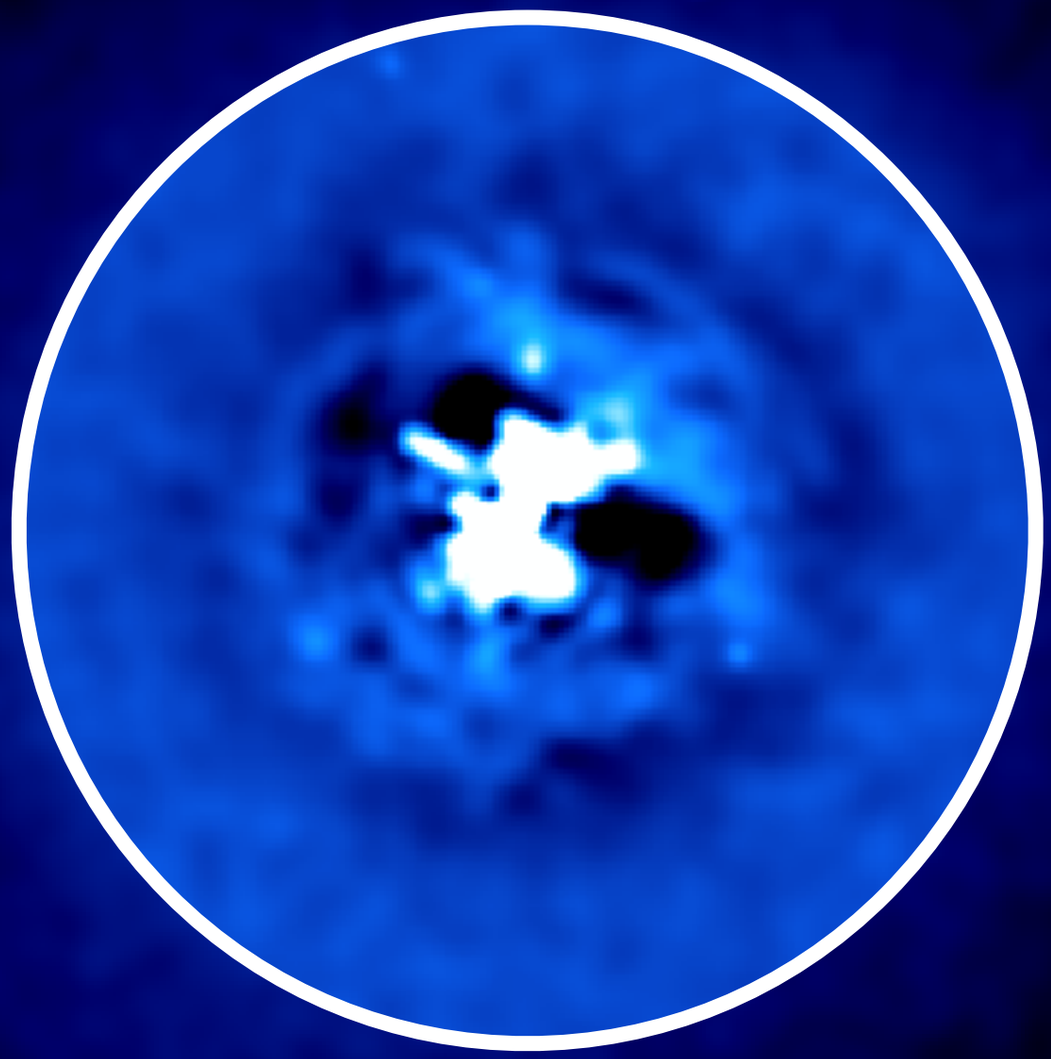

Jet-triggered
star formation?
5 kpc
Abell 2597

The cool core cluster Abell 2597 (z=0.08)

Chandra 120 ksec

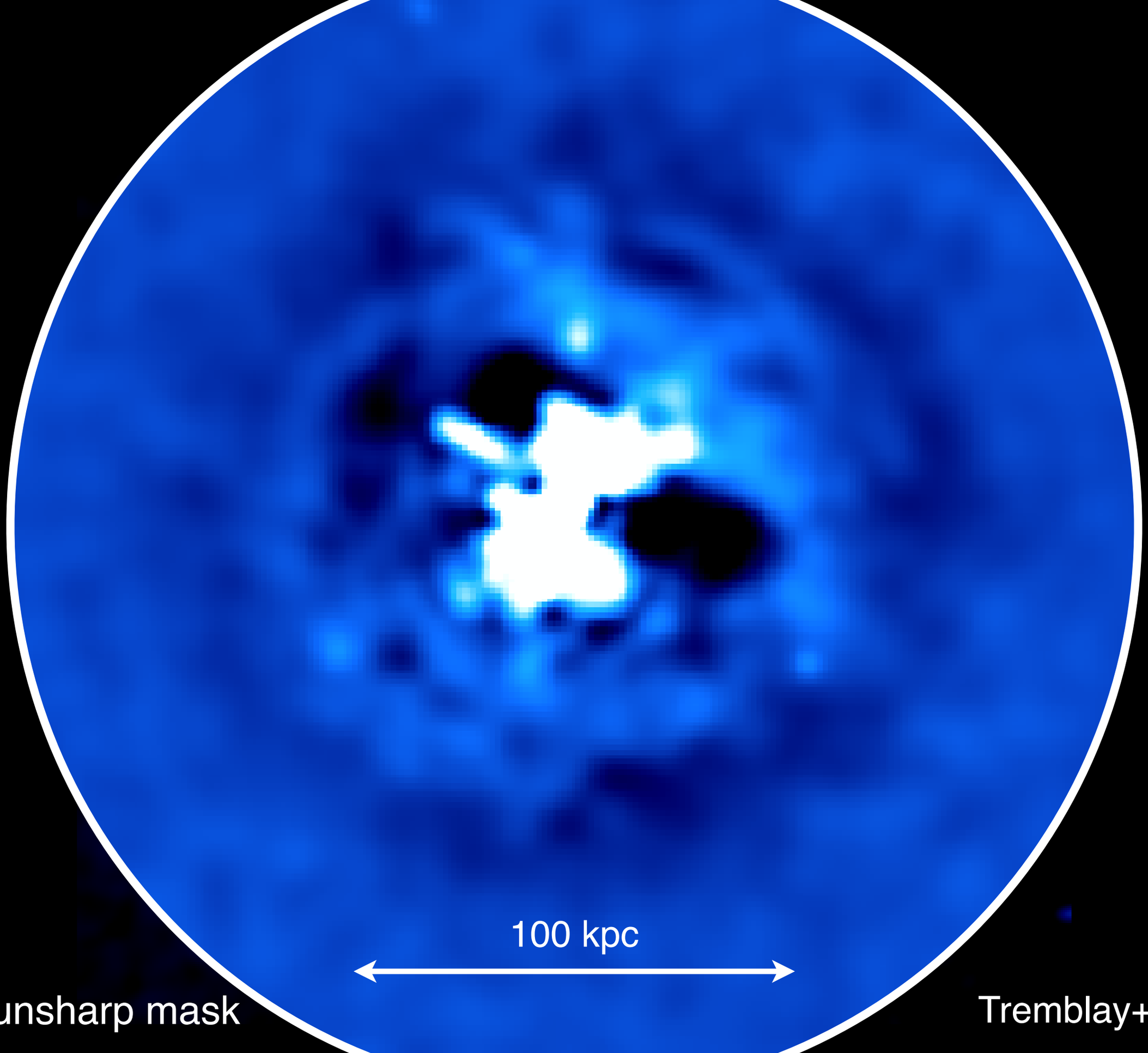
Tremblay+12a,b

X-ray cavity network within inner 100 kpc



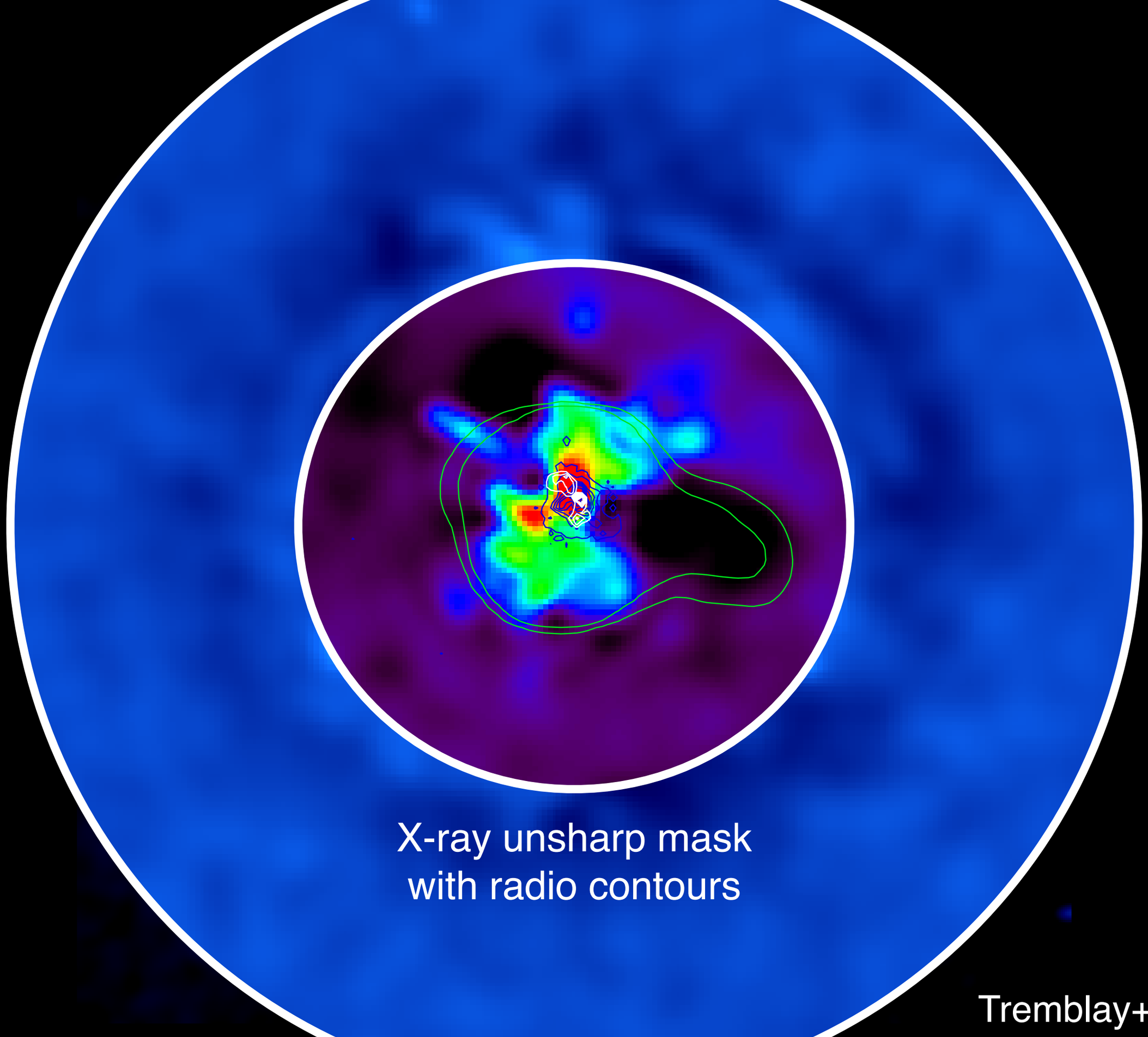
X-ray unsharp mask

Tremblay+12a,b



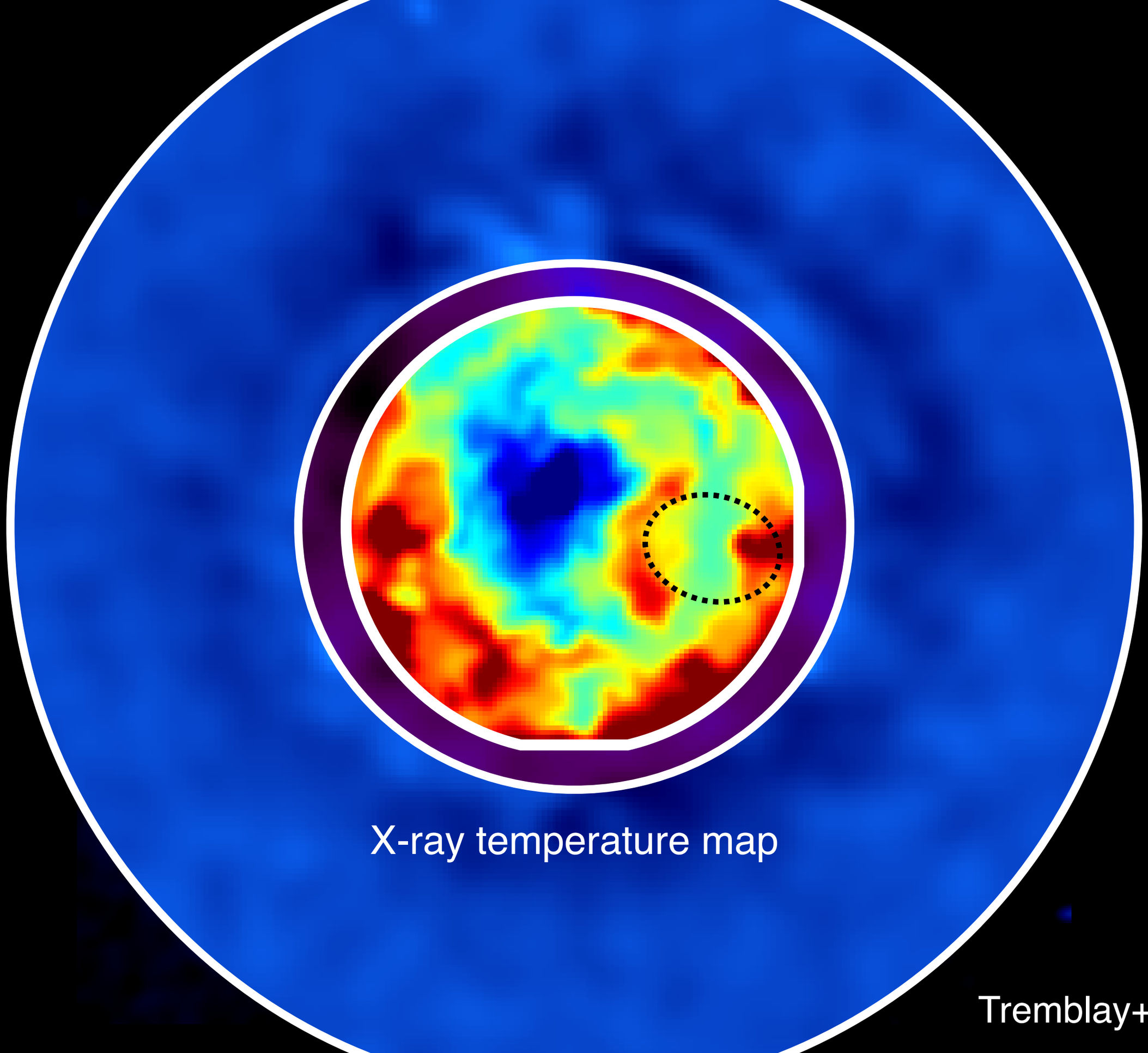
X-ray unsharp mask

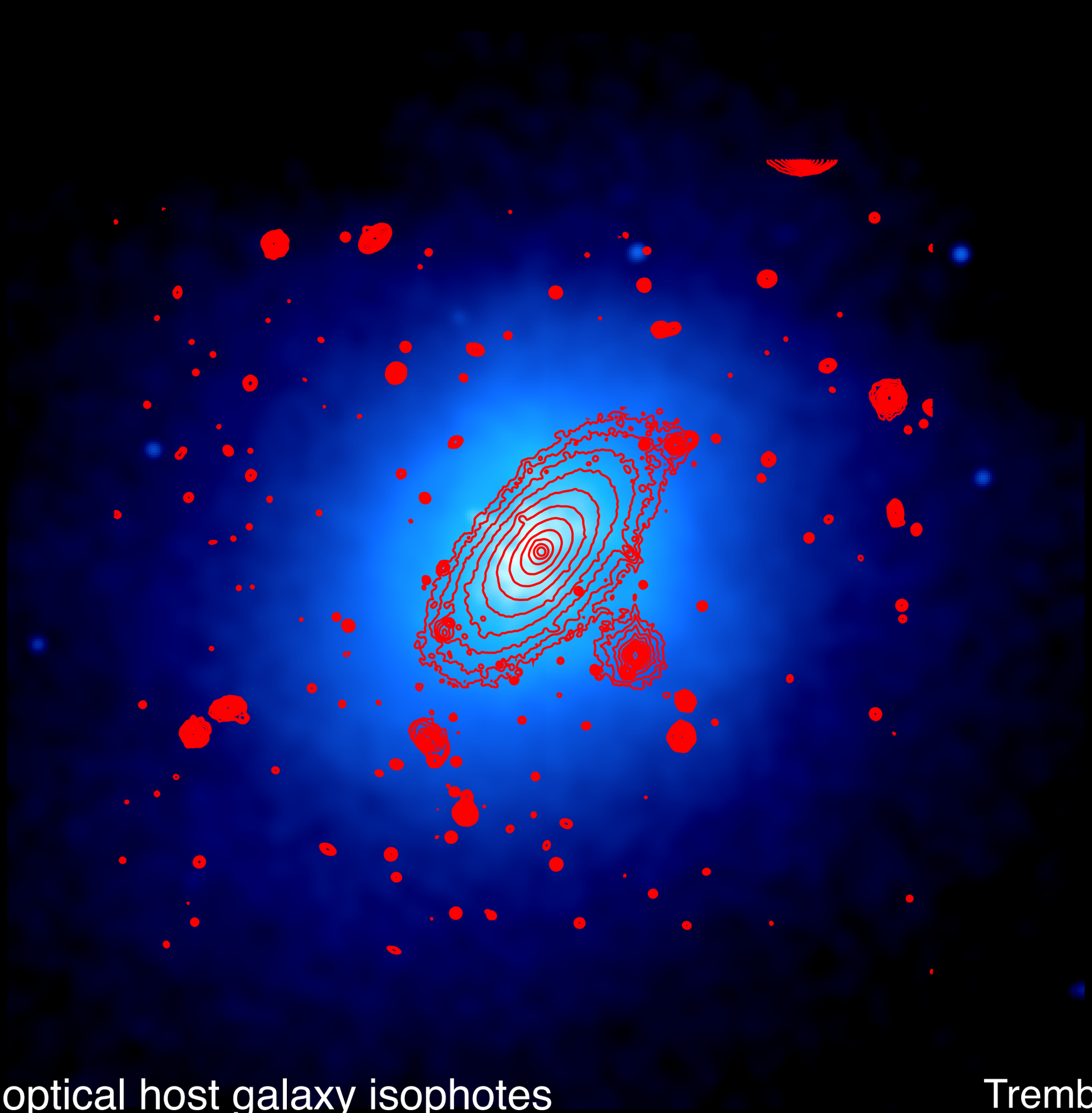
Tremblay+12a,b



X-ray unsharp mask
with radio contours

Tremblay+12a,b


X-ray temperature map
Tremblay+12a,b



X-ray with optical host galaxy isophotes

Tremblay+12a,b

HST R-band

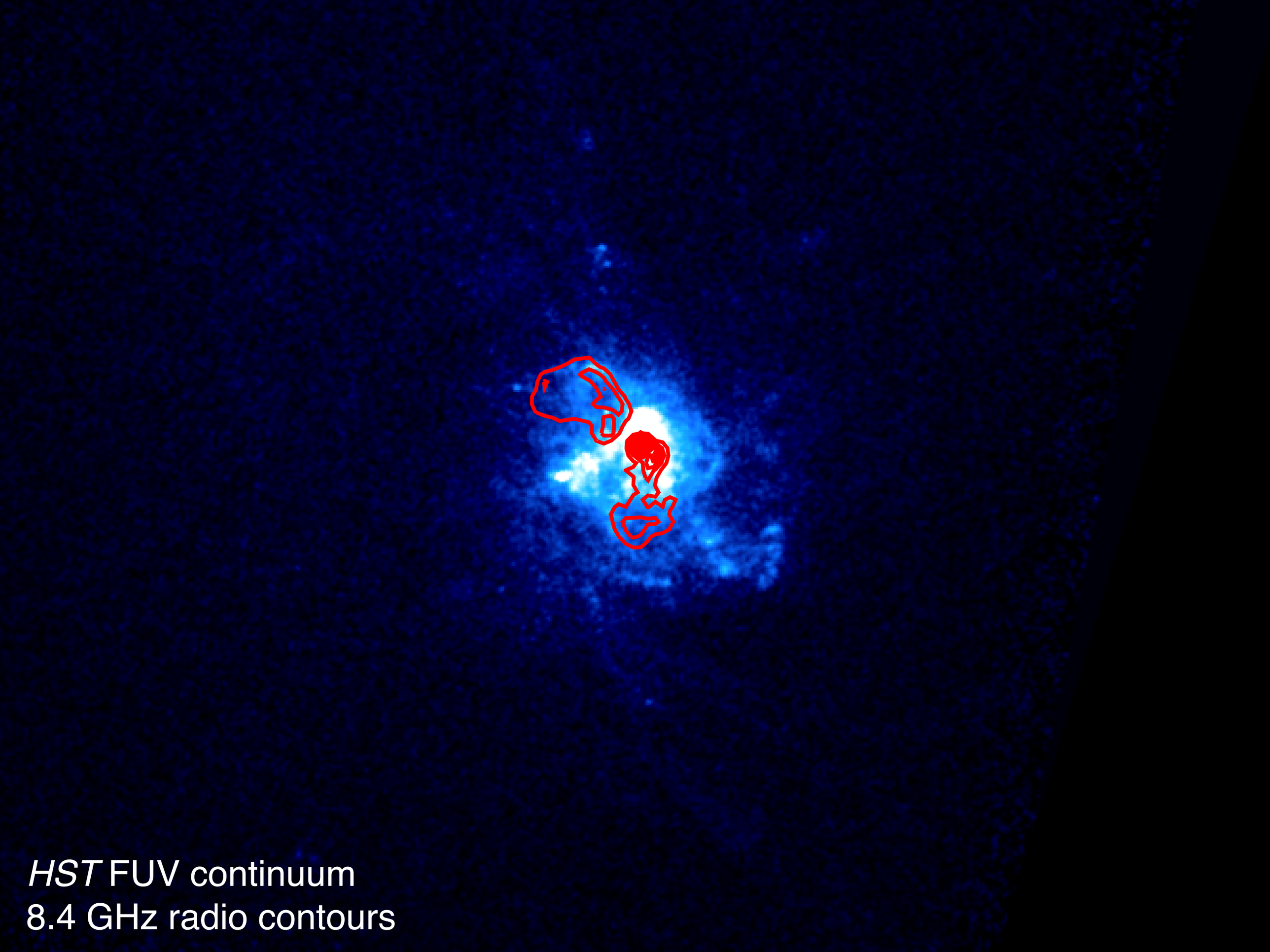
Tremblay+12a,b

HST R-band
H-alpha contours

Tremblay+12a,b

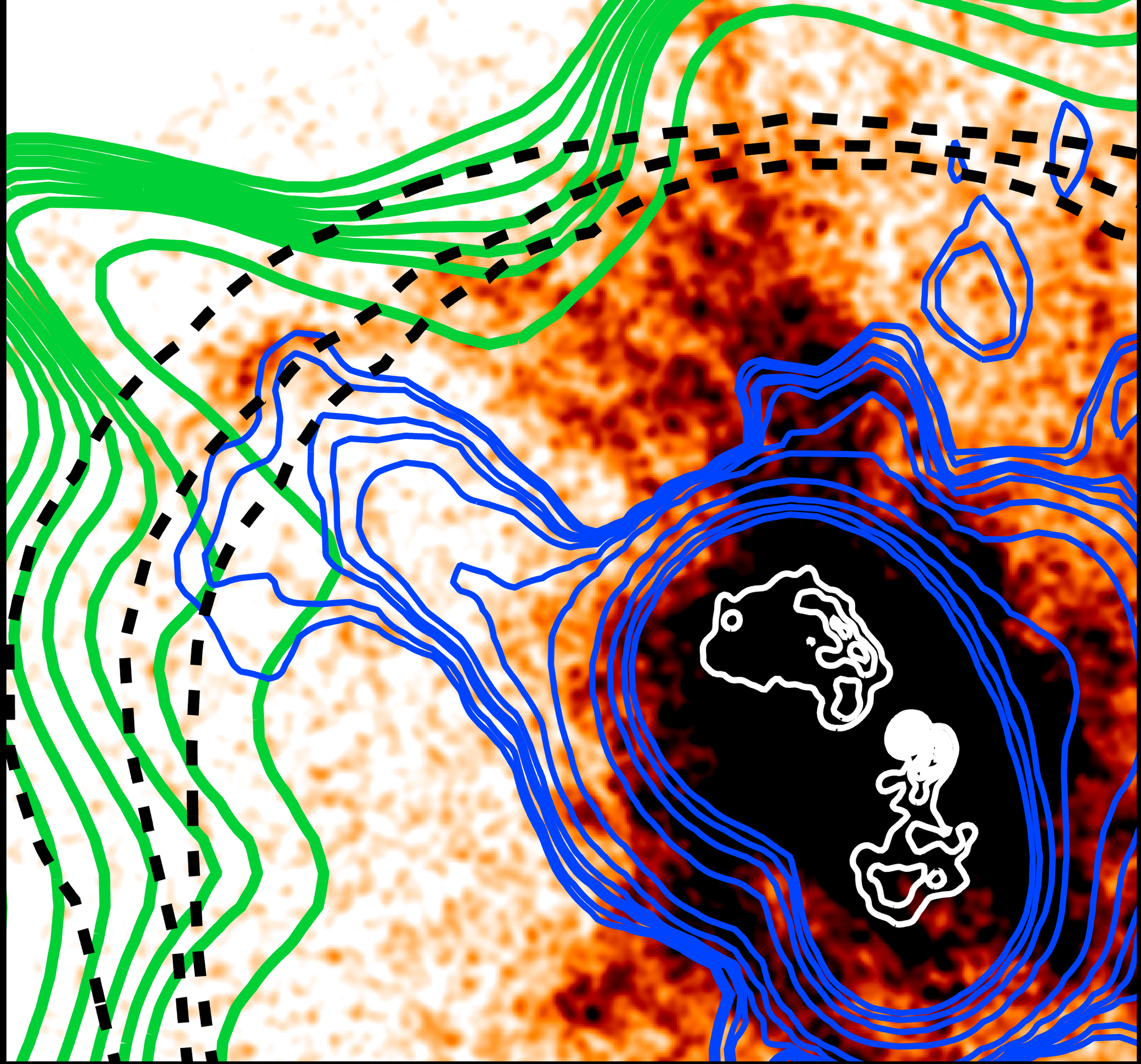
30 kpc

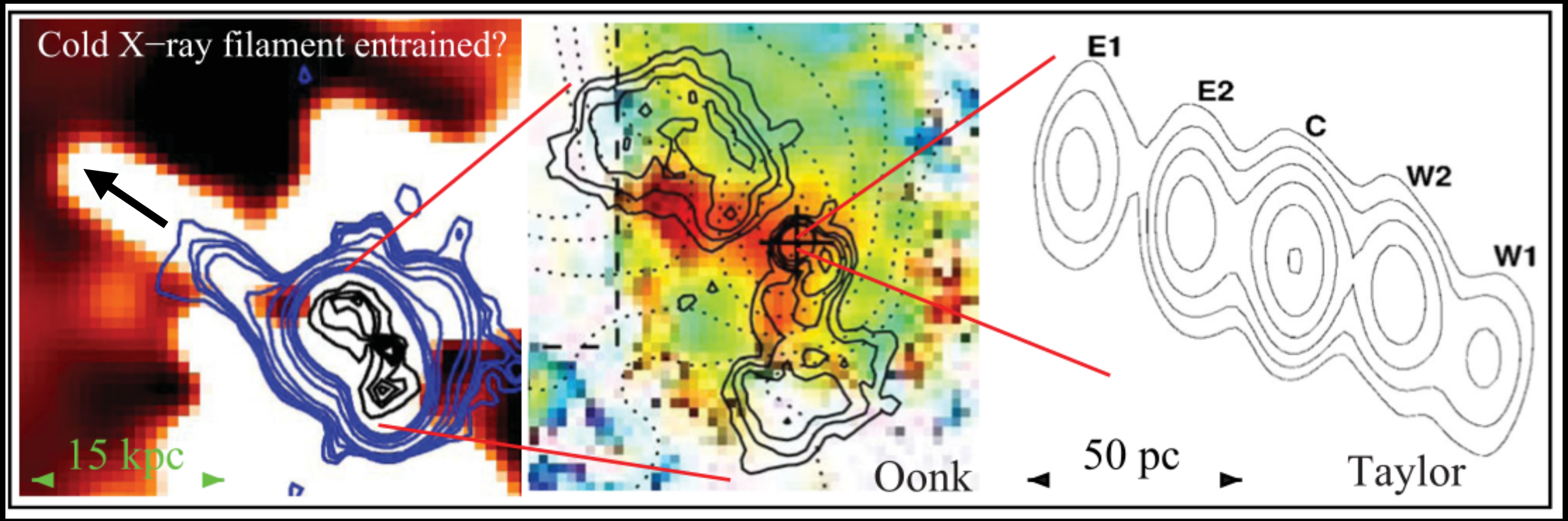
HST Ly-alpha


HST FUV continuum
8.4 GHz radio contours

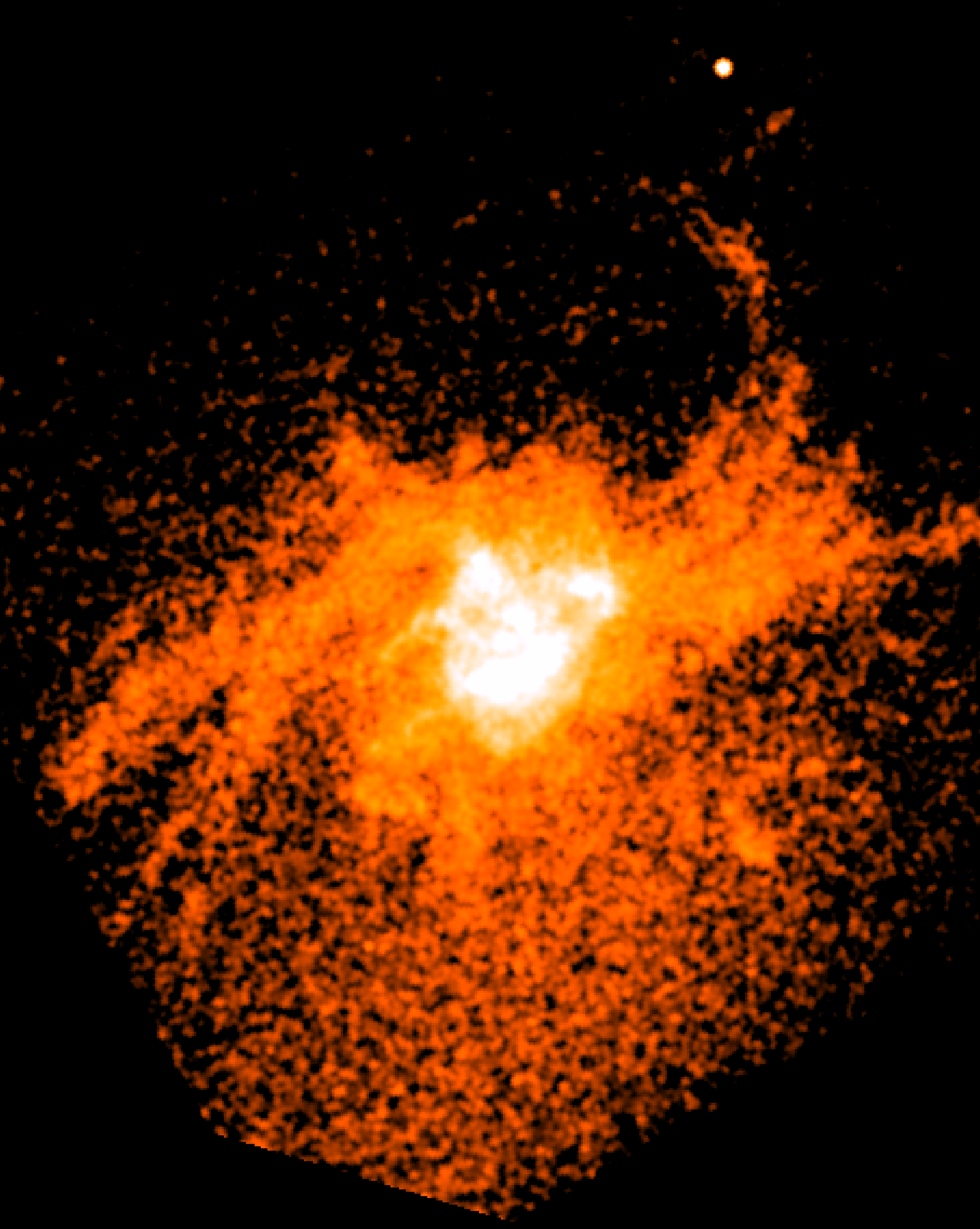
FUV cont. unsharp mask

HST far-ultraviolet continuum



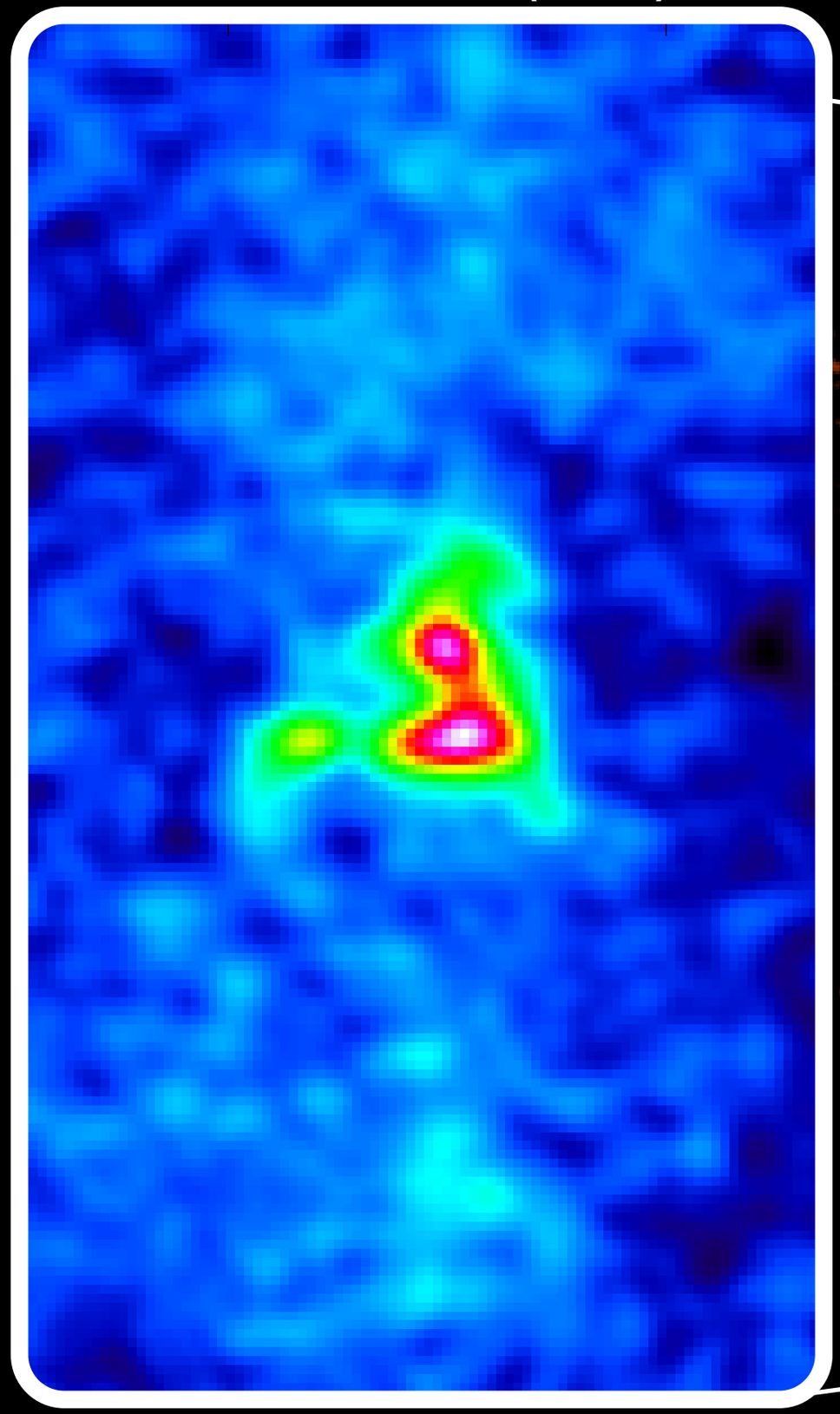


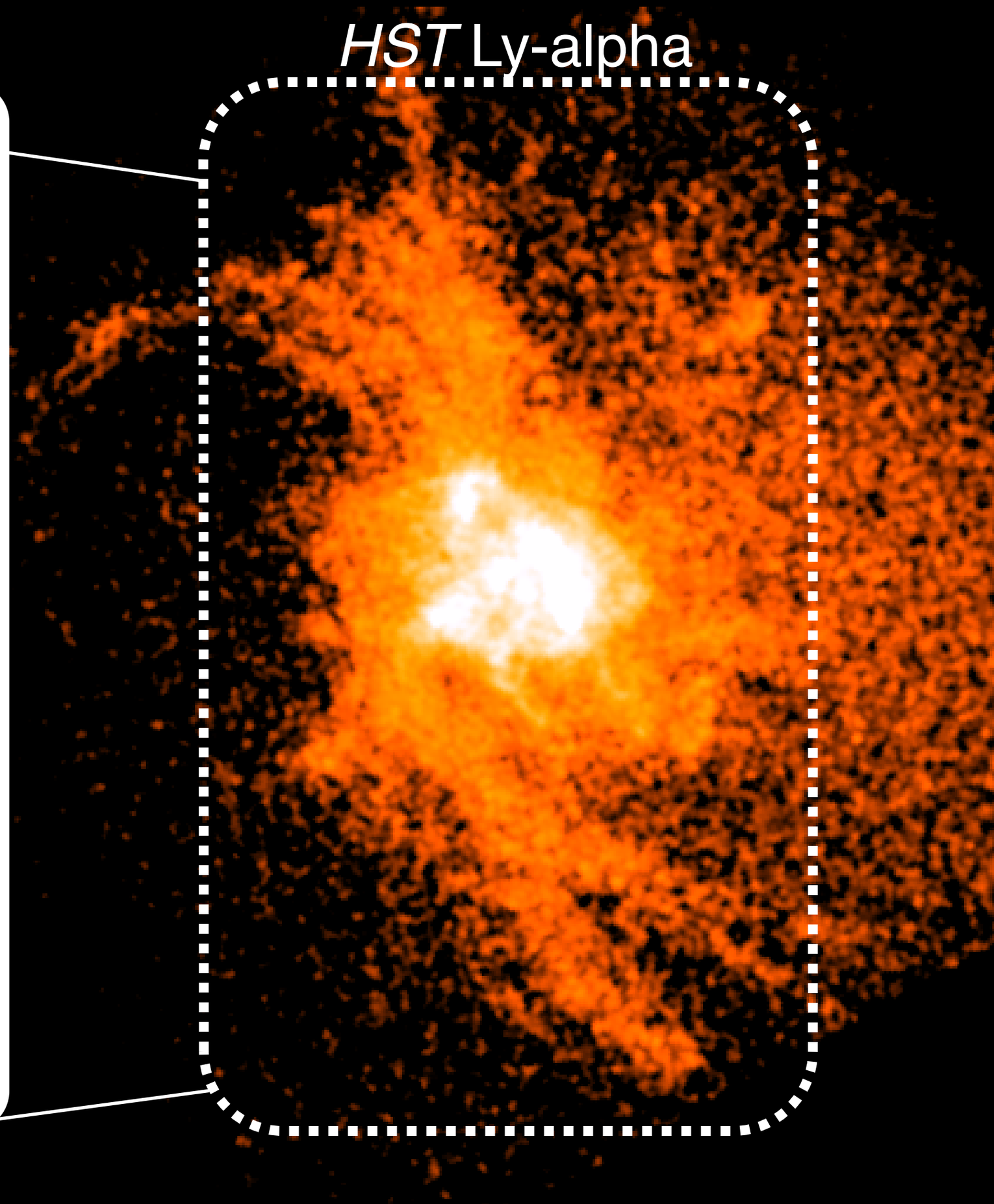
Tremblay+12a,b
Oonk+10
Taylor+99



ALMA CO(2-1)

HST Ly-alpha



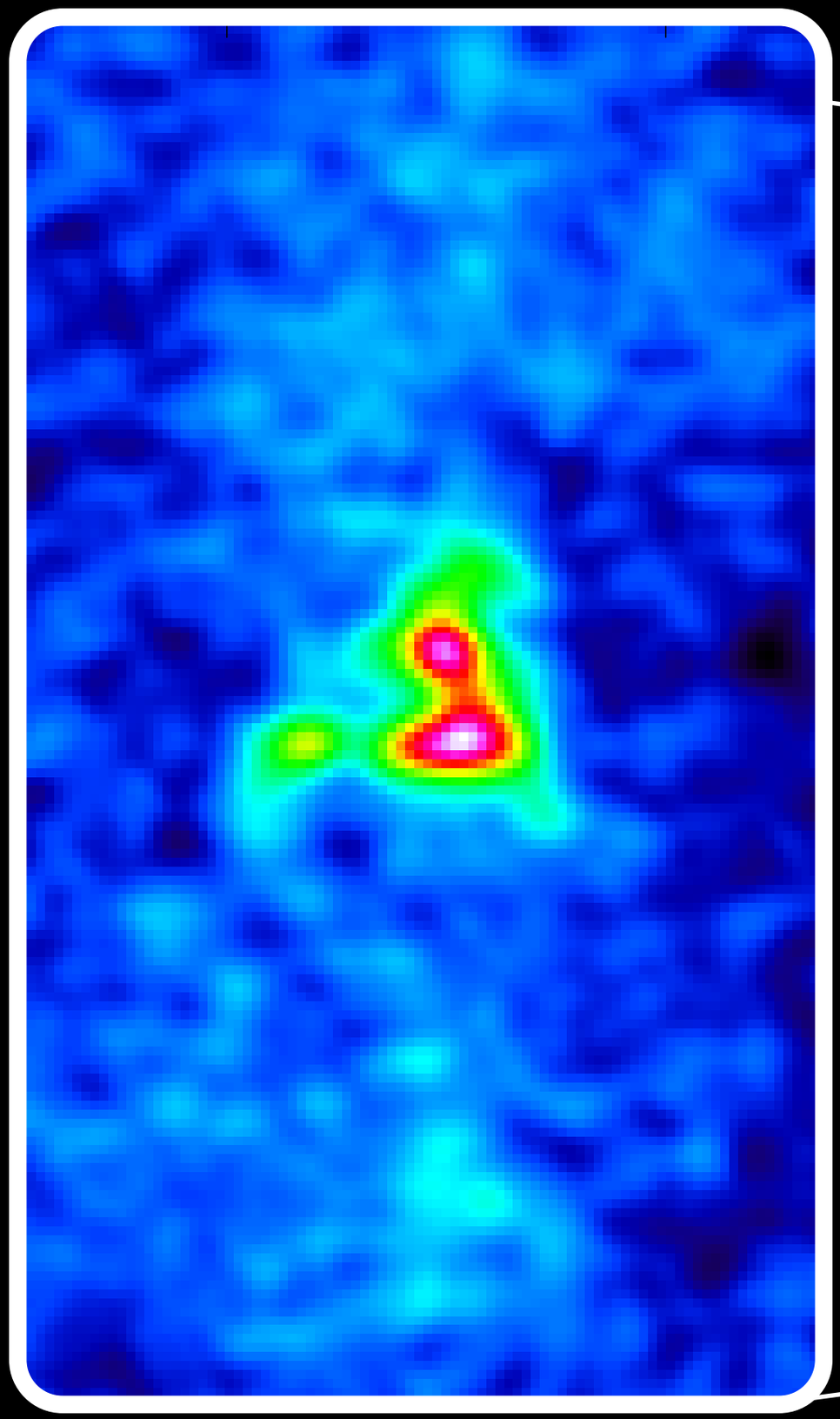


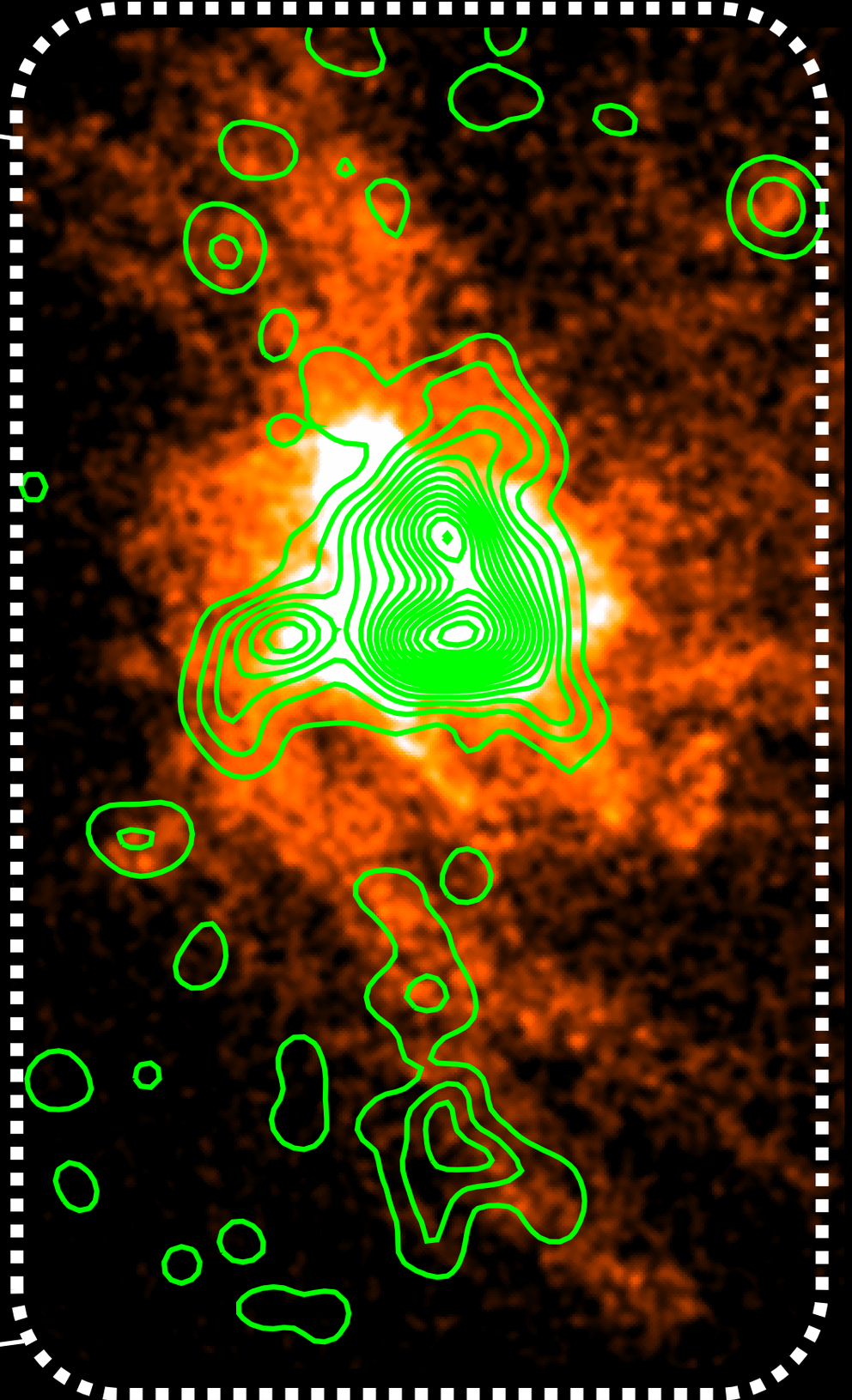
ALMA CO(2-1)

HST Ly-alpha

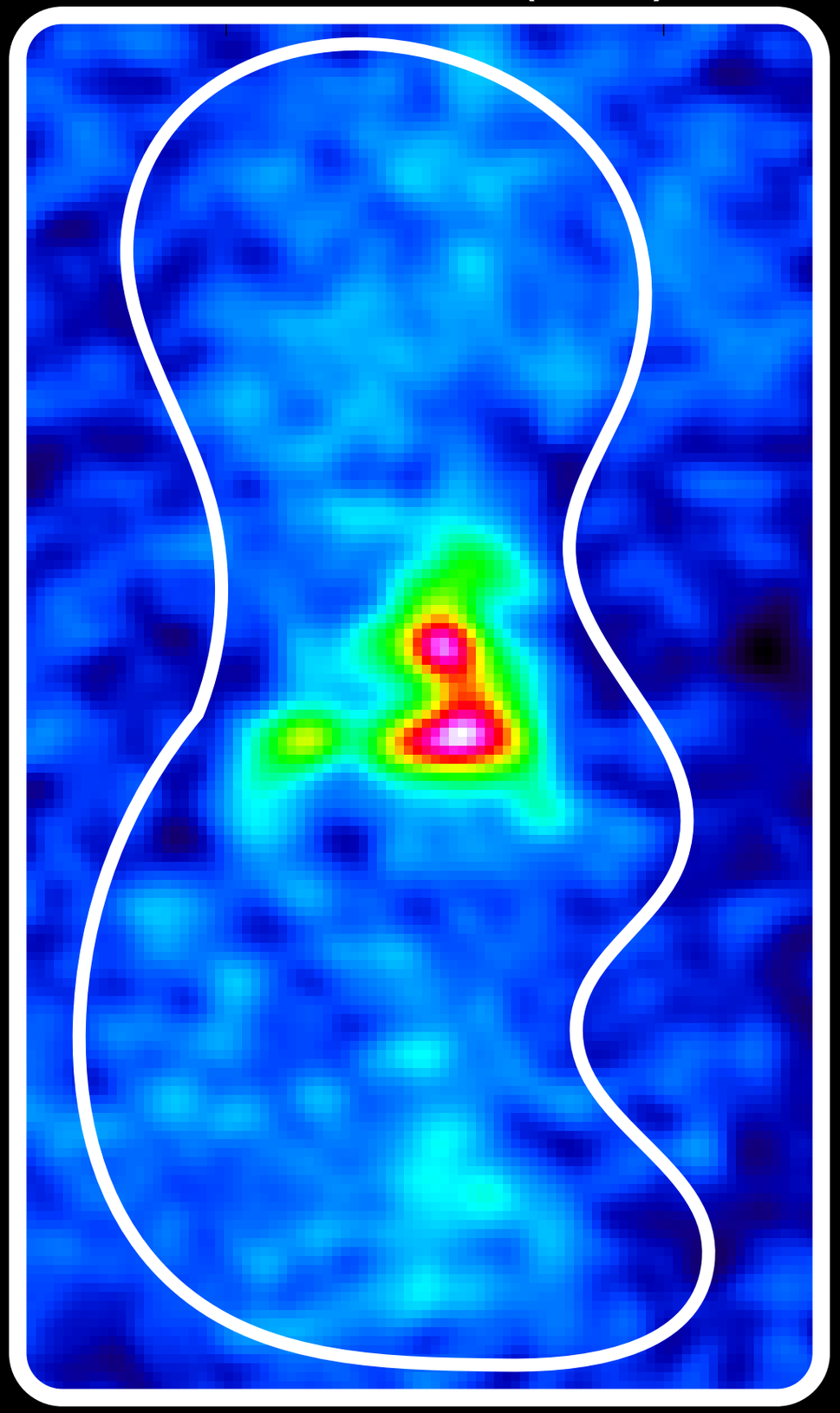
ALMA CO(2-1)

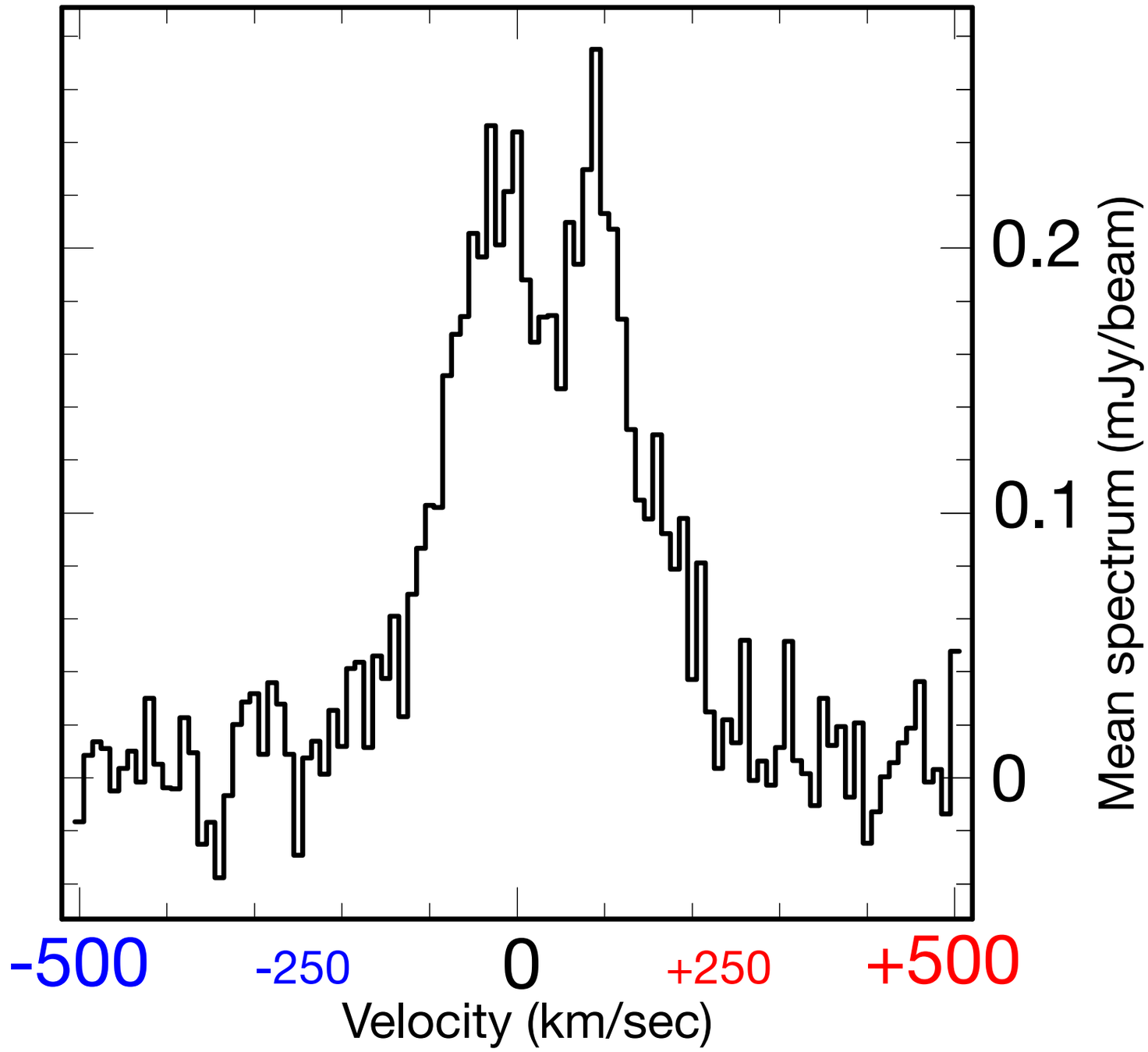
5 sigma ALMA contours



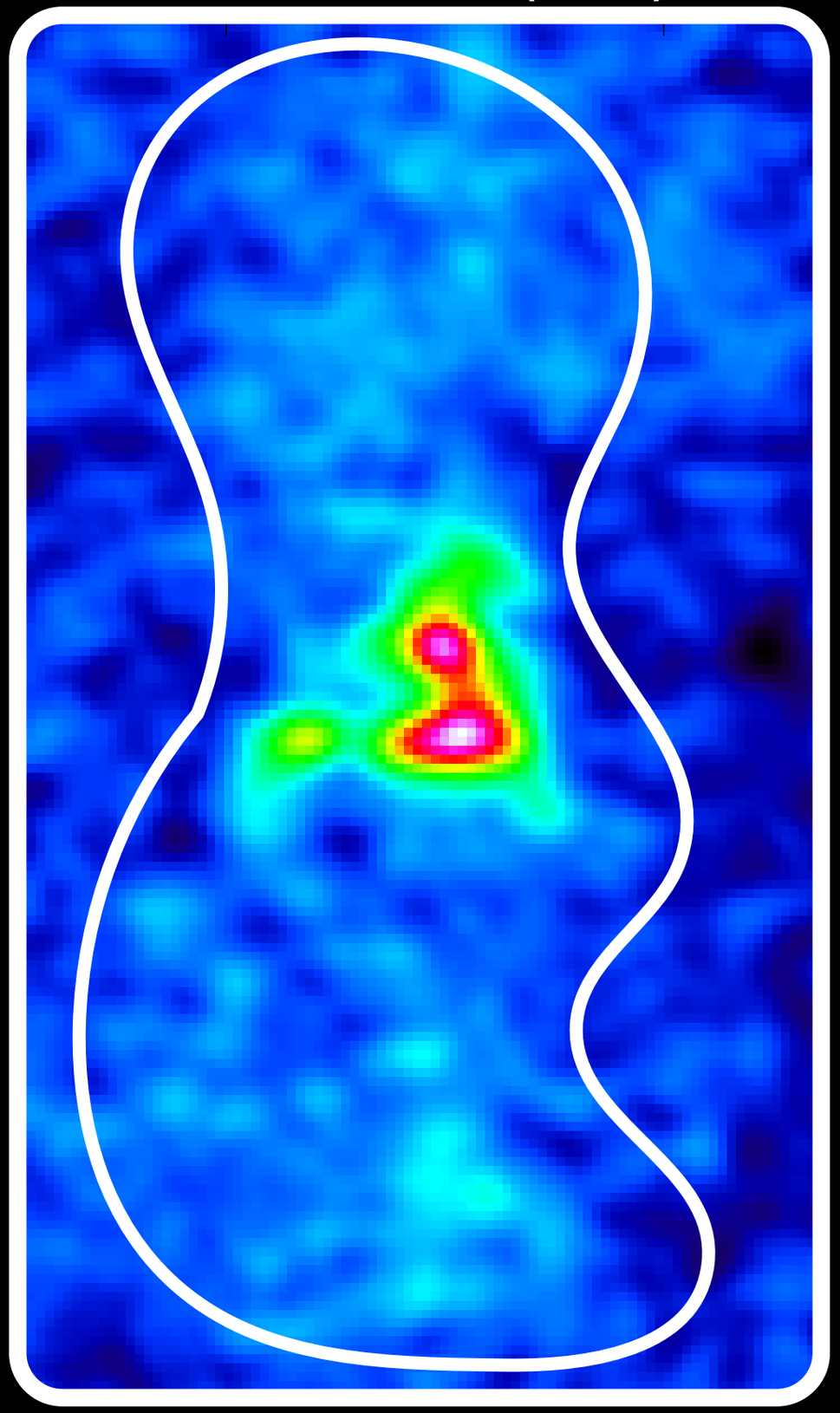


ALMA CO(2-1)




0.2
0.1
0
Mean spectrum (mJy/beam)
-500
-250
0
+250
+500
Velocity (km/sec)

ALMA CO(2-1)



peak CO(2-1) flux

20.2 ± 0.18 mJy

~2 x 10^9 $M_\odot$

of cold H_2

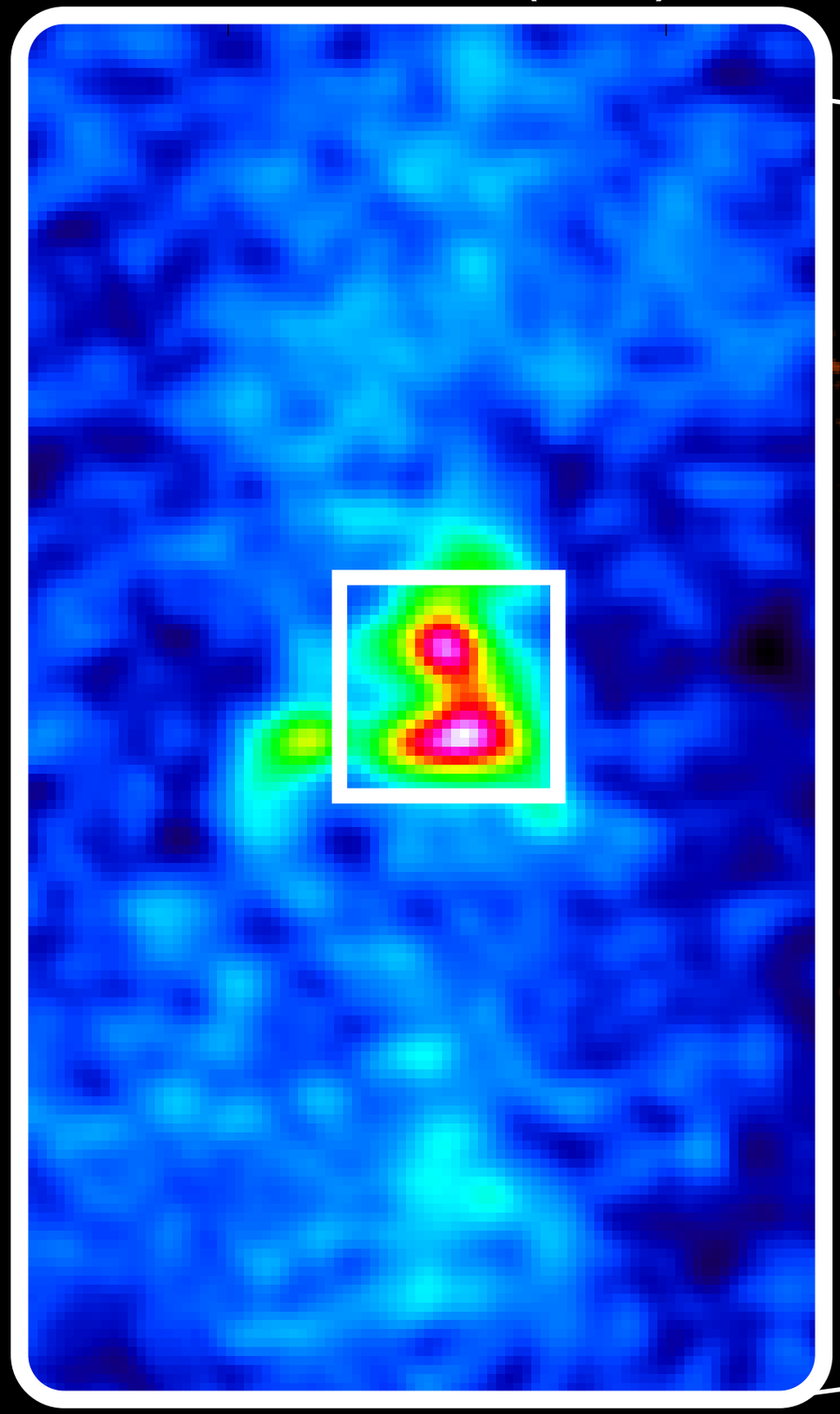
(assuming Galactic X_CO)

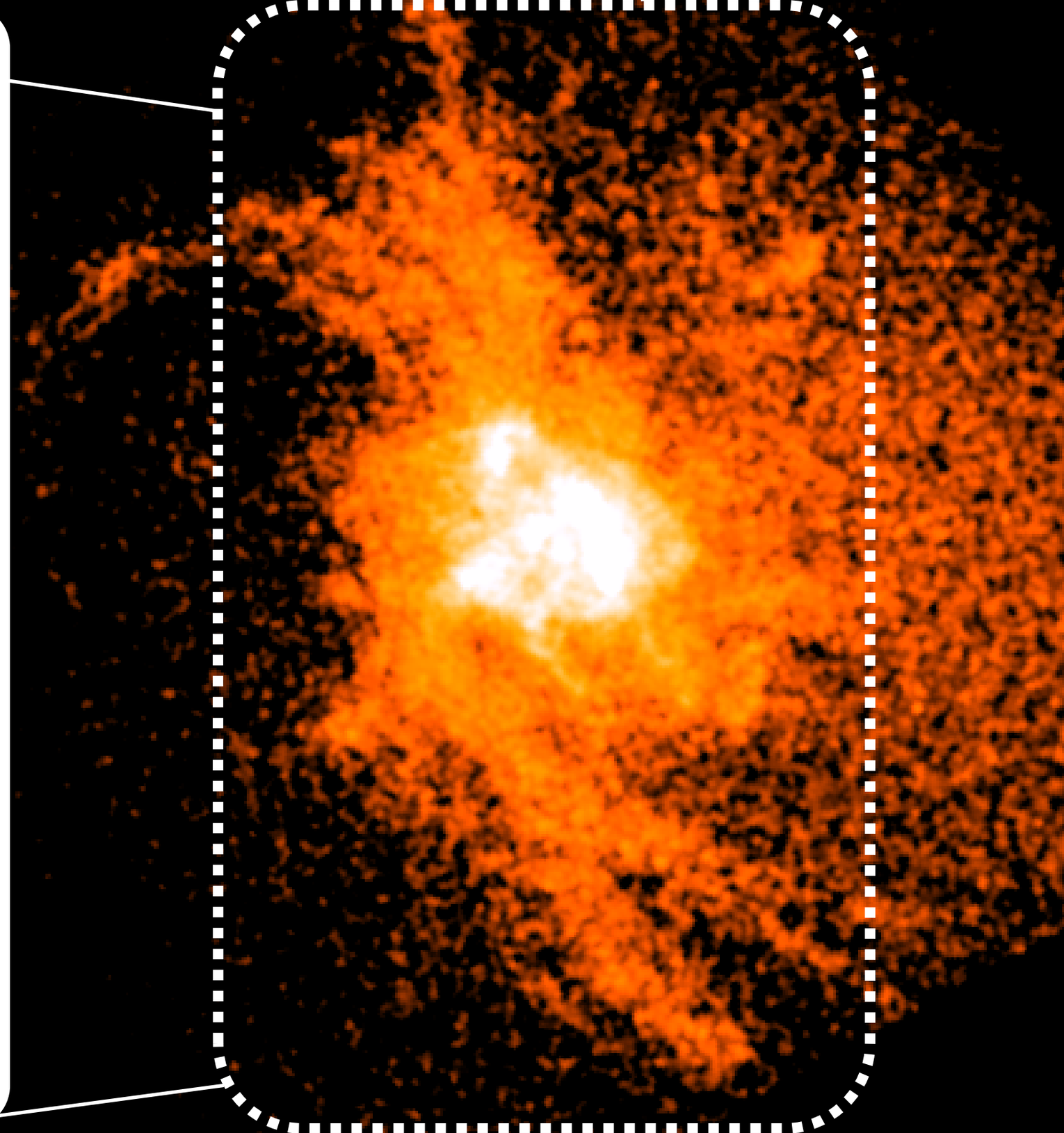
ONE

A star forming molecular balloon inflated by a jet

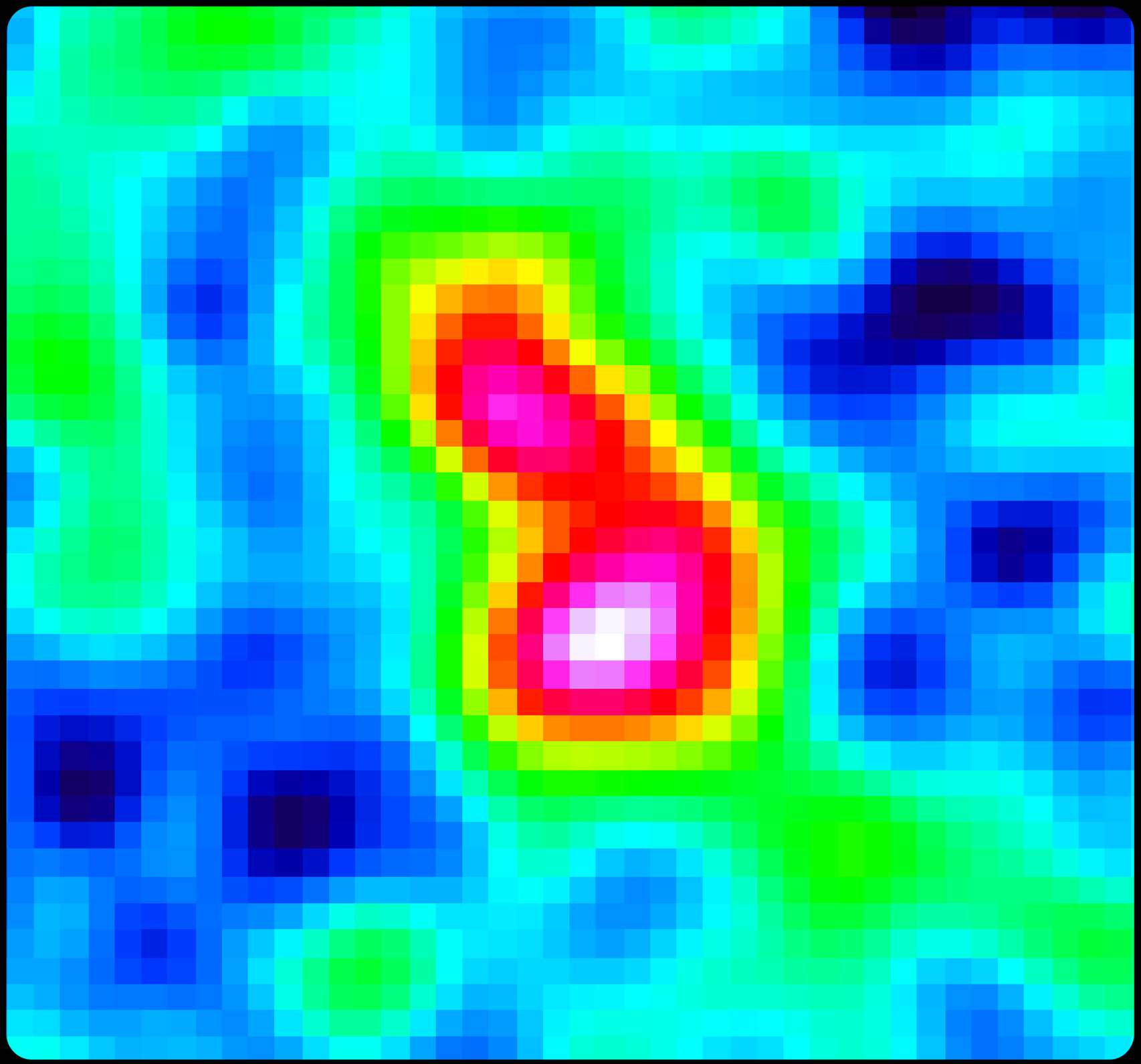
ALMA CO(2-1)

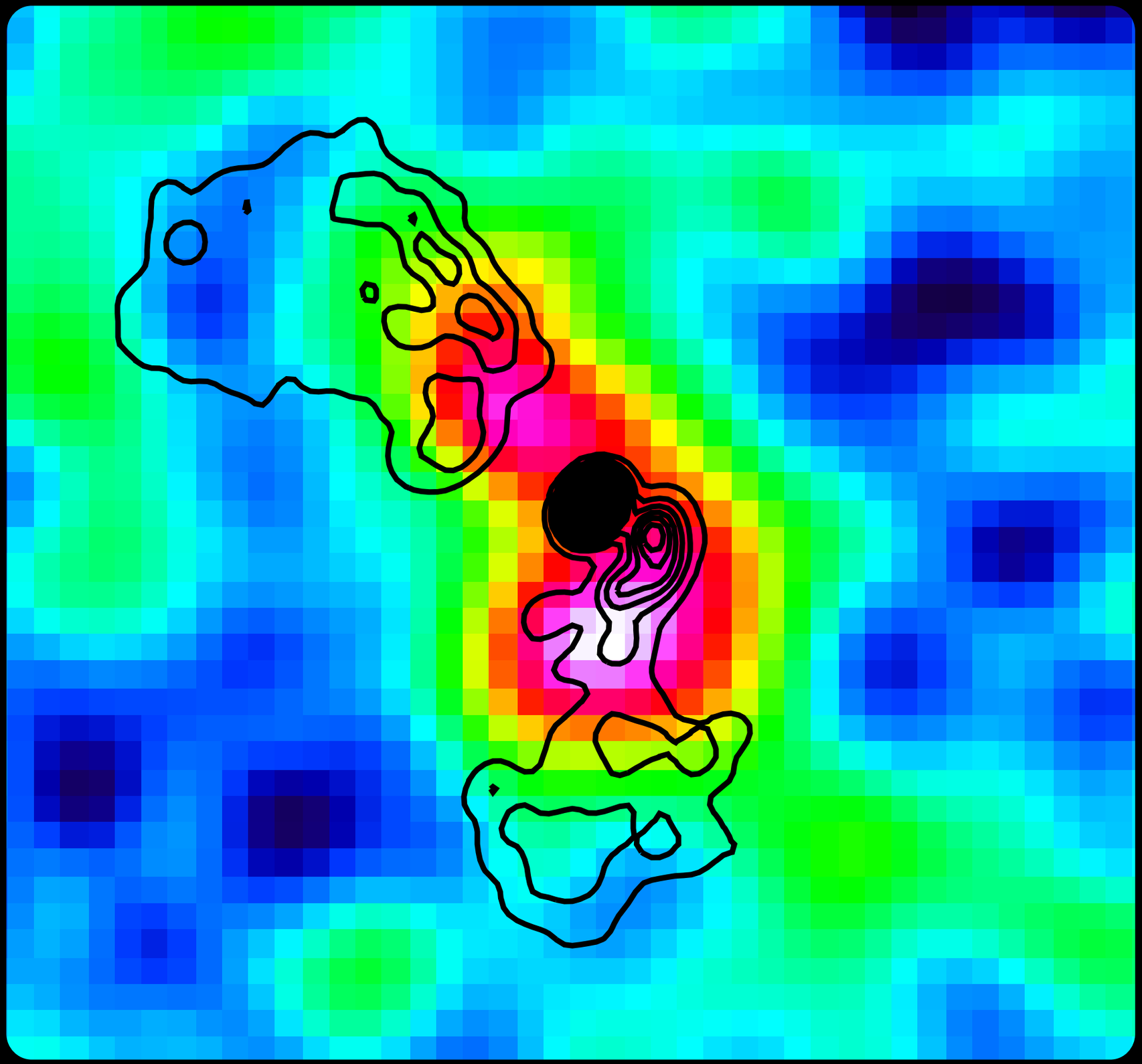
HST Ly-alpha

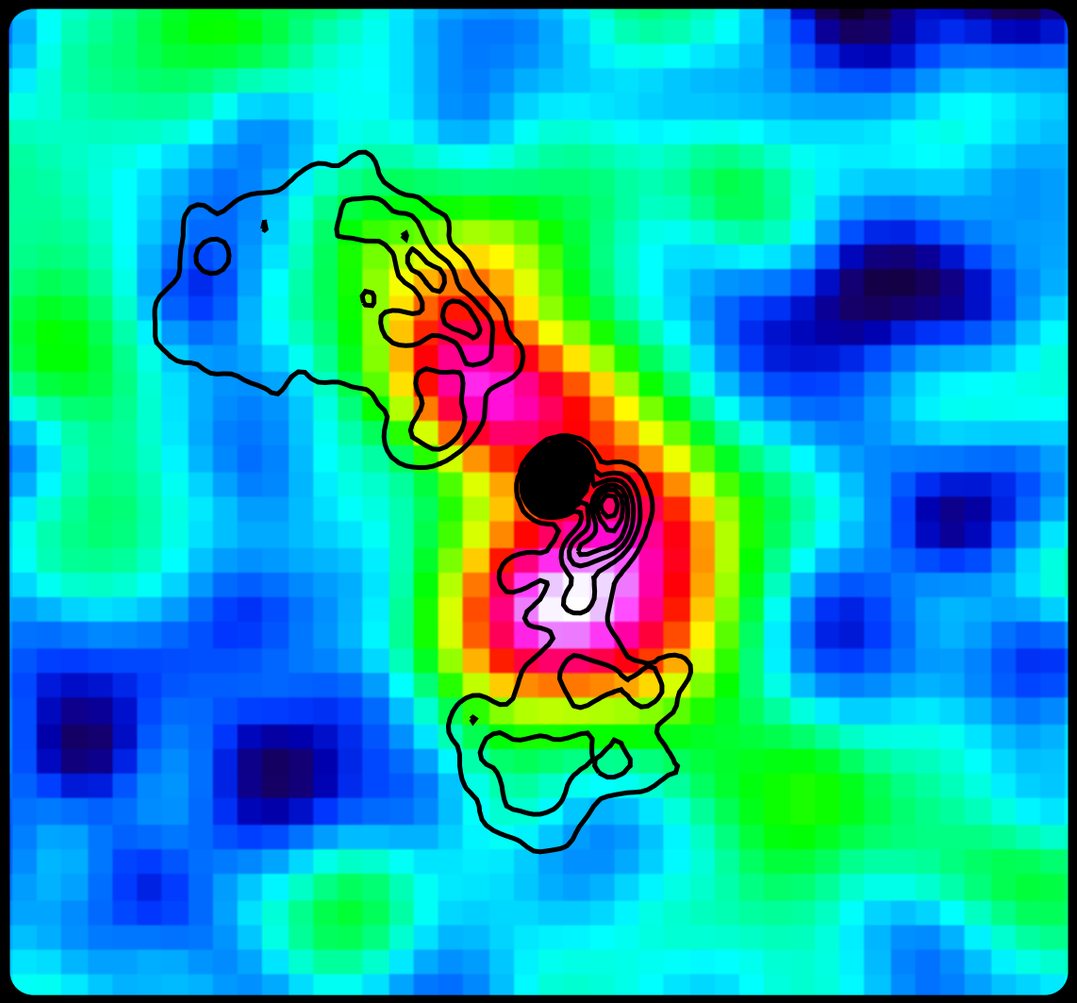


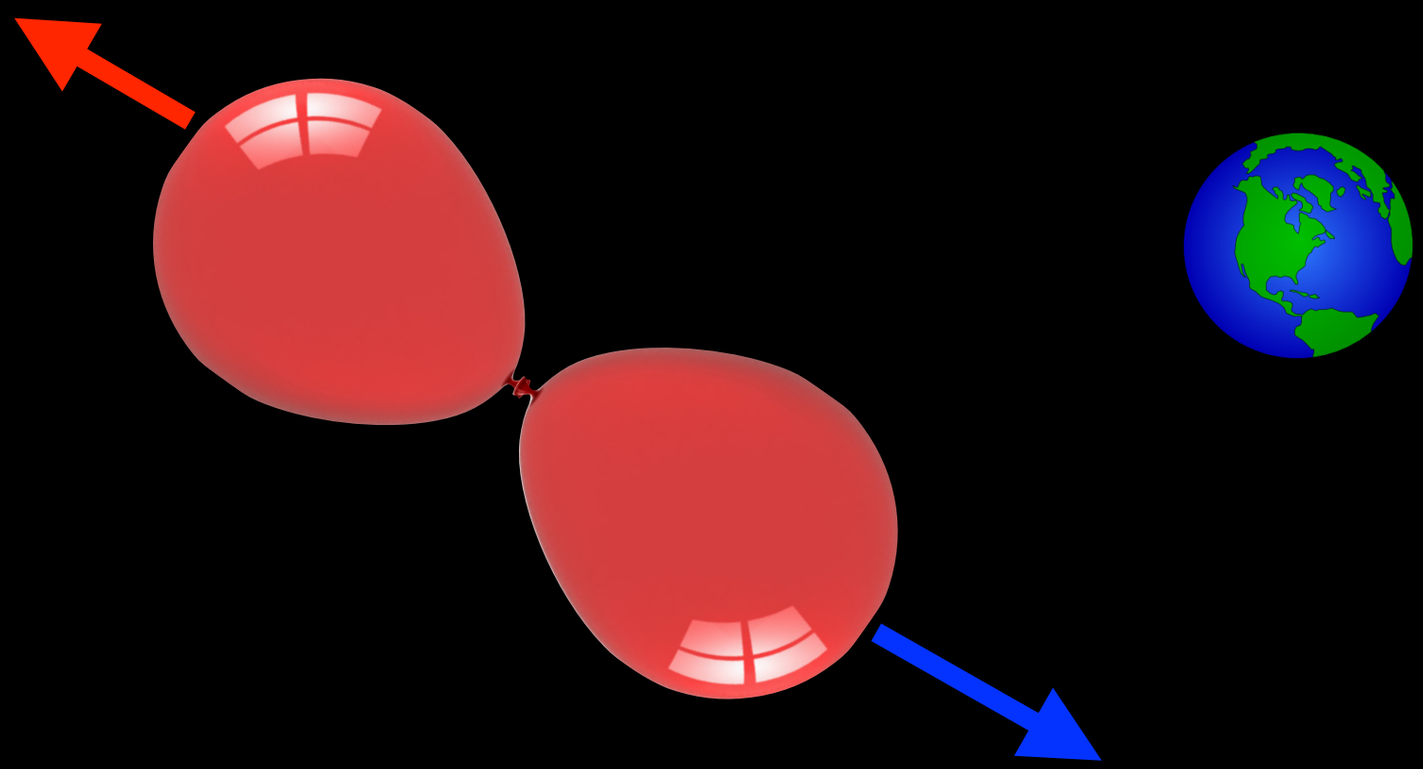


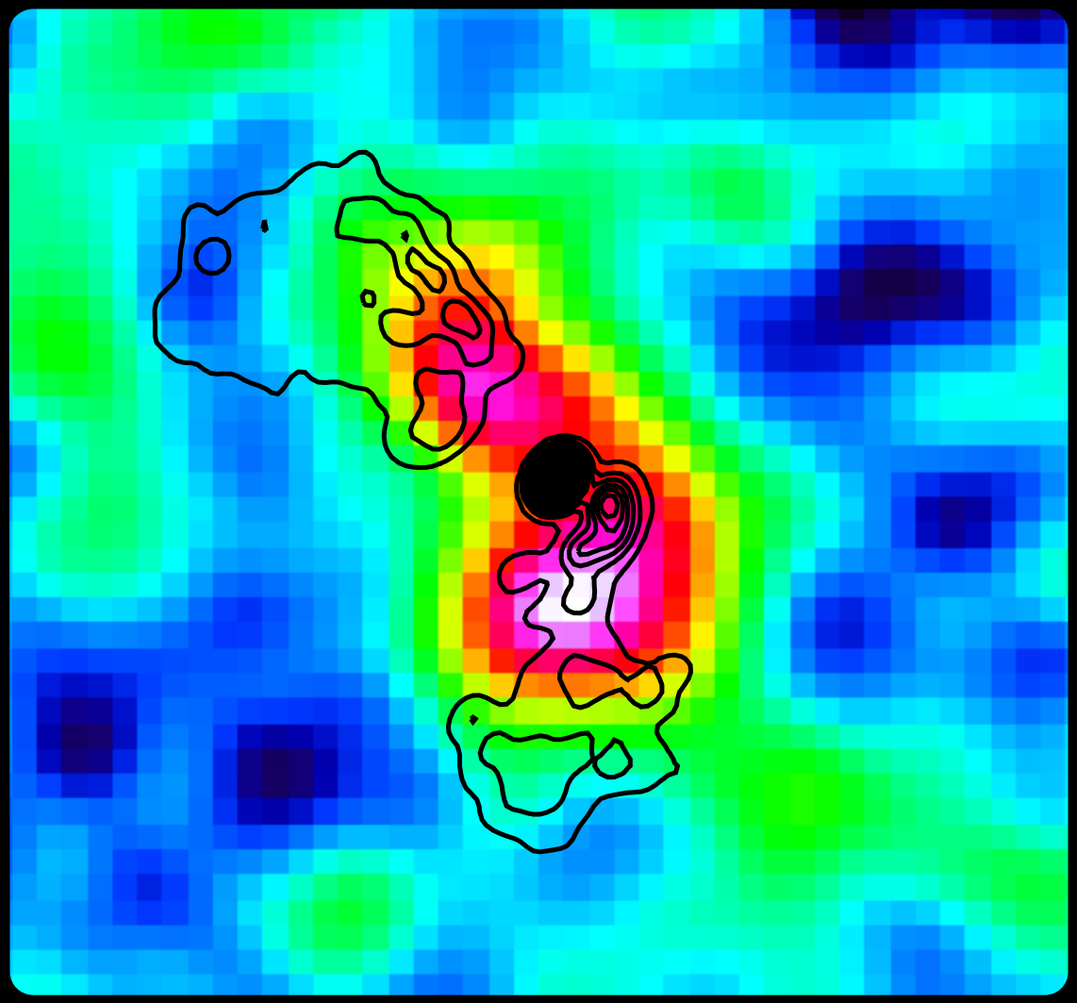
ALMA CO(2-1)

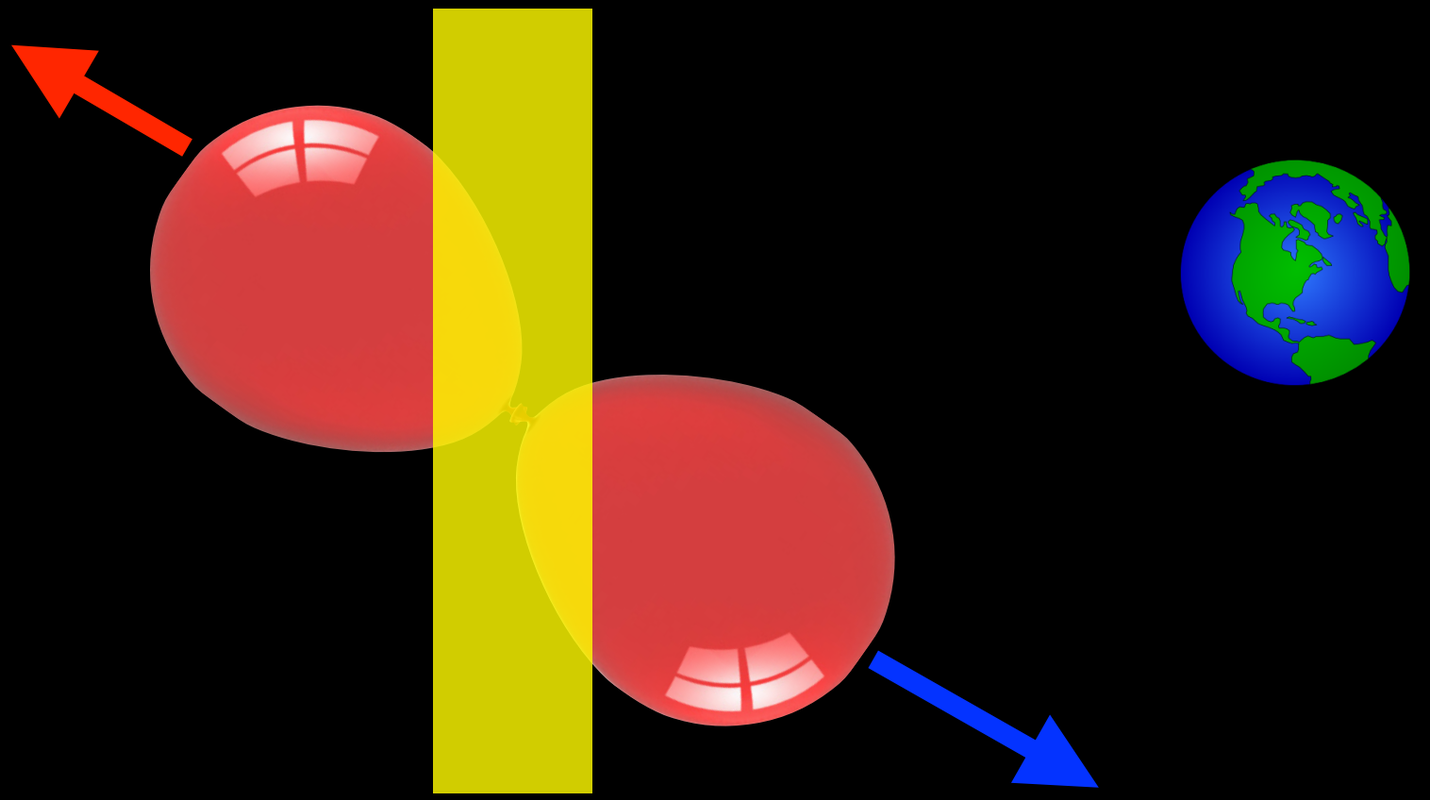






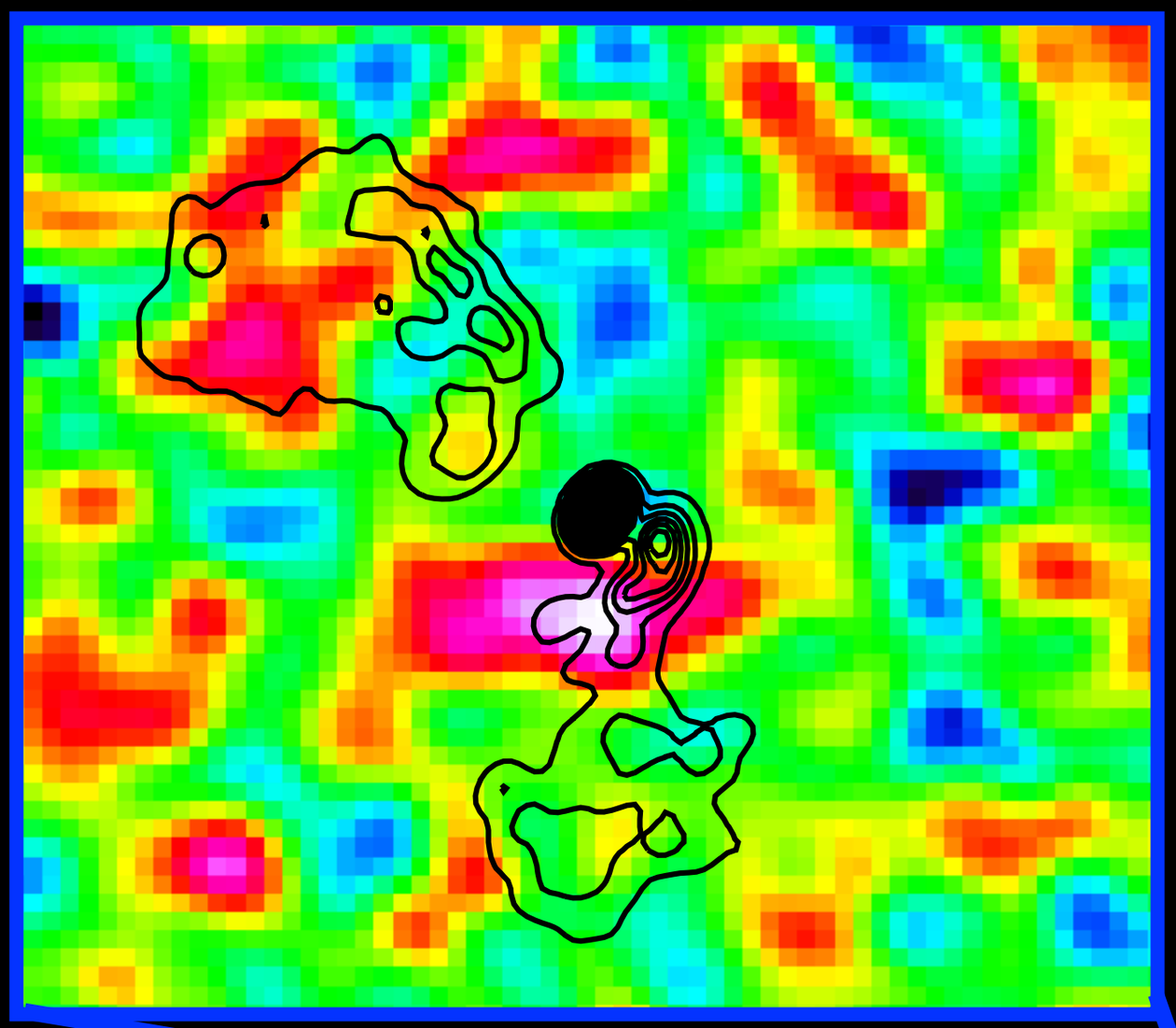


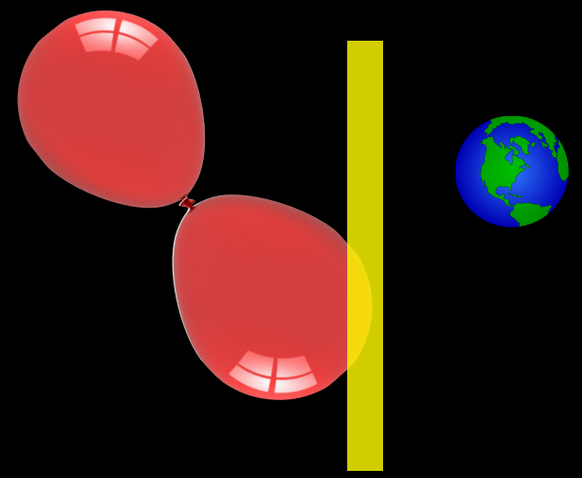


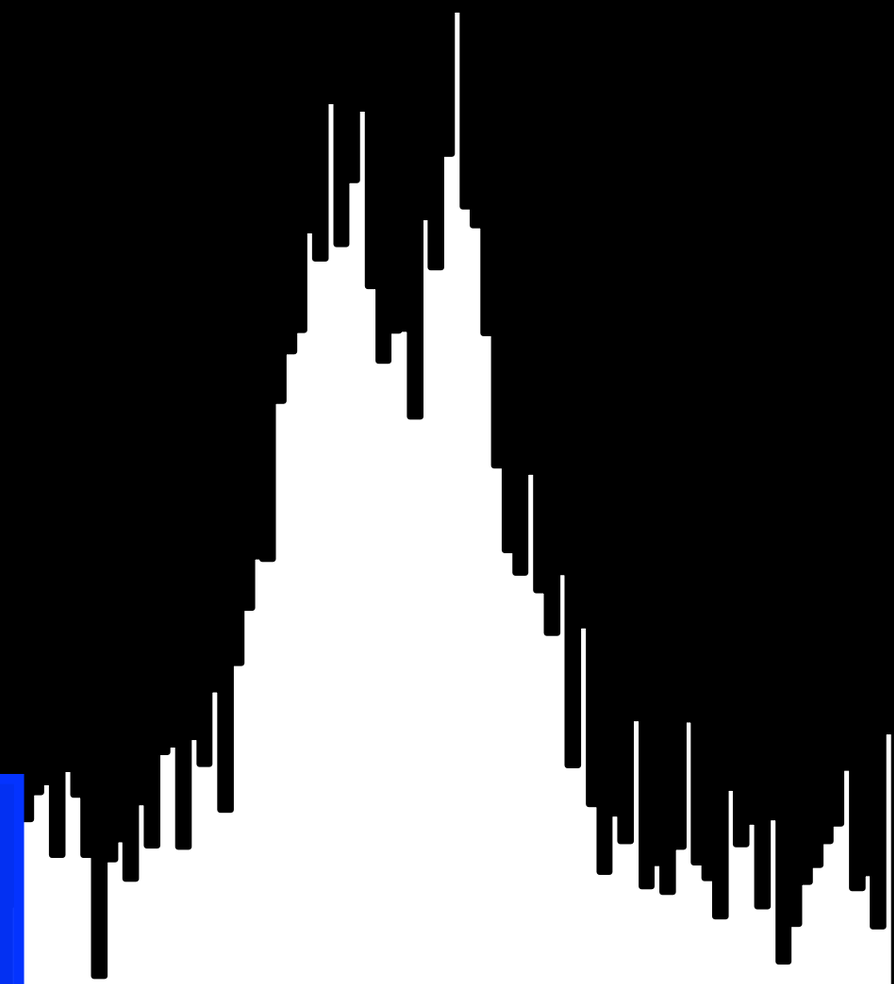


Approaching side of the molecular bubble

~-500 km/sec

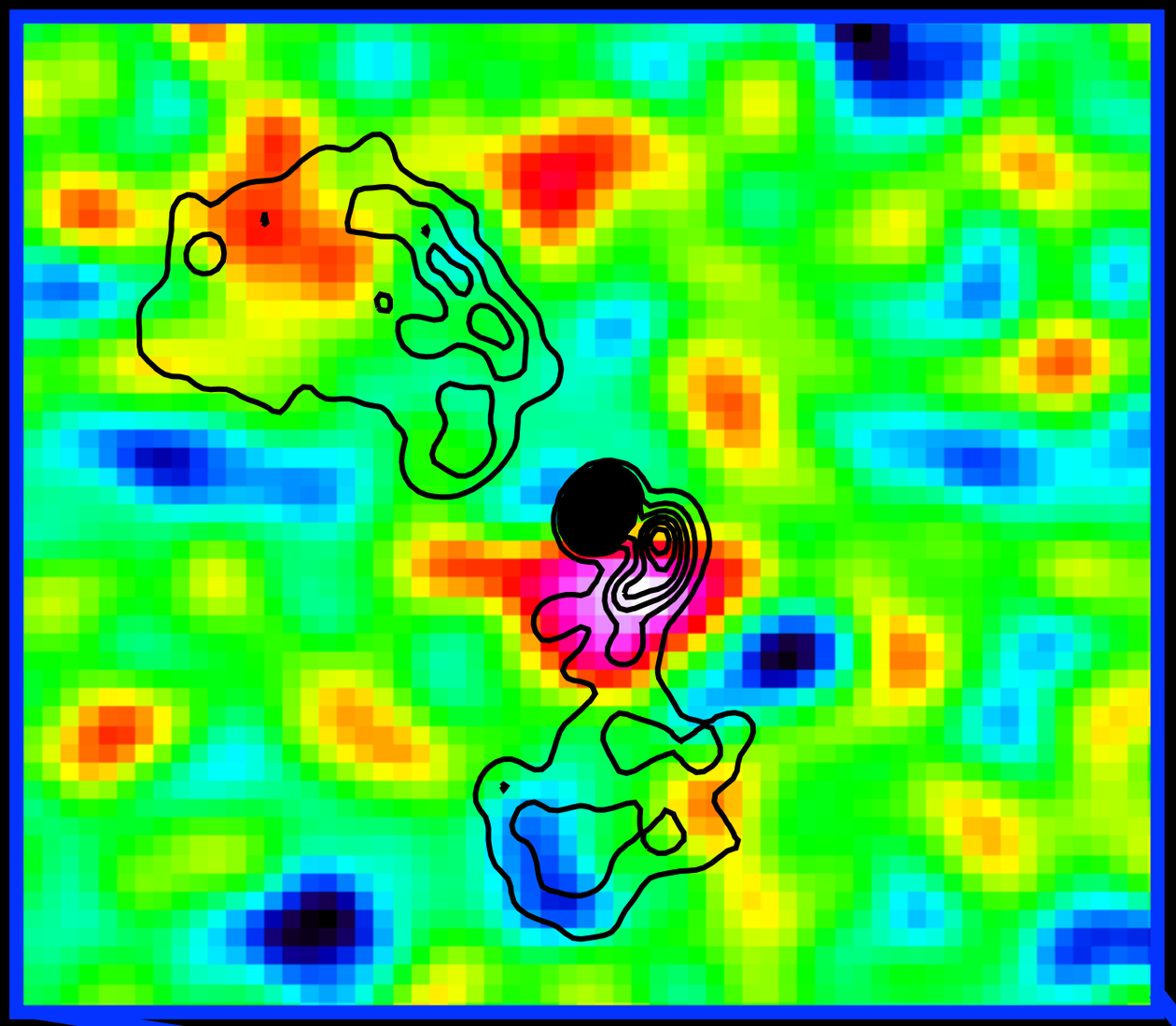


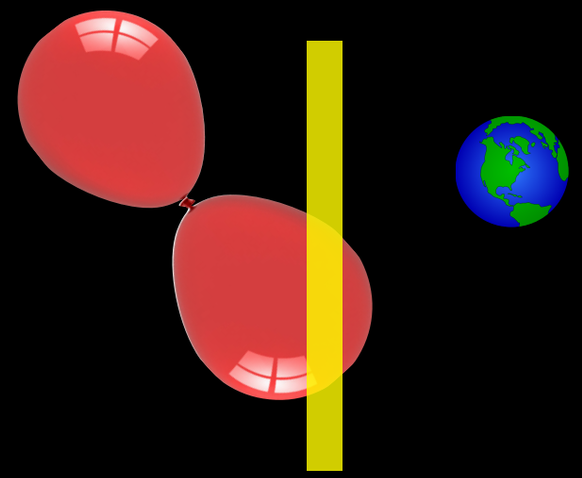


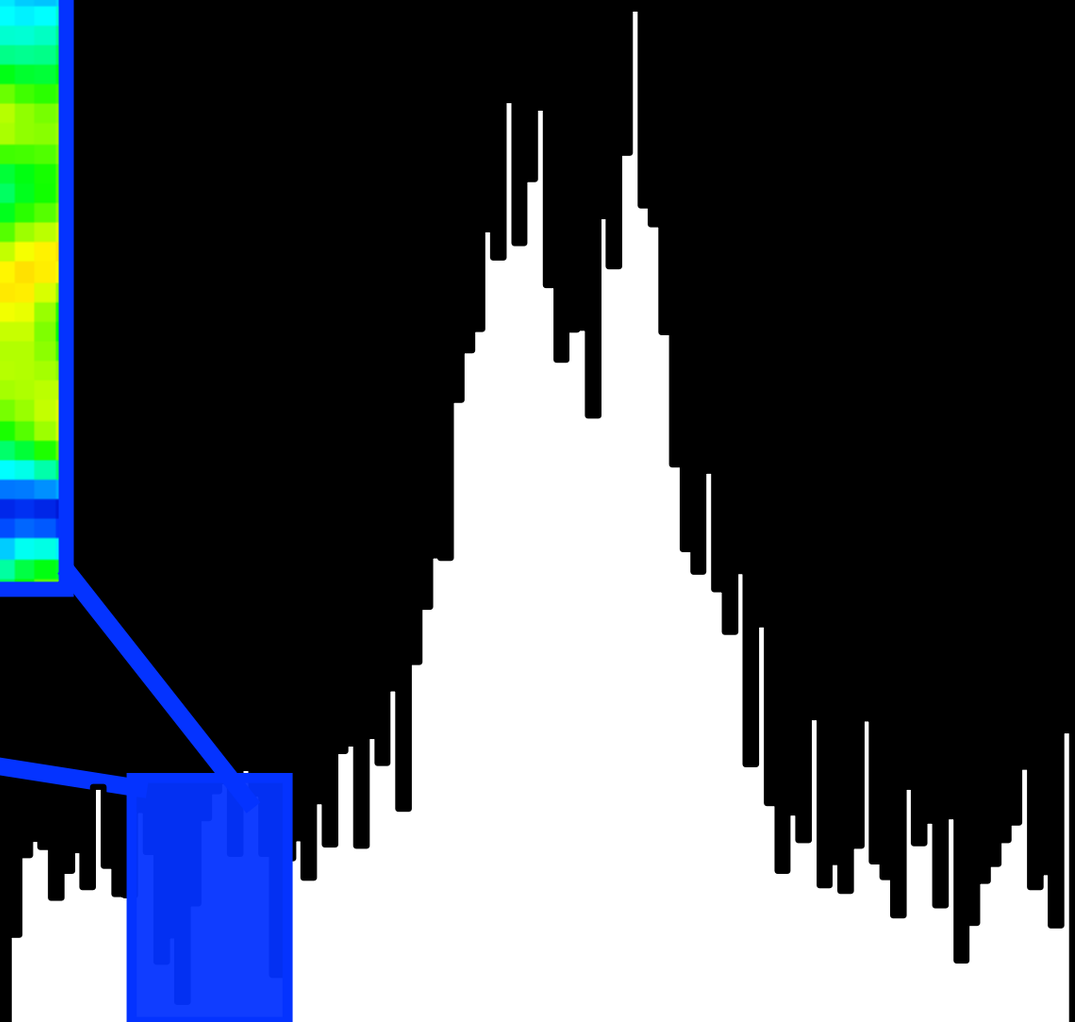


Approaching side of the molecular bubble

~-350 km/sec

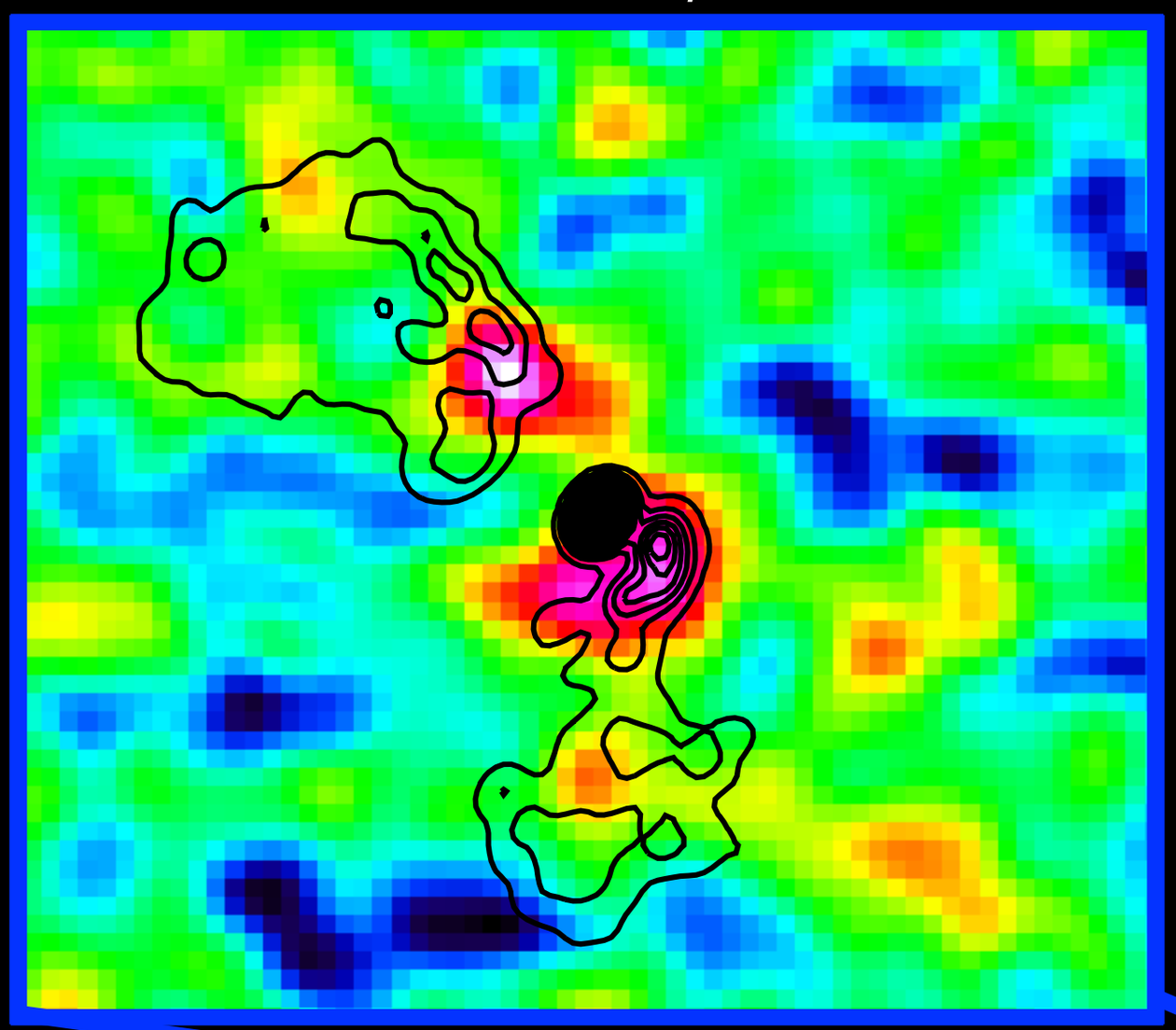


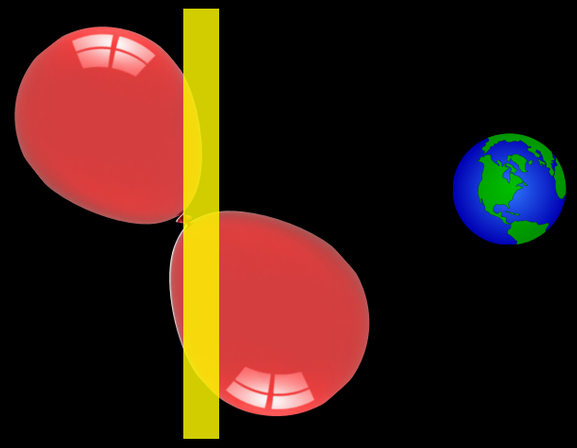


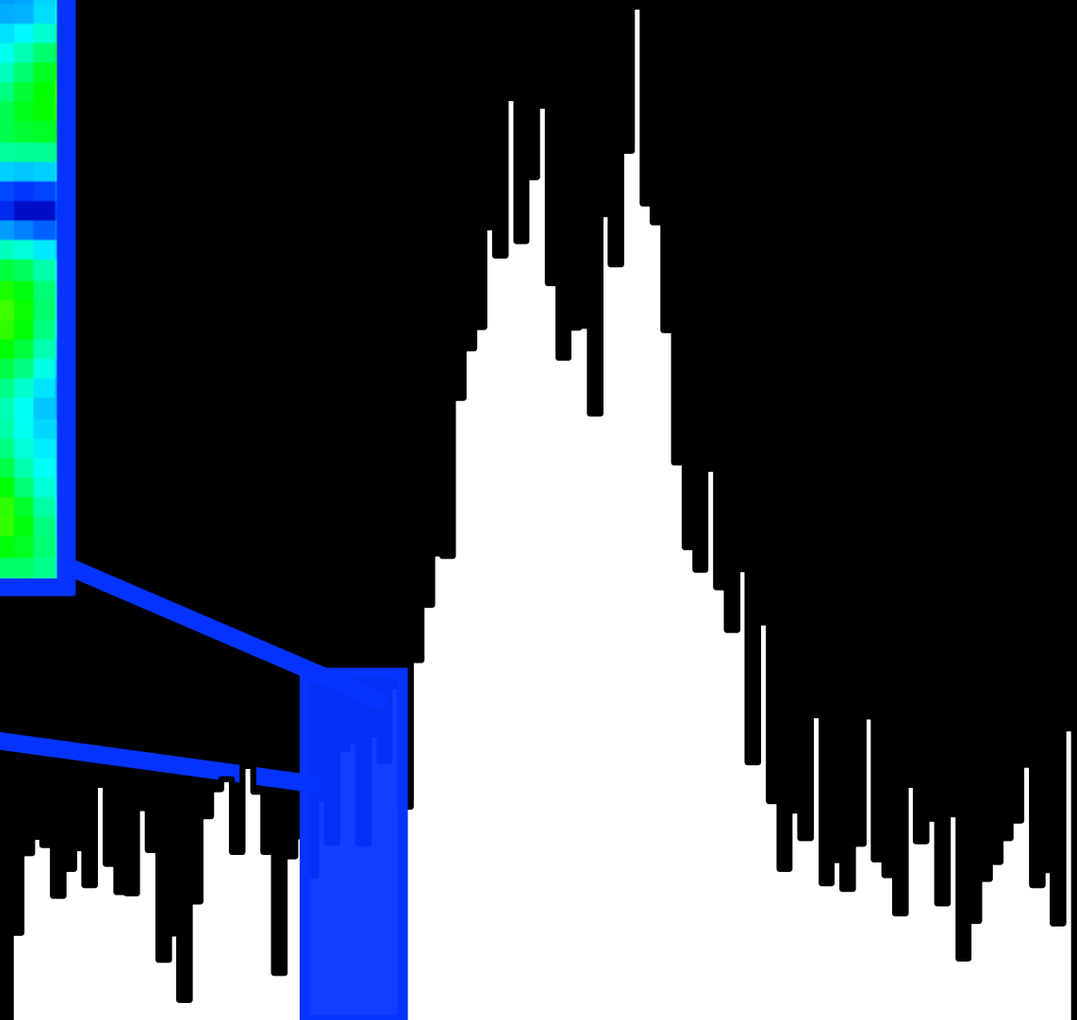


Approaching side of the molecular bubble

~-200 km/sec

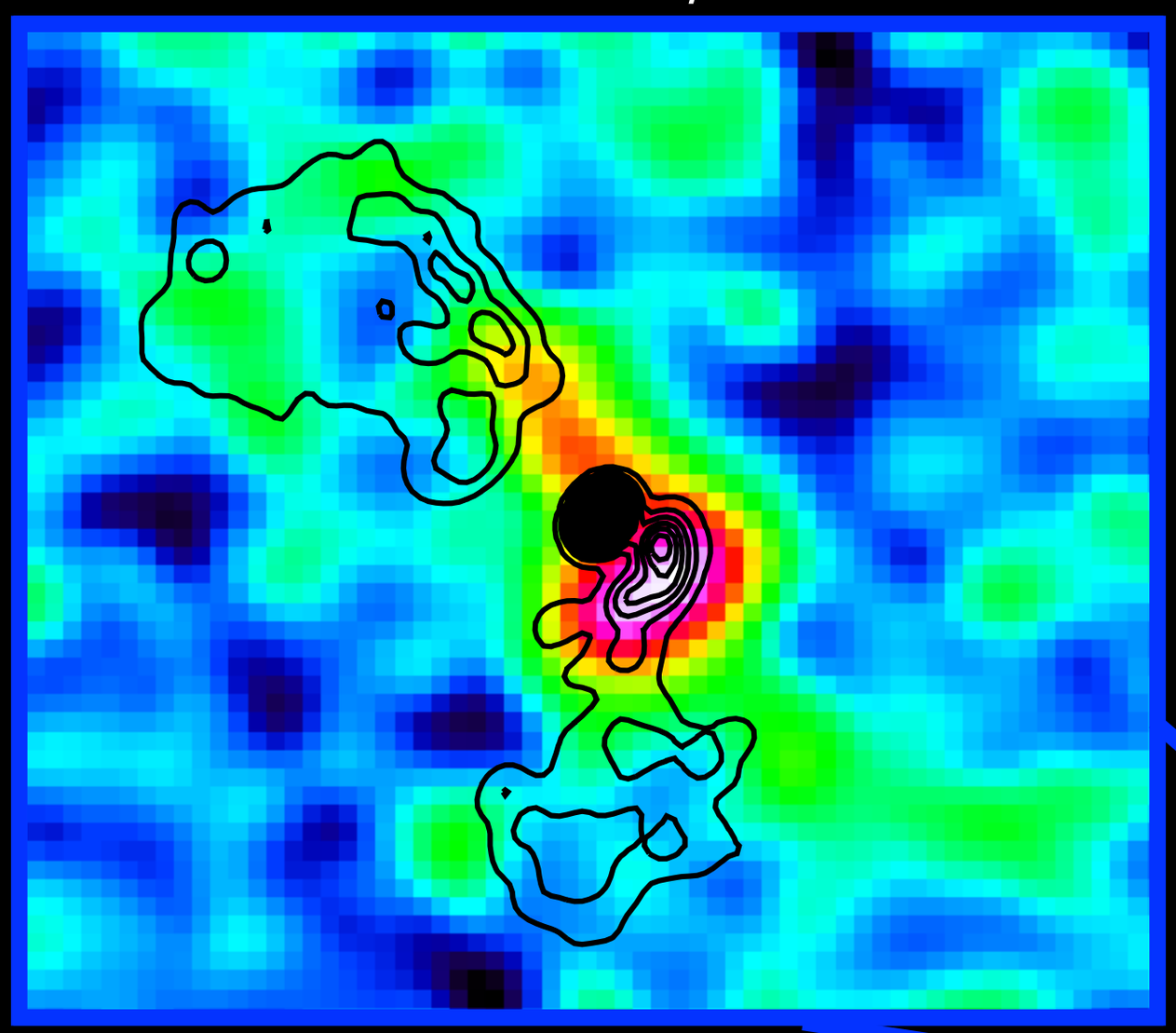


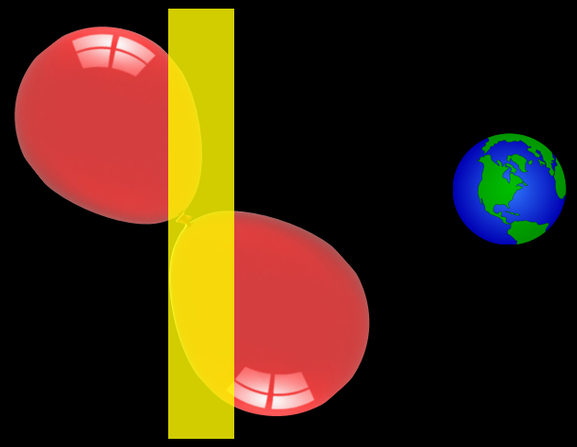


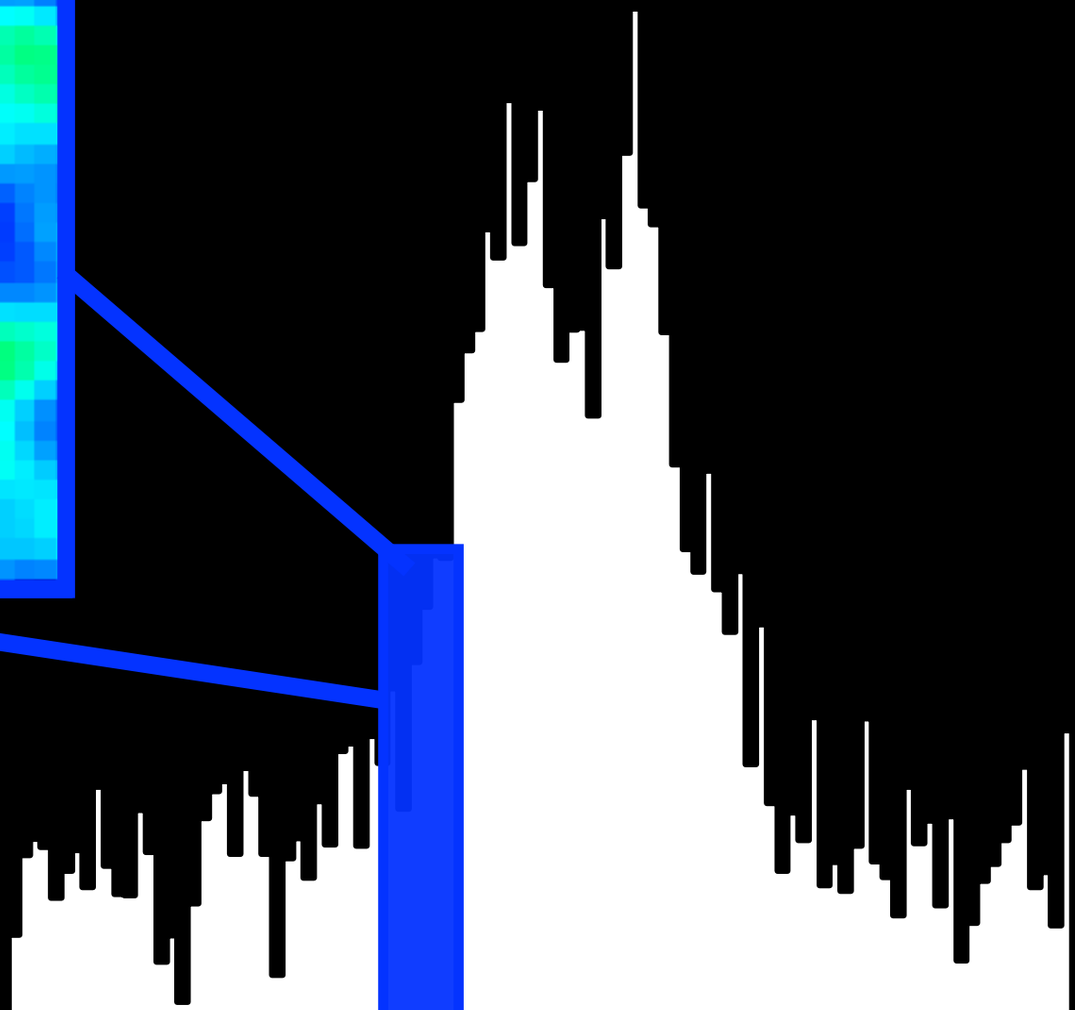


Approaching side of the molecular bubble

~-150 km/sec

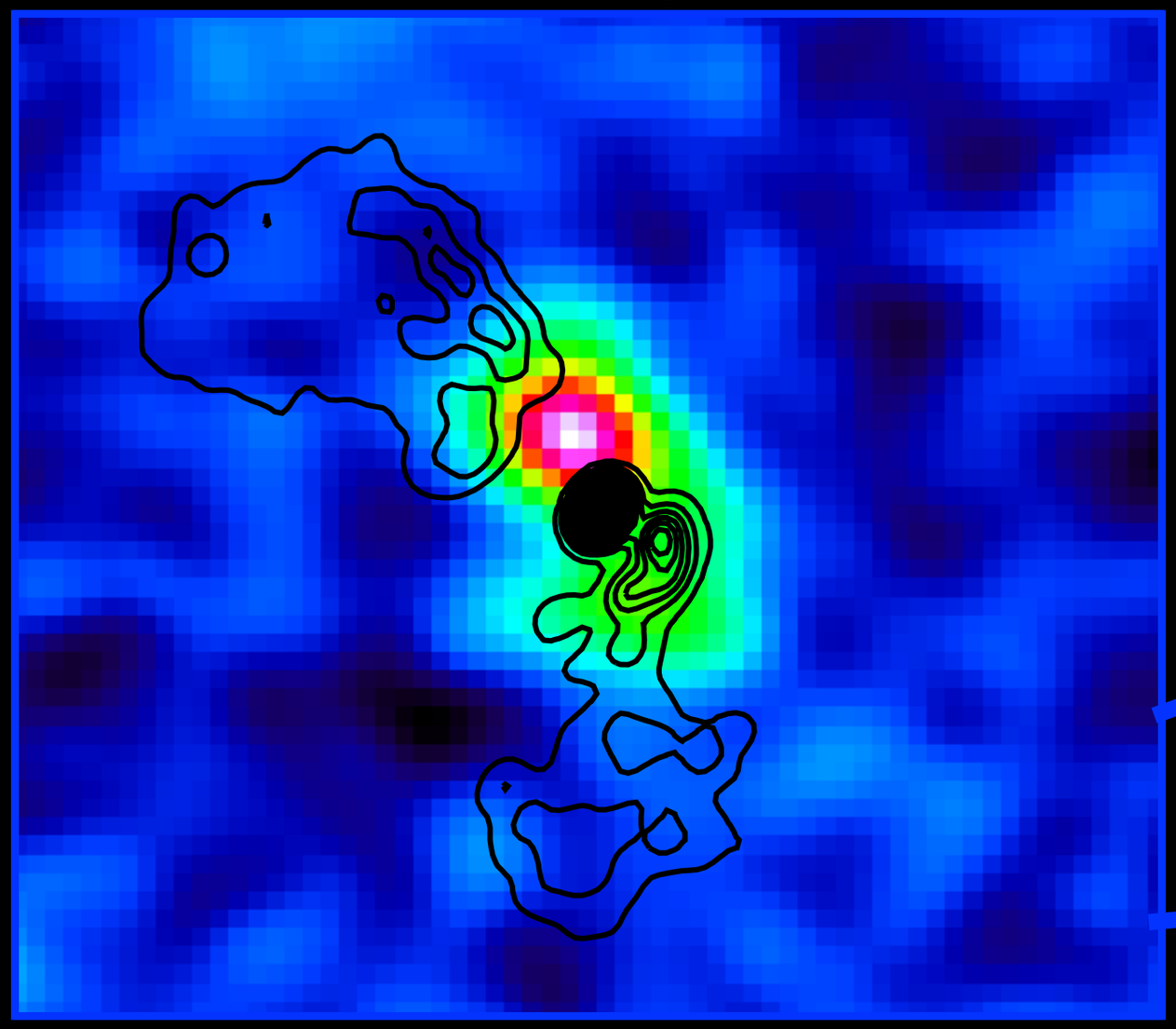


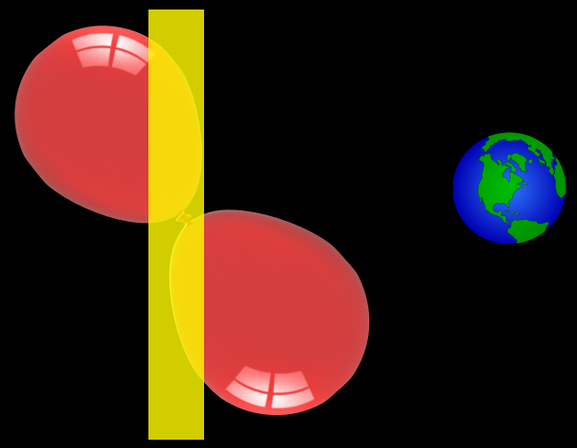


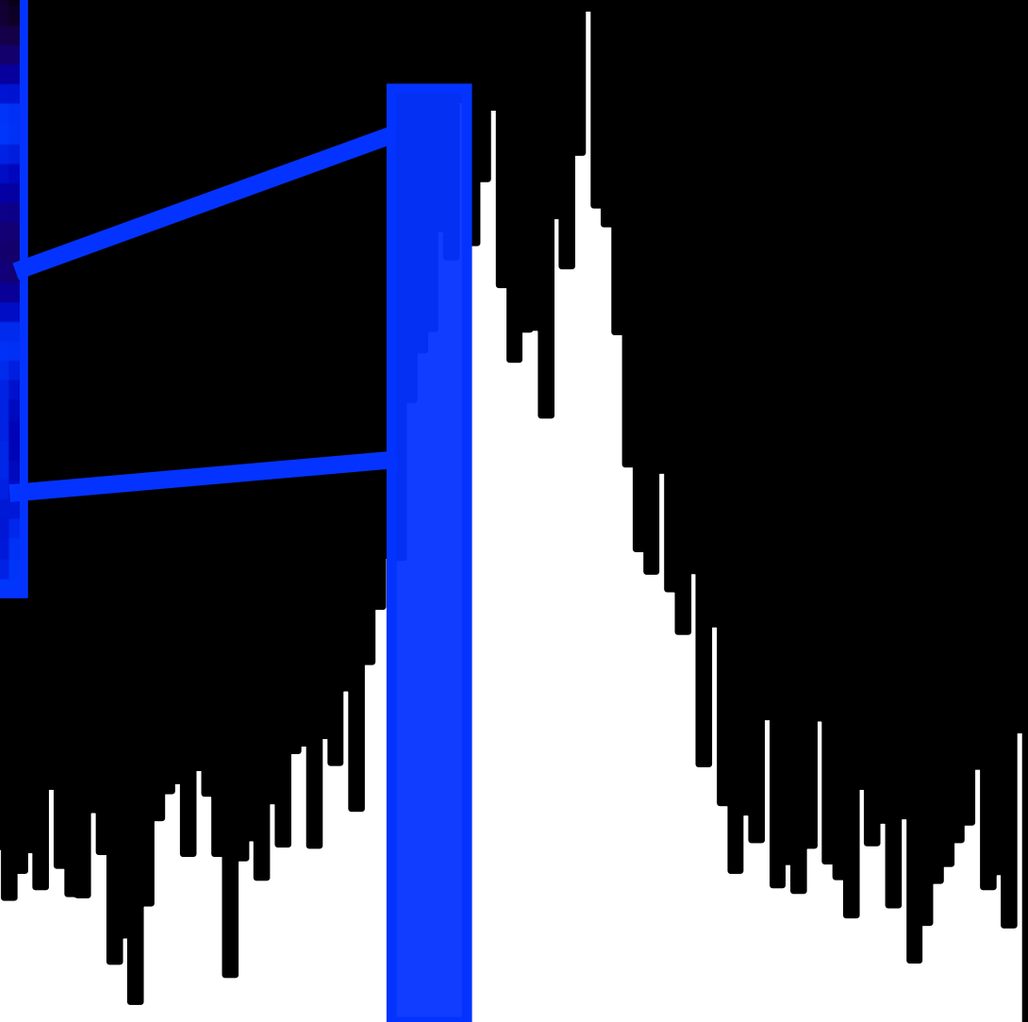


Approaching side of the molecular bubble

~-80 km/sec

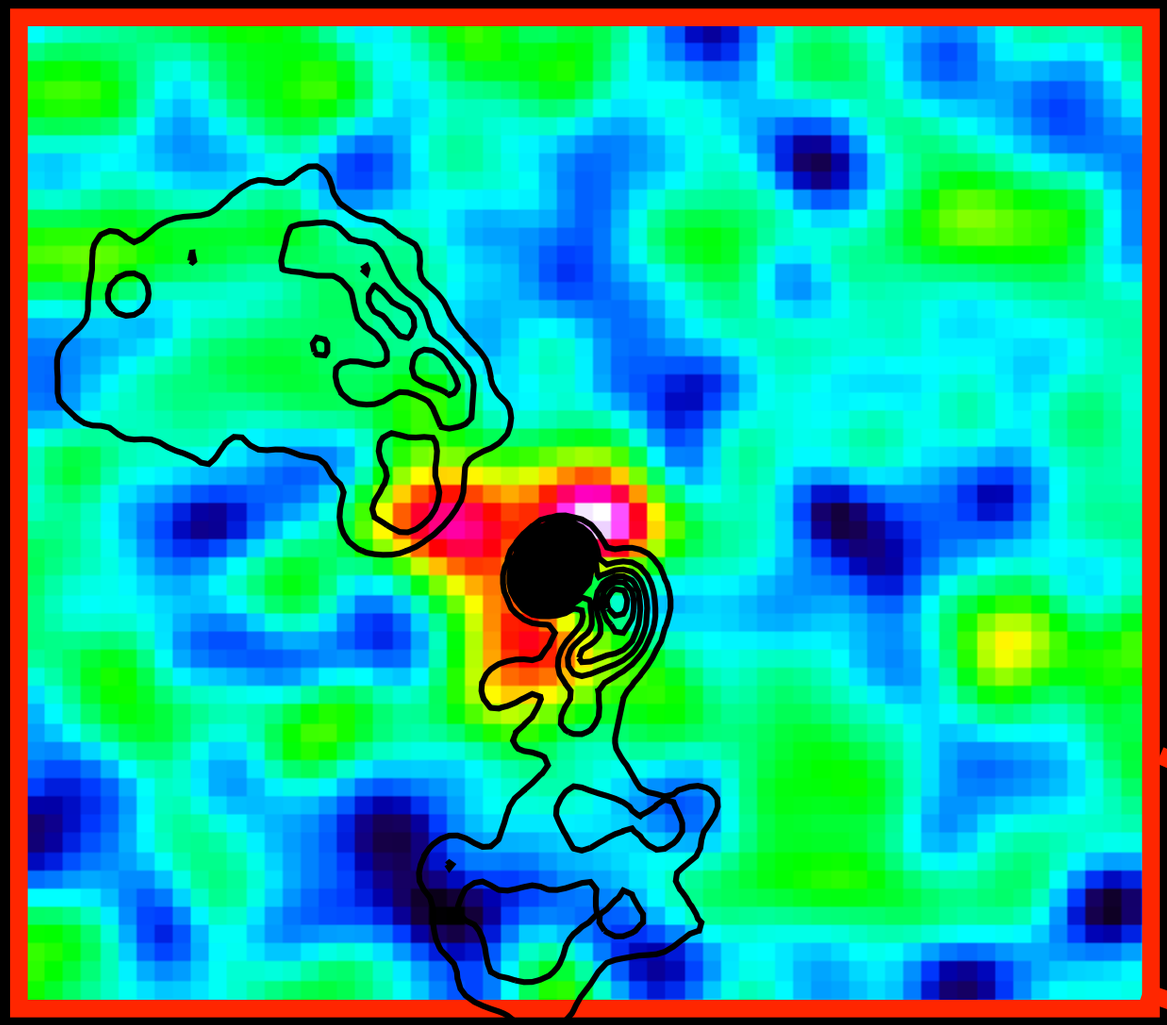


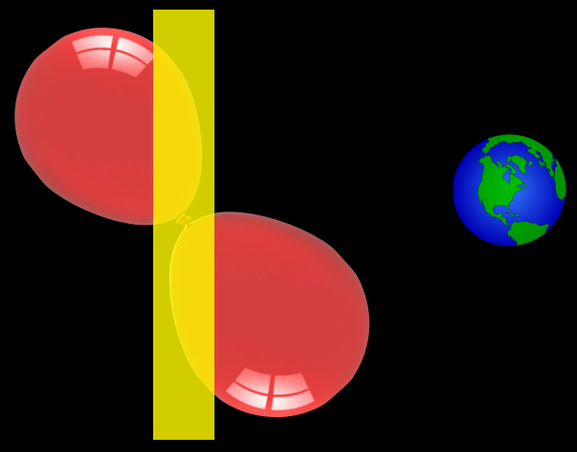


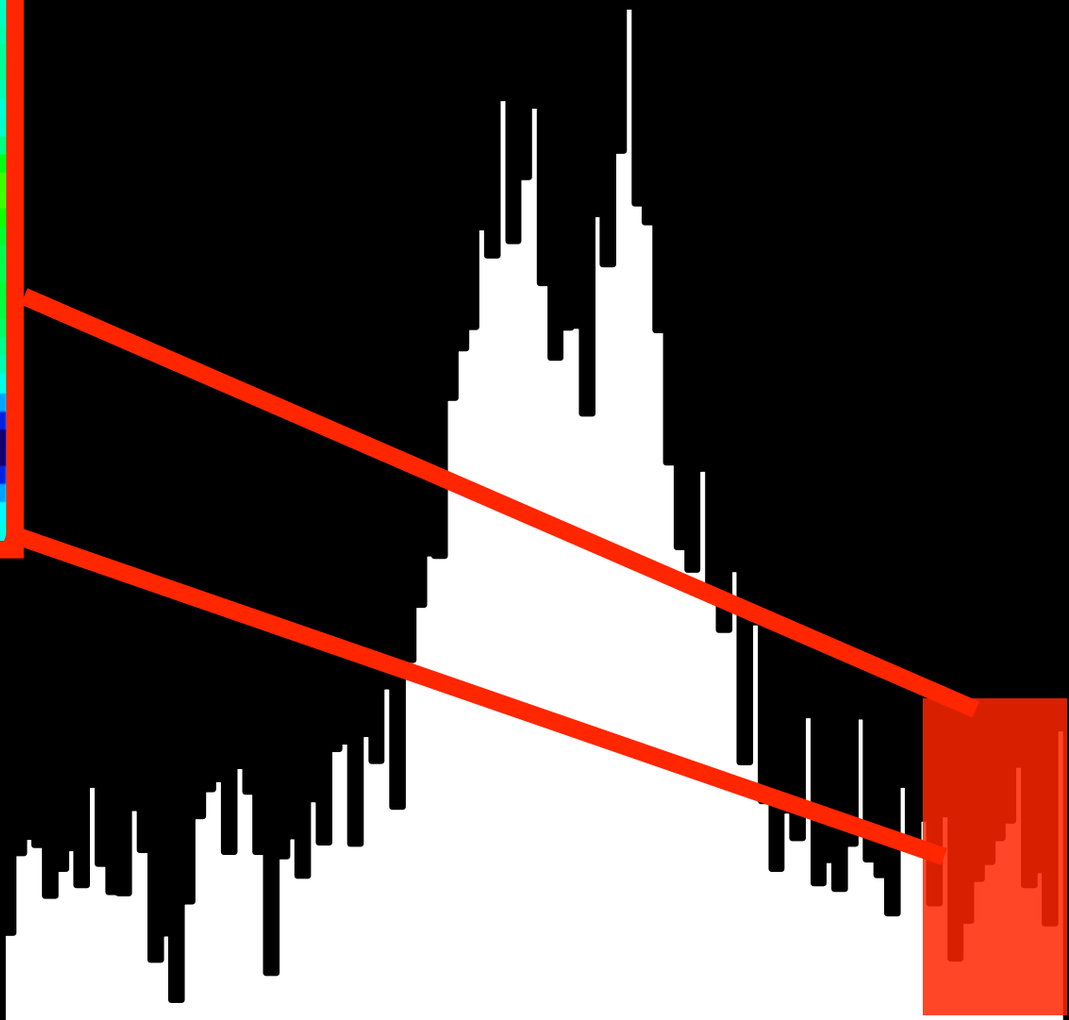


Receding side

~+500 km/sec

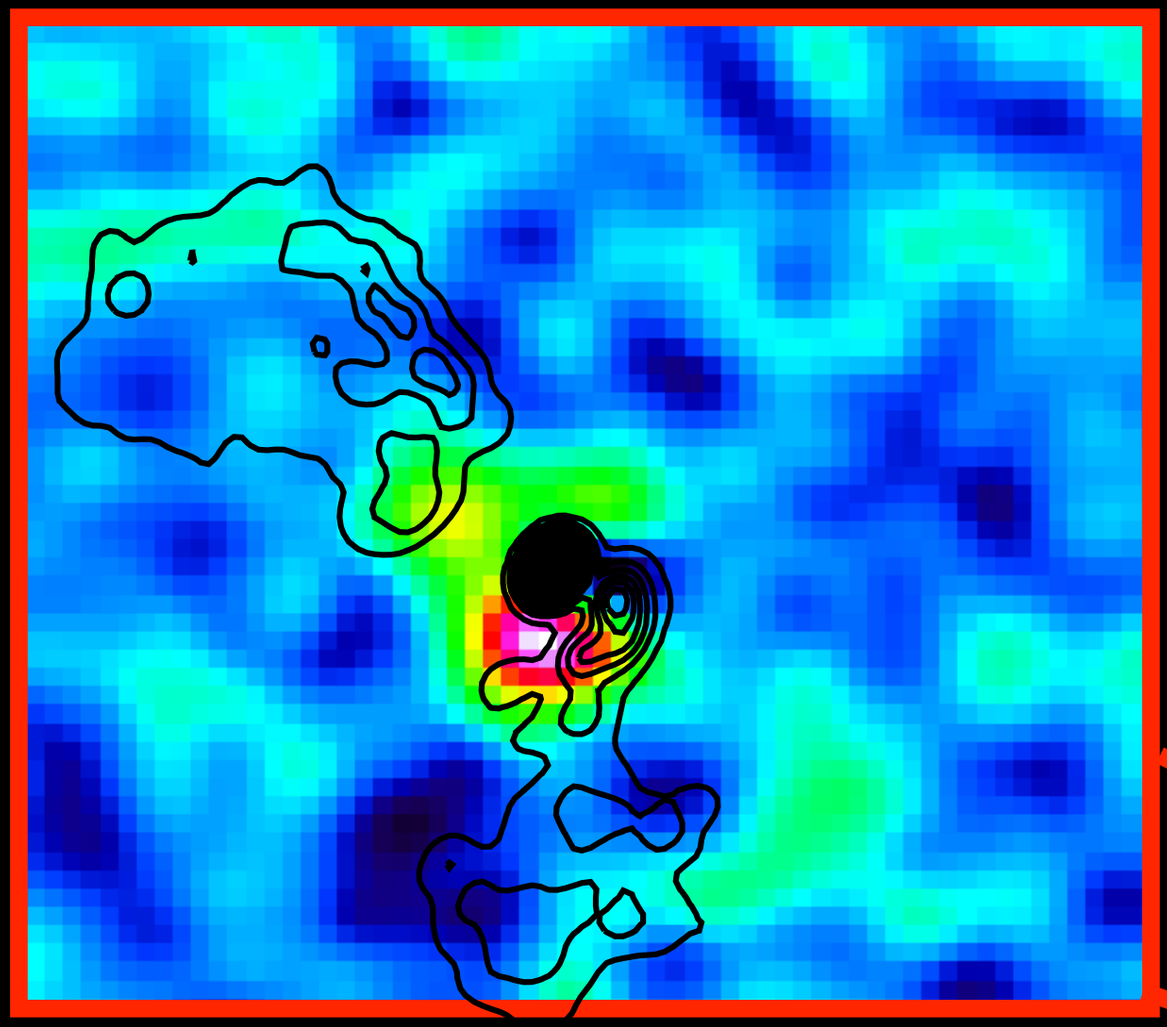


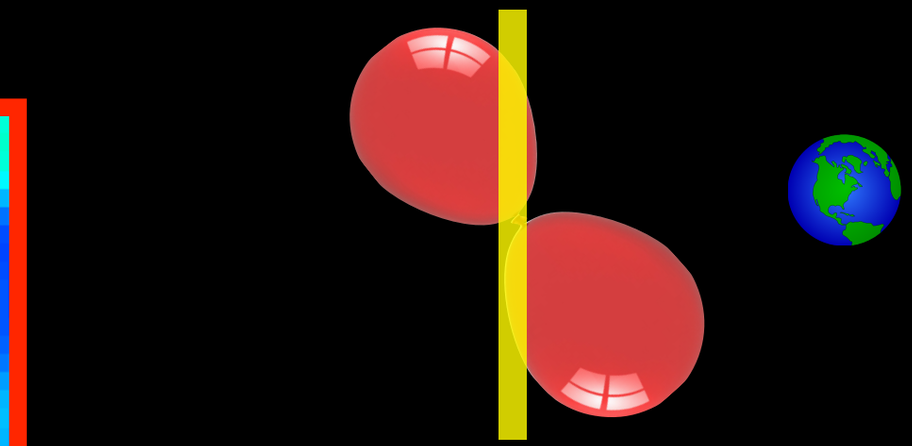


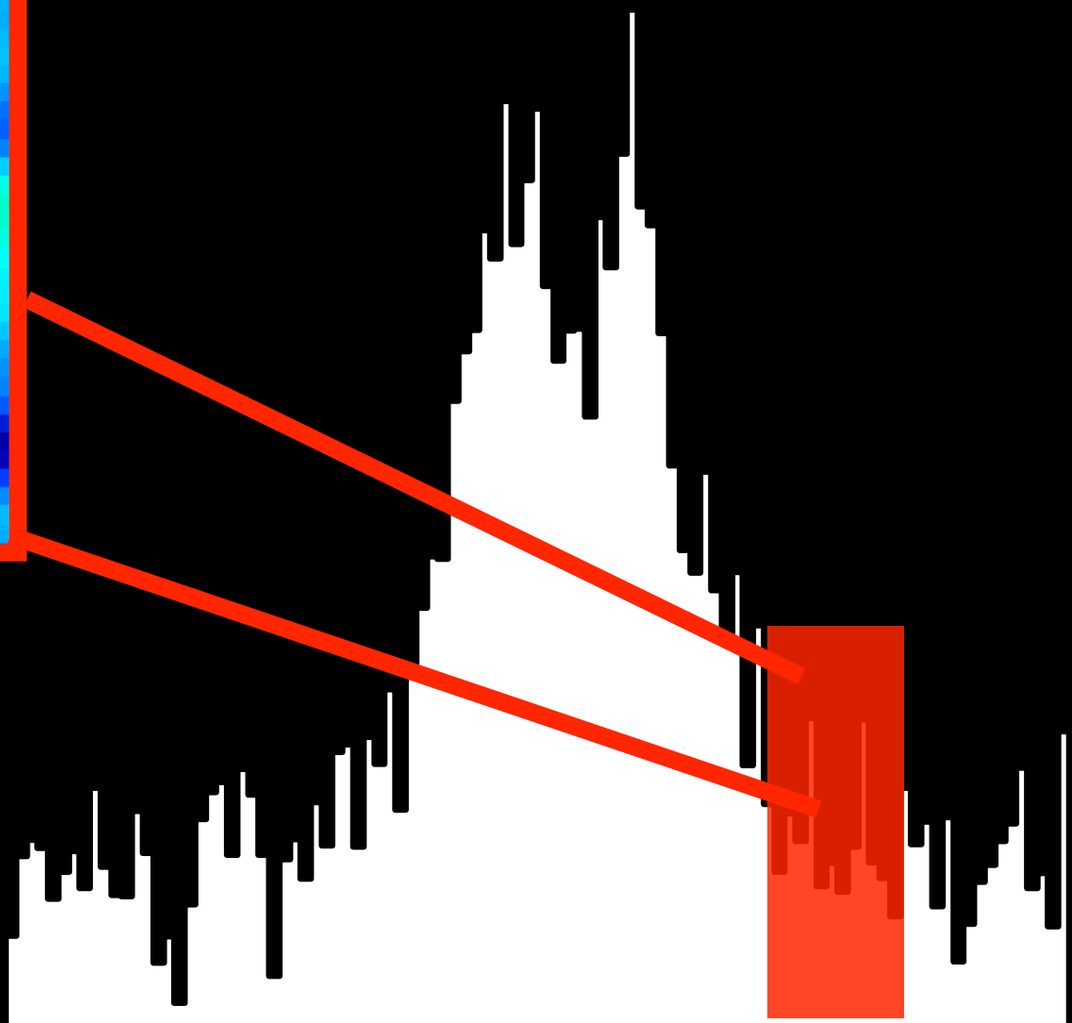


Receding side

~+300 km/sec

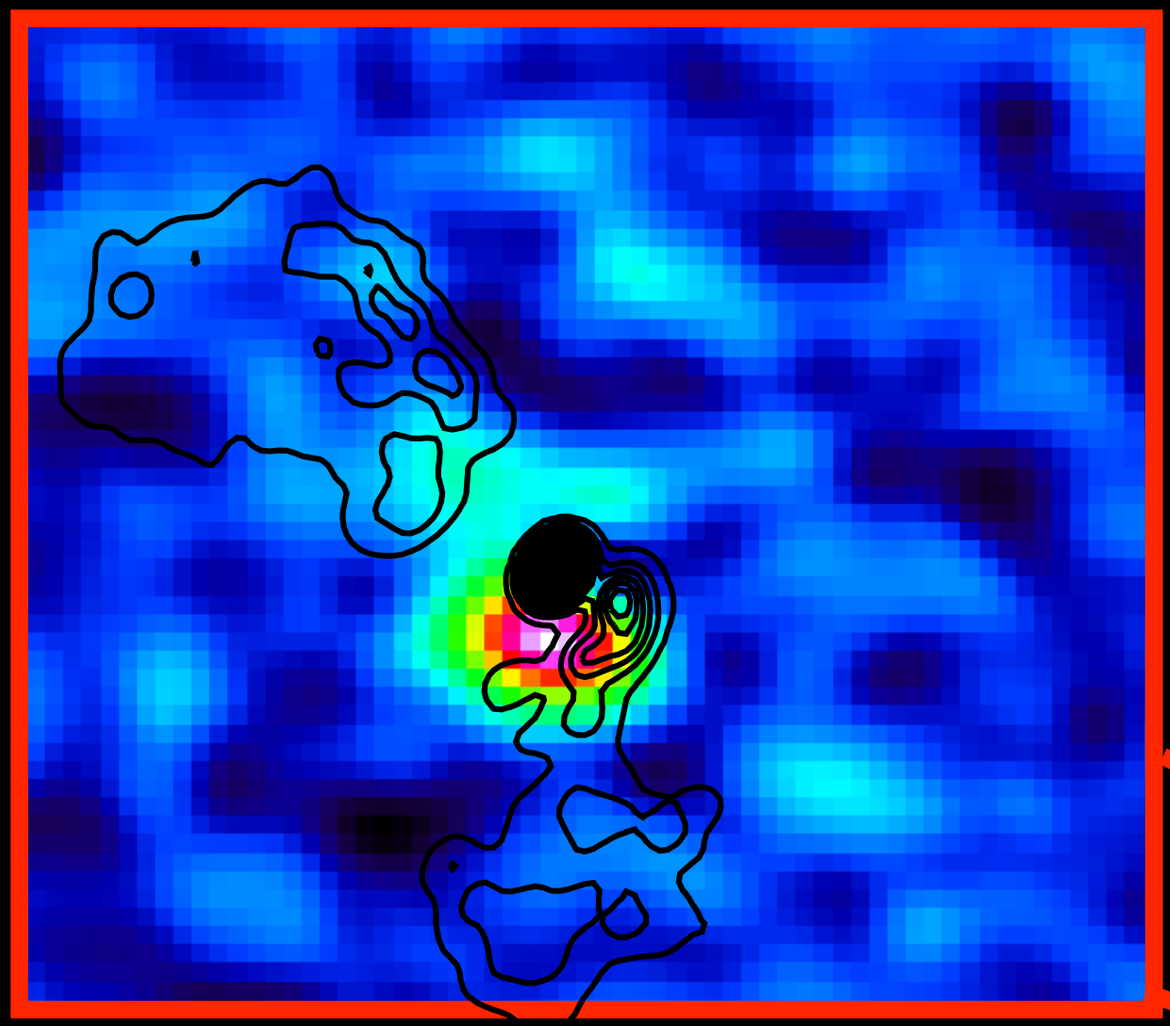


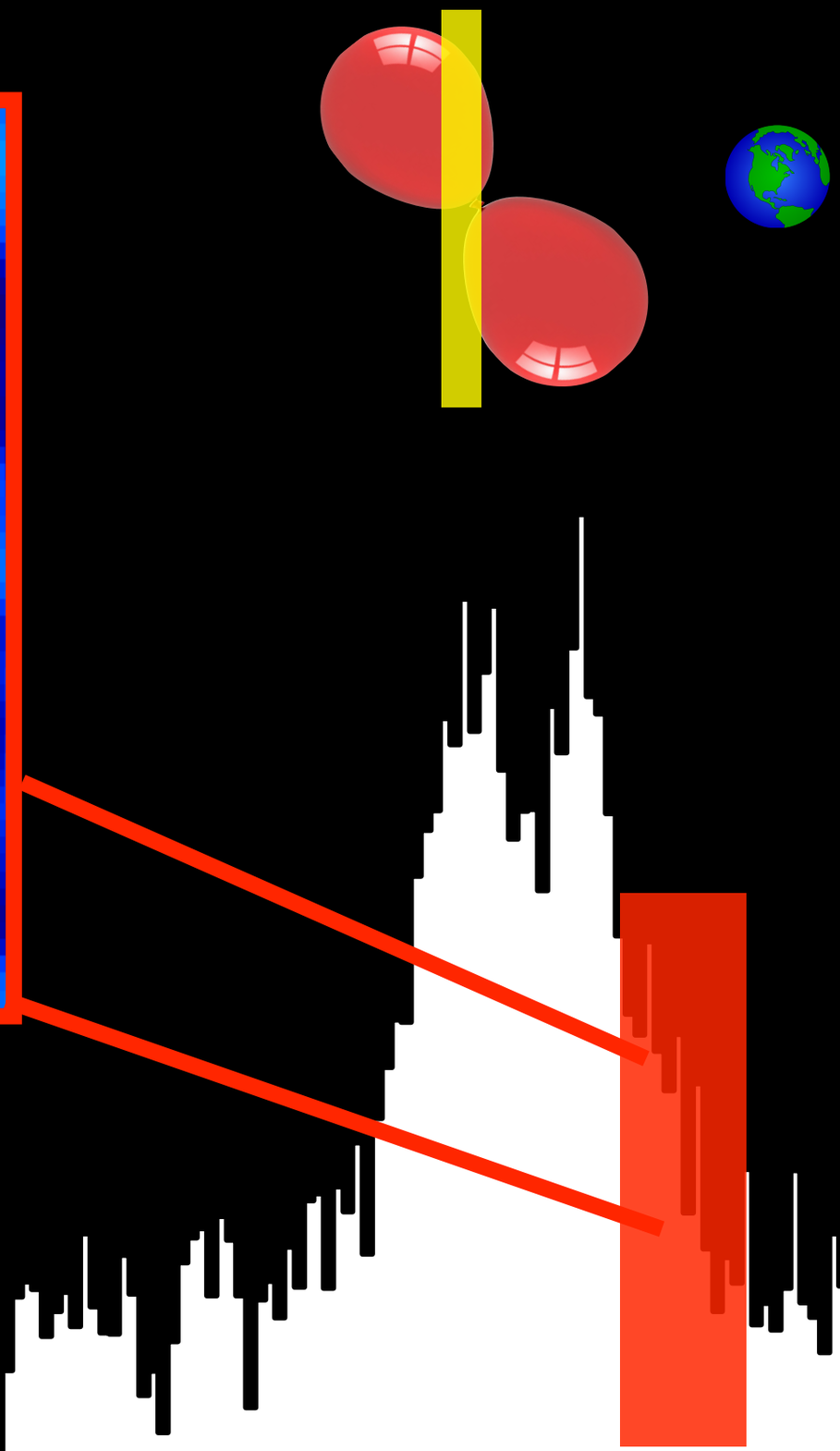


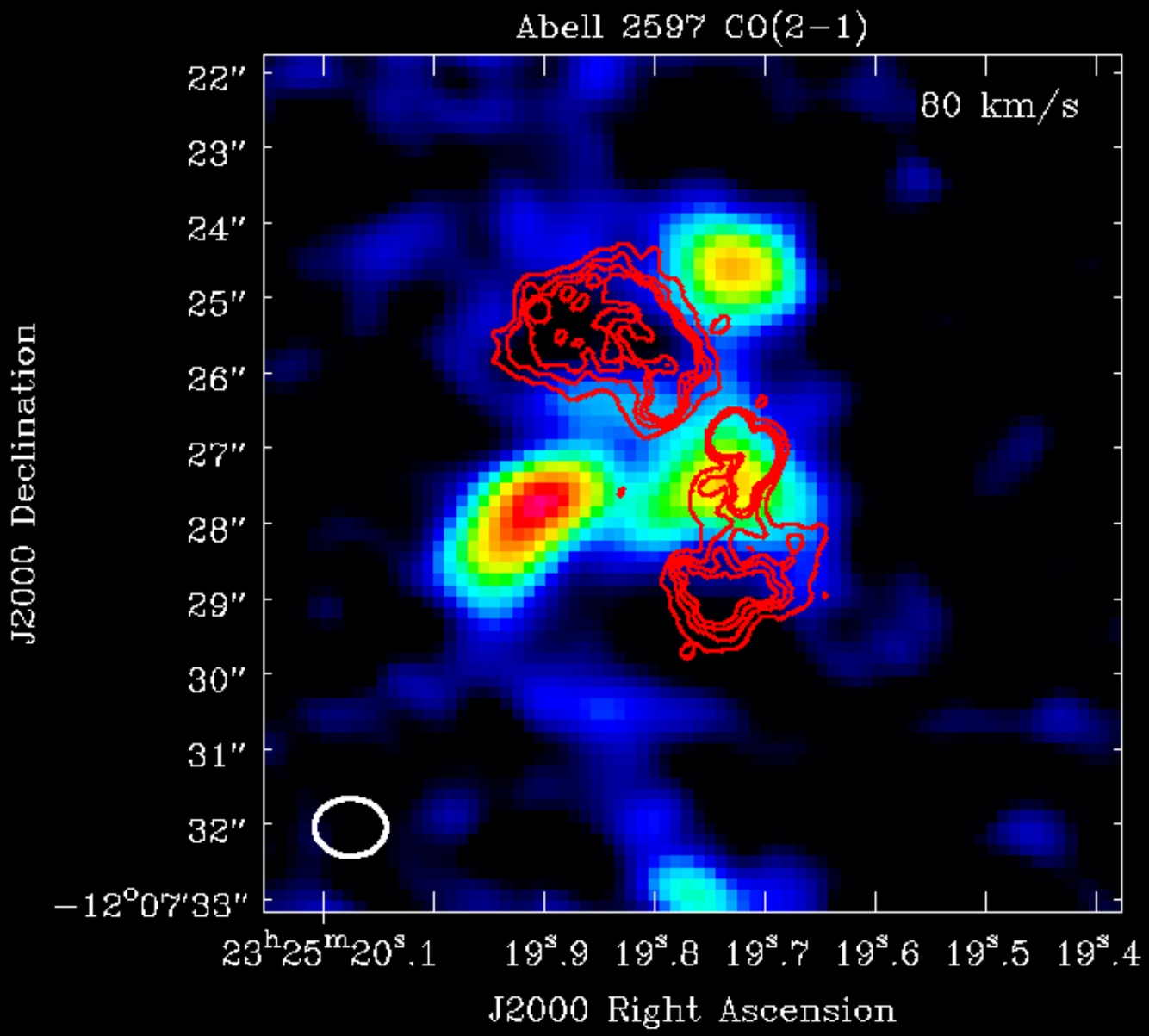


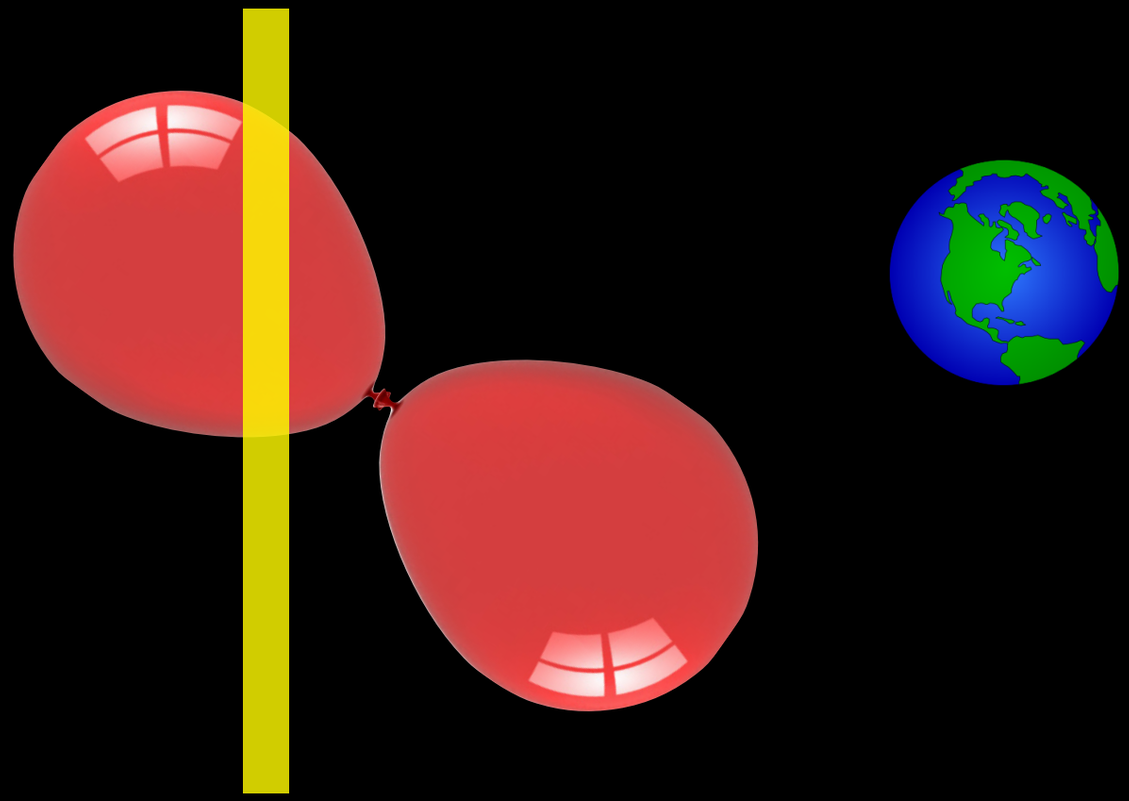
Receding side

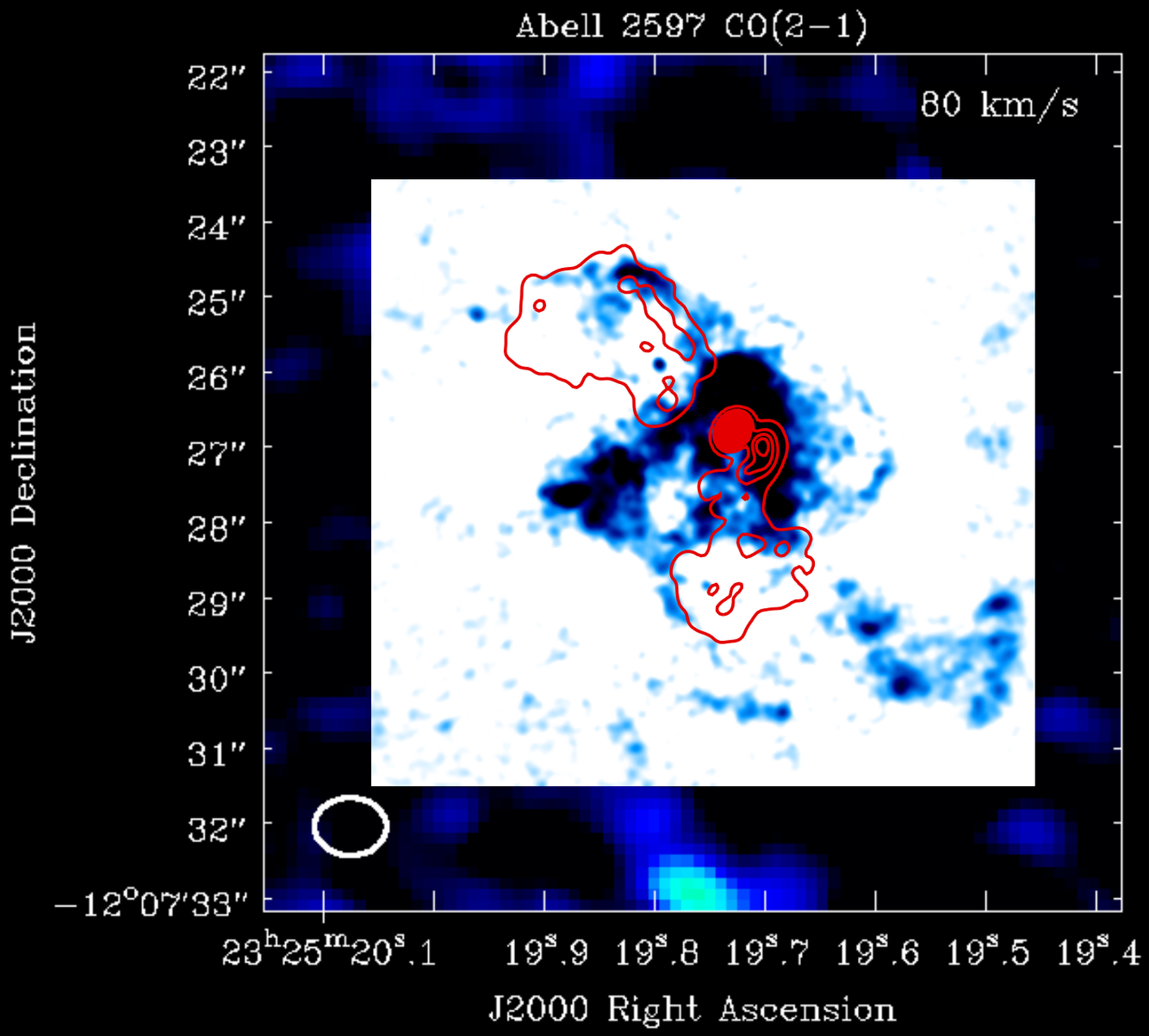
~+100 km/sec



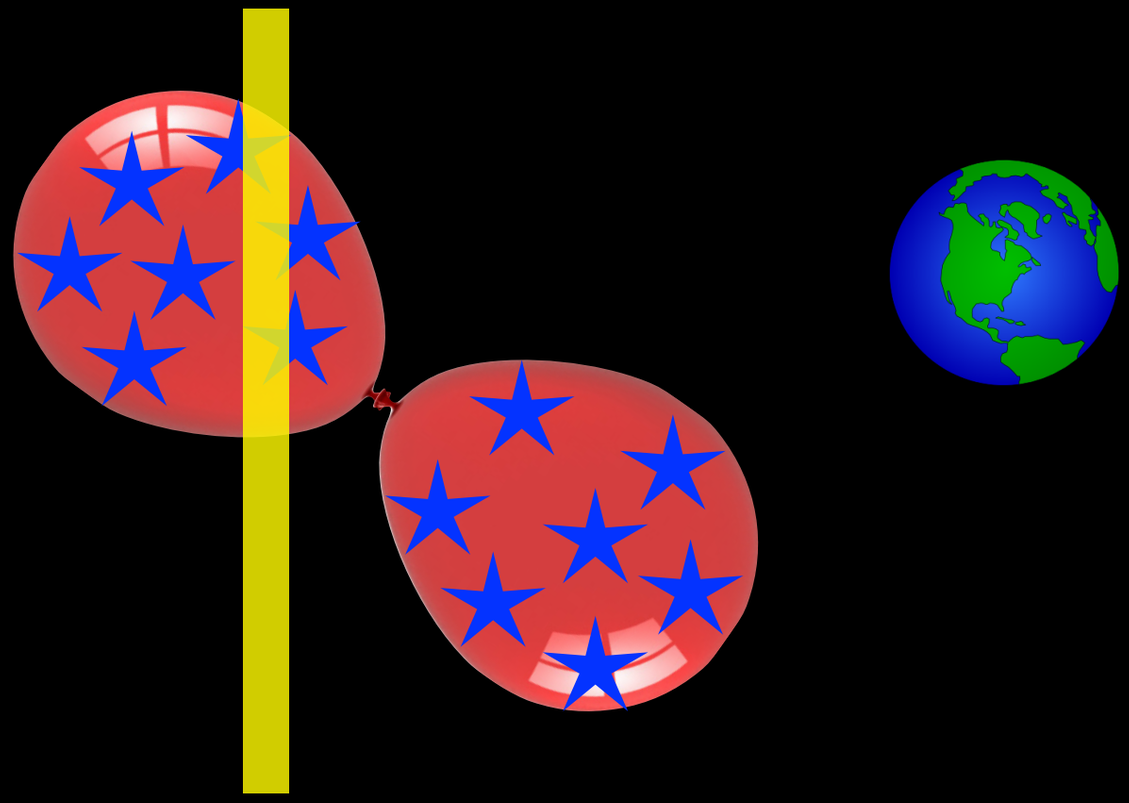



Abell 2597 CO(2−1)
80 km/s
22″
23″
24″
25″
26″
27″
28″
29″
30″
31″
32″
−12°07′33″
23h25m20s.1
19s.9
19s.8
19s.7
19s.6
19s.5
19s.4
J2000 Declination
J2000 Right Ascension



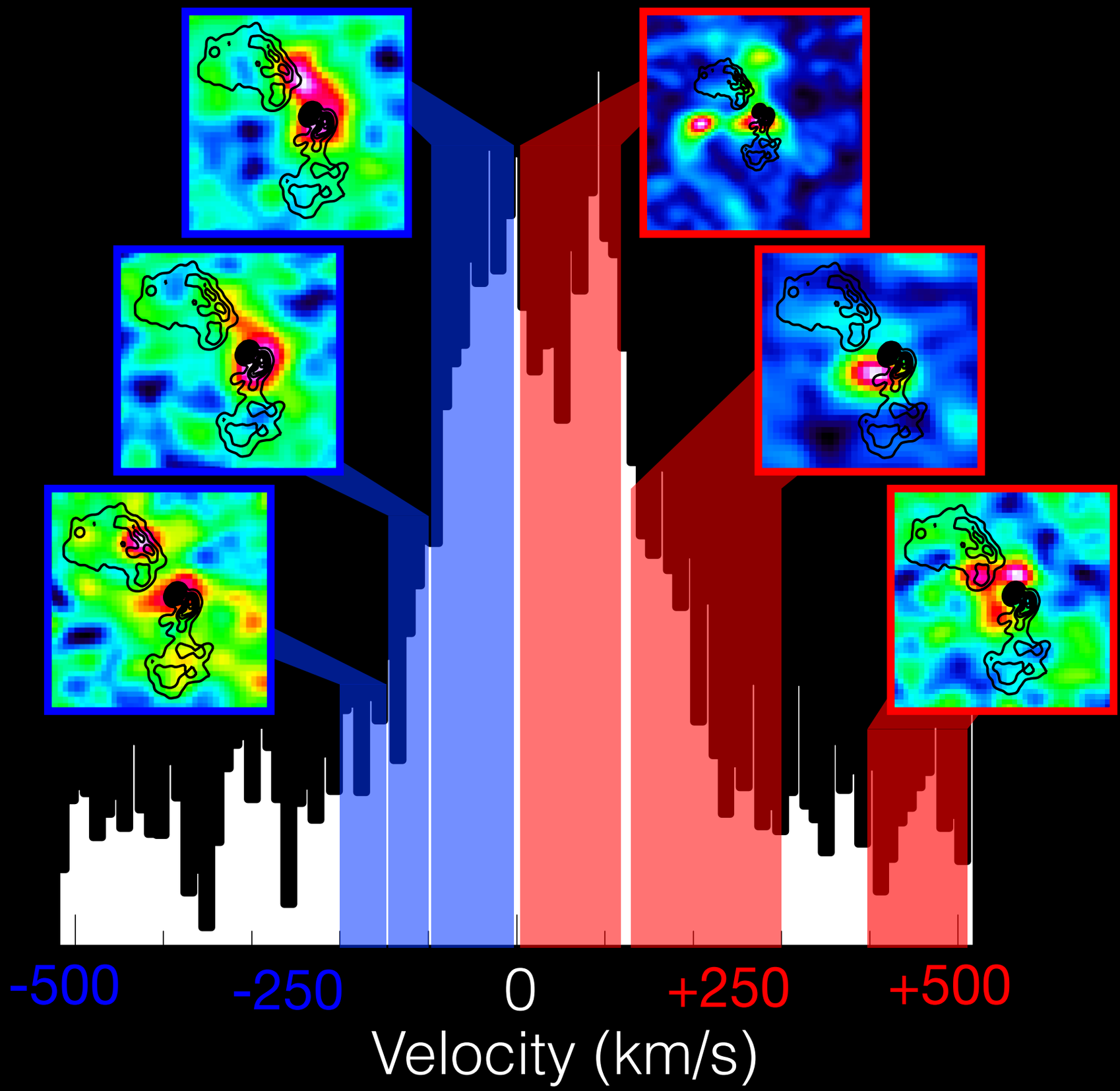


Molecular balloons painted with young stars?

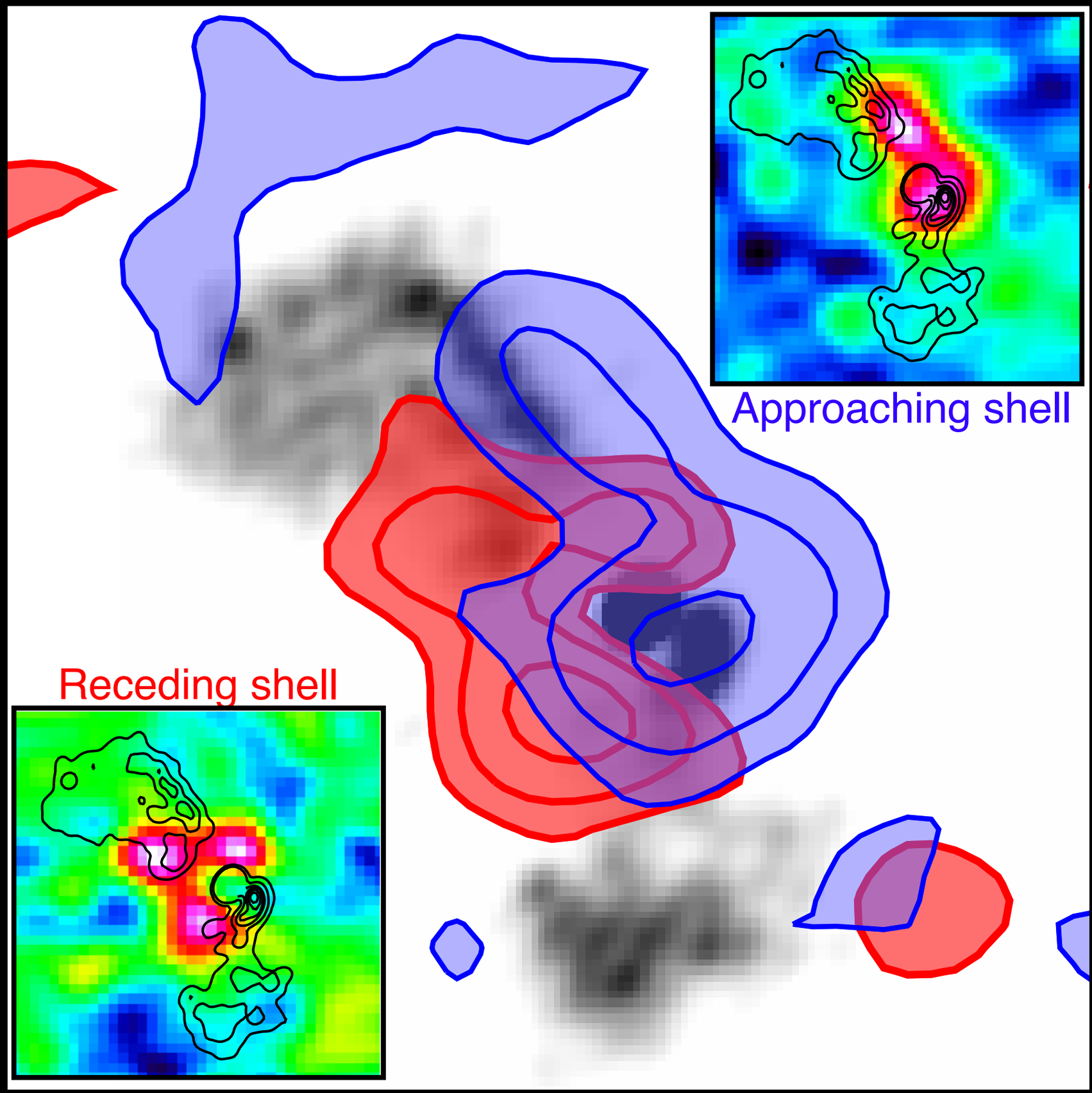


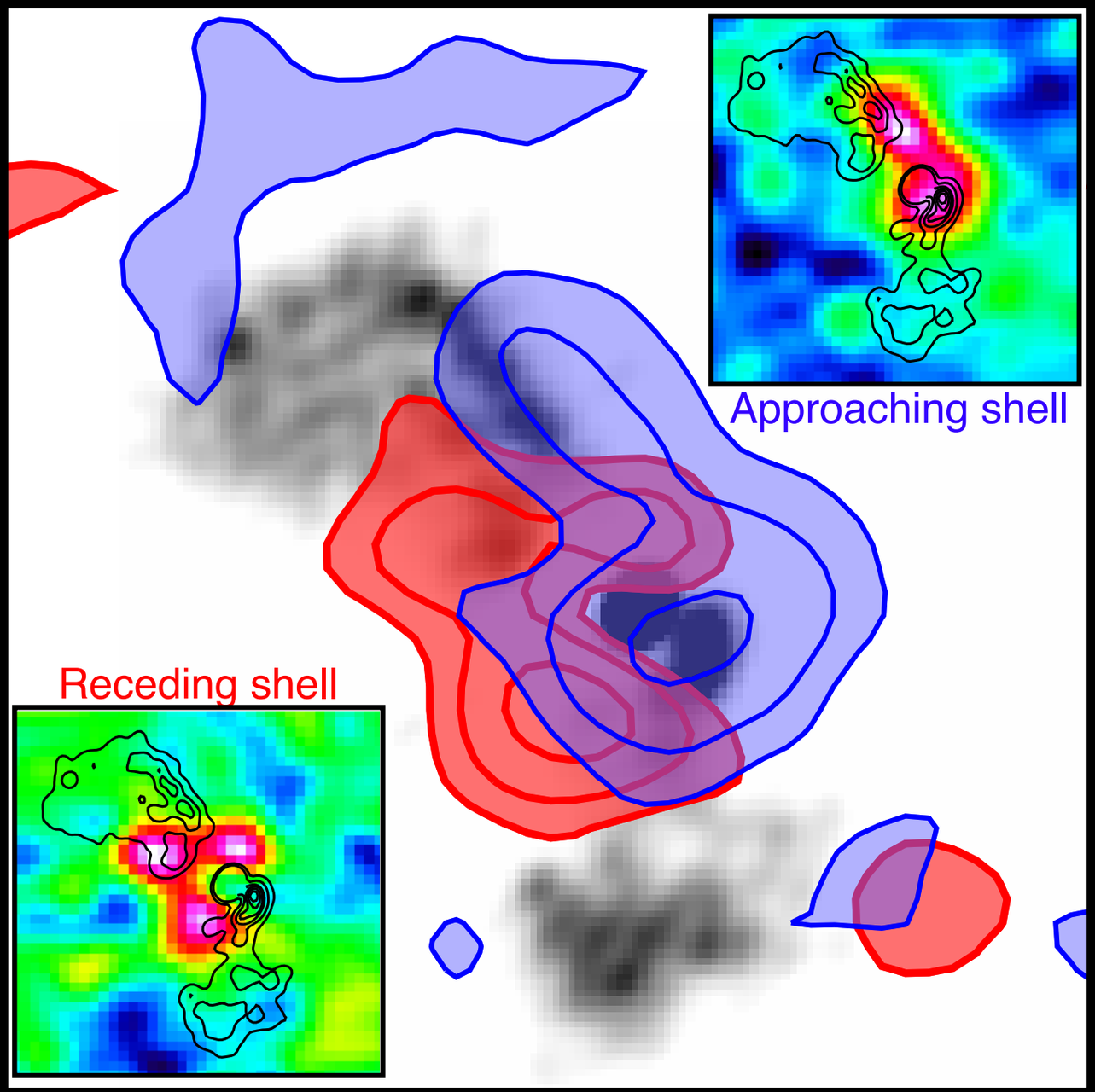
"Jet-triggered" star formation?

Symmetric velocity structures



Approaching and receding sides of the outflow





~500 million M_o

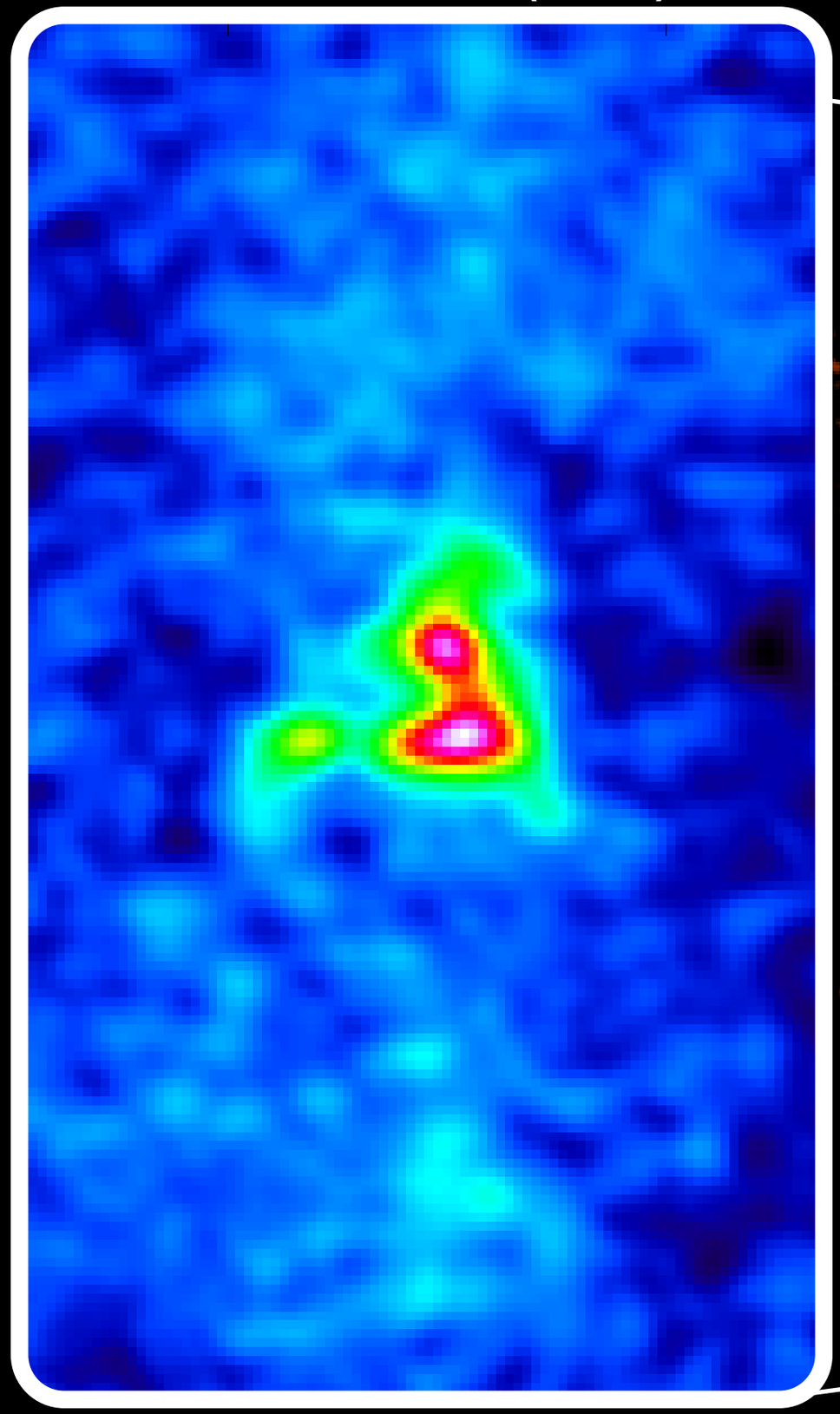
of molecular gas entrained in jet-driven outflow.

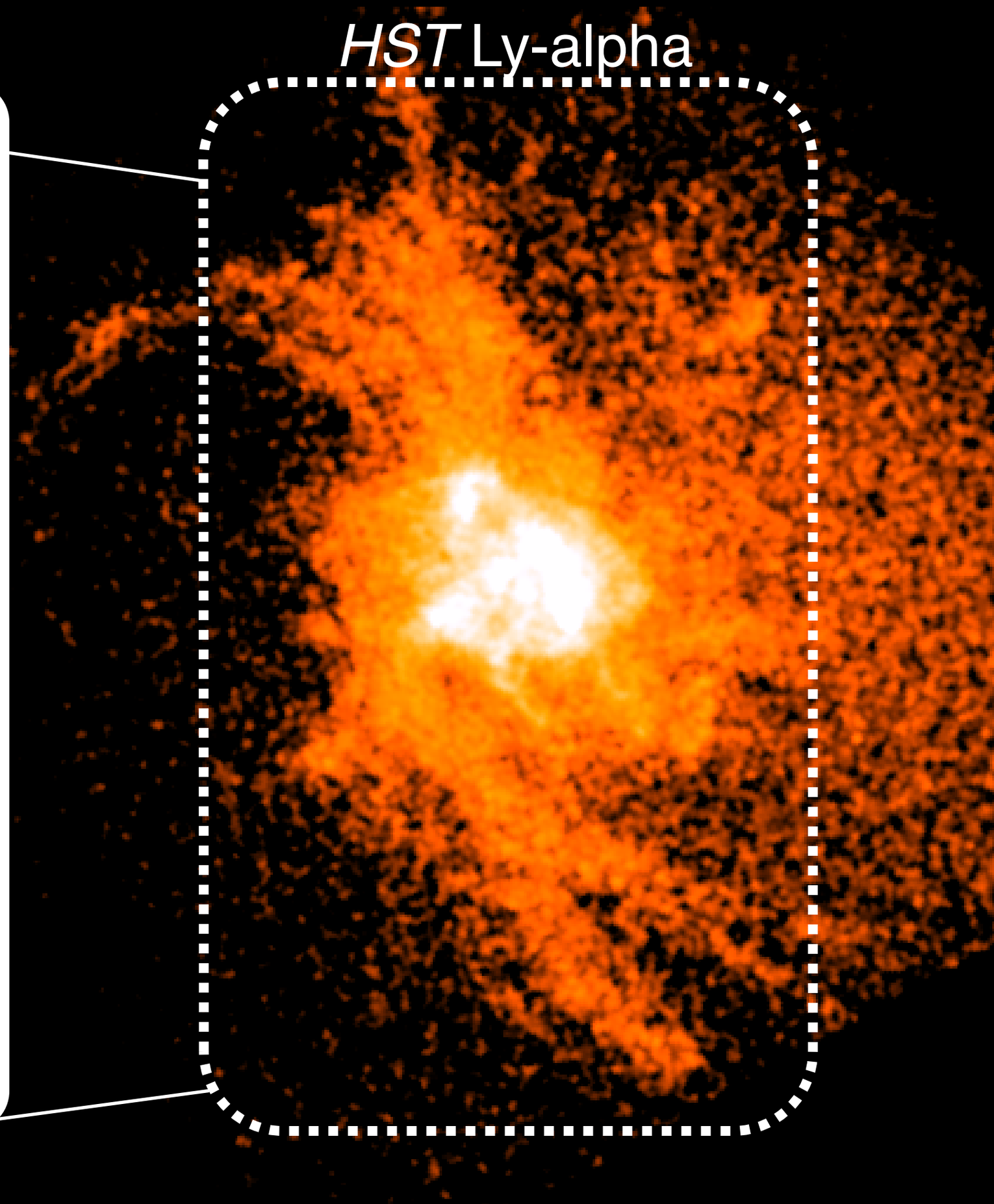
TWO

Ballistic molecular “rain” falling back from the fountain plume

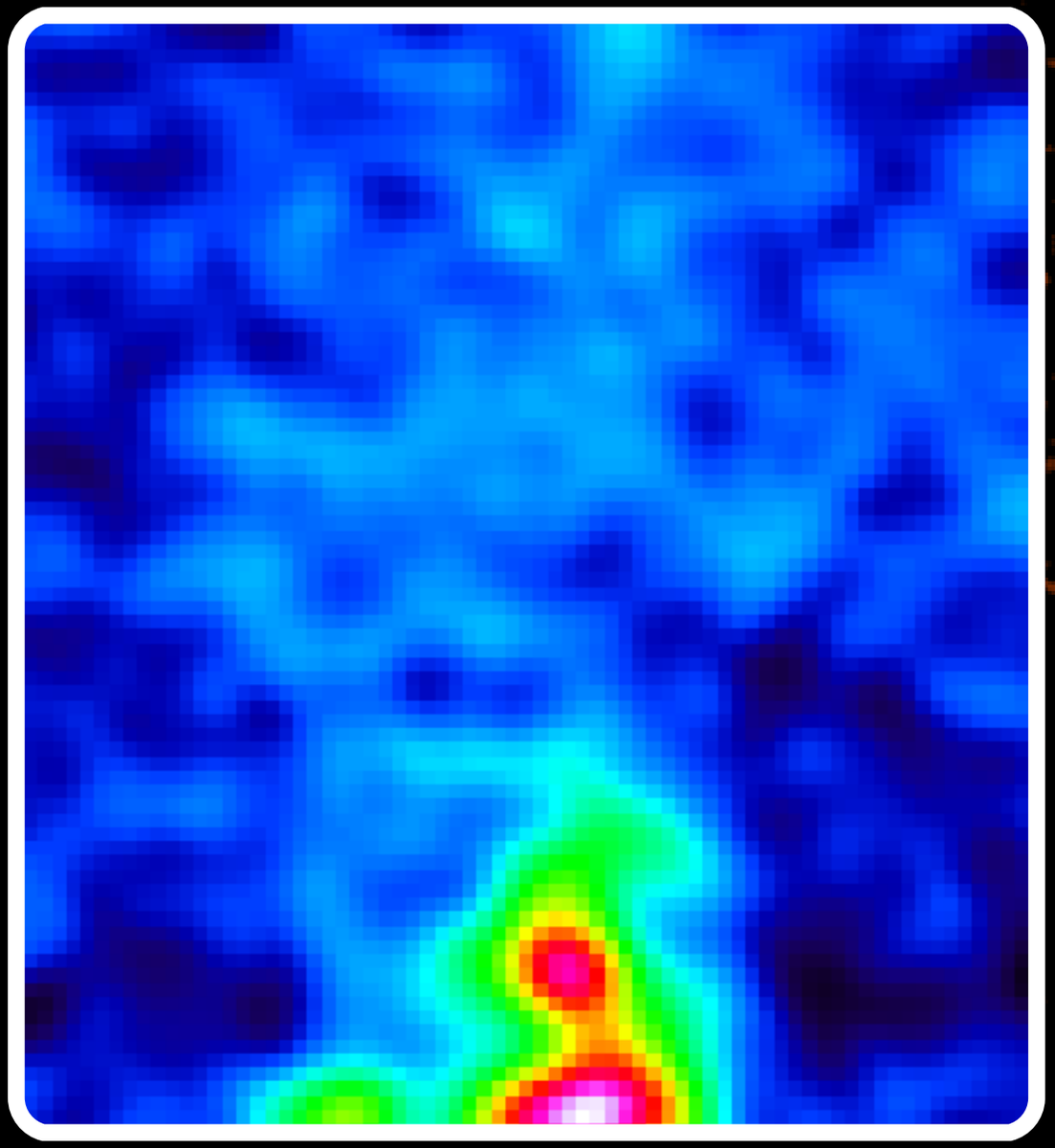
ALMA CO(2-1)

HST Ly-alpha

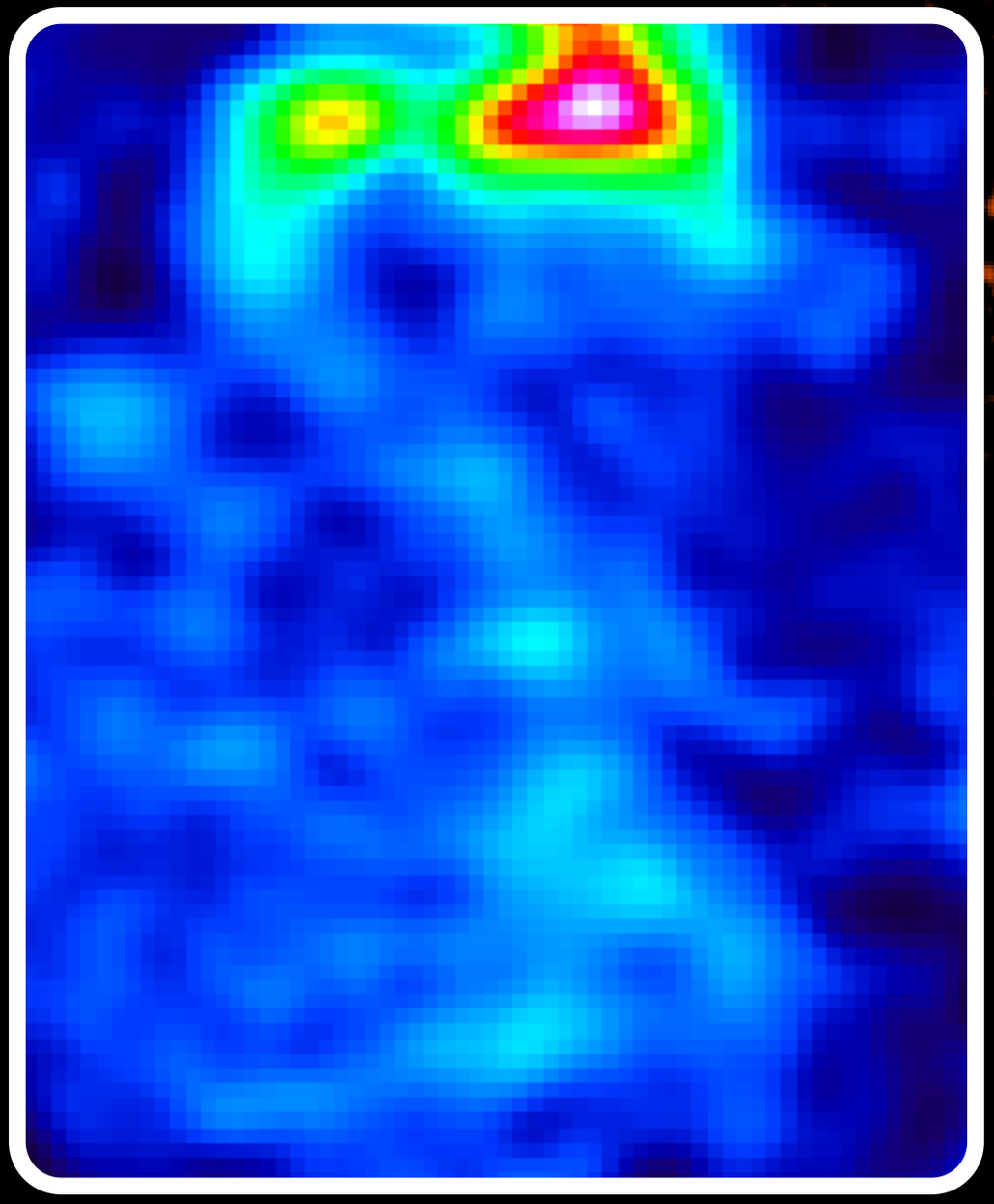


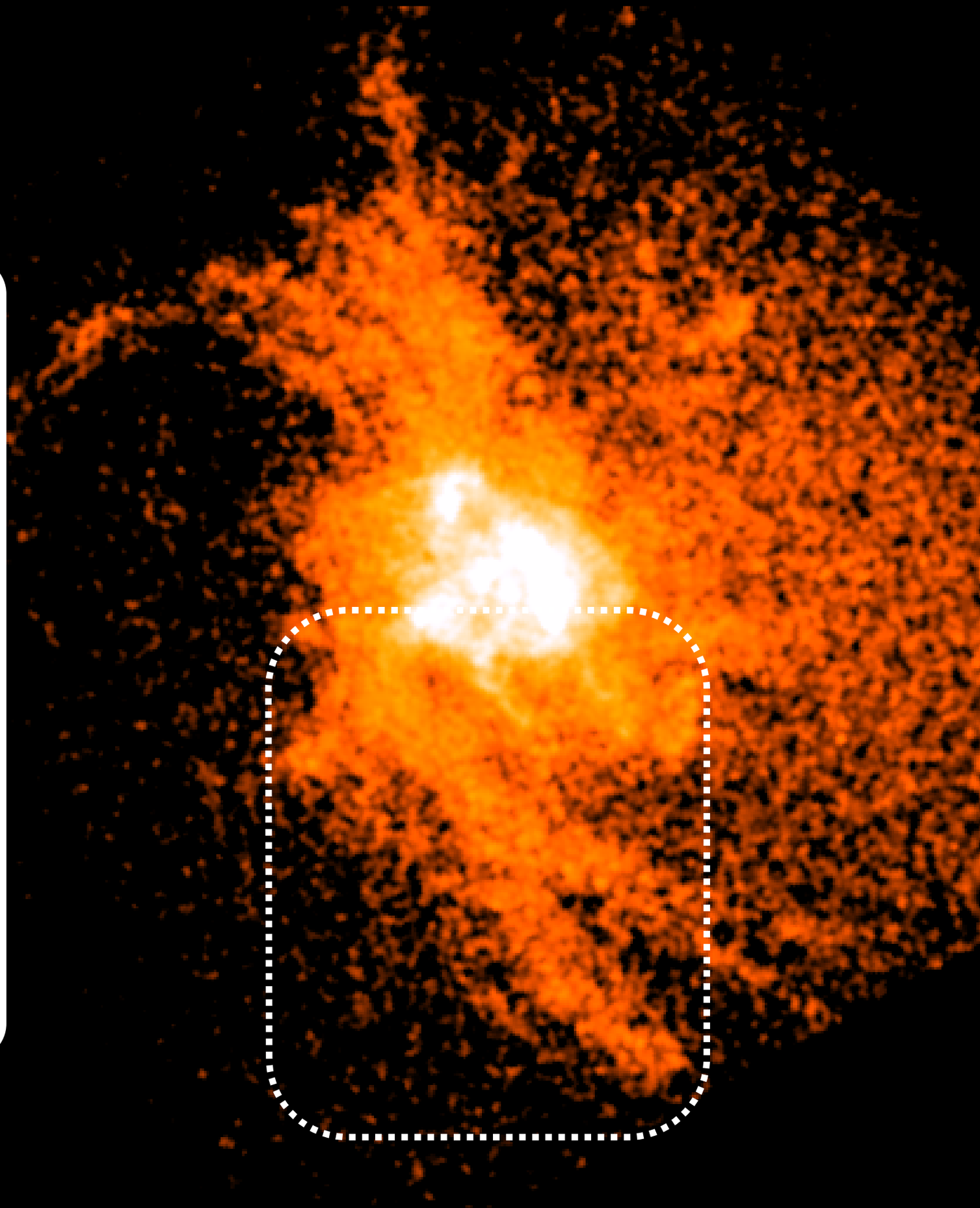


Northern Filaments

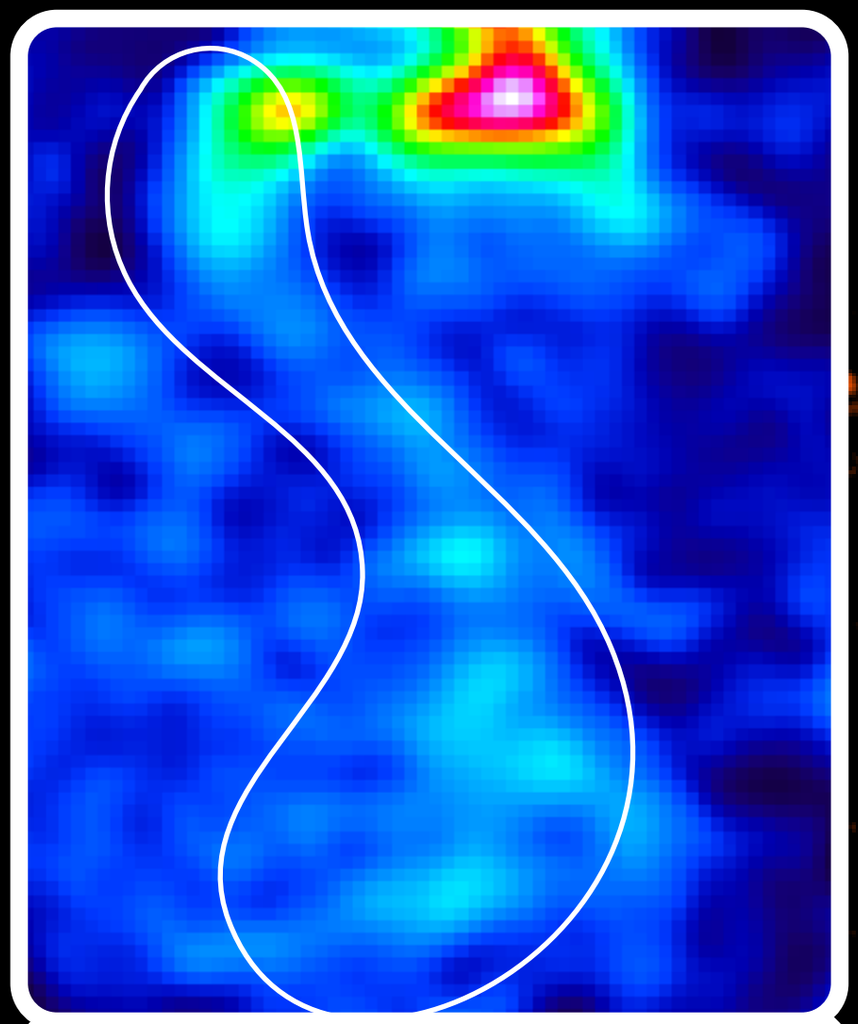


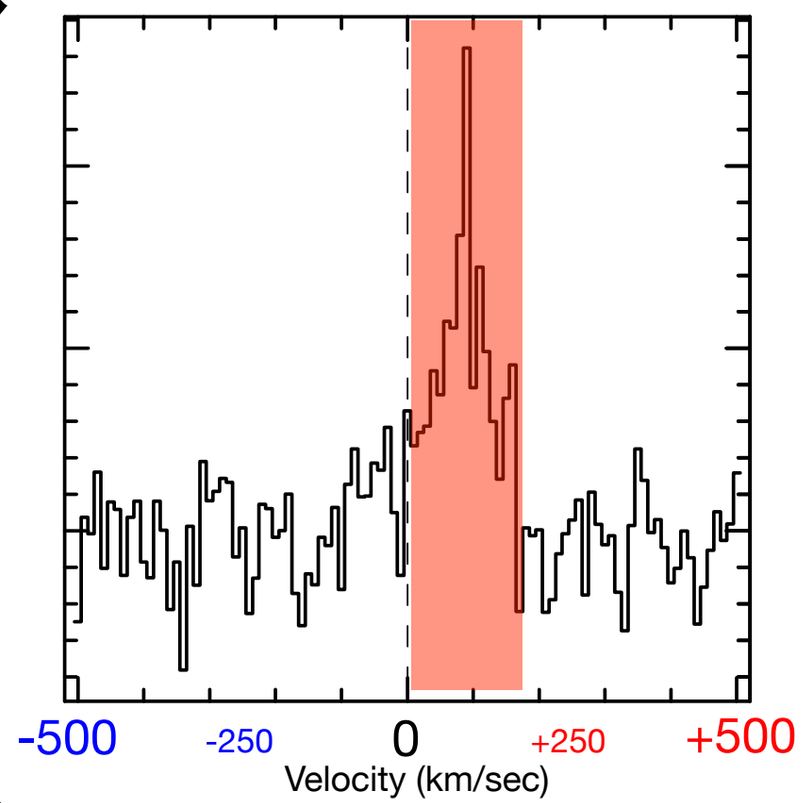
Southern Filaments

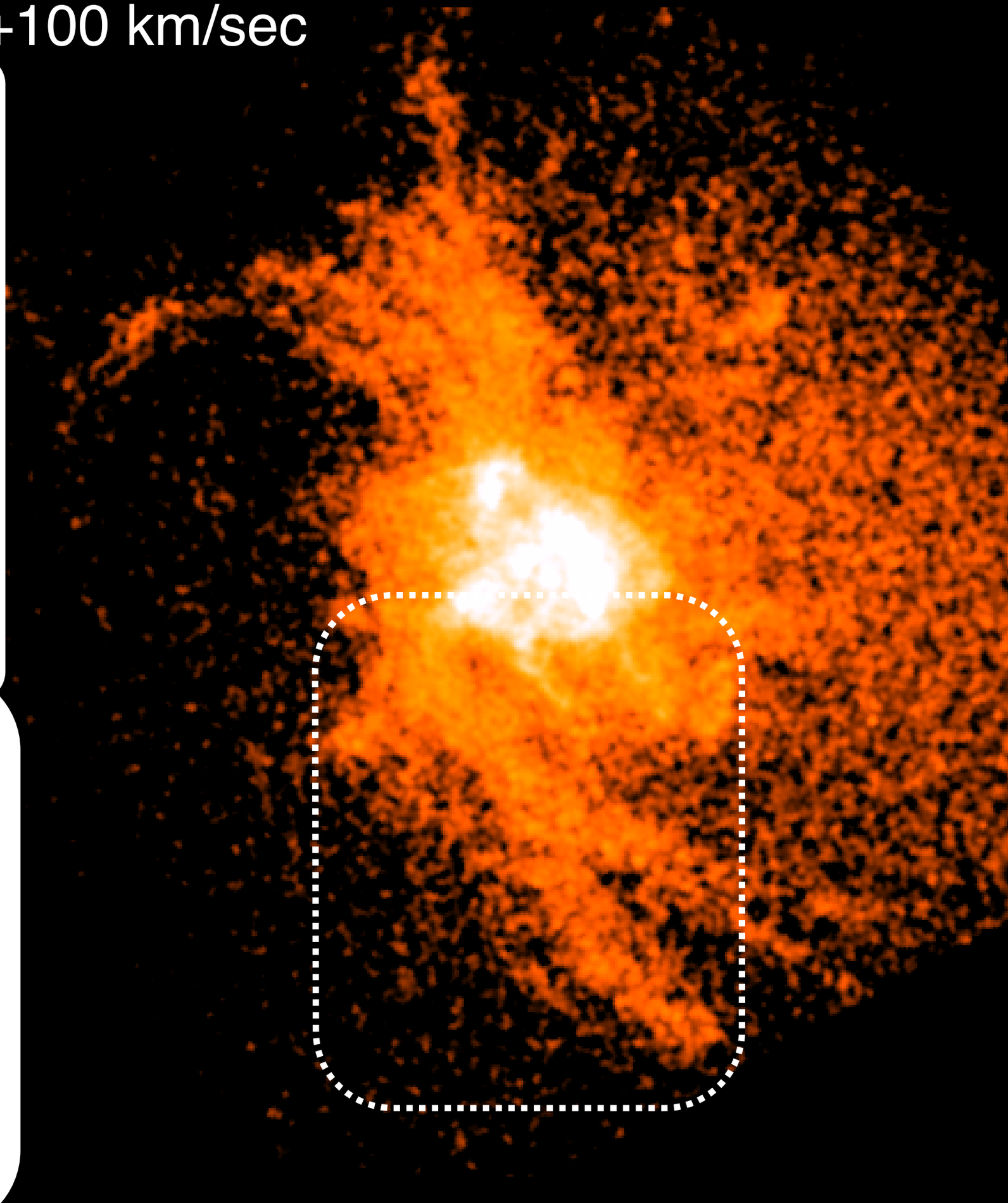




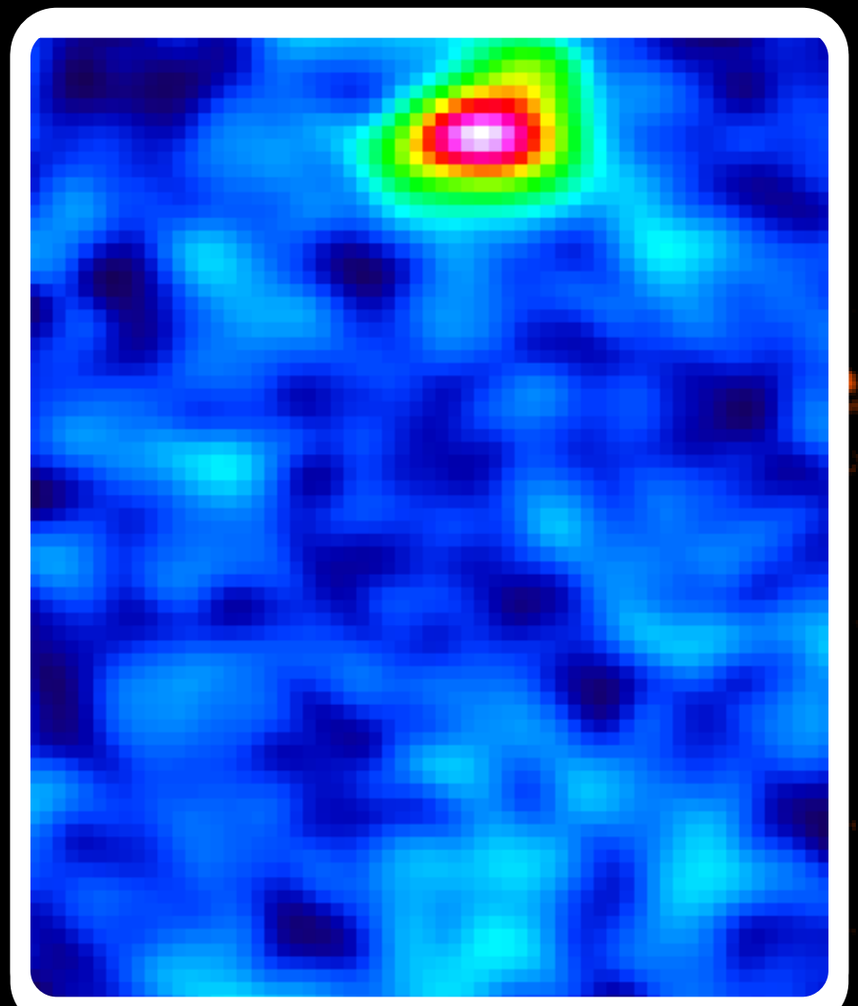
Southern Filaments @ +100 km/sec

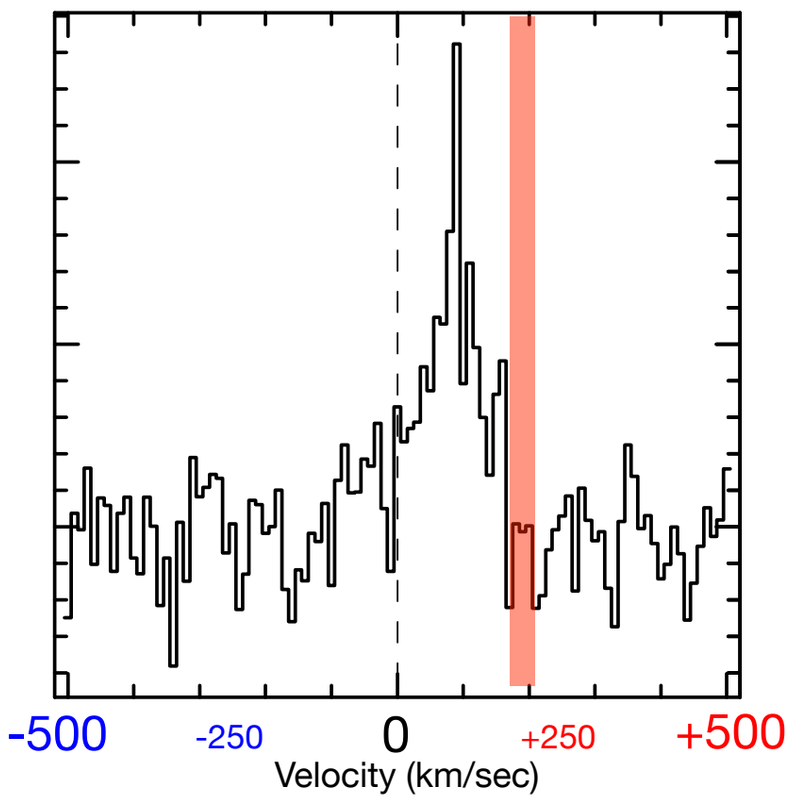


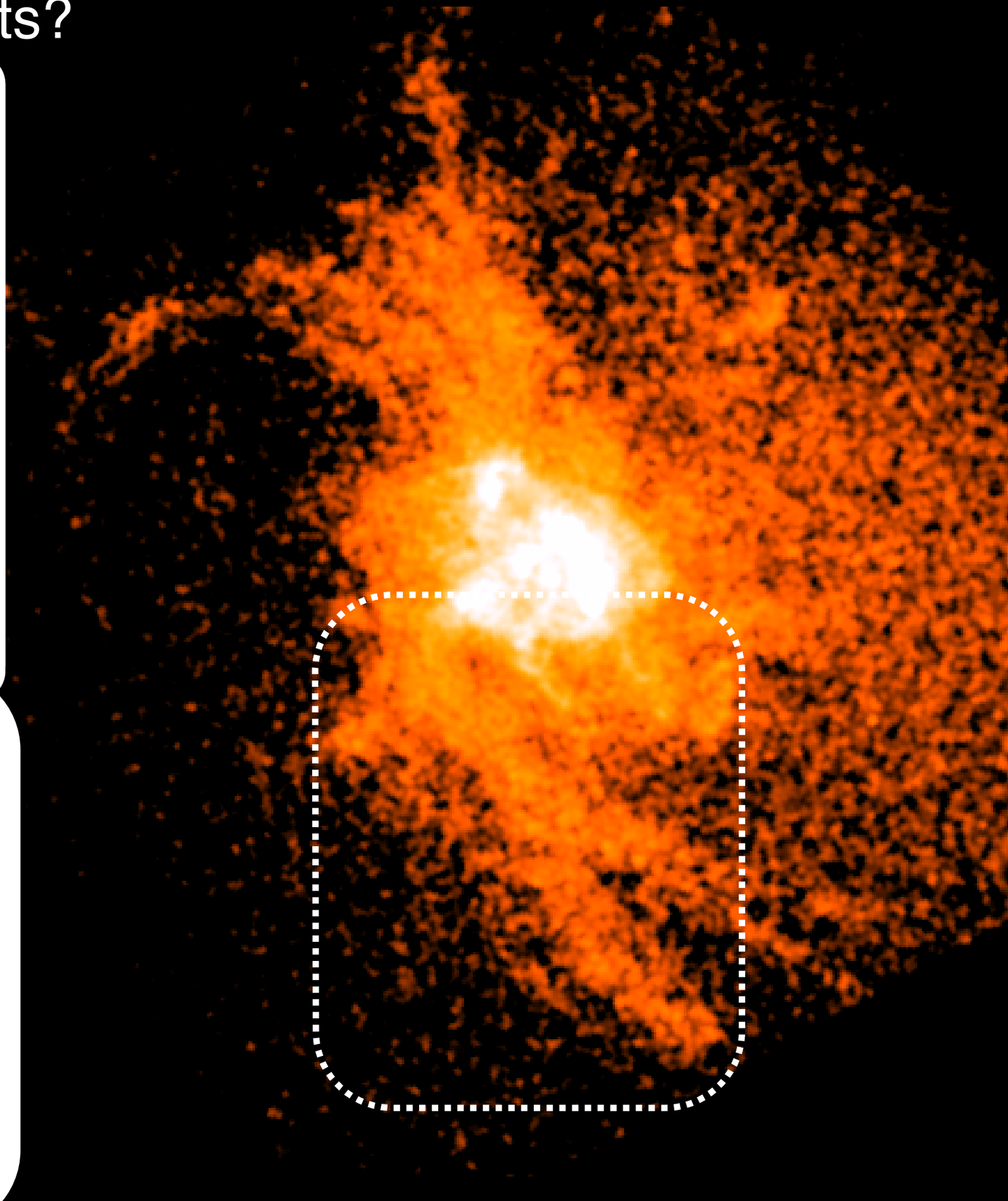




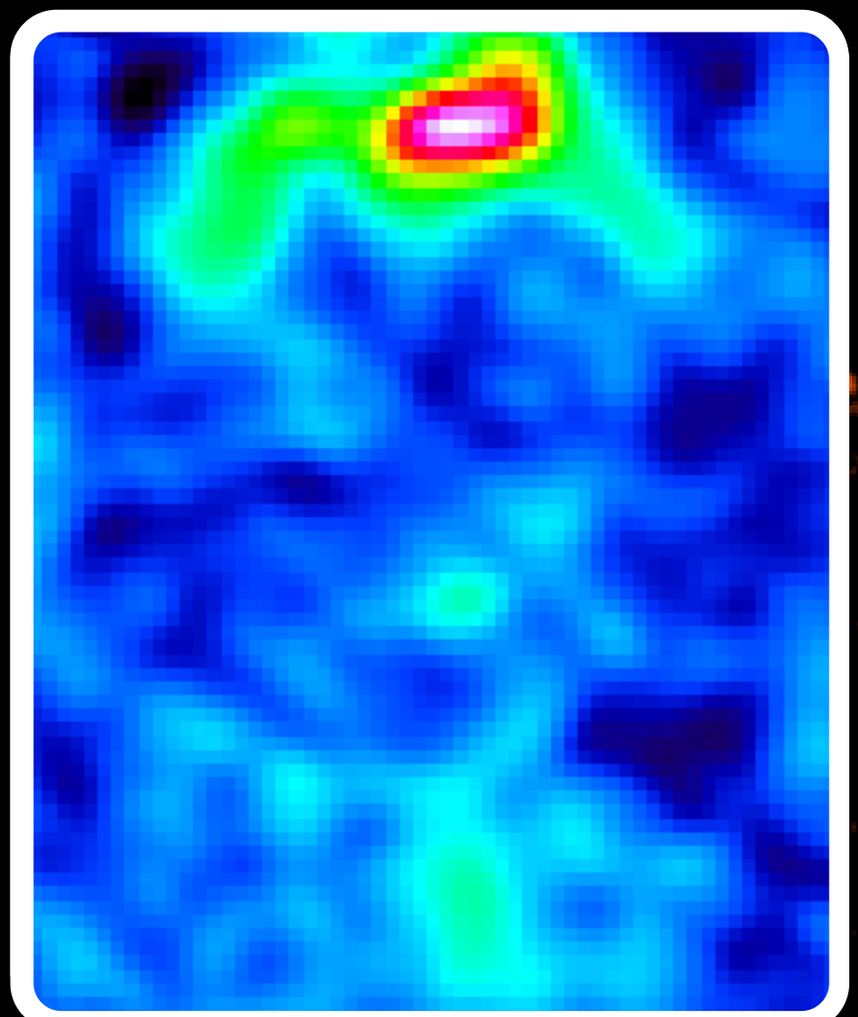
Slow rain down filaments?

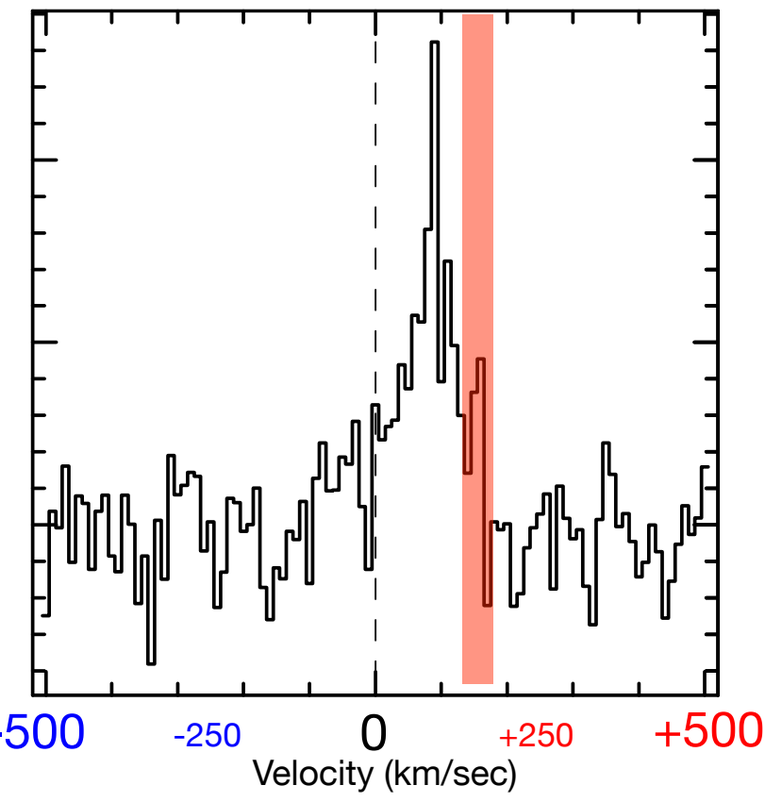




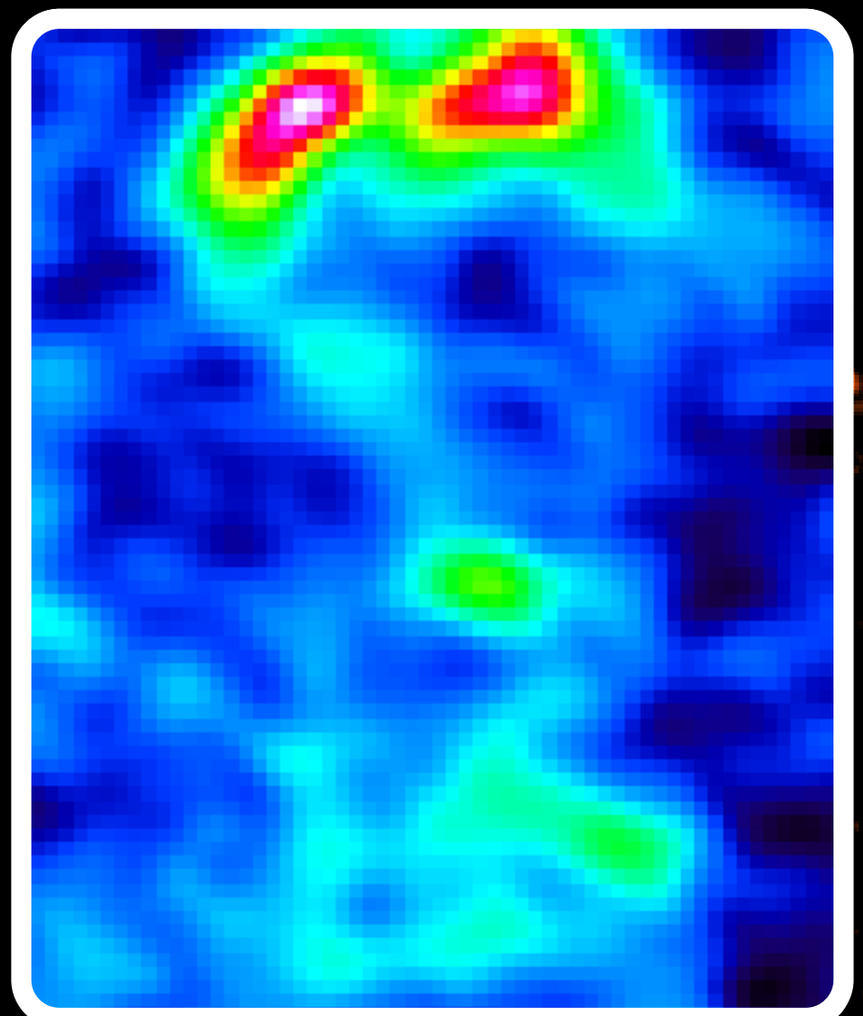


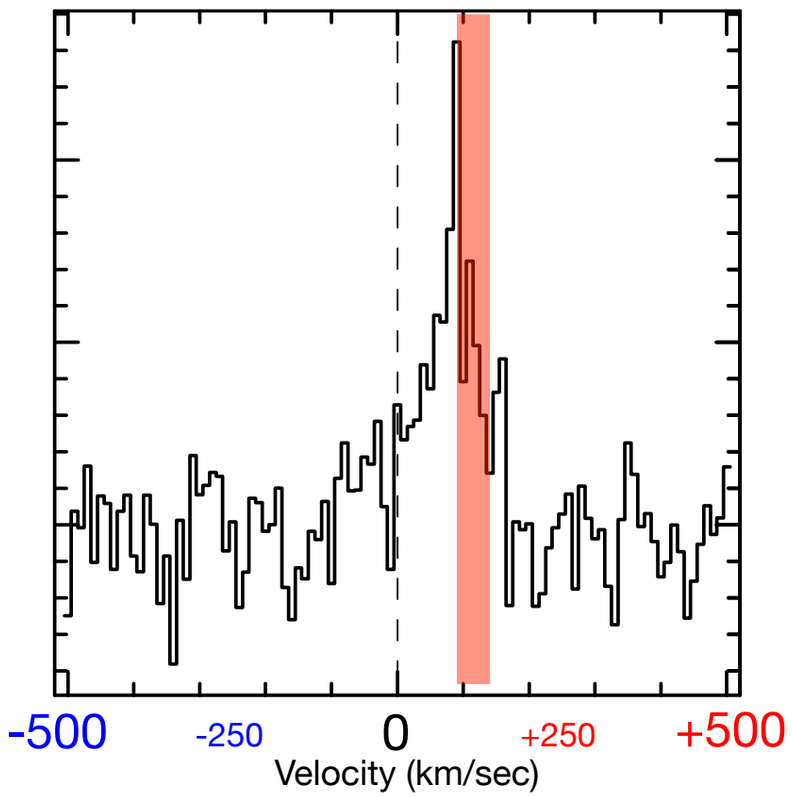
Slow rain down filaments?

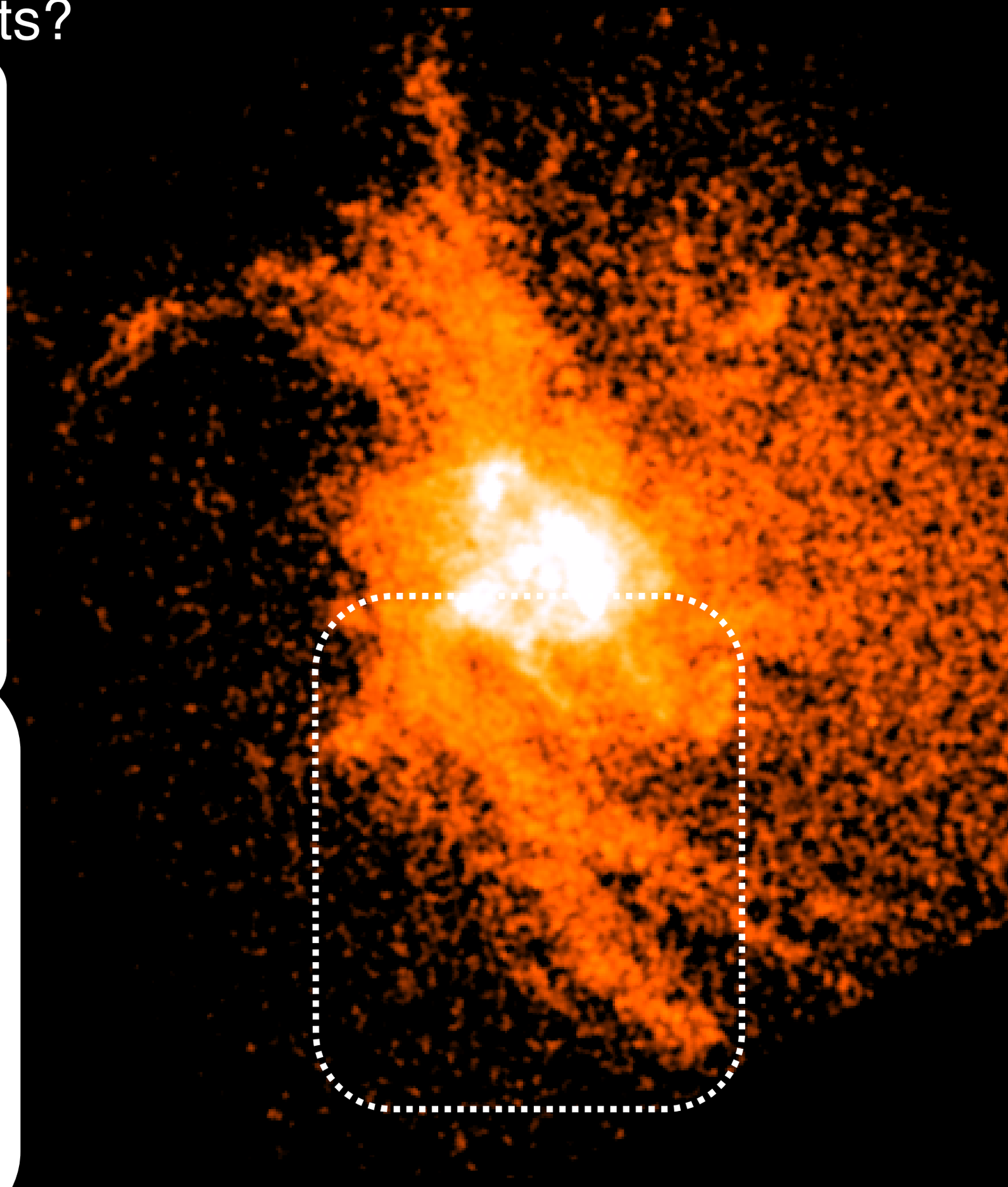




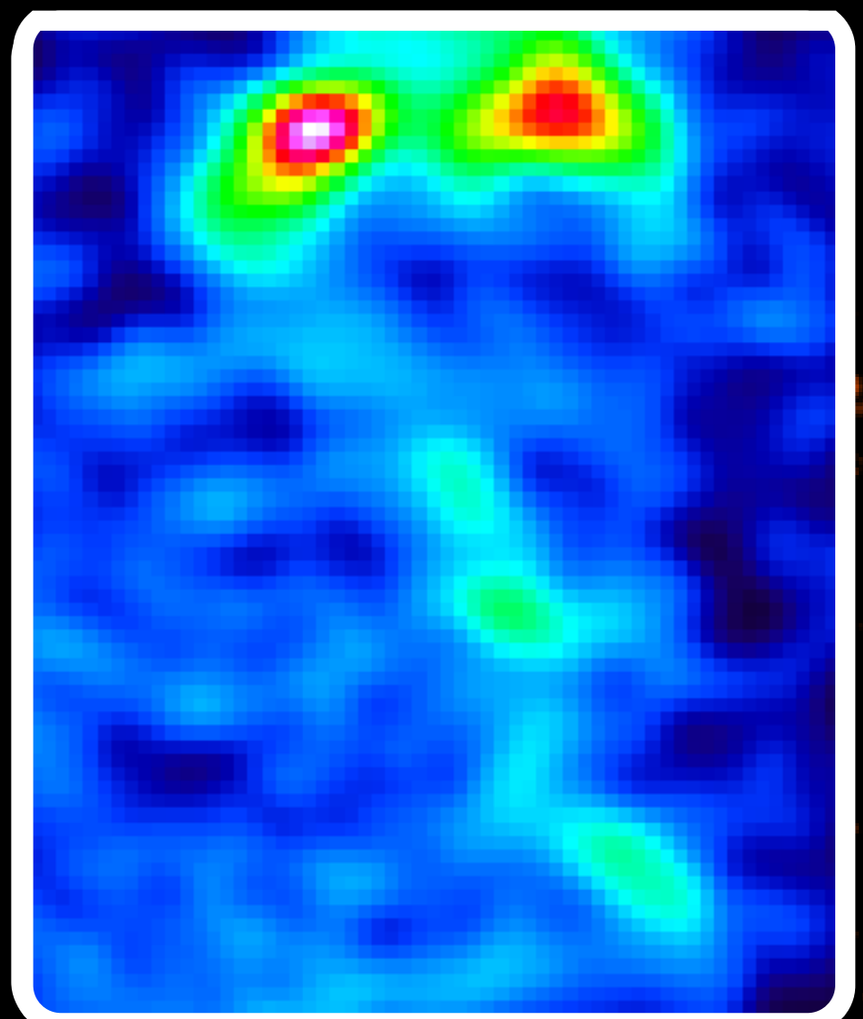
Slow rain down filaments?

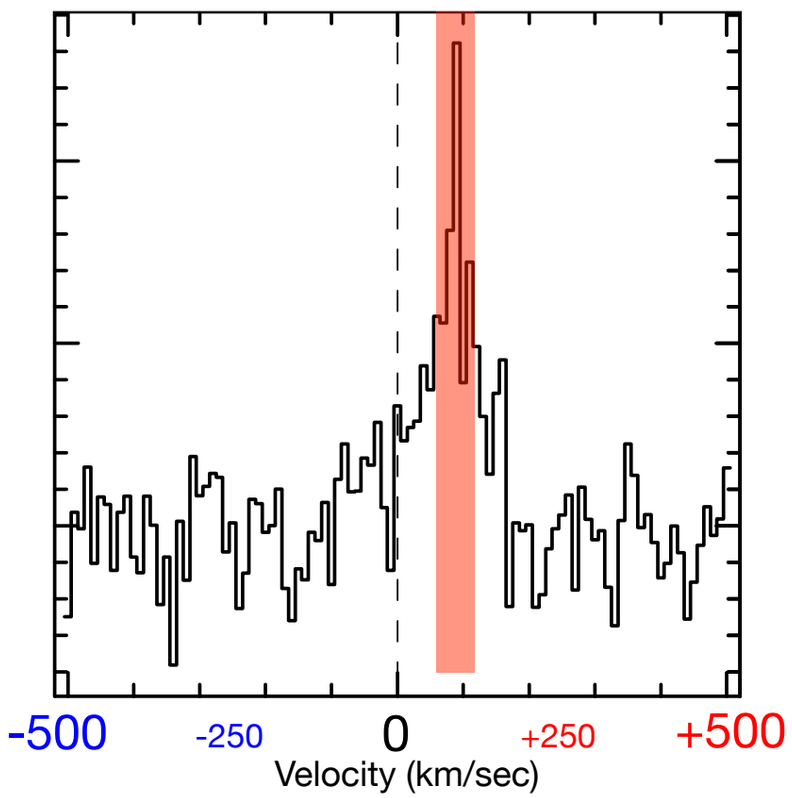


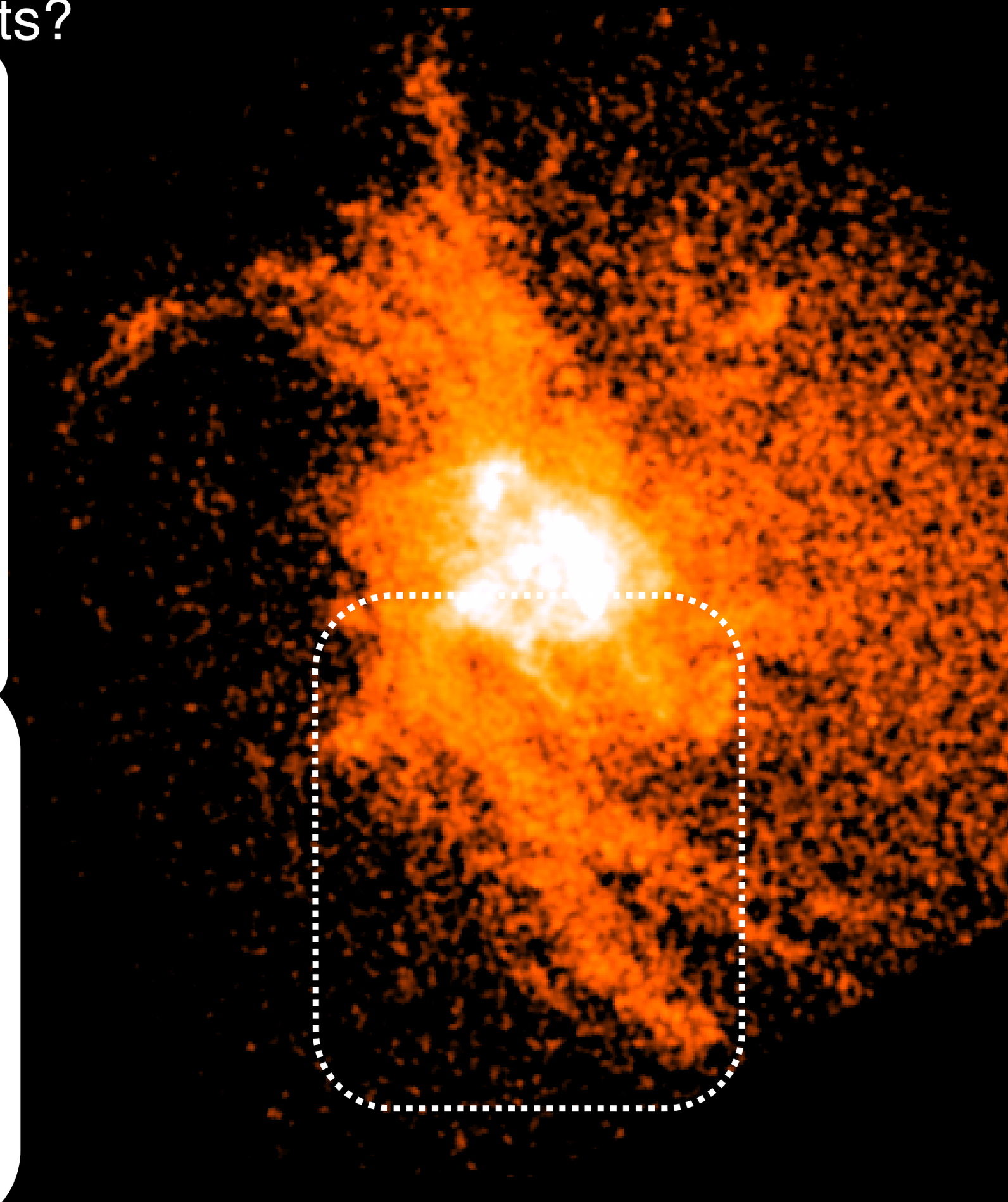




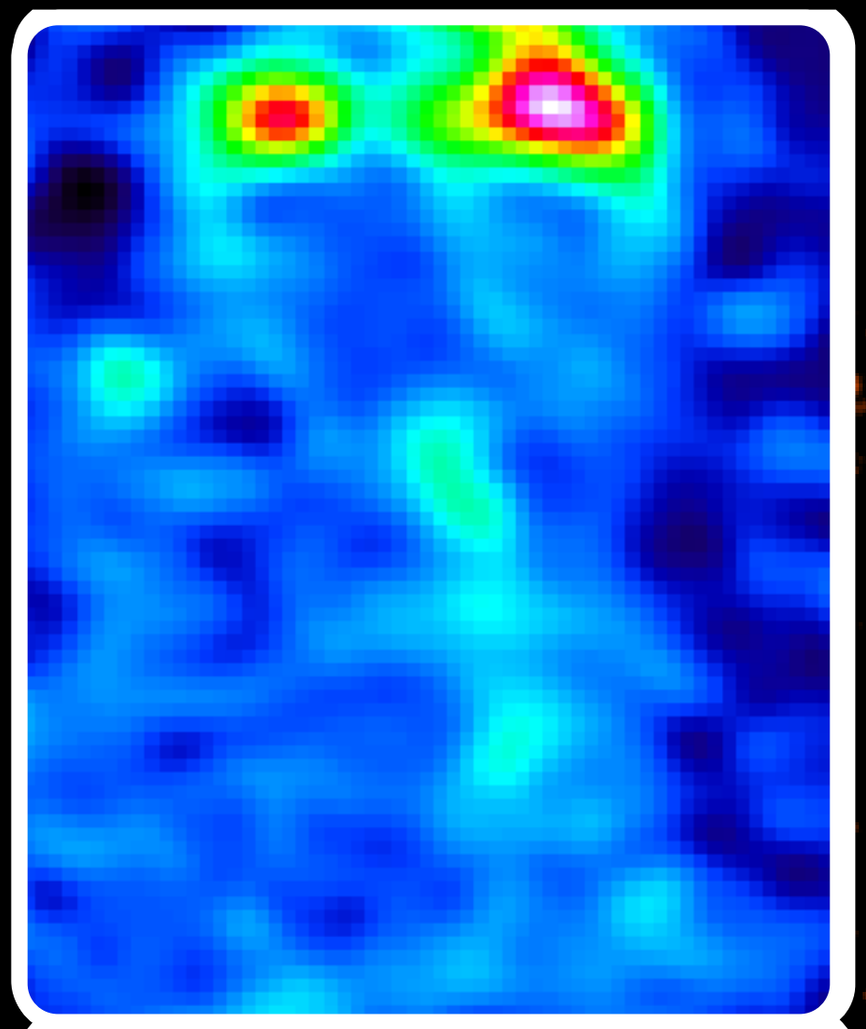
Slow rain down filaments?

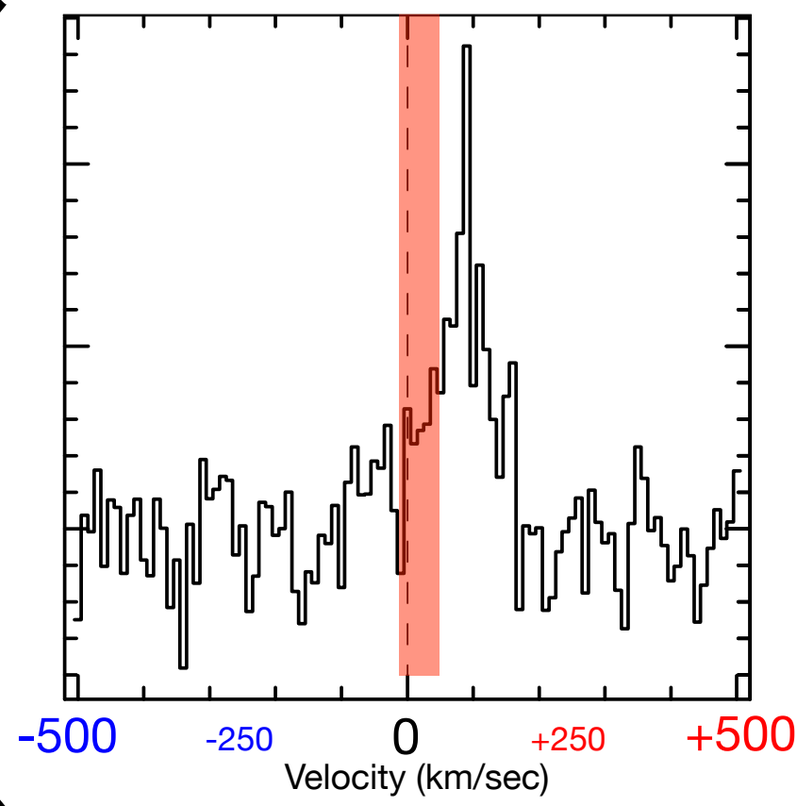


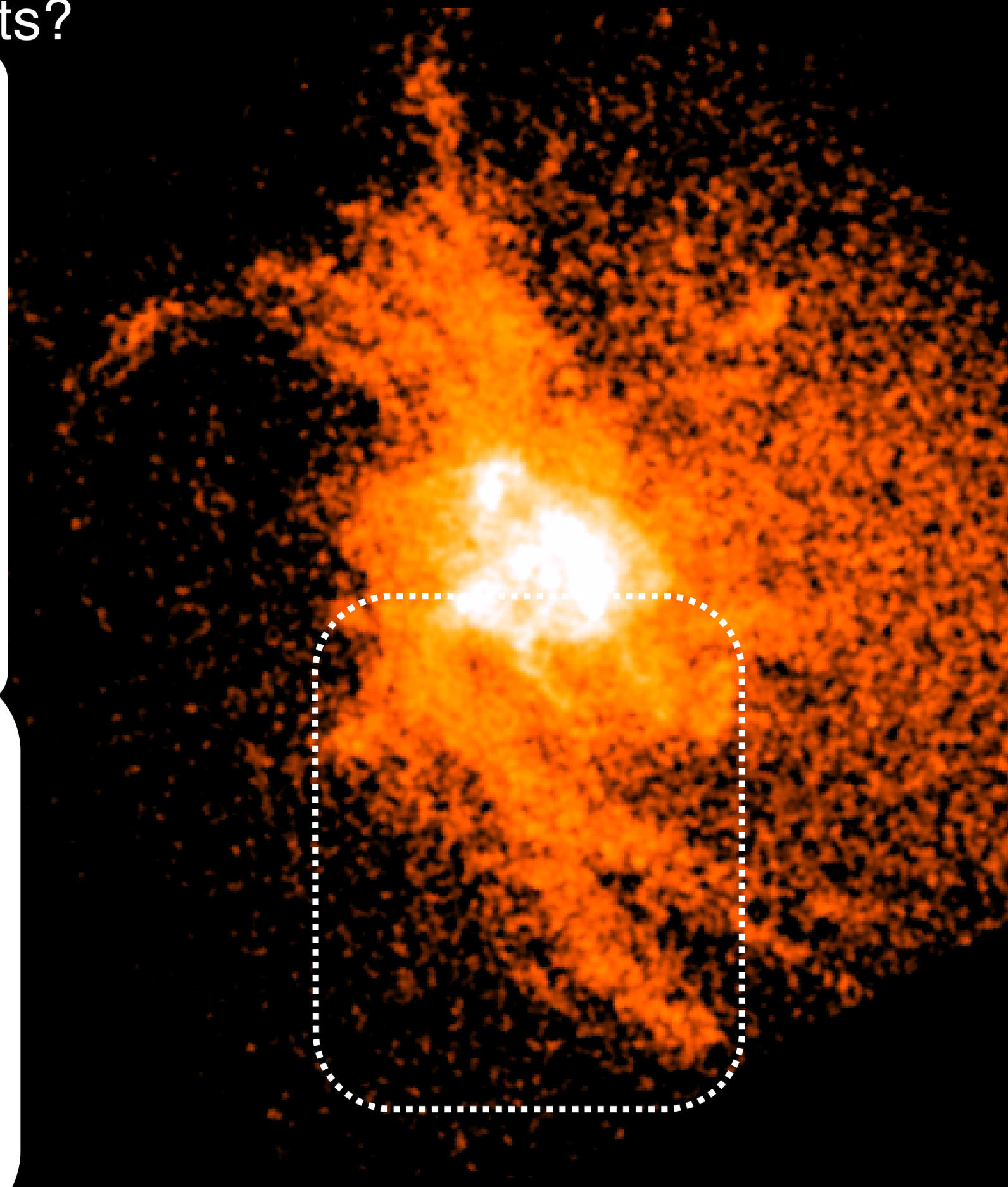




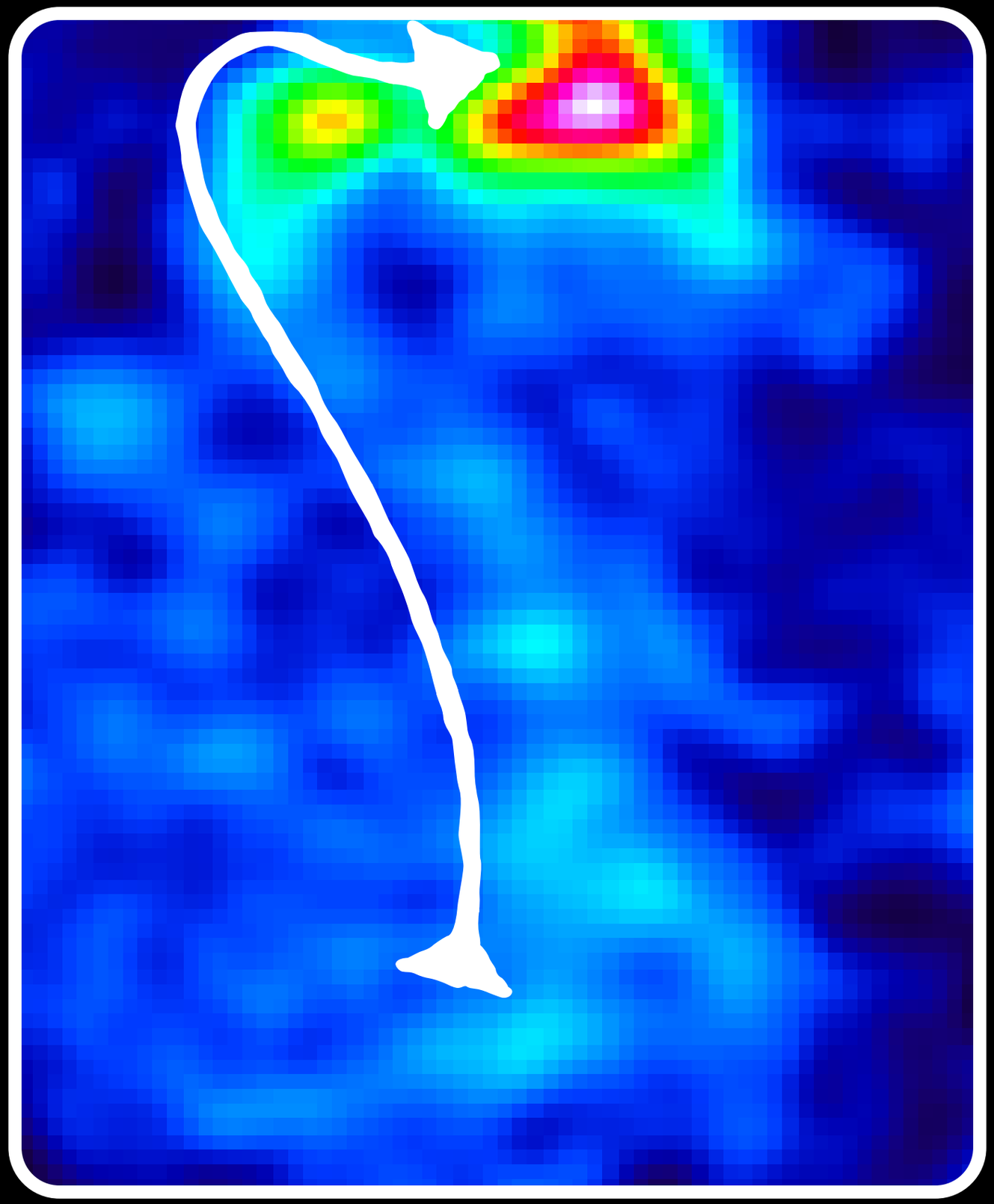
Slow rain down filaments?

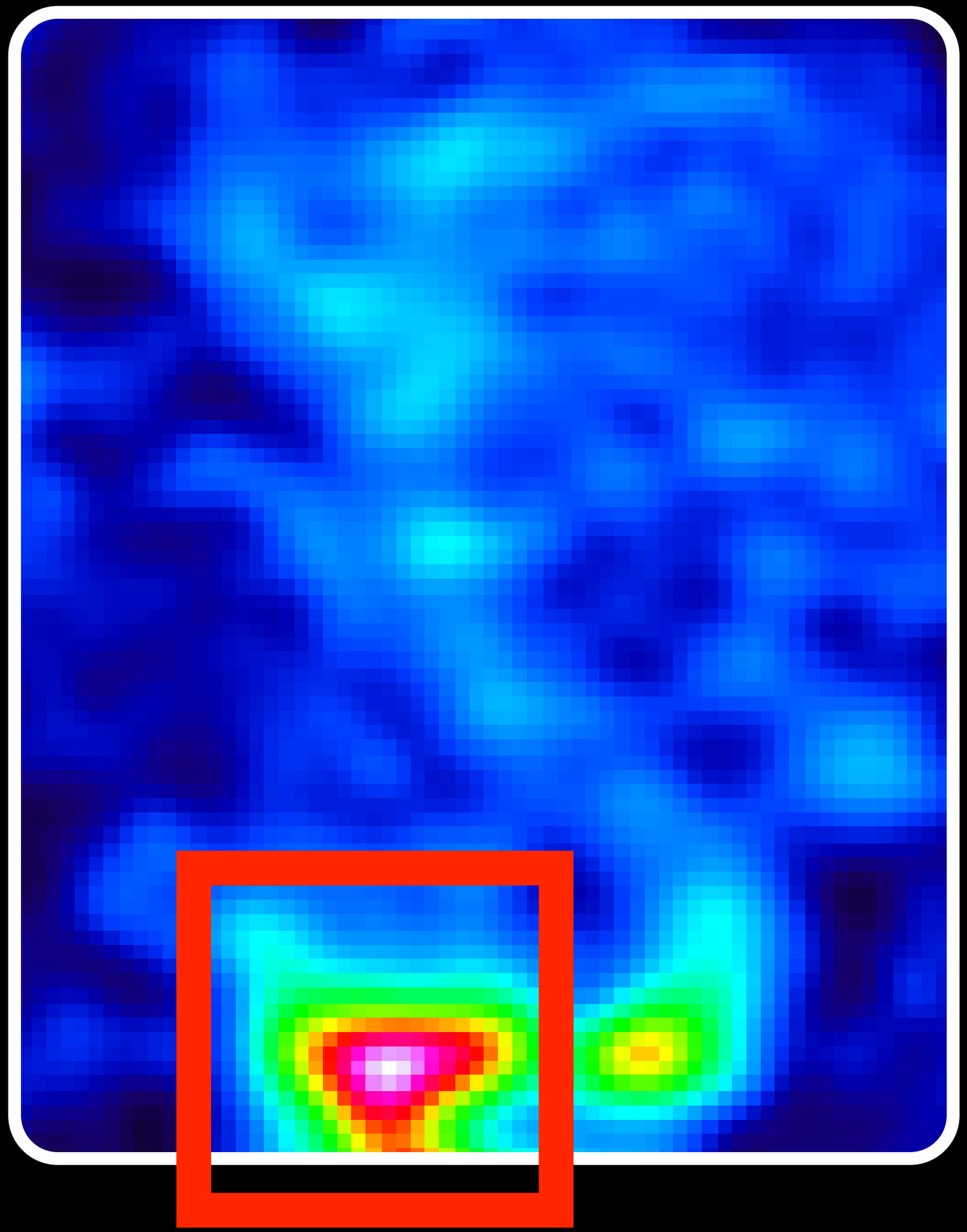


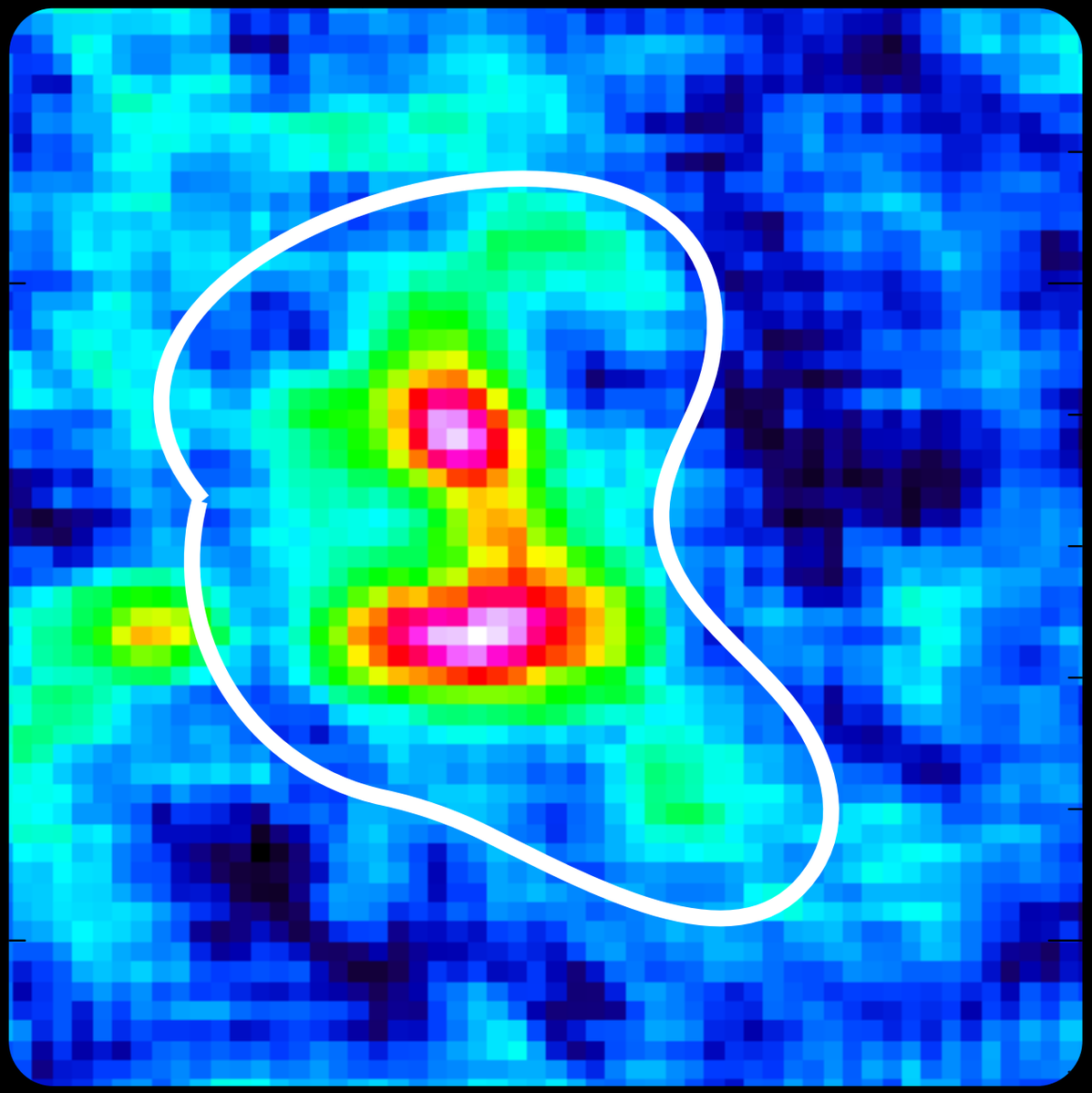


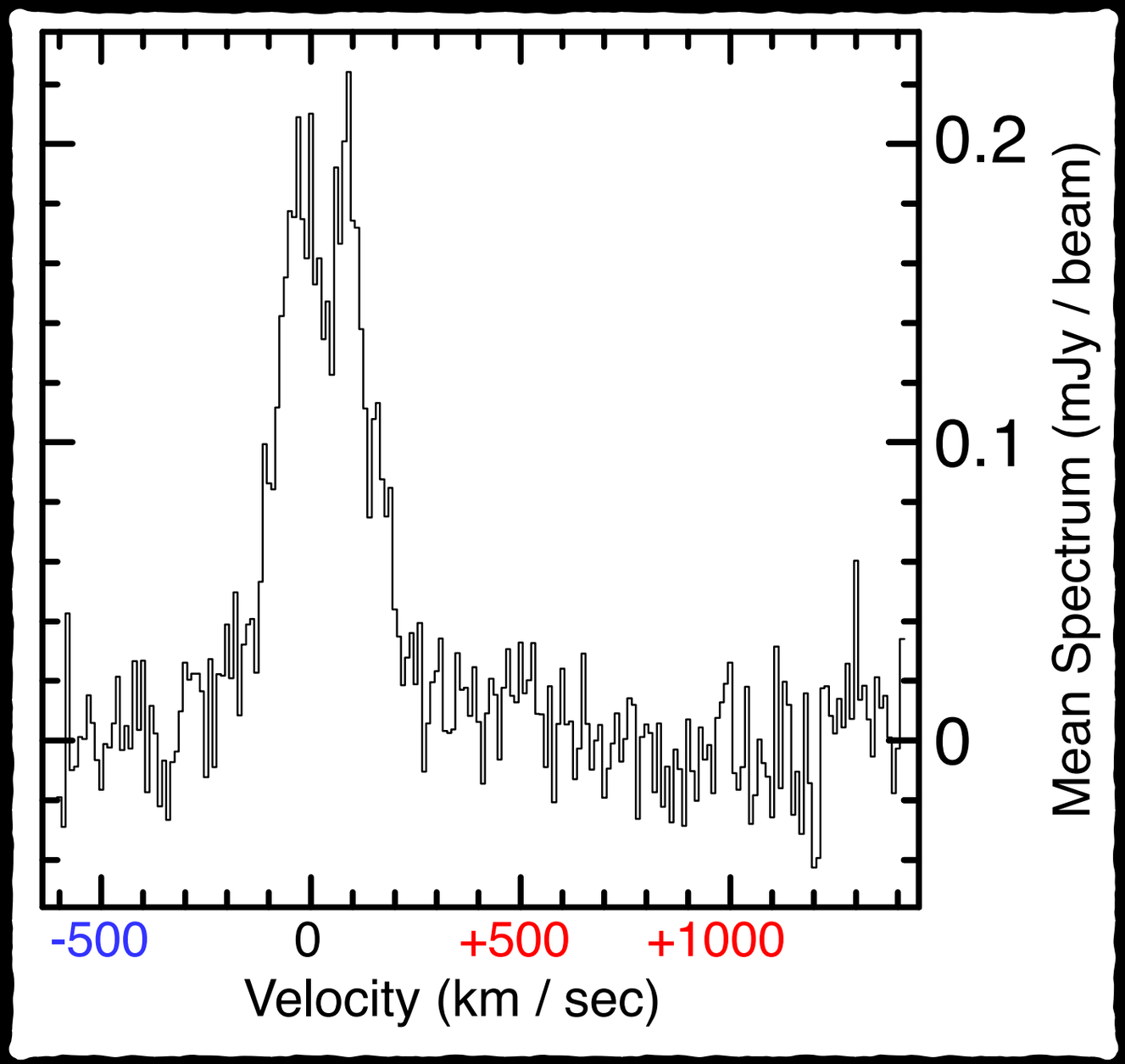


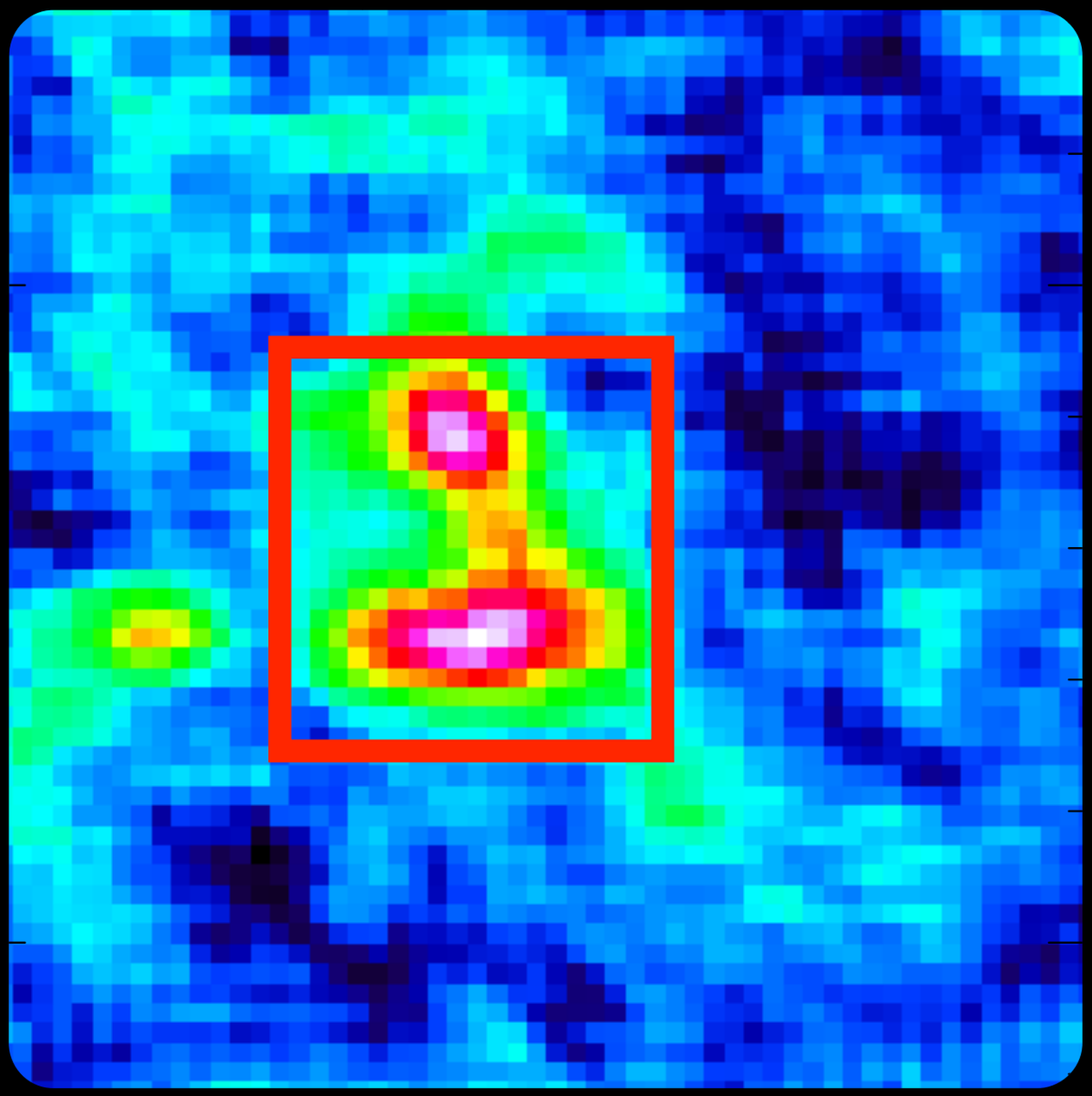
Slow drizzle down the filaments

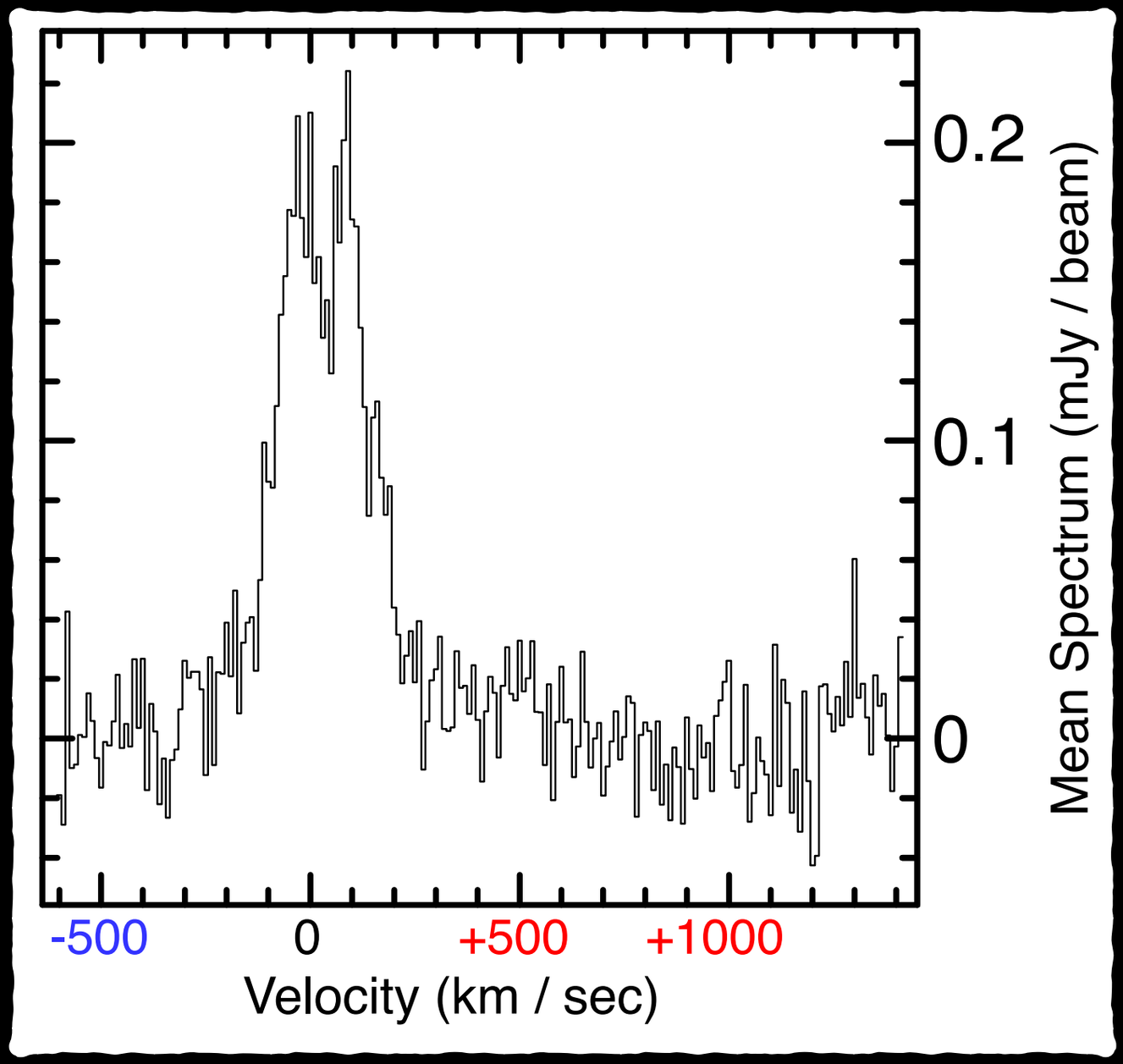


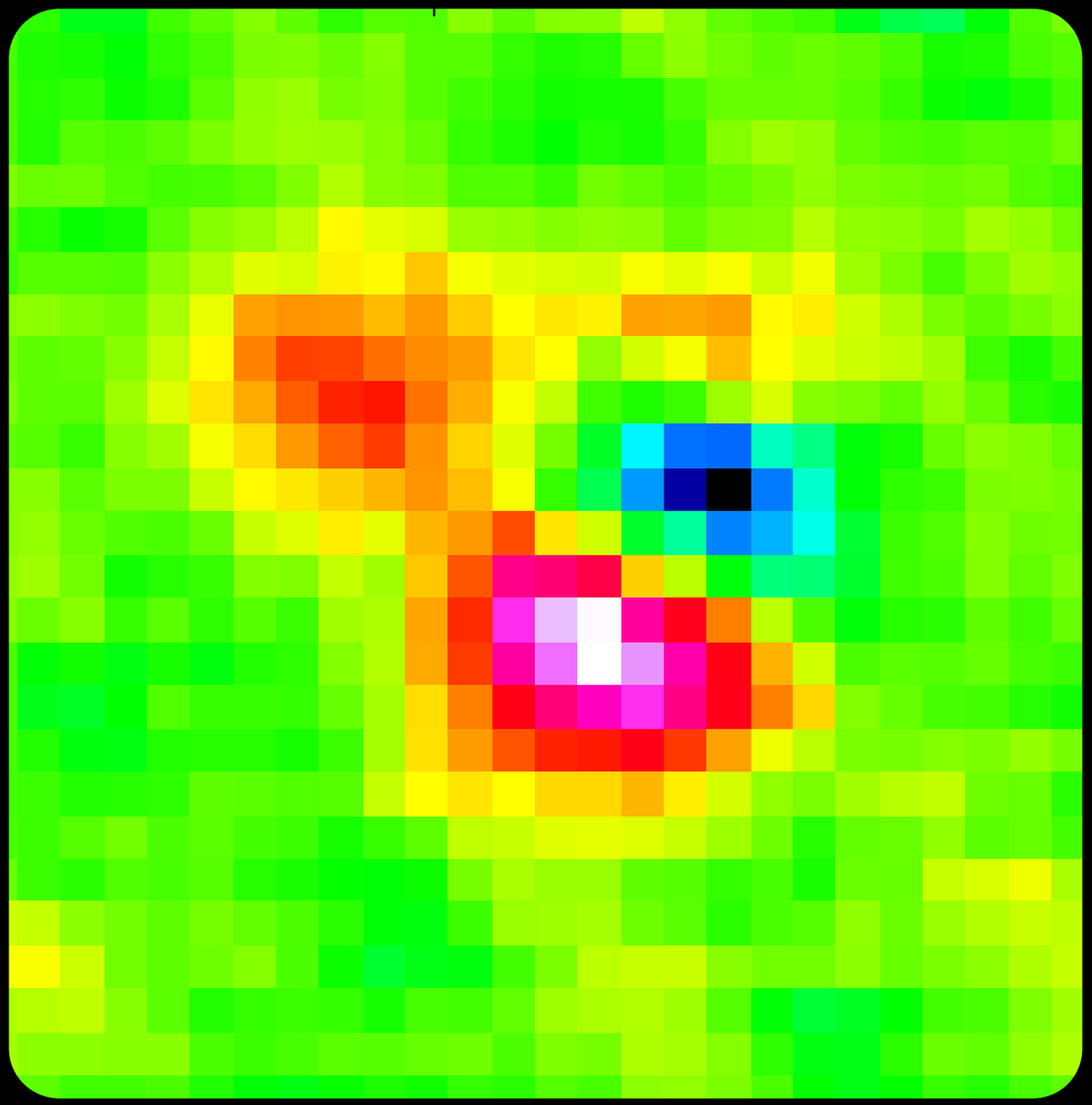


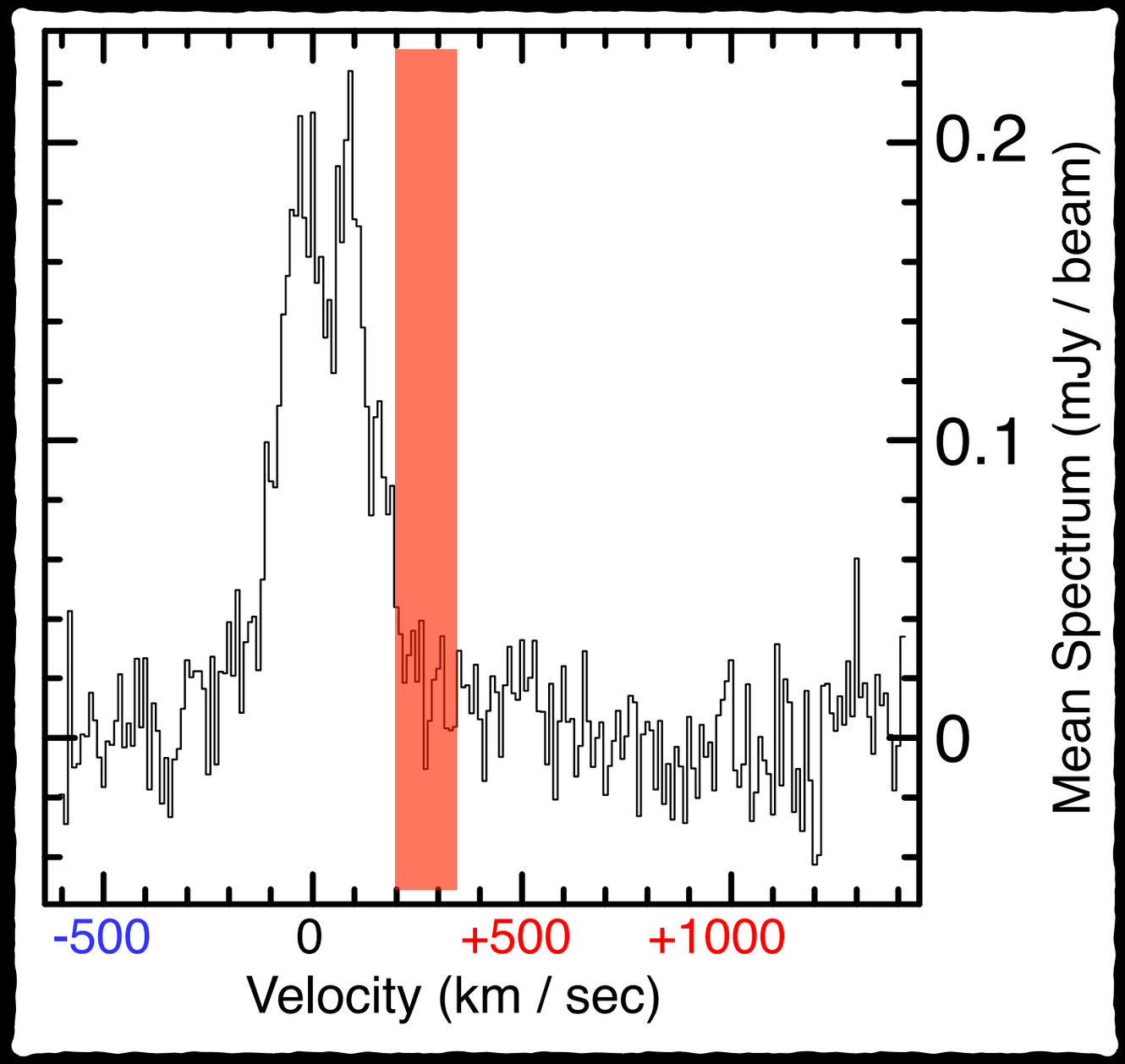


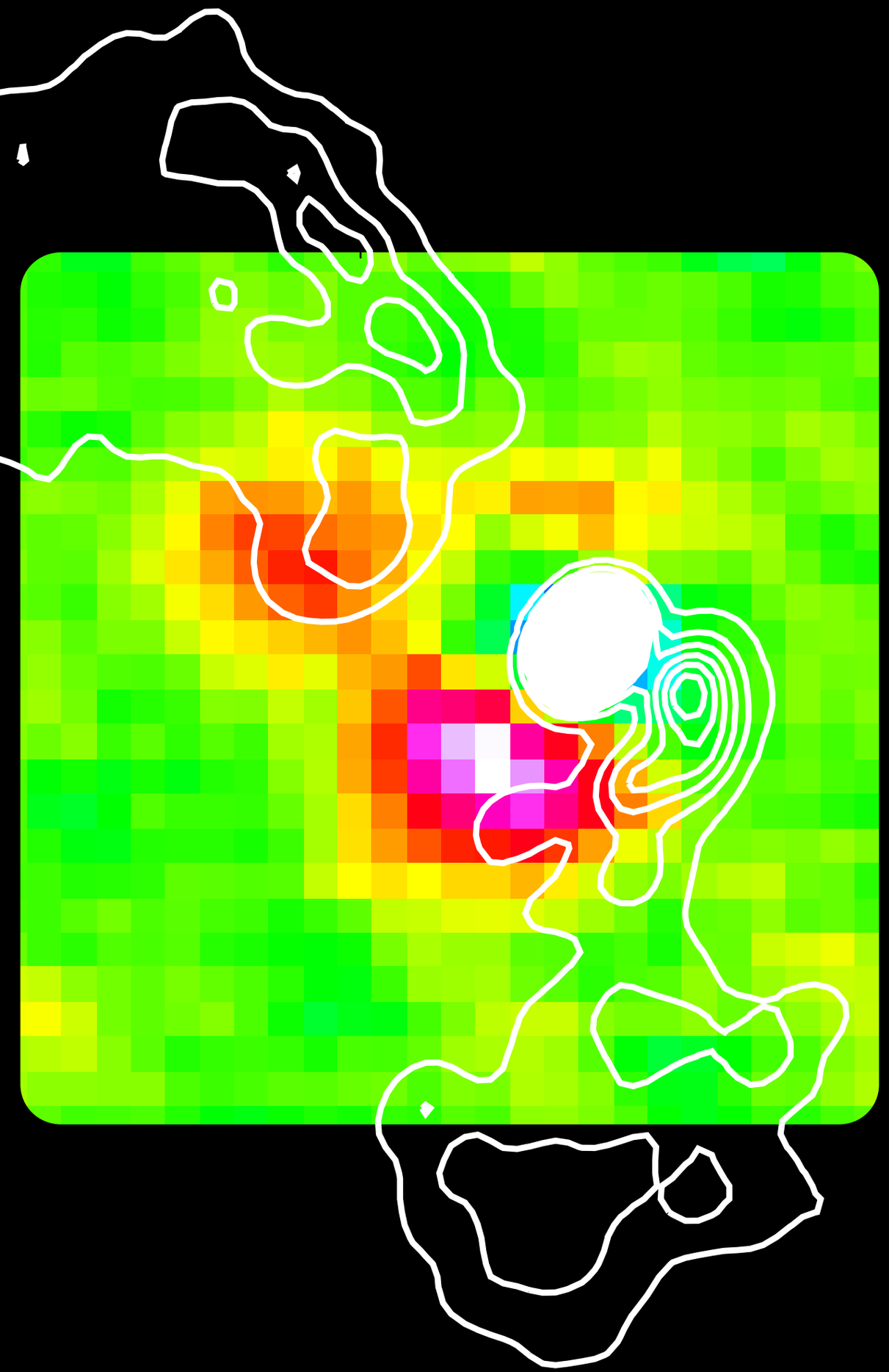

0.2
0.1
0
Mean Spectrum (mJy / beam)
-500
0
+500
+1000
Velocity (km / sec)

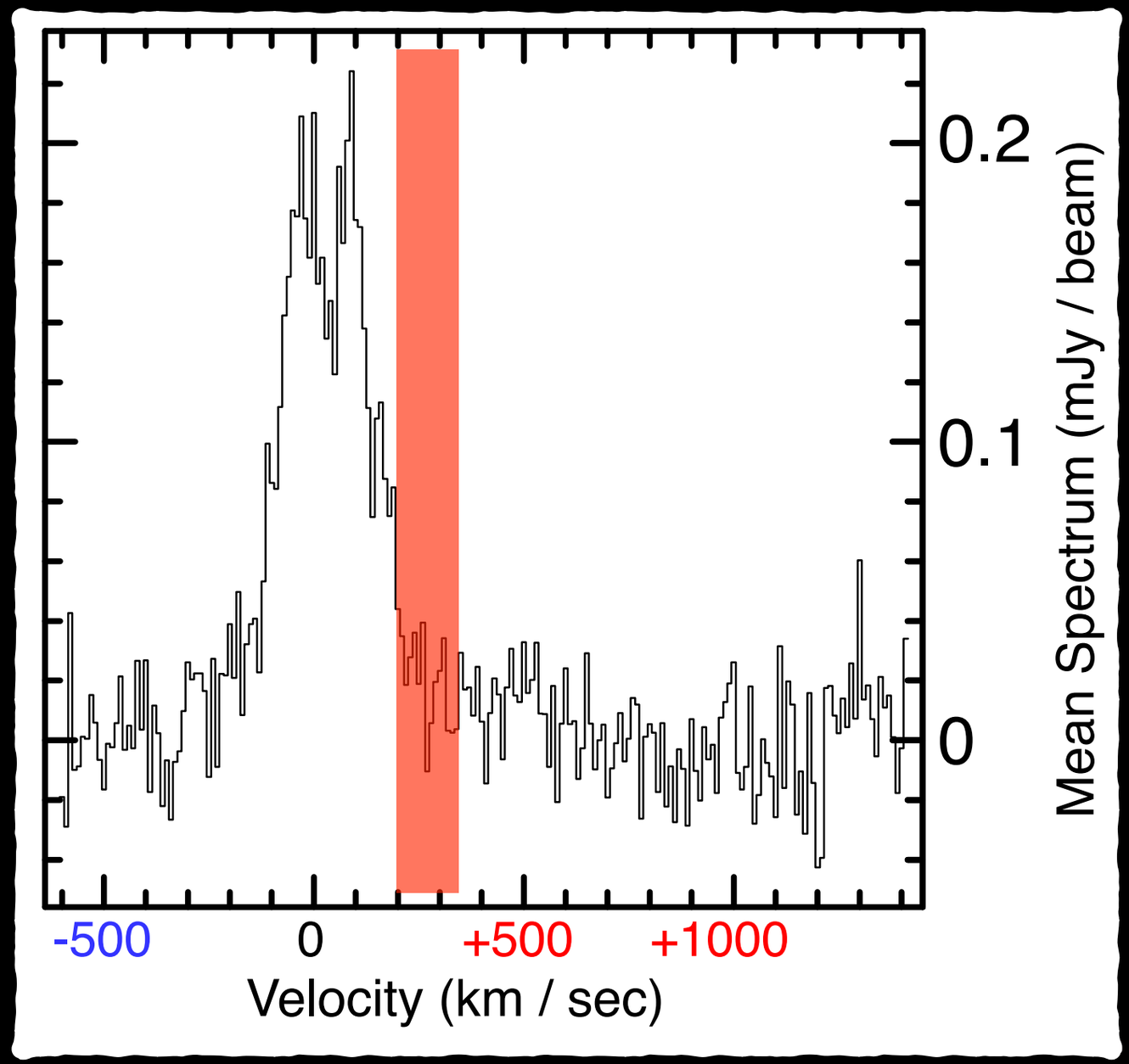


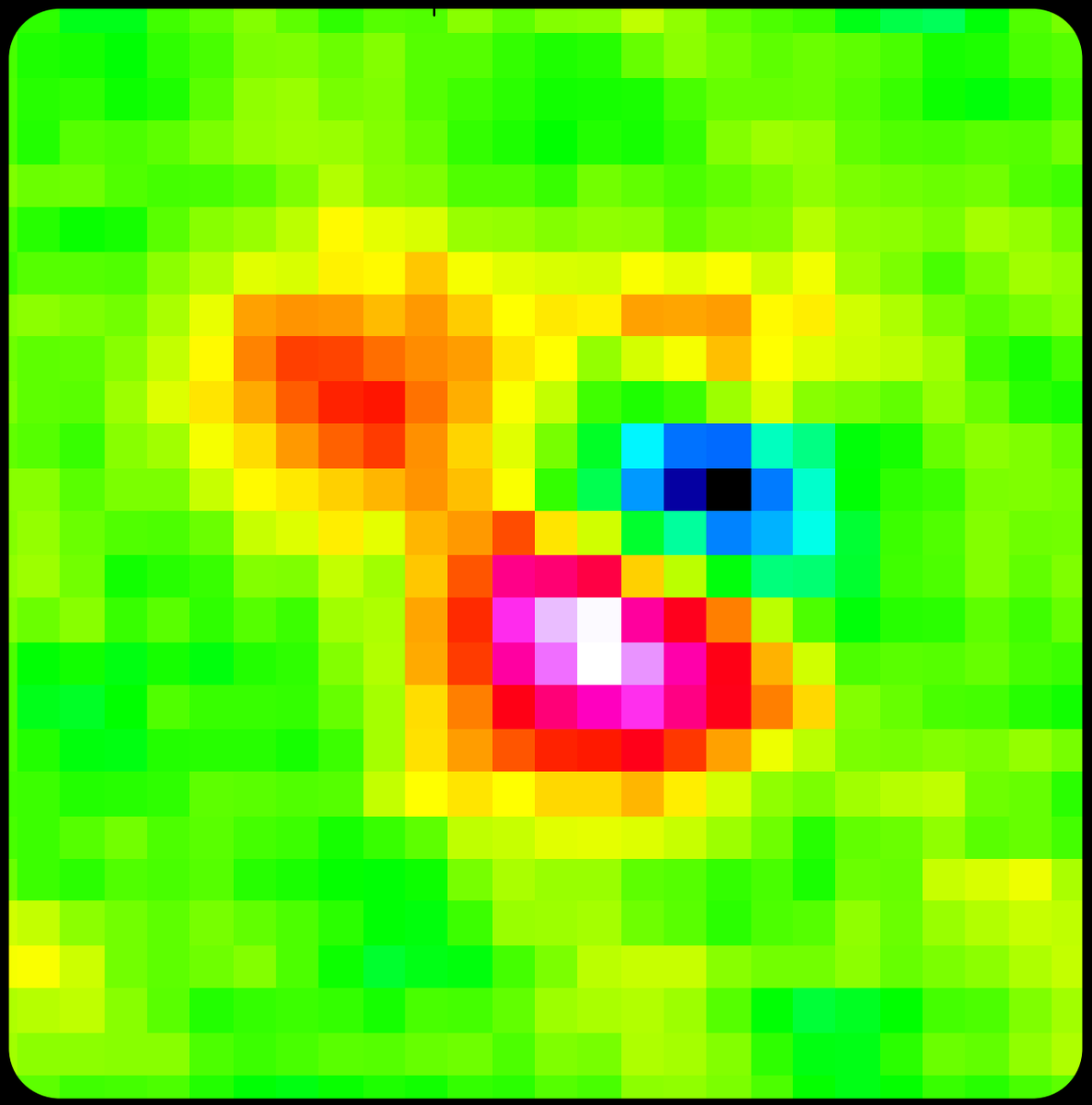

0.2
0.1
0
Mean Spectrum (mJy / beam)
-500
0
+500
+1000
Velocity (km / sec)

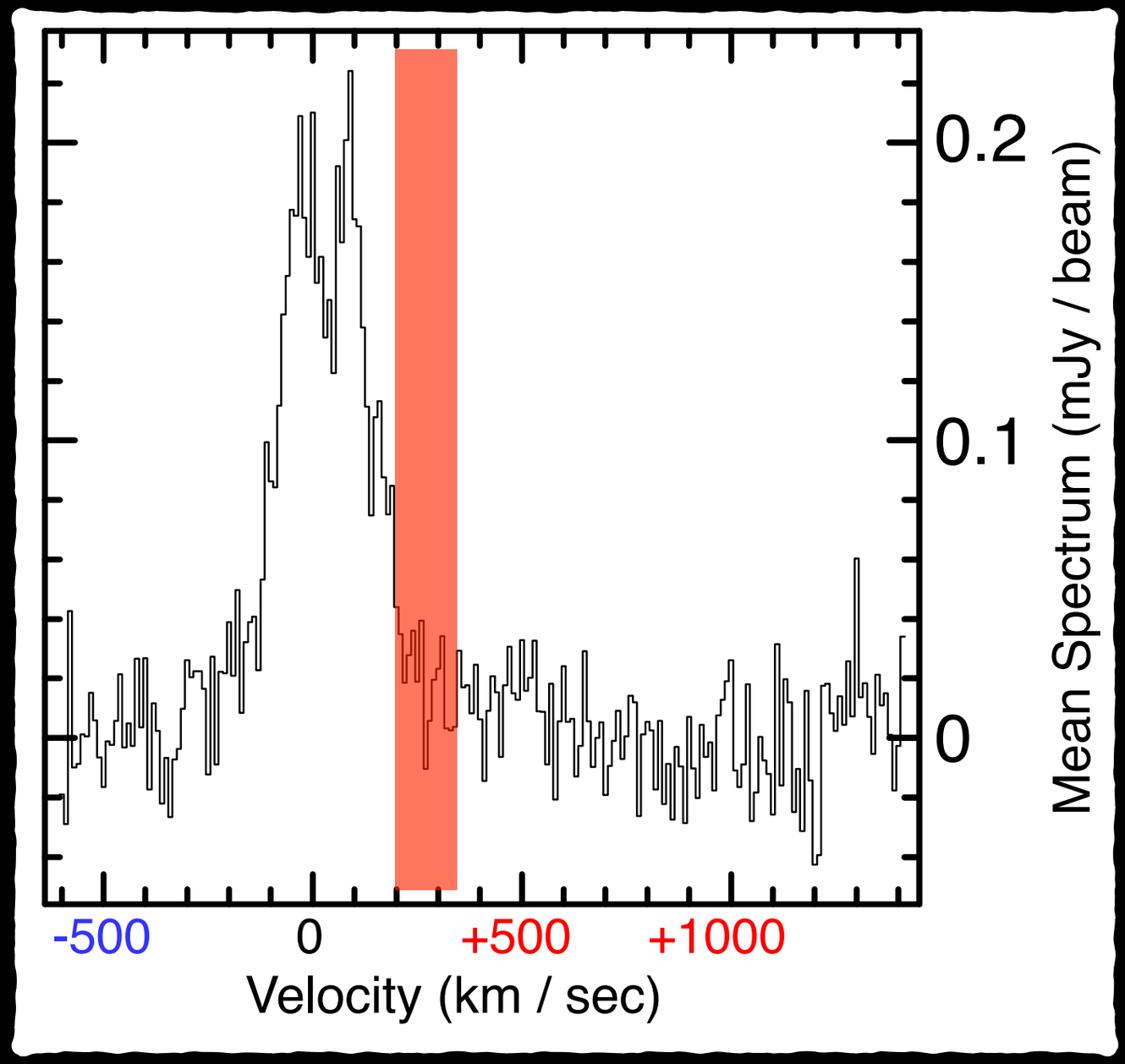


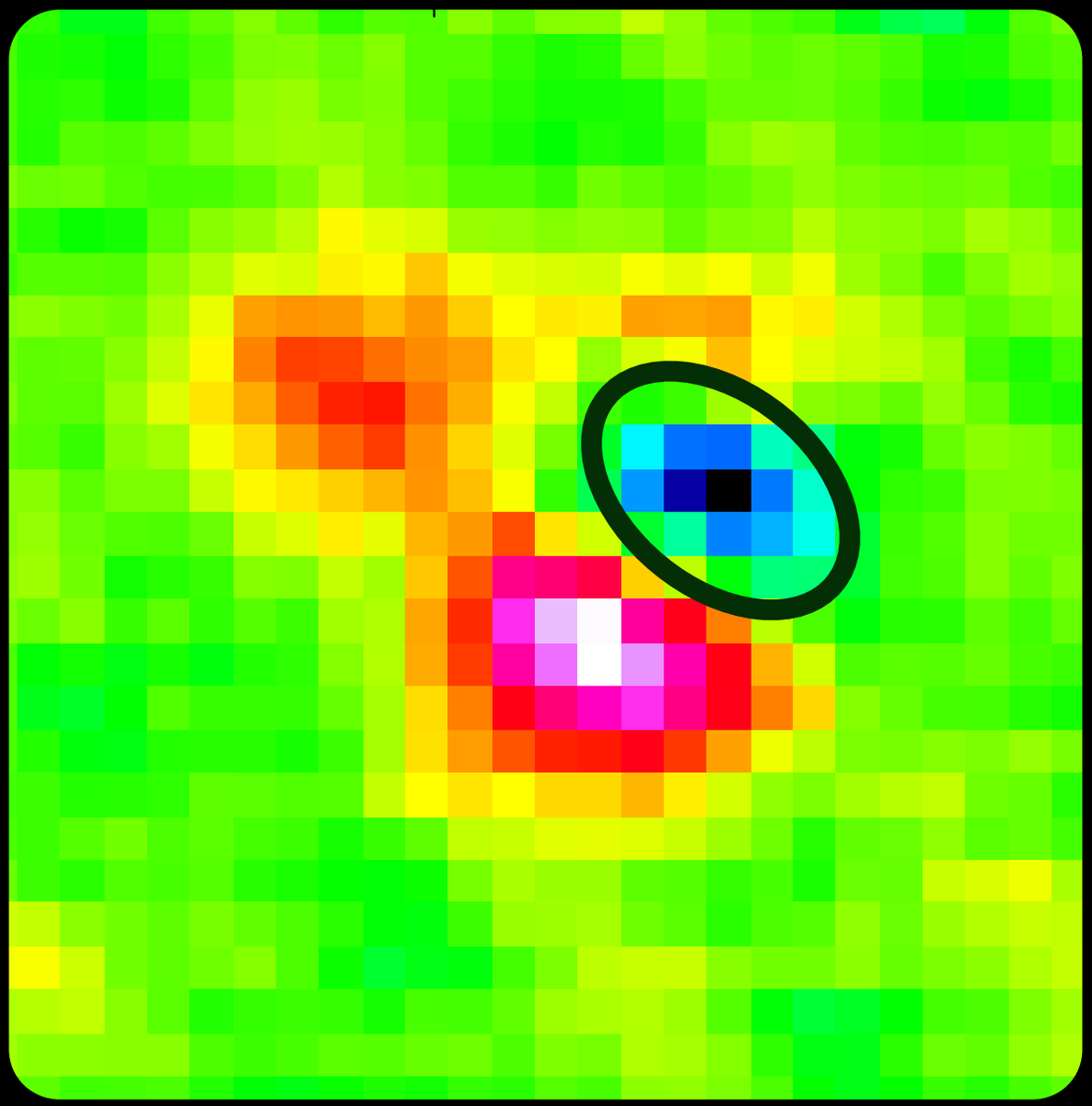

0.2
0.1
0
Mean Spectrum (mJy / beam)
-500
0
+500
+1000
Velocity (km / sec)

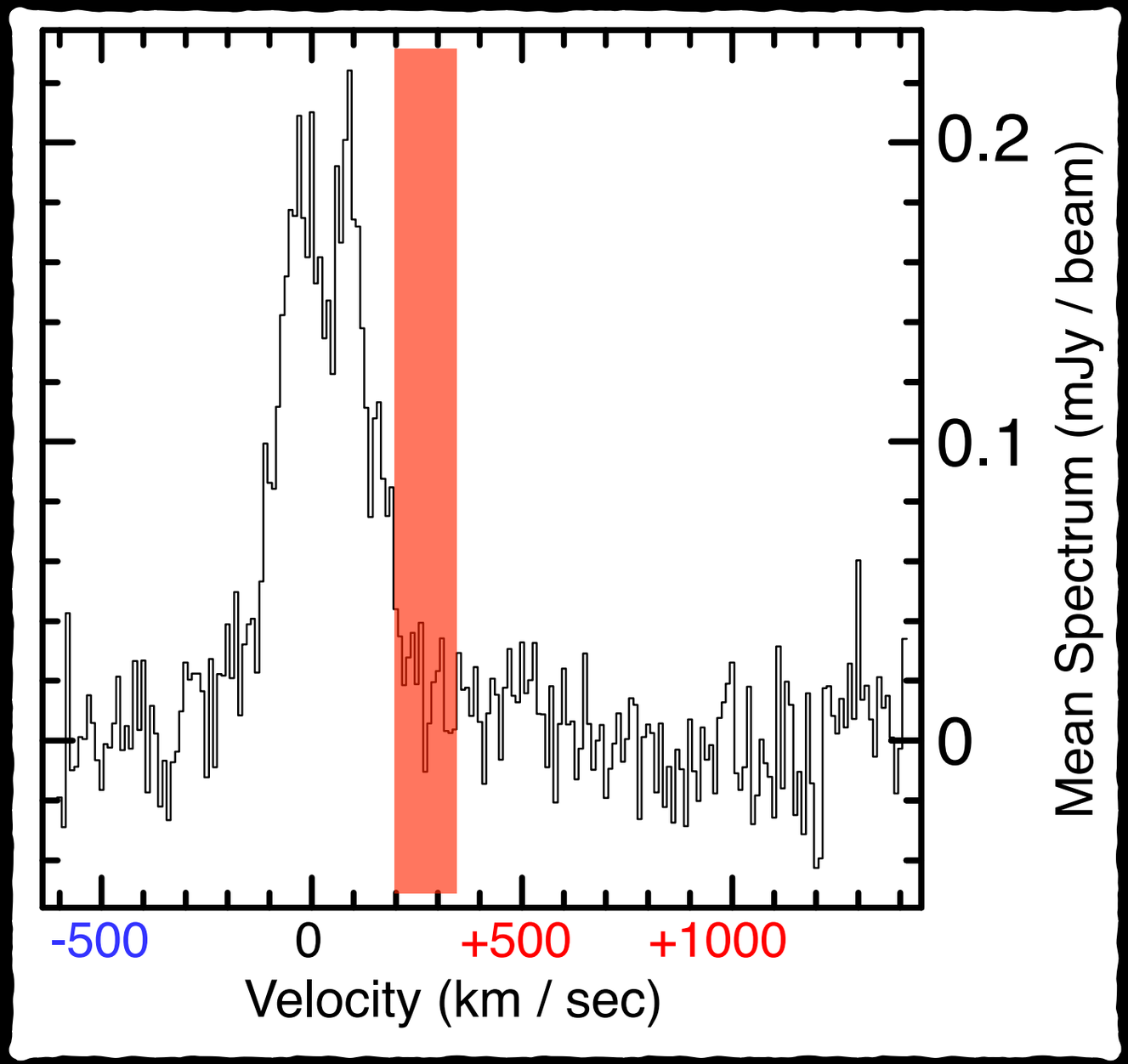


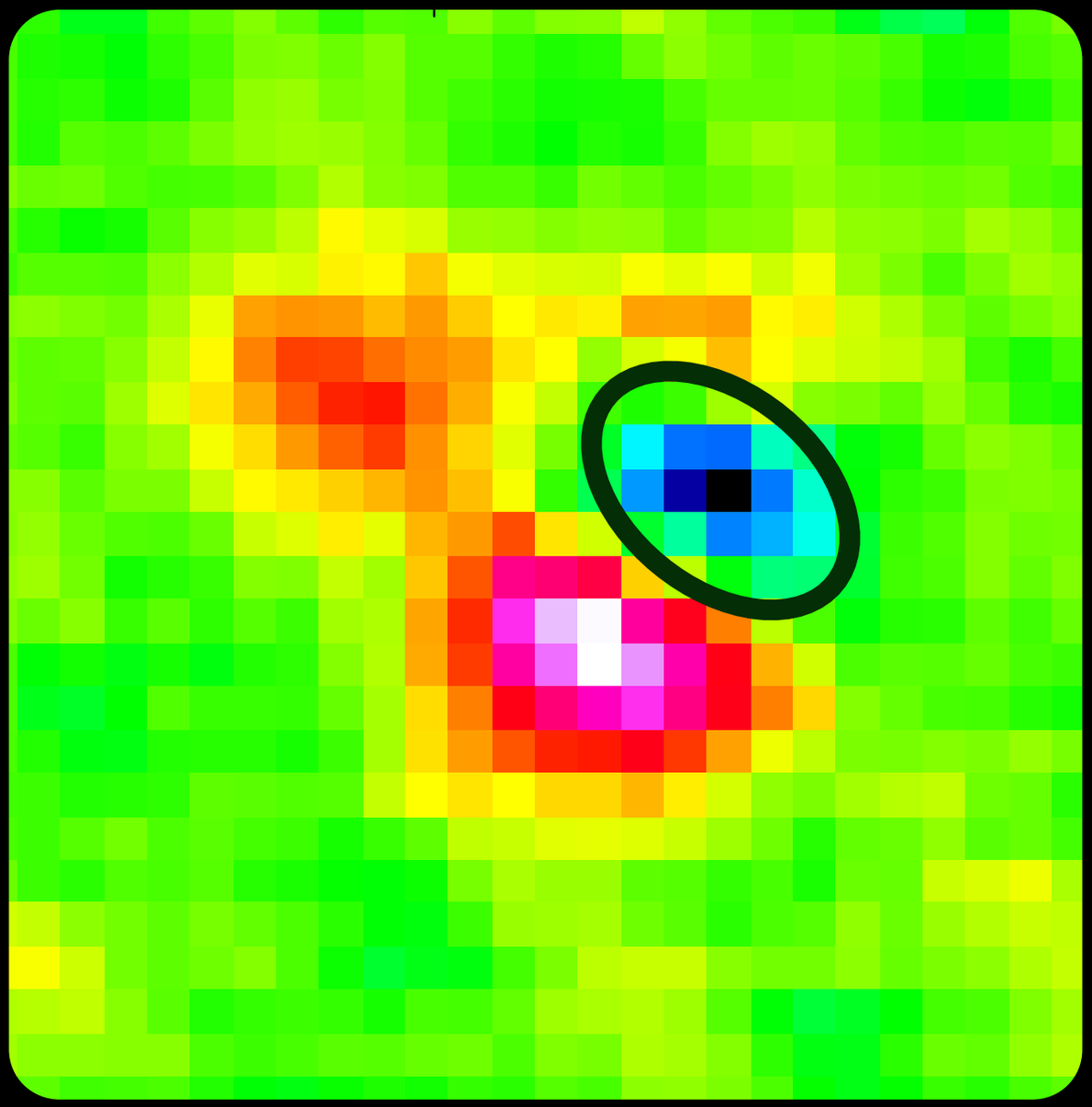

0.2
0.1
0
Mean Spectrum (mJy / beam)
-500
0
+500
+1000
Velocity (km / sec)

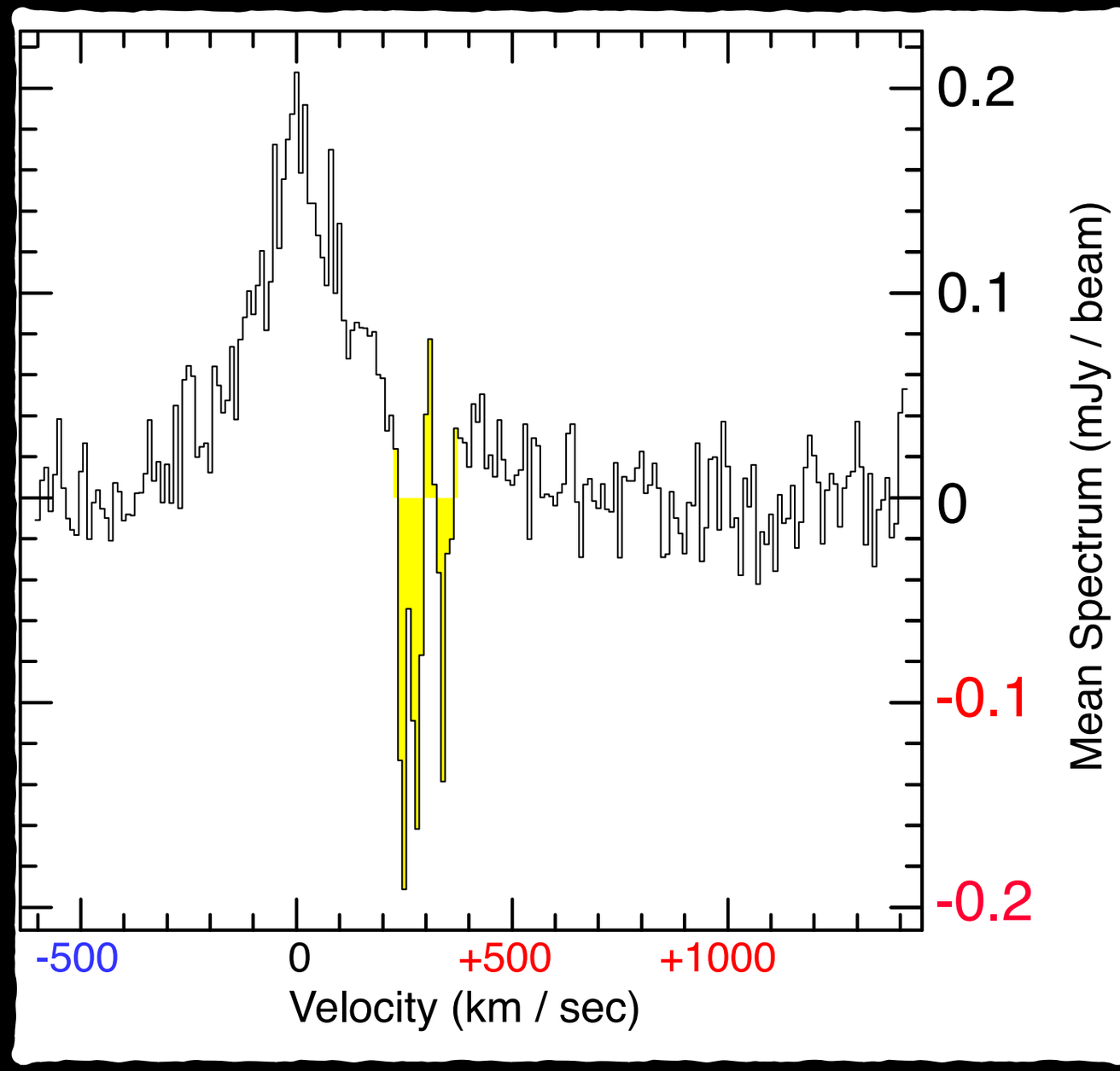


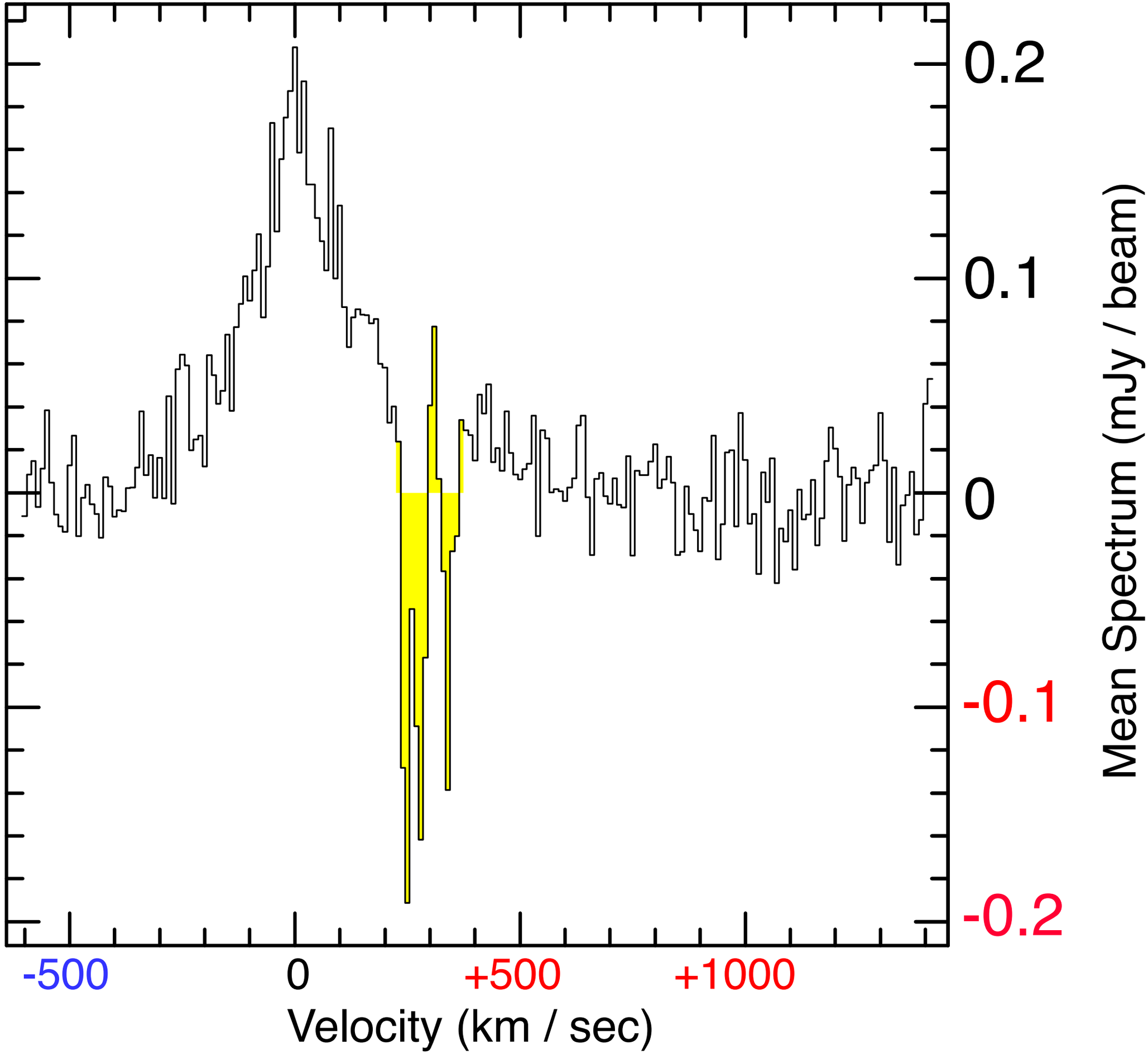

0.2
0.1
0
Mean Spectrum (mJy / beam)
-500
0
+500
+1000
Velocity (km / sec)

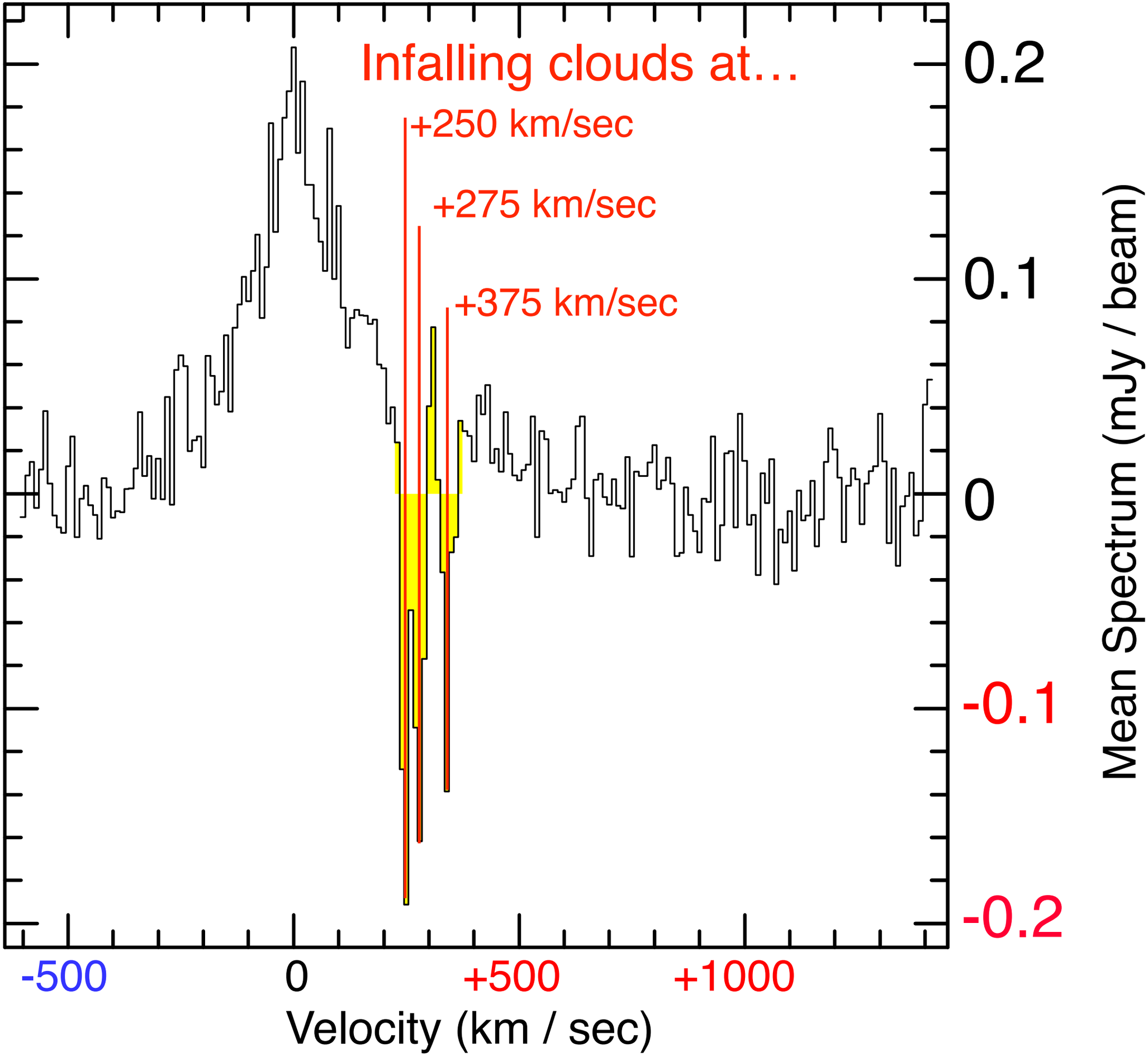



0.2
0.1
0
Mean Spectrum (mJy / beam)
-500
0
+500
+1000
Velocity (km / sec)



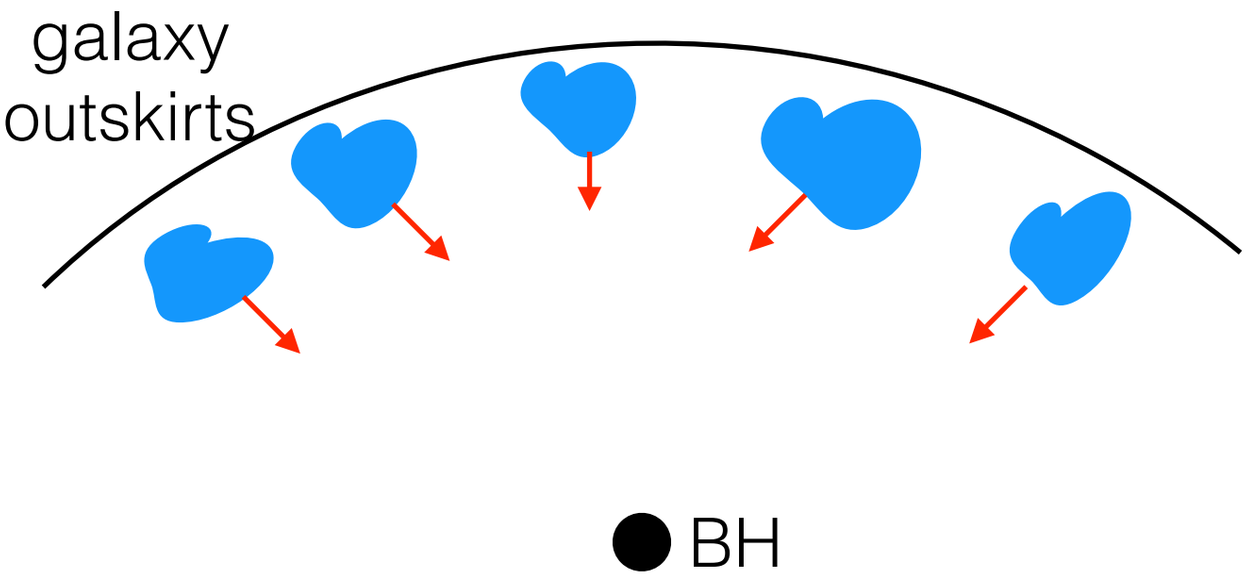

0.2
0.1
0
-0.1
-0.2
Mean Spectrum (mJy / beam)
-500
0
+500
+1000
Velocity (km / sec)

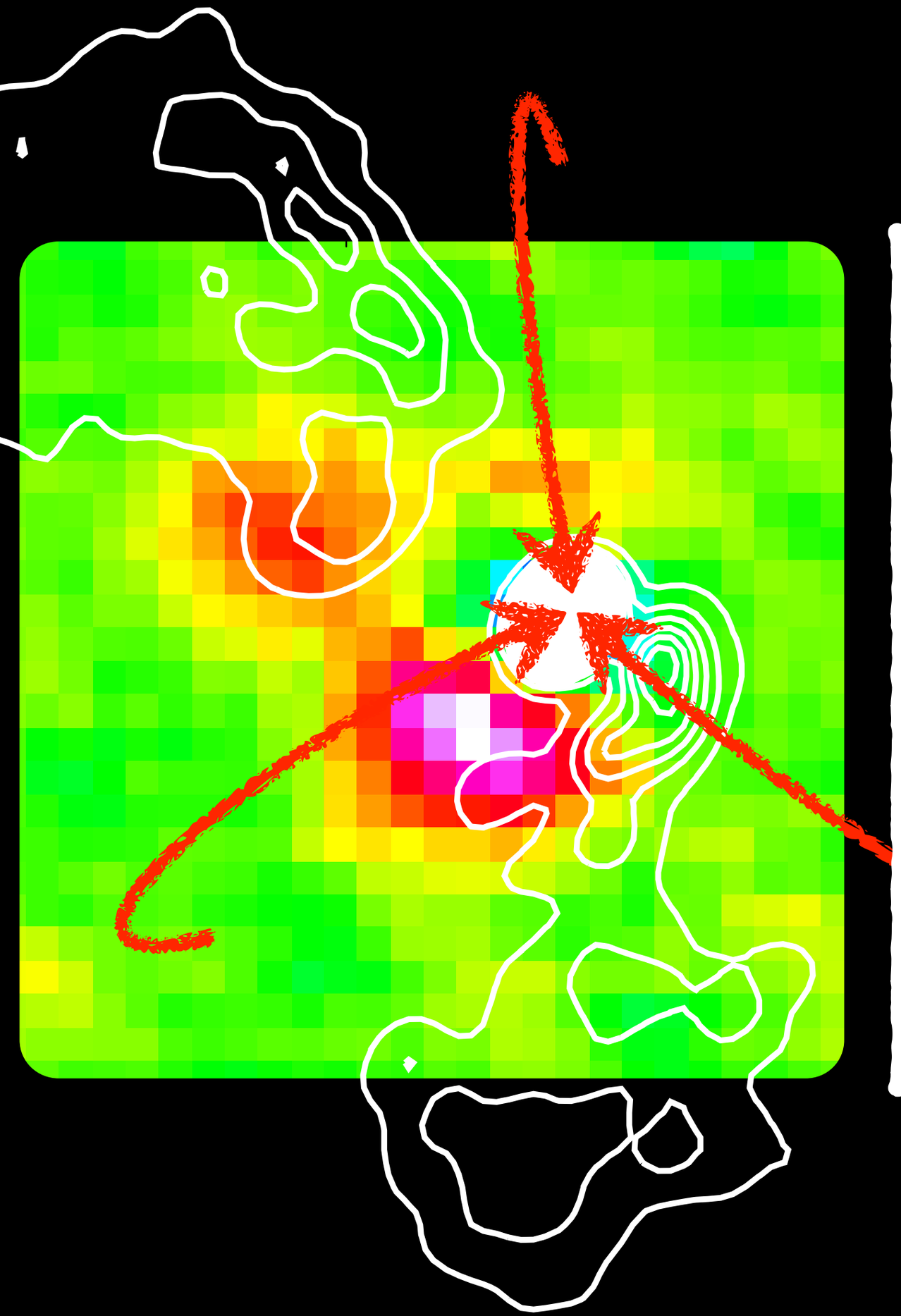

0.2
0.1
0
-0.1
-0.2
Mean Spectrum (mJy / beam)
-500
0
+500
+1000
Velocity (km / sec)


Infalling clouds at…
+250 km/sec
+275 km/sec
+375 km/sec
0.2
0.1
0
-0.1
-0.2
Mean Spectrum (mJy / beam)
-500
0
+500
+1000
Velocity (km / sec)

Could the infalling clouds be in the galaxy outskirts?

Unlikely.

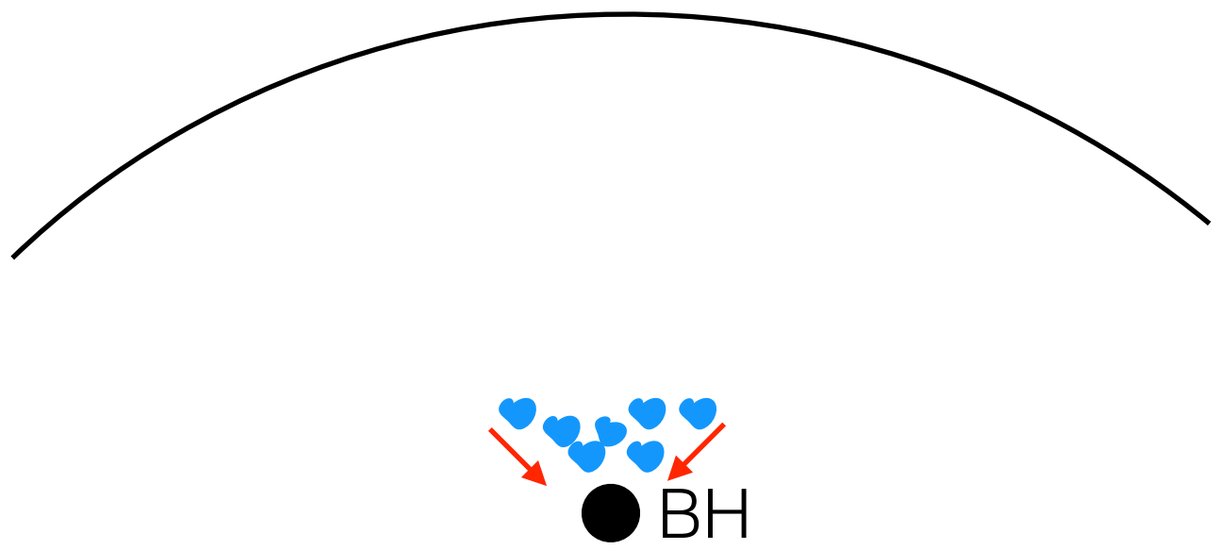


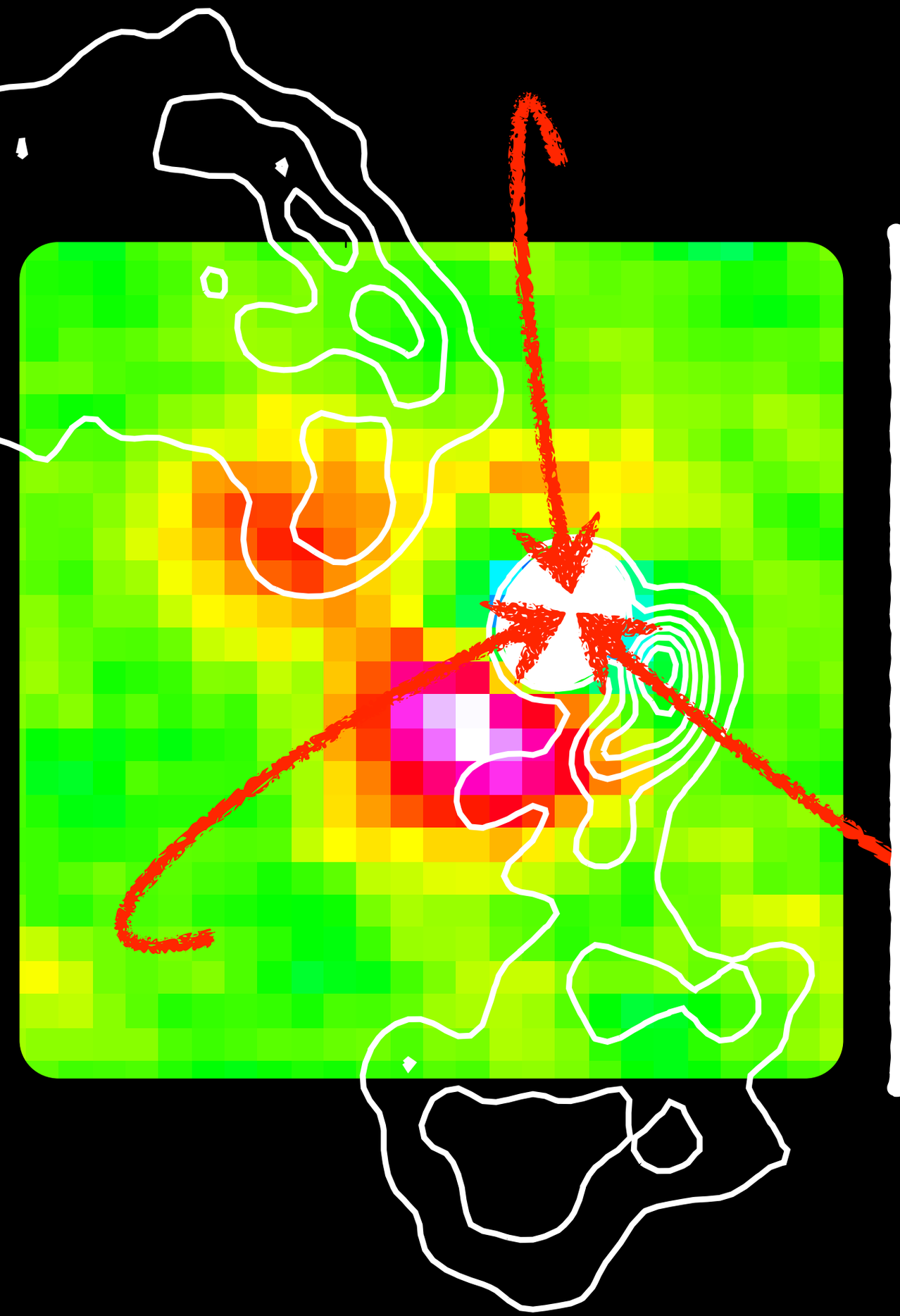


Pressure balance & virial arguments:

Clouds must attenuate continuum signal
with sufficiently large column while

(1) respecting pressure balance
(2) respecting observational constraints (FWHM)

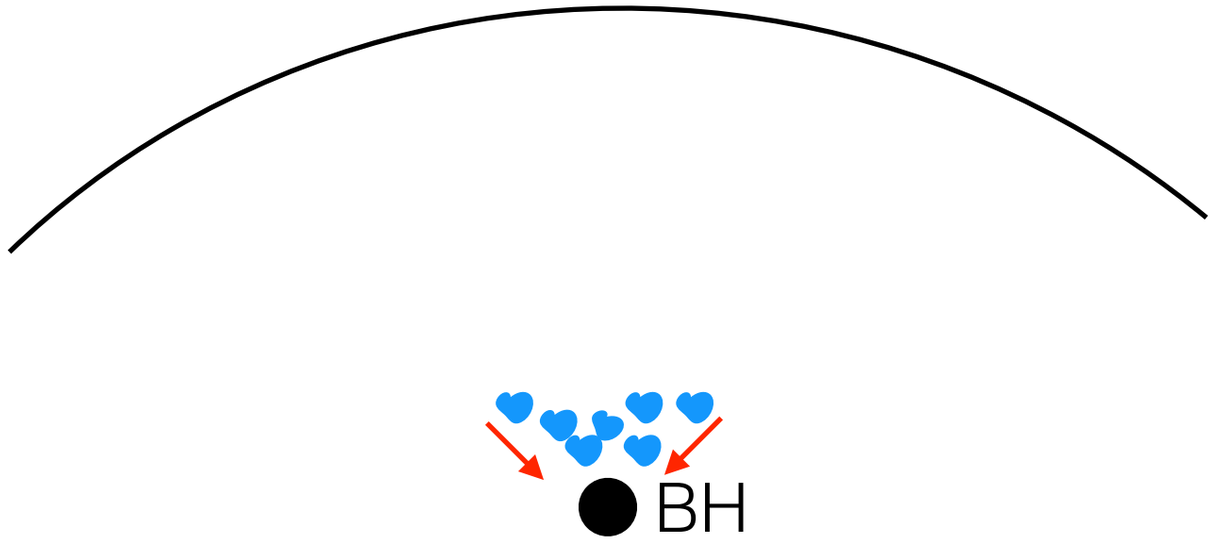




Virial & FWHM
give rough mass
for infalling clouds

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.

Partners in crime

Andy Fabian
Raymond Oonk
Francoise Combes
Philippe Salome
Chris O'Dea
Stefi Baum

Brian McNamara
Megan Donahue
Mike McDonald
Mark Voit
Tracy Clarke
Alice Quillen

Tim Davis
Roberto Galvan-Madrid
Malcom Bremer
Mike Wise
Anaelle Maury
Jeremy Sanders

grant.tremblay@yale.edu

Einstein Fellowship Symposium, Harvard/Smithsonian CfA, October 2014