

MULTIPHASE FOUNTAINS *with* BLACK HOLE PUMPS



Grant Tremblay
Einstein Fellow | Yale University



Cold gas

couples to black holes

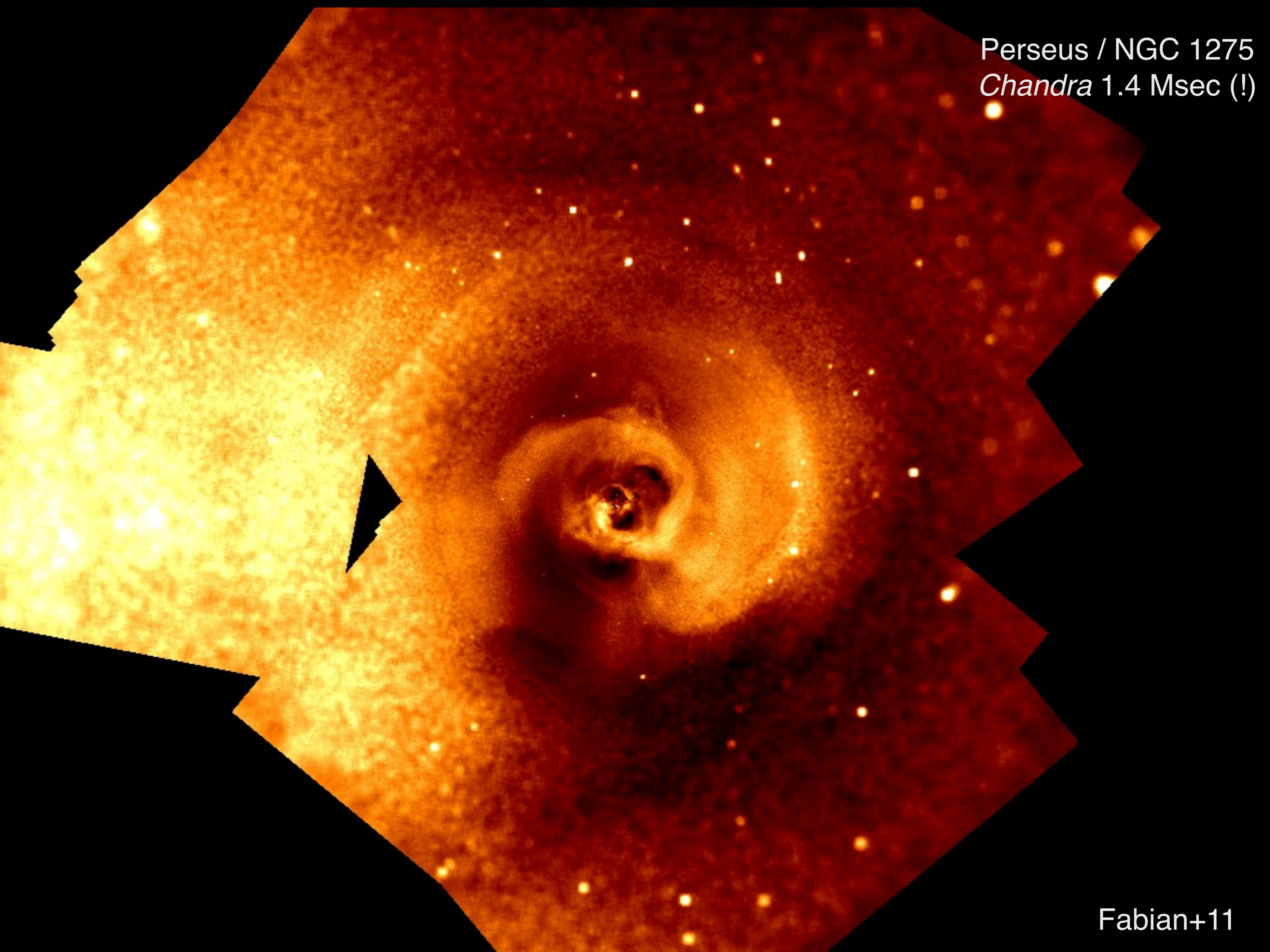
via *both* feedback & feeding

Pushing hot gas with jets is easy



it's about \$2,000 an ounce

Perseus / NGC 1275
Chandra 1.4 Msec (!)



Fabian+11

Perseus / NGC 1275
Chandra 1.4 Msec (!)

100 kpc

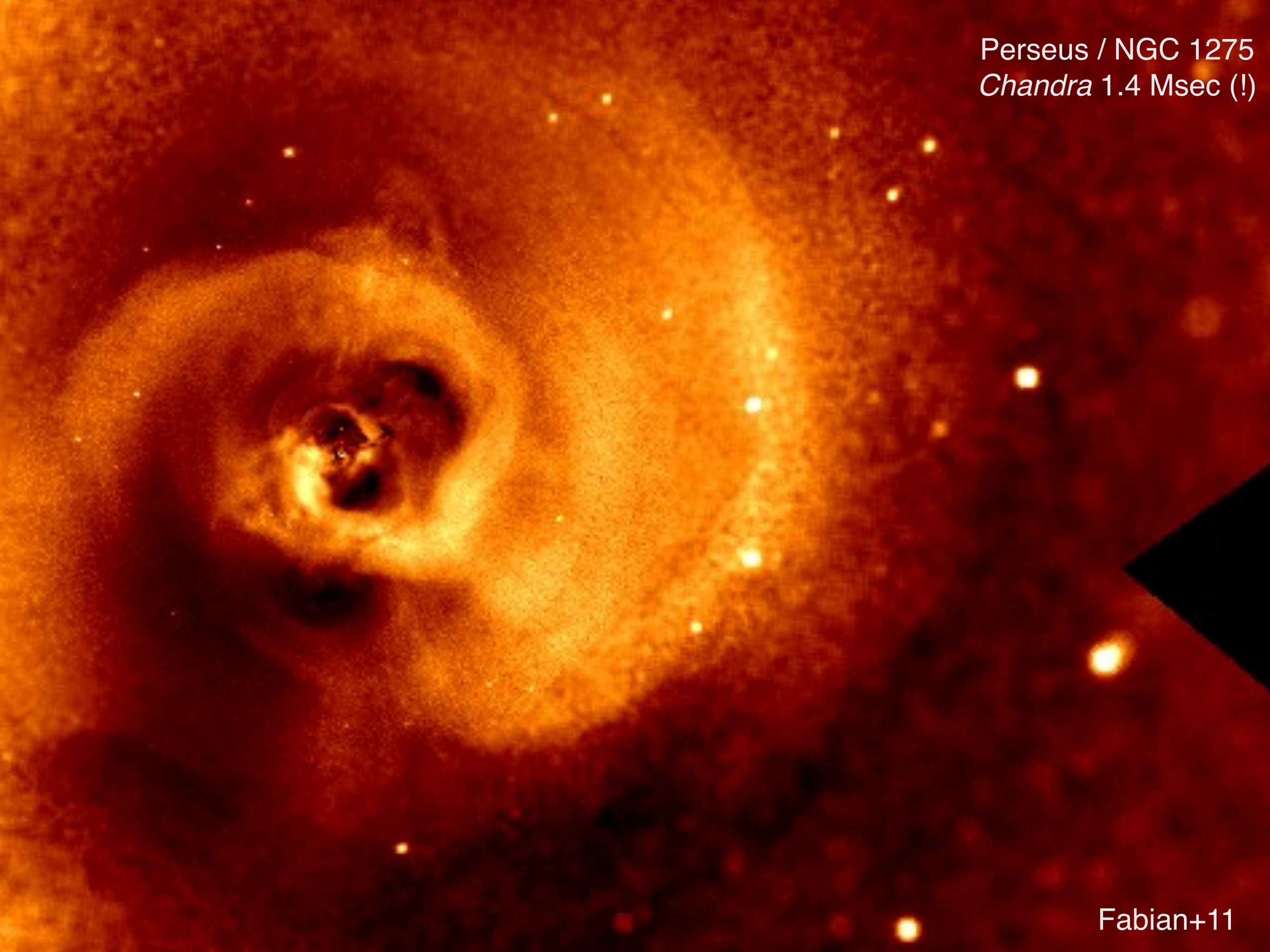


Fabian+11

Pushing warm gas with jets and bubbles is somewhat easy

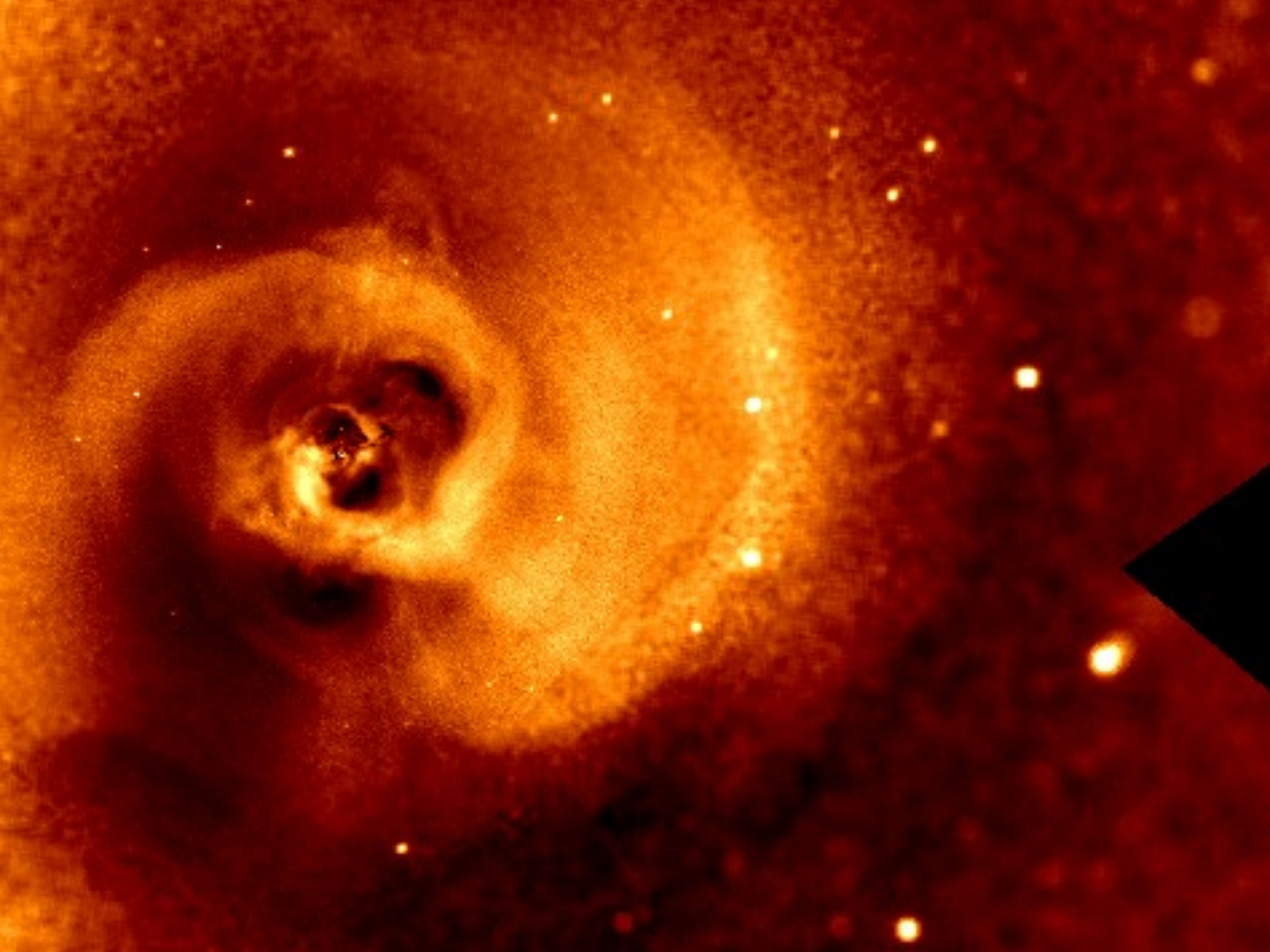


Perseus / NGC 1275
Chandra 1.4 Msec (!)



Fabian+11



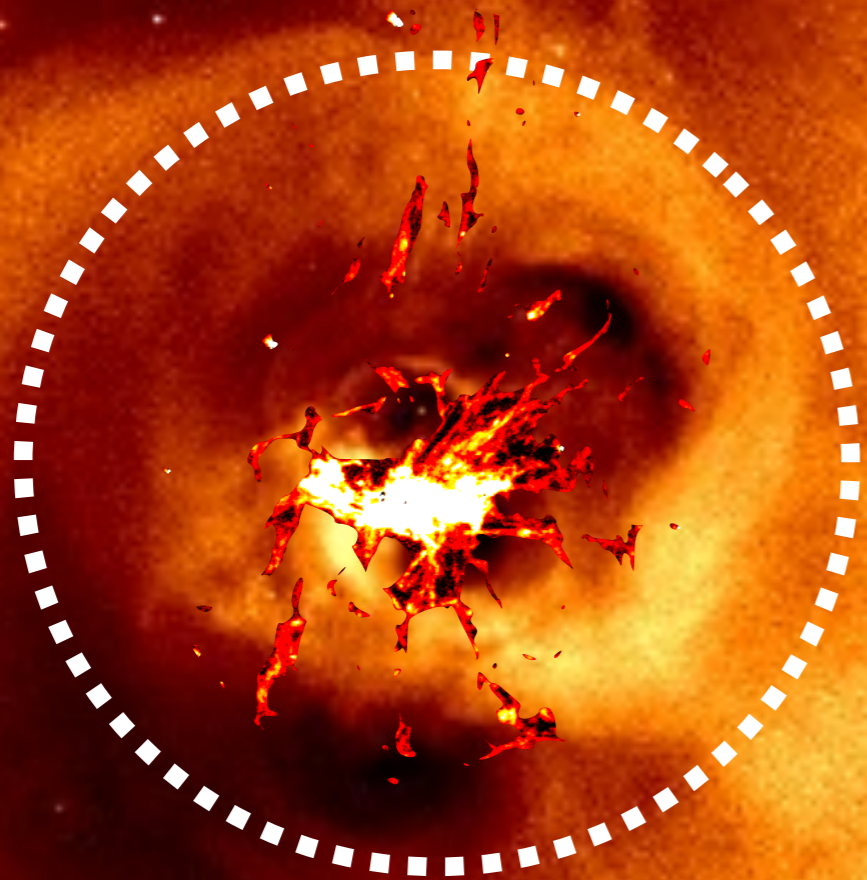




Increasing Lifetime
of Thermal Instabilities

The image shows a dense field of stars, likely a star cluster or the core of a galaxy. The stars are concentrated in a bright, yellowish-white central region, with their density decreasing as they move towards the edges. The background is a deep red, suggesting a redder stellar population or dust emission. A white arrow points from the right towards the center, indicating the direction of increasing lifetime of thermal instabilities.

Multiphase cooling “rain” when



$$t_{\text{cool}} < 10 t_{\text{dyn}}$$

(maybe)

(roughly; there's large scatter)

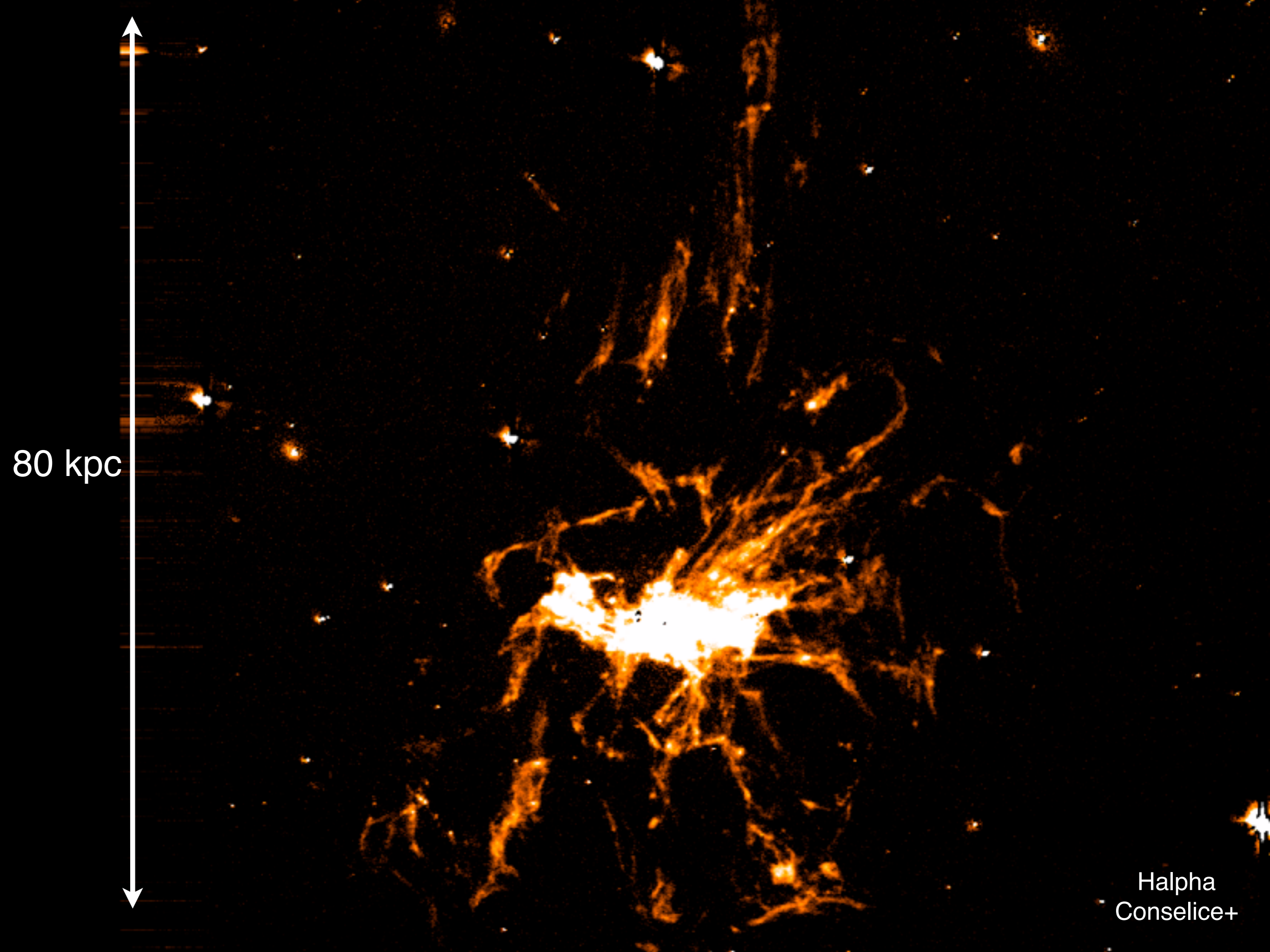
Gaspari+12,13,15

McCourt+12

Sharma+12

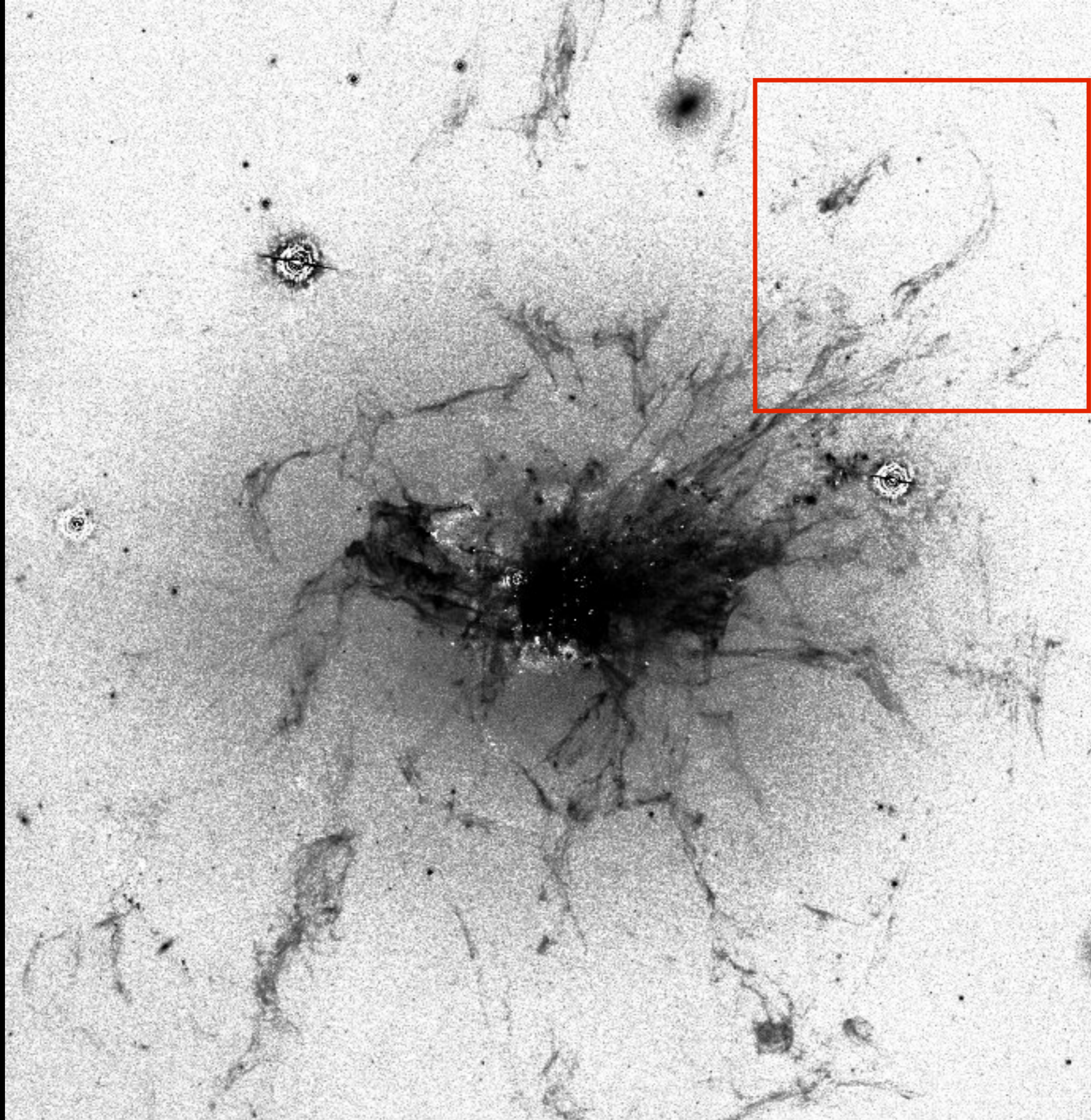
Voit+15, 16

McNamara+16

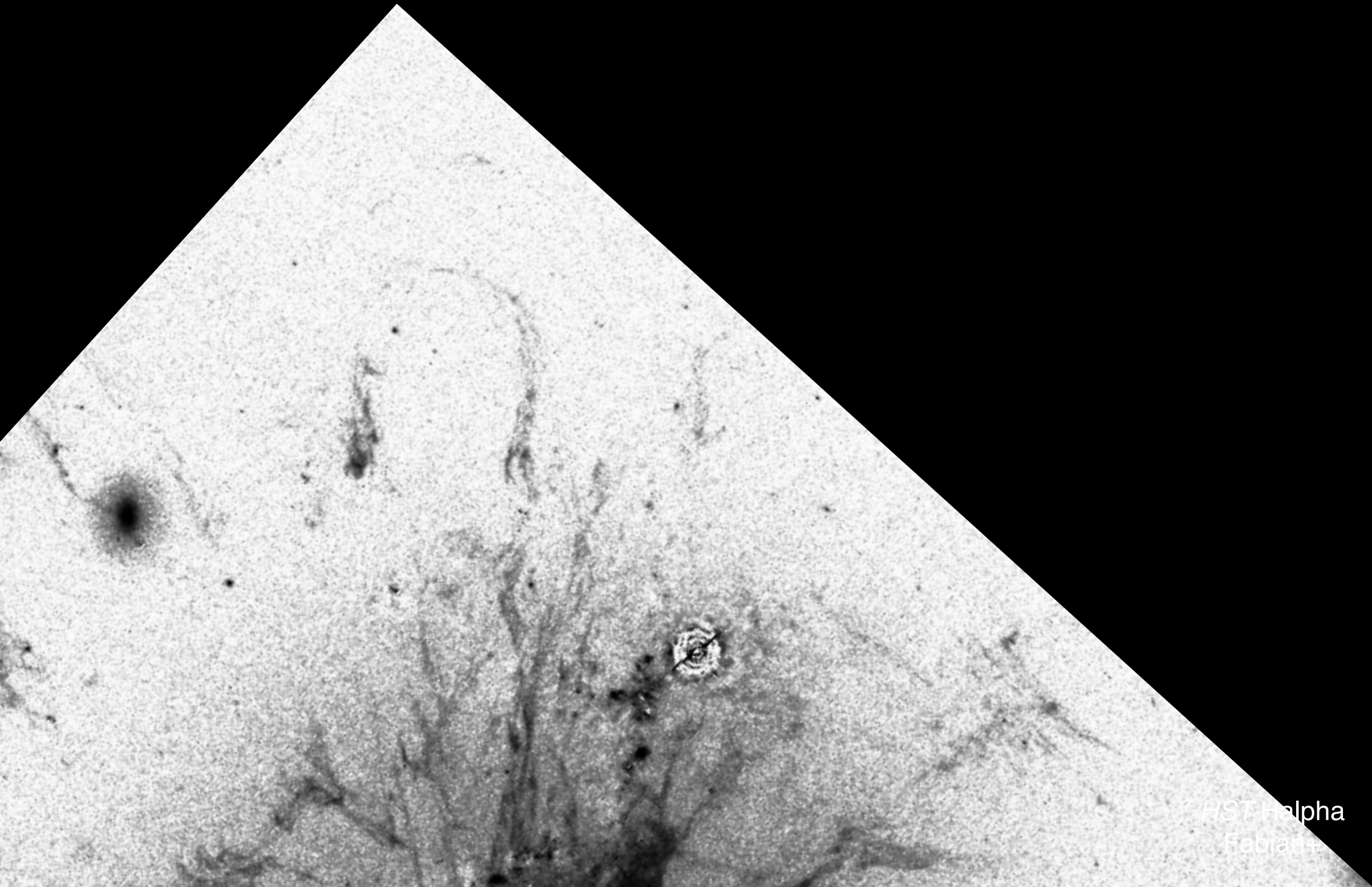


80 kpc

Halpha
Conselice+

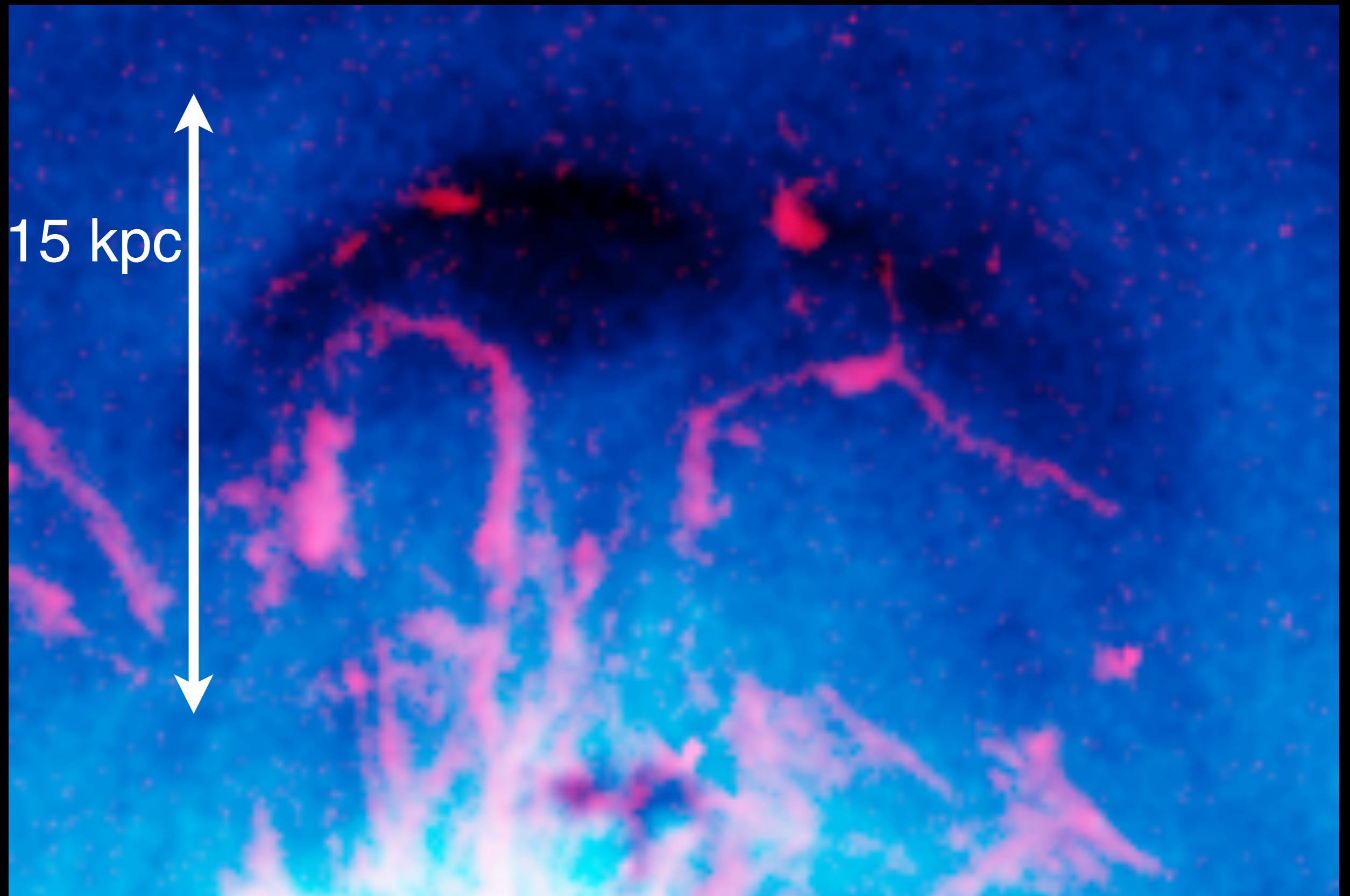


HST Halpha
Fabian+



HST Halpha
Fabian+

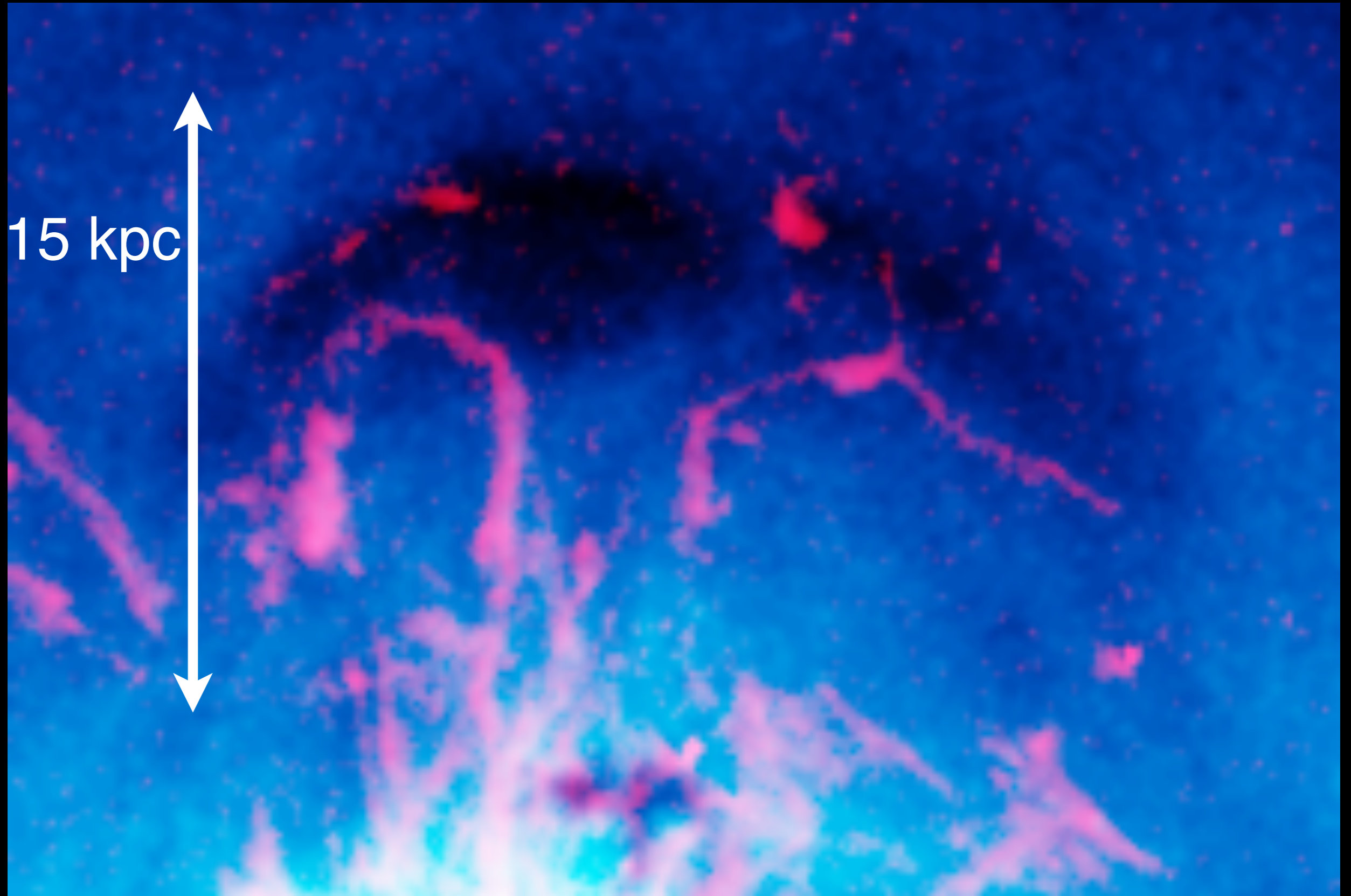
X-ray + Halpha



15 kpc

Fabian+ and many others

See Becky Canning's awesome work on Perseus



A1795

FUV

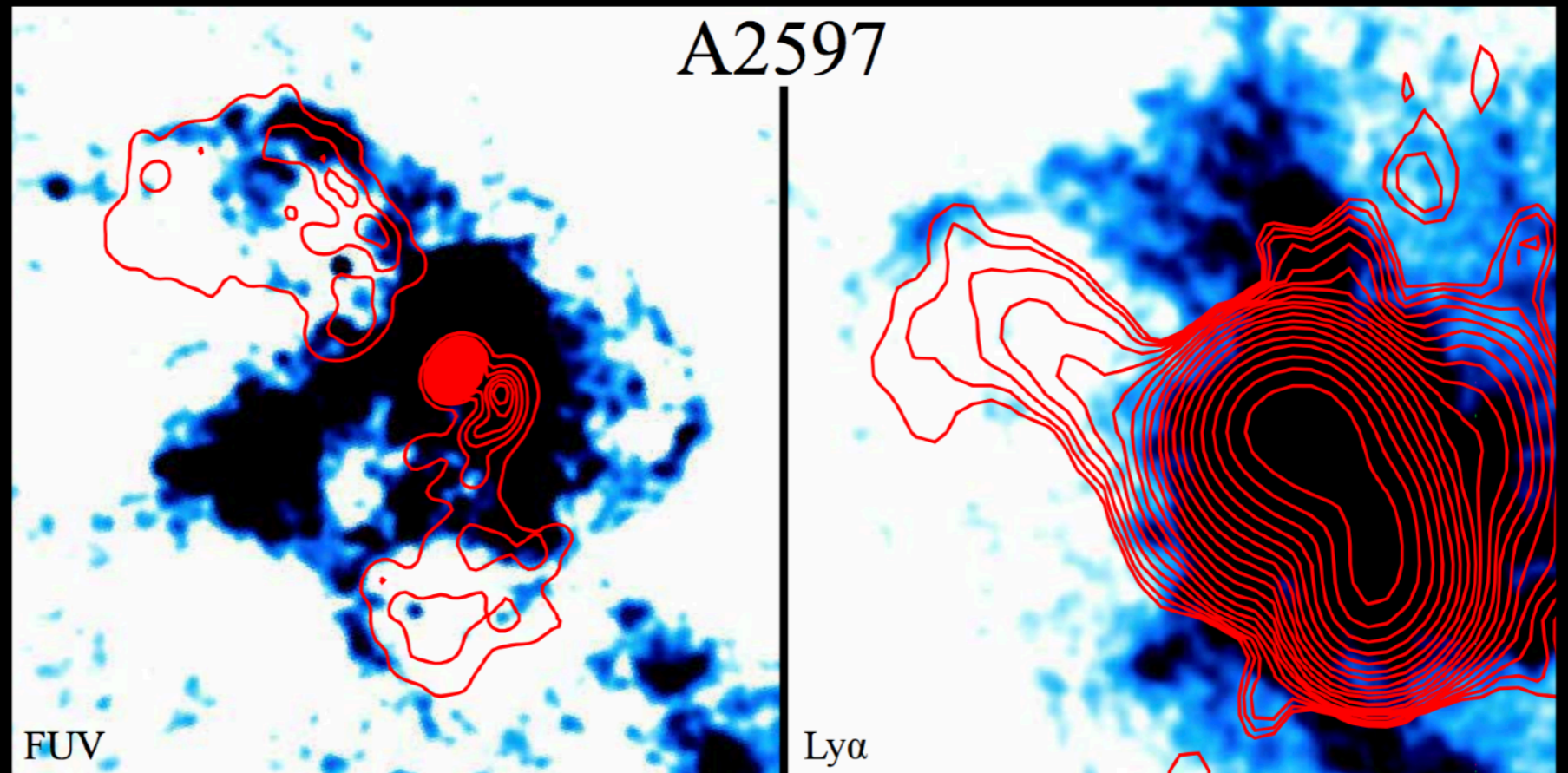
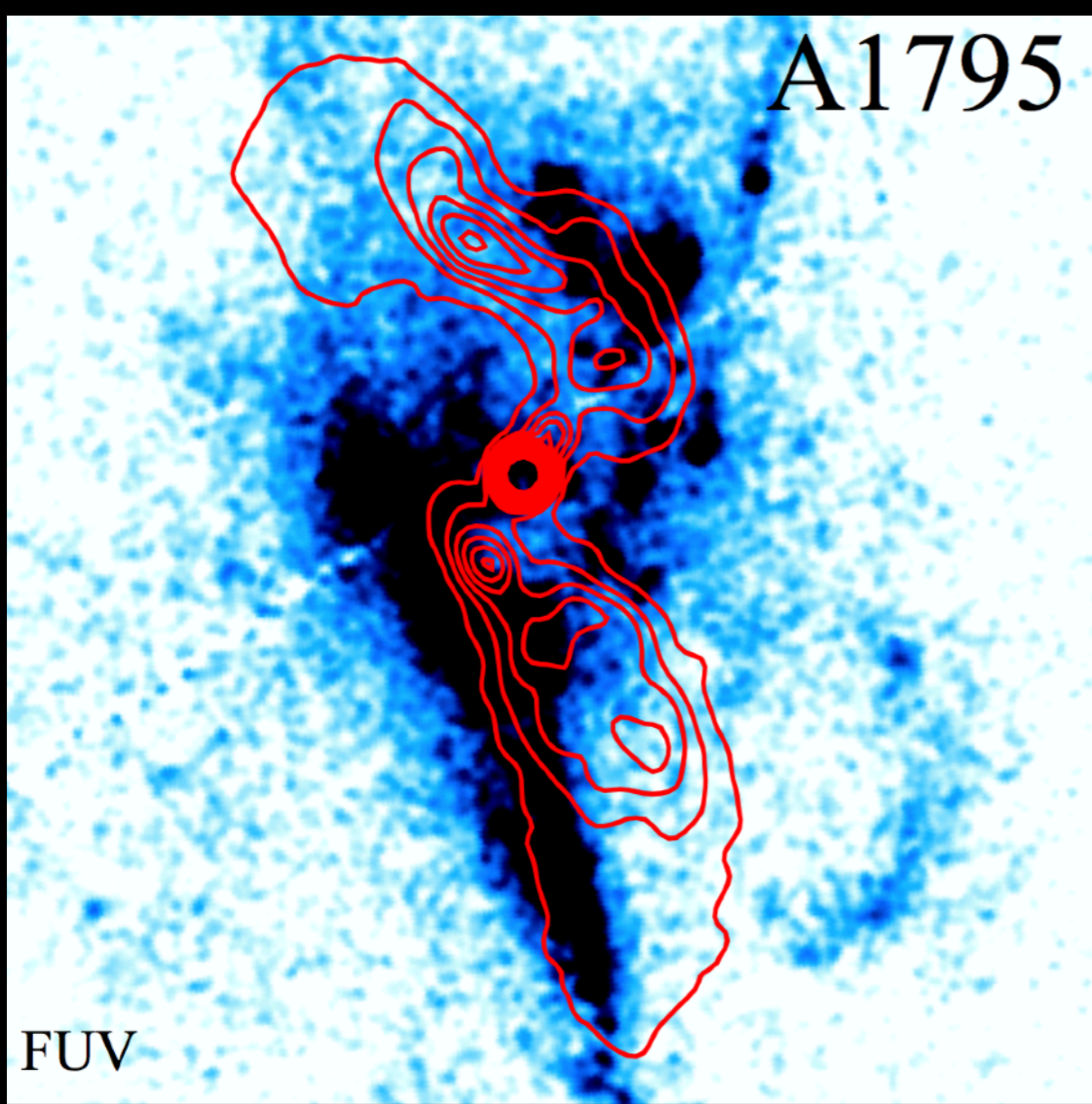
FUV continuum (young stars),
radio contours

Tremblay+15

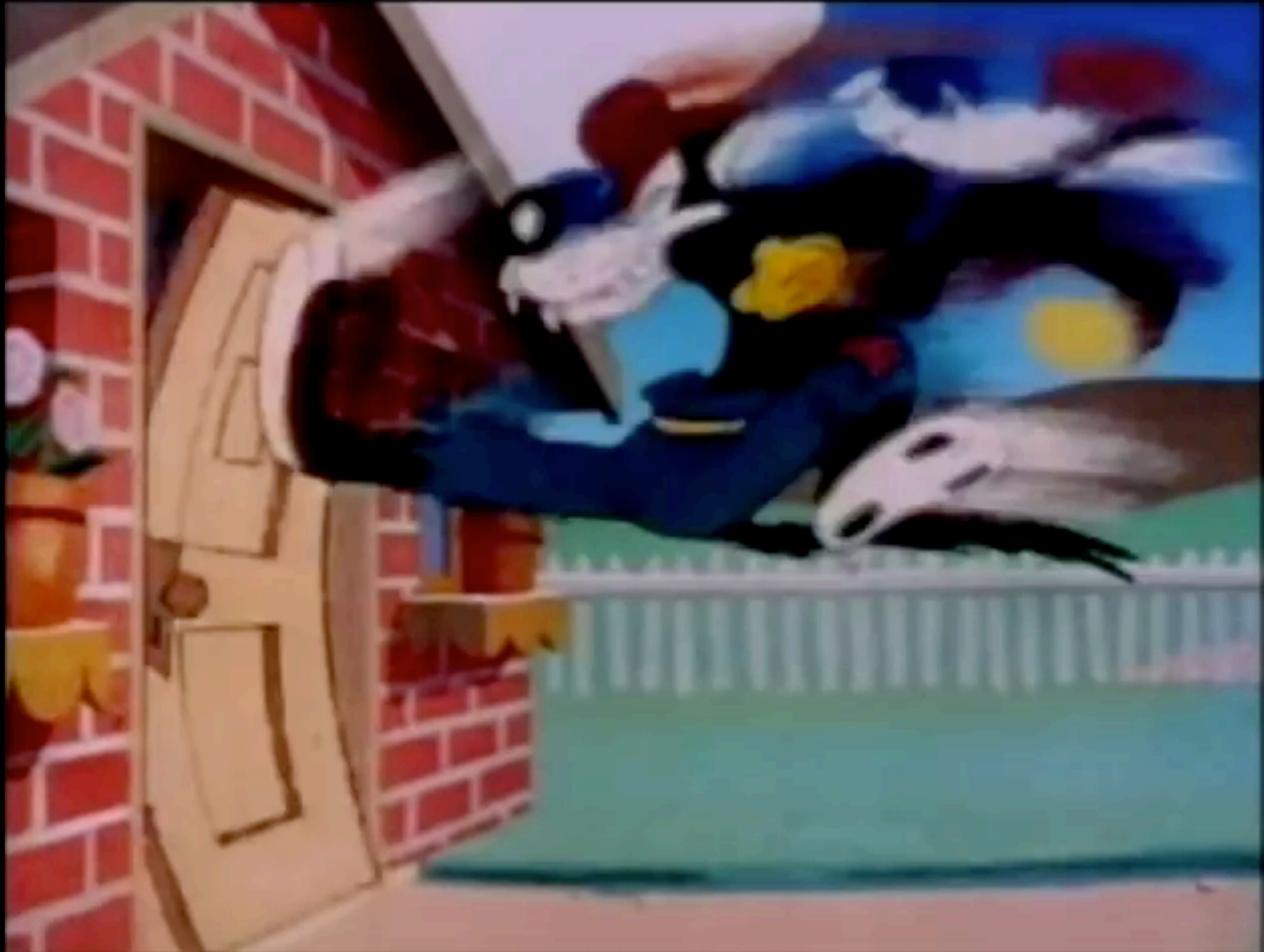
A2597

FUV

Ly α



Pushing cold gas around is hard



Work I'm ripping off...

Gaspari+12,13,14,16

McCourt+12

Sharma+12

Li+14

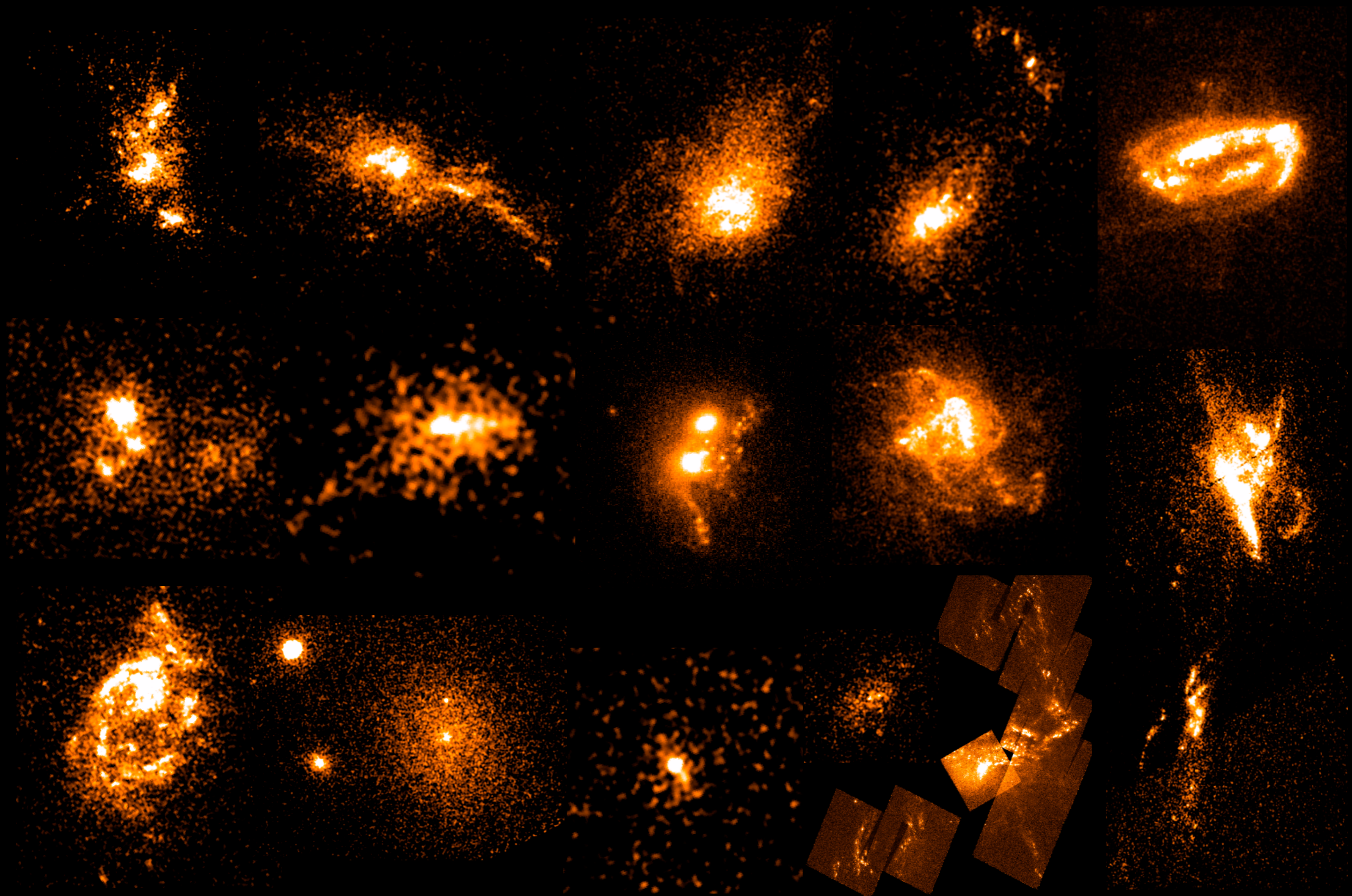
Voit+15, 16

McNamara+16

...building on decades of work by many
(including Paul, Christine, Bill, Becky...)



Fountain Plumes (?)



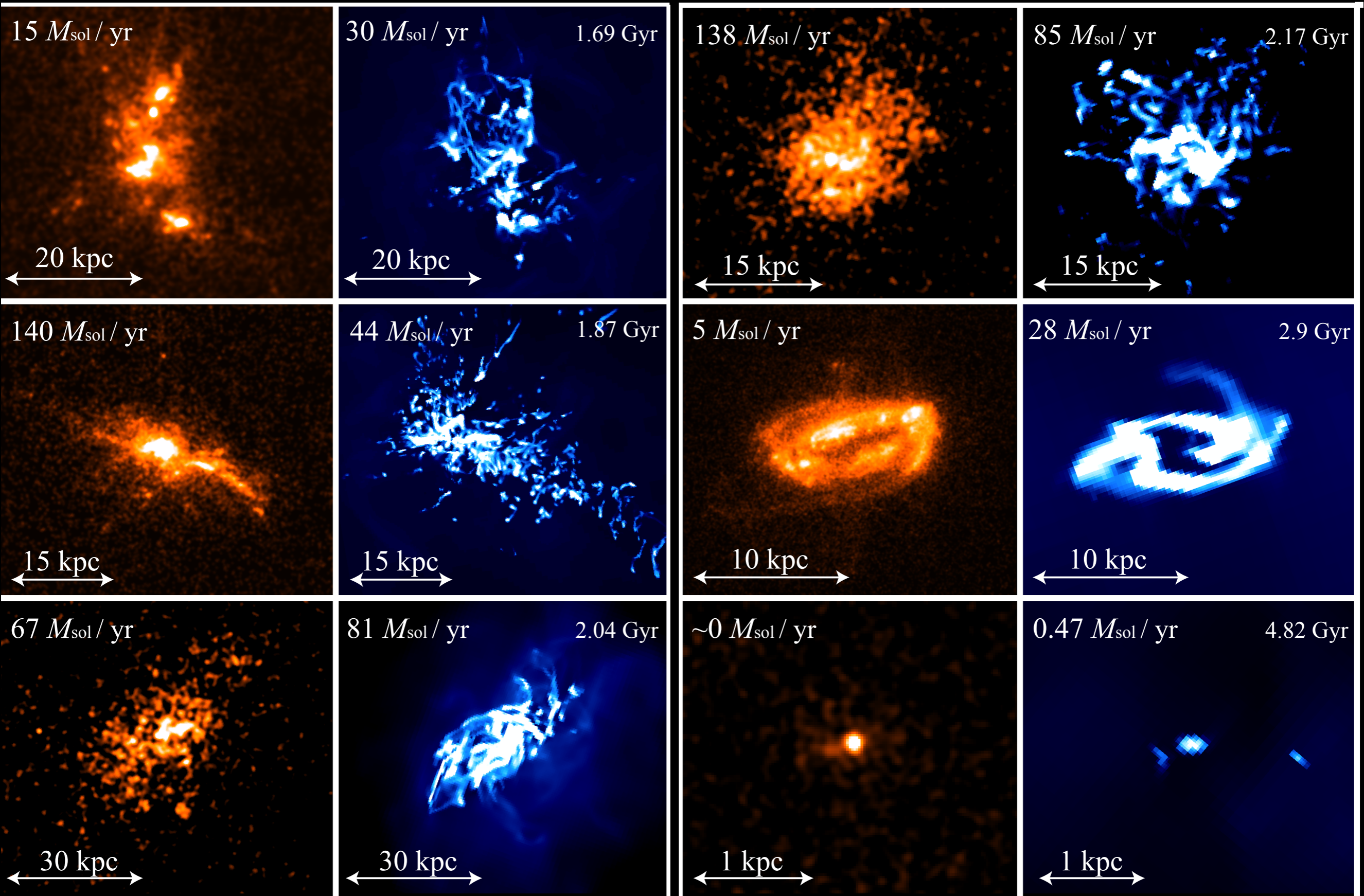
HST ACS/SBC FUV continuum (Tremblay+15)

Observation

Simulation

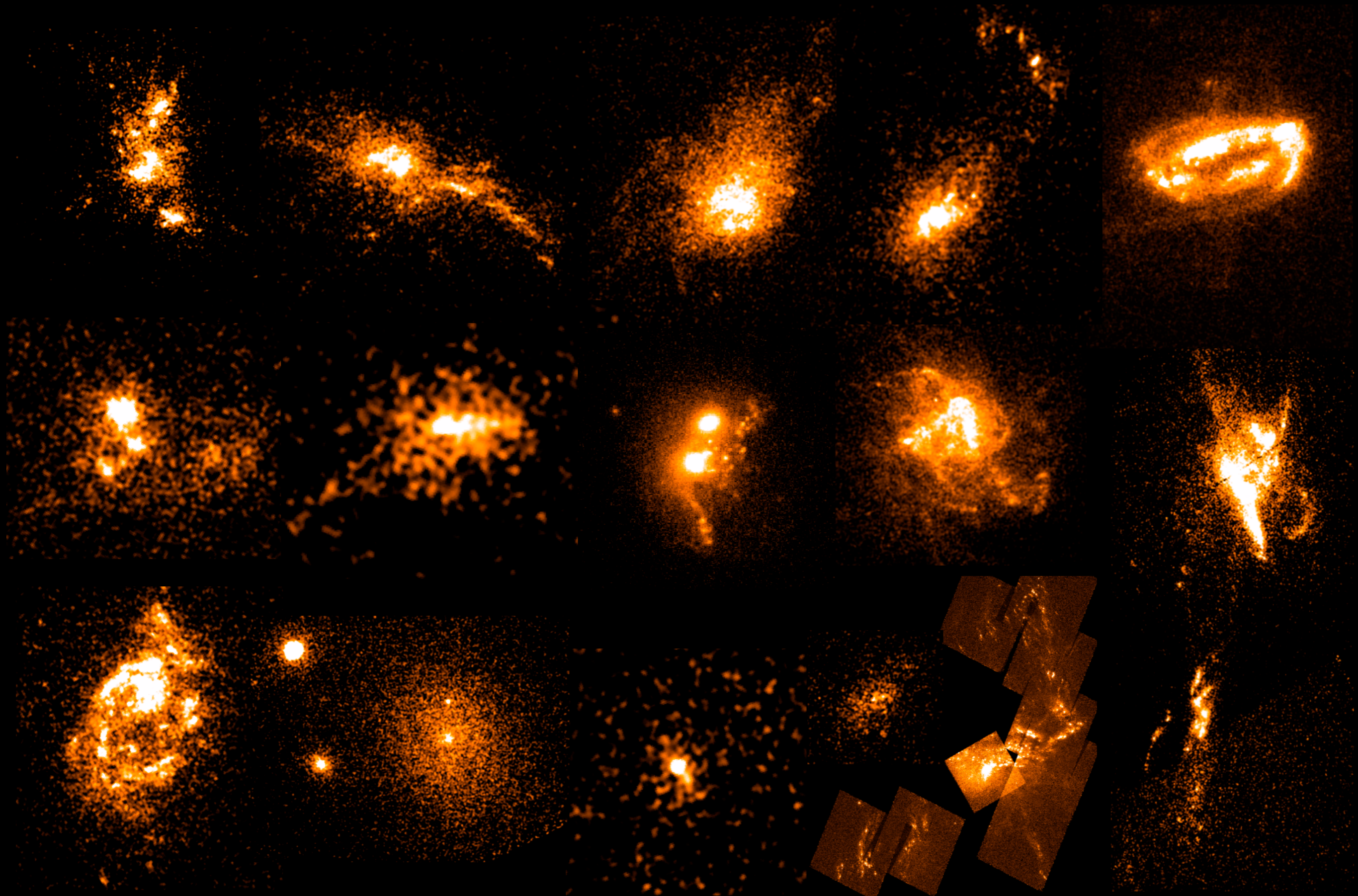
Observation

Simulation



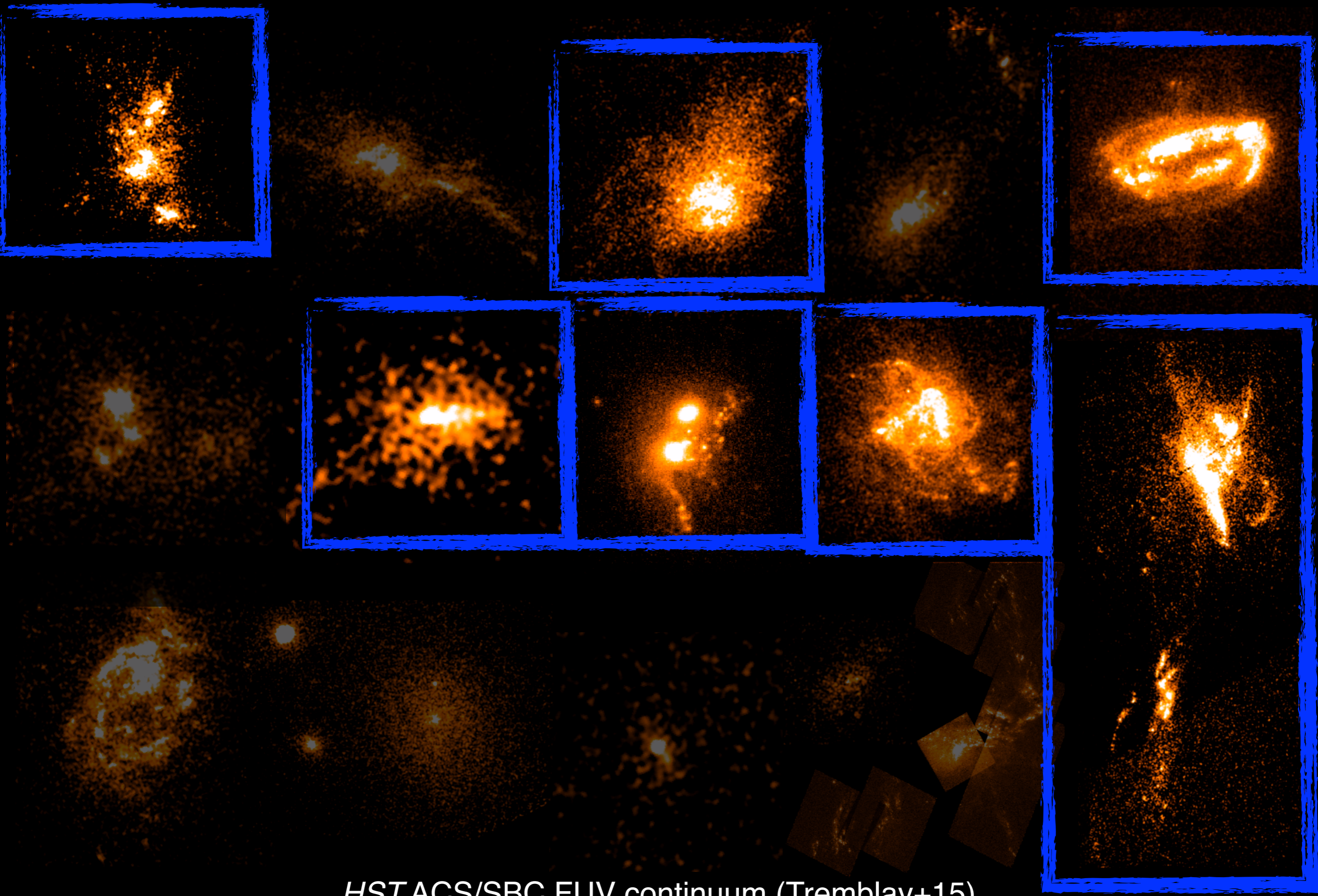
Tremblay+15, Li+14, + Max's talk

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

A1664

RX J1504

A1835

A1068

Hydra A

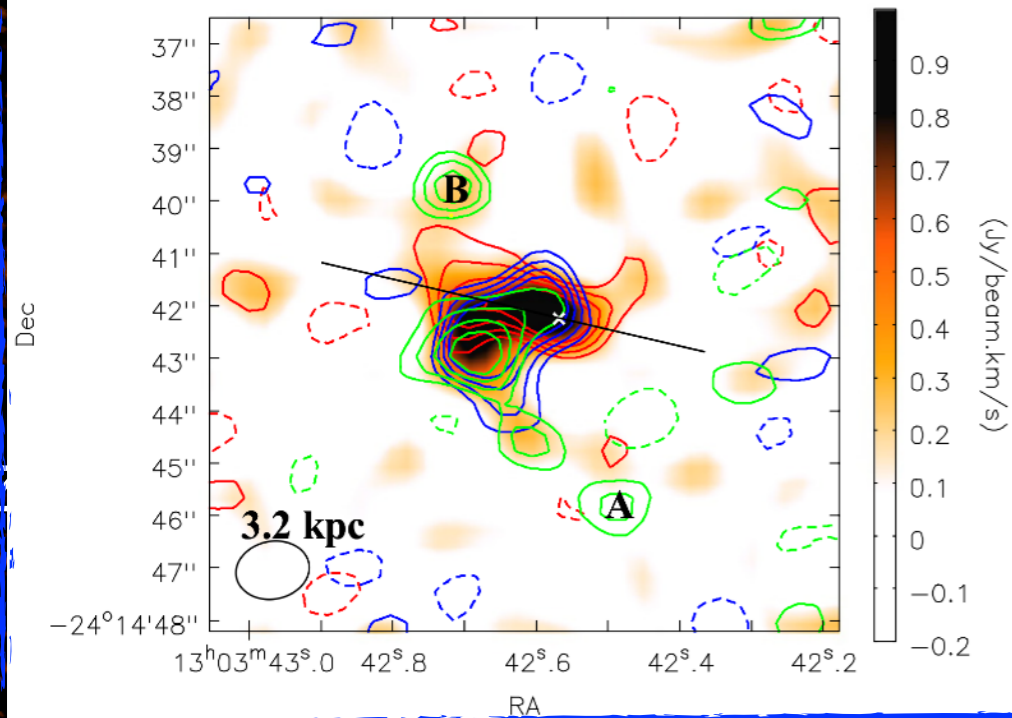
A11

PKS 0745

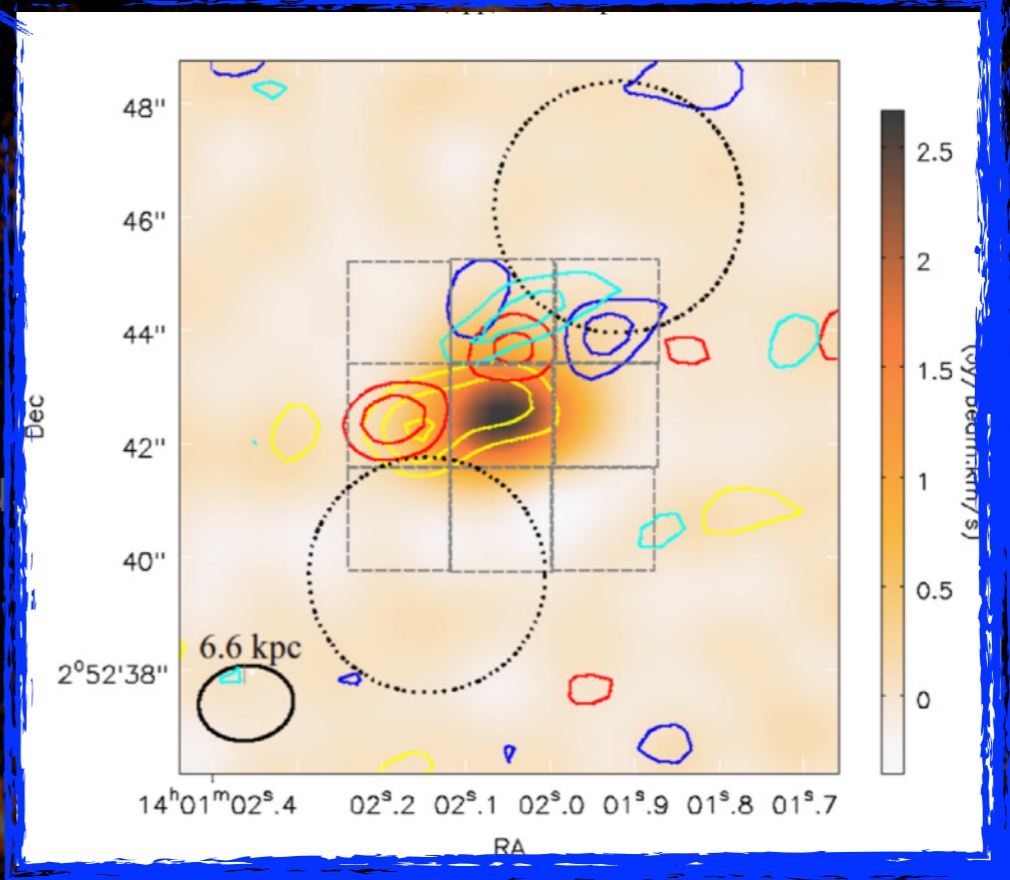
Zw3146

A2507

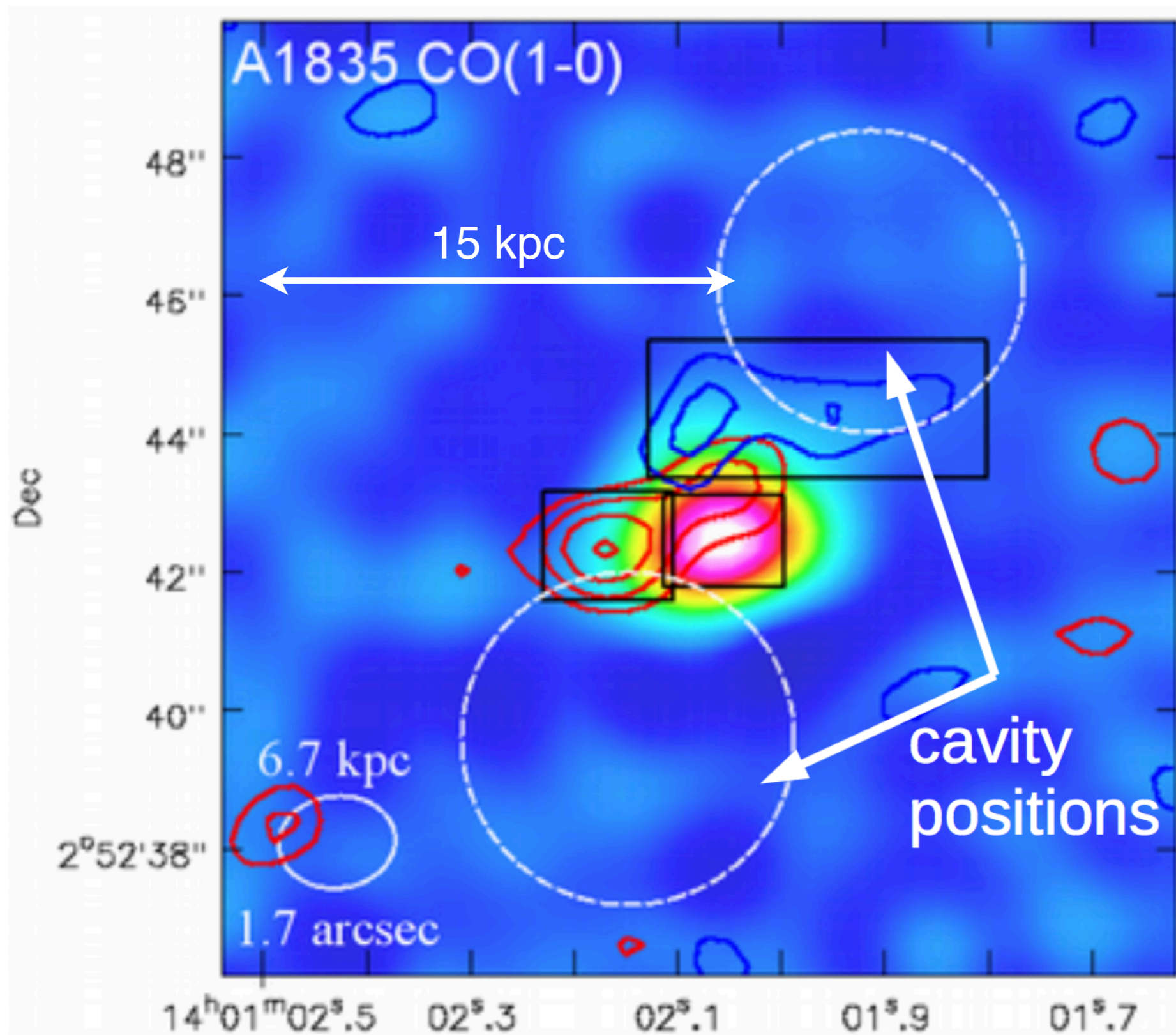
A1795



Russell+14



McNamara+14

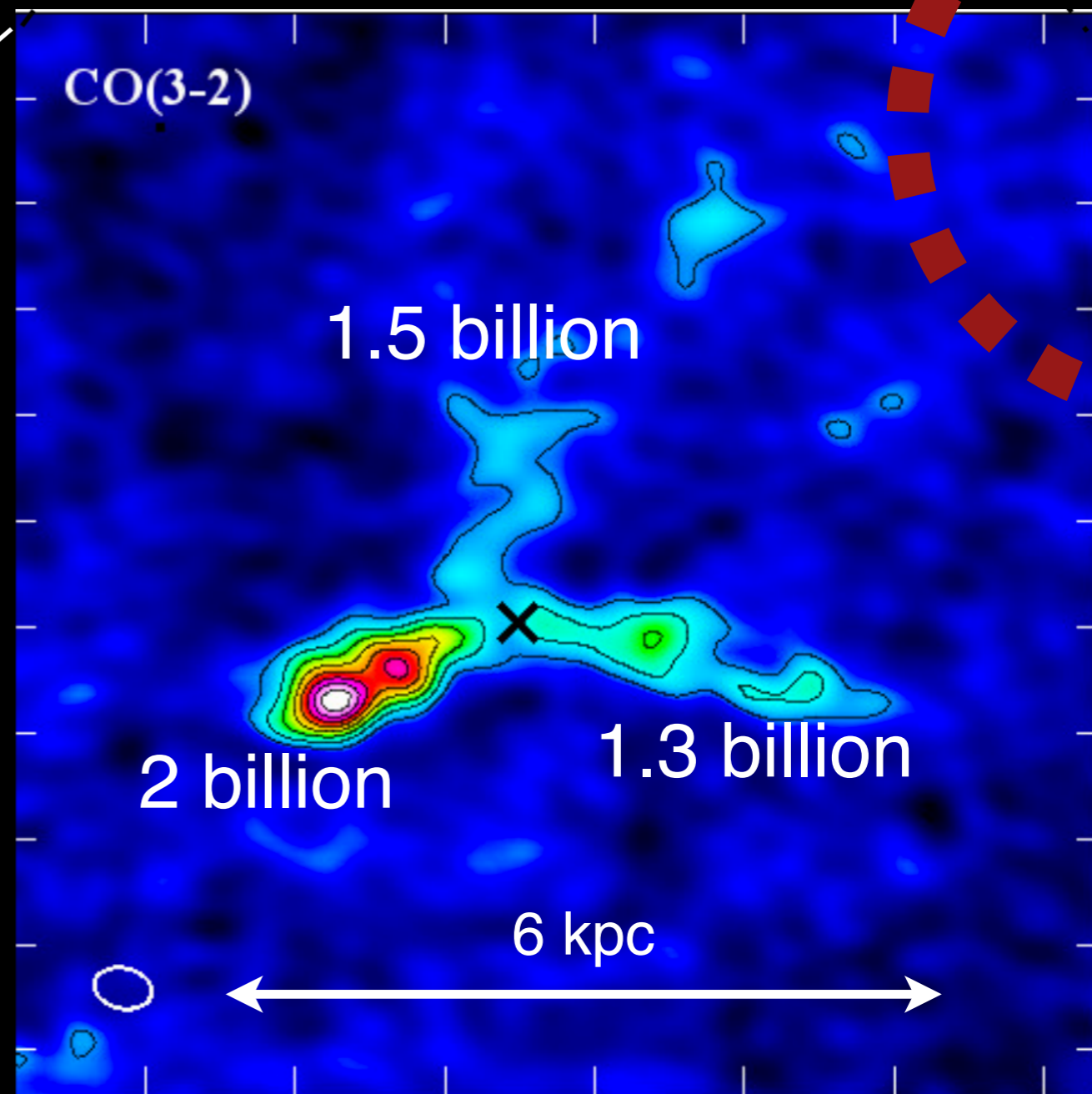
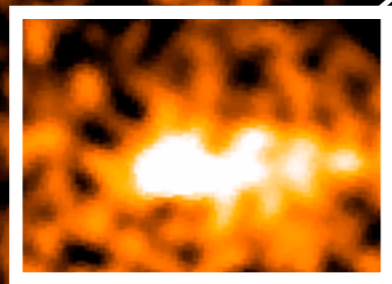


McNamara+14

PKS 0745-191

HST FUV

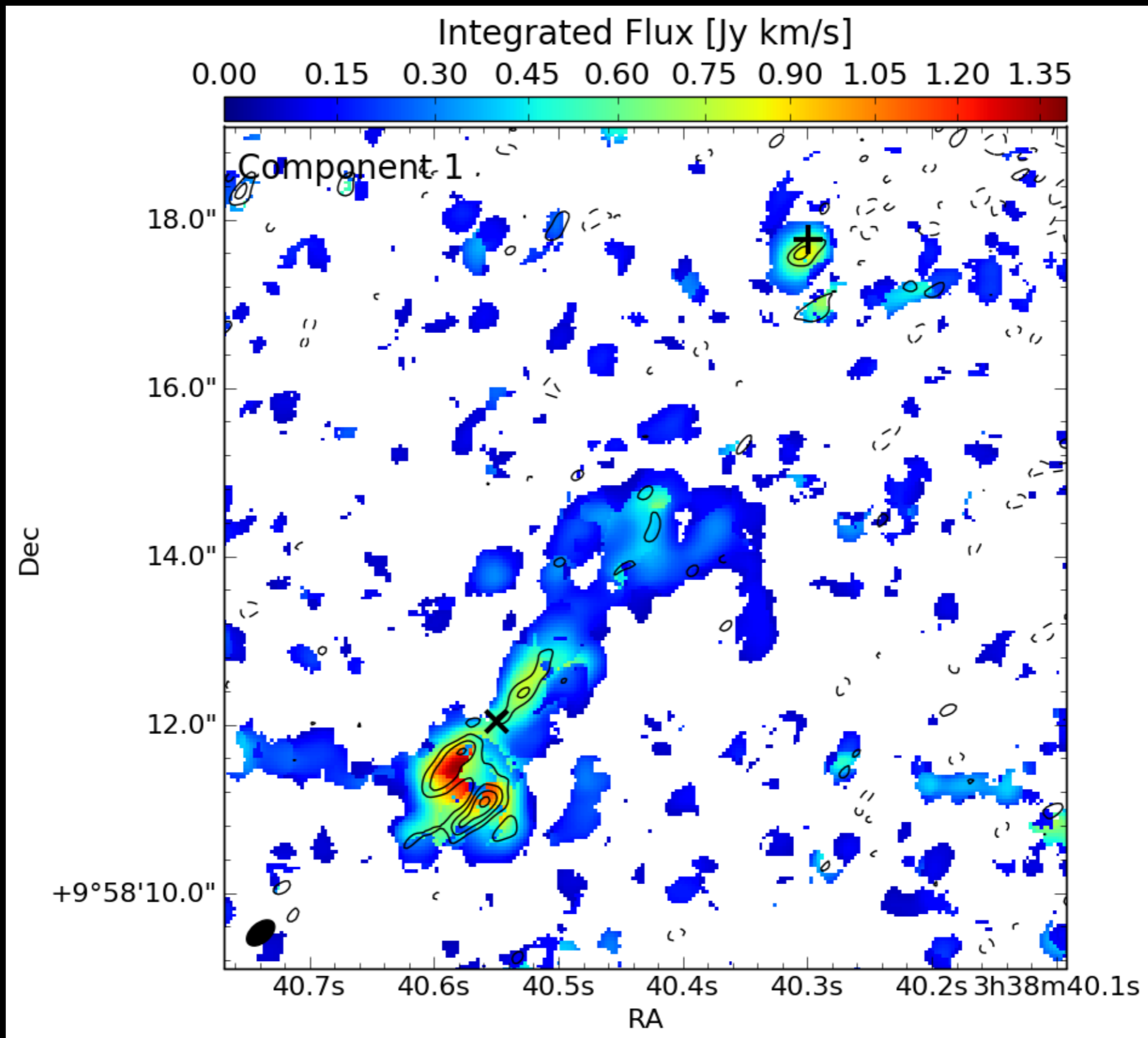
ALMA CO(2-1)



Tremblay+15

Russell+16

CO(3-2) in 2A 0335: Vantyghem+16



A1664

RX J1504

A1835

A1068

Hydra A

A11

PKS 0745

Zw3146

A2597

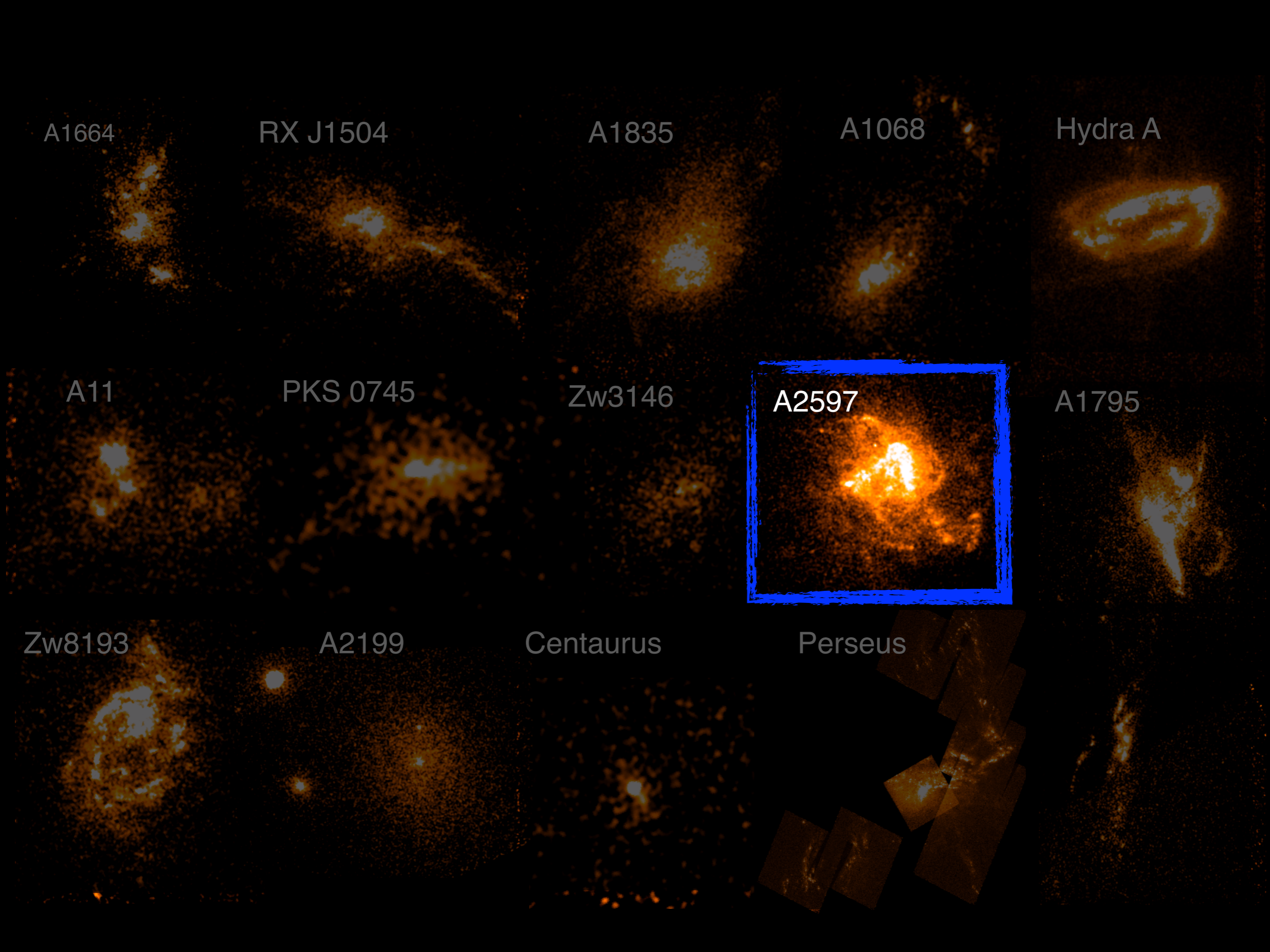
A1795

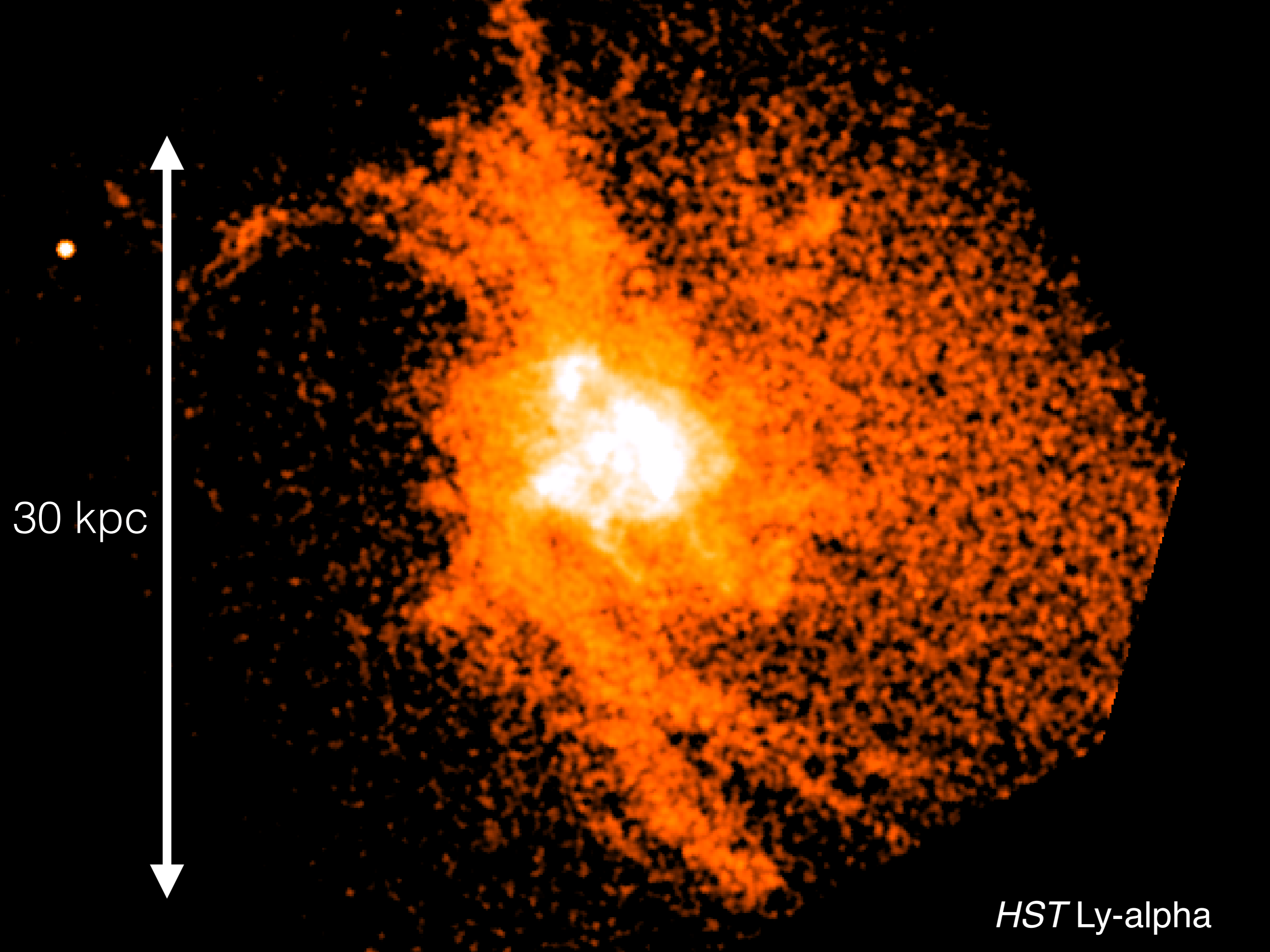
Zw8193

A2199

Centaurus

Perseus

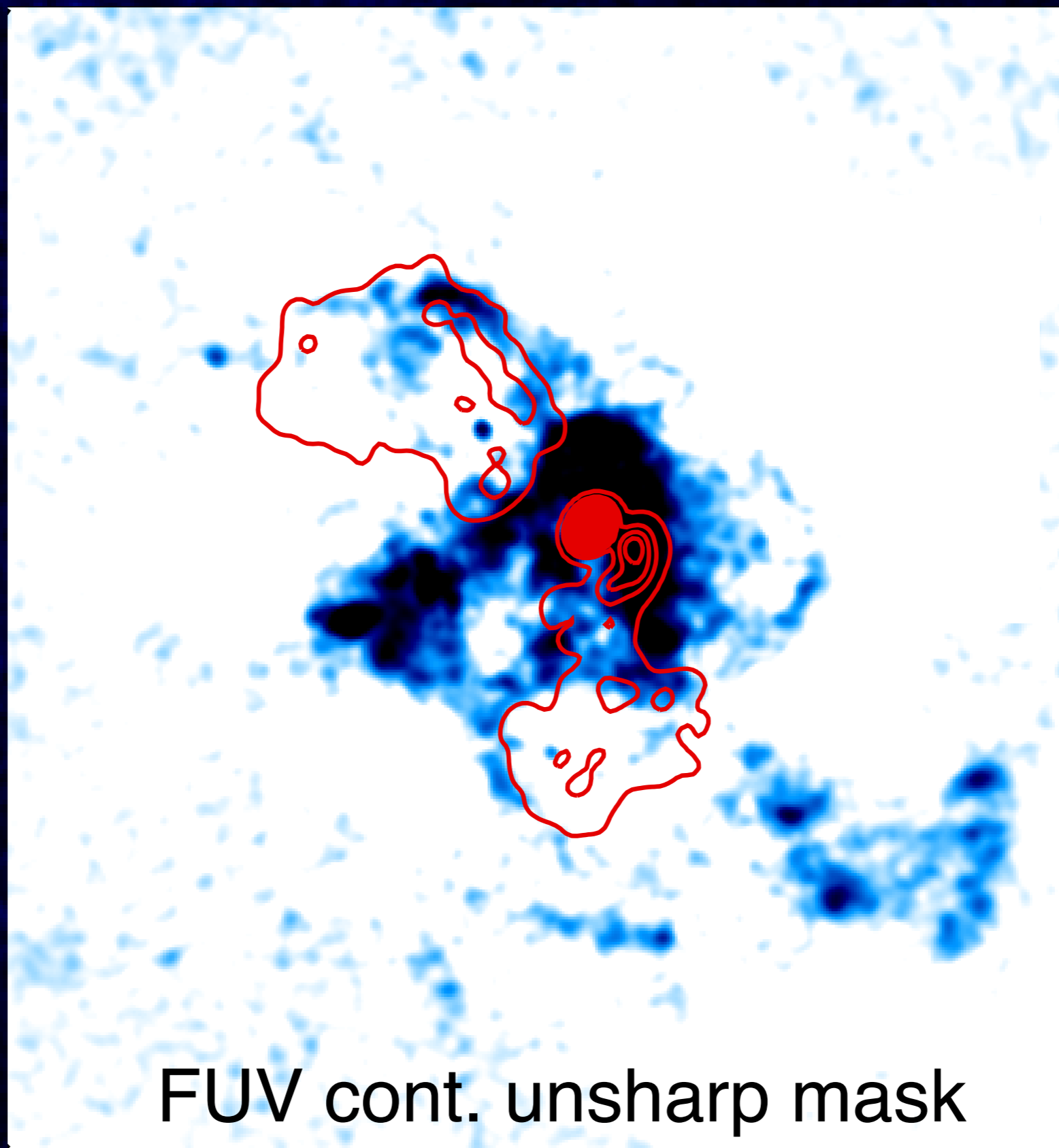




30 kpc

HST Ly-alpha

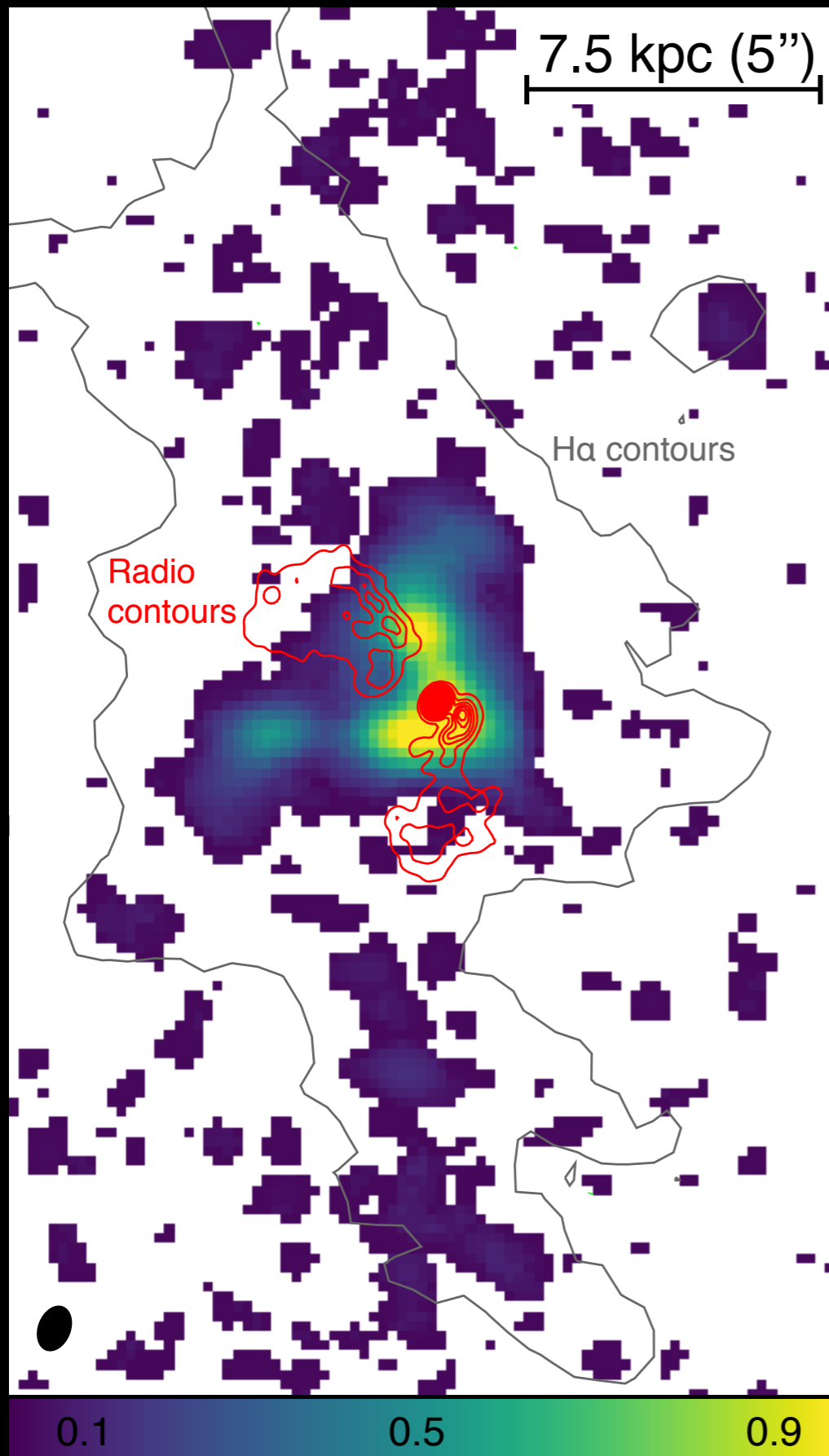
10 kpc



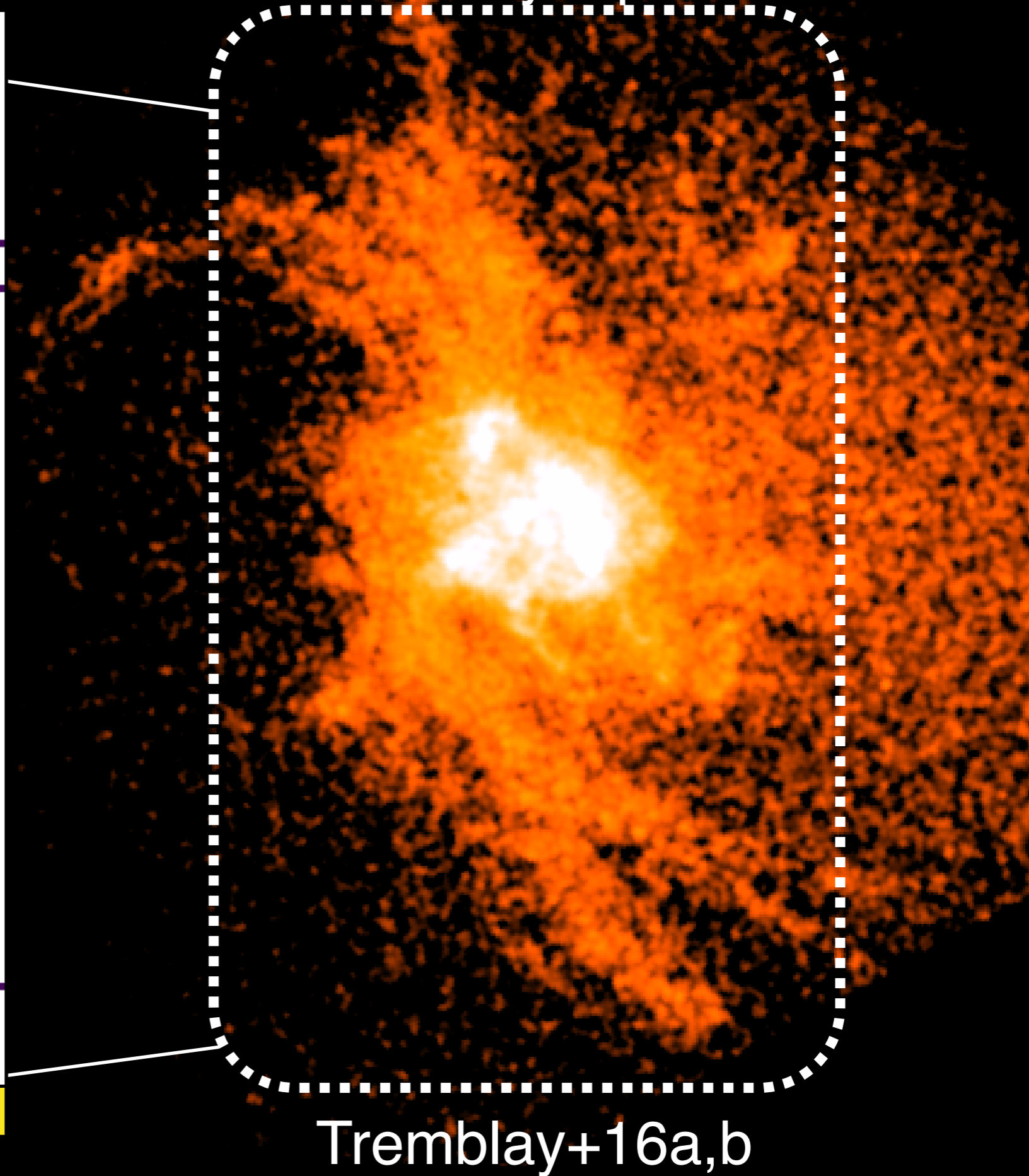
FUV cont. unsharp mask

HST FUV continuum
8.4 GHz radio contours

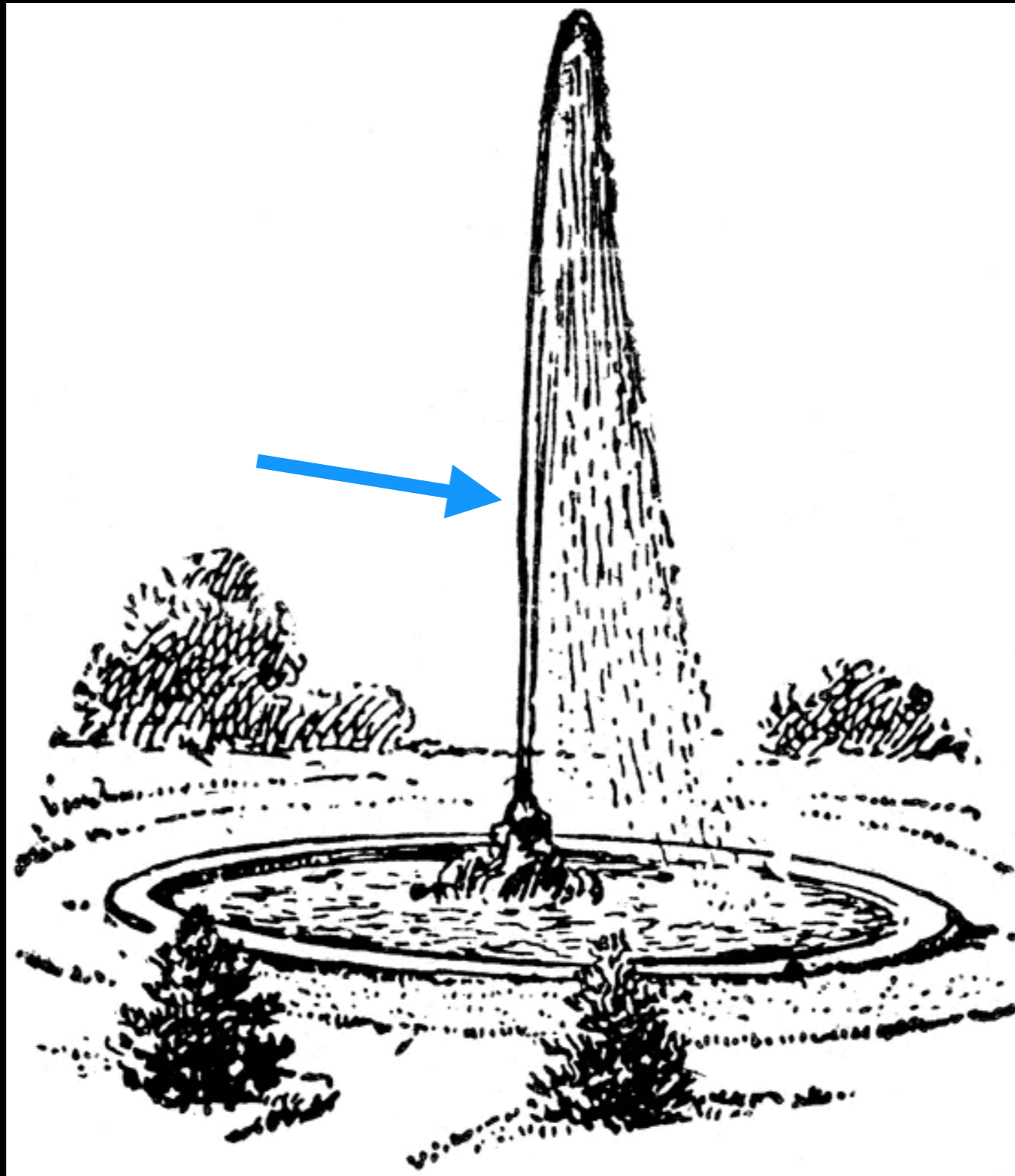
ALMA CO(2-1)

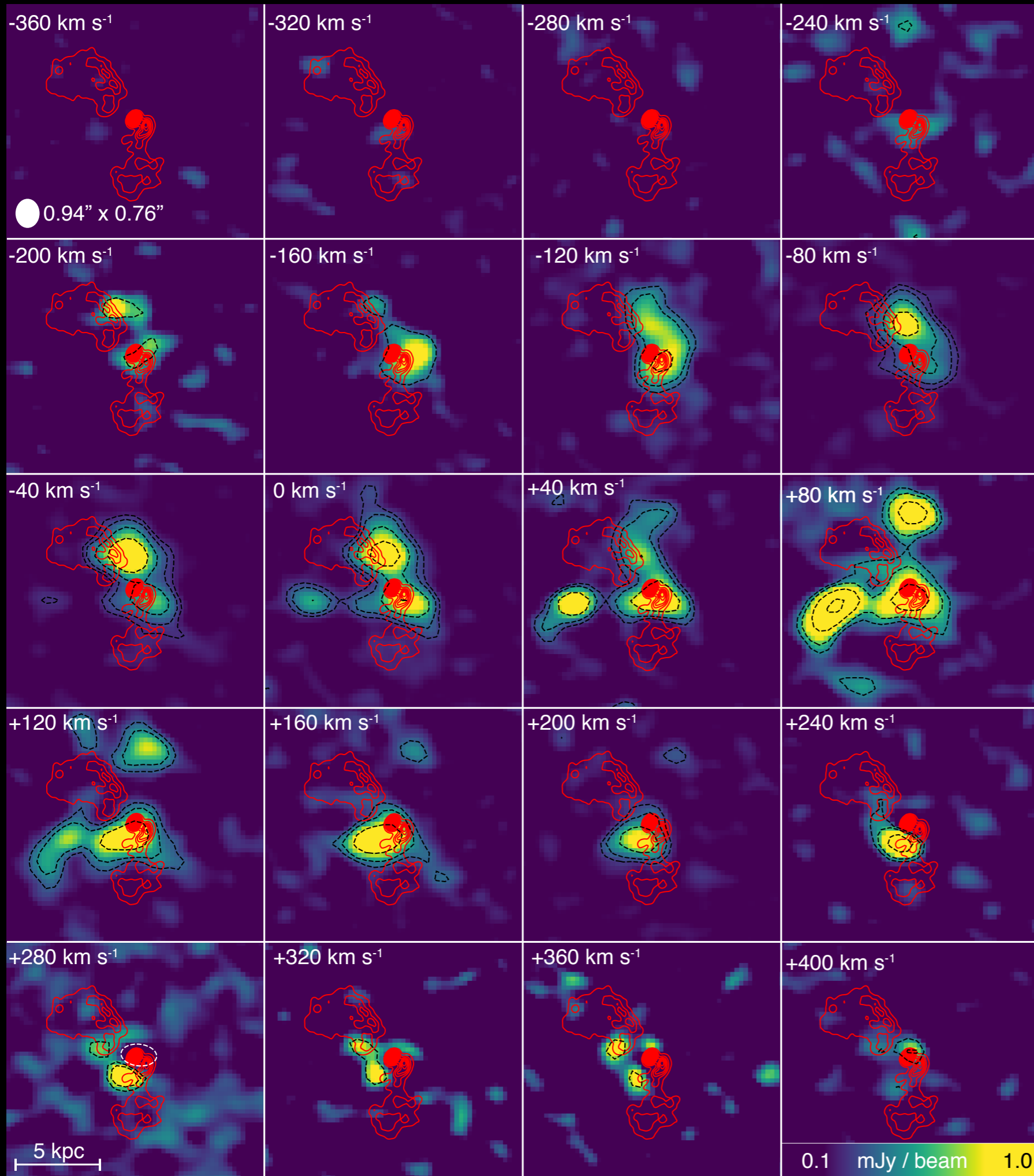


HST Ly-alpha



The Fountain's "Plume"

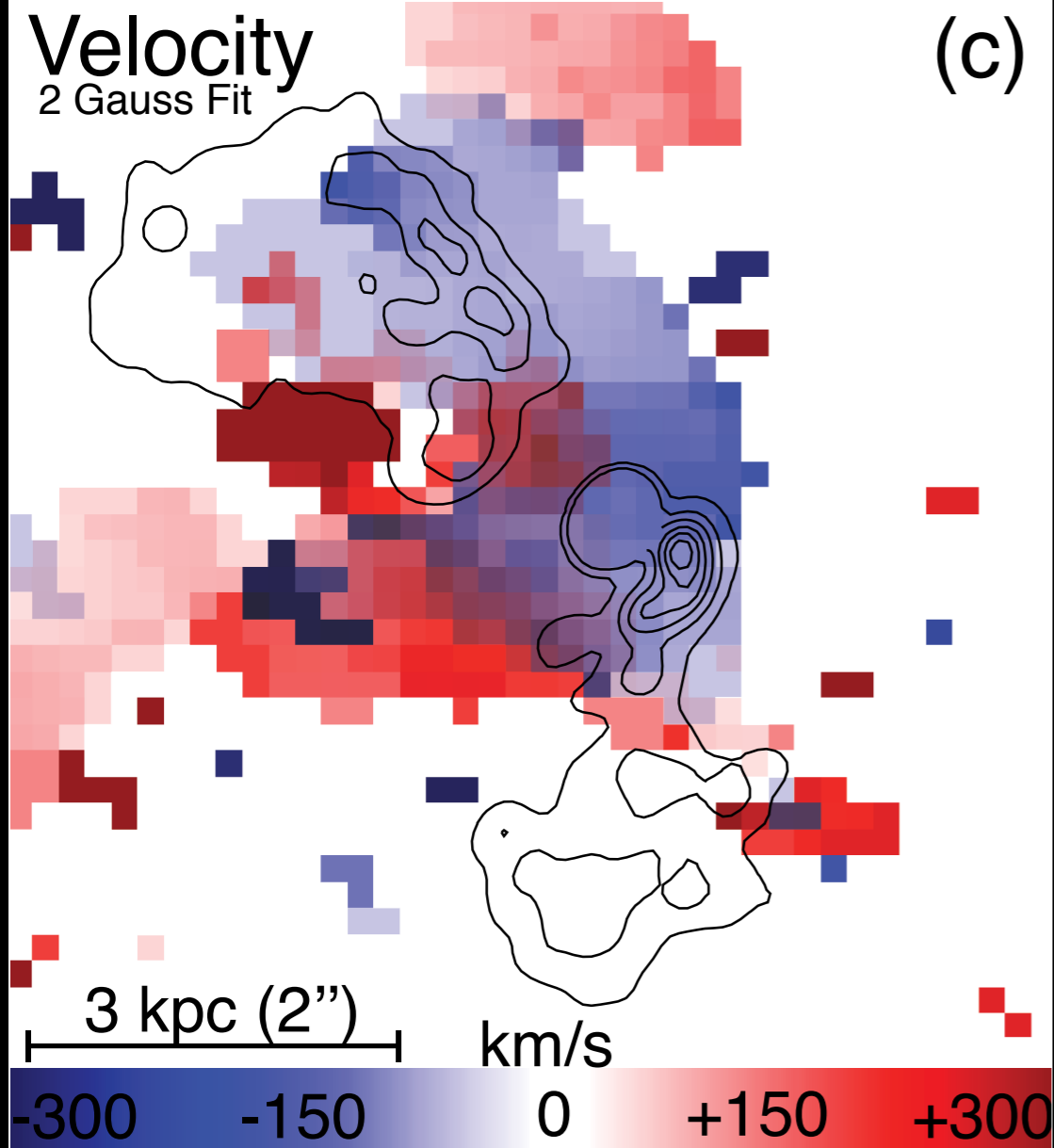




CO(2-1) channel maps

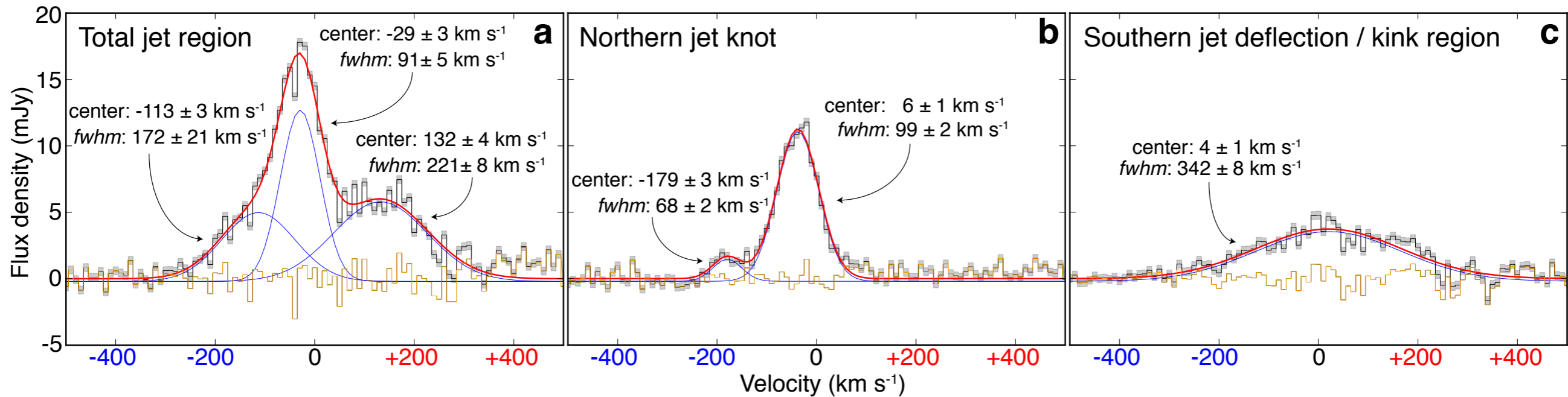
Structure over 700 km/s, clearly aligned with jet

Tremblay+16b

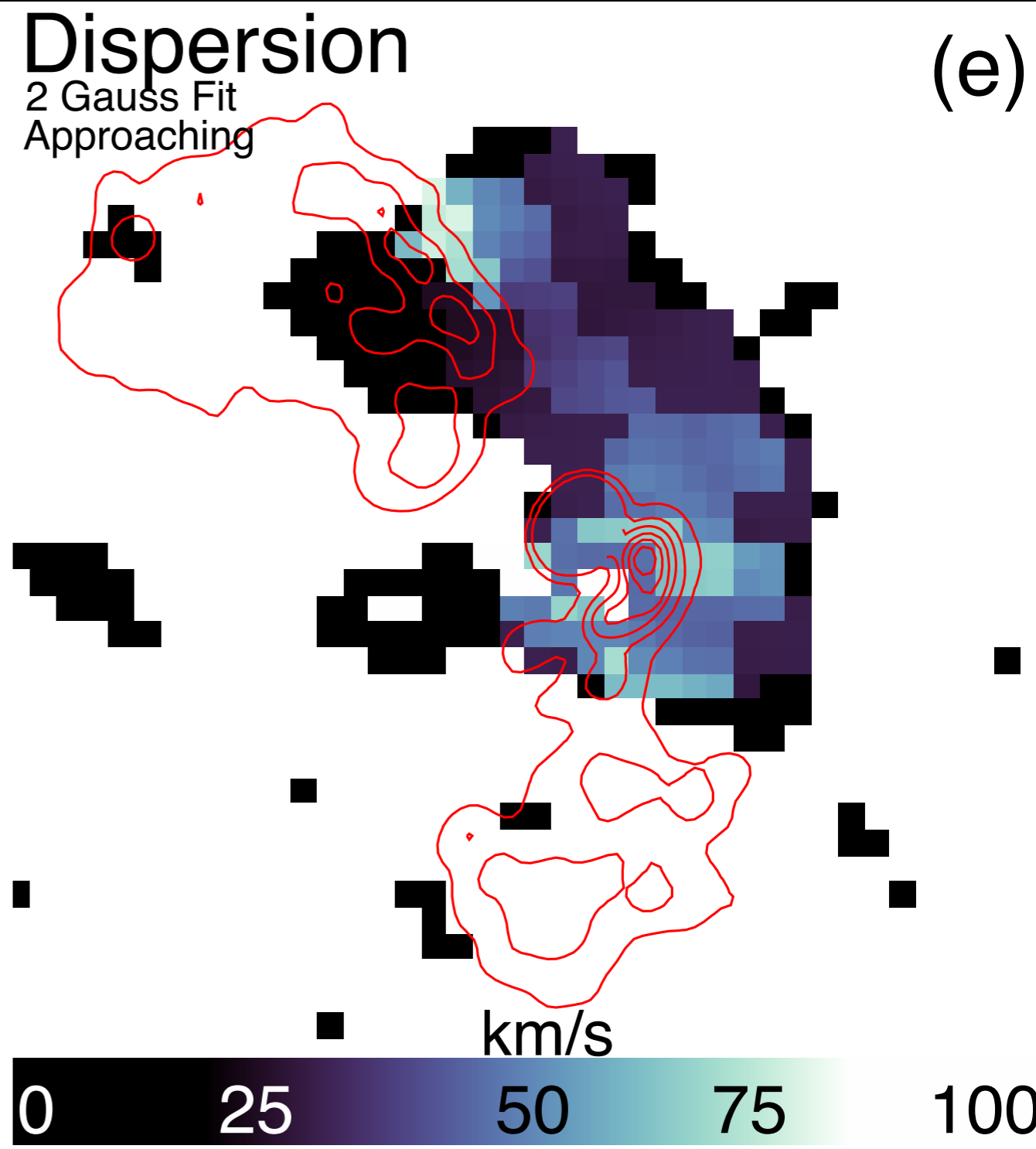
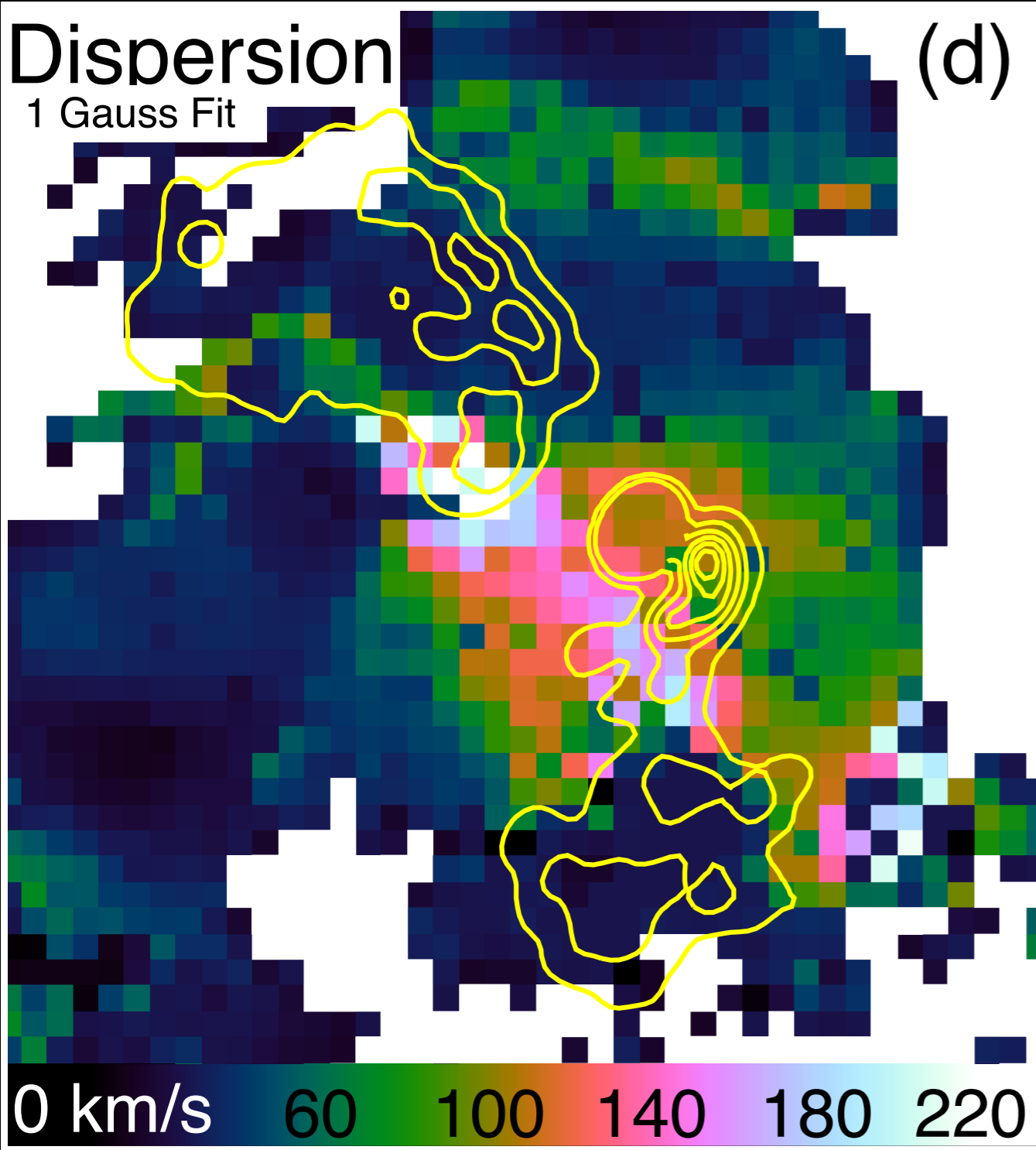


Cold “mist” may redirect jet

Tremblay+16b

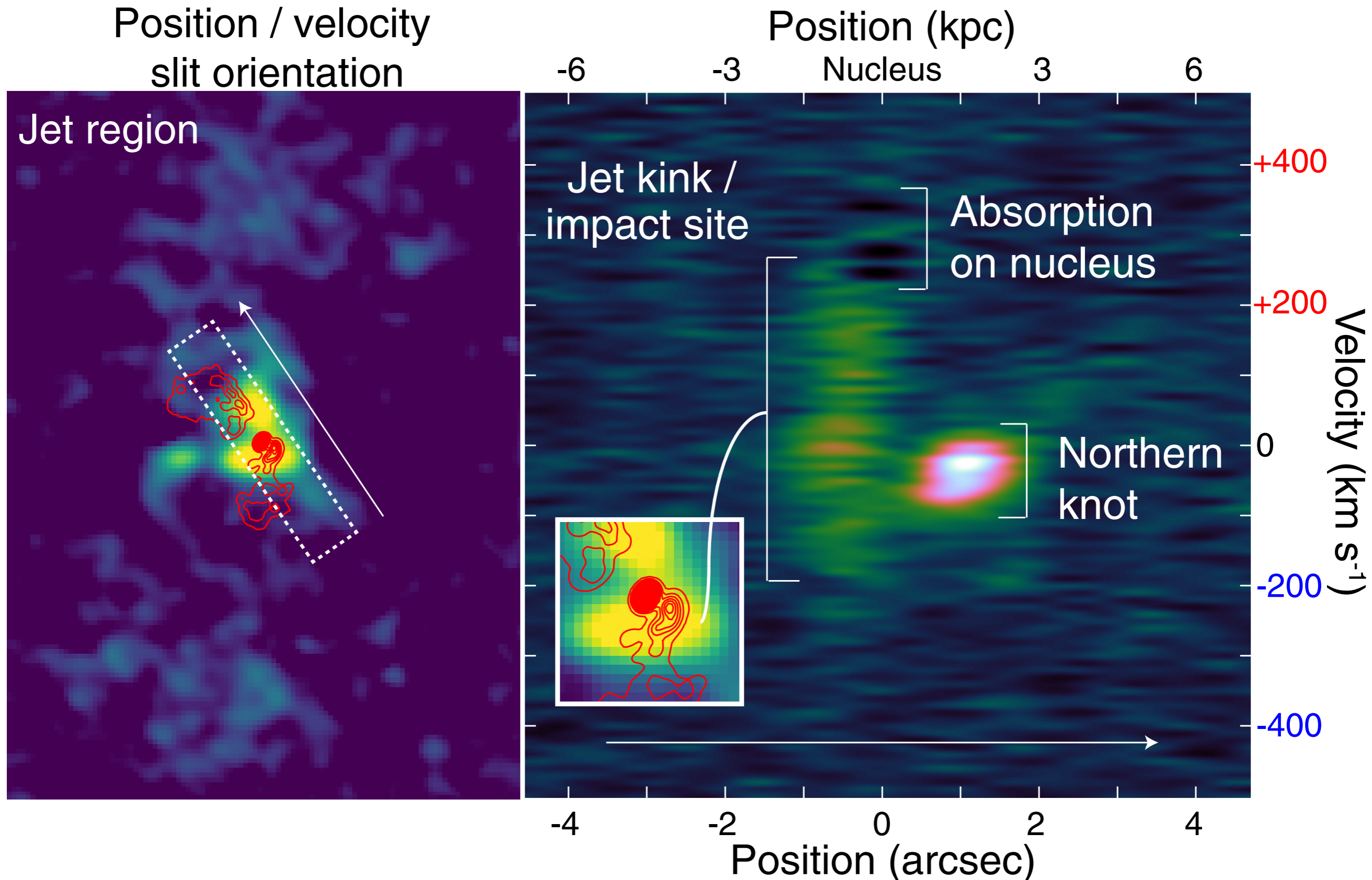


Cold “mist” stirred by the jet



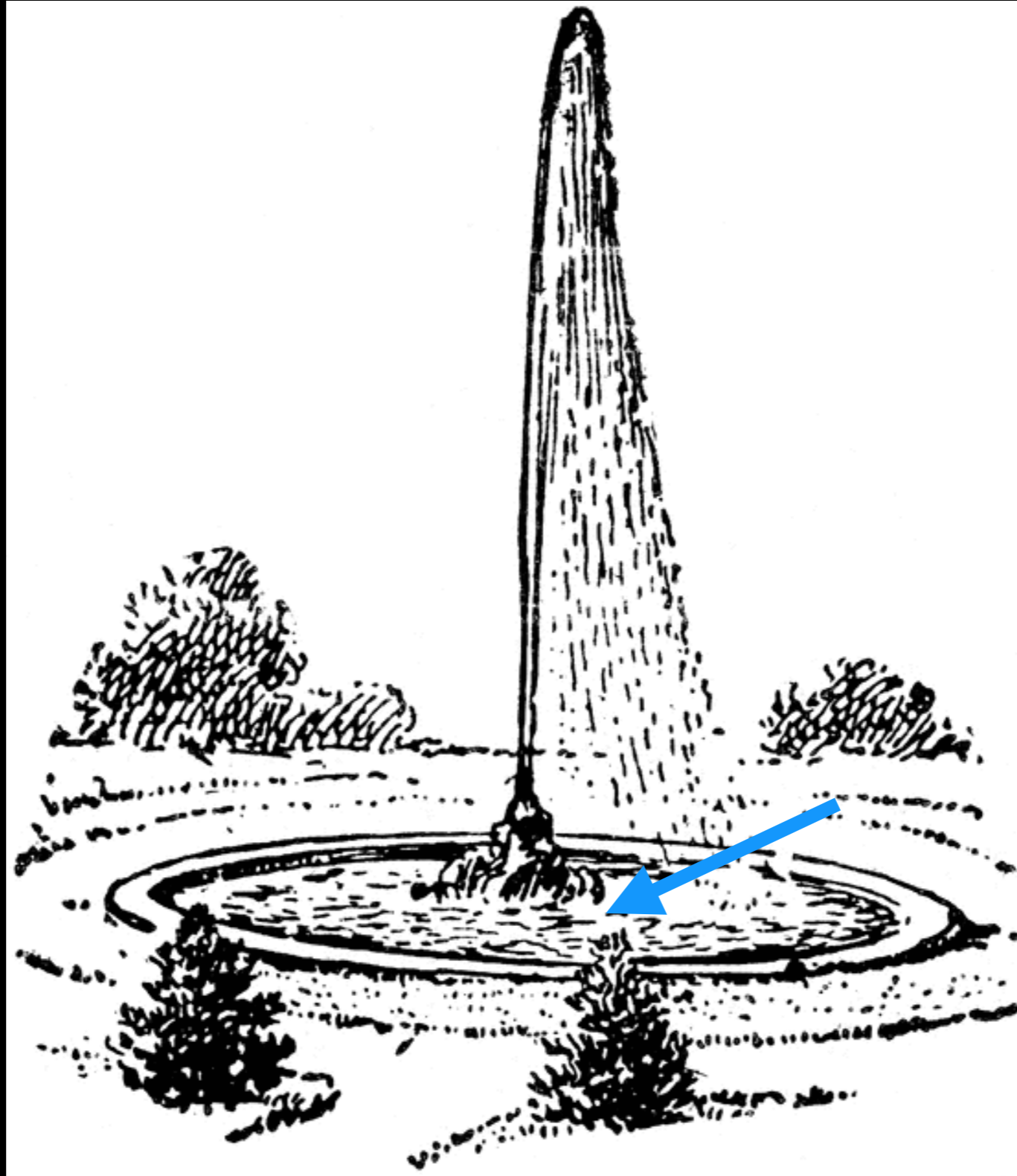
Tremblay+16b

Jet deflection site

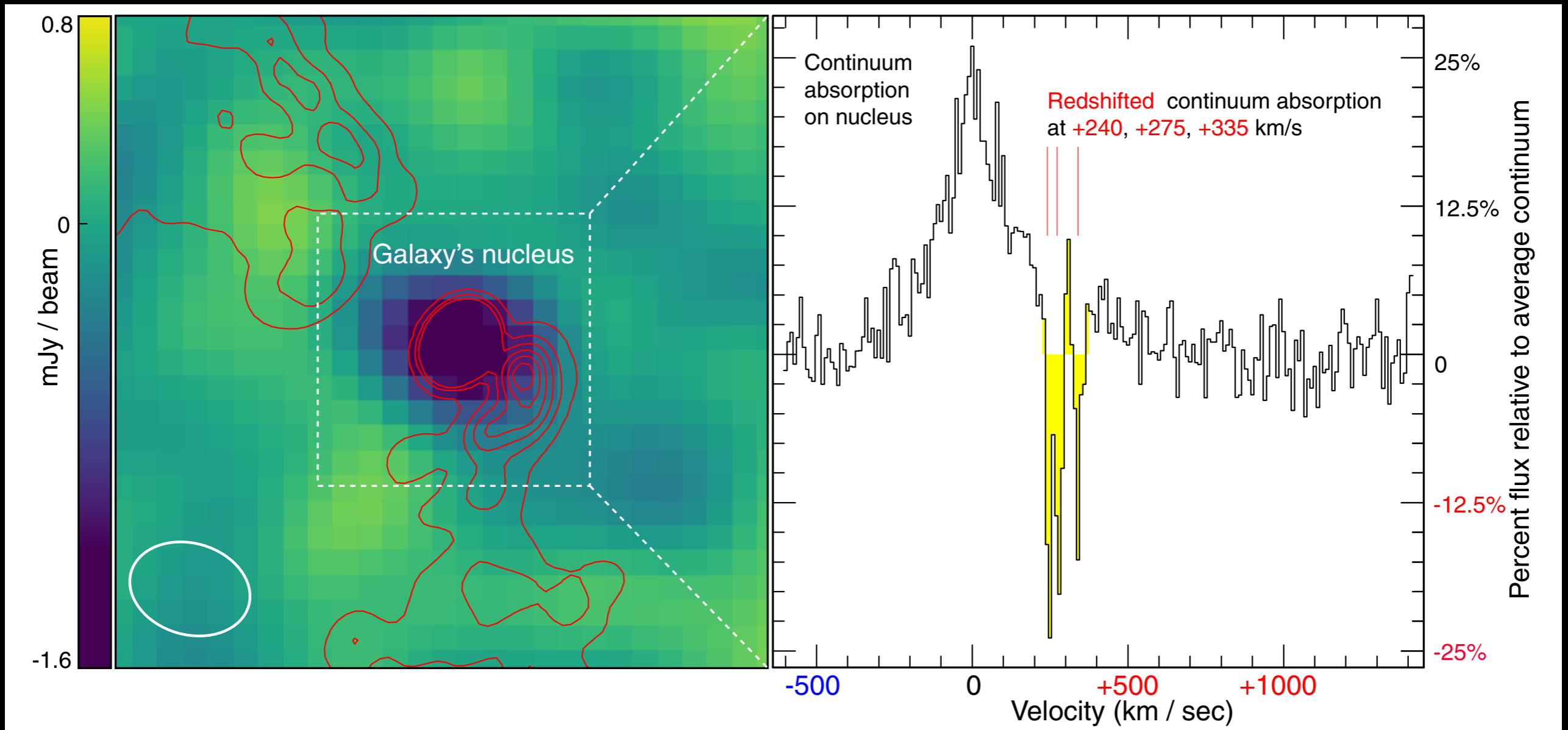


Tremblay+16b

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''

$10^{5-6} M_{\text{sol}}$ each

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

Low L , (nearly) radial orbit

<100 pc from BH, short ($\sim 10^6$ 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

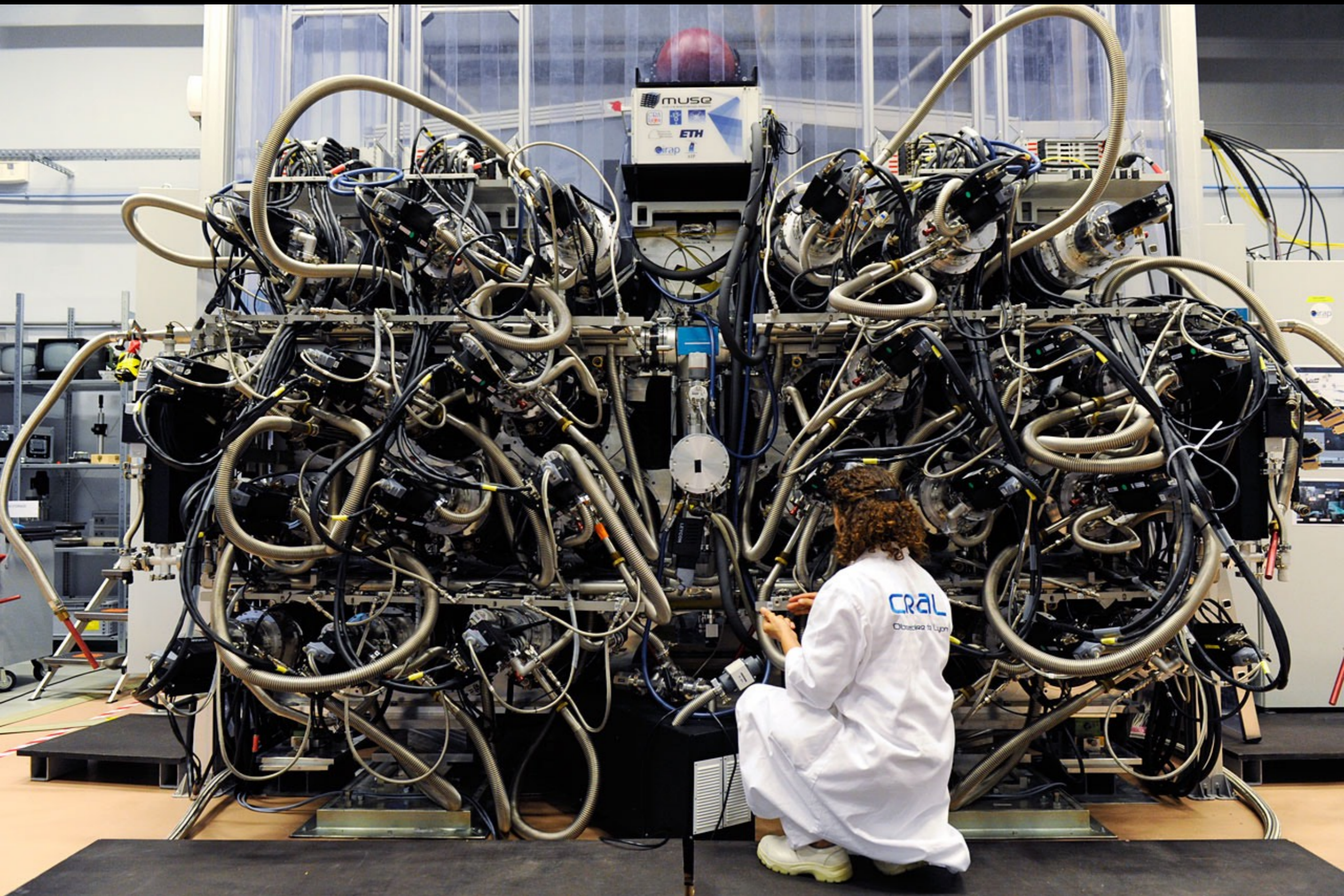
See Max's talk

for a *much* better explanation.

Shameless plug:



www.cars-survey.org



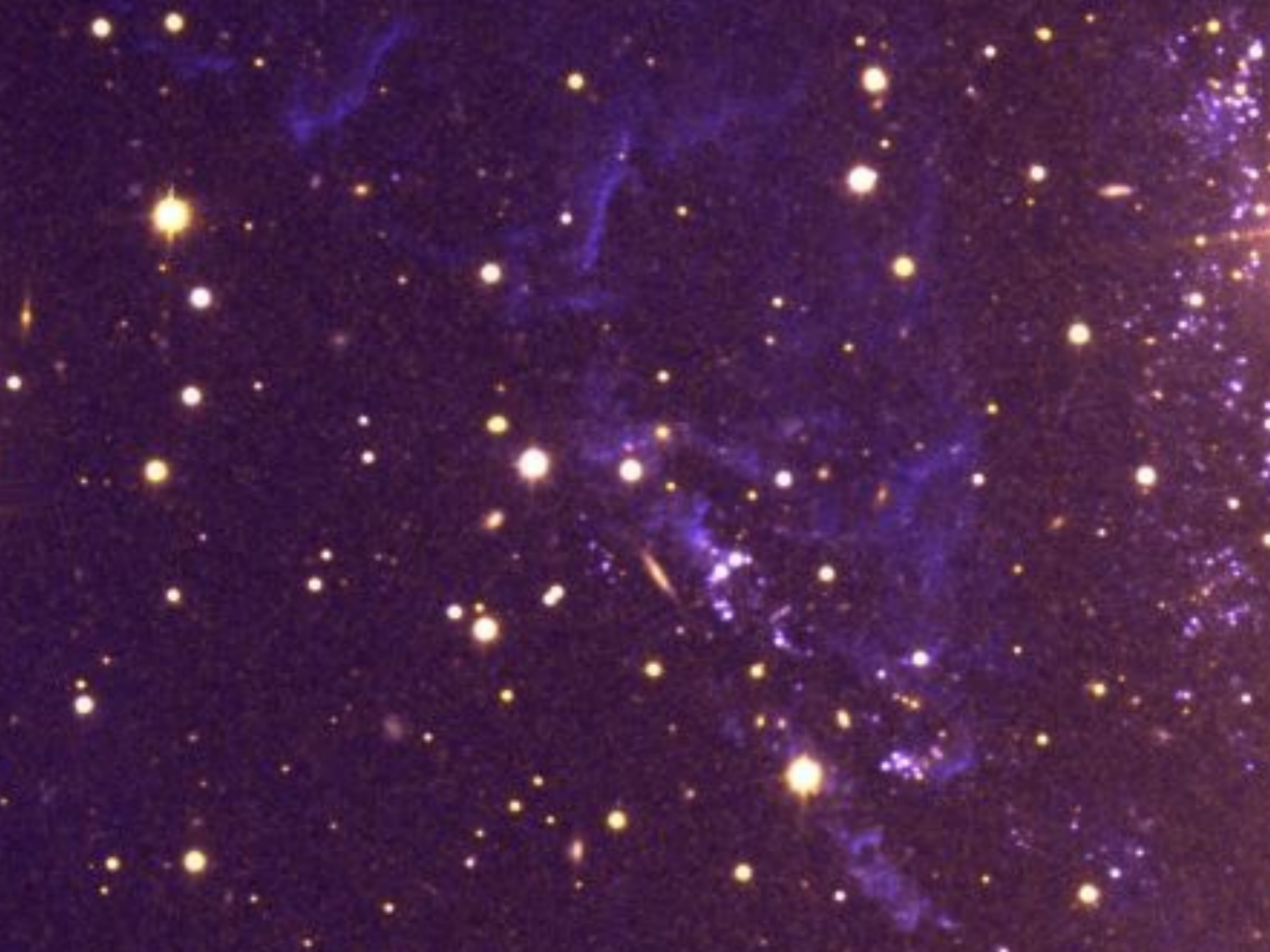




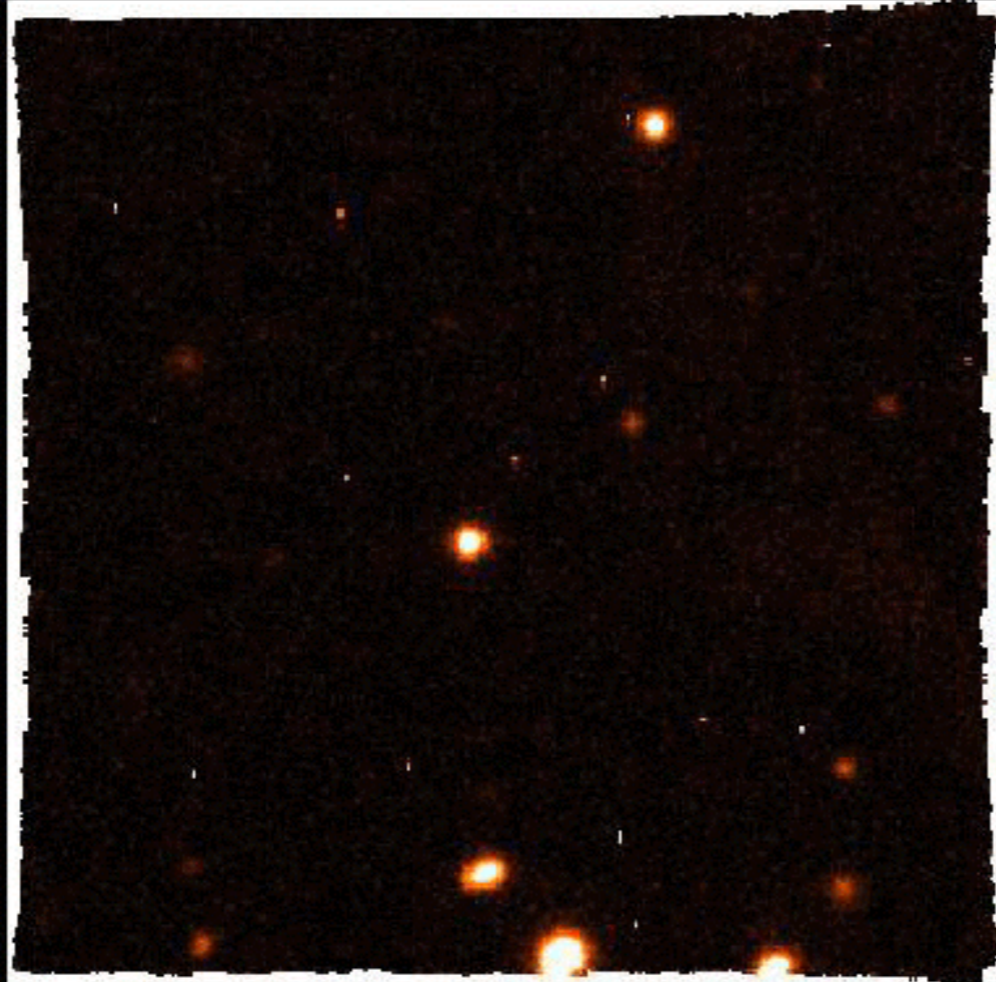




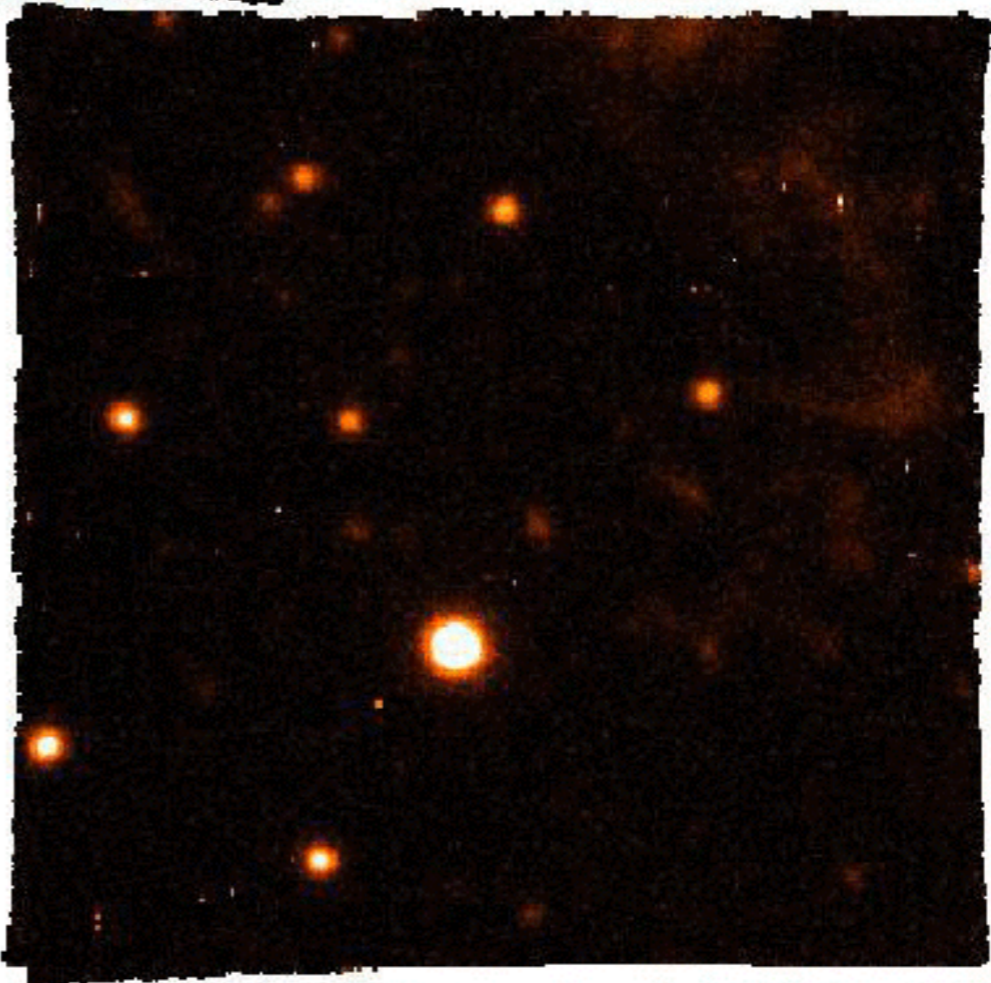
15 kpc from the galaxy's nucleus
VLT / FORS U+V band
Rejkuba+



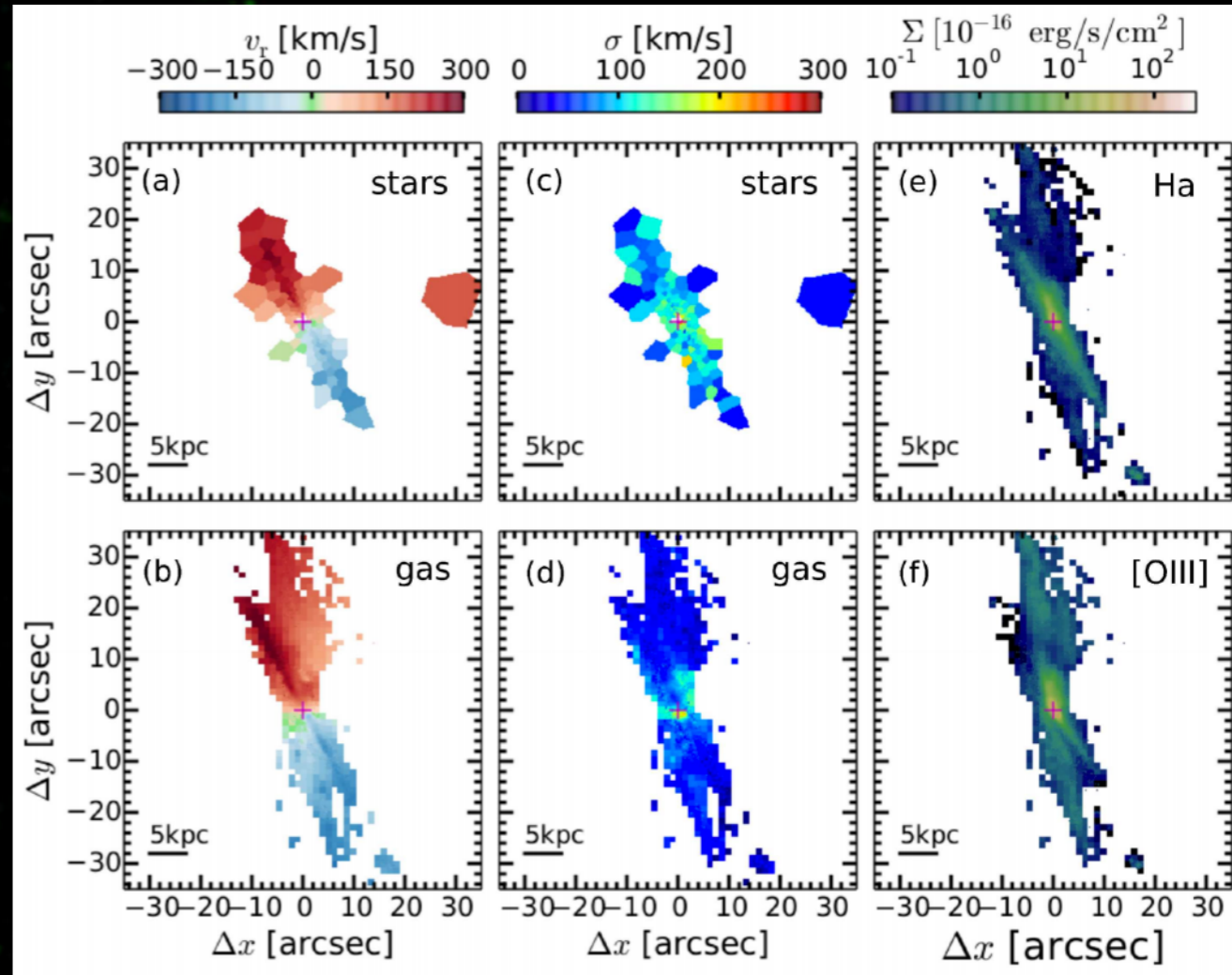
~2 kpc



MUSE H-alpha
Santoro+14
Hamer+15

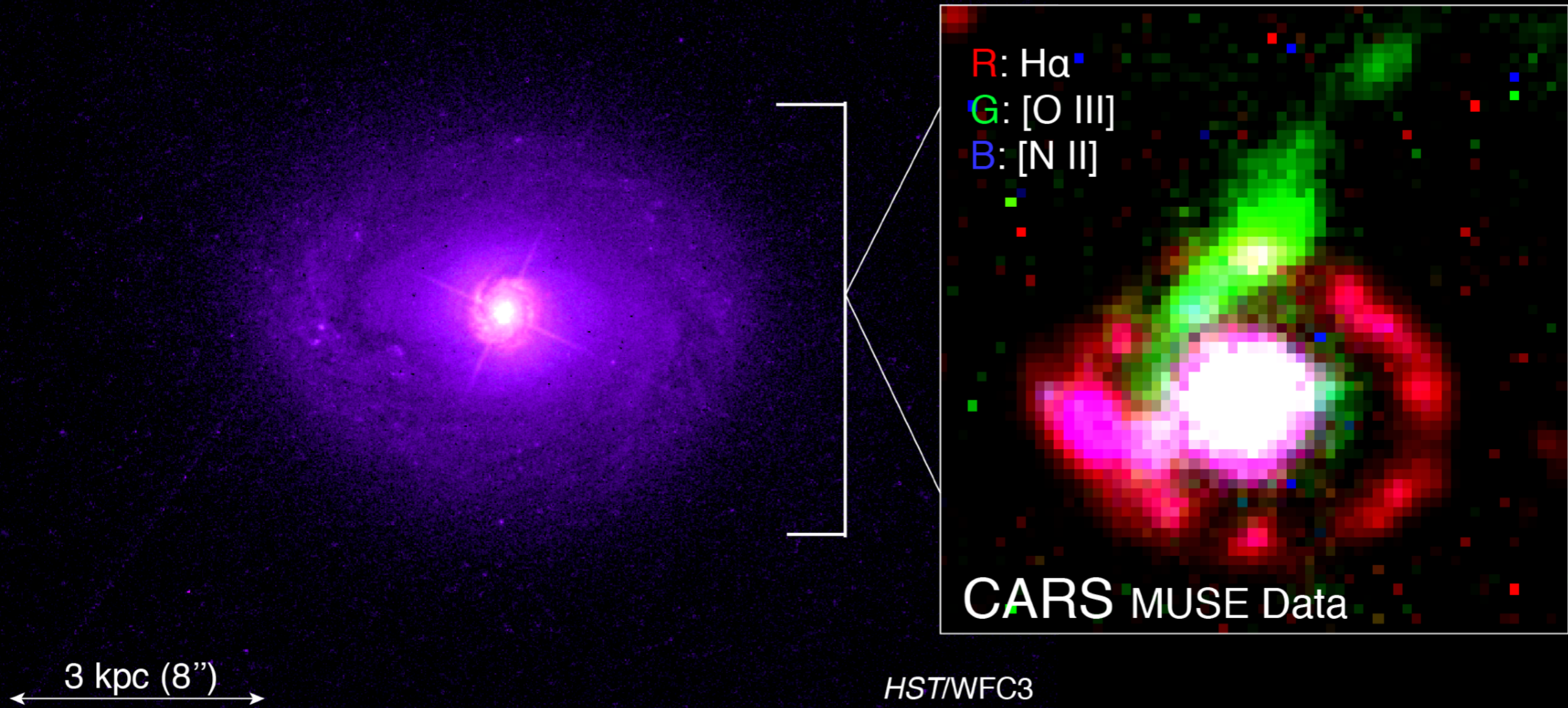


biconical
outflow



Mrk 1044 ($z=0.016$)

CARS *Chandra* Cycle 17 Target



HE 0351+0240 ($z = 0.03$)

R: H α
G: [O III]
B: Cont.

Apparent
Expansion
Direction

20'' (14 kpc)

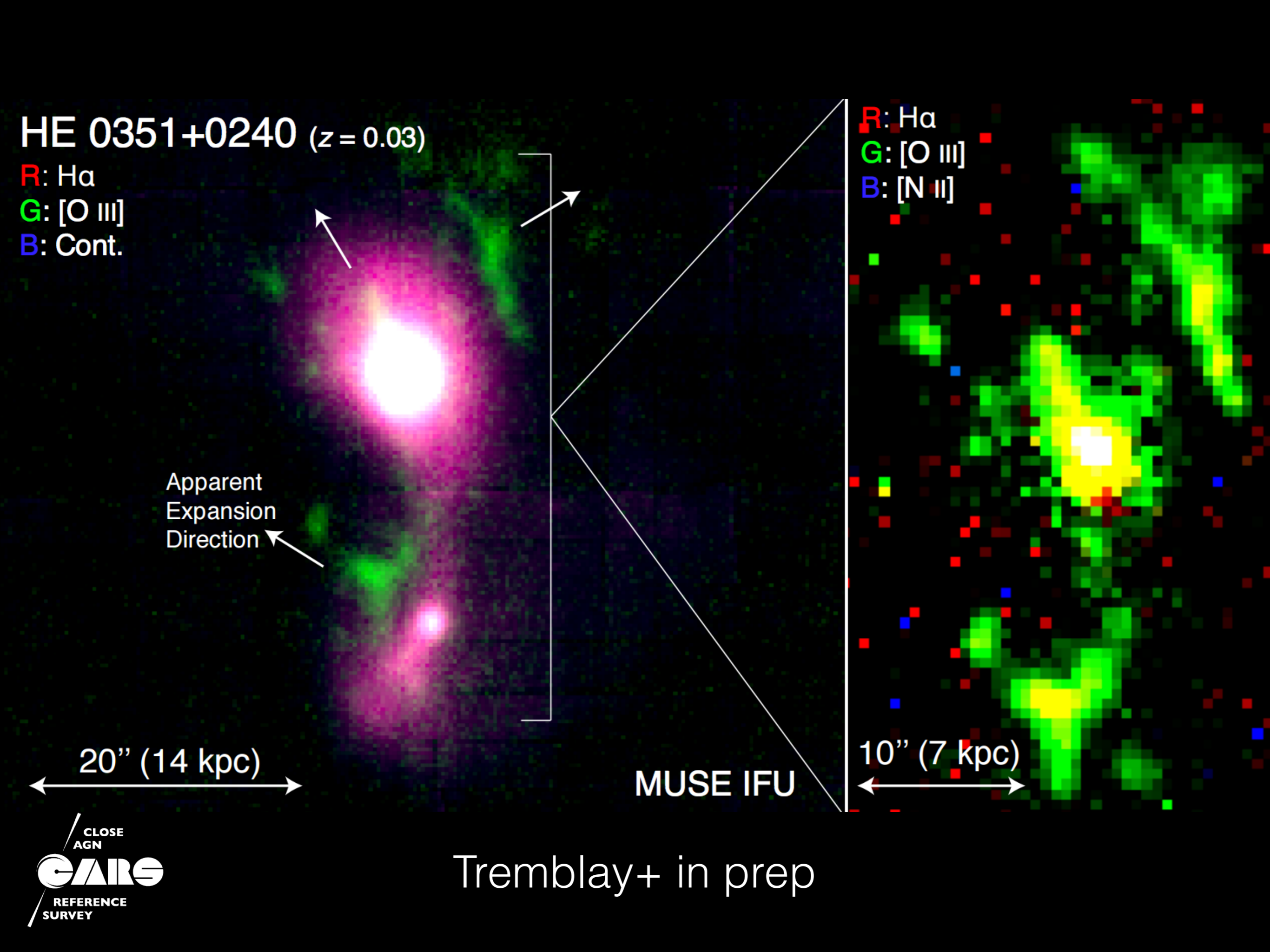
MUSE IFU

R: H α
G: [O III]
B: [N II]

10'' (7 kpc)

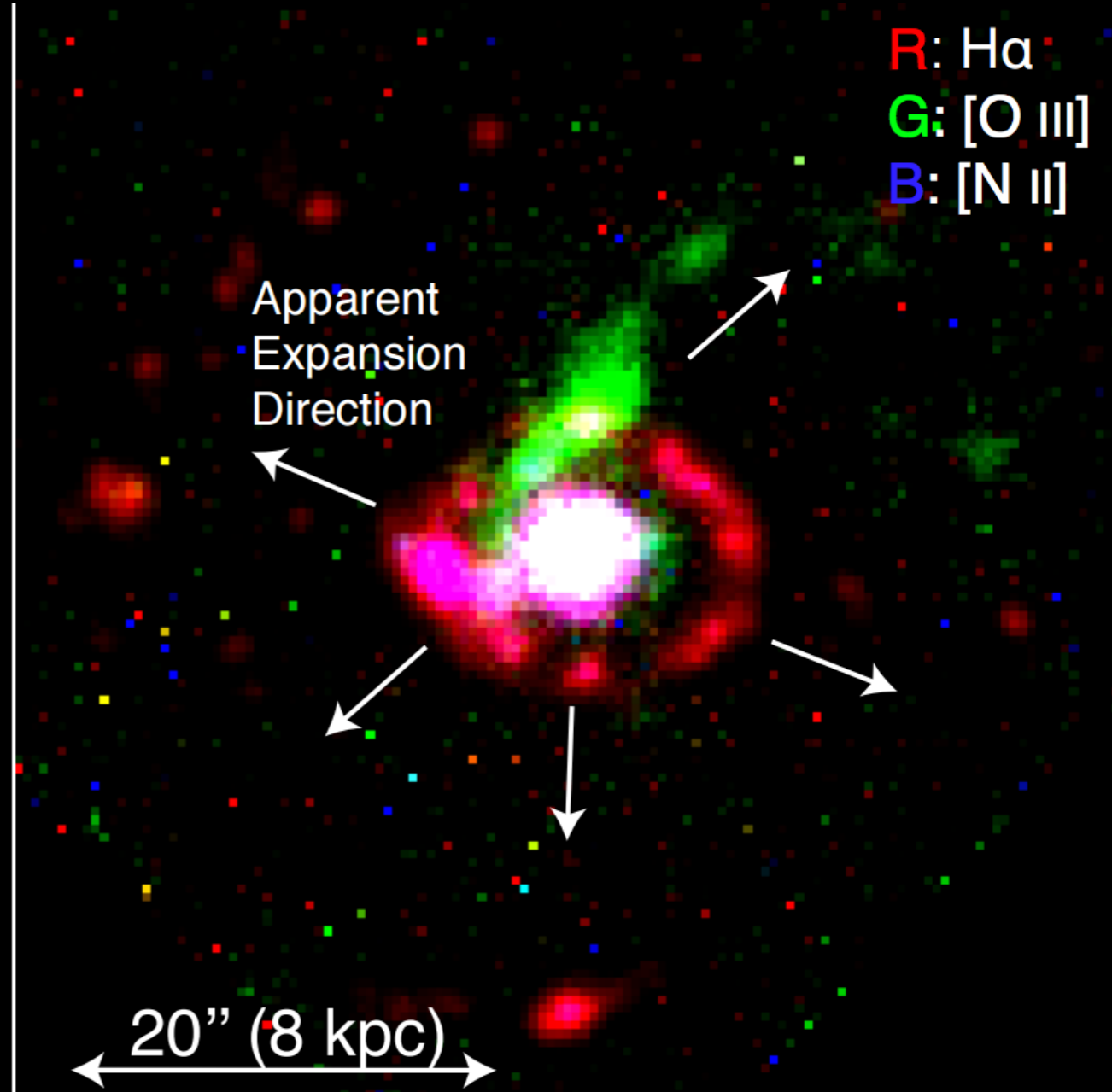
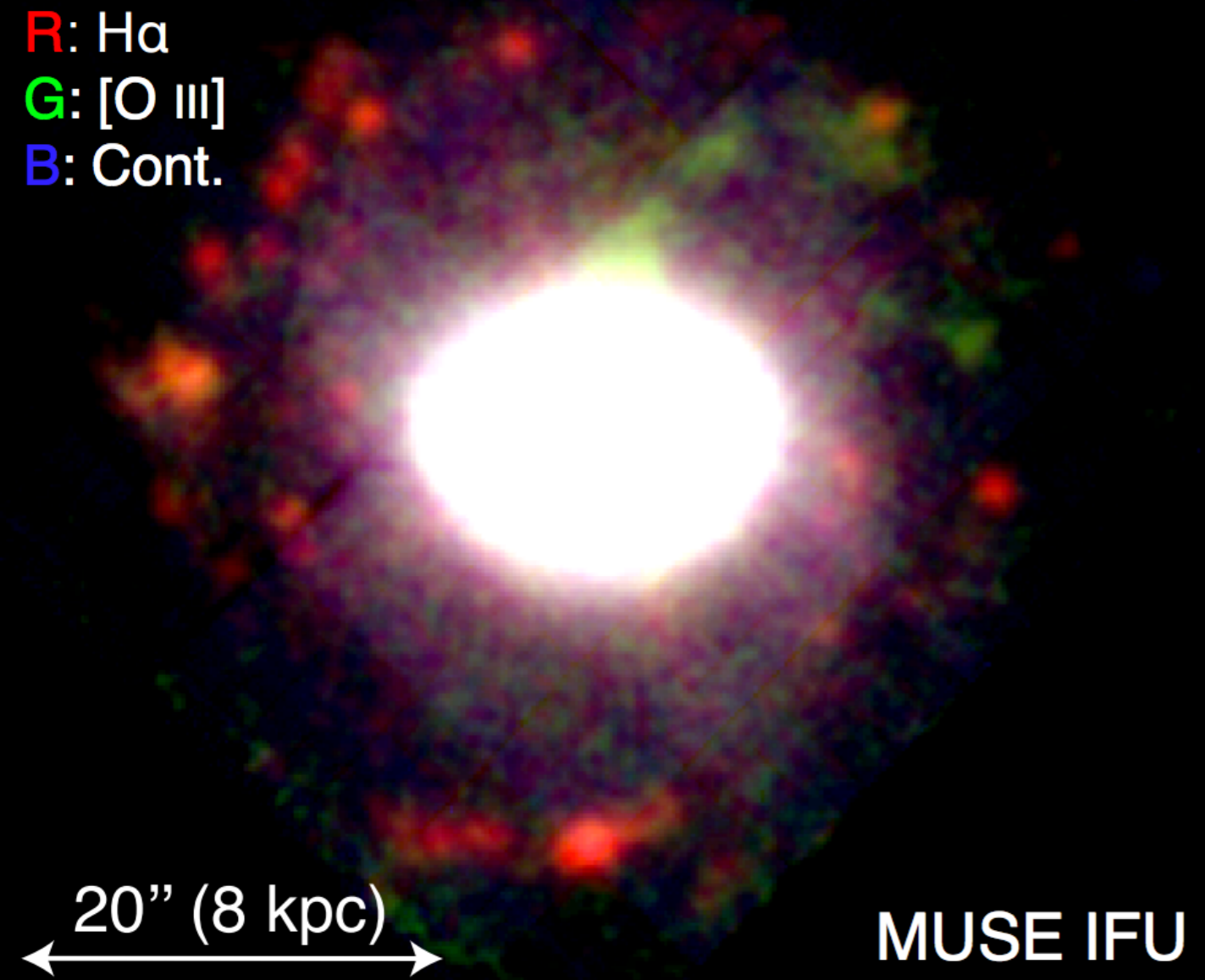


Tremblay+ in prep

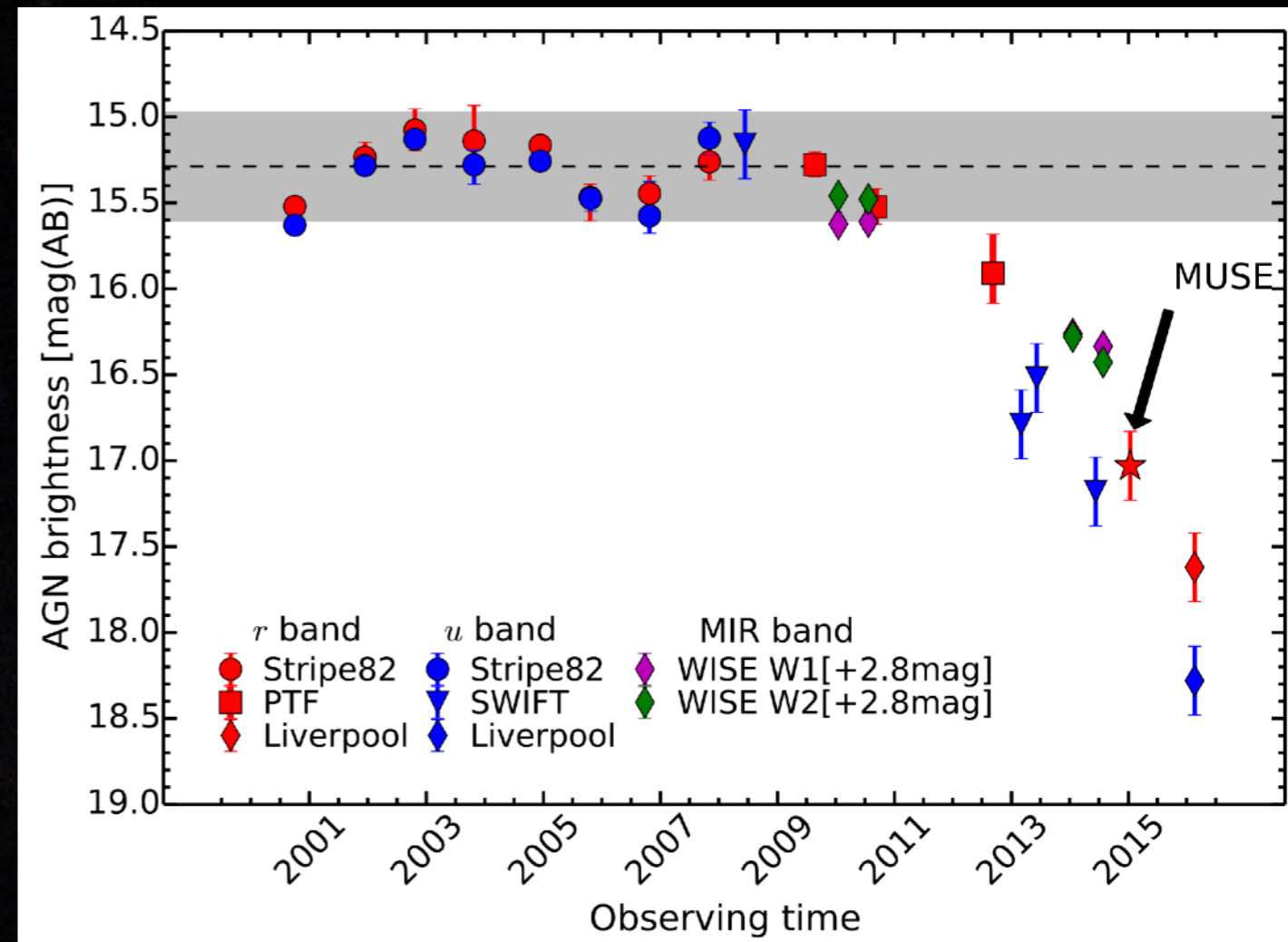


HE 0227-0931 ($z = 0.017$)

R: H α
G: [O III]
B: Cont.

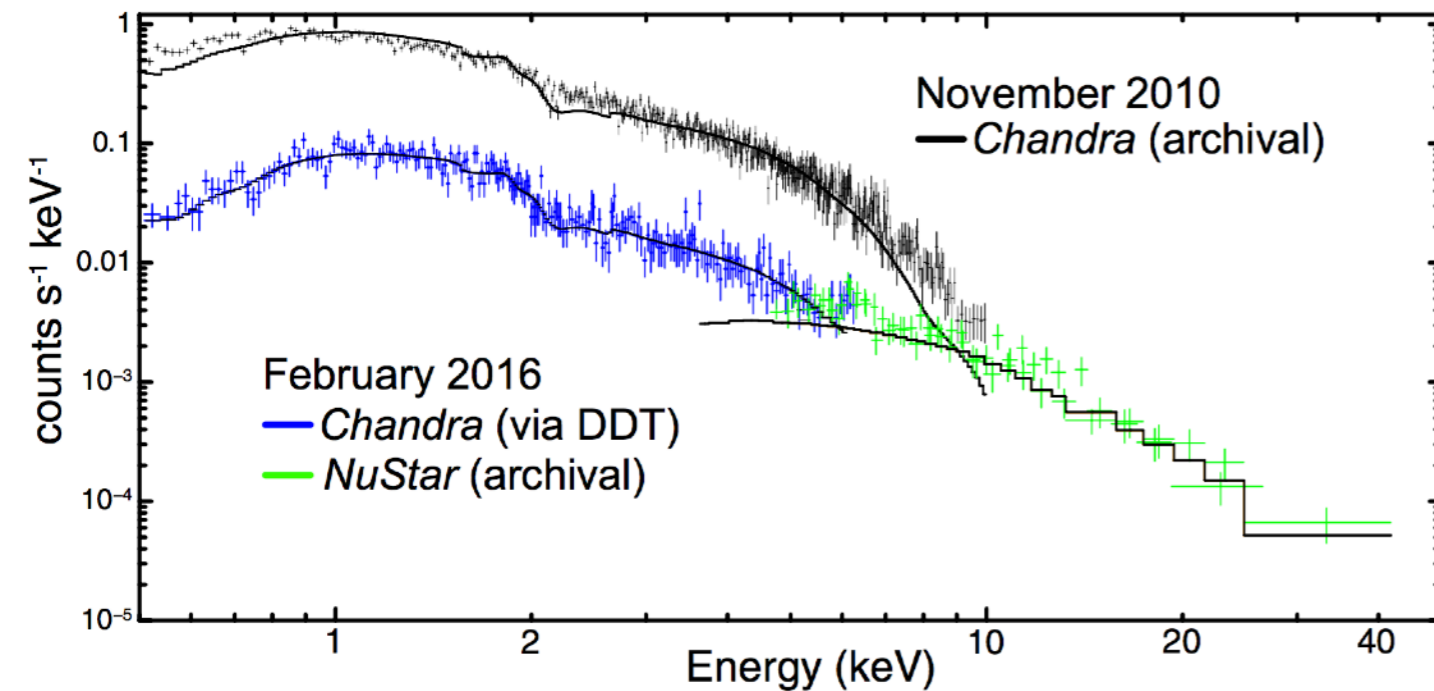


Mrk 1018's second return to the shadows

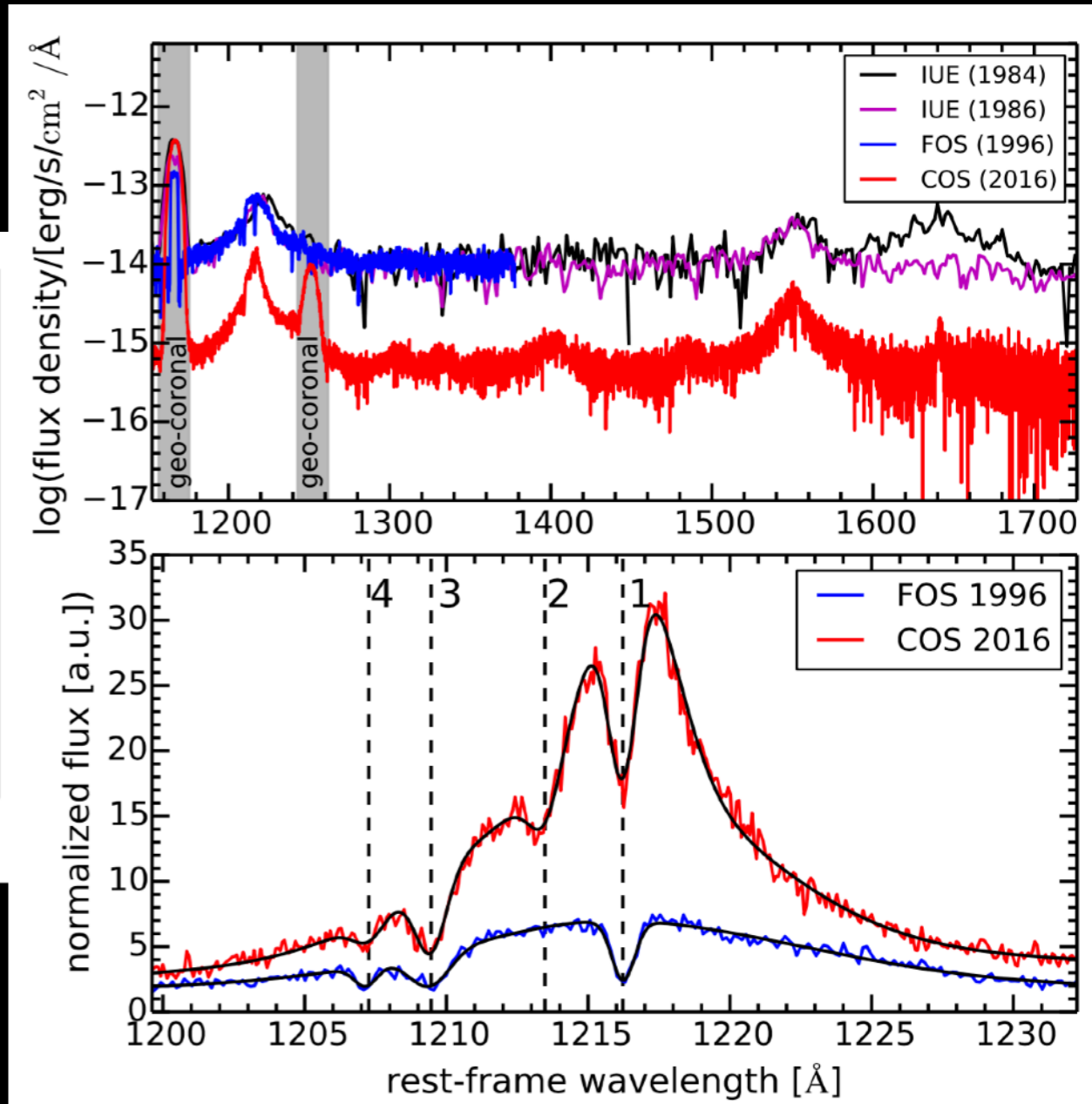


McElroy+16
Husemann+16

Chandra DDT



HST / COS DDT



Thanks, Belinda! :)

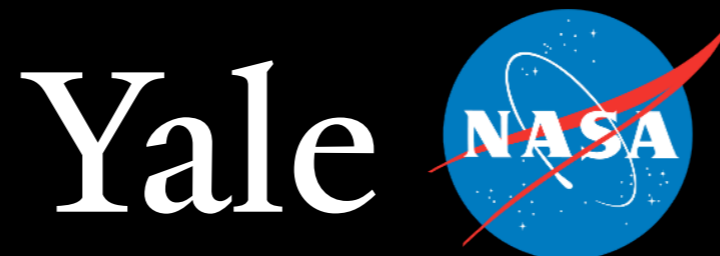
McElroy+16
Husemann+16

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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