# NGC 1275—Feedback in Action

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# **PERSEUS (A426)-Cool Core Cluster**

*Chandra* reveals complex galaxy-cluster IGM connections (A. Fabian+)

Dispersion 1030 km/s

M~$5 \times 10^{14}$ Msun, $M_{gas}$~$7 \times 10^{13}$ Msun

NGC 1275 BCG-***Laboratory for feedback***

Sanders & Fabian 2007, MNRAS, 381, 1381

*Sound waves in the Perseus cluster core* 1383

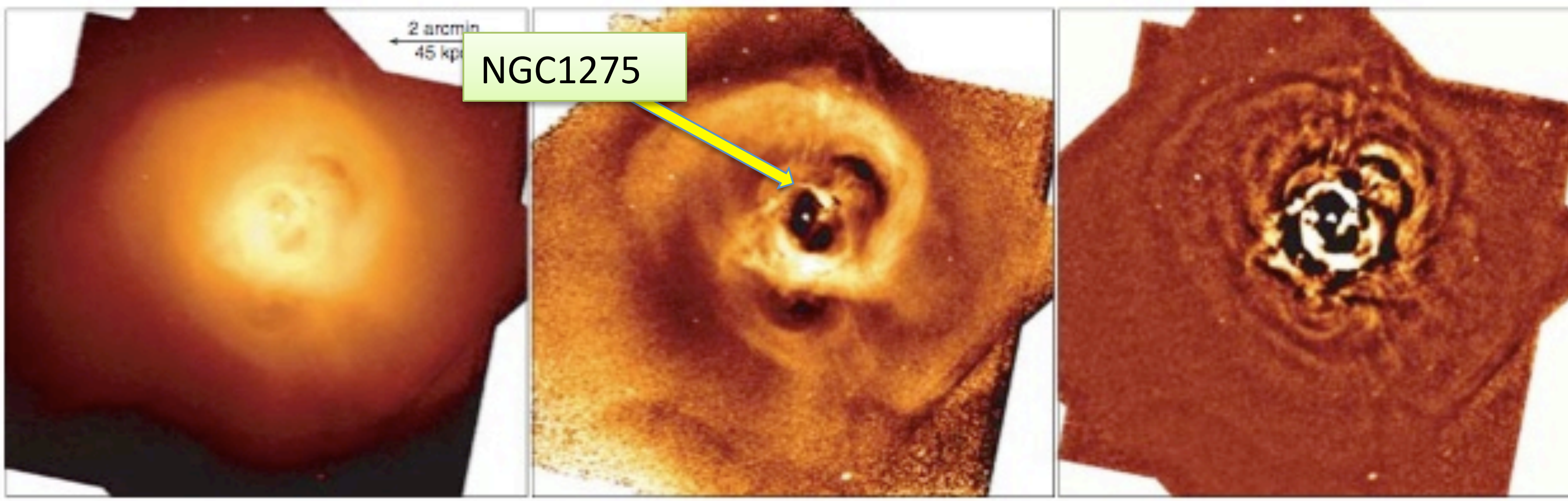



**Figure 1.** Surface brightness images of the cluster. Left-hand panel: 0.3–7 keV full-band X-ray exposure-map-corrected image, smoothed with a Gaussian of 1.5 arcsec. Middle panel: Image after subtracting King model fits to 40 sectors, smoothed with a Gaussian of 1.75 arcsec. Right-hand panel: Original image after high-pass filtering, then smoothing with a Gaussian of 1.5 arcsec.

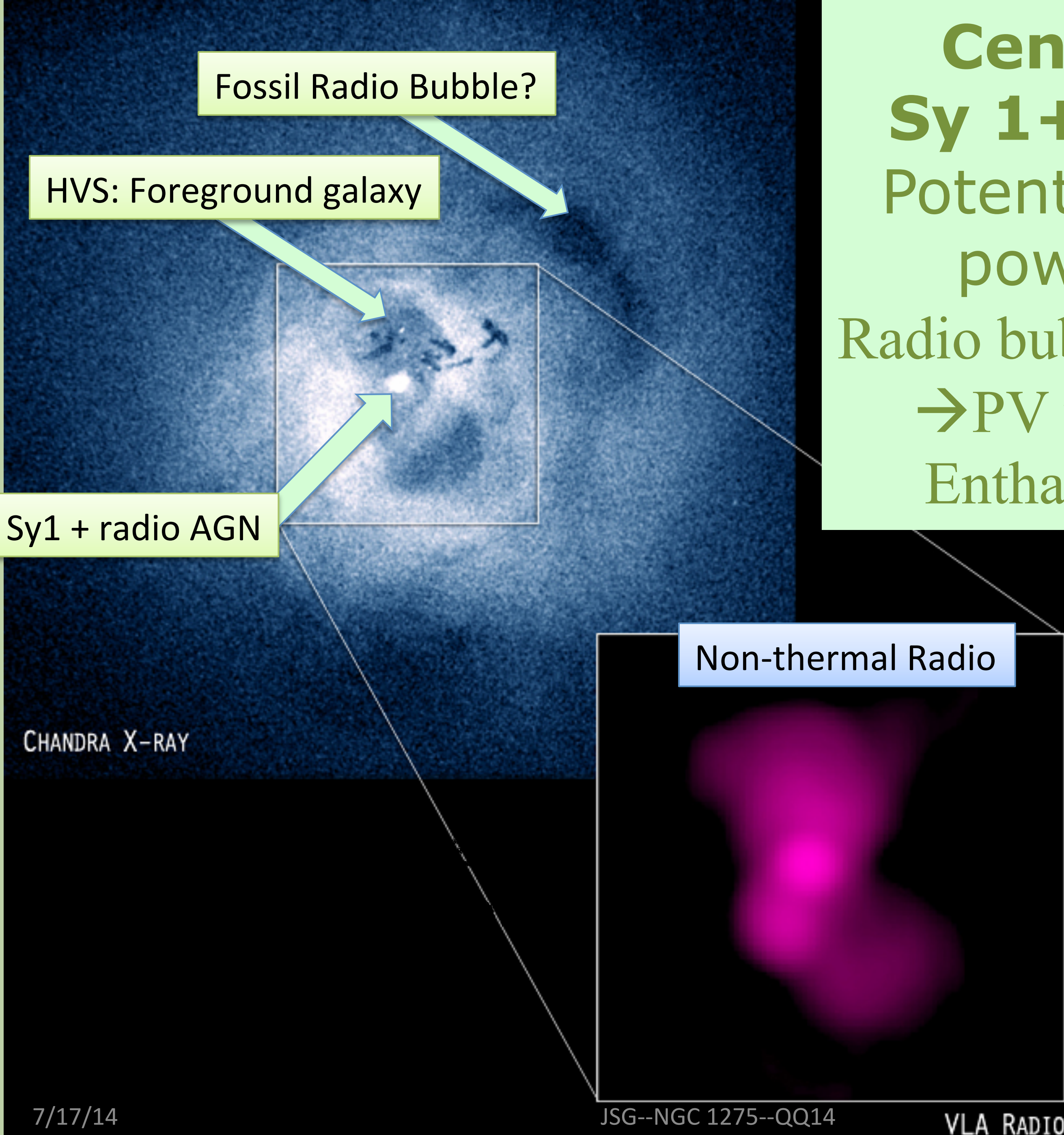
# Central AGN: Sy 1+ radio jets

Potential feedback power source

Radio bubble--X-ray void

→PV work by AGN

Enthalpy~3E59 erg




BUT inflow is semi-spherical and radio lobes are roughly bipolar.

Q14

# High Velocity System

***~3000 km/s redshift***

with respect to N1275

Absorbing cool gas-disrupted galaxy (spiral?) well in front of Per A

(Rubin et al. 1977, ApJ, 211)

D>60 kpc

M(gas) ~ 1E9 Msun

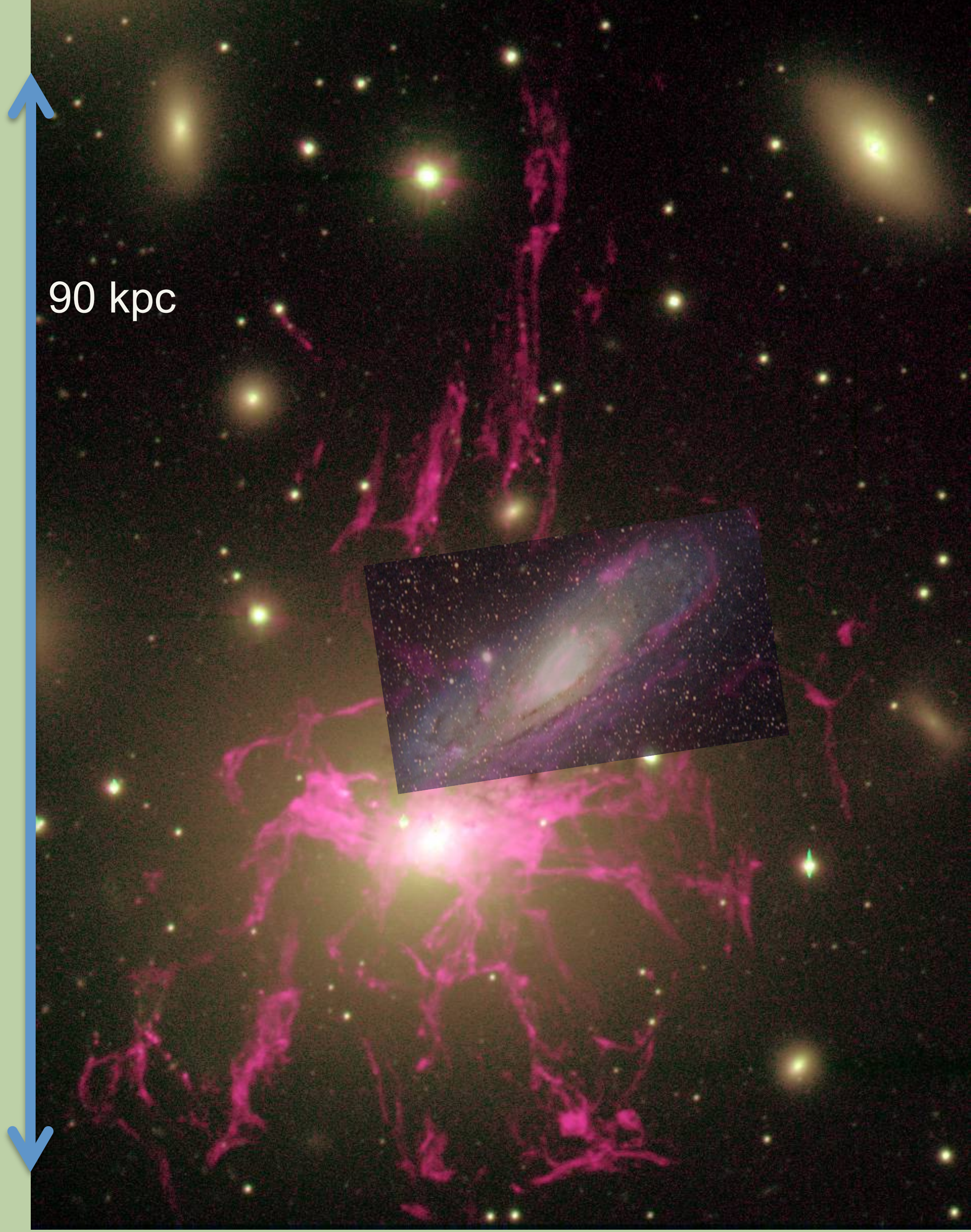
KE(gas) ~ $10^{59}$ erg

Gas from infalling galaxy a heating factor

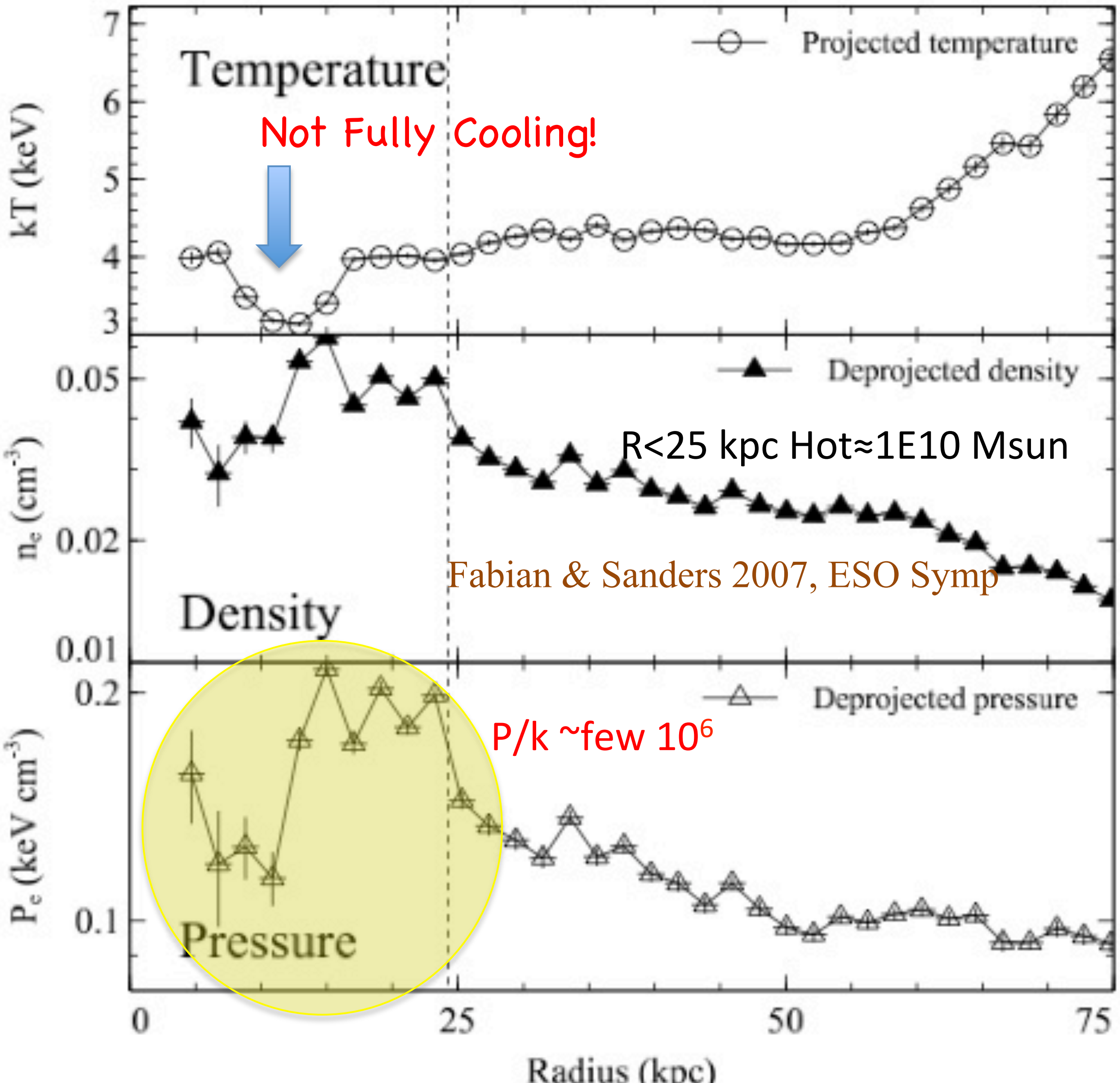
Gillmon et al. 2004, MNRAS, 348, 159; Sanders & Fabian 2007, MNRAS, 381, 1381

# BCG
# NGC1275
# $M_*$~$6x10^{11}$ Msun

# Giant Ionized Gas Filaments/ Sheets→ Signatures of ongoing feedback?




Conselice et al. WIYN 3.5-m




Optical galaxy over-pressured?
R<25 kpc :
**$10^{10}$ Msun of ICM**

Hydrostatic pressure equilibrium
→
Ionized gas density
~$10^2$ cm$^{-3}$ @ T=$10^4$ K

Molecular gas
~$10^4$ cm$^{-3}$ @ T=$10^2$ K

$B_{eq} \approx 100\ \mu G$

Horizontal filament thread B support:
$B_h \approx (4\pi\Sigma_{20}[\sigma^2/R])^{1/2}$
$\approx 12\ (\Sigma_{20})^{1/2}\ \mu G$
(molecular filament problem!)

Fabian et al. 2008, Nature, 454, 968

# NGC1275:
# ISM Structure & Properties: Stabilizing A Cooling ICM

**COOL GAS SINKS**

- AGN
- Supernovae
- Gas heating
- Star Formation
- High V impacts

**COOL GAS SOURCES**

+ ICM cooling
+ Stellar mass loss
+ Stripped gas

# Hα + emission lines: HST/ACS

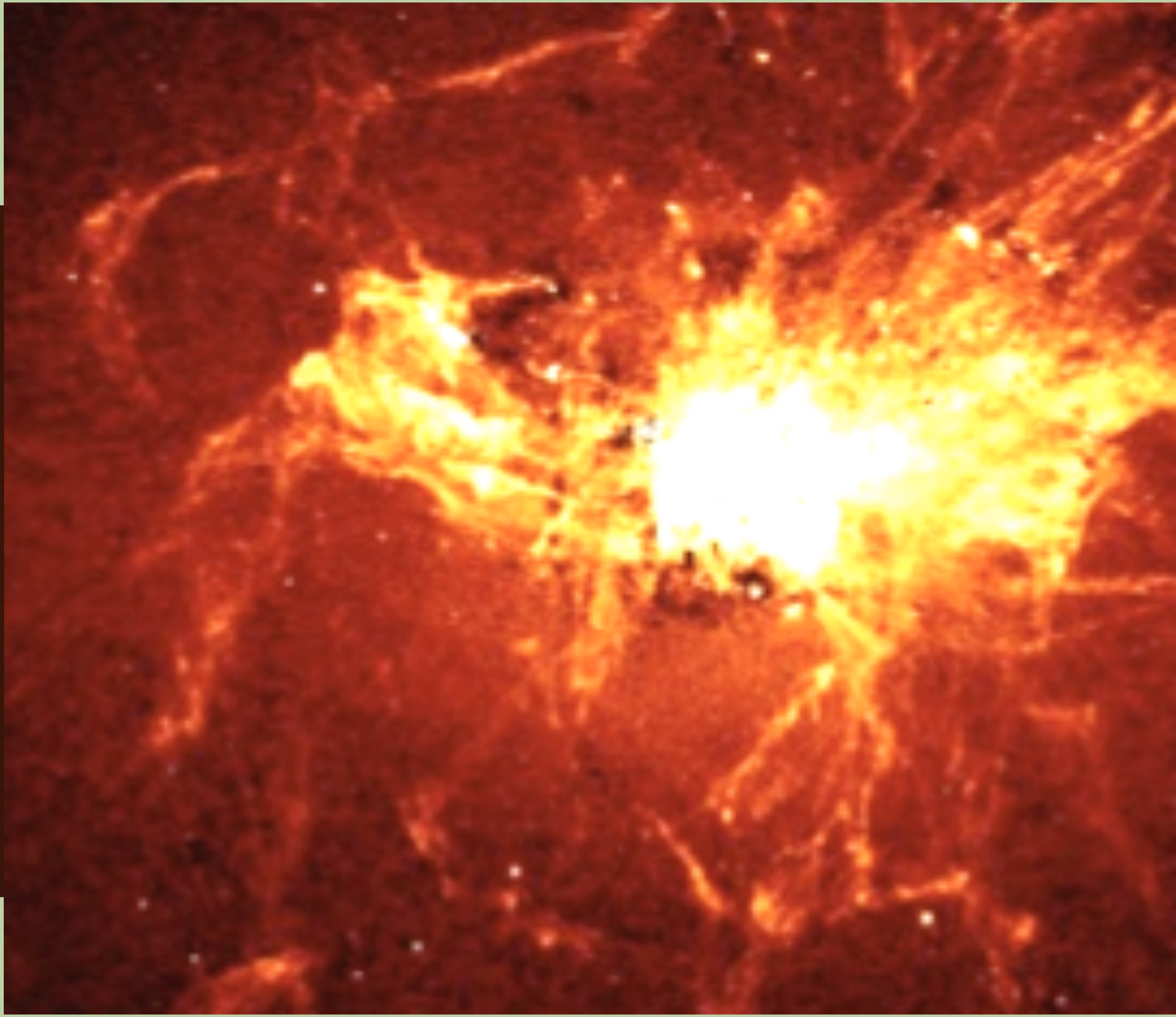
Ionized gas densities

EM~$10^3$ pc $cm^{-6}$
$W_{fil}$~100 pc
$N_e > 3f^{-0.5}$ $cm^{-3}$
~10 $cm^{-3}$

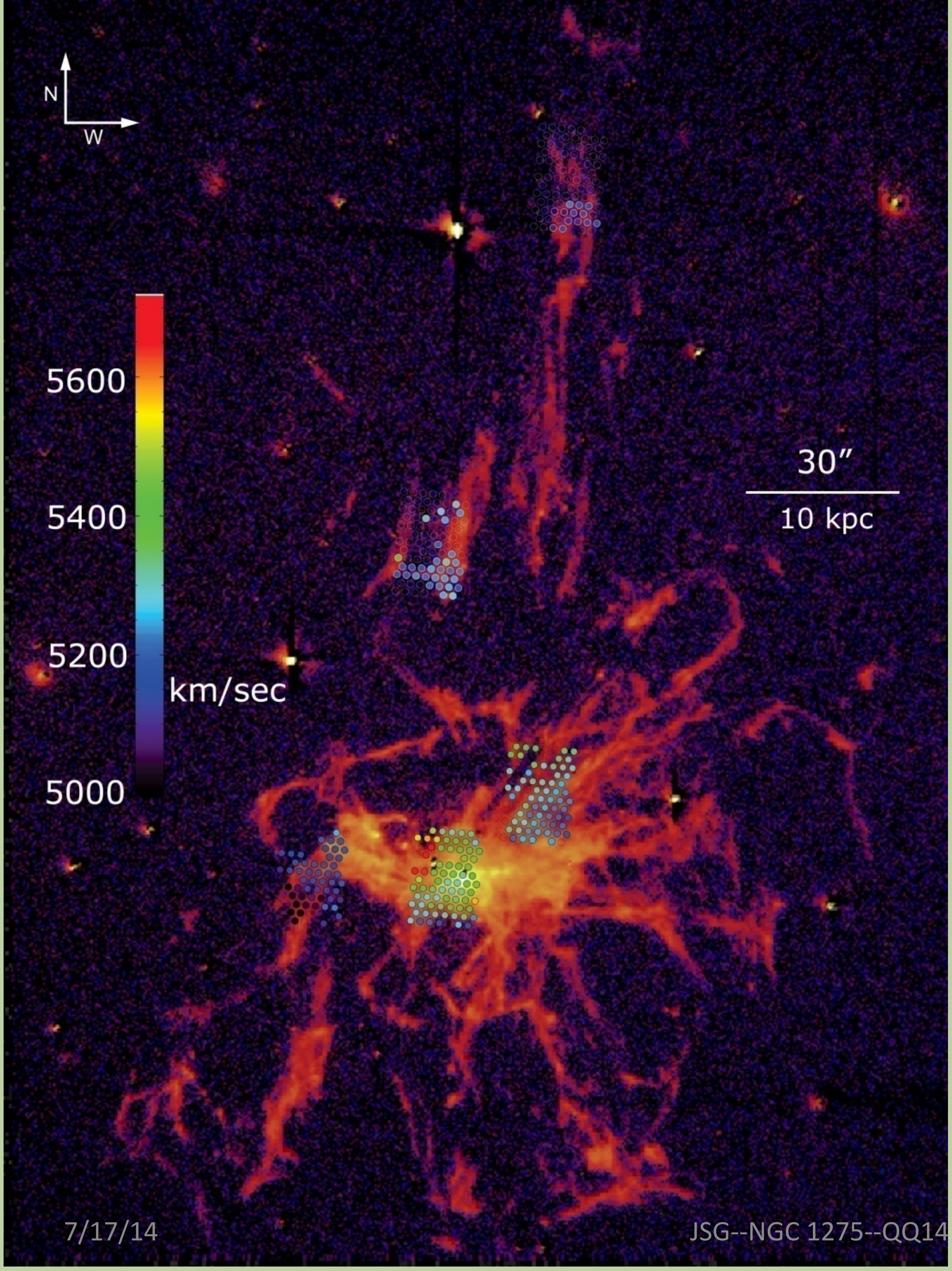
2 x $10^5$ $M_\odot kpc^{-1}$

M(HII)
~few x $10^8 M_\odot$

Thin extended filaments→ Magnetic fields



Fabian et al. (HST Team) 2008, Nature



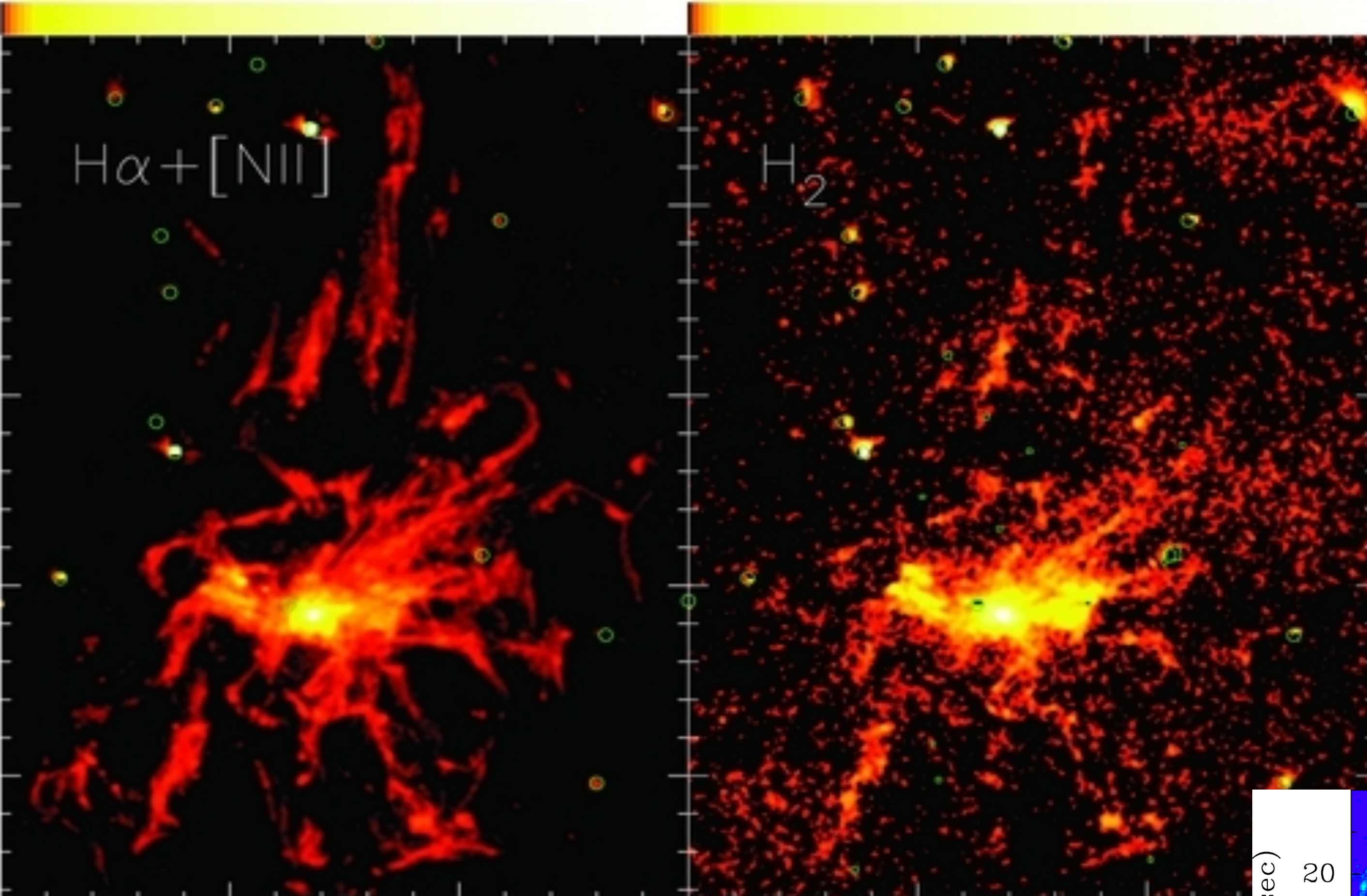

WIYN Densepak IFU
total velocity range
~400 km/s

V(fil) ~200 km/s
<< $c_s$(IGM)

Dynamically cool
Not hot ISM shocks!

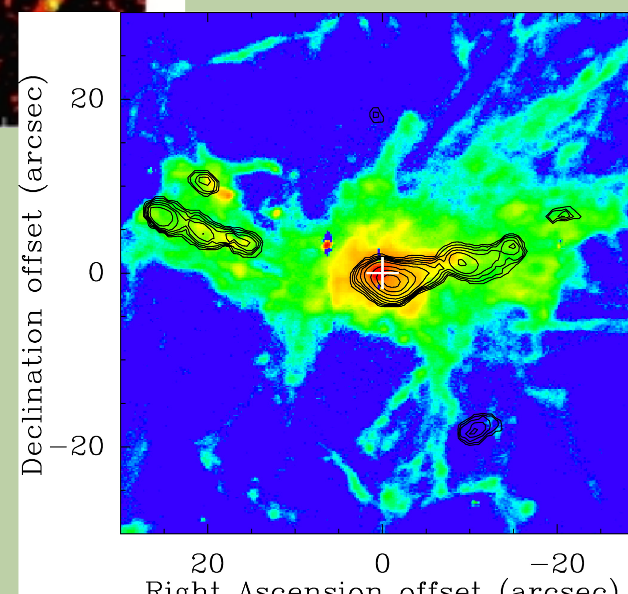
E(fil) ~
M(fil)$\langle v^2 \rangle$
> 4e57 erg

Cigan, Gallagher et al. Hatch+



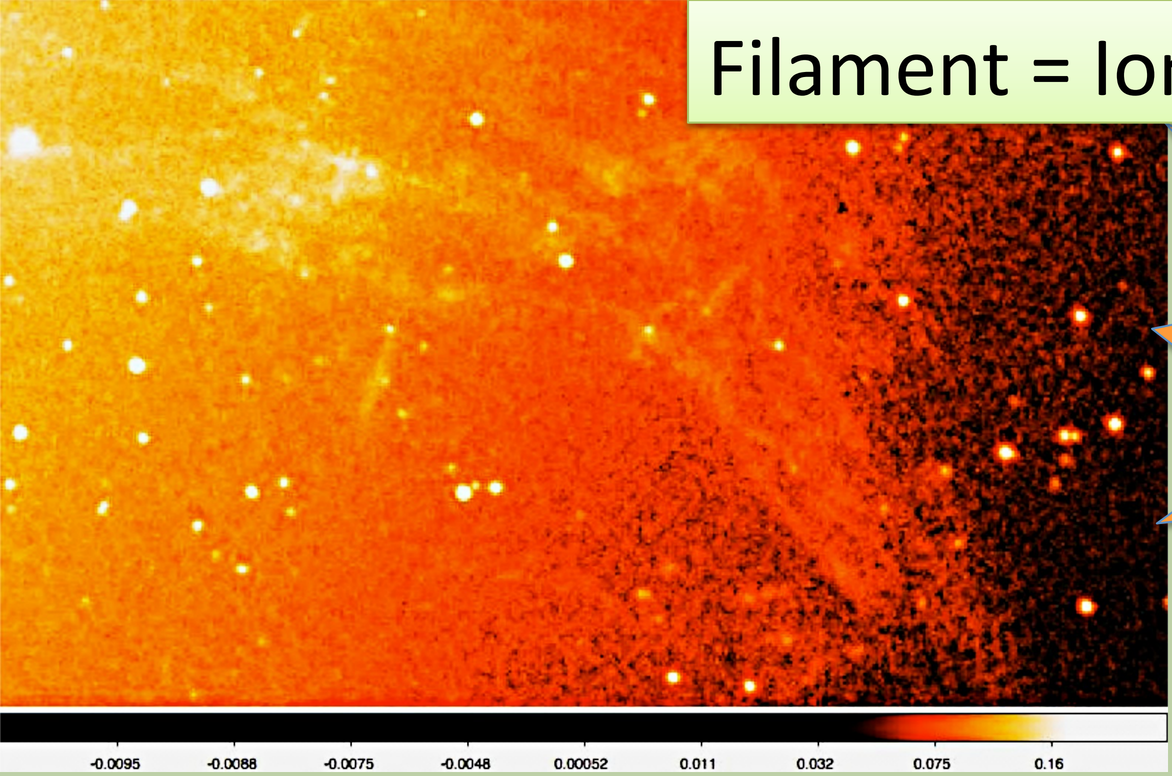

WIYN Hα+[NII]
CFHT $H_2$-narrowband
Lim+ 2012, ApJ, 744

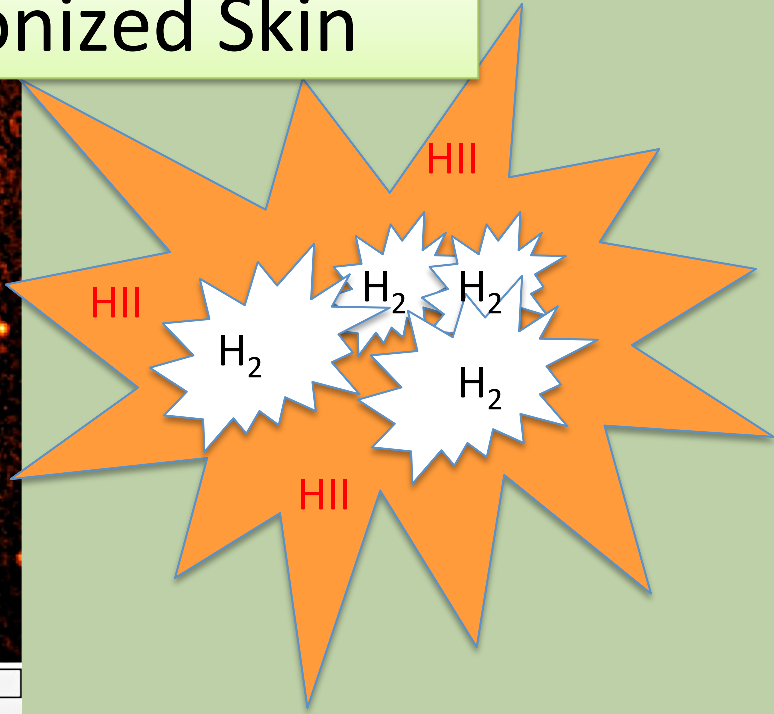
Lim+ 2008, ApJ, 672




Filaments : most of gas mass is ***molecular.***
Estimated $M_{mol} \approx 10^{10}$ Msun $\approx M_{hot}$(<25 kpc)
Filaments too dense to "float" with B-field
Dust!; Efficient line cooling
Filaments grow *in situ*?

# Filament = Ionized Skin




P/k ≈ $10^6$ → $n_e$ ≈ $10^2$ $cm^{-3}$ for $T_e$ ≈ $10^4$ K

EM → $n_e^2(2r)_{fil}$ → $\langle n_e \rangle \lesssim 10$ $cm^{-3}$

→ Gas filling factor << 1 – ionized *surfaces*

→ Molecular gas T≈100 K $\langle n_{H2} \rangle$≈$10^4$ $cm^{-3}$

***Multi-phase medium key to feedback process***

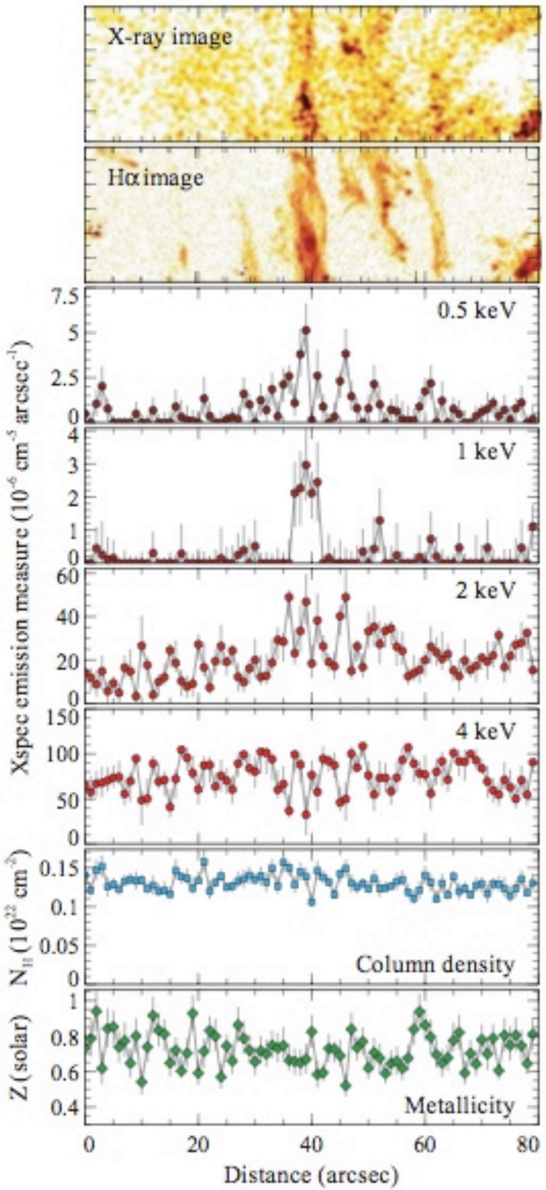



**Figure 16.** Emission measure profiles across the filaments in the different temperature components. The top panel shows an unsharp-masked 0.5–7 keV X-ray image rotated so that the bins lie across it. The second panel shows a similar Hα image. The next panels show the 0.5-, 1-, 2- and 4-keV temperature component XSPEC normalizations, measured from the 1 arcsec wide bins. The final panels show the best-fitting absorbing hydrogen column density and the metallicity of thermal components.

# LOCAL FEEDBACK

Enhanced X-ray at filaments
Increased ICM cooling rates
Unstable feedback on IGM?

Filaments → cooling → filaments
OR
Filaments → heating → evaporation
***Depends on heating/cooling rates***

Filaments can stimulate filament growth (Voit et al. 2008 ApJ, 681)

*Filament seeding issue*

Sanders & Fabian 2007, MNRAS, 381, 1381

# HII optical (contours) & X-ray emission closely related

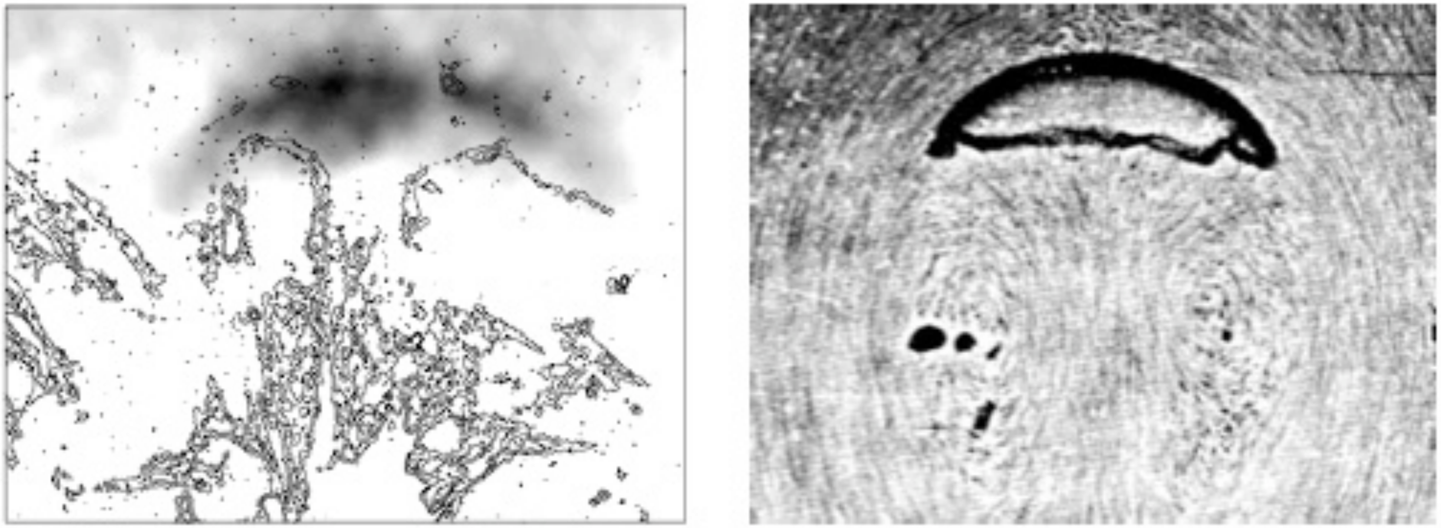


**Figure 3.** Left: contours from the Hα image rotated 50° counter-clockwise overlaid on a lightly smoothed X-ray image with levels chosen to emphasize the outer rising bubble. Right: a rising air bubble in water from Batchelor (1967, plate 15c; originally from Collins 1965).[1] This is effectively a two-dimensional bubble since it is confined between closely spaced parallel plates, but shows the cross-section and flow pattern well (see Van Dyke 1982 for a full bubble). The effect of surface tension is negligible in the right-hand panel (Batchelor 1967). Magnetic fields inside the bubble in the left-hand panel are sub-equipartition (Fabian et al. 2002), so unlikely to influence strongly the comparison here. A gas bubble in water may oscillate from side to side while rising.

Enhanced cooling + upward gas transport

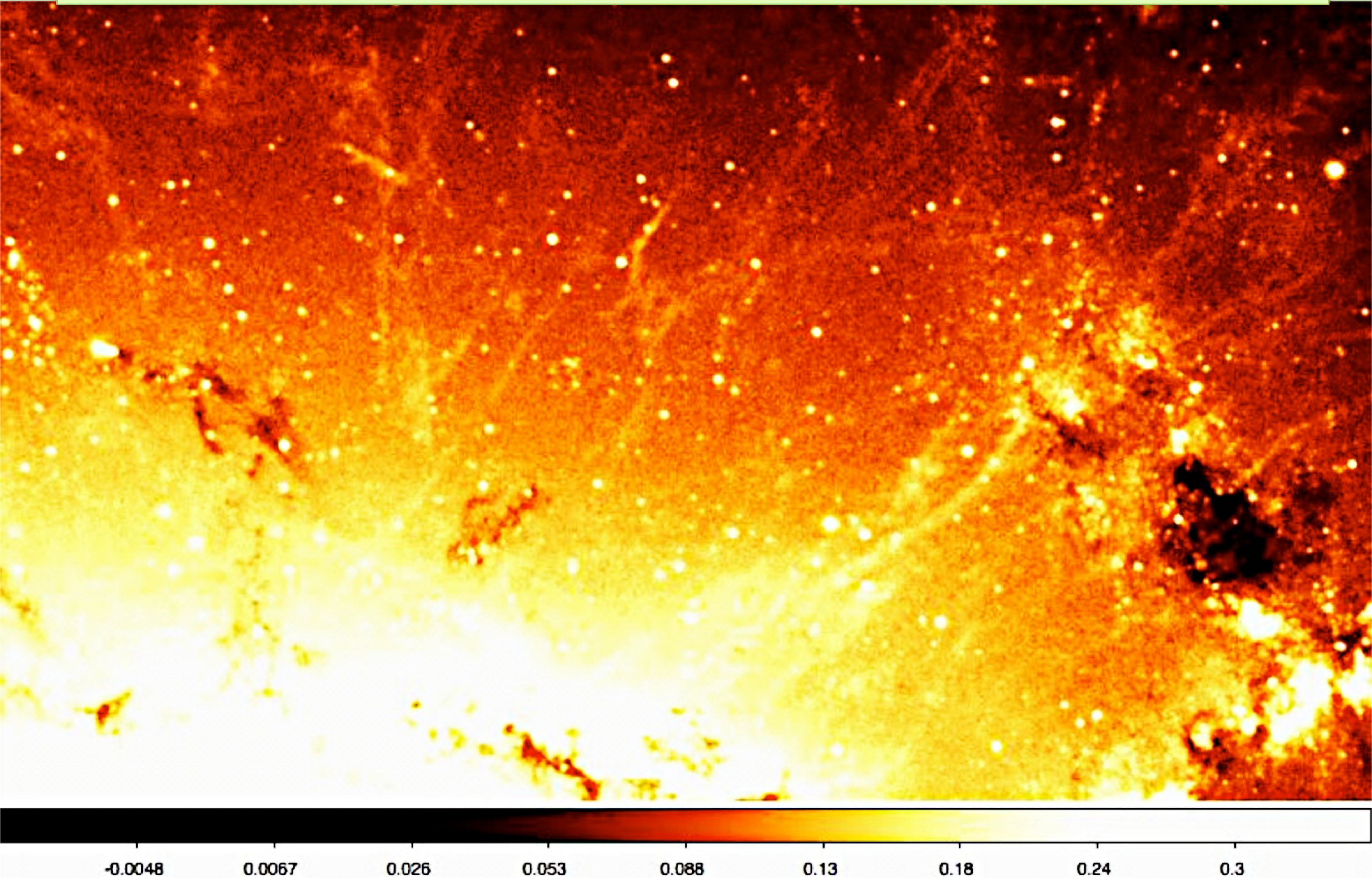
Are we seeing a wet-phase BCG-galaxy "drying out" process as cool gas is transported outwards?

***Do outer filaments disrupt/evaporate?***

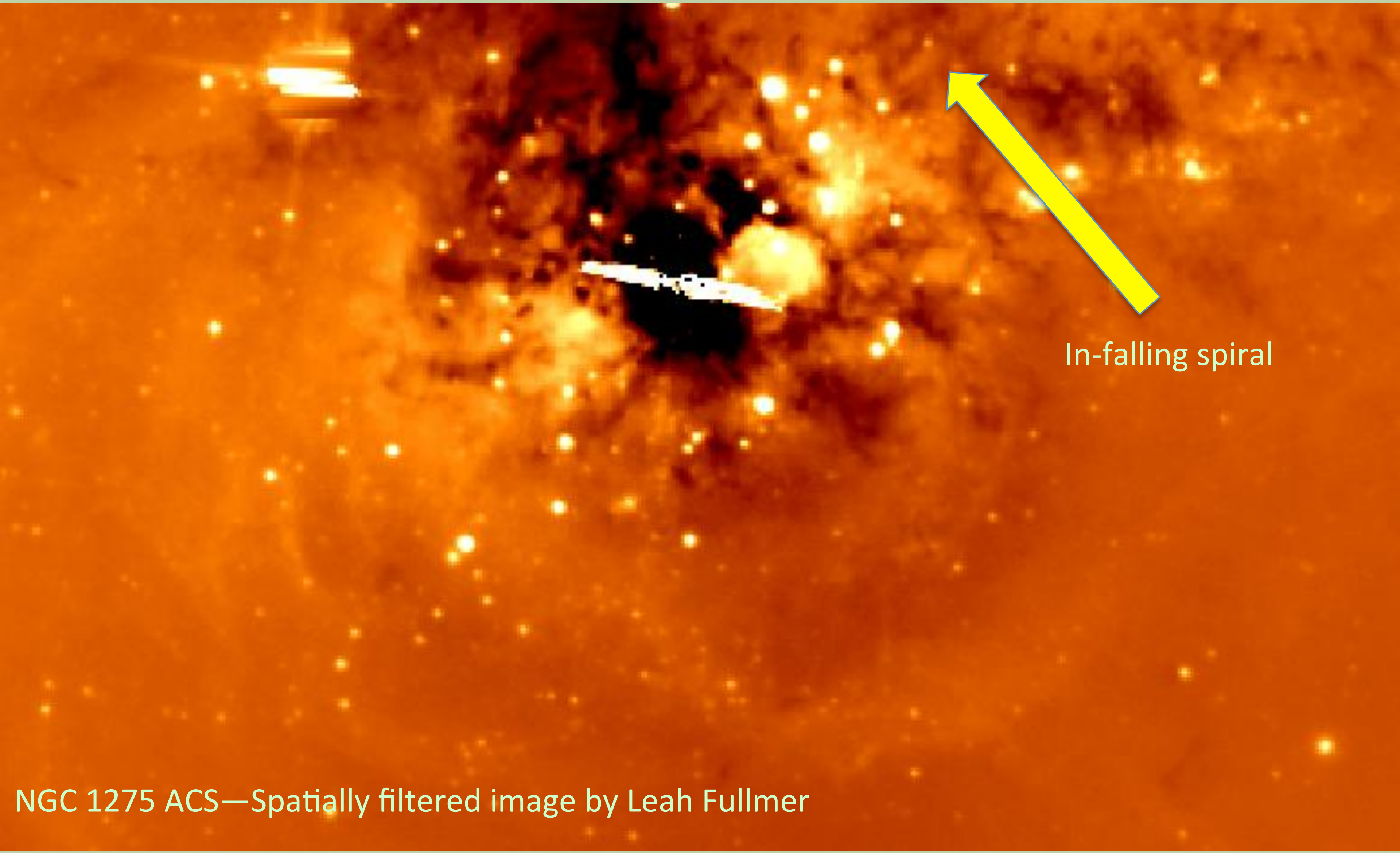


Fabian et al. 2003, MNRAS, 344, L48

# HST images: radial "seed" filaments at base of horseshoe

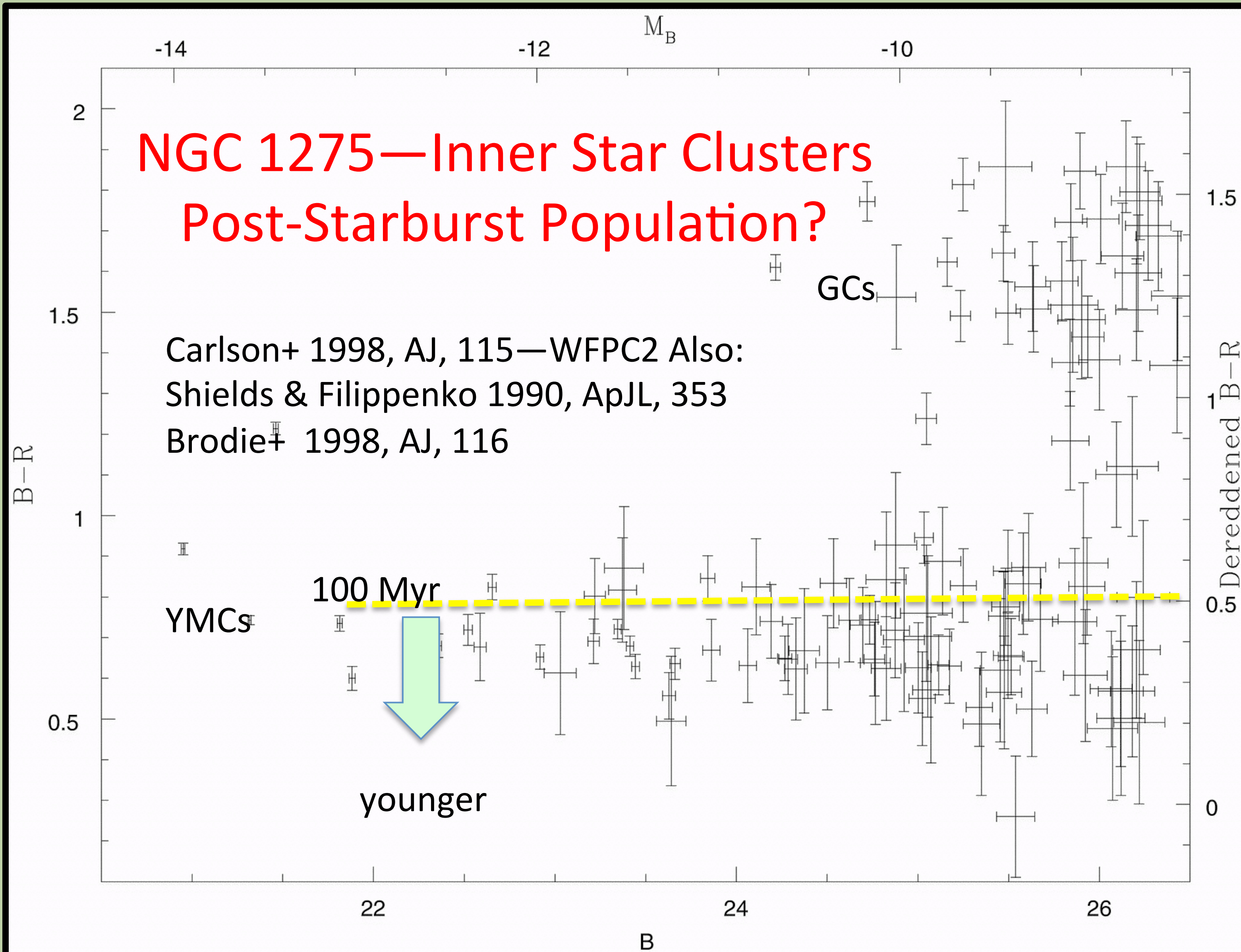


# Central massive young star clusters: Signposts of past intense star formation events

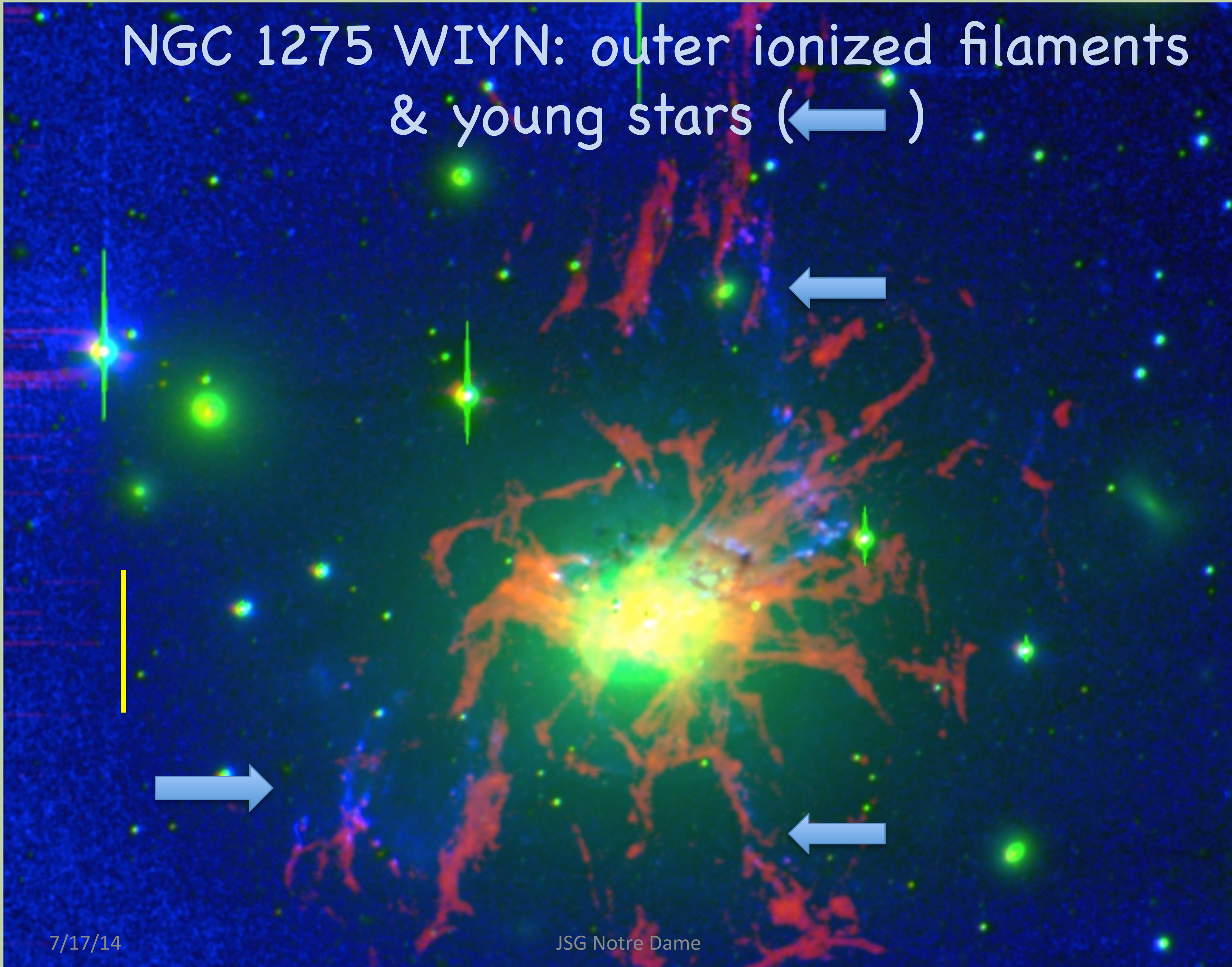


# NGC 1275—Inner Star Clusters Post-Starburst Population?

Carlson+ 1998, AJ, 115—WFPC2 Also:
Shields & Filippenko 1990, ApJL, 353
Brodie+ 1998, AJ, 116

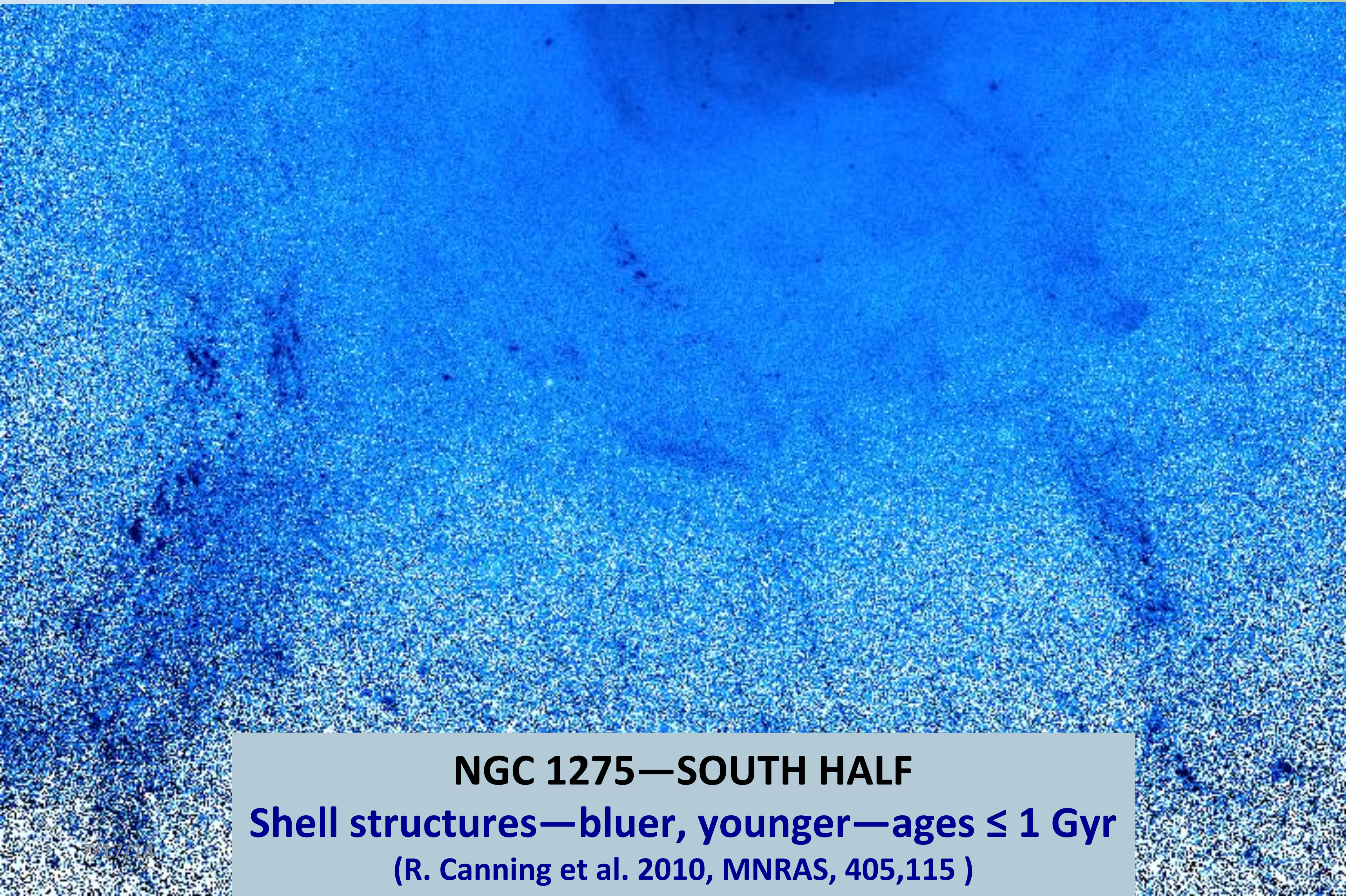


# NGC 1275 WIYN: outer ionized filaments & young stars ( )



Complex stellar structure across main body: Mergers vs. star formation?

"B-V" color map
ACS Images

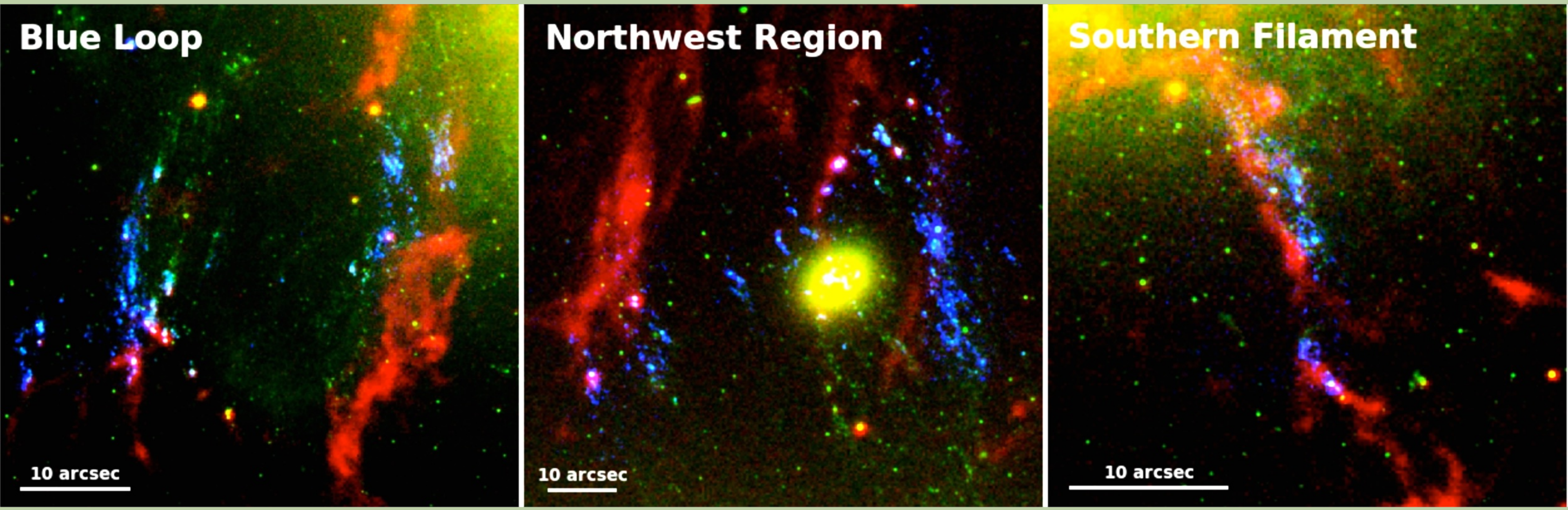


**NGC 1275—SOUTH HALF**

**Shell structures—bluer, younger—ages ≤ 1 Gyr**

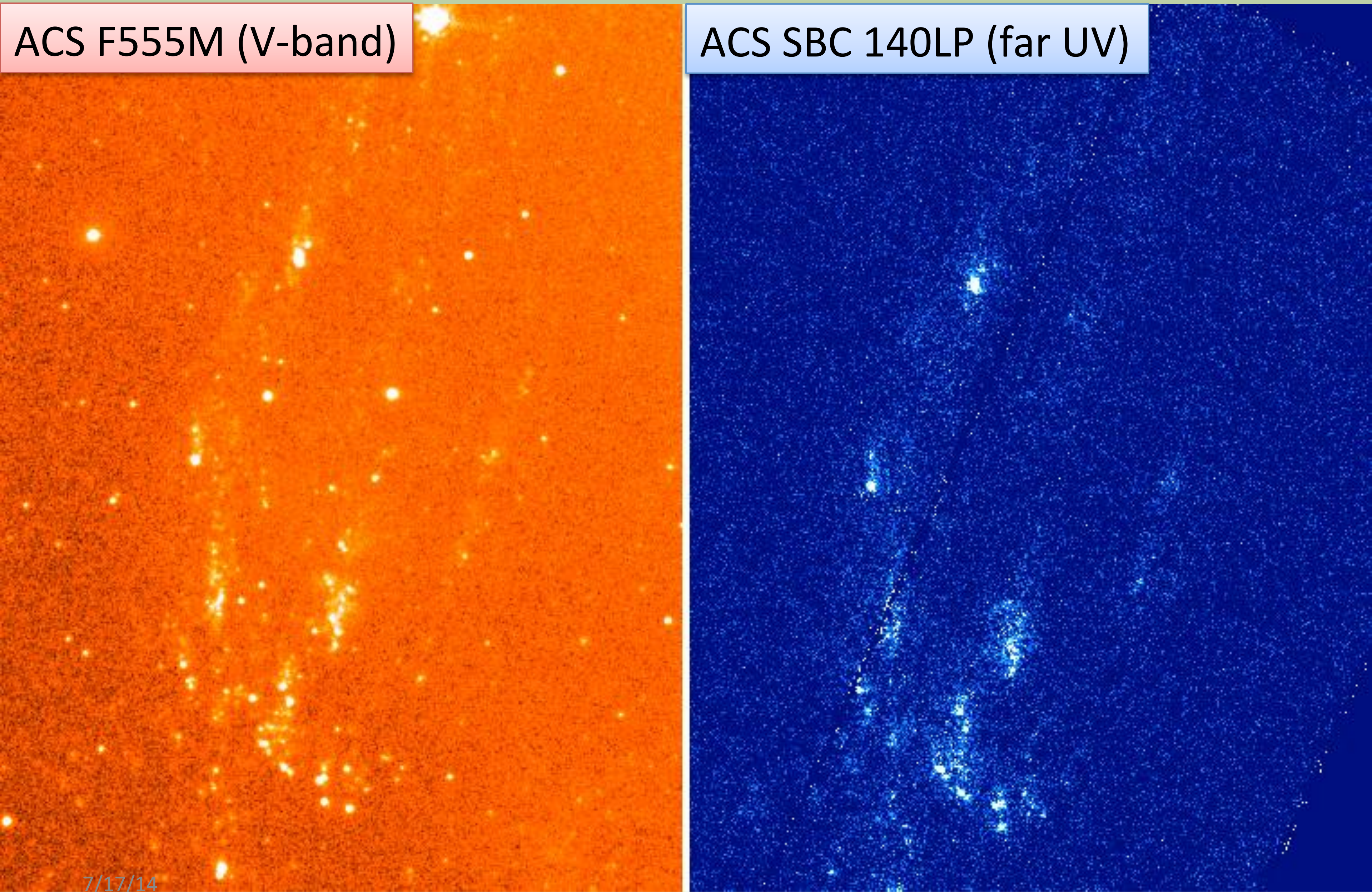
**(R. Canning et al. 2010, MNRAS, 405,115 )**

# NGC 1275—***Outer*** Young Stars & HII Filaments
# HST WFC optical + SBC FUV



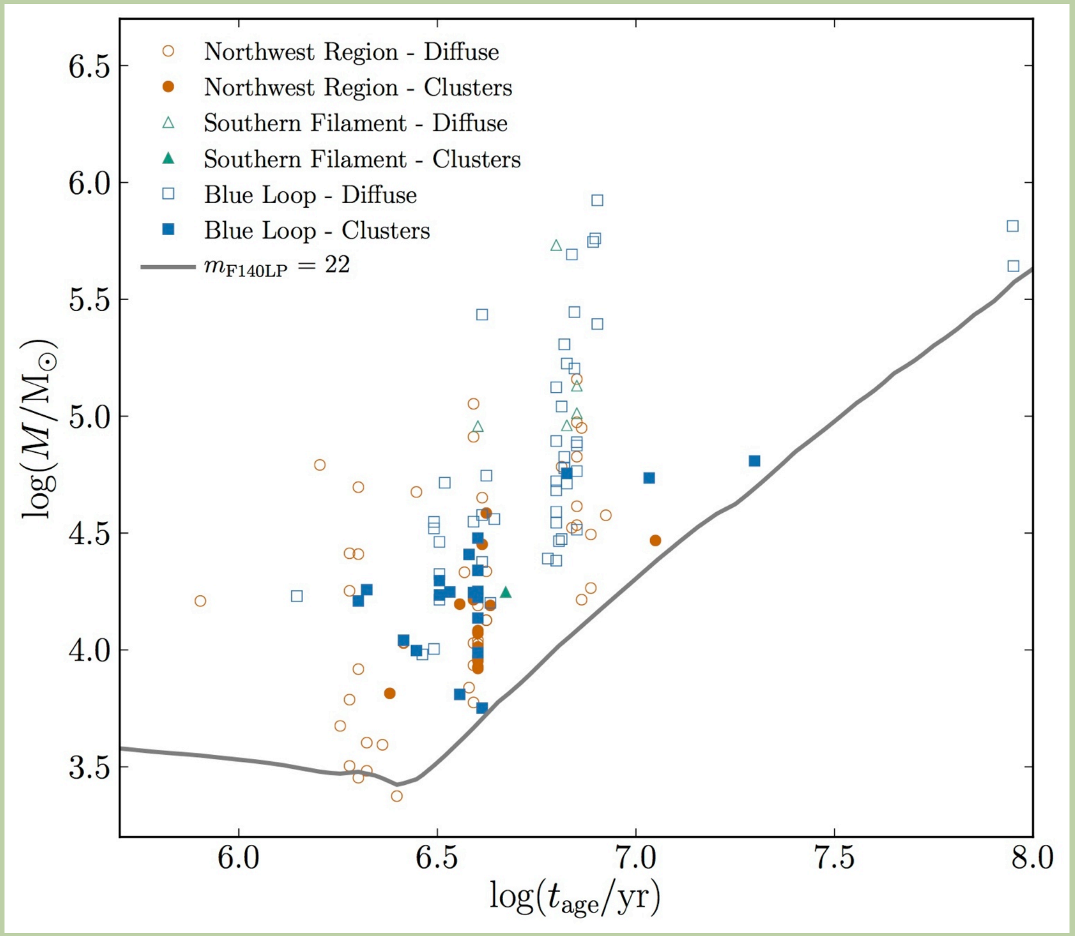

Canning, Ryon, Gallagher+ 2014, MNRAS in press

# Southern Star Forming Loop: Star Clusters in Galaxy Outskirts






Canning, Ryon, Gallagher, O'Connell et al. 2014 MNRAS in press

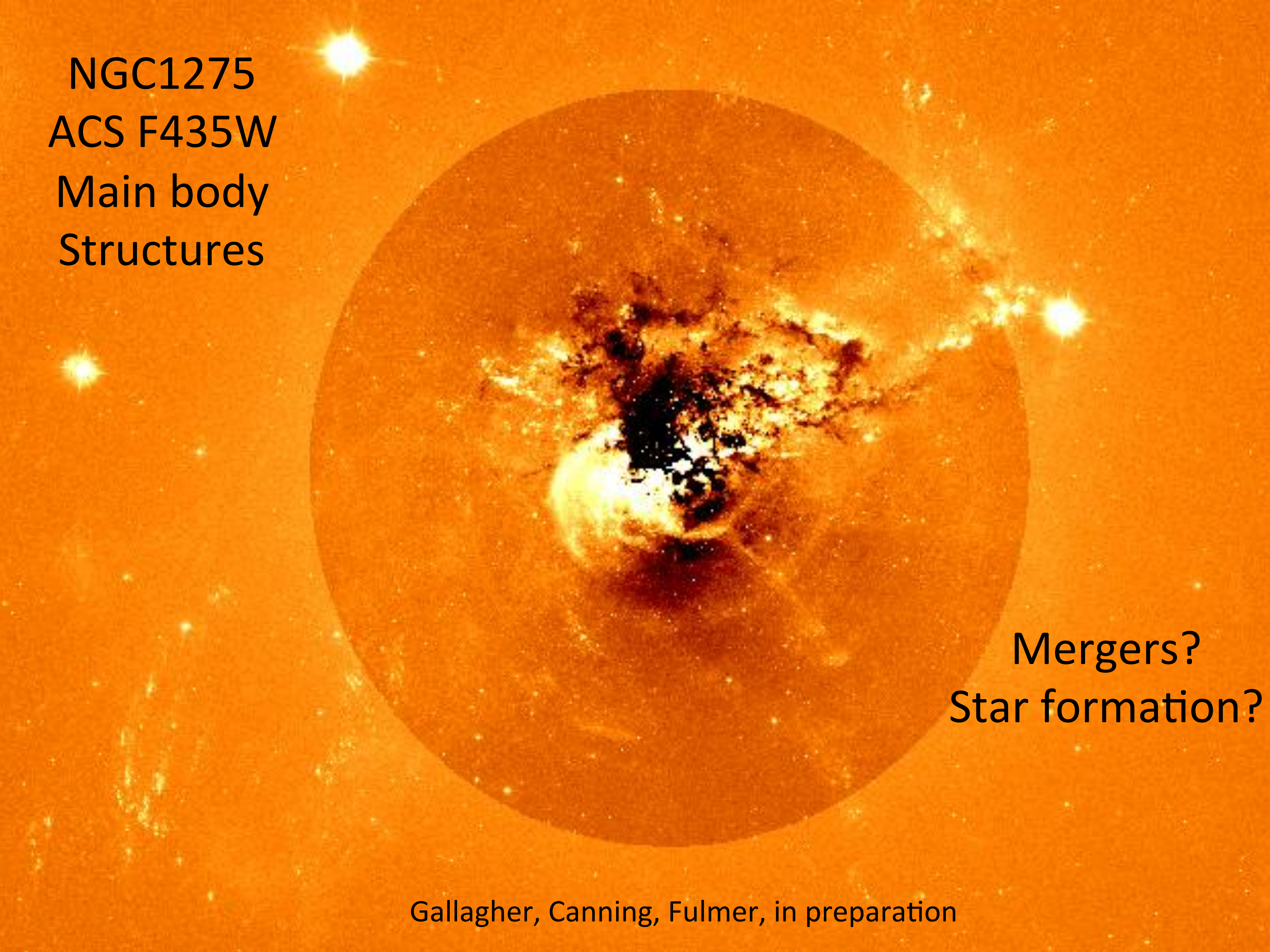


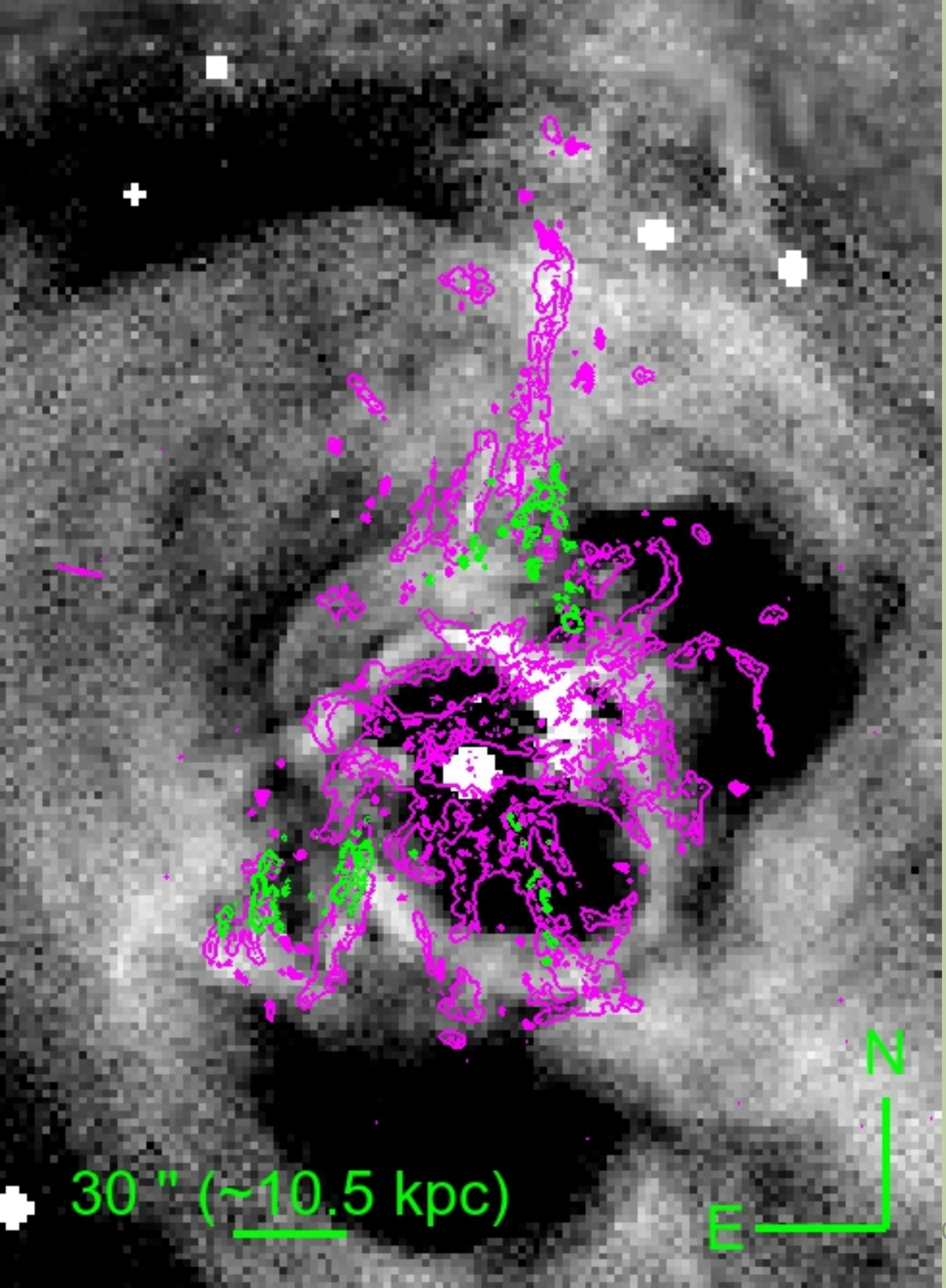

NGC 1275 Outer SF
SFR~2-3 Msun/yr

SFE </~10%
→
$dM_g/dt$~20-30 Msun/yr

Is SF disruption of filaments a substantial cool gas sink?

Mode for globular cluster formation? High GC frequencies in massive spheroids indicate process other than dry mergers?


NGC1275
ACS F435W
Main body
Structures
Mergers?
Star formation?
Gallagher, Canning, Fulmer, in preparation

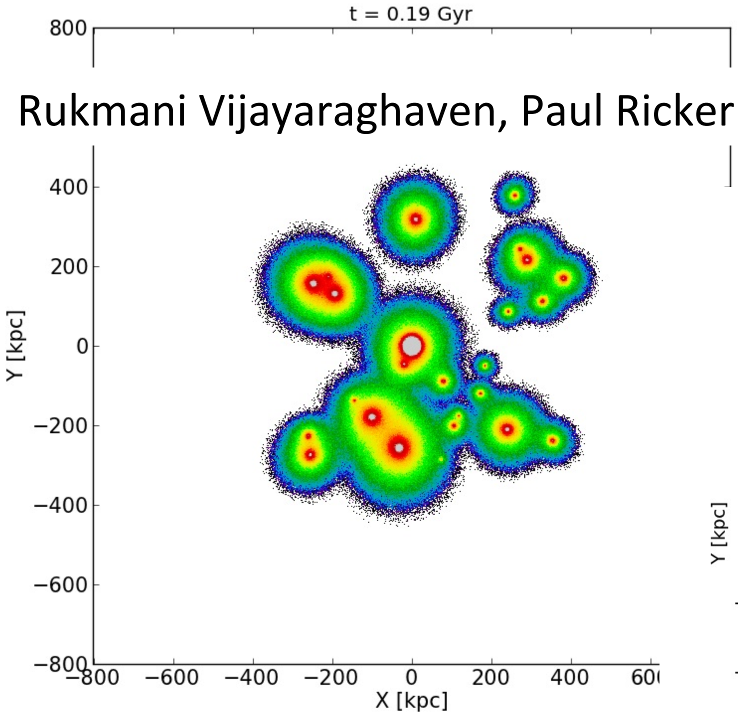


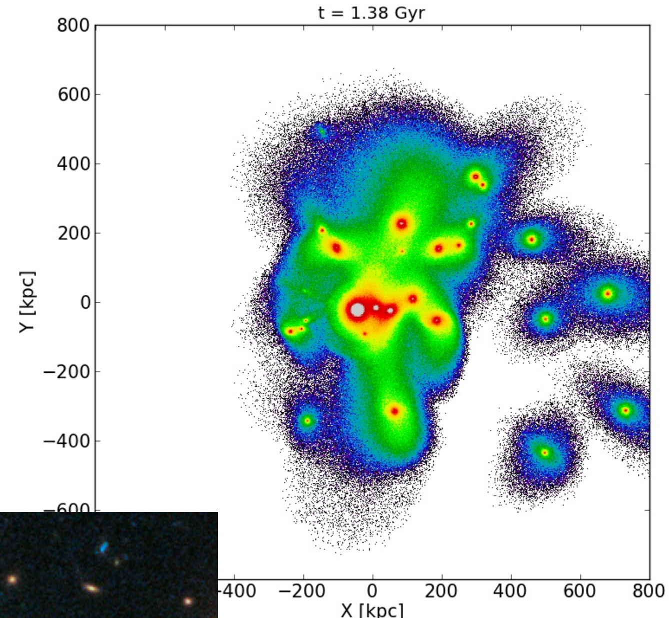

NGC 1275
X-ray
Halpha
UV
Combo

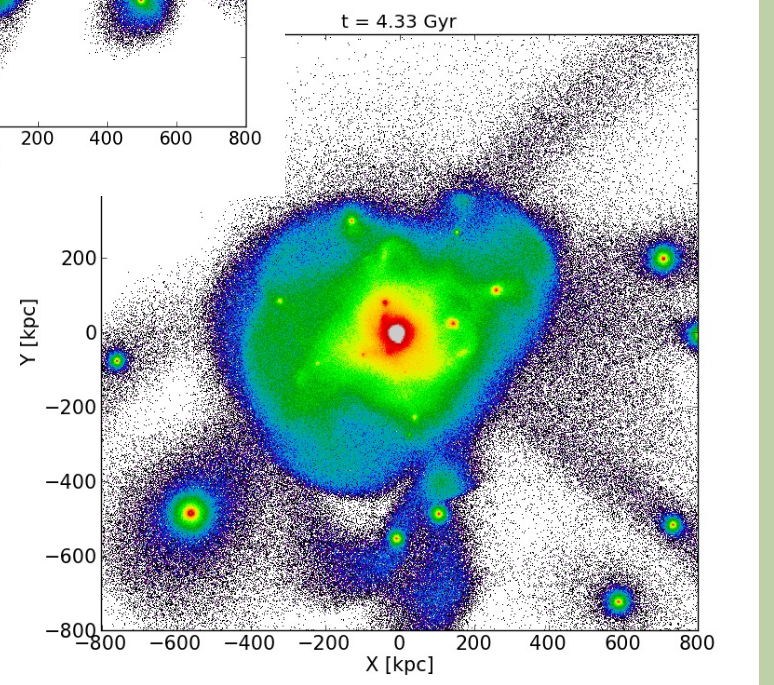
Canning+ 2014, MNRAS

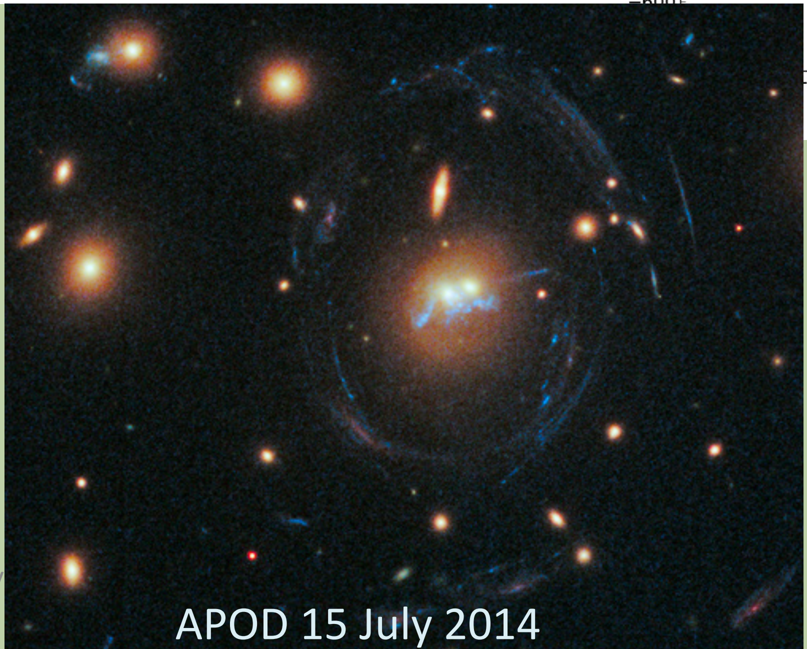
# BCG—Dry Merger Growth (Halo Models)

Rukmani Vijayaraghaven, Paul Ricker +



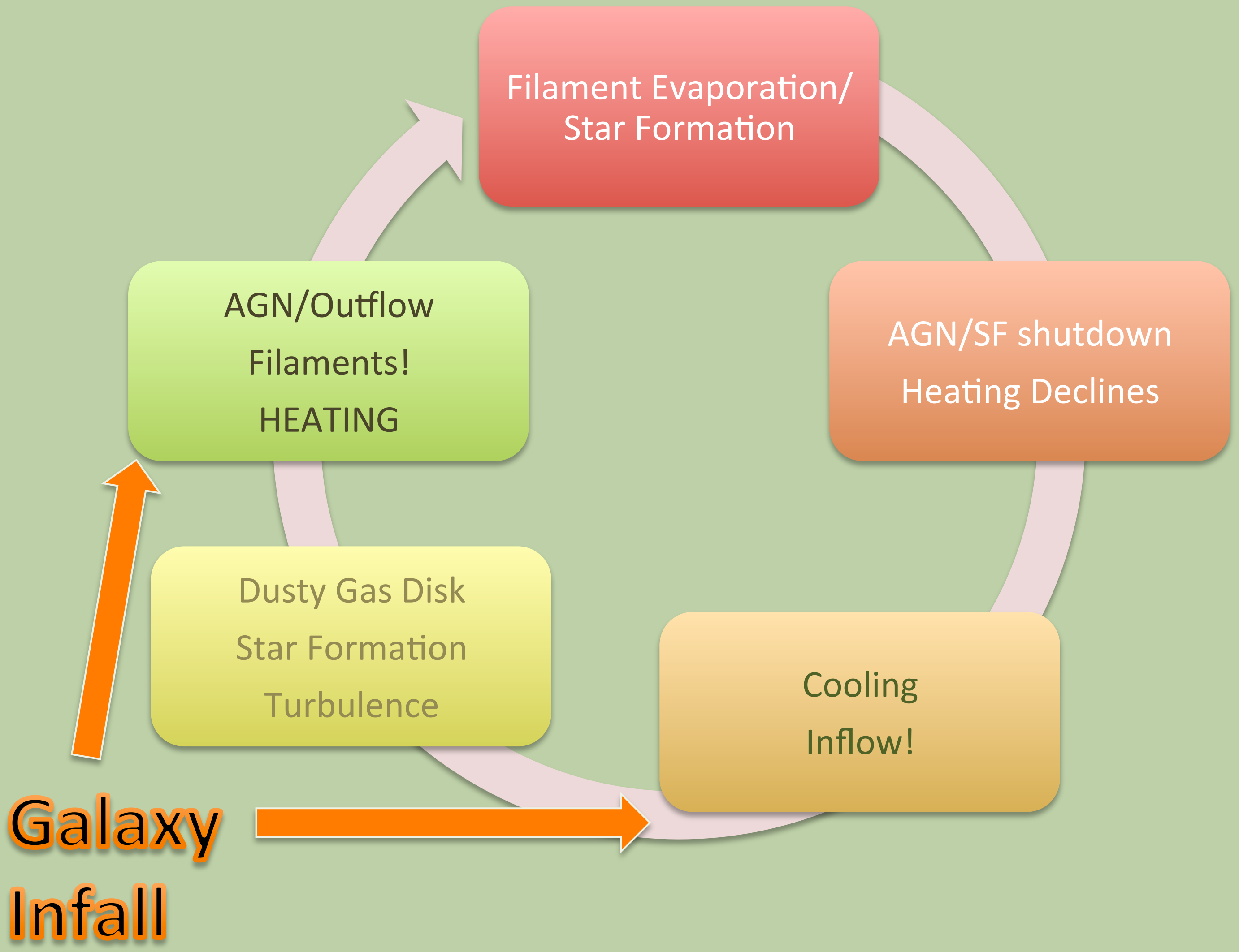



APOD 15 July 2014

# Life Cycle of NGC1275/BCG?



# Summary

- NGC 1275 strongly interacting with surrounding ICM; seen in x-ray→optical→radio
- *Radio lobes imply feedback via ICM/ISM displacement, heating and likely filament seeding*
- Magnetic fields play a significant role in filaments
- *Filaments host multi-phase cool ISM; grow by condensation in inner galaxy*
- Filaments host some star formation; some outer filaments form stars along entire length. Part of pressure/velocity transition to filament disruption?
- *Central YMCs suggest major SF event 100-300 Myr ago*
- NGC1275 could fit in cyclical feedback process in cool core galaxy clusters.