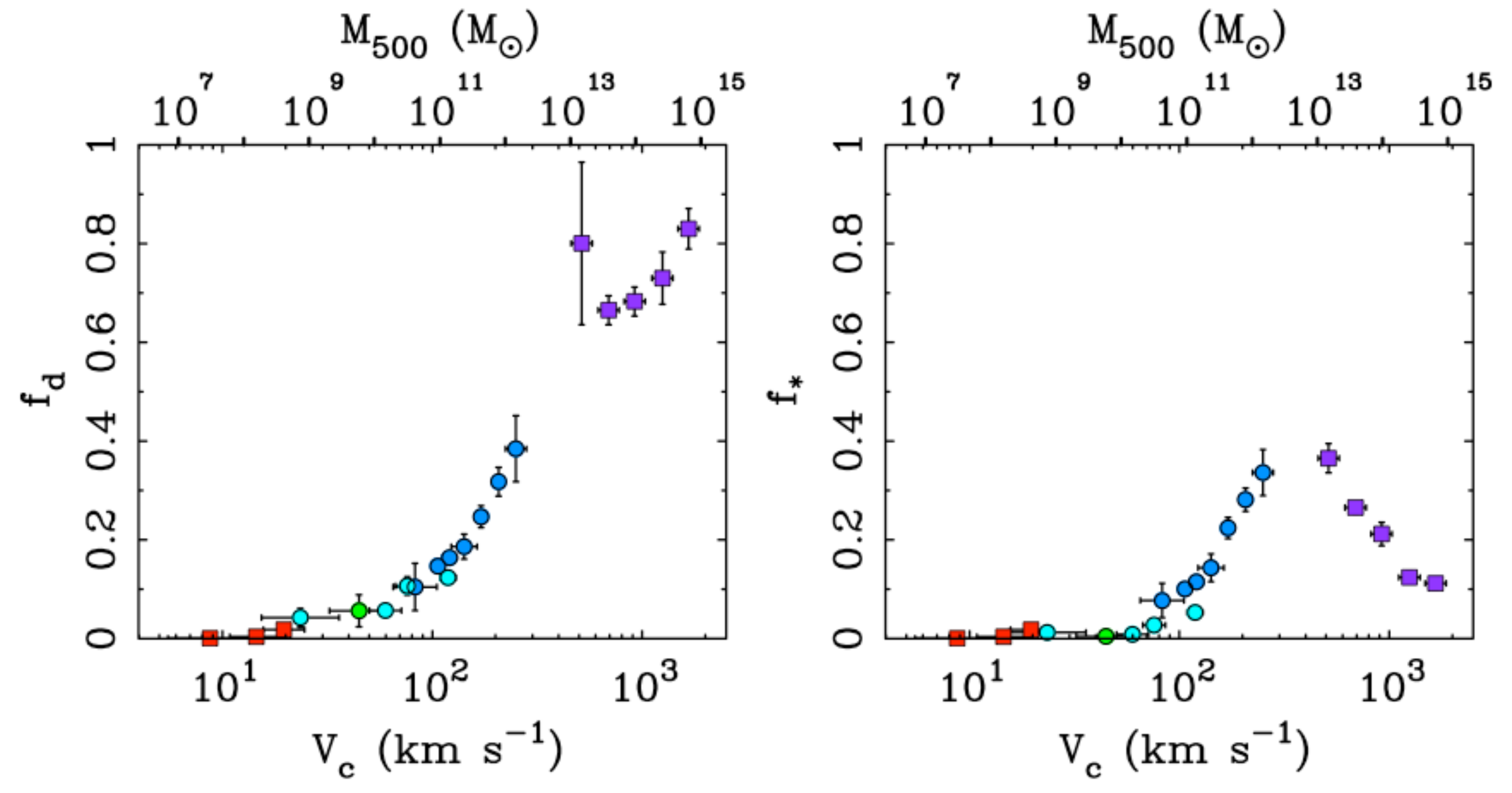
Stellar Feedback and Galaxy Formation

Mubdi Rahman, Elizabeth Harper-Clark

The Physics of the Intracluster Medium, UM

- Missing Baryons
- Starburst Feedback
  - Star driven outflows (stellar feedback)
  - ISM turbulence (a bit on star formation)
- QSO outflows (black hole feedback)
  - BAL/NAL outflows
  - Jets (won’t cover, since others have)

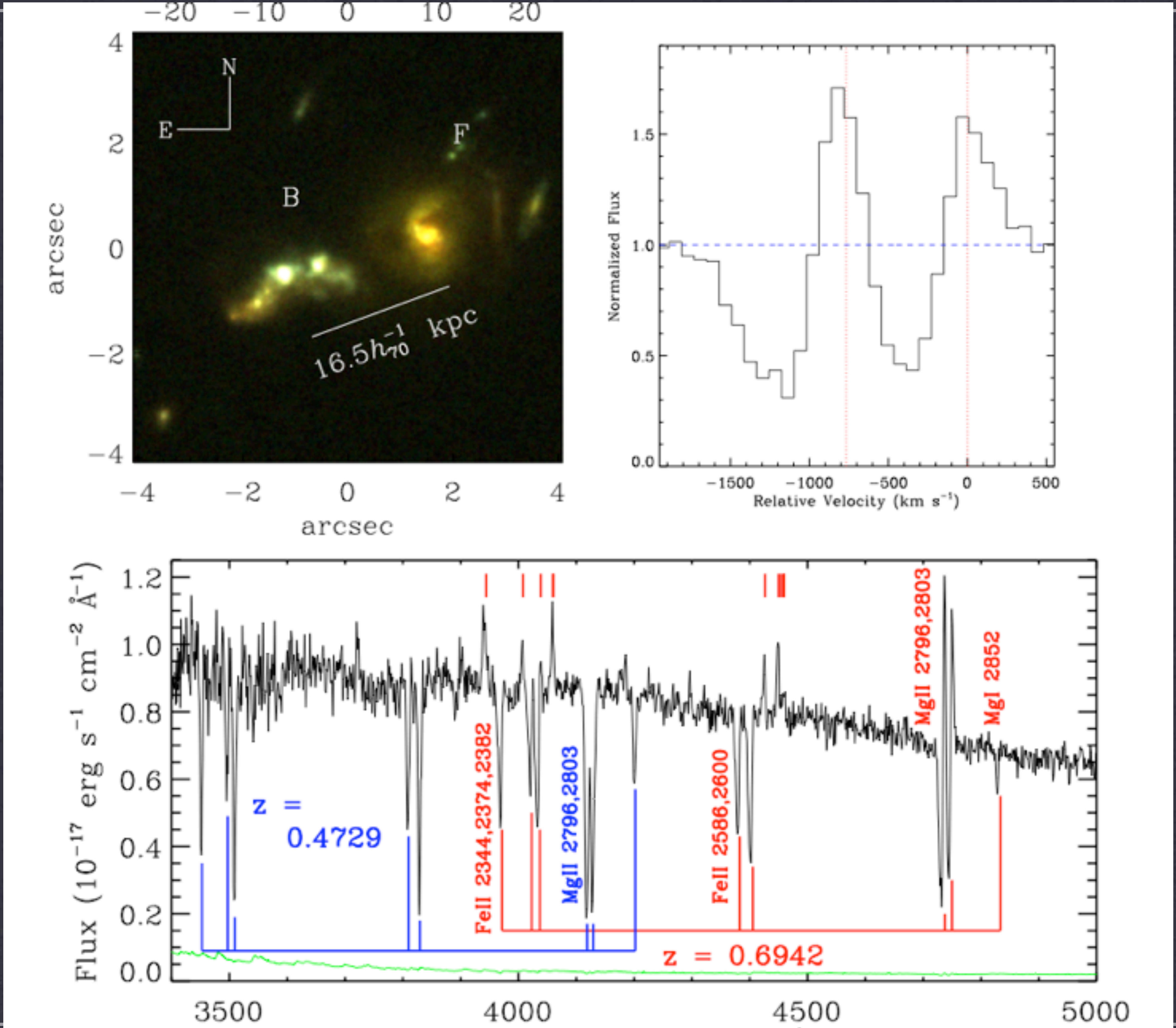


McGaugh et al 2010

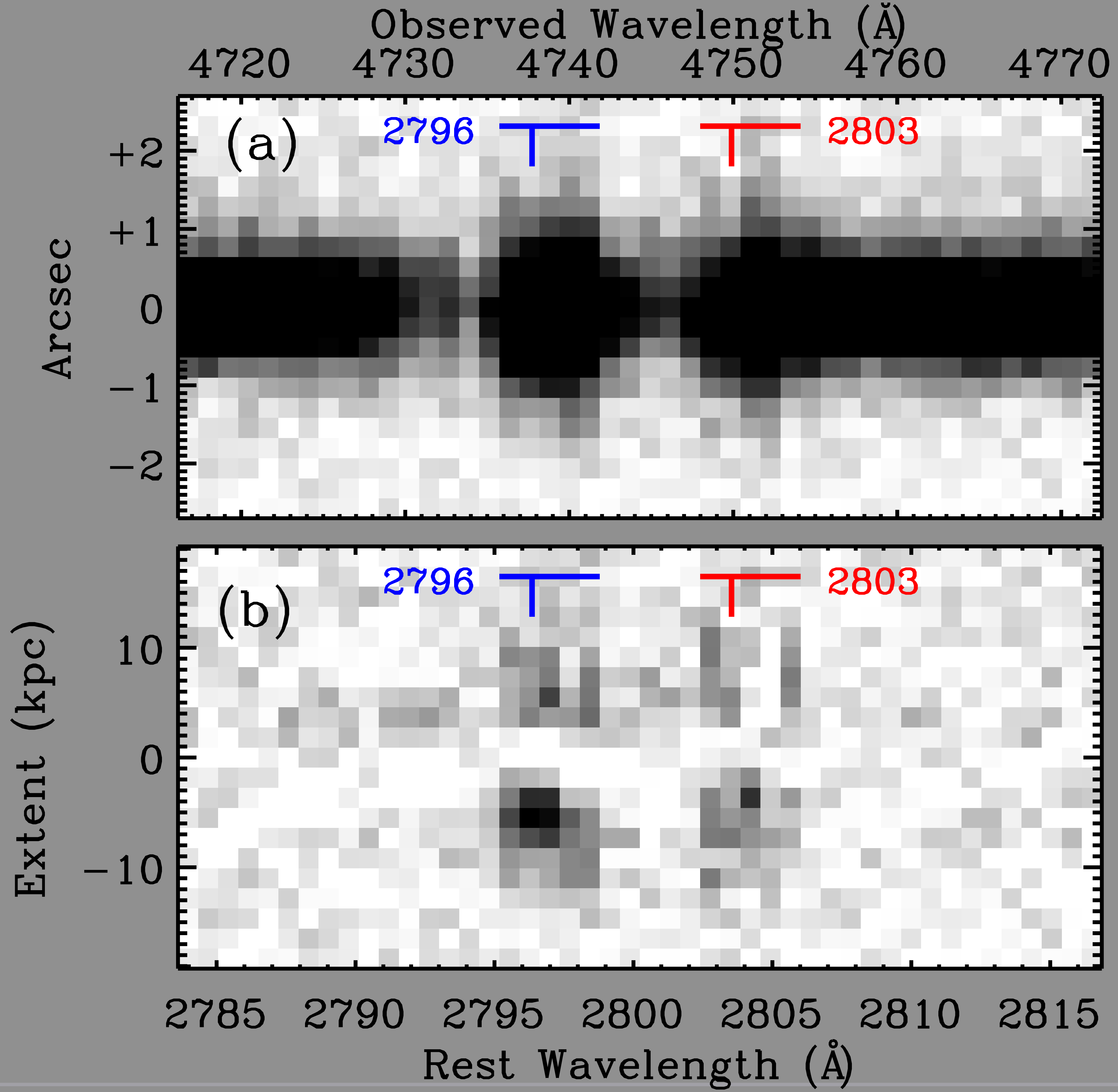
BARYON FRACTION (COMPARED TO COSMIC) IS LOW IN HALOS

SUGGESTS BARYONS ARE EJECTED FROM HALOS (COULD BE PREVENTED FROM ENTERING--HARD TO DO)

WE SEE OUTFLOWS, BOTH LOCALLY



AND AT HIGH REDSHIFT (0.69 HERE)


Observed Wavelength (Ă)
4720
4730
4740
4750
4760
4770
(a)
2796
2803
+2
+1
0
−1
−2
Arcsec
(b)
2796
2803
10
0
−10
Extent (kpc)
2785
2790
2795
2800
2805
2810
2815
Rest Wavelength (Å)

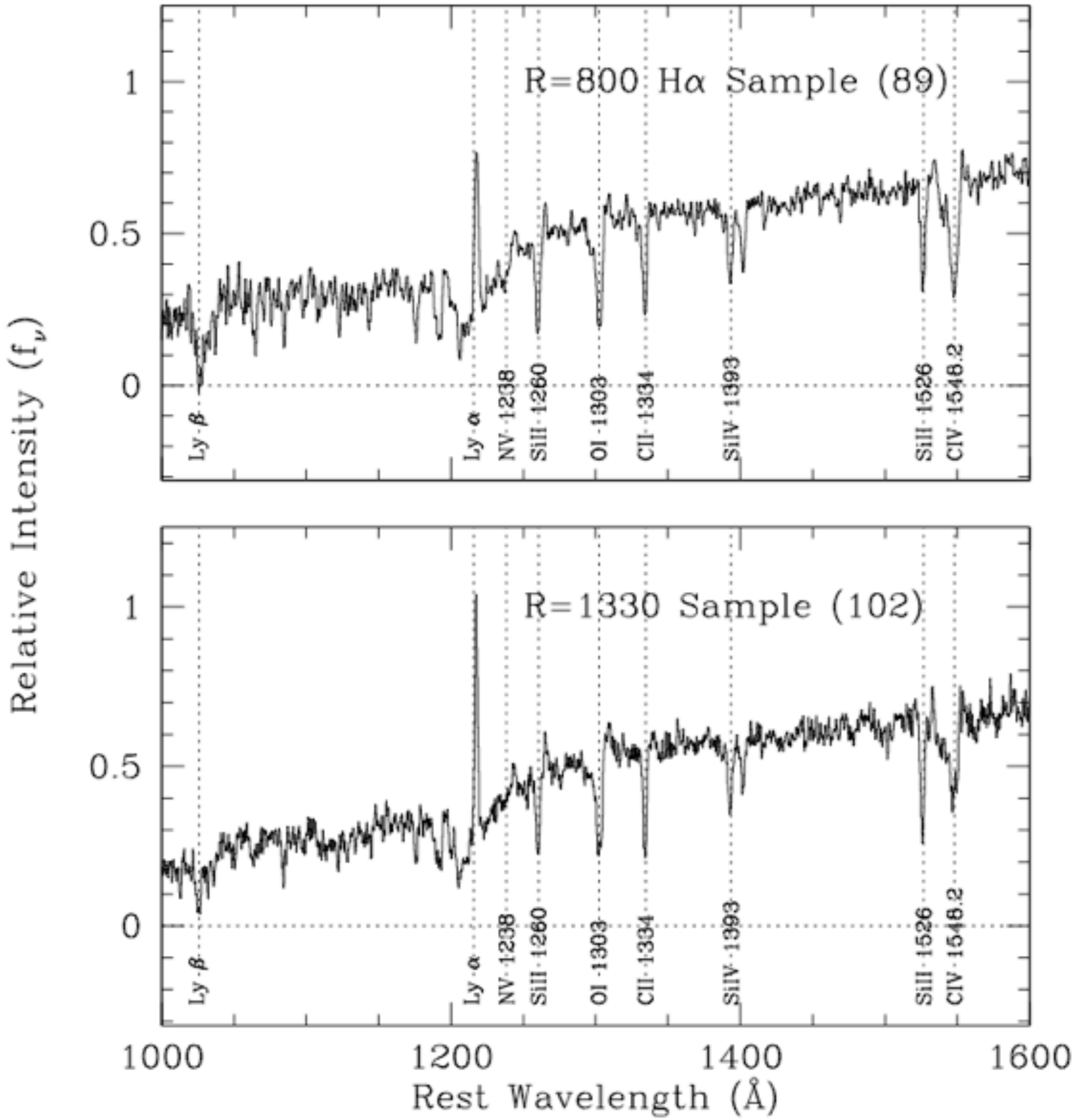
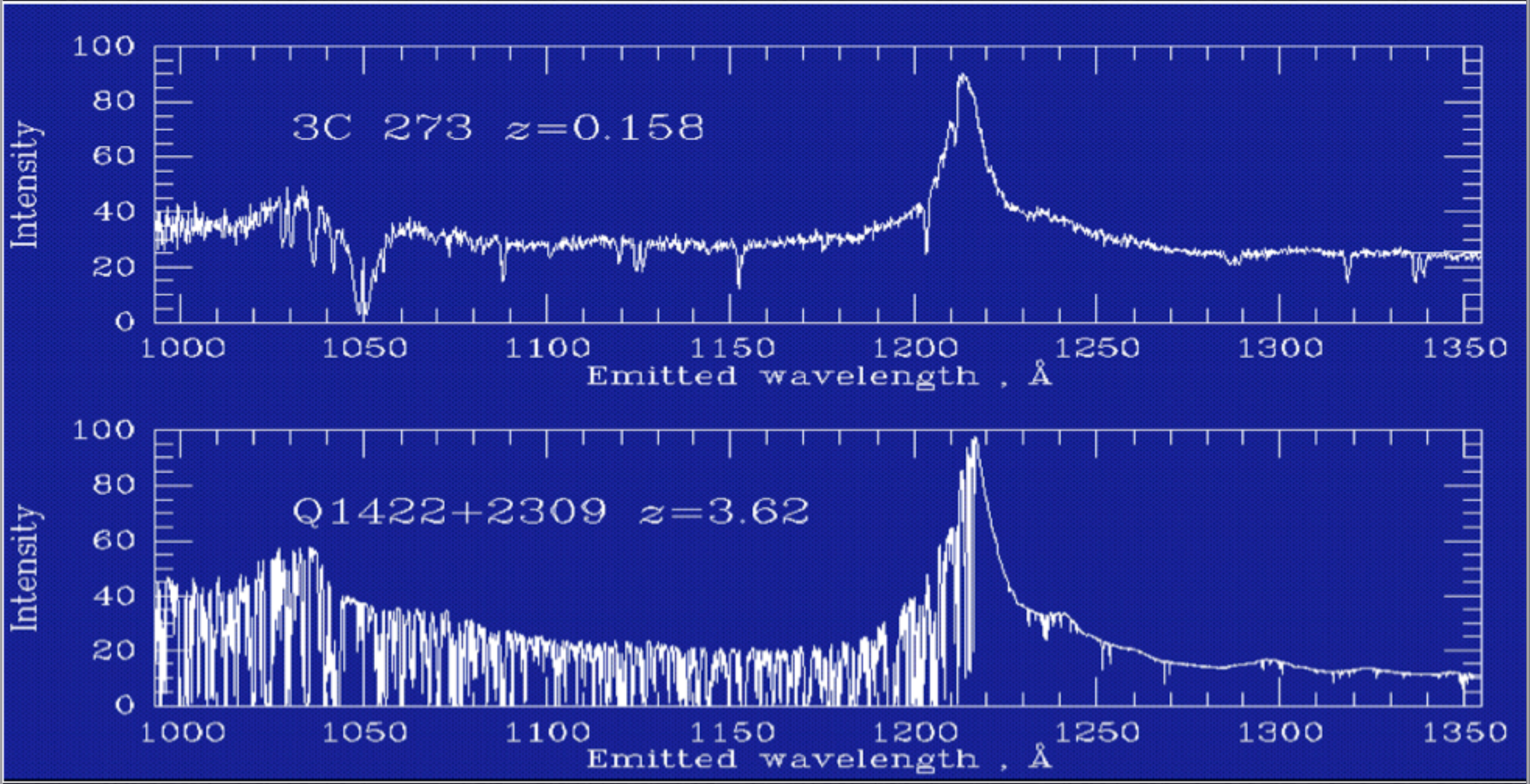


FIG. 5.— Composite rest-frame far-UV spectra for two independent samples of $z \sim 2.3$ galaxies. The top panel is an average of the 89 spectra in the Hα sample, with $R = 800$, after normalizing each to the same relative intensity in the range 1300–1500 Å. The bottom panel is a composite of 102 galaxy spectra obtained with higher spectral resolution ($R = 1330$), shifted into the rest frame using equations 2 and 4, and scaled as the first sample before averaging.

AT Z=2 (STEIDEL ET AL 2010)



AND AT VERY HIGH REDSHIFT, AS INTERVENING ABSORBERS

Supernova driven winds?

- Outflows are seen in neutral (NaD), lightly ionized gas (MgII), and moderately ionized gas (CIV)
- This gas is supposed to be driven by ram pressure from hot (10^7K) gas
- But hot gas destroys clouds, without accelerating them substantially

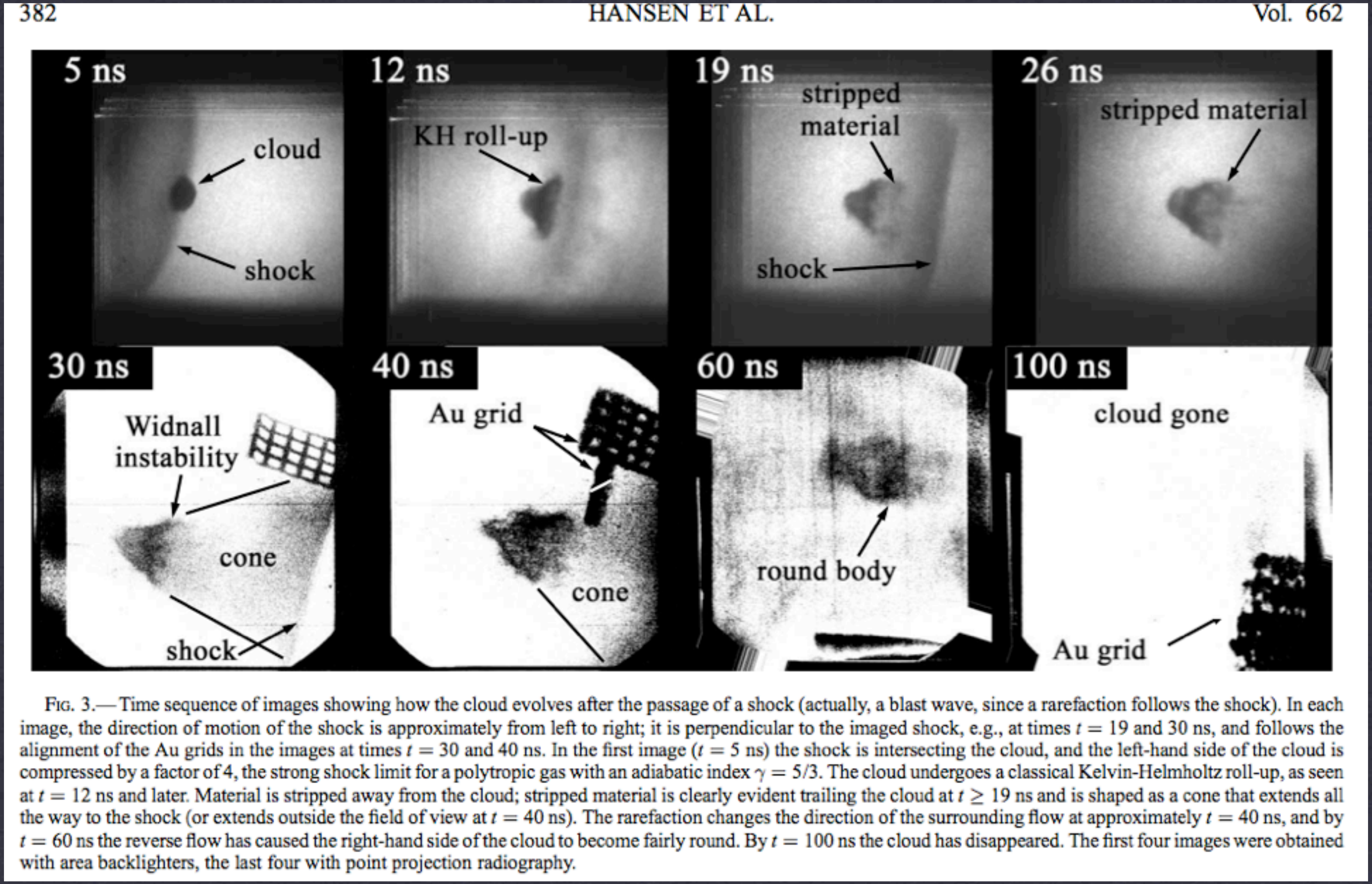


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FIG. 3.—Time sequence of images showing how the cloud evolves after the passage of a shock (actually, a blast wave, since a rarefaction follows the shock). In each image, the direction of motion of the shock is approximately from left to right; it is perpendicular to the imaged shock, e.g., at times $t = 19$ and 30 ns, and follows the alignment of the Au grids in the images at times $t = 30$ and 40 ns. In the first image ($t = 5$ ns) the shock is intersecting the cloud, and the left-hand side of the cloud is compressed by a factor of 4, the strong shock limit for a polytropic gas with an adiabatic index $\gamma = 5/3$. The cloud undergoes a classical Kelvin-Helmholtz roll-up, as seen at $t = 12$ ns and later. Material is stripped away from the cloud; stripped material is clearly evident trailing the cloud at $t \geq 19$ ns and is shaped as a cone that extends all the way to the shock (or extends outside the field of view at $t = 40$ ns). The rarefaction changes the direction of the surrounding flow at approximately $t = 40$ ns, and by $t = 60$ ns the reverse flow has caused the right-hand side of the cloud to become fairly round. By $t = 100$ ns the cloud has disappeared. The first four images were obtained with area backlighters, the last four with point projection radiography.

EXPERIMENTS, SIMULATIONS, ANALYTIC THEORY ALL AGREE

HANSEN ET AL APJ 622 379 (2007) 20-30 CLOUD CRUSHING TIMES TO DESTROY THE CLOUD

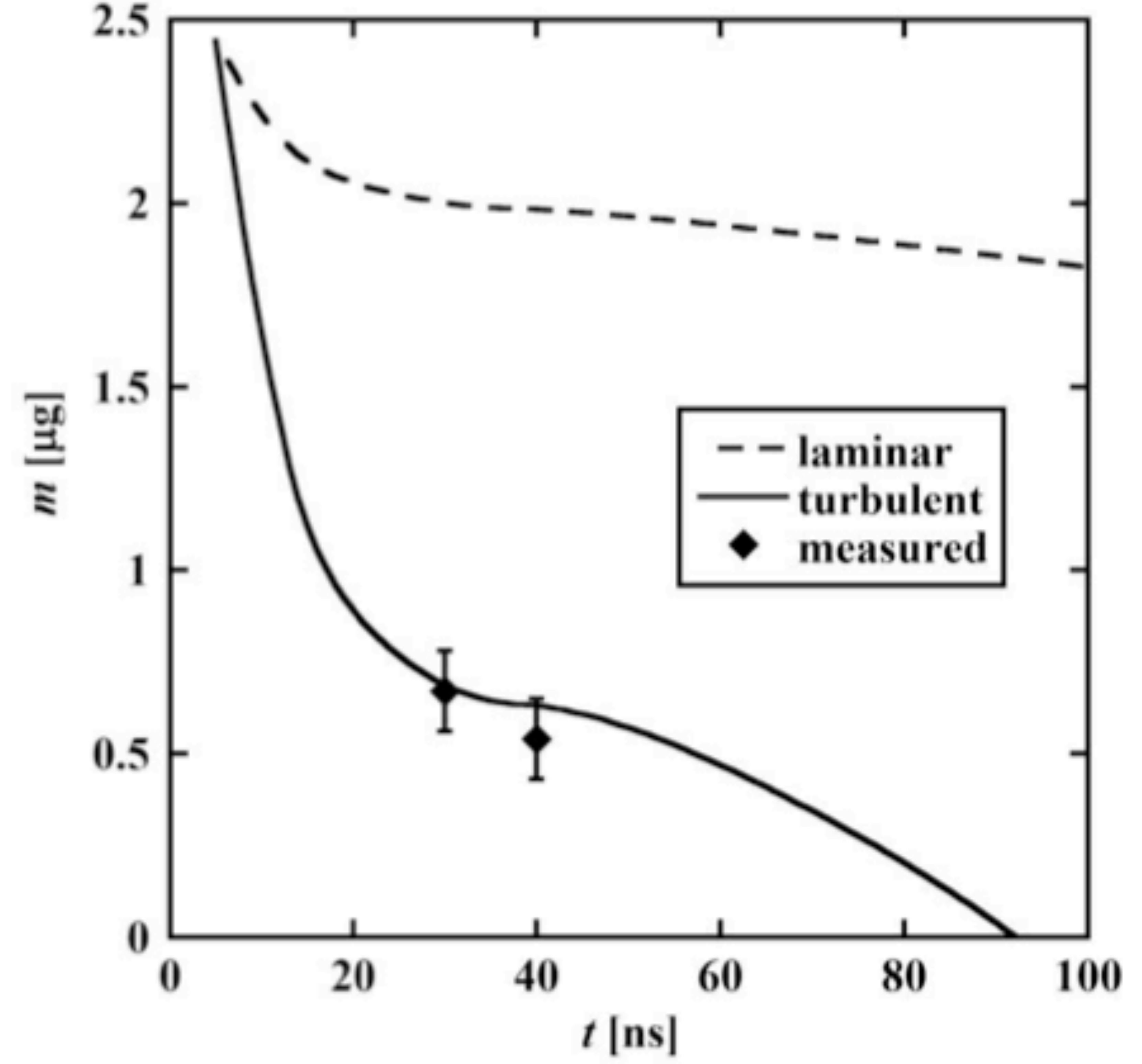
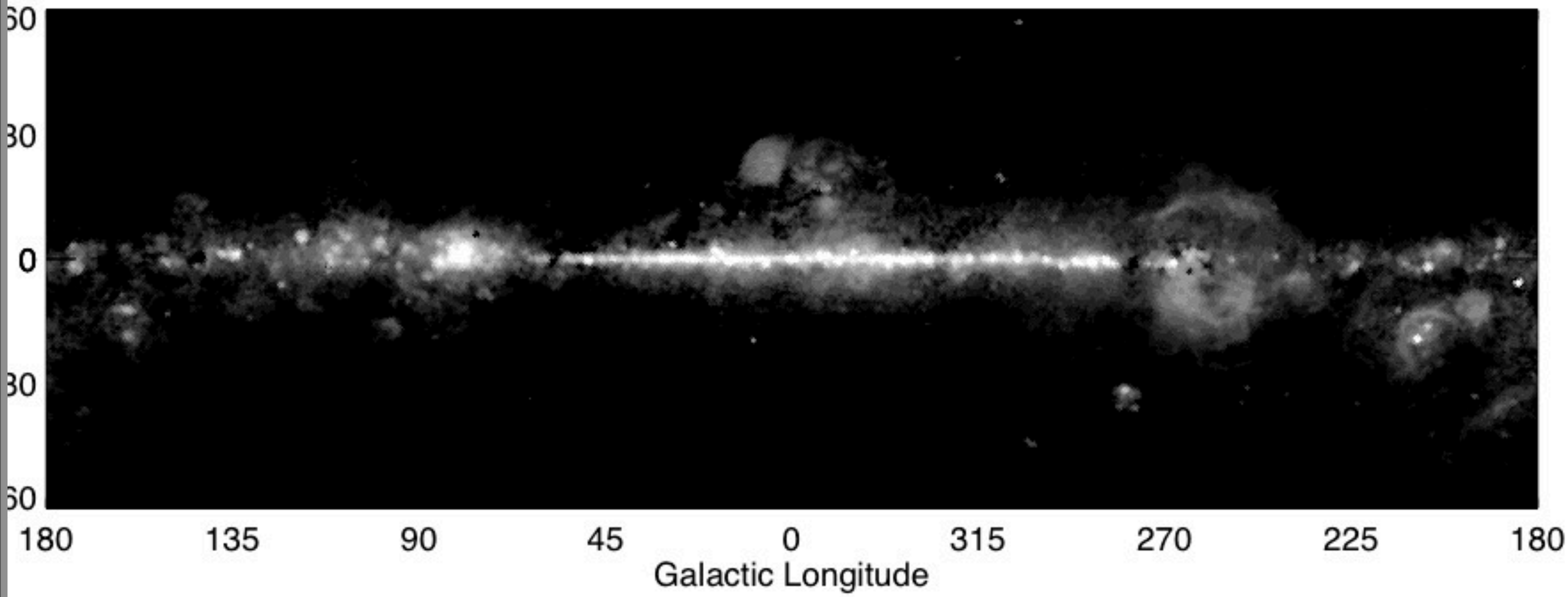


FIG. 7.—Cloud mass remaining as a function of time calculated using a lam-

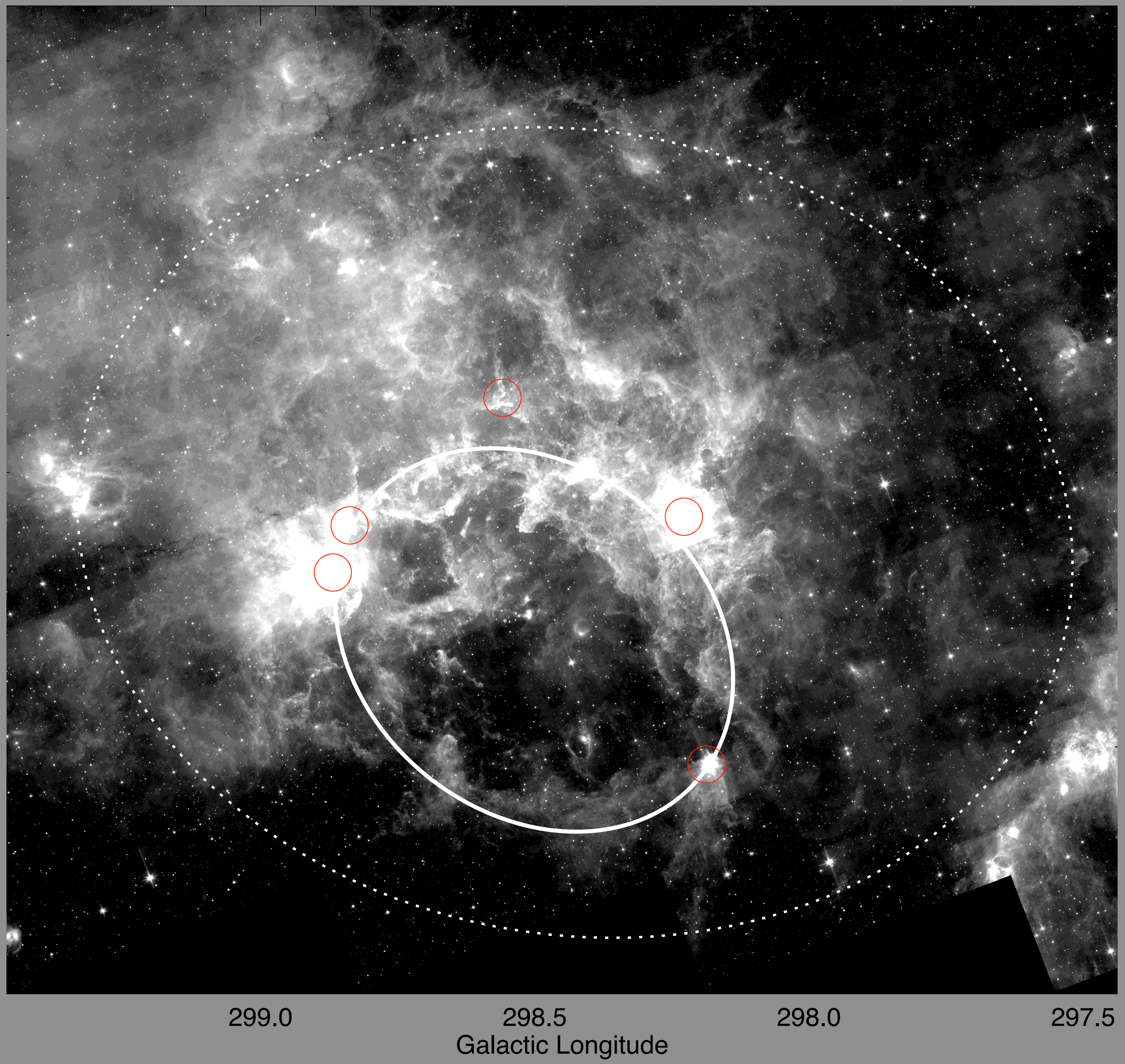
Dust-driven winds

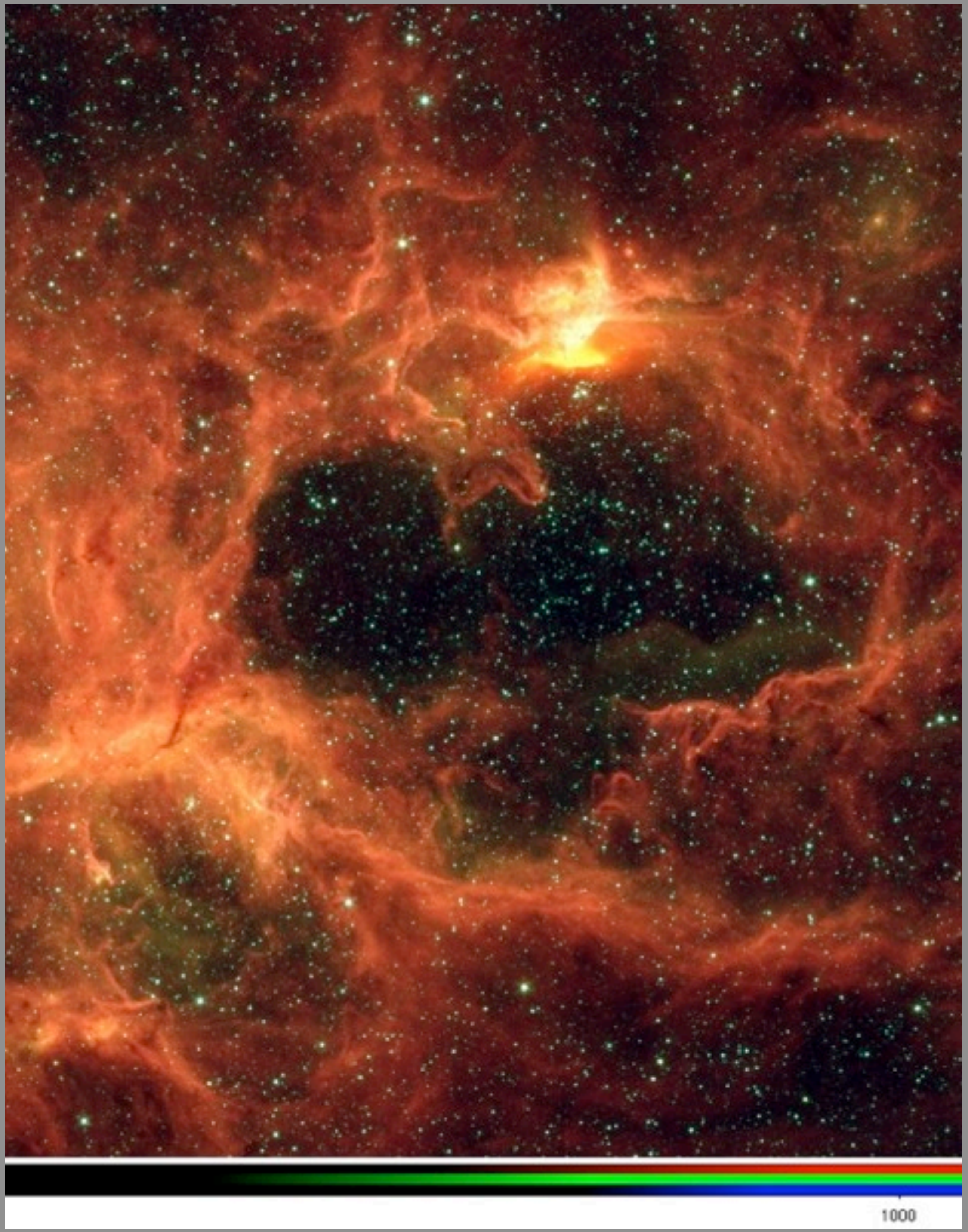
- Clearly some other acceleration mechanism is needed
- Outflows are seen to be dusty---suggesting radiative driving launches the gas
- Massive star clusters serve to radiatively launch galaxy scale winds
- See this process at work in the Milky Way
- Low diffuse x-ray emission---hot gas not dynamically significant



WMAP FREE-FREE MAP OF THE MILKY WAY

88 STAR FORMING COMPLEXES PRODUCE 75% IF THE FREE-FREE EMISSION

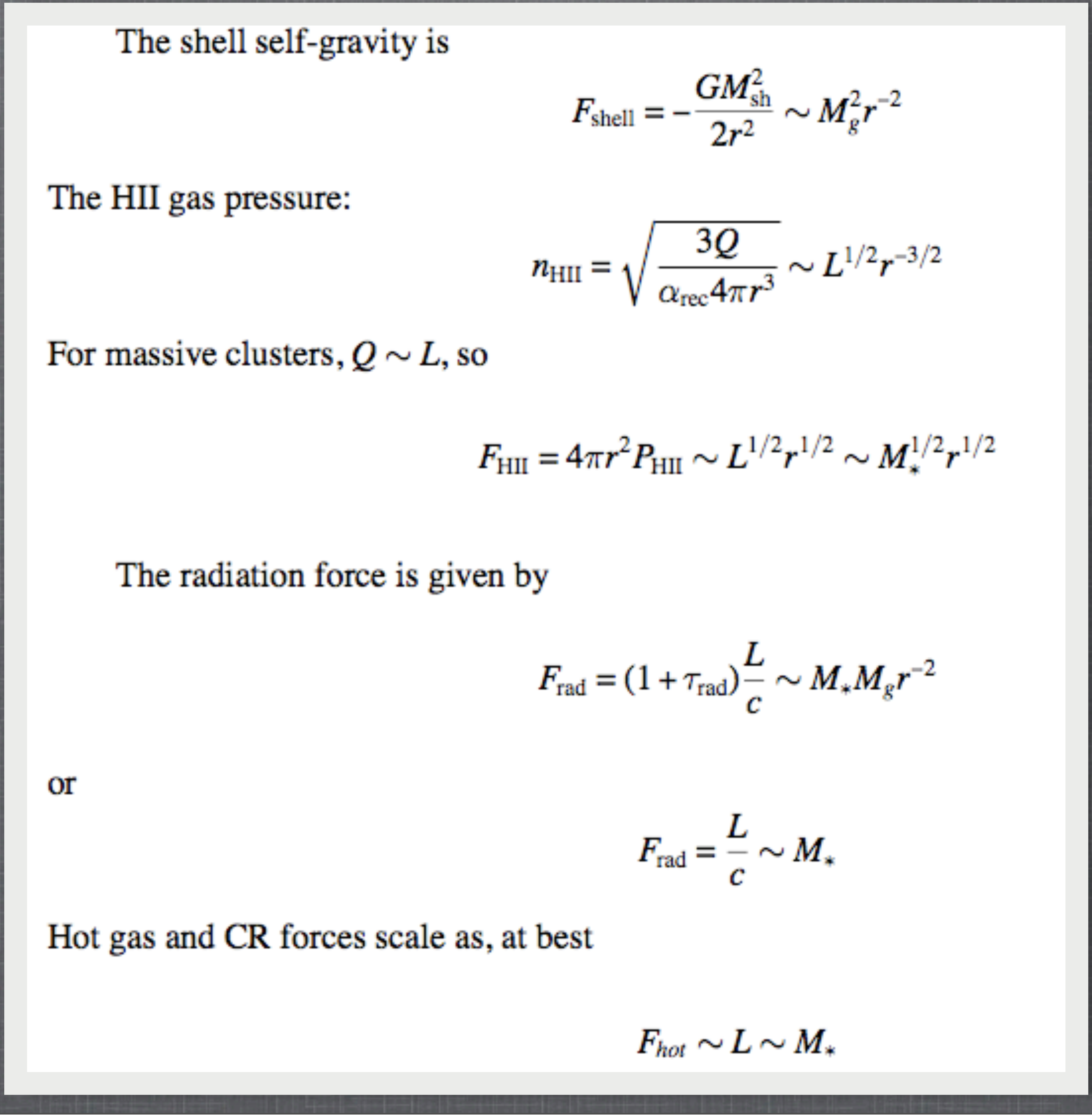




LEFT: G298 A 50,000 SOLAR MASS CLUSTER IN THE MILKY WAY

THE BUBBLE HAS BREACHED THE GAS DISK, AT ~20KM/S

SCALINGS



The shell self-gravity is

$$F_{\rm shell} = -\frac{GM_{\rm sh}^2}{2r^2} \sim M_g^2 r^{-2}$$

The HII gas pressure:

$$n_{\rm HII} = \sqrt{\frac{3Q}{\alpha_{\rm rec} 4\pi r^3}} \sim L^{1/2} r^{-3/2}$$

For massive clusters, $Q \sim L$, so

$$F_{\rm HII} = 4\pi r^2 P_{\rm HII} \sim L^{1/2} r^{1/2} \sim M_*^{1/2} r^{1/2}$$

The radiation force is given by

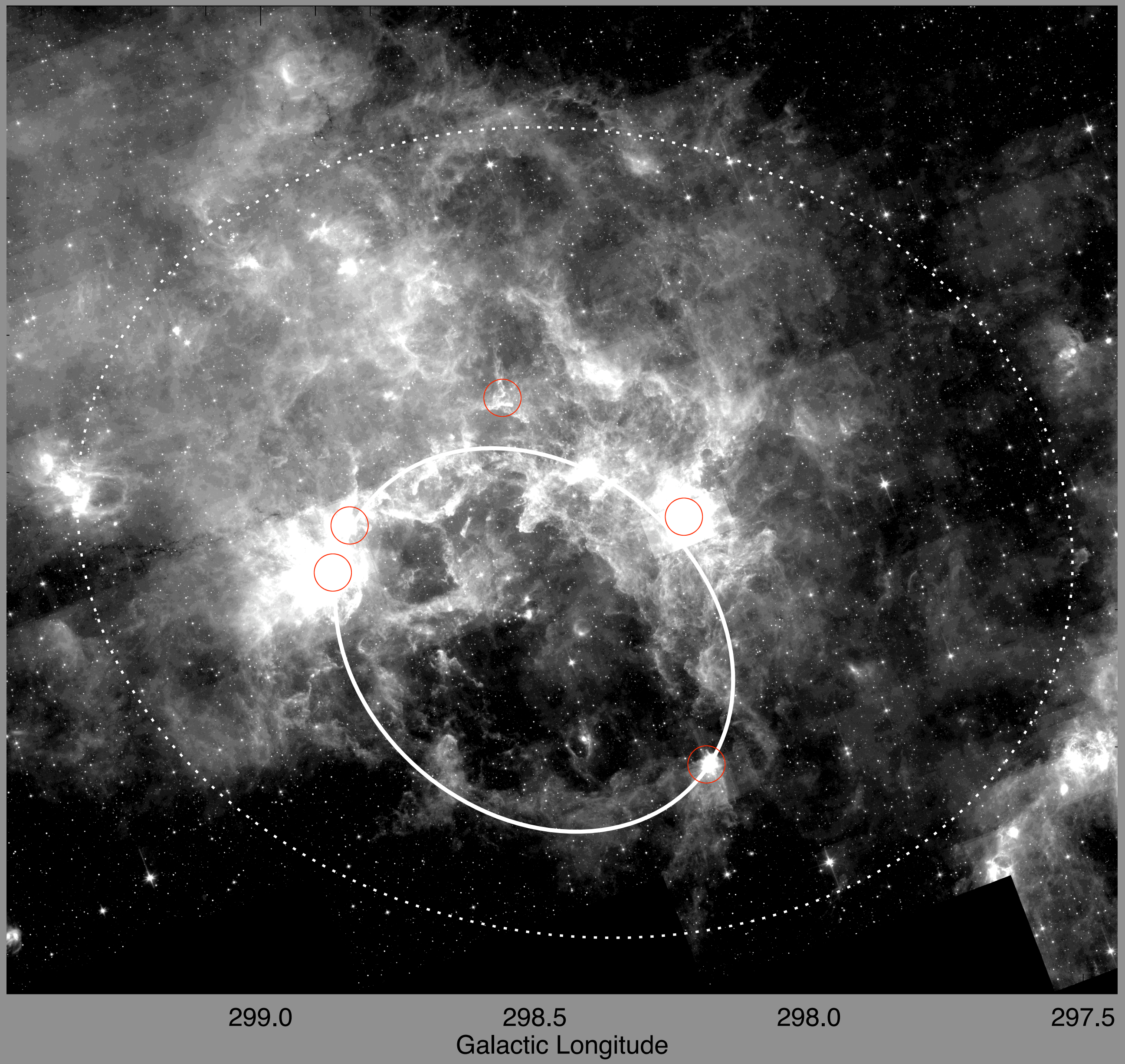
$$F_{\rm rad} = (1 + \tau_{\rm rad}) \frac{L}{c} \sim M_* M_g r^{-2}$$

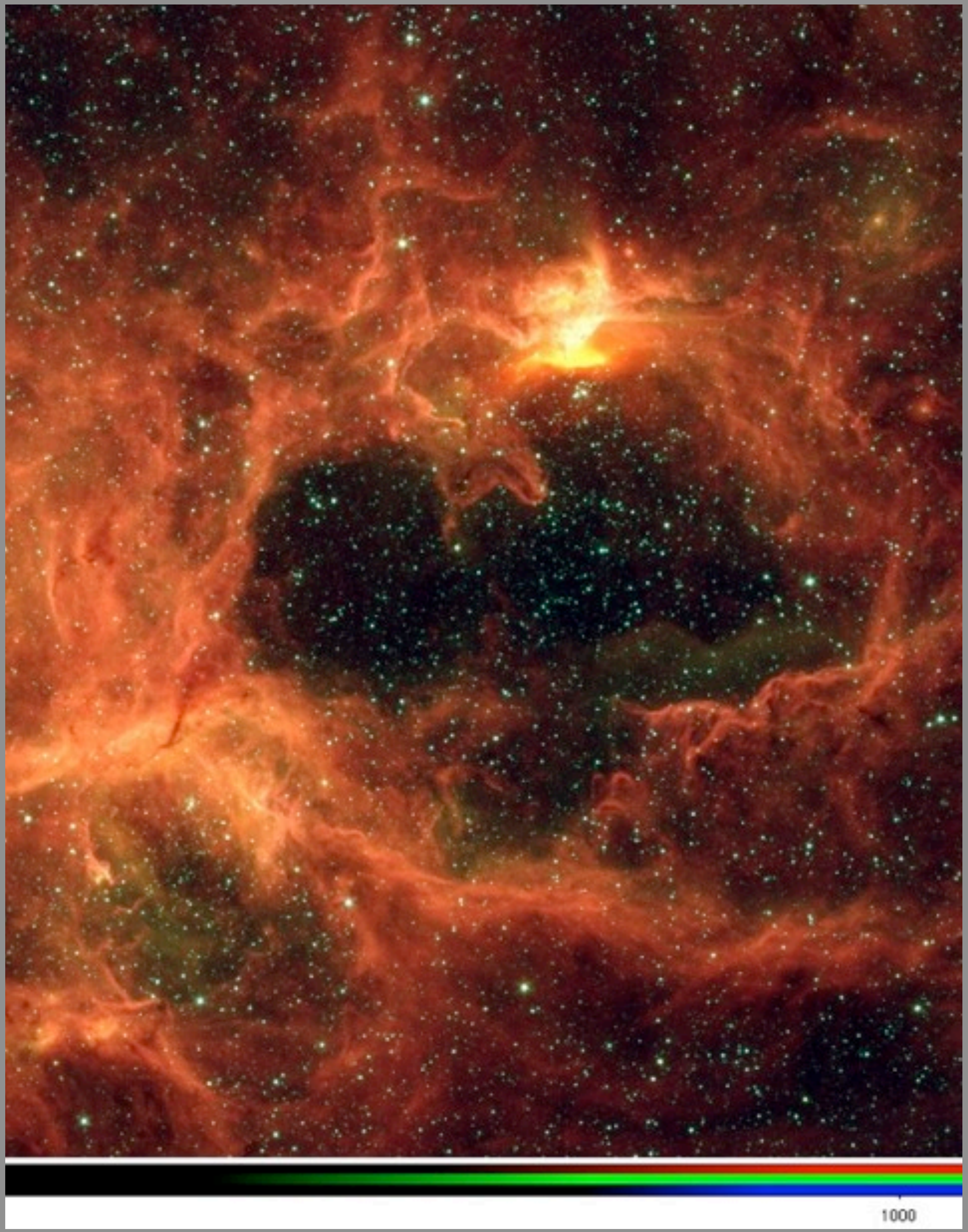
or

$$F_{\rm rad} = \frac{L}{c} \sim M_*$$

Hot gas and CR forces scale as, at best

$$F_{hot} \sim L \sim M_*$$





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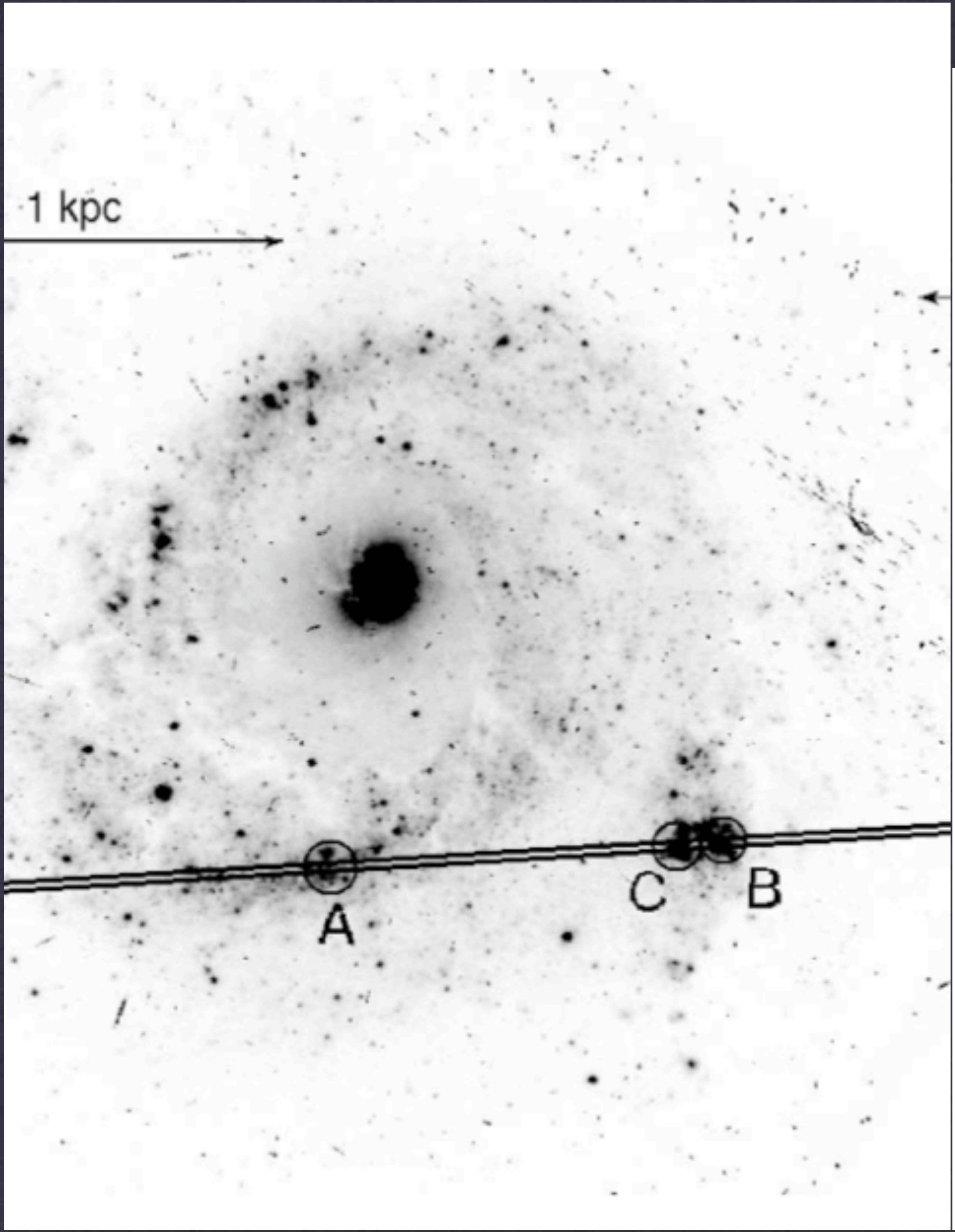


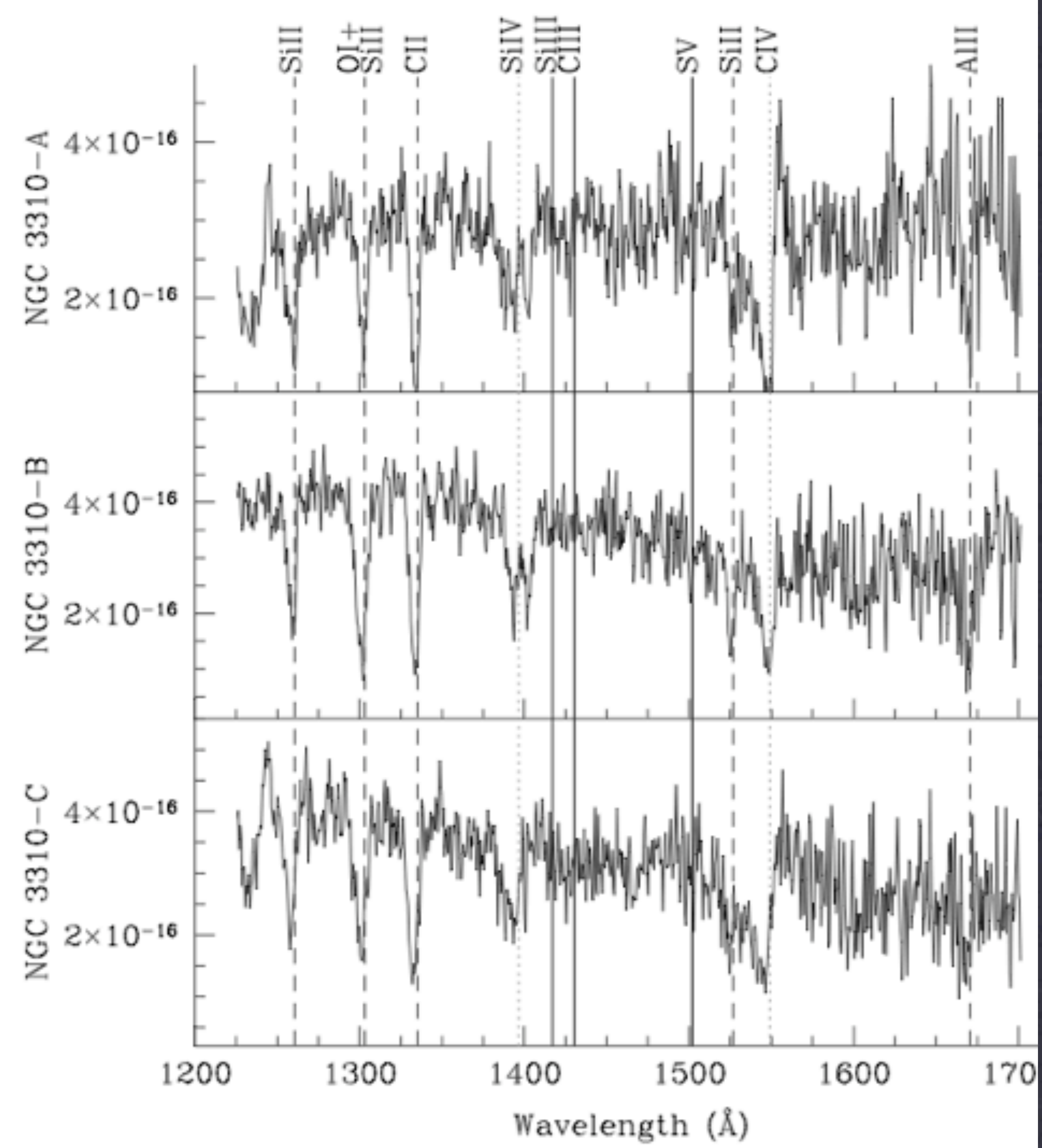
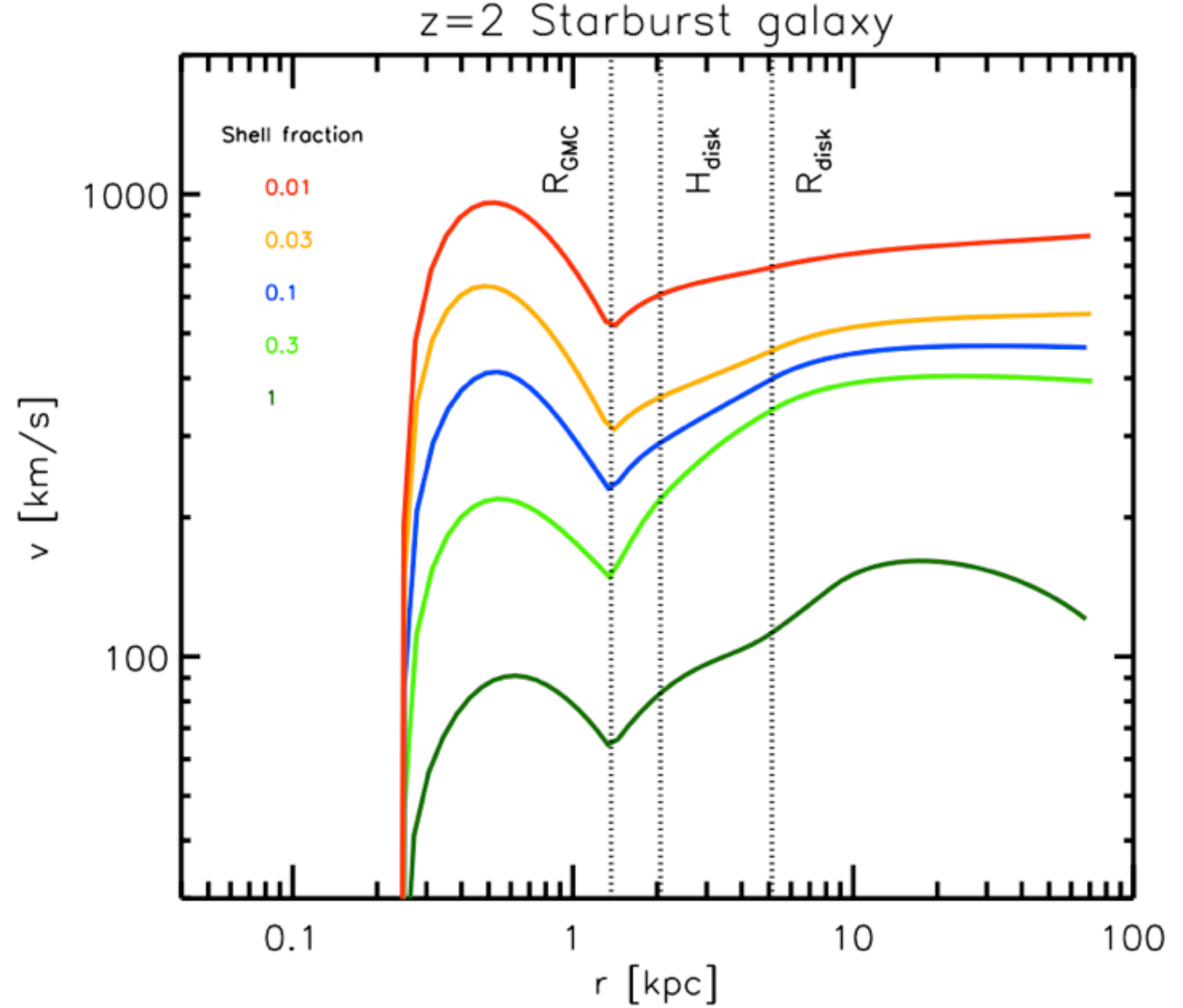


FIG. 5.—STIS G140L spectra of the three bright star clusters (A, B, and
observed in NGC 3310. The spectra have been deredshifted. The solid li

INDIVIDUAL STAR CLUSTERS DRIVE WINDS

Launching winds

- Massive cluster can radiatively launch winds to several hundred kilometers per second, well before SN explode (and we have just seen that O star winds leak out without affecting dynamics)
- At much larger distances, when the cloud crushing time is much longer, hot gas can “turn on the afterburners”, possibly more than doubling the momentum
- $L_w = L_{bol} (v_\infty/c) \sim 0.001 L_{bol}$ not important



CLUSTER DRIVEN (RADIATION PRESSURE ON DUST) OUTFLOWS

MURRAY, MENARD & THOMPSON arXiv:1005.4419

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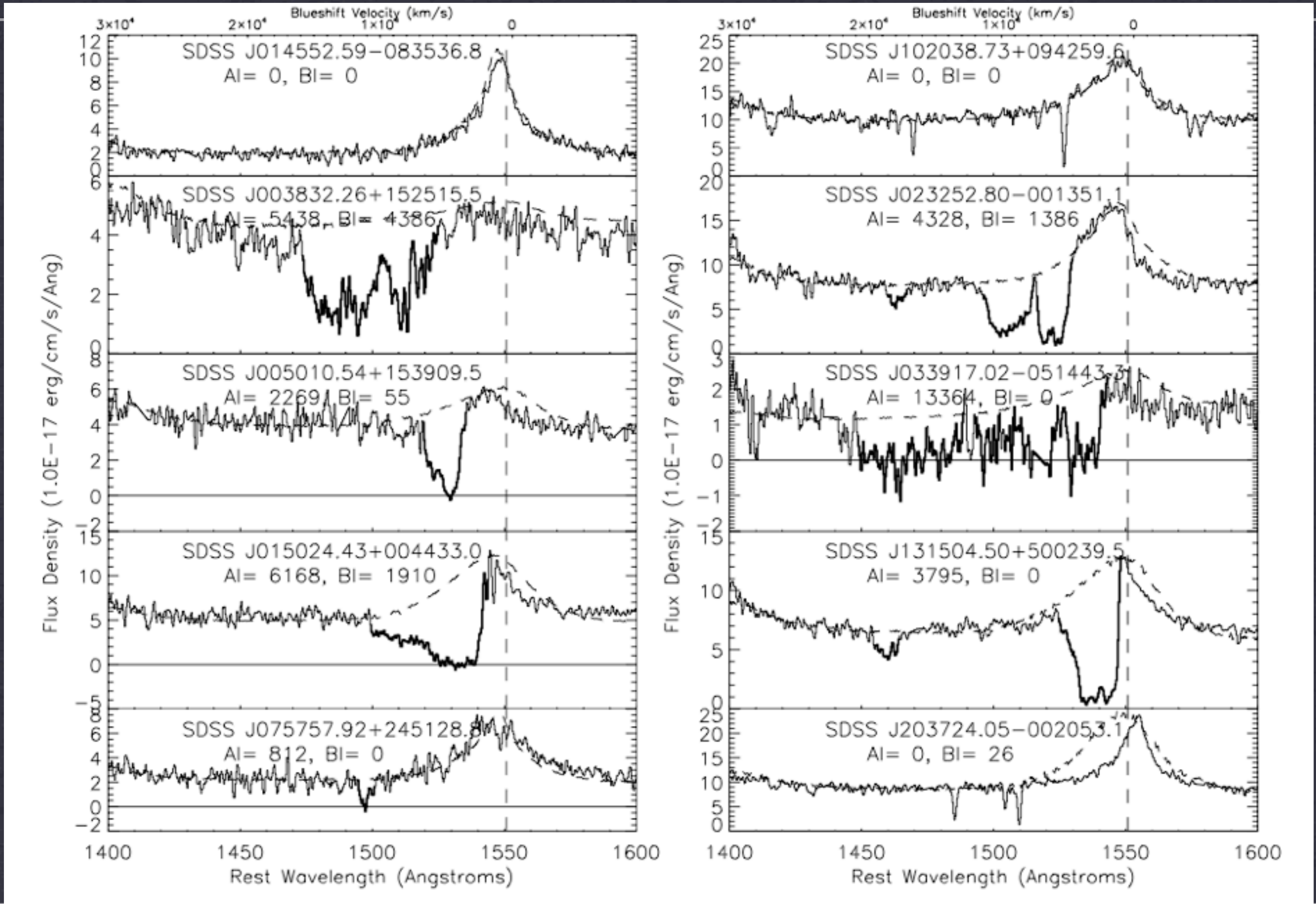
- $L_w = L_{bol} (v_\infty/c) \sim 0.001 L_{bol}$ (not important in clusters)

QSO winds

- Broad absorption lines show that QSOs drive winds
  - consistent with $dM_w/dt\ v_{wind} = L_{bol}/c$ (radiative driving, on lines)
- $L_w \sim L_{bol}\ (v_{wind}/c)\ C_f \sim 0.1 L_{bol}\ C_f$ $C_f \sim 0.2$ or a few percent of L_{bol}
  - Wind luminosities of 10^{44} erg/s typical for QSO
- Coupling this luminosity to the ISM is unlikely
- But the momentum could clear out ~10-100pc around the hole--- as could direct L_{bol}/c
  - This could lead to the M_{BH} - σ relation


Blueshift Velocity (km/s)
3×10⁴
2×10⁴
1×10⁴
0
SDSS J014552.59−083536.8
AI= 0, BI= 0
SDSS J003832.26+152515.5
AI= 5438, BI= 4386
SDSS J005010.54+153909.5
AI= 2269, BI= 55
SDSS J015024.43+004433.0
AI= 6168, BI= 1910
SDSS J075757.92+245128.8
AI= 812, BI= 0
SDSS J102038.73+094259.6
AI= 0, BI= 0
SDSS J023252.80−001351.1
AI= 4328, BI= 1386
SDSS J033917.02−051443.3
AI= 13364, BI= 0
SDSS J131504.50+500239.5
AI= 3795, BI= 0
SDSS J203724.05−002053.1
AI= 0, BI= 26
Flux Density (1.0E−17 erg/cm/s/Ang)
1400
1450
1500
1550
1600
Rest Wavelength (Angstroms)

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- It might be interesting for galaxy clusters---but probably not the main player

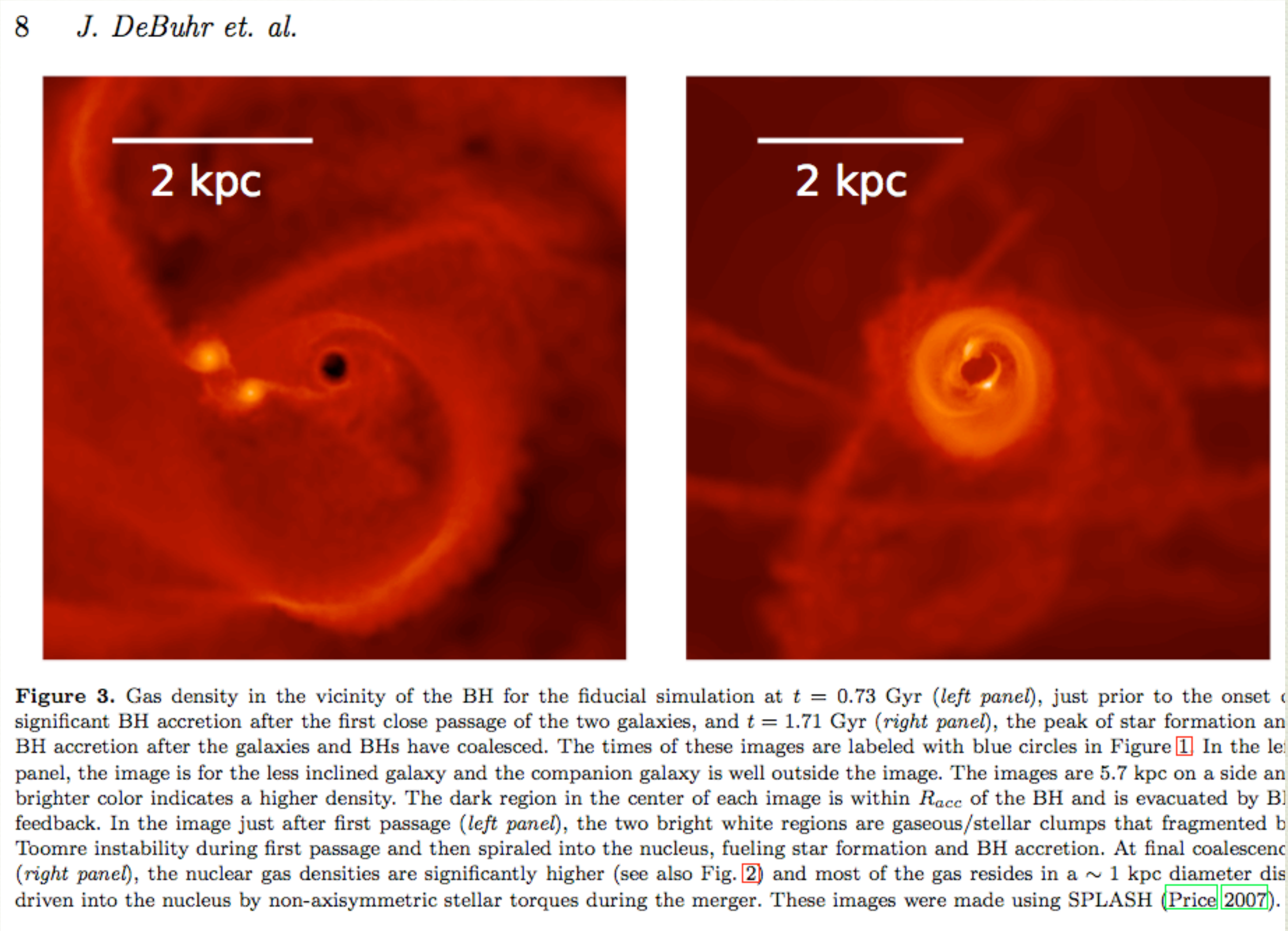

Figure 3. Gas density in the vicinity of the BH for the fiducial simulation at $t = 0.73$ Gyr (*left panel*), just prior to the onset
significant BH accretion after the first close passage of the two galaxies, and $t = 1.71$ Gyr (*right panel*), the peak of star formation an
BH accretion after the galaxies and BHs have coalesced. The times of these images are labeled with blue circles in Figure 1. In the le
panel, the image is for the less inclined galaxy and the companion galaxy is well outside the image. The images are 5.7 kpc on a side an
brighter color indicates a higher density. The dark region in the center of each image is within R_{acc} of the BH and is evacuated by B
feedback. In the image just after first passage (*left panel*), the two bright white regions are gaseous/stellar clumps that fragmented b
Toomre instability during first passage and then spiraled into the nucleus, fueling star formation and BH accretion. At final coalescenc
(*right panel*), the nuclear gas densities are significantly higher (see also Fig. 2) and most of the gas resides in a ~ 1 kpc diameter dis
driven into the nucleus by non-axisymmetric stellar torques during the merger. These images were made using SPLASH (Price 2007).

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Conclusions

- Stellar feedback probably limits the rate of star formation in galaxies
- Stellar feedback probably removes baryons from galaxy (but not cluster) halos
- Stellar feedback probably not important on the cluster scale
- QSO feedback, in the form of winds, may limit the mass of black holes
- It might be interesting in clusters, but jets are seen more often than broadline QSOs in cold core clusters, so jets seem like a better bet for feedback