Revealing A Highly Dynamic Cluster Core in Abell 1664 with Chandra

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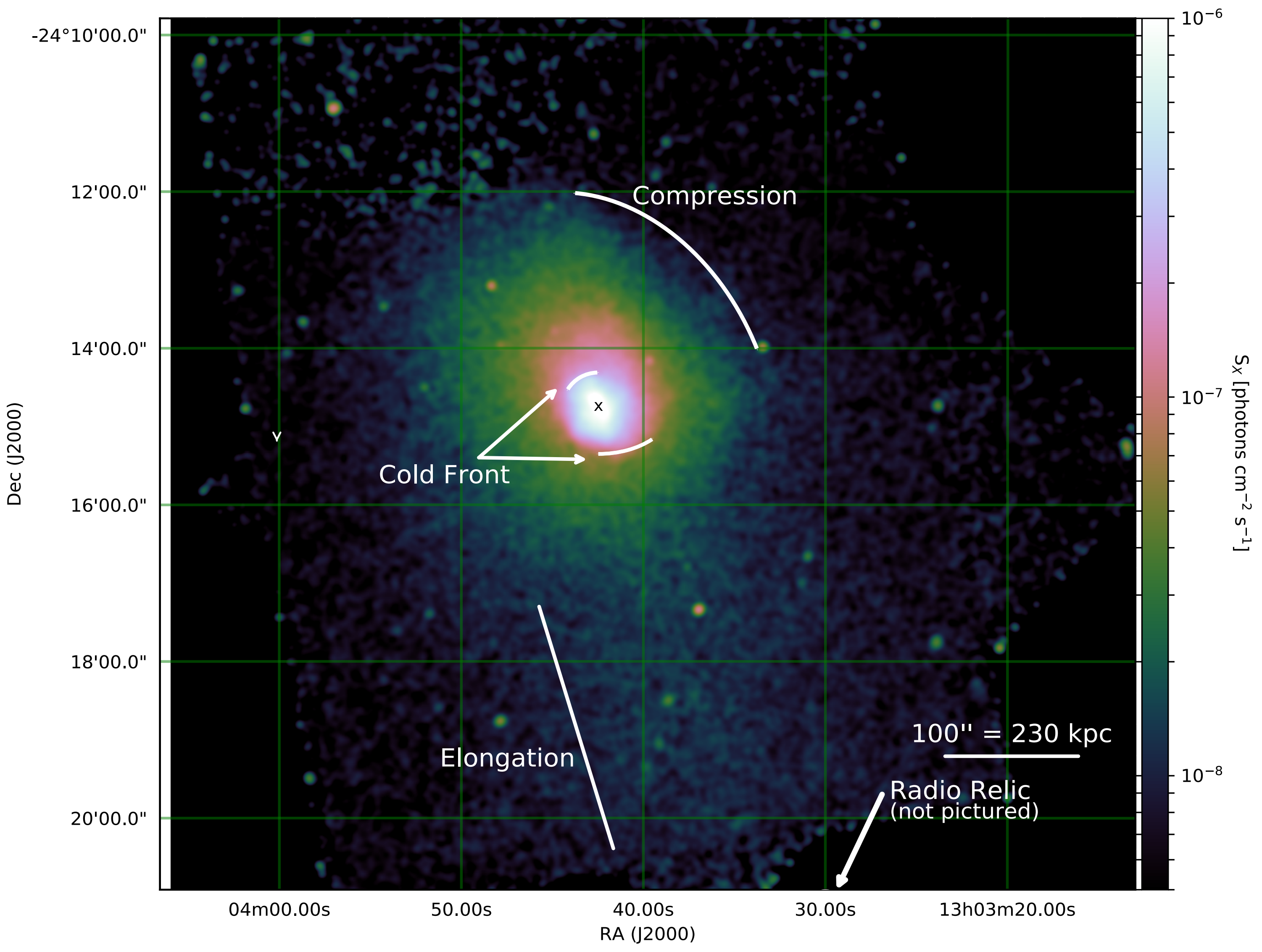
Abstract

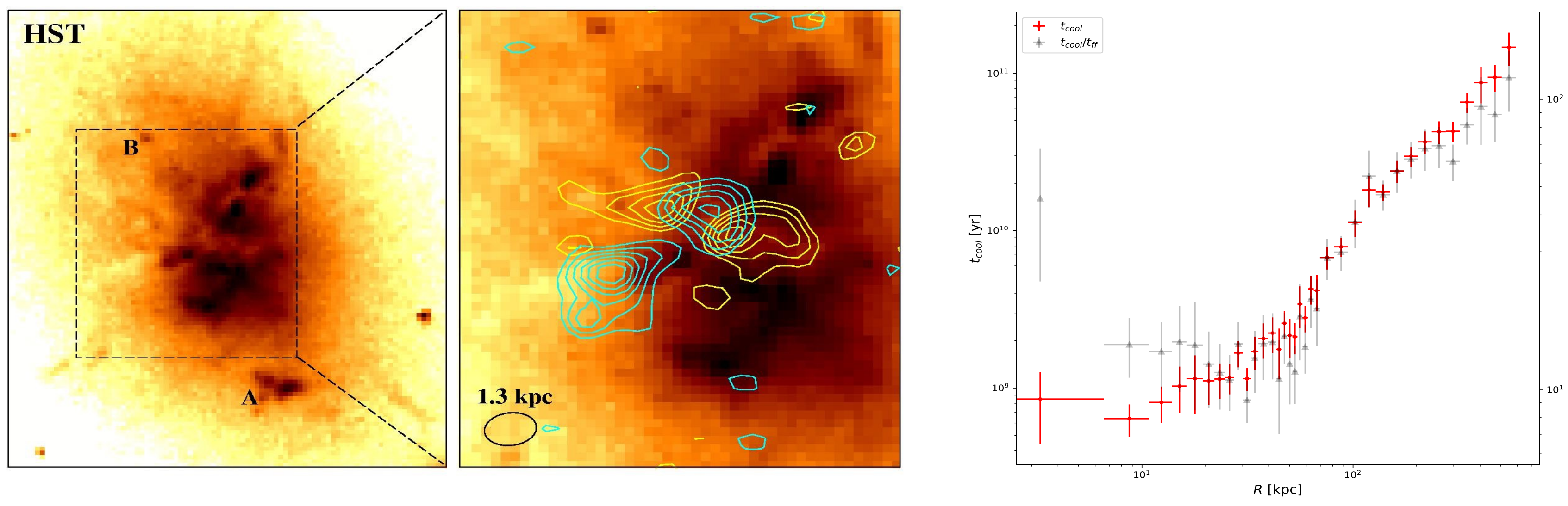
We present new, deep (245ks) *Chandra* X-ray observations of the galaxy cluster Abell 1664 (z=0.128). These data reveal rich structure, including cold fronts in the NE-SW direction, suggesting that the hot gas is sloshing in the gravitational potential. The central active galactic nucleus (AGN) appears to have recently undergone a mechanical outburst, as evidenced by our detection of cavities, which may explain the motion of cold molecular clouds previously observed with the *Atacama Large Millimeter Array (ALMA)*. The estimated mechanical power of the AGN may be enough to drive the molecular gas flows. Finally, the most rapidly cooling gas is mostly coincident with the molecular gas reservoirs, and may be fueling cold accretion onto the central black hole.



Exposure-corrected 240 ks *Chandr*a image of A1664 in the 0.5–7 keV band. Compression of the X-ray isophotes is visible 325 kpc (~140") NW of the cluster center, and again at 110 kpc (~50") to the South and at 50 kpc (~20") to the NE of the center, suggesting N-S gas sloshing on various scales.

Origin of the Giant Molecular Clouds

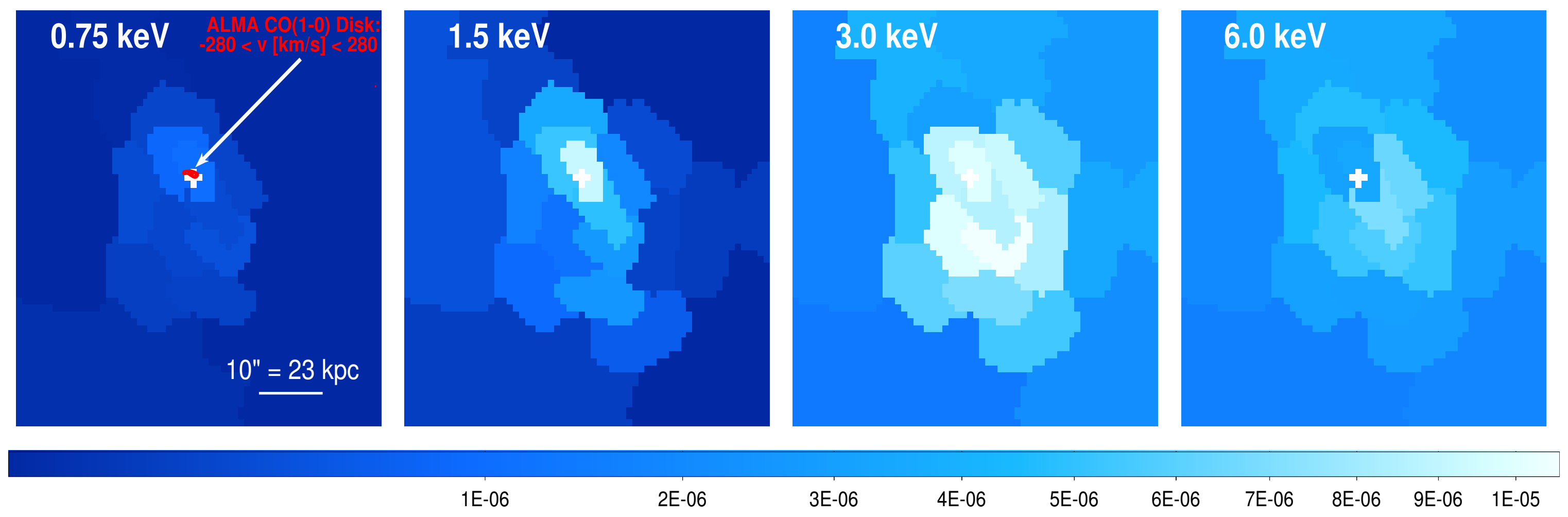
Abell 1664 hosts a giant reservoir (~ 10^{10} $M_\odot$) of cold molecular gas flows, first detected by Edge et al. (2001), and later resolved with *ALMA* by Russell et al. (2014). Our deeper Chandra observations were motivated by trying to determine the origin of these reservoirs. Studies have shown that the local cooling time of the intracluster medium (ICM), as well as some mixing timescale, appears to correlate with the presence of such thermal instabilities (e.g. Gaspari et al. 2012, McNamara et al. 2016, Voit et al. 2017). In this study, we focused on two major mechanisms which could be responsible for mixing of the ICM: gas sloshing and AGN feedback.



Left: *Hubble Space Telescope* (*HST*) observation of Abell 1664, with a zoom-in view of the central galaxy. The contours depict the distribution of the giant reservoir of cold molecular gas observed with *ALMA*, from Russell et al. (2014).
Right: cooling time profile as well as the ratio of t_{cool}/t_{ff}, which may be a sensitive indicator of thermal stability to cooling.

The Most Rapidly Cooling X-ray Gas

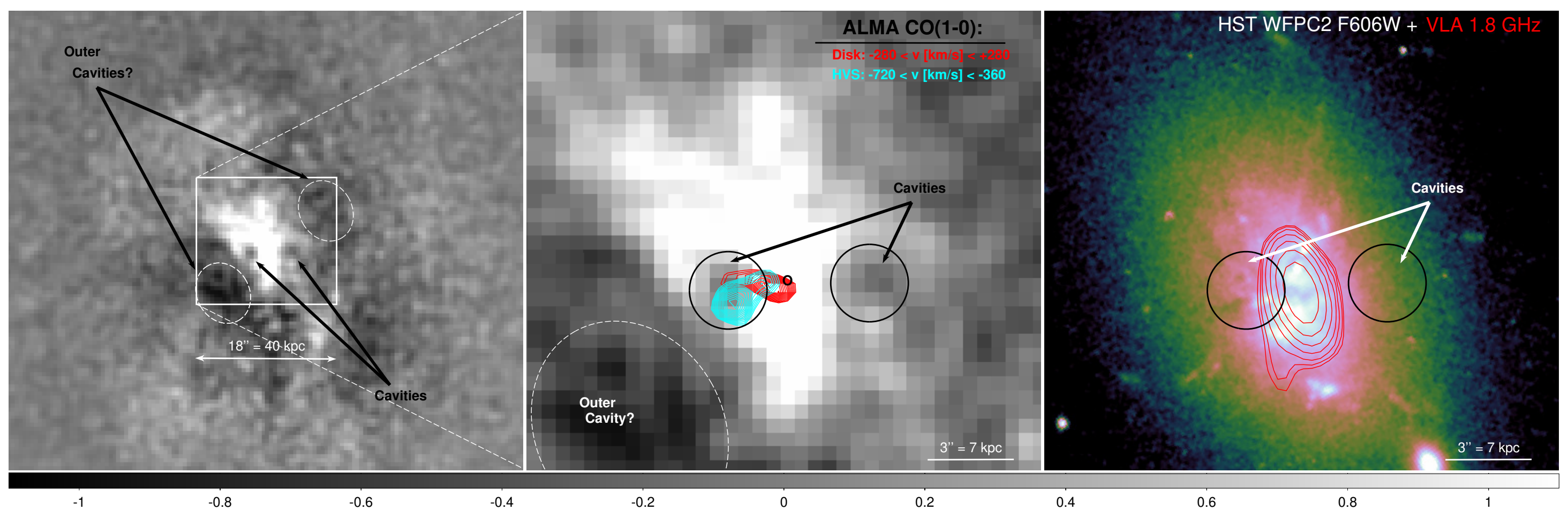
The specific details of how thermal instabilities in the ICM develop are still being investigated, but we can address whether there is sufficient cooling to fuel the massive cold gas reservoir in Abell 1664's central galaxy. To this end, we map temperature variations on the same spatial scale as the molecular gas and find that the most rapidly cooling gas is mostly coincident with the molecular gas. This potentially establishes a link between the cluster atmosphere on tens of kpc scales to the central black hole onto which the cold molecular gas could be accreting and fueling the AGN (Pizzolato & Soker 2010).



Multi-temperature maps of the inner ~20 kpc of Abell 1664, showing the normalization per unit area of each fixed-temperature model component, following the technique of Fabian et al. (2006). The coolest gas is coincident with the molecular gas reservoir revealed by *ALMA*, and may be serving as fuel for the central supermassive black hole.

X-ray Cavities Carved Out by the AGN

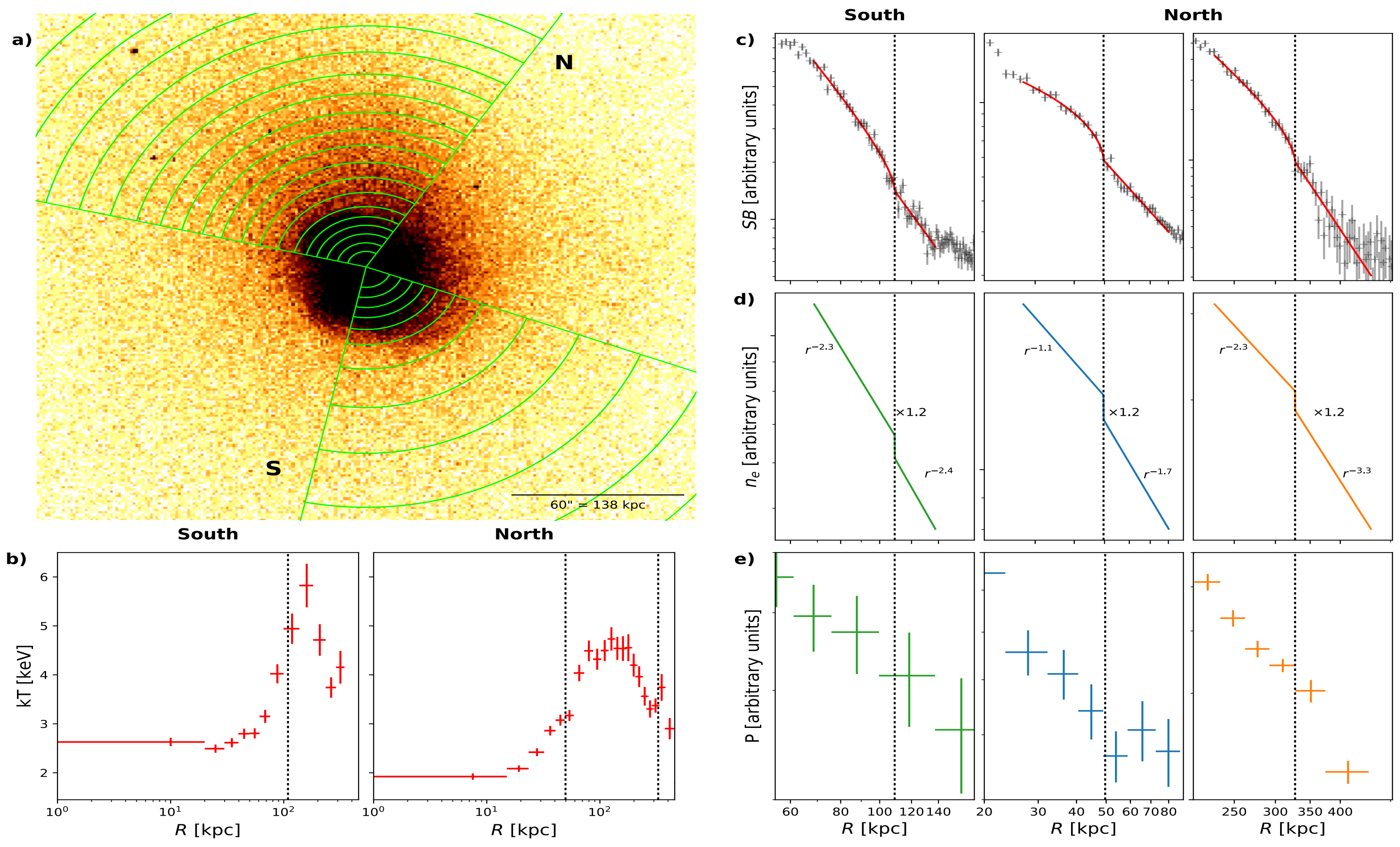
McNamara et al. (2016; see also Voit et al. 2017) suggest that uplift by buoyantly-rising radio bubbles, inflated by a central AGN, promotes thermally unstable cooling leading to the formation of cold filaments. Our deeper X-ray data enabled us to detect the X-ray cavities carved out by such radio bubbles. Just as in a dozen other systems observed by *ALMA,* the molecular clouds in Abell 1664 lie predominantly in filaments projected behind these X-ray cavities. Based on the *pV* work done by these cavities on their surroundings, we estimated the mechanical power of the AGN to be (1.1 ± 1.0) x 10^{44} erg/s, which may be enough to drive the molecular gas flows.



Left: *Chandra* normalized residual flux image, after subtracting four freely-varying beta models.
Center: zoomed-in view of the central region, pointing to X-ray cavities detected at >4σ and >6σ significance levels. The blue and red contours indicate the presence of massive molecular outflows detected with ALMA, and appear to be drawn up behind the cavities.
Right: *HST* image with 1.8 GHz *VLA* contours and cavity outlines overlaid.

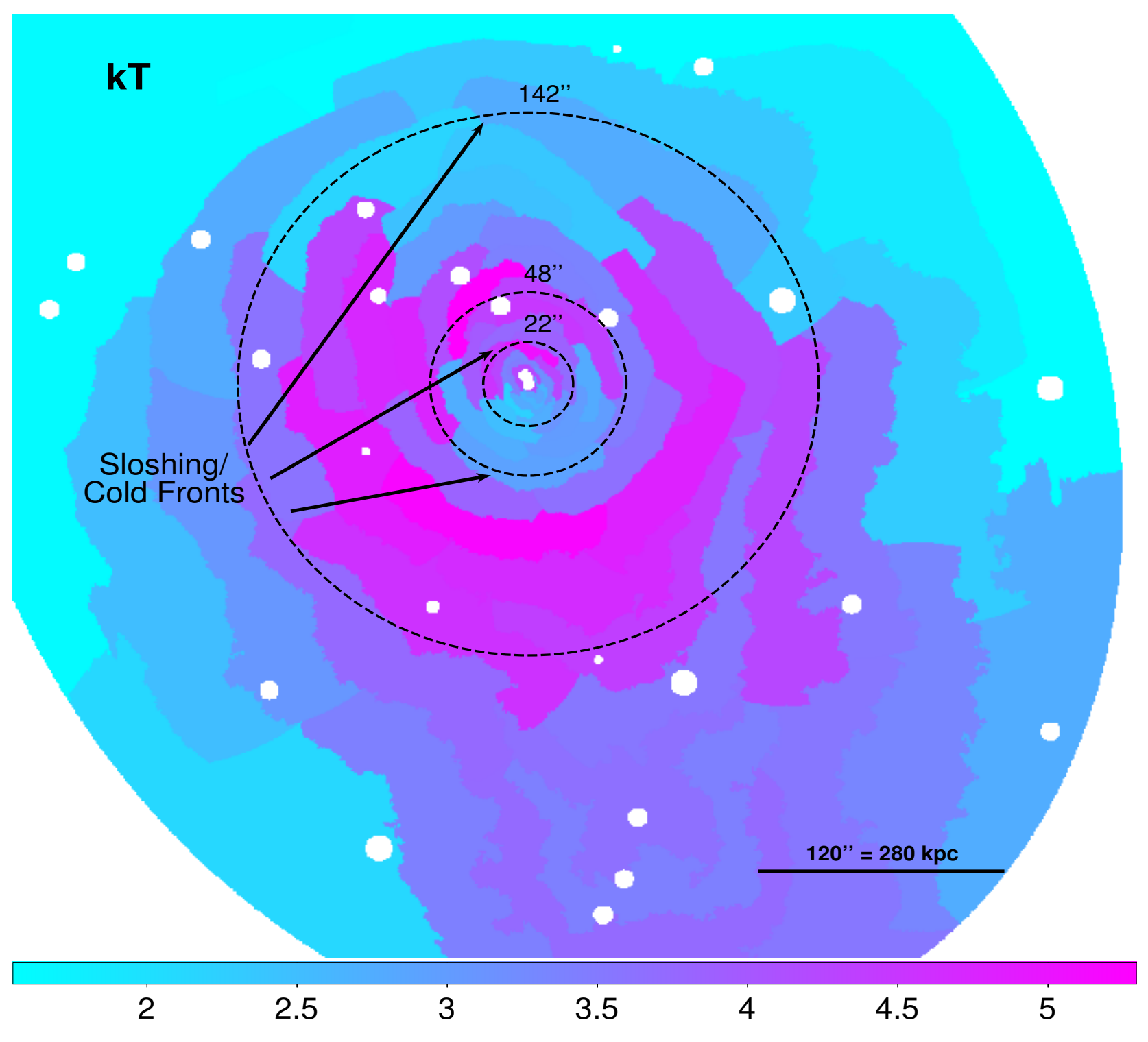
Core Sloshing on Multiple Scales

Careful analysis of the surface brightness profiles along certain directions reveal sharp edges that are consistent with density discontinuities behaving as a local, broken power law. While the density drops sharply, the temperature at each discontinuity rises sharply, but in such a way that the pressure remains smooth, indicating the presence of cold fronts (see Markevitch & Vikhlinin 2007).



Cold fronts in A1664. Panel **(a)** X-ray image showing the regions used for extraction of (projected) temperature profiles, shown in panel **(b)** . In panel **(b)** , the left-hand plots correspond to the (projected) temperature profile of the Southern sectors, while the right-hand plot corresponds to sectors in the Northern direction. Panel **(c)** 2D surface brightness profiles along the North and South directions, fit locally with the analytic line-of-sight projection of the 3D (i.e. deprojected) broken power-law density models given in panel **(d)**. Panel **(e)** shows the pseudo-pressure calculated from the product of panels **(b)** and **(d)**. Across each of the fitted density discontinuities, the pressure profile is smoothly varying, as is expected of a cold front in pressure equilibrium.

Cold Fronts: Temperature View



Temperature map, in units of keV, produced via contour binning (Sanders et al. 2006) with approximately 5000 counts per region.

Cold fronts are caused by galaxy mergers as infalling subhaloes are stripped of their gas and change the shape of the gravitational potential (Ascasibar & Markevitch 2006). As a result, the cluster core oscillates and causes changes in ram pressure, giving the infalling gas some angular momentum and resulting in a characteristic spiral pattern about the cluster core. The cold fronts revealed above are clearly visible here at various radii, where there is high temperature contrast between adjacent regions. These sloshing perturbations may also be responsible for the North-South molecular gas reservoir reported recently by Olivares et al. (2019), which is perpendicular to the gas flows studied here as well as the jet-cavity axis. Abell 1664 could thus provide an ideal laboratory for testing the relative importance of these mechanisms in the creation of thermal instabilities.

References

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