Discovery of a Pre-merger Shock Wave in Abell 98: A Missing Piece in Building the Most Massive Structures in Our Universe

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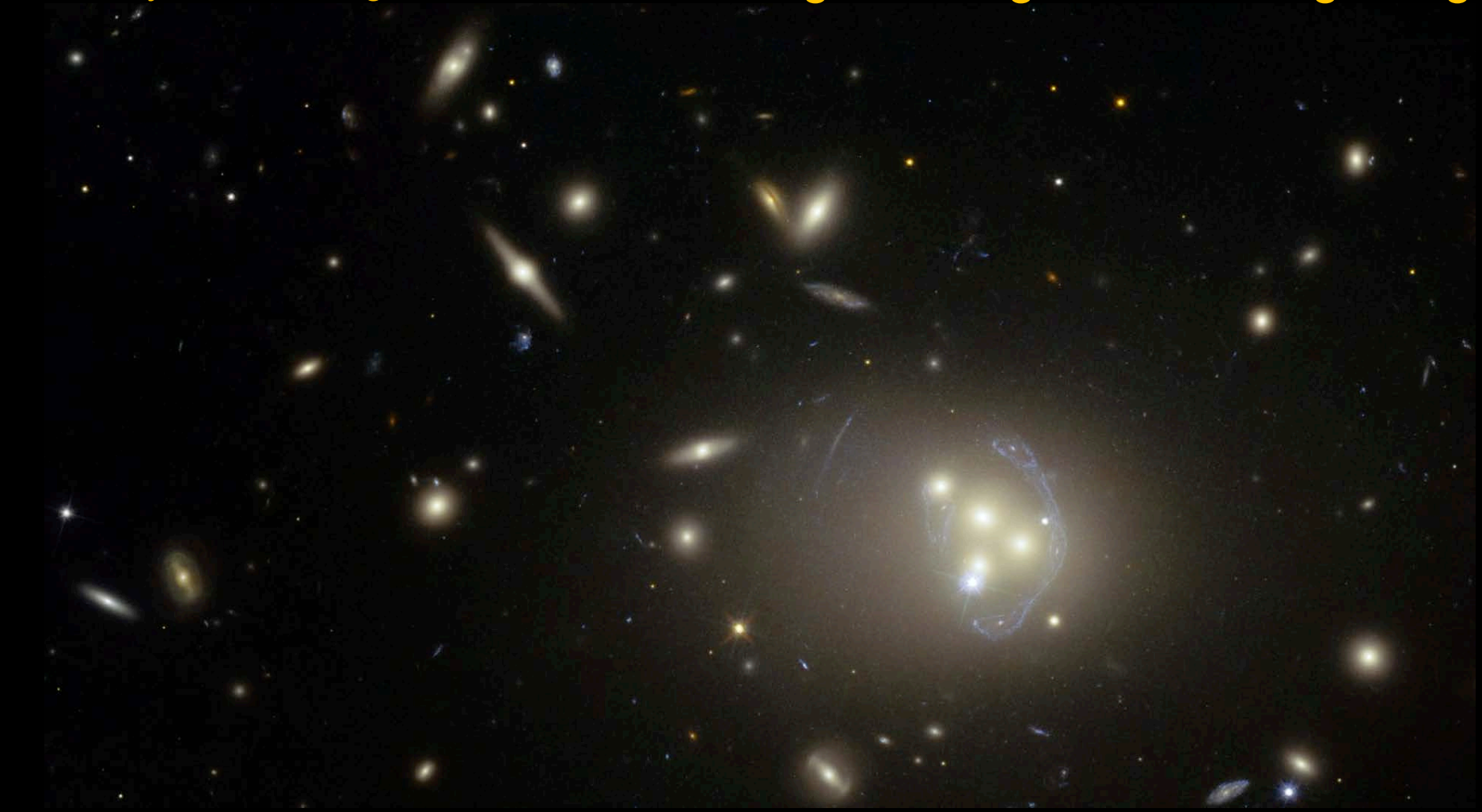
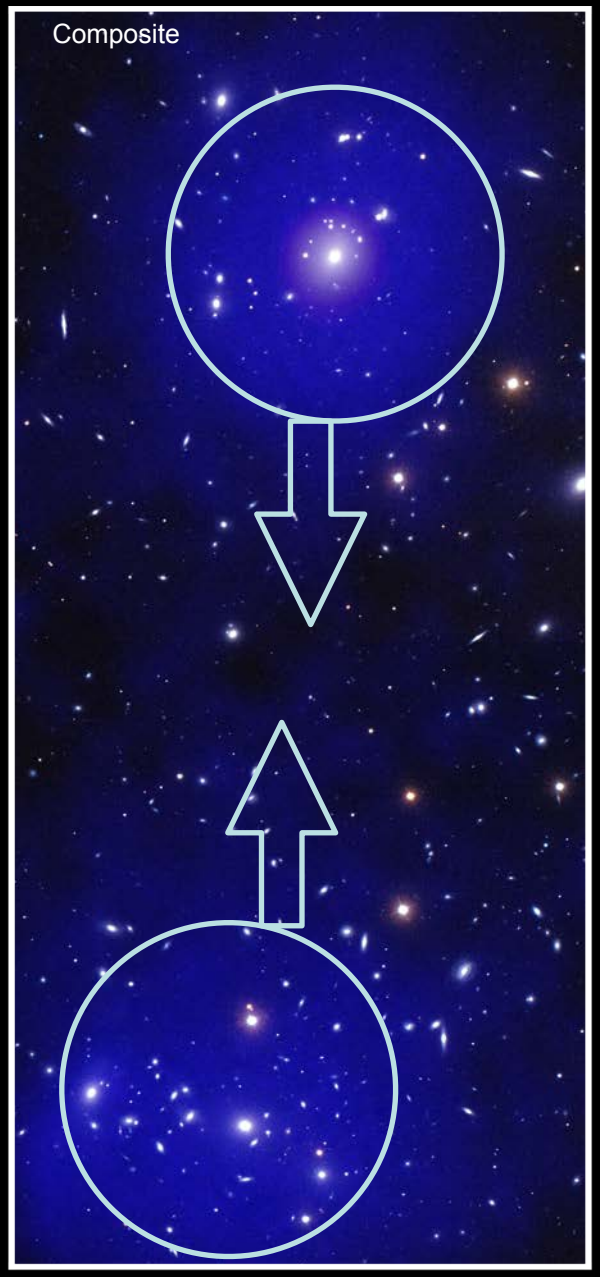
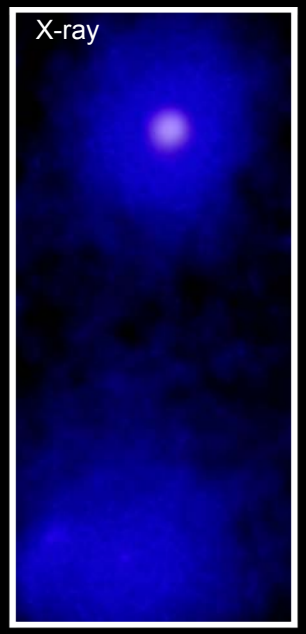
What are Galaxy clusters?

- They are the largest known gravitationally bound system in our Universe.
- They form via mergers of smaller subclusters and groups of galaxies
- Galaxy cluster mergers are the most energetic bang since the Big Bang!!







Galaxy cluster Abell 98

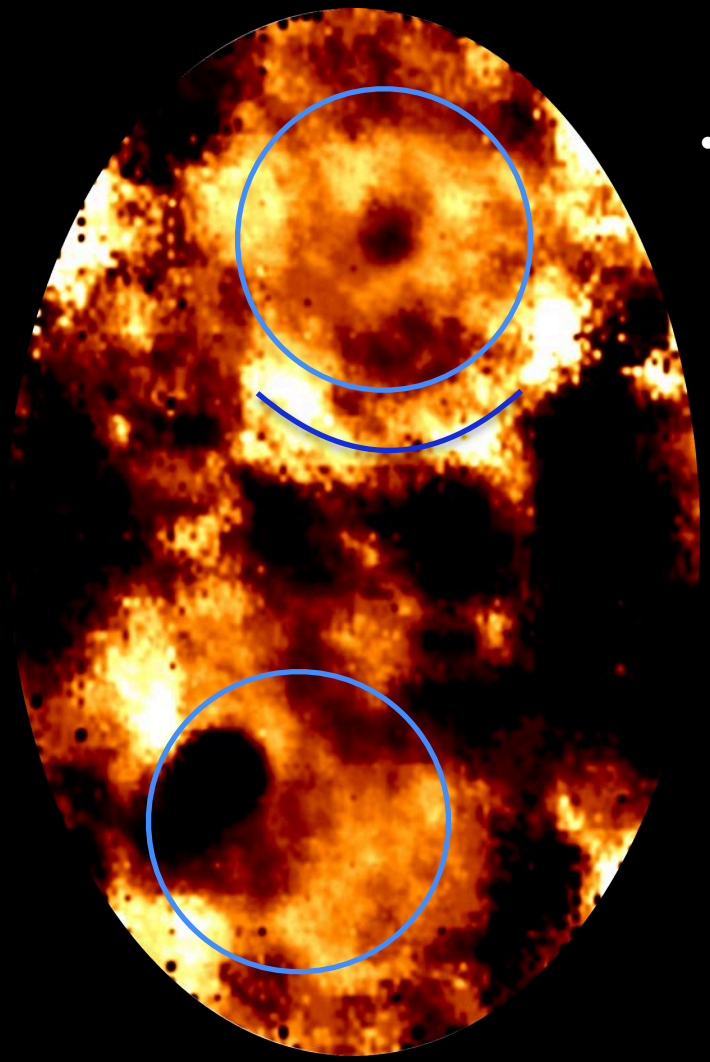
X-ray image: Chandra X-ray Observatory

Optical image: 3.5-meter WIYN telescope
Credit: Chandra public affairs

Details of Abell 98

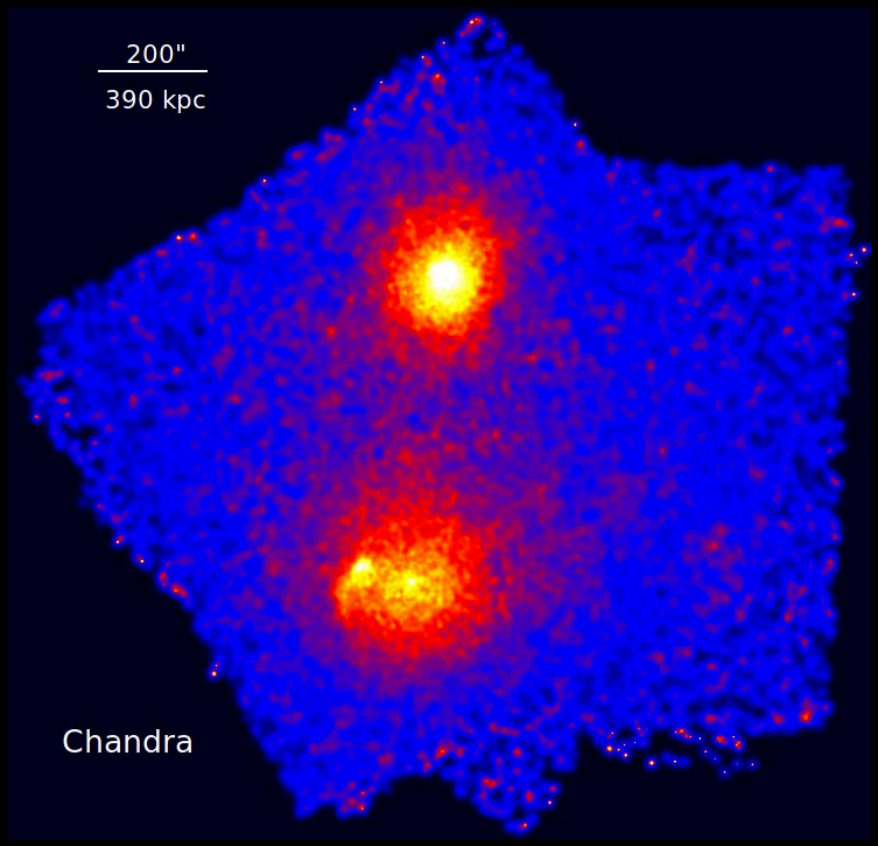
- Distance = 1.2 billion light-years (z = 0.1042)
- Distance between two cores 3 million light-years. They are at initial phase of merging
- Mass ~ 2×10^{14} solar masses (temperature = 30 million degrees kelvin)
- Observations of early-stage mergers are very rare!! They promise exciting new physics of cluster merger!

Temperature Map: An Image of Temperatures

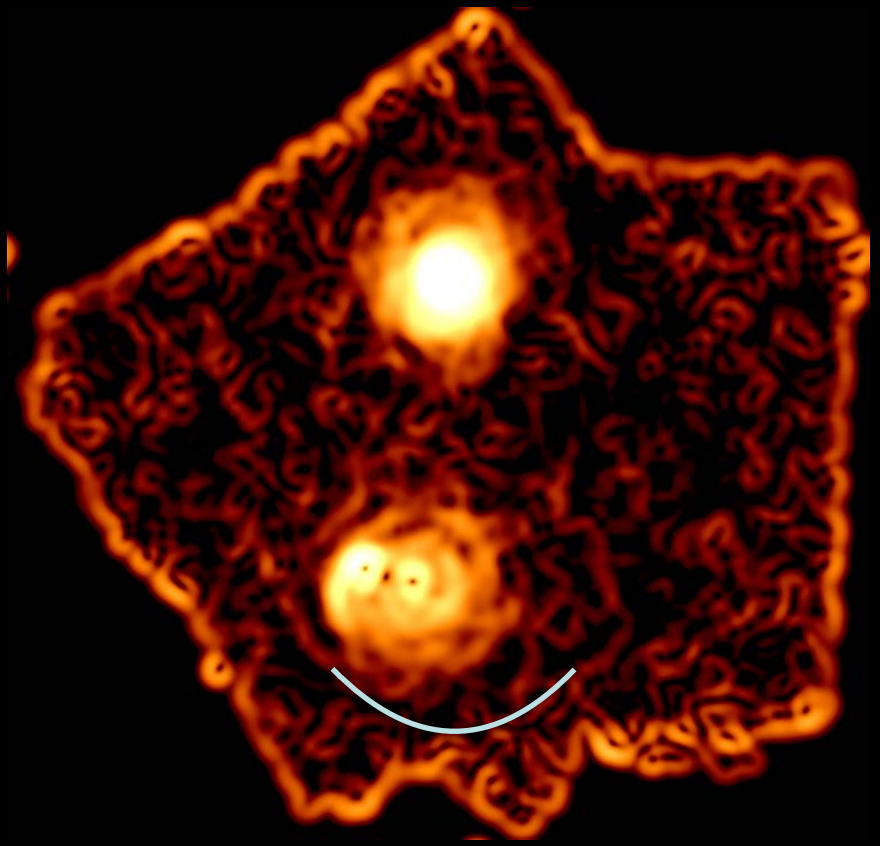


- Each pixel on the map represents temperature.
- The temperature map shows complex temperature structures between two cores.
- An “arc” of hot gas of 70 million degrees Kelvin present between two cores
- Is this “arc” telling a story here?
- This “arc” could be heated by a shock wave

Gaussian Gradient Magnitude (GGM) Image:
A technique to enhance sharp features

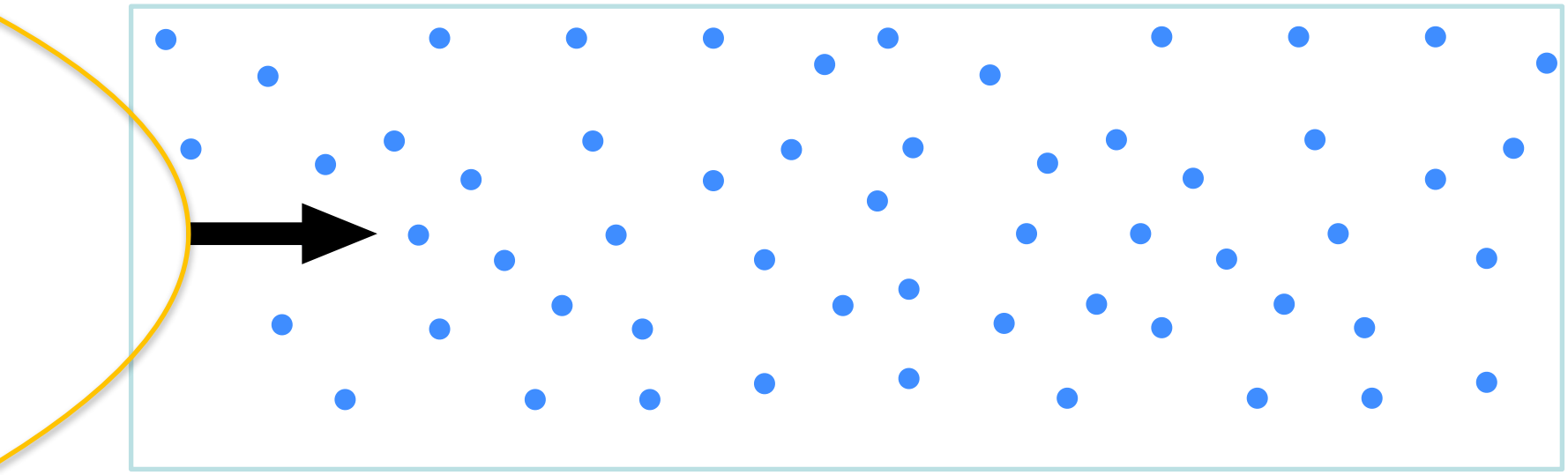


Actual Chandra image of Abell 98



GGM image (of left image) of Abell 98

Pressure measurement across the shock

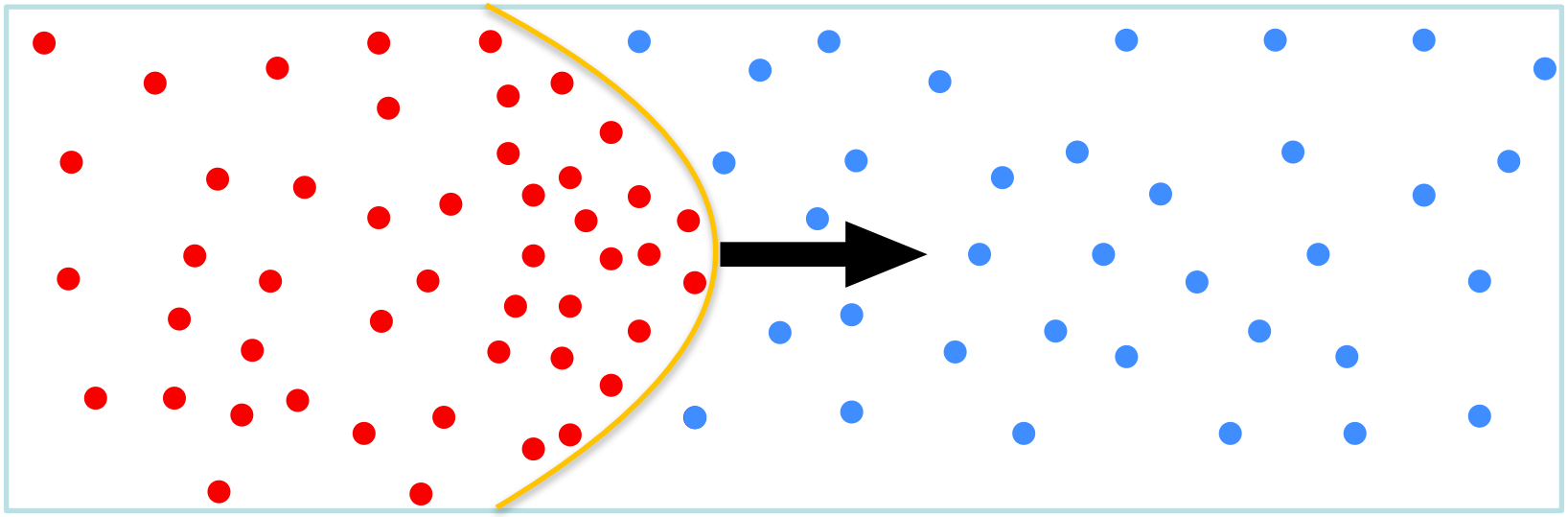


Blue: cooler gas

Pressure measurement across the shock

More dense

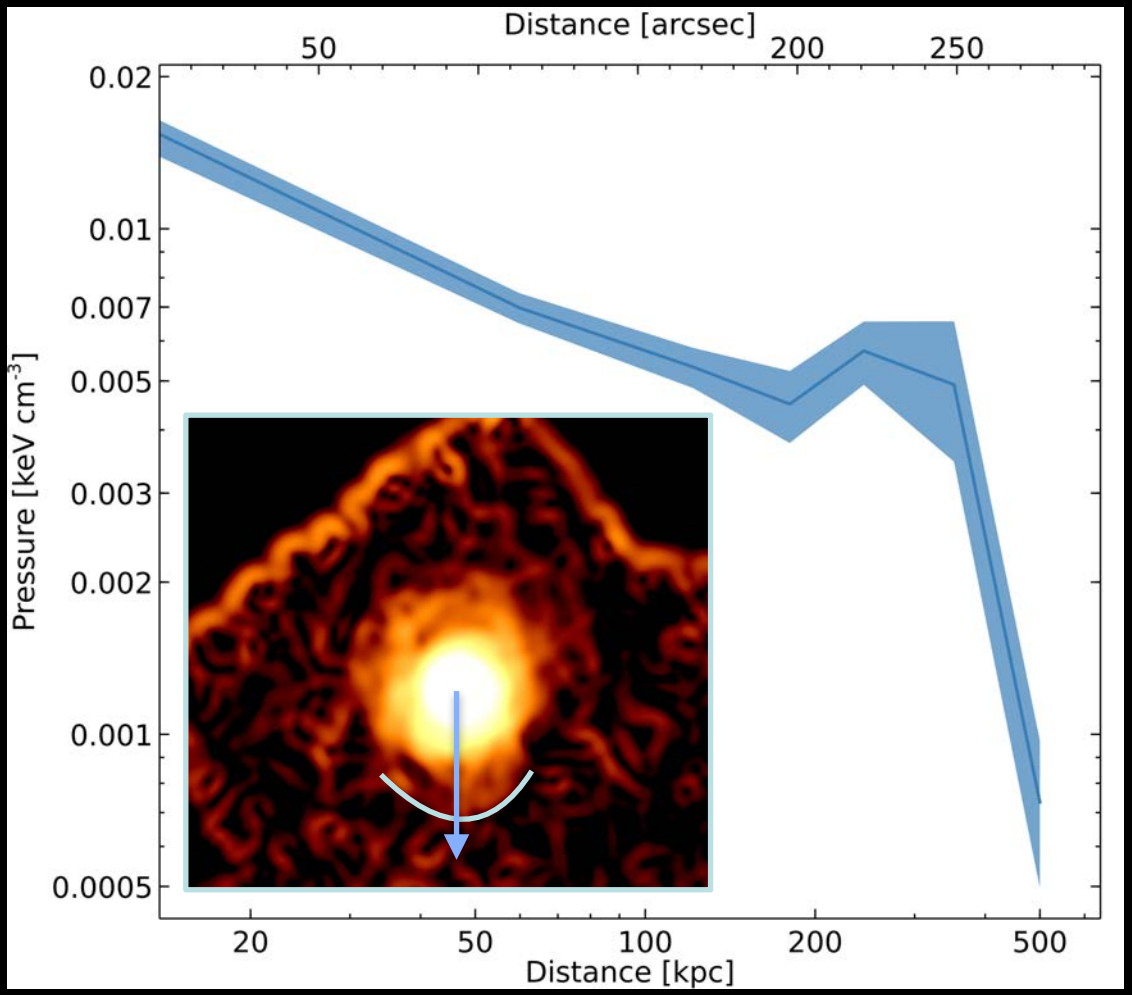
Less dense



Red: hotter gas

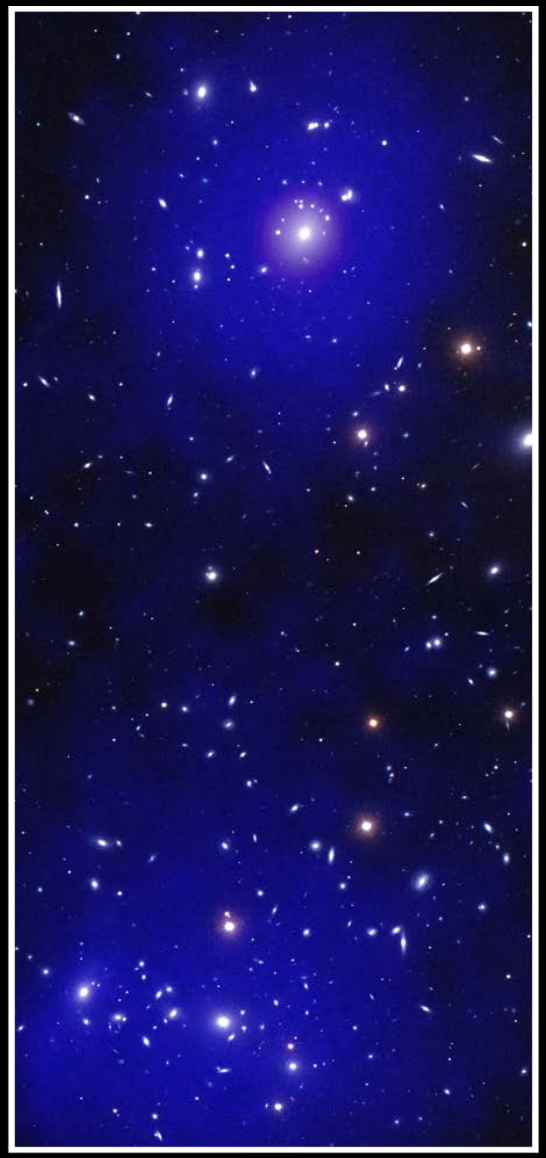
Blue: cooler gas

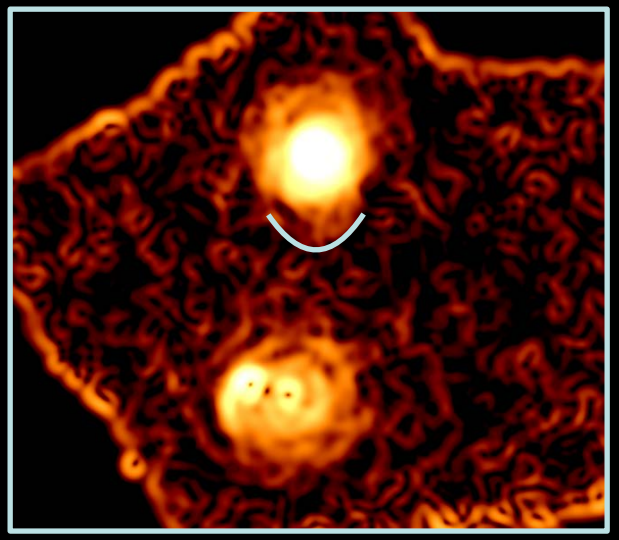
Pressure measurement across the shock



- We detected Mach 2.2 shock wave
- This is the "first" ever axial shock observed in an early-stage merging cluster!!

Takeaway





- For the “first” time, we detected an axial shock in an early-stage merging cluster Abell 98
- Such shock has long been predicted by theory and computer simulations, but not observed before
- Axial shock was an important “missing piece” of our picture of formation of the most massive structures in our Universe

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