Multi-wavelength Analysis of the Merging Galaxy Cluster Abell 115

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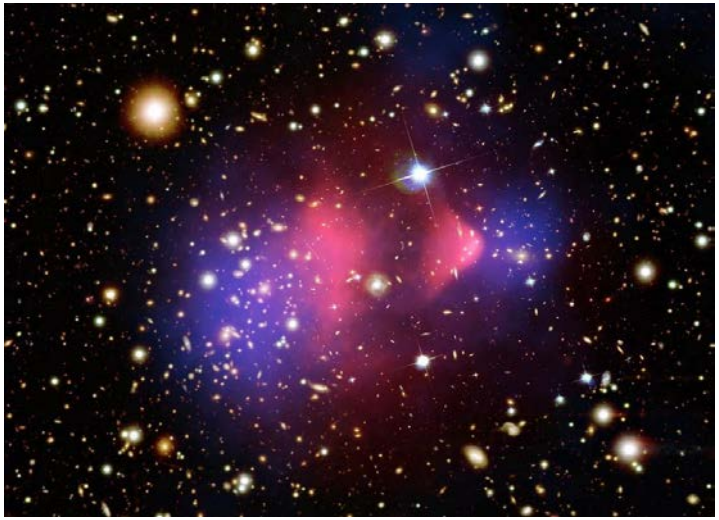
Merging Galaxy Cluster

Intro



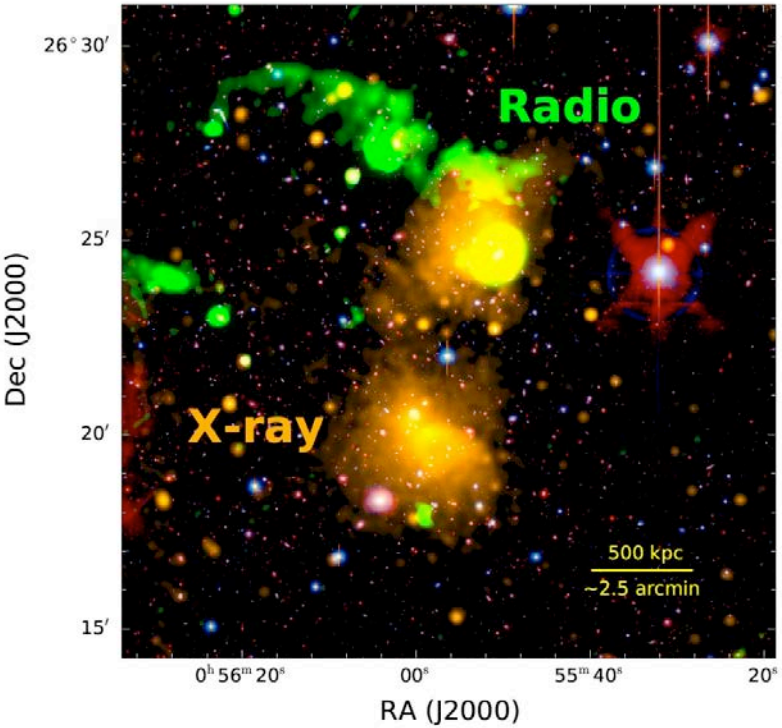
Collision velocity: $\sim 2000\ km/s$
Dissipated energy of merger shock:
$\sim 3\times10^{63}$ ergs (Sarazin 2002)
=> $\sim 8\times10^{49}$ kWh

한국전력공사 KOREA ELECTRIC POWER CORPORATION	Unit price (₩/kWh)	Total Price (₩)	# of the Earth
Household electricity	281	2.34×10^{52}	7.31×10^{34}
Industrial electricity	73	6.10×10^{51}	1.91×10^{34}

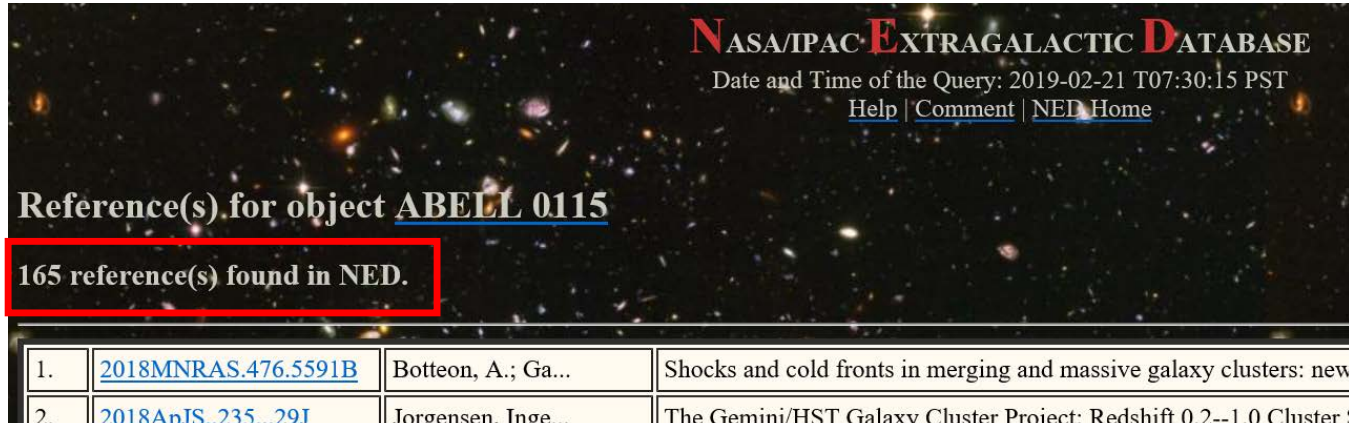
Global wealth: 3.2×10^{17}₩ (3.17×10^{14}\$)

Merging Galaxy Cluster Abell 115

Intro

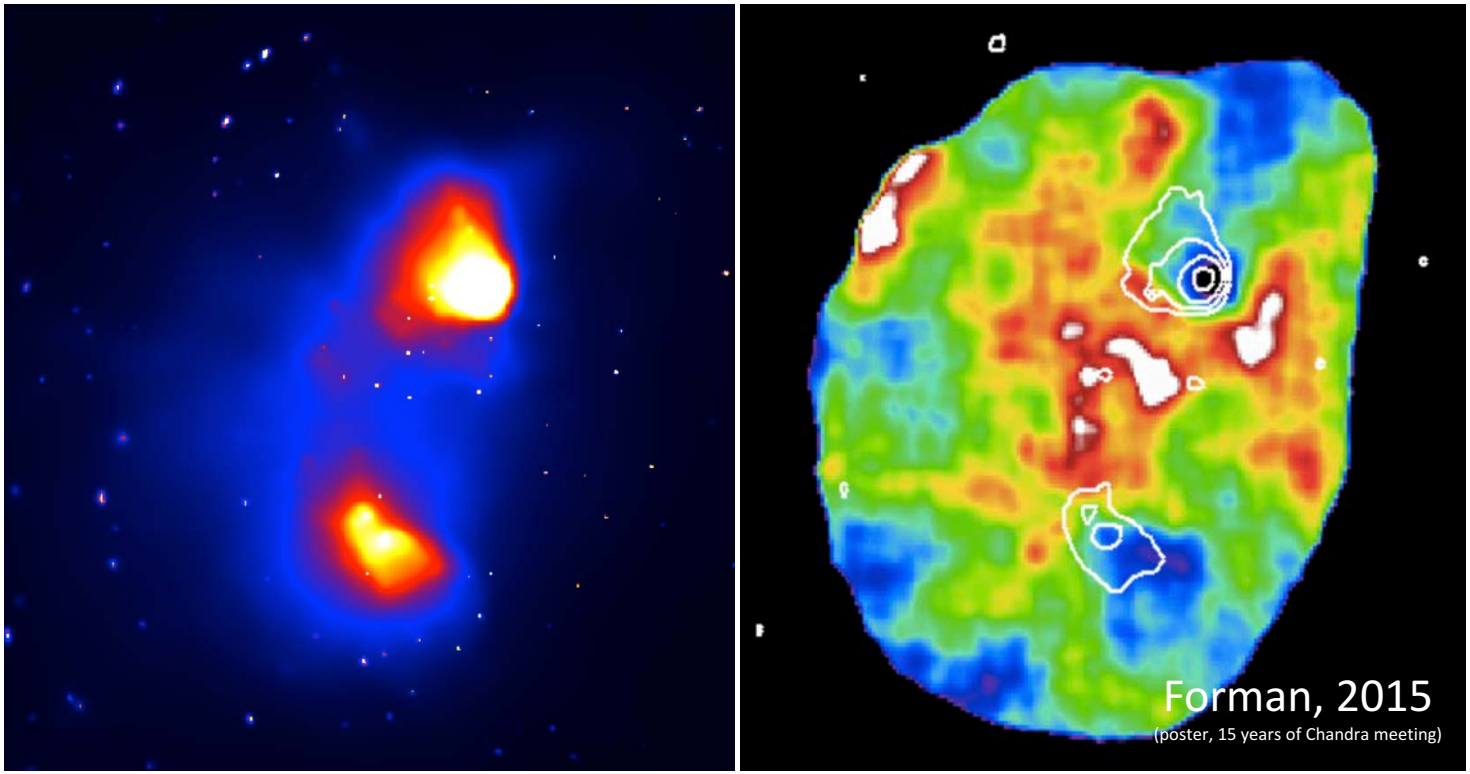


- **Double X-ray peaks** (Forman et al. 1981)
  - each showing a ram-pressure stripped tail
- **Extended Radio Relic** (Govoni et al. 2001) – evidence for the energetic collision
- **Post merger** system
- **Subaru V -and i'- band**
  CFHT g'- and r'- band
  Chandra ACIS-I
  VLA 1.4 GHz
  NED database, Keck/DEIMOS & MMT/Hectospec



X-ray Analysis on Abell 115

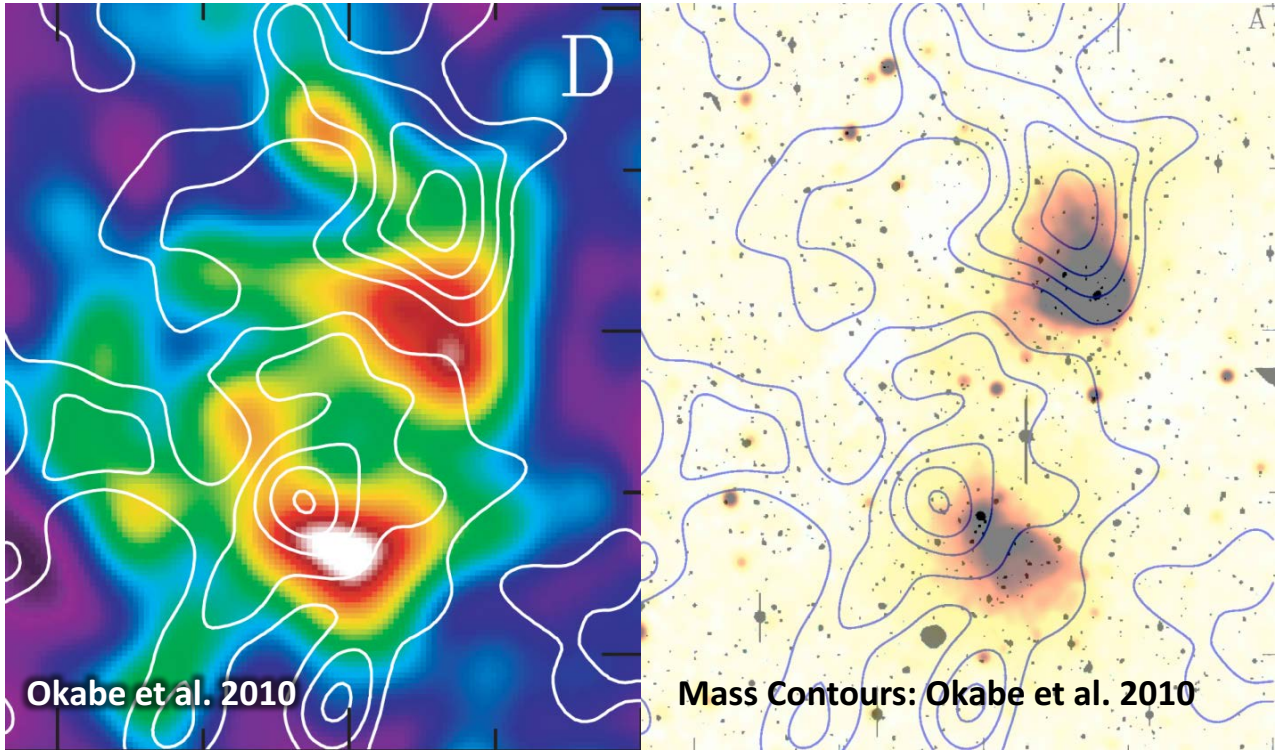
Intro



- Temperature maximum between X-ray peaks → the clusters are interacting.
- Both clusters host **cool cores** – usually found in relaxed clusters.
- The **location of the X-ray shock** ($\mathcal{M} \sim 1.4 - 2.0$) is coincident with the **west end of the radio relic** (Botteon et al. 2016) → Evidence of **Glancing Merger**

Offset Between Galaxy and Mass

Intro



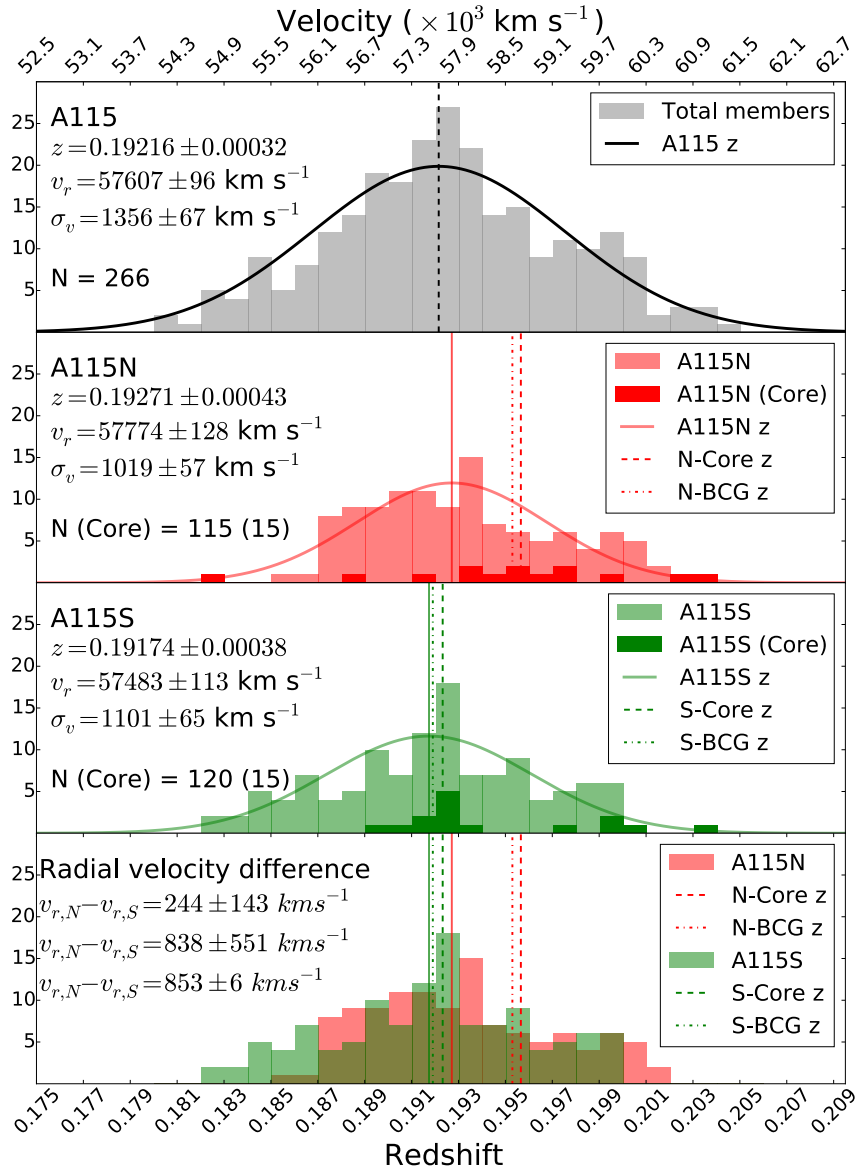
- There seem to be **offsets between galaxy peaks** and **weak-lensing mass peaks** in each cluster.

  → The offsets, if real, have important implications for **dark matter**.

- **Southern ICM** was ram-pressure stripped and **trails the mass peak**.
- **Northern X-ray peak** leads the **mass peak**.
- Okabe et al. (2010) have not estimated individual halo masses.

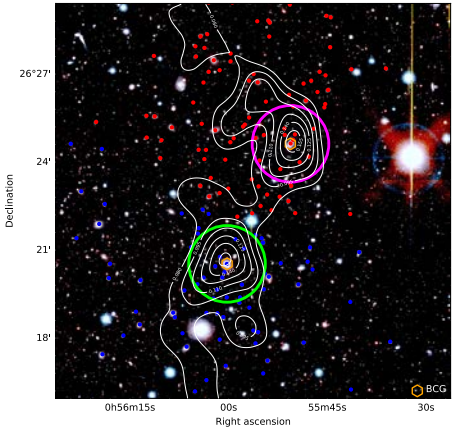
Multi-wavelength Ⅰ: Spectroscopy

NED database, Keck/DEIMOS (4.9 ks) & MMT/Hectospec



- Spectroscopic redshift galaxy catalog (Golovich et al. 2015 and Rines et al. 2018)
- Velocity dispersion: Bi-weight estimator (Beers et al. 1990)
- Dynamical mass: $M - \sigma_v$ scaling relation (Saro et al. 2013)
- Dynamical mass estimation

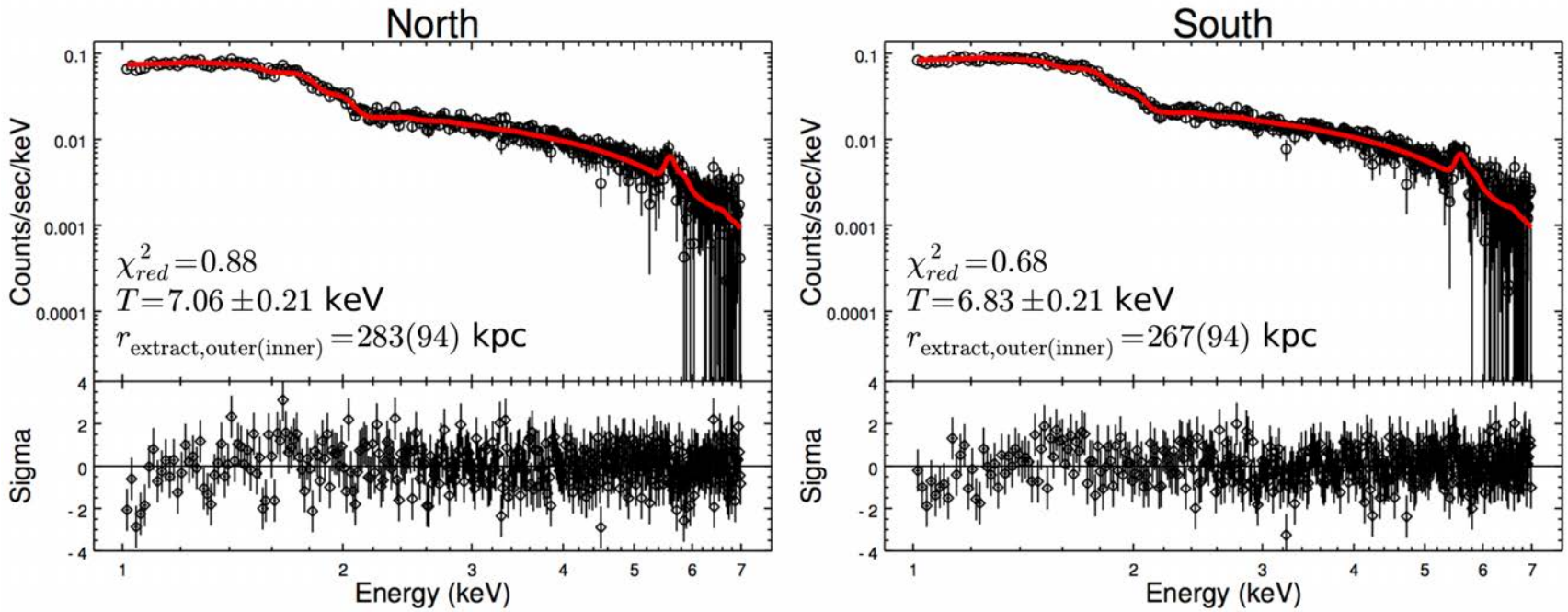
$$M_{North} = 16.3^{+2.8}_{-2.5} \times 10^{14} M_\odot$$
$$M_{South} = 20.4^{+3.7}_{-3.3} \times 10^{14} M_\odot$$
$$M_{Global} = 37.3^{+5.7}_{-5.2} \times 10^{14} M_\odot$$



Membership determination: Gaussian Mixture Modeling

Multi-wavelength Ⅱ：X-ray

Chandra/ACIS-I (360 ks)



1. Temperature measurement
MEKAL plasma model
(Kaastra & Mewe 1993; Liedahl et al. 1995)

2. Temperature to M_{500}
$M_{500} - T$ scaling relation
(Mantz et al. 2016)

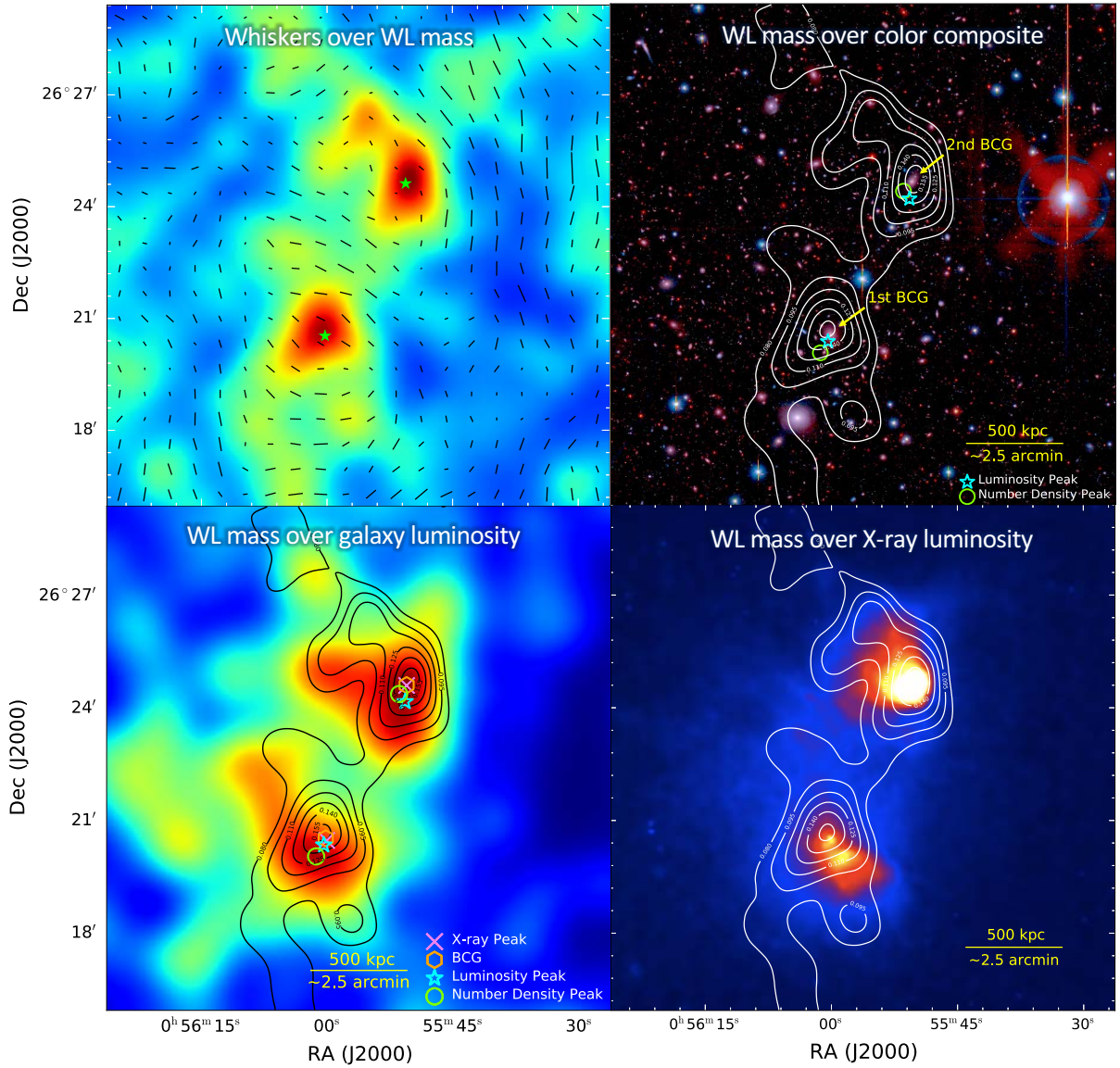
3. M_{500} to M_{200}
NFW halo with concentration relation of Dutton & Macciò (2014)

X-ray mass estimation

$$M_{Global} = 20.48^{+3.49}_{-2.71}\times10^{14}M_\odot$$
$$M_{North} = 9.00^{+2.03}_{-1.48}\times10^{14}M_\odot$$
$$M_{South} = 8.52^{+1.90}_{-1.38}\times10^{14}M_\odot$$

Multi-wavelength Ⅲ: Optical (Weak-Lensing)

Subaru / SuprimeCam (1.53 ks)



- **Two mass clumps** are **clearly detected** at the **3.8 σ and 3.6 σ** levels.
- **Mass distribution** is consistent with **BCGs** and **galaxy luminosity distribution**.
- **No offset** between **X-ray peaks** and **mass peaks.**

WL Mass Estimation

$$M_{North} = 1.58^{+0.56}_{-0.49} \times 10^{14} M_{\odot}$$
$$M_{South} = 3.15^{+0.79}_{-0.71} \times 10^{14} M_{\odot}$$
$$M_{Global} = 6.41^{+1.08}_{-1.04} \times 10^{14} M_{\odot}$$

Mass to Light Ratio

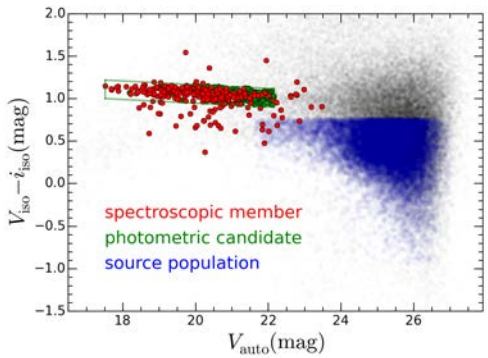
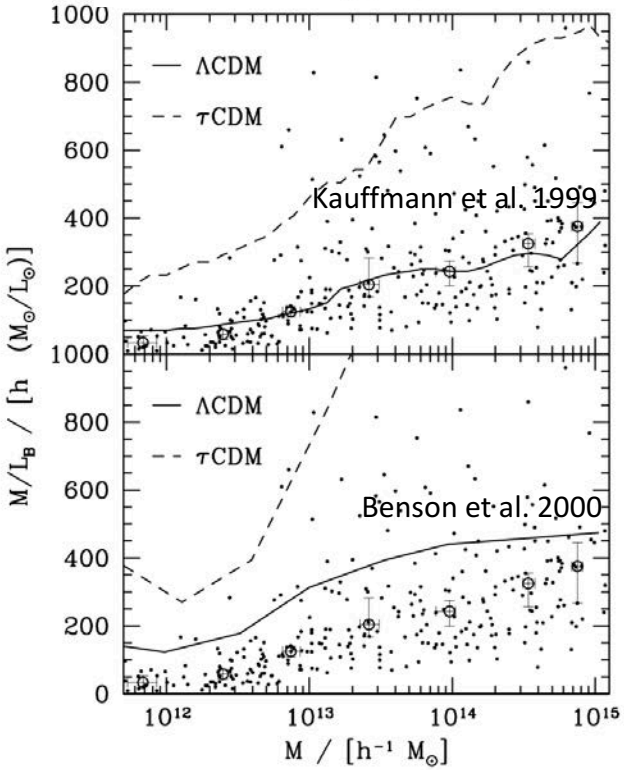


Table 6
Mass Comparison

M_{200c} $(\times 10^{14} M_\odot)$	Global	North	South
Weak Lensing	$6.41^{+1.08}_{-1.04}$	$1.58^{+0.56}_{-0.49}$	$3.15^{+0.79}_{-0.71}$
X-ray	$20.48^{+3.49}_{-2.71}$	$9.00^{+2.03}_{-1.48}$	$8.52^{+1.90}_{-1.38}$
Velocity Dispersion	$37.4^{+5.7}_{-5.2}$	$16.3^{+2.8}_{-2.5}$	$20.4^{+3.7}_{-3.3}$



Girardi et al. 2002

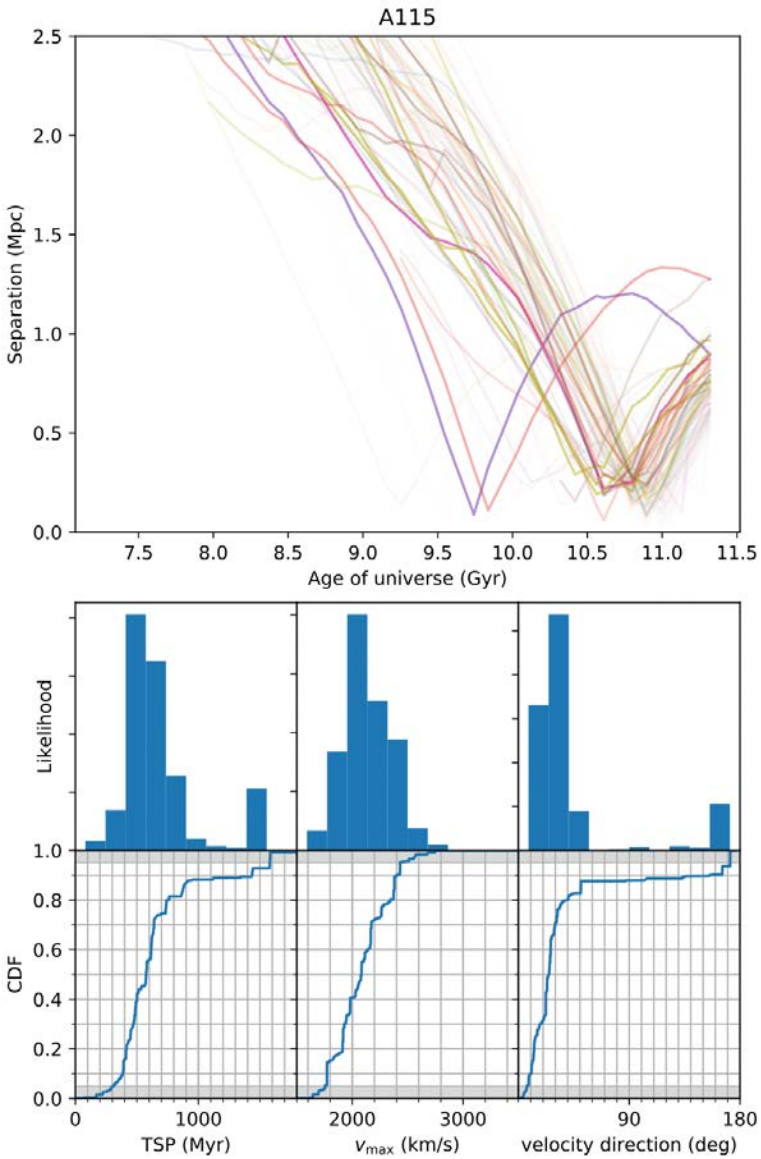
WL provides physically reasonable mass estimation!!

$M_\odot/L_{B\odot}$ of Abell 115

$M_\odot/L_{B\odot}$	Global	North	South
Weak-lensing	771^{+120}_{-115}	293^{+104}_{-91}	413^{+104}_{-93}
X-ray	2154^{+367}_{-285}	1003^{+226}_{-164}	1001^{+210}_{-153}
Dynamical	3837^{+585}_{-533}	1744^{+300}_{-267}	2120^{+384}_{-343}

Merging Scenario

Wittman et al. 2018



Initial input:
z = 0.1972
$V_{LOS} = 244 \pm 144\ km/s$
M1 = $1.58^{+0.56}_{-0.49} \times 10^{14} M_{\odot}$
M2 = $3.15^{+0.79}_{-0.71} \times 10^{14} M_{\odot}$

- Time since pericenter (TSP): $\sim 600\ Myr$
- Maximum collision velocity: $\sim 2000 km/s$
- The velocity direction: $< 25°$
- Separation vector: $< 19°$ with 68% of analogs
- Prefers the outgoing phase

  -> Short TSP and parallel relative vector to the separation vector

However, this seems to contradict the visual impression given by the cometary tails in X-ray emission!

Summary

- We performed a **multi-wavelength (optical, X-ray, and spectroscopy) analysis** on the **merging galaxy cluster Abell 115**.
- The **dark matter distribution** has **two clear peaks** that are **consistent with the galaxy luminosity distribution and BCGs**.
- The **weak-lensing mass of each subcluster** is obtained and the **mass ratio is ∼1:3**.
- We reconstruct the **merger scenario** of the cluster.