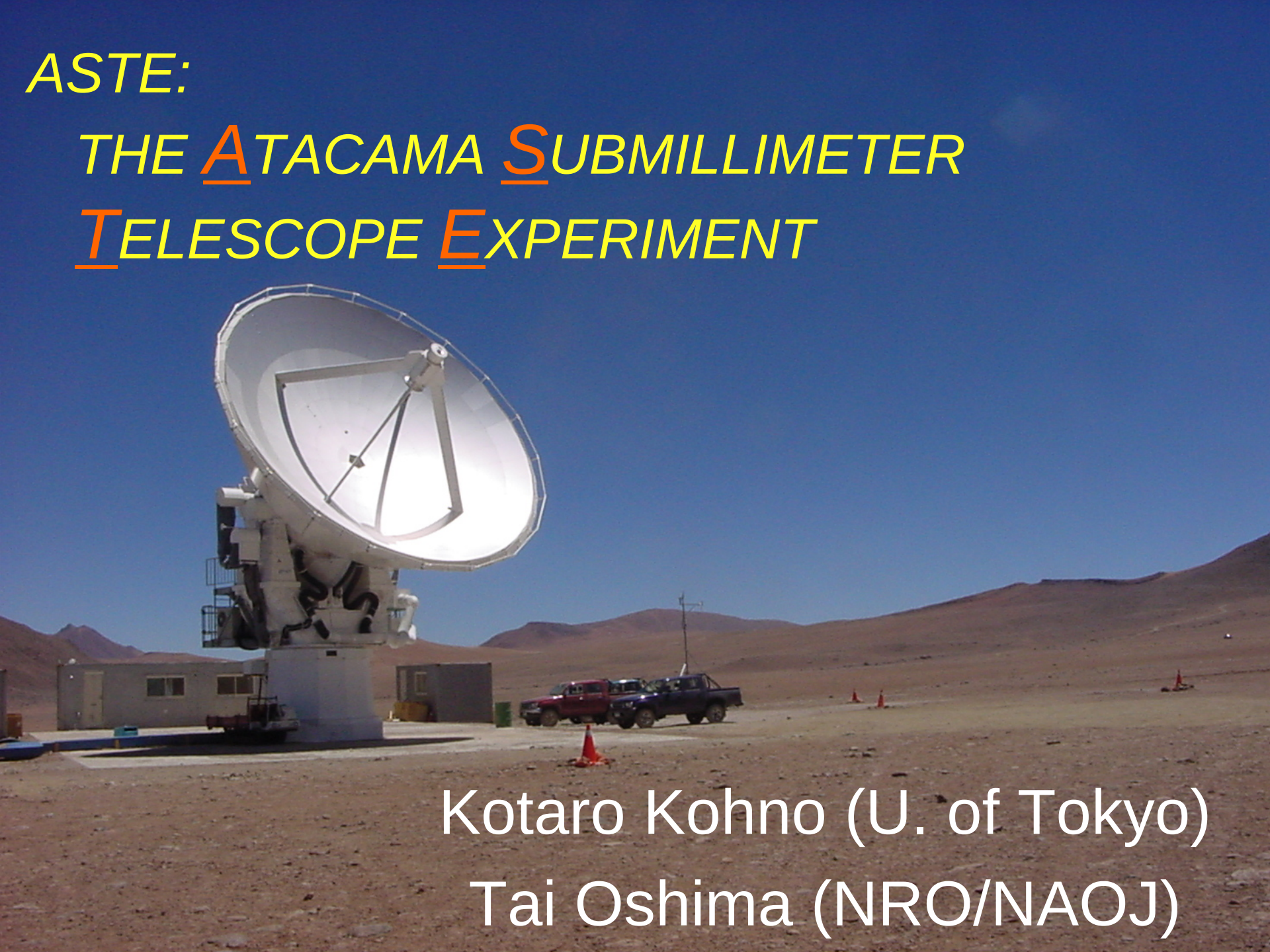
ASTE: THE ATACAMA SUBMILLIMETER TELESCOPE EXPERIMENT



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Tai Oshima (NRO/NAOJ)

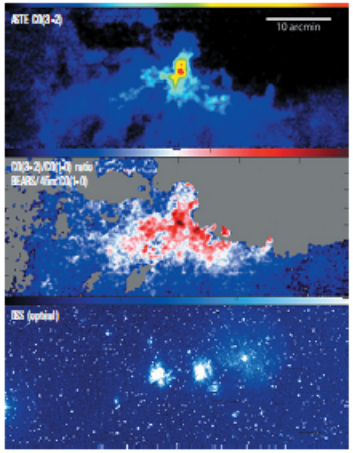
Science

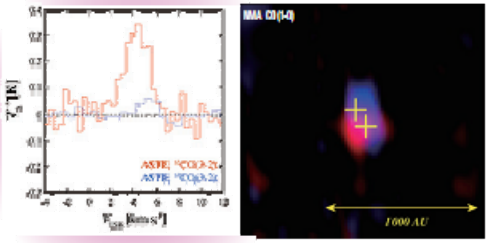
What do we observe?

Probing the Dark Universe with ASTE

Star and Planet Formation

Submillimeter-wave observations are essential for unveiling the dense molecular medium -- the cradles of stars. Gemini OB1 molecular cloud complex contains a lot of young massive stars surrounded by glowing gas and plasma called HII regions (bottom panel). New ASTE observations of this region have revealed widespread molecular gas in tremendous details (top panel). By studying the ASTE image together with a millimeter-wave image taken at the NRO 45m telescope, astronomers can now pinpoint exactly where the warmest gas is located (see middle panel, where red is warmer and blue is cooler gas).

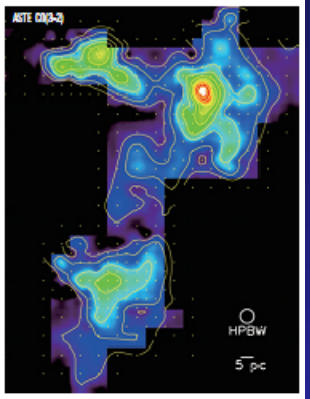




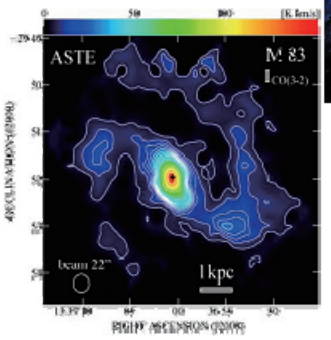
Astronomers use ASTE to study young forming planets. With its high spectral resolution, ASTE can probe the detailed motion of gas surrounding young stars that have just formed recently. The figure (left) shows the ASTE spectra of carbon monoxide gas in a proto-planetary system, and figure (right) is an image of the same region taken at the Nobeyama Millimeter Array. Gas velocity is shown in different colors in the image. By calculating the amount of gas and studying its gas motion, astronomers have a better understanding of how planets form, and this may ultimately give clues to how an Earth-like planet was formed.

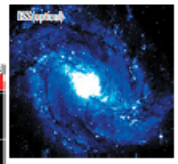
Magellanic Clouds

The Magellanic clouds are satellite galaxies to our Milky Way galaxy. Because they are mainly visible from the southern hemisphere, these are excellent target galaxies for ASTE. A region in the Large Magellanic Cloud called N159 is known by astronomers to be producing stars at an extremely high rate. Astronomers using ASTE have successfully produced an image (see figure) of the dense molecular gas, which is the fuel for massive star formation.



Nearby Galaxies



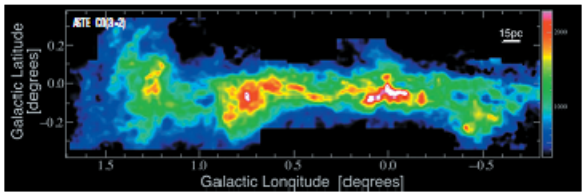


With its tremendous sensitivity to the faintest submillimeter waves, ASTE can probe the star forming gas in our neighboring galaxies that are millions of light years away. The figure (left) shows the ASTE observation of molecular (carbon monoxide) gas in the central region of a galaxy called M83. The figure (right) shows an image of M83 taken by an optical telescope. The center of the galaxy harbors a huge amount of dense gas, and this is believed to be where new stars are continuously being formed.

Future instruments like ALMA will be able to study these galaxies with much higher resolving power (see figure for an artist's conception of a distant galaxy).

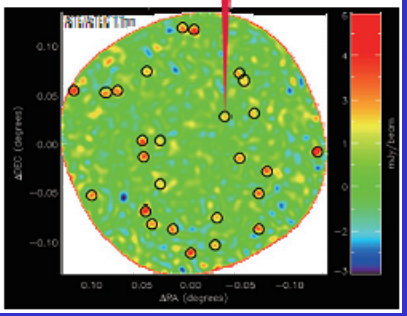
The Center of Milky Way Galaxy

The center of our Milky Way galaxy harbors a massive black hole surrounded by a wealth of molecular gas. ASTE has discovered that the motion of gas in this region is extremely violent and complex (see figure). Astronomers using ASTE are beginning to solve the mysteries surrounding the center of our own galaxy, and will ultimately try to understand how our galaxy was formed.



Distant Universe

Deep observations of the more distant universe become possible by combining the versatility of ASTE and the sensitivity of AzTEC. Star-forming galaxies residing in the distant universe that are too faint to be visible by optical telescopes become visible in mm/submillimeter wavelengths. The galaxies marked with dark circles were discovered by astronomers using the AzTEC camera onboard ASTE. Astronomers believe that these galaxies reside in an epoch when the universe was less than a few billion years old, and forming stars at an exceedingly high rate.

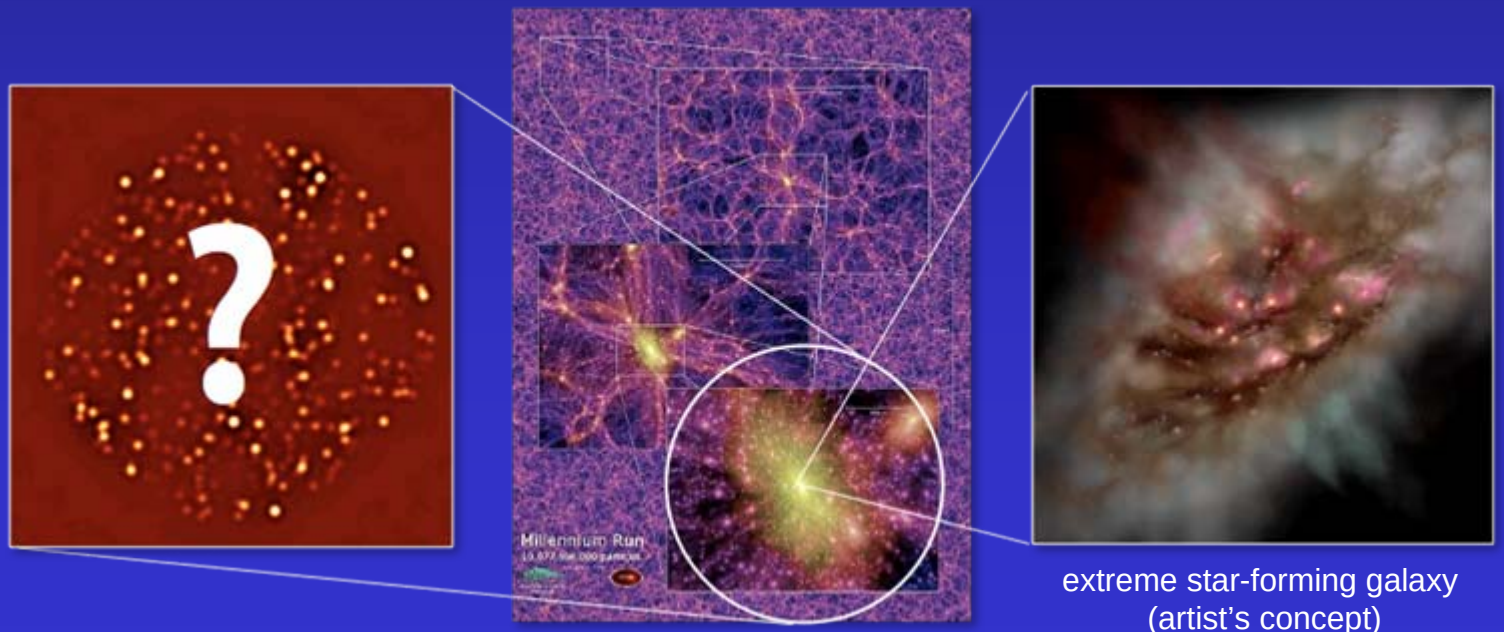


Star-forming galaxies

- When & where did galaxies form?
- When did star-formation start?
- They must be good tracers of matters

➔ look back in the long long,… past

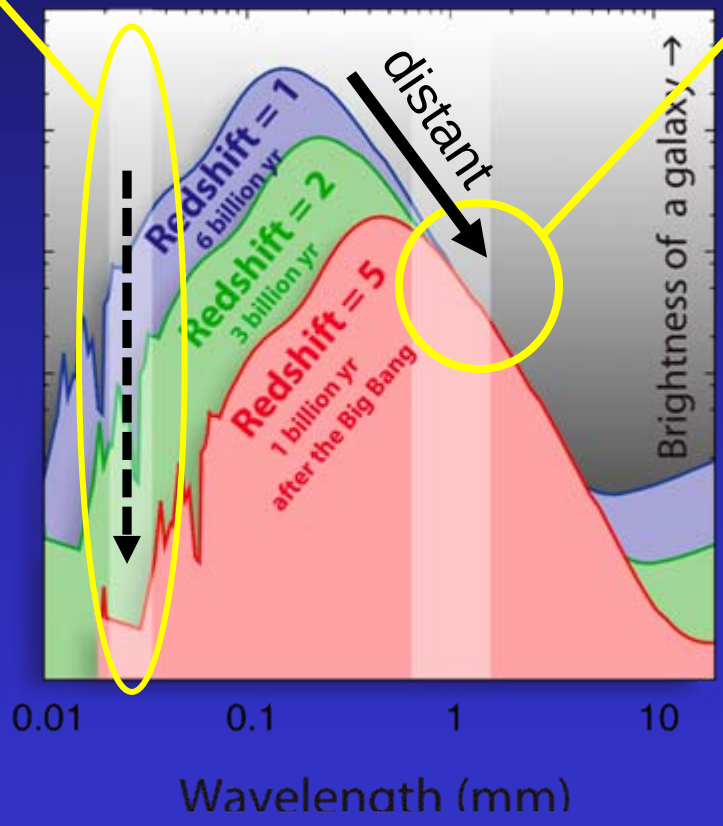
➔ search for distant galaxies!!



extreme star-forming galaxy
(artist's concept)

Sub-mm galaxies (SMGs): a window to the distant Universe

Visible light

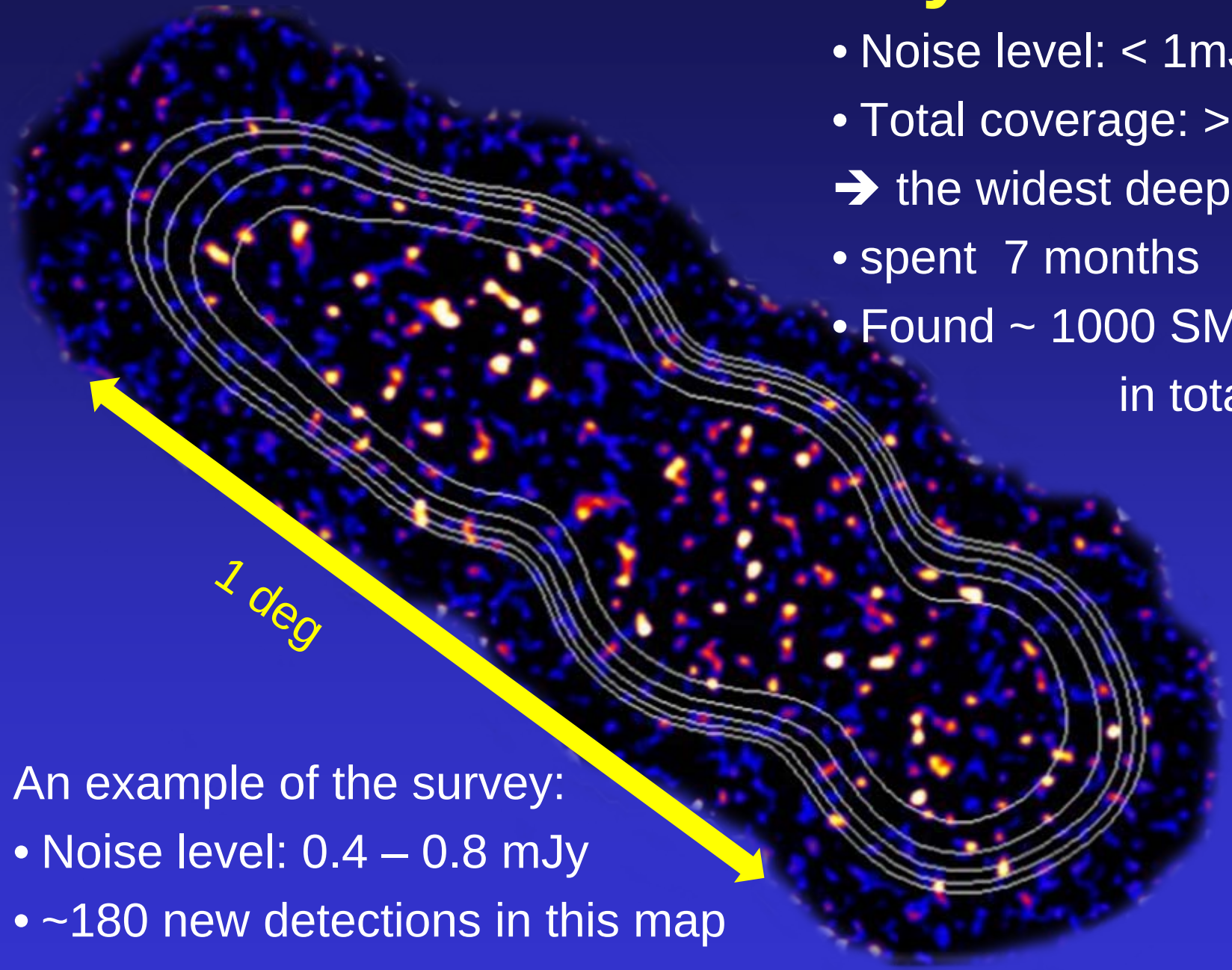


Sub-mm

Rapid decrease in Brightness

Brightness does not Decrease!!

AzTEC on ASTE survey of SMGs



- Noise level: < 1mJy
- Total coverage: >2 deg^2

➔ the widest deep survey

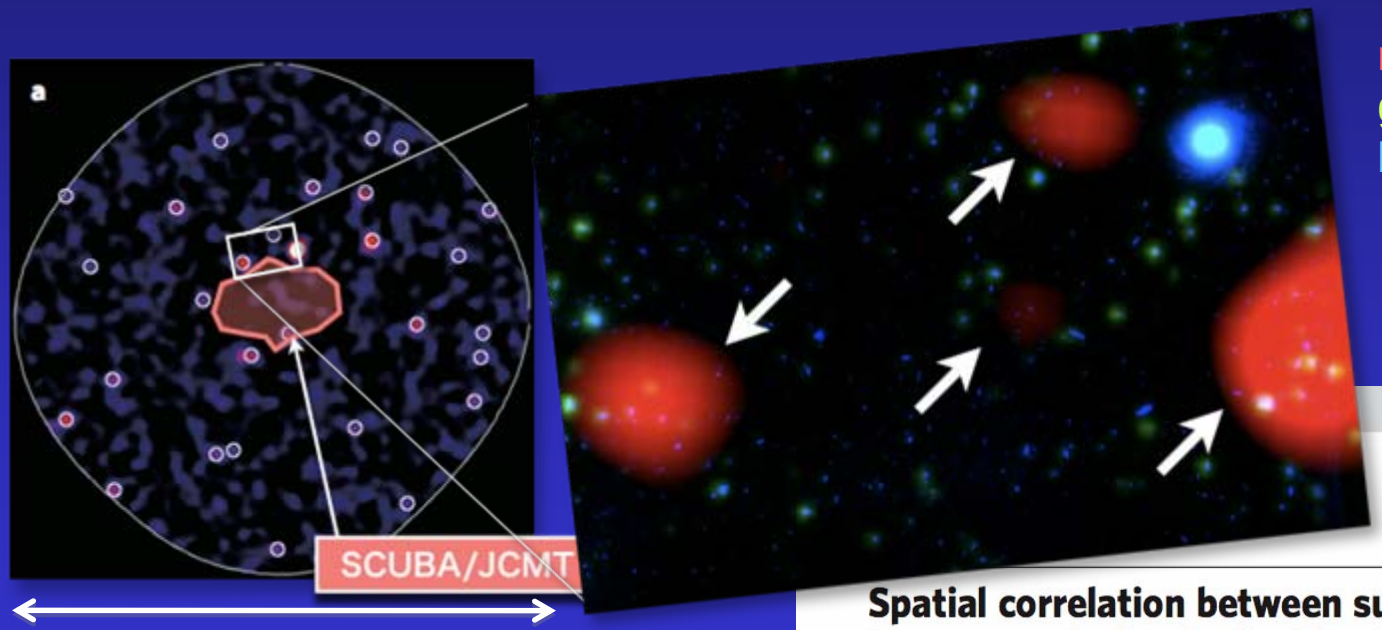
- spent 7 months
- Found ~ 1000 SMGs in total !!

An example of the survey:

- Noise level: 0.4 – 0.8 mJy
- ~180 new detections in this map

SMGs trace the large-scale distribution of matter

- Discovery of tens of SMGs clustering to young cosmic large-scale structure 11.5 billion light years away.



red: AzTEC/ASTE
green: Spitzer (infrared)
blue: Hubble (visible)

100 million light-year across

Tamura et al. (2009) Nature, vol. 459, pp. 61-63

nature

LETTERS

Spatial correlation between submillimetre and Lyman-α galaxies in the SSA 22 protocluster

Yoichi Tamura[1,2], Kotaro Kohno[3], Kouichiro Nakanishi[2,4], Bunyo Hatsukade[3], Daisuke Iono[3,4], Grant W. Wilson[5], Min S. Yun[5], Tadafumi Takata[2], Yuichi Matsuda[2], Tomoka Tosaki[4], Hajime Ezawa[4], Thushara A. Perera[5], Kimberly S. Scott[5], Jason E. Austermann[5], David H. Hughes[6], Itziar Aretxaga[6], Aeree Chung[5], Tai Oshima[4], Nobuyuki Yamaguchi[4], Kunihiko Tanaka[4] & Ryohei Kawabe[4]

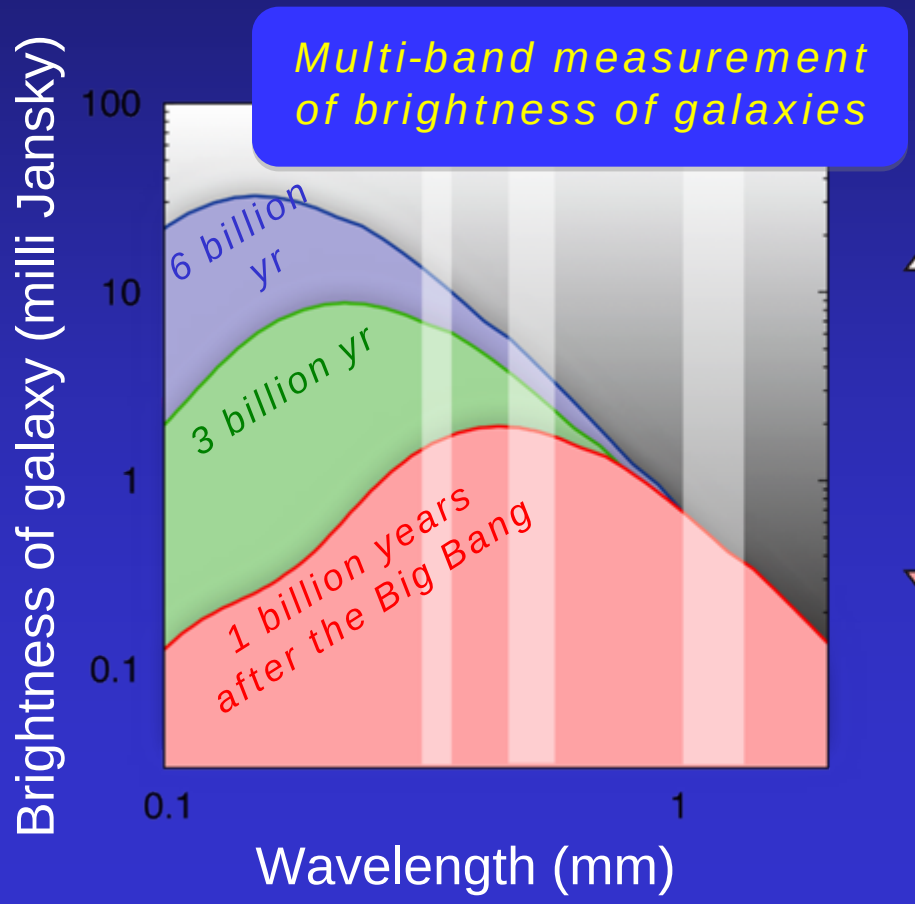
Lyman-α emitters are thought to be young, low-mass galaxies with ages of ~10^8 yr (refs 1, 2). An overdensity of them in one region of the sky (the SSA 22 field) traces out a filamentary structure in the

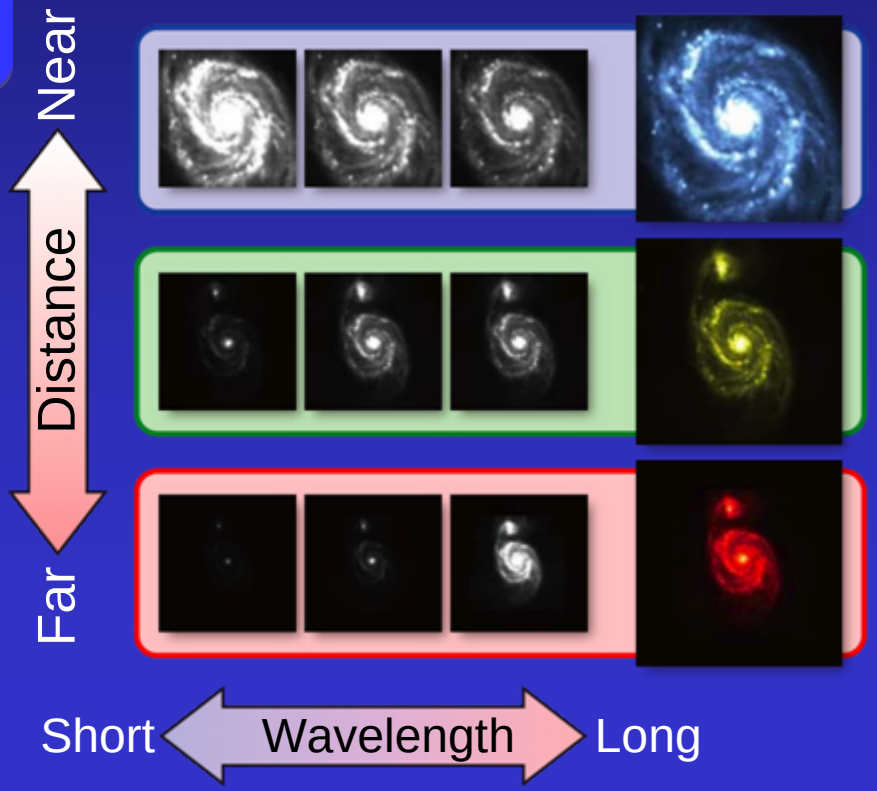
limited in sensitivity and spatial coverage, they support the idea that SMGs are related to large-scale structure. To better understand the connection between the formation of massive galaxies and large-scale

Distance measurement of SMGs

- Difference of color in sub-mm ➔ Difference of distance
  - ‘Redder’ galaxies = more distant

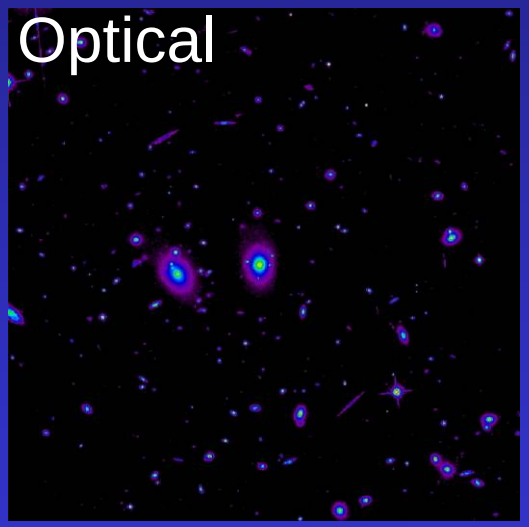
➔ Extensive MULTI COLOR SMG imaging observations!!!

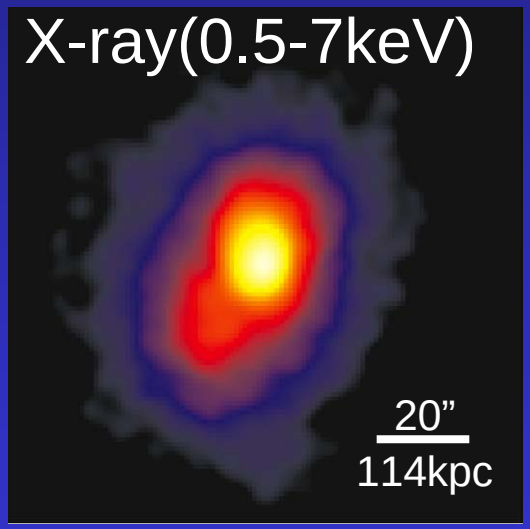




What is a galaxy cluster?

- Largest gravitationally collapsed object in the Universe
  - Optical: a cluster of 100 ~ 1000 galaxies
  - X-ray&SZ: Hot gas with $T=10^{7\sim8}K$, $n=10^{-2\sim-3}cm^{-3}$
  - Dominated by Dark matter:
    - Mass: $M_{tot}\sim10^{13\sim15}M_{sun}$
      - Galaxies : Hot gas : Dark matter = 5 : 15 : 80

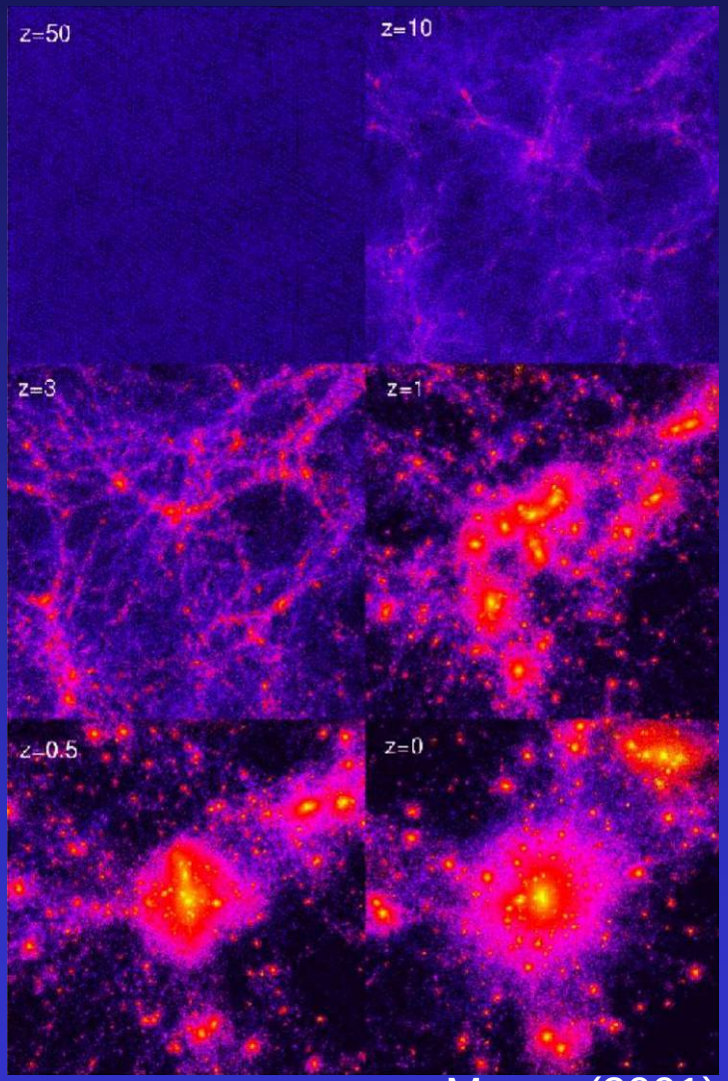




Evolution of galaxy clusters

- growth of cosmic density fluctuation, merging
- timescale ~ age of the Universe
- Clusters preserve important information on the history of cosmological structure formation

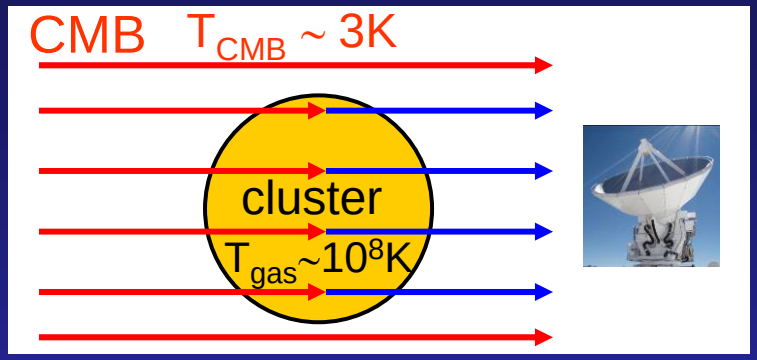
➔ physics of distant galaxy clusters

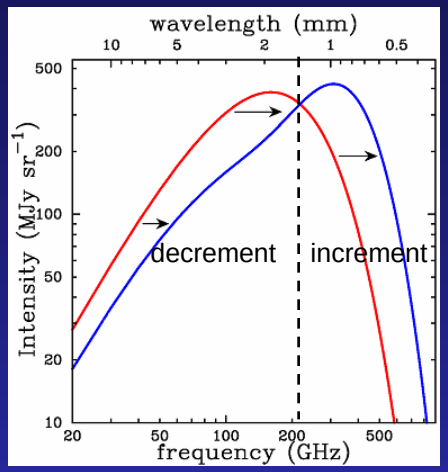


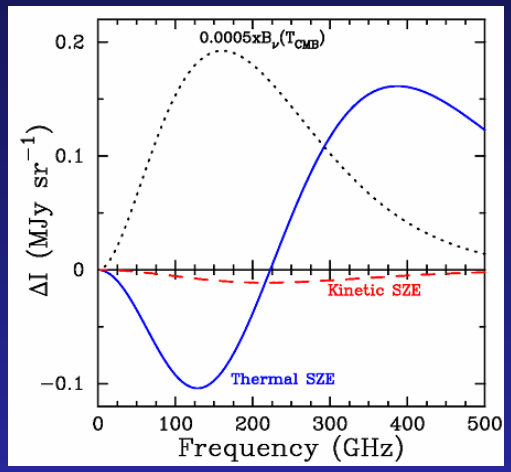
Moore (2001)

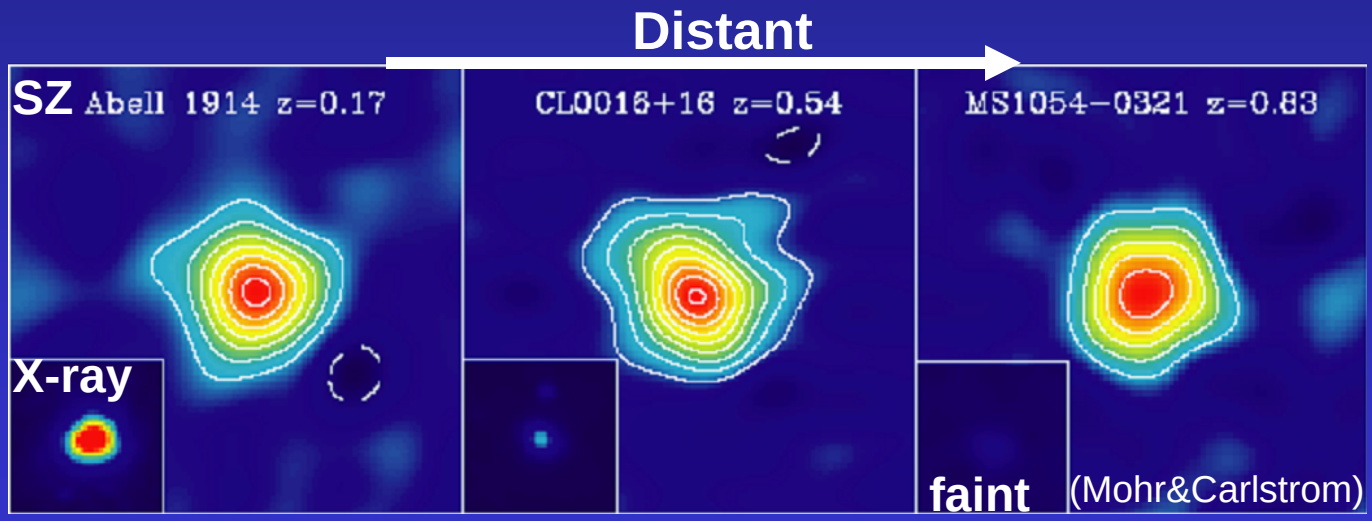
Sunyaev-Zel'dovich(SZ) effect

- SZ effect: spectral distortion of CMB by hot gas (inverse compton)







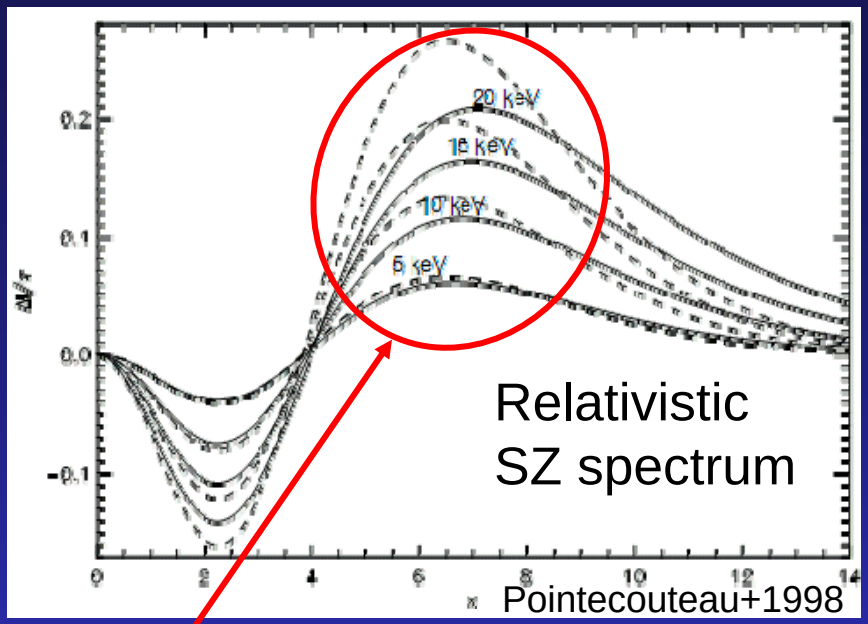


- Differential surface brightness is independent of redshift

➔ POWERFUL TOOL FOR DISTANT GALAXY CLUSTERS!!!

Temperature measurement of clusters

- Hot gas (~ 10keV, 10^8K)
  - probe for gravitational potential
  - ➔ mass estimation
  - ➔ tracer of matter
- Extremely hot gas (> 20keV)
  - Relics of cluster merger?
  - ➔ tracer of dynamic evolution
  - e.g. only one good measurement even with the best X-ray data (Ota+2008)



- Sub-mm band is important for T determination
  + powerful tool for distant clusters
- But,,,
  High quality & large area image not available at sub-mm band

➔ Extensive MULTI COLOR SZ imaging observations!!!