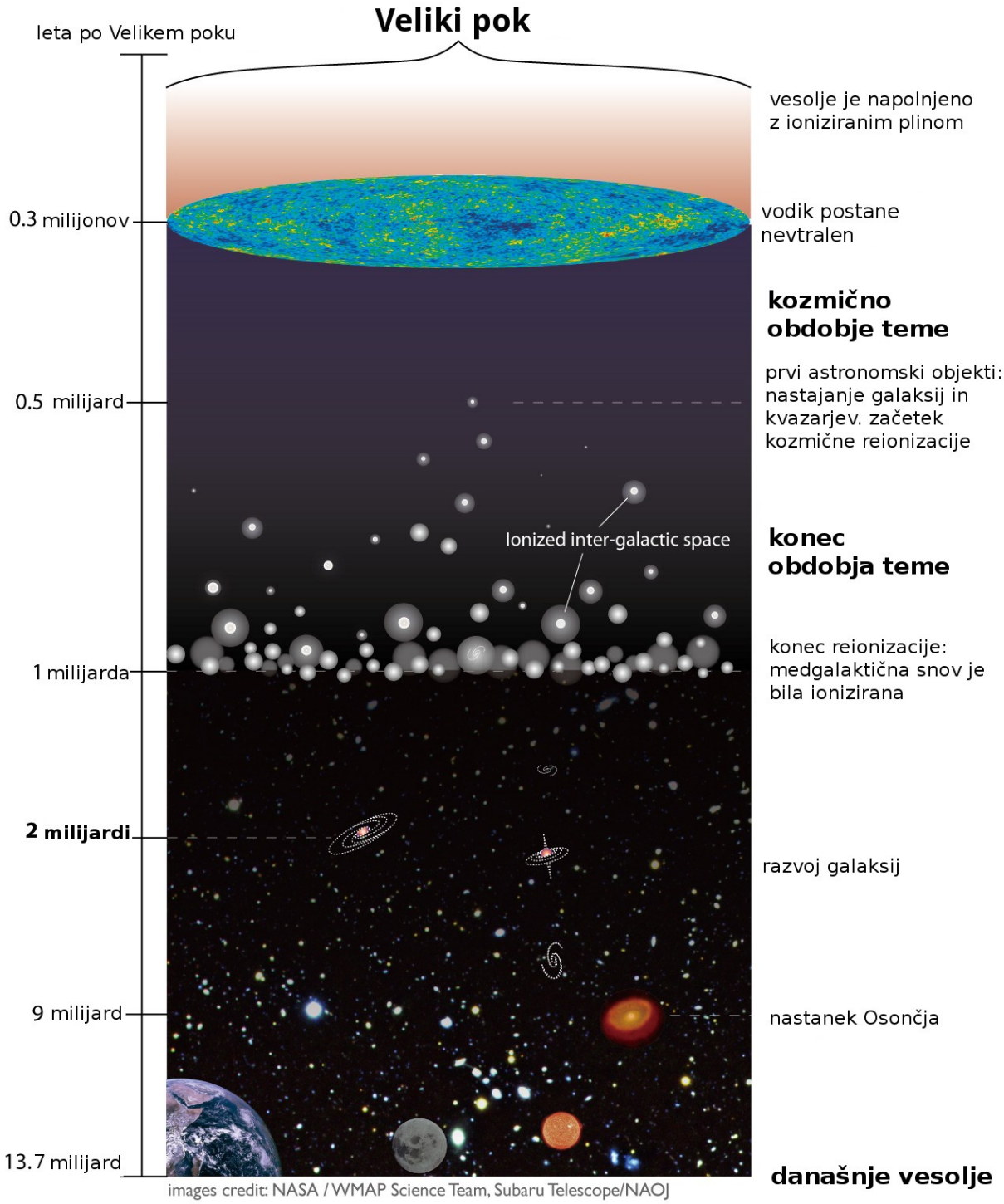
Sunjajev – Zeldovičev učinek

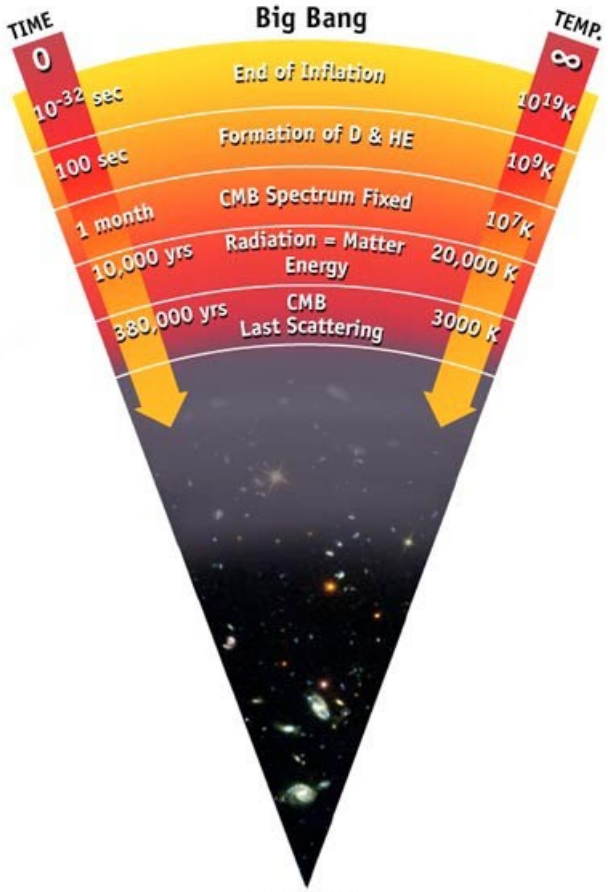
dr. Dunja Fabjan
Center odličnosti Vesolje-SI
Fakulteta za matematiko in fiziko,
Univerza v Ljubljani

Sprehod skozi vesolje, četrtek 7. marec 2013

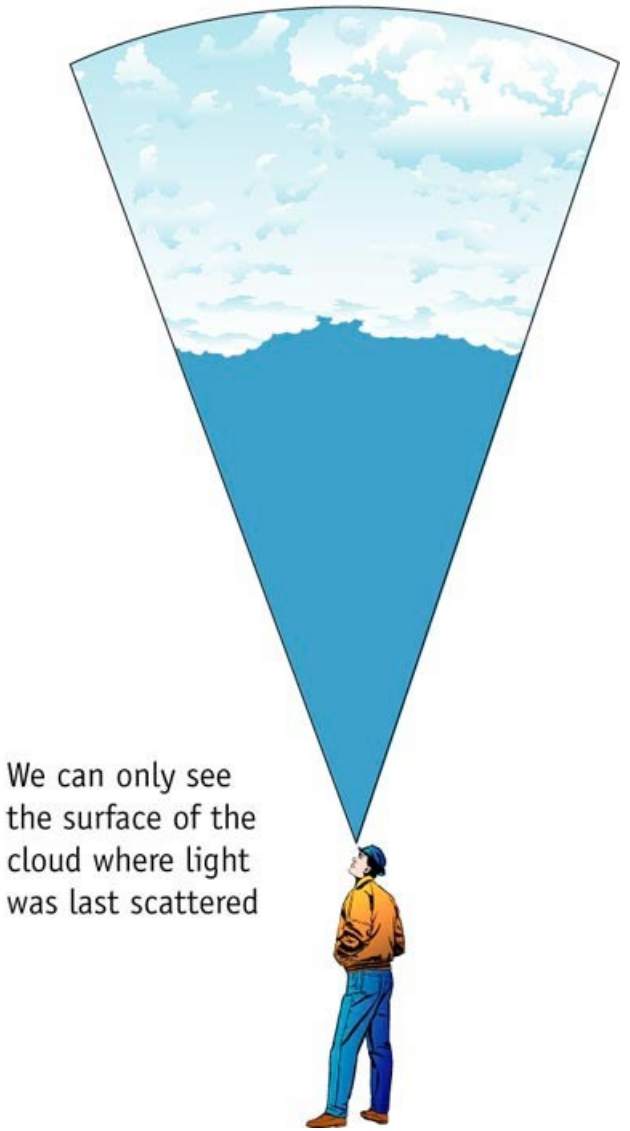
Kratka zgodovina vesolja



Površina zadnjega sipanja

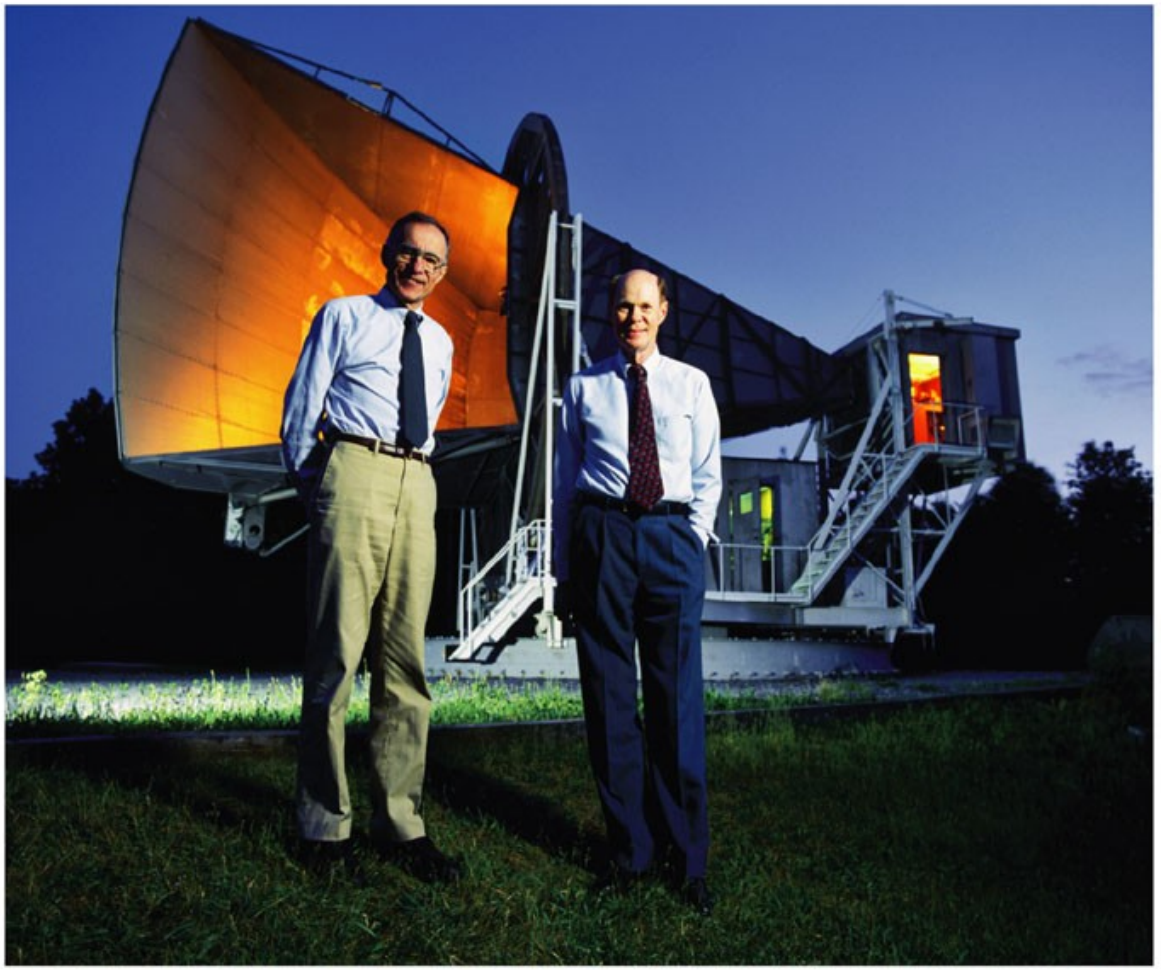


The cosmic microwave background Radiation's "surface of last scatter" is analogous to the light coming through the clouds to our eye on a cloudy day.



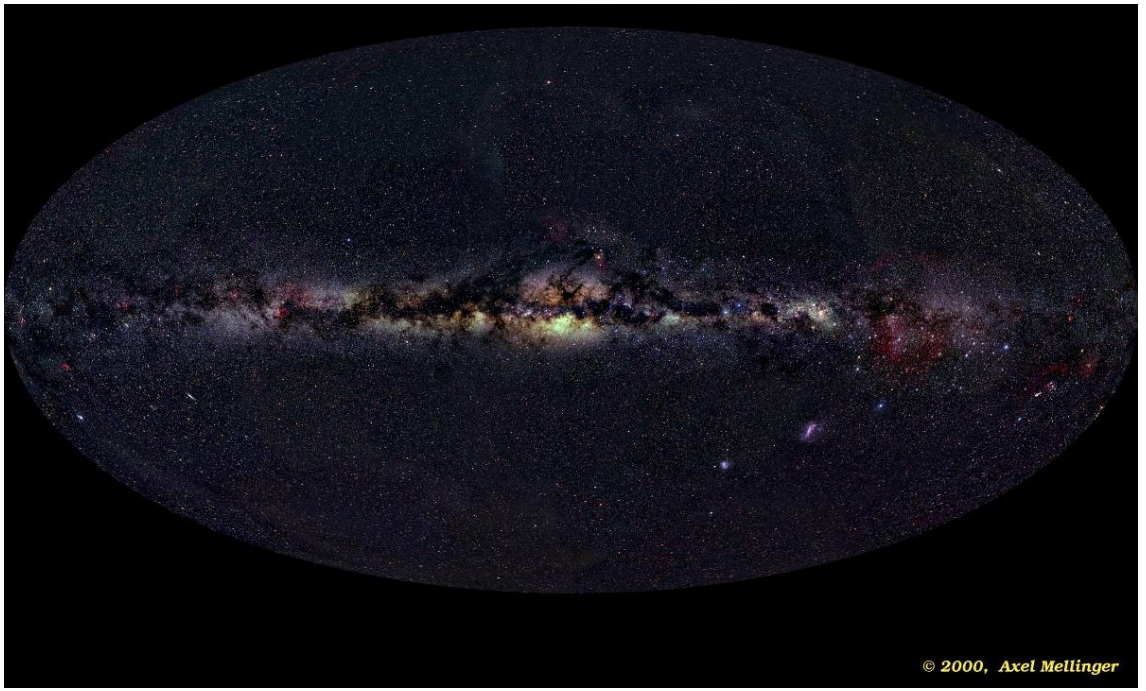
NASA/WMAP Science Team, http://map.gsfc.nasa.gov/universe/bb_tests_cmb.html

Prasevanje - odkritje



Arno Penzias
in Robert Wilson
Nobelova nagrajenca 1978

Prasevanje in neenakomernosti



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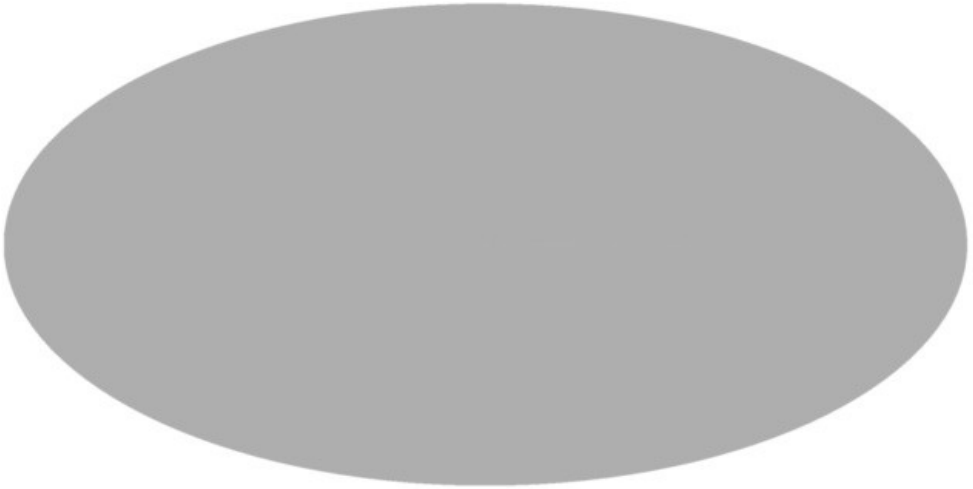

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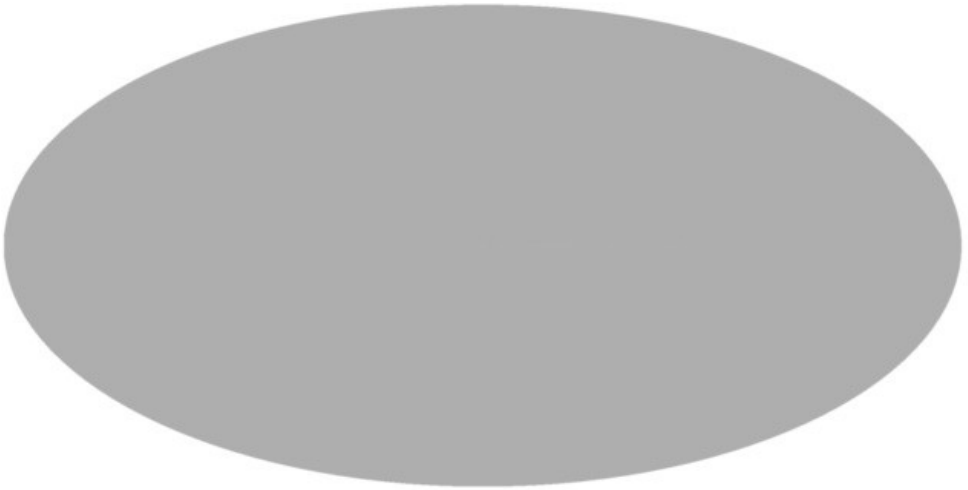
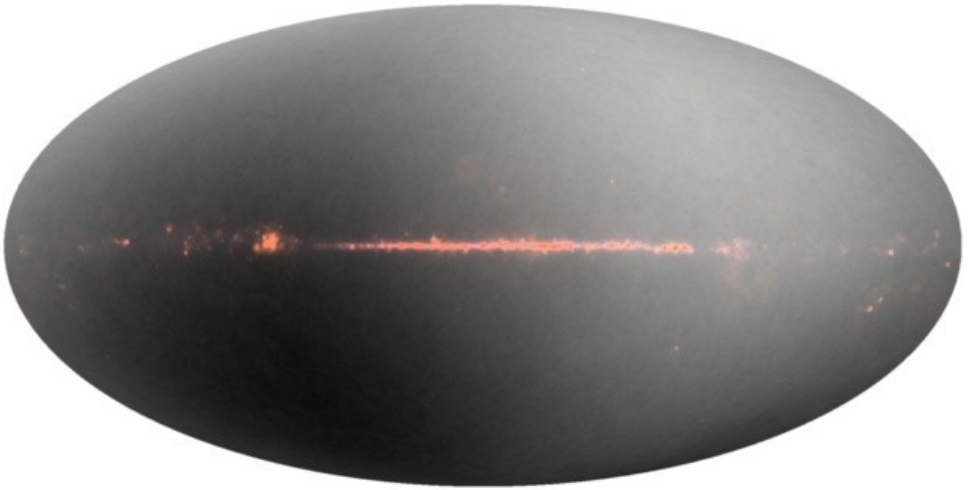
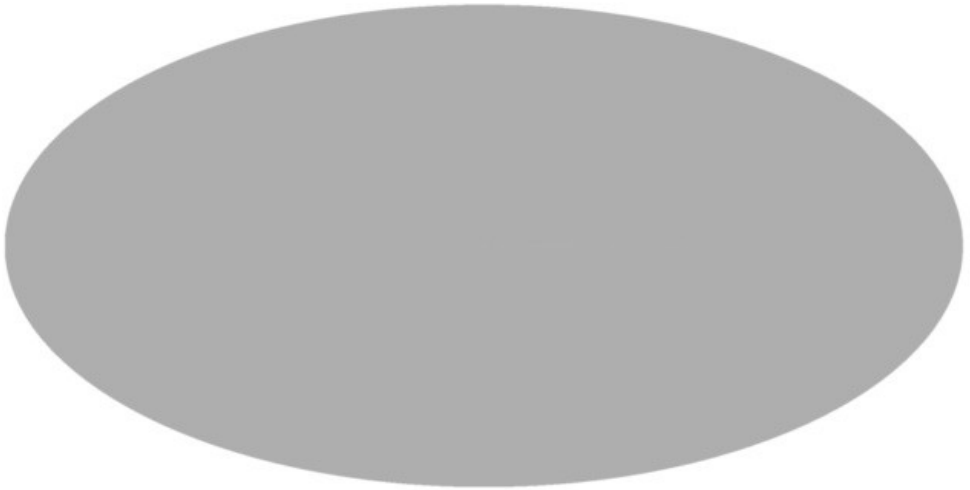
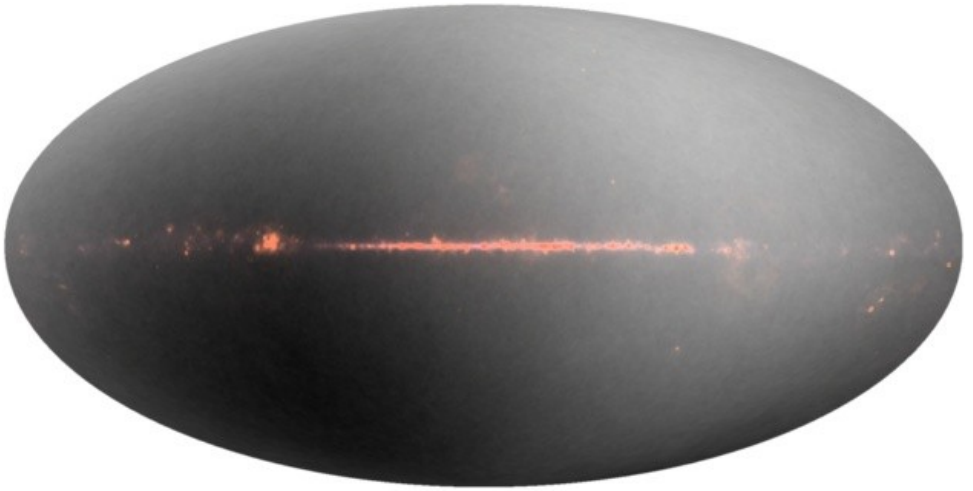


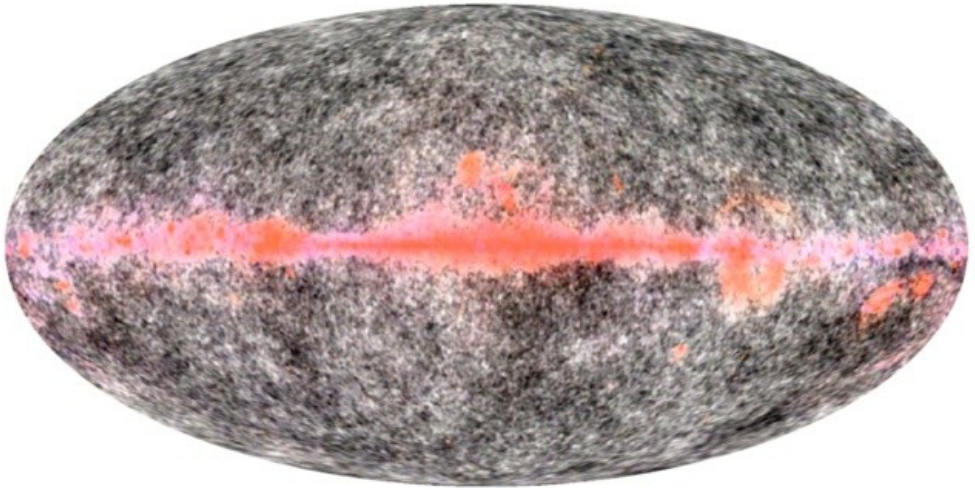


Ned Wright

Prasevanje in neenakomernosti

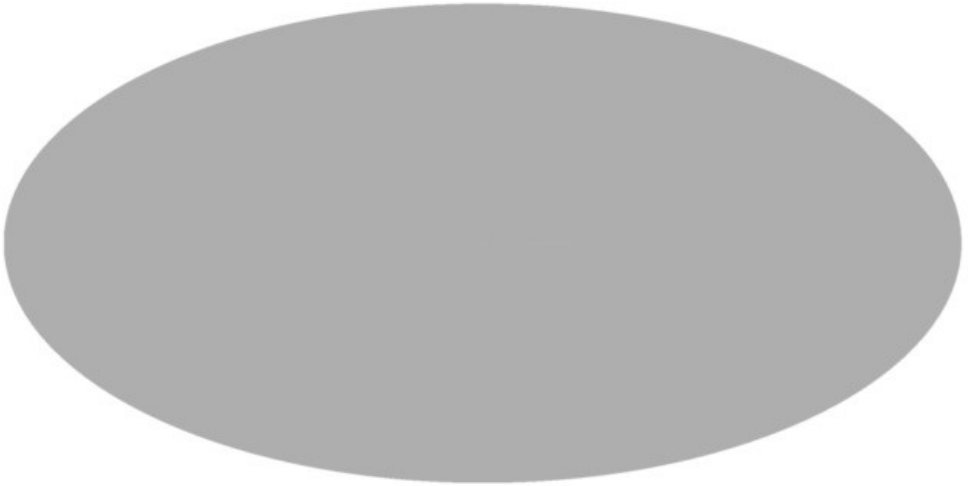


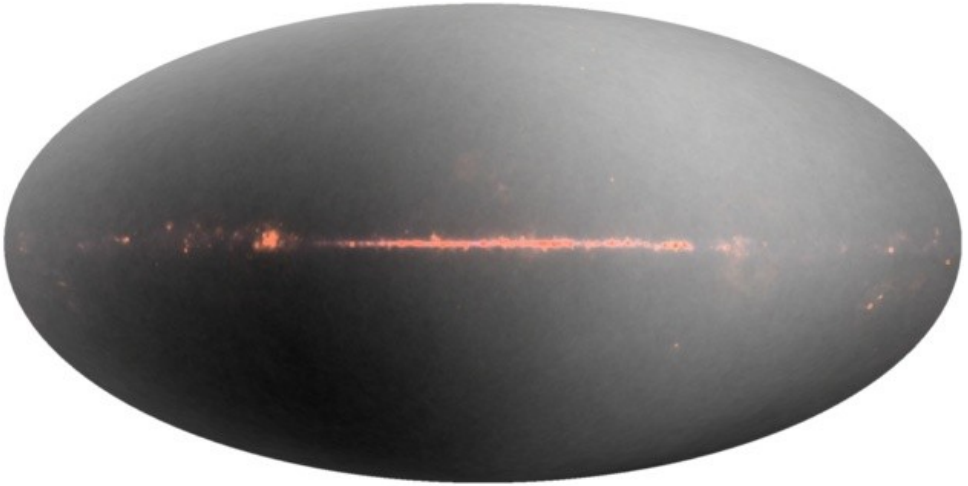


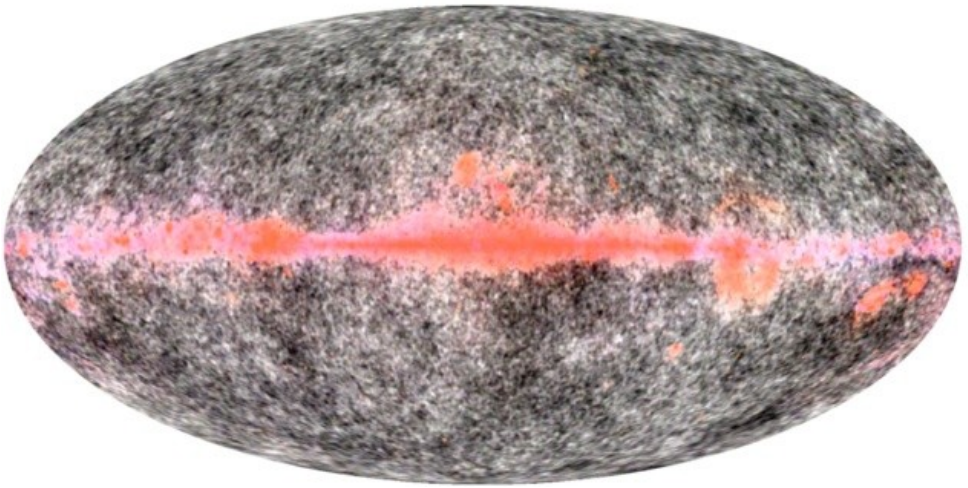


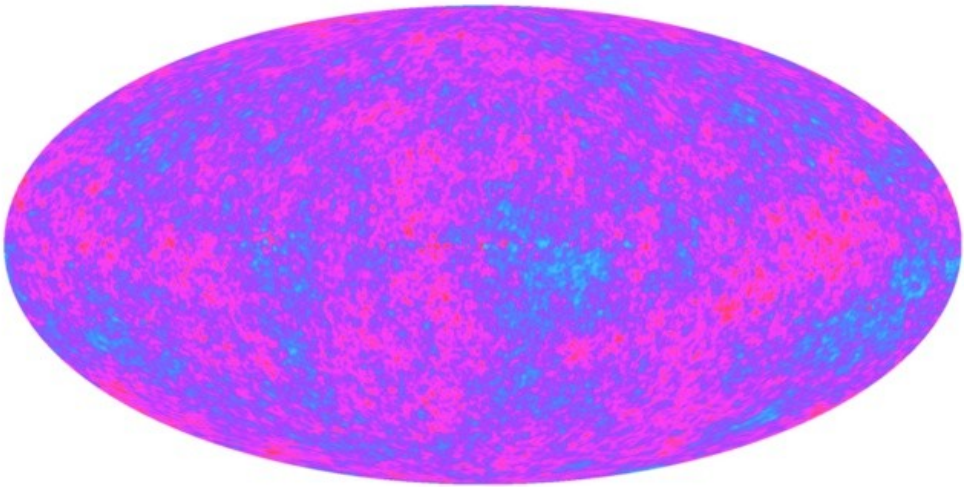
Ned Wright

Prasevanje in neenakomernosti









Ned Wright

Primarne in sekundarne neenakomernosti

- Modelski izračuni in porazdelitev snovi v vesolju

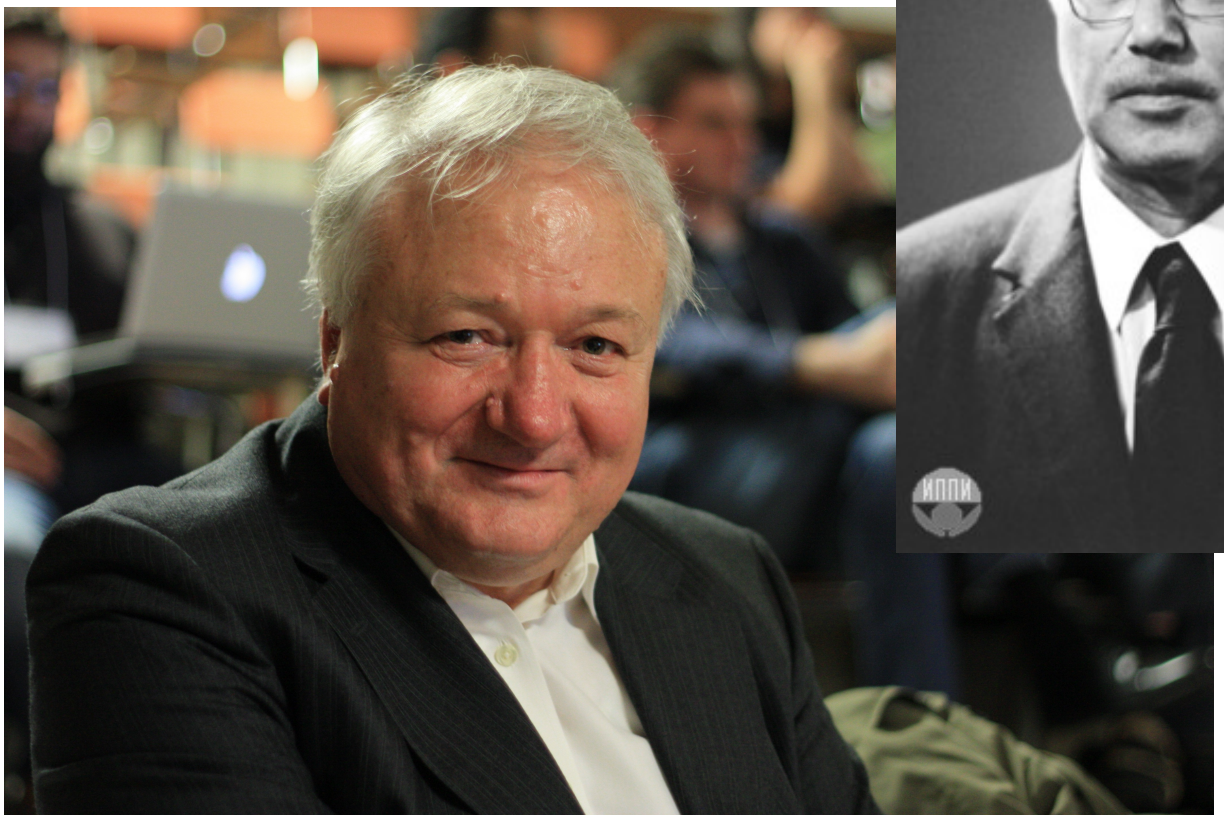
http://cosmicweb.uchicago.edu/filaments.html

Simulacije so bile izvedene na National Center for Supercomputer Applications,
Andrey Kravtsov (The University of Chicago) in Anatoly Klypin (New Mexico State University).
Vizualizacija: Andrey Kravtsov.

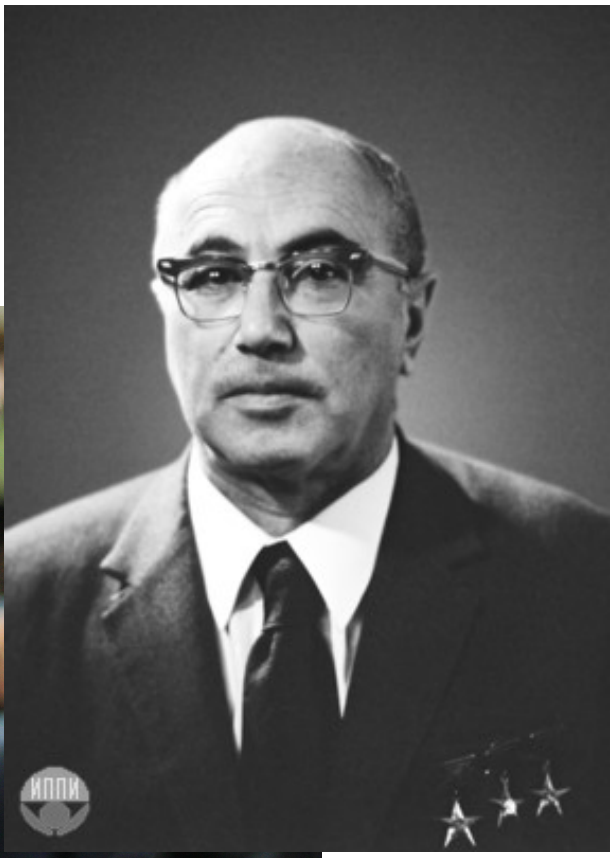
Jata galaksij

X-ray: NASA/CXC/MIT/E.-H Peng et al; Optical: NASA/STScI

Sunyaev in Zel'dovič



Rašid Sunjajev
(1943-)

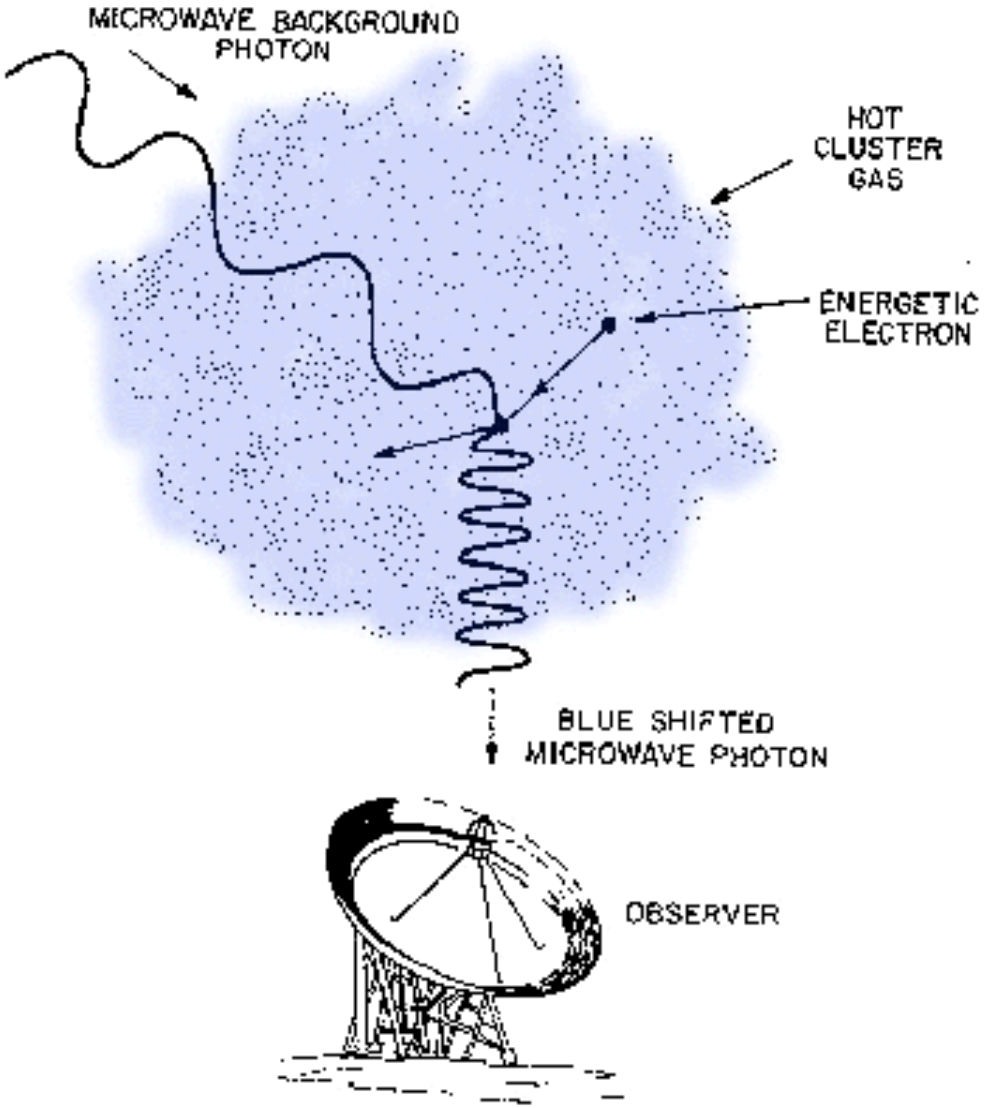


Jakov Zeldovič
(1914-1987)

Intervju v "Science", vol. 327, jan 2010

Slike (od leve proti desni): Science, Chandra Chronicles, ru.wikipedia.org

Sunjajev-Zeldovičev (SZ) efekt



Prirejeno po L. Van Speybroeck

Termični SZ efekt

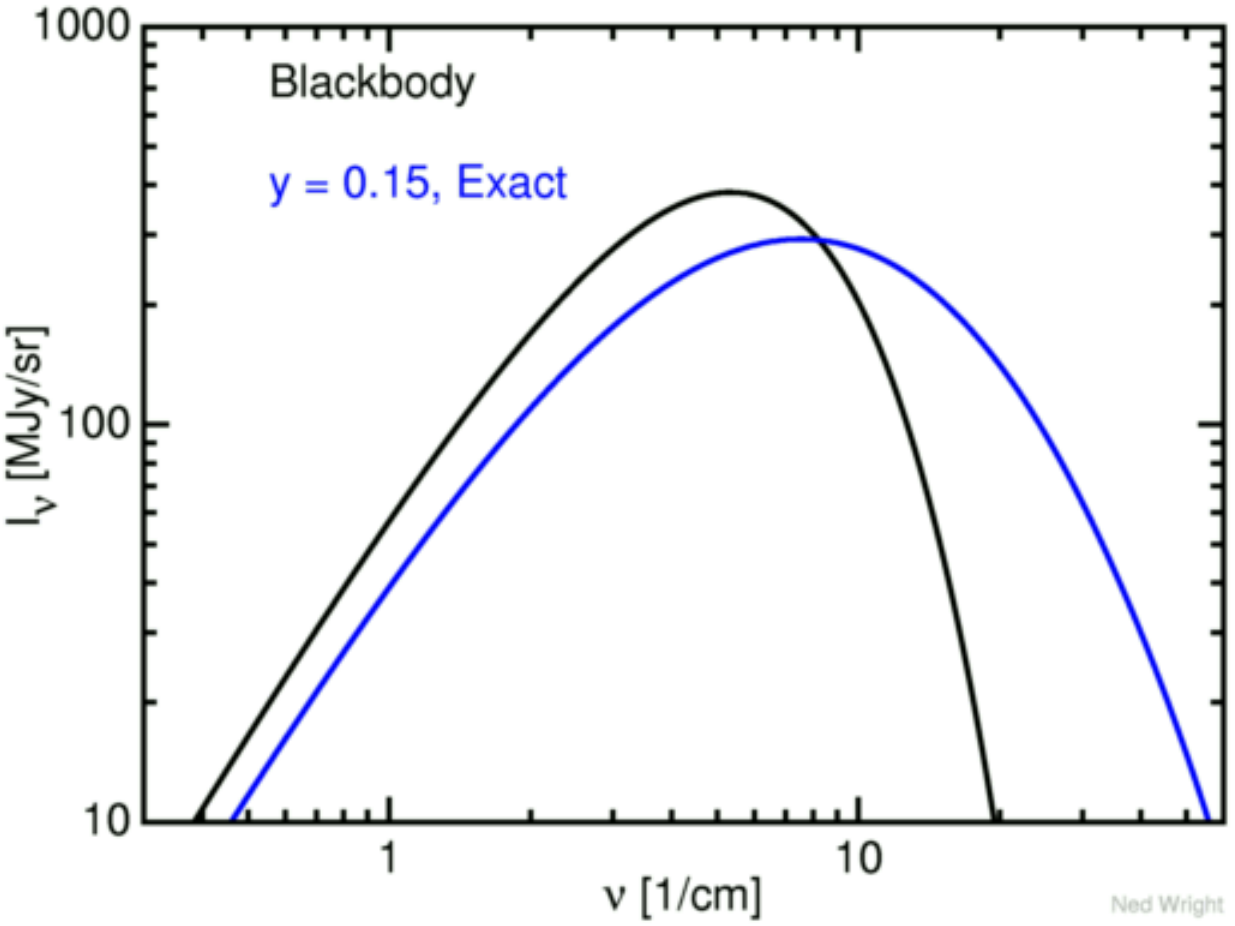
Inverzni
Comptonov pojav

$$y = \int n_e(r)\, \sigma_T\, \frac{k_B T_e(r)}{m_e c^2}\; dl$$

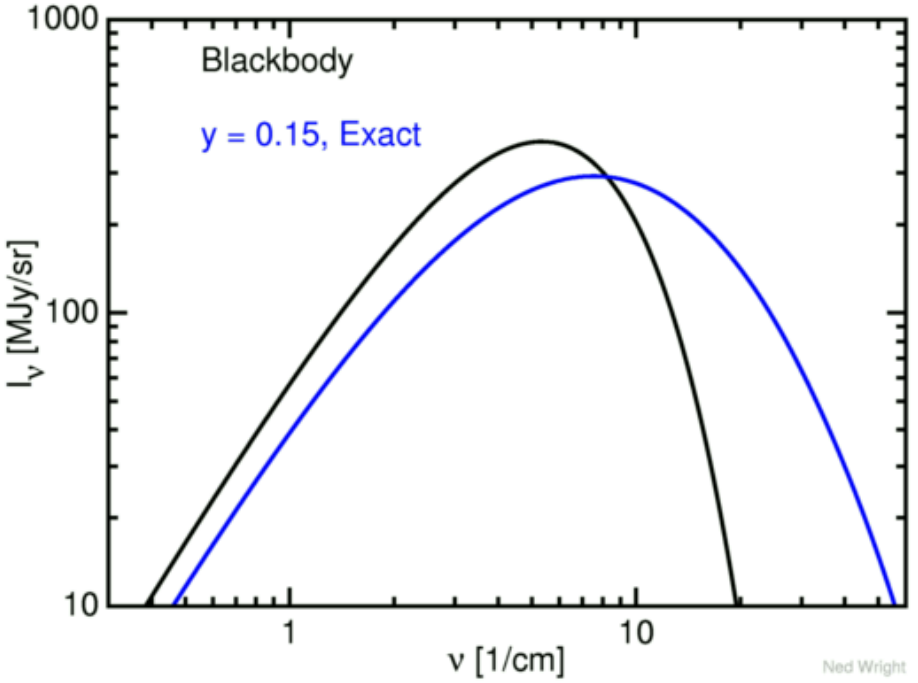
$$\frac{\Delta T}{T_{CMB}} = f(x)\, y$$

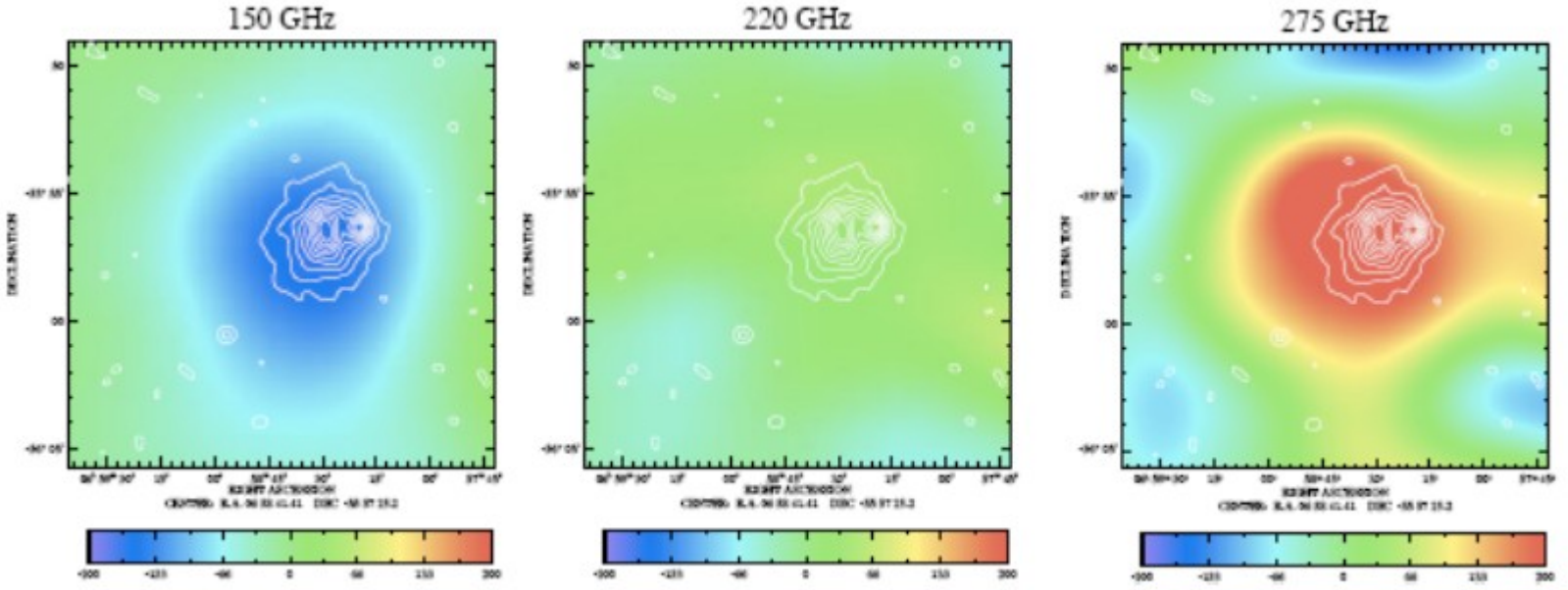
$$x = \frac{h\nu}{k_B T}$$

$$\Delta I = I_{CMB}\, g(x)\, y$$

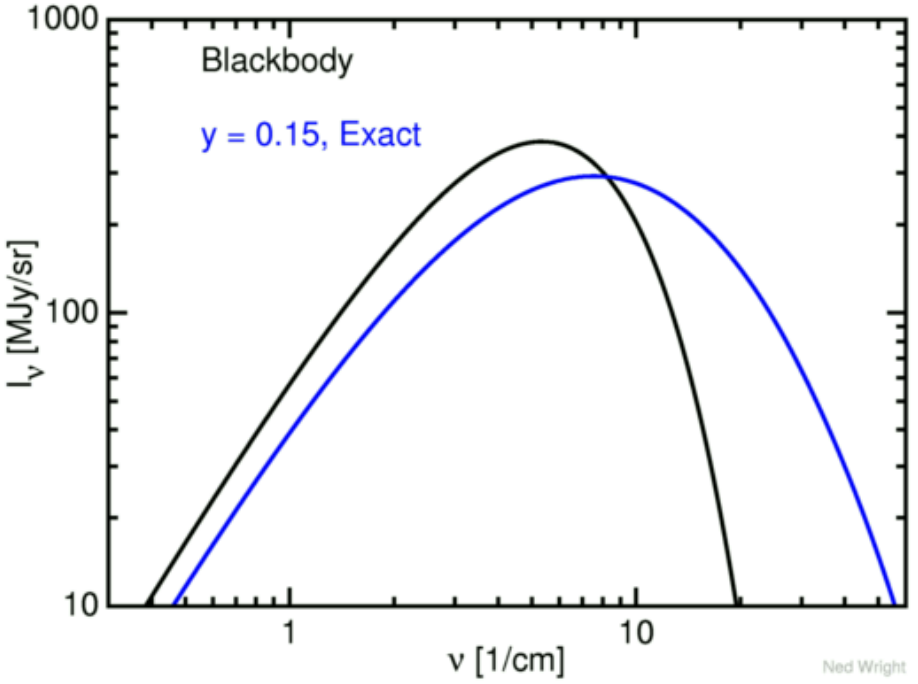


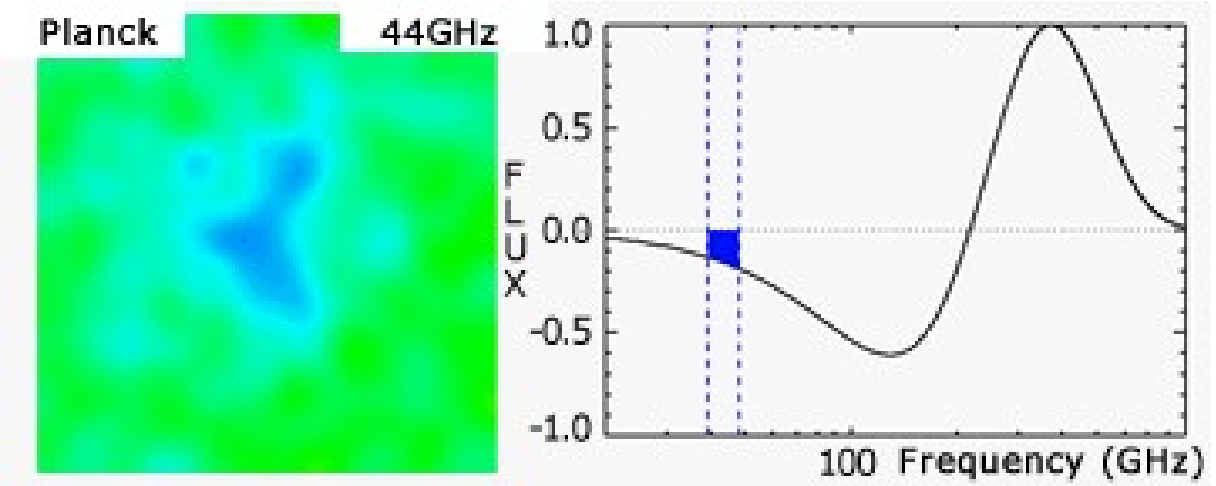
Termični SZ efekt





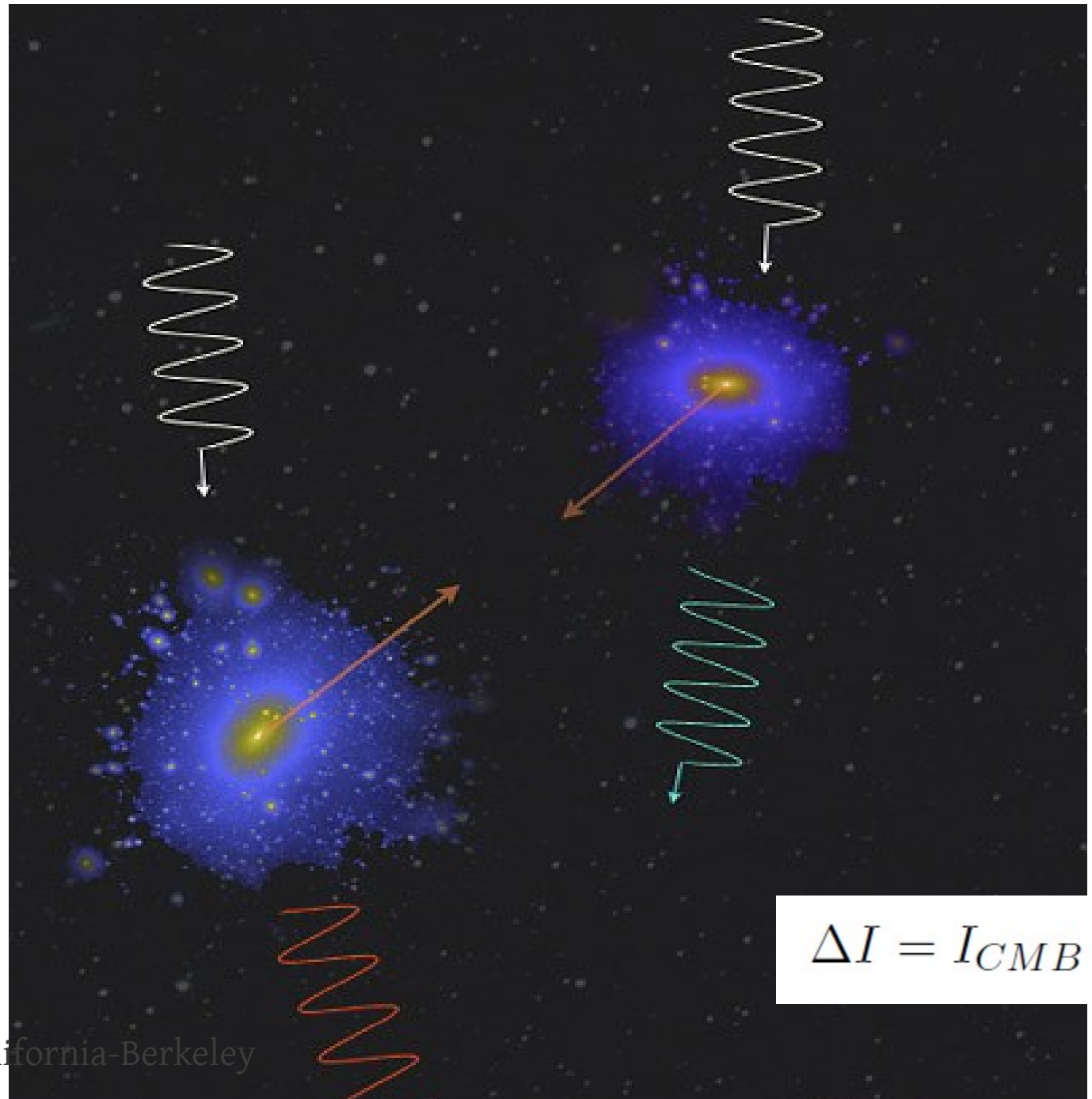
Termični SZ efekt





ESA/Planck Collabration

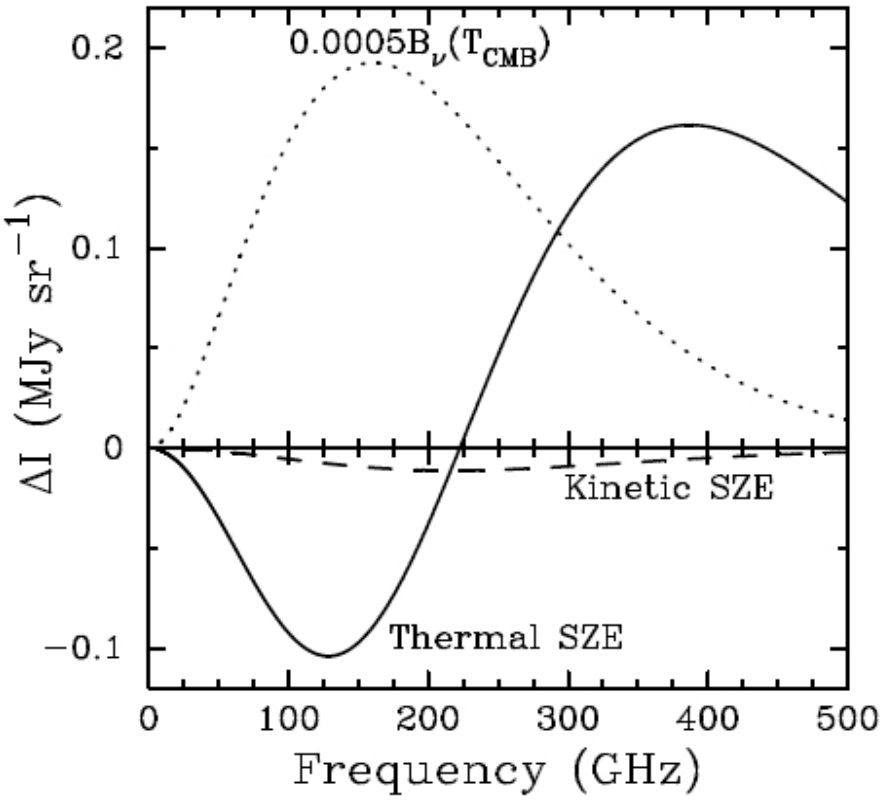
Kinematični SZ efekt



$$\Delta I = I_{CMB}\, \beta_z\, \tau_e\, h(x)$$

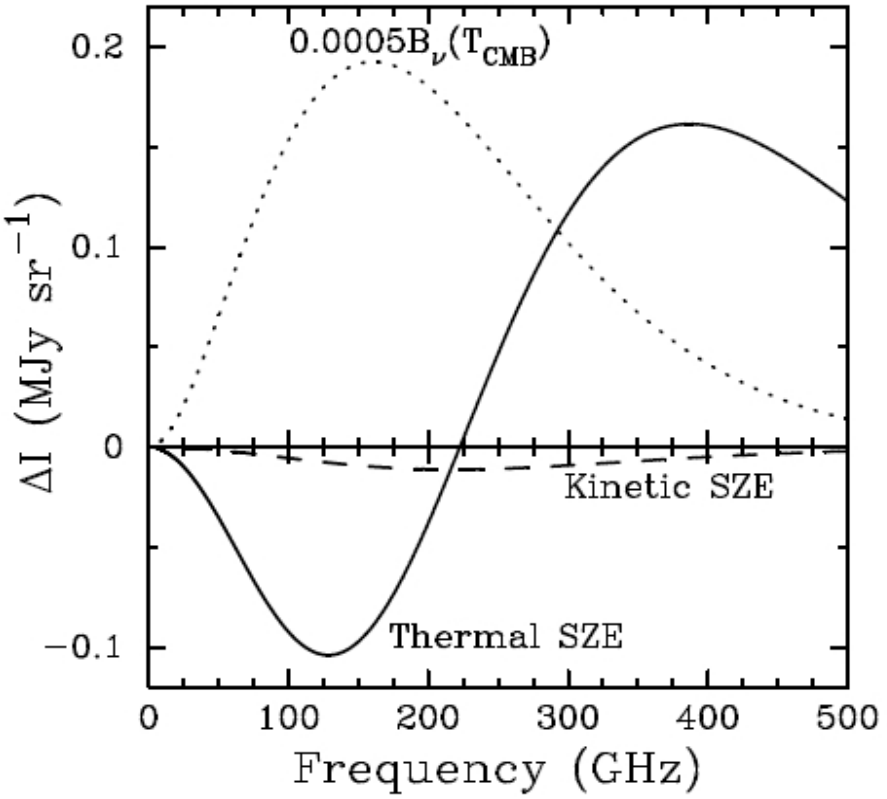
Sudeep Das,
University of California-Berkeley

Termični in kinematični SZ efekt

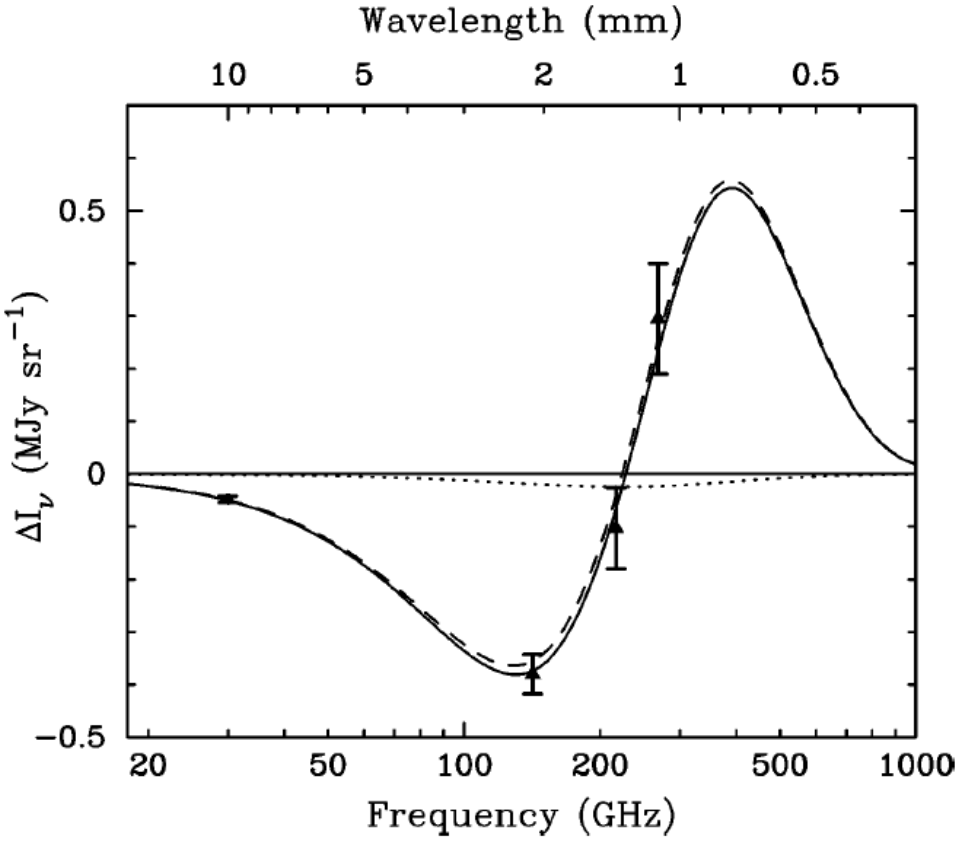


Carlstrom et al. 2002

Termični in kinematični SZ efekt

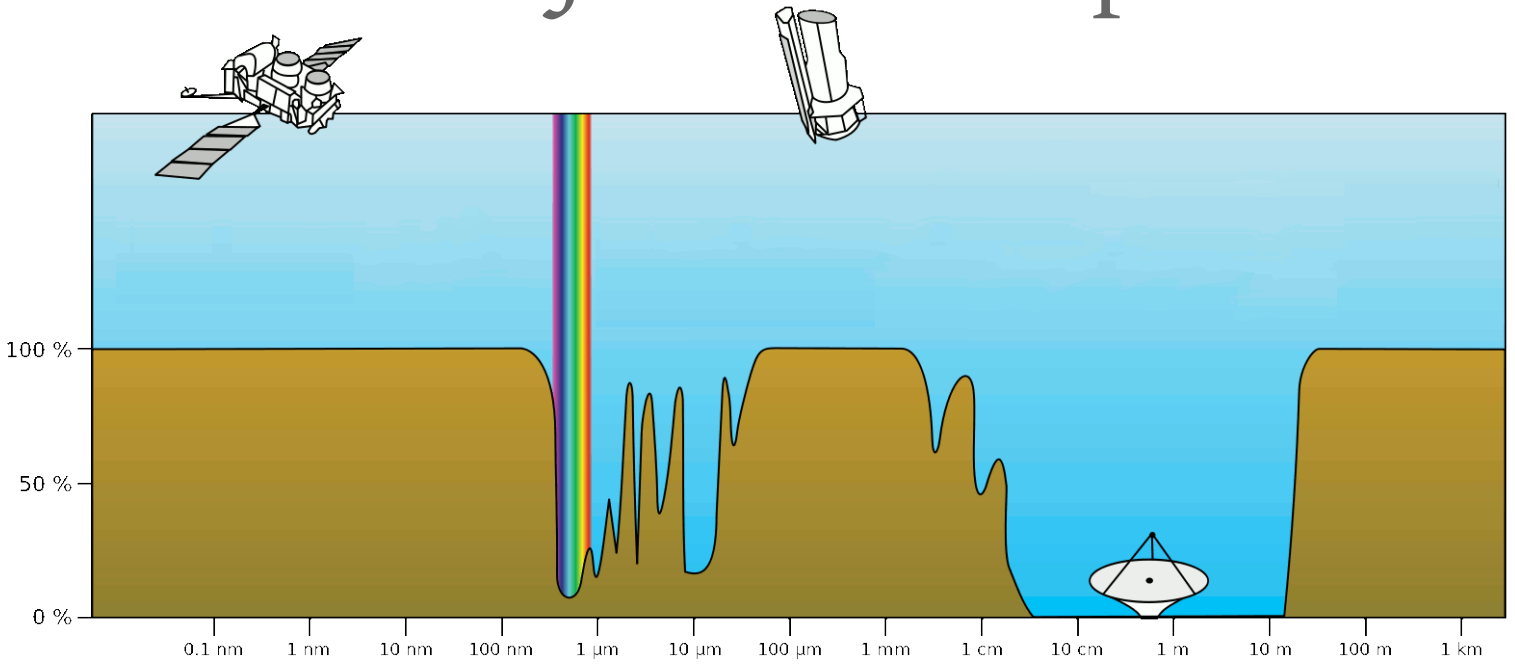


Carlstrom et al. 2002



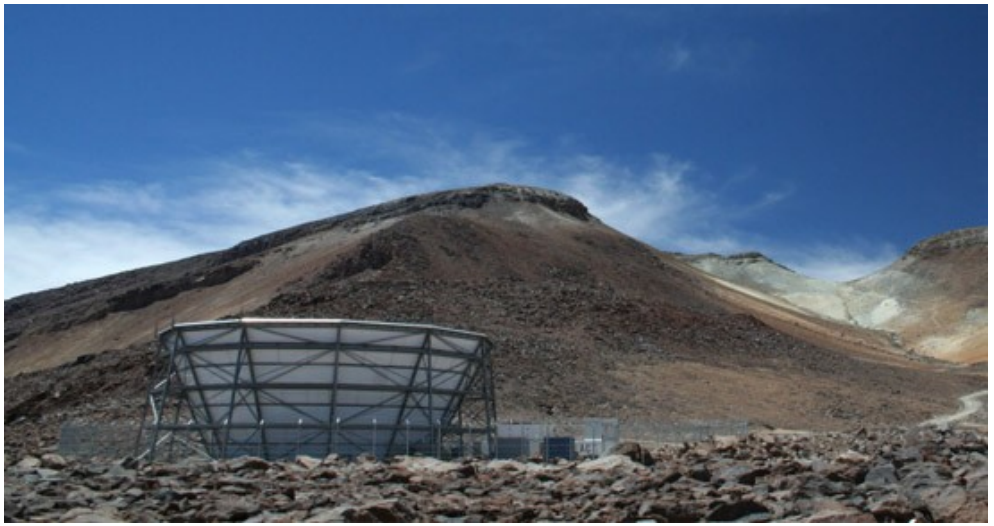
BIMA+SuZIE+Diabolo, jata galaksij Abell 2163

Radijski teleskopi



Avtorstvo: NASA

South Pole Telescope (slika: Jeff McMahon)



Atacama Cosmology Telescope
(slika: Wikipedija)

Radijski interferometri

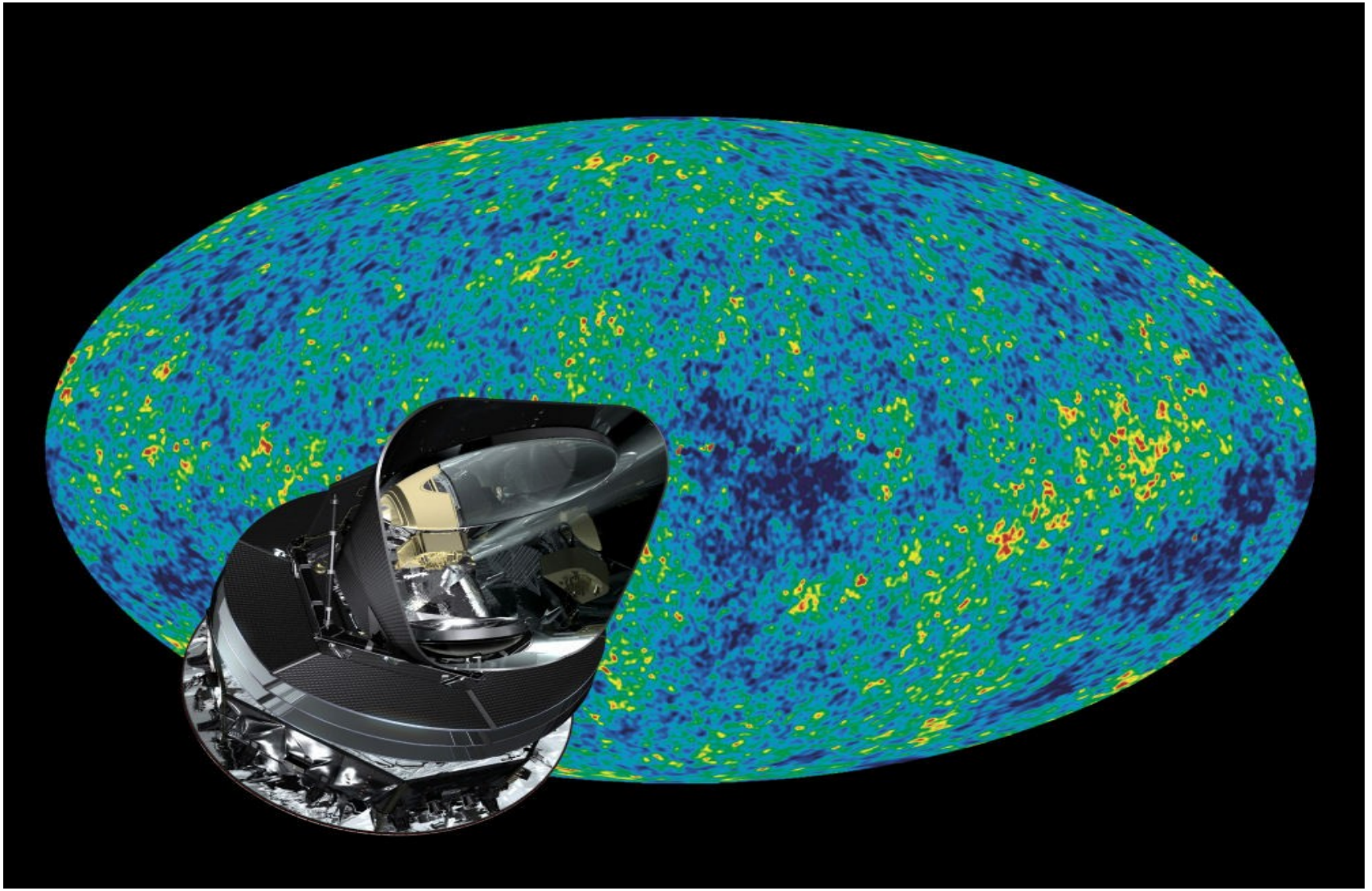
Teleskop Ryle
(prva interferometrična meritev SZ pojava, Jones et al. 1993)

OVRO – Owens Valley Radio Observatory

Radijski interferometri

ALMA – Atacama Large Millimeter/submillimeter Array
(slika: ESO/C. Malin)

Sateliti

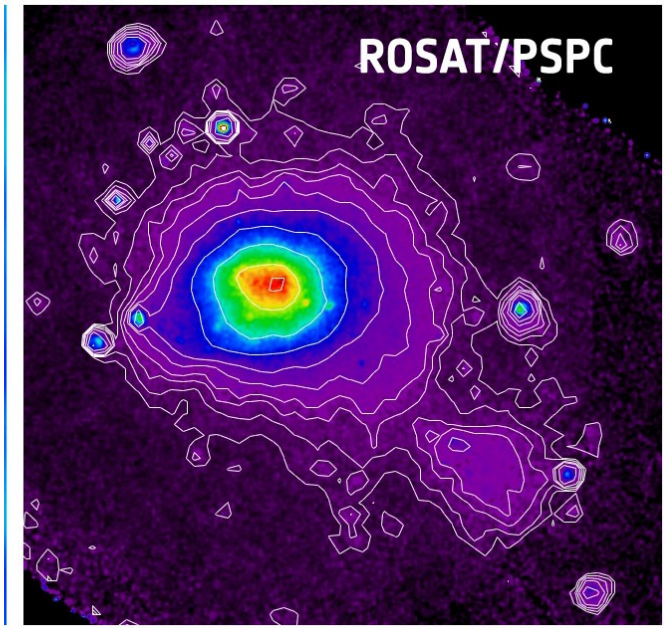


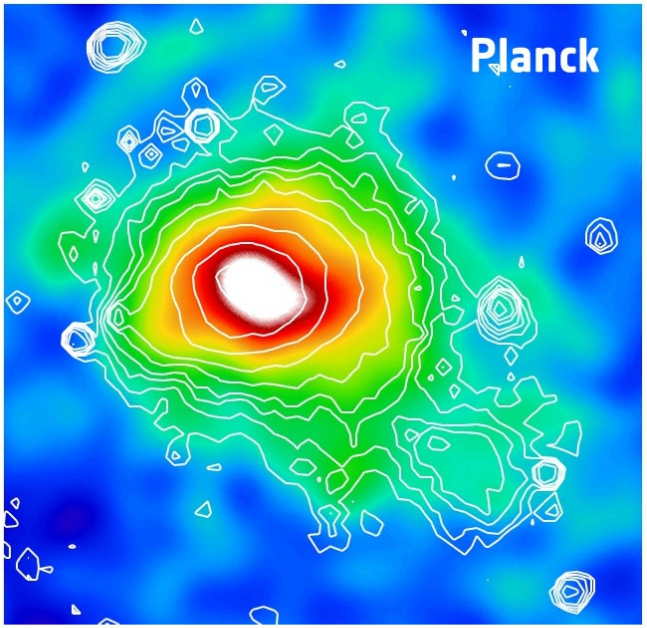
Slika: ESA/NASA/WMAP

Znanost s SZ efektom

- Termični SZ efekt
  - Kozmološke meritve (npr. Hubblova konstanta)
  - Lastnosti jatnega plina (npr. delež mase v jatnem plinu)
- Kinetični SZ efekt
- SZ pregledi neba
  - Test za kozmologijo

Merjenje Hubblove konstante





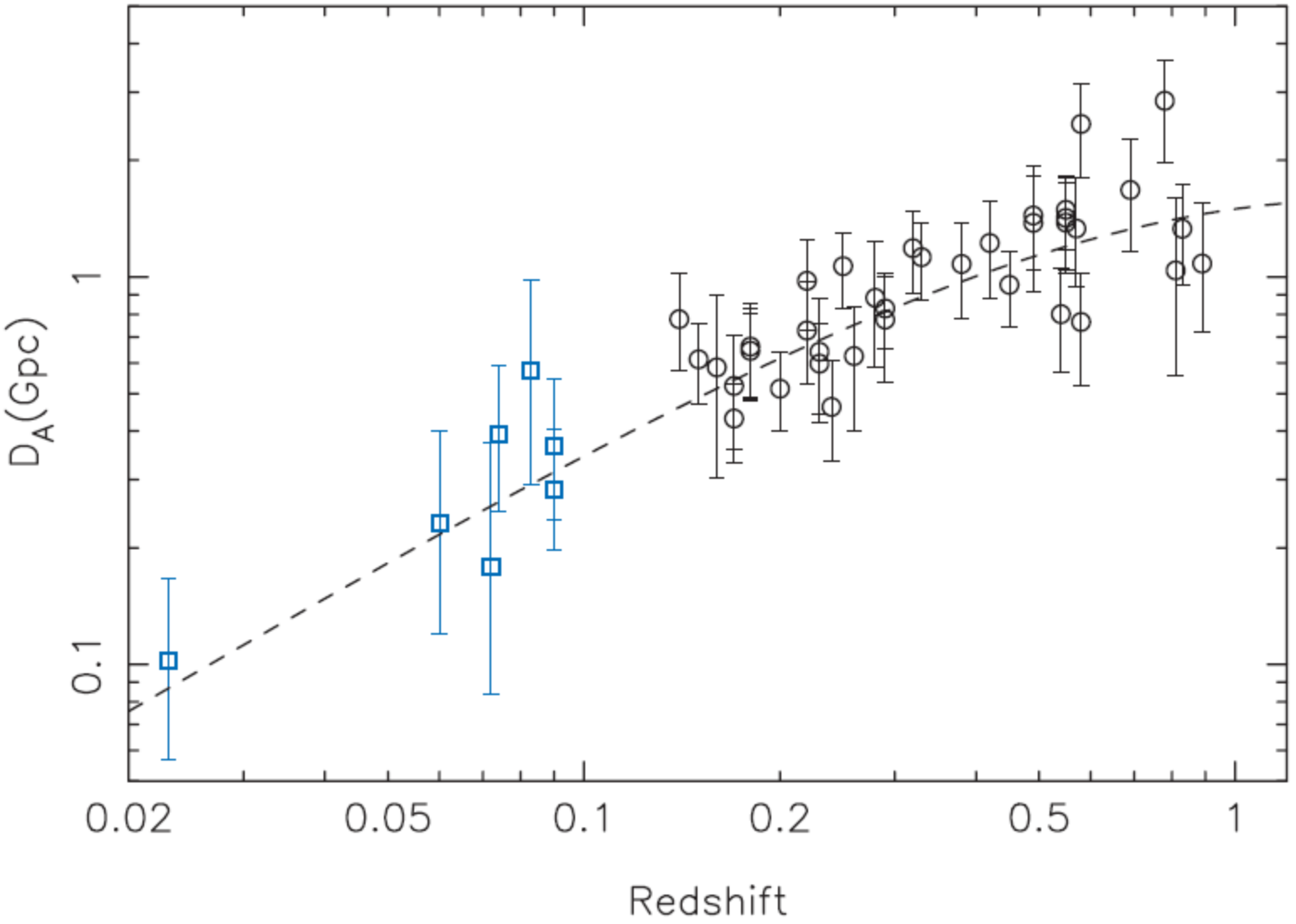
$$I_X \propto n_e^2 T_e^{1/2} L$$

$$L = D_A \theta$$

$$\Delta T_{SZ} \propto n_e T_e L$$

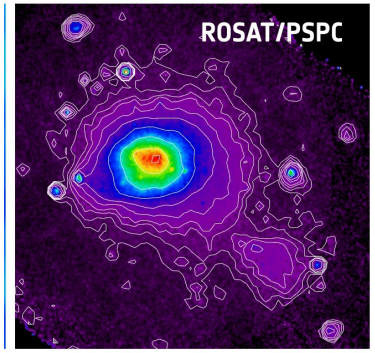
$$\left(\frac{\Delta T_{SZ}}{T_e L}\right)^2 \propto \frac{I_X}{T_e^{1/2} L}$$

Merjenje Hubblove konstante



Bonamente et al. 2006

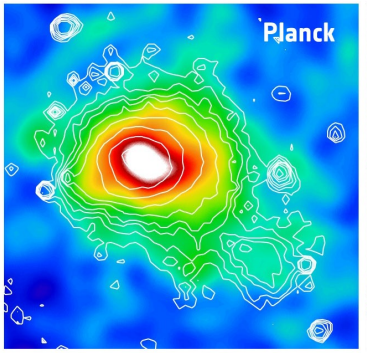
Lastnosti plina v jatah galaksij



Rentgenska svetloba

$T_e(r)$

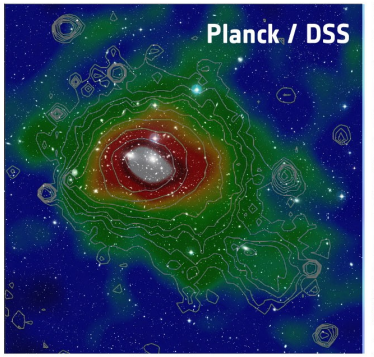
Sunyaev-Zeldovičev pojav



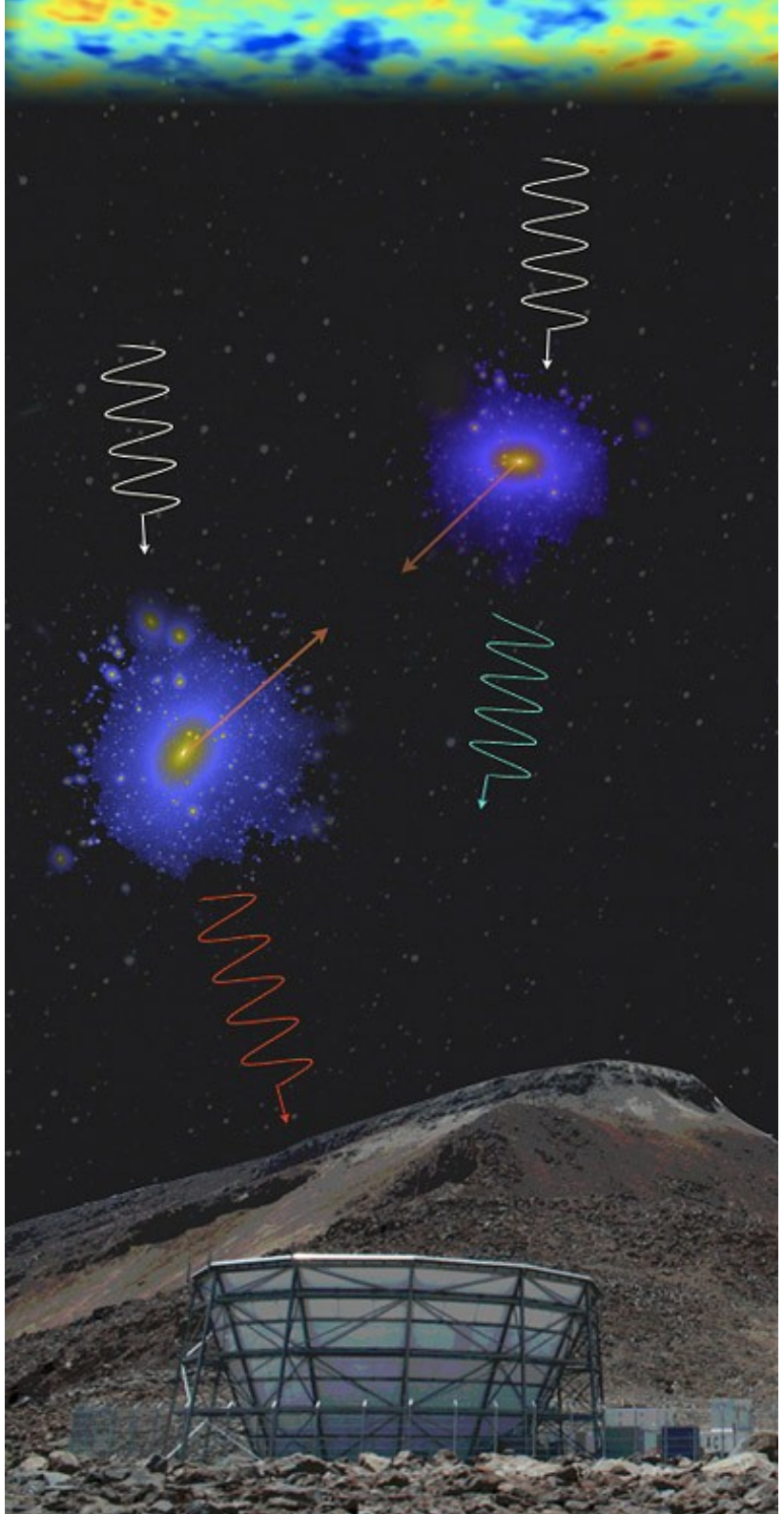
$n_e(r)$

M_{plin}

Gravitacijsko lečenje



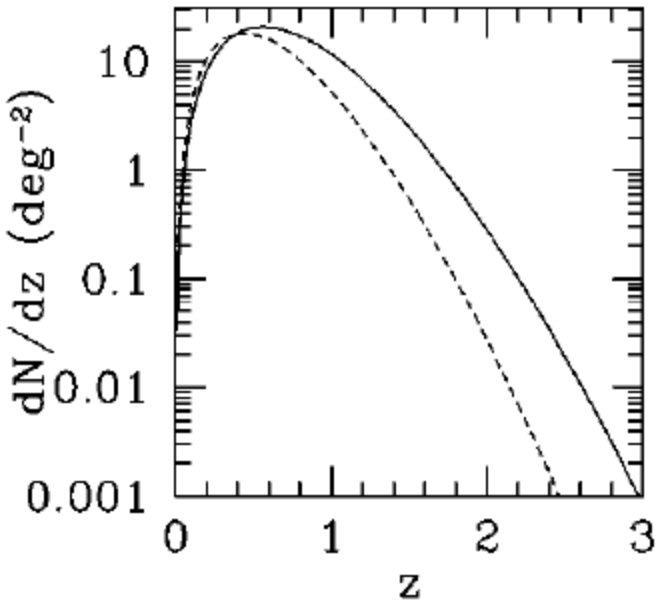
$$f_{plin} = \frac{M_{plin}}{M_{jate}}$$



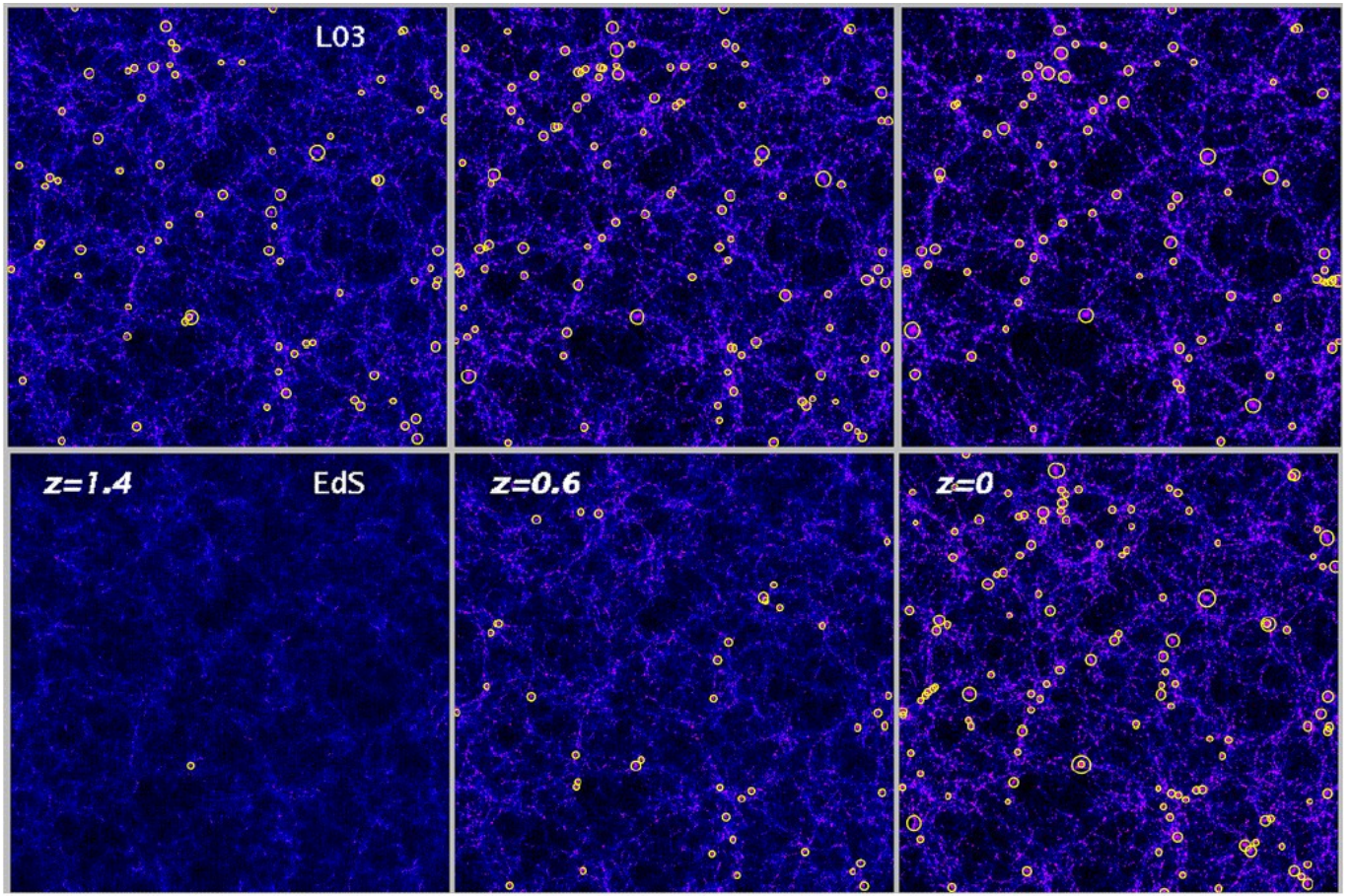
Kinematični SZ efekt

Sudeep Das, University of California-Berkeley

Številčna gostota jat na različnih rdečih premikih

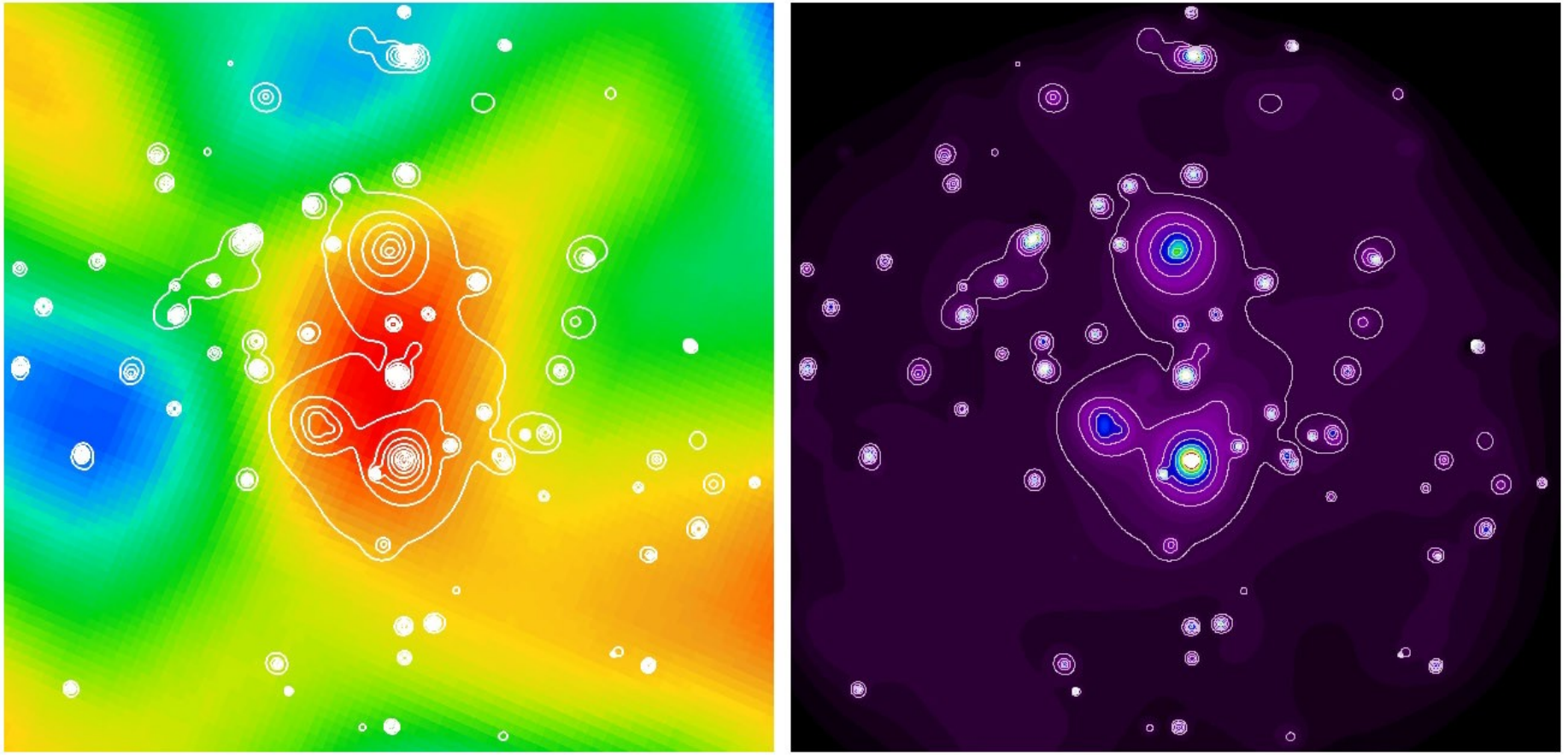


Carlstrom et al. 2002



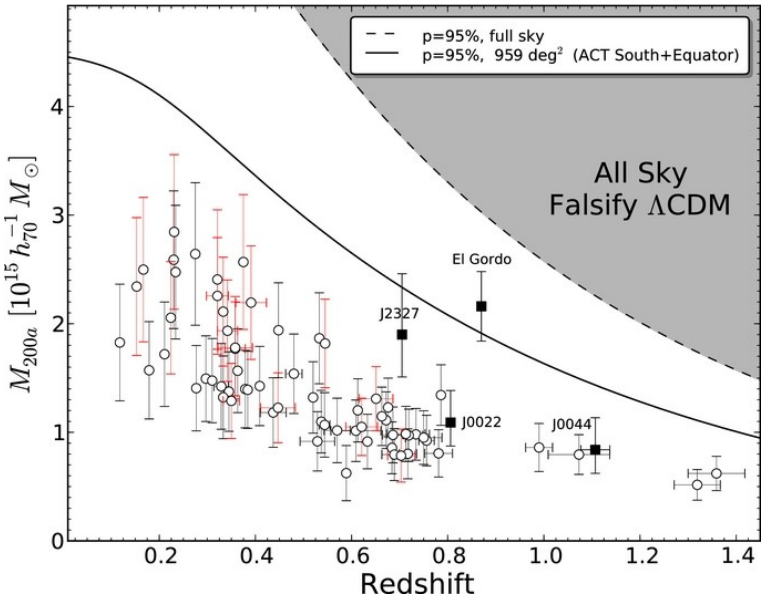
Borgani in Guzzo 2001

Novejša odkritja: nove oddaljene jate



PLCK G214.6+37.0 *Planck: ESA/LFI & HFI; XMM-Newton: ESA*

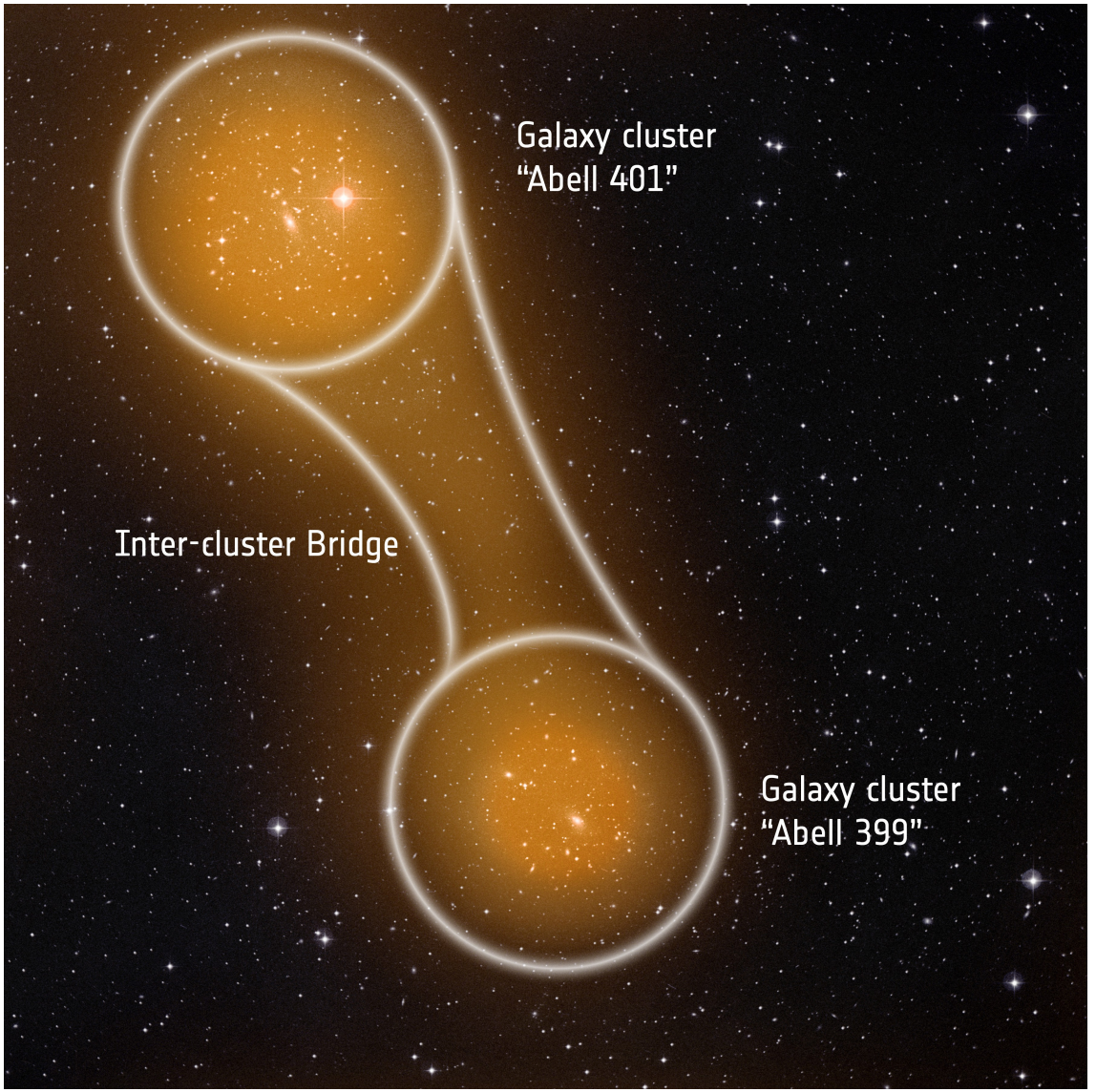
Novejša odkritja: jata galaksij El Gordo



Menanteau et al. 2012

ACT-CL J0102-4915
Rentgen.: NASA/CXC/Rutgers/J. Hughes et al;
Opt.: ESO/VLT & SOAR/Rutgers/F. Menanteau;
IR: NASA/JPL/Rutgers/F. Menanteau

Novejša odkritja: filamenti



SZ učinek (oranžna): ESA & Planck Collaboration;
Opt.: STScI Digitized Sky Survey

Kaj novega smo izvedeli?

- Sunjajev-Zeldovičev učinek nastane pri sipanju prasevanja na jatnem plinu
- SZ učinek ni odvisen od rdečega premika
- Uporabimo ga lahko v kombinaciji z rentgenskimi opazovanji (npr. meritev Hubblove konstante, masnega deleža v plinu, lastnosti plina v jatah)
- Pregledi neba z radijskimi teleskopi (zemeljskimi in vesoljskimi) odkrivajo nove jate in dodatno podkrepijo kozmološke meritve

Nekaj virov

- Obširnejši pregledni članki:
  - Carlstrom, Holder in Reese, Cosmology with the Sunyaev-Zel'dovich effect, http://ned.ipac.caltech.edu/level5/Sept05/Carlstrom/Carlstrom_contents.html
- Prosto dostopna predavanja:
  - dr. Katy Lancaster http://www.star.bris.ac.uk/katy/
  - prof. Ned Wright http://www.astro.ucla.edu/~wright/SZ-spectrum.html
  - prof. Wayne Hu http://background.uchicago.edu/~whu/physics/physics.html