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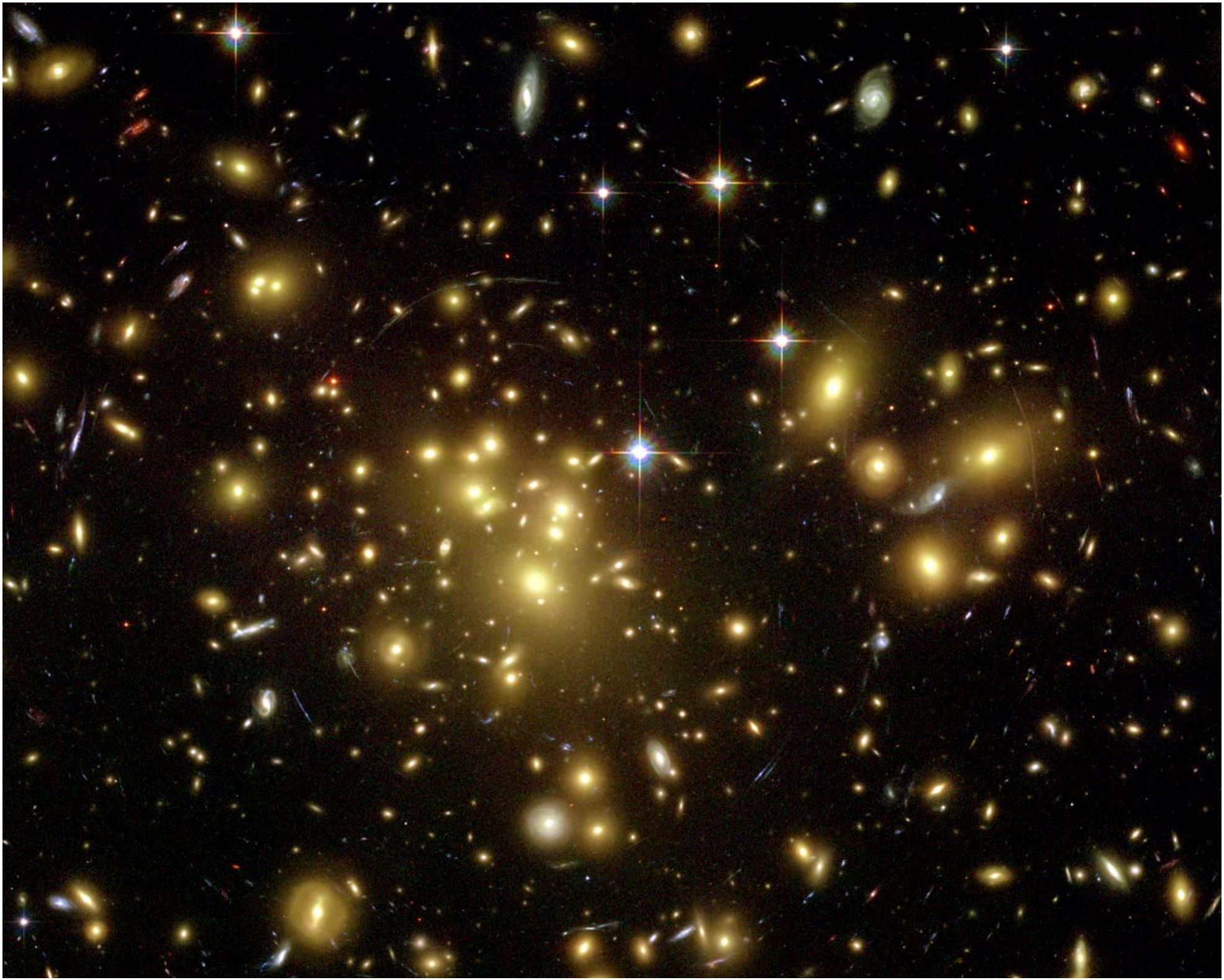
Essential Cosmology for the Next Generation
Puerto Vallarta, Mexico — 1/11/11

The South Pole Telescope Galaxy Cluster Survey

Outline

- What's a galaxy cluster?
- Why should we care?
- The Sunyaev-Zeldovich effect
- The South Pole Telescope
- Results
- What's next
- Summary



What a galaxy cluster is

X-ray: NASA/CXC/CfA/M.Markevitch et al.; Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.

The cluster mass budget

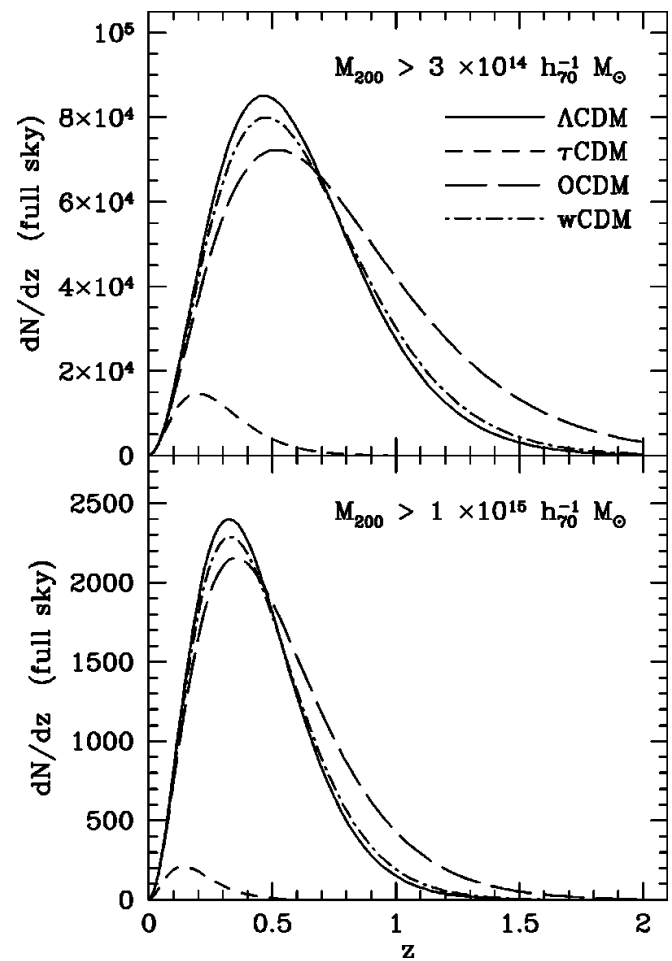
Matter component	% total mass	% baryonic mass	% stellar mass
Dark matter	***85-90***	***(na)***	***(na)***
Baryons	***10-15***	***100***	***(na)***
Hot gas	7-14	70-95	(na)
Stars	0.5-5	5-30	100
Galaxies	0.5-4	4-27	70-90
Intracluster stars	0.05-1	0.5-9	10-30
Non-luminous baryons	?	?	?

The galaxies make up ~1% of total cluster mass.

Why we care

- Dark energy equation of state: $w = p/\rho$
- Recent interest in non-Gaussian matter perturbations: f_{NL}
- Make-up, history, and fate of universe

Voit 2005



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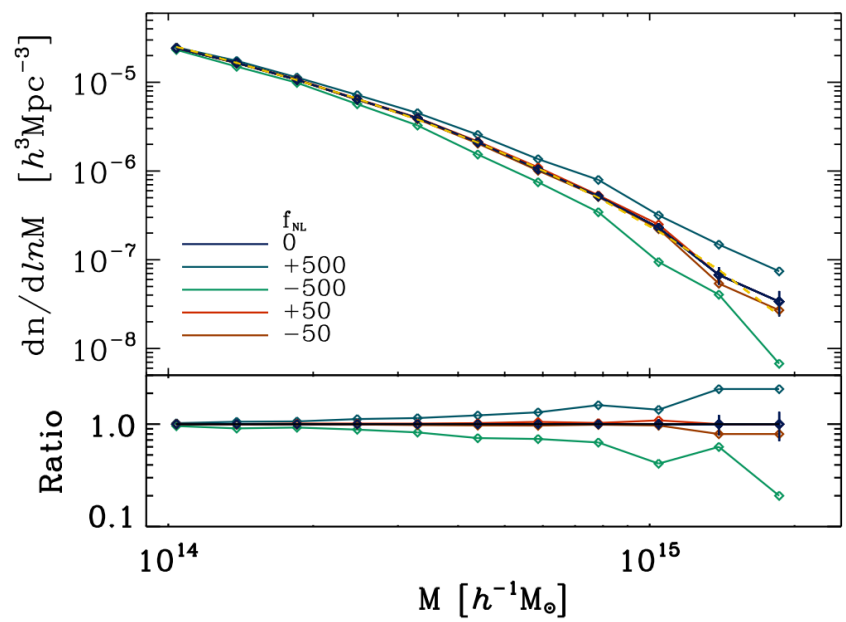
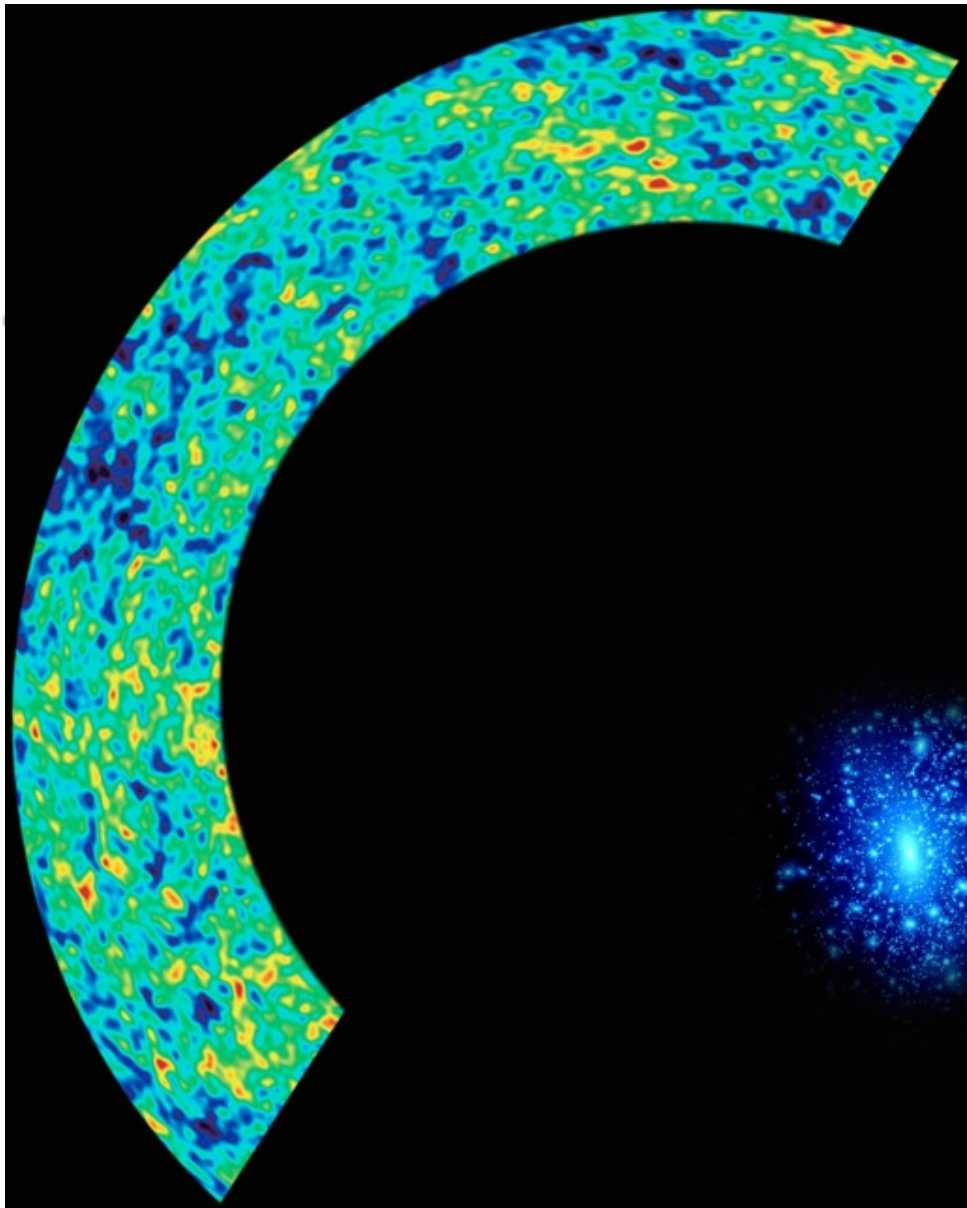
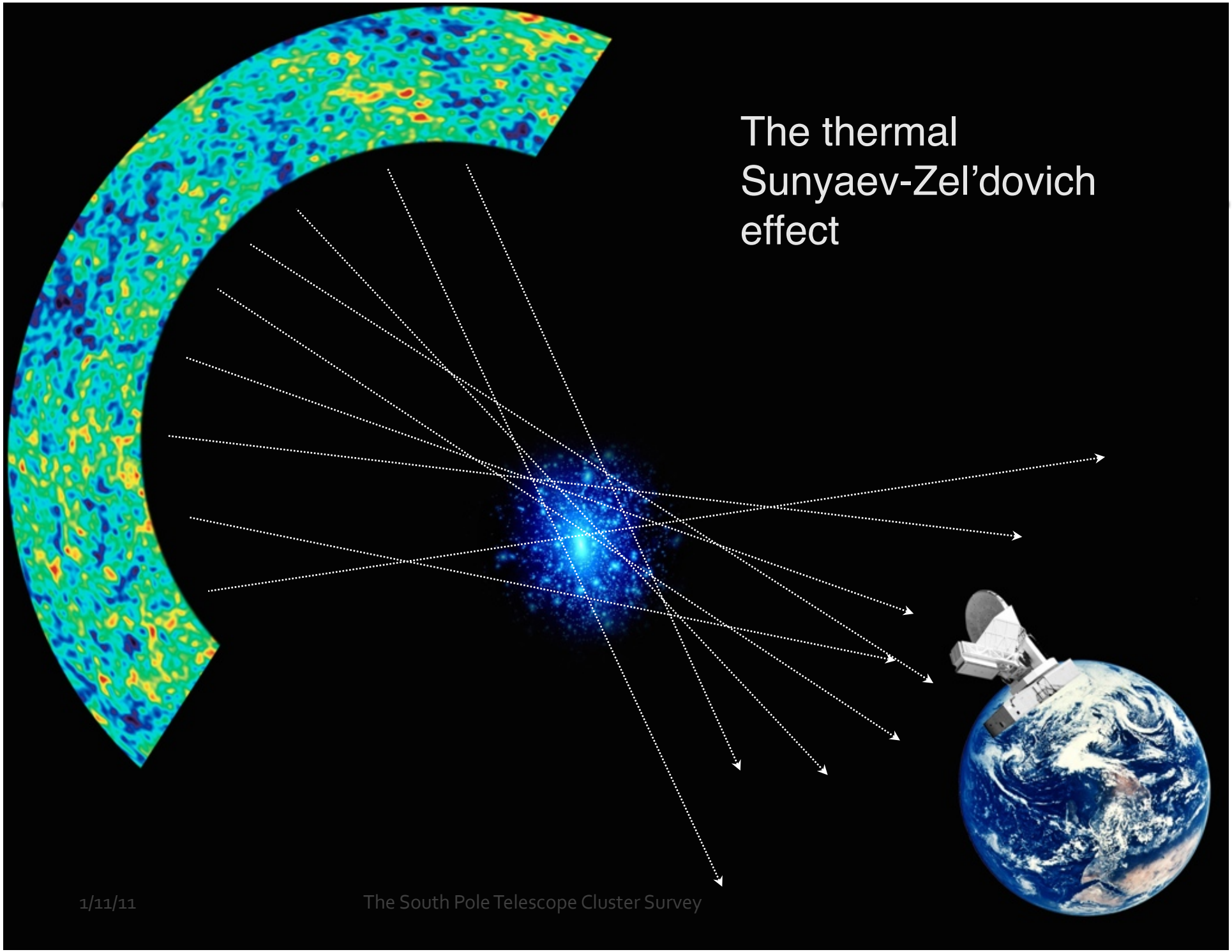
Dalal 2008





The thermal Sunyaev-Zel'dovich effect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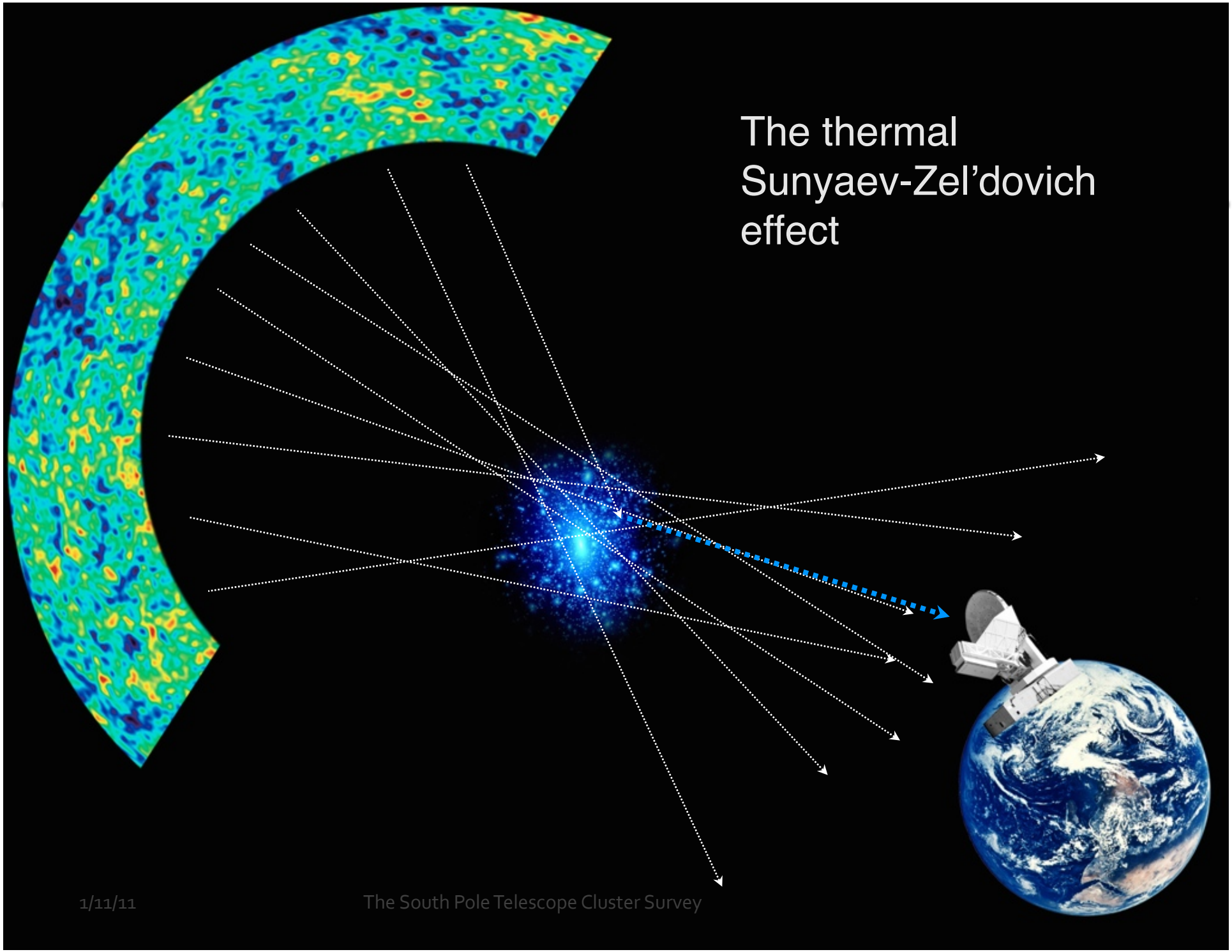
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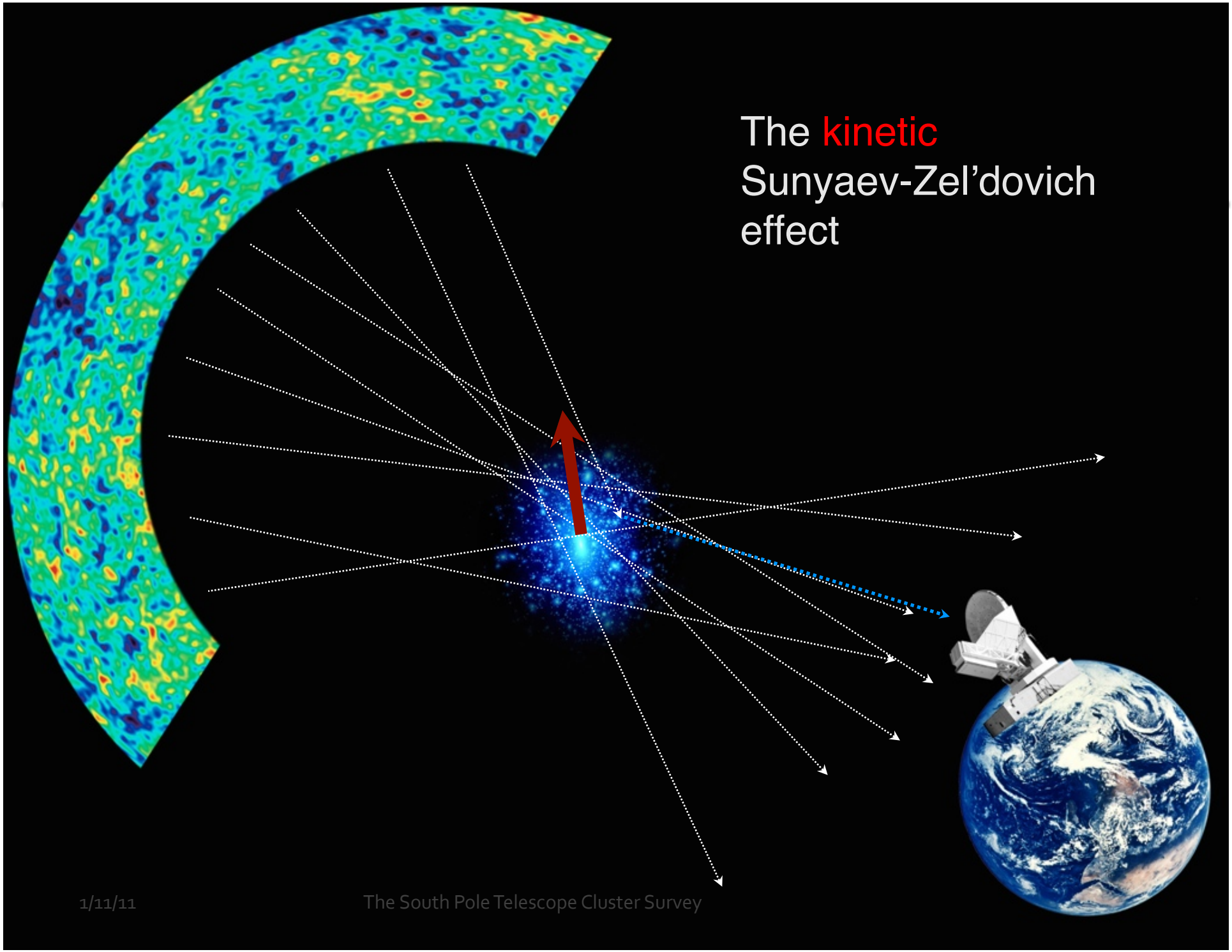
The kinetic
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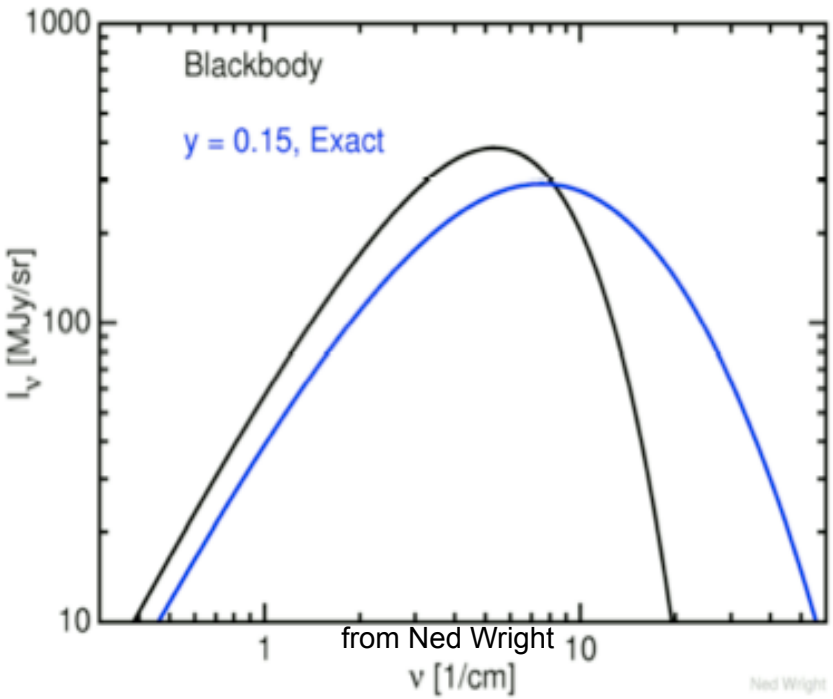
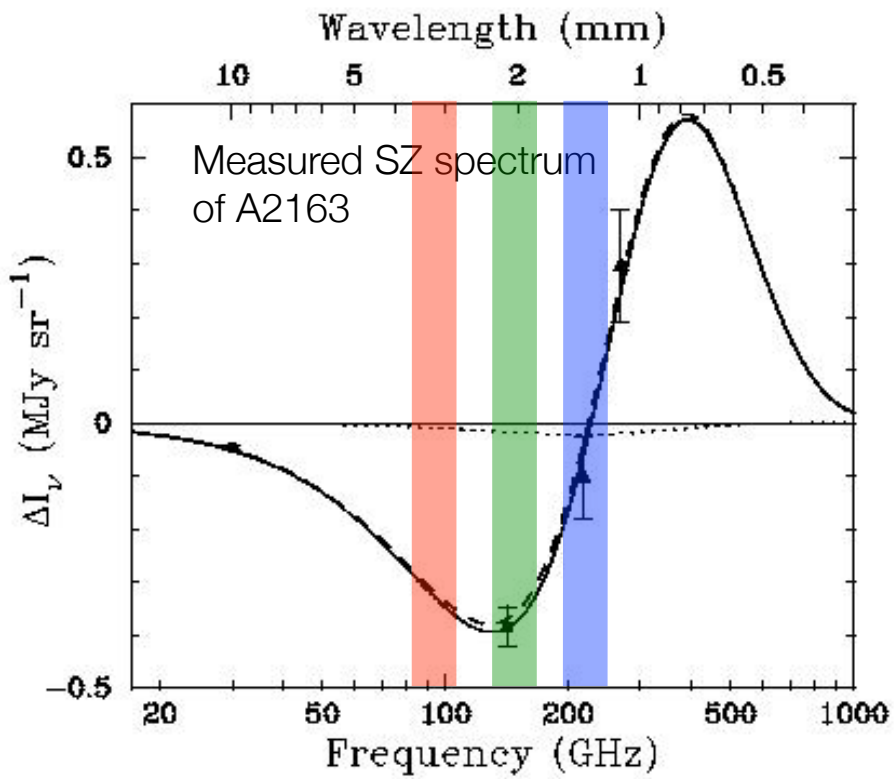
The Sunyaev-Zel'dovich effect



from Ned Wright



Take home message #1

SZ signal is not an emissive process but a spectral disortion, and so is nearly redshift independent†

Take home message #2

SZ signal is a direct probe of cluster gas pressure, and so is a good proxy for cluster mass

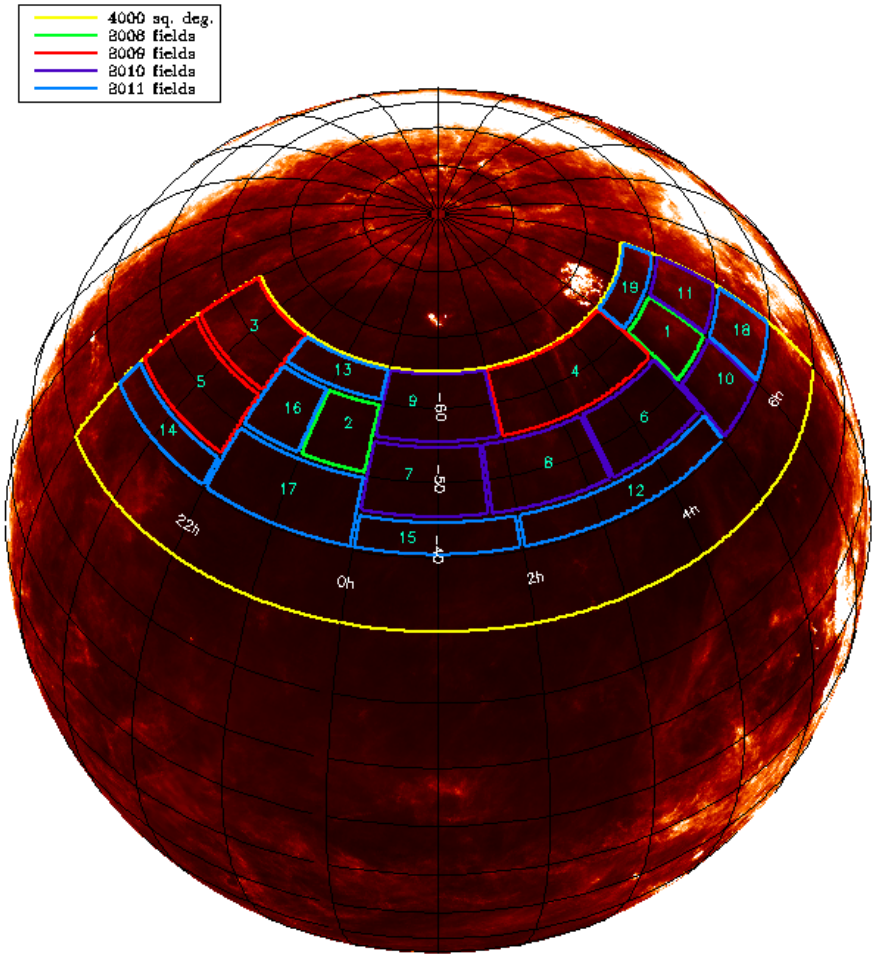
South Pole Telescope

- (Sub)millimeter wavelength telescope:
  - 10 meter aperture
  - 1' FWHM beam at 150 GHz
  - Off-axis Gregorian optics design
  - 20 micron RMS surface accuracy
  - 1 arc-second pointing
  - Fast scanning, up to 4 deg/sec in azimuth
- SZ receiver:
  - 1 sq. deg FOV
  - ~960 background limited pixels
  - Observe in 3+ bands between 95-220 GHz simultaneously
  - Modular focal plane

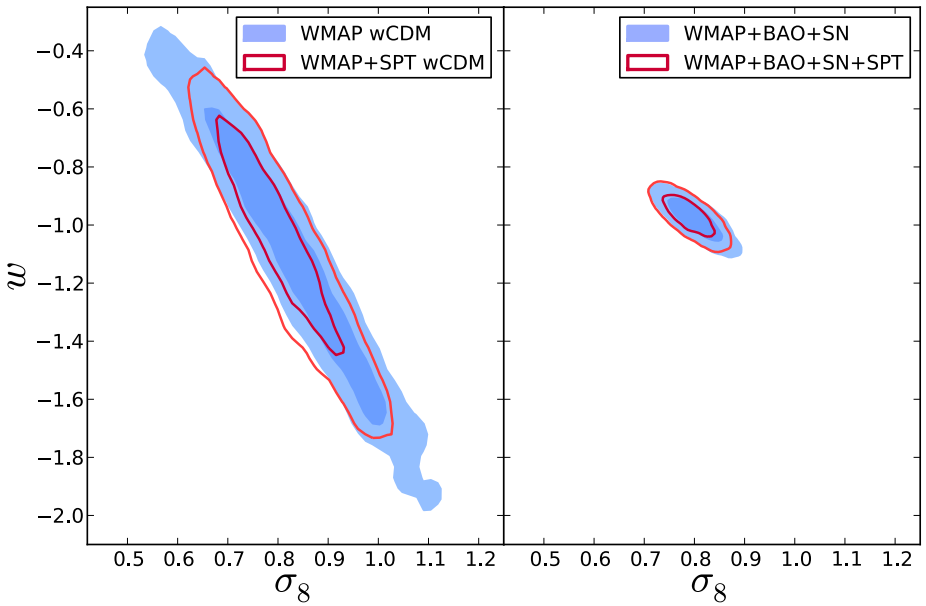
The SPT survey

2008-2011 SPT Fields

Field Name	Obs Year	Area [deg^2]
ra5h30dec-55	2008	90
ra3h30dec-60	2009	230
ra21hdec-50	2009	200
ra21hdec-60	2009	150
ra0h50dec-50	2010	160
ra1hdec-60	2010	150
ra2h30dec-50	2010	160
ra4h10dec-50	2010	160
ra5h30dec-45	2010	110
ra23h30dec-55	2010*	100
ra1hdec-42.5	2010S	110
ra3h30dec-42.5	2010S	170
ra6hdec-62.5	2010S	70
ra6h30dec-45	2010S	110
ra6h30dec-55	2010S	90
ra21hdec-42.5	2010S	110
ra22h30dec-55	2010S	80
ra23hdec-45	2010S	210
ra23hdec-62.5	2010S	70

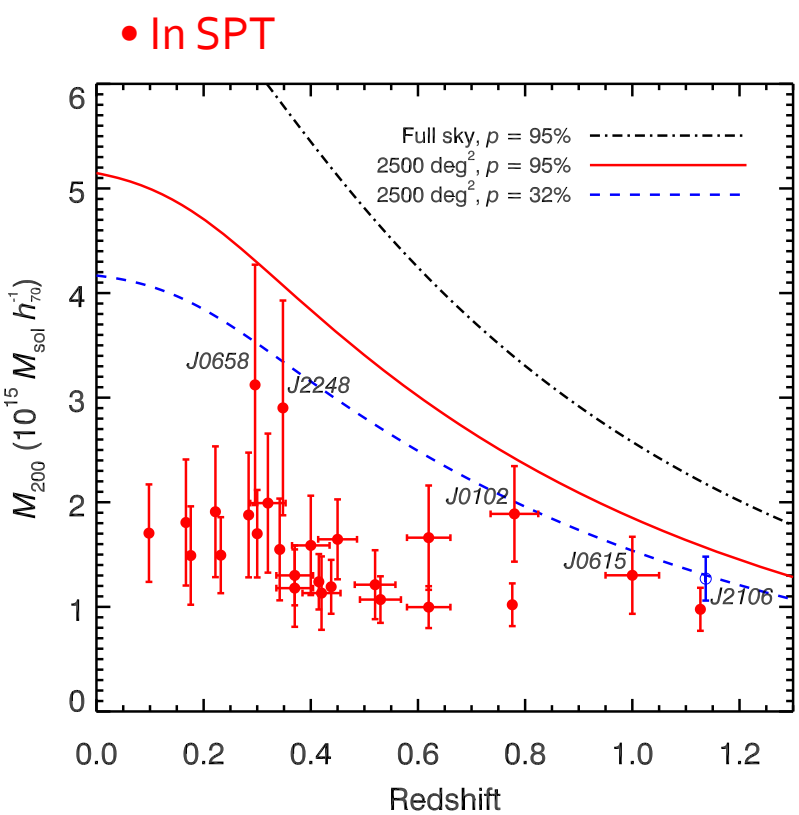


Results: 200 deg²



- Vanderlinde et al. (2010), ApJ
  - Optical studies by High et al. (2010), ApJ
  - X-ray studies by Andersson et al. (2010), arXiv:1006.3068
- 21 clusters
  - 12 previously unknown
  - $0.15 < z < 1.1$
  - median $z = 0.74$
  - $M_{200} \geq 0.5 \times 10^{15}\ M_{sol}$
- 30% improvement on *w* and σ_8 from WMAP7 alone

Results: 2500 deg²



- Williamson et al. (2011), arXiv:1101.1290
  - Highest z cluster, Foley et al. (2011), arXiv:1101.1286
- 26 clusters
  - 12 previously unknown
  - $0.098 < z < 1.13$
  - median $z = 0.40$
  - $M_{200} = 1\text{-}3 \times 10^{15}\ M_{sol}$
- Consistent with
  - ΛCDM
  - Gaussian density perturbations

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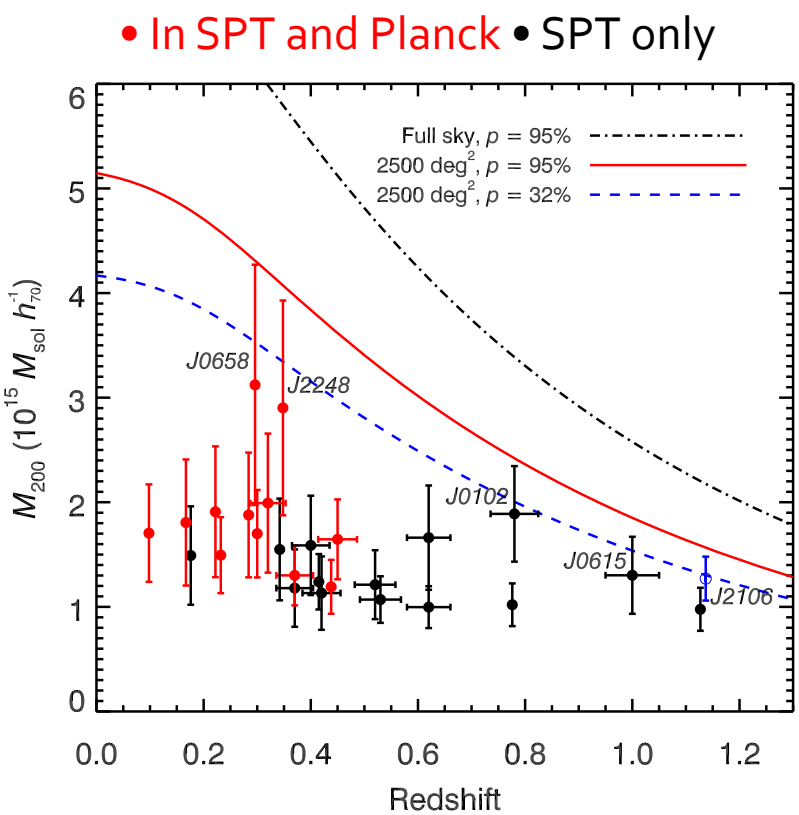

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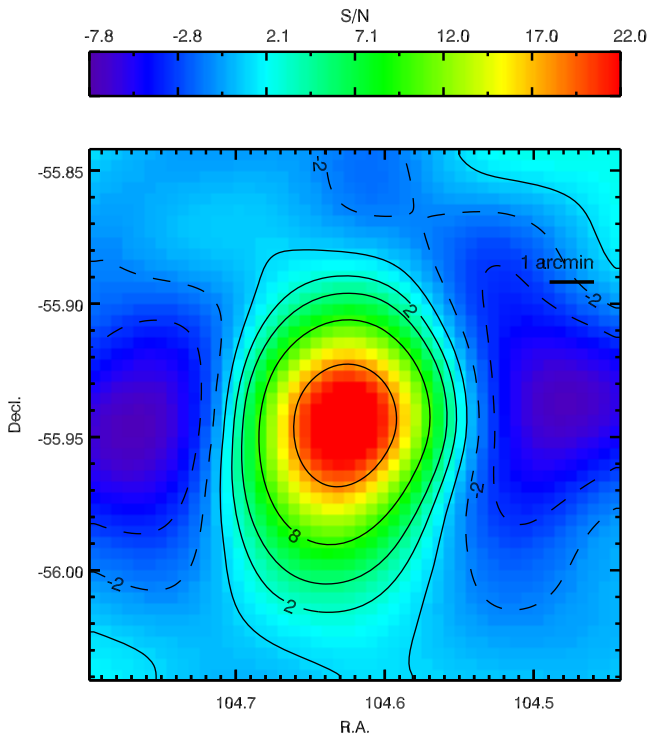
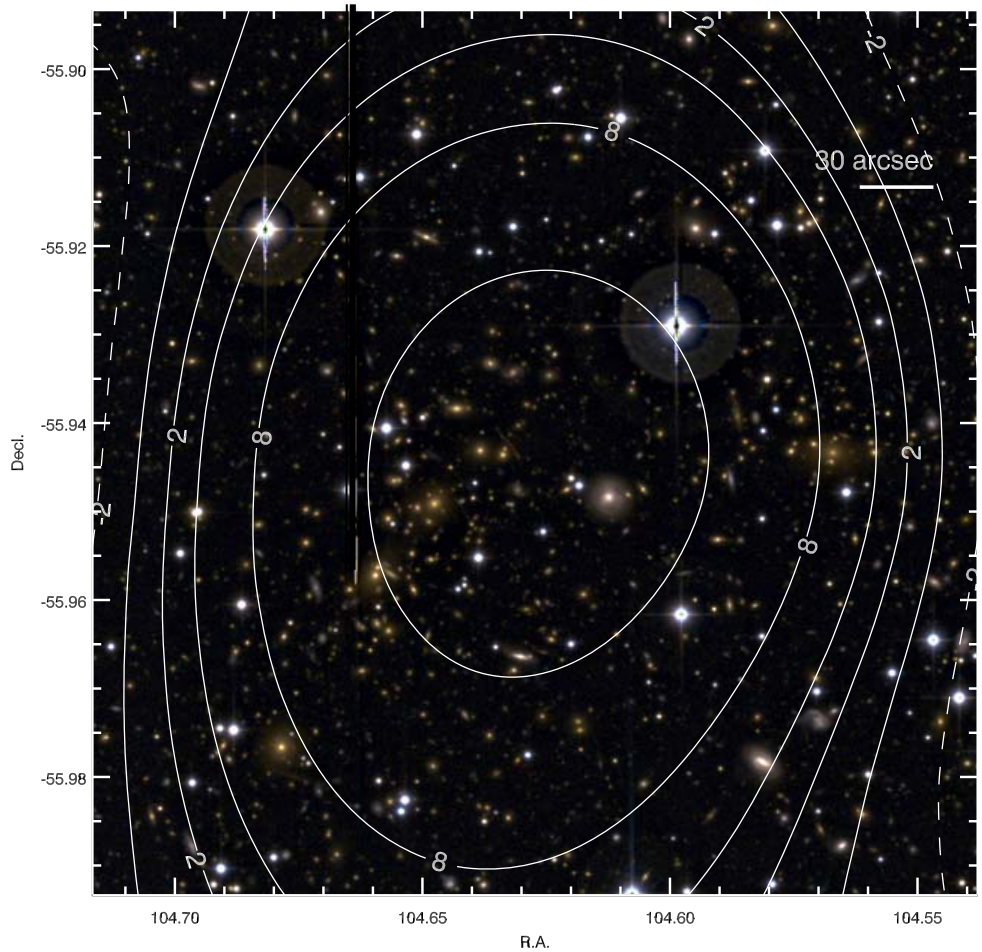
Results: 2500 deg²

SPT-CL J0658-5556
Bullet Cluster
The most massive cluster in our sample

$z = 0.296$, $M_{200} = 3.1\times10^{15}\ M_{sol}$





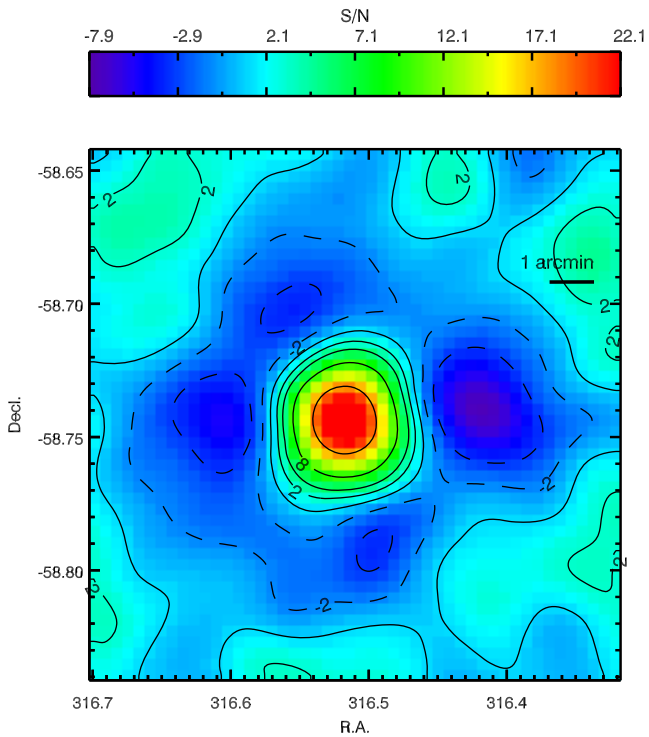
Results: 2500 deg²

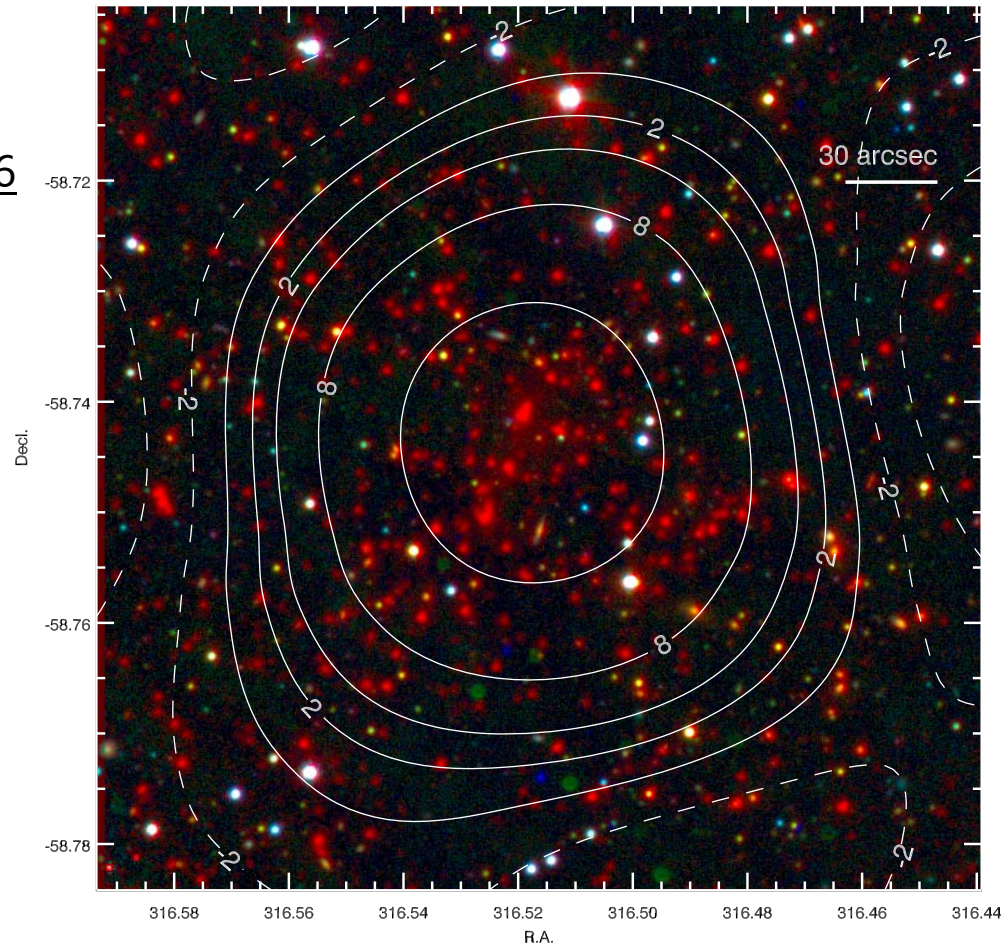
SPT-CL J2106-5844

The most massive known z > 1 galaxy cluster

Foley et al. (2011), arXiv:1101.1286

$z = 1.132$, $M_{200} = 1.3\times10^{15}\ M_{sol}$





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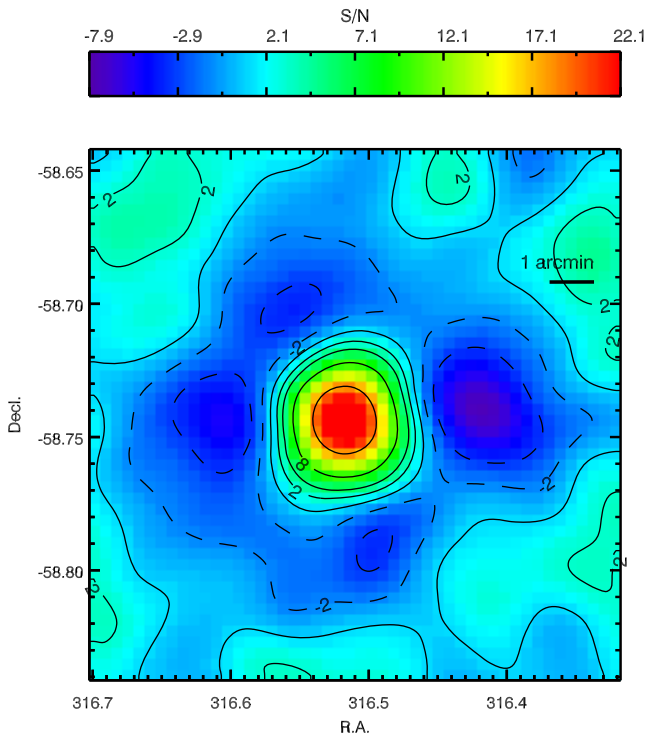

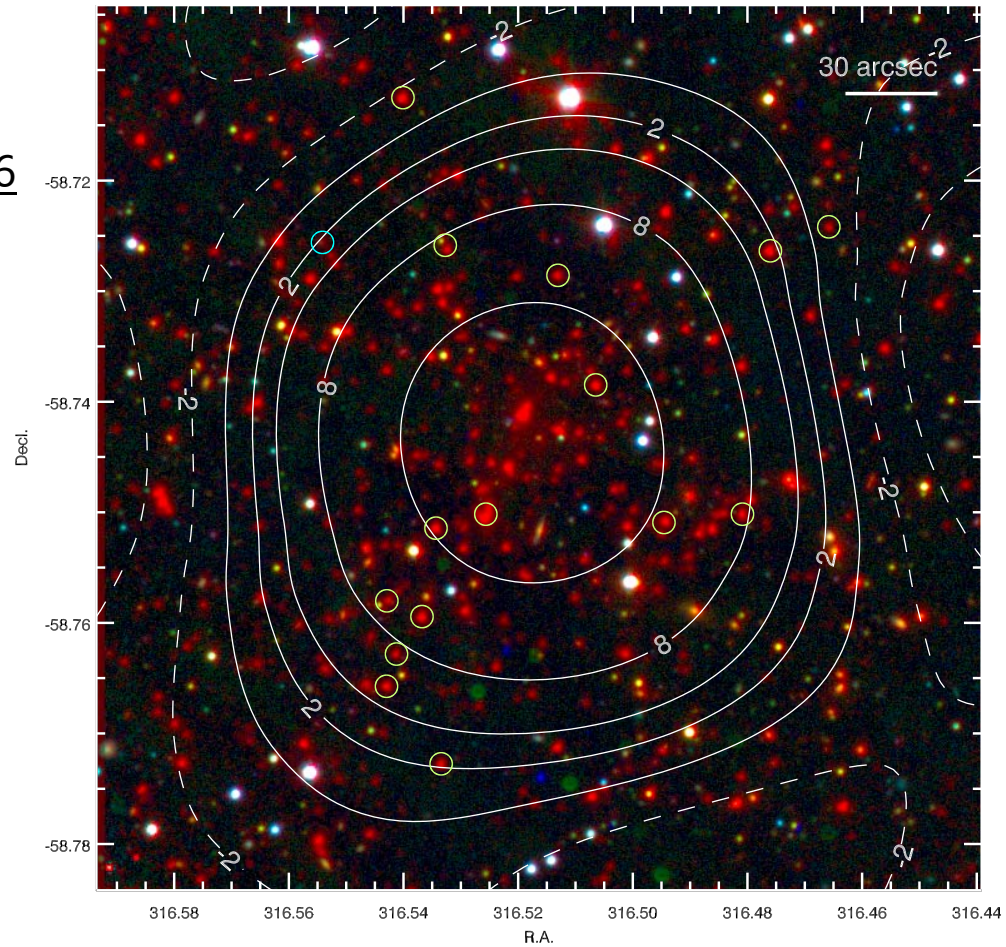

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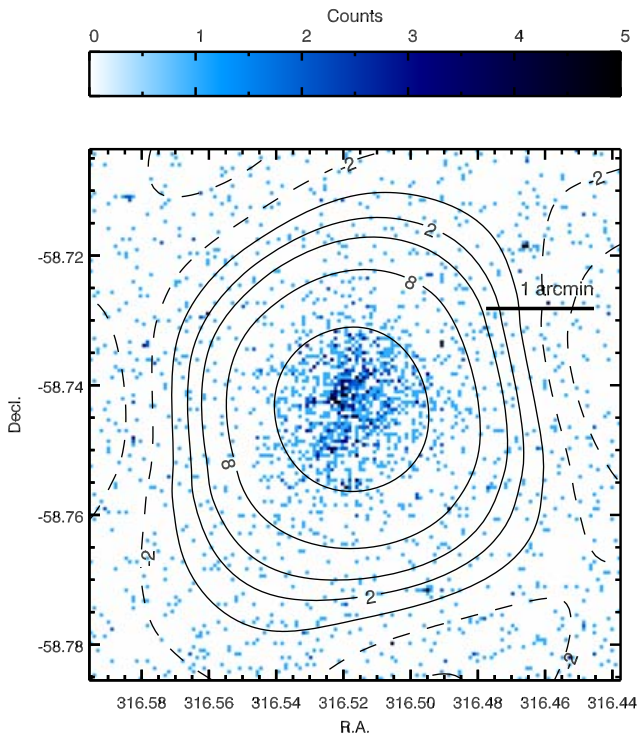

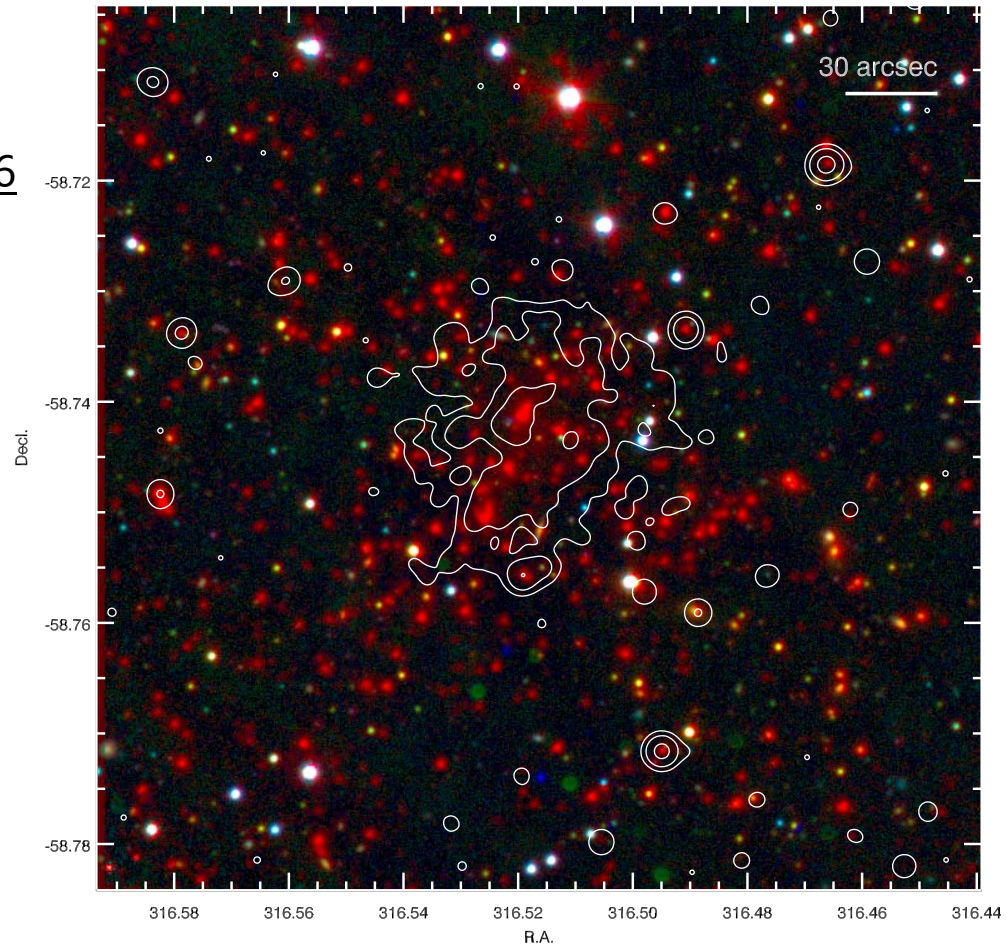

What's next?

- More SZ clusters from SPT, at all redshifts
- SZ mass-observable calibration with X-rays and weak gravitational lensing, for improvements in cosmological constraints and understanding of "gastrophysics"
  - Approved Magellan/Megacam 2011A weak lensing program for 9 clusters at $0.3 < z < 0.6$
  - Approved HST/ACS Cycle 18 weak lensing program for 7 clusters at $0.6 < z < 1$
  - Existing or scheduled X-ray observations of60 clusters
- The Dark Energy Survey: industrial scale optical studies of clusters
  - Joint SZ+optical studies down to low-mass scales
  - Stacked weak lensing
  - Lots of traditional galaxy and cluster studies, but deeper+wider

Summary

- Galaxy clusters are fascinating and useful
  - independent tests of dark energy
  - complementary to the Hubble expansion measurements
  - see Dark Energy Task Force report
- The Sunyaev-Zel'dovich effect
  - a novel way to survey clusters
  - remarkable property of ~ redshift-independent signal
  - good cluster mass observable
- The South Pole Telescope
  - a dedicated SZ experiment
  - dozens of new clusters, many at high redshift
  - clean selection
- The next 5-10 years will see a boom in galaxy cluster science: SPT, ACT, Planck, DES, …

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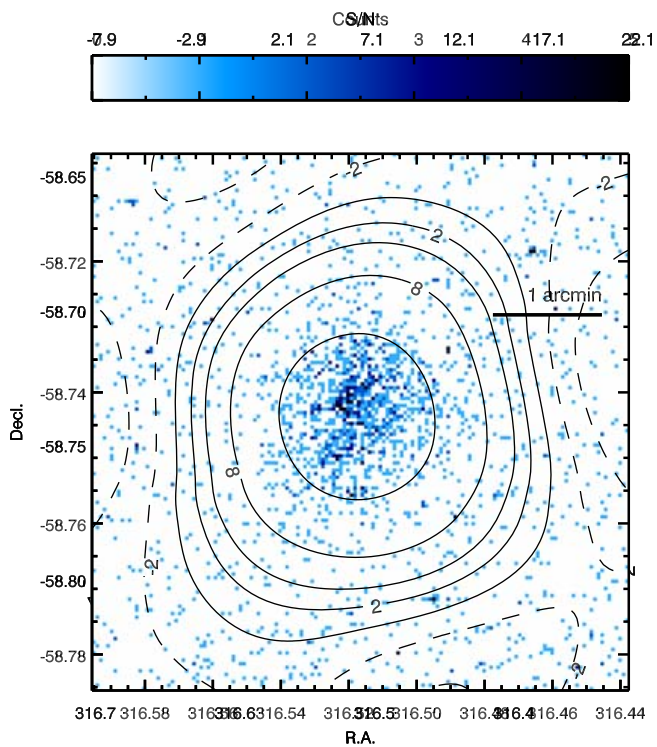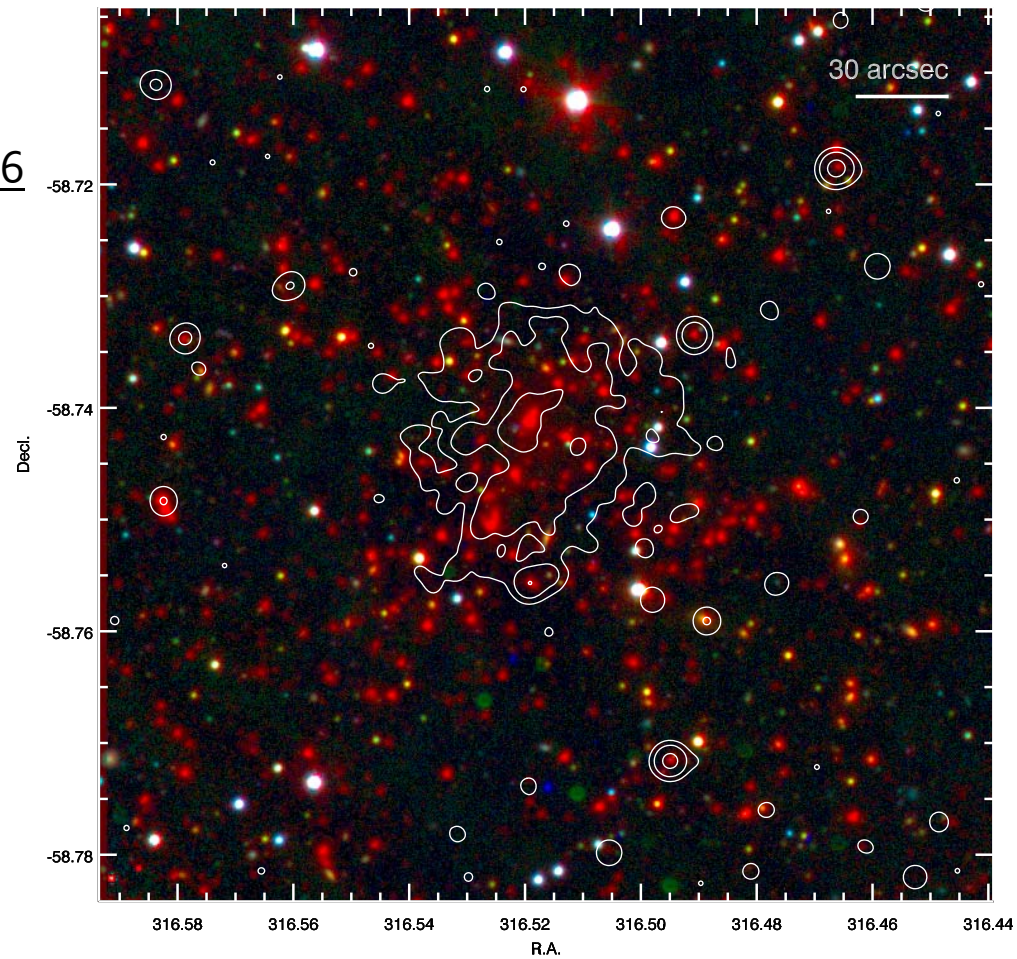
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