The 10-meter SPT and the SPT-SZ survey

Tom Crawford

University of Chicago / KICP

Photo credit: J. Dana Hrubes

Outline

I. Intro / motivation
   - Dark Energy with an SZ cluster survey

II. Science that comes for free

III. Recent results (rapid-fire)

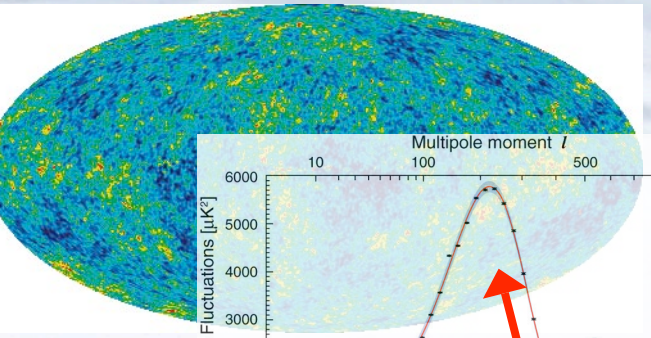
IV. What's so great about the South Pole?

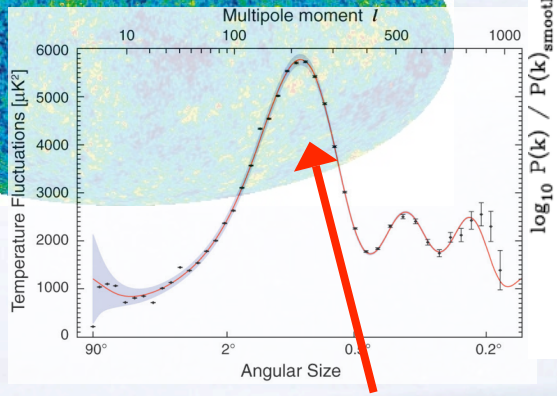
V. The Future?

Outline

I. Intro / motivation
   - Dark Energy with an SZ cluster survey

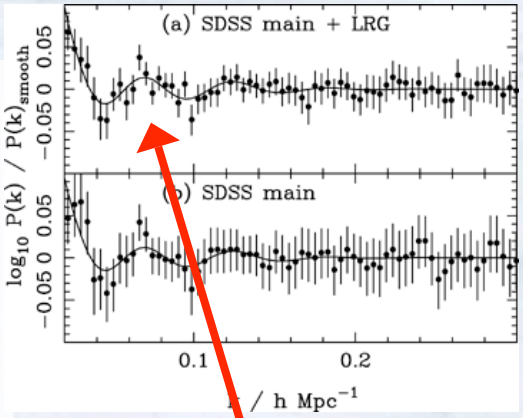
We Live in a Universe Dominated by Dark Energy



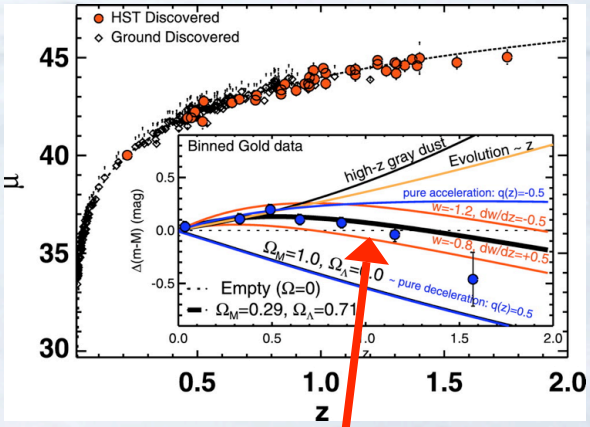


Komatsu et al 2008

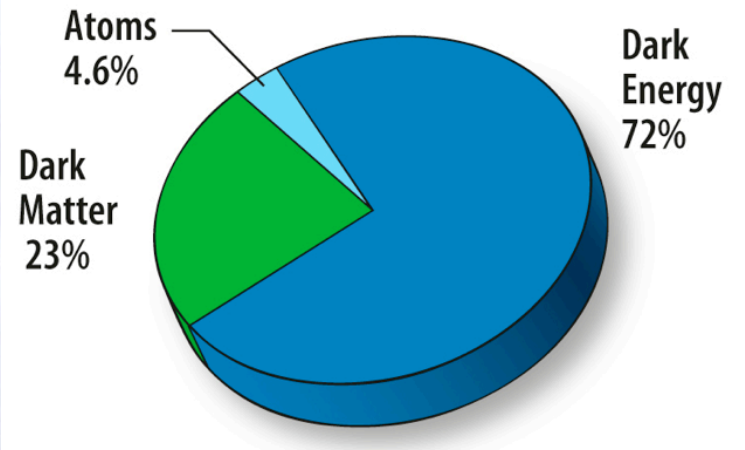
Percival et al 2007



Riess et al 2007



CMB + Large Scale Structure + SNe Ia



We live in a flat universe whose density is dominated dominated by dark energy

$$\Omega_\Lambda = 0.721 \pm 0.015$$

... but what is dark energy?

Dark Energy Constraints with Clusters of Galaxies

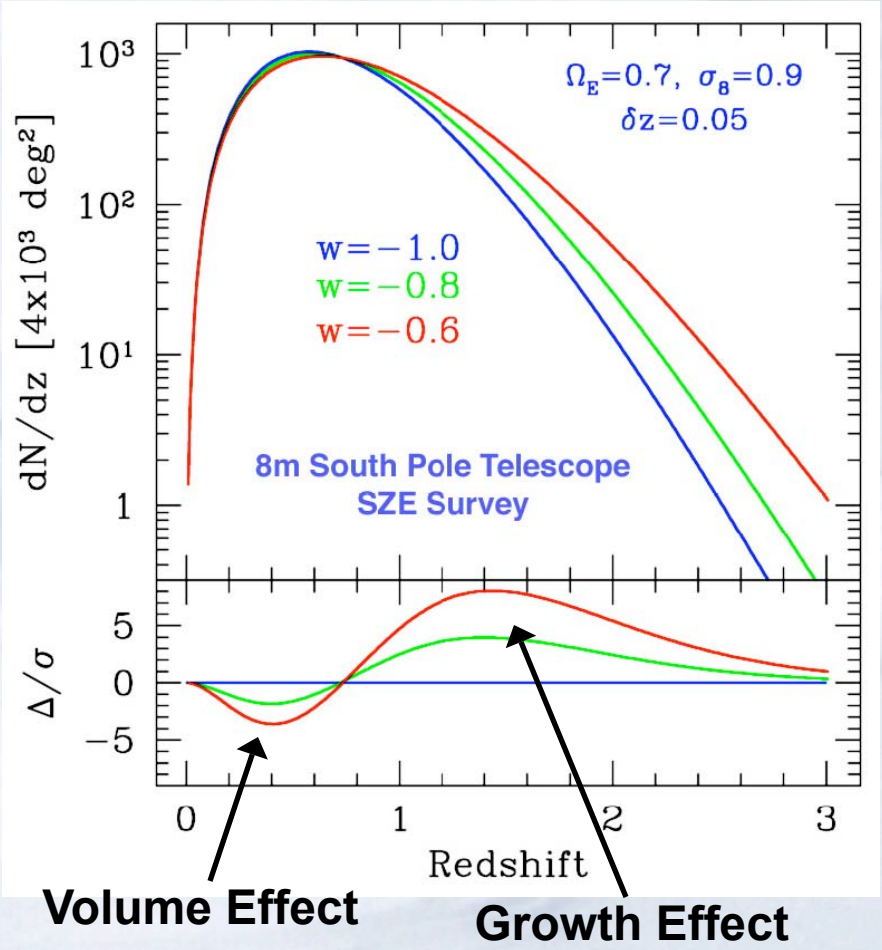
Cluster Abundance, dN/dz

$$\frac{dN}{d\Omega dz} = n(z)\frac{dV}{d\Omega dz}$$

Depends on:
Matter Power Spectrum, *P(k)*
Growth Rate of Structure, *D(z)*

Depends on:
Rate of Expansion, *H(z)*

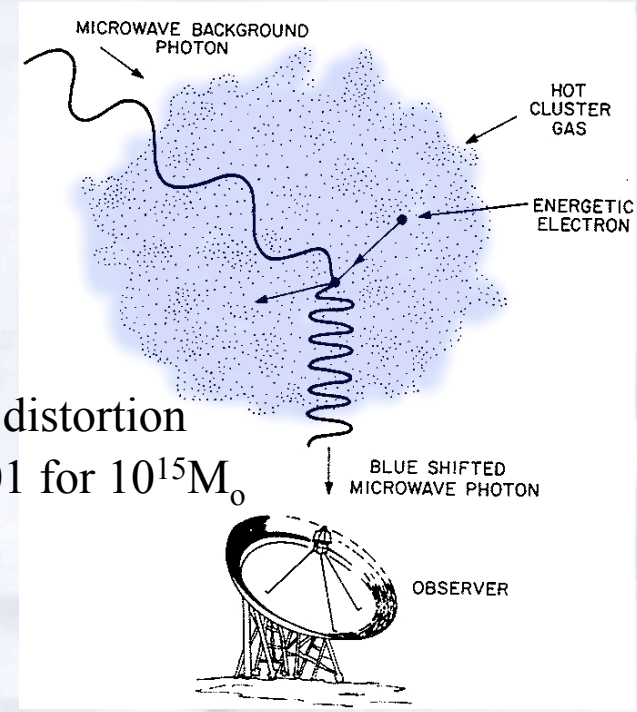
Credit: Joe Mohr



For fixed Ω_{DE} and less negative *w*:

1. Fewer clusters at low redshift, due to decreased volume surveyed
2. More clusters at high redshift, due to decreased growth rate

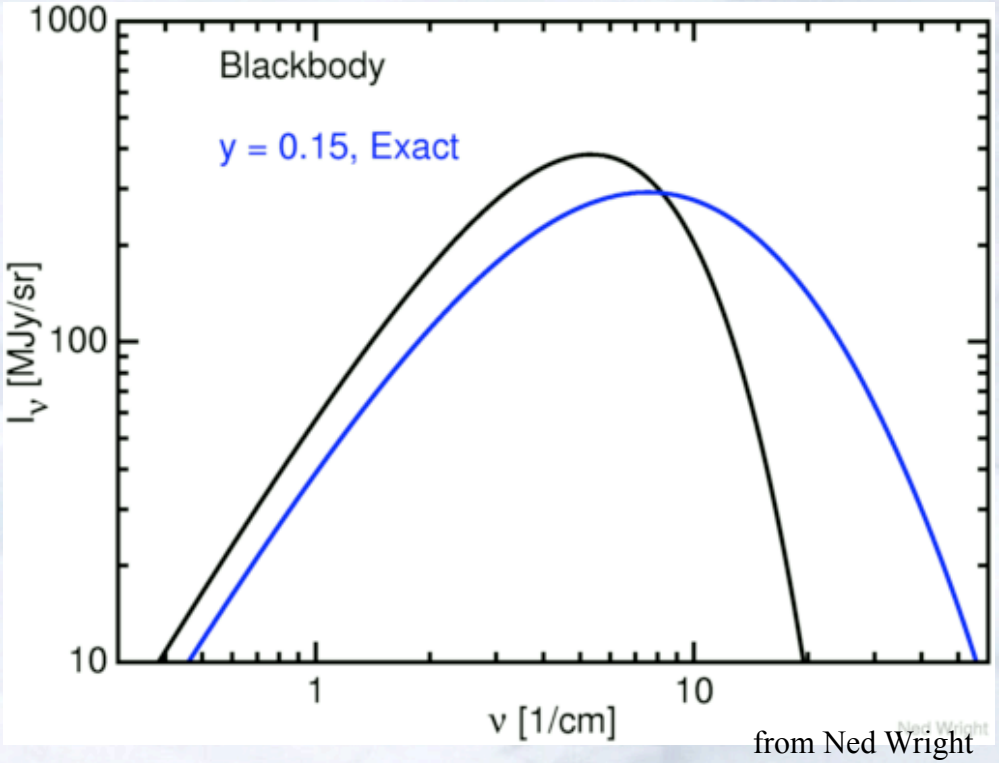
The Sunyaev-Zel'dovich Effect



Small distortion

$\tau_e \sim 0.01$ for $10^{15} M_o$

from Leon Van Speybroeck



from Ned Wright

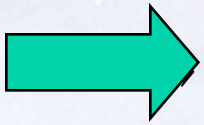
$$\textit{Redshift independent: } \frac{\Delta T_{SZE}}{T_{CMB}} \propto \int n_e T_e dl$$

T. Crawford, *The 10-m SPT*, Astrophysics from the South Pole, April 5, 2011

Requirements for an SZ cluster-finding machine

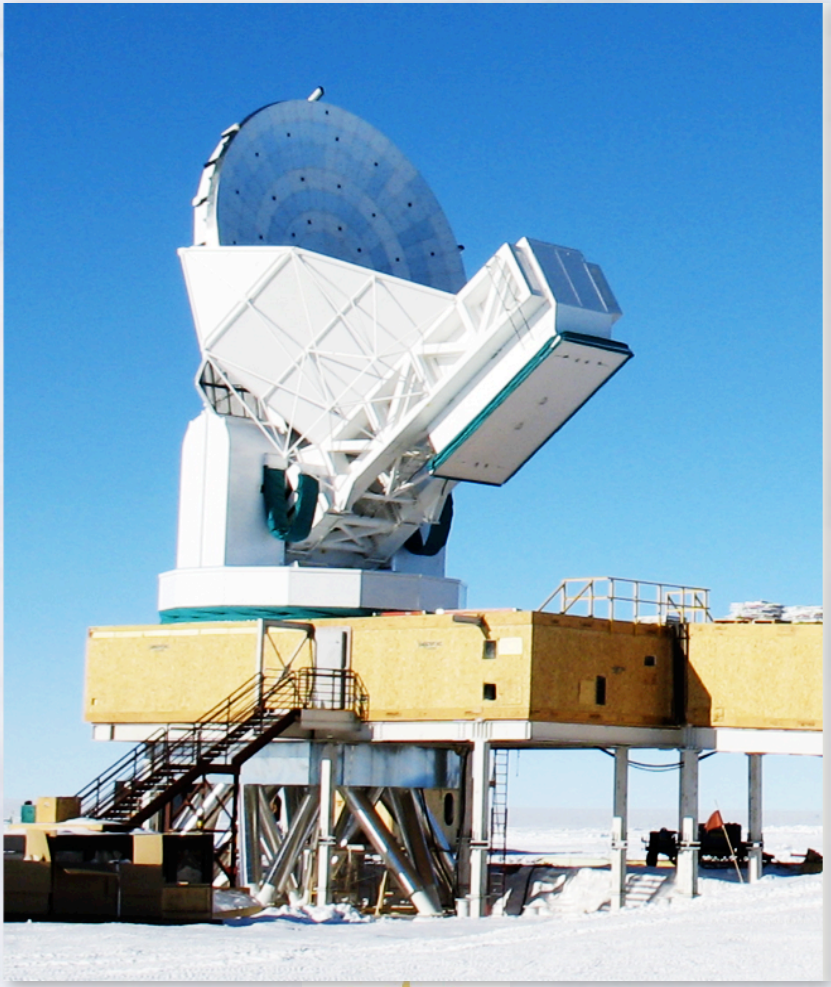
- **Resolution**
  - 1' is well-matched to typical cluster size at these redshifts
  - At 150 GHz this means you need a 8-10 meter dish

- **Mapping Speed**
  - (# of elements) / noise^2
  - At 150 GHz (from the ground), bolometers have reached photon background limit to sensitivity
  - Previous SZ/CMB instruments have on the order of tens of pixels (e.g. – ACBAR =16, QUAD = 31 pixels, ...)



Need more background-limited detectors!!!

The 10-meter South Pole Telescope (SPT)



Sub-millimeter Wavelength Telescope:

- 10 meter telescope (1' FWHM beam at 150 GHz)
- Off-axis Gregorian optics design
- 20 microns RMS surface accuracy
  - primary surface heated to prevent snow accumulation
- 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 with a modular focal plane

Fantastic site:

- more details later

Funded by NSF

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THE UNIVERSITY OF
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UCDAVIS
UNIVERSITY OF CALIFORNIA
ASTRONOMY
UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN
McGill
Harvard-Smithsonian
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CARDIFF
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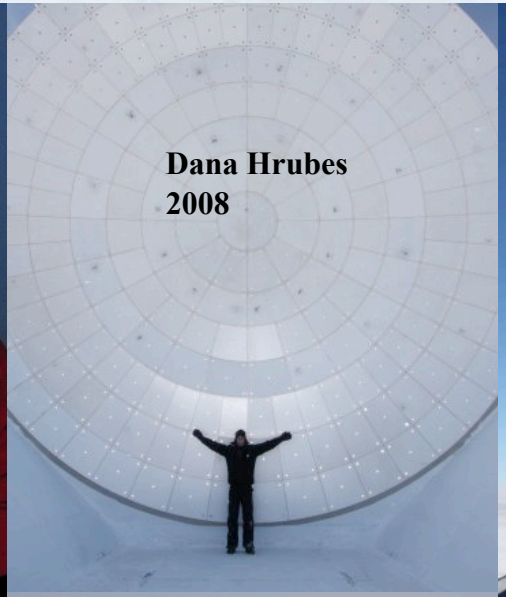
BERKELEY LAB
SPT Collaboration

SPT Heroes Gallery

Dana Hrubes and
Daniel Luong-Van
2010 AND 2011!!



Dana Hrubes
2008

Keith Vanderlinde
2008

Steve Padin
2007

Zak Staniszewski
2007

Ross Williamson and
Erik Shirokoff
2009

Outline

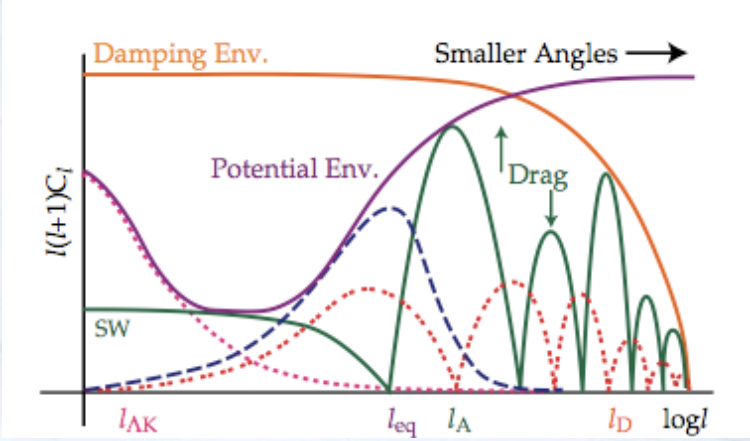
II. Science that comes for free

Outline

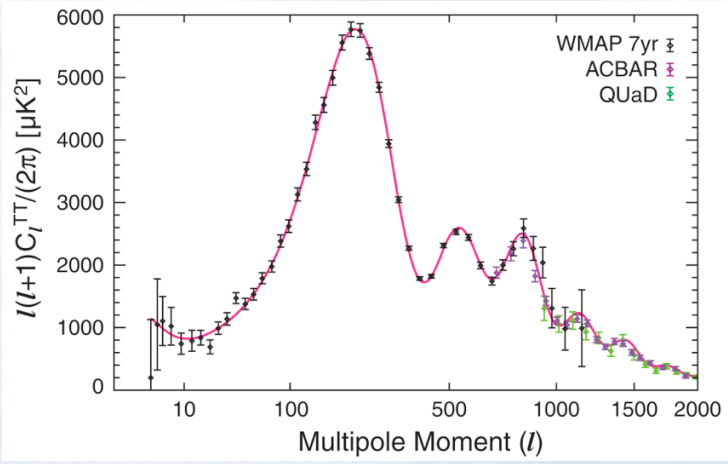
II. Science that comes for free
- small-scale CMB temperature anisotropy

1-minute CMB Anisotropies

- Largest scales: super-horizon potential fluctuations on the surface of last scattering.
- Intermediate (~1°) scales: potential fluctuations seed oscillations in tightly coupled matter-radiation fluid.
- Sub-degree scales: coupling not perfect; non-zero photon diffusion damps smaller fluctuations.
- Even smaller scales: secondary effects due to interactions with intervening matter.



Hu, Sugiyama & Silk (1996)



WMAP Science Team

1-minute CMB Anisotropies

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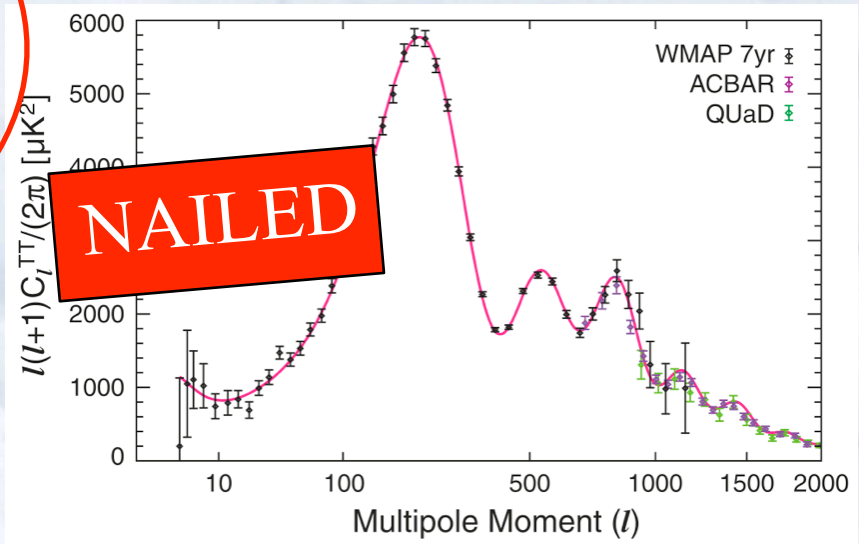

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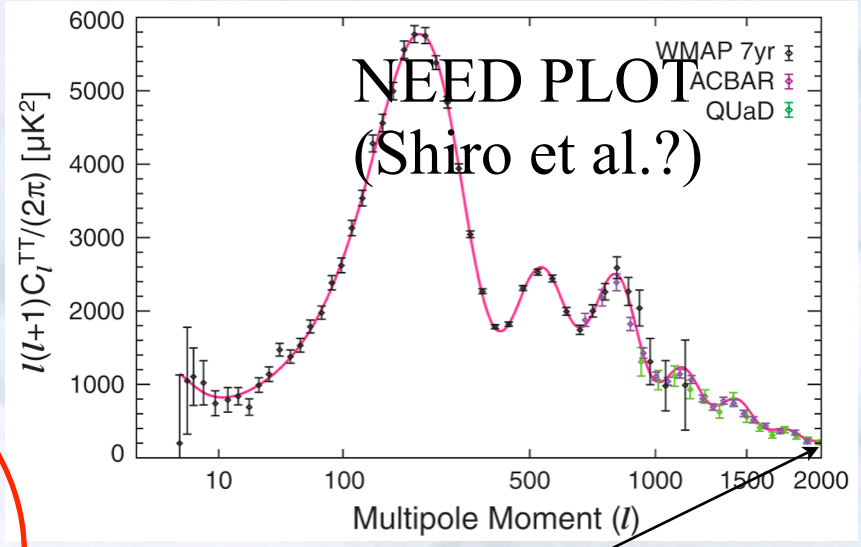


OPEN FOR BUSINESS

Science from small-scale CMB anisotropy

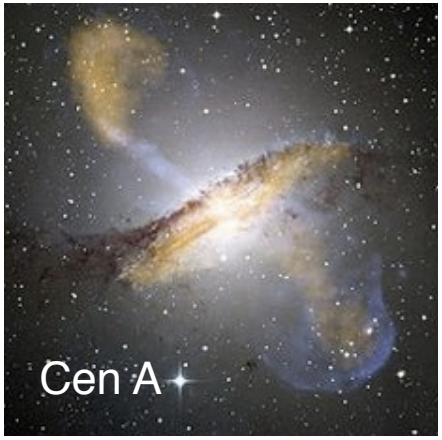
1. Science from the damping tail:
   - break parameter degeneracies
     - e.g., better constraints on n_s
   - damping length as standard ruler

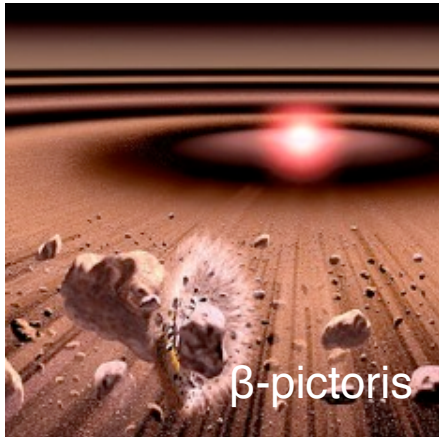
2. Science from secondaries:
   - independent measure of matter power spectrum amplitude from thermal SZ
   - reionization constraints from kinetic SZ
   - reconstruct gravitational potential from lensing

Outline

II. Science that comes for free
    - emissive sources

mm-wave sources of emission





Radio sources
Synchrotron dominated
Flux decreases with frequency

α~-1

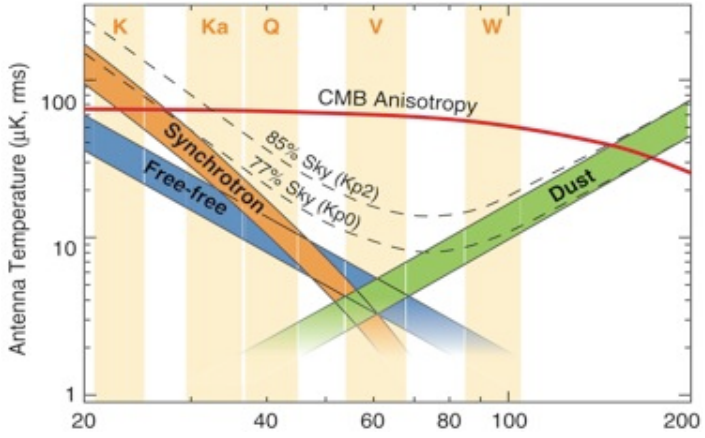
Dusty Star Forming Galaxies
Dust dominated (thermal)
Flux increases with frequency
High SFR and extinction

α~3

Galactic things
Dust emission
Debris disks
Cold galactic blobs

α~3

$$S_\nu \propto \nu^\alpha$$

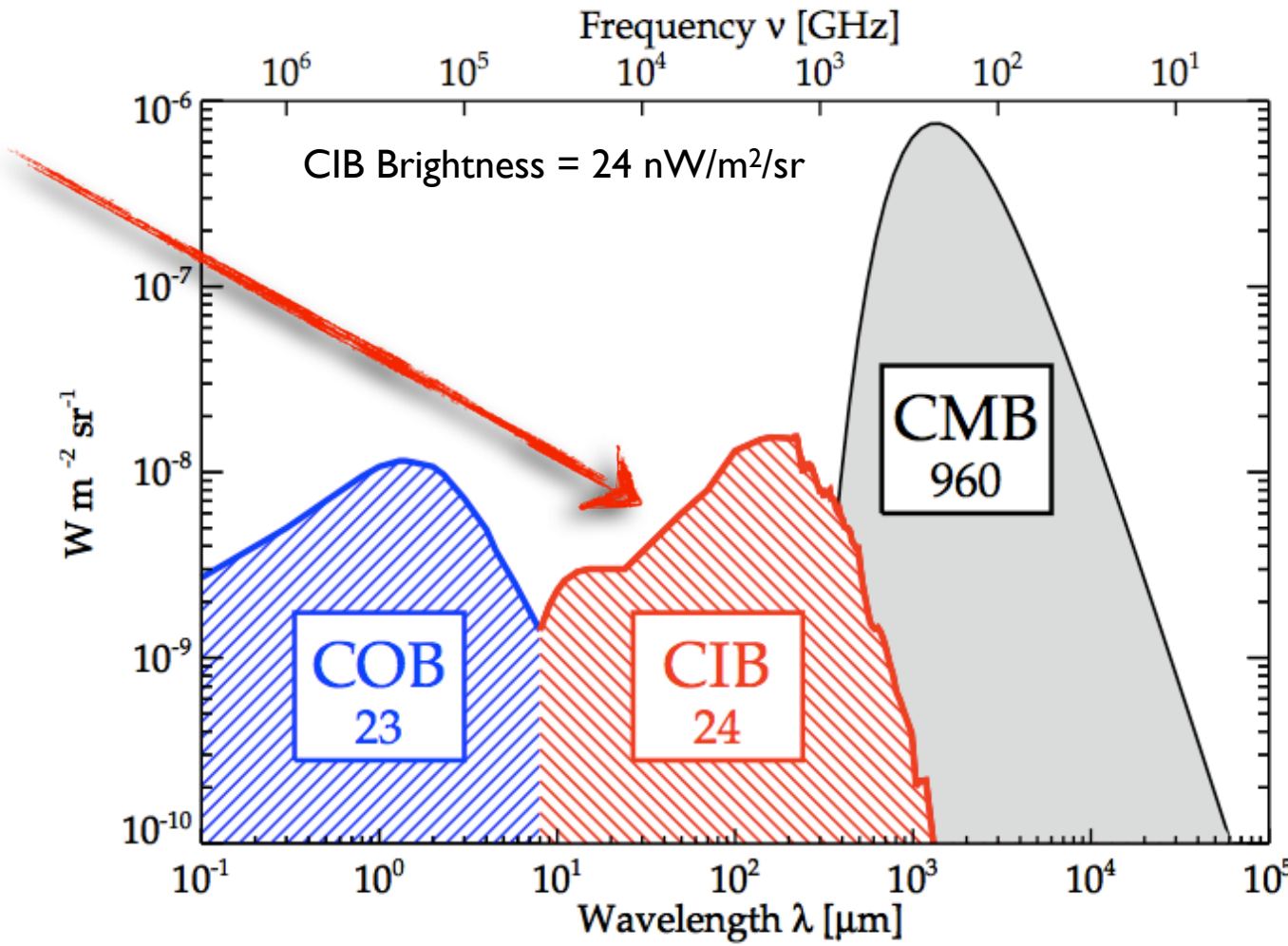


Bennet *et al.* 2003

Dusty sources are cosmologically important

Over half of the energy produced since the surface of last scattering has been absorbed and re-emitted by dust.

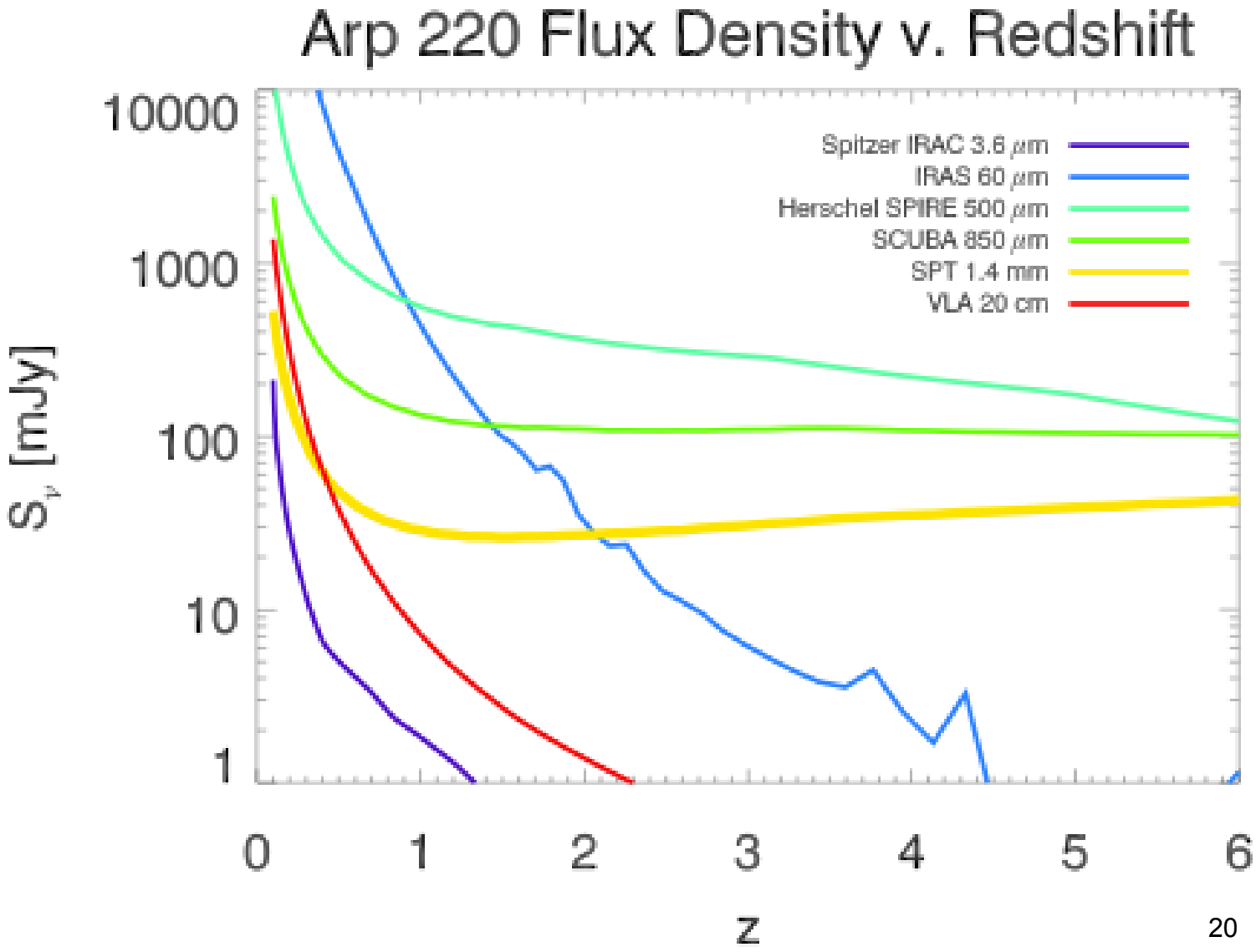
This background of dusty galaxies makes up the Cosmic Infrared Background (CIB)



Dole *et al.* 2006

Sub-mm magic

First pointed out in Blain & Longair 1993



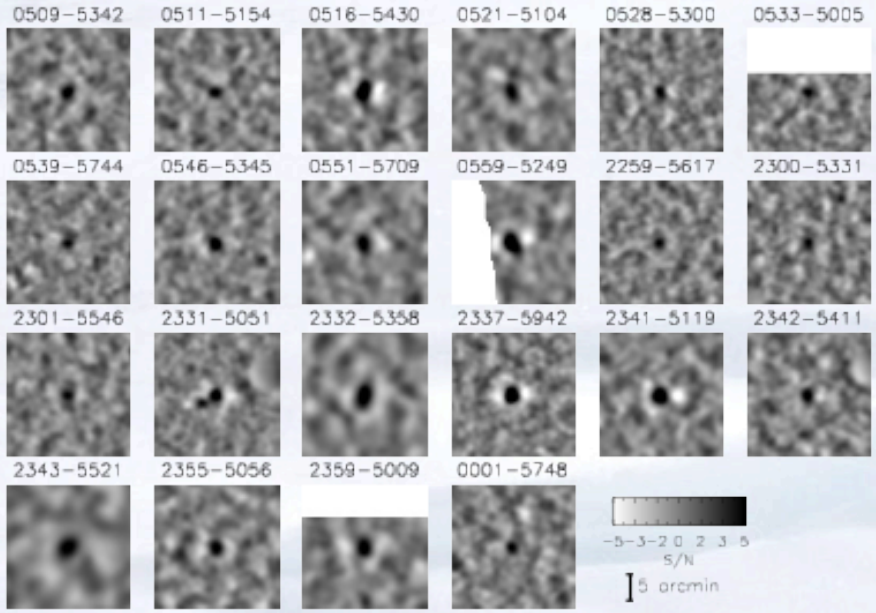
Outline

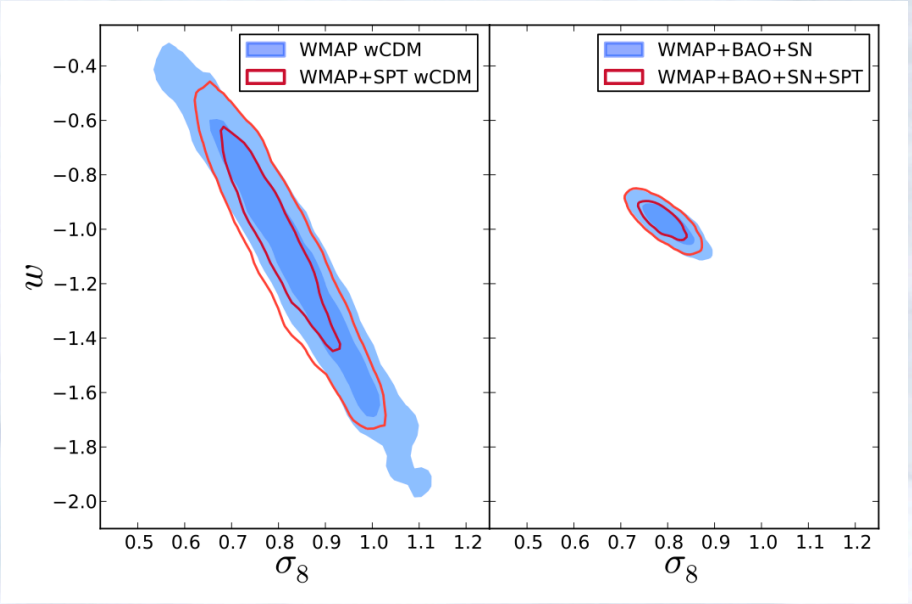
III. Recent results (rapid-fire)

Selection of published/submitted results

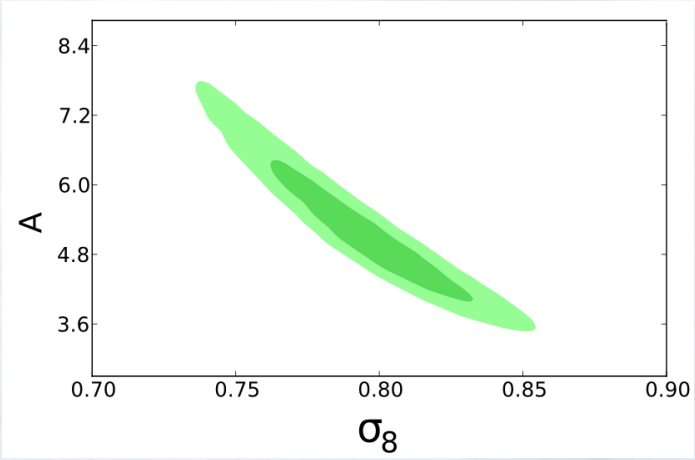
- First clusters discovered via their SZ signature
  Staniszewski+2009 ApJ 701, 32
- Cluster spatial profiles measured to the virial radius
  Plagge+2010 ApJ 716, 1118
- First detection of secondary CMB anisotropy
  Lueker+2010 ApJ 719, 1045
- First mm-wave detection of CIB anisotropy
  Hall+2010 ApJ 718, 632
- Discovery of high-redshift, strongly lensed dusty galaxies
  Vieira+2010 ApJ 719, 763
- First cosmological constraints from an SZ cluster survey
  Vanderlinde+2009 ApJ 722, 1180
- Discovery of the two most massive $z>1$ clusters
  Foley+2011 ApJ 731, 96; Brodwin+2010 ApJ 721, 90
- Testing ΛCDM with massive, high-redshift clusters
  Williamson+2011, ApJ submitted; Foley+2011 ApJ 731, 96

First cosmological results with SZ clusters: Vanderlinde et al., 2010

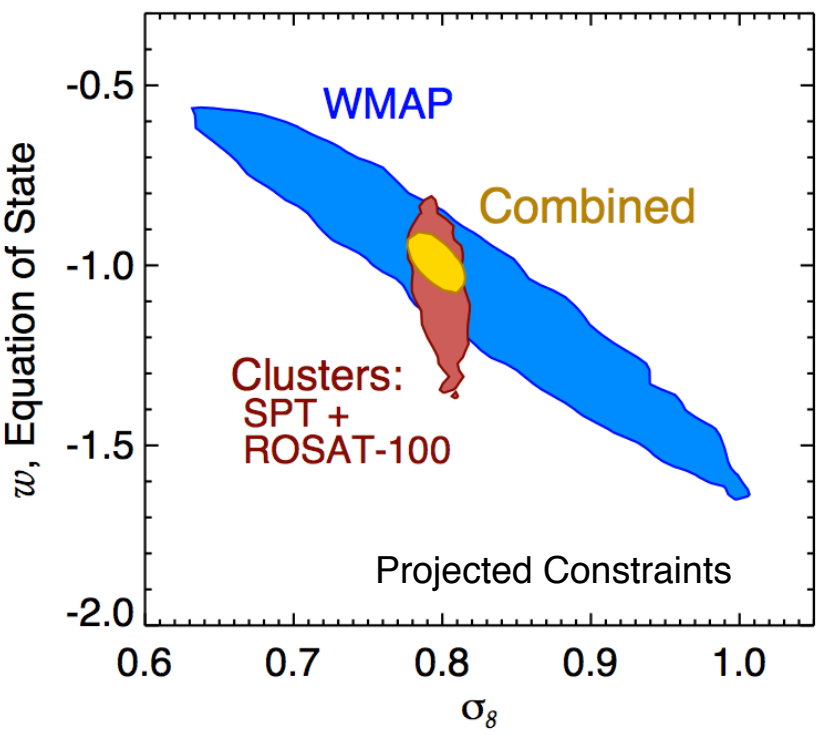


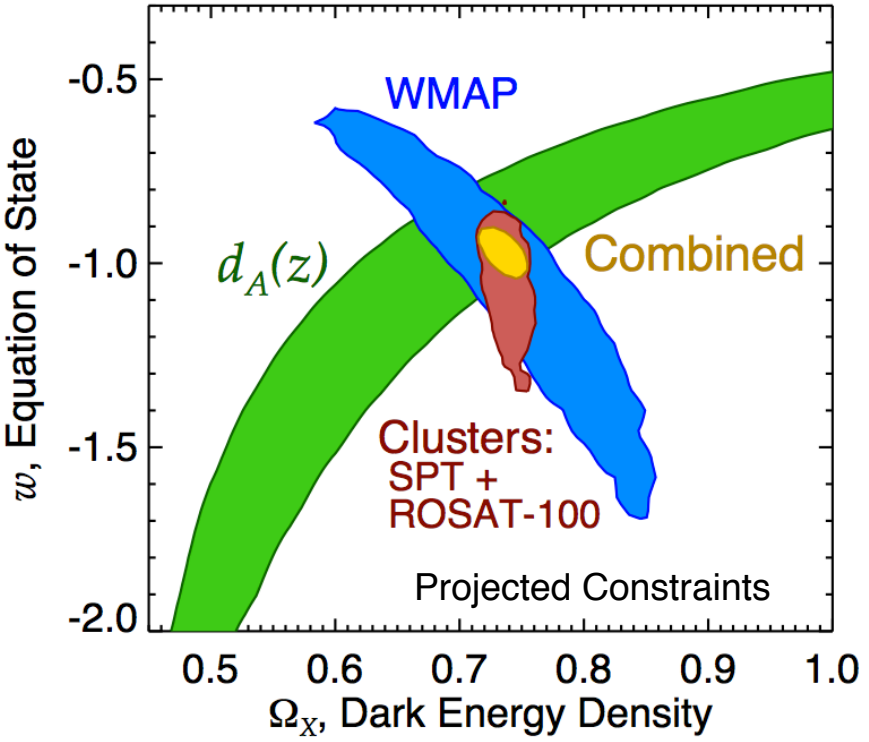


- 21 clusters
- slightly improve on WMAP-only
- constraints limited by scaling relation uncertainties



Projected Constraints from SPT Clusters





SPT 2500 deg^2 survey will detect ~440 clusters at $S/N > 5$. With mass calibration uncertainty of 5% mean and 10% evolution (z=0.0-to-1.0), will constrain σ_8 to +/-1.2% and w to +/-4.6%

- independent of geometric cosmological constraints (SN, BAO)
- 3.3% systematic uncertainty in w from mass calibration

DiscoveryNews ... hopes 360 undecillion is enough.

EARTH | SPACE | TECH | ANIMALS | DINOSAURS | ARCHAEOLOGY | HISTORY | HUMAN

Discovery News > Space News > Biggest Galaxy Gang From Young Universe Seen

BIGGEST GALAXY GANG FROM YOUNG UNIVERSE SEEN

The massive cluster is located 7 billion light-years from Earth and weighs as much as 800 trillion suns.

By Irene Klotz
Fri Oct 15, 2010 11:53 AM ET
1 Comments | Leave a Comment

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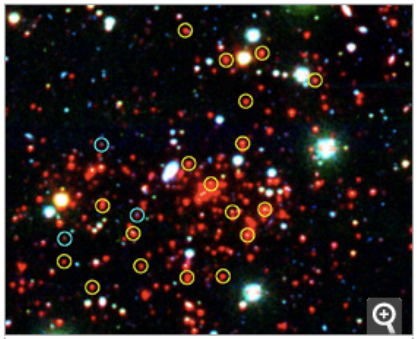

A massive galaxy cluster located 7 billion

THE GIST

- Astronomers find the biggest galaxy cluster from wh universe was half its present age.
- Three new observatories are mining the microwave background radiation from the Big Bang to pinpoint clusters.
- The new technique should provide evidence to supp refute current theories of how the universe evolved.

Astronomers on the hunt for the biggest, most distan gangs of galaxies have landed a prize catch, a behe of a cluster 800 trillion times more massive than the ferreted out by a new cosmic fishing net from when t universe was half its present age.

ASTROLOGERS' COMMUNITY

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Astrologers' Community > General Astrology > Other Astrology > Fixed stars, asteroids and other cosmic objects
SPT-CL J0546-5345 Galaxy cluster

Fixed stars, asteroids and other cosmic objects For astrology talks on fixed stars, Chiron, Sedna, Eris or an newly discovered or little known cosmic object.

POST REPLY

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03-25-2011, 12:23 AM

Bjorkstrand
Member

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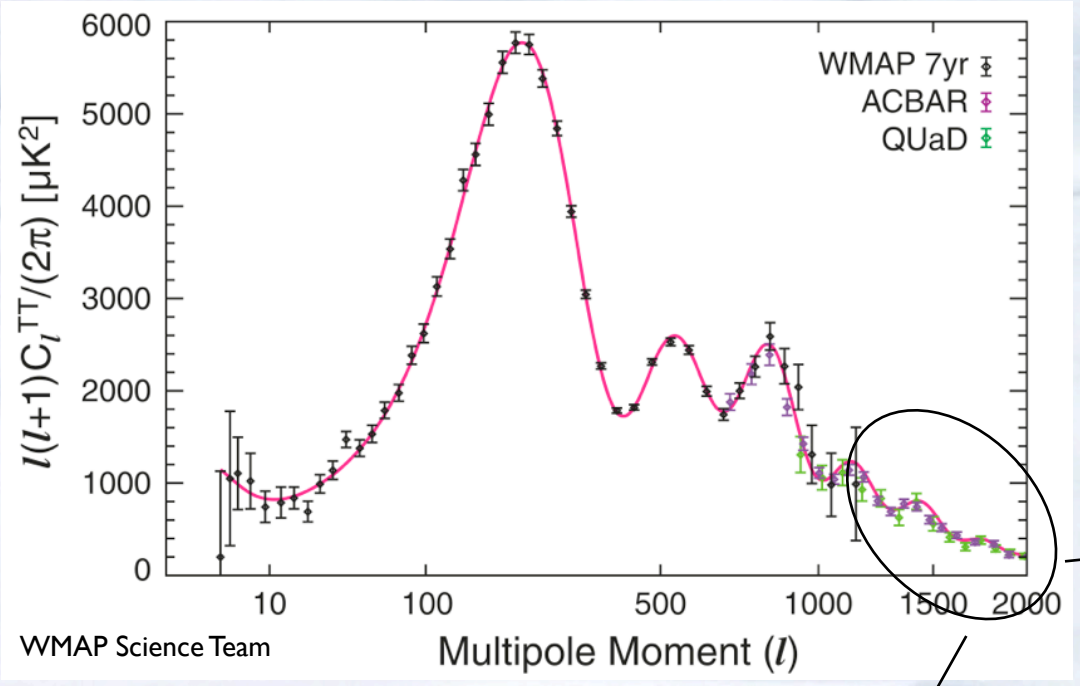
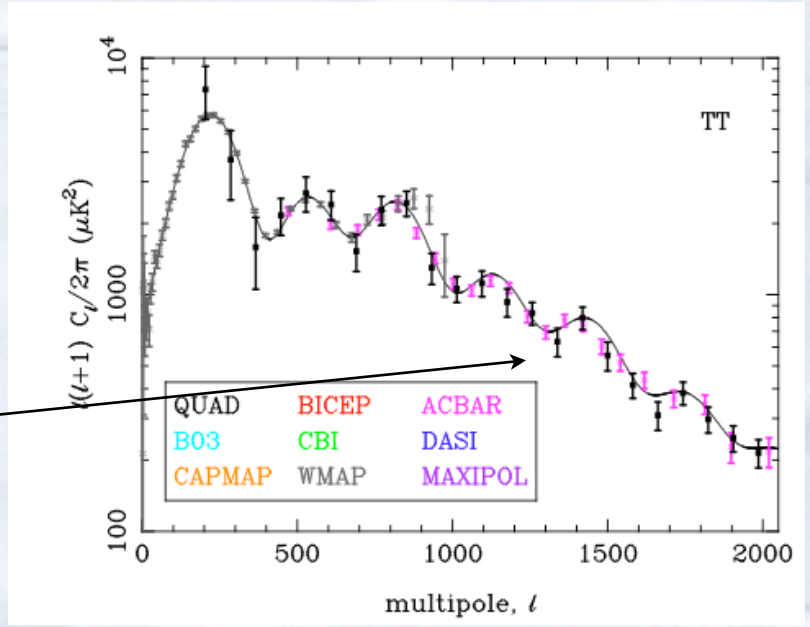
SPT-CL J0546-5345 Galaxy cluster

t is the most massive galaxy cluster ever.
May have something to do with facebook and cultures.
Jim


WMAP 7yr
ACBAR
QUaD
$l(l+1)C_l^{TT}/(2\pi)$ [μK²]
Multipole Moment (l)
WMAP Science Team


TT
QUAD
BICEP
ACBAR
B03
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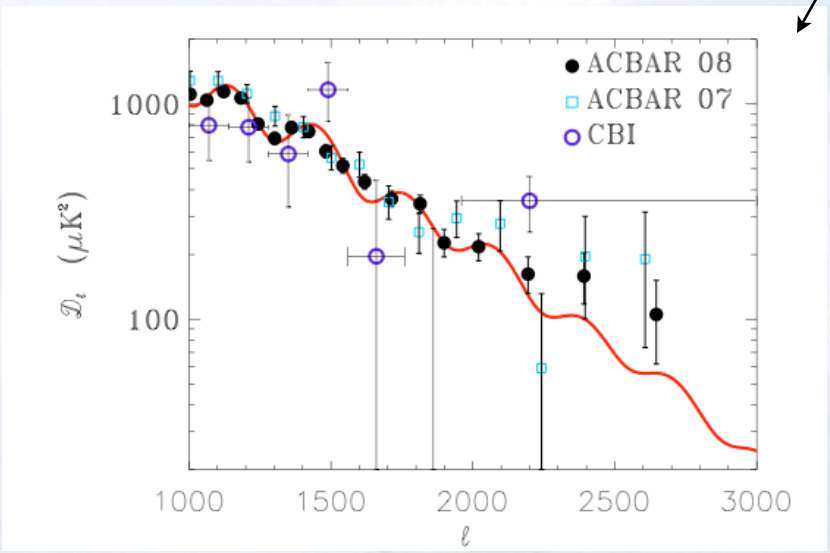
$l(l+1)\ C_l/2\pi\ (\mu K^2)$
multipole, l


ACBAR 08
ACBAR 07
CBI
$\mathcal{D}_l$ (μK²)
ℓ

- ~800 square degrees of 2008-2009 150 GHz data.
- cosmic-variance-limited to ℓ~2300.

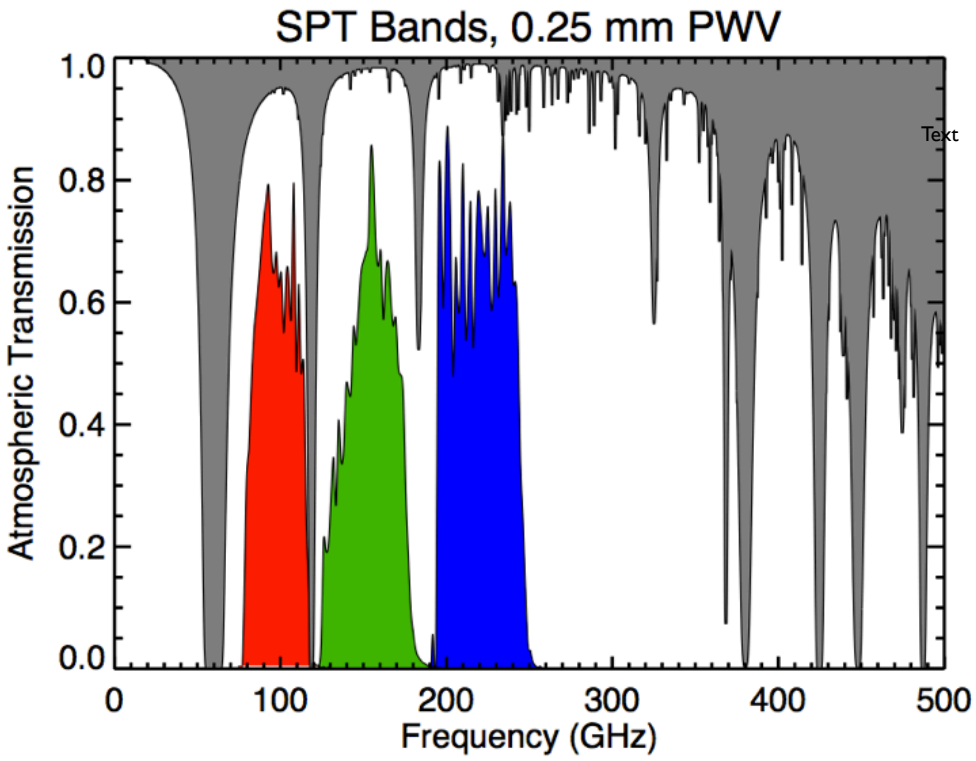
Keisler, et al. (2011, in prep.)

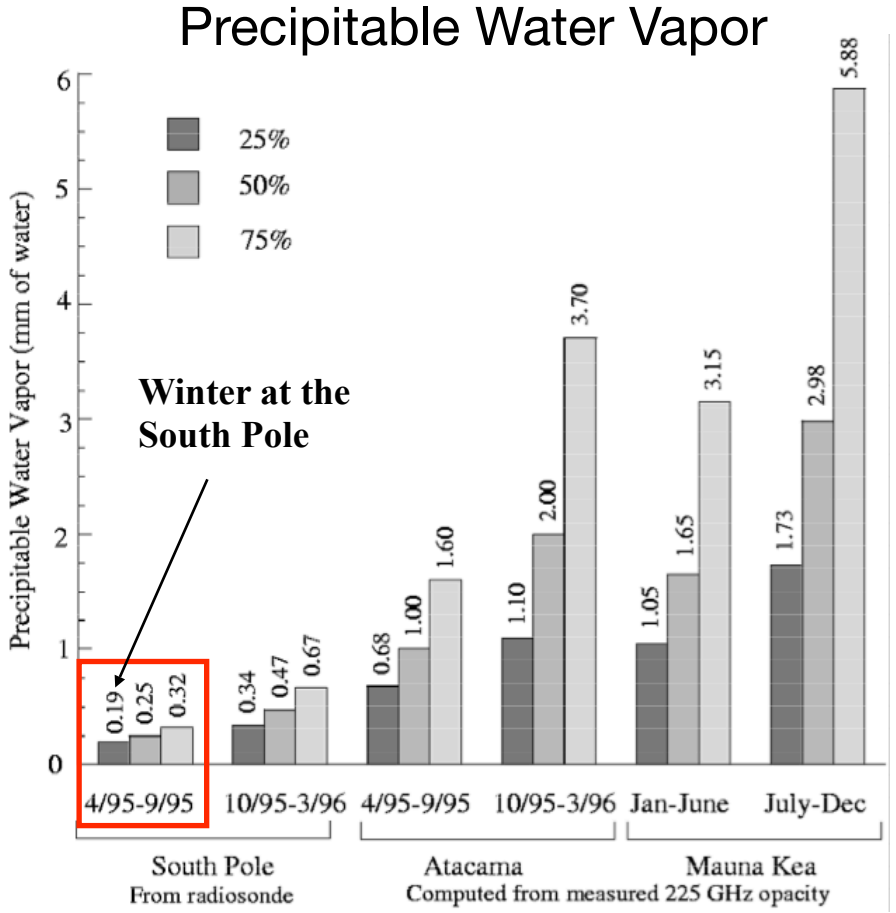
Outline

IV. What's so great about the South Pole?

What's so great #1: Atmosphere

- High Elevation: Median opacity at 225 GHz of ~0.06
- Dry, Stable Atmosphere: Extremely low water vapor (which causes ~degree scale atmospheric fluctuations)





Mapmaking from the South Pole

- Elevation=Declination
- Advantage: Sources/ Fields stay at constant elevation.
- Disadvantage: Azimuth-only scans cannot produce cross-linked maps.

http://www.yorku.ca/phall/N1740F04/L05/gtr2_poles.jpg

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Mapmaking from the South Pole

- Elevation=Declination
- Advantage: Sources/ Fields stay at constant elevation.
- Actually, no disadvantages.
- RELENTLESS OBSERVING

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http://www.yorku.ca/phall/N1740F04/L05/gtr2_poles.jpg

What's so great #3: Support

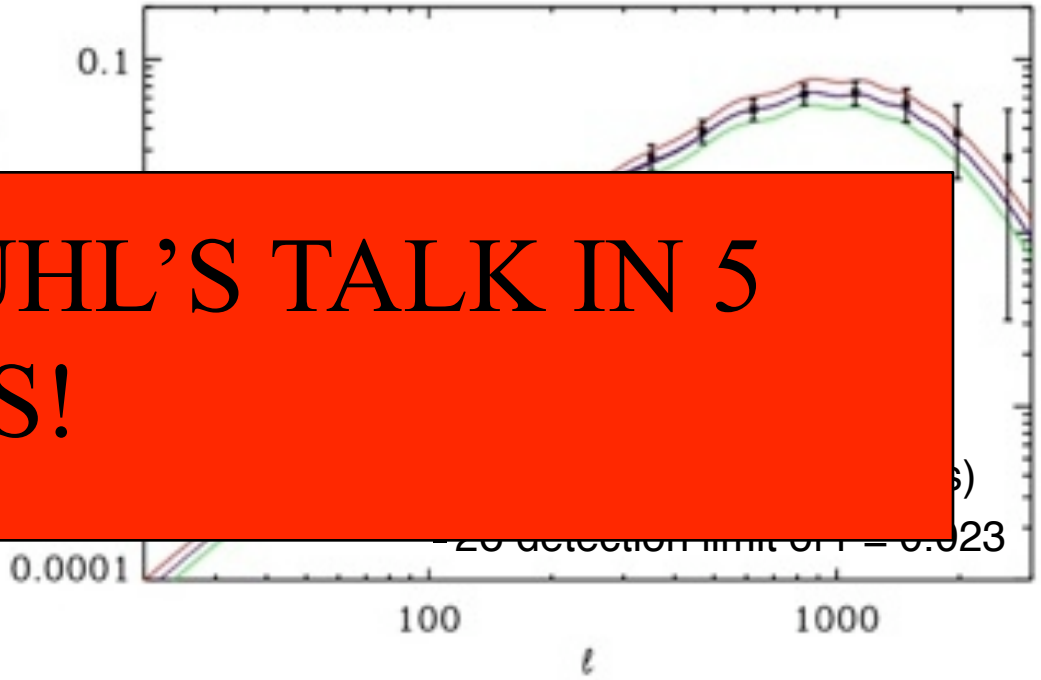
Outline

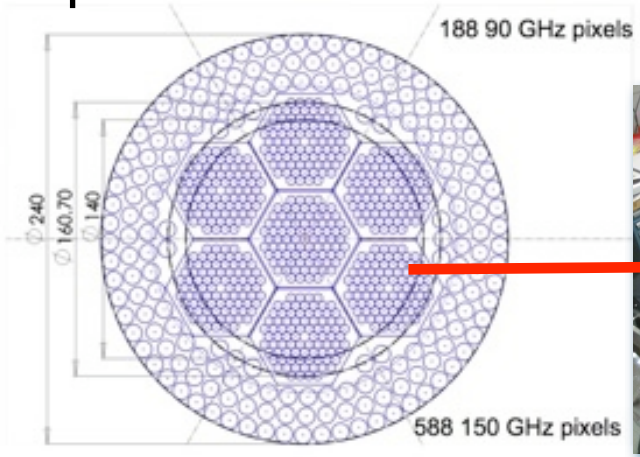
V. The Future?

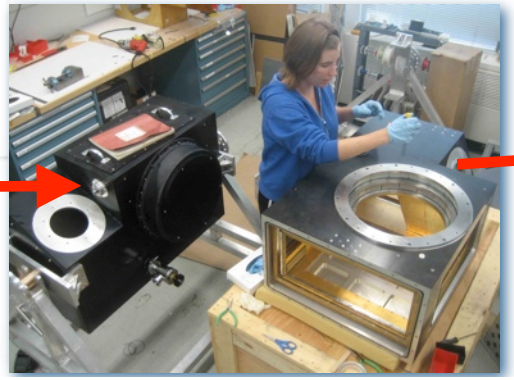
SPTpol: Polarization of the CMB

- Building a 760 pixel polarimeter for the SPT
- 90 GHz detectors fabricated
- 150 GH fabricated
- SPTpol built, integ
- Three times the mapping speed of SPT receiver

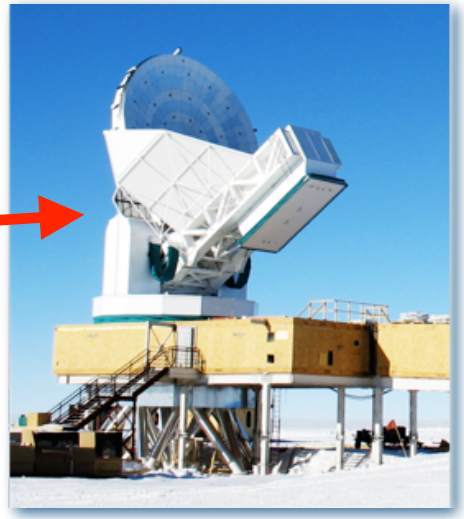
JOHN RUHL'S TALK IN 5 MINUTES!







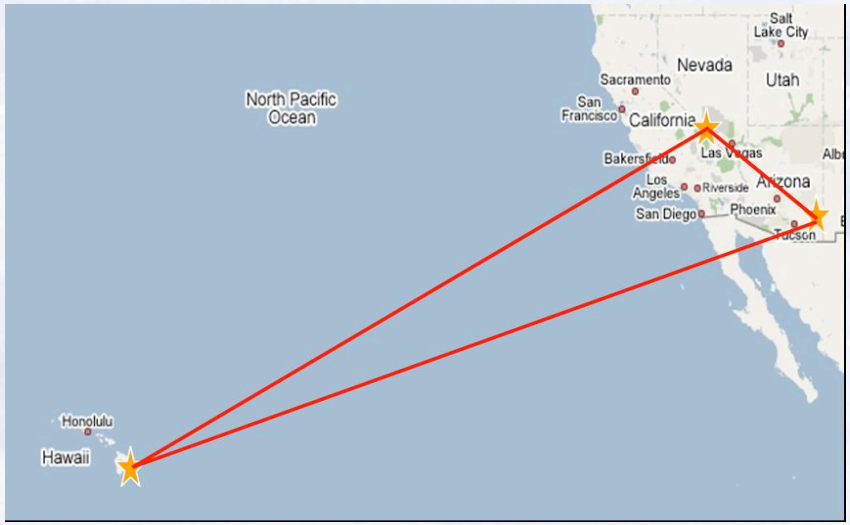
Abby Crites (U. Chicago)

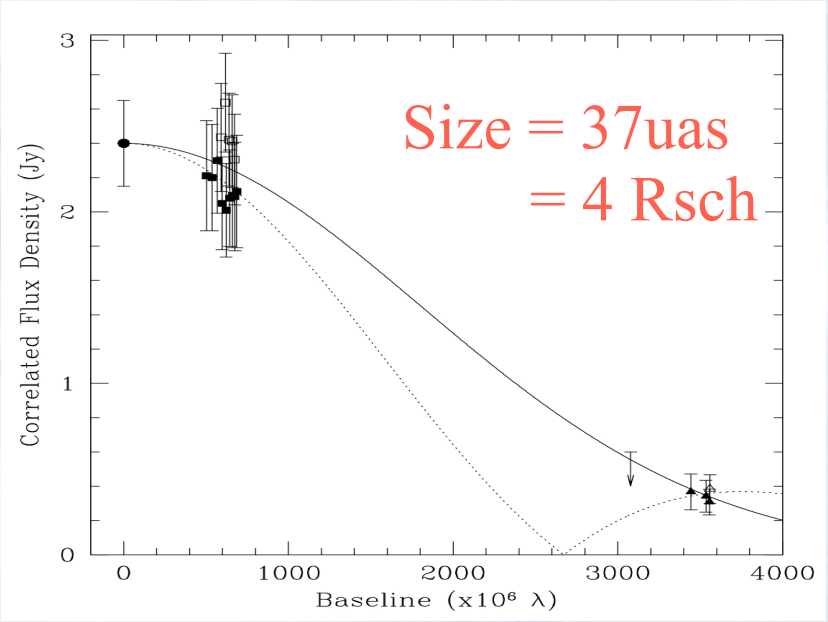


The Future: a fun summertime project

The Event Horizon Telescope

- A mm/submm VLBI array to explore the boundary of a black hole: impact on GR, AGN, BH physics.
- SgrA*, 4 million solar mass black hole at the GC, presents the largest event horizon of any BH

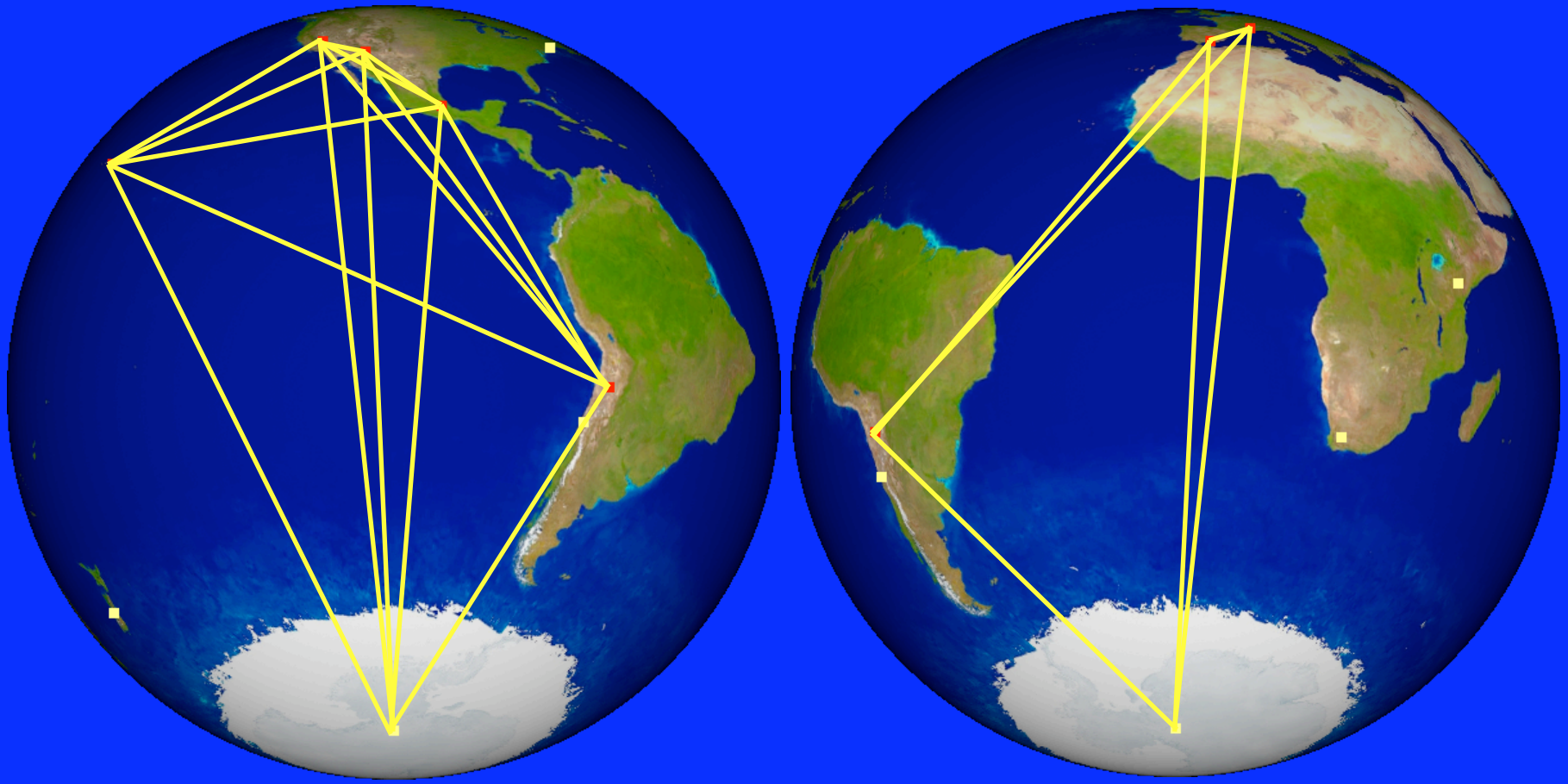




With 3 elements, EHT observations have revealed Schwarzschild radius scale structure in SgrA*.

T. Crawford, *The 10-m SPT*, Astrophysics from the South Pole, April 5, 2011

New (sub)mm VLBI Sites



Current: ARO/SMT + CARMA + Hawaii
Phase 1: 7 Telescopes (+ IRAM, PdB, LMT, Chile/ALMA)
Phase 2: 8 Telescope (SPole): critical due to long baselines and mutual visibility with *all* other sites.

The Future: 5-10 years out...

- submm-quality telescope + best mm/ submm site on Earth
  - filled focal planes
  - multichroic pixels
- multiple potential science goals
  - SZ clusters to lower mass, high-z galaxies, measure kinetic SZ, ...
- new infrastructure requirements?
  - increased data xfer bandwidth
  - ?

The Future: ?? years out...

The Future: ?? years out...

- 40m-class mm/submm telescope
  - 10m will be confusion-limited at submm
  - resolve cluster structure
  - Dome A?
  - $200M-class project

Thanks!

Photo credit: Keith Vanderlinde