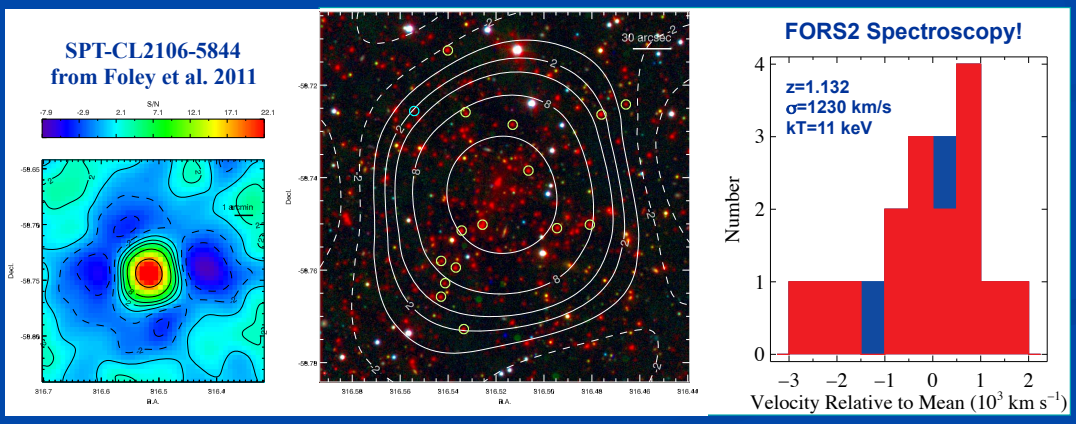
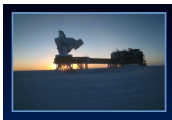
South Pole Telescope SZE Cluster Survey

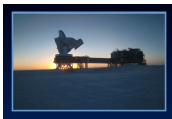
Joe Mohr
LMU and MPE, Munich





Overview

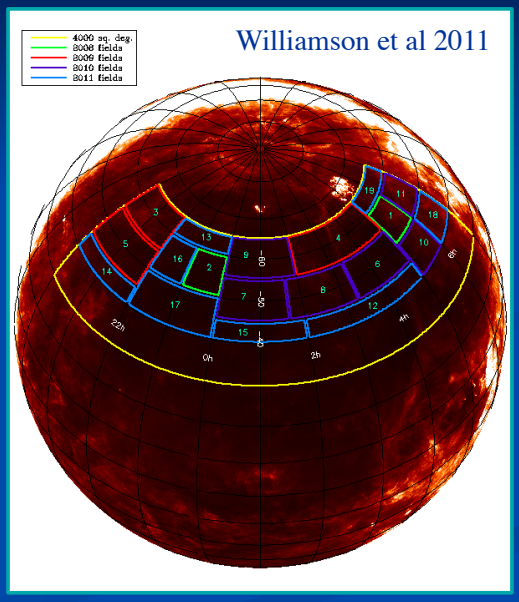
- Intro to the South Pole Telescope
  - SZE cluster finding
  - Optical followup
  - Initial cosmological results
  - A unique window on massive, high redshift clusters
- The SPT Survey plan and status
- Next steps:
  - Characterizing the 2008/2009 cluster sample
  - Incorporating additional mass calibration information



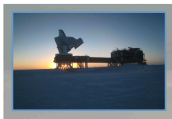
South Pole Telescope in Operation

PI: John Carlstrom (U Chicago)

- Funded by NSF in 2002
- Feb 16, 2007 SPT first light
- Science survey began May 2007 and continues today
- Deep, arcminute resolution maps now "routinely" produced



http://spt.uchicago.edu



South Pole Telescope

SPT Collaboration

John Carlstrom, PI

Berkeley (University of California)
- William Holzapfel
- Adrian Lee
- Martin White
- Sherry Cho
- Huan Tran
- Martin Lueker
- Jared Mehl
- Tom Plagge
- Christian Reichart
- Dan Schwan
- Erik Shirokoff
- Oliver Zahn

Berkeley Lab
- Helmuth Spieler

Case (Case Western Reserve University)
- John Ruhl
- Tom Montroy
- Zak Staniszewski

LMU / USM
- Joe Mohr
- (Karl Andersson)
- (Bob Armstrong)
- Gurvan Bazin
- Shantanu Desai
- Alex Saro
- Robert Suhada
- Jiayi Liu
- (Jeeseon Song)
- Alfredo Zenteno

The University of Chicago
- John Carlstrom
- Steve Padin
- Stephan Meyer
- Clem Pryke
- Wayne Hu
- Andrey Kravtsov
- Brad Benson
- Tom Crawford
- Will High
- Jeff McMahon
- Clarence Chang
- Kathryn Miknaitis

KICP (Kavli Institute for Cosmological Physics at the University of Chicago)
- Joaquin Vieira
- Abbie Crites
- Ryan Keisler
- Lindsey Bleem
- Jonathan Stricker

JPL
- Erik Leitch

Colorado (University of Colorado at Boulder)
- Nils Halverson

UC Davis (University of California)
- Lloyd Knox
- Jason Dick

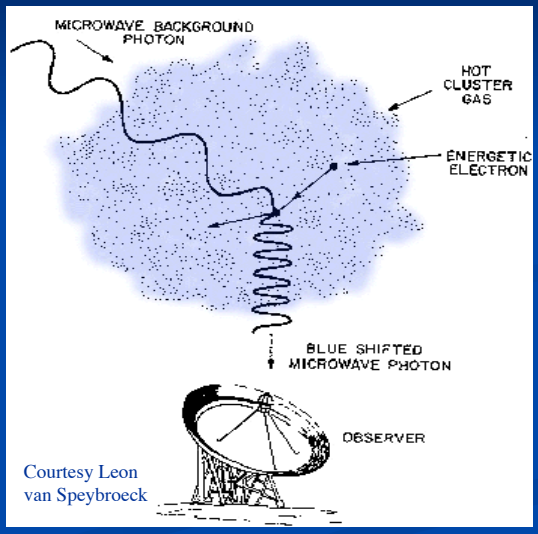
McGill
- Matt Dobbs
- Gil Holder
- Jonathan Dudley
- Keith Vanderline

Harvard-Smithsonian Center for Astrophysics
- Antony Stark
- Chris Stubbs
- Brian Stalder
- Jonathan Ruell

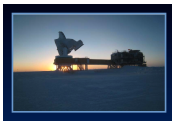
Cardiff University (Prifysgol Caerdydd)
- Peter Ade

Sunyaev-Zel'dovich Effect (1972)

- SZ effect (SZE) is inverse Compton scattering between low energy CMB photons and high energy cluster electrons
- SZE leads to a distortion of CMB spectrum and therefore it is redshift independent.
- SZE signal is a direct probe of total thermal energy in cluster electron population and hence a good proxy for cluster mass.

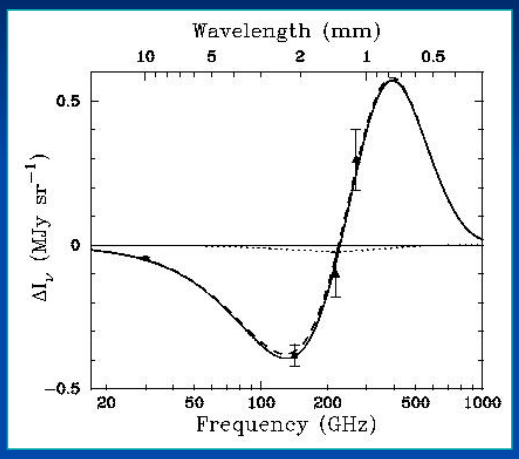


Courtesy Leon van Speybroeck

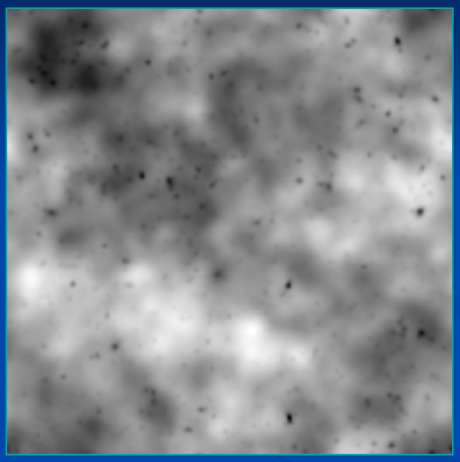


SZE Signature of Galaxy Clusters

Unique spectrum



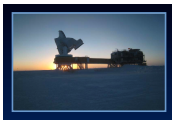
Unique angular scale



Simulations provided by M. White

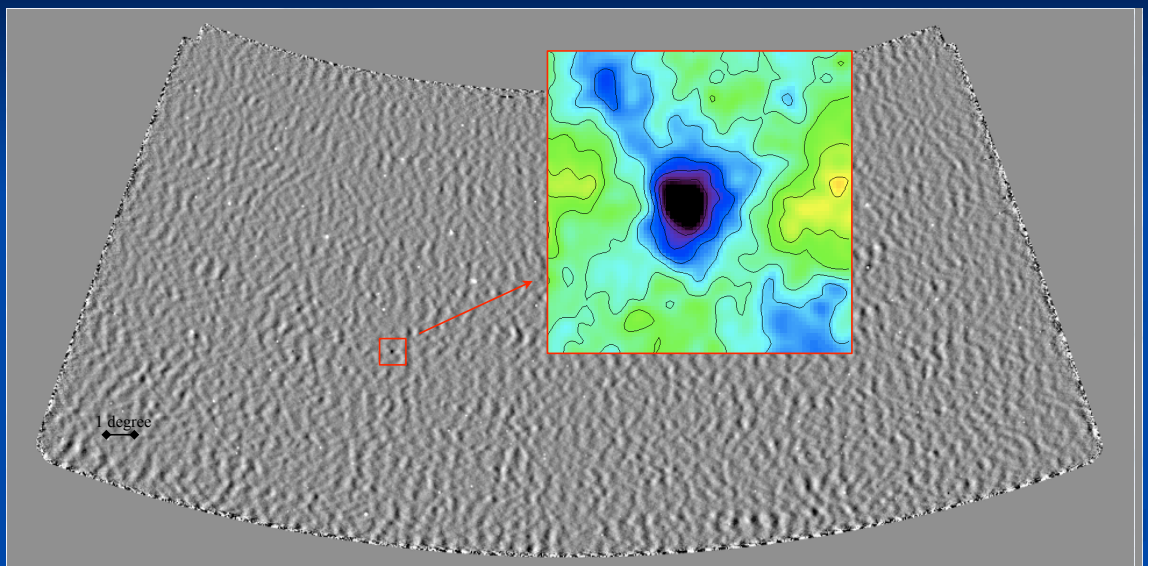
Cluster SZE flux proportional to total thermal energy in the electron population.

Promise: clean, low scatter, redshift independent cluster selection technique!

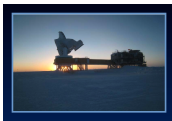


SPT Multi-frequency Survey

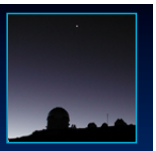
Figures from Tom Crawford



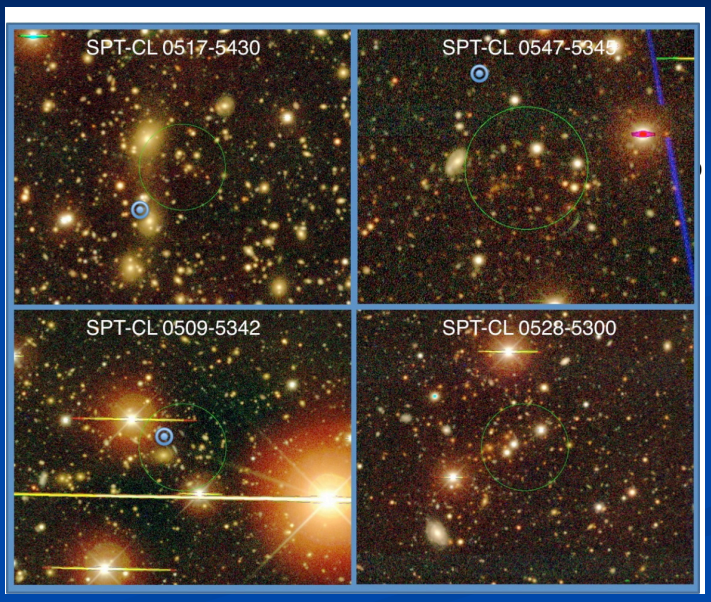
150 GHz



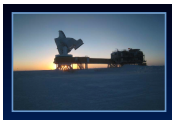
First SPT Clusters & First SZE Selected Galaxy Clusters



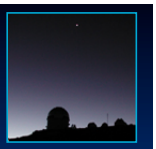
- July 14, 2008 initial candidate list was circulated
- Cross comparison to BCS imaging immediately indicated:
  - Our SZE candidates were real!
  - There was an ~arcminute scale absolute pointing error in the SPT maps
- Initial demonstration sample with BCS overlap and spanning full range of redshift published!



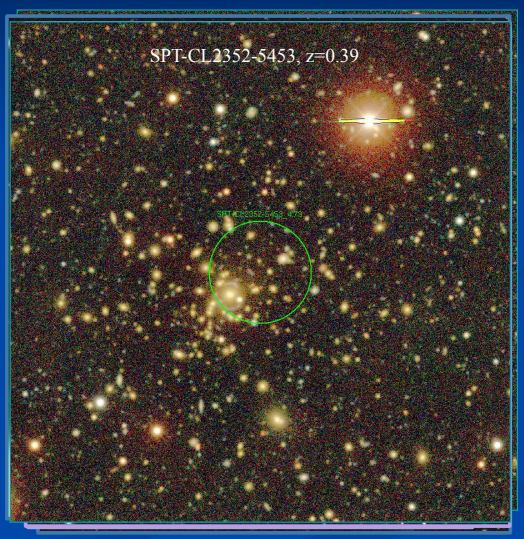
Staniszewski et al 2009

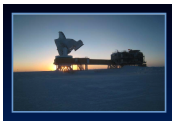


SPT Optical Followup



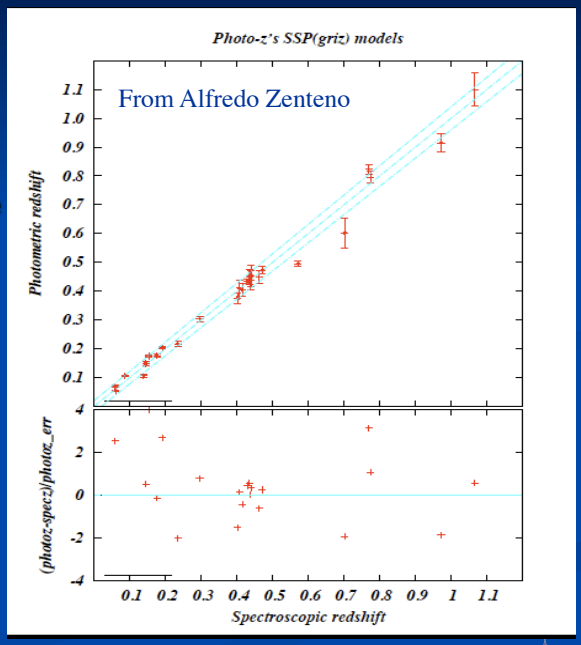
- Surface density of SPT clusters lower than expected, DES delayed to 2011, so adopted strategy of cluster by cluster followup
- Now, for each SPT candidate we
  - Examine the candidate location in DSS to roughly categorize as low/high redshift
  - Image w/Medium aperture for z>0.5
    Blanco 4m, Magellan 6.5m, (SOAR, NTT)
  - Image w/Small aperture for z<0.5
    Swope 0.9m, MPG 2.2m
- We use multiband photometry to get red sequence cluster redshifts and individual galaxy photo-z's

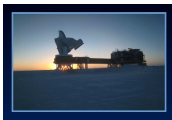




Photometric Redshifts

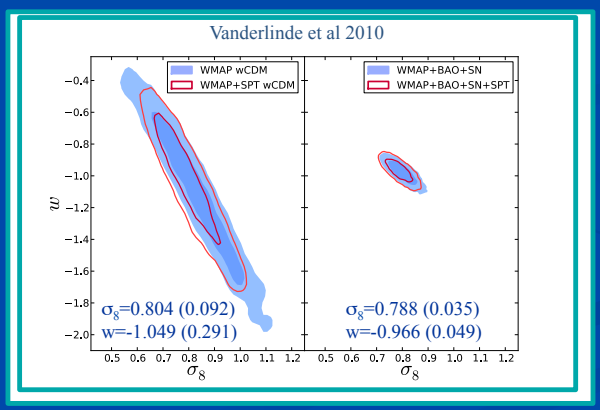
- Two sub-teams work pseudo independently to provide a crosscheck
- We calibrate photometry using the distribution of stars in color-color space (stellar locus)
  - See High et al 2009 for overview
- Spectroscopic followup program has allowed good cross-checks, and photo-z performance is good
  - Characteristic accuracy is ~0.03(1+z)

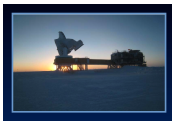




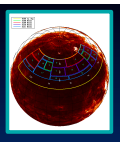
Initial Cosmological Analysis: 21 SPT S/N>5 systems from 2008 fields

- 21 SPT S/N>5 systems from 2008
  - Taken from 170 deg^2 – the first two fields in 23hr and 5hr
  - Highest S/N subset – low contamination in SZE-only selection
- Cosmological implications: (using 30% mass priors)
  - Provides some additional leverage on σ_8 (in combo with WMAP+)
  - No evidence of tension with WMAP+ in SPT only analysis (σ_8~0.76+/-0.08)





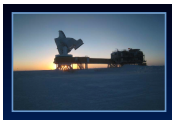
SPT Cluster Sample – Followup Status



- Increased focal plane sensitivity has led to increased yield
  - Currently scanning "final" field to 18 μK-armin² depth (150 GHz)
- At present we are followup limited

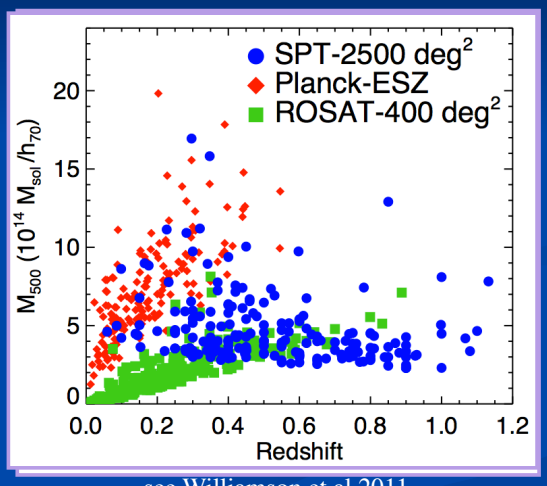
	<5% Contamination		~20% Contamination	
Year	Candidates >5σ	Followed Up >5σ	Candidates >4.5σ	Followed Up >4.5σ
2008	22	22	40	40
2009	98	98	184	184
2010	172	122	259	>153
2011	--	--	--	~53
Total:	**292**	242	**483**	>430

- 2011 has been similar to 2010, so in full sample we expect:
  - ~400 clusters at >5σ and ~600 clusters at >4.5σ over 2500 deg²

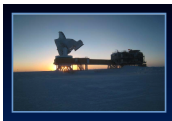


Characteristics of SPT Cluster Sample

- Mean redshift is ~0.55
- ~25% of sample is at z>0.8
- Mass selection is approx $M_{500}>3x10^{14}$ (Andersson et al 2011)
- With 2500 deg² solid angle the SPT survey provides unique window on rare, high mass clusters at any redshift!

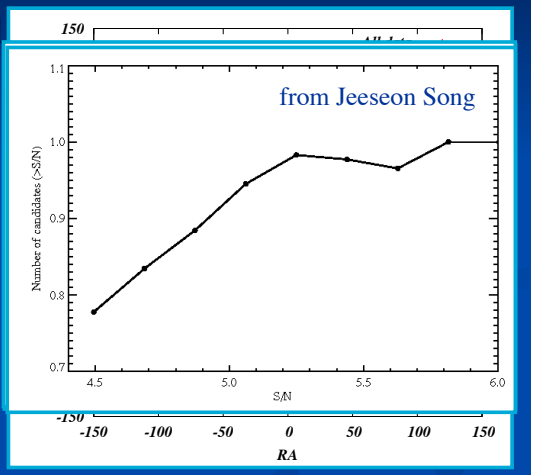


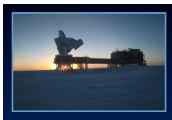
see Williamson et al 2011
from Brad Benson



Next Step: 2008+2009 Sample

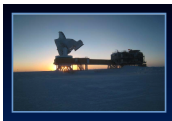
- Current focus is to prepare larger sample for cosmological analysis and release to the community
- 2008+2009 sample:
  - 750 deg^2 of SPT survey to full depth
  - 224 candidates at S/N>4.5 (120 at S/N>5)
  - Optical/NIR observations "complete"
  - 184 confirmed clusters at S/N>4.5
- Preliminary results from ensemble analyses (Song et al *in prep*)
  - Offsets between BCG and SPT position
  - Redshift distribution (50 with photoz>0.8!)
  - Purity/Contamination
    - Sims: 95% at S/N>5, 80% at S/N>4.5





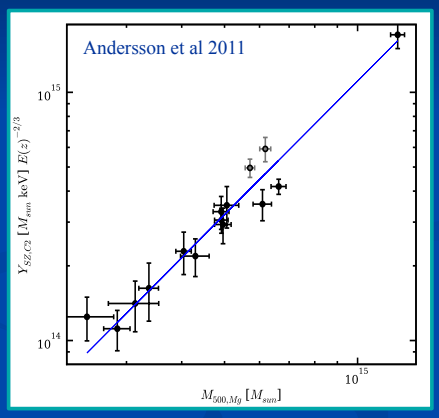
Next Step: Mass Calibration

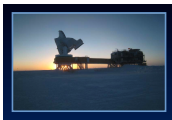
- Our cluster selection is tied to SZE signal- a cosmological analysis requires mapping from SZE S/N to cluster mass over full survey
  - We adopt power law relation: Normalization, Slope, Redshift Evolution and Scatter
- Vanderlinde et al initial cosmological analysis relied on Bode et al cluster "sims" calibrated using local cluster X-ray scaling relations
  - ~30% systematic mass uncertainty
  - ~20% (gaussian) intrinsic scatter
- Now building up calibration datasets within redshift bins extending to z~1.4
  - Pursuing X-ray, velocity dispersions, weak lensing
  - Given ~10X larger sample (184 vs 21), we need ~10% control of mass systematics to maintain similar balance between Poisson noise and mass systematics
  - Crudely speaking, we need ~2% level control of mass systematics for full sample of 600 clusters



Status of Mass Calibration Program: X-ray

- Gravitational collapse leads to $T_x/Y_x/M_{icm}$-mass relations
  - X-ray mass-obs relation well studied nearby
  - Low scatter (~10%), complex systematics
  - Strategy:
    - Obtain ~2000 source photons to enable Y_x, T_x and M_{icm} mass estimates
    - Use published calibration of mass-obs relations
    - Note: extrapolate from nearby calibration
- Status
  - Chandra obs of complete sample of 15 SPT selected clusters indicate cluster masses should be ~20% higher (Andersson et al 2011)
  - XMM observations of 19 systems (9 at z>0.8) *accepted*
  - Recent Chandra X-ray Visionary Program *accepted* (Benson et al) to complete observations of 80 most massive systems over full survey.

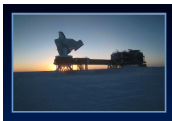




Status of Mass Calibration Program: Velocity Dispersions

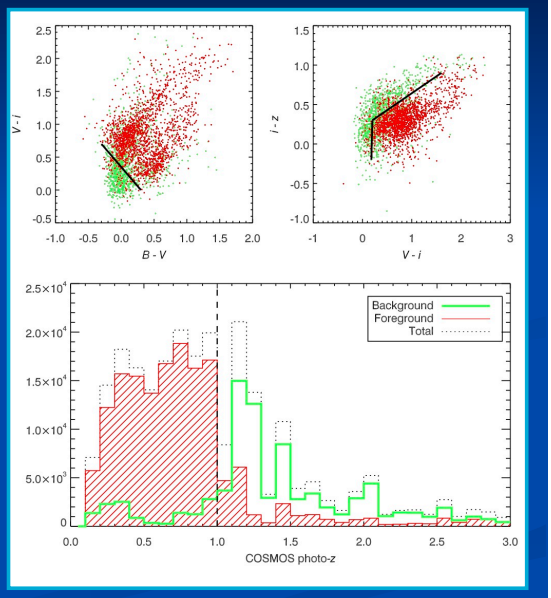
- Gravitational collapse leads to dispersion-mass relation

  Recent refs: Evrard et al 2008, White et al 2009
  - Use recent structure formation sims to characterize systematics
  - High scatter (40%), Less Complex Systematics
  - Strategy:
    - Obtain velocity dispersions using cluster red galaxies
    - Obtain 2 masks per cluster, providing 20 to 40 redshifts per cluster
- Status:
  - Ongoing VLT program (z>0.8 -20 accepted)
  - Ongoing Gemini Survey (z<0.8 -80 accepted)



Status of Mass Calibration Program: Weak Lensing

- Weak lensing provides masses independent of the cluster dynamical state
  - High scatter (25%), less complex systematics
  - Strategy:
    - Obtain shear maps with photo-z's for sample of clusters spanning survey
- Status:
  - Single cluster observed with Megacam as demonstration of concept (High et al)
  - Magellan Megacam observations of ~25 systems at z<0.5 pending
  - HST (F606W)+VLT (BIz) observations of 7 systems 0.6<z<1.0 accepted
  - HST observations of 7 systems at 0.9<z>1.2 accepted, VLT observations to be proposed



from Will High

Summary

- SPT cluster survey to 18 μK-armin^2 over 2500 deg^2 drawing to a close
- Optical/NIR followup effort to measure redshifts and remove contamination will wind down over the next year
  - Final sample will be ~400 clusters at S/N>5, 600 clusters at S/N>4.5
  - SPT-only selection has low contamination (~5% at S/N>5, ~20% at S/N>4.5), and with optical followup the sample has extremely high purity
- Cosmology
  - Uniform selection with mass (~independent of redshift) over large solid angle – opens new window on rare, massive clusters at high z
  - Initial cosmology tests with small sample promising
  - Next test is with sample of 184 (2008+2009 sample)
- Mass calibration effort using X-ray, dispersions and weak lensing ramping up