Photo from Alistair Walker

SPT

Dark Energy Survey

CORE The Cosmic Origins Explorer

Probing the Galaxy Cluster Population to High Redshift with the Sunyaev-Zel'dovich Effect

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7th KIAS Workshop on Cosmology and Structure Formation

LMU- Munich

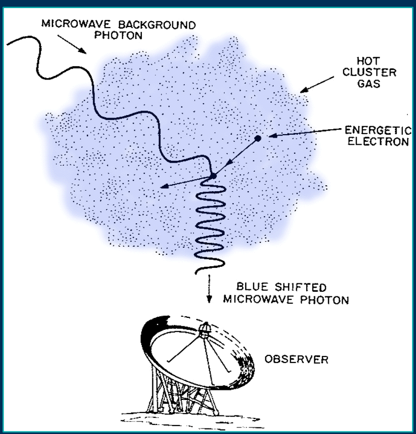
MPE

MAX-PLANCK-GESELLSCHAFT

Sunyaev-Zel'dovich Effect Galaxy Cluster Selection

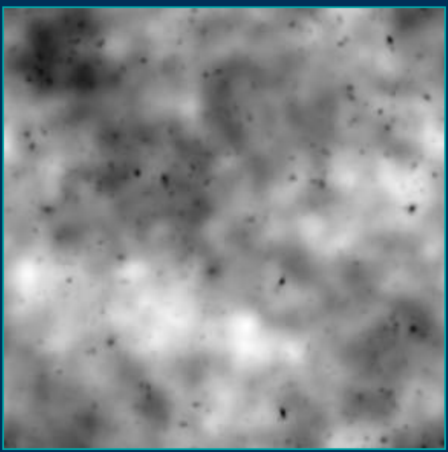
Cluster SZE Signature

- Measures total thermal energy in ICM
- Strongly correlated with mass (low scatter)
- Signature at fixed mass is ~independent of redshift!



Adapted from L. Van Speybroeck

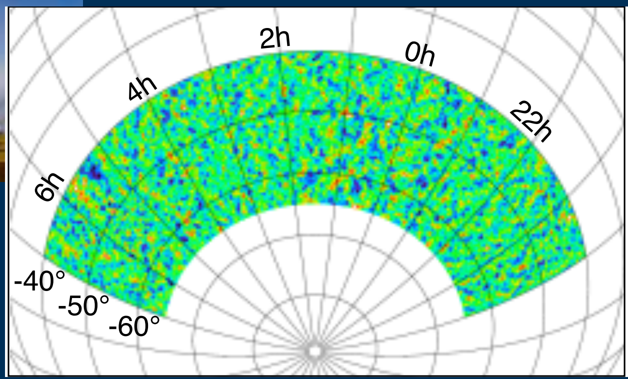
$$\frac{\Delta T(R)}{T_{cmb}} = -2\frac{\sigma_T}{m_e c^2}\int dl\, n_e(l,R) k_B T_e(l,R)$$



SPT-SZ 2500 deg^2 Survey

Carlstrom+ 2010

- Maps produced from bolometer time stream of ~10^5 T measurements/s integrated over 4 years with ~65% efficiency



- Matched filter selection
- Painstaking optical followup

First SZE selected clusters pulled from first year SPT data (Staniszewiski+09)

SPT-SZ Sample

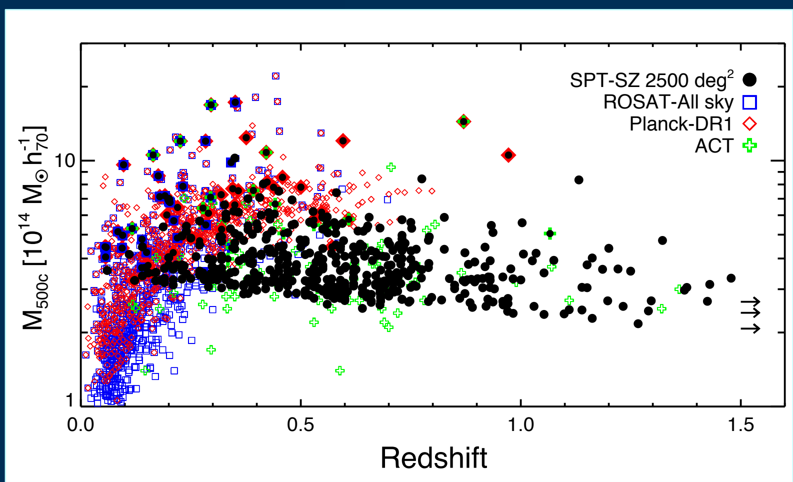
Song+12, Bleem+15

- 2500 deg^2 sample
  - 516 at ξ>4.5
  - 387 at ξ>5.0

    Bleem+15
- High z subsample
  - 36 at z>1
  - Max z_{spec}=1.47

    Bayliss+13
  - Highest phot-z

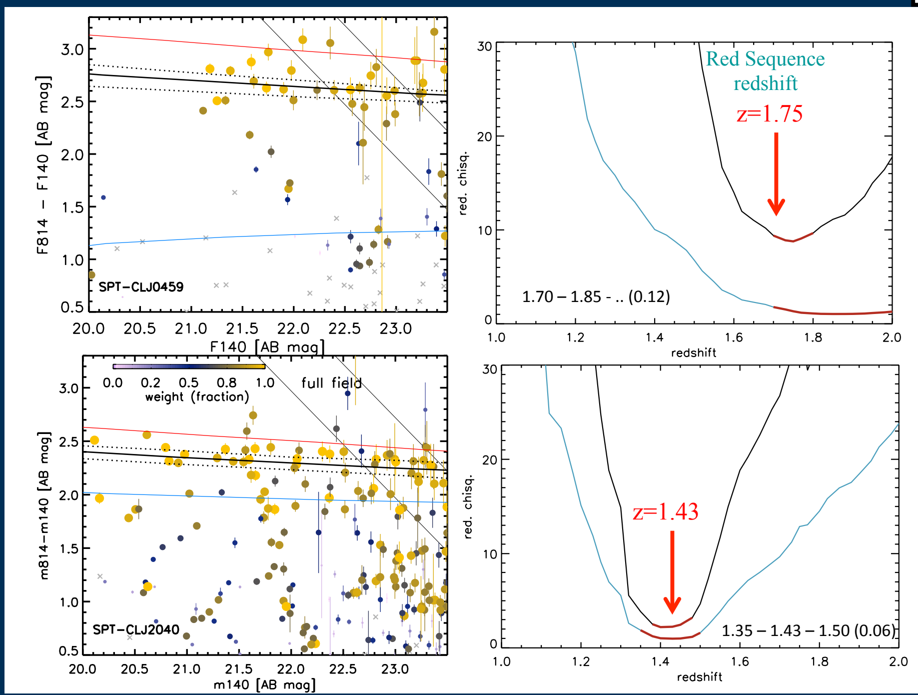
    Strazzullo+



- Clean sample with M_{500}>3x10^{14} M_o to z~1.7

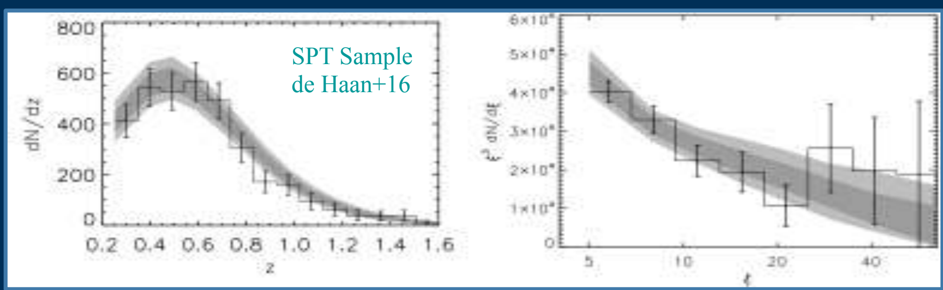
Highest Redshift: SPT-CLJ 0459

Strazzullo+

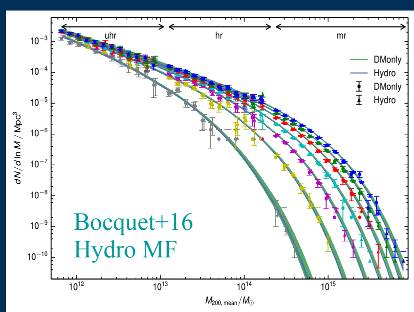


Cosmology with SPT Sample?

Bocquet+16; de Haan+16



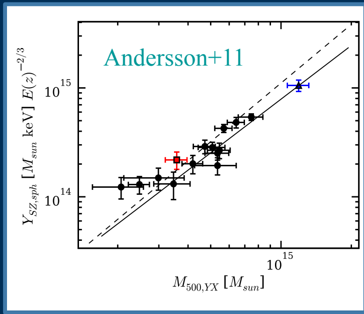
- Sure:
  (see Haiman, Mohr & Holder 2001)
  - Observable distribution $d^2N/dzd\xi$ must be mapped to cosmology dependent hydro mass function $d^2N/dzdM$
  - Need observable-mass relation



Observable-Mass Relation

Bocquet+15

- Statistical relationship between observable and underlying halo mass
  - Clusters are young, merging objects
  - Crucial for selection observable (S/N, Y, L_x)
  - Include lower scatter mass proxies (Y_x, M_{icm})



- SZE Observable-Mass relation
  - Minimum of four free parameters: power law plus (log-normal) intrinsic scatter

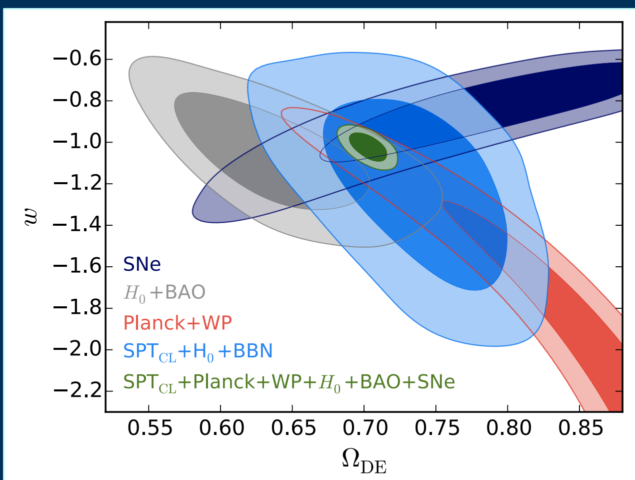
$$\zeta = A_{SZ}\left(\frac{M_{500}}{3x10^{14}h^{-1}M_{\circ}}\right)^{B_{SZ}}\left(\frac{E(z)}{E(0.6)}\right)^{C_{SZ}}$$

4 params: A_{sz}, B_{sz}, C_{sz} and D_{sz}

  - Parametrization allows systematic uncertainties to be included
  - Mass information added through weak lensing, galaxy kinematics, external priors

SPT Cluster Cosmology

de Haan+16



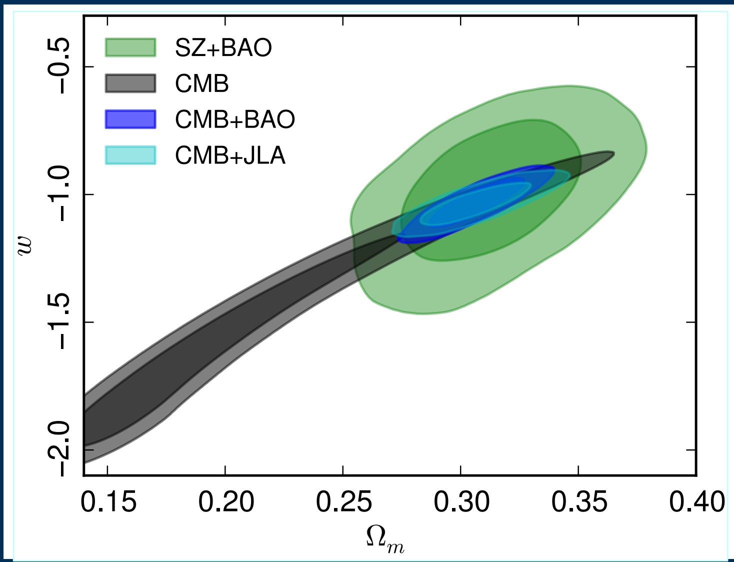
- 387 SPT clusters
- Mass calibration
  - 82 X-ray Y_xs
  - WL prior on Y_x-mass
- 14 parameters
  - 6 cosmological
  - 4 SZ mass-obs
  - 4 X-ray Y_x mass-obs
- Tension?
  - Insignificant in ΛCDM
  - Insignificant in wCDM

SPT Cluster Cosmology Constraints in good agreement with other probes within ΛCDM and wCDM models

SPT-SZ: w=-1.28+/-0.31 SPT-SZ++: w=-1.023+/-0.042

Planck Cluster Cosmology

Planck Collaboration XXIV (2015)

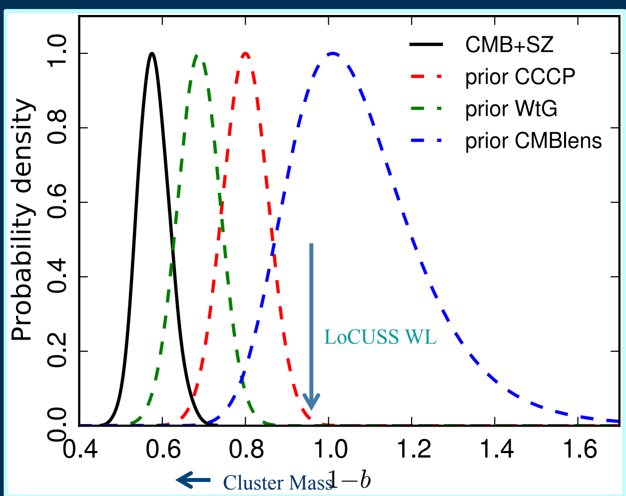


- 439 clusters
- Mass-obs rel'n
  - 3 params
    (C_{sz} fixed)
- Mass calibration
  - WL- WtG
  - WL-CCCP
  - WL-CMB
- Significant tension only if CMB WL used

PlanckSZE+BAO (CCCP): w=-1.00+/-0.18

Planck Cluster Mass Priors

Planck Collaboration XXIV (2015)



- External cosmology priors prefer higher masses than direct measurements
- CMB lensing and LoCUSS WL imply no hydrostatic mass bias (in conflict with simulations)
- Some tension among mass priors

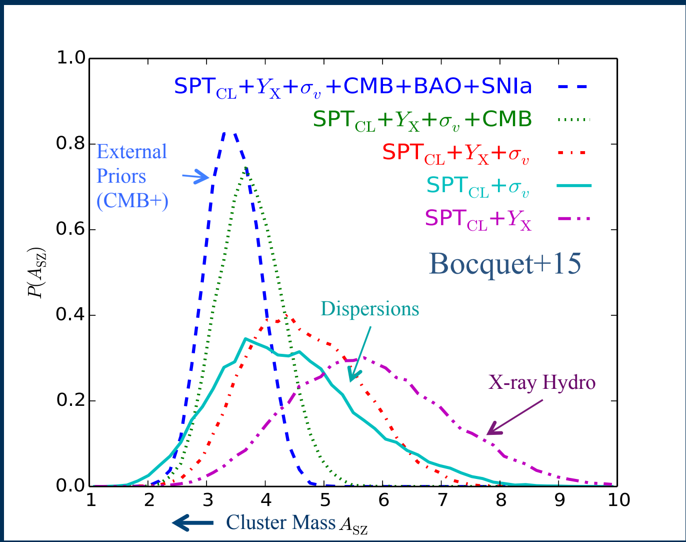
WtG:	1-b=0.69+/-0.07
CCCP:	1-b=0.78+/-0.09
CMBLens:	1-b=0.99+/-0.19
LoCUSS:	1-b=0.95+/-0.04

Planck adopts hydrostatic masses as baseline
b is hydrostatic mass bias scale factor
$M_{hydro} = b\, M_{true}$

SPT Cluster Masses

Bocquet+15

- External cosmo priors (also WMAP) tend to prefer higher cluster masses
- Direct constraints (WL, Dyn, Hydro) prefer lower values
- Constraints are still weak- everything statistically consistent



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SPT Mass Calibration Ongoing

- Direct mass calibration of clusters
  - Dynamical masses:
    - Bocquet+15 (with dispersions)
    - Capasso+ (Jeans analysis)
  - Magnification masses:
    - Chiu+16
  - Shear masses:
    - Dietrich+ (Magellan imaging)
    - Schrabback+ (HST+VLT imaging)
    - Stern+ (DES imaging)

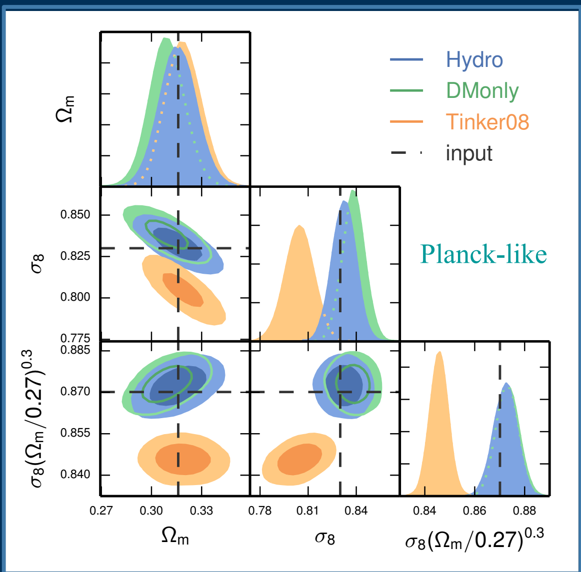
Do External Cosmological Priors Prefer Higher Cluster Masses?

- Evidence is intriguing but not compelling
- What might explain ***if*** future data show it is real?
  - Theoretical mass function wrong? (Bocquet+16)
    - Tinker mass function is biased on high mass end
    - $\Delta\sigma_8(\Omega_m/0.27)^{0.3}$~+0.02 (30% of the offset noted in Planck SZE analysis)
  - Unresolved systematics in the CMB data still possible-
    - Tension between base P15 CMB and CMB Lensing (Planck+15, Grandis+16)
  - Could incompleteness in the cluster sample play a role? (Gupta+16)
    - First measurement of 150GHz cluster radio galaxy LF
    - Indicates 2 to 5% incompleteness in SPT-SZ like survey
  - Revision of cosmological model required?

Baryon Impact on Mass Function

Bocquet+16

- For massive cluster surveys like Planck and SPT there is no significant impact of baryon physics on the MF
- Of greater importance is the difference between the Tinker and the Bocquet mass functions!
- Watson MF is parametrized incorrectly and has “artificial” cosmological sensitivity



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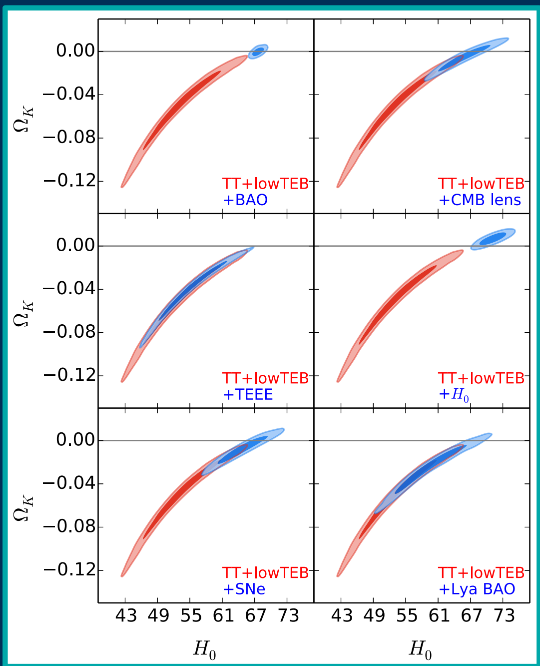
Systematics in CMB?

Grandis+16

- We heard yesterday (from Karim) about high-ℓ vs. low-ℓ 2σ tension
- Also a related A_L 2σ tension between Planck TT + low TEB and Lensing constraints
- Consistency with non-CMB data?
  - In flat ΛCDM there is 8σ surprise when adding H_o
  - Planck prefers curved Universe at 2.7σ
    - In curved ΛCDM model >3σ surprises exist between Planck TT + low TEB and BAO, SNe, H_o and CMB lensing



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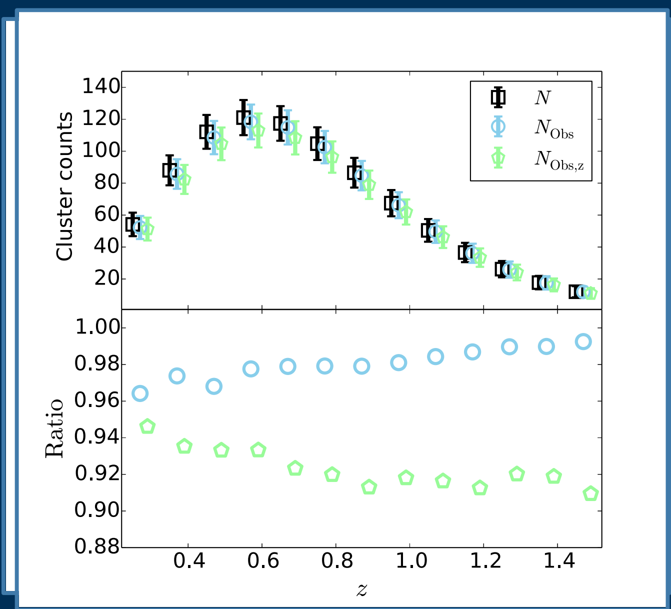
Cluster Radio Galaxies at 150GHz

Gupta+16

- Study the overdensity of high frequency radio galaxies 95, 150, 220GHz toward clusters
- Centrally concentrated
  - consistent with 1.4GHz- see Lin & Mohr 2007
- High-ν sources 10X rarer at a given luminosity
- Mock SPT-SZ samples with radio galaxies are incomplete at 2 to 5%



Gupta+ 16

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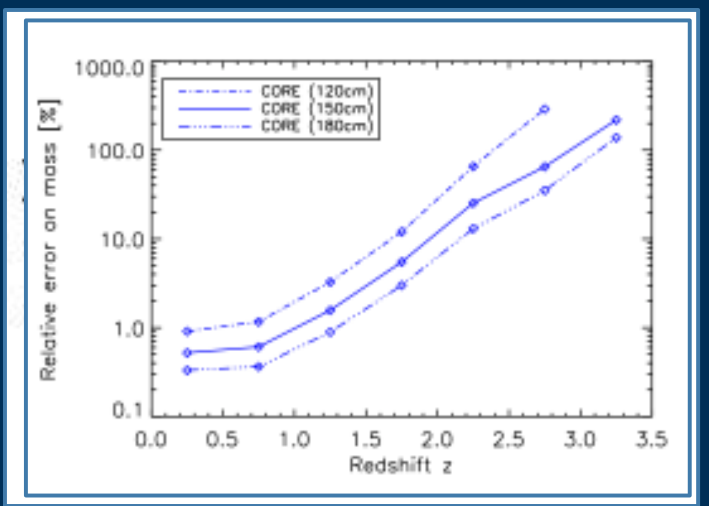
Future SZE Surveys

- SPTpol + SPT-3G + AdvACT underway
- CORE space mission proposed for ESA M5
- CMB-S4 ground based (US coordinated, seeking European participation)
- Large cluster samples:
  z>1.5: 500, 5000, 20,000 clusters
- Exquisite mass constraints



Melin+16 forecasts for CORE

Summary

SPT Cluster Cosmology

- Good agreement with CMB++ datasets and other probes in ΛCDM/wCDM
- WL and dynamical mass calibration ongoing- first wave of papers imminent
- Planck: Mixed story on agreement with CMB++ datasets in ΛCDM/wCDM
  - + WL mass constraints from WtG or CCCP
  - - CMB lensing constraints and Smith WL masses provide tension

Cluster mass measurements

- Improved direct measurements with WL and dynamical data needed
- Additional hydro simulation studies of MF needed

Larger samples and better calibration on the way

- SPT-3G, Core, CMB-S4
- And don't forget about eROSITA!!!

LMU Cosmology and Structure Formation Group

- Focus:

  Observational cosmology and structure formation studies

- Survey Projects

  South Pole Telescope
  Dark Energy Survey
  D-MeerKAT
  eROSITA
  Euclid
  LSST

- Group Members:

Research Scientists
Joerg Dietrich
Alex Saro
Veronica Strazzullo

Euclid subgroup
Martin Kümmel
Michael Wetzstein
Moham. Mirkazemi
Holger Israel
Thomas Vassallo

Postdoc Fellows
Matthias Klein
Maurillio Panella

PhD Students
Nikhel Gupta
Corvin Gangkofner
Raffaella Capasso
Sebastian Grandis