Theory, Analysis, Computing

Bhuvnesh Jain, UPenn

Katrin Heitmann, ANL

Martin White, Berkeley

Parallel Session 1: 3-5pm Tuesday:

- Novel Probes
- Synergies across Wavelengths (including CMBxLSS and IM)

Parallel Session 2: 8:30-10:30am Wednesday:

- Simulation and Data Challenges
- White paper brainstorming: *you* are invited!

Tuesday: 3-4pm

Theory, Analysis, and Computing: Novel Probes

Conveners: Bhuvnesh Jain (University of Pennsylvania), Katrin Heitmann (Argonne National Laboratory), Martin White (UC Berkeley)

15:00 **Small scale probes of DM and gravity: analysis challenges** *15'*

Speaker: Bhuvnesh Jain (University of Pennsylvania)

15:15 **Joint analysis of imaging + spectroscopic data** *15'*

Speaker: Alexie Leauthaud

15:30 **Simulation challenges** *15'*

Speaker: Susmita Adhikari

15:45 **Discussion** *15'*

Novel Probes: beyond wCDM, beyond 2-point functions

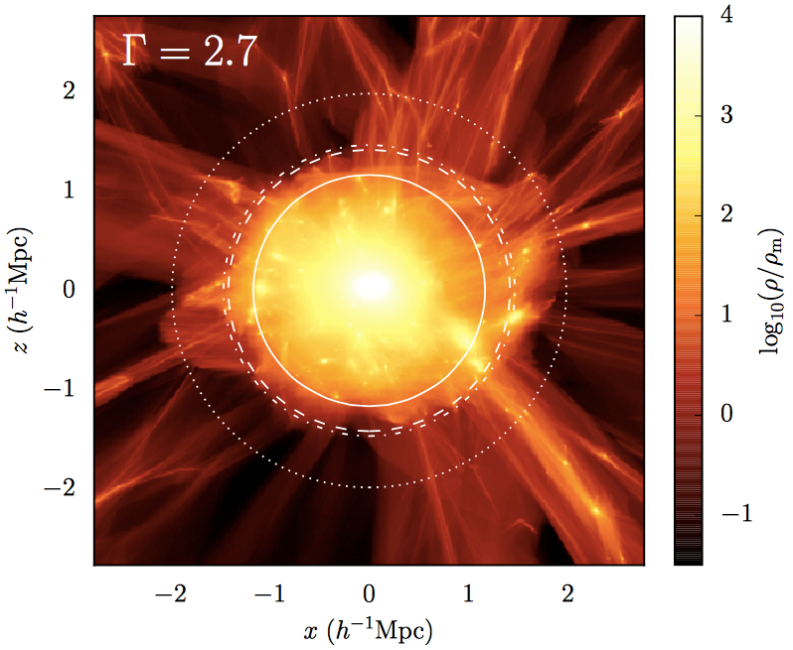
(and not ***just*** because we're bored of those)

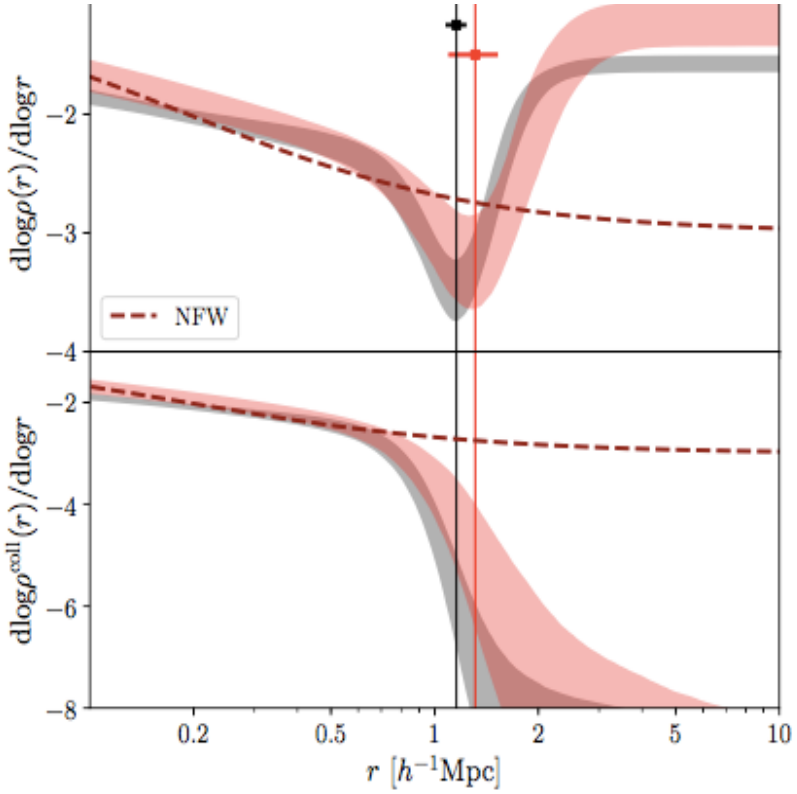
- LCDM has hung on with only 2-sigma hiccups, leaving dark energy models roughly where they were around 2000.
- Meanwhile gravity and DM models have risen and fallen in the last decade.
- The effective tests are ~equally divided between small and large scales.
- What are these small scale tests? Are they useful (Yes)? How can we promote and integrate them into the analysis of next gen surveys?

Gravity and dark matter in clusters

- Gravity
  - Lensing (imaging) vs. dynamical (spectro, X-ray/SZ) masses
  - Enhanced forces in infall regime
  - Profiles and splashback
- Dark matter
  - Inner structure altered by DM interactions
  - Subhalos and halo shapes
  - Merging clusters
  - Splashback and dynamical friction

The edge of halos: splashback





Diemer, Kravtsov; More+; Adhikari+; Baxter, Chang+; Chang,Baxter+ (DES collab)

Detection in mass and light (subhalos) -> a probe of cluster physics, DM and gravity

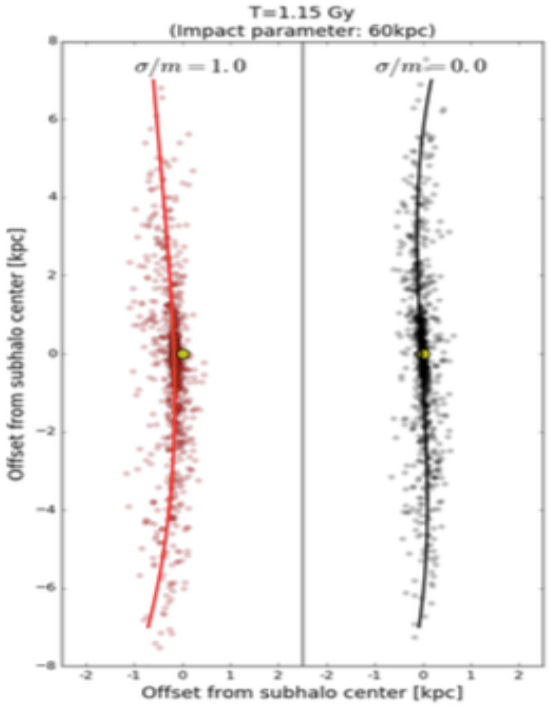
Susmita Adhikari talk

Gravity and dark matter in galaxies

- Gravity
  - Lensing vs dynamical mass
  - Morphology changes in light
  - Stellar evolution and pulsations
  - Supermassive Black Holes
- Dark Matter
  - Inner profiles of dwarf galaxies
  - Satellites of Milky Way and nearby galaxies
  - Dark substructure: a testable CDM prediction
  - Warped and disturbed disks

Gravity and dark matter inside galaxies

Gravity



Dark Matter

Larger scale analyses: Alexie Leauthaud

LIGO+
Gravity waves + photons!

- Gravity waves and gamma ray photons travel at the same speed, to 1 part in 10^{15}.

- Surviving theories either predict
  - Massless gravitons, e.g. GR
  - Very light gravitons ~ Hubble scale, e.g. massive gravity

- The rest are...dead.

- In fact, no appealing cosmic acceleration gravity model existed prior to the LIGO result. But new models are underway.
- Screening mechanisms are alive and well. So we can test modified gravity, string theory scalars and other physics via astrophysical/small scale analyses.

Gravity theories: dead and alive!

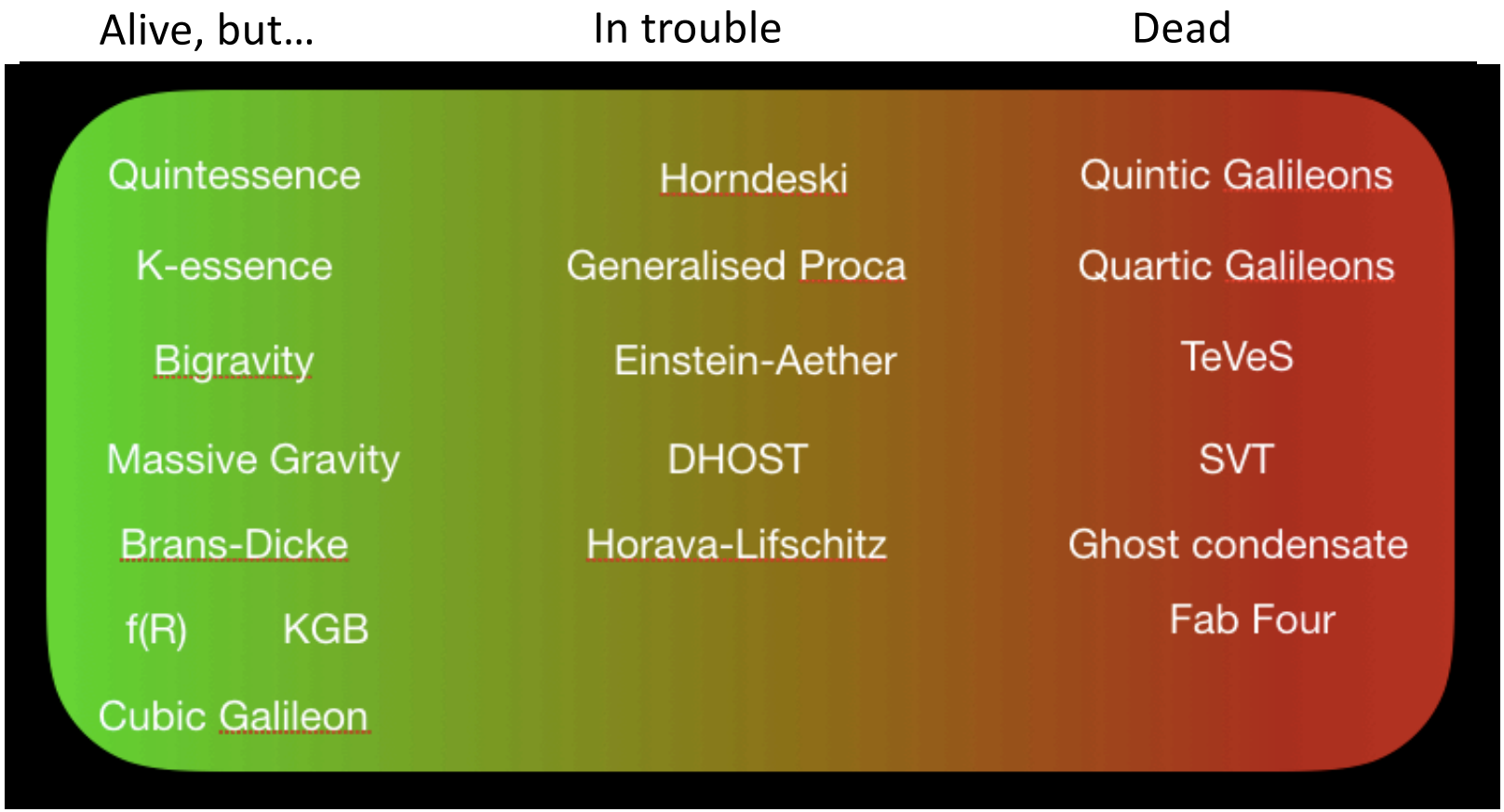


*Figure from **Tessa Baker** focuses on impact of LIGO result*

Gravity theories: dead and alive!

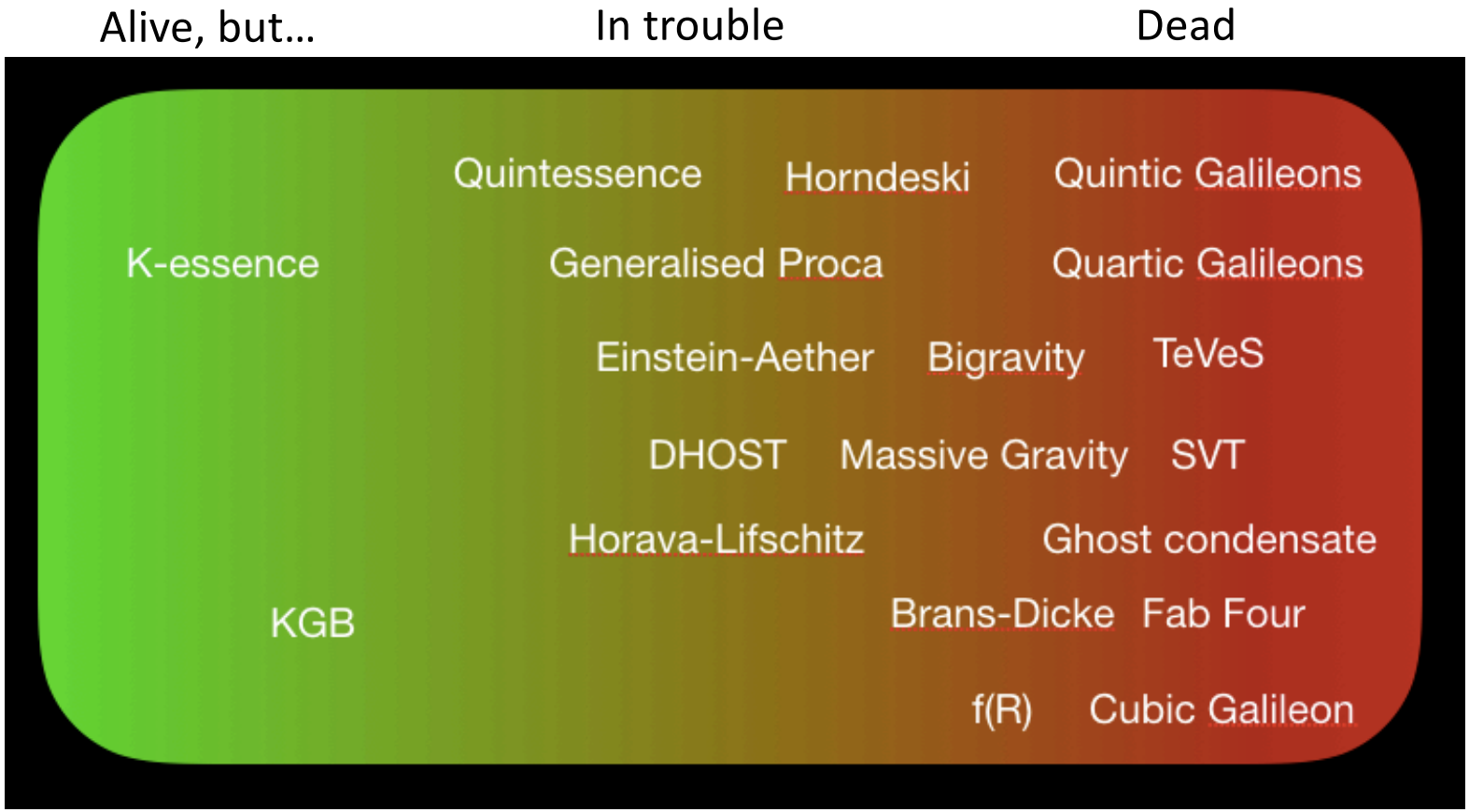


*Figure from **Tessa Baker:** LIGO+other constraints*

Discussion points

- Develop analysis tools so that there is comparable rigor in interpretation of small scale data
- Joint analysis of multi-wavelength data, imaging+spectroscopy, ground + space..
- Simulations, with a heavy dose of theory, and customized analysis tools
- These require major new effort. There's also the question: Dark matter (not where, but what): how does it fit?

Astrophysical analyses: a living review

Bring theorists, simulators and data analysts in different survey projects to the same ‘page’. Planned release by February. There will be three elements:

Living Review + Public Codes + Discussion Forum

If you’re interested, please check out

www.novelprobes.org

'Astrophysical tests' of dark sector interactions are a valuable, complementary probe of fundamental physics.

Theories of modified gravity aim to explain cosmic acceleration without invoking dark energy. Such theories typically posit new interactions due to the presence of additional fields. In addition to their signal on large scales, such theories predict new physics on the smaller scales of individual galaxies and clusters. Models of dark matter interactions also typically lead to signatures on small scales. A common feature of these new interactions is that different components of galaxies, in particular stars, dark matter and black holes, respond differently to external forces.

Such 'astrophysical tests' of dark sector interactions are a valuable, complementary probe of fundamental physics. Several types of tests, involving studies of black holes, stars, galactic structure and dynamics, and galaxy clusters have been developed

Review Outline (in preparation):

1. Introduction
2. Theory
    1. Producing cosmic acceleration through gravity
    2. Screening mechanisms
3. Surveys
    1. Current surveys and available datasets
    2. Planned surveys
4. Nonlinear gravity: analytical approaches
    1. Nonlinearity in GR vs. modified gravity
    2. Baryonic effects and small scale structure
    3. Novel estimators for the non linear regime
5. Simulations
    1. Cosmological simulations
    2. The algorithm: iterative relaxations with multi grid acceleration
    3. The main N-body codes in the market
    4. Different screening mechanisms require different variants of the algorithm
    5. The validity of the quasi-static approximation
    6. Speeding up N-body simulations of modified gravity
    7. Specialized simulations for 2-body systems
6. Astrophysical tests

...

Part I: Gravity sections; Part II: SIDM and other DM physics.

Open to interested contributors. Plan to connect with survey projects.

Synergies across Wavelengths

Tuesday: 4-5pm

Theory, Analysis, and Computing: Synergies across wavelength

Conveners: Bhuvnesh Jain (University of Pennsylvania), Katrin Heitmann (Argonne National Laboratory), Martin White (UC Berkeley)

16:00 **CMB x LSS: requirements of new analysis tools** *15'*
Speaker: Uros Seljak (LBNL)

16:15 **Multi-wavelength and multitracer maps from simulations** *15'*
Speaker: Marcelo Alvarez

16:30 **High-z tracers and IM** *15'*
Speaker: Phil Bull (JPL/Caltech)

16:45 **Discussion** *15'*

Synergies Across Wavelengths: Multiple Probes & Calibration

Marcelo Alvarez

CMB Lensing

(e.g. Lesgourgues et al. 2006; Pullen et al. 2016; CMB-S4; Modi et al. 2017; Schmittfull & Seljak 2017)

Photometric Redshift Calibration

Spectroscopic Surveys & 21-cm

(e.g. Alonso et al. 2017; Newman 2008; McQuinn & White 2013; Newman et al. 2015)

21cm Intensity Mapping

(e.g., Chang et al. 2008; Bull et al. 2015; Alonso et al. 2015; Alonso & Ferreira 2015; Xu et al. 2016; Obuljen et al. 2017; White & Padmanabhan 2017)

Cluster Counts & Mass Calibration

(e.g., Allen et al. 2011; von der Linden et al. 2014; Hoekstra et al. 2014; Shirasaki et al. 2015)

Cosmic Infrared Background

(e.g., Smith et al. 2012; Sherwin & Schmittfull 2015; Larsen et al. 2016; Tucci et al. 2016)

Sunyaev-Zel'dovich

(e.g., Mueller et al. 2015; Mueller et al. 2015; Alonso et al. 2016; Madhavacheril et al. 2017)

Multi-wavelength I: CMB x LSS

- Cluster profiles and cross-correlations with a variety of tracers will be much of the science from future CMB surveys.
- CMB provides y and kappa maps. Galaxy and IM surveys provide clusters, galaxies and other tracers -> Cross-correlate!
- Are we done? Probably not…

LSST + CMB-S4

- To optimize the products and analysis, need to go beyond plans for separate projects
  - Joint planning of data analysis: how do we combine the data?
  - Plans for simulations and mock catalogs/maps.
- Examples of challenges
  - Redshift range of low-z tracers: why and how to extend z-range?
  - Redshift measurement, especially at the high-z end
  - Large-scales: what's the lowest ell we can trust from DES, LSST?
  - CMB maps will use low-z tracers for validation and testing
  - *Thanks: Martin White*

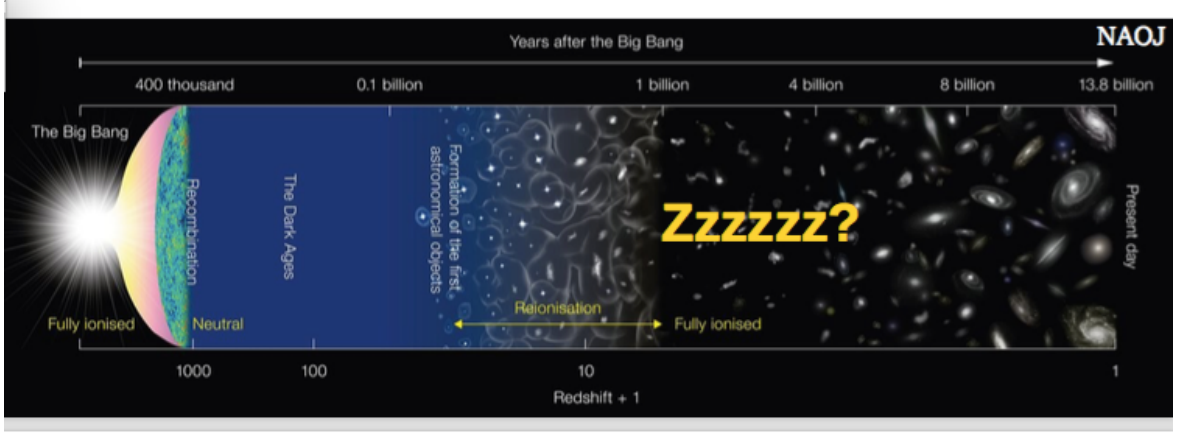
Why high redshifts?

Phil Bull

Are there reasons to make *cosmological* observations in the $2.5 < z < 6$ window?

$z < 2$: Cosmic acceleration, tests of GR

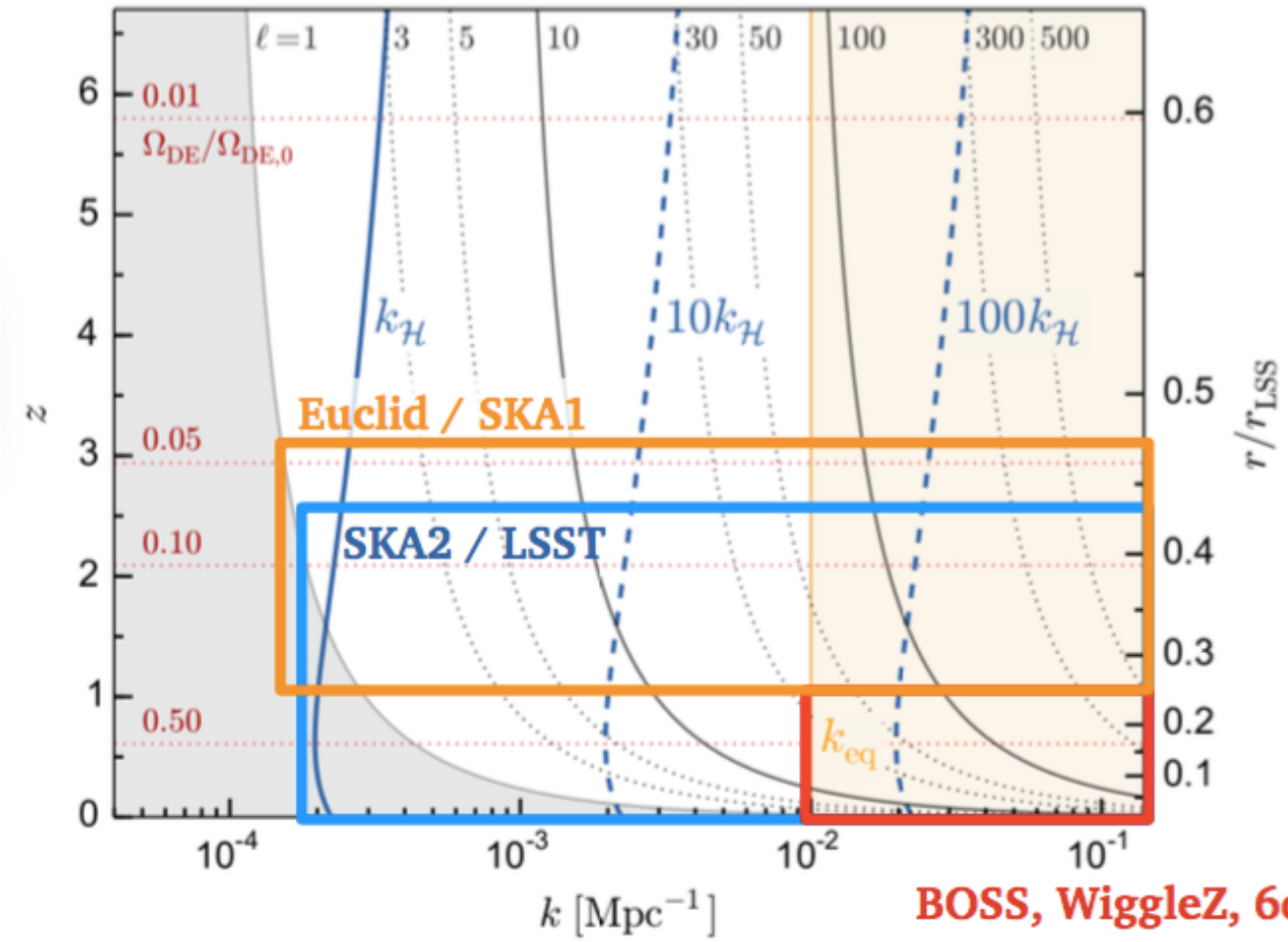
$z > 6$: EoR / dark ages / CMB



- **Maximize linear regime modes**
- f_{NL} , gravity tests
- Early dark energy
- Spatial curvature, neutrino mass measurement
  Phil Bull, Martin White

In case you thought cosmology is done

Phil Bull



Simulations and Data Challenges

Wednesday: 8:30-9:30am

Theory, Analysis, and Computing: Simulation and Data challenges

Conveners: Bhuvnesh Jain (University of Pennsylvania), Katrin Heitmann (Argonne National Laboratory), Martin White (UC Berkeley)

08:30 **Small scale analysis/nonlinear effects** *15'*
Speaker: Andrew Hearin (Argonne National Laboratory)

08:45 **Challenges for large surveys** *15'*
Speaker: Katrin Heitmann (Argonne National Laboratory)

09:00 **NOAO Data Lab: Current Status & Future Visions** *15'*
Speaker: Stephanie Juneau (NOAO)

09:15 **Discussion** *15'*

White paper thoughts/outline *1h0'*

Simulations & Computation

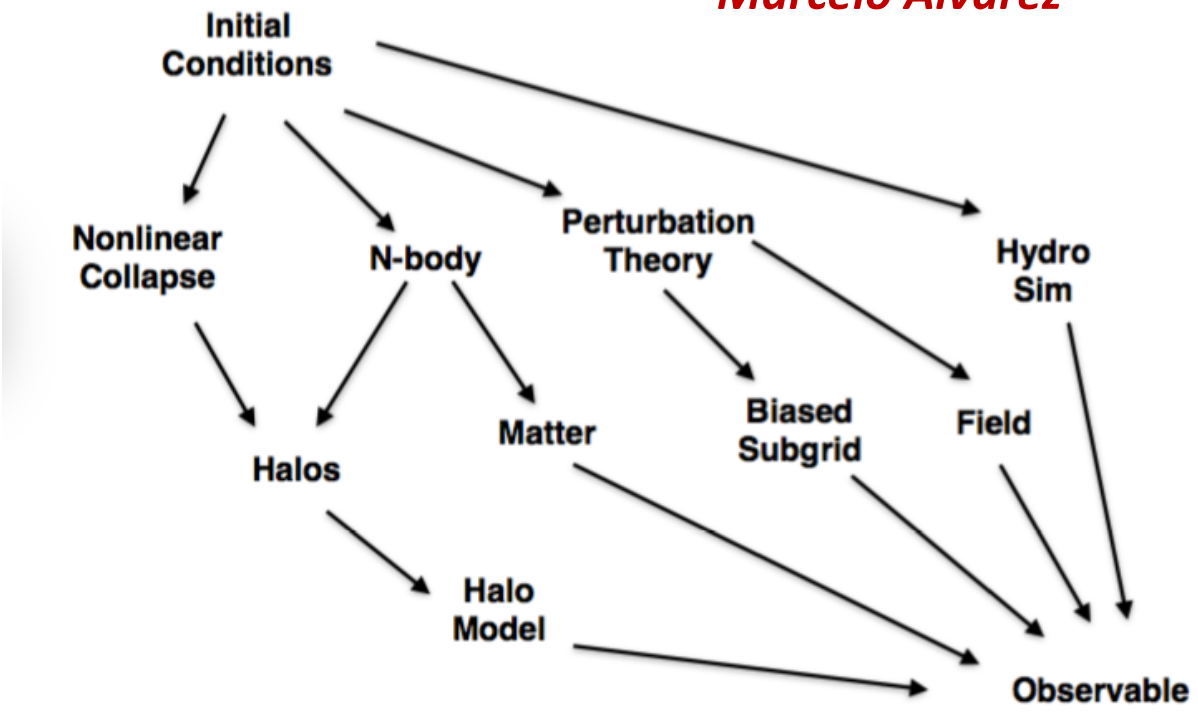
- Cosmological simulations and mock catalogs are needed for all future surveys.
- Even in current surveys like DES, they are among the most challenging deliverables.
- End-to-end simulations and multi-wavelength simulations have recently been developed.
- Analysis tools, like Cosmosis and CosmoLike, are essential.
- There are several open questions and needs for resources!

Questions for discussion

- How do we generate simulations and analysis tools for the different probes for ***different*** surveys: spectroscopic, imaging, CMB, IM.
- How do we ***test and validate*** simulations for ***specific surveys and analyses***? By 'independent' teams?
- Simulations serve multiple needs: covariances, systematics tests, code tests, develop new probes. Which are essential? Higher priority?
- How do we simulate 'beyond wCDM' models rapidly enough, and with real connections to data analysis?
- What is the path to integrating baryonic physics in sims?

Multiple Paths for Sky Simulations

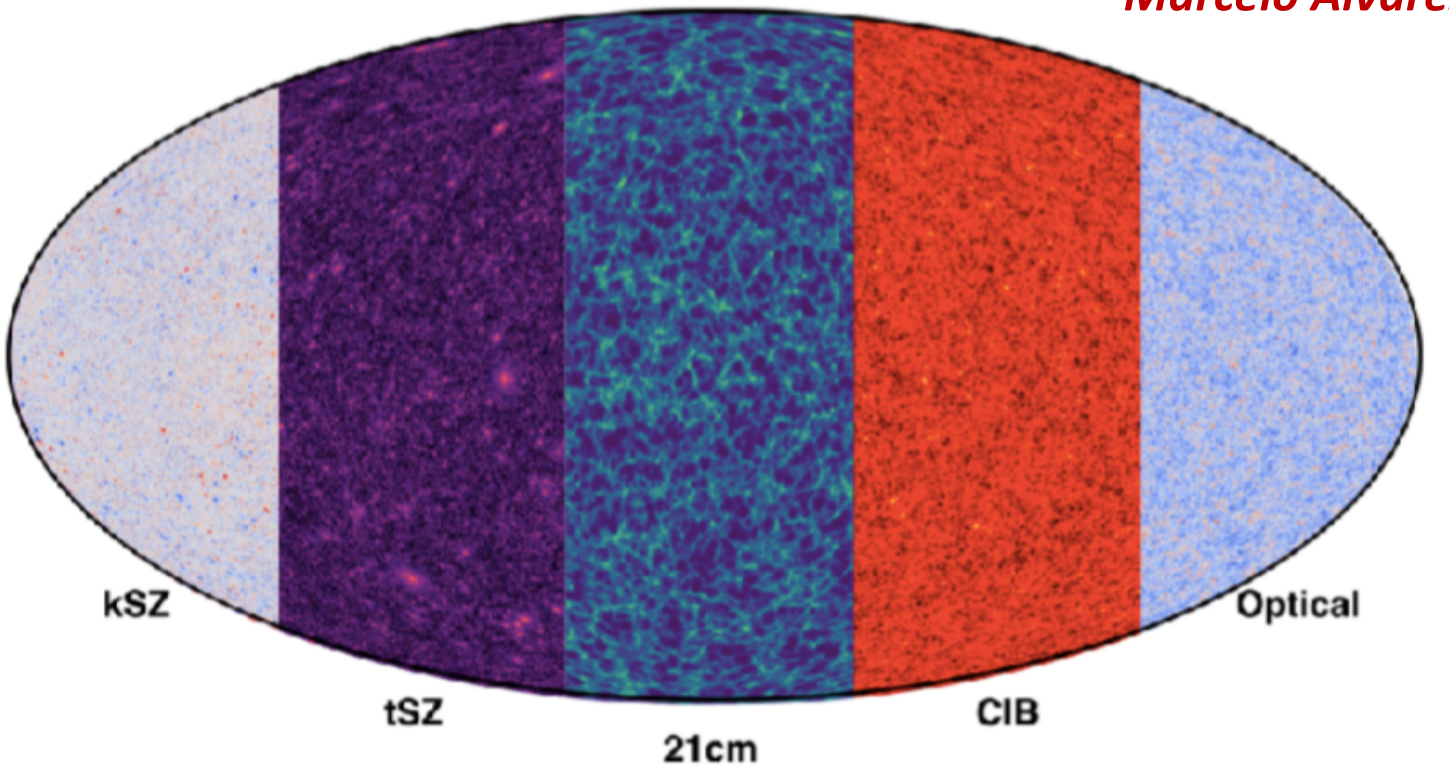
Marcelo Alvarez



The physics and survey needs determine one or a combination of these paths!

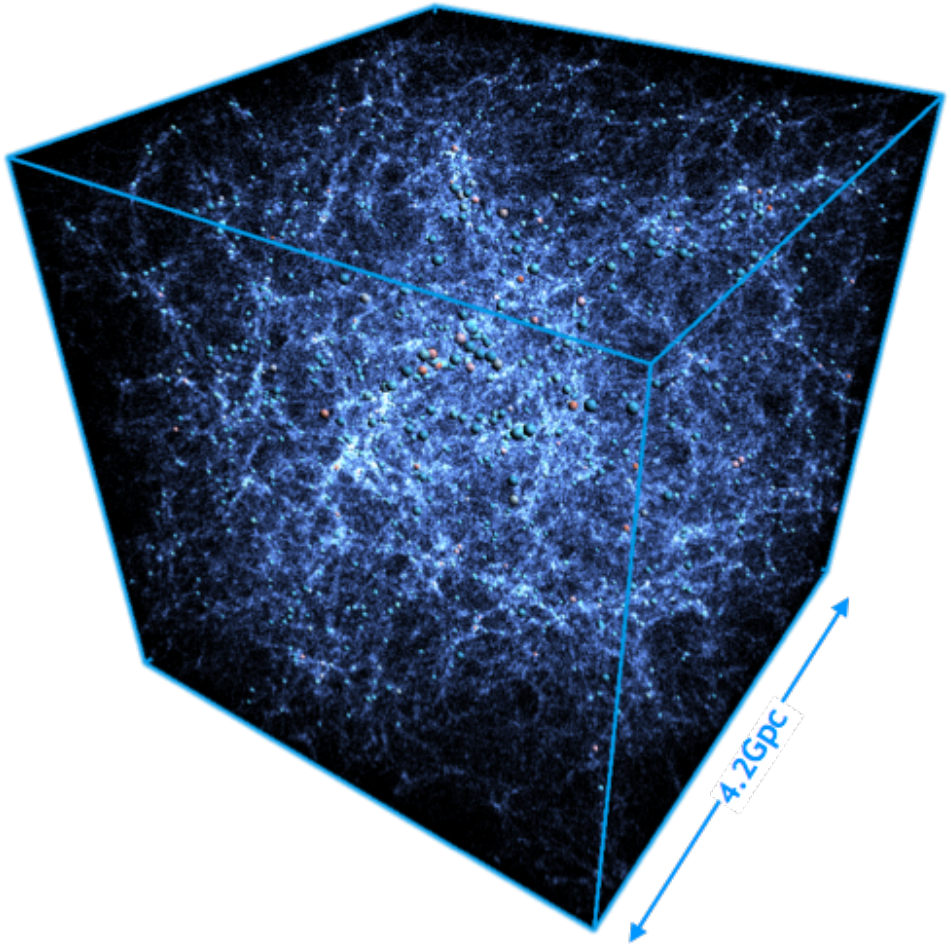
Fast Large Scale Structure Mocks with the Peak Patch Approach (with Bond, Battaglia, Stein, & van Engelen)

Marcelo Alvarez



Dark matter + Halos

Katrin Heitmann



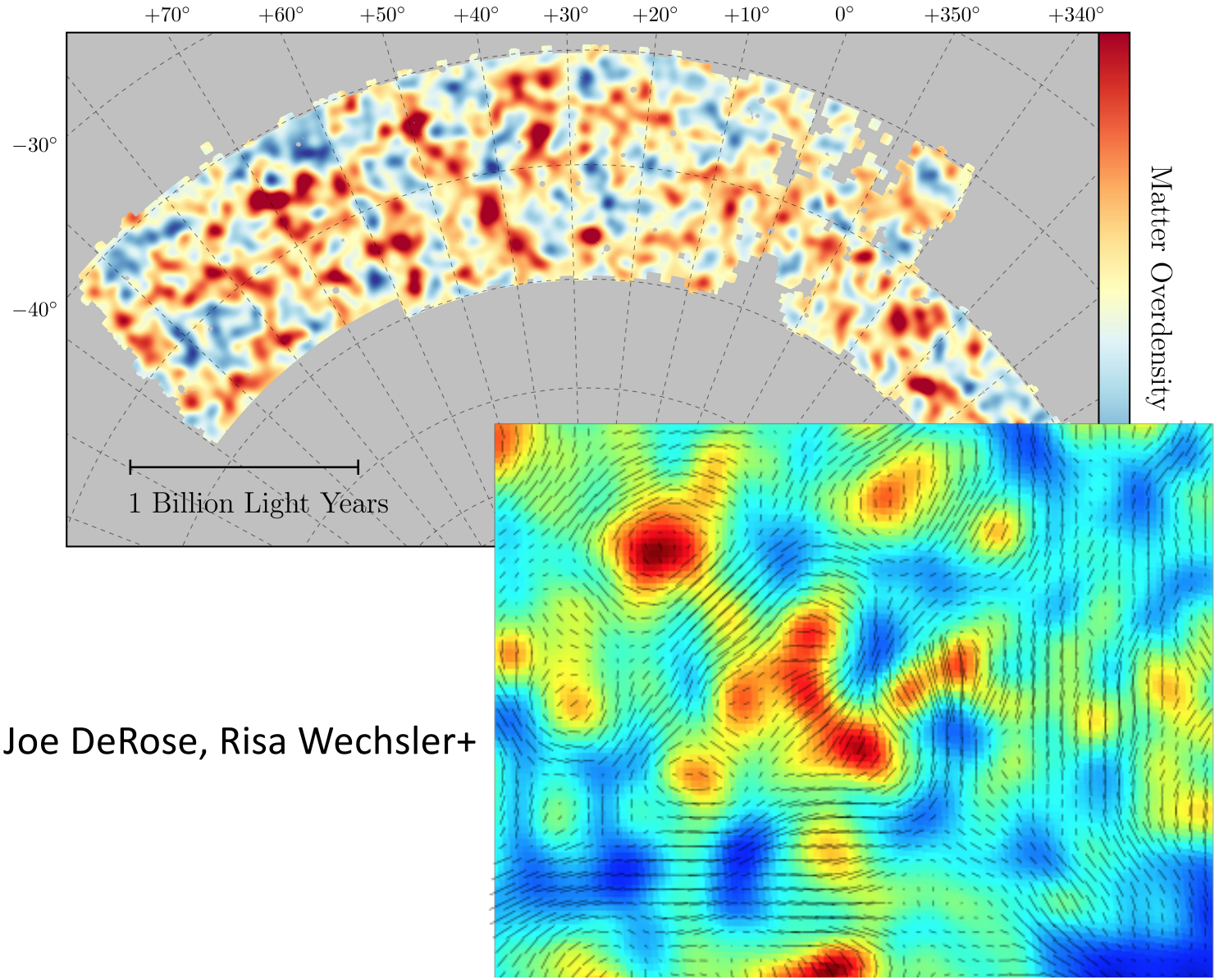
Multi-color galaxy images

LSST phosim image

Galsim multi-color

Katrin Heitmann

Simulated lensing and shear: DES



Joe DeRose, Risa Wechsler+

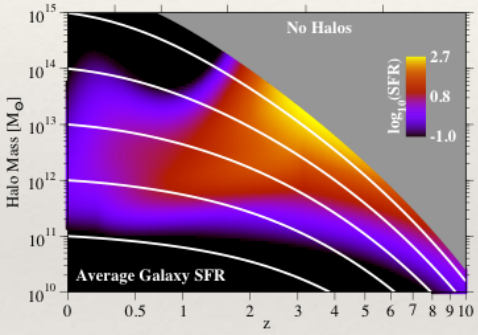
Modeling baryonic physics

Andrew Hearin

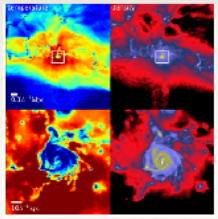
Hydro Simulation Emulation

Emulate multi-tracer cross-correlations with SZ, X-ray, etc

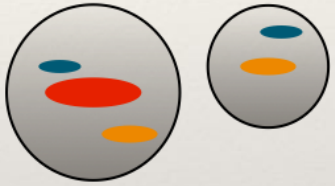
cheap LSS model



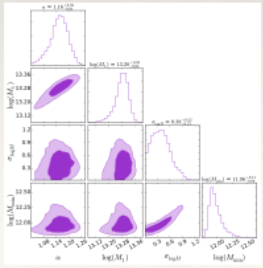
Adiabatic hydro suite



Monte Carlo populations of galaxies + cluster gas profiles

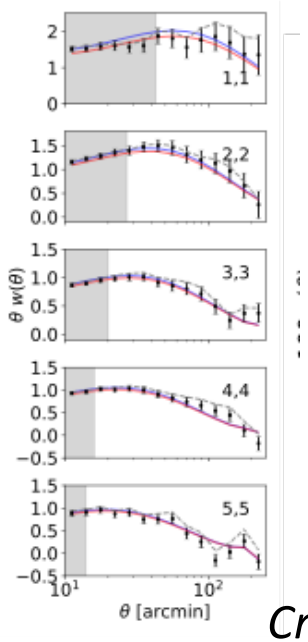


directly emulate χ^2

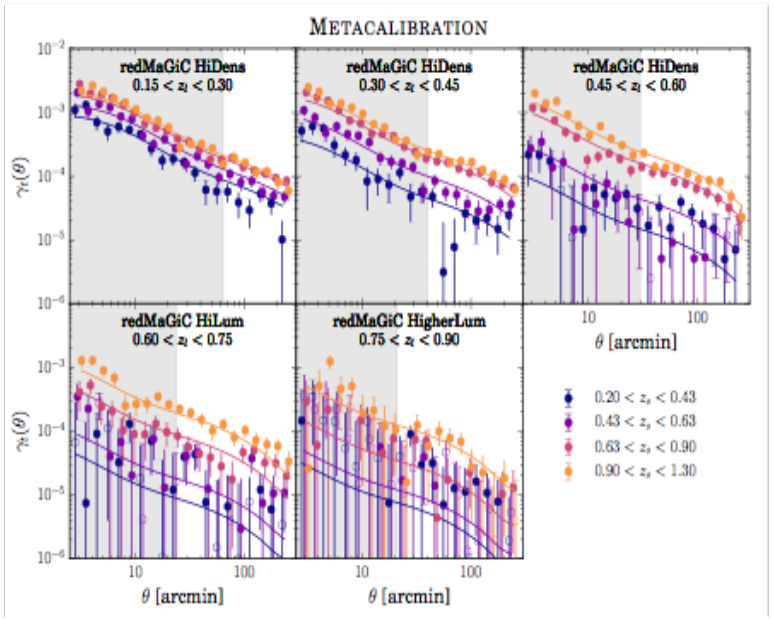


DES 3x2pt Functions

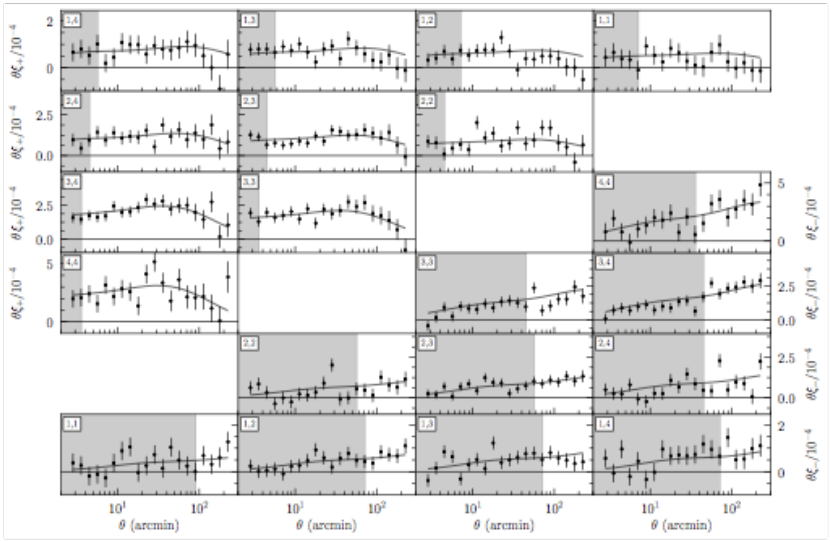
Galaxy w(theta)



Galaxy-shear



Shear-shear



Crocce+, Prat+, Troxel+, Krause+, MacCrann+, DES collaboration

Much of the signal-to-noise is in the nonlinear regime, currently discarded for cosmology. Nonlinear gravity and bias modeling: needs careful validation with simulations and data. How much information will we gain? Is the answer different for BAO, RSD (spectro surveys) and lensing, angular clustering and cross-correlations (imaging surveys, CMB)?

NOAO data lab

Stephanie Juneau talk

- Several challenges in common with LSST Data Center, STScI, and others.
- Goal: enable science analysis in close proximity to the data
- Tools include Jupyter Notebook server that can contact the databases through a Query Manager. Local disk space.
- Several questions up for discussion:
  - How will we deal with the differences in technologies, data models/formats, conventions?
  - Containers with software stack from other data centers – helpful?
  - public (astro community) versus private (survey team) needs for data access and analysis tools.

Please come to these amazing parallel sessions!

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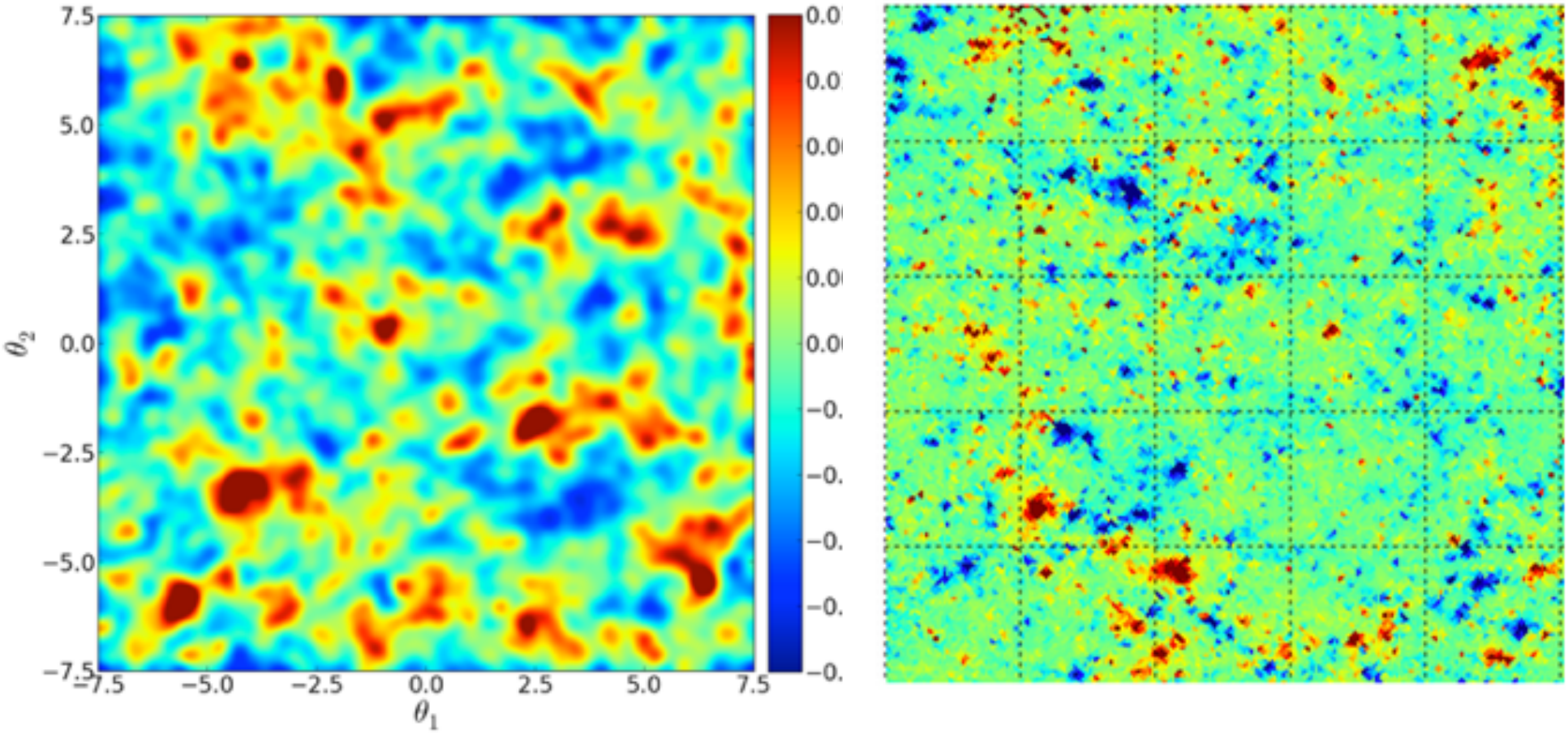
Backups

Projected maps: lensing and kSZ



Argonne group simulations