Modeling the CIB: Lessons Learned

Cosmological Signals from Cosmic Dawn to the Present
Aspen Center for Phyics – February 6, 2018

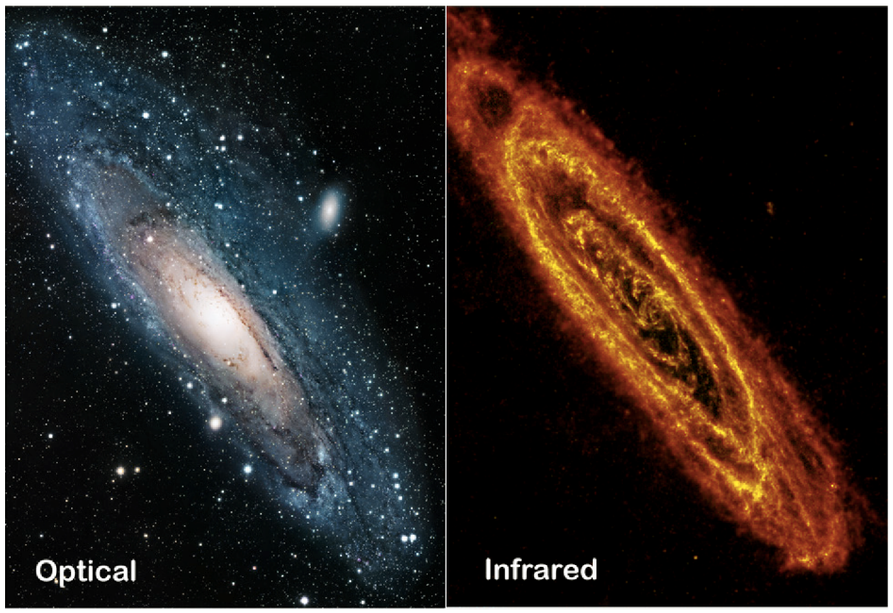
Marco Viero – KIPAC/Stanford University

Outline

- Intro to the CIB
  - ➡How is CIB relevant?
  - ➡How do we interpret (model) it?
- Brief History of Measurements and how Models Fail
  - ➡Spitzer, BLAST, Herschel, Planck, SPT…
- Lessons
  - ➡Non-linear properties need to be part of model from beginning
  - ➡Model parameters should include measurement-based priors

How CIB and Line-Intensity Mapping are Similar

- Trace Star Formation



- Limited by Source Confusion
- Strong Redshift Evolution

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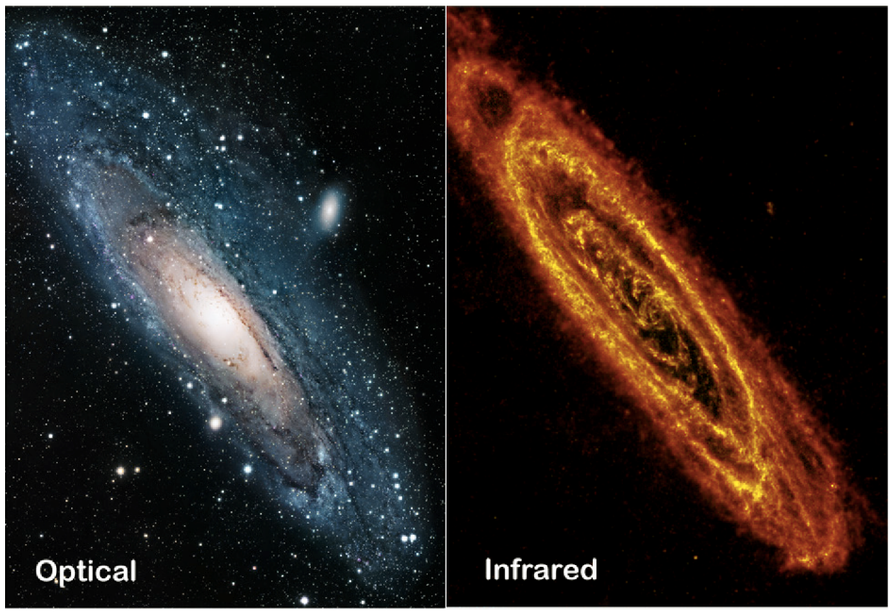

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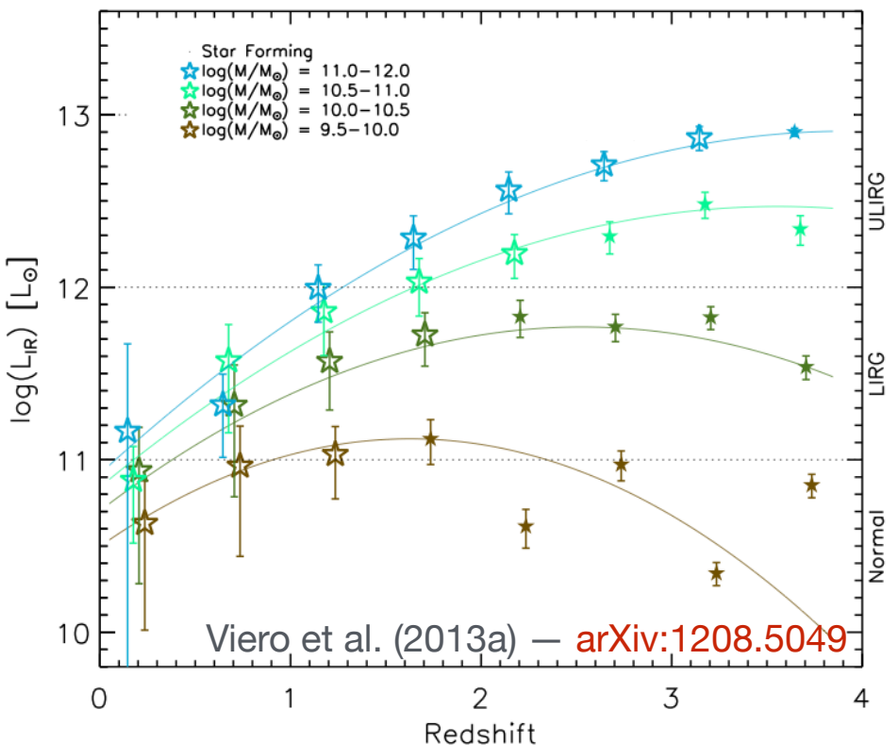

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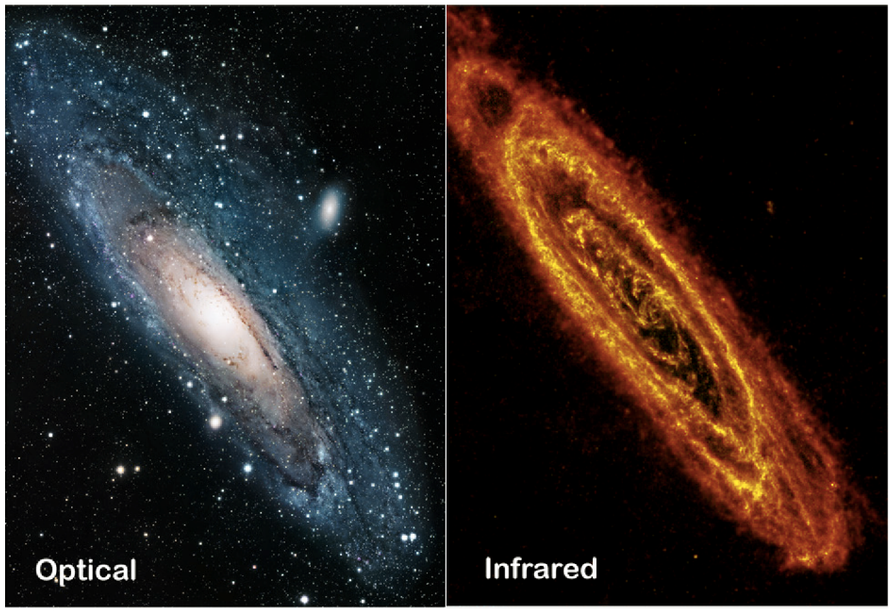

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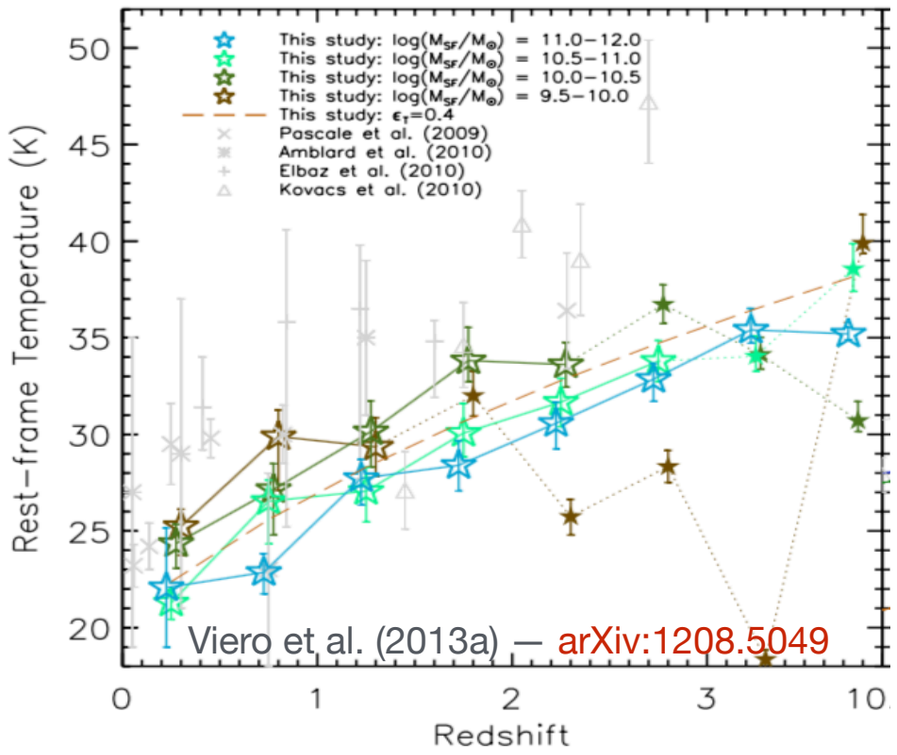

Viero et al. (2013a) — arXiv:1208.5049

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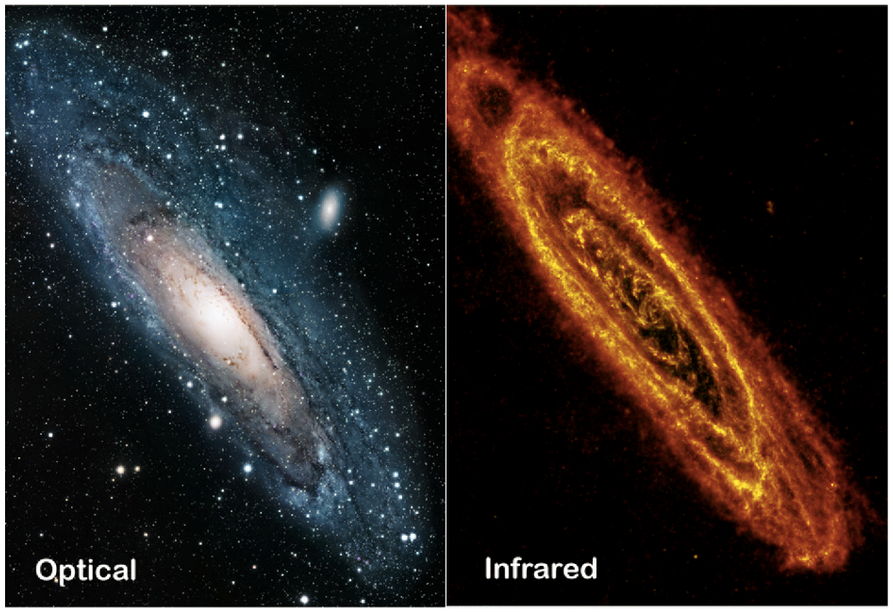

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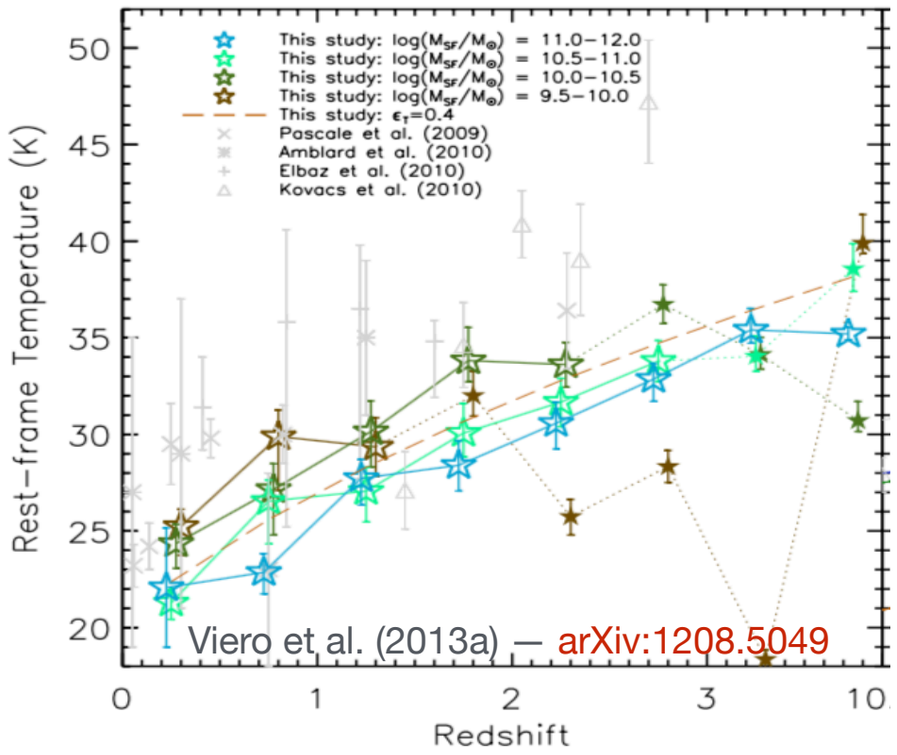

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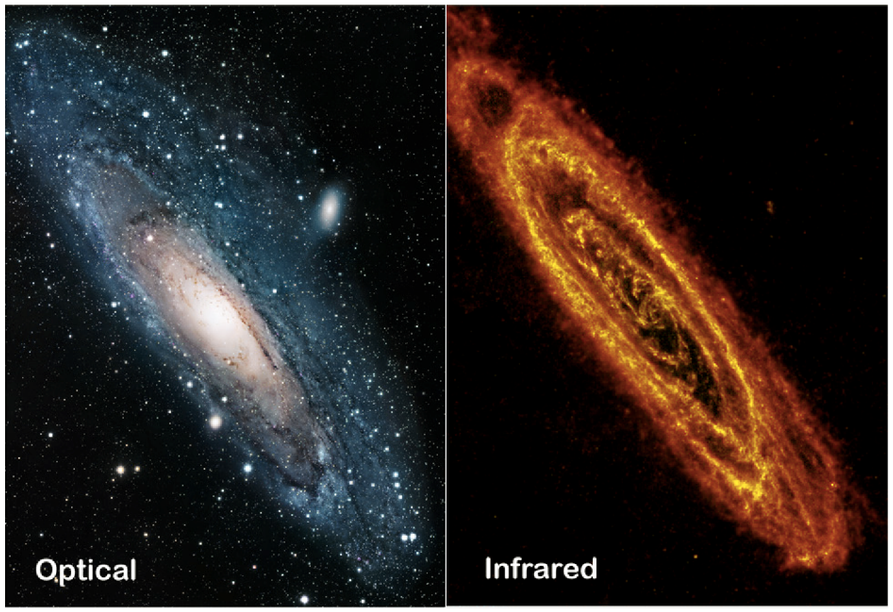

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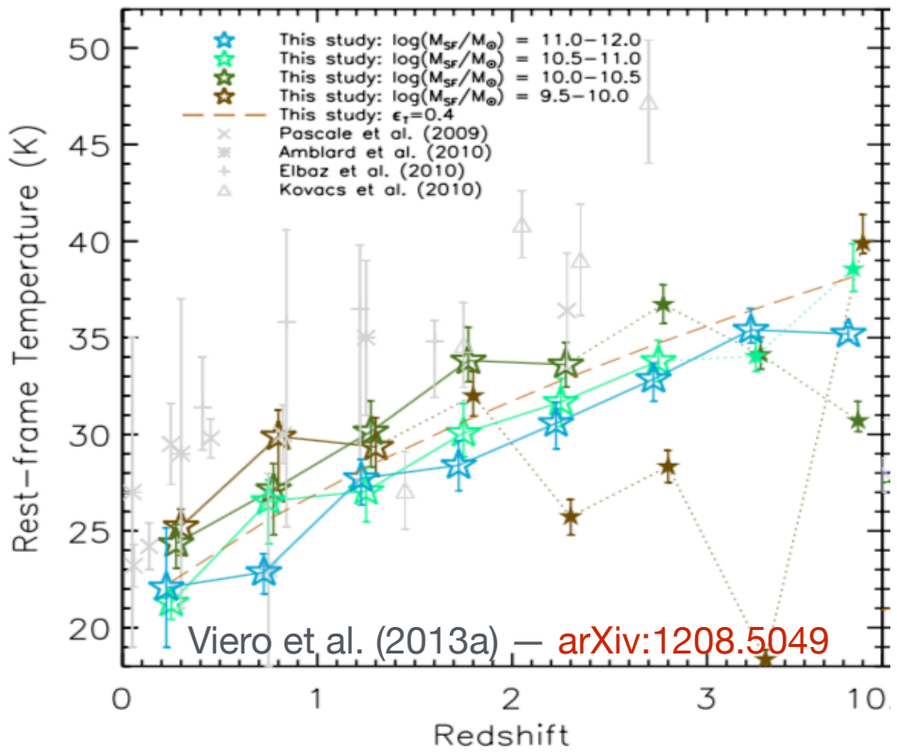

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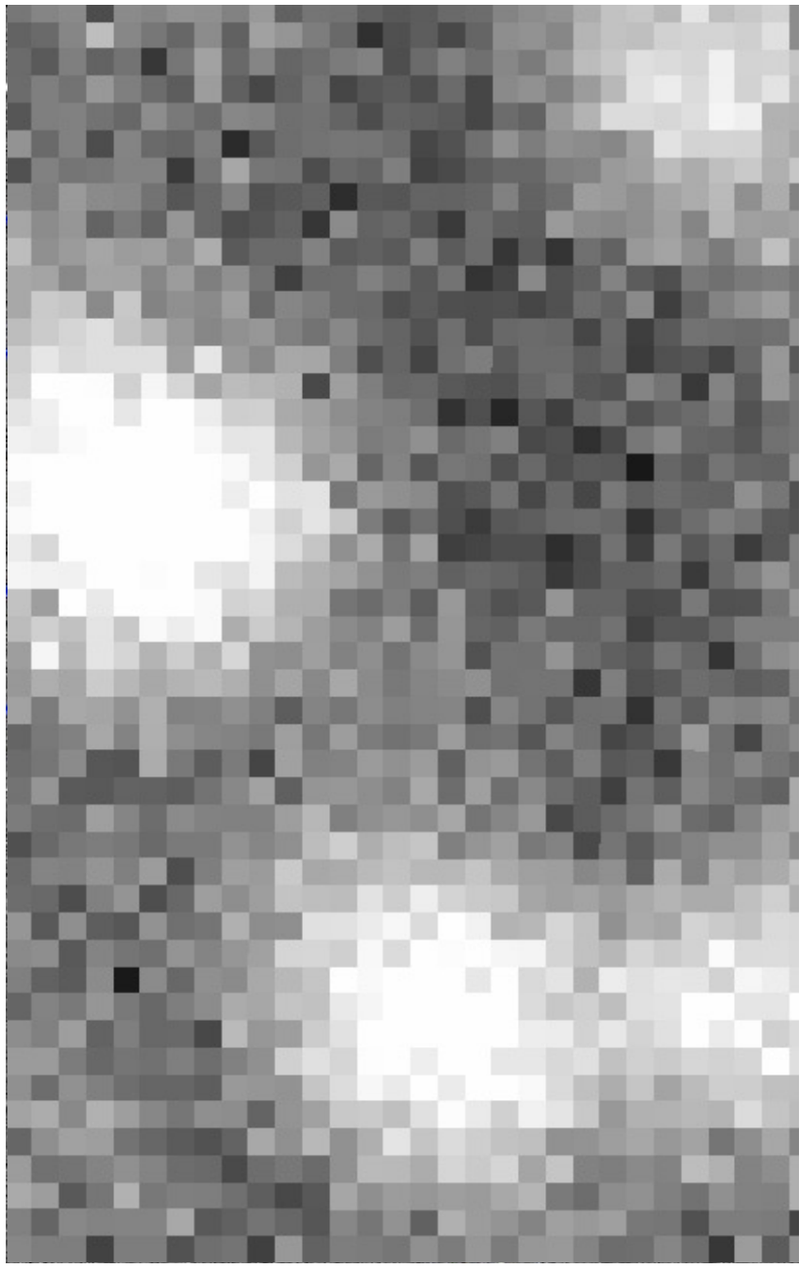

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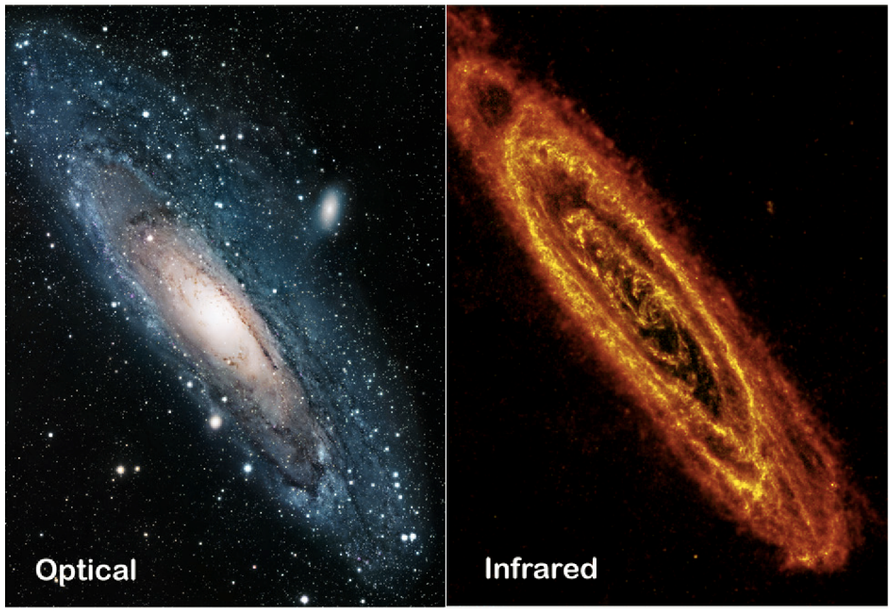

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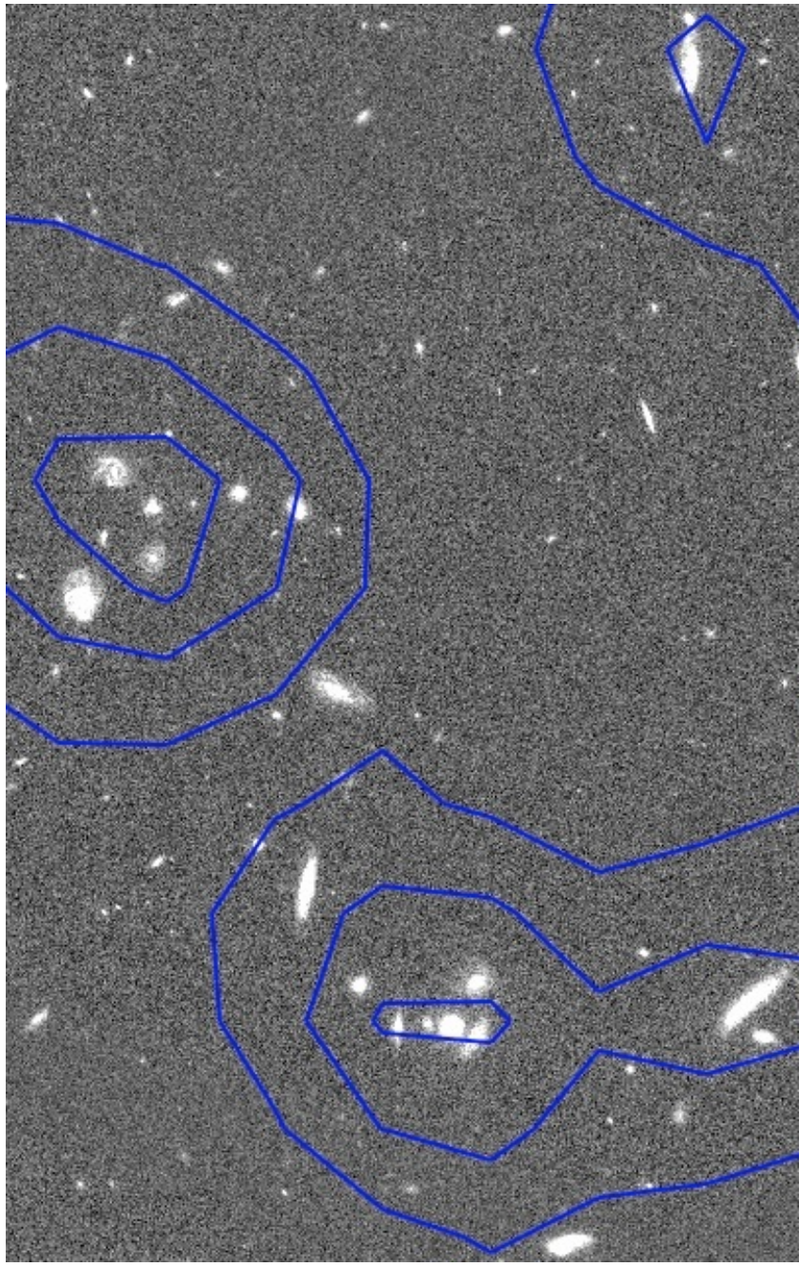

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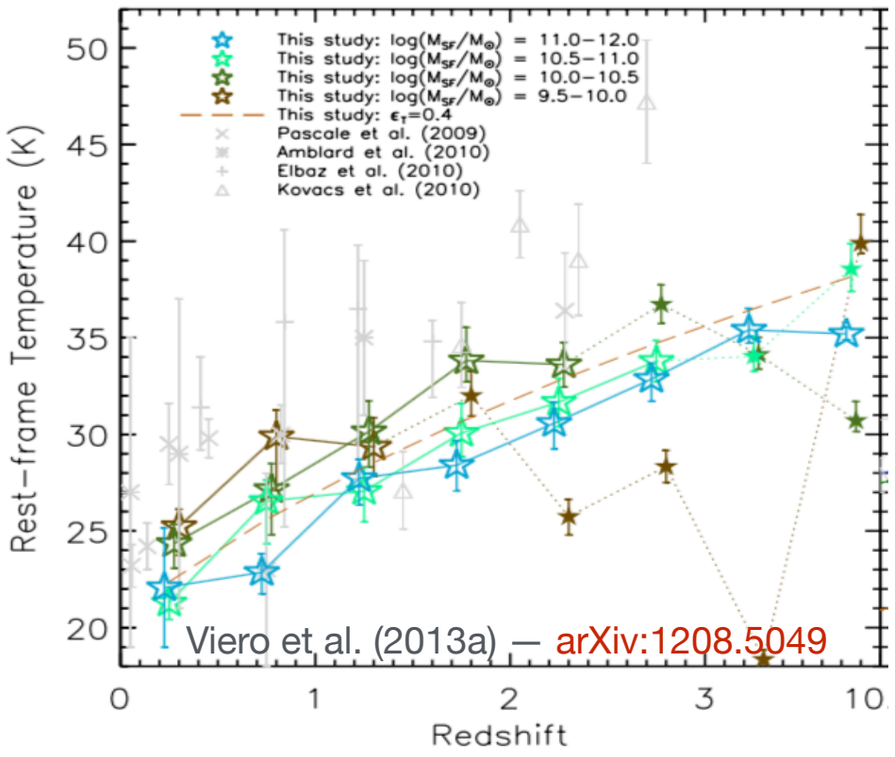

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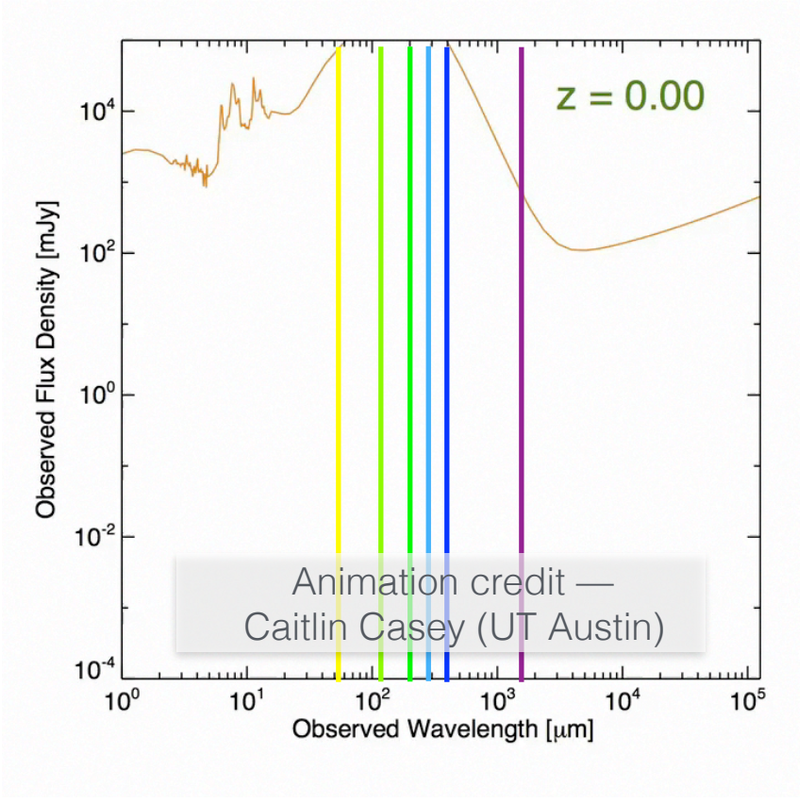

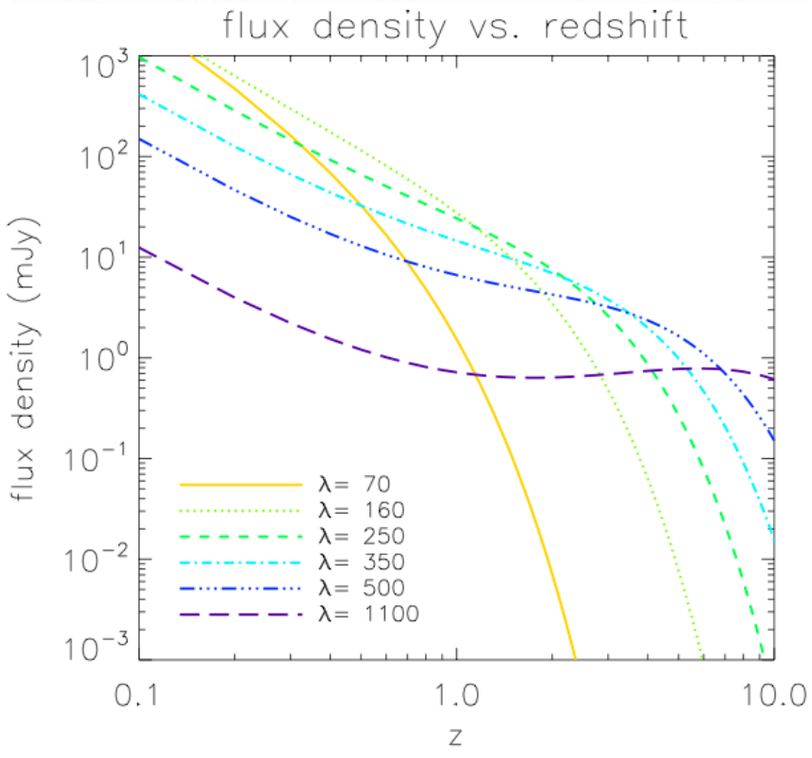

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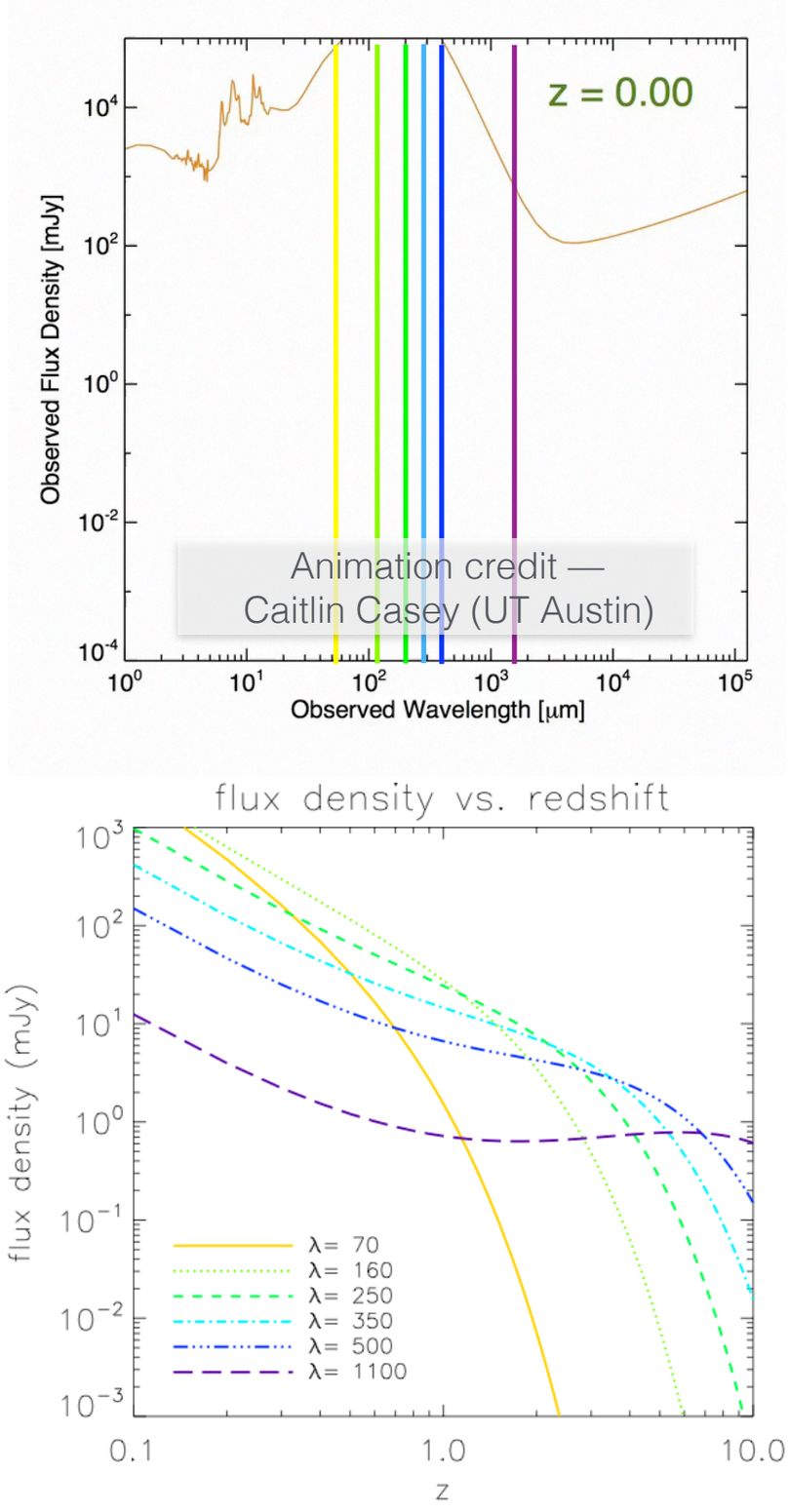

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  - ➡Galaxies at all redshifts projected on a 2D image
  - ➡Tease them out using sensitivity of different bands to redshifts

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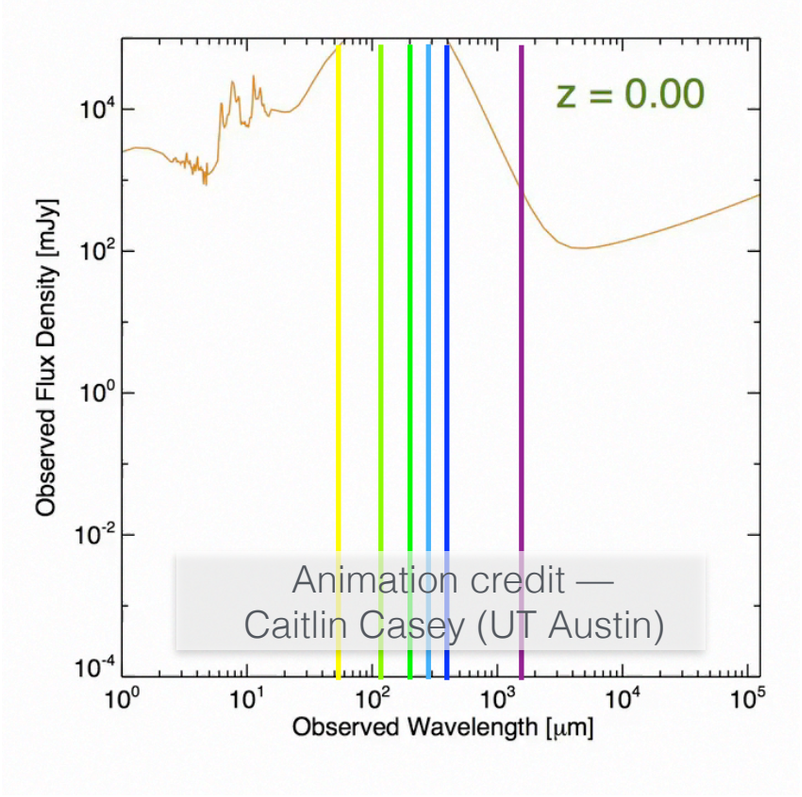

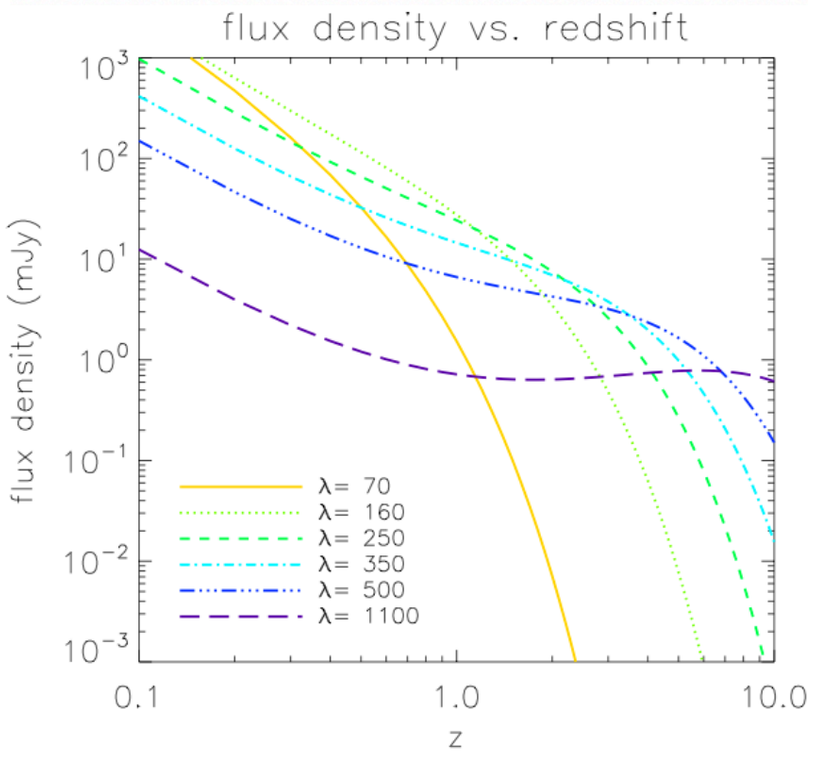

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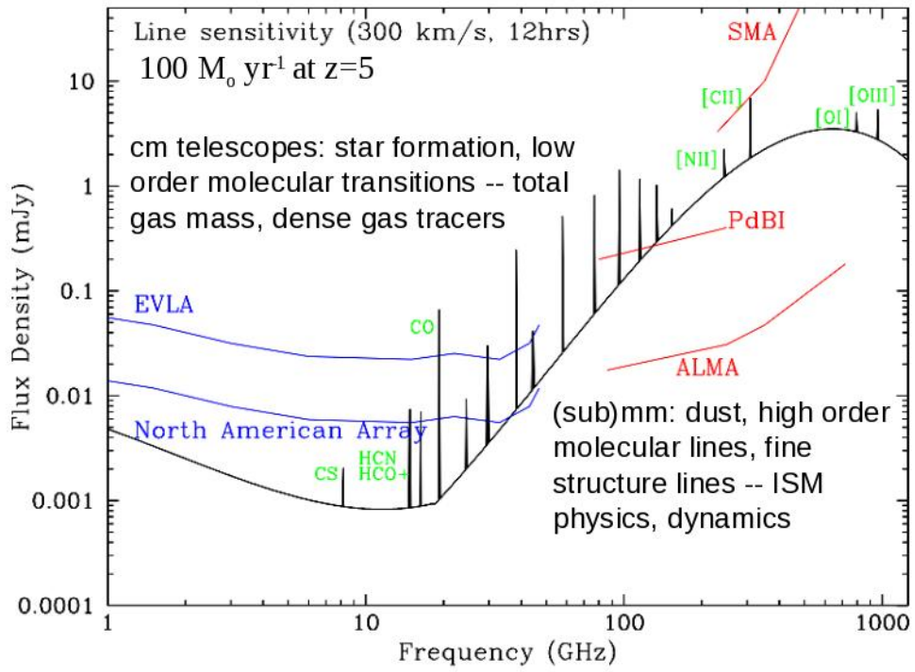
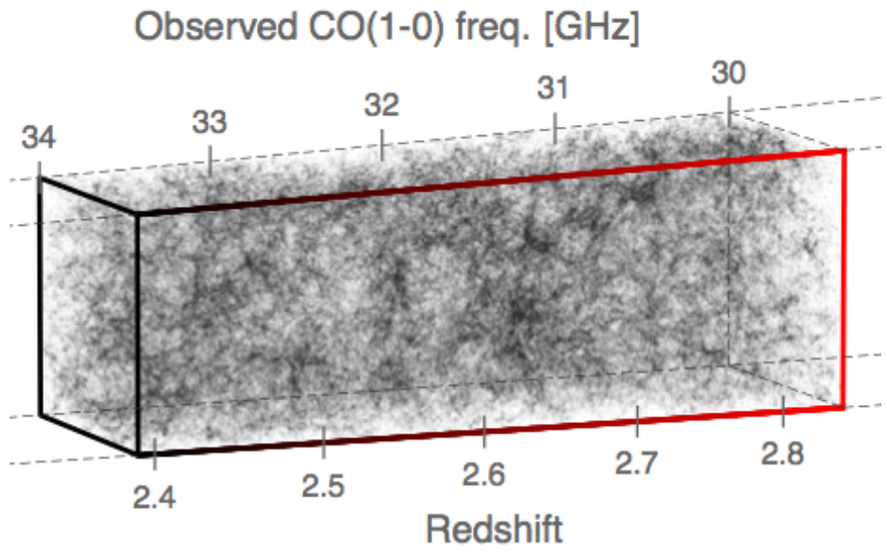
- Line-intensity cubes contain redshift information by default (assuming you know the line)

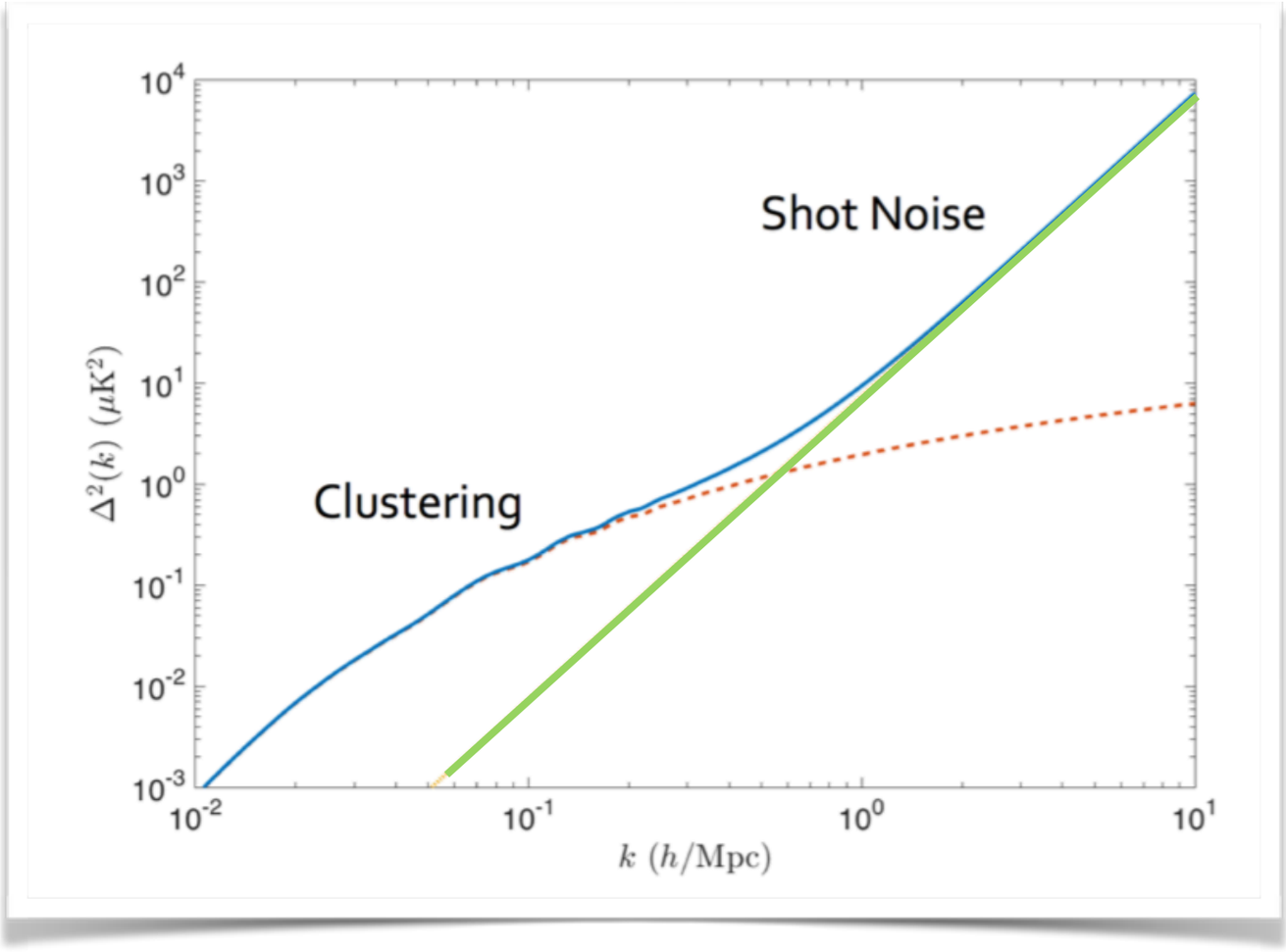


Carilli et al. (2010) — arXiv:1006.0988



Li et al. (2016) — arXiv:1503.08833

CIB Power Spectrum



Halo Model: see e.g., Cooray & Sheth (2000)

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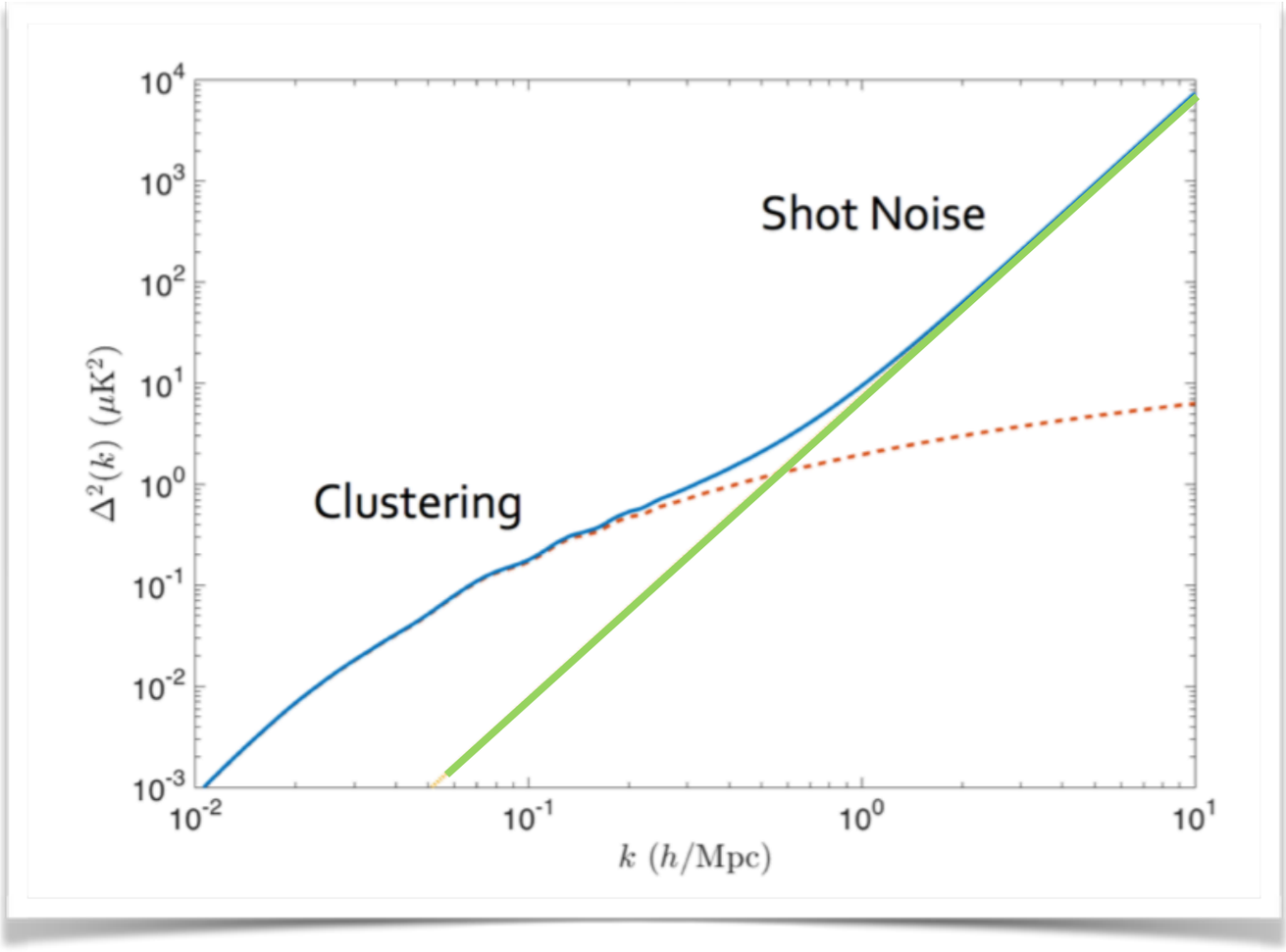
  ➡Poisson (or Shot) Noise
  - 2nd moment number counts



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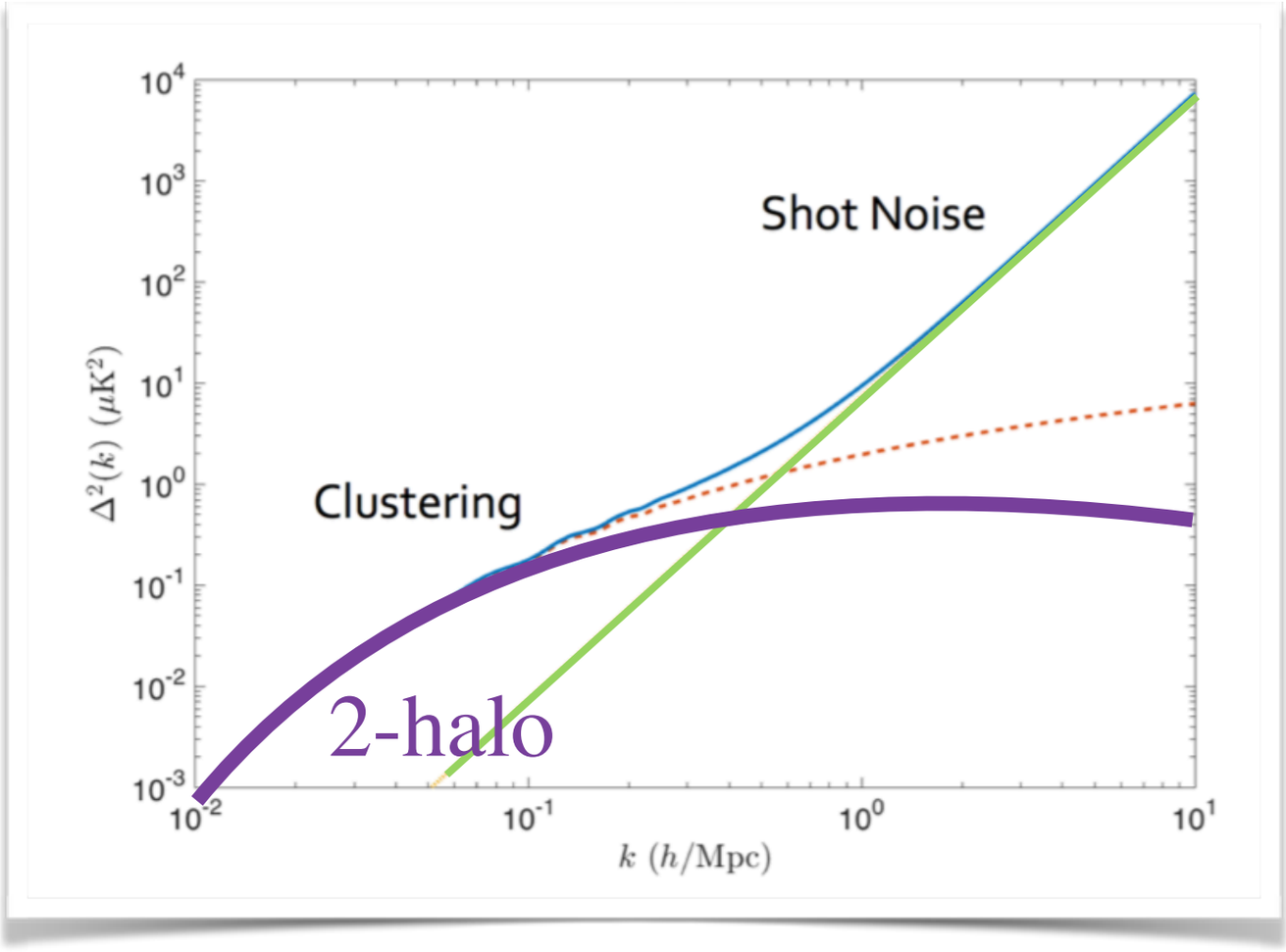
  - Large-scale bias
  - What halos dominate LIR



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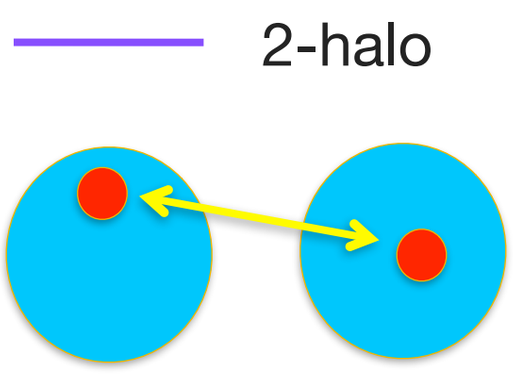

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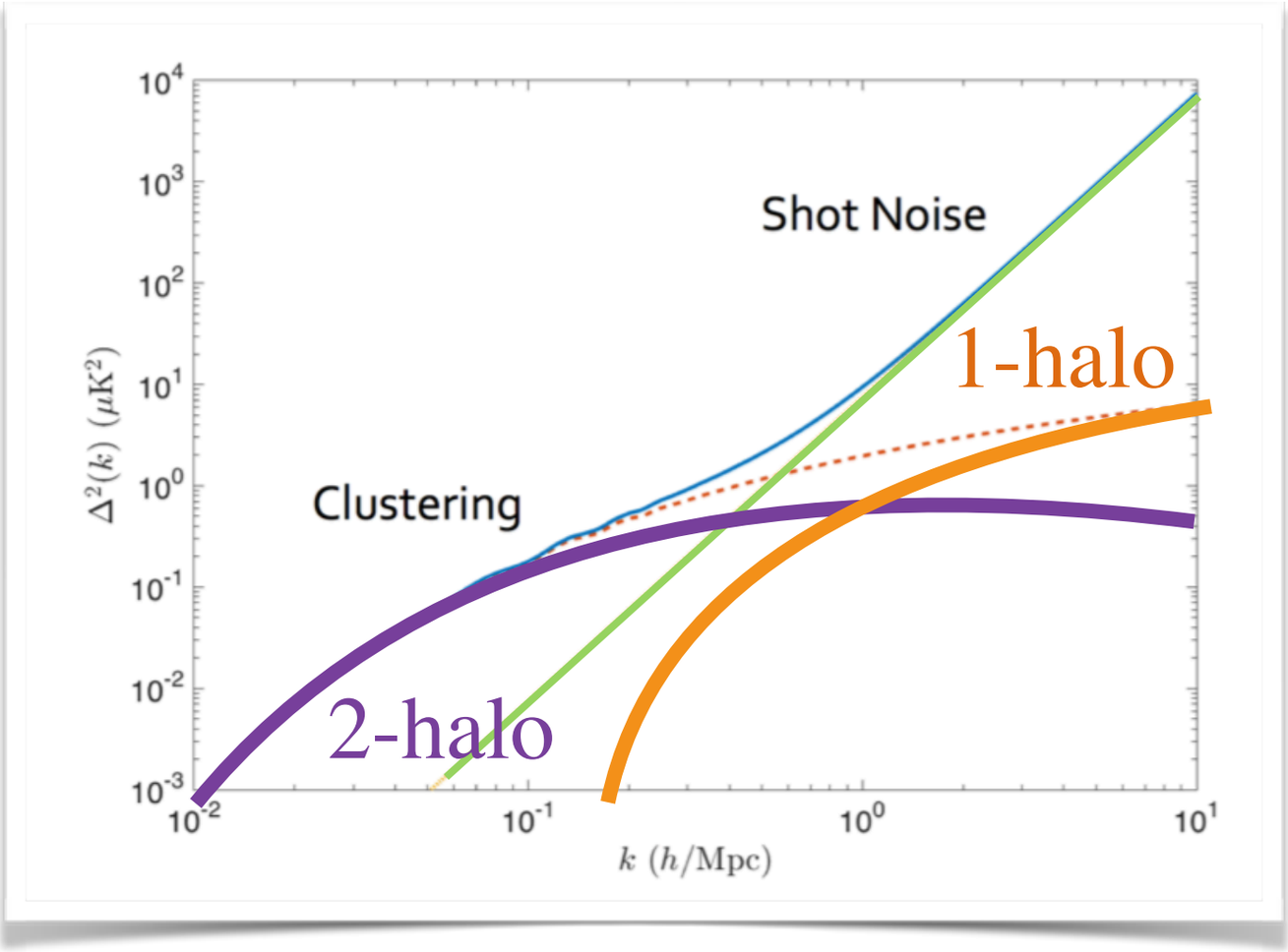
  ➡1-Halo (Non-Linear) Term
  - How to DSFGs occupy large halos
  - Potentially sensitive to *assembly bias*



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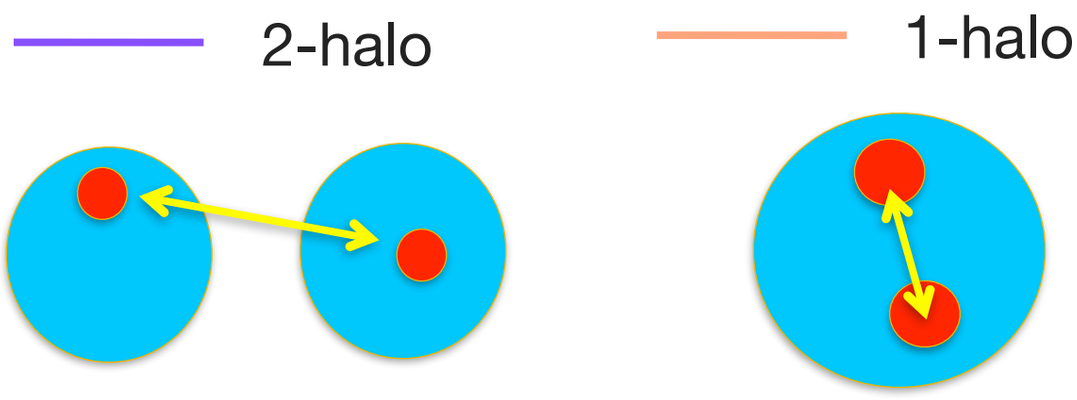

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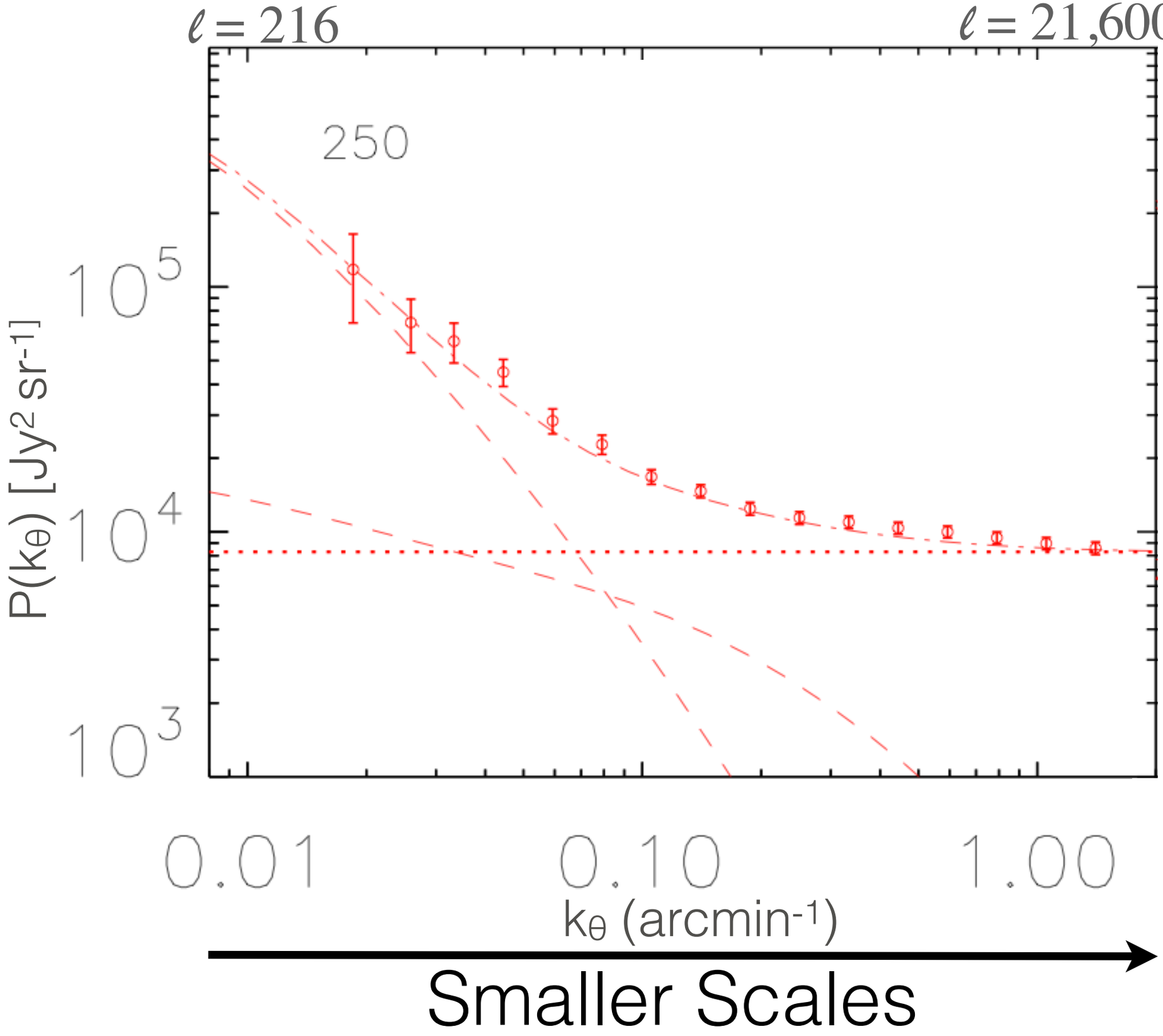

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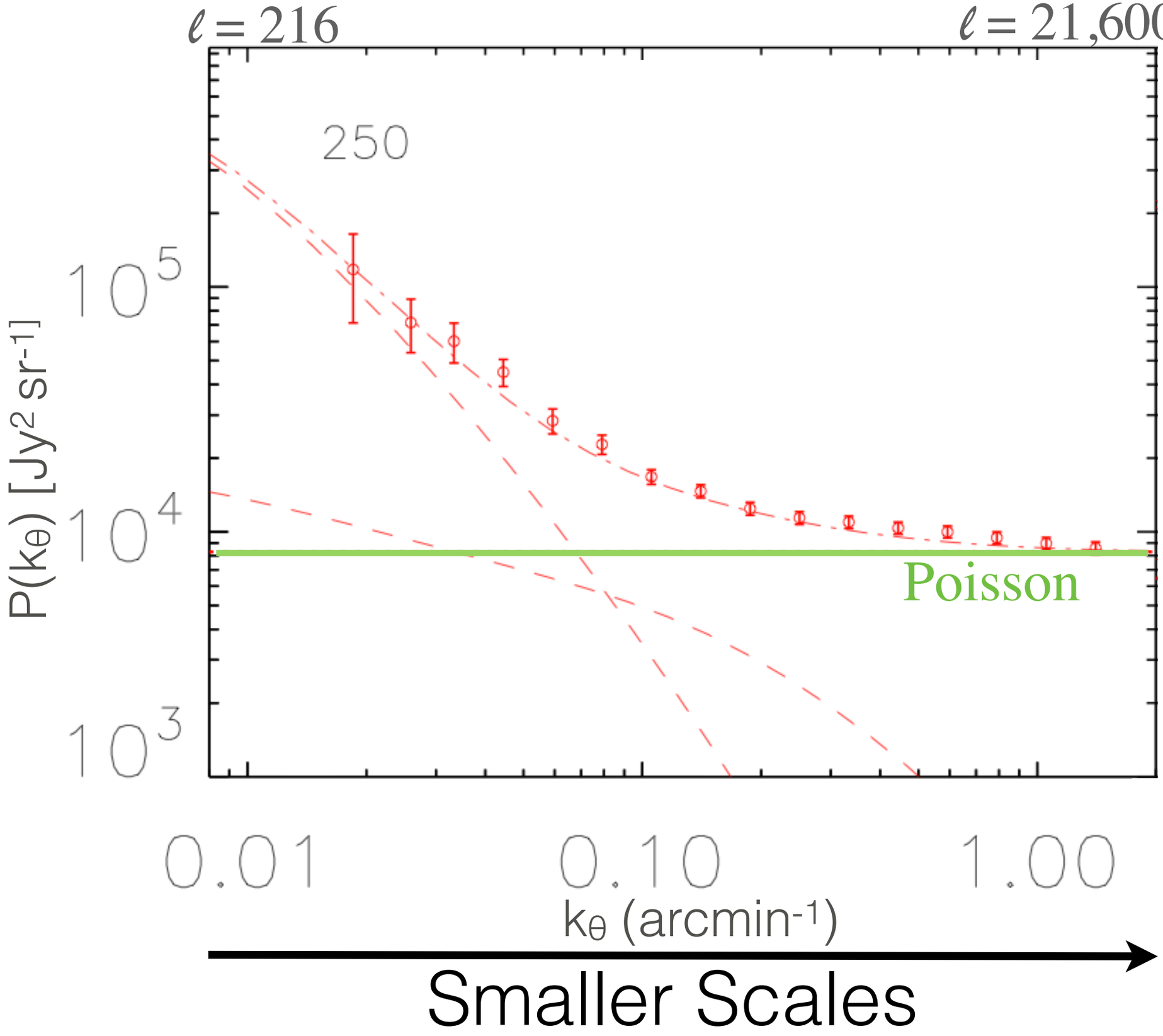

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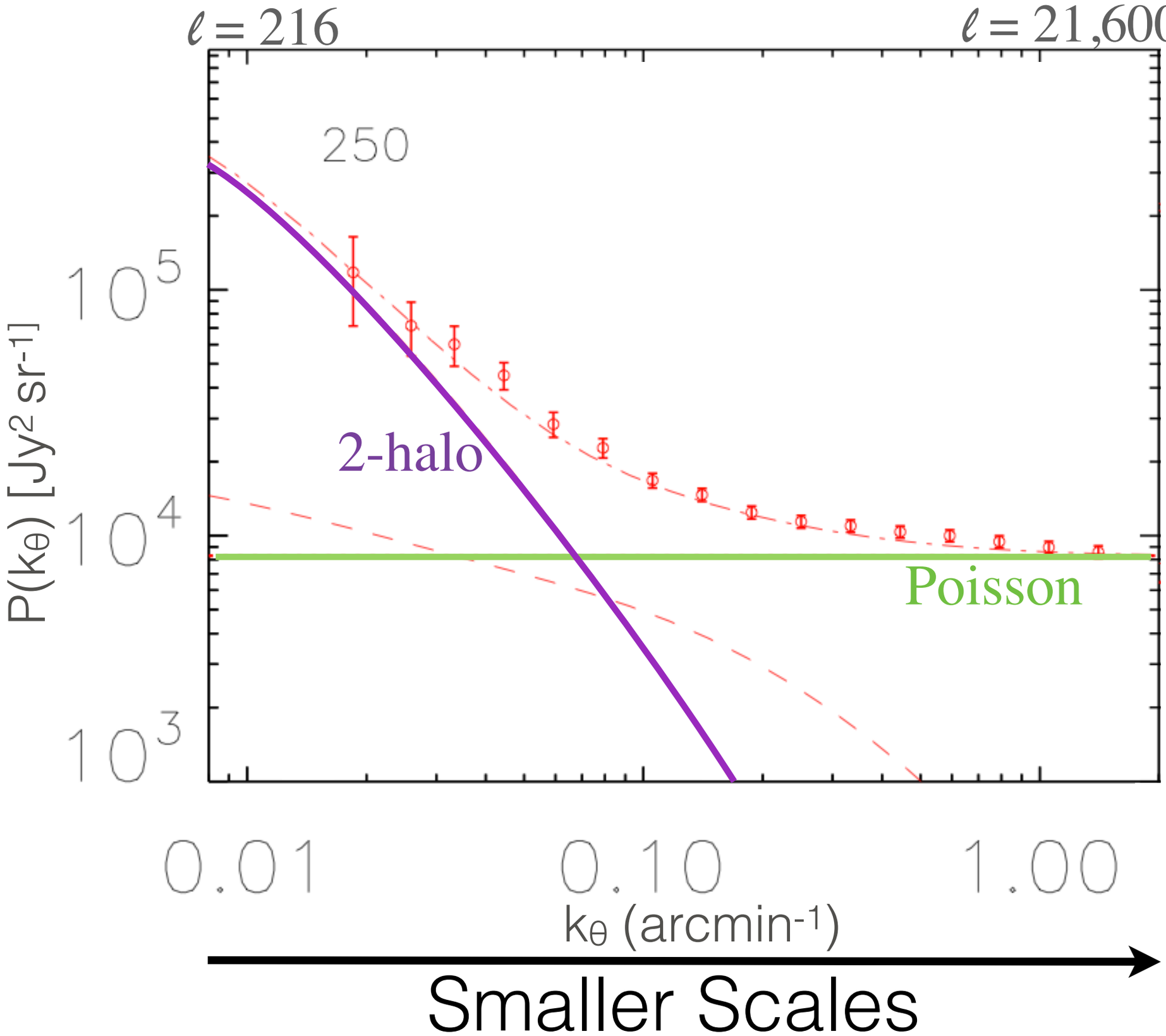

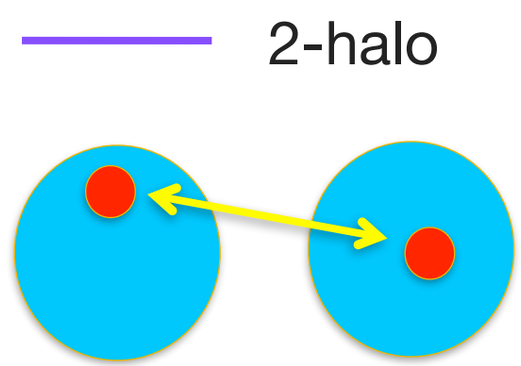

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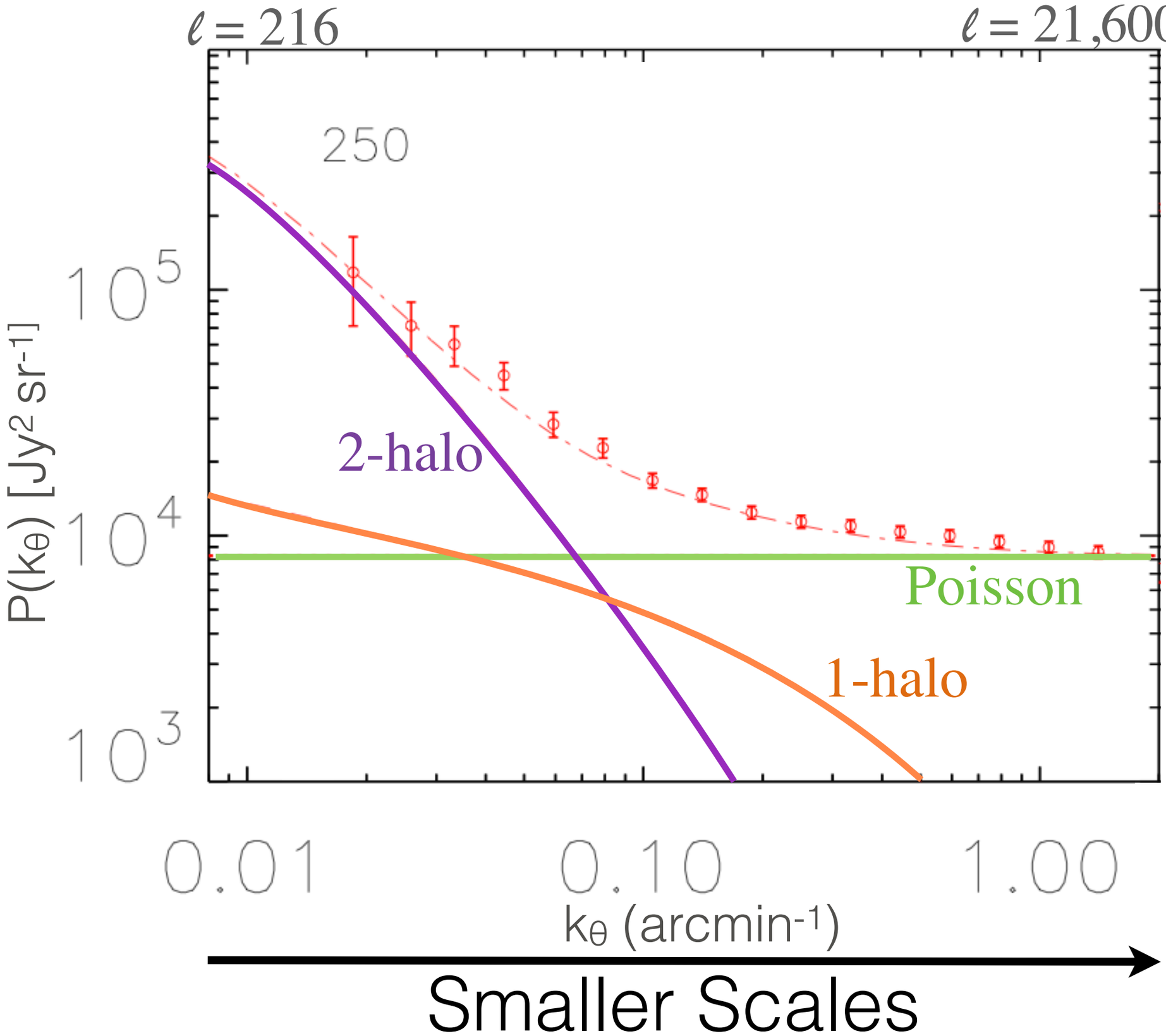
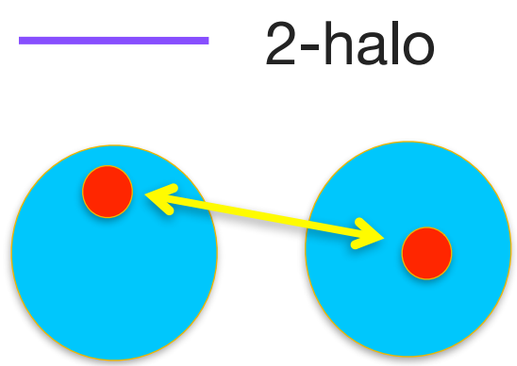
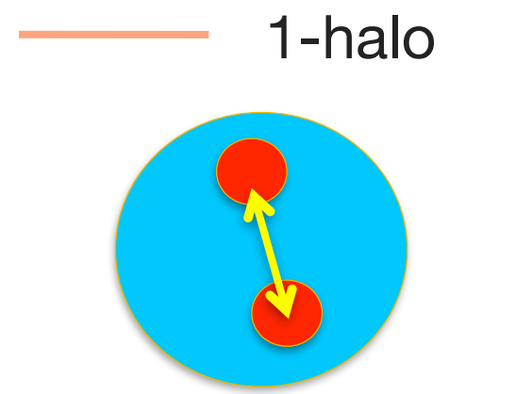






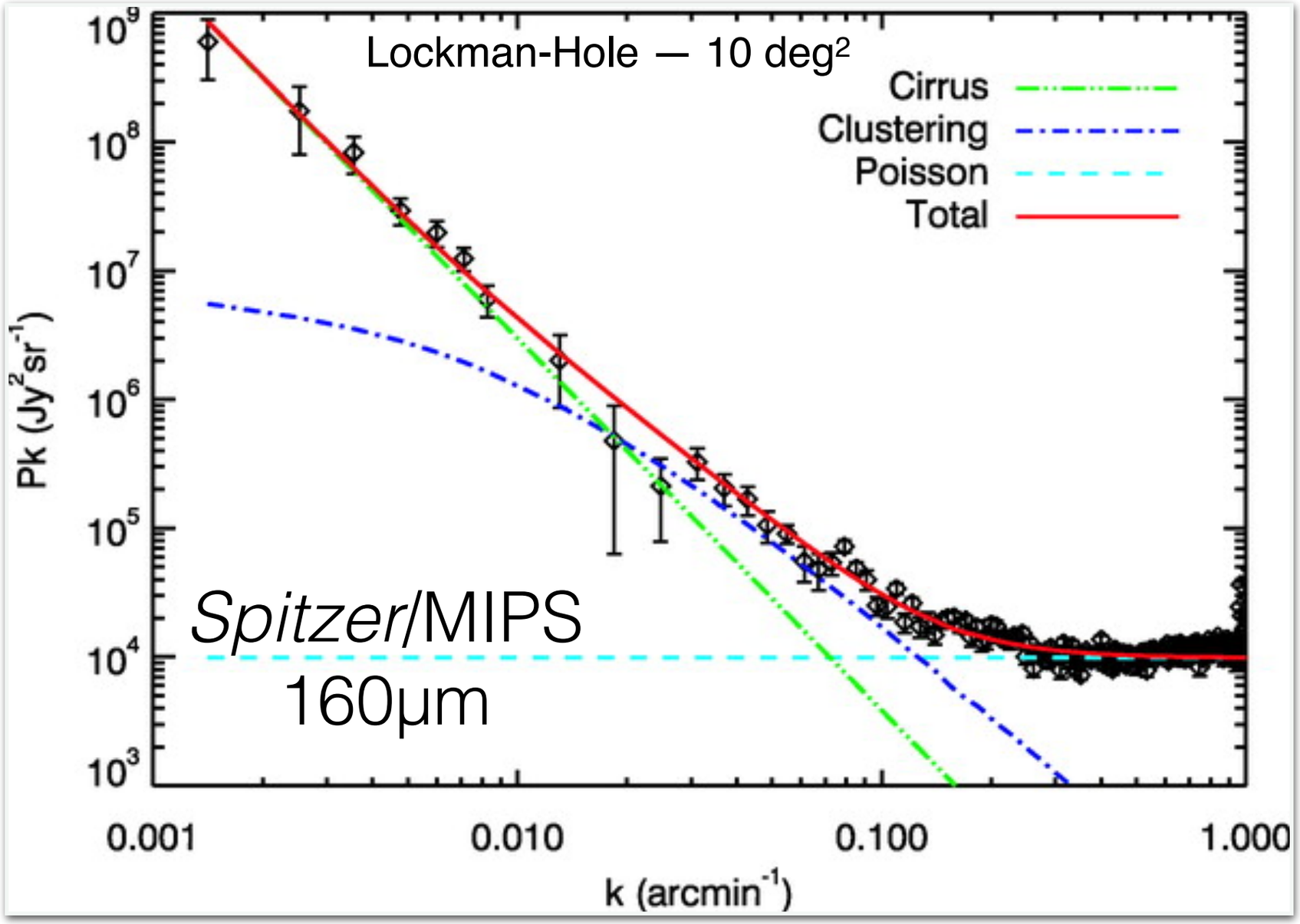
Quickly: What's inside an *Analytic* Halo Model?

A Typical Analytic Halo Model Contains:

- Luminosity to Halo Mass (L-M) Relation
  - ➡Is LIR tied to Halo mass (and if so, how?)
  - ➡Quiescent Fraction?
- SED
  - ➡Modified Blackbody (Graybody) or Templates?
    - ➡Fix beta (the RJ slope)?
- Redshift Evolution
  - ➡Of the Luminosity (e.g., Power Law?, Flatten at z~2?)
  - ➡Of the T_{dust}
- Shot Noise (Poisson) Terms
  - ➡Tied or Free?
- SZ effect Terms

CIB Models — Spitzer

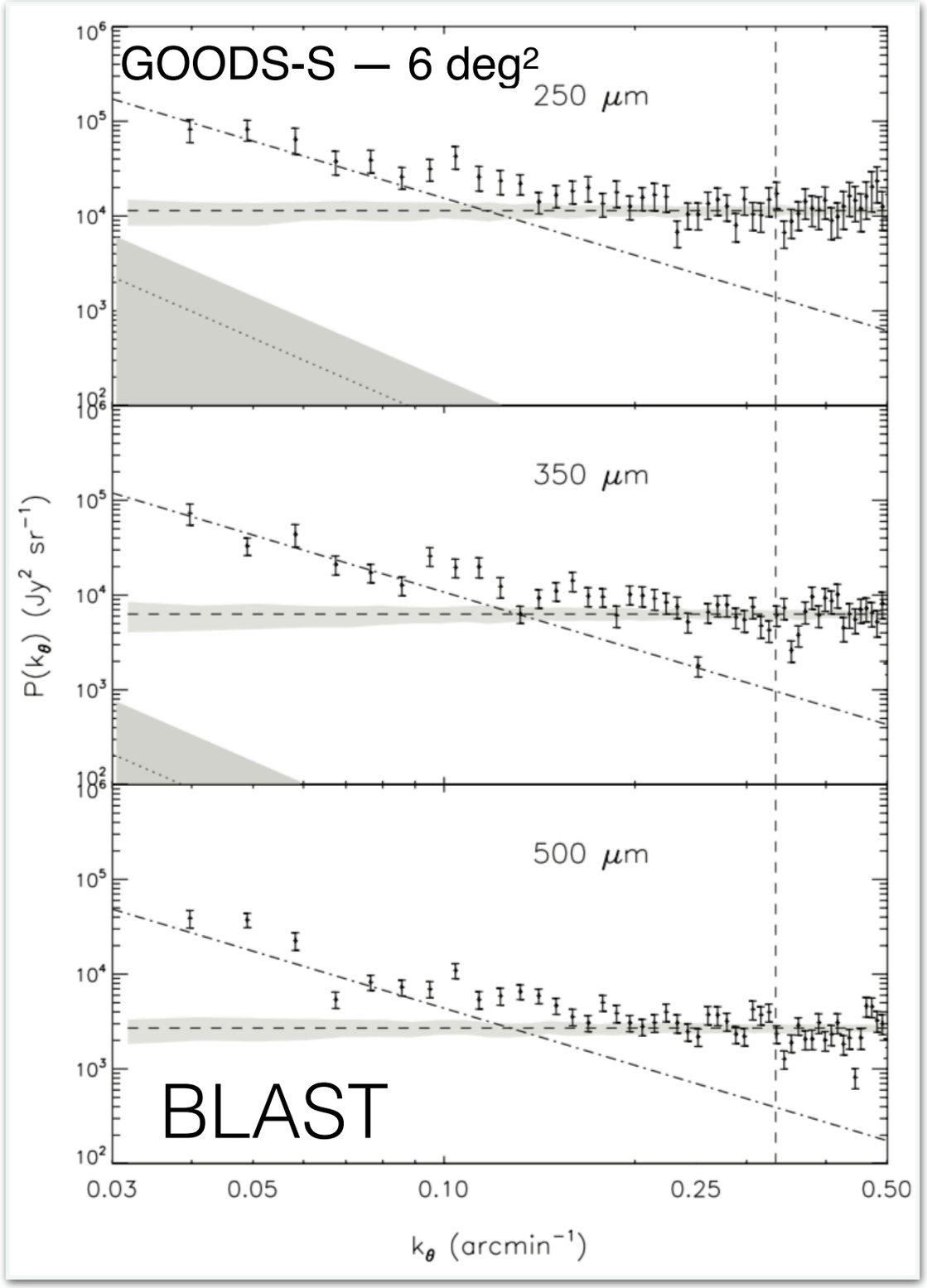
- First detection of the CIB power spectrum *Spitzer*/MIPS 160μm.
- Key Finding
  - ➡linear bias = 1.74+-0.16
- Galactic Cirrus dominates the low-ell signal.
- Problems:
  - ➡Though unable to justify at the time, we now know 1-halo term significant at k>0.1



Lagache et al. (**2007**) — arXiv:0707.2443

CIB Models — BLAST

- **BLAST** — balloon-based pathfinder to SPIRE on the *Herschel Space Observatory*
  - ➡Clean Patch, Cirrus Subdominant



Viero et al. (**2009**) — arXiv:0904.1200

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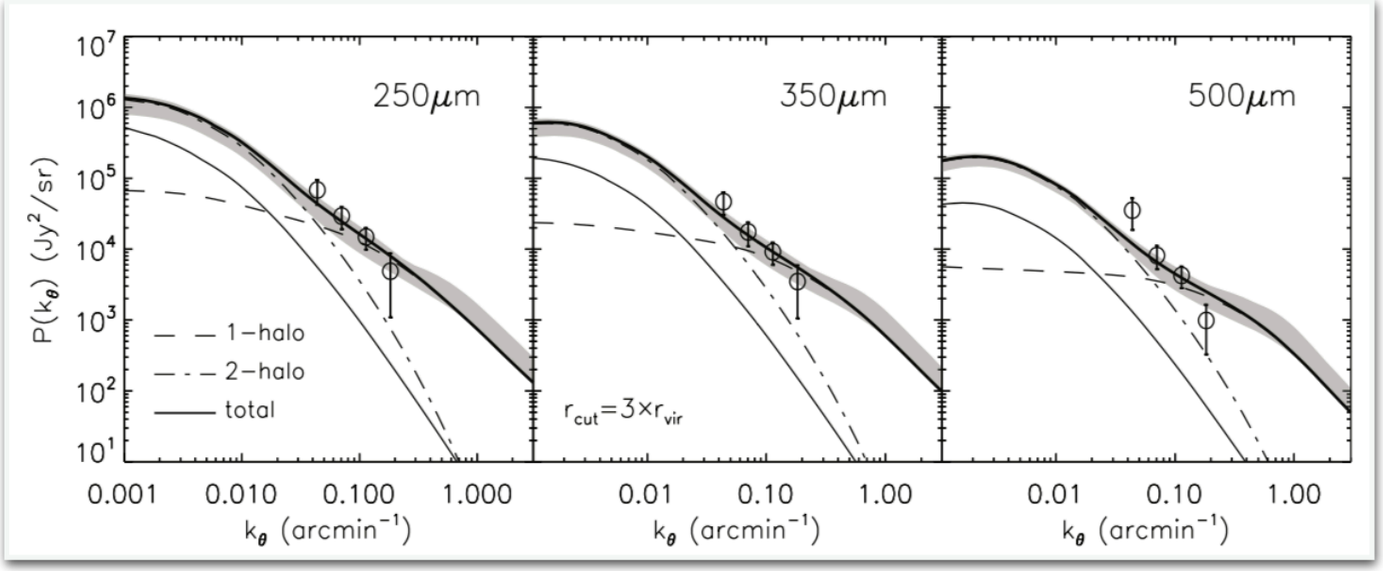
  - ➡effective bias = 2.2-2.6
  - ➡$\log(M_{min}/M_\odot) = 11.5$
  - ➡$\log(M_{eff}/M_\odot) = 12.8$
- Problems:
  - ➡No evolution with z.

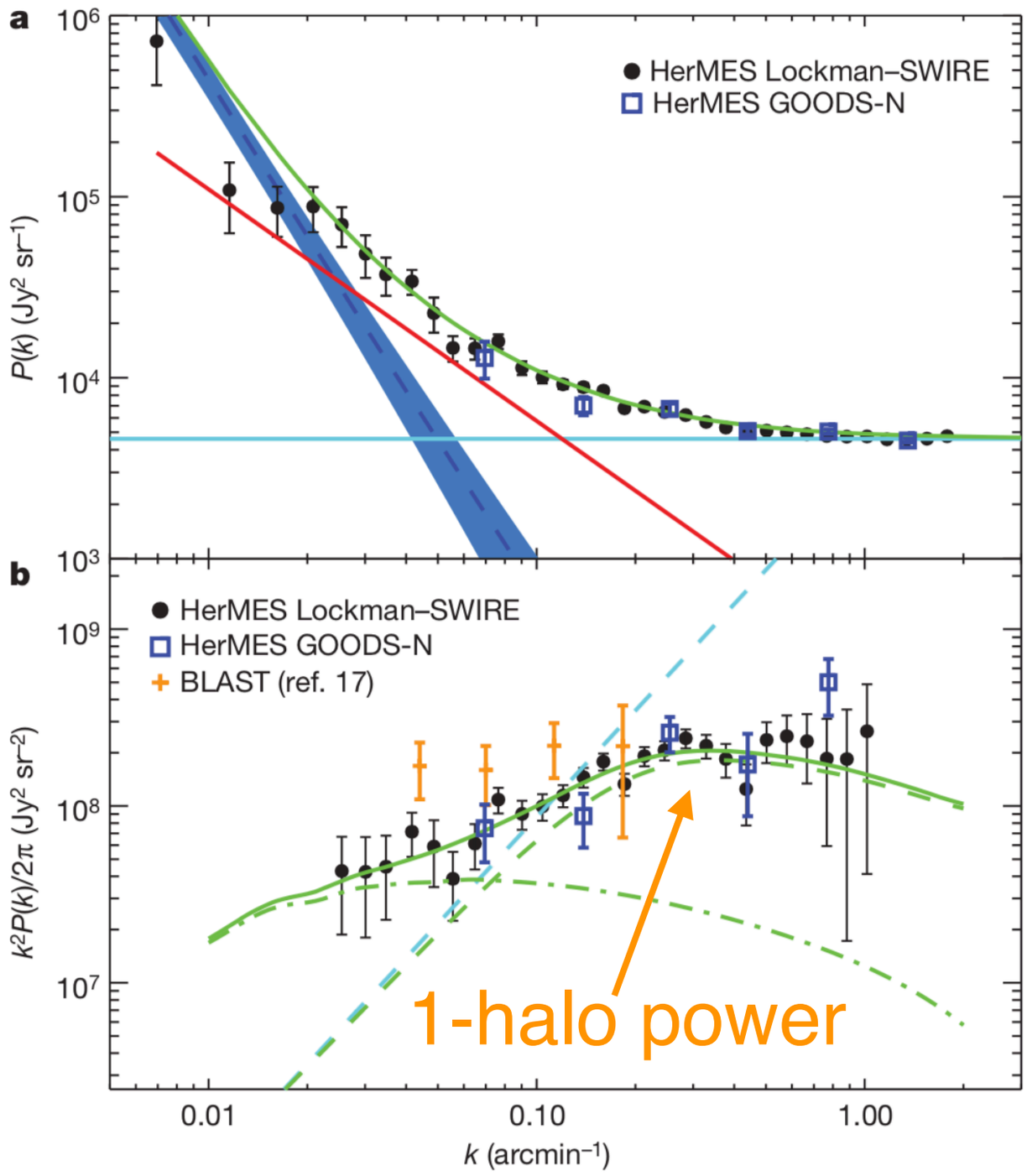


Halo Model: Mattia Negrello (Cardiff)

Viero et al. (**2009**) — arXiv:0904.1200

CIB Models — *Herschel*/SPIRE

- Published in *Nature*
- Key Findings:
  - ➡effective bias = 2.0-2.8
  - ➡$\log(M_{min}/M_\odot) = 11.5$
- Problems:
  - ➡(Too much cirrus removed)
  - ➡T_{dust} Constant
  - ➡All halos have same LIR, leads to *too many satellites* to explain 1-halo term



Amblard et al. (**2011**) — arXiv: 1101.1080

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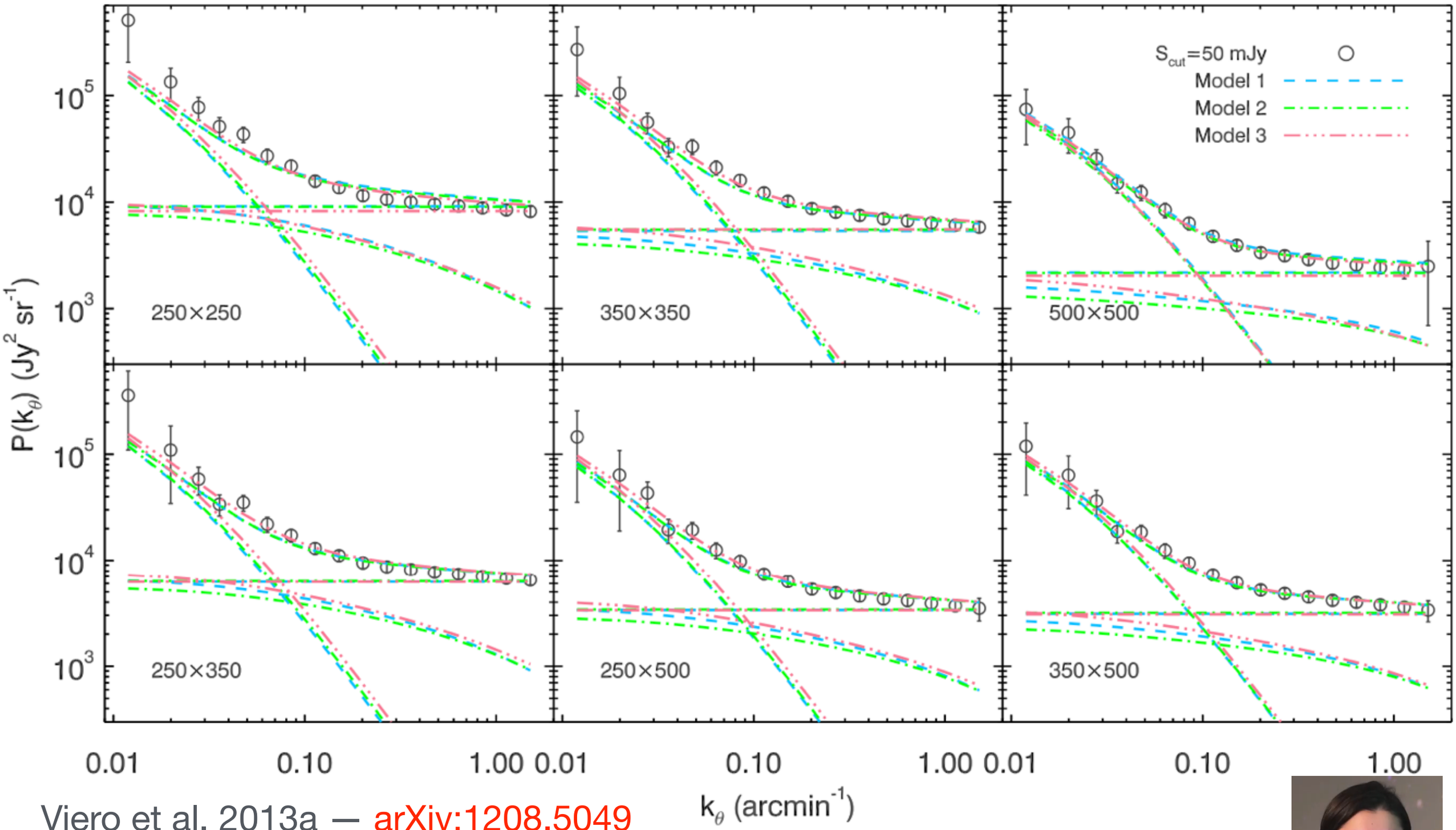

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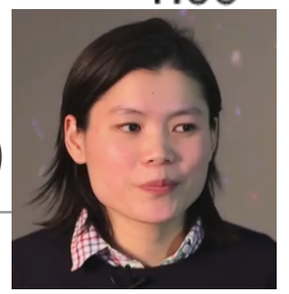
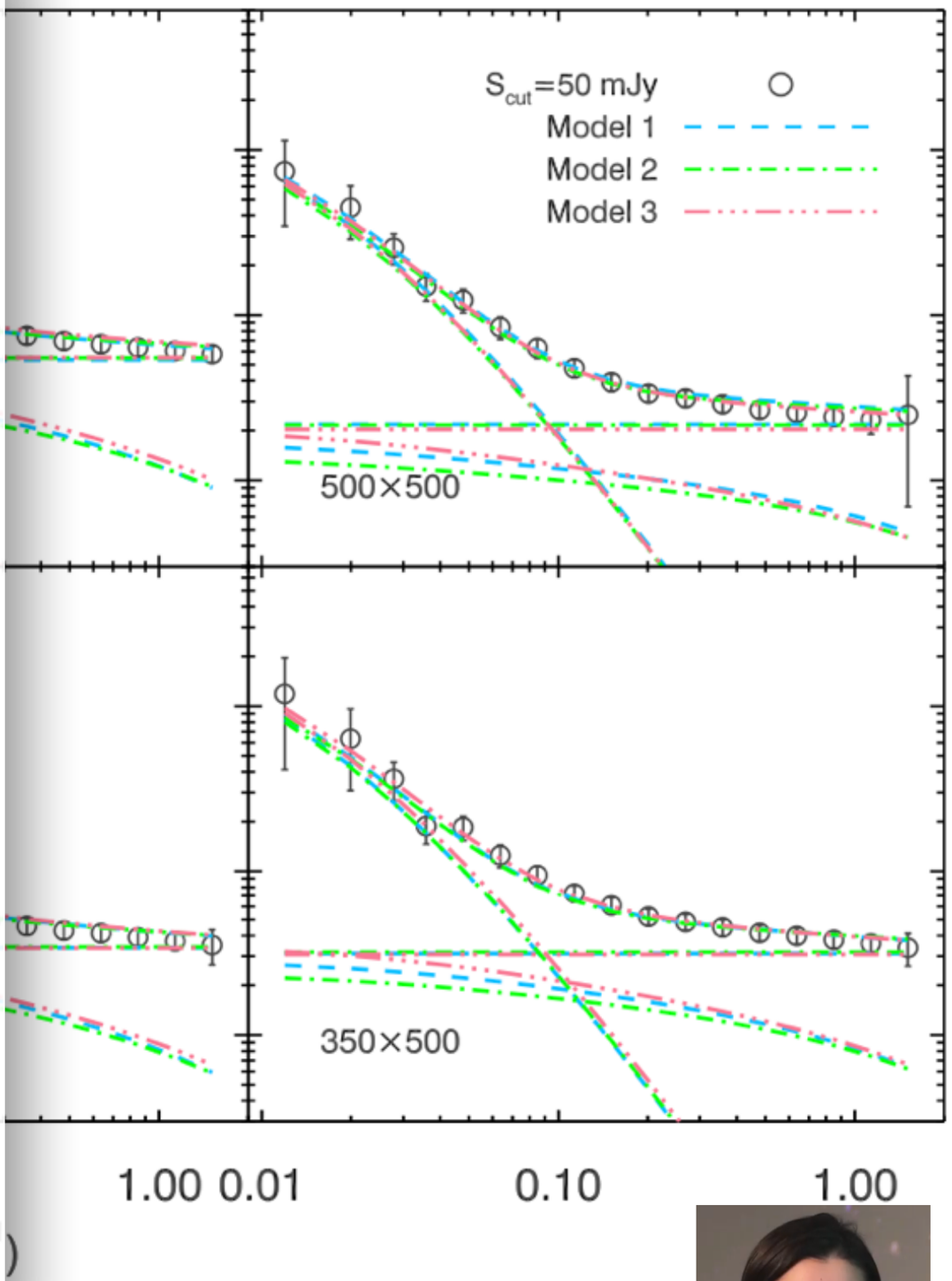


CIB Models — *Herschel*/SPIRE

- Adopted the luminosity-weighted, Shang+2012 halo model:
  - ➡Log-normal L-M relationship
  - ➡SEDs with 3 different T_{dust} models tried:
    - Fixed, Evolving, and Hot/Cold
- Key Findings:
  - ➡$\log(M_{min}/M_\odot) = 10.1 +\text{-} 0.6$
  - ➡$\log(M_{eff}/M_\odot) = 12.1 +\text{-} 0.5$
- Problems:
  - ➡Narrow range in frequencies led to weak constraints on SED/Luminosity evolution
  - ➡No Quiescent Galaxies
  - ➡Requires Flattening of Luminosity Evolution at z=2



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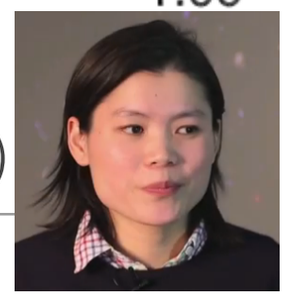

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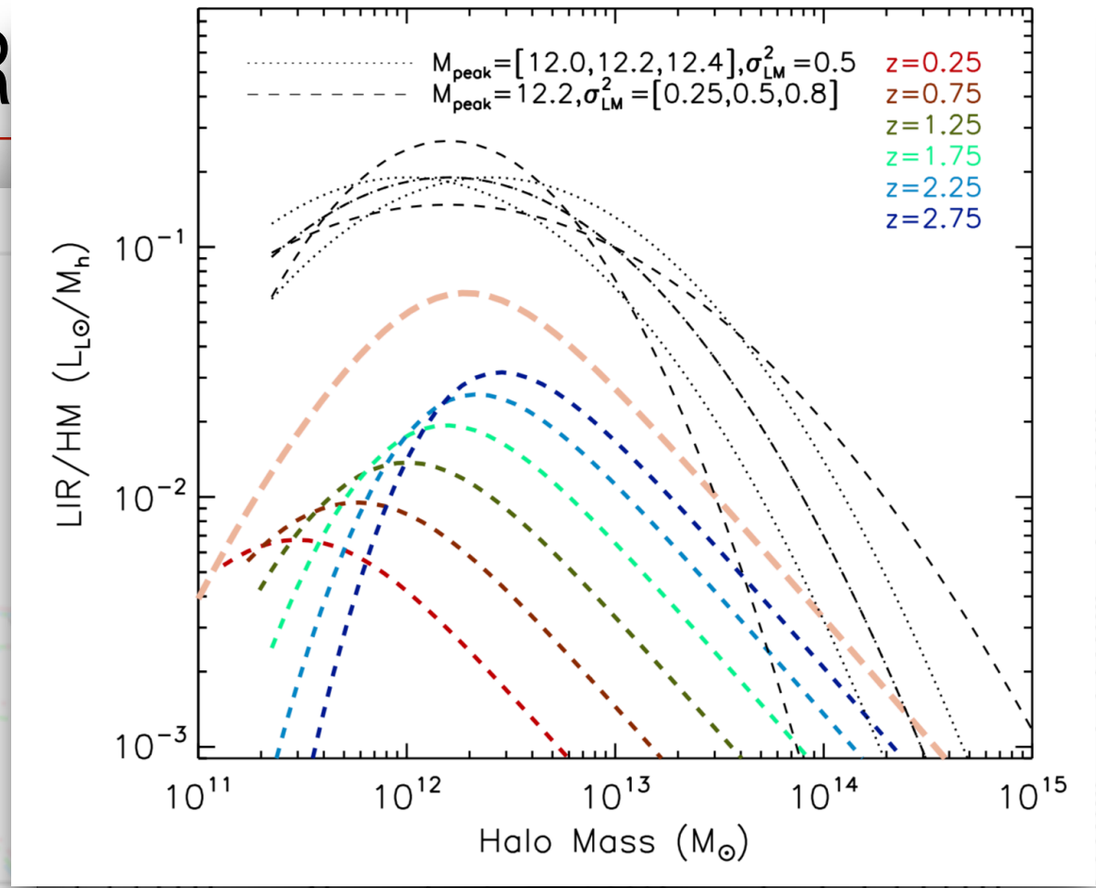

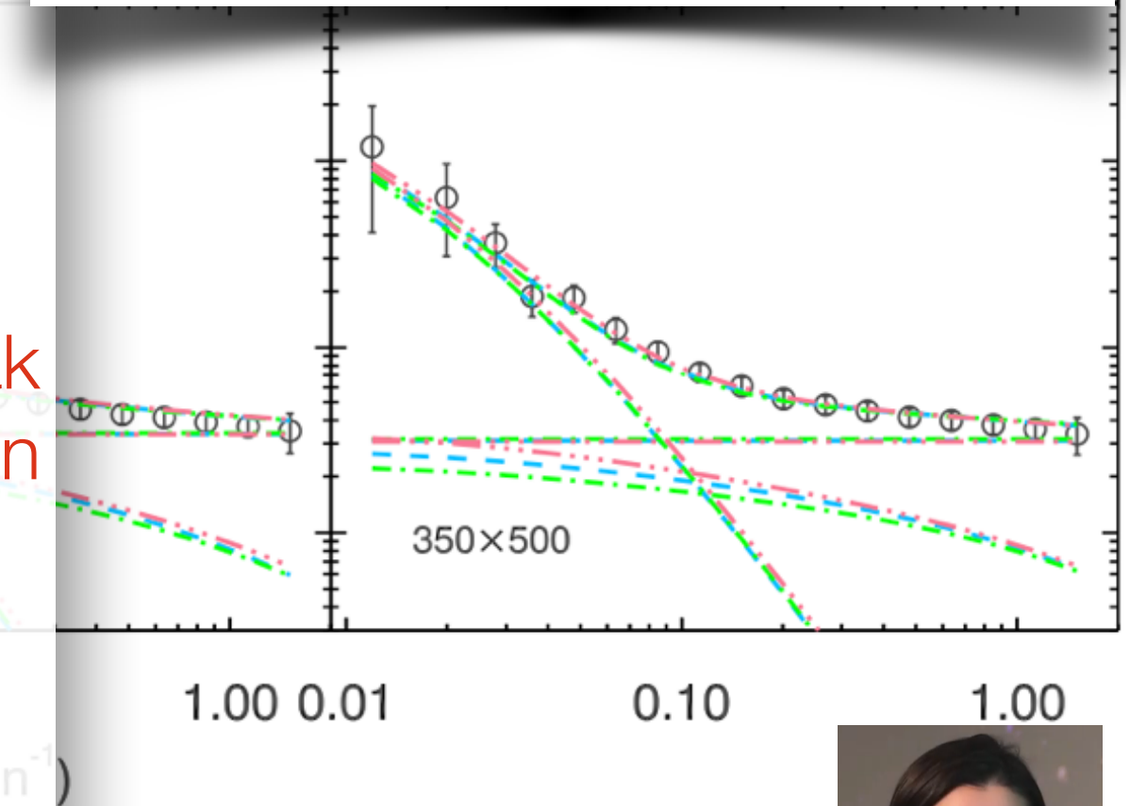

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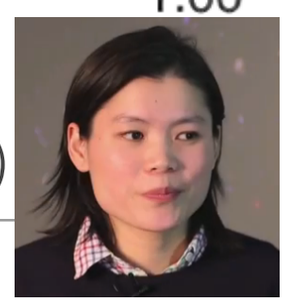
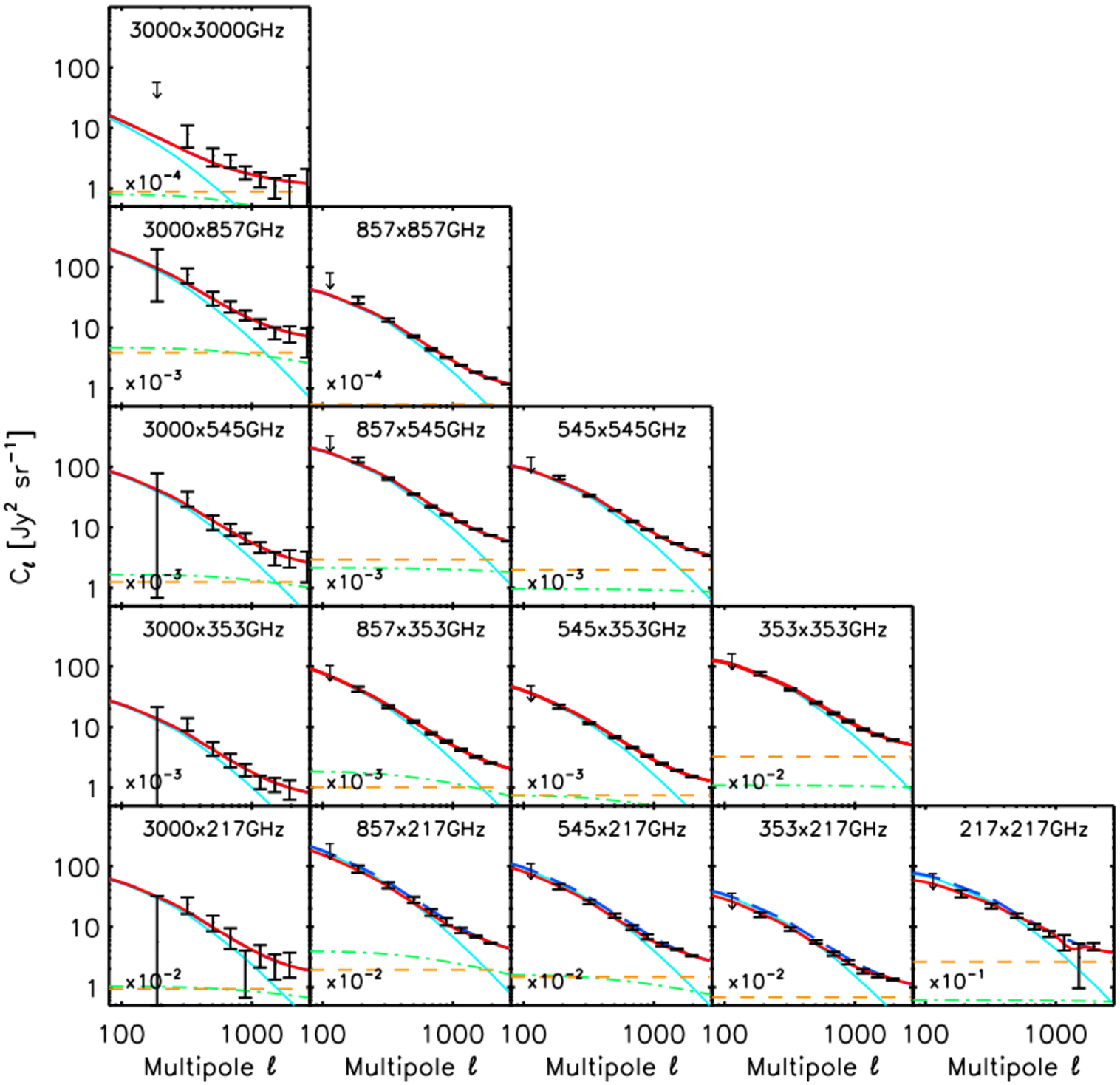


CIB Models — *Planck*

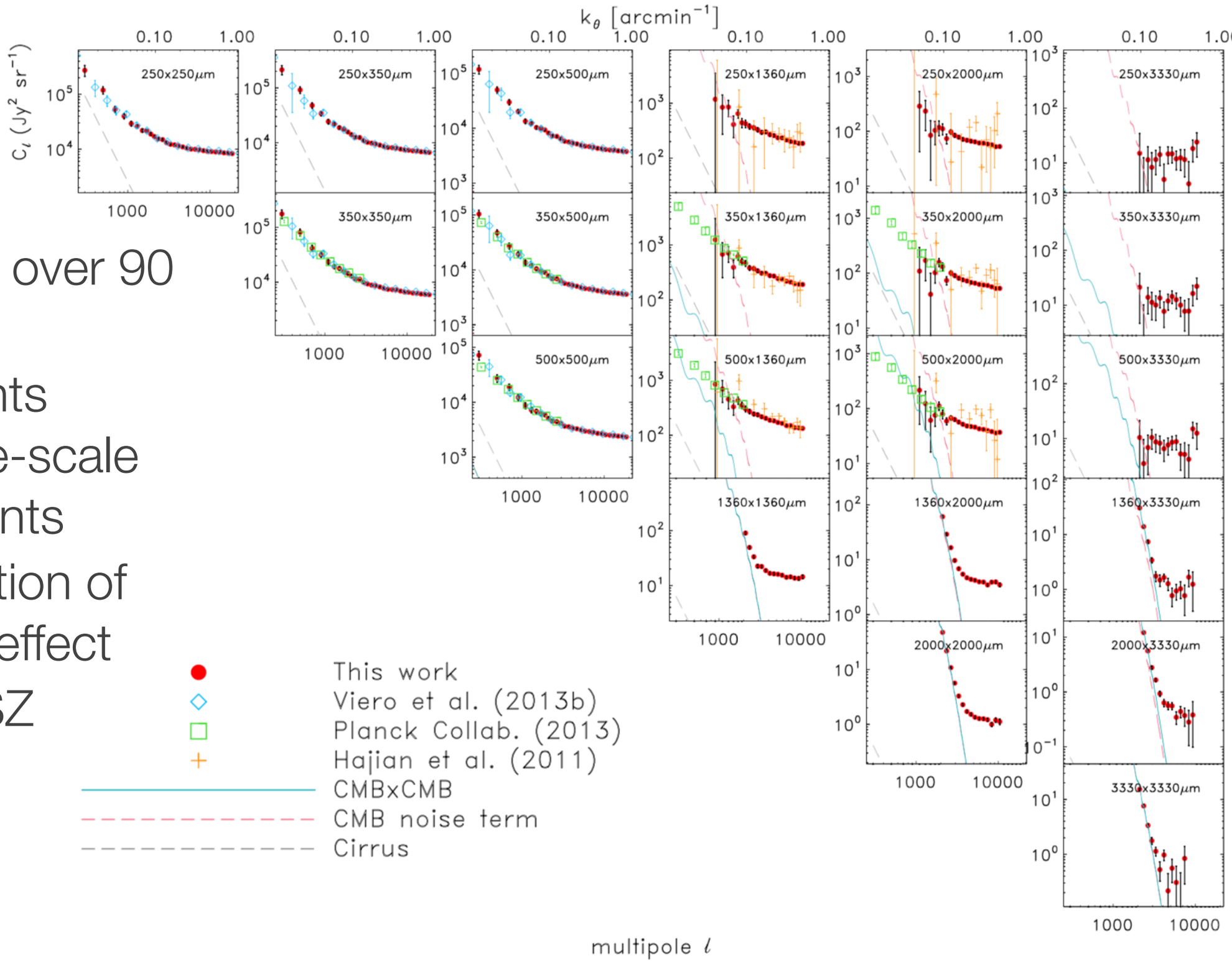
- Also adopted halo model of Shang+(2012)
- Key Findings:
  - ➡$\log(M_{eff}/M_{\odot}) = 12.6$
  - ➡first measurement of the bi-spectrum
- Problems:
  - ➡Large beam led to degeneracy between Poisson and 1-halo terms. Poisson high as a result.
- ➡Mak+ 2017 model found Poisson values closer to Viero+ 2013



Planck Collaboration XXX (**2014**) — arXiv:1309.0382

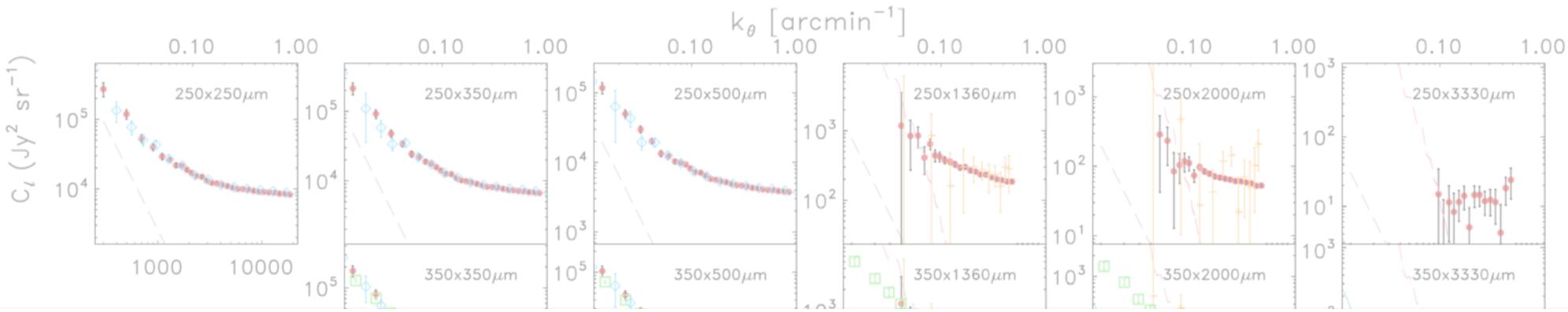
CIB Models —SPT x SPIRE

- SPTxSPIRE over 90 deg2
- Complements Planck large-scale measurements
- Clear detection of thermal SZ effect
- Tentative kSZ detection.



Viero et al. (**2018, in prep.**)

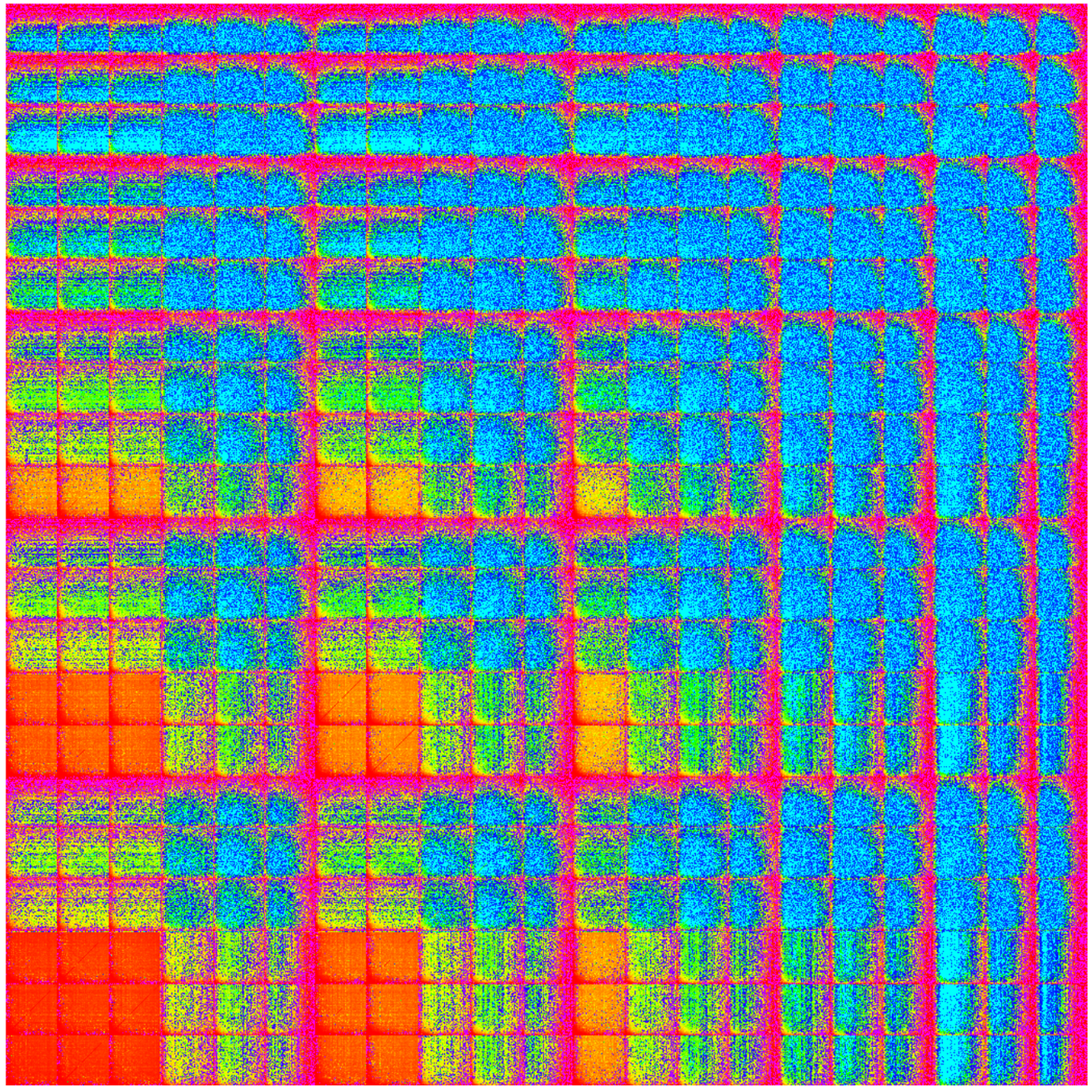
CIB Models —SPT x SPIRE



Viero et al. (**2018, in prep.**)

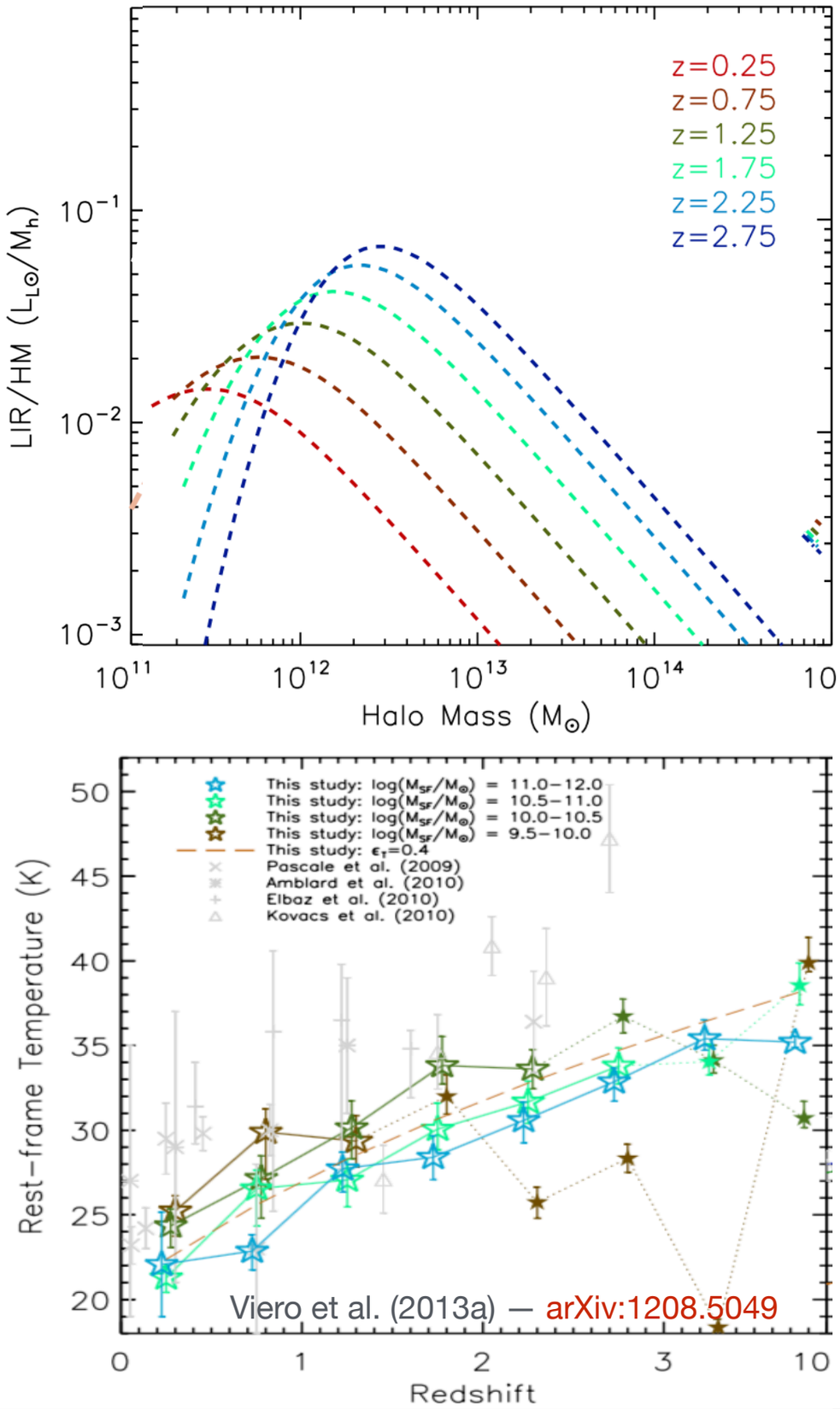
CIB Models — SPT x SPIRE

- Complicated Covariance
  - ➡No longer acceptable to assume off-diagonals negligible
- Simple model cannot fit:
  - ➡Large z/T_{dust} evolution
  - ➡Excess 1-halo term
  - ➡thermal/kinetic SZ effect
- This is an example of the modeling being behind the measurement!



Embrace Ancillary Data Sets

- Model parameters should adopt measurement-based priors re: SFR/SED
- If you don't have them, get them:
  - ➡e.g.,SIMSTACK is an easy tool for estimating the LIR of well-defined galaxy populations using FIR maps and **dense** galaxy catalogs.



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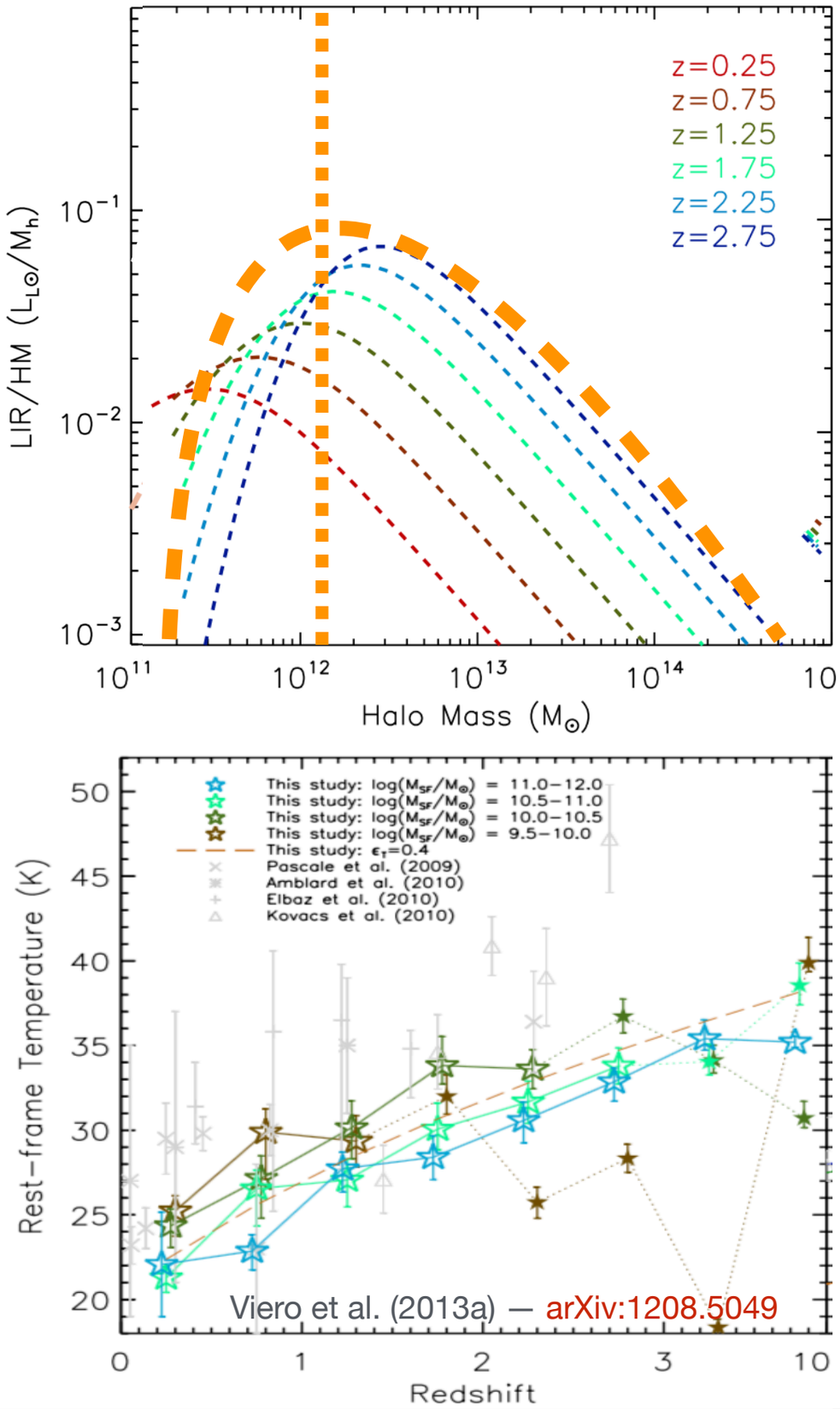

Lessons

- Don’t wait to have data to construct/improve your model.
- Poor assumptions about the 1-halo term will propagate into your conclusions.
- Beware of blindly adopting simple model forms:
  - ➡log-normal, power laws, etc.
- Simple models cannot *simultaneously* fit:
  - ➡Large z/T_{dust} evolution.
  - ➡Excess 1-halo term.
  - ➡Thermal/Kinetic SZ effect.
- Be ready for when it is no longer acceptable to assume off-diagonals negligible.