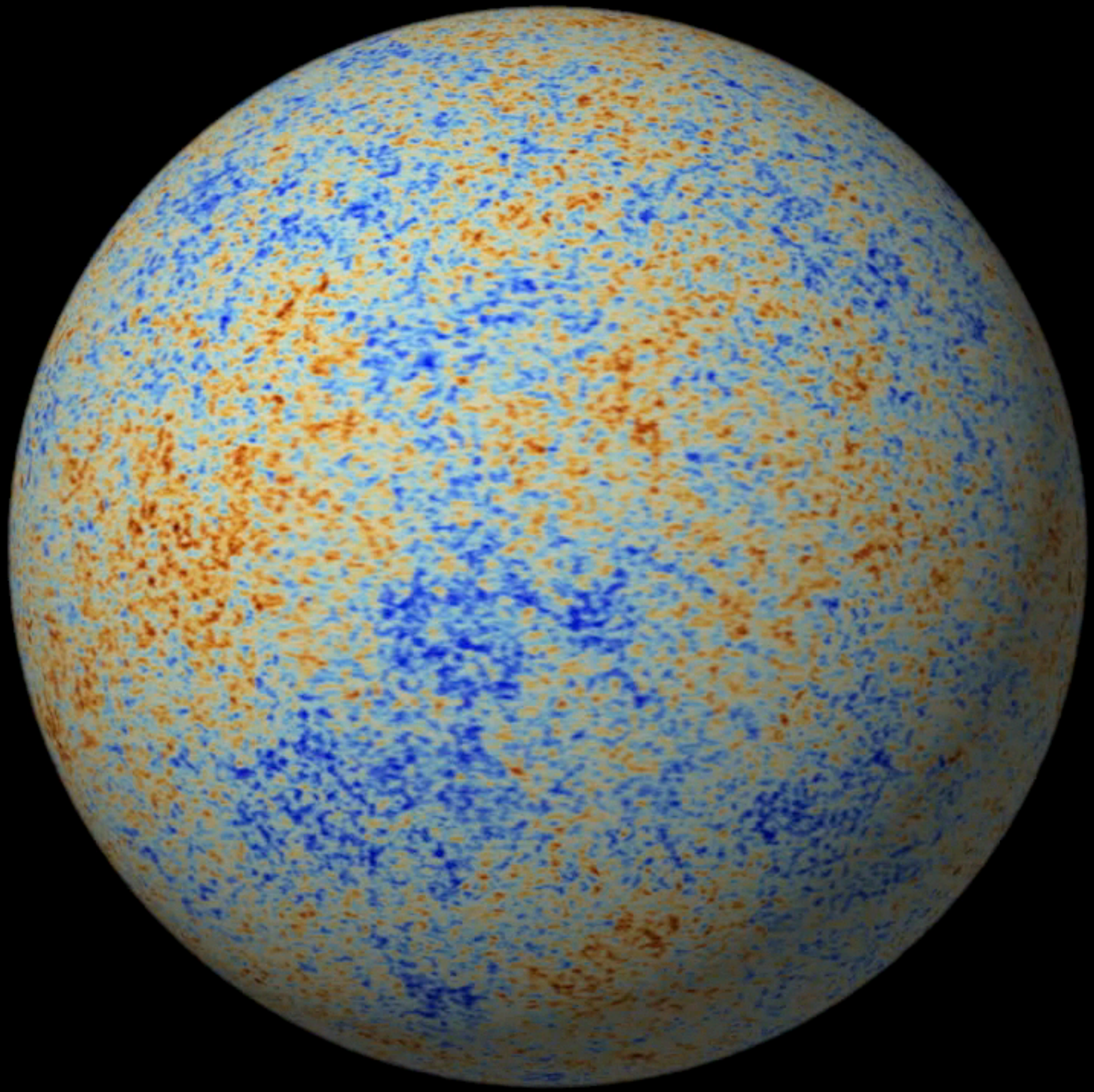
CMB-ish surveys

Douglas Scott

October 2018

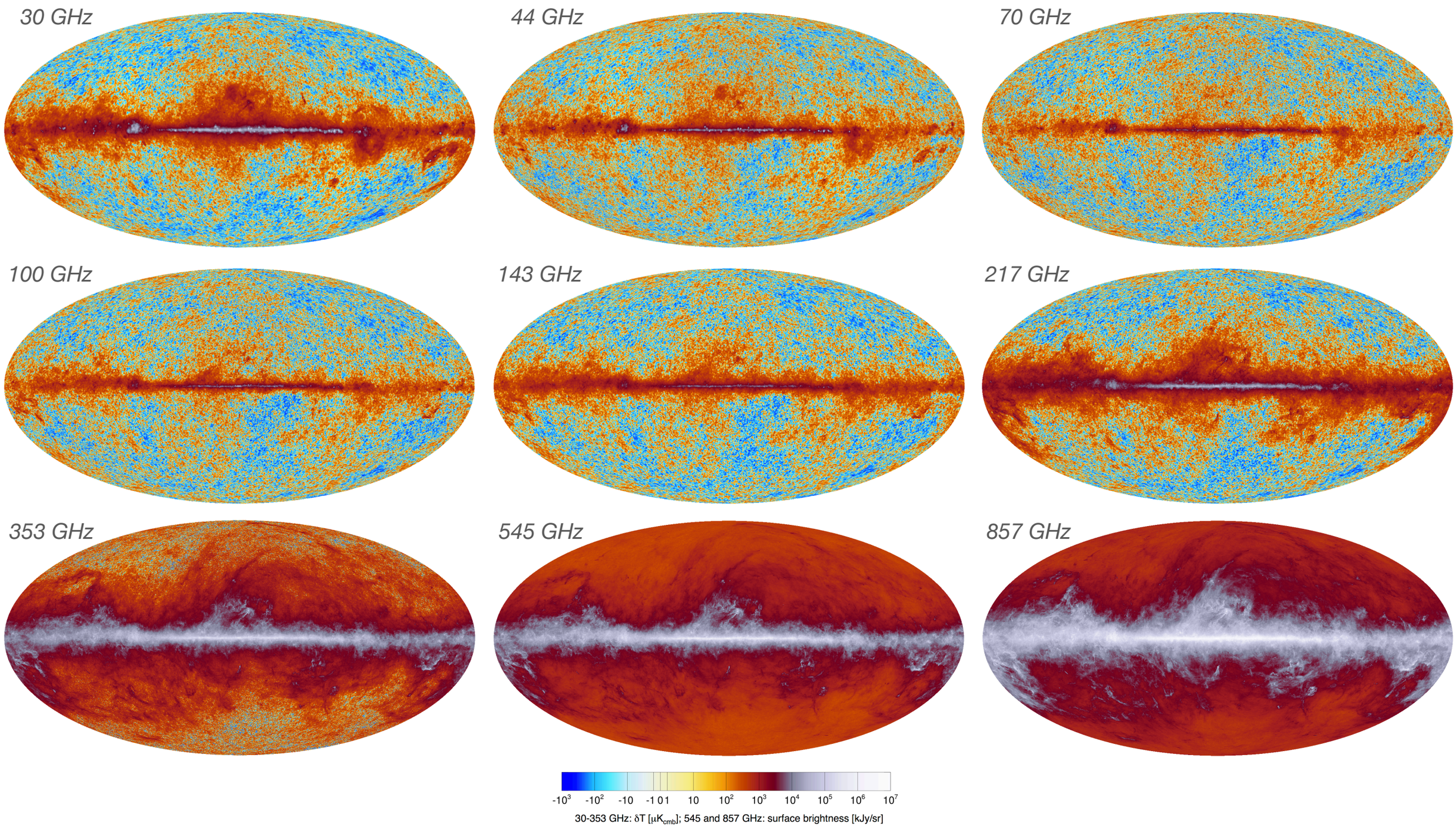


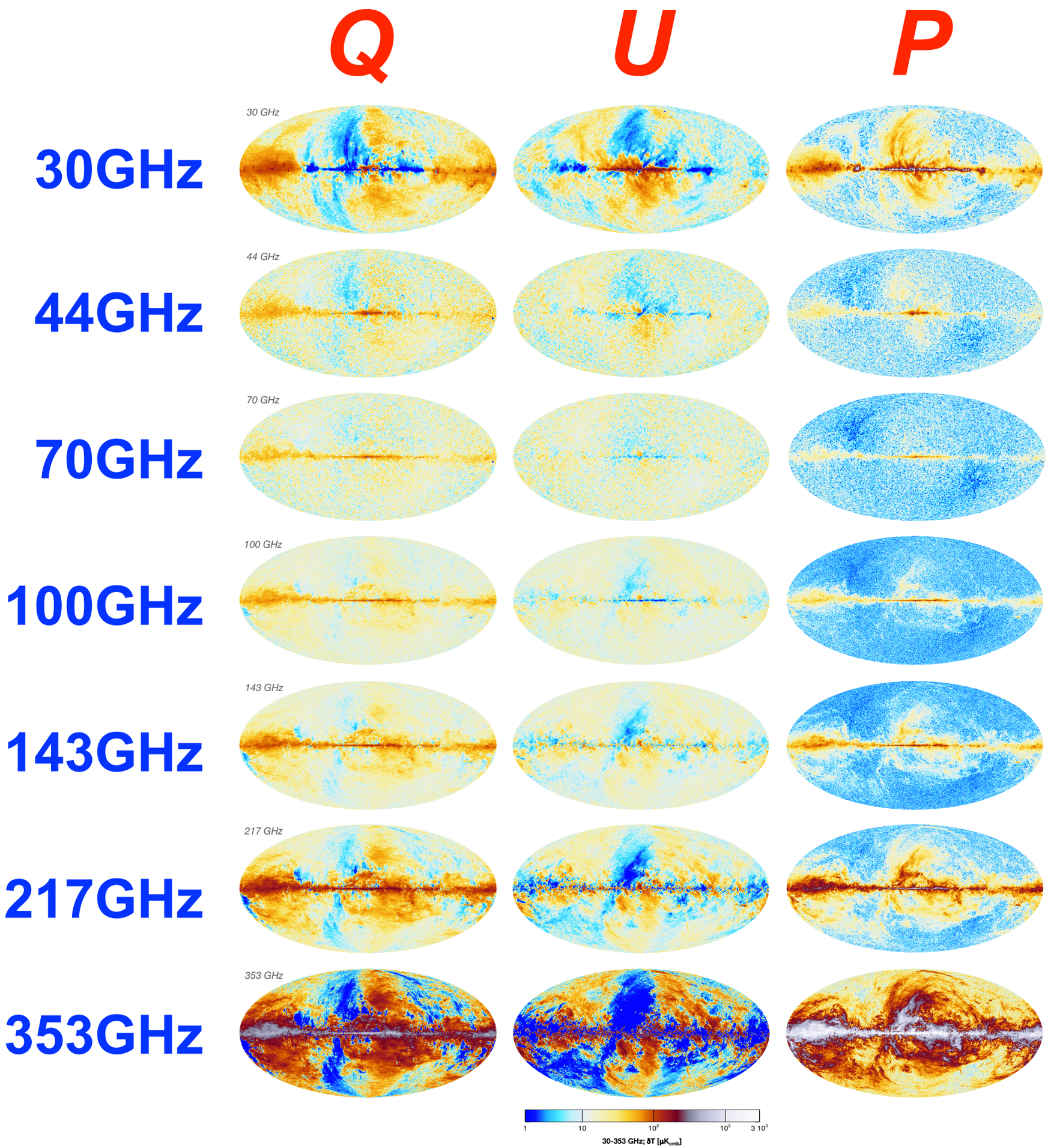
Planck papers

- "Technical papers"
  - 13 papers
- "Planck pre-launch status"
  - 13 papers
- "Planck early results"
  - 26 papers
- "Planck intermediate papers"
  - 54 papers
- "Planck 2013 results"
  - 32 papers
- "Planck 2015 results"
  - 28 papers
- "BICEP & Planck"
- "Planck 2018 results"
  - 13 papers (last 3 very soon!)

Instrumentation
Data processing pipeline
Simulations
Cosmic rays
Zodiacal emission
Component separation
Interstellar medium
Molecular clouds
Galactic magnetic fields
All-sky optical depth
Galactic cold clumps
SNRs & PNe
Anomalous microwave emission
Polarized dust radiation
All-sky CO map
Nearby galaxies
Radio sources & blazars
High-z extragalactic sources
Cosmic infrared background
CMB power spectra
Cosmological parameters
Gravitational lensing
Dipole & boosting effects
Integrated Sachs-Wolfe effect
Reionization
All-sky thermal SZ map
SZ cluster cosmology
Cluster physics
Peculiar velocities
Constraints on inflation
Topological defects
Non-Gaussianity
Isotropy & statistics
Geometry & topology
Dark energy & modified gravity
Primordial magnetic fields
Variation of fundamental constants
Parity & birefringence
Planet fluxes
...

All-sky maps of temperature/intensity at 9 separate frequencies

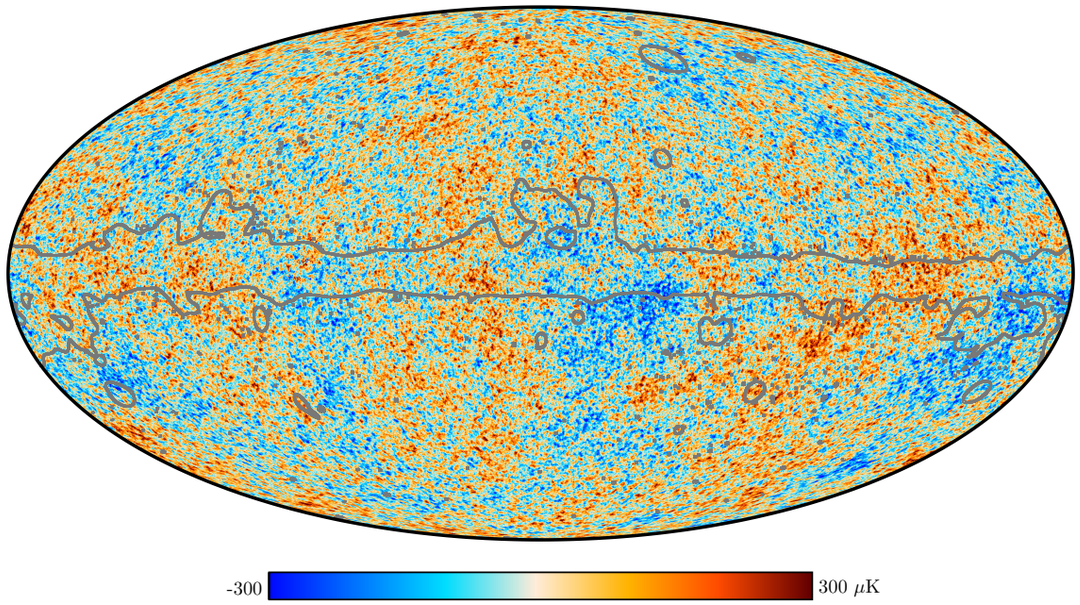




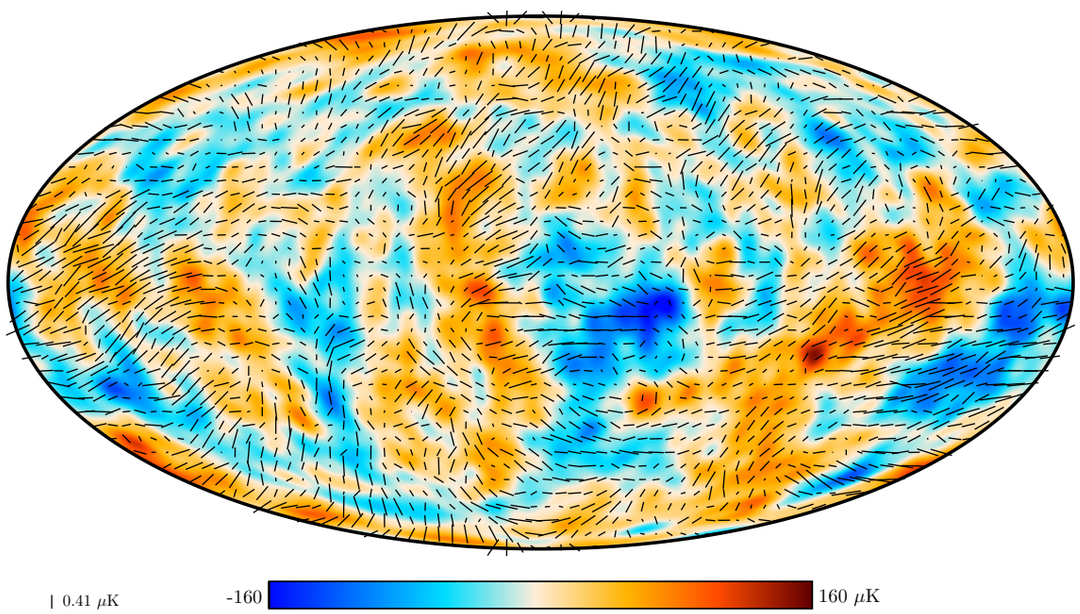
Plus all-sky polarization maps at 6 frequencies

Planck resolution 5′–30′

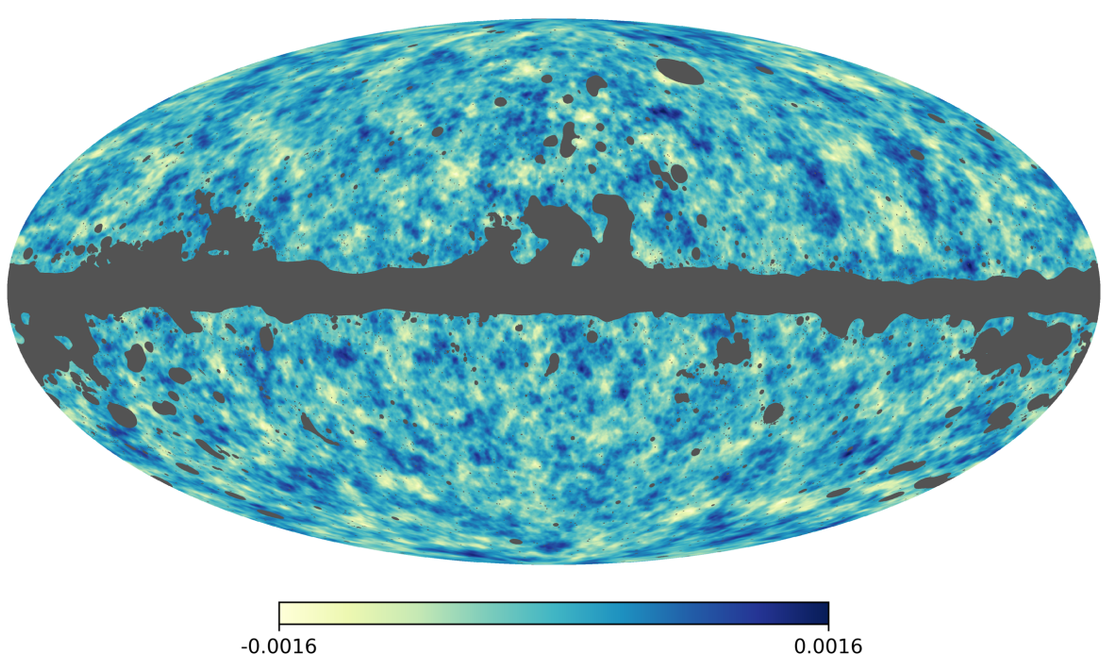
- **But the whole sky (wide field!)**
- **And large scales well measured (in fact so well measured that we're done, at least in temp.)**



CMB temperature



CMB temperature + polarization

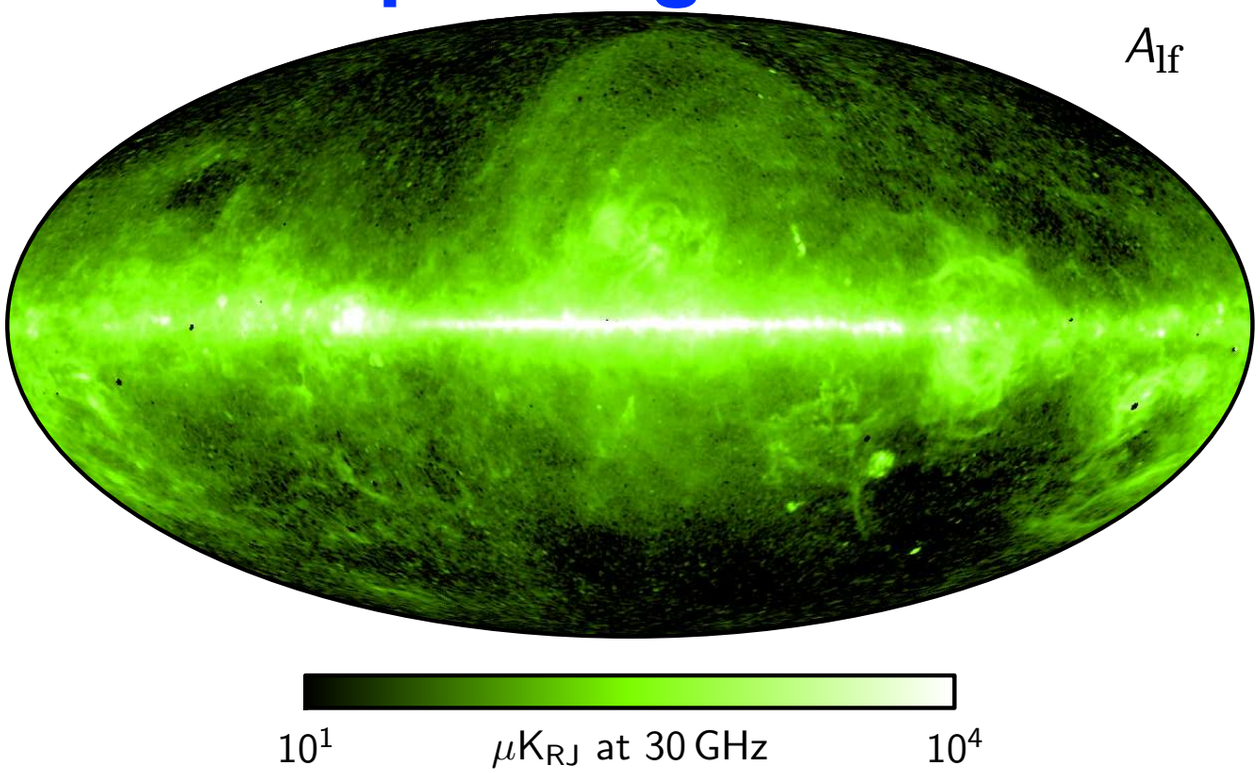


Lensing deflection

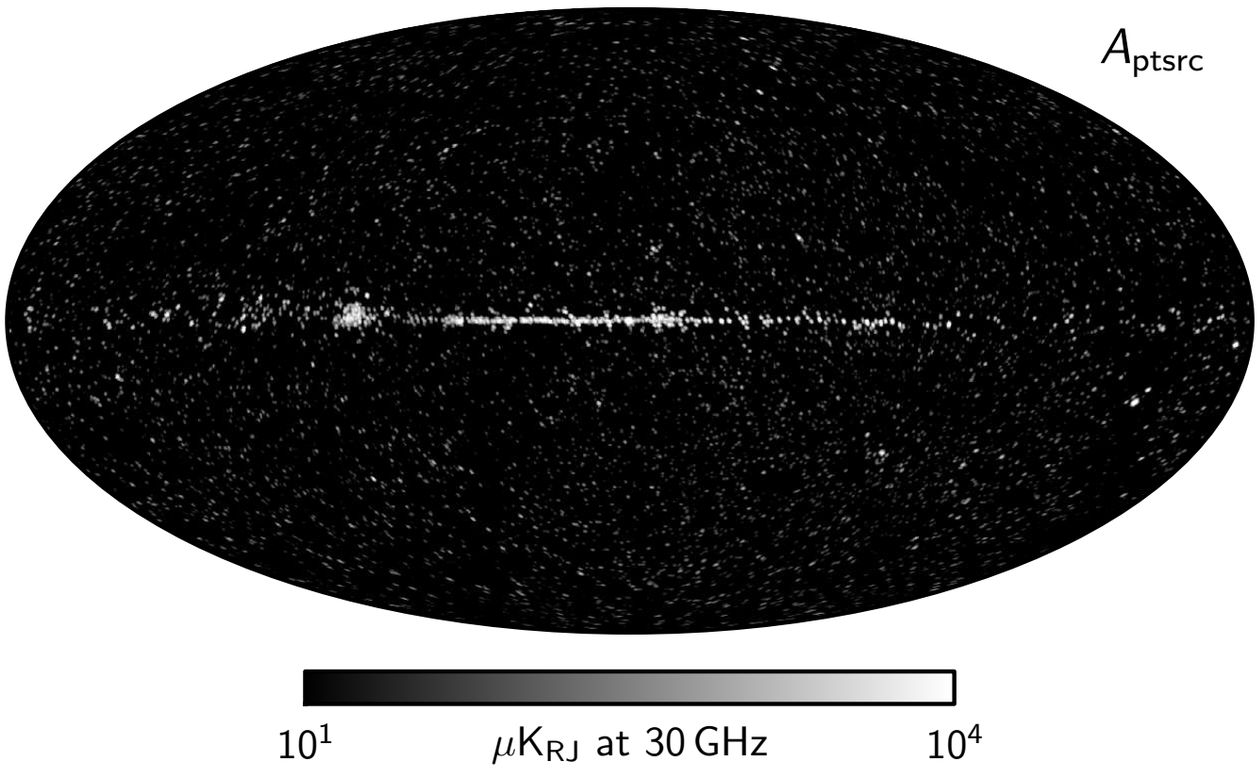
But can also study…

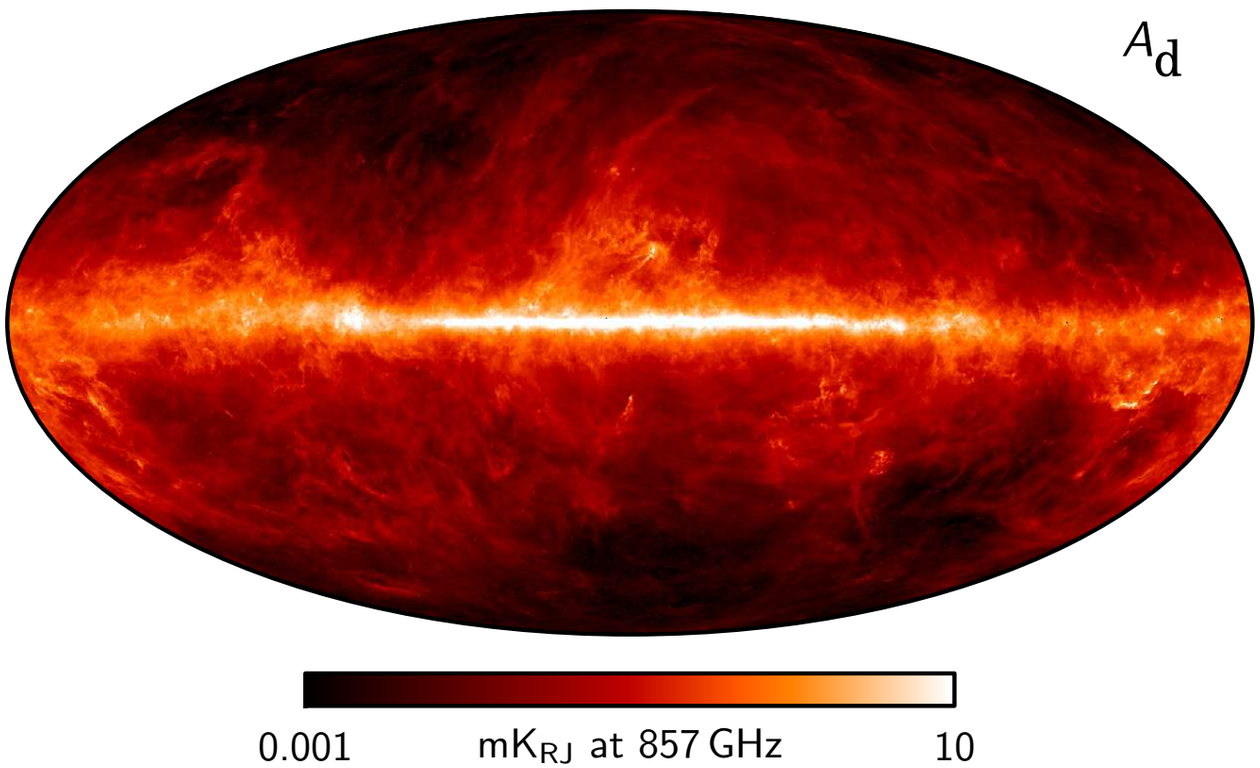
…Milky Way from the inside!

Synch. + free-free + spinning dust

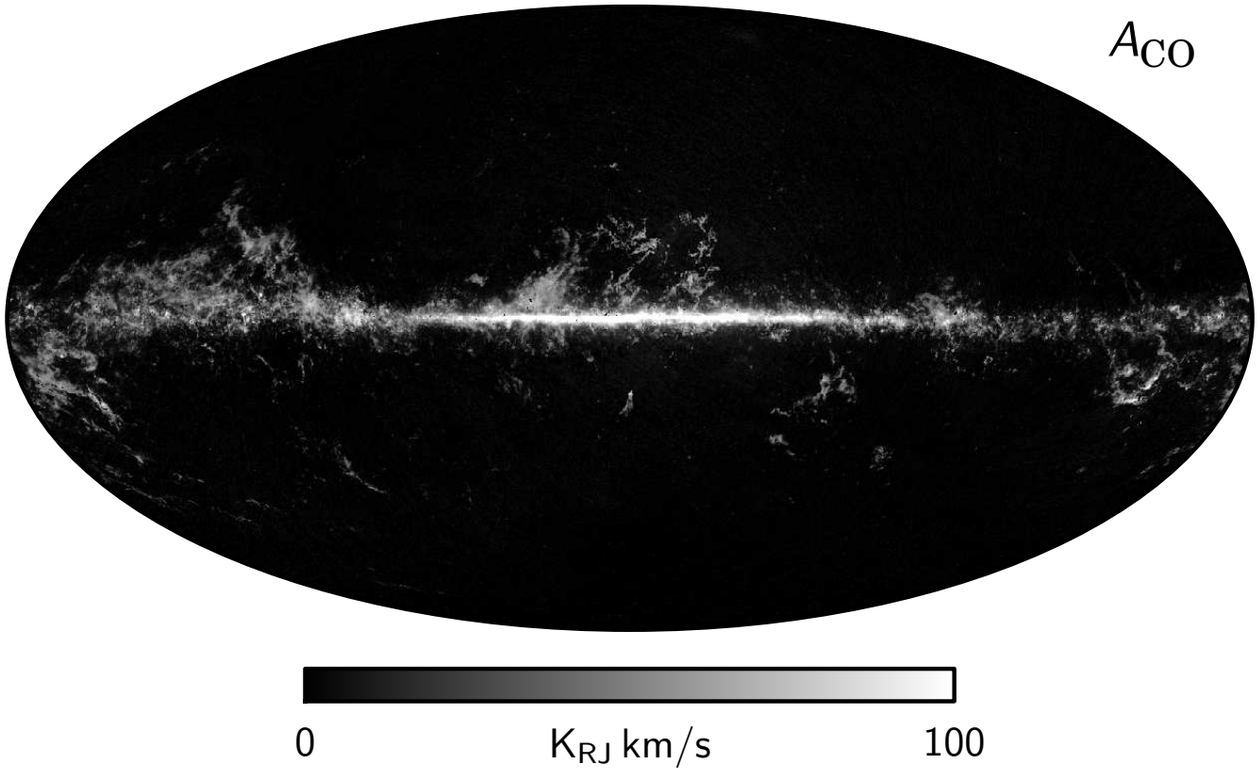


Radio point sources



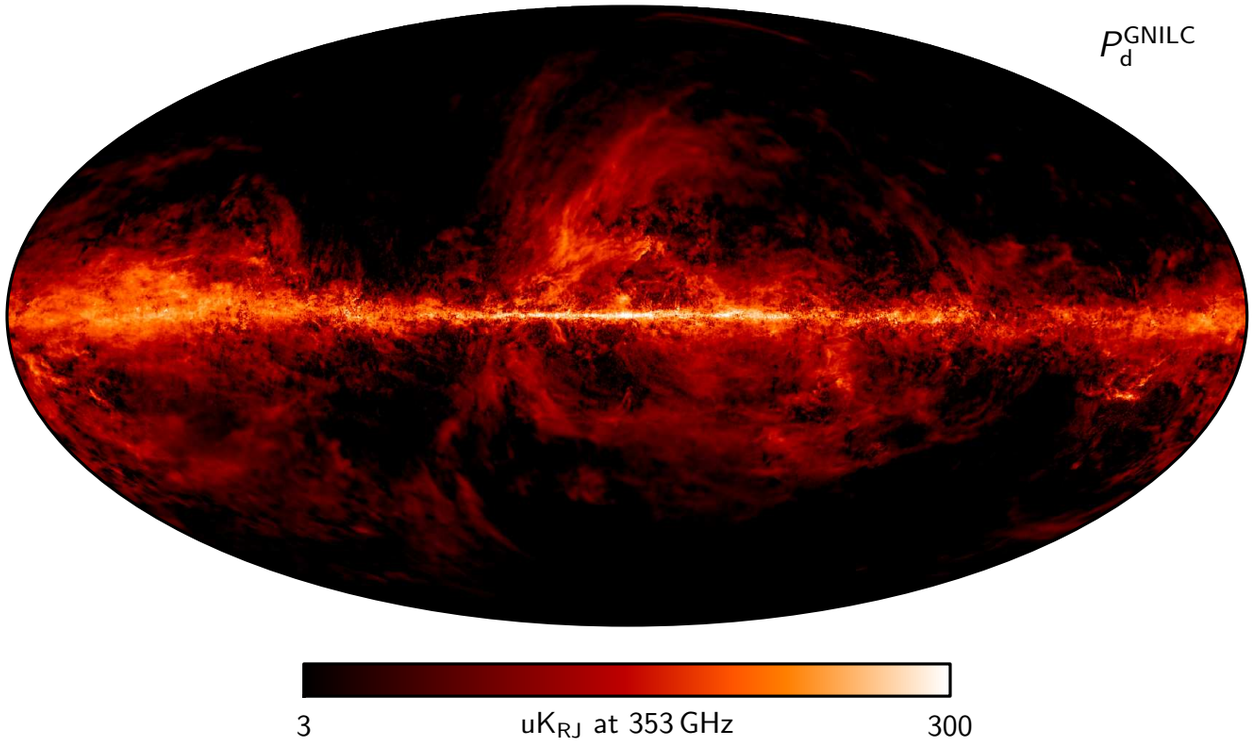


Thermal dust



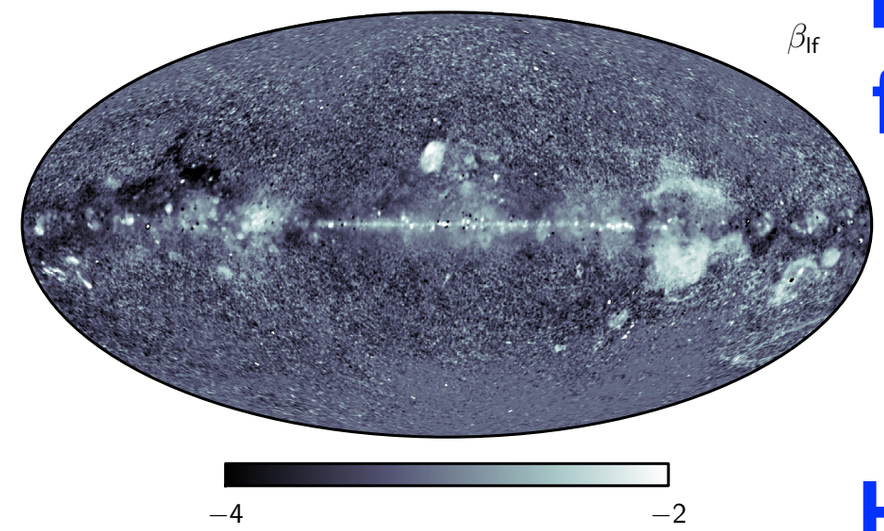
Carbon monoxide

Polarized dust amplitude

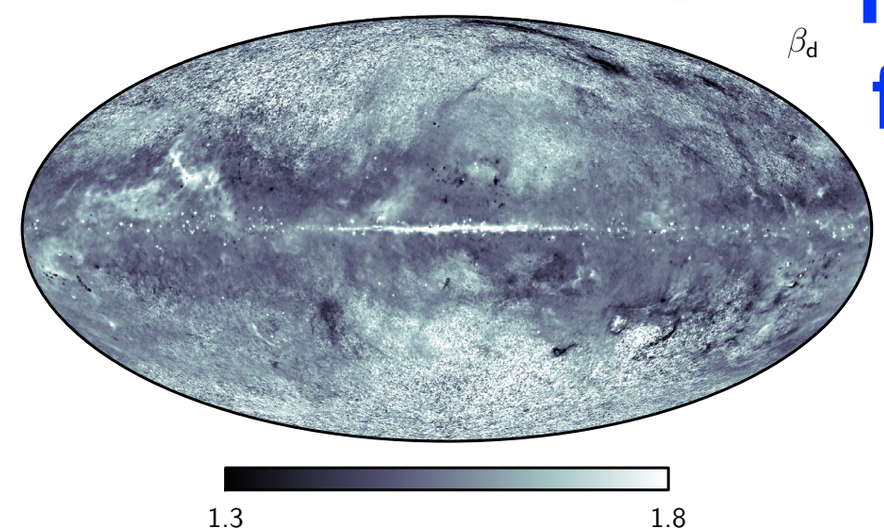


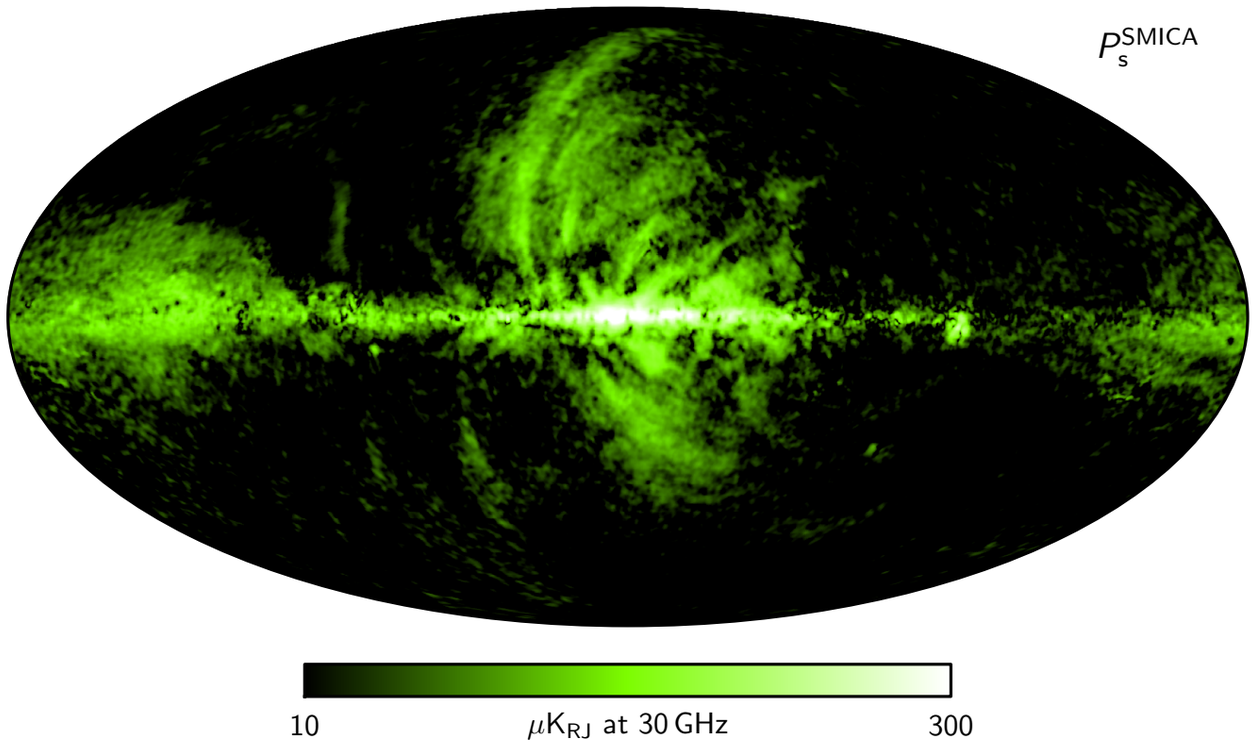
Spectral indices

Low freq.



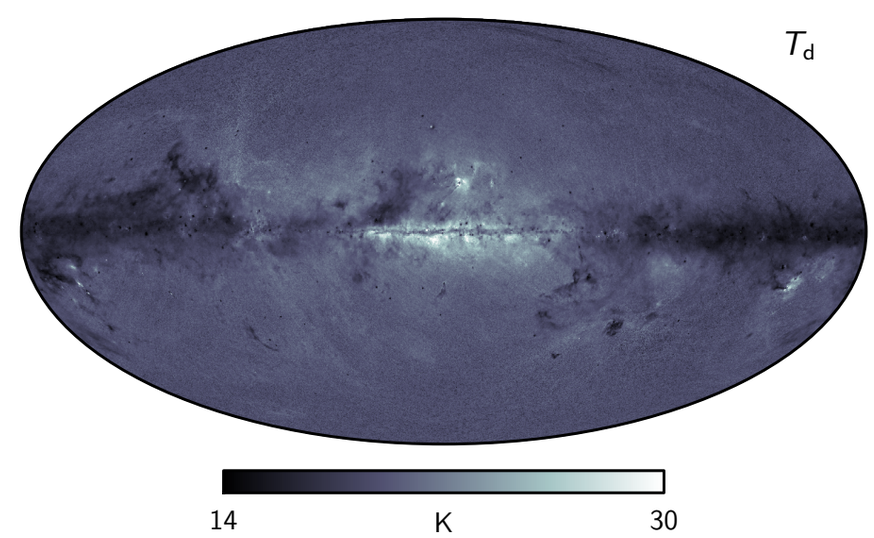
High freq.





Polarized synchrotron amplitude

Dust temperature



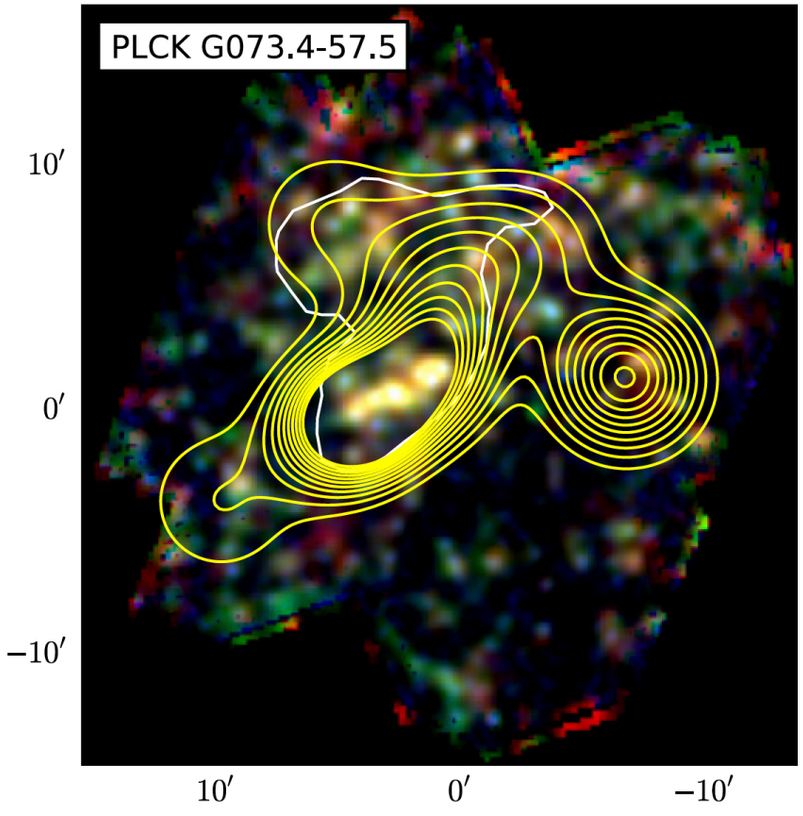
Plus other extragalactic signals (of decreasing S/N):

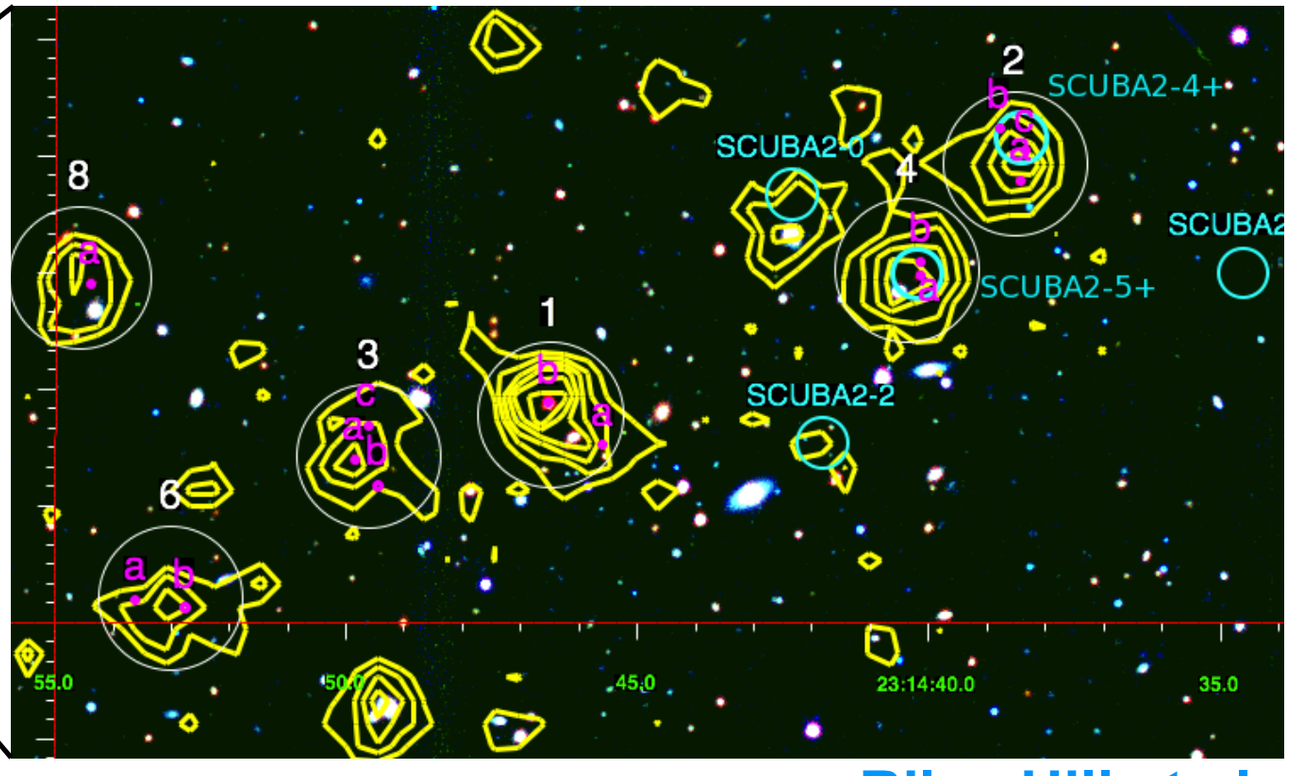
- **Cosmic infrared background**
- **Sunyaev-Zeldovich *y***
- **Integrated Sachs-Wolfe effect**
- **Kinetic SZ effect**
- **…**

Plus compact sources:

- **Proto-cluster candidates**
- **Strong lenses**
- **…**

Protoclusters



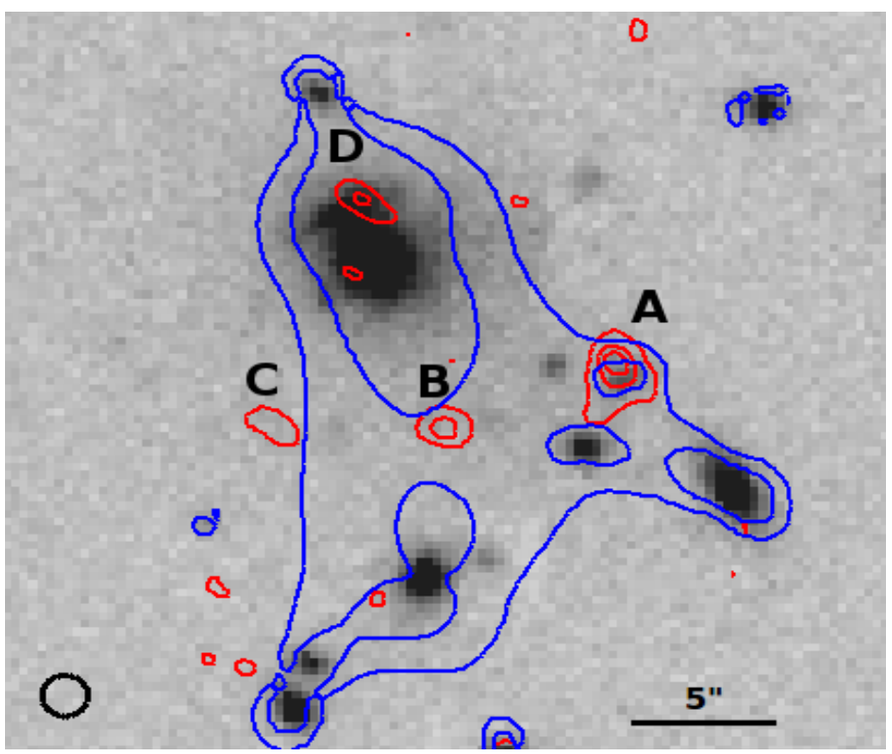


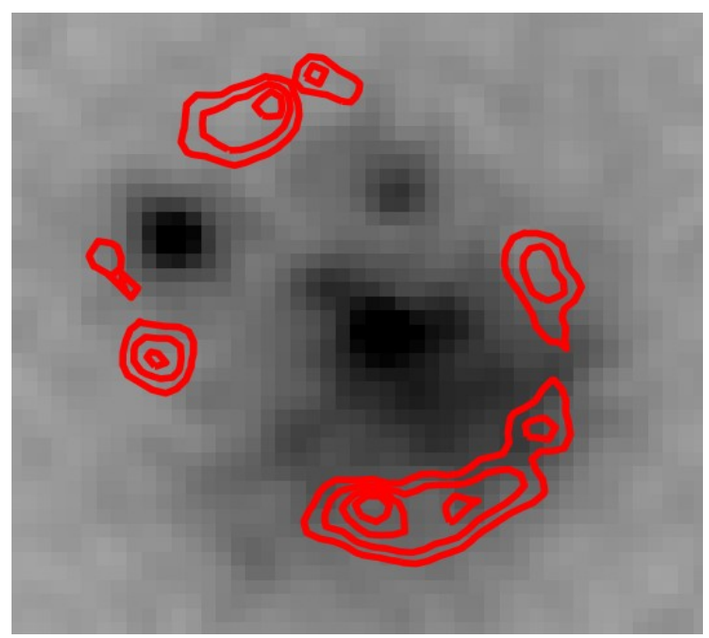
Riley Hill et al.

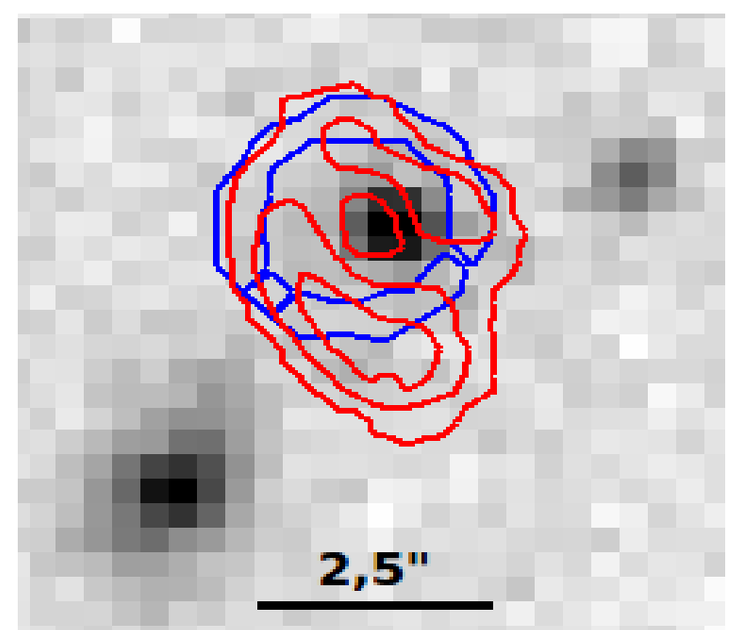
Herschel-SPIRE source overdensity in Planck blob

IRAC+VLT 3-colour image, SCUBA-2 and ALMA follow-up

Lenses







Optical + submm contours

Planck-derived sample gives brightest known submm lenses

Ongoing and near future experiments (better resolution/sensitivity/polarization):

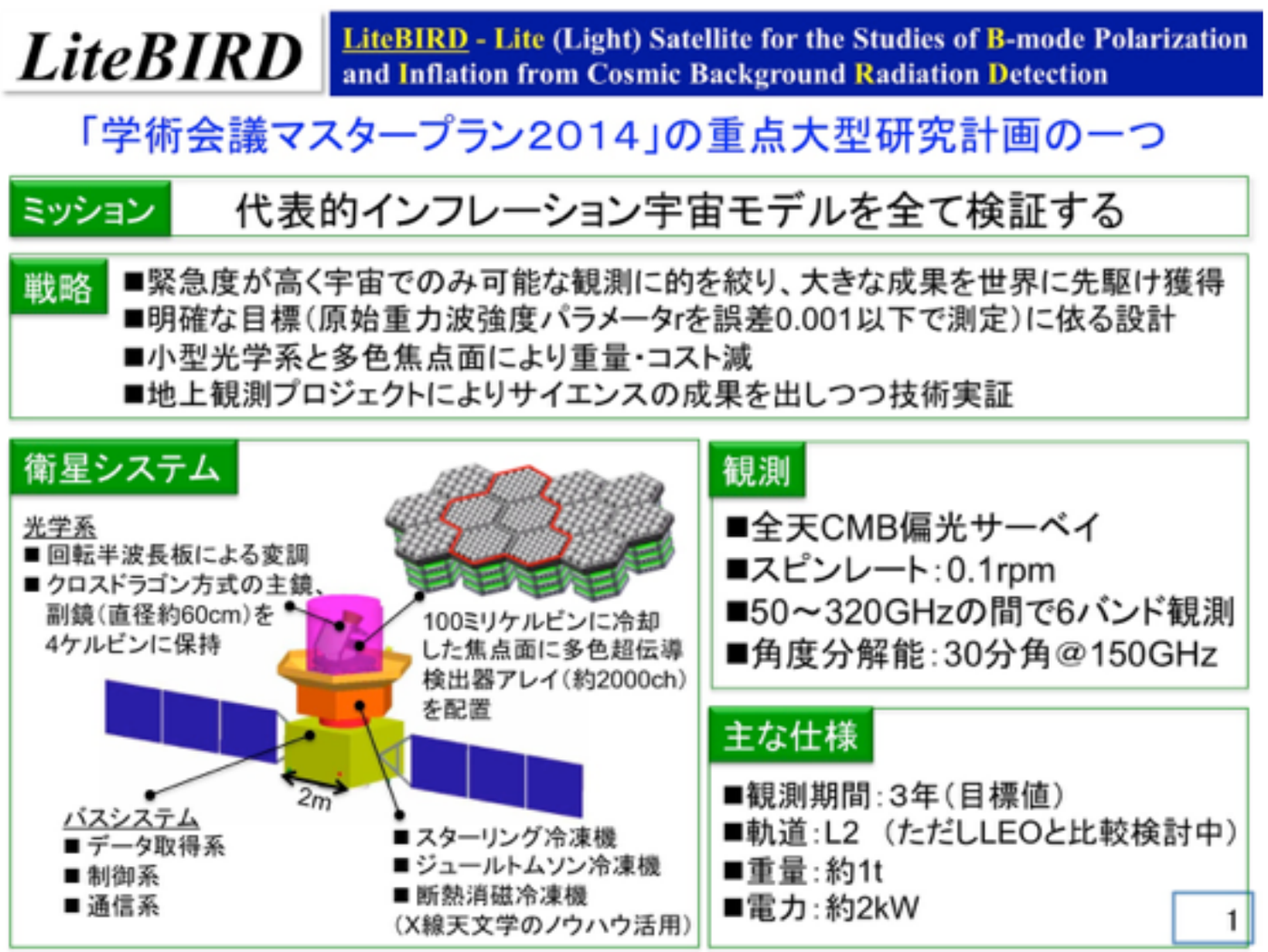
- ACT/ACTPol/AdvACT
- SPT/SPTPol/SPT-3G
- BICEP/Keck
- POLARBEAR/Simons Array
- Simons Observatory
- …

Future satellites:

- Litebird
- …

Litebird: JAXA (Japan) + partners

LiteBIRD is a millimetre-wavelength space satellite telescope being designed and built to map the CMB polarization on degree and larger angular scales. LiteBIRD will be instrumented with 2,622 detectors, spanning observation frequency bands from 40 to 400 GHz, with noise levels about 20 times lower than for the Planck satellite. The mission is led by JAXA (P.I.: Masashi Hazumi) and is presently in Phase A1. The Canadian-designed DfMUX bolometer readout system is the baseline for the mission.



- **Launch ~2026**
- **Study for Canadian involvement underway**
- **Ask Matt, Renee, Douglas or Dick**

CMB-S(tage)4

Primordial B modes: Simon Foreman already discussed this

- Constrain *r* at the 0.001 level
- Constrain (neutrino) N_{eff} at 0.05 level
- Survey ~half sky at mm to cm
- 20-270GHz, multiple channels
- ~500,000 detectors
- 2 distinct sets of telescopes
  ~0.5m and ~6m (Chile and SP)
- ~5% sky survey really deep
- + ~40% sky survey just deep

Commissioning 2025?
This will happen!

Why should I care about CMB-S4? (if I think r and N_{eff} are boring!)

- 40% of the (southern) sky
- Stokes I, Q, U
- SZ, lensing, …
- Galactic polarization + sources
- Cadence ~every couple of days
- 1.5′ beam at 150GHz (scales like $1/\nu$)

- Variable and moving sources?

Report writing for (US) decadal survey

- “Legacy archive” working group coordinators, DS + Lindsey Bleem
- Need help thinking about the non-cosmology stuff!

CMB Lensing Map

- **Legacy product will be a lensing map(s) for 40% of the sky covered by the wide area survey**
- **Excellent overlap with e.g., LSST, DESI, eRosita, etc**
- **Improved Cosmological Constraints via cross-correlations with other LSS Surveys (e.g., Doux+18, and others)**
- **Calibration of Systematic Errors in other surveys (e.g., Schaan+17, and others)**
- **High-redshift mass calibration via CMB halo lensing (clusters, AGN, other sources; e.g., Raghunathan+17, Melin+15, and others)**

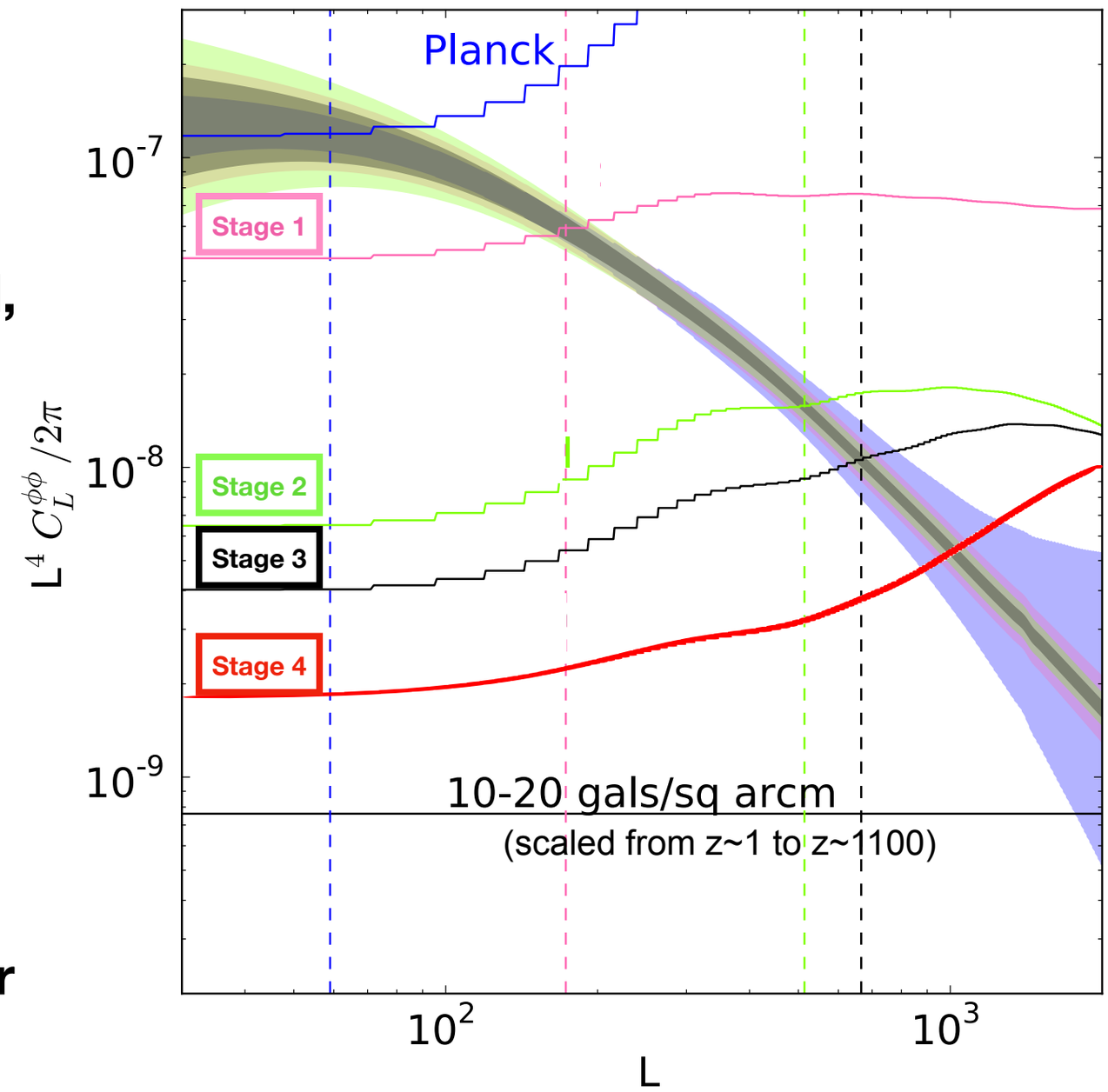
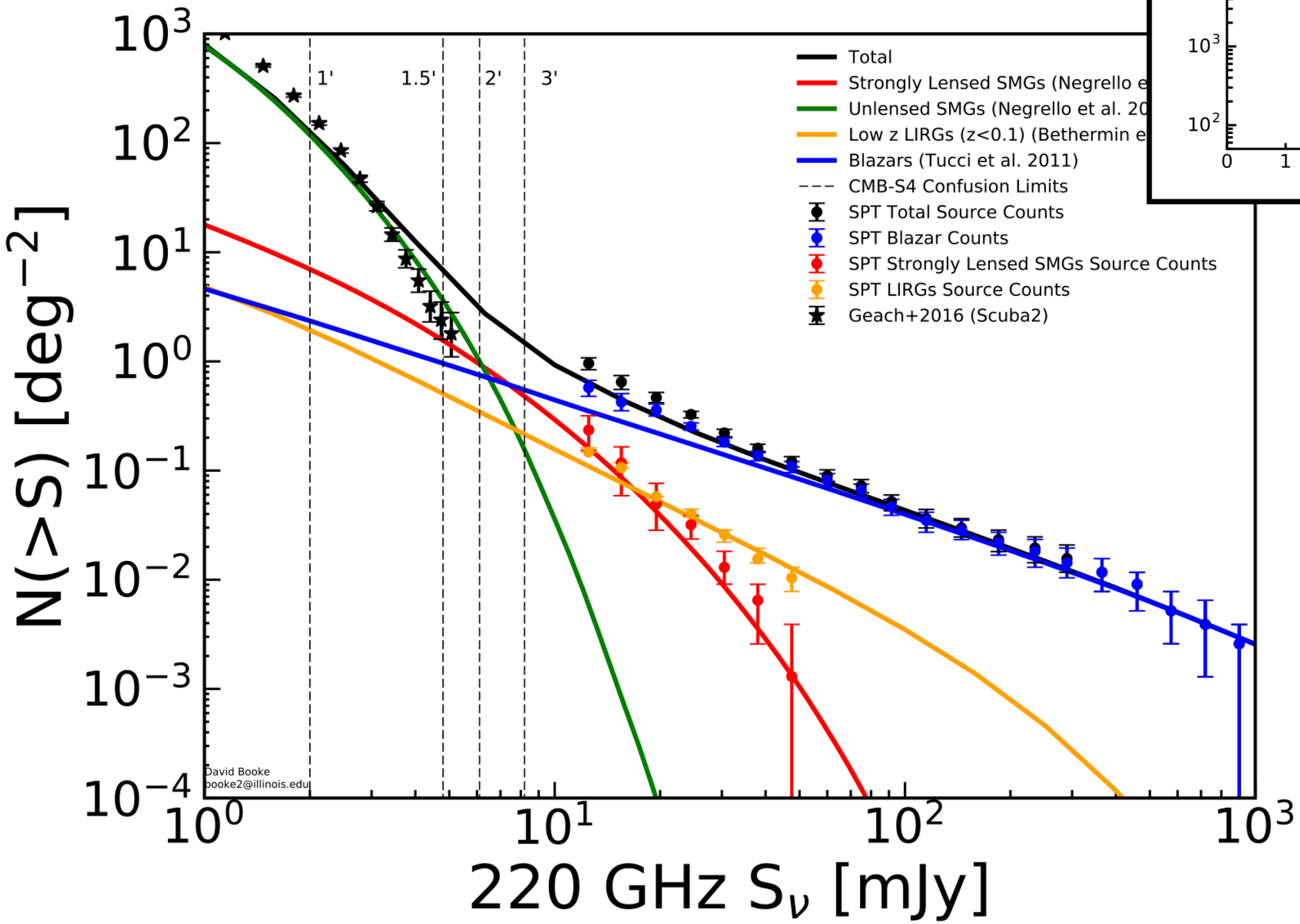
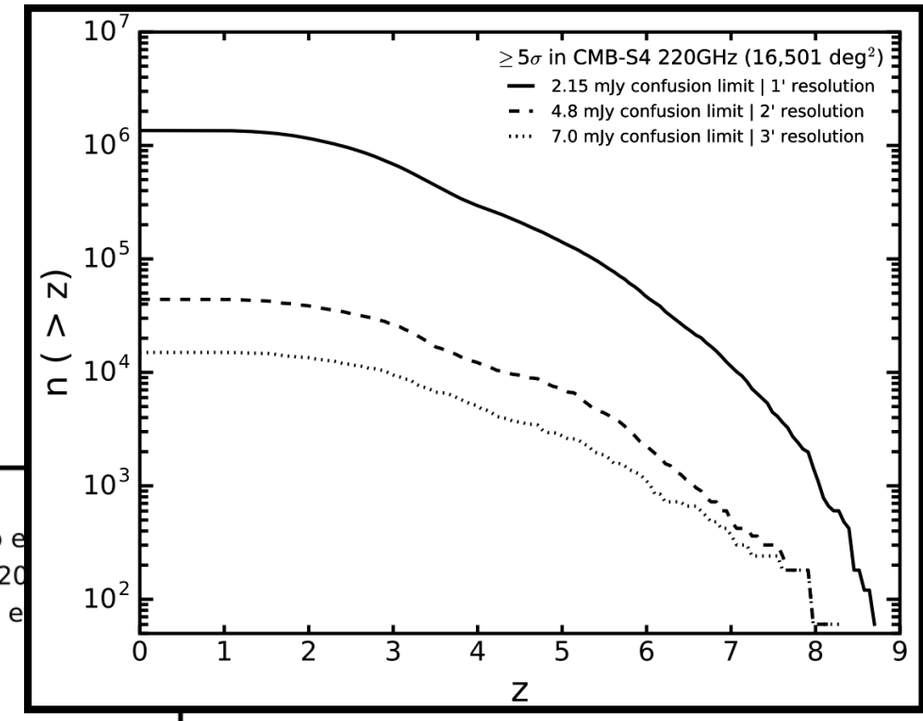


Figure G. Holder; S4 noise curve J. Meyers

Extragalactic Sources

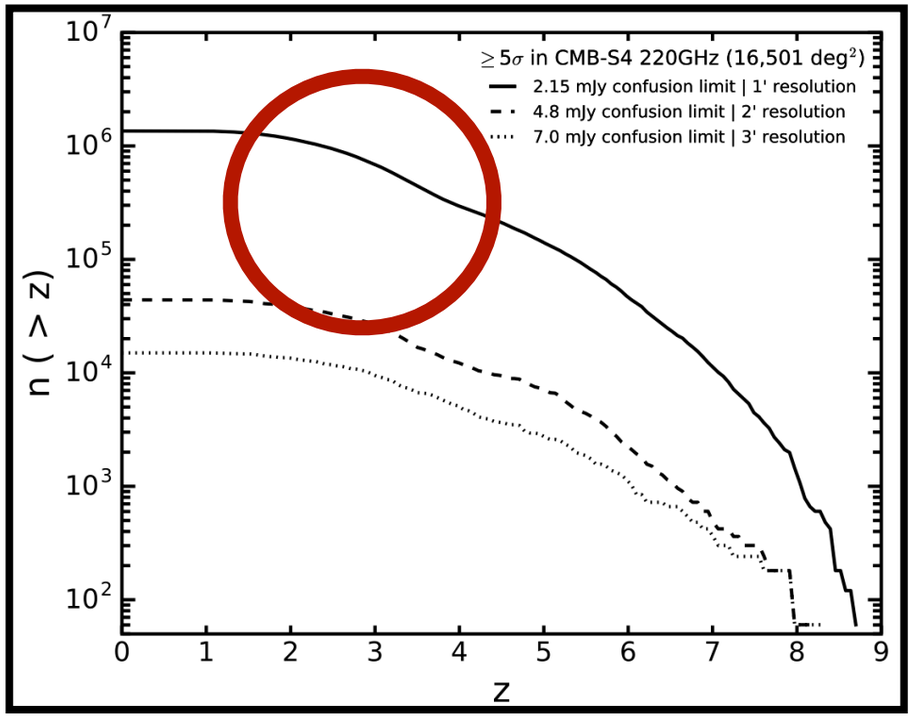




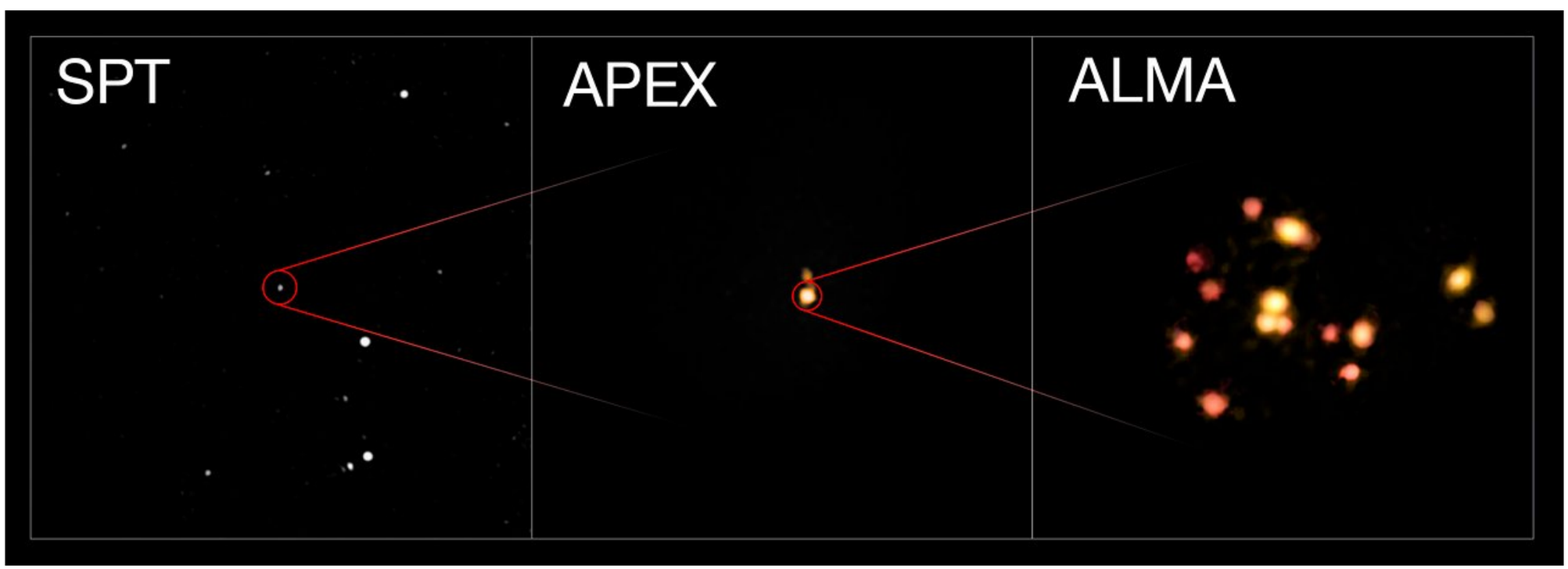
Figures from Joaquin Vieira

Extragalactic Sources

- **Some of the DSFGs identified by CMB-S4 will be protoclusters (high redshift progenitors of galaxy clusters)**

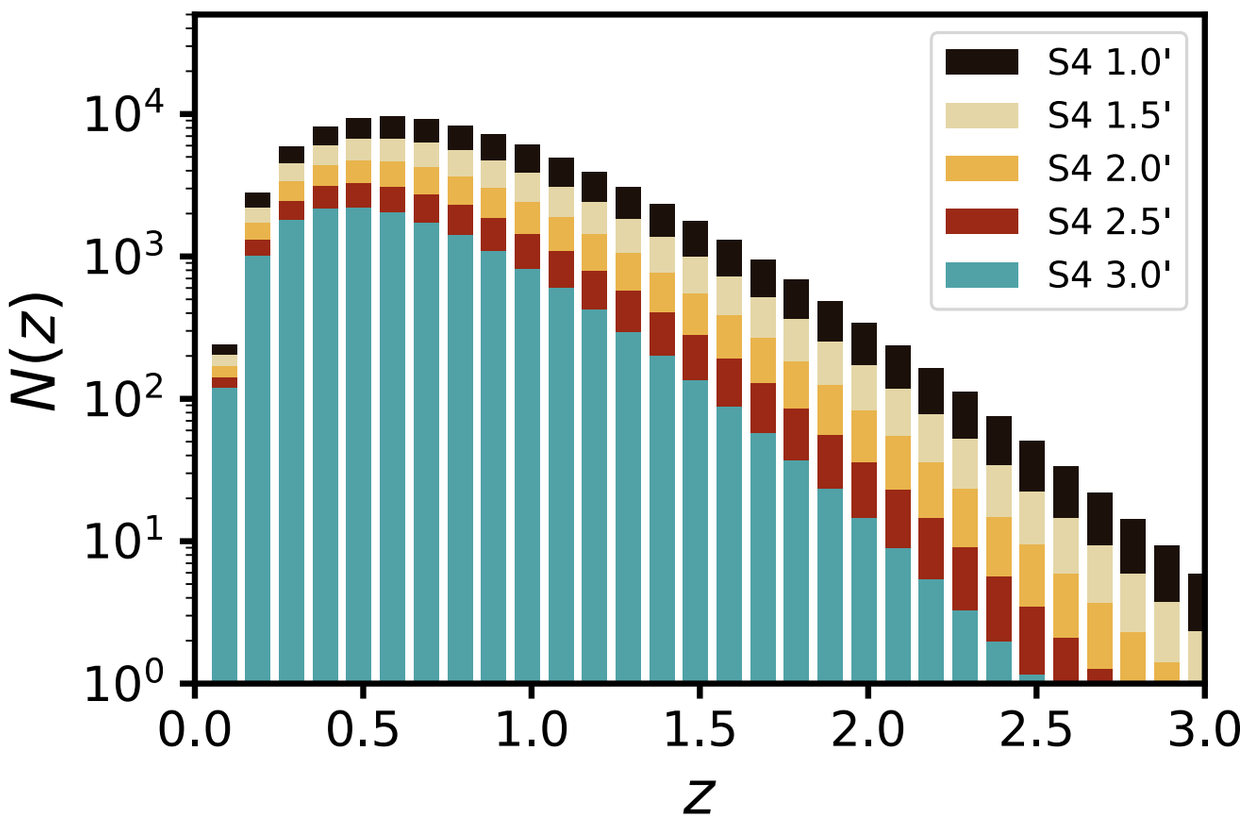


- Planck's "PHz" catalogue contains about 2000 "red peaks" in the CIB, over about a quarter of the sky
  - >200 followed up with Herschel, but we still don't really known what these are
  - there are hence no good theoretical predictions for their abundance
- CMB-S4 will detect many more



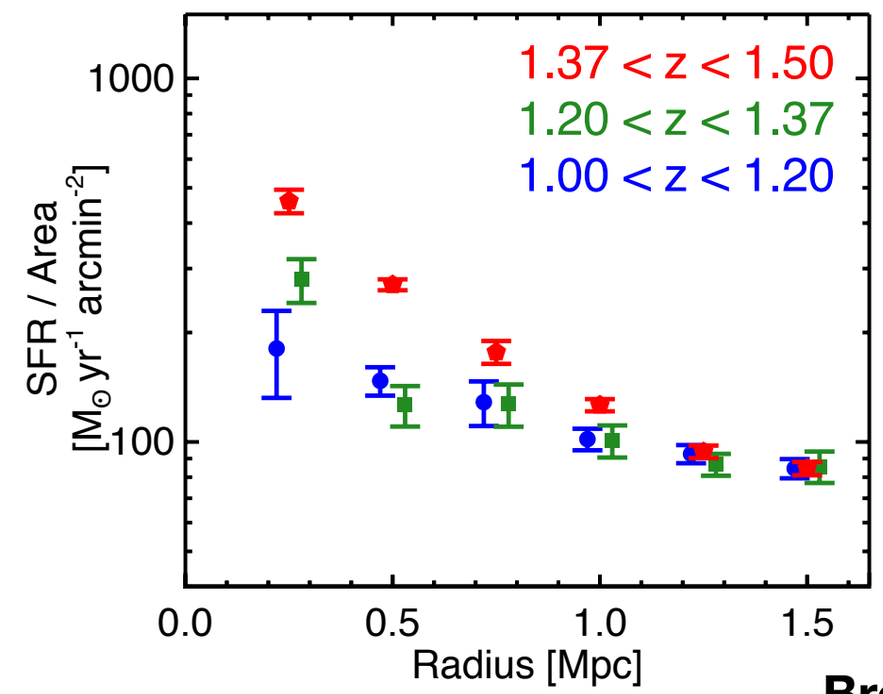
Credit: ESO/ALMA (ESO/NAOJ/NRAO)/Miller et al.

Galaxy Clusters: Cosmological and Astrophysical Implications

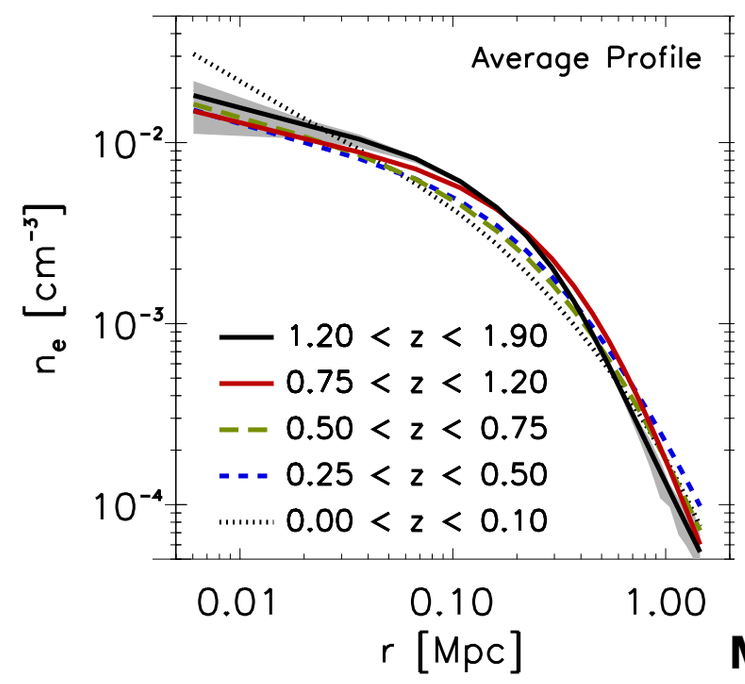


Madhavacheril, Battaglia, Miyatake 2017

"The number of massive galaxy clusters could emerge as the most powerful cosmological probe [if systematics can be controlled]" - DOE Cosmic Visions Dodelson+1604.07626



Brodwin+13

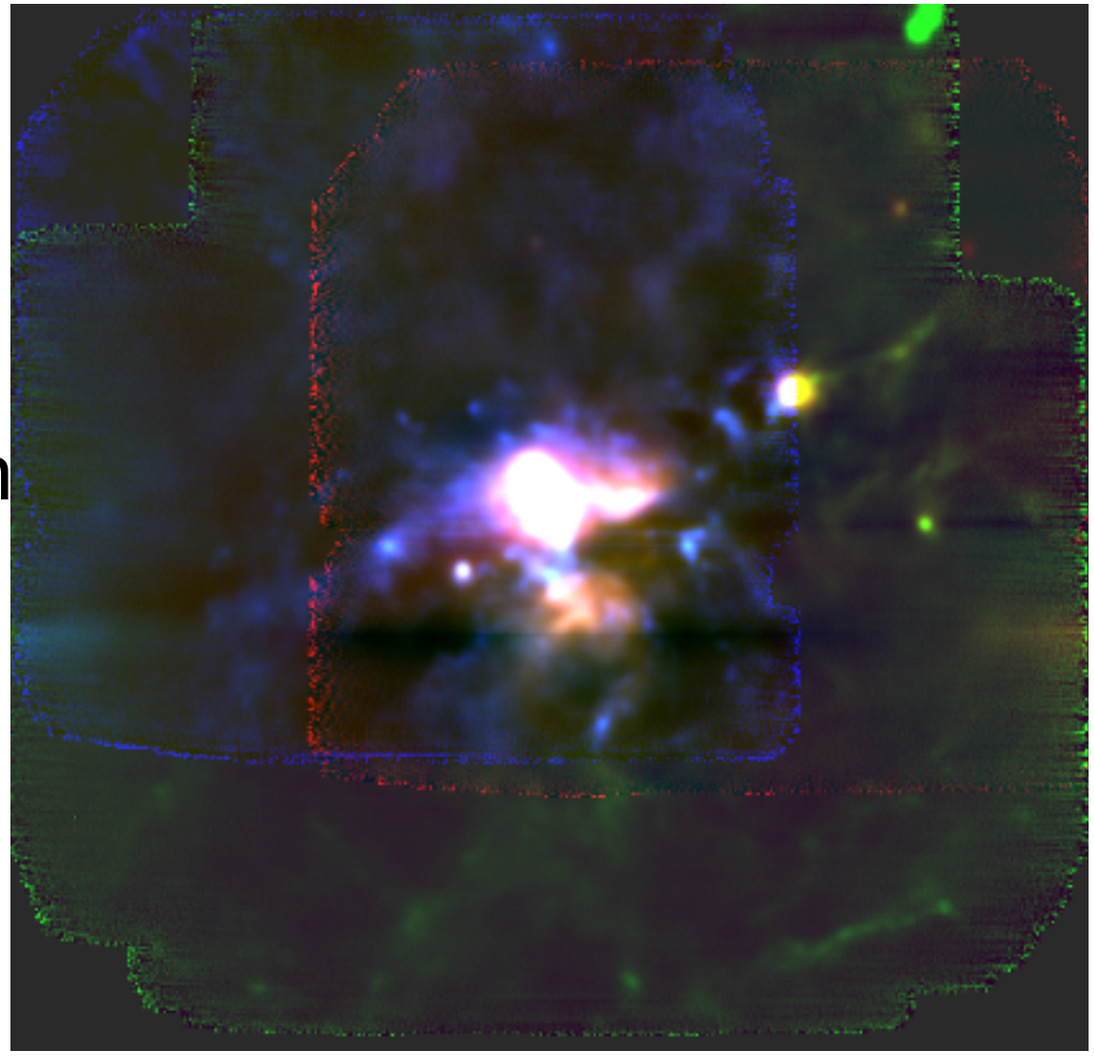


McDonald+17

Wonderful Synergy with LSST, Euclid, WFIRST, eRosita, *Athena*, *Lynx* and more!

Galactic Sources

- Planck (and earlier ground-based surveys) catalogue ~150 CO clouds at |b|>30º
- Planck also found hundreds of “cold cores” at high latitudes (some in known GMCs, others unknown)
- H-ATLAS discovered some sources associated with stars, including a few debris disk candidates
- As well as extracting Galactic sources in CMB-S4 maps, we can cross-correlate with stellar (and other Galactic) catalogues
- Not the highest priority - but does allow us to connect with another community of astronomers



RCW 38 HII region
(90,150, 220 GHz; rgb)
Credit: K Schaffer, SPT-SZ

HELP WANTED!

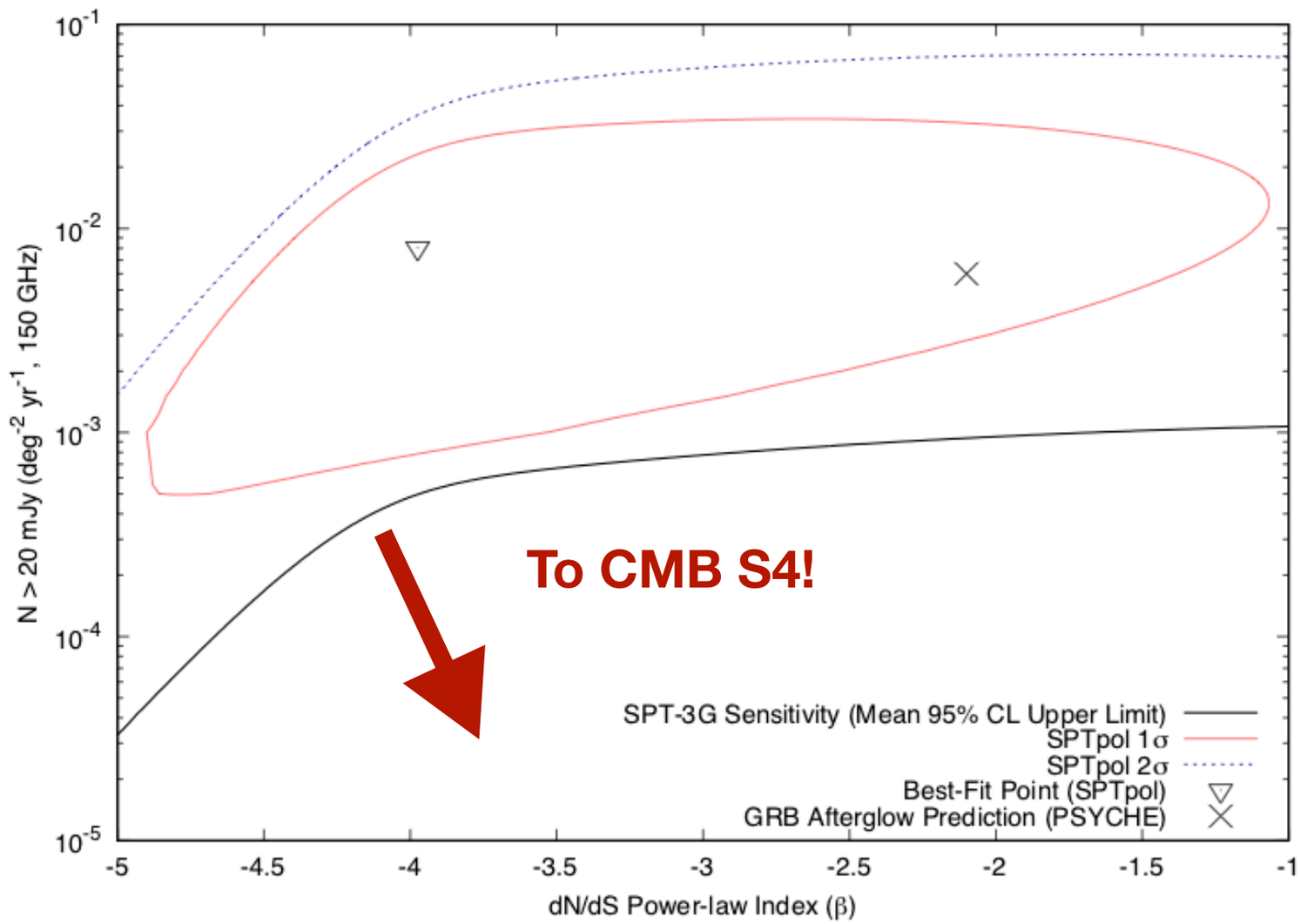
Transients - GRBs and FRBs

- **Orphan GRB afterglows (generic prediction of GRB models, but none yet detected)**

- **New probe of the Epoch of Reionization! CMB S4 should be able place interesting constraints on some models of GRBs from population 3 stars at z~20**

- **FRBs challenges include detector glitches, Cosmic Rays**

Figure by Nathan Whitehorn



Forecasting Machinery in place, need straw cadence to run projections for CMB-S4.

Near Earth Objects

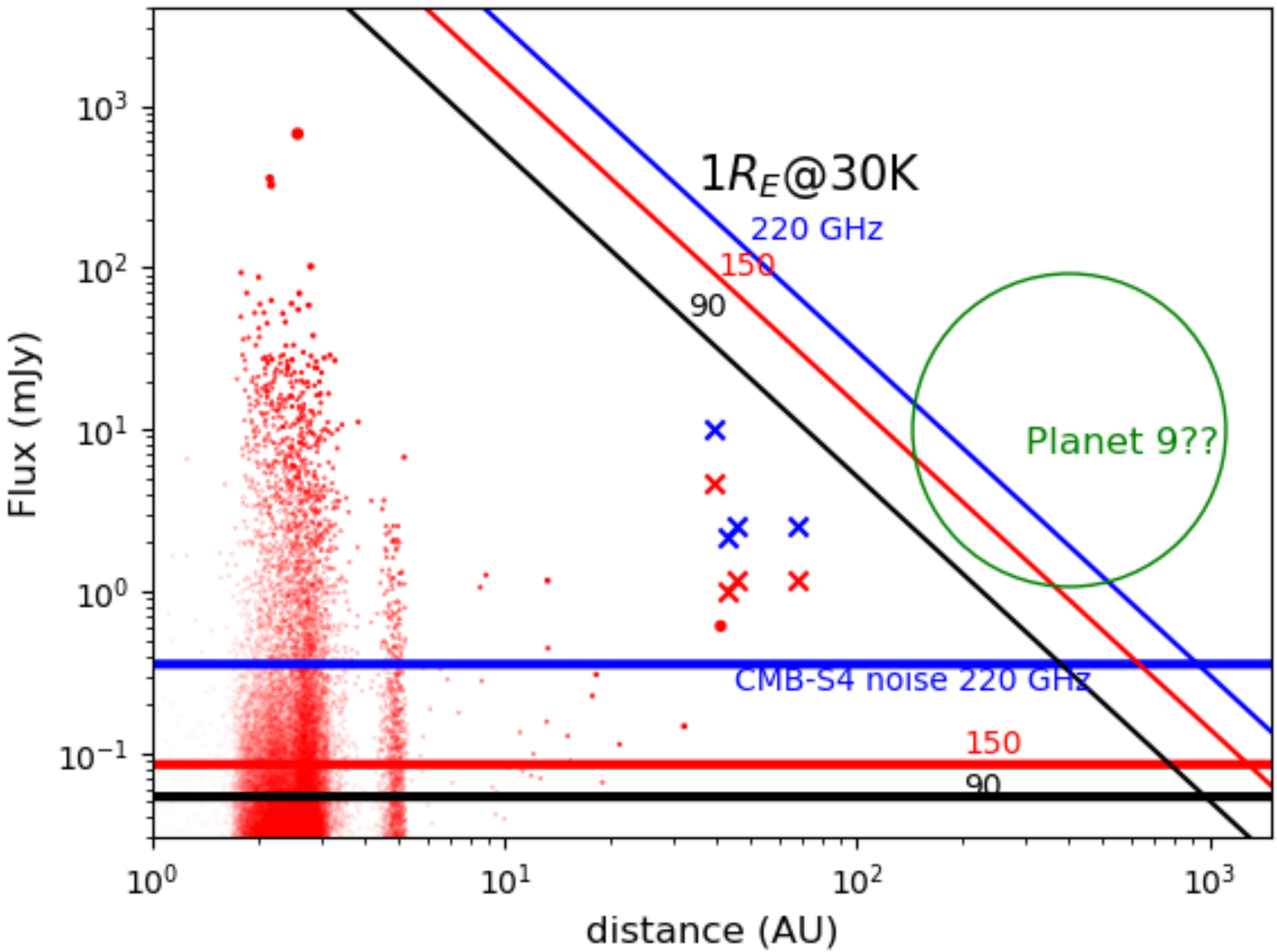


Figure by Gil Holder

Galactic sources

- In addition to Galactic polarization studies, CMB-S4 will detect sources within our Galaxy
- Mostly CMB-S4 people won't bother with Galactic sources - but they'll be seen anyway!
- Planck (and earlier ground-based surveys) catalogued ~150 CO clouds at |b|>30º
- Planck also found hundreds of "cold cores" at high latitudes (some in known GMCs, others unknown)
- H-ATLAS discovered some sources associated with stars, including a few debris disk candidates
- As well as extracting Galactic sources in CMB-S4 maps, we can cross-correlate with stellar (and other Galactic) catalogues

Proto-clusters

- SZ sources are already part of the CMB-S4 science case - hence a full catalogue + diffuse map
- But there are also “proto-clusters” with a different spectral signature - like redshifted clumps of DSFGs
- Planck’s “PHz” catalogue contains about 2000 “red peaks” in the CIB, over about a quarter of the sky
  - >200 followed up with Herschel, but we still don’t really known what these are
  - there are hence no good theoretical predictions for their abundance
- CMB-S4 will presumably detect many more with its smaller beamsize
- Perhaps CMB-S4 can bridge the gap between genuine clusters and proto-clusters?