WISE as the cornerstone for all-sky photometric redshift samples

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+ Polish WISE team: ***Kasia Małek****, M. Krupa, A. Kurcz,*
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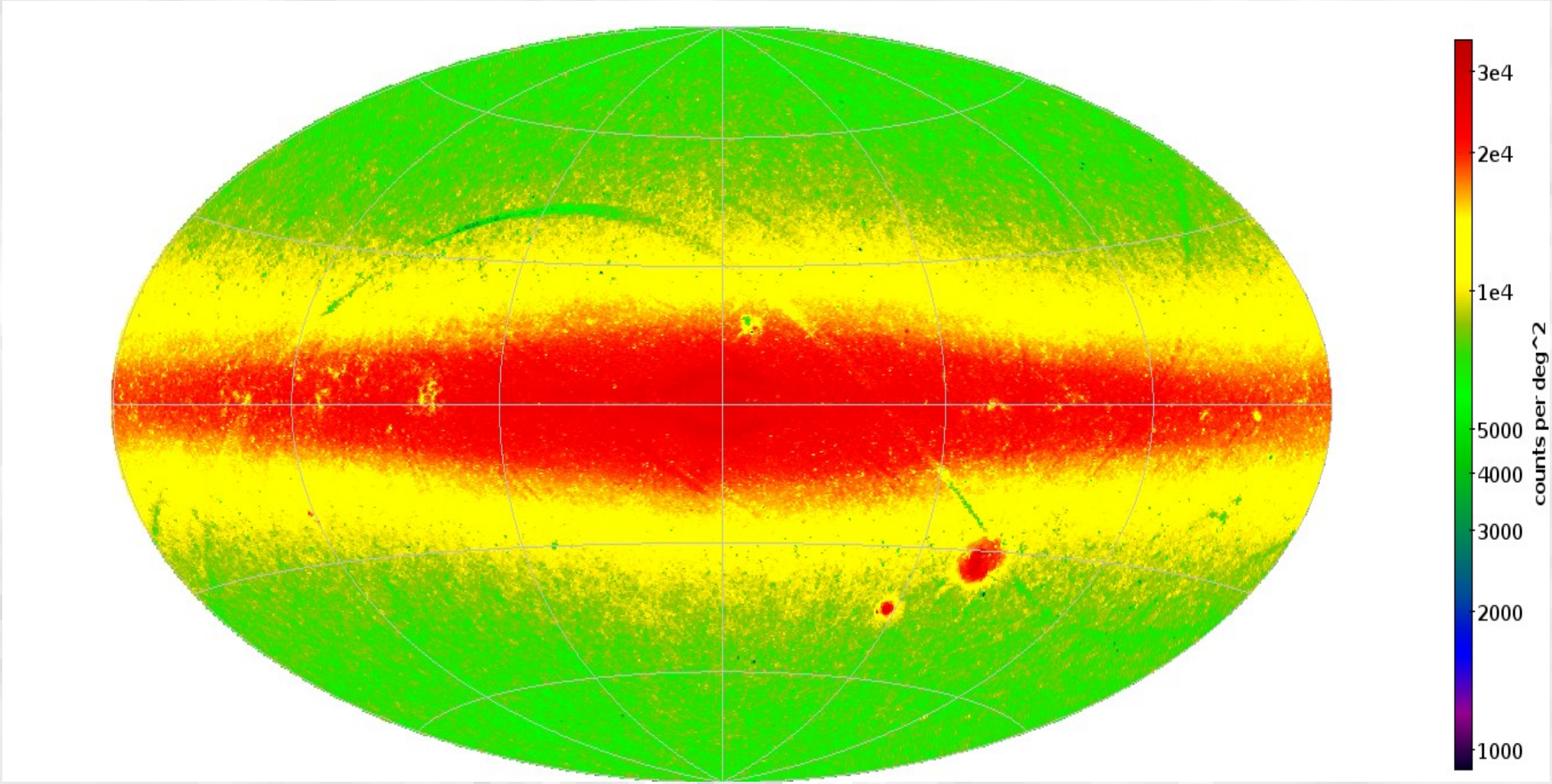
AllWISE W1<17

488 million sources



The need for all-sky galaxy surveys in three dimensions

- To obtain a **complete picture of the Universe** we ideally need to observe the **entire sky** (=4π steradians), in 3 dimensions and deep
- **Early Universe** very **homogeneous and isotropic**; but what about today? (the **Copernican Principle** needs to be studied *observationally*)
- Related **cosmological tests** require observing the whole celestial sphere in 3D*:*
  - Are the **CMB anomalies** confirmed as today's anisotropy and/or inhomogeneity?
  - How large are the **bulk flows** of galaxies? Are they in conflict with the CP?
  - What structures **pull the Local Group** of galaxies?
- Other probes – e.g. the **integrated Sachs-Wolfe** effect, **CMB lensing on LSS** or **baryon acoustic oscillations** – also need surveys of large coverage and volume

State of the art in all-sky (3D) galaxy surveys
(before our efforts)

- The **largest all-sky catalog of extended sources** (galaxies):
  the Two Micron All Sky Survey (**2MASS XSC**, Jarrett et al. 2000)
  1 million galaxies, complete up to K_s=13.9 mag (z~0.1)

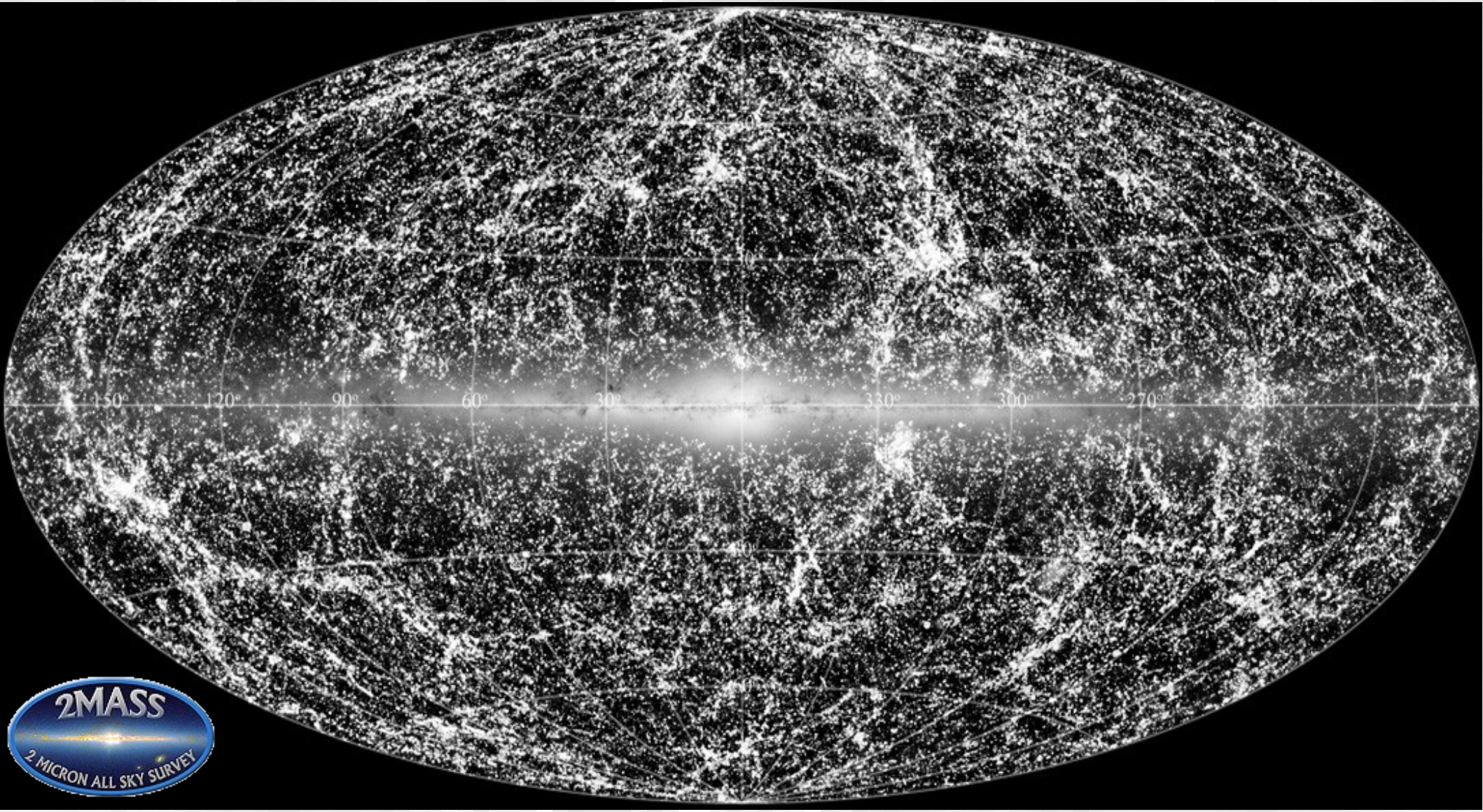
- 2MASS Redshift Survey of *44,000 galaxies* (**2MRS**, Huchra et al. 2012):
  complete all-sky redshift coverage, but only at <z>=0.03
- Going deeper with spectroscopic redshifts for 2MASS sources:
  the **2M++ compilation** by Lavaux & Hudson, 70,000 2MASS galaxies
- '**WISE XSC**' is still to be made (Jarrett, Magoulas, Cluver et al.)
  [but see the **WNGA** poster by Seibert & Neill on the largest WISE galaxies]

- Legacy: **SuperCOSMOS** catalog of all-sky photographic data,
  digitized and calibrated in Edinburgh (Hambly et al. 2001)

- See also the poster by Andras Kovacs on **WISE x 2MASS *PSC* galaxy sample**

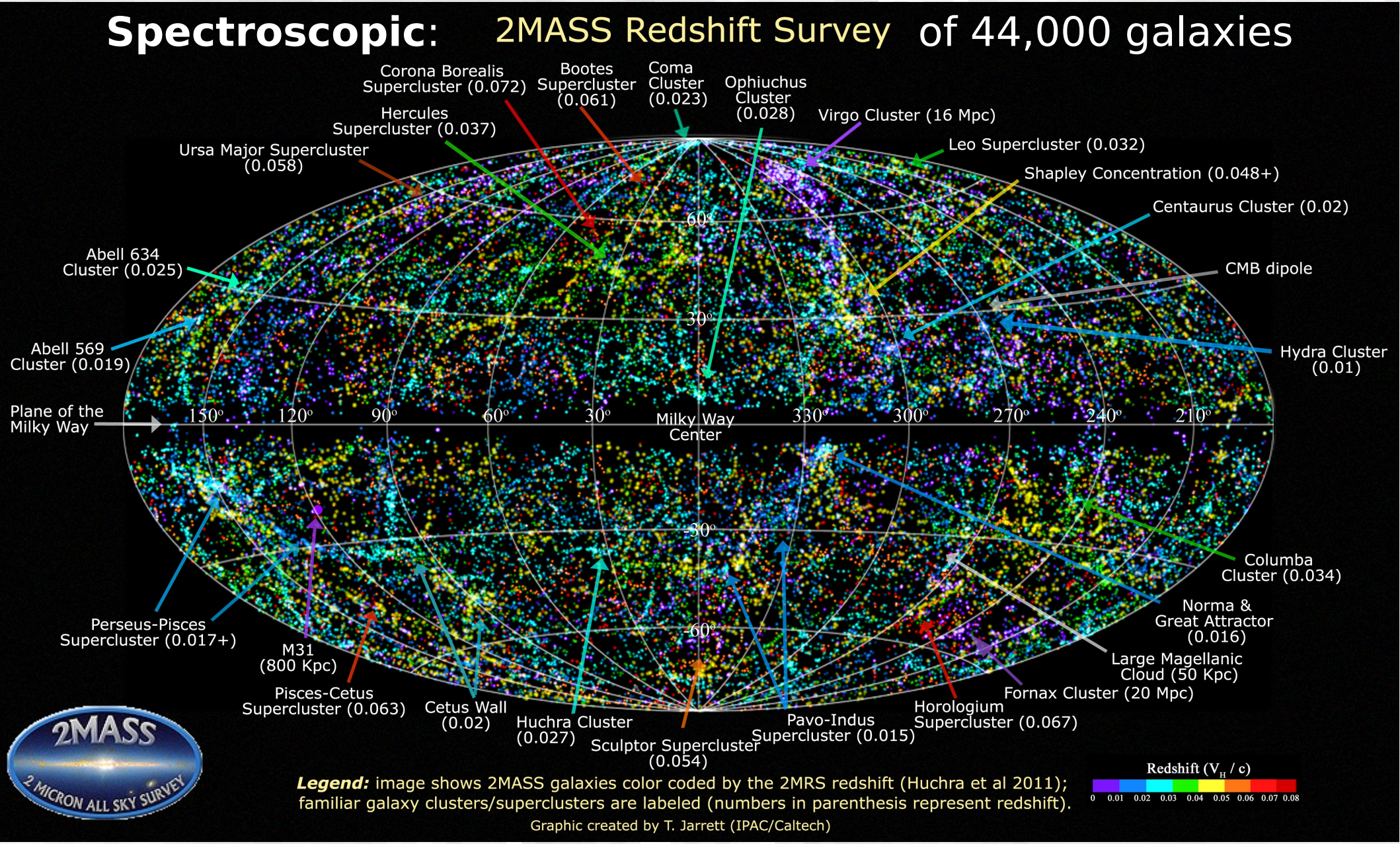
The largest all-sky catalogs of galaxies

Photometric: 2MASS XSC of 1 million galaxies



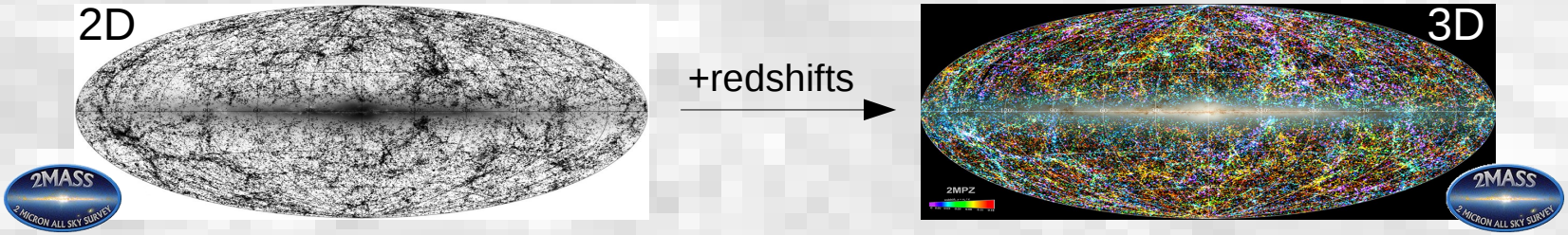
Jarrett 2004

The largest all-sky catalogs of galaxies



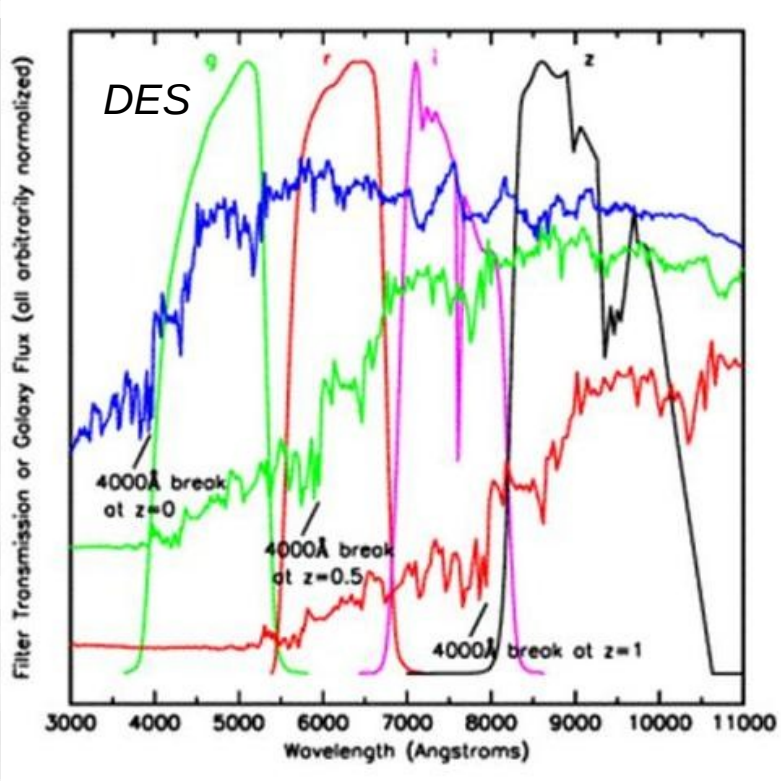
Huchra et al. 2012 (plot by Tom Jarrett)

Towards larger all-sky 3D catalogs



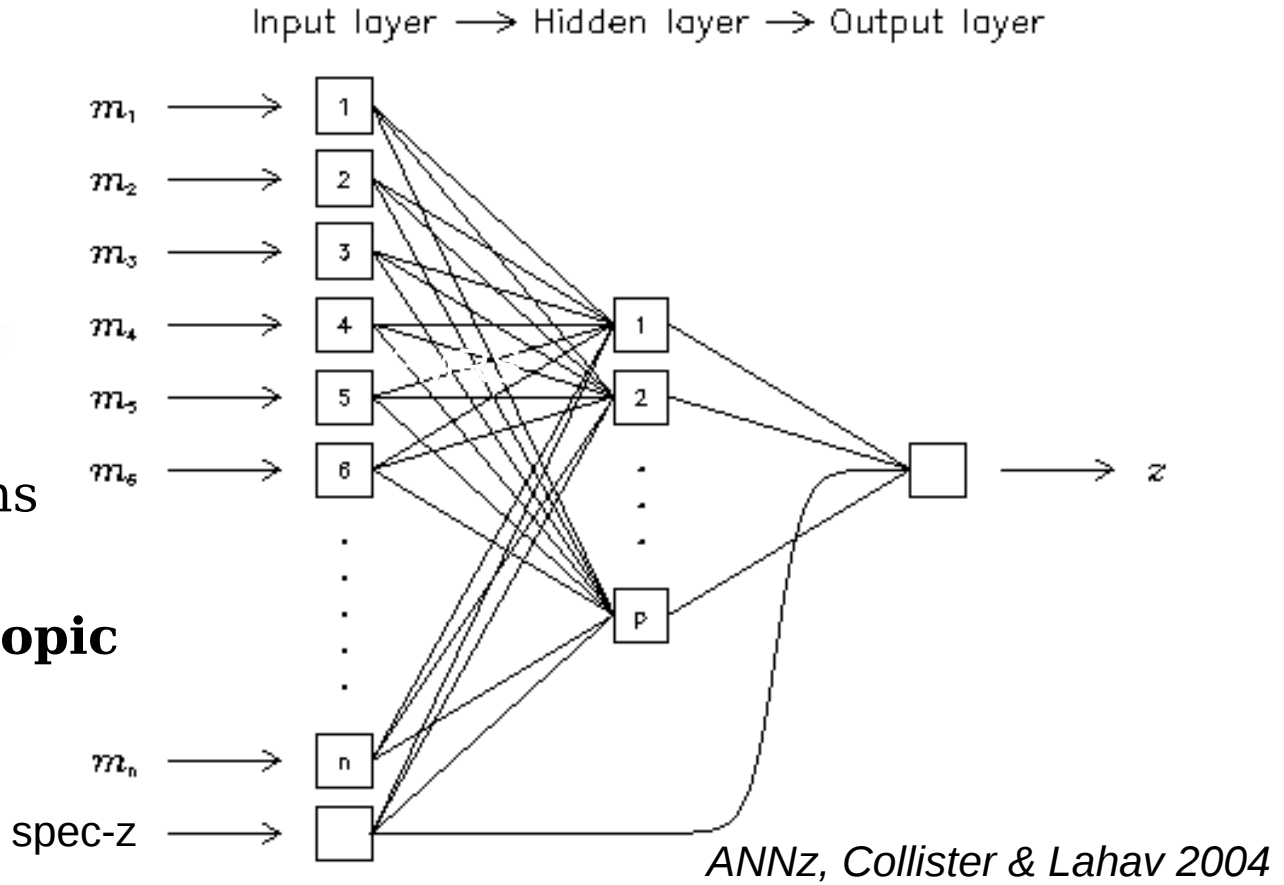
- **One third** of all 2MASS galaxies have **spectroscopic redshifts** from large surveys: **2MRS**, **2dFGRS**, **6dFGS** and **SDSS**
- **Not much hope** for supplementing the remaining 2/3 with **spec-z soon** (note however the **SPHEREx** proposal by Doré et al. arXiv:1412.4872)
- Adding the *third dimension* to the 2MASS XSC sample, an economic approach: ***photometric* redshifts** using appropriate z_spec calibration
- **Early attempts** for 2MASS by **Jarrett 2004** (2MASS only), **Francis & Peacock 2010** (2MASS x SuperCOSMOS) – before the advent of WISE
- **Precise 2MASS photo-z's** now possible thanks to adding WISE W1 & W2

Photometric redshifts via neural networks



- Cosmological **shift** of **lines** and of **continuum** + **decrease** in bolometric **flux** + **evolution** = wavelength-dependent **magnitude changes**

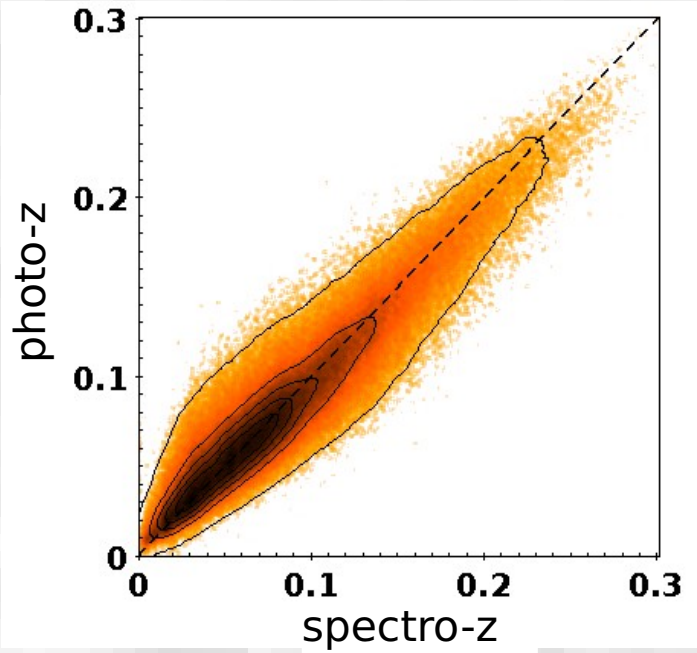
- **Machine learning** algorithms (such as **neural networks**) can be **trained** on **spectroscopic** data to derive best-fit **photo-z's** for a given set of passbands



ANNz, Collister & Lahav 2004

2MASS Photometric Redshift catalog (2MPZ)

- We cross-matched **2MASS XSC** (J H K_s) with **WISE** All-Sky (W1 and W2) and **SuperCOSMOS** (photographic B R I)
- We applied the ***ANNz*** *(Artificial Neural Networks,* Collister & Lahav 2004), trained on a representative spectroscopic subsample of 350,000 galaxies
- **2MPZ catalog** of **1 million galaxies**, **<z>=0.08**, covering **most of the sky**
- Some statistics of the photo-z estimates:
  → 1-sigma scatter $\boldsymbol{\sigma_{\Delta z}}$**= 0.015**
  → median error **|Δz|/z = 13%**
  → only **3% of outliers** $>3\sigma_{\delta z}$



- 2MPZ is **available for download** from the Wide Field Astronomy Unit at the Institute for Astronomy, Edinburgh:
  http://surveys.roe.ac.uk/ssa/TWOMPZ

MB, Jarrett, Peacock, Cluver & Steward, ApJS, 210, 9 (2014), arXiv:1311.5246

2MASS Photometric Redshift catalog

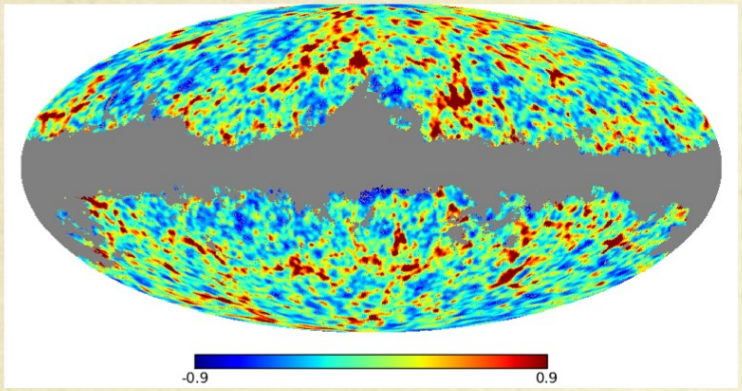
1 million galaxies in 3D

Color-coded by photometric redshifts

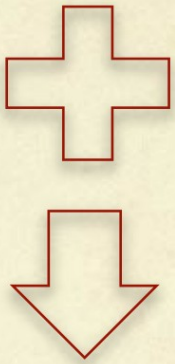
Plot by Tom Jarrett

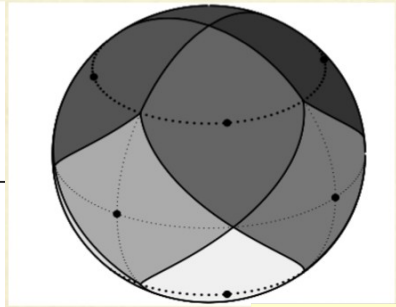
First cosmological results from 2MPZ:
integrated Sachs-Wolfe tomography

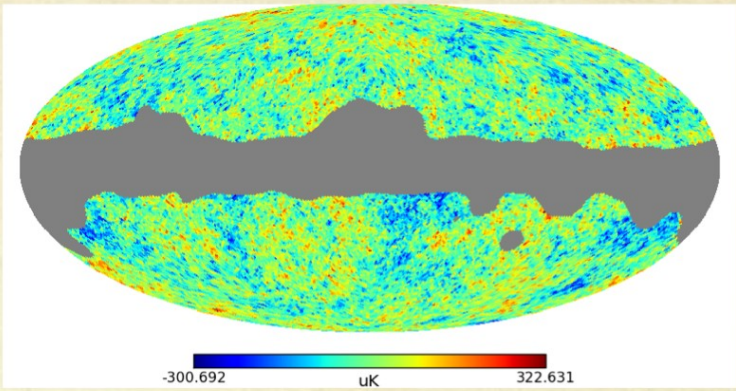
effort led by **Louise Steward** (UCT)



2MPZ galaxy distribution
in redshift shells





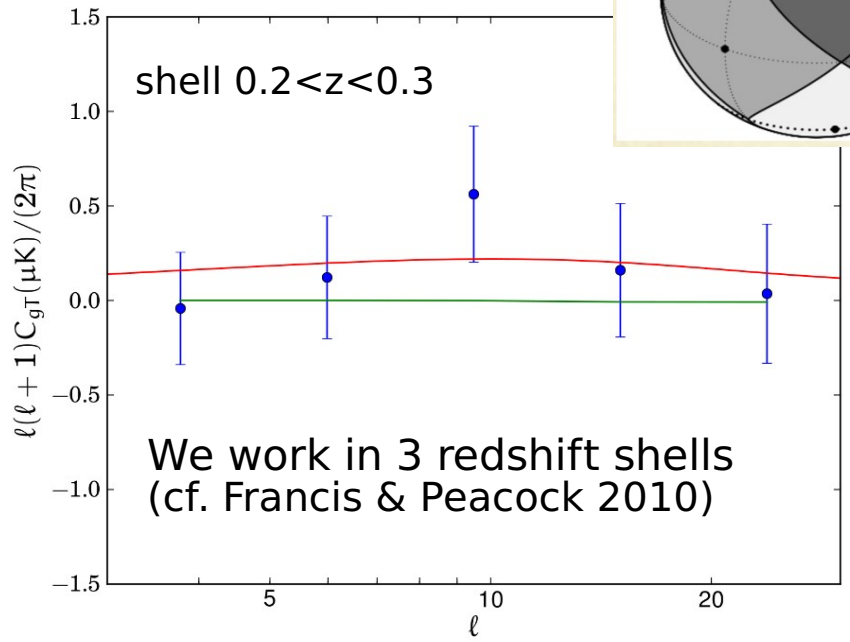


Planck temperature map

ISW signal and its significance

Cross-correlation

$$C_{gT} =$$



- We see **mild preference for ISW**: less than **2σ**, odds *~3.5 : 1* over no ISW (cf. odds *1.5 : 1* in Francis & Peacock '10)
- Good **photo-z's help**, but **2MASS** is **too shallow** even if it was fully spectroscopic

Steward, MB, et al. in prep.

Some other applications of the 2MASS Photo-Z catalog

- **Testing Isotropy in the Local Universe** (Appleby & Shafieloo, arXiv:1405.4595)
- **Identifying galaxy clusters** (Xu, Wen & Han, arXiv:1406.0943)
- **Looking for the transition to homogeneity** (Alonso et al., arXiv:1412.5151)
- **Integrated Sachs-Wolfe effect reconstruction** by the Planck team (Planck 2015 XXI, arXiv:1502.01595)

In preparation:

- **Local bulk flow** from luminosity function variations (Feix, MB, Nusser)
- **Cross-correlation with Fermi-LAT** gamma ray data for dark matter constraints (Cuoco, Branchini, MB)
- **Acceleration of the Local Group**: sources of the pull, **convergence?** (revisiting Erdogdu et al. 2006 & Bilicki et al. 2011) – PhD project of M Krupa

Going deeper than 2MASS over 75% of sky: WISE x SuperCOSMOS

- **All-sky photometric samples much deeper than 2MASS:**

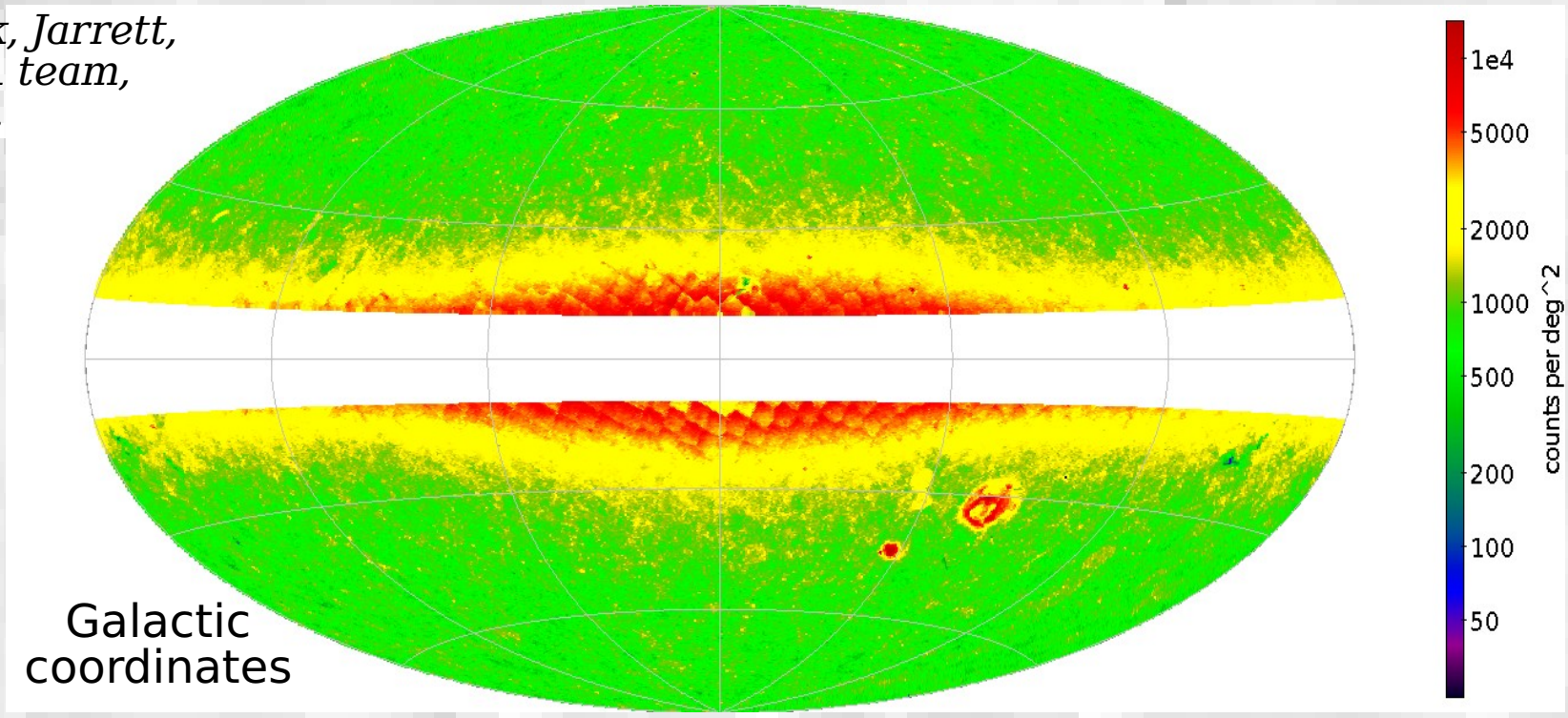
  WISE ($W1_{Vega}$<17) and **SuperCOSMOS** (R_{AB}<19.5 & B_{AB}<21)

- **Preselections** for a reliable **galaxy sample**:

  |b|>10°; detected in W1 & W2; extended in SuperCOSMOS, detected in B & R

- Cross-match gives **47 million sources**, but mostly stars (blends)

MB, Peacock, Jarrett, & the GAMA team, 2015 in prep.

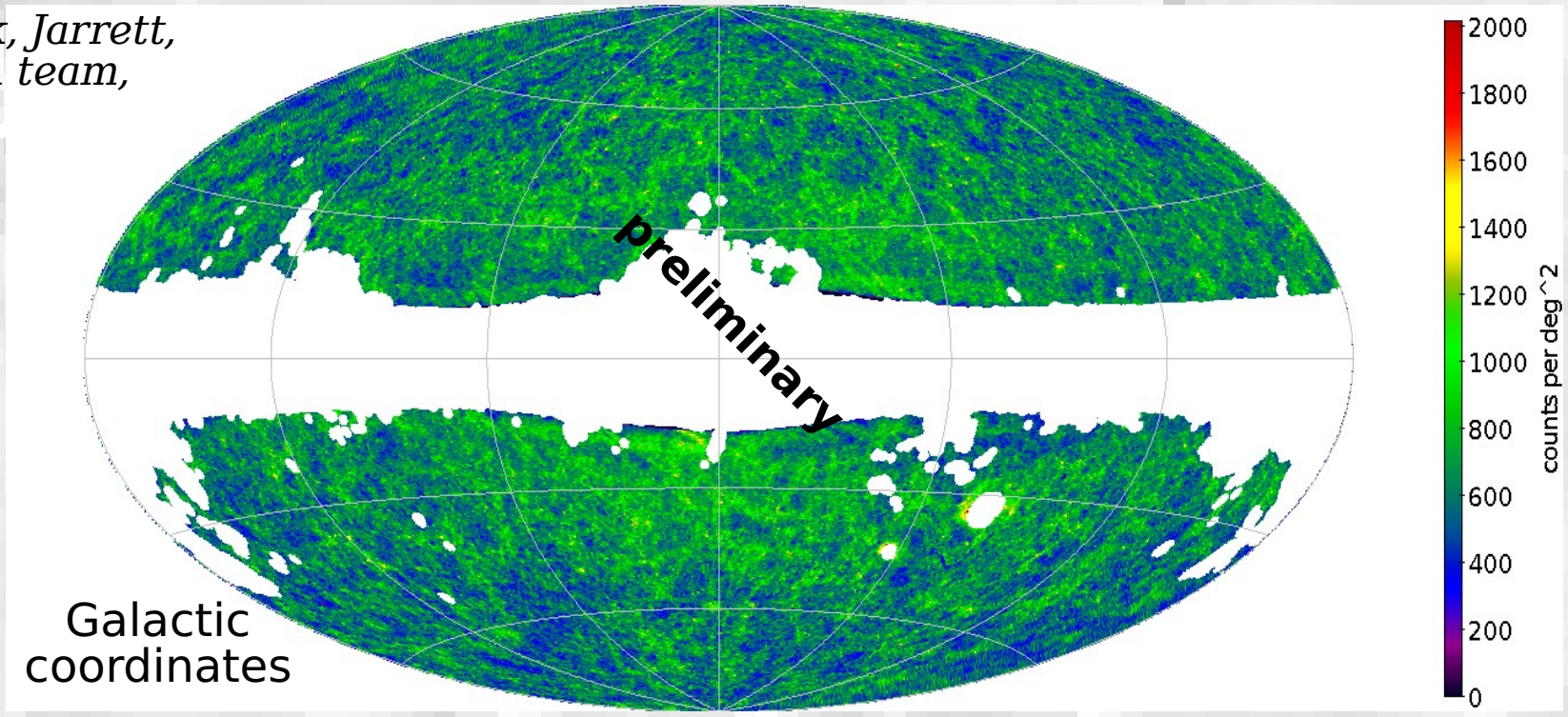


20 million galaxies
from WISE x SuperCOSMOS

- A color-based clean-up of stars and QSOs/AGNs gives **20 million galaxies**
- Star removal through a **position-dependent W1-W2 cut** for all-sky uniformity
- Quasar removal uses **all-sky availability of R-W2 & W1-W2** information
- Being refined with **automatic classification (Kasia Małek's talk)**

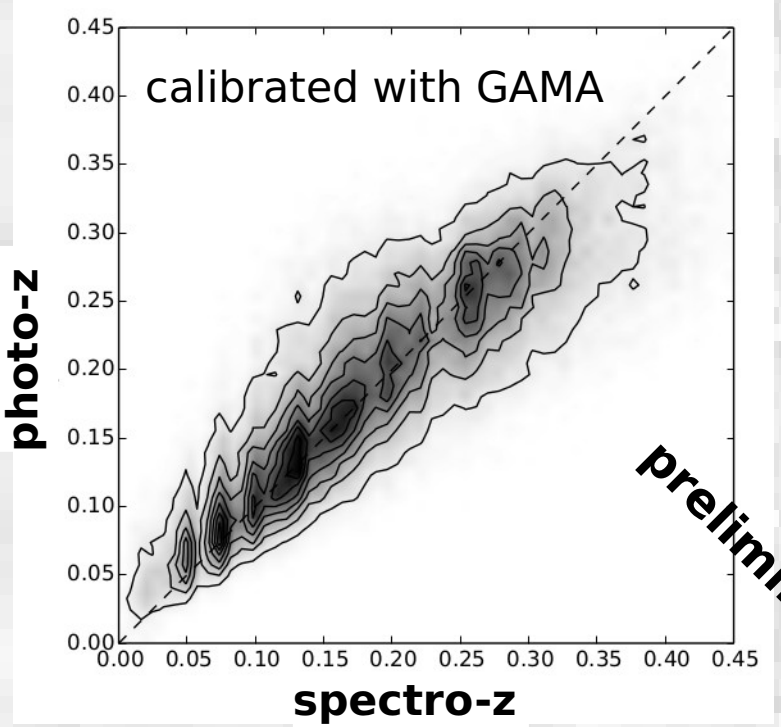
- Sample now used for **preselection** in a new hemispherical **TAIPAN** spec-z survey

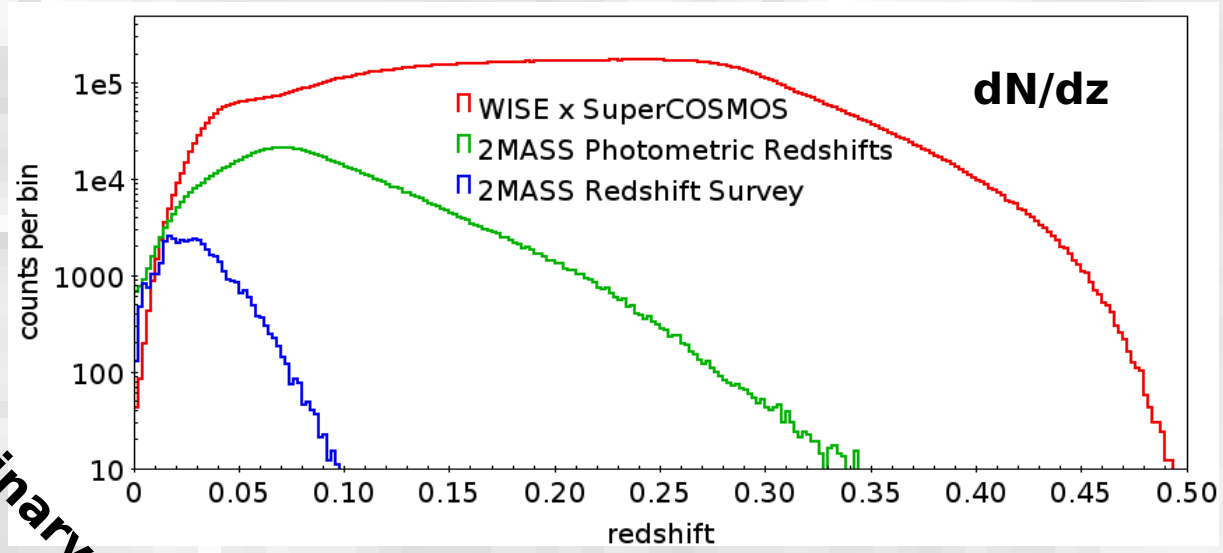
MB, Peacock, Jarrett, & the GAMA team, 2015 in prep.



The largest ~all-sky 3D sample

- **WISE x SuperCOSMOS photo-z catalog:** much deeper than 2MASS
- **Four photometric bands** for photo-z's: optical **B,R,** infrared **W1,W2**
- Training sets: **GAMA** most recent data and **SDSS DR10**
- Median redshift **z~0.2**, but probes the LSS reliably **to z~0.4**
- Photo-z performance: $\sigma_{\Delta z}$**= 0.03,** median **error 14%** and **3% outliers**



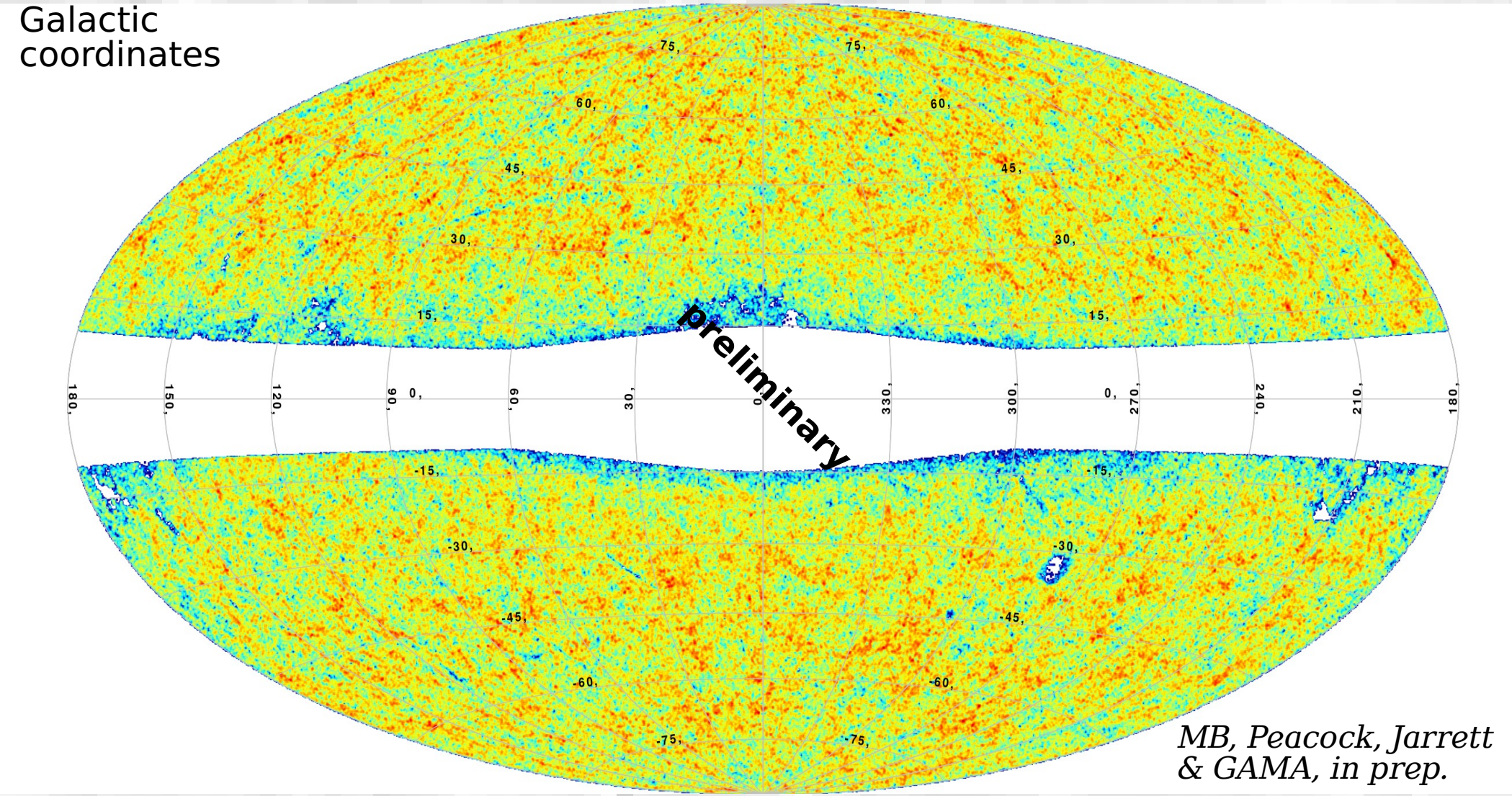


MB, Peacock, Jarrett & GAMA, in prep.

The cosmic web 2.5 Gyr ago

large-scale structure at z~0.2

shell of $0.19 < z_{phot} < 0.21$ 1.7 million galaxies

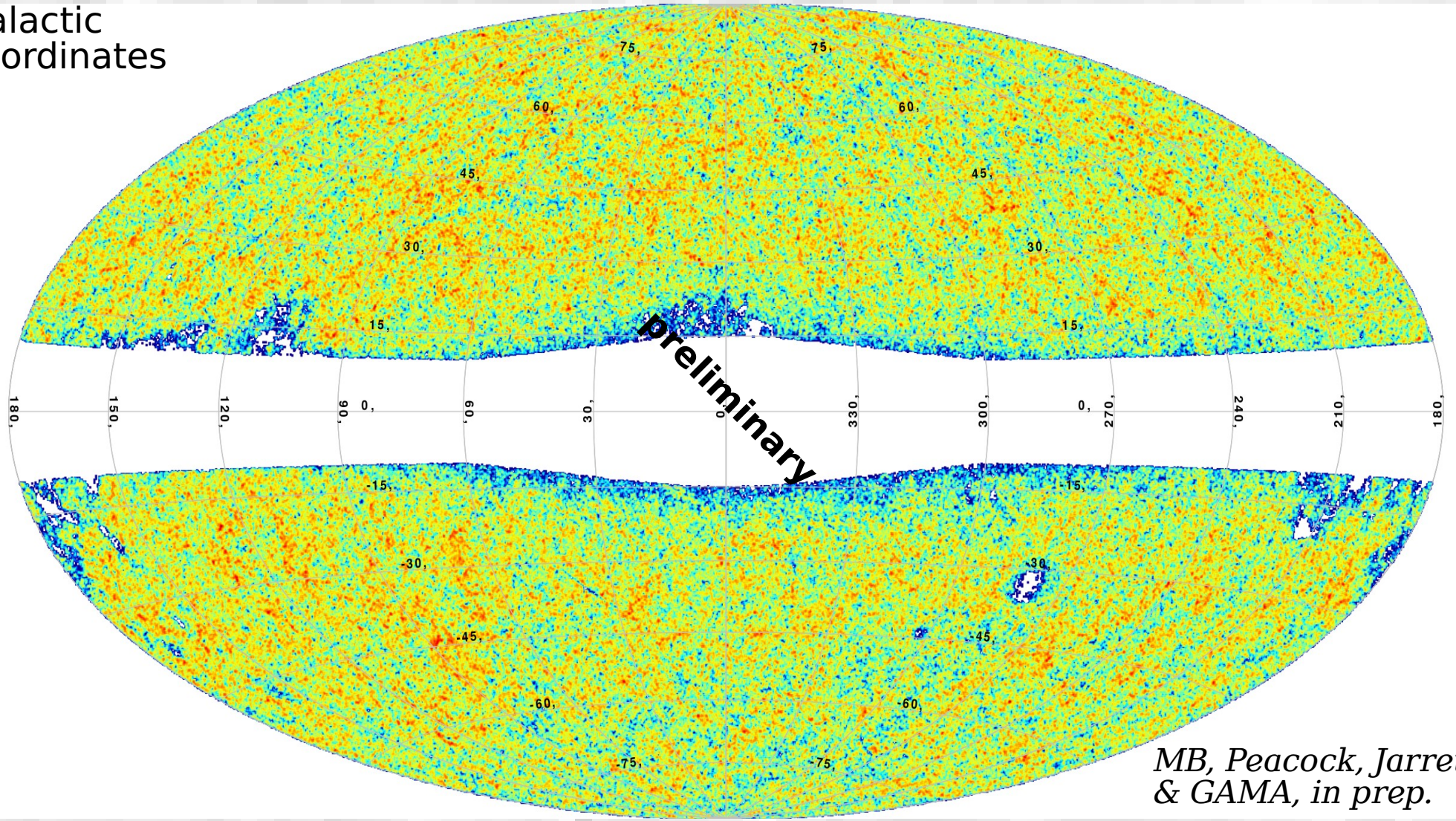


MB, Peacock, Jarrett & GAMA, in prep.

The cosmic web 3.5 Gyr ago

large-scale structure at z~0.3

shell of $0.29 < z_{phot} < 0.31$ 1.2 million galaxies



MB, Peacock, Jarrett & GAMA, in prep.

Possible cosmological applications
of the WISE x SuperCOSMOS photo-z catalog

Similar as for the 2MPZ but on scales ~3 times larger:

- **Testing isotropy and homogeneity** of the Universe up to z~0.4
- **Integrated Sachs-Wolfe** tomography with a hope for a decent S/N
- **Largest-scale bulk flow** studies with the luminosity function
- **Identifying galaxy clusters –** low-z supplement to MADCOWS (+photo-z's!)
- **Pull on the Local Group of galaxies** from scales >500 Mpc/h?

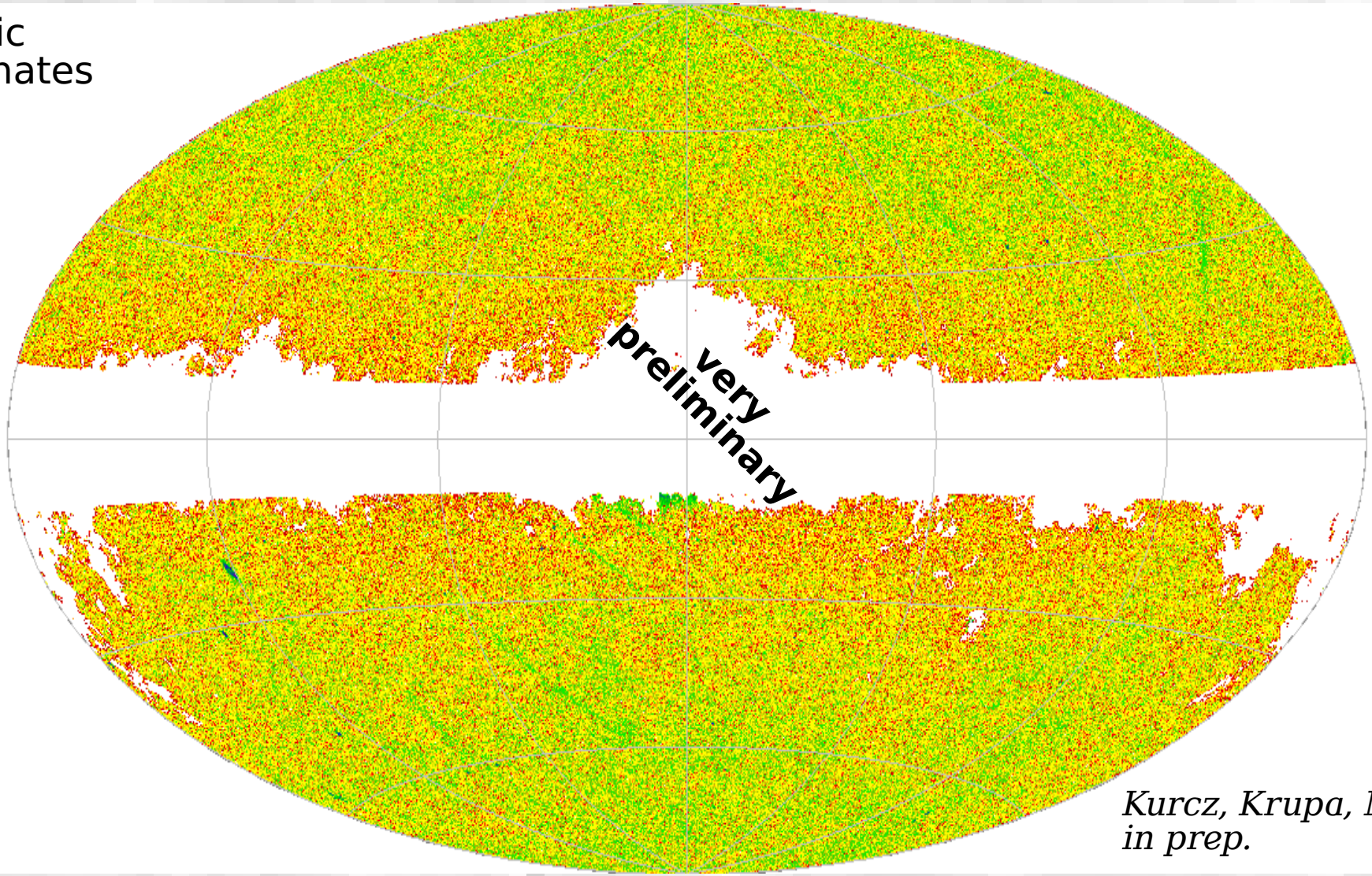
Not practicable so far with all-sky data (such as 2MASS):

- **Cross-correlation with CMB lensing** – Peacock & Bilicki in prep.
- **Angular BAO tomography** – cf. DES science case
- **Certainly many more** (a large **AGN/QSO population** – K. Małek's talk)

All-sky probes: time for WISE

- **One of the largest all-sky samples**: over **700 million** sources in AllWISE
- **WISE** itself is **much deeper** (~3 mag) **than 2MASS** as well as **than SuperCOSMOS**: another “layer” for extragalactic science
- Ongoing work at the University of Cape Town (Jarrett, Magoulas, Cluver): **large-scale structure** as seen by WISE (deep) in Galactic Caps (|b|>60)
- Full **cosmological potential of WISE** still to be explored: dominated by stars even at relatively high latitudes
- Of particular interest: **quasars** available **all-sky** for the first time
- In the queue: automatic **star-galaxy-QSO separation** in WISE only (MB & Polish WISE team: Kurcz et al. in prep.)
- Preliminary classification results: at W1<16 & |b|>10, we provisionally identify **~80 mln galaxies**, **70 mln stars** and **2 mln QSOs**

Very preliminary:
~2 million WISE AGNs/QSOs at W1<16



Kurcz, Krupa, MB et al.
in prep.

Summary

- **We now have access to the largest volumes on >3π steradians of the sky**
- **Third dimension at these scales possible (only) with photometric redshifts**
- **New galaxy catalogs (2MPZ, WISE x SuperCOSMOS) now probe up to z~0.4**
- **WISE is the crucial ingredient in the recipes for these catalogs**
- **2MPZ publicly available from http://surveys.roe.ac.uk/ssa/TWOMPZ**
- **Stay tuned for more: WISExSCOS photo-z's, ~all-sky classification, ...**