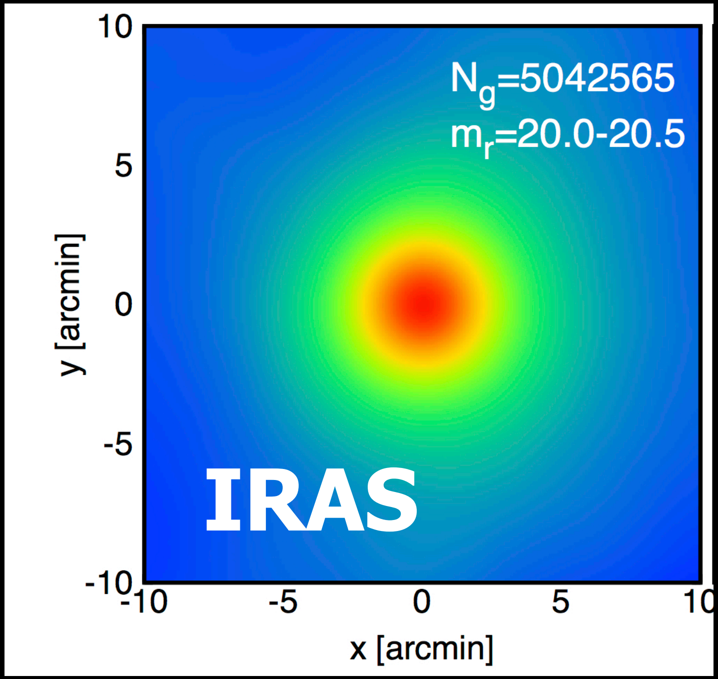
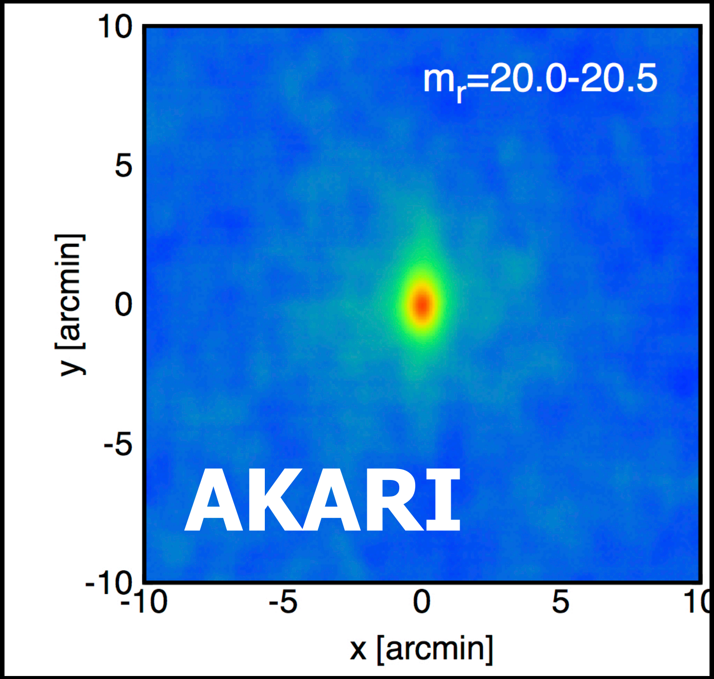
Spatial extent of dust from stacking image analysis of SDSS galaxies over IRAS and AKARI maps





Yasushi Suto *Department of Physics, The University of Tokyo*

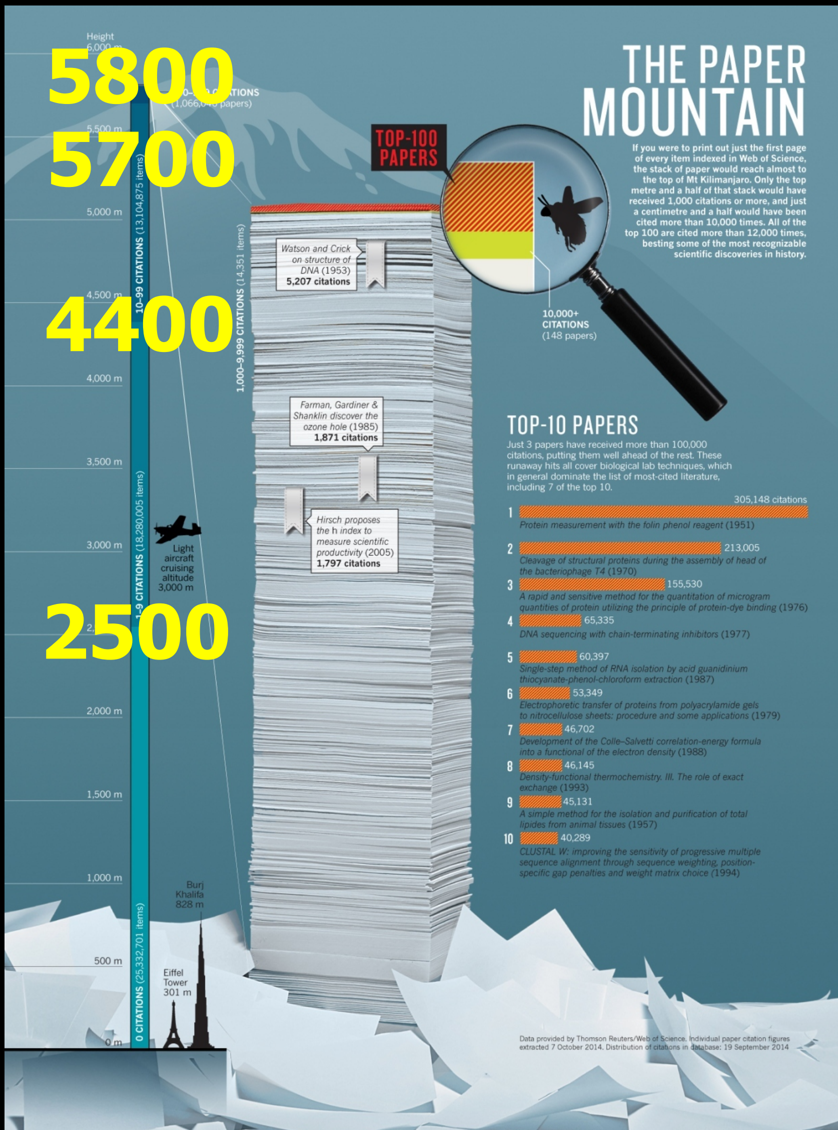
15:30-16:00 November 5, 2014 The 6th KIAS workshop on

Cosmology and Structure Formation

Top 5 cited papers in astronomy

	authors	citation	title
1	Schlegel, Finkbeiner & Davis (1998)	8880	Maps of Dust Infrared Emission for Use in Estimation of Reddening and Cosmic Microwave Background Radiation Foregrounds
2	Perdew & Zunger (1981)	8393	Self-interaction correction to density-functional approximations for many-electron systems
3	Perlmutter et al. (1999)	8288	Measurements of Omega and Lambda from 42 High-Redshift Supernovae
4	Riess et al. (1998)	8187	Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant
5	Spergel et al. (2003)	7801	First-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Determination of Cosmological Parameters

Nature 514(2014) 550-553, Oct. 30 issue



- Stacking the first page of all published papers almost reaches the top of Mt. Kilimanjaro (h=5800m)
- Only the top 1.5m (1.5cm) has citations >1000 (10000)
  - 0 citations at h=2500m
  - 1-9 citations at 4400m
  - 10-99 citations at 5700m
- the mountain is dominated by a completely invisible component ⇔ stacked dust !

A closer look

The most cited paper in history

Rank: 1 Citations: 305,148

Protein measurement with the folin phenol reagent

Lowry, O. H., Rosebrough, N. J., Farr, A. L. & Randall, R. J. J. Biol. Chem. 193, 265–275 (1951).

- *The most cited work in history, for example, is a 1951 paper describing an assay to determine the amount of protein in a solution. It has now gathered more than 305,000 citations — a recognition that always puzzled its lead author, the late US biochemist Oliver Lowry. "Although I really know it is not a great paper…I secretly get a kick out of the response," he wrote in 1977.*

from Nature article in Oct.30, 2014 issue

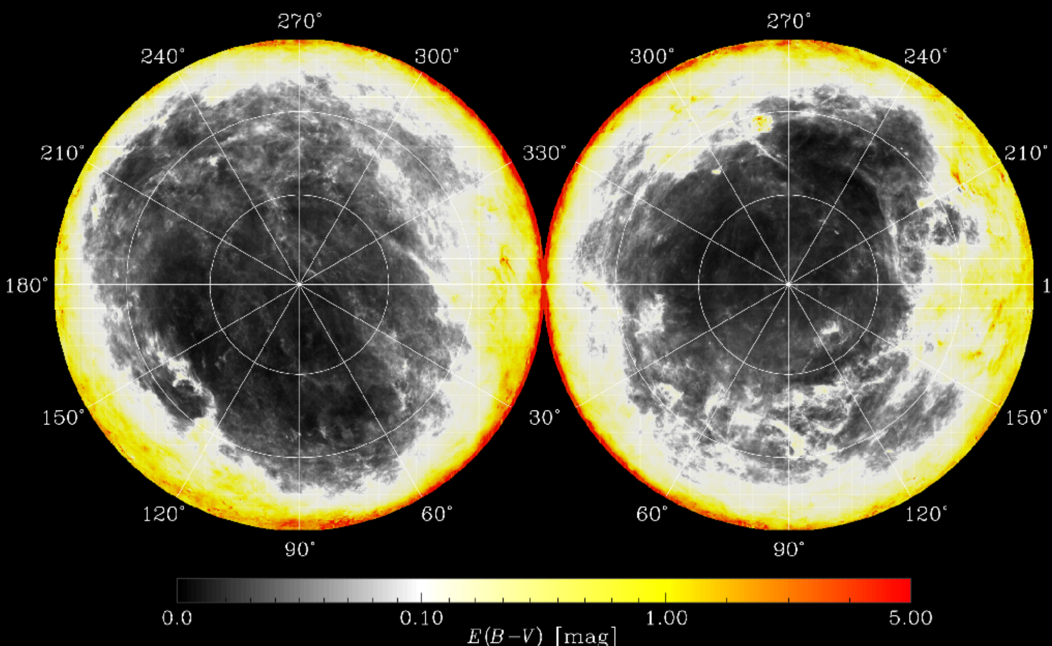
Discovery of the anomaly in the SFD Galactic extinction map using SDSS galaxy number counts

- K.Yahata, A.Yonehara, YS, E.L.Turner, T.Broadhurst, & D.P. Finkbeiner

  Publ.Astron.Soc.Japan 59(2007)205
- T.Kashiwagi, YS, A.Taruya, I.Kayo, T.Nishimichi & K.Yahata

  submitted to ApJ (2014)

SFD Galactic extinction map



Galactic extinction E(B-V) map (Schlegel, Finkbeiner & Davis 1998; SFD)

- The most fundamental dataset for all astronomical observations
- True large-scale structures revealed only after the extinction correction
- Its reliability is of vital importance in precision cosmology

SFD procedure to construct the Galactic extinction map

- COBE 100 μm+240 μm maps (0.7deg.pixel)
  - Remove zodiacal light and cosmic infrared background
  - Dust temperature map ⇒ temperature-dependent emissivity corrected 100 μm map
- Calibration of higher angular-resolution IRAS 100 μm map (5 arcmin. pixel)
- Assume

$$E(B-V)=pI_{100\mu m}X(T)$$

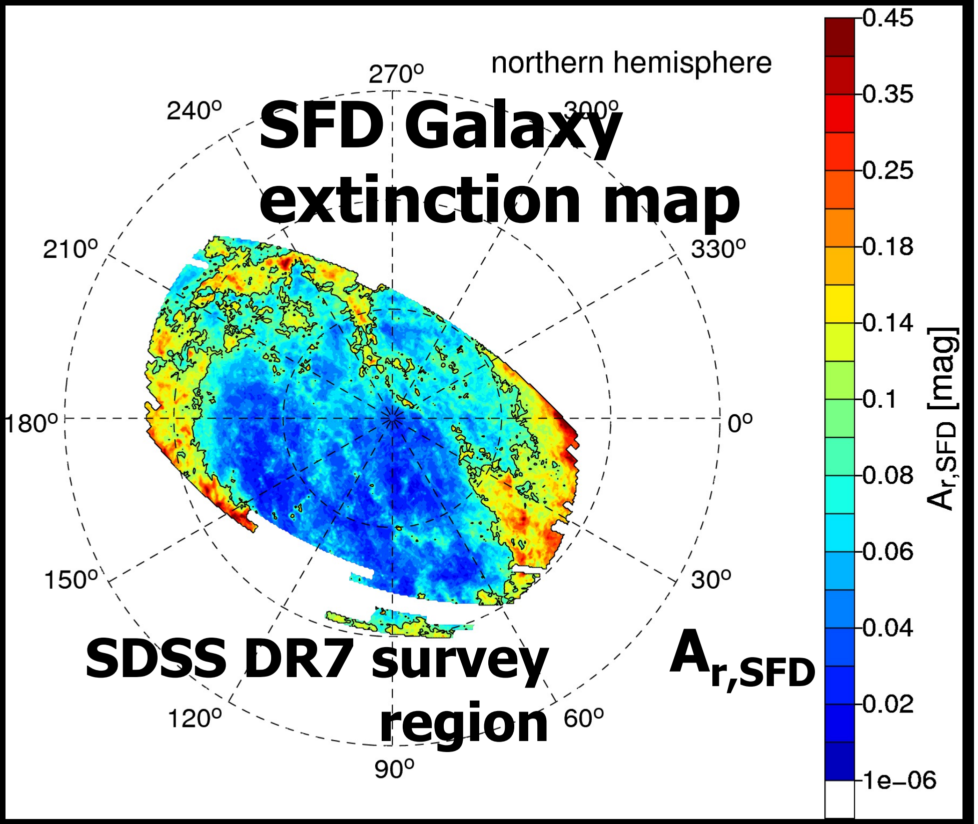
dust temperature correction factor

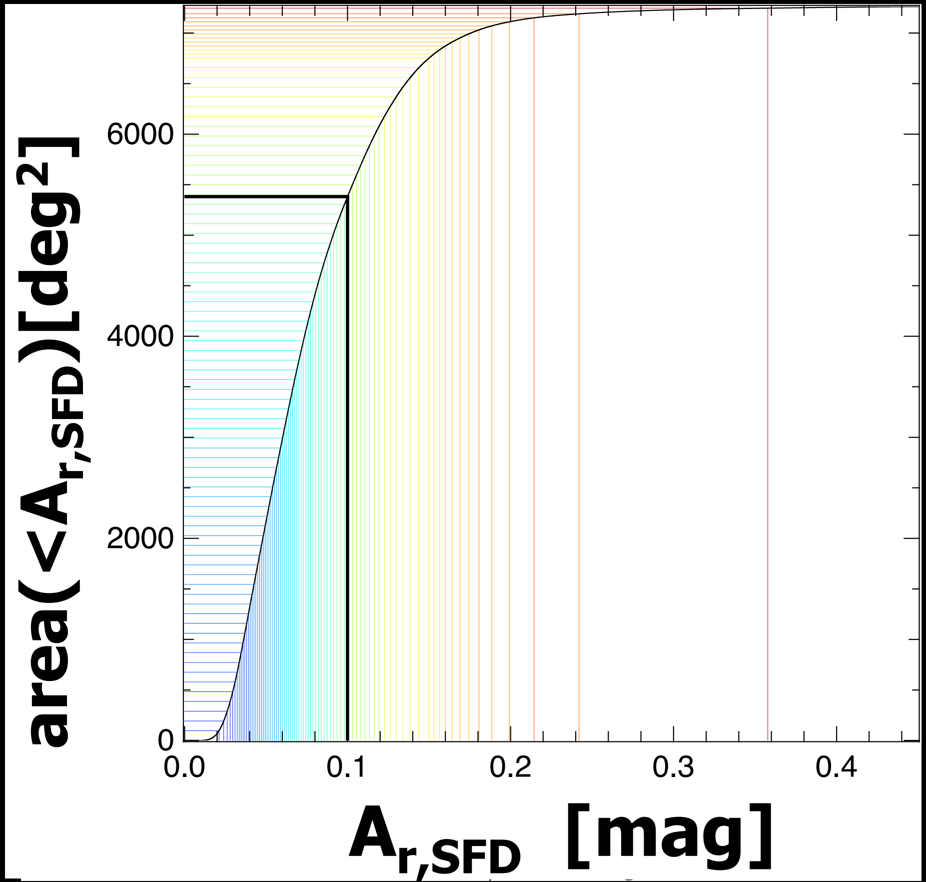
at each region and determine $p\sim 0.0184$ from the data

- Convert E(B-V) to A_{band} adopting $R_V=A_V/E(B-V)=3.1$

A_{SFD} map in SDSS DR7 survey region

3.6×10^6 galaxies ($17.5<r<19.4$) in 7270 deg^2 from SDSS DR7 photometric catalog

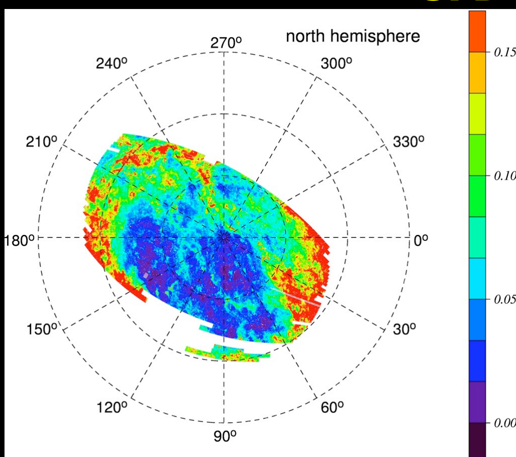


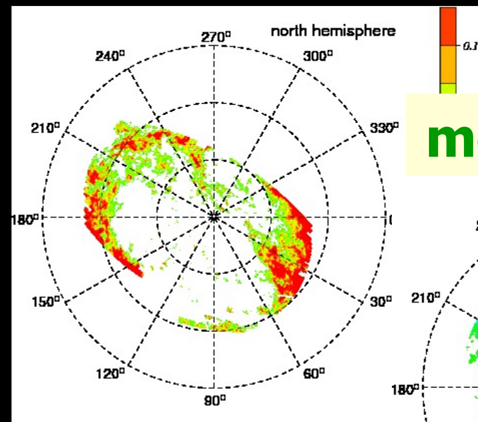


Kashiwagi et al. (2014), Yahata et al.(2007)

Estimating Galactic extinction from SDSS galaxy surface density

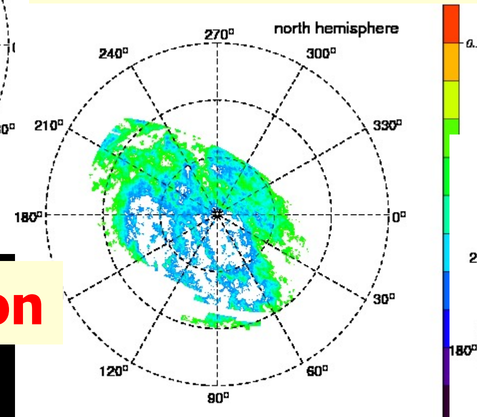
SDSS DR7 survey area (color coded according to A_{SFD})



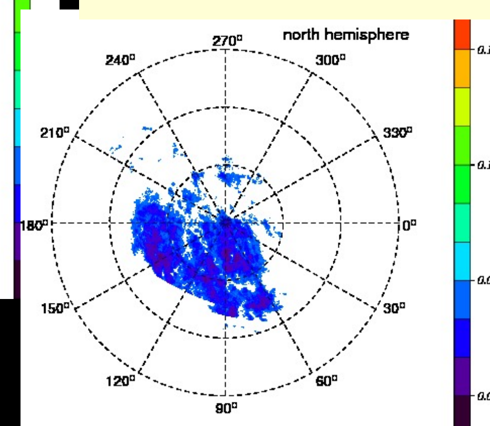


high extinction

medium extinction



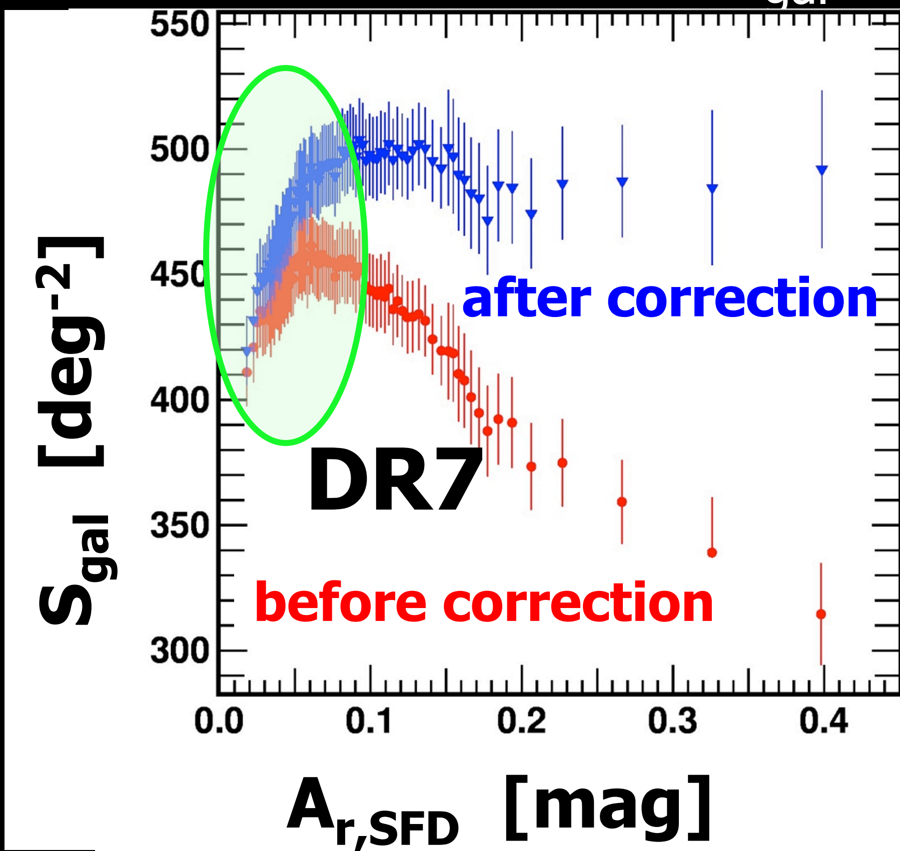
low extinction



- divide the SDSS DR7 survey area into many small regions according to A_{SFD}
- combine those non-contiguous regions into 84 bins for A_{SFD} with ~100 deg^2 each
- compute the SDSS galaxy number density S_{gal} for those bins

Anomaly of SDSS galaxy surface density S_{gal} as a function of A_{SFD}

- ***If A_{SFD} is perfect, we expect that***
  - Before correction: S_{gal} should monotonically decrease as a function of A_{SFD}
  - After correction: S_{gal} should be constant



(cosmological principle!)

- OK for A_{SFD} >0.1, but *quite the opposite for A_{SFD} <0.1*
  - ~70% of the SDSS survey area has A_{SFD} <0.1 !
- First pointed out by Yahata et al. (2007) for DR4, and confirmed by Kashiwagi et al. (2014) for DR7

Origin of the anomaly

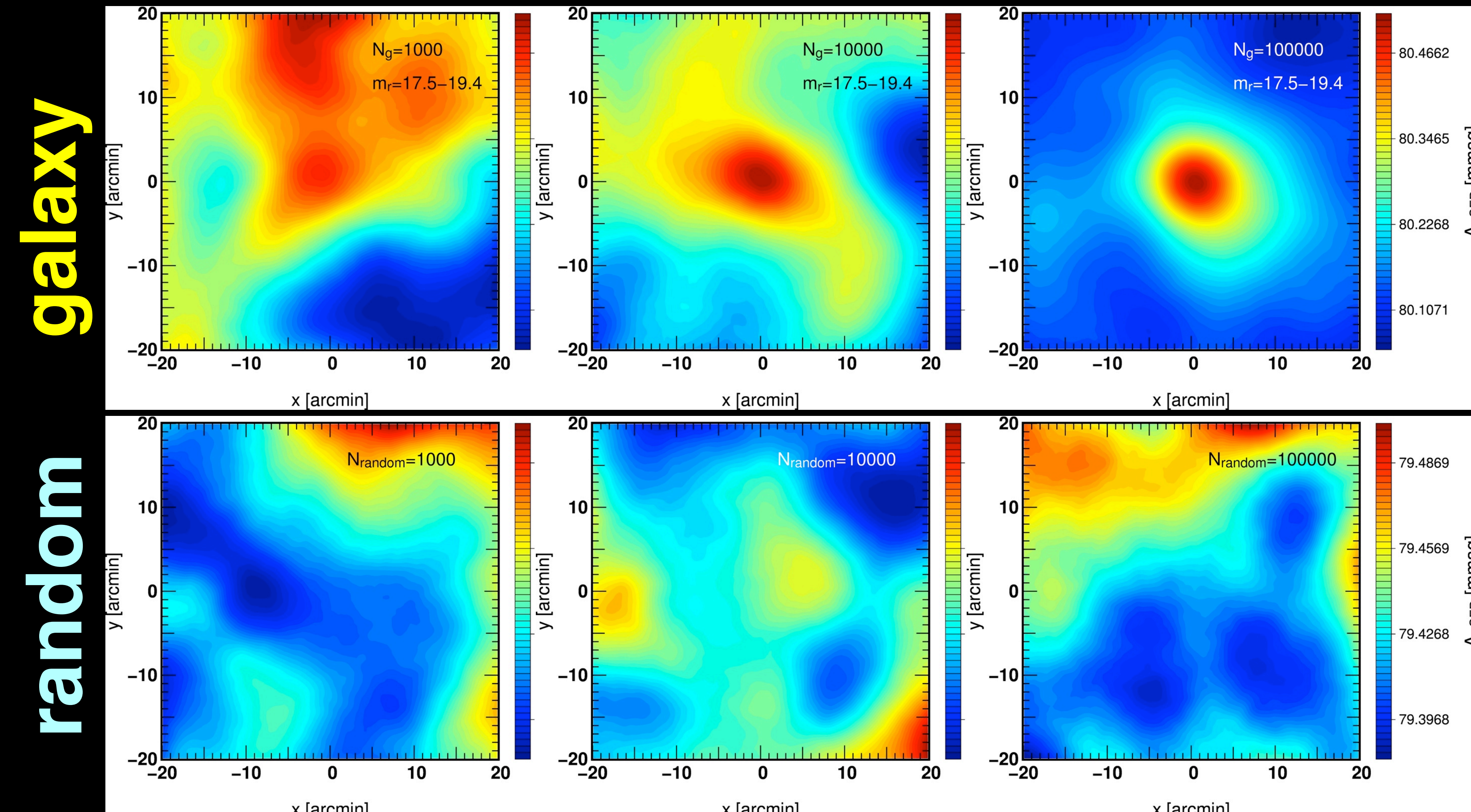
- A_{SFD} is estimated assuming that the ***extinction*** is proportional to the FIR ***emission*** flux (100 μm)
  - the anomaly indicates the positive correlation between galaxy surface density and the FIR flux at least where the real extinction is small
- 100 μm flux = Galactic dust + galaxies
  - contamination by the FIR emission from galaxies proposed by Yahata et al. (2007)

Direct detection of FIR emission of galaxies

- FIR emission of a majority of SDSS photometric galaxies is weak and cannot be detected individually.
- Can we detect their FIR emission statistically through stacking SDSS galaxies over the SFD map ? ⇒ *Yes !*

Kashiwagi, Yahata & YS
Publ.Astron.Soc.Japan 65 (2013)43

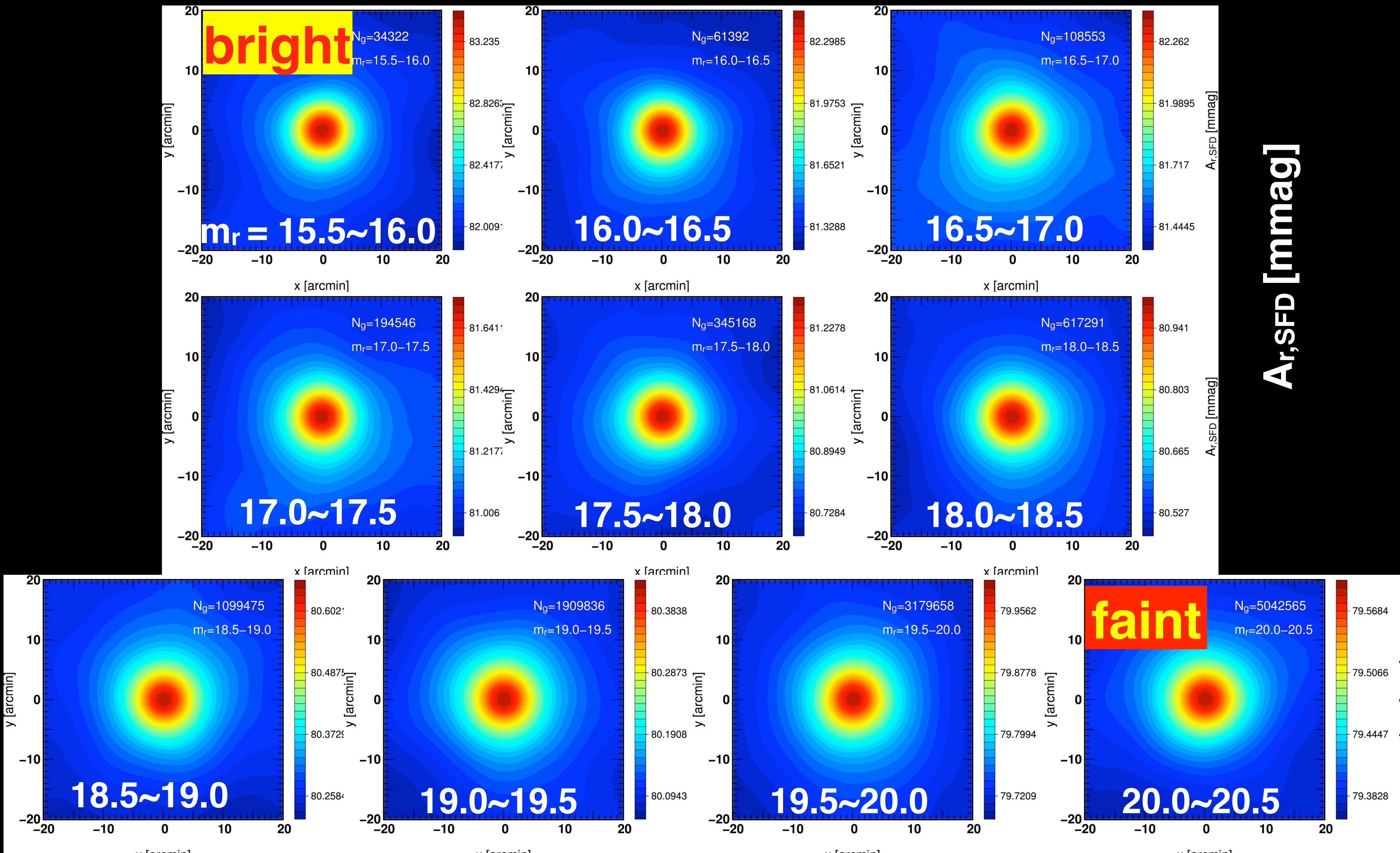
Stacking analysis of SDSS galaxies on the SFD map



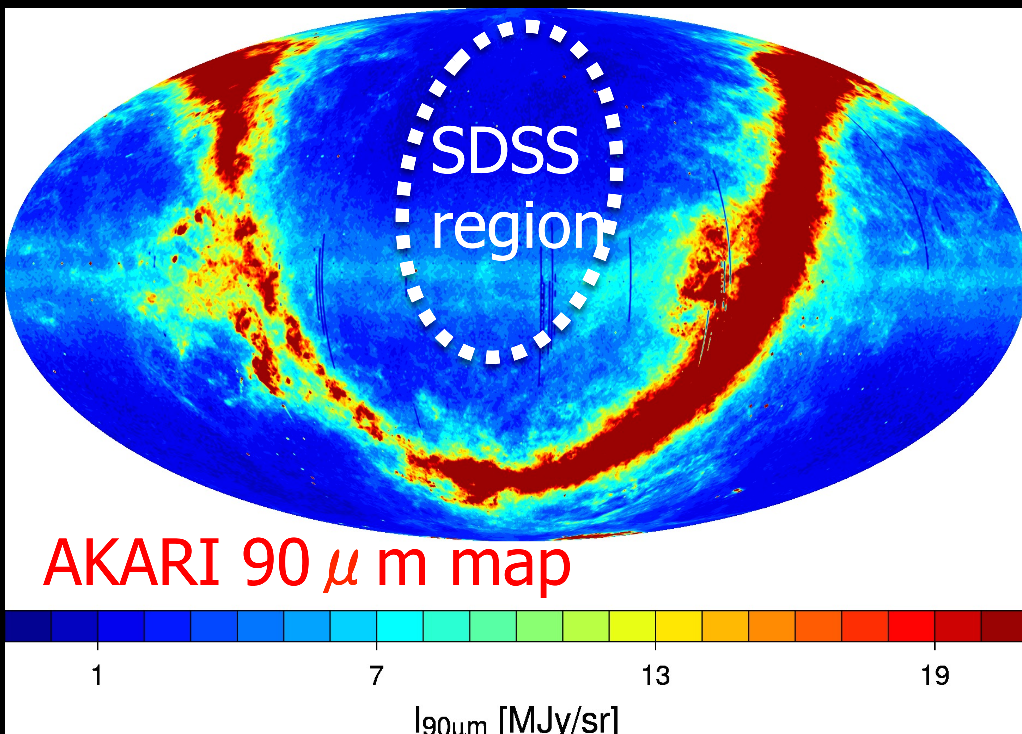
N = 10^3 **N = 10^4** **N = 10^5**

Magnitude dependence

Stacking SDSS galaxies ($15.5 < m_r < 20.5$) over SFD map according to their r-band magnitude ($\Delta m_r = 0.5$)



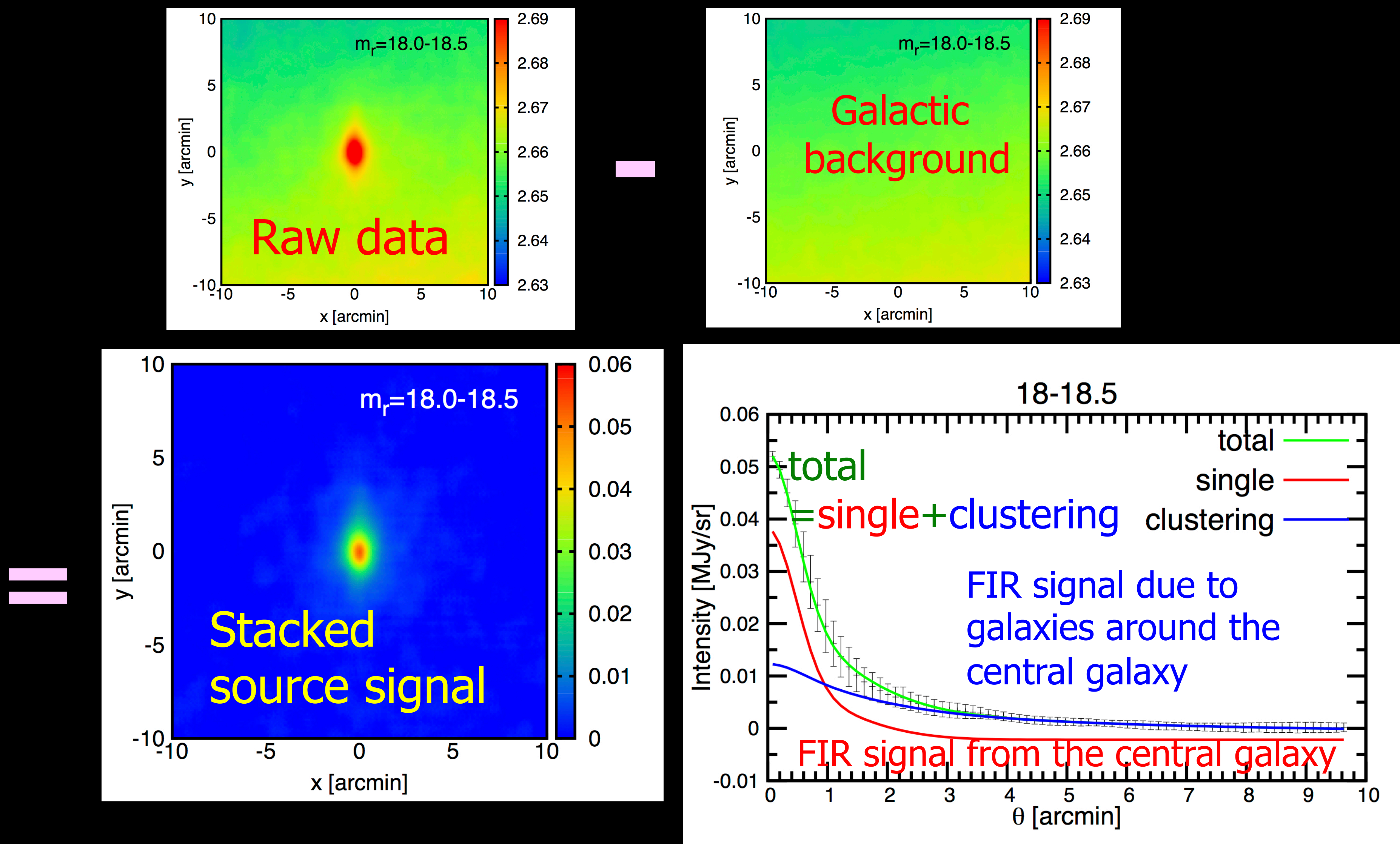
Stacking image analysis of SDSS galaxies on AKARI FIS 90 μm map



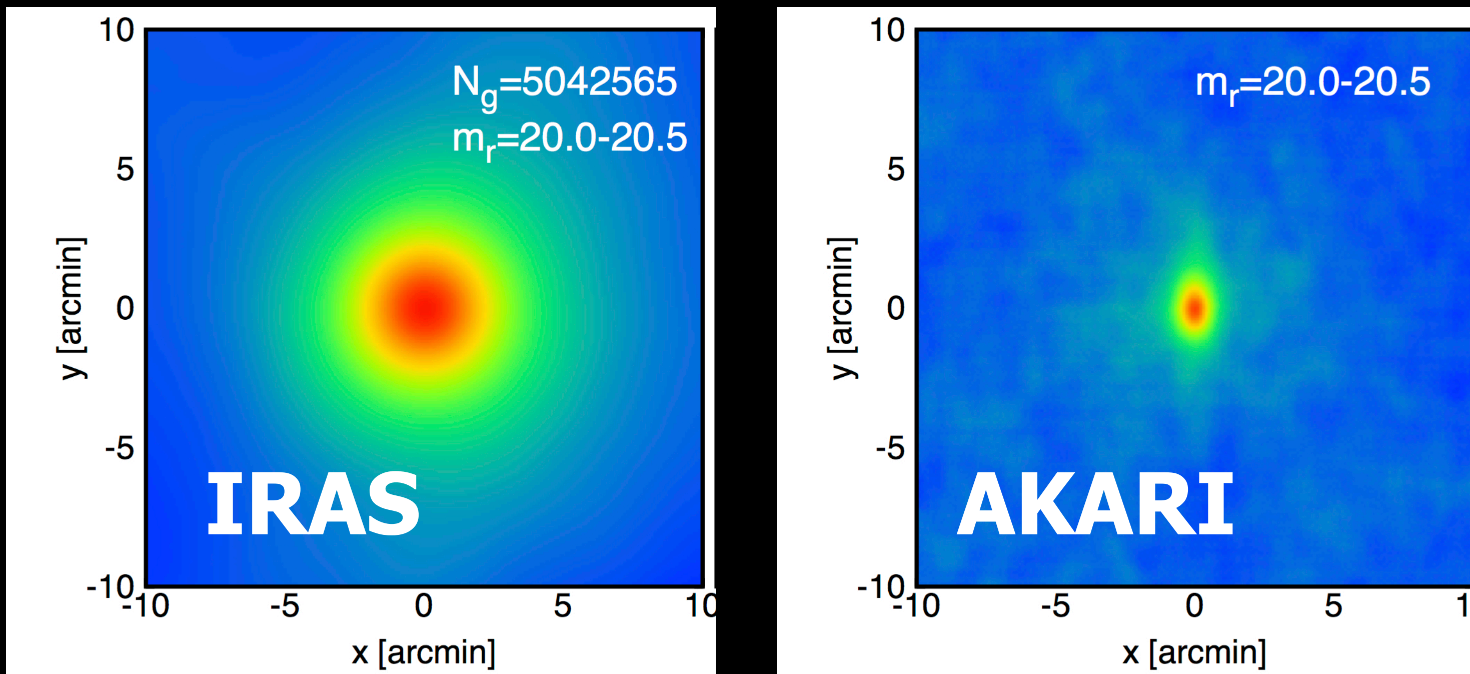
Arimitsu et al. (2014)

- AKARI (February 2006, launched)
  - FIS (Far-Infrared Surveyor) 65, 80, 140 & 160 μm
- AKARI PSF (FWHM)
  - 98″ (in-scan)
  - 55″ (cross-scan)
- c.f., IRAS PSF@100 μm ~6′

Stacked images of SDSS galaxies on AKARI@90 μm

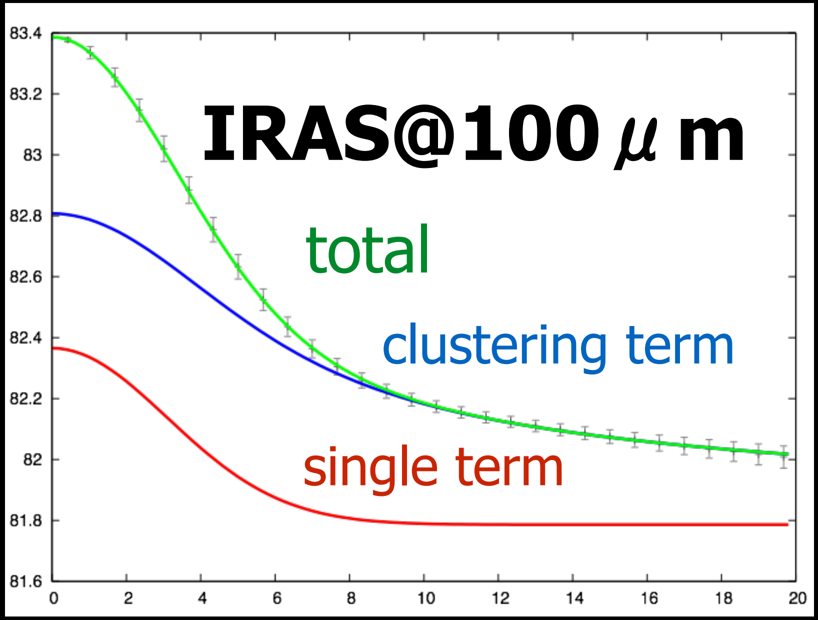


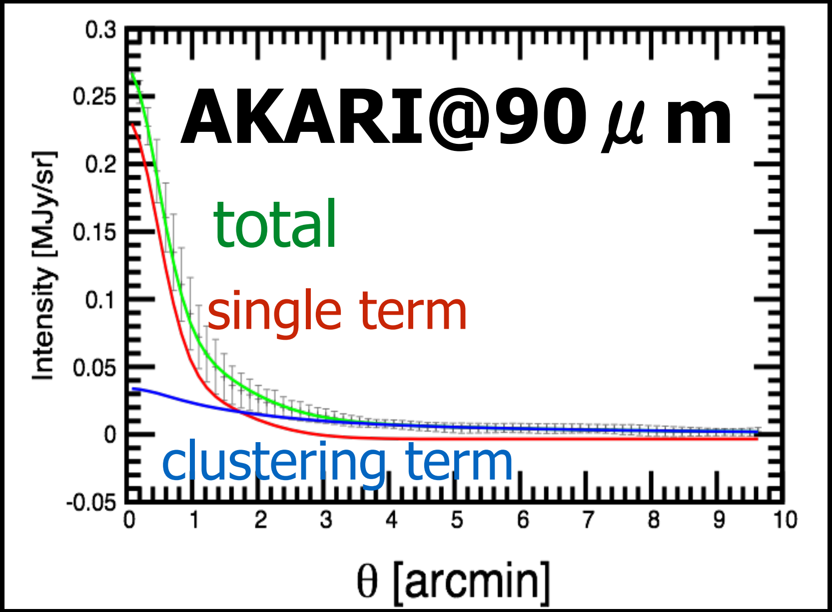
Angular resolution: IRAS vs AKARI



- Due to the poor angular resolution of IRAS, the FIR flux of stacked image is dominated by clustered galaxies, not by the central single galaxy

Angular resolution: IRAS vs AKARI





- Due to the poor angular resolution of IRAS, the FIR flux of stacked image is dominated by clustered galaxies, not by the central single galaxy

Numerical and analytic models to explain the anomaly of SFD map from the FIR emission of galaxies

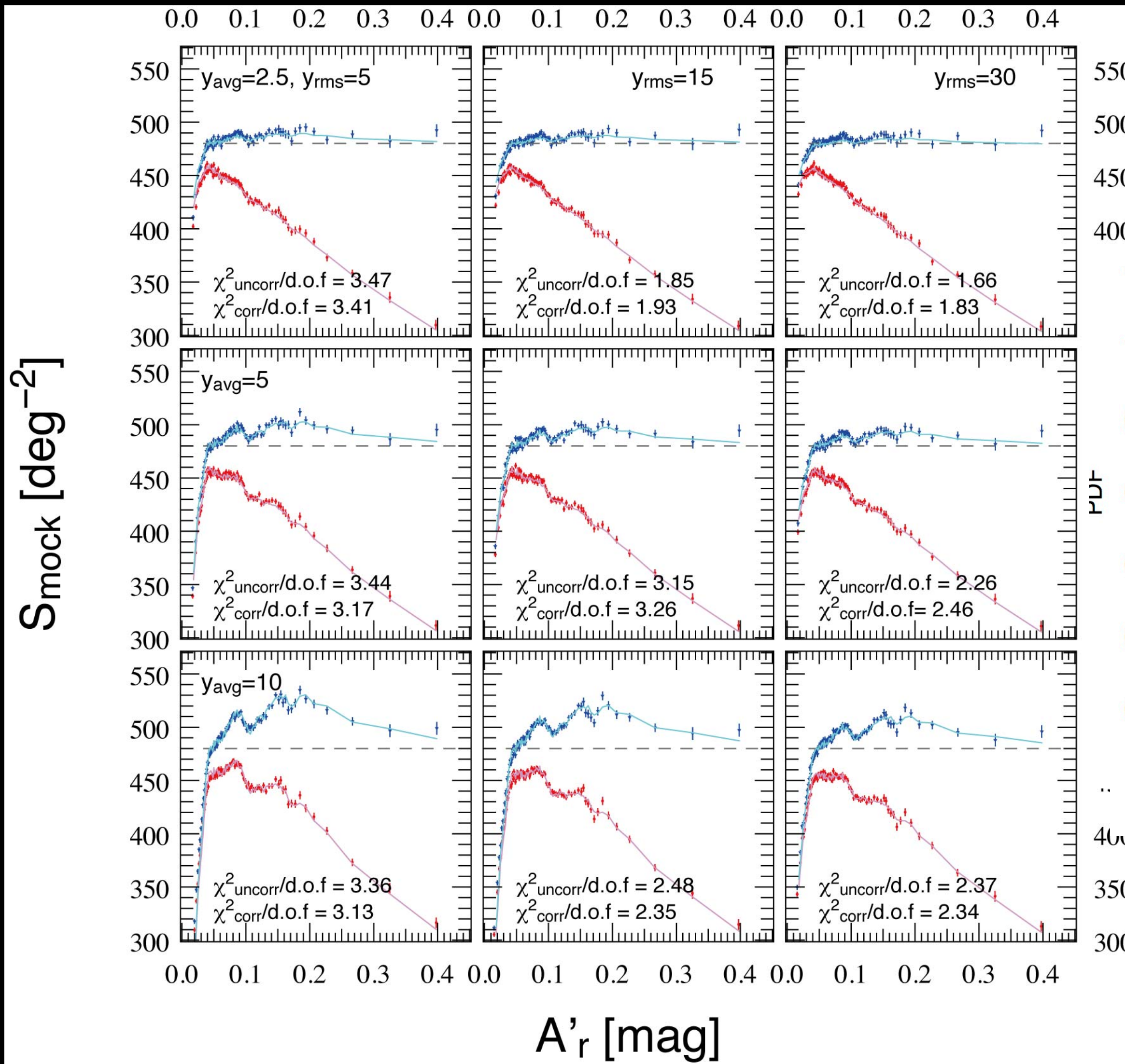
- T.Kashiwagi, YS, A.Taruya, I.Kayo, T.Nishimichi & K.Yahata

  submitted to ApJ (2014)

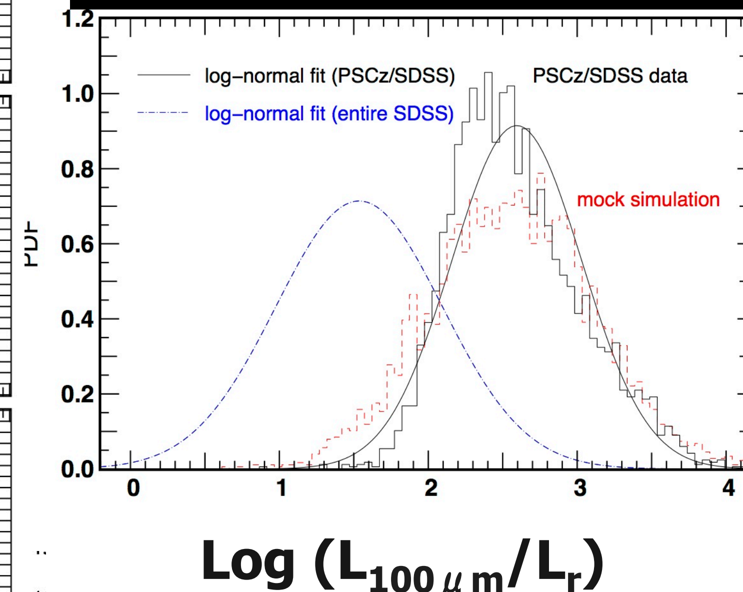
Analytic model for S_{gal} with contamination of FIR galaxy emission

- Poisson distributed galaxies (spatial clustering is ignored)
- Log-normal PDF for $y = (\nu L)_{100\mu m}/(\nu L)_r$ of each galaxy (characterized by y_{avg} and y_{rms})
- Compute the PDF of the additional extinction (converted from the FIR emission of galaxies) for a pixel on the SFD map with N galaxies $P_N(\Delta A)$
- Compute $N(A')$ and $\Omega(A') \Rightarrow S_{gal}(A')$ where $A' = A + \Delta A$
- Very good agreement with mock simulation results

Mock simulation vs. analytic prediction

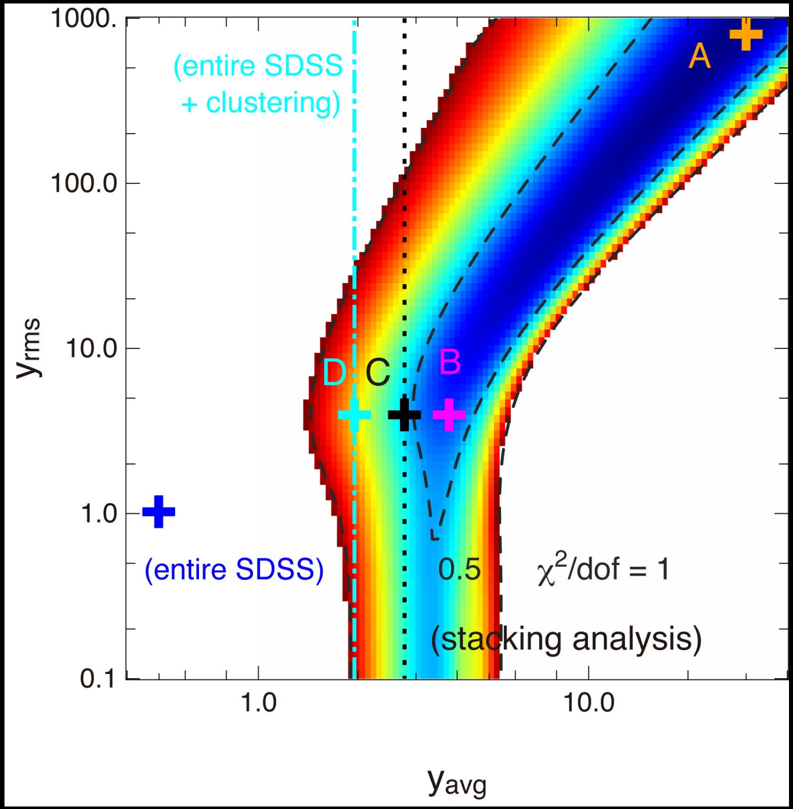


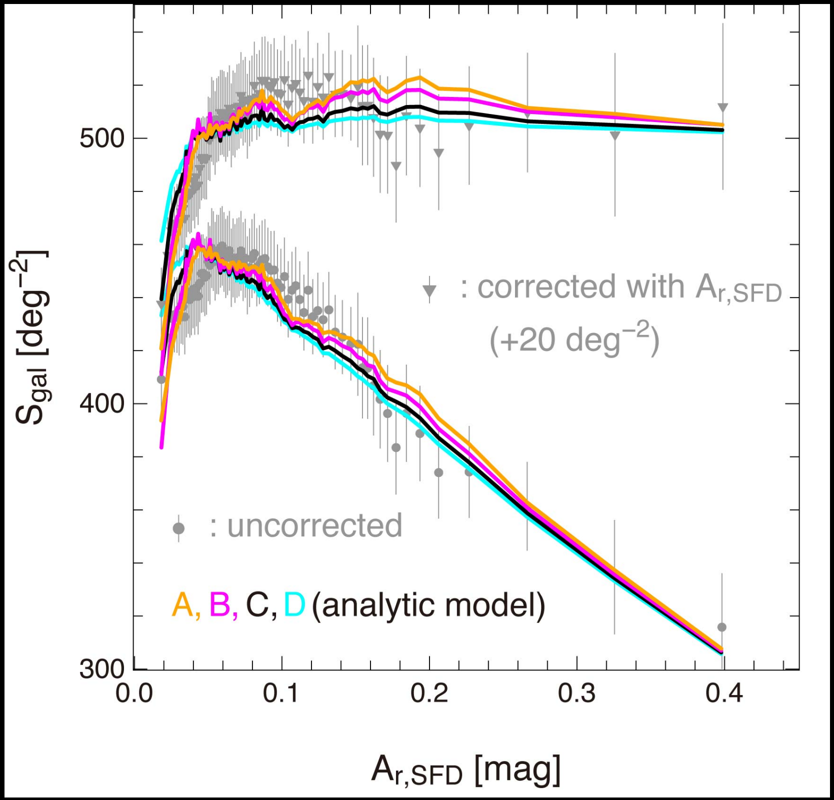
Log-normal PDF for $L_{100\mu m}/L_r$ of galaxies



PSCz/SDSS overlapped sample (3300 galaxies)

Fit to the observed SFD anomaly using the analytic model





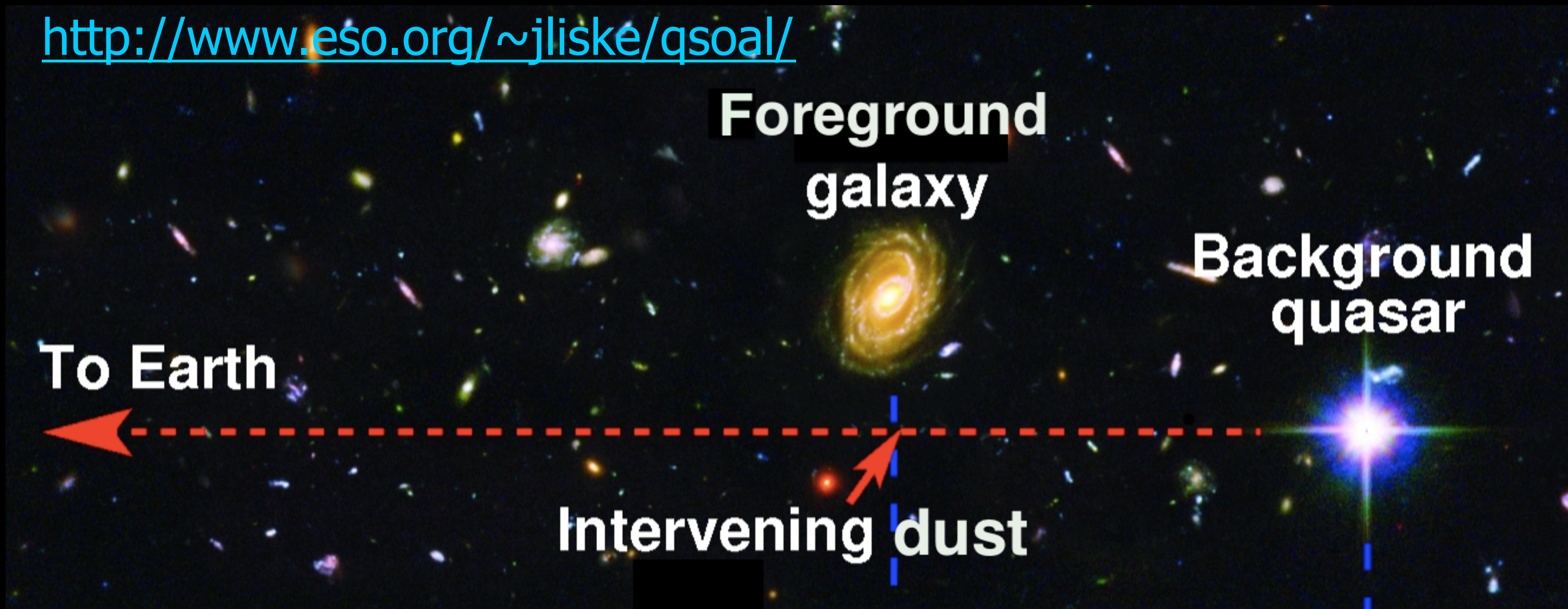
- Observed anomaly is reproduced by our current FIR galaxy emission model reasonably well, even if not completely

The spatial extent of the dust:

- associated with individual galaxies or extended over their common halos ? -

- T.Kashiwagi & YS: in preparation

Intergalactic dust is universal?



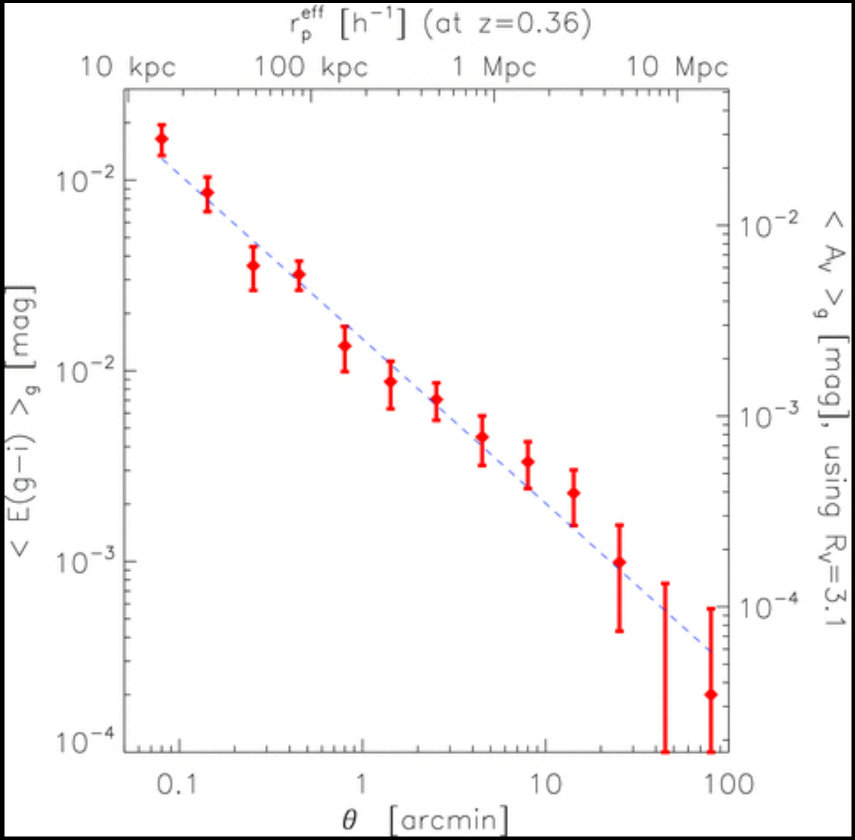
- Ménard, Scranton, Fukugita & Richards: MNRAS 405 (2010) 1025
  - Measure the reddening of background quasars due to the dust of SDSS galaxies from $<\delta m_Q(\Phi)\,\delta_g(\Phi+\theta)>$
  - Detected the presence of dust from 20kpc to several Mpc

Spatial distribution of intergalactic dust ?

$$\langle E(g-i)\rangle(\theta) = (1.5 \pm 0.4) \times 10^{-3} \left(\frac{\theta}{1\,\mathrm{arcmin}}\right)^{-0.86\pm0.19}$$

Ménard et al. (2010)

- Extended much beyond each galaxy ?
- Sum of dust associated with galaxies ?
  - Very similar to the galaxy angular correlation function power-law…



Stacking IRAS map to detect 100 μm emission of SDSS galaxies

- MSFR measure the ***absorption*** of dust
- Combining with the measurement of the ***emission*** of dust of galaxies, we constrain the dust temperature, which would distinguish intragalaxy and intracluster dust.
- Repeat the same stacking procedure
  - SDSS galaxies with $17<m_i<21$ that MSFR use
  - decomposition into three terms

$$I_{\rm total}(\theta, m_i) = I_{\rm single}(\theta, m_i) + I_{\rm clustering}(\theta, m_i) + C$$

Emission and absorption of dust

- Optical depth (extinction=scattering+absorption)

$$\tau(\theta,\lambda) = \kappa_{\rm ext}(\lambda)\Sigma_{\rm d}(\theta)$$

- Color excess

$$E_{g-i}(\theta,z) = \frac{2.5}{\ln 10}\left[\tau\Big(\theta,\lambda_g^{\rm rest}(z)\Big) - \tau\Big(\theta,\lambda_i^{\rm rest}(z)\Big)\right]$$

- Emission (optically thin approximation)

$$I(\lambda_{100\mu m},\theta,z) \quad = \quad \frac{1}{(1+z)^4}B\Big(\lambda_{100\mu m}^{\rm rest},T_{\rm d}(z)\Big)\tau(\lambda_{100\mu m}^{\rm rest}(z))$$

- Emission/absorption

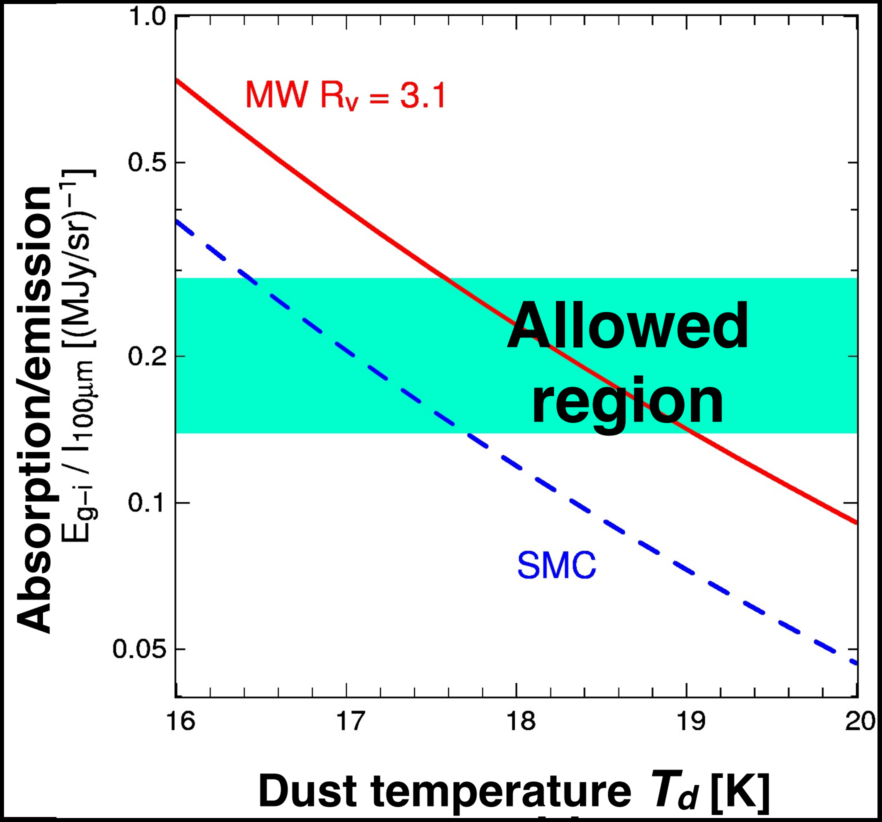
$$\frac{I(\lambda_{100\mu m},\theta,\bar{z})}{E_{g-i}(\theta,\bar{z})} = \frac{\ln 10}{2.5}\frac{1}{(1+\bar{z})^4}B(\lambda_{100\mu m}^{\rm rest}(\bar{z}),T_{\rm d}(\bar{z}))\frac{\kappa_{\rm abs}(\lambda_{100\mu m}^{\rm rest}(\bar{z}))}{\kappa_{\rm ext}\Big(\lambda_g^{\rm rest}(\bar{z})\Big) - \kappa_{\rm ext}\Big(\lambda_i^{\rm rest}(\bar{z})\Big)}.$$

constraining the dust temperature

- The ratio of emission and absorption compared with MW and SMC models (Weingartner & Draine 2001)

  http://www.astro.princeton.edu/~draine/dust/dustmix.html

- consistent with typical dust temperature of galaxies (~20K)
  - MSFR and we observed the absorption and emission of the same component, respectively.
  - Temperature of cluster/ intergalactic dust ???



Summary

- Detection of FIR emission from SDSS galaxies by stacking image analysis over the SFD（IRAS@100 μ m) and AKARI FIS@90 μ m
  - Largely explains the anomaly of SDSS galaxy number counts discovered by Yahata et al.(2007)
- The dust is unlikely to be extended over the cluster halo scales (～1Mpc)
  - The estimated dust temperature of ～20K is close to the dust temperature of galaxies
  - The amount of dust is consistent with that expected to be associated with SDSS galaxies from stacking analysis

Future prospects

- A new probe of unresolved (dusty) galaxy spatial correlations and/or dust profile of the hosting halo
- Possible correction to the SFD map and a future Galactic extinction map by ***Planck***
- FIR emission from SDSS quasars is also detected by stacking analysis, which we plan to explore in future

references

- *Detection of Far Infrared Emission from Galaxies and Quasars in the Galactic Extinction Map by Stacking Analysis*
  - Kashiwagi, Yahata + YS, PASJ 65(2013)43

- *The effect of FIR emission from SDSS galaxies on the SFD Galactic extinction map*
  - Yahata et al., PASJ 59(2007)205
- *Probing temperature of cosmic dust by FIR stacking analysis*
  - Kashiwagi + YS, in preparation
- *Modeling the anomaly of surface number densities of galaxies on the Galactic extinction map due to their FIR emission contamination*
  - Kashiwagi et al. , submitted to ApJ
- *Stacking image analysis of SDSS galaxies with AKARI FIS*
  - Okabe, Kashiwagi, YS + AKARI FIS team, in preparation