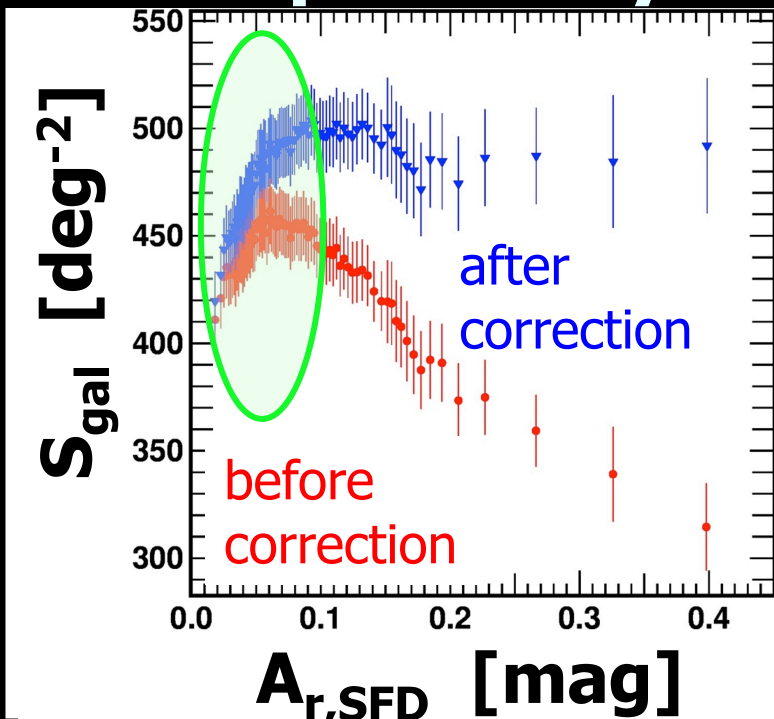
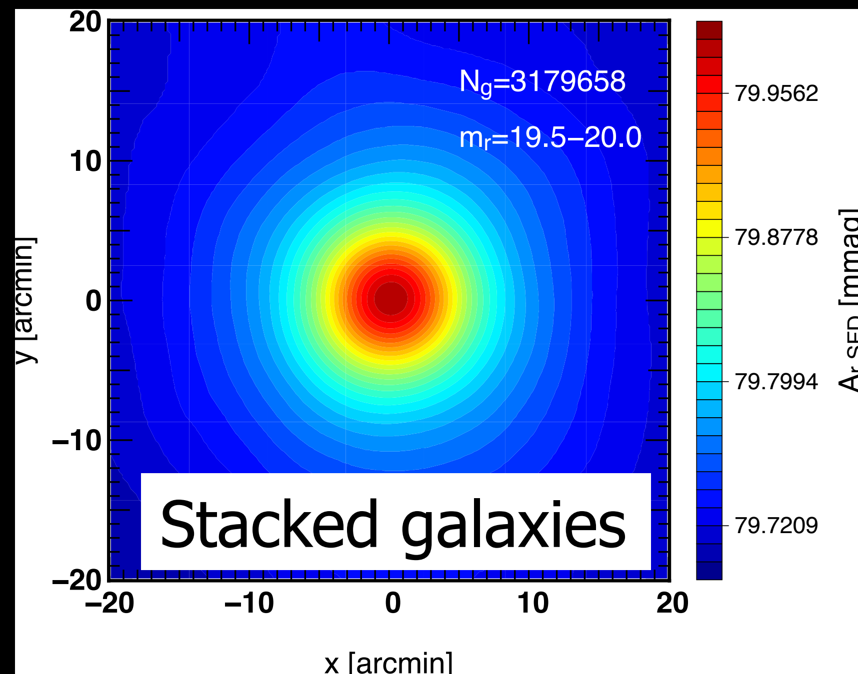
# Anomaly in the SFD Galactic extinction map and discovery of FIR emission of SDSS galaxies and quasars by stacking image analysis




## From Dark Matter to Galaxies

The 10th Sino-German Workshop on Galaxy Formation and Cosmology


**Yasushi Suto（須藤靖）*The University of Tokyo***


18-23 May, 2014, Xi'an (西安), China

**16:30-17:00 May 22**

# This talk is based on

- *Detection of Far Infrared Emission from Galaxies and Quasars in the Galactic Extinction Map by Stacking Analysis*
  - **T.Kashiwagi,** K.Yahata & YS
  - Publ.Astron.Soc.Japan 65(2013)43

- *The effect of FIR emission from SDSS galaxies on the SFD Galactic extinction map*
  - K.Yahata, A.Yonehara, YS, E.L.Turner T.Broadhurst, & D.P. Finkbeiner
  - Publ.Astron.Soc.Japan 59(2007)205

# Take home message

- Galactic dust extinction map is inevitably contaminated by emission of galaxies
  - The average contamination per galaxy is tiny $\Delta A \sim 1$mmag/galaxy, but persists on the entire map
- The stacking image analysis offers a new possibility to characterize the average SED of individually unresolved faint galaxies and quasars, and their clustering properties in a statistically fashion

# Top cited refereed astronomy papers published in 1900-2013 (ADS): 1st-5th

| | authors | citation | title |
|---|---|---|---|
| 1 | Schlegel, Finkbeiner & Davis (1998) | 8223 | Maps of Dust Infrared Emission for Use in Estimation of Reddening and Cosmic Microwave Background Radiation Foregrounds |
| 2 | Perdew & Zunger (1981) | 7330 | Self-interaction correction to density-functional approximations for many-electron systems |
| 3 | Perlmutter et al. (1999) | 7322 | Measurements of Omega and Lambda from 42 High-Redshift Supernovae |
| 4 | Spergel et al. (2003) | 7278 | First-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Determination of Cosmological Parameters |
| 5 | Riess et al. (1998) | 7208 | Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant |

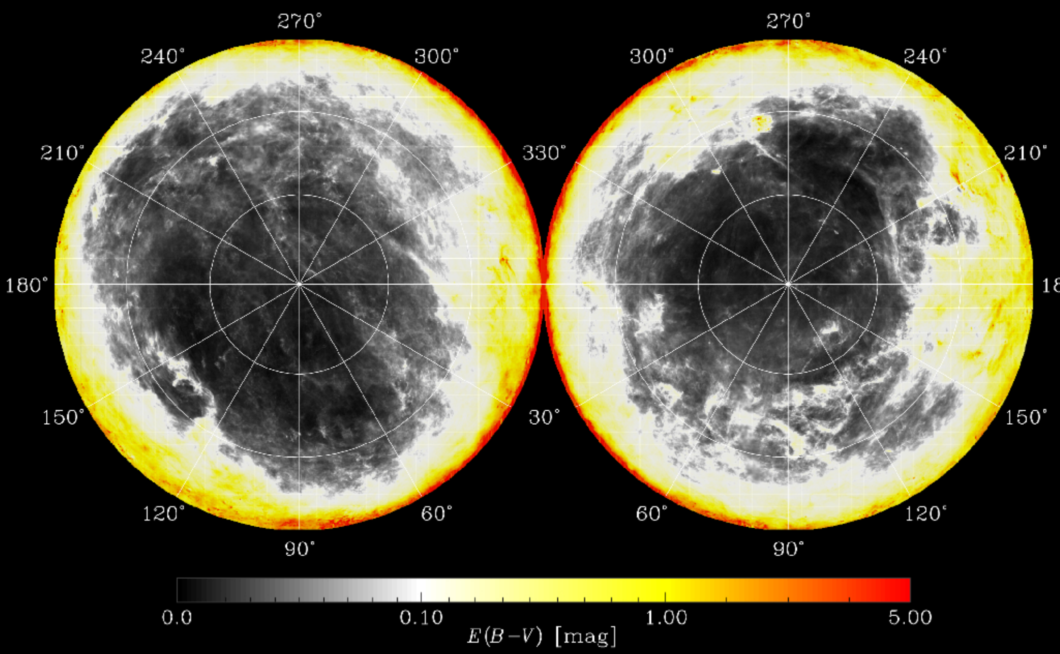
# Testing a reliability of the SFD Galactic extinction map with SDSS galaxy number counts

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

  Publ.Astron.Soc.Japan 59(2007)205
- T.Kashiwagi

  Master thesis (2011) submitted to U.Tokyo

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

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

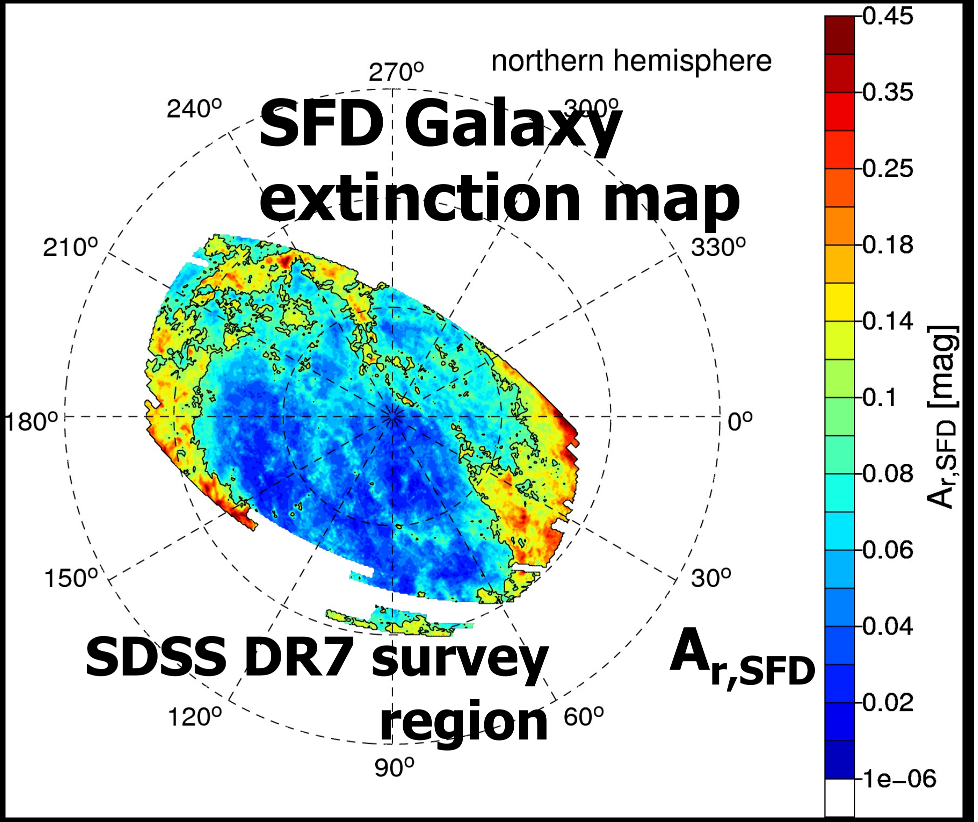
dust temperature correction factor

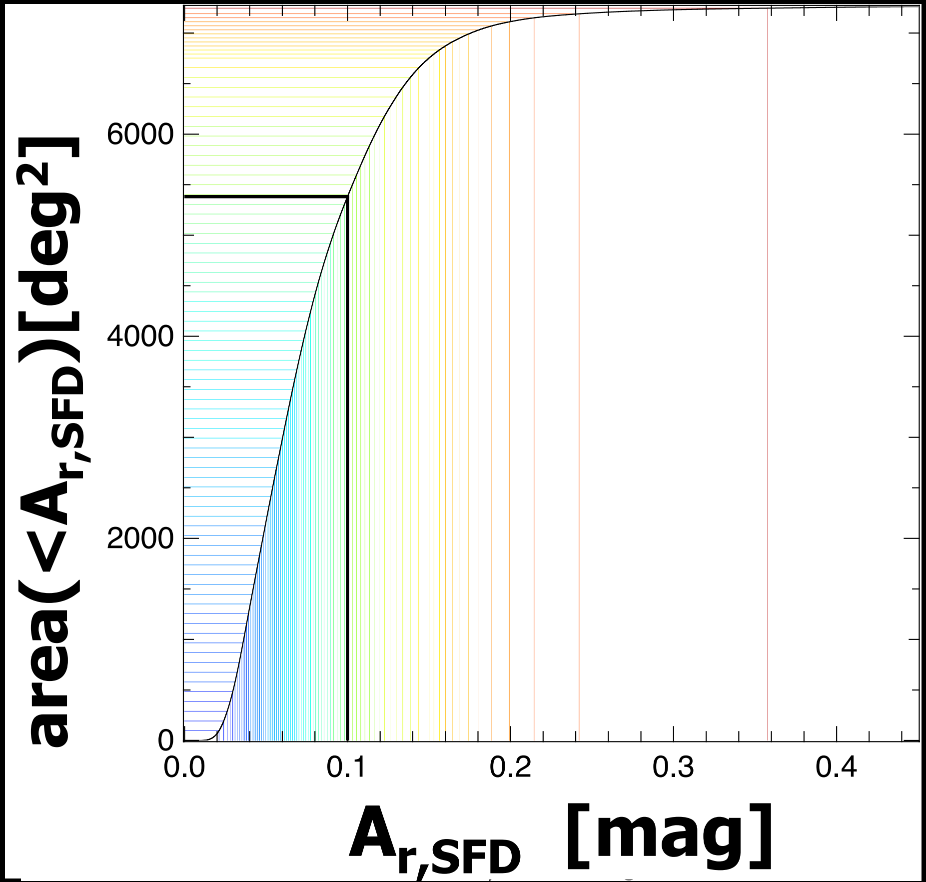
at each region and determine $p \sim 0.0184$ from the data

- 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

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

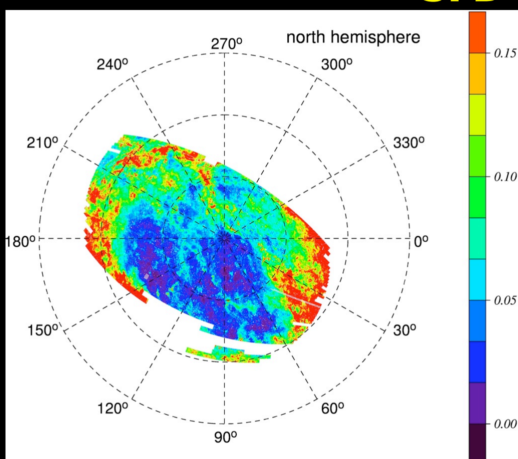


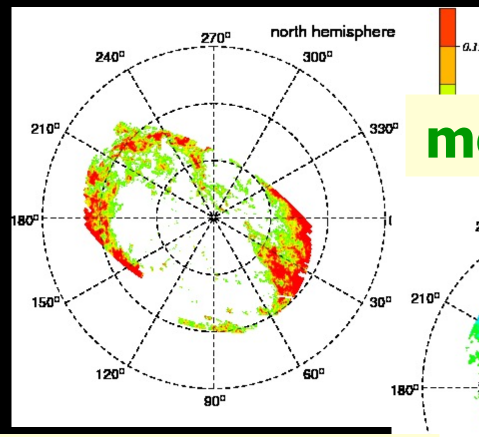




Kashiwagi (2011), Yahata et al.(2007)

# Testing SFD Galactic extinction against SDSS galaxy surface density

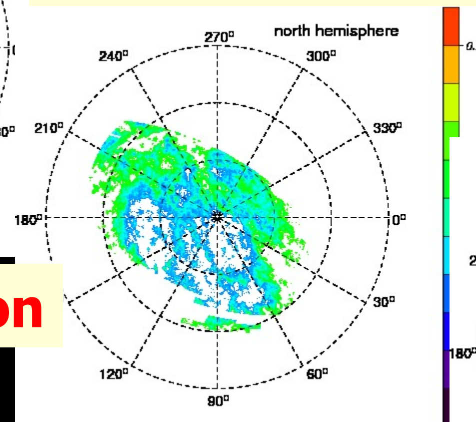
**SDSS DR7 survey area (color coded according to $A_{SFD}$)**



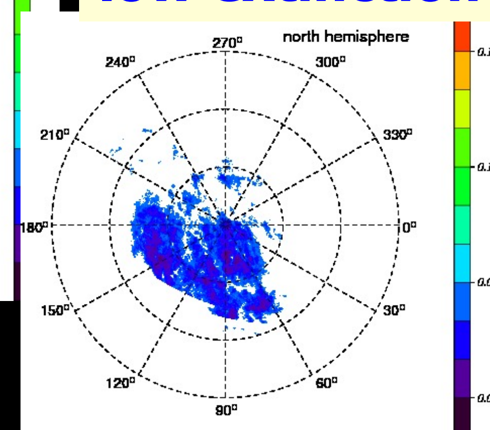




**high extinction**

**medium extinction**



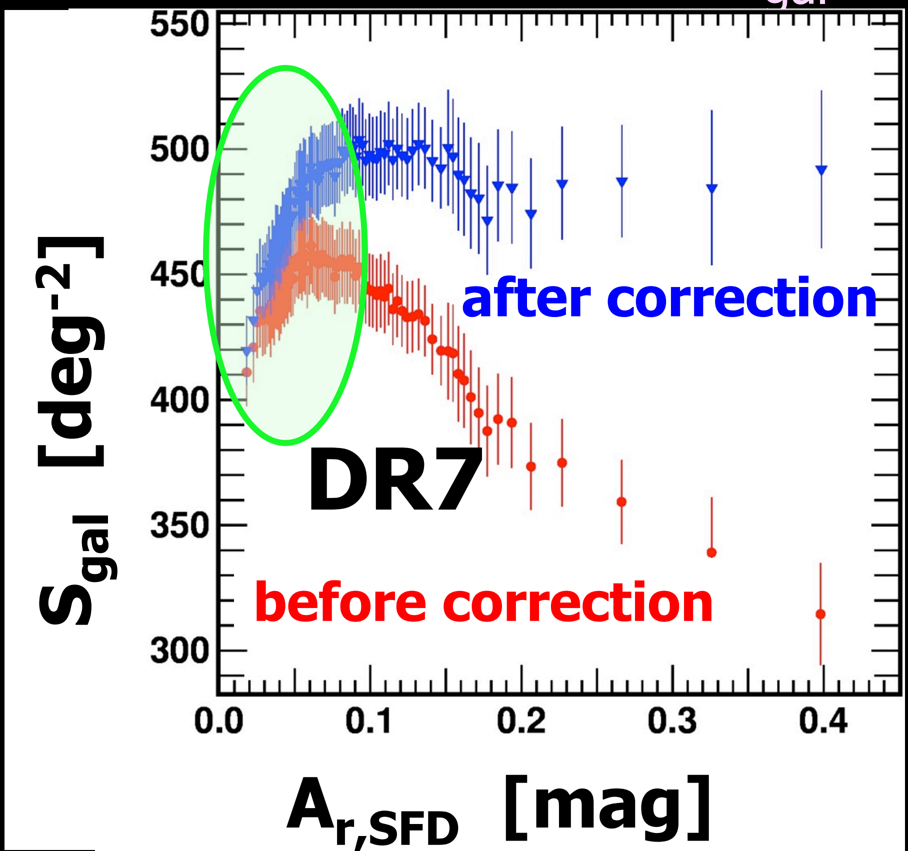

**low extinction**




- 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 $\sim$100 deg$^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 (2011) for DR7

# Origin of the anomaly

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

# Can we directly detect the FIR emission of galaxies ? - Stacking image analysis of SDSS galaxies -

- T.Kashiwagi, K.Yahata & YS

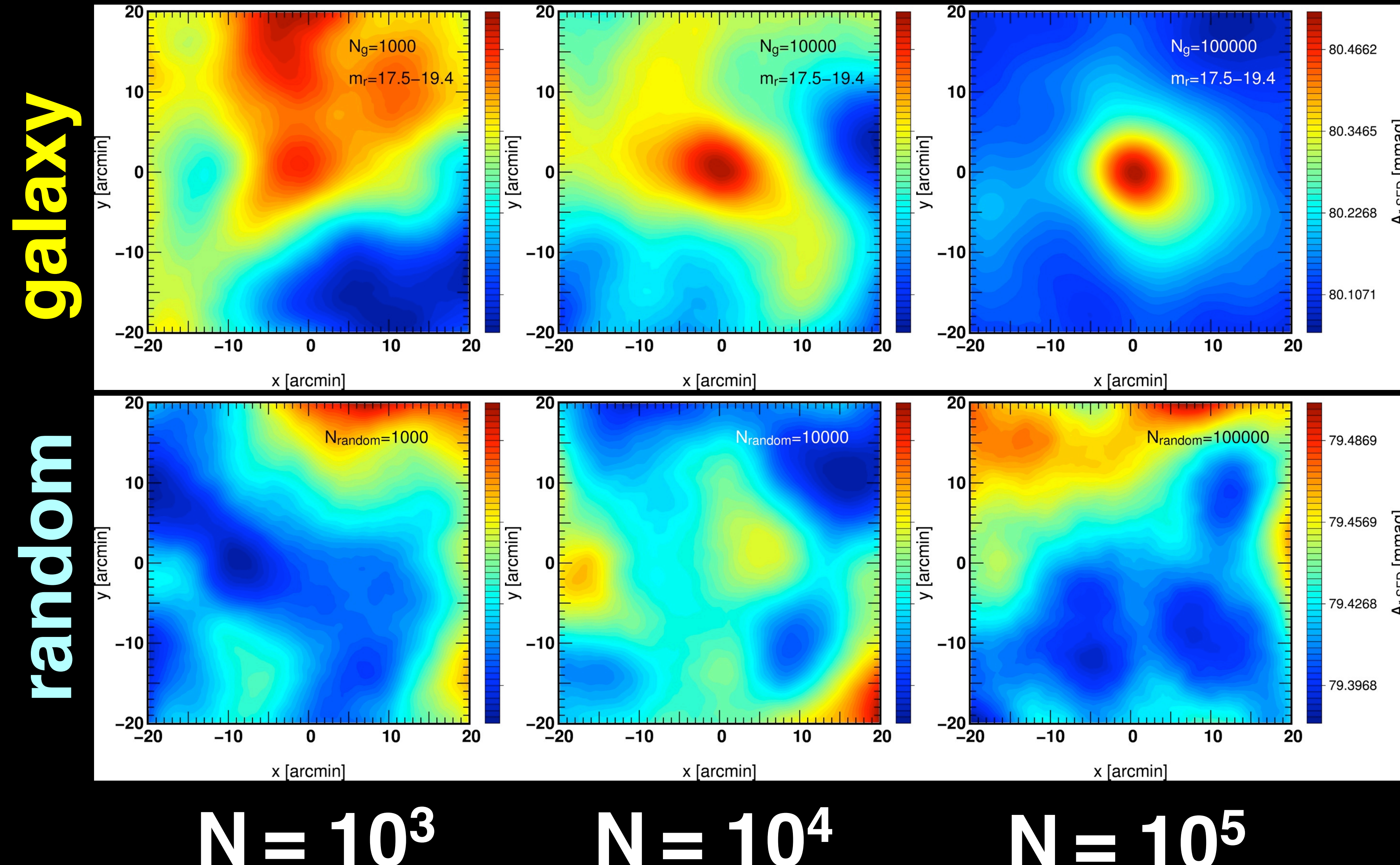
  Publ.Astron.Soc.Japan 65(2013)43

# 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 by stacking SDSS galaxies over the SFD map ? ⇒ *Yes !*

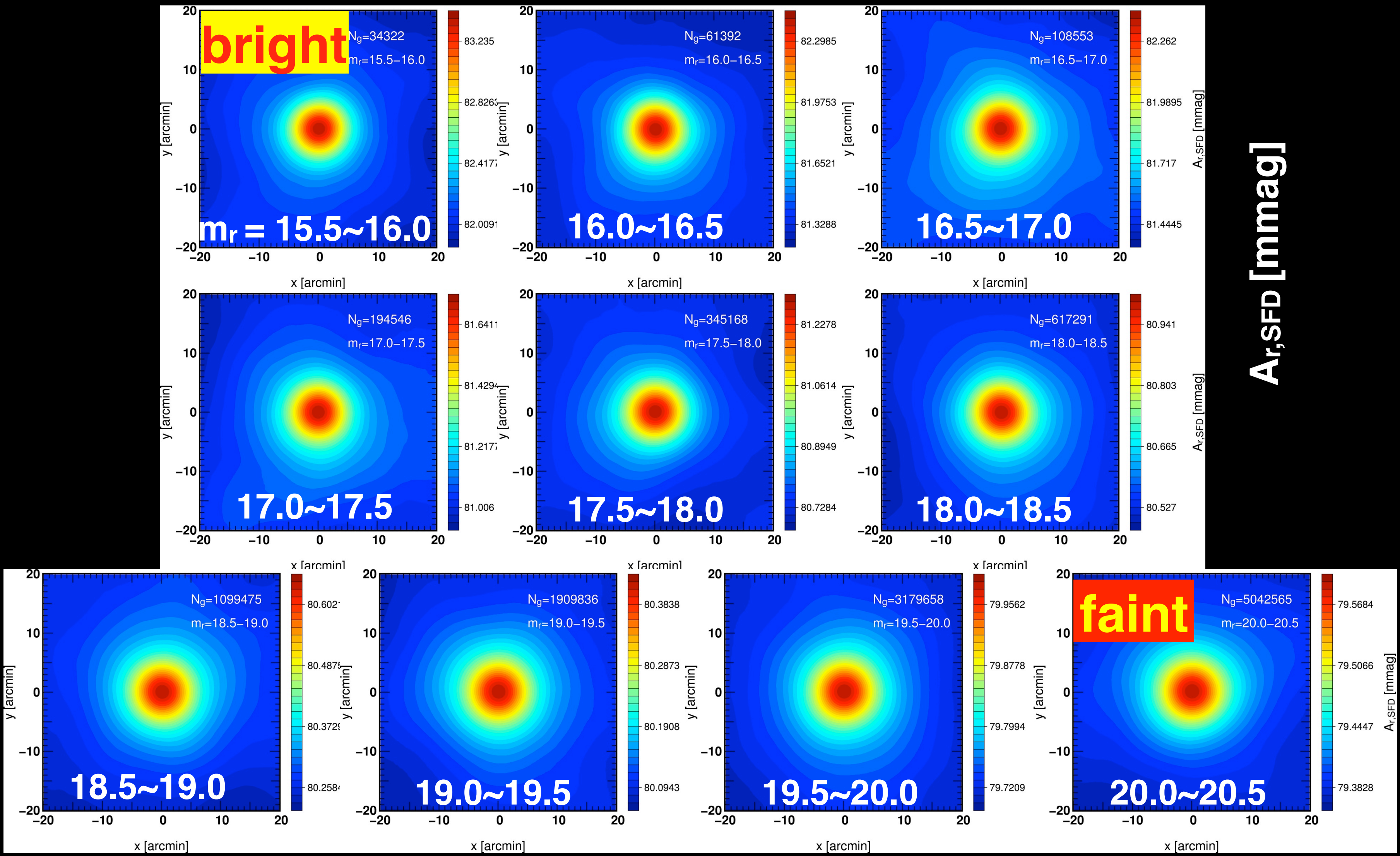
Kashiwagi, Yahata & YS
Publ.Astron.Soc.Japan 65 (2013)43

# Stacking image analysis of SDSS galaxies on the SFD map

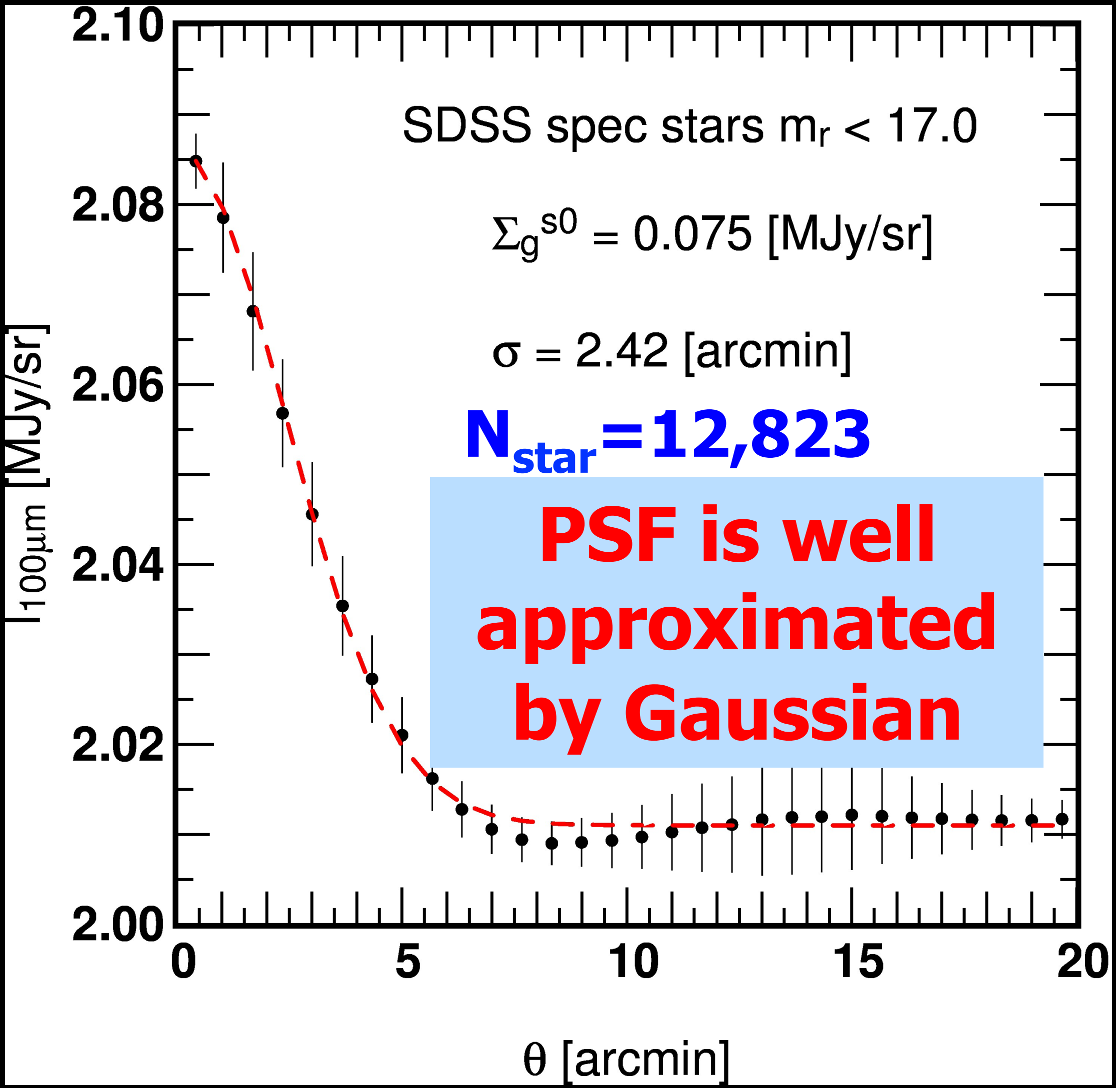


# Magnitude dependence

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

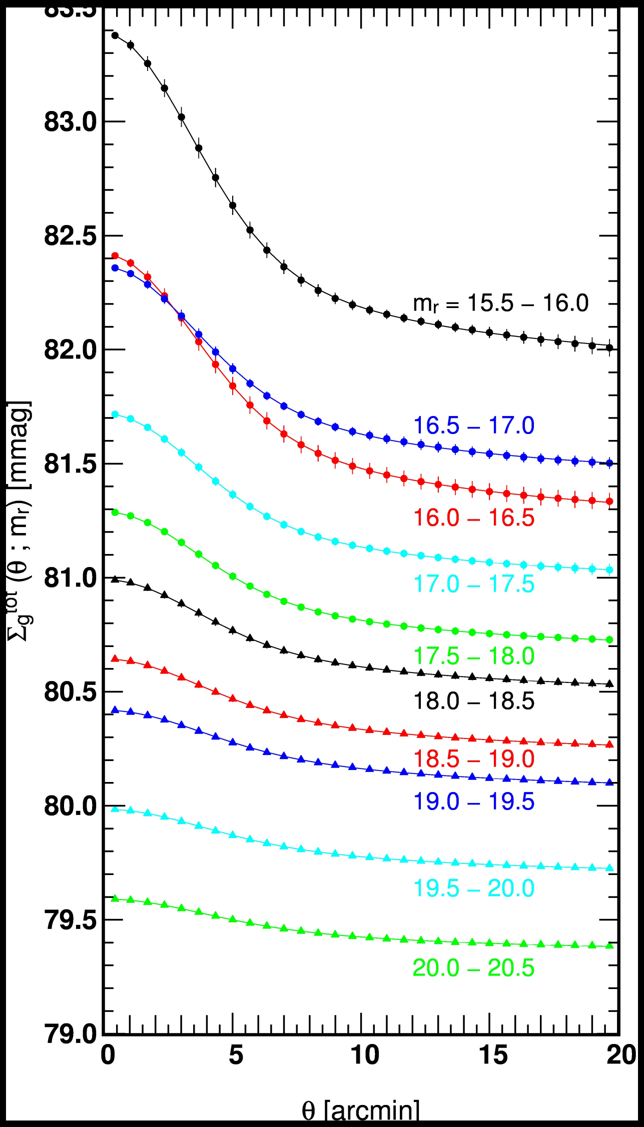


# Point spread function of IRAS 100μm map




- Angular resolution of SFD (IRAS) is low, ⇒ we need to its PSF to understand the stacked profile
- PSF is difficult to measure on SFD map since most of point sources are removed
- We use the original IRAS 100μm diffuse map, and stack stars with r<17 mag.

# Decompositions into single galaxy and clustering terms




$$\Sigma_{\rm g}^{\rm tot}(\theta;m_r) = \Sigma_{\rm g}^{\rm s}(\theta;m_r) + \Sigma_{\rm g}^{\rm c}(\theta;m_r) + C$$

$$\Sigma_{\rm g}^{\rm s}(\theta;m_r) = \Sigma_{\rm g}^{\rm s0}(m_r)\exp\left(-\frac{\theta^2}{2\sigma^2}\right)$$

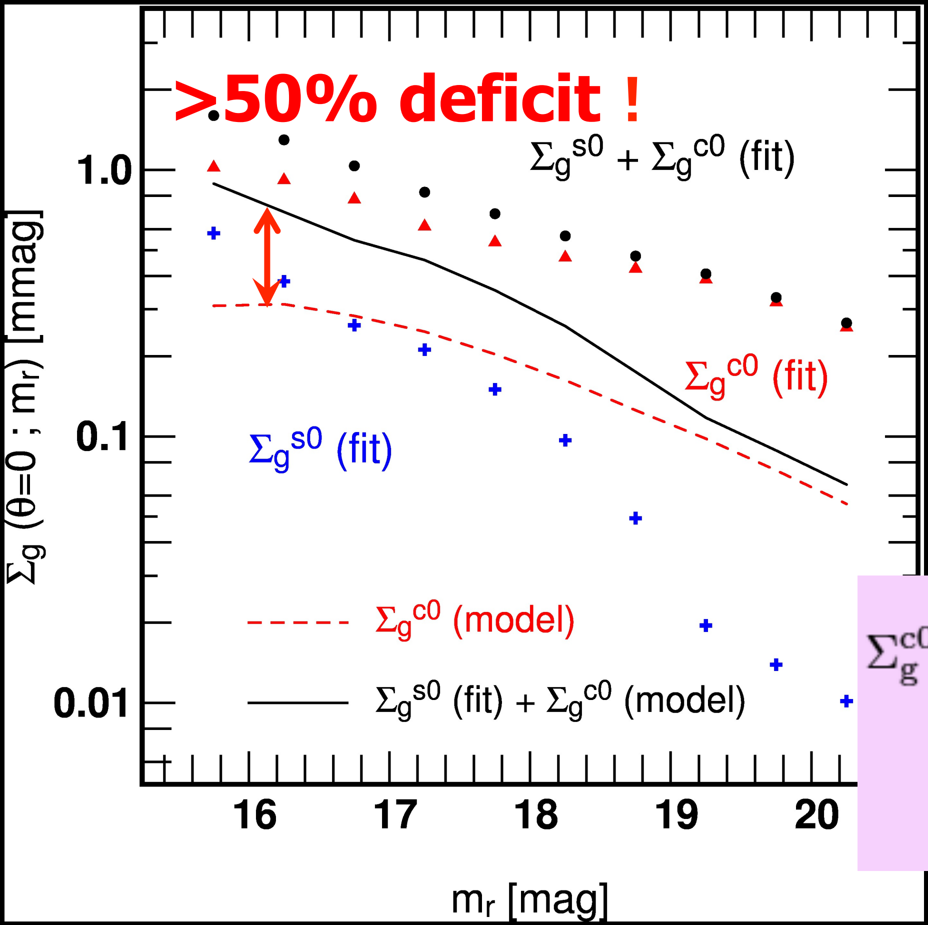
$$\Sigma_{\rm g}^{\rm c}(\theta;m_r) = \iint dm' d\varphi\ \Sigma_{\rm g}^{\rm s}(\theta-\varphi;m') \times w_{\rm g}(\varphi;m',m_r)\frac{dN_{\rm g}(m')}{dm'}$$

$$w_{\rm g}(\varphi;m',m_r) = K(m',m_r)(\varphi/\varphi_0)^{-\gamma},$$

$$\Sigma_{\rm g}^{\rm c}(\theta;m_r) = \Sigma_{\rm g}^{\rm c0}(m_r)\exp\left(-\frac{\theta^2}{2\sigma^2}\right) \times {}_1F_1\left(1-\frac{\gamma}{2};1;\frac{\theta^2}{2\sigma^2}\right)$$

simultaneous fit ⇒ σ=3.1′

# Extended dust emission around the halo hosting the central galaxy and/or contribution from unresolved galaxies ?




- The fitted clustering term is a factor of 2-3 larger than that expected from the measured angular correlation functions of resolved SDSS galaxies

$$\Sigma_{\rm g}^{\rm c0}(m_r) = 2\pi\sigma^2 \left(\frac{\varphi_0}{\sqrt{2}\sigma}\right)^{\gamma} \Gamma\left(1-\frac{\gamma}{2}\right) \times \int dm' \Sigma_{\rm g}^{\rm s0}(m') K(m', m_r) \frac{dN_{\rm g}(m')}{dm'}$$

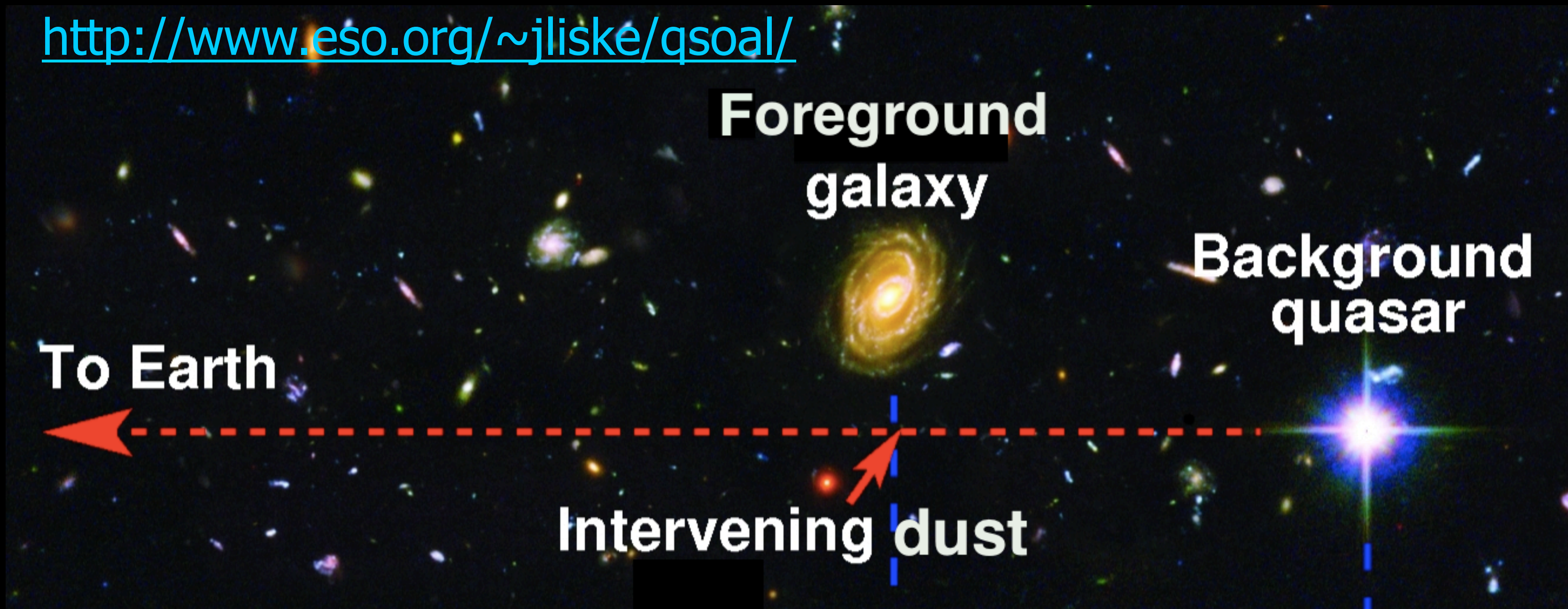
# The spatial extent of the dust:

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

- T.Kashiwagi & YS: in preparation

*Preliminary !*

# Intergalactic dust is universal?



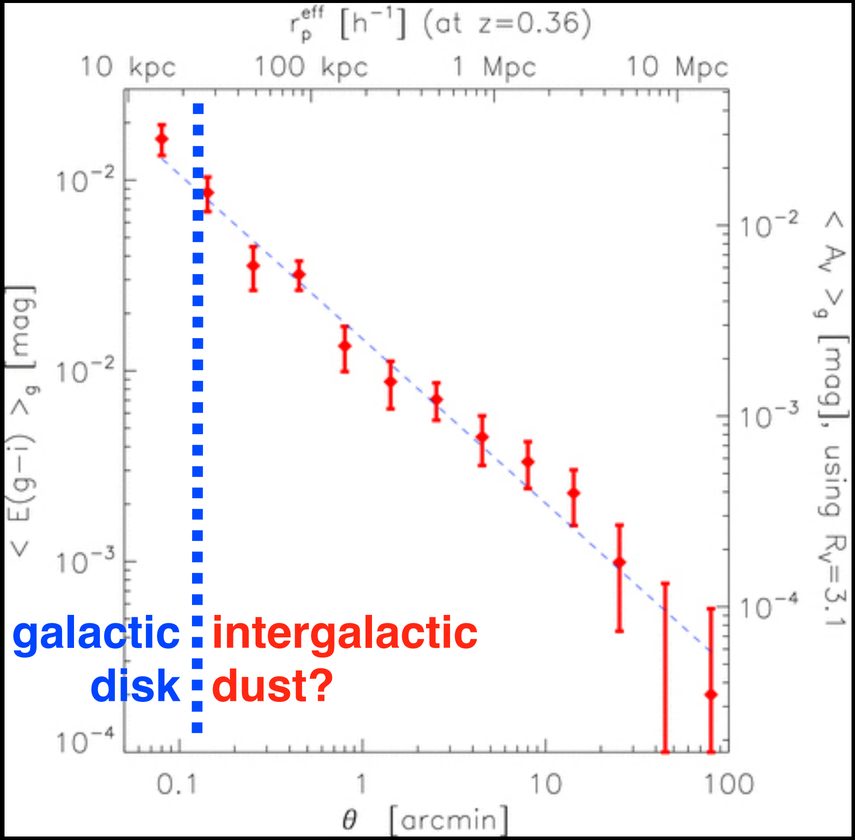

- Ménard, Scranton, Fukugita & Richards: MNRAS 405 (2010) 1025
  - Measure the reddening of background quasars due to the dust of SDSS galaxies from $\langle \delta m_Q(\Phi)\delta_g(\Phi+\theta) \rangle$
  - Detected the presence of dust from 20kpc to several Mpc

# 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 individual galaxies ?
  - Very similar to the galaxy angular correlation function power-law…



# Stacking IRAS map to detect 100μm 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

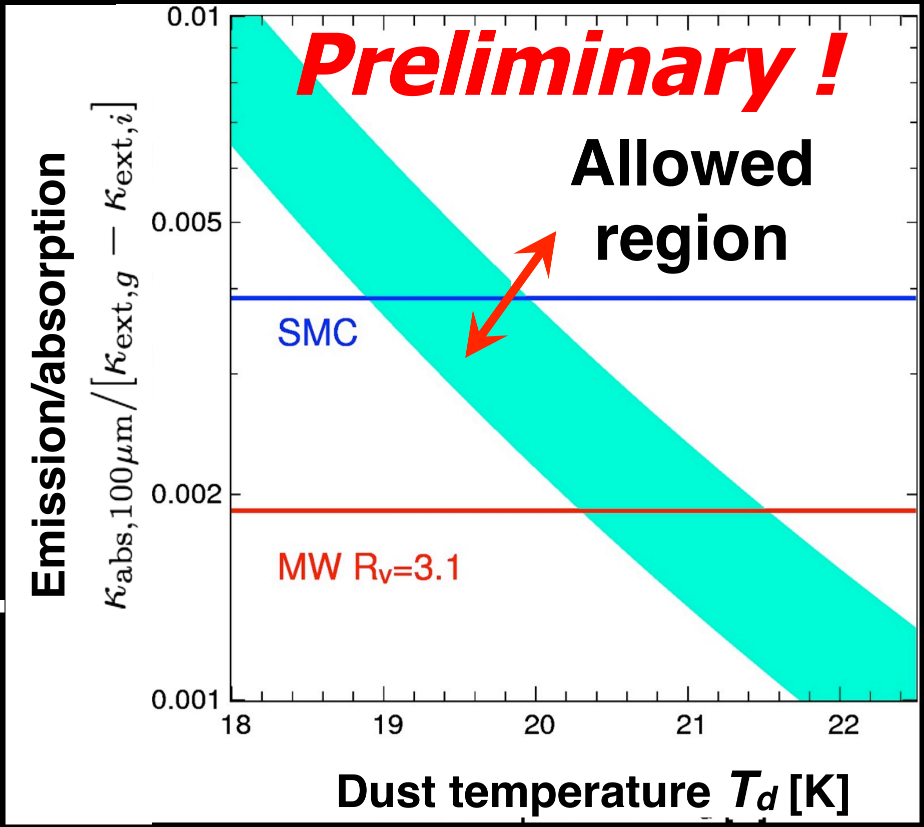
$$I_{\rm total}(\theta, m_i) = I_{\rm single}(\theta, m_i) + I_{\rm clustering}(\theta, m_i) + C$$

# constraining the dust temperature

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

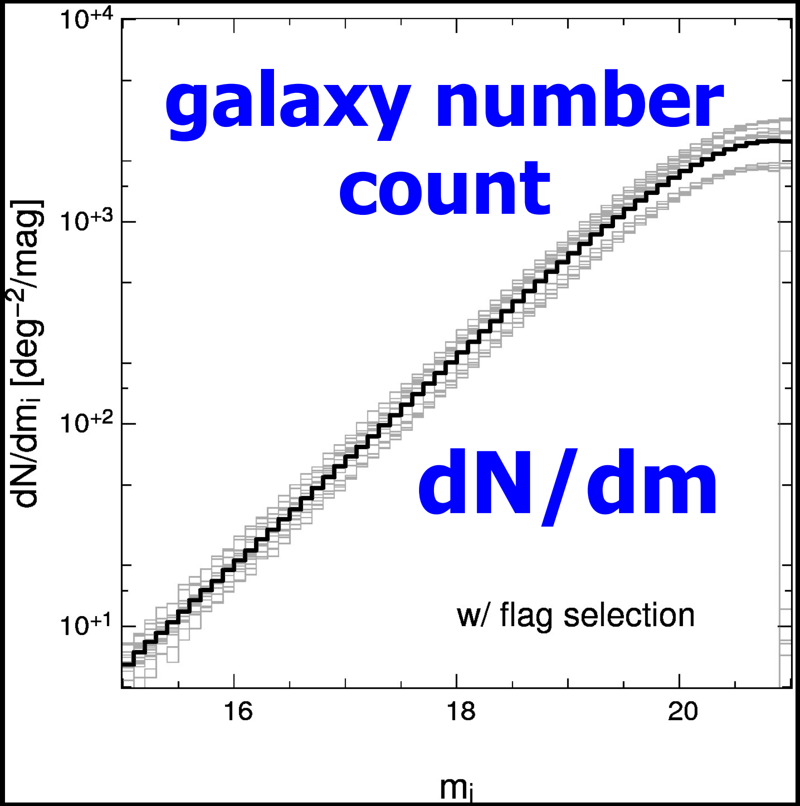
  http://www.astro.princeton.edu/~draine/dust/dustmix.html

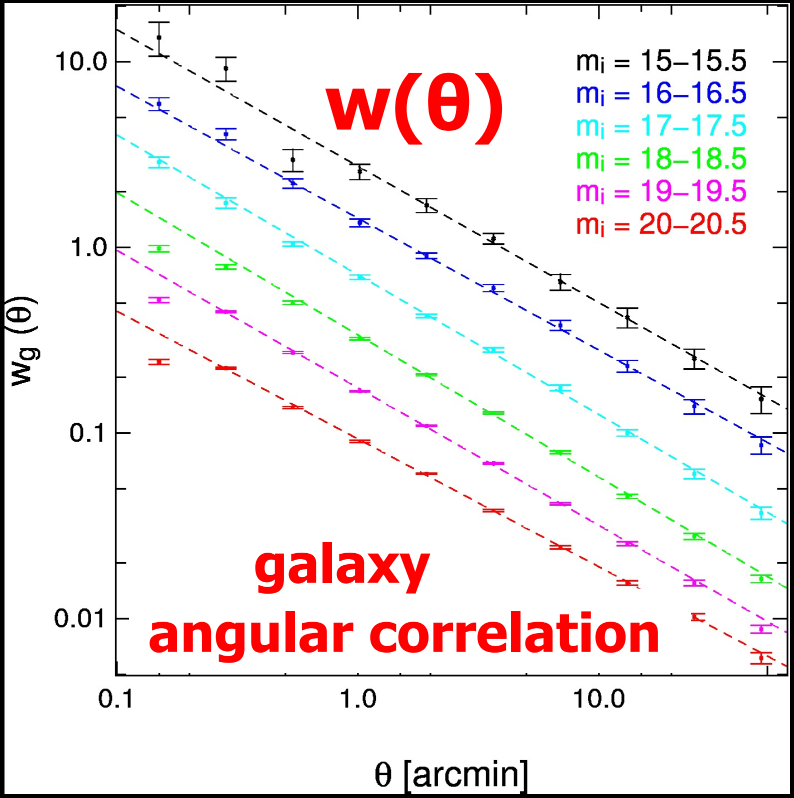
- **consistent with typical dust temperature of galaxies (~20K)**
  - MSFR and we observed the absorption and emission of the same component, respectively.
  - Temperature of intergalactic dust ???



# Contribution of SDSS galaxies to the 100μm emission $I_{clustering}(\theta,m_i)$

$$I_{\rm clustering}(\boldsymbol{\theta}, m_i) = \int dm' \frac{dN(m')}{dm'} \int d\boldsymbol{\varphi}\; I_{\rm single}(\boldsymbol{\theta} - \boldsymbol{\varphi}; m') w(\boldsymbol{\varphi}; m', m_i)$$

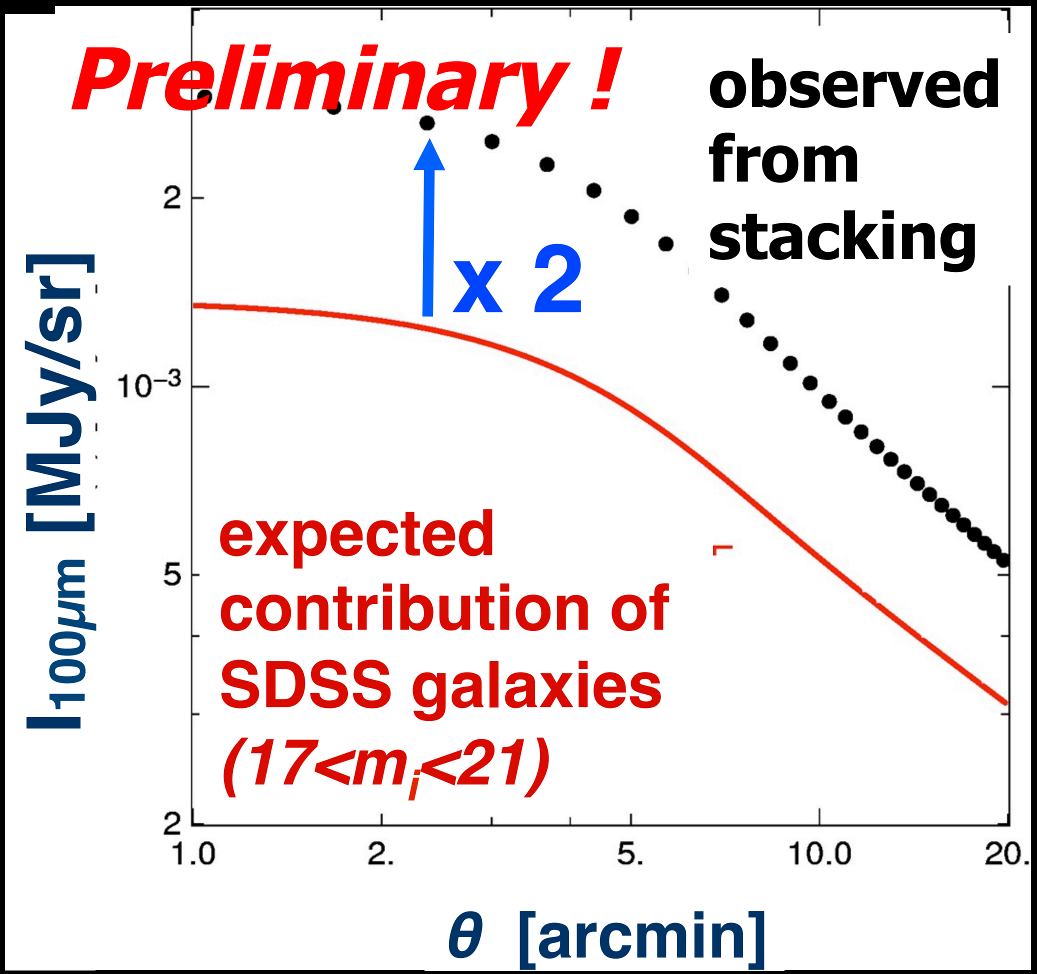


# ~50% is from SDSS galaxies

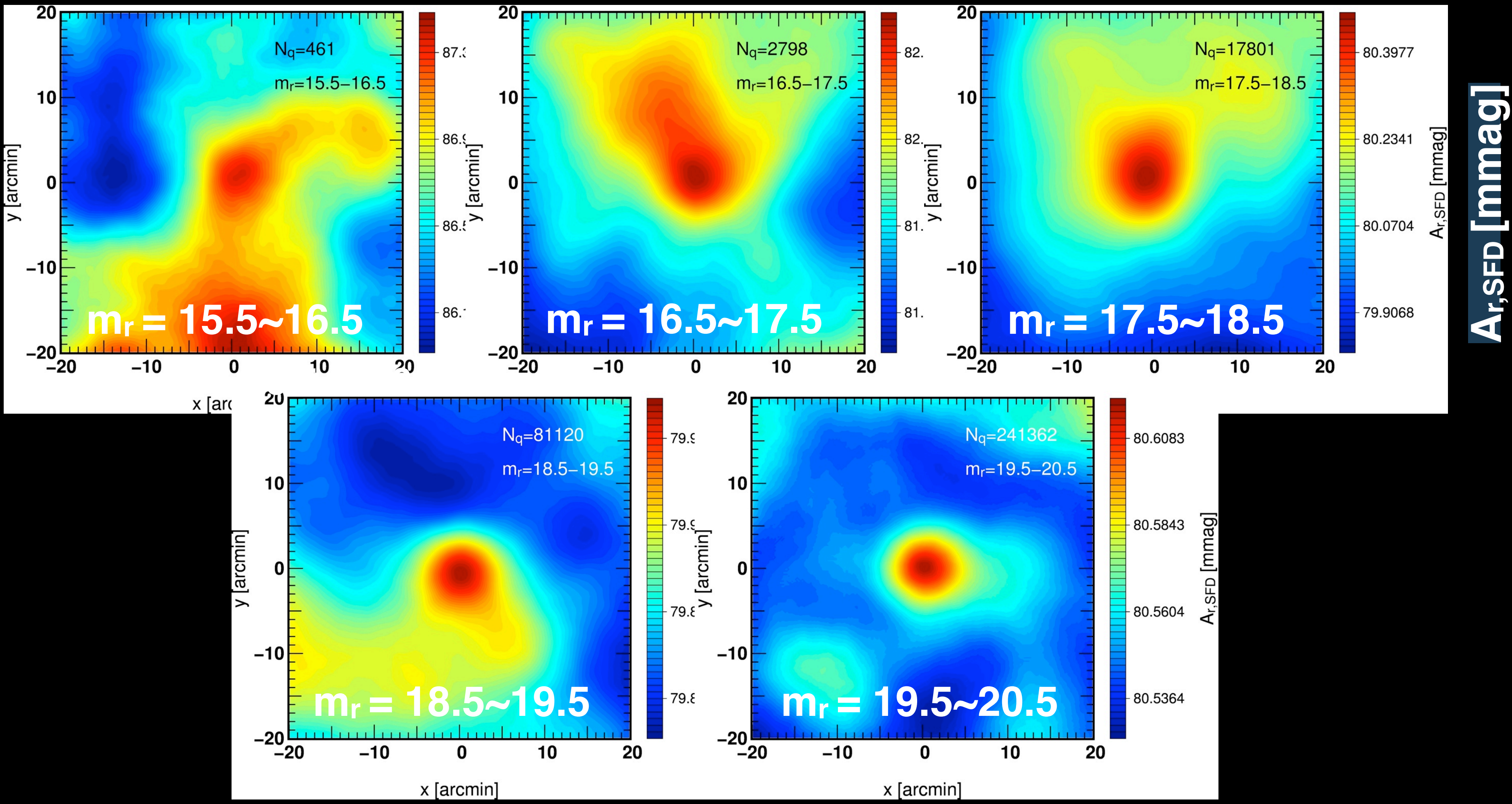
$$I_{\rm clustering,MSFR}(\theta) = \int_{17.0}^{21.0} I_{\rm clustering}(\theta; m_i') \frac{dN}{dm_i'} dm_i' \times \left( \int_{17.0}^{21.0} \frac{dN}{dm_i'} dm_i' \right)^{-1}$$

- SDSS galaxies explain 50% of the FIR flux
- The rest may be
  - extended dust component over cluster scales ?
  - sums of optically faint infrared galaxies ?

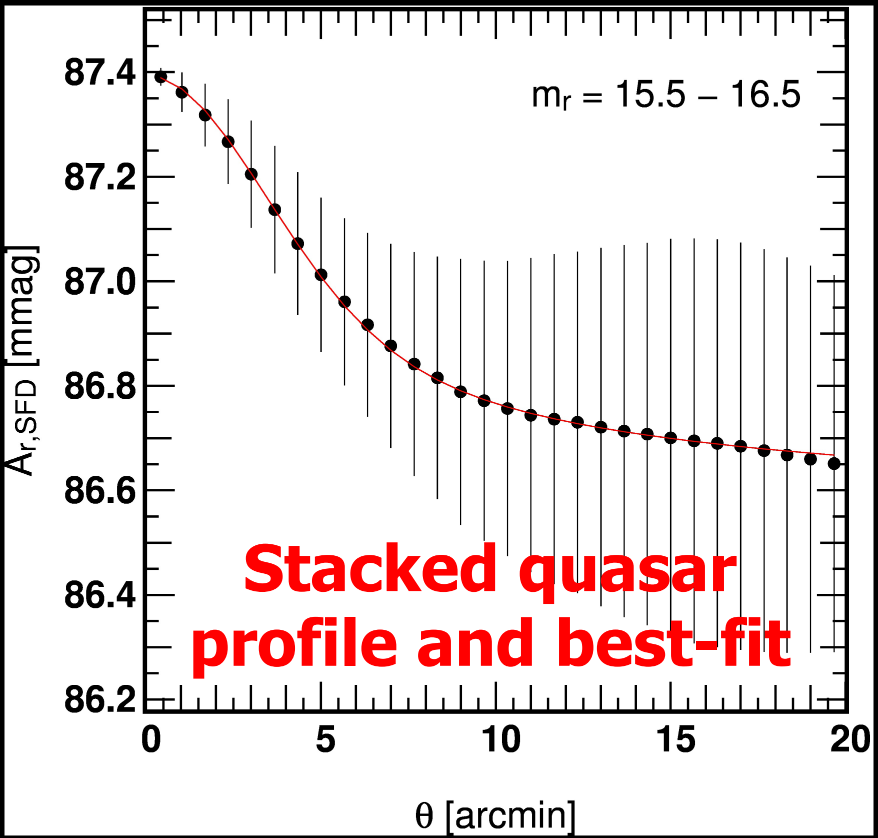


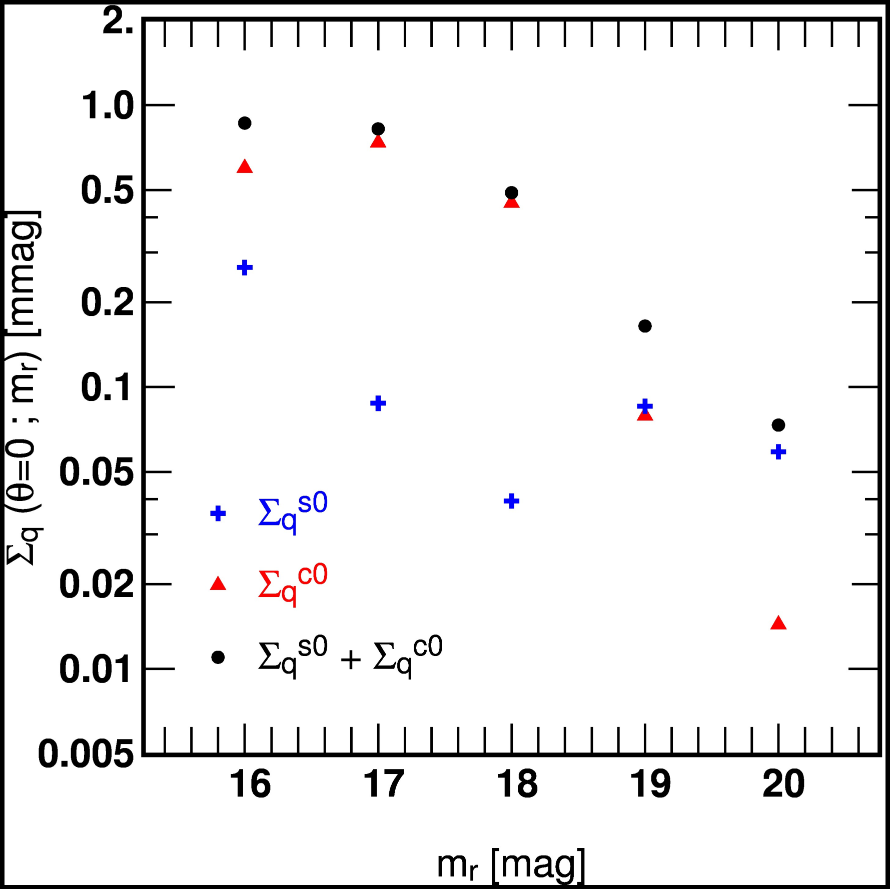
# Stacking SDSS quasars

Similar stacking analysis of SDSS photometric quasar catalogue (Richards et al. 2009) indicates the FIR signals as well.



# Profiles of stacked quasar images




Best-fit decomposition into the single and clustering terms

Quasars stacking should deserve further study…

# Summary of the first part

- Detection of FIR emission from SDSS galaxies by stacking image analysis over the SFD map (～ IRAS 100μm map)
  - Largely explains the anomaly of SDSS galaxy number counts as a function of $A_{SFD}$ discovered by Yahata et al.(2007)
  - Possible correction to the SFD map and a future Galactic extinction map with Planck/AKARI
  - A new probe of unresolved (dusty) galaxy correlations and/or dust profile of the hosting halo

# *Preliminary* summary of the second part

- Sum of dust associated with SDSS galaxies explains ~50% of the amount discovered via absorption by Ménard et al.(2010)
- Where is the remaining ~50% ?
  - Associated with non-SDSS galaxies ?
  - Not directly associated with individual galaxies, but smoothly extended over intracluster region ?
- FIR emission from SDSS quasars detected, should be explored in future.