Weak Lensing Cosmology

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Outline

- S₈ tension and weak lensing surveys
- Review of Stage-III survey results (biased towards HSC!)
 - Differences in analysis choices
 - Approaches for systematics
 - Non-linear regime
 - redshift uncertainties
 - intrinsic alignment
 - baryonic effects
- Cosmology with CMB lensing tomography with high-z galaxies

S₈ Tension

 $S_8 \equiv \sigma_8 \sqrt{\Omega_m/0.3}$

- σ_8 : Amplitude of linear power spectrum on the scale of 8 Mpc/h
- $\Omega_{\rm m}$: Energy dense of matter (incl. dark matter)

Most large scale structure probes prefer smaller S_8 compared to CMB, if we assume **ACDM**.







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| • CMB Planck TT,TE,EE+lowE • CMB Planck TT,TE,EE+lowE+lensing • CMB ACT+WMAP | | 0.834 0.832 0.84 | Aghanim et al. (2020) Aghanim et al. (2020) Aiola et al. (2020) | 2020d) 2020d) 0) | |
|--|--------------------------------|---------------------------------------|---|------------------------|--|
| | | | | Early Universe | |
| Weak Lensing (Cosmic S | Shear) | | | Late Universe | |
| • WL KiDS-1000 | | 0.759 | · Asgari et al. (20) | 21) | |
| • WL KiDS+VIKING+DES-Y1 | | 0.755 | Asgari et al. (20) | 20) | |
| WL KiDS+VIKING+DES-Y1 | 0.71 | | Joudaki et al. (20 | 020) | |
| • WL KIDS+VIKING-450 | 0. | 737 | Wright et al. (20 | 20) | |
| • WL KiDS+VIKING-450 | 0.651 | • | Hildebrandt et a | l. (2020) | |
| • WL KiDS-450 | 0 | .745 | Kohlinger et al. | (2017) | |
| • WL KIDS-450 | | 0.759 | Hildebrandt et a | l. (2017) | |
| • WL DES-Y3 | | 0.782 | Amon et al. and | Secco et al. (2021) | |
| WL DES-YI | | 0.804 | Homono et al. (20 | 18) | |
| WI USC-proude C | | 0.78 | Halliana et al. (2) | (10) | |
| • WL CEHTLenS | 0 | .74 | Ioudaki et al. (20 | 017) | |
| Weak Lensing + Galaxy (| Clustering | na anna anna anna anna anna anna anna | Joudaki et al. (20 | 517) | |
| *WL+GC HSC+BOSS | Justering | 0.795 | · Mivatake et al. (| 2022) | |
| •WL+GC+CMBL KiDS+DES+eBOSS+I | Planck | 0.7781 | García–García e | et al. (2021) | |
| • WL+GC KiDS-1000 3×2pt | 0 | 0.766 | Heymans et al. (| 2021) | |
| • WL+GC KiDS-450 3×2pt | 0 | 0.776 | Joudaki et al. (20 | 018) | |
| • WL+GC DES-Y3 3×2pt | | 0.773 | Abbott et al. (20 | 21) | |
| • WL+GC DES-Y1 3×2pt | 0.7 | 28 | · Abbott et al. (20 | 18d) | |
| • WL+GC KiDS+VIKING-450+BOSS | H | 0.8 | Tröster et al. (20 | 20) | |
| • WL+GC KiDS+GAMA 3x2pt | | | van Uitert et al. | (2018) | |
| Galaxy Clustering | | 0.751 | | | |
| GC BOSS DR12 bispectrum | 0.7 | 2 | • Philcox et al. (20 | 021) | |
| • GC BOSS+eBOSS | 0. | 736 | · Ivanov et al. (20 | 21) | |
| • GC BOSS power spectra | 0.7 | 29 | • Chen et al. (202) | 1) | |
| • GC BOSS DR12 | 0.703 | | I roster et al. (20 | 20) | |
| • GC BOSS galaxy power spectrum | 0. | 73 | White et al. (20 | 20) | |
| • GC+CMBL unWISE + Planck | | 0.784 | Vinite et al. (202 | (2021) | |
| Cluster Abundance (ant | | | KIOICWSKI CI al. | (2021) | |
| Cluster Abundance (opt. | + x- ray) | 0.78 | · Lesci et al. (202 | 1) | |
| • CC DES-Y1 | 0.65 | | · Abbott et al. (202 | 20d) | |
| • CC SDSS-DR8 | | 0.79 | · Costanzi et al. (2 | 2019) | |
| • CC XMM-XXL | | 0.831 | Pacaud et al. (20 | 18) | |
| • CC ROSAT (WtG) | | 0.77 | · Mantz et al. (201 | 15) | |
| Cluster Abundance (SZ) | (| 749 | | | |
| • CC SPT tSZ | - | 0.785 | · Bocquet et al. (2 | 019) | |
| CC Planck tSZ | | 0.793 | · Salvati et al. (2018) | | |
| CC Planck tSZ | | | · Ade et al. (2016) | d) | |
| Redshift Space Distortio | ns _{0,7} | | | | |
| • RSD | | .747 | Benisty (2021) | | |
| • RSD | | | · Kazantzidis and | Perivolaropoulos (| |
| 0.2 0.4 | 0.6 | 0.8 | 10 | 12 | |
| 0.2 0.7 | о.о г | 0.0 | 1.0 | 1.2 | |
| | $S_8 \equiv \sigma_8 \sqrt{S}$ | $\Omega_m / 0.3$ | Abdalla et al. (2 | | |









S₈ Tension

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Most large scale structure probes smaller S_8 compared to CMB, if we a Λ CDM.

| | • CMB Planck TT • CMB Planck TT • CMB ACT+WM | T,TE,EE+lowE T,TE,EE+lowE+lensin TAP | g | 0.834 0.832 0.84 | Aghanim et al. (2 Aghanim et al. (2 Aiola et al. (2020 | 020d) 020d)) Early Universe |
|---------|---|---|--------------------------------|---|---|---|
| | Weak Lens | sing (Cosmic | Shear) | | | Late Universe |
| | • WL KiDS-1000 • WL KiDS+VIK • WL KiDS+VIK • WL KiDS+VIK • WL KiDS+VIK • WL KiDS-450 • WL KiDS-450 • WL DES-Y3 | ING+DES-Y1 ING+DES-Y1 ING-450 ING-450 | 0.651 | 0.759 0.755 0.762 716 0.737 0.745 0.759 | Asgari et al. (202 Asgari et al. (202) Joudaki et al. (202) Wright et al. (202) Wright et al. (202) Hildebrandt et al. (202) Hildebrandt et al. (202) Hildebrandt et al. (202) Hildebrandt et al. (202) | 1) 0) 20) 0) (2020) 2017) (2017) Secco et al. (2021) |
| on the | • WL DES-Y1 • WL HSC-TPCH • WL HSC-pseud • WL CFHTLenS Weak Lens | F Io−Cr Sing + Galaxy | Clusterin | 0.78 0.74 0.795 | Troxel et al. (201) Hamana et al. (20 Hikage et al. (201) Joudaki et al. (201) | 8) 20) 9) 17) |
| | • WL+GC HSC+ • WL+GC+CMB • WL+GC KiDS- • WL+GC KiDS- • WL+GC DES- | BOSS L KiDS+DES+eBOSS -1000 3×2pt -450 3×2pt Y3 3×2pt | S+Planck | 0.7781 0.766 0.742 0.776 0.773 | Miyatake et al. (2 García–García et Heymans et al. (2 Joudaki et al. (20 Abbott et al. (202 | 022) al. (2021) 021) 18) 1) |
| matter) | WL+GC DES- WL+GC KIDS+ WL+GC KIDS+ Galaxy Clu GC BOSS DR12 | Y1 3×2pt VIKING-450+BOSS GAMA 3x2pt IStering bispectrum | • | 0.728 | Abbott et al. (201 Tröster et al. (202 van Uitert et al. (202 Philcox et al. (202 | 8d) 20) 2018) |
| | • GC BOSS+eBO • GC BOSS power • GC BOSS DR12 • GC BOSS galax | SS r spectra y power spectrum | 0.7 | 0.72 0.736 0.729 03 0.73 | Ivanov et al. (202 Chen et al. (2021) Tröster et al. (202 Ivanov et al. (202 | 1) (0) (0) |
| prefer | • GC+CMBL DE • GC+CMBL un Cluster Ab | LS+Planck VISE+Planck undance (op | t. + X-ray) | 0.784 | • White et al. (2022 • Krolewski et al. (2022 | 2) 2021) |
| assume | • CC AMICO KII • CC DES-Y1 • CC SDSS-DR8 • CC XMM-XXI • CC ROSAT (W | 08-DR3 (G) | 0.65 | 0.79 0.831 0.77 | Lesci et al. (2021) Abbott et al. (202 Costanzi et al. (201 Pacaud et al. (201 Mantz et al. (2015) |) 0d))19) 8) 5) |
| | • CC SPT tSZ • CC Planck tSZ • CC Planck tSZ | undance (Sz | .) | 0.749 0.785 0.793 | Bocquet et al. (20) Salvati et al. (201) Ade et al. (2016d) | 19) 8)) |
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| | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 |
| | | | $S_8 \equiv \sigma_8 \sqrt{1}$ | $\Omega_m/0.3$ | Abdalla | et al. (20) |









Large Scale Structure

HSC-Y1 cosmic shear: $S_8 = 0.78$



Hikage et al. (2019)

We need to measure the difference between LSS above. Challenge: Most of the matter is dark matter

Planck 2020 Primary CMB: $S_8 = 0.83$



Planck Collaboration (2020)

Credit: T. Nishimichi



Weak Gravitational Lensing

Credit: S. Bridle



Intrinsic galaxy (shape unknown) Gravitational lensing causes a shear

 (\mathcal{Z}_l) m $A(Z_{s})$ Weak lensing shear Matter density fluctuation Geometry of the Universe



Weak lensing enables us to measure matter (incl. dark matter) distributions in the Universe.

Weak Lensing Surveys: Now and Future

KiDS (Europe)



Primary Mirror [m]

2.6

Galaxy **Number Dénsity** [arcmin⁻²]





4.0

DES (USA)



8.2





2010

Inspired by E. Krause Credit: ESO, Fermilab/Reidar Hahn, NAOJ, ESA/C. Carreau, Rubin Obs/NSF/AURA, NASA



Weak Lensing Surveys: Now and Future



Krause Credit: ESO, Fermilab/Reidar Hahn, NAOJ, ESA/C. Carreau, Rubin Obs/NSF/AURA, NASA

Cosmic Shear



Redshift



- $\xi_{\pm}(\theta) = \langle \gamma_{+}(\theta')\gamma_{+}(\theta'+\theta) \rangle_{\theta'} \pm \langle \gamma_{\times}(\theta')\gamma_{\times}(\theta'+\theta) \rangle_{\theta'}$ $\sim \xi_{\rm mm}(\theta;\sigma_8,\Omega_{\rm m})$
- Note: θ is angular scales (not separation between galaxies)
- Correlation can be computed within a redshirt bin

Credit: Millennium Simlations



Cosmic Shear



Redshift





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Cosmic Shear





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- Note: θ is angular scales (not separation between galaxies)
- Correlation can be computed within a redshirt bin or across redshift bins
- Fourier space measurements $C_{\text{EE}}(l), C_{\text{BB}}(l)$ are also common now.

Credit: Millennium Simlations



Redshift



(Projected) Galaxy-galaxy clustering $w(\theta) \sim \langle \delta_g(\theta') \delta_g(\theta' + \theta) \rangle_{\theta'} \sim b^2 \xi_{\rm mm}(\theta; \sigma_8, \Omega_{\rm m})$ Linear bias factor

Linear bias approximation: $\delta_g \sim b \delta_m$ (valid at large scales)

Credit: Millennium Simulations



Redshift



Galaxy-galaxy lensing $\gamma(\theta) \sim \Omega_{\rm m}$

 $\sim \Omega_{
m m}$



$$\sum_{cr} (z_l, z_s)^{-1} \langle \delta_g(\theta') \delta_m(\theta' + \theta) \rangle_{\theta'} \quad \text{where}$$

$$\sum_{cr} (z_l, z_s)^{-1} b \xi_{mm}(\theta; \sigma_8, \Omega_m) \quad \sum_{cr} \propto \frac{D_A(z_l, z_s)}{D_A(z_l, z_s)}$$

Credit: Millennium Simulations





Redshift



Combination of Galaxy-galaxy clustering and lensing breaks the degeneracy between b and (σ_8, Ω_m) . Foreground galaxies are called tracers.



Galaxy-galaxy lensing
$$\begin{split} \gamma(\theta) &\sim \Omega_{\rm m} \Sigma_{\rm cr}(z_l, z_s)^{-1} \langle \delta_g(\theta') \delta_m(\theta' + \theta) \rangle_{\theta'} \quad \text{where} \\ &\sim \Omega_{\rm m} \Sigma_{\rm cr}(z_l, z_s)^{-1} b \xi_{\rm mm}(\theta; \sigma_8, \Omega_{\rm m}) \quad \Sigma_{\rm cr} \propto \frac{D_A(z_s)}{D_A(z_l, z_s) D_A(z_l)} \end{split}$$

Credit: Millennium Simulations







Redshift



If we have a spectroscopic sample for clustering

- $w_{\rm p}(R) \sim \left\langle \delta_g(R') \delta_g(R'+R) \right\rangle_{R'}$ $\Delta \Sigma(D) = \sum_{k=1}^{\infty} (-1) \omega(D) =$
- $\Delta \Sigma(R) \sim \Sigma_{\rm cr}(z_l, z_s) \gamma(R) = \Sigma_{\rm cr}(z_l, z_s) \langle \delta_g(R') \delta_m(R' + R) \rangle_{R'}$





3x2pt: Cosmic Shear + 2x2pt

Now we can combine everything :)

 $\xi_{\pm}(\theta), w(\theta), \gamma(\theta)$

Credit: Millennium Simlations





3x2pt: Cosmic Shear + 2x2pt

Now we can combine everything :)

 $\xi_{\pm}(\theta), w(\theta), \gamma(\theta)$

Credit: Millennium Simlations



Latest 3x2pt Analyses of Stage-III Surveys



 S_8 σ_8

KiDS 3x2pt is not shown here since the constraint on $\Omega_{
m m}$ is quite tight due to the use of BAO.

Miyatake et al. (2023)





Analysis Choice: Summary Statistics

DES-Y3 DES collaboration (2022)

Cosmic Shear

Real Space $\xi_{+}(\theta)$

Galaxy-galaxy clustering

Galaxy-galaxy lensing

Projected clustering with photometric galaxies $w(\theta)$

Use photometric galaxies as a tracer

HSC-Y3 Sugiyama et al. (2023) Miyatake et al. (2023)

KiDS-1000 Heymans et al. (2021)

Real space $\xi_{+}(\theta)$

Fourier Space $C_{\rm EE}(l)$

Projected clustering from BOSS $W_{\rm D}(R)$

Use BOSS galaxies as a tracer $\Delta\Sigma(R)$

3D clustering from BOSS and 2dFLenS $\xi_{gg}(s,\mu)$

Use BOSS and 2dFLenS galaxies as a tracer $C_{
m nE}(l)$ equiv. To $\gamma(heta)$



Analysis Choice: Redshift Bins



- DES uses lens-source pairs even if there is an overlap in redshift.
- in a single redshift bin (Cosmic shear only analyses were done using multiple source redshift bins. See Li et al. (2023) and Dalal et al. (2023)).
- KiDS uses lens-source pairs when a source bin is behind a lens bin.

HSC uses sources well separated from lenses. Cosmic shear is measured

Analysis Choice: Scale Cuts

| | DES-Y3 DES collaboration (2022) | |
|-----------------------------|--|-----------|
| Cosmic shear | ξ_+ : ~3 arcmin < θ < ~220 arcmin ξ : ~40 arcmin < θ < ~220 arcmin (depends on redshift bin) | ξ₊ ξ₋: |
| Galaxy-galaxy clustering | R > 8 Mpc/h | |
| Galaxy-galaxy lensing | R > 6 Mpc/h | |

HSC uses much smaller scale cuts for clustering and lensing, in which they need to consider non-linear regime.

HSC-Y3 Sugiyama et al. (2023) Miyatake et al. (2023)

KiDS-1000 Heymans et al. (2021)

 \pm : 8 arcmin < θ < 50 arcmin 30 arcmin < θ < 150 arcmin 100 < I < 2000(~5 arcmin < θ < ~100 arcmin)

2 Mpc/h < R < 30 Mpc/h

20 Mpc/h < s < 160 Mpc/h (Includes BAO information)

3 Mpc/h < R < 30 Mpc/h

I < 300($\theta > ~36$ arcmin or R~15 Mpc/h)



Systematics: Non-linear Effect

HSC-Y3 used non-linear scales to gain S/N

Challenges

- Accurate modeling of non-linear regimes
- Proper treatment of uncertainties in galaxy-halo connection





dark matter dark matter halos galaxies

Observables $\xi_{\rm hh} = \langle \delta_{\rm h} \delta_{\rm h} \rangle \qquad \qquad \xi_{\rm gg} = \langle \delta_{\rm g} \delta_{\rm g} \rangle \\ \xi_{\rm hm} = \langle \delta_{\rm h} \delta_{\rm m} \rangle \qquad \qquad \xi_{\rm gm} = \langle \delta_{\rm g} \delta_{\rm m} \rangle$ Clustering: $w_p(R)$ Weak Lensing: $\Delta \Sigma(R)$ Projection to 2-d

Modeling non-linear regimes Uncertainties between galaxy-halo connection Analytical convolution of HOD and marginalize over the HOD parameters





Dark Emulator: accurate non-linear model

 Run N-body simulations under 101 sets of cosmological parameters.

 $\vec{C} = (\omega_b, \omega_c, \Omega_\Lambda, A_s, n_s, w)$

- Run the Rockstar halo finder.
- Measure correlation functions, i.e., $\xi_{\rm hh}(r; \vec{C})$ and $\xi_{\rm hm}(r; \vec{C})$.
- Interpolate correlation functions across the cosmological parameter sets using PCA and Gaussian process.
- Achieved an accuracy for $\xi_{hh}(r; \vec{C})$ and $\xi_{hm}(r; \vec{C})$ better than 2%.
- **Unique cosmic emulator with halo statistics**



T. Nishimichi (Kyoto)



Nishimichi et al. (2019)



Galaxy-halo connection

- Use halo occupation distribution (HOD; 5 parameters) to distribute galaxies in a dark matter halo.
- Take into account the uncertainties in galaxy physics by marginalizing HOD parameters.



Information Content in Small Scales





We cannot extract information from scales less than ~2 Mpc/h because of the HOD marginalization.



Miyatake et al. (2022a)



Systematics: Redshift Uncertainties

- Bias in a lens or source redshift causes systematic bias in lensing signal.
- When using a spectroscopic sample for lenses, there is no bias in lens redshift.
- For source galaxies, photometric redshift (photo-z) is used, so we should always care about bias.
- When using a spectroscopic sample for lenses we only care about mean of source redshifts.

 $\langle \gamma \rangle = \langle \Sigma_{\rm cr}(z_l, z_s)^{-1} \Delta \Sigma(z_l) \rangle$ $= 4\pi G (1+z_l)^{-2} \chi_l \left[1-\chi_l \left\langle \frac{1}{\chi_s} \right\rangle \right] \Delta \Sigma(z_l)$



- We had almost no calibration sample except for COSMOS 30-band photo-z at z>1.1.
- We decided to use a flat prior $\Pi(\Delta z_{\rm ph}) = \mathcal{U}(-1,1)$, and self-calibrate by using multiple lens samples (Oguri & Takada, 2011).
- $\Delta z_{\rm ph} = -0.05 \pm 0.09$
- If we fix $\Delta z_{\rm ph}$, our S_8 constraint is shifted by 0.5*σ*.
- Downside: the error on S_8 is doubled once we use the flat prior.

An Extreme Case: HSC-Y3



Miyatake et al. (2023)





Systematics: Intrinsic Alignment

- Intrinsic shape of galaxies is affected by the tidal forces of a dark matter structure.
- There are two terms: II and GI.
- Both II and GI cause a systematic bias in cosmic shear (GI is dominant).
- Il causes a systematic bias in galaxygalaxy lensing.
- There are two models
 - NLA: Assumes galaxies linearly align with the tidal field.
 - TATT: Uses nonlinear perturbation theory to expand the field of intrinsic galaxy shapes interns of the tidal field and matter overdensity.



Troxel & Ishak (2014)



Intrinsic Alignment in Stage-III Surveys

- For cosmic shear, all surveys incorporated IA in their models.
- For galaxy-galaxy lensing, DES and KiDS incorporated IA in their models, but HSC not, due to the use of spectroscopic galaxies as a tracer and conservative selection for source galaxies.

DES-Y3



HSC-Y3

Intrinsic Alignment in Stage-III Surveys



Note: HSC tomographic cosmic shear analyses (Dalal et al, 2023; Li et al, 2023) adopted TATT as fiducial, did not detect IA, and S_8 constraints were not affected.

HSC-Y3 Sugiyama et al. (2023) Miyatake et al. (2023)

KiDS-1000 Heymans et al. (2021)

No IA detection

3 sigma detection Did not affect S_8 constraint (~0.1*σ*).

N/A

N/A



- AGN feedback pushes matter away from halo center and modifies small scale signals.
- Scale cut for small scales in cosmic shear measurements is applied to avoid scales affected by AGN feedback.

Systematics: Baryonic Effect

HSC-Y3 cosmic shear



Li et al. (2023)

Baryonic Effect on Cosmic Shear

- To recover Planck S_8 from DES and KiDS cosmic shear including small scales (data points outside of scale cuts), AGN feedback is required to extend to mildly non-linear scale (k~0.2 h/Mpc).
- It may be unrealistic to explain the S_8 tension only by Baryonic effect.







Baryonic Effect on Galaxy-galaxy Lensing

- ACT measured AGN feedback around CMASS sample through kSZ and tSZ signals.
- They also found large AGN feedback up to ~3 Mpc/h in lensing signal.
- HSC-Y3 scale cut (R> 3 Mpc/h) safely avoids the small scales affected by AGN feedback.
- Better to use $\Delta \Sigma(R)$ than $\gamma(\theta)$ to avoid mixing in angular scales.



S₈ Tension Updated



- Planck CMB aniso.
- Planck CMB aniso. ($+A_{lens}$ marg.)
- Planck CMB lensing + BAO
- SPT CMB lensing + BAO
- **ACT CMB lensing + BAO**
- **ACT+Planck CMB lensing + BAO**
- DES-Y3 galaxy lensing + BAO
- KiDS-1000 galaxy lensing + BAO
- HSC-Y3 galaxy lensing (Fourier) + BAO
- HSC-Y3 galaxy lensing (Real) + BAO





Hand et al. (2015)



Large scales



Small scales

Preston et al. (2023)



Recent Galaxy x CMB-lensing Studies

unWISE galaxies x Planck



Krolewski (2021)

Gaia-unWISE quasars x Planck



Going beyond z>2!

Selecting High-z Galaxies: Dropout Technique

- Broadband photometry can capture the Lyman break at 912Å.
- these galaxies are called Lyman break galaxies (LBG).



Selecting distant galaxies with Lyman break is called dropout technique, and

Ono et al. (2018)



LBG x Planck CMB Lensing

- ~1.5M LBG galaxies over 300 deg² of HSC field.
- Stacked Planck lens map behind LBGs
- Contamination from low-z galaxies is quantified by WL measurements with HSC.
- Obtained 3.5σ significance against the contamination signal.



Miyatake et al. (PRL, 2022)



Near future (in 2-3 years)

- The HSC LBG sample will be tripled with the final HSC data.
- ACT DR6 has a large overlap with HSC. Noise level is 5 x smaller than Planck. **S/N ~ 15**

Future (beyond 2-3 years)

- - z~3 dropouts: 4x10⁷ galaxies
 - z~4 dropouts: 10⁸ galaxies
 - z~5 dropouts: 2x10⁷ galaxies
- CMB-S4: 30 x smaller noise level lacksquarecompared to Planck.



(Can be optimistic since we need to deal with systematics)

The Future

• More galaxies from upcoming imaging surveys, according to Wilson & White (2019), for Rubin



Systematics to consider

Redshifts/contaminations

- Majority of contaminations are in low redshift: misidentification of 4000Å break as Lyman break.
- But the redshift distribution should be measured for precision cosmology.
- Currently we have ~1000 spec-zs. PFS, MSE and MegaMapper should help. See next slide for a medium-band survey.
- For the CMB lensing signal, contaminations can be quantified by weak lensing.
- Cosmic Infrared Background (CIB)
 - CIB lowers CMB lensing signal.
- Magnification bias

Severeness

• Lens galaxies can be preferentially selected where LSS along the line-of-sight is prominent, which can cause magnification bias in the CMB lensing signal. We checked our measurement is not prone to magnification bias, but it should be revisited to carry out precision cosmology.





HSC Medium-Band (MB) Filters



- 16 or 20 medium-band (MB) filters that cover 4000-10000Å.



Fabrication cost is funded (12 filters), and filters will be ready by S25A.

Performance of MB Filters



MB filters can be used for calibration to remove contamination.





Summary

- All the stage-III weak lensing surveys released intermediate results
 - Despite of different analysis choices, they consistently exhibit smaller $S_8\,$ compared to primary CMB.
 - A number of systematics were carefully tested in their analyses and followup studies: non-linear regime, photo-z, intrinsic alignment, baryonic effect.
- ACT lensing showed S_8 consistent with Planck primary CMB.
 - S_8 changes as a function of redshift?
 - In addition to the default science case of Stage-IV weak lensing surveys, where they measure large-scale structure at z<~2, we should to go higher redshift using galaxy-CMB lensing cross correlations!

Backup Slides

