# Updates in B03 (cosmology with spectroscopic survey)

Masahiro Takada (Kavli IPMU)

Cosmic Acceleration @ Sendai, Feb 2018

# Our team

- Masahiro Takada: oversee
- Naoyuki Tamura: PFS Project Manager
- Ryuichi Takahashi: simulations
- Naoki Yasuda: pipeline
- Ikuru Iwata: Subaru
- Yousuke Minowa: Subaru
- Surhud More: theory
- Kiyoto Yabe: PFS
- Tomomi Sunayama
- Hillary Child (JSPS, from Chicago)
- Kohei Hayashi (IPMU → KIAA → NAOJ)
- Teppei Okumura (IPMU → ASIAA)
- Hironao, Miyatake (JPL/Caltech → Nagoya)
- Yuki Moritani: PFS
- Chiaki Hikage
- Collaborators: Takahiro Nishimichi, Masato Shirasaki, .
- Students: H. Niikura, K. Akitsu, R. Murata, Y. Kobayashi, T. Nozawa, H. Ito, R. Tateishi, N. Sugiyama, T. Kurita

# Activities (FY2017)

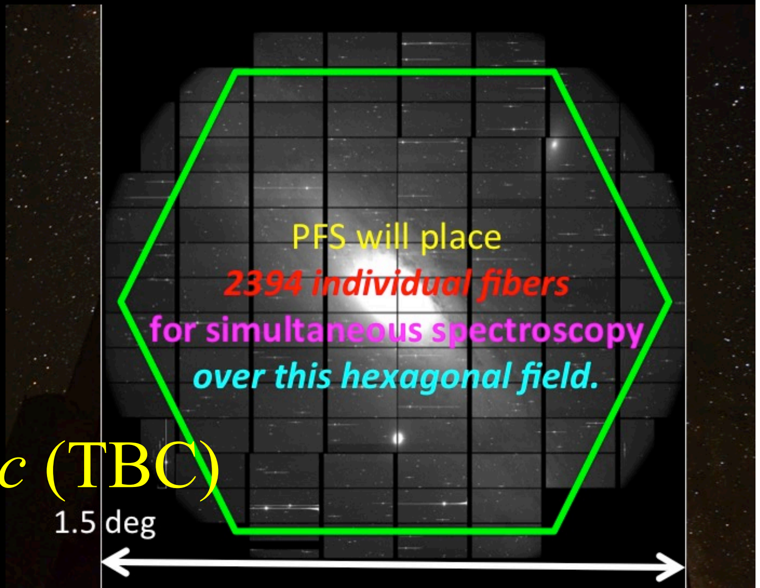
- PFS project (being led by N. Tamura, K. Yabe, Y. Moritani, …)
- HSC collaboration meeting @Sendai, May 14-19
- PFS Science WG meeting @MPA, Aug 6-10
- Dark Matter WS @Kanazawa, Oct 2-3
- Workshop with Nick Kaiser @Kyoto, Sep 11
- Cosmology WS @Hirosaki U., Oct 23-25
- Small workshop (A01, A02, B03) @Kyoto, Nov 9
- PBH WS @IPMU, Nov 13-17
- PFS collaboration meeting @IPMU, Nov 27-Dec 1
- Subaru-WFIRST meeting @NAOJ, Dec 18 - 20
- Many visitors (H. Child, N. Kaiser, G. Bernstein, B. Ratra, J. Prochaska, H. Hildebrandt, B. Leistedt, S. Ferraro, E. Baxter, Z. Slepian, Z. Zheng, ..)
- Regular group meeting (telecon, telecon, ….)

# Publications

- Many HSC papers (cosmology papers coming soon, see Hikage san's talk)
- Mandelbaum, Miyatake et al PASJ in press: *HSC shape catalog*
- Niikura, Takada, Yasuda et al, arXiv:1701.02151: *HSC microlensing constraints on PBHs*
- Osato et al. arXiv:1712.00094: *large-scale tide and halo shapes*
- Akitsu & Takada: arXiv:1711.00012: *LSS & large-scale tide*
- R. Takahashi et al. ApJ: *full-sky simulations for HSC and CMB*
- Shirasaki et al*:* MNRAS: *mock catalogs of g-g lensing (for HSC)*
- Okumura, Takada, More, Masaki, MNRAS: *RSD*
- Murata et al., ApJ in press: *modeling of SDSS clusters*
- *….*

# PFS - Fast facts

- Subaru *Prime Focus Spectrograph*:
  The spectroscopy part of the "SuMIRe" project.
  - Wide field: *~1.3 deg* diameter
  - High multiplicity: *2394 fibers*
    - Fiber diameter: ~1.05 arcsec
    - Fiber positioner pitch: ~85 arcsec
    - Minimum fiber separation: ~30 arcsec
  - Quick fiber reconfiguration: *~60-120 sec* (TBC)
    - *Dynamic* survey strategy is allowed.
  - VIS-NIR coverage: *380-1260nm simultaneously*
    - Low resolution mode: ~2.5 A resolution
    - Medium resolution mode (around 800nm): ~1.6 A resolution
- Aiming at start of science operation & survey program in *2021, as a facility instrument on Subaru Telescope.*



# The *growing* PFS collaboration

rs in Japan & other 6 countries are co-
ent development & survey planning.

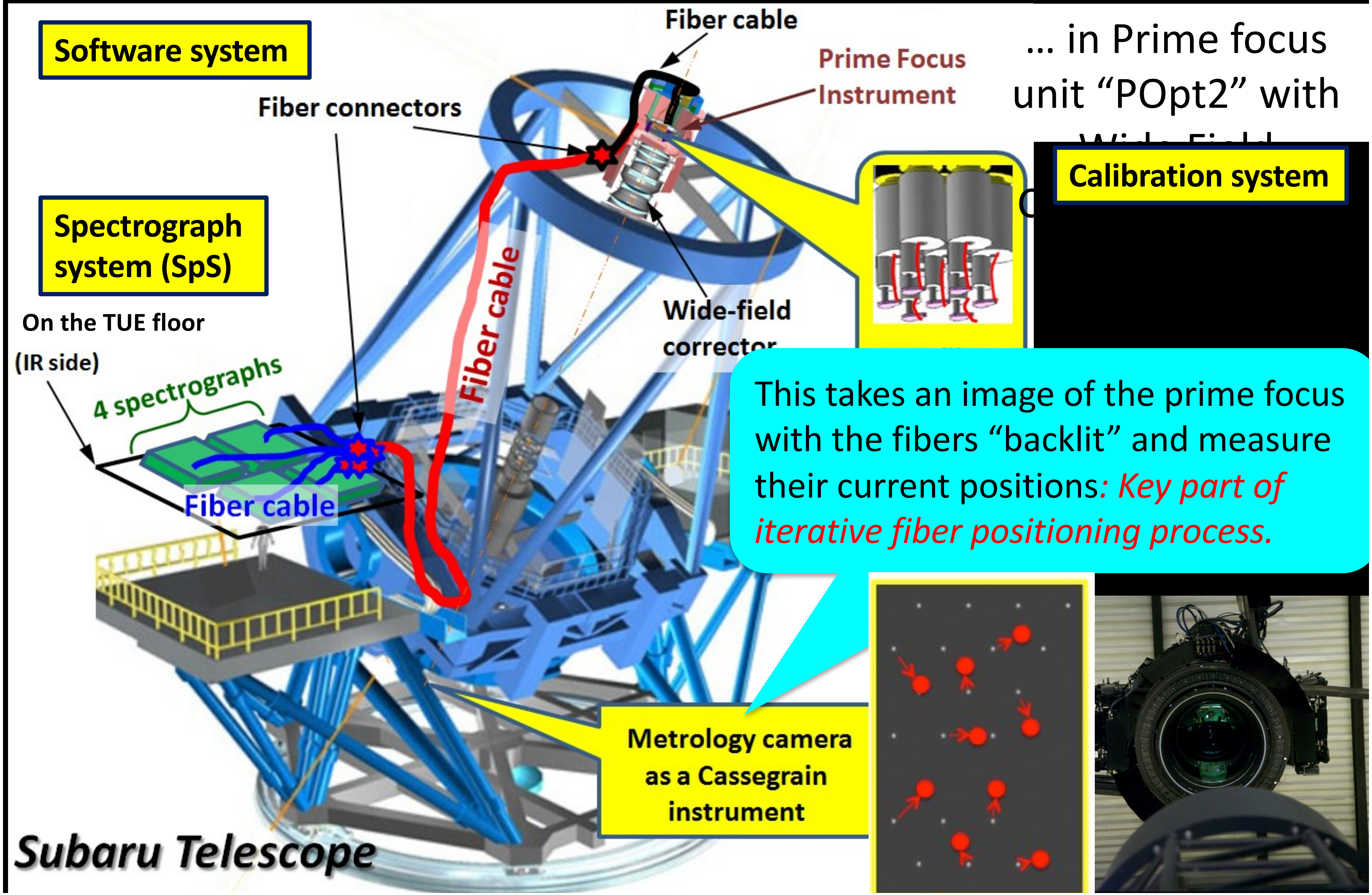


sities is
now in the formal process of participation.

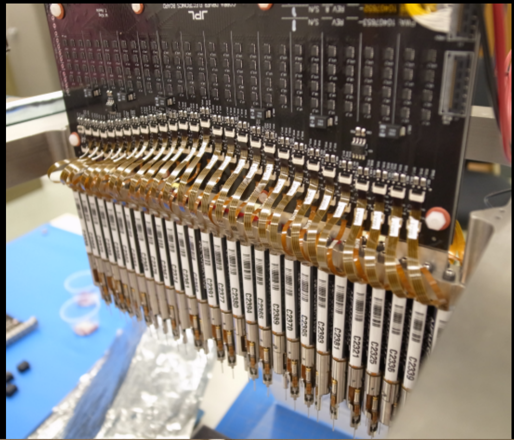
# PFS collaboration meeting

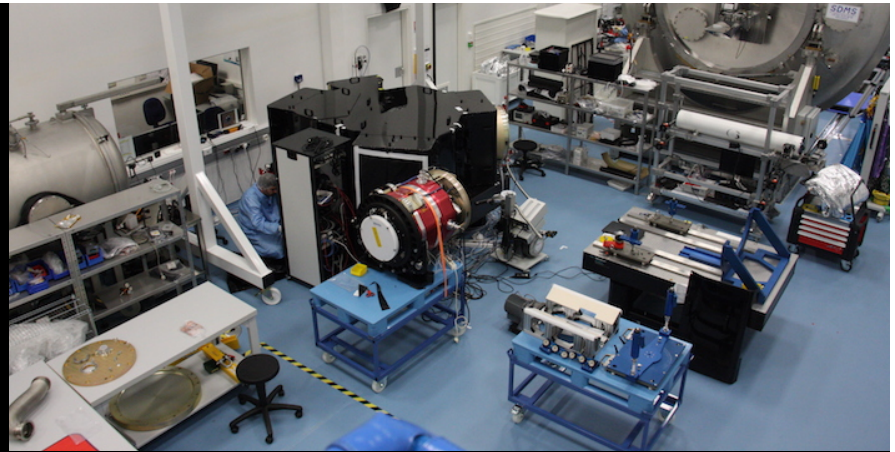
- The last one was the 9th meeting.
- 5 days from Nov 27 to Dec 1, at Kavli IPMU.
- ~130 participants (cf. ~80 for the last few times)

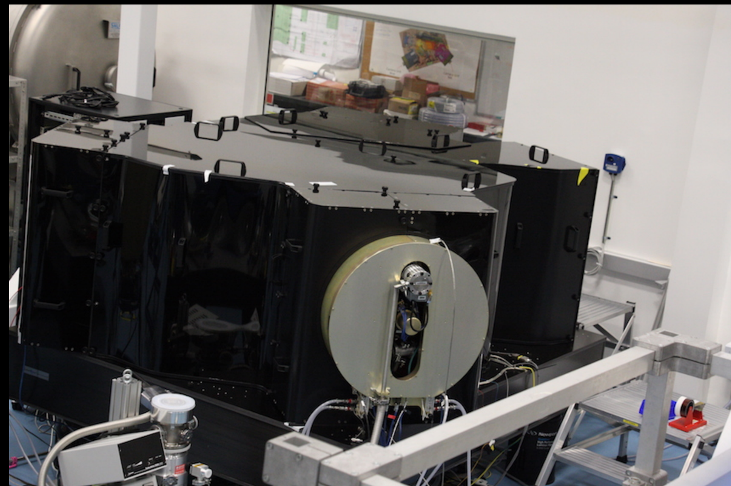
# PFS subsystems distribution

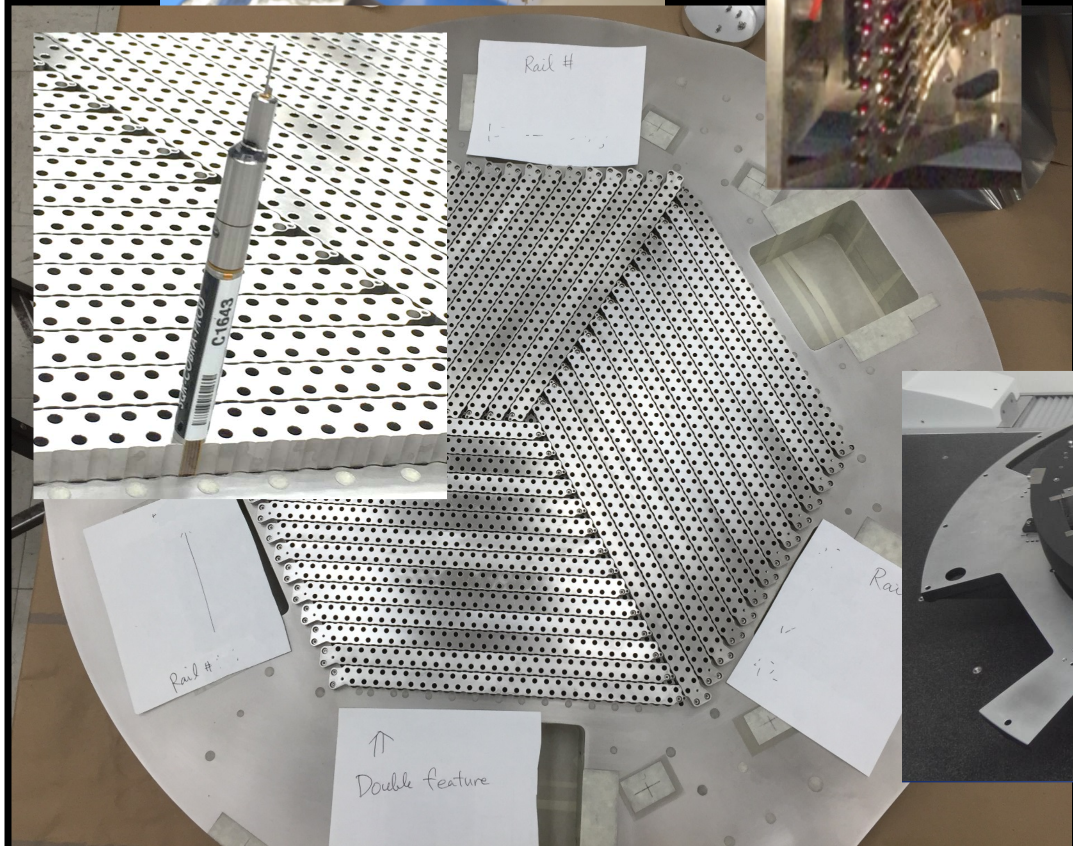


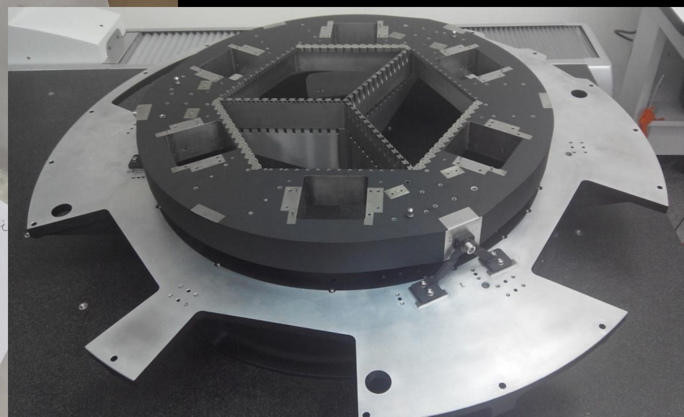
# PFS is REAL!!!

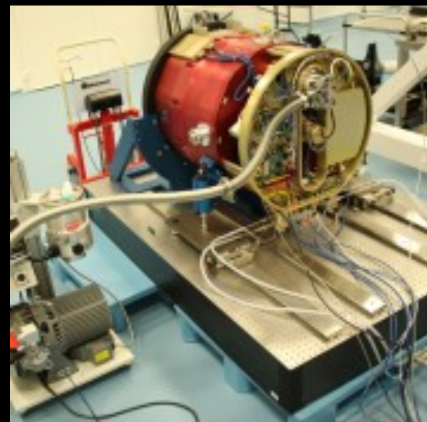






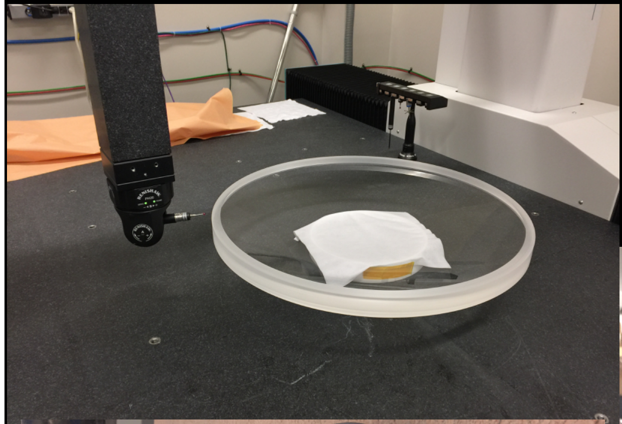
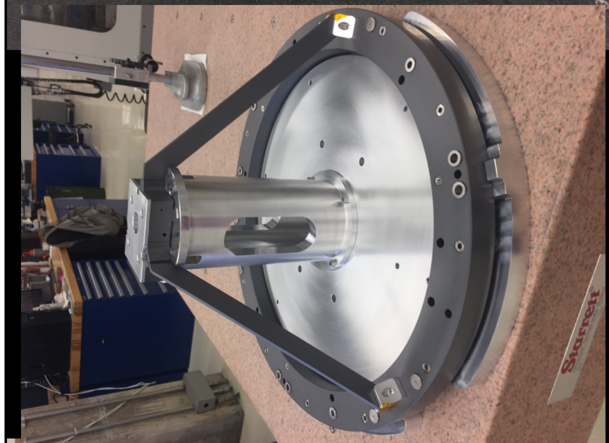
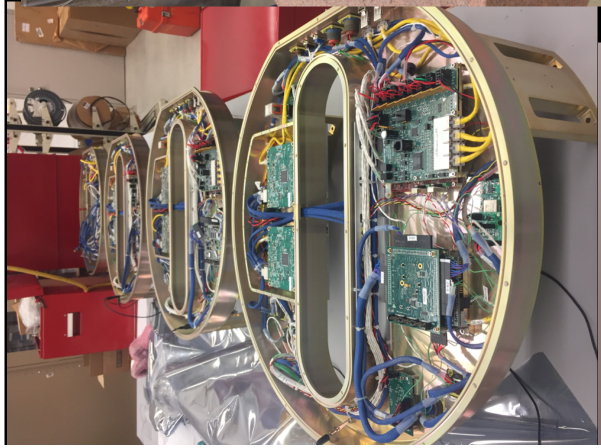
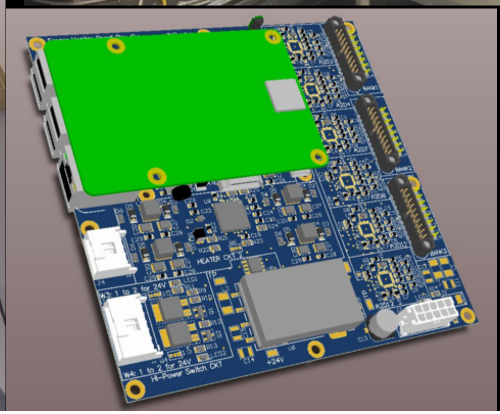
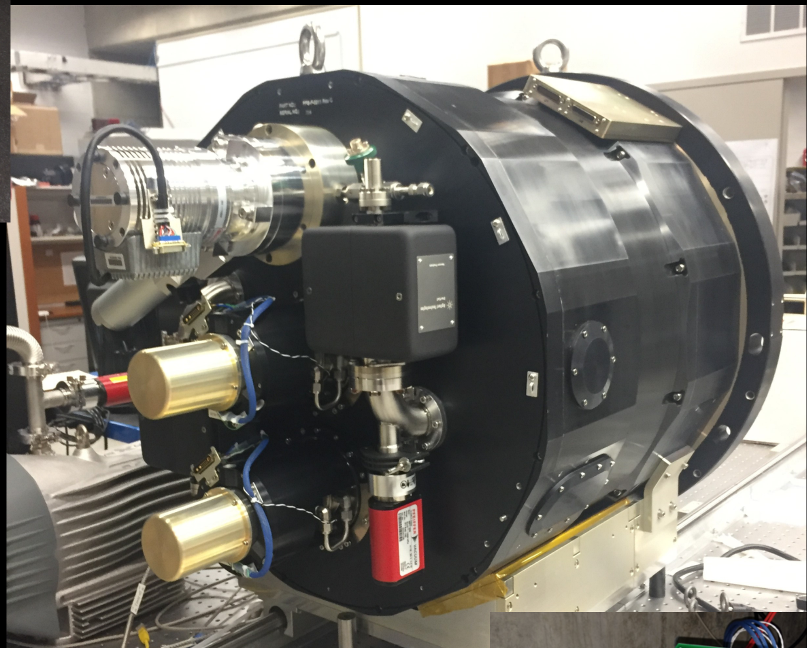


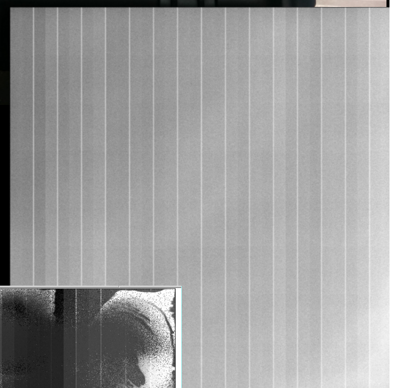



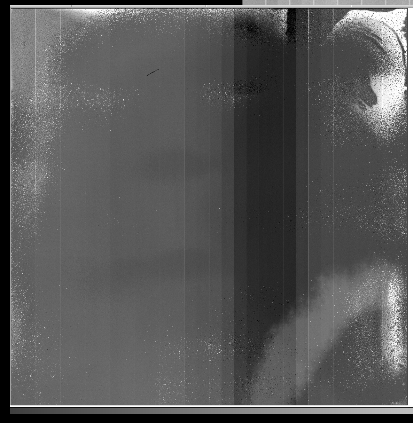


# NIR camera development

- 4x science-grade H4RG devices in hand. Characterization is ongoing.
- Parts production and integration are ongoing.

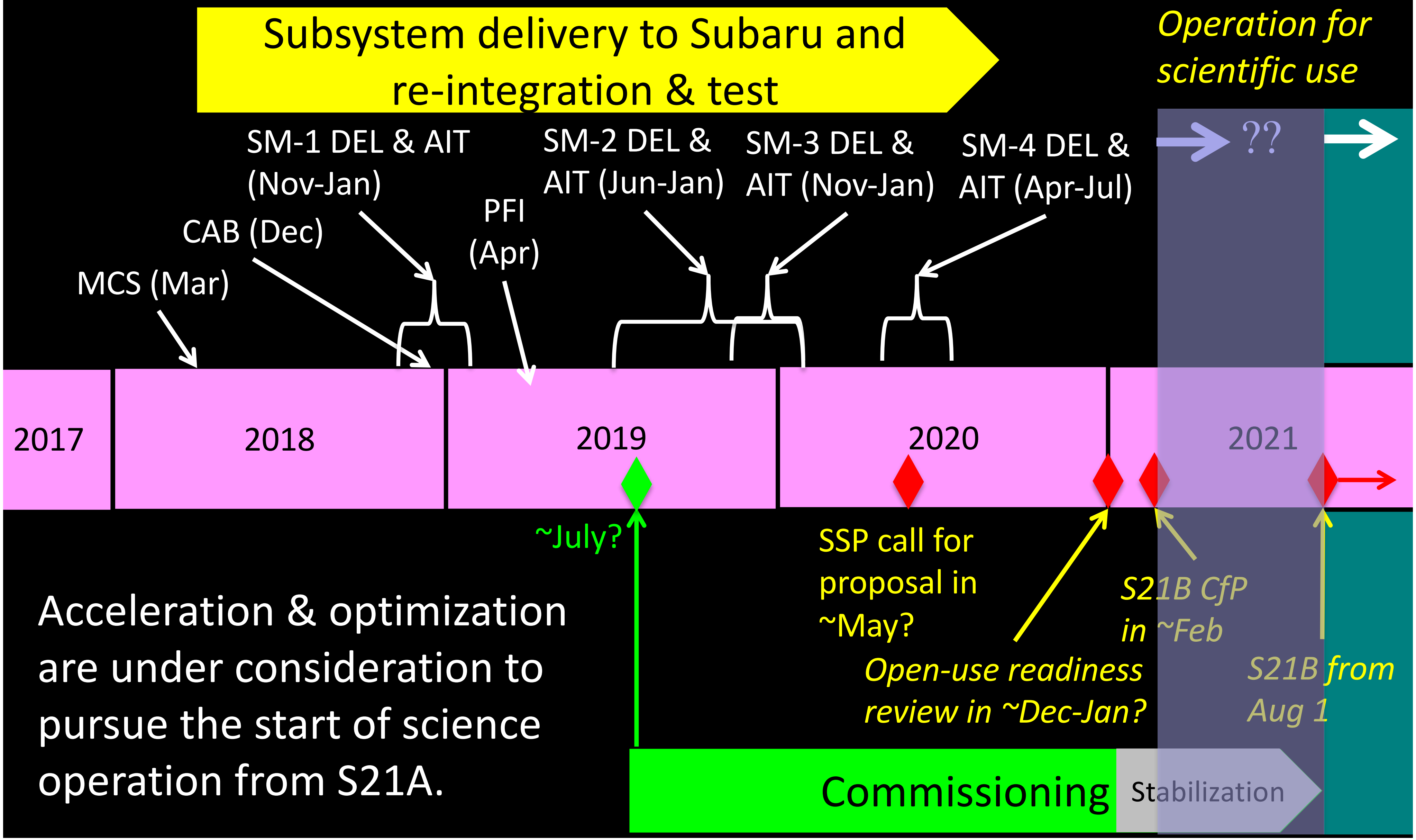




# Updated top-level schedule

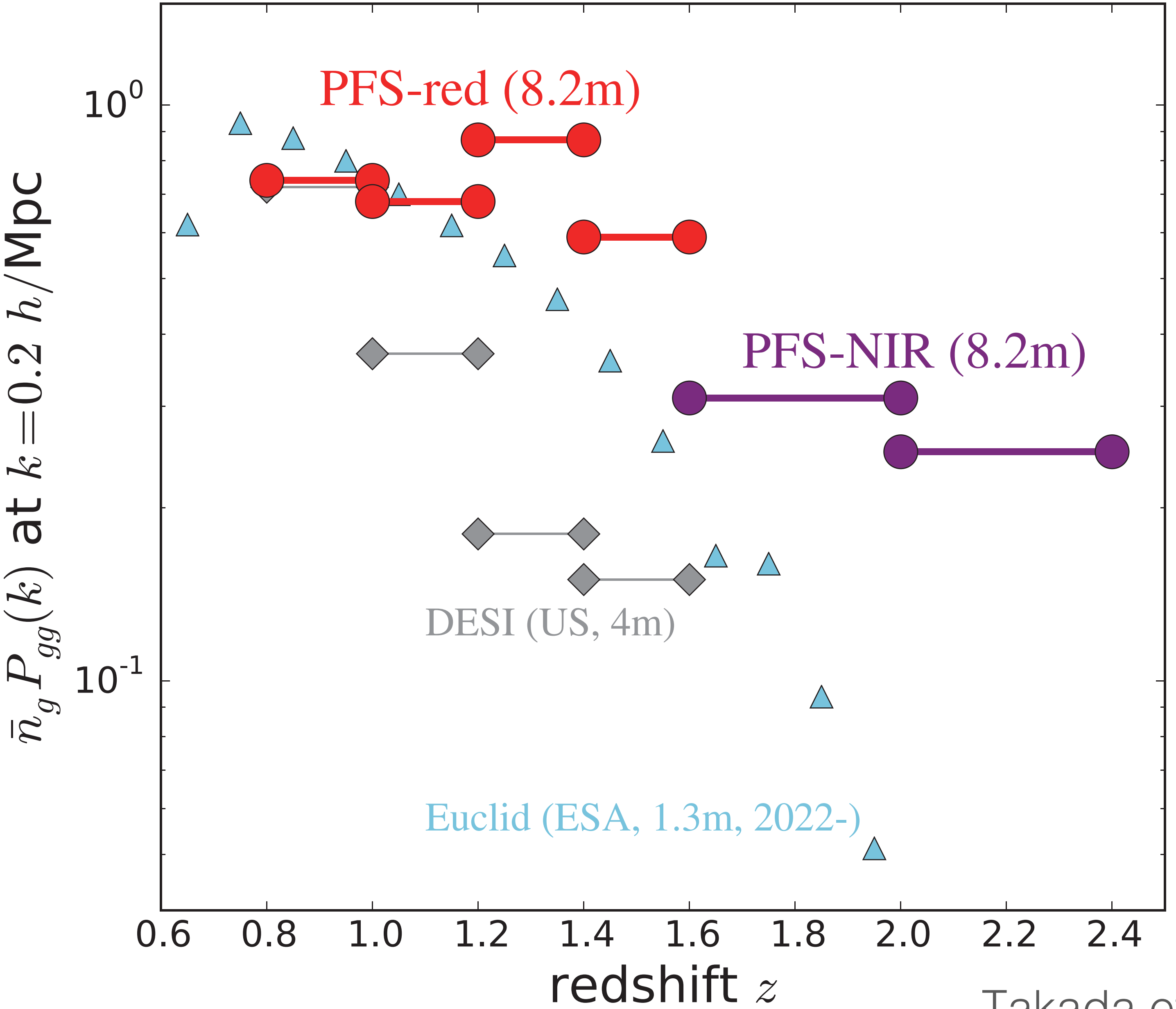
**The version TODAY.**
**Still somewhat fluid.**

"SM-N": Nth Spectrograph Module
"MCS": Metrology Camera System
"PFI": Prime Focus Instrument
"CAB": Fiber Cable on Telescope

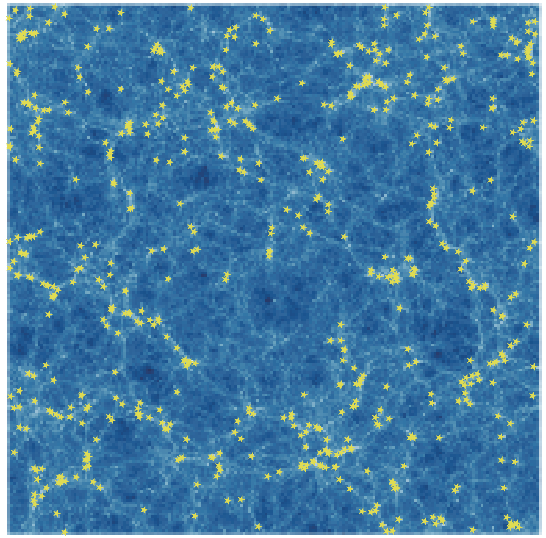


# Power of Subaru PFS

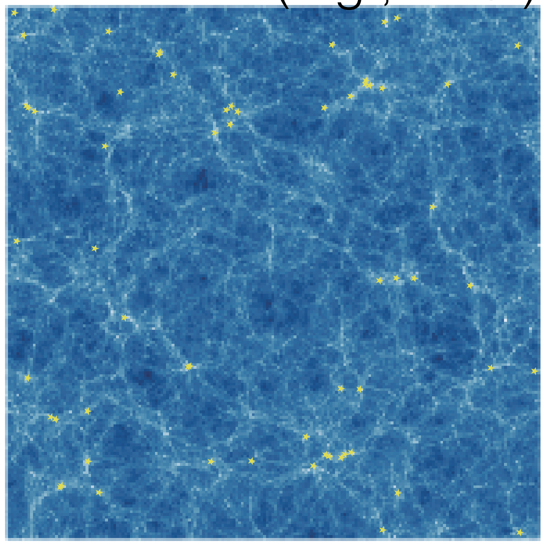
Best datasets at z>1… before WFIRST (NASA: 2025-)




PFS (8.2m) for z~1.5 slice



4m-class tel.(e.g., DESI)



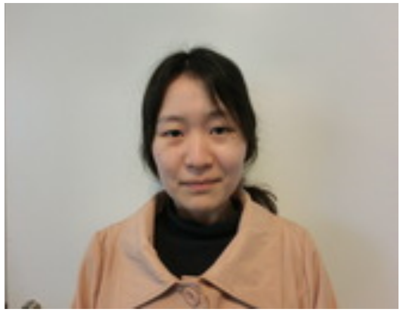
Takada et al. 14

Imaging + Spectroscopy (1.5M gals for 2.5m SDSS)

Distant (faint) universe = The universe in *the past*

*Subaru can probe the Universe at z~1!*

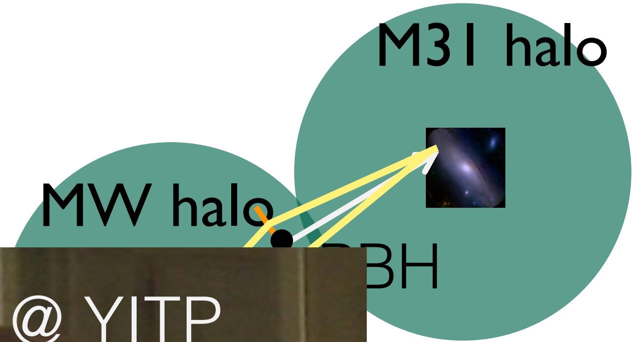
achievement report

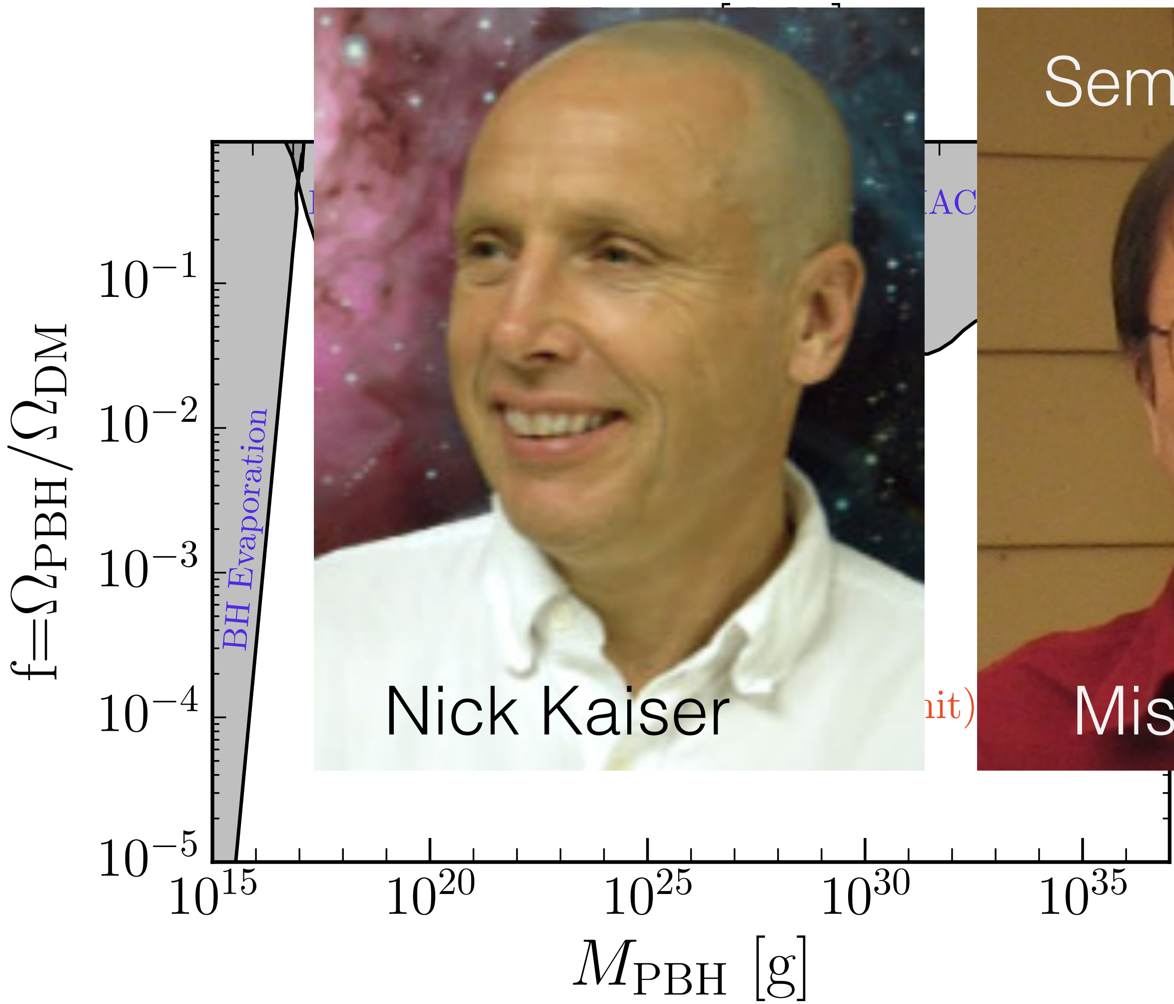


H. Niikura

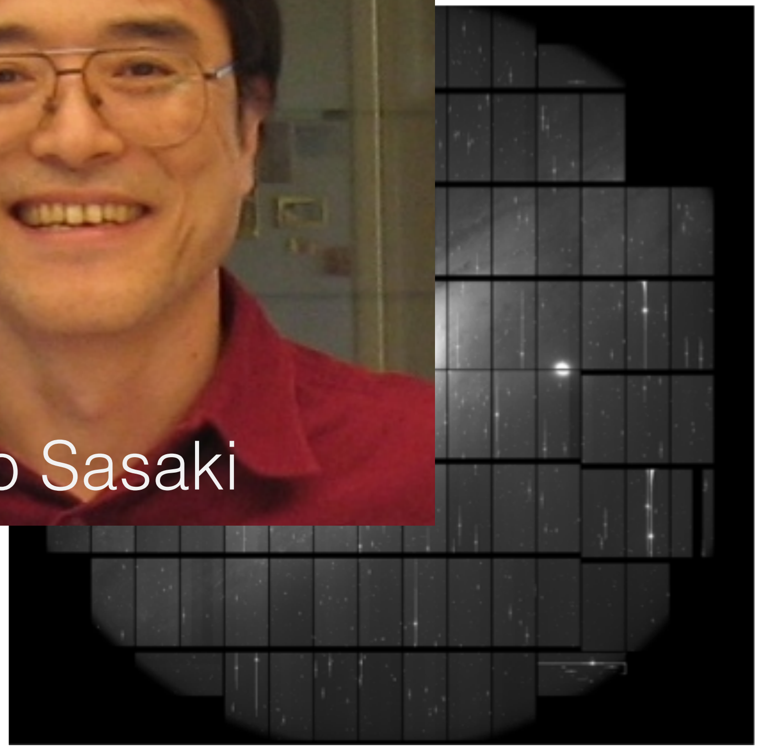
# Constraints on PBH with HSC

Our paper (Niikura, MT, Yasuda +) was about to be accepted bny Nature Astronomy



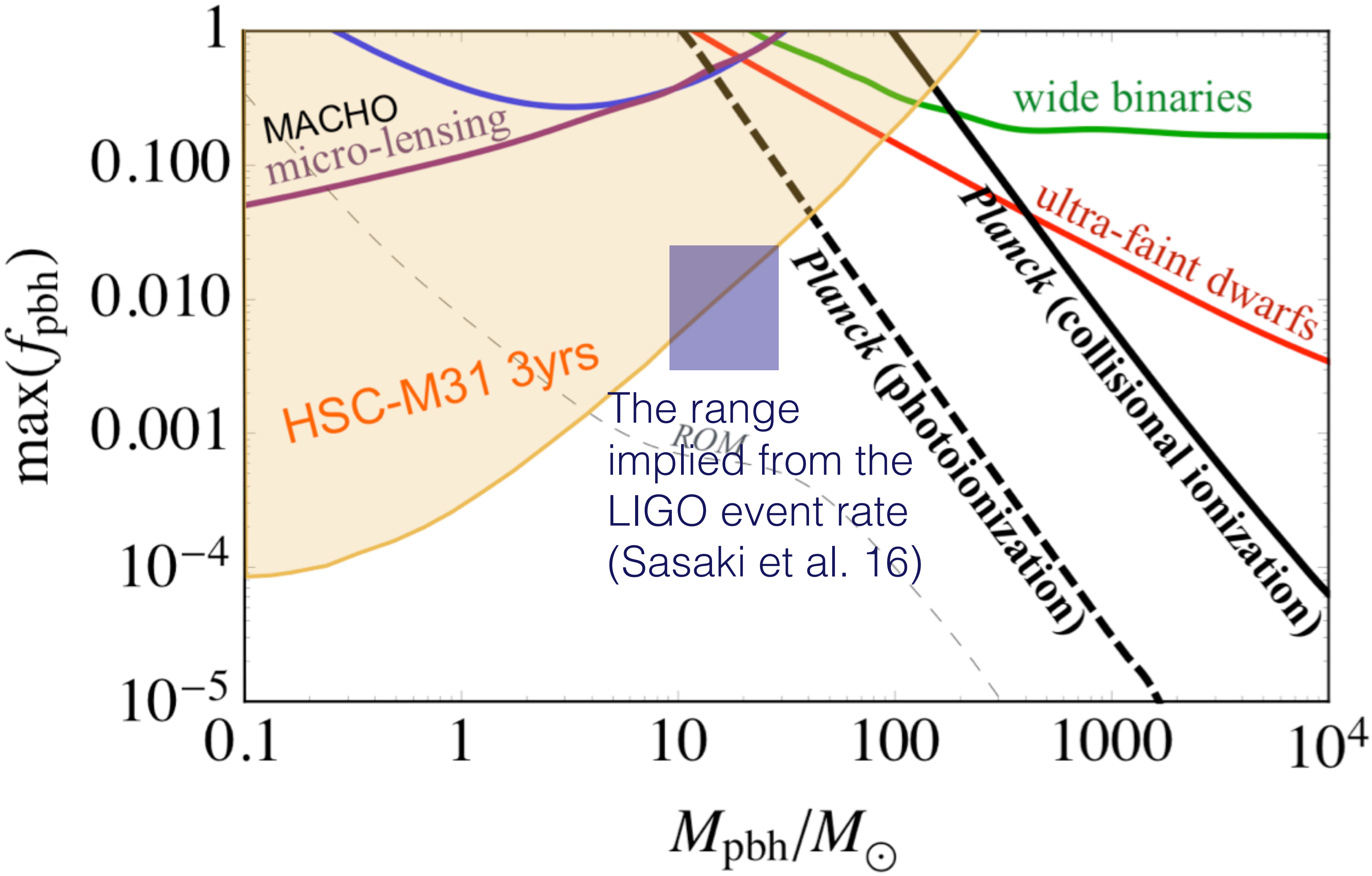





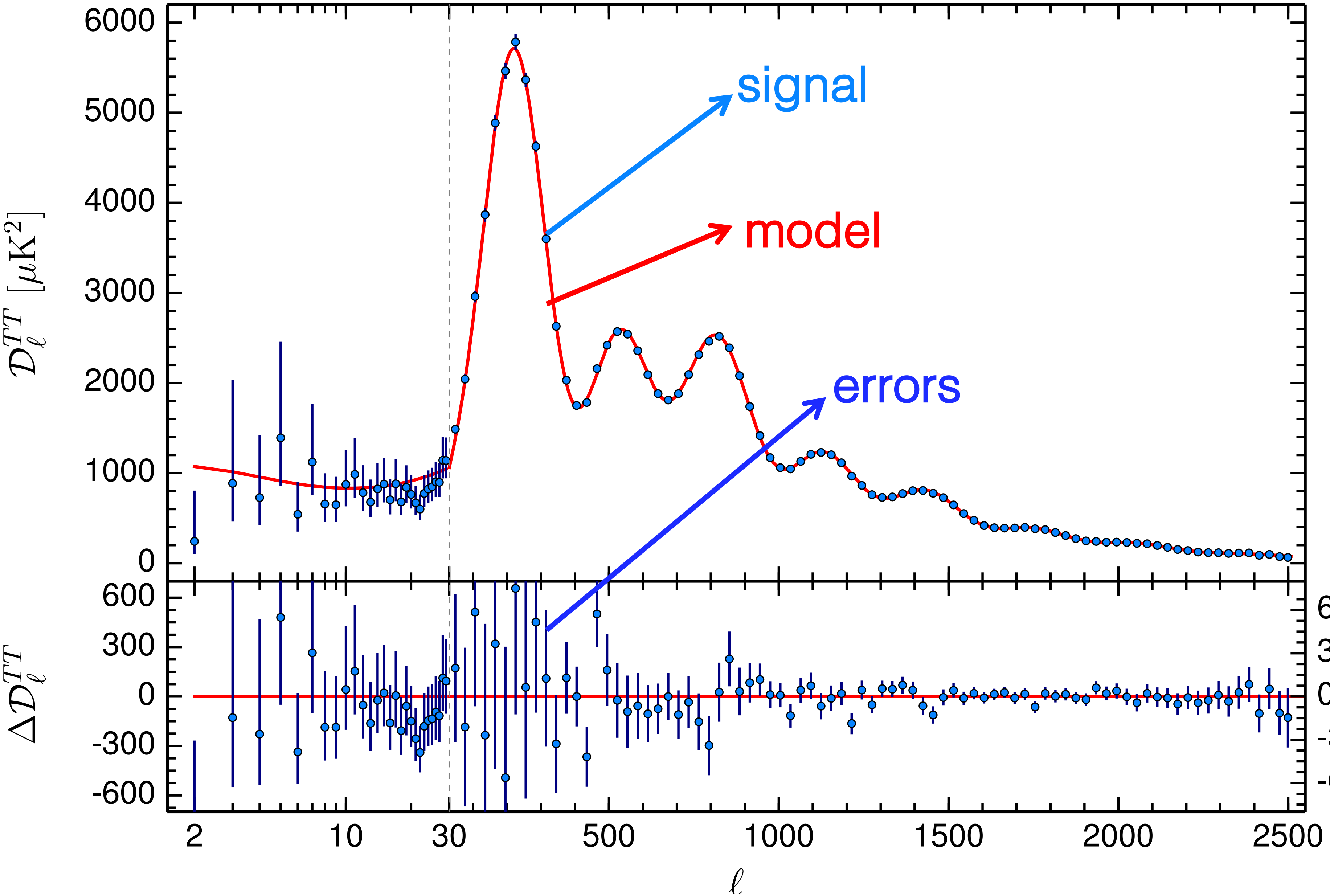


# Prospect for further HSC observation

only one or a few Subaru nights in total, sparsely sampled over 3yrs



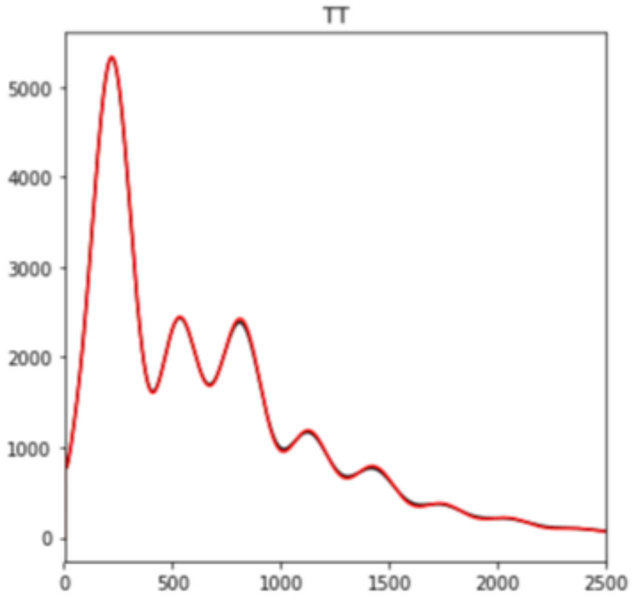
# signal, model, errors

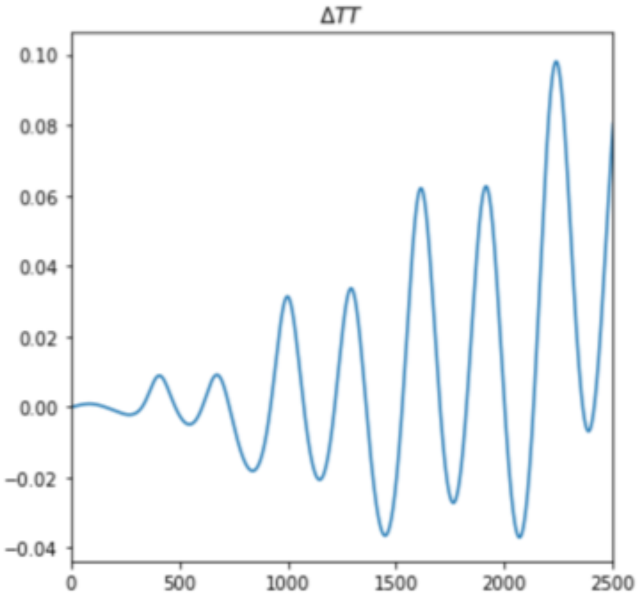


# signal, model, errors…

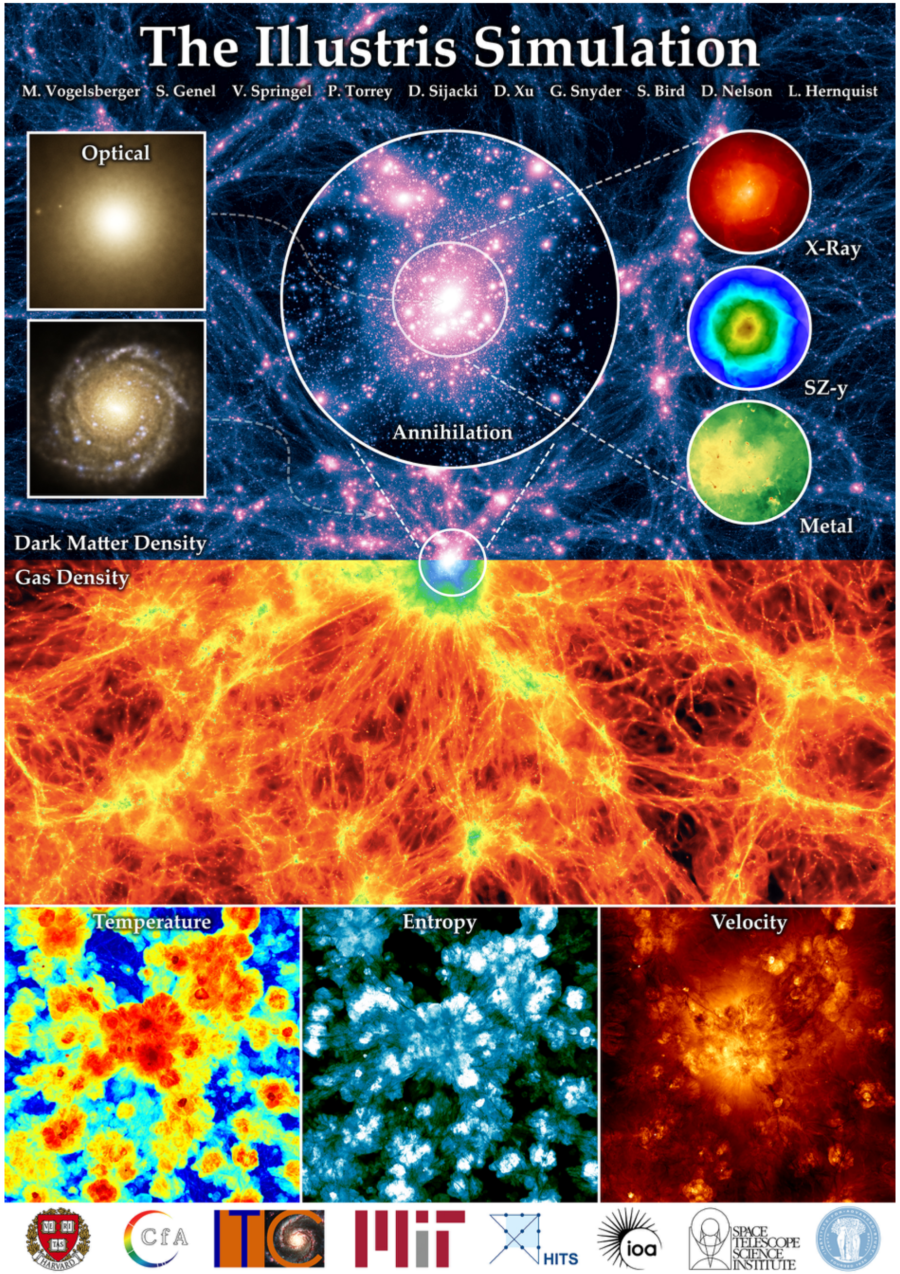
In [5]:
```
#plot the total lensed CMB power spectra versus unlensed, and fractional difference
totCL=powers['total']
unlensedCL=powers['unlensed_scalar']
print(totCL.shape)
#Python CL arrays are all zero based (starting at L=0), Note L=0,1 entries will be zero by default.
#The different CL are always in the order TT, EE, BB, TE (with BB=0 for unlensed scalar results).
ls = np.arange(totCL.shape[0])
fig, ax = plt.subplots(2,2, figsize = (12,12))
ax[0,0].plot(ls,totCL[:,0], color='k')
ax[0,0].plot(ls,unlensedCL[:,0], color='r')
ax[0,0].set_title('TT')
ax[0,1].plot(ls[2:], 1-unlensedCL[2:,0]/totCL[2:,0]);
ax[0,1].set_title(r'$\Delta TT$')
ax[1,0].plot(ls,totCL[:,1], color='k')
ax[1,0].plot(ls,unlensedCL[:,1], color='r')
ax[1,0].set_title(r'$EE$')
ax[1,1].plot(ls,totCL[:,3], color='k')
ax[1,1].plot(ls,unlensedCL[:,3], color='r')
ax[1,1].set_title(r'$TE$');
for ax in ax.reshape(-1): ax.set_xlim([2,2500]);
```

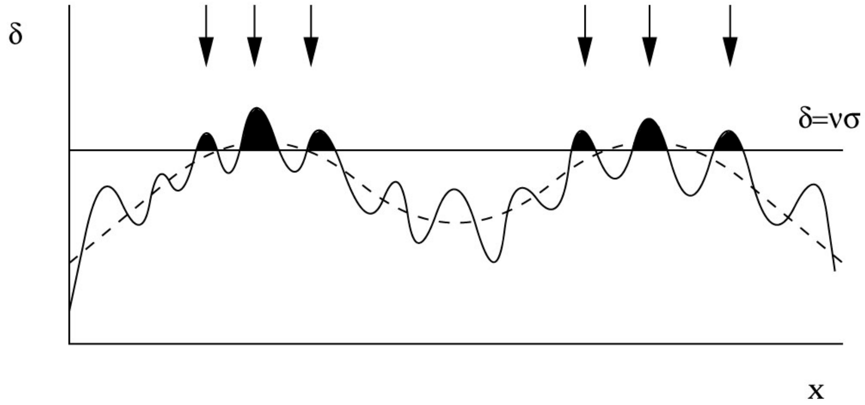
```
(2551L, 4L)
```



# Nonlinear, nonlinear, nonlinear…

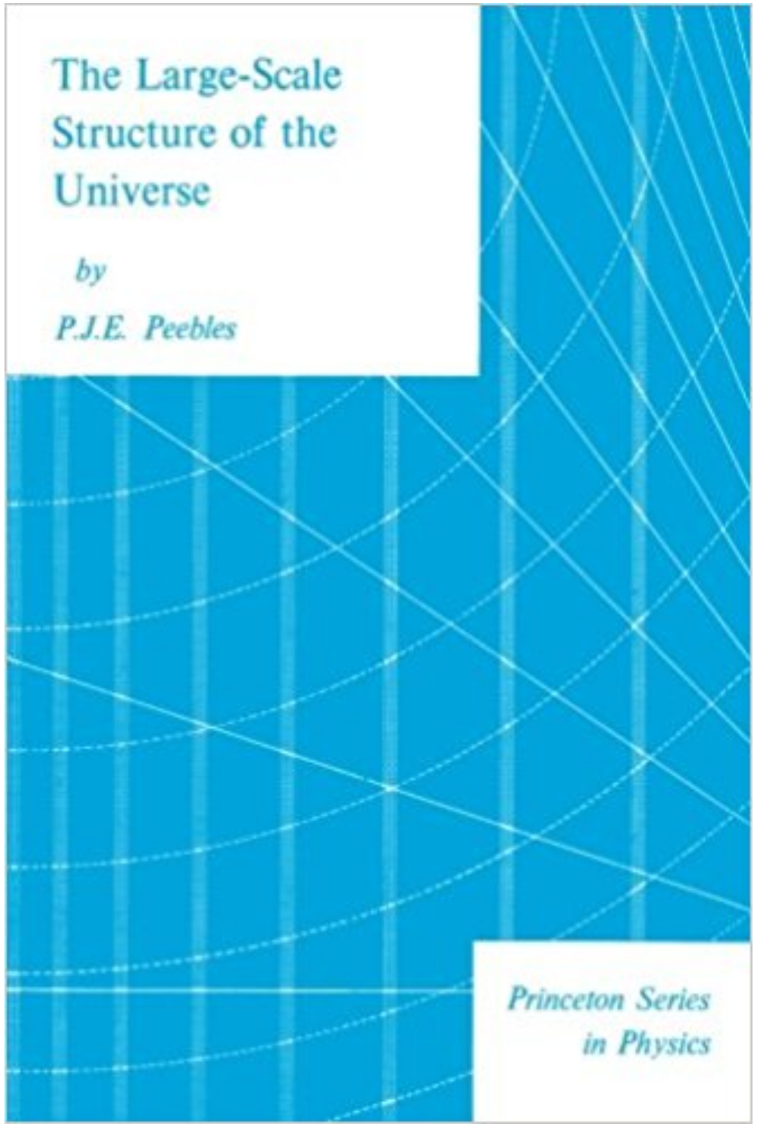



- Cosmology with galaxy surveys is more complicated than CMB (LHC ⇔ electron/positron colliders)
- Complications: Galaxy bias, nonlinear clustering, baryon …
- However, we should keep in mind which observables are clean or dirty; we have conservations (mass and momentum)
- E.g., halo bias is little affected by baryonic physics

# Equivalence principles of gravity

Peebles 1980: The Large-Scale Structure of the Universe




- Section 28
- Mass and momentum conservation
- The correction to power spectrum arising from any (uncontrolled) small-nonlinear physics starts with $P_{error}(k) \sim k^4$

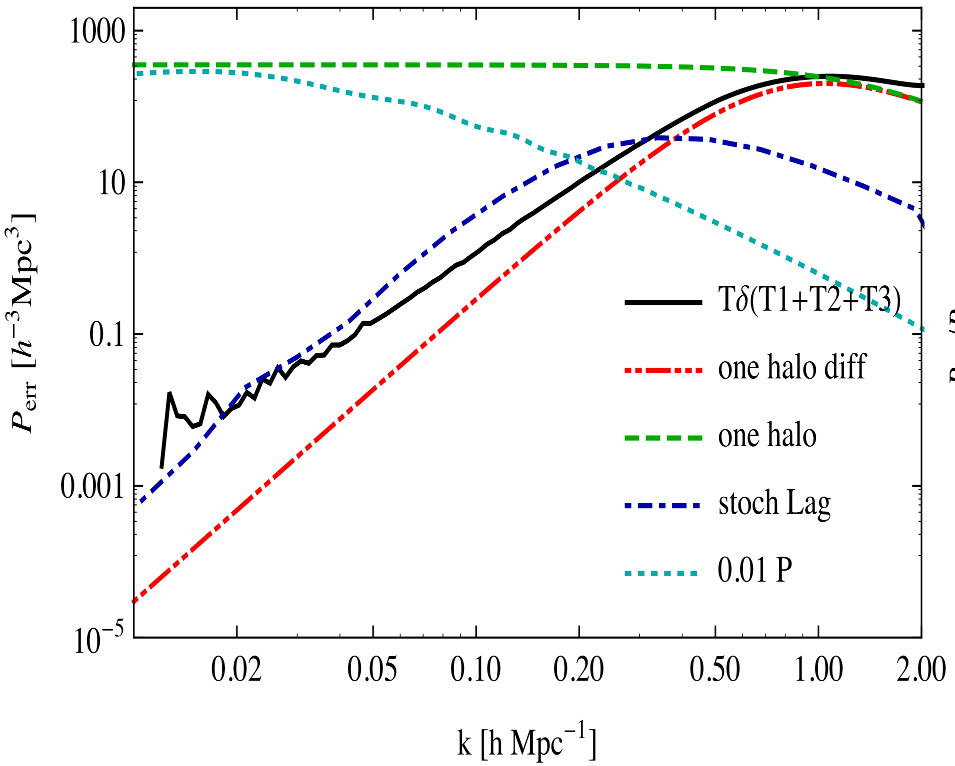
# Cosmological principles

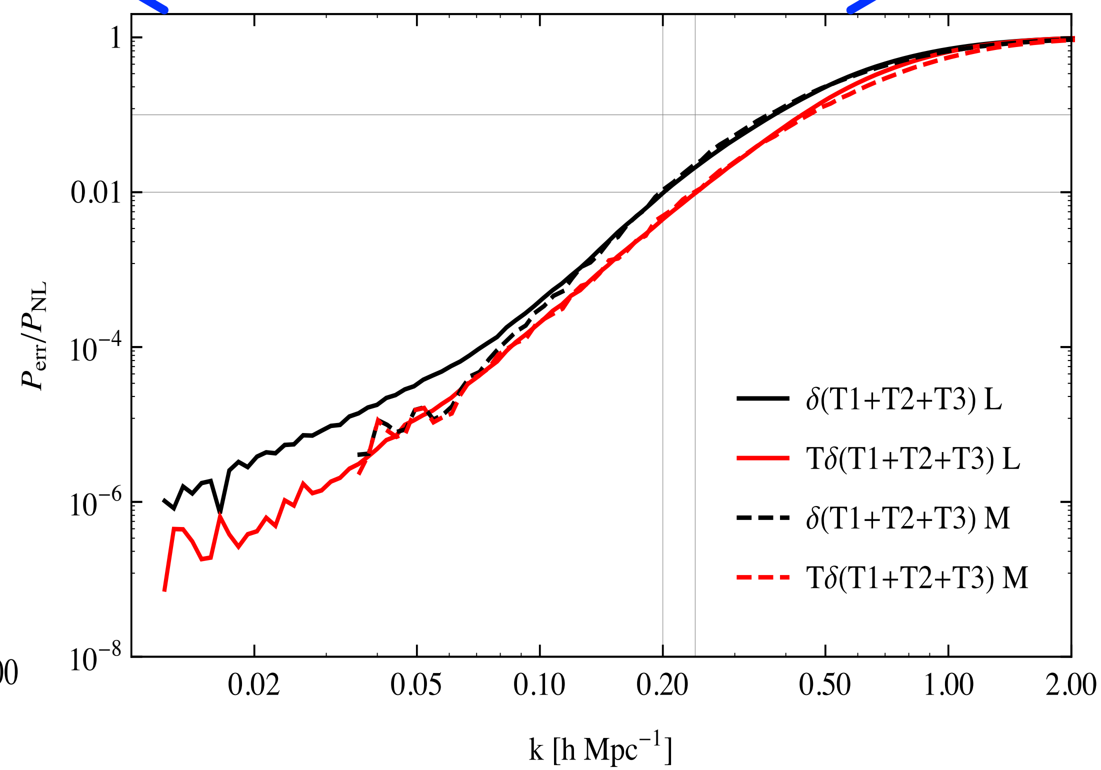
$$P_{\rm m}^{\rm NL}(k;t) = \underline{P_{\rm m}^{\rm well-modeled}(k;t)} + P_{\rm error}(k)$$

$$P_{\rm error}(k) \sim k^4$$

N-body simulations or PT

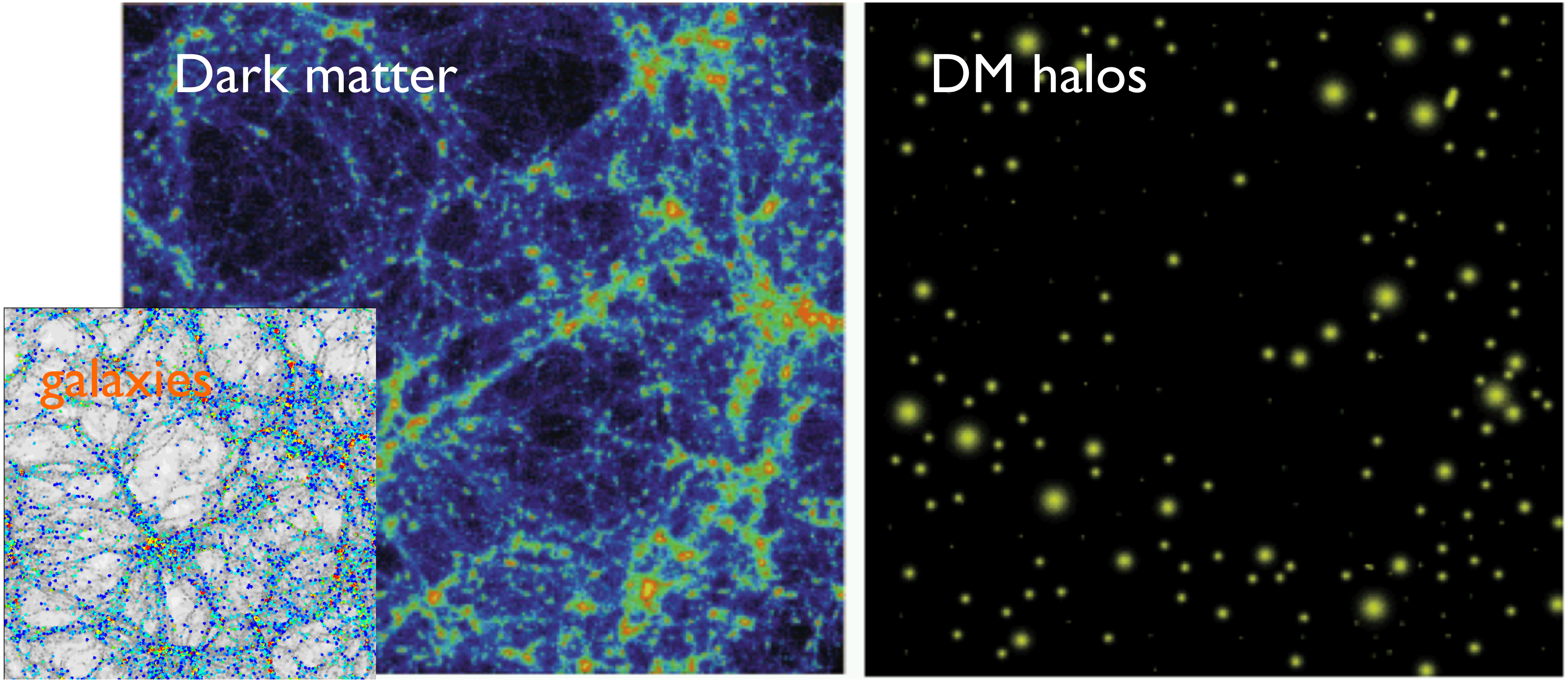
Clean information (inflation, primordial non-Gaussianity, axion, neutrino mass, …)




Baldauf, Schaan, Zaldarriaga 15

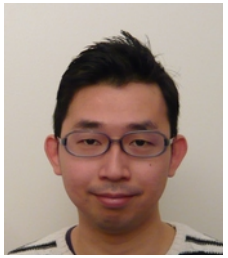
# Our approach: Cosmology with halos (not with galaxies)




- *Assumption*: Galaxies should be formed in dark matter halos (places of dark matter concentration)

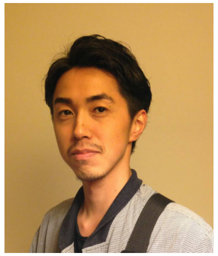
# Halo Emulator

Nishimichi et al. in prep.



**T. Nishimichi**

R. Takahashi

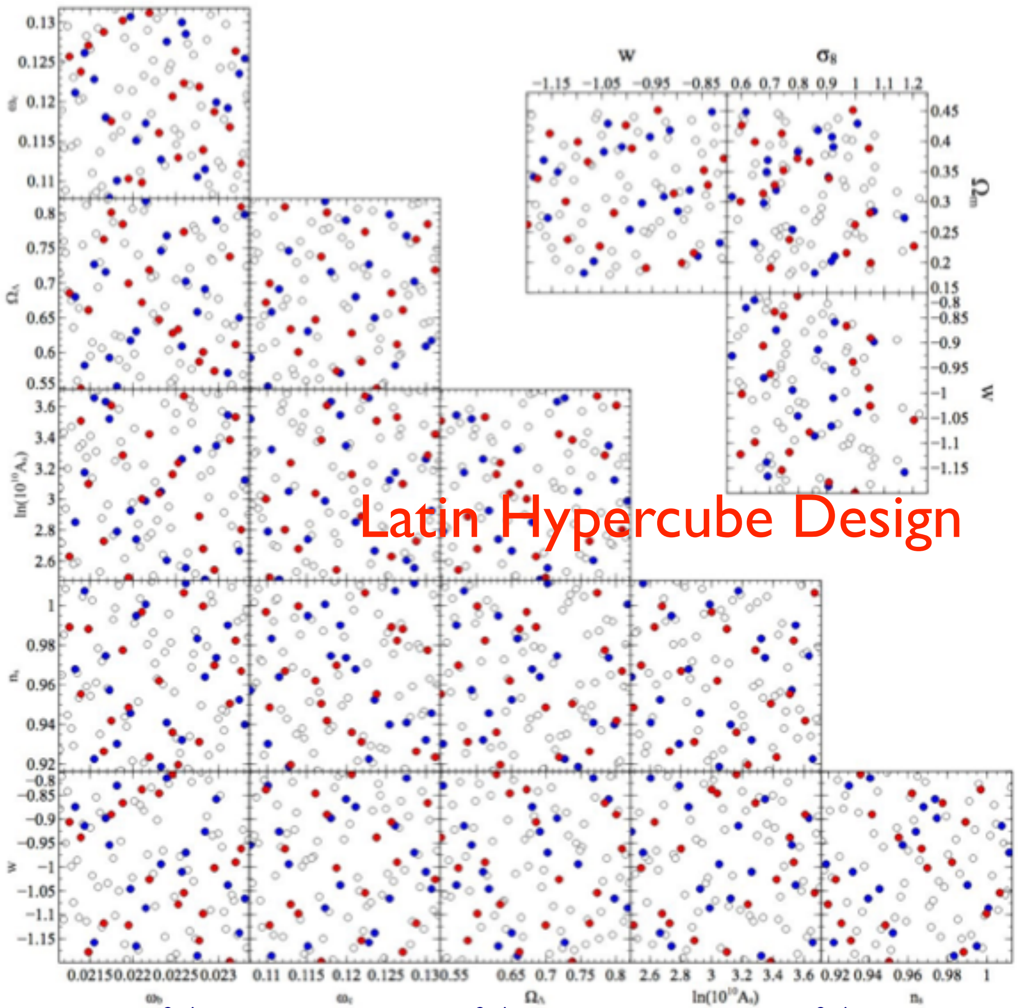


M. Shirasaki

K. Osato

T. Oogi

- 1Gpc/h or 2 Gpc/h, $N_{part}=2048^3$ for each realization
- 24 (20) realizations for Planck
- 60 realizations for different cosmologies
- 21 snapshots over 0<z<1.5 (stepped by growth rate)
- ~200Tb (so far)
- Post-processing (Rockstar)
  - Halos & subhalos
  - Halo center: the potential minimum
  - SO mass. Every member DM particle belongs to one halo (avoid double counting)




$\omega_b : \pm 5\%, \quad \omega_c : \pm 10\%, \quad \Omega_{\rm de} : \pm 20\%$

$\ln(10^{10} A_s) : \pm 20\%, \quad n_s : 5\%, \quad w_{\rm DE} : \pm 20\%$

jupyter tutorial Last Checkpoint: 06/29/2017 (autosaved)

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File Edit View Insert Cell Kernel Help

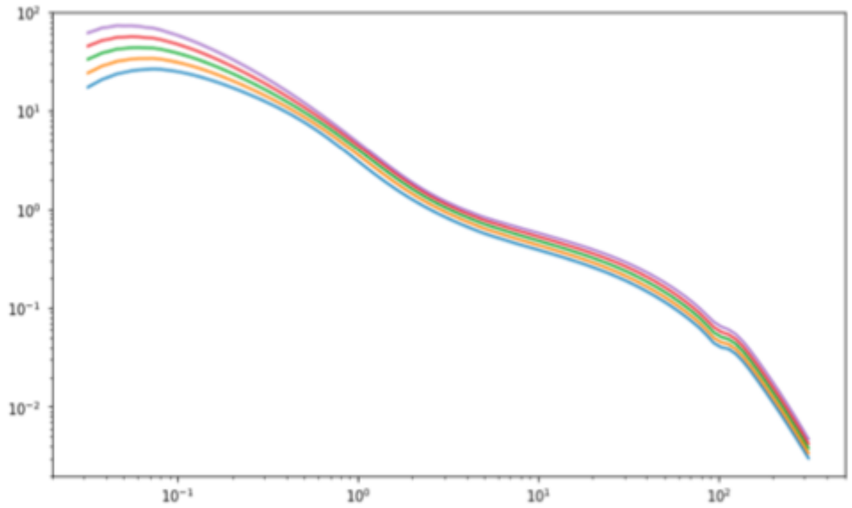
Not Trusted | Python 2

Code

### how to plot DeltaSigma(R) for a mass threshold halo sample

In [9]:
```
rs = np.logspace(-1.5,2.5,100)

plt.figure(figsize=(10,6))

Mmin = 3e12

for snap in [0,5,10,15,20]:
    emu.set_cosmology_predefined(0,snap)
    dsigma = emu.get_DeltaSigma_massthreshold(rs,Mmin)
    plt.loglog(rs,dsigma)
plt.ylim(0.002,100)
```

Out[9]: (0.002, 100)



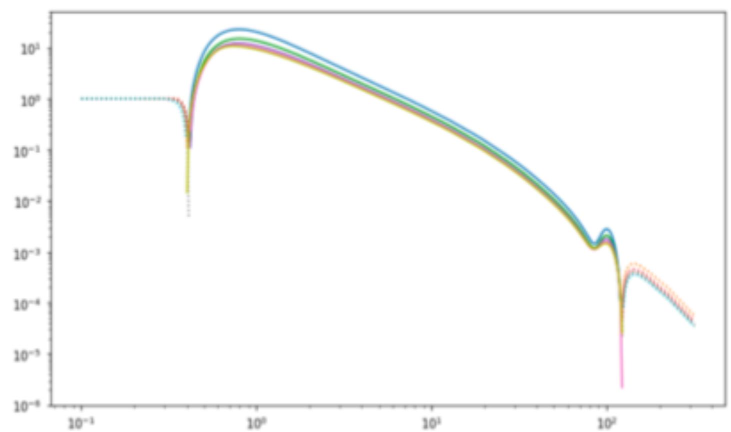

$$\xi_{\rm m}(r;z), \frac{{\rm d}n}{{\rm d}M}, \xi_{\rm hm}(r;z,M), \xi_{\rm hh}(r;z,M_1,M_2)$$

$$\Sigma(R;z,M), \Delta\Sigma(R;z,M), w_{\rm hh}(R;z,M_1,M_2), \cdots$$

as a function of cosmological model, redshift, mass, separation, ….

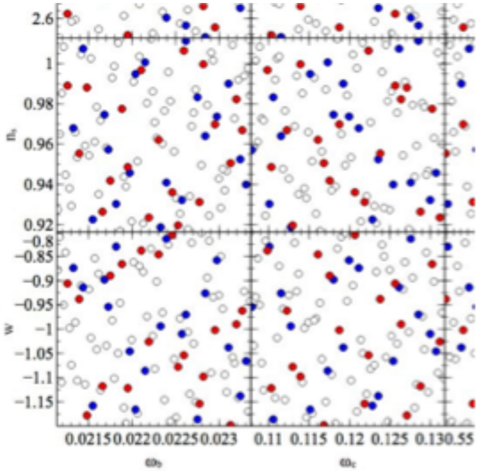
### how to plot halo-halo correlation for a mass threshold halo sample

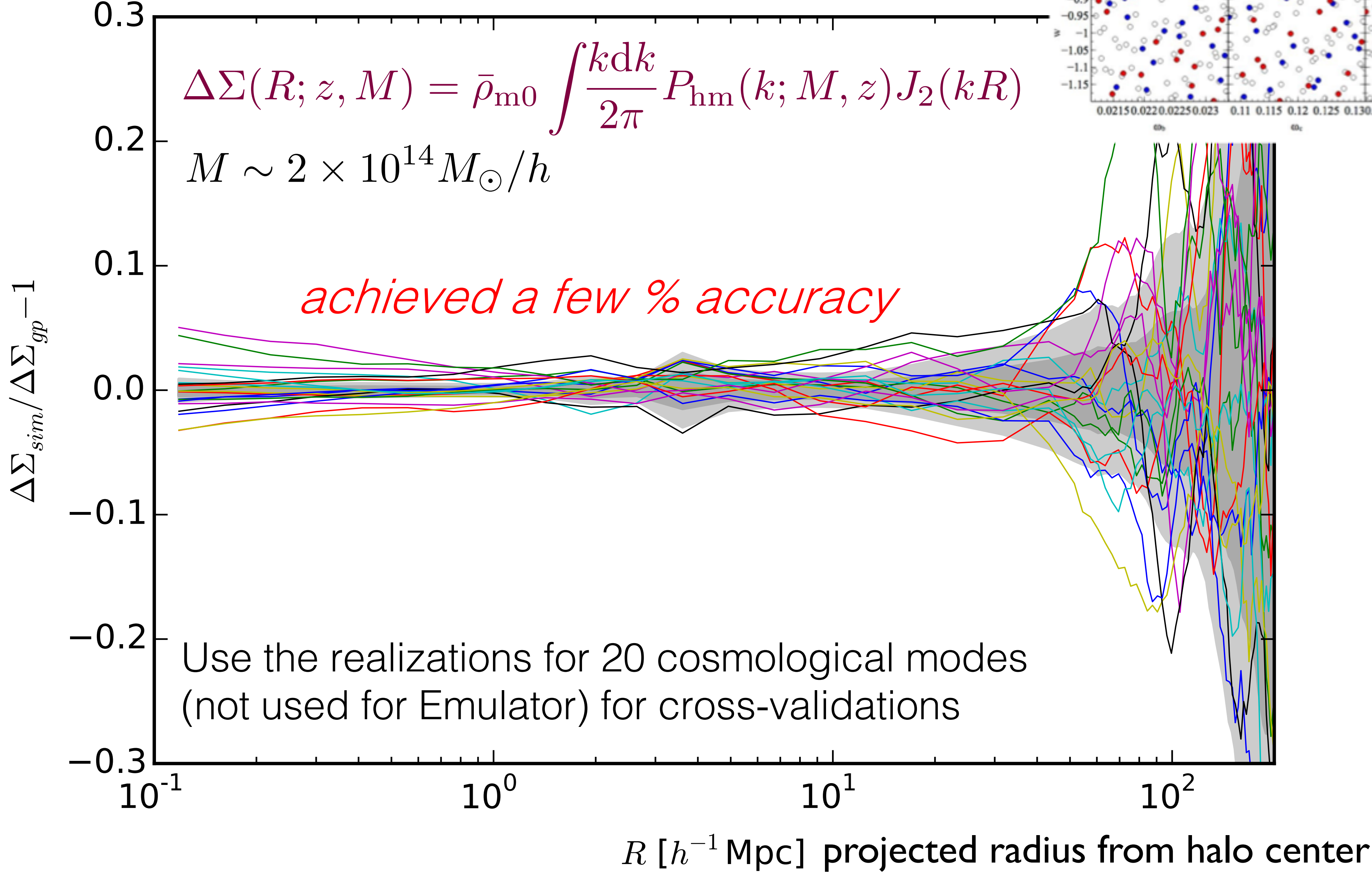
In [11]:
```
rs = np.logspace(-1,2.5,400)

Mmin = 3e12

plt.figure(figsize=(10,6))

for snap in [0,5,10,15,20]:
    emu.set_cosmology_predefined(0,snap)
    xih = emu.get_xiauto_massthreshold(rs,Mmin)
    plt.loglog(rs,xih)
    plt.loglog(rs,-xih,':')
```




Developing the python package for Halo Emulator

# Stacked lensing profile for cluster-scale halos





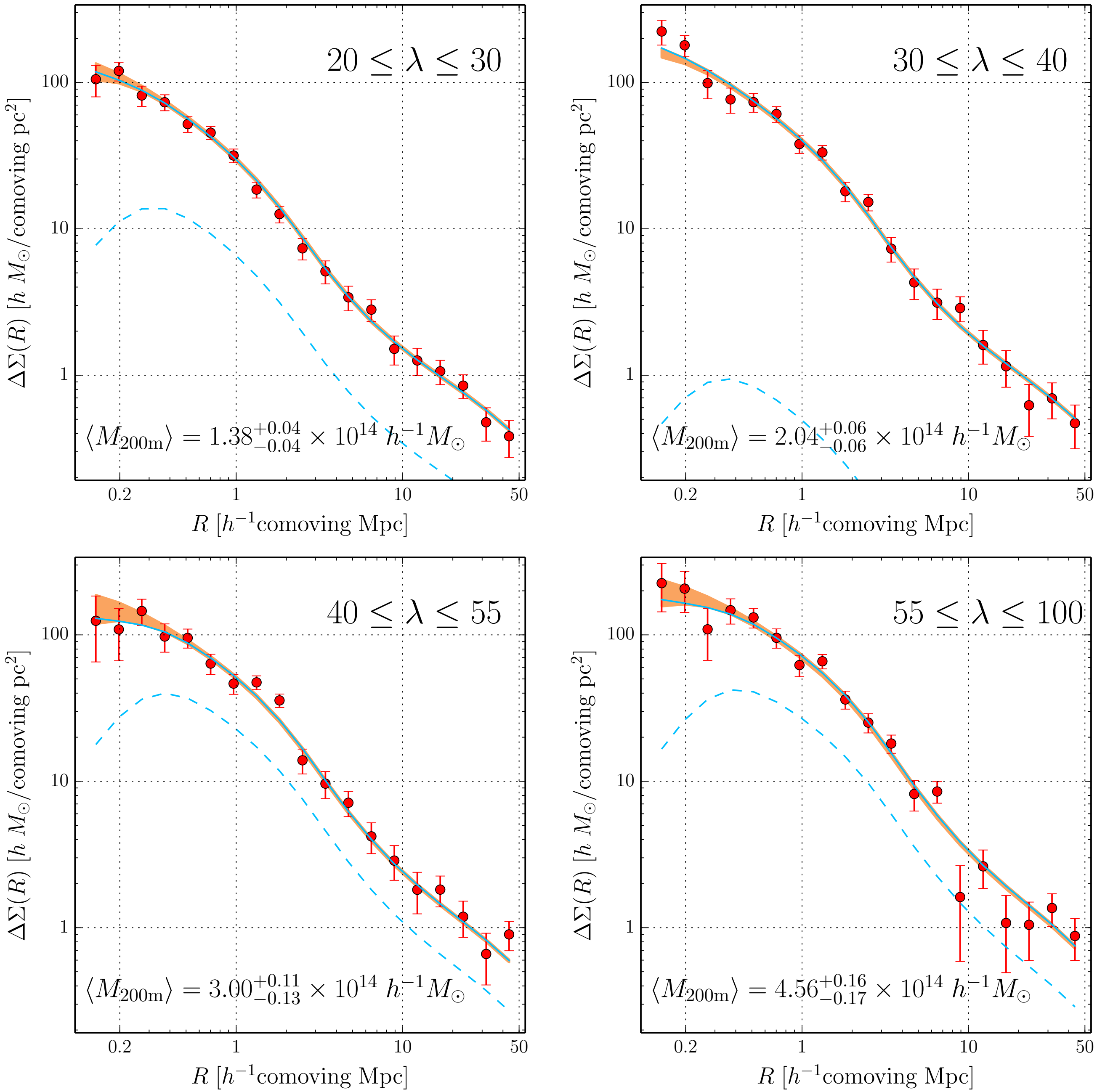
# From halo summary statistics to observables

- As long as statistical isotropy holds, any cosmological observables can be given by halo summary statistics rather than running N-body simulations…
- For example, galaxy-galaxy lensing or cluster lensing can be given by superposition of the average mass profiles of halos:

$$\begin{aligned}\Delta\Sigma(R) &= \frac{1}{N_{\rm g}}\sum_{M_{\rm h}} w(R;M_{\rm h})\Delta\Sigma(R;M_{\rm h}) + U_{\rm 1h}(R)\\ &= \frac{1}{N_{\rm g}}\int {\rm d}M_{\rm h}\underline{\frac{{\rm d}n}{{\rm d}M_{\rm h}}}S(M_{\rm h})\underline{\Delta\Sigma(R;M_{\rm h})} + U_{\rm 1h}(R)\end{aligned}$$

From Emulator

# Murata, Nishimichi, MT et al, ApJ in press




Ryoma Murata

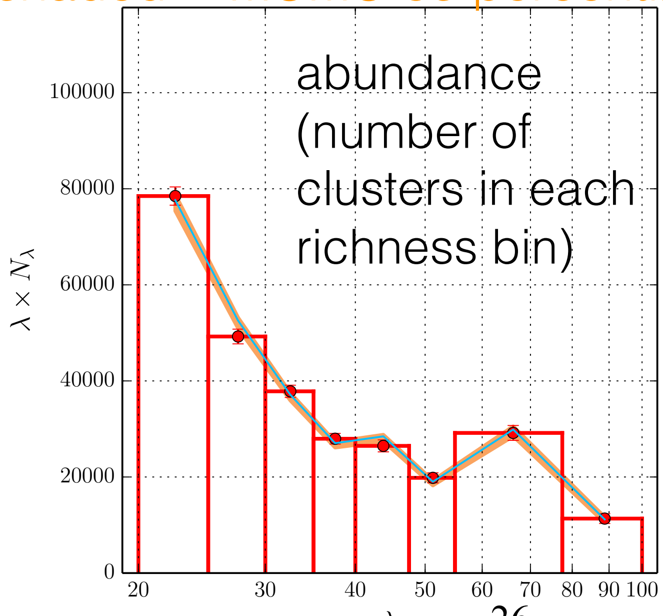
$\chi^2_{\rm min}/{\rm dof} = 79.5/75$

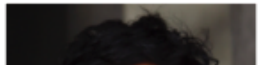
**Planck cosmology**

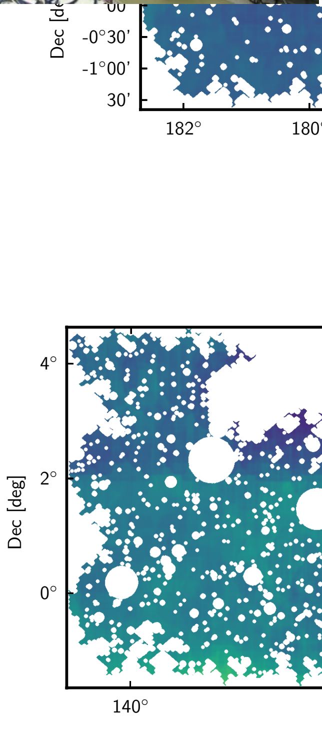
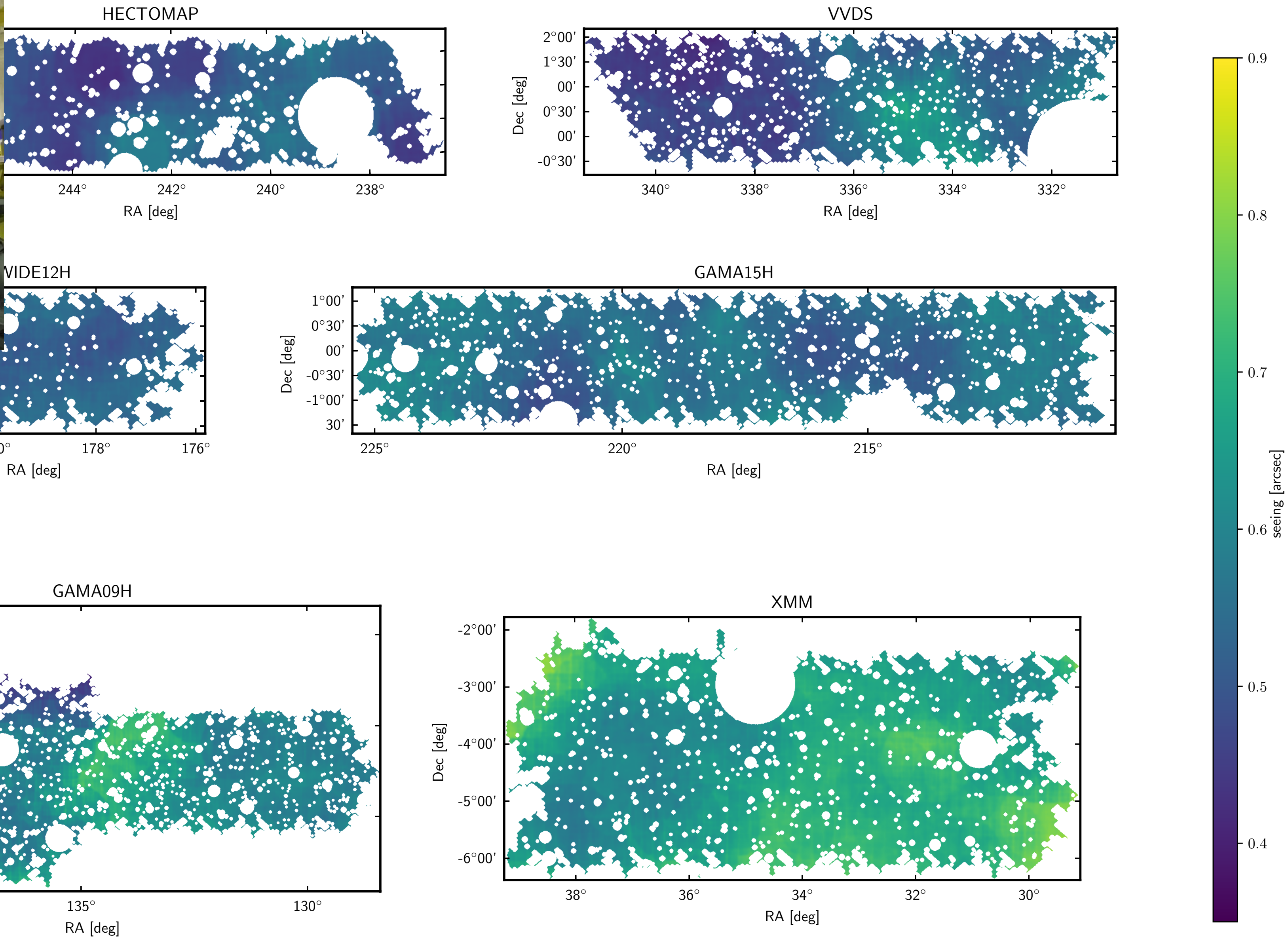
$\langle M_{200{\rm m},\ 20\leq\lambda\leq100} \rangle = 1.91^{+0.05}_{-0.05} \times 10^{14}\ h^{-1} M_\odot$

8,312 clusters
39M galaxy shapes

shaded = MCMC 68 percentile



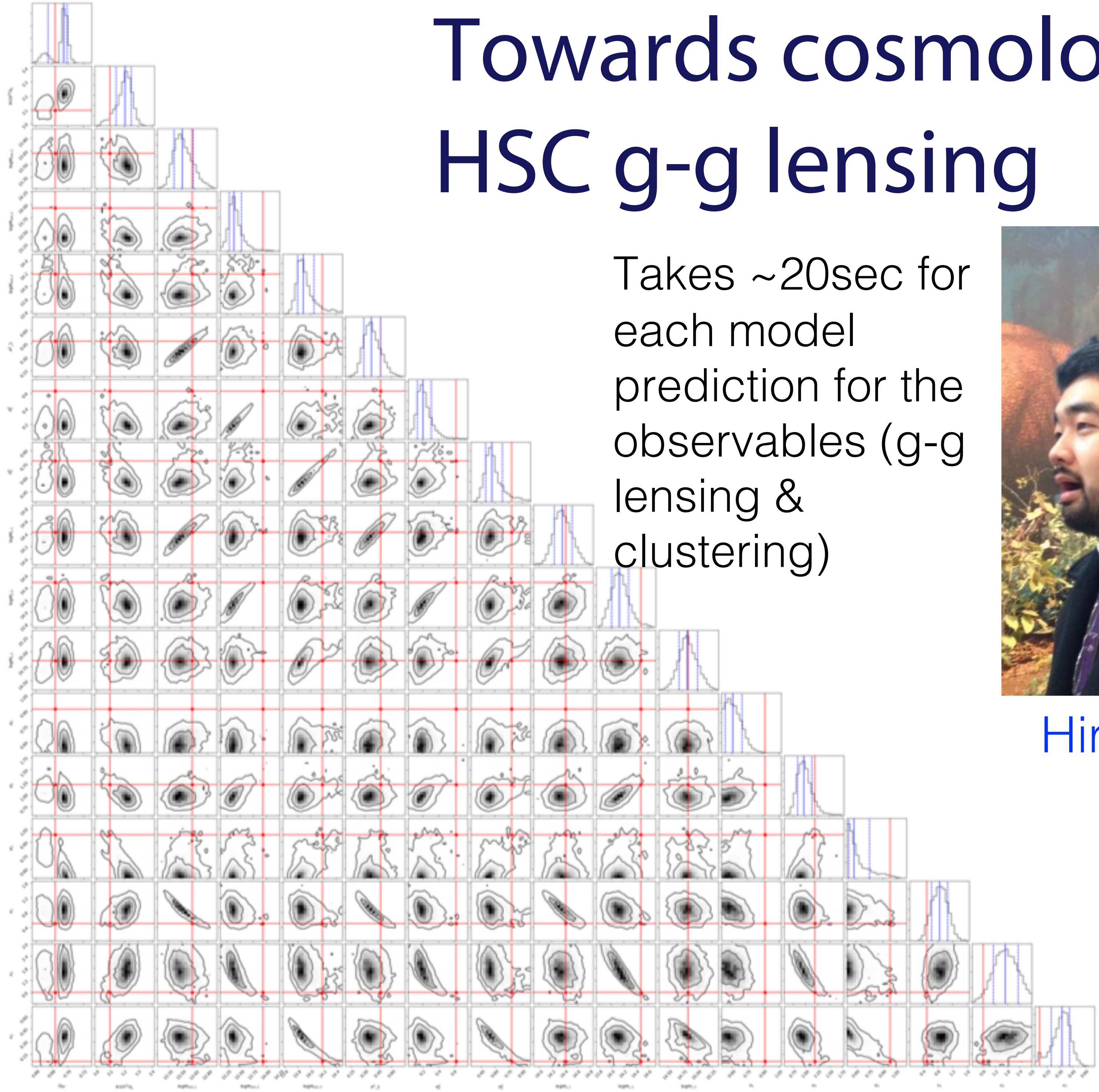



Radius from the lensing galaxy $R$ ($h^{-1}$ Mpc)

linear regime)

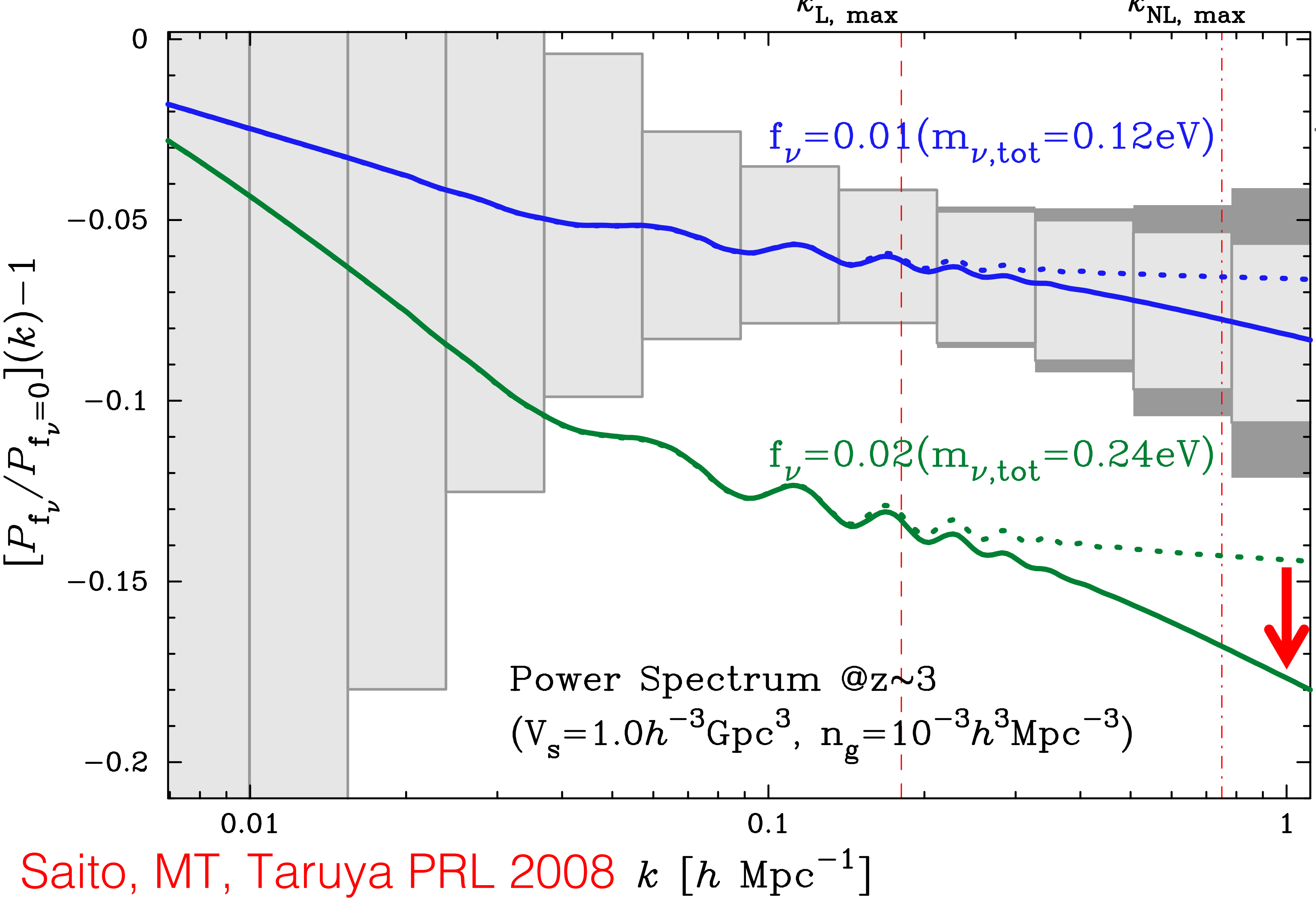
# Towards cosmology with HSC g-g lensing



Takes ~20sec for each model prediction for the observables (g-g lensing & clustering)

Hironao Miyatake
(Nagoya)

# Boosted cosmological sensitivity in



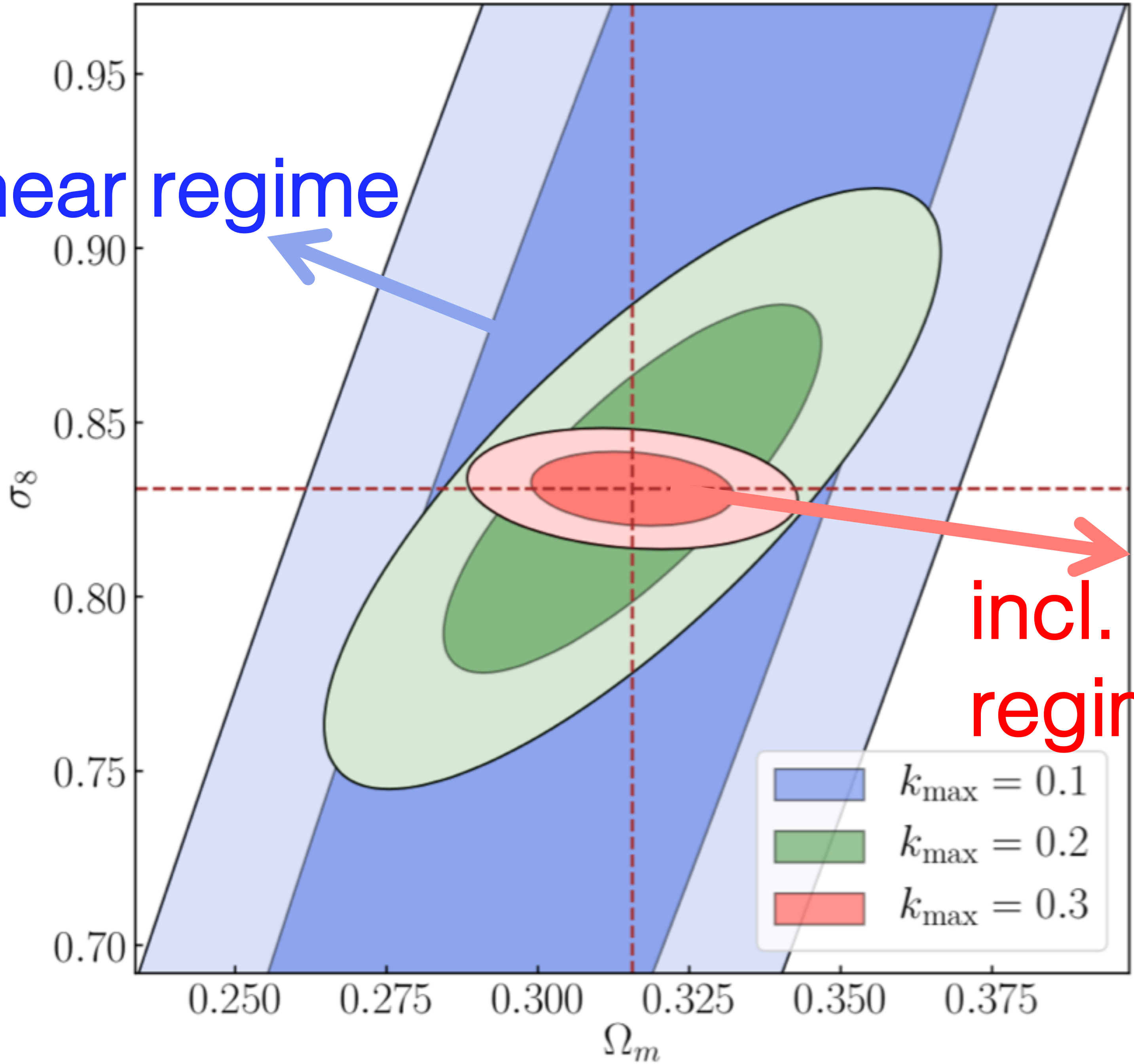

a

$+ \cdots$

Saito, MT, Taruya PRL 2008

Kobayashi, Nishimichi, MT + in prep.

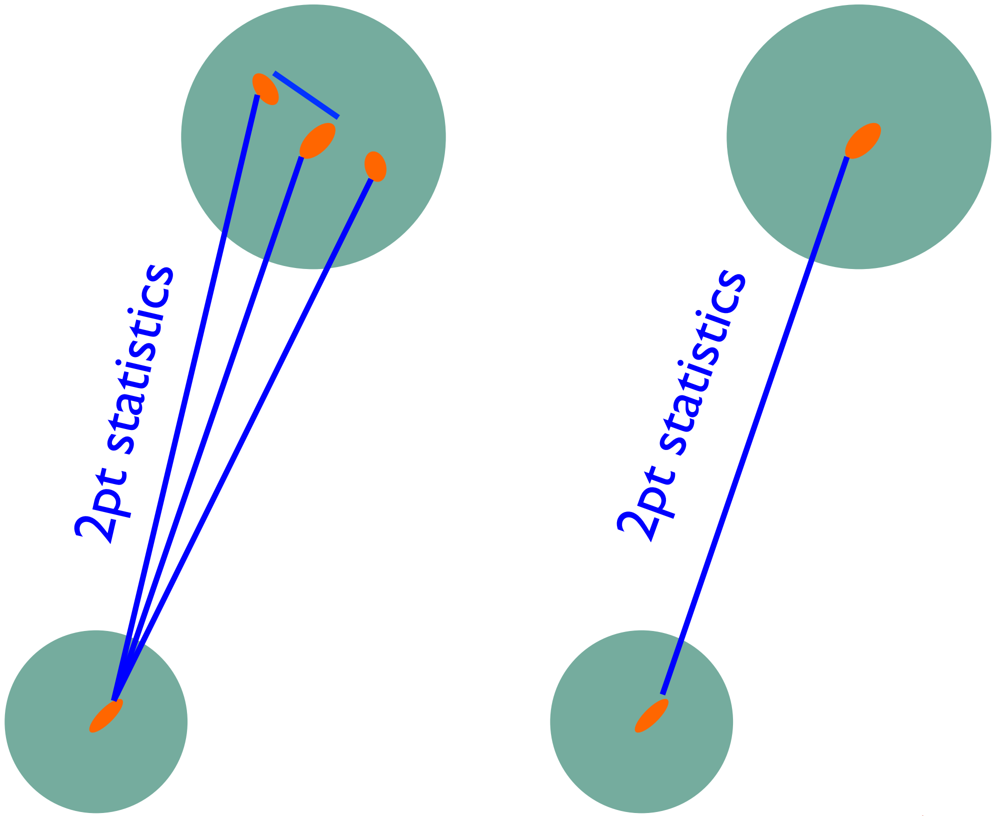
.inear regime




incl. nonlinear regime info.

Yosuke Kobayashi

# Satellite galaxies useful for cosmology?




- 2pt correlation of galaxies
- If we have satellite galaxies in the sample, …
  - More massive halos counted multiple times (more massive halos are more “biased” tracers)
  - 1-halo term at small scales (more affected by baryon)
  - Need to know how to populate galaxies in halos: HOD…

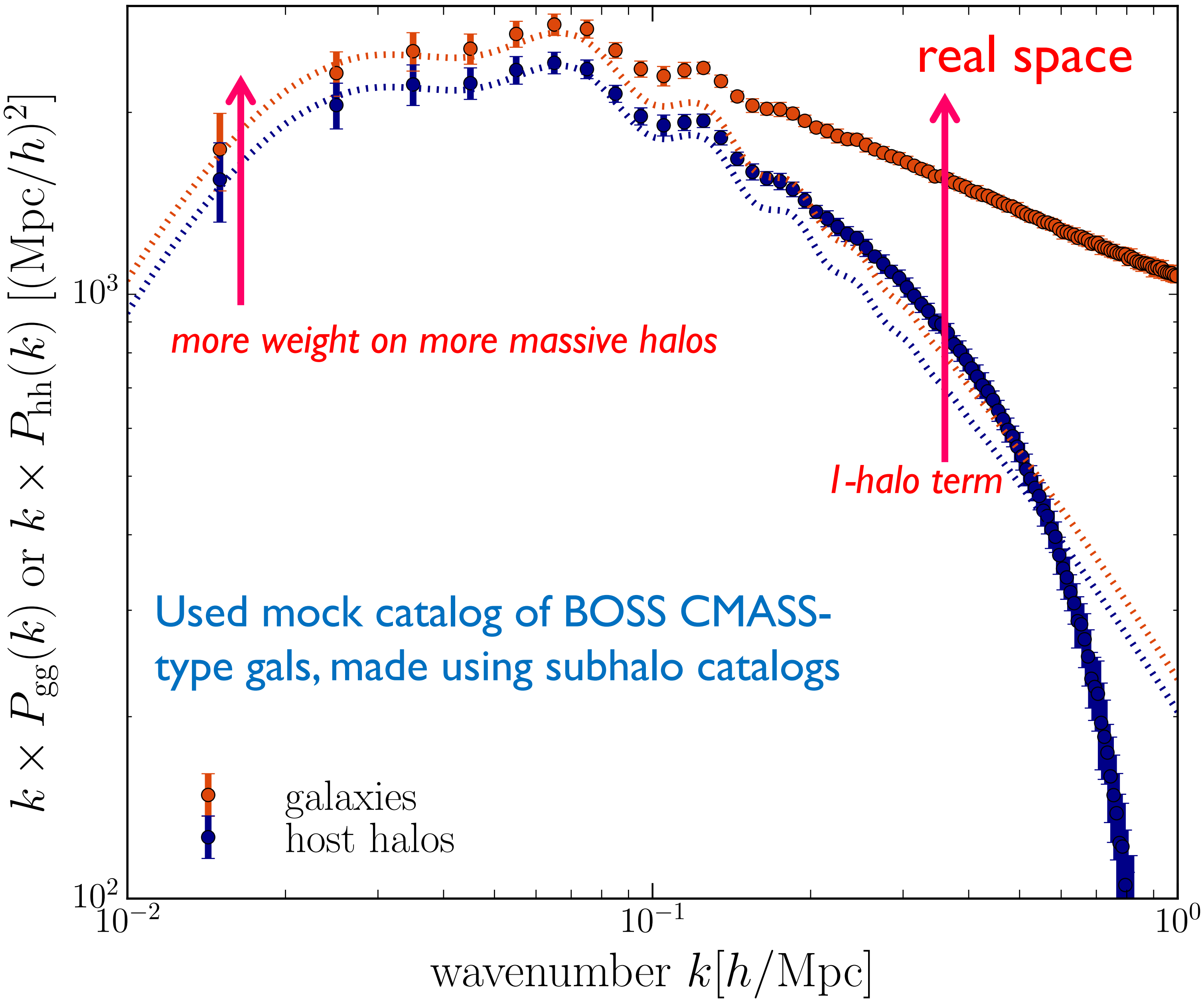
$$P^{\rm 1h}_{\rm gg}(k) = \frac{1}{\bar{n}_{\rm g}^2}\int {\rm d}M\, n(M) \langle N_g(N_g-1)\rangle(M)|u_g(k;M)|^2$$

$$P^{\rm 2h}_{\rm gg}(k) = \frac{1}{\bar{n}_{\rm g}^2}\sum_{M,M'} w(M;k)w(M';k)P_{\rm hh}(k;M,M')$$

cosmology

# Halos vs. Galaxies

Okumura, MT, + in prep.

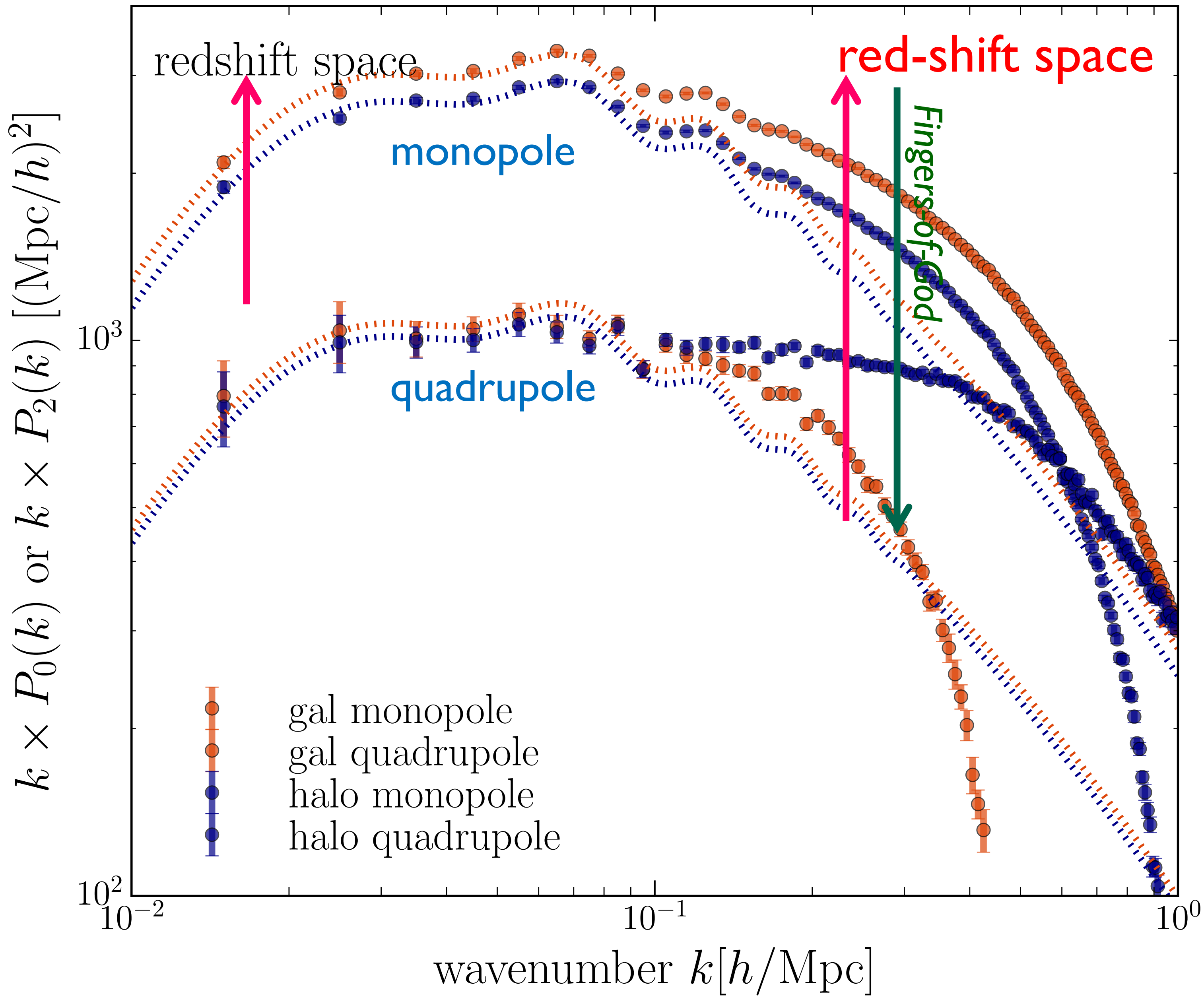


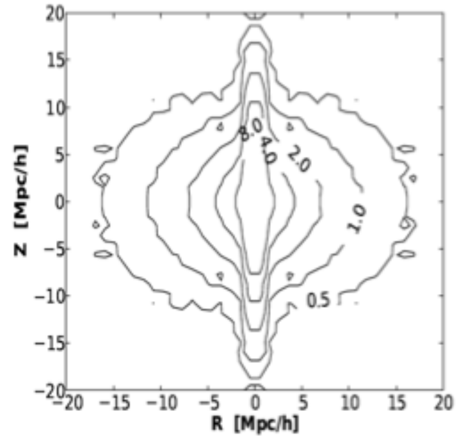

Teppei Okumura (IPMU)

2pt correlation function of galaxies is different from that of halos over all the scales

# Halos vs. Galaxies

Okumura, MT, + in prep.




In redshift, further Fingers-of-God effect ⇒ suppression

2pt correlation function of galaxies is different from that of halos over all the scales and in monopole and quadrupole

*A bad news*

# Summary

- We are doing really well (great team, great supports, …)
- PFS instrumentation and science preparation are well underway (Naoyuki Tamura, our hero!!!!)
- Halo Emulator: can compute the halo summary statistics (mass function, clustering, …) by a few seconds from the tabulated data of >200TB N-body simulations in 6-dimensional cosmological parameter space
- Publish cosmology papers with HSC data (Hikage et al., Miyatake et al.). Stay tuned!