DSU 2015, Kyoto, December 15th

SIMULATIONS OF STRUCTURE FORMATION AT LOW AND HIGH-REDSHIFTS

Naoki Yoshida (U-Tokyo/Kavli IPMU)

CONTENTS

The particle nature of dark matter

- mass, cross-section, charge
- γ-ray - cosmic shear cross-correlation

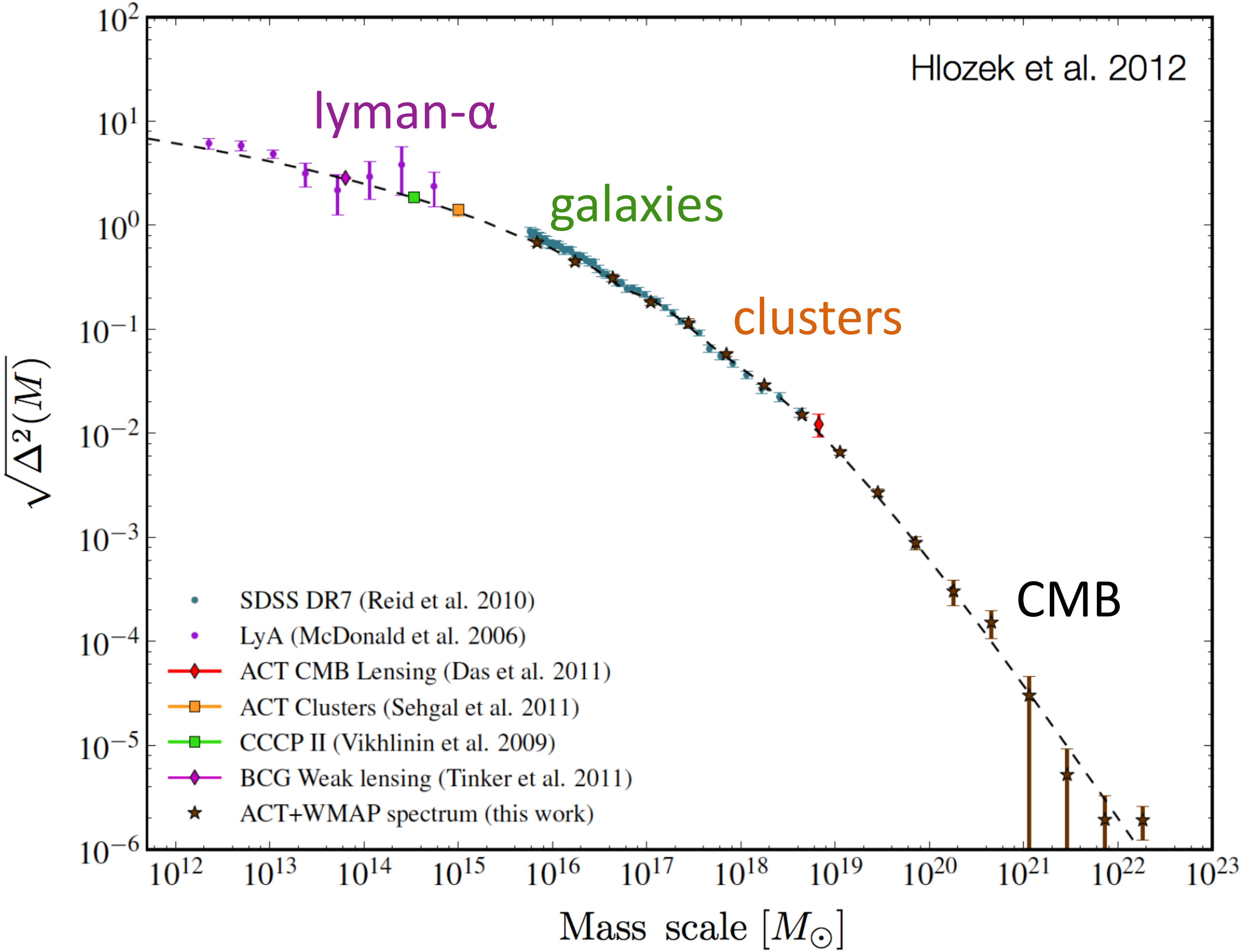
FIR line emitters at high-z

- ALMA detection of z=7 [OIII] line

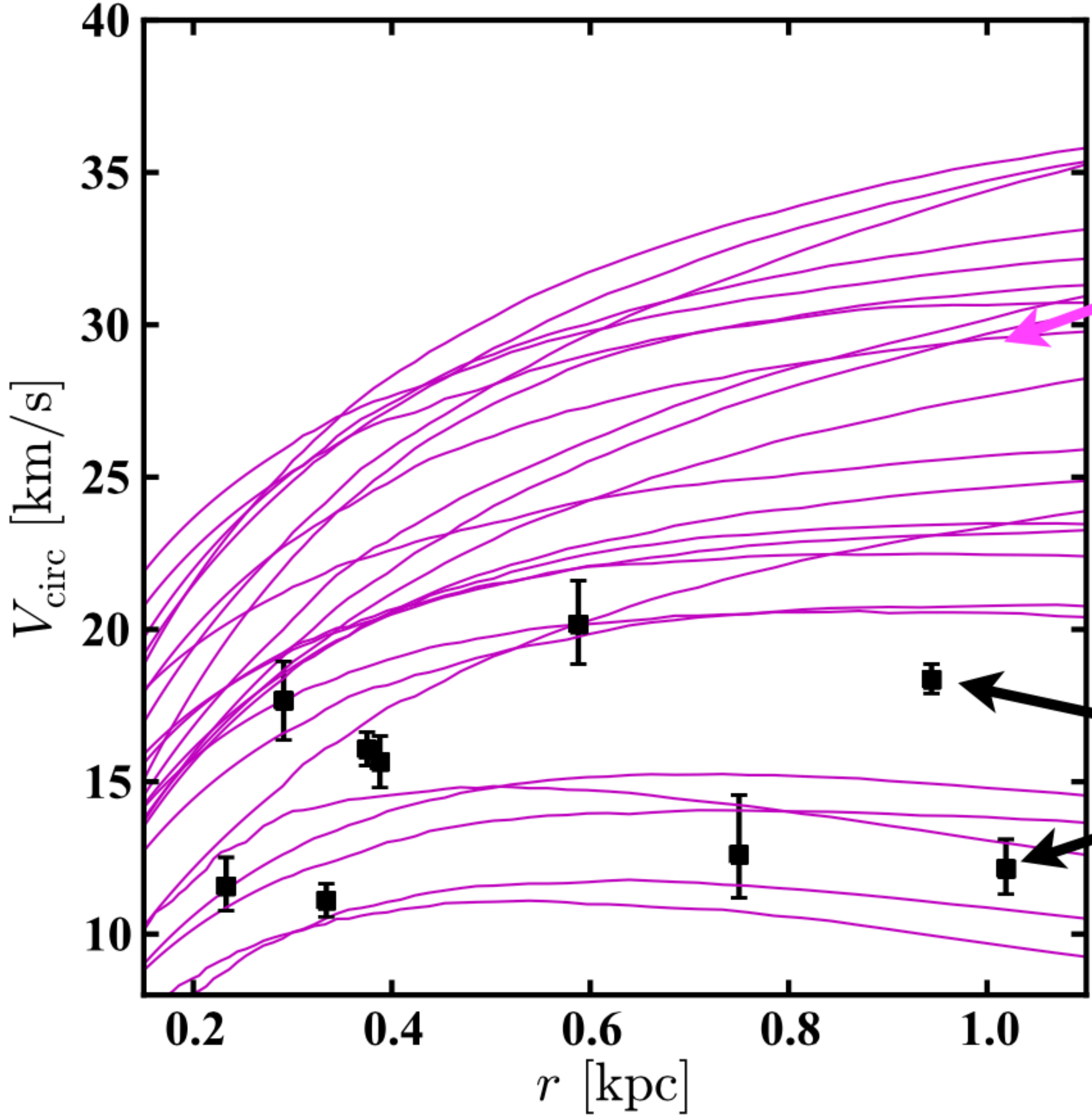
Beyond $N = 10^{12}$, to $N = 0$(!)

References Shirasaki, Horiuchi, NY, 2014; 2015 PRD
Osato, Shirasaki, NY, 2015, ApJ
Hirano, Zhu, NY, Spergel, Yorke, 2015, ApJ
Inoue, Shimizu, Okamoto, NY, 2014, ApJ
Inoue et al. in prep.

The success of ΛCDM continues…



Large halos without stars ?

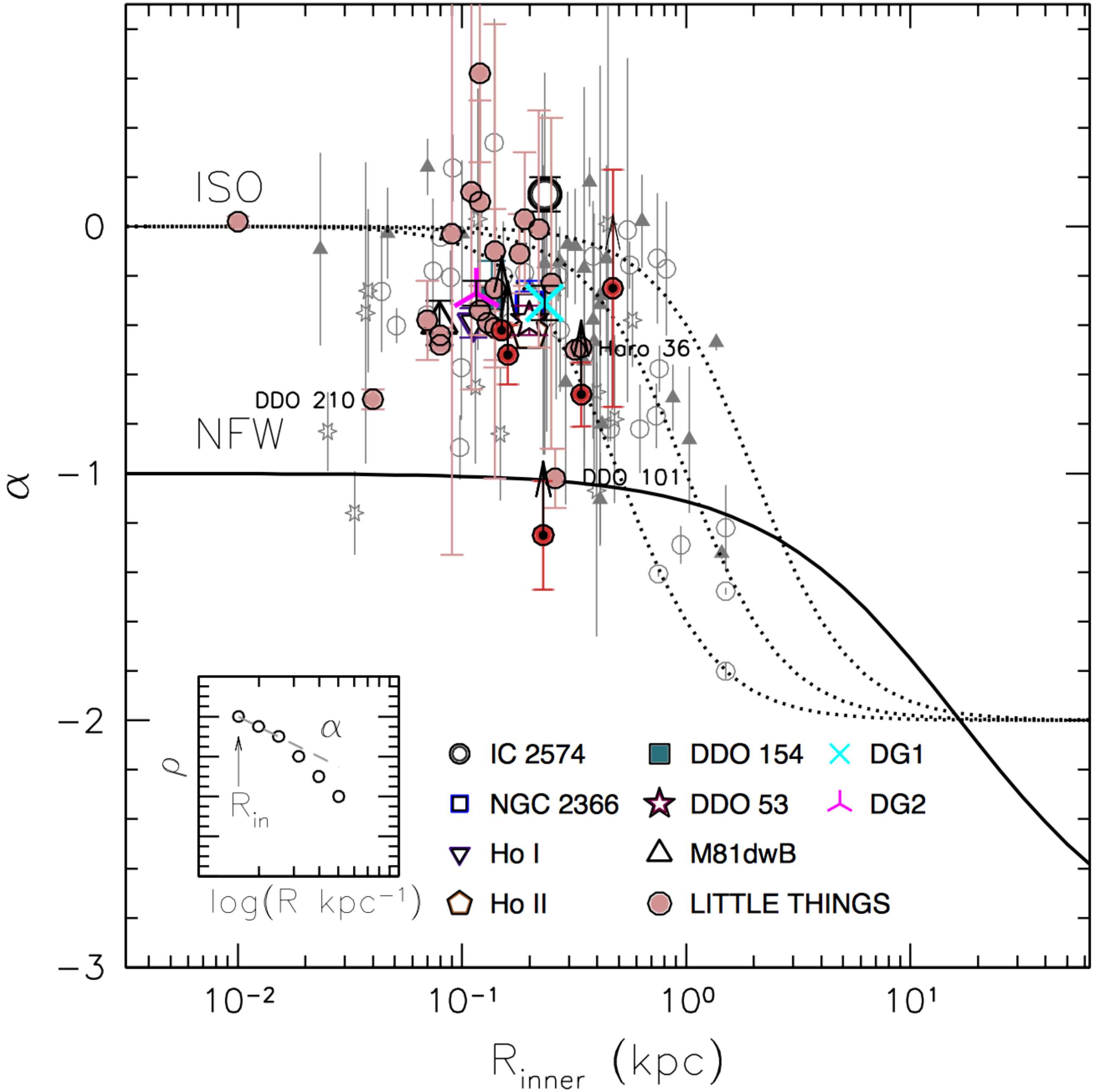


Mass profiles of subhalos

Observational data of Milky Way satellites

M. Boylan-Kolchin

Cores in dwarf galaxies ?



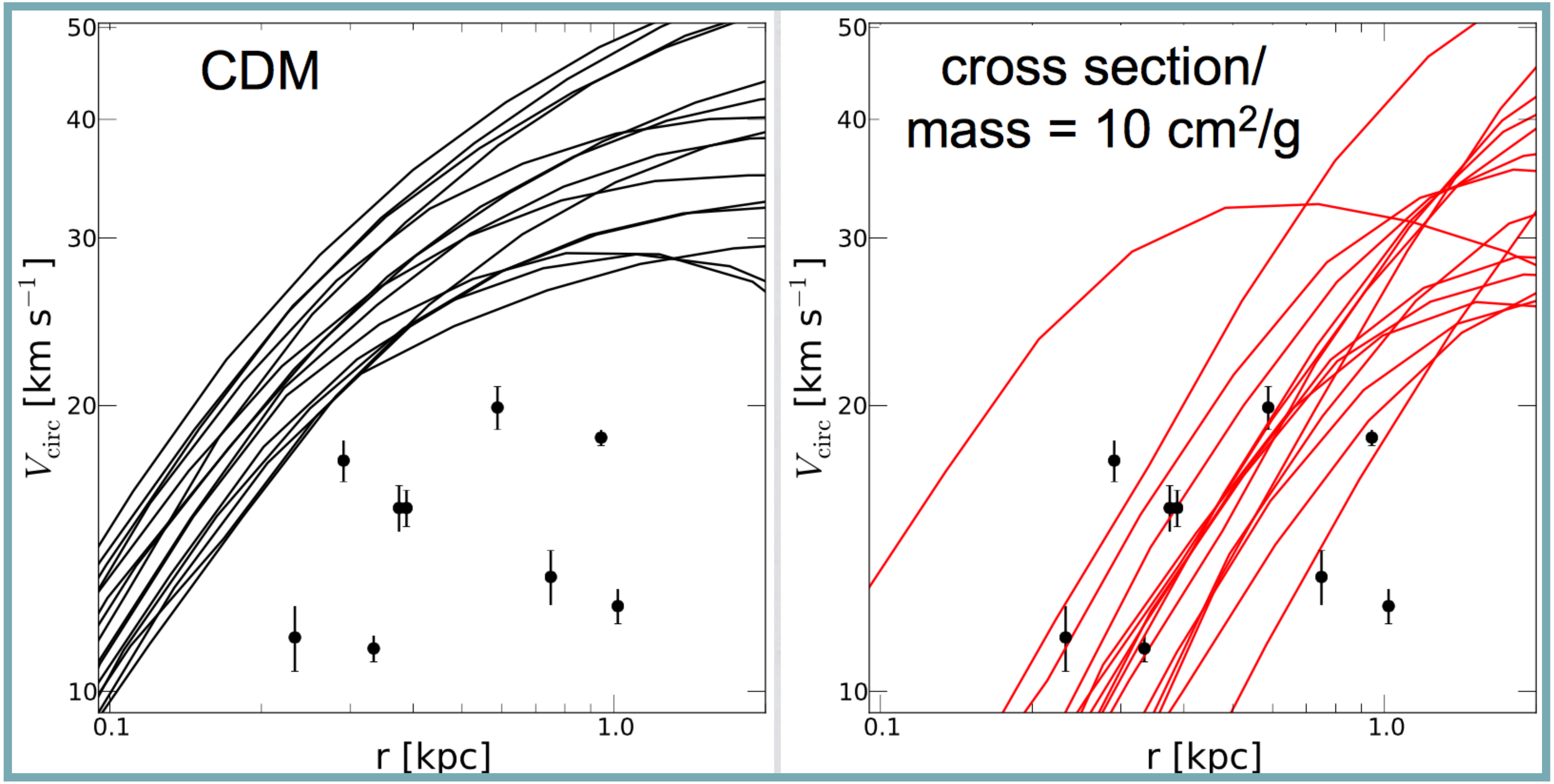
Oh et al. 2015
VLA HI survey

The logarithmic slope of the inner density profile α significantly smaller than 1 (of NFW)

Revived interest in SIDM

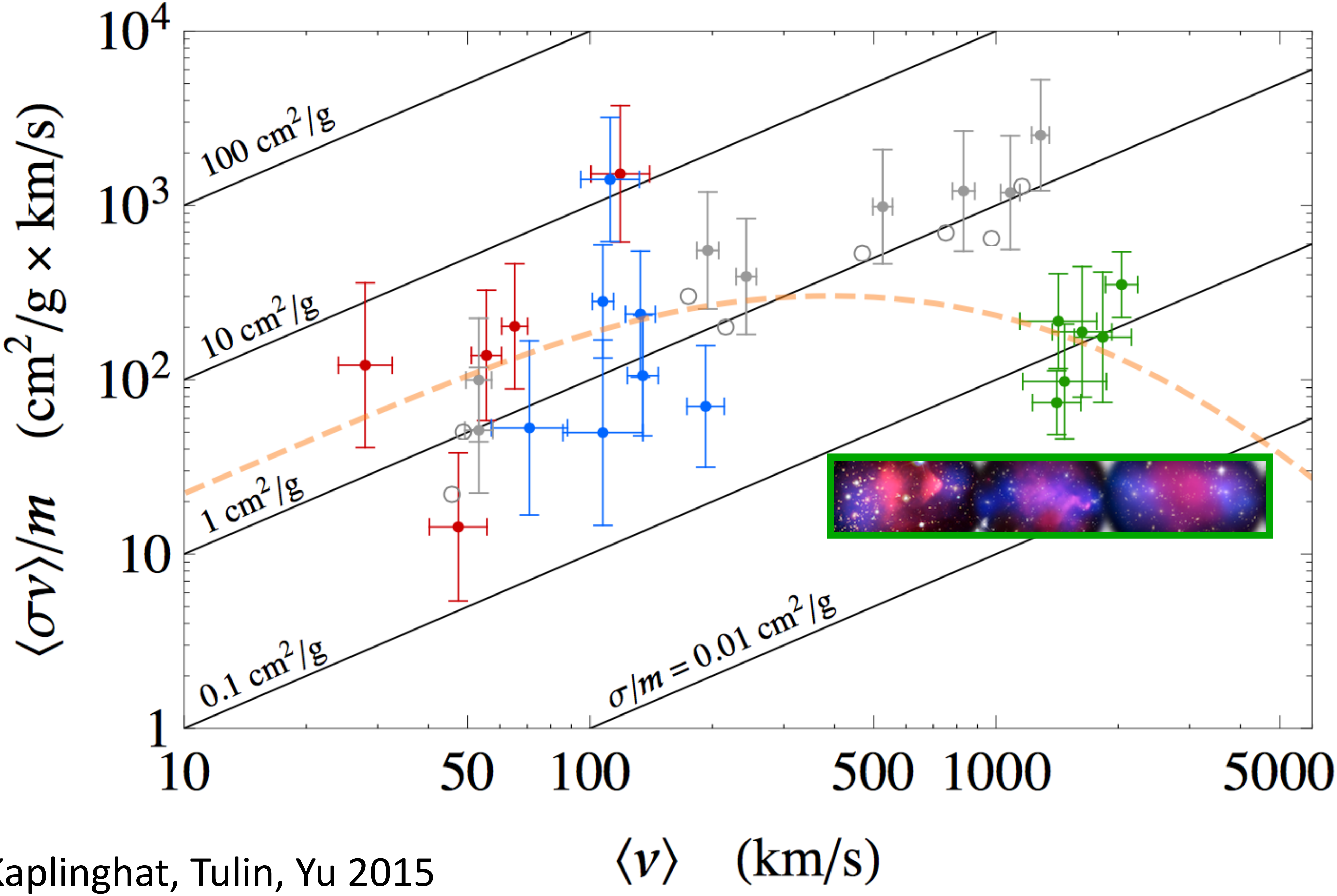
- Sommefeld enhancement and self-interaction (Buckley and Fox 2010)
- Yukawa-type interaction (Loeb and Weiner 2011)
- Dark matter atom and radiation (Cyr-Racine and Sigurdson 2012)
- Dark force and dwarf cores (Tulin, Yu and Zurek 2012, 2013)
- Partially interacting DM and galactic disks (Fan, Katz, Randall, Reece 2013)
- Effective theory (Bellazzini, Cliche, Tanedo 2013)

SIDM can resolve the TBTF problem



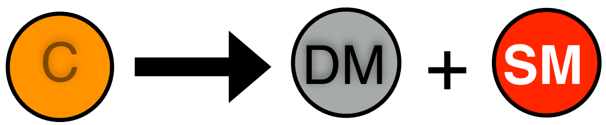
Vogelsberger et al. 2012

Velocity-dependent cross-section ?



Kaplinghat, Tulin, Yu 2015

Long-lived charged particles

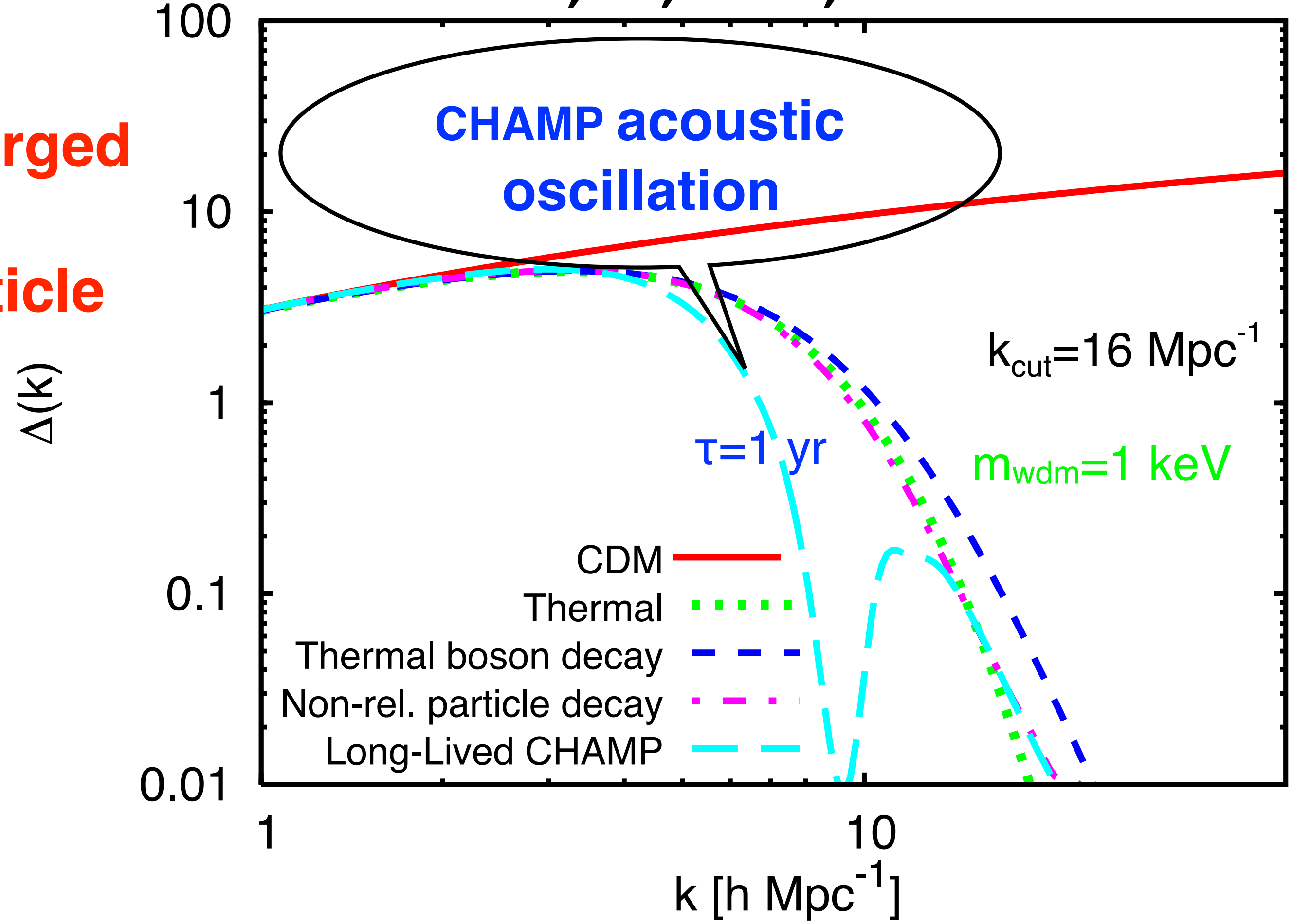


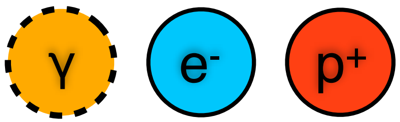
CHAMP

Neutral Dark Matter

Charged SM Particle

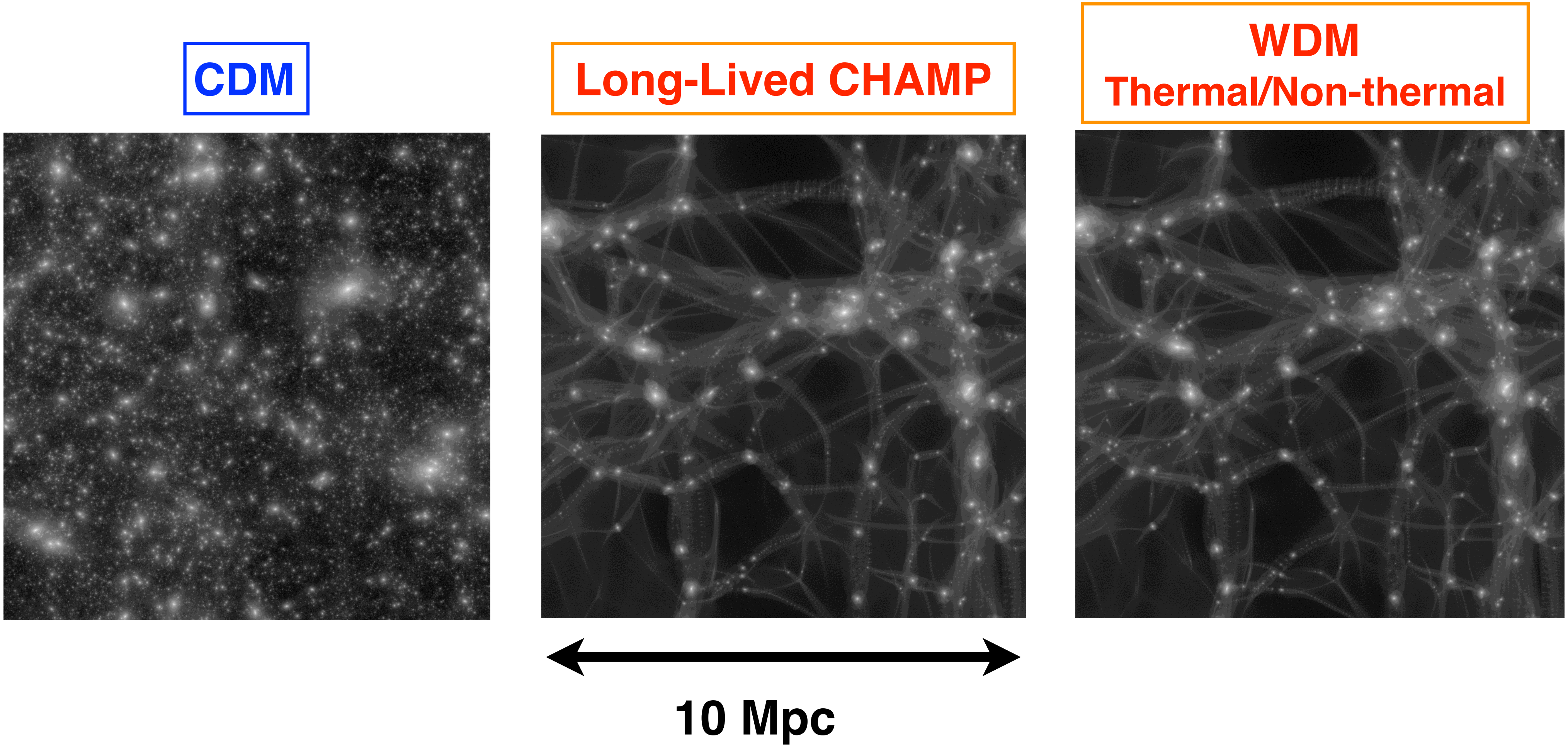
Kamada, NY, Kohri, Takahashi 2013





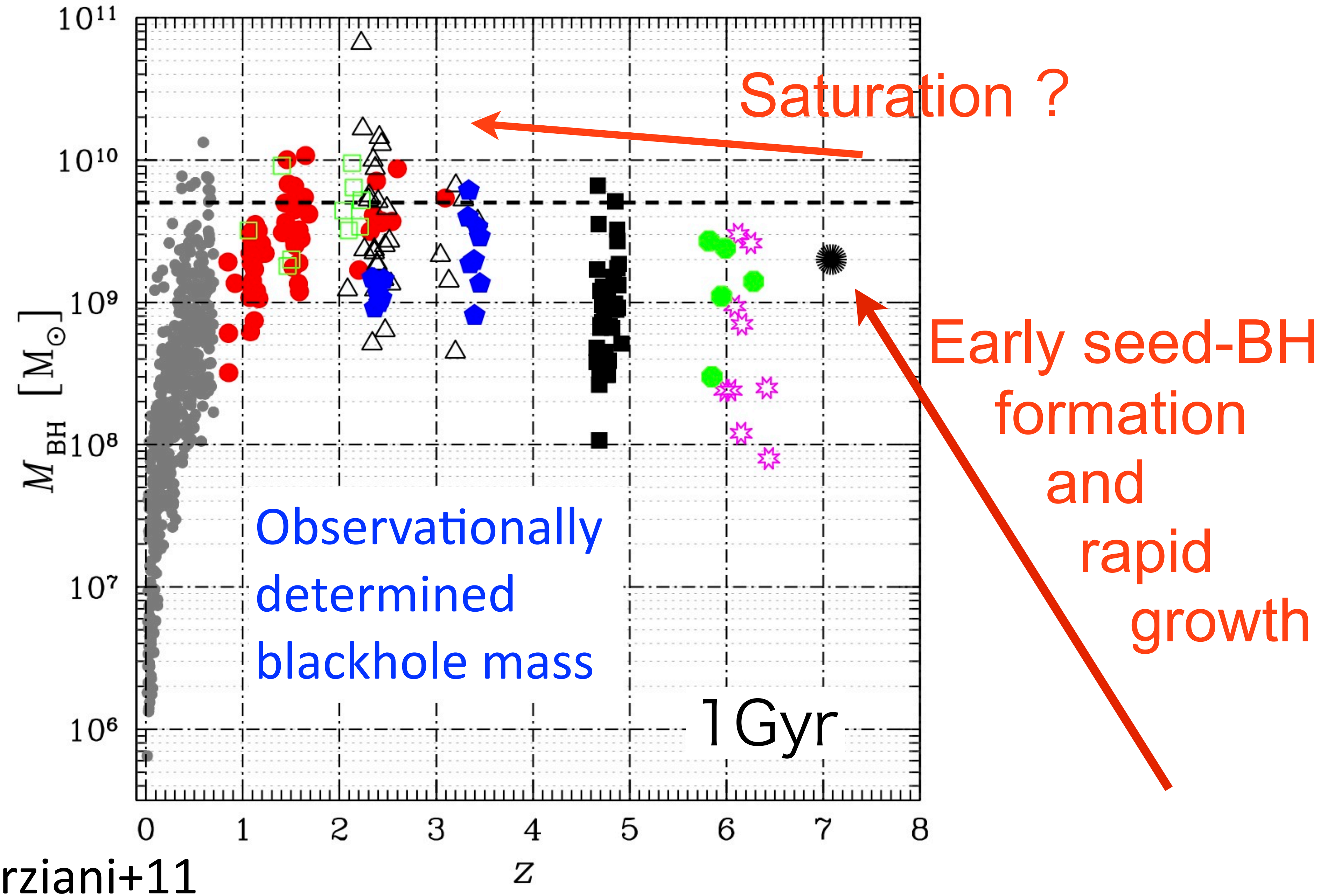
Plasma interaction prevents CHAMPs from falling into the bottom of gravitational potential. Effectively a WDM-like density fluctuations are generated.

Small structures in alternative models



Quite similar structure in Long-Lived CHAMP model and WDM models

Rapid growth of early blackholes

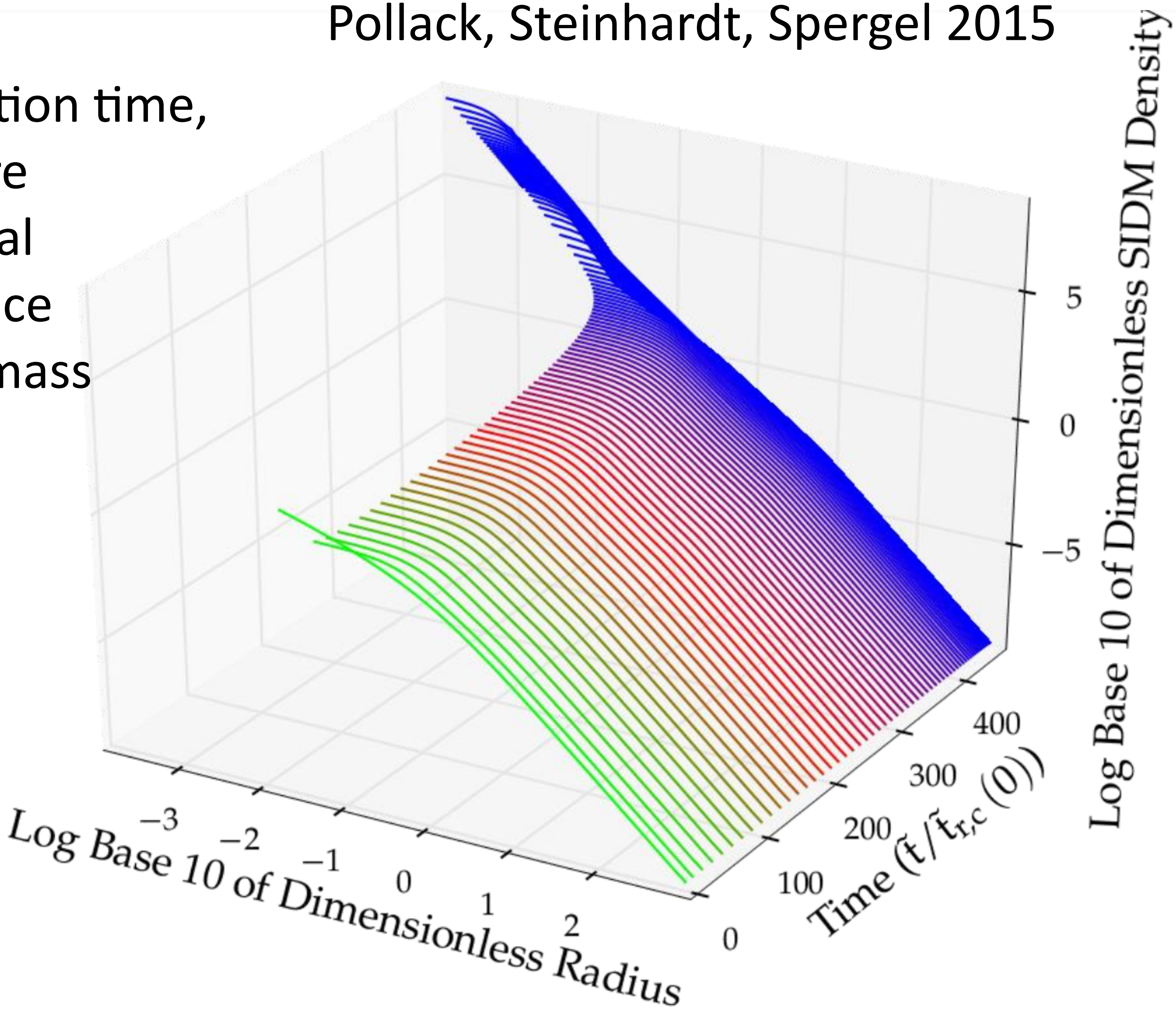


Marziani+11

Gravo-thermal collapse of a SIDM halo

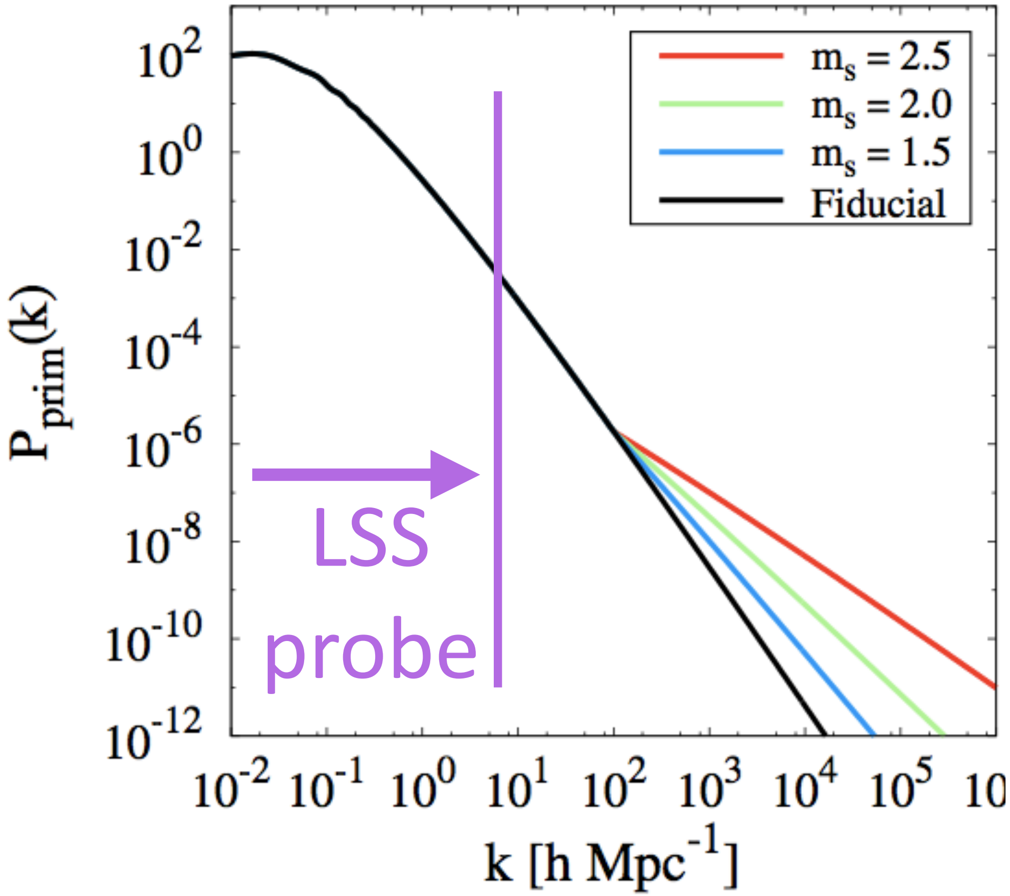
Pollack, Steinhardt, Spergel 2015

After a few relaxation time, the SIDM halo core goes gravo-thermal collapse, to produce a blackhole with mass of ~ 1% of M_{halo}

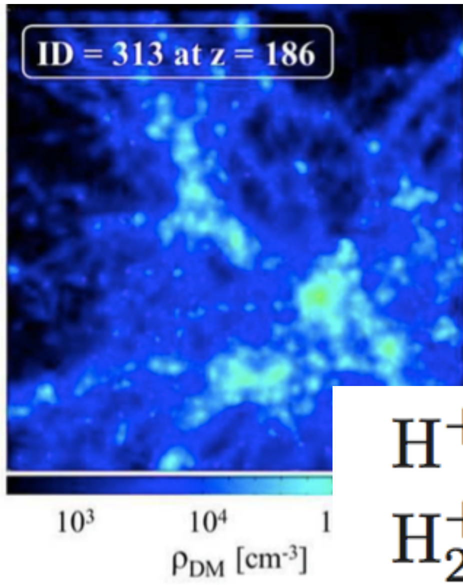


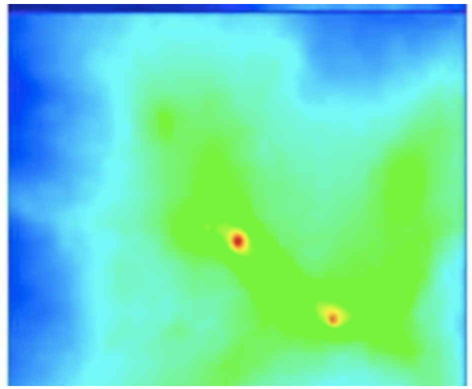
Blue *P*(*k*) and very early object

Hirano, Zhu, NY, Spergel, Yorke, 2015, ApJ

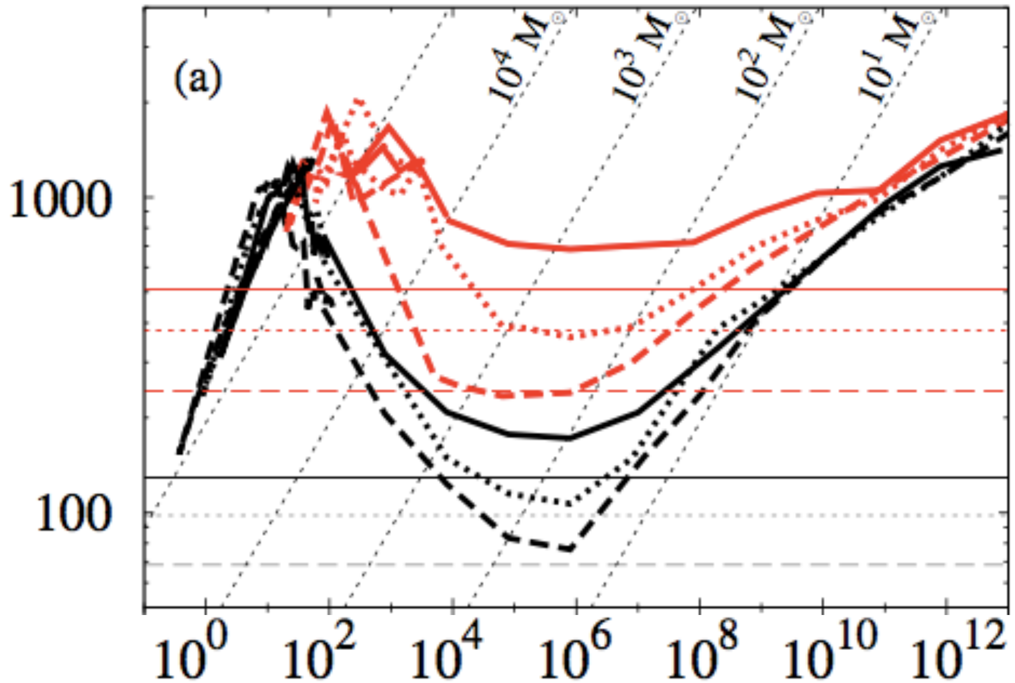


A 300 Msun star at z=186 !





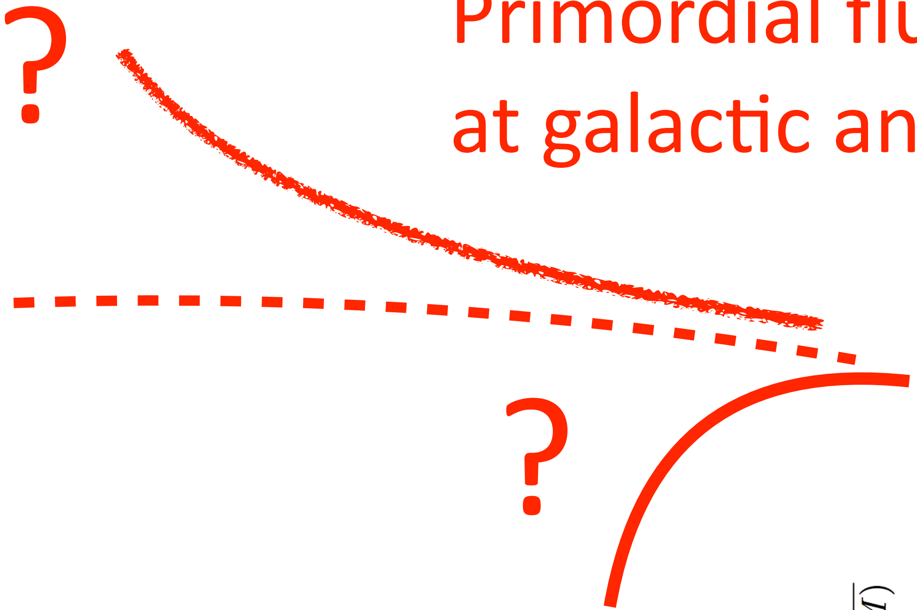
$$H^+ + H \rightarrow H_2^+ + h\nu$$
$$H_2^+ + H \rightarrow H_2 + H^+$$

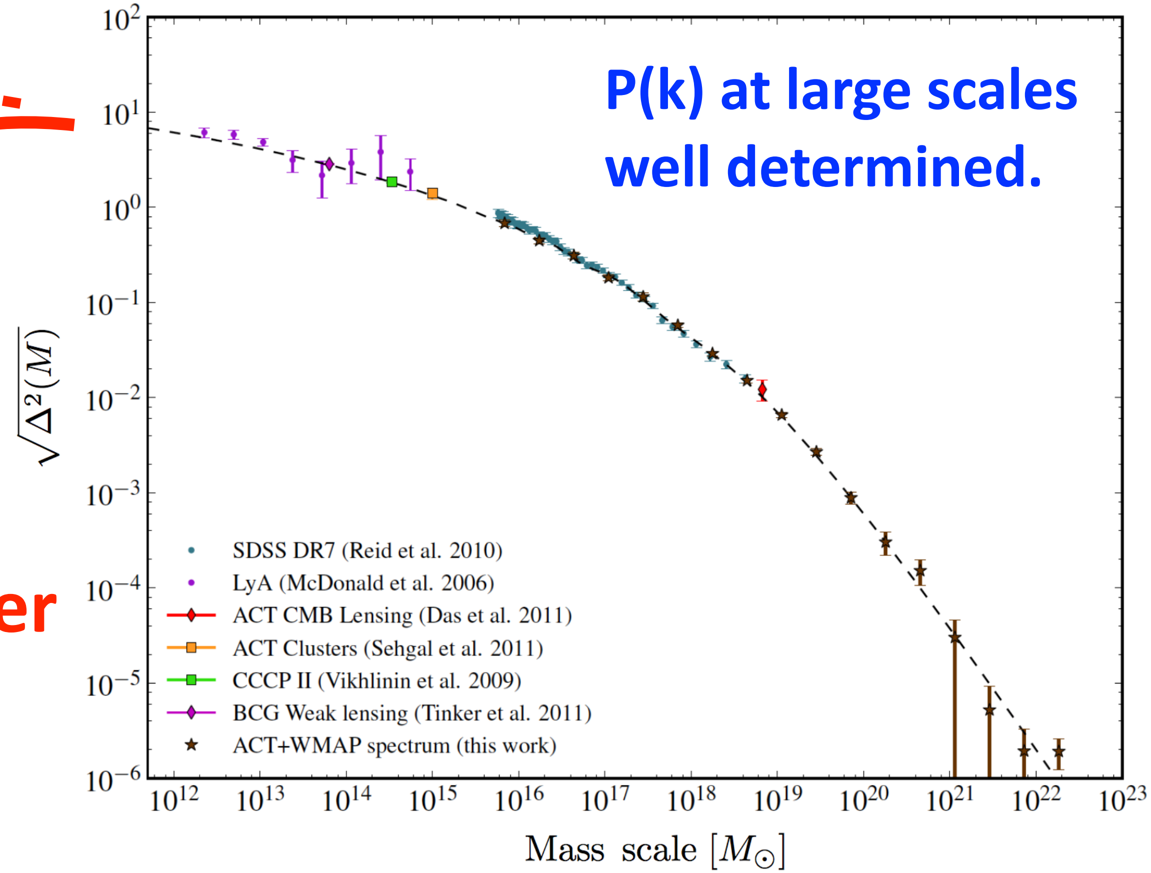


Blue tilted power or
enhancement at very small scales
e.g, Martin & Brandenberger 2001
Covi & Lyth 1999; Gong & Sasaki 2011

…and P(k) at small length scales.

Primordial fluctuations
at galactic and stellar scales



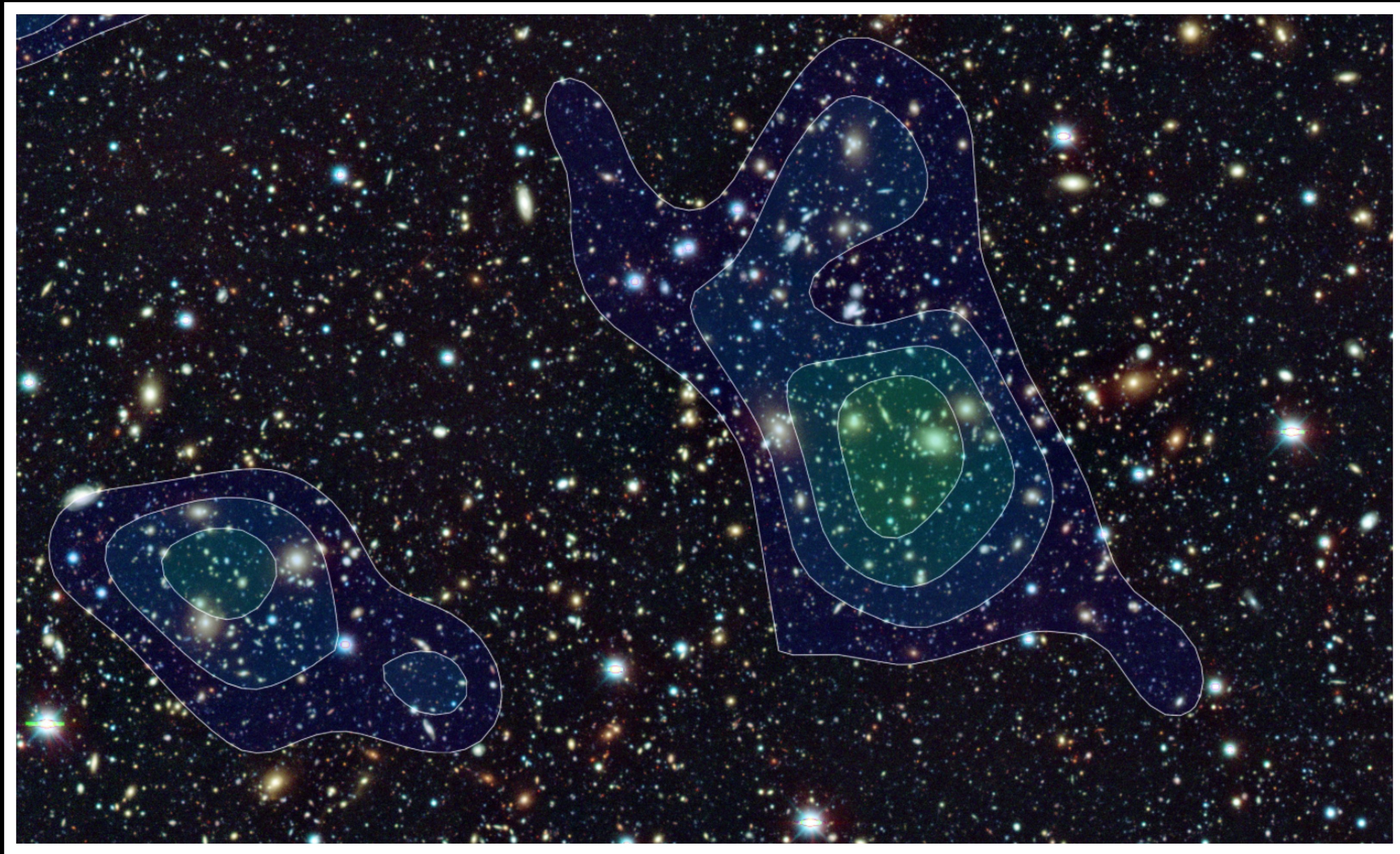


Hard to measure, but
a powerful probe
of the nature of dark matter
and/or
physics of inflation.

Indirect search
for
dark matter

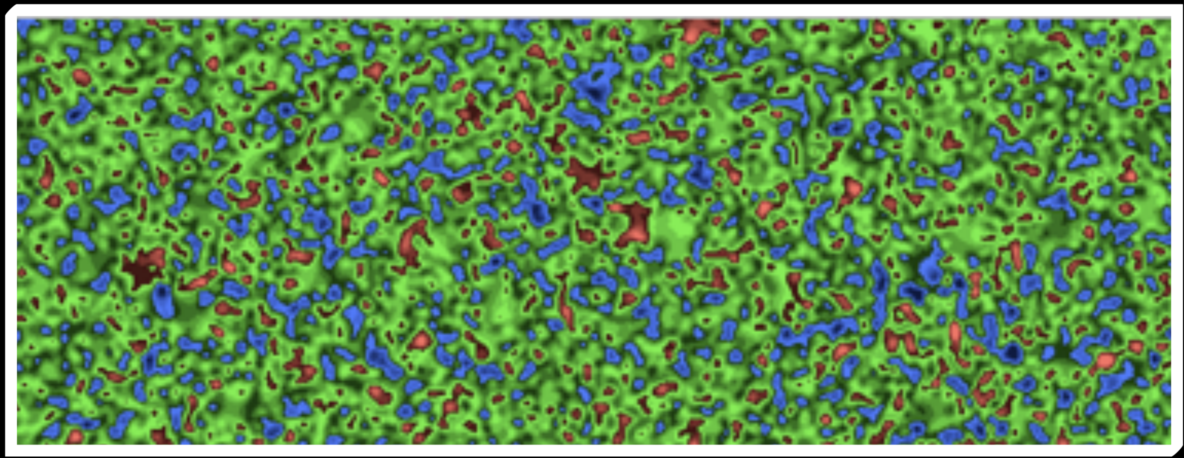
Visualizing dark matter

Small distortion of galaxy shapes → Grav. potential



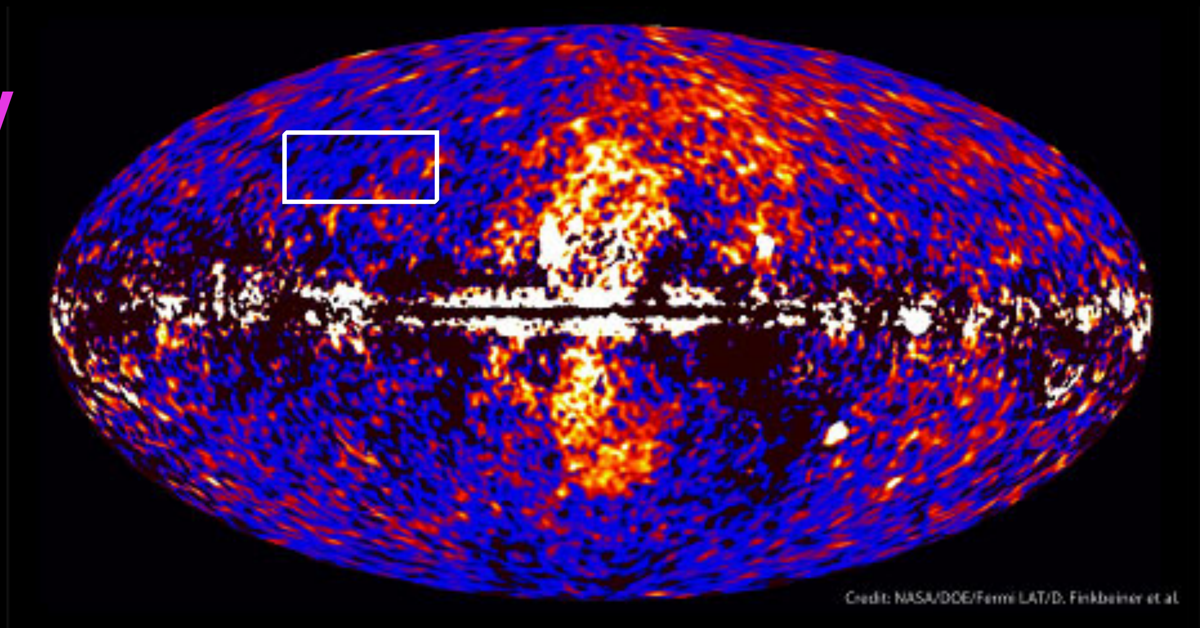
Recent snapshot from HSC survey

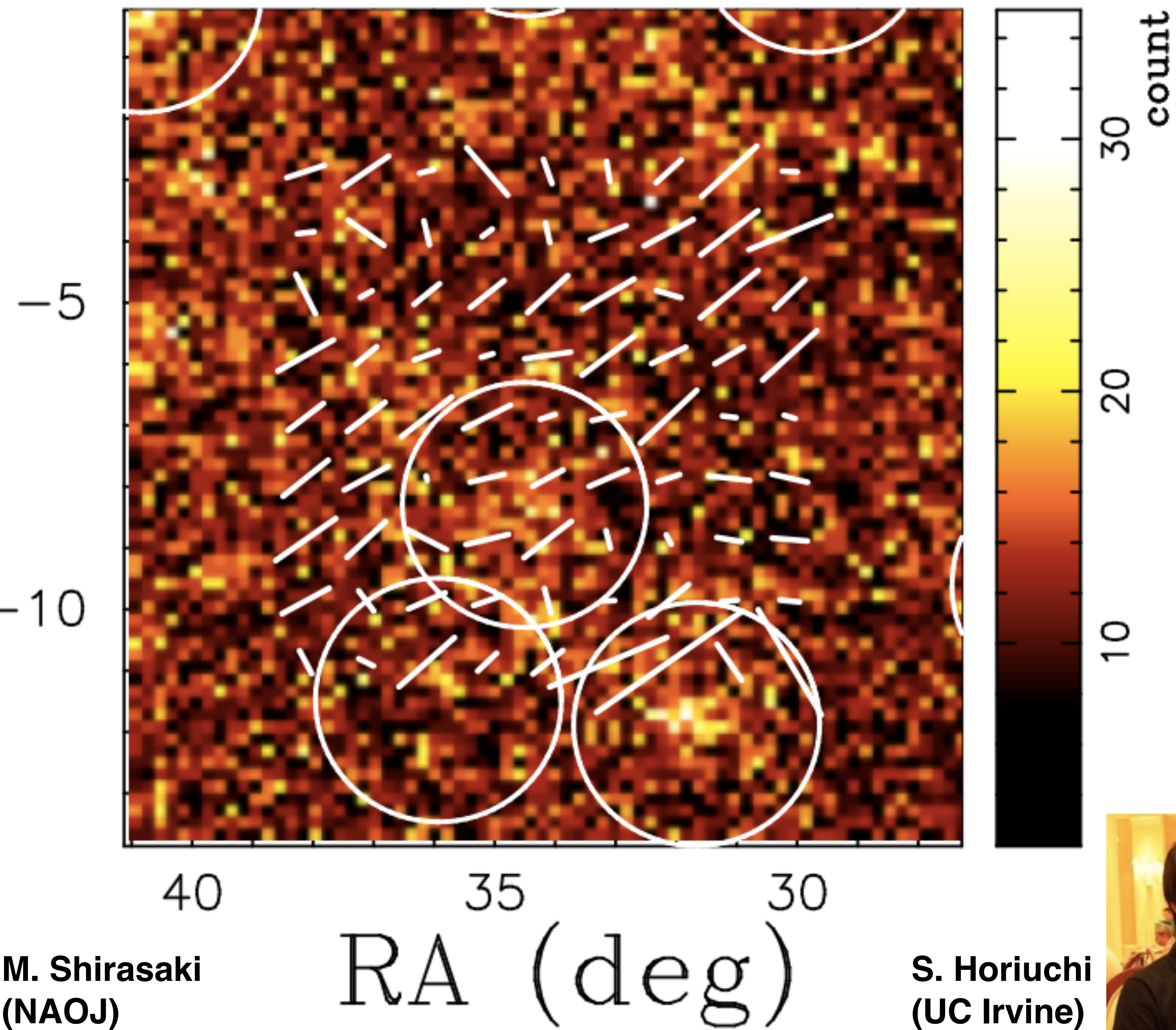
When we have two maps…



Dark matter distribution from CFHTLenS survey

Fermi all-sky γ-ray

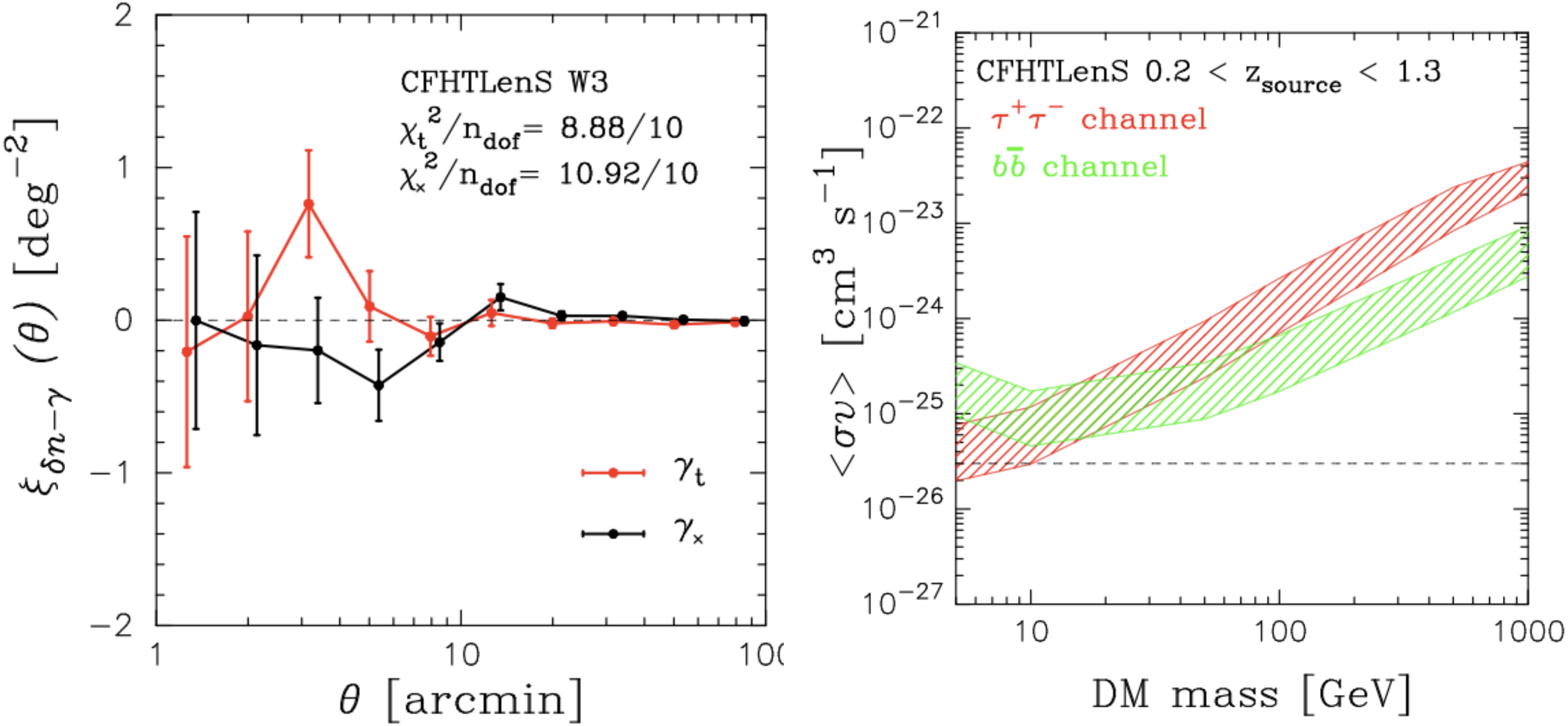




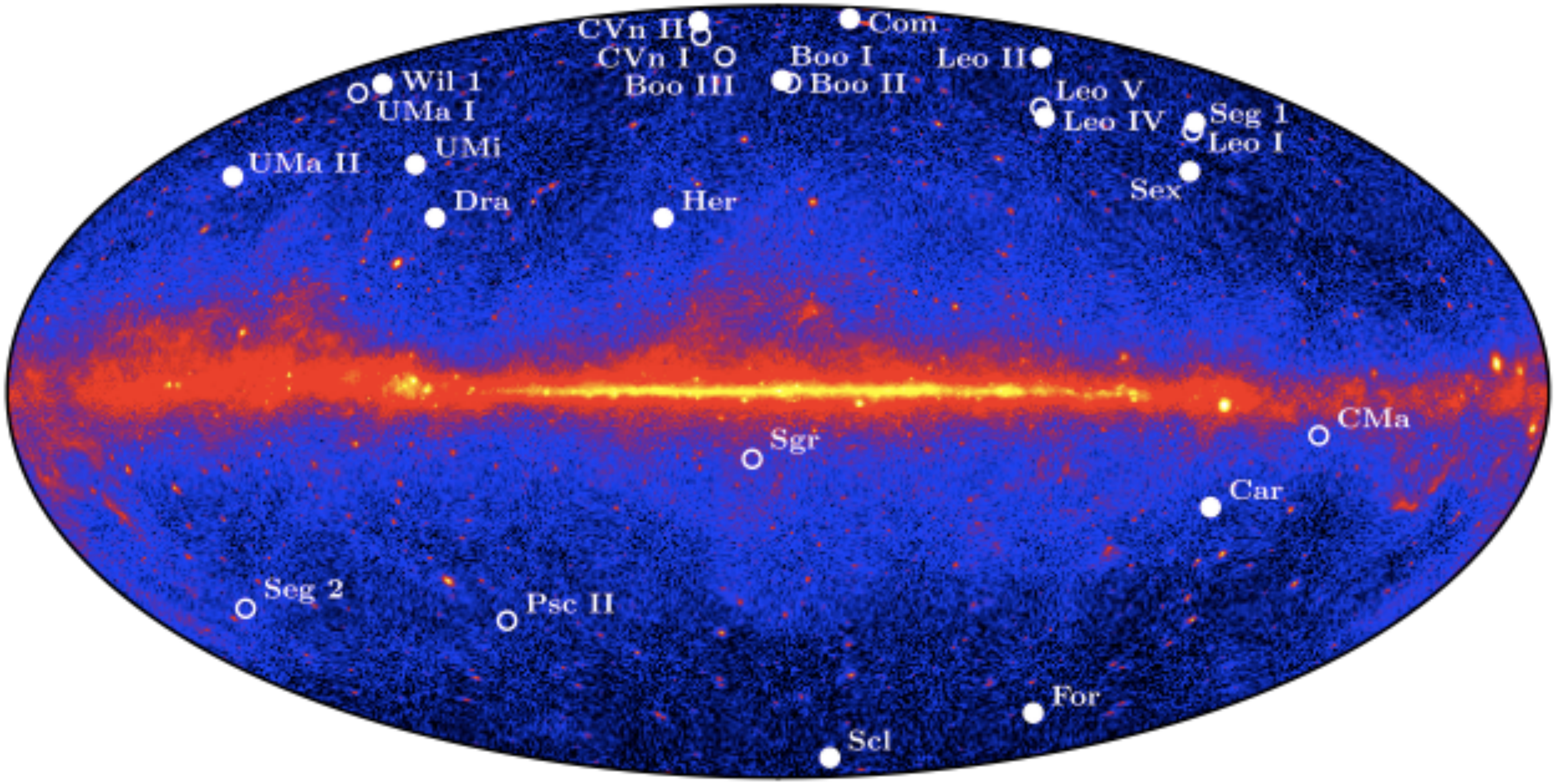
M. Shirasaki
(NAOJ)

S. Horiuchi
(UC Irvine)

The first "cosmological" constraints on the annihilation cross-section

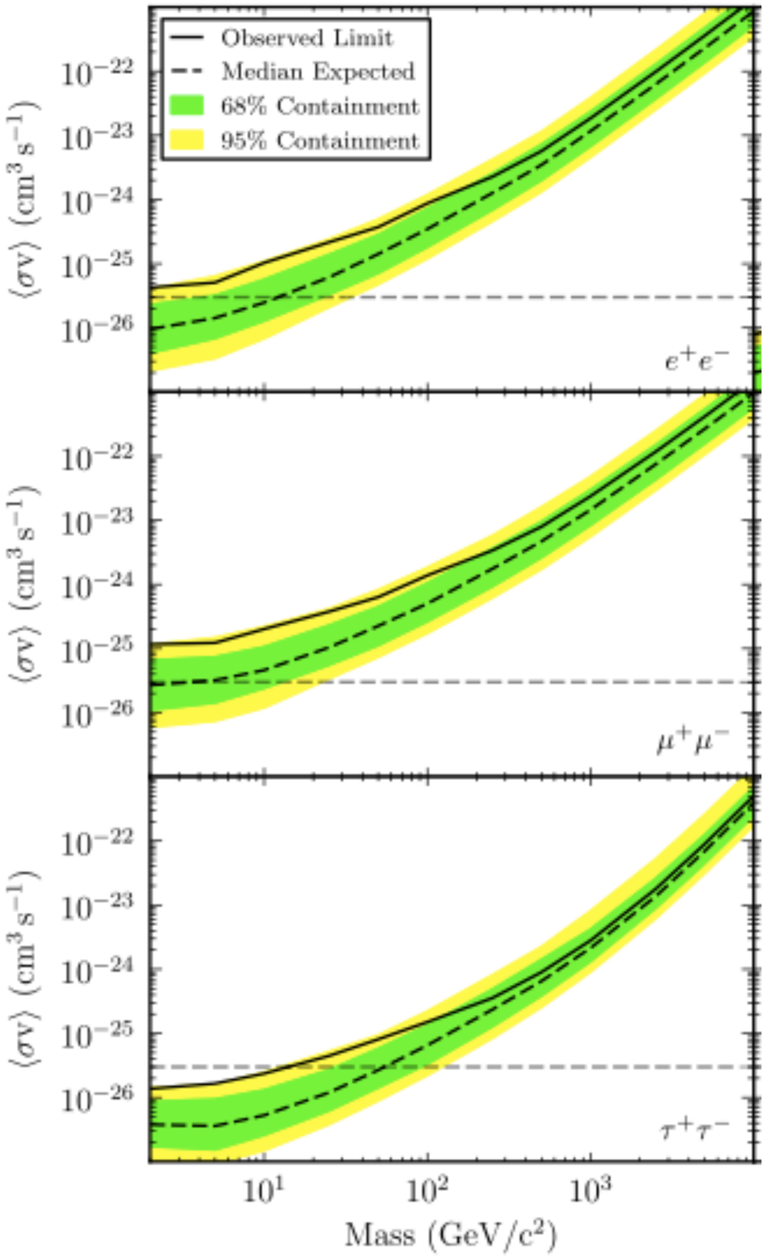


All-sky gamma-ray map



Fermi sat.
Ackermann et al. 2014
Circles indicate the locations of 25 Milky Way satellite galaxies

Annihilation cross-section



Fermi 4-year data

Search for excess γ-emission from dwarf galaxies

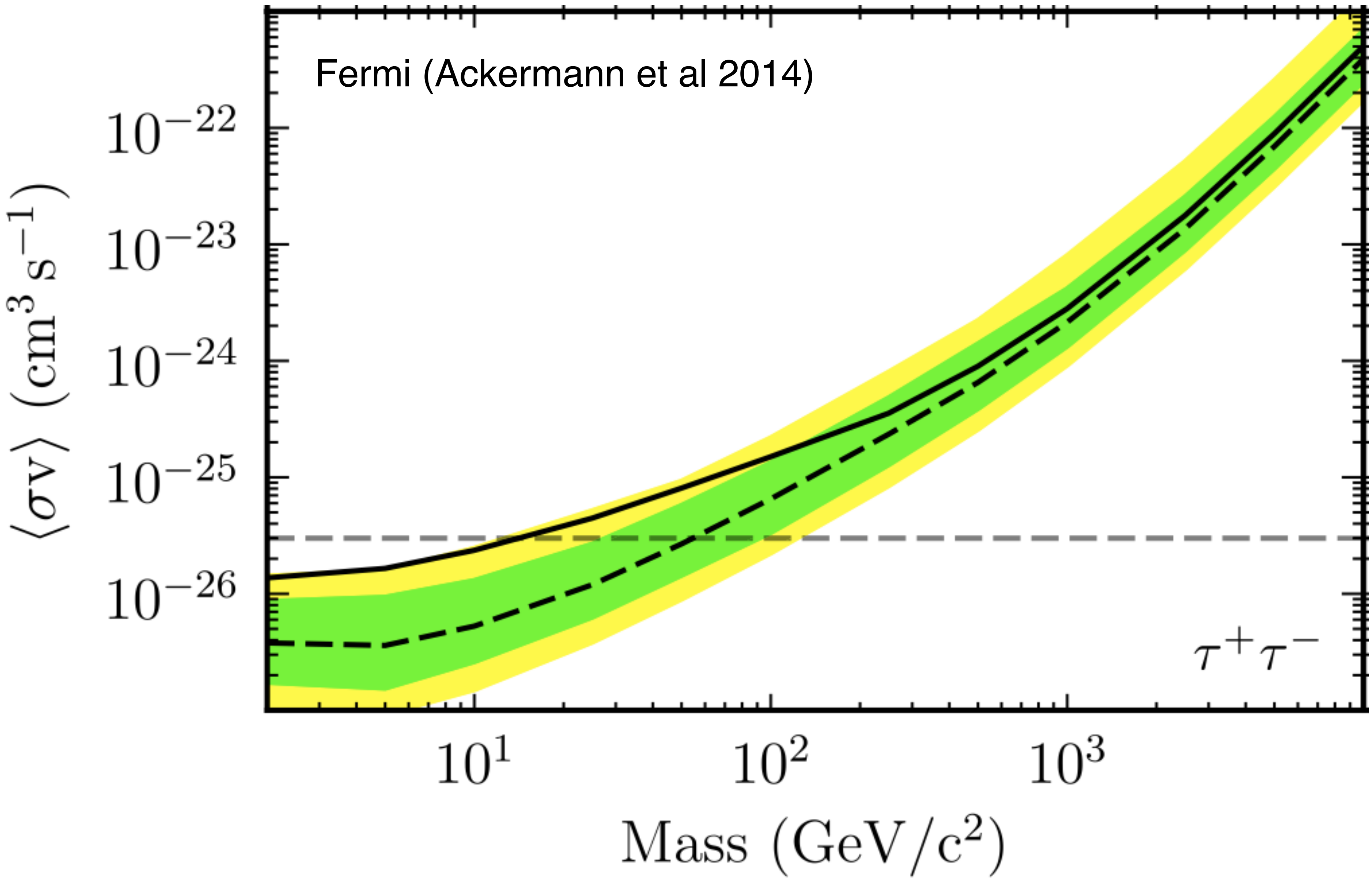
↓

No detection

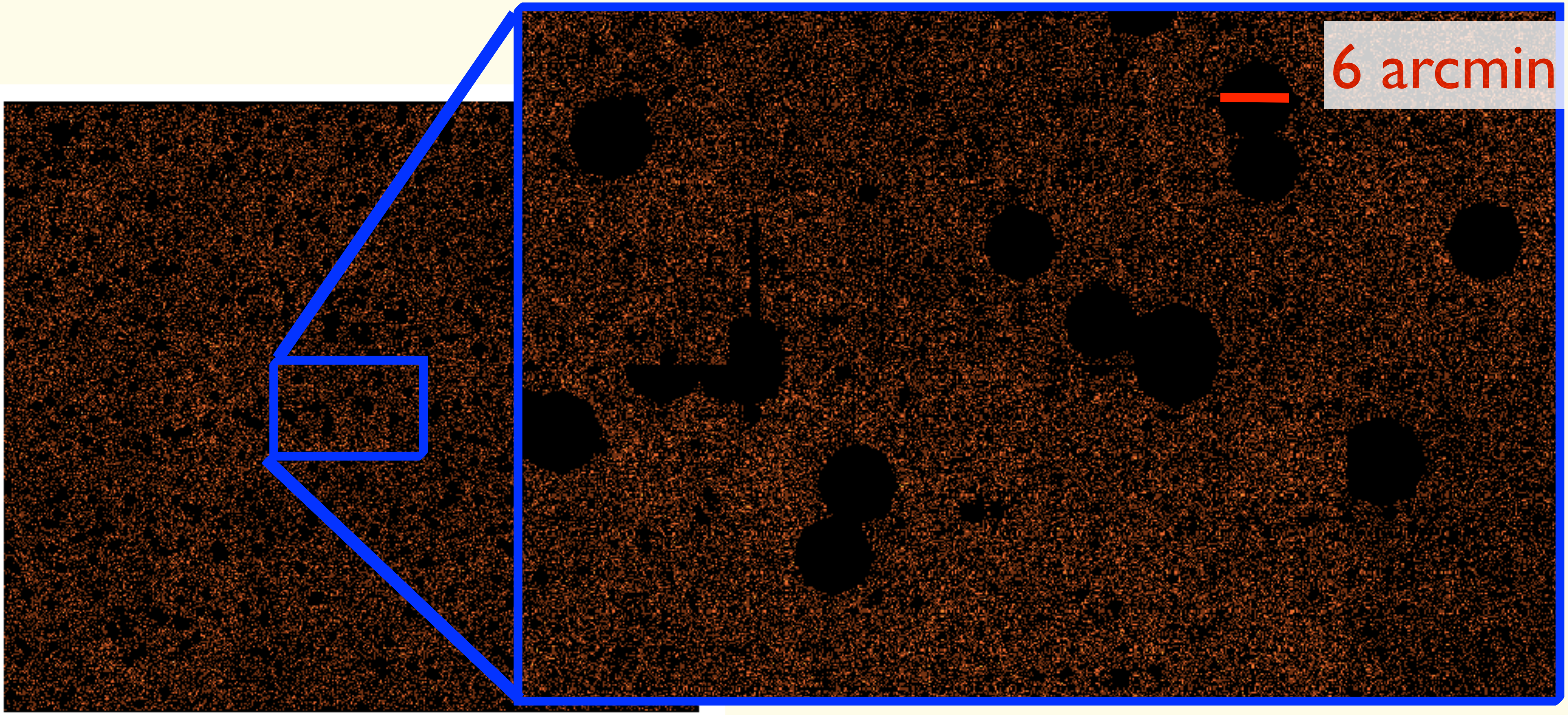
↓

Constraints on the annihilation cross-section

The "local" constraints



Dark matter distribution in a CFHT field



Number of source galaxies per grid (grid size=0.15 arcmin)

Lensing analysis

Observation
inhomogeneous shear map

Ray-tracing simulation
homogeneous shear map

$$\mathcal{K}(\boldsymbol{\theta}) = \int \mathrm{d}^2\phi \; \gamma_t(\boldsymbol{\phi} : \boldsymbol{\theta}) Q_t(\boldsymbol{\phi}),$$

add noise

continuous WL mass map

NOT directly compared!

continuous WL mass map

take up inhomogeneity

discard some pixels = paste mask field

$$\mathcal{K}(\boldsymbol{\theta}) = \int \mathrm{d}^2\phi \; \gamma_t(\boldsymbol{\phi} : \boldsymbol{\theta}) Q_t(\boldsymbol{\phi}),$$

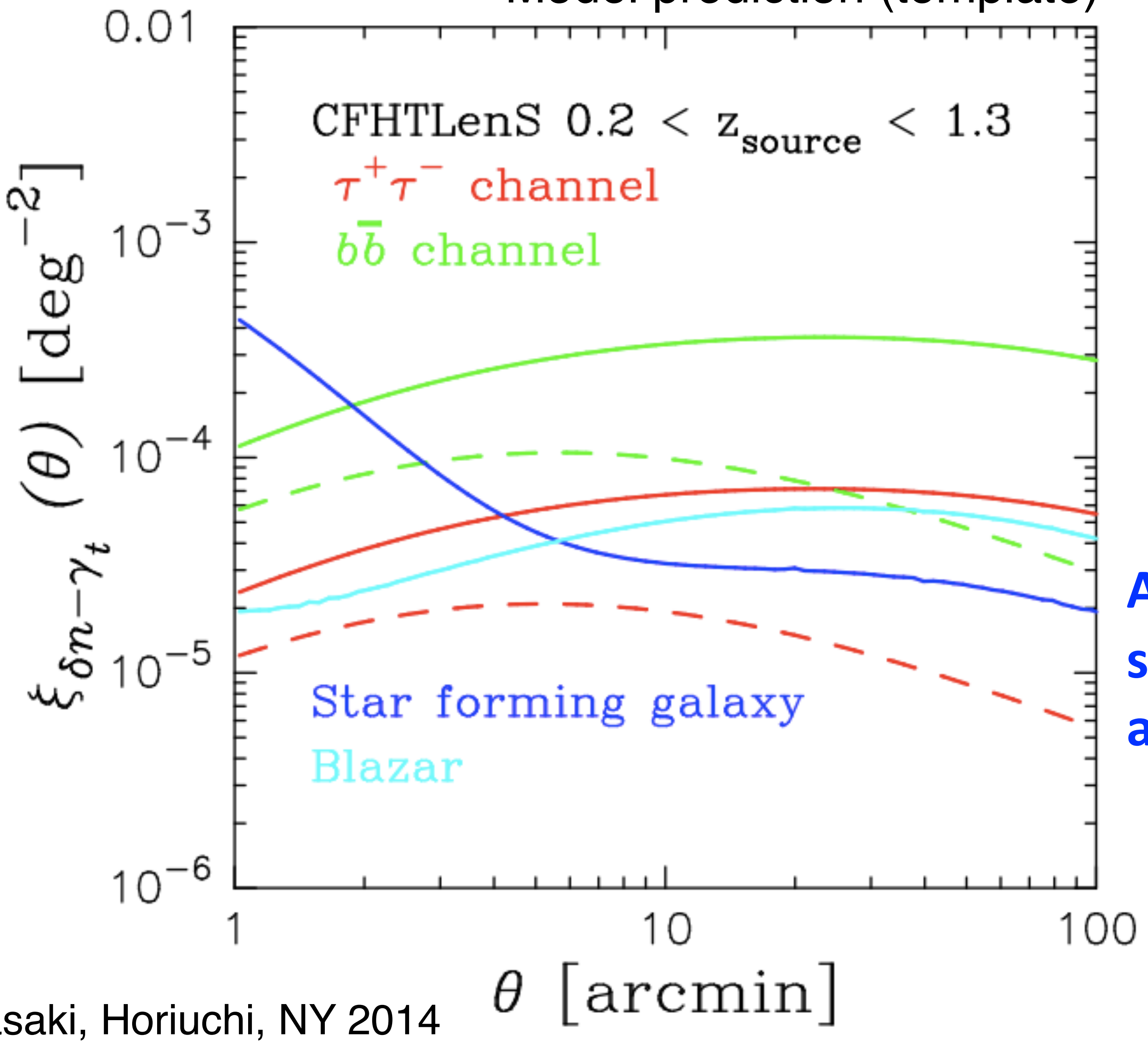
masked WL map

statistics

masked WL map

Shear -γ cross-correlation

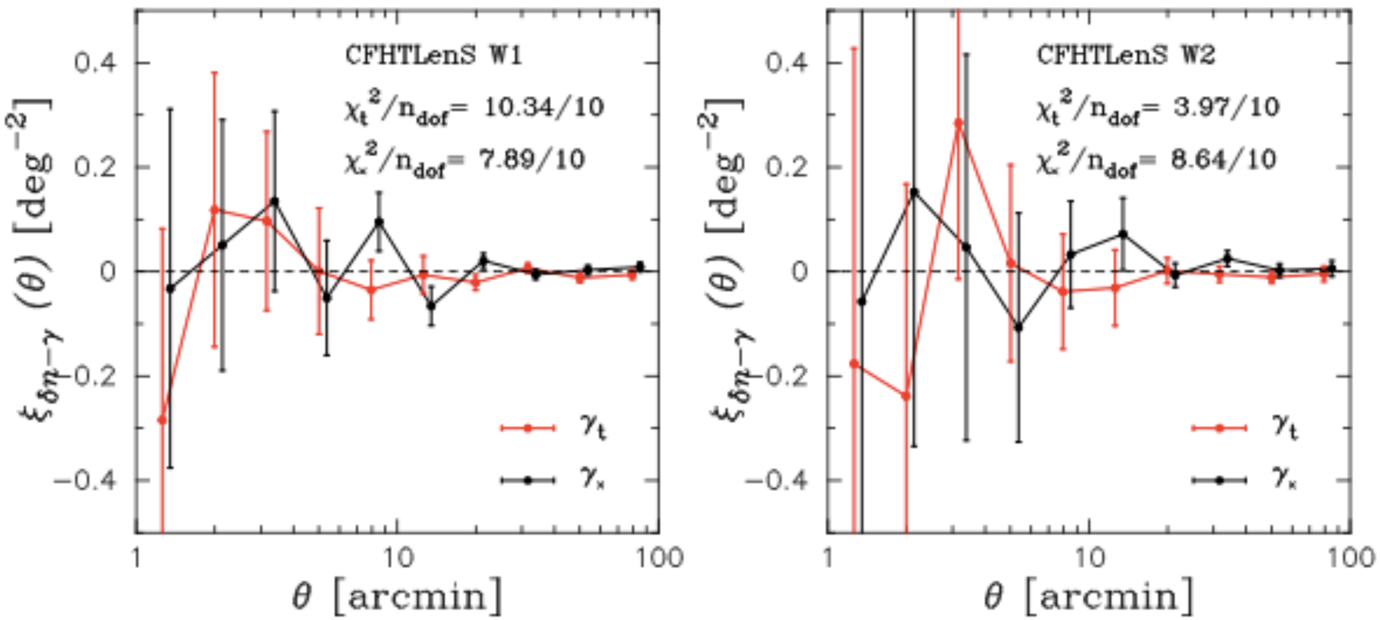
Model prediction (template)



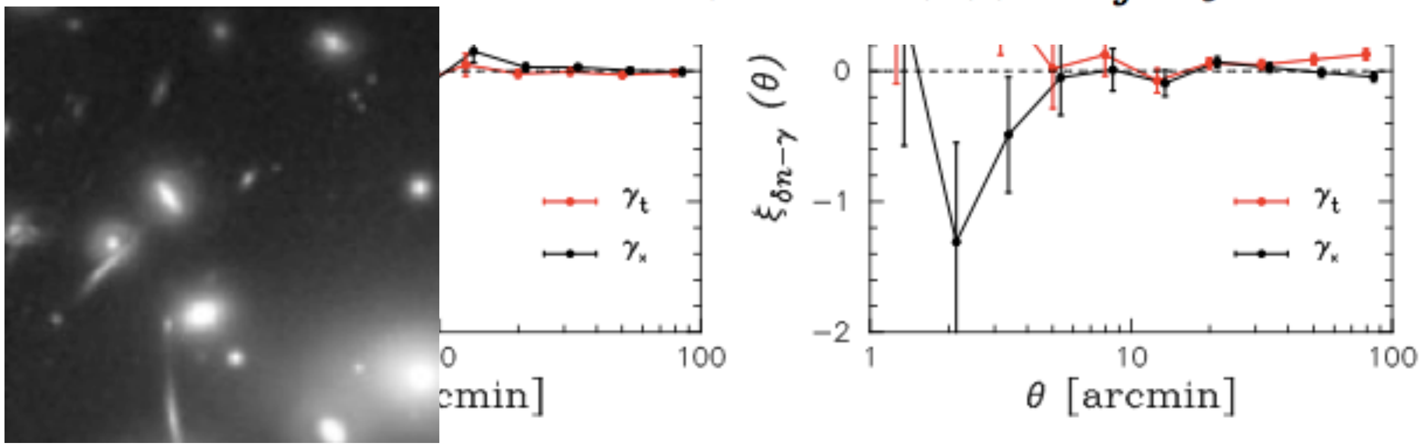
Astrophysical sources sub-dominant at large-angular scales

Shirasaki, Horiuchi, NY 2014

4 fields: 154 deg^2

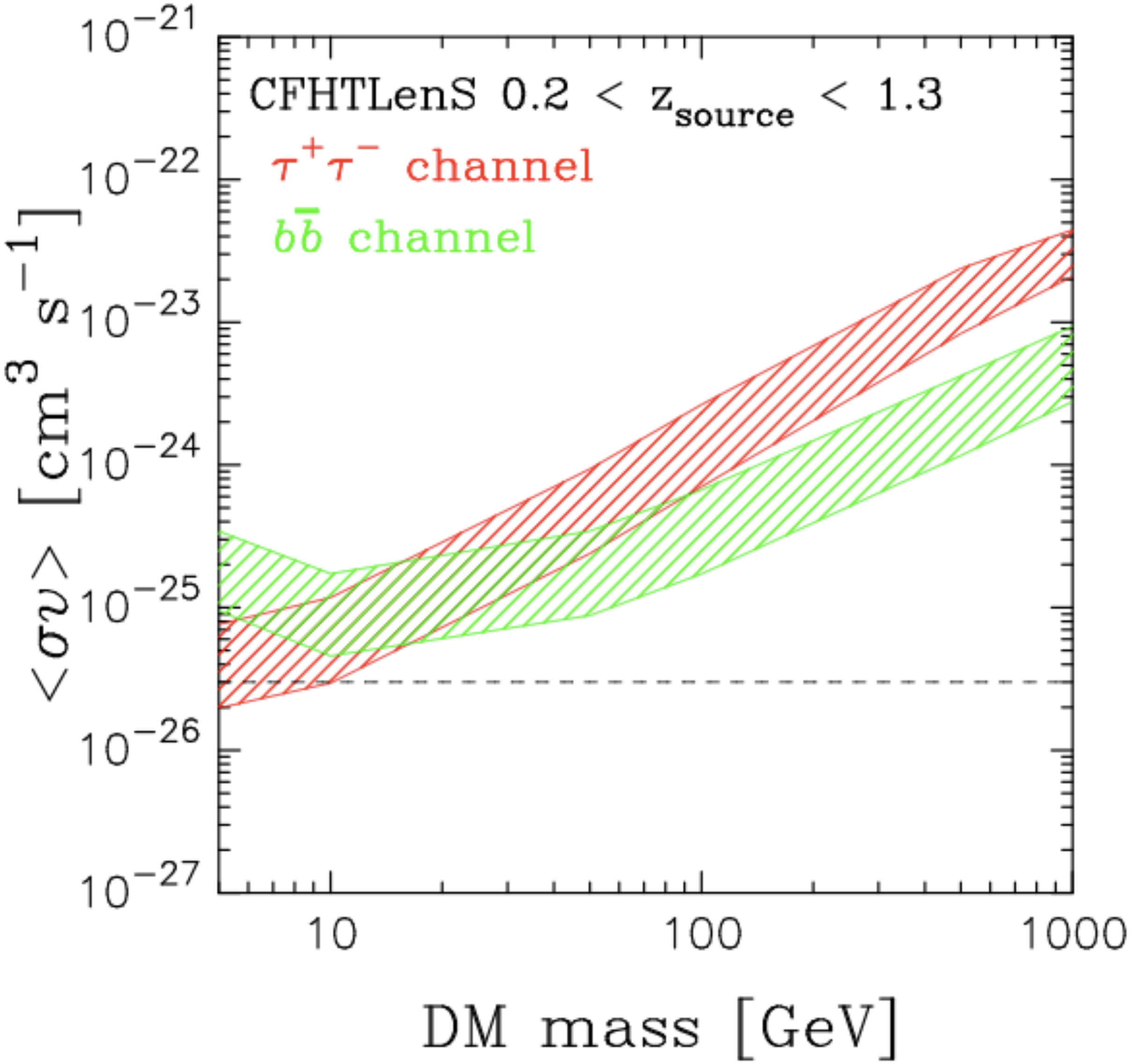


$$\xi_{\delta n-\gamma_t}(\theta) = \frac{\sum_{ij}(n_i^{\rm obs}(\boldsymbol{\phi}_i) - n_i^{\rm gm}(\boldsymbol{\phi}_i))w_j\epsilon_{t,j}(\boldsymbol{\phi}_i + \boldsymbol{\theta}_j)}{(1+K(\theta))\sum_{ij} w_j}$$

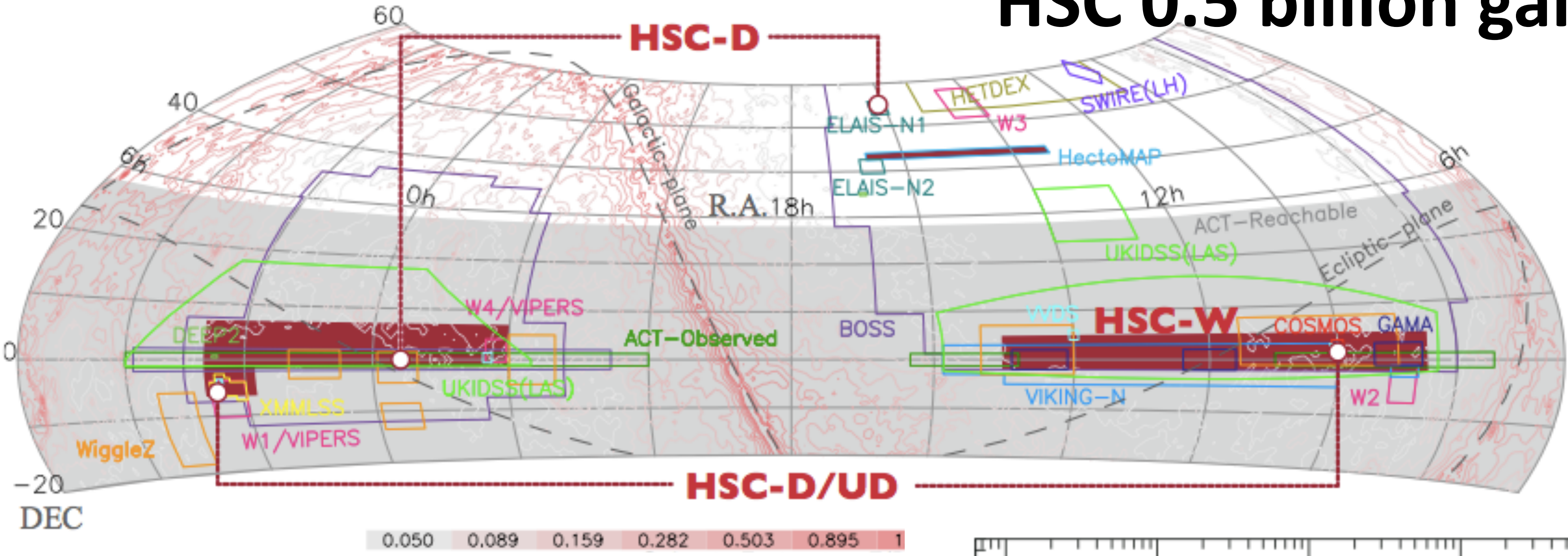


CFHT-Fermi cross-correlation

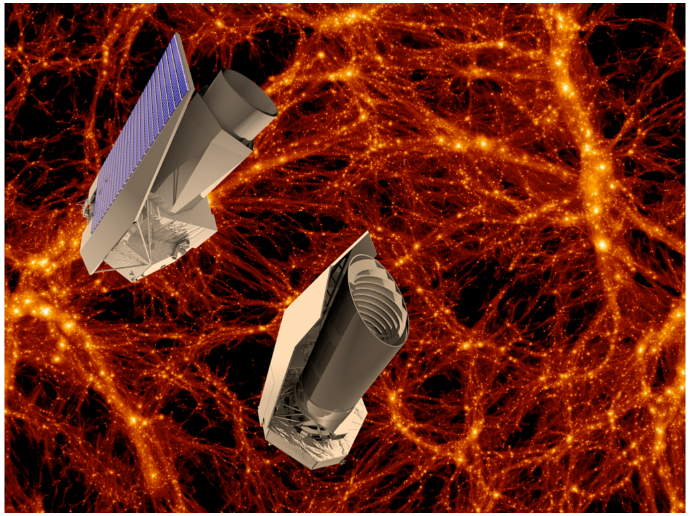
$\langle \sigma v \rangle$



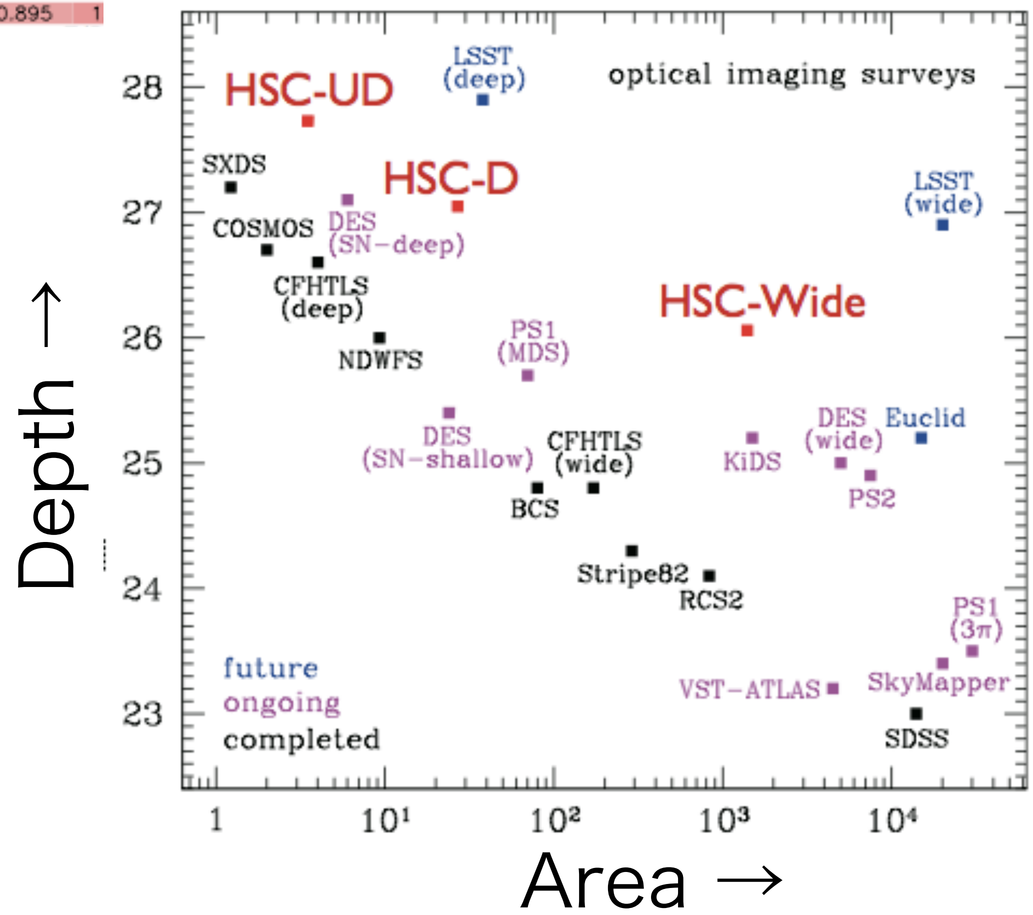
HSC 0.5 billion galaxies



Euclid (2020-)

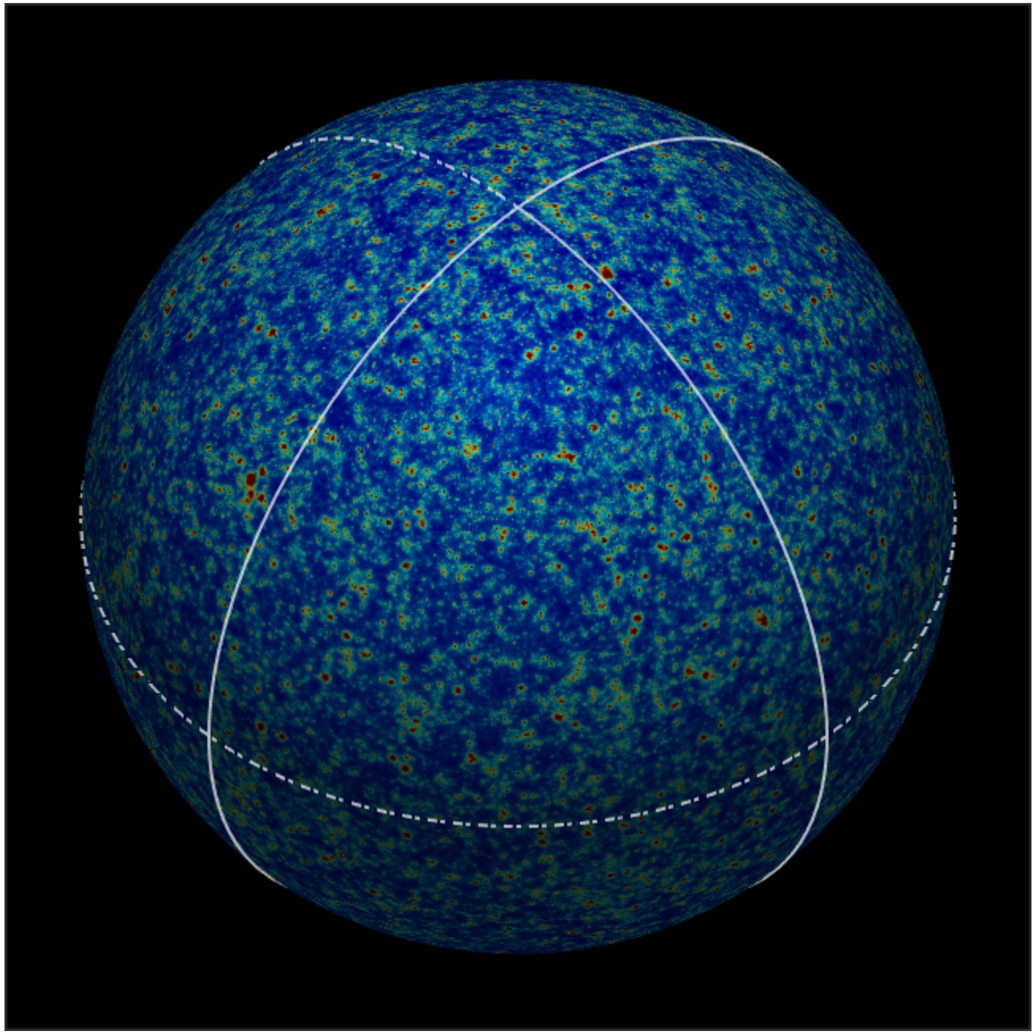


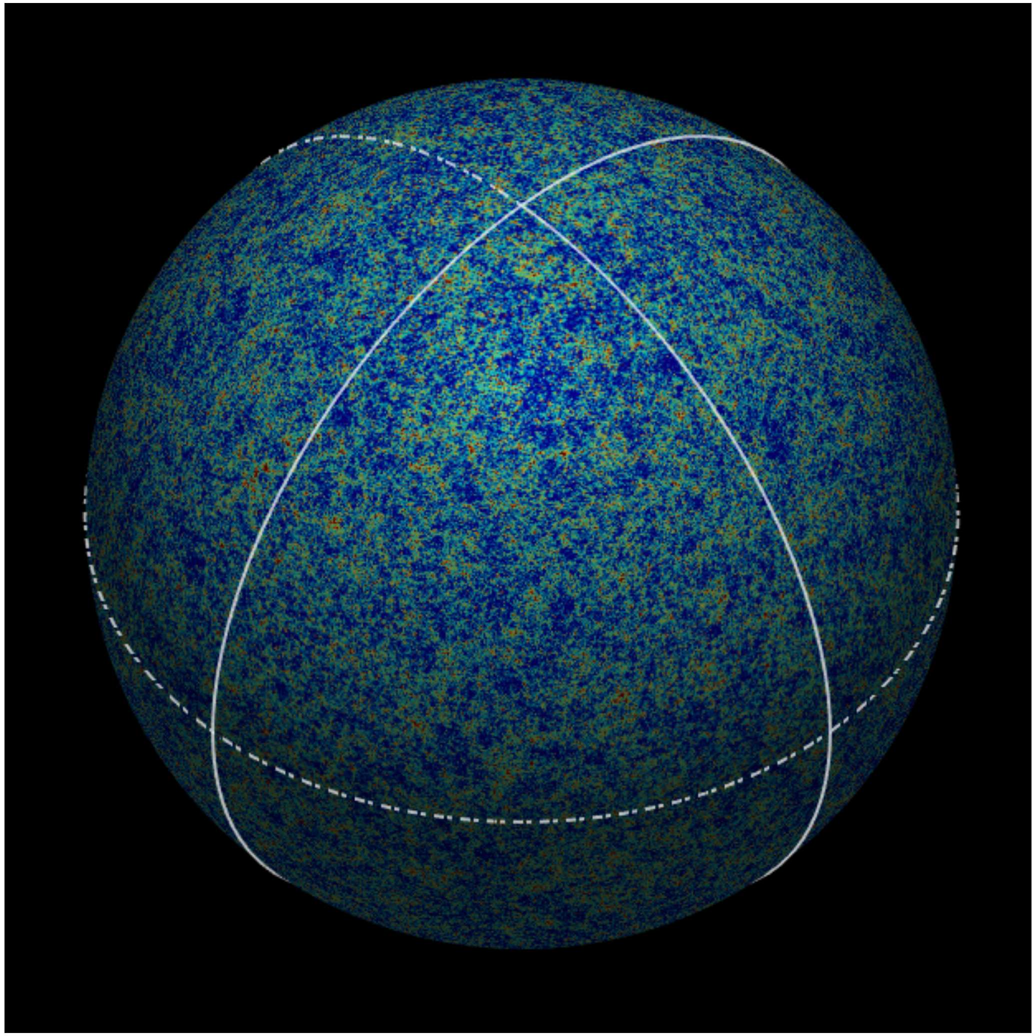
Dark matter, dark energy, test of gravity



All-sky simulation

Extra-galactic γ-ray (θ_{pix} ~ 0.2 deg) Weak lensing(θ_{pix} ~ 1 arcmin)

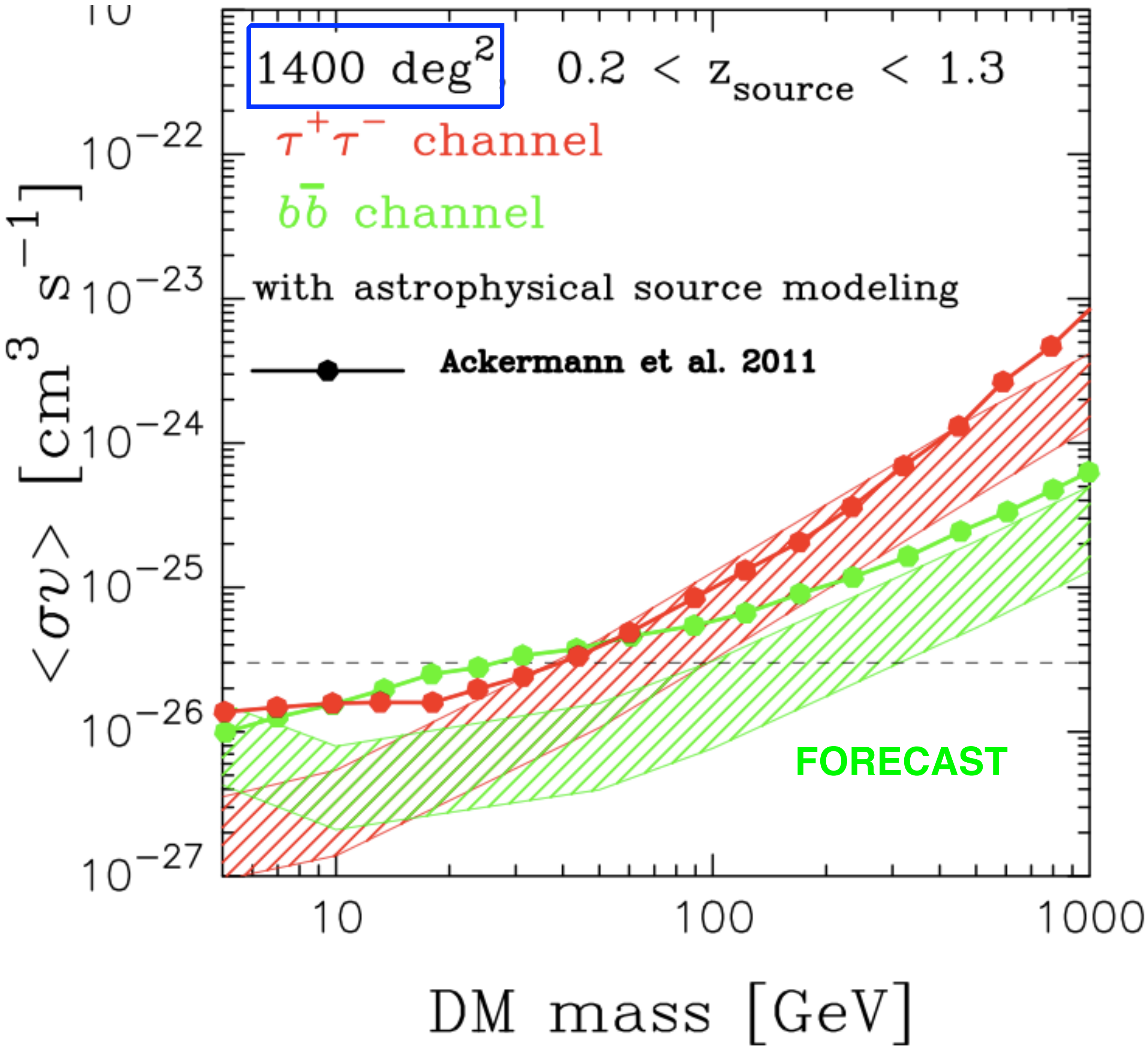




100 GeV, thermal cross section bb channel

Many HSC mocks

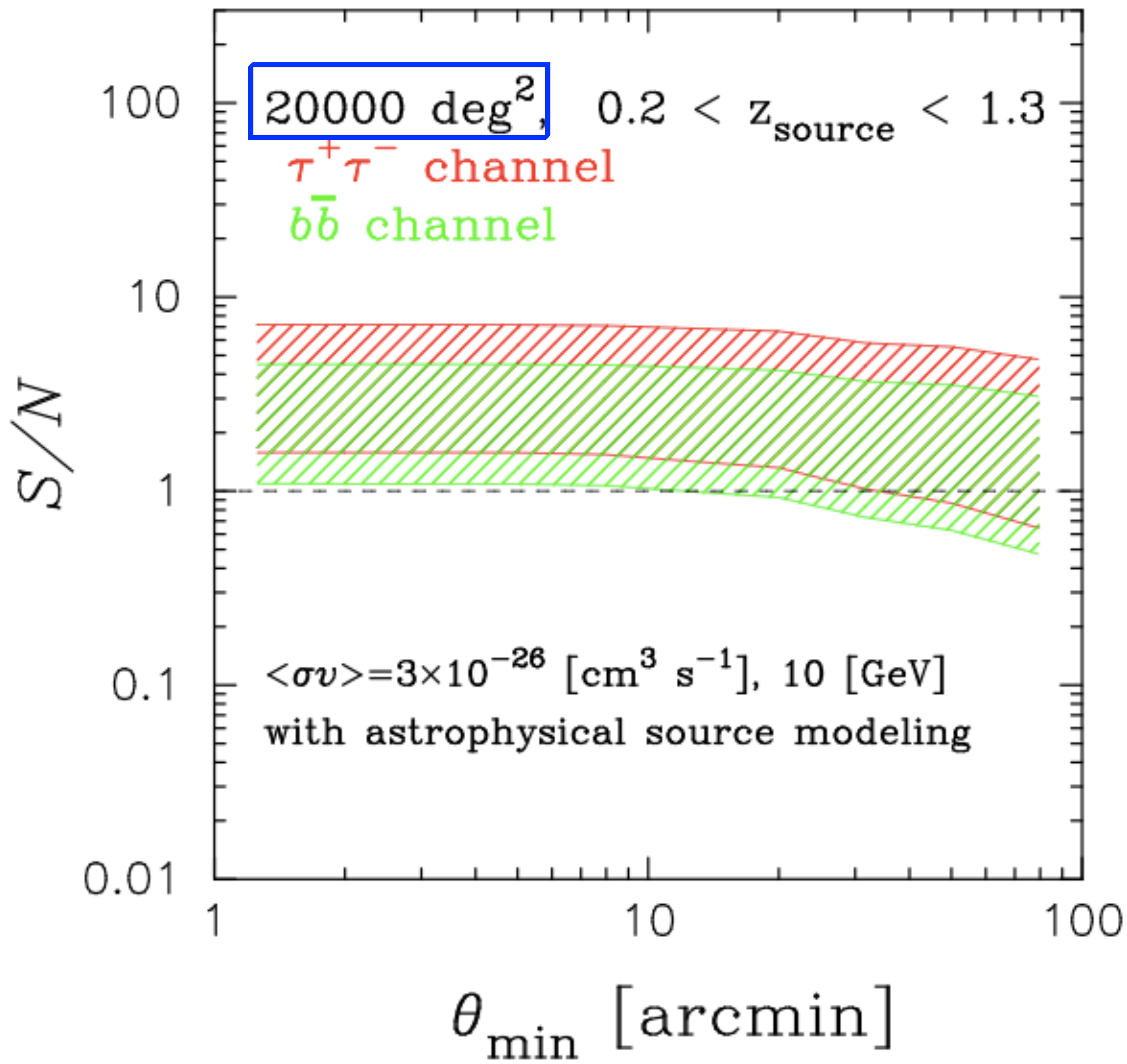
We'll use HSC!!!



1400 deg^2, 0.2 < z_{source} < 1.3
$\tau^+\tau^-$ channel
$b\bar{b}$ channel
with astrophysical source modeling
Ackermann et al. 2011
FORECAST
$<\sigma v>$ [cm^3 s^{-1}]
DM mass [GeV]

With LSST…

DETECTION with 3-5σ confidence is possible！！！



← This bound derived from the current Fermi data (only 4 years) and the current SFG/blazer model.

Galaxy distribution at high redshift

The Astrophysical Journal Letters, 780:L18 (5pp), 2014 January 10 doi:10.1088/2041-8205/780/2/L18

ALMA WILL DETERMINE THE SPECTROSCOPIC REDSHIFT $z > 8$ WITH FIR [O III] EMISSION LINES

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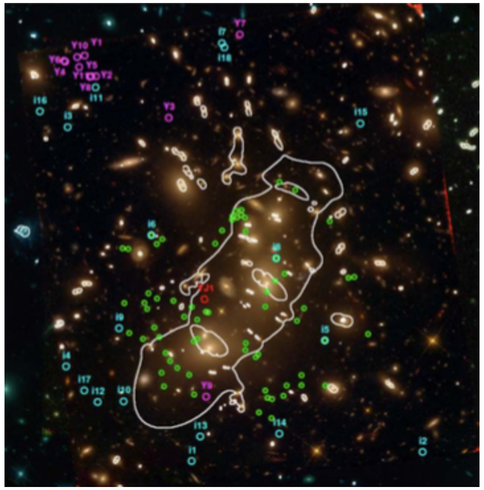
ABSTRACT

We investigate the potential use of nebular emission lines in the rest-frame far-infrared (FIR) for determining spectroscopic redshift of $z > 8$ galaxies with the Atacama Large Millimeter/submillimeter Array (ALMA). After making a line emissivity model as a function of metallicity, especially for the [O III] 88 μm line which is likely to be the strongest FIR line from H II regions, we predict the line fluxes from high-z galaxies based on a cosmological hydrodynamics simulation of galaxy formation. Since the metallicity of galaxies reaches at $\sim 0.2\,Z_\odot$ even at $z > 8$ in our simulation, we expect the [O III] 88 μm line as strong as 1.3 mJy for 27 AB objects, which is detectable at a high significance by <1 hr integration with ALMA. Therefore, the [O III] 88 μm line would be the best tool to confirm the spectroscopic redshifts beyond $z = 8$.

Key words: cosmology: observations – galaxies: evolution – galaxies: high-redshift

Online-only material: color figures

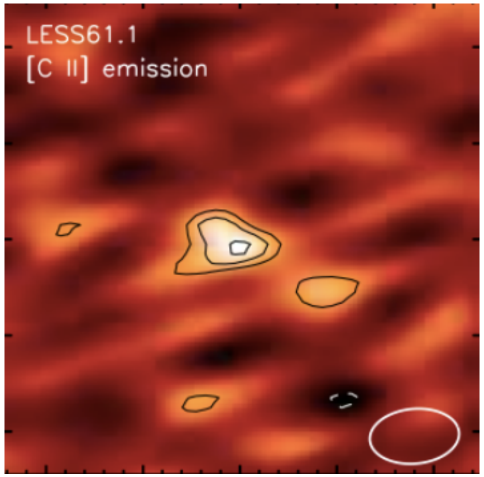


Hydrogen Ly-α

No sample at z > 8 (IGM abs.?)

UV/optical line

Target of JWST/TMT. Bright lines such as [OII]3727, [OIII]4959,5007. Recent success of CIII]1909@z=2。



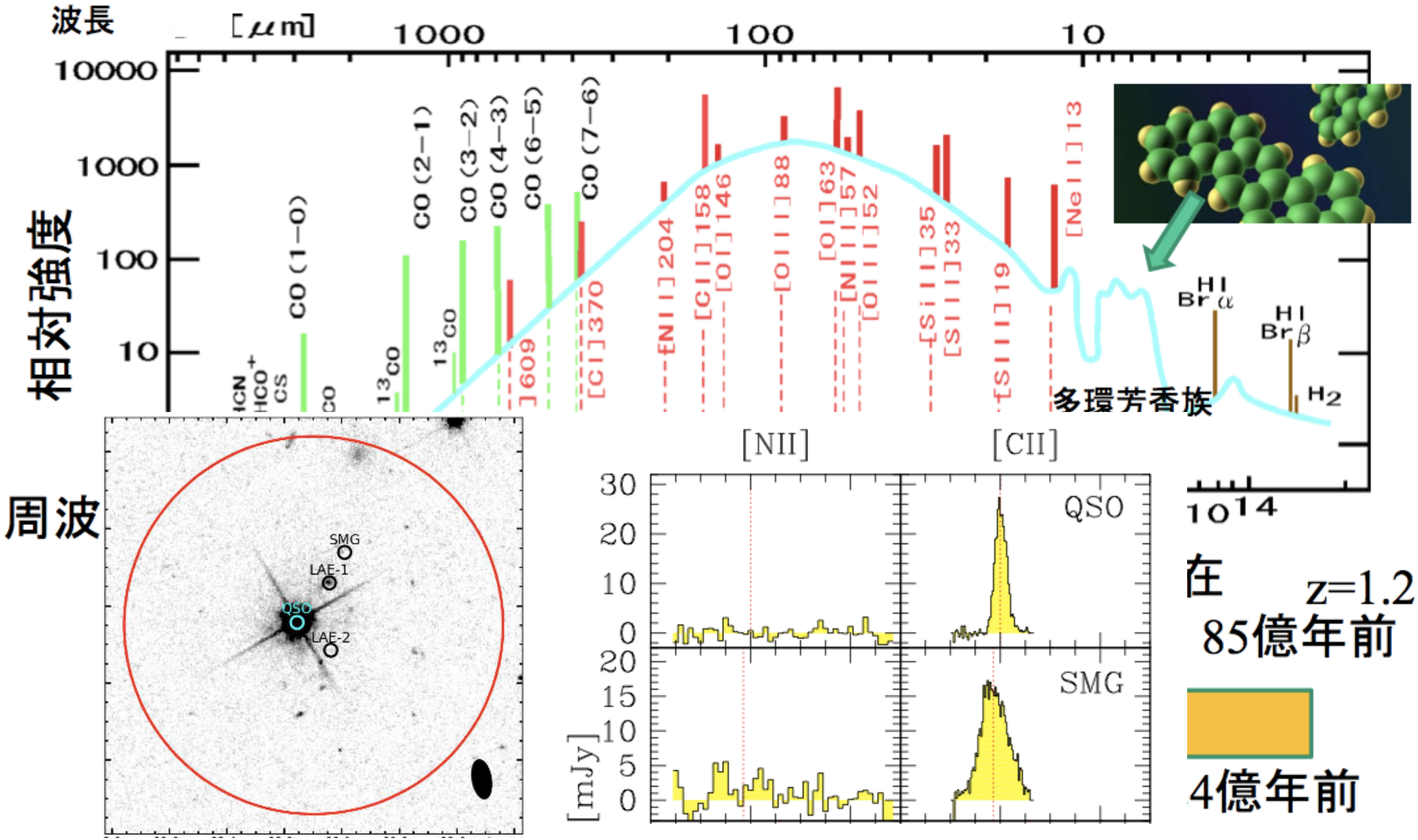
[CII] 158μm

ALMA detection@high-z. From PDR.

[OIII] 88μm

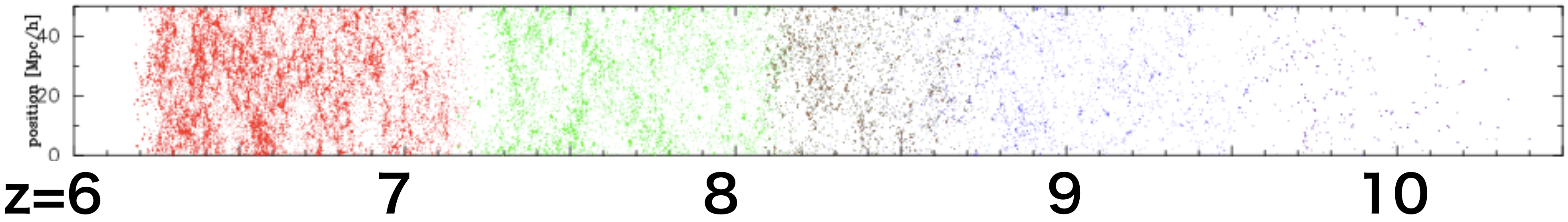
From HII regions, simple emission process.

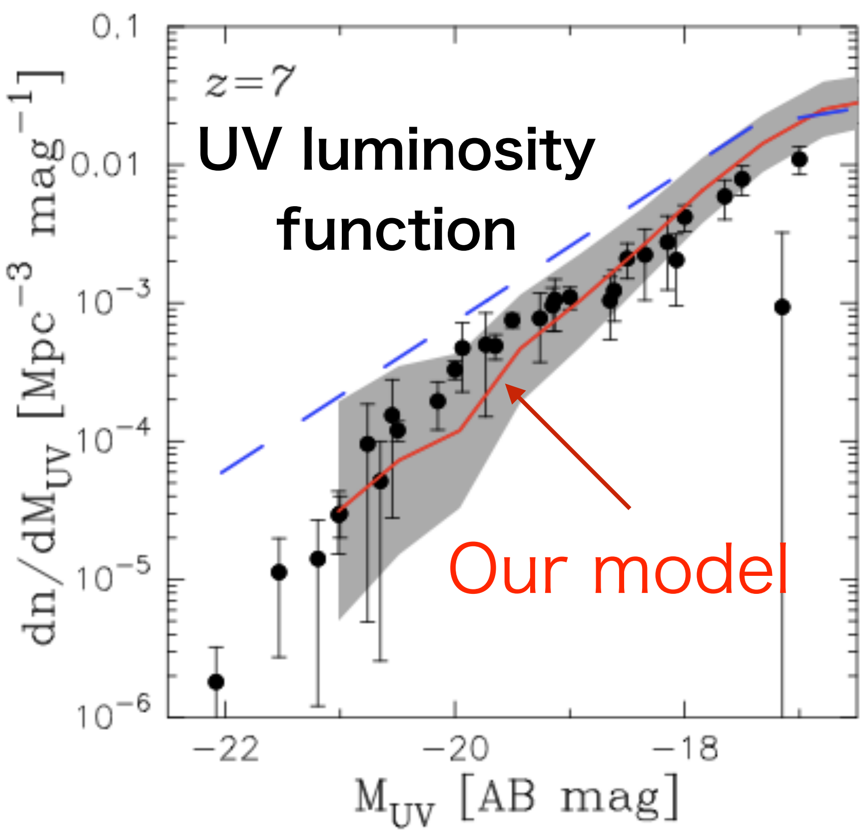
Submm lines

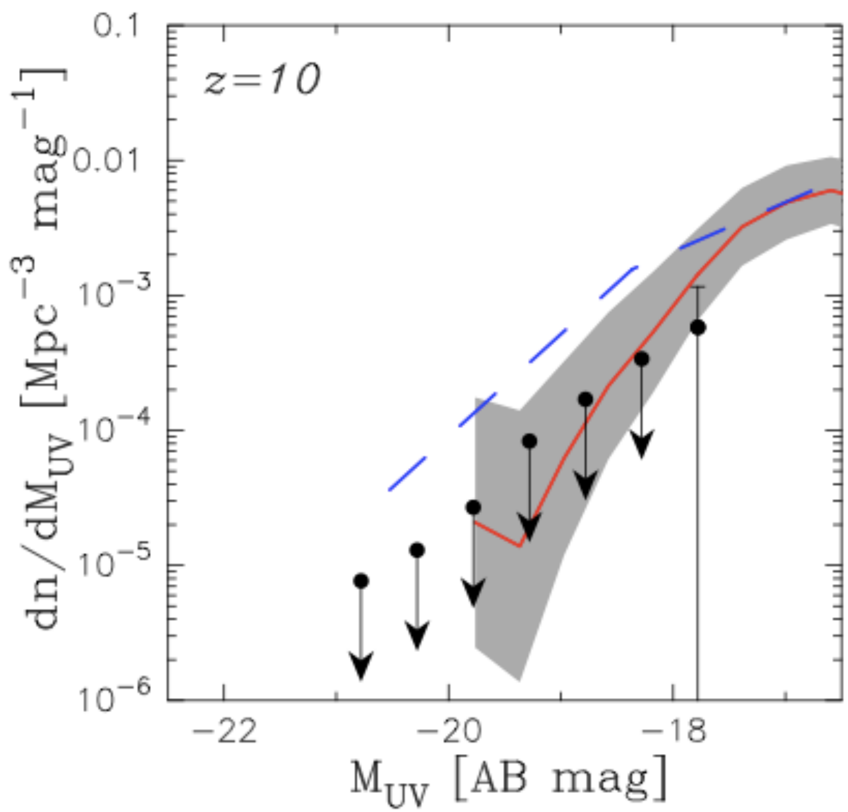


波長 [μm]
1000
100
10
10000
1000
100
10
相対強度
CO (1−0)
CO (2−1)
CO (3−2)
CO (4−3)
CO (6−5)
CO (7−6)
[NII]204
[CII]158
[OI]146
[OIII]88
[OI]63
[NIII]57
[OIII]52
[SiII]35
[SIII]33
[SIII]19
[NeII]13
HI Brα
HI Brβ
H2
多環芳香族
周波
在
z=1.2
85億年前
4億年前
SMG
LAE-1
QSO
LAE-2
[NII]
[CII]
QSO
SMG
[mJy]

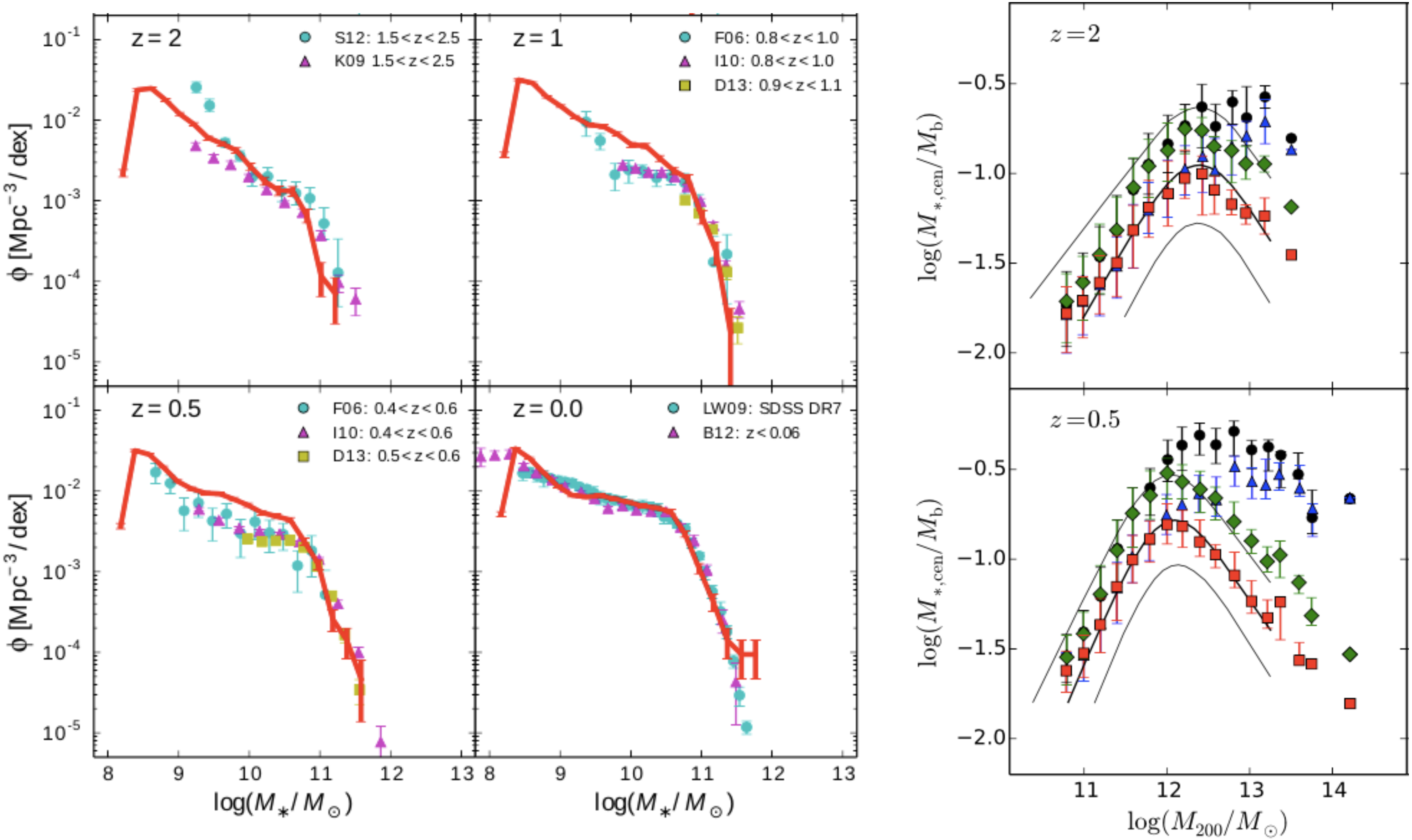
Cosmological simulations



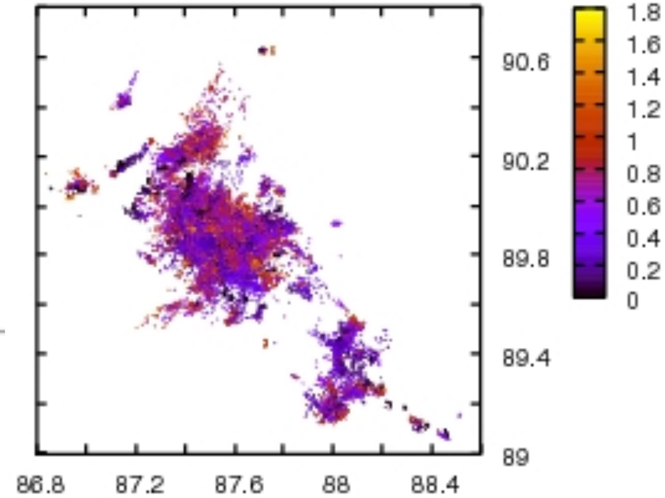




Reproduce SMF at z < 4



Galaxy SED



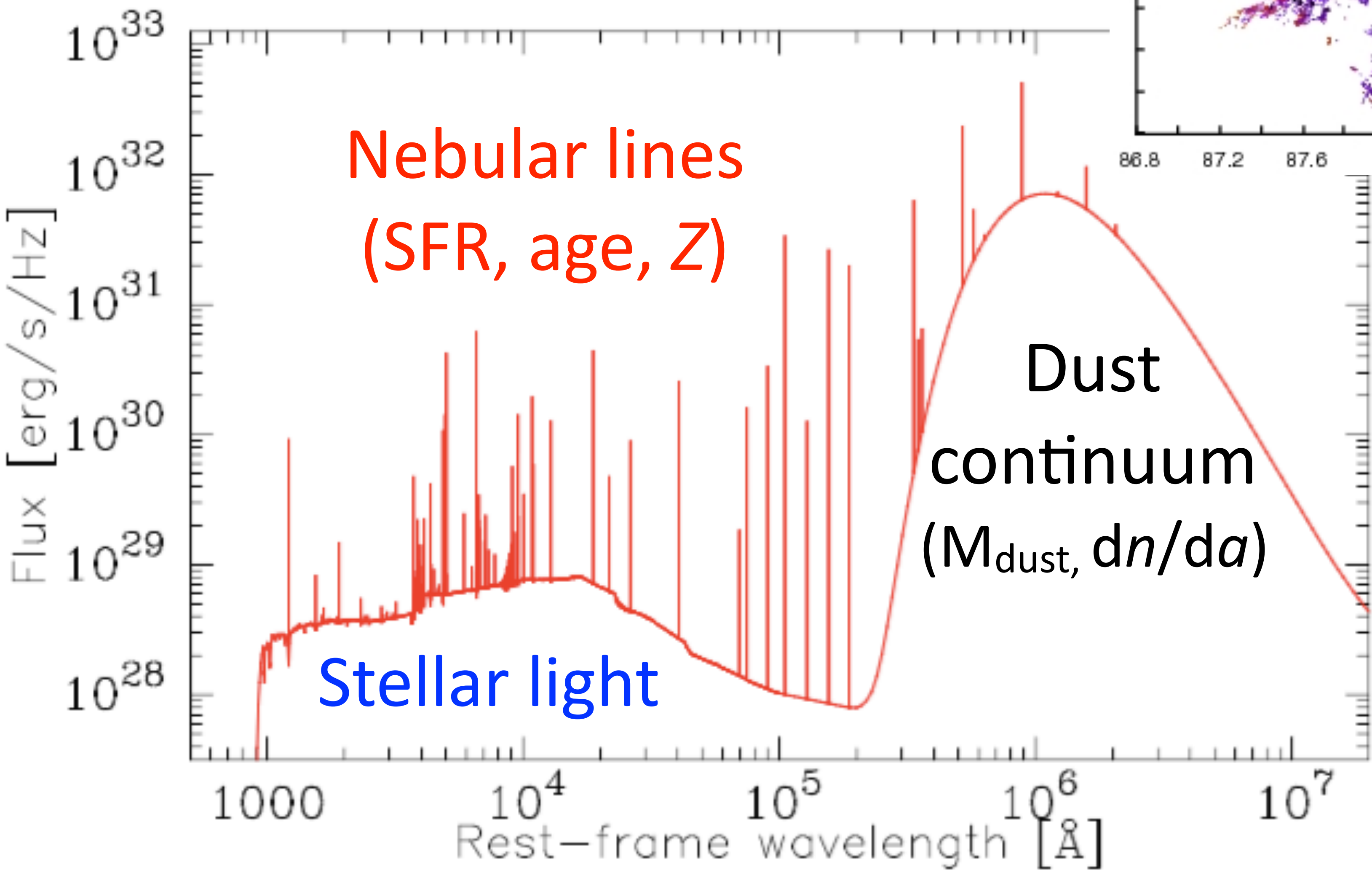
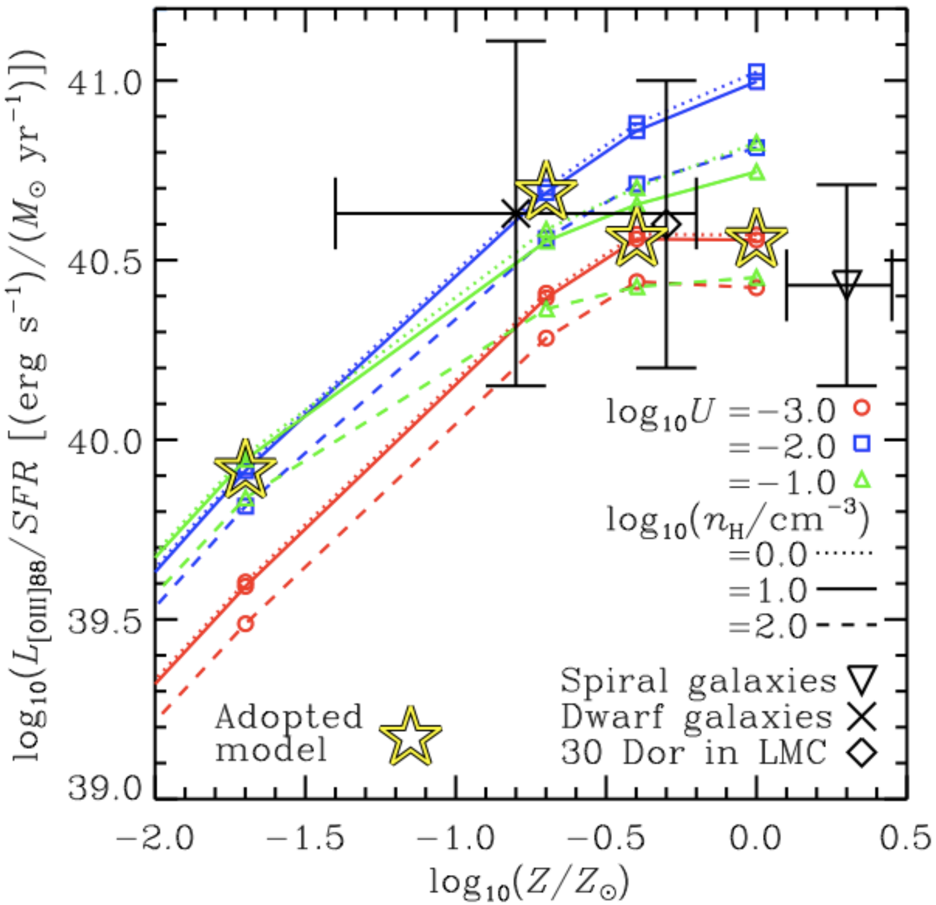
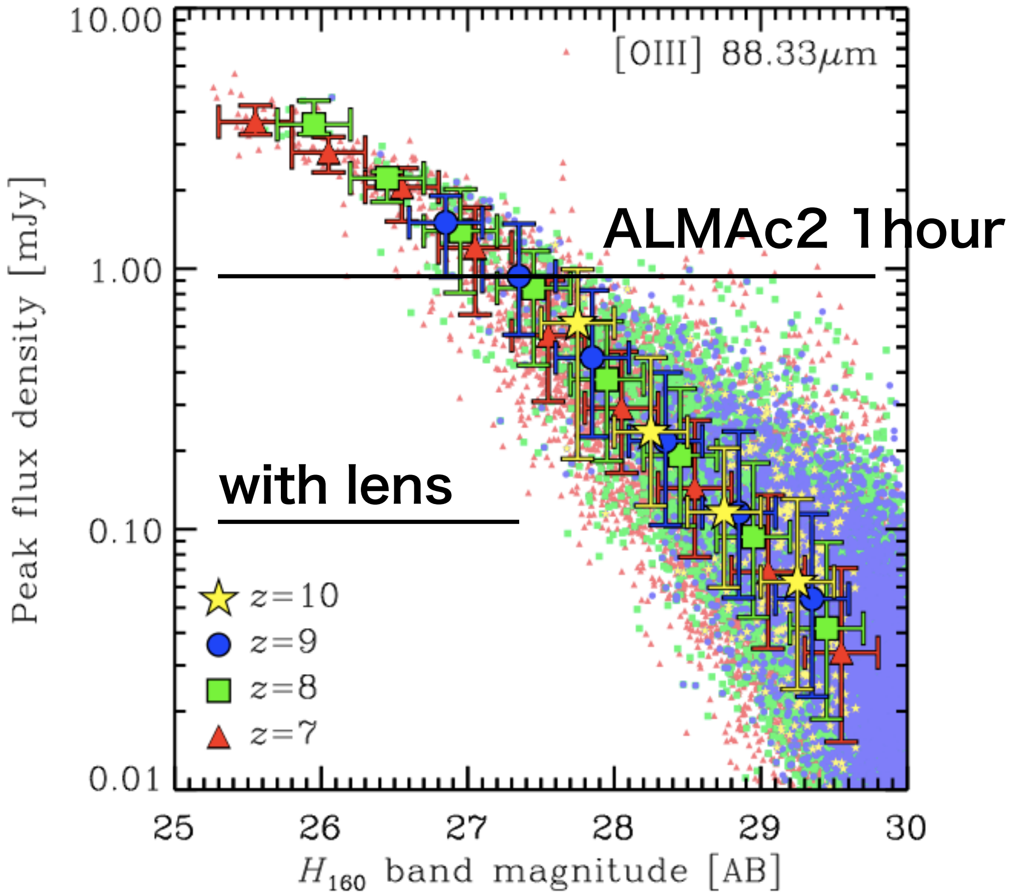


Figure 3. The spectral energy distributions of a simulated galaxy without the IGM attenuation.

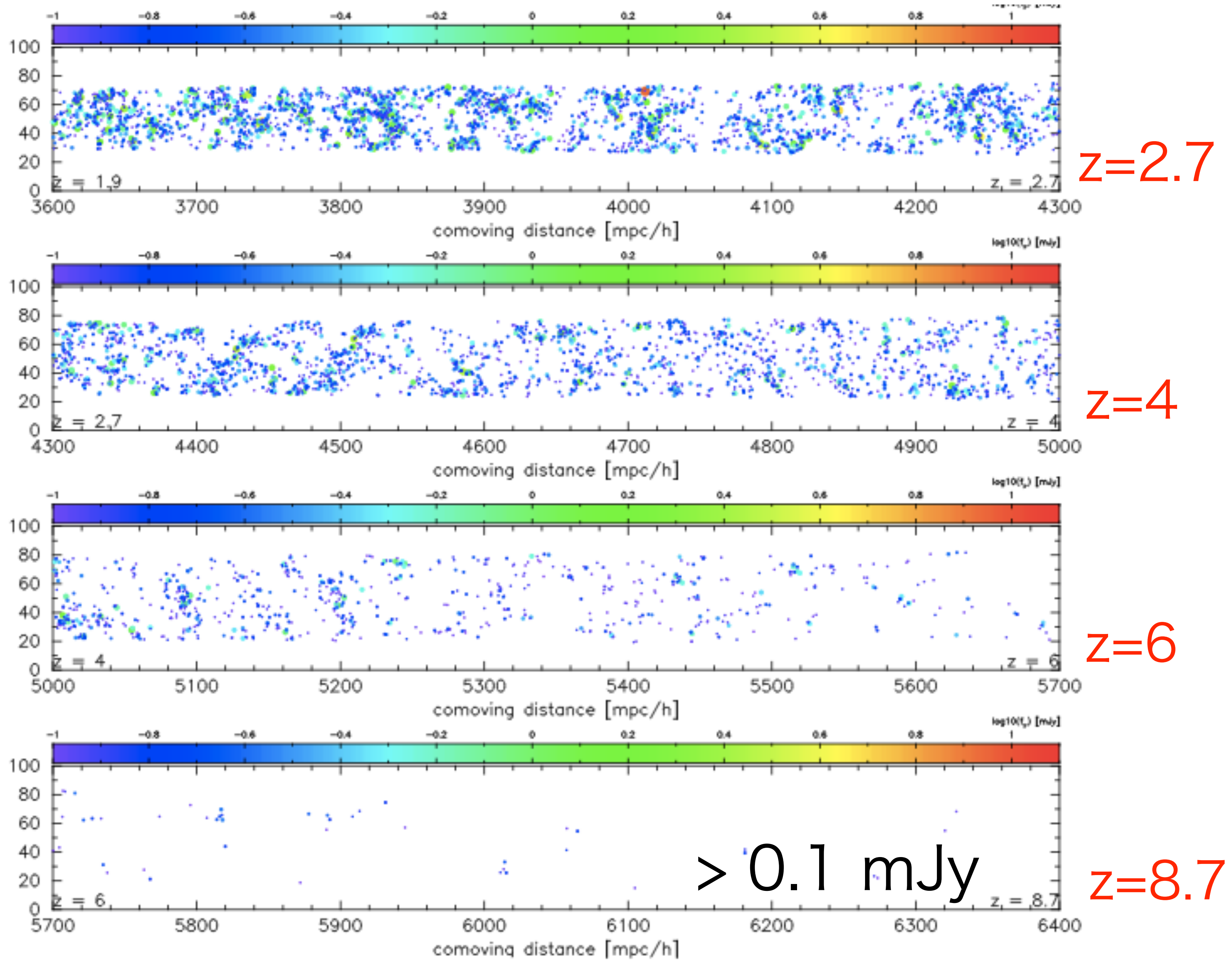
OIII emitters

Cosmo. simulation (Inoue, Shimizu, NY 2014, ApJL)





Submm galaxies on the light-cone



Discovery by ALMA!

Inoue et al. submitted

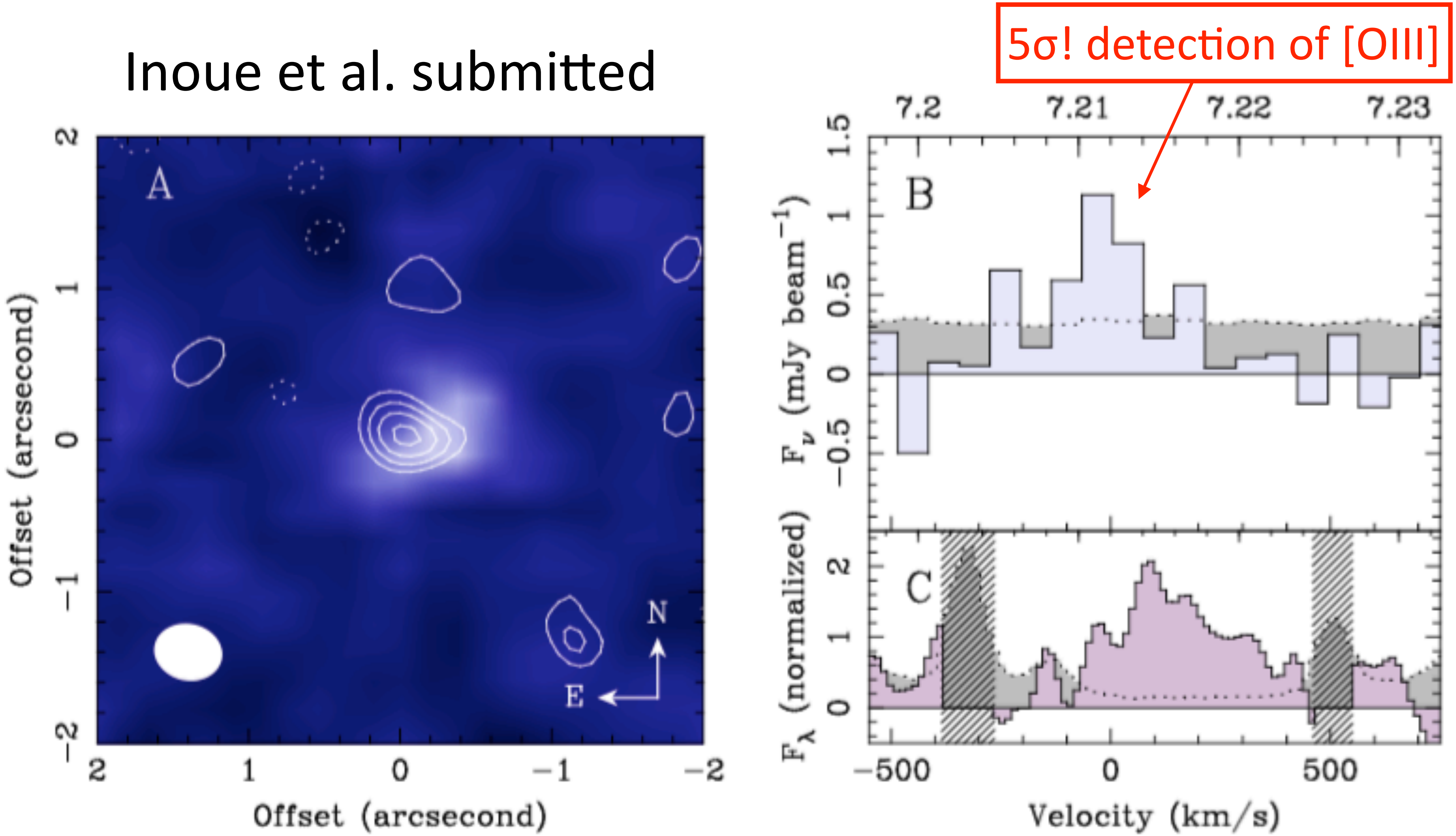
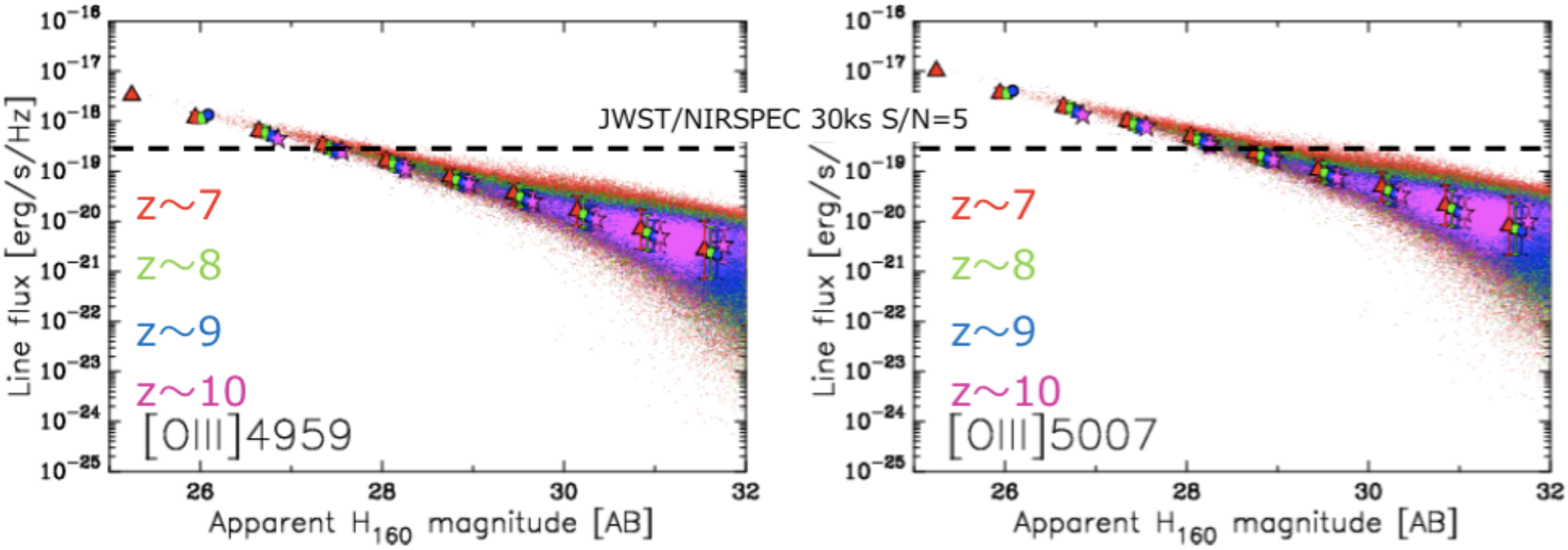


Figure 1: The [O III] 88 μm and Lyα emission images and spectra of SXDF-NB1006-2. (A) ALMA [O III] 88 μm image (contours) is overlaid on Subaru narrow-band Lyα image.

In near future, with JWST

[OIII]4959 & [OIII]5007

[OIII]4959, [OIII]5007 → ∼ 5 micron for z ∼ 9



Summary

On going and planned wide surveys can be used to map dark matter distribution, to probe the nature of dark matter and dark energy. Multi-wave correlation analysis will be a key technique.

Line emitters as new tracer of large-scale structure at high redshift (ALMA, SPICA)