SDSSの現状と今後

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2007年9月1日　RESCEU夏の学校＠強羅静雲荘

SDSS

米国ニューメキシコ州
アパッチポイント天文台

SDSSのまとめ

- First light：１９９８年５月
- SDSS-I ：　２０００年４月～２００５年６月
  - ８０００平方度、２億個の天体の撮像
  - 星１８．５万、銀河６７．５万、クエーサー９万の分光
- SDSS-II：２００５年６月～２００８年６月
  - The Sloan Legacy Survey：銀河８６万、クエーサー１０．５万
  - SEGUE (Sloan Extension for Galactic Understanding and Exploration)：星２４万
  - The Sloan Supernova Survey: 南天３００平方度の複数スキャン

Japan Participation Group

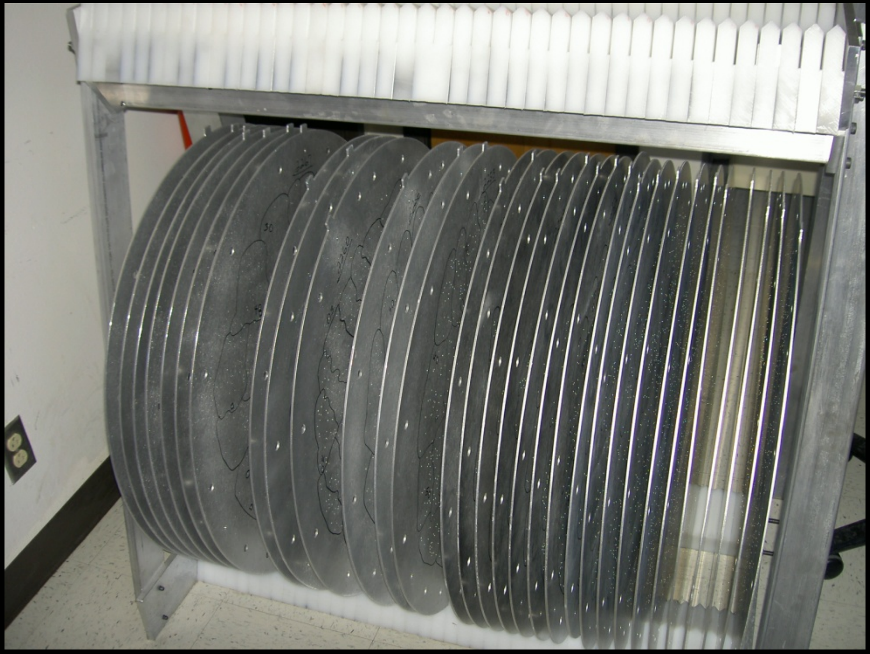
- １９９１年ワーキンググループ結成
- １９９２年　MOUの時点では、池内了、市川伸一、市川隆、岡村定矩、須藤靖、関口真木、土居守、濱部勝、福来正孝
- その後、嶋作一大、安田直樹、渡辺大、佐藤勝彦、松原隆彦が参加して、現在に至る
- １９９５年にRESCEUが発足して以来、JPGの多くがRESCEUのメンバー（岡村、須藤、土居、嶋作、佐藤）となった。また資金的にも多くの貢献をした。

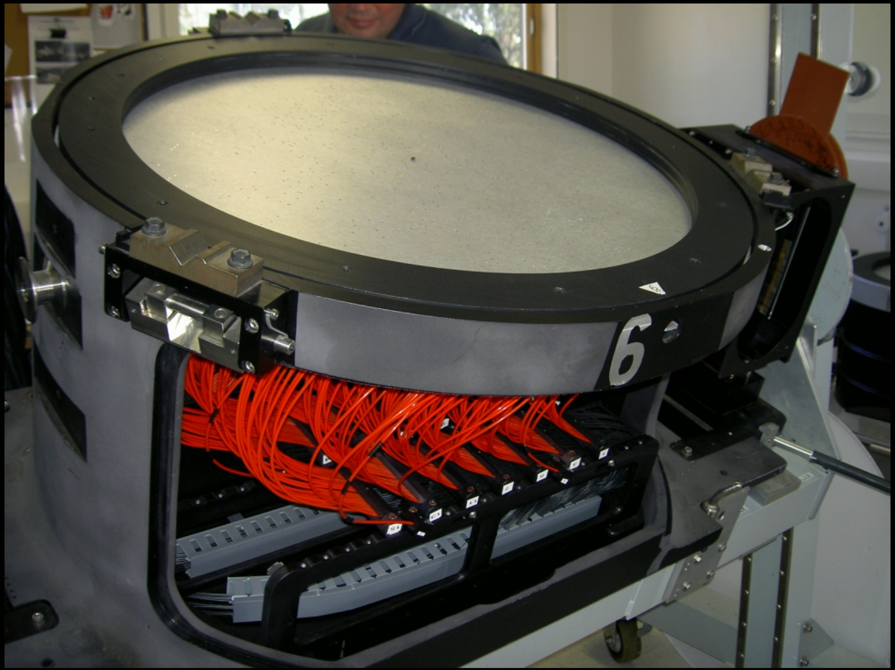
JPGの科学的貢献

- JPGは基礎的かつ重要な科学的貢献をした
  - モザイクカメラの製作（関口）
  - フィルターの製作（嶋作、土居、福来ほか）
  - 標準星の決定と較正（市川、嶋作、福来ほか）
  - 測光パイプラインの開発（安田ほか）
  - 重力レンズサーベイ（稲田、大栗ほか）
  - KL変換を用いた構造の定量化（松原）

RESCEU資金の主要な活用先

- Drilled plug plates (1枚712ドル)x1285枚≒1億円(この半分程度がRESCEUより)
- SDSSはRESCEU(が買わなかった穴)を通して空を見ている！





SDSS papers have had huge impact

- 1345 refereed papers to date
- These papers have been cited over 39,000 times
- 30 of the 200 most cited papers in astronomy since 2000 used SDSS data.
- Impact in many areas we didn't anticipate:
  - White dwarfs
  - Brown dwarfs
  - Ultra-low metallicity stars
  - Galaxy-galaxy lensing
  - Supernovae
  - Epoch of reionization
  - etc.

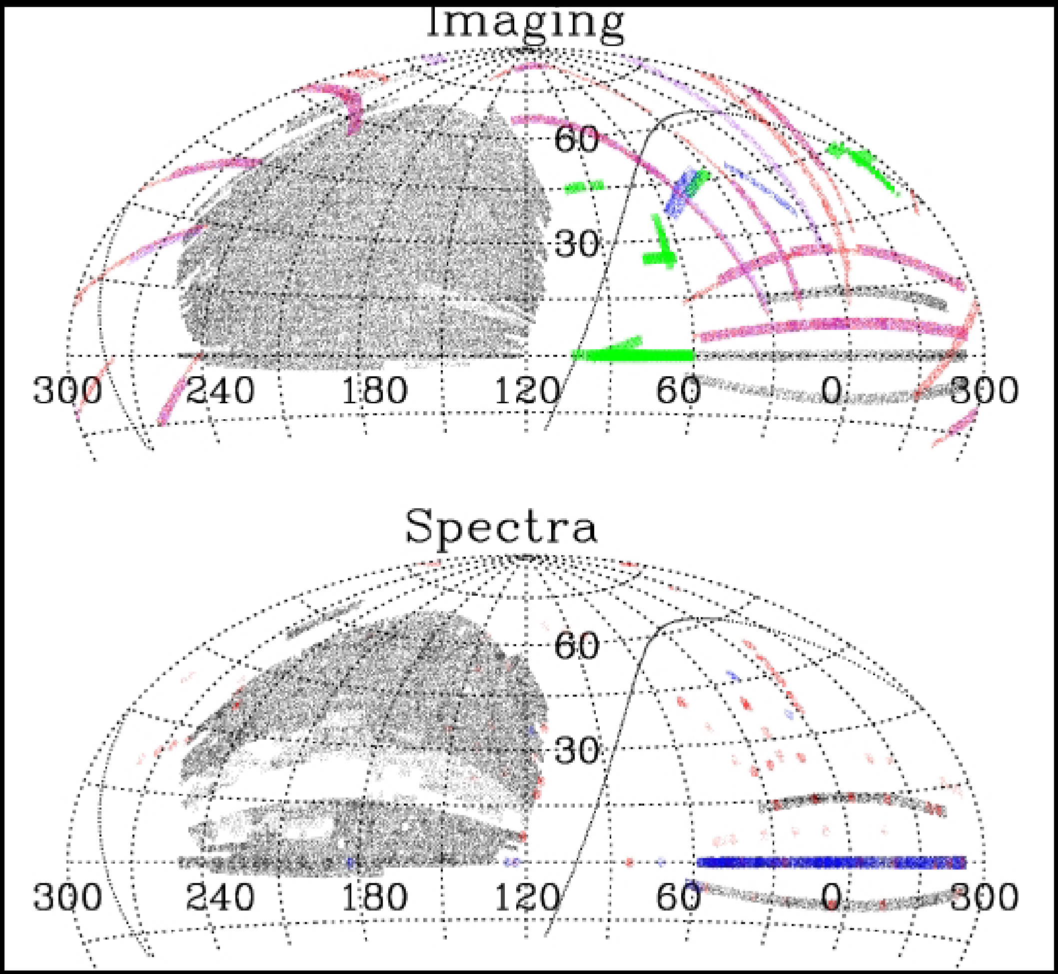
(Dec. 19, 2006@NAOJ, Michael Strauss)

ADS High-Impact Papers 2006

Facility	Number of Citations	Fraction of the Total
SDSS	1843	17.4%
ESO	1365	12.9%
HST	1124	10.6%
WMAP	1121	10.6%
Keck	642	6.0%
Kamiokande	372	3.5%
Chandra	365	3.4%
ACBAR	207	2.0%
NOAO (KPNO/CTIO)	202	1.9%
Las Campanas	176	1.7%

(Dec. 19, 2006@NAOJ, Michael Strauss)

SDSS DR6

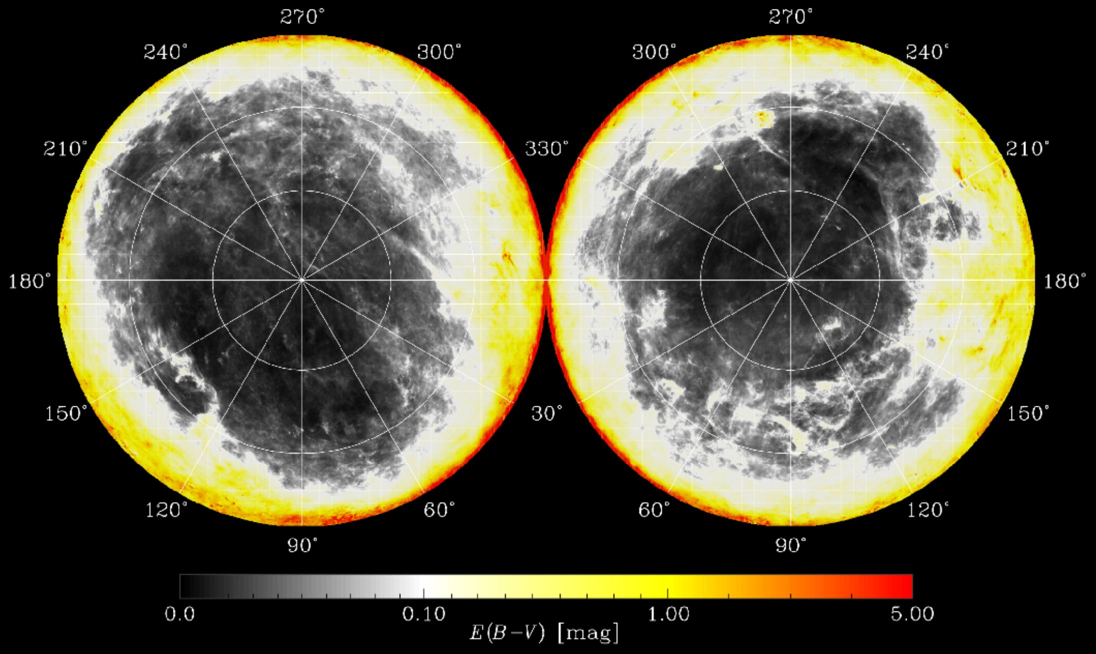


- The sixth data release of the Sloan Digital Sky Survey Adelman-MaCarthy et al. astro-ph 0707.3413
  - 287 million objects over 9583 deg^2
  - 790,860 galaxy spectra
  - 103,647 quasar spectra
  - 287,071 star spectra

Recent work related to SDSS at University of Tokyo: 鶏口牛後

- genus statistics and phase correlation of SDSS galaxies (Hikage et al. 2003, 2004,2005; Hikage, Matsubara, and Suto 2004; Park et al. 2005)
- 3pt correlation functions of SDSS galaxies (Kayo, Suto, Nichol et al. 2004)
- 2pt correlation functions of SDSS quasars and cosmological constant (Yahata et al. 2005)
- constraints on the deviation from Newton's law of gravity from SDSS galaxy power spectrum (Shirata, Shiromizu et al. 2005,2007; Yamamoto et al. 2006)
- testing the Galactic dust map against SDSS galaxy number counts (Yahata et al. 2006)
- Bispectrum and nonlinear biasing (Nishimichi et al. 2007)

Galactic extinction map vs. galaxy number counts

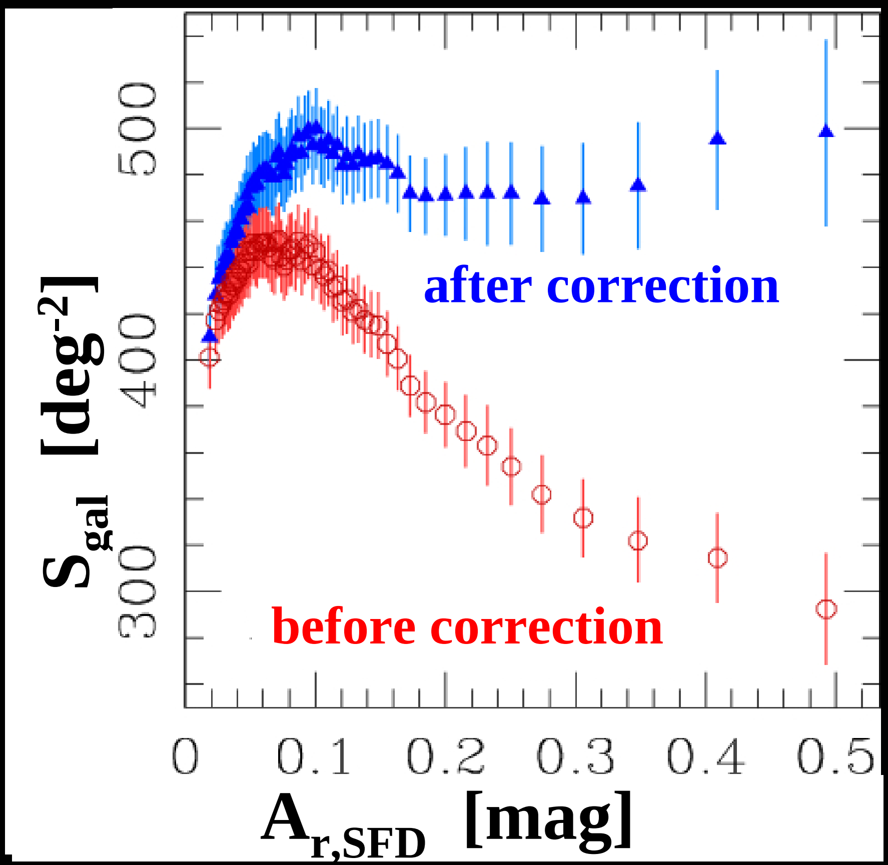


Galactic extinction map by Schlegel, Finkbeiner & Davis (1998: SFD)

- dust extinction estimated from *IR emission*
- can be used for *absorption correction* ???
- independent consistency check is needed

galaxy surface density S_{gal} vs. SFD extinction A_{SFD}

- ***If A_{SFD} is perfect***
  - **smaller S_{gal} at larger A_{SFD} before correction**
  - **constant S_{gal} after correction**



- confirmed for A_{SFD} >0.1, but *quite the opposite for A_{SFD} <0.1*
  - 68% of the SDSS survey area has A_{SFD} <0.1 !
- ***What's wrong ?***

Yahata, Yonehara, Suto, Turner, Broadhurst & Finkbeiner (2006)

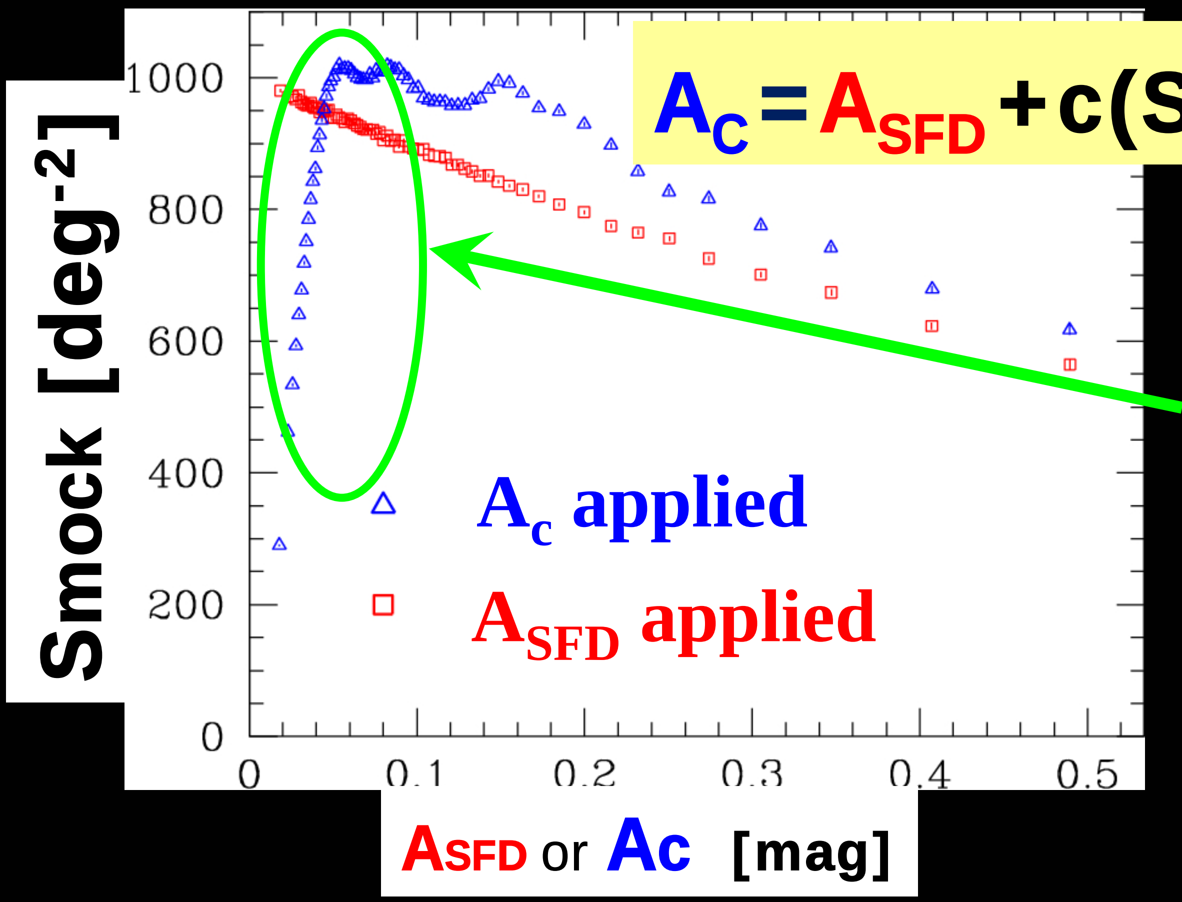
Origin of the anomaly ?

- A_{SFD} is estimated assuming that the reddening is proportional to the Far-infrared 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 ???

simulations to test the hypothesis

- **Poisson distributed galaxies in each pixel over the entire survey area**
  - ***assume that*** **A_{SFD} = true Galactic extinction, and *add* galaxy FIR contribution according to**

$$A_C = A_{SFD} + c(S_{mock} - \langle S_{mock} \rangle)$$



- **The use of A_C indeed reproduces the observed trend !**

Yahata et al. (2006) astro-ph/0607098

Tiny but systematic error in A_{SFD}

- **a typical amplitude of the systematic error in A_{SFD} is ～0.01mag**
  - c.f., mean flux of the background IR which was removed in making the SFD map is ～ 0.04 mag
- **this is tiny, but systematic**
  - S_{gal} ↑ ⇒ A_{dust} ↑ ⇒ S_{gal} ↑↑ becomes even larger after correction for A_{dust}
  - systematically overestimates the contrast of real structure
- **maybe important for precision measurements**

modified gravity vs. cosmological constant: from SDSS to WFMOS

Yamamoto, Bassett, Nichol, Suto & Yahata

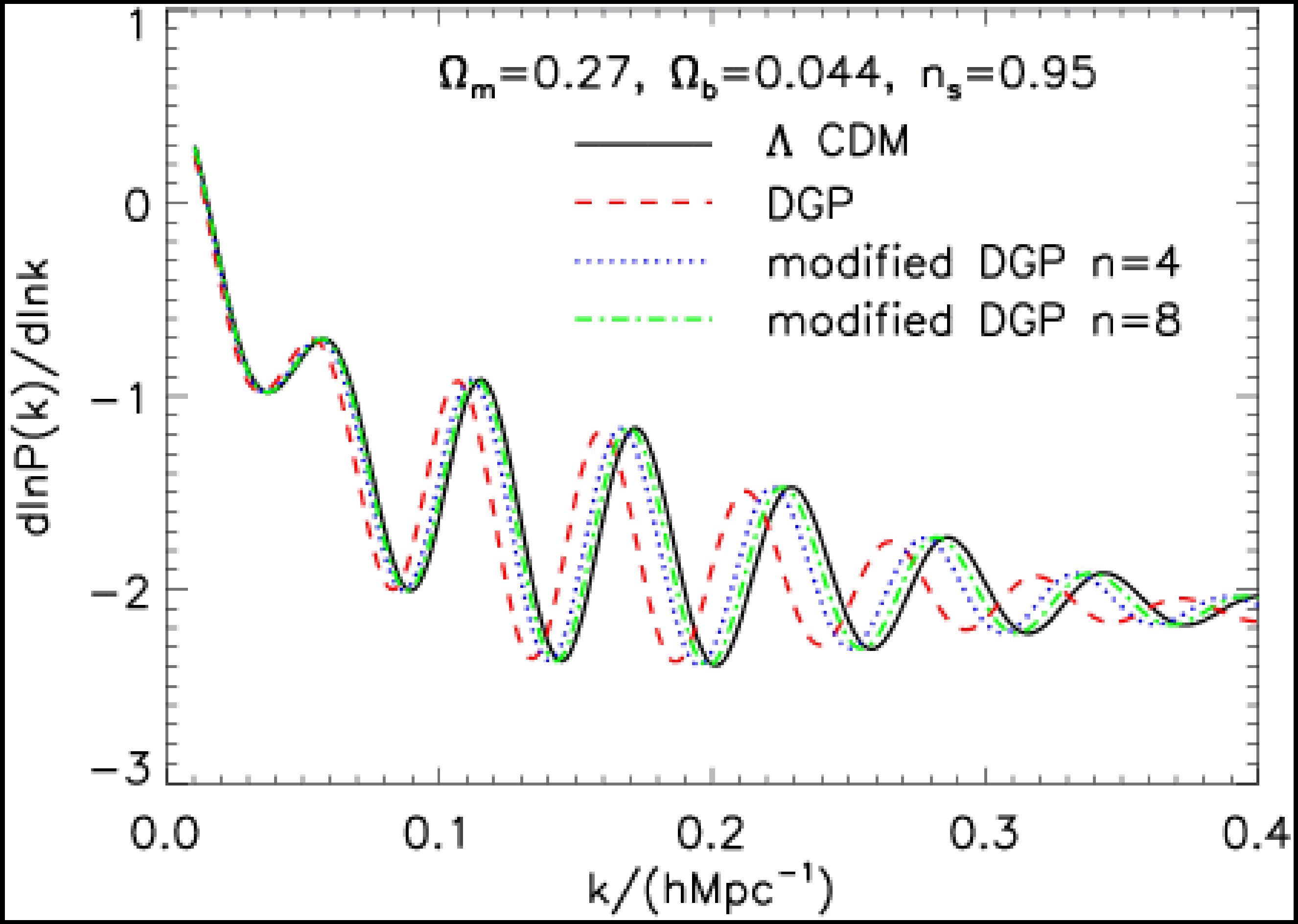
PRD 74(2006)063525

- modified Friedmann equation (spatially flat)

$$H^2 - \frac{H^{2/n}}{r_c^{2-2/n}} = \frac{8\pi G}{3}\rho$$

  - n=2: DGP model, n=∞ : cosmological constant
- r_c: key parameter ～1/H_0
  - $r<r_c$: 4D space-time, $r>r_c$: 5D space-time
  - if spatially flat $(H_0 r_c)^{2/n-2} = 1 - \Omega_m$

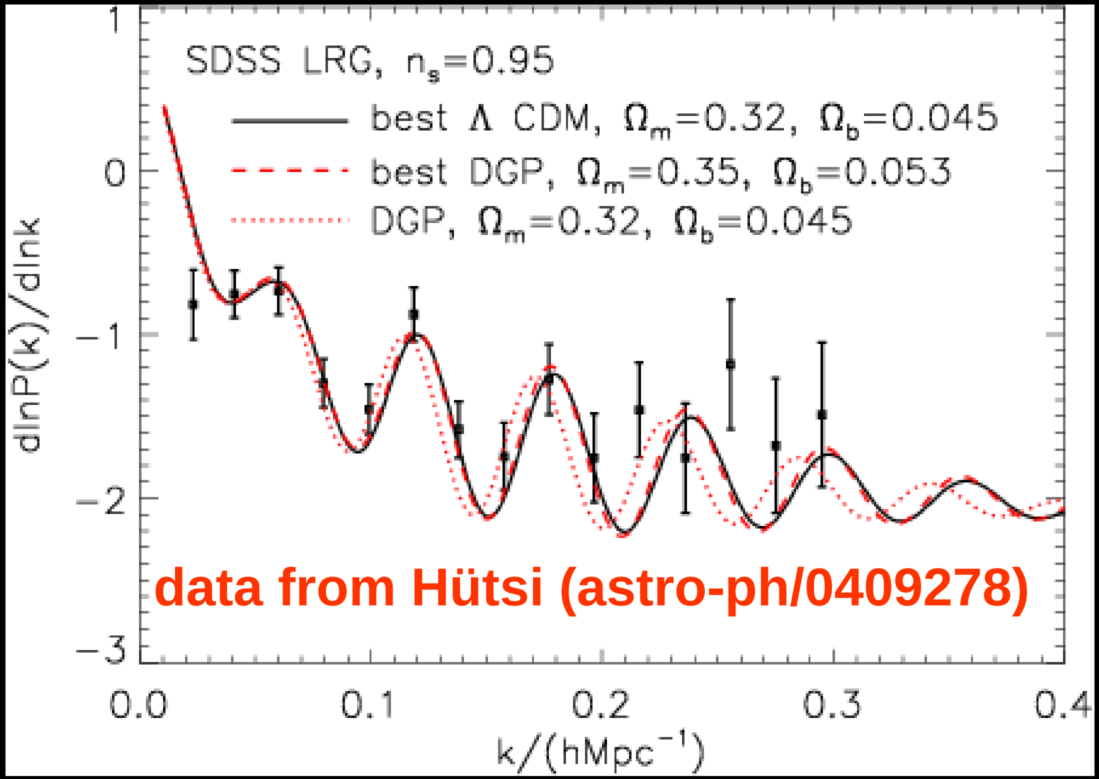
Predicted apparent shifts of BAO peaks

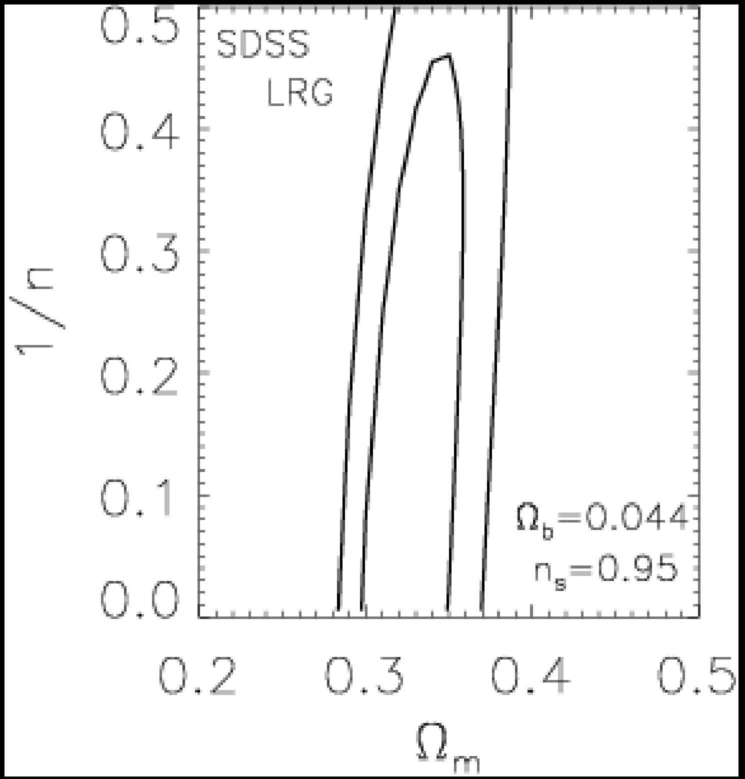


purely linear theory, observation in ΛCDM assumed

Yamamoto et al. (2006)

Current constraints from the SDSS LRG sample

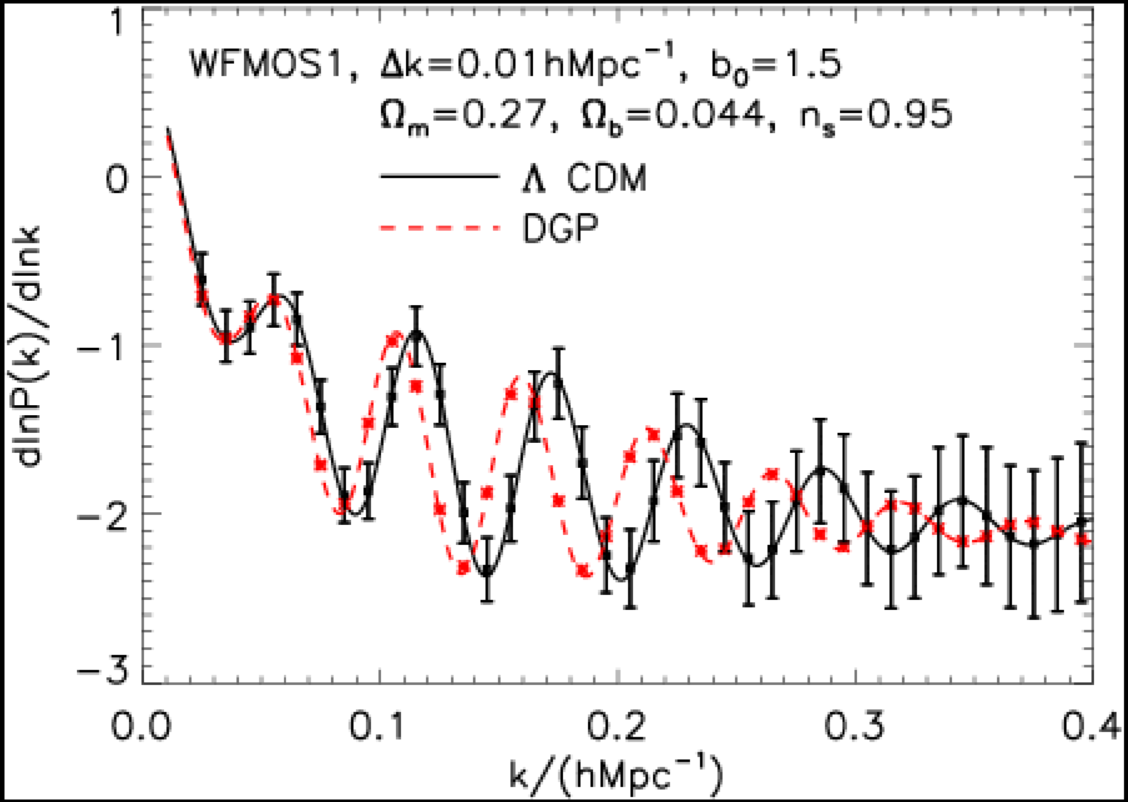


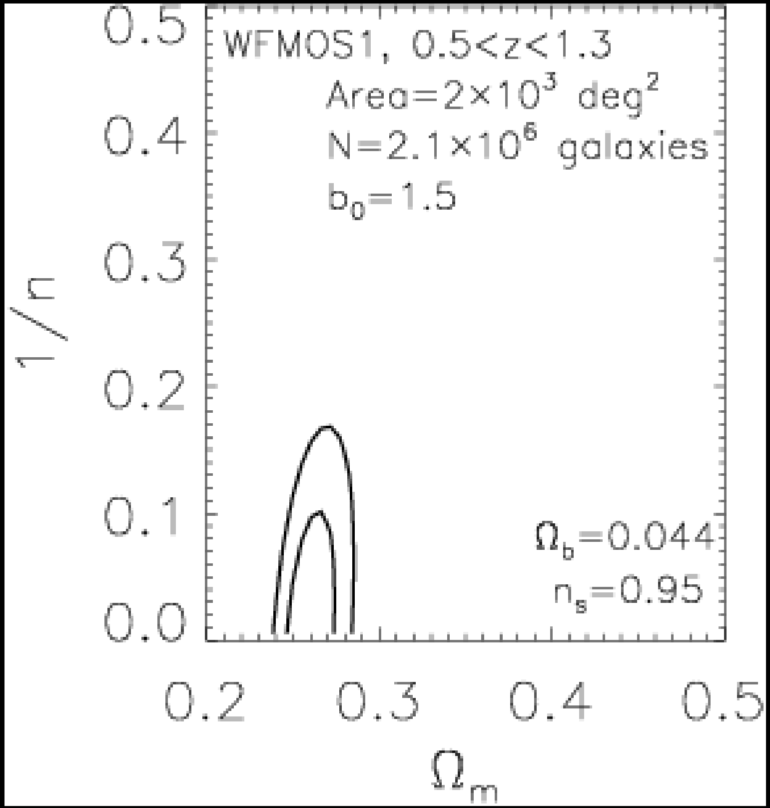


fit to linear theory for $k<0.2hMpc^{-1}$
observation in ΛCDM assumed

Yamamoto et al. (2006)

Expected constraints from future WFMOS z=1 sample





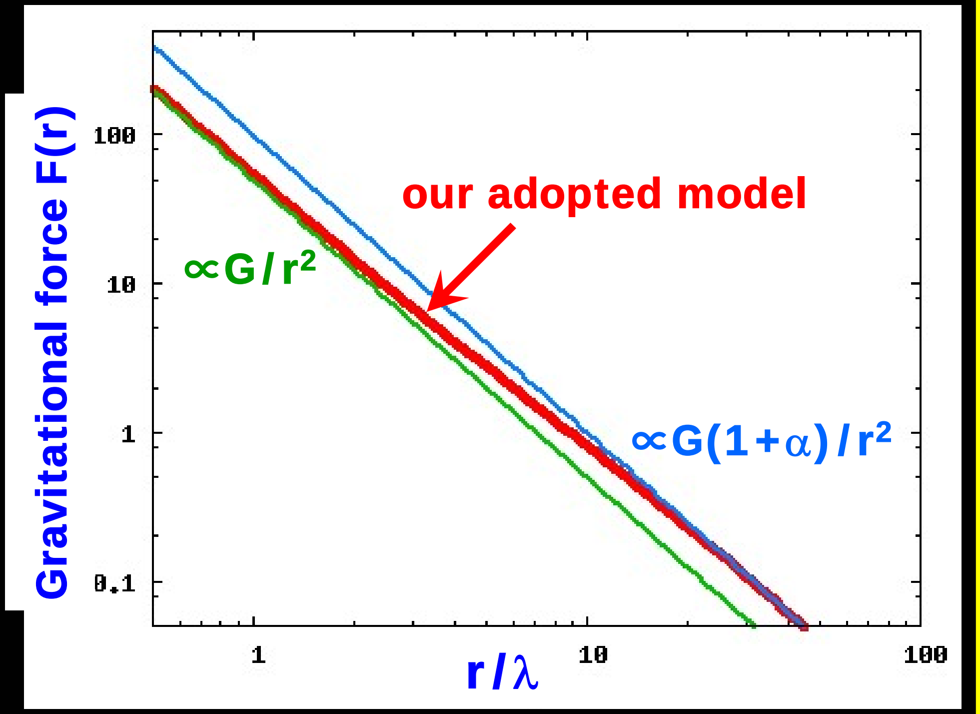
Yamamoto et al. (2006)

Empirical constraints on deviations from Newton's law of gravity via SDSS galaxy P(k)

- ad-hoc and empirical approach (Shirata et al. 2005,2007)
  - adopt the standard Friedmann model (i.e, ΛCDM) but with ***an additional Yukawa term*** to gravity
  - adopt the standard interpretation of CMB anisotropy as the initial condition for the primordial fluctuations
  - assume ***scale-independent bias of SDSS galaxies***

Yukawa-type additional gravitational potential

$$V(r) = -G\int d^3r' \frac{\rho(\mathbf{r}')}{|\mathbf{r}-\mathbf{r}'|}\left[1+\alpha\left(1-e^{-\frac{|\mathbf{r}-\mathbf{r}'|}{\lambda}}\right)\right]$$



small-scale: Newtonian gravity

$r \ll \lambda$:

$$V(r) \to -G\int d^3r' \frac{\rho(\mathbf{r}')}{|\mathbf{r}-\mathbf{r}'|}$$

large-scale: G ⇒ G(1+α)

$r \gg \lambda$:

$$V(r) \to -G(1+\alpha)\int d^3r' \frac{\rho(\mathbf{r}')}{|\mathbf{r}-\mathbf{r}'|}$$

stronger (weaker) gravity on large scales if $\alpha > 0$ ($\alpha < 0$), while cosmic expansion is dictated by "correct" G

Method (Shirata et al. 2005)

1) directly solve the linear perturbation eq. under the modified Newtonian potential:

$$\ddot{\delta}_{\mathbf{k}} + 2H\dot{\delta}_{\mathbf{k}} - 4\pi G\bar{\rho}\delta_{\mathbf{k}}\left[1 + \alpha\frac{(a/k\lambda)^2}{1+(a/k\lambda)^2}\right] = 0$$

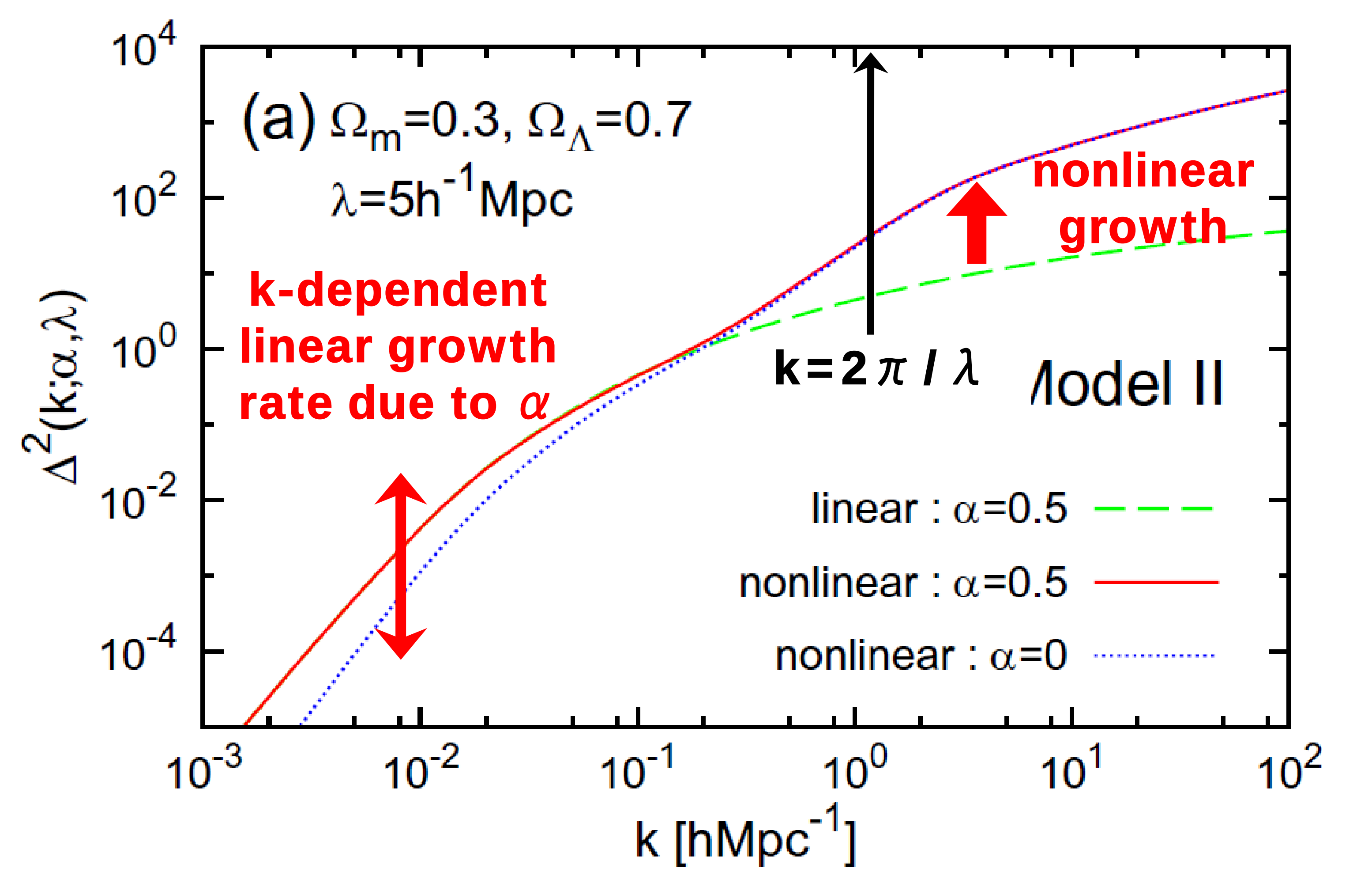
assuming the initial conditions of

$$\delta_{\mathbf{k}}(a_{ini}) = \delta_{\mathbf{k},\Lambda CDM}(a_{ini}), \quad \left.\frac{d\delta_{\mathbf{k}}}{da}\right|_{a=a_{ini}} = \left.\frac{d\delta_{\mathbf{k},\Lambda CDM}}{da}\right|_{a=a_{ini}}$$

2) apply the nonlinear correction using the Peacock-Dodds formula

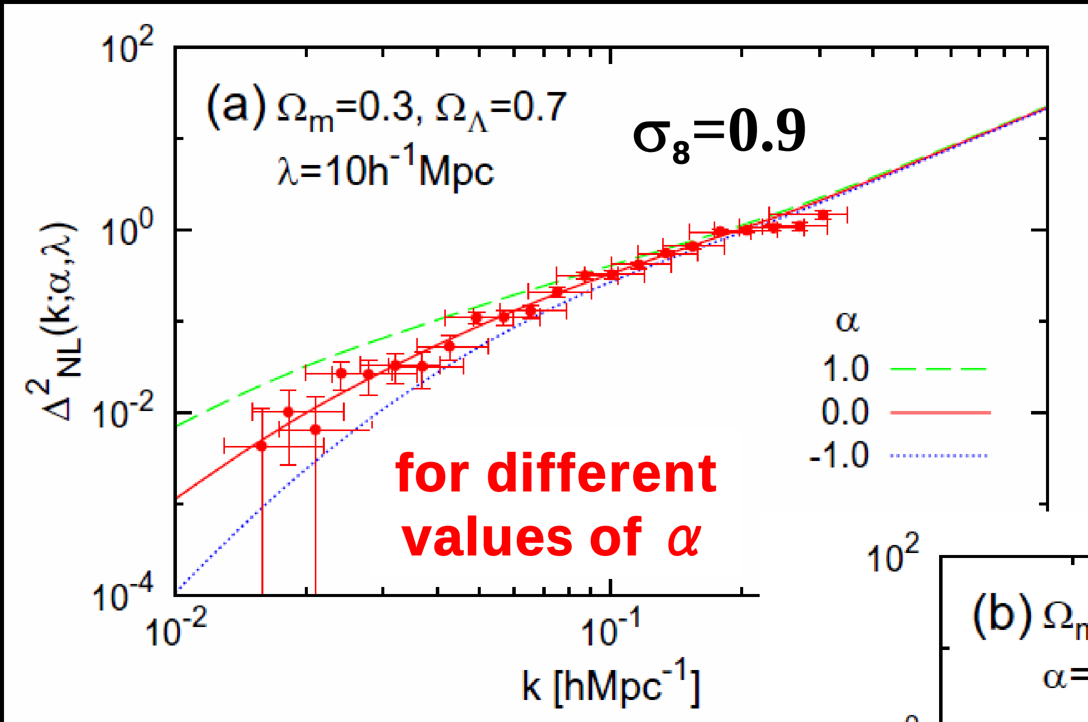
3) Compare the model predictions with SDSS galaxy P(k) ($0.01 < k[h^{-1}\mathrm{Mpc}] < 0.3$) assuming linear bias

Nonlinear correction for power spectrum applying the Peacock-Dodds fit

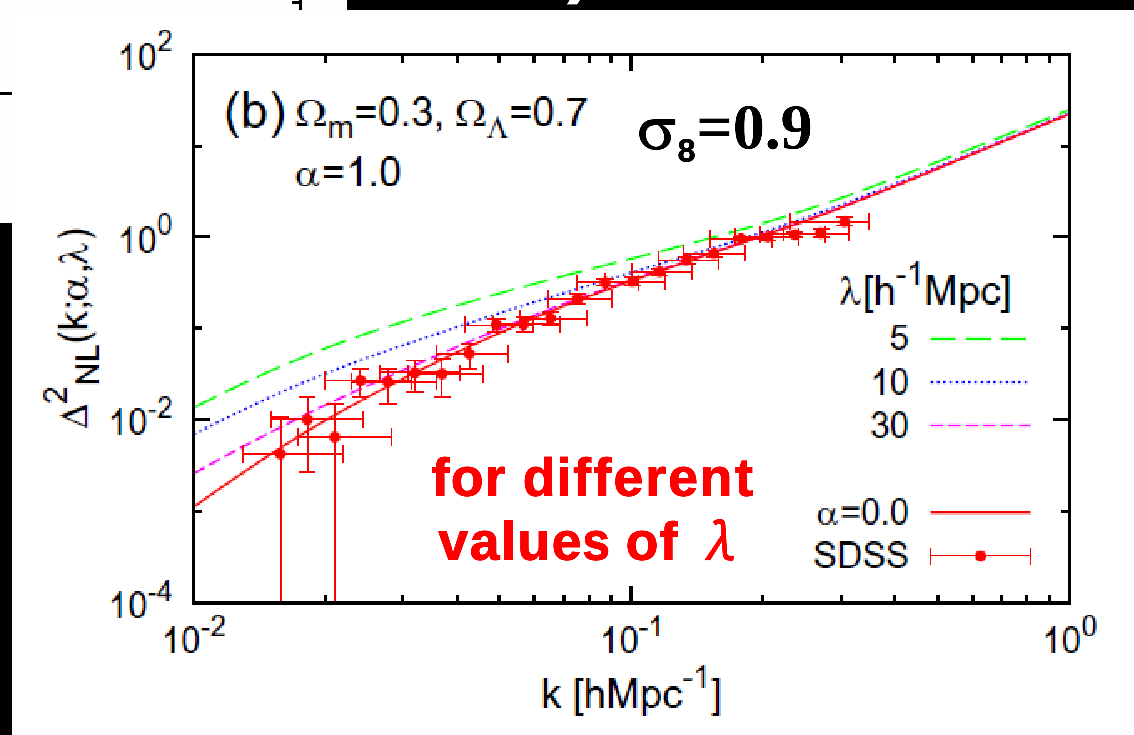


Shirata, Shiromizu, Yoshida & Suto: Phys.Rev.D 71(2005) 064030

Comparison with SDSS galaxy P(k)



● SDSS galaxy P(k) corrected for redshift-space distortion (Tegmark et al. 2004)

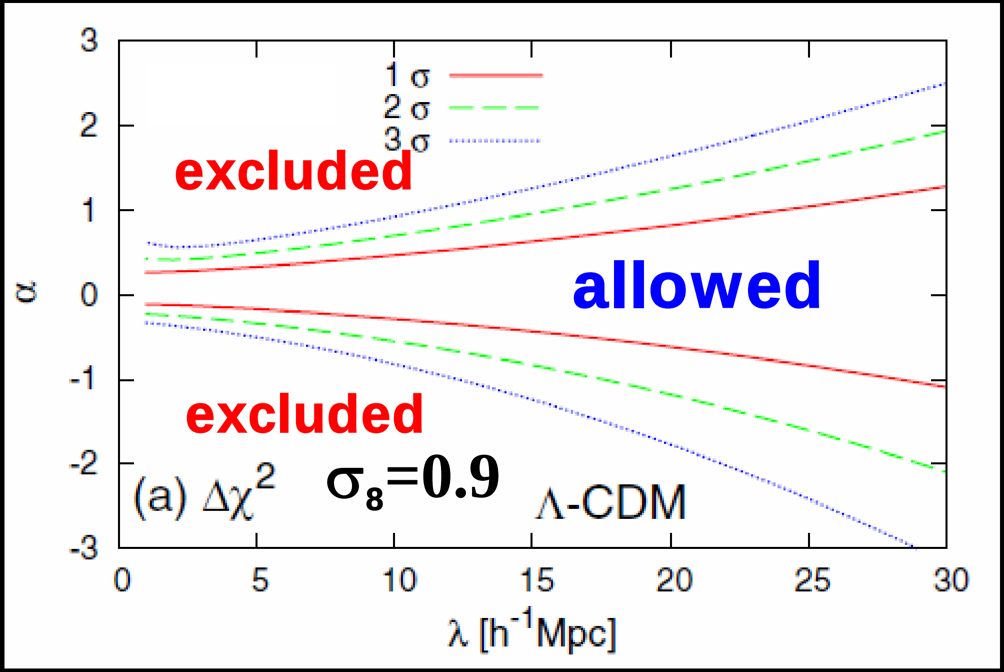


lines: model predictions by Shirata et al. (2005) for

$$V(r) = -G\int d^3r' \frac{\rho(\mathbf{r}')}{|\mathbf{r}-\mathbf{r}'|} \times \left[1+\alpha\left(1-e^{-\frac{|\mathbf{r}-\mathbf{r}'|}{\lambda}}\right)\right]$$

Constraints on model parameters

$$V(r) = -G\int d^3r' \frac{\rho(\mathbf{r}')}{|\mathbf{r}-\mathbf{r}'|}\left[1+\alpha\left(1-e^{-\frac{|\mathbf{r}-\mathbf{r}'|}{\lambda}}\right)\right]$$



Shirata, Shiromizu, Yoshida & Suto: Phys.Rev.D 71(2005) 064030

- $\lambda = 5h^{-1}$Mpc ⇒ $-0.5 < \alpha < 0.6$ (3σ limits)
- $\lambda = 10h^{-1}$Mpc ⇒ $-0.8 < \alpha < 0.9$ (3σ limits)

SDSSの今後

- AS2 (After SDSS-II)
  - BOSS (Baryon Oscillation Spectroscopic Survey): a precision measurement of the scale of the Universe at z = 0.5 and at z = 2.5
  - Galactic structure and stellar properties related to the evolution of the Milky Way
  - a large-scale, systematic survey for planets based on radial-velocity reflex motion of the parent star
- 2008年夏から開始？組織、資金、共同研究形態などまだ決まっていないことが多い。日本がどのようにかかわっていくかも未定。
- 請う、若手研究者の意見。