Checking a dark matter origin of a spectral line

Oleg Ruchayskiy

Ecole Polytechnique Fédérale de Lausanne

SnowPAC

March 25, 2010

Based on arXiv:1001.0644

with Alexey Boyarsky, Dima Iakubovskyi, Matt Walker, Signe Riemer–Sørensen, Steen H. Hansen

Dark matter decay signal

- If the signal found in Willman 1 is due to DM decay – we expect **detectable** signals from other objects.

- Decay flux is proportional to average **DM column density** within the FoV:

$$\mathcal{S} = \int_{\text{l.o.s.}} \rho_{\text{DM}}(r) dl$$

- Expected flux from another object:

$$F_X = F_{\text{Wil 1}} \times \frac{\mathcal{S}_X}{\mathcal{S}_{\text{Wil 1}}}$$

- $(\text{Signal/Noise}) \propto \mathcal{S}_X \times \sqrt{\text{Time} \cdot \text{Area} \cdot \Omega_{\text{fov}} \cdot \Delta E}$

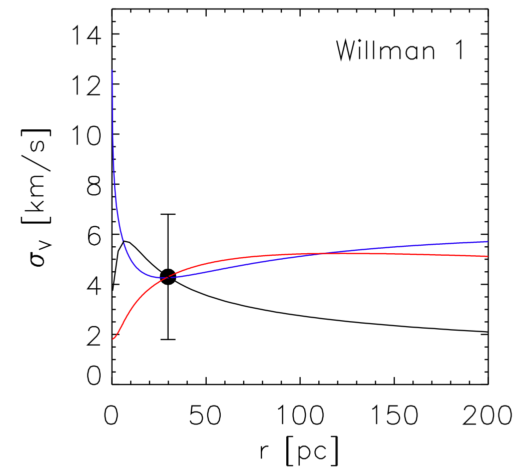
  $\Longrightarrow$ *XMM-Newton* usually provides an improvement in (Signal/Noise)

  Collection area of EPIC cameras ~ 4 times larger; FoV $\sim 13'$

Observational targets

$$\Delta(\text{Signal/Noise}) \propto \frac{\mathcal{S}_X}{\mathcal{S}_{\text{Wil 1}}} \times \sqrt{\text{Time} \times \text{Area} \times \Omega_{\text{fov}} \times \Delta E}$$

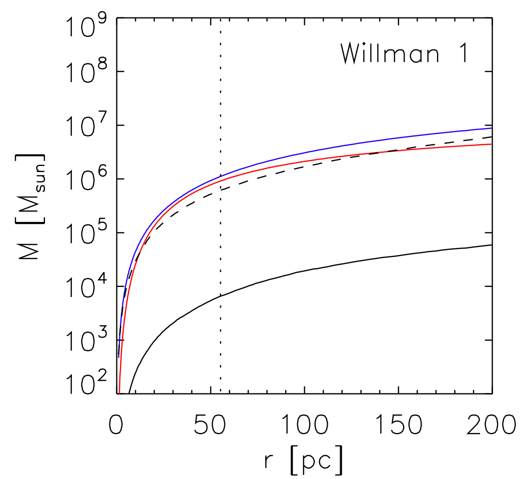
- DM content in Willman 1 (adopted in [Loewenstein & Kusenko'09])



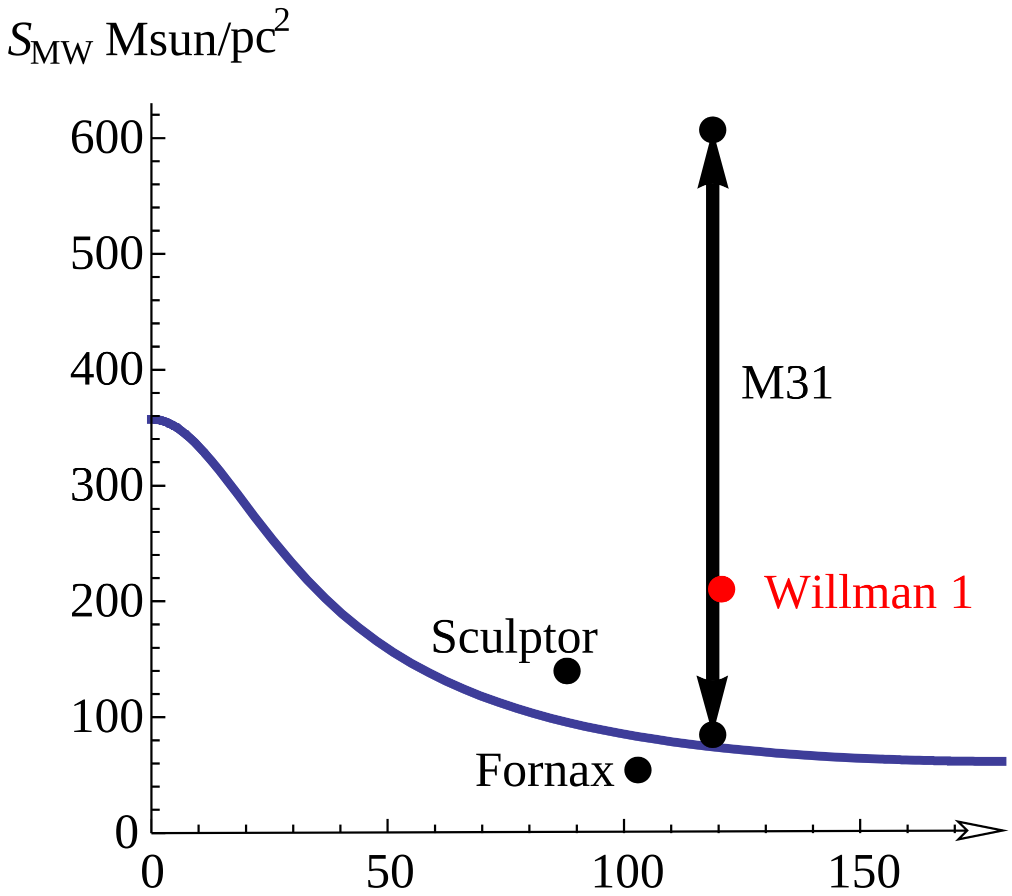
$$\mathcal{S}_{\text{Wil 1}} \simeq 210 M_\odot \, \text{pc}^{-2}$$

- This estimate is based on [Strigari et al.'08]

- In [arXiv:1001.0644] we used this estimate to be conservative



Observational targets



Objects for which archival data is available (used in [arXiv:1001.0644])

- **Fornax dSph** (XMM)
  $\mathcal{S}_F = 54.4 M_\odot\,\mathrm{pc}^{-2}$

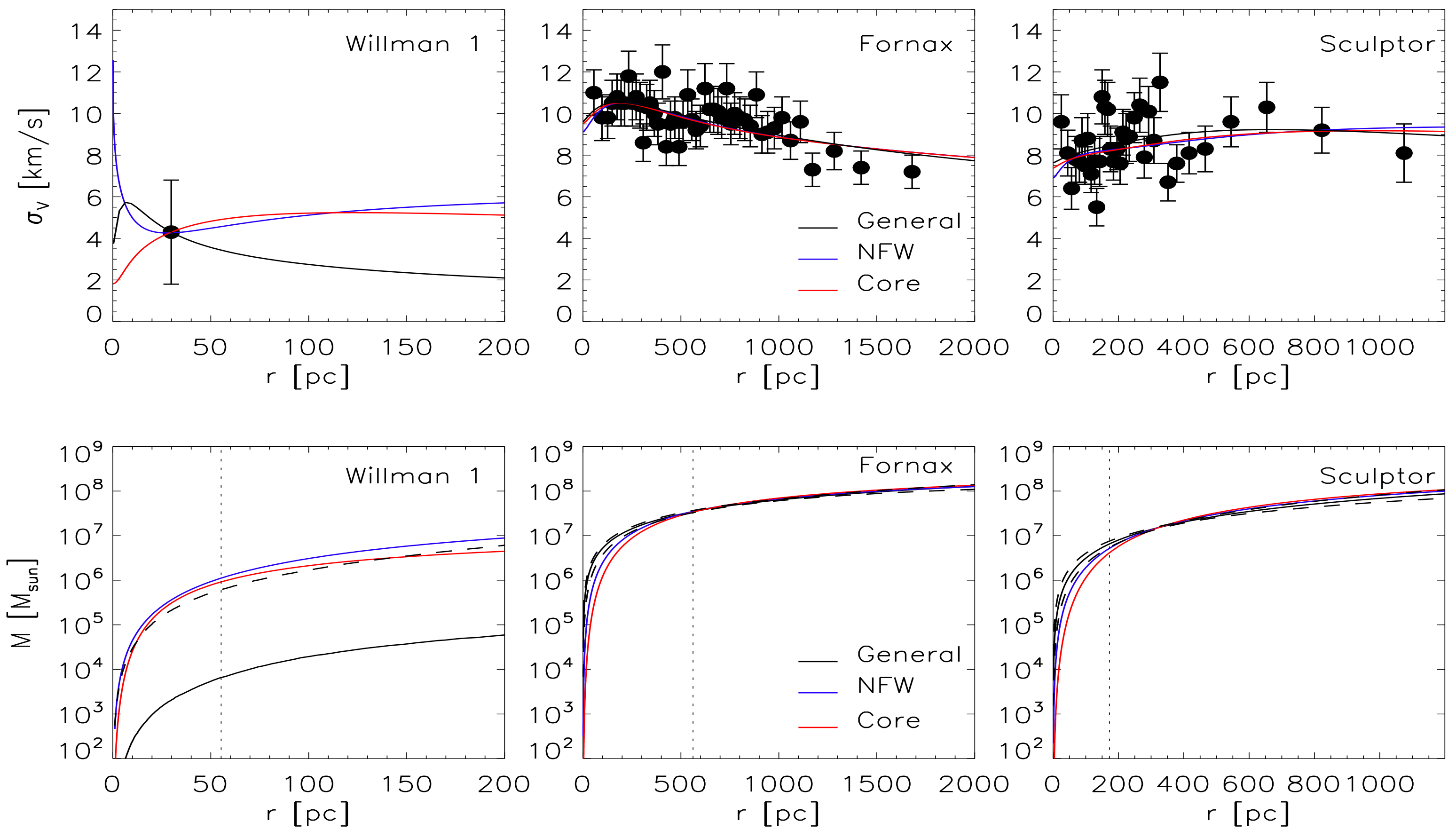
- **Sculptor dSph** (Chandra)
  $\mathcal{S}_{Sc} = 140 M_\odot\,\mathrm{pc}^{-2}$

- **Andromeda galaxy (M31)** : $90 M_\odot\,\mathrm{pc}^{-2} < \mathcal{S}_{M31} < 600 M_\odot\,\mathrm{pc}^{-2}$

- **Milky Way** : $70 M_\odot\,\mathrm{pc}^{-2} \lesssim \mathcal{S}_{\mathrm{MW}} \lesssim 95$

[Boyarsky et al. PRL'06; A&A'07]

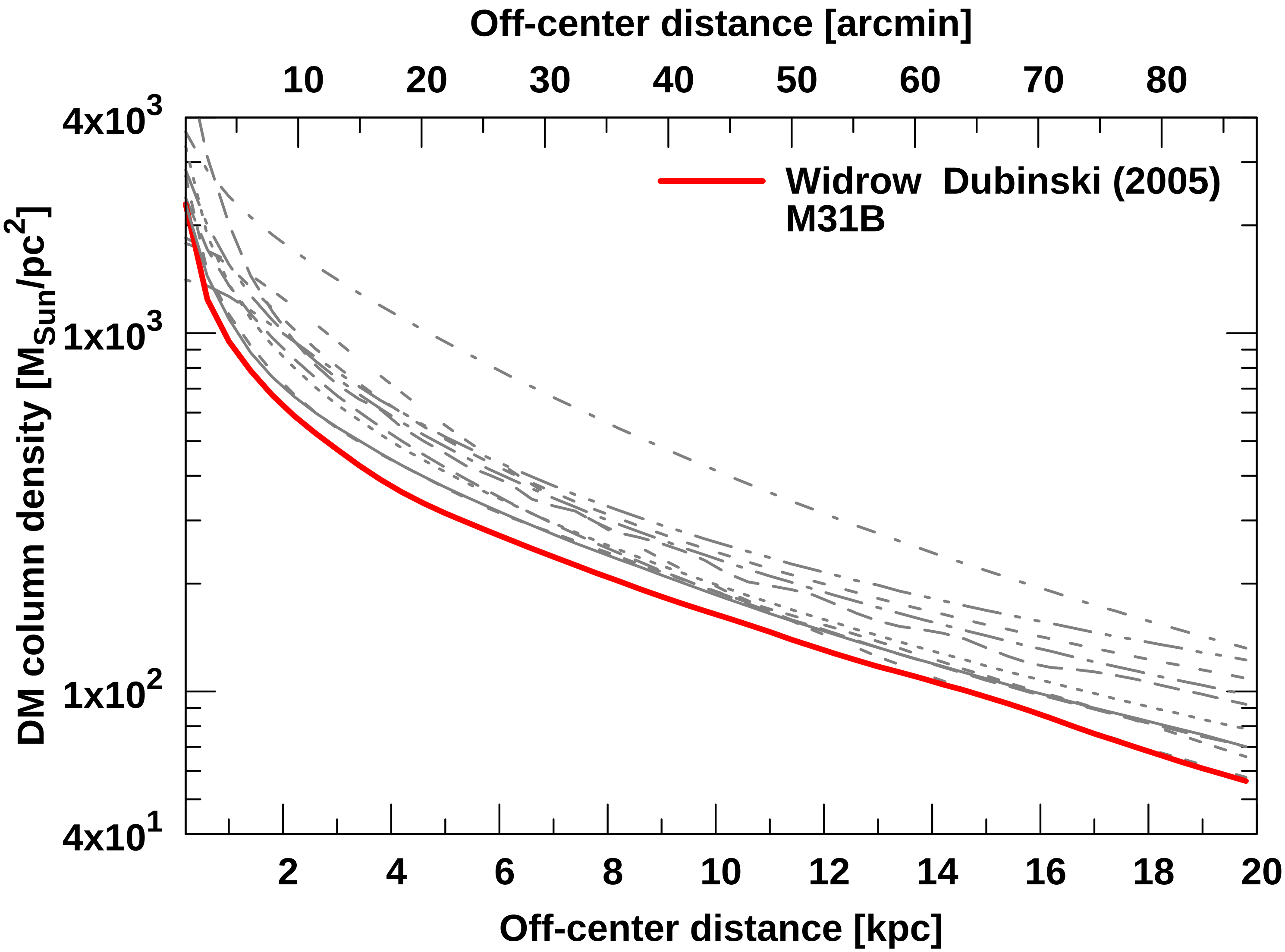
DM in Dwarf Spherodiadals



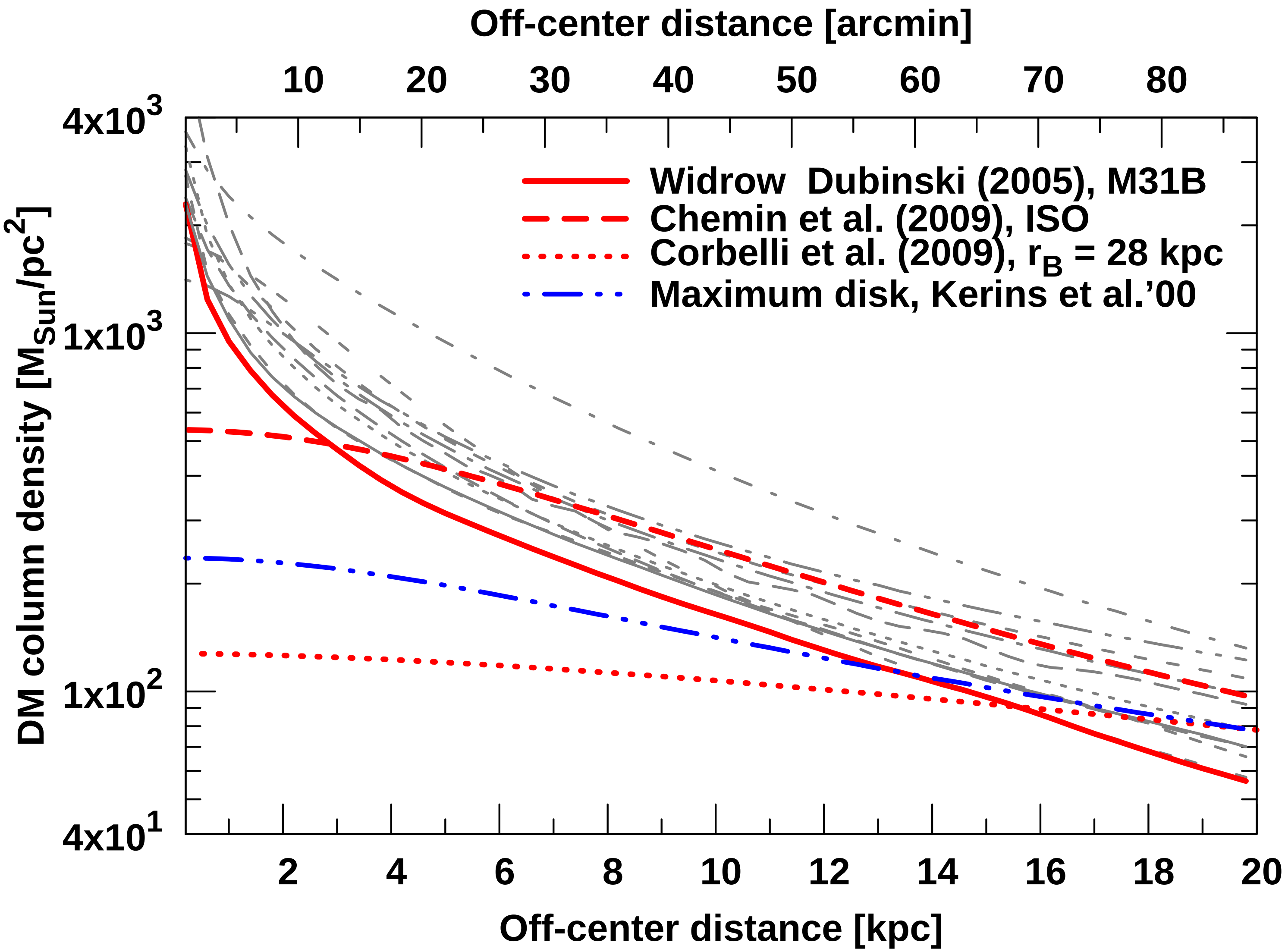
DM content in “classical” dSphs is much more certain. Very low diffuse emission in X-rays. Not much baryons. Classical dSphs – preferred observational targets. **[Boyarsky, O.R. et al. PRL’06]**

DM in Andromeda galaxy (2008)

Boyarsky, O.R. et al. MNRAS'08



DM in Andromeda galaxy (2010)



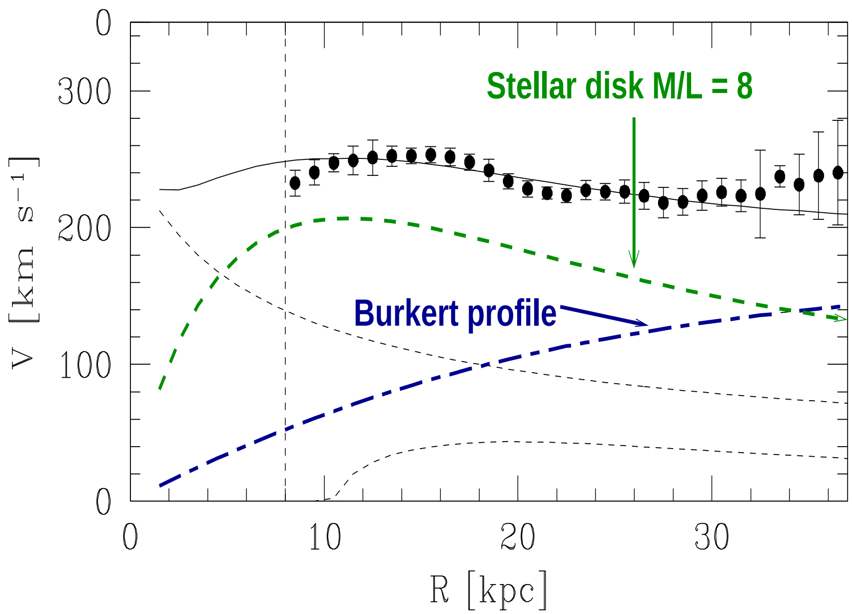
Boyarsky, O.R. et al. MNRAS'08

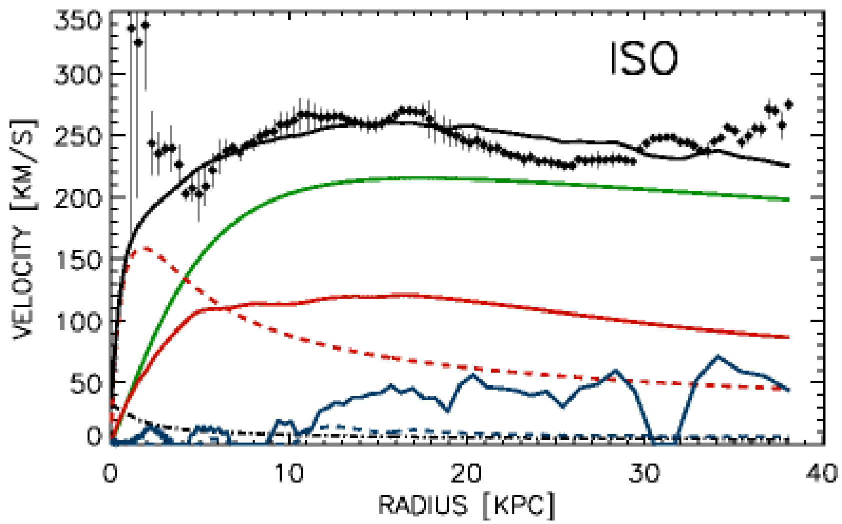
Chemin et al. 0909.3846

Corbelli et al. 0912.4133

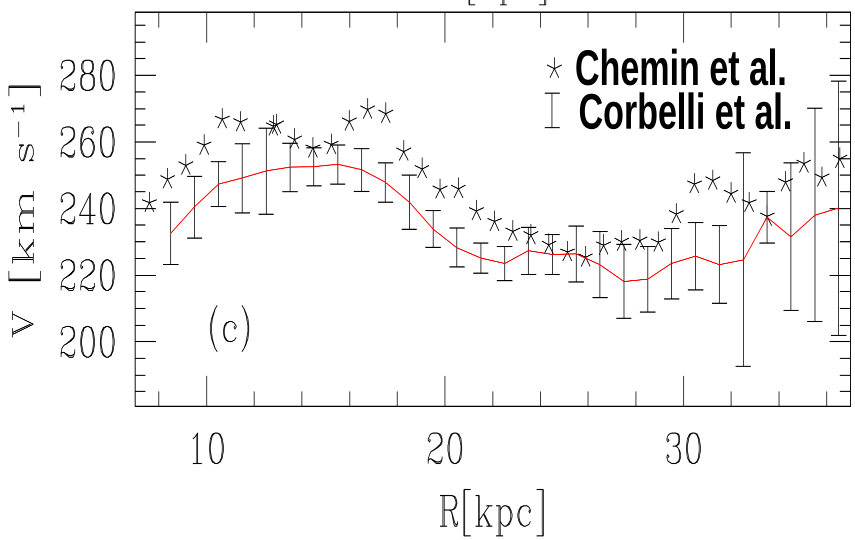
Kusenko & Loewenstein 1001.4055

New data and mass-to-light ratio in M31





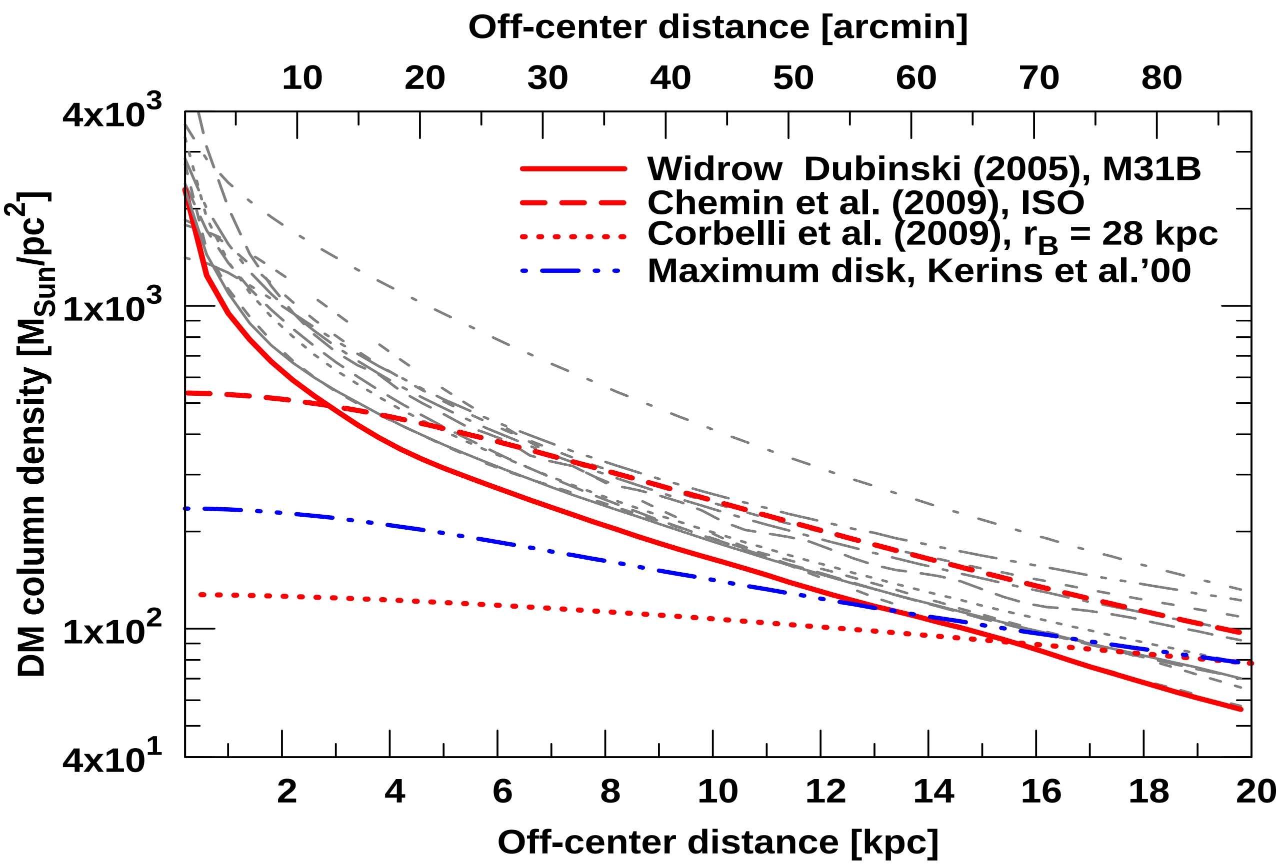
Chemin et al. ApJ 2009 [0909.3846]



Corbelli et al. A&A 2009 [0912.4133]

- New precise HI data resolve features within inner 5–8 kps
- **Chemin et al.** model this region
- **Corbelli et al.** exclude this region from the analysis

DM in Andromeda galaxy



- Bounds in [arXiv:1001.0644v1] are from 1–3 kpc and 2–8 kpc (based on the model by [Widrow & Dubinski'05]
- To be conservative in the final version we repeat the analysis for [Corbelli et al.'09] and added data from 10-20 kpc.

Checking for DM line in dSphs

- $E_{\text{line}} = (2.51 \pm 0.07)$ **keV**

  2.44 keV – 2.58 keV (1σ)
  2.30 keV – 2.72 keV (3σ)

- **Line flux** $F_{\text{Wil 1}} = (3.53 \pm 1.95) \times 10^{-7}$ **photons/cm^2/sec** (68% CL)

- No significant lines were found in spectra of dSphs

- We obtain the following exclusions

	$2.44 - 2.58$ keV	$2.30 - 2.72$ keV
Fornax dSph:	5.1σ	3.3σ
Sculptor dSph:	3.0σ	2.5σ
Fornax + Sculptor	5.9σ	4.1σ

- In case of the DM decay origin of the line we were expecting about 4σ detection from Fornax. However adding the line makes fit worse.

Checking for DM line in M31

Exclusion from Fornax + Sculptor dSph:	$2.44 - 2.58$ keV	$2.30 - 2.72$ keV
	5.9σ	4.1σ

Andromeda galaxy

- Diffuse spectrum above 2 keV is a featureless power law

MNRAS'08 [0709.2301]

	$2.44 - 2.58$ keV	$2.30 - 2.72$ keV
M31, 1kpc $< R <$ 3kpc:	22.7σ	20.1σ
M31, 5 kpc off-center: circle radius 3 kpc	10.4σ	10.4σ
M31, both regions	24.9σ	23.3σ

1001.0644

- Extremely significant exclusion from central 8 kpc of Andromeda!
- All bounds are based on the conservative DM estimate from **[Widrow & Dubinski'05]**!

Checking for DM line in M31

- Exclusion from Fornax and Sculptor dSphs:

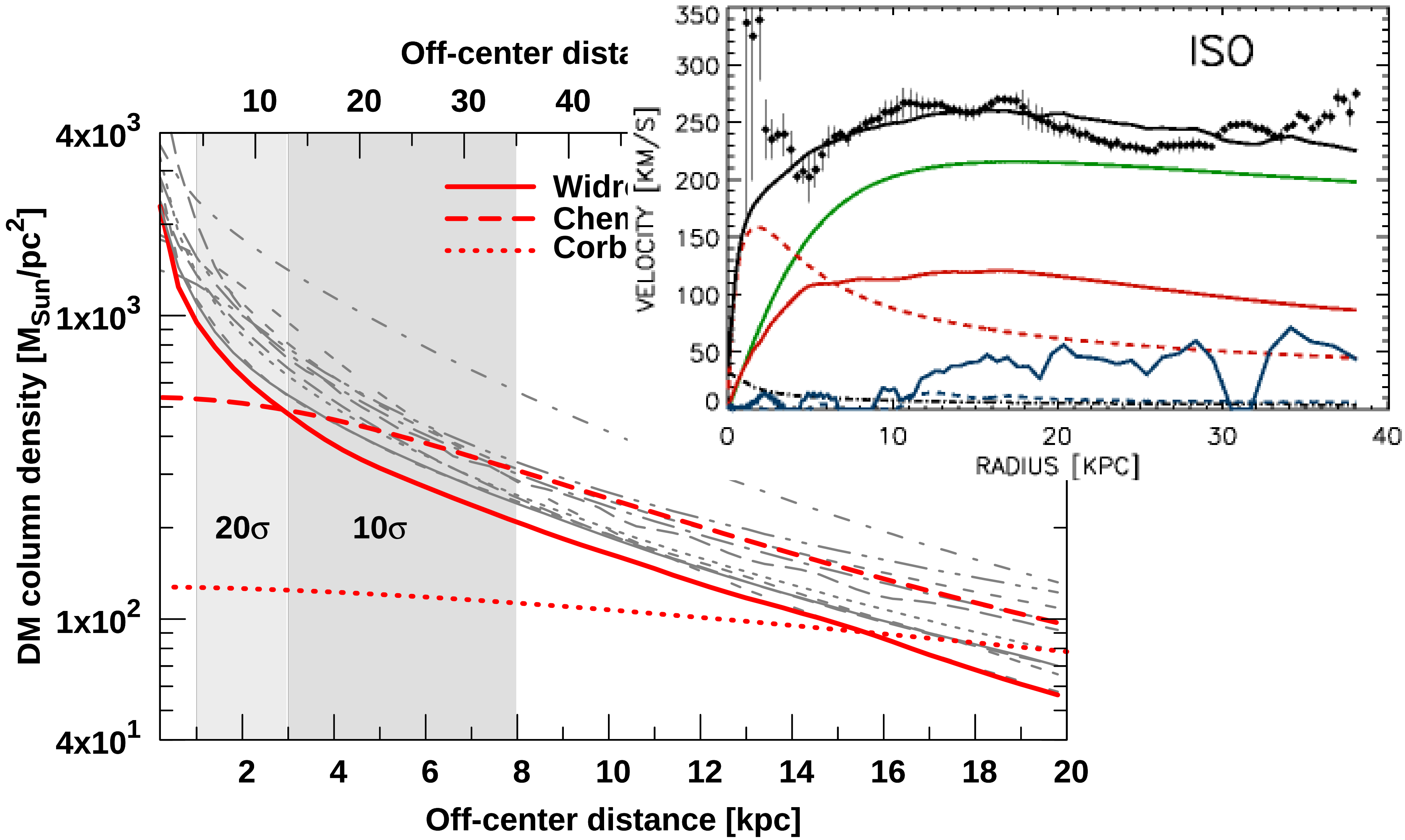
$2.44 - 2.58$ keV	$2.30 - 2.72$ keV
5.9σ	4.1σ

- Exclusion from **central 8 kpc of Andromeda**:

$2.44 - 2.58$ keV	$2.30 - 2.72$ keV	DM model
24.9σ	23.3σ	**[Widrow & Dubinski'05]**
7.9σ	6.9σ	**[Corbelli et al.'09]**

1001.0644

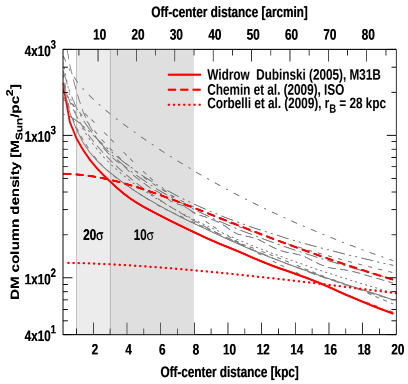
Checking for DM line in M31



In the final version of the paper we processed observations in the region $10 - 20$ kpc

1001.0644v2

Summary of exclusions



	"Consensus model" (Widrow & Dubinski, M31B)		Minimal DM amount (Corbelli et al., Burkert profile, $r_B = 28$ kpc, $M/L = 8$)	
	68%CL	99%CL	68%CL	99%CL
M31 within 8 central kpc	24.9σ	23.3σ	7.9σ	6.9σ
M31 10–20 kpc off-center	12.0σ	10.7σ	11.7σ	10.6σ
All M31 obs.	28.2σ	26.2σ	13.6σ	13.2σ
All M31 + Fornax	29.0σ	26.7σ	15.2σ	14.0σ

68% CL: 2.44 keV – 2.58 keV

99%CL: 2.30 keV – 2.72 keV

- The DM origin of the spectral feature in Willman 1 at ~ 2.5 keV is **excluded with 14σ significance**!

Future searches for the DM decay line

- Decaying DM would **provide a comparable decay signal from many objects**. This allows to check the DM origin of any "suspicious" line
- XMM will probably not find DM in Willman 1
- This should not stop us from further searching! Classical dSphs remain the best observational targets. To really push down the exclusion one needs **prolonged** (~ 1 Msec) **dedicated observations** of classical dSph with X-ray observatories
- Real improvement would come from the new generation of X-ray spectrometers with the excellent spectra resolution and large FoV.
- **EDGE/XENIA** proposed for NASA's *Cosmic Origins* and to ESA's *Fundamental Physics Roadmap*

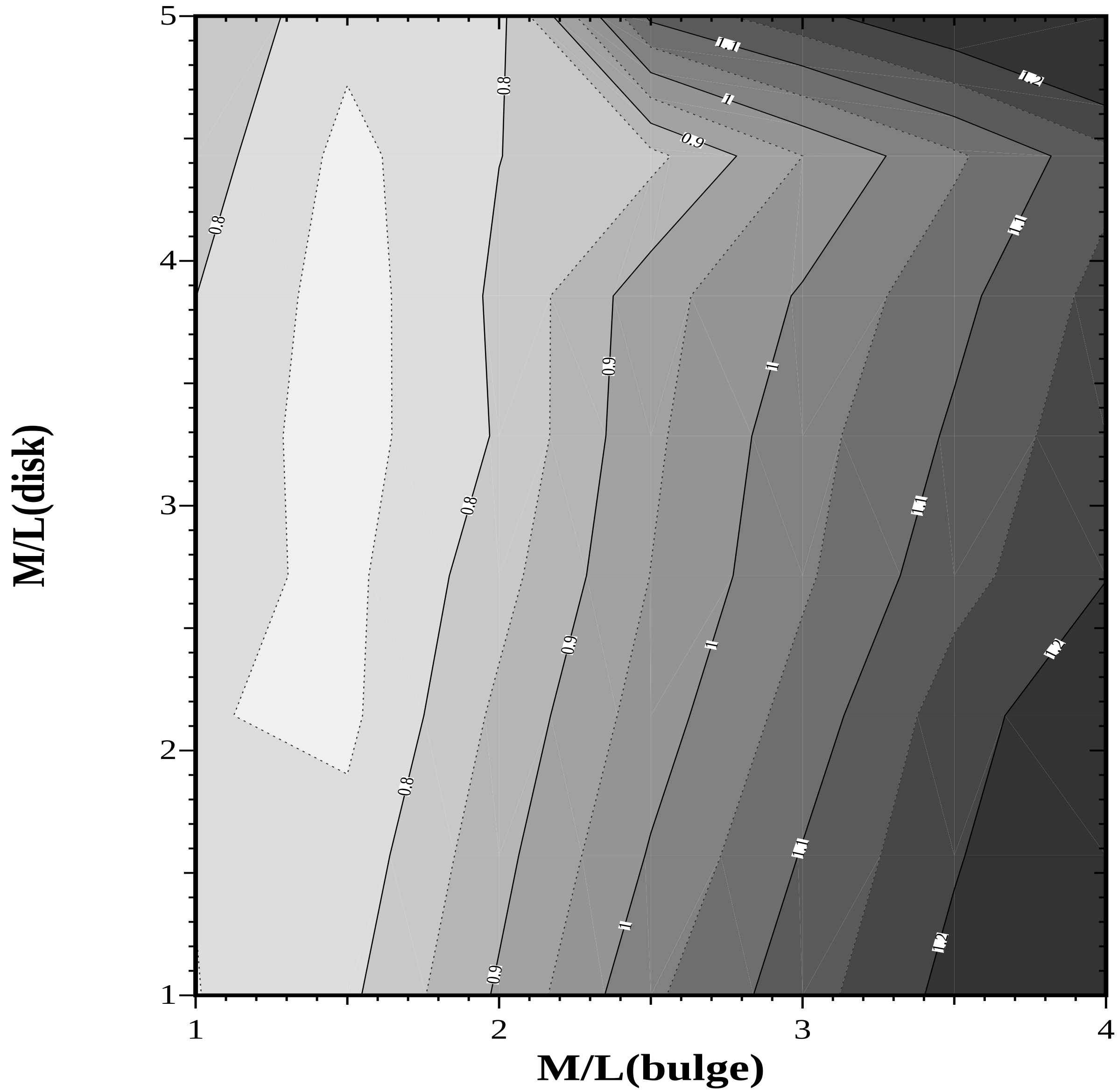
0906.1788

THANK YOU FOR YOUR ATTENTION

ADDITIONAL SLIDES

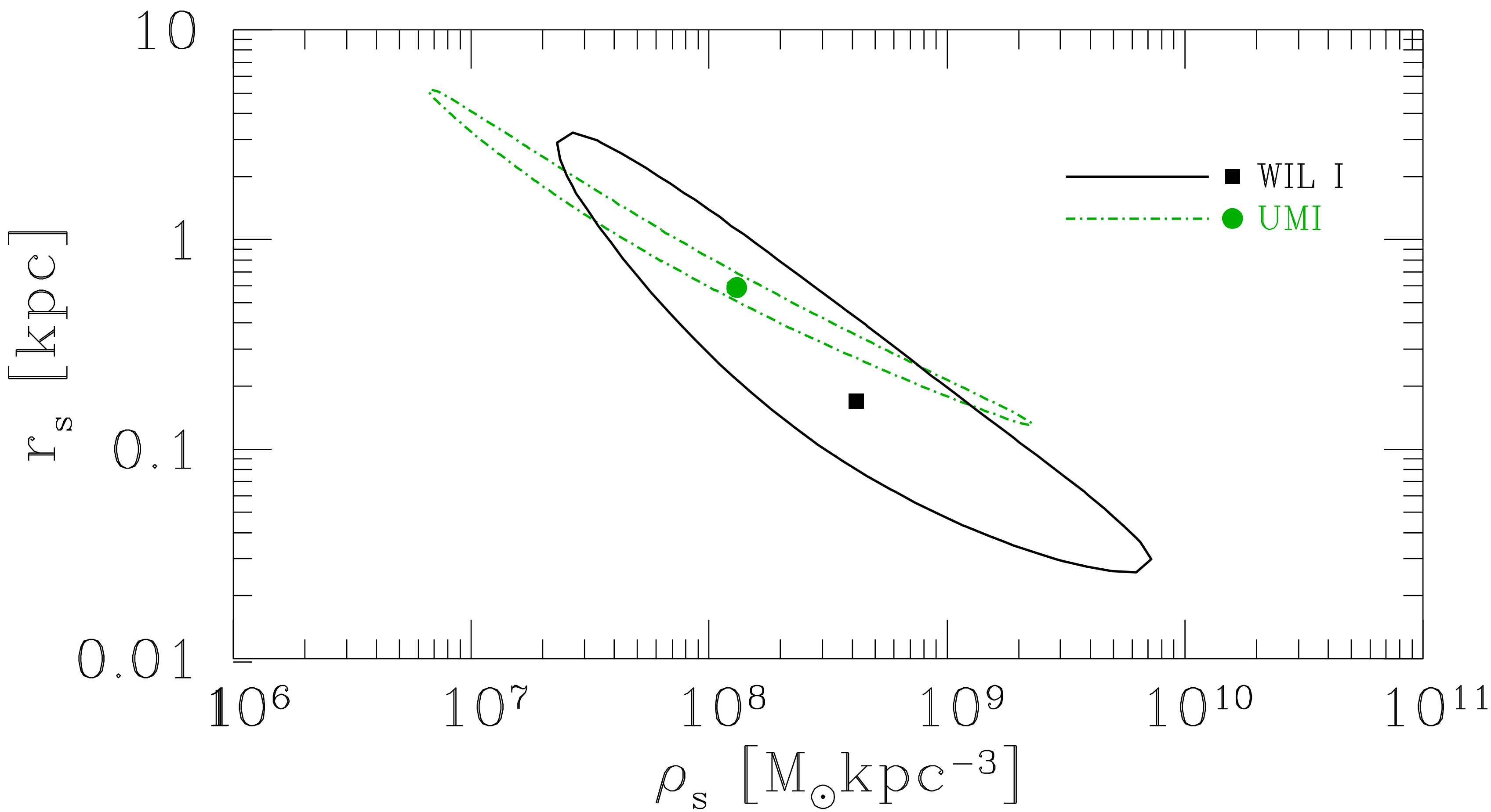
Mass-to-light ration in M31

Widrow & Dubinski'05



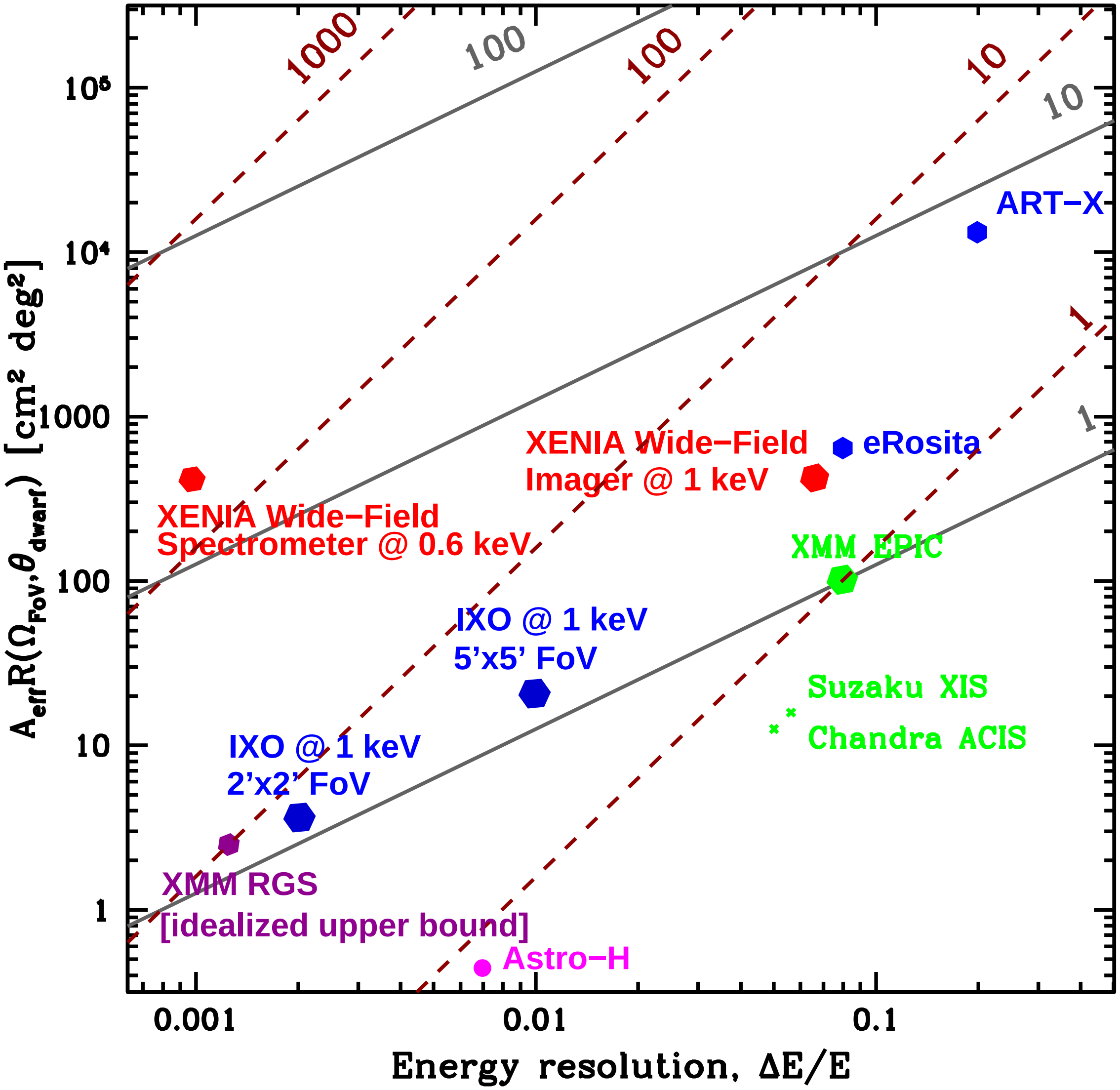
DM in Willman 1

Strigari et al.'08



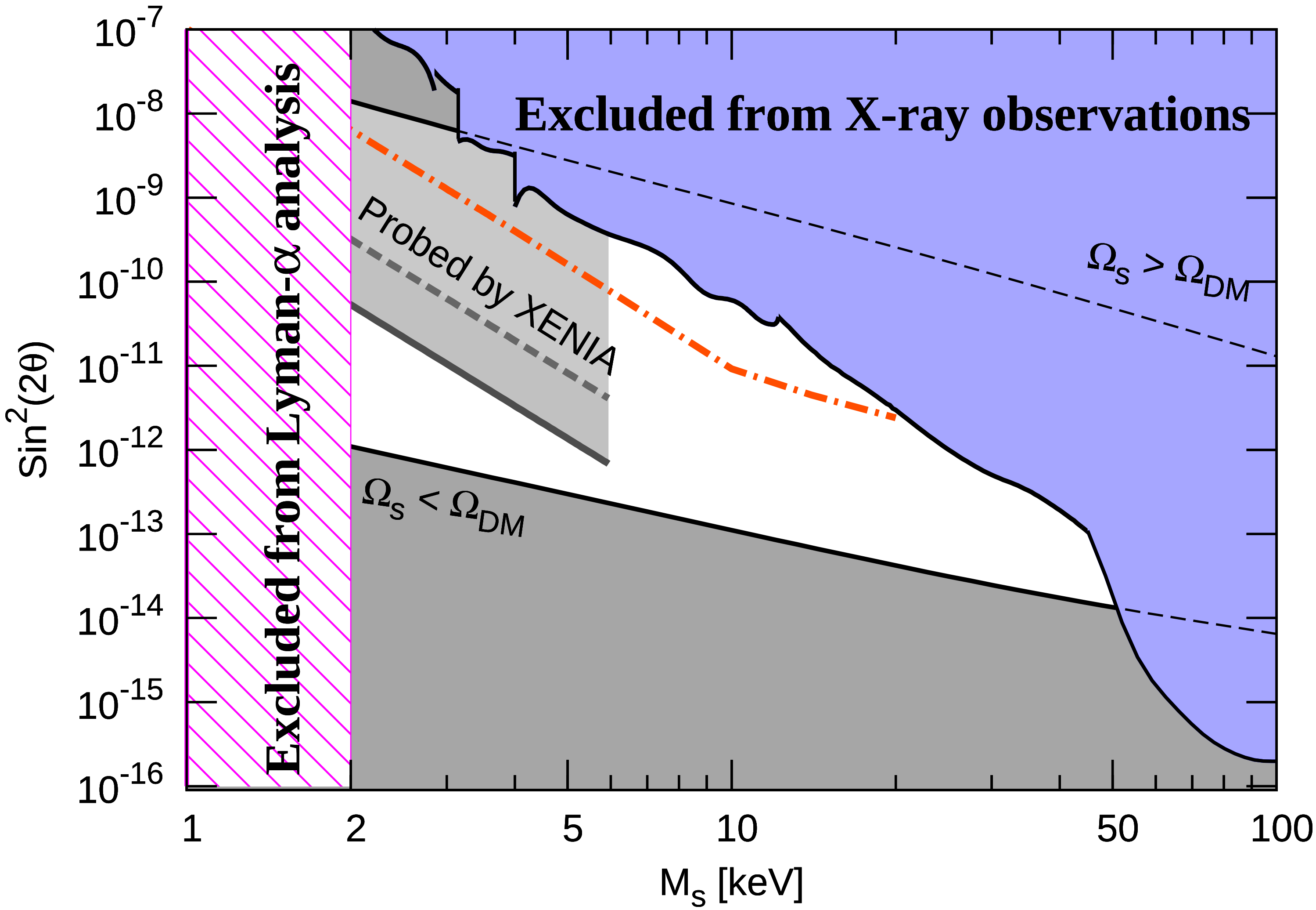
Uncertainty in $\mathcal{S}_{\mathrm{Wil\,1}}$ is factor 2-3; for Ursa Minor $\mathcal{S}_{UMi}$ changes by about 50% (within 90%CL).

Future missions



Boyarsky, den Herder, O.R. et al. Astropart.'08; white paper 0906.1788

Improved bounds on DM decay



M31 observations

ObsID	Cleaned exposure [ksec] (MOS1 / MOS2 / PN)	FoV $[\mathrm{arcmin}^2]$ (MOS1 / MOS2 / PN)
0109270101	16.8 / 16.7 / 15.3	335.4/ 336.0 / 283.6
0112570101	39.8 / 40.0 / 36.0	332.9/ 333.1 / 285.9
0112570401	29.8 / 29.9 / 23.5	335.6/ 336.1 / 289.5

Table 1: Cleaned exposures and FoV after the removal of point sources and OOT events (calculated using BACKSCAL keyword) of three `M31on` observations.

ObsID	Cleaned exposure [ksec] (MOS1 / MOS2 / PN)	FoV $[\mathrm{arcmin}^2]$ (MOS1 / MOS2 / PN)
0402560301	41.9 / 42.2 / 35.2	405.6/ 495.4 / 433.3

Table 2: Cleaned exposures and FoV (calculated using BACKSCAL keyword) of the observation `M31off` (obsID `0402560301`). The significant difference in FoVs between MOS1 and MOS2 cameras is due to the loss CCD6 in MOS1 camera.

M31 observations

ObsID	R [kpc]	Cleaned exposure [ksec] (MOS1 / MOS2 / PN)	FoV [arcmin^2] (MOS1 / MOS2 / PN)
0511380101	17.4	44.3 / 44.5 / 37.6	356.2 / 400.4 / 333.3
0109270401	17.2	38.5 / 38.4 / 33.5	387.8 / 384.1 / 366.7
0505760401	13.8	26.0 / 26.0 / 21.7	330.5 / 374.1 / 325.0
0505760501	13.2	23.8 / 23.8 / 19.8	344.8 / 395.2 / 313.2
0402561301	13.0	22.7 / 22.7 / 20.1	367.2 / 419.5 / 382.6
0402561401	13.0	39.3 / 39.3 / 33.7	349.9 / 408.3 / 343.6
0402560801	11.8	42.6 / 42.6 / 36.6	373.6 / 435.8 / 393.7
0402561501	11.0	38.5 / 38.5 / 34.0	369.3 / 421.0 / 407.5
0109270301	11.0	24.4 / 24.6 / 22.2	443.4 / 439.6 / 405.0

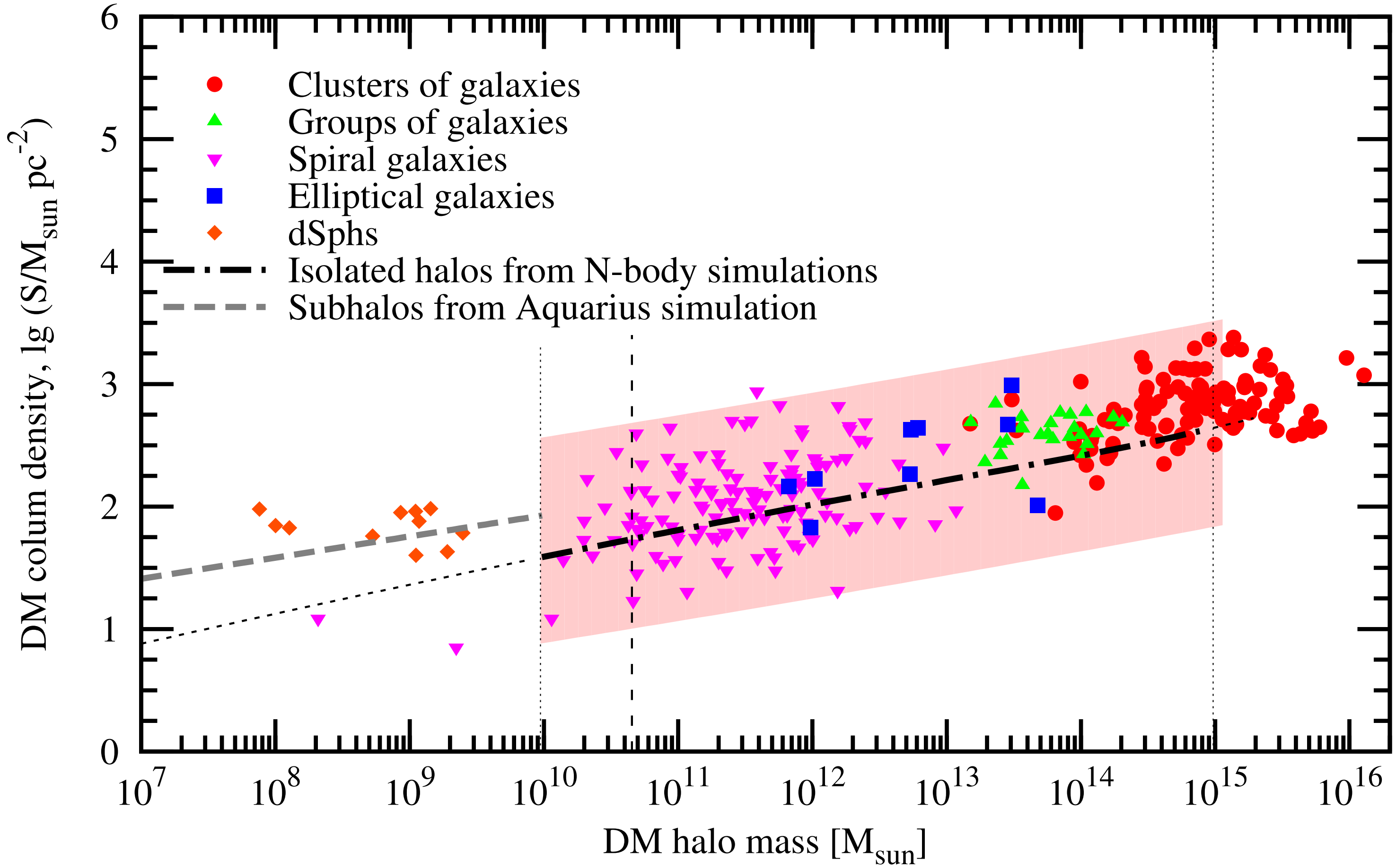
Table 3: Results of M31out observations.

XMM ObsID	Cleaned exposure [ksec] (MOS1 / MOS2 / PN)	FoV [arcmin^2] (MOS1 / MOS2 / PN)
0302500101	53.8 / 53.9 / 48.2	459.1 / 548.5 / 424.9

Table 4: Cleaned exposures of Fornax dSph observations

DM column density

0911.1774



$$\mathcal{S} \sim \left(M_{\text{halo}}\right)^{\approx 0.2}$$

TOC

TOC