Searching for the large-scale hot gaseous Galactic halo --Observations confront theories

Yangsen Yao in collaboration with
Michael A. Nowak
Q. Daniel Wang
Norbert S. Schulz
Claude R. Canizares

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Hot gas (~10^6 K) in and around the Milky Way

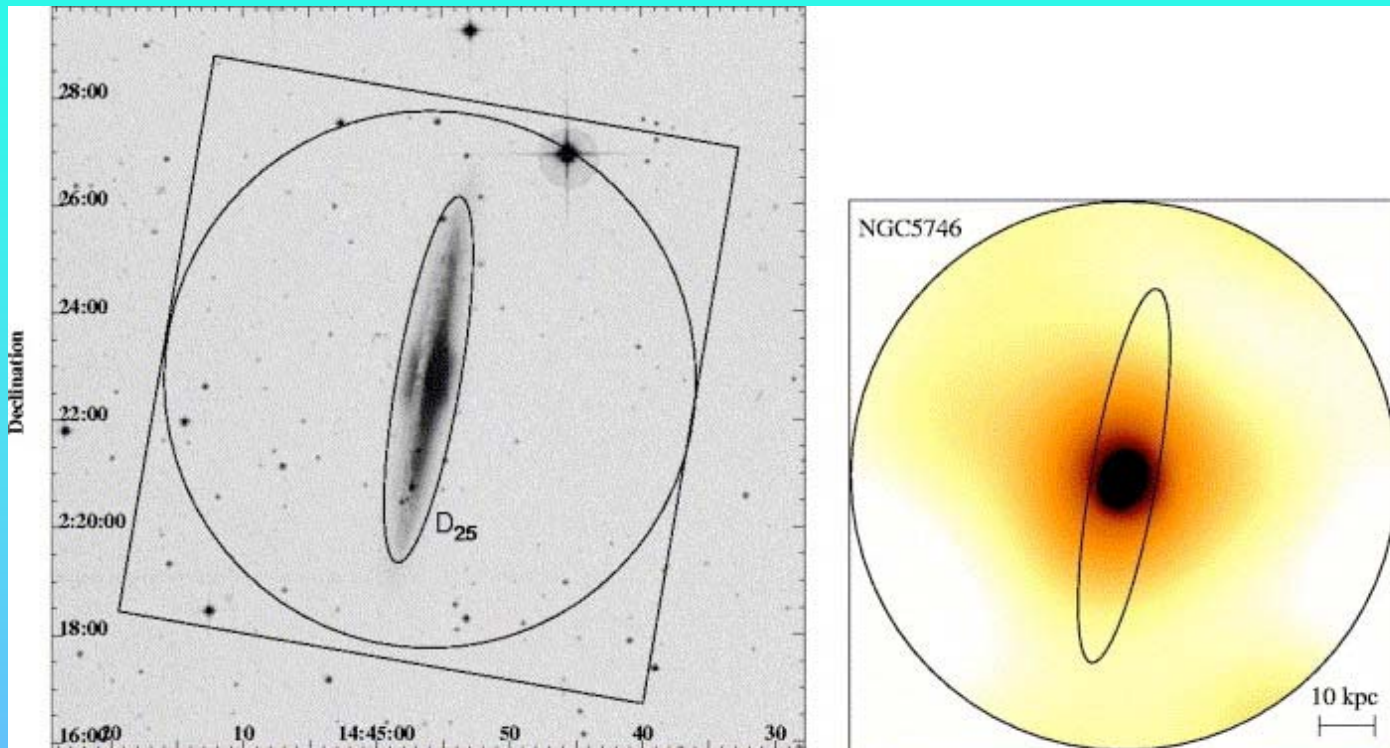
- Local hot bubble (Snowden et al. 1998)
  - L: ~100 pc;
  - NH: ~10^{18} cm^{-2}
- Hot Galactic disk (e.g., Savage et al. 2003)
  - L: ~2 kpc;
  - NH: ~10^{19} cm^{-2}
- Galactic halo (e.g., Sembach et al. 2003)
  - L: ~20-250 kpc
  - NH: ????????
- Intergalactic medium in the Local group
  - L: ~ 1 Mpc
  - NH: ????????

Theoretical basis: large-scale hot gaseous halo

- Theories and simulations for disk galaxy formation and evolution (e.g., NFW 1995; Toft et al. 2002)
- Gas in-fall --> gas heated (~10^6 K)--> cool --> fuel of galaxy formation
  - For massive (≥10^{11} $M_\odot$) spirals, cooling is inefficient --> long standing large-scale hot gaseous halo
  - Mass of the hot halo is comparable to that of stars and cool gas in the galaxy
- For the Milky Way
  - M_{virial} ~8x 10^{11} $M_\odot$ (Klypin, Zhao, & Somerville 2002)
  - For a universal baryon fraction f ~ 0.15, the baryon mass of the MK is ~1.2x10^{11} $M_\odot$
  - The total baryon mass found: 6x10^{10} $M_\odot$ (Dehnen & Binney 1991)
  - Half of baryons are missing, which is supposed to be in the large-scale hot gaseous halo (Maller & Bullock 2004)!!

Observations: (1) the only measurement

NGC 5746: optical and X-ray images (Pedersen et al. 2006)



NGC 5746

D: 29.4 Mpc,

circular velocity: 307 km/s

star formation rate: 1.2 $M_{\odot}$ yr^{-1} (no starburst)

Observations: (2) challenging

1. 200 net counts in 0.3-2 keV !!
2. The Halo is NOT there according to re-analysis of the same Chandra data; the previous detection of the extended halo is highly possible an instrumental artifact (Wang 2006)!!!
3. No detection around a less massive galaxy NGC 5170
   - D: 24.0 Mpc
   - Circular velocity: 250 km/
   - Star formation rate: 0.5 $M_{\odot}$ yr^{-1} (quiescent, no starburst)

X-ray emission measurement should be very difficult, due to low gas density and also possibly low metallicity.

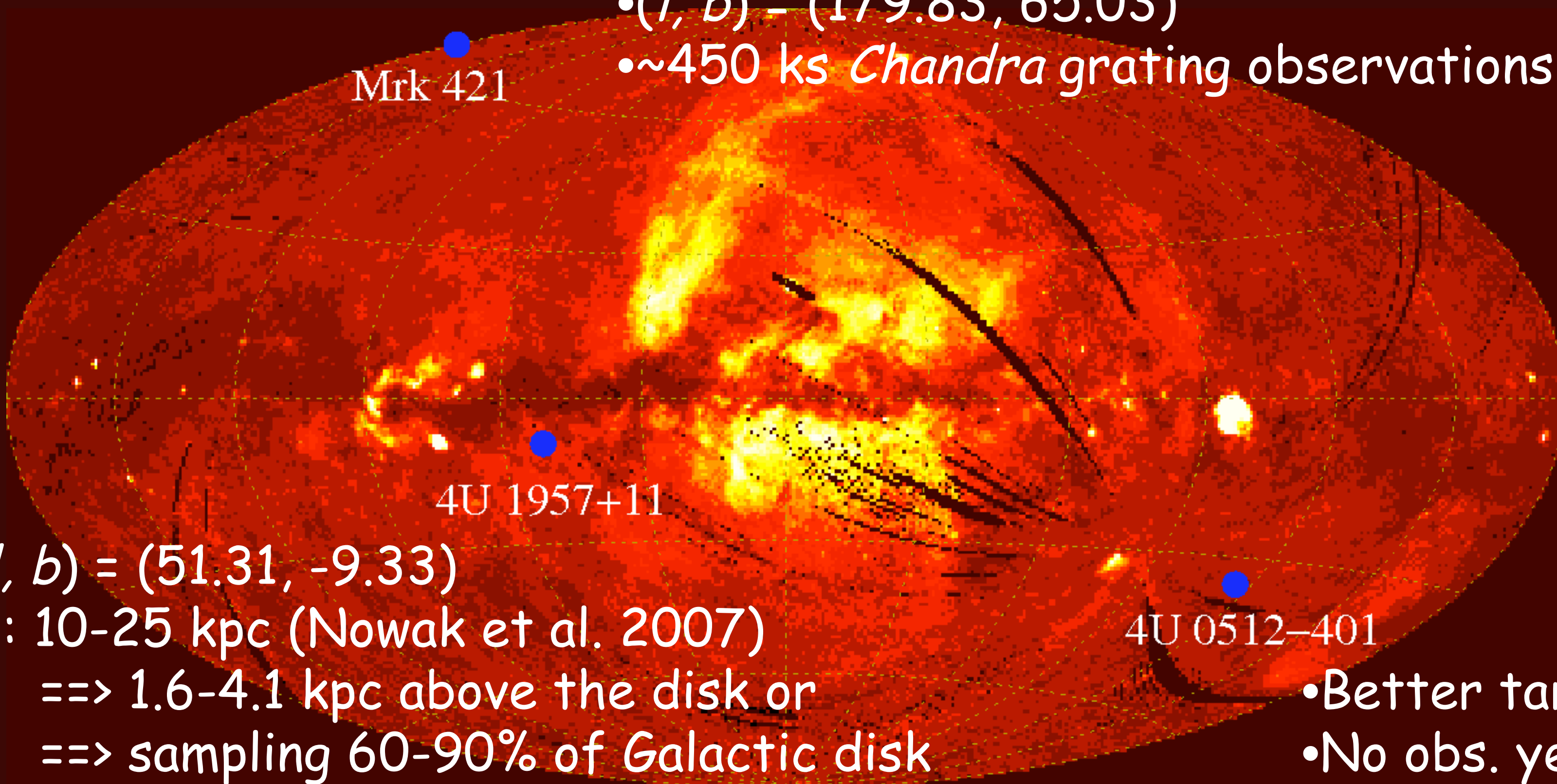
An absorption search

Strategy: differential technique

- Absorption toward extragalactic source: LHB + disk + halo (+ WHIM)
- Absorption toward a “high” latitude, distant Galactic source: LHB + disk
- Differential absorption: halo (+WHIM+some disk contribution) ==> upper limit from halo

Chandra targets

•(*l*, *b*) = (179.83, 65.03)
•~450 ks *Chandra* grating observations

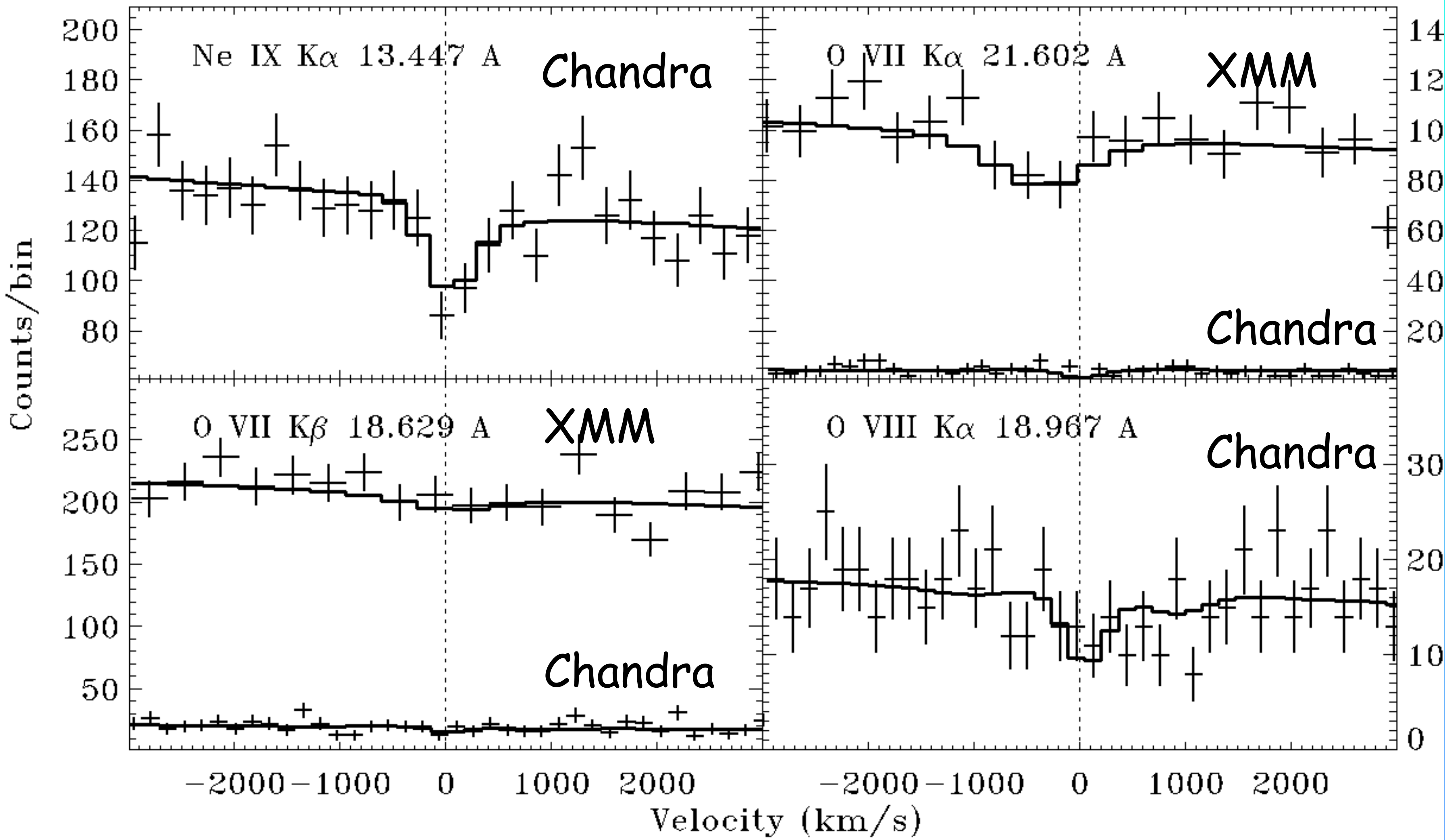


•(*l*, *b*) = (51.31, -9.33)
•D: 10-25 kpc (Nowak et al. 2007)
==> 1.6-4.1 kpc above the disk or
==> sampling 60-90% of Galactic disk
•67 ks HETG GTO and 45 K *XMM-Newton*

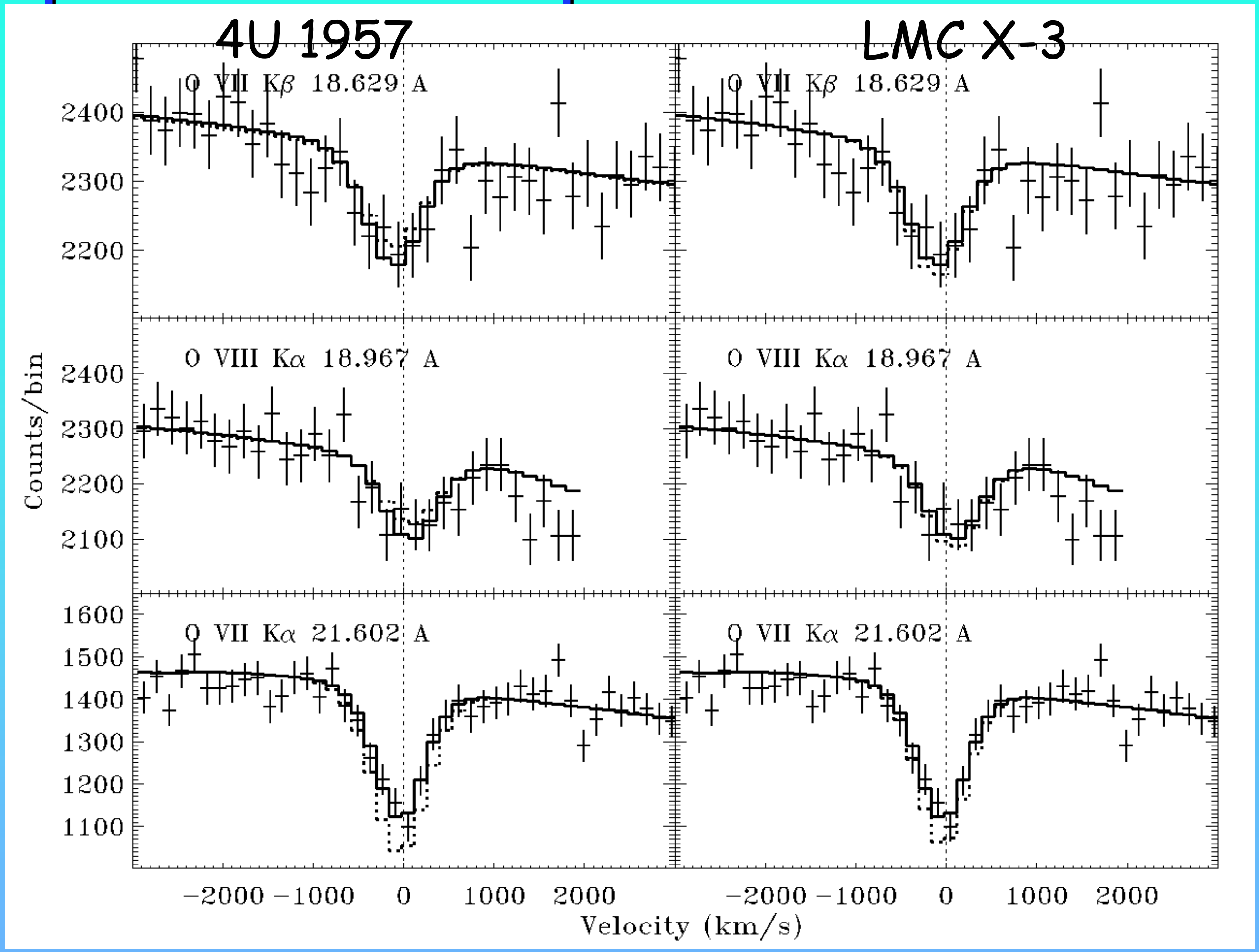
•Better target
•No obs. yet

RASS 3/4 keV SXB map (Snowden et al. 1997)

Absorption lines: 4U 1957+11 (V1408 Aql)



Absorption line comparison: Mrk 421



Note

Galactic latitude dependence has been considered

Results: some upper limits

Differential analysis of 4U 1957 and Mrk 421 sightlines

1) No ***metal*** (O and Ne) absorption beyond 4U 1957

2) $N_{OVII} < 5\times10^{22}$ cm^{-2} (95% confidence) or equivalent to $N_H < 9.1/A_O \times10^{18}$ cm^{-2} (A_O: gas metallicity in solar unit)

Assumption: disk gas and halo gas have same properties

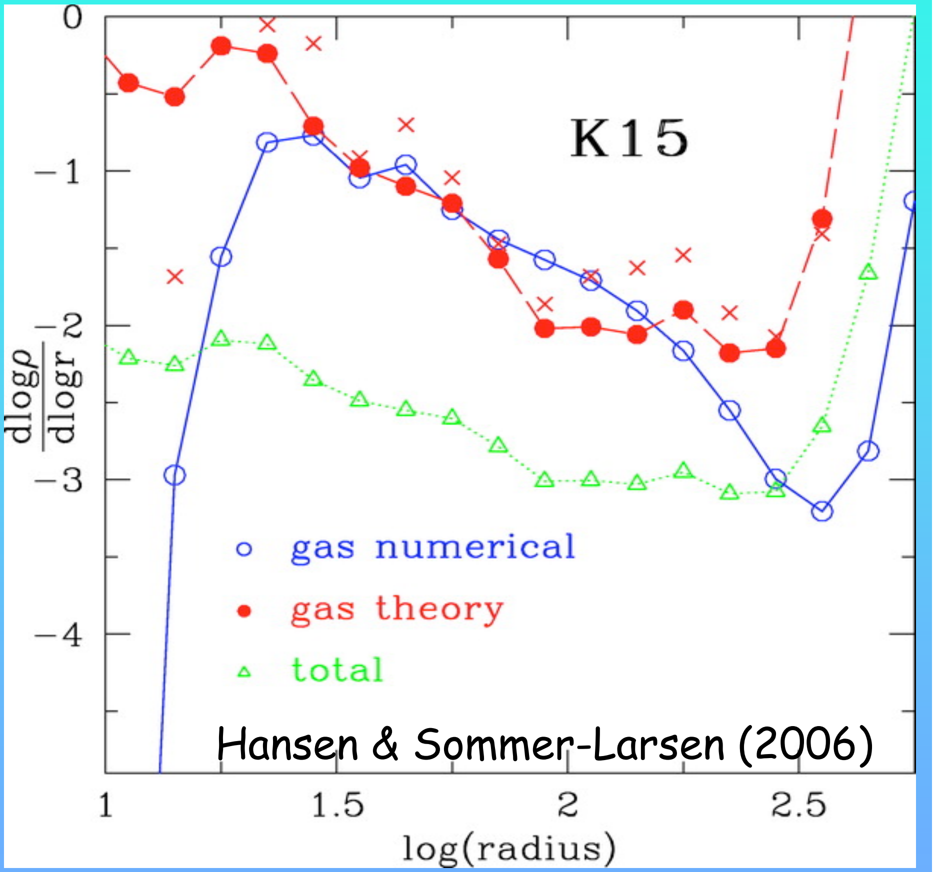
- Log(T): 6.23(6.21, 6.32)
- Vb: 70(50, 172) km/s

Results confront theories (1)

Power-law density distribution in halo: $\rho(r)= \rho_0(r/r_0)^{\alpha(r)}$
(Hansen & Sommer-Larsen 2006)

$N_H < 9.1/A_O \times 10^{18}\ cm^{-2} \Rightarrow$
$M_{halo} < 2.2 \times 10^9\ M_\odot$ for $A_O = 1$
$< 6.0 \times 10^{10}\ M_\odot$ for $A_O = 0.037$

In contrast:
Baryon missing in the WM:
$\sim 6 \times 10^{10}\ M_\odot$



Results confront theories (2)

A more flat density distribution derived the fragmentation cooling
(Maller & Bullock 2004)

$N_H < 9.1/A_O \times 10^{18}$ cm^{-2} $\Rightarrow$

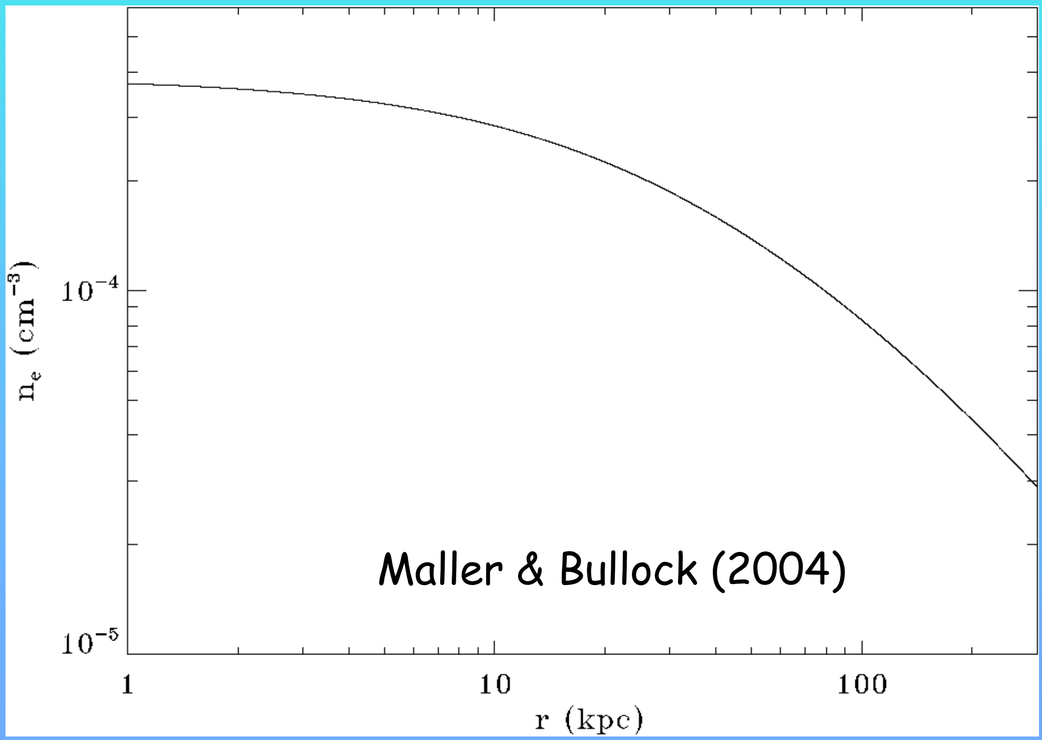
$M_{halo} < 5.1\times10^{9}\ M_\odot$ for $A_O = 1$

$< 6.0\times10^{10}\ M_\odot$ for $A_O = 0.085$

In contrast:

Baryon missing in the WM:

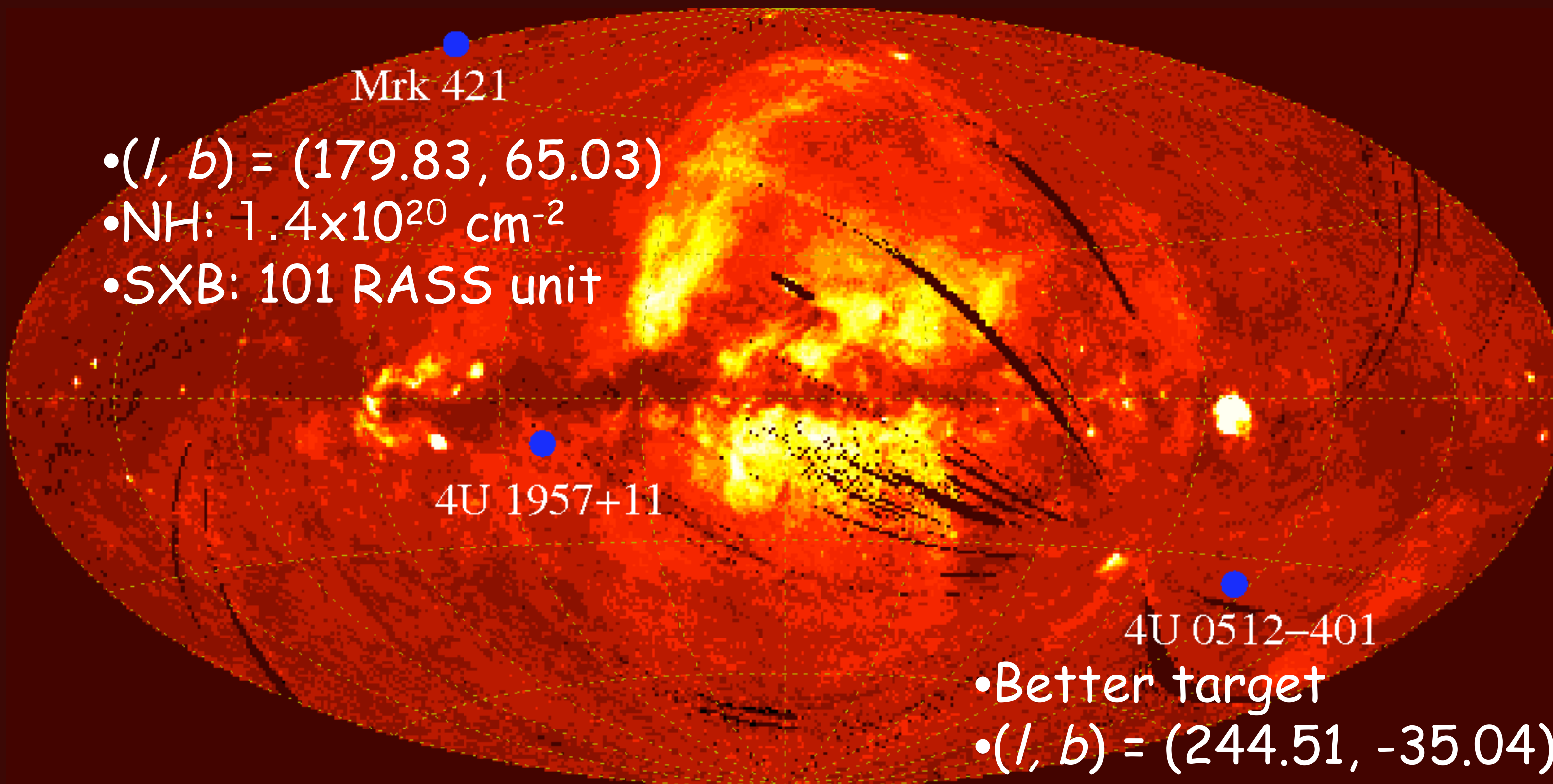
$\sim 6\times10^{10}\ M_\odot$



Summary:

- ✓ NO metal line absorption produced in the hot gaseous halo at > 10 kpc
- ✓ Or, if indeed about 6×10^{10} $M_{\odot}$ distributed in the large scale halo, the gas metallicity should be < 10%!!
- ✓ And …

A better Chandra target



- (l, b) = (179.83, 65.03)
- NH: 1.4×10^{20} cm^{-2}
- SXB: 101 RASS unit

- Better target
- (l, b) = (244.51, -35.04)
- D: 11 kpc (NGC 1851)
  ==> sample >95% disk gas
- NH: 3.5×10^{20} cm^{-2}
- SXB: 116 RASS unit

Absorption lines (2)

<u>Nature of lines:</u> intrinsic vs. ISM

- LMXB: no stellar wind
- Disk wind: possible
  - P: 9.33 hr, M_x: <16 $M_\odot$ ===> binary separation: <= 6 $R_\odot$
  - Fx (0.5-10 keV): 1.3×10^{-9} erg/cm^2/s
    ==> L: $1.19D^2_{10kpc}\times10^{37}$ erg/s
    ==> ionization para. $\log(L_x/nr^2) < 2$ to have NeIX
    ==> $R_w > 180\ R_\odot$
- ISM origin is more likely!

Results: some upper limits (2)