Searching for Dark Matter with X-ray lines

Perseus Cluster
(Chandra)

Kenny, Chun Yu Ng (吳震宇)
Weizmann Institute of Science

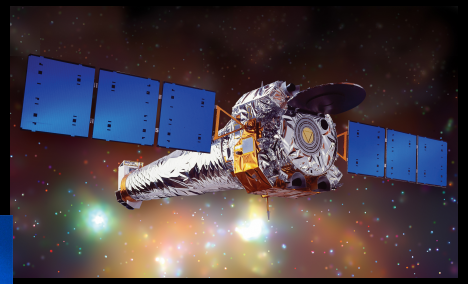
X-ray line Searches of Dark Matter

- Particle Dark matter Identification
  - Collider
  - Direct detection
  - Indirect detection

- Well Motivated Candidates
  - *Sterile Neutrino (keV)*
  - Axion-like Dark Matter
  - Gravitino
  - Exciting Dark Matter
  - ++++++

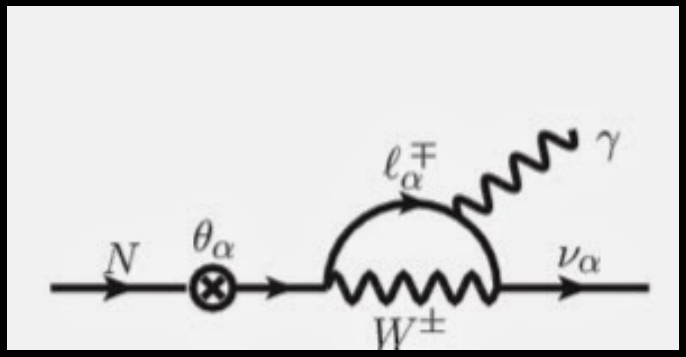
- Line signal (smoking gun signal)

Chandra (1999 -)



XMM Newton (1999 -)

Suzaku (2005 - 2015)

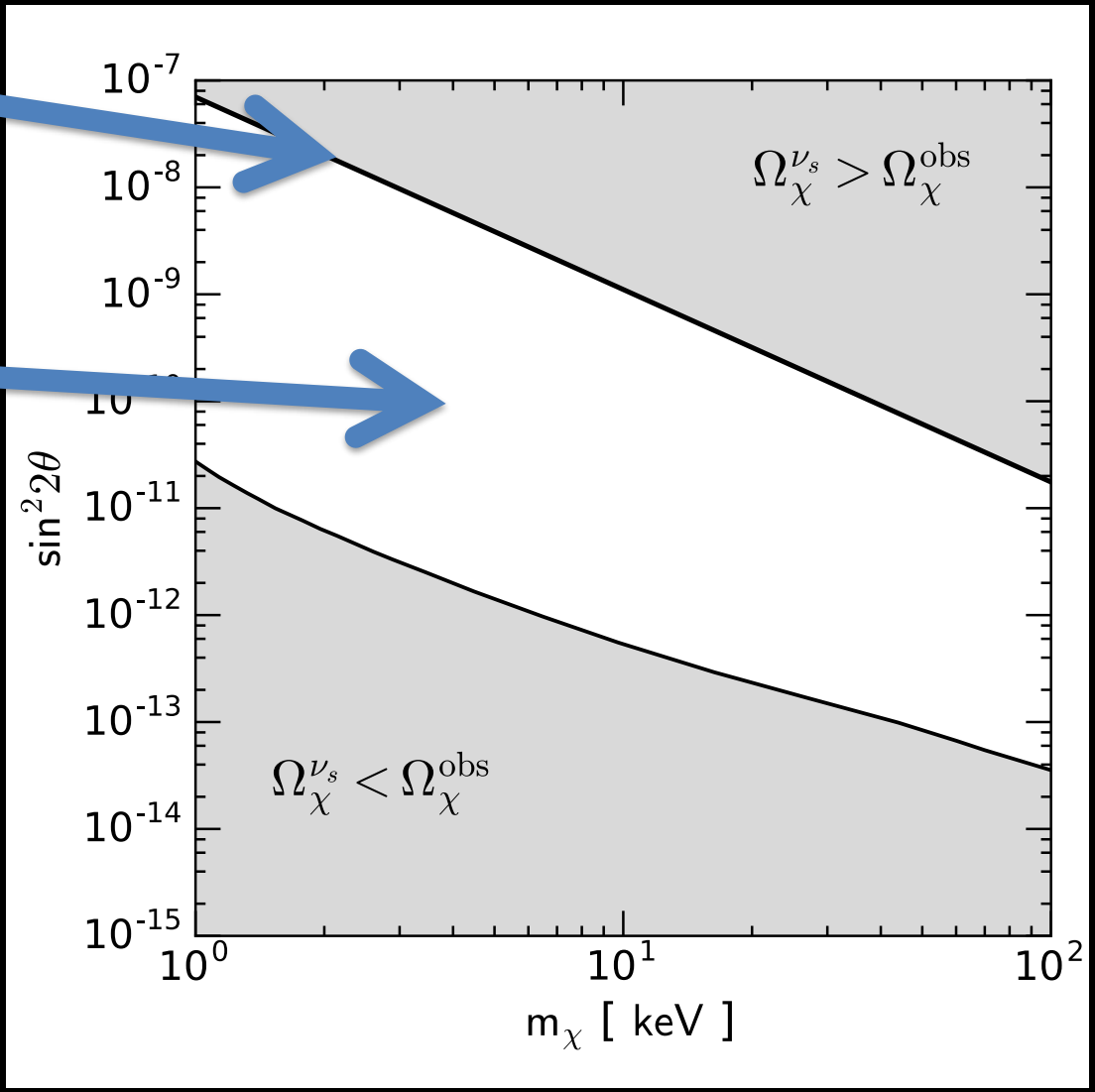


Sterile Neutrino Dark Matter Production

- Dodelson-Widrow 1994

$$\Omega_4 h^2 \simeq 0.3 \frac{\sin^2 2\theta}{10^{-8}} \left(\frac{m_4}{10\text{keV}}\right)^2$$

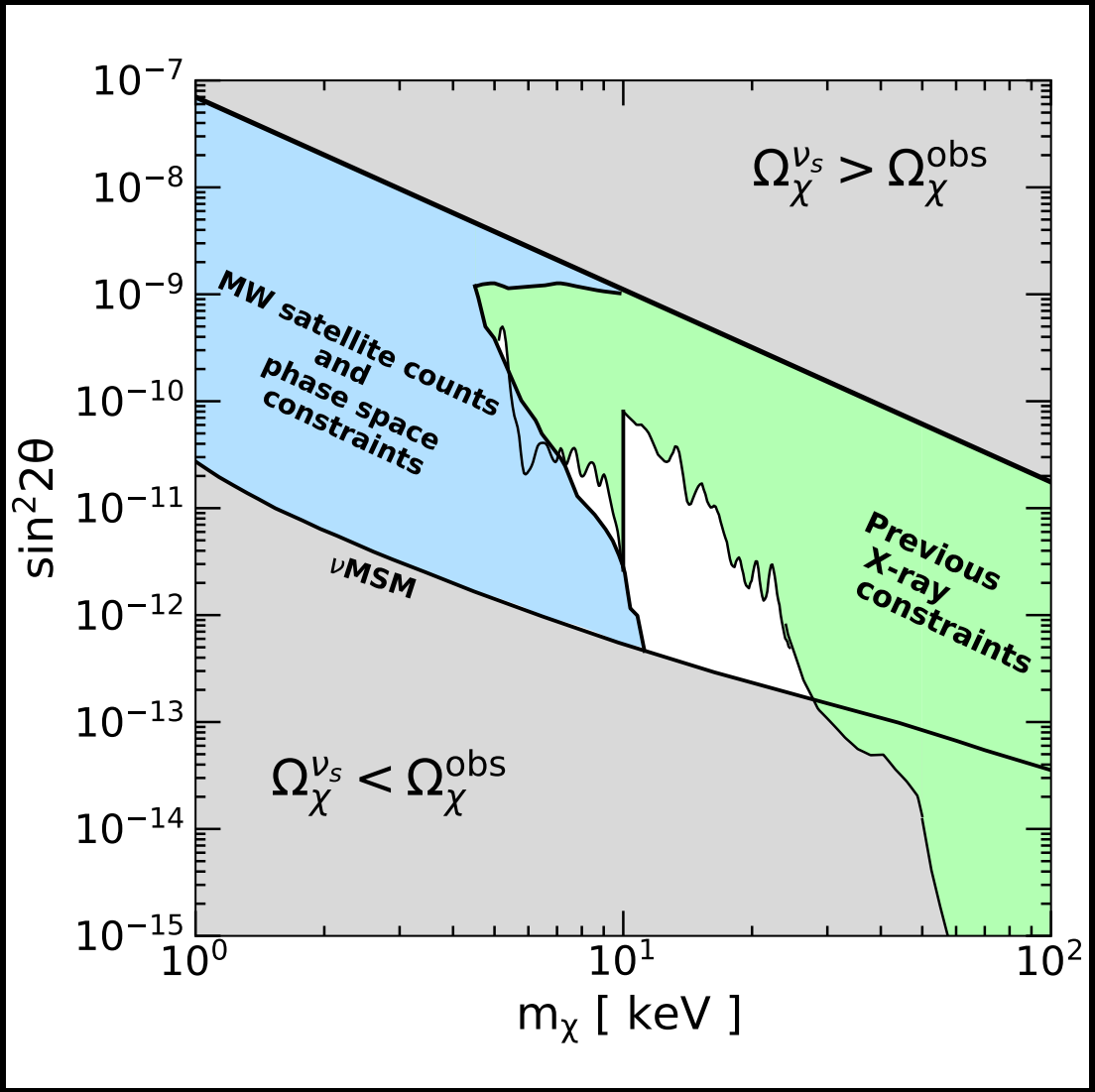
- Shi-Fuller (1999)
  - MSW effect due to primordial lepton asymmetry
- νMSM
  - Asaka, Blanchet, Shaposhnikov (2005)
  - Dark Matter
  - Neutrino mass
  - Leptogenesis
- Other production methods also proposed



Constrained from all sides

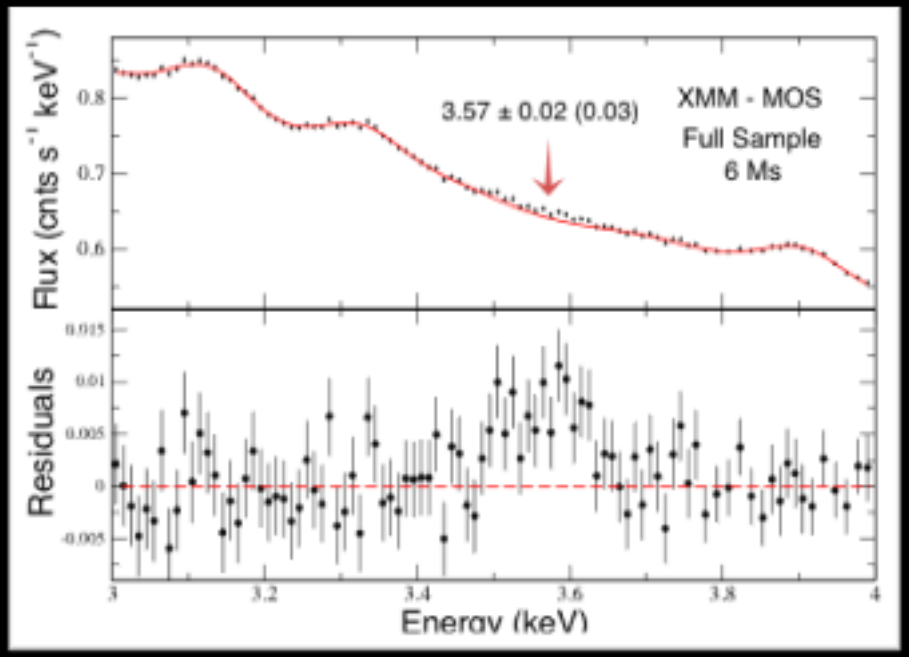
- Warm dark matter candidate
  - Schneider 2016
  - Cherry, Horiuchi 2017
- May solve the Small Scale problem!

- X-rays searches
  - Chandra
  - NuSTAR Bullet Cluster
  - ***Fermi GBM (KCYN 2015)***
  - Integral
  - ..



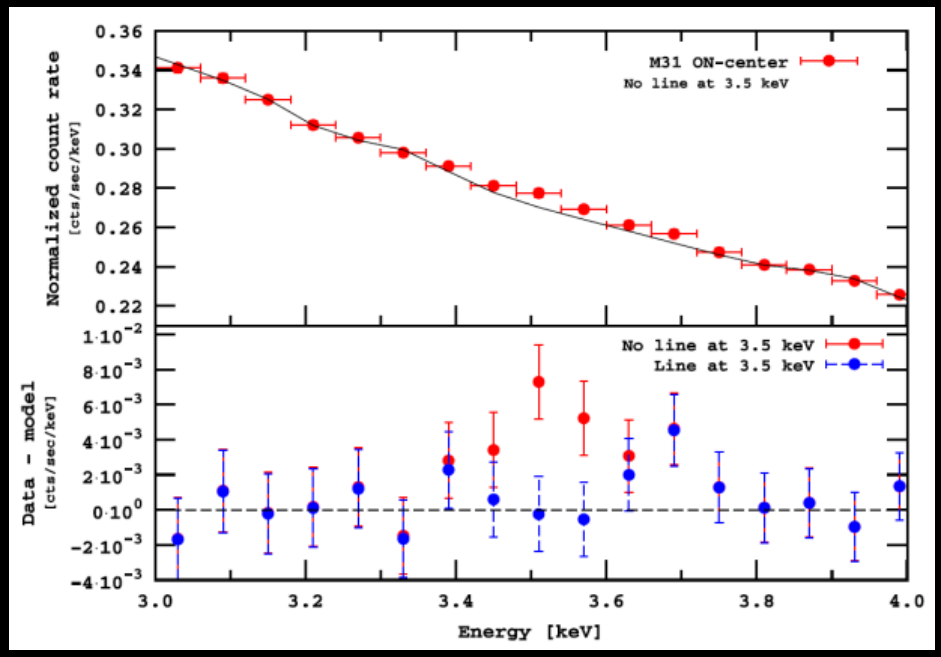
3.5 keV line excess!

- Bulbul et al (2014)



Stacked 73 clusters XMM-MOS (4-5σ)
Also
Chandra Perseus 2.5σ and 3.4σ

Boyarsky et al (2014)

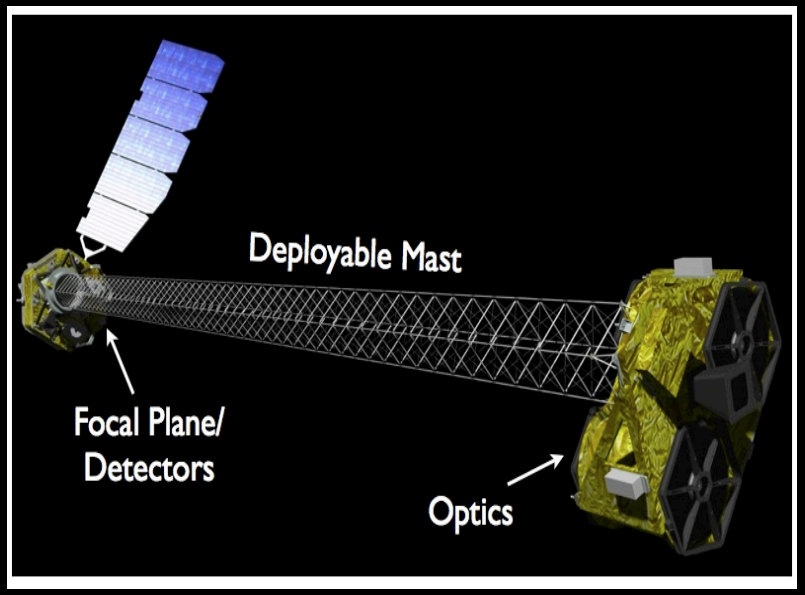


XMM-Newton M31

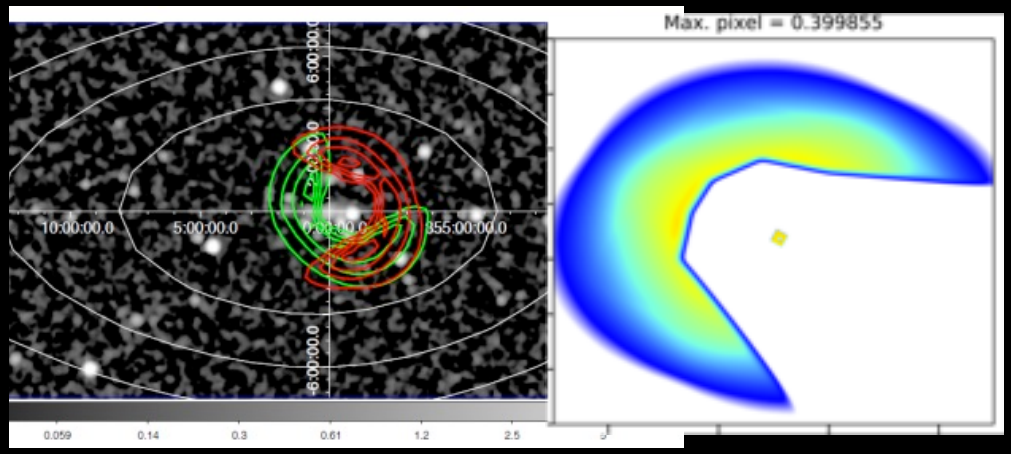
Many Follow-up detections and non-detections! But not ruled out!
Nature not clear!

NuSTAR

- **Nu**clear **S**pectroscopic **T**elescope **Ar**ray

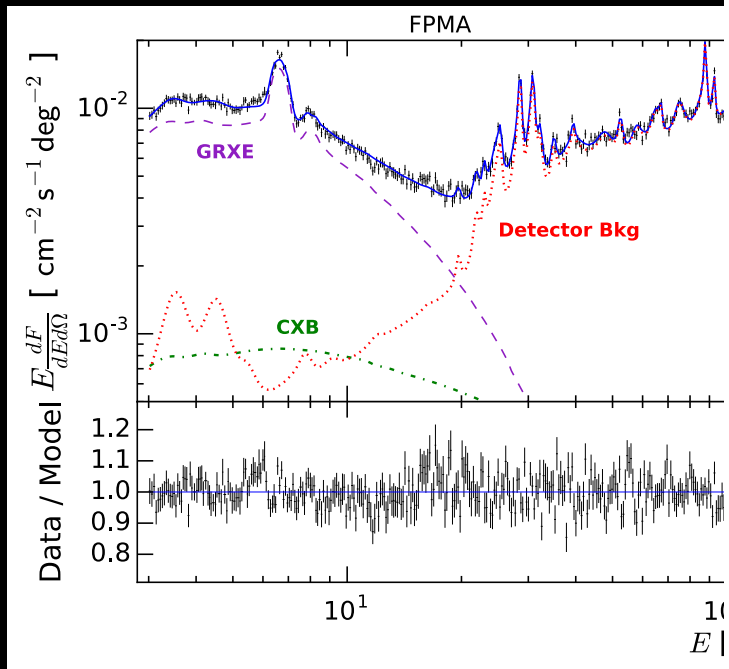


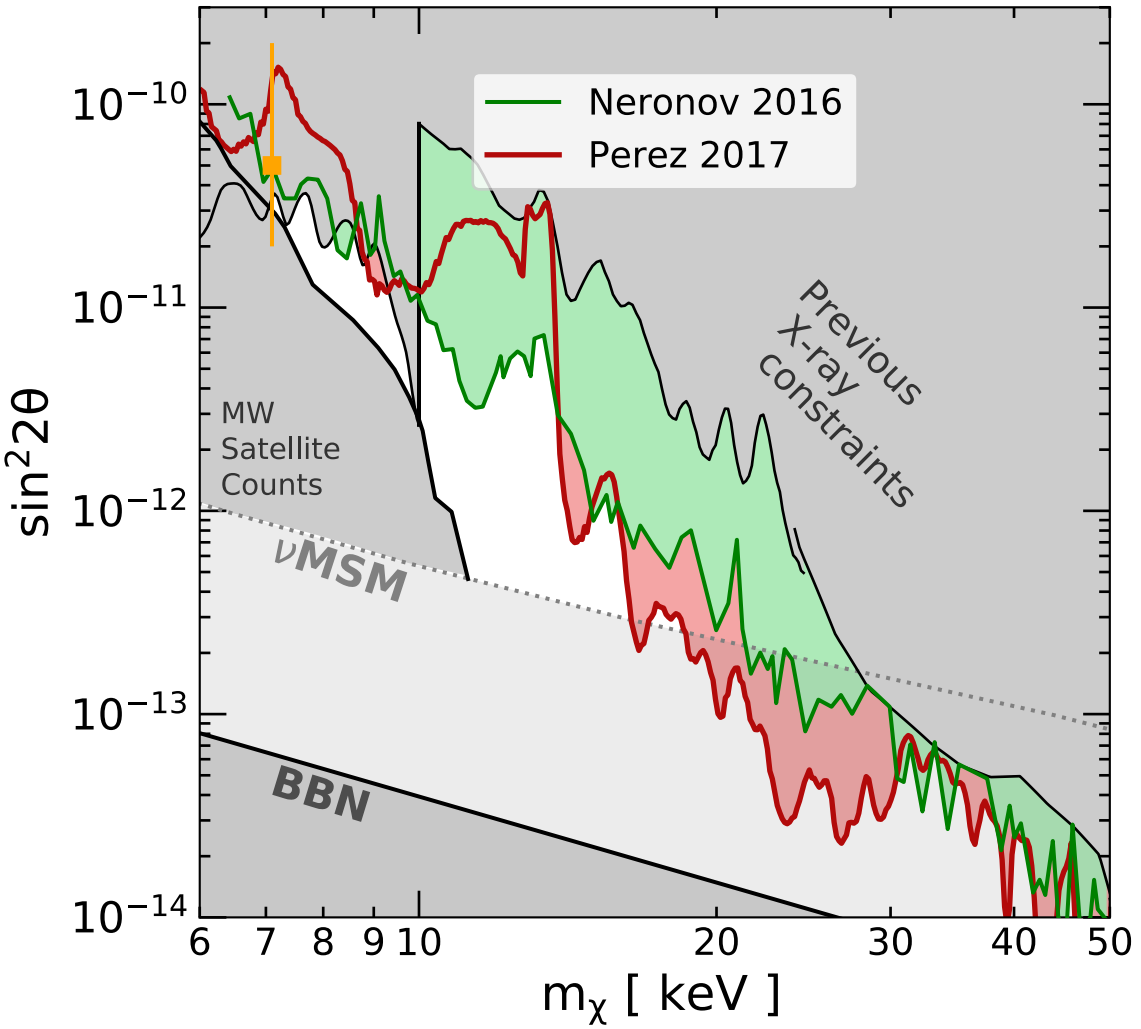
- Neronov, Malyshev, Eckert [1607.07328]
  - Diffuse sky, MW halo
- Perez, ***KCYN***, Beacom, Hersh, Horiuchi, Krivonos [1609.00667]
  - Galactic Center
- Zero bounce photons
  - 10X exposure!



NuSTAR constraints

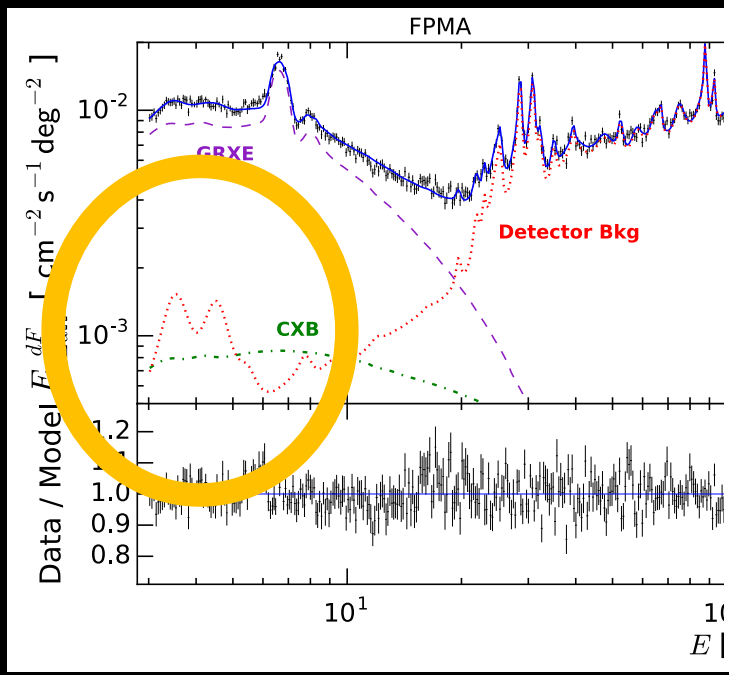
- 0.5 Ms Milky Way observation
- Neronov et al
  - 7.5 Ms blank sky

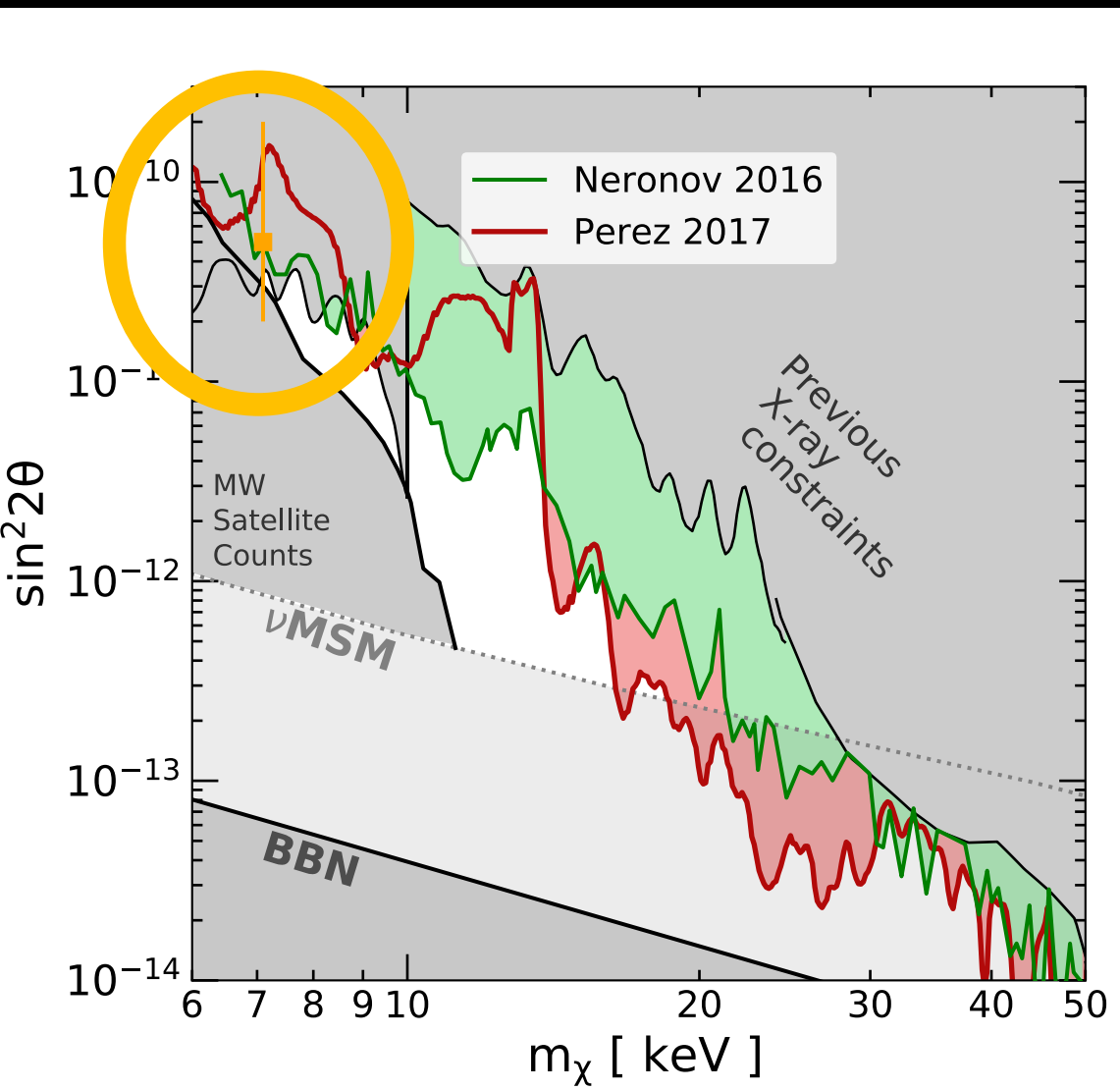




3.5 keV in NuSTAR?

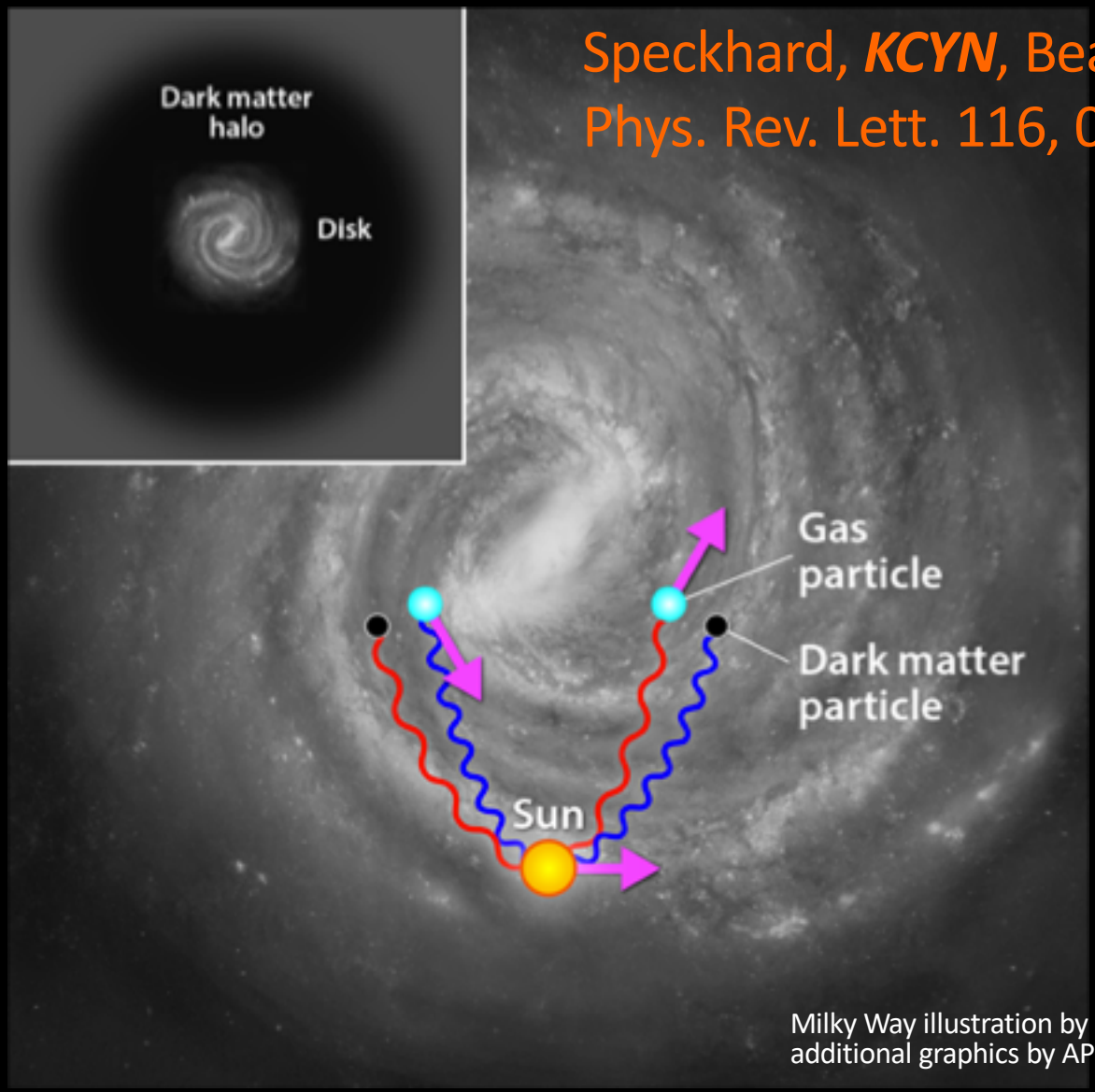
- 3.5 keV line in the NuSTAR background model
- Under Investigations





Dark Matter Velocity Spectroscopy

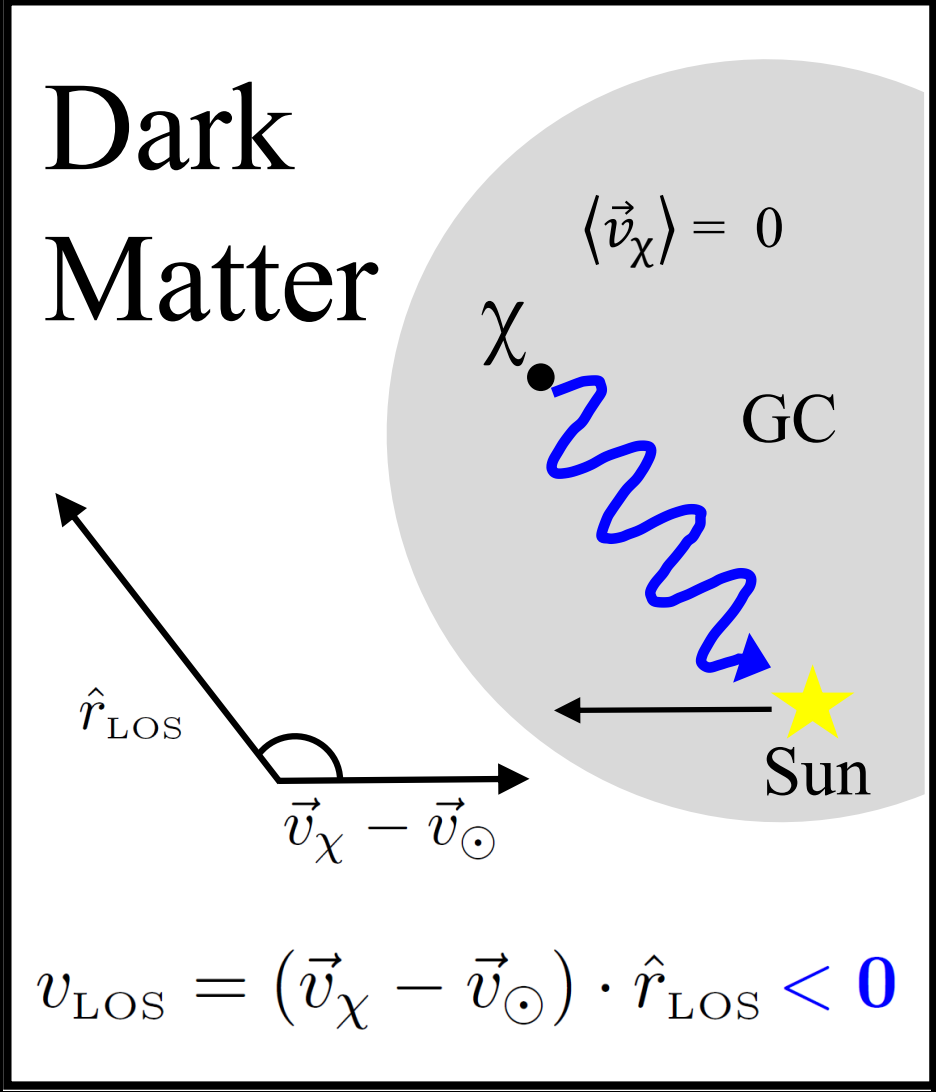
Speckhard, ***KCYN***, Beacom, Laha
Phys. Rev. Lett. 116, 031301



Milky Way illustration by Nick Risinger (CC:BY); additional graphics by APS/Alan Stonebraker

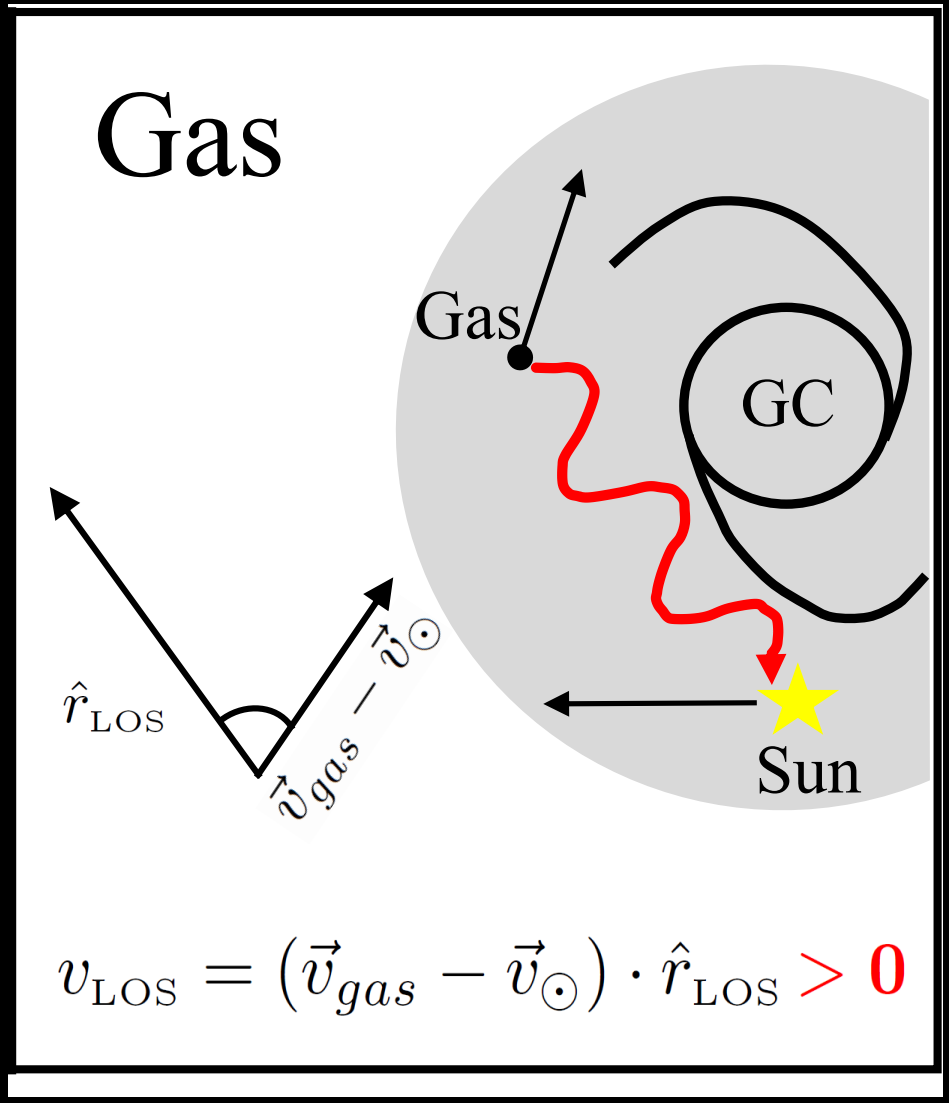
Milky Way dark matter (signal)

- Velocity of the Sun
  - (+)220km/s, +longitude
- Mean dark matter velocity ~ 0
- DM line
  - Blue shifted for +longitude



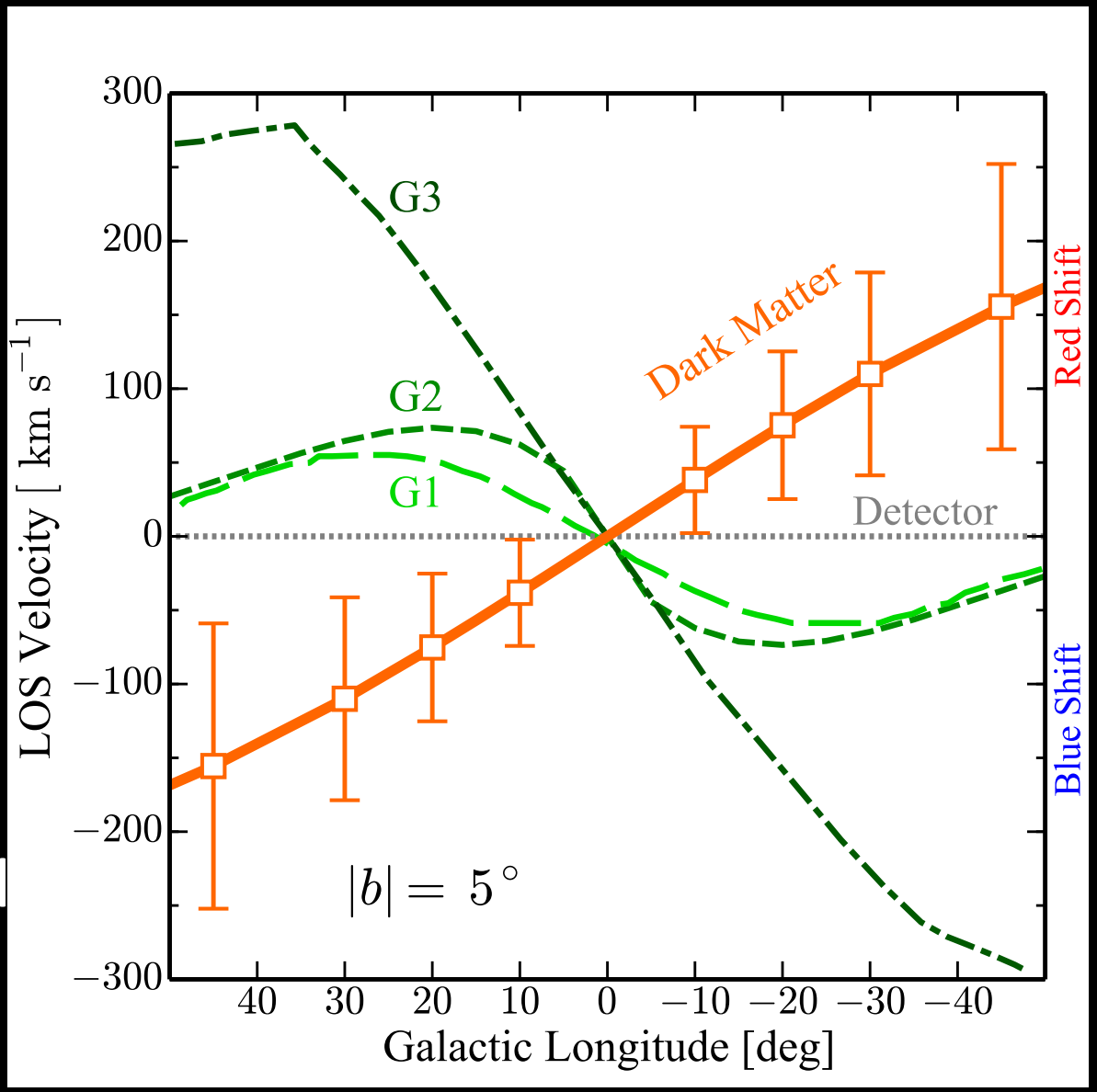
Milky Way Gas (Background)

- Gas and the Sun co-rotate in a disk
  - $V^2 \sim GM/r$
- Astro-physical line
  - Red shifted in + longitude!



DM – Astro Separation (MW)

- 0.1% energy resolution
- Clean separation
  - DM
  - Astro
  - Detector effect
- Two obs. -> 3.6σ
- Minimal theoretical uncertainty

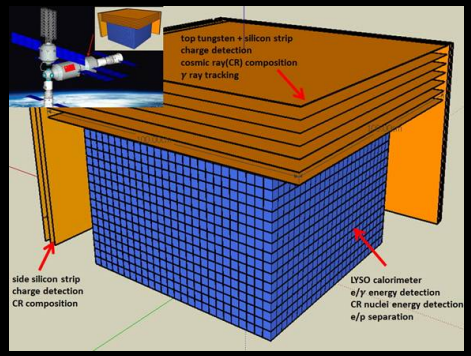


DM Velocity Spectroscopy

- Extra handle for testing line-like signal
  - The “smoking gun” sometimes is not enough
- X-ray/ 3.5 keV line
  - ~~Astro-H (Hitomi)~~ ----> XRAM (2021)
  - Micro-X/ sounding rockets

Figueroa-Feliciano+ [1506.05519]
Powell, Laha, ***KCYN,*** Abel [1611.02714]

- If DM decay/annihilation produces a line.
  - HERD (GeV-TeV)
    - Photons and electrons
    - 2020?



- Dark astronomy/cosmology

Conclusion

- Searching for dark matter with X-rays
  - Production vis mixing / νMSM under test
  - NuSTAR (new results in 2018 and 2019)
    - NuSTAR 3.5 line under investigation
  - *HXMT?*

- Velocity Spectroscopy
  - New Hitomi (maybe 2021)
  - Micro-X

Thanks you!