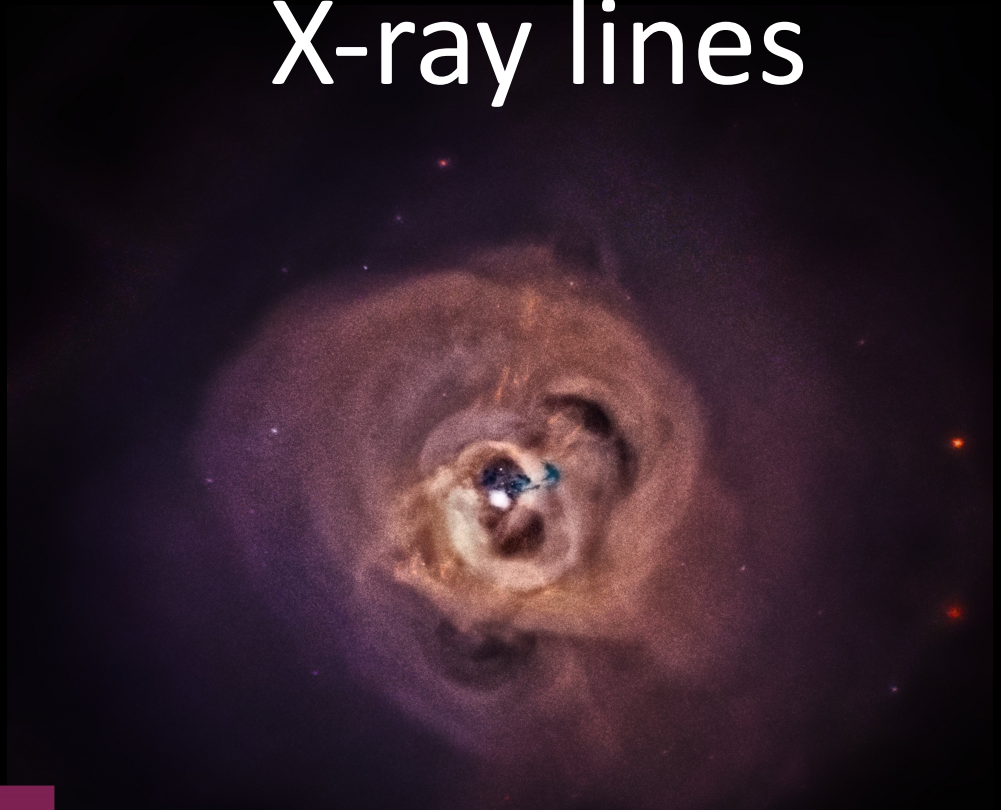
Searching for Dark Matter with X-ray lines



Perseus Cluster
(Chandra)

Kenny, Chun Yu Ng (吳震宇)
Marie Curie fellow
GRAPPA, University of Amsterdam

TeVPA 2019

References

- Searching for DM with NuSTAR
  - Galactic Center, 1609.00667
    - Perez, KCYN, Beacom, Hersh, Horiuchi, Krivonos
  - M31, 1901.01262
    - KCYN, Roach, Perez, Beacom, Horiuchi, Krivonos, Wik
  - Galactic bulge, 1908.09037
    - Roach, KCYN, Perez, Beacom, Horiuchi, Krivonos, Wik
- Dark Matter Velocity Spectroscopy
  - Speckhard, KCYN, Beacom, Laha, 1507.04744
  - Powell, Laha, KCYN, Abel, 1611.02714
- DM implication of GW detection of DM spikes
  - Hannuksela, KCYN, Li, 1906.11845

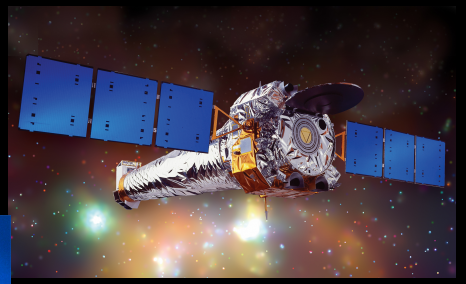
X-ray line Searches of Dark Matter

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

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

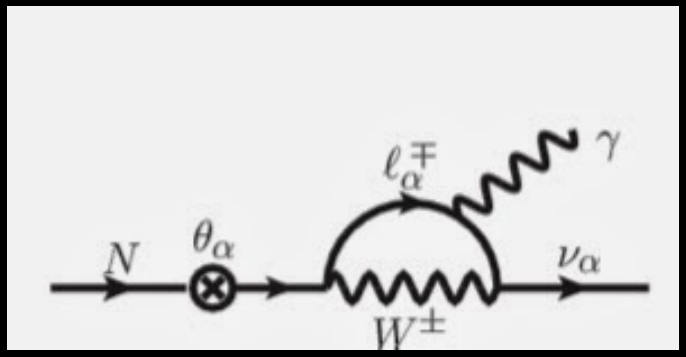
- Line signal (smoking gun signal)

Chandra (1999 -)



Suzaku (2005 - 2015)

XMM Newton (1999 -)



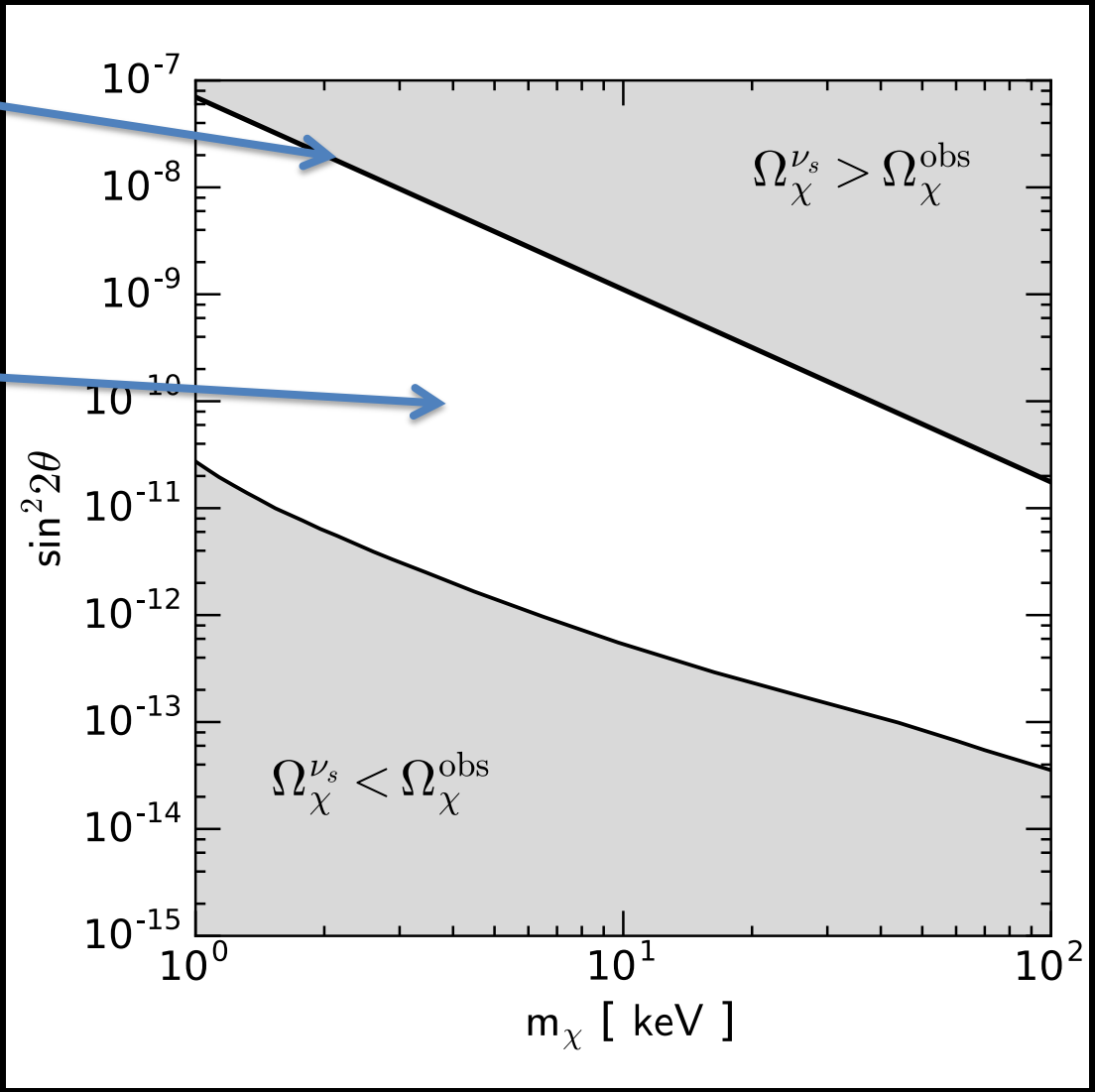
Sterile Neutrino Dark Matter Production

- 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

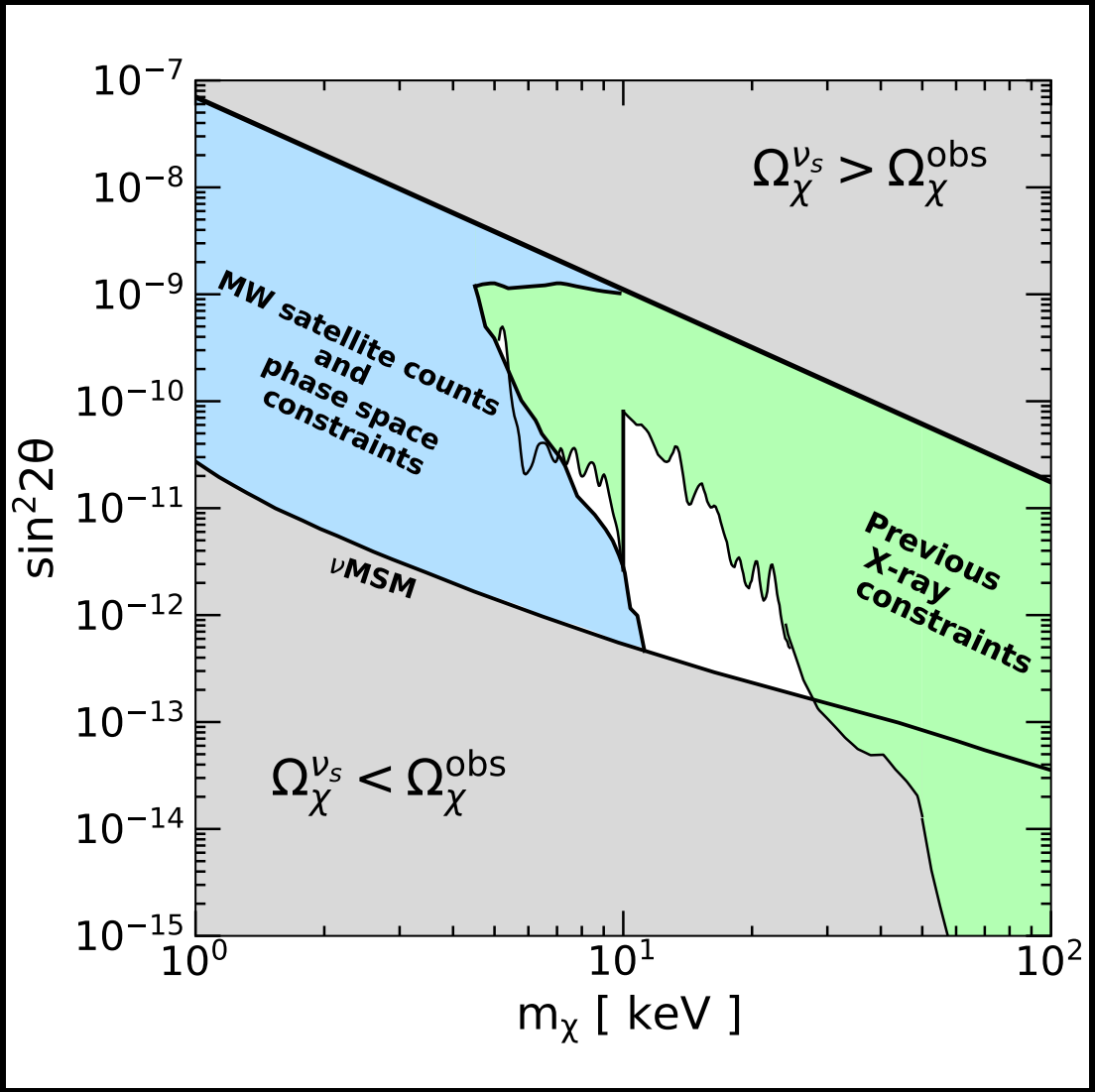
- Other production methods also proposed



Constrained from all sides

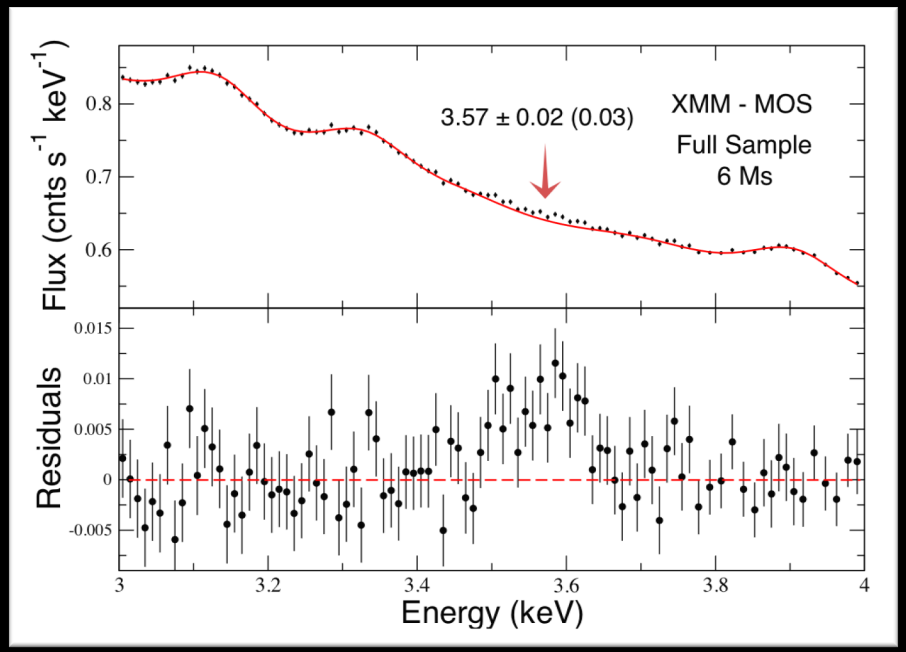
- Warm dark matter candidate
  - Schneider 2016
  - Cherry, Horiuchi 2017
- May solve the Small Scale problem!

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



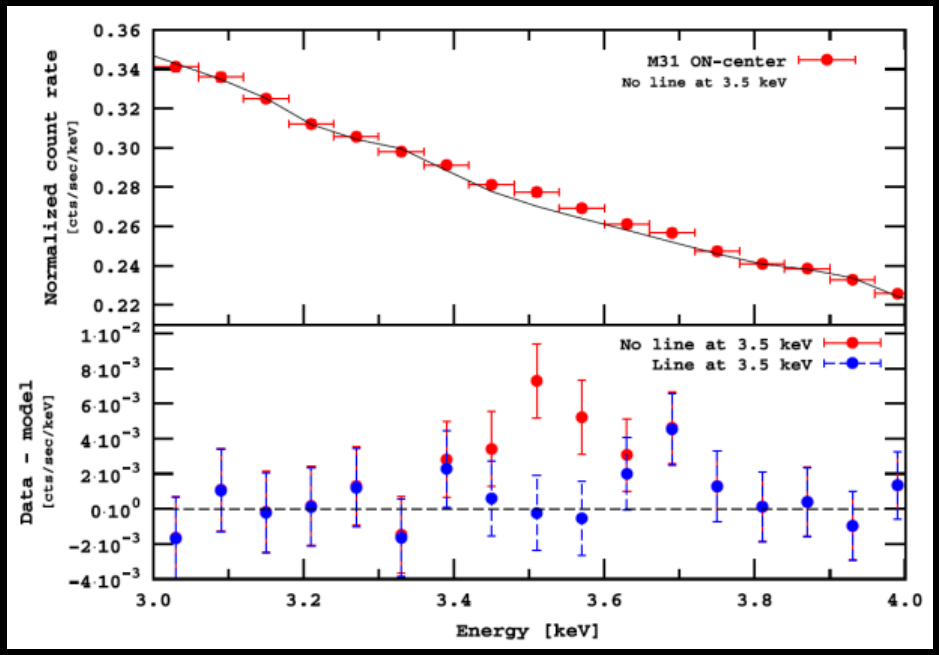
3.5 keV line excess!

- Bulbul et al (2014)



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

Boyarsky et al (2014)

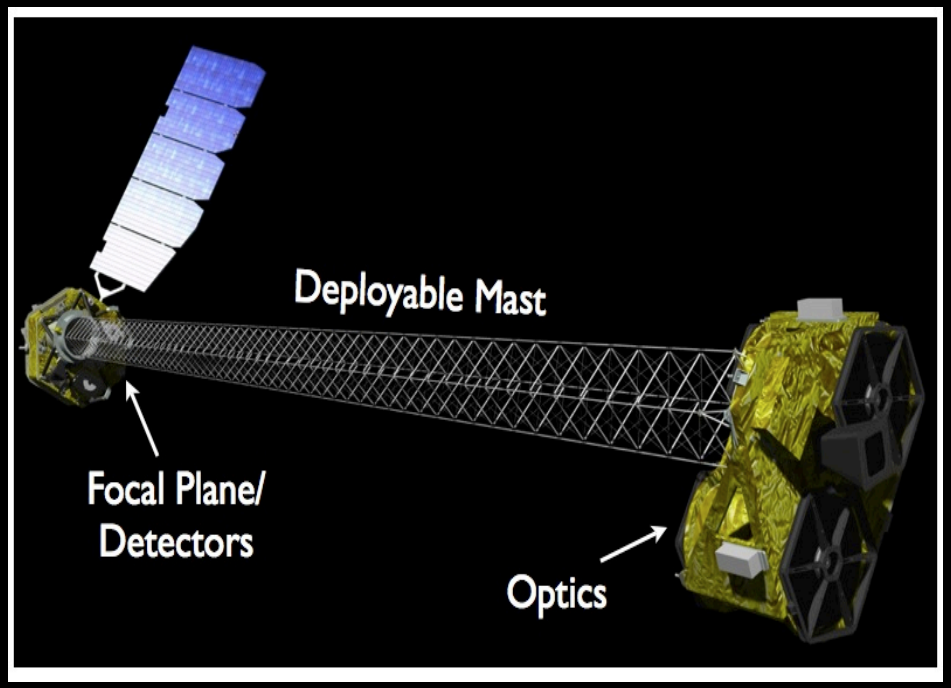


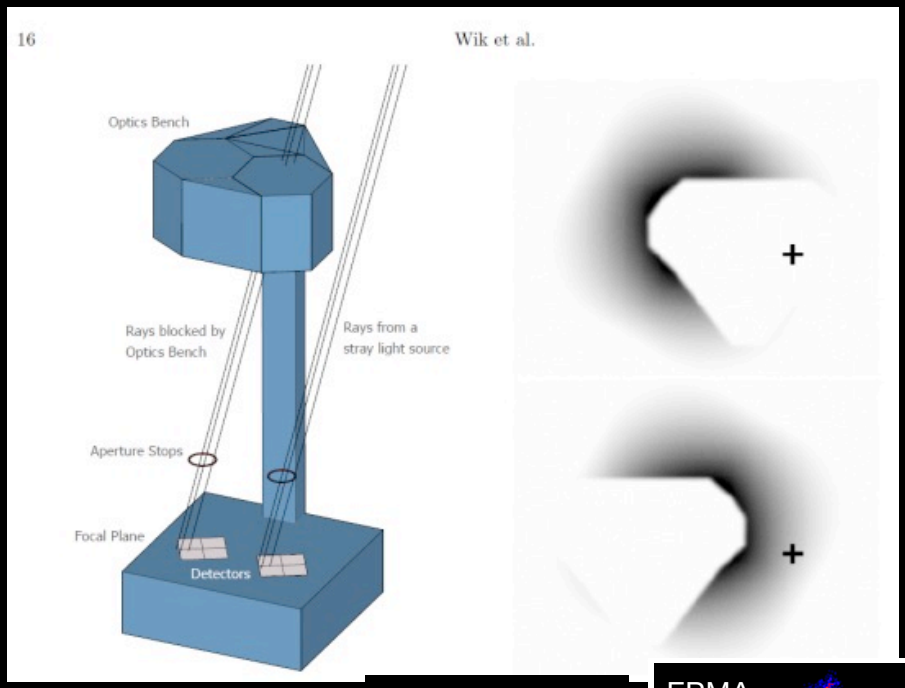
XMM-Newton M31

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

NuSTAR

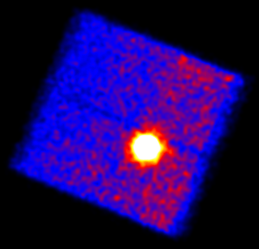
- **Nu**clear **S**pectroscopic **T**elescope **Ar**ray
  - Launch in 2012

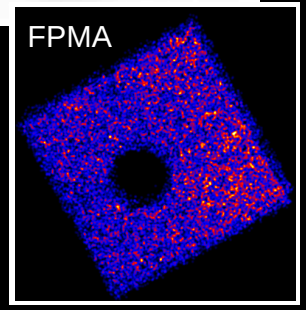




Zero Bounce Photon: Neronov+2016, Perez+2017

-> Large exposure for diffuse (DM) emission

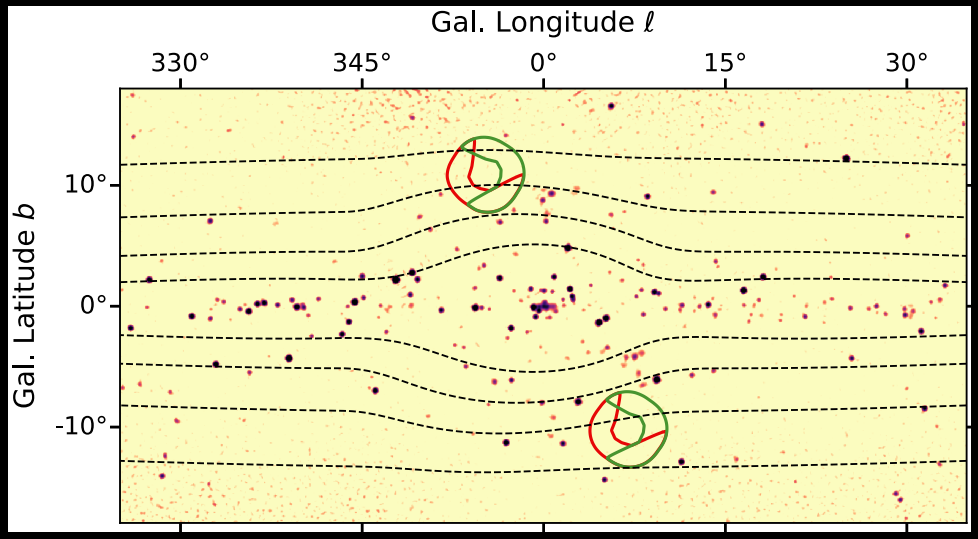


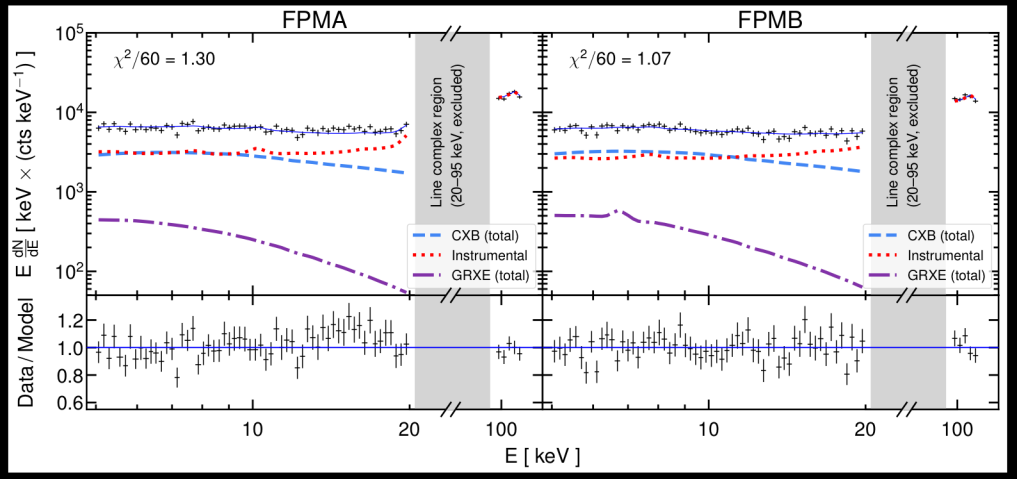


NuSTAR Galactic Bulge analysis

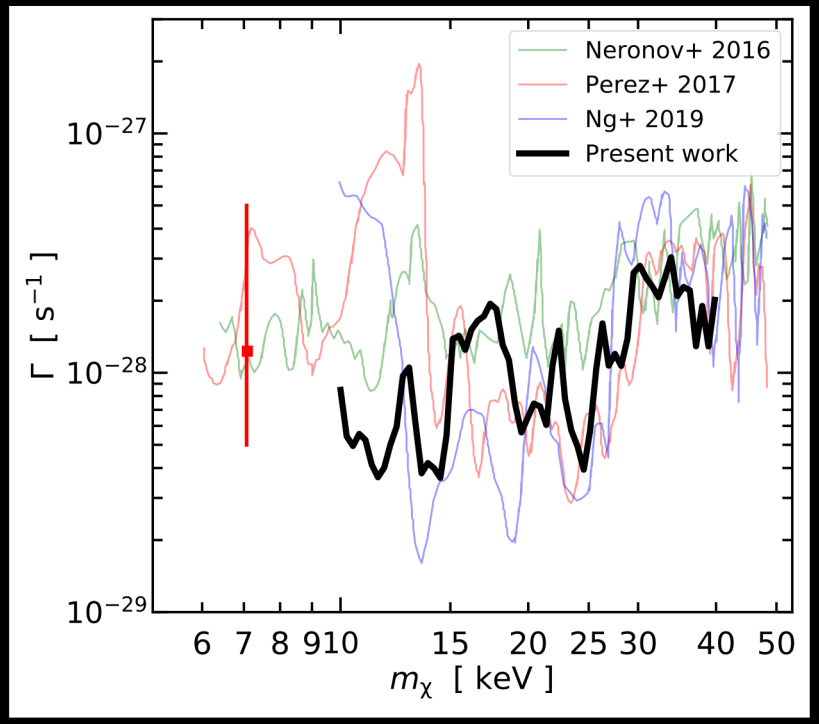
Galactic Center: Perez, KCYN, Beacom, Hersh, Horiuchi, Krivonos (1609.00667)
M31: KCYN, Roach, Perez, Beacom, Horiuchi, Krivonos, Wik (1901.01262)
Galactic bulge: Roach, KCYN, Perez, Beacom, Horiuchi, Krivonos, Wik (1908.09037)

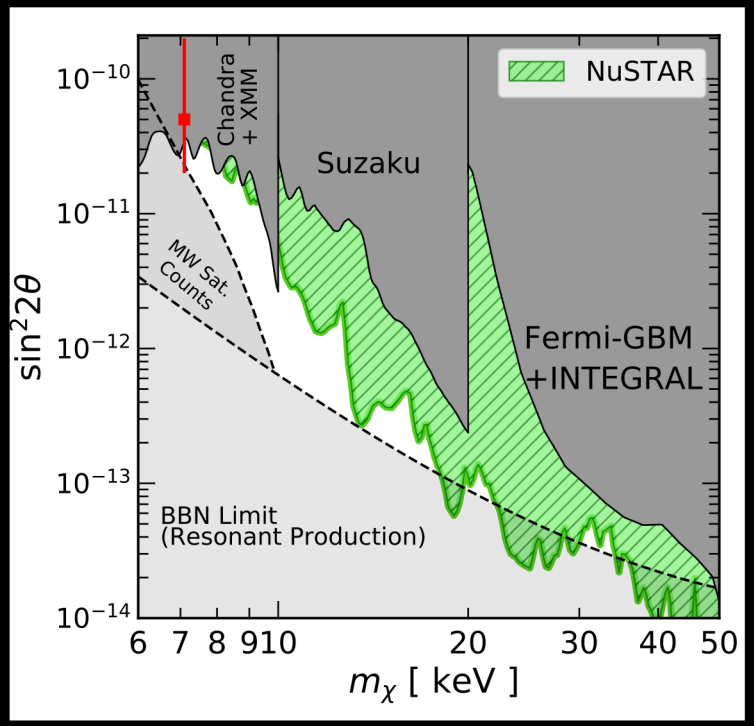
- Two dedicated observations
  - ~200ks
- Large J-factor
- Small Background
- ***>5 keV***
  - ***10 keV DM mass***





Closing the window with NuSTAR



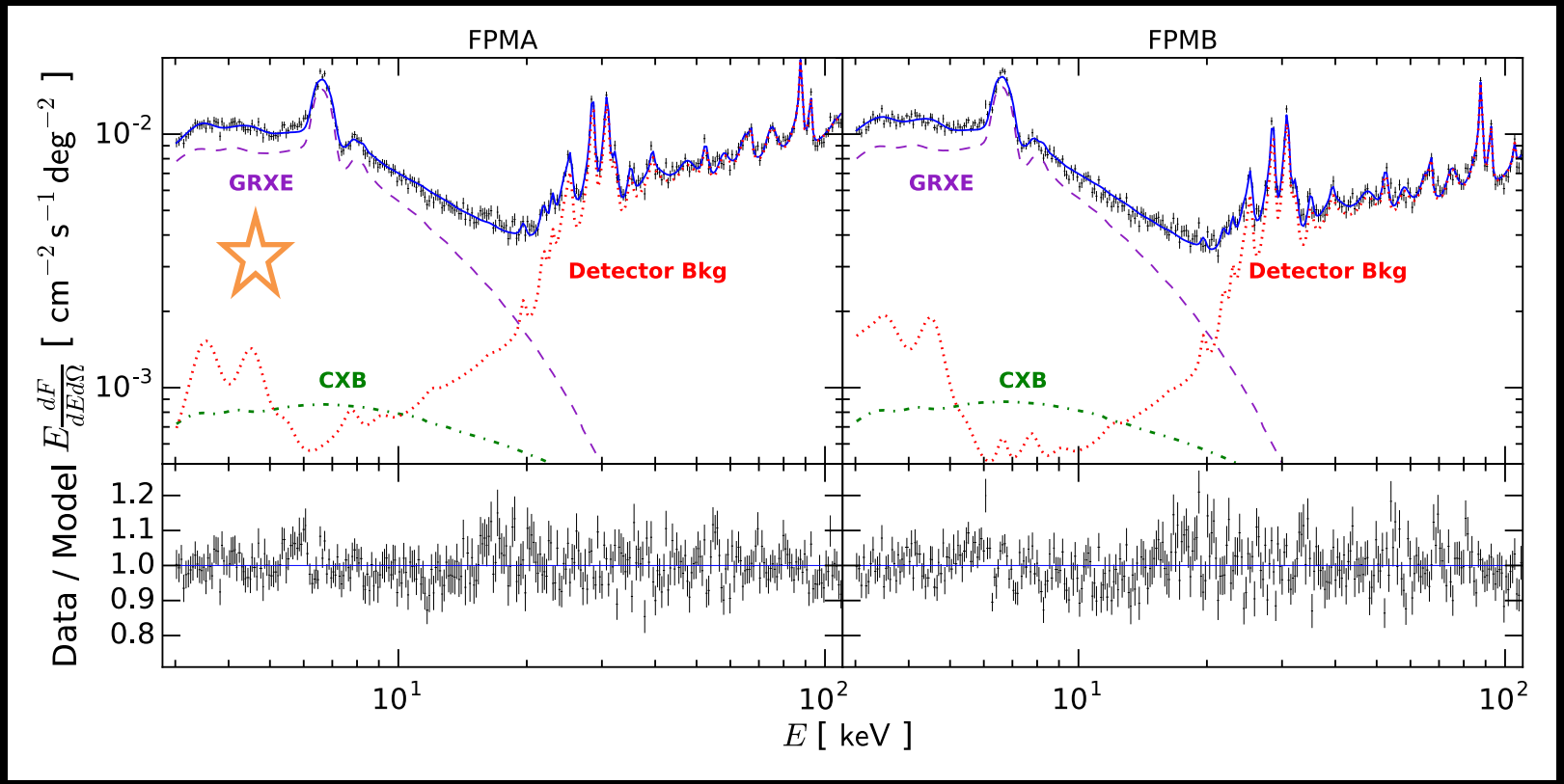


Roach+ 1908.09037

- More observations
- Include 3--5 keV data?
  - Testing the 3.5 keV line

NuSTAR Spectra

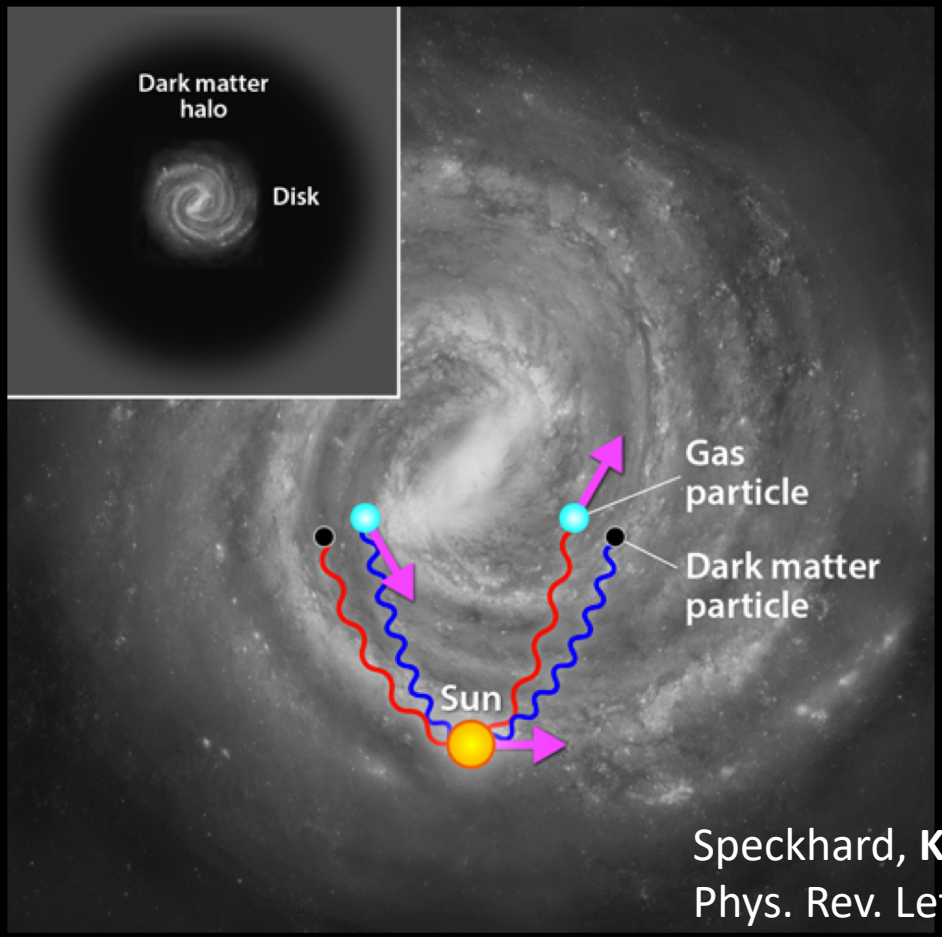
- 3.5 keV line in the default background model!
- Ongoing work to understand background <5 keV



Perez+ 2016

Dark Matter Velocity Spectroscopy

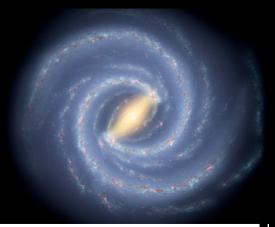
- *DM line diagnosis with line shift and broadening*



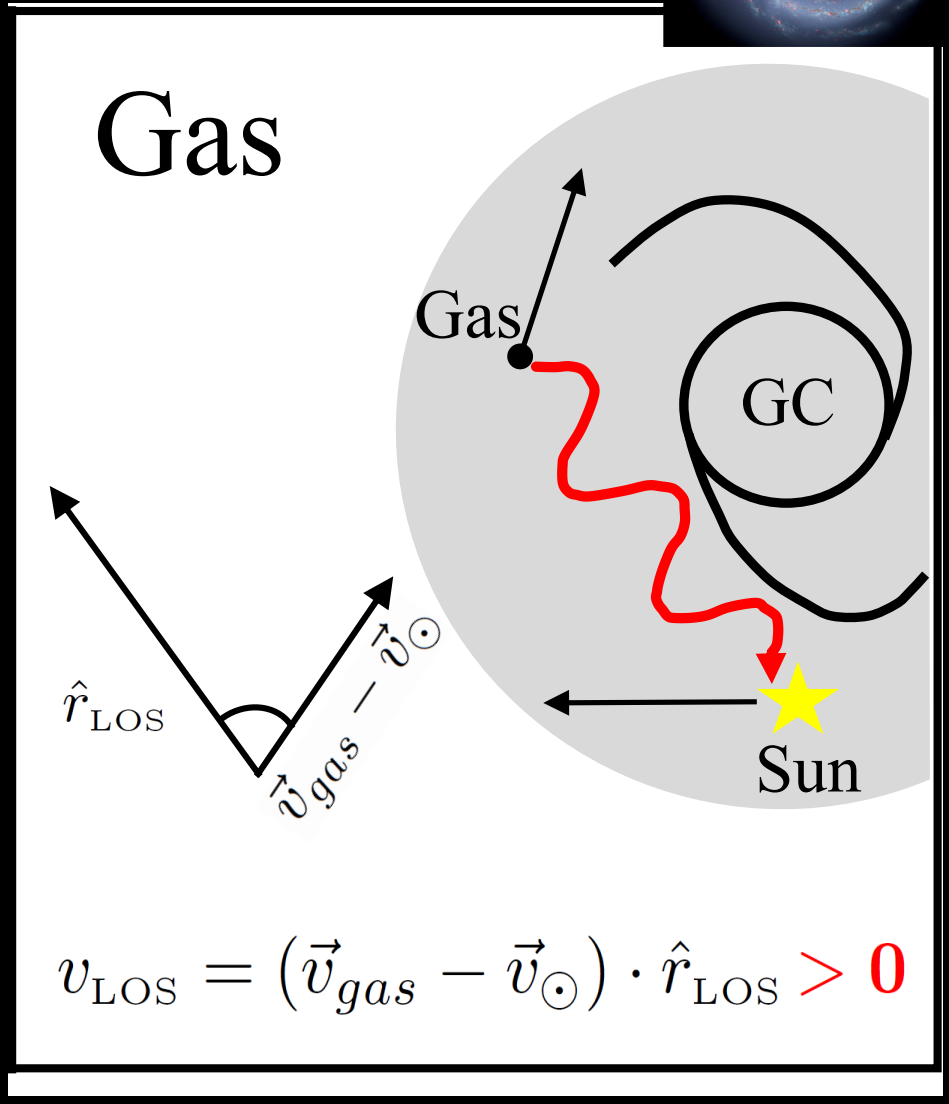
Speckhard, **KCYN**, Beacom, Laha Phys. Rev. Lett. 116, 031301

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

Milky Way Gas (Background)

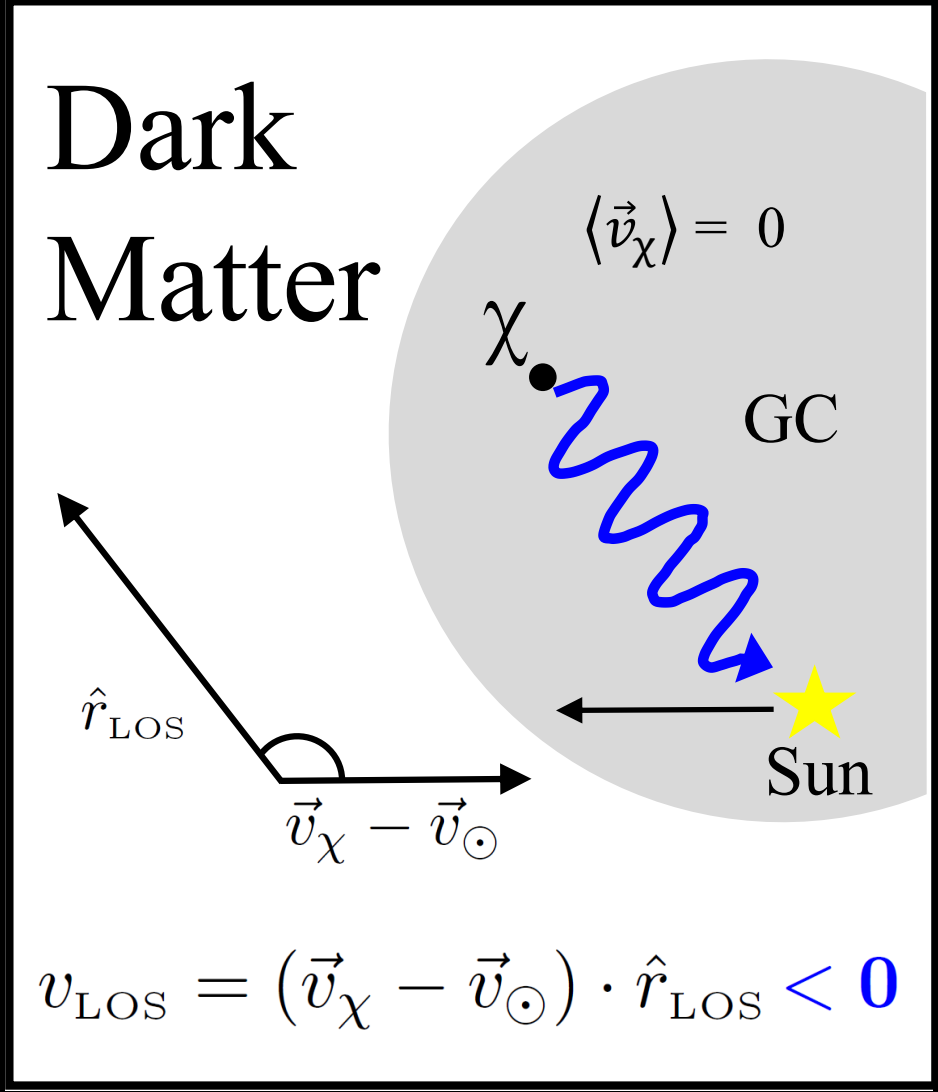


- Gas and the Sun co-rotate in a disk
  - $V^2 \sim GM/r$
- Astro-physical line
  - Red shifted in + longitude!



Milky Way DM

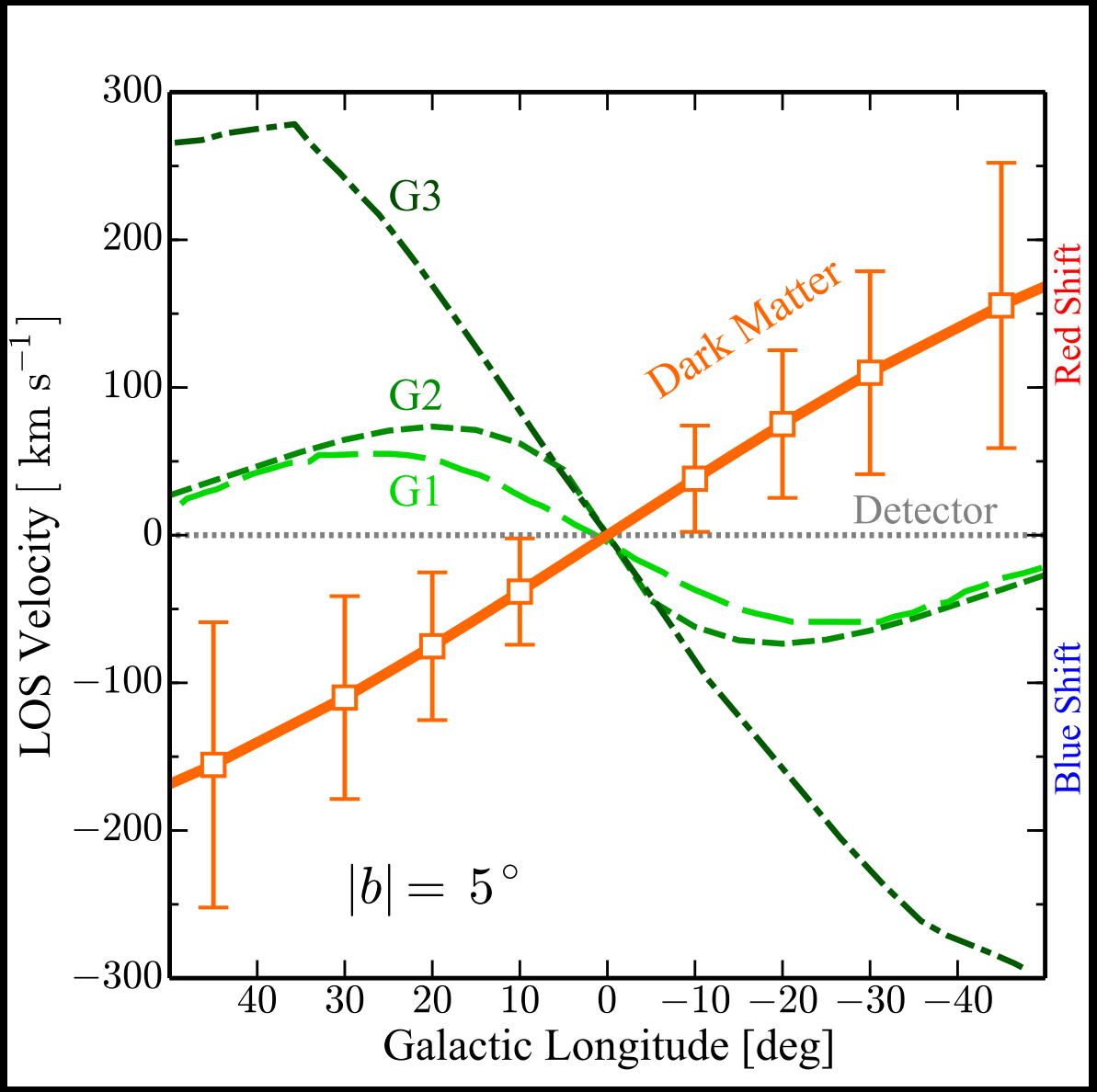
- Velocity of the Sun
  - (+)220km/s, +longitude
- Mean dark matter velocity ~ 0
- DM line
  - Blue shifted for +longitude



DM – Astro Separation (MW)

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

1611.02714
Powell, Laha, KCYN, Abel



High-resolution X-ray Spectrometers

- ~ 300 km/s → 10^{-3} energy resolution (!)
- RIP Astro-H/Hitomi
- XRISM (2020-2021?!)

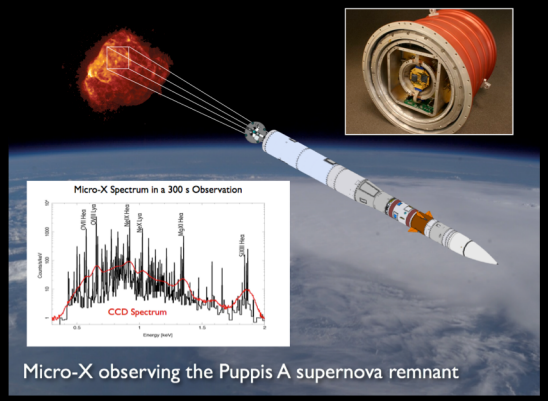
The XRISM project initiated by JAXA

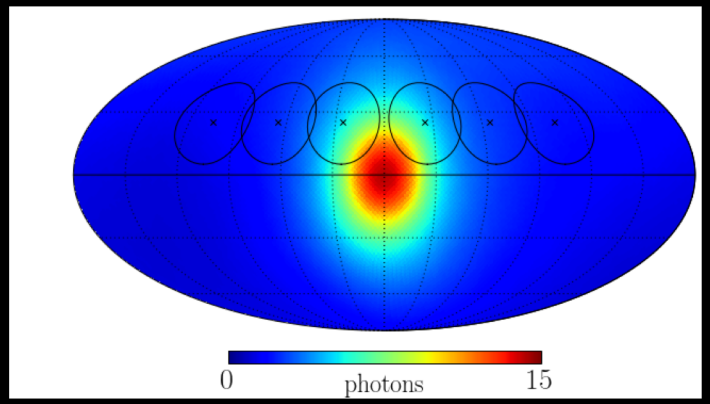
JAXA has established the project team for X-Ray Imaging and Spectroscopy Mission (XRISM, pronounced Krizm). spectroscopy capability of ASTRO-H, which had been in preparation under the name X-ray Astronomy Recovery M held in June, JAXA confirmed that all aspects of project implementation, including the management structure, fundi mitigation system are all satisfactory, and that the necessary countermeasures for the ASTRO-H anomaly recurren project team dated 2018 July 1.

XRISM is scheduled for launch during the Japanese Fiscal Year 2020 (April 2020-March 2021).

- Micro-X

1611.02714
Powell, Laha, KCYN, Abel

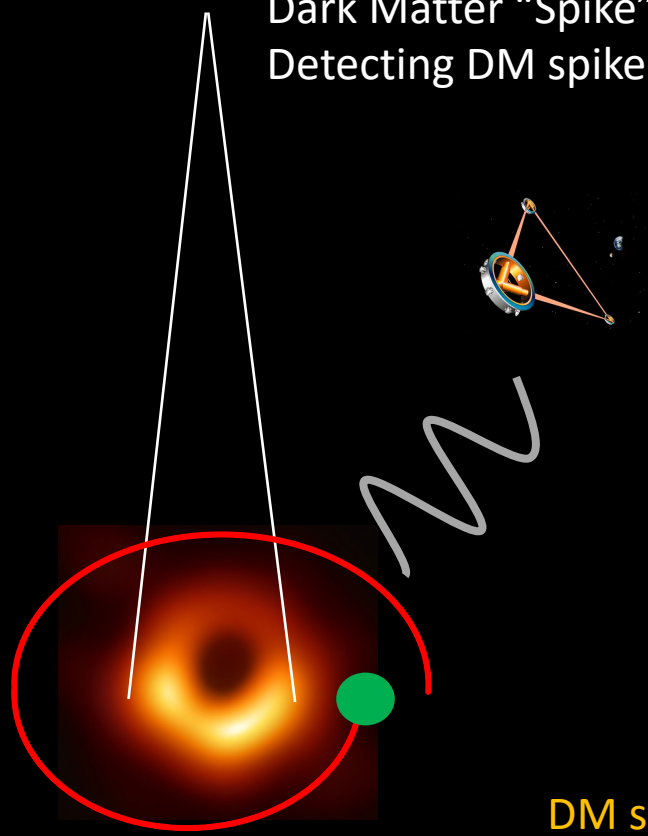




A new window to the Universe: Gravitational Waves!

- Extreme Mass Ratio Inspirals (EMRI)

Dark Matter "Spike" Gondolo Silk PRL 1999
Detecting DM spike with GW: Eda+ 2013, 2014



EHT

$$V_{\text{fermi}} \leq V_{\text{escape}}$$

$$\left(\frac{6\,\pi^2\hbar^3\rho}{m^4 g}\right)^{1/3} \leq \sqrt{\frac{2\,G\,(M_{BH}+M_\chi)}{R}}$$

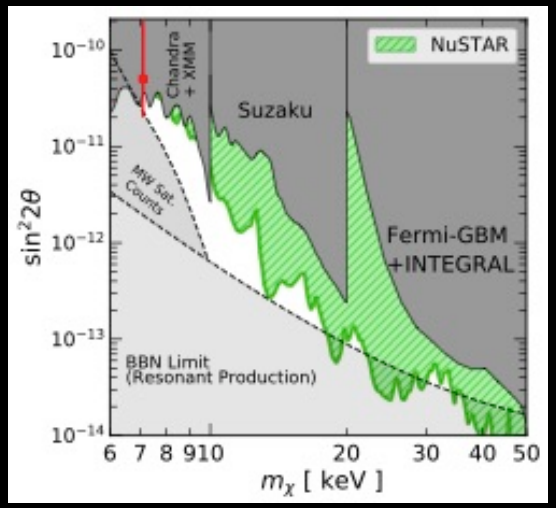
$$m_\chi \geq 30\ \text{keV}\left(\frac{\rho}{10^{20}\ \text{GeV/cm}^3}\right)^{1/4} \times \frac{1}{(R/20M_{BH})}$$

Hannuksela, ***KCYN,*** Li 1906.11845

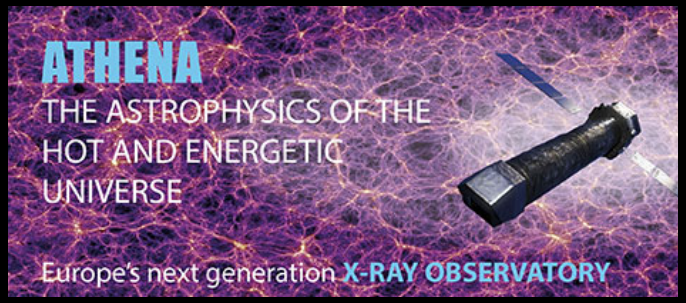
DM spikes are not compatible with keV sterile neutrino DM

Conclusion

- NuSTAR is closing the high-mass Sterile Neutrino DM window



- Jury is still out for the 3.5 keV line
  - NuSTAR low energy analysis soon
- Dark Matter velocity spectroscopy
  - XRISM (maybe 2021)
  - Micro-X (1 flight launched Jul 2018)
- Athena (203X)



Thanks you!

The Chinese University of Hong Kong

2020 --

- *Postdoc*
- *PhD students*

Theoretical Astro-particle physics

- *Dark Matter*
- *Multi-messenger Astrophysics*
- *Cosmology*

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