「すざく」による広がったTeVガンマ線放射VER J2019+368のX線観測(2)

Suzaku Observation of the extended TeV gamma-ray source VER J2019+368(2)

September 25, 2015@JPS meeting

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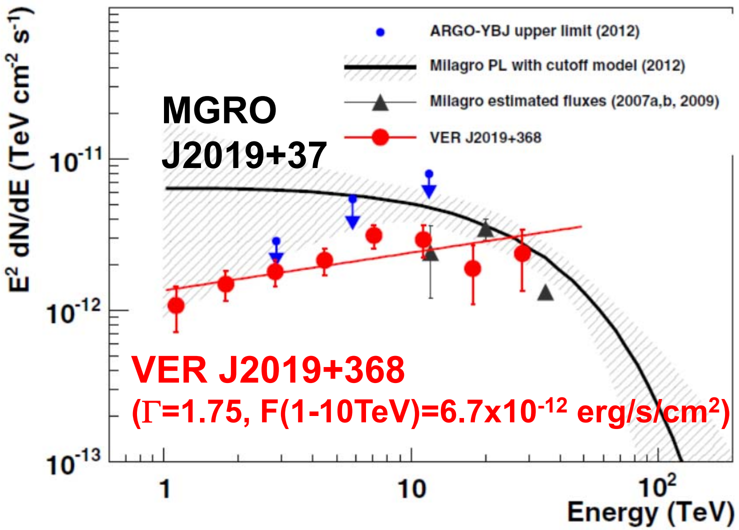
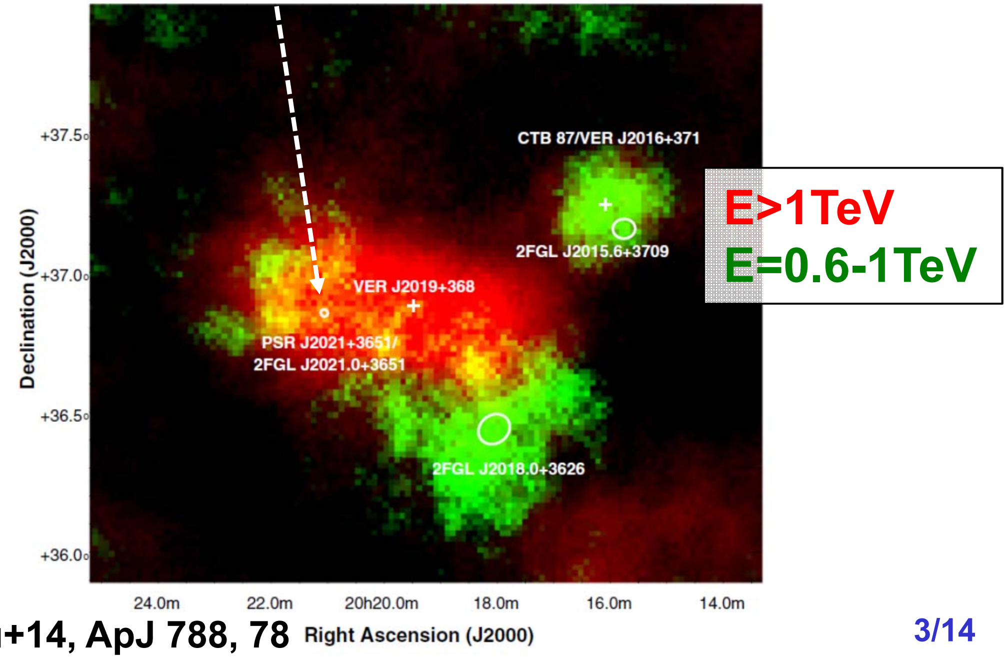
Contents

Past Obs. by Milagro & VERITAS

- Milagro reported an extended TeV γ-ray source MGRO J2019+37 in Cygnus-X direction (σ=0.7deg)
- It was resolved into multiple sources by VERITAS. The most luminous one, VER J2019+368, has the following properties
  - σ_{major}=0.34deg, positional coincidence with MGRO J2019+37, consistent spectrum in high energy => Main contributor
- Possible X-ray counterpart is PSR J2021+3651 & PWN G75.2+0.1

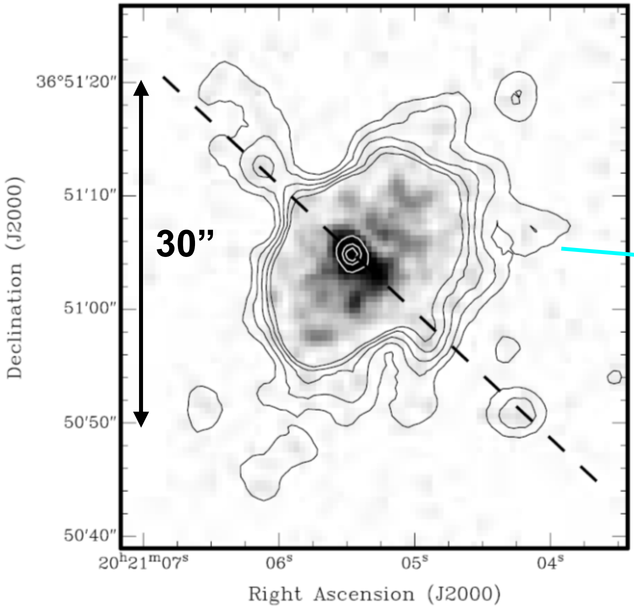




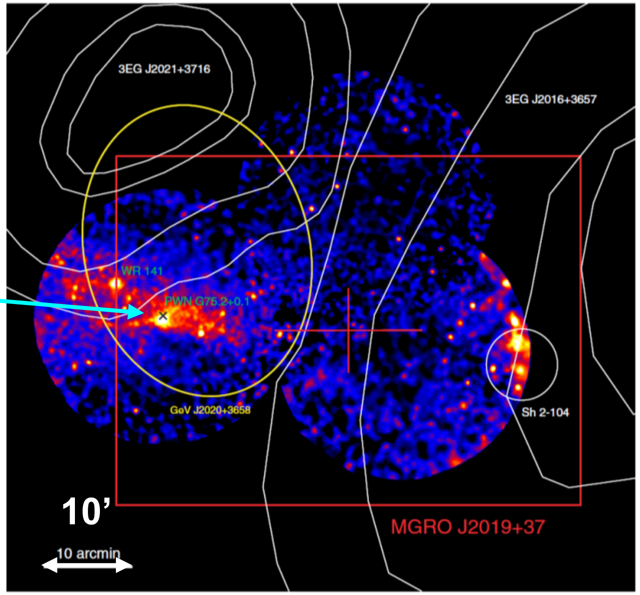
Aliu+14, ApJ 788, 78

Past Obs. in X-Rays

- **Possible X-ray counterpart is PSR J2021+3651 & PWN G75.2+0.1**
  - **PSR J2021+3651: young and energetic (τ=17 kyr, dE/dt=3.4x10^{36} erg/s)**
  - **Chandra revealed a ~20”x10” pulsar wind nebula (PWN G75.2+0.1)**
  - **XMM reported faint emission of 5’-10’ length in east and west**



Hessels+04, ApJ 612, 389



Zabalza+10, J. of Mod. Phys. D. 19, 811

Problems of the PSR/PWN Scenario

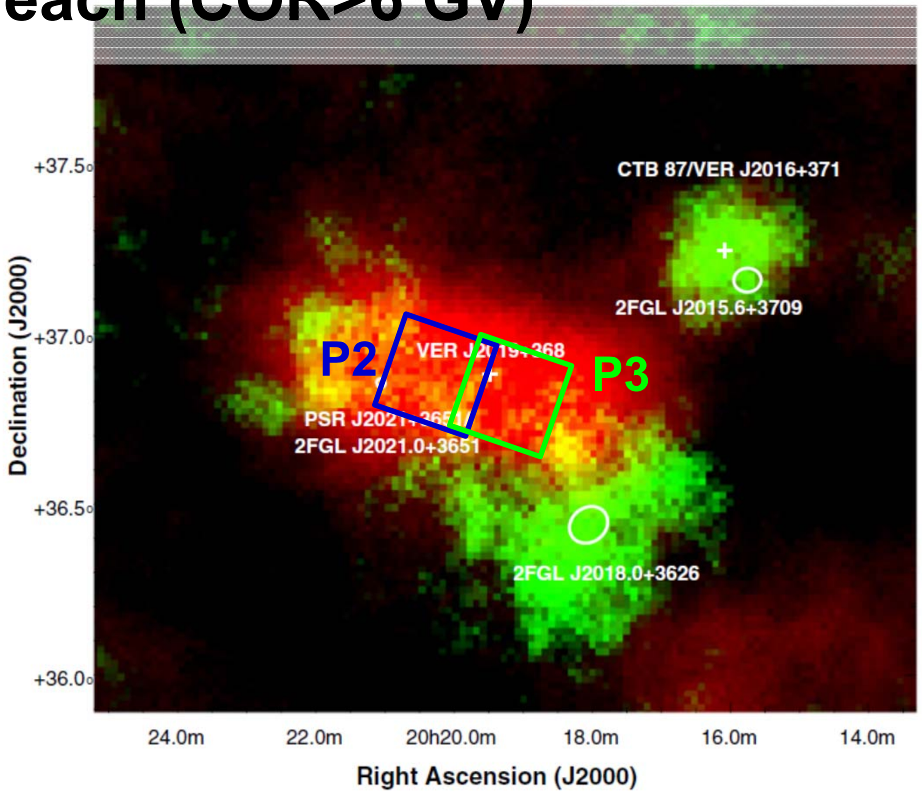
- Possible X-ray counterpart is PSR J2021+3651 & PWN G75.2+0.1
  - PSR J2021+3651: τ=17 kyr, $dE_{rot}/dt=3.4\times10^{36}$ erg/s
  - PWN G75.2+0.1: revealed by Chandra and found to extend out 5'-10' in length in east and west by XMM
- Several issues of the PSR/PWN scenario have been pointed out (e.g., Abdo+09, ApJ 799, 1059; Parades+09, A&A507, 241)
  - Large dispersion measure (370 pc/cm^3) and rotation measure (524 rad/m^2) indicate large distance to the source (d>10 kpc).
    - γ-ray luminosity of PSR too high compared to dE_{rot}/dt
    - Source size (~90 pc for 0.5 deg at 10 kpc) too large for high-energy electrons to fill before cooling
  - X-rays from only small portion of TeV emission

- Detailed study of the PWN properties (spectrum, morphology) and search for unknown extended emission by Suzaku-XIS

Suzaku Obs. of VER J2019+368

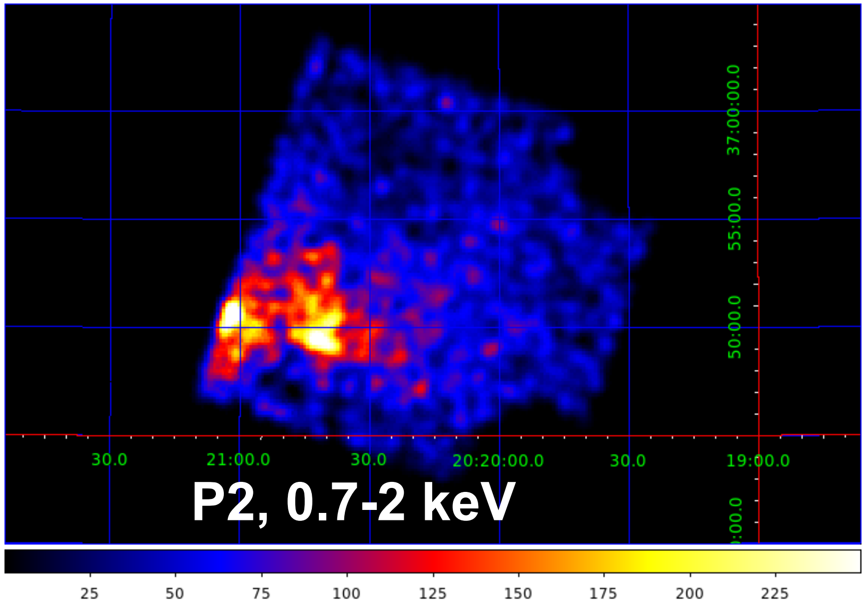
- **Two observations conducted in 2014 November.**
  - **P2 covers region of the PSR/PWN and TeV centroid**
  - **P3 covers the west part of VER J2019+368, in which no strong X-ray sources are reported**
- **Net exposure is ~35 ks each (COR>6 GV)**

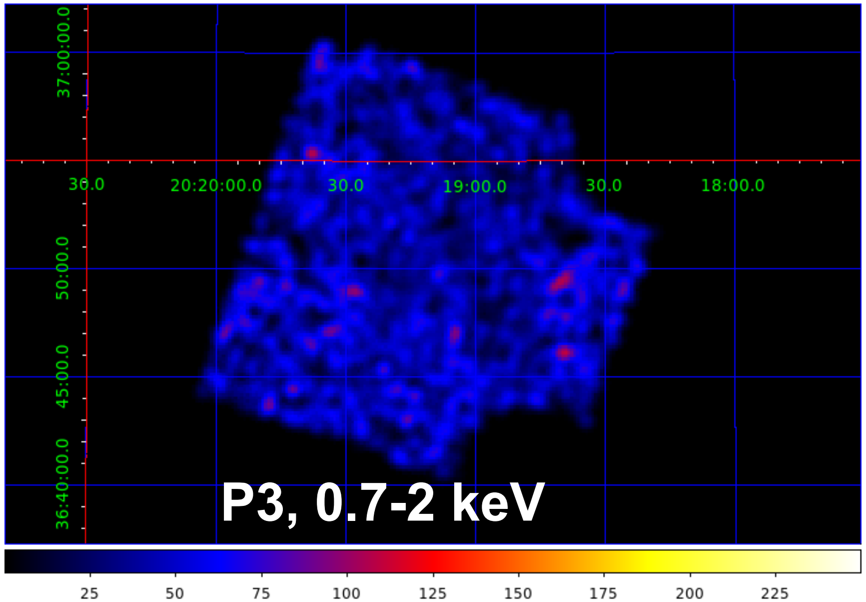
Position	RA (deg)	DEC (deg)	Net exp. (ks)
P2	305.07	36.85	35.0
P3	304.80	36.80	35.7



XIS Image (soft band)

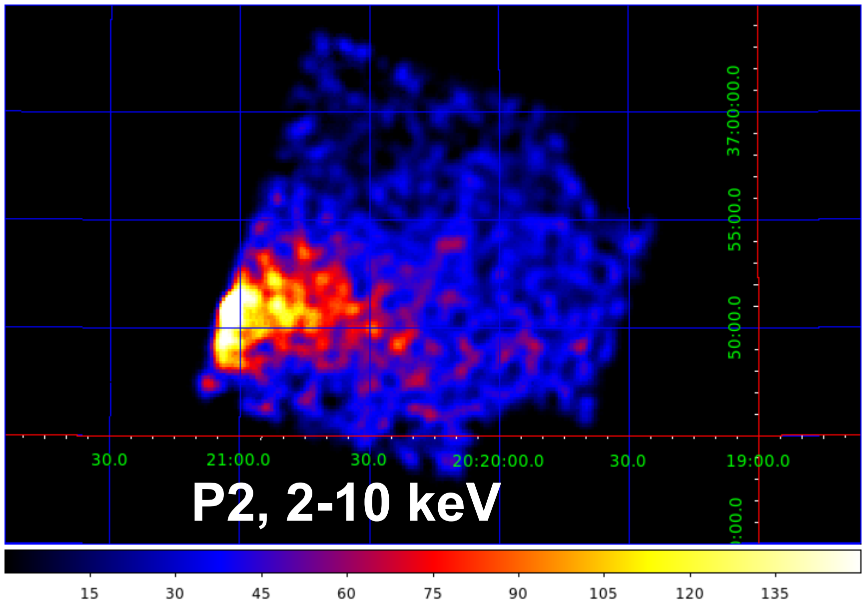
- **Soft band (0.7-2 keV) intensity map (XIS3, in unit of photos/s/cm^2/sr, nxb subtracted)**
- **PWN clearly detected in P2**
- **No obvious extended emission in P3**

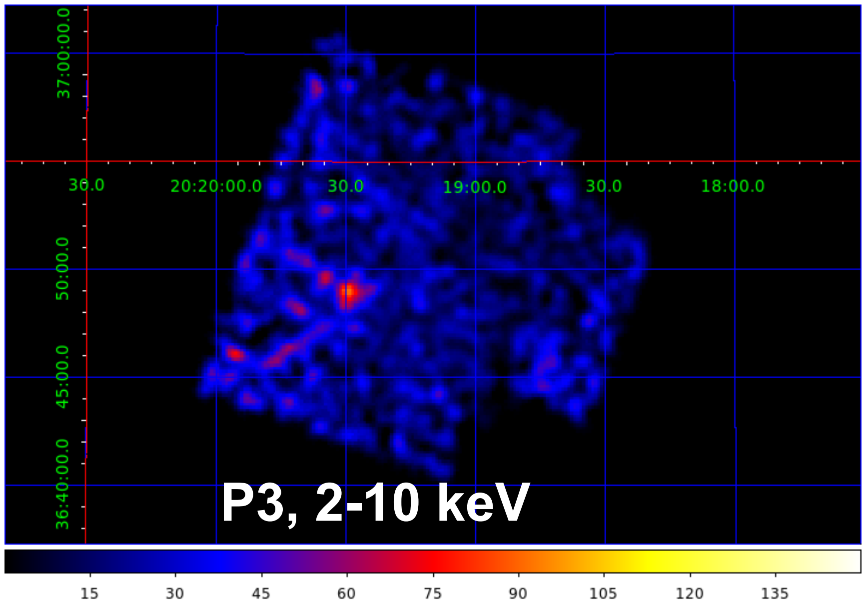




XIS Image (hard band)

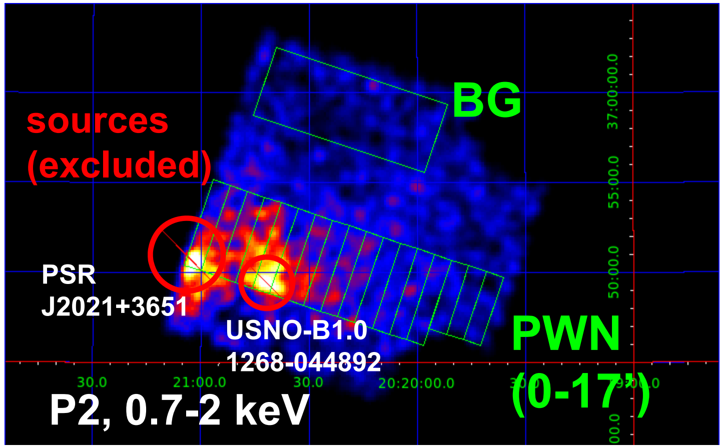
- Hard band (2-10 keV) intensity map (nxb subtracted)
- PWN clearly detected in P2
- No obvious extended emission in P3
- Size of PWN similar to that in soft band (see slide #11 for details)

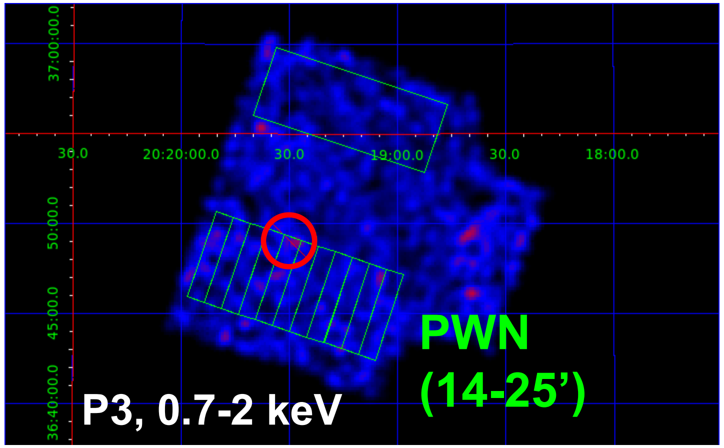


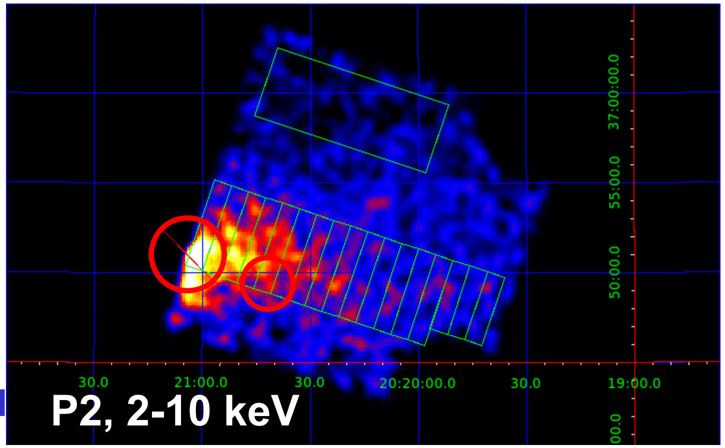


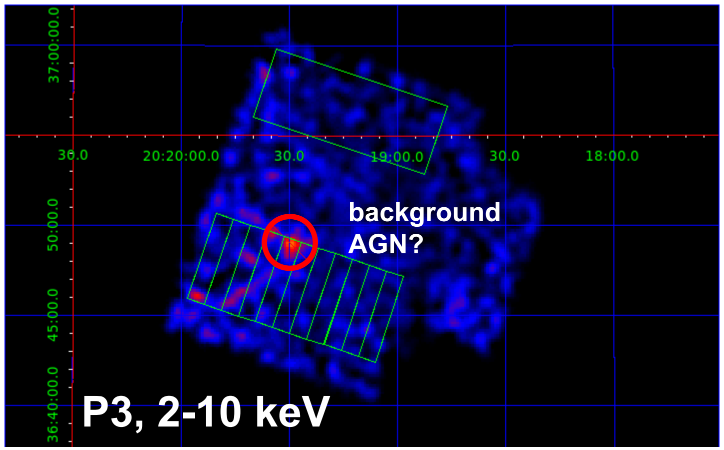
PWN-West Morphology (1)

- Source regions: 25 rectangles of 1’ x 5’ or 1’ x 4’ (unusable area of XIS0 and cal-source emitted regions avoided)
- BG region: 4’ x 10’





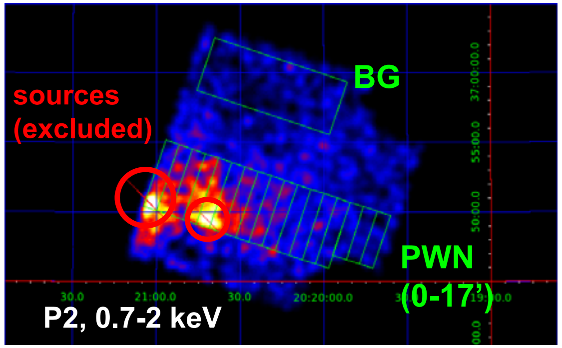


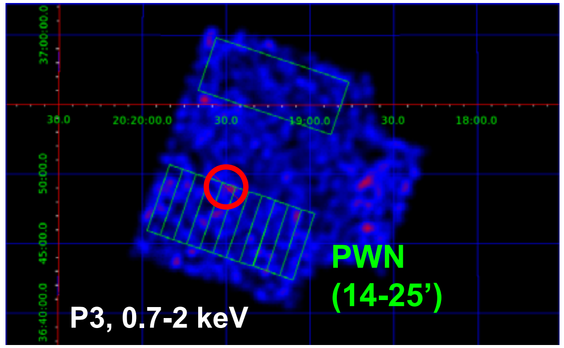


PWN-West Morphology (2)

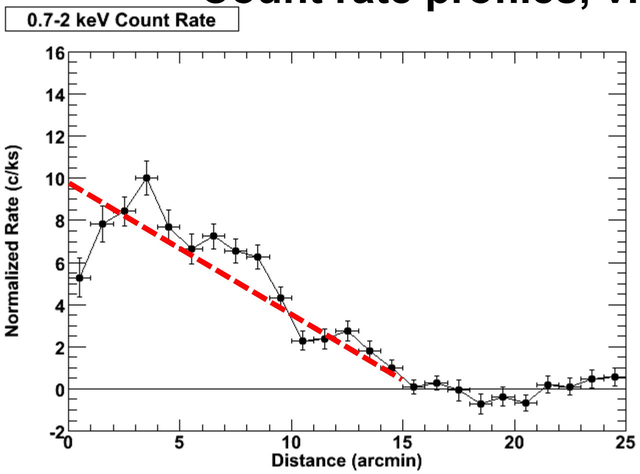
- Source regions: 25 rectangles of 1’ x 5’ or 1’ x 4’ (unusable area of XIS0 and cal-source emitted regions avoided)
- BG region: 4’ x 10’

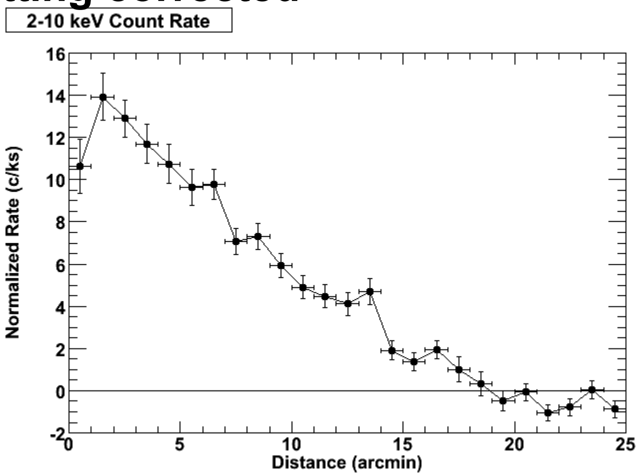
- PWN emission is detected at least <u>up to 15’, roughly reaches to the TeV centroid</u>
- No obvious emission beyond the TeV centroid
- In spectral analysis (arf calculation), we assume linear decrease of intensity (like dotted line below)





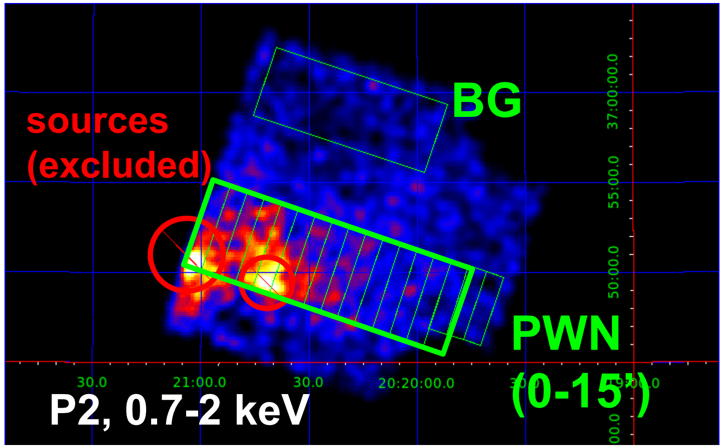
Count rate profiles, vignetting corrected





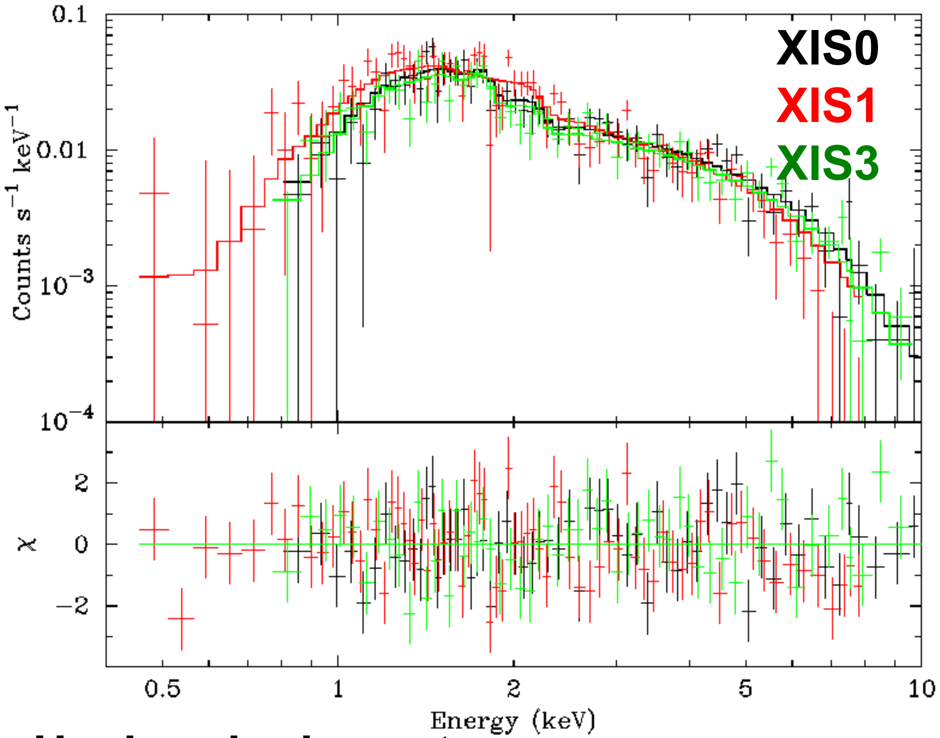
PWN-West Spectrum (1)

- **Procedure of the spectral analysis:**
  - 1) subtract the NXB
  - 2) apply vignetting correction in subtracting the BG (GRXE and CXB)
  - 3) calculate the response (arf) assuming linear decrease of the intensity in 0-15'



chi2/dof=211/188
N(H)=0.83(+/-0.12)x10^{22}
Γ=2.05(+/-0.12)

f(0.5-2 keV)=6.04x10^{-13} erg/s/cm^2
f(2-10 keV)=20.0x10^{-13} erg/s/cm^2



Unabsorbed spectrum:
$E^2F(E)$=906x10^{-6} (E/keV)$^{-0.05}$ keV^2/s/cm^2/keV

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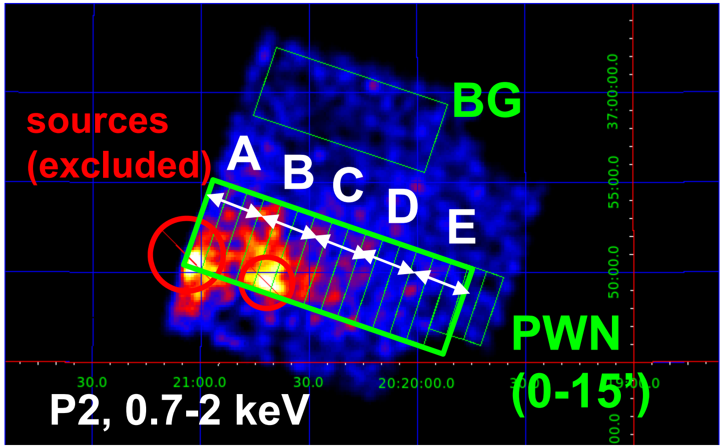
PWN-West Spectrum (2)

- **Procedure of the spectral analysis:**
  - 1) subtract the NXB
  - 2) apply vignetting correction in subtracting the BG (GRXE and CXB)
  - 3) calculate the response (arf) assuming linear decrease of the intensity in 0-15'



Reg.	N(H)	Γ	F(0.5-2keV) (10^{-13} erg/s/cm^2)	F(2-10keV) (10^{-13} erg/s/cm^2)
A (0'-3')	0.82 (+/-0.21)	2.07 (+/-0.21)	1.96	8.27
B (3'-6')	0.63 (+/-0.16)	1.96 (+/-0.18)	1.67	6.52
C (6'-9')	0.72 (+/-0.17)	2.06 (+/-0.18)	1.24	4.70
D (9'-12')	1.28 (+/-0.36)	2.30 (+/-0.32)	0.57	2.77
E (12'-15')	1.44 (+/-0.51)	2.29 (+/-0.42)	0.30	1.68

- **No significant spectral change observed**
- **From the obtained absorption of ~0.8×10^{22} cm^{-2}, d~3 kpc (instead of >10 kpc) indicated**

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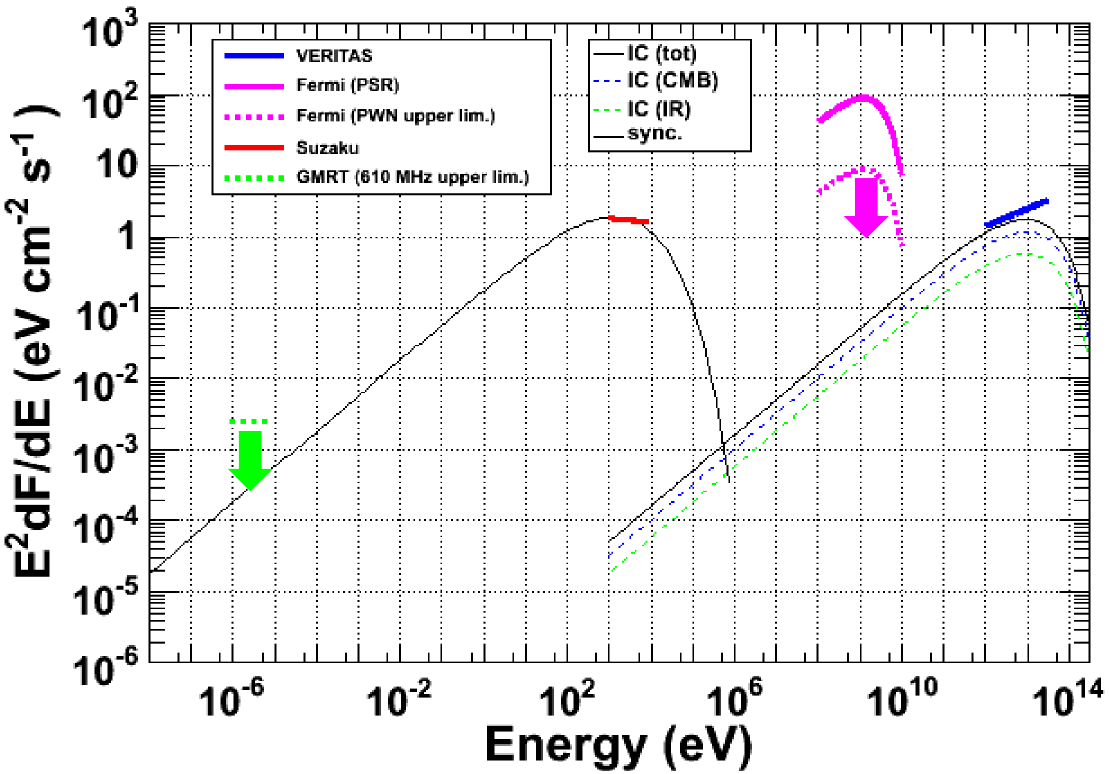
MW Spectrum (+ example of model)

- Data: Radio upper limit at 610 MHz, GeV PSR and PWN upper limit, VER J2019+368 and Suzaku PWN-West*2
- Model: E^{-2} electron spectrum with exponential cutoff at 0.1 PeV assumed
  - Synchrotron (B=3 μG) and IC (CMB, IR(T=20K, 0.4 eV/cm^3)) calculated

- Integrated spectrum is compatible with standard scenario (synchrotron by interstellar mag. field and IC by ISRF), although the details (cooling, morphology etc.) is yet to be investigated



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Summary & Future Plan

- VER J2019+368 is an extended (σ_{major}=0.34deg) and hard (Γ=1.75) TeV γ-ray source in Cyg-X direction
- PSR J2021+3651/PWN G75.2+0.1 is a possible counterpart, but several issues are pointed out (distance, morphology)
- We analyzed Suzaku-XIS data in detail
  - PWN detected up to 15' to the west (N(H)=8.2×10^{21} cm^{-2}, Γ=2.05, f(2-10 keV)=2.0×10^{-12} erg/s/cm^2)
  - No significant spectral change found
- Next Step: Discuss the scenario to explain X-rays and TeV γ-rays

Thank you for your Attention

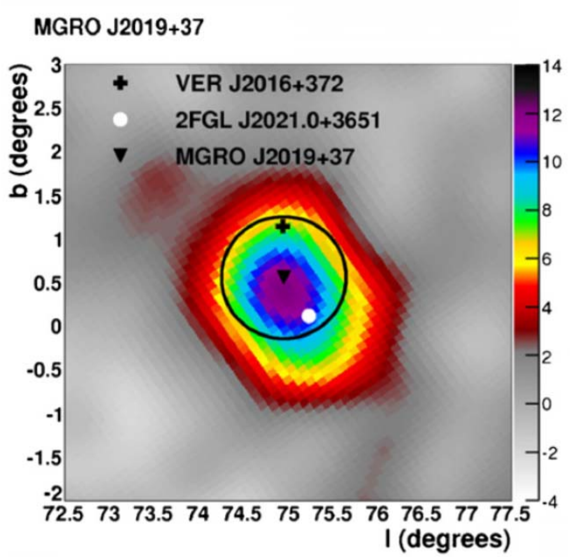
Reference

- Abdo+12, ApJ 753, 159
- Aliu+14, ApJ 788, 78
- Hessels+04, ApJ 612, 389
- Zabalza+10, J. of Mod. Phys. D. 19, 811
- Parades+09, A&A 507, 241
- Yoshida+11, PASJ 63, S717
- Mizuno+15, ApJ 803, 74
- Abdo+09, ApJ 700, 1059
- Etten+08, ApJ 680, 1417
- Watters+09, ApJ 695, 1289

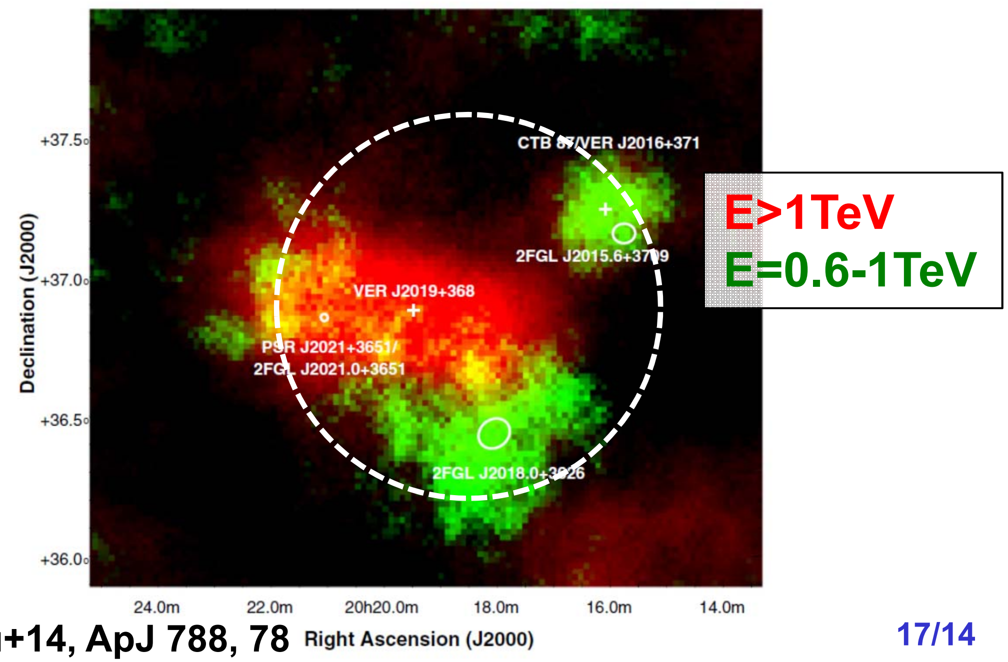
Appendix

Past Obs. by Milagro & VERITAS

- **Milagro reported an extended TeV γ-ray source MGRO J2019+37 in Cygnus-X direction (σ=0.7deg)**
- **It was resolved into multiple sources by VERITAS. The most luminous one, VER J2019+368, has the following properties**
  - **σ_{major}=0.34deg, positional coincidence with MGRO J2019+37, consistent spectrum in high energy => Main contributor**



Abdo+12, ApJ 753, 159



Aliu+14, ApJ 788, 78

Properties and Implications

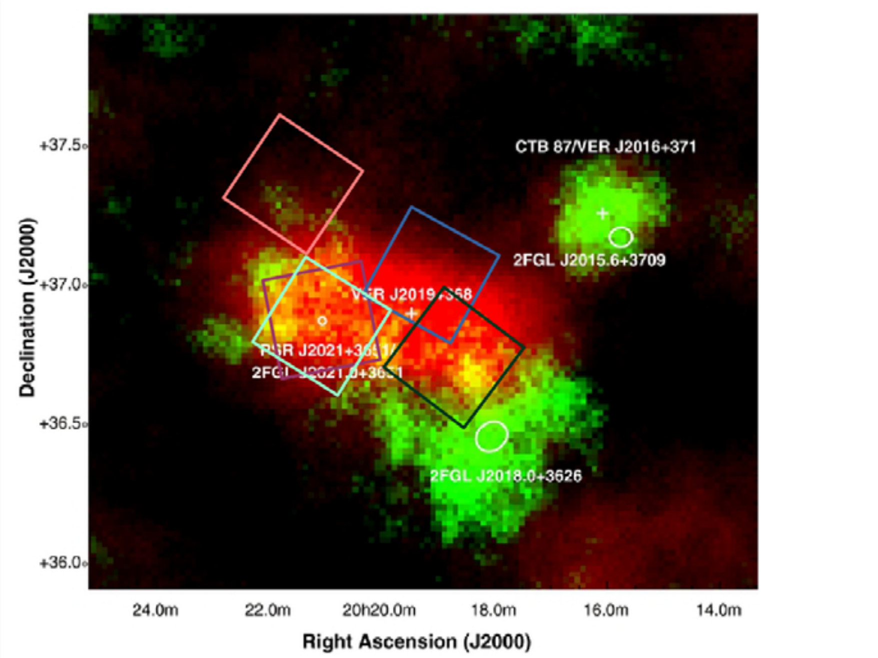
- N(H) of the PWN ~0.8x10^{22} cm^{-2}, similar to that of the PSR (Hessels+04)
  - Sources in Cygnus-X (d~1.4 kpc) shows absorption of (0.2-0.6)x10^{22} cm^{-2} (Yoshida+11), whereas Galactic total absorption is estimated to be (2-3)x10^{22} cm^{-2} (Mizuno+15). => d~3 kpc is indicated. Then the γ-ray luminosity of the PSR ~ 4.6x10^{35} erg/s < dE_{rot}/dt=3.4x10^{36} erg/s.
- F(2-10 keV)~2.0x10^{-12} erg/s/cm^2 for the west part of the PWN
  - F(1-10 TeV)/F(2-10 keV) ~3. It will be further reduced if we include the whole emission of the PWN
- PWN extends up to 15' to the west, roughly reaches to the TeV centroid
- No significant spectral change observed. No significant diffuse emission in P3 (beyond TeV centroid) found

- If all these properties can be explained simultaneously or not (=PWN scenario) in under investigation

XMM View of the VER J2019+368 Region

- **Advantages of XMM for the study of VER J2019+368**
  - **Good spatial resolution => reduction/estimation of the point-source contaminations**
  - **Large FOV => overall property of the PWN**

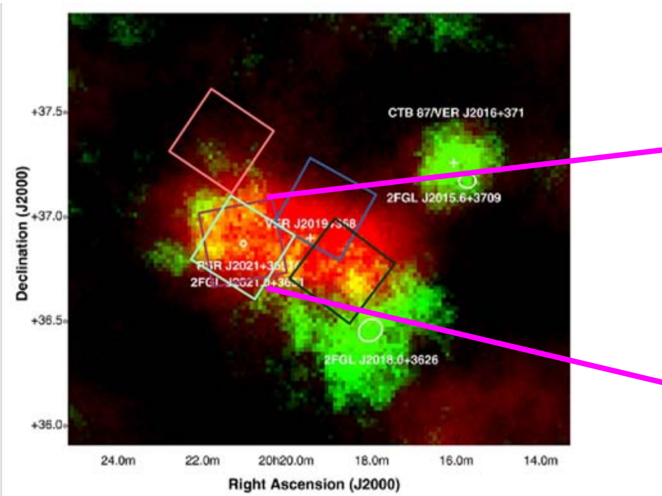
observation region	No. of obs.	Exposure [ks]
PSRJ2021+3651	1	127
WR142	2	61 , 20
MGROJ2019+37	1	48
IGRJ20188+3647	1	16
G75.2+0.1	2	34 , 30

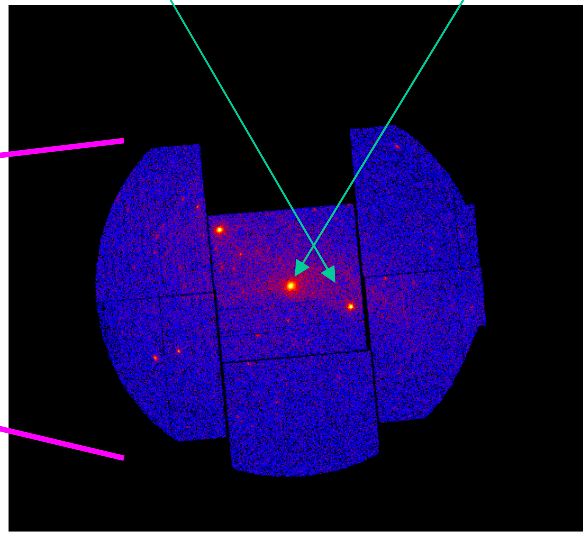


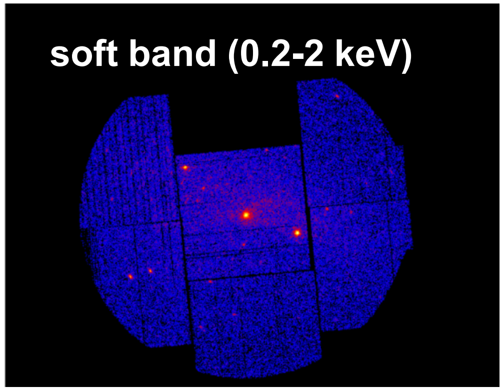
(Analysis done by N. Tanaka)

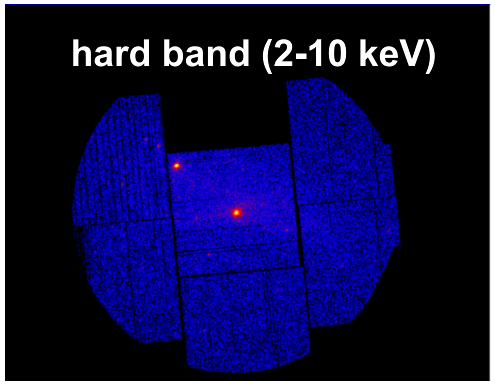
PSR J2021+3651 Region Seen by XMM (1)

- **Main sources of contamination to PWN-west are PSR J2021+3651 and a bright start USNO-B1.0 1268-0448692 (see also Etten+08)**





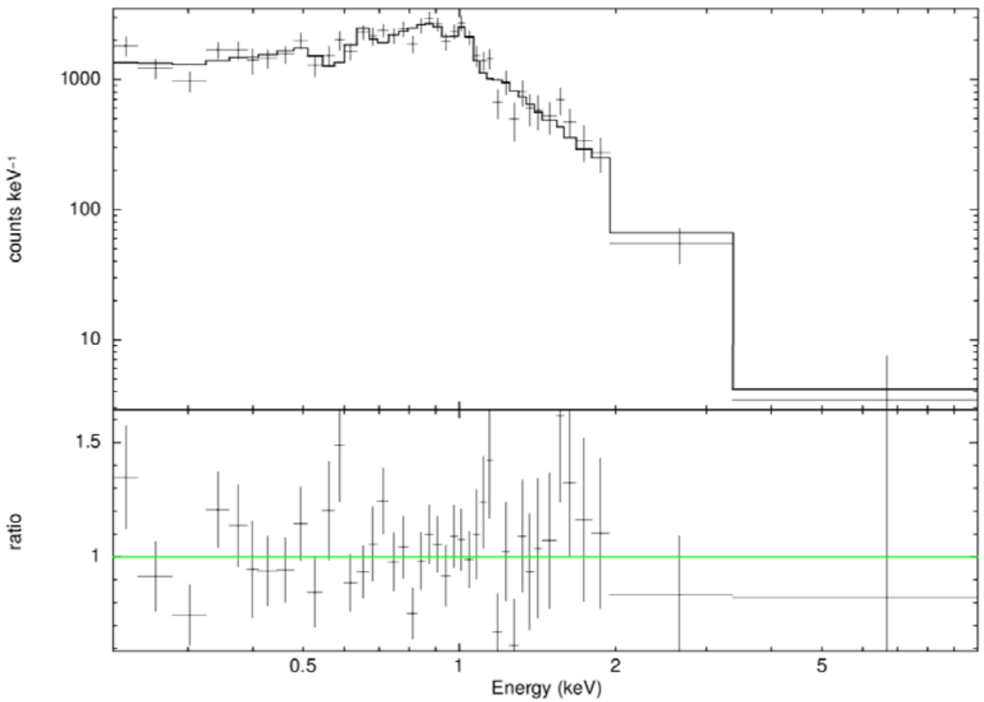


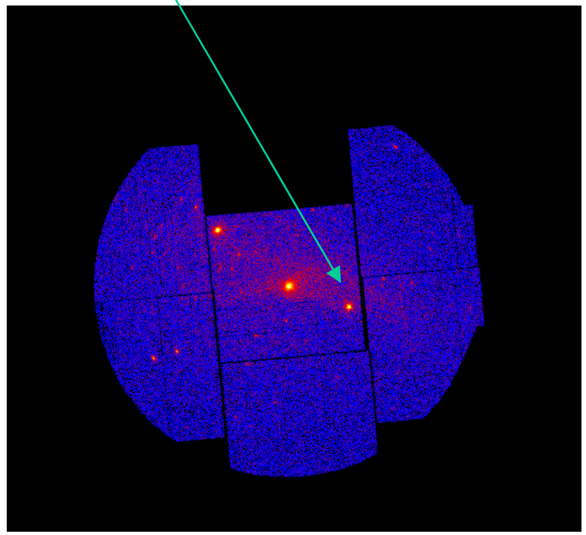


(Analysis done by N. Tanaka)

PSR J2021+3651 Region Seen by XMM (2)

- Main sources of contamination to PWN-west are PSR J2021+3651 and a bright start USNO-B1.0 1268-0448692 (see also Etten+08)





(Analysis done by N. Tanaka)

- Very soft spectrum (Γ>5), contribution to PWN-west is estimated to be ~10% and ~2% below and above 2 keV, respectively, even if we do not exclude the source.
- Contribution from less-bright sources is negligible.