Connection between the Supernova Remnant G284.3–1.8 and the Gamma-ray Binary 1FGL J1018.6–5856: Implications from X-ray Observations with Suzaku

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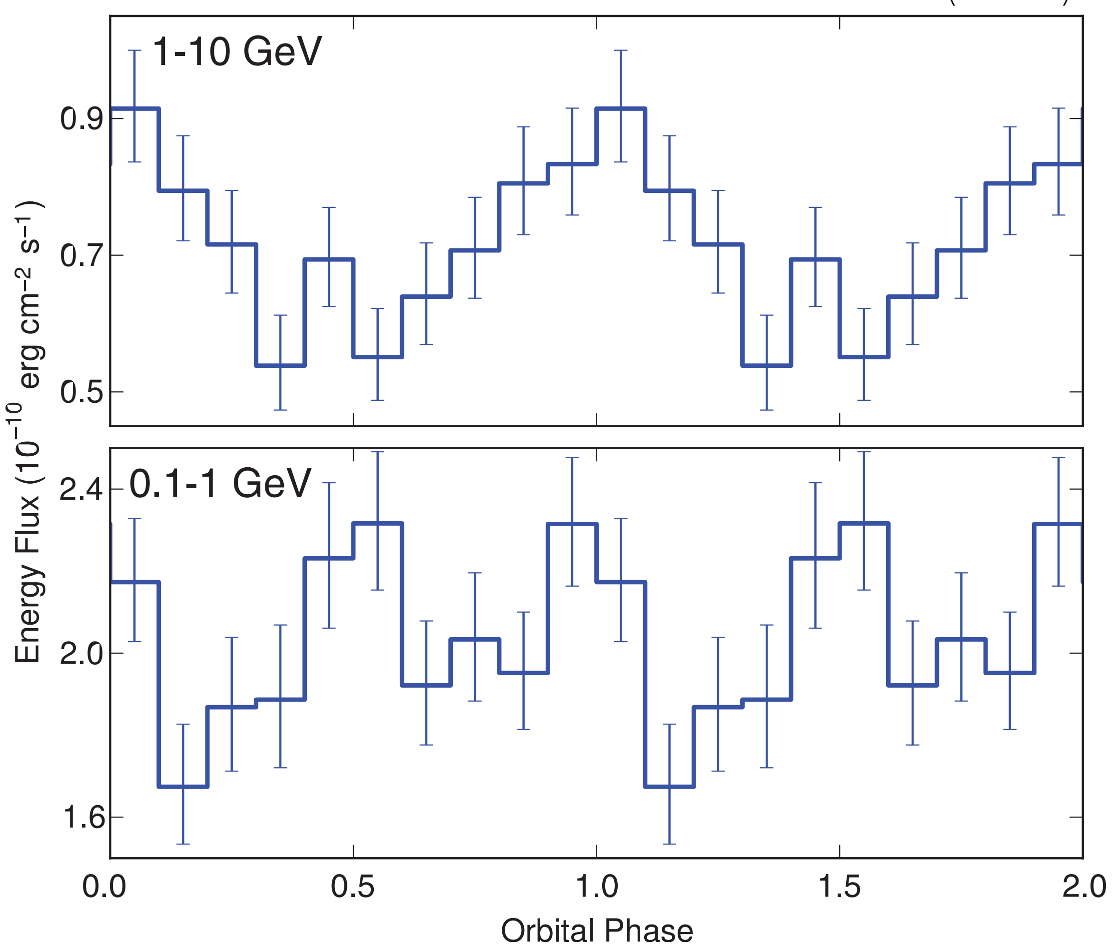
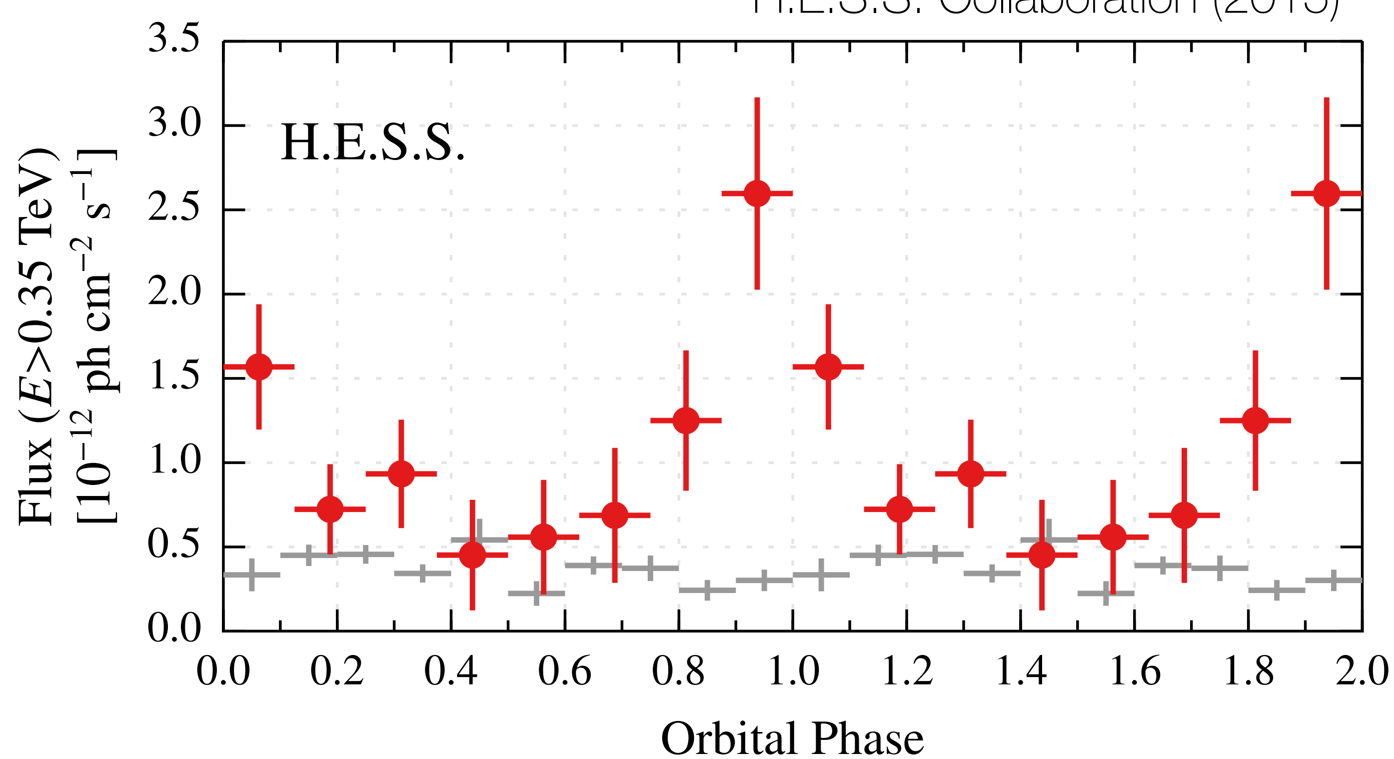
1FGL J1018.6–5856

- Periodic behavior (P = 16.58 days) found in the Fermi LAT data (Fermi LAT Collaboration 2012)
- Periodicity attributed to orbital modulation of the emission
- VHE counterpart discovered with H.E.S.S. (Abramowski+ 2012)
- Periodicity of VHE emission also found in the H.E.S.S. data (H.E.S.S. Collaboration 2015)
- Host star spectral type is O6V((f)), which is very similar to that of LS 5039

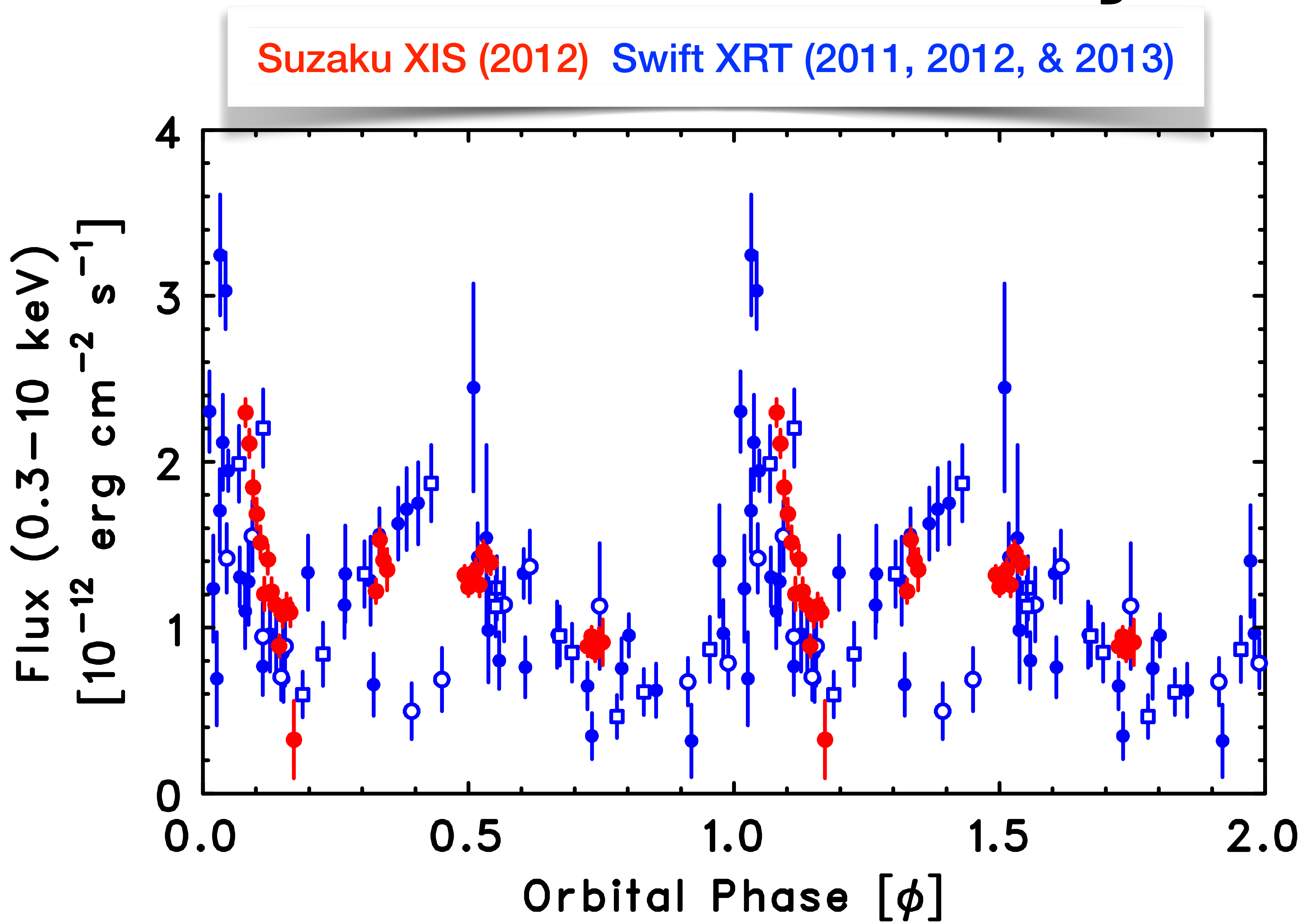
Fermi LAT Collaboration (2012)



H.E.S.S. Collaboration (2015)



1FGL J1018 in X-rays



- X-ray light curve appears stable (similar to LS 5039; see Kishishita, TT+ 2009)
- Difficult to be explained by accretion-powered activity
- Pulsar-wind scenario preferable for 1FGL J1018 (compact object = neutron star)?

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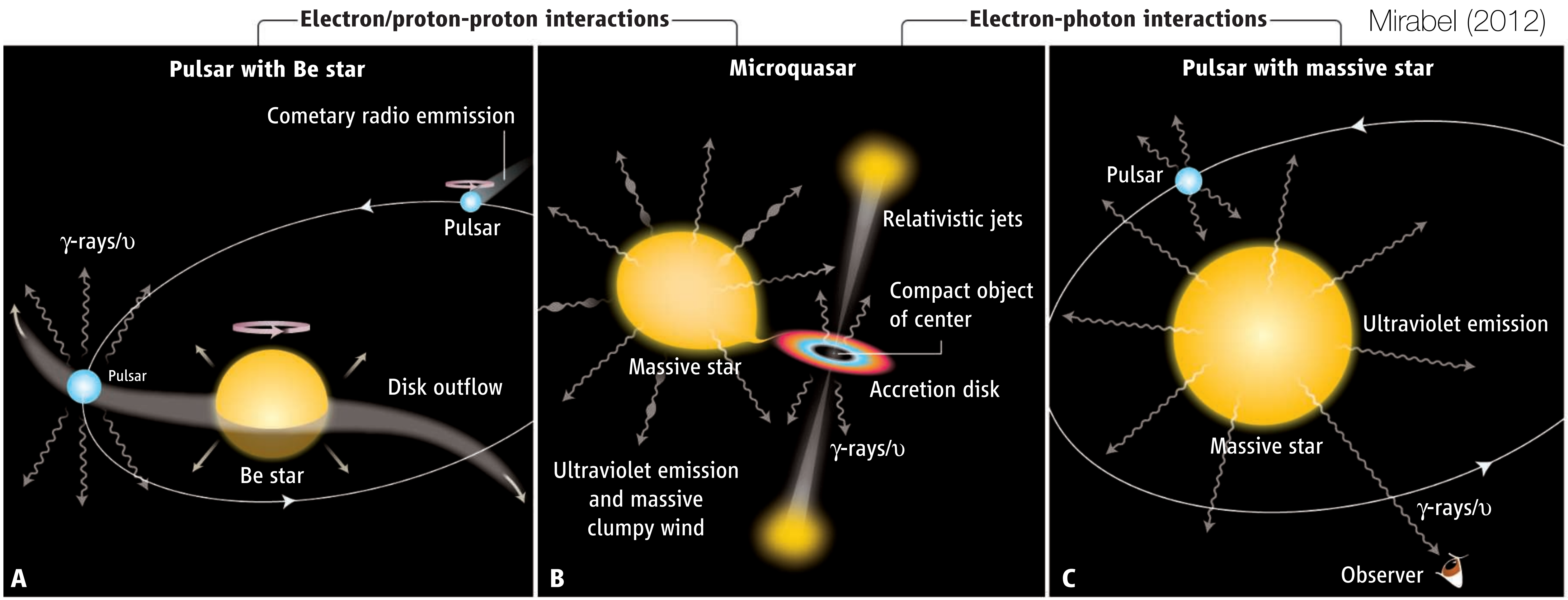

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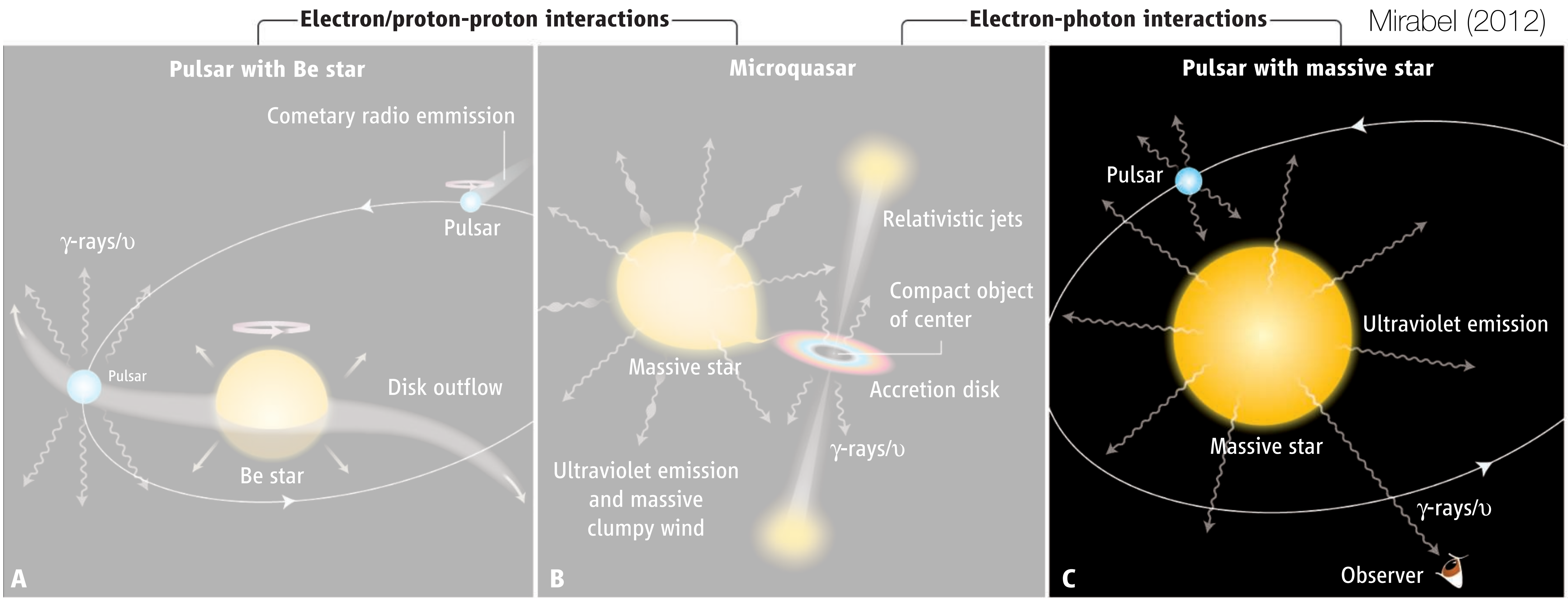
1FGL J1018 in X-rays

Mirabel (2012)



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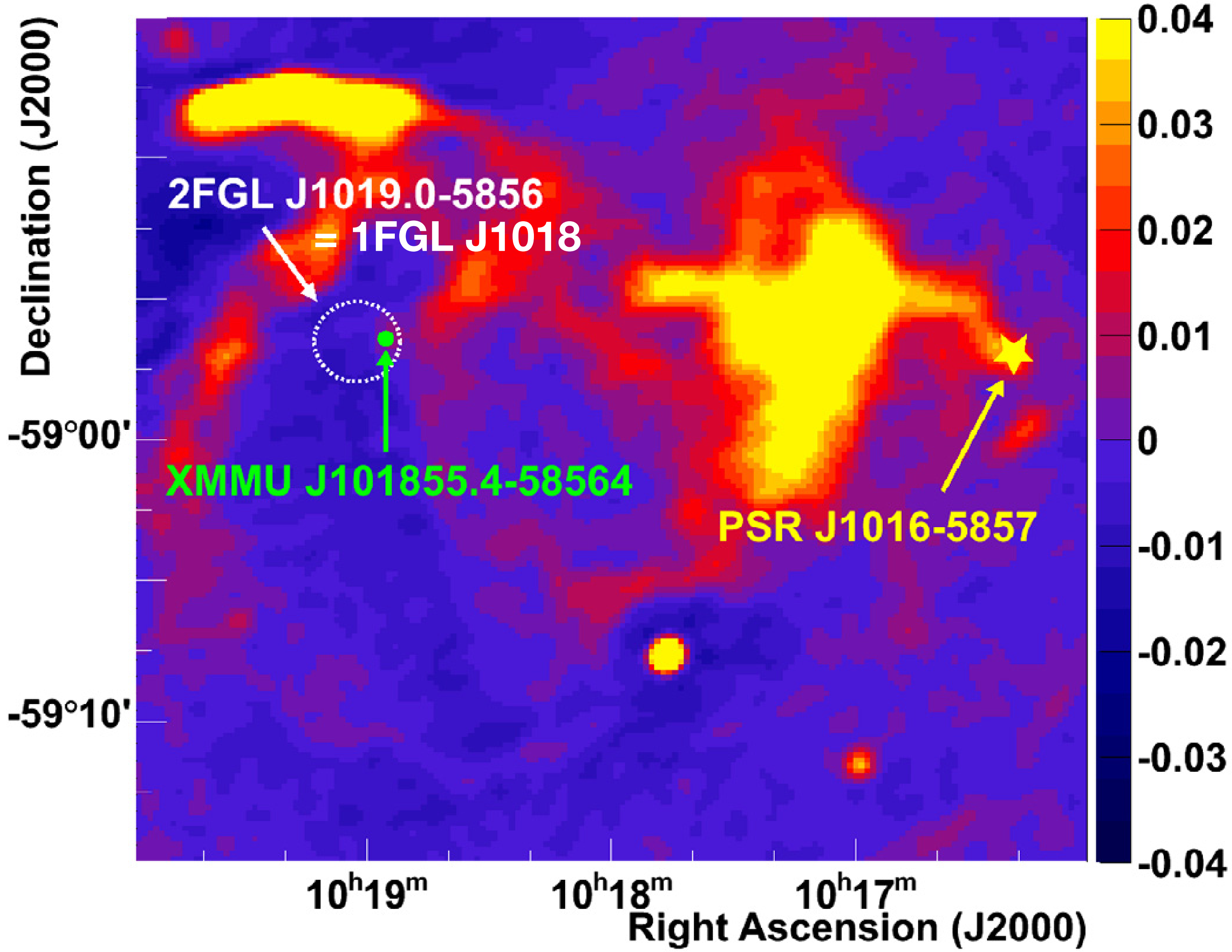
Surroundings of 1FGL J1018

- Positional coincidence with the supernova remnant (SNR) G284.3–1.8 (a.k.a. MSH 10–53)
- Age estimated to be 10^4 yr (Ruiz+ 1986)
- Connection with 1FGL J1018?
- Constraint on compact remnant?

MOST-Molonglo (834 MHz) (Abramowski+ 2012)



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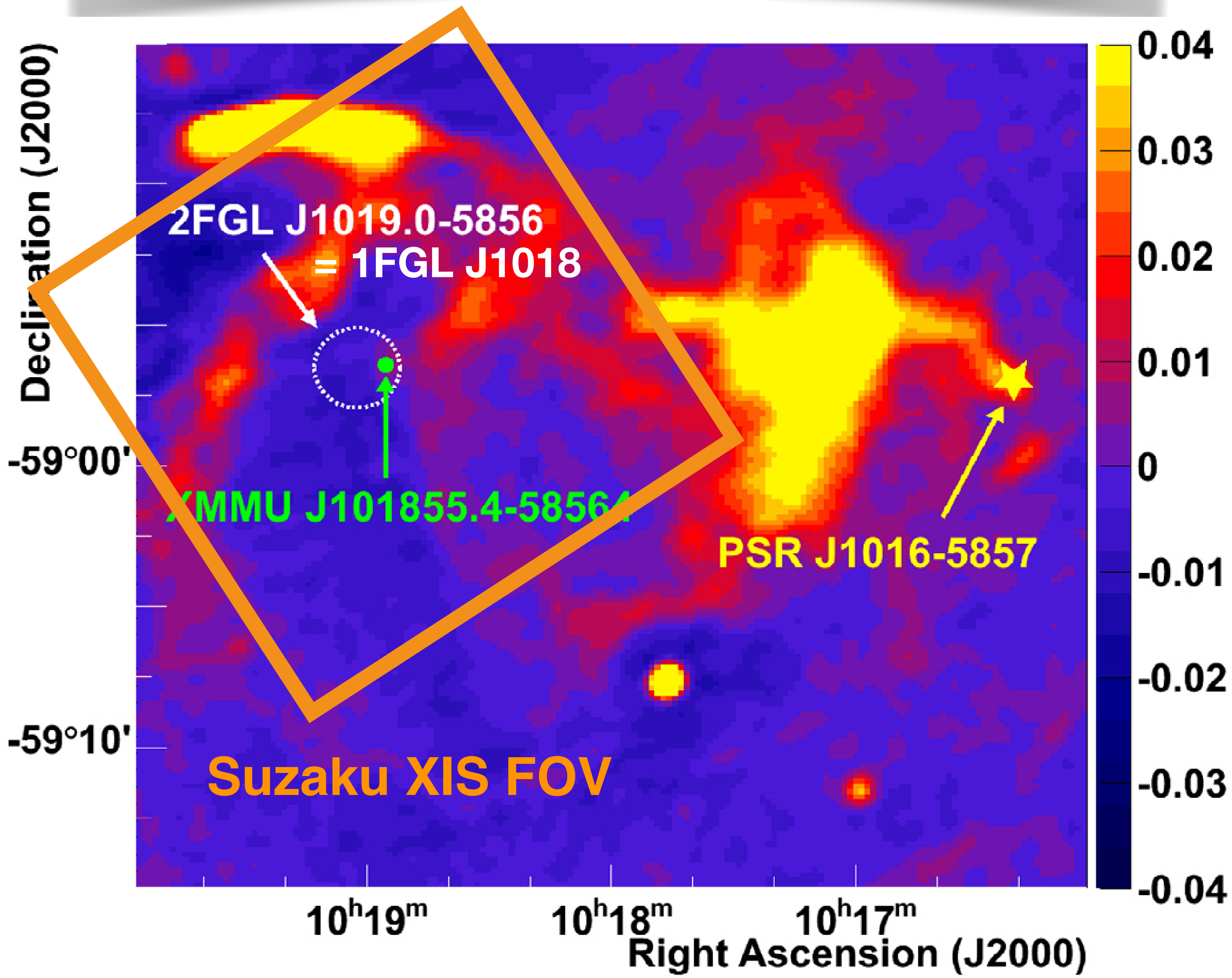
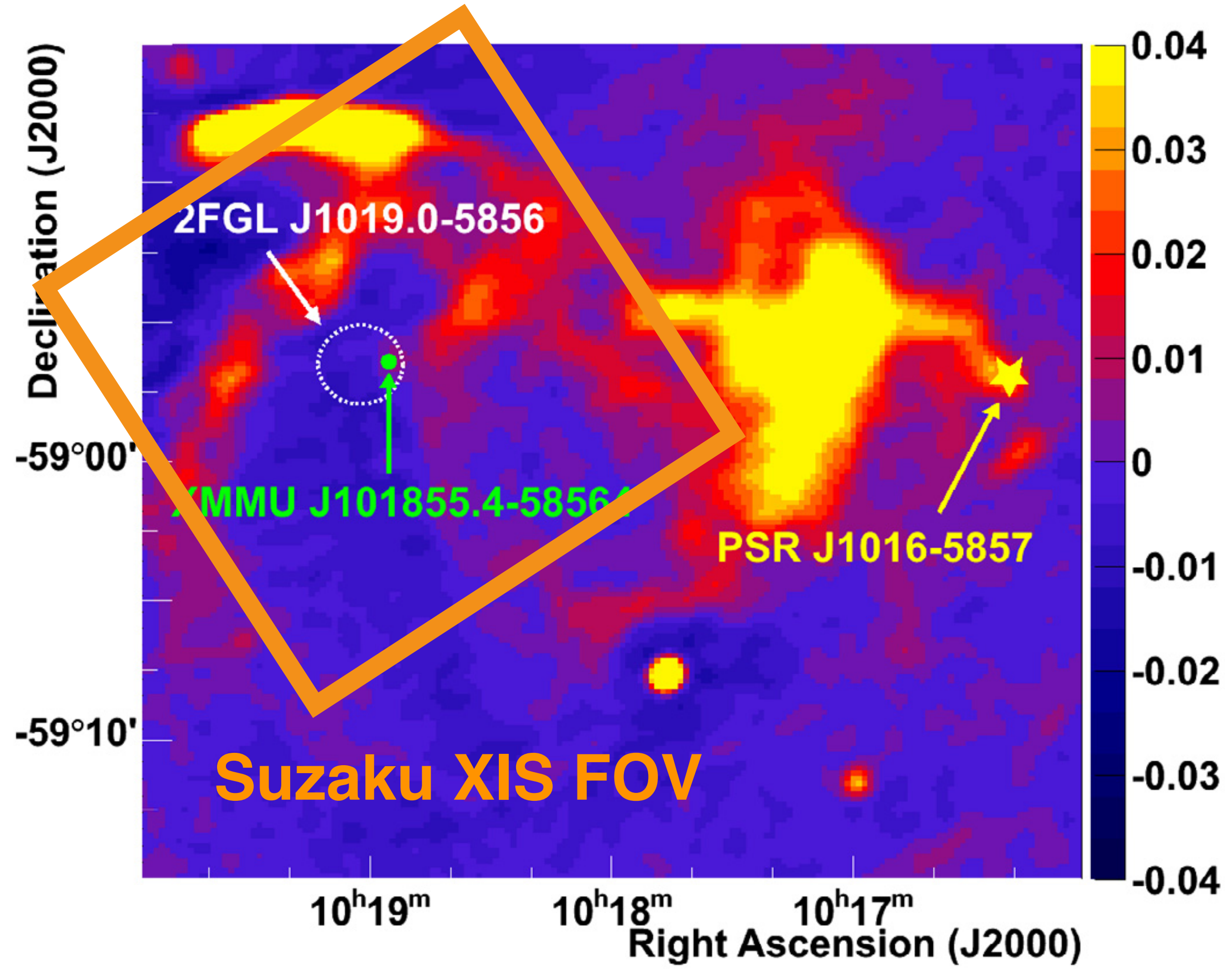


X-ray spectroscopy of G284.3–1.8 with deep Suzaku XIS data with a total exposure of 211 ks

Spectral Model

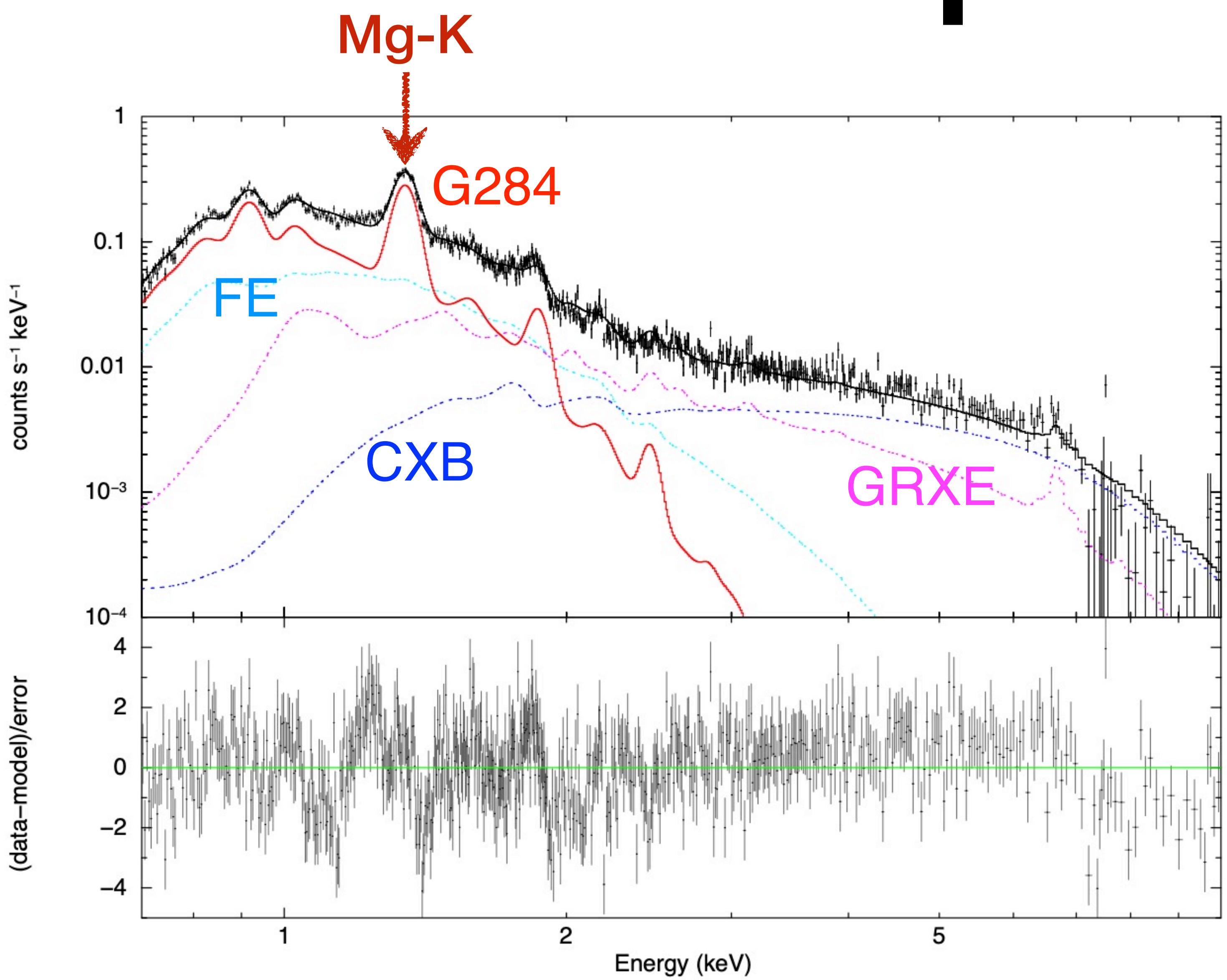
- Emission from G284 occupies almost the whole field-of-view of Suzaku XIS (no off-source region)
- Impossible to estimate background from off-source regions
- Model the X-ray background at the same time as the SNR



Spectral Model = G284 (NEI; non-equilibrium ionization)
+ Galactic Ridge X-ray Emission (GRXE; two-*kT* CIE)
+ Foreground Emission (FE; two-*kT* CIE)
+ Cosmic X-ray Background (CXB; power law)

We referred to Uchiyama+ (2013) for GRXE and FE, and Kushino+ (2002) for CXB models

G284 Spectral Fit



$N_{\rm H} = (6.7 \pm 0.3) \times 10^{21}\ {\rm cm^{-2}}$

$kT_e = 0.317^{+0.006}_{-0.004}$ keV

$n_e t > 1.6 \times 10^{12}\ {\rm cm^{-3}\ s}$

$Z_{\rm Ne} = 0.93^{+0.26}_{-0.09}$ solar

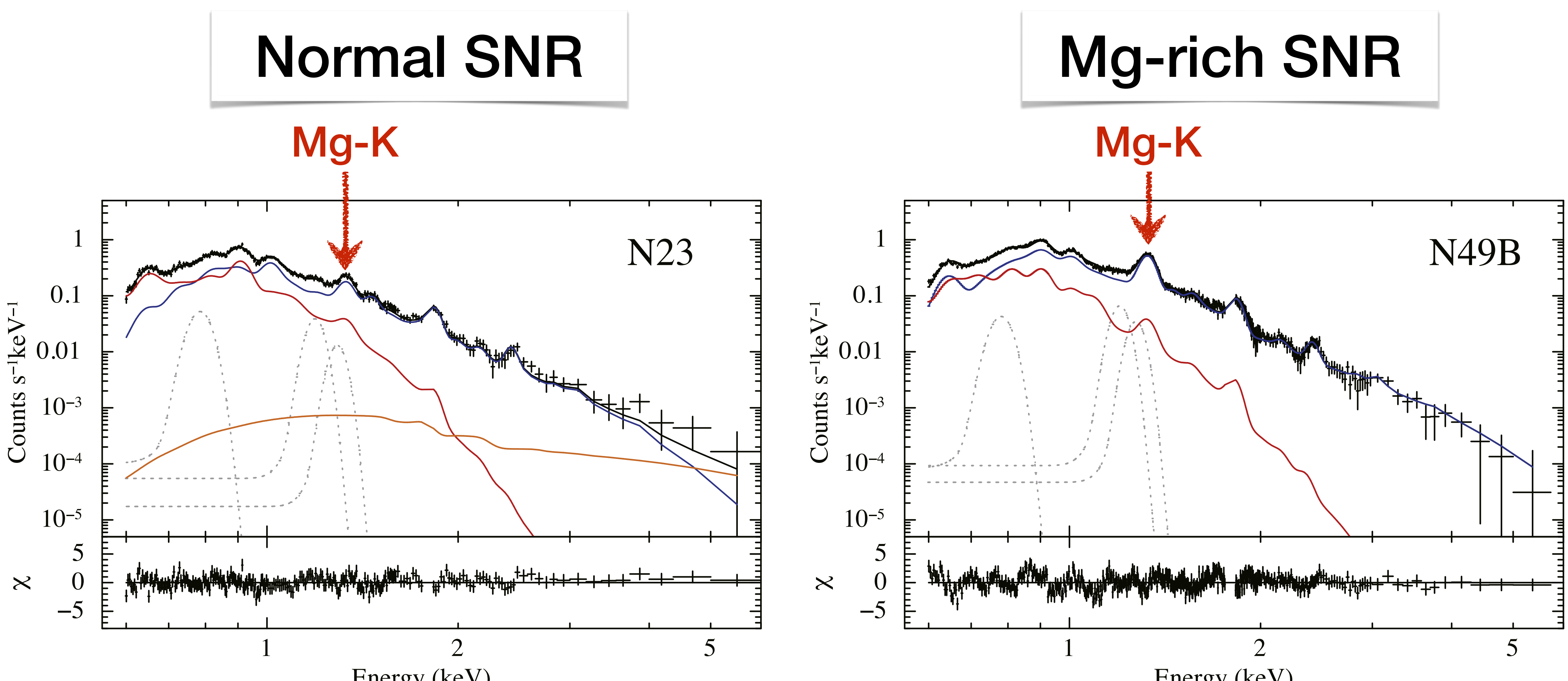
$Z_{\rm Mg} = 2.82^{+0.93}_{-0.42}$ solar

$Z_{\rm Si} = 1.94^{+0.25}_{-0.18}$ solar

- Absorption column density agrees well with that of 1FGL J1018 (6.4×10^{21} cm^{-2}), indicating similar distances between the SNR and the gamma-ray binary
- Consistent with the picture that G284 and 1FGL J1018 are the remnants of a common supernova explosion
- Strong Mg-K line → High Mg abundance compared to Ne (One of the few examples of Mg-rich SNR as already pointed out by Williams+ 2015)

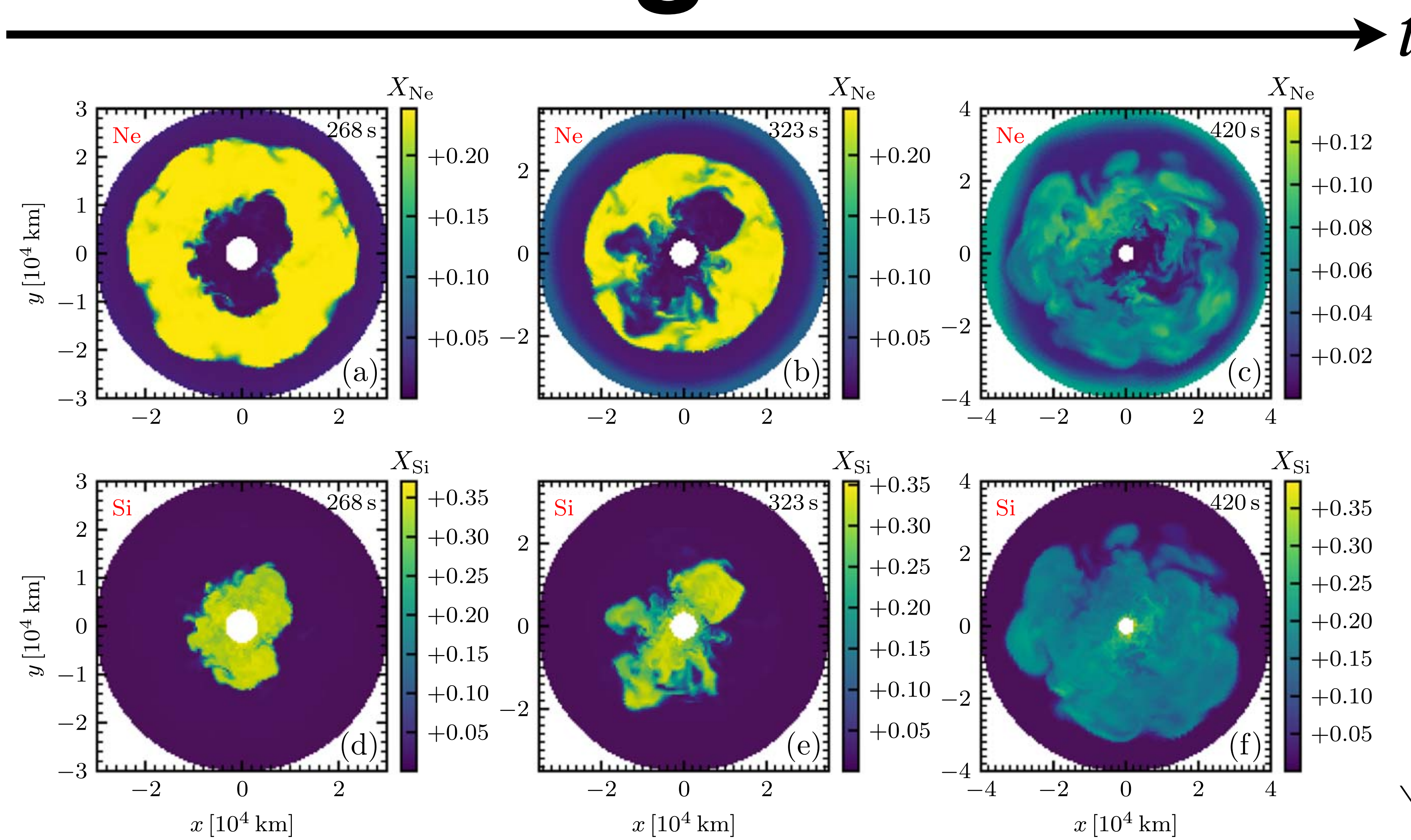
Mg-Rich SNRs

- Only a few examples reported so far such as N49B (Park & Bhalerao 2017) and G359.0–0.9 (Matsunaga+ 2024)
- Park & Bhalerao (2017) claimed a large mass (≳ 25 $M_\odot$) for the progenitor of N49B based on the Mg-rich ejecta mass
- The conclusion would be, however, changed by taking into account the recent progress in the understanding of stellar evolution (e.g., Yadav+ 2020)



Uchida+ (2015)

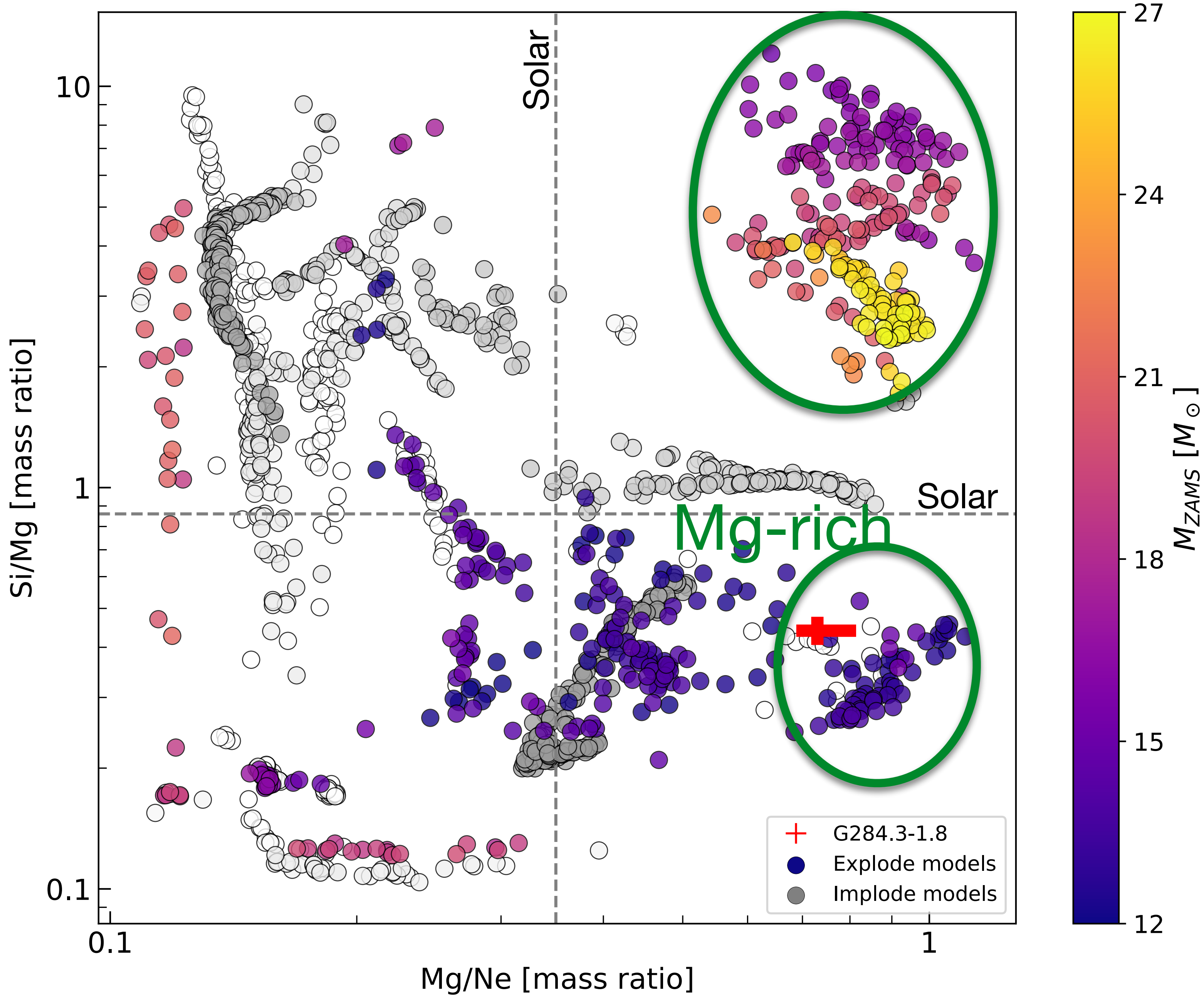
Shell Merger Process



Yadav+ 2020

- In the pre-supernova phase, Ne- or O-burning shell can be merged with outer O-Ne-Mg layer
- Such "shell mergers" can change the metal abundances so that Mg/Ne becomes higher than the cases without shell mergers (Sato+ 2024; Matsunaga+ 2024)
- Shell mergers also change the density profiles inside the star, resulting in higher supernova explosion probability

Progenitor of G284



- Stellar models taken from Sukhbold+ (2018), and distinction between exploding and non-exploding models based on Ertl+ (2016) (See Matsunaga+ 2024 for details)
- Initial mass of the progenitor of G284: < 15 $M_\odot$
- The supernova explosion should have left behind a neutron star

Conclusions

- We analyzed Suzaku X-ray data of the SNR G284.3–1.8, which positionally coincident with the gamma-ray binary 1FGL J1018.6–5856.
- The X-ray absorption column density of the SNR and the binary agree well with each other at ~ 6–7 × 10^{21} cm^{-2}, suggesting that the two objects are located at similar distances.
- The X-ray spectrum of G284 shows the strong Mg K-shell emission line, making the SNR one of the few examples of Mg-rich SNRs.
- Based on recent stellar evolution models, the high Mg-to-Ne mass ratios found in G284 can well be explained by pre-explosion shell mergers inside the progenitor.
- The initial mass of the progenitor of G284 is estimated to be $< 15\ M_{\odot}$.
- If so, the supernova explosion should have left a neutron star.
- On the other hand, the characteristics of 1FGL J1018 are well explained by the so-called pulsar-wind model.
- Our result suggests G284 and 1FGL J1018 are remnants of a common supernova.