Long-term variation of cosmic ray intensity observed with Nagoya multidirectional muon detector

Very Preliminary Results

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Nagoya-MD hut

- Correction of the atmospheric temperature effect.
- Long-term intensity variation observed with Nagoya-MD in 1970-2016 (47 years).
  - Variation spectrum of yearly mean intensity
  - Temporal variation of yearly mean modulation spectrum in 16 GV < Pm < 107 GV

    ⇒ "high-energy" cross-over of spectra in 1976 A>0 and 1987 A<0 solar minima.

Correction of GMDN data for the atmospheric temperature effect

(Mendonça+ ApJ 830:88 2016)

Mass Weighted Method:

$$\Delta I_T = \boxed{\alpha_{\mathrm{MSS}}} * \Delta T_{\mathrm{MSS}}$$

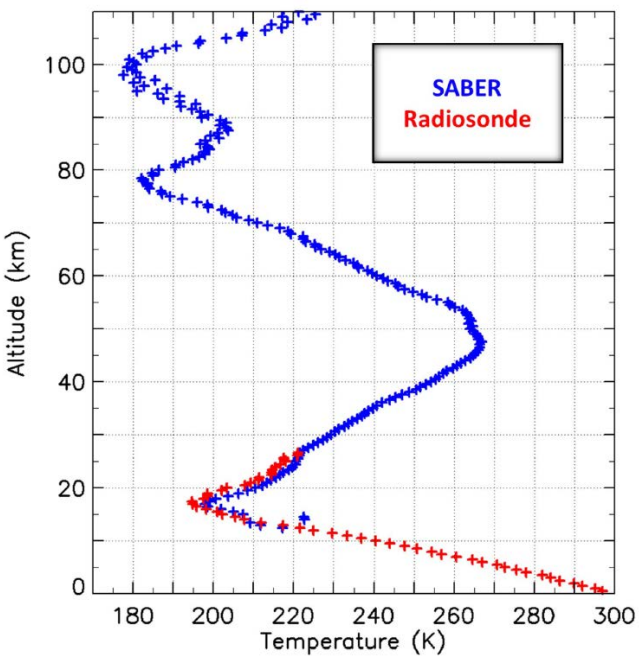
α_{MSS}(%/K) < 0

$$T_{\mathrm{MSS}} = \sum_{i=0}^{n} w[h_i] * \boxed{T[h_i]} \quad w[h_i] = \frac{x[h_i] - x[h_{i+1}]}{x[h_0]}$$

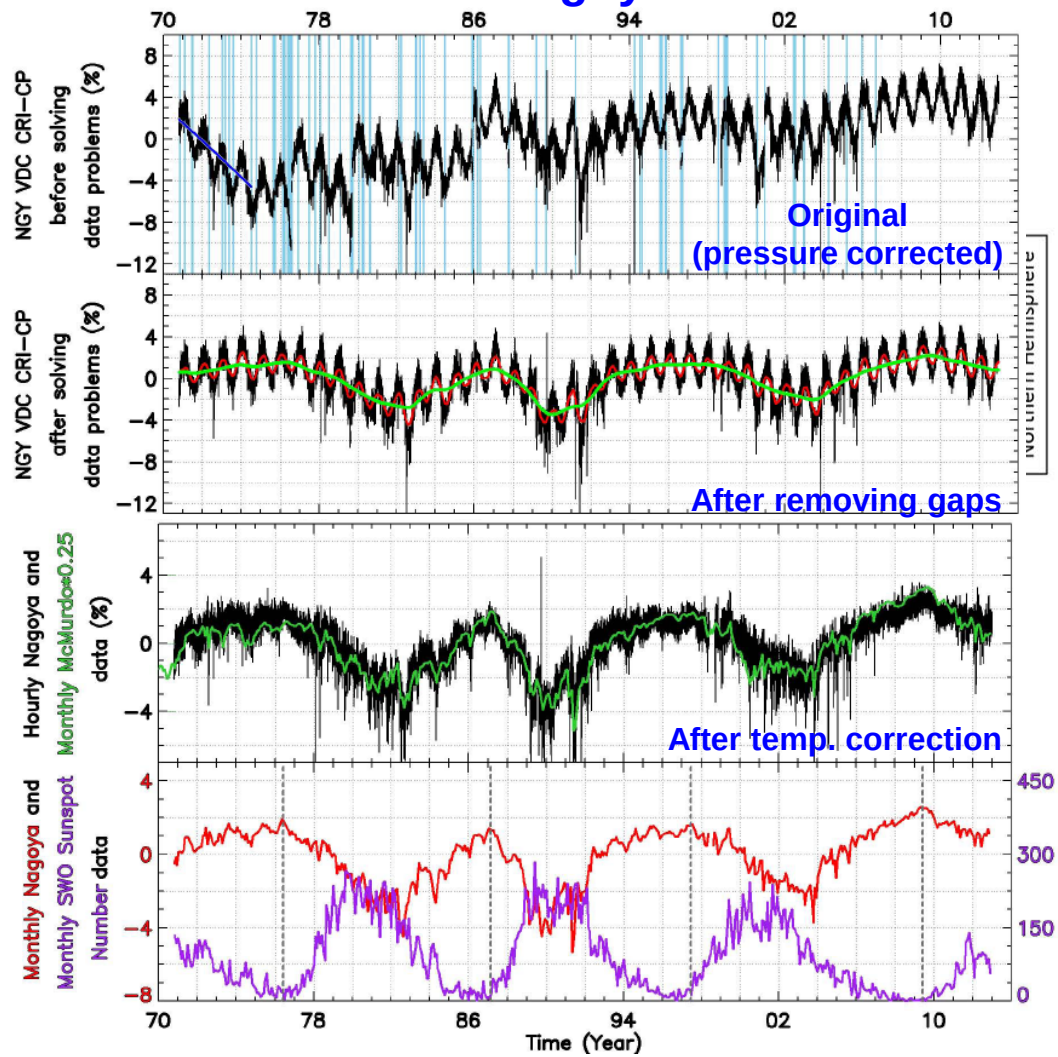
We use Global Data Assimilation System (GDAS) by NOAA's Air Resources Laboratory (ARL).

- SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) instrument on board the TIMED
- Integrated Global Radiosonde Archive, NOAA/ESRL Radiosonde Database

$T[h_i]$ is available at every 1°×1° grid on Earth's surface



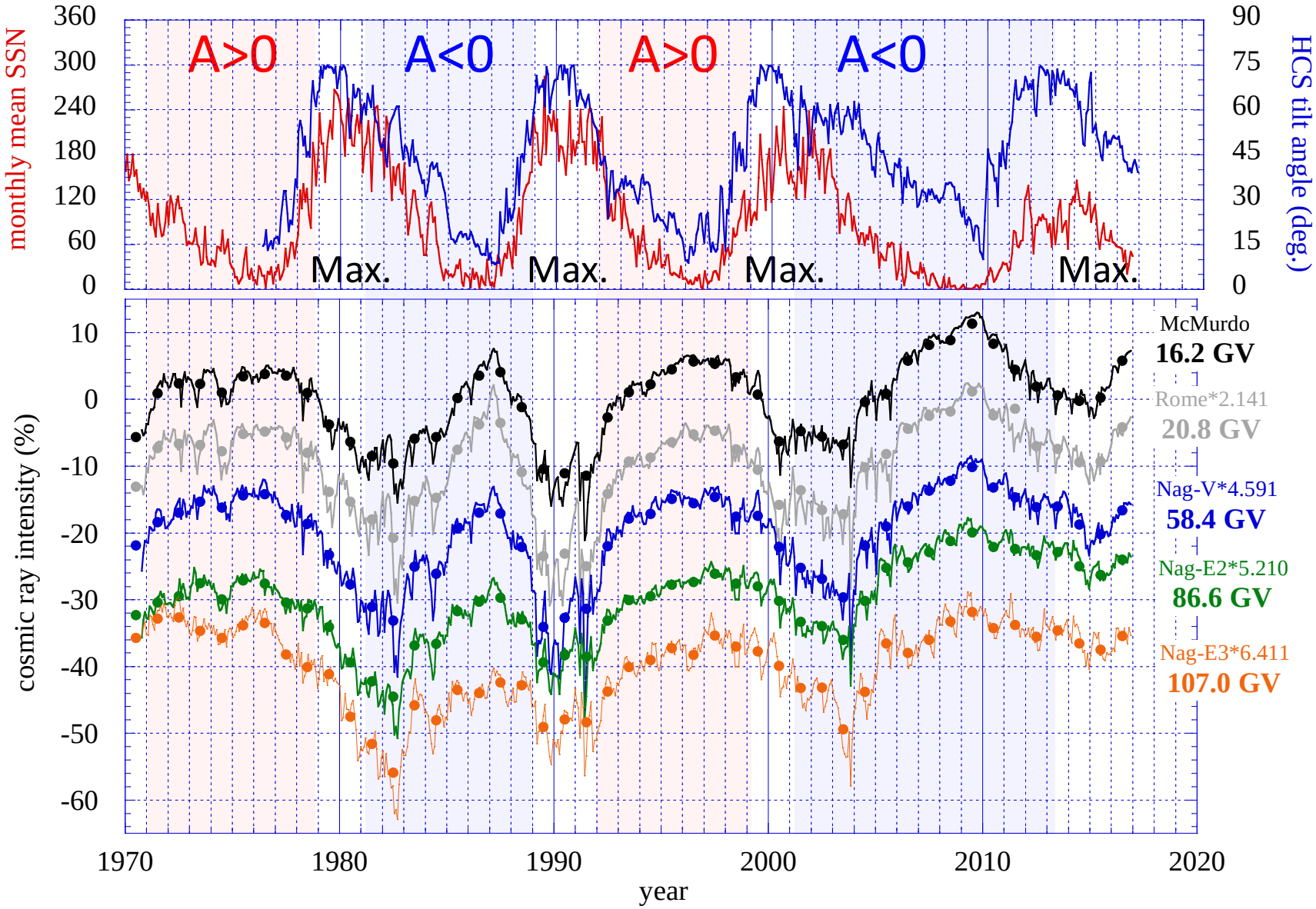
Nagoya-V



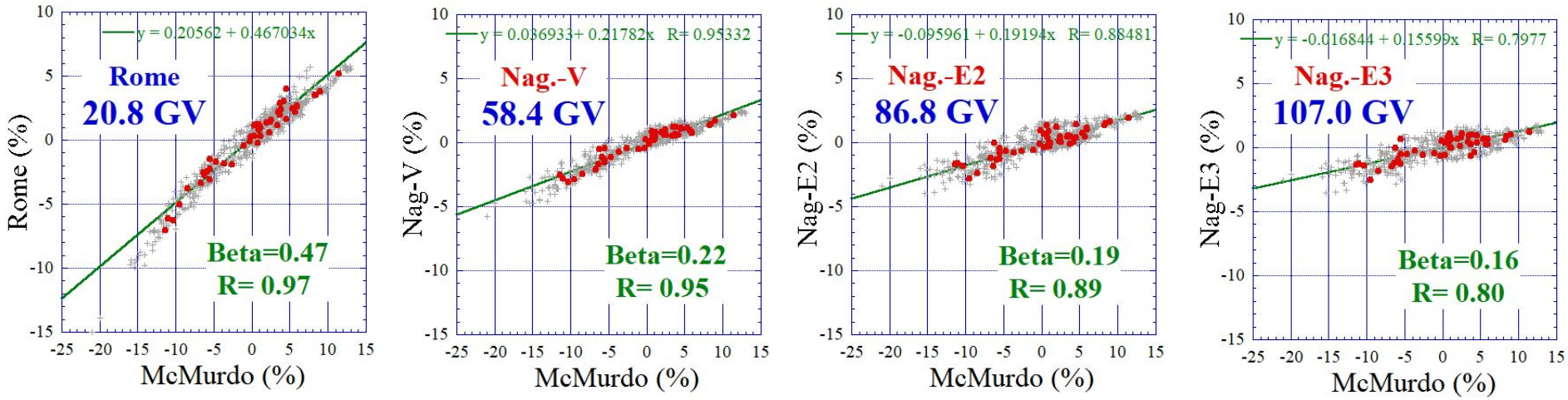
Data analyzed

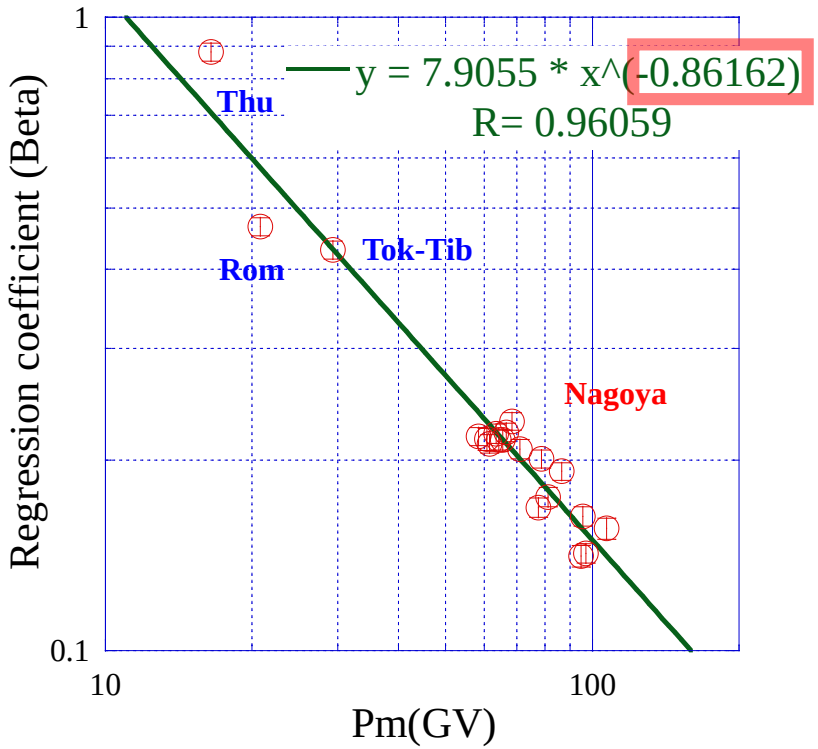
detector	Geographic lat. ; long. (°)	Alt. (m)	Geomag. cutoff rigidity Pc (GV)	Median primary rigidity Pm (GV)	Data period
McMurdo NM	-77.95; 166.60	48	0.01	**16.2**	1970-2016
Thule	76.50; -68.70	26	0.01	**16.5**	1970-1976 1978-2016
Rome NM	41.90; 12.52	60	6.32	**20.8**	1970-2016
Tokyo NM	35.75; 139.72	20	11.61	**29.3**	1970-1996
Tibet NM	30.11; 90.53	4300	14.1	**29.6**	1999-2016
PSNM	18.59; 98.49	2565	16.8	**35.5**	2008-2016
Nagoya MD (17 directions)	+35.15; 139.97	77	8.91 - 17.76	**58.4 - 107.0**	1970-2016

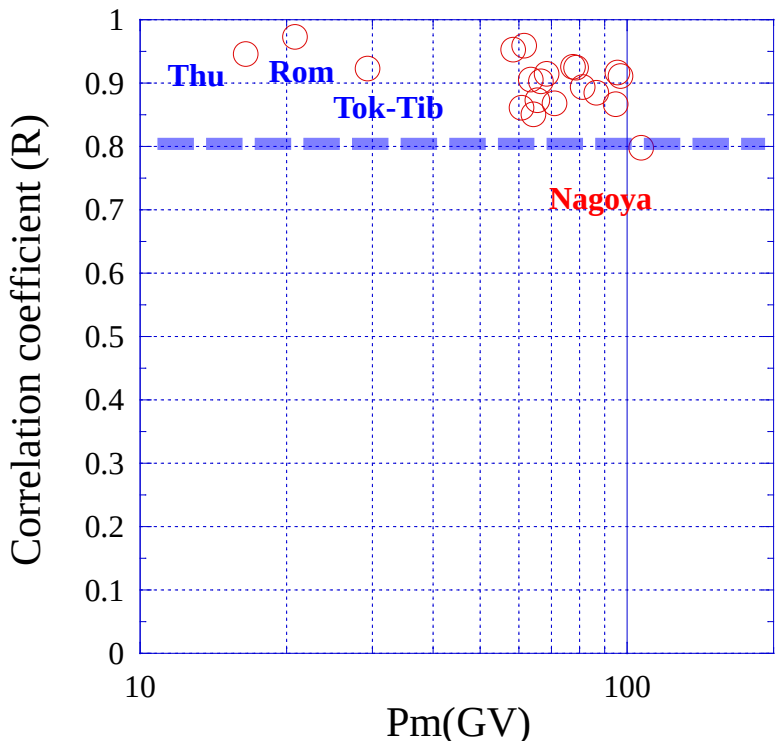
Long-term variations



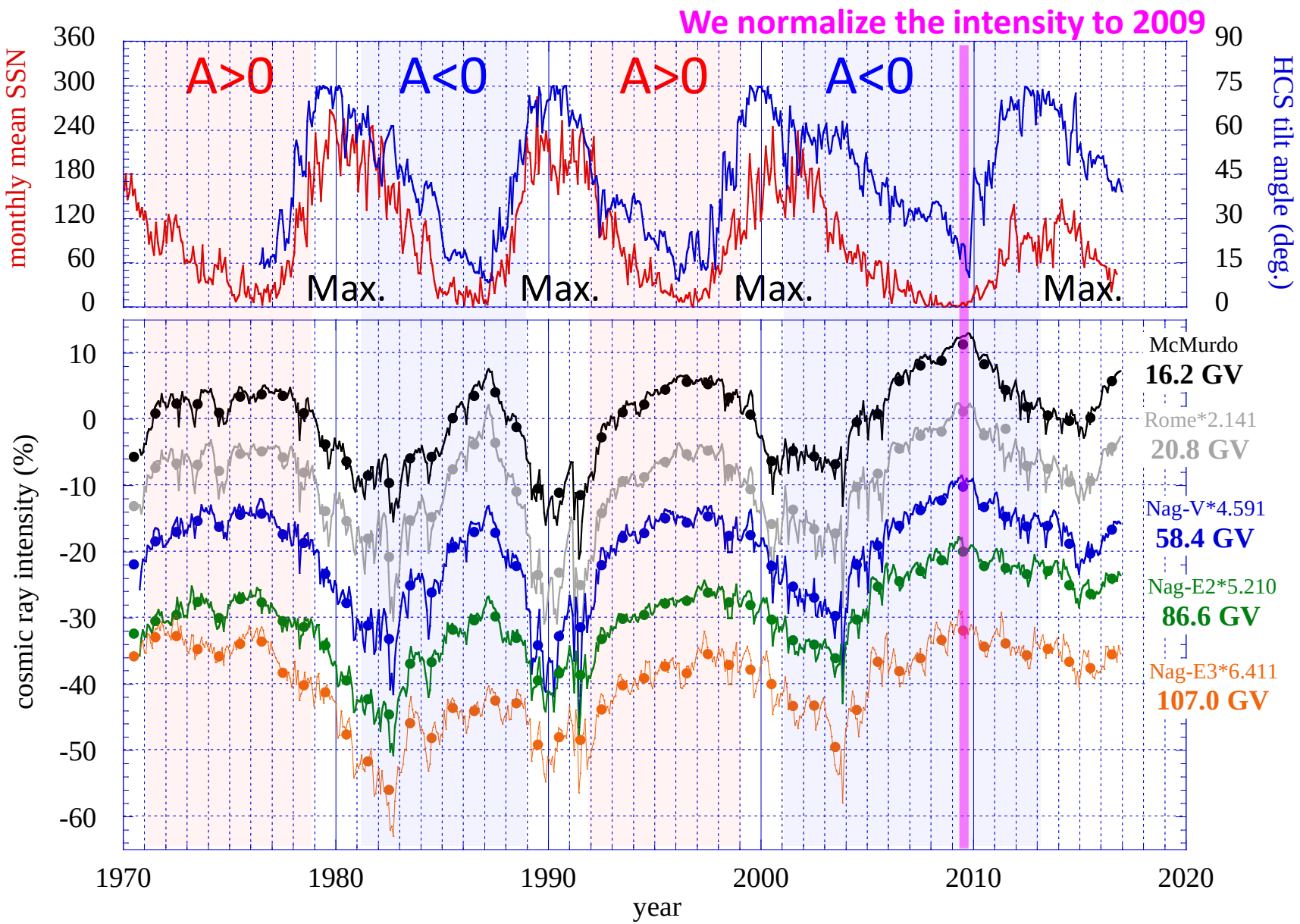
Variational spectrum







Long-term variations



Rigidity spectra relative to 2009

Observed GCR intensity modulation relative to 2009:

$$\Delta I_i^{obs}(t) = \{I_i^{obs}(2009) - I_i^{obs}(t)\}/I_i^{obs}(2009)$$

i : component (1~23)
t : year

Simple power-law model:

$$\Delta I_i^{fit}(t) = \int_{P_c}^{\infty} c(t) \left(\frac{p}{10GV}\right)^{\gamma(t)} R_i(p)dp / \int_{P_c}^{\infty} R_i(p)dp$$

$R_i(p)$: Response function (RF) of i-th component to primary GCRs with rigidity p (Nagashima's RF for NM, Murakami's RF for MD)

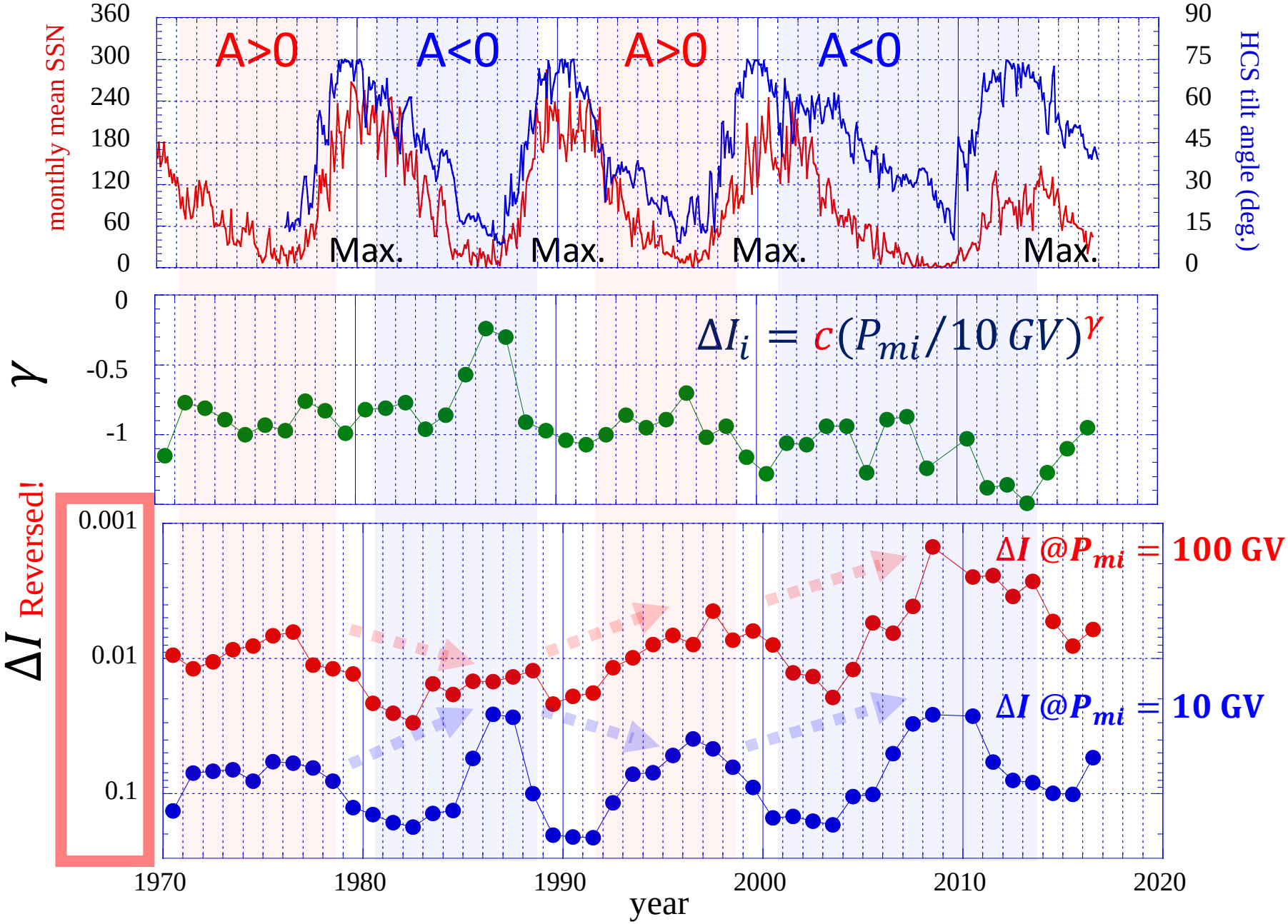
We obtain $c(t)$ and $\gamma(t)$ every year minimizing…

$$S = \sum_i \{1 - \Delta I_i^{obs}(t) - \Delta I_i^{fit}(t)\}^2 / {\sigma_i}^2$$

We compare $f(t)\Delta I_i^{obs}(t)$ with $\Delta I_i^{model}(t) = c(t)(\frac{P_{mi}}{10\ GV})^{\gamma(t)}$

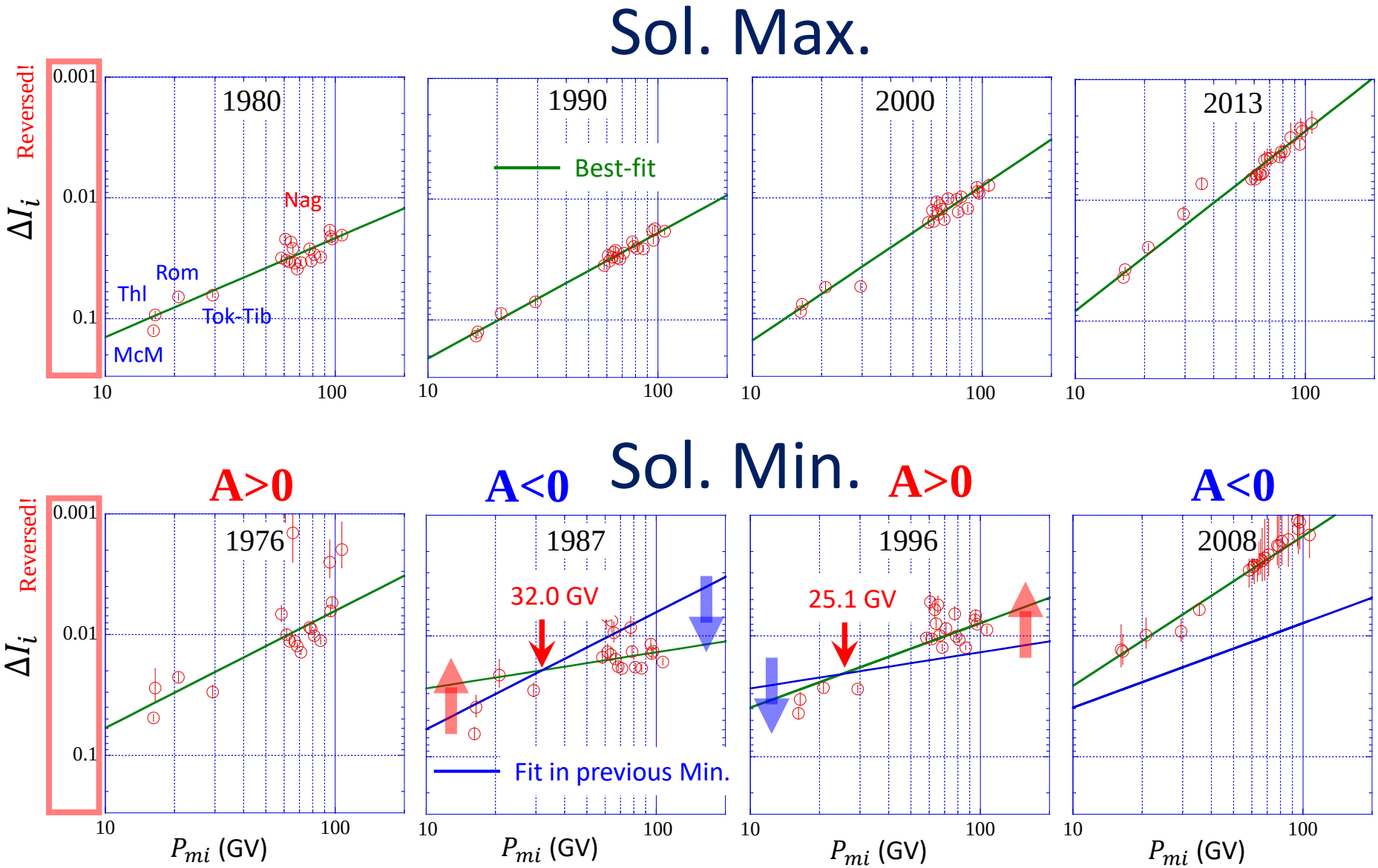
…where $f(t) = \Delta I_i^{model}(t)/\Delta I_i^{fit}(t)$

Variation of spectrum parameters



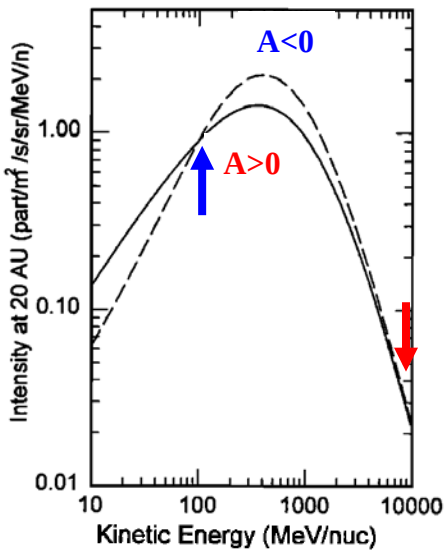
Rigidity spectra relative to 2009

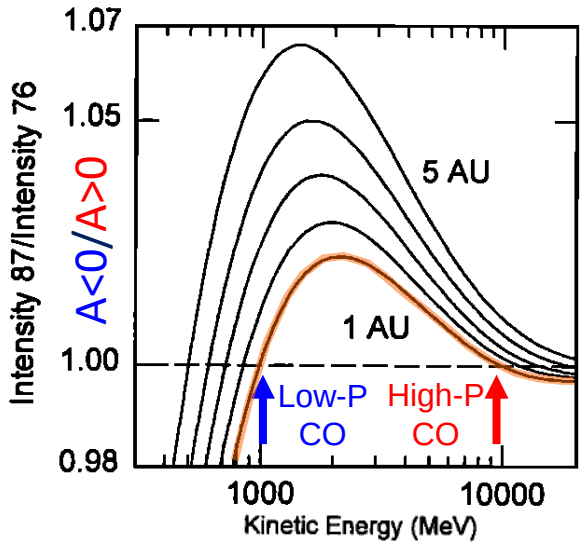
$$\Delta I_i = c(P_{mi}/10\,GV)^{\gamma}$$



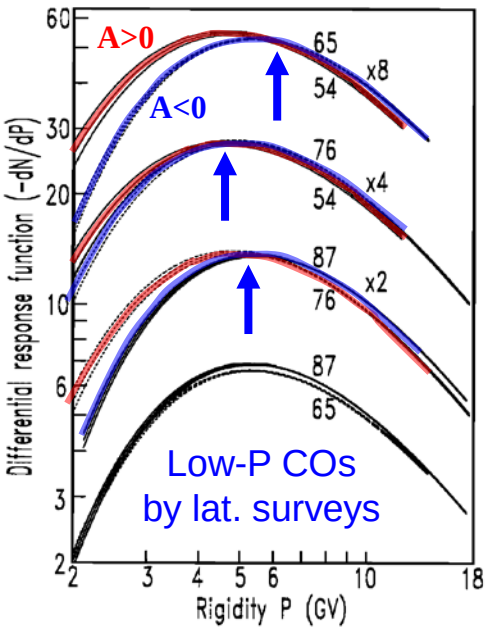
Drift model predicts cross-overs (COs)

Reinecke & Potgieter (JGR, 1994)

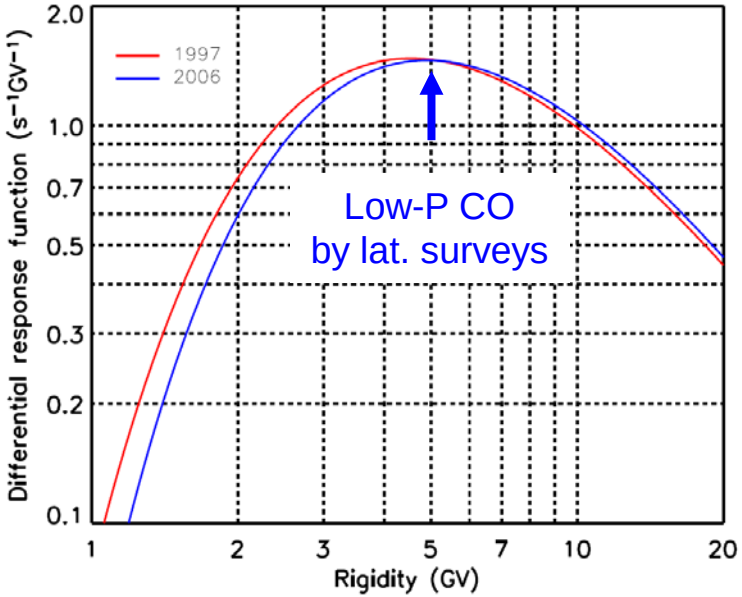




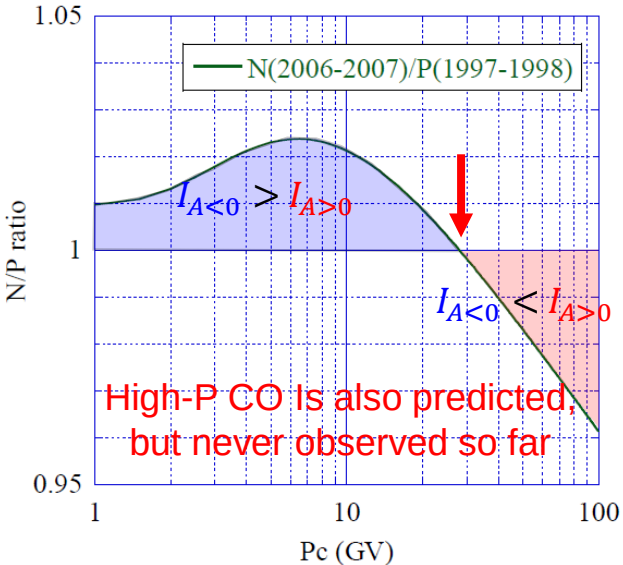
Moraal+ (JGR 94 1989)



Nuntiyakulu+ (ApJ 795 2014)



Ratio N(2006-2007)/N(1997-1998)



Summary and conclusion

- Based on observations with GMDN, we develop a correction method for the atmospheric temperature effect on the ground-level muon count rate.

- The corrected Nagoya MD data with NM data clearly show the rigidity dependence of long-term intensity variation in ~10-100 GV.
  - Overall, the variational spectrum of yearly mean data is consistent with p^(-0.9).
  - CR rigidity spectra in A>0 and A<0 minima show high-rigidity counterpart of the "cross-over" reported from NM latitude survey and predicted by the drift model.

- The long-term observation with Nagoya MD is very important for CR modulation study.