

there be official declarations of the quantities of waste produced.

1. Berkhout, F., *Radioactive Waste: Politics and Technology*, Routledge, London, 1991.
2. Nuclear Energy Agency, *Radioactive Waste Management in Perspective*, OECD, Paris, 1996, p. 9.
3. See, for example Sinha, R., *Indian Express*, New Delhi, 7 May 2000, p. 7.
4. Chidambaram, R. and Ganguly, C., *Curr. Sci.*, 1996, **70**, 21–35.
5. Rodriguez, P., Proceedings of the International Conference on Advances in Chemical Engineering (ICACHE-96), 11–13 December 1996, Indian Institute of Technology, Chennai, 1996, pp. 45–58.
6. Guha, S. B., Proceedings of an International Symposium on Experience in the Planning and Operation of Low Level Waste Disposal Facilities, International Atomic Energy Agency, Vienna, 1997, pp. 329–337.
7. Changrani, R. D., Bajpai, D. D. and Kodilkar, S. S., Proceedings of a Symposium, 9–13 November 1998, International Atomic Energy Agency, Vienna, 1999, pp. 65–72.
8. Glasstone, S. and Sesonske, A., *Nuclear Reactor Engineering*, Van Nostrand Reinhold Company, New York, 1981, p. 29.
9. Hibbs, M., *Nuclear Fuel*, 1 December 1997; ref. 7.
10. Balakrishnan, K., *BARC Newsl.*, April 1999, **183**; <http://www.barc.ernet.in/>
11. <http://www.npcil.org> (downloaded 24 January 2001).
12. http://www.barc.ernet.in/webpages/rca_india/articles.html; Sage, R. D., Stewart, D. D., Prasad, H. B. and Sethna, H. N., in Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1–13 September 1958, p. 26.
13. <http://www.barc.ernet.in/webpages/reactors/cirus.html>; Soman, S. D. and Abraham, P., *Health Phys.*, 1965, **11**, 497–505.
14. Annual Report of the Department of Atomic Energy 1997–98, Government of India, 1998, section 4, p. 1.
15. *Nuclear India*, Department of Atomic Energy, November–December 2000, vol. 34.
16. Sharma, S. K. and Chowdhury, R., Fifth Asian Symposium on Research Reactors, Taejon, Korea, 29–31 May 1996, pp. 187–192.
17. Tefft, S., *Nucleonics Week*, 17 December 1987; Chellaney, B., *ibid*, 5 March 1987.
18. Albright, D., Berkhout, F. and Walker, W., *Plutonium and Highly Enriched Uranium 1996*, Oxford University Press, Oxford, 1997, p. 181.
19. Ramanna, R., *Curr. Sci.*, 1997, **73**, 319–326; Subramanian, T. S., *Frontline*, 5 May 1995, p. 54.
20. Benedict, M., Pigford, T. H. and Levi, H. W., *Nuclear Chemical Engineering*, McGraw Hill, New York, 1981, p. 11.
21. Boulton, J., *Management of Radioactive Fuel Wastes: The Canadian Disposal Program*, Atomic Energy of Canada Research Company, 1978, p. 13.
22. Ref. 20, p. 242.
23. Sarkar, S. C., *Geology and ore mineralisation of the Singhbhum copper–uranium belt, Eastern India*, Jadavpur University, Calcutta, 1984, p. 193.
24. Ref. 21, p. 13.
25. Bhat, I. S., Iyengar, M. A. R., Gurg, R. P., Krishnamony, S. and Pillai, K. C., Conference Proceedings on Small and Medium Scale Nuclear Reactors, Delhi, 1991, pp. 532–539.
26. Gupta, M. P., Mondal, N. K., Bodke, S. B. and Bansal, N. K., Proceedings of an International Symposium on Experience in the Planning and Operation of Low Level Waste Disposal Facilities, International Atomic Energy Agency, Vienna, 1997, pp. 275–284.
27. Annual Report of the Department of Atomic Energy 1976–77, Government of India, 1977, p. 67.
28. Annual Report of the Department of Atomic Energy 1982–83, Government of India, 1983, p. 33.
29. <http://www.ontariopowergeneration.com/newgen/nuclear/OHNWasteMgmtRadioactive.asp>
30. Mullarkey, T. B., Jentz, T. L., Connelly, J. M. and Kane, J. P., *A Survey and Evaluation of Handling and Disposing of Solid Low-level Nuclear Fuel Cycle Wastes*, Atomic Industrial Forum, Washington, 1976, p. 15.
31. *World Nuclear Industry Handbook*, Nuclear Engineering International, 1998.
32. Hibbs, M., *Nuclear Fuel*, 30 March 1992.
33. *Nuclear News*, May 1996, p. 43.
34. Ref. 20, p. 575.
35. *Nuclear Power and You*, Nuclear Power Corporation, Government of India, December 1990, p. 16.
36. Ref. 7, p. 65.
37. *Operating Experience with Nuclear Power Stations in Member States in 1997*, International Atomic Energy Agency, Vienna, 1998.
38. Jungmin Kang, Seoul National University, pers. commun.
39. Sisodia, D. K., *Nu-Power*, 1999, **13**; <http://www.npcil.org/docs/raps1n.htm>

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A new feature of low latitude geomagnetic storms

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It has been shown that the geomagnetic storms during their main phase cause significant decrease in the geomagnetic H field at low latitudes, in addition to that expected due to the disturbance ring current. This additional westward equatorial ionosphere current at low latitude coincides in time with the period of high interplanetary magnetic B field, its southward direction and large auroral electrojet current. It is suggested that this auroral electric field associated with high latitude field-aligned currents and is transmitted to low latitudes by the earth and ionosphere transmission line processes.

MOOS¹ was the first to identify the characteristics of geomagnetic storms at a low latitude station, Colaba, India. He also found an additional solar daily variation (now called disturbance daily variation, SD) imposed on the normal daily variation (Sq) during disturbed days. Egedal² had discovered that the range of solar daily variation of the horizontal geomagnetic field H , shows a maximum within $\pm 3^\circ$ latitudes around the magnetic equator. Chapman³ explained the effect as due to an eastward-flowing band of current in E region of the

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ionosphere, which he named as 'Equatorial Electrojet'. Vestine *et al.*⁴, Chapman⁵ and Matsushita⁶ in their extensive study of Sq and SD variations at a number of stations around the world did not find any abnormal increase of the amplitude of SD in H at the equatorial station, Huancayo. An extensive analysis of SD as well as Dst variations of the geomagnetic field components H , D and Z was made by Sugiura and Chapman⁷. They did not find any special features of the storm effects at equatorial stations.

Yacob⁸, in his study of SD and Dst variations of H field at Indian observatories, Trivandrum, Annamalainagar and Alibag, found that the disturbances were of about the same magnitude at the three observatories during the night-time, while during the daytime the disturbances were enhanced near the equator. Rastogi⁹ showed that the disturbance daily variation of H at Trivandrum showed a significant midday decrease, besides the normal dawn maximum and dusk minimum observed earlier at all other stations. He suggested that the geomagnetic disturbances are associated with the imposition of an additional westward electric field during the daytime hours. Later, Rastogi¹⁰ showed that the decrease of H during the main phase of a geomagnetic storm is accentuated at stations near the magnetic equator and confirmed the westward electric field at low latitudes during storms. It was later shown that corresponding to the midday decrease of $SD(H)$, there was a corresponding midday increase of SD variations of the vertical Z component of the field at equatorial electrojet stations, suggesting the generation of a westward equatorial electrojet current during the main phase of the storm¹¹.

In this paper, an attempt has been made to identify the possible source of the westward current during the geomagnetic storms. The data used are from the stations in the Indo-USSR chain along 75°E geographic meridians. A list of these stations with their coordinates is given in Table 1. The decrease during magnetic storm has been

Table 1. Stations in the Indo-USSR chain along with their coordinates

| Observatory | Code | Coordinates of the observatories | | |
|----------------|------|----------------------------------|-------------------|----------------|
| | | Geog. lat. °N | Geog. long. °E | Dip lat. °N |
| Novosobersk | NVS | 55.0 | 82.5 | 58.5 |
| Novokazalinsk | NKK | 45.8 | 62.1 | 46.3 |
| Tashkent | TKT | 41.3 | 69.6 | 41.1 |
| Ashkhabad | ASK | 38.0 | 58.1 | 36.6 |
| Gulmarg | GUL | 34.1 | 74.6 | 31.4 |
| Sabhawala | SAB | 30.4 | 77.8 | 26.9 |
| Jaipur | JAI | 26.9 | 75.8 | 22.5 |
| Ujjain | UJJ | 23.2 | 75.8 | 18.2 |
| Alibag | ABG | 18.6 | 72.9 | 12.9 |
| Hyderabad | HYB | 17.4 | 78.6 | 10.8 |
| Annamalainagar | ANN | 11.4 | 79.5 | 3.0 |
| Kodaikanal | KOD | 10.5 | 77.5 | 1.8 |
| Ettayapuram | ETT | 9.2 | 78.0 | 0.5 |
| Trivandrum | TRD | 8.5 | 77.0 | -0.2 |

explained as due to a westward equatorial ring current in the magnetosphere caused by the gyration and drift of electrons and charged particles trapped in the radiation belt. This effect is well-represented by the equatorial Dst (H) index, suggested by Sugiura¹². The effect of ring current at any station at the geomagnetic latitude, λ_m , is given by $Dst \times \cos \lambda_m$. Thus, from the observed hourly mean H field on a stormy day, we subtracted the corresponding H field averaged on five international quiet days of the month to remove the effect of undisturbed current component. Further, to remove the effect of ring current we subtracted the corresponding hourly mean value of $Dst \times \cos \lambda_m$. The remaining residual ΔH would thus represent the effect of any current other than that in the ionosphere and in the radiation belt. These residual variations of ΔH are compared with the corresponding variation of the auroral current index AE and the interplanetary magnetic field magnitude B and the component of B normal to the ecliptic B_z .

Figure 1 shows the variations of the residual H field ($\Delta H - Sq(H) - Dst \times \cos \lambda_m$) at the three equatorial stations Trivandrum (TRD), Ettayapuram (ETT) and Kodaikanal (KOD) compared with the corresponding variations of Dst index, AE index, interplanetary magnetic field (IMF) (B) and IMF (B_z) on 11, 12 and 13 September 1986. The sudden storm commencement had occurred at 2336 h, 75°E MT on 11 September 1986. The Dst index showed a rise simultaneously with the sudden storm commencement (SSC), the AE index showed a small increase following SSC. The initial phase of the storm lasted up to 0530 h on 12 September 1986 after which the

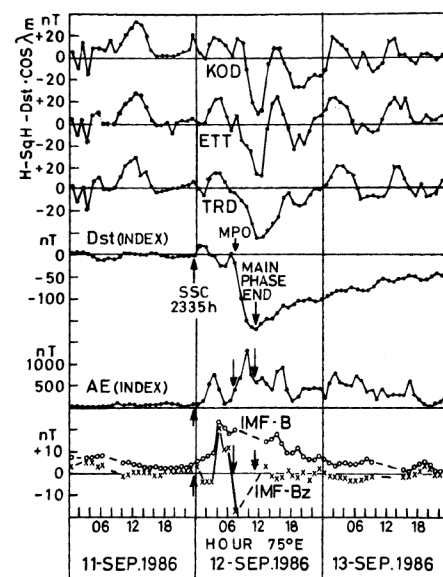


Figure 1. Temporal variations of $(H - Sq(H) - Dst \times \cos \lambda_m)$ at equatorial stations Trivandrum, Ettayapuram and Kodaikanal and Dst index during the magnetic storm starting at 2335 h on 11 September 1986. Variations of auroral current index AE , interplanetary magnetic field IMF (B) and its vertical component IMF (B_z) are also shown.

Dst started decreasing very fast, reaching a minimum value at about 1230 h on 12 September 1986. The main phase onset (MPO) coincided in time with the southward turning of IMF (negative B_z) and with the onset of large bursts of AE index. It is to be noted that IMF (B_z) reduced to almost zero level by 12 h, IMF (B) and AE index reduced to normal value by the end of the day on 12 September 1986, but the *Dst* index continued its slow recovery to its normal level even at the end of the next day on 13 September 1986. The residual value of the H field ($\Delta H - S_q(H) - Dst \times \cos \lambda_m$) at the equatorial stations started decreasing regularly at 0630 h on 12 September 1986, at the time of the MPO, reached a minimum value of about -40 nT at the end of the main phase and returned to normal value in a few hours. The interval during which the residual H field was below normal coincided with the interval when AE was large, IMF (B) was strong and IMF (B_z) was negative. This clearly suggests a magnetospheric source for the storm-time westward equatorial electrojet current.

The second storm discussed was with SSC at 0957 h on 19 December 1980. The residual H field ($H - S_q(H) - Dst \times \cos \lambda_m$), *Dst*, AE, IMF (B) and IMF (B_z) variations on 19 and 20 December 1980 are shown in Figure 2. The SSC at 0957 h had its impression on the residual H field at all low latitude stations from TRD at the equator to SAB near the S_q focus, by a sudden large increase of the field. It was also associated with the sudden increase of AE index and with the start of the increase in IMF (B) field. The MPO of the storm was at 1630 h, coinciding with the southward turning (negative IMF (B_z)) of the interplanetary magnetic field which facilitated the entry of solar plasma into the earth's atmosphere, associated with the energization of the auroral current shown by a sudden increase of AE index. The main phase ended around 2030 h when a slow northward turning of IMF (B_z) had started, accompanied by the decreasing trend in AE and slow recovery of the ring current index *Dst* to its normal value. It is interesting to note that the large decrease of the residual H field is very prominent at all latitudes from Trivandrum (geom. lat. -0.8°) to Novakazalinsk (geom. lat. 37.6°). This strong westward electric field imposed on the low and middle latitudes coincided with negative B_z , enhanced B and enhanced AE index.

Figure 3 shows the variations of ($H - S_q(H) - Dst \times \cos \lambda_m$) at stations along the Indo-Russian longitude sector, compared with the corresponding variations of the *Dst* index during the magnetic storm with SSC at 1034 h on 5 March 1981. Comparing these curves with those for interplanetary magnetic field B and B_z and AE index, it is seen that the large additional decrease of the magnetic field during the main phase of the storm was almost of the same magnitude at Trivandrum or at any station up to Tashkent. There is no equatorial enhancement because the main phase occurred during the evening hours when the equatorial electrojet field and hence the additional

conductivities at equatorial stations were greatly reduced. Still this additional decrease of the H field was concurrent in time with the large values of IMF (B), IMF (B_z) and AE.

There was a large decrease in the H field during the midday hours on the next day, at the equatorial stations only. The variations of ΔH (TRD) $-\Delta H$ (ABG) showing corresponding large negative values indicates that this is the effect of the counter electrojet event causing a decrease of ionospheric current and was not due to any magnetospheric current.

Indian scientists had realized at the early stages of ionospheric research that the critical frequencies of the F_2 layer on disturbed days increased at the equatorial station, Kodaikanal and decreased at the anomaly crest station, Ahmedabad on magnetically disturbed days¹³. This suggested a decrease of the fountain effect due to the decrease of

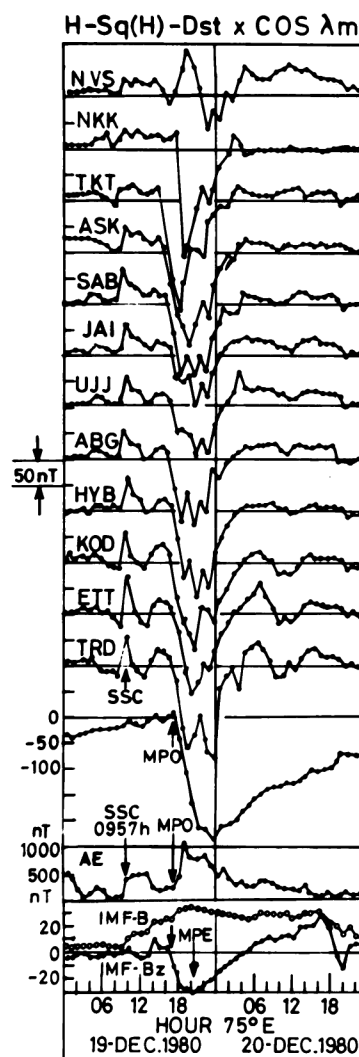


Figure 2. Temporal variations of ($H - S_q(H) - Dst \times \cos \lambda_m$) at stations in Indo-Russian chain during magnetic storm starting at 0957 h on 19 December 1980. *Dst*, AE, IMF (B) and IMF (B_z) are also shown for comparison.

equatorial electrojet during magnetically disturbed periods. As the geomagnetic variations at ground level are due to the combined effects of the electric currents in the ionosphere and magnetosphere, and the currents induced inside the earth due to these source currents, no direct evidence could be identified for the changes in the equatorial electrojet current with magnetic activity. It was the observations of ionospheric drift at Thumba which provided for the first time a parameter directly related to the magnitude and direction of the ionospheric electric field unaffected by other currents in the magnetosphere and inside the solid earth¹⁴. It was shown that the ionosphere drifts during the midday hours and hence the eastward electric field in the ionosphere decreased progressively with increasing magnetic activity¹⁵. The electric field was shown even to reverse into a westward direction

during a magnetic storm¹⁶. A direct link between the equatorial electric field and the interplanetary magnetic field was established, when the daytime drift speeds were shown to be linearly related to the IMF (B_z) component¹⁷. Later, studying the concurrent observations of the electron drifts in the ionosphere by the Doppler shift of VHF backscatter radar at Jicamarca, magnetograms at Huan-cayo and IMF recordings at satellite Explorer, Rastogi and Patel¹⁸ showed that a sudden reversal of B_z component of IMF during a compressed state of the magnetosphere produces a reversal of the equatorial ionospheric electric field. The sudden change of B_z produced an electric field at the magnetopause, which was immediately transmitted to the equator via the auroral zone open field lines. Kikuchi and Araki¹⁹ suggested this instantaneous transmission of the auroral electric field to low latitude through a parallel plane transmission line composed of the earth and the ionosphere²⁰. Onwumechilli *et al.*²¹ showed the incidence of coherent fluctuations of the geomagnetic H field at auroral and equatorial latitudes.

A magnetic storm is characterized by a sudden positive increase in the H component of the geomagnetic field (SSC). It is followed by the elevated H field (initial phase) for a period of an arbitrary length. This is followed by the development of depressed H component (main phase) and extending of H component to the normal level (recovery phase). The SSC was explained by Chapman and Ferraro²² due to the compression of the front side of the magnetosphere by the enhanced solar wind pressure. This is indicated by the sudden increase of scalar value of interplanetary magnetic field, IMF (B). Rostoker and Falthammer²³ suggested that the initial phase represents a period of time after the SSC during which the IMF is primarily northward. During this period, very little energy is entering the magnetosphere regardless of the speed and number density of the solar wind particles. The MPO was found to coincide in time with the southward turning of the component of the IMF normal to the ecliptic, IMF (B_z)²⁴. Kikuchi *et al.*²⁵ showed that the equatorial electric currents are connected to the magnetosphere through the region 1 and region 2 field aligned currents at high latitudes.

Figure 4 shows the possible mechanisms for the additional equatorial westward electric field during the main phase of the storm. The magnetic storm is initiated by the arrival of the high-speed plasma cloud from the sun, which causes the rather sudden increase in the interplanetary magnetic field in the magnetosphere and causing SSC. The continuing pressure by the solar wind with the presence of a northward IMF continues the elevated value of H related to the initial phase. The southward turning of IMF (negative B_z) causes the transfer of solar wind energy to the magnetosphere, energizing the ring current and leading to the large and rapid decrease of the H field associated with the main phase. Simultaneously, large auroral electrojet currents are generated and AE increases. With the northward

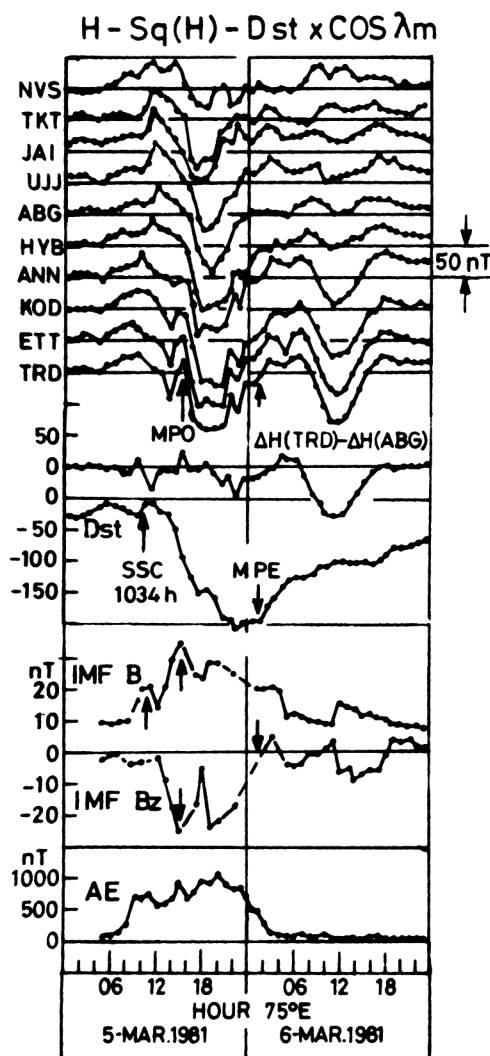


Figure 3. Temporal variations of $(H - Sq(H) - Dst \times \cos \lambda m)$ at stations along the Indo-Russian chain compared with the variations of equatorial electrojet current (ΔH (TRD) - ΔH (ABG)), Dst index, IMF (B) and IMF (B_z) and the auroral electrojet current AE .

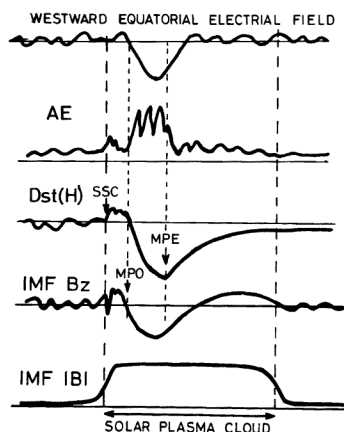


Figure 4. Suggested morphologies of interplanetary magnetic field B_z , Dst index, AE index and residual westward electric field during magnetic storms.

turning of IMF some hours later, the auroral electrojet (AE) decreases and ring current decreases, associated with the recovery phase of the storm. During the main phase of the storm, when IMF (B_z) is large and is southward, the magnetospheric electric field at high latitude extends to the equatorial ionosphere causing an additional decrease of H at the equatorial stations beside the one expected by the ring current alone.

1. Moos, N. A. F., Colaba magnetic data, 1846–1905.
2. Egedal, S., *Terr. Magn. Atmos. Electr.*, 1947, **52**, 449–451.
3. Chapman, S., *Arch. Meteorol. Geophys. Bioclimatol. A*, 1951, **4**, 368–390.
4. Vestine, E. H., Laporte, L., Lange, I. and Scott, W. E., *The Geomagnetic Field and its Application and Analysis*, C.I.W. Publ. No. 580, 1947.
5. Chapman, S., *Geofis. Pura Appl.*, 1951, **14**, 151.
6. Matsushita, S., *J. Geomagn. Geoelectr.*, 1953, **5**, 100.
7. Sugiura, M. and Chapman, S., *Sbh. Akad. Wiss. Gottingen. Maths. Phys. K.I. Sonderheft 4*, 1960, pp. 53..
8. Yacob, A., *Indian J. Meteorol. Geophys.*, 1966, **17**, 271–276.
9. Rastogi, R. G., *Curr. Sci.*, 1998, **74**, 457–460.
10. Rastogi, R. G., *Ann. Geophys.*, 1999, **17**, 438–441.
11. Rastogi, R. G., *J. Atmos. Terr. Phys.*, 2000, **62**, 695–700.
12. Sugiura, M., *Ann. Int. Geophys.*, 1964, **35**, 945.
13. Rajaram, G., *J. Atmos. Terr. Phys.*, 1977, **39**, 1125–1144.
14. Chandra, H., Misra, R. K. and Rastogi, R. G., *Planet. Space Sci.*, 1971, **19**, 1497–1503.
15. Rastogi, R. G., Chandra, H. and Misra, R. K., *Nature, Phys. Sci.*, 1971, **233**, 13–15.
16. Rastogi, R. G., Chandra, H. and Chakravarty, S. C., *Proc. Indian Acad. Sci.*, 1971, **74**, 62–67.
17. Rastogi, R. G. and Chandra, H., *J. Atmos. Terr. Phys.*, 1974, **36**, 377–379.
18. Rastogi, R. G. and Patel, V. L., *Proc. Indian Acad. Sci.*, 1976, **A82**, 121–141.
19. Kikuchi, T. and Araki, T., *J. Atmos. Terr. Phys.*, 1979, **41**, 927–936.
20. Akasofu, S. I. and Chapman, S., *J. Geophys. Res.*, 1963, **68**, 2375.
21. Onwumechilli, A., Kawasaki, K. and Akasofu, S. I., *Planet. Space Sci.*, 1973, **21**, 1–16.
22. Chapman, S. and Ferraro, V. C. A., *J. Geophys. Res.*, 1931, **36**, 171–186.

23. Rostoker, G. and Falthammer, C. G., *J. Geophys. Res.*, 1967, **72**, 5853–5863.
24. Patel, V. L. and Wiskerchen, M. J., *J. Geom. Geoelectr.*, 1975, **27**, 363–382.
25. Kikuchi, T., Luhr, L., Kitamura, T., Saka, O. and Schlegel, K., *J. Geophys. Res.*, 1996, **101**, 17161–17173.

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Glass based on a single proto-tile and inflation species without discrete diffractogram

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The discovery of quasicrystals in the 80s has led to a qualitative change in our understanding about atomic arrangements, including definition of solids having discrete diffractograms. Owing to this, the emphasis has now been shifted to reciprocal space from direct space that was in vogue prior to the seminal finding of quasi-periodic atomic arrangements having non-crystallographic point group symmetry. The purpose of this communication is to cite two specific examples of two-dimensional tiling from literature that do not possess discrete diffractograms, but have subtle distinctions in direct space. It will be shown that one of the above constructs offers the first ever example of an isotropic glass based on a single proto-tile. The second example, on the other hand, displays characteristics which are akin to those of glasses in reciprocal space, but possesses finite rank in direct space. The consequence of these will be discussed in relation to Pisot–Vijayaraghavan (PV) number. It will be concluded that foundation of Copernican crystallography incorporating these is still missing and needs further substantiation.

THE geometry of packings and coverings has always been at the centre of formulation of models of atomic arrangements in the solid state. A vast majority of these has been shown to possess a three-dimensional (d) unit

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