

The concluding report of
**Max Planck - India Partner Group in
Neutrino Physics and Astrophysics**
At Tata Institute of Fundamental Research (TIFR), Mumbai
With Max Planck Institute for Physics (MPP), Munich
Jan 2005 – Mar 2010

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1 People involved

1.1 Main Collaborators

- Partner Group Leader at TIFR: Dr. Amol Dighe
- Collaborating group leader at MPP: Dr. Georg Raffelt

1.2 Partner Group members at TIFR

- Postdocs:
 - Dr. Rishikesh Vaidya (2005–2006)
(Currently a faculty member at BITS, Pilani, India)
 - Dr. Abhijit Bandyopadhyay (2005–2007)
(Currently a faculty member at Vivekanand U., Howrah, India)
 - Dr. Ms. Pomita Ghoshal (2008–2009)
(Currently a postdoc at SISSA, Italy)
- Ph.D. Students:
 - Dr. Basudeb Dasgupta (2005–2009)
(Currently a postdoc at MPP Munich, Germany)
 - Dr. Ms. Shamayita Ray (2006–2009)
(Currently a postdoc at Cornell University, USA)
 - Mr. Diptimoy Ghosh (2008–present)
 - Mr. Arka Banerjee (2009–present)

1.3 Long-term Visitors at TIFR

- Collaborators related to Partner Group activities: Prof. Probir Roy, SINP, Kolkata; Prof. Srubabati Goswami, PRL, Ahmedabad; Dr. Narendra Sahu, U. Libre de Brussels; Dr. Sanjib Agarwalla, Virginia Tech U.; Dr. Alessandro Mirizzi, MPP; Dr. I. Bhattacharyya, GCECT, Kolkata; Dr. Georg Raffelt, MPP.
- Summer Students: Bhubanjoyoti Bhattacharya, IIT Kanpur (now U. Chicago); Amlan Mukherjee, IIT Kharagpur (now TIFR); Aniket Joglekar, IIT Bombay.
- University teachers for training in neutrino physics: Dr. Ms. Jyotsna Singh, U. Lucknow; Dr. Ms. Kalpana Bora, U. Guwahati.

2 Publications from Partner Group activities

2.1 Research Papers

1. “Neutrino mass hierarchy and three-flavor spectral splits of supernova neutrinos”, B. Dasgupta, A. Mirizzi, I. Tamborra and R. Tomàs, arXiv:1002.2943 [hep-ph].
2. “Triggering collective oscillations by three-flavor effects”, B. Dasgupta, G. G. Raffelt and I. Tamborra, arXiv:1001.5396 [hep-ph].
3. “Detecting the QCD phase transition in the next galactic supernova neutrino burst”, B. Dasgupta, T. Fischer, S. Horiuchi, M. Liebendörfer, A. Mirizzi, I. Sagert and J. Schaffner-Bielich, arXiv:0912.2568 [astro-ph.HE].
4. “Large U_{e3} and tri-bimaximal mixing”, S. Goswami, S. T. Petcov, S. Ray and W. Rodejohann, Phys. Rev. D **80**, 053013 (2009), [arXiv:0907.2869 [hep-ph]].
5. “Multiple spectral splits of supernova neutrinos”, B. Dasgupta, A. Dighe, G. G. Raffelt and A. Y. Smirnov, Phys. Rev. Lett. **103**, 051105 (2009), [arXiv:0904.3542 [hep-ph]].
6. “Renormalization group evolution of neutrino masses and mixing in the Type-III seesaw mechanism”, J. Chakraborty, A. Dighe, S. Goswami and S. Ray, Nucl. Phys. B **820**, 116 (2009) [arXiv:0812.2776 [hep-ph]].
7. “Texture zeroes and discrete flavor symmetries in light and heavy Majorana neutrino mass matrices: a bottom-up approach”, A. Dighe and N. Sahu, arXiv:0812.0695 [hep-ph].
8. “Renormalization group evolution of neutrino mixing parameters near $\theta_{13} = 0$ and models with vanishing θ_{13} at the high scale”, A. Dighe, S. Goswami and S. Ray, Phys. Rev. D **79**, 076006 (2009) [arXiv:0810.5680 [hep-ph]].
9. “Collective neutrino oscillations in non-spherical geometry”, B. Dasgupta, A. Dighe, A. Mirizzi and G. G. Raffelt, Phys. Rev. D **78**, 033014 (2008) [arXiv:0805.3300 [hep-ph]].
10. “Effect of collective flavor oscillations on the diffuse supernova neutrino background”, S. Chakraborty, S. Choubey, B. Dasgupta and K. Kar, JCAP **0809**, 013 (2008) [arXiv:0805.3131 [hep-ph]].
11. “Identifying neutrino mass hierarchy at extremely small θ_{13} through Earth matter effects in a supernova signal”, B. Dasgupta, A. Dighe and A. Mirizzi, Phys. Rev. Lett. **101**, 171801 (2008) [arXiv:0802.1481 [hep-ph]].

12. “CPT violation in long baseline neutrino experiments: a three flavor analysis”, A. Dighe and S. Ray, *Phys. Rev. D* **78**, 036002 (2008) [arXiv:0802.0121 [hep-ph]]
13. “Spectral split in prompt supernova neutrino burst: Analytic three-flavor treatment”, B. Dasgupta, A. Dighe, A. Mirizzi and G. G. Raffelt, *Phys. Rev. D* **77**, 113007 (2008) [arXiv:0801.1660 [hep-ph]].
14. “Collective three-flavor oscillations of supernova neutrinos”, B. Dasgupta and A. Dighe, *Phys. Rev. D* **77**, 113002 (2008) [arXiv:0712.3798 [hep-ph]].
15. “Signatures of heavy sterile neutrinos at long baseline experiments”, A. Dighe and S. Ray, *Phys. Rev. D* **76**, 113001 (2007) [arXiv:0709.0383 [hep-ph]].
16. “Radiatively broken symmetries of nonhierarchical neutrinos”, A. Dighe, S. Goswami and P. Roy, *Phys. Rev. D* **76**, 096005 (2007) [arXiv:0704.3735 [hep-ph]].
17. “Corrections to tribimaximal neutrino mixing: Renormalization and Planck scale effects”, A. Dighe, S. Goswami and W. Rodejohann, *Phys. Rev. D* **75**, 073023 (2007) [hep-ph/0612328].
18. “Constraints on flavor dependent long range forces from solar neutrinos and KamLAND”, A. Bandyopadhyay, A. Dighe and A. Joshipura, *Phys. Rev. D* **75**, 093005 (2007) [hep-ph/0610263].
19. “Solar model parameters and direct determination of solar neutrino fluxes”, A. Bandyopadhyay, S. Choubey, S. Goswami and S. Petcov, *Phys. Rev. D* **75**, 093007 (2007) [hep-ph/0608323].
20. “Quark-lepton complementarity with quasidegenerate neutrinos”, A. Dighe, S. Goswami and P. Roy, *Phys. Rev. D* **73**, 071301 (2006) [hep-ph/0602062].
21. “Phase effects during a supernova shock wave”, B. Dasgupta and A. Dighe, *Phys. Rev. D* **75**, 093002 (2007) [hep-ph/0510219].

2.2 Conference Proceedings / Lecture Notes

1. “Supernova neutrino oscillations: what do we understand?”, A. Dighe, J. Phys. Conf. Ser. **203**, 012015 (2010) [arXiv:0912.4167 [hep-ph]]. Talk given at TAUP 2009.
2. “Earth Effects And Mass Hierarchy With Supernova Neutrinos”, B. Dasgupta, Nucl. Phys. Proc. Suppl. **188**, 118 (2009). Talk given at NOW 2008, Otranto, Italy.
3. “Working group report: Neutrino physics”, S. Choubey *et al.*, Pramana **72**, 269 (2009). Report of WHEPP 2007.
4. “Physics potential of future supernova neutrino observations”, A. Dighe, J. Phys. Conf. Ser. **136**, 022041 (2008) [arXiv:0809.2977 [hep-ph]]. Plenary Talk given at Neutrino 2008, Christchurch, NZ.
5. “Neutrinos from a core collapse supernova”, A. Dighe, AIP Conf. Proc. **981**, 75 (2008) [arXiv:0712.4386 [hep-ph]]. Talk given at NuFact07, Okayama, Japan,
6. “Constraining flavor dependent long range forces from neutrino experiments”, A. Dighe, hep-ph/0611038. Talk given at ICHEP 06, Moscow.
7. “Physics with India-based neutrino observatory (INO)”, A. Dighe, “Moscow 2006, ICHEP”, 292. Talk given at ICHEP 06, Moscow, TIFR/TH/06-47.
8. “India-based Neutrino Observatory: Project report”, A. Dighe [INO Collaboration, M. S. Athar *et al.*], INO-2006-01.
9. “An introduction to neutrino physics”, A. Dighe, TIFR/TH/05-10, Lecture notes for the Neutrino Physics course given in the SERC school in IIT Kanpur.

3 Research and Teaching activities

3.1 Ph.D. and M.S. Theses, Student Projects

- Shamayita Ray: Ph.D. Thesis, “Neutrino oscillation phenomenology with fermions beyond the Standard Model”, October 2009
- Aniket Joglekar: VSRP (Visiting Students Research Program) Project report, “Three neutrino oscillations in matter”, July 2009
- Diptimoy Ghosh: Project report, “Neutrino mass models”, June 2009
- Basudeb Dasgupta: Ph.D. Thesis, “Nonlinear oscillations of supernova neutrinos”, August 2008
- Basudeb Dasgupta: M.Sc. Thesis, “Physics of supernova neutrinos”, Dec 2006.
- Shamayita Ray: Project report, “Atmospheric neutrinos: two and three neutrino oscillation models with one sterile species”, June 2006.
- Amlan Mukherjee: NIUS (National Initiative in Undergraduate Science) Project report, “Mystery of missing neutrinos”, Jan 2006.
- Bhubanjoyoti Bhattacharya: VSRP (Visiting Students Research Programme) Project report, “Neutrino propagation through non-monotonic matter density”, July 2005.
- Basudeb Dasgupta: Project report, “Neutrino flavor conversions while propagating through a non-monotonic density profile”, June 2005.

3.2 Lecture courses

- A. Dighe: TIFR Graduate courses in Neutrino Physics (Winter 2010, Winter 2009), Mathematical Methods (Autumn 2008), Electrodynamics (Autumn 2007), Particle Physics (Autumn 2006).
- A. Dighe: A short lecture course on “Neutrino Oscillations and Supernovae”, Universenet School, Oxford U. (Sept 2008).
- A. Dighe: A short lecture course on “Introduction to neutrino physics”, NIUS program, HBCSE, Mumbai (May 2006).

4 Conferences and Workshops

- JIGSAW07: The Joint Indo-German School And Workshop in Neutrino Physics and Astrophysics (Feb 2007) was an interwoven combination of school and workshop (4 days of school, 4 days of workshop and 4 days of school) that brought together more than 60 neutrino physicists from India, Germany and other countries. It encompassed a wide range of topics: (i) neutrino oscillation phenomenology, (ii) neutrino mass generation, (iii) leptogenesis, (iii) neutrino astrophysics and cosmology. It succeeded in training more than 30 Indian and German students in these areas. It also served as the “Auftakt” workshop of Max Planck Society and as an IMPRS recognized course.
- NuGoa09: An International workshop on Aspects of Neutrinos was organized by the Partner Group in Goa, India, in April 2009. It had about 50 participants from worldwide, and concentrated on (i) models of neutrino masses and mixing, (ii) CP violation in the leptonic sector and leptogenesis, (iii) physics prospects at long baseline experiments, and (iv) neutrino astrophysics and cosmology.
- JIGSAW10: The Joint Indo-German Supernova Astroparticle physics Workshop (Feb 2010), was a focussed workshop, which concentrated on supernova dynamics and neutrinos. It brought together about 25 experts on (i) the astrophysics of supernova neutrinos, (ii) flavor conversions inside the star, and (iii) the detection of neutrinos from a SN burst. It allowed enough opportunity for these experts to present the latest developments and discuss future avenues. This was the first workshop of its kind, bringing researchers from these three subareas together, and is expected to give rise to more interaction between these interconnected fields.
- Dr. A. Dighe has been on the National Organizing Committees of the DAE-BRNS Symposium in High Energy Physics, Kharagpur, Dec 2006; Workshop in High Energy Physics Phenomenology (WHEPP-X), Chennai, Jan 2008; Workshop in High Energy Physics Phenomenology (WHEPP-XI), Ahmedabad, Jan 2010; International Symposium on Perspectives in Fundamental Research (PFR2010), TIFR Mumbai, Mar 2010. He has also been the Program Committee Member of WIN07, SINP Kolkata, Jan 2007. He is on the Local Organising Committee of NuFact10, to be held in Oct 2010.

5 Conference Talks by Group members

- A. Dighe: “Particle astrophysics of neutrinos: some selected aspects”, Science Without Boundaries, IISc Bangalore, Dec 2009.
- A. Dighe: “Supernova neutrino oscillations: some new insights”, CTP 2009, Luxor, Egypt, Nov 2009.
- A. Dighe: “The elusive neutrino”, Young Indian Scientists’ Colloquium, TIFR Mumbai, Sep 2009.
- A. Dighe: “Supernova neutrino oscillations: what do we understand?”, TAUP 2009, Rome, Italy, July 2009.
- S. Ray: “Renormalization group evolution of neutrino masses and mixing in Type-III seesaw”, PHENO 2009, Madison, USA, May 2009; Nu Horizons 2009, HRI Allahabad, Feb 2009.
- P. Ghoshal, “Neutrino mass hierarchy determination via atmospheric neutrinos with future detectors”, PANIC 2008, Eilat, Israel, Nov 2008.
- B. Dasgupta: “Earth effects and mass hierarchy with supernova neutrinos”, NOW 2008, Otranto, Italy, Sep 2008.
- A. Dighe: “Collective oscillations of SN neutrinos: a three-flavour course”, Melbourne Neutrino Theory Workshop, Melbourne, Australia, June 2008.
- A. Dighe: “Physics potential of future supernova neutrino observations”, Neutrino 2008, Christchurch, New Zealand, May 2008.
- S. Ray: “Signatures of Heavy Sterile Neutrinos at Long Baseline Experiments”, Nu Horizons 2008, HRI Allahabad, Feb 2008.
- A. Dighe: “Supernova neutrinos: our current understanding”, Nu Horizons 2008, HRI Allahabad, Feb 2008.
- B. Dasgupta: “Three-flavor collective flavor transformations of SN neutrinos”, Nu Horizons 2008, HRI Allahabad, Feb 2008.
- P. Ghoshal: “Hierarchy sensitivity in future atmospheric neutrino detectors”, Nu Horizons 2008, HRI Allahabad, Feb 2008.
- A. Dighe: “Models of Majorana neutrino masses”, Workshop on Neutrinoless Double Beta Decay, TIFR Mumbai, Oct 2007.
- A. Dighe: “Supernova and neutrinos”, NuFact07, Okayama, Japan, Aug 2007.

- A. Dighe: “Constraining long range leptonic forces from neutrino experiments”, JIGSAW07, TIFR Mumbai, Feb 2007.
- B. Dasgupta: “Phase effects in neutrino conversions at supernova shock waves”, JIGSAW07, TIFR Mumbai, Feb 2007.
- A. Bandyopadhyay: “Determination of solar model parameters using solar neutrino flux measurements”, JIGSAW07, TIFR Mumbai, Feb 2007.
- A. Dighe: “Physics of supernova neutrinos”, WIN07, SINP Kolkata, Jan 2007.
- A. Bandyopadhyay: “Determination of solar model parameters using measurements of solar neutrino flux”, WIN07, SINP Kolkata, Jan 2007.
- A. Dighe: “Neutrinos in astrophysics”, DAE-BRNS Symposium in High Energy Physics, IIT Kharagpur, Dec 2006.
- A. Dighe: “Physics with India-based neutrino observatory (INO)”, ICHEP06, Moscow, Russia, Jul 2006.
- A. Dighe: “Constraining long range forces from neutrino experiments”, ICHEP06, Moscow, Russia, Jul 2006.
- A. Dighe: “SN as a cosmic competitor to neutrino factories”, Satellite meeting on “Physics with atmospheric neutrinos and neutrinos from muon storage rings”, IIT Bombay, Mumbai, Aug 2005.
- A. Bandyopadhyay: “Current neutrino oscillation parameters”, Satellite meeting on “Physics with atmospheric neutrinos and neutrinos from muon storage rings”, IIT Bombay, Mumbai, Aug 2005.
- A. Dighe: “Probing neutrino properties using a galactic supernova”, CuTAPP05, Ringberg Castle, Germany, Apr 2005.
- A. Dighe: “Galactic supernova for neutrino properties”, NNN05, Aussois, France, Apr 2005.

6 Utilization of Partner Group funds

- Fellowship / Salary supplement for A. Dighe
- **Travel to conferences/ workshops / summer schools**
 - A. Dighe: NNN05, Aussois, France, March 2005; CuTAPP05, Ringberg Castle, Germany, April 2005; Neutrino06, Santa Fe, USA, June 2006; ICHEP06, Moscow, Russia, July 2006; WIN07, Kolkata, Jan 2007; NuFact07 workshop, Okayama, Japan, August 2007; WHEPP-X, IMSc Chennai, Jan 2008; Nu Horizons 2008, HRI Allahabad, Feb 2008; Neutrino 2008, Christchurch, NZ, May 2008; MNTW, Melbourne, Australia, June 2008; NuGoa09, Goa, April 2009; TAUP 2009, Rome, Italy, July 2009; CTP 2009, Luxor, Egypt, Nov 2009; Nu Horizons 2010, HRI Allahabad, Feb 2010.
 - B. Dasgupta: ICTP summer school, Trieste, Italy, May 2005; Les Houches winter school, France, Nov 2005; ISAPP summer school, Munich, Germany, May-June 2006; WHEPP-X, IMSc Chennai, Jan 2008; Nu Horizons 2008, HRI Allahabad, Feb 2008; Neutrino 2008, Christchurch, NZ, May 2008; MNTW, Melbourne, Australia, June 2008; HEP Symposium, BHU, Dec 2008; NuGoa09, Goa, April 2009.
 - S. Ray: WIN07, Kolkata, Jan 2007; BCSPIN summer school, Beijing, China, June 2007; NuFact07 workshop, Okayama, Japan, August 2007; WHEPP-X, IMSc Chennai, Jan 2008; Nu Horizons 2008, HRI Allahabad, Feb 2008; Neutrino 2008, Christchurch, NZ, May 2008; Nu Horizons 2009, HRI Allahabad, Feb 2009; NuGoa09, Goa, April 2009; PHENO 2009, Madison, USA, May 2009.
 - P. Ghoshal: Neutrino 2008, Christchurch, NZ, May 2008; PANIC 2008, Eilat, Israel, Nov 2008; Nu Horizons 2009, HRI Allahabad, Feb 2009; NuGoa09, Goa, April 2009; NuFact 2009, Fermilab, July 2009.
 - D. Ghosh: NuGoa09, Goa, April 2009.
 - A. Bandyopadhyay, WIN07, Kolkata, Jan 2007.
- **Mutual visits between TIFR and MPP**
 - TIFR → MPP: Amol Dighe (May 2005), Basudeb Dasgupta (May 2006, June 2008), Probir Roy (April 2007).
 - MPP → TIFR: Kathrin Hochmuth (Jan 2007), Georg Raffelt (Feb 2007, Feb 2010), Andreas Biffar, Steve Blanchet, Allen Caldwell, Michael Plümacher, Timur Rashba, Leo Stodolsky, Florian Hahn-Woernle, Yvonne Wong (Feb 2007, for JIGSAW 07), Alessandro Mirizzi (Feb 2007, Jan 2008, Feb 2010), Basudeb Dasgupta, Irene Tamborra (Feb 2010, for JIGSAW10).

- **Other visitors**

- Collaboration visits: Prof. Srubabati Goswami (June 2007, Dec 2007, Mar 2009), Dr. Narendra Sahu (Aug–Sep 2007), Dr. Sanjib Agarwalla (Oct 2009), Dr. Ricard Tomàs, Dr. Pasquale Serpico, Prof. Christian Ott (Feb 2010, for JIGSAW10).
- Visits for training: Dr. Ms. Jyotsna Singh (May 2009), Dr. Ms. Kalpana Bora (June 2009).

- **Conferences organized:**

- JIGSAW 07 (Joint Indo-German School And Workshop), Feb 2007.
- NuGoa09 (Aspects of Neutrinos), April 2009.
- JIGSAW 10 (Joint Indo-German Supernova Astroparticle Physics Workshop), Feb 2010.

- **Equipment**

- Laptops and accessories, USB drives, external hard disks, software, books

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