Piyush Sharda

Title

The gas-phase metal distribution in galaxies

Abstract

We present a new model for the evolution of spatially-resolved gas-phase metallicities in galaxies from first principles. We show that metallicities depend on four ratios that collectively describe the metal equilibration time-scale, production, transport, consumption, and loss. When normalized by metal diffusion, metallicity gradients are governed by the competition between radial advection, metal production, and accretion of metal-poor gas from the cosmic web. The model naturally explains the varying gradients measured in local spirals, local dwarfs, and high-redshift star-forming galaxies. We use the model to study the cosmic evolution of gradients across redshift, showing that the gradient in Milky Way-like galaxies has steepened over time, in good agreement with both observations and simulations. Simultaneously reproducing the observed mass-metallicity and mass-metallicity gradient relations in the local Universe from the model also shows that galaxies transition from the advection-dominated to the accretion-dominated regime as they increase in mass. The same transition also occurs in galaxies from high to low redshifts, which mirrors the transition from gravity-driven to star formation feedback-driven turbulence. The shape of metallicity-based galaxy scaling relations is governed by the metal enrichment of outflows. Lastly, we show that the model also explains the observed relationship between metallicity gradients and galaxy kinematics at high redshift, and provides direct predictions for galactic chemical evolution that can be tested against future observations.

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EDUCATION & RESEARCH EXPERIENCE

Doctor of Philosophy | ***Astronomy & Astrophysics*** — Oct. 2018 – present
Australian National University (ANU) — Canberra, Australia
Title: The role of metals from molecular clouds to galactic discs
Advisor: Mark Krumholz

Master of Science (Hons.) | ***Physics*** [Distinction] — Aug. 2013 – Jun 2018
Birla Institute of Technology & Science (BITS) — Pilani, India

Postgraduate Research Student | ***Astronomy*** — Jan. 2018 – Jun 2018
University of Exeter (joint with BITS) — Exeter, UK

Undergraduate Research Student | ***Astronomy*** — Sep. 2017 – Dec 2017
Australian National University (joint with BITS) — Canberra, Australia

Summer Scholar | ***Astronomy*** — May. 2017 – Aug 2017
Harvard-Smithsonian Centre for Astrophysics — Cambridge, USA

Summer Scholar | ***Planetary Science*** — May. 2016 – Aug 2016
Physical Research Laboratory — Ahmedabad, India

Bachelor of Engineering (Hons.) | ***Electrical & Electronics*** [Distinction] — Aug. 2013 – Jun 2018
Birla Institute of Technology & Science (BITS) — Pilani, India

RESEARCH INTERESTS

Star formation, interstellar medium, galaxy formation and evolution, chemical evolution

HONORS & AWARDS

ASTRO3D Excellence Award for most papers led by an ECR in Australia	Dec 2021
Nominated by Australian Academy of Science to attend 71st Lindau Meeting (AU$ 7500)	Oct 2021
ANU Olin J Eggen Research Award for excellence in research (AU$ 2500)	Nov 2020
ANU RSAA Best Research Paper Award (AU$ 500)	Jul 2020
ANU Vice-Chancellor's Award for Impact and Engagement [Team Award]	Nov 2019
ASTRO3D Research Travel Grant (AU$ 7200) [Multiple Grants]	Sep 2019
Elected Fellow of the Royal Astronomical Society [FRAS]	Jun 2018
Australian Government Research Training Program Scholarship - International (AU$ 28000 p.a.)	Feb 2018
Australian Government Fee Offset Scholarship - International	Feb 2018
ANU RSAA Supplementary Research Scholarship (AU$ 3000 p.a.)	Feb 2018
BITS Off-campus Postgraduate Thesis Scholarship (₹ 20000)	Jan 2018
University of Exeter UK Tier 5 Sponsorship (£ 7500)	Jan 2018
BITS Off-campus Undergraduate Thesis Scholarship (₹ 15000)	Jul 2017
BITS Alumni Association Summer Scholarship ($ 2500)	Mar 2017
BITS Best Graduating Student in Physics	Jan 2017
Physical Research Laboratory Summer Scholarship (₹ 15000)	May 2016

Observing Proposals

Atacama Large Millimeter Array: Co-I Cycle 8 supplemental (2021, subm.)
Multi-*J* CO survey of LMC SNRs *[11 hours]*

***Chandra* X-ray Observatory: Co-I** Cycle 23 (2021)
Measuring The Expansion of the LMC SNR N132D in X-rays *[100 ks]*

***Chandra* X-ray Observatory: Co-I** Cycle 20 (2019)
Chandra Legacy Survey to Map Fe Emission in the LMC SNR N132D | *Chandra Large Program* *[1000 ks]*

Very Large Telescope / Multi Unit Spectroscopic Explorer: Co-I P 106 (2019)
The MAGPI Survey | *MUSE Large Program* *[224 hours]*

Professional Service & Community Involvement

Reviewer Mar 2021 – present
Reviewed manuscripts for MNRAS

Student ambassador - ANU College of Science Mar 2019 – present
Worked on ANU Future Research Talent Program for international students

Student representative - RSAA ANU Cultural Reform Committee Aug 2020 – present
Drafted documents detailing RSAA values, behavior and breaches policies

ANU Mount Stromlo Outreach Aug 2017 – present
Conducted Observatory tours, public lectures, stargazing, and public nights at Mt Stromlo

Founder - CB Das Award in Physics Jun 2018 – present
Established the CB Das Award for best graduating student in Physics at BITS

National Youth Leadership Forum Sep 2017
Invited to engage in science policy discussions with Members of Australian Parliament

McNamara-Saunders Astronomical Teaching Telescope Mar 2019 – Dec 2020
Mentored high school students on astronomy projects as part of Science Mentors Canberra

Student representative - RSAA ANU Giving Committee Jun 2020 – Jun 2021
Provided oversight on distribution of funds donated to the RSAA as part of workplace giving

Institute of Physics (UK) Outreach Jan 2018 – May 2018
Conducted astronomy sessions in schools as a part of IoP (UK) outreach

Data analysis experience

Atacama Large Millimeter-submillimeter Array (ALMA), *Chandra* X-ray Observatory, ESO VLT (MUSE)

Skills

Languages: Hindi (Native), English (Fluent), French (Intermediate)
Programming: Python, Fortran, IDL, Mathematica, MATLAB
Codes & Softwares: FLASH, SLUG, DESPOTIC, CASA, XSPEC, CIAO, GIDGET, TRIM, SDTrimSP, LZIFU

Seminars & Colloquia

1. **Hypatia Colloquium, European Southern Observatory** (Garching, Germany) Jun 2022 [Scheduled]
   The physics of gas-phase metal distribution in galaxies
2. **Astronomy Department, Yale University** (New Haven, USA) Jan 2022 [Scheduled]
   Chemical evolution of galaxies
3. **Astronomy Department, University of California San Diego** (San Diego, USA) Jan 2022 [Scheduled]
   Chemical evolution of galaxies

4. **Max Planck Institute for Astrophysics** (Garching, Germany) Dec 2021
   Formation of the first stars
5. **Kavli Institute, Massachusetts Institute of Technology** (Cambridge, USA) Dec 2021
   The physics of galactic metal distribution at high redshift
6. **CCAPP, Ohio State University** (Columbus, USA) Nov 2021
   Chemical evolution of galaxies
7. **Institute for Astronomy, University of Hawaii** (Hawaii, USA) Nov 2021
   The physics of metallicity gradients in galaxies
8. **Astronomy Department, University of California Davis** (Davis, USA) Nov 2021
   The physics of metallicity gradients in galaxies
9. **Institute for Theory & Computation, CfA** (Cambridge, USA) Sep 2021
   Modeling metallicity gradients in galaxies
10. **Hebrew University of Jerusalem** (Jerusalem, Israel) Sep 2021
    Modeling metallicity gradients in galaxies
11. **Universidad de Concepción, Chile** (Concepción, Chile) Mar 2020
    What sets the Population III IMF: magnetic fields versus radiation feedback
12. **University of Exeter** (Exeter, UK) May 2018
    Evolution of protostellar accretion discs
13. **University of Exeter** (Exeter, UK) Feb 2018
    Testing star formation theories in high-z galaxies

Conference Talks

1. **ASTRO3D Annual Science Meeting** (Canberra, Australia) Sep 2021
   Contributed talk on *When did the IMF become bottom-heavy?*
2. **ASTRO3D Annual Science Meeting** (Canberra, Australia) Sep 2021
   Contributed talk on *A new model for spatially-resolved galaxy metallicities*
3. **UK National Astronomy Meeting** (Bath, UK) Jul 2021
   Contributed talk on *Gas kinematics and metallicity gradients at high redshift*
4. **Annual Meeting of the Astronomical Society of Australia** (Canberra, Australia) Jul 2021
   Contributed talk on *When did the IMF become bottom-heavy?*
5. **Chemical Abundances in Gaseous Nebulae** (São José dos Campos, Brazil) May 2021
   Contributed talk on *The physics of gas-phase metallicity gradients*
6. **ASTRO3D ECR Seminar Series** (Canberra, Australia) May 2021
   Contributed talk on *The physics of gas-phase metallicities in galaxies*
7. **First Stars (ASTRO3D) Annual Science Meeting** (Canberra, Australia) Jun 2020
   Contributed talk on *Population III IMF*
8. **236$^{\text{th}}$ Meeting of the Americal Astronomical Society** (Washington D.C., USA) Jun 2020
   Contributed talk on *Effects of magnetic fields on Pop III IMF*
9. **First Stars VI** (Concepción, Chile) Mar 2020
   Contributed talk on *Magnetic field amplification in Pop III accretion discs*
10. **2$^{\text{nd}}$ Australia-ESO Conference** (Perth, Australia) Feb 2020
    Contributed talk on *Testing star formation theories in high-z galaxies*
11. **Galactic Archaeology with Metal-poor Stars** (Geneva, Switzerland) Sep 2019
    Contributed talk on *The effects of H_2 adiabatic index on Pop III star formation*
12. **ISSI Star Formation Workshop** (Bern, Switzerland) Mar 2019
    Contributed talk on *The effects of H_2 adiabatic index on Pop III star formation*

13. **Australian National Institute for Theoretical Astrophysics** (Melbourne, Australia) Feb 2019
    Contributed talk on *Testing star formation theories in high-z galaxies*

14. **European Week of Astronomy and Space Science** (Liverpool, UK) Apr 2018
    Contributed talk on *Testing star formation theories in high-z galaxies*

REFEREED PUBLICATIONS *[12 papers as first author, 2 with 20+ citations; h-index = 8, h-index (first author) = 7]*

1. First extragalactic measurement of the turbulence driving parameter: ALMA observations of the star-forming region N159E in the Large Magellanic Cloud
   Sharda, P., Menon, S. H., Federrath, C., Krumholz, M. R., Beattie, J. R., Jameson, K. E., Tokuda, K., Burkhart, B., Crocker, R. M., Law, C. J., Seta, A., Gaetz, T. J., Pingel, N. M., Seitenzahl, I. R., Sano, H., and Fukui, Y., *MNRAS*, accepted (*arXiv: 2109.03983*).

2. When did the initial mass function become bottom-heavy? [2 Citations]
   Sharda, P., and Krumholz, M. R., *MNRAS*, accepted (*arXiv: 2107.08634*).

3. Magnetic field amplification in accretion discs around the first stars [7 Citations]
   Sharda, P., Federrath, C., Krumholz, M. R., and Schleicher, D. R. G., 2021, *MNRAS*, 503, 2014

4. The role of gas kinematics in setting metallicity gradients at high redshift [3 Citations]
   Sharda, P., Wisnioski, E., Krumholz, M. R., and Federrath, C., 2021, *MNRAS*, 506, 1295

5. On the origin of the mass-metallicity gradient relation in the local Universe [7 Citations]
   Sharda, P., Krumholz, M. R., Wisnioski, E., Acharyya, A., Forbes, J. C., and Federrath, C., 2021, *MNRAS*, 504, 53

6. The MAGPI survey: Science goals, observing strategy, results and theoretical framework [8 Citations]
   Foster, C.; Mendel, J. T., Lagos, C. D. P., Wisnioski, E., Yuan, T., D'Eugenio, F., Barone, T. M., Harborne, K. E., Vaughan, S. P., Schulze, F., Remus, R.-S., Gupta, A., Collacchioni, F., Khim, D. J., Taylor, P., Bassett, R., Croom, S. M., McDermid, R. M., Poci, A., Battisti, A. J., Bland-Hawthorn, J., Bellstedt, S., Colless, M., Davies, L. J. M., Derkenne, C., Driver, S., Ferré-Mateu, A., Fisher, D. B., Gjergo, E., Johnston, E. J., Khalid, A., Kobayashi, C., Oh, S., Peng, Y., Robotham, A. S. G., **Sharda, P.**, Sweet, S. M., Taylor, E. N., Tran, K.-V. H., Trayford, J. W., van de Sande, J., Yi, S. K., and Zanisi, L., 2021, *PASA*, 38, e031

7. Viscous accretion disc model for pre-main sequence stars
   Sharda, P., Matt, S. P., Amard, L., and Krumholz, M. R., *ApJ*, submitted

8. The physics of gas phase metallicity gradients in galaxies [11 Citations]
   Sharda, P., Krumholz, M. R., Wisnioski, E., Forbes, J. C., Federrath, C., and Acharyya, A., 2021, *MNRAS*, 502, 5935

9. ALMA CO observations of gamma-ray supernova remnant N132D in the Large Magellanic Cloud: possible evidence for shocked molecular clouds illuminated by cosmic-ray protons [9 Citations]
   Sano, H., Plucinsky, P. P., Bamba, A., **Sharda, P.**, Filipović, M. D., Law, C. J., Alsaberi, R. Z. E., Yamane, Y., Tokuda, K., Acero, F., Sasaki, M., Vink, J., Inoue, T., Inutsuka, S., Shimoda, J., Tsuge, K., Fujii, K., Voisin, F., Maxted, N., Rowell, G., Onishi, T., Kawamura, A., Mizuno, N., Yamamoto, H., Tachihara, K., and Fukui, Y., 2020, *ApJ*, 902, 53

10. The importance of magnetic fields for the initial mass function of the first stars [24 Citations]
    Sharda, P., Federrath, C., and Krumholz, M. R., 2020, *MNRAS*, 497, 336

11. Spatially resolved *Chandra* spectroscopy of the Large Magellanic Cloud SNR N132D [8 Citations]
    Sharda, P., Gaetz, T. J., Kashyap, V. L., and Plucinsky, P. P., 2020, *ApJ*, 894, 145

12. The role of the H_2 adiabatic index in the formation of the first stars [10 Citations]
    Sharda, P., Krumholz, M. R., and Federrath, C., 2019, *MNRAS*, 490, 513

13. Testing star formation laws on spatially resolved regions in a $z \approx 4.3$ starburst galaxy [9 Citations]
    Sharda, P., da Cunha, E., Federrath, C., Di Teodoro, E. M., Tadaki, K., Yun, M. S., Aretxaga, I., and Kawabe, R., 2019, *MNRAS*, 487, 4305

14. Testing star formation laws in a starburst galaxy at redshift 3 resolved with ALMA [32 Citations]
Sharda, P., Federrath, C., da Cunha, E., Swinbank, A. M., and Dye, S., 2018, *MNRAS*, 477, 4380

15. Transition elements in supernova pre-solar grains [1 Citation]
Marhas, K. K., and **Sharda, P.**, 2018, *ApJ*, 853, 12

16. Offset fed slot antenna for broadband operation [Peer-reviewed conference paper]
Kumar, R., **Sharda, P.**, and Kumar, A. P. V., 2018, *Mat Sci. & Engg.*, 331, 012022