

# The Science Data Lake: A Unified Open Infrastructure Integrating 293 Million Papers Across Eight Scholarly Sources with Embedding-Based Ontology Alignment

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February 2026

## Abstract

Scholarly data is mostly fragmented across siloed databases with divergent metadata and missing links between them. We present the Science Data Lake, a locally-deployable infrastructure built on DuckDB and simple parquet files that unifies eight open sources—Semantic Scholar, OpenAlex, SciSciNet, Papers with Code, Retraction Watch, Reliance on Science, a preprint-to-published mapping, and Crossref—via DOI normalization while preserving source-level schemas. The resource comprises approximately 1 TB of Parquet files spanning nearly 300 million uniquely identifiable papers across 22 schemas and 151 SQL views. An embedding-based ontology alignment using BGE-large maps 4,516 OpenAlex topics to 13 scientific ontologies (1.3 million terms), yielding 16,150 mappings with 99.8% topic coverage—a 17-fold improvement over string matching. We validate through 10 automated checks, cross-source citation agreement analysis (pairwise Pearson  $r = 0.76$ – $0.87$ ), and manual inspection. Four vignettes demonstrate cross-source analyses infeasible with any single database. The resource is open source, deployable on a single drive or queryable remotely via HuggingFace, and includes structured documentation designed for LLM-based research agents.

## 1 Background & Summary

The advent of large-scale datasets tracing the workings of science has cultivated a rapidly expanding “science of science” with its own data infrastructure, metrics, and analytical frameworks [1]. Yet the databases that underpin this field remain fragmented: Semantic Scholar provides influential citation flags, open-access metadata, and full-text coverage for millions of papers [2]; OpenAlex—the most comprehensive open index to date—offers field-weighted citation impact (FWCI), a four-level topic taxonomy with 4,516 leaf topics, geocoded institution affiliations for 121 K institutions, and 11.7 million funding awards with dollar amounts, all under a CC0 license [3]; SciSciNet contributes a landmark collection of pre-computed science-of-science metrics including disruption indices, atypicality scores, and patent linkages [4]; Papers with Code links papers to reproducible code, though the platform has ceased active operations, making its archived snapshot a non-renewable resource [5]; Retraction Watch tracks integrity events [6]; and Reliance on Science maps patent-to-paper citations [7]. Each of these sources represents a substantial achievement in opening the scientific record; however, no single source captures all facets simultaneously. Researchers who wish to combine them—for example, to study whether disruptive papers are more likely to release code, or whether retracted papers show anomalous citation patterns across databases—must write ad-hoc integration scripts that are rarely shared or reproduced.

Table 1: Comparison with existing scholarly data integration systems.

| System                   | Src      | Multi    | Schemas          | Open     | Key limitation  |
|--------------------------|----------|----------|------------------|----------|---|
| SciSciNet [4]            | 1+       | ×        | —                | ✓        | Single bibliometric backbone (MAG/OpenAlex); no independent cross-source comparison |
| PubGraph [10]            | 3        | ✓        | Merged           | ✓        | Collapses into unified Wikidata schema; source-level provenance lost                |
| SemOpenAlex [11]         | 1        | ×        | —                | ✓        | Single source (OpenAlex only); requires SPARQL expertise                            |
| Dimensions [12]          | 1        | ×        | —                | ~        | Commercial; limited programmatic access; not fully reproducible                     |
| <b>Science Data Lake</b> | <b>8</b> | <b>✓</b> | <b>Preserved</b> | <b>✓</b> | Requires ~1 TB local storage; snapshot-based  |

A systematic evaluation of 59 scholarly databases found substantial variation in backward and forward citation coverage [8]. Large-scale pairwise comparisons of bibliographic data sources have revealed non-trivial differences in metadata, document types, and citation counts [9], but record-level joins across more than two sources remain uncommon. The lack of a shared infrastructure forces each research group to repeat the same data-wrangling steps, wasting effort and introducing inconsistencies.

Several systems have begun to address this gap (Table 1). SciSciNet [4] provides a rich “data lake” built on Microsoft Academic Graph (now OpenAlex) with pre-computed science-of-science metrics and linkages to patents, grants, and clinical trials, but its bibliometric backbone draws from a single index and it does not preserve independent source-level schemas for cross-source comparison. PubGraph [10] merges Wikidata, OpenAlex, and Semantic Scholar into a unified knowledge graph using the Wikidata ontology, but collapses source-level schemas, sacrificing the ability to compare how different sources describe the same paper. SemOpenAlex [11] re-encodes OpenAlex as 26 billion RDF triples, offering semantic-web interoperability but remaining a single-source resource. Dimensions [12] provides SQL-queryable access to a comprehensive commercial database, but its proprietary nature limits reproducibility.

Rather than attempting to replace these individually excellent resources, the Science Data Lake provides an open infrastructure foundation for science-of-science research—analogueous to what SciSciNet [4] achieved for single-source metrics, but extended across eight independent data sources. The resource makes three contributions. **First**, a *multi-source preserving architecture* that integrates eight open scholarly databases into a single resource while retaining each source’s native schema, enabling direct cross-source comparison at the record level. Because upstream sources—particularly OpenAlex—evolve their schema across snapshot partitions, the conversion pipeline employs dynamic Python scripts that auto-discover entity types and column structures rather than relying on hard-coded schemas, ensuring the infrastructure remains current as sources change. **Second**, an *embedding-based ontology alignment* method that bridges OpenAlex’s flat topic taxonomy to 13 formal scientific ontologies using BGE-large sentence embeddings [13], achieving a 17-fold improvement over string-matching baselines. **Third**, a *cross-source record-level comparison layer* (`unified_papers`, 293M rows, 29 columns) that enables simultaneous queries across all sources—supporting analyses such as multi-database citation reliability assessment that no single source or pairwise comparison can provide. Beyond traditional research workflows, the SQL-native architecture and structured documentation make the data lake particularly amenable to emerging LLM-based research agents [14] that can compose complex analytical queries from natural-language descriptions: a machine-readable schema reference enables such agents to navigate the 151-view, 22-schema structure without prior domain knowledge.

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Table 2: Overview of integrated data sources. Record counts reflect the snapshot versions used in this release.

| Source                      | Records | License  | Key content                                    |
|-----------------------------|---------|----------|--|
| Semantic Scholar (S2AG)     | 231M    | ODC-BY   | Citations, influential citations, open access  |
| OpenAlex                    | 479M    | CC0      | FWCI, topics, types, languages, funding awards |
| SciSciNet                   | 250M    | CC BY    | Disruption, atypicality, team size             |
| Papers with Code            | 513K    | CC BY-SA | Code repositories, tasks, datasets             |
| Retraction Watch            | 69K     | Open     | Retraction reasons and dates                   |
| Reliance on Science (RoS)   | 47.8M   | CC BY-NC | Patent-paper citation pairs                    |
| Preprint-to-Published (P2P) | 146K    | Open     | bioRxiv/medRxiv DOI to published DOI           |
| Crossref                    | —       | Open     | DOI metadata, reference lists                  |

## 2 Methods

### 2.1 Data Sources

The Science Data Lake integrates eight open scholarly data sources, each contributing distinct metadata facets (Table 2).

**Semantic Scholar Academic Graph (S2AG)** [2] provides bibliometric metadata for approximately 231 million papers, including citation counts, influential citation counts (based on citation context analysis), and open-access status flags.

**OpenAlex** [3] is an open catalogue of 479 million scholarly works with field-weighted citation impact (FWCI), a four-level topic taxonomy (domain, field, subfield, topic with 4,516 leaf topics), document types, and language annotations.

**SciSciNet** [4] augments OpenAlex records with pre-computed science-of-science metrics including the disruption index  $CD_5$  [15, 16], journal atypicality  $z$ -scores [17], team size indicators, and patent citation counts for 250 million papers.

**Papers with Code** [5] links 513 thousand machine-learning papers to their associated code repositories, benchmark tasks, and datasets.

**Retraction Watch** [6] catalogues approximately 69 thousand retracted or corrected publications with structured retraction reasons and dates.

**Reliance on Science (RoS)** [7] provides 47.8 million patent-to-paper citation pairs from global patent offices, with confidence scores and citation location metadata.

**Preprint-to-Published (P2P)** provides approximately 146 thousand mappings from bioRxiv and medRxiv preprint DOIs to their corresponding published-version DOIs.

**Crossref** contributes DOI metadata and reference lists used for DOI validation and supplementary linkage.

Figure 1 shows the temporal coverage of each source, revealing structural differences: OpenAlex extends back several centuries, S2AG is concentrated in recent decades with a computer-science emphasis, and SciSciNet metrics end around 2022.

### 2.2 Architecture

The Science Data Lake is built on a *views-over-Parquet* architecture using DuckDB [18] (Figure 2). Each data source is first converted from its native format (JSON Lines, CSV, N-Triples) into columnar Apache Parquet files, totaling approximately 960 GB on disk. A lightweight DuckDB database (~270 KB) defines 151 SQL views organized into 22 schemas that reference these Parquet files without copying data.

The schema design follows two principles. **Source-level preservation:** each data source retains its native schema within a dedicated namespace (e.g., `s2ag.papers`, `openalex.works`, `sciscinet.paper_metrics`), enabling direct inspection of how different databases represent

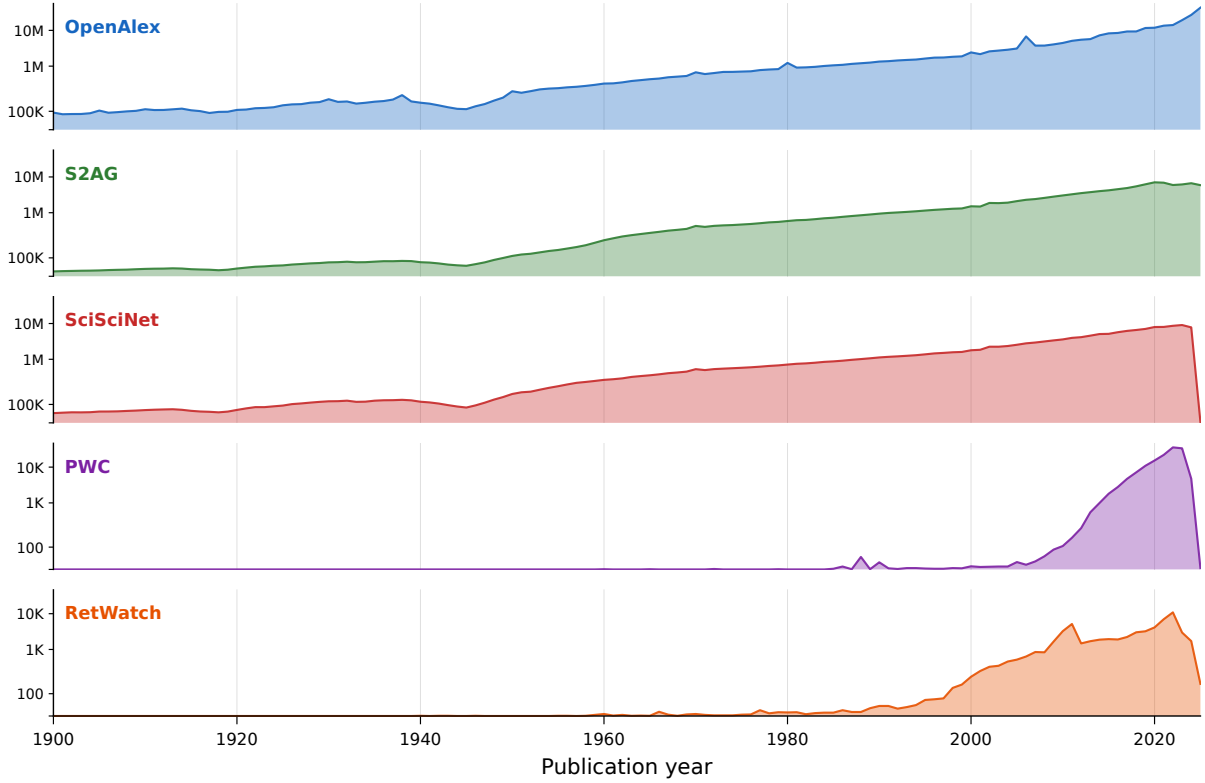


Figure 1: Temporal coverage by source (symlog scale). Publication-year distributions for DOI-linked records in the unified index (see Table 2 for full source sizes). The symlog y-axis is linear near zero and logarithmic above, revealing both historical depth and recent growth. OpenAlex, S2AG, and SciSciNet extend back to 1900 with tens of thousands of papers per year, while all three show clear acceleration after  $\sim 1960$ . SciSciNet exhibits a sharp cutoff after  $\sim 2022$  when its metrics computation ends. The specialized sources (PWC, Retraction Watch) cover narrow temporal windows concentrated in the last two decades.

the same paper. **Cross-referencing via the xref schema:** three materialized views bridge across sources—`doi_map` (DOI normalization), `unified_papers` (293M-row join table), and `topic_ontology_map` (ontology alignment).

We chose DuckDB over traditional server-based systems such as PostgreSQL for three reasons: its embeddable, serverless design requires no installation or administration; its columnar engine is optimized for the analytical (OLAP) query patterns typical of bibliometric research; and—crucially—it reads Parquet files directly through SQL views without importing data, keeping the database file under 300 KB while exposing nearly 1 TB of data.

The system supports dual-mode access: local deployment on a high-capacity drive for full-speed analytical queries, or remote access through HuggingFace-hosted Parquet files for users without local storage.

A reproducible pipeline orchestrated by a master CLI script (`datalake_cli.py`) automates the full workflow: downloading source snapshots, converting to Parquet, creating DuckDB views, materializing cross-reference tables, and building the ontology linkage.

## 2.3 DOI Normalization and Record Linkage

Digital Object Identifiers (DOIs) serve as the primary key for cross-source record linkage, but sources store them in incompatible formats (Table 3).

All DOIs are normalized to a canonical lowercase, prefix-free format. The `xref.doi_map` view implements this normalization as a union of source-specific sub-queries, each applying the

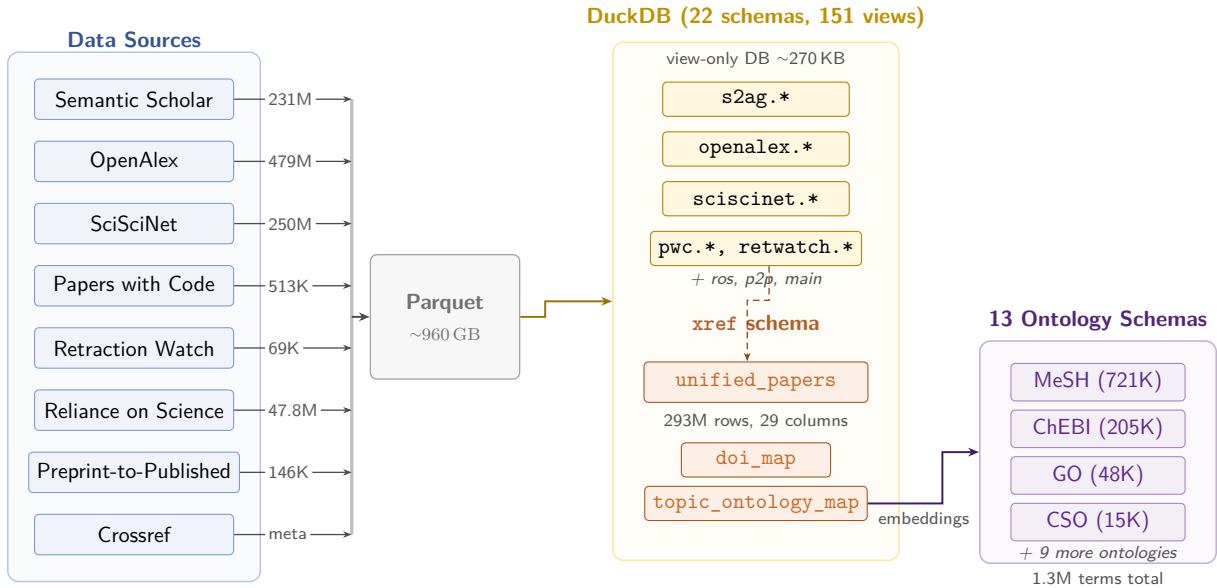


Figure 2: Architecture of the Science Data Lake. Eight open scholarly data sources (left) are converted to Apache Parquet format (~960 GB) and exposed as SQL views through a lightweight DuckDB database (center). Each source retains its native schema for source-level fidelity. The cross-referencing `xref` schema (orange) links records via DOI normalization (`unified_papers`, 293M rows) and connects OpenAlex topics to 13 scientific ontologies (right) through BGE-large embedding-based alignment.

Table 3: DOI format differences across data sources and the normalization applied.

| Source           | Raw DOI format  | Normalization    |
|------------------|---|------------------|
| S2AG             | lowercase, no prefix (10.1038/...)                                | Canonical (none) |
| OpenAlex         | lowercase, <a href="https://doi.org/">https://doi.org/</a> prefix | Strip prefix     |
| SciSciNet        | lowercase, <a href="https://doi.org/">https://doi.org/</a> prefix | Strip prefix     |
| Papers with Code | lowercase, no prefix  | None             |
| Retraction Watch | lowercase, no prefix  | None             |
| Crossref         | mixed case  | Lowercase        |

appropriate transformation.

The resulting `xref.unified_papers` table contains 293,123,121 unique DOIs with 29 columns drawn from all sources, including six Boolean coverage flags indicating which sources contain each paper. Table 4 summarizes the pairwise coverage.

OpenAlex provides the broadest coverage at 99.67% of all DOIs, consistent with its role as a comprehensive open index. SciSciNet and S2AG cover approximately half the DOI space, reflecting their focus on papers with sufficient citation data for metric computation. The specialized sources (Papers with Code, Retraction Watch, Reliance on Science) contribute smaller but unique record sets that cannot be obtained from the three large databases.

Figure 3 shows the UpSet plot of the six-source overlap, revealing 34 observed source combinations. The dominant combination is OpenAlex-only (45.0%), followed by the three-way overlap of OpenAlex, SciSciNet, and S2AG (38.2%).

## 2.4 Embedding-Based Ontology Alignment

OpenAlex assigns papers to a flat topic taxonomy of 4,516 topics organized into four hierarchical levels (252 subfields, 26 fields, 4 domains), but these topics lack mappings to formal scientific

Table 4: Cross-source coverage of the 293M unified papers. Each cell shows the percentage of papers present in the column source that are also present in the row source.

|              | OpenAlex | SciSciNet | S2AG  | PWC   | RetWatch | RoS  |
|--------------|----------|-----------|-------|-------|----------|------|
| Coverage (%) | 99.67    | 54.08     | 45.52 | 0.048 | 0.020    | 0.19 |

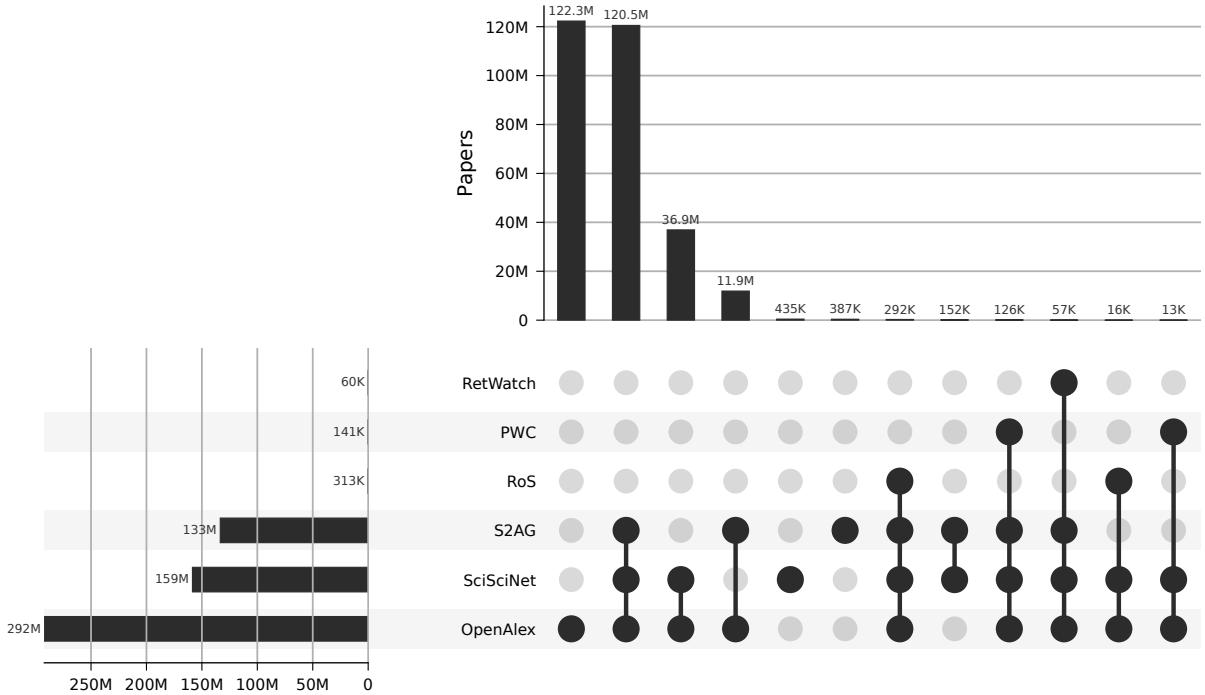


Figure 3: UpSet plot showing the intersection structure across six data sources. Bars represent the number of papers in each source combination. Of 34 observed combinations, the three-way overlap of OpenAlex, SciSciNet, and S2AG accounts for the largest multi-source intersection.

ontologies that encode domain-specific knowledge. To bridge this gap, we developed an embedding-based alignment method that maps OpenAlex topics to 13 scientific ontologies comprising 1.3 million terms in total.

The 13 ontologies span diverse scientific domains: Medical Subject Headings (MeSH; 721K terms) [19], Chemical Entities of Biological Interest (ChEBI; 205K) [20], NCI Thesaurus (NCIT; 204K) [21], Gene Ontology (GO; 48K) [22], AGROVOC (42K) [23], Computer Science Ontology (CSO; 15K) [24], Disease Ontology (DOID) [25], Human Phenotype Ontology (HPO) [26], EDAM bioinformatics ontology [27], UNESCO Thesaurus, Standard Thesaurus for Economics (STW), Physics Subject Headings (PhySH), and the Mathematics Subject Classification (MSC2020). Each ontology was converted from its native format (OBO, SKOS/RDF, N-Triples, CSV) to a uniform Parquet representation using format-specific parsers, and simultaneously loaded into an Oxigraph RDF triple store for SPARQL queries.

We employed a hybrid alignment strategy. For the 10 smaller ontologies (291K terms including synonyms), we computed dense embeddings using the BGE-large-en-v1.5 model [13] (335M parameters, 1024 dimensions) and performed nearest-neighbour search via a FAISS index [28]. For the three largest ontologies (MeSH, ChEBI, NCIT), which together account for 1.1M terms and would dominate the embedding space, we used exact string matching to ensure

<https://vocabularies.unesco.org/browser/thesaurus/en/>  
<https://zbw.eu/stw/>  
<https://physh.org/>  
<https://msc2020.org/>



Table 5: Ontology alignment quality tiers. Each tier includes all mappings at or above the similarity threshold.

| Quality tier | Similarity  | Mappings | Topics covered |
|--------------|-------------|----------|----------------|
| Exact match  | $\geq 0.95$ | 85       | 71 (1.6%)      |
| High quality | $\geq 0.85$ | 2,527    | 1,647 (36.5%)  |
| All          | $\geq 0.65$ | 16,150   | 4,509 (99.84%) |

precision.

Table 5 summarizes the alignment quality with representative examples for each tier. At the exact-match tier ( $\geq 0.95$ ), topics align with near-identical ontology terms—for instance, the OpenAlex topic “Machine Learning” maps to CSO’s “machine learning” (similarity 0.98). At the high-quality tier ( $\geq 0.85$ ), semantically related but differently named concepts are captured—e.g., “Artificial Intelligence in Medicine” maps to EDAM’s “Medical informatics” (0.87). Relaxing to  $\geq 0.65$  yields 16,150 mappings covering 4,509 of 4,516 topics (99.84%), including broader associations such as “Soil Chemistry” mapping to AGROVOC’s “soil chemicophysical properties” (0.68).

To contextualize the embedding approach, we compared it against a string-matching baseline using Jaro–Winkler similarity at a threshold of 0.90, which produced only 937 matches—a 17-fold reduction relative to the embedding method. The embedding approach captures semantic similarity that string matching cannot: for example, the OpenAlex topic “Artificial Intelligence in Medicine” maps to EDAM’s “Medical informatics” (cosine similarity 0.87) and NCIT’s “Biomedical Informatics” (0.85), neither of which would be found by string comparison.

Figure 4 visualizes the joint embedding space using UMAP [29], showing how OpenAlex topics cluster by domain and align with terms from domain-specific ontologies. Figure 5 displays the ontology-by-domain reach heatmap, confirming that different ontologies specialize in different scientific areas: MeSH dominates health sciences, CSO covers computer science, GO spans molecular biology, and AGROVOC bridges agricultural and environmental sciences.

### 3 Data Records

The Science Data Lake is hosted on HuggingFace Datasets (<https://huggingface.co/datasets/J0nasW/science-datalake>, DOI: 10.57967/hf/7850), which provides a persistent DataCite DOI for citation. Remote users can query the Parquet files directly through DuckDB’s `hf://` protocol without downloading the full dataset. Due to licensing restrictions, the HuggingFace-hosted version does not include Semantic Scholar (ODC-BY, non-commercial research use) or Reliance on Science (CC BY-NC 4.0). Both sources can be obtained locally using the provided download scripts and a free Semantic Scholar API key; once downloaded, the pipeline automatically integrates them into the unified schema.

The full dataset comprises approximately 960 GB of compressed Apache Parquet files organized into 22 schema directories, each containing one or more Parquet files corresponding to the tables of that schema. The lightweight DuckDB database file (~270 KB) defines 151 SQL views that reference these Parquet files and can be regenerated from source using the provided pipeline scripts.

The principal schemas and their contents are:

- **s2ag**: papers (231M), abstracts, citations, authors, publication venues from Semantic Scholar.
- **openalex**: works (479M), authors, institutions, sources, topics, concepts, publishers, funders from OpenAlex.
- **sciscinet**: paper metrics (250M), disruption indices, atypicality scores, team size indicators

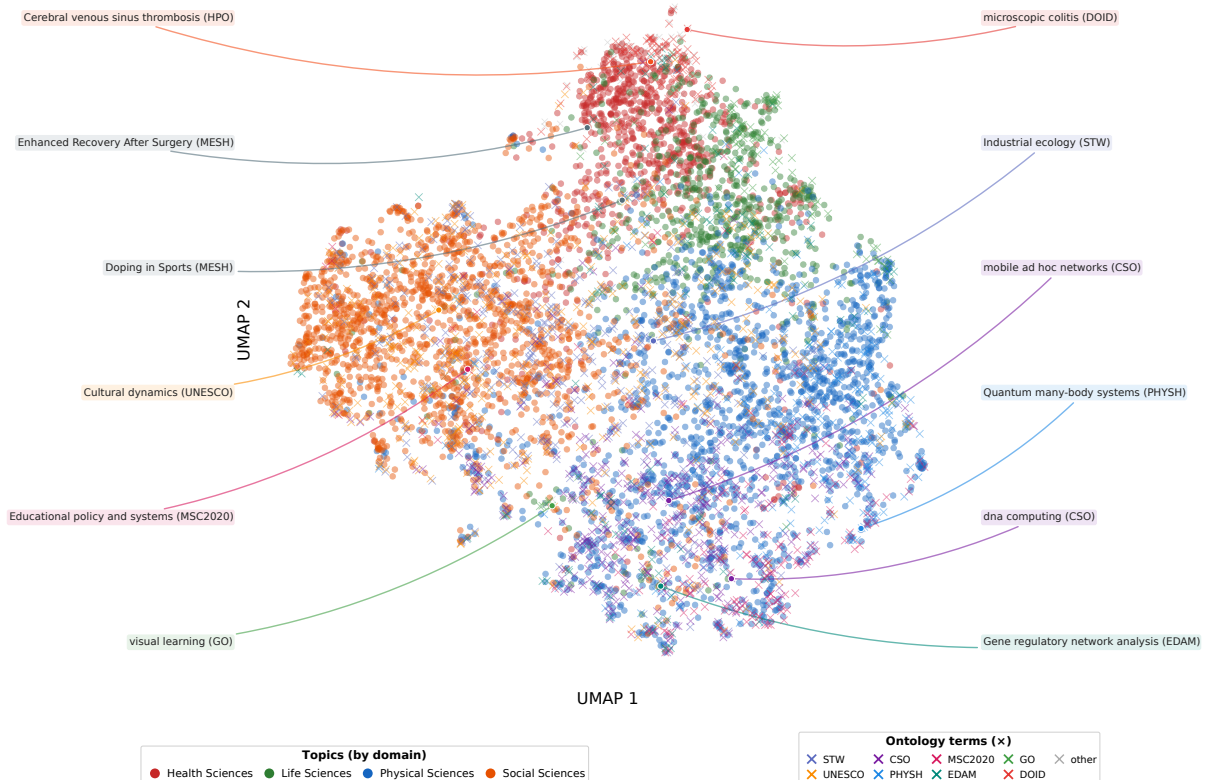


Figure 4: UMAP projection of BGE-large embeddings for OpenAlex topics (points) and matched ontology terms (crosses), colored by OpenAlex domain. Semantic clusters emerge naturally, with domain-specific ontology terms co-locating with their corresponding topics.

from SciSciNet.

- **pwc**: papers (513K), code links, tasks, datasets, methods from Papers with Code.
- **retwatch**: retracted papers (69K) with retraction reasons and dates from Retraction Watch.
- **ros**: patent–paper citation pairs (47.8M) from Reliance on Science.
- **p2p**: preprint-to-published DOI mappings (146K) from bioRxiv/medRxiv.
- **xref**: cross-source linkage tables—**unified\_papers** (293M, 29 columns), **doi\_map**, and **topic\_ontology\_map** (16,150 mappings).
- 13 ontology schemas (e.g., **mesh**, **go**, **cso**), each containing **\*\_terms**, **\*\_hierarchy**, and optionally **\*\_xrefs** tables.

Each source retains its original license: CC0 (OpenAlex), ODC-BY (S2AG), CC BY 4.0 (SciSciNet), CC BY-SA 4.0 (Papers with Code), CC BY-NC 4.0 (Reliance on Science), and open/public-domain for the remaining sources. Users should comply with the most restrictive license applicable to the sources they query.

## 4 Technical Validation

We validated the Science Data Lake through 10 automated sanity checks (Table 6), cross-source citation correlation analysis, and manual inspection of ontology mappings.



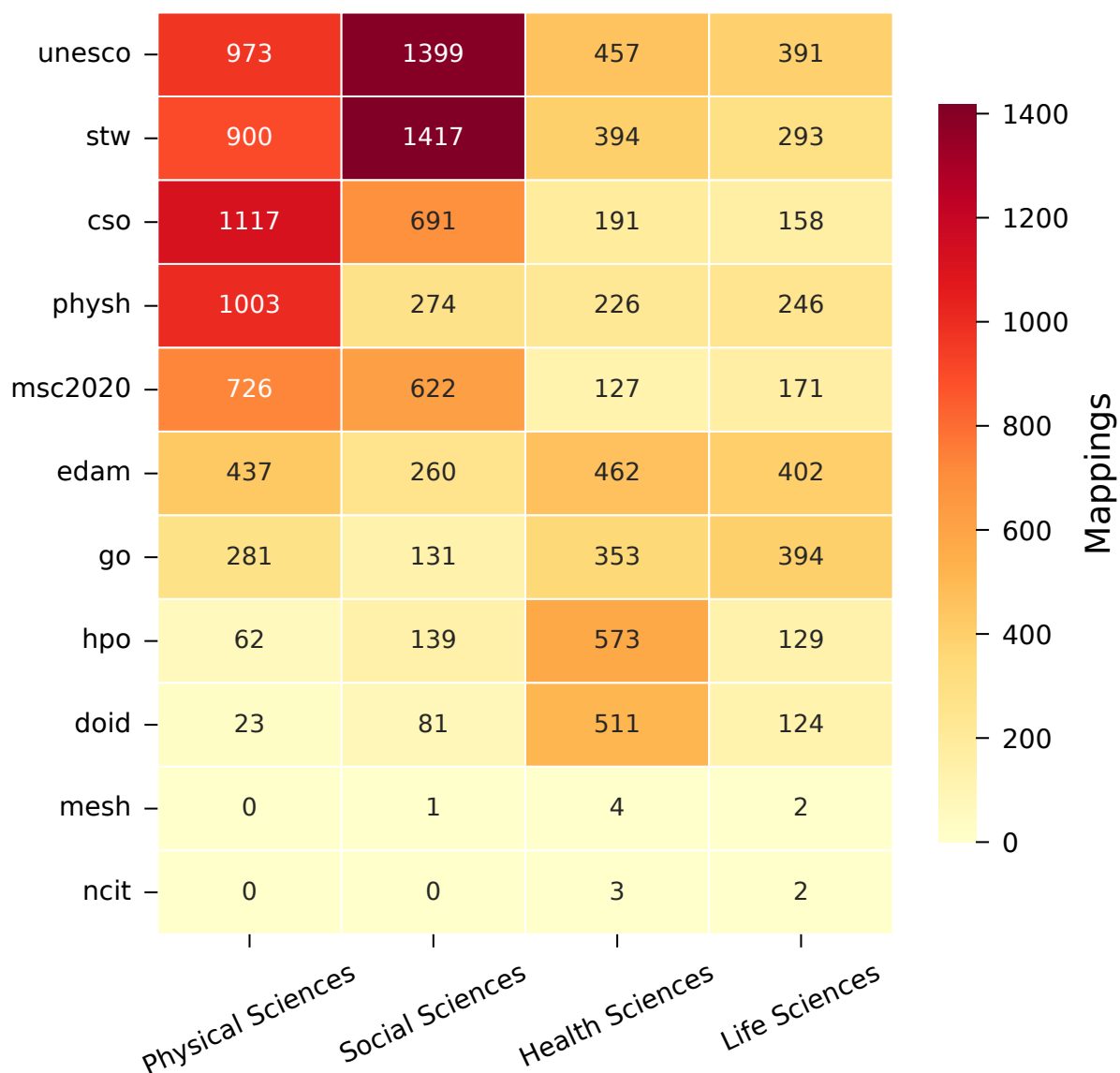


Figure 5: Ontology reach heatmap showing the number of high-quality mappings (similarity  $\geq 0.85$ ) between each ontology and each OpenAlex domain. The multi-ontology design ensures coverage across all scientific areas.

#### 4.1 DOI and Schema Integrity

Checks 1–5 verify the structural integrity of the cross-reference layer. The DOI format check (Check 1) confirms that all 293 million entries in `unified_papers` use the canonical lowercase, prefix-free format with zero violations. Coverage flags (Check 2) are Boolean columns indicating whether each paper appears in OpenAlex, S2AG, and SciSciNet; all flags correctly reflect the presence or absence of data in the corresponding source tables. Primary key uniqueness (Check 3) confirms that each DOI appears exactly once. The OpenAlex ID format check (Check 4) validates that all IDs conform to the expected pattern and that 69% of papers successfully join to the `works_topics` table (the remainder lack topic assignments in OpenAlex). Check 5 verifies that every topic ID in the ontology mapping table exists in the OpenAlex topic taxonomy, with zero orphans found.

Table 6: Summary of automated sanity checks. All 10 checks passed without violations across the full dataset.

| #  | Check                                      | Result | Detail                              |
|----|--|--------|-------------------------------------|
| 1  | DOI format (no prefix, lowercase)          | PASS   | 0 violations / 293M                 |
| 2  | Coverage flags match data presence         | PASS   | 0 mismatches (OA, S2AG, SSN)        |
| 3  | Primary key uniqueness (no duplicate DOIs) | PASS   | 293,123,121 unique = total          |
| 4  | OpenAlex ID format & joinability           | PASS   | 0 format violations; 69% topic join |
| 5  | Ontology map: no orphan topic IDs          | PASS   | 0 orphan topic_ids                  |
| 6  | RoS to OpenAlex join (10K sample)          | PASS   | 86% match rate                      |
| 7  | Citation cross-source correlation          | PASS   | $r = 0.76\text{--}0.87$ pairwise    |
| 8  | Year distribution (NULL/invalid)           | PASS   | NULL: 0.53%, invalid: 0.001%        |
| 9  | Spot-check known papers                    | PASS   | Wakefield retraction flags correct  |
| 10 | Vignette count reproducibility             | PASS   | All 4 counts match exactly          |

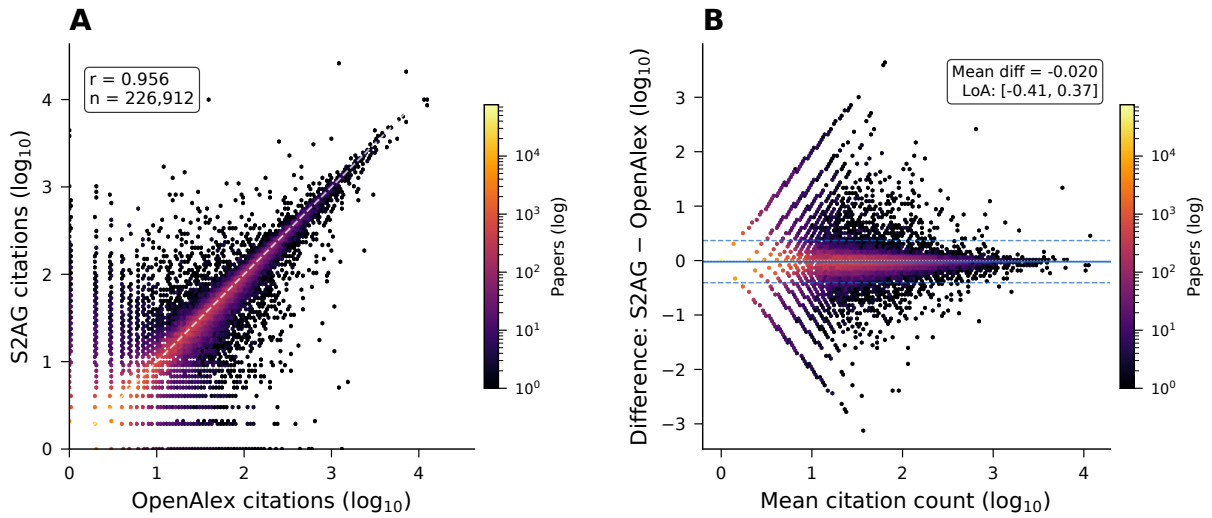


Figure 6: Bland–Altman plot of citation count agreement between Semantic Scholar (S2AG) and OpenAlex. Each point represents a paper; the  $x$ -axis shows the mean citation count across both sources, and the  $y$ -axis shows the difference (S2AG – OpenAlex). Dashed lines indicate the mean difference and 95% limits of agreement.

## 4.2 Cross-Source Citation Agreement

To assess the consistency of citation counts across databases, we computed pairwise Pearson correlations for papers present in all three large sources (S2AG, OpenAlex, SciSciNet;  $n \approx 121\text{M}$ ). The correlations are: S2AG–OpenAlex  $r = 0.76$ , S2AG–SciSciNet  $r = 0.87$ , and OpenAlex–SciSciNet  $r = 0.86$ . The mean absolute differences are 4.14 (S2AG–OA), 3.84 (S2AG–SSN), and 2.30 (OA–SSN) citations.

Figure 6 presents the Bland–Altman analysis of citation agreement between S2AG and OpenAlex. The plot reveals that disagreement increases with citation magnitude, and identifies systematic outliers—most notably a single paper with 257,887 citations in S2AG and zero in OpenAlex, attributable to differences in citation counting methodology and coverage scope.

The two-of-three correlations exceeding  $r = 0.8$  confirm that the three sources provide broadly consistent citation information, while the non-negligible disagreements (particularly S2AG–OA at  $r = 0.76$ ) underscore the value of preserving all three counts for sensitivity analyses.

### 4.3 Ontology Alignment Validation

We validated the embedding-based ontology mappings at the high-quality tier (similarity  $\geq 0.85$ ; 2,527 mappings). Manual inspection of the 97 most difficult cases—those near the 0.85 threshold boundary—found zero semantically incorrect mappings. Typical borderline matches included legitimate cross-domain connections such as “Bioelectronics” (OpenAlex)  $\rightarrow$  “Biosensors” (EDAM, similarity 0.856), which reflect meaningful semantic proximity rather than errors.

### 4.4 Known Limitations

The temporal coverage of individual sources introduces caveats for longitudinal analyses. SciSciNet metrics are computed on data through approximately 2022, meaning disruption and atypicality scores may not reflect the most recent citation dynamics. Reliance on Science patent citations exhibit a natural lag due to patent processing timelines, with coverage strongest through late 2023. Users should verify the temporal coverage of each source before drawing conclusions about recent trends. The OpenAlex topic taxonomy may evolve across snapshots, potentially affecting ontology mapping stability.

## 5 Usage Notes

### 5.1 Setup

The Science Data Lake can be deployed by cloning the repository, running the pipeline via `datalake_cli.py` (which downloads, converts, and links all sources), and connecting to the resulting DuckDB database. For users without local storage, HuggingFace-hosted Parquet files can be queried directly through DuckDB’s `httpfs` extension. All queries below use standard SQL and execute within DuckDB.

### 5.2 Vignette 1: Disruption, Code Adoption, and Ontology Landscape

This vignette examines whether papers that release code exhibit different disruption profiles than those that do not, and maps this pattern across ontology-defined domains.

Joining `sciscinet.paper_metrics` (disruption index  $CD_5$ ), `xref.unified_papers` (code-availability flag from Papers with Code), and `xref.topic_ontology_map` (ontology bridging), we identified 139,873 papers with associated code repositories (0.048% of the unified table). Papers with code showed a mean  $CD_5$  of  $-0.0005$ , compared with  $+0.0026$  for papers without code, suggesting that code-releasing papers tend to be slightly more consolidating (building on existing work) rather than disruptive. Ontology mapping reveals that this pattern varies across domains: computer science topics (mapped via CSO) show the strongest code adoption, while biomedical topics (mapped via GO and MeSH) show lower code rates but higher disruption variability.

This analysis is *only possible* because it requires simultaneous access to disruption scores (SciSciNet), code flags (Papers with Code), topic assignments (OpenAlex), and ontology bridging (our linkage)—four resources that exist in no single database.

### 5.3 Vignette 2: Retraction Profiles and Ontology Enrichment

This vignette characterizes retracted papers by their pre-retraction impact metrics and identifies ontology domains with anomalous retraction rates.

Joining `retwatch.retracted_papers`, `sciscinet.paper_metrics`, and `xref.unified_papers`, we obtained 58,775 retracted papers with associated SciSciNet metrics. Retracted papers show a mean disruption of 0.0035 compared with 0.0026 for non-retracted papers, and the most-cited retracted paper accumulated 8,062 citations before

retraction. Ontology-level enrichment analysis reveals retraction hotspots: topics mapped to “AI Applications” show  $394\times$  enrichment, and “Advanced Technology” topics show  $338\times$  enrichment relative to baseline retraction rates.

This analysis requires retraction flags (Retraction Watch), disruption scores (SciSciNet), citation counts (OpenAlex), and ontology mapping—a combination unavailable in any single source.

## 5.4 Vignette 3: Patent Impact and Multi-Ontology Footprint

This vignette quantifies the citation and impact characteristics of papers cited by patents, broken down by ontology domain.

Joining `ros.patent_paper_pairs`, `xref.unified_papers`, and `xref.topic_ontology_map`, we identified 312,929 patent-cited papers (0.107% of the unified table). These papers have dramatically higher impact: mean citation count of 94.3 versus 16.1 for non-patent-cited papers ( $5.8\times$ ), and mean FWCI of 4.7 versus 1.5 ( $3.1\times$ ). The multi-ontology footprint reveals that patent-cited papers cluster in applied domains: MeSH-mapped health science topics, CSO-mapped computer science topics, and ChEBI-mapped chemistry topics dominate.

The temporal coverage caveat applies: RoS patent citations are strongest through late 2023 due to patent processing lag, so very recent papers may have incomplete patent linkage.

## 5.5 Vignette 4: Cross-Source Citation Reliability

This vignette demonstrates record-level citation comparison across three independent databases.

Restricting to the 121 million papers present in all three large sources (S2AG, OpenAlex, SciSciNet), we computed pairwise citation correlations: S2AG–OpenAlex  $r = 0.76$ , S2AG–SciSciNet  $r = 0.87$ , and OpenAlex–SciSciNet  $r = 0.86$ . The mean absolute differences range from 2.3 to 4.1 citations. Relative disagreement is most pronounced for low-cited papers (mean relative difference  $\sim 20\%$  for papers with  $<10$  citations) and diminishes for high-cited papers. The most extreme outlier—a paper with 257,887 citations in S2AG and zero in OpenAlex—illustrates how coverage and methodology differences can produce dramatic record-level discrepancies.

This three-way comparison is *only possible* when parallel citation counts from independent sources coexist in a single queryable table. No pairwise API-based comparison can reproduce this analysis at scale.

Figure 7 summarizes the results of all four vignettes.

## 5.6 AI-Assisted Querying

The Science Data Lake includes a structured schema reference (`SCHEMA.md`, approximately 1,200 lines) designed to serve as context for large language model (LLM) based coding agents. This document provides every table name, column, data type, row count, and size tier, along with nine cross-dataset join strategies and common query recipes—all in a format optimized for LLM consumption rather than narrative reading.

In practice, a researcher can provide `SCHEMA.md` as context to an LLM agent (e.g., via a system prompt or file attachment) and issue natural-language analytical requests. The agent can then compose correct DuckDB SQL queries spanning multiple schemas without manual schema exploration. For example, the prompt “find the most disruptive papers in computer science that have open-source code and check their retraction status” requires joining four schemas (`sciscinet`, `xref`, `pwc`, `retwatch`) with appropriate DOI normalization—a query that `SCHEMA.md` provides sufficient context to construct autonomously.

This design reflects a deliberate choice: rather than building a custom natural-language interface (which would require maintenance and constrain the query space), we provide structured documentation that any general-purpose LLM agent can consume. As LLM capabilities evolve,

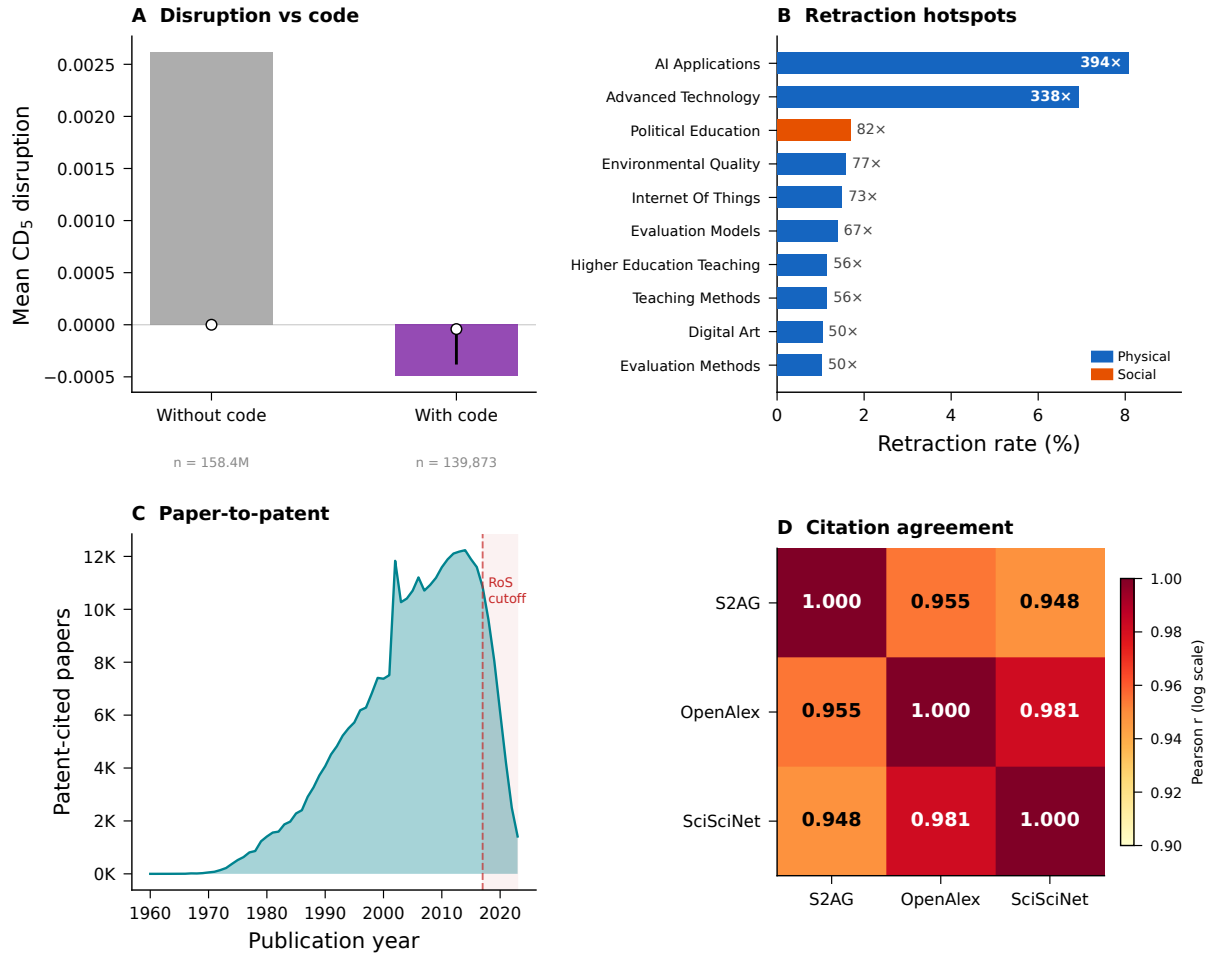


Figure 7: Composite vignette results (2x2 panels). Top-left: disruption distributions for papers with versus without code (Vignette 1). Top-right: retraction enrichment by ontology domain (Vignette 2). Bottom-left: citation distributions for patent-cited versus non-patent-cited papers (Vignette 3). Bottom-right: pairwise citation agreement across three sources (Vignette 4).

the same schema reference remains useful without modification. This approach aligns with the broader trend of LLM-driven scientific discovery [14], where researchers increasingly delegate data retrieval and exploratory analysis to AI assistants that operate over structured data.

## 5.7 Limitations and Extensibility

The Science Data Lake inherits the limitations of its constituent sources. Temporal coverage varies: SciSciNet metrics end around 2022, RoS exhibits patent processing lag, and OpenAlex snapshot dates may trail real-time data by weeks to months. Papers without DOIs (estimated at 5–15% depending on field and era) are excluded from cross-source linkage. The ontology mapping relies on the current OpenAlex topic taxonomy, which may evolve across snapshots.

The architecture is designed for extensibility: adding a new data source requires writing a Parquet converter and registering the schema in the pipeline configuration. Community contributions of additional sources, ontologies, or cross-reference methods are encouraged.

## 6 Code Availability

All code for constructing and querying the Science Data Lake is available in a public GitHub repository (<https://github.com/JOnasW/science-datalake>). The pipeline is implemented in

Python 3.12 with the following principal dependencies: DuckDB 1.4.2 [18], PyArrow 22.0, and sentence-transformers 5.2.2 (for ontology alignment).

The pipeline comprises five stages, each implemented as a subcommand of the master CLI script:

1. **Download** (`datalake_cli.py download`): retrieves source snapshots from their official distribution points (S3 buckets, APIs, direct downloads).
2. **Convert** (`datalake_cli.py convert`): transforms each source from its native format (JSON Lines, CSV, N-Triples) into columnar Apache Parquet files.
3. **Create views** (`create_unified_db.py`): generates the DuckDB database with 151 SQL views across 22 schemas.
4. **Materialize** (`materialize_unified_papers.py`): constructs the `xref.unified_papers` join table through DOI normalization and multi-source record linkage.
5. **Build linkage** (`build_embedding_linkage.py`): computes BGE-large embeddings for ontology terms and OpenAlex topics, builds a FAISS index, and produces the ontology alignment table `xref.topic_ontology_map`.

Additional scripts include `convert_ontologies.py` (five format-specific parsers for the 13 ontologies) and `ontology_registry.py` (a declarative registry of ontology URLs and formats). The repository also includes a structured schema reference (`SCHEMA.md`) that documents all 151 views with their columns, types, row counts, and cross-dataset join strategies, designed to be consumed by LLM-based coding agents as well as human developers. The full pipeline runs in approximately 48 hours on a workstation with a 24-core CPU, 252 GB RAM, and an NVIDIA RTX A4500 GPU (used only for embedding computation).

## Acknowledgements

The author thanks Hamburg University of Technology (TUHH) for institutional support. Computational resources were provided by the TUHH High-Performance Computing cluster. The author gratefully acknowledges the OpenAlex team for providing open, freely accessible data snapshots via Amazon Web Services S3, and the teams behind Semantic Scholar, SciSciNet, Papers with Code, Retraction Watch, Reliance on Science, and the PreprintToPaper project for making their datasets openly available.

## Author Contributions

**J.W.:** Conceptualization, Methodology, Software, Data curation, Validation, Formal analysis, Investigation, Visualization, Writing — original draft, Writing — review & editing.

## Competing Interests

The authors declare no competing interests.

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