Introduction to Databases

Data in Astronomy

- Much of astronomy, and especially survey astronomy, begins with *collecting sets of well defined measurements* on samples (or entire populations) of objects.

- We organize and publish these measurements as astronomical *catalogs*
  - These are collections of tables
  - Used to be published as (big, thick!) books

STELLARUM INERRANTIUM

CATALOGUS BRITANNICUS,

Ad Annum CHRISTI completum, 1689.

Ab Obſervationibus Grenovici in Obſervatorio Regio habitis,

ASSIDUIS VIGILIIS, CURA ET STUDIO,

JOANNIS FLAMSTEEDII,

ASTRONOMI REGII,

DEDUCTUS ET SUPPUTATUS.

FLAMSTEED.	Ordo Ptol.	Ordo Tych.	*In Conſtellatione Arietis. 66.* STELLARUM DENOMINATIO.	Bayeri Char.	Aſcenſio recta, 1690. G. M. S.	Diſtantia à Polo Boreo. G. M. S.	Longitudo. 1690. Si. G. M. S.	Latitudo. G. M. S.	Varia Aſc. R pro 60' longit. M. S.	Varia D. à P. pro 60' longit. M. S.	Magnitudo.
1					20 46 0	69 17 15	0. 26 58 25	11 4 58 B	58 7	22 25	7.6
2					21 25 45	71 15 25	26 48 15	9 1 26 B	57 52	22 19	7.6
3					22 26 15	74 10 55	26 36 18	5 57 3 B	57 31	22 12	6
4					22 51 15	74 36 55	26 49 4	5 23 59 B	57 28	22 07	7.6
5	1	1	Quæ in Cornu duarum præcedens.	γ	24 8 30	72 14 45	28 51 0	7 8 58 B	58 02	21 55	4
6	2	2	Sequens & Borea eſt.	β	24 23 30	70 43 55	29 37 59	8 28 16 B	58 22	21 50	3
7					24 39 45	67 57 45	1. 0 54 20	10 57 12 B	58 57	21 49	tel.
8	5	6	In Cervice.	ι	25 7 0	73 43 15	0. 29 10 57	5 26 12 B	57 54	21 44	6
9			In Vertice.	λ	25 11 0	67 56 25	1. 1 22 15	10 47 47 B	59 00	21 44	5
10					26 32 30	65 35 5	3 26 14	12 31 52 B	59 45	21 28	6.7
11					27 19 30	65 48 15	4 2 12	12 4 2 B	59 48	21 20	6
12		17	Infrà Lucidam.	κ	27 19 30	68 51 5	2 55 8	9 13 29 B	59 10	21 21	6.5
13	inf. 1	3	Infor. ſup. Caput, Lucida Arietis.	α	27 26 30	68 1 45	3 19 18	9 57 12 B	59 22	21 20	2
14					27 57 30	65 33 15	4 40 46	12 5 32 B	59 56	21 12	6
15					28 22 30	71 58 45	2 43 49	5 56 58 B	58 36	21 08	6
16					28 24 45	65 32 40	5 4 35	11 57 0 B	60 4	21 06	8
17	3	4	In Roſtro duarum Borea.	[illegible]	28 52 30	70 16 25	5 46 50	7 22 45 B	59 2	21 02	6
18					28 58 45	71 33 15	3 25 14	6 8 45 B	58 46	21 00	7
19					29 1 30	76 12 15	1 49 50	1 46 25 B	57 47	21 00	6.7
20					29 31 30	65 41 5	5 59 38	11 27 44 B	60 13	20 54	6
21					29 31 30	66 25 20	5 43 40	10 46 20 B	60 1	20 53	7
22	4	5	In Roſtro Auſtralior. 1 ad	θ	30 14 0	71 33 30	4 32 25	5 43 39 B	58 56	20 45	6.5
23			2 ad	θ	30 29 30	71 45 25	4 41 59	5 27 23 B	58 58	20 43	7
24			In extremitate Pedis poſterioris. *	ξ	32 1 30	80 48 15	3 0 49	3 33 31 A	57 1	20 23	6
25					32 42 30	81 12 25	3 30 53	4 9 43 A	57 00	20 16	7
26					33 20 0	71 33 0	7 19 13	4 44 7 B	59 18	20 5	6.7
27					33 26 0	73 41 55	6 41 33	2 40 42 B	58 46	20 4	6.7

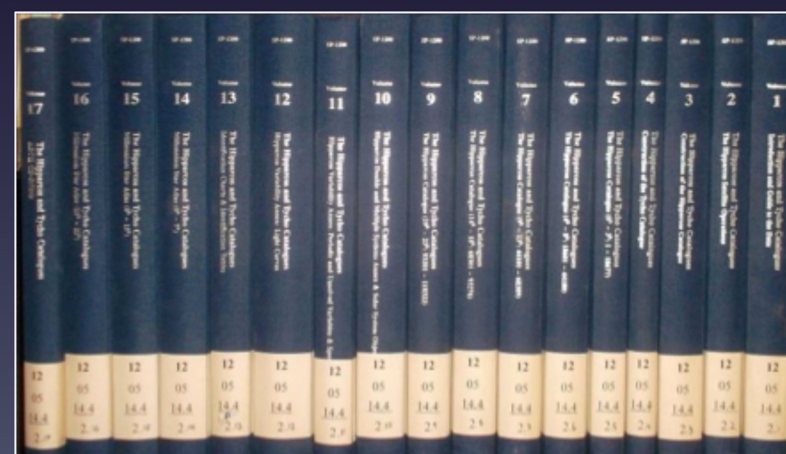
C

Left: The first page of J. J. Lalande's edited and corrected version of John Flamsteed's star catalogue, published in 1783. The stars shown here belong to the constellation Aries. In the first column, Lalande numbered each star consecutively by constellation. These are the numbers that we now call Flamsteed numbers.

👉 *2,935 entries (rows)*

From http://www.ianridpath.com/startales/flamsteed.htm

Below: Hipparcos & Tycho Catalogs (1997)



👆 *https://www.abebooks.com/book-search/title/hipparcos-tycho-catalogues/*

I photo.in


```
7757,301,1,74,186,6,8.12944435106658,26.6266172894736,17.04889,18.16535,0.01654805,0.02145229
7757,301,1,74,187,6,8.12783867556709,26.627245975921,17.37402,17.92875,0.02894481,0.02568013
7757,301,1,74,188,3,8.1273232252419,26.6251199416623,20.1466,21.35297,0.3003744,0.3302762
4288,301,1,39,682,3,24.516117042230,5,-1.16579446393527,22.97032,24.3259,0.2672399,0.5240437
4288,301,1,39,683,3,24.5179406515354,-1.1792069022485,22.62052,25.09109,0.1850479,0.6585805
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4136,301,1,61,935,6,36.4715922759092,-1.06093938828308,22.71782,23.14112,0.158014,0.1799687
4136,301,1,61,936,3,36.4717583013136,-1.1378448207726,22.81683,23.88123,0.1742272,0.3260605
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4288,301,1,40,311,3,24.6839203338022,-1.23631696217547,21.2002,21.67521,0.05694564,0.06316777
4288,301,1,40,312,3,24.6840602692246,-1.21784918362007,20.30287,21.04976,0.02972161,0.04032911
4288,301,1,40,313,6,24.684021669037,7,-1.08292772289886,24.92263,25.72778,0.68427,0.5471938
5598,301,1,61,792,3,351.787950113407,6.14573538435867,22.43574,23.83793,0.1125768,0.2867745
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2699,301,1,48,529,3,12.0832728187538,-3.52539818226738,22.29741,23.32008,0.1377919,0.2253349
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94,301,1,38,280,6,340.525793656628,-0.965210498356983,24.23321,26.07633,0.8058653,0.7702702
94,301,1,38,281,6,340.53257887691,-1.02365035629542,21.10608,21.15248,0.06605724,0.04672106
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4288,301,1,76,768,6,30.0899156247035,-1.19236549812758,22.64196,22.91776,0.1927483,0.2022232
7937,301,1,84,354,3,5.5913222647018,3,26.6120638856974,22.63659,23.76799,0.2950225,0.5986399
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3996,301,1,81,617,3,216.219379232008,11.9171402588482,22.60762,23.05279,0.1416738,0.1555459
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2986,301,1,59,253,6,127.588133654789,2.
5598,301,1,31,1254,6,347.289019727591,6
5598,301,1,31,1255,6,347.29268060286,6
5598,301,1,31,1256,6,347.294399617648,6.
```

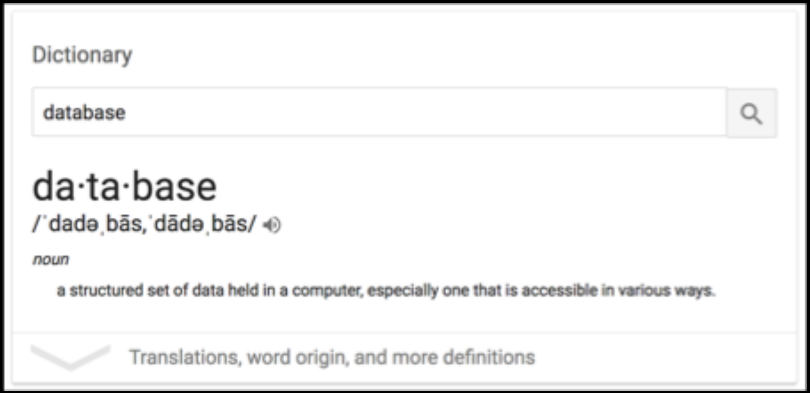

1,231,051,050 rows (SDSS DR10, PhotoObjAll table)
~500 columns

The Problems

1. *How do we store and organize our ever-growing catalogs?*

2. *How do we make it easy to explore and analyze those catalogs (ask questions) ?*

Databases



- Logically:
  - Organized collections of data
  - Typically, a set of tables and their relationships ("relational databases")
    - Terminology: for practical purposes, relation == table. For details, see http://en.wikipedia.org/wiki/Relation_%28database%29
  - A table is made up of rows and columns
    - Each row can be considered as an entry corresponding to some real-world object, listing its attributes
    - Columns define the attributes; each column has a well defined data type (e.g., integer, real, text, etc.)

- Physically:
  - A collection of files written in special format, that are accessed and manipulated using a *Database Management System* (DBMS)

Examples

Person

Login	LastName	FirstName
skol	Kovalevskaya	Sofia
mlom	Lomonosov	Mikhail
dmitri	Mendeleev	Dmitri
ivan	Pavlov	Ivan

Project

ProjectId	ProjectName
1214	Antigravity
1709	Teleportation
1737	Time Travel

Experiment

ProjectId	ExperimentId	NumInvolved	ExperimentDate	Hours
1214	1	1	NULL	1.5
1214	2	1	1889-11-01	14.3
1709	1	3	1891-01-22	7.0
1709	2	1	1891-02-23	7.2
1737	1	1	1900-07-05	-1.0
1737	2	2	1900-07-05	-1.5

Involved

ProjectId	ExperimentId	InvolvedId	Login
1214	1	1	mlom
1214	2	1	mlom
1709	1	1	dmitri
1709	1	2	skol
1709	1	3	ivan
1709	2	1	mlom
1737	1	1	skol
1737	2	1	skol
1737	2	2	ivan

~ 2005

http://goo.gl/jWDIzy

Table: runs New Record Delete Record

	run	ra	dec	mjdstart	mjdend	node	inclination	mu0	nu0
	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter
1	94	336.4327791...	-1.04429400...	51075.23321...	51075.45501...	286.855205	0.009477	336.4326667...	-1.05150869...
2	109	396.2418087...	-1.25055686...	51078.39078...	51078.47494...	283.3917469...	0.008279	36.24187915...	-1.25818616...
3	125	350.4697426...	-1.25274979...	51081.25575...	51081.49528...	287.818732	0.007781	350.4696642...	-1.25966106...
4	211	402.5811092...	-1.26517002...	51115.307	51115.46205...	283.2197800...	0.007975	42.58119581...	-1.27212059...
5	240	375.1896778...	-1.26440348...	51132.185032	51132.24885...	290.578187	0.010103	15.18965685...	-1.27446183...
6	241	403.0295478...	-1.26513669...	51132.26214...	51132.30359...	266.7155050...	0.005148	43.02963017...	-1.26869244...
7	250	15.35717871...	-1.03608421...	51133.183	51133.36699...	62.095899	0.024055	15.35688309...	-1.01856644...
8	251	85.88000457...	-1.00945333...	51133.37808...	51133.40792...	11.252511	0.037496	85.87982628...	-1.04560781...
9	256	-8.28409345...	-1.05720709...	51134.11449...	51134.13357...	58.141704	0.024019	351.7157311...	-1.03519263...
10	259	368.3751608...	-1.04718589...	51134.16041...	51134.39053...	299.408811	0.007597	8.375110834...	-1.05427670...
11	273	371.5027215...	-1.25773504...	51136.164	51136.38085...	286.5415300...	0.008068	11.50270590...	-1.26577186...
12	287	396.4868469...	-1.15429721...	51138.22760...	51138.40424...	295.298232	0.007857	36.48687773...	-1.16200488...
13	297	61.15102149...	-1.15372111...	51139.293	51139.37260...	92.038416	0.040845	61.15032199...	-1.13275302...

< 1 - 14 of 765 > Go to: 1

Interacting with Databases: Database Management Systems (DBMS)

- As mentioned before, a database can logically be thought of as a set of tables. Physically (on disk) it's stored as one or more files. They're written in a special format that generally should not be directly read or written.

- A ***Database Management System (DBMS)*** is needed to read and write it
  - A software product tool that allows us to read or write data in databases
  - It allows us to query for and retrieve (a potentially transformed) subset of data from one or more tables

- Note: the on-disk format is DBMS-specific

Structured Query Language

- **SQL**, or **Structured Query Language** is a special-purpose programming language designed for handling data managed by relational database management systems
- It is a language that virtually all databases "speak"
  - Allows one to ask for subsets of data, join tables, modify the outputs, as well as add and delete data in the database
  - Note: there are dialects and small differences from database to database

```
SELECT TOP 100
       objID, ra ,dec
FROM
       PhotoPrimary
WHERE
       ra > 185 and ra < 185.1
       AND dec > 15 and dec < 15.1
```

Above: An example query that returns the object ID, R.A., and Declination for objects in the PhotoPrimary table of the SDSS database that are within the given the ra/dec boundaries.

Why Databases for Astronomy:

1. *Catalogs map perfectly to database tables.*

2. *The DBMS abstracts away the problem of physical storage of catalogs: you start thinking in terms of tables, not files.*

3. *The DBMS provides a specialized declarative language to select/slice/dice/summarize the data contained within: you think more of what you need, rather than how to code it up.*

Common DBMS

- SQLite
  - http://sqlite.org
  - Easy to use, simple, reasonably fast, free
  - Comes with Anaconda, included in Python
  - The database is a single file
  - No need for special accounts, permissions, or servers
  - GUI: http://sqlitebrowser.org
  - Downsides:
    - Poor multi-user support
    - Does not scale well (won’t scale to tens or hundreds of millions of rows)

Common DBMS

- MariaDB (also, MySQL)
  - http://mariadb.org
  - Free, secure, scalable
  - Widely used and well supported
    - Comes in nearly all Linux distributions
    - There's no question that hasn't already been asked on StackOverflow ☺
  - Client/server architecture
  - More advanced features compared to SQLite
  - Can handle tables with billions of rows
  - MariaDB vs MySQL: use MariaDB
  - Planned to be used by LSST to serve its PB+ dataset
  - Disadvantages:
    - Steeper learning curve, more initial setup

Common DBMS

- PostgreSQL
  - http://postgresql.org
  - Free, secure
  - Similar to MySQL in terms of functionality
  - Some features are more advanced, performance can be better
  - Smaller community (though still widely used), steeper learning curve

Common DBMS

- MS SQLServer
  - Not free, but performant and scalable
  - Used by the SDSS archive
- Oracle Database
  - The "industry standard" for mission critical databases
  - (Very) expensive

- ***Typically, there's no need to use a commercial solution today, except in very specialized circumstances – the free/open source databases <u>usually</u> work well enough***

Non-Traditional DBMS

- "NoSQL" databases
- Systems for analyzing sets of large or unstructured data (e.g., web pages)

- **<u>Fast</u>**, **<u>very scalable</u>** (>petabytes of data), do not require fixed table schemas

- Examples: MongoDB, Hive, HBase, Cassandra, Redis, CouchDB, …
- Also: <u>Spark</u>, Hadoop

- Disadvantages:
  - More difficult to work with and primitive compared to relational databases
  - Less expressive query languages, require programming for most tasks
    - Note: This is rapidly changing!

Using a Database to Manage and Explore Astronomical Catalogs

SQL Basics

- CREATE
  - Creating tables
- INSERT/DELETE
  - Adding and deleting rows

- SELECT
  - Selecting a subset of data
  - Joining (combining) data from different tables

- More information: http://robots.thoughtbot.com/back-to-basics-sql

Creating a Database

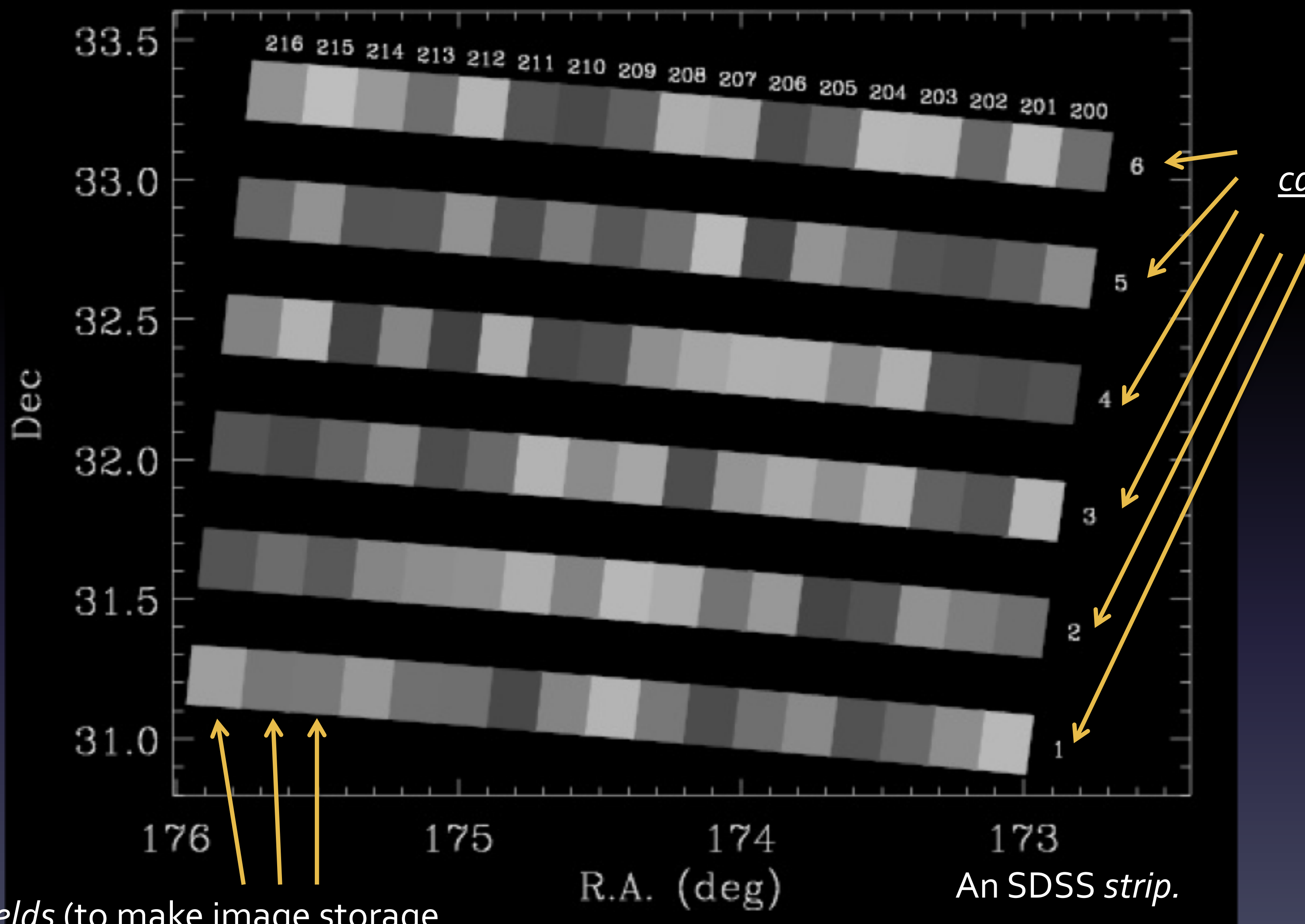
- The details of database creation and data import are DBMS specific, but the general idea is similar:
  1. Create the database itself
  2. Create the tables within the database
  3. Import the data

The “mini SDSS” Dataset

- Sample data:
  - See lectures/ lecture-08-databases/* in the class git repository
  - I extracted a random sample of ~50,000 objects from SDSS DR10 PhotoObjAll table. This is the catalog of all sources that the SDSS has detected and measured. The result is in sample.csv.
  - I also have a list of SDSS “runs” (observations) with details about each run (runs.txt)
  - I will import these two into a sqlite database

Observing pattern in one *observing* *run*.

http://www.sdss.org/dr12/imaging/imaging_basics



camcols

An SDSS *strip.*

fields (to make image storage and processing easier)

```
IW    sample.csv
run,rerun,camcol,field,obj,type,ra,dec,psfMag_r,psfMag_g,psfMagErr_r,psfMagErr_g
7757,301,1,74,186,6,8.12944435106658,26.6266172894736,17.04889,18.16535,0.01654805,0.02145229
7757,301,1,74,187,6,8.12783867556709,26.627245975921,17.37402,17.92875,0.02894481,0.02568013
7757,301,1,74,188,3,8.12732322524192,26.6251199416623,20.1466,21.35297,0.3003744,0.3302762
```

One SDSS <u>field</u>

frame-r-004570-4-0135

1489 px
(== 10′)

2048 px (== 13′)

```
    IW   sample.csv
run,rerun,camcol,field,obj,type,ra,dec,psfMag_r,psfMag_g,psfMagErr_r,psfMagErr_g
7757,301,1,74,186,6,8.12944435106658,26.6266172894736,17.04889,18.16535,0.01654805,0.02145229
7757,301,1,74,187,6,8.12783867556709,26.627245975921,17.37402,17.92875,0.02894481,0.02568013
7757,301,1,74,188,3,8.12732322524192,26.6251199416623,20.1466,21.35297,0.3003744,0.3302762
```

#1. Create the tables

```
CREATE TABLE sources (
        run             INTEGER,
        rerun           INTEGER,
        camcol          INTEGER,
        field           INTEGER,
        obj             INTEGER,
        type            INTEGER,
        ra              REAL,
        dec             REAL,
        psfMag_r        REAL,
        psfMag_g        REAL,
        psfMgErr_r      REAL,
        psfMagErr_g     REAL
);
```

```
CREATE TABLE runs (
        run             INTEGER,
        ra              REAL,
        dec             REAL,
        mjdstart        REAL,
        mjdend          REAL,
        node            REAL,
        inclination     REAL,
        muo             REAL,
        nuo             REAL
);
```

#2a. Prepare the input data

- Need to do some editing to remove the headers

```
    IW    runs.txt                                                                                          Row 7     Col 1
#      run        RA             Dec            MJDstart         MJDend           node  inclination      mu0         nu0
94 336.43277918259321 -1.0442940032626229 51075.233210700004 51075.455013770021 286.855205 0.009477 336.4326667809695 -1.0
109 396.2418087606826 -1.2505568685469386 51078.390782900002 51078.474943690046 283.391746999999 0.008279 36.2418791557513
125 350.46974267690877 -1.252749794374115 51081.255758900006 51081.495288979975 287.818732 0.007781 350.46966429004527 -1.
211 402.58110922053515 -1.2651700227414813 51115.307000000001 51115.462054849995 283.219780000001 0.007975 42.581195816086
240 375.18967787787483 -1.2644034848494636 51132.185032000001 51132.248851429977 290.578187 0.010103 15.189656853896887 -1
```

```
    IW    sample.csv
run,rerun,camcol,field,obj,type,ra,dec,psfMag_r,psfMag_g,psfMagErr_r,psfMagErr_g
7757,301,1,74,186,6,8.12944435106658,26.6266172894736,17.04889,18.16535,0.01654805,0.02145229
7757,301,1,74,187,6,8.12783867556709,26.627245975921,17.37402,17.92875,0.02894481,0.02568013
7757,301,1,74,188,3,8.12732322524192,26.6251199416623,20.1466,21.35297,0.3003744,0.3302762
4288,301,1,39,682,3,24.5161170422305,-1.16579446393527,22.97032,24.3259,0.2672399,0.5240437
```

#2b. Import

sqlite> .mode csv

sqlite> .separator " "

sqlite> .import runs.in runs

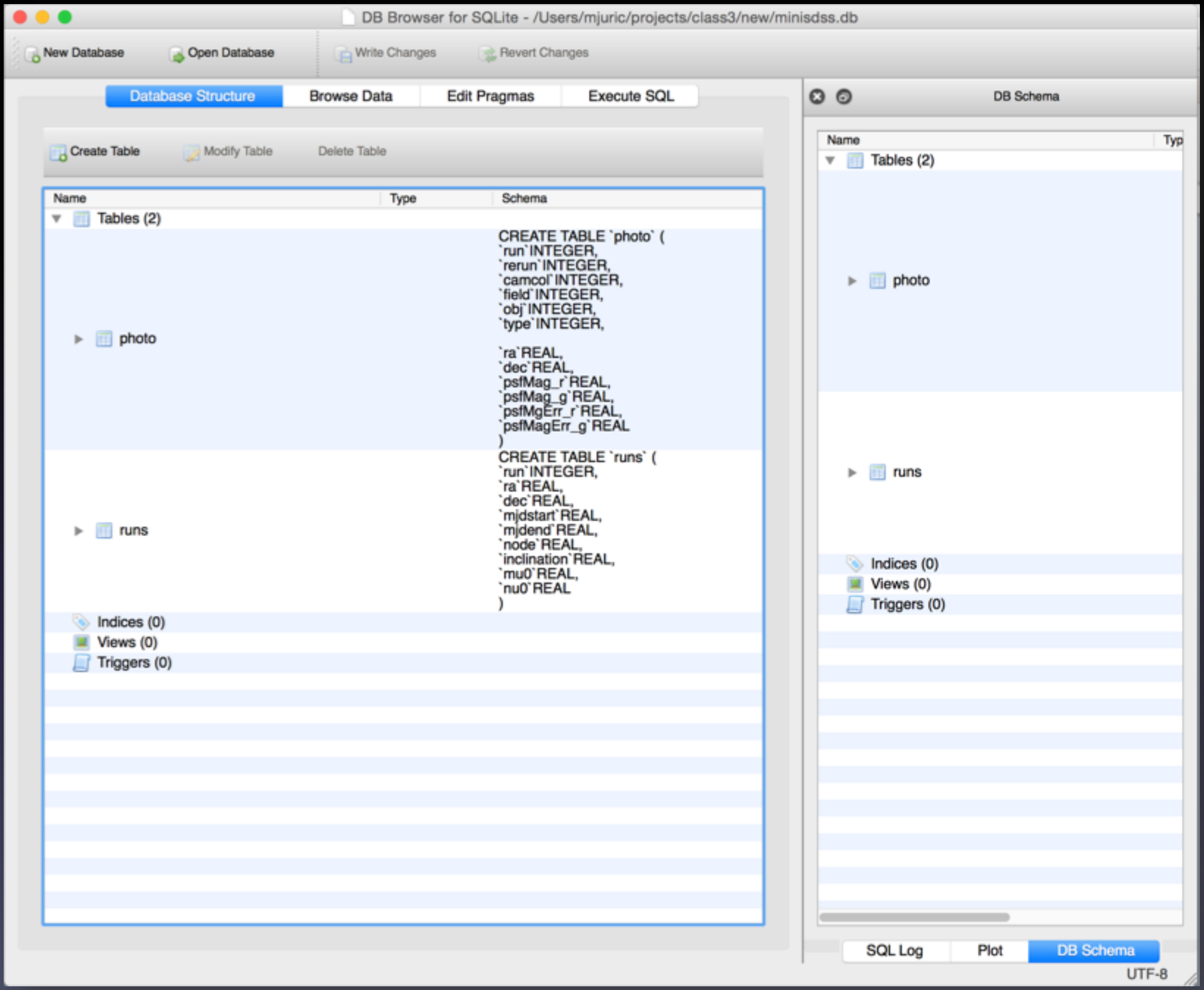
sqlite> .separator ","

sqlite> .import sample.in sources

sqlite> .quit

Sanity Check

: open -a "DB Browser for SQLite.app" sdss.db



Tip: add **`alias sqlitebrowser="open -a 'DB Browser for SQLite.app'"`** to your .bashrc then: `sqlitebrowser sdss.db`

SELECT Statement

- SELECT ra, dec, psfMag_r FROM sources
- SELECT ra, dec, psfMag_r FROM sources WHERE psfMag_r < 21.5
- SELECT ra, dec, psfMag_r FROM sources WHERE psfMag_r < 21.5 LIMIT 5
- SELECT COUNT(psfMag_r), AVG(psfMag_r) FROM sources WHERE psfMag_r < 21.5
- SELECT COUNT(*), run FROM sources GROUP BY run
- SELECT COUNT(*), run FROM sources GROUP BY run ORDER BY run
- SELECT COUNT(*) as ct , run FROM sources GROUP BY run ORDER BY ct

NULL

- How do we mark missing data?
  - Typical way to do this is to designate a value as “magic”
  - E.g.,: -9999 in our example database
- Relational databases provide us with a special constant, a “NULL”
  - The meaning is always clear (i.e. – no data)
  - Plays well with aggregate functions
    - I.e., AVG(), COUNT() ignore null values

UPDATE

- UPDATE sources

  SET psfMag_r = NULL

  WHERE psfMag_r = -9999.0

The table to update

Columns to update (and the values to use)

Selecting the subset of rows to update

JOIN: Joining tables

- Example:
  - Each row in the ‘sources’ table has a `run’ entry – the ID of the SDSS run where this object was observed
  - Each entry in the ‘runs’ table has a ‘mjdstart’ entry, indicating the time when the observing for this run started
  - How can we find the mjdstart for each object? An algorithm for doing it by hand:
    - For each row in the sources table:
      - Read off the value of ‘run’
      - Find the corresponding row in the ‘runs’ table
      - Read off the value of mjdstart

JOIN: Joining tables

- SELECT

  sources.ra, sources.dec, sources.run, mjdstart

  FROM

  sources

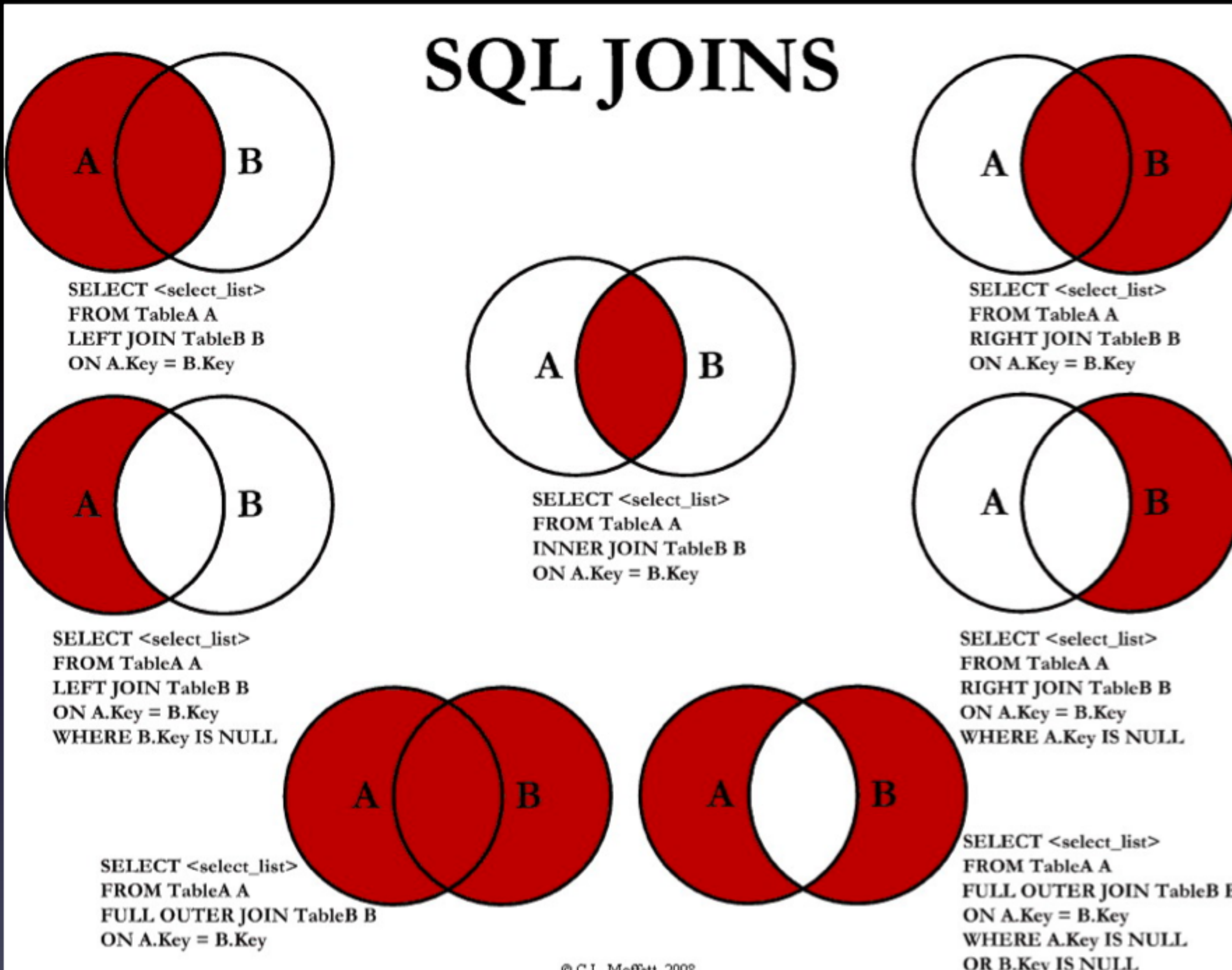
  JOIN runs ON sources.run = runs.run

The columns we're interested in.

Those appearing in more than one table need to be prefixed by the table name.

The table we're querying

Instructions how to join the runs table onto the sources table.



http://www.codeproject.com/KB/database/Visual_SQL_Joins/Visual_SQL_JOINS_orig.jpg

Doing all of this from Python

- Python can connect to a variety of databases
- SQLite module comes built into Python (sqlite3)

- We will also use a library called pandas ("Python Data Analysis Library")
  - http://pandas.pydata.org
  - Pandas provides high-performance data structures for manipulating and analyzing tabular data

- We'll also use astroquery (https://astroquery.readthedocs.io/en/latest/) to query remote databases.

More about SQL & Databases

- Interactive SQL tutorial
  - http://sqlzoo.net/wiki/Main_Page
- Introduction to SQL (Stanford)
  - https://class.stanford.edu/courses/DB/SQL/SelfPaced/courseware/ch-sql/seq-vid-introduction_to_sql/
- Introduction to SQL (Phil Spector, Berkeley)
  - https://www.stat.berkeley.edu/~spector/sql.pdf

- Databases in depth: CSE444
  - http://courses.cs.washington.edu/courses/cse444/

Some More Reading

- Pandas
  - 10 minute tutorial: http://pandas.pydata.org/pandas-docs/stable/10min.html
  - 10 minute tutorial video: http://vimeo.com/59324550
  - Pandas Tutorials: http://pandas.pydata.org/pandas-docs/stable/tutorials.html