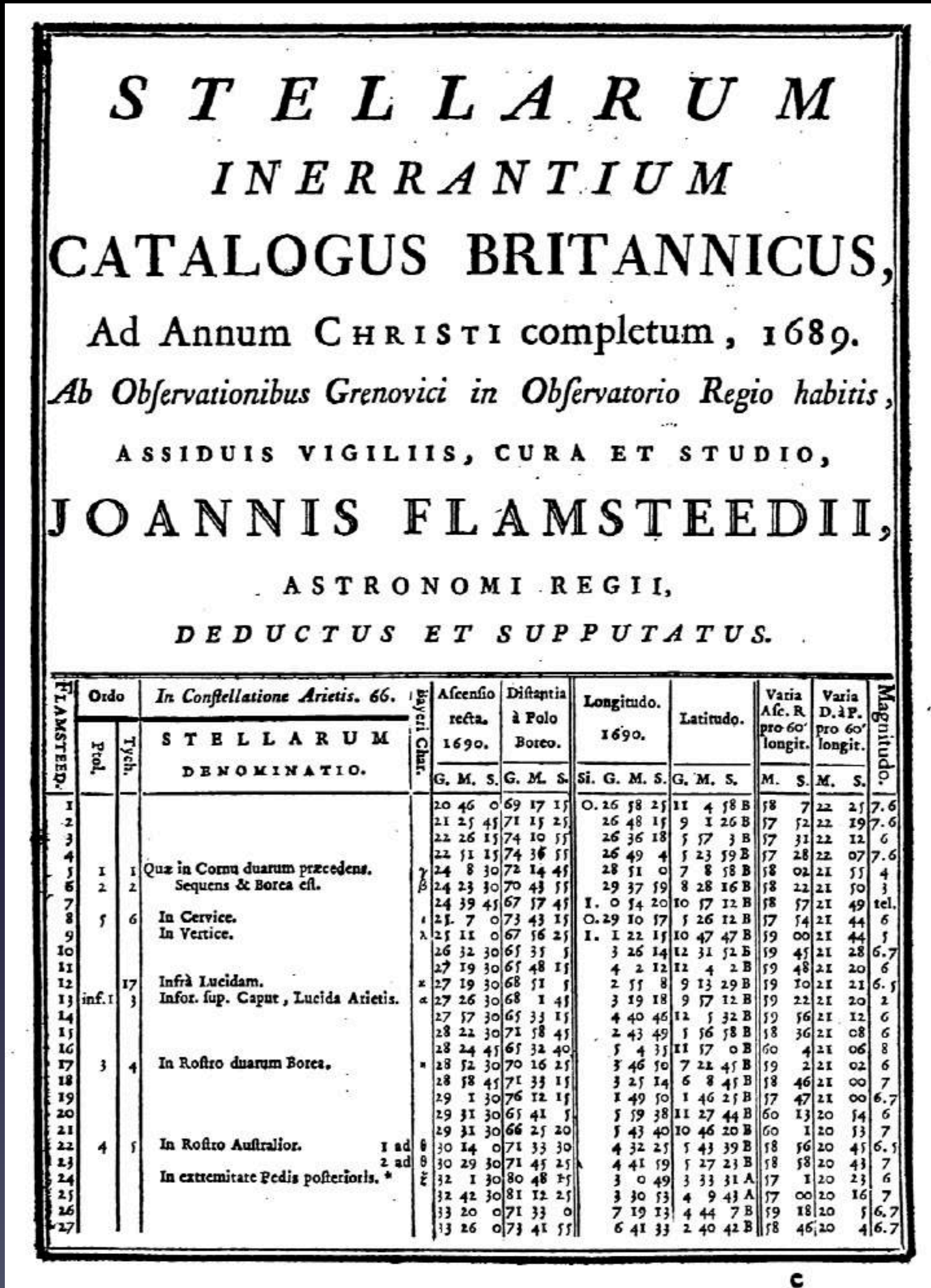
Introduction to Databases

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	I. 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	I. 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.		28 52 30	70 16 25	3 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

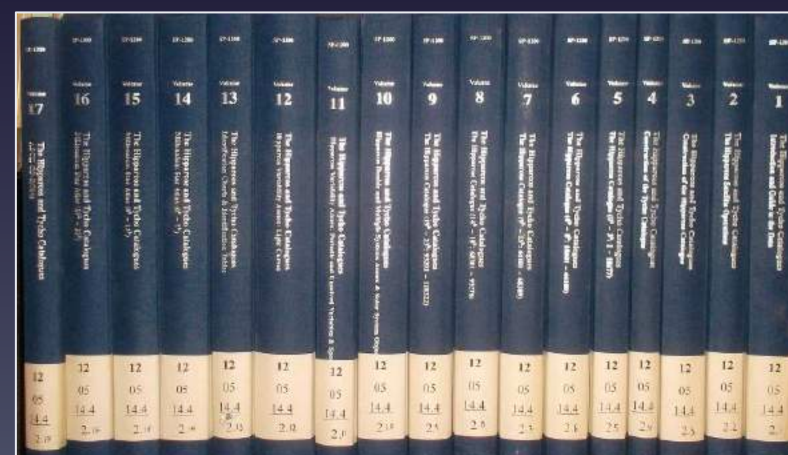
c

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
7757,301,1,74,188,3,8.12732322524192,26.6251199416623,20.1466,21.35297,0.3003744,0.3302762
4288,301,1,39,682,3,24.5161170422305,-1.16579446393527,22.97032,24.3259,0.2672399,0.5240437
4288,301,1,39,683,3,24.5179406515354,-1.1792069022485,22.62052,25.09109,0.1850479,0.6585805
4288,301,1,39,684,6,24.5189463293148,-1.15915086108891,21.4247,23.04125,0.06608655,0.1968172
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
4136,301,1,61,937,3,36.4717582434391,-1.13784497192974,22.81147,23.87586,0.1734457,0.3247895
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
4288,301,1,40,313,6,24.6840216690377,-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
5598,301,1,61,793,3,351.787950113434,6.14573538316393,22.43573,23.77753,0.1174541,0.2741905
5598,301,1,61,794,6,351.787349107439,6.14481612145222,24.6701,24.8507,0.4675894,0.4849904
2699,301,1,48,527,3,12.0760019016408,-3.32677418219699,22.18116,23.27577,0.126546,0.2270369
2699,301,1,48,528,6,12.0770027529666,-3.32913243320258,22.12757,23.79366,0.1215217,0.3403472
2699,301,1,48,529,3,12.0832728187538,-3.52539818226738,22.29741,23.32008,0.1377919,0.2253349
94,301,1,38,279,6,340.524768659138,-0.843090883870374,20.75028,21.13888,0.04839022,0.04644739
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
4288,301,1,76,766,3,30.0899167300738,-1.25189466355601,22.57054,22.91144,0.1807321,0.1984752
4288,301,1,76,767,3,30.0899962733195,-1.14314301954175,21.99419,23.78533,0.1094794,0.4162939
4288,301,1,76,768,6,30.0899156247035,-1.19236549812758,22.64196,22.91776,0.1927483,0.2022232
7937,301,1,84,354,3,5.59132226470183,26.6120638856974,22.63659,23.76799,0.2950225,0.5986399
7937,301,1,84,355,3,5.58984744314193,26.6157353187021,21.27009,22.13992,0.08808753,0.1490507
7937,301,1,84,356,6,5.59007089167375,26.5703384153732,24.52393,26.33231,1.060107,0.6528299
3996,301,1,81,615,6,216.223187662076,11.9472286471793,19.93735,21.0716,0.02294876,0.03470354
3996,301,1,81,616,3,216.23835672109,12.0534224512804,20.22574,21.24497,0.02592515,0.03942162
3996,301,1,81,617,3,216.219379232008,11.9171402588482,22.60762,23.05279,0.1416738,0.1555459
6354,301,1,29,2997,6,332.302798261878,41.2179102291468,20.95895,22.51458,0.04065189,0.1163793
6354,301,1,29,2998,6,332.355200585822,41.2447081319807,20.78153,22.35575,0.03523929,0.09754675
6354,301,1,29,2999,3,332.38785409452,41.2613314909198,21.00566,22.75478,0.04217106,0.1353208
2986,301,1,59,251,6,127.586395164415,2.97627035997022,24.42951,26.40598,0.6053675,0.9018285
2986,301,1,59,252,6,127.585997207459,2.98207493069978,25.42876,25.06479,0.5993609,0.8693208
2986,301,1,59,253,6,127.588133654789,2.
5598,301,1,31,1254,6,347.289019727591,6
5598,301,1,31,1255,6,347.292868060286,6
5598,301,1,31,1256,6,347.294399617648,6.
```

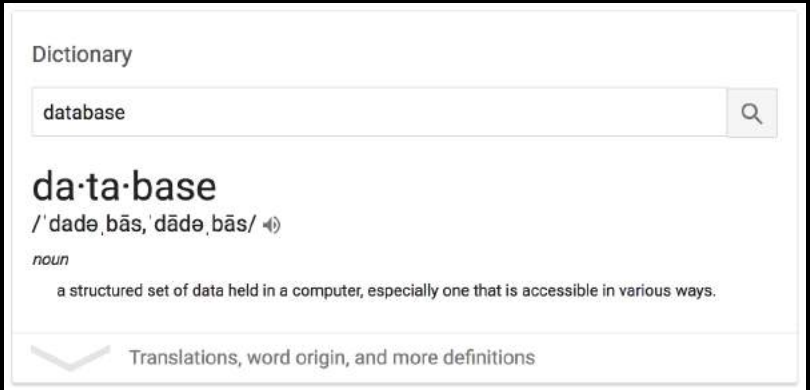

1,231,051,050 rows (SDSS DR10, PhotoObjAll table)
~500 columns

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

2000

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 <u>abstracts away the problem of physical storage of catalogs</u>: you start thinking in terms of tables, not files.*

3. *The DBMS provides a specialized <u>declarative language</u> to select/slice/dice/summarize the data contained within: you think more of <u>what</u> 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 usually work well enough***

Non-Traditional DBMS

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

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

- Examples: MongoDB, Hive, HBase, Cassandra, Redis, CouchDB, …
- Also: Spark, 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

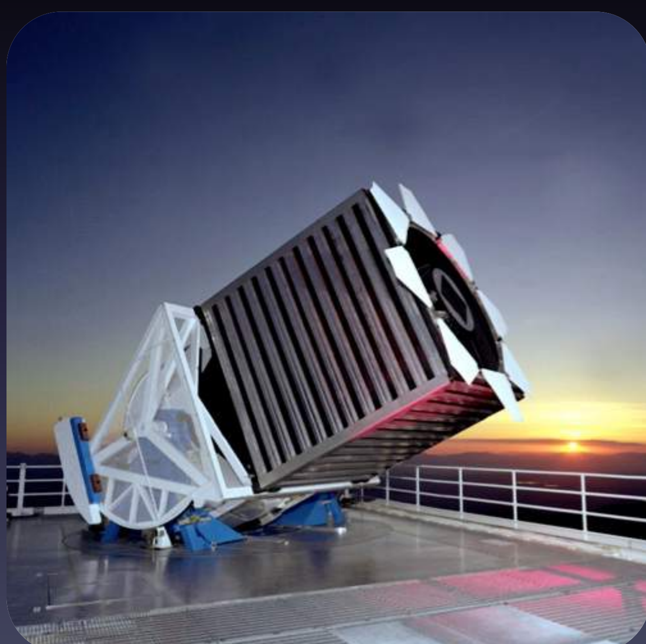
The “mini SDSS” Dataset

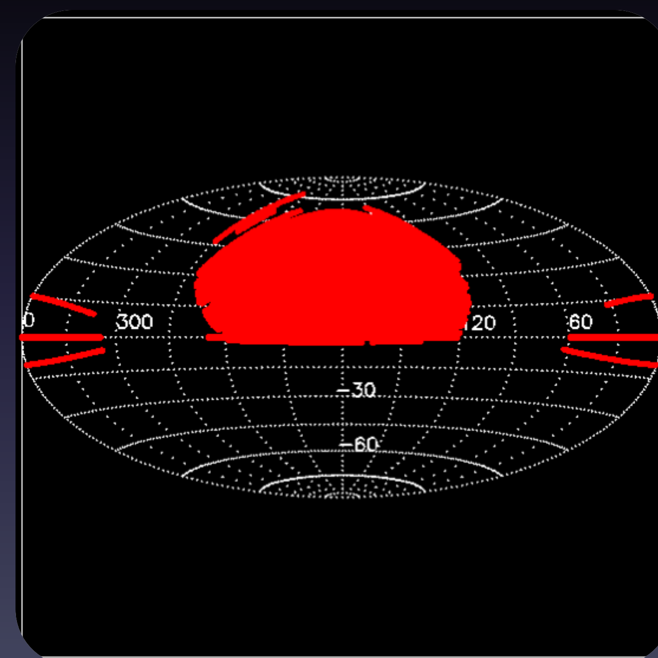
- Sample data:
  - See lectures/ lecture-06-databases/* in the class git repository
  - I extracted a random sample of ~50,000 objects from SDSS DR10 PhotoObjAll table. This is the catalog of all sources that the SDSS has detected and measured. The result is in sample.csv.
  - I also have a list of SDSS “runs” (observations) with details about each run (runs.txt)
  - I will import these two into a sqlite database

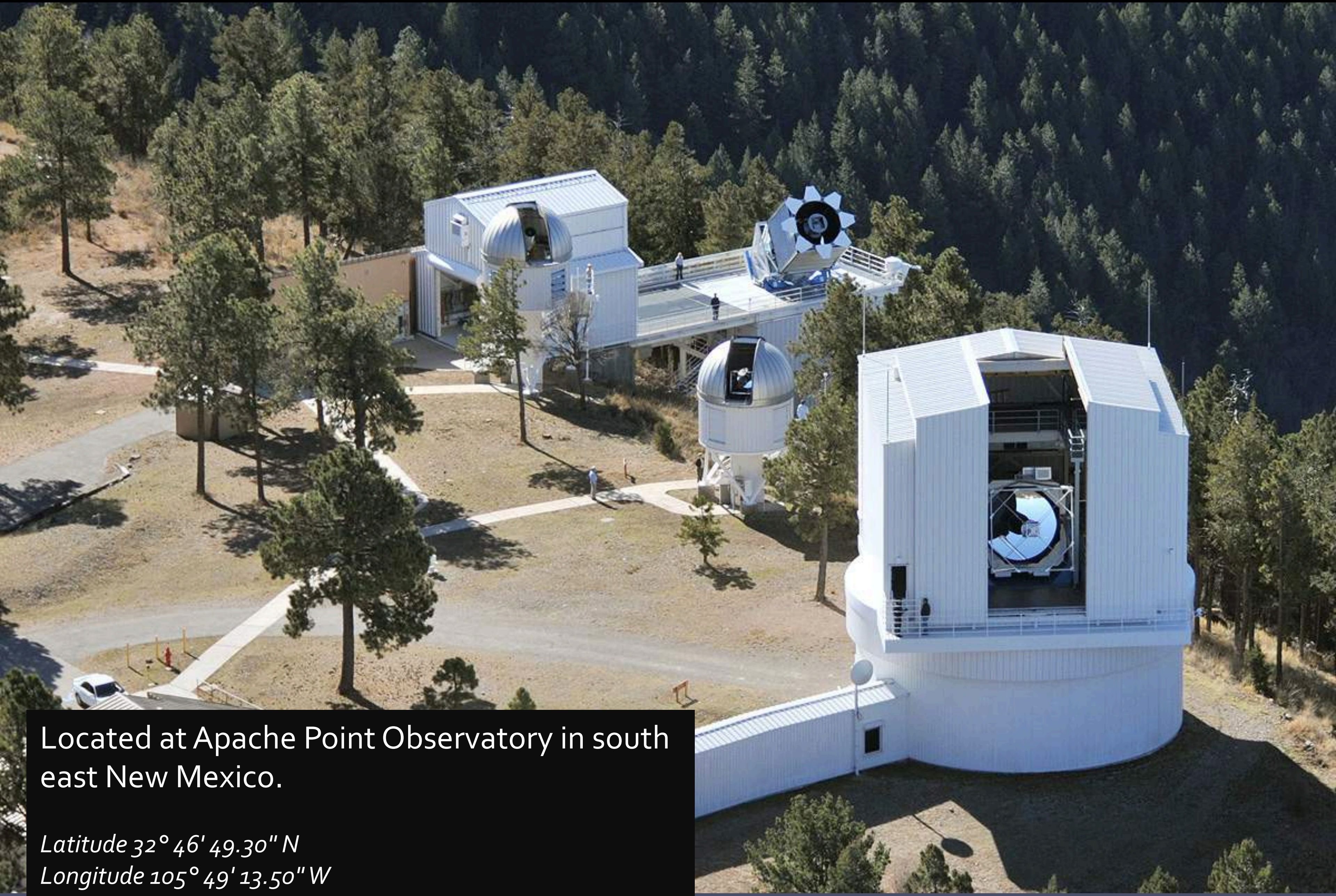
Sloan Digital Sky Survey

2.5m telescope   >14500 deg^2 0.1” astrometry   r<22.5 flux limit

5 band, better than 2%, photometry



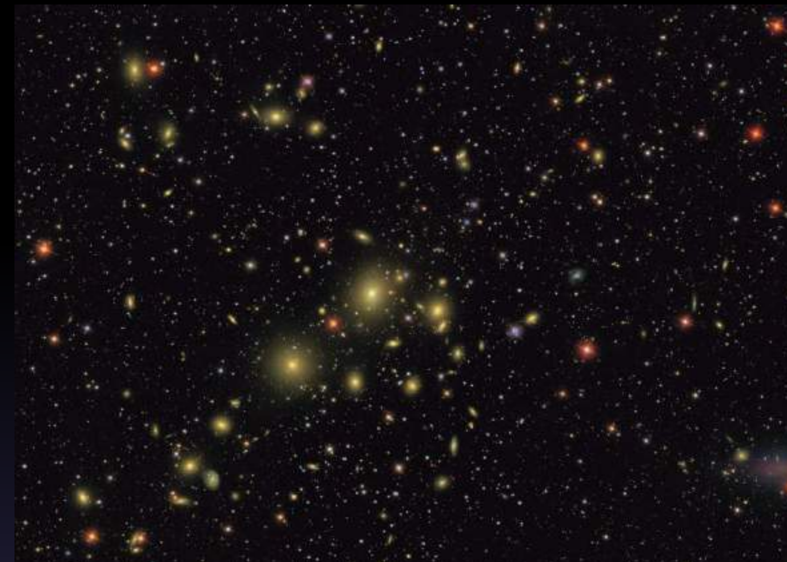


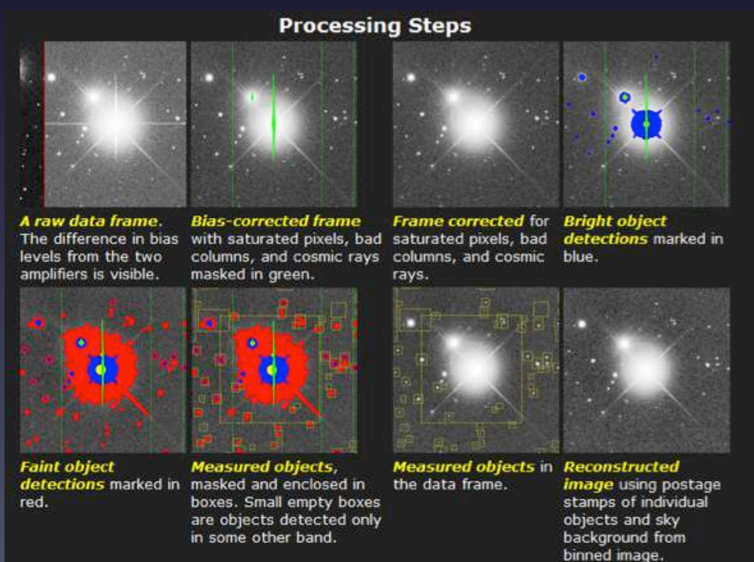


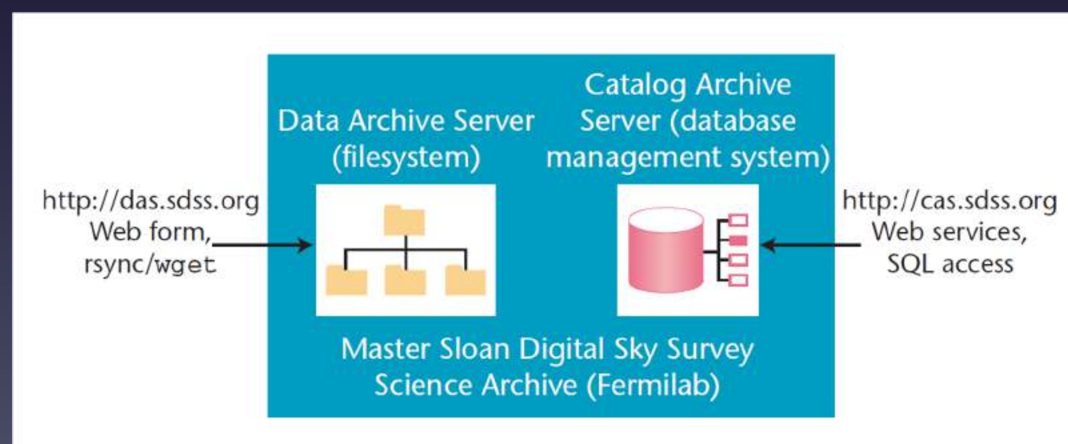
Located at Apache Point Observatory in south east New Mexico.

Latitude 32° 46' 49.30" N
Longitude 105° 49' 13.50" W
Elevation 2788m

Observing With SDSS



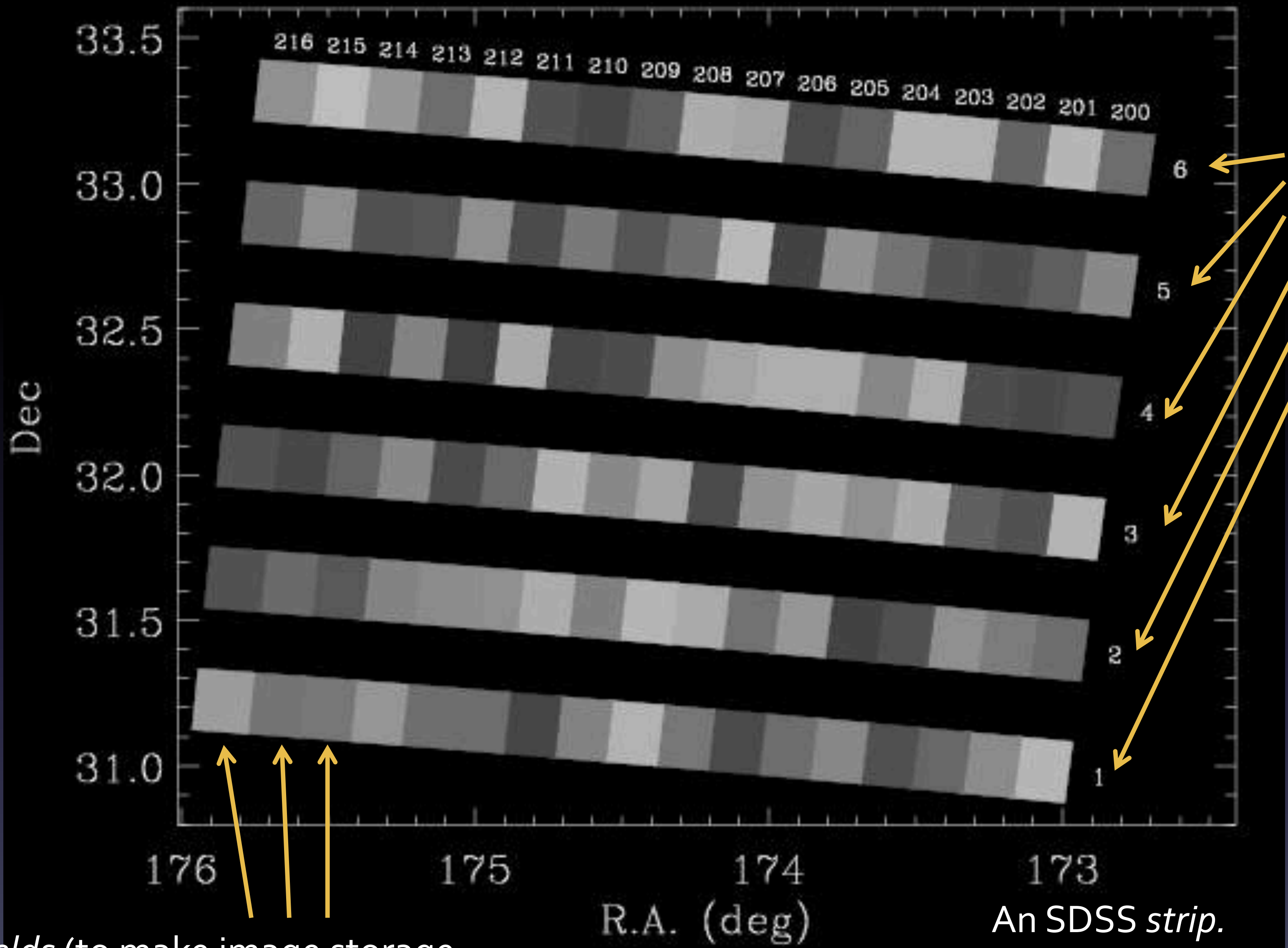




The result? A catalog of object positions and properties.

Observing pattern in one *observing run*.

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



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 field

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
```

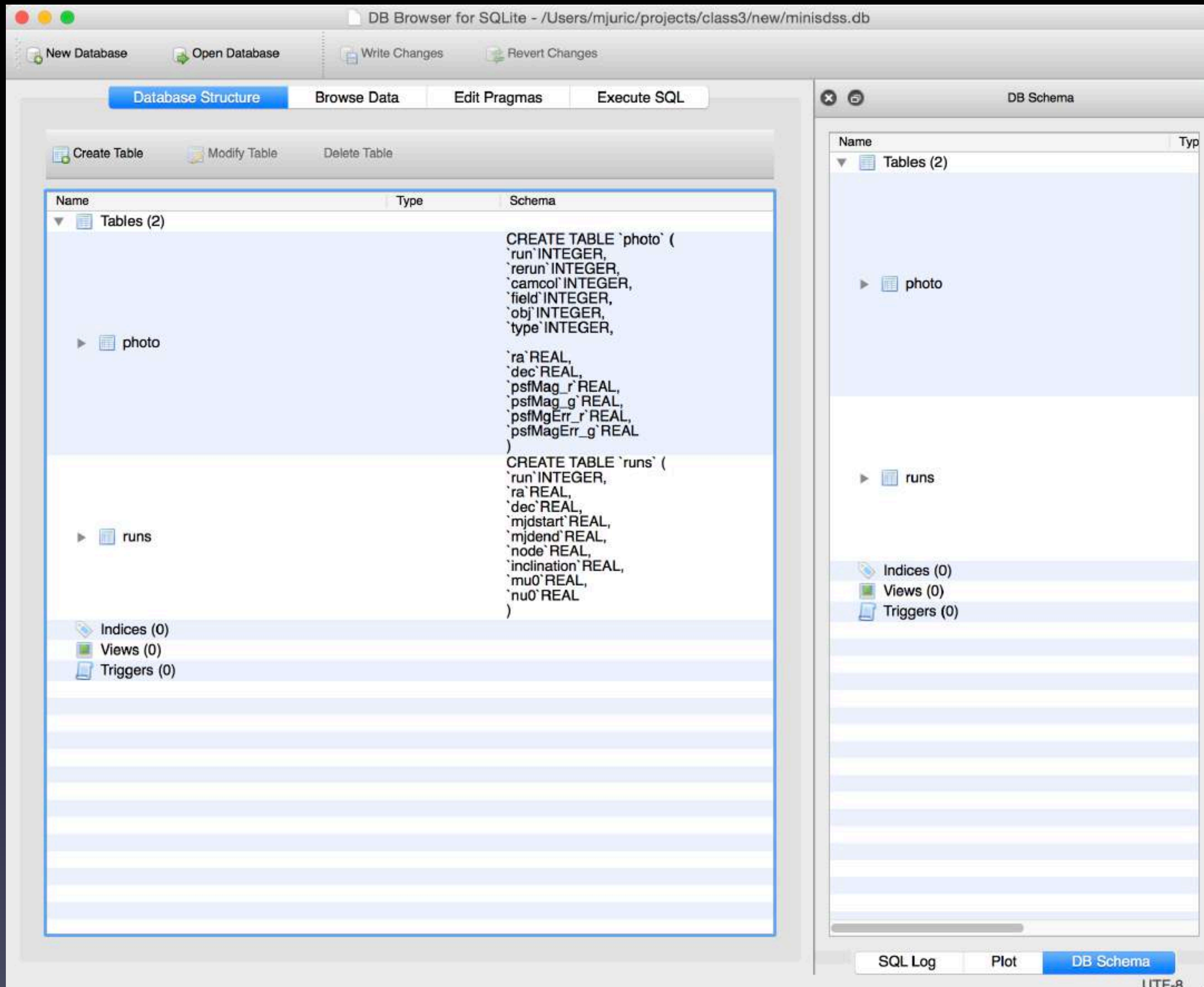
```
   IW   sample.csv
run,rerun,camcol,field,obj,type,ra,dec,psfMag_r,psfMag_g,psfMagErr_r,psfMagErr_g
7757,301,1,74,186,6,8.12944435106658,26.6266172894736,17.04889,18.16535,0.01654805,0.02145229
7757,301,1,74,187,6,8.12783867556709,26.627245975921,17.37402,17.92875,0.02894481,0.02568013
7757,301,1,74,188,3,8.12732322524192,26.6251199416623,20.1466,21.35297,0.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

Another way to think about it

	run	rerun	camcol	field	obj	type	ra	dec	psfMag_r	psfMag_g	psfMgErr_r	psfMagErr_g
1	7757	301	1	74	186	6	8.12944435106658	26.6266172894736	17.04889	18.16535	0.01654805	0.02145229
2	7757	301	1	74	187	6	8.12783867556709	26.627245975921	17.37402	17.92875	0.02894481	0.02568013
3	7757	301	1	74	188	3	8.12732322524192	26.6251199416623	20.1466	21.35297	0.3003744	0.3302762
4	4288	301	1	39	682	3	24.5161170422305	-1.16579446393527	22.97032	24.3259	0.2672399	0.5240437
5	4288	301	1	39	683	3	24.5179406515354	-1.1792069022485	22.62052	25.09109	0.1850479	0.6585805
6	4288	301	1	39	684	6	24.5189463293148	-1.15915086108891	21.4247	23.04125	0.06608655	0.1968172
7	4136	301	1	61	935	6	36.4715922759092	-1.06093938828308	22.71782	23.14112	0.158014	0.1799687
8	4136	301	1	61	936	3	36.4717583013136	-1.1378448207726	22.81683	23.88123	0.1742272	0.3260605
9	4136	301	1	61	937	3	36.4717582434391	-1.13784497192974	22.81147	23.87586	0.1734457	0.3247895
10	4288	301	1	40	311	3	24.6839203338022	-1.23631696217547	21.2002	21.67521	0.05694564	0.06316777
11	4288	301	1	40	312	3	24.6840602692246	-1.21784918362007	20.30287	21.04976	0.02972161	0.04032911
12	4288	301	1	40	313	6	24.6840216690377	-1.08292772289886	24.92263	25.72778	0.68427	0.5471938
13	5598	301	1	61	792	3	351.787950113407	6.14573538435867	22.43574	23.83793	0.1125768	0.2867745
14	5598	301	1	61	793	3	351.787950113434	6.14573538316393	22.43573	23.77753	0.1174541	0.2741905
15	5598	301	1	61	794	6	351.787349107439	6.14481612145222	24.6701	24.8507	0.4675894	0.4849904
16	2699	301	1	48	527	3	12.0760019016408	-3.32677418219699	22.18116	23.27577	0.126546	0.2270369
17	2699	301	1	48	528	6	12.0770027529666	-3.32913243320258	22.12757	23.79366	0.1215217	0.3403472
18	2699	301	1	48	529	3	12.0832728187538	-3.52539818226738	22.29741	23.32008	0.1377919	0.2253349
19	94	301	1	38	279	6	340.524768659138	-0.843090883870374	20.75028	21.13888	0.04839022	0.04644739
20	94	301	1	38	280	6	340.525793656628	-0.965210498356983	24.23321	26.07633	0.8058653	0.7702702
21	94	301	1	38	281	6	340.53257887691	-1.02365035629542	21.10608	21.15248	0.06605724	0.04672106
22	4288	301	1	76	766	3	30.0899167300738	-1.25189466355601	22.57054	22.91144	0.1807321	0.1984752
23	4288	301	1	76	767	3	30.0899962733195	-1.14314301954175	21.99419	23.78533	0.1094794	0.4162939
24	4288	301	1	76	768	6	30.0899156247035	-1.19236549812758	22.64196	22.91776	0.1927483	0.2022232
25	7937	301	1	84	354	3	5.59132226470183	26.6120638856974	22.63659	23.76799	0.2950225	0.5986399
26	7937	301	1	84	355	3	5.58984744314193	26.6157353187021	21.27009	22.13992	0.08808753	0.1490507
27	7937	301	1	84	356	6	5.59007089167375	26.5703384153732	24.52393	26.33231	1.060107	0.6528299
28	3996	301	1	81	615	6	216.223187662076	11.9472286471793	19.93735	21.0716	0.02294876	0.03470354
29	3996	301	1	81	616	3	216.23835672109	12.0534224512804	20.22574	21.24497	0.02592515	0.03942162
30	3996	301	1	81	617	3	216.219379232008	11.9171402588482	22.60762	23.05279	0.1416738	0.1555459
31	6354	301	1	29	2997	6	332.302798261878	41.2179102291468	20.95895	22.51458	0.04065189	0.1163793

	run	ra	dec	mjdstart	mjdend	node	inclination	mu0	nu0
1	7757	357.46468455299	26.2370212084082	54764.3239709	54764.41394614	274.998609	27.501019	358.243550054828	-1.05909244147316
2	7757	357.46468455299	26.2370212084082	54764.3239709	54764.41394614	274.998609	27.501019	358.243550054828	-1.05909244147316
3	7757	357.46468455299	26.2370212084082	54764.3239709	54764.41394614	274.998609	27.501019	358.243550054828	-1.05909244147316
4	4288	380.238668844454	-1.26523112087832	52971.18729258	52971.25695083	303.880318	0.004722	20.2386442030995	-1.26981991214775
5	4288	380.238668844454	-1.26523112087832	52971.18729258	52971.25695083	303.880318	0.004722	20.2386442030995	-1.26981991214775
6	4288	380.238668844454	-1.26523112087832	52971.18729258	52971.25695083	303.880318	0.004722	20.2386442030995	-1.26981991214775
7	4136	388.856034465364	-1.26065974279315	52909.39976125	52909.48434627	298.178935999999	0.003748	28.8560354414983	-1.2644074810812
8	4136	388.856034465364	-1.26065974279315	52909.39976125	52909.48434627	298.178935999999	0.003748	28.8560354414983	-1.2644074810812
9	4136	388.856034465364	-1.26065974279315	52909.39976125	52909.48434627	298.178935999999	0.003748	28.8560354414983	-1.2644074810812
10	4288	380.238668844454	-1.26523112087832	52971.18729258	52971.25695083	303.880318	0.004722	20.2386442030995	-1.26981991214775
11	4288	380.238668844454	-1.26523112087832	52971.18729258	52971.25695083	303.880318	0.004722	20.2386442030995	-1.26981991214775
12	4288	380.238668844454	-1.26523112087832	52971.18729258	52971.25695083	303.880318	0.004722	20.2386442030995	-1.26981991214775
13	5598	344.238636905503	5.74983273927427	53625.27321874	53625.35282817	274.996656	7.501585	344.342565351909	-1.26845524360177
14	5598	344.238636905503	5.74983273927427	53625.27321874	53625.35282817	274.996656	7.501585	344.342565351909	-1.26845524360177
15	5598	344.238636905503	5.74983273927427	53625.27321874	53625.35282817	274.996656	7.501585	344.342565351909	-1.26845524360177
16	2699	8.30257828310911	-3.5540225263115	52224.230625	52224.26213706	95.0783329999999	2.521424	8.29689813728684	-1.03658149355183
17	2699	8.30257828310911	-3.5540225263115	52224.230625	52224.26213706	95.0783329999999	2.521424	8.29689813728684	-1.03658149355183
18	2699	8.30257828310911	-3.5540225263115	52224.230625	52224.26213706	95.0783329999999	2.521424	8.29689813728684	-1.03658149355183
19	94	336.432779182593	-1.04429400326262	51075.2332107	51075.45501377	286.855205	0.009477	336.432666780969	-1.05150869113324
20	94	336.432779182593	-1.04429400326262	51075.2332107	51075.45501377	286.855205	0.009477	336.432666780969	-1.05150869113324
21	94	336.432779182593	-1.04429400326262	51075.2332107	51075.45501377	286.855205	0.009477	336.432666780969	-1.05150869113324
22	4288	380.238668844454	-1.26523112087832	52971.18729258	52971.25695083	303.880318	0.004722	20.2386442030995	-1.26981991214775
23	4288	380.238668844454	-1.26523112087832	52971.18729258	52971.25695083	303.880318	0.004722	20.2386442030995	-1.26981991214775
24	4288	380.238668844454	-1.26523112087832	52971.18729258	52971.25695083	303.880318	0.004722	20.2386442030995	-1.26981991214775
25	7937	354.472804463739	26.0412875302237	54860.11386787	54860.21213575	275.000158	27.497623	355.5503099727	-1.05616288462878
26	7937	354.472804463739	26.0412875302237	54860.11386787	54860.21213575	275.000158	27.497623	355.5503099727	-1.05616288462878
27	7937	354.472804463739	26.0412875302237	54860.11386787	54860.21213575	275.000158	27.497623	355.5503099727	-1.05616288462878
28	3996	207.595387665781	12.8326165550169	52812.15484032	52812.26596182	94.989552	14.999812	207.004726466407	-1.05589411128374
29	3996	207.595387665781	12.8326165550169	52812.15484032	52812.26596182	94.989552	14.999812	207.004726466407	-1.05589411128374
30	3996	207.595387665781	12.8326165550169	52812.15484032	52812.26596182	94.989552	14.999812	207.004726466407	-1.05589411128374
31	6354	329.999491928276	43.4733027947383	53994.16457295	53994.2935236401	178.712578999999	64.500878	308.24909302415	-1.05954433833196

1. For each row in the sources table, append the corresponding row from the runs table.
2. This results in an expanded, "joined", table.
3. Now select any the columns we need from this expanded table (with SELECT)…
4. (… and also filter it using a WHERE clause, if needed).

JOIN: Joining tables

The columns we're interested in.

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

- SELECT

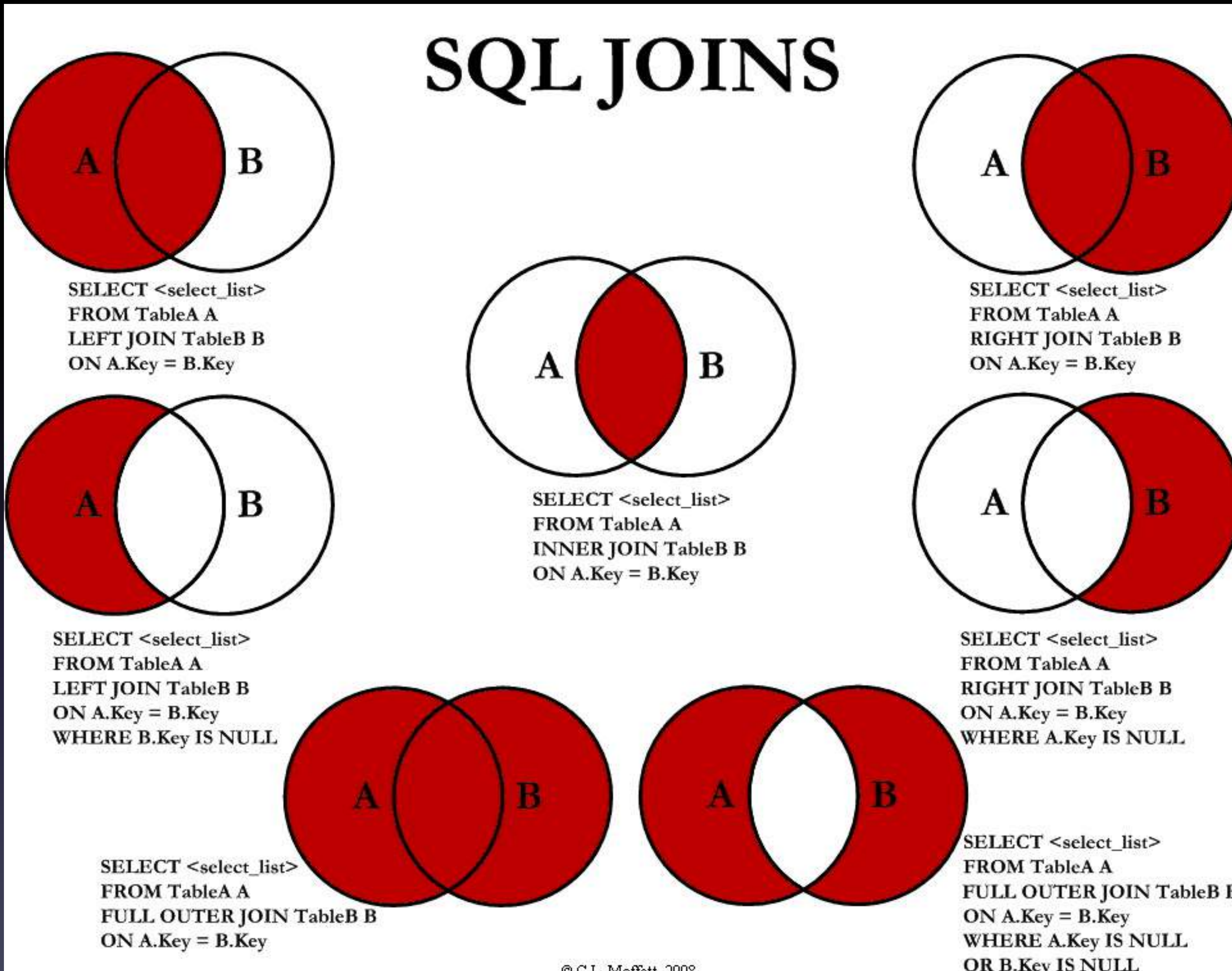
  sources.ra, sources.dec, sources.run, mjdstart

  FROM

  sources JOIN runs ON sources.run = runs.run

The tables we'll join

Instructions how to perform the join



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