AST1501 - Introduction to Research

Jo Bovy

How to access astronomical data

Overview

- Types of astronomical data
- Data from individual papers
- Small data sets
- Large data sets
- Cross-matching

Types of astronomical data

Types of astronomical data

- Focus in this class: public data sets useful for your work
- Table in a paper
- Small data sets: online-only table in a paper, small survey
    - CDS
- Large data sets: large surveys
    - Dedicated tools
    - Astroquery

Table in a paper

Name	Period (d)	Mass (kg)	Average orbit radius (km)	Astronomical unit (1 AU)	Radius weights (r_i)	Angular velocity (ω)
Mercury	87.969	0.3301×10^{24}	56 672 443.84	0.38709893	4.69091E-05	26.08840762
Venus	224.701	4.8676×10^{24}	108 207 517.8	0.72333199	0.001320004	10.21344422
Earth	365.256	5.9726×10^{24}	149 579 112	1.00000011	0.002238882	6.2831853
Mars	686.98	0.64174×10^{24}	226 923 421.8	1.52366231	0.000363432	3.340666584
Jupiter	4332.587	1898.3×10^{24}	777 657 818.7	5.20336301	3.699505551	0.529699953
Saturn	10 759.22	568.36×10^{24}	1 431 426 696	9.53707032	2.038821640	0.213302742
Uranus	30 685.4	86.816×10^{24}	2 869 262 907	19.1912393	0.624274378	0.074790328
Neptune	60 189.0	102.42×10^{24}	4 494 894 315	30.48168677	1.153633570	0.038129411
Pluto	90 465.0	0.0131×10^{24}	5 720 641 564	39.48168677	1.88377E-04	0.025368608

Note: These are basic data from NASA.

You find a useful (small) table in a paper, now what?

- IOP journals
  (ApJ, ApJS, AJ, ApJL, PASP)
    - All tables available in ASCII format!

Name	Period (d)	Mass (kg)	Average orbit radius (km)	Astronomical unit (1 AU)	Radius weights (r_i)	Angular velocity (ω)
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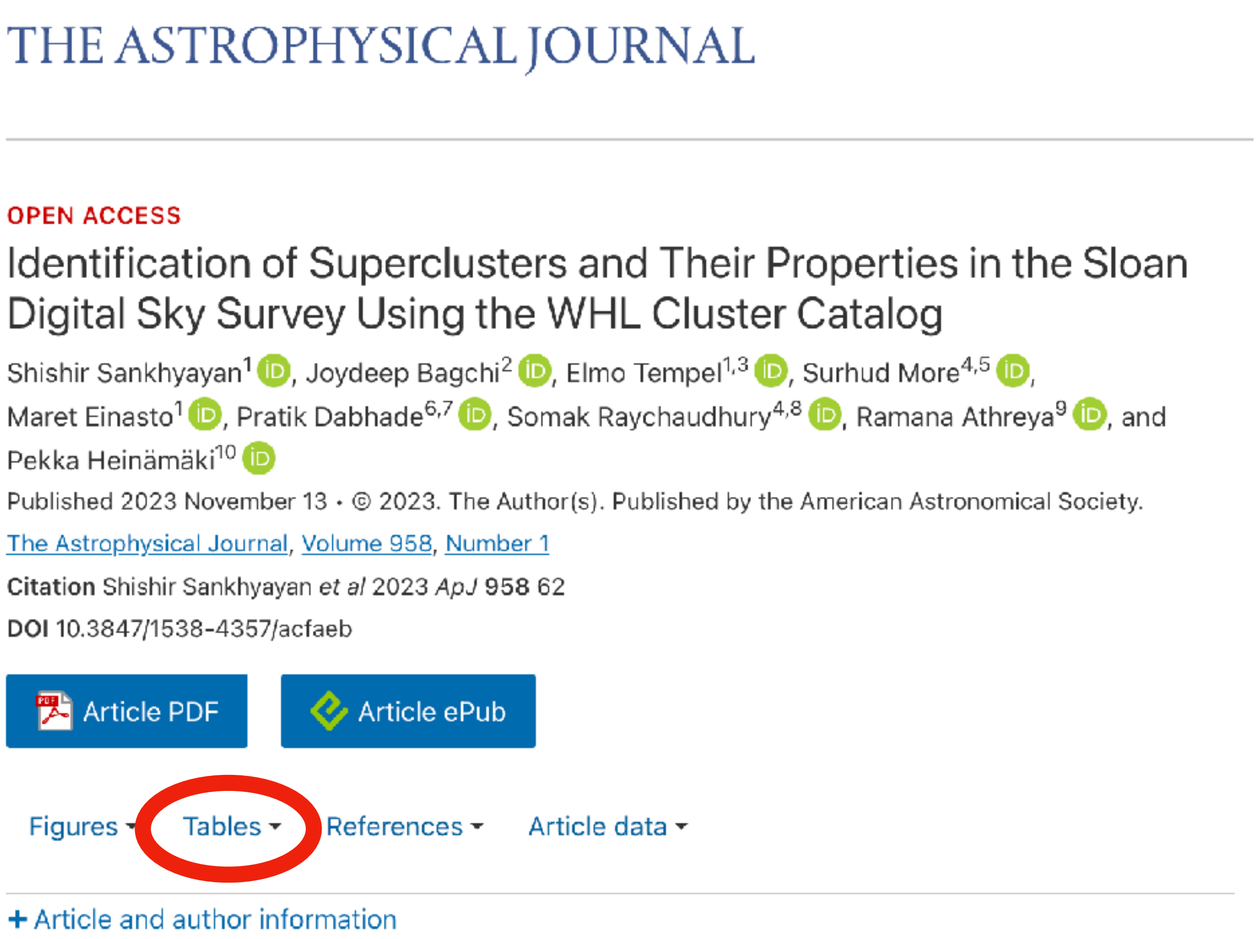

THE ASTROPHYSICAL JOURNAL

OPEN ACCESS

Identification of Superclusters and Their Properties in the Sloan Digital Sky Survey Using the WHL Cluster Catalog

Shishir Sankhyayan[1], Joydeep Bagchi[2], Elmo Tempel[1,3], Surhud More[4,5], Maret Einasto[1], Pratik Dabhade[6,7], Somak Raychaudhury[4,8], Ramana Athreya[9], and Pekka Heinämäki[10]

Published 2023 November 13 • © 2023. The Author(s). Published by the American Astronomical Society.

The Astrophysical Journal, Volume 958, Number 1

Citation Shishir Sankhyayan *et al* 2023 *ApJ* **958** 62

DOI 10.3847/1538-4357/acfaeb

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Figures Tables References Article data

+ Article and author information

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  - All tables available in ASCII format!

DOI 10.3847/1538-4357/acfaeb

Article PDF Article ePub

Figures ▾ Tables ▾ References ▾ Article data ▾

Skip to each table in the article

Their Masses

e	Mass	$N_{\rm mem}$	$N_{\rm Abells}$
c)	($10^{14}\,M_\odot$)		
)	(8)	(9)	(10)
10	257.106	54	2
59	255.164	57	7
40	210.629	41	10
50	196.421	38	1
10	191.222	44	0

luma (2): R.A. Column (3): decl. Column (4): R.A. of
mn: (6): redshift. Column (7): linear comoving size.
ent.

Table 3
Summary of the Properties of the Observed and Mock Superclusters

	WHL ($0.05 \leqslant z \leqslant 0.42$)	WHL ($0.05 \leqslant z \leqslant 0.366$)	Mock ($0.05 \leqslant z \leqslant 0.366$)
Linking Length l_o (Mpc)	20.65	19.22	19.88
Number of Superclusters	662	456	451
Median Mass ($10^{14}\,M_\odot$)	57.80	55.97	46.43
Median Size (Mpc)	64.87	60.49	60.83
Median Density Contrast	11.64	15.40	10.88
Median No. of Members	13	13	12

Table 3

superclusters covering a wide range of redshifts and sky areas is essential. Here, we present a large

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Table 3. Summary of the Properties of the Observed and Mock Superclusters

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Download table as: ASCII Typeset image

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      ASCII format!

Table 3
Summary of the Properties of the Observed and Mock Superclusters

	WHL (0.05 <or=z <or=0.42)	WHL (0.05 <or=z <or=0.366)	Mock (0.05 <or=z <or=0.366)
Linking Length l _o (Mpc)	20.65	19.22	19.88
Number of Superclusters	662	456	451
Median Mass (10^14 M _sun)	57.80	55.97	46.43
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Median Density Contrast	11.64	15.40	10.88
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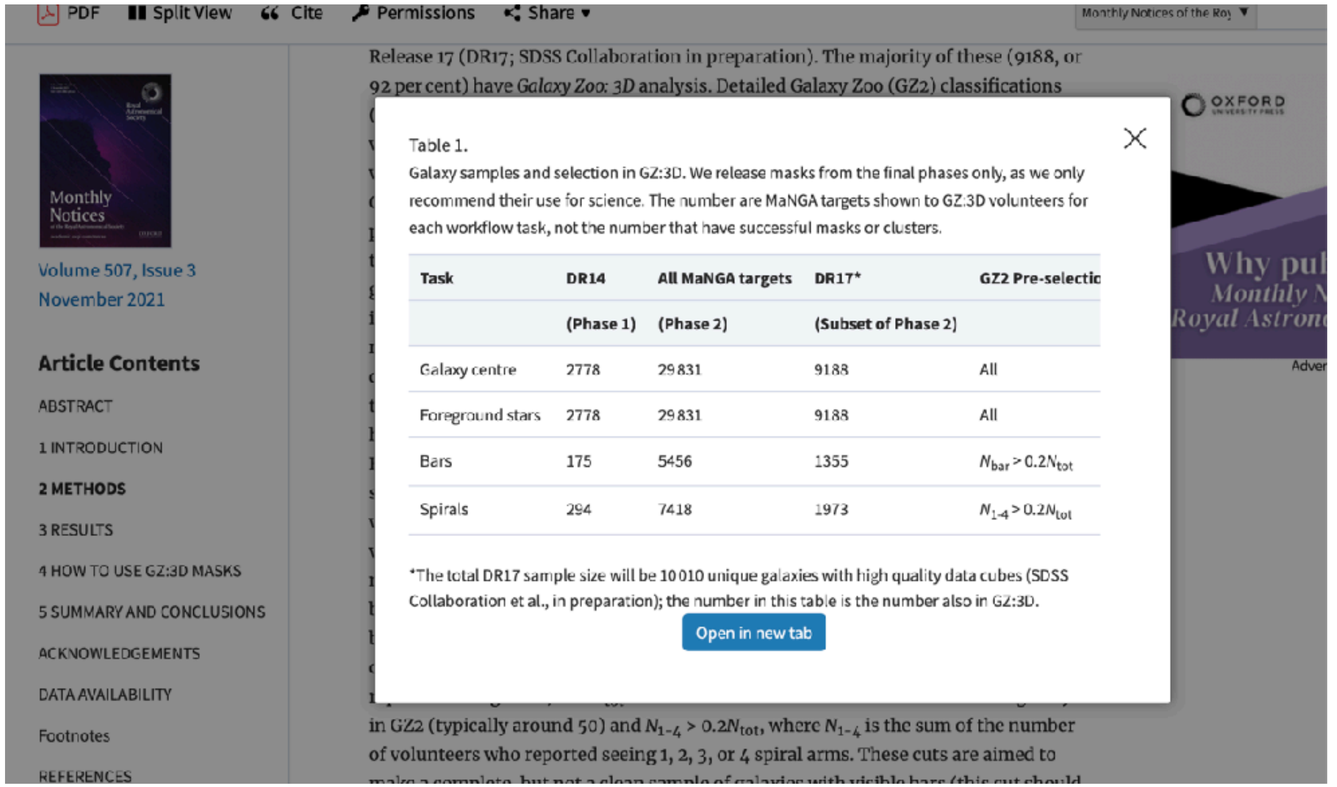
- Other journals: no machine-readable version generally available



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  machine-readable version
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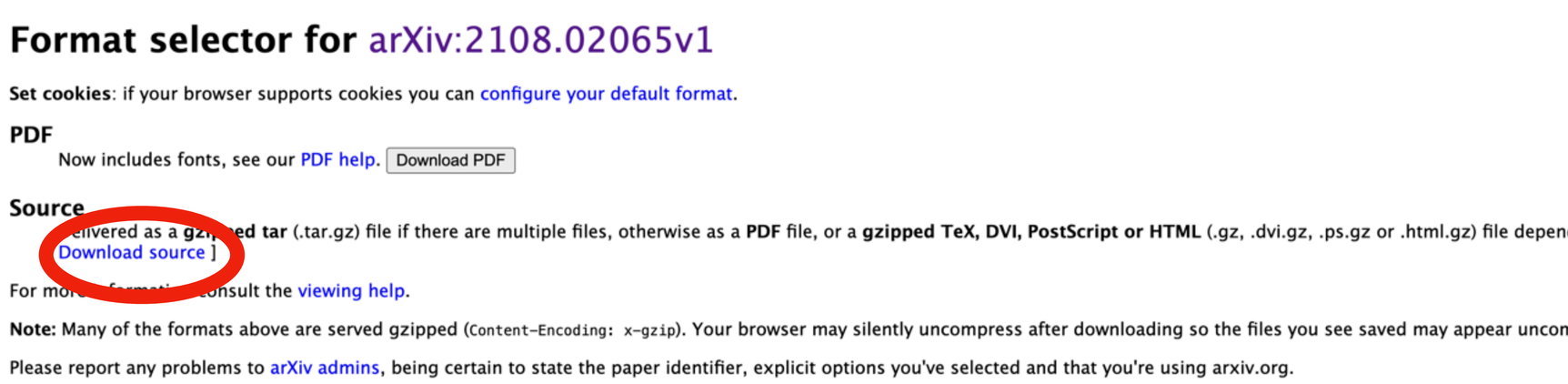
    - Download source (rename .zip)



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```
\begin{table*}
\caption{\label{tab:samples}Galaxy samples and selection in GZ:3D. We release ma
sks from the final phases only, as we only recommend their use for science. The
number are MaNGA targets shown to GZ:3D volunteers for each workflow task, not t
he  number which have successful masks or clusters. The total DR17 sample size w
ill be 10,010 unique galaxies with high quality data cubes (SDSS Collaboration e
t al. in prep.); the number in this table is the number also in GZ:3D.}
\begin{tabular}{lcccc}
Task & DR14  & All MaNGA targets  & DR17$^*$  & GZ2 Pre-selection \\
& (Phase 1) & (Phase 2) & (Subset of Phase 2) & \\
\hline
Galaxy Centre & 2778 & 29831 & 9188 & All \\
Foreground Stars & 2778 & 29831 & 9188 & All \\
Bars & 175 & 5456 & 1355 & $N_{\rm bar} > 0.2N_{\rm tot}$\\
Spirals & 294 & 7418 & 1973 & $N_{\rm 1-4} > 0.2N_{\rm tot}$ \\
\end{tabular}
\end{table*}
```

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- Other journals: no machine-readable version generally available
    - Can go to arXiv
    - Download source (rename .zip)
    - Copy and read with `astropy`

```
In [1]: from astropy.io import ascii

In [2]: table= r"""
   ...: \begin{table*}
   ...: \caption{\label{tab:samples}Galaxy samples and selection in GZ:3D. We re
   ...: lease masks from the final phases only, as we only recommend their use f
   ...: or science. The number are MaNGA targets shown to GZ:3D volunteers for e
   ...: ach workflow task, not the  number which have successful masks or cluste
   ...: rs. The total DR17 sample size will be 10,010 unique galaxies with high
   ...: quality data cubes (SDSS Collaboration et al. in prep.); the number in t
   ...: his table is the number also in GZ:3D.}
   ...: \begin{tabular}{lcccc}
   ...: Task & DR14  & All MaNGA targets  & DR17$^*$  & GZ2 Pre-selection \\
   ...: & (Phase 1) & (Phase 2) & (Subset of Phase 2) & \\
   ...: \hline
   ...: Galaxy Centre & 2778 & 29831 & 9188 & All \\
   ...: Foreground Stars & 2778 & 29831 & 9188 & All \\
   ...: Bars & 175 & 5456 & 1355 & $N_{\rm bar} > 0.2N_{\rm tot}$\\
   ...: Spirals & 294 & 7418 & 1973 & $N_{\rm 1-4} > 0.2N_{\rm tot}$ \\
   ...: \end{tabular}
   ...: \end{table*}
   ...: """

In [3]: tab= ascii.read(table)

In [4]: tab
Out[4]:
<Table length=5>
      Task           DR14    ...        GZ2 Pre-selection
     str16           str9    ...               str30
---------------- --------- ... ------------------------------
              --  (Phase 1) ...                             --
   Galaxy Centre      2778 ...                            All
Foreground Stars      2778 ...                            All
            Bars       175 ... $N_{\rm bar} > 0.2N_{\rm tot}$
         Spirals       294 ... $N_{\rm 1-4} > 0.2N_{\rm tot}$
```

Small data sets

Small, machine-readable data sets

- Extended table in a paper
  “Only a portion of this table is shown here to demonstrate its form and content. A machine-readable version of the full table is available.”

Table 1. Properties of 85,686 Groups and Clusters Extracted from the WHL Cluster Catalog within the Redshift Range $0.05 \le z \le 0.42$

ID	RA	Decl.	z	R_{200c}	M_{200c}	SCI
	(deg)	(deg)		(Mpc)	($10^{14}\ M_{\odot}$)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
J000000.6+321233	0.00236	32.20925	0.1274	1.72	5.9478	0
J000002.3+051718	0.00957	5.28827	0.1694	0.94	1.9627	0
J000003.5+314708	0.01475	31.78564	0.0916	0.94	1.6766	0
J000004.7+022826	0.01945	2.47386	0.4179	0.95	0.4769	0
J000006.0+152548	0.02482	15.42990	0.1731	1.13	1.5391	0

Note. Columns (1)–(4) are taken from the WHL catalog and columns (5)–(7) have been computed in the current paper (see Sections 3 and 4). Column (1): cluster identifier. Column (2): R.A. of the brightest cluster galaxy (BCG). Column (3): decl. of the BCG. Column (4): redshift of the BCG. Column (5): R_{200c} of the cluster. Column (6): M_{200c} of the cluster. Column (7): supercluster number to which the cluster belongs. SCI = 0 means the cluster is not a part of any supercluster.

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```
Title: Identification of Superclusters and their Properties in the Sloan
       Digital Sky Survey Using WHL Cluster Catalog
Authors: Sankhyayan S., Bagchi J., Tempel E., More S., Einasto M., Dabhade P.,
         Raychaudhury S., Athreya R., Heinamaki P.
Table: Properties of the WHL clusters used in this work
================================================================================
Byte-by-byte Description of file: apjacfaebt1_mrt.txt
--------------------------------------------------------------------------------
   Bytes Format Units     Label  Explanations
--------------------------------------------------------------------------------
   1- 16 A16    ---       ID     Cluster identifier as given in WH15
  18- 26 F9.5   deg       RAdeg  Right Ascension in decimal degrees of the BCG (J2000)
  28- 36 F9.5   deg       DEdeg  Declination in decimal degrees of the BCG (J2000)
  38- 43 F6.4   ---       z      Redshift of the BCG
  45- 48 F4.2   Mpc       R200c  Radius of sphere where matter density is
                                   200 times the critical density
  50- 56 F7.4   10+14Msun M200c  Mass within a sphere of radius R200c
  58- 60 I3     ---       SCl    Supercluster number
--------------------------------------------------------------------------------
J000000.6+321233   0.00236  32.20925 0.1274 1.72  5.9478   0
J000002.3+051718   0.00957   5.28827 0.1694 0.94  1.9627   0
J000003.5+314708   0.01475  31.78564 0.0916 0.94  1.6766   0
J000004.7+022826   0.01945   2.47386 0.4179 0.95  0.4769   0
J000006.0+152548   0.02482  15.42990 0.1731 1.13  1.5391   0
J000006.3+221220   0.02643  22.20558 0.3985 0.84  0.9030   0
J000006.6+100648   0.02755  10.11333 0.3747 0.93  1.8814   0
J000006.6+315235   0.02762  31.87626 0.2092 1.18  1.9203   0
J000006.6+292129   0.02765  29.35813 0.2489 0.92  1.0586   0
J000007.1-092910   0.02957  -9.48607 0.3332 0.80  1.3679   0
J000007.6+155003   0.03177  15.83424 0.1527 1.17  3.3484   0
J000007.7+185245   0.03208  18.87909 0.4085 1.03  2.3615   0
J000008.0+343316   0.03350  34.55436 0.2346 1.05  0.8036   0
J000008.6+085715   0.03580   8.95418 0.2799 0.88  1.2017   0
J000009.4+211655   0.03905  21.28191 0.2997 1.31  3.0975   0
J000000.0+230241   0.04154  23.04467 0.3778 1.06  1.4712 230
J000010.7+134747   0.04439  13.79632 0.1992 0.80  0.4341   0
J000011.4-092850   0.04770  -9.48058 0.4100 0.89  1.3098   0
J000012.6+103806   0.05238  10.63509 0.1694 1.43  3.7158 233
J000012.7+341335   0.05276  34.22628 0.2542 0.96  0.6371   0
J000012.8+070555   0.05317   7.09848 0.1290 0.89  0.8818   0
J000014.2+355136   0.05906  35.86013 0.2606 0.93  1.3806   0
J000015.0+081513   0.06265   8.25366 0.3113 0.98  1.0363   0
J000015.8+223812   0.06595  22.63655 0.3701 1.03  1.5920 230
J000016.9+235043   0.07057  23.84517 0.3106 0.93  0.8565   0
J000017.4-061436   0.07246  -6.24328 0.2921 0.87  0.9014   0
J000017.4+215540   0.07258  21.93041 0.3976 0.93  2.5386   0
```

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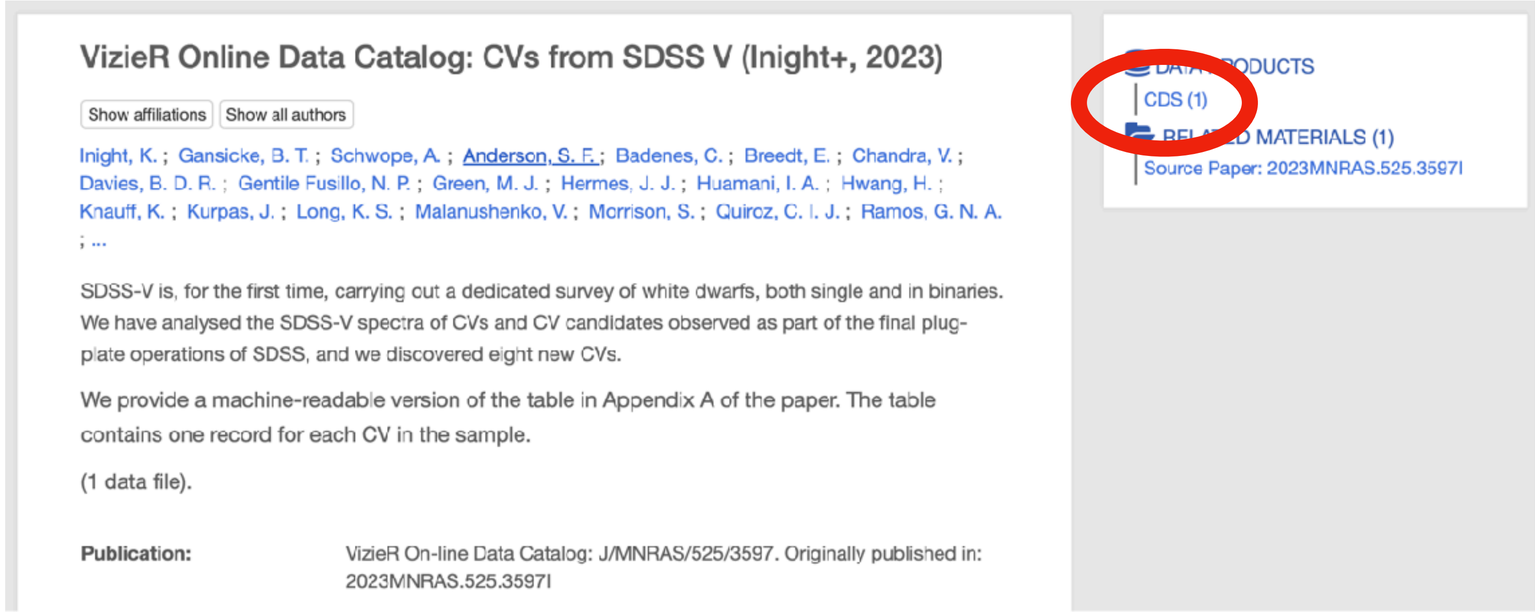
- ViZier Online Data Catalogs



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J/MNRAS/525/3597 CVs from SDSS V (Inight+, 2023)

Cataclysmic variables from Sloan Digital Sky Survey.
V. The search for period bouncers continues.
Inight K., Gansicke B.T., Schwope A., Anderson S.F., Badenes C., Breedt E., Chandra V., Davies B.D.R., Gentile Fusillo N.P., Green M.J., Hermes J.J., Huamani I.A., Hwang H., Knauff K., Kurpas J., Long K.S., Malanushenko V., Morrison S., Quiroz C.I.J., Ramos G.N.A., Roman-Lopes A., Schreiber M.R., Standke A., Stutz L., Thorstensen J.R., Toloza O., Tovmassian G., Zakamska N.L.
<Mon. Not. R. Astron. Soc., 525, 3597-3625 (2023)>
=2023MNRAS.525.3597I (SIMBAD/NED BibCode)

ADC_Keywords: Binaries, cataclysmic ; Photometry, SDSS ; Binaries, orbits ; Stars, white dwarf
Keywords: dwarf novae - cataclysmic variables - white dwarfs

Abstract:
SDSS-V is carrying out a dedicated survey for white dwarfs, single and in binaries, and we report the analysis of the spectroscopy of 118 cataclysmic variables (CVs) and CV candidates obtained during the final plug plate observations of SDSS. We identify eight new CVs, spectroscopically confirm 53 and refute eleven published CV candidates, and we report 21 new or improved orbital periods. The

Byte-by-byte Description of file: tablea1.dat

Bytes	Format	Units	Label	Explanations
1- 19	A19	---	SDSS	Unique reference for the SDSS object (JHHMMSS.ss+DDMMSS.s)
21- 49	A29	---	Name	Other name (where available)
51- 69	I19	---	GaiaEDR3	The unique source_id of the Gaia EDR3 counterpart source_id
71- 81	F11.8	h	Per	? Orbital period in hours
83- 92	F10.8	h	e_Per	? Error on orbital period
94	A1	---	n_Per	[:*] Note on Per (1)
96-100	F5.2	mag	Gmag	G-band magnitude from the Gaia EDR3 survey
102-105	I4	pc	Distance	? Distance from Bailer-Jones et al. (2021AJ....161..147B, Cat. I/352)
107-117	A11	---	VType	Classification using the taxonomy defined in the paper (2)
119-132	A14	---	Cartons	Cartons (3)
136-162	A27	---	Ref-disc	BibCode of the earliest identification of this CV
164-182	A19	---	Ref-sp	BibCode of the first published spectrum
184-204	A21	---	Ref-P	BibCode of the source of the orbital period
206-223	F18.14	deg	RAdeg	Right ascension (J2000)
225-243	F19.15	deg	DEdeg	Declination (J2000)

Note (1): Note on Per as follows:

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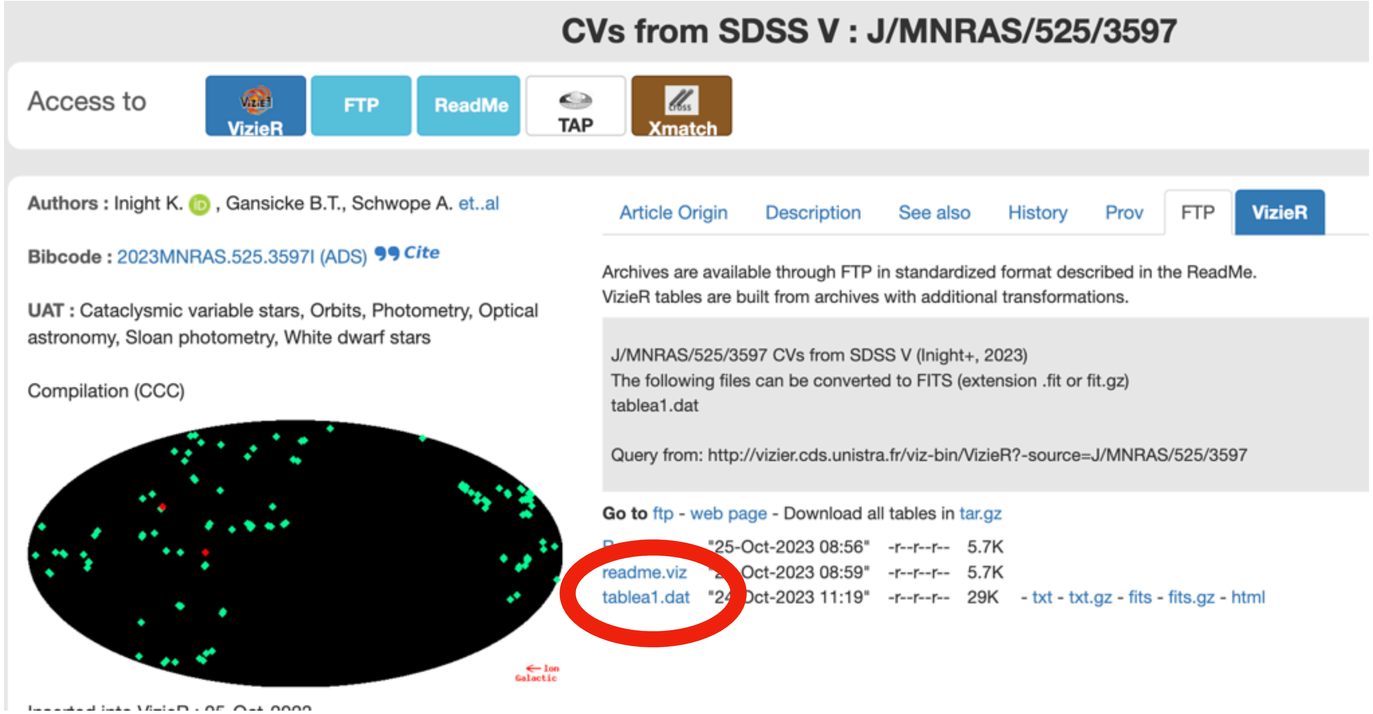

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  is available.”

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```
J000600.15+012129.8                              2738755406045571968  1.52       0.10       |19.57  352 WZ Sge:PS : gg,u2,wd        *This work
work             1.50064345676278   1.35827514714031
J003827.05+250925.0 1RXS J003828.7+250920        2806802123399581056  2.26826    0.00002    |18.63  503 SU UMa      cv,gg,u1,u2      *VSNET 12318
et al in prep   9.61272342040272  25.1569563739546
J003941.08+005427.5 SDSS J003941.06+005427.5     2543387617312121216  1.523      0.002      |20.76 1078 WZ Sge:     cv,u1,u2,u4      2005AJ....129.2386S
2010A&A...524A..86S     9.92118587245779   0.907630946264153
J004335.16-003729.7 SDSS J004335.14-003729.8     2530961280492678528  1.3721     0.0014     |19.85  447 WZ Sge:     cv,gg,u2,wd      2004AJ....128.1882S
2008MNRAS.391..591S    10.8965127441555   -0.624919920328629
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work            25.6128096966956    0.291604463777139
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2005ApJ...620..422S    28.9311192294966    0.468710388240133
J020712.72-014116.3 SDSSJ020712.71-014116.2      2494386992562185088  1.55       0.15       |20.27       Polar:     cv               2023MNRAS.524.4867I
work            31.8030160472918   -1.68784823887102
J020809.57+565239.7                               505110900157013376                         |18.77 2961 CV          u4               2021A&A...648A..44M
32.0398758932033   56.8777045605961
J021008.33+571121.0 UV Per                        457106501671769472  1.557      0.003      |17.75  250 SU UMa      cv               1985AJ.....90.1837S
1997PASP..109.1359T    32.5347258071429   57.1891648736762
J021315.48+533822.9 MASTER OT J021315.37+533822.7  455380951309048320  2.549      0.007     *|20.05 3224 SU UMa      cv               2013ATel.5536....1Y
2017PASJ...69...75K    33.3145094962966   53.6396813044143
J022102.79+732245.0 ASASSN-14jq                   546910213373341184  1.32427    0.00031   *|19.94  425 WZ Sge      cv,gg,wd         *ASAS-SN CV candidate
2015PASJ...67..105K    35.2616338626198   73.3791783513299
J022623.34+711831.5 AM Cas                        545338083544363392  3.9576     0.0003     |14.37  420 U Gem       cv,gg,u1,u2      1988AN....309...91R
1996PASP..108..894T    36.5972449914027   71.3087570542901
J023322.61+005059.4 HP Cet                        2500552912036565120  1.601      0.002      |20.12  683 WZ Sge:PS : cv               2002AJ....123..430S
2006MNRAS.373..687S    38.3442161025676    0.849827971521724
J024131.07+593630.5 ASASSN-16jv                   464373929923792384                         |19.84  607 U Gem       cv               *ASAS-SN CV candidate
40.3794706143822   59.6084629440548
```

Read with `astropy`

ApJ table

```
[In [1]: from astropy.io import ascii

[In [2]: tab= ascii.read("apjacfaebt1_mrt.txt",format='cds')

[In [3]: tab
 Out[3]:
 <Table length=85686>
        ID           RAdeg     DEdeg       z      R200c     M200c      SCl
                       deg       deg                 Mpc   1e+14 Msun
      str16         float64   float64   float64  float64   float64    int64
 ---------------- --------- -------- ------- ------- ---------- -----
 J000000.6+321233   0.00236 32.20925  0.1274    1.72     5.9478     0
 J000002.3+051718   0.00957  5.28827  0.1694    0.94     1.9627     0
 J000003.5+314708   0.01475 31.78564  0.0916    0.94     1.6766     0
 J000004.7+022826   0.01945  2.47386  0.4179    0.95     0.4769     0
 J000006.0+152548   0.02482  15.4299  0.1731    1.13     1.5391     0
 J000006.3+221220   0.02643 22.20558  0.3985    0.84      0.903     0
 J000006.6+100648   0.02755 10.11333  0.3747    0.93     1.8814     0
 J000006.6+315235   0.02762 31.87626  0.2092    1.18     1.9203     0
 J000006.6+292129   0.02765 29.35813  0.2489    0.92     1.0586     0
 J000007.1-092910   0.02957 -9.48607  0.3332     0.8     1.3679     0
 J000007.6+155003   0.03177 15.83424  0.1527    1.17     3.3484     0
 J000007.7+185245   0.03208 18.87909  0.4085    1.03     2.3615     0
 J000008.0+343316    0.0335 34.55436  0.2346    1.05     0.8036     0
 J000008.6+085715    0.0358  8.95418  0.2799    0.88     1.2017     0
```

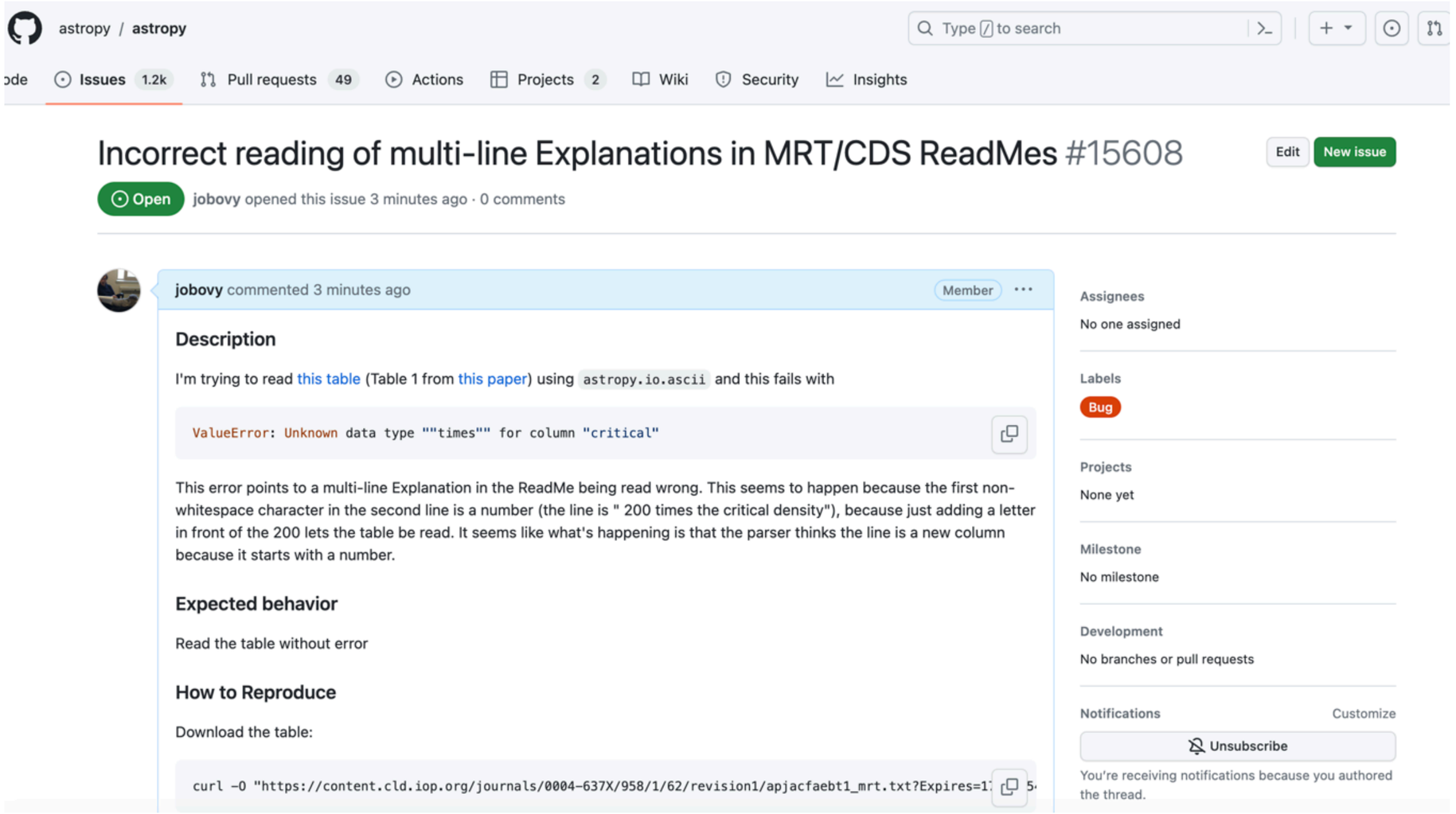
Read with `astropy`

ApJ table

```
[In [1]: from astropy.io import ascii                                          ]

[In [2]: tab= ascii.read("apjacfaebt1_mrt.txt",format='cds')                   ]
WARNING: UnitsWarning: 'the' did not parse as cds unit: At col 0, Unit 'the' not
 supported by the CDS SAC standard. Did you mean TH, Te, Th or he? If this is me
ant to be a custom unit, define it with 'u.def_unit'. To have it recognized insi
de a file reader or other code, enable it with 'u.add_enabled_units'. For detail
s, see https://docs.astropy.org/en/latest/units/combining_and_defining.html [ast
ropy.units.core]
---------------------------------------------------------------------------
KeyError                                  Traceback (most recent call last)
File ~/miniforge3/envs/py310/lib/python3.10/site-packages/astropy/io/ascii/core.
py:721, in BaseHeader.get_col_type(self, col)
    720     type_map_key = self.get_type_map_key(col)
--> 721     return self.col_type_map[type_map_key.lower()]
    722 except KeyError:

KeyError: 't'

During handling of the above exception, another exception occurred:

ValueError                                Traceback (most recent call last)
Input In [2], in <cell line: 1>()
----> 1 tab= ascii.read("apjacfaebt1_mrt.txt",format='cds')

File ~/miniforge3/envs/py310/lib/python3.10/site-packages/astropy/io/ascii/ui.py
:426, in read(table, guess, **kwargs)
    424     else:
    425         reader = get_reader(**new_kwargs)
--> 426         dat = reader.read(table)
    427         _read_trace.append(
    428             {
    429                 "kwargs": copy.deepcopy(new_kwargs),
   (...)
  File ~/miniforge3/envs/py310/lib/python3.10/site-packages/astropy/io/ascii/core.
  py:723, in BaseHeader.get_col_type(self, col)
      721     return self.col_type_map[type_map_key.lower()]
j     722 except KeyError:
  --> 723     raise ValueError(
      724         f'Unknown data type ""{col.raw_type}"" for column "{col.name}"'
      725     )

  ValueError: Unknown data type ""times"" for column "critical"

 [In [3]:                                                                      ]
```

Read with `astropy`

ApJ table



Read with `astropy`

CDS table

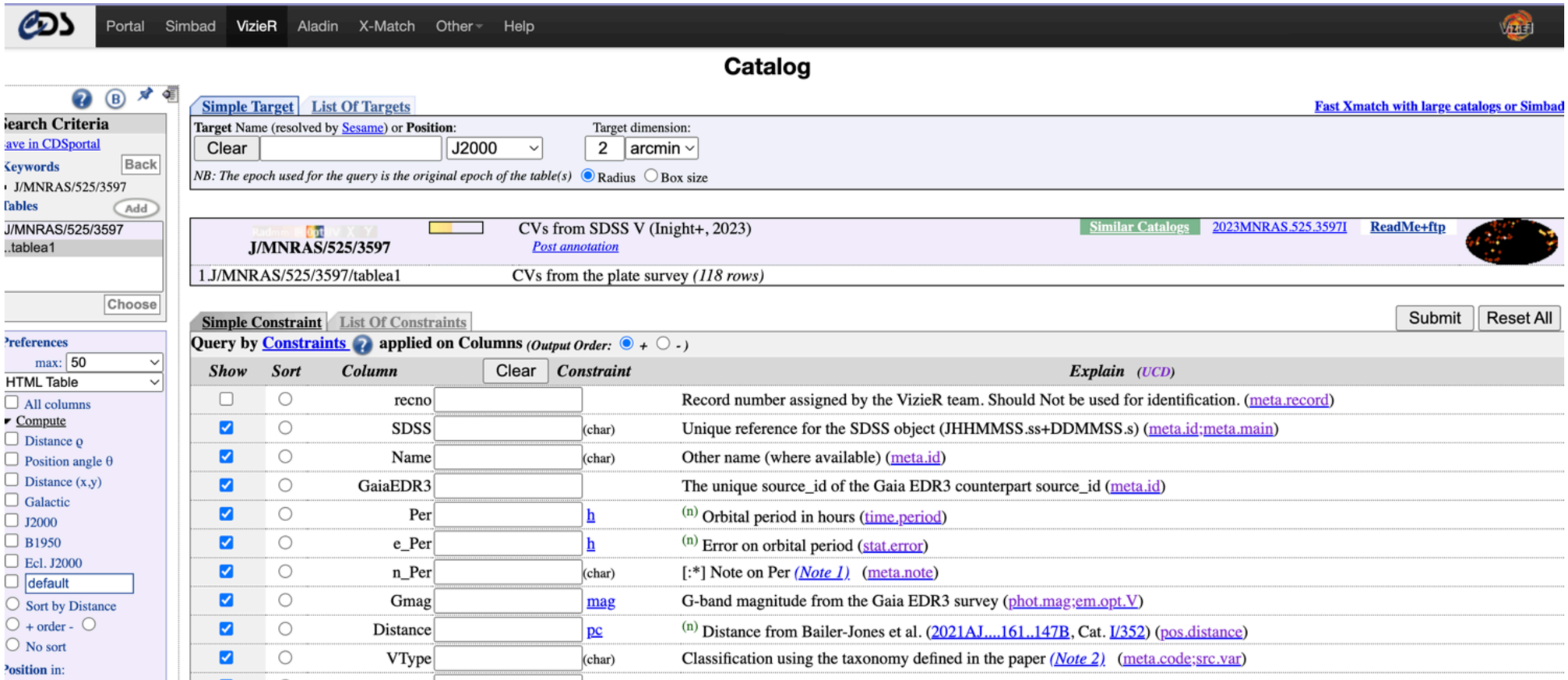
- Download the ReadMe and the data file

```
[In [1]: from astropy.io import ascii

[In [2]: tab= ascii.read("tablea1.dat",format='cds',readme='ReadMe')

[In [3]: tab
 Out[3]:
 <Table length=118>
         SDSS                       Name              ...       DEdeg
                                                      ...         deg
        str19                      str29              ...       float64
 ------------------- ------------------------------ ... ------------------
 J000600.15+012129.8                             -- ...   1.35827514714031
 J003827.05+250925.0          1RXS J003828.7+250920 ...   25.1569563739546
 J003941.08+005427.5       SDSS J003941.06+005427.5 ...  0.907630946264153
 J004335.16-003729.7       SDSS J004335.14-003729.8 ... -0.624919920328629
 J014227.07+001729.8                             -- ...  0.291604463777139
 J015543.47+002807.4                      FL Cet ...  0.468710388240133
 J020712.72-014116.3        SDSSJ020712.71-014116.2 ...  -1.68784823887102
 J020809.57+565239.7                             -- ...   56.8777045605961
 J021008.33+571121.0                      UV Per ...   57.1891648736762
 J021315.48+533822.9 MASTER OT J021315.37+533822.7 ...   53.6396813044143
 J022102.79+732245.0                    ASASSN-14jq ...   73.3791783513299
 J022623.34+711831.5                      AM Cas ...   71.3087570542901
 J023322.61+005059.4                      HP Cet ...  0.849827971521724
 J024131.07+593630.5                    ASASSN-16jv ...   59.6084629440548
 J040834.99+511448.2                      FO Per ...   51.2467108817714
 J041844.44+510731.2                      NS Per ...   51.1253428797512
 J042609.34+354144.5 MASTER OT J042609.34+354144.8 ...   35.6957043579609
                 ...                            ... ...               ...
 J183052.72+265514.9                    MGAB-V733 ...   26.9208015070436
 J183211.36+615505.9                    ASASSN-13ah ...   61.9183113412746
 J192914.75+202759.5                      NQ Vul ...   20.4665332884149
 J192927.83+202035.0          1RXS J192926.6+202038 ...    20.343046807248
```

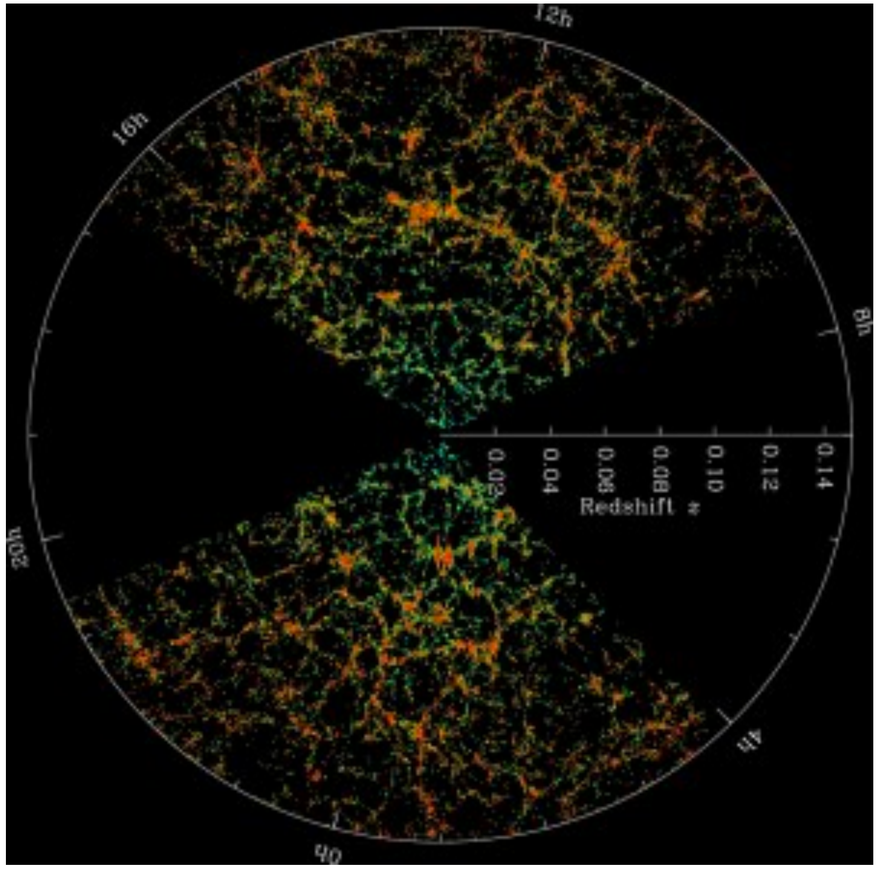
- (In javascript, use https://github.com/jobovy/vizier.js)

CDS best practices

- For reproducibility, always use the full files if you can
- Don’t use the query interface aside from experimentation:



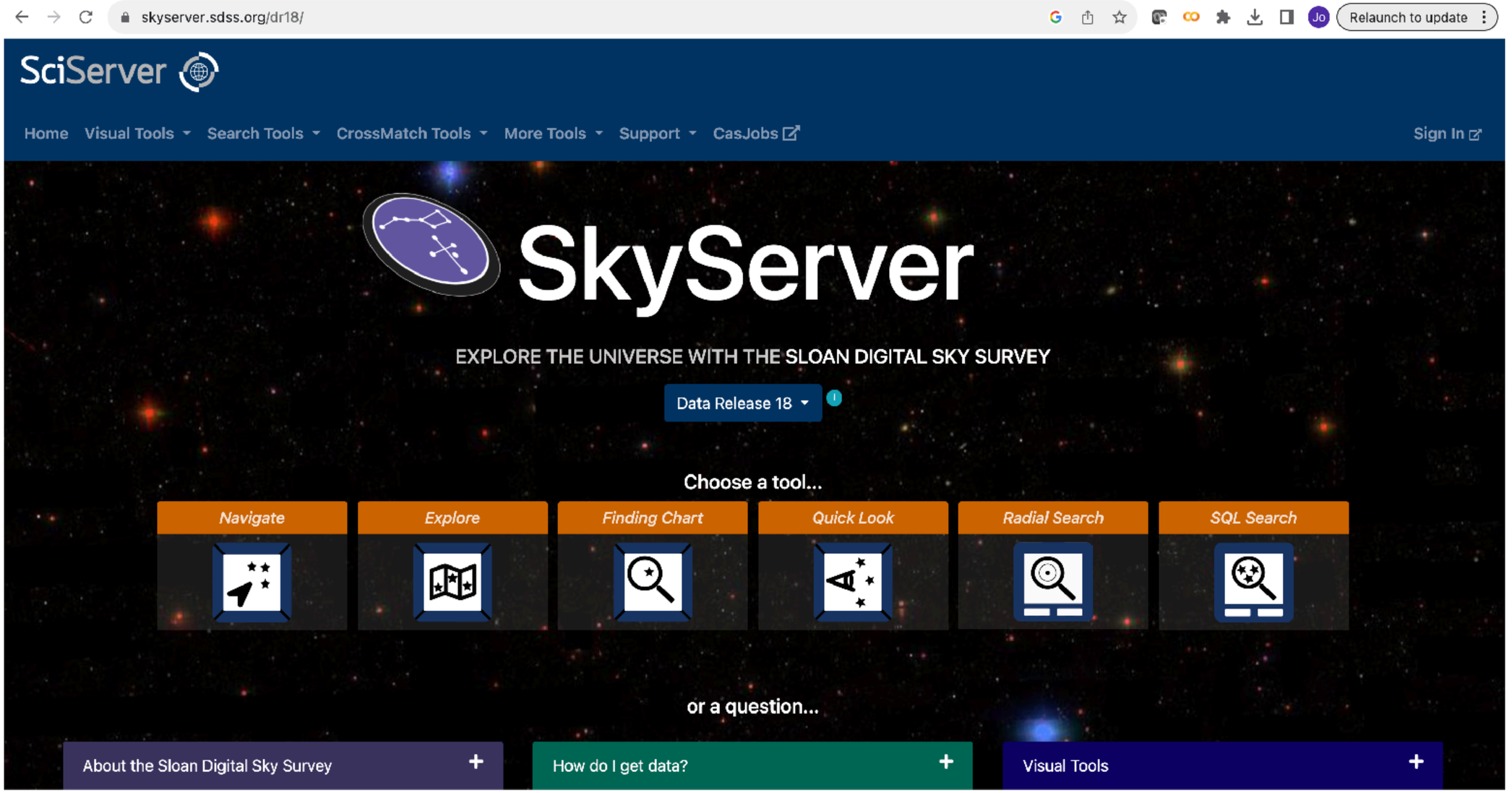
Large data sets



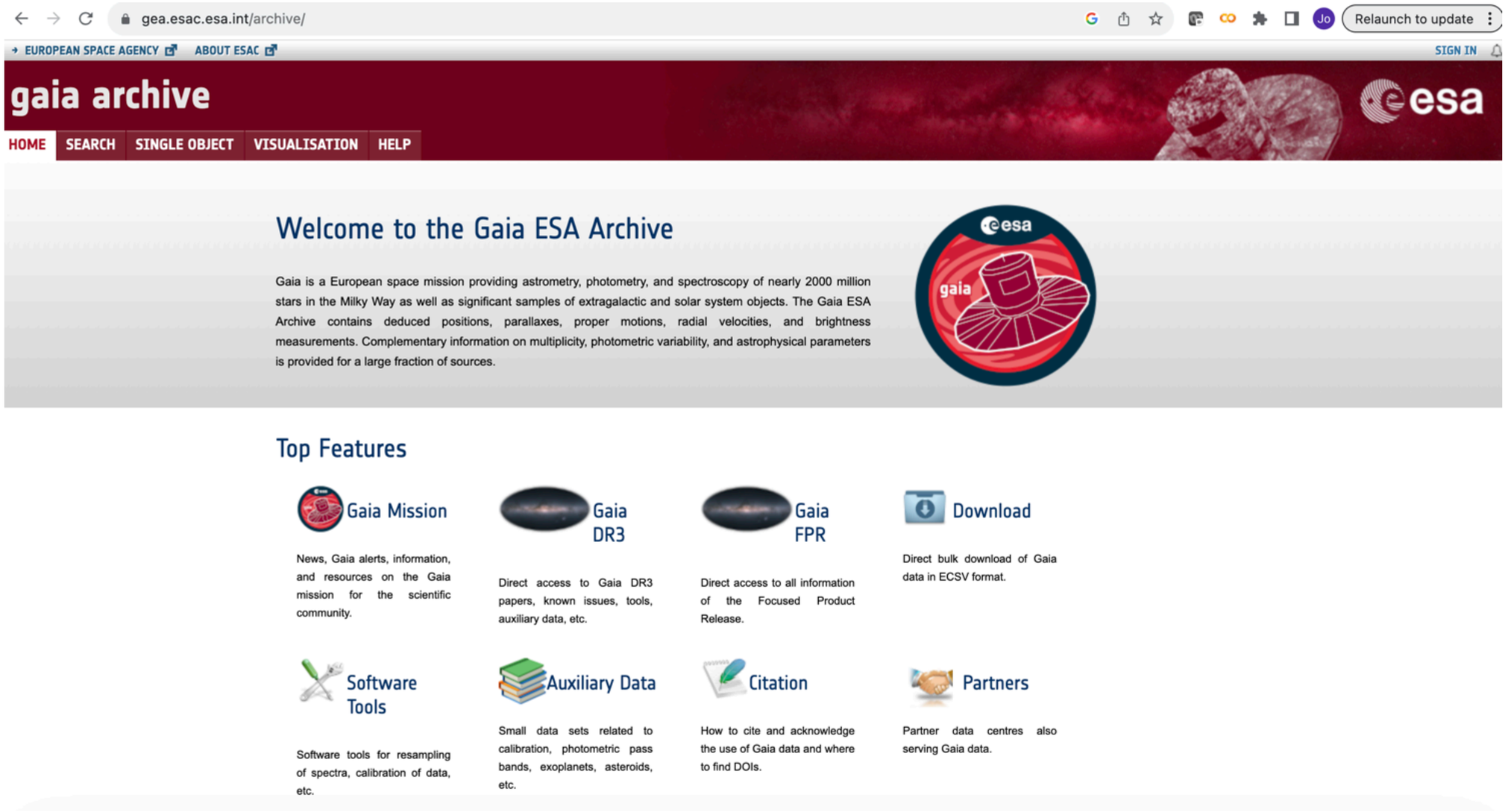
Large survey data

- Astrophysics has many large surveys and more so over time
    - E.g., SDSS (+APOGEE/MaNGA), 2MASS, Gaia, DES, DESI, LAMOST, PanSTARRS, WISE, FIRST, GALEX, Fermi
      Future: Rubin, Euclid, SKA, etc.
- Most efficient way to interact with collection of many objects is a *database*
- Databases can be search using SQL (Structured Query Language) or an astro-extension of it ADQL (Astronomical Data Query Language)
- Surveys often contain their own data + helpful data from other surveys in one database

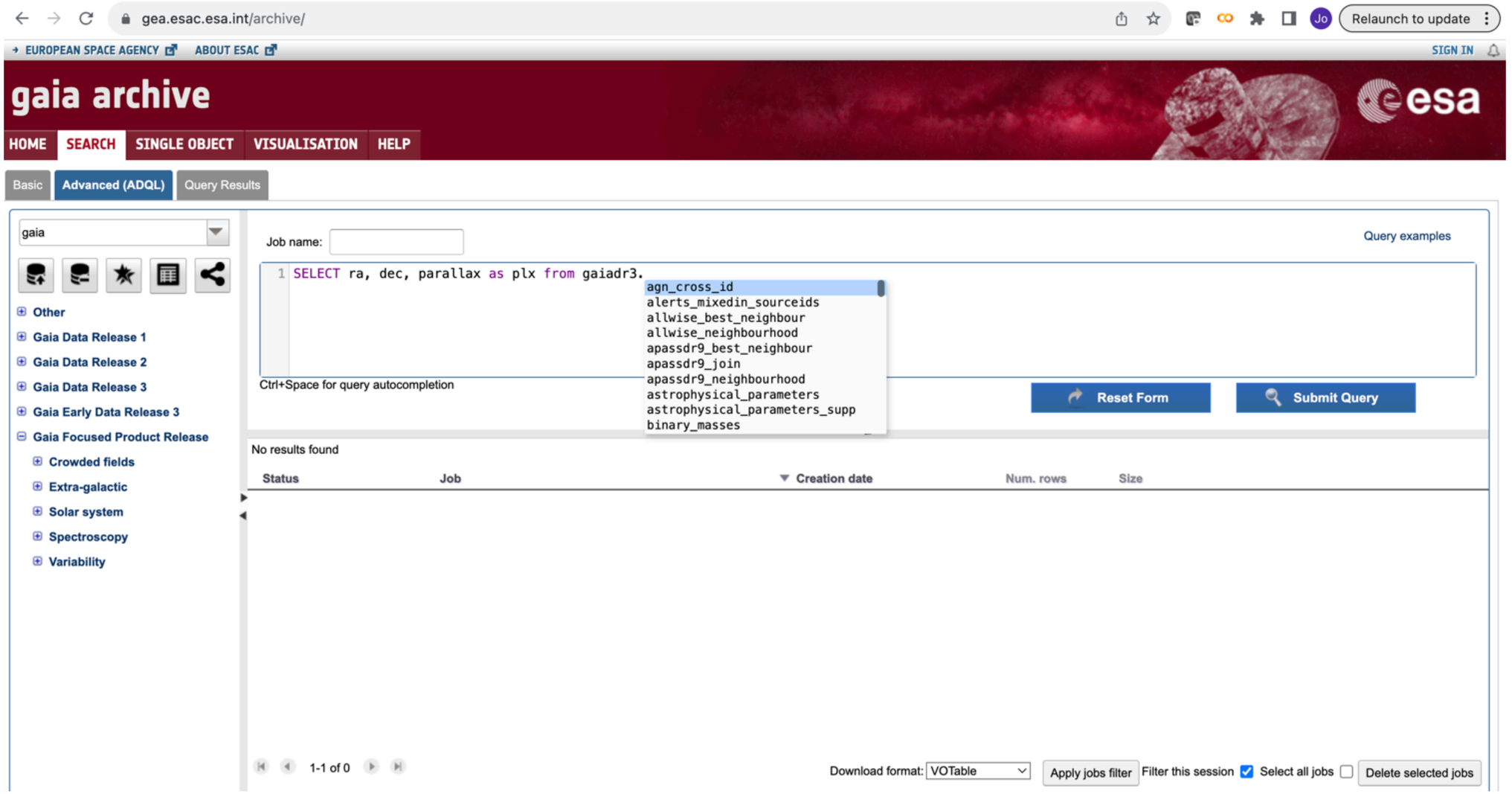
Example: SDSS



Example: Gaia



Example: Gaia



Very basic SQL

- Start query with SELECT then say what you want and what you want if FROM

```
SELECT ra, dec FROM PhotoPrimary
SELECT top 10 ra, dec, psfmag_i-extinction_i AS mag_i FROM
SpecPhoto
```

- Add constraints (WHERE) and JOIN on other table

```
SELECT p.ra, p.dec, s.psfmag_i-s.extinction_i AS mag_i
FROM PhotoPrimary AS p
JOIN SpecPhoto AS s ON p.objID = s.objID
WHERE (s.class='QSO')
```

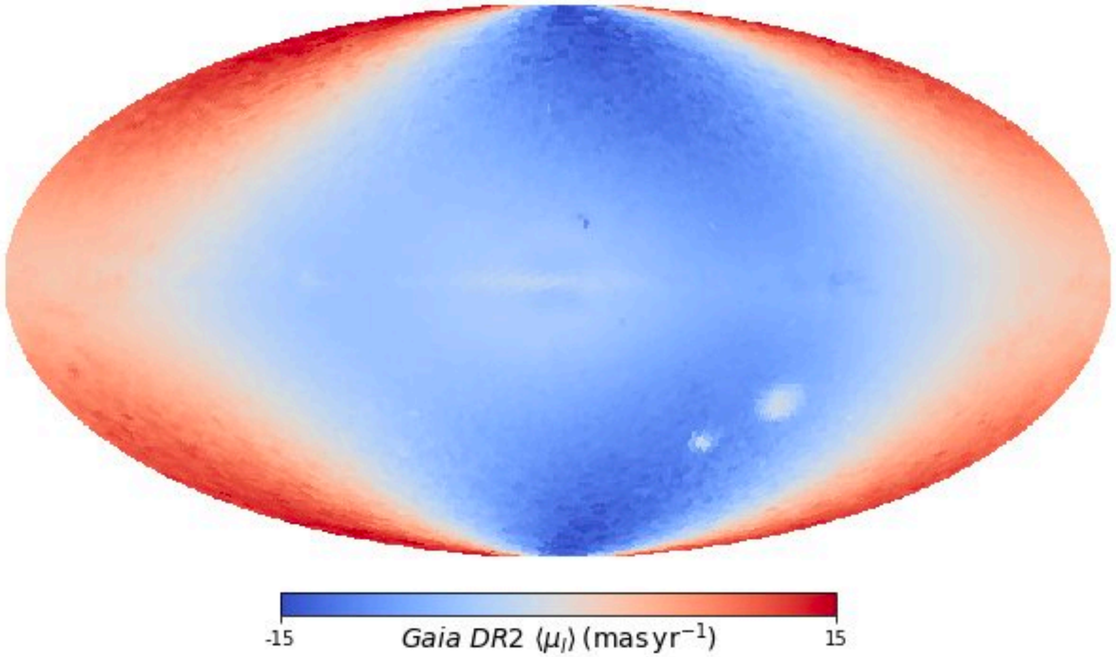
More advanced SQL

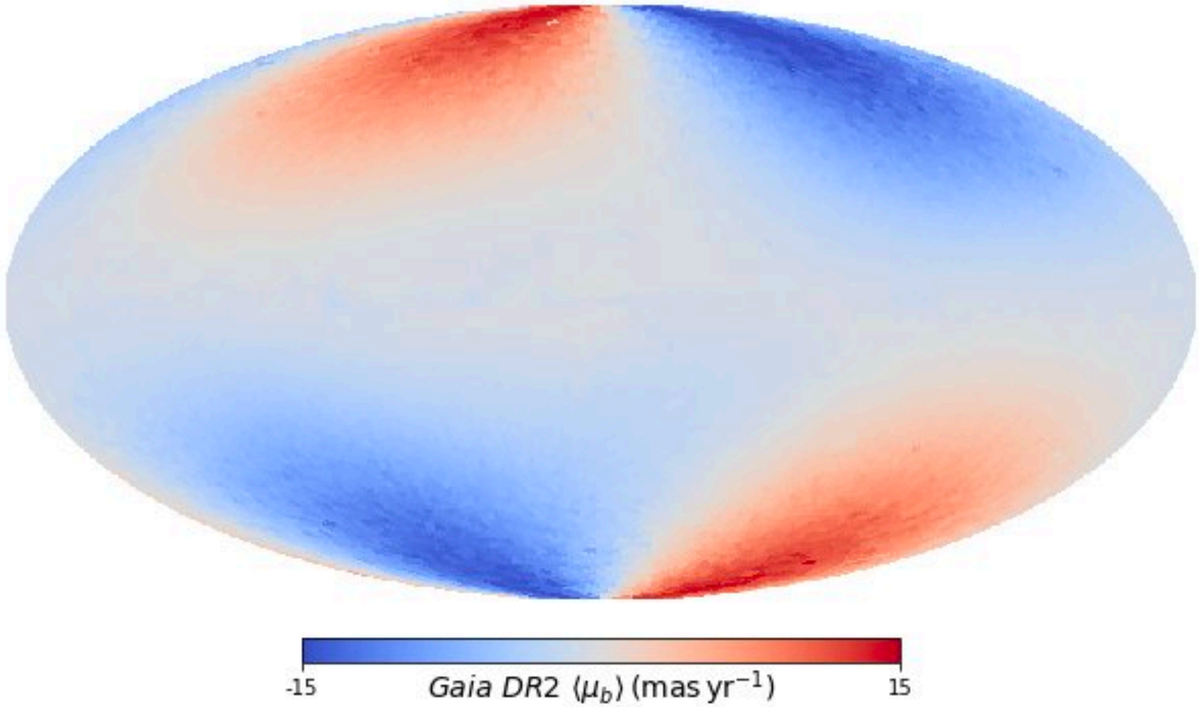
- Very powerful, e.g., can do calculations and histograms (Gaia example)

```
SELECT hpx5, AVG((c1*pmra+c2*pmdec)/cos(b_rad)) AS mpmll,
AVG((-c2*pmra+c1*pmdec)/cos(b_rad)) AS mpmbb
FROM (
          SELECT source_id/562949953421312 as hpx5,
          pmra, pmdec, radians(b) as b_rad, parallax,
          0.4559838136873017*cos(radians(dec))
          -0.8899880682656 28*sin(radians(dec))
          *cos(radians(ra-192.85947789477598)) as c1,
          0.8899880682656 28*sin(radians(ra-192.85947789477598)) as c2
          FROM gaiadr2.gaia_source
          WHERE phot_g_mean_mag < 17.
) tab
GROUP BY hpx5
```

- ADQL adds functions to do things like calculate offsets on the sky

More advanced SQL





astroquery

- Convenient Python interface to many astronomical data sets

```
python -m pip install -U --pre astroquery
```

- E.g., SDSS

```
from astroquery.sdss import SDSS
query = f"""select top 1 r-extinction_r as r0
FROM PhotoObjAll
WHERE objid=1237668367999172911"""
res= SDSS.query_sql(query,data_release=17)
print(f"The observed r-band magnitude is {res['r0']
[0]:.2f}")
```

astroquery

- Convenient Python interface to many astronomical data sets

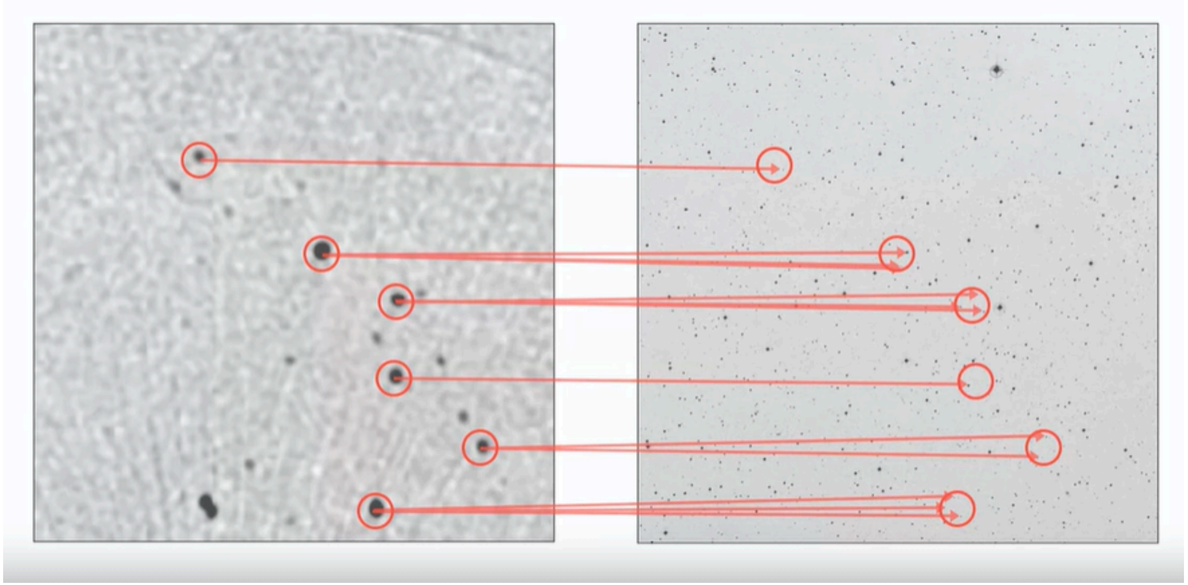
  ```
  python -m pip install -U --pre astroquery
  ```

- E.g., Gaia

```
>>> from astroquery.gaia import Gaia
>>> job = Gaia.launch_job_async("select top 100 designation,ra,dec "
...                             "from gaiadr3.gaia_source order by source_id")
INFO: Query finished. [astroquery.utils.tap.core]
>>> r = job.get_results()
>>> print(r)
     DESIGNATION               ra                 dec
                              deg                deg
--------------------- ----------------- --------------------
   Gaia DR3 4295806720  44.99615537864534 0.005615226341865997
  Gaia DR3 34361129088  45.00432028915398 0.021047763781174733
  Gaia DR3 38655544960 45.004978371745516 0.019879675701858644
 Gaia DR3 309238066432  44.99503714416301  0.03815169755425531
               ...
Length = 100 rows
```

- astroquery caches and is great for reproducibility

Cross-matching

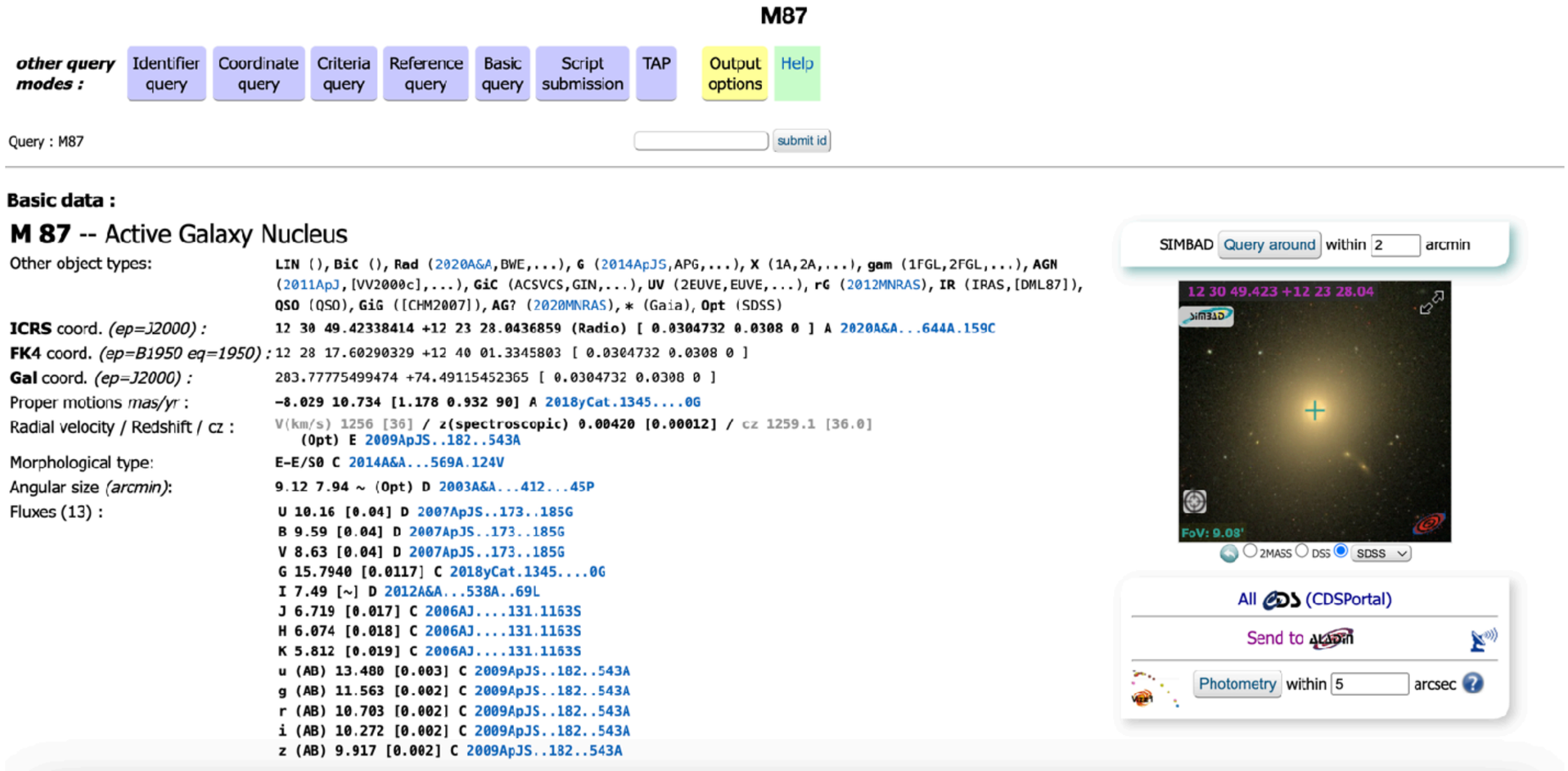


Cross-matching

- Every time you point a telescope at the sky, you have to figure out where it's pointing and what's in it
- Cross-matching is non-trivial because of resolution/crowding, proper motion, SEDs, …
- Typically, cross-matching is done by 2D position, requiring a close match in RA and Dec, but can also use magnitude/color or other properties —> expensive for large surveys

Finding all data on a single object

- Easiest using Simbad, either web:



Finding all data on a single object

- Easiest using Simbad, either web or through `astroquery`

```
[In [4]: from astroquery.vizier import Vizier

[In [5]: result = Vizier.query_object("M87")

In [6]: print(result)
TableList with 760 tables:
        '0:METAobj' with 5 column(s) and 7 row(s)
        '1:ReadMeObj' with 5 column(s) and 7 row(s)
        '2:I/122/bd' with 9 column(s) and 1 row(s)
        '3:I/151/table3' with 5 column(s) and 1 row(s)
        '4:I/252/out' with 8 column(s) and 2 row(s)
        '5:I/267/out' with 16 column(s) and 50 row(s)
        '6:I/272/m2000' with 6 column(s) and 2 row(s)
        '7:I/284/out' with 14 column(s) and 13 row(s)
        '8:I/297/out' with 19 column(s) and 18 row(s)
        '9:I/300/pm2000' with 12 column(s) and 3 row(s)
        '10:I/302/xcfields' with 9 column(s) and 2 row(s)
        '11:I/304/out' with 9 column(s) and 6 row(s)
        '12:I/313/lqrf' with 10 column(s) and 1 row(s)
```

Finding all data on a single object

- Easiest using Simbad, either web or through `astroquery`
- Other similar service is NED, focused on external galaxies (linked to by Simbad)
- Can also do regional searches with rectangles or circles using `astroquery` for given catalogs (e.g., Gaia)
    - This is often also possible on the survey's website

Cross-matching a catalog to another catalog

- Suppose you have a relatively large set of objects that you want to match to another large set of objects (could be a large survey)
  - Can do this locally with astropy:

```
>>> c = SkyCoord(ra=ra1*u.degree, dec=dec1*u.degree)
>>> catalog = SkyCoord(ra=ra2*u.degree, dec=dec2*u.degree)
>>> idx, d2d, d3d = c.match_to_catalog_sky(catalog)
```

  - Sometimes possible on a survey's website
  - CDS x-matching service: http://cdsxmatch.u-strasbg.fr/
    - Cross-match two VizieR catalogs to each other
    - Cross-match user catalog to VizieR catalog
    - Can be done programmatically (e.g., using cURL) or through `astroquery.xmatch`