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3. DATASETS & GLOBAL PARAMETERS

(1) Introduction

Extragalactic research often relies on making use of preexisting data. Knowing whats out there, how to access it, what it means, and what its limitations are, is an important aspect of your astronomical "competence". This topic aims to give a brief overview of the growing databases and catalogues which you may need in the future.

(2) WEB Literature Resources

- "Astrophysics Data System Abstract Service" (ADS)
  Gives access to on-line Journals, Conference Proceedings, and Abstracts.
- E-Preprint service of LANL astro-ph
  Contains preprints submitted by authors, a good way of keeping up with the most recent literature.
- Annual Reviews of Astronomy and Astrophysics, with a subset on galaxies to be found here.
- Encyclopedia of Astronomy and Astrophysics: (most written ~ 2000).

- It is important to organize your own growing library of papers.
  One approach is to use a software product, such as Papers by Mekentosj.

(3) Major WEB Resources

Rather than describe these in detail, it is best to simply try them out to see what's available.

- NASA/IPAC Extragalactic Database (NED)
  This has a remarkably wide coverage and set of tools : object search; images; SEDs; catalogues; literature.
  Check out the "knowledge base - level 5" which gives routes into many topics via review articles and books.
- Sloan Digital Sky Survey (SDSS)
  This provides a wide range of tools and projects to explore the vast SDSS database (currently, at DR-9 (data-release-9).
- Astronomical Data Center (ADC)
  A NASA site for astronomical data and catalogues from the literature.
- Centre de Donees astronomique de Strasburg (CDS)
  European center for astronomical data and bibliography. Routes to a variety of other sites.
- SIMBAD

Gives basic data on objects, with references to all papers which include the object.

- Digital Sky Survey (DSS)
  Easy way to view (and/or download) images from the many Schmidt sky surveys.
- SkyView
  created by HEASARC, allows you to access images of a region of sky from many of the all sky multiwavelength surveys.
- Aladin
  Ability to view the sky and superimpose many images and source lists at different wavelengths, and access information and references on these sources
- VizieR
  Great way to find catalogues of interest and download them

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(4) Optical Galaxy Catalogs

(a) Important, Currently Used Catalogs

RC3 : "Third Reference Catalogue of Bright Galaxies" 1991 deVaucouleurs et al.

This superceeds the RC1 (1964) and RC2 (1976). Gathers and reduces to common system : positions, classifications, magnitudes, colors, radial velocities and other information for ~23000 galaxies. A definitive and impressive work.

SDSS images of many RC3 galaxies can be found here: o-link

UGC : "Uppsala General Catalog of Galaxies" by Nilsen using PSS (1973)

Data on ~13000 galaxies north of -2.5deg, diameter 1 arcmin or more, or brighter than 14.5. Morphology and descriptions good. Commonly used. A related ESO/Uppsala survey of the ESO(B) plates extends the UGC to the south (1982, Lauberts), with densitometry by Lauberts and Valentijn (1989).

RSA : "Revised Shapley Ames" (1987) by Sandage and Tammann

Based on the original 1932 Harvard catalog. Positions, morphology, magnitudes, velocities for ~1200 galaxies brighter than m~13.2 (complete to m=12, but only 50% at m=12.7). Images illustrate the luminosity classes. Related catalogs/atlases from Sandage include the Hubble Atlas (1961), the Carnegie Atlas of Galaxies (1994), the Atlas of Galaxies Useful for Measuring the Cosmic Distance Scale (NASA 1988). These all have wonderful large format images.

PGC : "Principal Galaxy Catalogue" 1989 Paturel et al

A gargantuan list of ~73000 galaxies with cross-references, morphologies, sizes, magnitudes and velocities.
The RC3 uses the PGC number as primary ID.

(b) Previously Important or Less Used Catalogs

NGC : "New(!) General Catalog" originally from Dreyer (1880s), revised 1973 (RNGC) by Sulentic and Tifft

Contains star clusters, galaxies, HII regions, planetary nebulae. The catalog itself is not much used now, though the names obviously are. Closely associated is the IC (Index Catalog) of Dreyer which added ~7000 objects. Both are combined in the NGC 2000 catalog.

The "NGC/IC Project" to clarify all historical NGC & IC information is here: o-link
A compilation of modern NGC data, with links to DSS and SDSS images, is here: o-link

MCG : "Morphological Catalog of Galaxies" 1964, Vorontsov-Velyaminov and Arhipova (Moscow)

Coded descriptions and rough magnitudes for ~29000 galaxies above m=15 and north of -33. Not much used except for names if no others apply. Careful with names : MCG 8-11-11 is a different galaxy from MCG -8-11-11.

CGCG : "Catalog of Galaxies and Clusters of Galaxies" Zwicky (1961-1968) generated from PSS

N hemisphere. Positions and relatively reliable magnitudes (using defocussed images) for ~31000 galaxies. Nearly complete to m_{pg}=15.5; limit is 15.7. Also identifies 10000 galaxy clusters. Long used to define galaxy samples (magnitude limited) and for reasonable photometry.

Arp : "Atlas of Peculiar Galaxies" Arps famous 1966 atlas

About 340 peculiar galaxies, grouped by type of peculiarity. Excellent deep Palomar images. Extended to the south in "A Catalogue of Southern Peculiar Galaxies and Associations" by Arp and Madore (1987). Older related catalogs include : "Atlas and Catalog of Interacting Galaxies" (1959, 1977, Verontsov-Velyaminov) and "Catalog of Selected Compact Galaxies and of Post-Eruptive Galaxies" (CGPG) by Zwicky (1971).

NBG : "Nearby Bright Galaxies" 1988 by Tully.

A catalog specifically devoted to the three dimensional distribution of nearby galaxies.

Further lists of the major catalogs are given : here, and here, and here.

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(5) All Sky Surveys

It is often important to combine information from several wavebands
One way to do this is to make use of all-sky surveys.
Below is a partial list of the some of the more commonly used ones (see o-link for a full list).
Many can be accessed directly through:

- STScI's MAST (Multimission Archive at STScI): o-link
- NASA's SkyView: o-link

(a) Radio

- FIRST (Faint Images of the Radio Sky at Twenty centimeters; 1994-96): o-link
  20cm VLA survey of North Galactic Cap (10,000 square degrees).
  1 mJy limit and 5 arcsec resolution and 1.8 arcsec pixels. ~10^6 sources.

- NVSS (Northern VLA Sky Survey; 1994-96): o-link
  1.4 Ghz (20cm) VLA survey north of -40 dec (82% of all-sky).
  45 arcsec resolution, 15 arcsec pixels, complete to 2.5 mJy, 1.8 million sources

(b) Infrared

- IRAS (Infrared Astronomical Satellite; 1983): o-link
  IRIS (Improved Reprocessing of the IRAS Survey; 2005): o-link
  12, 25, 60, 100 micron all-sky images with resolution of ~4 arcmin. 75,000 starburst galaxies found.

- WISE (Wide-field Infrared Survey Explorer; 2010): o-link
  4 bands from 3 - 22 microns; 6 - 12 arcsec resolution; 100 × sensitivity of IRAS
  Launched Dec 2009, expected data release March 2012

- 2MASS (2 micron All-Sky Survey; 1997-2002): o-link
  J,H,K survey of the whole sky. Resolution ~1 arcsec, with 1 arcsec pixels.

(c) Optical

- DSS (Digitized Sky Survey; 1945-55 North, 1980-90 South): o-link
  Original Palomar and UK Schmidt sky survey plates scanned at STScI in the early 1990s.

Several plate colors/emulsions (E V J R N); most at 1.7 arcsec/pixel.

- Mellinger 3-color allsky image; 2005: o-link
  Alex Mellinger mosaic of 3000 SBIG CCD frames covering 70 fields of 40×27 degrees.
  This is primarily for visual aesthetic, the above link is to a flash pan/zoom

- SDSS (Sloan Digital Sky Survey; 2000-08): o-link
  1/4 sky; north galactic cap; 5 color imaging; full optical spectroscopy. See Section 8

(d) Ultraviolet

- GALEX (Galaxy Evolution Explorer; 2003-07): o-link
  Two bands: 1350-1780 A (FUV) and 1770-2730 (NUV) with resolutions 4.3 & 5.3 arcsec with 1.5 arcsec/pix.

- EUVE (Extreme Ultraviolet Explorer; 1991-93): o-link
  All-sky survey in 4 UV bands: 80, 170, 400, 550 Angstroms. 2 arcmin resolution; 1.5 arcmin pixels.

(e) X-ray

- RASS (ROSAT All Sky Survey; 1991): o-link
  3 soft X-ray bands: 0.25 0.75 1.5 keV; ~2 degree resolution, 45 arcsec/pix; 60,000 sources found.

- RXTE (Rosse X-ray Timing Explorer; 1996-2002): o-link
  2 Xray bands: 3-8 kev and 8-20 keV. Resolution ~1 degree; uneven exposure times.

(f) Gamma-Ray

- CGRO (Compton Gamma Ray Observatory; 1991-94): o-link
  Two Instruments: COMPTEL: 1-30 MeV resolution 3 deg; EGRET: 1MeV-10GeV, resolution 2-5 deg.

- Fermi (Fermi Gamma Ray Space Telescope; 2010): o-link
  Next generation beyond CGRO; 20 MeV - 100 GeV; Whole sky every 3 hours.

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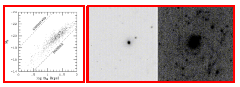
(6) Selection Effects in Surveys and Catalogs

The principal criteria which exclude galaxies from surveys and/or catalogs are :

- Apparent magnitude: usually some limit, (eg m=15.7 for CGCG)
- Angular size: either explicitly (eg UGC is ~1 arcmin; star/galaxy confusion can exclude compact galaxies)
- Surface Brightness: Low Surface Brightness (LSB) galaxies might be invisible below the sky.

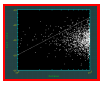
Some of these selection effects are illustrated here: [image]



(a) Malmquist Bias

- Flux (apparent magnitude) limited samples always over-represent **high luminosity objects**.
  These can be detected to larger distances and therefore a larger volume is included in the sample.
  Hence, the observed distribution of lumiosities is artificially skewed to high luminosity.

- This figure [image] (from Keel) illustrates the effect for the simple case of
  (a) uniform spatial distribution, *and*
  (b) Gaussian distribution of absolute magnitude
  A line of constant (limiting) magnitude is shown.
  Only objects above the line are included in the sample.



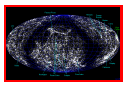
- Similar kinds of bias result from other selection effects (eg diameter, SB), and in general are very widespread in astronomy.
- In general "selection functions" must be applid to correct the bias. These can be difficult and uncertain. To illustrate, Trimble (1994, PASP 108 1073) remarks : "Any large gathering of observational cosmologists today will include at least one person who thinks that someone else in the room does not understand the Malmquist effect".

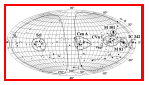
(7) Global Parameters

There are a number of standard global parameters which galaxy catalogues often list.
It can be quite complex to convert/reduce to a standard system (eg the RC3 introduction is long and detailed!)
Lets briefly review these, using the RC3 as example.

(a) Positions

- RA, Dec: epochs B1950 & J2000. Note that changing epoch can alter the order of catalogued objects (eg NGC ordered by RA-1855; while PGC number is ordered by RA-2000)
- Galactic Longitude & Latitude (l, b): [image]
  Zone of avoidance (MW dust) reduces the number of optically visible galaxies below b ~ 20.
  This is less apparent for IR & radio selected galaxies.
- Supergalactic Longitude & Latitude: corresponds to the flattened distribution of galaxies within 10 Mpc (see image of nearest 10 Mpc in SG coordinates)





NED provides a calculator for coordinate conversions: o-link

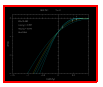
(b) Angular Sizes

- D_{25} : angular diameter to 25th B mag/ss ispohote (major axis)
  this is ~few % of sky and is about the size you would guess from the PSS
- D_0 : same as D_{25} but corrected for galactic extinction and galaxy inclination (ie corrected to "face on")
- A_e : "Effective" (circular) aperture diameter which would enclose half the total light (see below)

- R_{25} : major/minor **axis ratio** at the 25th B mag/ss isophote
  Note that conversion to inclination is not simply inverse sine (several prescriptions are used)

(c) Magnitudes

- B_T : Total **photoelectric** B magnitude, derived either from aperture photometry or surface photometry (CCD or calibrated photographic). Aperture data requires fitting to "growth curves" [image] allowing extrapolation to "infinite" aperture, or "Total" magnitude.



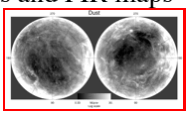
- B_T^o : Total B magnitude, corrected for three effects
  - galactic absorption, A_g,
  - internal absorption (to face on), A_i,
  - redshift: "K correction", since redshift brings a bluer part of the spectrum into the B filter
    this correction depends on both z and Hubble type (since different Hubble types have different spectra).

- m_B : Total **photographic** B magnitude. Since many sources of magnitudes (eg Zwicky's 31000 CGCG galaxies) are photographic, RC3 includes them but separately from the photoelectric magnitudes. They are less accurate than B_T, and need to be reduced to the standard system.

(d) Extinctions

- A_g : Galactic extinction in B band. After a complex history, RC3 uses the reddening maps of Burstein & Heiles (1978) derived from HI maps and faint galaxy counts. Since then, improved (by factor 2) maps have been derived from HI maps and FIR maps of COBE/DIRBE and IRAS.

  A NED calculator gives the galactic absorption at any location (o-link), and shown here: [image].



- A_i : Internal Extinction in the B band - ie extinction due to dust in the galaxy itself. This is much less well known, but is clearly a function of (a) the Hubble type and (b) the inclination. After a complex history, RC3 gives a prescription.

  Note that RC3 estimates extinction to "face on", while RSA estimates extinction to "no dust" (and therefore much higher values,

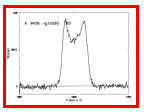
particularly for later Hubble types)

(e) Colors

- $(U-B)_T$; $(B-V)_T$; $(U-B)_e$; $(B-V)_e$: are colors for Total galaxy light, and effective (half light) apertures. They are also corrected for galactic and internal extinction and redshift, yielding $(U-B)_T^o$ etc.

(f) HI Kinematics and Fluxes

- W_{20}; W_{50} : The width of the integrated 21cm HI line profile, measured at the 20% and 50% height levels [image]. This measures the (projected) galaxy rotation velocity, and is an important parameter in, for example, the Tully-Fisher relation.



- m_{21} : HI "magnitude" is a measure of the integrated HI 21cm line flux. This is corrected for internal self-absorption (A_{21}) and a redshift (1+z) to yield m_{21}^o. The quantity m_{21}^o - B_T^o then represents an HI/L_B ratio, which is a standard parameter of galaxies (and increases along the Hubble sequence).

(g) Redshifts

- V_{opt}; V_{21} : Optical and 21cm systemic **heliocentric** velocities (*always* given as cz). Usually, these agree well.
- V_{GSR} : velocity (cz, weighted mean of V_{opt} & V_{21}) referred to the Galactic Standard of Rest (the center of the galaxy). This combines a transformation from HC to LSR (16.5 km/s towards l=53, b=+25) with a further transformation to the galactic center (220 km/s towards l=90, b=0). This can be used for distance estimates using the Hubble constant.
- V_{3K} : velocity referred to the frame of the CMB (microwave background): a tranformation from HC by 369 km/s towards l=264 b=+48. This may be better for distance estimates beyond about 5000 km/s. Note, for cz within ~5000 km/s people sometimes use a "Virgocentric Infall" model to correct both our and the galaxy's redshifts for large scale flows before applying the Hubble law.

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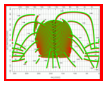
(8) Sloan Digital Sky Survey: SDSS

The SDSS is such a huge and remarkable survey that we should briefly review. [o-link]

(a) Survey Overview o-link

- Dedicated **telescope**: 2.5m f/5 at Apache Point Observatory (APO): [image]
- Specially designed **camera**: 1.5 square degrees, 120 Mpix, 30 × 2048^2 CCDs with u,g,r,i,z filters.
  Driftscan method: clock out the CCDs at the same rate the telescope scans a great circle.
  Each location gets 54 seconds of exposure (only!) in each filter.
- Two 320 fiber **spectrographs** use aluminum plates with holes plugged with 3 arcsec fibers.
  Dichroics split spectrum into separate blue and red channels: 3800 - 9200A coverage with R ~ 2000



- Survey (SDSS-I & SDSS-II) took 8 years (2000 - 2008), and covered 1/4 of the sky (8400 sq deg)[image]
- Photometry of 230 million objects (stars & galaxies)
- Spectra of: 930,000 galaxies; 120,000 stars; 120,000 quasars
  - Spectra Limits: galaxies r < 17.8; quasars i < 19.1 [image]
  - Imaging limits: u,g,r ~ 22; i ~ 21.3, z ~ 20.3

(b) SDSS Parameters

The scale and nature of the SDSS demands a careful approach to parameter definitions.
Ultimately, there are **many** parameters and their errors (and flags) defined
Here are just a few (taken from here: o-link)

(i) Magnitudes

SDSS defines all magnitudes using an **asinh** (= ln [x + √(x^2 + 1)]) function (see reference).
For S/N > 5 asinh magnitudes = normal magnitudes (i.e. -2.5 Log (flux), Pogson 1856)

For S/N < 5 asinh magnitudes are ~linear in flux.
They are therefore **much** better behaved at low flux levels (avoiding the divergence of Log 0).

Model Magnitudes
Fit pure deVauc & exponential → deVMag, expMag
Best fit linear combination of these → cmodelMag

Petrosian magnitude (petroMag)
Define petroRad = r_p by $I(r_p)/< I(< r_p) > = 0.2$ where I is surface brightness in flux units.
Then petroMag = flux inside $2r_p$
for exponential profile petroMag gets ~all the flux, for a deVauc profile it gets ~80%
Virtue: measures constant fraction of flux regardless of distance (or size), and is insensitive to sky noise.

(ii) "Morphology"

Concentration: = petro90/petro50
where these are radii enclosing 90% and 50% of the petrosian flux

Goodness of fit Likelihoods: deV_L, exp_L, star_L
use f(deV_L) = deV_L / (deV_L + exp_L + star_L) > 0.5 to select early type (deVauc) profiles.

Ellipticities and PA:
Measured from second moments or 25th isophote shape.

There are also **many** flags to identify problems with the analysis of a given object.

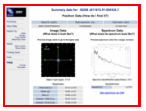
(iii) Spectra

Many emission & absorption line strengths, and continuum strengths
Redshifts, from both emission and absorption lines
Velocity dispersion from absorption lines (only early type, bulge dominated, spectra).
Classification of type (early, late, agn, etc) by comparing to a number of templates.

(c) Web Access and Analysis

The entire dataset is available online (o-link)
It can be interrogated in several ways; here are just two:

(i) Inspection "by hand"



There are "Finding Chart" (o-link) and "Navigate" (o-link) tools that accept a coordinate.
Easy to retrieve image, spectrum, parameters, link to NED etc.

(ii) Automatic data retrieval

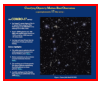
The SDSS databases can be interrogated using SQL (Structured Query Language)
This allows one to extract carefully defined sub-samples based on a variety of selection criteria.
There are **many** tables in the database, and the SQL searches can be quite sophisticated.
Here is (fairly extensive) tutorial: o-link; and here are many examples: o-link.

(d) Other large/deep galaxy surveys

The SDSS is not the only large deep survey. Here are some others:

- **2dFGRS**: o-link
  1500 square degrees in two stripes in N & S galactic polar regions.
  Photometry for 380,000 $b_J < 19.5$ galaxies and redshifts for 232,000 galaxies.

- **The Millenium Galaxy Catalogue**: o-link
  sub-region of SDSS & 2dFGRS: $10^h\ 00^m$ - $14^h\ 45^m \times 35$ arcmin.
  Deep (750s) B images of 10,095 galaxies with B < 24 and redshifts for all B < 20.



- **The Combo-17 Survey**: o-link
  1 degree square with deep (~3 hr on 2.2^m) images in 17 filters:
  classification & redshifts (photo-z) for 25,000 galaxies and 300 QSOs.

Galaxy & cluster evolution to z~1; Weak lensing; QSO evolution.

- **HST:**: there are several deep small-area surveys by HST:

  HUDF: Hubble Ultra Deep Field: 11 sq arcmin; 400 orbits with ACS: o-link

  GOODS: The Great Observatories Origins Deep Survey: 320 sq arcmin; HST, Spitzer, Chandra... o-link

  COSMOS: The Cosmic Evolution Survey: 2 sq deg; 2 million gals; o-link

(e) Some Papers from SDSS and MGC

Some of the important papers emerging from the SDSS and MGC surveys are listed: here

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