01_MLscikitL_PhotoZSimple_GetData

November 30, 2022

1 Step 1 : Extraction of Data from Table for PhotoZ estimation

Extract measured fluxes from Object table and redshift from thruth Table and save it in a file for later use Last verified to run on 2022-11-20 with LSST Science Pipelines release w_2022_40 Contact authors: Sylvie Dagoret-Campagne (DP0 Delegate) Target audience: DP0 delegates member

The extraction of the data is inspired from the tutorial notebook https://github.com/rubin-dp0/tutorial-notebooks/blob/main/08_Truth_Tables.ipynb

2 1) Imports

[1]:
```
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
from astropy.units import UnitsWarning
from astropy.table import Table
import warnings
```

[2]:
```
# Access to data via TAP service
from lsst.rsp import get_tap_service, retrieve_query
```

[3]:
```
# Access to data via Butler
import lsst.daf.butler as dafButler
import lsst.geom as geom
```

[4]:
```
import pickle
import os
import errno
import shutil
import getpass
```

[5]:
```
warnings.simplefilter("ignore", category=UnitsWarning)
pd.set_option('display.max_rows', 200)
```

[6]:
```
%matplotlib inline
```

[7]:
```
from matplotlib.patches import Polygon
from matplotlib.collections import PatchCollection
```

[8]:
```
params = {'axes.labelsize': 28,
          'font.size': 24,
          'legend.fontsize': 14,
          'xtick.major.width': 3,
          'xtick.minor.width': 2,
          'xtick.major.size': 12,
          'xtick.minor.size': 6,
          'xtick.direction': 'in',
          'xtick.top': True,
          'lines.linewidth': 3,
          'axes.linewidth': 3,
          'axes.labelweight': 3,
          'axes.titleweight': 3,
          'ytick.major.width': 3,
          'ytick.minor.width': 2,
          'ytick.major.size': 12,
          'ytick.minor.size': 6,
          'ytick.direction': 'in',
          'ytick.right': True,
          'figure.figsize': [18, 10],
          'figure.facecolor': 'White'
          }

plt.rcParams.update(params)
```

3 2) Configuration

Set up colors and plot symbols corresponding to the *ugrizy* bands. These colors are the same as those used for *ugrizy* bands in Dark Energy Survey (DES) publications, and are defined in this github repository.

[9]:
```
plot_filter_labels = ['u', 'g', 'r', 'i', 'z', 'y']
plot_filter_colors = {'u': '#56b4e9', 'g': '#008060', 'r': '#ff4000',
                      'i': '#850000', 'z': '#6600cc', 'y': '#000000'}
plot_filter_symbols = {'u': 'o', 'g': '^', 'r': 'v', 'i': 's', 'z': '*', 'y':␣
 ↪'p'}
```

3.0.1 Angles in degrees

- Select the sky region in RA and DEC.

[10]:
```
RA=62
DEC=-37
use_center_coords = "62, -37"
```

```
use_radius = "0.5"
```

3.0.2 Magnitude limit

- Want to put threshold on the magnitude of retrieved object to reasonable ones

[11]:
```
MAGLIMMIN = 17
MAGLIMMAX = 26
```

[12]:
```
# username
myusername=getpass.getuser()
```

[13]:
```
# temporary folders if necessary
NBDIR       = 'photoz_dp02'                        # relative path for this␣
 ↪notebook output
TMPTOPDIR   = "/scratch"                           # always write some output in␣
 ↪/scratch, never in user HOME
TMPUSERDIR  = os.path.join(TMPTOPDIR,myusername)  # defines the path of user␣
 ↪outputs in /scratch
TMPNBDIR    = os.path.join(TMPUSERDIR,NBDIR)      # output path for this␣
 ↪particular notebook
```

[14]:
```
FLAG_WRITE_DATAFRAMEONDISK  = True   # Select if query output will be saved on␣
 ↪disk
FLAG_READ_DATAFRAMEFROMDISK = True   # Select if the query can be red from disk␣
 ↪if it exists
FLAG_CLEAN_DATAONDISK       = False  # Select if the output queries saved in␣
 ↪file will be cleaned at the end of the notebook
```

[15]:
```
filename_result=f'fluxesredshift_result.pkl'
filename_result_skyinfo=f'tractpatch_result.csv'
fullfilename_result=os.path.join(TMPNBDIR,filename_result)
fullfilename_result_skyinfo=os.path.join(TMPNBDIR,filename_result_skyinfo)
```

4 3) Initialization

- create output directories of missing

[16]:
```
# create user temporary directory
if not os.path.isdir(TMPUSERDIR):
    try:
        os.mkdir(TMPUSERDIR)
    except:
        raise OSError(f"Can't create destination directory {TMPUSERDIR}!" )
```

[17]:
```
# create this notebook temporary directory
if not os.path.isdir(TMPNBDIR):
    try:
        os.mkdir(TMPNBDIR)
    except:
        raise OSError(f"Can't create destination directory {TMPNBDIR}!" )
```

5 4) Access to data

5.1 4.1 Table available to TAP service on DC2 simulation and its processing by DM

To access tables, we will use the TAP service in a similar manner to what we showed in the Intro to DP0 notebook, and explored further in the TAP tutorial notebook. See those notebooks for more details.

[18]:
```
service = get_tap_service()
```

5.1.1 List of the available catalogs & tables

The DP0.2 Documentation contains a list of all DP0.2 catalogs, and also a link to the DP0.2 Schema Browser where users can read about the available tables and their contents.

- https://dp0-2.lsst.io/data-products-dp0-2/index.html
- https://dm.lsst.org/sdm_schemas/browser/dp02.html

Print the names of all available tables

[19]:
```
results = service.search("SELECT description, table_name FROM TAP_SCHEMA.
 ↪tables")
results_tab = results.to_table()

for tablename in results_tab['table_name']:
    print(tablename)
```

```
dp01_dc2_catalogs.forced_photometry
dp01_dc2_catalogs.object
dp01_dc2_catalogs.position
dp01_dc2_catalogs.reference
dp01_dc2_catalogs.truth_match
dp02_dc2_catalogs.CcdVisit
dp02_dc2_catalogs.CoaddPatches
dp02_dc2_catalogs.DiaObject
dp02_dc2_catalogs.DiaSource
dp02_dc2_catalogs.ForcedSource
dp02_dc2_catalogs.ForcedSourceOnDiaObject
dp02_dc2_catalogs.MatchesTruth
dp02_dc2_catalogs.Object
```

```
dp02_dc2_catalogs.Source
dp02_dc2_catalogs.TruthSummary
dp02_dc2_catalogs.Visit
ivoa.ObsCore
tap_schema.columns
tap_schema.key_columns
tap_schema.keys
tap_schema.schemas
tap_schema.tables
uws.Job
```

[20]:
```
for c, columnname in enumerate(results['table_name']):
    print('%-25s : --> \t %-200s ' % (columnname, results['description'][c]))
```

```
dp01_dc2_catalogs.forced_photometry : -->        Forced photometry measurements
for objects detected in the coadded images, at the locations defined by the
position table. (747 columns)
dp01_dc2_catalogs.object  : -->          The object table from the DESC DC2
simulated sky survey as described in arXiv:2101.04855. Includes astrometric and
photometric parameters for objects detected in coadded images. (137 columns)
dp01_dc2_catalogs.position : -->         Select astrometry-related parameters
for objects detected in the coadded images, such as coordinates, footprints,
patch/tract information, and deblending parameters. (29 columns)
dp01_dc2_catalogs.reference : -->        Measurements for objects detected in
the coadded images, including photometry, astrometry, shape, deblending, model
fits, and related background and flag parameters. This table joined with the
position table is very similar to the object table, but with additional columns.
(236 columns)
dp01_dc2_catalogs.truth_match : -->      The truth-match table for the DESC
DC2's object table as described in arXiv:2101.04855. Includes the noiseless
astrometric and photometric parameters and the best matches to the object table.
(30 columns)
dp02_dc2_catalogs.CcdVisit : -->         Metadata about the 189 individual CCD
images for each Visit in the DC2 simulated survey.
dp02_dc2_catalogs.CoaddPatches : -->     Static information about the subset of
tracts and patches from the standard LSST skymap that apply to coadds in these
catalogs
dp02_dc2_catalogs.DiaObject : -->        Properties of time-varying astronomical
objects based on association of data from one or more spatially-related
DiaSource detections on individual single-epoch difference images.
dp02_dc2_catalogs.DiaSource : -->        Properties of transient-object
detections on the single-epoch difference images.
dp02_dc2_catalogs.ForcedSource : -->     Forced-photometry measurements on
individual single-epoch visit images and difference images, based on and linked
to the entries in the Object table. Point-source PSF photometry is performed,
based on coordinates from a reference band chosen for each Object and reported
in the Object.refBand column.
dp02_dc2_catalogs.ForcedSourceOnDiaObject : -->          Point-source forced-
```

```
photometry measurements on individual single-epoch visit images and difference
images, based on and linked to the entries in the DiaObject table.
dp02_dc2_catalogs.MatchesTruth : -->     Match information for TruthSummary
objects.
dp02_dc2_catalogs.Object  : -->          Properties of the astronomical objects
detected and measured on the deep coadded images.
dp02_dc2_catalogs.Source  : -->          Properties of detections on the single-
epoch visit images, performed independently of the Object detections on coadded
images.
dp02_dc2_catalogs.TruthSummary : -->     Summary properties of objects from the
DESC DC2 truth catalog, as described in arXiv:2101.04855. Includes the noiseless
astrometric and photometric parameters.
dp02_dc2_catalogs.Visit   : -->          Metadata about the pointings of the DC2
simulated survey, largely associated with the boresight of the entire focal
plane.
ivoa.ObsCore              : -->          Observation metadata in the ObsTAP
relational realization of the IVOA ObsCore data model
tap_schema.columns        : -->          description of columns in this tableset
tap_schema.key_columns    : -->          description of foreign key columns in
this tableset
tap_schema.keys           : -->          description of foreign keys in this
tableset
tap_schema.schemas        : -->          description of schemas in this tableset
tap_schema.tables         : -->          description of tables in this tableset
uws.Job                   : -->          Job history table.
```

[21]:
```
del results, results_tab
```

5.1.2 Object Table

- https://dm.lsst.org/sdm_schemas/browser/dp02.html#Object

5.1.3 MatchesTruth Table

- https://dm.lsst.org/sdm_schemas/browser/dp02.html#MatchesTruth

[22]:
```
results = service.search("SELECT column_name, datatype, description,\
                          unit from TAP_SCHEMA.columns\
                          WHERE table_name = 'dp02_dc2_catalogs.MatchesTruth'")
```

[23]:
```
results.to_table().to_pandas()
```

[23]:
```
            column_name datatype  \
0                    id     char
1         id_truth_type     char
2       match_candidate  boolean
3           match_chisq   double
4           match_count      int
```

```
5  match_n_chisq_finite      int
6        match_objectId     long
7            truth_type     long

                                             description unit
0  id for TruthSummary source. Potentially non-un…
1  Combination of TruthSummary id and truth_type …
2   True for sources that were selected for matching
3          The chi-squared value of the (best) match
4  Number of candidate object matches within matc…
5  The number of finite columns used to compute t…
6  objectId of matched entry in the Object table,…
7  Type of TruthSummary source; 1 for galaxies, 2…
```

The above is fine if the full description is not needed, but there are some important details that are being hidden by the line truncation above.

Try this instead.

[24]:
```
for c, columnname in enumerate(results['column_name']):
    print('%-25s %-200s' % (columnname, results['description'][c]))
```

```
id                        id for TruthSummary source. Potentially non-unique;
use id_truth_type for JOINs.
id_truth_type             Combination of TruthSummary id and truth_type fields,
used for JOINs.
match_candidate           True for sources that were selected for matching
match_chisq               The chi-squared value of the (best) match
match_count               Number of candidate object matches within match radius
match_n_chisq_finite      The number of finite columns used to compute the match
chisq
match_objectId            objectId of matched entry in the Object table, if any
truth_type                Type of TruthSummary source; 1 for galaxies, 2 for
stars, and 3 for SNe
```

[25]:
```
del results
```

5.1.4 TruthSummary Table

- https://dm.lsst.org/sdm_schemas/browser/dp02.html#TruthSummary

[26]:
```
results = service.search("SELECT column_name, datatype, description,\
                          unit from TAP_SCHEMA.columns\
                          WHERE table_name = 'dp02_dc2_catalogs.TruthSummary'")
```

[27]:
```
# results.to_table().to_pandas()
```

[28]:
```python
for c, columnname in enumerate(results['column_name']):
    print('%-25s %-200s' % (columnname, results['description'][c]))
```

```
cosmodc2_hp               Healpix ID in cosmoDC2 (for galaxies only; -1 for
stars and SNe)
cosmodc2_id               Galaxy ID in cosmoDC2 (for galaxies only; -1 for stars
and SNe)
dec                       Declination
flux_g                    Static flux value in g
flux_g_noMW               Static flux value in g, without Milky Way extinction
(i.e., dereddened)
flux_i                    Static flux value in i
flux_i_noMW               Static flux value in i, without Milky Way extinction
(i.e., dereddened)
flux_r                    Static flux value in r
flux_r_noMW               Static flux value in r, without Milky Way extinction
(i.e., dereddened)
flux_u                    Static flux value in u
flux_u_noMW               Static flux value in u, without Milky Way extinction
(i.e., dereddened)
flux_y                    Static flux value in y
flux_y_noMW               Static flux value in y, without Milky Way extinction
(i.e., dereddened)
flux_z                    Static flux value in z
flux_z_noMW               Static flux value in z, without Milky Way extinction
(i.e., dereddened)
host_galaxy               ID of the host galaxy for a SN/AGN entry (-1 for other
truth types)
id                        Unique object ID
id_truth_type             Combination of id and truth_type fields, used for
JOINs with MatchesTruth.
is_pointsource            1 for a point source
is_variable               1 for a variable source
mag_r                     Magnitude in r
ra                        Right Ascension
redshift                  Redshift
truth_type                1 for galaxies, 2 for stars, and 3 for SNe
```

[29]:
```python
del results
```

5.2 4.2) Build the ADQL query to retrieve usefull data for Photoz

Make a triple join tables:

– **dp02_dc2_catalogs.MatchesTruth** : the table that allow to match the object entries in the Truth table and DM reconstruction

– **dp02_dc2_catalogs.TruthSummary** : the table that conains true CosmoDC2 values

– **dp02__dc2__catalogs.Object**: The table of object generated by Rubin DM pipelines

5.2.1 Retrieve additional data for true galaxies that are matched to detected objects

With the query below we retrieve much more data for true galaxies, such as their true and measured fluxes and extendedness. Since we are only retrieving measurement data from the Object table for true galaxies, we retrieve the `cModelFlux` instead of the `psfFlux`, the latter being appropriate for point-sources (e.g., stars).

> **Notice:** Above, the column names in the retrieved results have no provenance: once the data is in the results table, it is unclear from which table it originated (i.e., whether it is a true coordinate or a measured coordinate). Below, we use the `AS` statement to rename columns to start with their origin table, in order to keep track of what is from a truth table (mt__ and ts__) and what is from the object table (obj__).
>
> **Notice:** Below, we use `truth_type = 1` to only retrieve truth and measurement data for "true galaxies."

[30]:
```
my_adql_query = "SELECT mt.id_truth_type AS mt_id_truth_type, "\
        "mt.match_objectId AS mt_match_objectId, "\
        "ts.ra AS ts_ra, "\
        "ts.dec AS ts_dec, "\
        "ts.truth_type AS ts_truth_type, "\
        "ts.mag_r AS ts_mag_r, "\
        "ts.is_pointsource AS ts_is_pointsource, "\
        "ts.redshift AS ts_redshift, "\
        "ts.flux_u AS ts_flux_u, "\
        "ts.flux_g AS ts_flux_g, "\
        "ts.flux_r AS ts_flux_r, "\
        "ts.flux_i AS ts_flux_i, "\
        "ts.flux_z AS ts_flux_z, "\
        "ts.flux_y AS ts_flux_y, "\
        "obj.coord_ra AS obj_coord_ra, "\
        "obj.coord_dec AS obj_coord_dec, "\
        "obj.u_cModelFlux AS obj_u_cModelFlux, "\
        "obj.g_cModelFlux AS obj_g_cModelFlux, "\
        "obj.r_cModelFlux AS obj_r_cModelFlux, "\
        "obj.i_cModelFlux AS obj_i_cModelFlux, "\
        "obj.z_cModelFlux AS obj_z_cModelFlux, "\
        "obj.y_cModelFlux AS obj_y_cModelFlux, "\
        "scisql_nanojanskyToAbMag(obj.u_cModelFlux) AS obj_u_cModelMag, "\
        "scisql_nanojanskyToAbMag(obj.g_cModelFlux) AS obj_g_cModelMag, "\
        "scisql_nanojanskyToAbMag(obj.r_cModelFlux) AS obj_r_cModelMag, "\
        "scisql_nanojanskyToAbMag(obj.i_cModelFlux) AS obj_i_cModelMag, "\
        "scisql_nanojanskyToAbMag(obj.z_cModelFlux) AS obj_z_cModelMag, "\
        "scisql_nanojanskyToAbMag(obj.y_cModelFlux) AS obj_y_cModelMag "\
        "FROM dp02_dc2_catalogs.MatchesTruth AS mt "\
        "JOIN dp02_dc2_catalogs.TruthSummary AS ts ON mt.id_truth_type = ts.
 ↪id_truth_type "\
        "JOIN dp02_dc2_catalogs.Object AS obj ON mt.match_objectId = obj.
↪objectId "\
        "WHERE CONTAINS(POINT('ICRS', ts.ra, ts.dec), CIRCLE('ICRS'," +␣
↪use_center_coords + ", " + use_radius + ")) = 1 "\
        "AND ts.truth_type = 1 "\
        "AND obj.detect_isPrimary = 1 "\
        "AND scisql_nanojanskyToAbMag(obj.g_cModelFlux) > " + str(MAGLIMMIN) +␣
↪" " + \
        "AND scisql_nanojanskyToAbMag(obj.g_cModelFlux) < " + str(MAGLIMMAX) +␣
↪" " + \
        "AND scisql_nanojanskyToAbMag(obj.r_cModelFlux) > " + str(MAGLIMMIN) +␣
↪" " + \
        "AND scisql_nanojanskyToAbMag(obj.r_cModelFlux) < " + str(MAGLIMMAX) +␣
↪" " + \
        "AND scisql_nanojanskyToAbMag(obj.i_cModelFlux) > " + str(MAGLIMMIN) +␣
↪" " + \
        "AND scisql_nanojanskyToAbMag(obj.i_cModelFlux) < " + str(MAGLIMMAX) +␣
↪" " + \
        "AND obj.refExtendedness IS NOT NULL "
print(my_adql_query)
```

```
SELECT mt.id_truth_type AS mt_id_truth_type, mt.match_objectId AS
mt_match_objectId, ts.ra AS ts_ra, ts.dec AS ts_dec, ts.truth_type AS
ts_truth_type, ts.mag_r AS ts_mag_r, ts.is_pointsource AS ts_is_pointsource,
ts.redshift AS ts_redshift, ts.flux_u AS ts_flux_u, ts.flux_g AS ts_flux_g,
ts.flux_r AS ts_flux_r, ts.flux_i AS ts_flux_i, ts.flux_z AS ts_flux_z,
ts.flux_y AS ts_flux_y, obj.coord_ra AS obj_coord_ra, obj.coord_dec AS
obj_coord_dec, obj.u_cModelFlux AS obj_u_cModelFlux, obj.g_cModelFlux AS
obj_g_cModelFlux, obj.r_cModelFlux AS obj_r_cModelFlux, obj.i_cModelFlux AS
obj_i_cModelFlux, obj.z_cModelFlux AS obj_z_cModelFlux, obj.y_cModelFlux AS
obj_y_cModelFlux, scisql_nanojanskyToAbMag(obj.u_cModelFlux) AS obj_u_cModelMag,
scisql_nanojanskyToAbMag(obj.g_cModelFlux) AS obj_g_cModelMag,
scisql_nanojanskyToAbMag(obj.r_cModelFlux) AS obj_r_cModelMag,
scisql_nanojanskyToAbMag(obj.i_cModelFlux) AS obj_i_cModelMag,
scisql_nanojanskyToAbMag(obj.z_cModelFlux) AS obj_z_cModelMag,
scisql_nanojanskyToAbMag(obj.y_cModelFlux) AS obj_y_cModelMag FROM
dp02_dc2_catalogs.MatchesTruth AS mt JOIN dp02_dc2_catalogs.TruthSummary AS ts
ON mt.id_truth_type = ts.id_truth_type JOIN dp02_dc2_catalogs.Object AS obj ON
mt.match_objectId = obj.objectId WHERE CONTAINS(POINT('ICRS', ts.ra, ts.dec),
CIRCLE('ICRS',62, -37, 0.5)) = 1 AND ts.truth_type = 1 AND obj.detect_isPrimary
= 1 AND scisql_nanojanskyToAbMag(obj.g_cModelFlux) > 17 AND
scisql_nanojanskyToAbMag(obj.g_cModelFlux) < 26 AND
scisql_nanojanskyToAbMag(obj.r_cModelFlux) > 17 AND
scisql_nanojanskyToAbMag(obj.r_cModelFlux) < 26 AND
scisql_nanojanskyToAbMag(obj.i_cModelFlux) > 17 AND
scisql_nanojanskyToAbMag(obj.i_cModelFlux) < 26 AND obj.refExtendedness IS NOT
NULL
```

5.2.2 Asynchronous query

[31]:
```
if FLAG_READ_DATAFRAMEFROMDISK and os.path.exists(fullfilename_result):
    df = pd.read_pickle(fullfilename_result)
    results = Table.from_pandas(df)

else:
    # Create and submit the job. This step does not run the query yet
    job = service.submit_job(my_adql_query,maxrec=1_000_000)
    # Get the job URL
    print('Job URL is', job.url)

    # Get the job phase. It will be pending as we have not yet started the job
    print('Job phase is', job.phase)

    # Run the job. You will see that the the cell completes executing,
    # even though the query is still running
    job.run()

    # Use this to tell python to wait for the job to finish if
    # you don't want to run anything else while waiting
    # The cell will continue executing until the job is finished
    job.wait(phases=['COMPLETED', 'ERROR'])
    print('Job phase is', job.phase)

    # A usefull funtion to raise an exception if there was a problem with the␣
 ↪query
    job.raise_if_error()

    # Once the job completes successfully, you can fetch the results
    async_tract_data = job.fetch_result()
    results = async_tract_data.to_table()


if FLAG_WRITE_DATAFRAMEONDISK:
    results.to_pandas().to_pickle(fullfilename_result)
```

5.2.3 synchronous query

[32]:
```
#%%time
#results = service.search(my_adql_query)
```

[33]:
```
t=results
```

5.2.4 Set table print format

[34]:
```
for column_name in t.colnames:
    typ=t[column_name].dtype
    if typ== 'float32' or typ=='float64':
        t[column_name].format = "{:.2f}"
t
```

[34]:
```
<Table length=132588>
mt_id_truth_type  mt_match_objectId   ts_ra  … obj_z_cModelMag obj_y_cModelMag
     str12              int64        float64 …     float64         float64
---------------- ------------------- ------- … --------------- ---------------
    7941880022_1 1651413688361451734   61.87 …           24.95              --
    7939461442_1 1651413688361451864   61.94 …           24.39           23.81
    7939458371_1 1651413688361450903   61.84 …           22.12           21.96
    7940601535_1 1651413688361451151   61.89 …           22.52           22.28
    7938042672_1 1651413688361451083   61.95 …           22.43           22.16
    7941544989_1 1651413688361451141   61.84 …           24.21           23.66
    7940893415_1 1651413688361451140   61.84 …           23.84           23.30
    7938684807_1 1651413688361451139   61.84 …           23.73           23.44
    7939458378_1 1651413688361451138   61.84 …           21.90           21.52
    7937797456_1 1651413688361451150   61.89 …           21.79           21.66
               …                   …       … …               …               …
    7956181272_1 1651343319617291053   62.05 …           25.19           24.54
    7950603005_1 1651343319617281700   62.09 …           23.81           24.45
    7945974730_1 1651343319617294579   62.07 …           24.65           25.60
    7944910088_1 1651343319617283869   62.10 …           26.56           25.64
    7941831848_1 1651343319617281528   62.01 …           25.06              --
    7939673691_1 1651343319617281540   62.13 …           22.77           22.44
    7950573205_1 1651352115710266746   61.83 …           24.71           25.09
    7939686730_1 1651343319617288280   62.21 …           23.21           23.01
    7945365877_1 1651290543059148909   61.90 …           24.84           24.27
    7939555785_1 1651352115710312116   61.99 …           26.10           25.72
```

5.3 4.3) Access to Data via the Butler

Butler repositories have both a database component and a file-like storage component. The database component can be accessed through the Butler registry, while file-like storage can be local (i.e., pointing to a directory on the local file system) or remote (i.e., pointing to cloud storage resources). DP0 uses Simple Storage Service (S3) buckets, which are public cloud storage resources that are similar to file folders. The S3 buckets store objects, which consist of data and its descriptive metadata.

5.3.1 Butler initialization

[35]:
```
butler = dafButler.Butler('dp02', collections='2.2i/runs/DP0.2')
```

```
<IPython.core.display.HTML object>
```

The database side of a data repository is called a `registry`. The registry contains entries for all data products, and organizes them by *collections*, *dataset types*, and *data IDs*. We can access a registry client directly as part of our Butler object:

5.3.2 Check datasets available through Butler

[36]:
```
registry = butler.registry
```

Collections

[37]:
```
for c in sorted(registry.queryCollections()):
    if (c == '2.2i/runs/DP0.1') | (c == '2.2i/runs/DP0.2'):
        print(c)
```

```
2.2i/runs/DP0.1
2.2i/runs/DP0.2
```

Datasets

[38]:
```
#for dt in sorted(registry.queryDatasetTypes()):
#    print(dt)
```

[39]:
```
#for dt in sorted(registry.queryDatasetTypes('*object*')):
#    print(dt)
```

[40]:
```
for dt in sorted(registry.queryDatasetTypes('*_tract')):
    print(dt)
```

```
DatasetType('diaObjectTable_tract', {skymap, tract}, DataFrame)
DatasetType('diaSourceTable_tract', {skymap, tract}, DataFrame)
DatasetType('diff_matched_truth_summary_objectTable_tract', {skymap, tract},
DataFrame)
DatasetType('forcedSourceOnDiaObjectTable_tract', {skymap, tract}, DataFrame)
DatasetType('forcedSourceTable_tract', {skymap, tract}, DataFrame)
DatasetType('match_ref_truth_summary_objectTable_tract', {skymap, tract},
DataFrame)
DatasetType('match_target_truth_summary_objectTable_tract', {skymap, tract},
DataFrame)
DatasetType('matched_truth_summary_objectTable_tract', {skymap, tract},
DataFrame)
DatasetType('objectTable_tract', {skymap, tract}, DataFrame)
```

[41]:
```
#for dt in sorted(registry.queryDatasetTypes('*object*')):
#    print(dt)
```

DeepCoadds and Objects

Data Id and data access in deepCoadd table

- data can be accessed by tract and patch (not RA, DEC)
- thus One need to know correspondence between RA,DEC <–> Tract,Patch

[42]:
```
coaddId = {'tract': 4226, 'patch': 17, 'band': 'r'}
coadd = butler.get('deepCoadd', dataId=coaddId)
```

[43]:
```
# Dump the individual visits of this coadd
#coaddInfo = coadd.getInfo()
#coaddVisits = coaddInfo.getCoaddInputs().visits
#coaddVisits.asAstropy()
```

[44]:
```
#coadd_objects = butler.get('objectTable_tract', dataId=coaddId)
#print(len(coadd_objects)
```

[45]:
```
#co_ra = coadd_objects.coord_ra.values
#co_dec = coadd_objects.coord_dec.values
#co_cF = coadd_objects.r_calibFlux.values
#co_cFf = coadd_objects.r_calibFlux_flag.values
#co_diP = coadd_objects.detect_isPrimary.values
#tx = np.where((co_diP) & (co_cF > 0.0) & (co_cFf == 0))[0]
#print('Number of coadd objects to plot: ', len(tx))
```

But need to know where is the tract and patch

- the easiest way to know in which tract and patches the DC2 data are distributed is to makea TAP query

[46]:
```
if FLAG_READ_DATAFRAMEFROMDISK and os.path.exists(fullfilename_result_skyinfo):
    # read sky info (tract,patches) from disk
    df = pd.read_csv(fullfilename_result_skyinfo,index_col=0)
    results_skyinfo = Table.from_pandas(df)

else:
    # retrieve sky info (tract,patches) from TAP service
    sync_tract_data = service.search("select tract,patch, \
    min(coord_ra) as minRA, \
    max(coord_ra) as maxRA, \
    min(coord_dec) as minDEC,\
    max(coord_dec) as maxDEC ,\
    avg(coord_ra) as meanRA, \
    avg(coord_dec) as meanDEC,\
    count(*) as num \
    from dp02_dc2_catalogs.Object group by tract,patch")

    results_skyinfo = sync_tract_data.to_table()
```

```
# Save for later use
if FLAG_WRITE_DATAFRAMEONDISK:
    results_skyinfo.to_pandas().to_csv(fullfilename_result_skyinfo)
```

Show table of tract and patches

```
[47]: #results_skyinfo
```

```
[48]: df_results_skyinfo = results_skyinfo.to_pandas().reset_index(drop=True)
      df_results_skyinfo.drop(df_results_skyinfo.columns[df_results_skyinfo.columns.
       ↪str.contains('unnamed',case = False)],axis = 1, inplace = True)
```

```
[49]: df_results_skyinfo.head()
```

```
[49]:    tract  patch      minRA      maxRA     minDEC     maxDEC     meanRA  \
      0   2897      0  51.618138  51.940079 -44.659022 -44.429505  51.778683
      1   2897      1  51.306939  51.635479 -44.660667 -44.431957  51.470803
      2   2897      2  50.995756  51.323245 -44.661524 -44.433645  51.157853
      3   2897      3  50.683944  51.010891 -44.661639 -44.434518  50.845443
      4   2897      4  50.371578  50.699079 -44.661533 -44.433656  50.534933

           meanDEC    num
      0 -44.539377  31027
      1 -44.543630  31819
      2 -44.543645  28954
      3 -44.543454  30291
      4 -44.544366  30738
```

Get list of tracts

```
[50]: list_of_tracts = np.unique(df_results_skyinfo['tract'].values)
      list_of_tracts
```

```
[50]: array([2897, 2898, 2899, 2900, 2901, 2902, 2903, 2904, 2905, 2906, 2907,
             2908, 3074, 3075, 3076, 3077, 3078, 3079, 3080, 3081, 3082, 3083,
             3084, 3085, 3086, 3256, 3257, 3258, 3259, 3260, 3261, 3262, 3263,
             3264, 3265, 3266, 3267, 3268, 3441, 3442, 3443, 3444, 3445, 3446,
             3447, 3448, 3449, 3450, 3451, 3452, 3453, 3454, 3631, 3632, 3633,
             3634, 3635, 3636, 3637, 3638, 3639, 3640, 3641, 3642, 3643, 3825,
             3826, 3827, 3828, 3829, 3830, 3831, 3832, 3833, 3834, 3835, 3836,
             3837, 4022, 4023, 4024, 4025, 4026, 4027, 4028, 4029, 4030, 4031,
             4032, 4033, 4034, 4035, 4224, 4225, 4226, 4227, 4228, 4229, 4230,
             4231, 4232, 4233, 4234, 4235, 4236, 4429, 4430, 4431, 4432, 4433,
             4434, 4435, 4436, 4437, 4438, 4439, 4440, 4441, 4636, 4637, 4638,
             4639, 4640, 4641, 4642, 4643, 4644, 4645, 4646, 4647, 4648, 4848,
             4849, 4850, 4851, 4852, 4853, 4854, 4855, 4856, 4857, 4858, 4859,
             4860, 5062, 5063, 5064, 5065, 5066, 5067, 5068, 5069, 5070, 5071,
             5072, 5073, 5074])
```

Min RA and Max RA and Min DEC and Max DEC for tracts

[51]:
```
patch_coords = df_results_skyinfo.groupby(['tract']).mean().
  ↪sort_values(by="tract")
```

[52]:
```
patch_coords.
  ↪drop(columns=["patch","minRA","maxRA","minDEC","maxDEC","num"],inplace=True)
```

[53]:
```
patch_coords.head()
```

[53]:
```
          meanRA    meanDEC
tract
2897   50.847278 -43.882198
2898   52.881212 -43.881946
2899   54.915204 -43.881658
2900   56.949101 -43.881727
2901   58.982980 -43.881880
```

5.3.3 Access to list of tracts & patches from skyMap structure in Butler

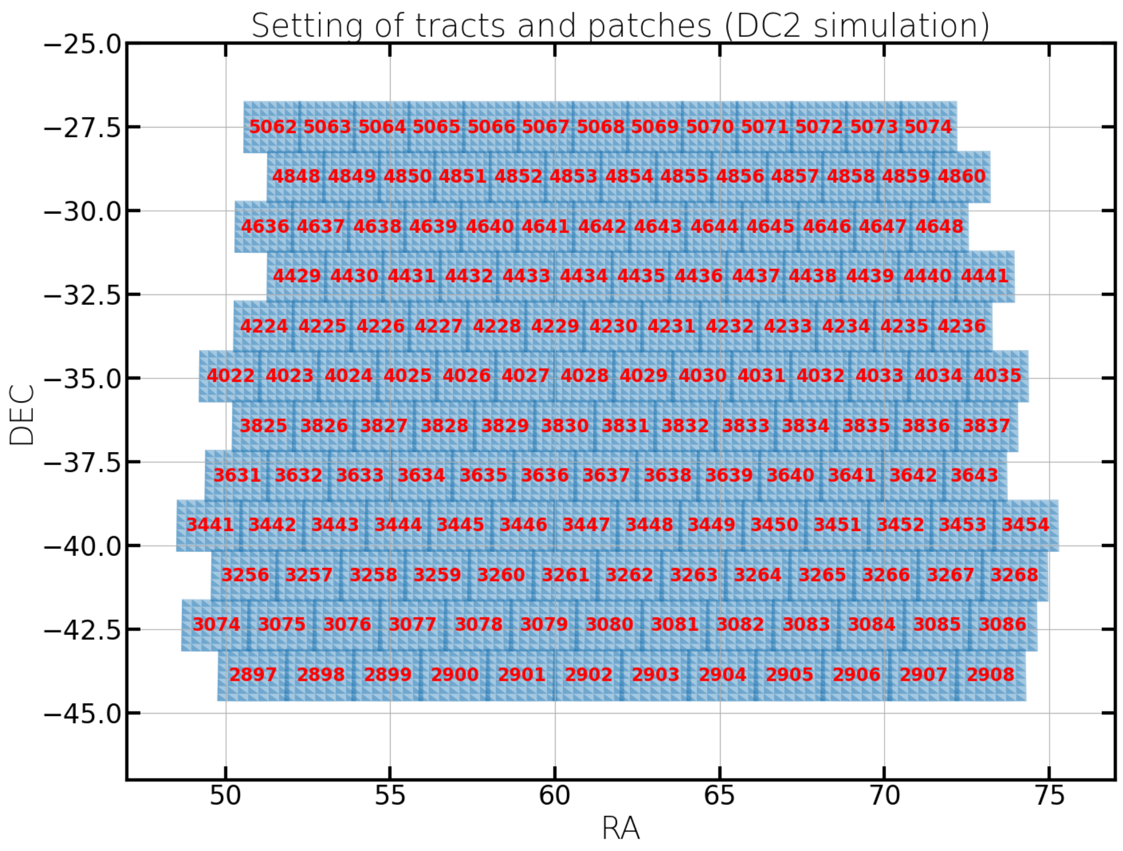
[54]:
```
skymap = butler.get('skyMap')
```

[55]:
```
numTracts=0
patches = []
# loop on tract
for tractInfo in skymap:
    tractID = tractInfo.getId()

    # exclude tract not having any objects in (outside DC2 data)
    if tractID not in list_of_tracts:
        continue

    # WCS for that patch
    tWCS=tractInfo.getWcs()

    # loop on patches inside the tract
    for patch in tractInfo:

        pID = patch.sequential_index
        ibb=patch.getInnerBBox()

        # corners of the patch
        corners = []
        # loop on corners of the patch
        for corner in ibb.getCorners():
            p = geom.Point2D(corner.getX(), corner.getY())
            coord = tWCS.pixelToSky(p)
            corners.append([coord.getRa().asDegrees(), coord.getDec().
↪asDegrees()])
            polygon = Polygon(corners,True)
            patches.append(polygon)
    numTracts+=1

print(numTracts)
```

```
157
```

[56]:
```
fig, ax = plt.subplots(figsize=(16,12))
p = PatchCollection(patches, cmap="jet", alpha=0.4)
ax.add_collection(p)

for index, row in patch_coords.iterrows():
    x=row["meanRA"]
    y=row["meanDEC"]
    ax.text(x, y,␣
↪str(index),horizontalalignment='center',verticalalignment='center',fontsize=16,fontweight="

ax.grid()
ax.set_xlim([47, 77])
ax.set_xlabel('RA')
ax.set_ylim([-47, -25])
ax.set_ylabel('DEC')
ax.set_title("Setting of tracts and patches (DC2 simulation)")
```

[56]:
```
Text(0.5, 1.0, 'Setting of tracts and patches (DC2 simulation)')
```



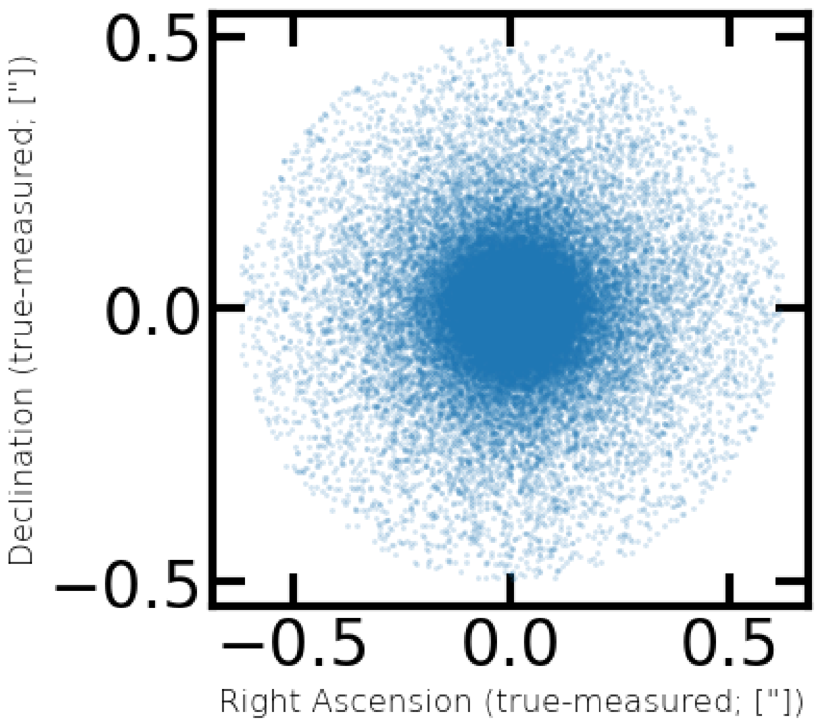
6 5) Check extracted data

6.1 5.1) Compare true and measured properties for true galaxies

6.1.1 Plot coordinate offsets for true galaxies

Below, plot the difference between the true and measured declination versus the difference between the true and measured right ascension.

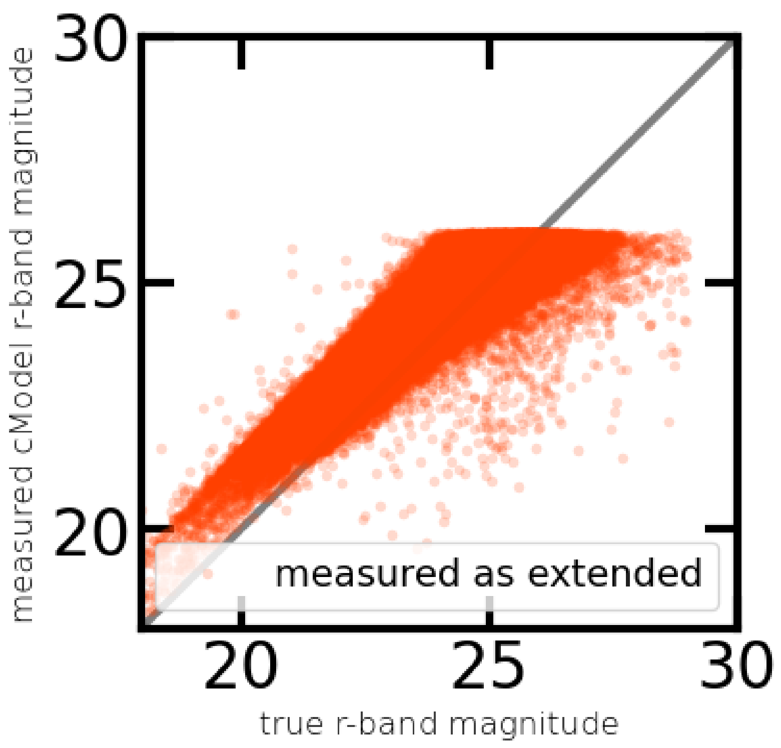
[57]:
```
fig = plt.figure(figsize=(4, 4))
plt.plot(3600*(results['ts_ra']-results['obj_coord_ra']), \
         3600*(results['ts_dec']-results['obj_coord_dec']), \
         'o', ms=2, alpha=0.2, mew=0)
plt.xlabel('Right Ascension (true-measured; ["])', fontsize=12)
plt.ylabel('Declination (true-measured; ["])', fontsize=12)
plt.show()
```



We see that the scatter is less than about 0.5 arcseconds. For the (DC2-simulated) LSST Science Camera's platescale of 0.2 arcsec per pixel, that's a measurement accuracy of 2.5 pixels. Note also that most galaxies' positions are measured to sub-pixel accuracy.

6.1.2 Compare true and measured r-band magnitudes for true galaxies

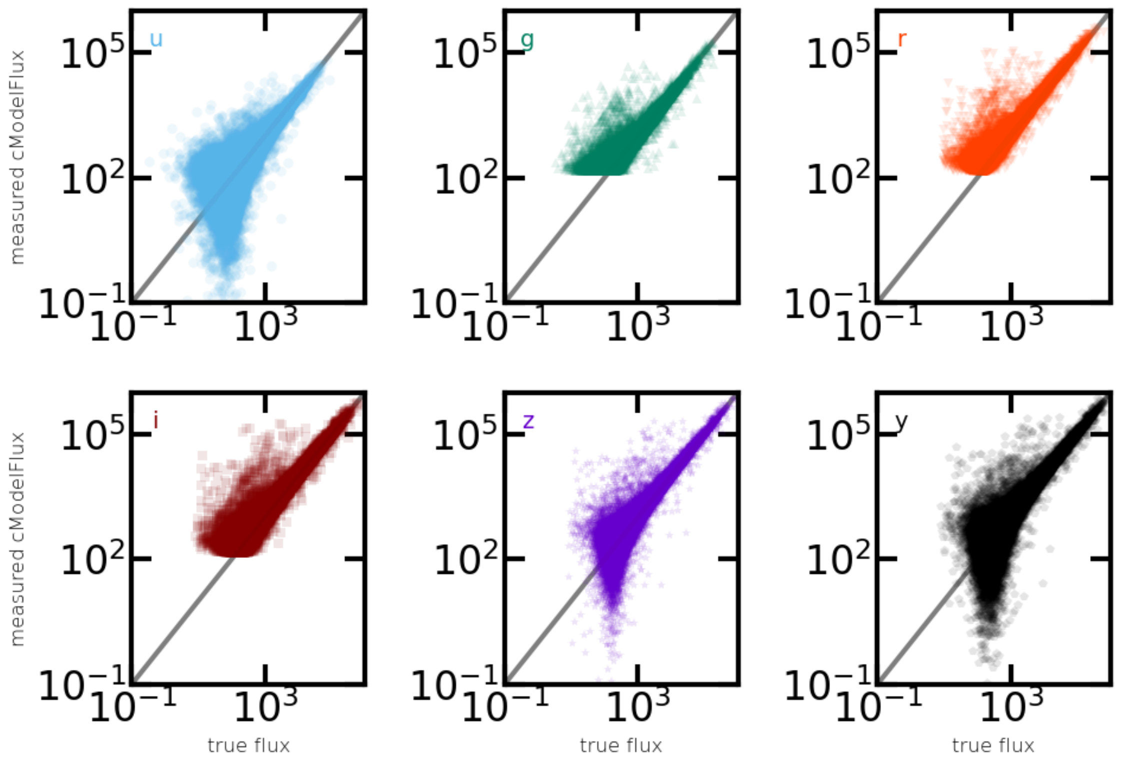
[58]:
```python
fig = plt.figure(figsize=(4, 4))
plt.plot([18,32], [18,32], ls='solid', color='black', alpha=0.5)
plt.plot(results['ts_mag_r'], results['obj_g_cModelMag'], \
         'o', ms=4, alpha=0.2, mew=0, color=plot_filter_colors['r'],\
         label='measured as extended')




plt.xlabel('true r-band magnitude', fontsize=12)
plt.ylabel('measured cModel r-band magnitude', fontsize=12)
plt.legend(loc='lower right')
plt.xlim([18,30])
plt.ylim([18,30])
plt.show()
```



6.1.3 Compare true and measured fluxes in all filters for true galaxies

[59]:
```
fig, ax = plt.subplots(2, 3, figsize=(10, 7))
i=0
j=0
for f,filt in enumerate(plot_filter_labels):
    ax[i,j].plot([0.1,1e6], [0.1,1e6], ls='solid', color='black', alpha=0.5)
    ax[i,j].plot(results['ts_flux_'+filt], results['obj_'+filt+'_cModelFlux'], \
                 plot_filter_symbols[filt], color=plot_filter_colors[filt], \
                 alpha=0.1, mew=0, label=filt)
    ax[i,j].loglog()
    ax[i,j].text(0.1, 0.9, filt, horizontalalignment='center',␣
 ↪verticalalignment='center',
                 transform = ax[i,j].transAxes, color=plot_filter_colors[filt],␣
 ↪fontsize=14)
    ax[i,j].set_xlim([0.1,1e6])
    ax[i,j].set_ylim([0.1,1e6])
    j += 1
    if j == 3:
        i += 1
        j = 0
ax[0,0].set_ylabel('measured cModelFlux', fontsize=12)
```

```
ax[1,0].set_ylabel('measured cModelFlux', fontsize=12)
ax[1,0].set_xlabel('true flux', fontsize=12)
ax[1,1].set_xlabel('true flux', fontsize=12)
ax[1,2].set_xlabel('true flux', fontsize=12)
plt.tight_layout()
plt.show()
```



6.1.4 Compare color-magnitude diagrams (CMDs) for true and measured properties of true galaxies

The following cells plot the true CMD at left in black, and the measured CMD at right in grey.

The first pair of plots uses the r-band for magnitude, and the g-r color. The second pair of plots uses the r-band for magnitude, and i-z for color.

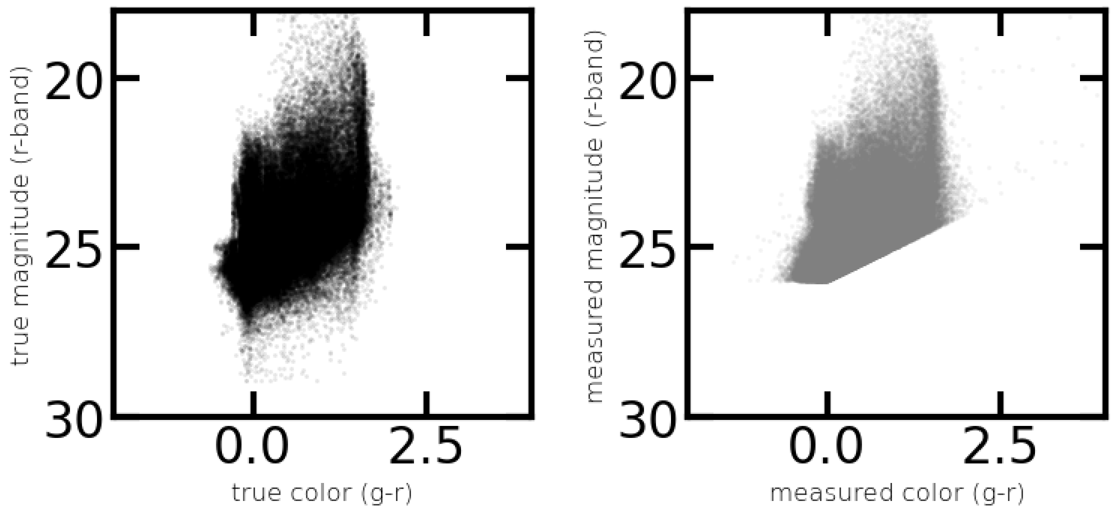
In the first set of plots, the effects of measurement uncertainties are correlated between the x and y axes because the r-band data is included in both axes. In the second set of plots, the i-band and the z-band are instead used for color. Notice how the effect of measurement uncertainties changes.

Recall that these plots do not contain data for stars, as only true galaxies were retrieved from the truth tables.

> **Warning:** Pink "RuntimeWarning" errors will appear due to a few of the measured fluxes in the denominator being zero. It is OK to ignore these warnings for the context of this tutorial, which focuses on retrieving truth data, but for scientific analyses

users should follow up and understand such warnings (e.g., use flags to reject poor flux measurements from their samples).

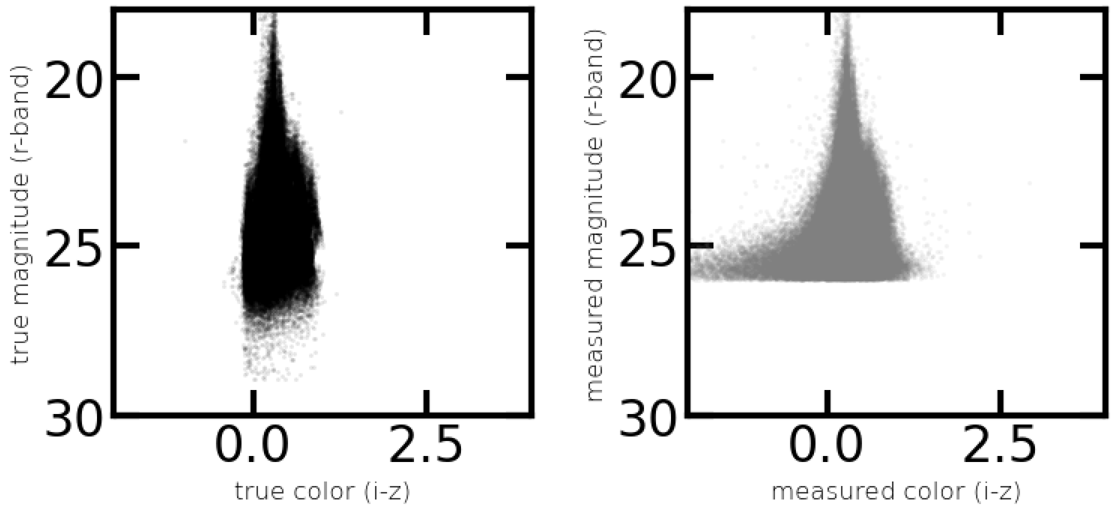
```
[60]: fig, ax = plt.subplots(1, 2, figsize=(8, 4))
ax[0].plot(-2.5*np.log10(results['ts_flux_g']/results['ts_flux_r']),␣
 ↪results['ts_mag_r'], \
           'o', ms=2, alpha=0.1, mew=0, color='black')

ax[1].plot(-2.5*np.log10(results['obj_g_cModelFlux']/
 ↪results['obj_r_cModelFlux']), results['obj_r_cModelMag'], \
           'o', ms=2, alpha=0.1, mew=0, color='grey')
ax[0].set_xlabel('true color (g-r)', fontsize=12)
ax[0].set_ylabel('true magnitude (r-band)', fontsize=12)
ax[0].set_xlim([-2, 4])
ax[0].set_ylim([30, 18])
ax[1].set_xlabel('measured color (g-r)', fontsize=12)
ax[1].set_ylabel('measured magnitude (r-band)', fontsize=12)
ax[1].set_xlim([-2, 4])
ax[1].set_ylim([30, 18])
plt.tight_layout()
plt.show()
```



```
[61]: fig, ax = plt.subplots(1, 2, figsize=(8, 4))
ax[0].plot(-2.5*np.log10(results['ts_flux_i']/results['ts_flux_z']),␣
 ↪results['ts_mag_r'], \
           'o', ms=2, alpha=0.1, mew=0, color='black')

ax[1].plot(-2.5*np.log10(results['obj_i_cModelFlux']/
 ↪results['obj_z_cModelFlux']), results['obj_r_cModelMag'], \
           'o', ms=2, alpha=0.1, mew=0, color='grey')
```

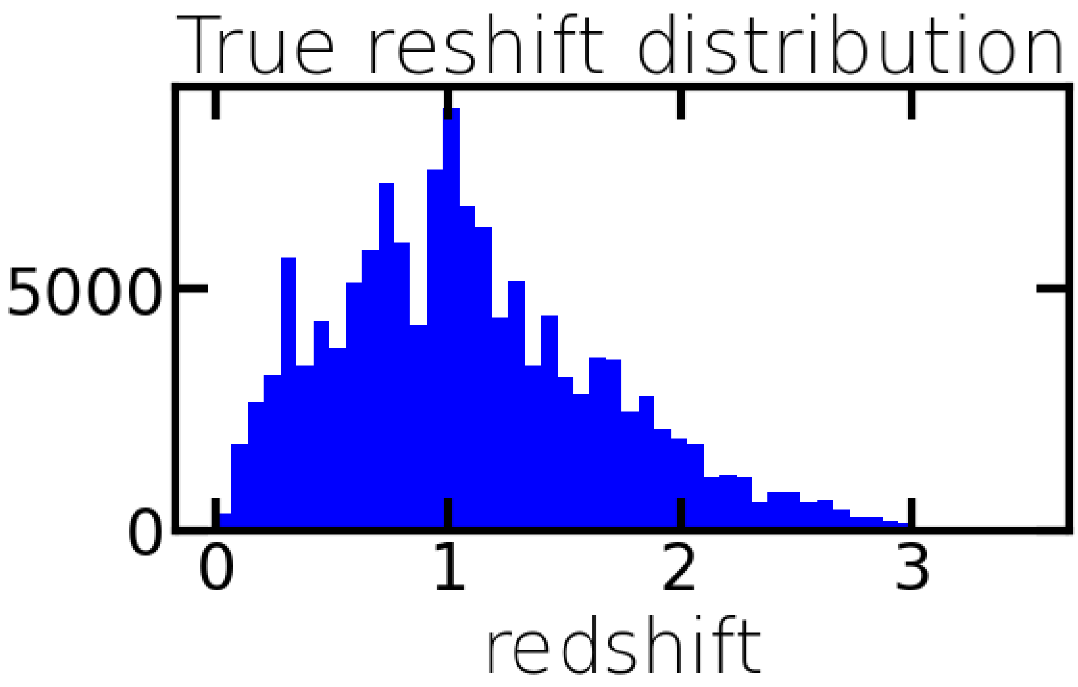
```
ax[0].set_xlabel('true color (i-z)', fontsize=12)
ax[0].set_ylabel('true magnitude (r-band)', fontsize=12)
ax[0].set_xlim([-2, 4])
ax[0].set_ylim([30, 18])
ax[1].set_xlabel('measured color (i-z)', fontsize=12)
ax[1].set_ylabel('measured magnitude (r-band)', fontsize=12)
ax[1].set_xlim([-2, 4])
ax[1].set_ylim([30, 18])
plt.tight_layout()
plt.show()
```

```
/tmp/ipykernel_64383/3318533333.py:5: RuntimeWarning: invalid value encountered
in log10
  ax[1].plot(-2.5*np.log10(results['obj_i_cModelFlux']/results['obj_z_cModelFlux
']), results['obj_r_cModelMag'], \
```



```
[63]: fig = plt.figure(figsize=(6, 3))
      ax=fig.add_subplot(1,1,1)
      ax.hist(results["ts_redshift"],bins=50,range=(0,3.5),facecolor="b");
      ax.set_xlabel("redshift")
      ax.set_title("True reshift distribution")
```

```
[63]: Text(0.5, 1.0, 'True reshift distribution')
```


True reshift distribution
5000
0
0
1
2
3
redshift

```
[ ]:
```