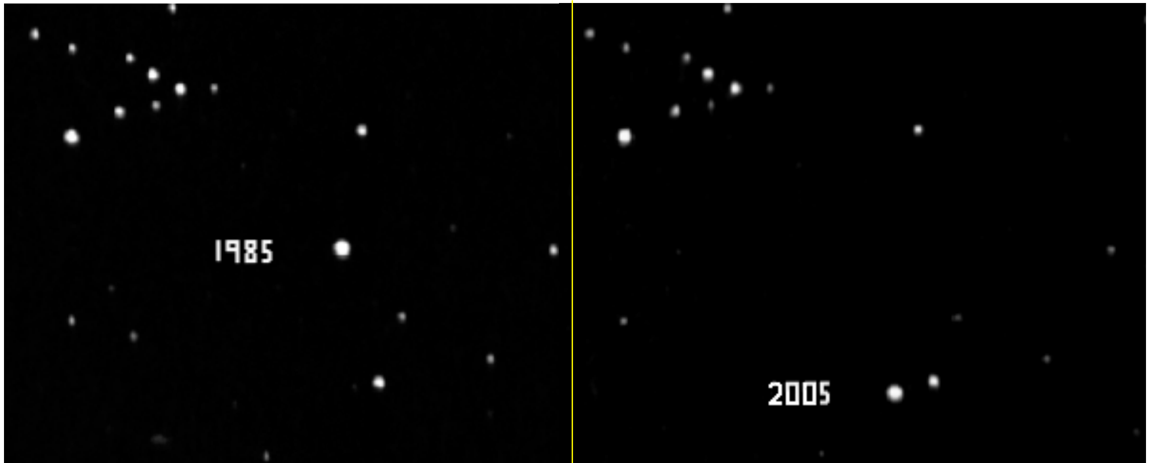
Time Domain Surveys:
Proper Motion

Time Domain Surveys: Parallax

- Another use of data from time domain surveys is the measurement of proper motion and parallax
- Parallax is the change in a star's position as the Earth orbits…it's inversely proportional to a star's distance
- Observations from the Earth's reference frame that are separated by 6 months are optimal to measure parallax. Observations every 12 months have the lowest utility
- Parallax *can* be measured for *some* stars in ground-based surveys, but cadences are typically not optimal
- Most surveys from the Earth's surface revisit the same patch of sky annually, rather than nearer every 6 months
- Some space-based missions, such as GAIA, are optimized to measure parallaxes

Time Domain Surveys: Proper Motion

- Proper motions can be easier to measure, even with cadences of 12 months



Barnard's Star in 1985 and 2005

- True motion on the plane of the sky and apparent, angular, and proper, motion are related by:
- $v_t = 4.74 \cdot \mu \cdot d$
  - v_t is the transverse velocity of the star in km/s
  - μ is the star's proper motion in arcsec/year
  - d is the distance to the star in pc

Time Domain Surveys: Proper Motion

- $v_t = 4.74 \cdot \mu \cdot d$
- e.g., Barnard's star has μ = 10.3"/yr and d = 1.83 pc, so v_t = 90 km/s

- Typically, current ground-based time domain surveys can measure proper motions at the level of 0.1"/yr
- If typical stars move at 10 km/s relative to the Earth, then their proper motions are visible in such surveys out to 70 lyr
- But, some "hyper-velocity" stars have motions visible out to > 10,000 lyr (see *Brown et al.* linked from the syllabus)

Time Domain Surveys: Proper Motion

- Obviously ($v_t = 4.74 \cdot \mu \cdot d$) objects with large proper motions tend to be closer to the Earth
- But, with sufficient precision for μ, we can measure the velocities of extragalactic objects, such as galaxies
- Galaxies in our Local Group are ~1 million lyr away, so if they move at 100 km/s, then μ needs to be measured to 70 *micro*arcseconds/yr, or 7 *milli*arcseconds/century
  - This *is* possible (see the *Brunthaler et al.* syllabus link)
- Extragalactic sources can also be classified by a *lack* of proper motion...this will become *very* useful as GAIA progresses to measure proper motions for many objects
- e.g., the *closest* known quasar is ~1 *billion* lyr distant

Temporal Queries of SDSS Stripe 82

- The *SDSS Stripe 82 Catalog Archive Server* is linked from the syllabus (it's different to the one that we used in earlier lectures to query the single-epoch SDSS data)
- To return all objects within 0.3 arcseconds of a sky position (*ra, dec)*, at any time of observation, use, e.g.:
- *SELECT p.ra, p.dec, p.psfmag_i, f.mjd_i, n.distance*60 FROM fGetNearbyObjEq(ra,dec,0.3/60) n, PhotoPrimary p, Field f WHERE n.objID = p.objID and f.fieldID = p.fieldID*
- Here, the "*n*" is the database of HTM indexes, the "*p*" is the database of imaging information for primary objects and the "*f*" database records the time that each image was observed
- The _*i* variables convey the fact that we only want to return magnitudes and times of observation (MJD) in the *i*-band

Temporal Queries of SDSS Stripe 82

- Code in my week12 directory can be edited to run:

  *SELECT p.ra, p.dec, p.psfmag_i, f.mjd_i, n.distance*60 FROM fGetNearbyObjEq(ra,dec,0.3/60) n, PhotoPrimary p, Field f WHERE n.objID = p.objID and f.fieldID = p.fieldID*

- The code is called stripe82query.py and takes RA and Dec as arguments passed at the command line
- The output will be the same whether you use my Python code or the online query, but my code can be spawned from other Python code using, e.g., *os.system*
- The output can be directed to a file and read back in:
  - *os.system("python stripe82query.py 29.2256832 0.4208970 > sqlresult.data")*

Python tasks

1. Cool stars that are close to the Earth will be red and could have high proper motion. Let's look for such stars...
   - Query SDSS Stripe 82 and retrieve time domain data for all objects with magnitude $i < 21.5$ that are within 1 arcmin of $(\alpha,\delta) = (14.66^o, 0.74^o)$
2. Plot RA against Dec for *all of the objects in the same plot*...can you see objects with multiple detections?
   - Each object may have an observation at *mjd_i = 0* for the *run* that corresponds to the coadded data (*run = 106* or *run =206*)...you can remove this observation
3. Zoom in to *xrange*=[14.654,14.658], *yrange*=[0.72,0.76]
   - Can you see an object that looks like its observations span a larger area (i.e. a high proper motion object)?

Python tasks

4. Retrieve only those observations that correspond to your object so that we can study them in more detail
   - e.g. use *astropy's separation* command to restrict to only observations near the RA, Dec of interest
5. For the observations of interest plot *mjd_i* against RA and then *mjd_i* against Dec and zoom into the plot
   - Does the object have visible motion in each coordinate?
6. Plot *mjd_i* against angular *distance* (d_{ang}, which was retrieved as part of the original SQL query)
   - How many *years* does *mjd_i* span for this object?
   - Estimate how d_{ang} changes and the star's proper motion.
   - If this star is moving at 10km/s, what is its distance?