

# **Time Domain Surveys: Proper Motion**

# Time Domain Surveys: Parallax

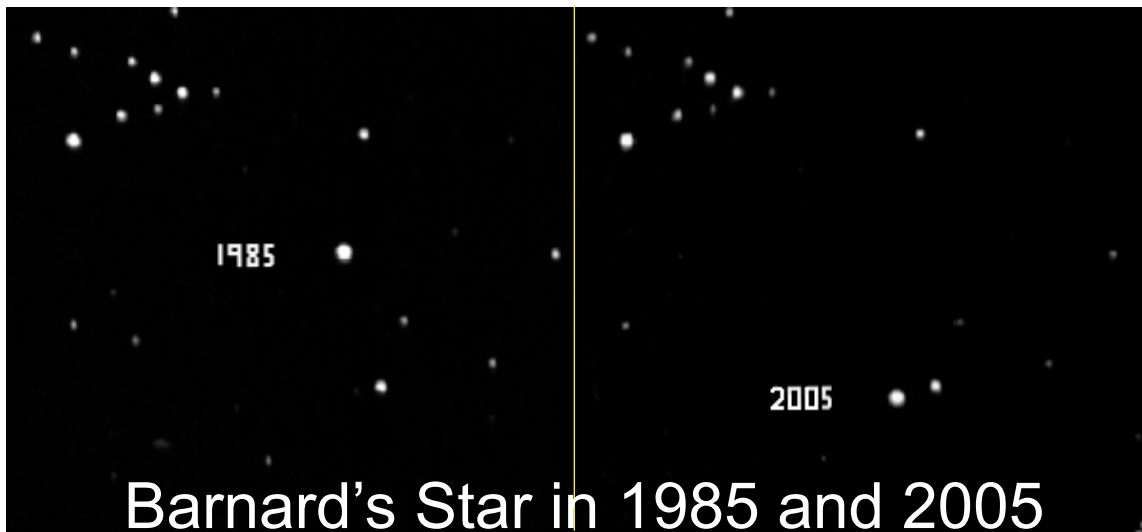
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- Another use of data from time domain surveys is the measurement of proper motion and parallax
  - Parallax is the change in a star's position as the Earth orbits...its inversely proportional to a star's distance
  - Observations from the Earth's 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
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# Time Domain Surveys: Proper Motion

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- Proper motions can be easier to measure with cadences of 12 months
- True motion on the plane of the sky and apparent, angular, and proper, motion are related by:
  - $v = p.d.c.\pi/(3600.180)$ 
    - $v$  is the true velocity of the star in km/s
    - $p$  is the star's proper motion in arcsec/year
    - $d$  is the distance to the star in light-years
    - $c$  is the speed of light ( $3 \times 10^5$  km/s)



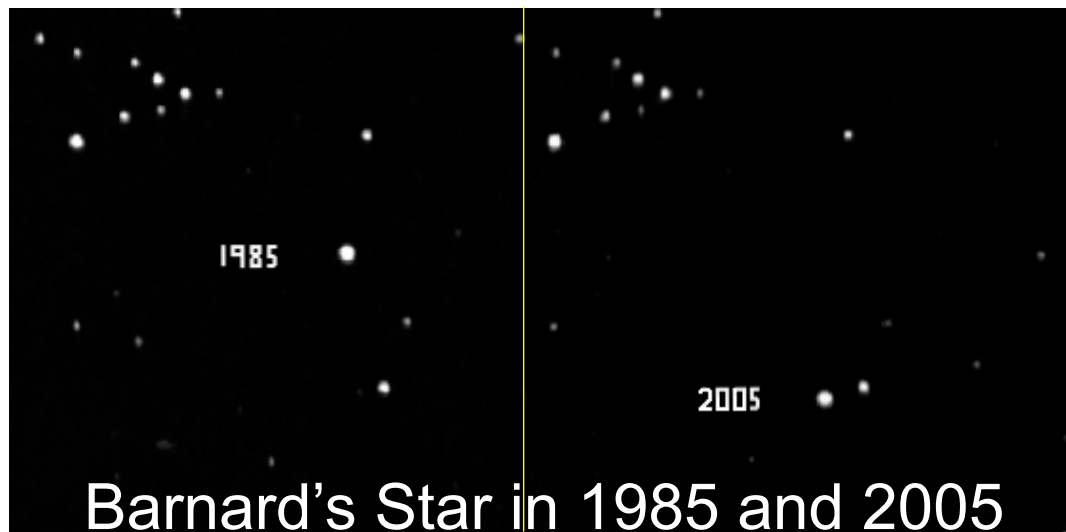
# Time Domain Surveys: Proper Motion

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- $p(\text{rad/yr}) = p(''/\text{yr}) \cdot \frac{\pi}{(3600 \times 180)}$

- $v = p(\text{rad/yr}) \cdot d \cdot c$

- e.g., Barnard's star has  $p = 10.3''/\text{yr}$  and  $d = 5.98 \text{ lyr}$ , so  $v = 90 \text{ km/s}$



- Typically, current ground-based time domain surveys can measure proper motions at the level of  $0.1''/\text{yr}$
  - If typical stars move at  $10 \text{ km/s}$  relative to the Earth, then their proper motions are visible in such surveys out to  $70 \text{ lyr}$
  - But, some “hyper-velocity” stars have motions visible out to  $> 10,000 \text{ lyr}$  (see *Brown et al.* linked from the syllabus)
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# Time Domain Surveys: Proper Motion

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- Obviously ( $v = d.p.c.\pi/(3600.180)$ ) objects with large proper motions tend to be closer to the Earth
  - But, with sufficient precision for  $p$ , we can measure the velocities of extragalactic objects, such as galaxies
  - Galaxies in our Local Group are  $\sim 1$  million lyr away, so if they move at 100 km/s, then  $p$  needs to be measured to  $70$  *microarcseconds/yr*, or  $7$  *milliarcseconds/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  $\sim 1$  *billion* lyr distant
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# Temporal Queries of SDSS Stripe 82

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- 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\_g, f.mjd\_g, 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  $_g$  variables convey the fact that we only want to return magnitudes and times of observation (MJD) in the g-band
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## Temporal Queries of SDSS Stripe 82

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- Code in my week12 directory can *remotely* run the query  
*SELECT p.ra, p.dec, p.psfmag\_g, f.mjd\_g, 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")*
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# Python tasks

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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  $(\alpha, \delta) = (14.66^\circ, 0.74^\circ)$
  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)?
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# Python tasks

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4. Retrieve only those observations that correspond to your object so that we can study them in more detail
    - i.e. use a *np.where* command to restrict the observations to only those near the RA, DEC of the object 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* (which was retrieved as part of the original SQL query)
    - How many *years* does *mjd\_i* span for this object?
    - Fit a line and estimate the star's proper motion
    - If this star is moving at 10km/s, what is its distance?
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