Coordinate Systems

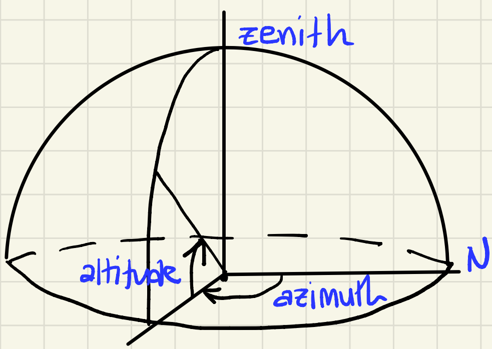
Topics: observing seasons, celestial motions, coordinates, time, precession, proper motion

Sources: Chromey Ch. 3

Basic Definitions:

zenith: the point at 90° elevation
nadir: the point at −90° elevation
meridian: the great circle intersecting the south celestial pole, north celestial pole, and local zenith
hour angle: the time before (−) or after (+) an object crosses the local meridian
celestial equator: projection of the Earth's equator onto the sky
celestial north pole: the point above the north pole of the Earth
ecliptic: the plane defined by the orbital plane of the Earth around the sun
galactic plane: plane which passes through the disk of the Galaxy

Azimuthal coordinates:



azimuth: degrees east of north along the horizon 0° − 360°
altidude or elevation: angle from the horizon, 0°−90°
zenith angle: $z = 90° - \text{altidude}$

airmass $= X = \sec z = \frac{1}{\cos z}$

z (deg)	X
0	1.00
10	1.02
30	1.15
45	1.41
60	2.00
70	2.92
80	5.75

↳ this eqn. is for a plan-parallel atmosphere (i.e. constant density, ignore curvature of Earth). It breaks down at $z \sim 75°$. At greater angles $X \to \infty$, when really the maximum on the horizon is usually < 40.

minimum airmass occurs when an object is on the meridian
the minimum zenith angle is given by:

$$z_{min} = |\text{observatory latitude} - \text{source declination}|$$

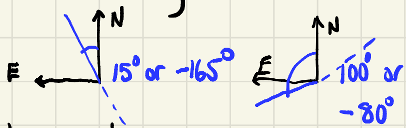
Equatorial Coordinates:

δ declination: the angle north or south of the celestial equator
α right ascension: time, in hours, minutes, seconds (sexigesimal) from the Vernal Equinox (RA=0), increases E

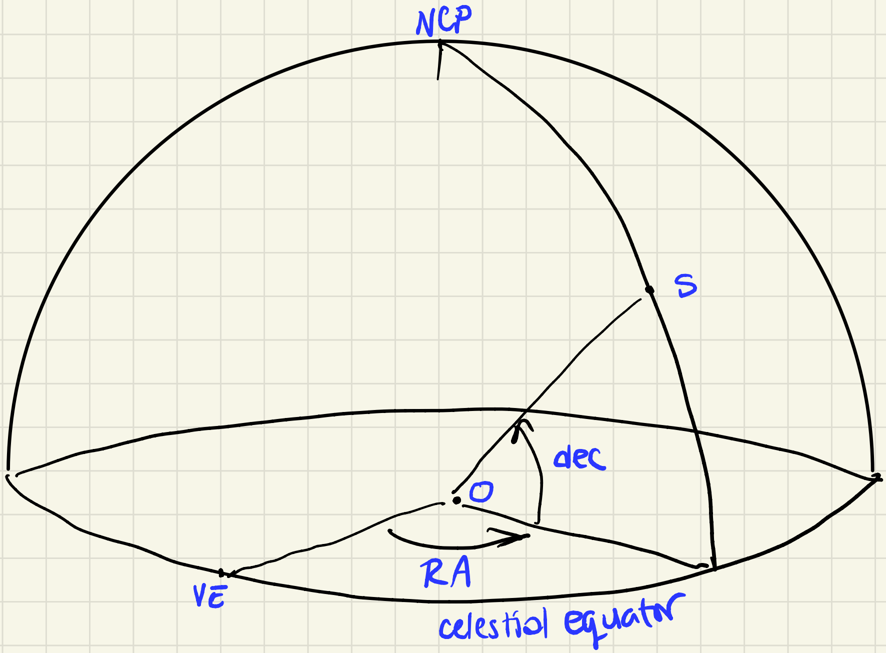
RA = 0, dec = 0 in Pisces is where the Sun is located on March 21

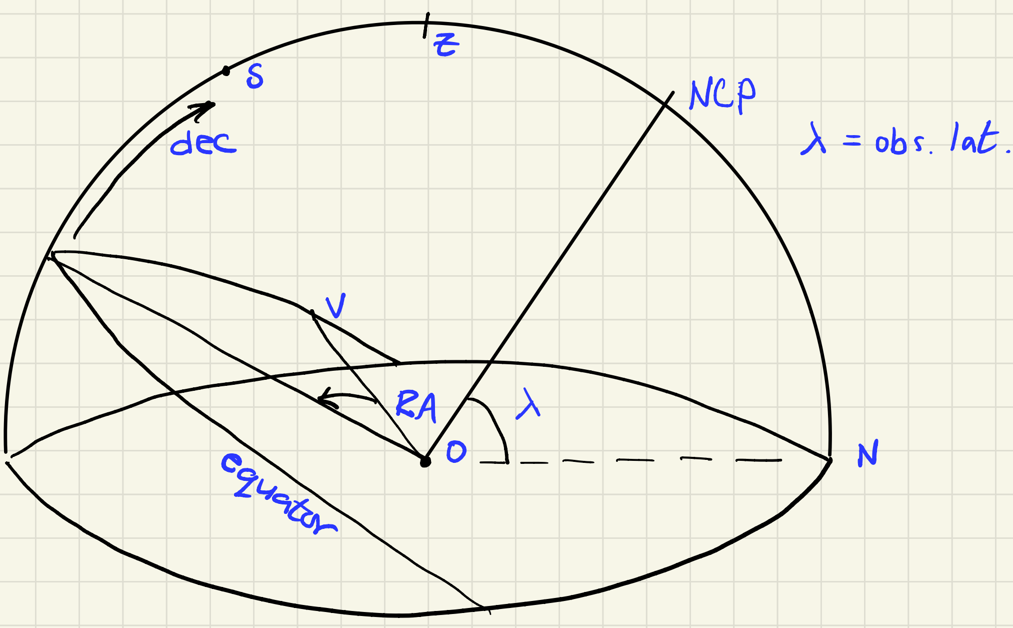
Epoch of coordinates: B1950 (Besselian; FK4) or
J2000 (Julian; FK5)
to correct for precession of Earth's axis

Position angle: the angle East of North onto the sky
(0° to 180° or 0° to −180°)



1 hour of RA = 15 degrees at the celestial equator
1 minute of RA = 15 arcminutes at the celestial equator
1 second of RA = 15 arcseconds at the celestial equator
at other dec, 1 hour of RA $= 15° \cos \delta$; similarly for min, sec


NCP
S
dec
O
RA
VE
celestial equator


Z
S
NCP
dec
λ = obs. lat.
V
RA
λ
O
N
equator

z.B. Convert the following equatorial coordinates in HMS format to degrees:

RA = 00:54:52.1

Decl. = 25:25:38.0

There are $\frac{360°}{24h} = 15°/h$ of RA. So,

$$RA = 15°/h \cdot \left(0h + 54m \cdot h/60m + 52.1s \cdot m/60s \cdot h/60m\right)$$

RA = 13.72°

$$Decl. = 25° + 25' \cdot °/60' + 38'' \cdot °/60' \cdot '/60'' = 25.43°$$

Now go the other way:

RA = 220.531°

Decl. = 35.4397°

$$RA = 220.531° \cdot h/15° = 14.7021h \rightarrow 0.7021h \cdot \frac{60m}{h} = 42.126m$$
$$\rightarrow 0.126 \cdot 60s/m = 7.56s$$

RA = 14:42:07.56

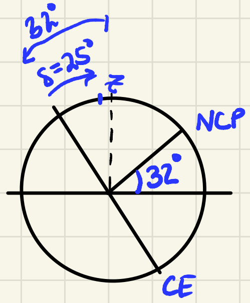
$$Decl. = 35.4397° \rightarrow 0.4397° \cdot 60'/° = 26.382'$$
$$\rightarrow 0.3820' \cdot 60''/' = 22.92''$$

Decl. = 35:26:22.92

2.B. You are observing at Kitt Peak National Observatory (KPNO) at a latitude of ~32°. What is the minimum airmass that NGC5548 will have at this site?

α : 14h17m59.534s
δ : +25d22m12.44s

$$\delta = 25 + \frac{22m}{60\,\%} + \frac{12.44s}{3600\,''\!/\!\%} = 25.137^\circ$$

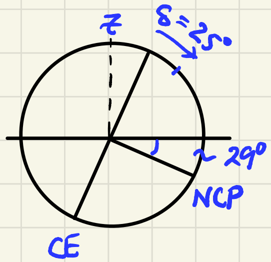


minimum zenith angle when NGC5548 crosses the meridian.

$$z_{min} = 32^\circ - 25^\circ = 7^\circ$$

$$X_{min} = \frac{1}{\cos z_{min}} = \frac{1}{0.99} = 1.01$$

What about from Las Campanas, which has $\lambda = 29°S$?



$$z_{min} = 29^\circ + 25^\circ = 54^\circ$$

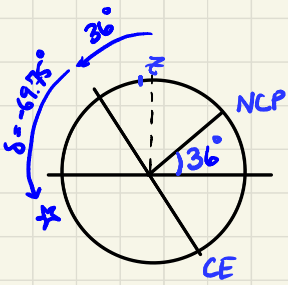
$$X_{min} = \frac{1}{\cos z_{min}} = \frac{1}{0.588} = 1.7$$

2.B. Can you observe the Magellanic Clouds from Nashville?

RA = 5h 23m 34s
Dec = −69° 45′ 22″

and $\lambda_{Nash} = 36°N$

$$\text{Dec.} = -\left[69° + 45' \cdot \frac{1°}{60'} + 22'' \cdot \frac{1°}{3600''}\right] = -69.75°$$



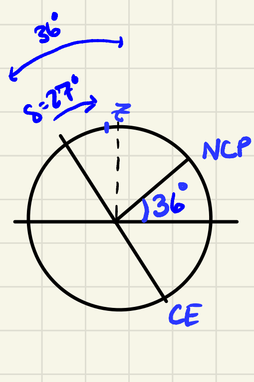
This source will be at

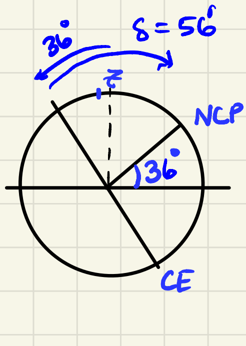
$$\lambda + |\delta| - 90° = 36° + 69.75° - 90° = 11.75°$$

so the Magellanic Clouds never rise in Nashville. The closest they get is ~12° below the horizon.

2.B. Is the Auriga constellation visible from Nashvill? It has:

$$27°53'29'' < \delta < 56°09'53'' \Rightarrow 27.87° < \delta < 56.16°$$





So Auriga will be entirely visible from Nashville.

It is within 9°–20° of zenith.

For very small separations, you can approximate the spherical surface of the sky as a plane and use the Pythagorean theorem, with a correction for declination.

$$\theta^2 = \Delta\delta^2 + \Delta\alpha^2 \cos^2 \delta_{avg}$$

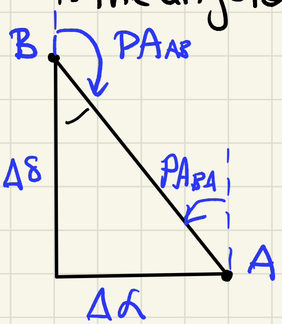
z.B.
Source A has position $\alpha = 13:00:00$, $\delta = 00:00:00$ and source B has position $\alpha = 13:01:30$, $\delta = 00:00:00$. What is the angular distance between these sources?

$$\Delta\alpha = 13h\,00m\,00s - 13h\,01m\,30s = 1m\,30s = 90s \text{ of RA}$$

we are at the equator so $\Delta\delta = 0$ and $\cos\delta = 1$

$$\theta = 90s \cdot 15 \ ^{arcsec}/_{s} = 1350 \text{ arcsec}$$

Source A has position $\alpha = 13:00:00$, $\delta = 40:30:01$ and source B has position $\alpha = 13:01:02$, $\delta = 40:32:20$. What is the angular distance between these sources?



for small separations

$$\Delta\alpha = (\alpha_B - \alpha_A) \cdot \cos\delta_{avg}$$
$$= 1m\,2s \cdot 15 \ ^{arcsec}/_{s} \cdot \cos(40.5196^\circ)$$
$$= 706.971 \text{ arcsec} \approx 707 \text{ arcsec}$$

$$\Delta\delta = 40d\,32m\,20s - 40d\,30m\,01s$$
$$= 2m\,19s = 139 \text{ arcsec}$$

$$\theta = \sqrt{707 \text{ arcsec}^2 + 139 \text{ arcsec}^2}$$

$$\theta \approx 720.535 \text{ arcsec}$$

PA of B relative to A? $PA_{BA} = \tan^{-1}(\Delta\alpha / \Delta\delta) = \tan^{-1}\left(\frac{707}{139}\right) = 79^\circ$

PA of A relative to B? $PA_{AB} = -(180^\circ - PA_{BA}) = -101^\circ$

Galactic coordinates (l, b):

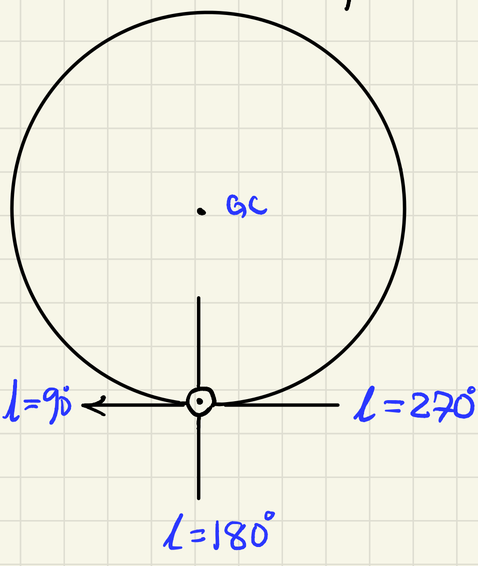
Galactic Plane ($b=0$): plane formed by the disk of the Milky Way. Inclined by 63° to the Celestial Equator.

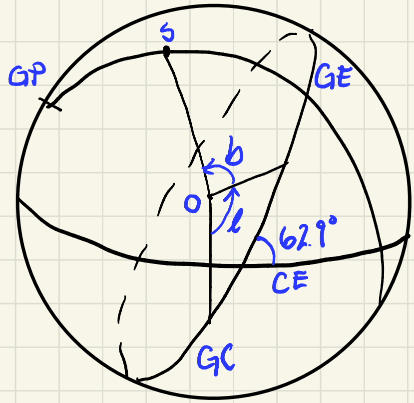
Galactic North Pole ($b=90°$): located in Coma Berenices at RA = 12:51, dec = +27

Galactic South Pole ($b=-90°$): located in Doradus at RA = 00:51, dec = −27

Galactic Center ($l=0, b=0$): located in Sagittarius at RA = 17:45, dec = −28:56

solar circle $R \sim 8$kpc



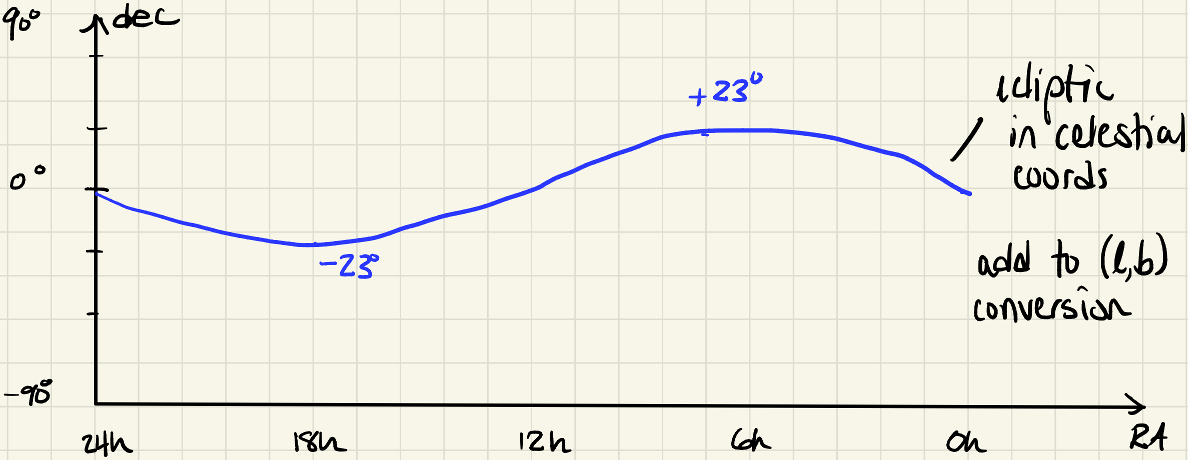


z.B.

By reading the handout chart, what is the RA and dec of a Galactic HII region at $l=30°$, $b=0°$? RA = 16h, dec = −10°

If you are observing in the Galactic Plane, where are asteroids most likely to cause confusion?

where the Galactic Plane crosses the Ecliptic plane.



add to (l,b) conversion

- looking at the conversion chart the ecliptic plane and galactic plane cross at RA ~ 17.5h, dec ~ −22° and RA ~ 5.5h and dec ~ 22°.

Ecliptic Coordinates:

- so named because eclipses occur in this plane
- the plane of the solar system, inclined 23.5° to celestial eq.

Ecliptic north: located in Draco, RA = 18:00:00, dec = +66.5°
Ecliptic south: located in Dorado, RA = 6:00:00, dec = −66.5°
Ecliptic lon = 0, lat = 0 located at RA = 00:02:33, dec = 00:16:41
Galactic center is at Ecliptic lon = 266°, lat = −5°

Time:

- International Atomic Time (TAI; acronym from French) is based on the atomic standard:

  1s = the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of cesium-133.

- solar time
  - not a very regular clock because the Sun does not move evenly:

    1. Our orbit is not circular. Earth moves faster in January when it is closer to the Sun. A day around Jan 4 is about 8s longer.

    2. Second effect due to "obliquity of the ecliptic". The ecliptic is tilted by 23.5° relative to the equator, so around the solstices it has a greater E-W component to its orbit. This makes these days ~20s longer.

  - eliminate these effects from time keeping with "mean sun", a body that moves along the celestial equator with uniform angular speed.

local mean solar time = hour angle of mean sun + 12 hours

Universal time (UT) is independent of longitude on Earth:

universal time = UT1 = mean solar time at 0° longitude (Greenwich)

UT1 is still not completely uniform due to longterm changes (e.g. precession is not perfectly known and comes into UT1 via the calculation of the mean sun). The mean solar day is getting longer by 0.0015s per century compared to SI time measured with atomic clocks.

Coordinated Universal time (UTC) is similar to UT1 but uses SI seconds. A leap second keeps it in step with UT1.

i.e. UT1 is based on Earth's rotation, UTC on atomic clock.

For any place on Earth:

$$\text{longitude} = (\text{Greenwich mean time} - \text{mean local time}) \cdot 15^\circ$$

For Nashville at longitude 86.7° W (−86.7° relative to Greenwich) we are ~6 hours behind UTC.

Julian Date

Dates begin on January 1, 4713 BC. JDs since 2000 may be found from:

$$JD = 2{,}451{,}544.5 + 365(Y - 2000) + N + L$$

where Y is the year, N is the number of days since the beginning of the year, and L is the number of leap days since January 1, 2001. Or use an online/py calculator.

Modified Julian Date (MJD) is commonly used to avoid large numbers:

$$MJD = JD - 2{,}400{,}000.5$$

Heliocentric Julian Date is usually used to correct for the fact that the Earth moves around the sun and light travel time may be 16 minutes different from one side of the orbit to the other.

Greenwich Sidereal Time (GST): effectively, the RA of something that is on the meridian in Greenwich.

$$GST \approx G + 0.0657 \times N + 1.002737 \times UT$$

N is the day of the year
UT is universal time in decimal hours
G is the GST at 0 UT on the zeroth day of the year in any given year; look up G in a table

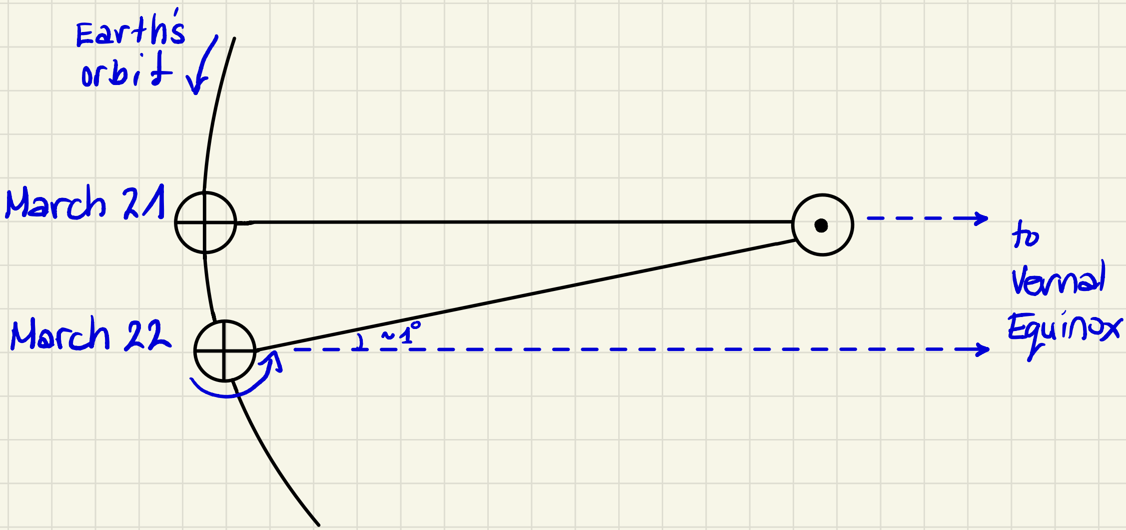
$$LST = GST + \text{longitude (deg)}/15$$

Finding things on the sky:

In order to know what is up in the night sky, it is important to think about how position and time are related.

We measure time on Earth by the position of celestial objects in the sky. Most often, we use solar time based on the position of the Sun on the sky. A solar day is defined as 24hr.

The Earth makes one full rotation each day, but because it has moved a little bit on its orbit, it has to rotate an extra ~1° to get from one solar noon to the next. The stars are so far away, the Earth's orbital motion is negligible.



It takes 23 hr 56 min 4.1 sec for Earth to rotate back to the Vernal Equinox. This is a sidereal day.

It takes an additional ~4 min for the Earth to rotate to face the Sun again. This is a Solar day.

$$ST = RA + HA$$

RA → right ascension

HA → hour angle

ST → sidereal time

local sidereal time (LST): ST is time wrt background stars
LST is RA on meridian at location

The Sun moves ~4 min/day or 30°/month towards +RA.

Approximately what is the Sun's RA today (early January)?
It is 9.5 months after the end of March

$RA_\odot = 0° + 9.5\text{ months} \cdot 30°/\text{month} = 285°$

What is the LST at midnight?
Opposite of the Sun at RA = 285° = 19h, so 105° = 7 h.

What range of RA could you observe from Kitt Peak tonight?
- nights now are pretty long, but just say 12 hours
- $RA_\odot$ = 19h and LST = 7 h at midnight.
- Can see ± 6h, so 1h – 13h

On March 21, what is the LST at Kitt Peak at sunset? Midnight? Sunrise?

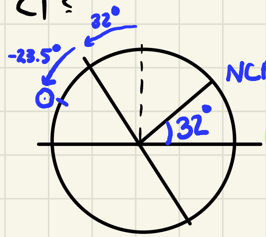
Assume sunset at 6pm, sunrise at 6am. $RA_\odot$ = 0h.
LST sunset = 6h
LST midnight = 12h
LST sunrise = 18h

What is the declination of the Sun on June 21? Sep 21? Dec 21? March 21?
- the axis of the Earth is tilted by 23.5°, so the min/max declination the Sun has is +/-23.5°. It is 23.5° on June 21, 0° on Sep 21, −23.5° on Dec 21, and 0° on Mar 21

From Kitt Peak, what is the airmass of the Sun at noonish on Dec 21? On June 21?

- on Dec 21 $\delta_\odot = -23.5°$.

$\lambda_{Tucson} \sim 32° N$

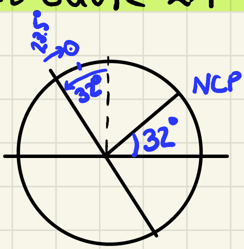


$z = 23.5° + 32° = 55.5°$

$X = \frac{1}{\cos 55.5°}$

$X = 1.76$

On June 21 $\delta_\odot = 23.5$



$z = 32° - 23.5° = 8.5°$

$X = \frac{1}{\cos 8.5°} = 1.01$

In which season are you most likely to observe clusters of galaxies from a Northern observatory?

- you can't observe extragalactic sources easily through the Galactic plane, so you need the N/S Galactic pole to be up.

$RA_{NGP} \sim 13h$
$RA_{SGP} \sim 1h$ $\Rightarrow$ $RA_\odot \sim 1h$ or $13h$
see things in north in spring
things in south in fall

When are you most likely to observe the Galactic center?

$RA_{GC} = 18h \rightarrow$ June

What minimum airmass does the GC achieve from Kitt Peak?

$\delta_{GC} \sim -29°$

$X = \sec 61° = 2.06$

$z = 32° + 29° = 61°$