

Topic E

“Measuring Stars”
Part 1: Stellar Distances
 (Web Version: 03-23-01)

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Fundamentals of the Stellar Population

Measurement in Science

2

Five Specific Sections

- 1) Stellar parallaxes & distances
- 2) Stellar motions
- 3) Magnitude scale
- 4) Absolute magnitudes
- 5) Spectral classification

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Question

How are these two columns different?

<ul style="list-style-type: none"> ▪ Distance from Sun ▪ Position on sky ▪ Motion on sky ▪ Observed brightness ▪ Observed color ▪ etc. 	<ul style="list-style-type: none"> ▪ Size ▪ Mass ▪ Density ▪ Temperature ▪ Luminosity ▪ Composition ▪ Age ▪ etc.
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Extrinsic vs. Intrinsic

<ul style="list-style-type: none"> ▪ Extrinsic <ul style="list-style-type: none"> • External not inherent • Observed . . . what we “see” • Apparent ▪ Intrinsic <ul style="list-style-type: none"> • Internal or inherent • Real . . . true . . . actual • Absolute 	
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Part 1. Stellar Distances

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Part I. Distances of Stars

- How far the stars?
 - Very basic question
 - Many *intrinsic* properties first need distance
- Example
 - Apparent magnitude = *observed* brightness
 - Absolute magnitude = *true (or real)* brightness

Requires knowledge of distance

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Measuring Stellar Distances

Several Dozen Methods

- Annual Heliocentric Parallax
- Moving Cluster Method
- Spectroscopic Parallax (various)
- Dynamical Parallax
- Period-Luminosity
- Globular Cluster Size
- Many more

Only first two "fundamental"

All others build on these for calibration

Don't need to copy list

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Parallax

- 1st method — depends on geometrical concept of *parallax*
- Familiar to ancient Greeks
- Used to justify Earth does *not* move
- Aristotle might have argued as follows . . .

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Conclusion

Aristotle

"Suppose Earth at 1, but next moves to 2, then star should also appear to move . . . but we never see this periodic shift . . . therefore the Earth cannot move!"

Always see star here

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This is Parallax!

"This is the parallax angle"

Student

Wall

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Parallax: Definition

"Apparent change in direction of object caused by change in observer's position that provides a new line of sight"

(See Fig. 8, 2nd page for definition)

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What Controls Parallax?

"How can I change the size of this angle?"

Student Wall

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1. Change Distance

Parallax *smaller* if distance *larger*

Student Wall

Watch parallax angle when move finger away

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Parallax & Distance Related

Parallax *smaller* if distance *larger*

Student Wall

We will learn how to use parallax to determine distance

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2. Changing The Base Line

"How else can I change the size of this angle?"

Change Base Line (distance between eyes)

Student Wall

... but usually fixed in length

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Parallax: Another Perspective

Image your *pet flea* sitting on your finger

Student Wall

What is the geometrical meaning of the parallax angle (to the flea)?

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Face On View

"What does your pet flea see?"

Hint →

Your pet flea

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The Stellar Parallax

See *Study Guide* Figure 8a

- 1) Opposite positions of Earth in orbit = Eyes
- 2) "Nearby" star = Finger
- 3) "Far away" stars = Wall

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The Stellar Parallax

Result

"Annual" Heliocentric Trigonometric *Stellar Parallax*

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The Stellar Parallax

Base Line = 2 AU

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The Stellar Parallax

Distance to Star ("d")

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Stellar Distances Very Large

All Three Distances
Almost Exactly Equal

Since d very large compared to 1 AU

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The Parallax Triangle

This Triangle Establishes The "Geometry"

Parallax "p" is one-half of observed shift

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Quoted Parallax Always "p"

... as if observe from #1 then Sun

Earth's Orbit

Very Distant Stars

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Base Line Fixed

Parallax changes *only* if distance changes

So "p" and "d" are related

Very Distant Stars

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Parallax and Distance

Let Distance = d

Earth's Orbit

Very Distant Stars

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Parallax and Distance

Now Make Distance = d/2

Big "p"

↑ Closer

Small "d" implies large "p"

Very Distant Stars

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"Parallax-Distance Relation"

What is mathematical relation between "p" and "d" ?

An inverse relation (but not simple)

Anyone remember?

(Hint: Think "trig")

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New Math

Can use a "branch of math" called

The "Mathematics of Skinny Triangles"

"Fat" $\tan p = b/d$

"Skinny" $p \approx 1/d$

p is very small!

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Here's How It Works

Let star's distance = d

Study Guide
Fig. 8b

Since p very small, we can use: $p \approx 1/d$

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Here's How It Works

Now let star's distance = $2d$

What happens to " p " ?

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Here's How It Works

Now let star's distance = $2d$

" p " halves

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Now For Some Numbers*

- Since angles very small . . .
Using degrees awkward
- Instead . . . use *arc seconds*

1 degree = 60 arc minutes (arc min or ')
1 arc min = 60 arc seconds (arc sec or ")

*See Study Guide, Fig. 8 "Definitions" (next page)

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Recall . . .

Moon's apparent (angular size) in degrees?

What is angular size in arc min & arc sec?

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Want to See an Arc Sec?

You can't . . . it's too small for eye to resolve

Eye can't see detail smaller than a few arc minutes!

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But . . . View a Quarter

From 3.1 miles . . .
 a *quarter* (15/16 in.)
 looks
one arc sec
 wide!

3.1 miles

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View a Foot

From 39 miles . . .
 a *foot* (12 in.)
 looks
one arc sec
 wide!

12 inch

39 miles

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View a Mile

From 206,265 miles . . .
 a *mile* (5280 ft.)
 looks
one arc sec
 wide!

1 mile

206,265 miles

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Notice . . .

If units same
 object looks
one arc sec wide

if distance
 206,265 times larger!

Same

1 mile

206,265 miles

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View a Foot Again

From 206,265 feet . . .
 a *foot* (12 in.)
 looks
one arc sec
 wide!

1 foot

206,265 feet
(39 miles)

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Or View a Kilometer

From 206,265 kilometers . . .
 a *kilometer*
 looks
one arc sec
 wide!

1 kilometer

206,265 kilometer

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So An Astronomical Unit

From 206,265 AU's ...

One AU (93 million mi.) looks *one arc sec* wide!

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The Parallax Triangle

For $p = 1''$ (one arc sec)

(approximately 40 miles!)

Study Guide Figure 8

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For 1 AU Base Line

Scale triangle up to 1 AU base line

If $d = 206,265 \text{ AU} \dots$ then $p = 1''$
(if $b = 1 \text{ AU}$)

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Try These

First ... let $p = 1''$ ▶ What is d ?

Answer: $d = 206,265 \text{ AU}$

[We will round to 200,000 AU]

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Here's How It Works

Now let $p = 1/2''$ ▶ What is d ?

Answer: $d = 2 \times 200,000 \text{ AU} = 400,000 \text{ AU}$

Remember $d \propto 1/p$

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Here's How It Works

Or let $p = 1/8''$ ▶ What is d ?

Answer: $d = 8 \times 200,000 \text{ AU} = 1,600,000 \text{ AU}$

Remember $d \propto 1/p$

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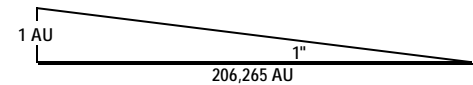
Can You Do These?

▪ $p = 1/4''$... $d = 4 \times 200,000 \text{ AU} =$	AU
▪ $p = 1/5''$... $d = 5 \times 200,000 \text{ AU} =$	AU
▪ $p = 1/10''$... $d = 10 \times 200,000 \text{ AU} =$	AU
▪ $p = 0.05''$... $d = (1/0.05) \times 200,000 =$	AU
▪ $p = 0.01''$... $d = (1/0.01) \times 200,000 =$	AU

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AU "Awkward"

No star known with even $p = 1''$!



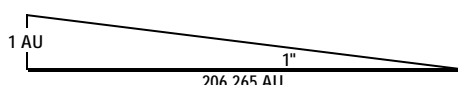
- Thus AU "impractical unit"
- Solution — Define a *new unit*

See Study Guide Fig. 8 (second page)

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The "Parsec"

Define ... One Parsec (pc)



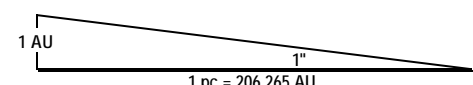
Distance if parallax = one arc sec (if $b = 1 \text{ AU}$)

(Contraction of "parallax" & "second")

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The "Parsec"

Define ... One Parsec (pc)



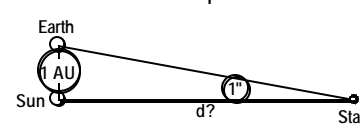
One Parsec = 206,265 AU (approx.)

(We will usually round to 200,000 AU)

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"p" to "d" Now "Trivial"!

First ... let $p = 1''$ ▶ What is d ?

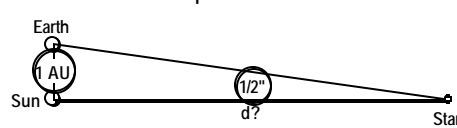


Answer: $d = 1 \text{ pc}$

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Again: Here's How It Works

Now let $p = 1/2''$ ▶ What is d ?



Answer: $d = 2 \times 1 \text{ pc} = 2 \text{ pc}$

Remember $d \propto 1/p$

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Again: Here's How It Works

Or let $p = 1/8''$ ▶ What is d ?

Answer: $d = 8 \times 1 \text{ pc} = 8 \text{ pc}$

Remember $d \propto 1/p$

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Can You Do These?

$p = 1/4''$... $d =$	$4 \times 1 \text{ pc} =$	pc
$p = 1/5''$... $d =$	$5 \times 1 \text{ pc} =$	pc
$p = 1/10''$... $d =$	$10 \times 1 \text{ pc} =$	pc
$p = 0.05''$... $d =$	$(1/0.05) \times 1 \text{ pc} =$	pc
$p = 0.01''$... $d =$	$(1/0.01) \times 1 \text{ pc} =$	pc

Notice p and d *reciprocals*

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Summary: Calculating Distance

Just remember — p & d *reciprocals*

$d (\text{pc}) = 1 / p (")$ ← Know

d in pc & p in arc sec

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Other Units of Distance

Awkward for stellar distances

- Feet *or* Meters
- Miles *or* Kilometers
- Astronomical Units (good in Solar System)

Easier for stellar distances

- Parsecs
- *One other* . . . Light Years

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Miles per Light Year?

Definition
Distance radiation travels in one year

$300,000 \text{ km/sec} \times \text{no. sec / yr} = 9,000,000,000,000 \text{ km}$
 $= 6 \text{ trillion miles}$
 (See *Study Guide*, Fig. 8, second side)

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Now: How Long for 1 PC?

$206,265 \text{ AU} \times 8.3 \text{ min/AU} = 1,700,000 \text{ minutes}$
 $= 3 \frac{1}{4} \text{ years (approx.)}$

Light Time = 8.3 min

So $1 \text{ pc} = 3 \frac{1}{4} \text{ ly}$

Recall Know! See Fig. 8 again

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Summary

$$\text{Distance (pc)} = \frac{1}{\text{parallax (arc sec)}}$$

See *Study Guide* Fig. 8

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Summary

One parsec = 200,000 AU
 = 3 light years
 (approximately)

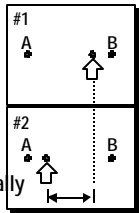
See *Study Guide* Fig. 8 (second side)

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How Parallaxes Measured*

- Image star field
- Repeat after about 6 months
- Measure positions on images (with "measuring device" — today digitally)
- Difference in positions yields parallax angle

* See *Study Guide* Fig. 9



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Results: A Question

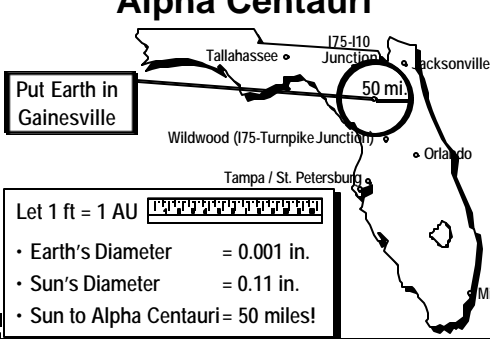
1) Which star closest to solar system?
Answer: Alpha Centauri (really a three star system)

2) How do we know?
Answer: Parallax measurement
 $p = 0.76''$ (about 3/4")
 $d = 4/3 \text{ pc} = 1.3 \text{ pc}$
 $= 4 \text{ ly}$

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See link in Fig. 9b on Web

Alpha Centauri



Put Earth in Gainesville

Let 1 ft = 1 AU

- Earth's Diameter = 0.001 in.
- Sun's Diameter = 0.11 in.
- Sun to Alpha Centauri = 50 miles!

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Fig. 9b on Web

Other Results

- First successful: *61 Cygni* (F. Bessel, 1838)
 $p = 0.29''$ (What is d in pc?)
 $d = 3.4 \text{ pc}$ (What is d in ly?)
 $= 11 \text{ ly}$
- Almost simultaneously
 - *Vega* (F. Struve) $p = 0.13''$ (8pc)
 - *Alpha Centauri* (T. Henderson) $p = 0.75''$ (1.3pc)

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