ASTRONOMY

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CONSTELLATIONS

location		
distance	pinky	one degree
	thumb pinky	twenty five degrees
latitude	observer latitude	North pole altitude
	north celestial pole	Polaris
	south celestial pole	southern cross pointers
longitude	compare	sunset sunrise
	time zone	prime meridian

sky chart		
sky chart	map	night sky
	180 degrees	N-S and W-S
ecliptic	plane	Earth Sun
	through	planets
equator	north celestial pole	Polaris
	perpendicular	plane

nomenclature		
nomenclature	constellation	brightness
	α Orion	Betelgeuse
Messier	fuzzy objects	not comets
	M1 to M110	clusters nebulae galaxies

TELESCOPES

camera		
camera	pinhole camera	darkened room
	one to one mapping	object to image
	focal length variable	length of room
	longer focal length	larger image size
exposure time	collect photons	make image
	time proportional	image size
	decrease time	increase pinhole size
	increase aperture	destroys mapping
lens	bends light	restores mapping
	focal length fixed	lens characteristic
	$f = F/D$	shape refractive index
plate scale	image size	on focal plane
	$\theta_{\text{arcsec}} = s \cdot d$	scale factor
	$\theta_{\text{radians}} = \dfrac{d}{F}$	small angle

telescope		
telescope	gather light	forms image
	eye piece	view image
collecting surface	lens refraction	mirror reflection
	mirror better	chromatic aberration
characteristics	magnitude	expands brightness
	magnification	expands size not clarity

magnitude		
magnitude	expand brightness	make image
	light gathering power	collecting surface
	proportional	aperture squared
limit	dimmest magnitude	telescope viewable
	with human eye	6 magnitude 7mm aperture
	$m_e - m_t = -2.5 \log\left(\frac{D_t^2}{D_e^2}\right)$	

magnification		
magnification	expand size	view image
	proportional ratio	of focal lengths
	collecting surface	eye piece
	$\Omega = \frac{f_o}{f_e}$	geometry
field of view	piece of sky	telescope viewable
	shrinks with	longer focal length
	$\Omega = \frac{FOV_e}{FOV_t}$	geometry
limit	smallest separation	distinguishable
	with telescope	light difraction
	$\theta = 1.22\frac{\lambda}{D}$	Rayleigh

GEOMETRY

spheres		
spheres	infinite sphere	distances angles
	planes center	poles perpendicular
distances	arc minutes	$60' = 1^{\circ}$
	hour angles	$1h = 15^{\circ}$
triangle	intersection	three great circles
	triangle sides	circle segments
	$A + B + C > 180^{\circ}$	sum excess
	Er^2	area
trigonometry	radians	small angles
	$\frac{\sin a}{\sin A} = \frac{\sin b}{\sin B} = \frac{\sin c}{\sin C}$	
	$\cos a = \cos b \cos c + \sin b \sin c \cos A$	

Earth		
Earth	locate	position
	Earth	surface
latitude ϕ	equator	great circle rotational
	parallel	lessor parallel equator
	north south	of equator
longitude λ	prime meridian	semi great circle
	west east	of prime meridian
	prime meridian	poles through Greenwich
departure	distance	same parallel
	$d = \Delta\lambda \cos \phi$	trigonometry

LOCAL

horizontal		
horizontal	observer on	Earth surface
	observation dependent	location and time
altitude a	zenith	straight overhead
	horizon	perpendicular plane
	north south	of horizon
azimuth A	cardinal	poles on horizon
	principal vertical	cardinals through zenith
	west east	of principal vertical
Earth-horizontal	at Earth equator	North pole on horizon
	each latitude change	horizon changes same
	observer latitude	North pole altitude

local equatorial		
local equatorial	observer on	Earth surface
	denote using	Earth equator
	independent of location	dependent on time
declination δ	north south	of equator
	any observer location	look to declination
hour angle h	west east	of observer meridian
	observer meridian	poles through location
	observation depends on time	Earth rotation 24 hours
horizontal-local equatorial	object culmination	at observer meridian
	zero hour angle	for this location
	highest altitude	zero azimuth

CONVERSIONS

observational		
Earth-horizontal	horizontal	local equatorial
	North pole altitude	observer latitude
	observer latitude	zenith to equator
horizontal-local equatorial	if culminates	north of zenith
	$a_{max} = 90^\circ + \phi - \delta$	culmination
	never set	horizontal
	$a_{min} = \delta + \phi - 90^\circ$	circumpolar
	declination	from observations
	$\delta = \frac{1}{2}\left(a_{min} - a_{max} + 180^\circ\right)$	substitution

general		
conversion	overlapping	spherical coordinates
	trigonometric triangle	with complimentaries
horizontal-local equatorial	$\sin h \cos \delta = \sin A \cos a$	
	$\cos h \cos \delta = \cos A \cos a \sin \phi + \sin a \cos \phi$	
	$\sin \delta = -\cos A \cos a \cos \phi + \sin a \sin \phi$	

CELESTIAL

equatorial		
equatorial	absolute	celestial coordinates
	independent of observer	location and time
declination δ	north south	of equator
	same as	local equatorial
right ascension α	west east	fixed point as zero
	vernal equinox	equatorial ecliptic intersection

ecliptical		
ecliptical	alternate	absolute coordinates
	Earth Sun orbit	for Solar System
ecliptic latitude	north south	of ecliptic plane
	ecliptic plane	Earth Sun orbit
ecliptic longitude	west east	vernal equinox
	vernal equinox	fixed point zero

galactic		
galactic	rotational plane	Milky Way
	fixed point	galaxy center
position	galactic latitude	north south
	galactic longitude	west east

TIME

time		
observer	observer on	Earth surface
	local time	depends on location
hour angle	time zero	culmination
	time elapsed	since transit
local sidereal time	sidereal	infinite sphere
	non rotating	frame reference
	$\text{LST} = h$	vernal equinox
	$\text{LST} = \alpha + h$	any star
equation of time	apparent solar time − mean solar time	
	mean deviation	obliquity eccentricity
	analemma	deviation vs day

day		
day	interval	object passage
	across	observer meridian
types	sidereal	distant point
	solar	Sun
relation	$\omega_{\text{sidereal}} = \omega_{\text{solar}} + \omega_{\text{orbit}}$	velocities
	$\dfrac{1}{P_{\text{sidereal}}} = \dfrac{1}{P_{\text{solar}}} + \dfrac{1}{P_{\text{orbit}}}$	periods

month		
month	interval	Moon passage
	across	background
types	sidereal	distant
	synodic	Sun
relation	$\omega_{\text{sidereal}} = \omega_E + \omega_{\text{synodic}}$	velocities
	$\frac{1}{P_{\text{sidereal}}} = \frac{1}{P_E} + \frac{1}{P_{\text{synodic}}}$	periods

year		
year	interval	Sun passage
	across	background
types	sidereal	distant
	tropical	vernal equinox
calendar	match seasons	March 21st
	tropical year	365.24219
	Julian	leap year
	Gregorian	except 100 not 400

ORBITS

orbits		
orbits	$\mathbf{F}_g = \frac{G m_1 m_2}{r^2}$	central force
	tangential radial	acceleration
	function of angle	polar coordinates
	$r(\theta) = \frac{r_0}{1 + e \cos\theta}$	conics
conics	circle	equidistant point
	ellipse	equal sum two points
	parabola	equal sum point line
	hyperbola	equal difference two points

energy		
energy	mechanical	potential kinetic
	$E = \left(\frac{L^2}{2mr^2} - \frac{GMm}{r}\right) + \frac{1}{2} m v_r^2$	
effective potential	$\frac{L^2}{2mr^2} - \frac{GMm}{r}$	proportional distance
	intersection	mechanical and potential
	turning points	radial velocity zero
circle	$E = \text{minimum}$	$v^2 = \frac{GM}{r}$
ellipse	$E < 0$	$\frac{GM}{r} < v^2 < \frac{2GM}{r}$
parabola	$E = 0$	$v^2 = \frac{2GM}{r}$
hyperbola	$E > 0$	$v^2 > \frac{2GM}{r}$

KEPLER

reduced mass		
reduced mass	two objects	simplify
	$F = \mu a_{rel}$	third law
	one object	fixed reference
	other orbits	with reduced mass
	$\mu = \dfrac{m_1 m_2}{m_1 + m_2}$	substitution

ellipse		
ellipse	gravitation	central force
	elliptical orbits	star at focus
	$-\dfrac{GM}{r_2} = \dfrac{d^2 r}{dt^2} - \omega^2 r$	acceleration
	$r = \dfrac{a(1 - e^2)}{1 + e \cos \theta}$	ellipse
eccentricity	$e = \dfrac{c}{a}$	definition
	$a^2 = b^2 + c^2$	Pythagoras
	$a - c$	periapsis
	$a + c$	apoapsis
vis viva	$E = -\dfrac{GMm}{2a}$	mechnical energy
	$v^2 = GM\left(\dfrac{2}{r} - \dfrac{1}{a}\right)$	substitution
virial	$U = -2K$	substitution
	$E = -K$	total mechanial
	lower orbit	more kinetic less total

sweep		
sweep	orbit sweeps	same area same time
	differentiation	geometry
	velocity	radial tangential
	$\frac{dA}{dt} = \frac{L}{2\mu}$	angular momentum
proportions	$\frac{\Delta t}{T} = \frac{\Delta A}{A}$	proportions
	$A = \pi a b$	scaling

period		
period	proportional	semimajor axis
	area sweep	complete period
	$\frac{P^2}{a^3} = \frac{4\pi^2}{G(m_1 + m_2)}$	substitution
	$\frac{P^2}{a^3} = 1$	solar system

MANEUVERS

rocket		
rocket	momentum	fuel exhaust
	mass velocity	continuous change
	$\Delta v = v_e \ln \frac{m_i}{m_f}$	integration
	velocity change	independent initial

Oberth		
Oberth	gravity well	increase velocity
	maximize	kinetic energy gain
	$\Delta K \approx m v \Delta v$	rocket equation
	proportional	initial velocity

Hohmann		
Hohmann	circular	to circular
	transfer	via elliptical
velocity	change required	vis viva
	change produced	rocket impulse
	$\Delta v_1 = \sqrt{\frac{GM}{r_1}} \cdot \left(\sqrt{\frac{2r_2}{r_1 + r_2}} - 1 \right)$	
	$\Delta v_2 = \sqrt{\frac{GM}{r_2}} \cdot \left(1 - \sqrt{\frac{2r_1}{r_1 + r_2}} \right)$	

PLANETS

history		
history	Hipparchus	magnitude
	Ptolemy	geocentric
	Copernicus	heliocentric
	Galileo	moons
	Kepler	elliptical

planets		
Copernicus	heliocentric	circular orbits
	allows compute	periods distances
	synodic	same configurations
configuration	perspective	of Earth
	opposition 180˚	conjunction 0˚
	quadrature 90˚	elongation angle
periods	$\omega_P = \omega_E + \omega_{\text{synodic}}$	inferior planet
	$\omega_P = \omega_E - \omega_{\text{synodic}}$	superior planet
distances	$\sin\theta = \frac{r_E}{r_P}$	inferior greatest elongation
	$\theta = (\omega_E - \omega_P)\tau$	superior opposition quadrature

EARTH

Earth		
Copernicus	heliocentric	Earth motion
	rotation	revolution
rotation	rotating	reference frame
	$\vec{\mathbf{a}}_{cor} = 2(\vec{\mathbf{v}} \times \vec{\mathbf{w}})$	Coriolis
	perpendicular	motion direction
	Foucault pendulum	hurricane swirl
revolution	aberration	observer motion
	parallax	observer position

aberration		
aberration	deflection due	observer motion
	relative velocities	catch raindrops
	$\tan\theta = \frac{v}{c}$	independent distance
motion	$20.5''$	semimajor
	$20.5'' \cdot \beta$	distance ecliptic

parallax		
parallax	deflection due	observer position
	$d = \frac{r}{\tan\pi''}$	geometry
	$d = \frac{206{,}265\ \text{AU}}{\pi''}$	parsec
motion	π''	semimajor
	$\pi'' \cdot \beta$	less than $1''$

MOON

distortions		
equatorial bulge	Earth rotation	Coriolis effect
	oblate distortion	kilometers
	precession	torque on rotation
	tilt rotation orbit	not spherical
tidal bulge	differential gravity	surface center
	prolate distortion	meters
	Moon Sun	spring neap
	tidal braking	synchronous rotation

orbit		
limit	differential gravity	critical distance
	$r_R = 2.44 \left(\frac{\rho_M}{\rho_m}\right)^{1/3} R$	Roche smallest
	$r_H = \left(\frac{M_\oplus}{M_\odot}\right)^{1/3} a_\oplus$	Hill largest
phase	configuration	Earth Moon Sun
	new dark full light	wax then wane

eclipse		
incline	5.1°	half each day
	nodes	intersection
eclipse	Sun Moon	near nodes
	Saros cycle	synodic repeats

RADIATION

orbits		
orbits	$\mathbf{F}_e = -\frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$	central force
	total energy	potential kinetic
	angular momentum	quantized
	$E_n = -R_H \frac{1}{n^2}$	Bohr
	$E = h\nu$	photon
spectrum	photon distribution	by wavelength
	unique lines	orbit transitions
Kirchhoff	tenuous gas	spectral lines
	solid liquid dense gas	continuous spectrum

spectral lines		
optical depth	star atmosphere tenuous	spectral lines
	photon absorption	through gas
	particle density	specific wavelength
	increasing depth	broadens line slowly
spectral lines	low spectral resolution	lines still detectable
	equivalent width	absorption area
	curve of growth	deduce optical depth
local thermal equilibrium	same temperature	long mean free path
	bring big guns	statistical thermodynamics
	determine proportion	excitation states
	stellar classification	Boltzmann Saha

blackbody		
blackbody	star main body dense gas	continuous spectrum
	spectral line broadening	optical thick all wavelengths
	specific elements irrelevant	perfect absorber emitter
Planck	energy intensity	function of frequency
	$J_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{h\nu/kT}-1}$	
	low energy Raleigh-Jeans	high energy Wien
	$\lambda_{max}T = b$	Wien
Stefan-Boltzmann	integrate intensity	all wavelengths
	$F = \sigma T^4$	power per area
	proportional	sphere distance
	$L = 4\pi r^2 \sigma T^4$	surface brightness

planet		
temperature	equilibrium	energy balance
	absorb energy	cross section albedo
	$W = \frac{L}{4\pi a^2}(1-A)\pi r^2$	substitution
	radiate energy	Stefan-Boltzmann
radiation	approximate sum	two blackbody spectra
	reflected sunlight	thermal emission
	emission modified	atmosphere absorption
atmosphere	terrestrial too hot	retain hydrogen helium
	mean free path	density collisions
	escape velocity	Maxwell-Boltzmann

BRIGHTNESS

magnitude		
apparent	luminosity distance	logarithmic flux
	$m_2 - m_1 = -2.5 \log\left(\frac{F_1}{F_2}\right)$	difference 5 factor 100
	$m = C - 2.5 \log F$	Vega zero
	$m = C - 2.5 \log L + 2.5 \log(4\pi) + 5 \log d$	
absolute	luminosity only	distance 10 parsecs
	$M = C - 2.5 \log L + 2.5 \log(4\pi) + 5$	
distance modulus	apparent vs absolute	distance vs 10 parsecs
	$m - M = 5 \log d - 5$	logarithmic distance

temperature		
spectrum	star approximate	blackbody
	spectrum mixture	continuum spectral lines
bolometric	total flux	all wavelengths
	measurement difficult	Sun zero
	$m_{bol} = C_{bol} - 2.5 \log F_{bol}$	apparent
	$M_{bol} = 4.74 - 2.5 \log\left(\frac{L}{L_\odot}\right)$	absolute
temperature	bolometric difficult	filter wavelength range
	$B - V = m_B - m_V$	color index
	difference in apparent	derive temperature
	$T \approx \frac{9000K}{(B-V) + 0.93}$	empirical

MASS

size		
size	angular diameter	Sun Betelgeuse
	$r \approx \frac{d\alpha}{2}$	small angle
	precise measurement	interferometry
	$\alpha_{\text{radians}} > \lambda / b$	slit distance
temperature	luminosity radius	effective temperature
	$L = 4\pi r^2 \sigma T^4$	Stefan-Boltzmann

mass		
mass	$M_A + M_B = \frac{4\pi^2}{G} \frac{a^3}{P^2}$	Kepler
	requires binary system	most have companions
visual	visually resolved	with telescope
	individual masses	from total and ratio
	$\frac{M_B}{M_A} = \frac{a_A}{a_B}$	visual ratio estimate
spectroscopy	visually unresolved	radial velocity Doppler
	$\frac{M_B}{M_A} = \frac{v_A}{v_B} = \frac{v_A \sin i}{v_B \sin i}$	same period for ratio
	lack inclination	statistically estimate
	double lined guess total	single lined guess unseen
eclipse	visually unresolved	variable brightness
	two eclipses	different flux blocked

RELATIONS

relations		
relations	most stars	main sequence
	well defined relations	mass radius luminosity
relations	larger stars	less dense
	more massive stars	more more luminous
lifetime	mass total fuel	luminosity rate of use
	$\tau \propto M/L \propto M^{-1.62}$	$M < 0.7 M_{\odot}$
	$\tau \propto M/L \propto M^{-2.92}$	$M > 0.7 M_{\odot}$

exoplanets		
visual	direct imaging	planet too dim
	astrometry ellipse	orbit too small
spectroscopy	lower temperature	Rayleigh-Jeans limit
	higher ratio	planet star luminosity
radial velocity	$\frac{\Delta\lambda}{\lambda} = \frac{v_r}{c}$	Doppler
	lack inclination	assume small planet
	$\frac{M_B}{M_A} = \frac{a_A}{a_B}$	center of mass
	$M_B \sin i \approx \left(\frac{M_A^2 P}{2\pi G}\right)^{1/3} v_A \sin i$	
eclipse	$i \approx 90^{\circ}$	transit probability small
	flux blocked	cross section
	four phases	star planet diameters
	combine radial velocity	mass of planet

ATMOSPHERE

atmosphere		
star	ball of gas	all atmosphere
	luminous	nuclear fusion
atmosphere	hydrostatic equilibrium	ionize increase pressure
	$\frac{dP}{dr} = -\frac{GM(r)\rho}{r^2}$	gravity and pressure
	$P \propto \exp\left(-\frac{r}{H}\right)$	scale height

temperature		
spectral lines	Balmer lines	hydrogen second level
	competing temp effects	neutral state second level
	$T \approx 10{,}000\,\mathrm{K}$	maximum Balmer
	other element lines	deduce temperature range
classification	with spectral lines	temperature sequence
	OBAFGKM LT	decrease temperature
	LT brown dwarfs	no luminous fusion

luminosity		
spectral lines	temperature primary	same spectral lines
	luminosity secondary	spectral line width
classification	I II III IV V VI	decrease in size
	smaller star more gravity	more pressure broadening
HR	luminosity temperature	main sequence
	luminosity class V	dense small dwarfs

INTERIOR

temperature		
structure	$\frac{dP}{dr} = -\frac{GM(r)\rho(r)}{r^2}$	hydrostatic equilibrium
	$\frac{dM}{dr} = 4\pi r^2 \rho(r)$	mass continuity
	$P(r) = \frac{\rho(r)kT(r)}{\mu m_p}$	equation of state
temperature	crude estimate	no energy generation
	$T_C \propto \frac{M}{R} \approx$ constant	main sequence all like Sun

transport		
transport	preferred mechanism	locally more efficient
	Sun internal radiation	external 30% convection
radiation	temperature gradient	net radiation force
	diffusion time	random walk
	$P_{\text{rad}}(r) = \frac{a}{3}T(r)^4$	Stefan-Boltzmann
	$\frac{dT}{dr} = -\frac{3\kappa(r)\rho(r)L(r)}{64\pi\sigma r^2 T(r)^3}$	photons
convection	high opacity	outward convection
	infinitesimal bubble	runaway displacement
	$\frac{dT}{dr} = \left(1 - \frac{1}{\gamma}\right)\frac{T(r)}{P(r)}\frac{dP}{dr}$	adiabatic gas

generation		
generation	energy from interior	carried to photosphere
	$\frac{dL}{dr} = 4\pi r^2 \rho(r)\epsilon(r)$	math energy producction
source	gravitation potential	Kelvin-Helmholtz
	$U_\odot = -q\frac{GM_\odot^2}{R_\odot}$	integration
	$t_{KH} = \frac{U_\odot}{L_\odot} \approx 50\,\mathrm{Myr}$	unreasnable lifetime
	nuclear fusion	reasonable lifetime
fusion	hydrogen to helium	overcome Coulomb
	high temperature kinetic	quantum tunneling
	proton proton chain	below 18 million K
	CNO cycle triple alpha	above 18 million K
verification	boundary conditions	photosphere
	helioseismology	sound waves
	particle physics	solar neutrinos

interstellar		
interstellar	low density mix	dust and gas
	extinction	nonspherical graphite ice
	reddening	shorter more extinguished
extinction	$F = F_0 e^{-\tau}$	optical depth
	$m_{\mathrm{obs}} = m_0 + 1.086\tau$	increase magnitude distance
reddening	color index shift	color excess
	$R = \frac{1}{(\tau_B/\tau_V) - 1} \approx 4.2$	ratio selective to total

EVOLUTION

formation		
collapse	dense cool	interstellar medium
	freefall period	density not radius
	$t_{ff} = \left(\frac{3\pi}{32G\rho_0}\right)^{1/2} \approx 40{,}000\text{yr}\left(\frac{3\times10^{-15}\,\text{kg m}^{-3}}{\rho_0}\right)^{1/2}$	
equilibrium	pressure gradient	at speed of sound
	proportional to radius	maximum stable radius
	$r_J \approx 2000\,\text{AU}\left(\frac{T}{10\,\text{K}}\right)^{1/2}\left(\frac{\rho_0}{3\times10^{-15}\,\text{kg m}^{-3}}\right)^{-1/2}$	
disk	rotationally supported	angular momentum
	$r_f = \approx 200\,\text{AU}\left(\frac{v_0}{0.1\,\text{km s}^{-1}}\right)^2\left(\frac{r_0}{4000\,\text{AU}}\right)^2\left(\frac{M}{M_\odot}\right)^{-1}$	
	distant orbit planet	scapegoat Jupiter
protostar	pieces fall center	hot dense center
	contract and ignition	Kelvin-Helmholtz

evolution		
prologue	protostar gravity	50 Myr
I main sequence	$H \rightarrow He$ fusion	10 Gyr
II red giant	He core gravity $H \rightarrow He$ shell	1 Gyr
III horizontal	$He \rightarrow C$ core $H \rightarrow He$ shell	100 Myr
IV asymptotic giant branch	$He \rightarrow C \;\; H \rightarrow He$ two shells	20 Myr
	brief luminous unstable	pulsate eject envelope
V planetary nebula	C/O core thermal hot	50 kyr
epilogue	white dwarf thermal	∞

REMNANTS

remnants		
evolution	stellar evolution	depends on initial mass
	higher mass stars	neutron stars black holes
remnants	LT brown dwarfs	$M < 0.08M_{\odot}$
	M He white dwarfs	$0.08M_{\odot} < M < 0.5M_{\odot}$
	AFGK C/O white dwarfs	$0.5M_{\odot} < M < 5M_{\odot}$
	B Ne/Mg white dwarfs	$5M_{\odot} < M < 7M_{\odot}$
	O neutron stars black holes	$M > 7M_{\odot}$

white dwarf		
main sequence	typical mass stars	$0.08M_{\odot} < M < 7M_{\odot}$
	dense leftover core	after eject envelope
	hydrostatic equilibrium	needs countering pressure
	electron degeneracy	Heisenberg
characteristics	radius mass	inverse relationship
	large gravity	small scale height
	spectral lines	pressure broadening
white dwarf	density increase	Heisenberg increase
	relativistic degeneracy	maximum stable mass
	$M_{\max} = 1.4M_{\odot}$	Chandrasekhar

neutron star		
main sequence	massive stars	initial $M > 7M_\odot$
	short life 30 Myr	shorter giant phase
	dense iron core	concentric fusing shells
core collapse	core reaches limit	Chandraskekhar
	supernova ejection	proton electron merge
	neutron degeneracy	Heisenberg
neutron star	$R \approx 10\,\mathrm{km}$	neutron electron ratio
	$M_{\max} = 3M_\odot$	Oppenheimer-Volkov
	detection via hot surface	or by pulsar radiation

black hole		
black hole	massive stars	initial $M > 18M_\odot$
	remnant mass larger	neutron star maximum
	light cannot escape	Schwarzschild radius
	detection via effects	accretion disk emissions

variables		
pulsating	main sequence stable	instability strip periodic
	pulsating brightness	matched opacity cycles
	standing sound wave	driven acounstic oscillation
	$\overline{M}_V = -2.76 \log(P/10\text{days}) - 4.16$	
cataclysmic	recurrent nova	star gas on white dwarf
	short scale height	hydrogen layer flash
supernova	Type Ib II	core collapse
	Type Ia	white dwarf above limit
	carbon flash	iron core blown up

GALAXIES

Milky Way		
size	star counting	number magnitude
	globular clusters	orbiting center
shape	thin thick disk	star factories
	spherical halo	eccentric orbits
	bulge with nucleus	Sagittarius A*
kinematics	rotation curve	constant with distance
	dark matter	neutrino WIMP MACHO
	differential rotation	Oort

classification		
classification	morphological	not evolutionary
	elliptical	eccentricity older
	spiral bar	arms dustlanes younger
mass	$M \approx 2.5\frac{\langle v^2\rangle r}{G}$	virial
	$\langle v^2\rangle = 3\sigma^2$	velocity dispersion
distances	distance ladder	each depend lower rungs
	radar	10 AU
	stellar parallax	200 pc
	Cepheids	25 Mpc
	Type Ia supernova	standard candle
	velocity dispersion	Faber-Jackson
	peak rotational speed	Tully-Fisher
	$cz = H_0 d$	Hubble

ACTIVE NUCLEUS

active galaxies		
active galaxies	material luminosity	nonstellar emission
	supermassive accretion	violent ejections
energetics	relativistic speeds	Schwarzschild
	gravity to kinetic	thermal to photons
Eddington	maximum luminosity	else blow away gas
	$L_E = 3.3 \times 10^{1}2 L_{\odot} \left(\frac{M_{\bullet}}{10^8 M_{\odot}} \right)$	
	$\dot{M}_E = 2 M_{\odot} \mathrm{yr}^{-1} \left(\frac{M_{\bullet}}{10^8 M_{\odot}} \right) \left(\frac{\eta}{0.1} \right)^{-1}$	
structure	accretion disk	relativistic radio jet
	different angles	different emissions
	different types	Seyfert quasar BL Lac

clusters		
clusters	hierarchical universe	wide range lengths
	galaxies 10 kpc	clusters 1 Mpc
collisions	stars neglible	except galaxy center
	galaxies the norm	tidal tails star factories
	input spirals organized	output elliptical entropy

UNIVERSE

universe		
observations	dark night sky	finite space time
	homogenous isotropic	Hubble expansion
	cosmic microwave	expansion cooling
universe	finite space time	Hot Big Bang
	$r(t) = a(t) r_0$	scale factor
	$v(t) = \left(\frac{\dot{a}}{a}\right) r(t)$	Hubble

scale factor		
expansion	energy conservation	Newton
	expansion proportional	mass density
	critical mass density	cosmological constant
	repulsive acceleration	Einstein
scale factor	$z = \frac{\lambda_0 - \lambda_e}{\lambda_e}$	Doppler
	$\frac{\lambda_e}{a(t_e)} = \frac{\lambda_0}{a(t_0)}$	expansion
	$1 + z = \frac{1}{a(t_e)}$	proportional redshift

Friedmann		
Friedmann	expansion proportional	energy density
	assume flat curvature	general relativity
	$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3c^2}\left[u_r(t) + u_m(t) + u_\lambda\right]$	
density	$u = 5200\,\mathrm{MeV\,m^{-3}}$	current expansion rate
	$\Omega(t) = \frac{u(t)}{u_{\text{total}}(t)}$	radiation matter constant
scale factor	vacuum dark energy	constant none
	nonrelativistic matter	volume $a(t)^3$
	relativistic radiation	volume length $a(t)^4$

history		
consensus model	consensus model	continued expansion
	$\frac{da}{dt} = H_0\left[\frac{\Omega_{r,0}}{a(t)^2} + \frac{\Omega_{m,0}}{a(t)} + \Omega_{\Lambda,0}\,a(t)^2\right]^{1/2}$	
	horizon $= 14{,}000\,\mathrm{Mpc}$	current energy density
	$\frac{d^2a}{dt^2} = H_0^2\left[-\frac{\Omega_{r,0}}{a(t)^3} - \frac{\Omega_{m,0}}{2a(t)^2} + \Omega_{\Lambda,0}\,a(t)\right]$	
history	radiation matter dominated	deceleration
	lambda dominated	future acceleration

acceleration		
acceleration	standard candles	at high redshifts
	expand radiation	expand distance
	$F_{\text{expand}} = \frac{L}{4\pi r^2(1+z)^2}$	universe is accelerating
	cosmic microwave angles	universe is flat