

# Seminar (ASTRO 589)

## Fall 2019

### Problem Set 1

Due 18 September 2019

Homework is the central part of this course. You are encouraged to collaborate with fellow students and/or to consult senior students, local postdocs and me. But, **please write the cod/solution by yourself**. Homework is strictly due by the beginning of the class on 18 September, and **no late homework will be accepted**.

1. Plot between redshift  $z = 0$  and  $z = 5$ ,

- (a) the comoving radial distance  $\chi(z)$ , the angular diameter distance,  $d_A(z)$ , the luminosity diameter distance,  $d_L(z)$ ,
- (b) the volume integrand  $dV/dz$ ,
- (c) the linear growth factor  $D(z)$ ,
- (d) the linear growth rate  $f(z)$

for the following three  $\Lambda$ CDM universes with the common matter density  $\Omega_m = 0.3$ , and dark-energy density  $\Omega_w = 0.7$  but with  $w = -0.8$  (dashed line),  $w = -1.0$  (solid line) and  $w = -1.2$  (dotted line).

*Instruction:*

- Hide the Hubble parameter  $h$  into the unit by using [Mpc/h].
- Turn in both the graphs and your code as PDFs (djeong@psu.edu). We won't kill trees for this.
- Use your favorite programming language in the list below: FORTRAN, C++, Python, IDL, Julia, Mathematica, but **DO NOT** use readymade packages such as astropy, etc. You may call standard integration routines (scipy.integrate, scipy.ode, or their equivalent).