

Title: PSI 2016/2017 Gravitational Physics (Review) - Lecture 14

Date: Jan 20, 2017 10:15 AM

URL: <http://pirsa.org/17010032>

Abstract:

Lecture 14: Testing Gravity

How well do we know gravity?

Solar system - weak field
AU scale

Cosmology - ? Galactic scale $\Rightarrow$ dark matter

Dark matter also input in structure formation

Dark matter also input in structure formation $\sim 25\%$

Dark energy at larger scales to explain late time acceleration.

Supernovae are dimmer than expected $\sim 70\%$

$$\rho + 3p < 0 \quad \Lambda \text{ has } p = \frac{\Lambda}{8\pi G} = -\rho \quad \Lambda \sim 10^{-122} M_{\text{pl}}^4$$

Early universe explained by inflationary paradigm,
lacks concrete model.

Gravity below $\sim$ mm not tested

Strong gravity less well tested

Can gravity be modified?

e.g. ? scalar-tensor theory

dark matter

Early universe explained by inflationary paradigm,
lacks concrete model.

Jordan-Brans-Dicke first explored (Mach's principle)

Matter content of universe defines rest frame

$$S = \frac{1}{16\pi} \int \sqrt{g} \left[-\Phi R + \omega \frac{(\partial\Phi)^2}{\Phi} \right]$$

$$\rightarrow G_{ab} = \frac{8\pi}{\Phi} T_{ab} + T_{\Phi ab} \leftarrow$$

$$\Phi^{-1} \nabla_a \nabla_b \Phi + \frac{\omega}{\Phi^2} \Phi_{,a} \Phi_{,b} \\ - g_{ab} \left(\Phi^{-1} \square \Phi + \frac{\omega}{2} \frac{(\nabla\Phi)^2}{\Phi^2} \right)$$

$$R + 2\omega \frac{\square \Phi}{\Phi} = \omega \frac{(\nabla \Phi)^2}{\Phi^2}$$

$$\rightarrow \square \Phi = \frac{8\pi \Phi}{3+2\omega} T$$

Solar system constrains $\omega > 7 \cdot 10^5$

Add potential & trace

Φ $-g_{ab}(\frac{1}{2}\Phi^{-1}\Box\Phi + \frac{\omega}{2}\frac{\Phi^{-1}\Box\Phi}{\Phi})$
Add potential & transform to Einstein frame

$$S = \int -\frac{M_p^2}{2}R + \frac{1}{2}(\partial\Phi)^2 - V + \mathcal{L}_m[\Psi, \overset{\substack{\uparrow \\ \text{conformal} \\ \text{factor}}}{A^2}g_{\mu\nu}]$$

conventional "Einstein" gravity, but matter
non-minimally coupled to g

form to Einstein frame

$$(\partial\phi)^2 - V + \mathcal{L}_m[\psi, A^2 g_{\mu\nu}]$$

↑
conformal
factor

gravity, but matter
led to g .

ϕ - e.o.m

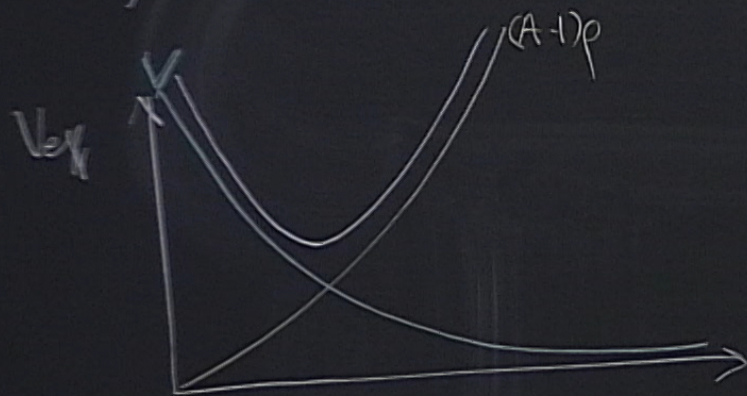
$$\square\phi + \frac{\partial V}{\partial\phi} + \frac{\partial\Lambda}{\partial\phi}\rho = 0$$

(in cos setting)

Can define an effective
potential

$$V_{\text{eff}} = V + (\Lambda^{-1})\rho$$

If V is a 'rolling' potential such as $1/\phi^n$

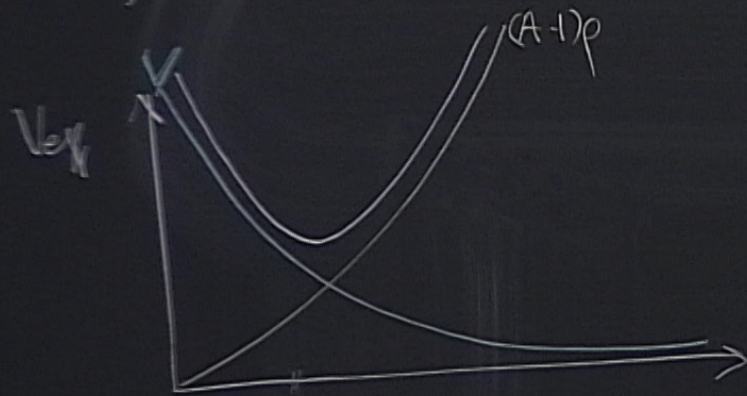


ϕ is 'frozen' in
regions of high p

SCREENING

If p large $V''(\phi_{min})$ large
& ϕ has high mass

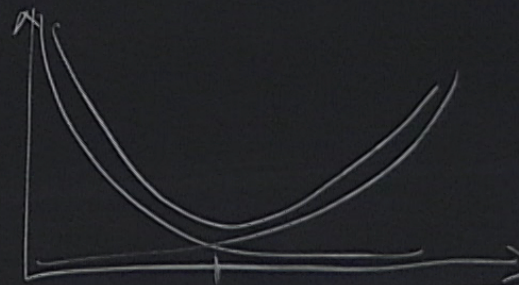
If V is a 'rolling' potential such as $1/\phi^n$



ϕ is 'frozen' in regions of high ρ

SCREENING

If ρ large $V''(\phi_{min})$ large
 $\&$ ϕ has high mass



χ^2/ϕ^n
 p
→
Test?

Cosmological consistency

- expansion history:
"recent geometry"
- formation of structure
- microwave background
- surveys of galaxies

Stellar main sequence

black holes

atom interferometry

Black Holes

Black holes obey "no hair" theorems

Only long range charges M, Q, J

e.g. massive scalar

$$-\phi''\left(1 - \frac{2q_m}{r}\right) - \frac{2(r - q_m)}{r^2} \phi' + m^2 \phi = 0$$

If

If b.h. has scalar charge, there is a soln to this eqn.

$$\phi \rightarrow 0 \quad \text{as } r \rightarrow \infty \quad (\text{finite energy})$$

$$\phi \rightarrow 0 \quad \text{as } r \rightarrow 2GM.$$

ie. ϕ has a turning pt, at which

$$\phi'' = \frac{m^2 \phi}{1 - 2GM/r} > 0 \text{ if } \phi > 0$$

* unless $\phi \equiv 0$ i.e. no charge

Very special

- static

For screened scalars, local matter such as accretion disc induces a scalar profile.

Event horizon telescope proposes to
image 'black hole' - light from near
event horizon is strongly lensed.

e.g. photon trajectories in SCH

$$V_{\text{eff}} \quad = \quad -1 + \frac{h^2}{r^2} - \frac{2GMh^2}{r^3} \quad (= \dot{r}^2)$$

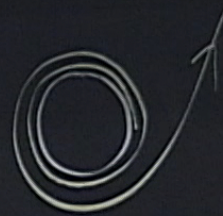
(geodesics)

take $r = 2GM + \epsilon$, $\dot{r} = 0$.

$$\frac{h^2}{r^2} \left(1 - \frac{2GM}{r}\right) = 1 \Rightarrow h^2 = 2GM\epsilon$$

$$\dot{\phi} = h/r^2 \sim \frac{1}{\sqrt{2GM\epsilon}}$$

Light 'hugs' event horizon & orbits several times before escaping.



Images distorted
Multiple orbits mean
geodesics are near
horizon for significant period

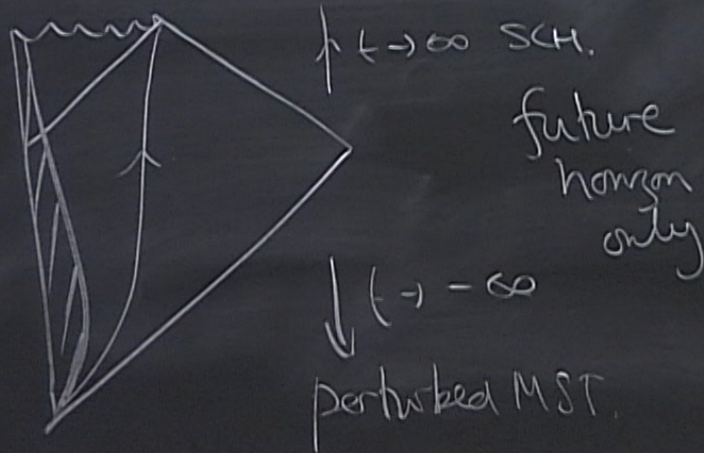
Black hole mergers consistent with GR
but strong gravity & high noise
— need templates for alternate theories
ideally for general parametrizations

Finally —

$$V_{\text{eff}} = V + (A-1)p$$

Finally - black hole evaporation?

Form black hole:



Information behind horizon
lost.

$$T_H = \frac{1}{8\pi G M}$$

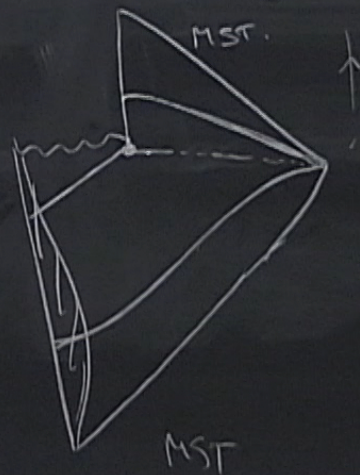
Loses energy at a rate

$$\propto T^4 (2\pi M)^2 \propto 1/M^2 \propto \dot{M}$$

First explored (Mach's principle)

Black hole evaporates in
time $\tau \sim 1/M_0^3$

Evap
b.h



Loss of
unitarity