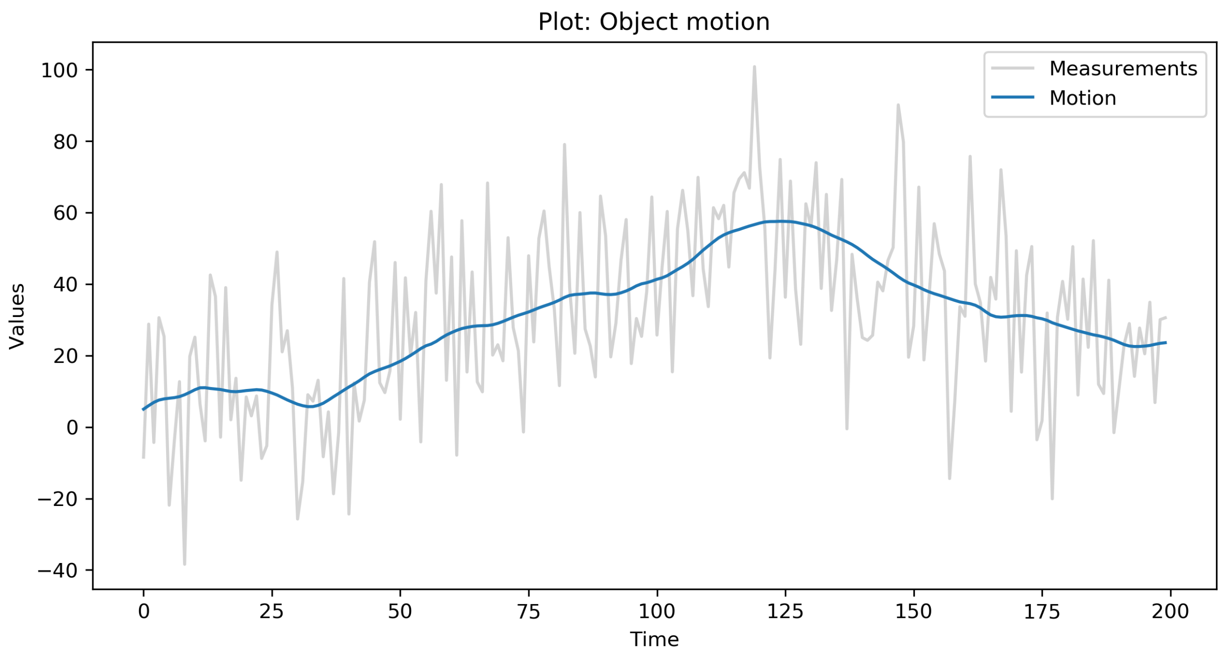
In [1]:
```
# Assignment 5
# Relationship between solar radio flux F10.7 and sunspot number
# Team 2:
#     Ekaterina Karmanova
#     Timur Chikichev
#     Yaroslav Okunev
#     Nikita Mikhailovskiy
#
# Skoltech, 08.10.2019
```

In [2]:
```
import numpy as np
import matplotlib.pyplot as plt
from matplotlib.pyplot import figure
```

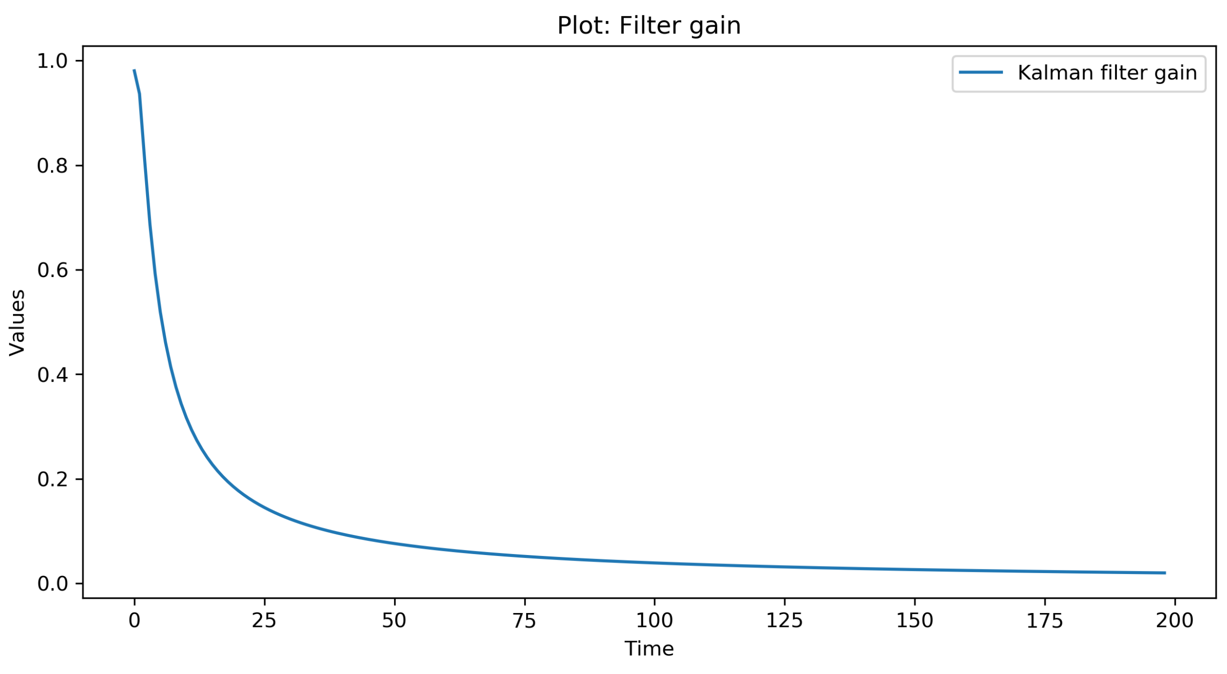
In [3]:
```
#Constants
#Size of trajectory
c = 200
#Initial conditions
x1 = 5
v1 = 1
t = 1
#Variance of acceleration noise
sa = 0.2
s2a = sa**2
a = np.random.normal(0,sa,c)
sn = 20
s2n = sn**2
n = np.random.normal(0,sn,c)
```

In [4]:
```python
X1 = np.matrix((5,1))
F = np.matrix(((1,t),(0,1)))
G = np.matrix((t**2/2,t)).T
H = np.matrix((1,0))

X = np.zeros([c,2])
X[0] = X1
for i in range (1,c):
    frst = np.matmul(F,np.asmatrix(X[i-1]).T)
    scnd = G.dot(a[i-1])
    X[i] = np.add(frst,scnd).T

Z = np.zeros(c)
for i in range (c):
    Z[i] = H.dot(X[i])+n[i]

figure(num=None, figsize=(10, 5), dpi=300, facecolor='w', edgecolor='k')
plt.title('Plot: Object motion')
plt.plot(Z, label='Measurements',c='lightgrey')
plt.plot(X.T[0], label='Motion')
plt.xlabel('Time')
plt.ylabel('Values')
plt.legend()
plt.show()
```



In [18]:
```
#Developing Kalman Filter
X0 = np.matrix((2,0))
P00 = np.matrix(((10000,0),(0,10000)))

#Covariance matrix Q
Q = 0 #np.matmul(G,G.T)*s2a
R = s2n
I = np.matrix(((1,0),(0,1)))

#Kalman filtering
P = P00
X_f = np.zeros([c,2])
K_f = np.zeros([c,2])
P_g = np.zeros(c)
X_f[0] = X0
for i in range (1,c):
    X_p = F.dot(np.asmatrix(X_f[i-1]).T)
    Pz = np.add(F.dot(P).dot(F.T),Q)
    frst = np.add(H.dot(Pz).dot(H.T),R)
    K = Pz.dot(H.T).dot(np.linalg.inv(frst))
    pre_scnd = np.subtract(Z[i],H.dot(X_p))
    scnd = K.dot(pre_scnd)
    P = np.matmul(np.subtract(I,np.matmul(K,H)),Pz)
    X_f[i] = np.add(X_p,scnd).T
    K_f[i] = K.T
    P_g[i] = np.sqrt(P[0,0])
#deleting first row
K_f = np.delete(K_f, 0, 0)
P_g = np.delete(P_g, 0, 0)
```

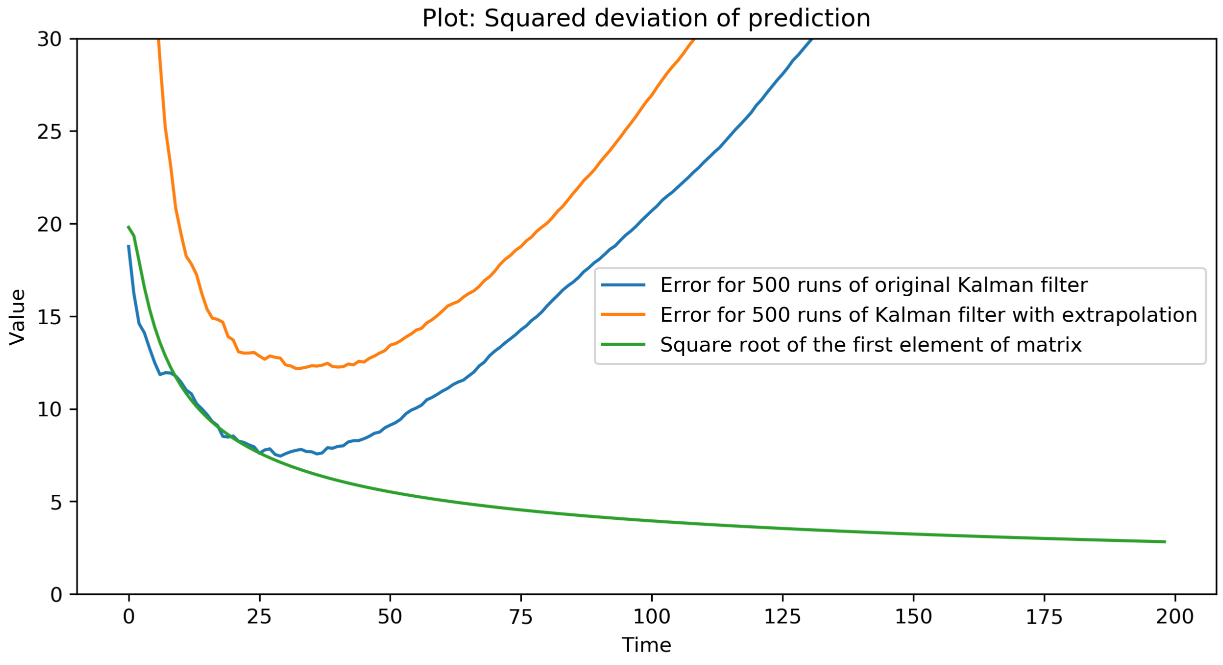
In [19]:
```
#6 Plot filter gain K
figure(num=None, figsize=(10, 5), dpi=300, facecolor='w', edgecolor='k')
plt.title('Plot: Filter gain')
plt.plot(K_f.T[0], label='Kalman filter gain')
plt.xlabel('Time')
plt.ylabel('Values')
plt.legend()
plt.show()
```



```
In [12]: def run(n,seven=False, P_init=np.matrix(((10000,0),(0,10000))) ):
             def gen():
                 a = np.random.normal(0,sa,c)
                 n = np.random.normal(0,sn,c)
                 X1 = np.matrix((5,1))
                 F = np.matrix(((1,t),(0,1)))
                 G = np.matrix((t**2/2,t)).T
                 H = np.matrix((1,0))

                 X = np.zeros([c,2])
                 X[0] = X1
                 for i in range (1,c):
                     frst = np.matmul(F,np.asmatrix(X[i-1]).T)
                     scnd = G.dot(a[i-1])
                     X[i] = np.add(frst,scnd).T
                 Z = np.zeros(c)
                 for i in range (c):
                     Z[i] = H.dot(X[i])+n[i]
                 return X.T,Z

             def kalman(z_g):
                 P = P_init
                 X_f = np.zeros([c,2])
                 X_f7 = np.zeros([c-7,2])
                 X_f[0] = X0
                 F7 = F
                 for i in range (6):
                     F7 = F7.dot(F)
                 for i in range (1,c):
                     X_p = F.dot(np.asmatrix(X_f[i-1]).T)
                     Pz = np.add(F.dot(P).dot(F.T),Q)
                     frst = np.add(H.dot(Pz).dot(H.T),R)
                     K = Pz.dot(H.T).dot(np.linalg.inv(frst))
                     pre_scnd = np.subtract(z_g[i],H.dot(X_p))
                     scnd = K.dot(pre_scnd)
                     P = np.matmul(np.subtract(I,np.matmul(K,H)),Pz)
                     X_f[i] = np.add(X_p,scnd).T
                     if i < c-7 and seven:
                         X_f7[i] = np.matmul(F7,X_f[i])
                 if(seven):
                      return X_f7.T
                 else:
                     return X_f.T

             if seven:
                 co = c-7
             else:
                 co = c
             error = np.zeros(co)
             for i in range (n):
                 cur_x,cur_z = gen()
                 res = kalman(cur_z)
                 if seven:
                     for i in range (7):
                         cur_x = np.delete(cur_x, i, 1)
                 s = np.power(np.subtract(cur_x[0],res[0]),2)
                 error = np.add(s,error)
             final = np.zeros(co)
             for k in range (2,co):
                 final[k] = np.sqrt(error[k]/(n-1))
             return final
```

In [13]:
```
err_k = run(500)
err_k7 = run(500,True)
```

In [20]:
```
#deleting first row
err_k = np.delete(err_k, 0)
err_k7 = np.delete(err_k7, 0)

figure(num=None, figsize=(10, 5), dpi=300, facecolor='w', edgecolor='k')
plt.title('Plot: Squared deviation of prediction')
plt.plot(err_k, label='Error for 500 runs of original Kalman filter')
plt.plot(err_k7, label='Error for 500 runs of Kalman filter with extrapolation')
plt.plot(P_g, label='Square root of the first element of matrix')
plt.xlabel('Time')
plt.ylabel('Value')
plt.ylim((0, 30))
plt.legend()
plt.show()
```



In [ ]: