Albedo Echo Delay Effects on HXR Burst Light Curves

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Summary of HXR Albedo Effects

CONTRIBUTES TO –

Intensity

Spectrum

Imaging

Polarisation

LIGHT CURVE

EARLY HXR ALBEDO STUDIES

BASICS

Tomblin, F. F. 1972, Ap J 171, …

Santangelo, N. 1973, Sol Phys. 29, 143

Henoux, J.C. 1975, Solar Phys 42, 219

Langer, S. H .& Petrosian, V. A. 1977, Ap J.215 666

Bai, T & Ramaty R.A.1978 ApJ 219, 705

1) Studies of Albedo SPECTRUM

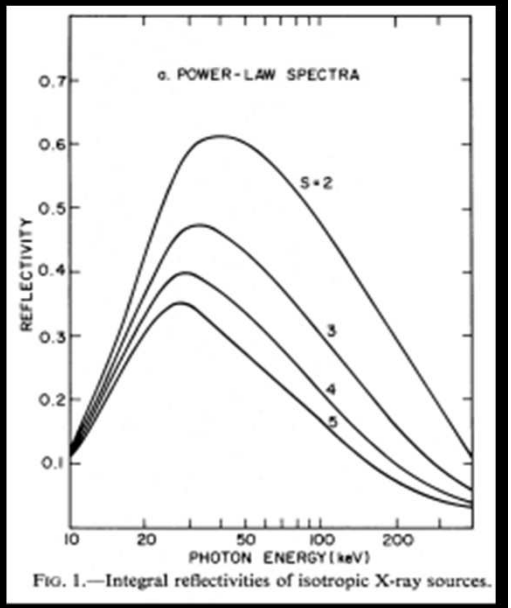


FIG. 1.—Integral reflectivities of isotropic X-ray sources.

Total HXR spectrum – primary + albedo for strong downward beaming

Langer, S. H.;

Petrosian, V. A. 1977,

Ap J.215 666

"Total HXR spectrum contains Info on beam anisotropy"

NOTE bump around 25 keV

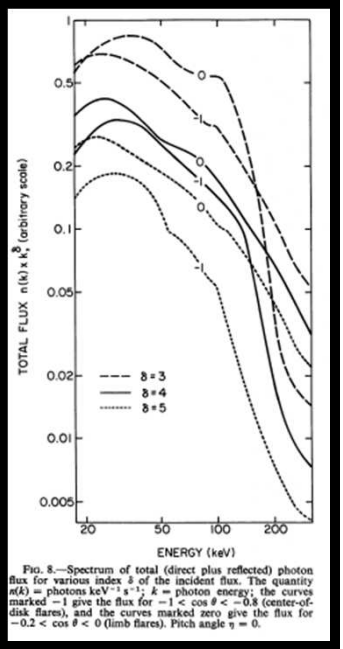


FIG. 8.—Spectrum of total (direct plus reflected) photon flux for various index δ of the incident flux. The quantity $n(k)$ = photons keV^{-1} s^{-1}; k = photon energy; the curves marked -1 give the flux for $-1 < \cos\theta < -0.8$ (center-of-disk flares), and the curves marked zero give the flux for $-0.2 < \cos\theta < 0$ (limb flares). Pitch angle $\eta = 0$.

Stereoscopic Electron Spectroscopy of Solar Hard X-Ray Flares with a Single Spacecraft

- Kontar and Brown 2006 ApJ 653L149

Came up with the same idea 3 decades later but with RHESSI data to apply it…

Constrained (spatially averaged) fast electron *f(v)* to be much less anisotropic than for highly beamed injection

Jeffrey & Kontar 2011 A&A 536, 93

POWERFUL MONTE CARLO CODE FOR MODELLING ALBEDO IN GENERAL

- Spatially resolved hard X-ray polarization in solar flares: effects of Compton scattering and bremsstrahlung emission

2) Studies of HXR source HEIGHT and albedo patch size

Brown, J. C., van Beek, H. F., McClymont, A. N. 1975, A&A 41, 395

Determination of the height of hard X-ray sources in the solar atmosphere by measurement of photospheric albedo photons

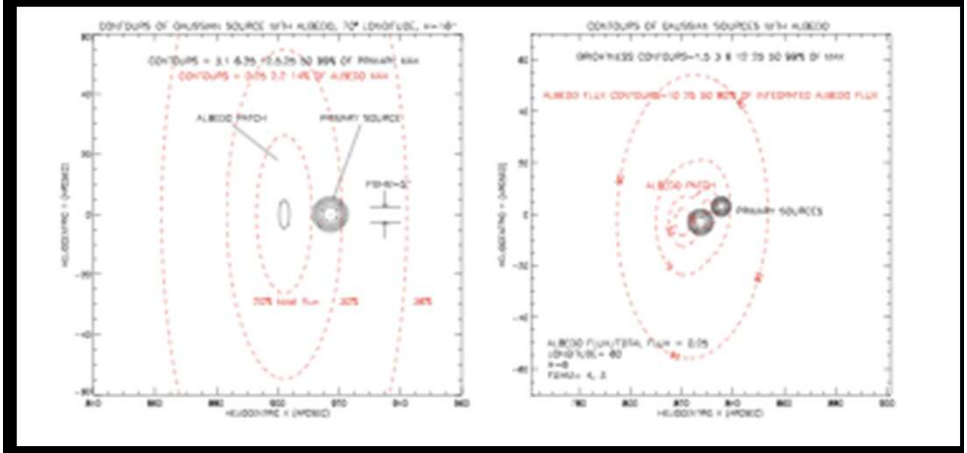
ıth a single satellite. Tomblin
al. (1973) have shown that
ɔmpton backscatters a large
ım a hard X-ray source in the
h this is a scattering rather
s, it effectively provides a
ce of primary X-rays which
viding a parallactic "height-
ı this paper we propose one
ɛct angular resolution of the
ich accompanies any primary
that the necessary measure-
icable by reference to the
l X-ray heliograph currently
Space Research Laboratory,
the NASA Solar Maximum

the source height. McClymo
show that this is indeed the case
tric accuracy would have to b
arc seconds resolution to succe
Since such measurements are
strumentation, we are of the op
proposed here is the only one

2. Spatial Distribution of the Al

Tomblin (1972) and Santang
investigated the effect of t
scattering on the spectrum and
received at the earth from
explicitly considered the spa

Hurford & Schmahl Albedo Patch



3) Studies of Albedo TIME DELAY

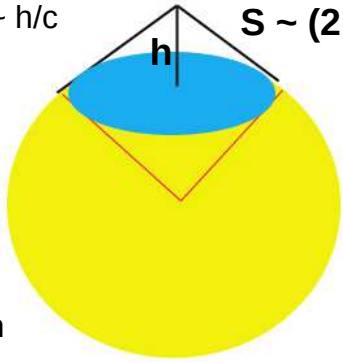
- ?? NOTHING ON THIS SINCE

  Bai, T. 1978
  Solar Phys, vol. 59, 141

  Determination of the source height and anisotropy of solar hard X-rays by measurements with good time resolution

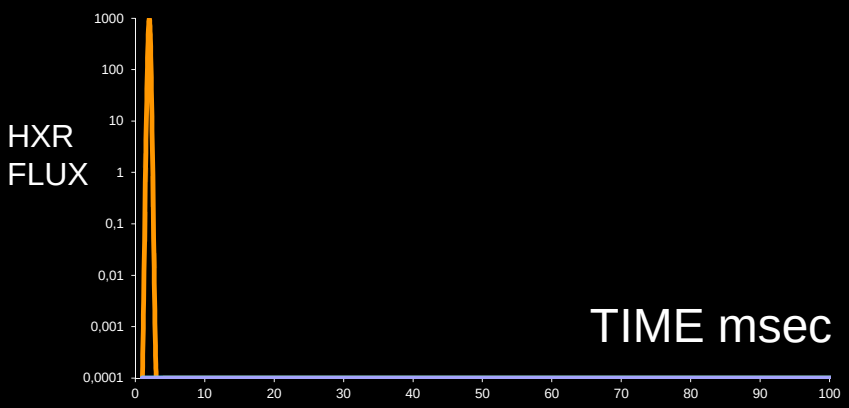
Bai mainly addressed the specular point echo delay delay whereas…

Specular point delay ~ h/c
~ 3ms x (h/1000 km)

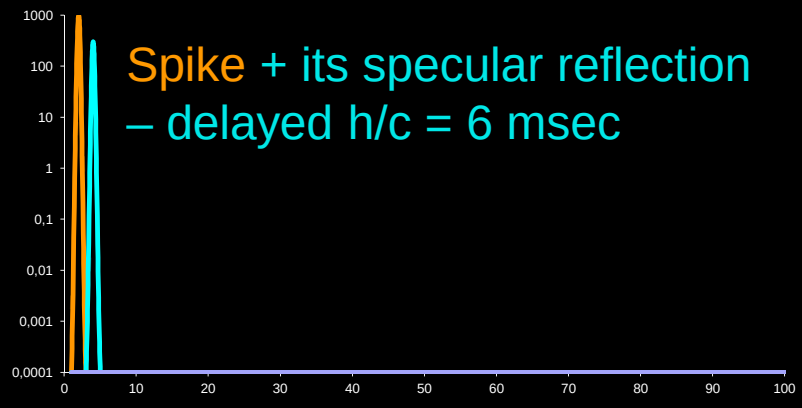


Albedo patch horizon
Delay ~ S/c ~
100 ms x $(h/1000\ km)^{1/2}$

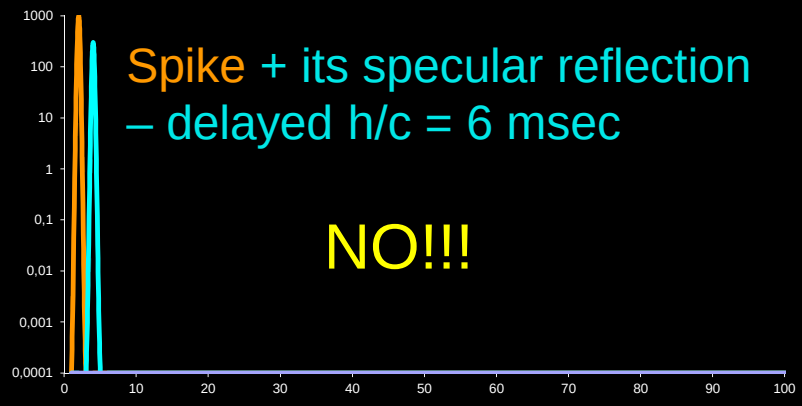
Light curve arising from a primary spike at t = 0



Is the total light curve like this? (Bai 1978)



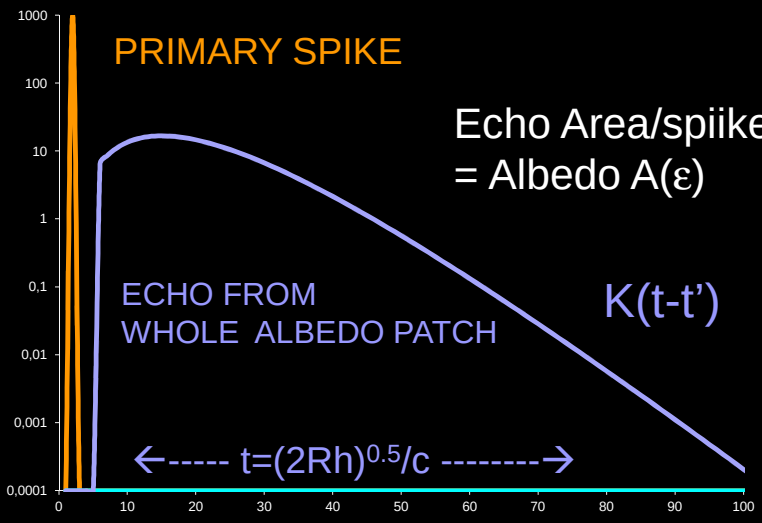
Is the total light curve like this? (Bai 1978)



Spike + its specular reflection – delayed h/c = 6 msec

NO!!!

NO – IT'S LIKE THIS



OBSERVED LIGHT CURVE I(t) IS A CONVOLUTION OF THE PRIMARY LIGHT CURVE $I_o(t)$ WITH THE ECHO TRANSFER FUNCTION K

$$I(t) = I_o(t)\left[1 + A(\varepsilon)\int_{t'} I_o(t')K(t-t')dt'\right]$$

CONCLUSIONS – 1
Need for deconvolution of HXR light curves

- In analysing any high time (subsecond) resolution modelling HXRB light curves the primary light curve should be deconvolved from the data through the albedo echo profile K

CONCLUSIONS - 2
ENERGY DEPENDENT HXR PULSE DELAYS

In light curves observed at more modest time resolution (>> 10 ms) the albedo echo will delay the mean photon arrival time <t> of pulses by times

~ 100 ms x (h/1000 km)$^{0.5}$

at 30 keV and decreasing to ~ 6 ms x h(km) above 100 keV

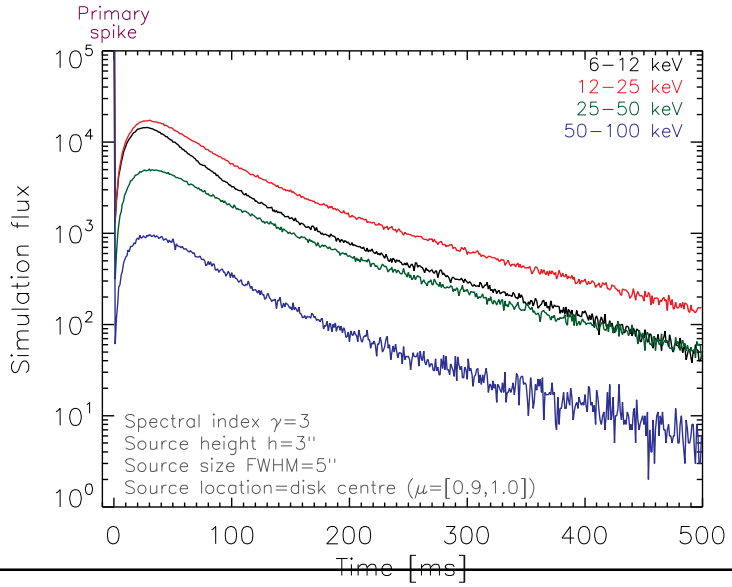
WHY ???

Mean arrival time of HXR pulse as function of energy ε

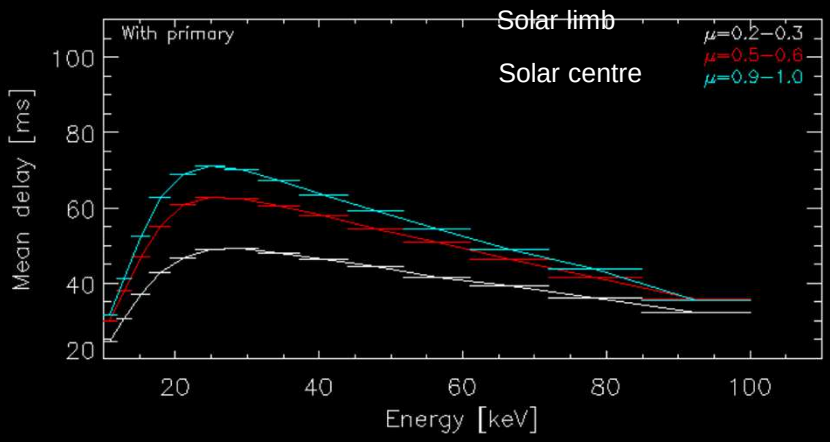
$$<t>(\varepsilon) = \int_{t'} I(t')t'dt' \Big/ \int_{t'} I(t')dt' =$$

$$= \frac{\int_{t'} I_o(t')[1+\kappa(t-t')A(\varepsilon)]t'dt'}{\int_{t'} I_o(t')[1+\kappa(t-t')A(\varepsilon)]dt'}$$

TOTAL HXR LIGHT CURVES



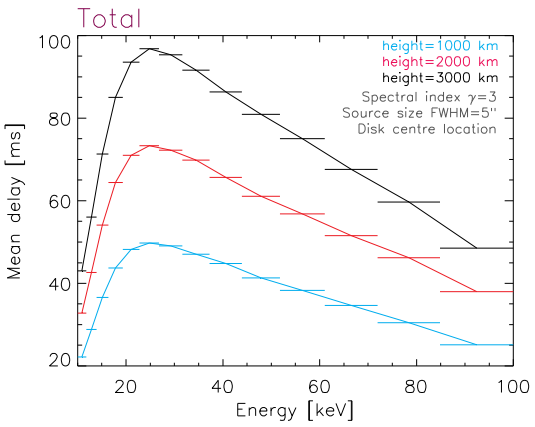
Total Flux - Energy dependent time delays – Variation with solar position



Source height h =1500 km
Spec Index δ = 3

Disk Centre delay (ms) approx $70/(E/20keV)^{-1/2}$
Similar to ToF for 7000km loop

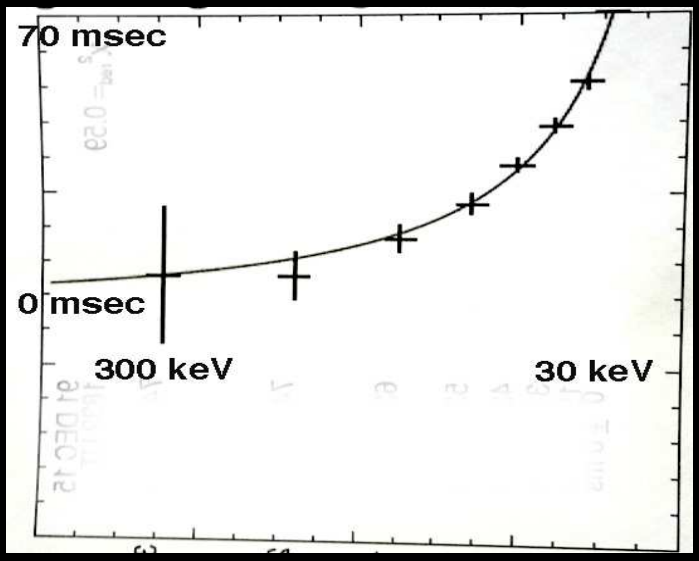
EFFECT OF PRIMARY SOURCE HEIGHT



QUESTION ??

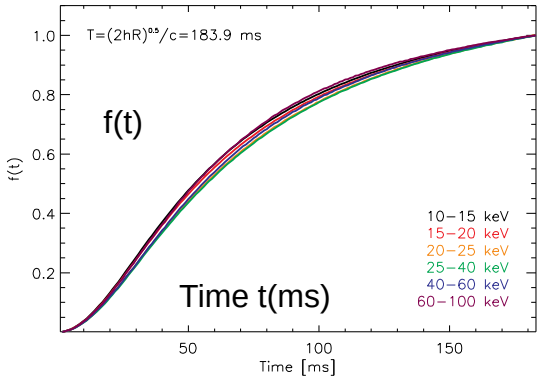
- How much effect does this energy dependent albedo echo delay have on the Aschwanden interpretation of energy dependent delays as electron time of flight?

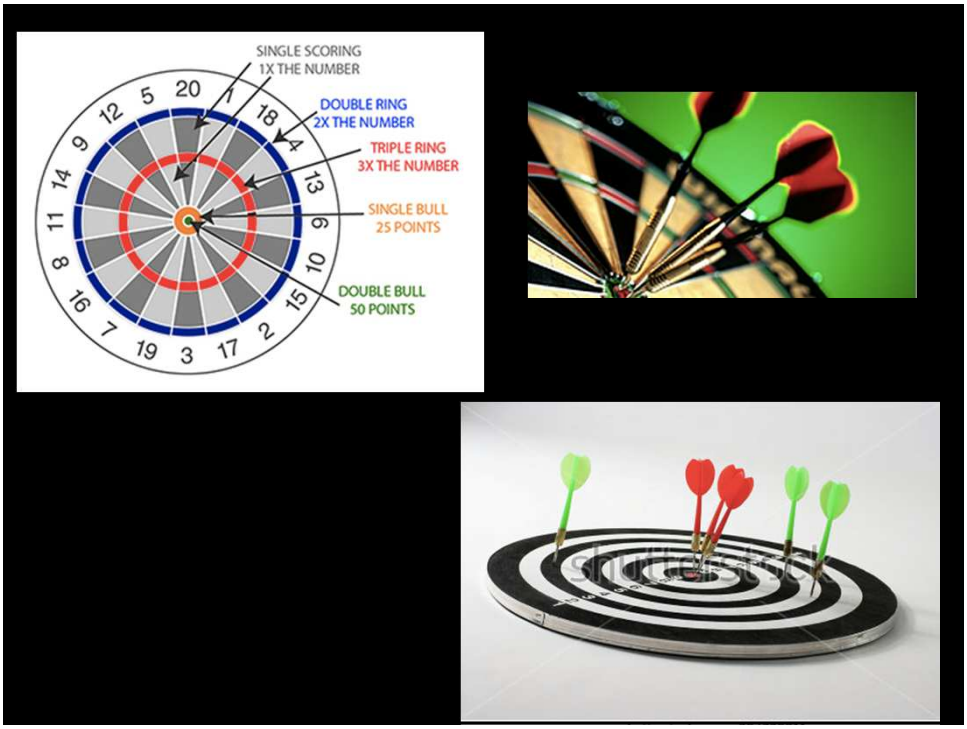
Energy Dependent HXR delays (Aschwanden & Schwartz)



Cumulative echo light fraction f(t)

$$= \int_0^t I(t)\,dt \Big/ \int_0^T I(t)\,dt$$




SINGLE SCORING
1X THE NUMBER
DOUBLE RING
2X THE NUMBER
TRIPLE RING
3X THE NUMBER
SINGLE BULL
25 POINTS
DOUBLE BULL
50 POINTS
20
1
18
4
13
6
10
15
2
17
3
19
7
16
8
11
14
9
12
5