Pileup and the ACIS/HRMA Point Spread Function

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ACIS Operation (TE mode)

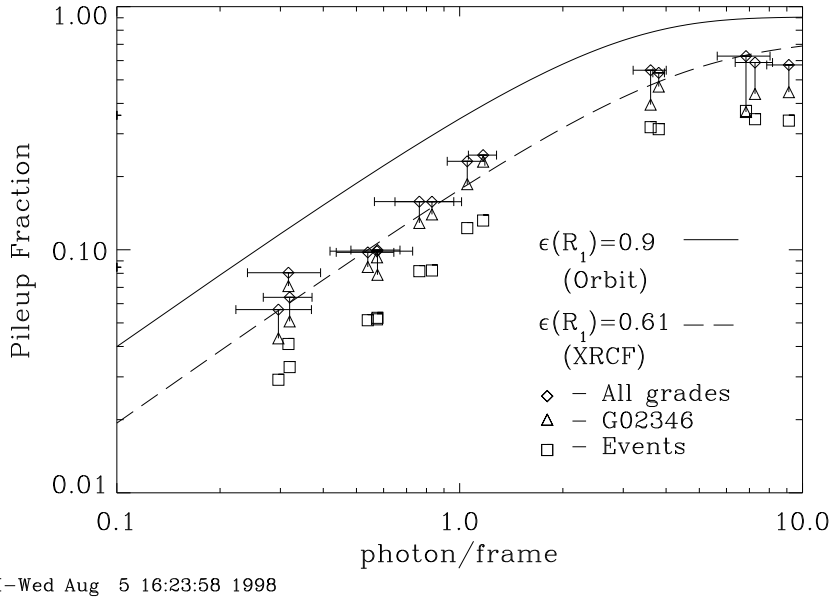
- ACIS is shutterless CCD detector.
  - frame exposed for τ_{frame} (typically $\sim$3 s);
    X-ray photons $\Rightarrow$ e^- charge clouds, $\#\, e^- \propto$ photon energy
  - frame xfr: transfer collected charge rapidly to frame store;
    parallel transfer rate $\equiv 40\mu$s per parallel transfer.
  - each pixel of column sees short exposure of all emission along the column $\Rightarrow$ transfer streak or smear.
  - transfer $\ll$ dither; “instantaneous smeared snapshot”

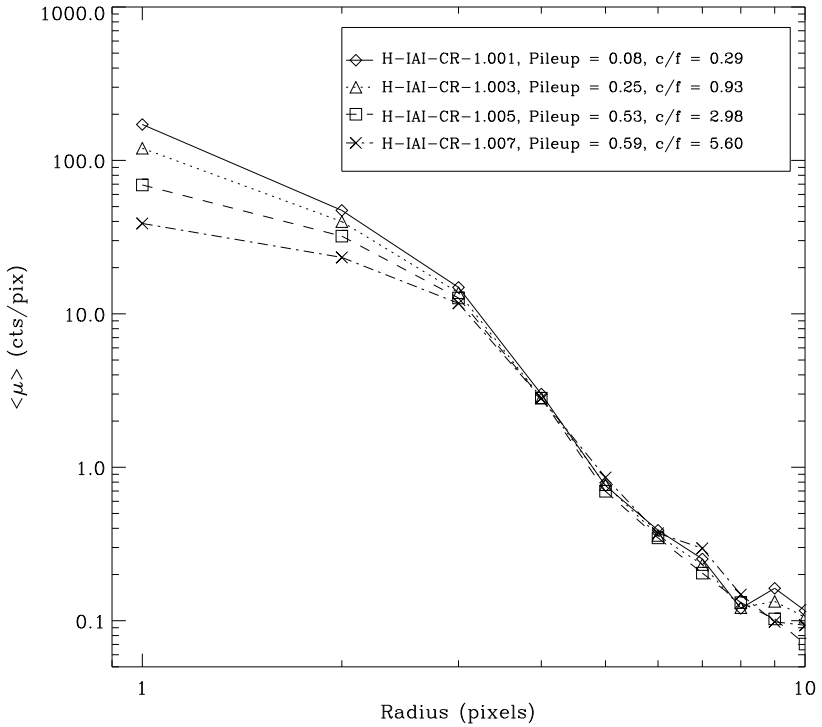
ACIS and Pileup

- Overlapping charge clouds in same 3×3 pixel detect island $\Rightarrow$ pileup
  - spectral distortion: piled event energy is too large
  - grade distortion:
    - altered charge distribution in 3×3 island
      $\Rightarrow$ “grade morphing”
  - count rate depression:
    - good grades $\Rightarrow$ worse grades $\Rightarrow$ bad grades
      (*e.g.*, g0 $\Rightarrow$ g6; g6 $\Rightarrow$ g7 or worse)
    - some bad grades rejected on board.
  - spatial shift of detected event:
    - pixel with maximum charge shifted;
      pix with largest charge $\Rightarrow$ center of detect island
  - worst for center of near on-axis point source PSF
    narrow PSF core $\Rightarrow$ high count rate for single pixel

Ground Data

- Pileup effect on PSF: depression of central part of the PSF.
- PSF “peakier” on orbit $\Rightarrow$ larger effect





Pileup Observations

Experiment design

- source: isolated pulsar PSR J0437-4715;
  count rate $\sim$0.2 ct s^{-1}
- use different frame times to obtain different pileup rates.
  - Initial choices:
    $\tau_{\mathrm{frame}} = 0.4$s, 1.5s, 3s, 6s, 10s ($\sim$0.08–2 ct/frame)
  - Observed so far:
    $\tau_{\mathrm{frame}} = 0.4$s, 1.5s, 3s

Pileup Observations: Dither

Aim: make data as similar to real data with different count rate.

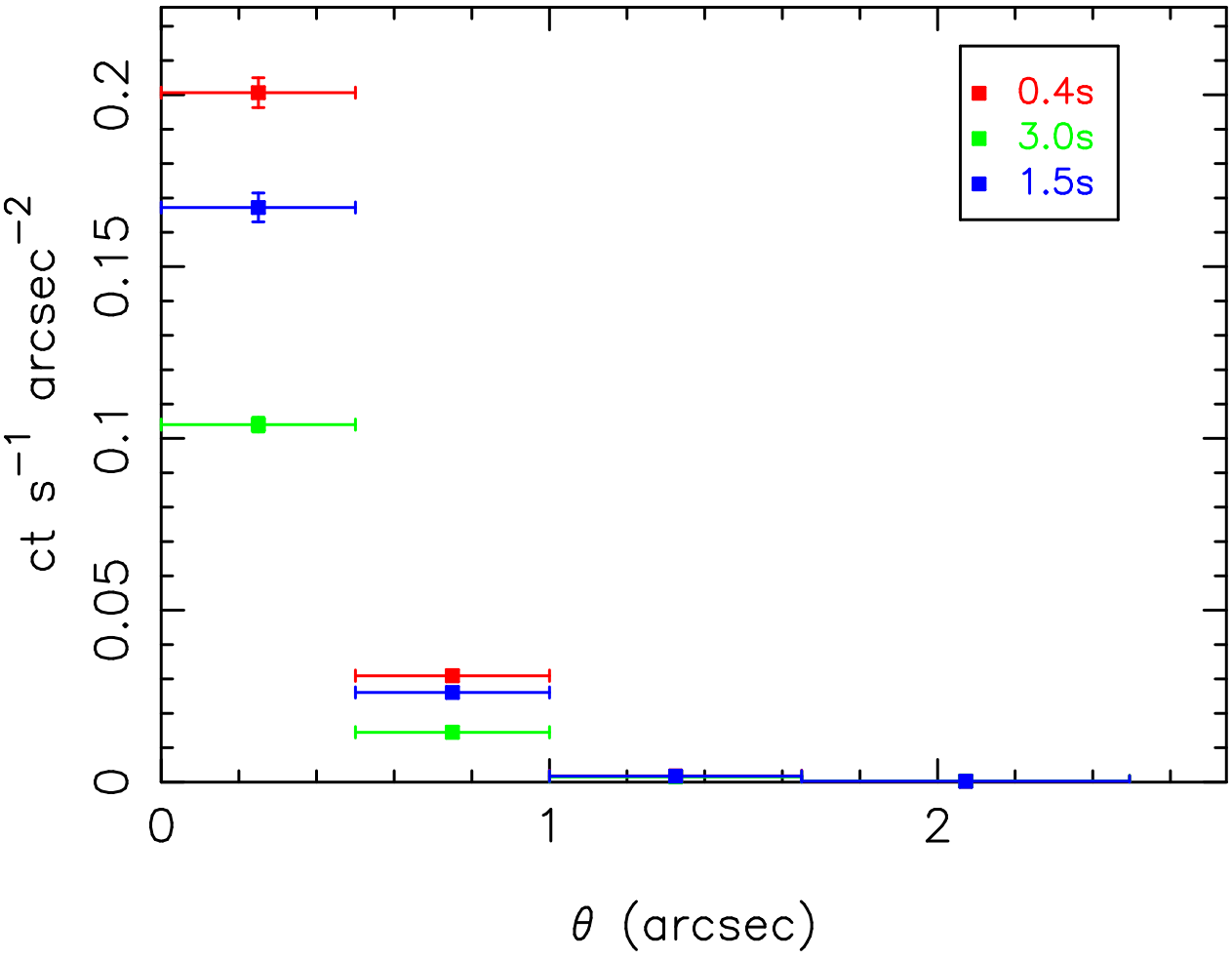
- dither: max velocity is 0.3 pix/sec
  - Different frame times $\Rightarrow$ max travel/frame varies
    $\Rightarrow$ shorter τ_{frame}, too "slow"; longer τ_{frame}, "too fast".
  - 6s, 10s frame time:
    dither travel comparable to pixel size
    $\Rightarrow$ aspect reconstruction degradation
- solution: scale dither periods inversely with $\tau_{\text{frame}}/3\,\text{sec}$.
  - limitation: operational limitation on dither period; shortest observation not quite scaled to τ_{frame}
- shorter frame times $\Rightarrow$ more frame transfers
  - larger deadtime: $\propto 1/\tau_{\text{frame}}$; $\sim$10% for $\tau_{\text{frame}} = 0.4$s.
  - more transfer streak events; $\sim$10% for $\tau_{\text{frame}} = 0.4$s

The Observations

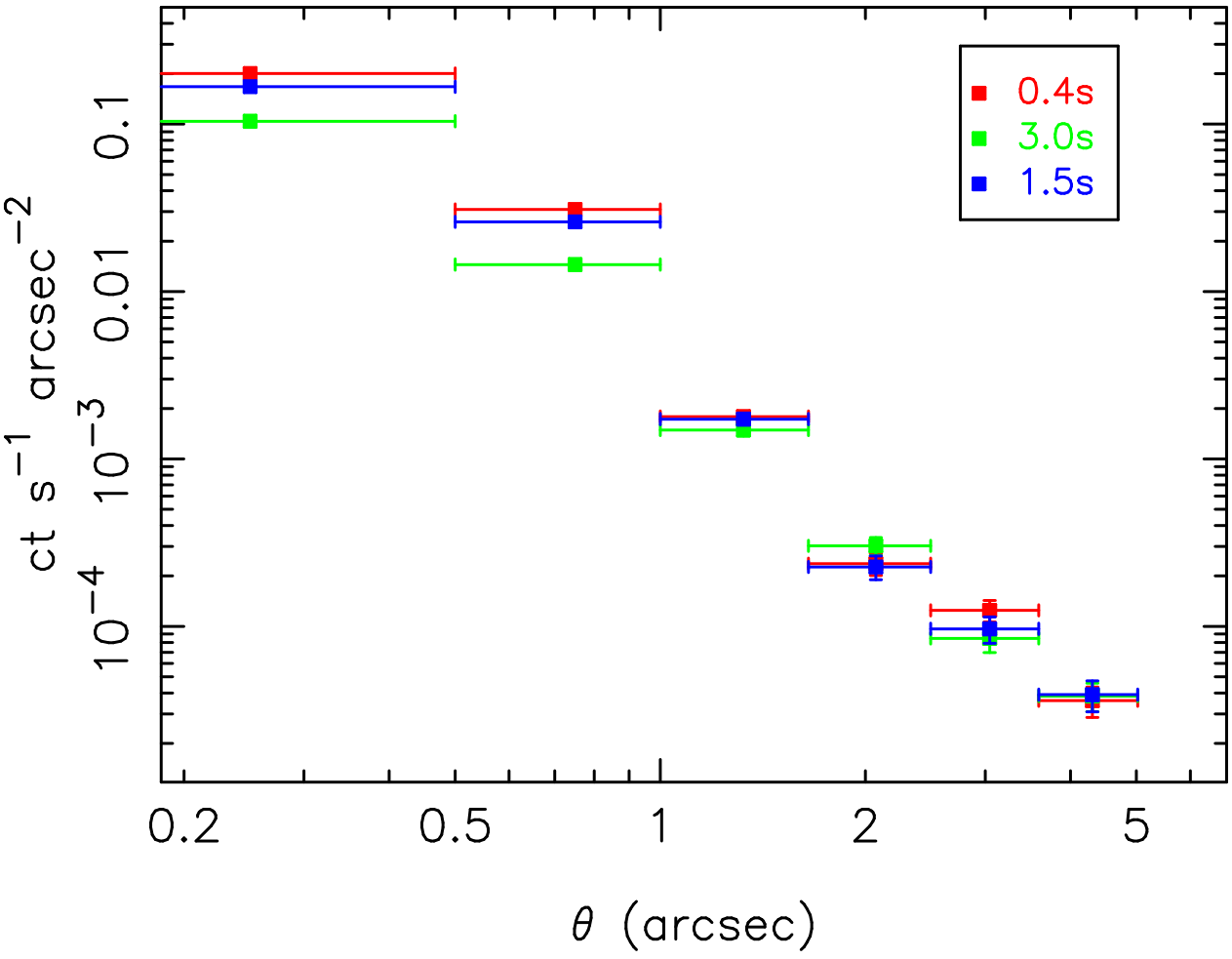
ObsID	τ_{frame} (s)	Ontime (ks)	Exposure (ks)	# Frames	$1-$ DTC
6154	0.4	25.188	22.438	57110	0.09305
6157†	0.4	9.450	8.570	21426	0.09305
6156	1.5	21.179	20.615	13743	0.02663
6155	3.0	24.628	24.295	8098	0.01350

$^{\dagger}\sim 4'$ off-axis

Pileup: PSF Profile



Pileup: PSF Profile



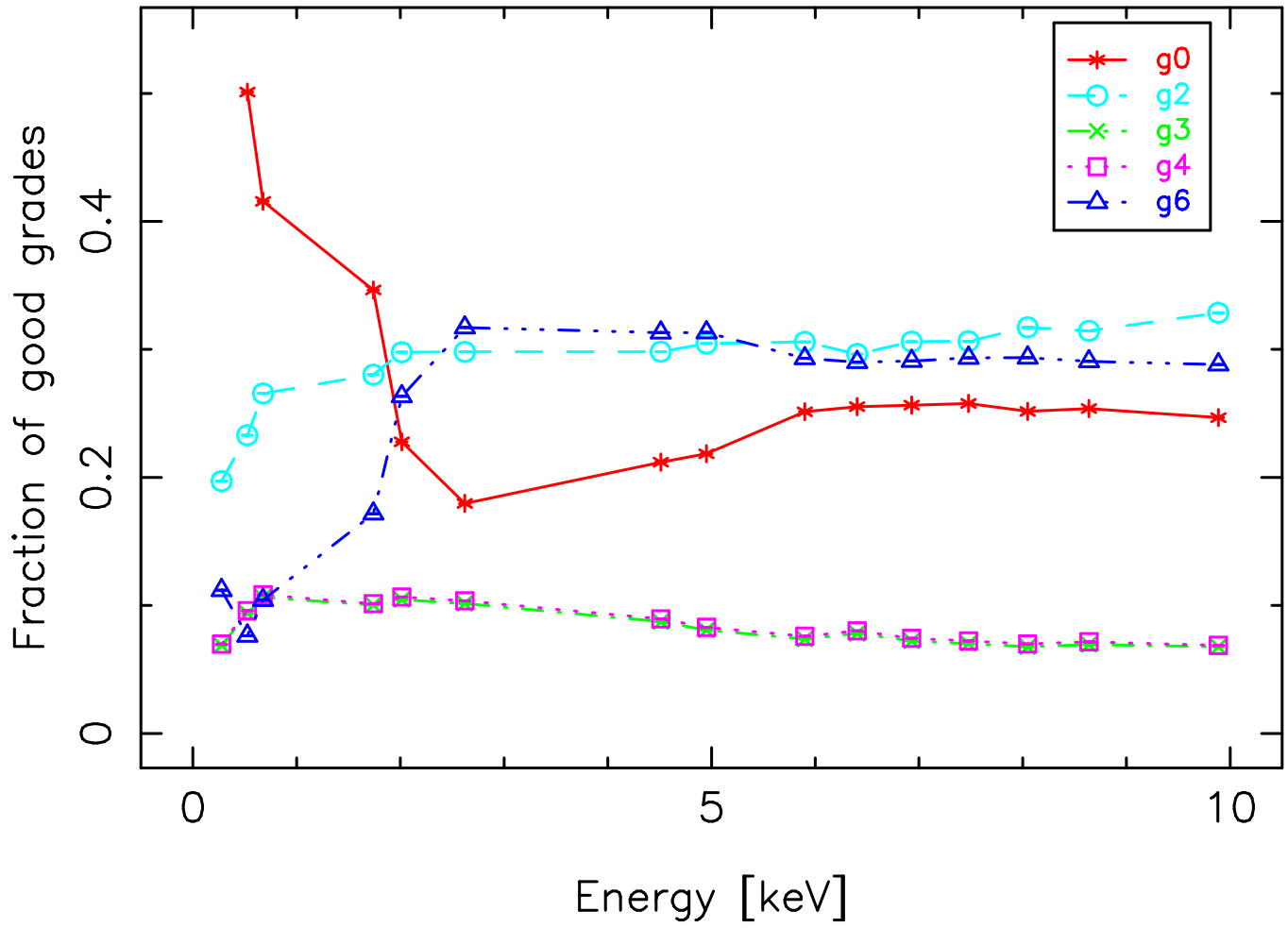
Diagnosing Pileup

Is $\tau_{\mathsf{frame}} = 0.4$ s data effectively unpiled?

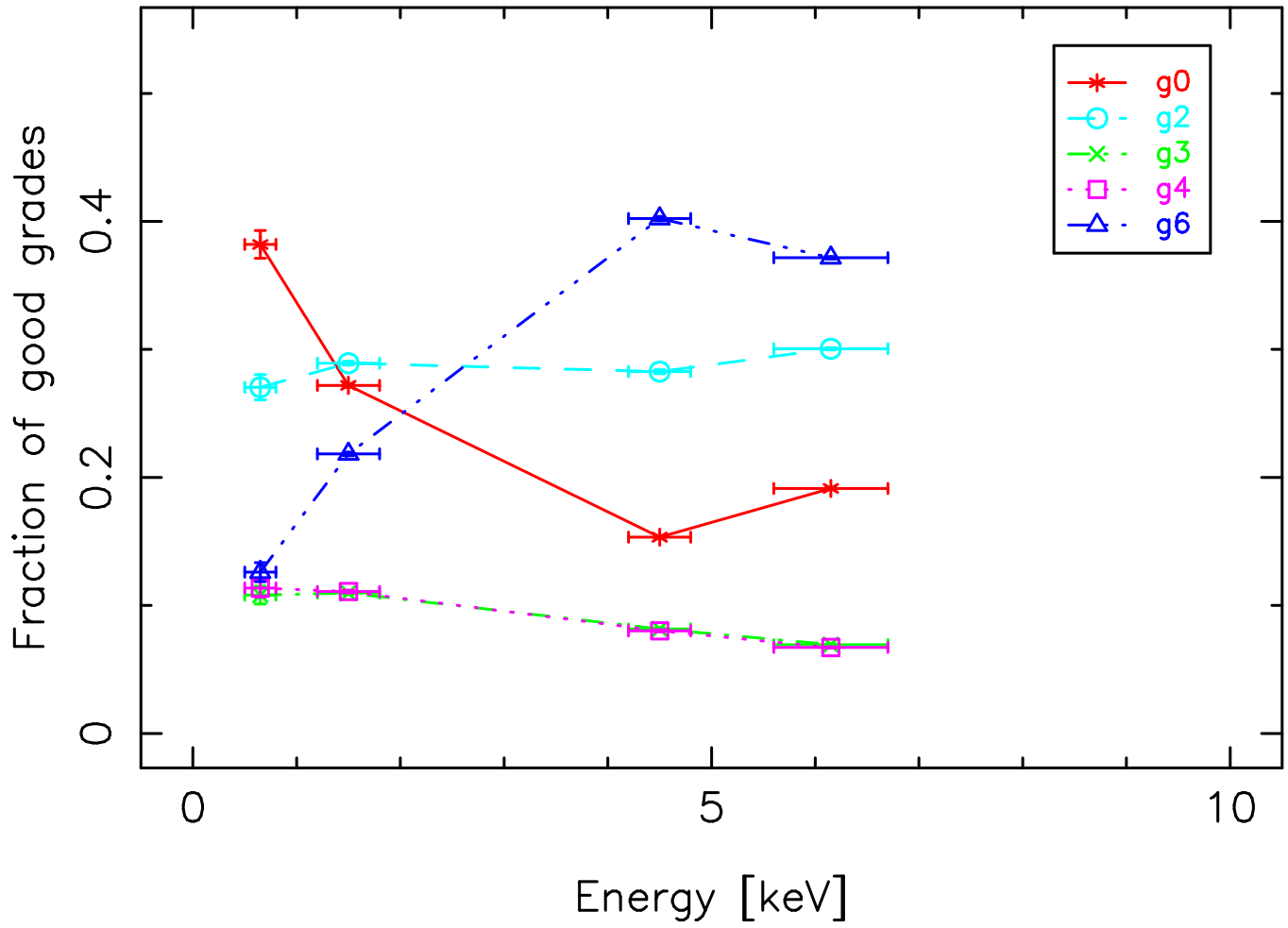
Tools:

- grade fractions: look for grade morphing effects, but. . .
  what is zero-pileup limit?
  - ground: subassembly data
  - on-orbit: faint sky sources; external calibration source
- spectral fi tting: look for spectral distortion
  - simultaneous fi t to all three obsids using pileup model:
    `pileup(phabs(bbodyrad + bbodyrad + powerlaw))`

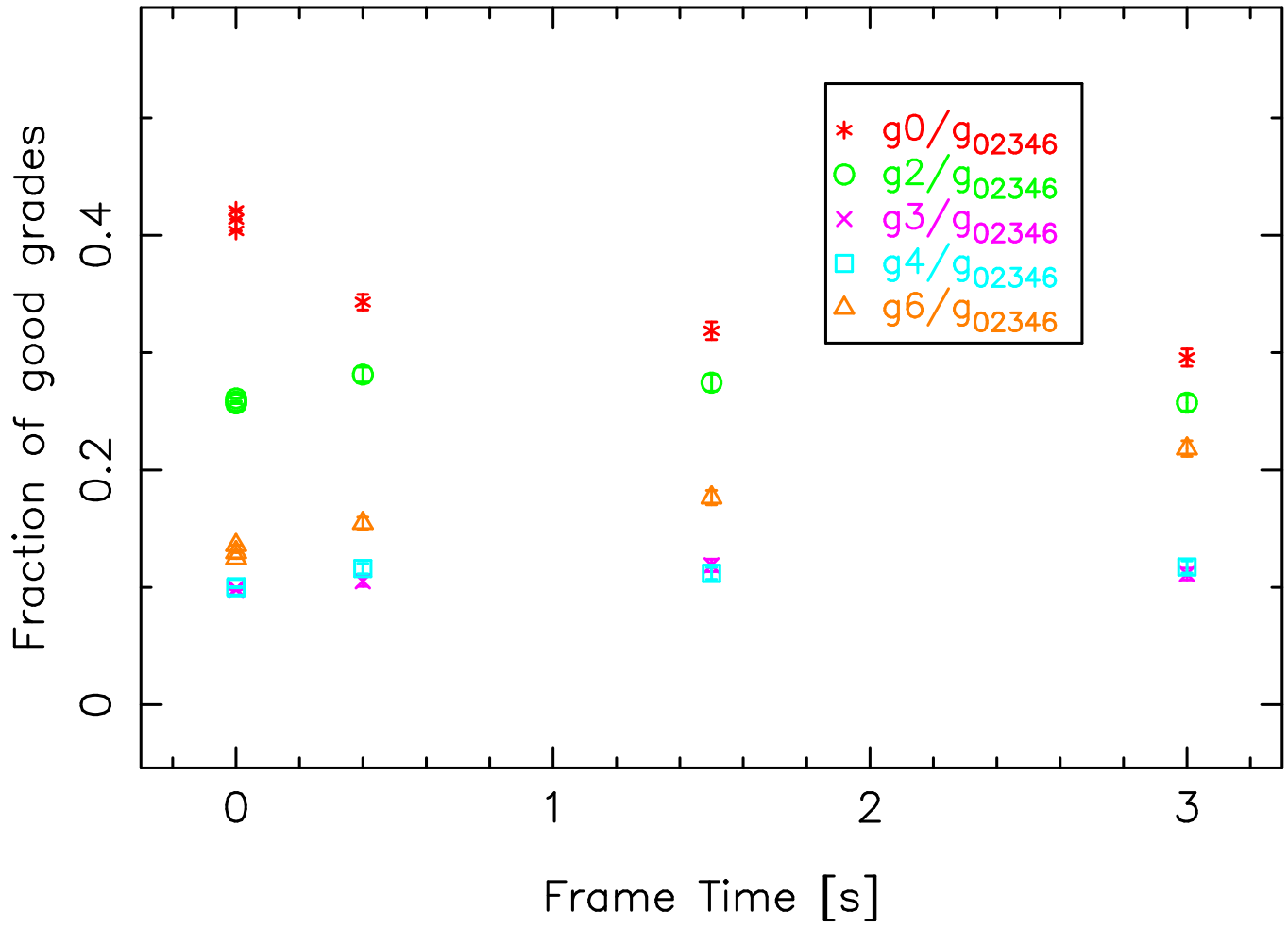
Grade Fractions [g_n/g_{02346}], Subassembly Data



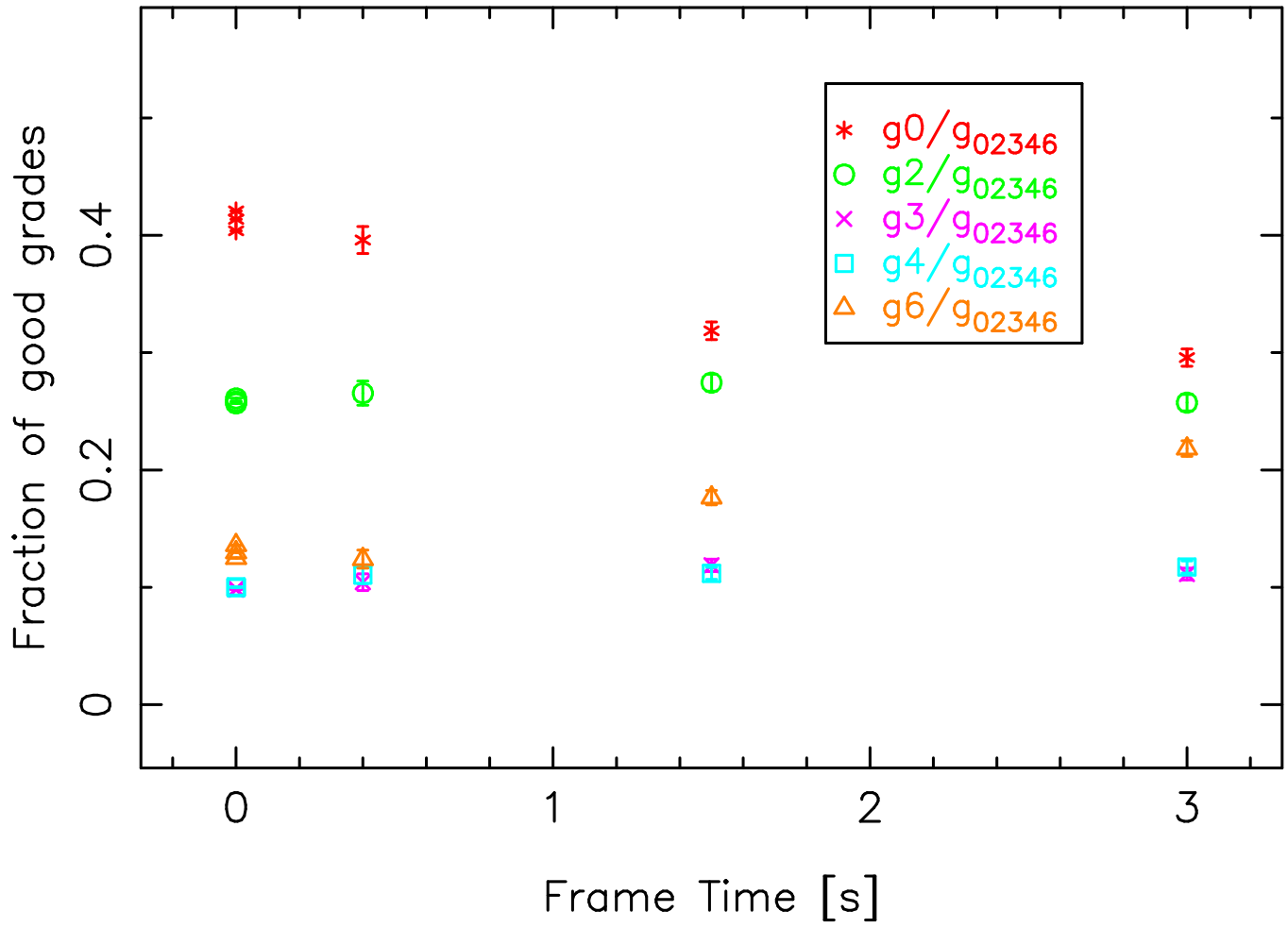
Grade Fractions [g_n/g_{02346}], Ext Cal Source



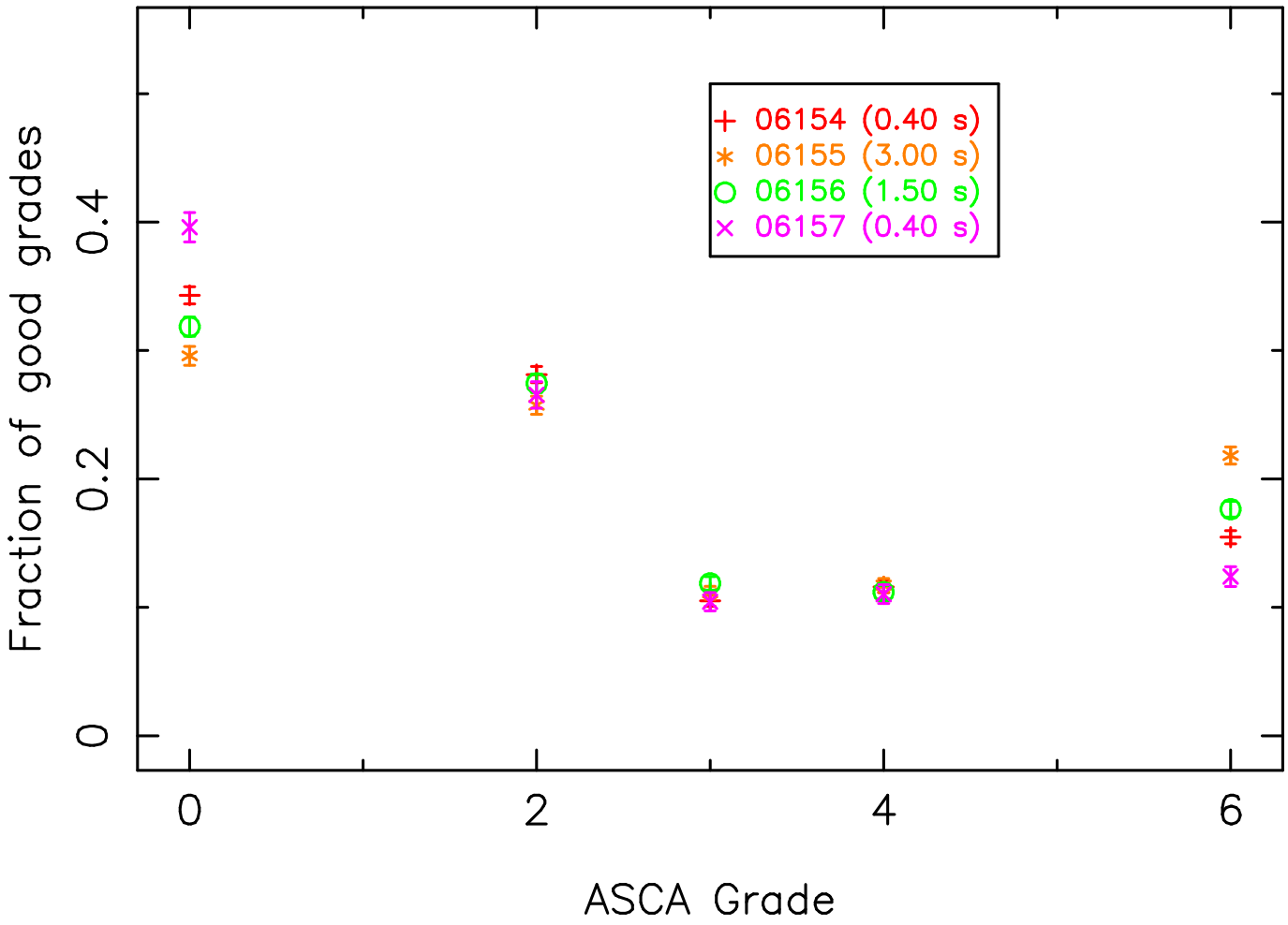
Grade Fractions [g_n/g_{02346}] vs. Frame Time



$[g_n/g_{02346}]$ vs. Frame Time; 0.4s obs off-axis

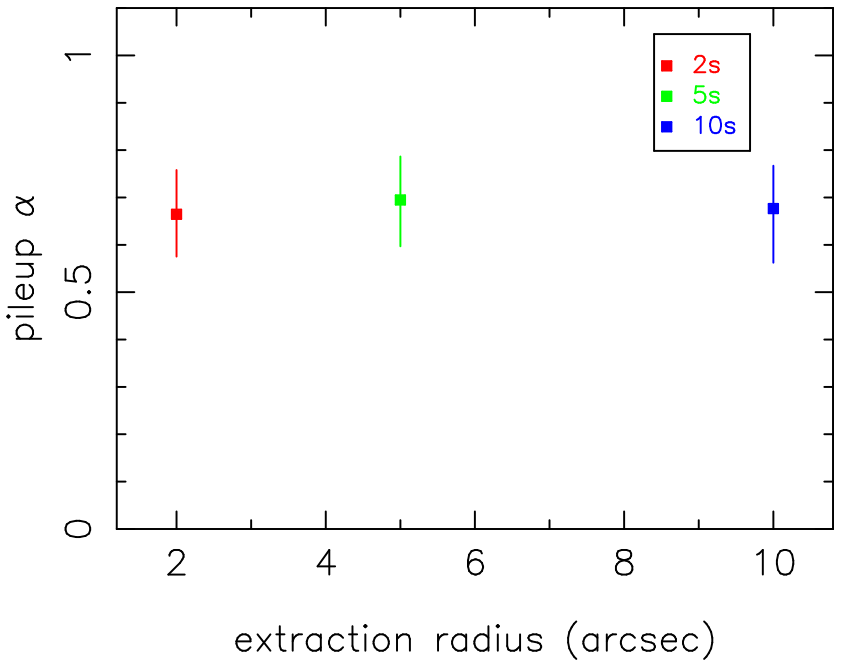


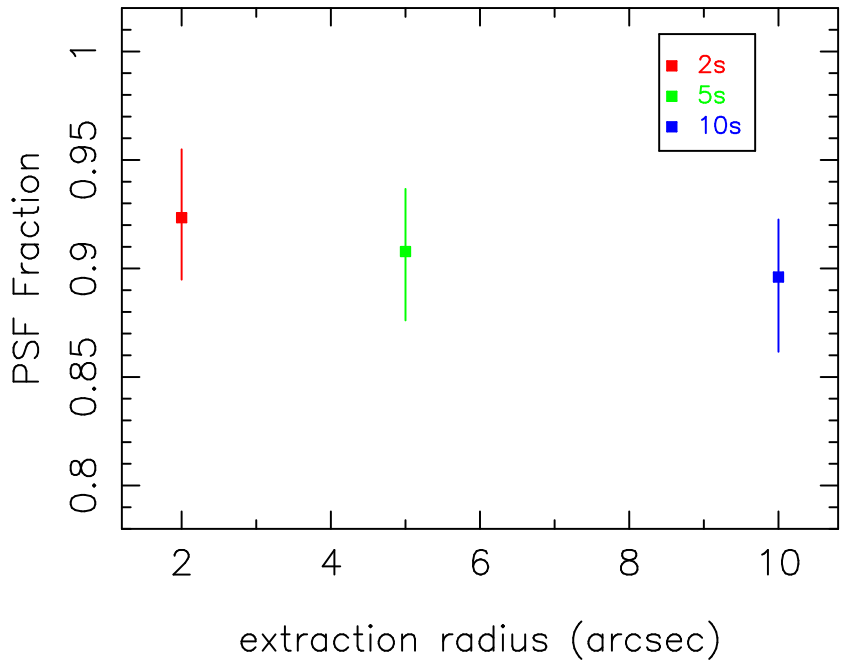
Grade Fractions [g_n/g_{02346}] vs. Grade



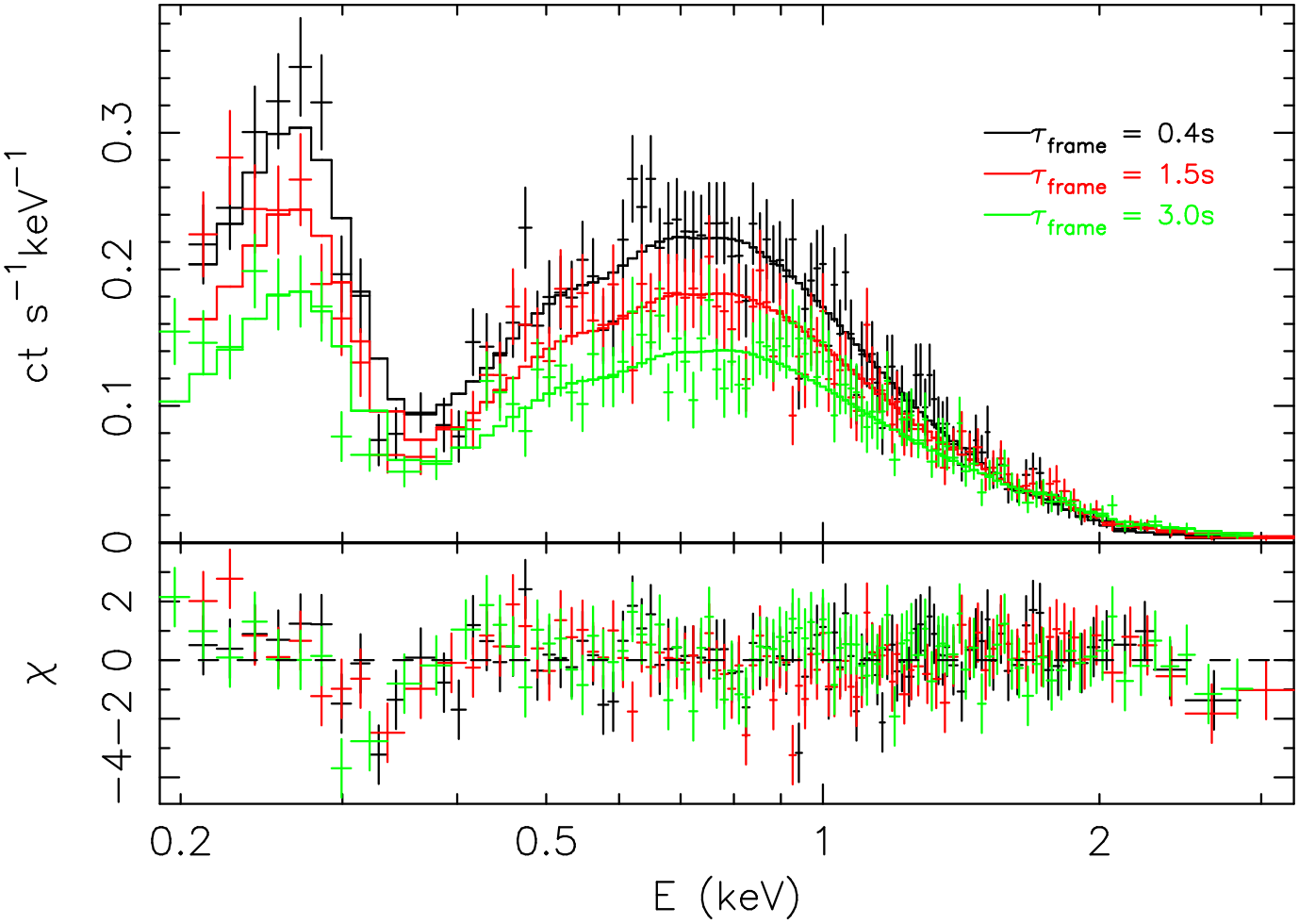
PSF Pileup Fitting

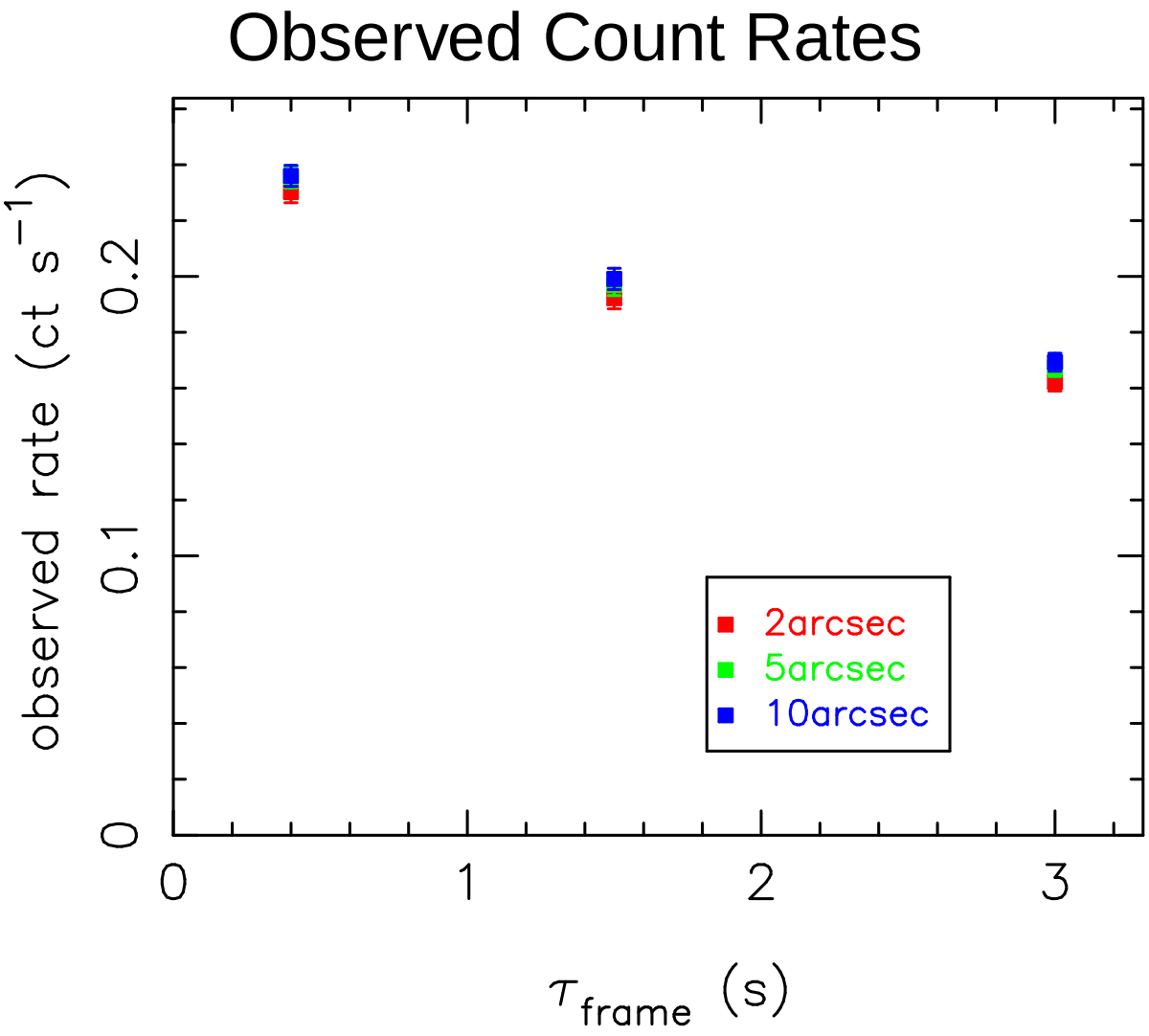
- simultaneous fi t to all three obsids using pileup model:
  `pileup(phabs(bbodyrad + bbodyrad + powerlaw))`
- circular extraction radii: 2″, 5″, 10″



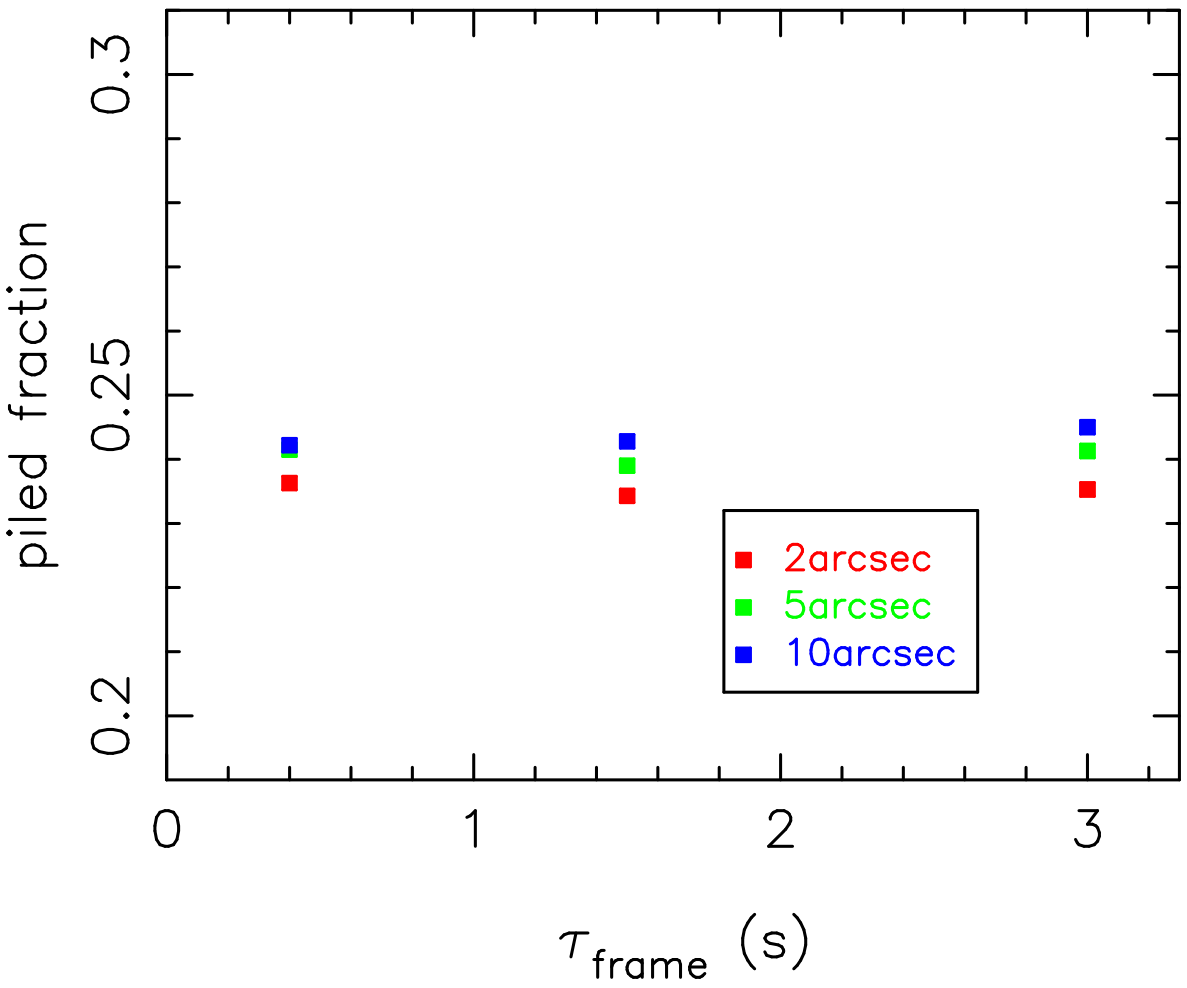


Pileup Model Spectral Fits: $\chi^2/\mathrm{dof} = 0.98$

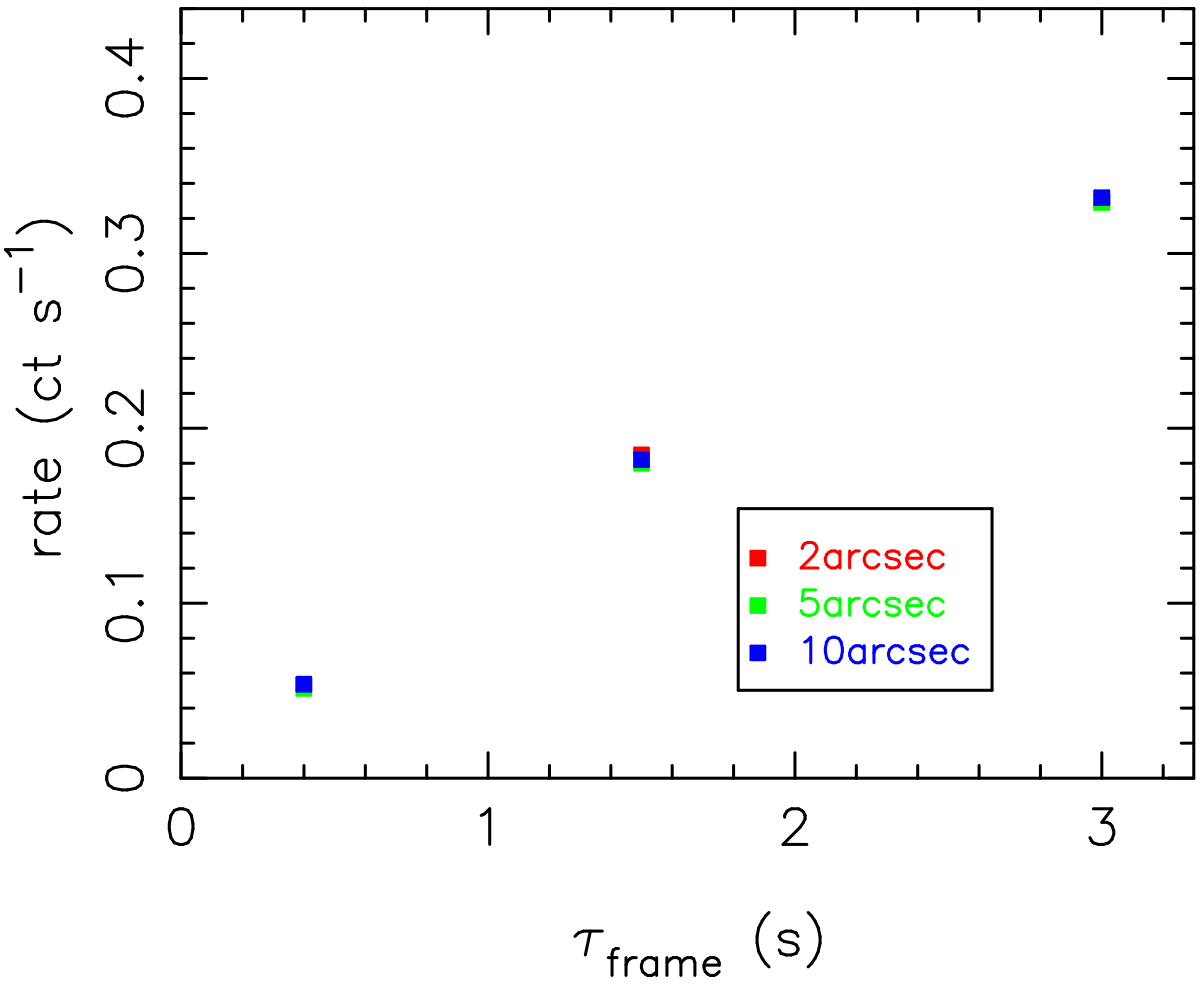



Observed Count Rates
observed rate (ct s^{-1})
0
0.1
0.2
0
1
2
3
τ_{frame} (s)
2arcsec
5arcsec
10arcsec

Pileup-Corrected Rates



Pileup Fraction



Summary

- analyzed initial set of pileup observations
  - frame times 0.4s, 1.5s, 3.0s
- how unpiled is the shortest frame time data?
  - grade ratios $\Rightarrow$ still signifi cant; off-axis data closer to subassembly values
  - spectral fi tting with pileup model $\Rightarrow$ $\sim$5% pileup
- depression of PSF core examined for pileup $\sim$5%–35%