

Lessons from Chandra: **Comparing the Wolter I and
Wolter-Schwarzschild prescriptions
to optimize sensitivity for Gen-X.**

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The image shows the AXR logo, which consists of a stylized 'AXR' in a circle. To the right of the logo is a blue and red emblem. Below the logo is the text 'International Workshop on Astronomical X-Ray Optics AXRO2009'. The text continues: 'Villa Lanna, Prague, Czech Republic December 6 - 9 (10)'. Below this is an image of a satellite with a large, cylindrical, gold-colored structure. To the right of the satellite is the text: 'The Workshop is organized by Astronomical Institute of the Academy of Sciences of the Czech Republic and Czech Technical University in Prague'. At the bottom left is the text: '45 participants from 7 countries are presenting and discussing technologies for future X-ray astronomy missions such as IXO of ESA/NASA/JAXA and Generation X by NASA'.

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Generation-X Science Objectives

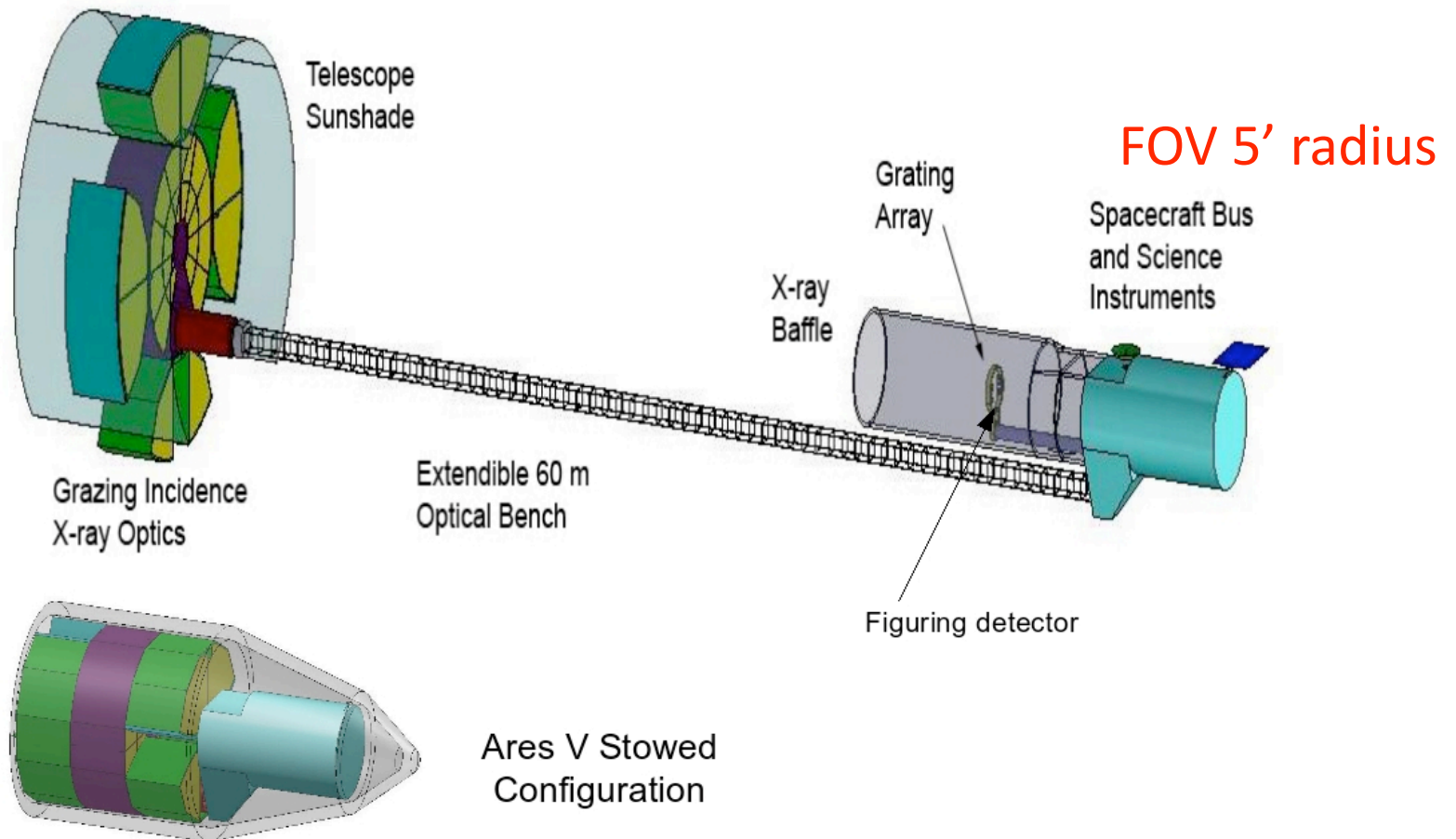
- **Detect first black holes, $z \sim 10-20$**
- **What is the Gen-X sensitivity in a 1 Msec Observation?**
- Evolution of Black Holes, Galaxies, Elements, from formation to the present
- Behavior of matter in extreme environments of Density, Gravity, Magnetic fields, Kinetic Energy.

First Black Holes

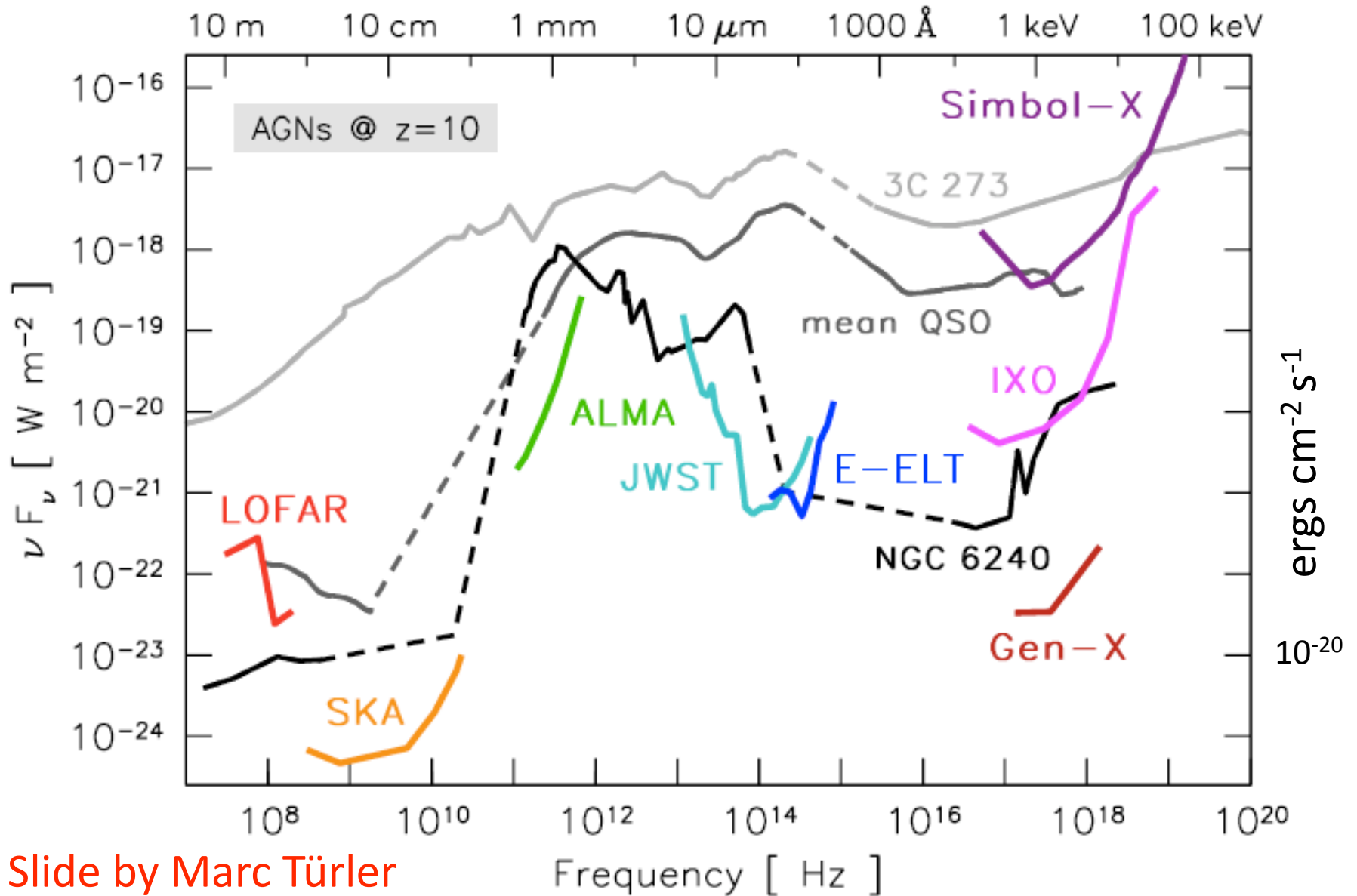
1. First massive stars, Pop III, $M > 260$ explode to form black hole. (Wyithe, J. S. B., Loeb, A, [2003ApJ...595..614W](#))
 1. Fiducial $M=1000$
 2. $L_x = L_{\text{edd}} = 1.3 \times 10^{41}$ ergs/s
 3. $F_x = 4 \times 10^{-20}$ at $z=15$
2. Form in cloud, $M_{\text{BH}} = 100$'s, $M_{\text{cloud}} = 1000$'s, L_{edd} is that of cloud. (Begelman et al. [2008MNRAS.387.1649B](#))
 1. Fiducial $M=10,000$
 2. $L_x = L_{\text{edd}} = 1.3 \times 10^{42}$ ergs/s
 3. $F_x = 4 \times 10^{-19}$ at $z=15$
3. Direct collapse of cloud, $M_{\text{BH}} = 10^3$ to 10^5 . (Natarajan and Treister [2009MNRAS.393..838N](#))
 1. Fiducial $M=10^5$
 2. $L_x = 0.1 * L_{\text{edd}} = 1.3 \times 10^{42}$ ergs/s
 3. $F_x = 4 \times 10^{-19}$ at $z=15$

Gen-X enabled by Ares V

50 m² at 1 keV, 0.1"HPD on-axis



5 σ , 10⁶ seconds, on-axis



Slide by Marc Türlér

Grazing Incidence Prescriptions

Wolter I:

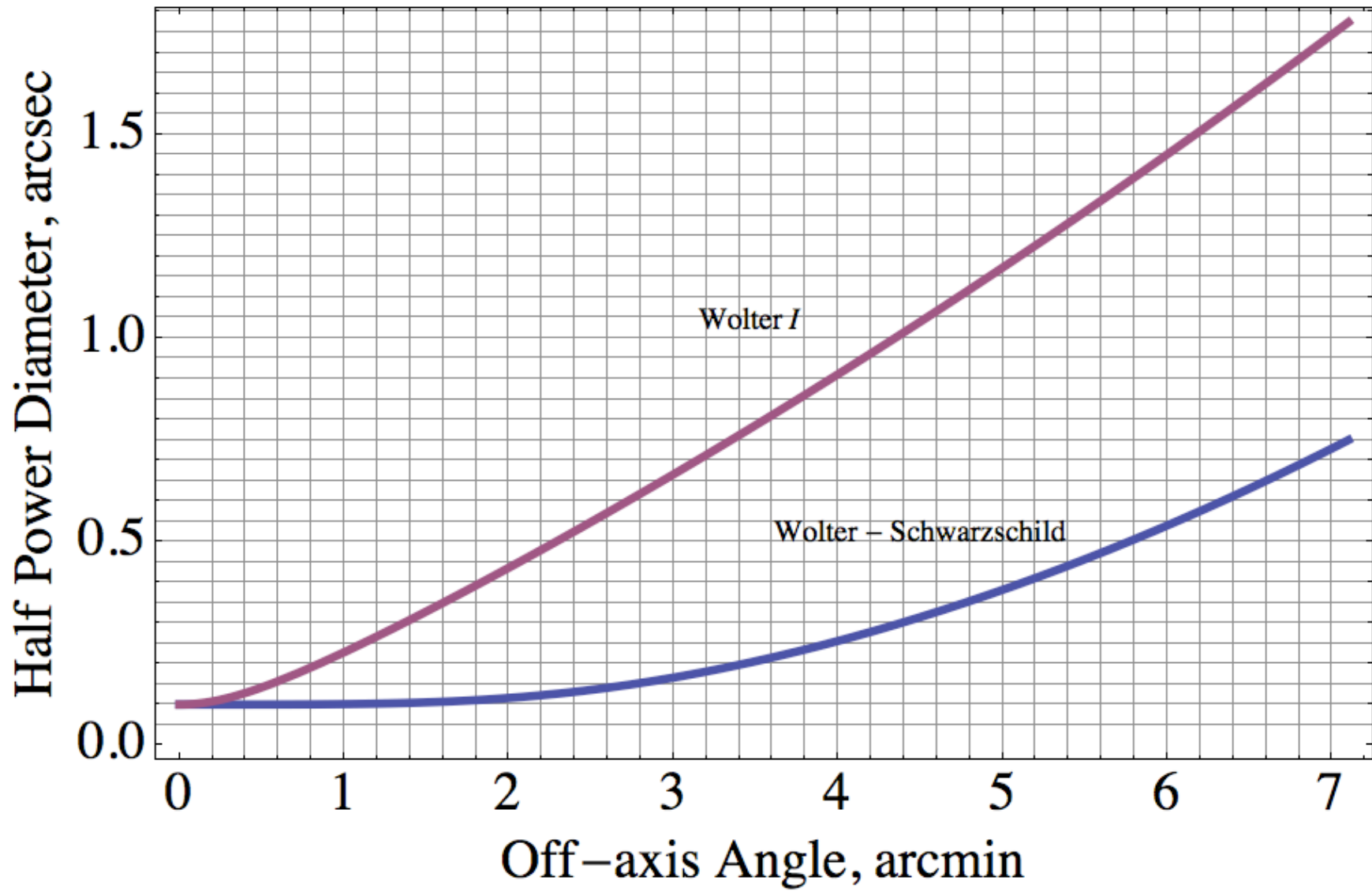
- Exact paraboloid and hyperboloid
- $\sigma = 0.4 \tan^2(\theta)(L/Z)/\tan(\alpha) + 4 \tan(\theta) \tan^2(\alpha)$
- Ref: VanSpeybroeck and Chase, Applied Optics, **11**,440, 1972

Wolter-Schwarzschild

- Polynomial
- Satisfies Abbé sine condition
- $\sigma = 0.54 \tan^2(\theta)(L/Z)/\tan(\alpha)$
- Ref: Chase and VanSpeybroeck, Applied Optics, **12**,1042,1973

L is the plate length, Z is the focal length, angles are in radians, α is grazing angle at intersection plane. θ is the offaxis angle of interest. $HPD = \sigma / 0.6745$

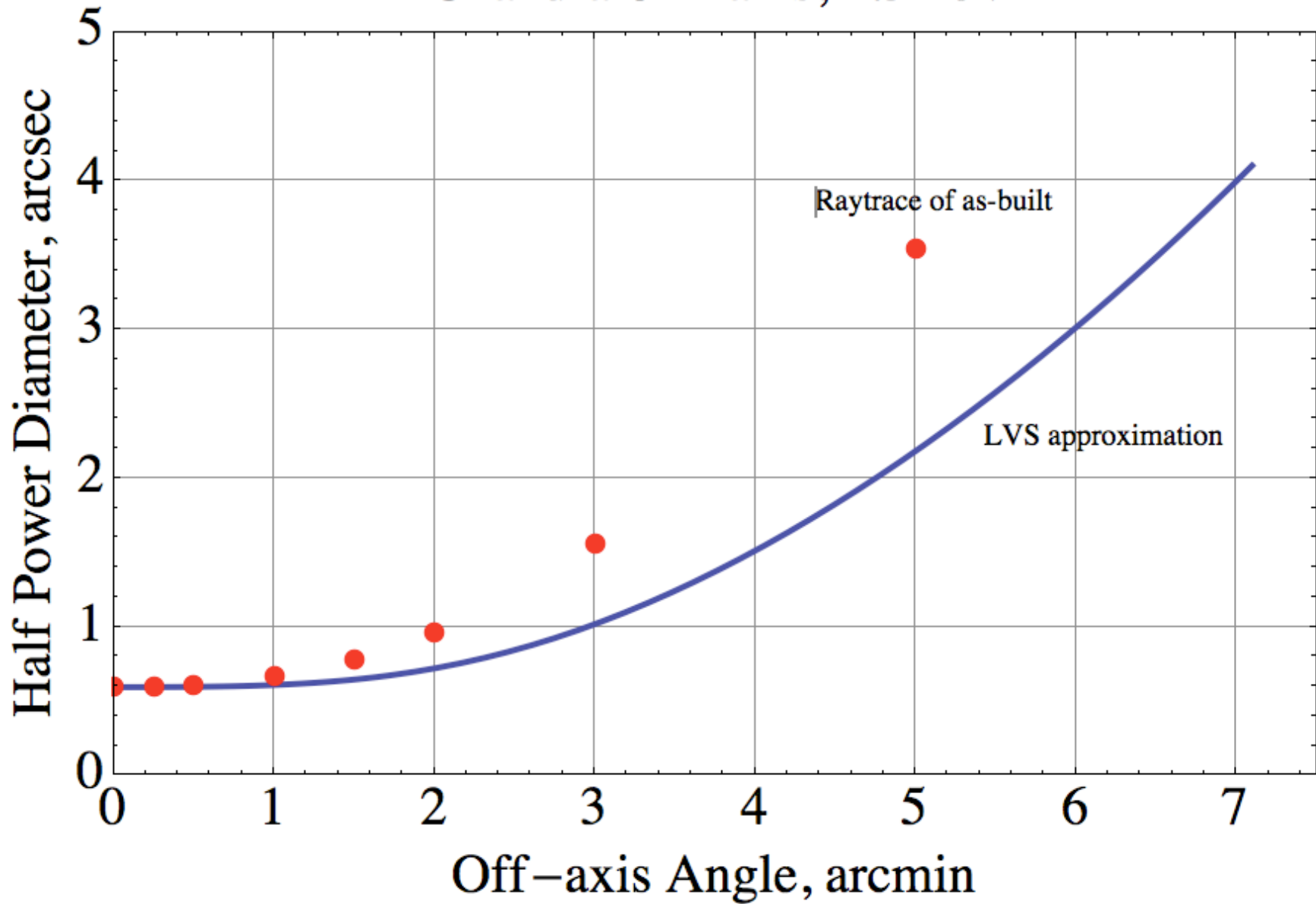
Off-axis performance, W I vs. W-S , Flat Focal Plane



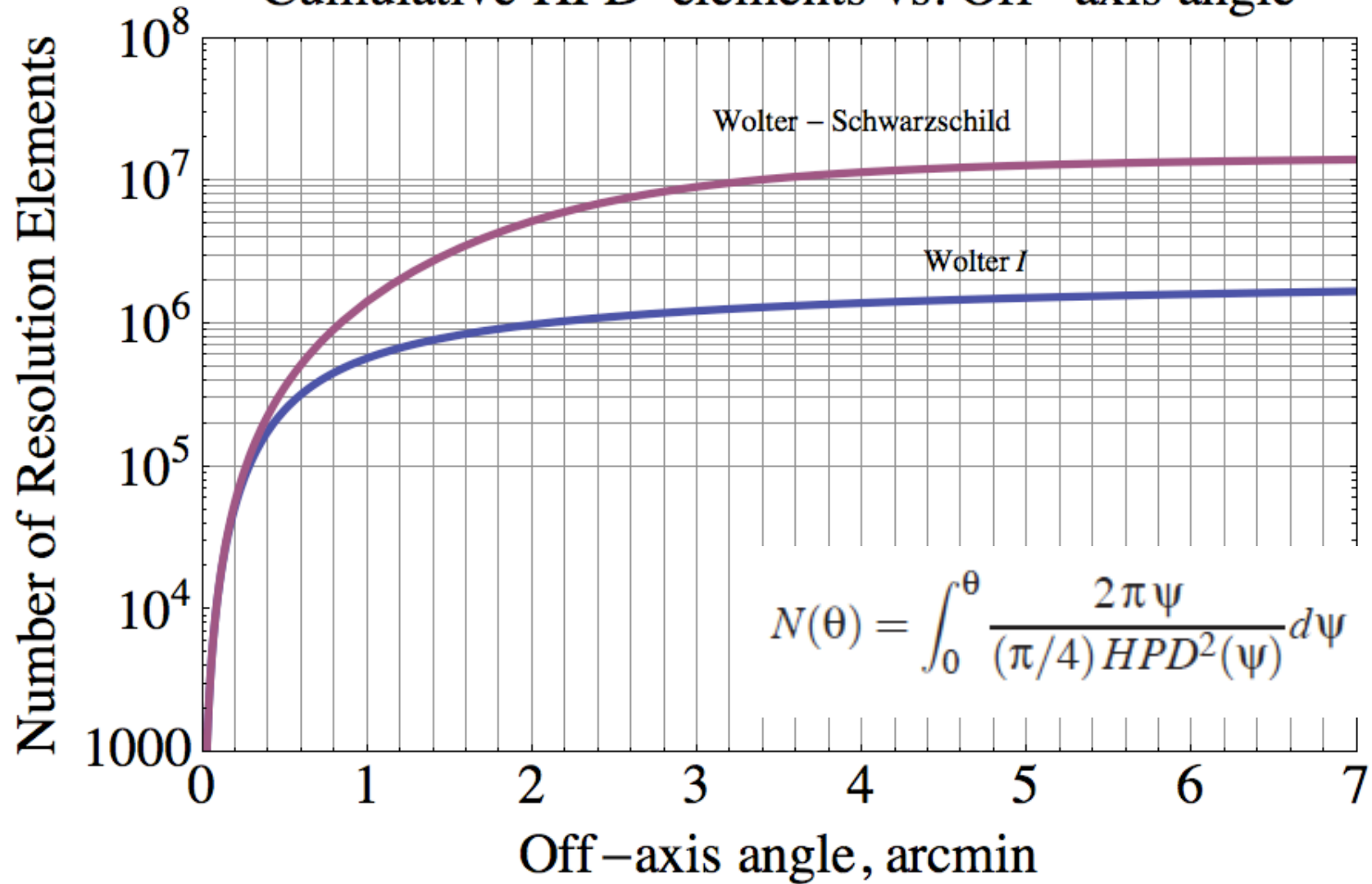
Caveats I

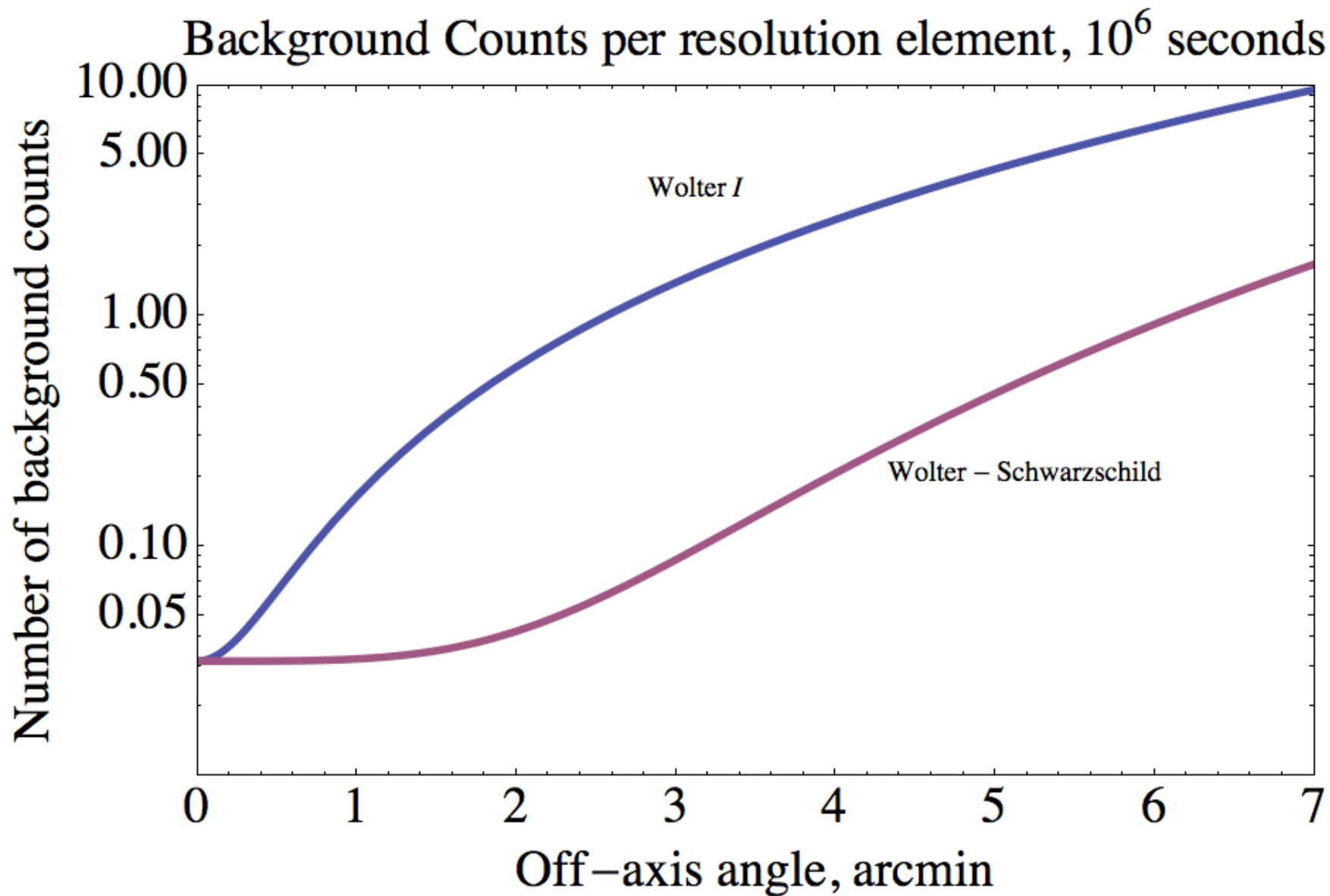
- Blur circle radius is curve fit to raytrace results
 - 90% of results less than 20% errors
 - No results worse than 30%
- Gen-X $L/Z = 0.0166$. Fits are L/Z from 0.035 to 0.176
- Fits are on ideal, curved focal surface. We extrapolate to flat focal plane by doubling terms in θ^2 .
- Convert from blur circle radius to HPD by assuming exact Gaussian shape

Chandra off-axis, 1.5 keV



Cumulative HPD elements vs. Off-axis angle





background specification of $0.004 \text{ counts ks}^{-1} \text{ arcsec}^{-2}$ in the 0.1 to 2 keV range

What does sensitivity mean?

Probability is ϵ for a false detection

1. At a particular position of interest, how many counts, N_0 , are required to conclude a source is present?
2. In a field how many counts, N_0 , are required so that no more than j false sources are expected to be detected?
3. How strong must a source be, so that there is a probability p that it is detected above the detection threshold level N_0 ?
4. How strong must a source be, so that to confidence ϵ it is above the detection threshold N_0 ?

4 counts per Msec = 3.3×10^{-20} erg s^{-1}

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3σ significance, $\epsilon = 0.00135$

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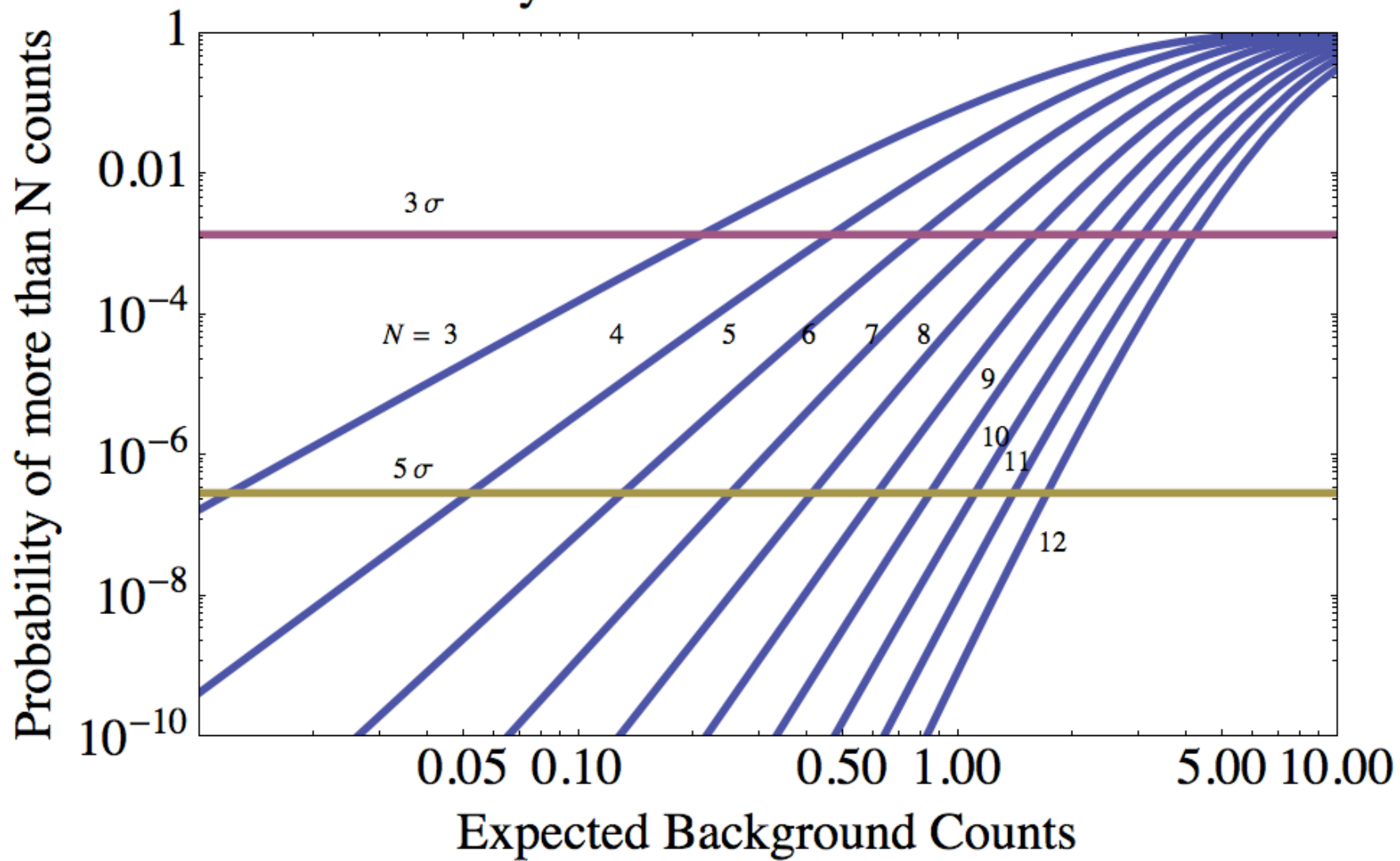
$j < \epsilon * (\# \text{ or resolution elements}).$ For 5σ , $\epsilon=2.866 \times 10^{-7}$

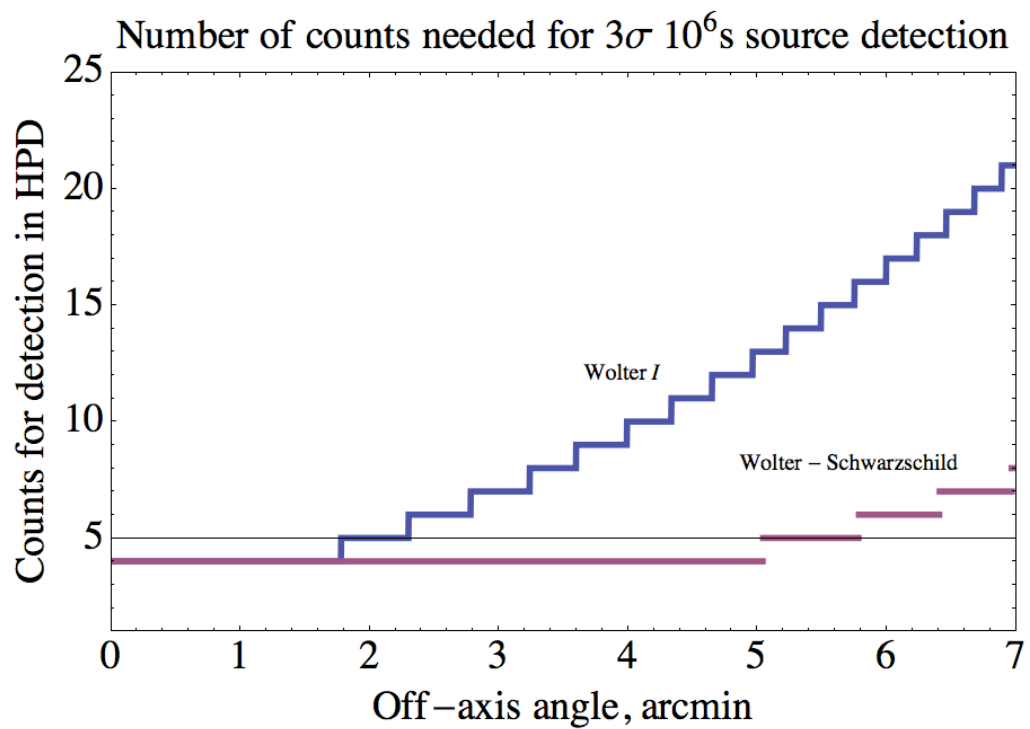
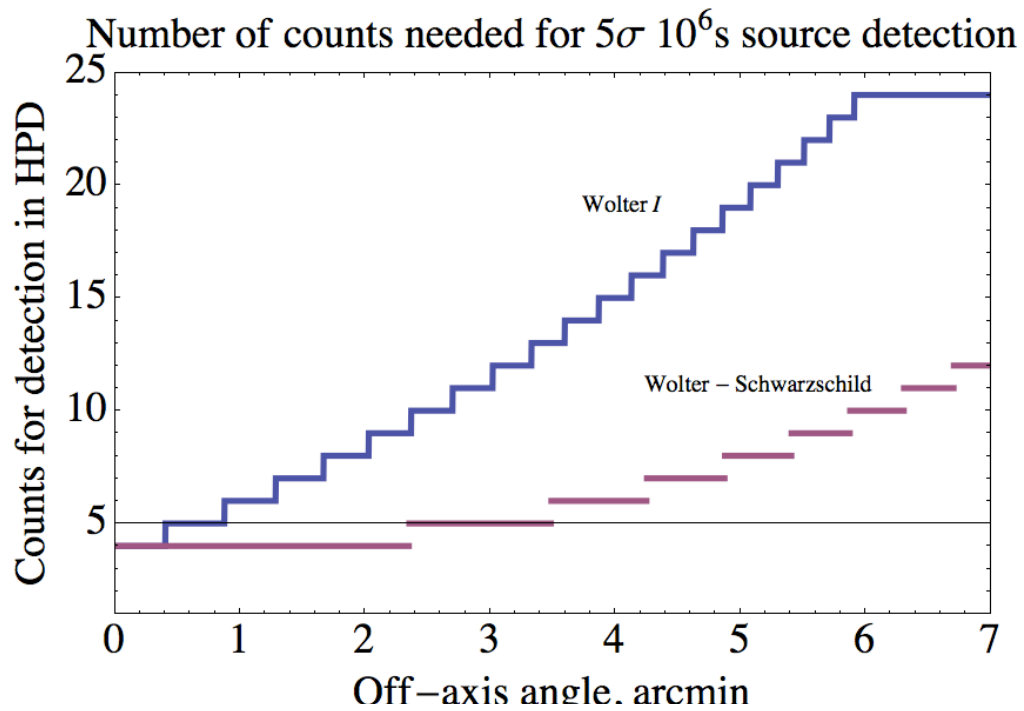
$j=3.6$ or 0.43 for W-S or W-I, respectively

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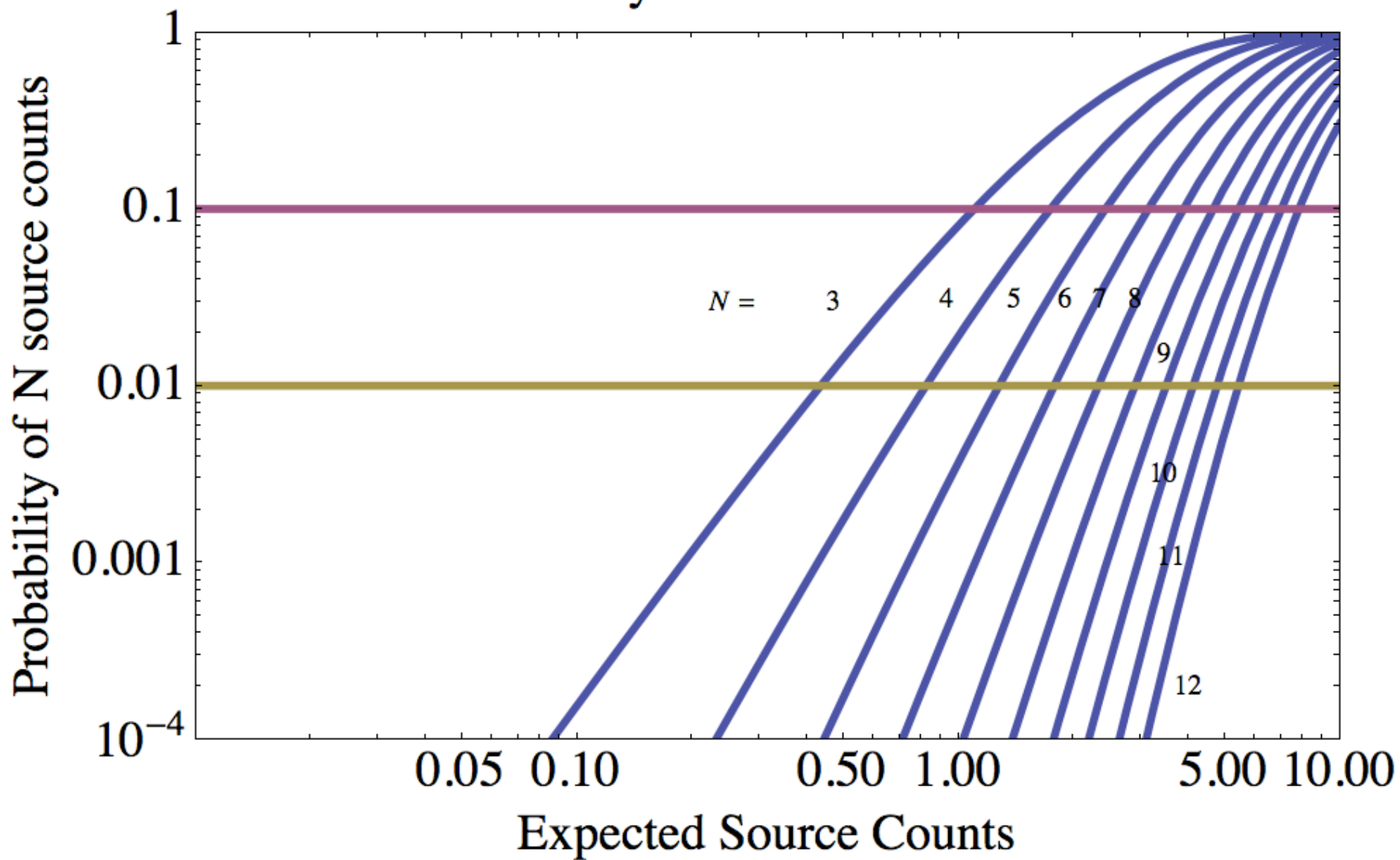
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Probability of a false source in one element





Probability of a source detection



Caveats II

- We have a concept to adjust 10^4 mirror elements on-orbit, to optimize the on-axis resolution. **We cannot conceive of acquiring data and adjusting off-axis to an exact shape**
- We expect the real Gen-X will have off-axis performance intermediate to W I and W-S.

Conclusions I

- W-S more than twice as sensitive as W I
- Future study will determine requirements on initial shape of Gen-X elements which may bias final shape closer to W-S