Very low afterglow CsI(Tl) scintillator using antimony and other metal cations

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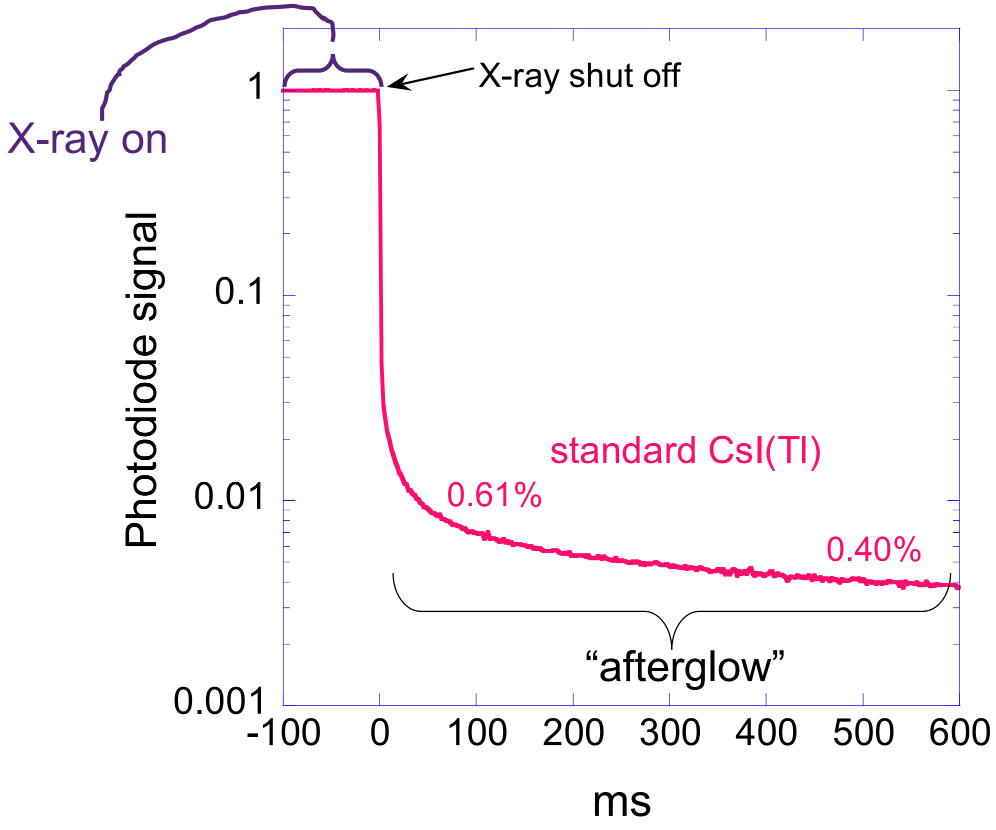
CRYSTALS

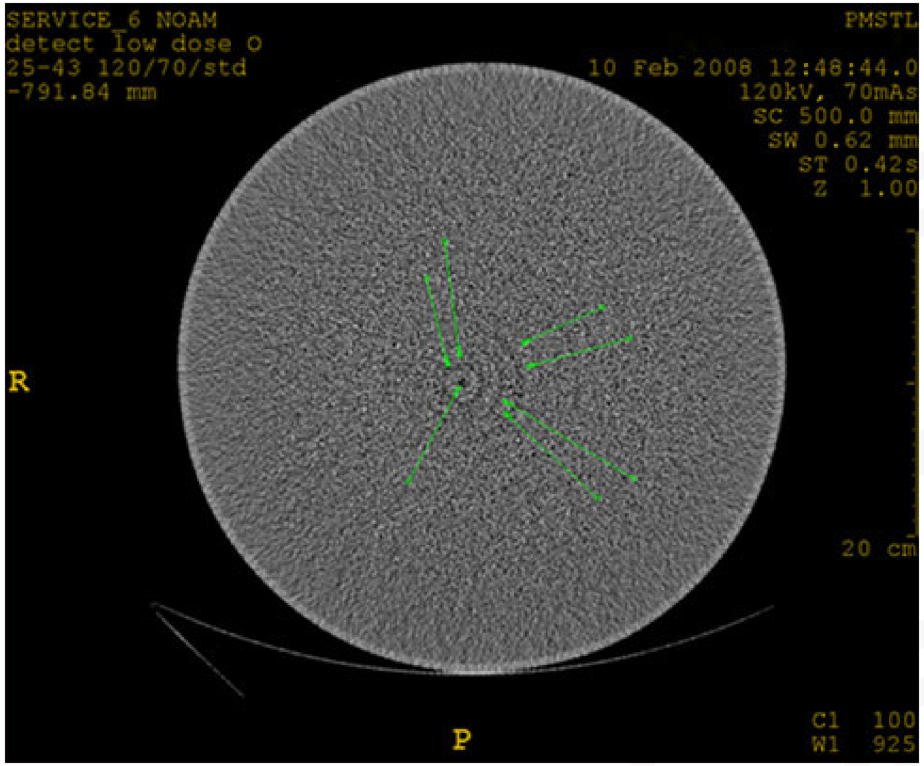
SAINT-GOBAIN

Scintillator afterglow causes degradation of CT images

Afterglow is the long-lived time component of scintillation pulse decay that lasts many milliseconds



Scintillators with high afterglow will produce arcs and rings in the reconstructed images from CT scans, particularly apparent in image regions extending from areas of low attenuation to higher.



Arcs and rings in a water phantom

Shefer, E., Altman, A., Behling, R. et al., Curr Radiol Rep 1, 76–91 (2013). https://doi.org/10.1007/s40134-012-0006-4

Doesn't low afterglow CsI already exist? What are we trying to do?

Co-dopants have been previously discovered that suppress afterglow

Eu^{2+} 2005 [1]

Sm^{2+} 2007 [2]

Bi^{3+} 2012 [3]

Yb^{2+} 2014 [4]

[1]Brecher C, Ovechkina EE, Gaysinskiy V, Miller SR, Nagarkar VV, Bartram RH, Lempicki A, *Proc. 8th Intl. Conf. Inorg. Scint. & Appl. - SCINT2005* ,pp. 407-410.
[2]Bartram RH, Kappers LA, Hamilton DS, Lempicki A, Brecher C, Gaysinskiy V, Ovechkina EE, Nagarkar VV, *9th Intl. Conf. Inorg. Scint. & Appl. - SCINT2007*
[3]Totsuka et al, Apr. 20, 2012, *Applied Physics Express*, The Japan Society of Applied Physics, pp. 052601-1 to O526O1-3
[4]Wu, Y., Ren, G., Nikl, M., Chen, X., Ding, D., Li, H., Pan, S. and Yang, F., 2014, *CrystEngComm*, 16 (16). pp. 3312-3317

$CdWO_4$, GOS and garnet ceramics have low afterglow

Many CsI(Tl) CT systems still exist
- CsI(Tl) has many desirable properties – high light output, good spectral match to silicon, cheap bulk crystal growth
- Find a co-doping solution that works throughout a large ingot grown via Bridgman technique
  - High segregation of above elements reduces usable fraction of ingot
  - High concentrations of co-dopants reduce light output
    - Find co-dopants that suppress afterglow at very low concentrations
    - Use 2 or more with different segregation rates to enhance and overlap regions of good performance

large Bridgman ingot

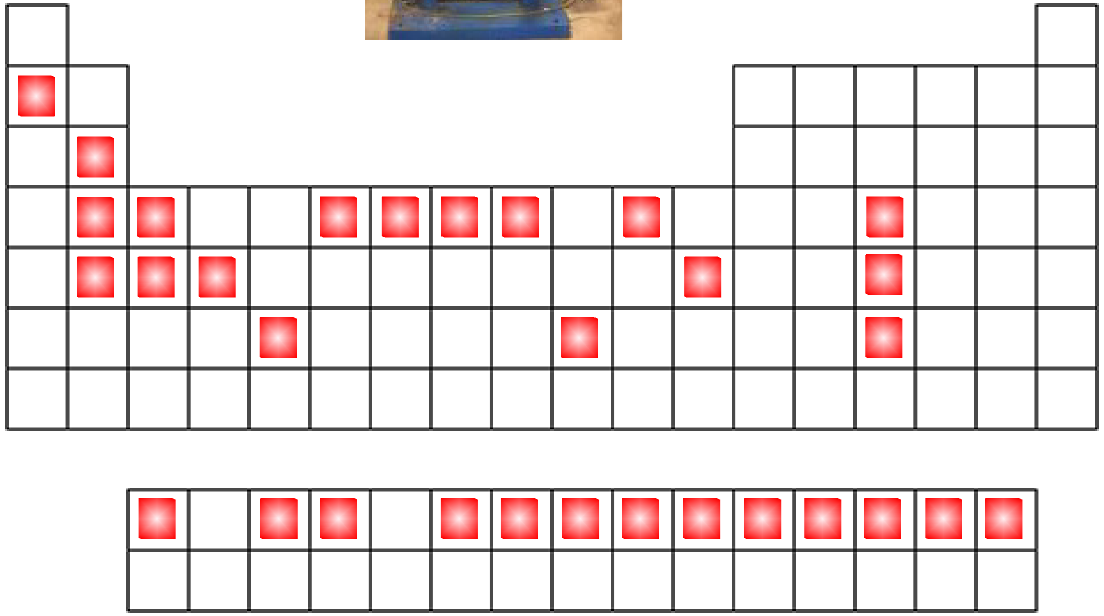
Experimental strategy used an "Edisonian" method

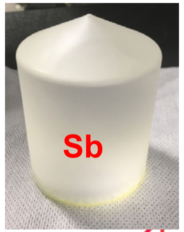
Use two versatile R&D Bridgman furnaces

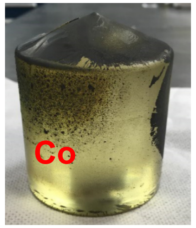
- 63 mm diameter graphite crucibles
- crystals up to 100 mm long
- up to 1300º C
- sealed or unsealed
- vacuum to several atm pressure

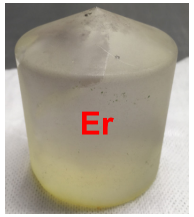
From 2018-now, **104** crystals were grown covering **31** candidate co-dopants and combinations

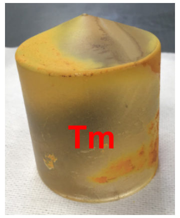
- Li, Mg, Ca, Sc, Cr, Mn, Fe, Co, Cu, As, Sr, Y, Zr, Cd, Sb, La, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ta, Pt, & Bi
- limited to elements & compounds with m.p. <1300º C
- focused mostly on those elements with more than 1 possible valance state

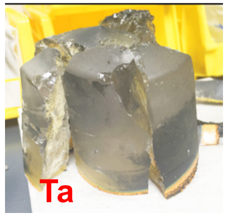






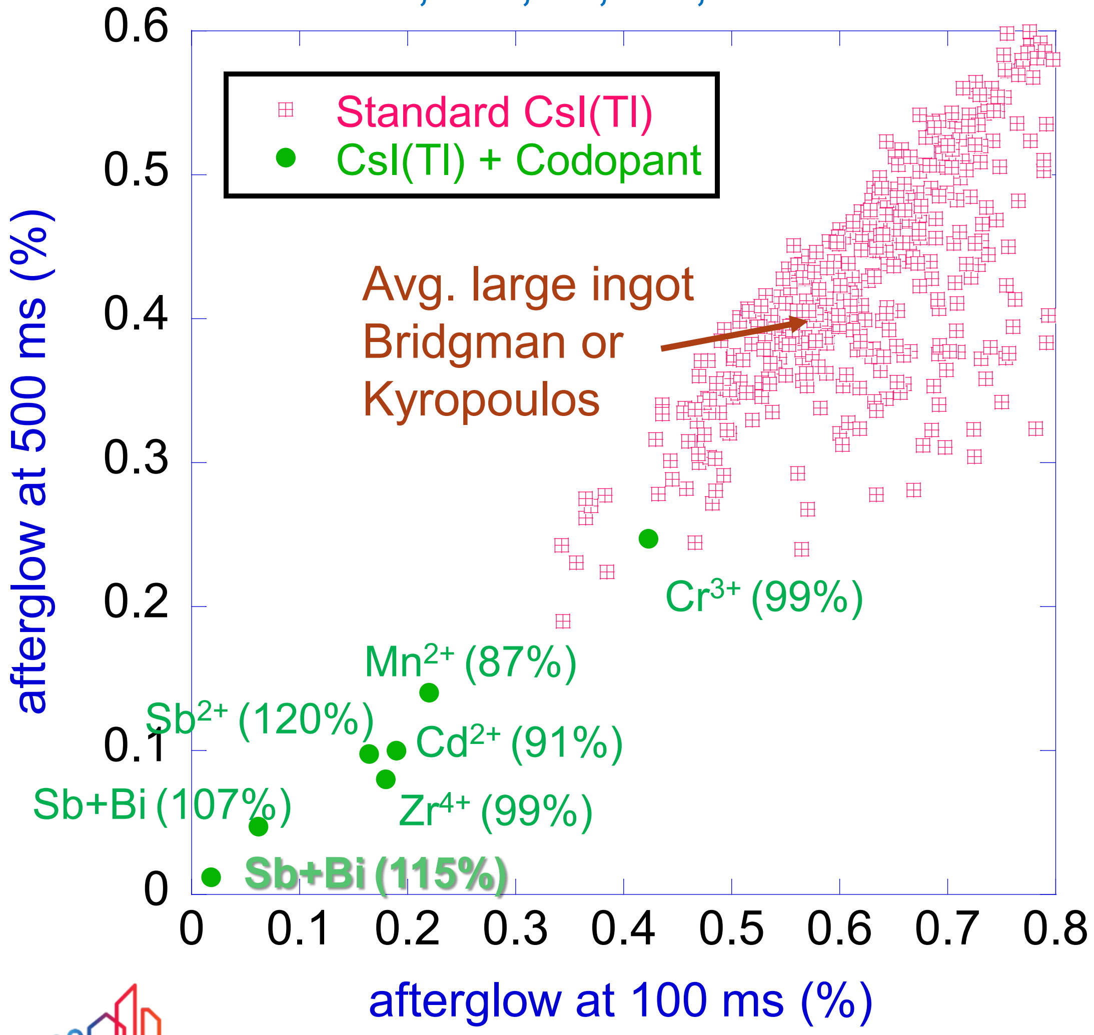






Several new, **good** afterglow suppressing co-dopants were found

Cr, Mn, Zr, Cd, Sb



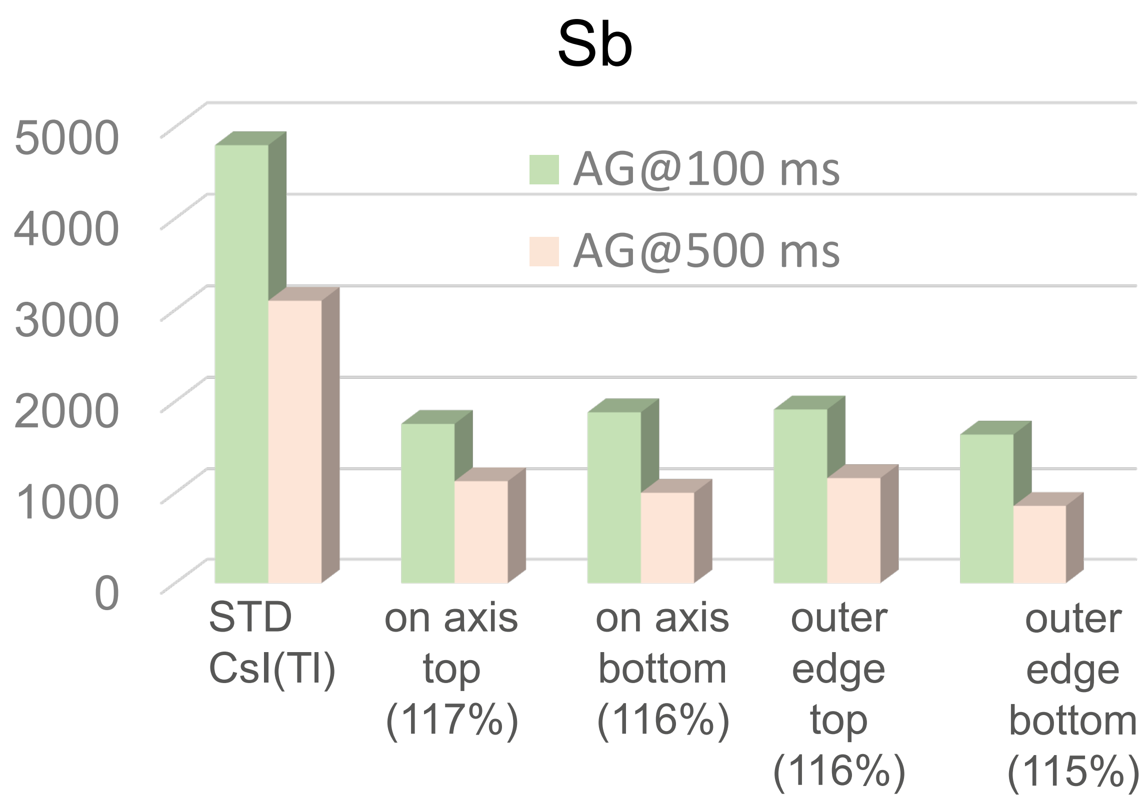
Good: light output equivalent to standard CsI(Tl)
afterglow better than best of standard

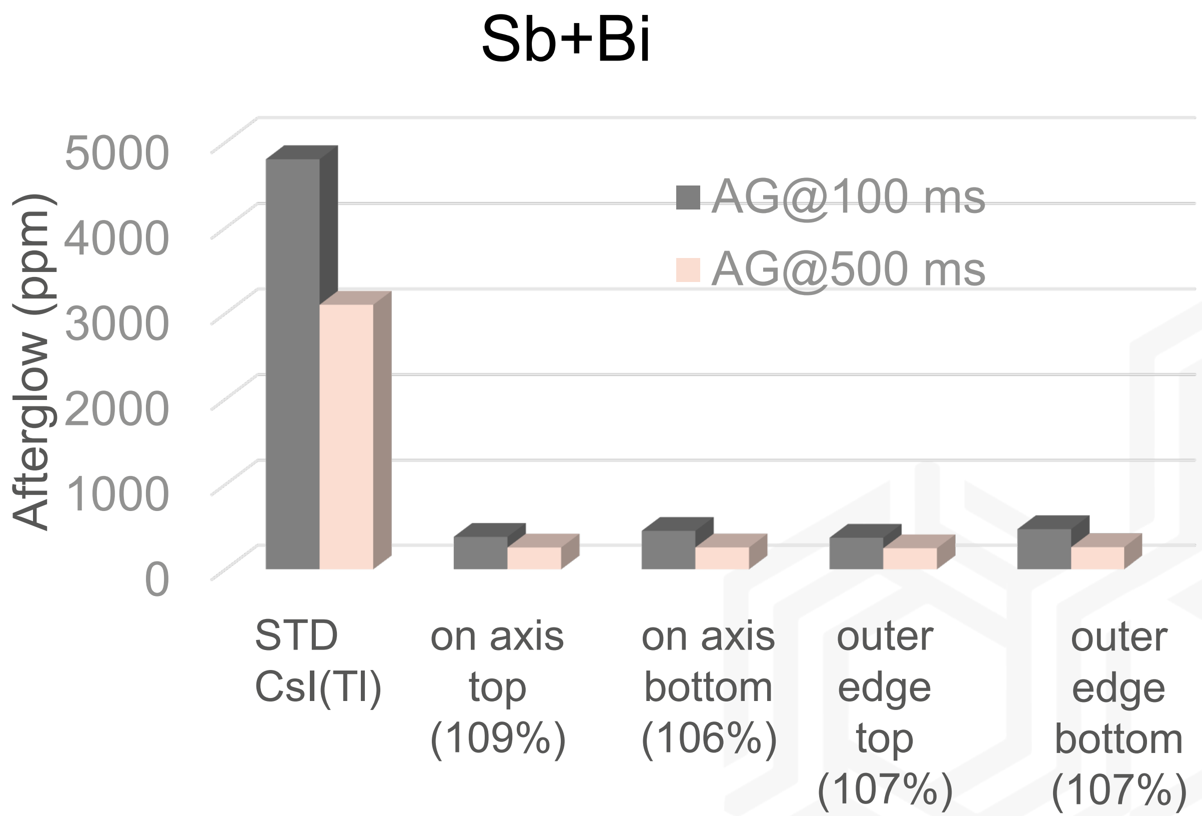
Sb particularly good. Light output is higher than standard CsI(Tl)

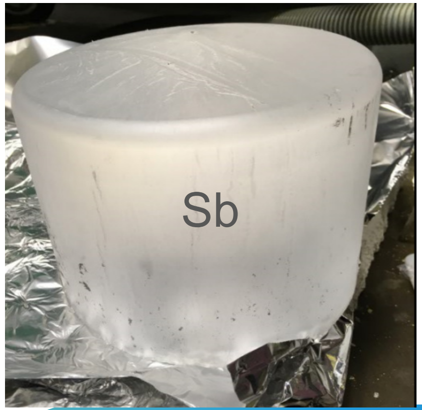
Using Sb and Bi together = extremely good

	AG 100ms	AG 500ms	Rel. light output
Typical Sb+Bi	0.06%	0.05%	1.07
Best Sb+Bi	0.018%	0.012%	1.15

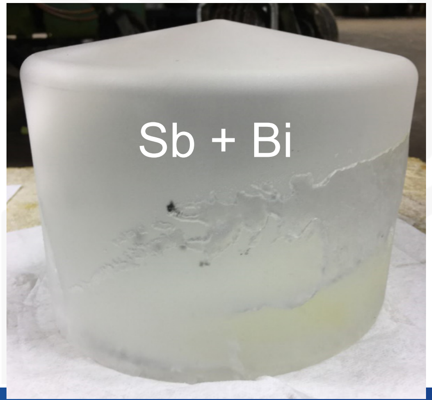
Sb and Sb+Bi work well throughout large ingots



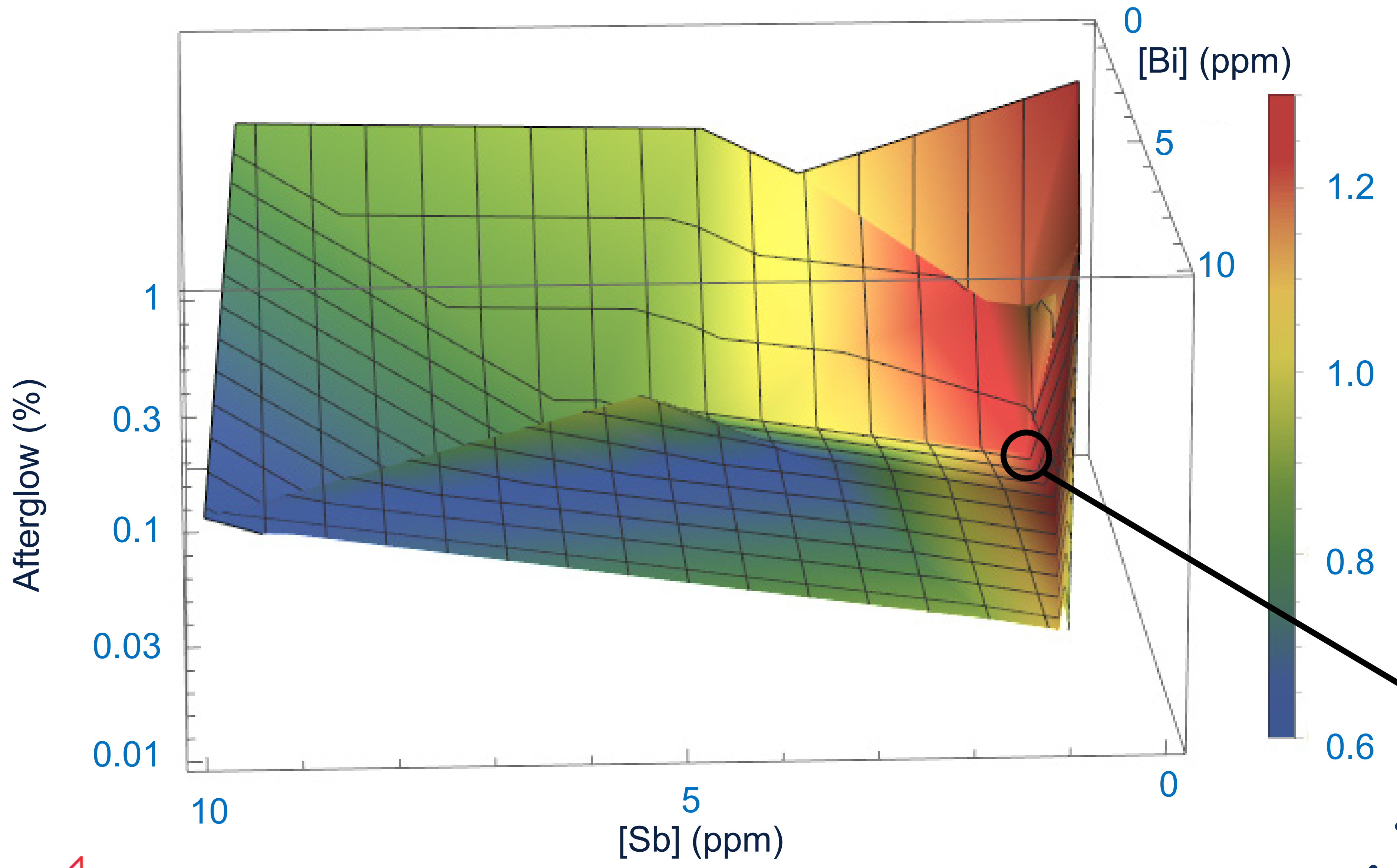




ϕ200mm x 150mm ingots
(production scale)



Very little Sb and Bi is required to produce afterglow suppression



Nice region
- ~1 ppm of each
- minimum afterglow
- enhanced light output

Summary – several new afterglow suppressing co-dopants found and Sb + Bi is particularly good

- Cr, Mn, Zr, Cd & Sb can reduce afterglow without sacrificing light output
- Sb can enhance light output
- Sb + Bi can enhance light output and achieve <0.02% at 100ms (0.06% typical)
- Good performance (AG & LO) achieved throughout large ingots with Sb and Sb+Bi
- Pixels and arrays can be sampled to interested customers