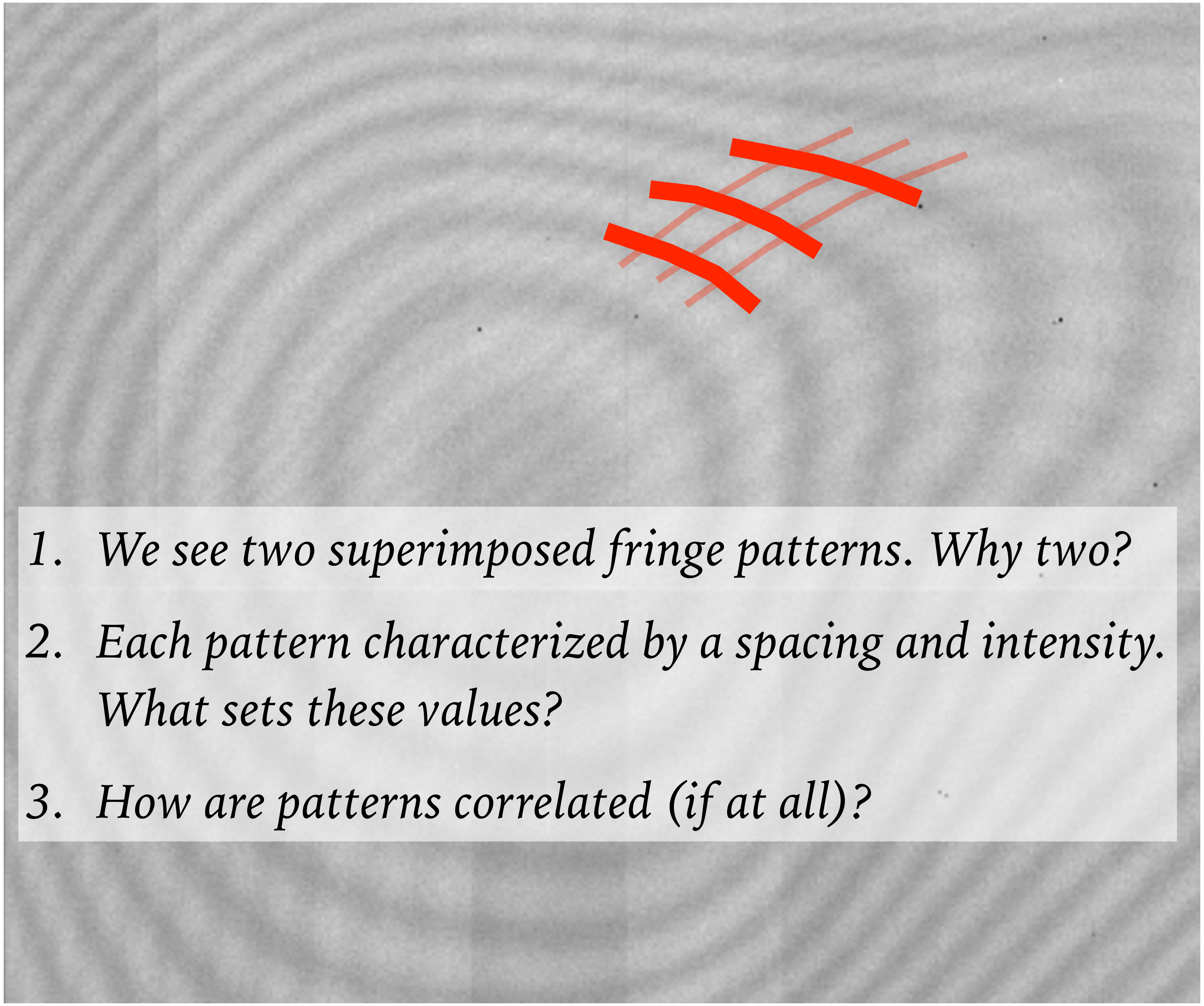
FRINGE SCIENCE

David Kirkby, UC Irvine

LSST-DESC Survey Simulations Telecon
1 September 2016



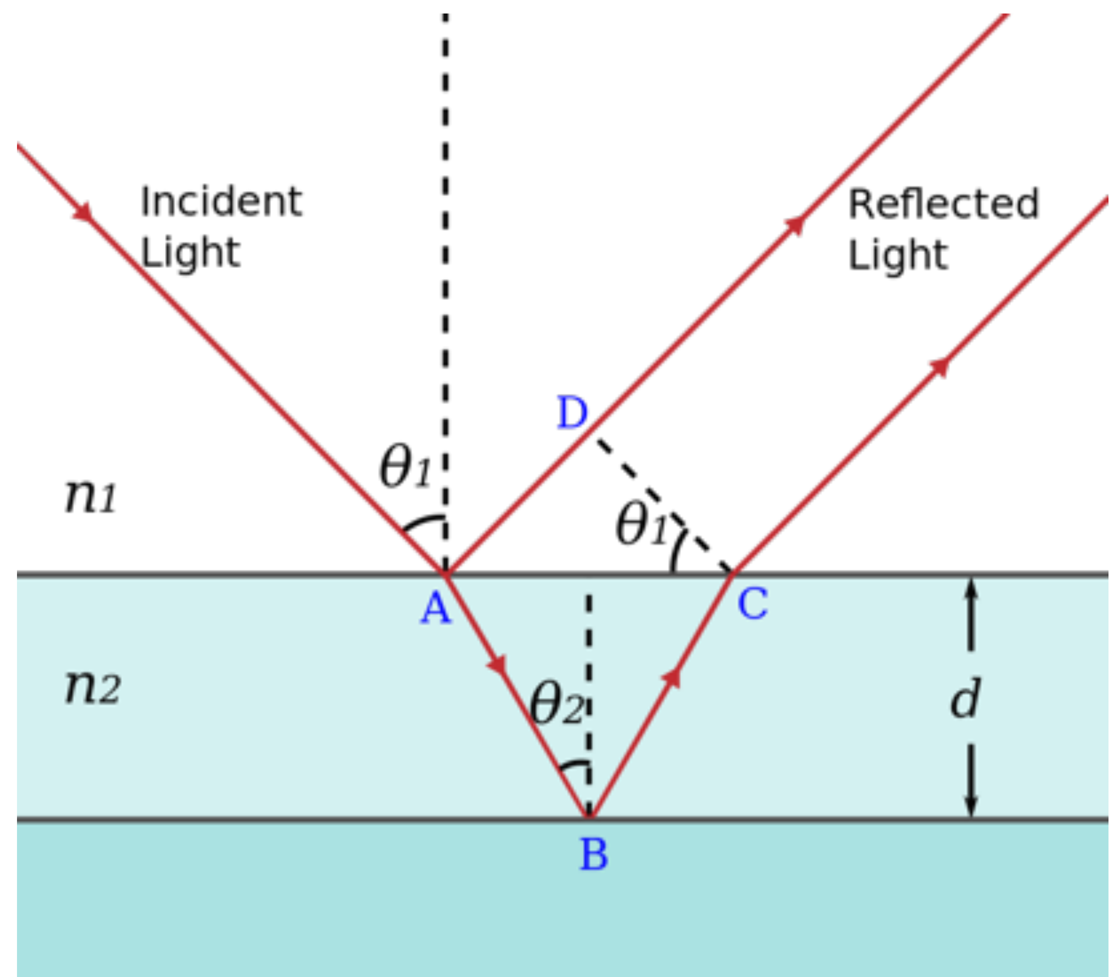
E2V sensor illuminated at 980nm

(HyeYun Park talk at Oxford SAWG Session)

THIN-FILM INTERFERENCE 101

- Paths with different optical lengths $ds = n(x,\lambda)\, dx$ interfere.
- OPD = m λ is constructive for m=1,2,…
- Effect depends on wavelength and geometry.

$$OPD = n_2(\overline{AB} + \overline{BC}) - n_1(\overline{AD})$$
$$= 2n_2 d \cos(\theta_2)$$

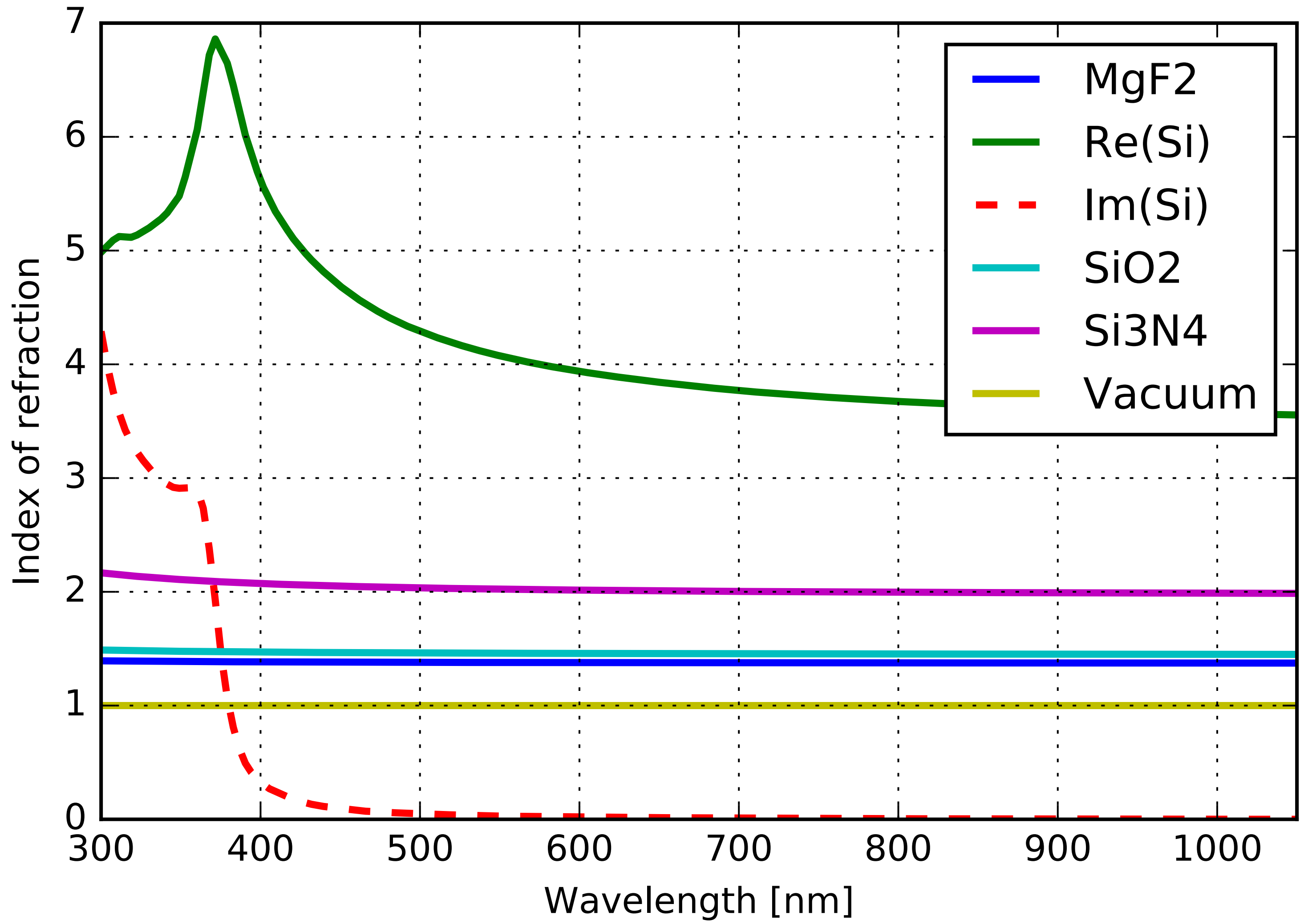


COMPLICATIONS

- Sensors are illuminated with a complex variable spectrum (OH emission lines) and converging (f/1.234) annular beam.
- Sensors are complex multilayer (proprietary) structures.
  - Need to solve for self-consistent EM fields respecting boundary conditions at each interface, considering polarization & phase.
- In a sensor, we detect absorbed photons (via conversion to an electron-hole pair), not reflected / transmitted rays.
  - Short wavelengths are most strongly absorbed, leading to weak reflections and resulting interference.
  - Interference is a 3D phenomenon, even though we only measure its 2D projection.

MATERIAL PROPERTIES

- Absorption can be modeled as an imaginary “extinction” component of the index of refraction.
- Only silicon (bulk + gates) absorbs in optical.



PREVIOUS WORK

- Malumuth et al, “Removing the Fringes from Space Telescope Imaging Spectrograph Slitless Spectra”, PASP Volume 115, Issue 804.

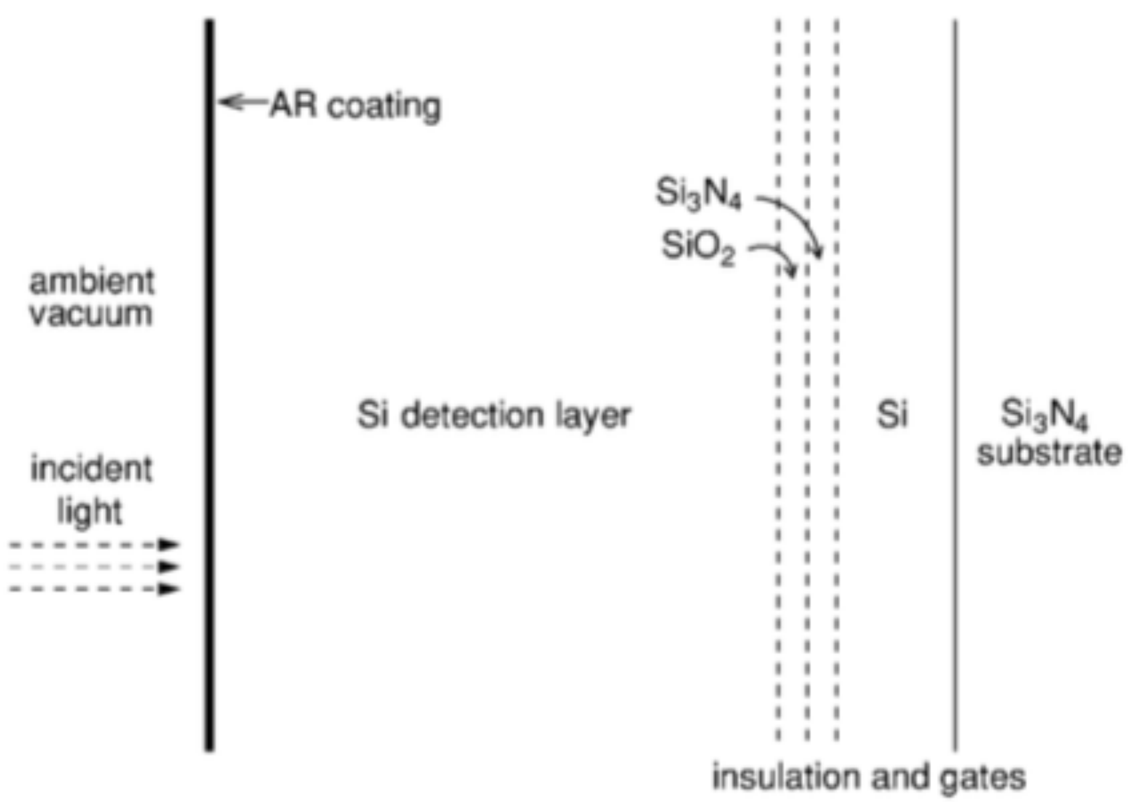


FIG. 2.—Schematic depiction of STIS CCD structure. Relative thicknesses of the layers are not to scale. Although the insulation and gate layers are planar in our model, they have a complex three-dimensional structure in reality (e.g., see Figs. 1.13 and 1.14 of Janesick 2001).

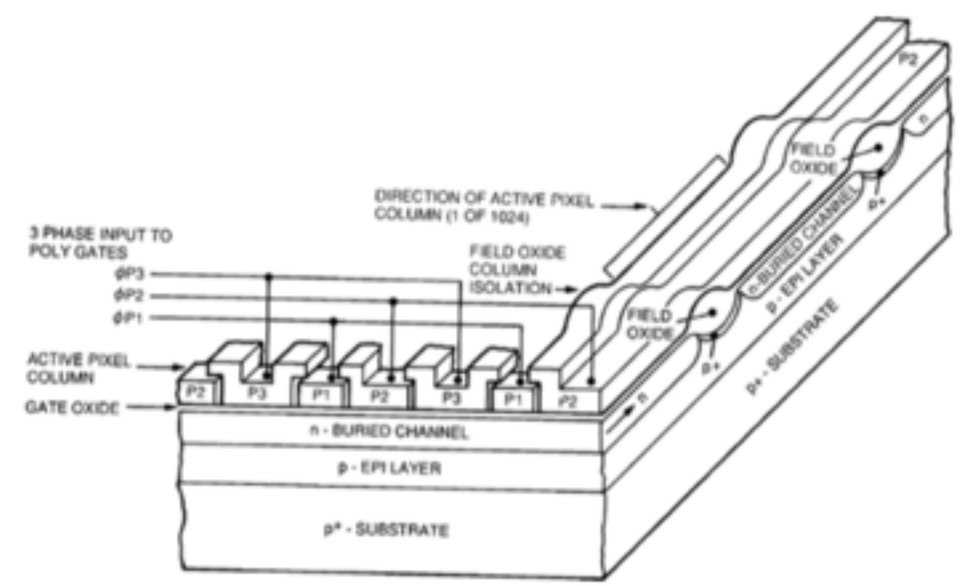


Figure 1.13(b) Cross-section showing signal channel and channel stop regions.

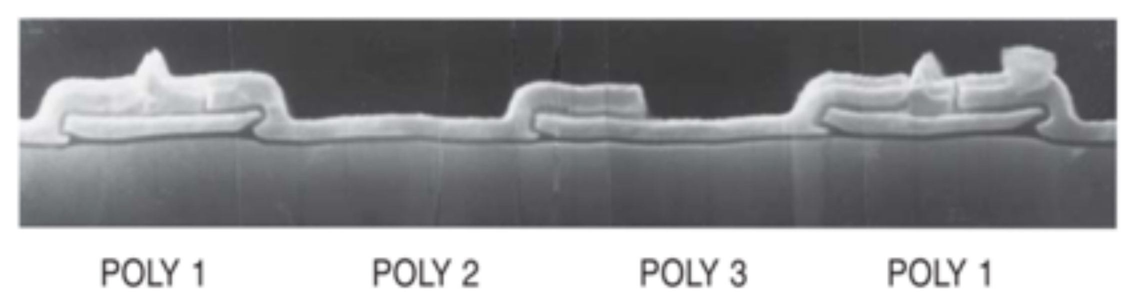


Figure 1.14 SEM cross-section image of a WF/PC I 15-μm pixel.

Attenuates reflection

TABLE 1
Structure of STIS CCD

Layer (n) (1)	Purpose (2)	Material (3)	Nominal Thickness[a] (d_n) (μm) (4)	Model Thickness (d_n) (μm) (5)	Roughness (μm) (6)
0	Ambient medium	Vacuum	Infinite	Infinite	...
1	AR coating	MgF_2	0.06	0.06	0.01
2	AR coating	Si_3N_4	0.03	0.03	0.02
3	Detection	Si	13–15	13–15	0.06
4	Insulation	SiO_2	0.07	0.28	0.06
5	Gate	Si_3N_4	0.06	0.24	0.08
6	Structures	Si	0.40	0.81	0.10
7	Substrate	Si_3N_4	Effectively infinite	Infinite	0.11

[a] Nominal thickness provided by SITe.

LSST

proprietary AR

100 μm

0.15 μm

1.0 μm

thin passive biasing layer (also proprietary)

NB: no second fringe pattern!

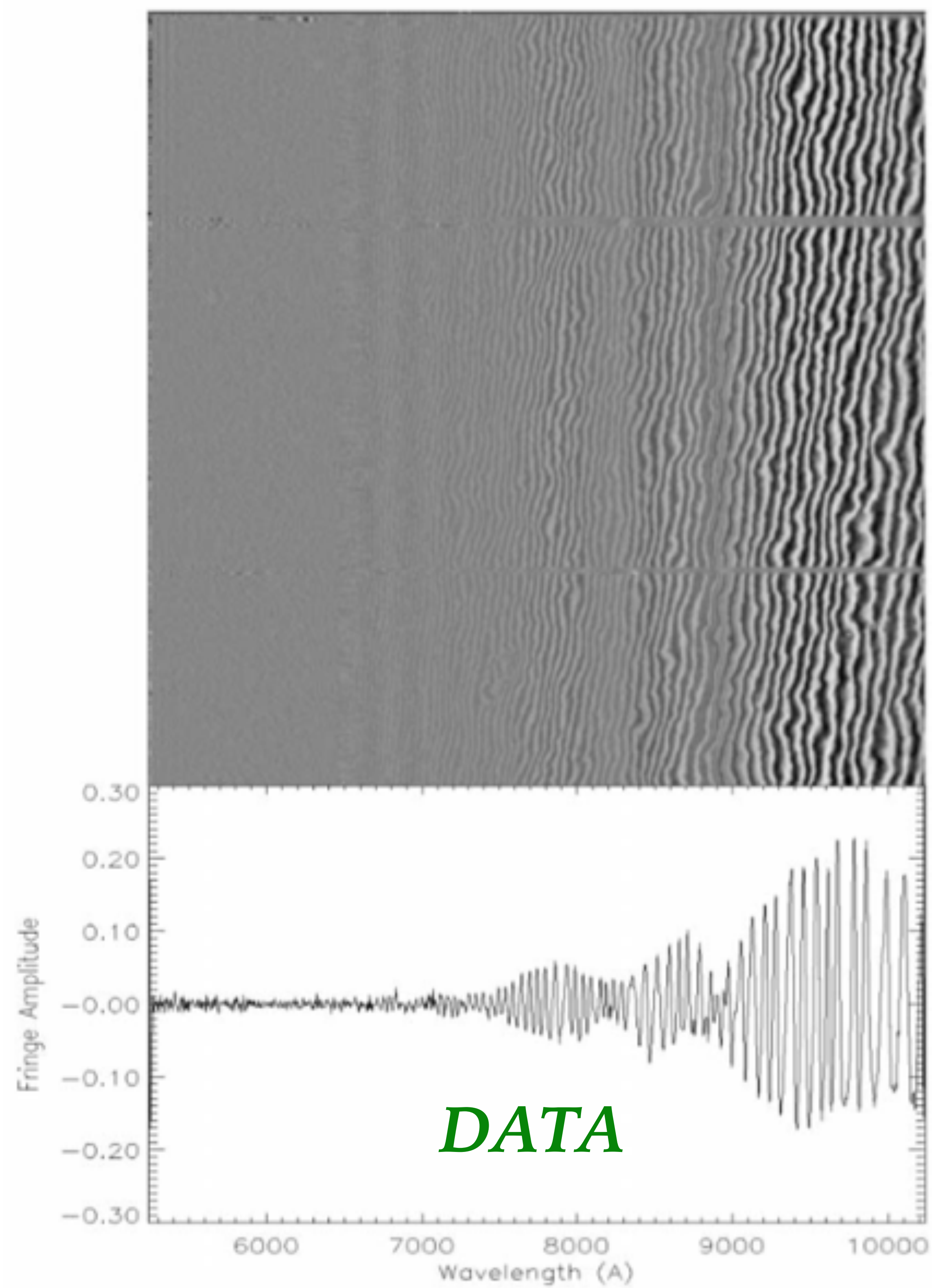


FIG. 1.—Fringe-flat image that has been normalized by a spline fit to the lamp spectral output and stretched from −30% to +30%. The lower panel is a plot of the mean of the three rows 511, 512, and 513 of this 1024 × 1024 pixel image. The fringe pattern has nodes at 6900, 7400, 8200, and 8900 Å. These nodes are vertical in the image, even though the fringes are tilted.

NB: assumes normal incidence.

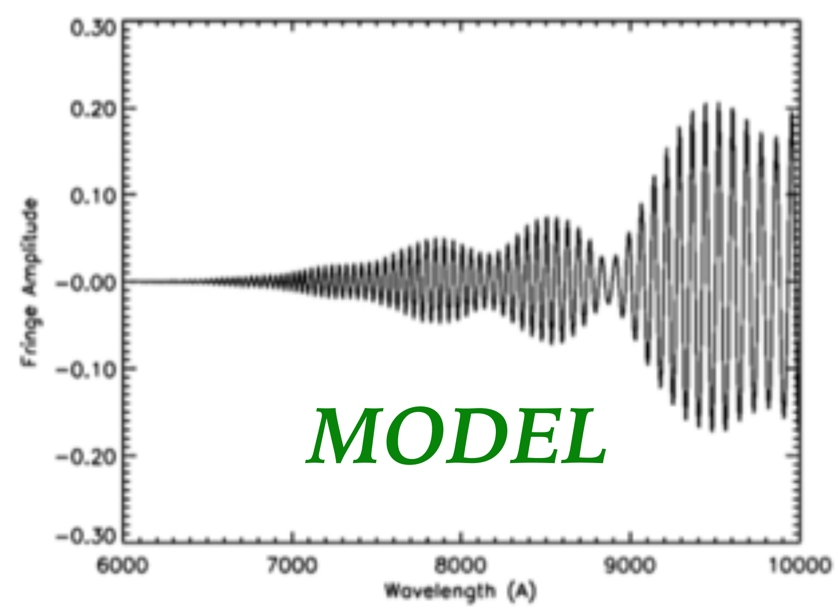
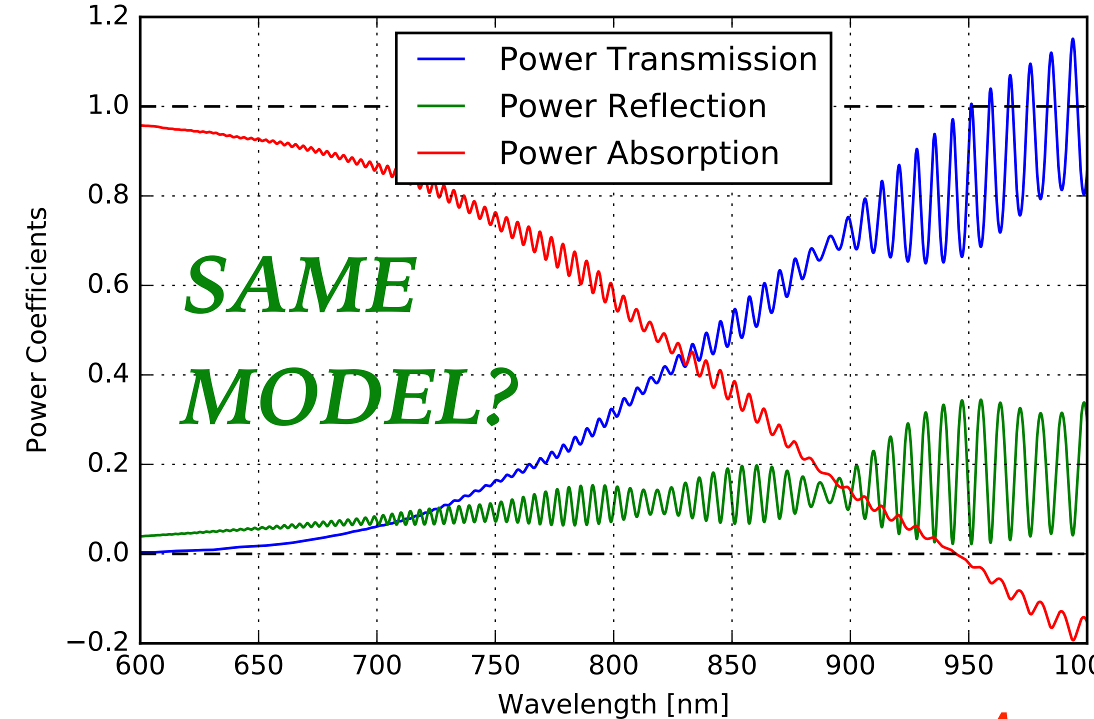
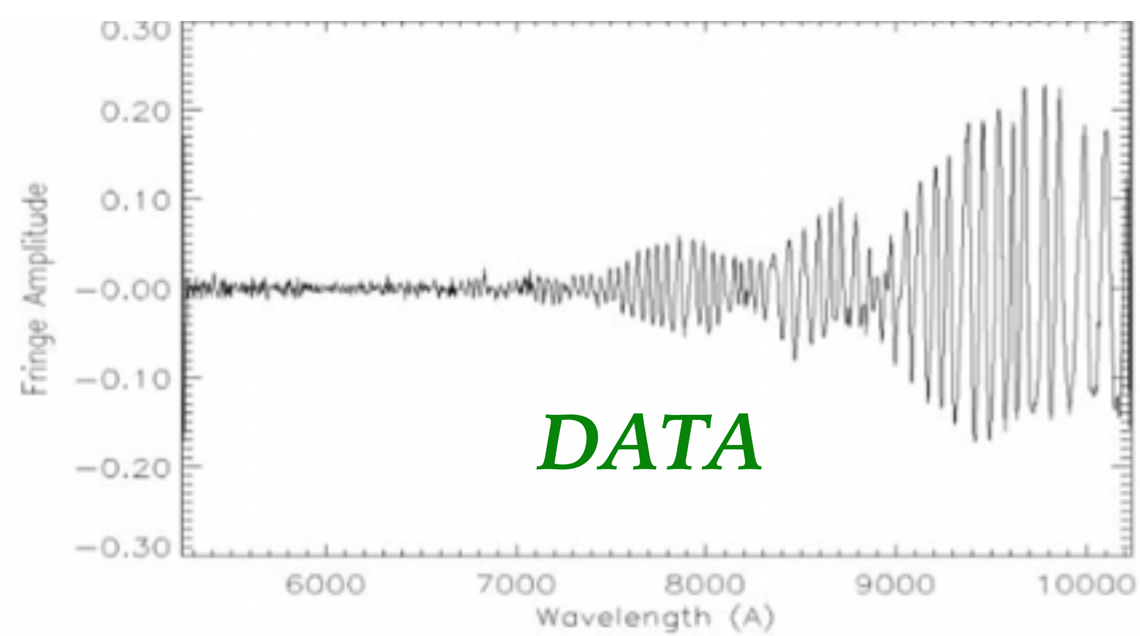


FIG. 4.—Fringe amplitude of the full model for the central pixel using the derived values for each layer's thickness and roughness. These values are not unique; different sets of values can give very similar patterns. The quality of the calibration data on hand is not sufficient to distinguish between models with subtle differences. The pattern is much like the observed fringe flats (see Fig. 1), except that the fringe spacing is very regular here and it is not in the observed fringe flats. This is because this model is for a single pixel with a single value of d, (the thickness of the detection layer), while the fringe flats are for a row of pixels of slowly varying thicknesses within the structure.

T > 1 (!)



A < 0 (!)



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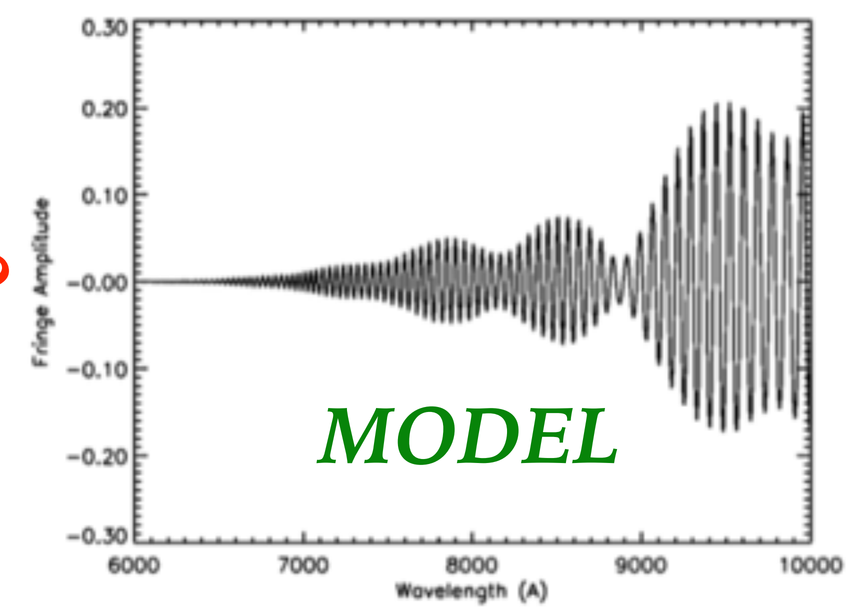

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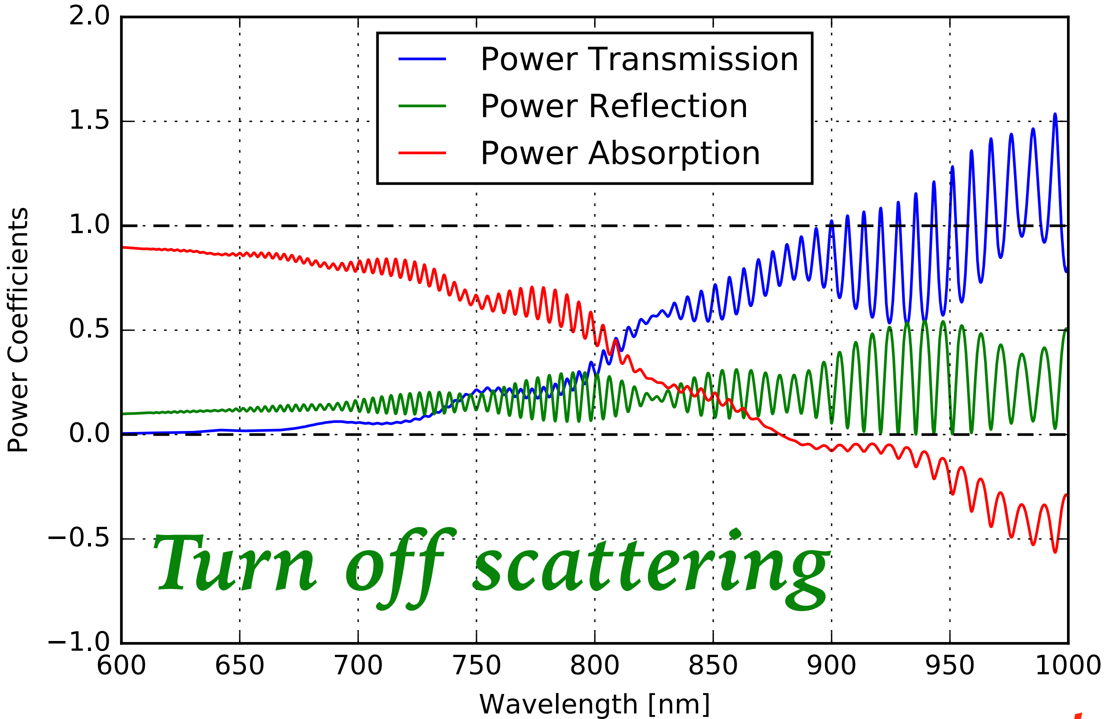
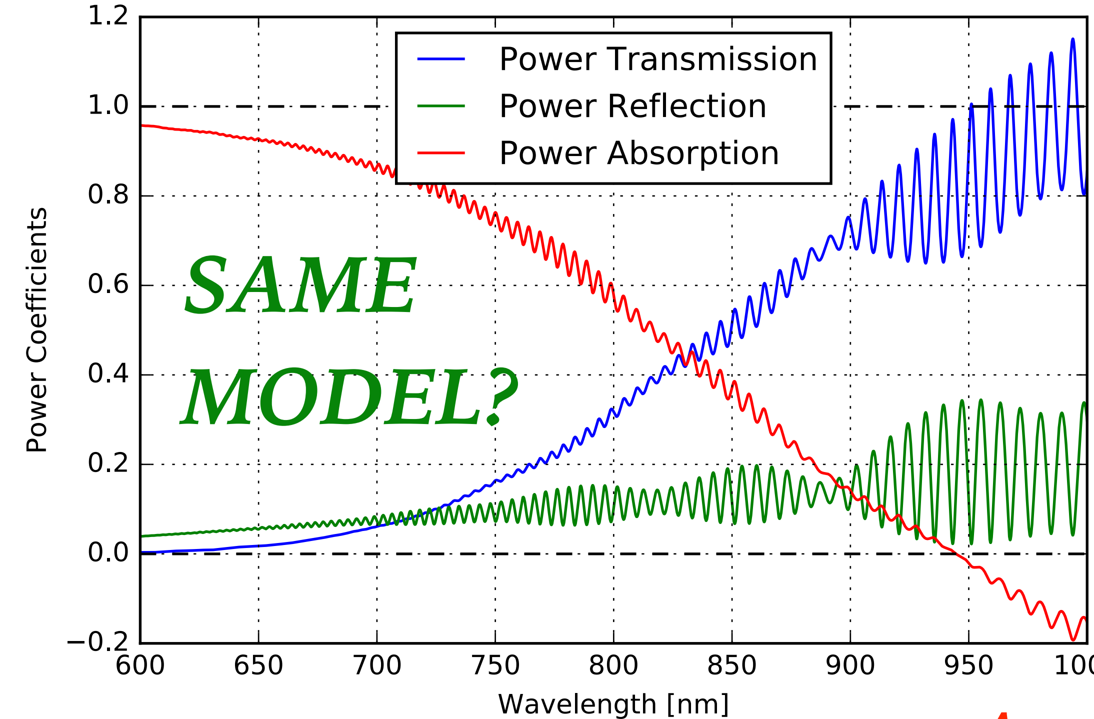
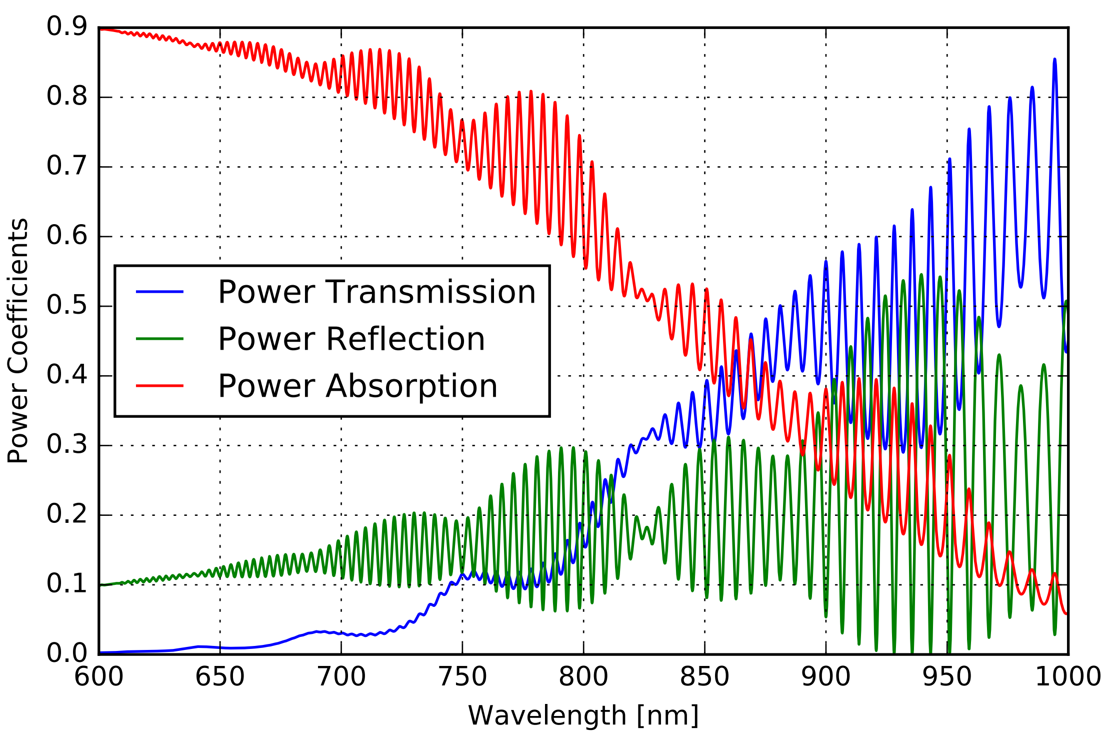
worse! *T > 1 (!)*





worse! *A < 0 (!)*



Transfer Matrix Method python pkg:

https://github.com/sbyrnes321/tmm

http://arxiv.org/abs/1603.02720

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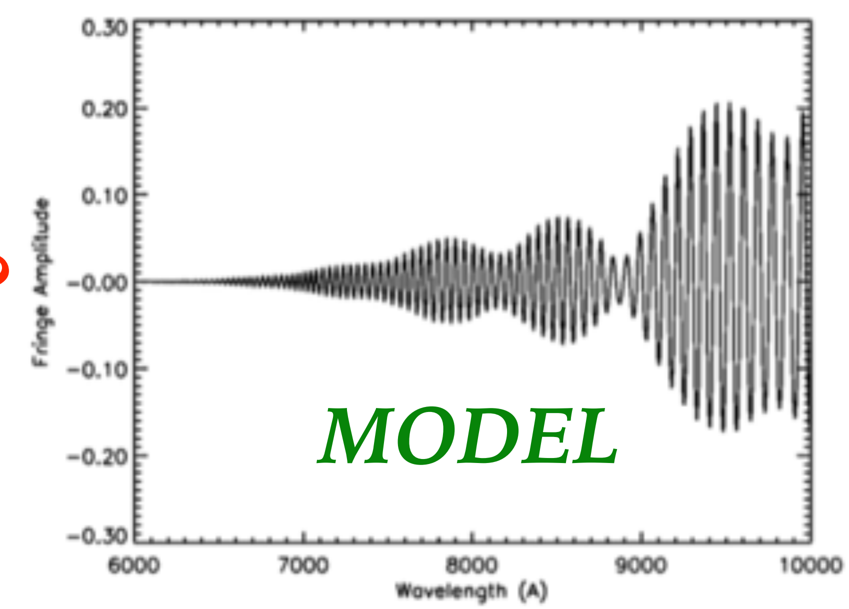

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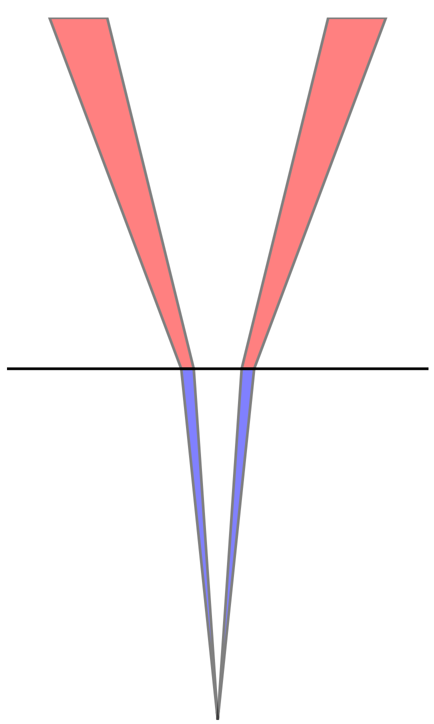
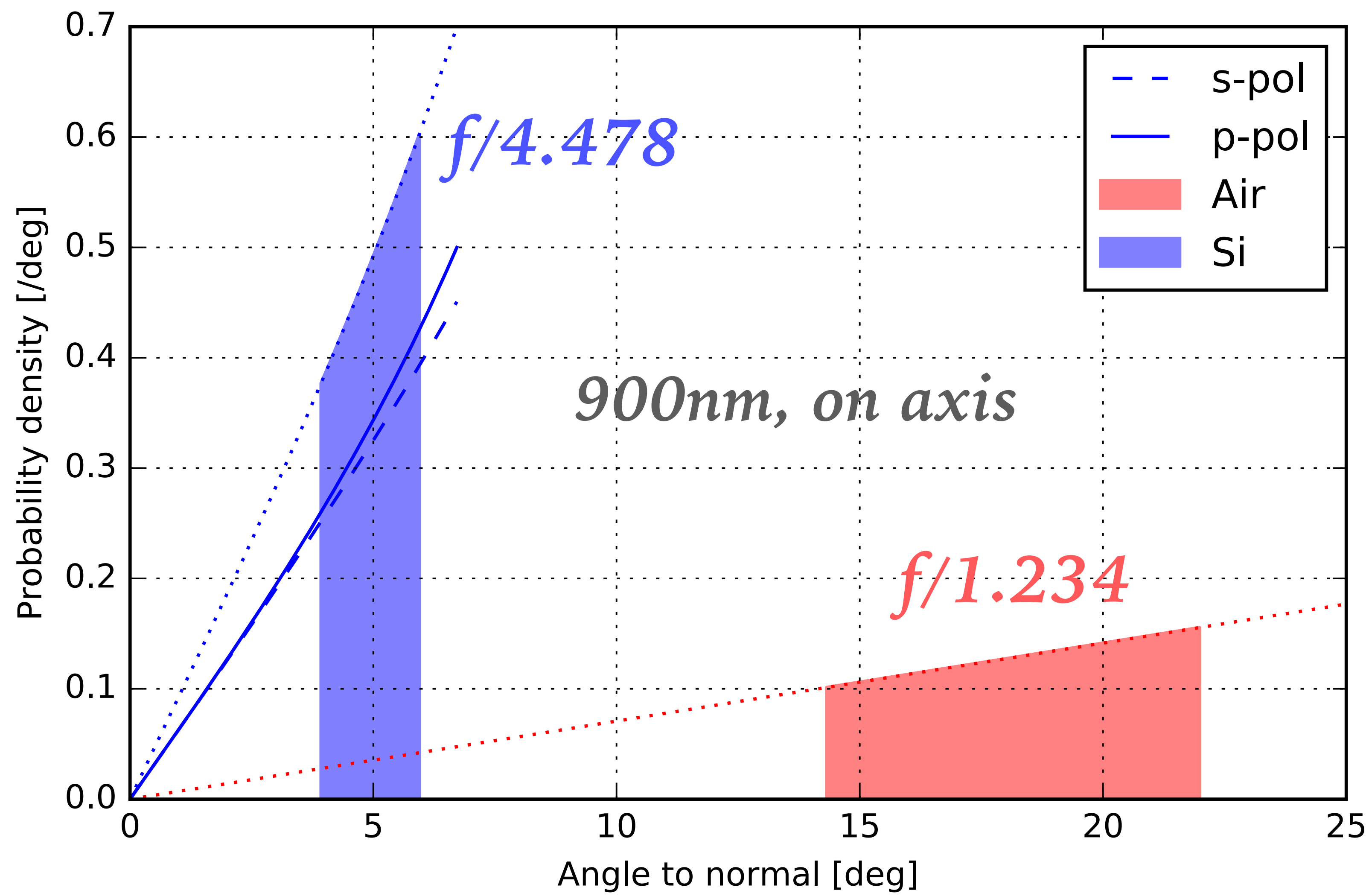
LSST CONVERGING BEAM

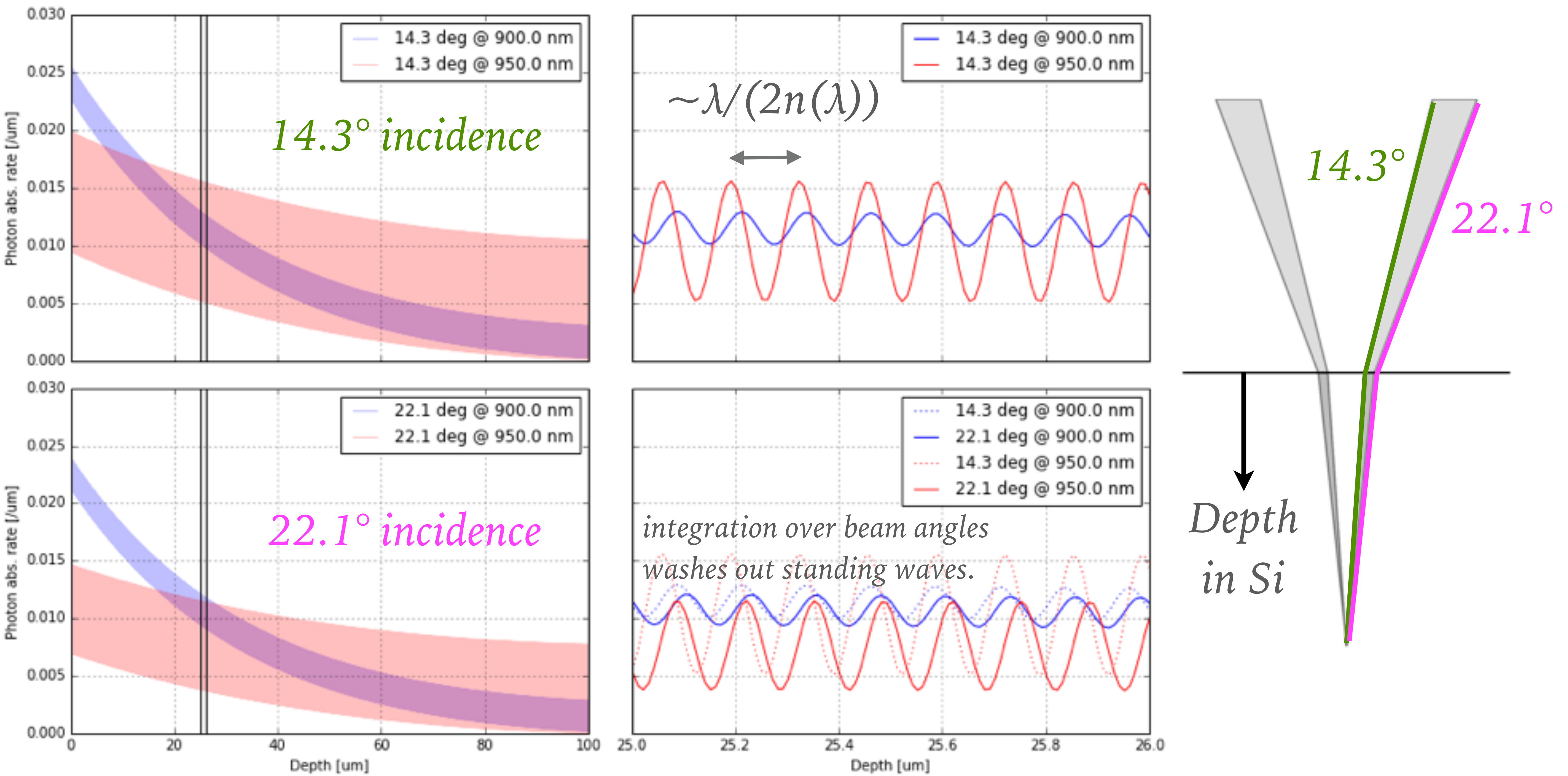
- No photons enter at normal incidence!
- Beam probably has small polarization (~10%) in sensor, depending on details of AR coating.
- Ignore off-axis beam for now.





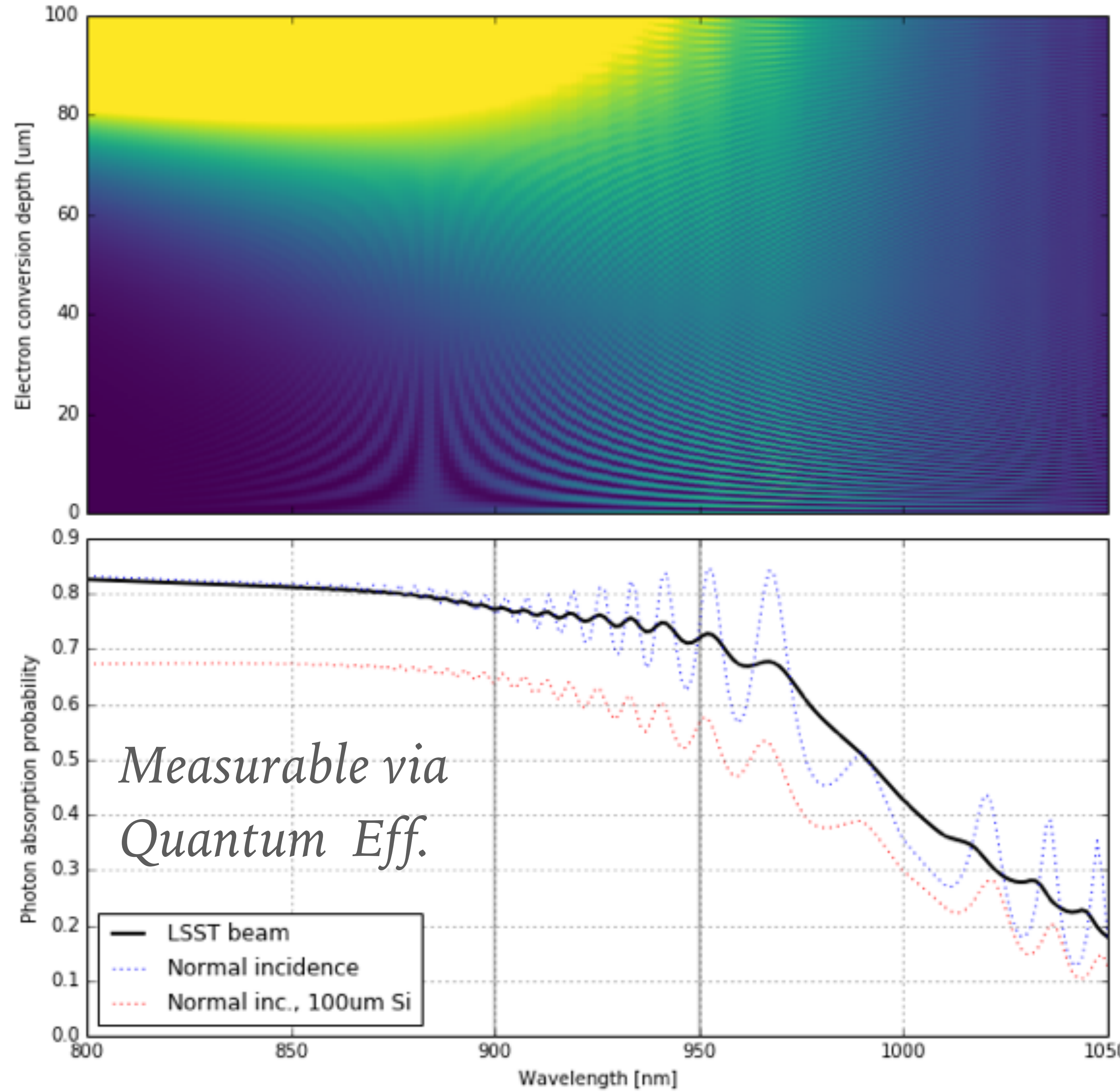
ABSORPTION RATE

- ➤ Absorption probability decays exponentially with depth.
- ➤ Exponential modulated by standing waves.



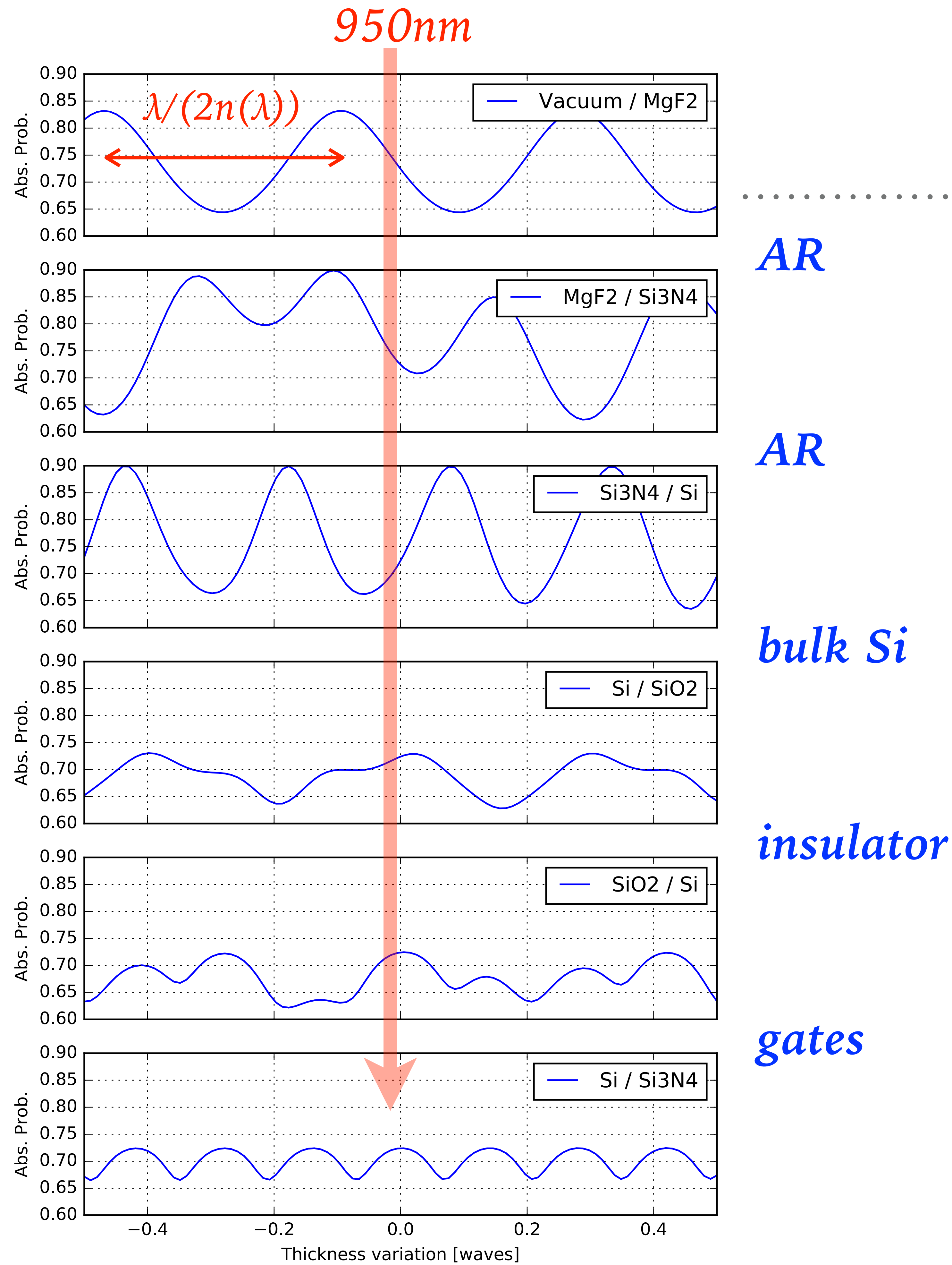
ABSORPTION RATE

- Integrate over all LSST beam angles.
- LSST z & y bands.
- Moiré patterns are plotting artifact.
- AR coating works!



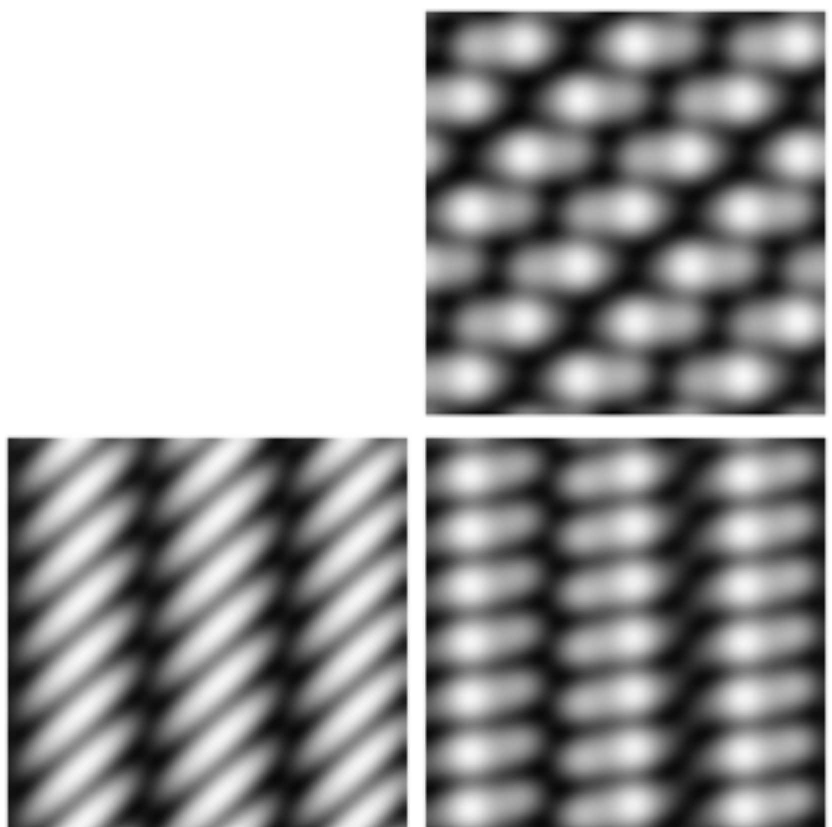
THICKNESS VARIATIONS

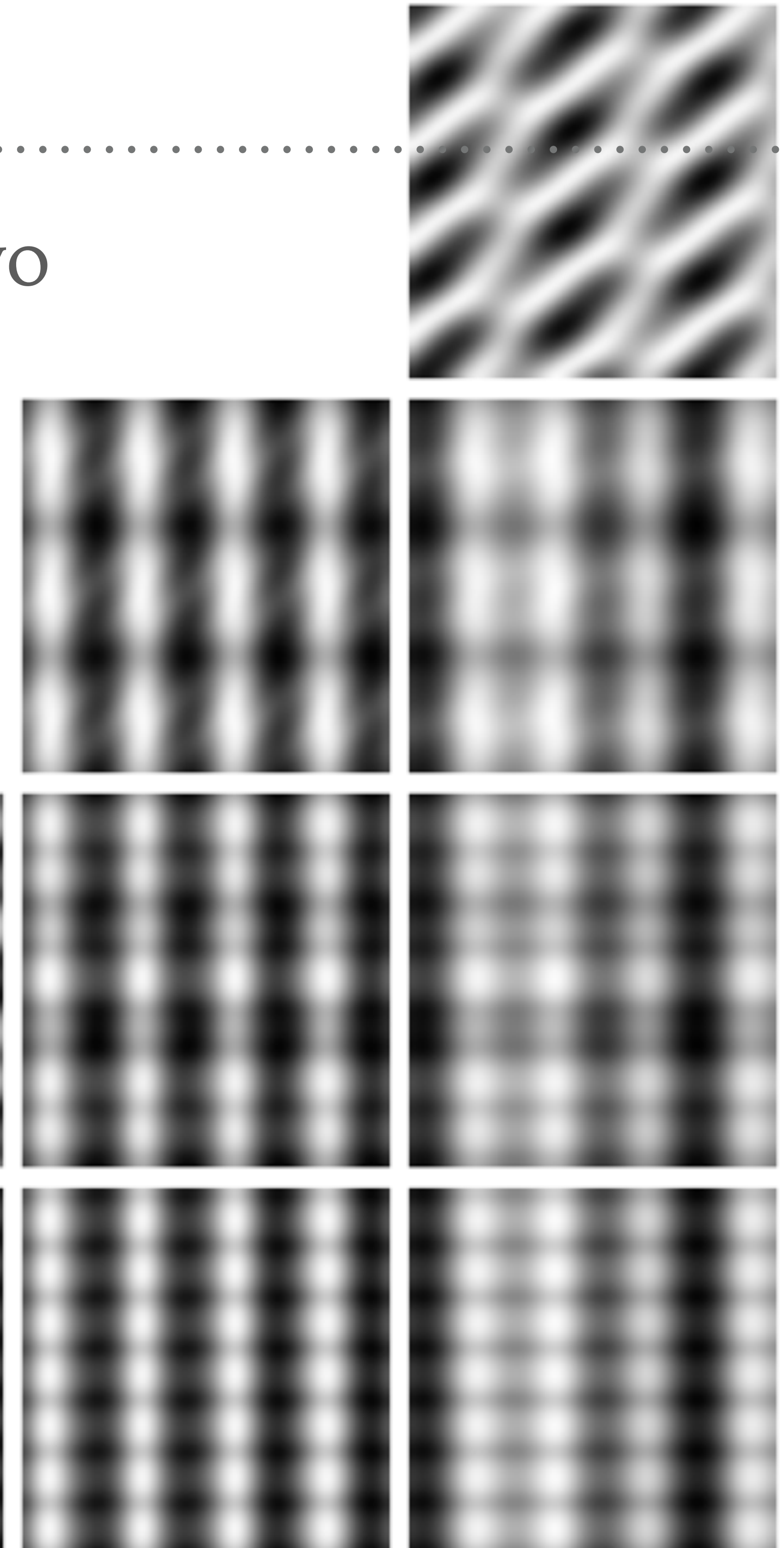
- Introduce slope to at each interface in turn.
- Thicknesses of adjacent layers are anti-correlated.



THICKNESS VARIATIONS

- Need independent variations in two interfaces to produce double fringe patterns.



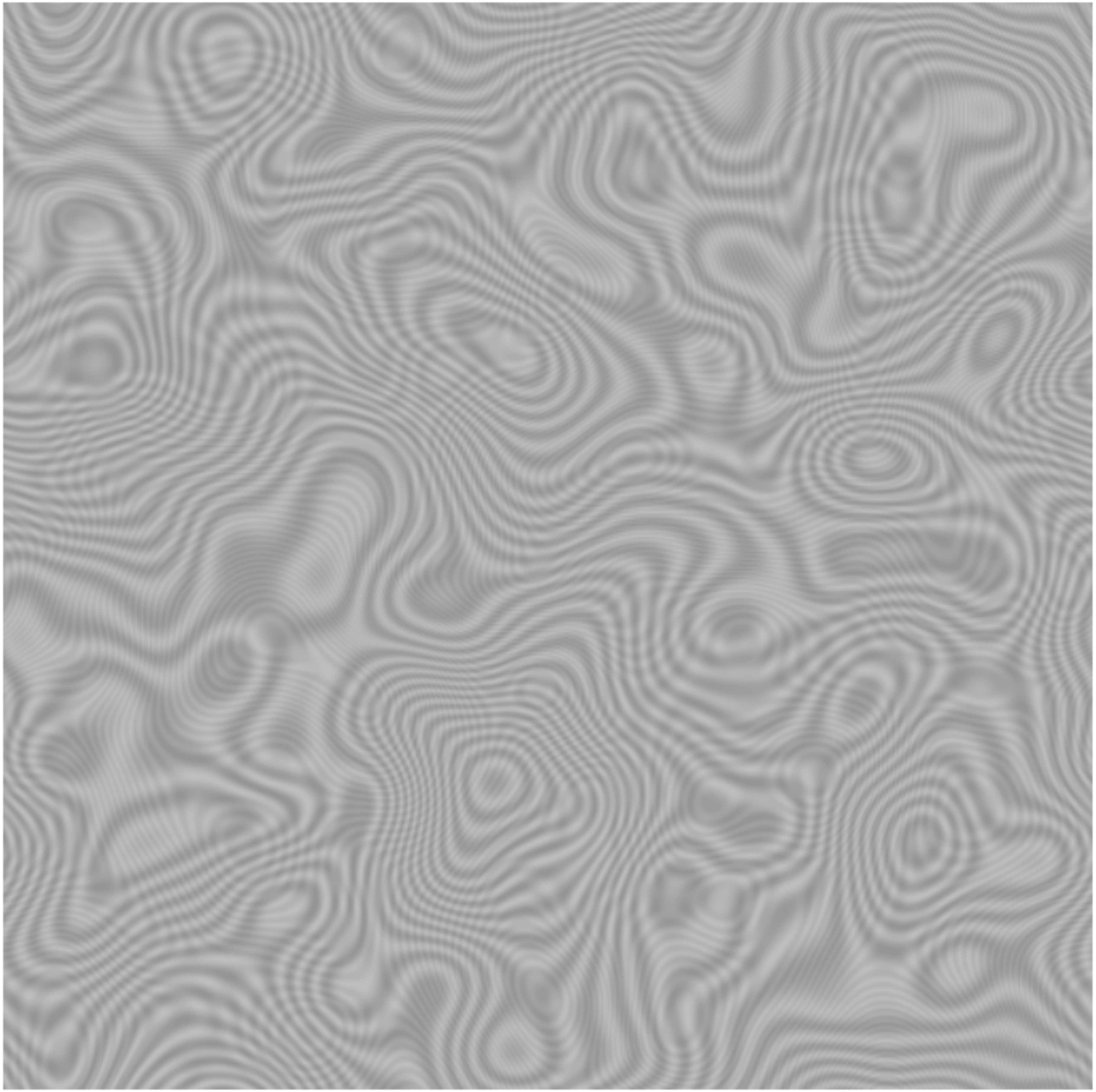


FRINGE PATTERNS

- The EM solution requires unrealistic detailed knowledge of the (internal) geometry but provides some useful insights for interpreting observed fringe patterns:
  - Different media correspond to different length scales and fringe pattern intensities.
  - Patterns not necessarily aligned with thickness gradients.
  - Patterns not simply sinusoidal modulations.
  - Correlated variations can produce honeycomb patterns.

SIMULATED FRINGING

- Straightforward to simulate the types of fringes we observe since complex correlations are not observed:
  - Generate uncorrelated random thickness variations in two non-adjacent layers (as Gaussian random fields).
  - Each $\Delta z = \lambda/(2\, n(\lambda))$ yields one fringe.



POSSIBLE NEXT STEPS

- Notebook used to produce all plots is in:
  - https://github.com/dkirkby/AstroCCD
- Integrate over sky spectrum.
- Implement expected variations in OH sky emission.
- Study off-axis beam.