Feature Intensity Mapping

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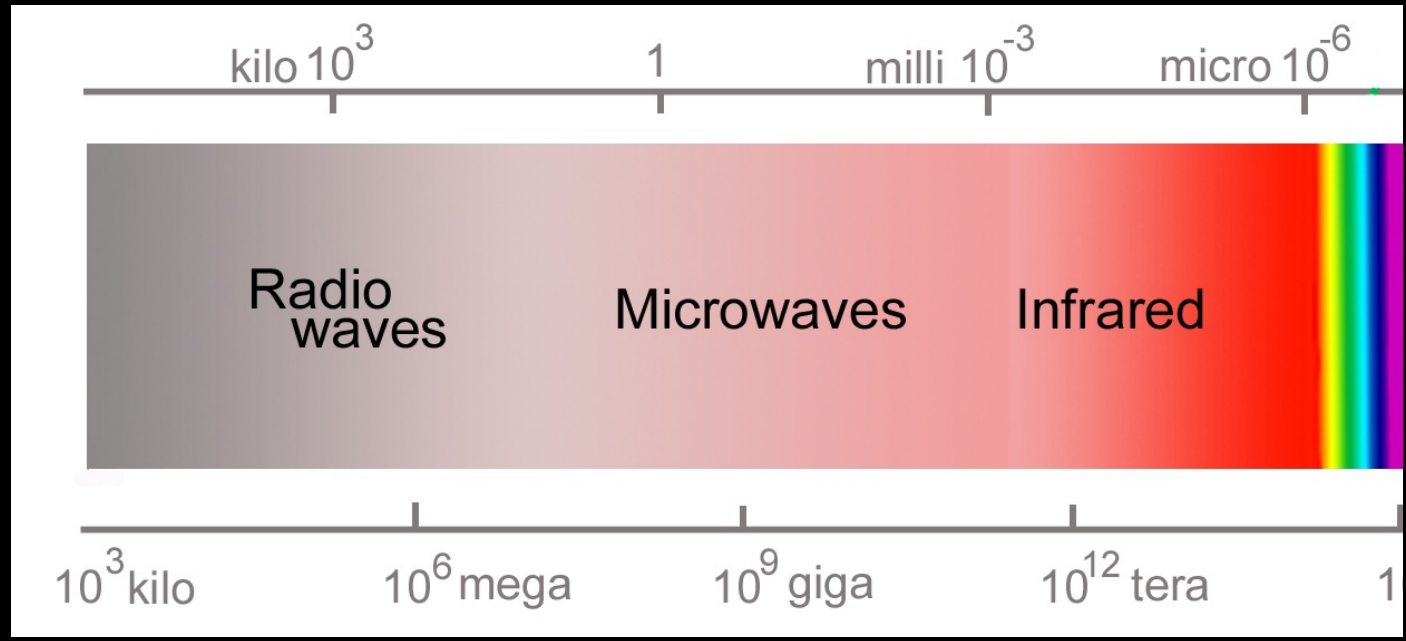
Caltech/JPL

In collaboration with
Brandon Hensley (JPL)
Thomas Lai (Caltech—IPAC)

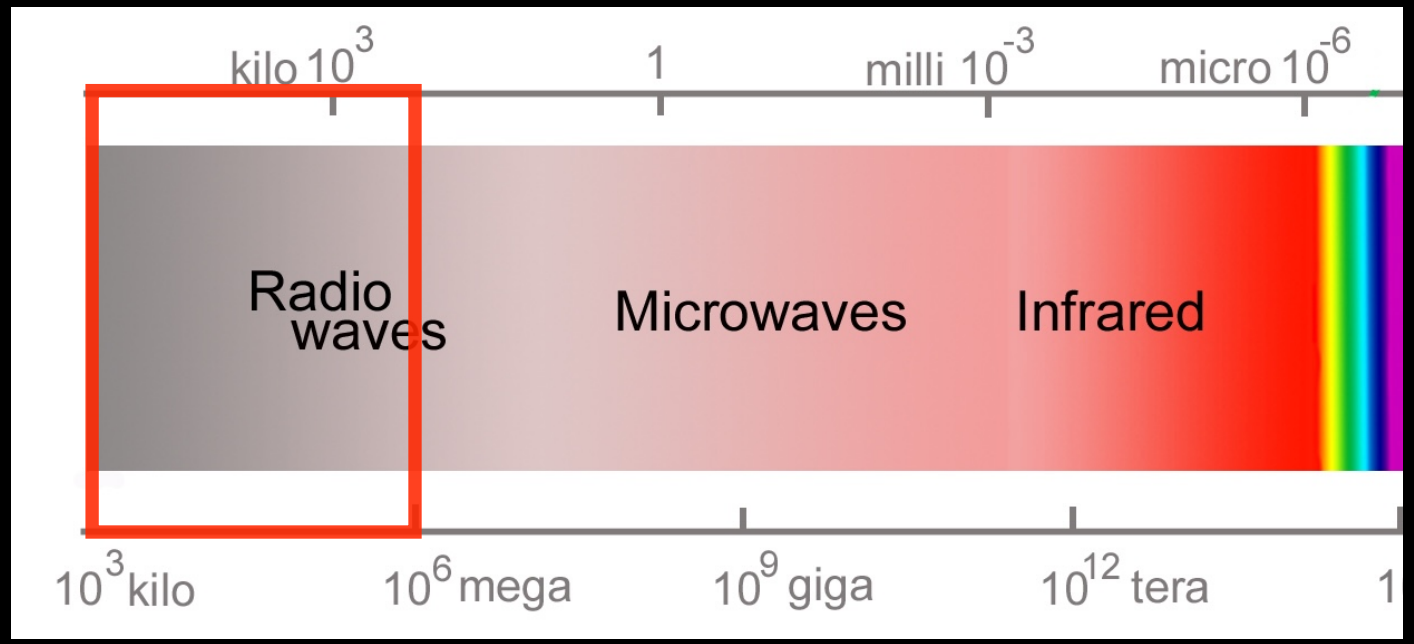
June 04, 2025, LIM25 Conference

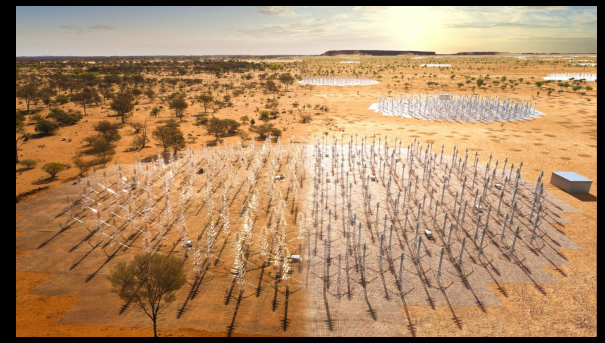
LIM Spectral Coverage



LIM Spectral Coverage

Radio
21 cm





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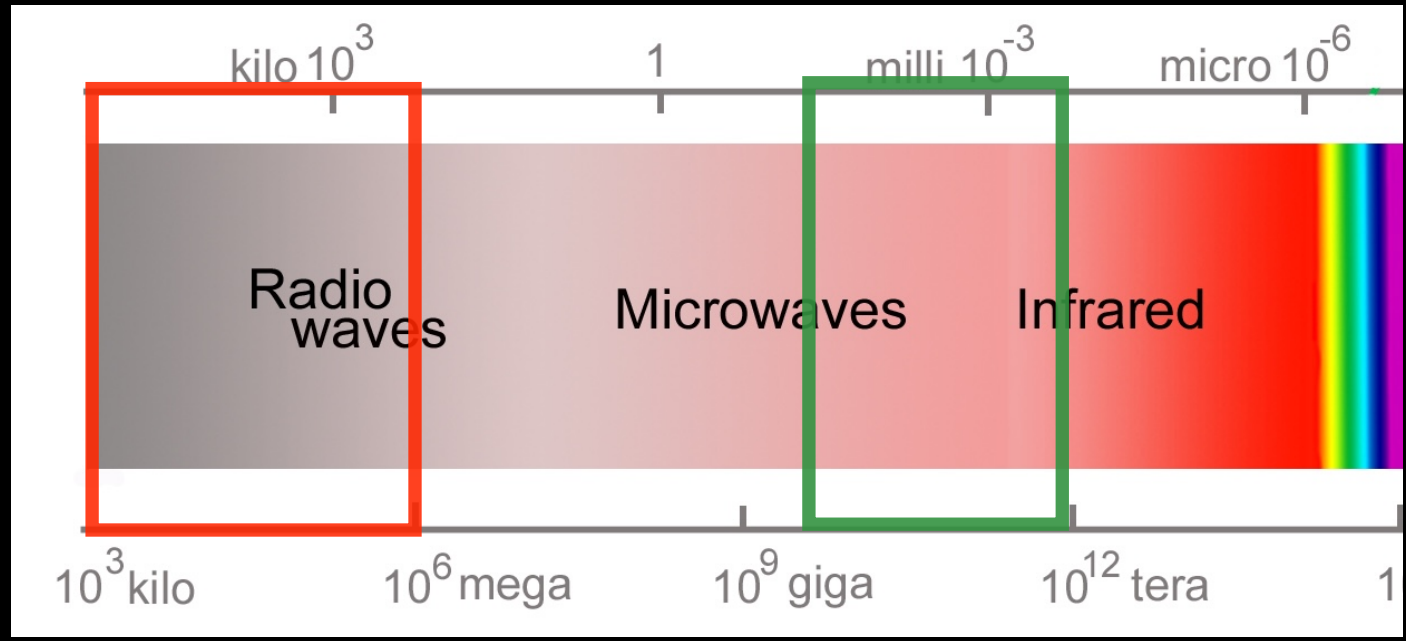
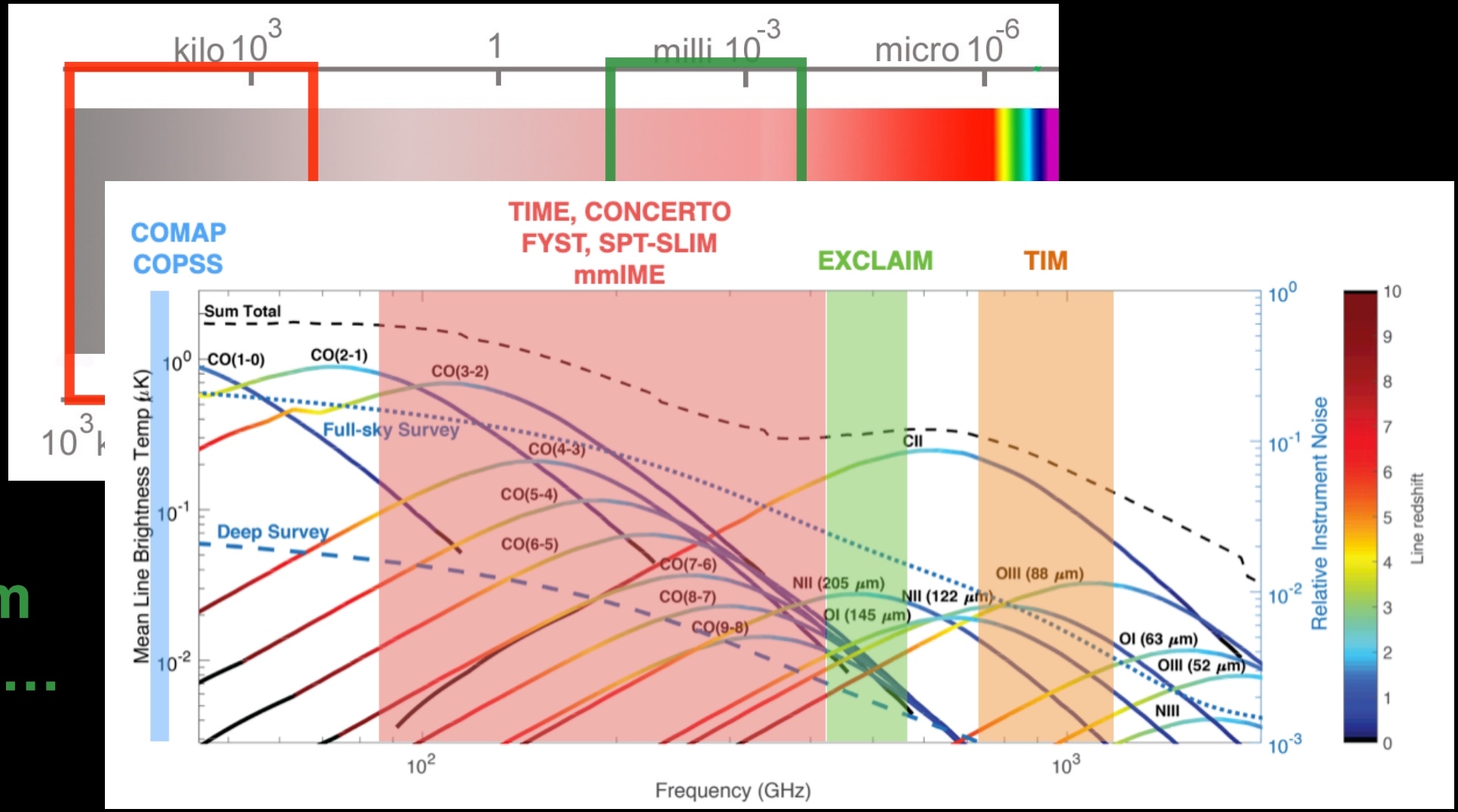


(sub)mm
C II, CO, …

LIM Spectral Coverage



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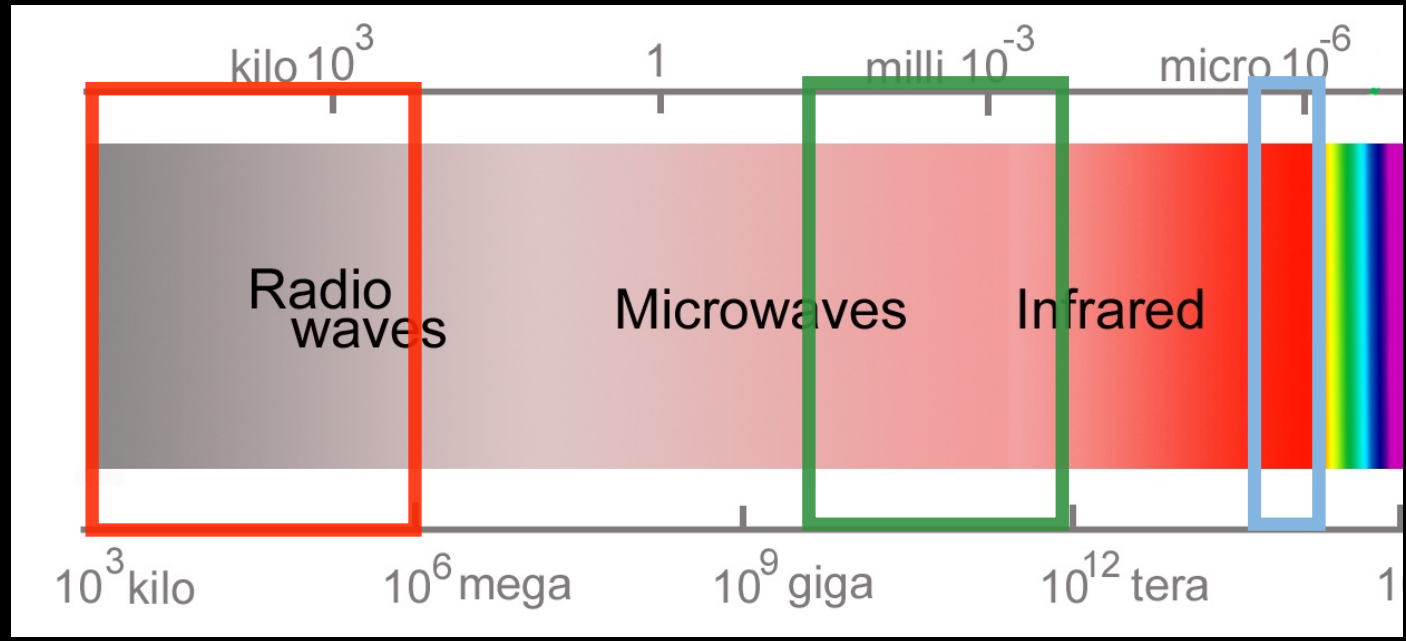
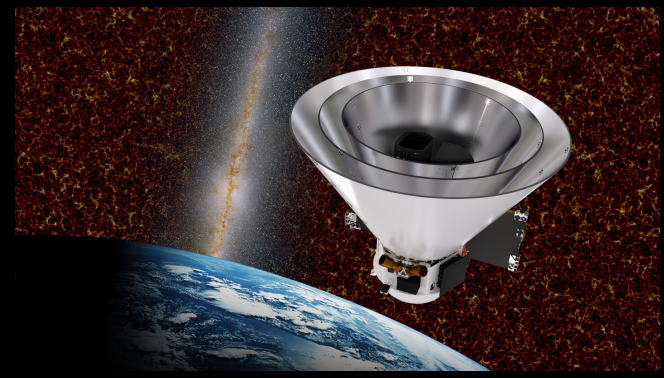


SPHEREx

Near-IR
Lyα, Hα, Hβ, [O II], [O III]



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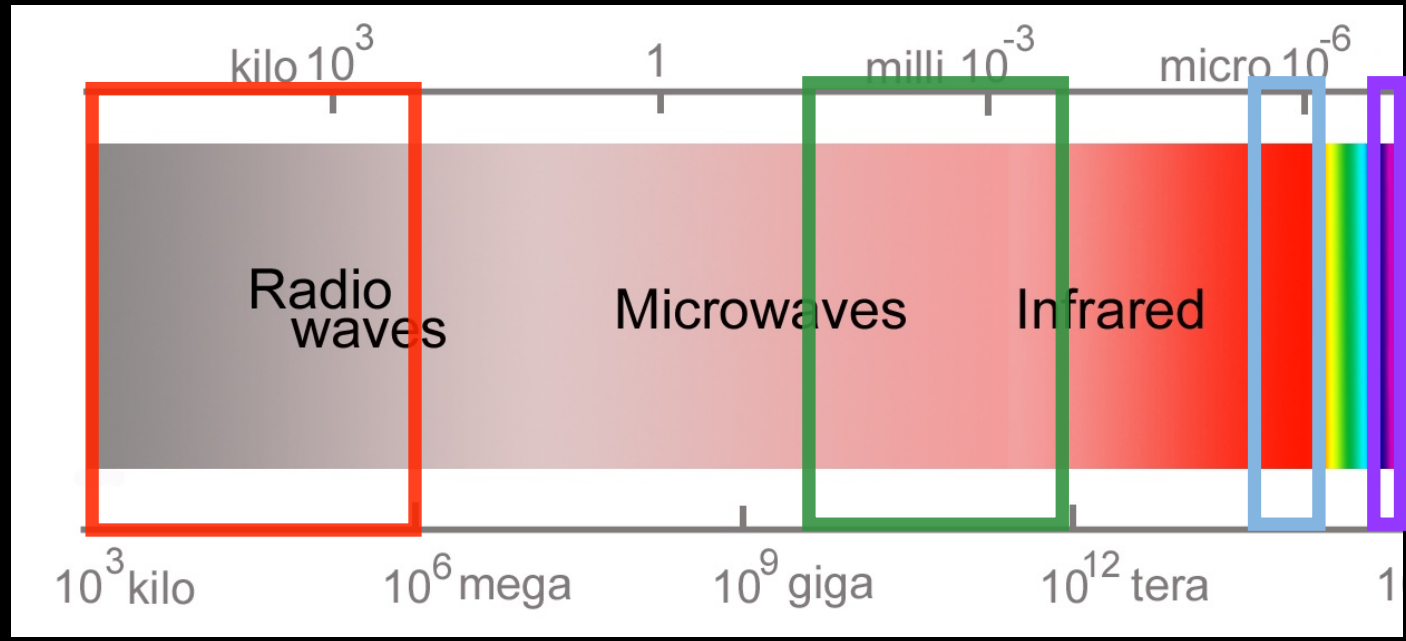
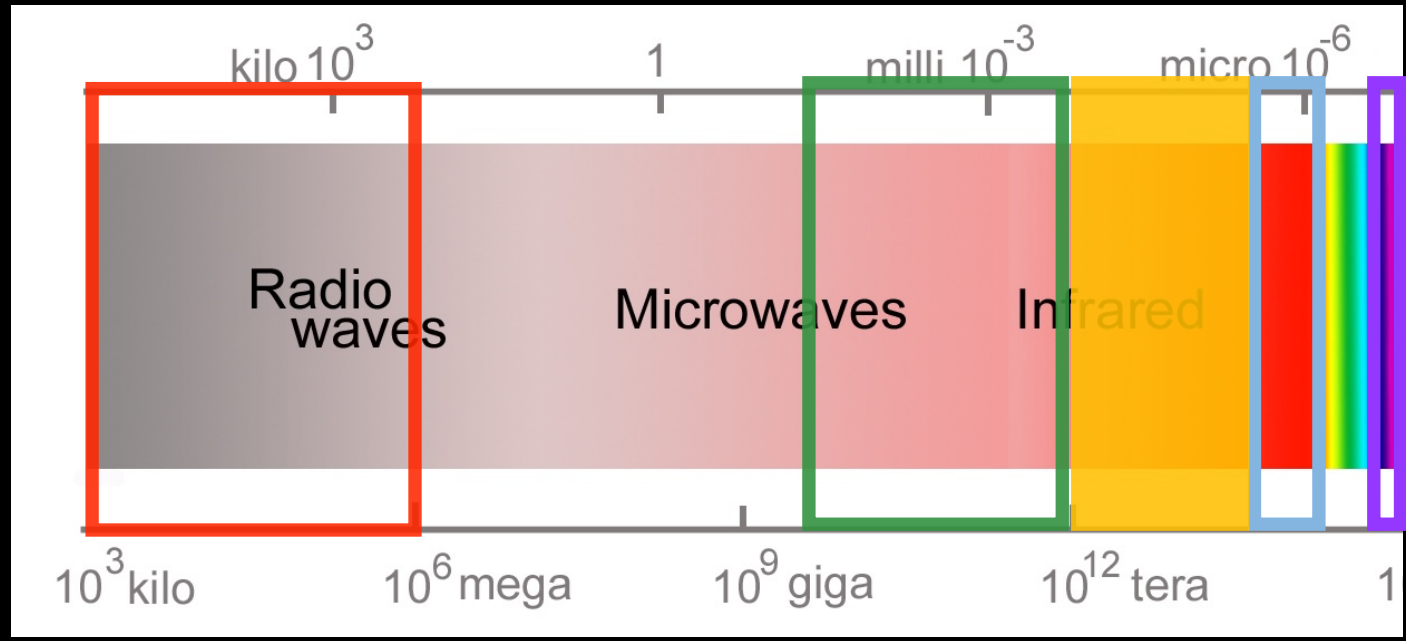


HETDEX

Optical Lyα

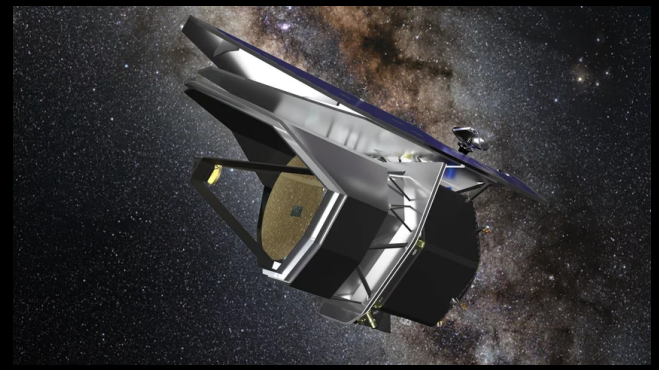
LIM Spectral Coverage



Far-IR

Star Formation — [Ne II]
BH Accretion — [O IV]
Metallicity — [O III], [N III]
ISM Turbulence/Shocks — H_2
Dust — PAHs

PRIMA



PRIMA (PRobe far-Infrared Mission for Astrophysics)

- NASA Probe-Class mission at Phase A study (2032 launch if selected)
- Two instruments:
  - PRIMAger: imager (25 – 80 um; R=8); polarimetry (91 — 232 um)
  - FIRESS: spectrometer (R > 85; 240 — 235 um)

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PRIMA's core science program addresses three themes:

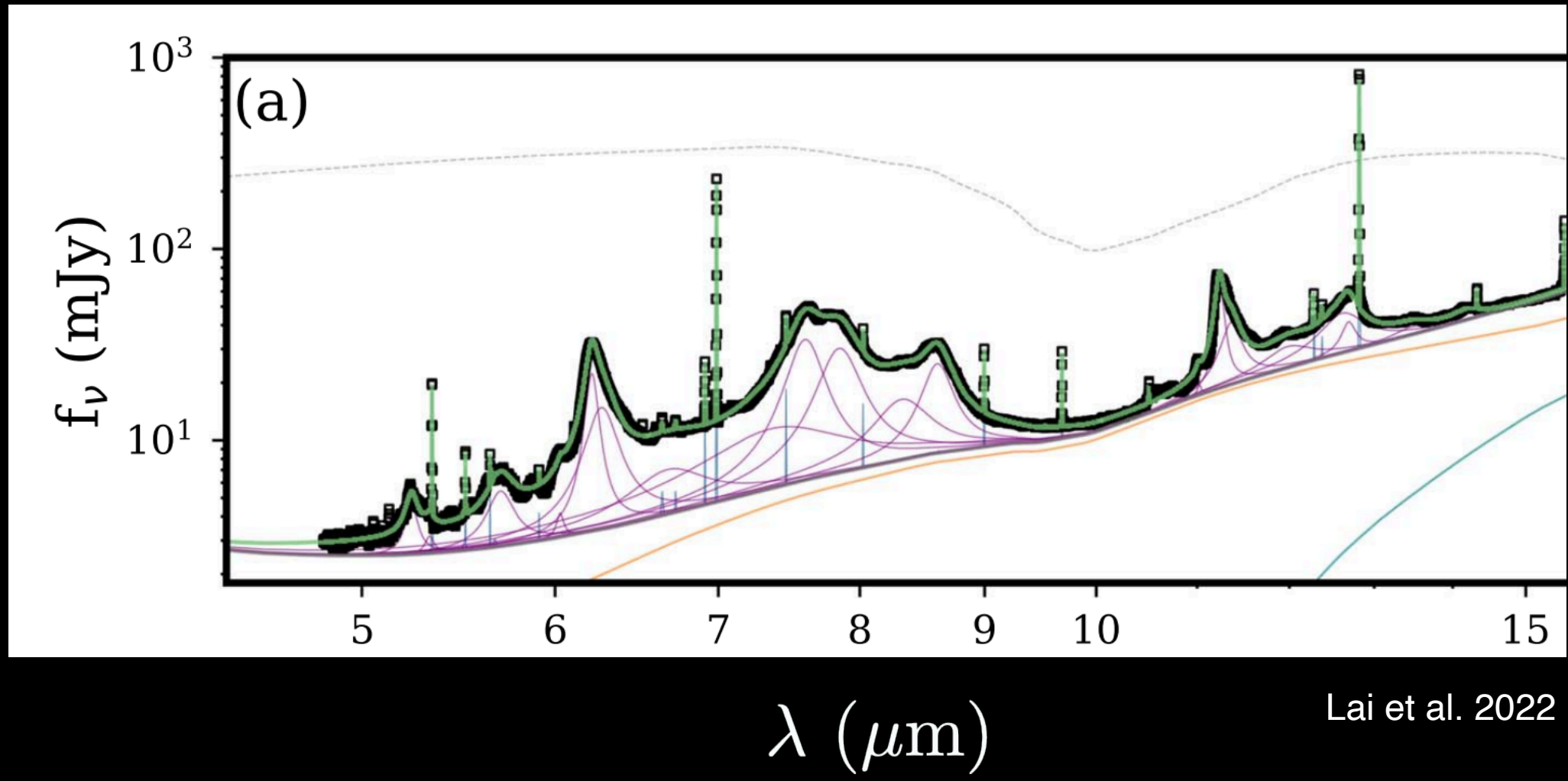
Theme 1. Origin of Planets and their Atmospheres

→ Theme 2. Co-Evolution of Galaxies and Supermassive Black Holes Since Cosmic Noon

→ Theme 3. Buildup of Dust and Metals

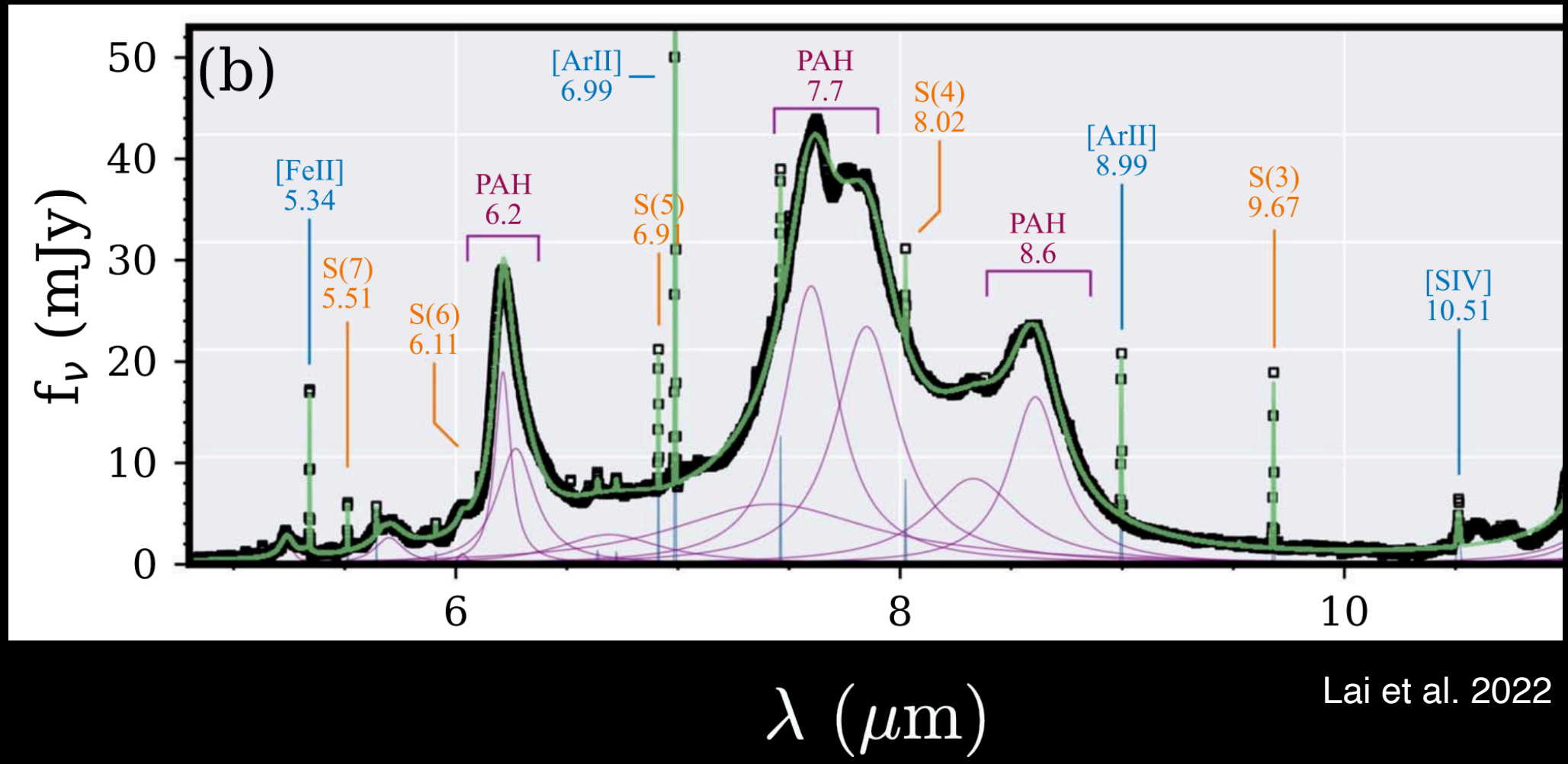
Star Formation — [Ne II]
BH accretion — [O IV]
Metallicity — [O III], [N III]
ISM turbulence/Shocks — H_2
Dust — PAHs

Galaxy SED in IR



Lai et al. 2022

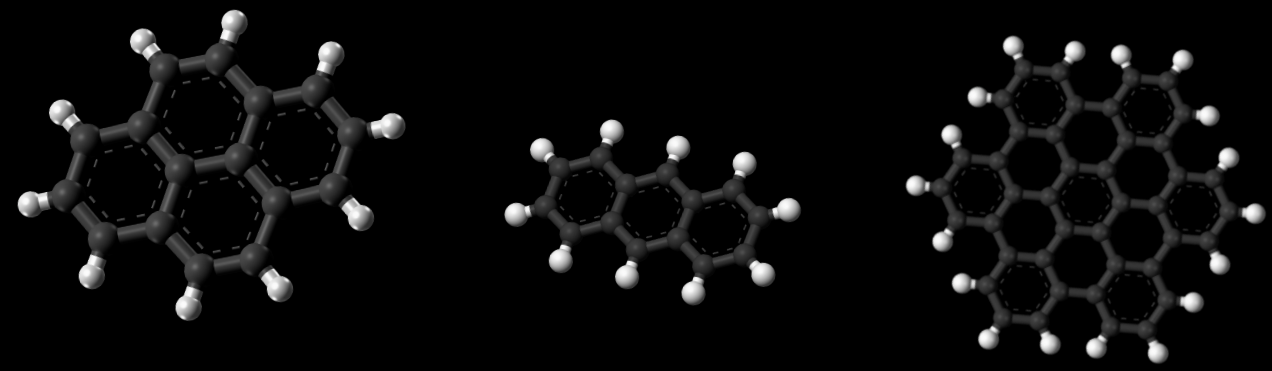
Galaxy SED in IR



Lai et al. 2022

What are PAHs (polycyclic aromatic hydrocarbons)

- Fused carbon rings + hydrogens
- Vibrational transition bands at 3 — 20 um
- Contribute up to ~20% of the total LIR
- Govern the energy budget in the ISM
  - tracers of star formation, metallicity, and dust in the ISM
- Ratio of short and long wavelength PAH bands informs the PAH grain size



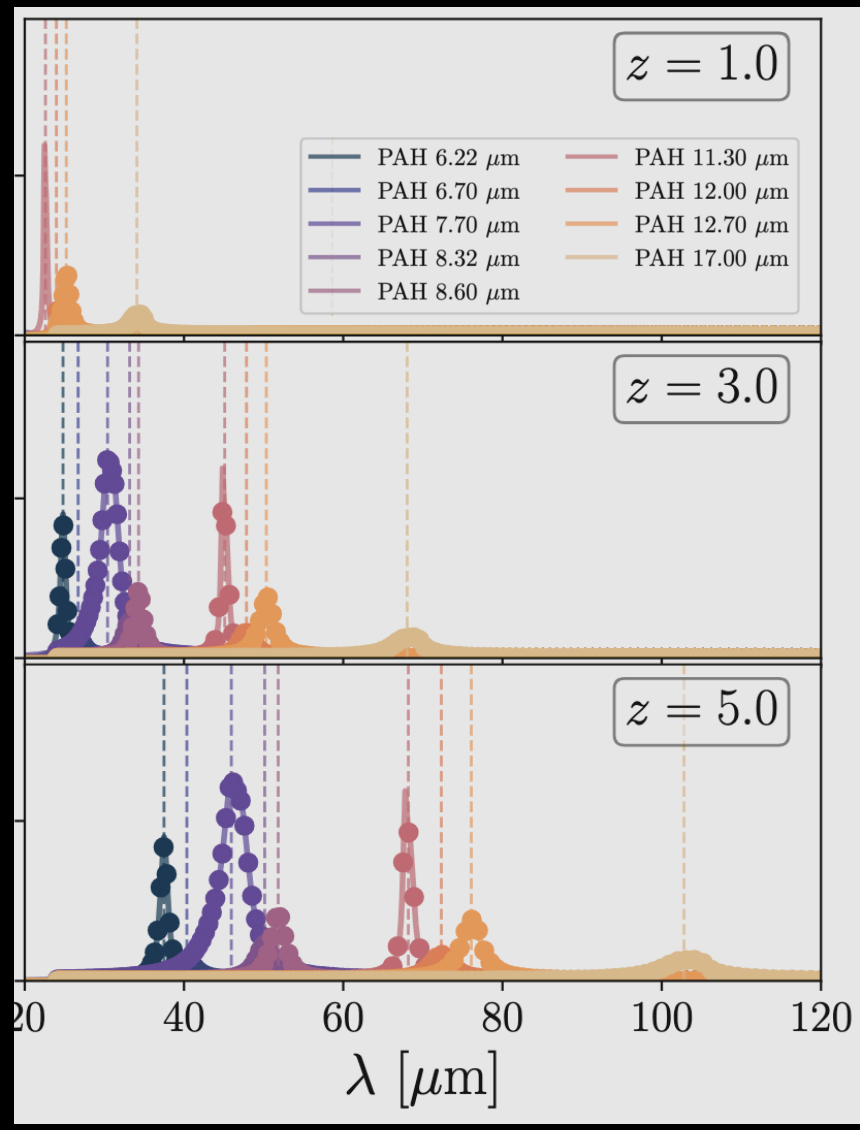
“Line Intensity Mapping” with PAHs?

Line Intensity Mapping with PAHs

- PAHs are NOT narrow lines

PAHs as seen by
the PRIMA spectrometer
FIRESS

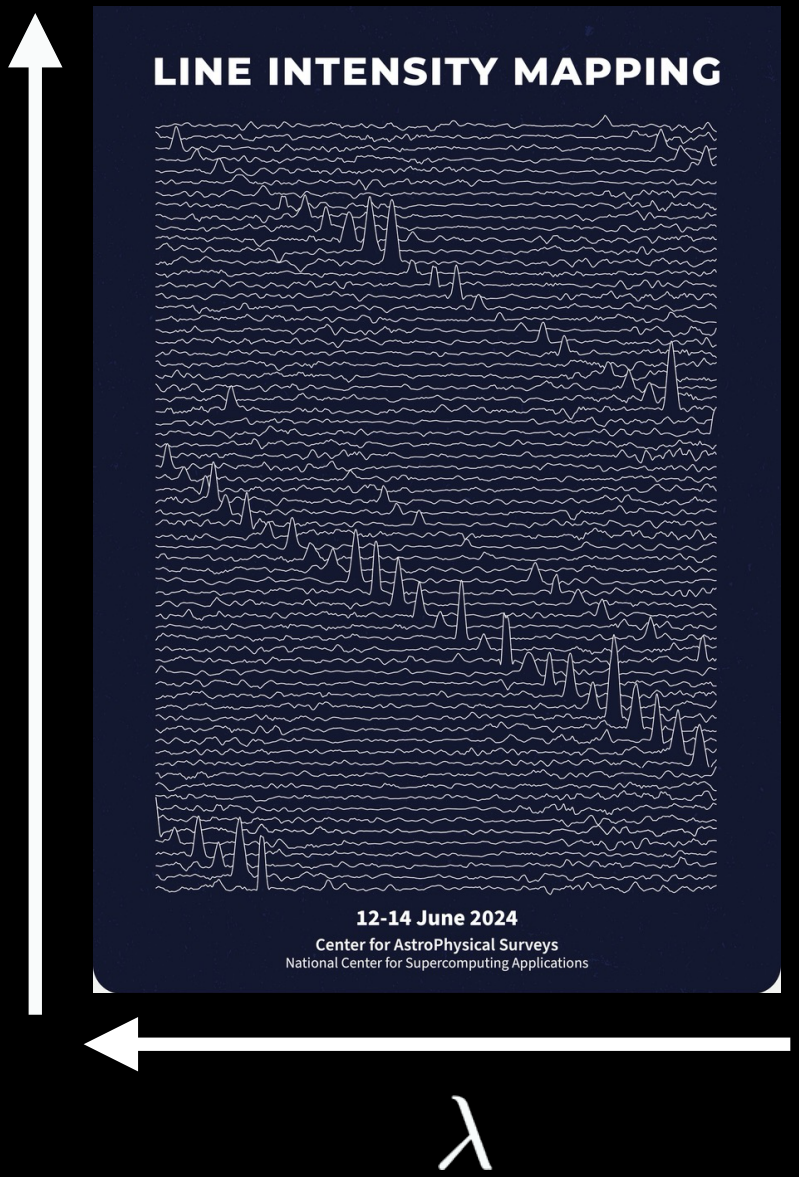
Cheng, Hensley & Lai
2025 in prep.



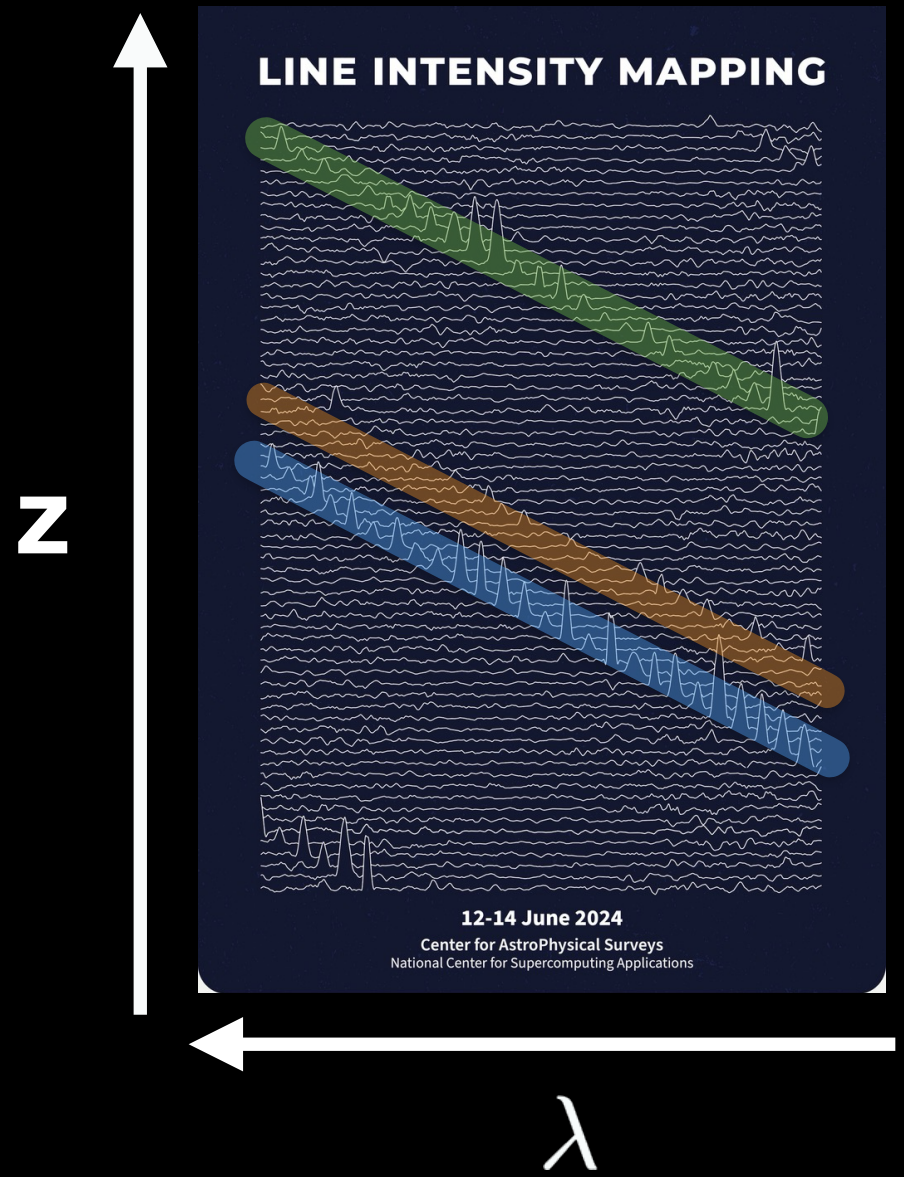
Feature

“Line Intensity Mapping” with PAHs?

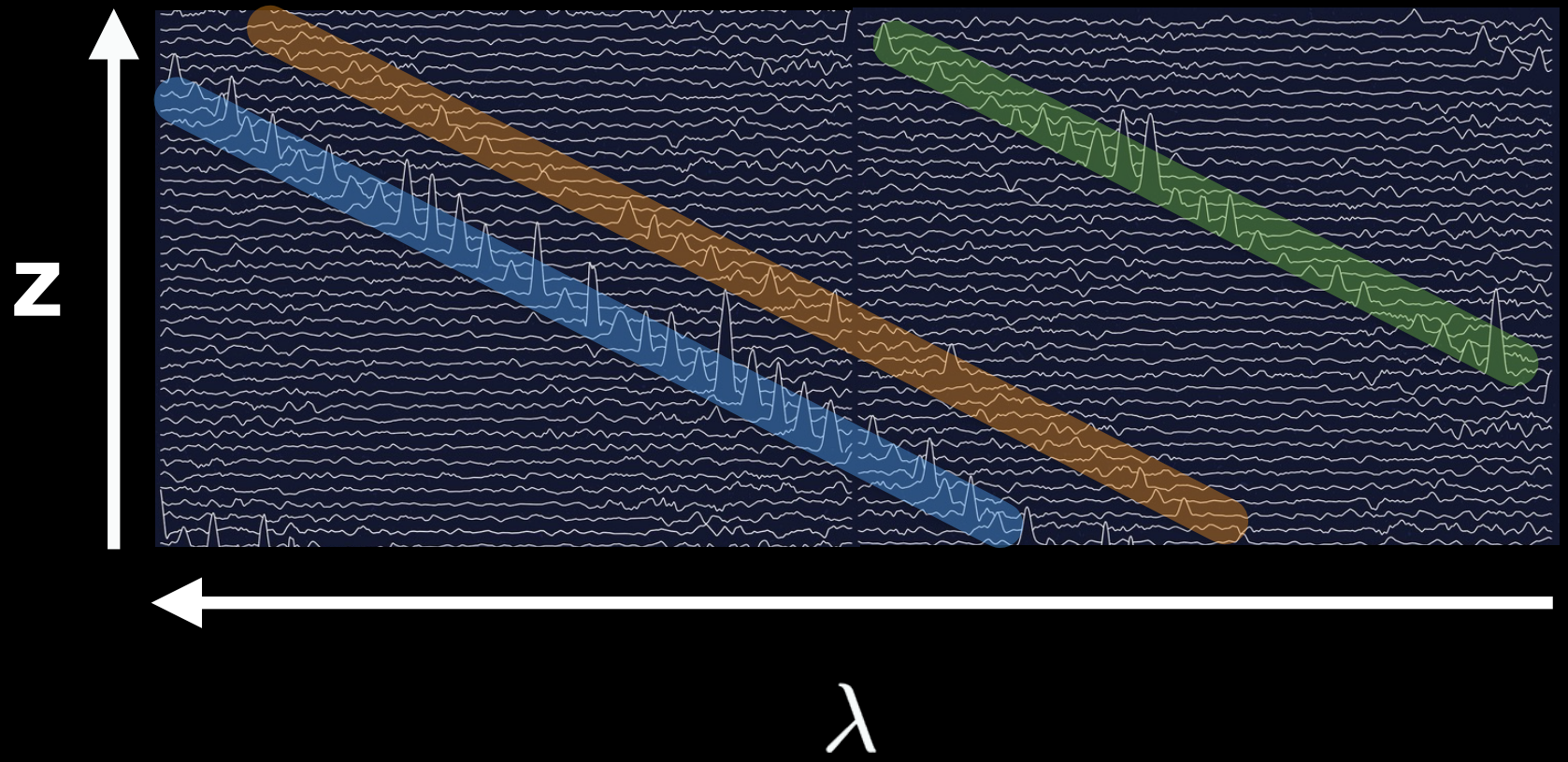
Multi-line Intensity Mapping



Multi-line Intensity Mapping



Multi-line Intensity Mapping



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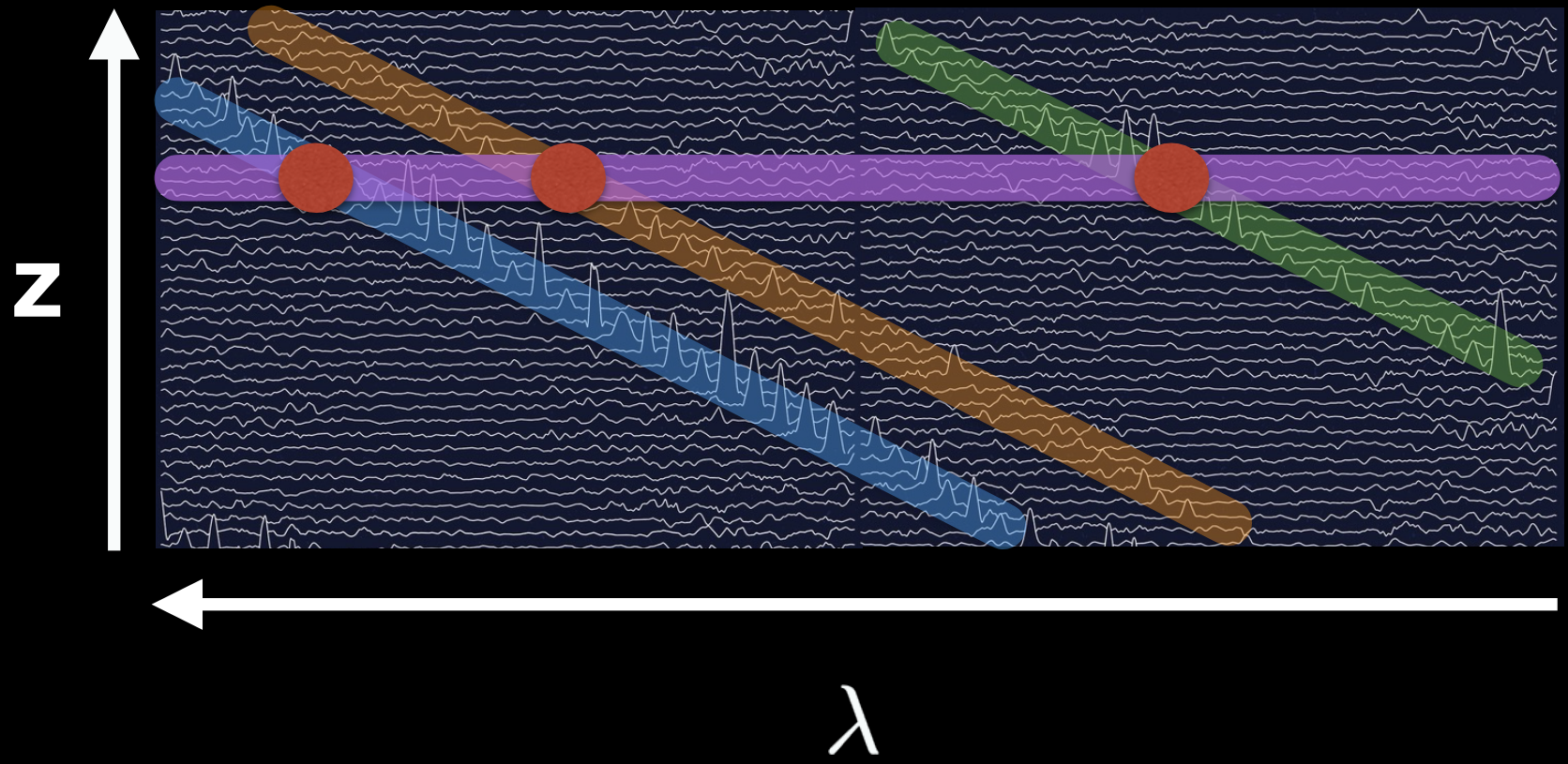

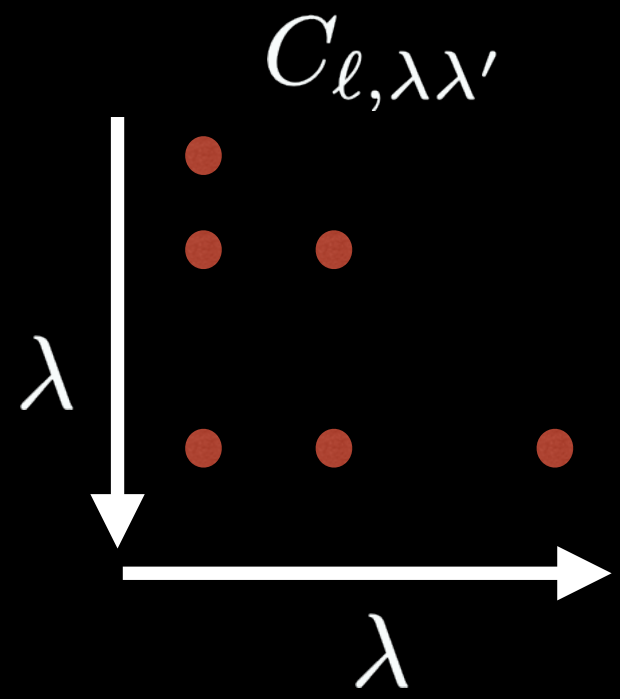

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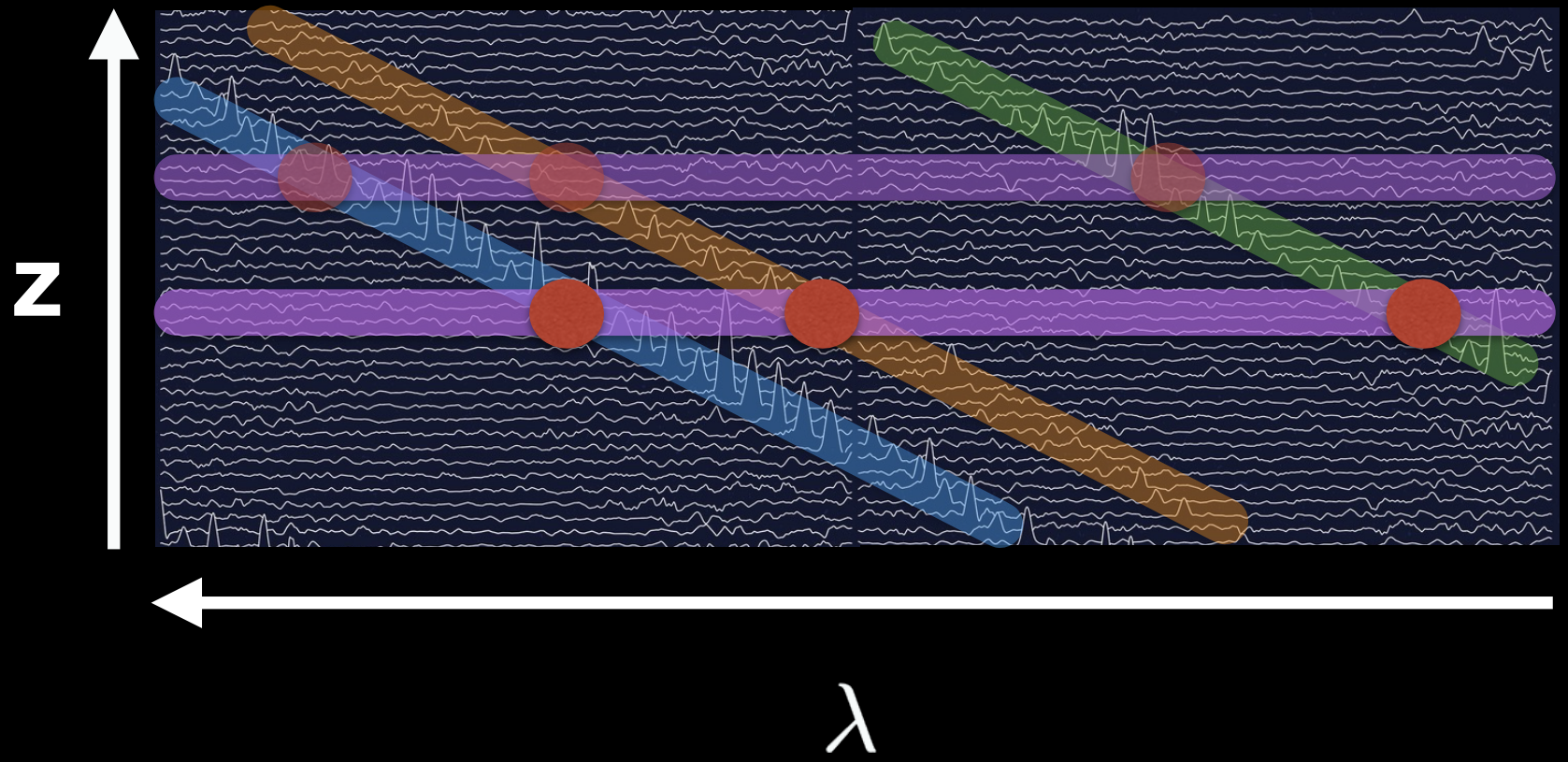

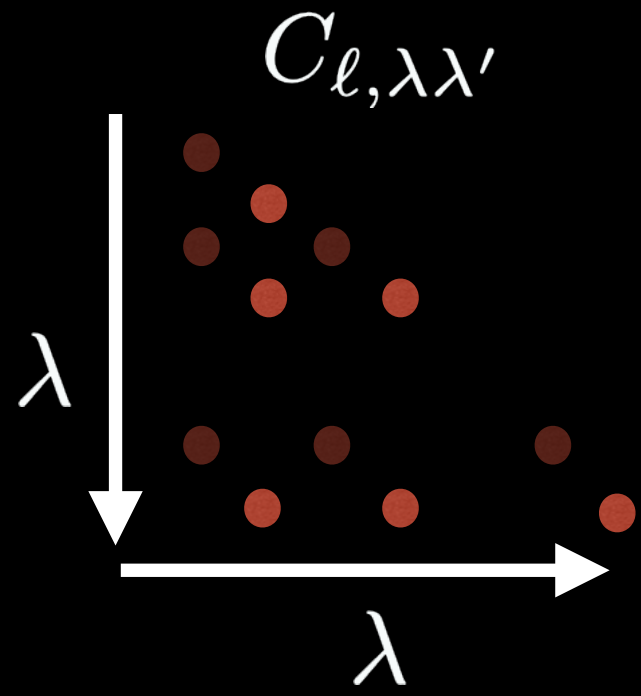

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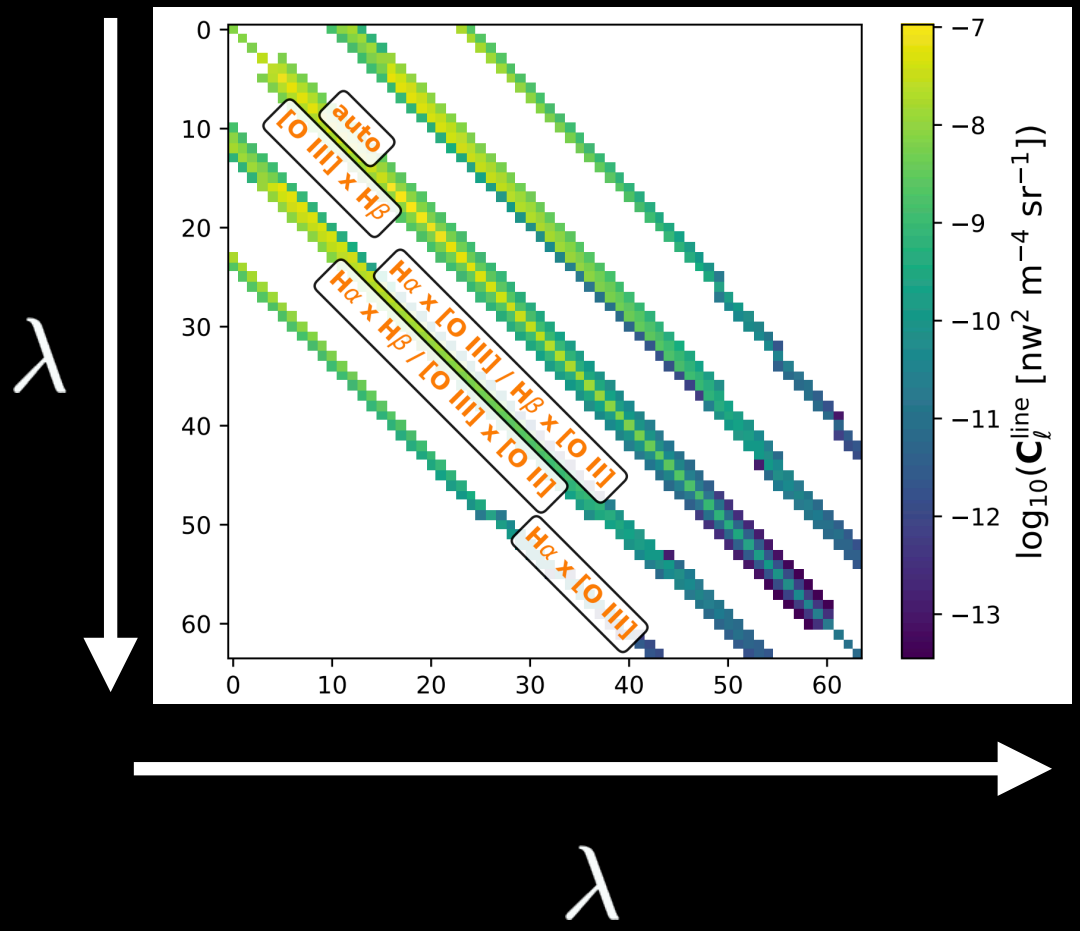
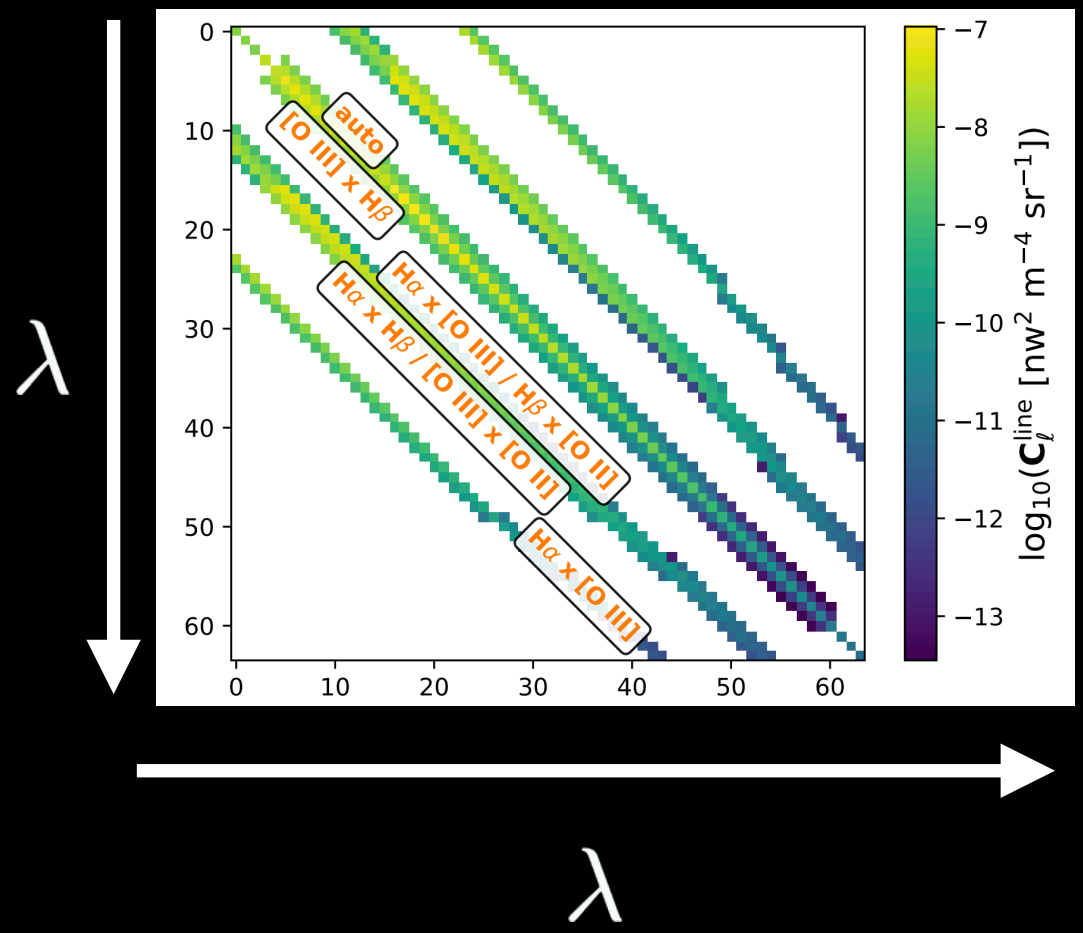
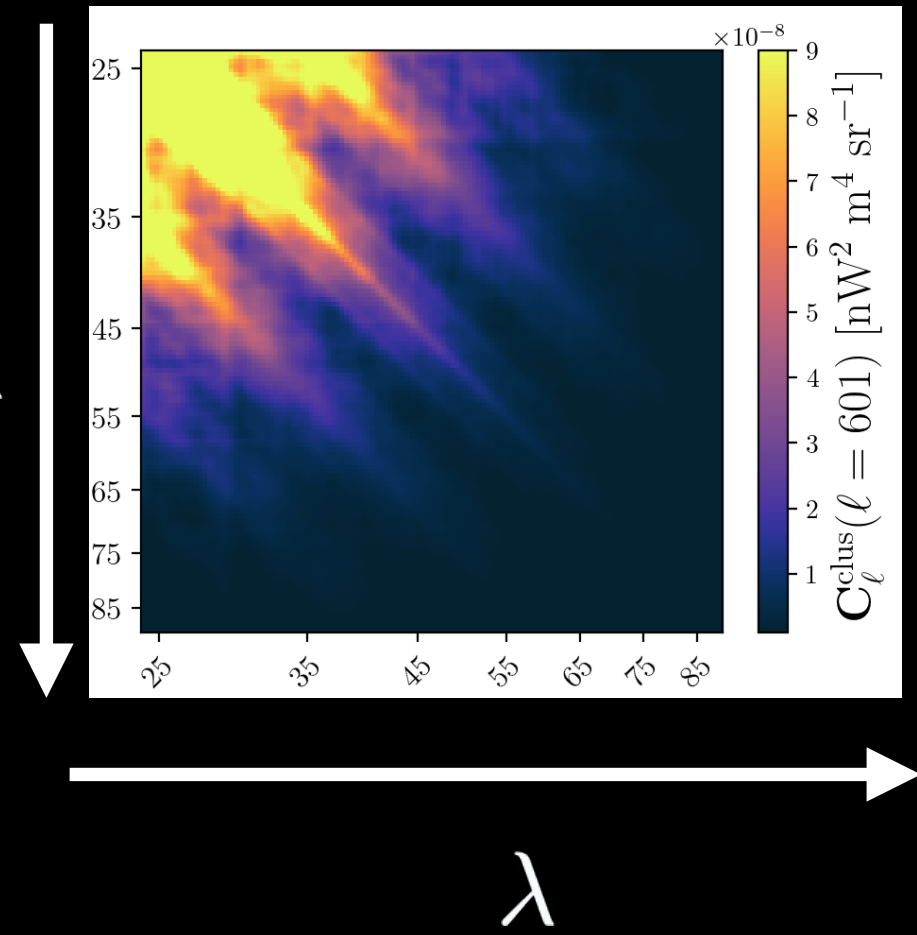
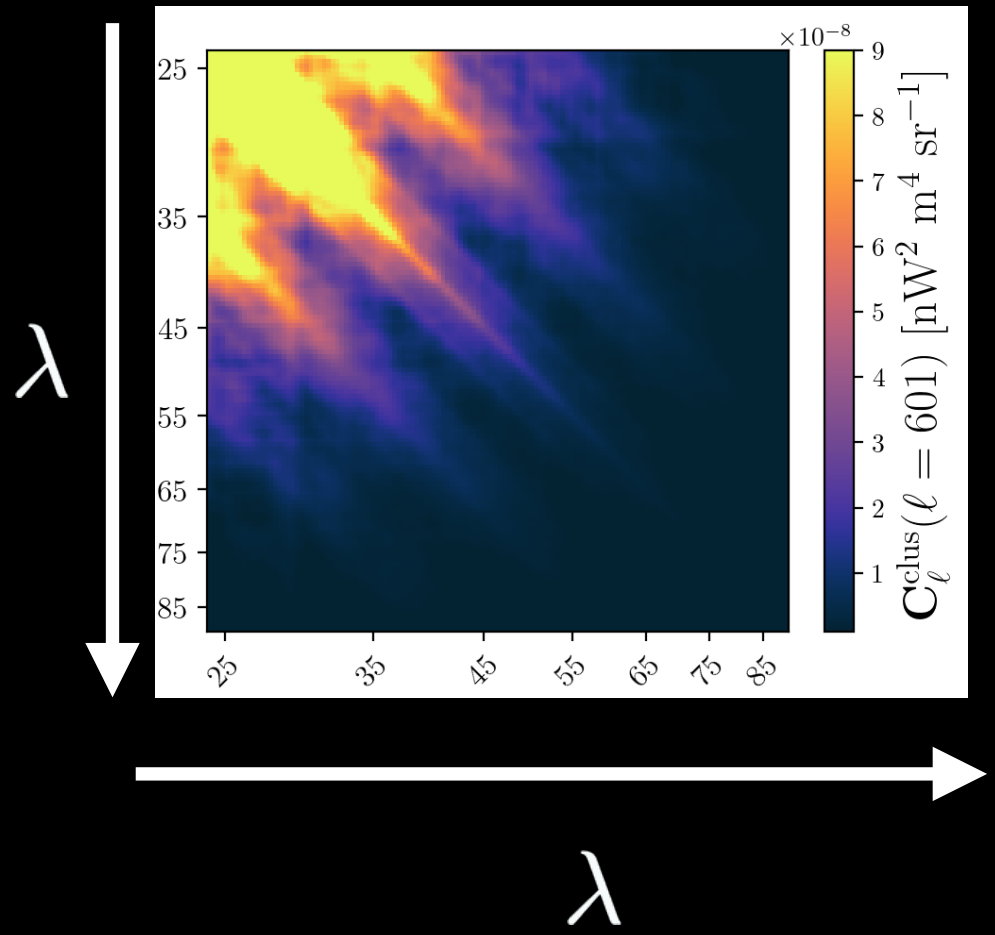


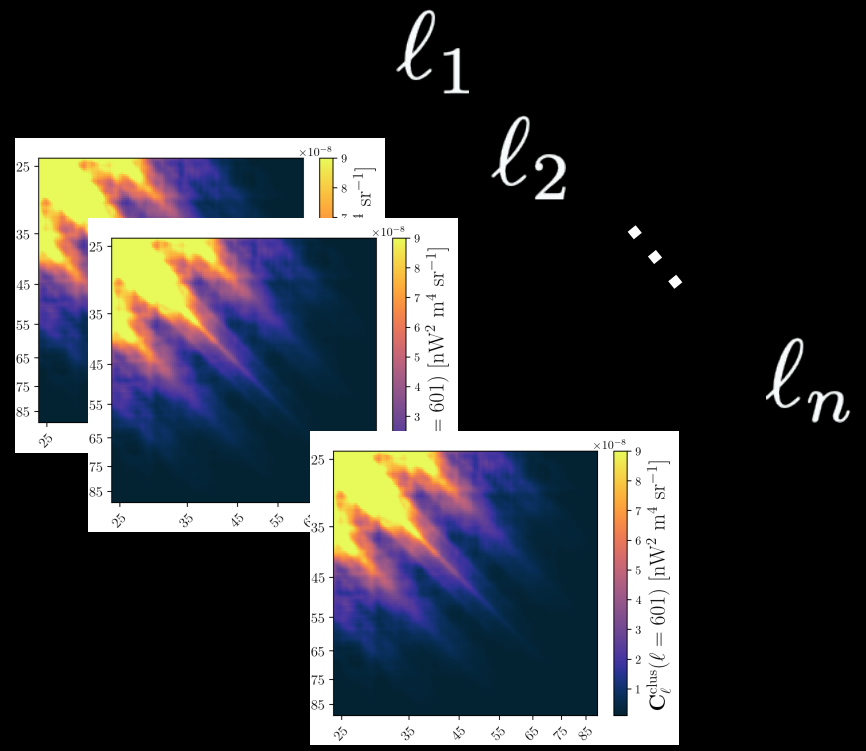
Multi-feature Intensity Mapping





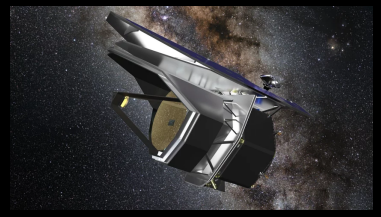
Multi-feature Intensity Mapping



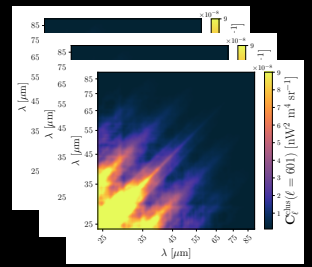


Bayesian Inference

$I^{\rm data}(\lambda, \hat{\theta})$



$C^{\rm data}_{\ell,\lambda\lambda'}$



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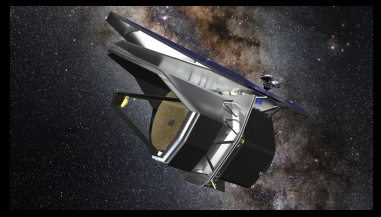

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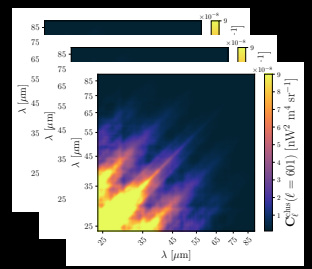
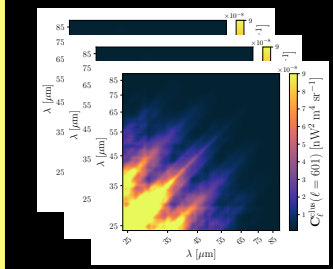


$\{\theta\}$

$\begin{cases} b_1 I_1(z) \\ b_2 I_2(z) \\ \vdots \end{cases}$

$C^{\rm model}_{\ell,\lambda\lambda'}$



Bayesian Inference

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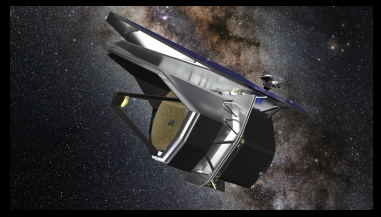

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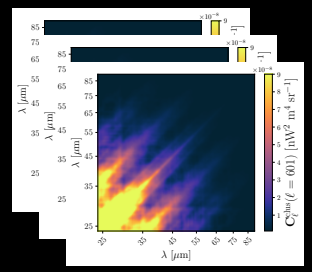
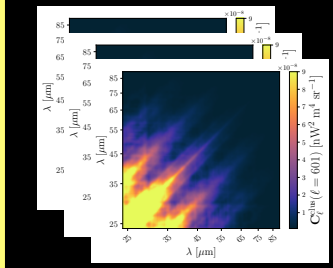


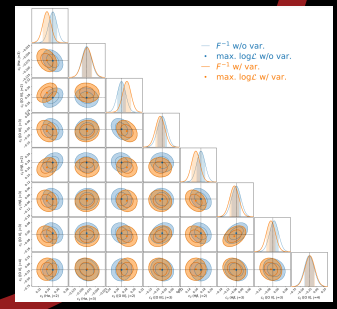
$C^{\rm model}_{\ell,\lambda\lambda'}$



$\begin{cases} b_1 I_1(z) \\ b_2 I_2(z) \\ \vdots \end{cases}$

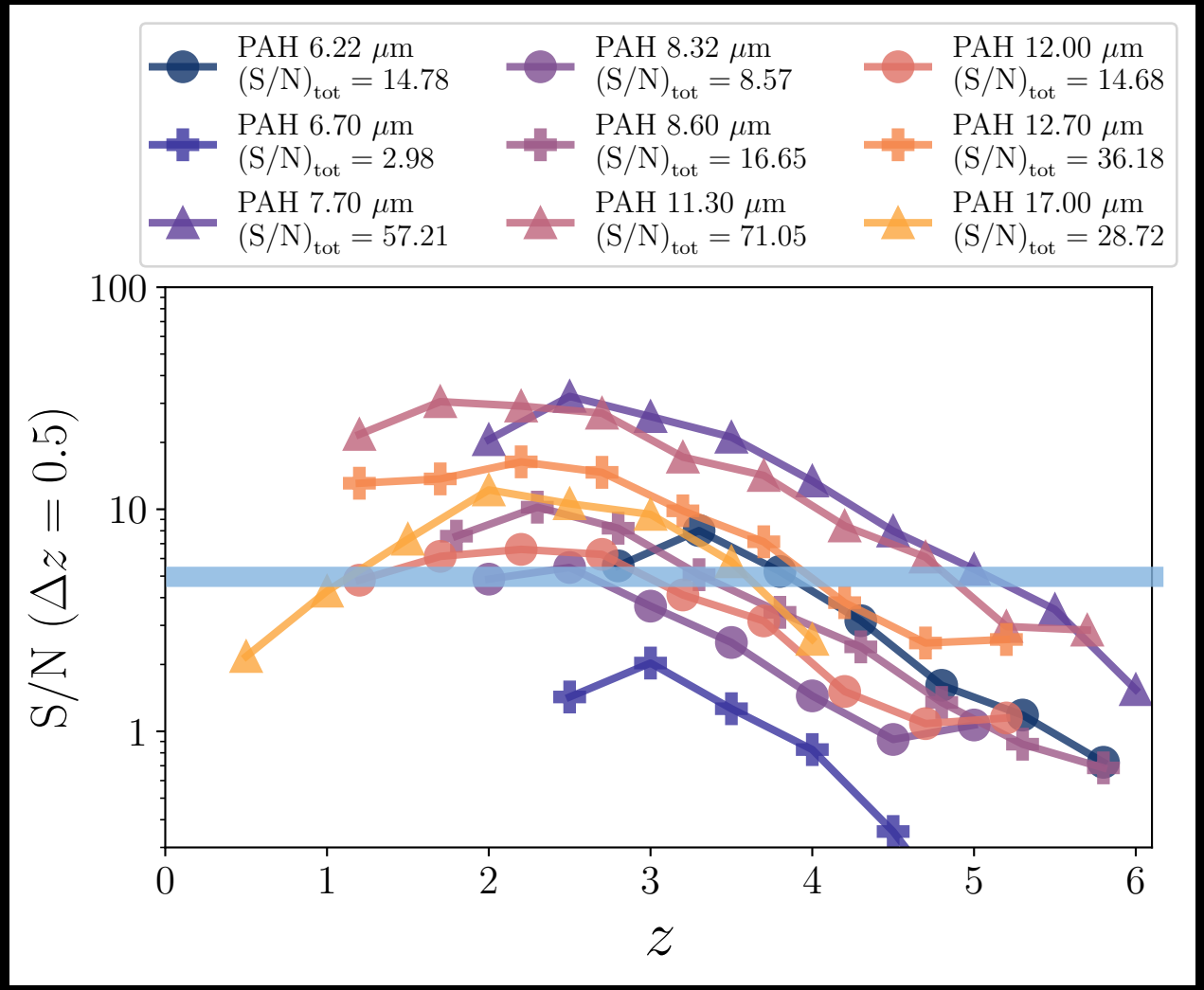
$\{\theta\}$

$$\ln\mathcal{L} = -\frac{1}{2}\sum_{\ell} \mathrm{Tr}\left(C^d_\ell (C^m_\ell)^{-1}\right) + \log|C^m_\ell|$$



PAH Intensity Mapping Sensitivity

PRIMA
(PRIMAger)
1000 hrs
1 deg²



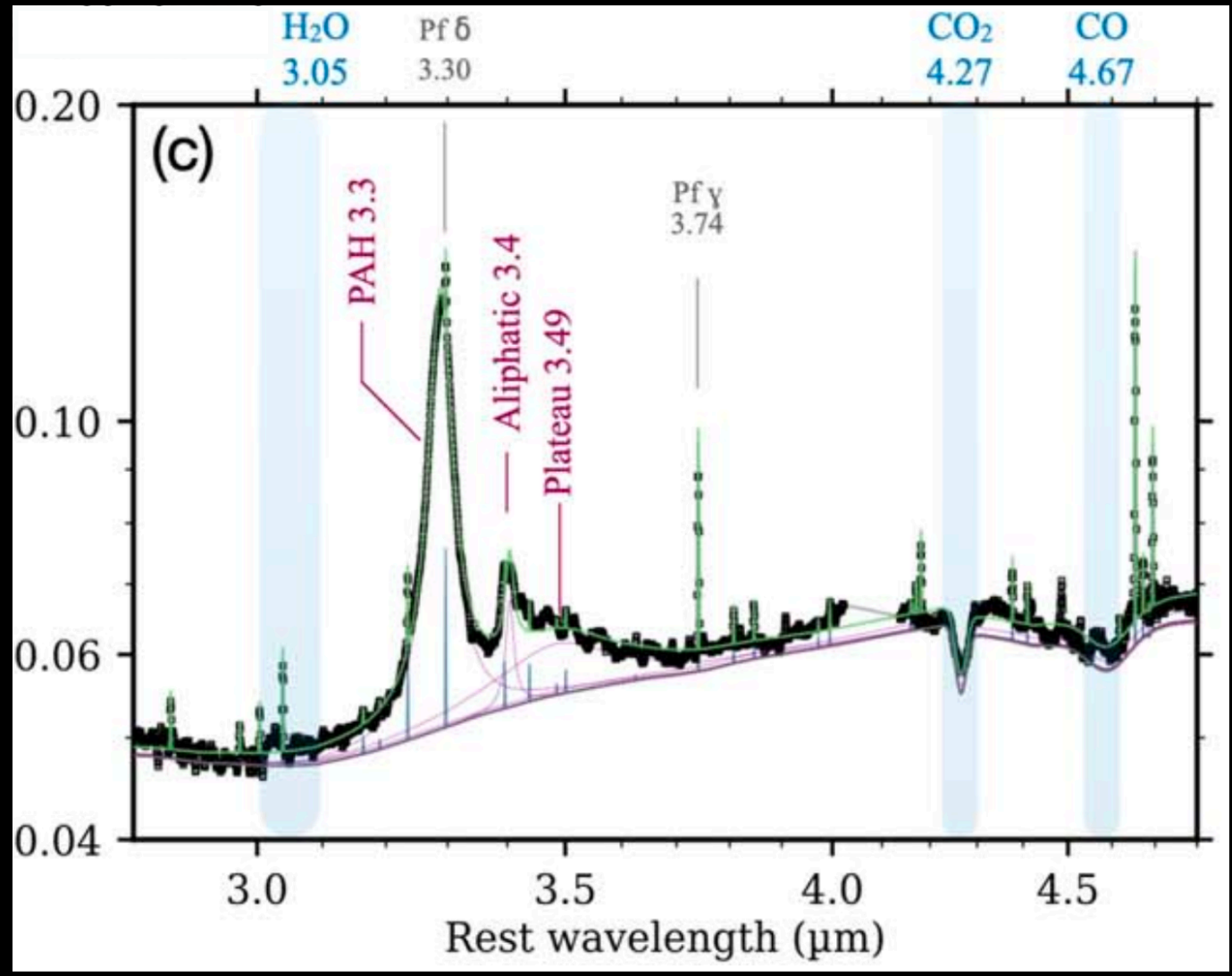
Cheng, Hensley & Lai
2025 in prep.

“Feature Intensity Mapping” in the near future!

Near-IR Spectrum

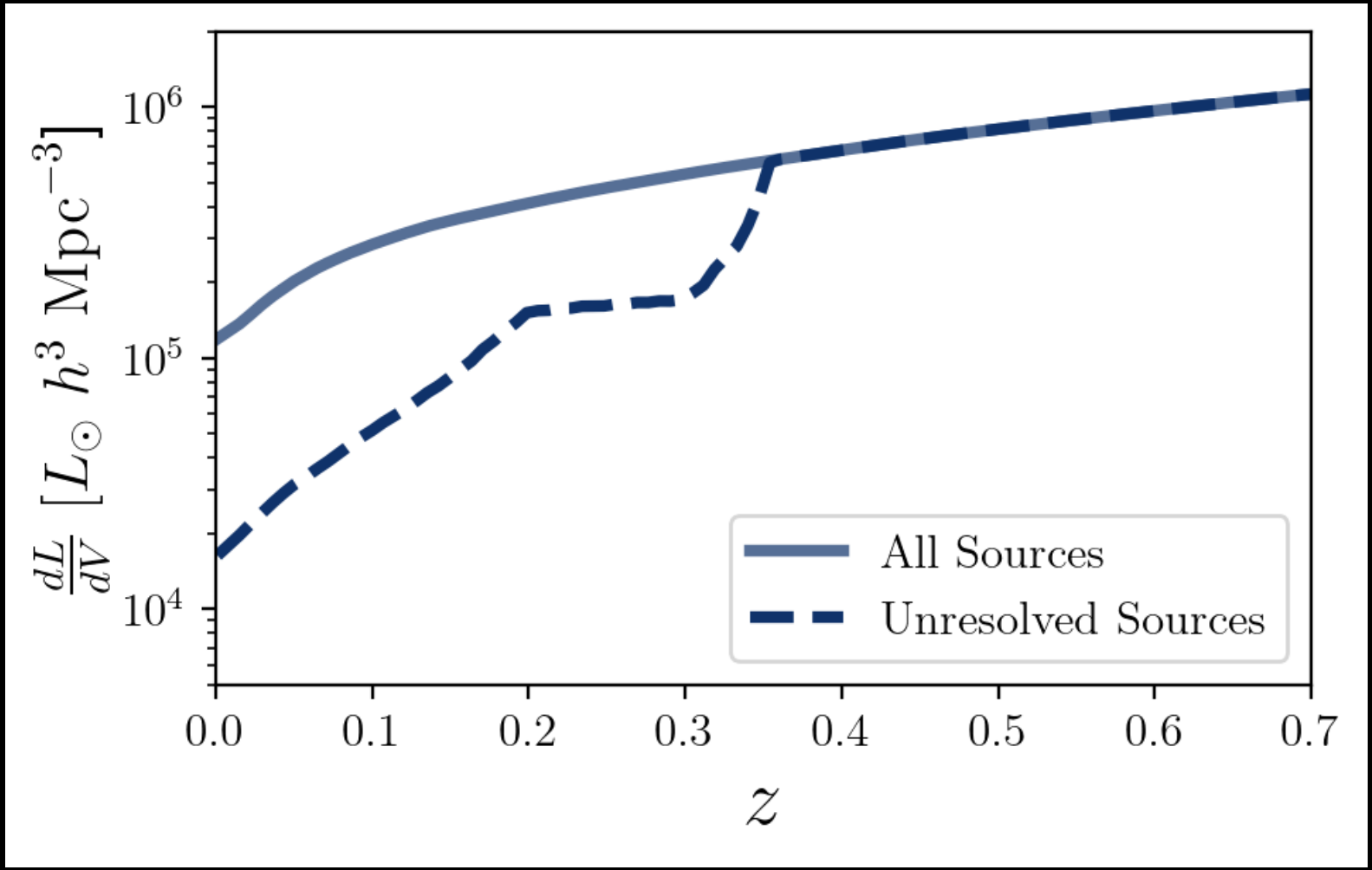
SPHEREx:
0.75 — 5 um

PAH 3.3 @ z = 0 — 0.5



Lai et al. 2023

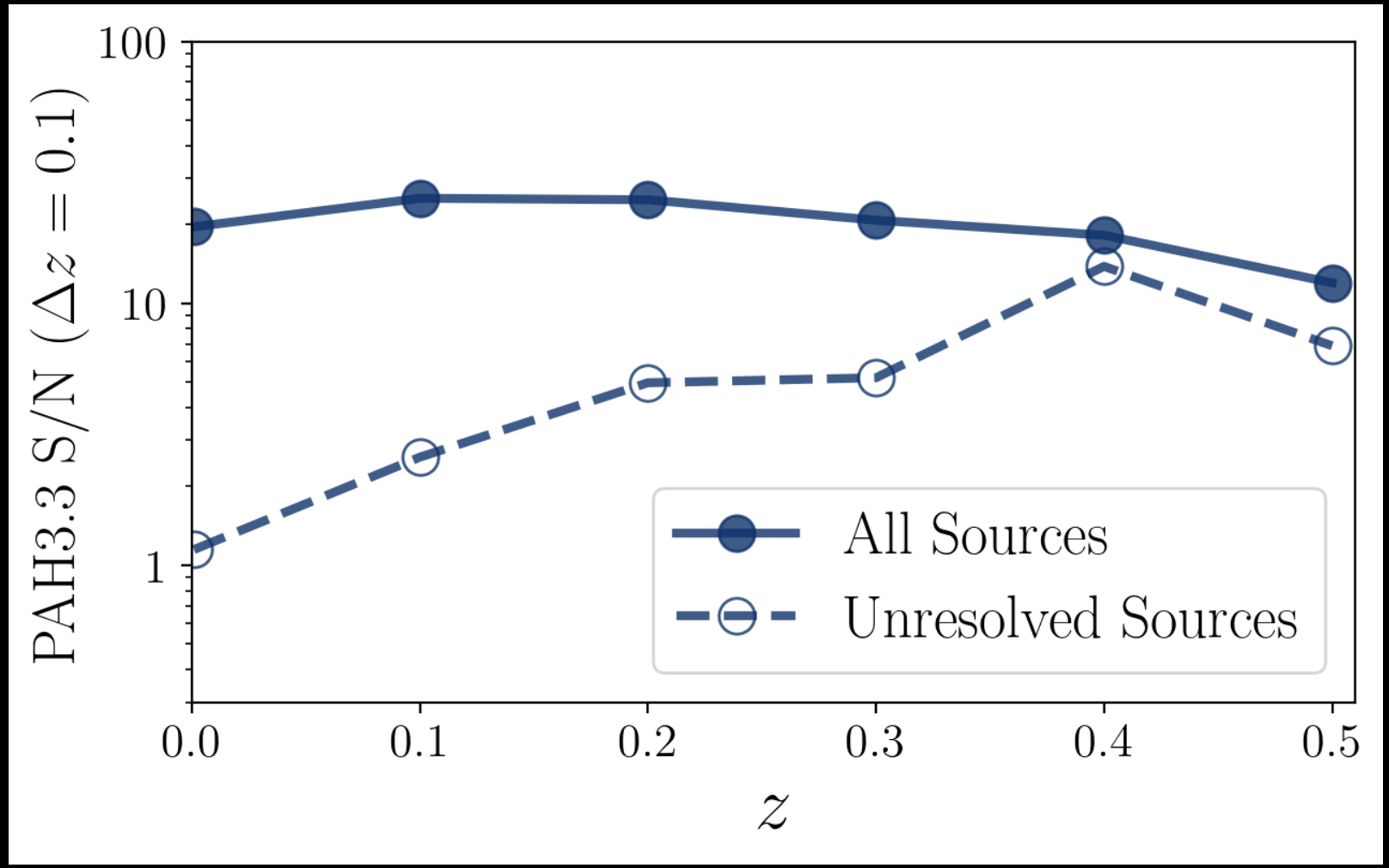
Do we Need Intensity Mapping at z < 0.5?



Individual PAH 3.3 detection limit from Zhang et al. 2025

Cheng, Hensley & Lai 2025 in prep.

PAH 3.3 um Sensitivity in SPHEREx



Cheng, Hensley & Lai
2025 in prep.

Conclusion

- PRIMA will open up the LIM measurement in FIR for multiple lines and PAHs
- We develop the “feature intensity mapping” formalism, an analogy of LIM for mapping broad spectral features such as PAHs
- PRIMA is capable of mapping multiple PAHs from z=1 — 5
- SPHEREx can perform IM with PAH 3.3 um with high S/N at $z < 0.5$