Tomographic retrieval of thermosphere gravity waves from the Far Ultraviolet Imager (FUVI) on the future DYNAGLO CubeSat mission

Maggie Zheng[1,2], Aimee Merkel[1], Scott Palo[2]

[1]CU Boulder/LASP [2]CU Boulder/Aerospace Engineering Science

INTRODUCTION

Abstract

- **Gravity waves (GWs)** play a crucial role in the transfer of momentum and energy throughout the Earth's atmosphere
- There are **limited measurements of GWs**, especially in the mesosphere and lower thermosphere (MLT)
- The DYNamics Atmosphere GLObal-Connection (DYNAGLO) CubeSat mission (planned to launch in Spring 2026) will provide the community with **global thermosphere gravity wave measurements**
- DYNAGLO will fly the Far Ultraviolet Imager (FUVI) and measure **aurora emission** and **neutral density variations in OI (135.6 nm) and N_2 (LBH)**
- Utilizing tomographic methods on FUVI measurements would provide coincident observations of **both vertical and horizontal wavelengths**, enhancing DYNAGLO science

DYNAGLO CONOPS

In nominal science operations, two identical 6U DYNAGLO CubeSats will use a Far Ultraviolet Imager (FUVI) instrument to image airglow emission over the dayside thermosphere and the auroral oval and measure variations in OI (135.6 nm) density, N_2 (LBH) density, and aurora emission. The two satellites will be in a string-of-pearls formation with 5 minutes of separation maintained by differential drag. DYNAGLO will fly each CubeSat in a 600 km orbit, using the 40° FOV, nadir-pointing FUVI to image a ~150 km emission layer (Fig. 1).

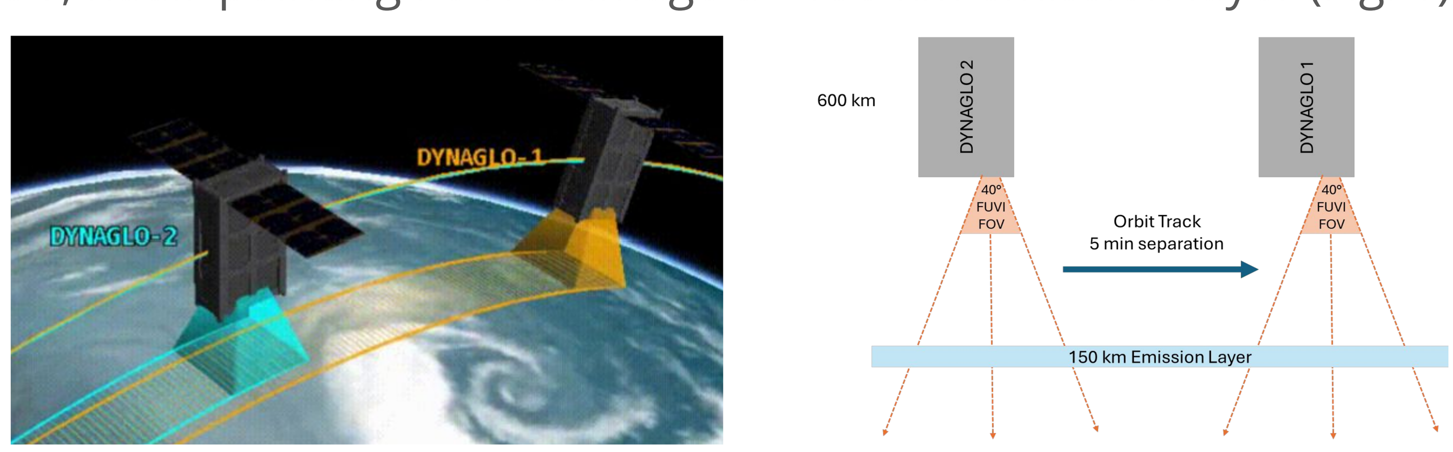

Fig. 1: DYNAGLO string of pearls formation for nominal science. Each CubeSat images the dayside thermosphere with a nadir-facing FUVI

DYNAGLO will provide horizontal wavelengths of medium to large scale GWs (100 km to >1000 km), as well as frequency of occurrence, geographic location, phase speeds (120 m/s to 1100 m/s) (Fig. 2).

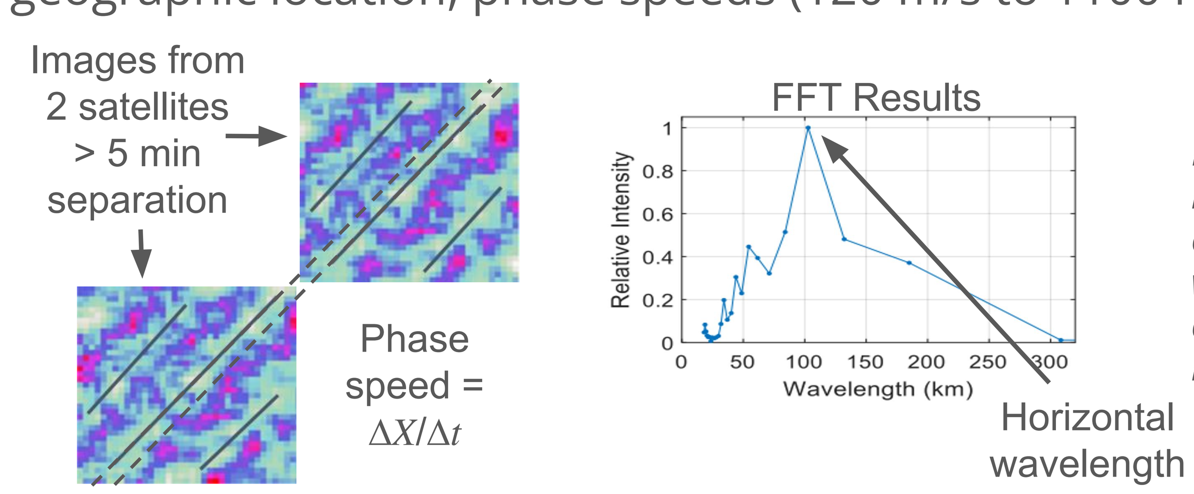

Fig. 2: Simulated FUVI images. Phase speed and horizontal wavelength can be determined from the images.

WHAT IS TOMOGRAPHY?

Tomography is a process to reconstruct a 3D feature or 2D slices of a feature using multiple measurements at varying viewing angles. Tomographic methods have been applied to a wide variety of different measurements, from X-ray images (Fig. 3) to GPS or radio beacon signals (Fig. 4). Space-based limb and nadir scans of FUV airglow emissions have been used to tomographically reconstruct auroral or ionospheric structures using instruments such as GUVI and SSULI/SSUSI (Fig. 5).

Examples of Tomography:

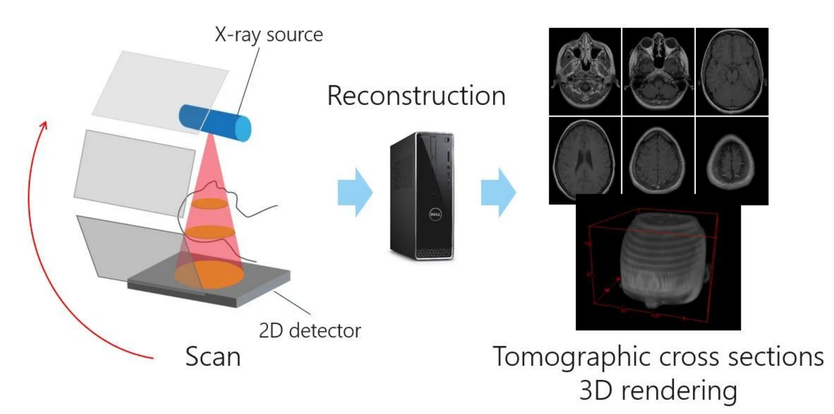

Fig. 3: Schematic of tomographic methods applied to X-ray CT scans to provide biomedical imaging [1]

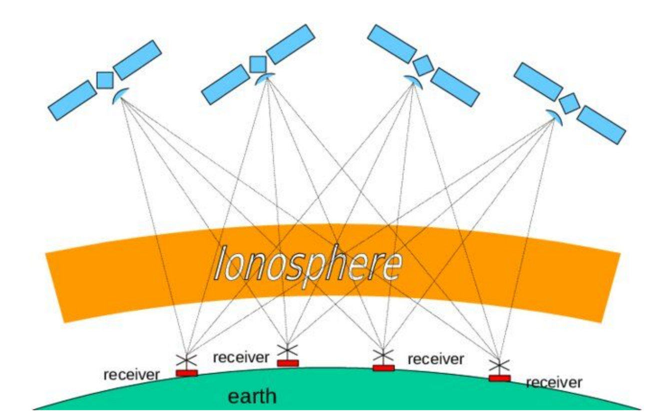

Fig. 4: Schematic of GPS signal viewing geometries, adapted from van de Kamp (2013). Tomographic methods applied to GPS-derived TEC measurements have been commonly used to study the ionosphere. [2]

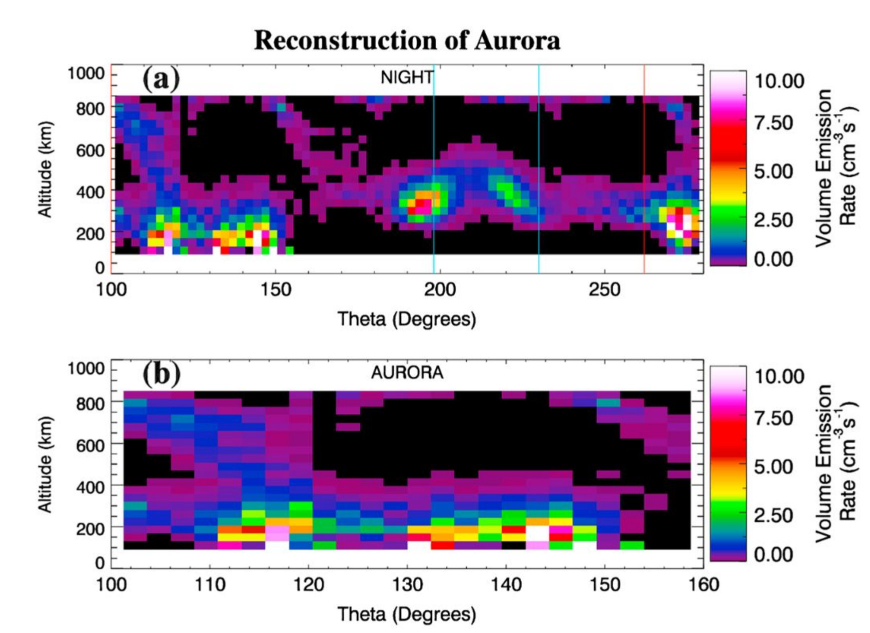

Fig. 5: SSULI/SSUSI tomographic reconstructions using VERT method, Hei et al. (2017) [3] (a) Full orbit reconstruction of nighttime ionosphere (b) Reconstruction of auroral structure

Mathematical Overview:

Radon Transform:

$$\mathcal{R}f(t,\theta) = \int_{-\infty}^{\infty} f(x(s), y(s))ds = \int_{-\infty}^{\infty} f(t\cos\theta - s\sin\theta, t\sin\theta + s\cos\theta)ds$$

- The Radon transform involves integrating an unknown function *f* along a line $l_{t,\theta}$ (See Fig. 6)
- This represents projection data obtained along a particular viewing angle
- The original function can be reconstructed with methods such as filtered back projection, algebraic reconstruction technique (ART), or multiplicative ART (MART)

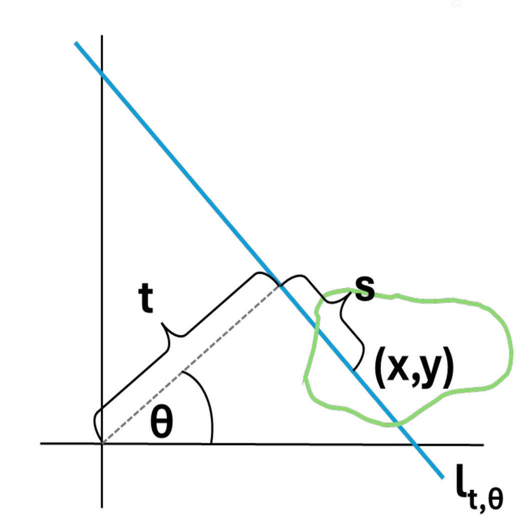

Fig. 6: Description of Radon Transform coordinate system, adapted from Beatty (2012) [4]

CONCEPT

In order to apply tomographic methods, the DYNAGLO CubeSats would be maneuvered into a special tomography mode configuration in order to maximize the number of viewing angles. Tilting the spacecraft allows imaging of the same common volume simultaneously (Fig. 7).

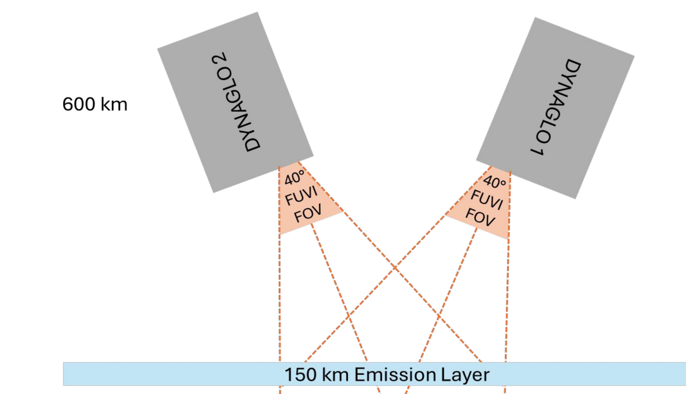

Fig. 7: One concept of special tomography operations, where the two DYNAGLO CubeSats are oriented toward each other

In a special tomography mode, DYNAGLO would be able to provide information on the vertical structure of the GWs, such as in the visualization in Fig. 8b. Coincident observations of both vertical and horizontal GW wavelengths would enhance DYNAGLO science by providing a means to calculate other parameters, such as momentum flux, dissipation altitudes, and maximum wavelengths of propagating GWs prior to dissipation [9], [10], [11].

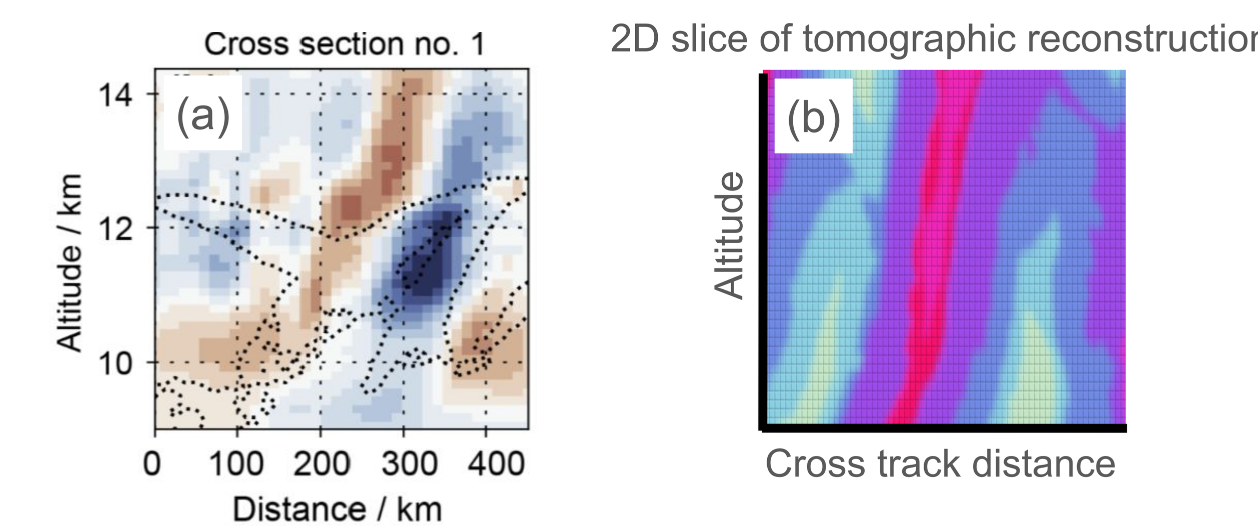

Fig. 8: (a) Example of tomographic reconstruction of GWs from limb sounder adapted from Krish et al. (2018) [5]. 2D slice of gravity wave structure across the orbit track (b) Concept of DYNAGLO tomographic retrieval output. 2D slice of gravity wave structure across the orbit track

Determining how to leverage tomographic retrievals from FUVI measurements is still in a preliminary conceptual phase. The determination of the optimal configuration for the spacecraft during tomographic operations would maximize the number of viewing angles while accounting for spacecraft drag or decreased power generation. In addition, the inversion problem to retrieve tomographic reconstructions from limited viewing angles results in a severely underdetermined problem, thus requiring careful selection of a regularization scheme to retrieve a solution.

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Contact Information:
maggie.zheng@lasp.colorado.edu

References

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