An important advance in understanding Instability breakdown using imagers, a lidar, modeling, and laboratory data. (A CEDAR success story)

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INTRODUCTION

- **From the very beginning a CEDAR goal was to foster collaboration and to develop well-instrumented ground sites.**

- **Andes Lidar Observatory (ALO) - Cerro Pachon Chile (30S)**
  - Started in late 2009 (lidar, radar, optical instrumentation)
  - This was formulated by Professor Gary Swenson (University of Illinois)
  - Supported by NSF
  - Many papers and cutting-edge instrumentation has been deployed there

- **This study, which brings together ground-based data, state of-the-art-modelling and laboratory data for its interpretation, is an example of CEDAR collaborative science.**

Background

- **In February 2016 a new imager was deployed.**
  - **Aerospace Nightglow Imager 2 (ANI2)**
    - **Jim Hecht, Lynette Gelinas, Rick Rudy**
    - 2048 x 2048 pixels over 28-degree FOV = ~25 m pixels
    - Binned 1024 x1024
    - ~20 s cadence

- **Two Instruments already existed at ALO.**
  - **Aerospace Nightglow Imager 1 (ANI1)**
    - 256 x 256 pixels over 70-degree FOV = 500 m pixels (few s)
  - **Na W/T lidar (Embry-Riddle)**
    - Winds and Temperatures Every Minute

- **Modeling**
  - **Dave Fritts (GATS Inc.), Richard Walterscheid (Aerospace Embry-Riddle)**

What Did We Hope to See

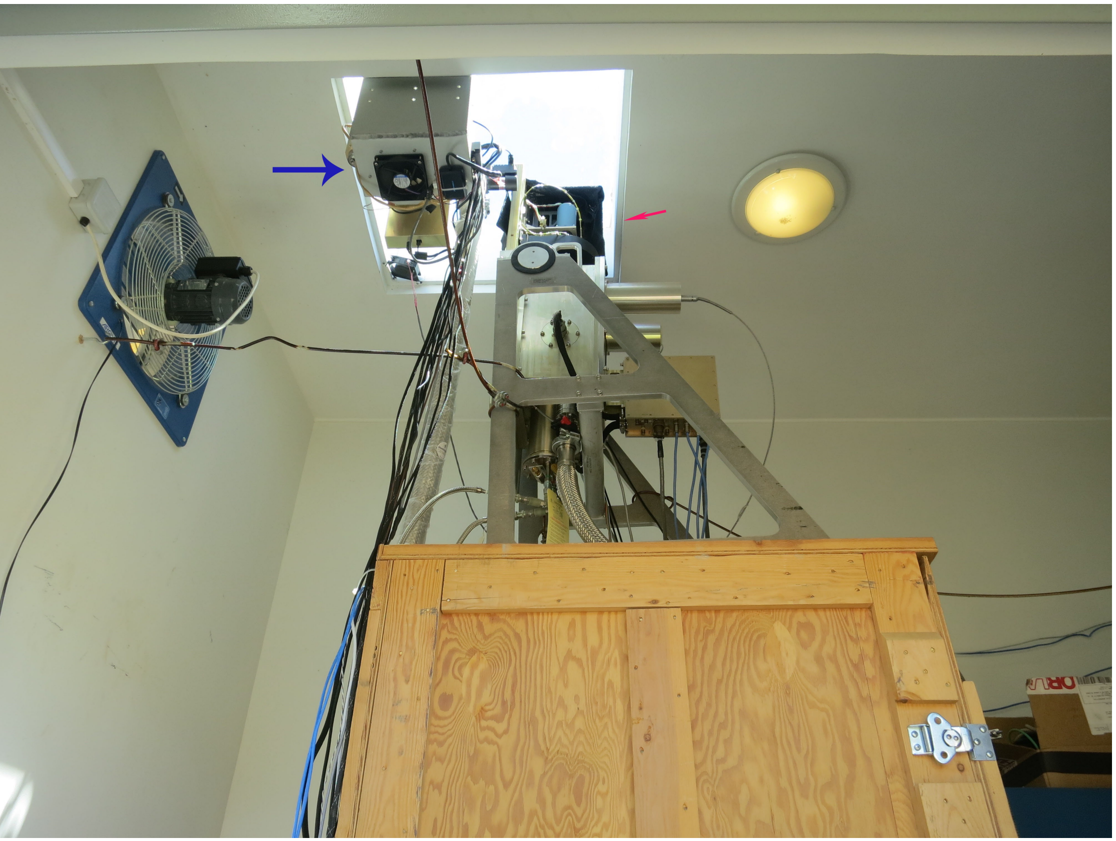
- **When the atmosphere cools rapidly and large wind shears exist, unstable structures can form.**
  - In the lower atmosphere Kelvin-Helmholtz Instabilities (KHIs) produce certain types of billow clouds.
  - In the upper atmosphere in the airglow region (85 km) they appear as wavelike features in airglow images. When they breakdown they form turbulence.

- **Whenever a new instrument is deployed with new capabilities one hopes to see new phenomena.**
  - ANI2 has high spatial resolution and we expected that new data would reveal new information on how KHIs breakdown into turbulence.

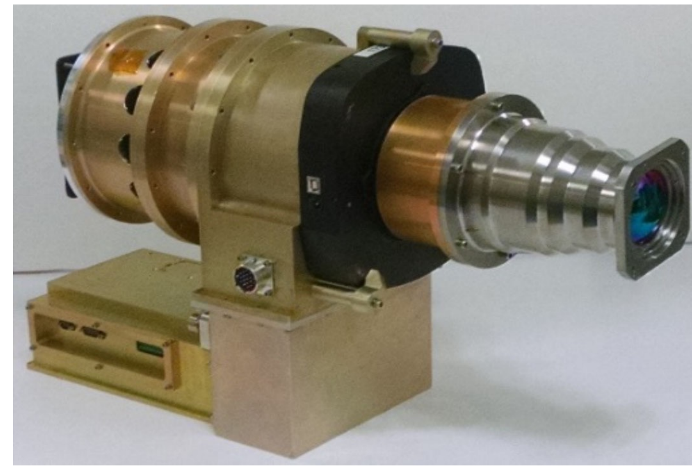
- **We know from the modelling that Dave Fritts has performed that as those studies have increased their resolution, they have revealed new features in the breakdown process.**
  - An example are the vortex rings predicted in Gravity Wave breakdown that ANI1 saw over ALO in a previous study.

Imagers at ALO

Blue Arrow ANI2 (in window) **ANI1** (on box)



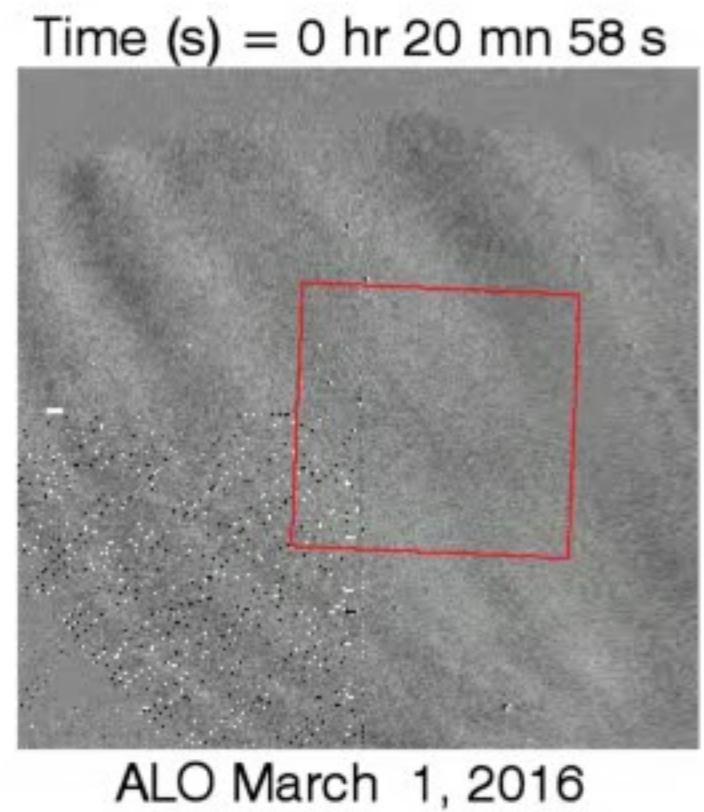
ANI2



Prototype of NIRAC, a high-spatial resolution airglow imager now on the International Space Station.

- **Difference Images Every ~ 20-25 s ANI1 and ANI2**

ANI1 ~20/50s Difference Movie



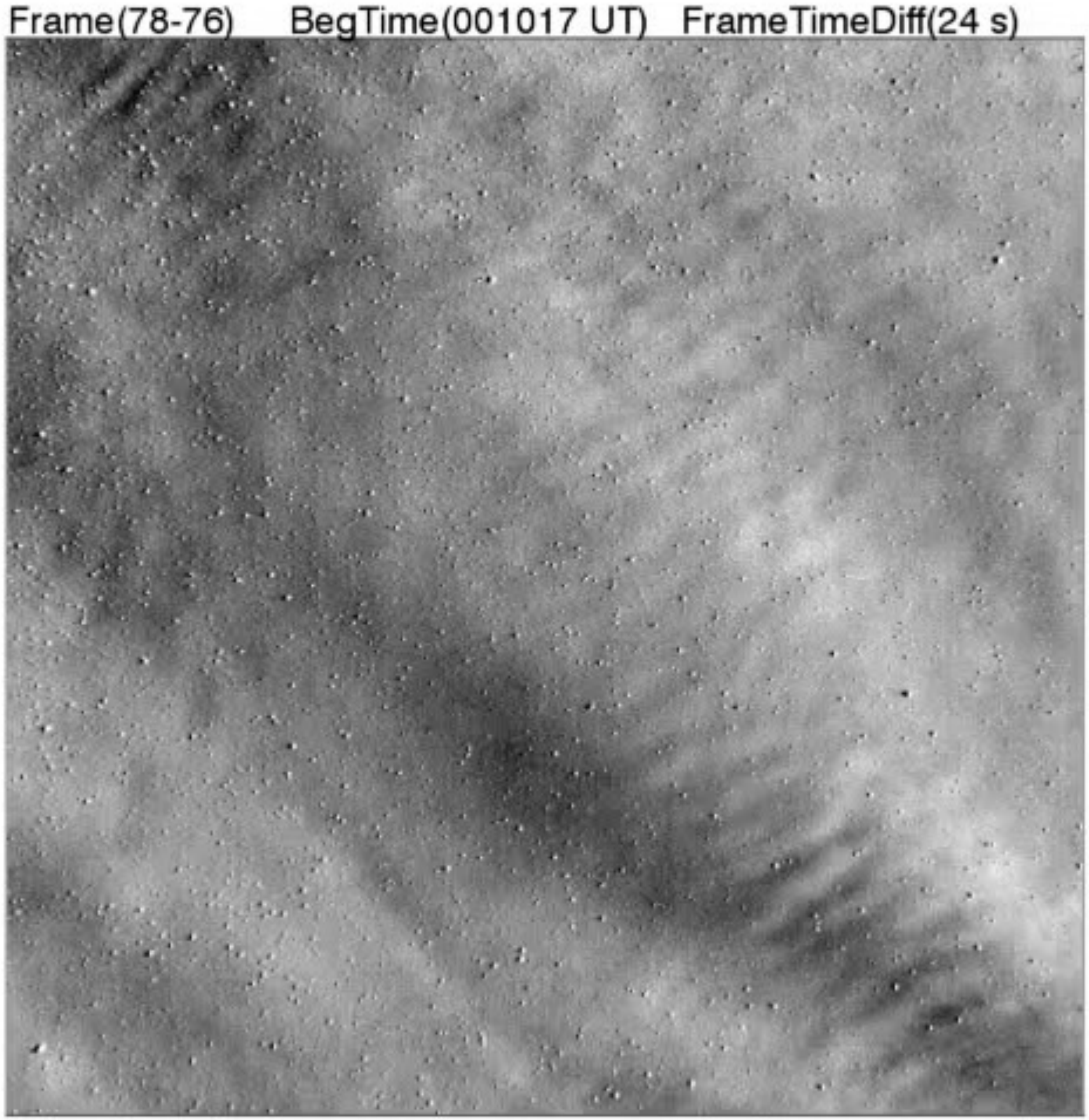
Red Box FOV of ANI2
Gravity Waves Move from Lower Left to Upper Right
KHIs Move from Lower Right to Upper left

ANI2 Difference MOVIE

Gravity Waves (GWs) are aligned **Perpendicular to KHI** billows

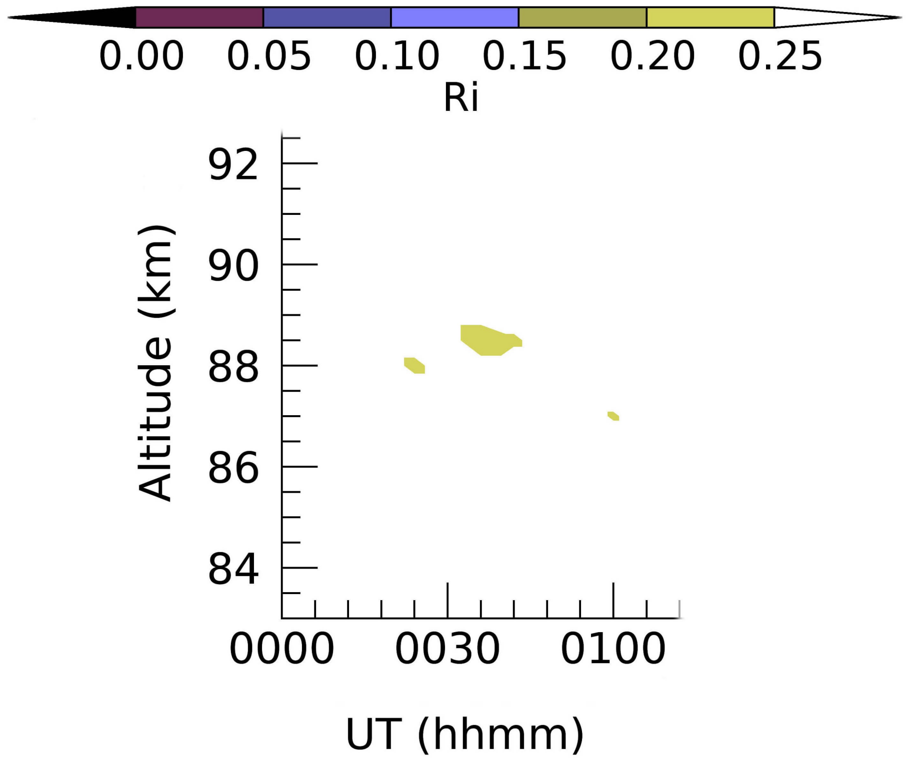
GWs Propagate From **Lower Left (SE) t[o] Upper Right (NW)**

KHI Billows Propagate Perpendicular to the GWs **Lower Right to Upper Left**



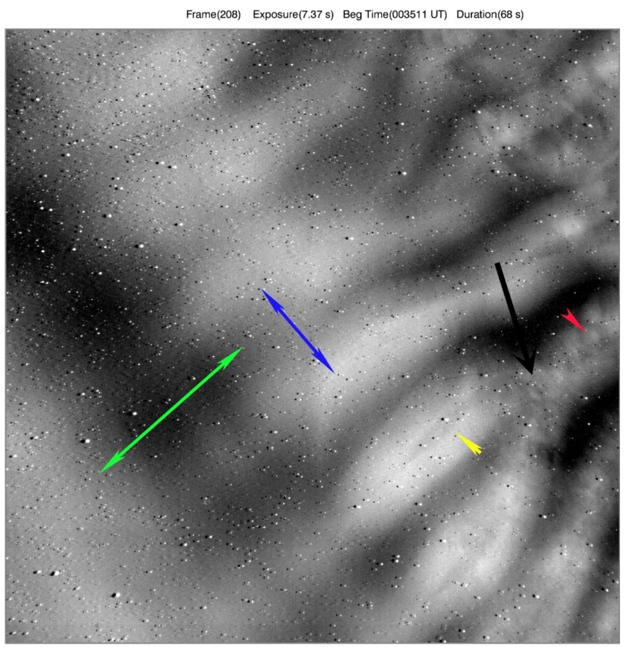
OVERVIEW

ALO Lidar Data Showing Unstable Layer around 0035 UT on 03/01/16



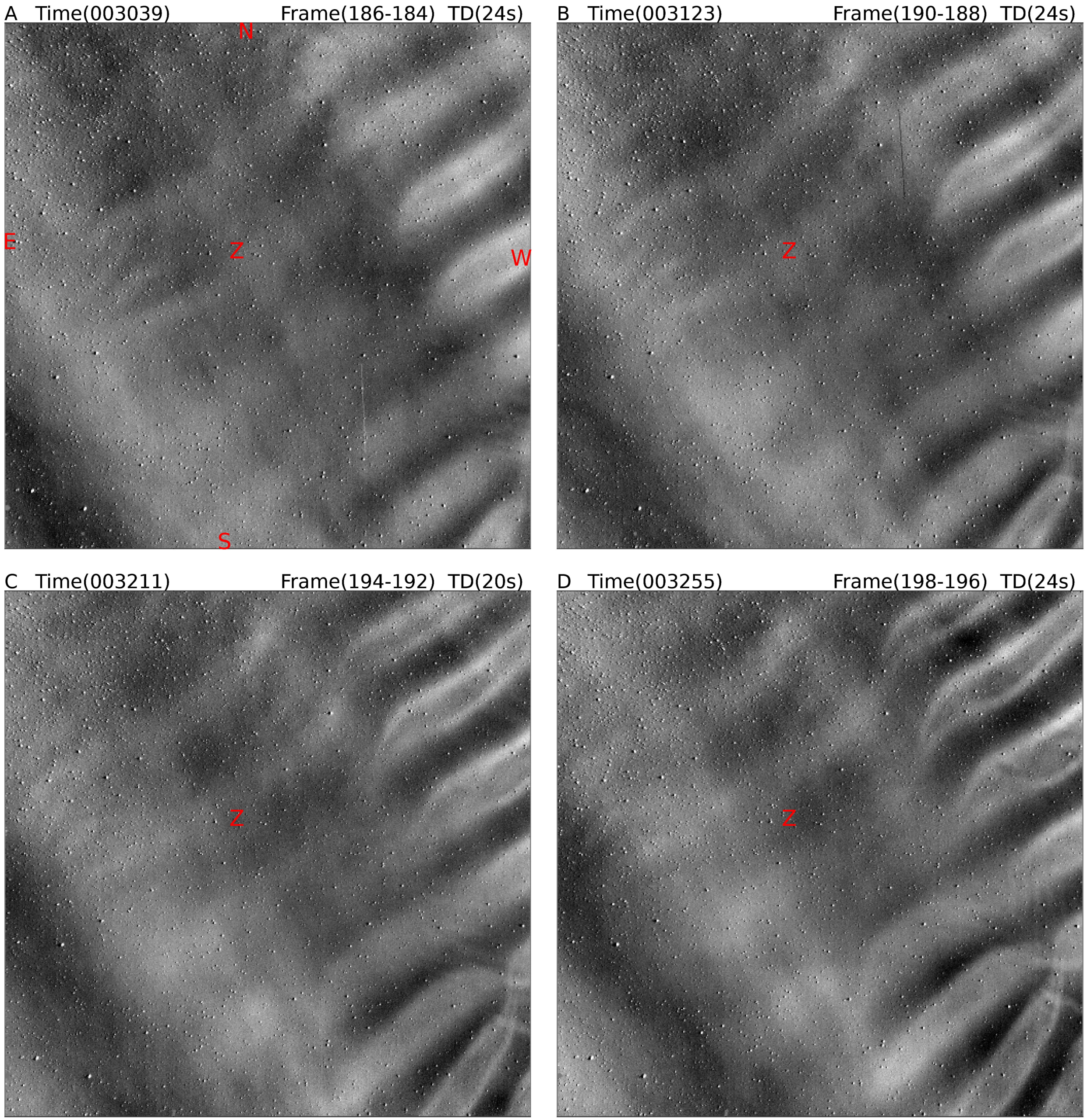
Ri=Richardson Number~Buoyancy/Shear <0.25 (Unstable, allow KHIs to Form)

OH ANI2 Data Over 60 x 60 km At 0035 UT Showing KHIs Evolving Into Turbulence

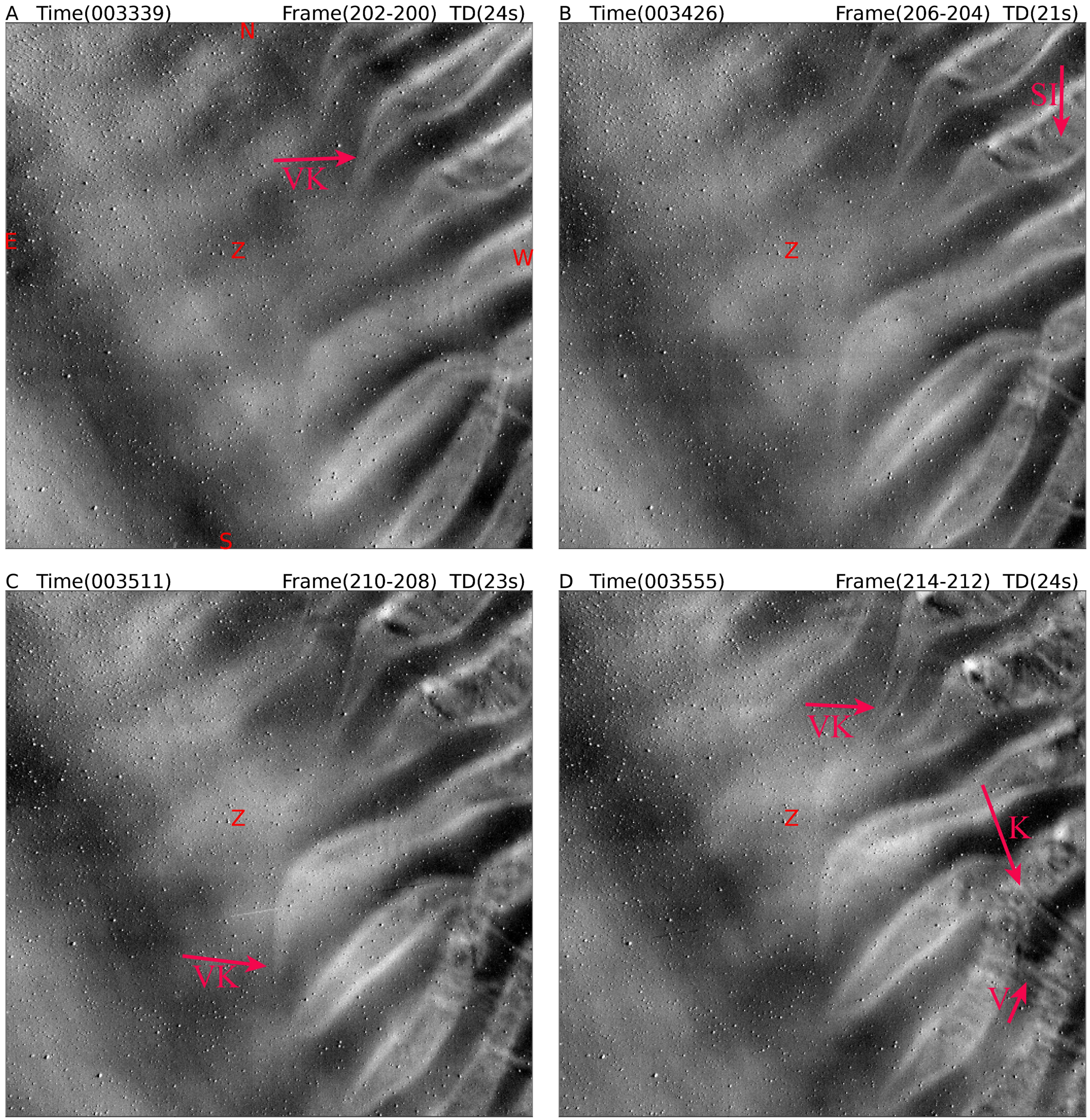


Green Arrow-GW Wavelength
Blue Arrow-KHI Wavelength
Black Arrow-Knot where two KHIs join

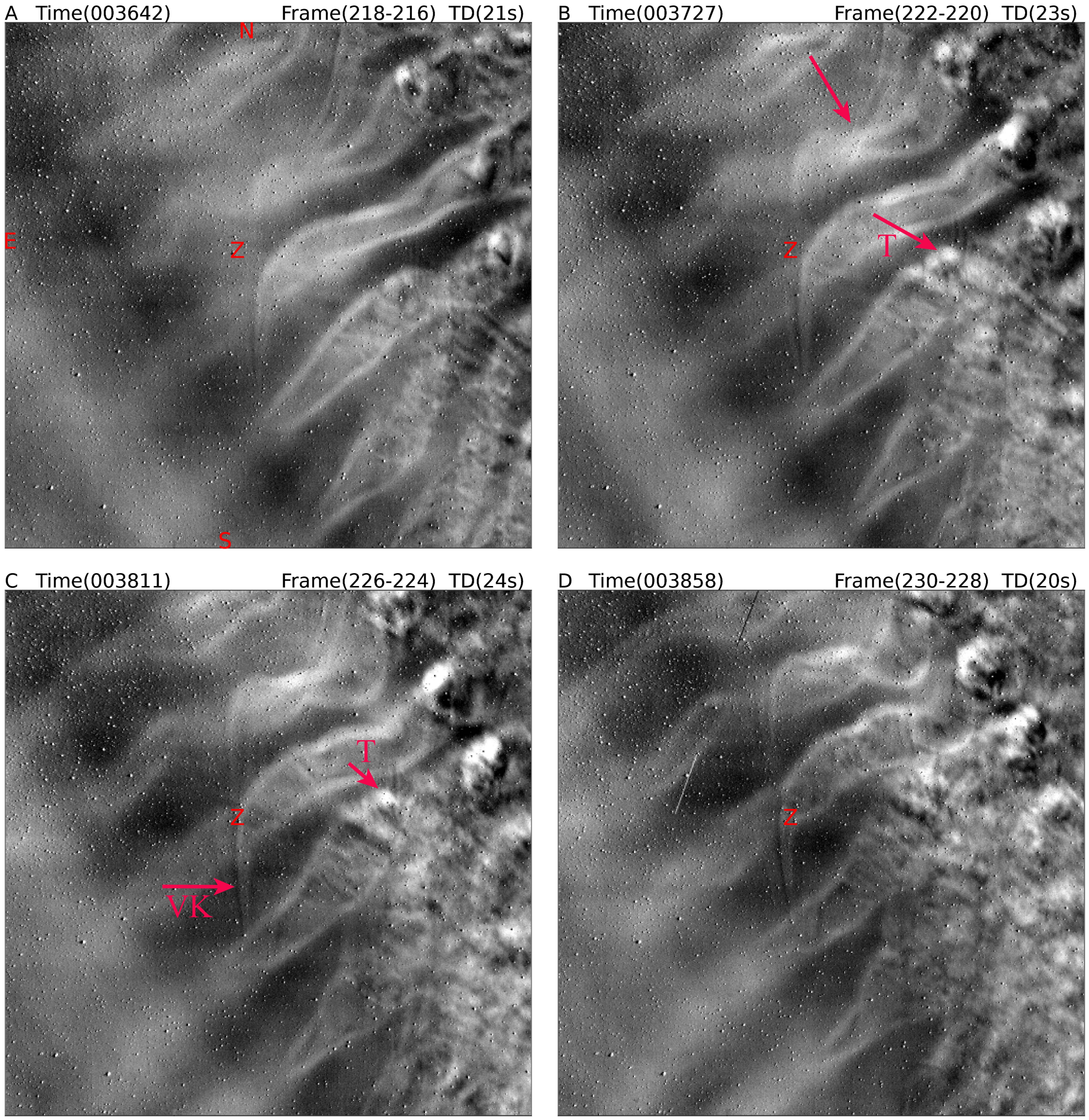
KNOTS ARE A SITE OF ENHANCED TURBULENCE- A KEY DISCOVERY OF THIS JOINT OBSERVATIONAL MODELING STUDY



These images showing the KHIs just as the first Knots appears (lower right) but before turbulence production has begun.



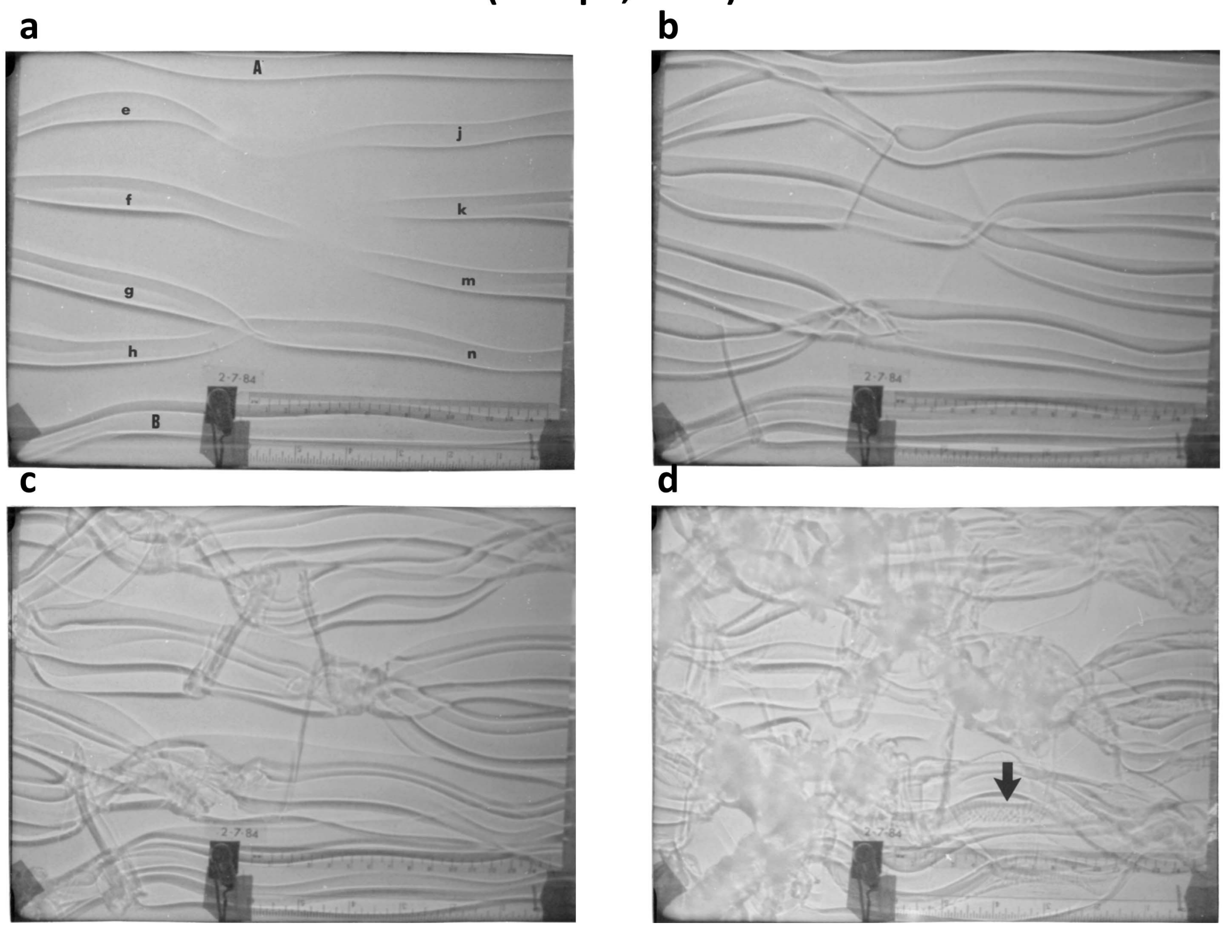
The arrow marked K in lower right panel points to a Knot showing enhanced turbulence. The arrows marked VK point to vortex tubes that will join to form Knots



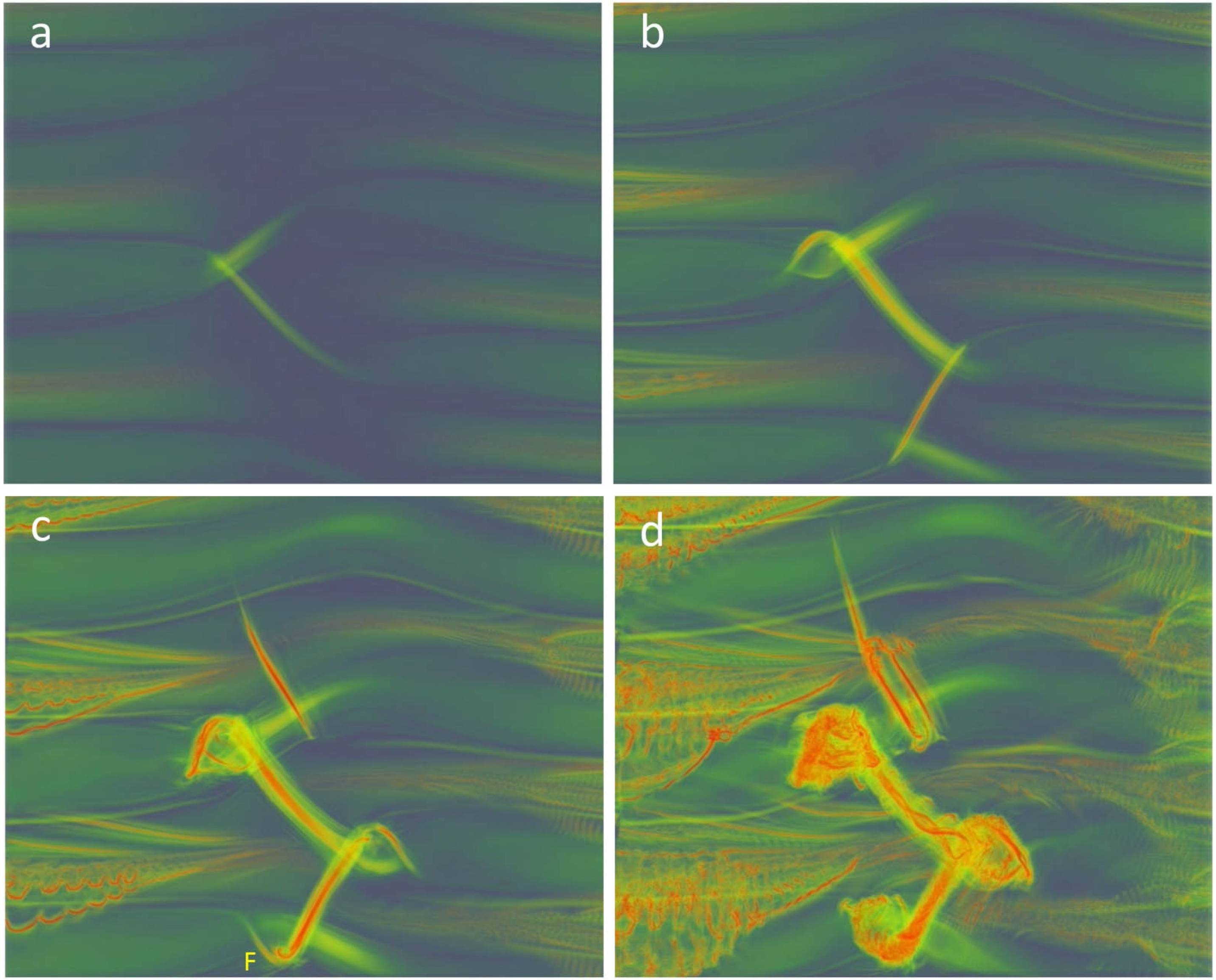
The feature labelled T(red arrow in lower left panel) was followed in time and a large energy dissipation rate of ~1 W/kg was measured.

Laboratory data from Professor Steve Thorpe revealed similar features including Knots in 2002. He also hypothesized that an Internal GW travelling at right angles might influence Knot development.

KHI billow instability "knots" seen in the laboratory (Thorpe, 2002)



However, the significance of the Knots were not fully revealed until Dave Fritts computer modeling revealed….



…that Knots are indeed the source of considerable enhanced turbulence and energy dissipation.

SUMMARY

- **Intense KHI Billows were observed to form when the atmosphere was revealed by ALO Lidar Data to become unstable.**
  - Right Angles to Underlying GW
  - Intensification affected by the passage of underlying GWs
  - This is probably due to GWs modifying the shear layer and decreasing Ri
    - This effect still needs to be modeled

- **Billow Interaction form Knots similar to what is seen in the lab.**

- **Energy Dissipation in one part of the Knot region was quite high (1W/kg).**

- **Computer Simulations by Dave Fritts have shown that Knots are a source of enhanced turbulence.**

- ***AGU Research Spotlight***
  - **Newly Identified Instabilities Enhance Atmospheric Turbulence Jan 12, 2021.**

- Hecht, J. H., Fritts, D. C., Gelinas, L. J., Rudy, R. J., Walterscheid, R. L., & Liu, A. Z. (2021). **Kelvin-Helmholtz billow interactions and instabilities in the mesosphere over the Andes Lidar Observatory: 1. Observations.** *Journal of Geophysical Research: Atmospheres*, 126, e2020JD033414.
- Fritts, D. C., Wieland, S. A., Lund, T. S., Thorpe, S. A., & Hecht, J. H. (2020). **Kelvin-Helmholtz billow interactions and instabilities in the mesosphere over the Andes Lidar Observatory: 2. Modeling and interpretation**. *Journal of Geophysical Research: Atmospheres*, **125**, e2020JD033412.