A Parametric Study of Oxygen Ion Cyclotron Harmonic Waves by an Oxygen Ring Distribution

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Introduction

- Earth's magnetosphere is full of collisionless magnetized plasma composed of e^-, H^+, He^+, and O^+ ions with energy from several eV to hundreds MeV.
- The plasma waves can resonate and scatter the ions and electrons in space and lead a precipitation of the charged particles into Earth's ionosphere.
- Oxygen (ion) cyclotron harmonic (OCH) waves are electromagnetic emissions with the wave frequency at or near the harmonics of the oxygen ion cyclotron frequency.
- The wave normal angle (WNA) of OCH waves is nearly 90 degrees (perpendicular to the ambient magnetic field; WNA is defined as the angle between the wave vector and ambient magnetic field)
- OCH waves can be excited by energetic (~keV) oxygen ions of a ring-like distribution in a gyrotropic plasma.
- Bi-Maxwellian ring-like distribution

$$f_r(v_{||}, v_\perp) = \frac{n_r}{\pi^{1.5} a_{||} a_\perp^2 C_r} \exp\left(-\frac{v_{||}^2}{a_{||}^2}\right) \exp\left(-\frac{(v_\perp - v_r)^2}{a_\perp^2}\right)$$

$$C_r = \exp\left(-\frac{V_r^2}{a_\perp^2}\right) + \sqrt{\pi}\frac{V_r}{a_\perp}\,\mathrm{erfc}\left(-\frac{V_r}{a_\perp}\right)$$

- In this study, we perform a parametric study of OCH waves by an oxygen ring distribution. We investigate the effects of the concentration (η_{ho}, i.e., n_r), velocity (v_r) and temperature (T_r, i.e., $a_\perp^2$) of the oxygen ring, total oxygen ion concentration (η_o), and wave normal angles (WNA).

OCH Wave Observation

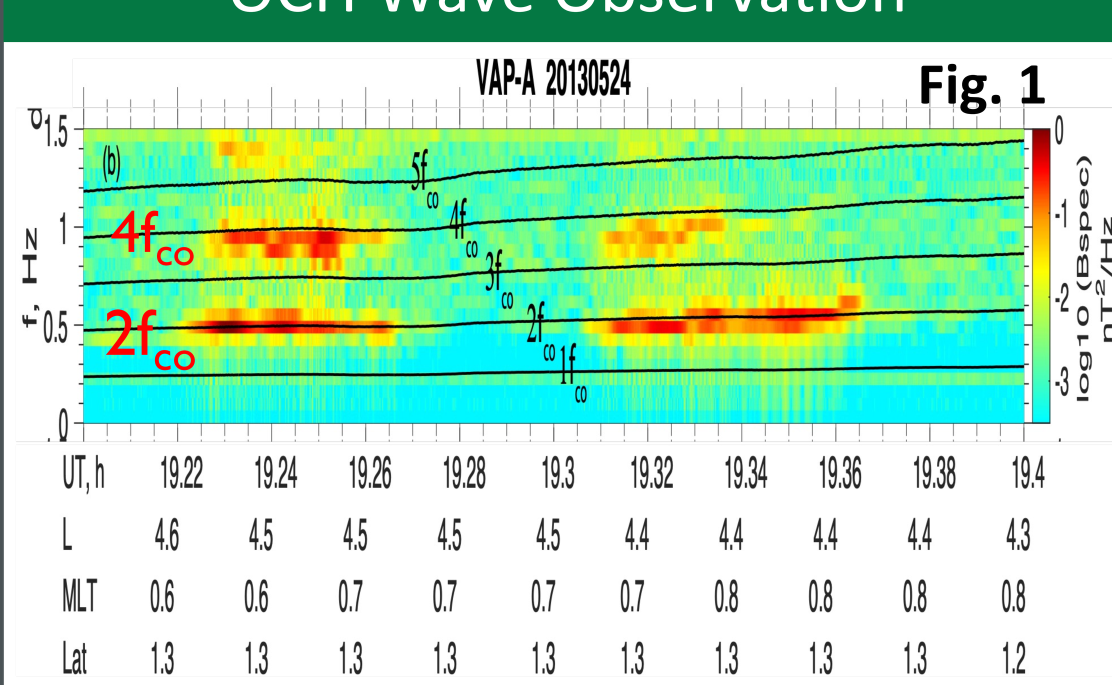

Fig. 1

Conclusions

Dependences on ring temperature and WNA are not shown here due to poster limitation. Please check our paper for these results. Below is the principal conclusions of the paper.

- Growth rates increase and frequency extends to higher O^+ harmonics as O^+ ring and total O^+ concentrations increase or ring temperature decrease.
- OCH waves shift from the H^+-EMIC mode to the MS mode as the O^+ ring velocity increases. Thus, the frequency can extend to higher O^+ harmonics. Correspondingly, polarization shifts from B_y (transverse) dominance to B_z (compressional) dominance.
- As WNAs increase, the OIBM wave becomes stronger and extends to a wider frequency range, while H^+-EMIC mode is weaker and limited to a narrower frequency range.
- The growth rates increase as k corresponding to O^+ ring and cold plasma wave mode become closer. Peak growth rates follow first peak of J_n^2 when $k_{J_n^2} > k_{cwm}$, and then, shift to cold plasma wave mode when $k_{J_n^2} < k_{cwm}$, which can explain the O^+ ring velocity and WNA dependences.

Publication

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Wave Properties With Frequency Below Proton Gyrofrequency f_{ch}

Plasma temperature:
- Cold e^-: 2 eV
- Cold H^+: 2eV
- Cold O^+: 2 eV
- O^+ ring: 1.5 keV, v_r/V_A=1
- No helium

Ion mass (reduced):
- m_o/m_h=16, m_h/m_e=100

Ion concentration:
- $\eta_{ho}= n_{ho}/n_o$=0.5
- $\eta_o=n_o/n_e$=0.05

Other conditions:
- c/V_A=10
- WNA=87 deg (B_x<<B_z)

Coordinates:
- Z: parallel direction (along ambient magnetic field)
- Y: perpendicular to wave vector **k** and Z-axis
- X: **k** is inside XZ plane

Dispersion relation and linear growth rate (LGR) — **PIC for validation by TACC**

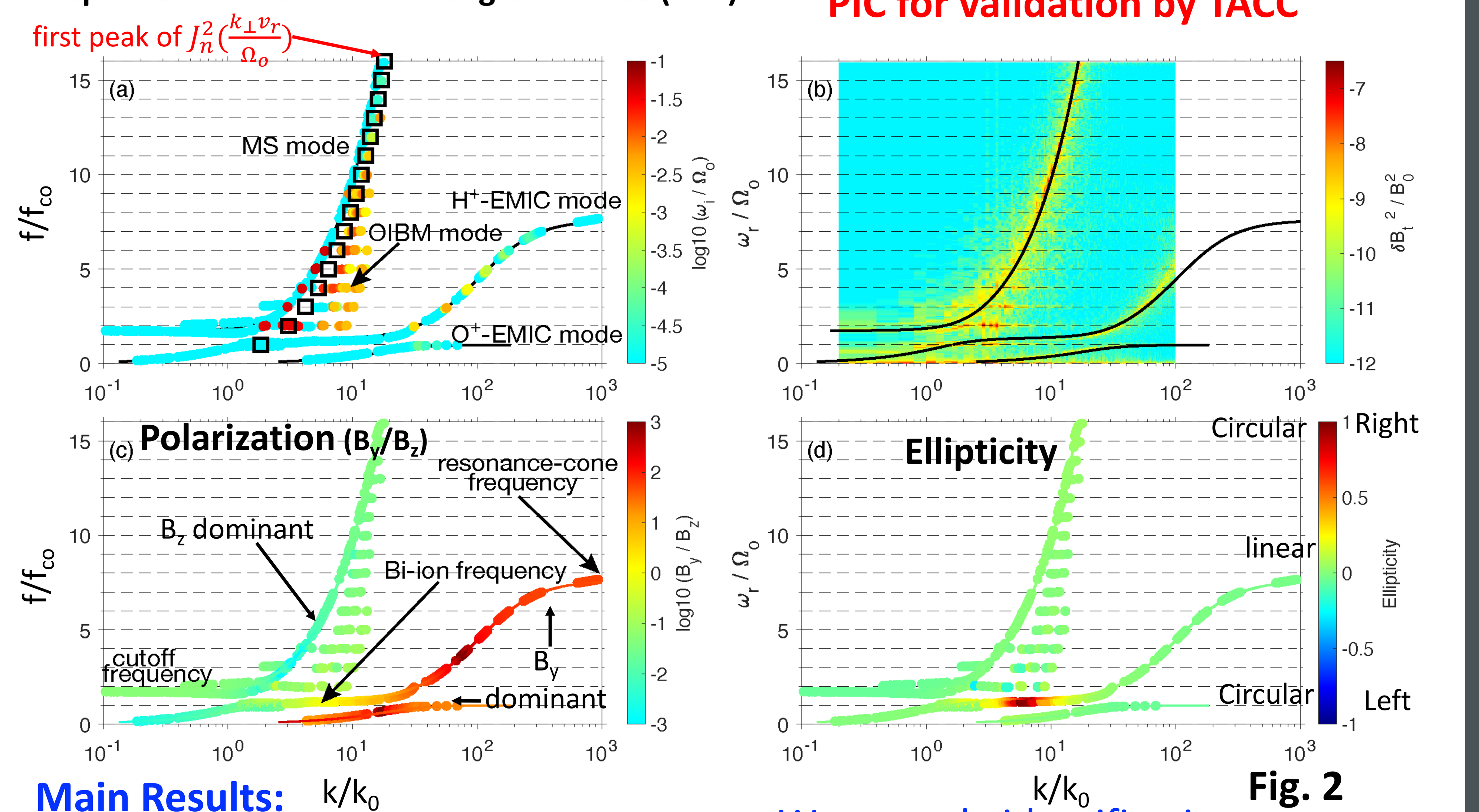

Fig. 2

Main Results:
- 4 wave modes are related to OCH wave
- Large growth rates follow the first peak of $J_n^2(\frac{k_\perp v_r}{\Omega_o})$
- Results of Instability analysis and Particle-in-cell (PIC) are consistent
- Wave mode identification:
  - MS-mode (B_z>>B_y)
  - O^+-EMIC mode(B_z<<B_y)
  - H^+-EMIC mode (B_z>>B_y) with f<f_{bi-ion}
  - H^+-EMIC mode (B_z<<B_y) with f>f_{bi-ion}
- Ellipticity~1 near f_{bi-ion} and ~0 elsewhere

Energetic Oxygen Ion Ring Concentration η_{ho} Dependence

- LGR increases with η_{ho}
- OIBM extends to wider k and higher frequencies
- 1st harmonic mode is excited and mode conversion occur when cold O^+ is absent (η_{ho}=1)

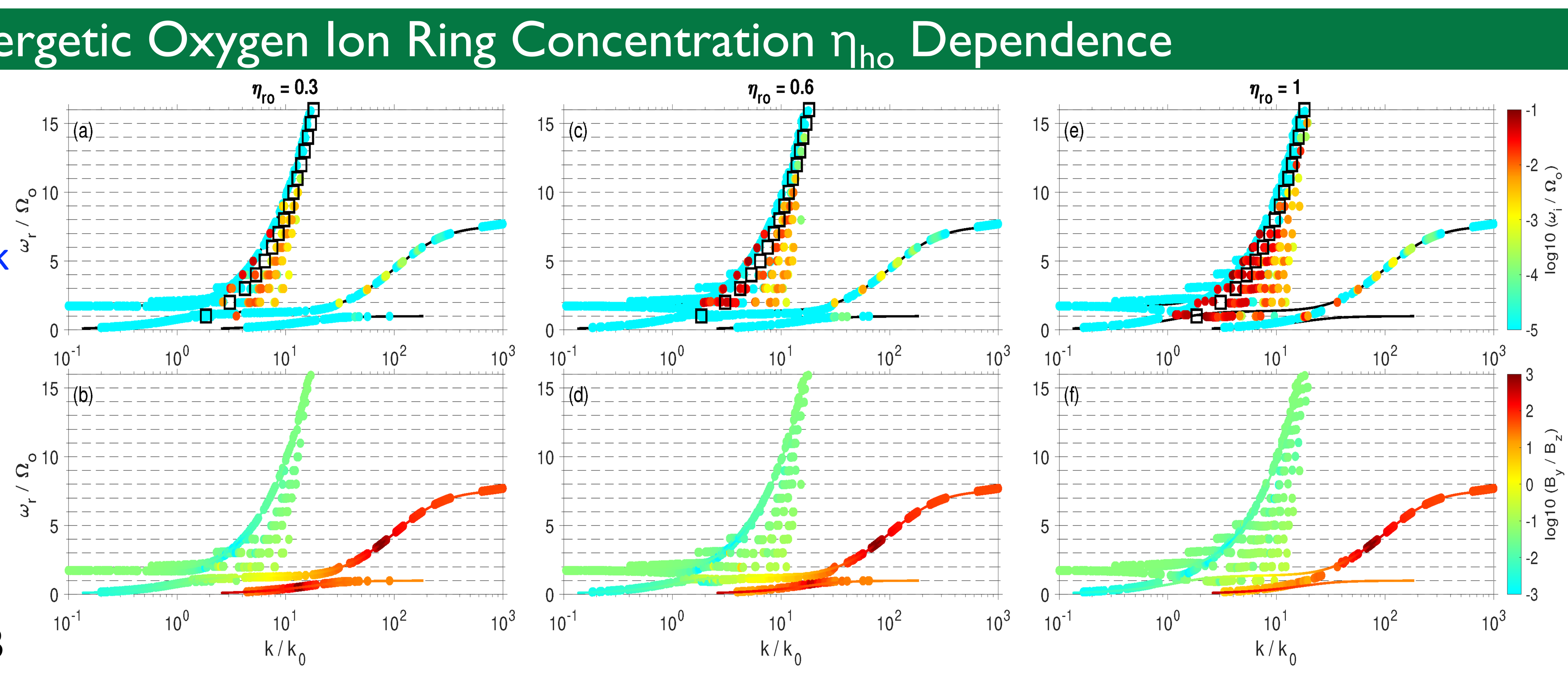

Fig. 3

Total Oxygen Ion Concentration η_o Dependence

- LGR increases with η_o
- f_{cutoff}, f_{bi-ion}, and $f_{res-cone}$ increases with η_o
- OIBM start to decouple with cold plasma modes (MS, O^+-EMIC, and H^+-EMIC modes)

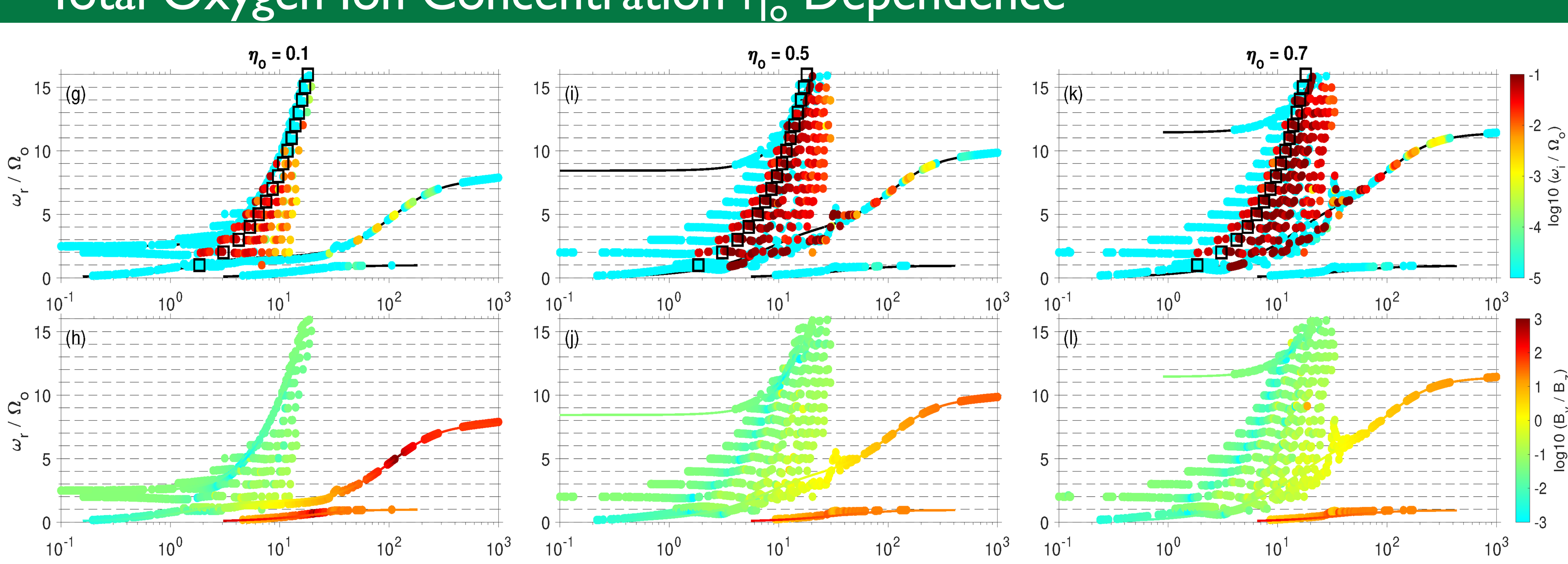

Fig. 4

Oxygen Ring Velocity v_r Dependence

- Large LGRs follow the first peak of $J_n^2(\frac{k_\perp v_r}{\Omega_o})$ when $k_{J_n^2} > k_{cwm}$. Here $k_{J_n^2}$ and k_{cwm} are wavenumber corresponding to J_n^2 and any of the wave mode, respectively. Thus, peak LGRs shifts from H^+-EMIC mode to MS mode and OIBM becomes stronger with increasing v_r.

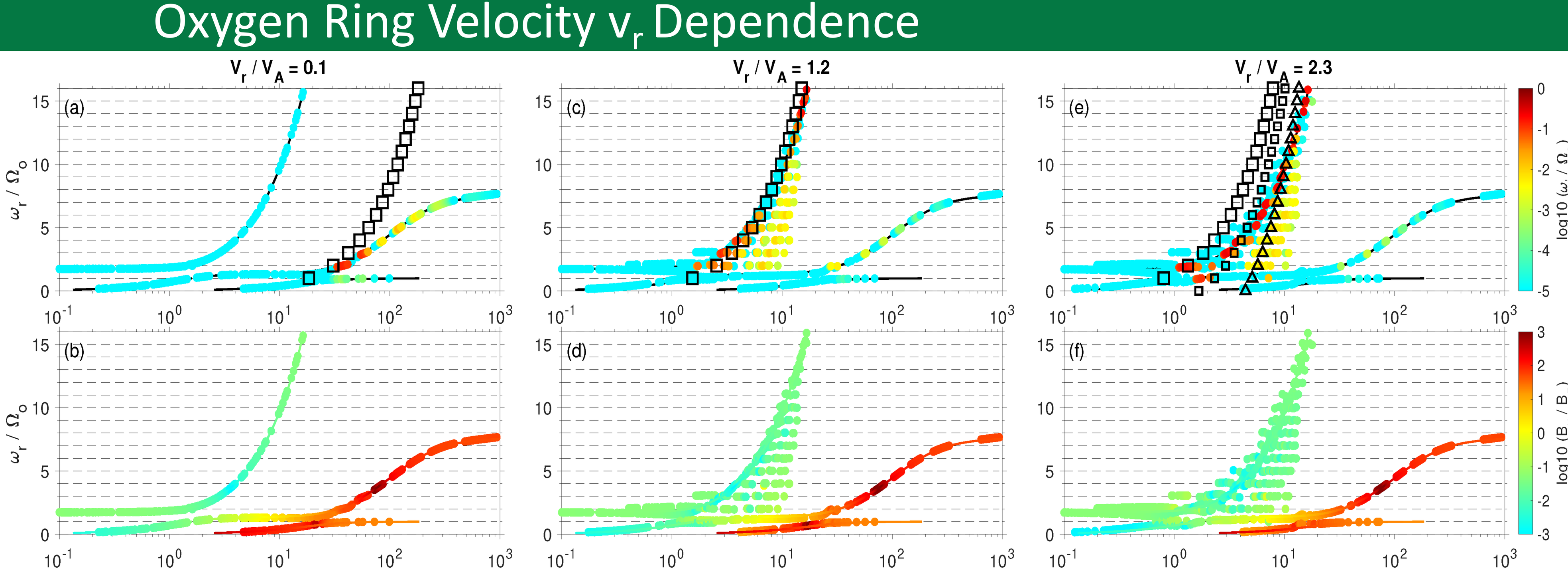

Fig. 5

- As v_r increases more, peak LGRs are along MS mode due to large damping from cold O^+ once wave is away from cold wave modes and considerable growth due to other J_n^2 peaks (small squares and triangles in panel (e)).