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MODELARE TEORETICA SI COMPUTATIONALA IN SEISMOLOGIA CORONALA GLOBALA SOLARA SI STELARA: CONEXIUNI UNDE GLOBALE - LOCALE , CAMPURI MAGNETICE – VARIABILITATI

Director contract:
Lect.dr.Alexandru Marcu

Obiective 2007

1. Investigarea proprietatilor undelor EIT coronale- originea undelor EIT; total realizat

2. Stabilirea naturii undelor EIT ; partial realizat

Lucrari cu factor de impact

1. *Dispersive shock waves in the solar wind*
   Ballai, I. ; Forgács-Dajka, E. ; Marcu, A., Astronomische Nachrichten, Vol.328, Issue 8, p.734 ,2007
2. *Global Coronal Seismology*
   Ballai, I.,Solar Physics, Volume 246, Issue 1, pp.177-185 ,2007
3. *MHD waves at a spherical interface modelling EIT waves*
   Douglas, M.;Ballai,I..,Astronomische Nachrichten, Vol.328, Issue 8, p.769 ,2007

Reviste BDI

1. *Thermally Damped Waves in the Solar Corona*
   Marcu,A.; Ballai,I., AIP Conference Proceedings, Volume 934, pp. 64-70 ,2007
2. *Sampling the Coronal Magnetic Field*
   Ballai, I., AIP Conference Proceedings, Volume 934, pp. 44-53, 2007

Obiective 2008

1. Studiul mecanismelor de propagare EIT .Stabilirea unei efemeride multiperiodice pentru predictia momentelor minim primar al strălucirii; total realizat

2. Studiul dampingului undelor EIT considerand dependenta acestuia de efectele disipative si de strcturarea gravitationala. Studiul propagarii undelor MHD in simetrie sferica, modeland undele EIT ca si ghiduri de unde si unde captate; partial realizat

3. Cercetarea sistemului binar cu eclipse Y Leonis; total realizat

Lucrari cu factor de impact

1. *"Thermally damped linear compressional waves in a 2D solar coronal model"*, Marcu **A.,** Ballai I., Orza B., IAUS 247, Cambridge Univ.Press,, pp. 320-323, 2008.
2. *"Forced oscillations of coronal loops driven by EIT waves"*, Ballai I., Douglas M., Marcu, A., Astronomy and Astrophysics, 488, pp.1125-1132 ,2008
3. *"The problem of phase mixed shear Alfven waves in the solar corona revisited"*, Mocanu G., Marcu A.,Ballai I., Orza B, Astronomische Nachrichten, , 328, Nr.8,pp.780-785, 2008
4. "*MHD waves at a spherical interface modelling coronal global EIT waves*", Douglas, M., Ballai, I, IAUS 247, Cambridge Univ.Press,, pp. 251-254, 2008
5. *"Coronal global EIT waves as tools for multiple diagnostics"* Ballai, I., Douglas, M., IAUS 247, Cambridge Univ.Press,, pp. 243-250, 2008
6. "*Coronal global EIT waves as tools for multiple diagnostics"* , Ballai, I., Douglas, M., IAU 247 Cambridge Univ.Press, Volume 247,p. 243-250, 2008
7. *" Nonlinear theory of resonant slow waves in anisotropic and dispersive plasmas* " Clack,T. M.; Ballai, I., Physics of Plasmas, Volume 15, Issue 8, pp. 082310-082310-12 ,2008.

Reviste BDI

1.*"Discovery of a short-periodic pulsating component in the eclipsing binary Y Leonis"*, Turcu, V., Pop, A, Moldovan, A, Comissions 27 and 42 of the IAU Information Bulletin on Variable Stars, nr.5826, pp. 1-4, 2008

Participari la Simpozioane si Conferinte internationale:

1.*"Standing waves in a solar periodic structures"*
Marcu A., Mocanu G., Orza B. Conference Proceedings Exploring the Solar System and The Universe,1043,pp. 314-318, 2008
2.*"Y Leonis reloaded",*
Pop, A, Turcu, V., Marcu A., AIP Conference Proceedings Exploring the Solar System and The Universe,1043,pp. 420-422, 2008

Obiective 2009

1. Stabilirea minimului energetic al undei EIT care este capabila sa produca oscilatia buclelor coronale ; partial realizat
2. Unde stationare-analogii mecanice. Determinarea momentelor de minim primar (eventual si secundar) al stralucirii; total realizat
3. Organizarea unui workshop international: Challenges in coronal global seismology; nerealizat

Lucrari cu factor de impact

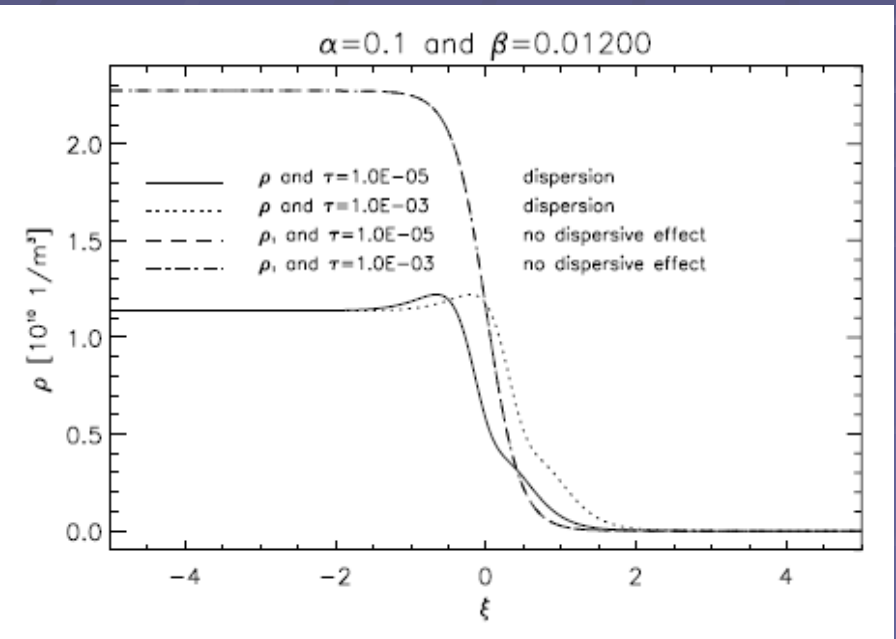
1. *"Nonlinear resonant absorption of fast magnetoacoustic waves in strongly anisotropic and dispersive plasmas",*
   Clack, T. M.; Ballai, I, Physics of Plasmas, Volume 16, Issue 4, pp 042305- 042305-11 ,2009
2. *"On the validity of nonlinear Alfven resonance in space plasmas",*
   Clack, T.M, Ballai, I, Astronomy and Astrophysics, Volume 494, Issue 1, 2009, pp.317-327
3. *"EIT driven oscillations in solar coronal loops*",
   Mocanu, G., Marcu A.,Orza, B. sent to be published in Geophysical & Astrophysical Fluid Dynamics, 20/08/2009
4. *"Photometric Disturbances of the Primary Minimum Light Profile of Y Leonis",*
   A. Pop, V. Turcu, A. Marcu, D. Moldovan, sent to be published in Astrophysics and Space Sciences,24/08/2009

Reviste BDI

1. "Forced oscillations of stratified coronal loops driven by EIT waves",
   Marcu, A., Mocanu, G. Orza, B. TIM09, accepted to be published in AIP , 2009
2. *"Forced oscillations of stratified thin coronal loops driven by EIT waves"*,
   Marcu A., Mocanu, G.Orza, B. Studia Physica LIV, Issue 1, Pages: 65-71, 2009
3. *"Y Leonis: Evidence for Multimode Pulsations in the Primary Compon",*
   V. Turcu, A. Pop,D. Moldovan, Simpozionul Between Earth and Stars,
   din cadrul editiei a XI-a a ZILELOR ACADEMICE TIMISENE, 28 – 29 mai 2009

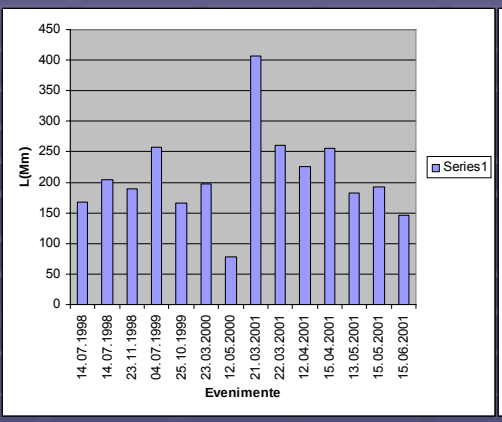
Modele teoretice si computationale

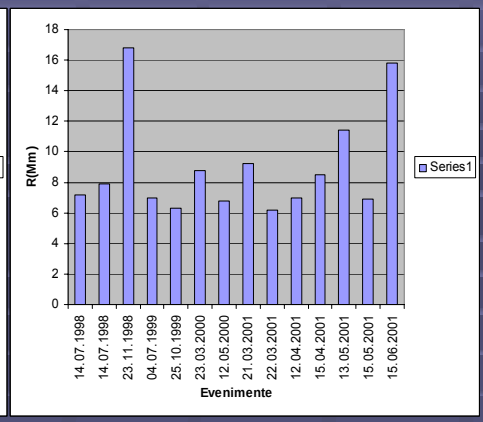
1. Undele compresive in procesul de propagare al vantului solar pot deveni unde de soc atunci cand, crestera in amplitudine este balansata de fenomene dissipative. Efectele dispersive induse de prezenta curentilor Hall influenteaza generarea si propagarea undelor de soc. **Am stabilit limita de la care efectele dispersive conduc la aparitia solitonilor si deci la transferul de energie si am demonstrat ca aceste efecte influenteaza masiv amplitudinea si viteza de propagare a undelor de soc.**

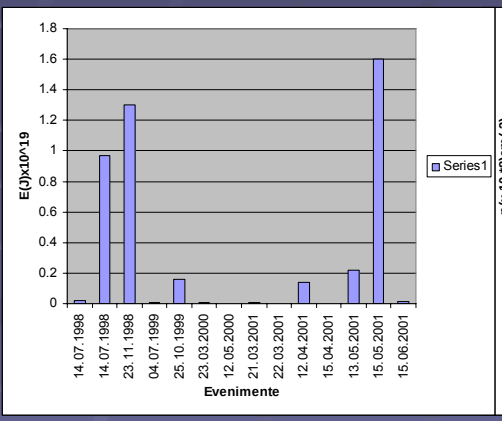


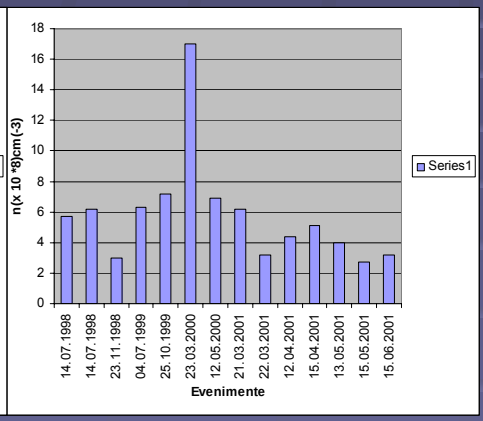
2. Am sistematizat observatiile si analizele de scala larga ale perturbatiilor de la nivel coronal, in scopul determinarii unui model de decriptare a informatiilor si energiilor pe care undele o poarta, astfel incat in domeniul seismologiei coronale globale , sa putem determina si mapa campul magnetic la nivelul regiunilor linistite ale Soarelui.Astfel putem sa estimam valorile de energie transferate structurilor magnetice coronale de catre undele EIT, capabile sa genereze oscilatii ale acestora, detectabile la nivel observational. Un proces important al analizei noastre, care da informatii legate de camp si energie, este cel al interactiunii undelor EIT cu alte entitati magnetice coronale, interactiune studiabila prin calculul lungimilor de damping corelate cu valorile energetice de initiere a oscilatriilor. **Am stabilit factorii ce influenteaza procesul oscilatoriu in urma interactiunii dintre undele EIT si buclele coronale: dimensiunea spatiala a buclelor coronale, inaltimea la care se produce interactiunea, orientarea spatiala a bulei coronale, distanta dintre sursa EIT si bucla coronala, energia minima de dislocare 1016-1019J, tipurile de plasma, efecte disipative, dispersive , Hall , neideale si absorbtie rezonanta, prezenta vortexurilor, frecventa si forma undelor EIT.**

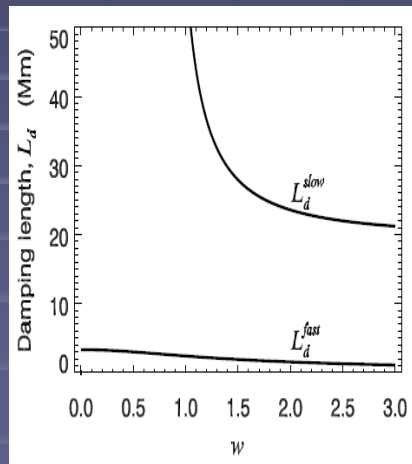
3. Observatiile demonstreaza ca in corona solara undele sunt rapid atenuate. Unul din mecanismele atenuarii rapide este cel al efectelor neideale dar si/sau al prezentei neomogenitatilor **transversale.Stiind ca din lungimile de atenuare se pot determina indirect structura si valoarea campului magnetic coronal, am demonstrat efectul indus de prezenta conductiei termice asupra miscarilor transversale ale buclelor coronale**. Rezultatele obtinute sunt in perfecta concordanta cu datele observationale

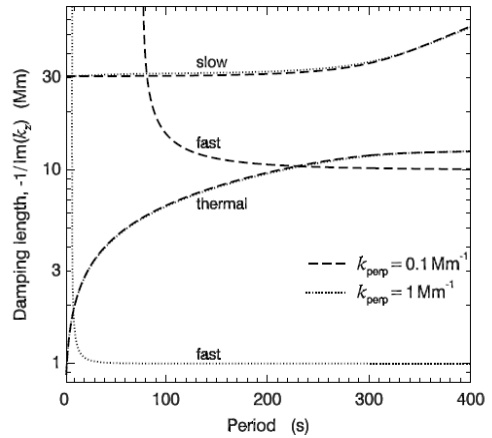


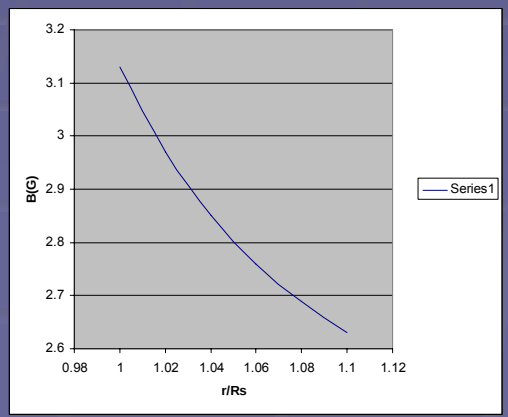


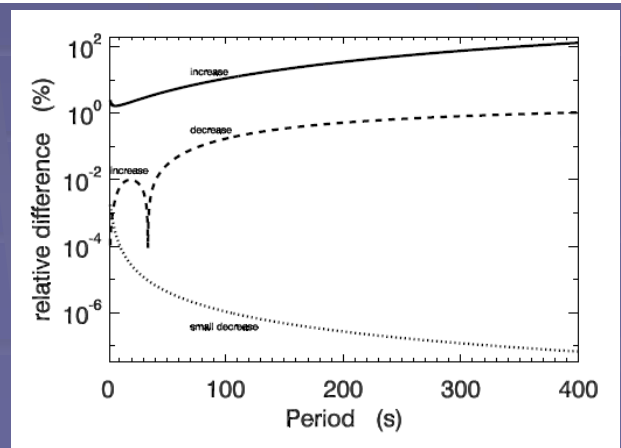




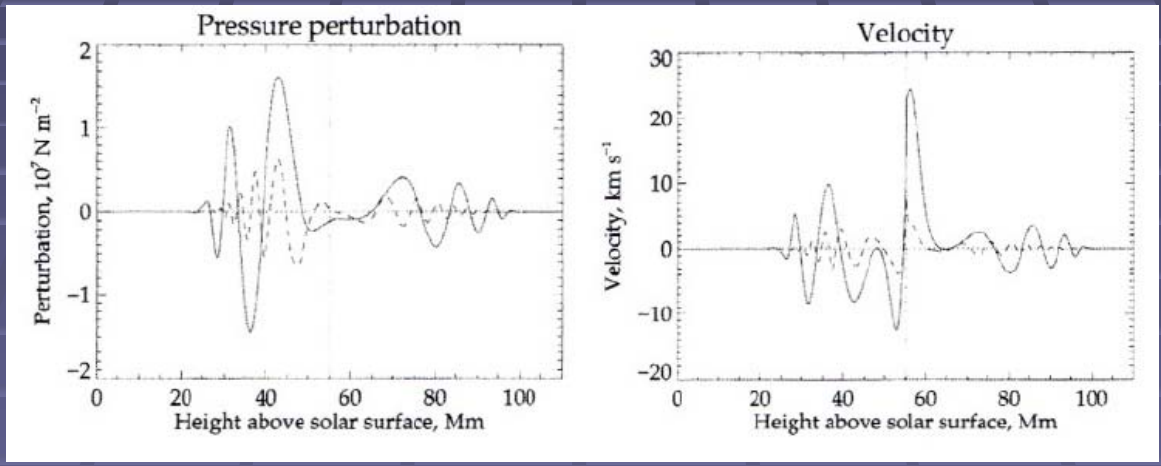


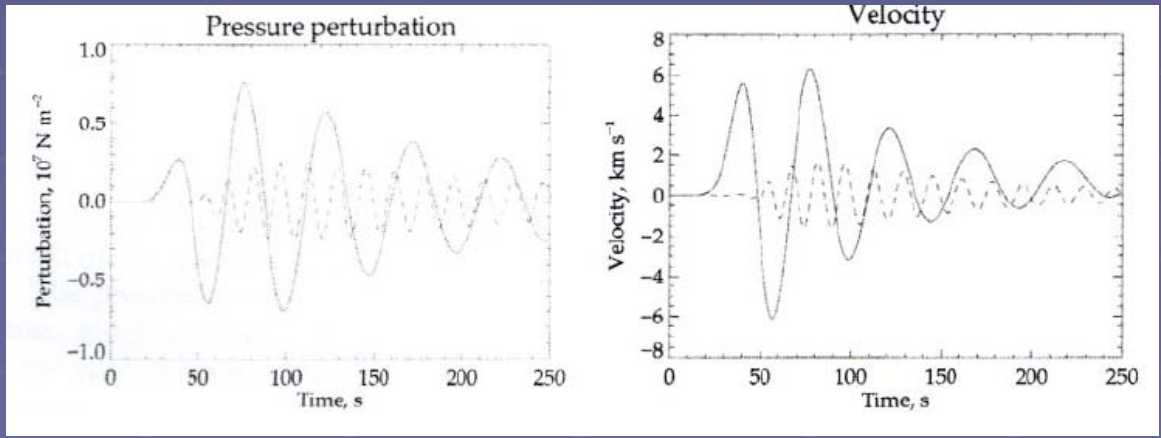






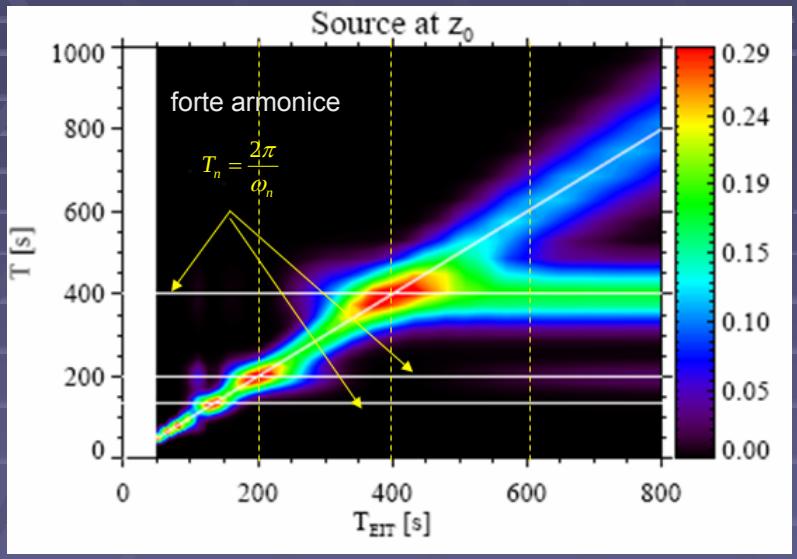
4. Datele observationale de lunga durata, demonstreaza ca sursele undelor globale (ce se propaga pe distante mari, uneori comparabile cu raza Soarelui) sunt evenimente eruptive de tip flares sau ejectari de masa coronala (CME). Modelul matematic creeat de noi, considera unda EIT ca o unda de suprafatace se propaga in lungul interfetei densitatii sferice de raza constanta. Am reusit simulari numerice pentru unde de suprafata radiale generate de pulsuri de presiune intense si spontane. **Am constatat ca propagarea este simetrica si genereaza un larg gradient de presiune la interfata, ca unda este generata la anumite distante de serse, ca amplitudinea este atenuata ceea ce ne-a permis sa concluzionam ca portiunile intaunecate ce se vad in observarea undelor EIT se explica prin existenta unor regiuni de plasma rarefiata unde gradientii largi de presiune evacueaza mult material plasmatic..**



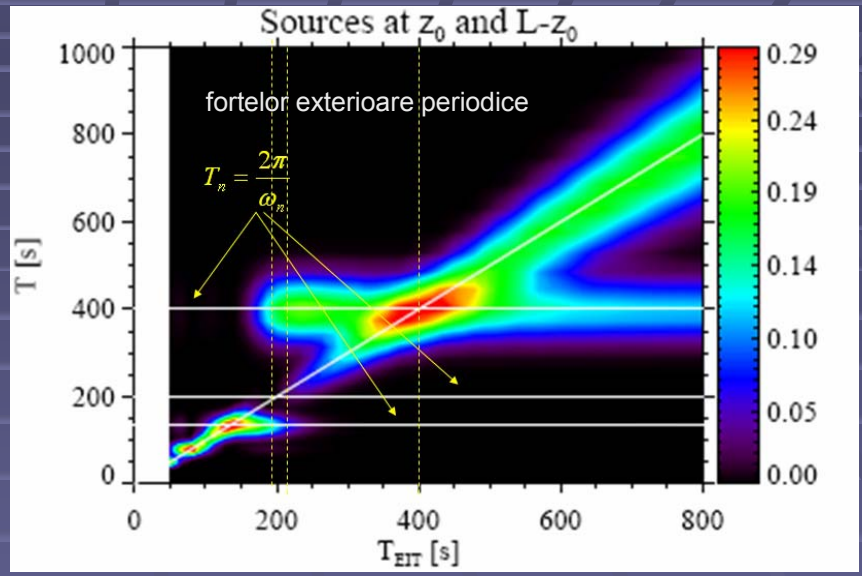


5. *Modelul teoretic al oscilatiilor transversale ale buclelor coronale induse de interactiunea acestora cu undele* ***EITstabileste pentru prima data o corelare puternica intre frecventa oscilatiilor tranversale ale buclelor coronale si frecventa undelor EIT avand ca perspectiva si corelarea cu natura acestor unde***

Din punct de vedere analitic, ecuatia care descrie propagarea modului transversal este de tipul Klein Gordon neomogen, neomogenitatea fiind datorata prezentei undelor EIT.Astfel tipurile de oscilatii care pot fi generate in buclele coronale depind de caracteristicile undei EIT



The periods of oscillations generated by an EIT wave acting at z=z0. The period of the driver is changed in the interval 50 to 800 s.

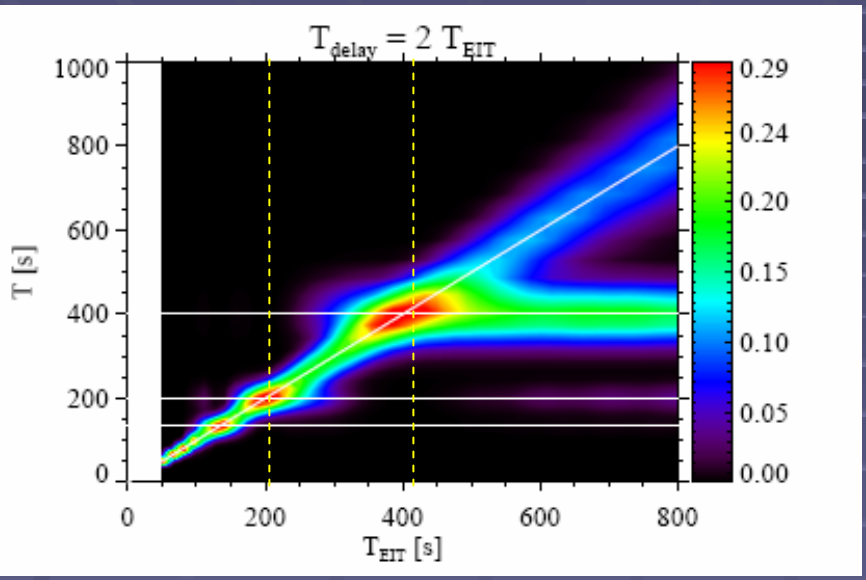


The periods of oscillations generated by an EIT wave interacting with the coronal loop at z=z0. and z=L-z0 intwo points, symmetric-ally situated from de ends of the loop

Pentru perioade cuprinse intre 50 si 800 s, analiza wavelet indica : T_{EIT} > 600s modurile ce pot fi generate sunt cel fundamental si prima armonica dar de foarte mica putere, 200s< T_{EIT}<400s oscilatia driverului este prezenta, dar foarte slabe in comparative cu modul fundamental, T_{EIT}<200s modul fundamental este foarte slab dar sunt prezente primele doua armonici .Zonele rosii corespund rezonantei intre driver si bucla coronala.

In cazul fortelor exterioare periodice in faza se poate constate ca oscilatiile ce pot fi excitate in bucla coronala poarta mai degraba caracteristicile driverului si mai putin proprietatile modului fundamental.

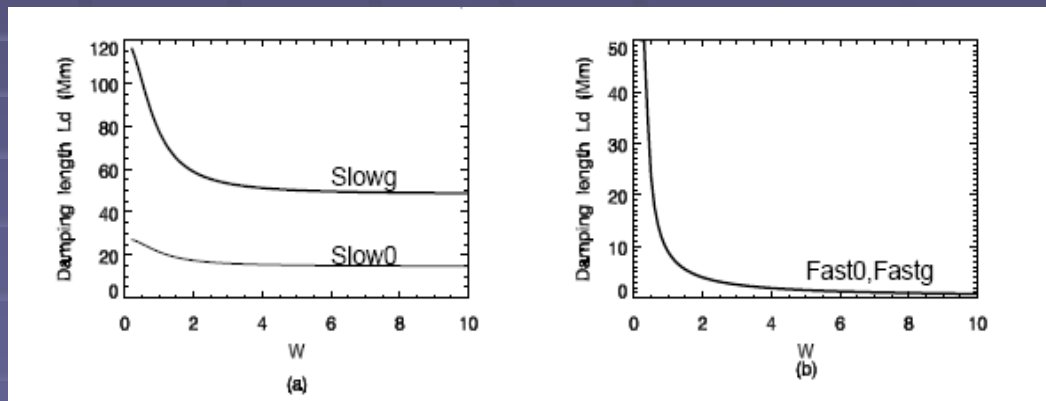
In cazul in care undele EIT actioneaza ca unde de soc de latime finita, perioadele de oscilatie generate apartin modurilor normale de vibratie ale buclei in timp ce in cazul in care undele EIT excita armonic arcada, modurile de vibratie rezultate vor fi o suprapunere de unde stationare



The periods of oscillations generated by an EIT wave interacting with the coronal loop at $z=z_0$. and $z=L-z_0$, the second interaction is delayed by a time corresponding to the double EIT waves' period

Analiza desfasurata demonstreaza ca modurile de vibratie generate in urma intercatiunii undelor EIT cu o bucla coronala ofera predominant informatii despre unda EIT (natura si propagare) si mai putin despre bucla coronala.

6. Observatiile de inalta rezolutie (**TRACE si SOHO**) a undelor in structuri coronale au pus in evidenta dampingul rapid al modurilor, lungimea de damping fiind uneori de acelasi ordin de marime cu lungimea de unda. Atenuarea rapida a modurilor in buclele coronale ne permite determinarea valorilor campului magnetic (intensitate, structura) cat si a coeficientilor de transport (mult utilizati in studierea mecanismului de incalzire coronala)

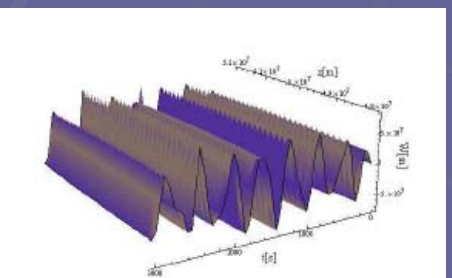


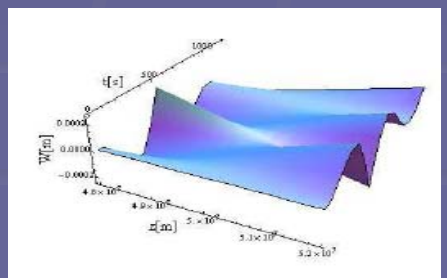
Considerand un model 2D am demonstrat ca principale cauze ale dampingului undelor sunt:
-gradul de structurare transversala
-temperatura.

7. Campul magnetic induce o directie preferentiala in miscarea plasmei, miscare ce trebuie luata in considerare in modelarea matematica a atenuarii amplitudinii undelor Am reusit formularea unui model matematic care sa tina cont de coeficientii disipativi reali si care **conduce la excluderea mecanismului amestecului de faza al undelor Alfven dintre modelele propuse in literatura de specialitate pentru explicarea fenomenului de incalzire a formatiunilor plasmatice coronale.**

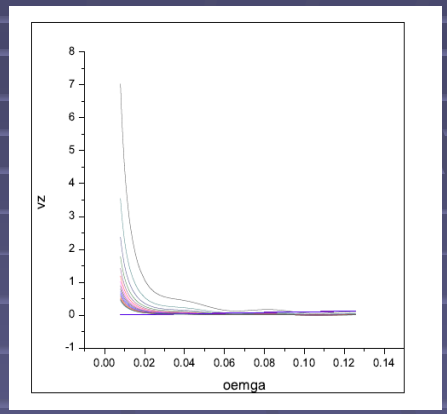
Perioada de atenuare a undelor stationare atinge in cazuri concrete 119 ore, iar ordinul de marime al lungimii de atenuare in cazul undelor progresive este de patru ori mai mare decat in cazul izotrop,
rezultat in perfecta concordanta cu datele observationale

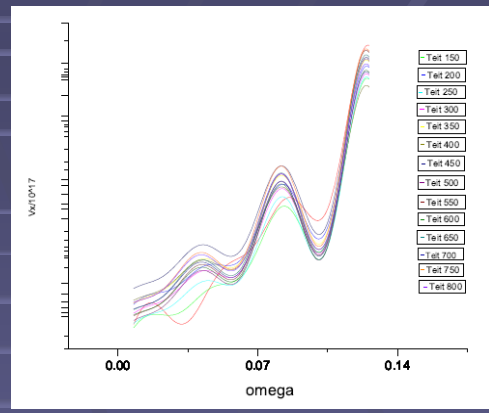
8. In aproximatia MHD liniara adoptata pentru efectuarea calculelor, **modurile excitate de un driver EIT in bucla sunt decuplate, astfel incat se poate vorbi despre un mod transversal si unul longitudinal**.





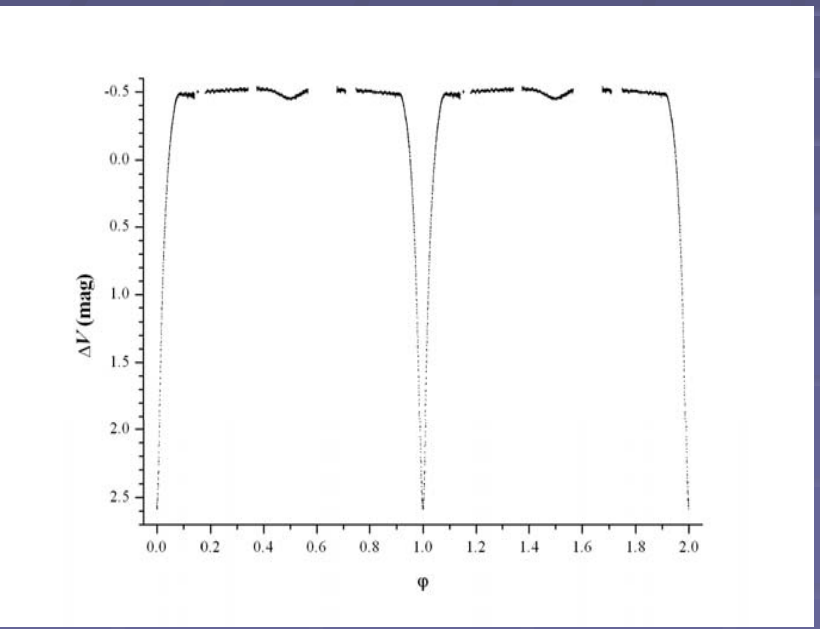
9. S-a studiat efectul gravitatiei si al variatiei densitatii din buclele coronale asupra modurilor de vibratie rezultate in urma interactiunii dintre undele EIT si formatiunile magnetice coronale



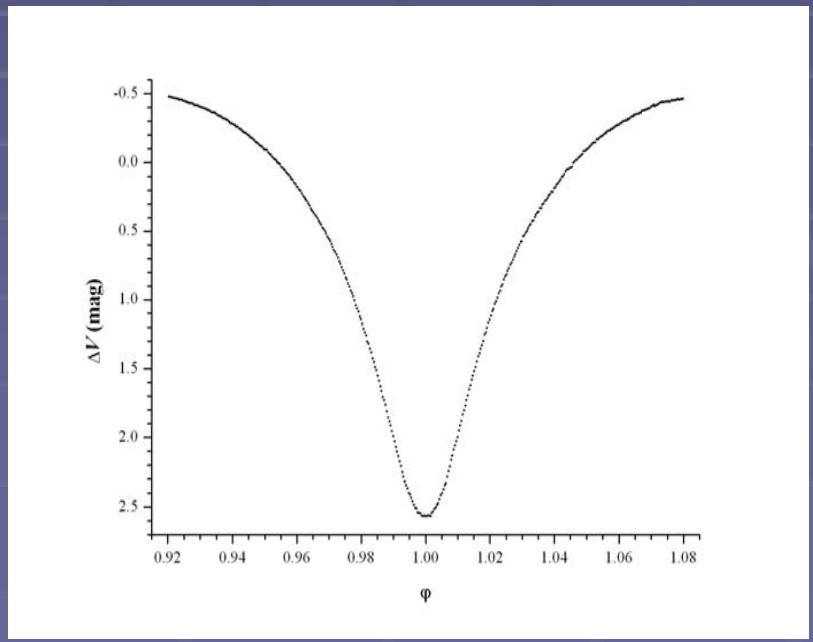


S-a constatat ca vitezele de deplasare ale pertubatiilor depind de:
- frecventele modurilor normale de vibratie ale buclei coronale cat
- frecventa undei EIT
Analiza pertubatiilor ca functie de unghiul facut de directia fortei EIT cu directia campului magnetic la echilibru a dus la concluzia ca, pertubatia este maxima cand forta este perpendiculara pe camp.
Ca noutate, pentru descrierea analitica a driverului ce actioneaza asupra buclei, am folosit o functie modulata in timp, a carei perioada de modulatie coincide cu perioada observata a undelor EIT

10. Curba de lumina a sistemului binar cu eclipsa observata de noi in sezonul iarna-primavara 2009 (**6162 imagini CCD**). Se disting, intre minimele principale si cele secundare ale curbei de lumina, pulsatiile scurt-periodice (descoperite de noi), de mica amplitudine ale componentei principale. Este vorba despre prima curba de lumina aproape completa a acestei binare obtinuta dupa cea publicata de Johnson in 1960 in *The Astrophysical Journal*.



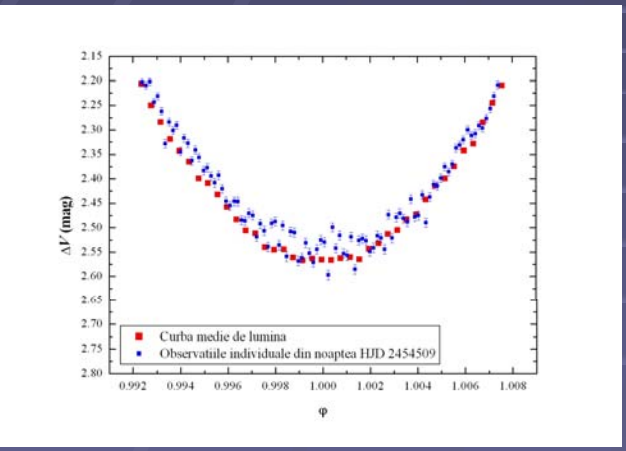
11. Profilul minimului principal al curbei de lumina a sistemului binar Y Leonis obtinut prin reducerea la acelasi ciclu si medierea celor 6 minime principale individuale observate de noi in intervalul 2008 – 2009. Aspectul simetric al minimului principal sugereaza absenta unui disc de acretie asociat transferului de materie dinspre componenta secundara spre componenta primara, prin punctul Lagrangeian L1. De asemenea, se constata absenta unor distorsiuni semnificative ale curbei de lumina de tip „unda migratoare" ca si in cazul sistemelor binare active de tip RS Canum Venaticorum

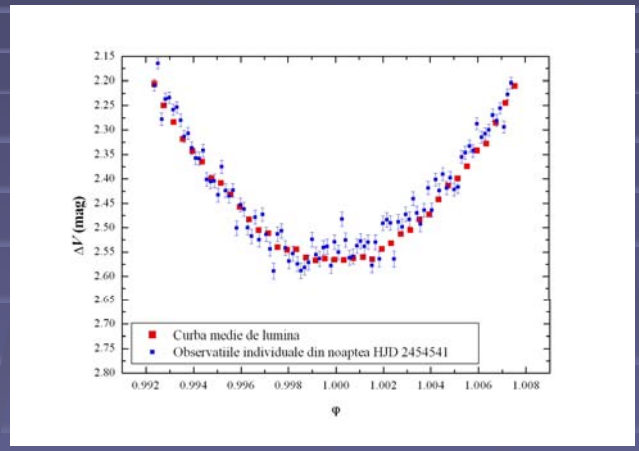


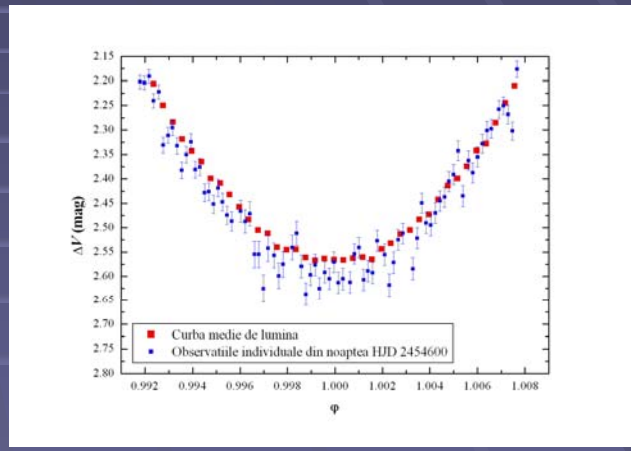
12. Variabilitatea profilului minimelor principale ale stralucirii in raport cu profilul curbei medii de lumina in regiunea minimului principal. Cauzele posibile sunt:

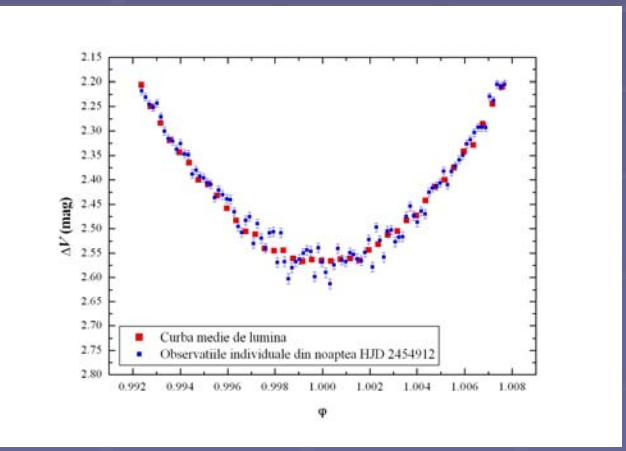
(i) influenta fotometrica a pulsatiilor componentei principale,

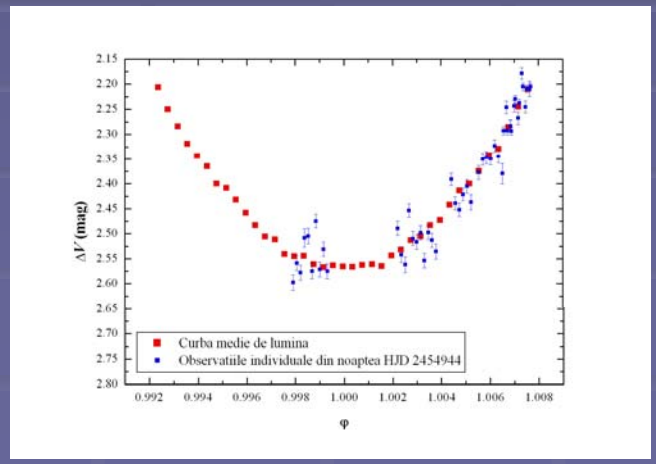
(ii) (ii) activitatea cromosferica asociate activitatii magnetice ciclice a componentei secundare a sistemului binar.

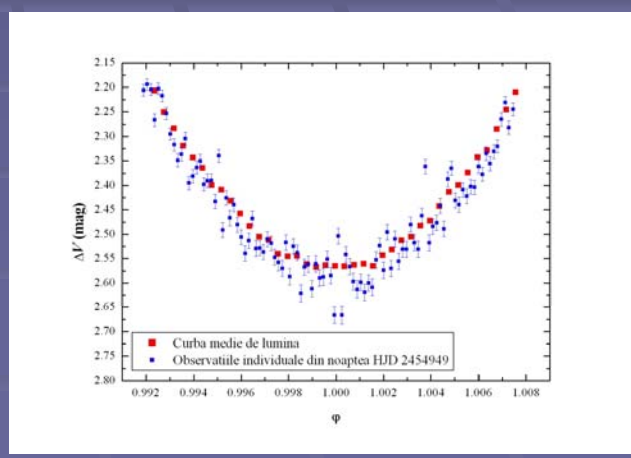




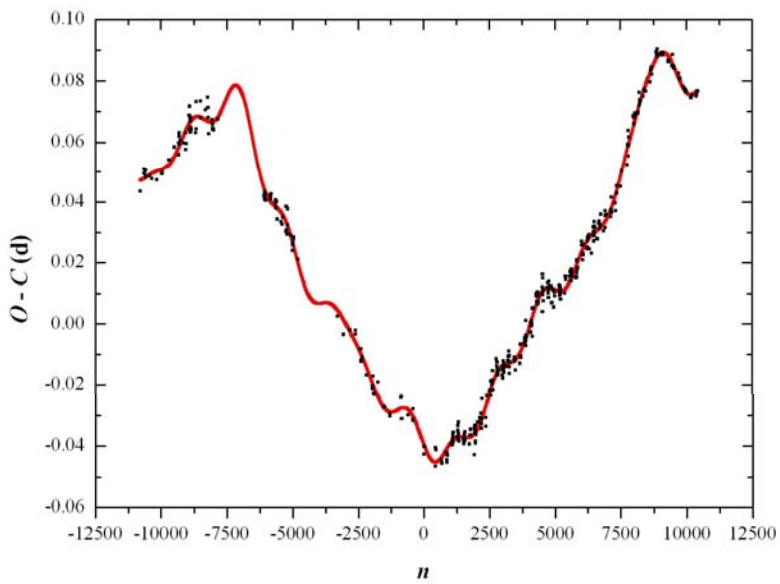








13. Curba *O-C* („observat - calculat”) care caracterizeaza variatia perioadei orbitale a sistemului binar Y Leonis. De asemenea, este prezentat modelul preliminar stabilit de noi pe baza datelor observaționale disponibile in literatura, precum si a celor 6 momente de minim principal al stralucirii determinate de noi. Modelul reprezinta o suprapunere a unui termen parabolic si a unui termen multiperiodic constand din serii Fourier trunchiate asociate celor 5 periodicitati detectate (cu probabilitate de incredere de 100 %) si ameliorate de noi: 76.24 ± 0.30, 13.87 ± 0.25, 10.49 ± 0.10, 9.10 ± 0.05, si 7.570 ± 0.033 ani. Mecanismele fizice implicate in modularea perioadei orbitale a sistemului Y Leonis pot fi: *prezenta unor companioni stelari sau planetari nedetectati* pana in prezent si *activitatea magnetica ciclica a componentei secundare*.

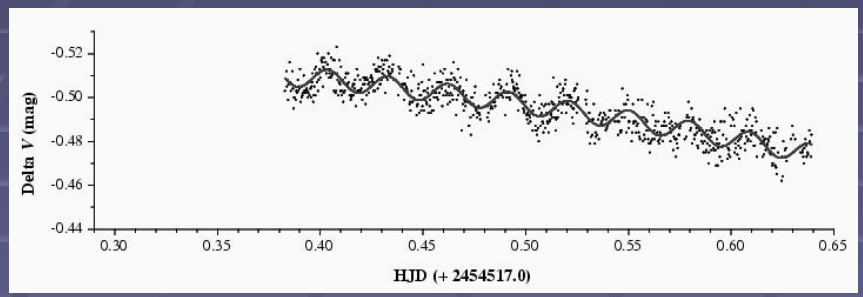


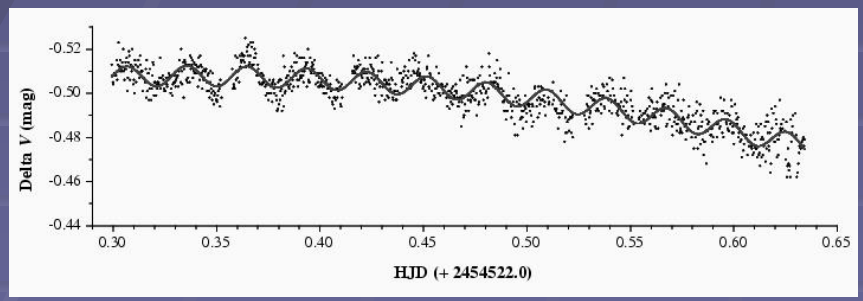
Examinarea celor 5 periodicitati detectate de noi din perspectiva celor doua mecanisme ne-a condus la urmatoarea interpretare preliminara:

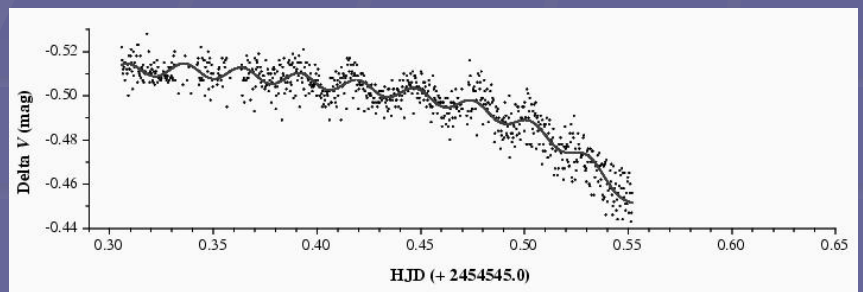
- **modulatia lung periodica de 76.24 ani ar putea fi datorata activitatii magnetice ciclice a componentei secundare. Conform modelului lui Applegate (1992) valoarea inductiei campului magnetic subsuperficial al acestei stele ar fi de 3.61 kG. Interpretarea acestei periodicitati ca fiind datorata prezentei unui companion stelar nedetectat conduce la o masa a acestuia de aproximativ 0.97 mase solare, adica superioara masei componentei secundare, cca. 0.73 mase solare;**

- **celelalte 4 periodicitati, cuprinse intre 7.57 si 13.87 ani, ar putea fi asociate unor companioni stelari ipotetici, mai putin masivi, cu mase cuprinse intre 0.27 si 0.12 mase solare.**

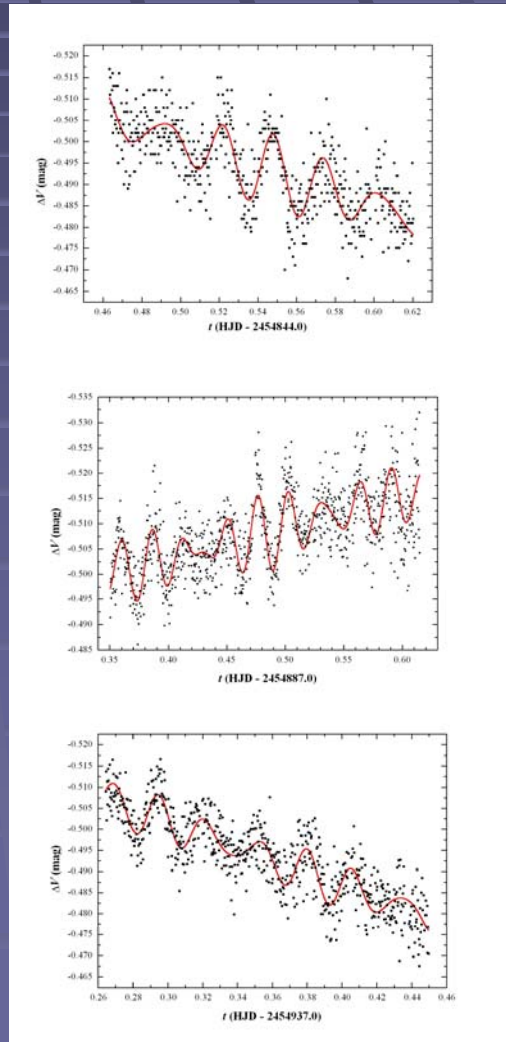
14. In anul 2008 observatiile efectuate de noi asupra sistemului binar cu eclipse Y Leonis ne-au permis descoperirea pulsatiilor scurt-periodice de tip delta Scuti ale componentei primare a acestui sistem binar. Perioada pulsatiilor este de aproximativ 41 minute, iar semi-amplitudinea curbei de lumina este de 4.09 mmag. Mentionam ca acesta a fost cel de-al 22-lea sistem binar de tip Algol cu componenta pulsanta descoperit pana la acea data. Au fost obtinute si analizate **2680 imagini CCD** obtinute in filtrul V al sistemului fotometric Johnson-Cousins.







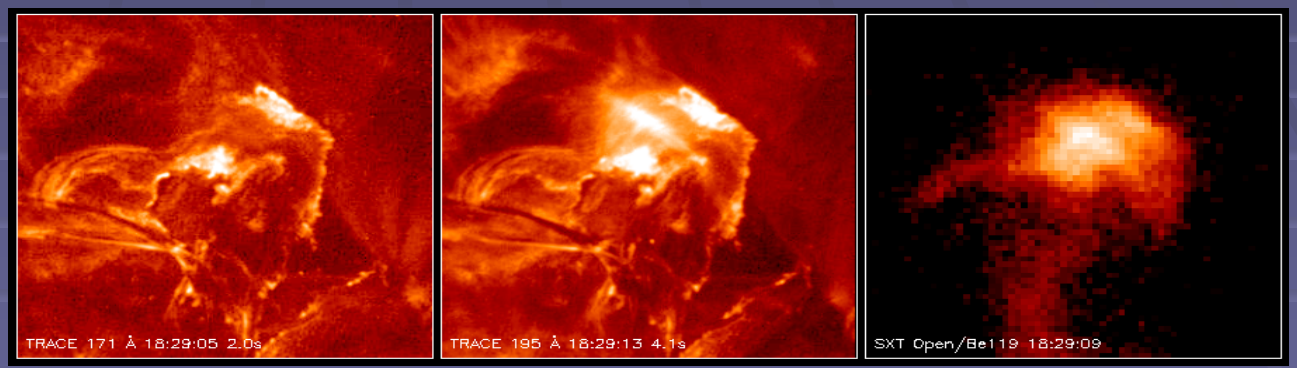
15. Datele observationale obtinute de noi pe straluciri minime in sezonul de observatii iarna-primavara 2009 (**2196 observatii CCD**) ne-au permis punerea in evidenta pentru prima data a caracterului multiperiodic al pulsatiilor de tip delta Scuti componentei primare a sistemului binar cu eclipse Y Leonis. Valorile periodicitatilor detectate de noi sunt de aproximativ: 41, 32, si 35 minute. Semi-amplitudinile acestor componente sunt cuprinse intre 1.3 si 5.9 mmag.

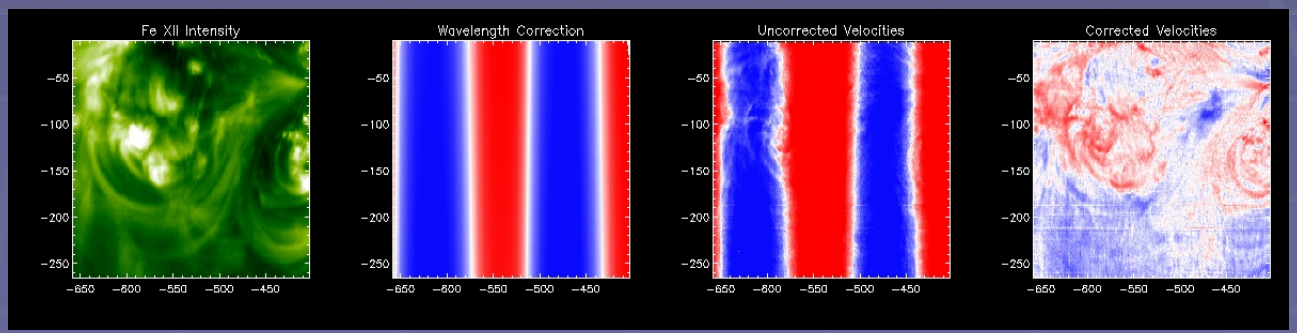


Doctoranzi:

Vlad Turcu - sustine teza in noiembrie 2009

Orza Beniamin - acceptat pe o pozitie PhD la Univ. Sheffield, UK
activitati sustinute din contract
- Stagiu de pregatire , prelucrari satelitare de date (Armagh- Irlanda de Nord)
- Pregatire implementare soft Pde2D (Prof. Ballester J. Univ. Palma)





Mocanu Gabriela - masterat si acceptata pe o pozitie PhD la UBB