

WEBVTT

1

00:00:00.000 --> 00:00:00.960

Conny Aerts: introduction.

2

00:00:02.220 --> 00:00:05.460

Conny Aerts: and got that and for liking my drawing.

3

00:00:06.870 --> 00:00:11.880

Conny Aerts: So it's a real pleasure to be with you, even though only virtually.

4

00:00:11.880 --> 00:00:12.269

Conny Aerts: To.

5

00:00:12.660 --> 00:00:25.320

Conny Aerts: tell you a little bit about one of my passions called astrocytes knowledge and i'm going to specifically focus on the gravity gravity inertial side of things today if you don't know what that is that's fine.

6

00:00:27.660 --> 00:00:30.210

Conny Aerts: Let me give you a straightaway a take home message.

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00:00:30.750 --> 00:00:40.050

Conny Aerts: we're going to do gravity inertial modes this have low frequencies and the nice thing about them is that they really direct and localized information.

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00:00:40.410 --> 00:00:50.580

Conny Aerts: Of the seller interior specifically of stars that have a competitive core and the surrounding area here is where all the action lies in the life of such stars.

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00:00:50.580 --> 00:00:51.390

Conny Aerts: So these.

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00:00:51.420 --> 00:01:10.950

Conny Aerts: This is my my favorite type of mode for them now, how do we do that on the graph you see here one template right curve in the Left panel of 1500 days in the right panel zoom on like 20 stays and you see beautiful oscillations beating against each other.

11

00:01:11.970 --> 00:01:18.660

Conny Aerts: Positive interference negative interference and the art is to get the information.

12

00:01:18.660 --> 00:01:19.680

Kareem Julian El-Badry: From the physics.

13

00:01:19.710 --> 00:01:25.050

Conny Aerts: Of that near core region out of such a lacquer and so that's what we will be doing.

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00:01:25.710 --> 00:01:41.190

Conny Aerts: So what's in the light curve well says make waves created by the up and down motions of the non radio modes right here, you see again alive curve in the upper graph already a zoom in now again gravity modes that have beautiful.

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00:01:42.450 --> 00:01:45.060

Conny Aerts: Signature seismic signature right.

16

00:01:46.200 --> 00:01:53.370

Conny Aerts: And if you remember from you know studying periodic phenomena in a sphere, because that's basically.

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00:01:53.370 --> 00:01:57.330

Conny Aerts: What we're using as an approximation a periodic.

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00:01:57.810 --> 00:02:08.520

Conny Aerts: phenomenon that is a sign of variability in the time series of whatever quantity that you're measuring and here is the relative brightness that we measure from space.

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00:02:08.790 --> 00:02:18.030

Conny Aerts: If you fourier transform that well, then you get a high peak at the frequency of your oscillation and that's what you see in the lower panel, of course.

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00:02:18.720 --> 00:02:29.250

Conny Aerts: So what we are doing a seismologist is fourier transform the brightness variations that satellites measure for us from space at very high precision.

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00:02:29.610 --> 00:02:40.320

Conny Aerts: And in that fourier transform you see the amplitude of the Eigen modes as upper bars here, and for this star, for instance, it has a dominant oscillations.

22

00:02:40.830 --> 00:02:52.800

Conny Aerts: In the frequency region around 75 micron hurts right, you see, various oscillations because there's, not a single big it's, not a single sign it's a it's a complex beating.

23

00:02:53.160 --> 00:03:06.570

Conny Aerts: pattern of sinus auto variability right and so these fourier transforms help us tremendously to get the Eigen frequencies of the star on our plates, and these Eigen frequencies are actually.

24

00:03:07.500 --> 00:03:26.910

Conny Aerts: shapes are they get their value from the interior of the star where the waves have their dominant energy and for gravity to inertial waves, this is deep deep, deep down in the interior and from an evolutionary point of view that's what we want all right now we can do this.

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00:03:28.260 --> 00:03:33.600

Conny Aerts: Since what I call the space age, which is about a decade old on me this is very reason.

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00:03:34.320 --> 00:03:47.100

Conny Aerts: Why, because if you want to unravel the Eigen frequencies from such a fourier transform well, then you better work with uninterrupted data and we're doing star quakes annual variations yeah.

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00:03:47.940 --> 00:03:56.190

Conny Aerts: parts per thousand two parts per million so when we tried it from the ground, and we have tried that, for many, many years.

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00:03:57.120 --> 00:04:09.990

Conny Aerts: Well then, the fluctuations in the earth's atmosphere really bother us and the fact that we can only during the night do our work bother us even more so, ever since the space age, starting with coral.

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00:04:10.650 --> 00:04:23.100

Conny Aerts: Launched in 2006 operational for six years, then we have the magnificent kepler and now we have the also magnificent test which is literally operating right now for us.

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00:04:23.640 --> 00:04:30.780

Conny Aerts: For us, that is to say 200 exoplanets it's fine you can all have your exoplanets just as long as I can have my start with all right.

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00:04:31.260 --> 00:04:42.990

Conny Aerts: And so we have, in fact, hundreds of thousands of light curves like two of which i've shown to work with so from the observational side of things, we are swamped with data right.

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00:04:43.620 --> 00:04:54.690

Conny Aerts: Now the art is to get the physics, out of the day now So how do we work well, a little bit of simple background a star we approximated as a.

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00:04:55.320 --> 00:05:00.300

Conny Aerts: cashier sphere, it is rotating around them access and he has.

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00:05:00.870 --> 00:05:13.410

Conny Aerts: I gimbals yeah and I can frequencies, how do you get to derive them from a theoretical point of view, you have your stellar structure equations conservation laws of physics, that your cash experience to fill.

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00:05:14.040 --> 00:05:21.300

Conny Aerts: And then you preserve that and you're assuming that we are in the linear approach, that is to say, we consider.

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00:05:22.050 --> 00:05:33.660

Conny Aerts: Non radio oscillation modes in the linear machine yeah so your your up and down motions are supposed to be small compared to the total radius of the stuff.

37

00:05:34.590 --> 00:05:48.270

Conny Aerts: yeah in that case, if that's the case and if your star if your star is a slow rotator, then you can describe each of these arguments by a spherical harmonic and that's what you see on the graph here, and this is a spherical money.

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00:05:48.660 --> 00:05:56.670

Conny Aerts: Of the green two, there are two white bands these particles don't move during the oscillation the red and the blue ones they do.

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00:05:57.270 --> 00:06:14.940

Conny Aerts: Read is moving away from your blue is coming towards you, and so you see the the surface pattern of this node and the interior

pattern described by the number of nodes in the interior of the star which you cannot directly see of course, because that is what's happening inside.

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00:06:15.780 --> 00:06:28.470

Conny Aerts: Now, if we move that or if we translate what I just said into mathematical formula yeah then each of simulation mode has a displacement sector described by a spherical harmonic.

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00:06:28.800 --> 00:06:42.300

Conny Aerts: And this vertical harmonic is active with a certain period of the mode or a frequency of the mode the noted here as Ω the angular it mode frequency, it depends on the degree of the mode on the mode order.

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00:06:42.510 --> 00:06:49.890

Conny Aerts: So he hasn't made to order is the number of nodal lines white lines through the symmetry axis which we usually take as a rotation axis.

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00:06:50.130 --> 00:07:06.570

Conny Aerts: And that's how you describe your Eigen mode, so you have a spatial part which is the spherical harmonic and you need to know where this and you have a temporal part which is the frequency of the oscillation more and we have not one mode active but hundreds of them right.

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00:07:07.680 --> 00:07:12.480

Conny Aerts: Now these modes, they have different physical different physical.

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00:07:13.500 --> 00:07:22.680

Conny Aerts: Property let's say, depending on the dominant acting restoring forces and i've listed five of them here, so we have the the two basic restore the pressure force.

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00:07:23.490 --> 00:07:36.570

Conny Aerts: If that's the dominant restoring force you create acoustic waves and you know them very well sound waves if buoyancy, on the other hand, is dominant restoring force we speak of gravity waves, these have a different character, they have.

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00:07:38.280 --> 00:07:46.890

Conny Aerts: Usually, a lower frequency than the acoustic waves and the acoustic waves go up and down and up and down because it's pressure that is a dominant force.

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00:07:48.390 --> 00:07:58.950

Conny Aerts: Here, but with gravity they have mainly more horizontal motion than vertical most in a rotating Star and all stars rotate, no matter how slow, we also have a coriolis force.

49

00:07:59.730 --> 00:08:07.470

Conny Aerts: And if that force is acting as dominant historian first you create what we call inertial waves, if your stars magnetic recreate.

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00:08:08.700 --> 00:08:12.900

Conny Aerts: We have a Lawrence for us and we create alpha in waves and if you're.

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00:08:13.950 --> 00:08:21.840

Conny Aerts: In a binary or a multiple system in general and tides come into play, then, then, then we speak of Title now three of these.

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00:08:23.130 --> 00:08:27.420

Conny Aerts: waves types are indicated in dark blue, why is that well.

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00:08:28.590 --> 00:08:38.790

Conny Aerts: that's because the other two are in red and the red is actually the message that I want to bring gravity waves and inertial ways they typically have periodicity of the order of the day.

54

00:08:39.600 --> 00:08:48.090

Conny Aerts: Now, if you want to do that type of US versus Margie from the ground you're really screwed because we happen to live on a planet that revolves with a period of a day.

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00:08:48.510 --> 00:09:02.340

Conny Aerts: And that is horrible to disentangle yeah so it's really only thanks to the NASA kepler mission that we made an immense progress you grow as a precursor it helped us discover gravity modes in stars.

56

00:09:02.610 --> 00:09:21.420

Conny Aerts: But the five months of the quran mission that it focused on fields of you was too short actually to do to do this work so that already tells you that gravity oh inertial actresses morris's like me, we have to be very patient and the four years of kepler data for us is fantastic yeah.

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00:09:23.730 --> 00:09:30.300

Conny Aerts: Let me still give a recap For those of you who are more or not familiar with most at all.

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00:09:30.570 --> 00:09:45.180

Conny Aerts: let's start with the easy cases, so that the sun is of course the the best star that we know and he knew seismology for us set the scene for all stars, like the sun having an outer convection zone, they have stochastic excitation.

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00:09:45.690 --> 00:09:57.000

Conny Aerts: via the turbulence in the convective Emerald and that creates sound waves typically now sound waves have high frequency for the sun, the strongest solar.

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00:09:57.300 --> 00:10:12.240

Conny Aerts: quakes they peek typically at 3000 micrograms here is a 16 sick and an almost copy of the sun, you would say spectroscopy split with glory the copy and as process knowledge is not, why not, because you see the dominant.

61

00:10:13.380 --> 00:10:24.990

Conny Aerts: Power of the oscillation speaks around let's say here 2150 ish micro hurts now, so this is lower than the 3000 of the sun, so this is a bigger star.

62

00:10:25.560 --> 00:10:34.830

Conny Aerts: And that's just like a musical instrument right the tones the frequencies go down as your instrument is bigger, so this star is bigger and from that.

63

00:10:35.130 --> 00:10:51.630

Conny Aerts: You can see why i've indicated here that we can derive very effectively in the fourier transform of the LIFE curve how big a star is if it is a sunlight start with solar like oscillations created by the outer envelope, because that.

64

00:10:52.320 --> 00:11:06.270

Conny Aerts: You can scale now you also see, there is a pattern here there is what we call the big frequency pattern in the same topics of high frequencies in the equations you can show that there is regularity, you see it here in front of you.

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00:11:07.980 --> 00:11:23.370

Conny Aerts: For a real case and the spaces between modes of equal degree what we call the large spacing is actually a measurement of the mean the

density inside your Star and it stars, like the sun, you can immediately couple that.

66

00:11:24.480 --> 00:11:35.760

Conny Aerts: When you have the radius because you know that from the frequency of maximum power to the mass of the star so by measuring this large frequency spacing along with the frequency of maximum power.

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00:11:36.210 --> 00:11:41.700

Conny Aerts: You can actually did use with a very high precision, the mass and the radius of your stuff.

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00:11:42.630 --> 00:11:52.500

Conny Aerts: Now you can also derive more from what we call the small frequency spacing, and this is a between quadruple and Rachel modes typically you can work that out.

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00:11:52.800 --> 00:11:57.300

Conny Aerts: This is another measurement of the sound speak, but of the sound speed gradient inside your stuff.

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00:11:57.750 --> 00:12:02.250

Conny Aerts: And as the star lives its life, it creates evermore helium in its Center.

71

00:12:02.610 --> 00:12:14.520

Conny Aerts: And so the gradient of the sounds speed is big there because your sound speed is all of a sudden, has a hiccup where it encounters the helium core right and that's, of course, a direct measurement of the age of this stuff.

72

00:12:15.180 --> 00:12:19.380

Conny Aerts: So as dating stars becomes possible.

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00:12:19.860 --> 00:12:27.450

Conny Aerts: it's not so easy to derive ages of stuff right, so this is what you get in the simple case of acoustic oscillations.

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00:12:27.660 --> 00:12:40.710

Conny Aerts: So, the talk is not going to work further from that this is pretty standard, you can do it for all stars that have under convictions those, including red giants that are very near to the end of their life, and this is how.

75

00:12:41.280 --> 00:12:46.350

Conny Aerts: galactic archaeologists like our work, because all of a sudden, they have a good age dating too.

76

00:12:47.010 --> 00:13:00.000

Conny Aerts: But I am taking you to a different case before I do that I send you i'll show you a gallery here of red giants that have been observed by the K to mission which is sort of the refurbished kepler.

77

00:13:00.360 --> 00:13:07.110

Conny Aerts: After it's lost its two of his gyroscopes and what you see here is a gallery from Dennis telos paper.

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00:13:08.130 --> 00:13:25.770

Conny Aerts: Beautiful black signal, and it goes to lower and lower and lower and lower and lower frequency, what do you see happening, the stars are climbing up the rich and branch and or increasing their size, so this is stellar evolution in action right, I still find this.

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00:13:27.060 --> 00:13:39.360

Conny Aerts: amazing every day if I look at it so by looking at the way the maximum power shifts to lower frequency you get an increase in size and you get older sister.

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00:13:39.930 --> 00:13:47.460

Conny Aerts: yeah so what people who do acoustic modesto seismology do is scale the physics, of the sun.

81

00:13:48.150 --> 00:13:54.810

Conny Aerts: According to this very famous scaling relations that were already invented before space as sources Margie started.

82

00:13:55.230 --> 00:13:58.560

Conny Aerts: And if you have a spectroscopic effect if temperature measurement.

83

00:13:58.830 --> 00:14:12.840

Conny Aerts: You do really get a very high precision radius mass ah mean density gravity of the stuff, which is very convenient as a service, we asked for us is more just deliver that to all sorts of topics, including X or planetary studies.

84

00:14:13.200 --> 00:14:22.500

Conny Aerts: And galactic structure stirs now we're going to leave that regime on the right here, we were here so far and we're going to move here to lower frequencies.

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00:14:22.830 --> 00:14:32.490

Conny Aerts: The gravity most of stars, they are dominant Lee restores I wouldn't see and they have low frequency values for their arguments.

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00:14:32.790 --> 00:14:42.300

Conny Aerts: And then you have to care about the interplay between the rotation frequency see of your Star and the mode frequencies are because stars happened to have rotation periods of like.

87

00:14:43.620 --> 00:14:54.150

Conny Aerts: let's say a fraction of a day until very many days so in the in the low frequency regime, you have to care when the coriolis force happens.

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00:14:54.870 --> 00:15:00.390

Conny Aerts: or it's connected to a rotation frequency that comes in the neighborhood of your buoyancy frequency.

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00:15:00.990 --> 00:15:12.120

Conny Aerts: which sets the mood cavity of gravity motion, and so, in reality, we do not have the simplistic situation that we can do our equations while ignoring the rotational.

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00:15:12.810 --> 00:15:17.610

Conny Aerts: forces or the Lawrence force if you're in the magnetic style.

91

00:15:18.600 --> 00:15:27.750

Conny Aerts: But let's start easiest here is again such a gallery and Nice gallery I I love this plot is made by one of my former PhD students so i'm a bit biased.

92

00:15:28.110 --> 00:15:43.890

Conny Aerts: You see again seven stars here kepler data beautiful light curves have quite a variety and again there's a trend here so overbroad is in red, now is the fourier transform and then again this trend from high to low down.

93

00:15:44.760 --> 00:15:59.550

Conny Aerts: With acoustic Moses I showed before that was you know big star go into smaller stars here, this has nothing to do with the size of

the star, these are gravitating ocean modes and here the position of this.

94

00:16:01.590 --> 00:16:13.140

Conny Aerts: fourier transforms and this the character of the peaks in the free transform well they tell me that this story is a very slow rotator and, as I go down.

95

00:16:13.710 --> 00:16:24.660

Conny Aerts: The stairs have faster and faster rotation rotation in the position where the gravity inertial most have their strongest probing power and that's.

96

00:16:25.320 --> 00:16:34.170

Conny Aerts: adjacent to the core of the convective core, these are the type stars is are stars with masters between typically three and nine solar masses.

97

00:16:34.440 --> 00:16:44.850

Conny Aerts: They have a fierce convective core that is fully mixed and the gravity most they travel in the radiative part of the star, and they have their highest most energy.

98

00:16:45.120 --> 00:16:50.190

Conny Aerts: right next to the core and that's exactly where you want to learn about the physics okay.

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00:16:50.550 --> 00:16:58.680

Conny Aerts: So now, how do I know that this is a measurement of the miracle rotation rate that's out of experience, so let me walk you through that.

100

00:16:59.130 --> 00:17:12.150

Conny Aerts: let's assume we have a B type star in the in the cartoon here So here we are in the regime of low frequencies, so the systematics that you have seen before in the acoustic regime was.

101

00:17:12.570 --> 00:17:20.250

Conny Aerts: A better the gifts a frequency spacing here we have a pattern that gives a period spacing.

102

00:17:21.030 --> 00:17:27.210

Conny Aerts: Areas of the modes if the frequency is lower than one of the frequencies high and that's the period of the month.

103

00:17:27.540 --> 00:17:34.680

Conny Aerts: And that gives a regularity and you see that brought us that regularity plotted here let's look at this star the upper one.

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00:17:35.040 --> 00:17:43.170

Conny Aerts: The Gray symbols here are for a non rotating star so here i'm safe to ignore the coriolis force and what you see plotted is the.

105

00:17:43.710 --> 00:17:54.750

Conny Aerts: difference in the mode periods between modes of consecutive radio order and justice for a large frequency spacing of acoustic modes and now it's.

106

00:17:55.170 --> 00:18:01.830

Conny Aerts: I do the periods of a mode that has a real orders let's say 10 like in the cartoon minus the same.

107

00:18:02.520 --> 00:18:10.260

Conny Aerts: modes, but then with the radio order nine let's say Okay, and then you see that this is about 4000 seconds right.

108

00:18:10.650 --> 00:18:17.400

Conny Aerts: And we plot that against the periods of these modes and so each dot here is an Eigen mode of this particular.

109

00:18:17.760 --> 00:18:29.550

Conny Aerts: stellar mode right So you see some regularity here, and you see sort of a periodic deviation from a constant value now if stars rotate and all stars do.

110

00:18:30.240 --> 00:18:37.800

Conny Aerts: Then you must make a distinction between the gravity waves that are moving along the rotation or against rotation.

111

00:18:38.220 --> 00:18:46.200

Conny Aerts: And if your wave moves along the rotation, it will come into your line of sight faster because rotation and the waves are traveling together right.

112

00:18:46.710 --> 00:18:58.320

Conny Aerts: If your wave travels opposite to the rotation, then we call it a retrograde wave, then it takes longer before you see back in your line of sight in the same way yeah so if.

113

00:18:58.890 --> 00:19:09.840

Conny Aerts: You have program modes, as we call it so working along with the rotation your frequency, for your period let's talk periods at once it comes back at you faster.

114

00:19:10.470 --> 00:19:20.460

Conny Aerts: If you have rotation versus non rotation, so the appearance of the most as seen in an inertial frame of an observer are lower shorter, I should say.

115

00:19:20.880 --> 00:19:34.770

Conny Aerts: And if you subtract two numbers that are smaller than your value is small So what does that mean if you're thorough this this pattern gets tilted to shorter periods and lower period spaces right.

116

00:19:35.310 --> 00:19:45.240

Conny Aerts: And for this star this rotates it's 5% of its critical rotation, this one at 10% etc, and this one at 20% So what do you see.

117

00:19:45.720 --> 00:19:54.270

Conny Aerts: Well, if you can did use the frequencies of the gravity or inertial waves, you have their periods by inverting them.

118

00:19:54.690 --> 00:20:04.920

Conny Aerts: You subtract their periods and you put them in such a diagram than the slope that you see in the batter is an immediate measure of the miracle rotation frequency of your stuff.

119

00:20:06.330 --> 00:20:23.190

Conny Aerts: This was unknown before we had four year kepler light curves in and analyze mobile way, so this started only 2015 and we have no Center calibrates because we're looking at phenomena that are not happening some sun doesn't have fast rotation.

120

00:20:24.330 --> 00:20:32.820

Conny Aerts: In a conflict difficult right so do stars do this because the previous graph was admittedly stellar models.

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00:20:33.630 --> 00:20:41.340

Conny Aerts: Yes, these are real stars and they do it yeah so here, you see, to guide your eye again a fourier transform but, mind you now.

122

00:20:41.640 --> 00:20:53.010

Conny Aerts: The X axis is not frequencies period that because we are in that a symbiotic regime and the red lines they sort of a guide your eyes to see the pattern here if you're not used to it, then.

123

00:20:53.310 --> 00:21:02.640

Conny Aerts: That might help and here you have the star is beautiful star with this kick number a downward trend, these are programmed most it's as simple as that right.

124

00:21:03.180 --> 00:21:21.840

Conny Aerts: And here, it also has retrograde most working against the rotation in the traveling, especially against the rotation right and so by measuring the slope of this pattern, you can actually immediately say how fast the rotation of the stars.

125

00:21:23.280 --> 00:21:38.970

Conny Aerts: Now assets we can try to do these things very few years and we are able to but it's very important to have some different teams setting up methodology, because we have to train ourselves and learn, and this is.

126

00:21:39.360 --> 00:21:46.650

Conny Aerts: Something that we have to learn the beautiful thing is there are about four different methods to derive rotation frequencies and they all.

127

00:21:46.890 --> 00:21:58.470

Conny Aerts: Work fantastically consistently, so we are very confident we can arrive rotation frequencies of stars and we have done that, by now, the Community when I say we that's the.

128

00:21:58.770 --> 00:22:13.290

Conny Aerts: Community working in this field, and we have beautiful young people joining, I find it fantastic about 1800 stars, where this has worked from kepler data we need kepler data to do this right now, here they are in this.

129

00:22:13.740 --> 00:22:32.070

Conny Aerts: Core a rotation frequency plotted as a function of gravity, to make them comparable with all the red giant people who love red giants ostracism ology acoustic models as well beautiful but then you see here in the early life of the stars, because these will all become a giant later on.

130

00:22:33.120 --> 00:22:38.850

Conny Aerts: You see how this how big the spread is in miracle rotation frequency and what we actually found was.

131

00:22:39.900 --> 00:22:49.770

Conny Aerts: Not according to the theory that almost all the stars have nearly rigid rotation it's something that we have to work on, because the theory is not.

132

00:22:50.670 --> 00:22:56.400

Conny Aerts: According to what we thought prior to space ostracism ology now, why is this important.

133

00:22:56.910 --> 00:23:04.740

Conny Aerts: Because of the chemical evolution of the star, because if stars rotate in their interior and they do it fast near their convective for yeah.

134

00:23:04.950 --> 00:23:15.690

Conny Aerts: In this overshoot area as it is cold right, then you mix matter much more efficiently that's at least what we anticipate a rotational mixing is a microscopic phenomenal.

135

00:23:16.140 --> 00:23:22.440

Conny Aerts: Now, other than that we have the nuclear burning that changes your chemistry, and we also have microscopic.

136

00:23:23.010 --> 00:23:33.540

Conny Aerts: phenomenon due to upcoming the food fusion heavy elements, then to sink and light elements than to levitate and you have the radiative levitation that pushes also.

137

00:23:33.930 --> 00:23:51.000

Conny Aerts: outward against gravity let's see right so once we have the rotation determined for all the stars and we have very many now we can look at the consequences for the mixing and see if the 30 year old theory of rotational mixing, for instance, if that works right.

138

00:23:51.930 --> 00:24:01.020

Conny Aerts: Well, maybe we need something, in addition, at least to this to this rotational mixing, and this was found by this star is one of my bed stars be start.

139

00:24:01.350 --> 00:24:11.610

Conny Aerts: Where we have done forward as processing modeling and you see the best forward model in blue here when we assume that there is no envelope mixing.

140

00:24:12.150 --> 00:24:15.180

Conny Aerts: Why do we assume that, for the start because it's an adulterous loyalty.

141

00:24:16.110 --> 00:24:23.580

Conny Aerts: And then you seen the residuals it's not clear there is periodic deviation ha that is chemical mixing that we're looking at.

142

00:24:23.790 --> 00:24:31.320

Conny Aerts: We don't know percent of course it could be rotation, but it's a star that has a rotation period of about 200 days it's extremely low.

143

00:24:31.740 --> 00:24:35.580

Conny Aerts: So if you add envelope mixing you really improve the model.

144

00:24:36.030 --> 00:24:47.760

Conny Aerts: And what we are doing now and i'm showing my student Vincent here, I always show a picture of a student if I show something that's unpublished, we are now developing inversion methods, where we hope to.

145

00:24:48.390 --> 00:24:54.930

Conny Aerts: improve the stellar modeling by investigating the physical ingredient that causes this mixing.

146

00:24:55.350 --> 00:25:06.330

Conny Aerts: And that's what you see here so in inversion What do you do you exploit the deviation from the frequencies that you measure and from the frequencies that you have in a model.

147

00:25:06.960 --> 00:25:18.360

Conny Aerts: By reconstructing a pattern, an important function that is not perfectly assumed in the theory solar physicists do that by the sound speed yeah.

148

00:25:18.720 --> 00:25:29.160

Conny Aerts: Here we have the brain feisal a frequency, I will not go into detail, you can ask me about it, this is still very first ideas and of new inversion methods.

149

00:25:29.430 --> 00:25:35.340

Conny Aerts: But bottom line is, if you do that, then you get a higher big in the brain Pfizer frequency.

150

00:25:35.640 --> 00:25:48.000

Conny Aerts: And the blue here is the improved version from the inversion so we can now start to deduce chemical profiles, because the bruin feisal a frequency in such stars.

151

00:25:48.210 --> 00:25:55.110

Conny Aerts: Has a chemical gradient that is dominance in there, and so this can lead us to win improved.

152

00:25:55.440 --> 00:26:08.280

Conny Aerts: higher level of mixing and the theory behind it, and then you see that even for a star, that is an ultra slow rotator we do need mixing happening i'm speeding up a bit because my time is running out.

153

00:26:09.030 --> 00:26:13.440

Conny Aerts: What we have done now is created or tested eight theories.

154

00:26:14.100 --> 00:26:26.940

Conny Aerts: of mixing inside stars on the sample of be stars just to see can we unravel them so like constant envelope mixing so here's the mixing profile to fully misconduct if Courtney overshoot region and then envelope mixing.

155

00:26:27.390 --> 00:26:37.680

Conny Aerts: envelope missing you do waves waves, also a transport particles due to share instabilities usually coupled to rotation or due to rotational mixing.

156

00:26:38.340 --> 00:26:52.650

Conny Aerts: Which here together, and then we evaluate which of these theories works best well, we have some answers, it seems that the convective penetration couple to share instabilities works best, and this is a work in.

157

00:26:53.760 --> 00:27:02.310

Conny Aerts: A recent nature astronomy paper by one of my former students, where you see the 26 stars and here you see the size of the convective core.

158

00:27:02.640 --> 00:27:12.480

Conny Aerts: as a function of the mass of the convective core and you see stellar evolution in action again because the younger ones have bigger convective course and you shrink along the evolution downward.

159

00:27:13.200 --> 00:27:15.600

Conny Aerts: Now what is interesting is that there is a correlation.

160

00:27:16.110 --> 00:27:24.630

Conny Aerts: Of the macroscopic mixing that we did use from the seismology and the rotation frequency but it's not a clean one relationship.

161

00:27:24.900 --> 00:27:33.600

Conny Aerts: Particularly because there are also two stars done by other teams independently from us, and they are slow rotates with an incredible amount of weeks okay.

162

00:27:34.290 --> 00:27:44.850

Conny Aerts: We can compare it with eclipsing binaries again, you can ask me about it, I have no time to discuss it, but the bottom line is that if we use all the eclipsing binaries.

163

00:27:45.120 --> 00:27:51.540

Conny Aerts: And we look at the amount of helium that you can construct, by the time that you reach the end of the main sequence.

164

00:27:51.810 --> 00:28:07.350

Conny Aerts: You can create twice as much helium than anticipated in standard theory that has no Emerald mixing so for the chemical evolution of the galaxy this is really an important result that would say alright, so you know now what.

165

00:28:07.800 --> 00:28:15.720

Conny Aerts: We are achieving what's the caveat we are assuming that the stars are spheres, and in my future plan, I have.

166

00:28:16.680 --> 00:28:26.340

Conny Aerts: The ambition to improve that and to look at these cartoons here on the right and to realize that the higher the rotation frequency, the more the stars are.

167

00:28:27.150 --> 00:28:38.880

Conny Aerts: obliques and we need to take that into account, I think i'm going to stop here I, we are doing the first steps, this is again, one of my PhD students results, so you see a picture, but in.

168

00:28:39.450 --> 00:28:57.210

Conny Aerts: In the interest of time if there is an interesting that I will go into details, how we do that we are coupling multi the structure models to one the evolution models and then we can work out what is important, or how important discipline says, but let me end by my.

169

00:28:57.270 --> 00:28:59.280

Morgan Elowe MacLeod: Would you would you tell us about that.

170

00:28:59.280 --> 00:29:03.150

Conny Aerts: place, I can with you know, let me formally and the same.

171

00:29:03.150 --> 00:29:03.630

Morgan Elowe MacLeod: again.

172

00:29:03.900 --> 00:29:12.510

Conny Aerts: Sorry sorry sorry about this here is my dream for the next 10 years and I can also explain you about that, but I prefer that you ask them questions actually.

173

00:29:15.330 --> 00:29:16.380

Morgan Elowe MacLeod: Thank you so much.

174

00:29:20.130 --> 00:29:28.140

Morgan Elowe MacLeod: Well, everyone feel free to type questions in the chat to me, and then I will.

175

00:29:29.700 --> 00:29:31.140

Morgan Elowe MacLeod: call on you to ask them.

176

00:29:32.400 --> 00:29:42.030

Morgan Elowe MacLeod: But maybe I can use my privilege to ask you to tell us a little bit more about sort of the Multi dimensional perspective okay.

177

00:29:42.240 --> 00:29:42.510

Conny Aerts: So.

178

00:29:42.960 --> 00:29:44.280

Morgan Elowe MacLeod: Thank you, sorry.

179

00:29:46.260 --> 00:29:47.880
Conny Aerts: yeah that's that's why i'm.

180
00:29:49.290 --> 00:30:02.430
Conny Aerts: Putting a lot of graphs in my slides so that you can see what I wanted to say in case, time is running so so stars are not spheres, they are a flattened steroids right, and so what we have been doing is.

181
00:30:03.210 --> 00:30:25.470
Conny Aerts: Setting up a nice collaboration with Michelle yeoh Torah, who is a geophysicist astrophysicist in to lose he has a 2d structure code called so you would say a staff with because he's French speaking and what does Esther do it, it computes fully consistently two dimensional stars now.

182
00:30:27.000 --> 00:30:35.190
Conny Aerts: flattened by rotation, where he takes on board all transport processes due to rotation in self consistent way.

183
00:30:35.670 --> 00:30:45.030
Conny Aerts: Now, what we have also learned in in the gravity inertial actresses Margie of F type stars because joey my student, he is working on F type stars.

184
00:30:45.390 --> 00:30:57.570
Conny Aerts: Is that these stars also have atomic diffusion and you might think it's not so important, but it is, it is equally important than the rotation, and this is maybe a bit of a surprise.

185
00:30:58.200 --> 00:31:14.040
Conny Aerts: But F stars do live long and the settling and the radiative levitation they do accumulate so joey has been doing, thanks to the help of our own daughter, who was formerly attached to your university.

186
00:31:15.810 --> 00:31:28.230
Conny Aerts: And who is a MISA experts, so we have encoded Joe has encoded a faster way to do radiative levitation and to translate the rotational shear.

187
00:31:29.520 --> 00:31:39.000
Conny Aerts: profile that comes from an ester to the structure model and plugged it into Mesa because Esther cannot do sell revolution, it is a structure codes.

188

00:31:39.480 --> 00:31:47.130

Conny Aerts: And of course we want to do stellar evolution for our work, we want to age, the stars and then you get this mixing profile that you see here so again the contract if core.

189

00:31:47.580 --> 00:31:56.070

Conny Aerts: A penetrative convection because we seem to find for be stars that this works better for the stars as a description and then this sheer.

190

00:31:56.580 --> 00:32:01.710

Conny Aerts: rotational mixing profile that comes straight out of this Esther model.

191

00:32:02.490 --> 00:32:10.380

Conny Aerts: Of the star that we have, and this is for one star, where we have them forward modeling in a spherical assumption, we know it's not perfect.

192

00:32:10.860 --> 00:32:19.980

Conny Aerts: And we also know that we can't really fit the mold trapping of that of the stars right So if you do this coupling of these.

193

00:32:20.760 --> 00:32:30.450

Conny Aerts: Higher dimensionality let's say, then you can predict how the oscillation modes look like you get such a signature, which is similar to what we see any stars.

194

00:32:30.750 --> 00:32:38.520

Conny Aerts: This is a very in the mass, and this is very in the mentality, because of course mentality has an immense impact on radiative levitation.

195

00:32:40.440 --> 00:32:53.700

Conny Aerts: So this is where it stands, we have in proved effective for the speed with which means I can handle the evolution of these stellar models, right now, this is unpublished well it's submitted that you see.

196

00:32:55.050 --> 00:33:03.480

Conny Aerts: We actually just before this talk or the referee reports, which is very positive, so it also be in the literature and then we can.

197

00:33:04.260 --> 00:33:21.420

Conny Aerts: improve, something that was a quite a failure so far on my behalf, all our graphical inertial forward modeling of F type stars told

us that we can't use envelope mixing, because if we put it in we destroy all the beautiful mode trapping.

198

00:33:22.860 --> 00:33:40.350

Conny Aerts: Now it turns out that rotational mixing works one way and the radiative levitation works against it, and if you put these two together, then we end up with realistic mixing levels as you see them here but sorry this was again a mini lecture.

199

00:33:42.060 --> 00:33:47.580

Conny Aerts: So I don't know if that answers your question, more or less that you had, but this is working, progress is coming up.

200

00:33:47.880 --> 00:33:48.630

Morgan Elowe MacLeod: This is amazing.

201

00:33:49.860 --> 00:33:53.730

Morgan Elowe MacLeod: So I think Charlie has a question, if you want to go ahead and unmute.

202

00:33:55.980 --> 00:33:58.470

Charles Conroy: Sure hi Connie That was a wonderful talk.

203

00:33:59.220 --> 00:34:00.480

Conny Aerts: Thank you hi shiny.

204

00:34:00.900 --> 00:34:08.490

Charles Conroy: So I guess my questions in the broad category of what we can learn about the evolution of the rotation of the core so.

205

00:34:08.910 --> 00:34:10.230

Charles Conroy: As I understand right, you can.

206

00:34:10.620 --> 00:34:19.560

Charles Conroy: directly from the size models you measure the current rotation of the core and then all this mixing stuff must be more of a kind of integrated effect.

207

00:34:20.370 --> 00:34:30.300

Charles Conroy: So is there a way to combine them in some way to learn about the history of rotation or or is it just that most these mixing actually is is kind of a more instantaneous measure.

208

00:34:30.750 --> 00:34:39.480

Conny Aerts: I love it well it's when you say integrated, we really do probe the positions in different positions in the star where this mixing score is happening.

209

00:34:40.140 --> 00:34:48.300

Conny Aerts: So in principle that's why we are developing new inversion methods, but there is nothing like this in the literature so i'm.

210

00:34:48.690 --> 00:35:02.010

Conny Aerts: very happy to have a very clever students unraveling that so first are we can deduce it layer by layer if we succeed in improving our initial mathematical formula.

211

00:35:02.520 --> 00:35:14.250

Conny Aerts: But then of course we see this whole diversity of stars that have different mixing levels, and so they translate immediately two very different chemical chemical production.

212

00:35:15.420 --> 00:35:24.120

Conny Aerts: And I guess for people like you, you want to integrate that across the galaxy right so so you you you better have some understanding.

213

00:35:24.420 --> 00:35:34.440

Conny Aerts: of which parameters in the star determine the amount of helium that you get somewhere in the core but also how the different layers of the star have they're mixing.

214

00:35:36.180 --> 00:35:48.780

Conny Aerts: Distribution let's say i'm not sure i'm answering your question Charlie but I mean you know if you take one of these eight theories, the consequence of this is quite different, for the different theories.

215

00:35:49.320 --> 00:35:58.770

Conny Aerts: And what we do now, for the moment is measured the height of these green shapes mixing shapes, but we want to do better, and we want to also.

216

00:35:59.280 --> 00:36:09.600

Conny Aerts: Not only have the global, integrated heights and consequence, but also the interior positioning scientists and so, for this, I need some more time.

217

00:36:10.440 --> 00:36:22.710

Conny Aerts: We have only really started with a set a very clever student that i'm very pleased with what we have, but I need I need a few more I need some more time let's see to to to.

218

00:36:23.190 --> 00:36:23.850

Conny Aerts: defend it.

219

00:36:24.300 --> 00:36:33.690

Charles Conroy: Can I ask a follow up question I just clarify when I was trying to get at is if the star went through an earlier phase where the core was very rapidly rotating.

220

00:36:33.930 --> 00:36:34.380

Conny Aerts: mm hmm.

221

00:36:34.620 --> 00:36:37.080

Charles Conroy: And then, but but, but today it's more slowly rotating in the.

222

00:36:37.080 --> 00:36:44.370

Charles Conroy: corn with that earlier phase of rapid rotation and this consequent mixing leave a fingerprint.

223

00:36:44.490 --> 00:36:45.840

Charles Conroy: On the present day structure.

224

00:36:46.530 --> 00:36:57.930

Conny Aerts: absolutely correct and so by we have a 68 stars with what I call to my standards good gravity inertial forward modeling.

225

00:36:58.950 --> 00:37:16.680

Conny Aerts: that's all that's totally insufficient right but we had zero until five years ago, and we had to invent new methodology, so you have to see it like that it's not like the 10s of thousands of returns So there you just scale the sun, I mean that's simple.

226

00:37:17.760 --> 00:37:26.160

Conny Aerts: So, so we have to fill diagrams like this, because if I look at these stars, and these are very slow road haters, but they are not old.

227

00:37:27.840 --> 00:37:37.860

Conny Aerts: that's one thing on the other hand, we also have this is Nicole rotation it's not the surface okay so, on the other hand, we have old stars.

228

00:37:38.940 --> 00:37:40.290

Conny Aerts: That you know.

229

00:37:41.670 --> 00:37:52.470

Conny Aerts: That rotate quite fast, but maybe not as fast as we thought because local conservation of angular momentum is not working for the stars and that's something we learned.

230

00:37:53.190 --> 00:38:05.160

Conny Aerts: So I think the the simplistic picture that you're sort of aiming for is too simplistic, in the sense that star shrink.

231

00:38:05.610 --> 00:38:16.410

Conny Aerts: They stay rigid through data along the main sequence, this is not at all what we had anticipated and there are other phenomena at play then rotation for the mixing of the elements.

232

00:38:18.000 --> 00:38:27.870

Conny Aerts: And for the moment we just have small samples to see correlations as you see here in this graph there is a correlation between the envelope mixing and the rotation.

233

00:38:28.200 --> 00:38:34.230

Conny Aerts: But it's the correlation coefficient is literally all point six so it's not the only thing that matters.

234

00:38:34.890 --> 00:38:47.880

Conny Aerts: And that's why we're putting in this radiative levitation, which is a pain cpu is but anyway, with somebody like our daughter, we have the best person in our collaboration to deal with the diagnosis.

235

00:38:49.770 --> 00:38:50.160

Conny Aerts: Okay.

236

00:38:50.190 --> 00:38:50.940

Charles Conroy: Thanks, thank you.

237

00:38:53.940 --> 00:38:56.280

Morgan Elowe MacLeod: um did you want to go ahead and unmute.

238

00:38:57.660 --> 00:39:04.530

Ramesh Narayan: Oh yeah so firstly yeah Thank you very much for this remarkably clear seminar it's wonderful.

239

00:39:05.760 --> 00:39:06.180

Ramesh Narayan: So.

240

00:39:06.270 --> 00:39:17.130

Ramesh Narayan: Thank you yeah my question, or maybe confusion is kind of related to what Charlie was asking, so we have a radiative envelope.

241

00:39:17.700 --> 00:39:24.330

Ramesh Narayan: about this call the corresponding rapidly some Omega the surface is spinning slow.

242

00:39:25.050 --> 00:39:41.700

Ramesh Narayan: So there must be a whole profile of Omega Oh well, maybe i'm wrong on that, but there must be I expect a profile of Omega as a function of radius and that profile is going to determine things like how the sheer instability works or even the mixing and things like that.

243

00:39:42.150 --> 00:39:55.530

Ramesh Narayan: So what does not clear to me, is, are you actually solving for omega of our or is that coming from some model which is using your sound like vector viscosity or pain, or whatever how exactly that been done.

244

00:39:55.650 --> 00:40:06.270

Conny Aerts: Yes, thank you for the question very good question well the started, I was showing let me go back to that this star, this is the first, this is a very special star.

245

00:40:07.110 --> 00:40:16.050

Conny Aerts: We are trying to do rotation inversion right, so we have the miracle rotation rate that we measure straight from the slope.

246

00:40:16.560 --> 00:40:22.890

Conny Aerts: We we don't have pressure modes in this in this star else we could do envelope rotation, but we can't.

247

00:40:23.520 --> 00:40:33.180

Conny Aerts: But, in general, we do have a profile and for this star it's actually a very special profile because it sort of says that it's almost counter-rotating the core from the envelope.

248

00:40:33.930 --> 00:40:46.200

Conny Aerts: So this is not at all what we had anticipated and what is even also well, you could call it controversial some people don't like i'm not very popular in some evolutionary.

249

00:40:47.790 --> 00:40:58.530

Conny Aerts: theory communities, all the stars that are spotted here and there are many it's not an exception because this one started, we started off was really showing an almost rigid rotation.

250

00:40:58.920 --> 00:41:08.970

Conny Aerts: And even a slight counter rotation, but the the almost all these stars on the main sequence, and they do cover masses from 1.329 solar masses nowadays.

251

00:41:09.390 --> 00:41:20.910

Conny Aerts: They have almost rigid rotation and they cover the entire main sequence, so the simple model of a shrinking core due to angular momentum conservation and an expanding envelope.

252

00:41:21.690 --> 00:41:35.310

Conny Aerts: The rotation estimates that we get to not show that now we don't have profiles for 1800 stars, we only have the mean rotation frequency for all the stars, but there are about.

253

00:41:36.390 --> 00:41:41.460

Conny Aerts: A handful of stars, where we see or where we have.

254

00:41:41.490 --> 00:41:43.110

Robert Noyes: Also, an envelope rotating and.

255

00:41:43.110 --> 00:41:51.990

Conny Aerts: it's almost regions so it's not an all the standard classical way of dealing with rotation profiles now.

256

00:41:53.070 --> 00:41:57.510

Ramesh Narayan: yeah so I guess the question is what's keeping it in Bridget rotation.

257

00:41:57.870 --> 00:42:04.410

Ramesh Narayan: haha angular momentum transport that's why I asked if it viscosity or is it magnetic fields what's going on.

258

00:42:05.100 --> 00:42:08.220

Conny Aerts: uh huh I have a backup slides I anticipated this.

259

00:42:09.960 --> 00:42:18.240

Conny Aerts: Alright, so here are all the stars, where we have both near core and envelope rotation and the envelope rotation is in the triangle.

260

00:42:18.810 --> 00:42:29.640

Conny Aerts: And this is what I assembled in in a review paper okay so for the moment, there are two theories being developed that can explain this.

261

00:42:29.970 --> 00:42:36.480

Conny Aerts: One theory is based on internal gravity waves triggered by the core convection at the interface layer

262

00:42:36.960 --> 00:42:44.790

Conny Aerts: And these waves travel and they are very efficient in angular momentum transport, and so I can highly recommend these papers.

263

00:42:45.330 --> 00:42:55.020

Conny Aerts: tammy righteous was the first one who came up with this she can explain with her a numerical simulations to three the hydro simulations.

264

00:42:55.680 --> 00:43:05.640

Conny Aerts: That rigidity has sustained throughout the land right another family of explanations is magnetism and here, Jim fuller Oh, the beautiful paper on decks.

265

00:43:06.090 --> 00:43:20.610

Conny Aerts: On tailoring stability, due to a magnetic field that could be hidden inside the core it's a competitive score that rotates fast, so you expect there to be magnetism and then you can also explain.

266

00:43:22.500 --> 00:43:35.040

Conny Aerts: By magnetic diffusion you could say that's the angular momentum is evacuated from the core to the outer layers right I wouldn't claim that these theories are.

267

00:43:36.660 --> 00:43:51.720

Conny Aerts: proven solid I wouldn't even choose whichever is more convenient, I think we are still in an exploratory phase, particularly

for the main sequence here because we we don't have rotation profiles yet.

268

00:43:52.860 --> 00:44:00.450

Conny Aerts: that's what should come from our molding versions, that we are developing now for gravity oh inertial modes so.

269

00:44:02.400 --> 00:44:11.490

Conny Aerts: yeah we need fixes people are working on them, several of them are in fact already implemented in one the evolution codes.

270

00:44:12.240 --> 00:44:17.640

Conny Aerts: Because there's typically knobs that you can tweak in terms of diffusing processes.

271

00:44:18.510 --> 00:44:23.100

Conny Aerts: If i'm really ambitious, which is what I tend to be I really want to go to.

272

00:44:23.490 --> 00:44:39.120

Conny Aerts: Higher dimensions, we need that because you're actually reformulating three dimensional or at least two or three dimensional phenomena and you're plugging them into a one the formula with the with the diffusion coefficient, and this is a limitation.

273

00:44:40.860 --> 00:44:41.310

Ramesh Narayan: Thank you.

274

00:44:48.990 --> 00:44:50.910

Morgan Elowe MacLeod: Sorry, I was just trying to unmute myself.

275

00:44:52.200 --> 00:44:57.780

Morgan Elowe MacLeod: john Raymond has a I think related question about kind of the rotation and how that affects.

276

00:44:58.620 --> 00:45:06.150

John C. Raymond: No thanks that was really an interesting talk, my question was so much the same as what ramesh asked that i'll ask something completely different.

277

00:45:09.180 --> 00:45:22.830

John C. Raymond: In the solar case it's proven to be fairly difficult to get GMO measurements is there sort of a one sentence explanation for why it works better in many of the stars that you've looked at.

278

00:45:24.930 --> 00:45:36.840

Conny Aerts: Yes, sure so solar type stars, if you have GMOs cannot propagate into convective android let me that's the basic answer right, and so the GMOs in the sun yeah.

279

00:45:37.950 --> 00:45:46.950

Conny Aerts: They are probably there, but we just can't detect them right and So here we don't have that problem, because we have a fully radiative outer envelope.

280

00:45:47.250 --> 00:45:57.510

Conny Aerts: And there's nothing preventing us from detecting them let's say right and and the GMOs cavity of the stars, in fact, they also have a process for that.

281

00:45:58.530 --> 00:46:04.770

Conny Aerts: You see, that here, you know, so this is the broom Pfizer frequency of a stellar model, this is an F star.

282

00:46:05.400 --> 00:46:19.560

Conny Aerts: Here you have all the the GMOs propagating here's you see this the p modes and for this start is only a very thin convective outer layer, so there is no problem for the most to reach the surface and to reach us observers so.

283

00:46:21.870 --> 00:46:28.980

Conny Aerts: it's a it's a natural consequence of stars having a convicted core and radiative envelope.

284

00:46:30.000 --> 00:46:37.080

Conny Aerts: there's a whole bunch of excitation mechanisms that I didn't discuss but we understand fairly well how these modes get excited.

285

00:46:37.590 --> 00:46:47.610

Conny Aerts: I always say it's very difficult not to oscillator for any object and then it's a method to get this information out of the data and, of course, and.

286

00:46:48.330 --> 00:46:59.310

Conny Aerts: We have an easy time now with with the kepler data also test data to detect the Eigen frequencies of coherent modes, as I call it so.

287

00:46:59.970 --> 00:47:05.730

Conny Aerts: dance moves are much harder to detect unless the damping time is Rome enough.

288

00:47:06.120 --> 00:47:15.120

Conny Aerts: Right so so for the majority of stars also for evolve read Chinese, by the way they have mixed mode says we call them and so these are these are most sets.

289

00:47:15.390 --> 00:47:21.960

Conny Aerts: can pass this even essence region that scene, right here at once you start evolves the orange goes down the blue goes up.

290

00:47:22.170 --> 00:47:33.030

Conny Aerts: And then you can couple these modes together, because the venison zone is becomes thin enough and that's what you seen rare chance and that's why we also were able to detect many of the.

291

00:47:33.330 --> 00:47:42.870

Conny Aerts: wealth of the correlation in red chance actually from mixed most ever pressure mode character in the envelope for the gravity mode character in the interior, so you know.

292

00:47:43.530 --> 00:47:57.000

Conny Aerts: The bottom line is gravity most are all over the place, we just haven't been able to detect them they're my favorite most they go deep into the star that that's where all the action lies of the stellar evolution right.

293

00:47:58.560 --> 00:47:59.490

John C. Raymond: Great thanks.

294

00:48:02.040 --> 00:48:02.520

Morgan Elowe MacLeod: Harvey.

295

00:48:03.540 --> 00:48:03.990

Morgan Elowe MacLeod: Do you wanna.

296

00:48:04.380 --> 00:48:15.660

Abraham Loeb: yeah what beautiful a discussion I had a question about the implications for Rehman so for sun like stars, of course, the remnant would be white dwarfs and.

297

00:48:17.430 --> 00:48:22.680

Abraham Loeb: But then more massive stars end up in neutron stars of black holes and.

298

00:48:24.060 --> 00:48:33.810

Abraham Loeb: And so the the spin of the remnant would depend on indeed the angular momentum distinguish if the core is in correlation with the envelope then.

299

00:48:35.010 --> 00:48:48.240

Abraham Loeb: The rotation period will be quite long, and so I was wondering, do you expect similar processes to operate also at higher masses and what are the implications for the remnants the spin of the remnants.

300

00:48:48.360 --> 00:48:53.490

Conny Aerts: Yes, that's a very good question, of course, and here I need to test because kepler.

301

00:48:55.320 --> 00:49:03.870

Conny Aerts: The liver is deliberately avoided high masses because it's the newest is for the planet hunters so with all respect the test is now delivering us.

302

00:49:06.300 --> 00:49:11.910

Conny Aerts: oscillation signature up to like 50 solar masses so i'm slowly getting there right.

303

00:49:12.900 --> 00:49:22.980

Conny Aerts: it's it's not the beautiful coherent most that i've used in this talk, but we see more stochastic stochastics coming and going but it's gravity.

304

00:49:23.370 --> 00:49:29.910

Conny Aerts: cleanly internal gravity waves, and so I am optimistic, as I am, as a person.

305

00:49:30.570 --> 00:49:42.810

Conny Aerts: We will have to reinvent new modeling methods, because what I didn't discuss here and what is crucial it's sort of a seat and under the carpets in this talk is that the identification of the.

306

00:49:43.590 --> 00:49:55.620

Conny Aerts: modes is critical, I need to be able to label the spatial geometry of the most before I can do my work, so to speak, and for these high masses in the test data.

307

00:49:57.450 --> 00:50:03.420

Conny Aerts: This is difficult for us, for the moment but it's coming up, and so I wouldn't say that.

308

00:50:04.020 --> 00:50:15.330

Conny Aerts: Above nine solar masses, which is what you want to know I wouldn't say that stars rotate rigidly not at all, because in my early days, it was the country if we had.

309

00:50:16.290 --> 00:50:30.450

Conny Aerts: So called better sufi stars they do have more rapidly spinning coordinate envelope, and so one of my students is actually doing an analysis of a test star right now.

310

00:50:31.560 --> 00:50:39.240

Conny Aerts: it's 50 solar masters, I know it's not where you I mean you still want me to go higher, but I have to gradually understand what's going on.

311

00:50:39.690 --> 00:51:00.600

Conny Aerts: And that star has an eight times faster rotation then envelope rotation, so I am pretty sure that the the mass regime that kepler gave us is not at all these are actually started will become my doors, to be honest, because we just reached nine sort of master so so the higher up.

312

00:51:01.770 --> 00:51:07.770

Conny Aerts: again have to ask for your patience, because we, the data is sitting in some hard disks right here.

313

00:51:08.340 --> 00:51:16.620

Conny Aerts: And we need more time to develop the methodology what is blocking us this also because this, no matter how beautiful the machine is.

314

00:51:17.040 --> 00:51:26.160

Conny Aerts: It only gives us one year in the continuous viewing zone and luckily the LM sees in there, so for us that's great because we will also exploit mental effects but.

315

00:51:26.970 --> 00:51:36.570

Conny Aerts: This is now doing the third year, so we have one year data one year gap when your data and this sounds simple but it's not equivalent to three years continuously.

316

00:51:36.990 --> 00:51:50.670

Conny Aerts: So, from a data analysis point of view, we have some work to do, but it will come I just need you know I need five more years to come with a concrete spin progenitor spin because that's what you want to have right.

317

00:51:51.270 --> 00:51:52.590

Abraham Loeb: We will invite you again.

318

00:51:53.280 --> 00:51:53.730

Okay.

319

00:51:55.050 --> 00:51:57.090

Conny Aerts: I love Boston sort of with pleasure yeah.

320

00:52:00.270 --> 00:52:07.680

Morgan Elowe MacLeod: On on on that can I ask one more question about the sort of multi dimensional character.

321

00:52:09.120 --> 00:52:09.660

Morgan Elowe MacLeod: So.

322

00:52:11.760 --> 00:52:27.420

Morgan Elowe MacLeod: Depending on the mechanism and if its rotation, for example, there might be angular dependence of how these fusion kind of works like towards the poles versus towards the equator and, especially, as your object becomes a plate so then does it matter.

323

00:52:28.440 --> 00:52:35.040

Morgan Elowe MacLeod: Or, in what ways does it matter how we're viewing this play object, I mean, I know that you.

324

00:52:36.090 --> 00:52:39.960

Morgan Elowe MacLeod: Besides, like the geometric cancellation of the mode itself like.

325

00:52:41.460 --> 00:52:45.060

Morgan Elowe MacLeod: Maybe you can just talk more about that I don't have a perfectly formulated question but.

326

00:52:45.060 --> 00:52:58.080

Conny Aerts: Yes, So yes, it does matter yeah but there's also good news because if you have a new blade star, you know it's tilted in some way towards you, and of course interferometry can tell you how.

327

00:52:58.920 --> 00:53:11.550

Conny Aerts: How it is inclined, but we also gets an estimates, this is also being worked out, right now, we also get an estimate of the inclination angle from the most.

328

00:53:14.070 --> 00:53:32.520

Conny Aerts: Nuts straightforwardly because the and I haven't used the amplitude of the most I haven't discussed that at all and that's because we don't know very well how to do it, but working on it as well, but let's assume that we could somehow say all the modes in in rotation only.

329

00:53:33.570 --> 00:53:46.050

Conny Aerts: multiplex they have the same energy and this is an untrue statement it's not true it's false but let's assume, then by comparing the amplitude of the retrograde progress and.

330

00:53:46.890 --> 00:53:55.440

Conny Aerts: solo modes, you can work out the inclination, this is what again solar people can do if you have sun like stars, this is just working right.

331

00:53:56.130 --> 00:54:13.410

Conny Aerts: In our case, it doesn't work like that, because the mode energy of the progress retrograde and solo mode is not equal, we notice there are counter examples where we have an inclination right, so we know this is not true and that's partly also because we have no linear phenomena.

332

00:54:14.640 --> 00:54:15.090

Conny Aerts: Right.

333

00:54:16.290 --> 00:54:27.690

Conny Aerts: And we would have to unravel that and then we can estimate an inclination so we do have some estimates, but the the error bars are still quite or the uncertainty regions, I prefer to say.

334

00:54:28.230 --> 00:54:37.770

Conny Aerts: are still quite large, but it does make sense, what we get out of the seismology and once you know that, then you can of course use that in going to.

335

00:54:38.640 --> 00:54:51.180

Conny Aerts: To to or 3D because you're absolutely right, what we are doing now in the you know one one plus one D, as I call it that one diamond spatial one time evolution code like Mesa or whatever code you're using.

336

00:54:52.380 --> 00:54:56.280

Conny Aerts: We assume that actually there is a little rotation.

337

00:54:57.840 --> 00:55:05.910

Conny Aerts: And that rests on the assumption that the horizontal mixing is instantaneous, and that is sort of is an average.

338

00:55:07.020 --> 00:55:09.390

Conny Aerts: But i'm sure that real stars.

339

00:55:11.520 --> 00:55:17.130

Conny Aerts: You know, have more imagination than us hydrodynamic says, for the moments.

340

00:55:17.340 --> 00:55:20.370

Morgan Elowe MacLeod: Was amazing because it's a pathway to find out.

341

00:55:21.450 --> 00:55:33.600

Conny Aerts: yeah we were trying so what we what I and that's why I love this picture so much that's what I want to do in the night before I retire, and this is, this is my path.

342

00:55:34.080 --> 00:55:36.180

Morgan Elowe MacLeod: So along those lines.

343

00:55:36.300 --> 00:55:37.890

Morgan Elowe MacLeod: yeah with a couple minutes left did.

344

00:55:37.890 --> 00:55:43.350

Morgan Elowe MacLeod: You want to sort of, say, any last words and maybe it's this picture.

345

00:55:43.650 --> 00:55:53.910

Conny Aerts: Yes, i'm swamped with data, either from us versus mythology or from binary tea or from clusters all very good age dating tools we are.

346

00:55:55.140 --> 00:56:03.720

Conny Aerts: very sure now that our one the stellar evolution theory is not the end of the story, it has been used for half century but.

347

00:56:04.350 --> 00:56:12.930

Conny Aerts: We have to do better, we can do better than that and we can only do it now actually thanks to seismology so it really is is.

348

00:56:13.890 --> 00:56:23.970

Conny Aerts: yeah measurement from the interior it's not so surprising for me that we, I mean people call the surprising results, no, we haven't looked inside stars and.

349

00:56:24.330 --> 00:56:31.170

Conny Aerts: You know we're looking since a decade now, and for these more massive stars well we can't scale the sun.

350

00:56:31.530 --> 00:56:43.380

Conny Aerts: it's it's tedious mathematical integral equations and that's what I like because i'm mathematician by training and this heavy computational science so it's it's computation astrophysics so.

351

00:56:43.800 --> 00:56:53.100

Conny Aerts: My upper right corner of the spinner is sort of this is being done at observational parts and i'm going gradually.

352

00:56:54.780 --> 00:56:56.820

Conny Aerts: Well, I mean the middle i've always been in the middle.

353

00:56:57.630 --> 00:57:08.250

Conny Aerts: But we need to, we need to do better on the 3D by making simulations, and this is not my ballpark you, you have institute's that are really.

354

00:57:08.550 --> 00:57:21.060

Conny Aerts: Very good at that I would say it's a matter of having the simulations they are usually done on a secular timescale dynamical time scale, not on an evolutionary time scale and working through the spinner.

355

00:57:21.450 --> 00:57:28.620

Conny Aerts: in finding out the best way to have mean field models from these hydro simulations and plugging them into.

356

00:57:30.030 --> 00:57:37.860

Conny Aerts: Several revolution calls that can calculate the evolution of flattens ferrets that's my dream and with that i'll shut up.

357

00:57:40.110 --> 00:57:54.870

Morgan Elowe MacLeod: Thank you so much, this has been such an educational and and sort of exciting hour and it's been a real pleasure so hope everyone will join me in thanking us there is and it's been such a pleasure to have you.

358

00:57:57.420 --> 00:58:02.010

Conny Aerts: Likewise, was a real pleasure to be with you actually and if you have questions.

359

00:58:02.010 --> 00:58:02.640

Conny Aerts: Please ask.

360

00:58:02.670 --> 00:58:04.800

Conny Aerts: This is blooming field and I love working.